TESE DE DOUTORAMENTO

THE EVOLUTION OF OPTICAL INSTRUMENTATION, LASER TECHNOLOGY, AND SCIENTIFIC THOUGHT IN ASTRONOMY: THE RAMON MARIA ALLER ASTRONOMICAL OBSERVATORY ACTIVITIES AND ARAB ASTRONOMY

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The Evolution of Optical Instrumentation, Laser Technology, and Scientific Thought: the Ramon Maria Aller Astronomical Activities and Arab Astronomy

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The Evolution of Optical Instrumentation, Laser Technology, and Scientific Thought: the Ramon Maria Aller Astronomical Activities and Arab Astronomy

D. José Ángel Docobo Durántez, Catedrático de Astronomía do Departamento de Matemática Aplicada da Universidade de Santiago de Compostela

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Asdo. José Ángel Docobo Durántez

INFORME DO TITOR DA TESE

The Evolution of Optical Instrumentation, Laser Technology, and Scientific Thought: the Ramon Maria Aller Astronomical Activities and Arab Astronomy

D. Marcelino Agís Villaverde, Catedrático de Filosofía do Departamento de Filosofía da Universidade de Santiago de Compostela

INFORMA:

Que a presente tese, realizada por D. ***Hatem Abdullah Hamdan Al-Ameryeen*** baixo a dirección do profesor José Ángel Docobo Durántez, foi tramitada a través do Programa de Doutoramento en Filosofía, e, como titor da mesma, dou o Visto e Prace a súa presentación considerando que cumpre cos requisitos esixidos no Regulamento de Estudos de Doutoramento da USC, e que non incorre nas causas de abstención establecidas na Lei 40/2015

En Santiago de Compostela, 11 de marzo de 2020

Asdo. Marcelino Agís Villaverde

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CONTENTS

SHORT ABSTRACT

This Doctoral Dissertation was written by Hatem Abdullah Al-Ameryeen under the direction of José Ángel Docobo, Full Professor of Astronomy and Director of the Ramón María Aller Astronomical Observatory (OARMA) at the University of Santiago de Compostela, Galicia, Spain. Philosophy and the History of Science have had significant impact on technological advances in astronomical instrumentation in past centuries. Therefore, we think that further knowledge can contribute to our recognition and planning of the long-term evolution of optical tools and laser technology. The Ramón Maria Aller Astronomical Observatory (OARMA) at USC has a long tradition in the study of binary and multiple stars since the early 20th century. Today, OARMA is an international reference regarding double and multiple stars. In addition, this Astronomical Observatory plays a vital role in the enrichment and diffusion of scientific knowledge and thought in Astronomy in Spain, in general, and, Galicia, in particular. In spite of the renowned central role in the advancement of in the ancient and medieval eras, Astronomy as well as other Sciences have suffered a stunning decline in Arab region after the 15th century. Therefore, it is critical that the Arab countries establish themselves in A&SS and their technologies in the 21st century. Strengthening the relevance of leading-edge technologies and research will be pivotal to address the essential problems facing Arab societies.

ABSTRACT

This Doctoral Dissertation was written by Hatem Abdullah Al-Ameryeen under the direction of José Ángel Docobo, Full Professor of Astronomy and Director of the Ramón María Aller Astronomical Observatory (OARMA) at the University of Santiago de Compostela, Galicia, Spain. This text explains several objectives proposed by Professor Docobo in the field of scientific thought and is framed within the lines of research of the History and Philosophy of Science. Philosophy and the History of Science have had significant impact on technological advances in astronomical instrumentation in past centuries. Therefore, we think that further knowledge can contribute to our recognition and planning of the evolution of optical tools and laser technology. OARMA at USC has a long tradition in the study of binary and multiple stars since the early 20th century and, today, is an international reference regarding double and multiple stars. In spite of their renowned central role in ancient and medieval eras, Astronomy as well as other Sciences, have suffered a stunning decline in the Arab region after the 15th century. Therefore, it is critical that the Arab countries establish themselves in Astronomy and Space Sciences (A&SS) and associated technologies in the 21st century. Strengthening the relevance of leading-edge technologies and research will be pivotal to addressing essential problems facing Arab societies. In our opinion, it is important that the History of Science and its relationship with the evolution of human thought have a significant role in educational curricula in Arab countries.

The body of the Doctoral Dissertation consists of five chapters. After the Introduction, Chapter 1 explains the extraordinary advances of human knowledge with respect to the Universe achieved by means of observation, the proposal of theories later confirmed, the fundamental role of the telescope in a multiplicity of observations, and the use of other techniques such as spectrometry, photography, and photometry which are supposed to represent the initiation of the field of Astrophysics as

an essential branch of Astronomy today. We then go through the historical development of astronomical instruments and their latest techniques and laser technology, the new generation of telescopes as well as the future space missions.

In Chapter 2, we begin with the explanation of the importance of the study of Binary and Multiple Stars as a FUNDAMENTAL field of research in Astronomy from a mathematical point of view (Astrodynamics) as well as from the perspective of Physics (Astrophysics). We describe new insight into the history and evolution of binary systems from ancient times to the present. OARMA's main field of research is Binary and Multiple Stars. The different contributions of astronomical activities carried out by OARMA members in this field of research under the supervision of the Director of this Dissertation are analyzed. Docobo's analytical method for calculating the orbital solution of those systems provide a very useful, versatile, and friendly application to determine the physical and dynamical parameters of binary and multiple stars systems. On the other hand, OARMA plays a vital role in the enrichment and diffusion of scientific knowledge and thought in Astronomy and for this reason their activities deserve to be taken into account in this research.

We include in this chapter the presentation of the article Physical and Dynamical Parameters of the Triple Stellar System: HIP 109951, developed by us within the frame of international collaboration with S. G. Masda, J. A. Docobo, and other astronomers and published in an international journal.

In Chapter 3, we present the first section of the study of Arab Astronomy. It is designed to demonstrate how Arab Astronomy in ancient and medieval eras may have contributed to the historical progression of scientific and philosophic concepts of Astronomy and played a valuable role in the transfer and the preservation of ancient scientific knowledge for posterity. The main objective of this section is to recognize and review the contributions of the Arab and Muslim scholars in antiquity to the sciences of Astronomy. Ultimately, the goal is to provide a new view of the history of Astronomy in order to launch and support a renaissance in Astronomy in the Arab world today.

In Chapter 4, the second section of the study of Arab Astronomy is described. The major aim of this section is to provide an overview of A&SS in Arab countries and also to consider the future of the most important initiatives and projects in that part of the world. We discuss the emergence and subsequent phases of change in Astronomy activities on all levels and critically assess the present state of A&SS. We also consider all of the activities carefully in order to provide new insights into many significant issues including the social status of modern scientific knowledge in these disciplines in the areas of applied science and technology.

In the last Chapter, we aim to describe the reality of education and scientific research in A&SS in the Arab World at the present time. Moreover, we illustrate the present and future outstanding projects in this science area as well as attempt to provide biographies of some recent Arabic Arab scholars in these fields. The common objective of the three last Chapters is designed to ignite the Arab scientific future revolution in these areas of research.

RESUMEN

La presente Tesis Doctoral fue realizada por Hatem Abdullah Al-Ameryeen bajo la dirección de José Ángel Docobo, Catedrático de Astronomía y Director del Observatorio Astronómico Ramón María Aller (OARMA) de la Universidad de Santiago de Compostela, Galicia, España.

Actuó como Tutor el Catedrático de Filosofía, Prof. Dr. Marcelino Agís Villaverde.

La Memoria trata de conseguir varios objetivos en el ámbito del pensamiento científico y se encuadra dentro de las líneas de investigación de la Historia y Filosofía de la Ciencia. Dichos objetivos, sugeridos por el profesor Docobo, pueden circunscribirse en los tres siguientes:

1- Explicar y describir los extraordinarios avances tanto del conocimiento como del pensamiento en relación con el Universo, los cuales se alcanzaron gracias a la evolución de la instrumentación óptica, de las técnicas astronómicas y, ya más recientemente, la tecnología láser, pero sobre todo por la capacidad del ser humano en progresar e innovar. Todo ello dentro de una prespectiva histórica y filosófica en el contexto científico.

En este sentido es necesario destacar las contribuciones fundamentales de la Ciencia en general y en particular de las Matemáticas y de la Física, siendo en esta última, y en concreto en Óptica, donde haremos más énfasis a lo largo del trabajo. En efecto, el incesante desarrollo de sofisticada instrumentación, así como de técnicas específicas y detectores de última generación para las diferentes longitudes de onda del espectro electromagnético tales como la Óptica Adaptativa (AO), los fotómetros ultrasensibles, los espectrógrafos y espectrómetros de alta resolución, instrumentos astrofotónicos, las técnicas astrométricas y fotométricas de alta resolución, las infraestructuras para la detección de las Ondas Gravitatorias, etc.

han constituido en las últimas décadas una auténtica revolución en lo que al conocimiento del Cosmos se refiere. Pero en Ciencia se avanza basándonos a lo anteriormente logrado y por ello es preciso no olvidarse de las circunstancias históricas, sociales y científicas que facilitaron primero el descubrimiento y después la evolución de la tecnología telescópica gracias a la cual tenemos cada vez una más completa información de la posición que ocupamos en el Universo. La observación astronómica fue, es y será imprescindible, desde el modesto anteojo de Galileo Galilei hasta los extraordinariamente grandes telescopios tanto en tierra como espaciales, así como aquellos pertenecientes a la inmediata nueva generación de telescopios.

Es además necesario describir el contexto científico en el que aparecieron y se desarrollaron técnicas astronómicas esenciales como la espectroscopía, la fotografía y la fotometría, que en su día dieron lugar a la aparición de una fundamental nueva rama de la Astronomía, la Astrofísica, gracias a la cual el conocimiento del ser humano del Cosmos creció exponencialmente en menos de dos siglos, pasando prácticamente solo del estudio de nuestro Sistema Solar a poder abarcar multitud de objetos galácticos y extra galácticos, y últimamente a poder descubrir y estudiar planetas en torno a otras estrellas.

2- Dentro del amplísimo conjunto de líneas de investigación de la Astronomía actual, las estrellas binarias juegan un papel vital ya que a partir del estudio de todos sus tipos se puede acceder a información imprescindible sobre los parámetros estelares básicos como son las masas, las distancias a dichas estrellas, el tamaño de estas, sus órbitas, etc. Todo ello conlleva drásticamente al avance científico y al pensamiento humano cara al Universo que habitamos.

Se hace necesario demostrar la influencia actual y el valor histórico del OARMA en los estudios sobre binarias a nivel mundial. El Observatorio que fundó el Padre Aller en 1943, como consecuencia del traslado de su Observatorio particular de Lalín (Galicia, España) a la Universidad compostelana, es en la actualidad una referencia internacional en la investigación de las estrellas binarias sobre todo después del gran esfuerzo realizado en las últimas décadas después de su recuperación a partir de 1981. Los distintos proyectos de investigación desarrollados, dirigidos por el profesor Docobo, han permitido a los investigadores del centro poderse desplazar a centros astronómicos de primer nivel tanto en Europa como en América y Asia. Se han publicado más de un centenar de publicaciones en revistas internacionales, incluyendo entre estas un original método de cálculo de órbitas diseñado por el Director con el que se obtuvieron más de 300 en diferentes países. Se organizaron varios congresos internacionales y nacionales, se ha adquirido instrumentación puntera y se han formado numerosos doctores. Aparte de todo ello, es preciso poner en valor la proyección social del Observatorio, con numerosísimas actividades para todos los públicos no solo en su sede de Santiago de Compostela sino incluso en distintos lugares de Galicia tanto para la ciudadanía en general como en centros escolares, penitenciarios, y de rehabilitación. Todo ello hace que este centro de la Universidad de Santiago merezca que se le considere no solo por el trabajo estrictamente científico sino también por su labor divulgativa a través de diferentes programas de observación y de charlas enriquecedoras del conocimiento que estimulan de forma muy significativa a la sociedad a reflexionar sobre cuestiones tan trascendentes como puede ser el lugar que ocupamos en el Cosmos, si puede haber algún tipo de vida en otros lugares dentro o fuera del Sistema Solar, sobre nuestra propia existencia, etc.

3- Poner en valor y analizar las contribuciones del mundo árabe a la Astronomía desde la antigüedad hasta el presente. En efecto, dar cuenta con todo tipo de detalles de todas estas aportaciones fundamentales realizadas en un pasado esplendoroso es uno de los puntos clave que nos llevan también a investigar cual es el estado actual de las cosas en investigación, docencia y divulgación de la ciencia astronómica en los distintos países árabes, así como sus proyectos cara hacia un futuro prometedor. Esto último, completamente inédito, ha supuesto múltiples contactos con profesores e investigadores, con Universidades, Institutos, y otros Centros, fundamentalmente del mundo árabe pero también de otros países, con el objetivo de acceder a sus líneas de investigación, a los proyectos actuales y futuros en Astronomía y Ciencias del Espacio, así como también a los convenios entre estados, proyectos comunes de carácter internacional, etc. En este sentido, nos ha parecido conveniente establecer una hoja de ruta relativa al desarrollo previsto de estas ciencias, así como de su impacto. Nunca antes se había preparado un informe tan amplio que de seguro será de gran interés no solo para los científicos e historiadores de la Ciencia, sino incluso para los responsables de la Ciencia a nivel global.

Una vez expuestas nuestras pretensiones con la presente Memoria, no debemos de olvidar que la Filosofía y la Ciencia son disciplinas interrelacionadas desde siempre y que han evolucionado juntas influenciadas la una por la otra. No hubo una distinción clara entre filósofos y científicos hasta el siglo XIX [1]. Podemos argumentar que la Ciencia no pudo existir sin la Filosofía, proporcionando a esta un camino de teorías empíricas y conceptos, mientras que la Filosofía ha prestado asistencia y apoyo al método científico. La Filosofía también dicta que áreas de la Ciencia pueden o no ser verificadas, esbozando la separación entre las cuestiones físicas y metafísicas. Por otra parte, dado que la Ciencia y la tecnología están entrelazadas, el progreso de la primera, en general, y de la Astronomía, en particular, dependen de la sofisticación de los instrumentos ópticos y de sus técnicas, en tanto que el progreso de la instrumentación de alta tecnología depende de las ideas y del pensamiento científico. Desde esta perspectiva, intentamos comprender el papel clave de como el pensamiento científico se une a su evolución histórica para apoyar la nueva revolución en instrumentación astronómica y tecnología [2].

El estudio de la Historia y de la Filosofía de la Ciencia proporciona una amplia visión de todas las ciencias, su naturaleza y fundamentos, orígenes y lugar en la revolución científica, así como su impacto en la metamorfosis en la civilización actual [3]. En Historia de la Ciencia, algunos de los métodos tradicionales se usan para estudiar el comienzo de las ciencias, como estas fueron empleadas para desarrollar el razonamiento humano, como evolucionaron, y como fueron enlazadas a sus contextos mental y cultural. En Filosofía de la Ciencia, las ciencias mismas son tratadas con un análisis filosófico serio para investigar la naturaleza de la ciencia, en general. Ello nos permite distinguir entre la actividad científica y como las teorías se formaron, explicaron, y confirmaron [4]. Más aún, ello proporciona explicaciones acerca de dilemas morales tanto por las ciencias, así como la investigación del contenido fundamental de estas y como eso en antiguas cuestiones filosóficas: cual es la naturaleza del espacio, el tiempo, y la materia; que es la vida; y que es el pensamiento. Por otra parte, la Historia y la Filosofía de la Ciencia son peculiares al unir Historia, Filosofía y Ciencia, con investigaciones en cada una de ellas que a menudo interrelacionan de forma considerable [5].

El estudio de la Historia de la Ciencia se ha desarrollado muy significantemente a lo largo del siglo XX y tiene dos funciones principales: la primera es entender como el conocimiento científico crece, y la segunda es comprender la noción de ciencia en si misma que relaciona cuestiones como que métodos son genuinamente científicos y que clase de conocimiento es actualmente ofrecido por la ciencia. Además, la Historia de la Ciencia relaciona varios hechos sobre cosas que han ocurrido en diferentes épocas del pasado.

En relación con la estructura de esta Tesis Doctoral, después de la Introducción General, en el Capítulo 1 tratamos de explicar los extraordinarios avances del conocimiento humano con respecto al Universo conseguidos mediante la observación, la proposición de teorías luego confirmadas, el papel esencial del telescopio, y con él multitud de observaciones, utilizando nuevas técnicas como la espectroscopia, la fotografía, y la fotometría, que representaron el inicio de la Astrofísica como una rama esencial de la Astronomía moderna.

Luego haremos un recorrido a través del desarrollo del instrumental astronómico a lo largo de la historia, así como de las técnicas de observación empleadas. En este sentido, es preciso destacar las importantes contribuciones de la óptica, tanto en el pasado como en la actualidad, y las que se esperan para los próximos años. Estamos hablando de aportaciones como detectores específicos para diferentes longitudes de onda, tecnología láser, óptica adaptativa, así como las inmediatas misiones espaciales, como el telescopio espacial James Webb. El propósito de este capítulo además de lo expuesto es también poner énfasis en la íntima relación del uso de instrumentación de última generación con la posibilidad de llevar a cabo nuevos e importantes descubrimientos en la frontera de la Ciencia.

Todo ello nos lleva a un mejor conocimiento del Universo y al mismo tiempo a hacernos comprender mejor el lugar que ocupamos en él, y lo importante que es innovar en ciencia y el emprendimiento sin límites que el ser humano es capaz de llevar a cabo siguiendo el método científico.

La siguiente parte de nuestra investigación está concentrada en el estudio de las estrellas binarias y múltiples y el amplio estudio que de ellas se hace en el Observatorio Astronómico Ramón María Aller (OARMA, http://www.usc.es/astro) de la Universidad de Santiago de Compostela (USC) y a ellas dedicamos el Capítulo 2 de esta Memoria. El OARMA, que jugó (y juega) un importante papel en la astronomía española tanto en su producción científica como en el enriquecimiento cultural cara a la universidad a través de la transmisión del conocimiento y el estímulo del pensamiento científico, es hoy en día una referencia internacional en el campo de las estrellas dobles y múltiples [6], [7].

Fue fundado en el 1943 por el padre Aller como continuación de su Observatorio particular [8], [9]. Aller trajo consigo de Lalín sus principales instrumentos de observación a Compostela, entre ellos el refractor Steinheil y el teodolito. Después de los complicados años acaecidos luego de su fallecimiento en 1966, durante los cuales el Observatorio careció de dirección científica, el Centro fue física y científicamente recuperado a partir del otoño de 1981 cuando el Dr. José Ángel Docobo regresó a Santiago de Compostela atendiendo la llamada del Rector Suárez Núñez, siendo nombrado Director del OARMA en junio de 1983 coincidiendo con la IV Asamblea Nacional de

Astronomía, cuya celebración en Santiago él mismo promovió. Aunque el profesor Docobo es gallego y licenciado por la USC, estaba como profesor en la Universidad de Zaragoza donde defendió su Tesis Doctoral en 1978 bajo la dirección del profesor Dr. Rafael Cid.

El OARMA es el único Observatorio Astronómico dentro del Sistema Universitario de Galicia, y su actual prestigio científico y social es el producto de décadas de enorme esfuerzo, en distintos frentes desde los años ochenta, tal y como queda reflejado en sus memorias anuales de actividades y en algunas publicaciones [6], [10].

En efecto las líneas de actuación del profesor Docobo se centraron desde un primer momento en no solo dotar al Observatorio de sus medios indispensables, sino también en recuperar la calidad de la docencia de la Astronomía en la USC. Hubo que conseguir para el Centro presupuesto, personal, instrumentación, poner al día la biblioteca, organizar congresos, solicitar proyectos de investigación, efectuar campañas de observación en grandes telescopios, comenzar a publicar resultados en revistas internacionales y dirigir Tesis Doctorales para formar a los primeros colaboradores. Una amplia información de la situación actual queda reflejada en la página web del OARMA (http://www.usc.es./astro), con distintas secciones sobre docencia, líneas de investigación, instrumentación, publicaciones, la mayoría de estas en revistas incluidas en el JRC, congresos organizados, divulgación, datos meteorológicos, etc [7].

Entre las publicaciones hay aquellas relativas a datos de observación obtenidas sobre todo utilizando grandes infraestructuras tanto situadas en suelo español como en Francia, Rusia, Estados Unidos, Chile, etc. Otras muchas están dedicadas al cálculo de órbitas de estrel las dobles usando, desde 1984, el método analítico diseñado por el profesor Docobo, pero, entre ellas, son destacables aquellas en las que se describen metodologías novedosas aplicables tanto en el caso de binarias visuales y espectroscópicas como en el caso de sistemas estelares múltiples. Tampoco hay que olvidar el catálogo de órbitas de estrellas dobles visuales, OARMAC, que mantiene el Observatorio desde el año 2000, ni tampoco la edición de la Circular de Información de la Comisión G1 (antes No. 26) de la IAU.

Son numerosas las Tesis Doctorales que dirige y dirigió el profesor Docobo en las últimas décadas, y multitud las actividades de divulgación que promovió. La recuperación de la estación meteorológica permitió desde 1982 establecer un acuerdo de colaboración con la AEMET (Agencia Estatal de Meteorología), antes INM (Instituto Nacional de Meteorología). En definitiva, la investigación, docencia, divulgación, y la sección meteorológica, son las cuatro patas de la mesa que el profesor Docobo dirige y cuida como si fueran sus propios hijos.

La calidad de la docencia impartida por el equipo del OARMA en Matemáticas, Física, Óptica, y en el llamado Cuarto Ciclo Universitario (para mayores de 50 años) está contrastada desde hace tiempo. En cuanto a la divulgación, que ha sido una constante desde los años ochenta, ésta se potenció y consolidó gracias a iniciativas propias del profesor Docobo, como el PECAS (Programa de Extensión Cultural de Astronomía), ya en su edición XXIII; TODOCOSMOS con actividades en más de 50 ayuntamientos gallegos, o el CAMINO DE LAS ESTRELLAS. LAS ESTRELLAS DEL CAMINO, en íntima relación con el Xacobeo 2021.

El Observatorio dispone también de varios telescopios, destacando el de 0.62 m de apertura, el segundo en el ámbito universitario español. Son también instrumentos importantes las dos cámaras para Interferometría Speckle, entre otra instrumentación de calidad.

Aparte de todos estos logros científicos, Docobo considera además una prioridad que el Observatorio funcione oficialmente como un Centro de Interpretación del Cosmos, cosa que ya viene haciendo de facto, pero para ello se precisa mucho más apoyo de las instituciones. La divulgación, en este caso de la Astronomía, debe de hacerse por personas muy expertas con altos conocimientos en su materia. Solo así es posible transmitir correctamente los conocimientos a la sociedad, contestar con rigor a cualquier pregunta formulada e incentivar la curiosidad, el pensamiento científico y el gusto por el saber.

Como ya hemos comentado, entre las diferentes líneas de investigación que a día de hoy se cultivan en el OARMA, destaca aquella relativa a las Estrellas Binarias y Múltiples, siguiendo la escuela creada por Ramón María Aller Ulloa [6]. Una binaria es un par de estrellas que debido a su mutua atracción gravitatoria hace que ambas componentes describan órbitas en torno al centro de masas del sistema. Dichos movimientos orbitales son equivalentes a tomar una de las estrellas como fija y estudiar la órbita relativa de la otra en torno a ella. Este es un campo de investigación de enorme interés y es por ello que la IAU le dedica una Comisión, la G1. El valor de las masas estelares (calculadas a partir de las órbitas y de la paralaje) es imprescindible para conocer su camino evolutivo. Esto por si solo ya es una justificación fundamental para el estudio de estos sistemas, pero el interés de su investigación abarca muchas más líneas de trabajo en relación con la formación, estructura, evolución y dinámica de las estrellas. Se estima que más del 50% de las estrellas de nuestra galaxia forman parte de sistemas binarios. Aunque no tan numerosos, los sistemas triples, en los que una tercera estrella orbita el centro de las masas de las otras dos, mucho más cercanas entre sí, son también de gran interés tanto en Astrodinámica como en Astrofísica [11].

El descubrimiento de los movimientos orbitales de las estrellas dobles por parte de William Herschel a finales del siglo XVIII fue la prueba de que la ley de gravitación de Newton era realmente universal ya que antes solo había sido constatada en nuestro Sistema Solar. Ello significó un hito importante en el pensamiento científico, sin duda un gran paso para entender las dinámicas en el Universo.

Hoy en día, las paralajes se obtienen con extraordinaria precisión gracias a las misiones espaciales, especialmente la actual misión Gaia (Gaia Colaboración, 2018), pero, por ello, también necesitamos órbitas muy seguras para que con toda esta información deducir valores de las masas de gran calidad. En este sentido el método analítico ideado por el profesor Docobo en 1985 [12], [13] ha demostrado ser una herramienta enormemente versátil no solo para determinar los elementos orbitales de las binarias visuales, sino también para obtener posteriormente los distintos parámetros estelares deducidos a partir de ellos.

Sin duda debido al gran prestigio que el OARMA consiguió en las últimas décadas, fundamentalmente en el ámbito internacional, el Prof. Docobo fue elegido por votación Vicepresidente de la Comisión 26 (Estrellas Dobles y Múltiples) de la IAU en 2006 para los tres años siguientes, pasando a ocupar la Presidencia en el intervalo 2009 – 2012.

La última parte de la Tesis se corresponde con el estudio de la Astronomía en el mundo árabe, tanto en la antigüedad, como en el medievo y en la actualidad. Dada su amplia extensión hemos considerado oportuno dedicar tres capítulos de la Memoria a este tema. El propósito de esta aportación, también sugerida por el profesor Docobo, es reunir y destacar todas las contribuciones relevantes de la Astronomía árabe a lo largo de los tiempos hasta exponer en detalle el estado actual de la investigación, docencia, infraestructuras, divulgación y proyectos de futuro de los distintos países que componen esta comunidad; nos interesa especialmente hacer un pormenorizado análisis de la Astronomía que se hace hoy en día en esta parte del mundo. La Astronomía árabe que tanto contribuyó en su día no solo al avance de esta ciencia en sí, sino también al de otras relacionadas con ella, como la Historia de la Astronomía, la Historia de la instrumentación científica y de la Filosofía, así como al Pensamiento Científico, merece un minucioso estudio sobre su pasado, presente y futuro. Obviamente para profundizar en todo esto, ha sido preciso realizar un sinfín de consultas tanto a organismos oficiales como particularmente a astrónomos, y en este sentido ha sido fundamental la relación profesional del Director de esta Tesis con su colega el Catedrático jordano, profesor Mashoor Al-Wardat. Gracias a ello, hemos podido disponer de información de primera mano tanto de investigadores como de universidades, institutos de investigación, de los organismos y responsables de conducir la ciencia y la docencia en dichos países. Nuestra visita a la Unión Árabe para la Astronomía y Ciencia del Espacio (AUASS) y al Centro Regional para la Educación en Ciencias del Espacio y Tecnología del Oeste Asiático (RCSSTE) se produjo gracias a la colaboración científica entre estos dos profesores.

En el Capítulo 3, hemos elaborado una completa revisión de la Astronomía árabe correspondiente a las épocas antigua y medieval en tanto que luego, en los Capítulos 4 y 5, nos ocupamos de la época moderna. De esta última, hemos separado las actividades y organizaciones relacionadas con la Astronomía y las Ciencias del Espacio (A&SS), de lo que constituye la educación y divulgación, la investigación científica, los proyectos más destacables de futuro, así como la hoja de ruta para el desarrollo de la A&SS en los países árabes.

El mundo árabe tiene una larga historia en relación con la Astronomía con bien conocidas y relevantes aportaciones ya desde las antiguas civilizaciones de Mesopotamia, Babilonia, y el antiguo Egipto [14]–[17]. Mesopotamia contribuyó eficazmente a la ciencia astronómica, produciendo diarios astronómicos de enorme interés, así como textos relativos a observaciones en tablas cuneiformes, identificando los planetas y proponiendo algunas constelaciones (Leo, Taurus, Scorpius, Auriga, Gemini, Capricorn, y Sagitaurius) que forman parte a día de hoy de las 88 aceptadas oficialmente par la IAU. Los astrónomos mesopotámicos fueron capaces de predecir eclipses de Luna, así como obtener las efemérides de los cuerpos celestes. El logro más importante de esta civilización fue probablemente la mejora de los fundamentos matemáticos de la Astronomía. Los Babilonios, dividieron el cielo en tres partes y crearon el zodíaco. Los antiguos egipcios hicieron grandes avances desarrollando tablas y configurando un calendario basado en la Luna y las estrellas. Dividieron el día en 24 horas y el año en 365 días [18], [19].

Durante la Era medieval, conocida también como edad de oro, la Astronomía árabe alcanzó su máximo esplendor. A partir del siglo VIII fueron traducidos al árabe gran cantidad de manuscritos científicos griegos junto con otros trabajos, salvando para la posteridad el contenido de los tesoros bibliográficos de la malograda Biblioteca de Alejandría. Se establecieron numerosas teorías tanto de Astronomía Esférica como de Matemáticas, fueron construidos Observatorios Astronómicos, inventados instrumentos y mejorado otros, las teorías de Ptolomeo fueron cuestionadas y refinadas, y la Astronomía se separó de la Astrología. Además de todo ello, fueron presentados varios sofisticados modelos Astronómicos [20]–[23].

Ya en la actualidad, en la última década la Astronomía y las Ciencias del Espacio han protagonizado impresionantes avances, tanto desde el punto de vista de la técnica, como de la observación y de los trabajos de índole teórica. Se puede decir que la Astronomía opera como un trampolín que impulsa también la investigación de otras ciencias.

Para animar a las comunidades árabes a introducir estos campos del saber es necesario construir observatorios públicos, incrementar el número de asociaciones astronómicas amateurs, además de organizar proyectos educativos que estimulen el interés en todos los niveles. Actualmente, muchos países árabes tienen importantes programas tanto espaciales como astronómicos que ya han contribuido sustancialmente a avances en ciencia y tecnología y que han motivado a talentos a entrar en estas áreas de la Ciencia. Muy significantes infraestructuras y proyectos han sido desarrollados, en particular La Misión Marciana de los Emiratos (EMM) [24] y el Estudio de Exoplanetas de Qatar (QES) [25].

Sin duda, estratégicos programas a desarrollar próximamente en los países árabes serán garantes de avances en investigación espacial y astronómica, ayudando a alcanzar economías sostenibles en este siglo XXI.

En resumen, la Tesis Doctoral que se presenta con el título " The Evolution of Optical Instrumentation, Laser Technology, and Scientific Thought in Astronomy: the Ramon Maria Aller Astronomical Observatory Activities and Arab Astronomy", está estructurada de la siguiente forma:

Introducción General

Capítulo 1. The Historical Evolution of the Instrumentation and Astronomical Techniques and the Impact of Scientific Thought

Capítulo 2. The Contributions of Binary Star Research to Astronomy and Scientific Thought

Capítulo 3. Astronomy in the Arab World in Ancient and Medieval Times

Capítulo 4. Arab Astronomy and Space Sciences in Modern Times: Activities and Organizations

Capítulo 5. Education, Scientific Research, and Future Outstanding Projects in Arab Astronomy and Space Science

Cada capítulo lleva su propia introducción, conclusiones, y referencias.

Conclusiones

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LIST OF ABBREVIATIONS

A&SS	**A**stronomy and **S**pace **S**ciences
ADS	**A**itken **D**ouble **S**tar Catalog
AIPS	**A**stronomical **I**mage **P**rocessing **S**ystem
ALFA	**A**daptive **O**ptics with **L**aser for **A**stronomy
ALMA	**A**tacama **L**arge **M**illimeter/Submillimeter **A**rray
ALTAIR	**ALT**titude conjugate **A**daptive optics for the **I**nfra**R**ed
AO	**A**daptive **O**ptics
ArAS	**Ar**ab **A**stronomical **S**ociety
ArAS-MO	**Ar**ab **A**stronomical **S**ociety **M**obile **O**bservatory
ASAL	**A**lgerian **S**pace **A**gency (**A**gence **S**patiale **AL**gérienne)
AU	**A**stronomical **U**nit
AUASS	**A**rab **U**nion for **A**stronomy and **S**pace **S**cience
AVLIS	**A**tomic **V**apor **L**aser **I**sotope **S**eparation
AW-ROAD	**A**rab **R**egional **O**ffice of **A**stronomy for **D**evelopment
AWSA	**A**rab **W**inter **S**chool for **A**strophysics
BAO	**B**yurakan **A**strophysical **O**bservatory
BD	**B**onner **D**urchmusterung Star Catalogue
BDS	**B**urnham **D**ouble **S**tar Catalog
CCD	**C**harged-**C**oupled **D**evice
CFHT	**C**anada–**F**rance–**H**awaii **T**elescope team
CGRO	**C**ompton **G**amma-**R**ay **S**pace Telescope Observatory
CHARA	**C**enter for **H**igh **A**ngular **R**esolution **A**stronomy
CoRoT	**Co**nvection, **Ro**tation and planetary **T**ransits
CRAAG	**C**enter for **R**esearch in **A**stronomy, **A**strophysics, and **G**eophysics
CSA	**C**anadian **S**pace **A**gency
CVBS	**C**lose **V**isual **B**inary **S**tars
CXO	**C**handra **X**-Ray Space **O**bservatory
DARPA	**D**efense **A**dvanced **R**esearch **P**rojects **A**gency
E-ELT	**E**uropean **E**xtremely **L**arge **T**elescope
ELOT	**E**gyptian **L**arge **O**ptical **T**elescope
ELTs	**E**xtremely **L**arge **T**elescope
EM	**E**lectro**M**agnetic
EMCCD	**E**lectron **M**ultiplying **C**harged-**C**oupled **D**evice
EMM	**E**mirate **M**ars **M**ission
ESA	**E**uropean **S**pace **A**gency
ESIG	**E**mirates **S**pace **I**nnovation **G**roup
ESO	**E**uropean **S**outhern **O**bservatory
EUVE	**E**xtreme **U**ltra**V**iolet **E**xplorer
EVO	**E**gyptian **V**irtual **O**bservatory
EXOSAT	**E**uropean **X**-ray **O**bservatory **SAT**ellite

FGS/TFI	**F**ine **G**uidance **C**amera hold a Near-Infrared **T**uneable **F**ilter **I**maging
FIRST	**F**ar **I**nfra**R**ed and **S**ubmillimetre Space **T**elescope
FMRO	**F**arid and **M**oussa **R**aphael **O**bservatory
FUSE	**F**ar **U**ltraviolet **S**pectroscopic **E**xplorer
GAIA	**G**lobal **A**strometric **I**nterferometer for **A**strophysics
Gaia DR1	First **Gaia D**ata **D**elease
Gaia DR2	Second **Gaia D**ata **D**elease
GALEX	**GA**laxy **E**volution **Ex**plorer
GMT	**G**iant **M**agellan **T**elescope
GORS	**G**eneral **O**rganization of **R**emote **S**ensing
GW	**G**ravitational **W**aves
Hipparcos	**HI**gh **P**recision **PAR**allax **CO**llecting **S**atellite
HST	**H**ubble **S**pace **T**elescope
IAC	**I**nternational **A**stronomical **C**enter
IASS	**I**nstitute of **A**stronomy and **S**pace **S**cience at Al al-Bayt University
IAU	**I**nternational **A**stronomical **U**nion
IAUDS	**I**nternational **A**stronomical **U**nion Commission 26 (**D**ouble **S**tars) /Commission G1 Information Circular
ICOP	**I**slamic **C**rescents **O**bservation **P**roject
IDL	**I**nteractive **D**ata **L**anguage
IDS	**I**ndex Catalogue of Visual **D**ouble **S**tars
INAO	**I**raqi **N**ational **A**stronomical **O**bservatory
INT4	**Fourth** Catalog of **Int**erferometric Measurements
INTEGRAL	**INTE**rnational **G**amma-**R**ay **A**strophysics **L**aboratory
IR	**I**nfra**R**ed
IRAF	**I**mage **R**eduction and **A**nalysis **F**acility
ISRA	**I**nstitute of **S**pace **R**esearch and **A**erospace
IUE	**I**nternational **U**ltraviolet **E**xplorer
JAS	**J**ordanian **A**stronomical **S**ociety
JCR	**J**ournal **C**itation **R**eport
JWST	**J**ames **W**ebb **S**pace **T**elescope
KACST	**K**ing **A**bdulaziz **C**ity for **S**cience and **T**echnology
KAO	**K**ottamia **A**stronomical **O**bservatory
KCSCE	**K**ottamia **C**enter of **SC**ientific **E**xcellence of Astronomy and Space Sciences
KNRO	**K**uwait **N**ational **R**adio **O**bservatory
KSA	**K**ingdome of **S**audi **A**rabia
LASER	**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
LBOI	**L**ong-**B**aseline **O**ptical **I**nterferometry
LBT	**L**arge **B**inocular **T**elescope
LBT	**L**arge **B**inocular **T**elescope
LCRSSS	**L**ibyan **C**enter for **R**emote **S**ensing and **S**pace **S**cience
LGS	**L**aser **G**uide **S**tars
LIGO	**L**aser **I**nterferometer **G**ravitational-Wave **O**bservatory

LISA	**L**aser Space-based **I**nterferometer **S**pace **A**ntenna
LLNL	**L**awrence **L**ivermore **N**ational **L**aboratory
LSST	**L**arge **S**ynoptic **S**urvey **T**elescope
LTAO	**L**aser **T**omography **A**daptive **O**ptics
MACAO	**M**ultiple **A**pplication **C**urvature **A**daptive **O**ptics
MBRSC	**M**ohammed **B**in **R**ashid **S**pace **C**entre
MIDAS	**M**otif **I**nteractive **D**ata **A**nalysis **S**ystem
MK	**M**organ-**K**eenan
NARSS	**N**ational **A**uthority for **R**emote **S**ensing & **S**pace Sciences
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NGS	**N**atural **G**uide **S**tar
NGST	**N**ext **G**eneration **S**pace **T**elescopes
NIRSpec	Wide-Field Multi-Object **N**ear-**I**nfra**R**ed **Spec**trometer
NORT	**N**etwork of **O**riental **R**obotic **T**elescope Project
NRIAG	**N**ational **R**esearch **I**nstitute of **A**stronomy and **G**eophysics
NSSTC	**N**ational **S**pace **S**cience and **T**echnology **C**enter
OAO	**O**rbiting **A**stronomical **O**bservatory
OARMA	**O**bservatorio **A**stronómico **R**amón **M**aría **A**ller / Ramon Maria Aller Astronomical Observatory
OARMAC	**OARMA** Binary star orbits **C**atalog
OAS	**O**man **A**stronomical **S**ociety
PARSEC	**P**aranal **A**rtificial **R**eference **S**ource for **E**xtended **C**overage
QAC	**Q**atar **A**stronomical **C**enter
QEERI	**Q**atar **E**nvironment and **E**nergy **R**esearch **I**nstitute
QES	**Q**atar **E**xoplanet **S**urvey
RAS	**R**ussian **A**cademy of **S**cience
RCSSTE-WE	**R**egional **C**entre for **S**pace **S**cience and **T**echnology **E**ducation for **W**estern **A**sia
RMS (r.m.s)	**R**oot **M**ean **S**quare
RTAC	**R**eal-**T**ime **A**tmospheric **C**ompensation
SAA	**S**irius **A**stronomy **A**ssociation
SAO	**S**pecial **A**strophysical **O**bservatory
SASGP	**S**audi **A**rabian **S**pace **G**eodesy **P**rogram
SB1	**S**ingle-lined **1** **S**pectroscopic **B**inary
SB2	Double-lined **2** **S**pectroscopic **B**inary
SCASS	**S**harjah **C**enter for **A**stronomy and **S**pace **S**ciences
SCRS	**S**audi **C**enter for **R**emote **S**ensing and GIS Center
SDS	**S**outhern **D**ouble **S**tar Catalogue
SED	**S**pectral Energy **D**istribution
SEOS	**S**udan **E**arth **O**bservation **S**atellite
SI	**S**peckle **I**nterferometry
SIMBAD	**S**et of **I**ndications **M**easurements and **B**ibliography for **A**stronomical **D**ata
SIRTF	**S**pace **I**nfrared **T**elescope **F**acility
SKA	**S**quare **K**ilometre **A**rray (Radio Telescope)

SOAR	**SO**uthern **A**strophysical **R**esearch (Telescope)
SRSSA	**S**udanese **R**emote **S**ensing and **S**eismology **A**uthority
SSASS	**S**udanese **S**ociety for **A**stronomy and **S**pace **S**cience
SSP	**S**audi **S**atellite **P**rogram
ST	**S**pace **T**elescopes
TMT	**T**hirty-**M**eter **T**elescope
TMT	**T**hirty-**M**eter **T**elescope
TRAPPIST	**TRA**nsiting **P**lanets and **P**lanetesImals **S**mall **T**elescope
TSA	**T**unisian **S**pace **A**gency Society
UACN	**U**AE **A**stronomical **C**ameras **N**etwork
UAE	**U**nited **A**rab **E**mirates
UAESA	**U**nited **A**rab **E**mirates **S**pace **A**gency
USC	**U**niversidade de **S**antiago de **C**ompostela / **U**niversity of **S**antiago de **C**ompostela
UV	**Ul**tra**V**iolet
VLT	**V**ery **L**arge **T**elescope
WDS	**W**ashington **D**ouble **S**tars
WFE	**W**ave-**F**ront **E**rror
WFS	**W**ave **F**ront **S**ensor
WSO–UV	**W**orld **S**pace **O**bservatory-**U**ltra**V**iolet Project

INTRODUCTION

We cannot perceive that the planet we inhabit is in rotation and this has been a factor in a very long historical controversy as to whether the Earth is at the center of the Universe or not. Likewise, there are multiple phenomena and concepts that we cannot easily assimilate. Space, time, and life itself form a trilogy that is at least difficult for human beings to explain. The Andromeda galaxy is the most distant object that we can see with the naked eye. However, when we are observing it on a dark autumn night, it is difficult to comprehend when we know that we are seeing it as it was two and a half million years ago and not as it is right now.

The human, even if he/she wants to try to explain everything, soon finds his/her own limitations. The dimensions of the Cosmos are unimaginable to us as is its origin. What was there before the Big Bang? Is the Universe we know unique? These are some of the questions that the everyday people may ask themselves from time to time in relation to the Universe but immediately forgets about in the certainty that nobody is going to give him a definitive answer. Science has its most plausible theory, but doubt remain. On the other hand, religions often give us a biased vision of reality among other things because their existence is based on the weakness of our thinking and on the need we have for someone to help us understand the meaning of our existence and above all of our end. However, deep down, even if the very believers do not share it, they are still human products.

Our multiple, numerous, and stressful daily activities taking us away are from the reality of the Cosmos. In the cities, light pollution is the main ally of the loss of our contact with heaven. Daily life tends to make us not even consider our place in the Universe. We believe that our planet is the whole and that everything else is out there, very far away, and many times when we look at the sky at night we see that many people lack the ability to distinguish objects that we know are very close from others that are extremely distant. It's us and outer space. Without intending to, we return to Ptolemy's Geocentrism [1] and, to some extent, this is natural as it is our most basic perception [2].

In fact, Philosophy and Science are intertwined disciplines and have always evolved together, each influencing and being influenced by the other [3]. There was no real distinction between scientists and philosophers until the 19th century. Maybe we can argue that science could not exist without philosophy, in other words, we can say that science provided philosophy a way of empirically testing theories and concepts, while philosophy has assisted in supporting the scientific method used today. Philosophy also dictates what areas science can and cannot verify, delineating the boundary between physical and metaphysical questions. While science and technology are interwoven, the progress of science, in general, and Astronomy, in particular, depend on the sophistication of optical instruments and their techniques, whereas the progress of high-technology instruments and apparatus is dependent and based on scientific thought. From this perspective, we attempt to understand the key role of how scientific thought merges with historical evolution in order to promote the new revolution in astronomical instruments and laser technology [4].

The study of the History and Philosophy of Science affords a broad appreciation of all sciences in terms of their nature and fundamentals, origins, and place in the scientific revolution and impact role in the metamorphosis to modern civilization [5]. In the History of Science, some of the traditional historical methods are used to study the perception of how the sciences started, how they were employed to develop the human reasoning, how they evolved, and how they are linked to their mental and cultural contexts. In the philosophy of science, the sciences themselves are brought under thoughtful philosophical analysis in order to investigate the nature of science in general. It allowed us to distinguish between scientific activities, how theories are formed, explained, and confirmed [6]. It afforded explanations about moral dilemmas raised by the sciences as well as investigated the fundamental content of individual sciences and how it bears on the ancient philosophical questions: what is the nature of space, time, and matter; what is life; and what is thought?. On the other hand, History and Philosophy of Science are peculiar in integrating history, philosophy, and science with investigations in each that are often strictly interwoven [7].

In addition, the study of the History of Science also developed very significantly during the 20th century and it has two principal functions: the first is to understand how scientific knowledge grows and the second is to understand the notion of science itself which involves the questions of what methods are genuinely scientific and what kind of knowledge science actually offers us. Furthermore, the History of Science involves various facts about things that occurred in many different times in the past and compiling it in order to bring out the relationships between facts, indicating where there is continuity and where there is a break with the past. In reality, it necessary to take into account the personalities of scientists themselves in order to realize how they arrived at their various outcomes. Also, studying the History and Philosophy of Science makes us perceive a dimension of intellectual work that is sometimes overlooked, in other words, the social and spiritual circumstances in which work is done.

The relationship between scientists and philosophers in modern times are tense and unhealthy. Stephen Hawking in his book, ‘’The Grand Design: new answers to the ultimate questions of life’’ (co-authored with Leonard Mlodinow and published in 2011) [8]. He said that " We each exist for but a short time and, in that time, we explore but a small part of the entire Universe. But humans are a curious species. We wonder, we seek answers. Living in this vast world that is by turns kind and cruel and gazing at the immense heavens above, people have always asked a multitude of questions: How can we understand the world in which we find ourselves? How does the universe behave? What is the nature of reality? Where did of all this come from? Most of us do not spend most of our time worrying about these questions but almost all of us think about them some of the time. Traditionally, these are questions for philosophy, but philosophy is dead'. Philosophy has not kept up with modern developments in science, particularly physics. Scientists have become the bearers of the torch of discovery in our quest for knowledge". He also continued "the fundamental questions about the nature of the Universe could not be resolved without hard data such as that currently being derived from the Large Hadron Collider and Space research".

The foremost intention of this work is to improve, promote, advocate, and disseminate this area of research in Arab countries. Nowadays, as our Arab reality is witnessing a decline in the level of scientific thinking on the one hand, and the level of philosophical reflection on the other [9], it is necessary to further focus on this area of research in order to grasp the Philosophy and History of Science. This information helps us to understand the educational and cultural dimensions that help scientific progress in that region of the world [10], [11]. As a matter of fact, the Arab communities desperately need it as soon as possible.

Astronomy is perhaps the best illustration of significant research aiming to develop our thought and knowledge well beyond our World [12]. Astronomy is also an excellent case to understand the intricate relationship between Science, Technology, and Philosophy. Furthermore, Astronomy is a subject that naturally encourages and inspires global partnership and collaboration. Astronomers have been studying the phenomena that occur in the same sky with similar aims to understand and common databases that are accumulated and accessed. Today, astronomical facilities such as world-class telescopes commonly are open to international guest observers and global cooperation n in the development, construction, and operation of powerful new facilities as well as future projects is common.

Historically, Philosophy, from one hand and Astronomy, on the other hand, have been highly integrated disciplines, philosophers argued that Astronomy was born from Philosophy.

Nevertheless, after the exceptional revolution in observational instrumentations and their technologies, Astronomy distanced itself from the philosophical method, leading to a dramatic change in methodology and Philosophy of Science. Scientists and philosophers have both attempted to understand the origin of the Universe [13], the origin of the human being, and human consciousness in order to decode our potential future, our identities, our cultures, and civilizations by means of the latest generation of scientific instruments, technologies, and discoveries in Astronomy science. Consequently, the Philosophy, as an important means of enhancing perception and knowledge, should no longer be an isolated domain of natural science. It must develop a strong relationship with these scientific disciplines, which are reflected in a renovated and powerful sense of the relationship between Philosophy, Science, and Technology [14].

In our work, we will layout a selective summary of Philosophy aiming to pinpoint some relevant highlights as developed from its earliest roots. We will relate how, over the centuries, improved scientific optical devices and new astronomical technology led to remarkable and revolutionary advances in understanding our place in the Universe. In that sense, we attempt to describe the complex interaction between Astronomy, optical instruments, astronomical techniques, and technology developments based on advanced scientific reflection. On the other hand, open discussion and fruitful collaboration between astronomers and philosophers are required for the betterment of both academic fields, scientific astronomical research, and knowledge as a whole. Philosophical intervention is necessary for answering some of the most fundamental difficulties in Astronomy and collaboration between the two disciplines must continue to increase in the coming years.

As a matter of fact, Philosophy and the History of Science had paramount impact on technological advances in the astronomical instrumentations in past centuries. Therefore, we think further knowledge can contribute to our recognition and planning of longer-term evolution of the optical tools and laser technology. Some questions to consider are, what could be the implications of the results coming from these improvements?, what are the limitations to knowledge that we can obtain?, to what level of accuracy of the Cosmos phenomena can be tackled by these future cutting-edge technologies?, and many other relevant issues and explanations about the prediction of the origin of the Universe.

In this Dissertation, we present the emblematic books on Philosophy and the History of Science. Understanding Philosophy of Science by James Ladyman [15], The Structure of Scientific Revolutions by Thomas S. Kuhn [16], The Invention of Science: The Scientific Revolution from 1500 to 1750 by David Wootton [17], The Norton History of Astronomy and Cosmology by John D. North and N. Swerdlow [18], Theories of the World from Antiquity to the Copernican Revolution by Michael Crowe [19], Modern Theories of the Universe from Herschel to Hubble by Michael J. Crowe [20], Astronomy through the Ages: The Story of the Human Attempt to Understand the Universe By Robert Wilson [21], Stargazer: The Life and Times of the Telescope By Fred Watson [22], Integrating History and Philosophy of Science - Problem, and Prospect by R. Cohen, J. Renn, and K. Govroglu [23], An Introduction to the History and Philosophy of Science by R. DeWitt [24], Scientific Controversies: Philosophical and Historical Perspectives By Peter Machamer [25], Ground breaking Scientific Experiments, Inventions, and Discoveries of the 17th Century By Michael Windelspecht [26], and Instrumental Realism: The Interface between Philosophy of Science and Philosophy of Technology by D. Ihde [4] as well as others are essential references that provide a wide perspective in this subject.

Even though in ancient Greece, Aristarchus of Samos conceived of the Earth as just another planet around the Sun, the fact is that his innovative idea was forgotten and geocentrism took hold of humanity until Copernicus in the 16th century postulated that it was the Sun that really occupied the central position in the Universe. (Figure 0-1). Even so, his legacy took time to be accepted. Symbolic figures such as Tycho Brahe created their own model with the Earth at the center again, the Sun moving around it and the rest of the planets revolving around the Sun. His disciple, Kepler, was a fervent follower of Copernican ideas, and that, together with the collection of measurements of the positions of Mars obtained by Tycho Brahe, enabled Kepler to enunciate the three laws governing planetary motion in the early 17th century [27] [55]. (Figure 0-2).

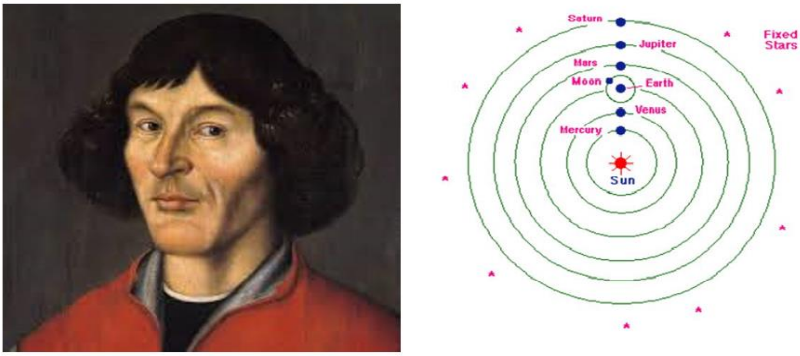

Figure 0-1 Left, Nicolas Copernicus (1473 – 1543), the astronomer who began the revolution in modern Astronomy, Right, the Copernican Universe Model (Credit: https://www.pas.rochester.edu/~blackman/ast104/copernican9.html)

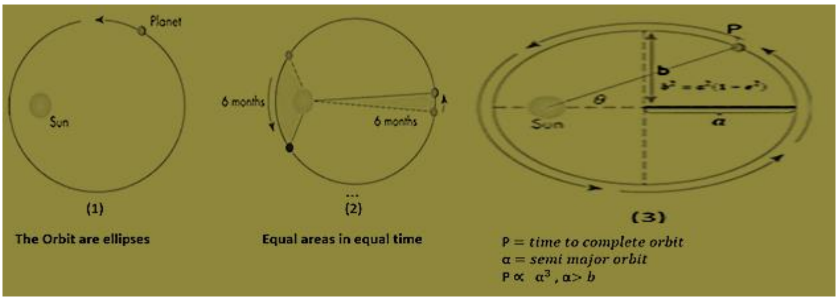

Figure 0-2 Kepler's Three Laws of the Planetary Motion (Source: https://www.helioseducore.com/keplers-laws-of-planetary-motion/)

During the Golden Age of Astronomy, the telescope had been invented, perhaps by Hans Lippershey in 1608 [28]. Later, Galileo Galilei made his improved version of the telescope in 1609 and he carried out the first observations of celestial objects with this instrument. The telescope that directed at the sky allowed him first to observe the Lunar craters, the star conglomerate of the Milky Way, and in the early January 1610, the four brightest satellites of Jupiter (Figure 0-3) [29]. In the following months, he observed the phases of Venus, the sunspots and the "strange" shape of Saturn. All this constituted a real revolution in the knowledge of the Cosmos and contributed drastically to the unstoppable advance of Astronomy as a science [30]. The discovery of the so-called Galilean satellites of Jupiter (Figure 0-4) was fundamental. Another celestial body had appeared in relation to which other stars were moving. As a matter of fact, there was no single attractor in the Universe. The first telescope was refractor type and its design were based on lenses in 1609. A few decades after that, Isaac Newton introduced the first reflecting telescope, using mirrors. For more than four centuries following that, scientists have continued to develop and improve telescopes and their capabilities have increased dramatically with time [55].

In the same 17th century, Isaac Newton established the Law of Universal Gravitation which provides a scientific basis for Kepler's three empirical laws by accounting for the force that keeps the planets in orbit around the Sun, the Moon in relation to the Earth, and Jupiter's satellites in their movement around this planet. His friend, Edmund Halley, realized that the comet that came in 1531, 1607, and 1682 was the same one and that it would return in 1757. It did so at the end of 1758, but the prognosis was still good, and it was named Halley's comet in his honor. It was thus proven that comets also fulfilled Kepler's laws, but Halley's most important discovery was not this one [55].

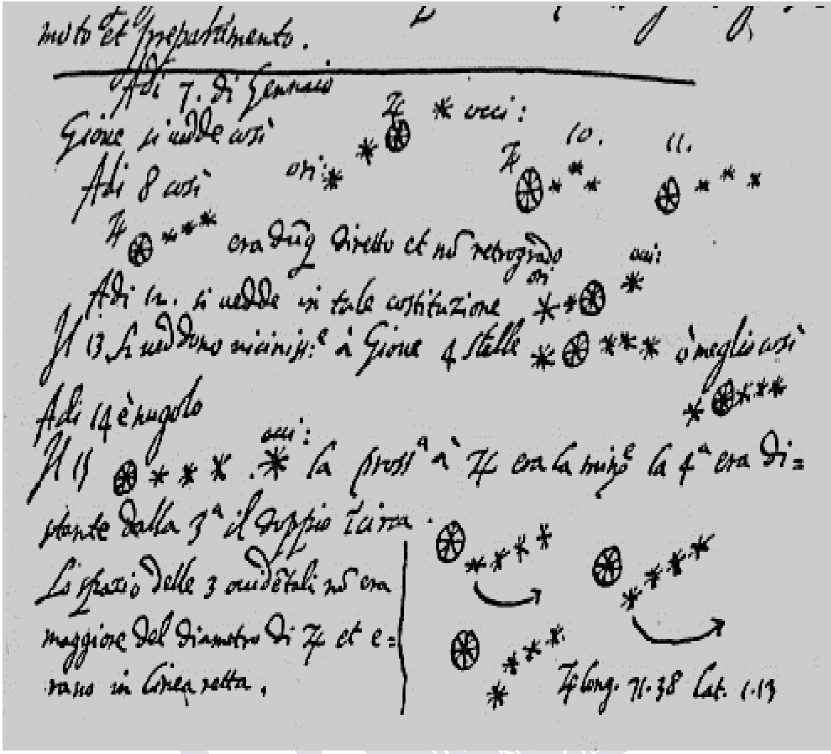

Figure 0-3 Galileo's first recording of the moons near Jupiter, the "Ann Arbor manuscript" from January 1610 (Credit: the University of Michigan Library)

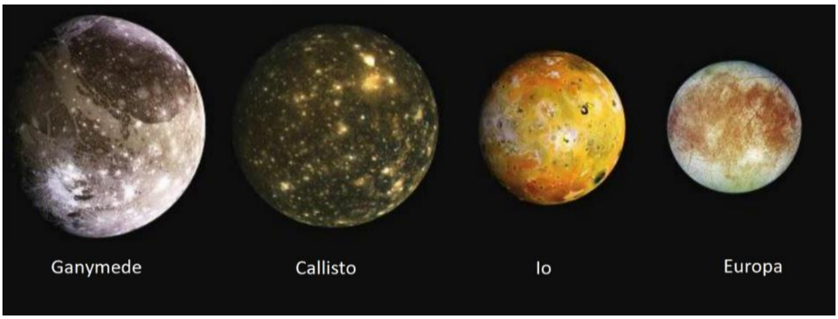

Figure 0-4 Galilean satellites of Jupiter were discovered by Galileo Galilei in 1610 (Credit: NASA)

The Heliocentric Model of the Solar System was already established and recognized but what about the stars? It was still admitted that they were all above a celestial vault of the incalculable radius. The work of Edmund Halley led to an important advance in knowledge concerning the stellar world by discovering the Proper Motion of the stars [31] [32]. The fact that some of the stars had moved more than others since antiquity made him think that not all of the stars are located at the same distance from us. Based on that idea, he endeavoured to measure said distances, at least of the most brilliant stars that he supposed are closer to us [33].

Several important astronomers tried to measure said stellar distances without success, for example, Sir William Herschel (Figure 0-5), who discovered the planet, Uranus, among other things. Herschel's reasoning was logical. A nearby star observed from Earth throughout the year should describe on apparent small ellipse against the background of distance stars which is called the ellipse of the parallax (Figure 0-6) [34]. For that reason, Herschel selected pairs of stars apparently very close to each other with one much brighter that the other. Base on that, he supposed that the brilliant star is closer to us and the other much farther away. Therefore, due to parallactic movement, the brighter star, should move around the dimmer star.

Obviously, said movement should have an annual periodicity that would reflect the movement of the Earth around the Sun. Herschel was able to perceive said movement, but it would take more than a year to be completed. However, that was not the searched for parallactic movement. Instead, he was discovering the orbital movement of double stars. The detection of the ellipse of the parallax was much more difficult due to the enormous distances at which the stars are located. Finally, in 1838, Friedrich Bessel successfully accomplished the task.

Figure 0-5 A German-born British astronomer Frederick William Herschel (1738 – 1822) was one of the great observers of all times (Credit: http://planetfacts.org/william-herschel)

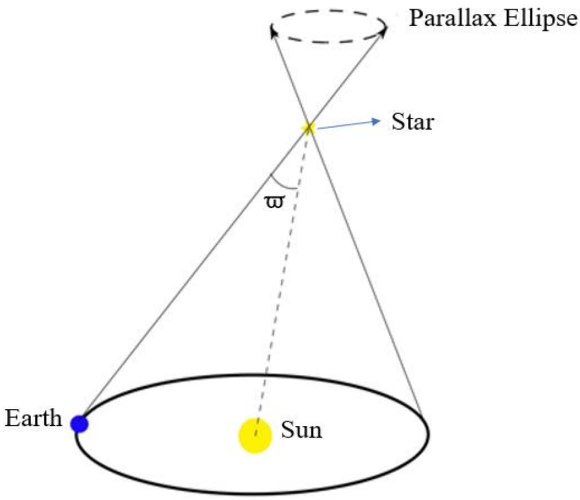

Figure 0-6 The parallactic movement: the Earth orbit and the parallax ellipse of a star

During the 18th and 19th centuries, the knowledge of the Solar System grew thanks to both the mathematical advance in the calculation of orbits and the discoveries of two planets: Uranus, coincidentally by Herschel, and Neptune, which was a consequence of the astronomical calculation taking into account the perturbations observed in the orbit of Uranus. The truth is that at the beginning of the 20th century, it was still assumed that the Universe was circumscribed to a single entity to which all observed objects belonged. The distances measured through the variables of the Cepheid stars and, above all, Hubble's Law allowed us to confirm what was already assumed, that those spiral-shaped objects that were observed everywhere were other galaxies different from ours, the Milky Way.

A gradual shift of emphasis from Astronomy to Astrophysics took place through the 19th century [35]. It can be attributed to three critical technical breakthroughs: the measurements of reliable distances for the stars by the method of geometric parallax, the development of spectroscopy as a tool for astrophysics, and the invention of photography. These developments, in turn, necessitated improvements in the design and construction of telescopes. The combination of these technological developments and advances in the understanding of fundamental physical processes led to the extraordinary growth of Astrophysics and Cosmology in the 20th and 21st centuries. Moreover, spectroscopy had played a significant role with applications ranging from the study of celestial dynamics, chemical properties, Universe dynamics, and, more recently, the search and characterization for extrasolar planets. The most revolutionary development in observational Astronomy in the 20th century was the transition from discovering with the human eye, to the photographic plates of the late 19th century, to the high-efficiency solid-state detectors of the last century.

Until the middle of the 20th century, progress in astronomical observation ran into almost insurmountable problems imposed by the Earth’s atmosphere at that time. Scientific advances came with new techniques such as Adaptive Optics (AO) and Laser Technology to overcome this issue. New windows were opened on the entire domain of the electromagnetic spectra, such as Radio, Infrared, Gamma-ray, and X-ray as well as the Gravitational-waves since the late 20th century. In the last decades, unprecedented spatial and angular observations made from Space Telescopes placed above the Earth's atmosphere that have ushered in renewed and unparalleled progress in Astronomy and Astrophysics research capability. In the future, newly precision-industrial technologies in Quantum and Photonic Optics will enable further progress in enhancing the capabilities of these instruments and techniques while potentially reducing the size and cost.

Throughout the last century, the hierarchical nature of the Universe has been perfectly established [36]. Our Solar System along with approximately two hundred thousand million other stars constitutes a unit with a barred spiral form that is the Milky Way Galaxy (our galaxy). It is written with capital letters and it, along with others (more than forty), form the denominated Local Group to which Andromeda also belongs (figure 0-7) as well as our satellite galaxies, the Clouds of Magallanes.

In turn, the Local Group [37] with other groups of galaxies constitutes the Virgo supercluster [38] which, in turn, is within the Laniakea supercluster [39] and so on. The number of galaxies in the known universe may exceed two hundred billion. Humans landed on the Moon 50 years ago and, after dozens of space missions, we think of one day reaching the planet, Mars, which on an astronomical scale, is right next door. But landing on our natural satellite, the Moon was almost an unthinkable achievement. Humanity demonstrated the technological capacity to be able to walk on a heavenly body situated almost four hundred thousand kilometers away but, psychologically, it meant more. Human beings had entered the Cosmos for the first time.

Figure 0-7 The Andromeda galaxy. One of the galaxies belonging to the Local Group which is larger than the Milky Way (Credit: NASA)

On the other hand, one of the most fundamental questions any human being can ask is: are we alone in the Cosmos? Maybe this question is as old as humankind itself [40]. Before we can answer if there are other planetary systems capable of supporting life, we must first find them. In the last three decades, scientists have begun to discover the exoplanets [41]. An exoplanet is known as a planet moving around other stars. Exoplanets are fascinating because they may solve mysteries about our Solar System. There is a wealth of data available to study different types of galaxies and stars which has enabled astronomers to develop models and theories on star and galaxy formation and to place our galaxy and star among them. It is striking, however, that already in the 16th-century thinkers like Giordano Bruno suggested that the stars were other suns and therefore capable of retaining planets around them [42]. However, their discovery was not possible until the technology advanced enough to create high-resolution spectrometry and hypersensitive photometers.

The science of exoplanet detection is still in its infancy but, in the coming years, humankind will make great progress in this field. We must clarify, of course, that all of the discovered planets, Super-Jupiter, Hot-Jupiter, Neptune-Like, Super-Earths, and Rocky Planet, are in our vicinity. The great majority are less than 1,000 light-years away and all belong to our Galaxy; the total number of exoplanets discovered by all observatories as well as space missions is more than 4000. However, our current instruments and technology do not yet allow us to detect life on other planets. In this sense, the next launching of the James Webb Space Telescope (JWST) represents a great hope as it is equipped with indicators that can provide us with reliable data on the existence of characteristics in these planets and even on the elements that make them up [43].

The formation of planetary systems is considered natural today as a by-product of star formation, so it would not be unreasonable to admit that in the Milky Way alone there may be more than ten billion planetary systems. It is true that around very different types of stars the so-called habitable zones around them differ considerably due to the stellar temperatures themselves. Even so, it is possible that, of that number, a million of them may have planets similar to ours, that is, with an atmosphere and liquid water or, in other words, habitable.

We find it very difficult to admit that the conditions that once existed on Earth could have existed on other exoplanets, all because we still believe ourselves to be the brain of the Cosmos when we only live on a fragile planet that moves around an ordinary star. If our planet were, for example, in the Andromeda galaxy, we would probably never know from there that this solar system to which we belong exists. Furthermore, how many habitable and inhabited planets, like ours, can there be in the Universe? Probably hundreds of millions. Then why haven't that possible inhabitants contacted us? Simply because we were isolated. The light emitted by the closest star to the sun, Proxima Centauri, takes more than four years to reach us. NASA's Kepler Space Mission discovered and confirmed the first Earth-size planet (in the habitable zone) in 2014 and named it Kepler-186f [44]. (Figure 0-8). The Kepler-186f was detected by using the transit method with a period of 130 days and a distance of 582 light-years (LY). Furthermore, the Trappist-1 planetary system (Figure 0-9) discovered by NASA just over two or three years ago, with three planets in the habitable zone, is 39.6 light-years away [45]. We always talk about the aliens and us, without thinking that there may be different civilizations already in contact with each other, and this could be possible both in the Galaxy and in many other galaxies. Our isolation (not loneliness) may be eternal because of the vast distances that separate us from other stars.

The Earth, as a planet, is about four billion years old and life emerged only about two or three hundred million years later. This is very little on a geological scale which indicates that the appearance of life can be a natural event, not as complicated as we often say. There was indeed a very long evolution (which is still going on) in which complex cells, plants, invertebrates, vertebrates, hominids, and present-day human beings successively appeared but to say that all this is a miracle and challenging to reproduce in any other part of the Cosmos is ridiculous. It's like going back to Geocentrism with a lack of perspective on what it means that there could be billions of situations where similar incidents occur and whose result could be, in some instances, individuals who are different but more intelligent than we are. We remain in irrational social Geocentrism.

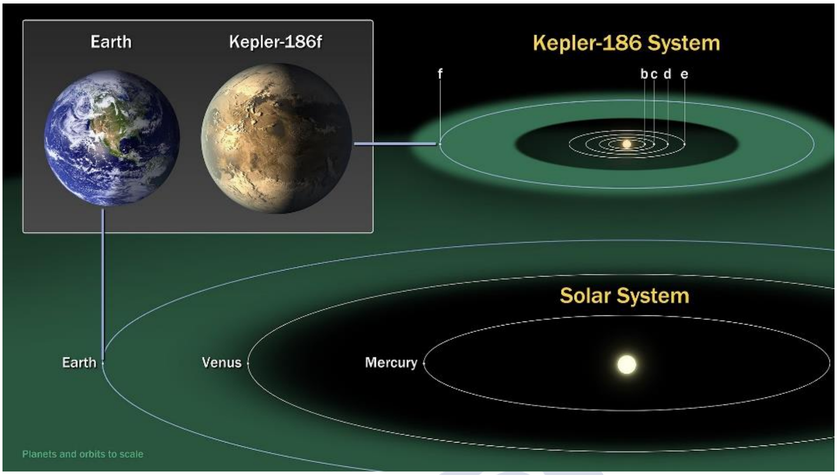

Figure 0-8 The first Earth-sized exoplanet Kepler-186f discovered by the Kepler Space Telescope in 2014 (Credit: NASA)

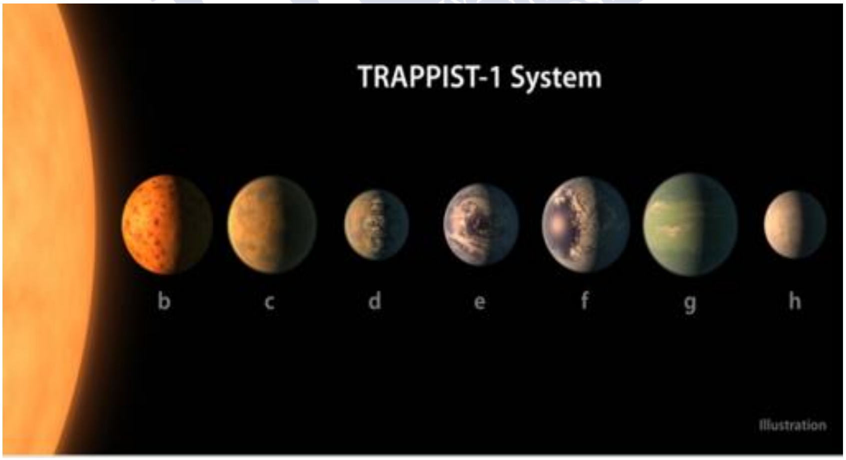

Figure 0-9 The TRAPPIST-1 is a planetary system consisting of 7 exoplanets, located 39.6 light-years away from the Solar system near the ecliptic, in the constellation of Aquarius (Credit: NASA)

In discussing the historical study of science, we must identify types of knowledge that have become known, with time, as science. Developments in the sciences show that we can identify three broad areas of knowledge that would qualify as science, thus: natural science, social science, and applied science. It is the concern of natural science, in general, and Astronomy, in particular, to use observation and empirical evidence in describing, predicting, and understanding natural phenomena or occurrences which led to the development of scientific instruments, in general, and astronomical optical devices, in particular. The history of the development of optical instrumentations and their cutting-edge technologies played a crucial role in our understanding of the nature of our Universe as well as any other part of our understanding of the nature of modern human existence.

The next part of our research will be concentrated on the study of the binary and multiple stars at the Ramón Maria Aller Astronomical Observatory (OARMA, http://www.usc.es/astro) at the University of Santiago de Compostela (USC). OARMA has played a vital role in the enrichment of scientific knowledge and thought in Astronomy in Spain, in general, and, Galicia, in particular. Today OARMA is an international reference regarding double and multiple stars [46], [47]. It was founded in 1943 by Father Aller as a continuation of his personal Observatory in his birthplace of Lalín (Pontevedra). Aller brought his principal observation instruments with him to Compostela. Among them, the Steinheil refractor and the teodolite stand out. After some difficult years following the death of Prof. Ramón Mria Allerduring which the Observatory lacked scientific direction, the Center was physically and scientifically recuperated beginning in 1981 when Dr. José Angel Docobo came back to Santiago de Compostela and was named as the Director of OARMA in 1983. Although he is Galician, he returned from the University of Zaragoza where he was teaching and completed his Ph. D. in Astronomy under the direction of Professor Dr. Rafael Cid.

OARMA is a unique Astronomical Observatory in the Galician University System after great efforts and accomplishments on numerous fronts including budget and financial support, personnel, instrumentation, library, observation campaigns at large international Observatories, conference organization, publication of a great number of research articles in indexed journals. The long list of OARMA publications can be consulted on its website (http://www.usc.es/astro/publicaciones/publicacionesing.htm), but it should also be noted that the catalog of OARMAC (binary star orbits and ephemeris) has been compiled, and the Information Circular of IAU Commission G1 (formerly Commission 26) has been published by OARMA members since 1993. Furthermore, the direction of doctoral dissertations, teaching in various Departments, the initiation of novel initiatives in the field of diffusion, etc. OARMA functions include research, teaching, diffusion, and operation of the meteorological station. Those are the four pillars of the Observatory which Prof. Docobo directs and cares for as though they were his own children.

The quality of teaching of the OARMA team in Mathematics, Physics, Optics, and Cycle 4 (for people older than 50 years) has been established for years. Diffusion programs developed by Dr. Docobo such as PECAS (The Cultural Extensión Program in Astronomy) or TODOCOSMOS (with activities in 50 Galician localities) are recognized, including at the National level. The meteorological station is both manual and automatic and is coordinated with the State National Agency of Meteorology (AEMET). There is a collection of uninterrupted daily data since 1982. The Observatory has a 0.62-m aperture telescope, the second one in the Spanish University system, as well as several telescopes and two cutting-edge Speckle Interferometry Cameras, among other instrumentations. (Figure 0-10).

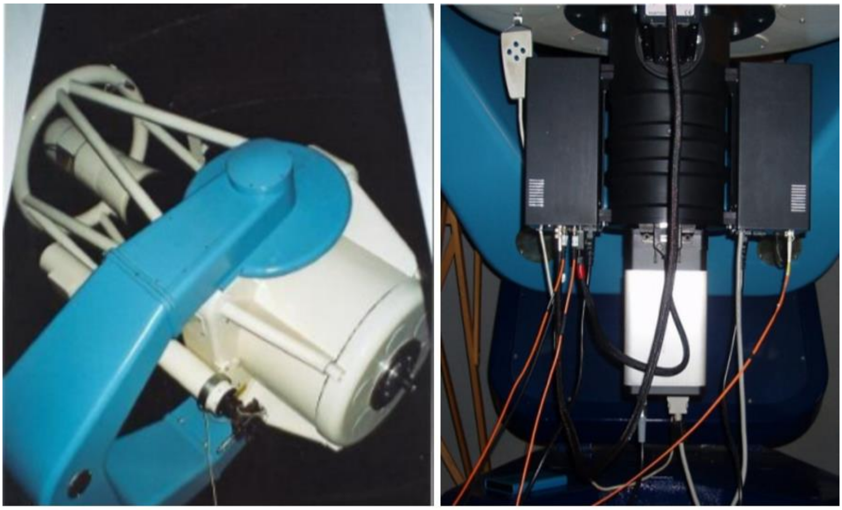

Figure 0-10 Left, the 0.62-m aperture Ritchey-Chretien Telescope at OARMA. Right, the OARMA EMCCD speckle camera installed at the telescope (Credit: OARMA)

In addition to these scientific achievements, Docobo also considers it to be a priority that OARMA function as a Center of Interpretation of the Cosmos. It is to serve interested citizens, including children, in the learning and understanding of purely scientific concepts and fundamentals as well as to think and to transmit to people an understanding of the place that we occupy in the Cosmos, attempting to replace the geocentric explanation that is held by a large part of society.

As commented, the main field of research at OARMA is Binary and Multiple Stars, following the school that Ramón María Aller established at the USC and continued by J. A. Docobo. ‘’Due to the high prestige that OARMA enjoys and especially for all work developed in the international field on this subject to that field’’. Prof. Docobo was elected during the period 2009 - 2012 to be the President of said Commission of the International Astronomical Union. Binary and Multiple Stars are one of the essential objects in stellar Astronomy; they allow us to obtain the basic physical elements of the stars accurately. Moreover, we can test some of the aspects of stellar atmosphere models, stellar evolution models, and general relativity by studying binary systems. Scholars in Astronomy and Astrophysics study stellar formation, structure, and the evolution of the stars from their properties in order to understand the structure of the universe we live in. The fundamental parameters relevant to the evolution of the stars are their masses and chemical composition, among others. On the other hand, the physical and dynamical parameters of binary and multiple systems play a clear-cut role in understanding more about the formation and evolution of those systems. One of those problems is the stellar mass which gives insight into the evolution of binaries. A precise parallax of the binary system, especially from the Gaia astrometric mission (Gaia Collaboration 2018), is essential in enhancing the value of absolute magnitudes and binary orbits with reliable stellar masses. Docobo's analytical method to calculate the orbital solution of the binary and multiple systems also plays a pivotal role in calculating other stellar parameters [49], [50].

The last part of our research will be centered on the study of Astronomy in the Arab world in ancient, medieval, and modern times. The Arab world has a long history of Astronomy with well-known achievements in ancient and medieval eras and they played a vital role in the advancement of this science. Furthermore, the study of Arab Astronomy is necessary as it is related to many disciplines including the History of Astronomy, History of Science, History of Scientific Instruments, and Philosophy and Scientific Thought. The purpose of this work which was also suggested by Prof. J. A. Docobo is to summarize and highlight the contributions of the Arab world in Astronomy from ancient times to the present. We recount the historical trajectory in order to demonstrate in detail the actual research, teaching, and diffusion of Astronomy in the different Arab countries as well as their proposals for a promising immediate future.

In order to perform and accomplish this part of our study, the director of this Dissertation made contacts with his colleague, Professor Mashhoor Al-Wardat, in order to assist me to establish contact with researchers, Universities, Institutes, Organizations, and other centers that conduct Astronomy in Arab countries with the objective of recognizing their lines of research, the available research facilities, agreements with other states, international projects, etc. My visit to the Arab Union for Astronomy and Space Sciences (AUASS) and the Regional Centre for Space Science and Technology Education for Western Asia (RCSSTE) took place thanks to the good friendship and mutual scientific collaboration between these two professors.

We strive to present a full picture of the status of Arab Astronomy in this study. In order to execute that, we split this part of work into three sections. First, we attempt to provide a review of Astronomy in ancient and medieval eras. In the second part, we discuss Astronomy and Space Science (A&SS) in the Arab world in modern times part-I including activities and organizations involved in A&SS. In the last part, Astronomy and Space Science A&SS in the Arab world in modern times part-II, we cover education, scientific research, future outstanding projects, and a roadmap for the development of A&SS in the Arab world.

Ancient civilizations such as Mesopotamia, Babylonians, and old Egypt [51], [52] provided numerous contributions in Astronomy, produced rich astronomical diaries and observational texts in cuneiform tablets, identified the planets (Mercury, Venus, Mars, Jupiter, and Saturn), and invented the astrological constellations that are still accepted today (Leo, Taurus, Scorpius, Auriga, Gemini, Capricorn, and Sagittarius). The presence of the constellations throughout the year was used for agricultural reasons. The Babylonians divided the sky into three parts and created a Zodiac. Astronomers in Mesopotamia were able to foresee lunar eclipses as they followed the heavenly bodies to predict their position in the future. The most significant achievement of Mesopotamian Astronomy was the improvement of the mathematical hypothesis of Astronomy. The ancient Egyptian civilization made great strides in Astronomy by developing sophisticated time-keeping tables and producing a Luni-stellar calendar. They invented the Star Clock to follow the position and motion of the celestial bodies, dividing the day into 24 hours.

During the Medieval Era also known as the Golden Era, Arab Astronomy reached its peak. Since the eighth century, Arab scholars and astronomers have translated many Greek scientific manuscripts and other works into the Arabic language. Many theories in Spherical Astronomy and Mathematics were produced and several observatories were established, numerous astronomical instruments were invented and improved, Ptolemy's theories and hypotheses were questioned and refined, and Astronomy was separated from Astrology. In addition, several sophisticated astronomical models and techniques were presented.

Over the last four centuries, Astronomy as well as other Sciences, in the Arab region suffered a stunning decline [53], [54]. Only a few Arab universities offer specialized programs in Astronomy, Astrophysics, and Space Sciences. There are no specialized programs or research in the field of the History of Astronomy. Therefore, it is critically necessary for the Arab countries to establish themselves in A&SS and their technologies for the 21st century, strengthening the relevance of leading-edge technologies and research which will be pivotal to addressing of the essential problems facing Arabic societies.

In the last decade, Astronomy and Space Science in the Arab world has made impressive technical, observational, and theoretical advances. Astronomy operates as a springboard and catalyst for more extensive scientific research. In order to encourage the Arabic communities to participate in these fields, it is necessary to construct public observatories, increase amateur astronomical societies, and organize school educational projects that promote this interest at all levels. At present, many Arab countries have vibrant Space programs and Astronomy programs that have already contributed substantially to advances in science and technology and have motivated talented individuals to enter the field. Several significant facilities and projects are being developed, in particular, the Emirate Mars Mission (EMM) and Qatar Exoplanet Survey (QES) projects. Continued developments in A&SS in the Arabic region will guarantee advances in astronomical and space research thereby helping them to achieve sustainable economies in the 21st century.

The body of this Doctoral Dissertation consists of five chapters. After the Introduction, Chapter 1 explains the extraordinary advances of human knowledge with respect to the Universe achieved by means of observation, the proposal of theories later confirmed, the fundamental role of the telescope in a multiplicity of observations, and the use of other techniques such as spectrometry, photography, and photometry which are supposed to represent the initiation of the field of Astrophysics as an essential branch of Astronomy today. We shall then go through the historical development of astronomical instruments and their latest techniques and laser technology as we have emphasized that following of this development in a historical context is important for overall understanding. In this sense, we endeavor to highlight the extraordinary contributions of Optics in the past as well as in the present (and the future) brought about by the progressive development in astronomical instrumentations and their advanced technologies such as specific detectors for different wavelengths, laser technology, adaptive optics, and future space missions with the James Web telescope. The purpose of this chapter is to demonstrate the role that is implied by recent development in instrumentations, cutting-edge technologies, new discoveries, and theoretical refinements in Astronomy. They lead us to a new picture of the Universe and our place in it that is quite different from the traditional, different even from the picture we might have painted just a decade or two ago.

In Chapter 2, we begin with the explanation of the importance of the study of Binary and Multiple Stars as an important field of research in Astronomy from a mathematical point of view (Astrodynamics) as well as from the perspective of Physics (Astrophysics). We describe new insight into the history and evolution of binary systems from ancient times to the present.

OARMA's main field of research is Binary and Multiple Stars.The different contributions of astronomical activities carried out by OARMA members in this field of research under the supervision of the Director of this Dissertation are analyzed. Docobo's analytical method for calculating the orbital solution of those systems provide a very useful, versatile, and friendly application to determine the physical and dynamical parameters of binary and multiple stars systems. Many astronomers and scholars have employed this method to calculate hundreds of orbits in the last years. On the other hand, Al-Wardat's method gives a solution to solve close visual binary stars (CVBS) by building Synthetic Spectral Energy Distributions (SED) for each component of the binary star system and then combine them to get the entire SED of the system in order to compare it with the observational data.

We include in this chapter the presentation of the article, Physical and Dynamical Parameters of the Triple Stellar System: HIP 109951, developed by us within the frame of international collaboration with S. G. Masda, J. A. Docobo, and other astronomers and published in the international journal, Astrophysical Bulletin included in the JCR. The aforementioned methods (Docobo's and Al-Wardat's) allow us to accurately obtain the basic physical and dynamical elements of those binary and multiple systems accurately. In the context of this dissertation, they serve to show the scientific importance of said system in order to advance astronomical and philosophical thought about the origin and evolution of our Universe.

In Chapter 3, we present the first section of the study of Arab Astronomy. It is designed to demonstrate how Arab Astronomy in ancient and medieval eras may have contributed to the historical progression of scientific and philosophic concepts of Astronomy and played a valuable role in the transfer and the preservation of ancient scientific knowledge for posterity. It is necessary to provide a suitable review and attempt to illuminate the scientific impact of the ancient Arab realm on Astronomy and the great effort of Arab scholars and astronomers. The main objective of this section is to recognize and review the contributions of the Arab and Muslim scholars in antiquity to the sciences of Astronomy. Ultimately, the goal is to provide a new view of the history of Astronomy in order to launch and support a renaissance in Astronomy in the Arab world today.

In Chapter 4, the second section of the study of Arab Astronomy is described. The major aim of this section is to provide an overview of A&SS in Arab countries and also to consider the future of the most important initiatives and projects in that part of the world. Following the developments in A&SS that have occurred in that region, we discuss the emergence and subsequent phases of change in Astronomy activities on all levels and critically assess the present state of A&SS. We also consider all of the activities carefully in order to provide new insights into many significant issues including the social status of modern scientific knowledge in these disciplines in the areas of applied science and technology. This will help us highlight the interplay between the political, intellectual, and scientific transformations which have occurred throughout the last two centuries that negatively affected Arab science. As a comprehensive study for those interested in A&SS in the modern Arab world, we have examined a wide range of historical sources, manuscripts, journals, and newspapers, including interviews with several Arab astronomers and specialists. We spread this information with the intention to increase of awareness among international researchers. The objective is to develop and promote interest within Arab society to enter the information and technological race in order to achieve a knowledge-based economy as well as sustainable development in Arab countries.

Chapter 5 corresponds to the last section of the study of A&SS. In this part, we aim to describe the reality of education and scientific research in A&SS in the Arab World at the present time. Moreover, we illustrate the present and future outstanding projects in this science area in the Arab World as well as attempt to provide biographies of some recent Arabic exemplary scholars in these fields. On the other hand, we offer our roadmap for the development of A&SS in Arab states in order to provide a framework that points out the strength of the system and provides detailed recommendations for further improvement in its coherence and impact. The common objective of these three sections is designed to ignite the Arab scientific future revolution in these areas of research.

During the time spent in preparation for this work at OARMA, the author has participated in the following publication "Physical and Dynamical Parameters of the Triple Stellar System: HIP 109951". Journal: Astrophysical Bulletin, 2019, Vol 74. No 4, pp.464-474 (Quality control: JCR Q3 impact factor 0.969). It is also our intention to publish five articles as soon as possible. Some of them are already in processing in the Web of Science Journals.

Finally, we point out that all of this work developed here and carried out was supported by the Spanish “Ministerio de Economía, Industria y Competitividad” under the Project AYA-2016-80938-P (AEI/FEDER, UE) and by the “Xunta de Galicia” under the Rede IEMath-Galicia, ED341DR2016/022 Grant, for which the Director of this Dissertation, Jose Angel Docobo, is responsible.

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1. CHAPTER 1: THE HISTORICAL EVOLUTION OF OPTICAL INSTRUMENTATION, LASER TECHNOLOGY, AND ASTRONOMICAL TECHNIQUES AND THE IMPACT OF SCIENTIFIC THOUGHT

1.1. INTRODUCTION

Due to the development of human thought and understanding, we have been able to move from an obsolete geocentric model of the Universe to a point at which we now know our real position in the grand scheme. In ancient times, people practiced Astronomy by observing the sky with the naked eye to describe the natural phenomena they saw and, then demonstrated their respect, fear, and an inability to understand. However, astronomers today discover planets around other stars and realize that our planet, the Earth, is one among many. Astronomy has significantly contributed to the development of larger telescopes and more sophisticated receivers with which space discovery maintains a promising future. Thus, the rapid evolution of the science of Astronomy and knowledge movies scientists to conduct and develop innovative research.

Astronomy is a fascinating science which inspires and stimulates human beings to exploit scientific knowledge and technology in order to better understand the Universe. Therefore, it can be utilized to provide extensive knowledge to astronomers, stimulating their interest in further studies and inspiring new scientific method perspectives. Furthermore, Astronomy not only aims to answer fundamental inquiries about the mysteries of the Universe, but it also promotes advance technological development as well as knowledge-based economic growth. In addition to this, Astronomy has been an essential factor in the development of human thought in terms of beauty, elegance, and a fascination of heaven as a source of wonder for the observers. Moreover, Astronomy has driven developments in several areas of contemporary technology such as new key discoveries in Physics, Chemistry, and Biology, as well as the creation of new scientific branches such as Astrophysics, Astro-chemistry, Astrobiology, Astrodynamics, Astro-engineering, Astro-informatics, and Mathematics.

Indeed, advancements in technology throughout human history have propelled changes in the way astronomers engage with their science or come to acquire new knowledge, as well as having profoundly impacted the practice of Astronomy. This study will explain the extraordinary advances of human knowledge with respect to the Universe achieved by means of observation, the proposal of theories later confirmed. Moreover, the fundamental role of the telescope in a multiplicity of observations and the use of techniques such as Spectrometry, Photography, and Photometry represent the initiation of the field of Astrophysics as an essential branch of Astronomy today. In this sense, it is necessary to highlight the extraordinary contributions of Optics in the past and the present brought about by the progressive development in instrumentation as well as techniques, such as specific detectors for different wavelengths, Laser Technology, Adaptive Optics, and future space missions.

All of the heavenly objects have been emitting various forms of electromagnetic (EM) radiation depending upon their properties and, through the study of this radiation, we gain knowledge regarding the Universe. Most of the spectra from these distant celestial objects are too faint for the human eye to see. In order to gather this information, astronomers use telescopes as an observational tool. The telescope is used to assemble that spectra to form enlarged images of very distance celestial objects. Telescopes with lenses or mirrors are used in order to collect or focus a portion of spectra from the EM radiation that allows us to research the celestial objects. As we know, our eyes are not sensitive to several parts of spectra alike Gamma-rays, X-rays, Ultraviolet, Infrared, and Radio-waves. Therefore, understanding something you cannot see is difficult but not impossible. In order to gather more information from other sections of the EM spectrum, scientists began to develop more sophisticated telescopes that were indeed sensitive to those particular wavelengths they were interested in investigating. Fundamentally, everything that astronomers have discovered about the universe depends on the information contained in the electromagnetic radiation that has arrived to the Earth. In past times, humans only used visible EM radiation to explore the Universe; each part of the EM radiation provides a different portion of the story about the Cosmos' puzzle. Using more than one part of the electromagnetic radiation at a time gives scientists a more comprehensive picture of the Cosmos.

The history of astronomical instruments is extensive in multiplie connected fields. In this part of our study, we provide a selective review of some relevant highlights. We recount how, over the centuries, improved scientific optical instruments and new astronomical techniques led to remarkable and revolutionary advances in understanding our place in the Universe. The need to study the faintest astronomical objects requires superior electronics and extreme-precision state-of-the-art optics as well as ultra-modern and futuristic engineering. Astronomy has also played a vital role in the development of Space Technology that has opened up the Cosmos for study across the entire EM radiation. Cutting-edge Ground-based and Space-based Telescopes are among the most advanced instruments ever created and are outstanding educational vehicles for providing the most advanced astronomical knowledge for humanity [1].

Based on this considerable evolution in technological instruments and advanced techniques in Astronomy in current times, we can only wonder what scientific and philosophical revolution that came after each development. We are now at an unprecedented time in human history. For the first time since the dawn of philosophical and scientific thought, it is within our grasp to answer, rigorously and quantitatively, three fundamental questions: Are there other forms of life in the planets on our Solar System or Other new discovered System? and Are there other planets orbiting other stars like our own Earth, and could they harbour life? For the time being, no other indication of life has ever been identified either on the other planets or stellar in the Solar System or elsewhere in the Universe [2].

Astronomical discoveries are based on observation. Since the dawn of civilization, astronomers have looked for patterns in what they observe, detect, and responded accordingly to formulate astronomical theories and make predictions. Initially, astronomers entirely depended on their senses to make observations for heaven. But as science developed, astronomers also developed instruments to extend their observational powers beyond our physical limits. In the early 17th century, Astronomy took a significant leap forward with the invention of the telescope and its use to discover and study the sky. Telescopes have enabled scientists to monitor new objects and to see larger and larger portions of the sky in their constant quest to understand our Universe [3]. Every development in telescopes led to the opening of a new window of opportunity to understand the Universe and to the subsequent revolution in the way of thinking and accumulating knowledge about our Universe.

In fact, the emergence of the telescope was a significant event in the history of science and technology for several reasons: it marked the invention of a new tool, it changed human kind's perception of the Universe, and it modified the scientific way in which the philosophers used to think in the most ancient eras. Despite the evolution of powerful ground telescopes, the Space telescopes will furtherly expand our knowledge regarding our existence and place in the Universe.

An important shift in Astronomy took place in the nineteenth century. This gradual shift is attributed to three key scientific steps that allowed for this leap forward: Spectroscopy, Photometry, and the invention of Photography. The combination of Photography and Spectroscopy in the nineteenth century led to the birth of Astrophysics and Cosmology Science. These new techniques required advancements in the design and configuration of telescopes. There are two main techniques for analysing the incoming light from a celestial object. One is called Spectroscopy and the other, Photometry [4], [5]. Spectroscopy is the study of the types of EM radiation that emanates from celestial objects. Spectroscopy plays a crucial role in Astronomy. By gathering and analyzing the electromagnetic spectrum from a distant object, astronomers can identify what type of object it is and determine a number of characteristics of astronomical objects. It can reveal the chemical composition, temperature, density, mass, distance, luminosity, radial velocity, and some of the physical properties. Spectroscopy is done at three significant fragments of radiation: Visible Spectrum, Radio, and X-ray. Photometry represents the science of measuring the illumination of celestial objects. Its measures can produce massive amounts of information about cosmic objects. Photometry is used to acquire quantitative dynamic measurements of astronomical objects using electromagnetic radiation. The technique to obtain quantitative measurements of astronomical objects transformed Astronomy from a merely descriptive science to one with unusual explanatory power. Historically, different types of measuring equipment produced data requiring different kinds of treatment to provide useful photometric results. Photometry has been most commonly carried out using the human eye in the earliest times, and later, Photographic Plates, Photomultipliers, and the Charge-Coupled Device (CCD and modern photometers.

By the mid-20th century, Adaptive Optics (AO) was introduced and revolutionized the performance of the telescope. AO is a unique optical technique used to correct the distortion caused by the turbulence of the Earth's atmosphere, thus allowing the observation of finer details of much fainter celestial objects, as well as to enormously improve the power of telescopes. This technological progress permitted scientists in the late 20th century to build a new generation of extremely large telescopes and even more sensitive imaging systems. With these new generation telescopes, new areas of research have been opened by expanding the observable entire EM wavelength region. Astronomers have developed specific types of telescopes that allow them to observe and identify new regions of the EM spectra directly such as the Infrared, Ultraviolet, X-ray, Gamma-ray, Submillimeter, and Microwaves. In addition, Adaptive Optics (AO) and Laser Technology [6] have played a crucial role in the improvement of telescope performance and have led to essential advances in our astronomical understanding. They permit today's large high performance ground and space telescopes to operate close to their reliable diffraction limits.

Astronomy has a rich history of using photography. Recently, the techniques of photography in Astronomy have become much more advanced. Digital photographic devices and their corresponding software, capturing the nature of the astronomical objects is no longer difficult for astronomers. Those astonishing images which contain valuable information. In modern times, astronomical research has benefited extraordinarily from digital photography that allows data and images to be produced and analysed with a level of high-resolution not previously achievable. The revolutionary advances made in Astronomy during the twentieth century were in large part due to the introduction of computers. Computers have given astronomers the ability to collect and share data at high speeds but have also changed how Astronomy is done. They play a key role in the advancement of astronomical research and discovery. And allow astronomers to process more data and develop more complex scientific modelling in order to study the large scale of the Universe. Modelling astronomical phenomena has always been an important tool for astronomers and, with the support of computers, it is possible to create more models and to formulate theories about phenomena that are otherwise impossible to study today.

Finally, we believe that new advanced astronomical instruments and techniques, no less than new ways of thought, can give us insight into the structure of the Universe in order to foster further intellectual understanding.

Section Two, describes the Telescope Era: New Insights and Historical Perspective from the Galileo Telescope to the James Webb Telescope. Section Three illustrates the Pivotal Role of Adaptive Optics (AO) and Laser Technology in development Astronomy. In Section Four, the evolution in Spectroscopy, Photometry, and Photography in Astronomy will be regarded. Section Five proposes the Innovative and New Advanced Astronomical Instruments and Techniques such as the Gravitational-Wave Astronomical Instruments, Astroinformatics, and the Photonic and Quantum Instruments. In the last Section, we draw conclusions.

1.2. EVOLUTION IN OPTICAL INSTRUMENTATION AND LASER TECHNOLOGY IN ASTRONOMY

We will divide the evolution of optical instruments in Astronomy into two parts: firstly, the naked eye astronomical era, and secondly, the telescope era since its discovery until the space telescopes of today and tomorrow.

1.2.1. Naked Eye Astronomy

Since the dawn of history, the naked eye has been the primary tool used for revealing and showing the secrets of the Universe. The naked eye as an astronomical optical instrument was widely employed for studying the sky at that time. The observational power of our eyes is limited by the wavelength of the EM radiation it can detect. Moreover, it has a low angular resolution. Only a small fraction of the EM spectrum can be detected by the naked eye; this portion is referred to as visible spectrum, and it has wavelengths ranging from approximately blue (400 nm) to red (700 nm). The angular resolution of the naked eye under the perfect observation circumstances is less than 1 arc-minute [7].

Furthermore, the naked eye serves also as a camera because it forms images of what is observed on the retina. The human eye is composed of only two positive lenses: the cornea and the crystalline lens. In addition to this, the retina operates like the sensor of the camera system. Hipparchus in 129 BC conventionally measured visual star brightness in "magnitudes" the naked eye; he hence executed the first star catalog. Later on, Ptolemy arranged the naked-eye visible stars into six categories, the brightest ones corresponding to the first magnitude and the faintest ones to the sixth.

Moreover, the ancient astronomers had been limited by what they were capable of observing in the sky by their human senses, in general, and the naked eye in particular. Such weaknesses associated with observing with the naked eye led astronomers to start developing astronomical instruments to assist them in their observation and study of the sky. Due to that, several astronomical instruments were invented and developed to be used in astronomical observation before the telescope era such as different types of the Astrolabe, the Nocturnal, the Armillary Sphere, the Cross-Staff, the Quadrant, and the Dioptra [8]. (Figure 1-1). All these instruments were designed to obtain the position of celestial objectives as well as to determine their motion.

In the 16th century, the Danish astronomer Tycho Brahe (1546–1601) made several of the innovative astronomical instruments and employed them in his observational programs. Tycho built a 65-cm radius azimuthal quadrant from brass with an estimated accuracy of 48.8 arcsec in 1577 and he used it for observations of the comet in the same year. In 1580, Tycho built a large brass globe to record the position of stars and constellations with great accuracy. A year later, that he also constructed a 1.6-m radius armillary sphere which consisted of a spherical framework of rings centered on Earth, that describes lines of celestial longitude and latitude and other astronomically important features such as the ecliptic. Moreover, the triangular Sextant that had a 1.6-m radius was built by Tycho in 1582. Later, he continued building new innovative instruments such as a 3-m equatorial armillary in 1585, a 1.6-m revolving wooden quadrant in 1586, and a 2-m radius revolving steel quadrant with estimated accuracy equal to 36.3 arcsec [9]–[11]. (Figure 1-2).

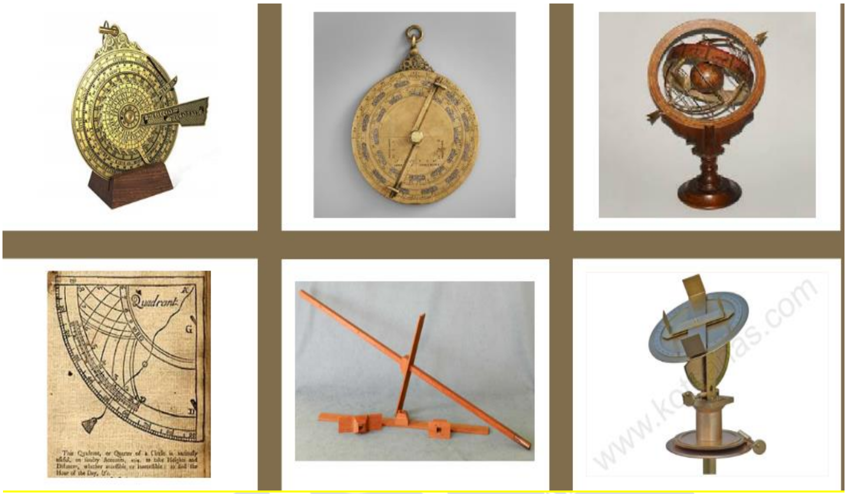


Figure 1-1 *Some Astronomical observation instruments before the telescope Era (Top, left to right: the Astrolabe, the Nocturnal, and the Armillary Sphere. Down, left to right: The Cross-Staff, the Quadrant, and the Dioptra) (Source: Measuring the Heavens: Astronomical Instruments before the Telescope by R. Egler)*

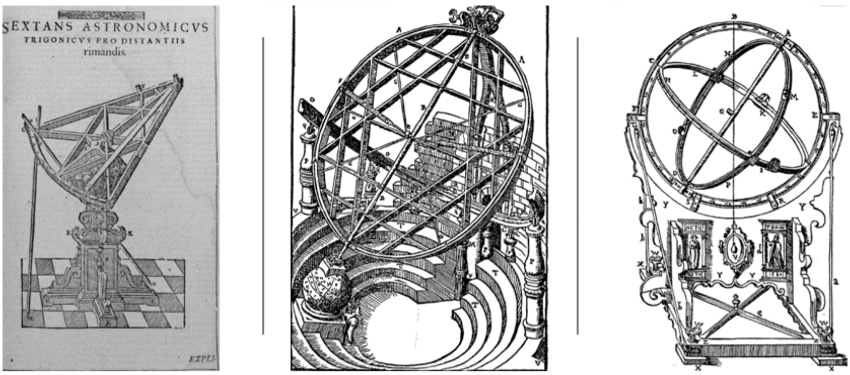


Figure 1-2 From left to right: Tycho Triangular Sextant, Tycho's Great Armillary, and Tycho's Equatorial Armillary (Source:https://www2.hao.ucar.edu/Education/FamousSolarPhysicists/tycho-brahes-observations-instruments)

1.2.2. The Telescope Era: New Insights and Historical Perspective from the Galileo Telescope to the James Webb Telescope

Historically, the invention of the telescope was a confusing puzzle [12]–[15]. For more than four centuries many scientific historians have argued about who invented the telescope. Several names from different countries have been suggested as the inventors of the telescope such as Leonard Digges, Sacharias Janssen, Paolo Sarpi, Jacob Metius, and Giovanni Della Porta, Raffaelo Gualterotti, Giambattista Della Porta, Cornelis Drebbel, Girolamo Fracastoro, Lowys Lowyseen, Raffael Gualeterotti [12], [16]–[18], and Juan Roget [13], [14]. In 1975, Albert Van Helden published a paper titled "The Historical Problem of the Invention of the Telescope". In this paper, he provided a summary on the topic, starting from the first moment the telescope emerged as a useful tool in the 17th century. Nick Pelling also published a paper called "Who Invented the Telescope" in 2008, based on two Spanish articles published by Josep María Simón De Guilleuma in 1958 [13], [19]. De Guilleuma claimed in his work that the first inventor of the telescope is Juan Roget in Catalonia, Spain, sometime before 1608. Many historians of science in the field of history of the telescope widely confirmed and credited instead that the telescope was invented for the first time by Hans Lippershey in 1608 [17], [18], [20]–[22]. Nevertheless, it is possible that the invetation was due to two apprentices at the Lippershey's workshop.

In 1609, Galileo Galilei constructed the first astronomical refracting telescope and used it for systematic astronomical observations [23]. The first Galileo refracting telescope consisted of a wooden tube including a two-lenses system at both ends of the tube, a bi-convex lens (with a focal length of 47.5 mm) working as an objective lens (front) and a plano-convex lens (with a focal length of 980 mm) functioning as an ocular eyepiece. The initial version of the Galileo telescope could magnify up to around 8x and, later on, he performed important improvements on the configuration of his telescope in order to allow magnifications up to 20x. (Figure 1-3). Galileo used his instrument to undertake significant observations that allowed him to be the first to observe that the Moon's surface was not smooth, to discover the individual stars of the Vía Láctea (Milky Way), the moons of Jupiter, to study Saturn, to observe the phases of Venus, and to study sunspots on the Sun, and most importantly his observations led him to accept and strengthen his belief in Copernicus' theory [24], [25]. In 1610, Galileo published his observations in an important book called Sidereus Nuncius or the Starry Messenger [26]. In addition, Galileo was the first to introduce the "Diaphragm" to improve the image quality of the telescope by reducing the spherical and chromatic aberration [3].

Figure 1-3 Galileo's First Telescope (Credit: https://www.mpg.de/7913340/Galileo_Galilei_telescope)

In 1611, Johannes Kepler performed another improvement on the Galilean telescope design by using a convex lens for the eyepiece (ocular part) instead of using a concave lens [17]. The new design is known as ´´Keplerian Telescope Configuration´´. It allowed making additional improvements in the telescope magnification by increasing the focal length between the combination of the lenses system [23, pp. 281–295]. Figure 2- 4 demonstrates the difference between Galilean and Keplerian telescope configuration. In the mid-17th century, astronomer Christiaan Huygens provided the most prominent theoretical contribution to the development of the telescope optics [17]. In

1655, he built a telescope that allowed him to discover Saturn’s ring system and its large moon, Titan. Furthermore, Huygens invented the largest telescope in 1684, the so-called aerial telescope or the tubeless telescope [27]. Johannes Hevelius constructed the largest refracting telescope in the 17th century by improving the lenses: he built a 150-foot focal length telescope with lenses up to 8 inches in diameter on the shore of the Baltic Sea and used it to study and discover the Moon´s surface details [28]. (Figure 1-5). Giovanni Domenico Cassini used the new huge powerful refracting telescope installed at the Paris Observatory, made by the excellent lens maker Giuseppe Campania in 1664, to produce a series of new astronomical discoveries such as the four moons of Saturn, he also measured the period of rotation of Jupiter on its axis, discovered the bands and spots on Jupiter, and measured the period of rotation of Mars on its axis [29]. Although the power of refracting telescopes increased during the 17th century and a series of crucial astronomical discoveries surfaced, the refracting telescopes suffered from insuperable chromatic and spherical aberrations that made the acquired images blurred and distorted [17].

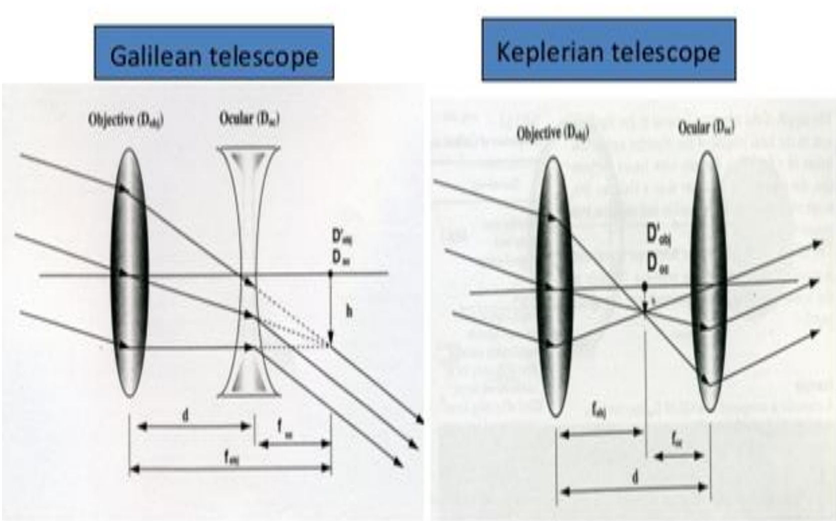


Figure 1-4 The difference between Galilean and Keplerian telescope configuration

Figure 1-5 The Hevelius 150 Foot Non-achromatic Refractor Telescope (Credit: Houghton Library, Harvard University)

A revolutionary step in telescopic design occurred when Isaac Newton produced his first reflector telescope in 1668 (Figure 1-6). He used 2-inch diameter concave spherical mirrors including a flat angled secondary mirror and a convex eyepiece lens. The idea of the reflector telescope had been mentioned for the first time by James Gregory in 1663 in what was known in the following years as the Gregorian Telescope [30]. The problem with the Gregorian model was that it relied on a parabolic primary mirror with a central hole and an elliptical secondary mirror which brought about an issue about the outlook of the image shaped by the primary mirror. Newton overcame this problem by employing a small diagonal mirror to deflect the image to the side, where it shall be viewed through the eyepiece. Robert Hooke used Georgian design in order to build his reflecting telescope in 1672. This construction was based upon two mirrors but with a concave primary and a convex secondary lens. He suggested, to use three or four plane mirrors strategically arranged within a tube, in order to drastically shorten the telescope tube [31]. Laurent Cassegrain made considerable improvement in the Gregorian design for a reflector telescope known as a "Cassegrain Telescope" in 1672. Cassegrain's design used a parabolic primary mirror and a hyperbolic convex secondary mirror and this design allowed him to create a telescope with a long focal length while having a short tube length as well as to cancel aberrations from the primary mirror [32].

In 18th century, minor improvements were made to the configuration of the telescope. The next influential advancement came in 1729 by Chester Moor Hall who invented the achromatic lens and exploited it in building the first refracting telescope free from chromatic aberration [33]. William Herschel was renowned for being the most famous telescope maker in the late 18th century and he produced a sophisticated mirror from a metal alloy with high reflectivity, high ability to resist the tarnishing, and ability to keep its shape during temperature changes [34]. He used this mirror to build a 16-cm reflecting telescope with a focal length of 2.14 m in 1778 [35]. Additional progress in Herschel's reflecting telescope was made in 1783 by constructing a 48-cm telescope [35]. With this telescope, he posed a major contribution to the advancement of Astronomy as well as produced his very early catalogue of double stars. In 1789, he constructed the first giant reflecting telescope under the patronage and support from King George III. This telescope had a 1.2-m diameter mirror and 12-m focal length and it remained the biggest telescope in the world for more than half a century [35], [36]. In addition, by using these telescopes, Herschel discovered two moons of Uranus: Titania and Oberon and two moons of Saturn: Enceladus and Mimas and created "the General Catalogue of Nebulae" [37], [38]. Figure 1-7 shows several types of William Herschel's astronomical telescopes [35].

Figure 1-6 Newton's Reflecting Telescope (Source: http://www.andrewdunnphoto.com/)

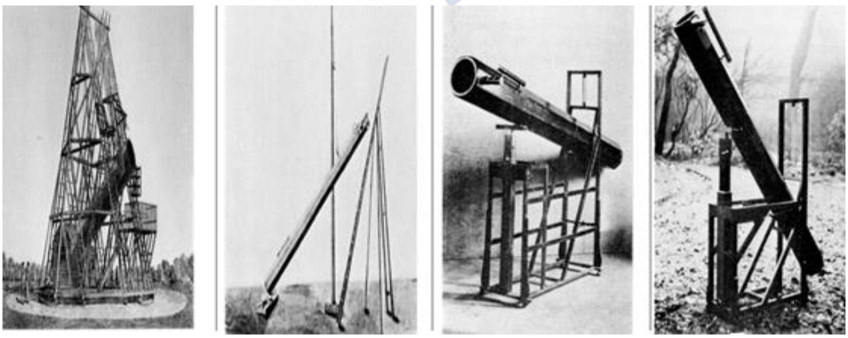


Figure 1-7 Several Types of William Herschel´s Telescopes (from left to right, the Herschel 40 Foot Telescope, the Herschel 20 Foot Telescope, the Herschel 10 Foot Telescope, and the Herschel 7 Foot Telescope) (Credit: William Herschel's astronomical telescopes by A. Maurer)

The early 19th century witnessed several advances and improvements in telescope designs and the emergence of giant telescopes. Joseph von Fraunhofer examined theories aimed at improving the performance of refracting telescopes and attempted to solve the main technical problems of lens manufacturing. He focused on improving the quality of the large lenses for the telescope [39]. In 1824, Fraunhofer and Friedrich Von Struve built the Great Dorpat Refractor Telescope at Tartu Observatory in Estonia (Figure 1-8). The Dorpat telescope was the first modern achromatic refracting telescope that has a 24.4-cm diameter with focal length of 4.34 m [40]. Jean Foucault introduced more improvement in mirror manufacturing by using a silver coating for metalized-glass mirrors. He produced a high-quality modern reflecting telescope in 1857.

Figure 1-8 The first Great Telescope: a 24-cm Great Dorpat Refractor at Tartu's Old Observatory (Credit: https://travelpast50.com/struve-geodetic-arc-tartu-university-estonia/)

At the beginning of the 20th century, George Ellery Hale (Figure 1-9) began to design and construct the largest telescope in the world of that time at the Mount Wilson Observatory. The new reflecting telescope had a 2.5-m mirror diameter which was known as "the Hooker Telescope" [41], [42]. Astronomers have used the Hooker telescope to observe objects that formed early in the history of the Universe as well as to understand the scale and nature of the Universe. In 1948, the Hale telescope was installed at the Palomar Observatory in California, United States. The Hale telescope is one of the largest reflecting telescopes of the 20th century and it has a 5.1 m diameter concave mirror made from Pyrex glass which distinguished low thermal expansion, covered with a thin layer of aluminium and the thickness varies between 49.8 cm at the center and 59.7 cm at the outer edge [43] . Moreover, the Hale telescope played a pivotal role in the evolution of astronomical research in the last century [44]. Figure 1-10 shows the Hooker and Hale telescopes. Bernhard Schmidt succeeded in inventing a new type of telescope by using a single concave spherical mirror and correction plate, he developed a short focal length optical system with a large field of view called the “Schmidt Telescope” in 1930 [45]. Schmidt’s telescope was used to acquire images of the large sections of the sky without any distortion. The first Schmidt telescope has a 44 cm spherical mirror and a 36 cm diameter correction plate that afforded a 15-degree field of view 15. Later, the first large Schmidt telescope was built at Mount Palomar Observatory in 1948 known as “Big Schmidt” that had a 132-cm mirror diameter [46].

The Byurakan Astrophysical Observatory (BAO, https://www.bao.am/) was founded in 1946. At the observatory, a 2.6-m Cassegrain telescope which installed in 1975. Located in Mount Aragats in the village of Byurakan in Armenia at an altitude of 1406 m above sea-level. (Figure 1-11). The Hale telescope was the largest effective telescope in the world from 1949 until the establishment of the Russian Big Telescope Altazimuth (BTA-6, http://astro.vaporia.com/start/bta6.html) in 1976. BTA-6 is a 6-m diameter reflector telescope with a monolithic mirror. It is of the Ritchey-Chrétien design and is installed at Mount Pastukhov, (Russia) and belongs to the Special Astrophysical Observatory (SAO-RAS).

A major leap in the construction of the ground-based telescope took place with the Keck I telescope and later the Keck II in the late of 20th century. The Keck I and Keck II Observatory Telescope (http://www.keckobservatory.org/) was established in 1993 and 1996 respectively in Mauna Kea , Hawaii, USA. A twin of the 10-m diameter telescope was installed including advanced adaptive optics that used computer-driven mirrors to observe and detect the visible and infrared regions of the electromagnetic spectra [48], [49]. Early in the 21st century, several extremely large ground telescopes were constructed. In 2005, the Large Binocular Telescope (LBT, http://www.lbto.org/) was installed in Arizona, USA. The LBT consisted of two 8.4-m diameter mirrors and used an advanced adaptive optics system to achieve high-resolution imaging from the ground [50]. The Large Synoptic Survey Telescope (LSST, http://www.lsst.org/lsst/) will be in operation in 2020. The LSST is an 8.4-m diameter survey telescope including the world's largest digital camera of 3,200 Megapixels [51]. In 2021, the Giant Magellan Telescope (GMT, http://www.gmto.org/) will function, consisting of seven 8.4-m diameter objective mirrors and will principally observe in the visible electromagnetic spectra [52]. The Thirty-Meter Telescope (TMT, https://www.tmt.org) is scheduled to run in the coming year. It will be designed with a 30-m diameter primary mirror made up of 492 smaller segments objective including the latest Adaptive Optics technology and will allow scientists to explore the mysterious period in the life of the universe when the first stars and galaxies were formed [53].

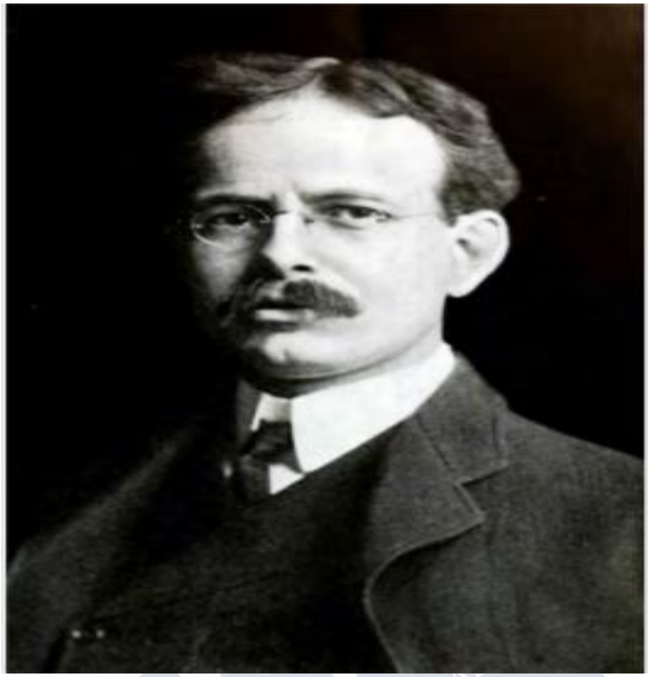
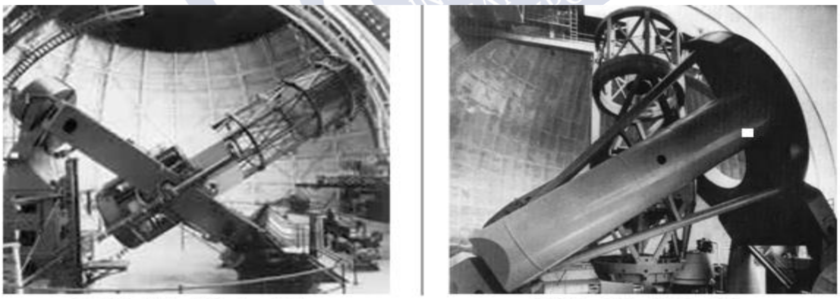


Figure 1-9 George Ellery Hale (1868–1938)[1] (Credit: George Ellery Hale by W. S. Adams, 1938)



A 100-inch (1-m) Hooker Telescope A 200-inch (2-m) Hale Telescope

Figure 1-10 The Hooker and Hale telescopes [Credit: The 100-inch Telescope of the Mpount Wilson Observatory by H. Jones)]

[1] George Ellery Hale´s work led to the construction of several large telescopes, including the 1 m refractor telescope at Yerkes Observatory and three reflector telescopes: the 1.5 m at Mount Wilson Observatory in 1908 and 2.5 m Hooker telescopes at Mount Wilson Observatory in 1917, and the 5.1-m Hale Telescope at Palomar Observatory in 1948 (completed after he died). He is described as a master telescope builder [47].

Figure 1-11 The 2.6-m BAO telescope. J. Gómez (left) and L. Piccotti (right) at BAO (OARMA researchers, 2017) (Credit: OARMA)

In the second decade of the 21st century, other world-class and new generation ground telescopes will be constructed from 20- to 100-m in diameter, equipped with the latest advanced technological instruments often operating at the diffraction-limit through superior Adaptive Optics technologies (AO) systems. In 2012, the European Southern Observatory (ESO, http://www.eso.org/sci/facilities/eelt/) approved a project to launch a 40-m diameter class ground telescope called the European Extremely Large Telescope (E-ELT) as a top priority for the European Scientific Community. The construction phase in the E-ELT began in 2014 and is planned to run in 2025. E-ELT is an Adaptive Optics telescope and will be the largest optical/near-infrared telescope in the world. It consists of five mirrors (3 classical mirrors: M1, M, and M3) and 2 flat fold mirrors (M4, M5). M1 has 39.3- m diameter as a hexagonal segmentation elliptic concave mirror with a 69-m radius of curvature, M2 has a 4.2-m diameter convex secondary mirror, M3 has a 4.0-m diameter concave tertiary mirror, M4 has a 2.4-m diameter deformable adaptive mirror, and M5 has a Tip-tilt correction adaptive mirror of 2.6 m X 2.2 m [54]. Moreover, E-ELT will be equipped with cutting-edge instrumentation as well as multiple Laser Guide Star Units [54]. In addition, Table 2-1 lists the major world-class optical and infrared ground-based telescopes, that arranged from largest to smallest according to the diameter of the telescope mirror.

In the 1930s, Radio Astronomy was discovered by Karl Jansky through his work as a radio engineer at the Bell Telephone Laboratories in Holmdel, New Jersey. He detected radio waves from outside of the solar system (Figure 1-12) [56]. In 1937, Grote Reber followed up Jansky's steps and built the first radio telescope and, in 1944, he published the first radio frequency map of the sky. The radio telescope allowed astronomers to collect and investigate radio waves released by extremely distant celestial objects as well as distant galaxies [57]. In 1953, Joun Kraus assembled an innovative radio telescope including a 110-m Antenna. He revealed the distance of the known celestial objects at the edge of our Universe and presented a full-complete survey of the radio sky [58]. The National Radio Astronomy (https://public.nrao.edu/, NRAO) established in 1993, the Very Long Baseline Array Radio Telescope Project (VLBA) to employ in a wide range of scientific radio astronomical programs. The VLBA is a network of ten observing stations located across the United States that include ten identical 25-meter diameter antennas, which are separated by a range of distances from intrastate (200 km) to transcontinental (8600 km) (with the most extended baseline between Mauna Kea, Hawaii and St. Croix, Virgin Islands). Furthermore, the VLBA can observe at wavelengths across the centimeter-to-millimeter radio spectrum (90 cm to 3 mm) in nine discrete receiver bands spanning 1.2 to 96 GHz and two narrow sub-gigahertz bands covering 312 to 626

MHz [59]. The capacities and improvements of radio telescopes have grown dramatically in the last decades. Besides, Radio telescopes will answer fundamental questions and address some of the crucial issues concerning our understanding of the Universe such as star and galaxy formation, the Big Bang theory, dark energy, the role of magnetism in the Cosmos, Universe expansion, and exploration beyond Earth. In 2013, the Atacama Large Millimeter/Submillimeter Array (ALMA, http://www.almaobservatory.org/) was established on a high-altitude site at 5000 m above sea level in Chile. The ALMA radio telescope encompasses 66 units that contain an array of up to sixty-four 12-m diameter high-precision antennas [60]. Also, many radio telescope projects were designed to observe the sky at low, medium, and high frequencies like the Square Kilometre Array Radio Telescope (SKA), the Expanded Very Large Array Radio Telescope (EVLA), and the Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST, http://fast.bao.ac.cn/en/) [61]–[63]. Those projects are equipped with the latest instrumentation with high-sensitivity, survey speed, image fidelity, high temporal resolution, and wide field-of-view. Table 1-2 lists the major ground-based radio telescopes of the world.

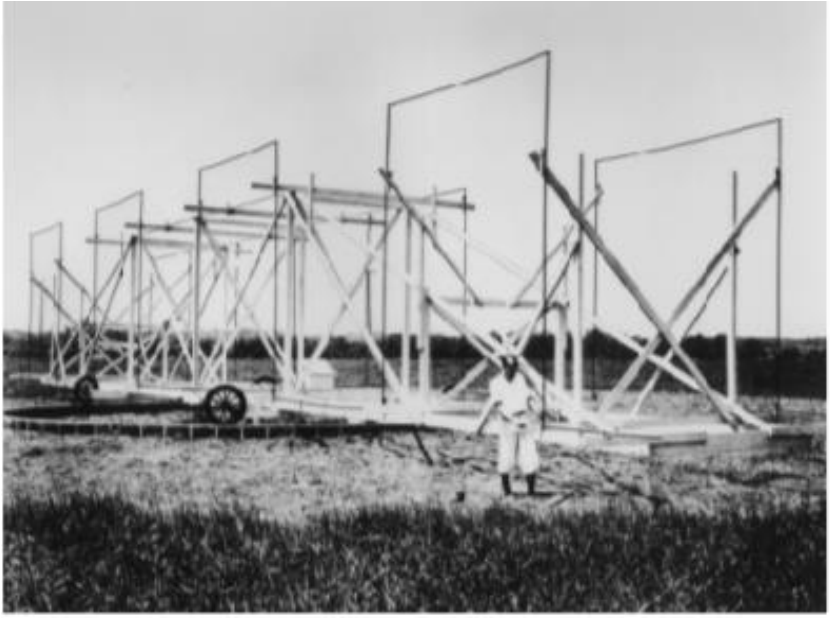


Figure 1-12 The first Radio Telescope used by Karl Jansky, Bell Telephone Laboratories, Holmdel, New Jersey, USA (Credit: Early History of Radio Astronomy by G. C. Southworth, 1956)

As mentioned above, the EM spectrum consists of Gamma rays, X-rays, UV, visible light, IR, microwave, and radio radiation, and astronomers depend on the information carried by the EM radiation to study our Universe. Table 1-1 presents a review of the EM radiation types, the bands of this spectra, and typical astronomical objects that each class of EM radiation emit. In fact, the Earth's atmosphere allows only visible light and radio waves to penetrate to the surface of the Earth and a few narrow EM spectral bands such as that of the IR or UV spectra are partially blocked. Earth´s atmosphere blocks the other bands of the EM radiation including X-rays and gamma rays. On the other hand, the atmospheric turbulence blurs the resolution of the astronomical images even when they are observed and captured through the most powerful ground-based telescopes equipped with cutting-edge AO technology. Due to these difficulties, astronomers and engineers have designed Space Telescopes that are sensitive to different wavelengths of the EM in order to study and explore the Universe and record details that could never be observed from Earth. (Figure 1-13 and 1-14).

Table 1-1 The EM radiation types, the bands of the spectrum, and typical astronomical objects that emit each class of EM radiation

Type of Radiation	Wavelength Range (nm)	Typical Astronomical Sources
Gamma rays	Less than 0.01	Nuclear reactions (require very high-energy processes)
X-rays	0.01-20	Gas in clusters of galaxies, supernova remnants, solar corona
Ultraviolet	20-400	Supernova remnants, very hot stars
Visible	400-700	Stars
Infrared	10^3-10^6	Cool clouds of dust and gas, planets, moons
Microwave	10^6-10^9	Active galaxies, pulsars, cosmic background radiation
Radio	More than 10^9	Supernova remnants, pulsars, cold gas

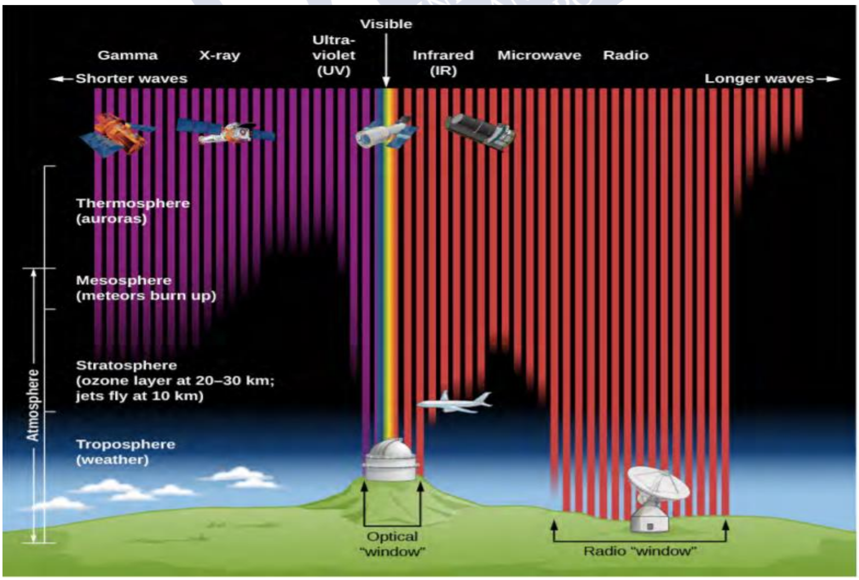


Figure 1-13 The bands of the EM spectrum and how Earth's atmosphere transmits them (Credit: STScI/JHU/NASA)

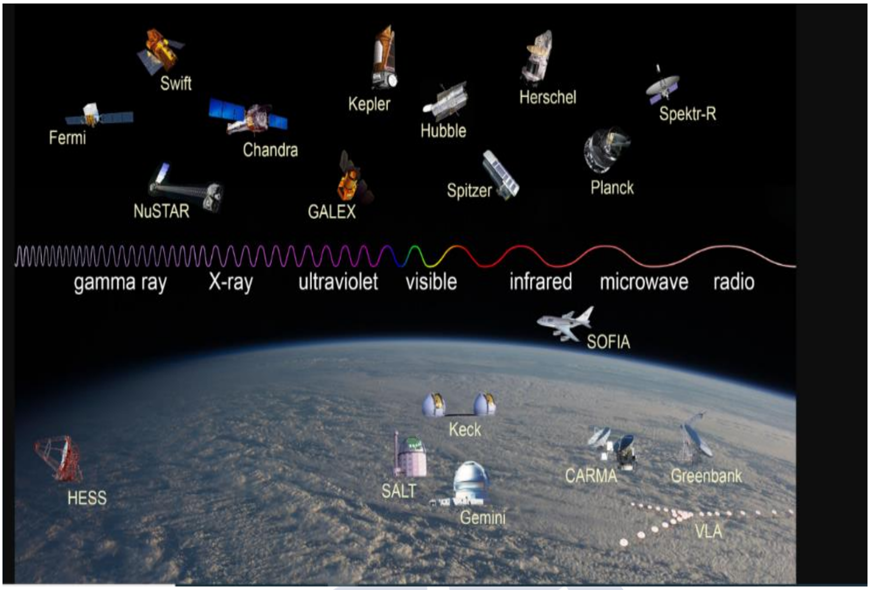


Figure 1-14 Some of the Ground and Space Telescopes and the band width of EM spectra able to detected (Credit: Observatory images from NASA, ESA (Herschel and Planck), Lavochkin Association (Specktr-R), HESS Collaboration (HESS), Salt Foundation (SALT), Rick Peterson/WMKO (Keck), Gemini Observatory/AURA (Gemini), CARMA team (CARMA), and NRAO/AUI (Greenbank and VLA); background-image from NASA)

In the 1960s, the trend toward space telescopes began when scientists started attacking giant balloons to telescopes as a means to carry them above Earth's atmosphere. The first astronomical satellite project called Ariel-1 was launched in 1962 and was designed and manufactured by NASA's Goddard Space Flight Center (GSFC). Ariel-1 was utilized to investigate the ionosphere and its relationship to solar radiation including cosmic rays and solar emission in UV and X-ray frequencies. Later, a series of another five satellites were launched as follows: Ariel-2 in 1964, Ariel-3 in 1967, Ariel-4 in 1971, Ariel-5 in 1974, and Ariel-6 in 1979 to investigate astronomical objectives in the radio and X-ray range.

NASA also launched a series of four unmanned space observatories called the Orbiting Astronomical Observatory (OAO) between 1966 to 1972. The first is OAO-1 and was successfully launched in 1966, OAO-2 launched in 1968 and carried telescopes and spectrometers to study UV radiation, OAO-B launched in 1970 and failed to reach its orbit, and OAO-3 launched in 1972 (later named Copernicus). It carried an 81-cm diameter UV telescope in order to study ultraviolet emissions from interstellar gas and stars in the distant reaches of the Milky Way.

A major leap in Space Astronomy occurred when the International Ultraviolet Explorer (IUE) was launched in 1978 as a collaborative project among NASA, ESA, and the British SERC. The IUE was equipped with a 45-cm diameter reflector and spectrographs operating in the far and mid UV wavelength regions. In the following years, many space telescopes or observatories were placed above the Earth´s atmosphere, the Hakucho Satellite, which known as the (CORSA-B, https://heasarc.gsfc.nasa.gov/docs/hakucho/hakucho.html) launched in 1979 and was the first X-ray Astronomy Japanese satellite. The Infrared Astronomical Satellite (IRAS, https://irsa.ipac.caltech.edu/IRASdocs/iras.html) was a joint project of the USA, UK, and the Netherlands. It was launched in 1983 and was equipped with Ritchey-Chretien telescope reflectors with a 57-cm entrance aperture in order to conduct a sensitive and unbiased survey of the sky in four wavelength region centered at 12, 25, 60, and 100 micrometers (μm) [64].

In 1983, the European Space Agency's X-ray Observatory (EXOSAT, https://heasarc.gsfc.nasa.gov/docs/exosat/exosat.html) was launched [65]. The main goal of the EXOSAT was to use lunar occultation to obtain precise positional information for the relatively small number of known X-ray sources at that time. The High Precision Parallax Collecting Satellite, Hipparcos [66], (https://www.cosmos.esa.int/web/hipparcos/home) was an astrometrical satellite launched in1989 for measuring high precision parallaxes, Proper Motion, and photometry [67] and it was able to observe the entire celestial sphere from its location in space. Hipparcos made high precision measurements successfully for more than 118,000-star positions at 0.001 arcsec accuracy as well as some 1,050,000 stars positions at 0.025 arc seconds. All of these results achieved by the mission were published in the Hipparcos and the Tycho Catalog.

With the coming of the Space Telescope Age, many telescopes and their instrumentation were sent into orbit. One of the most successful astronomical telescopes launched into space to date has been the Hubble Space Telescope (HST, http://hubblesite.org/). HST is the first major (2.4-m diameter) Space telescope to be installed in orbit in 1990 and it has been marked as the most significant advance of scientific instruments in astronomical technologies since Galileo's telescope [68]. Since then, HST has modernized and reshaped our understanding of the Universe and uncovered a cosmos of unexpected wonders. At the same time, it continues to provide extensive views of mysterious and unique astronomical discoveries as never seen before. (Figure 1-15).

In 1991, following the Hubble Space Telescope, NASA designed and launched the Compton Gamma-Ray Space Telescope Observatory (CGRO, https://heasarc.gsfc.nasa.gov/docs/cgro/cgro/). The CGRO is a sophisticated Space Telescope dedicated to observing the high-energy Universe [69]. The CGRO carries two telescopes: the Imaging Compton Telescope (COMPTEL) and the Energetic Gamma Ray Experiment Telescope (EGRET) in order to detect an unprecedentedly broad range of gamma ray's high-energy radiation.The Chandra X-Ray Space Observatory (CXO) was launched into space in 1999 and was used to study detailed high-resolution studies of the structure of extended X-ray sources in the Universe [70].

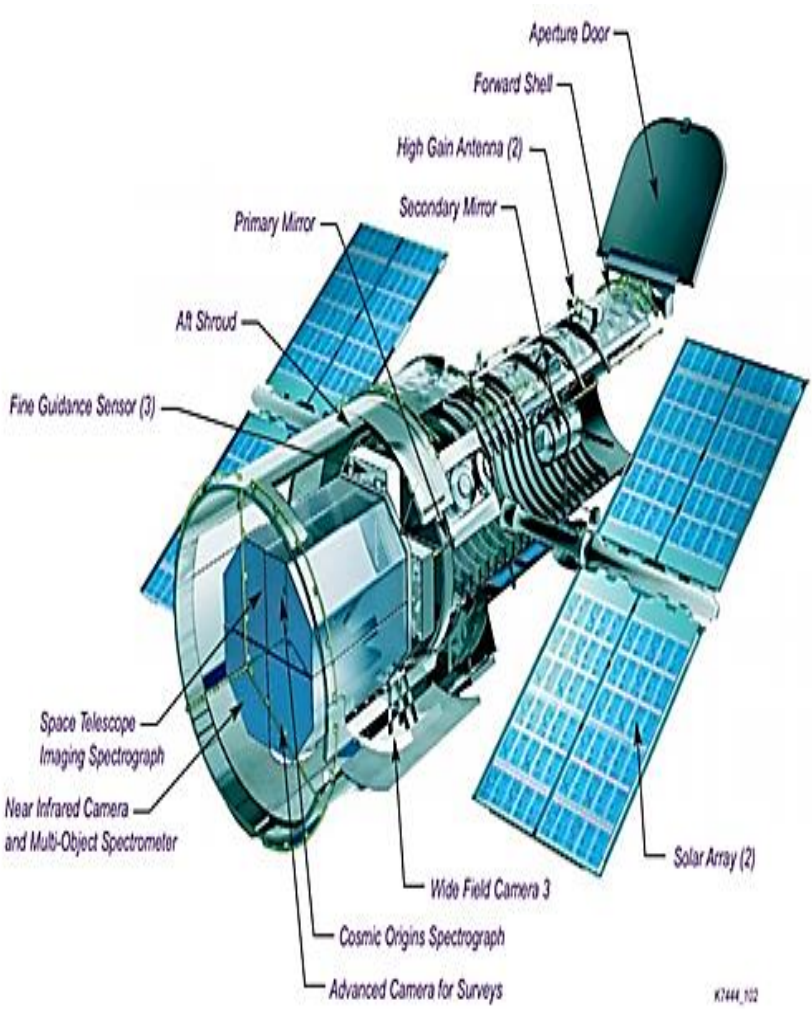


Figure 1-15 The Hubble Space Telescope (HST) (Credit: NASA)

With the advent of the 21st century, the Next Generation Space Telescopes (NGST) will be designed to detect the infrared part of the EM spectrum as well as some regions of the visible spectrum (in particular in the red and up to the yellow part of the visible spectrum), parts of the spectrum which are particularly blocked by the Earth´s atmosphere [71]. In 2003, the Spitzer Space Telescope (SST), formerly named the Space Infrared Telescope Facility (SIRTF, http://www.spitzer.caltech.edu/), was launched. SST is an Infrared Space Telescope designed to study the early Universe in the infrared spectrum [72]. The Herschel Space Observatory (https://www.herschel.caltech.edu/) was launched by the European Space Agency (ESA) in 2009 as the largest and most powerful Far InfraRed and Submillimetre Space Telescope (FIRST) [73]. It is a passively cooled telescope and has a 3.5 m diameter primary mirror made out of 12 segments combined to form a monolithic mirror blank as well as a total Wave-front Error (WFE) of less than 6 µm. FIRST observes and detects the sky in far infrared and sub-millimetre wavelengths of electromagnetic spectra to study the formation of the first galaxies and first stars [74].

Today, advancements in astronomical scientific research, as well as the exploration of the mysteries of the Universe, are always accomplished by merely building larger and more effectual space telescopes. The James Webb Space Telescope (JWST, http://www.jwst.nasa.gov/) is being planned and fabricated in order to be considered as a massive, as the most powerful and most worthy tool in the history of astronomical instrumentation. JWST is a joint cooperative project of the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Canadian Space Agency (CSA). It will launch in 2021 to unleash scientific successes and breakthroughs of the HST mission. Furthermore, JWST will be placed in orbit at Lagrange point 2 (the Lagrange points are five different equilibrium points that represent where the combined centripetal force of solar orbit and opposing gravity from the two bodies). The JWST has a 6.55 m-diameter mirror made up of 18 hexagonal beryllium segments, optimized for diffraction-limited performance in the near-infrared (1–5 µm) and mid-infrared (5–28 µm) wavelength spectral regions in order to follow up and examine the contents of the faint extragalactic Universe and, possibly, the ignition first stars. JWST is characterized as a "cool" telescope and is designed to operate at very low temperatures (around -230° C) that will presumably provide us with an unprecedented view of the Universe at near and mid-infrared wavelengths and will allow specialists to study a vast range of the distant celestial objects [75]. JWST will be equipped with four cutting-edge scientific instruments as follows: a Wide-Field

Near-Infrared Camera (NIRCam), a Wide-Field Multi-Object Near-Infrared Spectrometer (NIRSpec), a Mid-Infrared Camera and Spectrograph (MIRI), and a Fine Guidance Camera hold a Near-Infrared Tuneable Filter Imaging (FGS/TFI) [75]. The scientific objectives of JWST are divided into four major research themes: the End of the Dark Ages: First Light and Reionization, the Assembly of Galaxies, the Birth of Stars and Protoplanetary Systems, and Planetary Systems and the Origins of Life [75]. (Figure 1-16).

In Space Astronomy, UV Astronomy is a very required branch of astronomers, the UV region of the EM spectrum is highly sensitive to many underlying astronomical and astrophysical processes. In fact, throughout more than six decades, astronomers have had ready continuous access to the UV region in the Universe from space, in other words, all UV observations carried out from space. Many space missions have launched to implement UV studies such as the Orbiting Astronomical Observatory (OAO-2 and OAO-3), the Thor Delta satellite 1A (TD-1A), the Astronomical Netherlands Satellite (ANS), the International Ultraviolet Explorer (IUE), the Soviet Astron Orbital Station (ASTRON), the European Space Agency's X-ray Observatory (EXOSAT), the Hubble Space Telescope (HST), the Extreme Ultraviolet Explorer (EUVE), the Far Ultraviolet Spectroscopic Explorer (FUSE), and the Galaxy Evolution Explorer (GALEX).

Recently, the next generation UV space telescope will be in the World Space Observatory-Ultraviolet Project (WSO–UV, http://www.wso-uv.es/index.php?id=33). The WSO–UV is an international cooperation between Russia and Spain as major partners, and the Ukraine and Germany as minor ones. It is equipped with a1.7-m aperture Ritchey-Chretien telescope with a focal length of 17-m. The telescope was designed for observations in the UV region (115 - 320 nm) and provides a corrected field of view equal 0.5 degrees. Furthermore, the WSO-UV is carrying some of the sophisticated multipurpose devices such as High-Resolution Spectroscopy, the High-Resolution Double Echelle Spectrograph (HIRES), Long-Slit Low Resolution, High

Sensitivity Imaging, and Slit-Less Spectroscopy [76], [77]. Table 1 - 4 lists the past, present, and future Space Telescope.

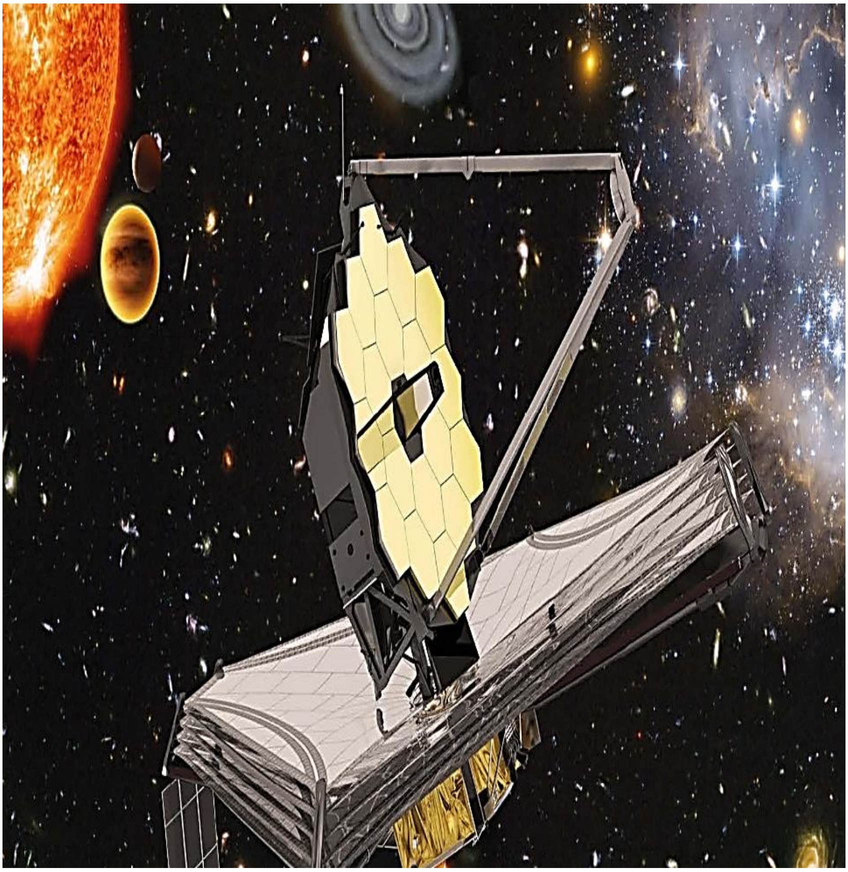


Figure 1-16 The James Webb Space Telescope (JWST) (Credit: ESA)

Astronomical Astrometry is one of the quintessential disciplines in Astronomy and Astrophysics [78]. It is concerned with the accurate measurement and study of the positions and motions of celestial objects, from planets and other Solar system objects to stars within Milky Way Galaxy and beyond, to galaxies and clusters of galaxies within the Universe. Since the invention of the telescope, astrometric measurements have developed and improved dramatically (and made an incredible breakthrough to understand the Universe) by obtaining accurate astrometric measurements via ground-based telescopes necessary due to difficult to control systematic observation errors and, thereby, overcome the disturbing effects of the Earth's atmosphere. In the late 20th century, the space-based astrometric telescope is able to overcome these issues and provide measurements of the stellar position to an accuracy equal to 0.00001 arcsec. Astrometry from space has unprecedented power over ground-based measurements such as the all-sky coverage that is relatively stable and temperature and gravity invariant [79]. Also, the operating environment delivers precision, accuracy, and sample volume that are several orders of magnitude greater than ground-based results as well as the absolute astrometry is desirable. In 1989, ESA launched the first space telescope for astrometric studies, Hipparcos, and it provided the positions, parallaxes, and annual proper motions for about 100,000 stars with an unprecedented accuracy of 0.007–0.0009 arcsec for stars brighter than 9 magnitudes [80].

As a continuation of the ESA mission to collect accurate astrometric measurements with the space telescope, Gaia (acronym of the Global Astrometric Interferometer for Astrophysics, https://sci.esa.int/web/gaia), astrometric space missions were launched in 2013 to provide an enormous advance in the quality and quantity of stellar astrometric data with accuracy up to 0.00001 arcsec [81]. The main goal of Gaia is to measure and create the most precise three-dimensional map of more than one billion stars in our Galaxy as well as to allow scientists to study the velocities of stars in great detail by providing three-dimensional velocity distribution of those stars [82]. In addition, with this outstanding astrometric, photometric, and spectroscopic data set afforded by Gaia's mission, astronomers were able to calculate the physical and dynamical parameters of the stellar populations in the Milky Way galaxy. Gaia is equipped with two identical telescopes, each with three rectangular and flat-folding mirrors to contain a focal length of 35m. The primary mirror apertures of 1.45-m by 0.50-m point in directions separated by the basic angle of 106.5deg along the scanning circle. It also holds three scientific instruments: a focal plane assembly, photometric instrument, and the spectroscopic instrument which is known as Radial Velocity Spectrometer (RVS). The first Gaia data release (Gaia DR1) took place in 2016 [83] based on the collected data on the first 14 months of the mission. In 2018, the second was release (Gaia DR2) based on 22 months of data [84, p. 2], and the third is expected in 2020.

Table 1-2 The major world class optical and infrared ground-based telescopes arranged by the telescope diameter from largest to smallest

Observatory and Website	Location	Establishment	Description
European Extremely Large Telescope (EELT, http://www.eso.org/sci/facilities/eelt/)	Cerro Armazonas, Chile	First light 2025	The E- ELT is a revolutionary scientific project of constructing a 39-m diameter sophisticated telescope that will be the most significant visible/near-infrared telescope in the world. It can correct for the Earth's atmospheric distortions (from the begin operating). The E-ELT will tremendously advance astronomical knowledge by enabling comprehensive studies of planets around other stars, galaxies in the Universe, super-massive black holes, and the dark matter of the Universe.
Thirty-Meter Telescope (TMT, www.tmt.org)	Mauna Kea, Hawaii, USA	First light 2025	The TMT is a new class of extremely large telescopes with a 30-m prime mirror diameter (consisting of 492 segments with total collecting area of 655 m2). It will observe in wavelengths ranging from the ultraviolet to the mid-infrared that provide new observational opportunities to study and detect celestial objects with unprecedented sensitivity.

Giant Magellan Telescope (GMT, www.gmto.org)	Las Campanas Observatory, Chile	First light 2024	The GMT will employ seven 8.4 m primary mirror segments and seven 1 m secondary mirror segments to form a single optical surface of a 25.4-m aperture with a diffraction-limited. The secondary mirrors are actually flexible and manufactured by the most sophisticated AO technology.
Southern African Large Telescope (SALT, www.salt.ac.za)	Sutherland, South Africa	First light 2005	The SALT is the largest single optical telescope in the southern hemisphere. It consists of the 11-m full hexagonal primary mirror which is composed of 91 individual 1-m hexagonal mirrors. It can detect the EM spectra from faint or distant objects in the Universe and its instruments operate from the near-UV bands to the near-IR (320 to 1700 nm).
Gran Telescopio Canarias (GTC or GRANTECAN, http://www.gtc.iac.es)	La Palma, Canary Islands, Spain	First light in 2007 and Scientific production in 2009	The GTC telescope has a 10.4-m diameter single monolithic mirror which consists of 36 individual hexagonal segments that act together as a single mirror. GTC is an ambitious Spanish astronomical project aiming to construct one of the most advanced optical and infra-red telescopes in the world.

Keck I and Keck II (www.keckobservatory.org)	Mauna Kea, Hawaii, USA	First light (Keck I) in 1993 and (Keck II) in 1996	The Keck I and Keck II primary mirrors are 9.96-m in diameter, comprised of 36 hexagonal segments that operate in concert as a single piece of reflective glass. Its legacy of exploration has contributed to all areas of Astronomy and Astrophysics research, such as the discovery of exoplanets, the study of planets, stars, galaxies formation, black holes, and the chemical composition and evolution of the Universe.
Hobby-Eberly Telescope (HET, www.as.utexas.edu/mcdonald/het)	at the McDonald Observatory in Davis Mountains, Texas, USA	First light 1997	The HET is a fixed-elevation telescope that has a 9.2-meter spherical primary mirror constructed in a tilted Arecibo-style configuration with a moving star tracker at prime focus to track and detect astronomical objects.
Large Binocular Telescope (LBT, www.lbto.org)	Mount Graham, Arizona, USA	First light 2004	The LBT utilizes two 8.4-m diameter primary mirrors mounted side-by-side in order to provide a collecting area equivalent to an 11.8-meter circular aperture. Each mirror has a paraboloidal surface with a focal length of 9.600 meters. This co-phased imaging system with adaptive optics gives the telescope the diffraction-limited resolution of a 22.65-m aperture.

Large Synoptic Survey Telescope (LSST, www.lsst.org)	Cerro Pachón, Chile	First light 2021	The LSST is an 8.4-meter primary mirror that uses a special three-mirror design which creates an unusually wide field of view in order to perform a survey of the whole sky in only three nights. The scientific objective of the LSST is to conduct a 10-year survey of the sky including the study of Dark Matter and the Dark Energy.
Subaru Telescope (https://subarutelescope.org/)	Mauna Kea, Hawaii, USA	First light 1999	The Subaru is an 8.2-m primary mirror diameter telescope designed to reduce atmospheric thermal turbulence. It is operated by the Japan National Large Telescope (JNLT).
Very Large Telescope (VLT)	Atacama Desert, Chile	First light 2000	The VLT is one of the latest optical telescopes. It consists of four Unit telescopes with primary mirrors of 8.2-m diameter and four movable 1.8-m diameter auxiliary telescopes, and it can work together. Moreover, the VLT provides remarkably high-resolution images by using a unique technique called optical interferometry which allowed it to obtain and capture EM radiation from the most distant and most remote objects in the Universe.

Gemini North (http://www.gemini.edu/)	Mauna Kea, Hawaii, USA	First light 1999	The Gemini North is an 8.1-m diameter optical/infrared telescope that employs sophisticated state-of-the-art adaptive optics systems including the ALTAIR. Both Gemini North and South were built and are operated by a partnership of 7 countries including the United States, United Kingdom, Canada, Chile, Australia, Brazil, and Argentina.
Gemini South (http://www.gemini.edu/)	Cerro Pachón, Chile	First light 2000	The Gemini South is an 8.1-m diameter optical/infrared telescope and employs sophisticated state-of-the-art adaptive optics systems known as the Gemini Multi-Conjugate Adaptive Optics System (GeMS). Both Gemini North and South were built and are operated by a partnership of 7 countries including the United States, United Kingdom, Canada, Chile, Australia, Brazil, and Argentina.

The Magellan Telescopes (Two telescopes: Walter Baade and Clay) (http://www.lco.cl/telescopes-information/magellan/)	Las Campanas Observatory, Chile	First light in 2000 and second in 2002	The Magellan consists of two identical telescopes. Each one has a 6.5-m primary mirror aperture and they are aligned in an alt-azimuth design.
Multi-Mirror Telescope (MMT, www.mmto.org)	Mount Hopkins, Arizona, USA	First light 1979	The first configuration of the MMT telescope was effectively six small "individual" telescopes mounted in a circular array on the same support structure. Each of the six telescopes had a primary mirror with a diameter of 1.8-m. In 1998, the MMT telescope was updated to a single 6.5-m primary mirror diameter and is now operated by the MMT Observatory (MMTO), a joint venture of The Smithsonian Institution and The University of Arizona.
Big Telescope Altazimuth (BTA-6, http://astro.vaporia.com/start/bta6.html)	Mount Pastukhov, Russia	First light 1976	The BTA-6 is a 6-m diameter telescope with a monolithic mirror and is of the Ritchey-Chrétien design.

Center for High Angular Resolution Astronomy (CHARA, http://www.chara.gsu.edu/)	Mount Wilson, California, USA	First light 2000	The CHARA Array consists of six 1-m aperture telescopes arranged in a Y-shaped configuration yielding 15 baselines ranging from 34 to 331-m as well as 10 possible phase closure measurements
Hale Telescope (http://www.astro.caltech.edu/palomar/about/telescopes/hale.html)	California, USA	First light 1948	The Hale Telescope has a 5.1-m primary mirror diameter and is considered to be the first giant telescope in history and the largest effective telescope in the world until the 1990s. The telescope was named in honor of the noted American astronomer, George Ellery Hale.

Table 1-3 Major radio telescopes in the world

Observatory and Website	Location	Establishment	Description
Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST, http://fast.bao.ac.cn/en/)	Guizhou, China	2016	The FAST is a Chinese science project to build the biggest single-dish radio telescope in the world. The active main reflector of the FAST is a fixed 500-m which directly corrects for spherical aberration and will be equipped with a variety of instruments and terminals for different scientific proposes.
Arecibo Observatory (www.naic.edu)	Arecibo, Puerto Rico, USA	1963	This radio telescope has a 305-m diameter fixed dish, the largest in the world until 2016 and covers an area of approximately 20 acres (0.08 square kilometers).
Green Bank Telescope (GBT, https://greenbankobservatory.org/)	Green Bank, USA	2000	The GBT consists of a 110 x 100 m steerable dish that was designed and built by NRAO. It can be used for Chemistry, Physics, and Astronomy (Planetary Science and Cosmology) scientific research.

Effelsberg 100-m Telescope (MPIfR, https://www.mpifr-bonn.mpg.de/en/effelsberg)	Bonn, Germany	Constructed from 1968 to 1971 and inaugurated in 1972	This radio telescope has a 100-m diameter of the steerable dish and used to observe pulsars, cold gas- and dust clusters, and the sites of star formation. It is designed to allow observations in the decimeter and centimeter wavelength regions and it is an imperative part of the worldwide network of radio telescopes
Lovell Telescope http://www.jb.man.ac.uk/	at Jodrell Bank, Manchester, England	1957	The Lovell radio telescope has a 76-m diameter steerable radio telescope conceived by Sir Bernard Lovell. It plays a key role in world-leading research on pulsars, testing our understanding of extreme physics including Einstein's General Theory of Relativity nowadays

Canberra Deep Space Communication Complex (CDSCC, www.cdscc.nasa.gov)	Tidbinbilla, Australia	2003	This radio telescope equipped with a 70-m steerable dish and operated by the Canberra Deep Space Communication Complex, part of NASA's Deep Space Network. In addition to that, there are currently four radio 34-meter radio dishes that work together in order to receive data from spacecraft on Deep Space Network (DSN) missions
Goldstone Deep Space Communications Complex (GDSCC, www.gdscc.nasa.gov)	Barstow, California, USA.	1958	The GDSCC is one of three complexes around the world known as the NASA Deep Space Network (DSN), consists of a 70-m steerable dish and five 34-m dishes.
Parkes Observatory Telescope (www.parkes.atnf.csiro.au)	Parkes, Australia	1961	This radio telescope constructed with a 64-m steerable dish in 1961 and later in 1987 updated to 70-m steerable dish. The Parkes radio telescope is the largest single-dish telescope in the southern hemisphere dedicated to Astronomy and is able to observe at frequencies from 0.3 to 43 GHz.

Square Kilometre Array (SKA, www.skatelescope.org)	South Africa and Western Australia	Expected in 2020	The SKA will have a collecting area of up to one million square meters. It will use a combination of several thousand 15-m wide dishes spread over at least 3000 km.
Atacama Large Millimeter/ Submillimeter Array (ALMA, http://www.almaobservatory.org/)	Atacama Desert, Northern Chile	ALMA full operation 2013	The ALMA comprises 66 (7-m and 12-m) high-precision antennas dishes and operates at wavelengths of 0.32 to 3.6 mm. It is spread over distances of up to 16 kilometers in order to study light from some of the coldest objects in the Universe. Moreover, the ALMA has opened a new window on the Universe, capturing never-before-seen details about the very first stars and galaxies, probing the heart of our Milky Way Galaxy, and directly imaging the formation of planets.

Very Large Array (VLA, https://public.nrao.edu/telescopes/vla/)	Socorro, New Mexico, USA	1980	The VLA consists of 28 antennas that are each 25-m in diameter dish with nine aerials distributed along each of three equiangular arms extending out to 21 km from the center and operated by NRAO. The VLT affords high diffraction-limited images of astronomical objects with the highest resolution at 1.4 GHz of 1.4 arcsec and at 45 GHz of 0.05 arcsec.

The Expanded Very Large Array (EVLA, http://www.aoc.nrao.edu/evla/)	Socorro, New Mexico, USA	2012	The EVLA is a comprehensive technical upgrade of the VLA and provides a cutting-edge radio telescope of unprecedented sensitivity, resolution, and imaging capability by modernizing and extending the VLA facilities. The EVLA is used for four major scientific topics: 1- Measuring the strength and topology of magnetic fields (the Magnetic Universe), 2- Enabling unbiased surveys, and imaging of dust-shrouded objects which are obscured at other wavelengths (the Obscured Universe), 3- Enabling rapid response to, and imaging of, rapidly evolving transient sources (the Transient Universe), and 4-Tracking the formation and evolution of objects in our Universe (the Evolving Universe).

Westerbork Synthesis Radio Telescope (WSRT, http://old.astron.nl/radio-observatory/radio-observatory)	Westerbork, Netherlands	1970	The WSRT is an array of 14 steerable 25-m diameter parabolic dish antennae working together and is equivalent in collecting area to a single dish of 94 m in diameter. It is a powerful radio telescope that uses a technique called "aperture synthesis" to generate radio images of the sky.
Very Long Baseline Array (VLBA, https://public.nrao.edu/telescopes/vlba/)		1993	The VLBA is a collection of ten identical 25-m antennae located across the USA. It provides the most accurate positions and distances of stars and is used as a tool for mapping the Universe. In addition, the VLBA is utilized to track Near-Earth Asteroids and studying Black Holes.
Australia Telescope Compact Array (ATCA, https://www.narrabri.atnf.csiro.au/)	Several sites in Australia	1988	The ATCA is made up of six 22-m identical antenna and is used by astronomers to study the structure and evolution of our Universe.

IRAM (www.iram-institute.org)	Sierra Nevada, Spain	1984	The IRAM telescope is a 30-m dish parabolic antenna which is used to explore distance cosmic objects such as nearby galaxies and interstellar clouds. It is one of today's largest and most sensitive radio telescopes for analyzing millimetre waves.

Table 1-4 Past, Recent, and Future Space Telescope

Observatory and Website	Establishment	Bands of the Spectrum	Description
International Ultraviolet Explorer (IUE)	1978	UV	The IUE was dedicated to making astronomical spectrographic observations in the range of the ultraviolet. It carried a 45-cm diameter reflector and spectrographs operating in the far- and mid-UV wavelength regions. It was a collaborative program among NASA, ESA, and the British SERC.
InfraRed Astronomy Satellite (IRAS, https://irsa.ipac.caltech.edu/IRASdocs/iras.html)	1983	IR	The IRAS is a 57-cm entrance aperture in order to conduct a sensitive and unbiased survey of the sky in four wavelength regions centered at 12, 25, 60, and 100 micrometers (μm).

HIgh Precision PARallax COllecting Satellite (Hipparcos, https://www.cosmos.esa.int/web/hipparcos)	1989	Visible, IR, and UV	Hipparcos is a single all-reflective, eccentric Schmidt telescope, with a diameter of 29-cm and operated by ESA and carried on a spacecraft.
Hubble Space Telescope (HST, https://hubblesite.org/)	1990	Visible, Uv, and IR	The HST is a 2.4-m aperture primary mirror telescope, formerly called the "Large Space Telescope (LST)" and later, the "Space Telescope (ST)".

Extreme Ultraviolet Explorer (EUVE, https://heasarc.gsfc.nasa.gov/docs/euve/euve.html)	1992	Short UV bands	The EUVE is a space mission devoted to conducting a photometric survey of the entire sky over the short UV wavelengths (7 - 76) nm. It is equipped with three 40-cm telescopes used to carry out an all-sky EUV survey in four photometric bands and spectrometer to carry out a deep survey. It was placed in a circular orbit of 550 km above the Earth's surface.
Chandra X-Ray Observatory (CXO, https://chandra.harvard.edu/)	1999	X-ray	The Chandra telescope system consists of four pairs of very sensitive mirrors and their support structure. It is a telescope specially designed to detect X-ray emissions from very hot regions of the Universe.

XMM-Newton (https://sci.esa.int/web/xmm-newton)	1999	X-rays	The XMM-Newton carries three superior X-ray telescopes. Each of them contains a primary mirror module integrated with 58 high-precision concentric mirrors. It is used to detect elusive X-rays in order to help to solve many of the Universe's mysteries ranging from enigmatic black holes to the formation of galaxies.

International Gamma-Ray Astrophysics Laboratory (INTEGRAL, http://sci.esa.int/integral/)	2002	gamma rays, X-rays, and visible light	The INTEGRAL is the first space mission that can concurrently observe and discover objects in gamma rays, X-rays, and visible light in order to provide to the astronomical community at large with an unprecedented combination of imaging and spectroscopy to explore the most dynamic phenomena that occur in the Universe. The main purposes to study the violent explosions known as gamma-ray bursts, powerful phenomena such as supernova explosions, and black holes.

Galaxy Evolution Explorer (GALEX, http://www.galex.caltech.edu/)	2003	UV	The GALEX is a mission to accomplish imaging and spectroscopic sky-surveys at near and far-UV wavelengths (135 -280 nm) and is conducted by NASA. It is outfitted by a 50-cm primary mirror Ritchey-Chretien telescope. The main purpose of the GALEX is to provide the first comprehensive map of galaxies and bring us closer to understanding how they were built.
Spitzer Space Telescope (SST, www.spitzer.caltech.edu)	2003	IR	The Spitzer is an 0.85-m diameter primary mirror space telescope for IR Astronomy and includes three scientific instruments providing imaging and spectroscopy at wavelengths from 3.6 to 160 μm.

Convection, Rotation, and planetary Transits Telescope (CoRoT, https://sci.esa.int/web/corot)	2006	Visible	CoRoT was the first space mission devoted and designed for exoplanetary research and operated in a circular polar orbit 896 km above the surface of Earth. It carried a 27-cm primary mirror telescope with a 1.1-m focal length and a 4-CCD wide-field camera.

Fermi Gamma-ray Space Telescope (Fermi, https://fermi.gsfc.nasa.gov/)	2008	Gamma-ray	The Fermi is a powerful space observatory that opens a wide window on the Universe at the gamma-ray bands and offers enormous opportunities for determining the nature of these sources and advancing scientific knowledge in Astronomy. It was formerly called the Gamma-ray Large Area Space Telescope (GLAST). The Fermi has two instruments, the primary instrument is the Large Area Telescope (LAT). LAT is a wide field-of-view imaging telescope covering the energy range ~20 MeV to 300 GeV. The secondary is the Gamma-ray Burst Monitor (GBM) which is sensitive to X-rays and

			gamma-rays with energies between 8 keV and 40 MeV.
Herschel Space Observatory (FIRST, https://sci.esa.int/web/herschel)	2009	IR	The Herschel or the formerly named Far Infrared and Sub-millimetre Telescope has a 3.5-m diameter primary mirror and is operated by ESA. It is used to study cool objects in the Universe and in our Solar System at IR to submillimetre wavelengths.

Planck (https://sci.esa.int/web/planck)	2009	Microwave and submillimeter	The Planck space telescope is an unobscured 1.5 m aperture off-axis aplanatic telescope passively cooled to 40 K with very high-quality reflector surfaces including cutting-edge broadband detectors covering the range 30–857 GHz. The Planck mission operated in Lissajous orbits around the second Lagrange point, L2, located at a distance of 1.5 million km above the Earth. It was employed to detect the oldest light in the Universe as well as the cosmic microwave background radiation, and to map the early Universe's subtle fluctuations in temperature and polarization.

Wide-field Infrared Survey Explorer (WISE, http://wise.ssl.berkeley.edu/mission.html	2009	IR	The WISE is an infrared-sensitive cryogenic telescope with a 0.4-m diameter equipped with the latest megapixel infrared cameras to image the entire sky. The scientific objectives of WISE are to find the most luminous galaxies in the Universe and the closest stars to the Sun. It is employed to conduct a wide variety of studies ranging from the evolution of planetary debris discs to the history of star formation in normal galaxies.

Kepler Space Telescope (http://kepler.nasa.gov)	2009	Visible Light	The Kepler is a 1.4-m primary mirror diameter telescope designed to search for extrasolar planets, especially those in the habitable zone of the Milky Way galaxy where liquid water might exist on the surface of these planets. After ten years of the Kepler mission, it discovered 2,681 new exoplanets and there are more than 2,900 candidate planets awaiting confirmation. In 2014, the Kepler mission was updated to the K2 mission in order to continue exoplanet discoveries on the ecliptic plane.

Stratospheric Observatory for Infrared Astronomy (SOFIA, https://www.sofia.usra.edu/)	2010	Infrared	The SOFIA is a Boeing 747SP aircraft modified to carry a 2.7-m reflecting telescope and equipped with advanced cameras, spectrometers, and polarimeters that operate in the near-, mid- and far-infrared wavelengths. It flies at/or above 12.5 Km above the Earth and is designed to observe the solar system in order to study star formation, planets, comets, and asteroids.

Spektr-R (http://www.russianspaceweb.com/spektr_r.html)	2011	Radio	The Spektr-R is a space radio telescope and is part of the RadioAstron Project initiated by the Astro Space Center (ASC) of Lebedev Physical Institute of Russian Academy of Sciences (RAS). The telescoping antenna consists of a deployable parabolic reflector of 10-m diameter equipped with a complex of 1.35, 6.2, 18, and 92 cm receivers.

Nuclear Spectroscopic Telescope Array (NuSTAR, https://www.nustar.caltech.edu/)	2012	X-ray	The NuSTAR is a scientific mission with the purpose to study the Universe in high energy X-rays to better understand the dynamics of black holes, exploding stars and the most extreme active galaxies. It is consisting of two X-ray telescopes and equipped with the most advanced generation of hard X-ray optics and detector technologies to perform high-sensitivity observations at X-ray energies from 3 – 79 keV.

Global Astrometric Interferometer for Astrophysics (Gaia, https://sci.esa.int/web/gaia)	2013	Visible Light	The Gaia is equipped with two identical telescopes with three rectangular and flat-folding mirrors with a focal length of 35 m. These two telescopes utilize ten mirrors of different sizes and surface shapes to collect, focus, and direct light to Gaia's instruments for detection.
Transiting Exoplanet Survey Satellite (TESS, https://tess.mit.edu/)	2018	Visible Light	The TESS is a continuation of the Kepler mission in the search for planets outside of our solar system by using the transit method including those that could support life. It will employ four wide-field optical CCD cameras to monitor at least 200,000 of the brightest stars near the Sun.

Spektr-RG (SRG, http://www.russianspaceweb.com/spektr_rg.html)	2019	X-Ray	The Spektr-RG is an international cooperative space mission that carries two instruments: the Extended Roentgen Survey with an Imaging Telescope Array (eROSITA) and the Astronomical Roentgen Telescope X-ray Concentrator (ART-XC) X-ray telescopes. It is situated in orbit at the Lagrange point, L2, of the Sun-Earth system, 1.5 million kilometers away from Earth. The main objectives of the SRG are to carry out an all-sky survey in the soft X-ray range (0.3–11 keV) with outstanding sensitivity and to perform a detailed study of selected astronomical objects during subsequent observations in the hard energy range up to 30 keV.

James Webb Space Telescope (JWST) (http://www.jwst.nasa.gov/)	2021	IR	The JWST is a 6.55 m-diameter mirror made up of 18 hexagonal beryllium segments, optimized for diffraction-limited performance in the near-infrared (1-5 μm) and mid-infrared (5-28 μm) wavelength spectral regions in order to follow up and examine the contents of the faint extragalactic Universe and possibly the ignition of the first stars.

World Space Observatory-Ultraviolet Project (WSO-UV, http://www.wso-uv.es/index.php?id=33).	Expected 2023	UV	The WSO-UV is a 1.7-m aperture Ritchey-Chretien telescope with a focal length of 17-m. The telescope was designed for observations in the UV region (115 - 320 nm) and provides a corrected field of view equal to 0.5 degrees. Furthermore, the WSO-UV is carrying some sophisticated multipurpose use devices such as High-Resolution Spectroscopy, the High-Resolution Double Echelle Spectrograph (HIRES), Long-Slit Low Resolution, High Sensitivity Imaging, and Slit-Less Spectroscopy. Furthermore, the WSO-UV is a Russian-Spanish Project.

1.3. THE PIVOTAL ROLE OF ADAPTIVE OPTICS (AO) AND LASER TECHNOLOGY IN ASTRONOMY

Adaptive Optics (AO) played a crucial role in the improvement of the telescope performance that has led to considerable advances in our understanding of a multitude of heavenly observation circumstances [6]. AO is a technology used in Ground-Based Telescope to correct for the wavefront aberrations and loss of image quality caused by atmospheric turbulence that leads to drastic degradation and aberration in the quality of images that can be taken with a telescope. It will enable future astronomers to achieve virtually diffraction-limited performance with the Extremely Large Telescope as well as Space Telescopes that are currently under development, thereby significantly improving spatial and spectral resolution which will be obtained in astronomical photos. AO is a good illustration of the advance in telescope accomplishments that can be driven by technological developments. Recently, AO has revolutionized the telescope performance. All powerful new telescopes equipped with AO have resulted in dramatically high-resolution images of the celestial objects in the sky that most scientists only a few decades ago would not have dreamed possible. This allows astronomers to study the deep universe more than ever before. The key elements of the AO system are as follows: 1- a corrective element such as a deformable mirror to flatten the aberrated wavefronts, 2- a wavefront sensor to measure the aberrations, 3- a light source to drive the sensor, and 4- a wavefront reconstruction. (Figure 1-17).

In Horace Babcock's paper "The Possibility of Compensating Astronomical Seeing" published in 1953, he suggested and introduced the Adaptive Optics system concept as a correction mechanism for compensation of the Earth´s atmosphere turbulence effect on an ground astronomical telescope [85]. Figure 1-18 illustrates the first AO system by

Horace Babcock. Following Babcock's suggestion for AO, the first significant development in the AO system for astronomical telescope arose in 1974. Richard Muller and Andrew Buffington presented a new technique for the correction of the Earth's atmospheric distortion in telescope images which can be conveniently applied within telescopes [86]. Figure 1-19 shows the schematic of the real-time correction of atmospherically degraded telescope images through image sharpening. This technique was employed to build a 30-cm aperture telescope by using six movable mirrors to compensate for atmospherically induced phase distortion in 1977 [87]. Furthermore, in the 1970s, John Hardy and others developed another AO system to be employed in ground-based telescopes, this system being called Real-Time Atmospheric Compensation (RTAC). RTAC was an AO optical imaging system capable of correcting optical wave-front errors in real-time at frequencies in the kilohertz range. It used a wavefront sensor, reconstruct, and deformable mirror, similar to AO systems that we standard wide use today [86], [88]–[90]. (Figure 1-20).

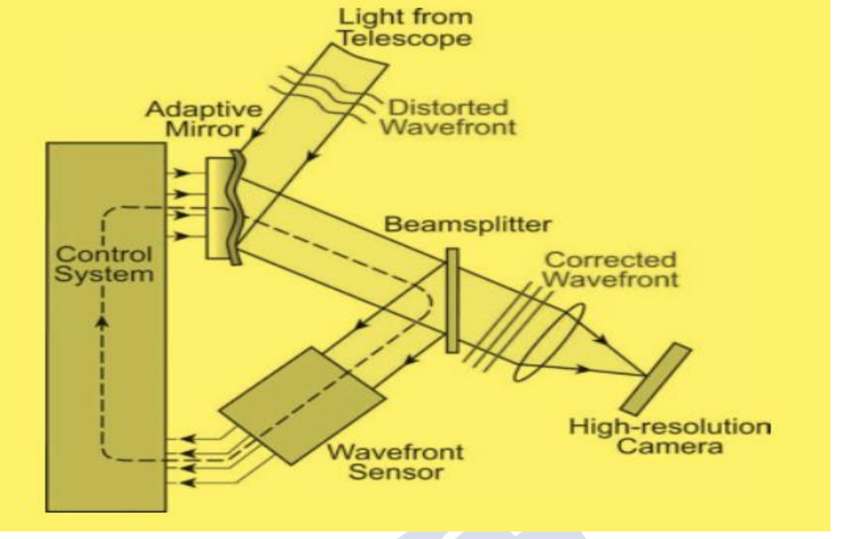


Figure 1-17 Schematic Diagram of a Simple Adaptive Optics Elements System[2] *(Credit: Encyclopaedia of Solar System by L. McFadden et al., 2006)*

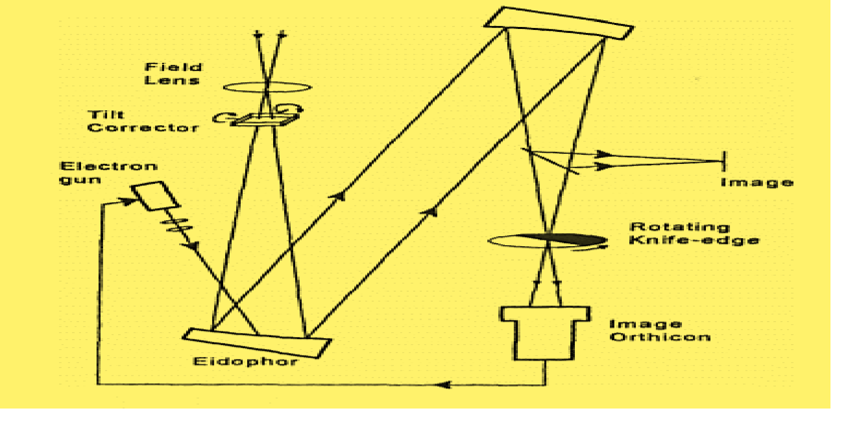


Figure 1-18 The Adaptive Optics Seeing Compensator proposed by Horace Babcock in 1953 (Credit: The Possibility of Compensating Astronomical Seeing by H. Babcock)

[2] Light from the telescope is collimated and sent to an adaptive or deformable mirror. If there were no atmospheric turbulence, the wavefront of the light would be perfectly straight and parallel. The light has then reflected a beamsplitter, where part of the light is reflected in the wavefront sensor. The wavefront sensor measures the distortion of the wavefront and sends a correction signal to the adaptive mirror. The adaptive mirror is capable of changing its shape to remove the deformations in the light wave caused by the atmospheric turbulence. In this way, the light with a corrected wavefront reaches the high-resolution camera, where a diffraction-limited image is formed [91].

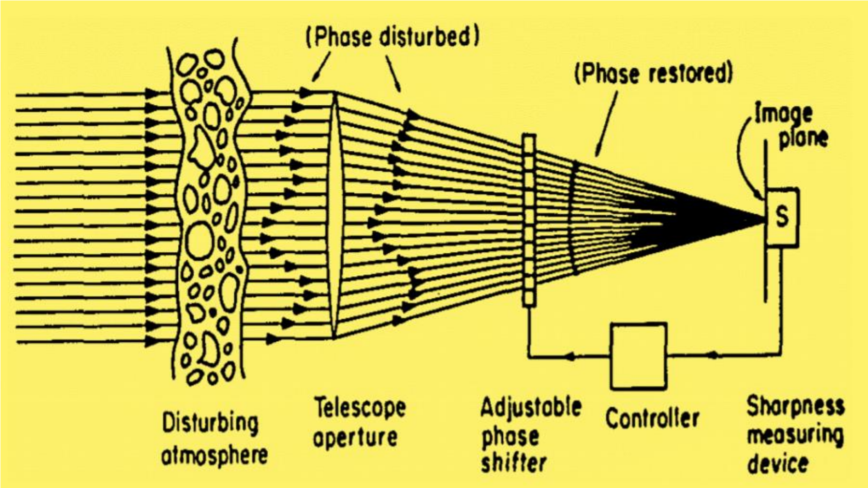


Figure 1-19 Schematic Diagram of Image-Restoring System by Richard Muller and Andrew Buffington (Source: Real-time correction of atmospherically degraded telescope images through image sharpening by R. Muller and A. Buffington)

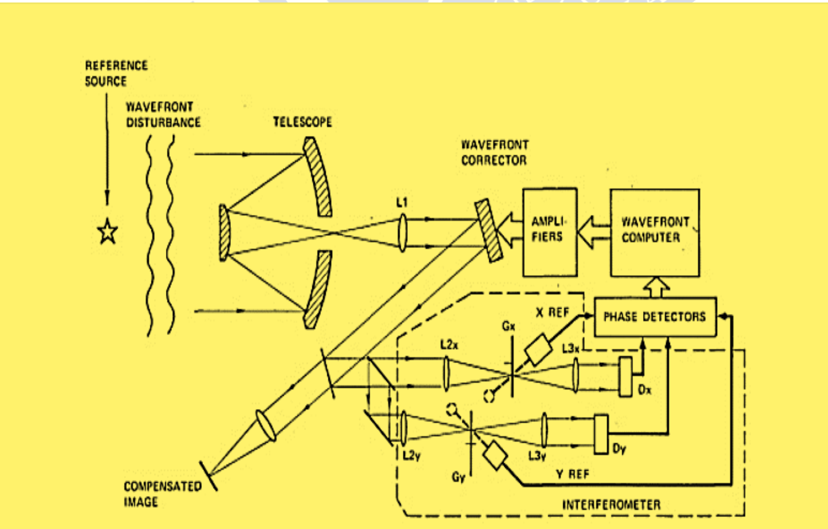


Figure 1-20 Full Diagram of a Real-Time Atmospheric Compensation System (RTAC) (Source: Real-time atmospheric compensation by J. Hardy, J. Lefebvre, and C. Koliopoulos)

At the beginning of the 1980s, the Defense Advanced Research Projects Agency (DARPA) and the U.S. Air Force implemented the first practical AO system, the Compensated Imaging System (CIS), on the 1.6-meter telescope on top of Haleakala on the island of Maui in Hawaii (AMOS) [92]. By mid-1980s, advanced developments in AO components had occurred, new progress in deformable mirrors, wavefront sensors, a light source to drive the sensor, and a wavefront reconstructor enabled the astronomers to astonishingly advance in the performance of the telescopes. In the late 1980s, the COME-ON AO prototype system was established at the Observatoire de Haute-Provence in France. COME-ON consisted of a 19-actuator deformable mirror, a 20 sub-aperture Shack–Hartmann wavefront sensor (WFS), and a 32 × 32 pixel near-infrared (NIR) imager. The first run of the COME-ON AO system was applied on the 1.52-m telescope and obtained diffraction-limited at wavelength near-Infrared spectra [93]. Figure 1-21 shows the first astronomical AO corrected image obtained with COME-ON.

In the early 1990s, the COME-ON-Plus AO system was established based on the Come-On prototype. It was an update of the Come-On AO system with a 52-actuator deformable mirror and 30 Hz correction bandwidth. It was installed on the 3.6-m telescope in, the La Silla Observatory in Chile and used successfully to attain high-accuracy results that equal 0.2 arcsec (the diffraction-limited) [94], [95].

In addition to this, during the 1990s, a new type of wavefront sensor was invented called a "curvature sensor"' together with a new type of deformable mirror called "bimorph" at the Institute for Astronomy of the University of Hawaii (UH) [96]; this technological development in AO was incorporated into the to a 2.2-m telescope at Mauna Kea Observatory [97]. Subsequently, the Probe the Universe with Enhanced Optics (PUEO) AO system was developed by the Canada–France–Hawaii Telescope team (CFHT). The PUEO system was installed on the 3.6-m telescope in CFHT [98], [99]. In 2003, the European South Observatory (ESO) Adaptive Optics Department set up a new AO program called the Multiple Application Curvature Adaptive Optics

(MACAO) aiming at advancing development in the wavefront correction and wavefront sensor instrumentations for the Very Large Telescope (VLT) instruments [100].

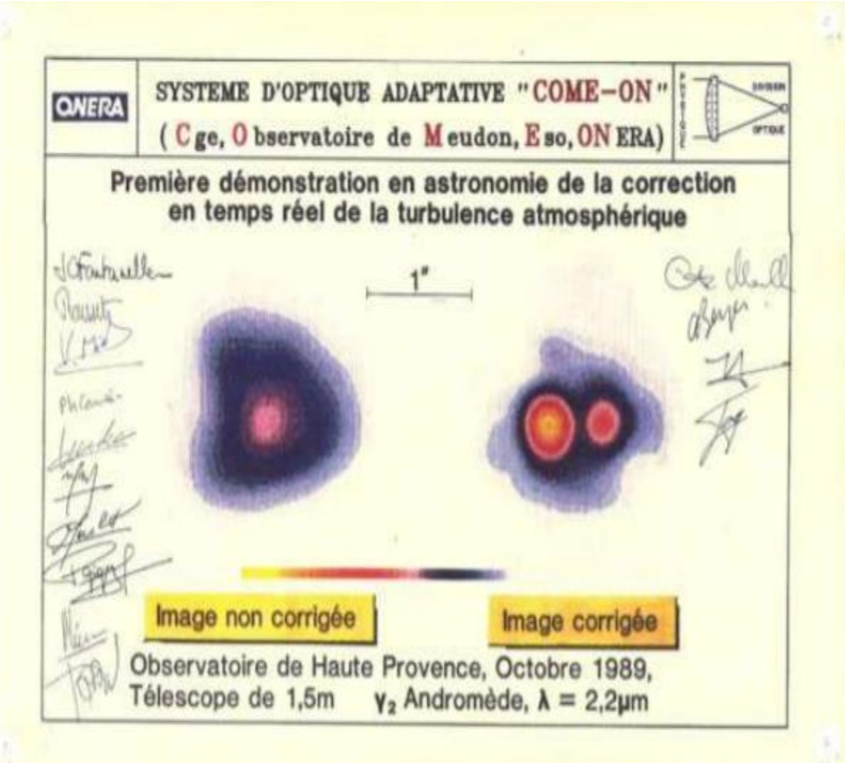


Figure 1-21 The first astronomical AO corrected image obtained with COME-ON (Source: First diffraction-limited astronomical images with adaptive optics By G. Rousset et al. 1990)

The University of Hawaii assembled a new AO system called Hokupa'a AO system in 1997. Hokupa'a is a superior curvature-sensing AO system that implements a 36-element curvature wavefront sensor (WFS) and a bimorph deformable mirror to achieve near-diffraction-limited resolutions. Hokupa`a is installed on an 8-m telescope at the Northern Gemini Observatory [101]. An upgrade of Hokupa`a AO is known as the Hokupa'a-85 (H85) which employ an 85-element curvature wavefront sensor (WFS) and a bimorph deformable mirror set up at the Gemini

Sout h Observatory [102]. Later on, H85 was replaced by a new AO system called "a ALTtitude conjugate Adaptive optics for the InfraRed" (ALTAIR). ALTAIR is unique among AO systems and is designed with the deformable mirror (DM) in order to adapt to high altitudes. It uses a 177-actuator deformable mirror, a separate tip-tilt mirror (TTM) to correct for image blurring and distortion caused by atmospheric turbulence, equipped with a Shack-Hartmann wave-front sensor (WFS) [103]–[105]. The Gemini Observatory has developed an AO system for direct detection of extrasolar planets called the Gemini Planet Imager (GPI) in 2010. The GPI was incorporate into the 8-m Gemini South telescope including an advanced AO imaging polarimeter/integral-field spectrometer [106]. The Gemini Multi-conjugate AO System (GeMS) at the Gemini South telescope was completed in 2011. GeMS is the first AO system using the Sodium-based Multi-Laser Guide Star (LGS) with five LGSs and two deformable mirrors to measure and compensate for atmospheric distortions [107].

Since the beginning of the 21st century, dramatic technological development for key components of the AO system has occurred. The Keck Observatory was the first to make use of AO technology on large telescopes. Keck-I and Keck-II 10- m telescopes have an the AO system which consists of a tip-tilt mirror (TT), a 349-actuator Xinetics deformable mirror (DM), and a dichroic beam splitter that directs the visible light to the 20 × 20 sub-aperture Shack-Hartmann wave-front sensor (WFS) and the infrared light to the science camera, in addition to two control loops driving the TT and the DM [108], [109]. In recent times, the Keck Observatory has begun to develop the Next-Generation Adaptive Optics System named Keck All-Sky Precision Adaptive Optics (KAPA). KAPA is an innovative technology that will deliver significantly sharper images of the Universe in nearly 100 % of the night sky [110].

The Very Large Telescope (VLT) placed in Atacama, Chile is managed by the European Southern Observatory (ESO) and used as an advanced AO system. Lately, VLT began to develop a next-generation AO called the Ground Atmospheric Layer

Adaptive Corrector for Spectroscopic Imaging System (GALACSI) [111] and the Multi-Unit Spectroscopic Explorer (MUSE) [112]. The next generation of extremely large telescopes such as the Thirty Meter Telescope (TMT), the Giant Magellan Telescope (GMT), the Large Synoptic Survey Telescope (LSST), the James Webb Space Telescope (JWST), and the European Extremely Large Telescope (E-ELT) are all designed with the latest AO technologies with a solidified core embedded into their configurations. Moreover, AO will be a significant part of their standard observing modes and has been a substantial factor in optimizing their designs for the upcoming years.

The AO system requires a reference source, usually a close bright star, but there are not always sufficient stars that are bright enough in the visible night sky which means that adaptive optics correction can only be done in a small percentage of the sky. In 1985, R. Foy and A. Labeyrie put out the idea to create Laser Guide Stars (LGS) as artificial stars to probe the atmosphere when no Natural Guide Star (NGS) is available in the region of the astronomical object [113]. LGS has been introduced in order to produce artificial reference sources for AO compensation and significantly enlarge the sky coverage of AO telescopes. LGS creates an artificial star by pointing a laser into the atmosphere to excite sodium atoms. This can be obtained in two ways: first by using Rayleigh scattering from the lower portion of the atmosphere air molecules at altitudes of 10 - 15 km (Rayleigh Guide Stars); the second technique is the use of laser-produced resonance fluorescence of atomic sodium in the mesosphere at a height of ~ 95 km (Sodium Guide Stars).

The first sodium LGS was built at the Mauna Kea Observatory by L. A. Thompson and C. S. Gardner in 1987 in order to demonstrate the usefulness and fitness of Sodium LGS for operation in the ground telescope [114]. In 1994, the Lawrence Livermore National Laboratory (LLNL) developed a new type of laser called the Atomic Vapor Laser Isotope Separation (AVLIS) and used it at Lick Observatory in California to create the brightest Sodium LGS that would cover a wide area in the sky [115]. The Adaptive Optics with Laser for Astronomy

(ALFA) laser system was installed on a 3.5-m telescope at the Calar Alto Observatory, Spain in 1996. In order to achieve a reliable guide star for the AO known as ALFA Laser Guide Stars [116]. Following the ALFA laser guide stars, the Paranal Artificial Reference Source for Extended Coverage (PARSEC) developed as the second generation laser guide stars at Paranal Observatory in Chile in 2006 [117]. The first sodium solid-state laser source was developed for use with the 3.5-m ARC telescope at Apache Point Observatory in 1995. Furthermore, the University of Chicago developed a new generation of the sodium solid-state laser which was installed on the 5-m Hale telescope at Palomar Observatory, California, in 2004 [118]. All Extremely Large Telescope (ELTs), as well as Space Telescopes (ST) currently under design and construction, have a cutting-edge AO Laser Guide System. For this reason, TOPTICA Photonics and its partner, MPB Communications, have developed a novel guide star laser system in order to overcome the limitations of dye, solid-state, and pulsed laser formats. It is called the Toptica Sodium-Star Laser Guide Stars Source and is used in the Keck Observatory with the TMT and the GMT telescopes. Moreover, the Gemini MCAO System (GeMS) required five sodium LGS to operate and the Raman-scattered JGS photons system was established in the Very Large Telescope (VLT) in 2017 [118].

Today, more advanced improvements in the LGS techniques, as well as development in laser technology, have occurred recently one technique is Laser Tomography Adaptive Optics (LTAO) (Figure 1-22) [119] which is an AO system that employs a combination of the LGS and NGS in order to provide correction using a single deformable mirror towards a direction within the observable region of the instrument. LTAO is used in the Giant Magellan telescope. Updates are still ongoing in LGS. The ROBO-AO Laser Guide Stars System (ROBO-AO) is currently being built. It is the first robotic autonomous LGS AO system operating in the sky and it is based on an artificial star produced by Rayleigh scattering of a near UV laser. Robo-AO achieves high target throughput by minimizing overhead times to less than one minute per target [120].

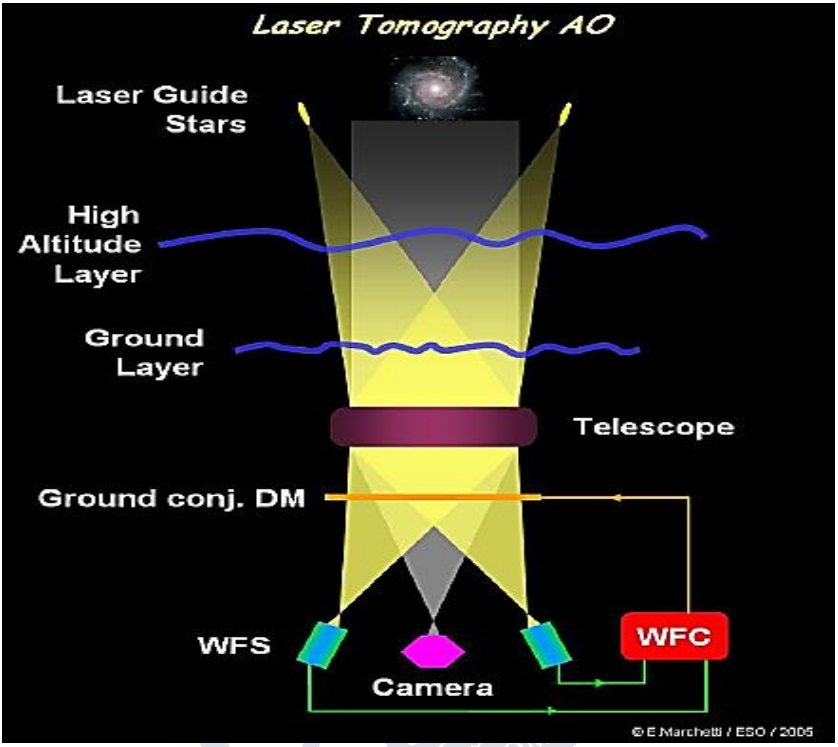


Figure 1-22 The Laser Tomography Adaptive Optics (LTAO) concept (Source: Adaptive Optics for Extremely Large Telescopes By Robin Arsenault et al. 2006)

1.4. THE EVOLUTION IN SPECTROSCOPY, PHOTOMETRY, AND PHOTOGRAPHY IN ASTRONOMY

There are two main techniques for analysing the incoming EM radiation from celestial objects. One is called Spectroscopy and the other is called Photometry. Spectroscopy is used to study the types of electromagnetic radiation emanating from celestial objects and it plays a crucial role in Astronomy. By gathering and analysing the electromagnetic spectrum from a distant object, astronomers can identify what type of object it is and determine a series of its characteristics. It can reveal the chemical composition, temperature, density, mass, distance, luminosity, velocity, and even some of the physical properties [121].

The history of spectroscopy traces back to the early 17th century. Isaac Newton (1643–1727) first showed that sunlight could be dispersed into a continuous series of colors using a new optical tool called prism. William Hyde Wollaston improved Newton's design in 1802 by constructing a spectrometer and adding a lens to focus the Sun's spectra [122]. In 1814, Josef Von Fraunhofer (1787–1826) completed his most significant achievement by inventing the spectroscope. In the Fraunhofer spectroscope design, he replaced a prism with a diffraction grating as the source of wavelength dispersion. (Figure 1-23). Fraunhofer applied this equipment to examine and discern 574 individual lines in the spectrum of the Sun when adequately dispersed known as (Fraunhofer Lines). He developed the spectroscope to the stage that it became a precise and quantitative scientific instrument in Astronomy [122]. Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) exposed the dark lines in the Sun's spectra that due to the selective absorption of a continuous spectrum produced by the hot interior of the Sun by cooler gases at the surface[123], [124].

John William Draper used visual observation and handmade drawings to produce the Moon spectra in 1840 [125]. (Figure 1-24). William Huggins (1824–1910) applied the spectroscope and Doppler’s principle to observe emission lines in the spectra of Nebulae (NGC 6543) in 1868 [126]. A year after that, Huggins developed a technique to determine the radial velocity of a star by measuring the Doppler shift in the spectral lines of the star. Furthermore, he was the first to observe a nova’s spectrum, the first to observe the Solar prominences in a new way without using the Solar eclipse method, and he also identified the ultraviolet lines of hydrogen on photographic plates.

Angelo Secchi (1818–1878) was the first to attempt to classify stellar spectra. He studied the spectra from over 4,000 Stars and developed a stellar classification system. In 1863, he divided stars into four broad spectral classes using common absorption features of hydrogen as follows: Class I (sharp hydrogen lines) and Class II (weaker hydrogen lines with numerous metallic lines) stars. By 1866, he had added Class III (bands stronger towards the blue plus metallic lines) and, in 1868, Class IV (deep red stars with groups opposite to Class III). He later added Class V (emission spectra) [123], [127].

Figure 1-23 Josef von Fraunhofer (1787–1826) demonstrating the Spectroscope (Source http://scihi.org/joseph-fraunhofer-solar-spectrum/)

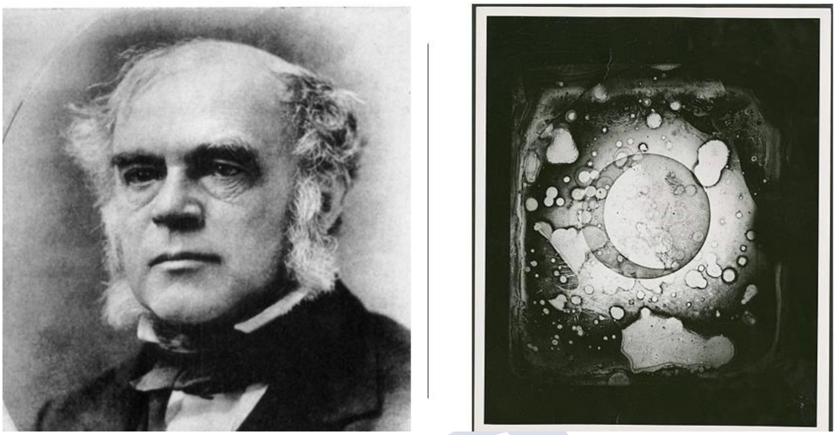


Figure 1-24 Left, John William Draper (1811- 1882). Right, the first Moon Photograph attributed to him. (Credit: New York University Archives)

Henry Draper (1837–1882) was a pioneer in stellar spectroscopy and he photographed for the Spectra of Vega Star the first time by using a 72-cm reflector telescope and a quartz prism in 1872. Williamina Fleming (1857-1911), Annie Jump Cannon (1863-1941), and Antonia Maury (1866-152) published Henry Draper Catalog. The Henry Draper Catalog is an astronomical catalogue with astrometric and spectroscopic data for more than 225,000 of the brightest stars. A new catalog system is arranged according to star temperature based on the spectral types from O, B, A, F, G, K, and M letters [124], [128].

Edward Pickering began a program of astronomical spectroscopy using an objective prism to be enabled to determine up to 200 stellar spectra. In 1890, Pickering presented the Draper Catalog Classification which contains 10,351 star spectra organized by the general appearance of their spectra [129]. In 1943, William Morgan (1906-1964), Philip Keenan (1908-2000), and Edith Kellman (1911-2007) introduced a new system to star spectra classification with two parameters: temperature and luminosity. The new classification is called the Yerkes Spectral Classification, otherwise known as the MKK Classification. In

1953, MKK was renamed as MK or the Morgan-Keenan classification and is currently used to classify stellar spectra [130]. Lastly, in the late 1980s to mid-1990s, because of new discoveries, new spectral classes (L and T) were established. L and T spectral class had a short history but already rich for coolest stars [131].

In order to perform astronomical spectroscopy measurements, several instruments are used. These spectroscopy instruments provide differently astronomical information, but all have the ability to split light into its wavelengths. The spectroscope used a type of dispersing element to separate the EM radiation (Prism, Diffraction Grating, Grism, and Narrow-Band Imaging). The prism spectroscope was used visually for stellar spectroscopy as only bright stars could readily be observed. In the mid-nineteenth century, the prism spectroscope was improved by adding more than one prism combined to the lens in order to give higher dispersion and resolving power. Joseph Fraunhofer built a diffraction-grating spectroscope by using diffraction-grating instead of a prism. Various significant improvements in diffraction grating technology took place between the 1880s and the 1950s, and these eventually resulted in useful astronomical spectroscopy [4]. More recently, in order to make astronomical spectroscopy studies more precise, the development of astronomical spectroscopy technologies has occurred [132].

Photometry has always played a key role in astronomical observation research. Astronomers made great efforts to ensure that such photometry is of the highest accuracy achievable [133]. It represents the science of measurement of the illumination of celestial objects and these measures can produce massive amounts of useful information on such objects. Photometry is concerned with obtaining quantitative dynamic measurements of astronomical objects using electromagnetic radiation. The technique to obtain quantitative measurements of astronomical objects transformed Astronomy from a merely descriptive science to one with unusual explanatory power. Historically, different types of measuring equipment produce data requiring different kinds of treatment to provide useful photometric results.

Photometry has been most commonly used with the human eye in the earliest times, then with Photographic Plates, Photomultipliers, and the Charge-Coupled Device (CCD). Photometric measurements are made with instruments called photometers.

Two comprehensive studies in the history of photometry were accomplished. Harold F. Weaver published a series of articles in Popular Astronomy and provided a summary of astronomical photometry up to the introduction of the photoelectric photometry period. His work divided photometric history into four categories, as follows: 1- the initial era regarded the naked eye used in photometry, 2- the second period introduced mechanical instruments in photometry, 3- the third era began with the introduction of photography in photometry, and 4- the fourth era began with the use of photoelectric in photometry [5]. In 1996, John Hearnshaw presented another excellent study in the history of astronomical photometry. His work covered the development of astronomical photometry from the ancient visual efforts to the implementation of photoelectric photometry up to the beginning of the modern era of charge-coupled devices (CCDs) [134].

Factually, the early commencement of astronomical photometry based on the magnitude scale can be traced back to the ancient era. Hipparchus, in 129 BC, produced the first Star Catalog. His catalog contained 850 stars including their position and brightness. He classified them into six magnitude scales: the brilliant stars are first, the second magnitude equals half of the first magnitude, third magnitude equal half of the second magnitude, and so on until the faint ones in the sixth magnitude. In fact, the Hipparchus Star Catalog was the first scientific step in astronomical photometry science [135]. Three centuries after Hipparchus's, Ptolemy introduced a Star Catalog of 1,028 Stars in 125 AD [135][12]. Some correct

In 964 AD, Abdul-Rahman al-Sufi presented his Star Catalog in “The Book of the Fixed Stars”. Al-Sufi’s Star Catalog was based on Ptolemy’s traditional work [136]. Al-Sufi’s star catalog contained 55 astronomical tables (Zij) as well as star charts for 48 constellations. His catalog was divided into three main ranges: the first group consisted of the 21 northern constellations, the second group of the 12 constellations of the Zodiac, and the last group contained the 15 southern constellations [136].

In the late 16th century, Tycho Brahe completed his inventory with the positions and magnitudes of 1,004 fixed stars. Tycho's work improved by an order of magnitude the positional precision achieved by Hipparchus, Ptolemy, and al-Sufi. Many historians of science consider the Tycho catalog to be a pillar in the history of Astronomy [9], [11], [137], [138]. The full inventory was compiled with some modifications by Johannes Kepler in 1627 as part of the Tabulae Rudolphinae [139]. In addition to the previous, Johann Bayer used Tycho´s method to assemble his unique Star Atlas called the Uranometria Atlas of 1603, the first great celestial atlas to cover the entire sky [140]. In the 19th century, the most comprehensive directory was the great Bonner Durchmusterung Star Catalog (BD) which contained something over one million stars. The BD catalog consisted of 458,000 stars, the Sudliche Durchmusterung contained 133,000 stars, and the Cordoba Durchmusterung, 580,000 stars. BD was carried out with the Bonn Observatory telescope between 1859 to 1862 and represented progress in the precision of the absolute photometry of these stars [141], [142].

The visual photometry method was based on the idea that the naked eye was an ideal photometric instrument and should play an essential role in all photometric measurements. Pierre Bouguer laid the foundation of visual photometric measurements in the early 18th century. In 1725, Pierre Bouguer succeeded in estimating the intensity of Lunar light by comparing its light to that of a candle [143], [144]. Carl Steinheil designed and built a comparison photometer called Stenheil´s prism photometer in 1836. In 1866, Luding Seidel used Stenheil´s prism photometer to make the first reliable photometric measurements. In the mid-

19th century, Johann Zöllner established a new type of visual photometer. Zöllner´s photometer was designed for comparing an artificial light source with starlight by means of the polarization of light [134, p. 61], [145]. In 1877, Edward Pickering produced a new meridian photometer tool and used that photometer to execute the Harvard Photometry Catalog of 4,260 stars in 1884. Despite the fundamental successes of visual photometry, the visual photometer was criticized as many believed that the naked eye was not reliable as an essential instrument for brightness matching [145].

During the late 19th and early 20th century, advancement in photometry science came with the introduction of photography in Astronomy. The technique of photographic photometry in astronomical research provided new possibilities for more precision, accuracy, and reliable photometric measurements. Photographic plates have more spectral sensitivity than the human eye. Advances also occurred in astronomical photometry after using photographic plates. Photographic plates can be used in photometry to obtain the two-dimensional intensity distribution of elongated objects such as galaxies and nebulae and to obtain the total intensities of stellar images. In 1857, George William Bond used the photographic plate to carry out photometric observations of the double-star containing Mizar and Alcor [135]. Another important development in photographic plate photometry was implemented by Revd Espin in 1883. He used trailed stars to estimate and compile a catalog of 500 stars. Henrietta Leavitt used photographic plate photometry to discover more than 1,777 variable stars and determine their magnitude in 1908. Her main contribution led to the discovery of the Cepheid variables [135], [146]. Edwin Hubble used Cepheid variable stars to estimate the distance from the Andromeda galaxy. Photographic plate photometry has been used intensively to assemble several photographic plate surveys of the entire sky.

A new era of photometry began after electrical and electronic techniques were applied in the late 19th century [135]. Photoelectric photometry began to evolve in astronomical research and was implemented for the first time by George Minchin in 1892. Another improvement was carried out by William Monck in the same year. At the beginning of the 20th century, Joel Stebbins played a crucial role in the development of astronomical photometry transitioning into the modern age of highly sensitive linear photodetectors. He was an innovator in the application of the sensitive electric detector to measure the brightness of celestial objects. Moreover, he developed a new technique by using a photoconductive cell in 1907 [147]. Paul Guthnick manufactured a new type of photoelectric cell called photoemissive. Photoelectric photometry was intensively implemented until around the 1940s when the photomultiplier tubes were finally invented. In 1940, Vladimir Zworykin used photomultiplier tubes in astronomical photometry. A few years later, Albert Whitford and Gerald Kron developed a new type of photomultiplier tubes that would be then used to study eclipsing binary stars as well as to achieve the first photometric observation of a stellar flare [5], [134], [135].

Further improvement in photography technology led to an increase of the potential accuracy of photometric measurements. Beginning in the 1980s, CCD photometry gradually became a powerful tool in astronomical photometry. CCD photometry provides extremely sensitive light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum [148].

The ultimate objective of astronomical photometry is to determine aspects of the spectral nature of a celestial object’s through a more straightforward and rapid method than obtaining the spectrum itself. To allow for astronomical data from different photometry instruments to be compared, several photometric systems have been adopted. Christiaan Sterken gave a comprehensive definition of photometric systems as “a calibrated subspace of magnitudes (or fluxes) and color indices (or flux gradients) where the zero points and scales of (each) magnitude and color have been carefully defined and calibrated by adequate (stellar) standards” [149]. The visual system was traditionally the first of all photometric systems since it was based on the sensitivity of the human eye. In fact, the human eye served as a detector with an effective wavelength of about 550nm [5], [134].

By exploiting astronomical photometry, astronomers can divide the EM radiation into several wavelength scales and define an intensity centered at that wavelength. William Herschel was the first to achieve a major improvement in the photometric magnitude scale system and he attempted to find a relation between the intensities of stars and their magnitude. He realized that the intensity of a star and its magnitude were inversely proportional to the square of the magnitude. Additionally, he created the first reliable naked eye estimate of the brightness of stars. In 1838, his son, John, found that all stars were increased by a ratio of 0.41 times in magnitude and he realized that there are, in fact, differences in this scale for the telescopic and naked eye scale [134]. In 1856, Norman Pogson estimated a logarithmic mathematical relation between these intensities and magnitude scales [150], [151]. This relation defined the magnitude as follows: one star that has an apparent brightness 100 times greater than that of a second star is by definition five magnitudes brighter. Therefore, each magnitude corresponded to a ratio of luminosities equal to the fifth root of 100 (approximately 2.512).

$$m - m_0 = -0.4 \left(\log_{10} I - \log_{10} I_0\right)$$

Following the unveiling of photoelectric photometry, several critical photometric systems based on using photomultipliers as detectors were developed during the mid-20th century. The most widely used photometric system appeared to be the UBV system defined by Johnson and Morgan in 1953. The UBV photometric system has played a central role in astronomical photometry research for over half a century. Recently, astronomers have concentrated on several photometric systems, each one based on a selective passband spectrum. In order to accomplish effective research in Astronomy, astronomers should be using one of the standard photometric systems, such as UBVRI, uvby, Geneva, DDO, Washington, RGU, RIs, and Vilnius standard systems

[152]. Figure 1-25 demonstrates the Genealogy Tree of an entire group of traditional photometric systems positioned on detector branches. Each main branch represents photometric detector systems and the buds represent photometric bands arranged by wavelength along the vertical axis.

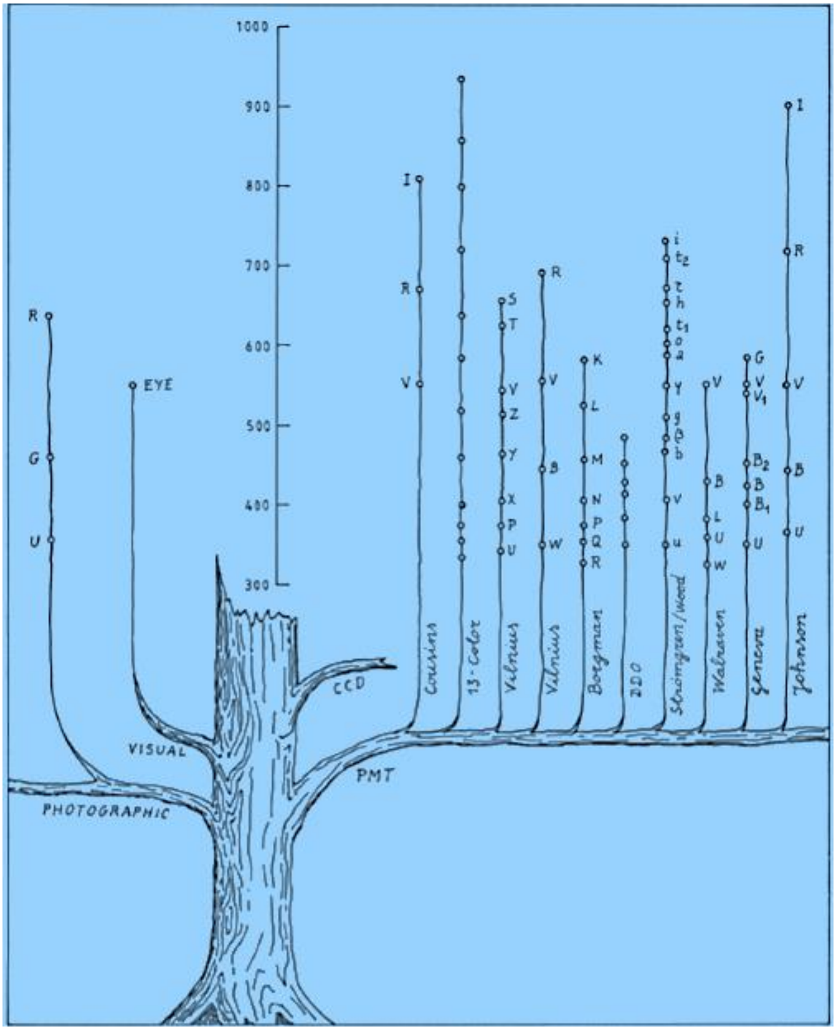


Figure 1-25 The Genealogy Tree of traditional photometric systems (Credit: Photometric Precision and Accuracy by Sterken C., Milone E.F., Young A.T., 2011)

Photography has always played an important role in Astronomy. Astronomical Photography allows astronomers to advance thanks to the acquisition of highly accurate images of the sky in order to improve our astronomical knowledge and increase our understanding of the Cosmos [154]. The first known attempt at astronomical photography was by Thomas Wedgwood. He started a series of experiments to obtain "Sun pictures" at the beginning of the nineteenth century [155]. In 1826, Joseph Nicéphore Niépce combined the "camera obscura" with photosensitive paper to produce the first permanent image (Heliograph). Later, Louis Daguerre, in collaboration with Joseph Nicéphore Niépce, invented this technique known as the daguerreotype in 1839 which was the first successful form of photography [156]. In the same year, Louis Jacques Mande Daguerre took the first unsuccessful (blurred) daguerreotype image of the Moon. In 1840, John William Draper succeeded in obtaining the first in-focus image of the Moon by using a 13 cm reflecting telescope with a long focal length. John William Draper is known as the first astrophotographer. In the mid-19th century, John Adams Whipple and William Cranch Bond managed to capture the image of the first star,Vega [124], [155]. Astronomical photography has been evolving with the progressive development of increasingly sophisticated technology. By the second half of the twentieth century, three-color composite astronomical photography was developed by Bill Miller, David Malin, and Mark Hanna [157], [158]. This innovative technique allowed astronomers to maximize the amount of details visible in the astronomical photographs.

The astronomical photographic plate has played a significant role in the Astronomy for virtually more than a century since astronomical photographic plates were employed as detectors and used for data storage at that time. By the end of the 19th century, the development of photographic plates had progressed to the point where they had become the primary tool for astronomical research. In the 1970s, significant developments in photography occurred when charge-coupled devices (CCD) were invented. CCDs allowed for light detection and made digital color cameras possible, which profoundly changed photography technology in

Astronomy. These cameras were applied in imaging as well as information storage. Since 1983, CCD cameras first started to replace photographic plates in telescopes. CCDs have several advantages as far as astronomical images are concerned over other electronic and photographic imaging tools. CCDs are small, high-quantum efficient, and low-cost. They provide excellent stability over a wide range of electromagnetic spectra and high quantum efficiency, and broad spectral response. Furthermore, CCDs have the remarkable feature of detecting X-ray spectra [159, pp. 13–25].

Photography has been alleged to free us from the human bias of the past, and has it also been recognized as capable of recording original reality without manipulation [160], [161]. Recently however, the human hand has been reintroduced into photography to improve and intensify the quality of photographic images. This manipulation technique in images is called image processing [162]. Image processing in Astronomy is a significant field of research, especially with the recent improvements in space exploration missions and the development of more technical telescopes. Image processing involves various different techniques to improve the analysis of the properties of celestial objects or to produce preliminary results from image data. Image processing in Astronomy is used for the detection and classification of celestial objects and to understand the physical and geometrical properties of the object in the image by performing spectrum analysis using signal data [163], [164].

With the introduction of digital imaging to Astronomy, the upgrading of image resolution is seemingly one of the most substantial requirements for superior astronomical instruments as well as image processing. Currently, astronomers and astrophysicists use several advanced image processing software developed specifically for a large number of astronomical data reduction, analysis, and visualization mechanisms. They include: AIPS (Astronomical Image Processing System) [165], IRAF (Image Reduction and Analysis Facility) [166], Motif Interactive Data Analysis System (MIDAS) [167], Interactive Data Language (IDL) [168], and STARLINK [159], [169].

At the beginning of the twenty-first century, a new outstanding method in photography emerged under the name of Computational Photography. This procedure uses a multitude of data from images or image sensors and combines it algorithmically to compute a photo that would be impossible to achieve with any other means of photography. The main technique in computational photography is called Plenoptic or Light field photography [170]. Recent outstanding advances in imaging technologies offer exciting new opportunities for astronomers to study the Universe. These new technologies will contribute to the increased capacity of the next generation of space telescopes as well as will help to foster new developments in astronomical and space research.

1.5. THE FUTURE OF ASTRONOMICAL INSTRUMENTATION AND TEQNIQUES: SOME NEW INNOVATIVE TECHNOLOGIES

1.5.1. Gravitational-Wave Astronomical Instruments and Advanced in Technology.

EM radiation has until now been the sole source of information for scientists about the Universe. Every type of electromagnetic radiation reveals something unique about the Universe. The most surprising aspect of the Universe is that only about 4% of its content is in the form of visible matter (i.e., capable of producing electromagnetic radiation). That means that all of the stars, planets, exoplanets, and galaxies currently seen make up only 4% of the Universe. The rest, traditionally classified as dark matter and dark energy can only produce gravitational radiation, if, they generates any signal at all [171].

In recent times, Gravitational Waves (GW) have been used as an observational tool for Astronomy [172]. GW radiation already delivers an important contribution to the understanding of the dynamics of many known planetary systems, such as binary neutron stars, cataclysmic variables, young neutron stars, low-mass X-ray binaries, Cosmic background radiation, and galaxy formation [173]. GW were detected for the first time in 2015 by using a sensitive instrument called the Laser Interferometer Gravitational-Wave Observatory (LIGO) [174]. This first GW detection occurred when two black holes crashed into one another. This discovery generated a new exceptional observational method through which to explore the Universe and resulted as well in an embodiment of human thought to endeavor acquisition of new knowledge. Moreover, GW data provides robust evidence to support one of the predictions of the Einstein General Theory of Relativity of 1915. According to the observed Gravitational-waves, Einstein’s theory has passed all experimental or observational tests to which it has has ever been subjected [175], [176].

GW allowed for a new interesting field in Astronomy to emerge, known as Gravitational-wave Astronomy [177], [178]. In the future, Gravitational-wave Astronomy will unveil a new area of astronomical research that could revolutionize humankind’s understanding of the Universe in which we live. Furthermore, Gravitational-wave Astronomy requires new generation ultra-sensitive observation instruments for Ground-based and Space-based observatories as well as a new generation gravitational wave detectors [175].

Over the last decade, several Ground-based and Space-based interferometric gravitational-wave detectors were constructed, such as the Ground-based Laser Interferometer Gravitational-Wave Observatory (LIGO) in the USA, the Ground-based Gravitational-Wave Interferometer in Germany (GEO600), the Gravitational Wave Interferometer (VIRGO) at the European Gravitational Observatory in Italy, the Ground-based Gravitational-Wave Interferometer in Japan (TAMA), and the Laser Space-based Interferometer Space Antenna (LISA). All of the aforementioned have begun initial procedures with unprecedented sensitivity levels. In addition, this suite of interferometric detectors can be expected to open up the gravitational wave window for astronomical observation and exploration [175].

The gravitational wave detectors are currently gathering data and the next generation of detectors, that is being planned for the next decade, is the first step in establishing the field of Gravitational-Wave Astronomy through the detection of the most luminous GW sources in the Universe. These detectors are making it possible to observe a wider variety of astronomical phenomena, as well as to play a vital role as a new tool for increasing our knowledge of fundamental Physics, Cosmology, and Astrophysics. These are some of the prominent questions that gravitational wave observations maybe soon clarify for scientists. Was Einstein right regarding the Theory of General Relativity? Is the nature of gravitational radiation as his theory predicts or is it something different? How did the Black Holes in Galactic nuclei form? What were the physical conditions at the time of the Big Bang? What is the nature of Quantum Gravity and what is the origin of Space and Time? How many Spatial dimensions are there?

Gravitational-wave astronomical research required the improvement and expansion of the limits of sensitivity in detectors which has resulted in developments that have actually profited other fields of science [179], [180]. This highly productive interchange between GW and other spheres of science and technology will likely continue in the upcoming years, providing tangible benefits to the scientific society. In the future, the GW super-sensitive detectors of Ground-based and Space-based instruments will discover astonishing phenomena, as well as provide new insight directed toward many of the most mysterious astronomical phenomena known in Cosmos.

1.5.2. New Era of Photonic and Quantum Optics Instruments for Astronomy (Astrophotonic Instruments).

In fact, Astronomy is based upon the interpretation of subtleties in the electromagnetic spectra that come from astronomical objects. In the early 21st-century, Quantum Optics looks to have the potential of becoming a different information window on the Universe. All of the classical astronomical instruments and imaging systems deal with measuring the first-order spatial and temporal coherence of light radiation while light has other degrees of freedom. Quantum Optics predicts effects that had never been conceived with the classical light theory. Further advancements in Quantum Optics technology have made it possible to overcome the diffraction limit in optical instruments. Moreover, it will present and transmit more important information compared to what is traditionally carried on the classical optical astronomical instruments obtained in recent times. The aim is to develop innovative technology for the following generations of the ground-based as well as space-based telescopes and their auxiliary instruments such as Spectrographs, Photometers, Imaging Systems, and Interferometry. Photonic and Quantum Optics technologies provide a promising platform for building next-generation instruments that are flexible in terms of light manipulation, as well as being compact and cost-effective [181], [182].

Lately, Photonic and Quantum Optics applications to Astronomy research is a fast developing field that lies at the border of Astronomy and Photonics [183] and is called Astrophotonics [184] . The first application of Photonics in Astronomy is Long-Baseline Optical Interferometry (LBOI) [185]. In the upcoming years, a wide variety of astronomical instruments were developed such as Astrophotonics Spectrometer, Astrophotonics Spectrograph [186], [187], Photonic Lantern, Quantum-Assisted Telescope Arrays [188], and QuantEYE [189]. Unquestionably, if the future of data processing and artificial intelligence rests in quantum computers, the future of astronomical research rests in quantum telescopes as well as in other quantum astronomical instruments [190].

1.5.3. Astroinformatics: New Era of the Paradigm for Data-Intensive Astronomy

Once the telescope observations are terminated and the data is assembled, the astronomer handles the task of data analysis and processing. In recent times, due to the exponential growth in astronomical data production and with the aim of effectively coping with and obtaining the maximum scientific benefits from this useful information, a new domain of Astronomy has appeared that is known as Astroinformatics. It is necessary for it to become a standalone research discipline, aiming to manipulate astronomical datasets obtained from astronomical instruments and their techniques in order to employ and increase scientific knowledge and discovery about the Universe from these large datasets. Astroinformatics has focused on the need to establish realistic and effective tools for accessing and using this increasingly massive amount of information in order to exploit the available space for optimizing astronomical research capabilities. In addition, Astroinformatics comprises a set of naturally related specialties including data organization, data description, astronomical classification taxonomies, astronomical concept ontologies, data mining, machine learning, and visualization [191], [192].

1.6. CONCLUSIONS

Over the past decades, our knowledge of the Universe has changed dramatically. A massive number of exoplanets have been discovered. Accurate measurements of primordial radiation left from the Big Bang have enabled scientists to determine the age and structure of the Universe. Furthermore, current astronomical observations have highlighted that most of the matter in the Universe is dark and that the expansion of the Universe is accelerating in unexpected and unexplained ways. Such recent discoveries, coupled with potent new observing techniques, have produced unprecedented scientific opportunities for astronomical research and education in upcoming years [78], [82].

The evolution of astronomical instruments and techniques has revolutionized the way we think about systems within the Cosmos and has changed our essential understanding of the make-up of the Universe. New prominent technologies will continue to be developed in order to reveal the Universe mysteries [193]. As a result of extraordinary technological development in Astronomy in recent times, scientists can now refrain from providing hypotheses about the nature of the Universe and start to understand it like never before. Since the telescope was invented at the beginning of the 17th century, technological innovations have allowed for important scientific discoveries.

The modern eras of Astronomy have witnessed significant advances in instrumentation, astronomical techniques, and methodology as well as new discoveries about our Universe [78]. Advancements in technology throughout human history have boosted changes in the way astronomers engage with their science or come to acquire new knowledge and have profoundly impacted the practice of Astronomy. New cutting-edge telescopes combined with advanced imaging tools, superior software, and supercomputer technology can accurately measure the positions and brightness of thousands of celestial objects in a matter of seconds. As a result of these highly sophisticated instruments, astronomers are spending much less time at the observatory working with telescopes to collect data.

The new generation of telescopes will study the cosmic microwave background intensively, detecting the minute fluctuations from which galaxies formed as well as determining when and where the first stars formed. Space-based telescopes have unlocked unprecedented access to Infrared and X-ray wavelengths that are blocked by Earth’s atmosphere [71] [79]. Active and Adaptive Optics systems allow today’s largest optical telescopes to operate at the limits of their performance and will enable the construction of the next generation of powerful telescopes [85], [89].

No other indication of life has ever been identified either on the other planets in the Solar System or elsewhere in the Universe. Since Copernicus first described the construction of our solar system nearly 500 years ago, ours has been the only Solar system known to astronomers until recent times. Astronomers have discovered almost 5000 additional extrasolar planets which are also called exoplanets [194]. Exoplanets have masses ranging from a few times the mass of Earth to several times the mass of Jupiter. One of the main goals of Astronomy research for the upcoming decades is to explore new exoplanets. These objects provide a good understanding of the formation of planetary systems and are offering exceptional intellectual knowledge for humankind about our Universe. The astronomers are poised for executing vast steps in understanding these new realms such as studying their physical and chemical properties, proposing theories of their structure and formation, and directly imaging some exoplanets in order to significant indications regarding life on these exoplanets [195].

The following generation of optical astronomical instruments [175], [182] will require other innovations across many disciplines and collaboration among many scientists and engineers [85]. The current state of technology to support the fabrication, testing, alignment, and performance verification of ground and space telescopes and their instruments are very promising and inspiring. Further improvement in these areas is required to enable the Physics that will be applied to make paradigm-shifting scientific observations and discoveries. While improvements are still needed in these areas of technology, we should also marvel at the progress already made by scientists. Technology in space optical instruments fields has advanced rapidly over a few last years and new innovative techniques and tools have been developed to meet the growing needs of the scientific community. Advanced development has led to improved accuracy, reduced costs, and the construction of amazing cutting-edge Space Telescopes [196]. Finally, present technological scientific instrument know-how is still far from complete or ideal in terms of performance in astronomical and space research, leaving several challenges that will likely be addressed in the coming years.

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2. CHAPTER 2: THE CONTRIBUTIONS OF BINARY STAR TO ASTRONOMY AND SCIENTIFIC THOUGHT.

2.1. INTRODUCTION

A binary star is composed of two stars orbiting the center of mass of the system due to their mutual gravitational attraction. This movement is equivalent to that in which one component is supposed to be fixed, normally the most brilliant (the main component) and the other component (the secondary) moves around it. Sometimes the terms binary and double star are confusing. Nevertheless, the last one must be used only for wide systems, while binary refers to close systems. It commonly occurs that the brightness (and consequently the magnitude) are similar for both components. In that case, astronomers consider the main component to be that with more " Right Ascension". Right Ascension is a celestial coordinate that plays a role similar to the geographic longitude on the Earth.

The Ramon Maria Aller Astronomical Observatory (OARMA) has a long tradition in binary star research, especially visual binaries and double stars (http://www.usc.es/astro/ingles.htm) . Father Ramón María Aller was the founder of the Astronomical Observatory of the University of Santiago de Compostela in 1943 (named Observatorio Astronómico Ramón María Aller, OARMA, since 1983). He was the first to introduce binary star studies in Spain. R. M. Aller initially worked in his personal observatory in Lalín and later moved his observatory to the campus of the University of Santiago de Compostela (USC) at the Residence (today, Campus Vida). He used his personal Steinheil refractor to create various lists of micrometric measurements of double stars as well as being the first person to calculate the double star orbits in Spain (systems O∑77 and O∑1932) [25]-[29]. The Director of this Doctoral Dissertation, Professor Jose Angel Docobo, after he was officially named the Director of OARMA in June 1983 (from 1981 he was the responsible). His research has played an important rolein the study of binaries and multiple stars in Spain. Prof. Docobo, thanks to development research projects, began to use large telescopes in order to perform binary observations and, in 1985, he published an analytical method for orbit calculation with which more than 300 orbits have been calculated. The majority of Dr. Docobo's doctoral students, Alberto Abad, Josefina F. Ling, Cristina Prieto, Manuel Andrade, Ahmad Abushattal, Jorge Gómez, and Pedro Pablo Campo also carried out double and multiple star research, particularly regarding observation and orbit calculation.

Jordan, like many of the developing countries in the Arab region, lacks astronomical facilities. As a Jordanian, I am grateful for the pivotal role of OARMA, in general, and the Director of this Dissertation, in particular, for the opportunity and cooperation provided to enhance astronomical research and thought in Jordan. OARMA will continue to provide facilities and equipment for scientific partnerships with research groups in Jordan for the development of scientific research in Astronomy and Astrophysics in cooperation with Professor Mashhoor Al-Wardat. As a result of this collaboration, Docobo's method for the calculus of visual double star orbits has been applied successfully in numerous research studies as well as by Master degree students at many Jordanian universities such as Mutah University, Al al-Bayt University, Al-Hussein Bin Talal University, and Yarmouk University.

2.2. HISTORY OF BINARY STAR SYSTEMS: EVOLUTION, CLASSIFICATION, AND SCIENTIFIC IMPORTANCE

2.2.1. A Short History of the Emergence and Evolution of Binary Star Systems

Historically, only two double stars were discovered using the long-focal and non-achromatic refractors of the 17th century. The first double star was discovered was Mizar (Xi Ursae Majoris) that was commonly attributed to the Italian astronomer, Giambattista Riccioli, in 1650 although it is possible that Galileo Galilei also observed Mizar earlier in 1617. Mizar forms a double star with Alcor that is easily separated with the naked eye. Robert Hooke discovered the second one called Gamma Aries (ɣ-Ari) in 1664, in the northern constellation of Aries [7].

In 1718, James Bradley noted that Gamma Virginis was a binary star system in the constellation of Virgo. He also discovered 61 Cygni as a new double star in Cygnus in the 1750s [1, p. 139]. In 1767, British astronomer, John Michell, performed a statistical analysis of the distribution of stars in the sky and showed that there are more close pairs than one would expect if they were randomly distributed. Consequently, the term " double star" was expressed by him for the first time. The systematic search and observation of double stars began in the late 18th century [7]. In 1776, Christian Mayer started to observe double stars systematically and suggested a new method to study the poorly understood phenomenon of the proper motion of the stars by measuring a change in the relative positions of the components in close double stars at that time. In 1779, Mayer published his work on double stars in ‘’Mayer’s Double Star Catalogue’’ which is considered to be the first double star catalog and contains a list of 72 pairs [2]. Therefore, Mayer’s work might be considered to be the beginning of Double Star Astronomy.

At the same time, Sir William Herschel began a systematic search for double stars assisted by his sister, Caroline. First, he assumed that double stars were merely optical phenomena and introduced the term, ‘’binary system’’. In addition, he was the first astronomer able to detect and recognize the first orbital motions outside of the Solar System. His discovery was accidental because he intended to detect ‘’parallactic motion’’, that is to say, the apparent ellipse that each star describes as a reflection of the orbital motion of the Earth. This method was used in order to measure the parallax angle, equivalent to the distance from the star to us. Using this methodology, he discovered more than 800 double stars and, in 1782, published his first Catalog of Double Stars including 269 binary systems [3]. Moreover, a second catalog containing 434 additional binary stars was published in 1785 [4]. In 1784, John Michell applied his earlier statistical view to Herschel’s first catalog and realized that most of the binary star systems listed by Herschel were physical systems. In 1833, Friedrich Wilhelm Bessel published a catalog of binary stars which consisted of 38 pairs measured with the Fraunhofer heliometer. He performed the first parallax measurements and calculated the distance to the 61 Cygni binary star system [5].

Friedrich Georg Wilhelm Struve made the next significant advancement in binary star astronomy using the Fraunhofer refractor telescope equipped with an excellent driving clock to obtain more than 10,000 micrometric measurements with unprecedented accuracy between November 1824 and February 1827 and detected nearly 3,000 double stars [6]. John Herschel had followed his father’s work in binary stars (Sir William Herschel) and he published the first catalog of binary stars in the southern hemisphere that contained 417 systems and used the first time ordered in Right-Ascension, including accounts of other measurements besides his own. Furthermore, John Herschel published his general catalog of nebulae and clusters of stars in 1864 and he worked on an extensive catalog of all known binaries until his death in 1871 [7]. The catalog contained about 10,300 binaries and was completed by others as well as published posthumously in 1884. Otto Struve as well continued his father

Wilhelm's work in binaries and published a catalog of binary stars that became known as O∑ or the Pulkowa double star catalog which included 547 binaries [7].

In addition, other astronomers made significant contributions to Binary Star Astronomy. William Rutter Dawes carried out extraordinary and distinguished measurements of double stars between 1828 to 1867 and published his results in the "Catalogue of Micrometrical Measurements of Double Stars" in 1867 [8]. Ercole Dembowski re-observed and revised the Dorpat Catalogue by W. Struve using a 7-inch Merz refractor. The first set of these revised stars was published in 1857 and the complete version of the Dorpat Catalogue was published posthumously in 1883 [9]. In 1783, John Goodricke suggested that the variability of Algol is due to the eclipses produced by a second star moving around the primary.

Important advances in Binary Star Astronomy occurred after the Doppler effect was discovered which played an important role in binary science. In 1842, Christian Doppler suggested that the wavelength of the light must vary proportionally with the radial velocity of movement of the source of light with respect to the observer [7]. In 1846, the astronomer Armand Louis Fizeau applied Doppler's theory to electromagnetic spectra. In 1889, the first spectroscopic binary was discovered at the University of Harvard by Edward Pickering. He had discovered the first double-lined spectroscopic binary that remarkably was one of the components of the first visual binary Mizar. In the same year, Hermann Vogel discovered the first single-lined spectroscopic, the close binary star system called " Spica". Johannes Hartmann provided further development in binary star studies after he discovered the interstellar medium in 1904. He noticed that the spectra of certain binary stars exhibited two absorption lines whose wavelengths did not change despite the periodic variation of all their other spectral lines. He found that these fixed lines belonged to ionized Calcium and concluded that the lines must have originated somewhere in the line of sight of the observer. The first catalog of spectroscopic binaries was published by William Campbell, Heber Curtis, and Sebastian Albrecht in 1905.

The catalog contained 140 systems [10]. In 1910, Campbell published a second catalog of spectroscopic binaries that included 303 binaries [11].

The modern era of binary star discovery was begun by Sherburne Wesley Burnham's astronomical work. By the end of the 19th century, Burnham had discovered and published some 1,290 pairs. Moreover, his binary star data are distinguished because of their great accuracy. He was able to resolve sub-arc binaries as well as publishing the General Catalog of Double Stars within 121° of the North Pole containing 13,665 binaries, known as the BDS (Burnham Double Stars) [7]. George Washington Hough discovered 648 double stars from 1881 to 1906. Thomas. J. J. See used the 24-inch refractor at the Lowell Observatory, assisted by W. A. Coggeshall and S. L. Boothroyd. They discovered more than 500 new double stars at the beginning of the 20th century [12]. Thomas Henry Espin began to use a 17.5-inch reflector telescope in order to discover double stars and he published a list of 2,575 binaries systems in 1901. At the end of the 19th century, William Hussey began a systematic search for binary stars in Bonner Durchmusterung catalogue that down to ninth magnitude, with the aid of the 12" and 36" refracting telescopes at Lick Observatory. He published more than 1,300 new binary star having resolved them [12].

Eric Doolittle began to develop Burnham's work in order to maintain, revise, and expand this work. Doolittle set up a card catalog planned to contain a complete record of measurements and orbits published after 1906. After Doolittle's untimely death in 1920, Robert Aitken received Burnham's and Doolittle's work including the BDS Catalog and a collection of books and pamphlets on double stars. In 1932, Aitken published the "New General Catalogue of Double Stars within 120° of the North Pole" which became known as Aitken Double Stars (ADS) that contained 17,181 binary stars. In the ADS Catalog, the number of spectroscopic binaries increased dramatically from 140 in 1910 to 1340 in 1932 [13]. Furthermore, Aitken published a new list of 1865 binaries [14]. Robert Innes began to study double stars in the Southern Hemisphere; his first Reference Catalogue of

Southern Double Stars contained 2,140 pairs. In 1927, Innes published his second catalog of southern double stars that became known as the Southern Double Star Catalogue (SDS which included the discovery of 1628 new double stars [15]. Following the epoch of Aitken and Innes, Hamilton Jeffers and Willem van den Bos worked together to publish the Index Catalog of Visual Double Stars (IDS) which provided information about binary stars in both the Northern and Southern Hemispheres for the first time in 1961.

The important work of the other astronomers in the field of double star research must be taken into account, such as R. Jonckheere, who studied and measured close double stars using the 33-cm refractor to discover 3,350 doubles, most of them faint and of low brightness. P. Baize made 24,044 measurements of double stars from 1925 to 1971 and he published a method for calculating the dynamic parallaxes [16] as well as an outstanding study in mass-luminosity relationship [17]. In the early 1940s, the study of young binary star systems began with A. Joy and G. van Biesbrock. They found that several young stars (RW Aur, UY Aur, UX Tau, UZ Tau, and S CrA) were binary systems with separations of the order of 1" [18]. Moreover, R. Baillaud also discovered and cataloged 3,016 pairs from a Photographic Catalog of the Sky.

Ramon María Aller Ulloa was really the person that introduced the study of double stars in Spain [19] (We will speak further of him later in this Chapter). Other astronomers also played a notable part in the study of double and multiple stars such as W. F. Rabe, G. P. Kuiper, F. Holden, P. Muller, G. M. Popovic, D. J. Zulević, P. Couteau, W. D. Heintz, C. E. Worley, I. Dommanget, Y. Balega, H. McDlister, A. Tokovinin, C. Allen, C. Scarfe, W. Hartkopf, J.A. Docobo, and J. F. Ling, Z. Cvetkovic, D. Mason, V. Tamazian, and many others [19].

2.2.2. Classification of Binary Star Systems

Traditionally, binary stars are classified into four main types according to their specific observational characteristics the technique used to discover and study them.

1- Visual binary: A system consisting of two stars that can be distinguished from each other by direct vision through the naked eye, by photographic cameras (traditional cameras or CCDs), or by using state-of-the-art high-resolution techniques such as speckle interferometry. Because the two stars revolve around each other at a relatively large distance, their movements can be monitered and their relative positions recorded accurately and, when the arc is sufficient, it is possible to calculate the orbit and then to obtain the total mass of the system [21].

2- Spectroscopic binary: A system of two very close stars which are apparently single when viewed through a powerful telescope It is, therefore, difficult to disperse their optical duplicity even utilizing the largest astronomical telescopes and, in the majority of the cases, it is not possible to optically resolve the binary. In this case, their nature as binaries is proven observing the periodic variation of the spectral lines as a practice of the Doppler-Fizeau effect. (Figure 2-1). This observational technique uses a spectrograph (to break spectra into component frequencies) to record the Doppler displacement in the spectrum resulting from the movement away of one of the two stars or the approaching of the other as they move around the center of gravity in the orbital period. In addition, a binary in which the orbital variation is observed in the spectral lines of both stars is called a double-lined spectroscopic binary. If the spectral lines of only one star are visible in the spectrum, we speak of a single-lined spectroscopic binary [21].

3- Eclipsing binaries: A system of two adjacent stars in which our line of sight is contended (or nearly so) in the orbital plane, that are physically bound together by a common gravity effect and orbiting the center of their common gravity. Because of this orbital motion, one of the stars sometimes passes in front of the other and blocks light, thereby producing mutual eclipses between the components. (Figure 2-2) [21].

4- Astrometric Binaries: A system of two stars in which one of these stars is very dim or when one of the components is much brighter than the other in such a way that its companion cannot be observed but, from the periodic movement of the brightest star referred to other stars, the existence of a second star can be deduced. In general, this type is detected by utilizing a program studying the absolute astrometry by periodicities in the proper motion and/or the parallax. Sometimes astrometric binaries are considered a subclass of visual binaries [20].

On the other hand, many scholars consider that a better classification of binaries based on the distance between the components (the configuration of the system). They were classified into two groups.

1- Wide binary: This type can be described as "long-distance stellar relationships" with a separation distance between the components, in general, of more than 50 astronomical units (AU), just beyond Pluto's orbit. They are usually resolved by means of optical techniques.

2- Close binary: This type can be described as "interacting binaries". The components affect each other and affect the evolution of the system and they are able to transfer their mass from one to the other. In the middle of the 20th century, Zdenek Kopal classified the close binary stars into three sub-groups based on the degree to which each stellar surface fills its critical the Roche lobe (Figure 2-3) [21].

I. Detached system: Both stars are too small to fit into the Roche lobe.
II. Semidetached system: One of the stars has filled the space of the Roche lobe.
III. Contact system: Both stars have filled the Roche lobe.

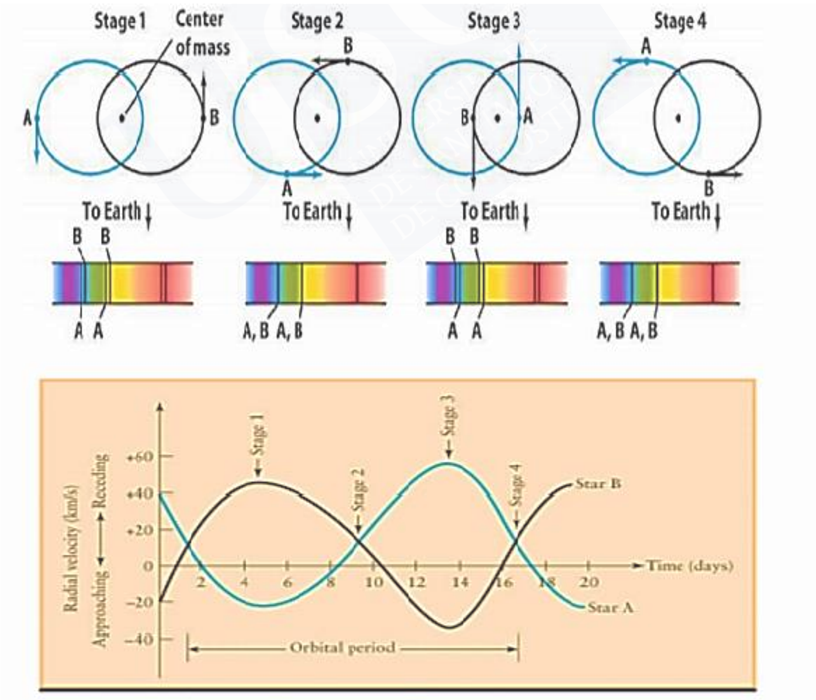


Figure 2-1 The Doppler-Fizeau effect in a spectroscopic binary system

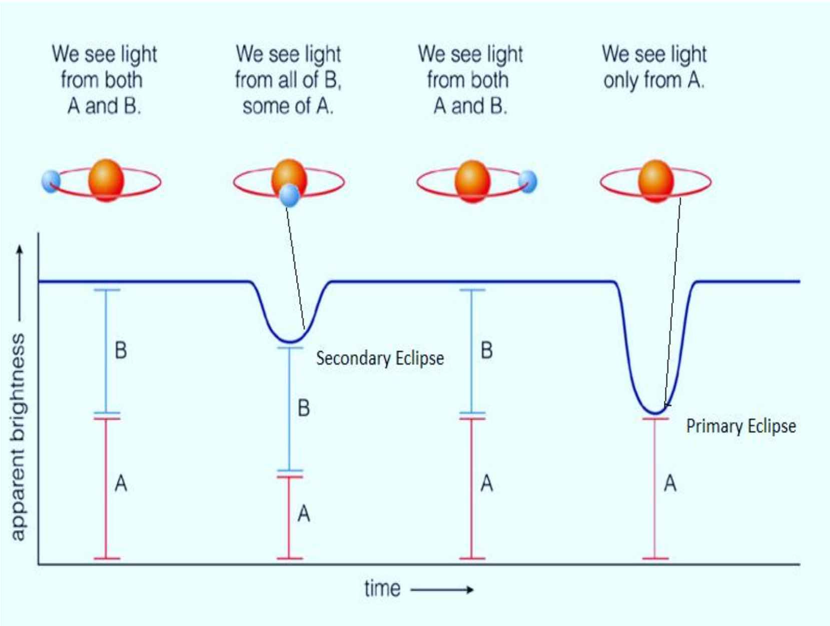
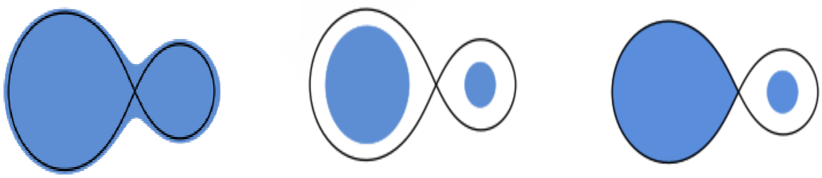


Figure 2-2 Eclipsing Binary Stars (Credit: ESA)



Detached system **Semidetached system** **Contact system**

Figure 2-3 Classification of close binaries by Roche lobes (Credit: https://www.aavso.org/vsots_wuma)

2.2.3. Why are Binary Stars important?

Binary stars are the focus of one of the most important fields of research in Astronomy, in general, and Stellar Physics, in particular [22]. They are the fundamental source to obtain the values of stellar masses. On the other hand, binary and multiple stellar systems have influence in three main areas of Astrophysics and Astrodynamics. First, these systems provide rich information in terms of obtaining the fundamental parameters in stellar physics and evolution theory from the masses, orbits, dynamical and orbital parallaxes, size of the components, etc. The masses can be linked to other properties of the two stars, such as luminosity, color, parallaxes, and radius and they can provide very stringent constraints on stellar models. It is thanks to the orbital motions and the precise calculation of orbits based on visual, spectroscopic, and photometric observations that we are able to assign realistic masses not only to stars but to exoplanets and planetary satellites as well. Second, the statistical information of binaries provides evidence of star formation mechanisms and environmental effects in the Galactic gravitational potential and in clusters. Although a number of good results have been obtained in nearby star clusters and associations, the knowledge of the field population has been somewhat limited until recently by a lack of large, complete samples of binaries. Third, the binary scenario is invoked to explain several important types of astrophysical phenomena such as Type Ia supernovae, cataclysmic variables, and stellar x-ray sources. Also considered as primary targets of the forthcoming field of Gravitational-wave Astronomy since their orbital evolution is entirely controlled by the emission of gravitational waves and leads to the ultimate coalescence (merger) of the components [22].

2.3. THE HISTORIC VALUE AND THE SCIENTIFIC PROGRESSION OF THE BINARY STAR STUDIES AT OARMA FROM RAMON MARIA ALLER TO JOSE ÁNGEL DOCOBO

2.3.1. The Epoch of the Establishment and Stagnation of OARMA

As mentioned earlier, the Ramón María Aller Astronomical Observatory (OARMA, http://www.usc.es/astro) has a long tradition in binary star studies especially, visual binaries but also recently in spectroscopic binary research. In 1912, Aller begun to make a name for himself in Spanish Astronomy after he published his paper: "Observations of the Johannesburg Comet 1910a" [19] [23] [24]. In 1917, he built an observatory in Lalín (Galicia, Spain) which consisted of two wooden sheds, one of which housed the theodolite and the other, a 67-mm refractor telescope. He decided to enlarge his collection of observation instruments with the addition of a 12-cm refractor with a focal length of 1.8 m [24]. Furthermore, he received an instrument (a Steinheil refractor) that was acquired in Germany in 1924 and installed in Lalín one year later. OARMA was established at the current Campus Vida of the University of Santiago de Compostela (USC) in 1943 by Father Aller as a continuation of his personal Observatory in his birthplace of Lalín. (Figure 2-4).

R. M. Aller introduced the study of double stars in Spain as well as being the first Spanish member of the IAU Double Stars Commission. In both installations (Lalín and Santiago), he used his personal Steinheil refractor in order to perform his first micrometric measurements. His measurements reached admirable precision and he published them in six articles in the Astronomische Nachrichten [25]–[29], the principal European astronomical journal at that time. In addition, he calculated the first visual double star orbits in Spain: O∑77 and O∑1932. The main aspects of the Father Aller research program in the following years were: 1- measurements of double stars, 2- the study of planetary surfaces, and 3- chance observations, including occultations, the position of comets, falling stars, and so on.

In this sense, Father Aller was extraordinarily productive with 78 publications (articles, notes, bibliographic comments), also solving hundreds of astronomical and mathematical problems, and editing four books including Algorithmia, Astronomy at naked eye, and Introduction to Astronomy (1st and 2nd editions). He directed five doctoral dissertations and was the first to use the Galician language in Astronomy in his Essays in the journal, Logos. For more further information about the life and work of Father Aller, Prof. J. A. Docobo published many biographies such as ‘’La Obra Científica de Aller Ulloa’’ in 1991 [30], ‘’Ramón María Aller Ulloa, pioneer of astronomical research in Galicia’’ in 2011 [24], and exceptional books in the Galician and Spanish languages entitled ‘’Ramón María Aller Ulloa: Astronomer and Mathematician (Biographies)’’ in 2014 and 2016, respectively. Moreover, Professor Docobo directed the Doctoral Dissertation of Cecilia Doporto Regueira in the Faculty of History that was entitled ‘’The Human Projection of Ramon María Aller Ulloa, his Scientific Legacy and the Museum House of Lalín’’ [31]. Docobo also suggested and directed the video ‘’ Ramón María Aller, Astronomer’’ in three languages (Spanish, Galician, and English) [32], [33]. The English version (http://tv.usc.es/mmobj/index/file_id/4338) has been visited 2,305 times. The Spanish version (http://tv.usc.es/mmobj/index/file_id/4335) has been visited 2,366 times and the Galician version (http://tv.usc.es/mmobj/index/file_id/4336), visited 3776 times.

Aller's doctoral students, Enrique Vidal and Rafael Cid (who later served as Professors at the Universities of Santiago de Compostela and Zaragoza, respectively) were also devoted to the theoretical study of double stars and, particularly, to orbit calculation methods. Enrique Vidal (Figure 2-5) was the first to publish that, with three observations (θ, ρ, t) or three normal points, it is possible to calculate the parabolic orbit of a binary [34]. Rafael Cid resolved the so-called Main Problem for the first time that consisted of obtaining the seven orbital elements of a visual binary using only seven observation data (three normal points and the position angle at a fourth time), that is to say, without using the areal constant [35]. Professor Aller died on 28 March 1966 at the age of 88. After his death, he left his observation instruments as well as the majority of his library collection to the Astronomical Observatory of the USC [23].

Figure 2-4 Left, the Observatory at Lalin in 1925. Right. ORAMA, The installation at USC Campus Vida at present (Credit: OARMA)

Figure 2-5 Father Ramón Maria Aller (center) with two of his disciples, Dr. Enrique Vidal Abascal (left) and Dr. Rafael Cid Palacios (right). Courtesy of Enrique Vidal Costa (Credit: OARMA)

2.3.2. The Epoch of the Revival, Renovation, and Prolific Scientific Productivity of OARMA

After some difficult years following the death of Father Aller during which the Observatory lacked scientific direction, the Center was physically and scientifically recuperated beginning in 1981 when Prof. José Angel Docobo (Figure 2-6) returned to Santiago de Compostela and, two years later, was named as the Director of OARMA by the President of the University of Santiago de Compostela. Although he is Galician, he came to Compostela from the University of Zaragoza where he was teaching and completed his Ph. D. in Astronomy under the direction of Professor Rafael Cid, (Figure 2-5 and 2-7) entitled ‘’Application of the Perturbation Theory to the Study of Triple Stellar Systems’’. At that time, the Observatory was in very poor physical condition and both the library as well as the instrumentation crucially needed to be updated. Dr. Docobo assumed responsibility for the scientific research work of the Center as well as the physical recuperation of the Observatory.

Since 1983, the Observatory was entered a new significant epoch and has played a vital role in developing and disseminating astronomical knowledge in Galicia, in particular, and Spain, in general (more information about the history of the Observatory in [36]). Moreover, the Observatory is today an international reference in double star research. OARMA (http://www.usc.es/astro/) functions include research, teaching, diffusion, and operation of the meteorological station. Those are the four pillars of the Observatory which Professor Docobo directs and cares for as though they were his own children. In the 1980s, Docobo developed a very practical and versatile global algorithm that allows the determination of the visual orbit from three normal points which is known as Docobo’s Method [37], [38] of which we will speak further on following Section. Docobo’s Method has been widely used in several countries to calculate more than 300 orbits of visual binaries during the last decades.

From the first moment, Docobo made great efforts to restore the Observatory to a sound scientific position. He endeavoured to update its facilities, administration, and contributions. Docobo's extraordinary efforts led to the modernization and replacement of the OARMA instrumentation with the latest astronomical tools in order to keep up with global development. As a result of that, OARMA has world-class instrumentation, such as, the A 0.62-m Ritchey-Chretien Reflector Telescope with a 6.20 m focal length (the second one in the Spanish University system), an EMCCD Speckle Interferometry Camera, an ICCD Speckle Interferometry Camera, a Medium Resolution ALTAIR Spectrograph, a SBIG-SGS Spectrograph, an OCULTATION Photometer, a THREAD Micrometer and several upper-level CCD Cameras for astronomical photography. Furthermore, the Observatory includes a valuable library which contains thousands of books and studies, with OARMA team are constantly updating them. Recently, the Observatory incorporated a new 16-inch telescope. (Figure 3-8).

During the last three and half decades, the OARMA research team directed by Prof. Docobo has developed a number of research projects on binary and multiple stars supported by official bodies such as the Xunta de Galicia, the Spanish Ministry of Education and Culture, the Spanish Ministry of Science and Innovation, etc. All of these projects were administered by Professor Docobo as the Principle Investigator and they are summarized it as follows.

1. Study of the dynamics of multiple star systems. Developed from 1988 to 1990.
2. Multiple star systems: astrometric observation and calculation of orbits, masses, and parallaxes (CICYT/ ESP 89-0730). Developed from 1990 to 1992.
3. Obtaining astrometric measurements and astrophysical parameters of interest from double and multiple stars (XUGA 24301B92/ DGICYT/ PB 92-1074). Developed from 1993 to 1995.
4. Obtaining astrometric measurements and astrophysical parameters of interest from double and multiple stars (PGC). Developed from 1993 to 1996.

5. Double and multiple star Astrometry and Astrophysics (XUGA 24301B96). Developed from 1997 to 1999.

6. Investigation of close binaries with "T" Tauri components. Developed from 1998 to 1999.

7. Astrometry and Astrophysics of late-types double stars with variable components. Developed from 1999 to 2001.

8. Multiple star systems with late-type variable components: interferometry, photometry, and spectroscopy (AYA 2001-2003). Developed from 2001 to 2004.

9. Multiple star systems with variable late-type: interferometry, photometry, and spectroscopy (PGIDIT02 PXIC24301PN). Developed from 2004 to 2007.

10. An astrometric, photometric, and spectroscopic study of multiple star systems with late-type variable components (AYA2004-07003). Developed from 2006 to 2009.

11. Speckle interferometry, spectroscopy, and photometry of late-type double and multiple stars (PGIDIT06 PXIB243031PR). Developed from 2007 to 2010.

12. Speckle interferometry, differential photometry, spectroscopy, and fundamental astrophysical parameters of double and multiple stars (AYA2007-67324). Developed from July 2009 to September 2010.

13. XII Meeting: Celestial Mechanics (AYA2009-06022-E) Double and Multiple Stars: Dynamics, Physics, and Instrumentation (AYA2009-06007-E). Developed from July 2009 to August 2010.

14. High Precision Astrometry and fundamental parameters of Double and Multiple Stars (AYA2010-18433). Developed from January 2011 to December 2011.

15. A study of the astrophysical and dynamical properties of double and multiple stars using speckle interferometry, photometry, and spectroscopy

(AYA2011-26429). Developed from January 2012 to December 2015.

16. Study of closed binaries of special astrophysical interest dynamic in the Gaia era (AYA2016-80938-P). Developed from December 2016 to December 2020.

In addition, the OARMA Research Group GI-1565 has participated as a member of the IEMath-Galicia Network since 2011, receiving funding through it.

Figure 2-6 Professor José Ángel Docobo, the Director of OARMA since 1983, standing next to the portrait of Prof. Ramon Maria Aller (Credit: OARMA)

Figure 2-7 Prof. R. Cid (in the center) in the 1990s at the University of Zaragoza (Spain) with six of his disciples (from left to right): Dr. A. Vigueras, Dr. M. Palacios, Dr. J. A. Docobo, Dr. A. Abad, Dr. J. Rivera, and Dr. A. Elipe (Credit: A. Elipe)

Figure 2-8 Prof. José Ángel Docobo with the R. M. Aller refractor at OARMA (Credit: OARMA)

2.3.2.1. National and International Scientific Collaboration and Agreements

Due to limited facilities in the beginning time of the Observatory run regarding the astronomical instrumentation, Prof. Docobo established several collaboration agreements in order to develop and improve scientific research at OARMA. Docobo's research groups were able to access some of the internationally renowned astronomical facilities installed in recent years in Spain and across the world, aiming to further the scientific capacity of OARMA to prepare for the challenges of the 21st century by acquiring new instruments and installing them in the Observatory.

In fact, the ample contacts of Prof. Docobo permitted the doctoral students and researchers at OARMA to be able to conduct micrometric measurements and Speckle Interferometry (SI) observations in several observatories across the world, including working with leading groups at an international level in order to enhance their fundamental educational experiences in modern Astronomy. As a result, the OARMA research team under the supervision of Prof. Docobo has centered its research on advanced imaging techniques to achieve relative positions and differential photometry of binaries, particularly SI, as the first steps in binary and multiple star research.

As a result of these collaboration agreements, J. F. Ling completed research visit stays as the Nice and the Pic du Midi observatories; C. Prieto at CHARA (USA); J. F. Ling, and C. Prieto at the Llano de Hato (Venezuela), J. Blanco at SAO, J. Gomez at BAO, SAO, and SOAR; A. Abushattal at the Cambridge Observatory; L. Piccotti at BAO and Calen (France), and P. Campo at the Cambridge Observatory and BAO.

In 198, as the new Director of OARMA, Professor Docobo created and developed many connections, collaborations, and partnerships with the most prominent specialists of the contemporary period in the fields of double and multiple star research, such as, P. Couteau, Y. Balega, H. McAlister, W. Hartkopf, B. Mason, A. Tokovinin, R. Griffin, and others in order to promote his novel vision of OARMA to provide high-quality training and teaching for doctoral students as well as collaborators in latest research methodology. Moreover, Professor Docobo stated " It is essential that doctoral students and OARMA collaborators travel outside of the country in order to be in touch with outstanding specialists and to know and use more powerful instrumentation". On the other hand, Docobo established collaboration agreements with several observatories and research centers in order to carry out observation runs and campaigns but in other cases the observational time was achieved through the time allocation committee of those observatories including those listed below.

1. The Fabra Observatory (Catalonia, Spain).
2. The Yebes Observatory (Castilla-La Mancha, Spain).
3. The Nice Observatory, today known as the Côte d'Azur Observatory (Nice, France) and the Pic du Midi Observatory (France).
4. The Calar Alto Observatory (Sierra de Filabres, Almeria, Spain).
5. The Special Astrophysical Observatory (SAO, Russia).
6. The Byurakan Astrophysical Observatory (BAO, Armenia).
7. The Montsec Observatory (Catalonia, Spain).
8. The University of Chile.
9. The Observatory of the Institute of Astronomy (Cambridge United Kingdom).

During the 1980s and 1990s, Professor Docobo and his colleagues worked at the Fabra Observatory (Barcelona), the Nice Observatory, the Pic du Midi Observatory (France), and the Calar Alto Observatory (Almería) in order to perform micrometer measurements and observations campaigns. Also, thanks to the invitation from Dr. Paul Couteau, Prof. Docobo and Dr. Ling carried out several stays at the Nice Observatory and the Pic du

Midi Observatory. (Figure 2-9). As a result of these observation campaigns and the consequent calculation of orbits, Docobo and OARMA members have published numerous scientific articles between 1982 and 2000 in high impact scientific journals as well as in the IAU Commission 26 Double and Multiple Stars Information Circular (since 2015 known as G1). They are listed below: Abad, Docobo, and, Della Prugna [39]; Couteau, Docobo, and Ling [40]; Couteau Docobo, Eliped, and Ling [41]; Docobo and Prieto [42], Docobo ([43]–[47]; Docobo and Balega [48]; Docobo, and Costa [49]–[53], [54, pp. 00593–0040], [55]–[62], Docobo and Ling [63]–[71], [72, pp. 19471–0810], [73]–[75], [76, pp. 23529–0313], [77], [78], [79, pp. 23517–0637], [80]–[86]; Docobo, Ling, and Prieto [87]; Docobo and Prieto [88]–[95]; Docobo and Tamazian [96]; Docobo and Vasyuk [97]; Docobo, Ling, Lanchares, Elipe, and Abad [98]; Docobo et al. [99], [100]; Ling and Lanchares [101]; and Ling and Prieto [102].

Figure 2-9 Dr. P. Couteau and Dr. J. A. Docobo at the Pic du Midi Observatory in the early 1990s (Credit: Dr. J. A. Docobo)

2.3.2.2. Speckle Interferometry and Binary Stars at OARMA: Further Scientific Research Productivity and Collaboration at the Global Level

Speckle Interferometry (SI) is one of the modern high-resolution techniques utilized to study and resolve binary stars in order to obtain information about practically all of the physical parameters. In 1970, Antoine Labeyrie [103] invented the SI suggesting a method for the analysis and correction of the Earth's atmosphere turbulence by the construction of filled-aperture interferometry utilizing the turbulence cells of the atmosphere over the telescope to constructively interfere and produce diffraction limited information.

In the early 1990s, Prof. Docobo introduced Speckle Interferometry measurement technique at OARMA. In order to obtain and install the SI camera at OARMA facilities, he made the first contacts with McAlister, the Director (and founder) of the Center for High Angular Resolution Astronomy at the Georgia State University (CHARA, Atlanta, USA). Unfortunately, due to the prohibitive prices and limited financial support at that time, the project was frozen [104]. Nevertheless, instead of obtaining the SI camera, he sent C. Prieto (Docobo's doctoral student at that time) to CHARA in 1991 for a three-month research visit to familiarize himself with this technique and to be able to participate in observation campaigns. During the organization of the 1996 International Workshop, Docobo established a collaboration agreement with Yuri Balega (Figure 2-10), the Director of the Special Astrophysical Observatory (SAO, Russia) at that time, in order to construct an ICCD camera for the Observatory (Figure 2-11). With the great financial support supplied by the Xunta de Galicia (Regional Government of Galicia) in the late 1990s, OARMA finally was able to acquire its first speckle camera from SAO. In the following years, Docobo and Tamazian played a crucial role in order to install this ICCD camera at the Centro Hispano-Aleman at Calar Alto Observatory in the 1.52 m and the 3.5 m telescopes [105]–[107]. After the arrival of Dr. V. Tamazian as a member of the OARMA staff in 1994, the Center opened a new line of work in relation to double stars with variable components.

From 2000 to 2010, the OARMA research team directed by Prof. Docobo has developed a number of research projects on binaries supported by Spanish official bodies. Thanks to the role that Prof. Docobo to update the Observatory telescope, the Ritchey-Chretien 0.62m aperture telescope was installed at the Center in 2003. The OARMA research team carried out diverse campaigns observing relatively wide binaries using the OARMA ICCD Speckle Interferometry camera as well as other CCDs cameras in order to perform speckle measurements of binaries. As a result of these campaigns, a massive number of scientific results were published in the International Journals, Conference Proceeding as well in Information Circular of International Astronomical Union Commission 26. The scientific publications of OARMA from 2001 to 2010 listed as follow: Abad, Docobo, and F. Della Prugna [108]; Andrade [109]–[114]; Docobo [115]–[120] ; Docobo and Andrade [121]–[126]; Docobo, Andrade, and Campo [127, p. 11]; Docobo, Balega, and Tamazian ; Docobo and Ling [116], [128] [129]–[133] [129], [134]–[154]; Docobo and Tamazian [123], [155]–[166]; Docobo, Tamazian, Kraus, and Woitas [162]; Docobo, Tamazian, and Woitas [167]–[169]; Ling [170] [171]–[185]; Docobo, Tamazian, Andrade, Ling, Balega, Lahulla, and Maximov [105], [106], [186]–[193]; Tamazian [194]–[196]; Melikian, Tamazian, Docobo, et al. [197], [198], [199, p. 448], [200], [201]; Tamazian and Docobo [202]–[206]; Trigo-Rodriguez, Docobo, et al. [207]–[209]; Woitas, Tamazian, Docobo, and Leinert [205], Woitas, Tamazian, and Docobo [206].

Since 2010, the Observatory was entered a new exceptional era in astronomical research in terms of both Observatory facilities as well as scientific research at a world-class level. Prof. Docobo o obtained sufficient financial support to modernize and develop the OARMA instruments. In 2009, OARMA received funds from the Spanish Ministry of Education and the Xunta de Galicia to acquire the latest Speckle Interferometry camera with an EMCCD detector as well as an Altair Spectrograph and a SBIG-SGS Spectrograph. The OARMA EMCCD SI camera was designed to merge a speckle-oriented optical configuration together with a PhotonMax EMCCD detector from Princeton Instruments. The new EMCCD camera system yields relative positions of binaries as well as the differences of magnitude between their components, information that is fundamental for the study of the physical properties of these celestial objects. The EMCCD camera was successfully installed for the first time on the 0.62-m OARMA Ritchy-Chretien telescope. Prof. Docobo obviously understood that it was necessary to take more advantage in order to achieve the fitting scientific performance of the EMCCD camera by attaching it to at least a 2m class telescope [212]. He began to directly communicate with other observatories and research centers in order to transport and attach the instrument on the 2-m aperture telescopes installed in those places.

In 2010, Prof. Docobo signed a collaboration agreement with Prof. H. Harutyunyan, Director of the Byurakan Astrophysical Observatory (BAO, Armenia) in order to transport, install, operate, and use the OARMA's speckle camera on the BAO 2.6-m telescope. Moreover, this cooperation created research opportunities for Docobo's research group to carry out one interferometric observation campaign per year for five years and, later, the agreement was extended [212].

Prof. Docobo continued offering the global level observation programs for his research groups, he signed a new collaboration agreement with the Director of the Special Astrophysical Observatory (SAO, Russia) in 2011. This agreement permitted the OARMA members to execute SI observations on the 6-m aperture telescope of SAO. In addition, Prof. Docobo collaborated with, R. A. Mendez, the Professor and Researcher at the University of Chile. By means of this collaboration, Jorge Gomez (an OARMA researcher) was able to arrange and obtain observation time on the 4.1m telescope installed at the Southern Astrophysical Research (SOAR Chile) as well as travel to La Serena (Chile) in order to participate in image acquisition. In addition, Prof. Docobo established collaboration with Prof. Roger Griffin at the Cambridge Observatory (Cambridge Observatory) in order to utilize the 0.91-m telescope of that University for spectroscopic observations.

In this decade, the collaboration between OARMA with these prestigious research centers led to the successful accomplishment of SI observation campaigns for the OARMA staff. The following campaigns were carried out at several locations such as SAO in 2012, 2013, 2014, 2015, and 2016; SOAR in 2015; BAO since 2010 to 2019; at the Observatori Astronòmic del Montsec

(OAdM) in 2016; the Calern Observatory in 2017 and 2018; and the Cambridge Observatory in 2014, 2015, and 2016. As well as researchers from the University of Chile have recently joined the OARMA's research groups in order to perform observational and to carry out the calculation of orbits with visual and spectroscopic binaries and multiple systems by Docobo's method. For more information about speckle interferometry, see the Doctoral Dissertation of Jorge Gómez Crespo prepared under the direction of Professor Docobo (see the MINERVA repository) and defended in 2019: Double and Multiple Stellar Systems: Observational Techniques, Data Administration, and Scientific Results [104].

To demonstrate all of the work developed by the OARMA members in the field of binaries and multiple systems, in general, and Speckle Interferometry, in particular, the results obtained from these campaigns have been published in different astronomical journals since 2011: Andrade and Docobo [213]–[215]; Al-wardat, Docobo, Abushattal, and Campo [216]; Campo and Docobo [217]; Docobo [24], [218]–[220]; Docobo and Andrade [221], [222]; Docobo, Andrade, and Campo [218], Docobo, Andrade, Campo, and Ling [219]; Docobo and Gomez [212], [225], [226]; Docobo, Griffin, Tamazian, Horch, and Campo [227]; Docobo, Griffin, Campo, and AbuShattal [227], Docobo and Ling [228]; Docobo, Ling, and Campo [229]; Docobo and Tamazian; Docobo et al. [212], [225]–[227], [230]–[239]; Gomez, Docobo, Campo, and Mendez [240]; Melikian, Tamazian, and Docobo [197], [241]; Melikian, Tamazian, et al. [242]–[247]; Ling [248]; AbuShattal, Docobo, and Campo [249], Piccotti, Docobo, Carini, Tamazian, Bracato, Andrade, and Campo [250].

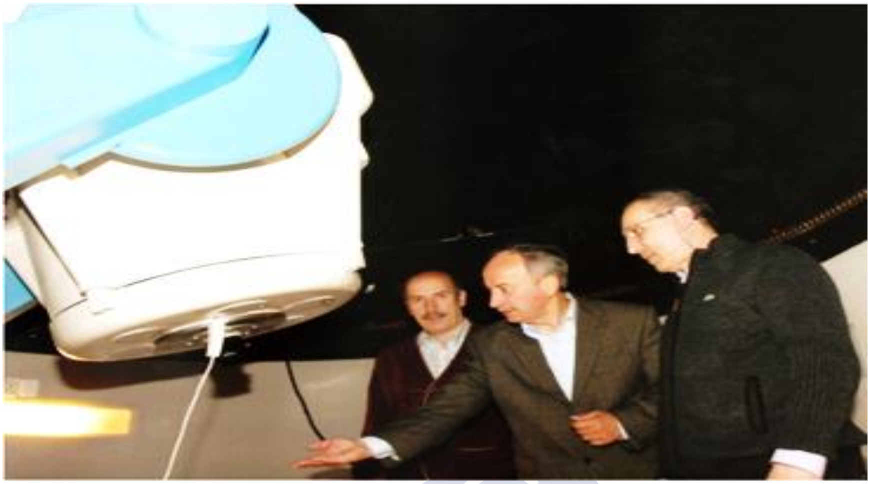


Figure 2-10 Left to Right: J. A. Docobo, Y. Balega, and V. Tamazian with at the big dome of OARMA in 2006 (Credit: OARMA)

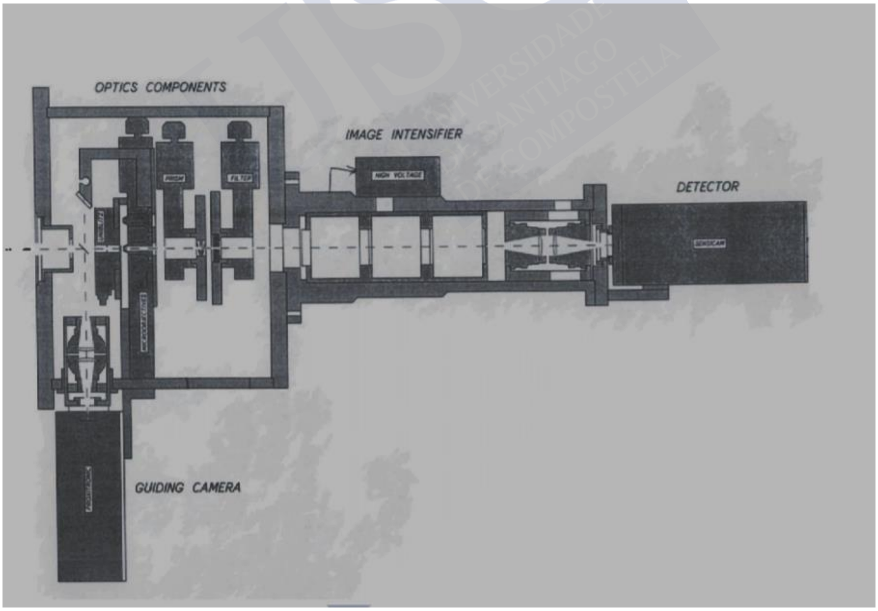


Figure 2-11 Design the OARMA´s ICCD camera (Credit: OARMA)

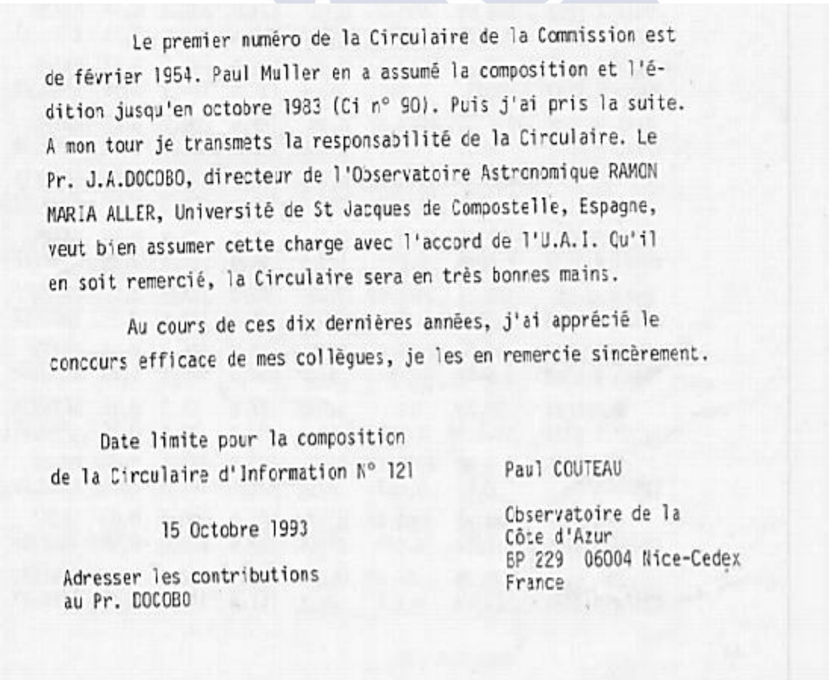
2.3.2.3. Information Circular of the International Astronomical Union Commission 26 (IAUDS): OARMA Significant Role

Since its constitution in 1919, International Astronomical Union (IAU) began to coordinate astronomical research in double and multiple stars at a world level and was called Commission 26 (Double and Multiple Stars, IAUDS). R. M. Aller was elected to be a member of Commission 26 in 1948. The Information Circular was begun in 1954 by Paul Muller, later, Paul Couteau took over the responsibility to edit the Information Circular until 1993. In 1993, from Dr. Paul Couetau, transferred the responsibility to edit the Information Circular of IAU Commission 26 to Prof. Docobo (Figure 2-12). Since then, Docobo proposed that the Circular is published in English (with an ISBN number) and named Dr. Ling as co-editor. (Figure 2-13).

The Circular announces new orbits, observations, scientific meetings, publications, obituaries, and other information of interest to Commission 26 (G1) members. The Information Circular (http://www.usc.es/astro/circularing.html) is the essential channel for news about double and multiple stars for members of the IAU Commission 26 (G1). It is also circulated to other scholars, observatories, and astronomical centers. Since 1993 and ongoing to present, Prof. Docobo and Dr. Ling have edited and published about 68 issues of Information Circular (Information Circular, number 121 to number 199). Issues of the IAUDS are available online at the Commission 26 Webpage (http://ad.usno.navy.mil/wds/dsl/Comm26/circularintro.html), the G1 Webpage (http://ad.usno.navy.mil/wds/bsl/G1_pub ic.html), and the OARMA webpage (http://www.usc.es/astro/circularing.html).

On the other hand, the high prestige that OARMA enjoys relates to the field of Double and Multiple Stars. Professor Docobo was elected in 2006 in the IAU General Assembly in Praga a Vice-President of Commission 26 for the period 2006 – 2009, and in the IAU General Assembly in Rio (2009) passed to the Presidency of said Commission until 2012. (Figure 2-14 and 2-15). Dr. Ling was elected as a member of the Organizing Committee (2000 -2006) as well Dr. Tamazian (2009 – 2015). (Figure 3-16) Until 2015, there were two Commissions responsible for the study of binaries, Number 26 (Double and Multiple Stars) and Number 42 (Close Binaries). At the General Assembly of the IAU celebrated in Hawaii, both Commissions merged into the actual G1, with the name "Binary and Multiple Stars". The OARMA team has been an effective member and has played a significant role in calculating and publishing orbits. They have been able to employ Docobo's method to calculate large numbers of double and multiple systems.

On the other hand, Prof. Docobo has published orbits in all of the IAUDS Circulars since 1982. Table 3-1 listed the orbit(s) and the OARMA author(s) who announced them in each time period as proposed from 1982 to 2019.



Le premier numéro de la Circulaire de la Commission est de février 1954. Paul Muller en a assumé la composition et l'édition jusqu'en octobre 1983 (Ci n° 90). Puis j'ai pris la suite. A mon tour je transmets la responsabilité de la Circulaire. Le Pr. J.A.DOCOBO, directeur de l'Observatoire Astronomique RAMON MARIA ALLER, Université de St Jacques de Compostelle, Espagne, veut bien assumer cette charge avec l'accord de l'U.A.I. Qu'il en soit remercié, la Circulaire sera en très bonnes mains.

Au cours de ces dix dernières années, j'ai apprécié le conccurs efficace de mes collègues, je les en remercie sincèrement.

Date limite pour la composition
de la Circulaire d'Information N° 121

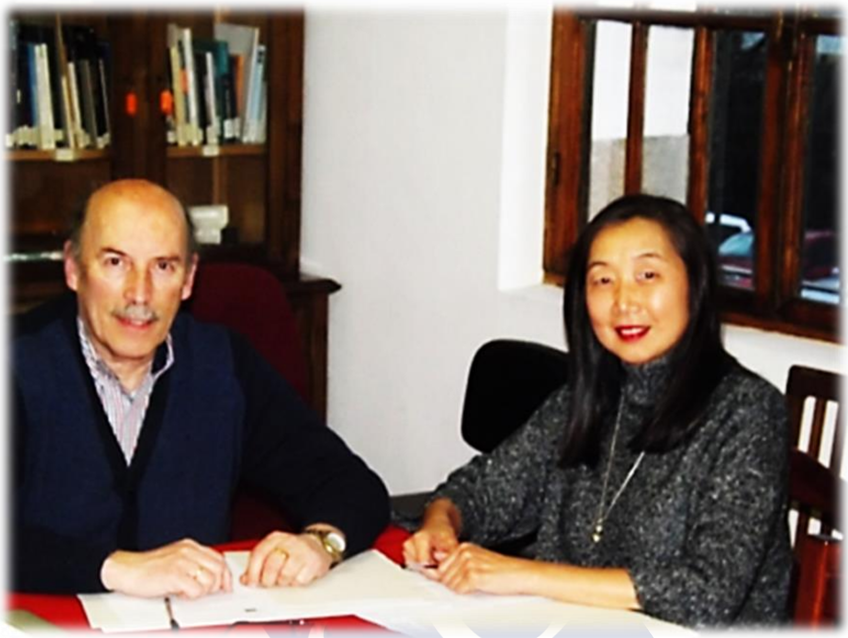
15 Octobre 1993

Adresser les contributions
au Pr. DOCOBO

Paul COUTEAU

Observatoire de la
Côte d'Azur
BP 229 06004 Nice-Cedex
France

Figure 2-12 Formal letter from Dr. P. Couteau to transfer the responsibility to edit the Information Circular of IAU Commission 26 to Dr. J. A. Docobo in the Circular number 120 dated on 15 October 1993 (Credit: OARMA)



.Figure 2-13 Prof. J. A. Docobo and Dr. J. F. Ling, the current editors of the Information Circular Commission 26 (Since 2015 G1) (Credit: OARMA)

Figure 2-14 IAU Commission 26, General Assembly in Praga 2006 (Credit: OARMA)

Term	President	Vice President	Secretary
1919-1922	Robert Aitken		
1922-1925	Robert Aitken		
1925-1928	Robert Aitken		
1928-1932	Ejnar Hertzsprung		George van Biesbroeck
1932-1935	Ejnar Hertzsprung		
1935-1938	Ejnar Hertzsprung		
1938-1948			
1948-1952	Willem van den Bos (R. Aitken, honorary)		
1952-1955	Paul Muller		
1955-1958	Paul Muller		Peter van de Kamp
1958-1961	Peter van de Kamp		Sarah Lippincott
1961-1964	Peter van de Kamp	Richard Woolley	Sarah Lippincott
1964-1967	Kai Strand	Paul Couteau	Jean Dommanget
1967-1970	Paul Couteau	Jean Dommanget	Sarah Lippincott
1970-1973	Jean Dommanget	Sarah Lippincott	Otto Franz
1973-1976	Sarah Lippincott	Paul Muller	Otto Franz
1976-1979	Paul Muller	Otto Franz	
1979-1982	Otto Franz	Mario Fracastoro	Jean Dommanget
1982-1985	Mario Fracastoro	Karl Rakos	
1985-1988	Karl Rakos	Harold McAlister	
1988-1991	Harold McAlister	Helmut Abt	
1991-1994	Helmut Abt	Charles Worley	
1994-1997	Charles Worley	Hans Zinnecker	
1997-2000	Hans Zinnecker	Colin Scarfe	
2000-2003	Colin Scarfe	William Hartkopf	
2003-2006	William Hartkopf	Christine Allen	
2006-2009	Christine Allen	Jose Docobo	
2009-2012	Jose Docobo	Brian Mason	
2012-2015	Brian Mason	Yuri Y. Balega	

Figure 2-15 Figure 12 Officers of IAU Commission 26 (Source http://www.astro.gsu.edu/wds/bsl/c26_history.html)

1961-1964	O. Eggen, P. Muller, K. Strand, W. van den Bos
1964-1967	O. Eggen, P. Muller, J. Dommanget, P. Kulikovsky, R. Petrie
1967-1970	O. Eggen, P. Muller, K. Strand, P. Kulikovsky, P. van de Kamp
1970-1973	P. Couteau, P. Muller, K. Strand, A. Deutsch, P. van de Kamp
1973-1976	P. Couteau, A. Batten, K. Strand, A. Deutsch, J. Dommanget, O. Franz
1976-1979	R. Harrington, A. Batten, M. Fracastoro, C. Worley, S. Lippincott
1979-1982	R. Harrington, P. Kulikovsky, P. Muller, C. Worley, A. Poveda, C. Scarfe
1982-1985	J. Dommanget, O. Franz, W. Heintz, H. McAlister, A. Poveda, C. Scarfe
1985-1988	J. Dommanget, H. Abt, P. Couteau, M. Fracastoro, R.S. Harrington, A. Kiselyov
1988-1991	P. Bernacca, E. van Dessel, P. Couteau, R. Harrington, A. Kiselyev, K. Rakos
1991-1994	P. Bernacca, E. van Dessel, H. Zinnecker, Y. Balega, F. Fekel, C. Scarfe
1994-1997	C. Allen, W. Hartkopf, A. Tokovinin, Y. Balega, F. Fekel, C. Scarfe
1997-2000	C. Allen, W. Hartkopf, A. Tokovinin, J. Armstrong, R. Mathieu, M. Valtonen
2000-2003	F. Fekel, P. Lampens, J. Ling, J. Armstrong, R. Mathieu, M. Valtonen
2003-2006	F. Fekel, P. Lampens, J. Ling, J. Davis, E. Oblak, T. Oswalt
2006-2009*	Y. Balega, B. Mason, D. Pourbaix, C. Scarfe, J. Davis, E. Oblak, T. Oswalt
2009-2012	Y. Balega, D. Pourbaix, C. Scarfe, F. Arenou, M. Scardia, V. Tamazian
2012-2015*	F. Arenou, M. Scardia, V. Tamazian, T. ten Brummelaar, P. Lampens, B. Reipurth, A. Tokovinin

Figure 2-16 Figure 13 Organizing Commitee of IAU Commission 26

Table 2-1 Orbits and the OARMA authors, IAU Commission 26 (G1), Information Circular, 1982 - 2019

Circular Number	Year	The orbit(s) and the OARMA author(s) who announced them
87	**1982**	Costa and Docobo, New orbit for IDS 00412-2247, IDS 17467-3442, IDS 22237+0032, IDS 22232+1144, and IDS 22336+7221
88	**1982**	Costa and Docobo, New orbit for IDS 05174+0231
89	**1983**	Costa and Docobo, New orbit of WDS 00048-3420, WDS 02106+0610, WDS 033383+6821, WDS 11075-1757, WDS 11310+2820, WDS 12372+2654, WDS 22255+2157, WDS 23075+0209, and WDS 23511+2447
90	**1983**	Costa and Docobo, New orbit for WDS 00542-0113, WDS 00545-0144, WDS01502+0228
91	**1983**	Costa and Docobo, New orbit for WDS 00189+5128, WDS 09057-2821, WDS 14182-3810, WDS 19298+6324, WDS 19471-2543, and WDS 23304-2802
92	**1984**	Docobo and Costa, New orbit for WDS 00597+0103, WDS 04404+4313, WDS 05544+5813, WDS 06432+0744, WDS 06567+3949, WDS10596-0341, and WDS18410+3934
93	**1984**	Docobo and Costa, New orbit for WDS 00571+0520, WDS 00594+3617, WDS 06443+5934, WDS13154+1818, and WDS 13458-1840
94	**1984**	Docobo and Costa, New orbit for WDS 08234, WDS 15105+6030, and WDS 19522+5033
95	**1985**	Docobo and Costa, New orbit for WDS 04009+3749, WDS 15475+6050, WDS 17457+0716, and WDS 21454+1650
96	**1985**	Docobo and Costa, New orbit for WDS 07282+3166
97	**1985**	Docobo and Costa, New orbit for WDS 00314+4621
98	**1986**	Docobo and Costa, New orbit for WDS 16107+4653
99	**1986**	Docobo and Costa, New orbit for WDS 2233+7221 and WDS 22357+3700
100	**1986**	Docobo and Costa, New orbit for WDS 04142+1617
101	**1987**	Docobo and Costa, New orbits for WDS 08568+4733 and WDS 08568+4733
102	**1987**	Docobo and Costa, New orbits for WDS 20166+3905
103	**1987**	Docobo and Costa, New orbit for WDS 21397+2817

104	**1988**	Docobo, New orbits for WDS 00594+3617 and WDS 23075+0209
105	**1988**	Docobo and Costa, New orbit for WDS 00463+2205 and WDS 03555+0448
106	**1988**	Docobo and Costa, New orbit for WDS 18508+0319
107	**1989**	Docobo and Costa, New orbit for WDS 00593-0040
108	**1989**	Docobo and Costa, New orbit for WDS 04256+1852
109	**1989**	Docobo and Costa, New orbit for WDS 00550+4006.
110	**1990**	Docobo and Costa, New orbits for WDS 17505+0715 and WDS 22575+4728
111	**1990**	Docobo and Costa, New orbits for WDS 01050+3649, WDS 04432+5932, and WDS 23115+3813
112	**1990**	Docobo and Costa, New orbits for WDS 14159-0704 and WDS 17323+2849
113	**1991**	Docobo and Costa, New orbits for WDS 17366+0722, WDS 17533-3444, and WDS 17563+0259; Docobo and Prieto, New orbit for WDS 07079-1542
114	**1991**	Docobo and Prieto, New orbit for WDS 08214-0136
115	**1991**	Docobo, New orbits for WDS 10282-2549 and WDS 23078+6338; Docobo and Ling, New orbits for WDS 15428+5059 and WDS 16515+0113
116	**1992**	Docobo and Ling, New orbit for WDS 20232+2052.
117	**1992**	Docobo and Ling, New orbit for WDS 07573+0108
118	**1992**	Docobo and Ling, New orbit for WDS 15416+1941; Docobo and Prieto, New orbit for WDS 19549+5049
119	**1993**	Docobo and Ling New orbits for WDS 04262+3443 and WDS 08267+2433
120	**1993**	Docobo and Ling, New orbit for WDS 01497-1414; Docobo and Prieto, New orbit for WDS 05482+0137
121	**1993**	Docobo and Ling, New orbits for WDS 03310+2937 and WDS 20311+3332
122	**1994**	Docobo and Ling New orbit for WDS 11136+5525 and WDS 15088-4517; Docobo and Prieto, New orbit for WDS 19398-2326
123	**1994**	Docobo and Ling, New orbit for WDS 20494+1124
124	**1994**	Docobo and Ling, New orbits for WDS 01039+3528, WDS 05411+1632, and WDS 21000+4005
125	**1995**	Docobo and Ling, New orbits for WDS 10585+1711, WDS 15370+6427
126	**1995**	Docobo and Prieto, New orbit for WDS 06053+7400
127	**1995**	Docobo and Ling, New orbits for WDS 00596-0111, WDS 17575+1057, and WDS19471-0810

128	**1996**	Docobo and Ling, New orbit for WDS 19487+1503; Docobo and Prieto, New orbit for WDS 05276-2055
129	**1996**	Docobo, New orbit for WDS 15262-2819
130	**1996**	Docobo and Ling, New orbit for WDS 19172-6640; Docobo and Prieto, New orbit for WDS 09001-1228
131	**1997**	Docobo and Ling, New orbits for WDS 23506-5142 and WDS 23529-0313
132	**1997**	Docobo and Ling, New orbit for WDS 19055+3352
133	**1997**	Docobo and Ling, New orbit for WDS 17103-1544 and WDS 22401+0112
134	**1998**	Docobo and Ling, New orbits for WDS 19180+2012 and WDS 23382+5514
135	**1998**	Docobo and Balega, New orbit for WDS 13320+ 3109; Docobo and Ling, New orbits for WDS 05413+1632, WDS16384+3514, WDS 20311+3333, WDS 20494+1124, and WDS 23517-0637; Docobo and Tamazian, New orbit for WDS 14310-0548
136	**1998**	Docobo and Ling, New orbits for WDS 15390+2545,17075+3810
137	**1999**	Docobo and Ling, New orbit for WDS 22077+2622
138	**1999**	Docobo and Ling, New orbits for WDS 01450+2703 and WDS 23199+2844
139	**1999**	Docobo, Tamazian, Abelleira, Blanco, Lanchares, Balega, Maximov, and V. Vasyuk, New orbits for WDS 16584+3943, WDS 16584+3943, and WDS 18035+4032; Docobo and Ling, New orbit for WDS 16584+3943 and WDS 18035+4032
140	**2000**	Docobo and Ling, New orbits for WDS 03423+3141, WDS 06503+2410, and WDS 19411+1349
141	**2000**	Docobo, New orbit for WDS 00243+5201; Docobo and Ling, New orbits for WDS 00593-0040, WDS 01233+5808, WDS 02039+4220; Docobo and Vasyuk, New orbit for WDS 02537+3820
142	**2000**	Docobo and Ling, New orbits for WDS 00593-0040, WDS 01233+5808, WDS 02039+4220.
143	**2001**	Docobo, New orbit for WDS 01048+0135; Docobo and Ling, New orbit for WDS 18466+3821, WDS 22357+5413; Ling, New orbit for WDS 12429+0516
144	**2001**	Docobo, New orbit for WDS 04475+4324; Docobo and Ling, New orbit for WDS 07043-0303, WDS 11047-0413, WDS 15370+6426, and WDS 19039+2642; Ling, New orbit for WDS 03591+0948
145	**2001**	Docobo and Ling, New orbit for WDS 00546+1911, WDS 02398+0009, WDS 106393+4200, WDS 11308+4117, and WDS 20216+1930; Ling, New orbit for WDS 18236-2610

146	**2002**	Docobo and Andrade, New orbit for WDS 23186+6807; Docobo and Ling, New orbit for WDS 12409+2708, WDS 18035+4032, and WDS 19180+2012; Docobo and Tamazian, New orbit for WDS 04271+2542 and WDS 04295+2617; Docobo, Tamazian, and Woitas New orbit for WDS 04142+2813, WDS 04148+2813, and WDS 04220+2658
147	**2002**	Docobo and Ling, New orbit for WDS 17075+3810 and WDS 19487+1504; Docobo, Tamazian, and Woitas New orbit for WDS 00321+6715; Ling, New orbit for WDS 00427-6537; Docobo, Tamazian, Woitas, and Leinert, New orbit for WDS 04325+1732
148	**2002**	Docobo and Ling, New orbit for WDS 03503+2535, WDS 06573-3530, WDS 20151+3742, WDS 21593+4606, and WDS 22329 +5348; Ling, New orbit for WDS 01343-0827
149	**2003**	Docobo and Ling, New orbit for WDS 17221+2310, WDS 19089+3404, and WDS 20216+1930
150	**2003**	Docobo and Andrade, New orbit for WDS 14369+4813; Docobo and Ling, New orbit for WDS 06503+2409 and WDS 14138+3059, Andrade, New orbit for WDS 21597+4907; Ling, New orbit for WDS 01084-5515; Tamazian, New orbit for WDS 04220+1932
151	**2003**	Docobo and Ling, New orbit for WDS 16044-1122; Ling, New orbit for WDS 02405-2408 and WDS 06579-4417
152	**2004**	Docobo and Ling, New orbit for WDS 01023+0552, WDS 08285-0231, WDS 11363+2747, and WDS 15088-4517; Docobo and Tamazian, New orbit for WDS 07467+2001
153	**2004**	Docobo and Ling, New orbit for WDS 01049+3649, WDS 08267+2432, and WDS 17324+2848; Ling, New orbit for WDS 19520-1021
154	**2004**	Andrade, New orbit for WDS 05117+0031; Docobo, New orbit for WDS 23020+4800; Docobo and Ling, New orbit for WDS 19282-1209 and WDS 22241-0450; Ling, New orbit for WDS 23431+11501
155	**2005**	Docobo and Ling, New orbit for WDS 01040+3528, WDS 15416+1941, WDS 17104-1544, and WDS 19411+1349; Ling, Prieto, and Magdalena, New orbit for WDS 00318+5431, WDS 15234-5919
156	**2005**	Docobo and Andrade, New orbit for WDS 00243+5201 and WDS 00516+2237; Docobo and Ling, New orbit for WDS 01450+2703; Docobo and Tamazian, New orbit for WDS 02288+3215
157	**2005**	Andrade, New orbit for WDS 18208+7120 and WDS 19351+5038; Docobo and Andrade, New orbit for WDS 20374+7536; Docobo and Ling, New orbit for WDS 08285-0231, WDS 10373-4814, and WDS 17584+0428; Docobo and Tamazian, New orbit for WDS 03006+4753, WDS 04364+3413, and WDS 04464+4221, and WDS 09498+2111

158	**2006**	Docobo and Ling, New orbit for WDS 03503+2535, WDS 04163-6057, and WDS 15416+1940; Docobo and Tamazian, New orbit for WDS 02159+0638, WDS 07036+3941, WDS 08585+3548, WDS 10059+3412
159	**2006**	Andrade, New orbit for WDS 21287+7034; Docobo and Andrade, New orbit for WDS 00568+6022; Docobo and Ling, New orbit for WDS 17104-1544, WDS 22241-0450, and WDS 23382+5514; Docobo and Tamazian, New orbit for WDS 12417-0127; Ling, New orbit for WDS 05289-0318
160	**2006**	Andrade, New orbit for WDS 16198+2646; Docobo and Ling, New orbit for WDS 14138+ 3059 and WDS 20311+ 3333; Docobo and Tamazian, New orbit for WDS 00321+6715 Aa and WDS 17563+0259; Docobo, Tamazian, and Campo, WDS 00321+6715 Aa-B; Ling, New orbit for WDS 07546-0248
161	**2007**	Docobo, Andrade, and Campo, WDS 01409+1117; Docobo and Ling, New orbit for WDS 14138+3059 and WDS 20311+3333; Docobo and Tamazian, New orbit for WDS 16450 2928 and WDS 18044 0337; Ling, New orbit for WDS 23175+1652
162	**2007**	Docobo, Balega, and Tamazian, New orbit for WDS 08033+5251, WDS 22083+2409, and WDS 23334+4251; Docobo and Ling, New orbit for WDS 00596-0111, WDS 20151+3742, and WDS 23506-5142; Docobo and Tamazian New orbit for WDS 04258+1800; Ling, New orbit for WDS 00209+1059
163	**2007**	Docobo and Ling, New orbit for WDS 11363+2747, WDS 16044-1122, WDS 17575+1058, and WDS 21000+4004; Ling, New orbit for WDS 00366+5609
164	**2008**	Docobo and Ling, New orbit for WDS 05482+0137, WDS 08017-0836, and WDS 22302+2228; Docobo, Tamazian, and Melikian, New orbit for WDS 16171+5516; Ling, New orbit for WDS 23103+3229
165	**2008**	Docobo and Ling, New orbit for WDS 17366+4827 and WDS 18570+3254; Docobo and Tamazian, New orbit for WDS 05353-0523 and WDS 16171+5516; Ling, New orbit for WDS 08127+2613 and WDS 08456+8442
166	**2008**	Docobo and Ling, New orbit for WDS 03310+2937, WDS 10585+1711, WDS 15370+6426, and WDS 23529-0309; Docobo and Tamazian, New orbit for WDS 14189+5452, WDS 16230+3803, and WDS 19559+2500; Docobo, Tamazian, Kraus, and Weigelt, New orbit for WDS 05353-0523; Ling, New orbit for WDS 07374+3852
167	**2009**	Docobo and Ling, New orbit for WDS 15136+3453 and WDS 16283-1613; Docobo and Tamazian, New orbit for WDS 15513-0305 and WDS 16254+3727; Ling, New orbit for WDS 23072+6050

168	**2009**	Docobo and Ling, New orbit for WDS 01259-4754 and WDS 06573-3530; Docobo and Tamazian, New orbit for WDS 14459+2344 and WDS 20325-1637; Ling, New orbit for WDS 23175+1652
169	**2009**	Docobo and Ling, New orbit for WDS 16057-3252; Docobo and Tamazian, New orbit for WDS 14588+3551 and WDS 18363+2143; Ling, New orbit for WDS 01006+4719
170	**2010**	Docobo and Ling, New orbit for WDS 22455+1112; Docobo and Tamazian, New orbit for WDS 13482+2248, WDS 15347+2655, and WDS 17161+2316; Ling, New orbit for WDS 00149-3209
171	**2010**	Docobo, New orbit for WDS 04475+4324; Docobo and Andrade, New orbit for WDS 21158-5316 and WDS 21477-3054 (2); Docobo and Campo, New orbit for WDS 04132+2258; Docobo and Ling, New orbit for WDS 03310+2937, WDS 03423+3141, and WDS 21000+4004; Ling, New orbit for WDS 19083+2706 and WDS 19222-0735
172	**2010**	Docobo and Campo, New orbit for WDS 04395-4507 and WDS 19531-2528 (2); Docobo and Ling, New orbit for WDS 01158+0947 and WDS 01277+0521; Ling, New orbit for WDS WDS 20524+2008 and WDS 21051+0757
173	**2011**	Docobo and Ling, New orbit for WDS 04021-3429 and WDS 17075+3810; Docobo and Tamazian, New orbit for WDS 21395+3009; Ling, New orbit for WDS 03130+4417, WDS 04357+3944, and WDS 22202+2931; Docobo and Andrade, New orbit for WDS 02396-1152 and WDS 13320-6519
174	**2011**	Docobo and Campo, New orbit for WDS 21552-6153 and WDS 23586-1408; Docobo and Ling, New orbit for WDS 09207-0742, WDS 23409+2022; Docobo and Tamazian, New orbit for WDS 16341+4226; and Ling, New orbit for WDS 09273+0614 and WDS 15002+2129
175	**2011**	Docobo and Andrade, New orbit for WDS 16115+0943; Docobo and Campo, New orbit for WDS 16054-1948; Docobo and Ling, New orbit for WDS 15390+2545 and WDS 17115-1630; Docobo and Tamazian, New orbit for WDS 00095+1907; and Ling, New orbit for WDS 16229-1701
176	**2012**	Docobo and Andrade, New orbit for WDS 12064-6543, WDS 12446-5717, and WDS 21044-1951; Docobo and Campo, New orbit for WDS 04395-4507, WDS 09379+4554, and WDS 13539-1910; Docobo and Ling, New orbit for WDS 21593+4606, WDS 23307+1759, and WDS 23382+5514; Docobo and Tamazian, New orbit for WDS 23191-1328; and Ling, New orbit for WDS 02249+3039.

177	**2012**	Docobo and Andrade, New orbit for WDS 02396-1152, WDS 04515-3454, WDS 06253+0130, WDS 07003-2207, WDS 08291-4756, WDS 08345-3236, WDS 09173-6841, WDS 09442-2746, WDS 12064-6543, WDS 13117-2633, WDS 13320-6519, WDS 14373-4608, WDS 16057-0617, WDS 17221-7007, WDS 17542+1108, WDS 19035-6845, WDS 21158-5316, WDS 21477-3054, and WDS 21579-5500; Docobo and Campo, New orbit for WDS 00095+1907 and WDS 14165+3334; Docobo and Ling, New orbit for WDS 06393+4200, WDS 16384+3514, WDS 22077+2622, and WDS 23382+5514; Docobo and Tamazian, New orbit for WDS 16229+3803; and Ling, New orbit for WDS 17471+4737 and WDS 20157+4339
178	**2012**	Docobo and Andrade, New orbit for WDS 02396-1152, WDS 19035-6845, and WDS 20154+6412; Docobo and Campo, New orbit for WDS 02382+4604, WDS 04093-2025, and WDS 17591+3228; Docobo and Ling, New orbit for WDS 04163-6057, WDS 15457+5040, WDS 16057-3252, and WDS 19411+1349; and Ling, New orbit for WDS 15313-3349
179	**2013**	Docobo and Campo, New orbit for WDS 09100-2845, WDS 20599+4016 (I y II), and WDS 23078+6338; Docobo and Campo, New orbit for WDS 04263+3443, WDS 12409+2708, and WDS 12533+4246; Docobo and Tamazian, New orbit for WDS 08585+3548; and Ling, New orbit for WDS 09414+3857
180	**2013**	Docobo and Campo, New orbit for WDS 20527+4607, WDS 22493+1517, and WDS 23357-2729; Docobo and Ling, New orbit for WDS 10269+1931, WDS 15420+4203, and WDS 16584+3943; and Ling, New orbit for WDS 15041-0653
181	**2013**	Docobo and Andrade, New orbit for WDS 20374+7536 and WDS 21597+4907; Docobo and Campo, New orbit for WDS 13007+5622; Docobo, Campo, Horch, and Andrade, New orbit for WDS 19264+4928; Docobo, Campo, and Horch, New orbit for WDS 19027+4307; Docobo and Ling, New orbit for WDS 00126-1142, WDS 19089+3404, and WDS20151+3742
182	**2014**	Docobo, Al-wardat, and Campo, New orbit for WDS 13175-0041 (I y II; Docobo and Campo, New orbit for WDS 18434-5546; and Docobo and Ling, New orbit for WDS 00546+1911, WDS 00593-0040, and WDS 01497-1414
183	**2014**	Docobo and Campo, New orbit for WDS 12415-4858 and WDS 12597-0349; and Docobo and Ling, New orbit for WDS 06298-5014
184	**2014**	Docobo, Andrade, Campo, and Ling, New orbit for WDS 07346+3153; and Docobo and Campo, New orbit for WDS 02543+5246

185	**2015**	Docobo, Tamazian, Campo, Malkov, and Chulkov, New orbit for WDS 02366+1227, WDS 02434-6643, WDS 03244-1539, WDS 08507+1800, WDS 09128-6055, WDS 11532-1540, WDS 17375+2419, WDS 17375+2419, and WDS 22408-0333; and Docobo and Ling, New orbit for WDS 13535-3540 and WDS 17366+0723
186	**2015**	Docobo and Campo, New orbit for WDS 10373-4814 and WDS 13123-5955; and Docobo and Ling, New orbit for WDS 12429+0516
187	**2015**	Docobo and Campo, New orbit for WDS 12597-0349 and WDS 23357-2729; Docobo, Gómez, and Campo, New orbit for WDS 01500-0408, WDS 02514-2139, WDS 18434-5546, WDS 20002-5522, WDS 20081-3929, WDS 22007-5002, and WDS 22504-1744; Docobo and Ling, New orbit for WDS 09001-1228, WDS 11136+5525, and WDS 17506+0714; and Ling, New orbit for WDS 00028+0208
188	**2016**	Docobo and Campo, New orbit for WDS 05140+5126, WDS 06541+6052 (I y II), and WDS 22361+7253; Docobo, Gomez and Campo, WDS 01477-4358, WDS 02512+0141, WDS 03189-0101, WDS 04142-4608, WDS 06274-2544, and WDS 18434-5546; Docobo and Ling, New orbit for WDS 02257+6133, WDS 21000+4004, and WDS 22570+2441; and Ling, New orbit for WDS 09524+2659
189	**2016**	Docobo, Gómez, and Campo, New orbit for WDS 14262-4523 and WDS 15332-2429; and Ling, New orbit for WDS 18126-7340
190	**2016**	Docobo and Campo, New orbit for WDS 20203+3942, WDS 21439+2751, and WDS 22100+2308; Docobo, Campo, and Abushattal, New orbit for WDS 04107-0452; Docobo and Ling, New orbit for WDS 19069+4137 and WDS 21125+2821; and Ling, New orbit for WDS 03035-1059
191	**2017**	Docobo and Campo, New orbit for WDS 05373+6642 and WDS 12301-1324; Docobo, Tamazian, and Campo, New orbit for WDS 04295+2617; and Docobo and Ling, New orbit for WDS 02039+4220, WDS 08285-0231, and WDS 11363+2747
192	**2017**	Docobo and Campo, New orbit for WDS 15136+3453, WDS 15317+0053, WDS 18465-0058, WDS 19110-0726, and WDS 19549+5049; Docobo, Horch, and Campo, New orbit for WDS 19264+4928; Docobo, Tamazian, and Campo, New orbit for WDS 23191-1328; and Docobo and Ling, New orbit for WDS 01048+0135, WDS 16514+0113, WDS 22329+5348, WDS 23020+4800, and WDS 23199+2844

193	**2017**	Docobo and Andrade, New orbit for WDS 14369+4813; Docobo and Campo, New orbit for WDS 00469+4339, WDS 01072+3839, WDS 01337-1213, WDS 02318+8916, WDS 04195+3800, WDS 19496-5525, WDS 22485+3106, and WDS 23378+6601; Docobo, Campo, and Horch, New orbit for WDS 13133+1621 (I e II); and Docobo and Ling, New orbit for WDS 17533-3444 and WDS 19471-0809
194	**2018**	Docobo and Campo, New orbit for WDS 04506+1505; Docobo, Campo, Andrade, and Horch, New orbit for WDS 05465+7437; Docobo, Campo, and Gómez, New orbit for WDS 05272+1758, WDS 05525-0217, WDS 06073+2641, WDS 06255+2320, WDS 06502+3624, and WDS 13598-0333; Docobo and Ling, New orbit for WDS 03423+3141, WDS 14138+3059, and WDS 17584+0428; and Ling, New orbit for WDS 10544+3840
195	**2018**	Docobo, Gómez, Campo, Andrade, Horch, Costa, and Méndez, New orbit for WDS 06478+0020, WDS 07003-2207 (I e II), WDS 07013-0906 (I e II), WDS 10174-5354, WDS 12155-3106, WDS 12572+0818, WDS 13044-1316, WDS 14243-3838, WDS 16094-3103, WDS 17115-1630, WDS 17119-0151, WDS 17563+0259, WDS 18464-2755, and WDS 19035-6845
196	**2018**	Docobo, Balega, Campo, and Abushattal, New orbit for WDS 01108 6747; Docobo, Balega, and Campo, New orbit for WDS 02262 3428; and Docobo, Campo, and Abushattal, New orbit for WDS 14492 1013
197	**2019**	Docobo and Campo, New orbit for WDS 00447 4817, WDS 03095 4544, and WDS 09264-4215; Docobo, Campo, and Gomez, New orbit for WDS 09477 2036 and WDS 15521 1052; Docobo and Ling, New orbit for WDS 00310-1005, WDS 01023 0552, and WDS 04093-0756; and Ling, New orbit for WDS 01084-5515
198	**2019**	Docobo and Campo, New orbit for WDS 03494-1956, WDS 18280 0612, WDS 20205-2749, WDS 20267-4334, WDS 22134-3729, and WDS 22313-0633; and Docobo and Ling, New orbit for WDS 04590-1623
199	**2019**	Docobo and Campo, New orbit for WDS 04445+3953 and WDS 04478+5318; Docobo, Campo, and Gomez, New orbit for WDS 06426+3955; and Docobo and Ling, New orbit for WDS 16384+3514

2.3.2.4. The Catalog of Orbits and Ephemerides of Visual Double Stars (OARMAC)

The astronomers and scholars calculating the orbits of visual double and multiple stars are aware of the significance of existence a complete and up-to-date ephemeris catalog. Since the time of Father Aller, as mentioned, the study of double star orbits has been a high-level tradition at OARMA. In fact, J. Costa made the complete collection of the data cards containing the up-dated orbits that was maintained in the Observatory throughout the sixties, seventies, and the eighties. Prof. Docobo proposed the compilation of a new orbit and ephemerides catalog since 1993, again at the International Workshop on Double Stars and Celestial Mechanics that held in Santiago de Compostela in 1996 [251] .

The OARMAC (http://www.usc.es/astro/catalog.htm) is organized in the following manner. In the first line, the 2000.0 coordinates are listed of the Washington Double Star Catalog (WDS) number; the second line includes the Aitken Double Star Catalogue (ADS) number and the name of the star (if any). The third line shows the visual magnitudes and spectral type that figure in the WDS, the fourth line contain a letter (A, B or C) which indicates the system´s capacity to have a reliable orbit on the basis of OARMAC criteria; the Roman numeral II and III in order to distinguish if the system has two or three calculated. In the fifth line, represent a row of numbers from 0 through 10 and each number has indicated scientific diverse meaning. The Hipparcos Catalog number, the Hipparcos parallax, and the standard error listed in line six, as well on line seven provide the number of orbits for each star. In the eighth line, the orbital elements are placed in order: P, (n), T, e, a, i, Ω, **ω** as well as the name of the orbit´s author. On the ninth line, many letters may be listed (N, E, X, Y, and Z) for some important commentaries and interpretations. On the tenth line, the orbit´s bibliographic reference is given and the eleventh line gives the Ephemerides for the following years [186].

In 2001, Docobo published the first version of the OARMAC catalogue that initially contained 1,545 orbits of 1,208 systems. Coinciding with that, the first on-line version was released that initially included 1,545 orbits of 1,208 systems, authored by J. Docobo, J. Ling, J. Costa, M. Costado and P. Magdalena, with a brilliant preface written by P. Couteau. The OARMAC is generally updated once annually, and comprises 2225 orbits of 1817 systems [186].

2.3.2.5. Organization of National and International Conferences at OARMA

From 1983, Prof. Docobo promoted and organized the following Scientific Meetings.

1- The Fourth Scientific Meeting of Astronomy and Astrophysics/Santiago de Compostela, Galiza, Spain (1983).

The Fourth Scientific Meeting of Astronomy and Astrophysics was held at the University of Santiago de Compostela from 6th - 11th June 1983. The Local Organizing Committee (LOC) consisting of E. Garcia-Rodeja (Chairman, Dean of Faculty of Maths), J. A. Docobo, C. Pajares (Dean of Faculty of Physics), and J. M. Costa. This Scientific Meeting was sponsored by "Instituto Geografico Nacional" and the "Ramon Maria Aller Observatory". In fact, the Director of this Dissertation played a pivotal role and took care of all the logistics details to ensure a nice stay for all the participants and provided great effort in order to the organizational and scientific success of the meeting in Galicia. Moreover, this Scientific Meeting brought together 142 participants who presented their latest results in many diverse subjects in Astronomy and Astrophysics. Taking advantage this meeting, Prof. Docobo proposed that the Observatory was named Ramon Maria Aller Observatory in homage to his founder.

2- **INTERNATIONAL WORKSHOP Visual Double Stars: Formation, Dynamics and Evolutionary Tracks/ Santiago de Compostela, Galiza, Spain (1996).**

OARMA hosted and organized this International Workshop at USC, in 1996, coinciding with the Anniversary that celebrated 500 years since the establishment of the University [252]. The Scientific Organizing Committee was formed by Drs. C. Allen, P. Couteau, J. A. Docobo, R. Dvorak, A. Elipe, S. Ferraz-Mello (Co-Chairman), H.A.McAlister, M. Valtonen, C.Worley (Chairman) and H. Zinnecker. The Local Organizing Committee was formed by Drs. J. A. Docobo (Chairman), A. Elipe, J. F. Ling, C. Prieto, and V. Tamazian. This International Workshop was devoted to Double Stars and Celestial Mechanics, moreover, this was the first workshop jointly supported by IAU Commissions 7 (Celestial Mechanics) and 26 (Double and Multiple Stars). As a matter of fact, the most prominent researchers in Celestial Mechanics and Double Stars met in Santiago de Compostela in order to establish closer relationship, to exchange experience, and to execute and coordinate common research. Investigators of the two Commissions, worked together as members of the Scientific Committee.

Thanks to the role that Prof. Docobo played in the establishment of the collaboration agreements, throughout this International Workshop, the OARMA members be able to conduct a research stay visits as well as using the most sophisticated astronomical instrumentations and technologies. Docobo signed a cooperative agreement with the Director of the Special Astrophysical Observatory (SAO, Russia) at that time. Moreover, Docobo has established cooperation with to install an ICCD camera in the 1.52-m and the 3.5-m telescopes at the Centro Hispano-Aleman at Calar Alto. In fact, Docobo officially announced for the OARMA Visual Double Stars Catalogue in order to demonstrate his views in front of those most outstanding scholars in the fields of double and multiple stars. On the other hand, OARMA members have participated in diverse scientific articles such as Docobo [251]; Ling and Docobo [253]; Tamazian, Docobo, Chavushyan, Vlasyuk [254]; and Prieto and Docobo [255].

The proceedings were published by the Kluwer Academic Publishers (ASTROPHYSICS AND SPACE SCIENCE LIBRARY, Vol 223, 1997. ISBN 0-7923-4793-5. Total pages: 503. Eds: J. A. Docobo, A. Elipe and H. A. McAlister) [252]. (Figure 2-17 and 2-18).

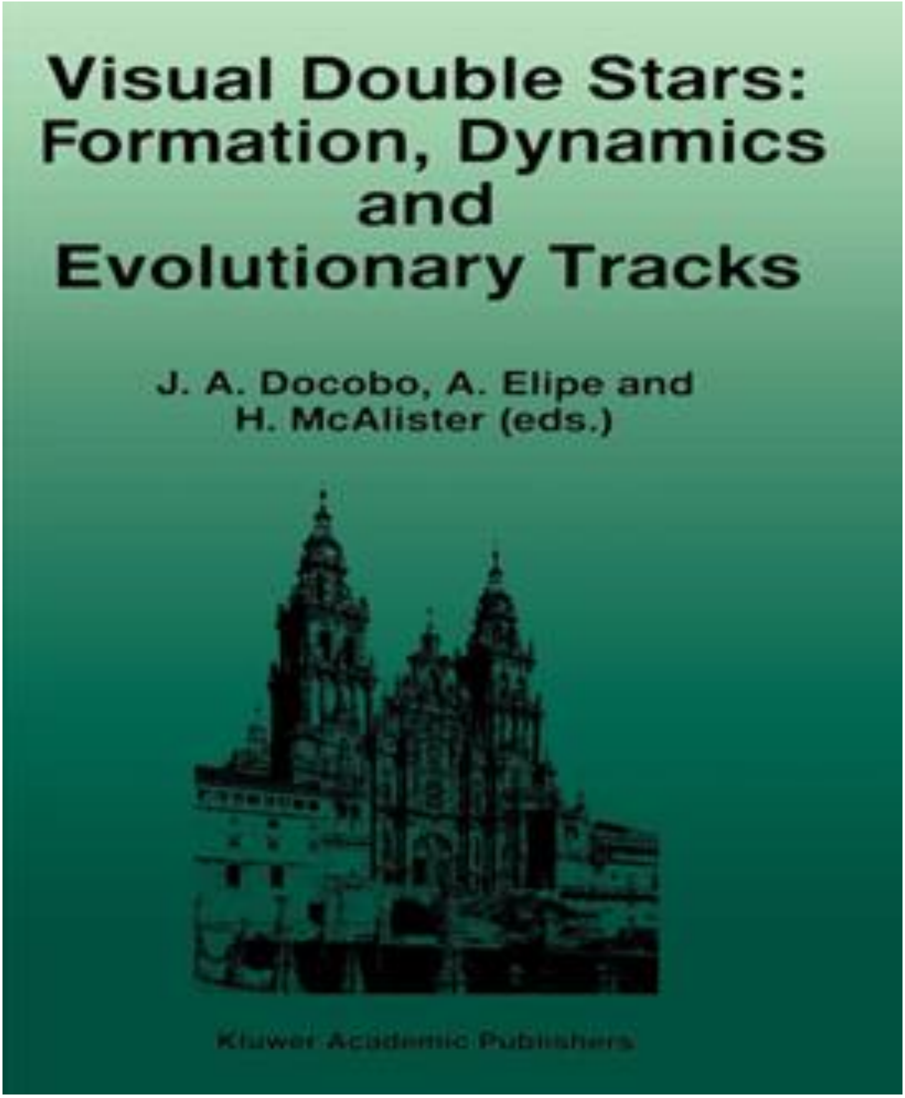


Figure 2-17 Proceedings of the 1996 International Workshop on Visual Double Stars: Formation, Dynamics, and Evolutionary Tracks (Credit: OARMA)

Figure 2-18   1996 Workshop Participants (Credit: OARMA)

3- The Fourth Scientific Meeting of the Spanish Astronomical Society (SEA)/ Santiago de Compostela, Galiza, Spain (2000).

The Fourth Scientific Meeting of the SEA took place at the University of Santiago de Compostela (USC) from 11 to 14 September 2000. The Scientific Organization Committee consisted of R. Dominguez (Chairman), X. Barcóns, J. A. Docobo, F. Moreno, and J. M. Rodríguez, as well as the Local Organization Committee including of J. A. Docobo (Chairman), J. Ling, V. Tamazian, C. Prieto, and M. Andrade. Thanks to the role played by the Local Organizing Committee in the organizational and scientific success of the meeting, they provided an all-embracing effort and took care of all the logistics details to ensure a pleasant accommodation for all the participants.

This event brought together 156 participants (Figure 2-19) who displayed their latest research on many different subjects in Astronomy and Astrophysics. As a matter of fact, this Meeting has gained more attention as compared with the previous scientific meetings of the Society, the numbers of oral presentations and poster contributions (95 and 51, respectively) are rapidly increasing. This Scientific Meeting confirmed and reinforced the importance of SEA conferences as a point of reference to assess the interests and achievements of astronomical and astrophysical research areas in Spain. During the meeting, Docobo´s research group presented their latest results in seven reports as follow: Docobo [256]; Docobo and Tamazian [257], [258]; Docobo, Tamazian, Balega, Blanco, and Maximov [107]; Docobo, Ling, Blanco, and Abelleira [259]; Tamazian, Docobo, Melikian, and Karapetian [260]; Andrade and Docobo [261]. Moreover, the proceedings were published and all of the scientific contributions of this event are available [262]. In addition, Prof. Docobo had invited H. McAlister as an invited speaker. During his time as a President of the IAU Commission 26, Prof. Docobo organized the following International Workshops in Santiago de Compostela.

Figure 2-19 Fourth Scientific Meeting of the Spanish Astronomical Society (SEA) Participants, Santiago de Compostela, Spain, 2000 (Credit: OARMA)

4- INTERNATIONAL WORKSHOP: Double and Multiple Stars: Dynamics, Physics, and Instrumentation/ Santiago de Compostela, Galiza, Spain (2009).

The Workshop (http://www.usc.es/astro/ds/ds.html) hosted at USC on 10-11 December 2009 and addressed different general topics including the dynamics, physics, and interventions relative to double and multiple stars as well as was the nature of exoplanets to the expected results of the Gaia Astronomical Satellite Mission [263]. The Scientific Committee: Y. Balega, J. Docobo (Chairman), B. Mason, D. Pourbaix, C. Scarfe, and V. Tamazian. Also, the Organizing Committee: M. Andrade, P. Campo, J. Docobo (Chairman), I. Fernández, J. F. Ling, and V. Tamazian (Secretary).

All these topics are within the framework of the IAU Commission 26 but scientists from other fields attended the Workshop as well. In addition, OARMA members have published in diverse scientific articles such as Docobo [218]; Docobo and Ling [228]; Tamazian, Docobo, Balega, Melikian, and Malogolovets [245]; Melikian, Tamazian, Docobo, .Karapetian, and Kostandyan [241]; and Melikian, Tamazian, Docobo, Karapetian, Kostandyan, and Samsonyan [197]. The proceedings were published by the AIP Series (AIP Conference Proceedings 1346. Ed. J. A. Docobo, V. S. Tamazian, Y. Y. Balega. ISBN 978-0-7354-0902-6. 2011) [264]. (Figure 2-20).

5- **INTERNATIONAL WORKSHOP: Binaries Inside and Outside the Local Interstellar Bubble/ Santiago de Compostela, Galiza, Spain (2011).**

This International Workshop (http://www.usc.es/congresos/iwb2011) addressed diverse topics related to double and multiple stars research as well as issues such as the age of the Local Interstellar Bubble to the future of the Washington Double Star Catalog [265]. All of these topics are within the framework of the IAU Commission 26. The Scientific Committee Y. Balega, J. Docobo (Chairman), B. Mason, V. Tamazian. The Organizing Committee: M. Andrade, P. Campo, J. Docobo (Chairman), I. Fernández, J. Ling, and V. Tamazian (Secretary). Also, OARMA staff published scientific papers in this Workshop such as Docobo, Andrade, and Campo) [223]; Docobo, Ling, and Campo [229]; and Melikian, Tamazian, Karapetian, and Samsonyan [246]. The proceedings were published by the AIP Series (AIP Conference Proceedings Volume 1346, 2011, Ed. J. A. Docobo, V. S. Tamazian, Y. Y. Balega). (Figure 2-21).

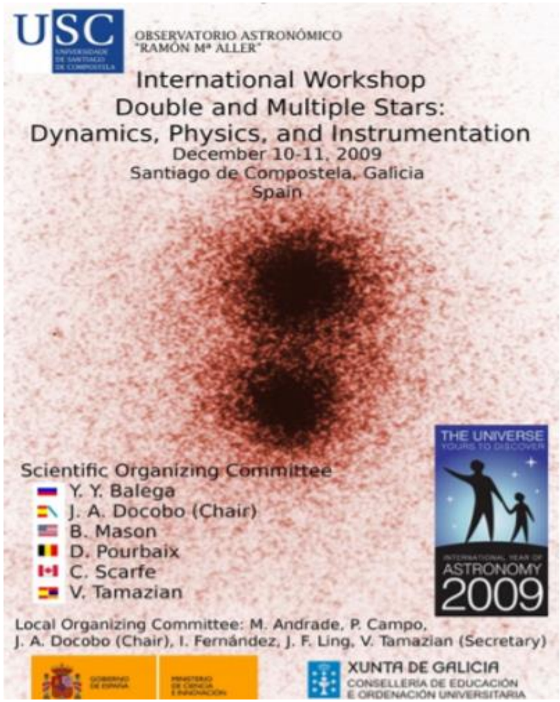


Figure 2-20 Left: the 2009 Workshop poster, Right: Participants Photograph of the 2009 Workshop (Credit: OARMA)

Figure 2-21 2011 Workshop Participants, from left to right and from top to bottom: J. González, M. Brea, P. Campo; V. Lanchares, O. Malkov; H. Abt, V. Tamazian, M. Andrade, B. Mason; J. Prieur, M. Scardia, J. A. Docobo, J. Ling, W. Hartkopf, N. Melikian, Y. Balega (Credit: OARMA)

6- Four Workshops on Celestial Mechanics (VIII, XII, XIV, and XVII Jornadas de Trabajo en Mecánica Celeste, JTMC).

The JTMC has been an initiative of the Group of Space Mechanics at the University of Zaragoza since 1998. The main objective of JTMC is to promote and improve personal contacts between researchers in Astrodynamics fields. OARMA hosted and organized four JTMC meetings.

A- VIII Workshop on Celestial Mechanics (VIII-JTMC)/ Rianxo, Galiza, Spain (2005)

The VIII-JTMC (http://www.usc.es/congresos/8jtmc/index.html) was hosted on 27-28 June 2005 in Rianxo, Galiza, Spain and organized the participation of the most outstanding researchers in Celestial

Mechanics (50 participants). The members of the Scientific Committee were J. Docobo (Coordinator), A. Elipe, V. Lanchares, M. Lara, J. Álvarez, P. Yanguas; and the Organizing Committee was formed by M. Andrade, J. Docobo (Coordinator), J. González, J. Ling, C. Prieto, A. Tamazian, and V. Tamazian. A number of research papers were presented by the members of OARMA such as Docobo and Andrade [266]; Prieto and Ling [267].

B- XII Workshop on Celestial Mechanics (XII-JTMC)/ Lalin, Galiza, Spain (2009)

The XII-JTMC (http://www.usc.es/congresos/12jtmc/index.html) was hosted on 1-3 July 2009 in Lalín, Galiza, Spain in the International Year of Astronomy. The Scientific Committee of the XII-JTMC consisted of J. Docobo, A. Elipe (Coordinator), M. Ollé, A. Pascual, J. Álvarez, and P. Yanguas; and the Organizing Committee was formed by M. Andrade, P. Campo, J. Docobo (Coordinator). Approximately 50 investigators in the fields of Astrophysics, Astrodynamics, Double and Multiple Stars as well as other divisions of Astronomy particpated. In addition, the OARMA members presented two scientific articles by Docobo [23]; Docobo and Andrade [268]. As well as several posters and oral presentations. In this meeting, Docobo announced the recuperation of the historical Observatory in Lalin where R. M. Aller initiated his astronomical research in Galicia. (Figure 3-22).

C- XIV Workshop on Celestial Mechanics (XIV-JTMC)/ Ribadeo, Galiza, Spain (2014)

The XIV-JTMC (http://www.usc.es/astro/14jtmc/14jtmc.html) was organized by OARMA and hosted in Ribadeo, Galiza, Spain, on 17-18 July 2014. Approximately 25 specialists in Celestial Mechanics and Double Stars met in Ribadeo. The XIV-JTMC Scientific Committee was formed by J. Docobo, A. Elipe (Coordinator), V. Lanchares, J. LLibre, M. Ollé, and P. Yanguas, as well as the Organizing Committee, consisted of J. Docobo (Coordinator), P. Campo, and M. Andrade. OARMA members presented three contributions ‘’An analytic algorithm to calculate the inclination, the ascending node, and the semimajor axis of spectroscopic binary stars using a single astrometric measurement and the parallax'' by Docobo, Campo, and Andrade; ''Stability and habitability of extrasolar planets in binary star systems'' by Campo and Docobo; and ''Analysing orbital stability in Castor'', Andrade and Docobo.

D- XVII Workshop on Celestial Mechanics (XVII-JTMC)/Santiago de Compostela, Galiza, Spain (2018).

The XVII-JTMC (http://www.usc.es/astro/17jtmc/) was organized and hosted in Santiago de Compostela, Galiza, Spain, on 25 - 27 June 2018, on the commemoration of the 75th anniversary of the establishment of the Observatory at USC. The members of the XVII-JTMC Scientific Committee were J. A. Docobo, M. Andrade, E. Barrabés, A. Elipe (Coordinator), E. Tresaco, and P. Yanguas, and the Organizing Committee, consisted of J. A. Docobo (Coordinator), M. Andrade, P. Pablo, J. Gómez, J. González, J. Ling, L. Piccotti, and V. Tamazian. Many scientific presentations were offered by OARMA staff as listed below: J. Docobo, ''75 years of the Ramón María Aller Astronomical Observatory''; L. Piccotti and J. Docobo, ''Gravitational waves of compact binary and triple objects''; J. Docobo, P. Campo , and V. Tamazian, ''An algorithm to separate combined spectra in close binary stars''; A. AAbushattal, J. Docobo, P. Campo, and M. Al-Wardat, ''What spectroscopic binaries can we resolve with a specific telescope?''; and C. Vázquez and J. Docobo, ''Photometric techniques for detecting exomoons''. (Figure 3-23).

In addition, since the JTMC inception in 1998, Prof. Docobo has participated effectively and continuously in all of the editions (only three people did it: Elipe, Docobo, and Lanchares) for example, in the VI-JTMC that was hosted by the University of Navarra in 2003, Docobo and Andrade presented ''A study of stability in triple star systems with loss of mass''. Moreover, in the VII- JTMC edition at the Royal Naval Institute and Observatory in 2004, Andrade and Docobo participated with ''On the restricted elliptic problem of three bodies with variable masses''. At the IX-JTMC hosted at Jaca (supported by the University of Zaragoza) in 2006, Docobo, Andrade, and Campo displayed ''A new version of Docobo´s method to determine orbits in double stars''. In 2007, a version the X-JTMC took place at the campus of the Autonomous University of Barcelona, Bellaterra, Spain; Andrade and Docobo presented ‘’Periastron Effect Enhancement by Kozai Resonance: the BU 1099 AB System’’. The XI-JTMC in Ezcaray (2008, supported by the University of La Rioja, Spain), Docobo and Andrade presented ‘’Long-term stability for the Bb planetary-like object in the triple stellar system, Gl 22’’. The University of Zaragoza hosted the XIII-JTMC in 2012. OARMA researchers offered these presentation: ‘’Some curious equations that appear in the teaching of the two-body problem’’ (Docobo), ‘’A Study of some four-body configurations in exoplanet scenarios’’ (Campo and Docobo), and (Andrade and Docobo)‘’ Accurate computation of stellar masses in double and multiple stars’’ .

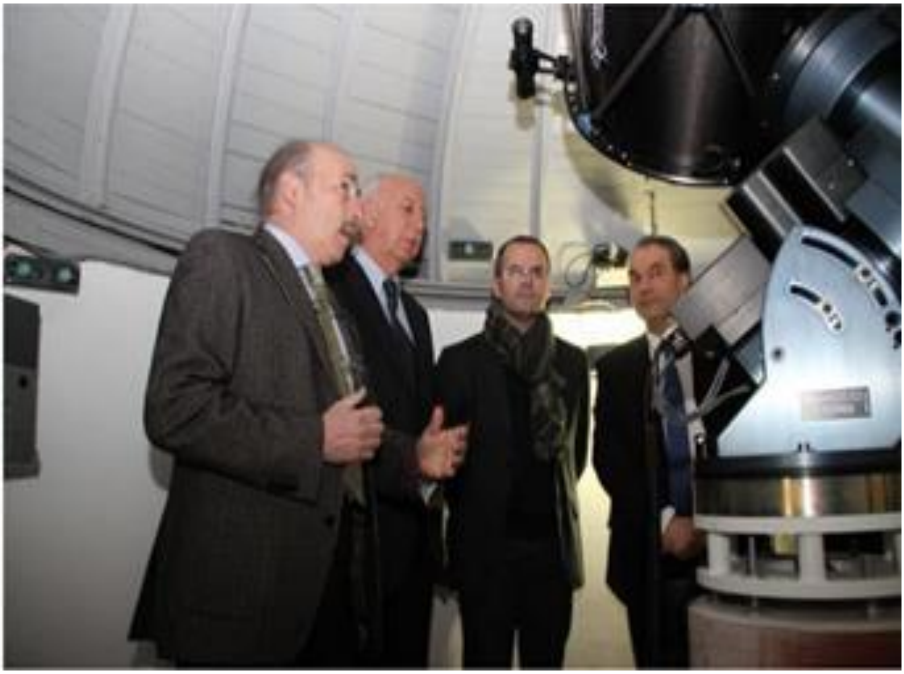


Figure 2-22 Prof. Docobo explaining the benefits of the new Lalín telescope to the Rector of the USC, Prof. Casares, to the Councilor for Education, D. Xesús Vázquez, and to the Mayor of Lalín, D. Xosé Crespo on the opening day (Credit: OARMA)

Figure 2-23 XVII Workshop Participants in front of the OARMA, June 2018 (Credit: OARMA)

2.3.2.6. Edition of the Astronomical Books by OARMA

Since the time of Professor Aller, the Observatory has edited and published books on Astronomy and other related sciences. Ramon Maria Aller had published four books: ALGORITMIA. Principios Fundamentales de la Ciencia de los Números (1918); Introducción a la Astronomía (1943); Astronomía a Simple Vista (1948); and Introducción a la Astronomía 2nd Edición (1957). Throughout the last four decades, the Observatory continued with the production of scientific books. The listed below presented the edition books that accomplished by OARMA since 1983.

1- Astronomía 280 problemas resueltos. J. A. Docobo and A. Elipe (1983).

2- Las publicaciones científicas del Dr. D. Ramón María Aller Ulloa. J. A. Docobo (1991).

3- Curso de astronomía. A. Abad, J. A. Docobo, and A. Elipe, Prensas de la Universidad de Zaragoza (2002). (Figure 2-24).

4- Curso de astronomía (2nd Edition, improved and extended). A. Abad, J. A. Docobo, and A. Elipe, Prensas de la Universidad de Zaragoza (2017), ISBN 978.84.16935.673.

5- A Long Night of Stars. J. A. Docobo (Scientific Director), 2004.

6- Early education about the Sky. Daytime and Night-Time Astronomy, the classrooms. J. A. Docobo, 2005.

7- Proceeding of the VIII Workshop on Celestial Mechanics. J. A. Docobo, A. Elipe, 2006.

8- A Bibliographic and Documental Exhibtion: The 50th Anniversary of the bachelor's degree in Mathematics at USC.

J. A. Docobo, I. Fernández. USC Faculity of Mathematics, 2007.

9- Stories about the Stars. L. González, J. A. Docobo (Scientific Director), 2008.

10- The 30 Most Important Constellations in our Sky (Trilingual edition). J. A. Docobo and M. Brea, 2010.

11- Aproximación histórica al desarrollo de la astronomía en España. I. Fernández. J. Docobo (Scientific Director), 2011.

12- Mathematics and Astronomy in Galicia. I. Fernández and J. A. Docobo, 2011.

13- Proceeding of the XII Workshop on Celestial Mechanics. J. A. Docobo, A. Elipe, R. Barrio, 2011.

14- International Workshop on Double and Multiple Stars: Dynamics, Physics and Instrumentation. J. A. Docobo, V. S. Tamazian, Y. Y. Balega, 2011.

15- International Workshop: Binaries Inside and Outside the Local Interstellar Bubble. J. A. Docobo, V. S. Tamazian, Y. Y. Balega, 2012.

16- Ramón María Aller Ulloa: Astrónomo e matemático. J. A. Docobo (In Galician language, 2014).

17- Ramón María Aller Ulloa: Astrónomo e matemático. J. A. Docobo (In Spanish, 2016) [310].

18- Astronomia A Ollo Ceibe. Ramon M. Aller (translation to Galician language of Astronomía a Simple Vista), J. A. Docobo, 2018, IBN 978.84.16533.60.2.

In the last decades, Prof. Docobo promoted the reedition of some books by R. M. Aller: Astronomía a Simple Vista (1998 and 2009), and ALGORITMIA (2018). Furthermore, in 1983 Prof. Garcia-Rodeja reedited Introducción a la Astronomía (hand written versión).

Figure 2-24 From left to right: A. Abad, A. Elipe, and J. A. Docobo, authors of the ´´Curso de Astronomía´´ Book. (Credit: OARMA)

2.3.2.7. Direction of Doctoral Dissertations at OARMA

Prof. J. A. Docobo has continually directed an important number of Master Theses and Doctoral Dissertations specifically related to binary and multiple star systems and exoplanets as well as the History of Science. To date, Docobo proposed and supervised nine Doctoral Dissertations (defended before 2020), seven of them were related to the study of binary and multiple stars. We list all of the Doctoral Dissertations below.

1- Study of the Multiple Star Systems [269], defended in 1984 by Alberto Abad Medina.
2- Application of the Stroboscopic Method to the Three Bodies Stellar Problem (Aplicación del método estroboscópico al problema estelar de tres cuerpos) [270], defended in 1989 by Josefina F. Ling Ling (co-director, A. Abad).
3- Analytical Solutions to the Two Body Problem with Slowly Decreasing Mass (Soluciones analíticas del problema de 2 cuerpos con masa lentamente decreciente) [271], defended in 1995 by Cristina Prieto Gómez.
4- The Gylden-Mescerskij Problem in Perturbed Scenarios. Methods and Applications (O problema de Gyldén-Mescerskij em cenários perturbados. Métodos e aplicações) [272], defended in 2007 by Manuel Andrade Baliño.
5- Historical Approximation of the Development of Astronomy in Spain (Aproximación histórica al desarrollo de la Astronomía en España) [273], defended in 2009 by Iván Fernández Pérez.
6- The Human Projection of Ramon María Aller Ulloa, his scientific legacy and the Museum House of Lalín (La proyección humana de D. Ramón María Aller Ulloa, su legado científico y la Casa Museo de Lalín) [31], defended in 2017 by Cecilia Doporto Regueira.
7- The Modeling of the Physical and Dynamical Properties of Spectroscopic Binaries with an Orbit [274], defended in 2017 by Ahmad Abushttal.

8- Double and Multiple Stellar Systems: Observational Techniques, Data Administration and Scientific Results [104], defended in 2019 by the author Jorge Gómez Crespo.
9- Dynamics of Exoplanets and Exosatellites in Binaries [275], defended in 2019 by Pedro Pablo Campo Díaz.

Currently, Docobo is the Director of the Doctoral Dissertations of Luca Piccotti, Ignacio Torralba Elipe, Iago Isasi Freire, Carlos Vázquez Monzón, and Maria Carmen Villanueva as well the author of this dissertation.

2.3.3. Docobo’s Method for Calculating Binary Star Orbits

Docobo's analytical method for calculating binary star orbits has proved to be a very useful and versatile application. In his famous and distinguished article, " On the Analytic Calculation of Visual Double Star Orbits" published in 1985 [37], J. A. Docobo announced a new algorithm that permits the determination of the visual orbit from three normal points. In fact, Docobo's mathematically developed method can be considered to be a natural approach to analytically determine the seven orbital elements (P, T, e, a, i, Ω, and ω) in a simple way.

Historically, there are two analytical methods that have been used to calculate the visual double star orbits, the Thiele-Innes-Van den Bos method [276], [277] and the Rafael Cid method [35]. The Thiele-Innes-Van den Bos method was the first used to calculate the elliptical orbit of a binary star based on three complete observations of the position angle, angular separation, and observing time (θ, ρ; t) together with the constant of the areas of the apparent orbit C which must be obtained from the rest of additional observation data [278]. In order to avoid calculating the constant of areas C, R. Cid proposed a method in 1958 in which only position angles and angular distances would intervene as data which is known as Cid's Method. Rafael Cid (a disciple of Father Ramon María Aller) presented an analytical method that only uses observational data which are the same as the previously mentioned from three complete observations (θ_i, ρ_i; t_i)$_{i=1,2,3}$ and an incomplete observation of the form (θ_4; t) [35].

In the publication of this method, Docobo commented: ‘’It is clear that progressively changing the value of C in the Thiele-Innes-Bos method or changing the fourth angle using Cid's Method produces a series of different orbits that all pass through the three points given, in other words, three observations defined a set of Keplerian orbits whose corresponding apparent orbits passes through those points (we will call this set, E), where each orbit is defined by its seven orbital elements, that is, (P, T, e, a, i, Ω, ω)’’. This is the idea of the method developed by Dr. J. A. Docobo. Thanks to the simplicity of Docobo's Method that established a simple logarithm that using the base points (θ_i, ρ_i; t_i)$_{i=1,2,3}$, permits the establishment of a mapping from the interval (0, 2π) to the set, E. If these base points belong to different revolutions, it is necessary to substitute the interval (0,2π) for (0, ∞). Taking into attention and obviously, the three base points must be observations with great weight, or they are "virtual" points belonging to areas with the maximum degree of observational evidence in their favor.

Therefore, one of the principal advantages of the Docobo Method is that is that it is not necessary to calculate the value of the constant of the area.

In the first version of Docobo´s Method [37], some control epochs were chosen in which with each orbit, Ephemerides were calculated that were contrasted with the observations in order to select finally the one that better fits with those presented. It is clear that the three base points and those corresponding to the control epochs are either observations of great weight or they pertain to areas with a high probability that the orbit will pass through them. Currently [38], the few continue epochs were replaced by the set of the observation epoch, therefore, with each orbit we calculated the residuals in θ and ρ and we obtained the r.m.s (Root Mean Square) in each of the coordinates. Looking for minimum r.m.s is a good criterium to select the orbit. The process not only introduces a leap of efficiency in what strictly refers to the adjustment of the orbit to points of quality but, at the same time, as by-products of the mentioned application for each orbit can be calculated the constant of the areas, C, and of course, the angle of position in a fourth epoch, θ_4. For this reason, we can say that this method includes simultaneously Thiele-Innes-Van den Bos and the Cid methods. With Docobo's, more than 300 orbits have been calculated by different astronomers in different countries during the last years and published in international journals and/or in the Information Circular of the Commission 26 (Double and Multiple Stars, recently G1) of the International Astronomical Union.

Prof. Docobo first programmed his method in FORTRAN. The facilities and versatility of Docobo's method encouraged Dr. P. Campo (researcher of the OARMA) also to program it in MATLAB since 2011. Docobo's Method is currently available in FORTRAN and MATLAB programming languages [279]. This powerful improvement provided many advantages in terms of simulation facilities, clarity, and high efficiency.

In 2018, Docobo, Tamazian, and Campo et al. demonstrated the usefulness of Docobo's Method in order to calculate the orbit of visual binaries with a very short arc. The calculus of the orbital parameters in accordance with the selection criteria is explained in detail. One of the chief advantages of this method is that it allows us to put certain constraints on the most likely orbital solutions, by using an available realistic estimate of the global mass of the system [238].

Another important result achieved by Docobo and his team [232] was to establish an algorithm that permits the determination of the 3D orbits of a spectroscopic binary (double-line or single-line) based on the spectroscopic orbit and a speckle measurement and the parallax.

The algorithm obtained in Doctoral Dissertation of A. Abushattal, proposed and directed by Prof. Docobo, is noteworthy. It obtained the most probable 3D orbit of a spectroscopic binary with the objective of optically resolving its components, suggesting the size of the necessary telescope in each case [279].

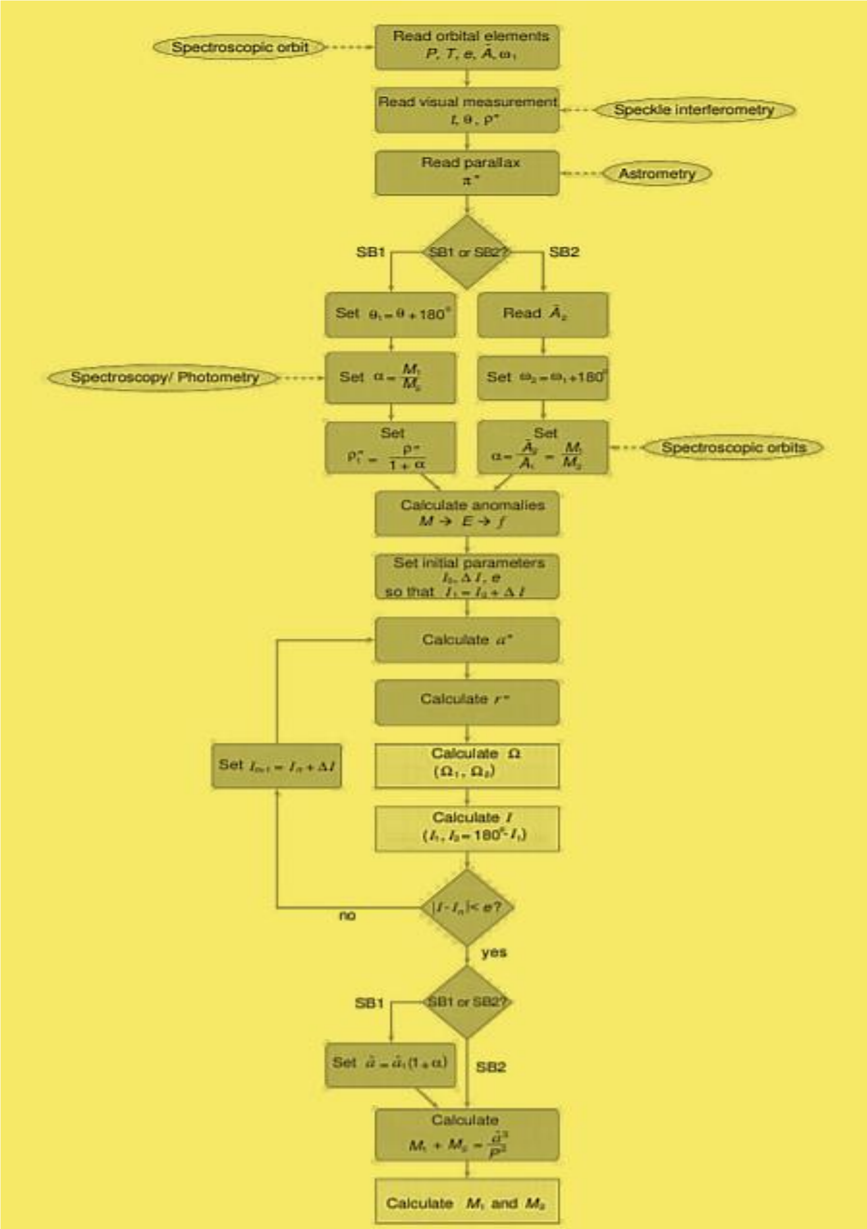


Fig. 3. Flowchart of the algorithm.

Figure 2-25 Flowchart of the method to obtain the 3D orbit of a spectroscopic binary using a speckle measurement and parallax (Credit: J. A. Docobo)

2.3.4. Al-Wardat's Method for determining Binary Star Parameters.

The study of binary stars plays a key role in determining many stellar parameters which is more complicated in the case of close visual binary stars (CVBS). Some of the physical and geometrical parameters can be estimated directly in the cases of eclipsing and spectroscopic binaries while there is no direct way to estimate the parameters of CVBSs [280]. Al-Wardat's method presents a solution to this problem by combining spectrophotometry with atmospheric modelling in an integrated solution. This results in accurately determining the effective temperature, radius, and luminosity for each component of the CVBS. In order to use Al-Wardat´s method to build synthetic spectral energy distributions, (SED), for each component of the binary stars system, and then combine them to calculate the entire SED of the system in order to compare it with the observational data [216], [281], [282]. Figure 3-26 shows the flowchart of Al-Wardat's Method for analyzing binaries where the upper panel describes the calculation of the input parameters for model atmospheres, while the lower one describes the computational procedures.

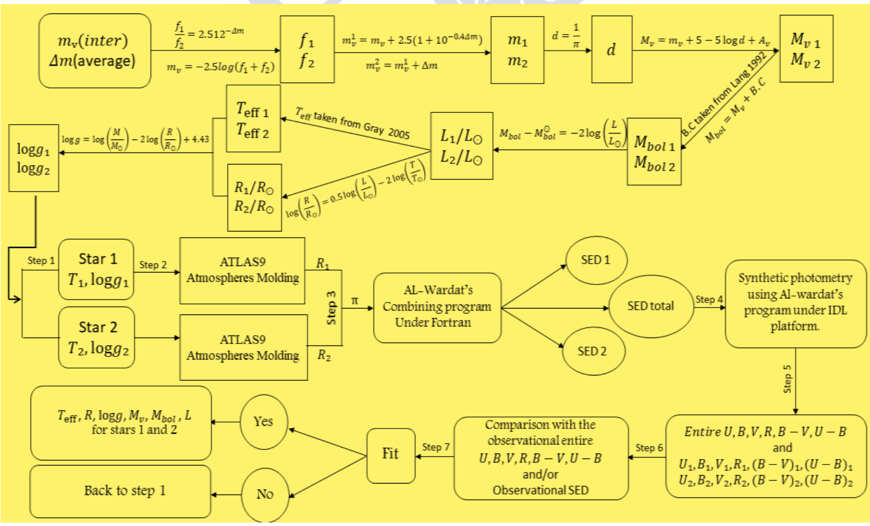


Figure 2-26 Flow chart of Al-Wardat's method for analyzing CVBS (Credit: M. Al-Wardat)

2.4. SCIENTIFIC AND PHILOSOPHICAL THOUGHT IN THE PHYSIACAL AND DYNAMICAL PARAMETRES OF THE DOUBLE AND MULTIPLE STELLAR SYSTEM

This section will be dedicated to the article, ‘’**Physical and Dynamical Parameters of the Triple Stellar System: HIP 109951’’**, developed within the frame of international collaboration with astronomers of several countries: S. G. Masda (Yamen), J. A. Docobo (Spain), A. M. Hussien (Jordan), M. K. Mardini (Jordan), H. A. Al-ameryeen (Jordan), P. P. Campo (Spain), A. R. Khan (India), and J. M. Pathon (India) and published in the Astrophysical Bulletin (Vol 74. No 4, pp.464-474, 2019). This research is an example of the importance of group teamwork, especially in a global science such as Astronomy. In this paper, we demonstrate the utility of Docobo's Method combined with Al-Wardat's Method in order to obtain the complete set of stellar parameters of the HIP 109951 multiple star system. In the context of this dissertation, it serves to show the scientific importance of the study of binary and multiple stars in order to enrich astronomical and philosophical thought about the origin and evolution of the Universe. On the other hand, this article contributes important information and knowledge concerning the physical and dynamical properties of double and multiple star systems within the research lines of Commission G1 of the International Astronomical Union which are those of the main research lines of the OARMA's members of the University of Santiago de Compostela.

In this study, the initial information for the HIP 109951 system was obtained from several astronomical sources which are distinguished by easy availability and high credibility. All of this information comes after hard work for many years by astronomers, astrophysicists, and software developers around the world. In our case, the information about the coordinates, parallaxes, magnitudes, spectral types, photometric data, radial velocities, proper motion, and the previous studies, each of them was obtained from various sources as:

1- The Astronomical Database SIMBAD (Set of Indications Measurements and Bibliography for Astronomical Data) is a database for millions of astronomical objects which include 1.500.000 stars; 450.000 galaxies; 100.000 planetary nebulae, 650.000 objects observed with different methods (X-ray, IR, Radio) [283]. It also contains a bibliography and identification for them. This resource is the result of collaboration among the Observatories de Paris, the Institut d'Astrophysique de Paris, and the de Bordeaux. The website (http://simbad.u-strasbg.fr/simbad/) provides easy access to the database and permits searching with an identifier, coordinates, and the physical criteria of each object.

2- The VizieR Database is an astronomical catalog published by the Centre de Données of Strasbourg which is another Big Data resource. The website is (http://vizier.u-strasbg.fr/index.gml) and it contains links to different catalogues and has been available since 1996. It is one of the data sources of the Astrophysical Virtual Observatory which is the European Virtual Observatory (EURO-VO), a huge database that contains data centers, scientists, developers of Astro-software, and astronomical data archives [284].

3- VizieR Online Data Catalog: Gaia DR2 (Gaia Collaboration, 2018).

The contents of Gaia DR2 is the five-parameter astrometric solution - positions on the sky (alpha,delta), parallaxes, and proper motions as well as for more than 1.3 billion sources, with a limiting magnitude of G=21 and a bright limit of G~=3 [285].

4- The 4th Catalog of Interferometric Measurements of Binary Stars (INT4; http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/int4). The INT4 catalog includes 104,618 published measures of binary and multiple star systems obtained by high-resolution techniques (Speckle Interferometry, photoelectric occultation timings, etc.) as well as 30,956 negative examinations for duplicity [286, p. 5].

5- The HIPPARCOS and the Tycho Catalogues were released in 1997, as a collaboration between the European Space Agency (ESA) and the FAST, NDAC, TDAC and INCA Consortia [287]. This version provided astrometric and photometric data for 1,058,332 stars comprising 1,052,031 stars observed by Tycho Catalog and supplemented by the 6,301 stars from the HIPPARCOS Catalog.

6- The NASA/IPAC Extragalactic Database (NED)

The NED (http://ned.ipac.caltech.edu) is a research tool in the form of a central archive that accumulates published data, is organized for fast, flexible retrieval, and is accessible to all astronomers [288]. This service was designed in response to an increasing need driven by ever-larger data sets collected in surveys, by the exponential growth in the volume of the technical literature, and by a greater tendency among astronomers to take a multi-spectral approach to the study of astrophysical problems. NED also includes images for over 773,000 extragalactic objects from 2MASS, from the literature, and from the Digitized Sky Survey.

In addition, HIP 109951 is a triple system formed by three components: A, Ba, and Bb. It was first discovered by the astrometrical satellite, HIPPARCOS. Later, Tokovinin [289] studied the radial velocities of the system and confirmed that the B component was binary. By means of this fact, the Ba and Bb components have different magnitudes and the pair can be considered to be a single-lined spectroscopic binary, SB1. For this reason, it is probable that the difference of magnitude between their components is equal to or greater than 1.5. Its parallax was recently published by the Gaia project as ϖ_{Gaia} = 15.1176 ± 0.5342 mas [289] . the former values of the parallax were those measured by HIPPARCOS, the first value $\varpi_{Hip} = 15.04 \pm 1.52\, mas$ and the revised HIPPARCOS measure $\varpi^{*}_{Hip} = 16.09 \pm 1.07\, mas$. This parallax values implicate a kinematic distance of 66.148 ± 0.002, 15.04 ± 1.52, and 62.15 ± 0.004 pc, respectively [290]. Speckle interferometry revealed a separation between the main component, A, and the Ba-Bb pair to be close to 0.4 arcsec and it yielded 17 relative position measurements after the first astrometric measurement by HIPPARCOS on 1991.25 (HIPPARCOS Catalog). The entire observational SED for the HIP 109951 system was taken from [291] (Figure 2-27). It was obtained using a low-resolution grating (325/4◦ grooves/mm, 5.97 A/px˚ reciprocal dispersion) within the UAGS spectrograph on the Zeiss-1000 telescope at the (SAO-Russia) and it covers the wavelength range from 3700 A° to 8000 A°.

In this research, the fundamental information for HIP 109951 was obtained from the SIMBAD database and is presented in Table 2-2 and Table 2-3 includes photometric data of the system from the NASA/IPAC, the HIPPARCOS and the Tycho Catalogs, and Stromgren. The magnitude differences (Δm) between the two main components of the visual system $(A,\ Ba + Bb)$ along with filters used in the observation expressed in nm as well as a reference for each measurement from the Fourth Catalog of Interferometric Measurements of Binary Stars (INT4, [292]) are given in Table 2-4.

Table 2-2 Fundamental data from SIMBAD for the HIP 109951 system

Property	HIP 109951 (HD 211276)	Source of data
$(\alpha)^3{}_{2000}$	$22^h\ 16^m\ 06^s.565$	SIMBAD
$\delta^4{}_{2000}$	$-07^\circ 05' 26''.62$	-
SAO	145984	-
Sp. Typ.	G5	-
$E(B-V)$	0.061 ± 0.002	NASA/IPAC[5]
$E(B-V)$	0.052 ± 0.002	NASA/IPAC[6]
A_V	0.19 ± 0.002	NASA/IPAC[3]
A_V	0.16 ± 0.002	NASA/IPAC[4]

[3] Right Ascension
[4] Declination
[5] [293]
[6] [294]

Table 2-3 Photometric data of the system, HIP 109951, from the HIPPARCOS and the Tycho Catalogs, including BT and VT Tycho-magnitudes, Stromgren photometry, and trigonometric HIPPARCOS and Gaia parallaxes

Property	HIP 109951 (HD 211276)	Source of data
$V_J(Hip)$	8.72	[287]
B_J	9.43 ± 0.03	[295]
$(V-I)_J$	0.76 ± 0.00	[287]
$(B-V)_J$	0.71 ± 0.002	[287]
B_T	9.58 ± 0.03	[295]
V_T	8.82 ± 0.02	[295]
$(u-v)_s$	0.96 ± 0.003	[296]
$(v-b)_s$	0.68 ± 0.003	[296]
$(b-y)_s$	0.44 ± 0.003	[296]
First ϖ_{Hip}(mas)	15.04 ± 1.52	[287]
Second ϖ_{Hip}(mas)	16.09 ± 1.07	[290]
ϖ_{Gaia} (mas)	15.12 ± 0.534	[285]

Table 2-4 Magnitude difference between the components of the HIP 109951 system and available errors, along with filters used to obtain the observations

Component vector	Δm (magnitude)	$\sigma_{\Delta m}$	Filter ($\lambda/\Delta\lambda$) nm	Reference
A–B	1.83	0.87	V_{Hip} : 550/40	[287]
	1.92	0.04	545/30	[297]
	1.87	0.04	545/30	[298]
	1.70	0.13	648/41	[299]
	1.88	0.08	545/30	[300]
	1.53	*	754/44	[301]
	1.88	0.03	545/30	[302]
	1.81	*	698/39	[301]
	1.70	*	698/39	[301]
	1.44	*	754/44	[303]
	1.94	*	550/40	[303]
	1.86	0.10	550/40	[304]
	1.76	0.10	550/40	[304]
	2.00	*	551/22	[305]
Ba – Bb	≥ 1.50			

***The errors are not given in INT4. In this Table, B represents the binary ($Ba - Bb$).**

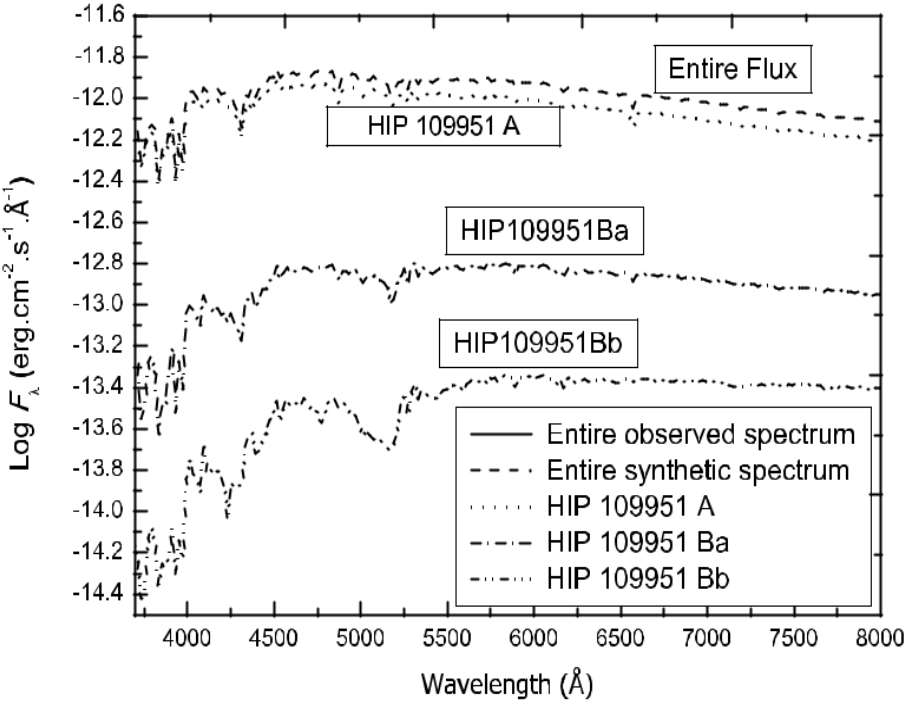


Figure 2-27 The observed SED of the HIP 109951 close triple system compared with the synthetic SED using the Kurucz blanketed models [306]. The observed SED is shown with a black solid line

2.4.1. Orbit and Orbital Parameters of the HIP 109951 System

The orbital solution plays a vital role in calculating stellar masses. This solution involves P: period in years; T: periastron time in years, e: eccentricity; a: semi-major axis in arcsec; i: angle of inclination in degree; Ω: longitude of the ascending node in degree; and ω: longitude of the periapsis in degree. The first orbit of the A-Ba, Bb system with a period of 134 yr and a semi-major axis of 0.567 arcsec was computed by Horch et al. [303] using the code published in [307] which led, together with the first HIPPARCOS parallax of 15.04 ± 1.52 mas [287], to a mass sum of 2.98 ± 0.91$M_\odot$. The orbit was then modified in [308] and [309] by a completely different method. Their estimated masssums were 2.18 ± 0.44 M and 3.35 ± 6.52 $M_{\odot}$, with periods of 80.57 and 44 years, respectively. The former orbit of the system was calculated by Tokovinin [289] using high-resolution radial velocities and speckle measurements. He calculted a mass sum of 2.58 M using a visual orbit with a period of 50.49 years and the Gaia parallax [287].

In order to improve the orbital solution, we have used Docobo's analytic method [37], [38], [231], [238]. Docobo presented an algorithm that is easy to program and constitutes a friendly process not only for calculating but also for the previous study of periodic solution. Furthermore, this method permits us to obtain the following outputs: 1- Dynamical parallax; 2- Total system mass; 3- The double areal constant of the apparent orbit; 4- Three-dimensional orbit with additional RV measurements; and 5- Position angle in the fourth epoch. It is well known that this method is based on the selection of three base points and, with them, the family of relative orbits with corresponding apparent orbits that pass through the base points is generated. Solution selection can be based on different criteria although the most commonly used procedure is to calculate the root mean squares (RMS) of the residuals in the position angles and the separations. Necessary, the weights of the observations must be taken into account. Docobo´s method is also useful for determining the exterior orbit of the triple system once the interior is known. J.A Docobo and M. Andrade published powerful formulas to calculate the mass and determine the spectral type of each component of multiple stellar systems in 2006 [126].

Tables 2-5 and 2-6 contain information about the Speckle observation and the residuals in θ and ρ obtained with the new calculated orbit, (the best orbital elements), and the RMS, respectively. In Table 2-5, Columns 1, 2, and 3 show the epochs and the relative position measurements taken from the INT4. The residuals, Δθ and Δρ, obtained with the orbit presented in this paper, are listed in Columns 4 and 5. Column 6 contains the reference numbers. At the bottom, the *rms* in θ and ρ are included. Besides, orbits, total masses, and quality controls published for the HIP 109951 system, compared with the orbital solution calculated in this work were listed in Table 2-6. The apparent orbit of the visual binary, A-Ba, Bb, is shown in Figure 2-28. The relative orbit was calculated with Docobo's method using measurements from the INT4 [292]. As usual, the origin point represents the position of the primary component and the dashes indicate the line of the nodes. The red star represents the first HIPPARCOS measurement.

Table 2-5 Position measurements and residuals

Epoch	θ, degree	ρ, arcsec.	$\Delta\theta$, degree	$\Delta\rho$, arcsec	Reference
1991.25	333.0	0.180	0.0	0.024	[287]
1999.8152	70.50	0.297	0.8	0.002	[298]
2000.7672	73.5	0.309	-1.4	-0.001	[312]
2000.7672	76.0	0.311	0.6	0.000	[300]
2003.6368	87.4	0.344	-0.6	-0.002	[301]
2004.8152	92.5	0.357	-0.1	-0.002	[302]
2006.5173	98.6	0.374	-0.3	0.000	[301]
2006.5174	97.7	0.366	-1.2	-0.008	[301]
2007.8171	103.7	0.383	0.3	0.000	[302]
2007.8199	103.9	0.391	0.5	0.008	[302]
2008.4723	105.7	0.390	0.2	0.003	[304]
2008.7018	107.1	0.390	0.8	0.002	[304]
2008.7670	105.8	0.389	-0.7	0.000	[313]
2008.76.70	105.7	0.390	-0.8	0.001	[313]
2009.7553	108.6	0.399	-1.1	0.005	[305]
2013.5537	121.2	0.407	-0.2	0.004	[309]
2014.7629	125.0	0.403	-01	0.000	[314]
2016.961	131.9	0.397	0.1	-0.002	[289]
r.m.s			0.686	0.004	

Table 2-6 Orbits, total masses, and quality controls published for the HIP 109951 system, compared with the orbital solution calculated in this work

Parameters	[303]	[308]	[309]	[289]	This work
P, yr	134 ± 1.4	80.574 ± 1.145	44 ± 24	50.49 ± *4.32*	50.090 ± 2.000
T_0 , yr	212.0±*1.3*	1991.763±*1.339*	1989.0±*5.30*	1989.88±*0.16*	2040.38 ± *2.000*
E	0.580±*0.0014*	0.450± *0.008*	0.55±*0.59*	0.451±*0.044*	0.449 ± *0.008*
a, arcsec	0.567±*0.007*	0.389±*0.0042*	0.30± *0.16*	0.2834±*0.020*	0.282 ± *0.008*
i, degree	45.3 ± *2.2*	36.0±*0.50*	36.0±*101.0*	17.7 ± *13.6*	15.1 ± *5.5*
Ω, degree	248.7±*1.2*	71.8±*1.2*	160.0±*62*	262.0± *3.0*	267.6 ±*10.0*
ω, degree	119.5±*3.6*	273.9±*1.2*	126.0±*104*	45.2 ± *96*	39.2 ± *15.2*
rms (θ), degree	0.780	1.034	-	0.711	0.686
rms (ρ), arcsec	0.009	0.006	-	0.005	0.004

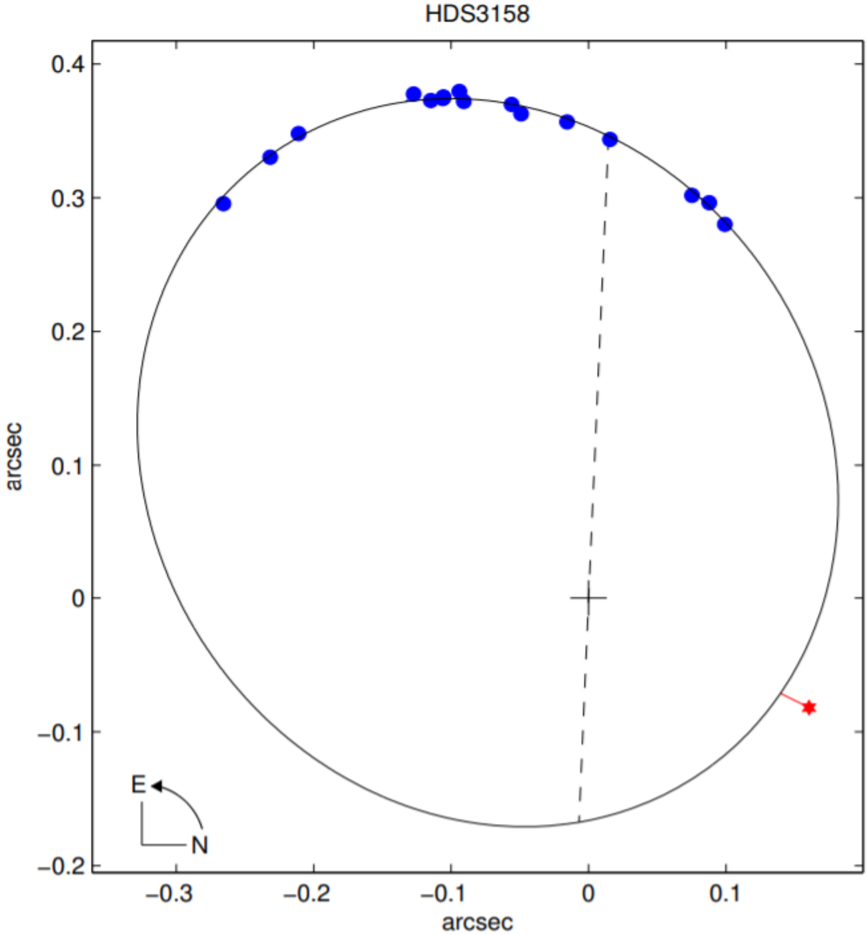


Figure 2-28 The apparent orbit of the center of light of ***Ba****,* ***Bb*** *subsystem around the primary,* ***A.*** *The relative orbit was calculated with Docobo's Method using measurements from the INT4. As usual, the origin point represents the position of the primary component and the dashes indicate the line of the nodes. The red star represents the first HIPPARCOS measurement.*

2.4.2. Physical Parameters of the System HIP 109951

In order to derive the physical parameters of this stellar system, we have employed Al-Wardat´s complex method [280], [315–318]. It is well known this method is based on build Synthetic Spectral Energy Distribution (SED) for each component of the stellar system compared with the observed one.

2.4.2.1. Masses

It is possible to determine the present and the future of a star from its mass. As a result, the calculated orbital parameters from Docobo´s method can be employed with the latest Gaia parallax and the revised HIPPARCOS parallax (second HIPPARCUS parallax) to calculate the total mass (M_{tot}) of the system (in solar masses) using Kepler’s Third Law as follows:

$$M_{tot} = \left(\frac{a^3}{\varpi^3 P^2}\right) M_\odot \qquad (1)$$

$$\frac{\sigma_M}{M} = \sqrt{9\left(\frac{\sigma_\pi}{\pi}\right)^2 + 9\left(\frac{\sigma_a}{a}\right)^2 + 4\left(\frac{\sigma_P}{P}\right)^2} \qquad (2)$$

The obtained results are 2.59 ± 0.40$M_\odot$, and 2.15 ± 0.35$M_\odot$, respectively, which will subsequently be compared with the derived masses from the positions of the components on the HR diagram (Figure 2-29) as defined by their physical parameters using Al-Wardat’s complex method.

2.4.2.2. Atmospheric Modeling

Model atmospheres are numerical models that attempt to correctly estimate the structure of the outer regions of stars. Since the knowledge of the physical structure of atmospheres is critical for calculating precise theoretical spectra, the field of stellar atmospheres is significant for better understanding stars. Such theoretical spectra serve as a vital link between theory and observational stellar Astronomy.

We begin estimating the physical properties which involve two parameters: the magnitude difference (Δm) between the components and the entire visual magnitude, m_v . The value of Δm is taken from speckle interferometric observations while the second parameter is taken from photometric data [287].

First, we analyze the system as a binary , $(A - B)$, following the Al-Wardat method using $\Delta m_{A,B} = 1.88$ as the average value for the complete list of Δm measurements corresponding to the 545–551 nm V -band filters (Table 2-4). Because the Ba, Bb system is considered to be SB1, it is reasonable to admit that $\Delta m_{Ba,Bb} \geq$ 1.5. We will take the real value of 1″.5 magnitude difference between the components of the Ba-Bb system. Combining each of the magnitude differences with the entire visual magnitude, m_v, in the Johnson V -band filter (Table 2-3) and then with the parallax allowed us to calculate the apparent and absolute magnitudes of the individual components (m_v^* and M_V^*) using the following simple relationships:

$$m_v^A = m_v + 2.5(1 + 10^{-0.4\Delta m}) \quad (3)$$

$$m_v^B = m_v^A + \Delta m \quad (4)$$

$$M_v - m_v = 5 - 5\log d - A_v \quad (5)$$

which yield: $m_v^A = 8^m.90 \pm 0.05$ and $m_v^B = 10^m.78$ for the primary and secondary components of the system. Here, we adopt the entire visual magnitude of the Ba-Bb system is the visual apparent magnitude of the component B, so $m_{Ba,Bb}$ is equal to $10^m.78$. Using $m_v^{Ba} = m_v^B + 2.5(1 + 10^{-0.4\times1.5})$, the apparent magnitude of the (Ba – Bb) can be separated as follows: $m_v^{Ba} = 11^m.02$ and $m_v^{Bb} = 12^m.52$ for the primary and secondary of the sub-binary components, respectively. On the other hand, regarding the absolute magnitude, we have $M_V^A = 4^m.61 \pm 0.09$

and M_V^{Ba}= 6^m. 73 ± 0.07 for the primary of the sub-binary components of the triple system, respectively. We adopted the recently published interstellar absorption for HIP 109951 as A_v= 0.19 [319] and the distance of the system was estimated using d = $^1/_\varpi$ where ϖ is expressed in arcsec, while the error of distance was estimated using σ_d= σ_ϖ/ϖ^2.

As for the errors in equations (3), (4), and (5), they were calculated using the following equations, respectively:

$$\sigma_{m_v^A} = \pm\sqrt{\sigma^2_{m_v} + \sigma^2_{\Delta m}\left(\frac{10^{-0.4\Delta m}}{1+10^{-0.4\Delta m}}\right)^2} \quad (6)$$

$$\sigma_{m_v^A} = \pm\sqrt{\sigma^2_{m_v^A} + \sigma^2_{\Delta m}} \quad (7)$$

and

$$\sigma_{M_V^*} = \sqrt{\sigma^2_{m_v^*} + \left(\frac{5\log e}{\varpi_{Gaia}}\right)^2 \sigma^2_{\varpi_{Gaia}}} \quad (8)$$

Since the value of the error of visual magnitude, (σ_{m_v}), was extremely small and not given in the photometric data in Table 2, it can be ignored in equation (6). Starting from the estimated absolute magnitudes of the individual components of the system, and using the relation of absolute magnitude-effective temperature $[M_V - T_{eff}]$, mass-luminosity $[M - L]$, spectral type absolute magnitude $[S_P - M_V]$ [320], [321] and theoretical equations of the main stars:

$$\log\left(^R/_{R_\odot}\right) = 0.5\ \log\left(^L/_{L_\odot}\right) - 2\ \log\left(^{T_{eff}}/_{T_\odot}\right) \quad (9)$$

$$\log g = \log\left(^M/_{M_\odot}\right) - 2\log\left(^R/_{R_\odot}\right) + 4.43 \quad (10)$$

We obtain the preliminary stellar parameters, as follows: $T_{eff}^{A} = 5840\,K$, $\log g^{A} = 4.38$, $R^{A} = 1.16\,R_{\odot}$ for the primary component of the system and : $T_{eff}^{Ba} = 5015\,K$, $\log g^{Ba} = 4.52$, $R^{Ba} = 0.71R_{\odot}$ for the primary component of the sub-binary system and : $T_{eff}^{Bb} = 4340\,K$, $\log g^{Bb} = 4.64$, $R^{Bb} = 0.59R_{\odot}$ for the secondary component of the sub-binary system. Here, the effective temperature of the Sun was taken as 5777 k and its bolometric absolute magnitude as $4.^{m}75$.

For the sake of analyzing and estimating the physical and geometrical parameters of HIP 109951, we used Al-Wardat's complex method which employs Kurucz Atlas9 line-blanketed grid models [306] to construct individual SEDs and a special subroutine to calculate the entire synthetic SED in order to compare it with the observational one in an iterated manner to obtain the best fit between them.

The entire synthetic SED of the system which is related to the energy flux of the components located at a distance d (pc) from the Earth according to the following equation is:

$$F_{\lambda}^{A-B}.d^{2} = H_{\lambda}^{2}.R_{A}^{2} + H_{\lambda}^{b}.R_{B}^{2} \tag{11}$$

where

$$H_{\lambda}^{b}.R_{B}^{2} = H_{\lambda}^{Ba}R_{Ba}^{2} + H_{\lambda}^{B}R_{B}^{2} \tag{12}$$

As a result, equation 11 can be written as

$$F_{\lambda} = \left({}^{1}/_{d}\right)^{2}\left(H_{\lambda}^{A}R_{A}^{2} + H_{\lambda}^{Ba}R_{Ba}^{2} + H_{\lambda}^{Bb}R_{Bb}^{2}\right) \tag{13}$$

where R_A, R_B, and R_{Bb} are the radii of the components in solar units, H_{λ}^{A} ,H_{λ}^{Ba} , *and* $H_{\lambda}^{Bb}$are the flux for the entire SED of the system at the surface of the Earth in units of ergs cm-2 s-1Å-1.

Several tests have been performed on the calculated physical and dynamical parameters. First of all, we compared the entire synthetic SED of the system with the observational spectrum, then we compared the entire synthetic color indices and magnitudes of the system, particularly $(B-V)_J$, V_J, and the magnitude difference, Δm, with the entire observed photometry of the system. Following all of the steps of the fitting and the iteration method of different sets of parameters as well as the best fit between the color indices of the observed and theoretical synthetic spectra, we obtained the best agreement between the synthetic and observed spectra on the Gaia parallax [285] utilizing the following parameters (Figure 3-30): $T_{eff}^{A} = 5836 \pm 80\,k$, $T_{eff}^{Ba} = 5115 \pm 80\,k$, $T_{eff}^{Bb} = 4500 \pm 80\,k$, $\log g_A = 4.45 \pm 0.05$, $\log g_{Ba} = 4.60 \pm 0.06$, $\log g_{Bb} = 4.65 \pm 0.06$, $R_A = 1.159 \pm 0.039 R_{\odot}$, $R_{Ba} = 0.634 \pm 0.05 R_{\odot}, and$, $R_{Bb} = 0.521 \pm 0.06 R_{\odot}$.

On the other hand, we obtained the best agreement between the synthetic and observed spectra based on the revised HIPPARCOS parallax [290] utilizing the same stellar parameters excluding the radii of three components which were as follows (Figure 2- 27): $R_A = 1.090 \pm 0.039 R_{\odot}$, $R_{Ba} = 0.596 \pm 0.05 R_{\odot}, and$, $R_{Bb} = 0.490 \pm 0.06 R_{\odot}$.

There are two solutions for the close visual triple system, one using the Gaia parallax and the other using the revised HIPPARCOS parallax. But, as a result of the mixed point spread function (PSF) of two components, the Gaia parallaxes of bright stars (especially close binaries) may be significantly distorted by systematic errors and the high accuracy of the Gaia parallax is not final proof of the adequacy of this value of parallax for this star . That is why, the solution using the revised HIPPARCOS parallax [290] is better for representing the best physical and dynamical parameters for the HIP 109951 triple system, taking into account the errors of the observed spectrum and magnitudes.

Using the aforementioned parameters of the triple system, we obtain the stellar luminosities of the components: $L_A = 1.24 \pm 0.091 L_{\odot}$, $L_{Ba} = 0.22 \pm 0.09 L_{\odot}$, and $L_{Bb} = 0.090 \pm 0.05 L_{\odot}$. The individual bolometric magnitudes are: $M_{bol}^{A} = 4.52 \pm 0.08\, mag$, $M_{bol}^{Ba} = 6.39 \pm 0.08\, mag$, and $M_{bol}^{Bb} = 7.36 \pm 0.05\, mag$.

Based on the calculated physical and dynamical parameters, specifically the effective temperatures (T_{eff}) and the stellar luminosities (L), we estimated the masses using the theoretical evolutionary tracks method with the location of the components on the H-R diagram (Figure 26) as follows: $M^{A} = 1.05 \pm 0.16\, M_{\odot}$, $M^{Ba} = 0.83 \pm 0.09\, M_{\odot}$, and $M^{Bb} = 0.67 \pm 0.04\, M_{\odot}$. This result allowed us to propose the new spectral types of the triple system as follow: $S_p^{A} \approx G1.5, S_p^{Ba} \approx K1.5$, and $S_p^{Bb} \approx K7$. The total mass of the system was estimated using Al-Wardat's method to be $2.55 M_{\odot}$, coinciding to a large extent with those given by Docobo's analytical method as $2.59 M_{\odot}$ using the Gaia parallax.

To estimate the metallicity and ages for HIP 109951, one should use the synthetic isochrones tracks as a function of metallicity and age given by [322] when T_{eff} and the luminosity of the binary system are known. The initial chemical compositions of all phases of $[Z = 0.0004 , Y = 0.23]$, $[Z = 0.001 , Y = 0.23]$, $[Z = 0.004 , Y = 0.24]$, $[Z = 0.008 , Y = 0.25]$, $[Z = 0.019 , Y = 0.273]$ $(solar\ solution)$, and $[Z = 0.03 , Y = 0.30]$ from the zero-age main sequence star to the first phase of carbo burning. One can see that the metallicity of the system is subject to the position of the system's components on the synthetic isochrones tracks. As a result, the metallicity for HIP 109951 is $Z = 0.008$ as in (Figure 2-30) and the helium of the system is $Y = 0.25$, while the system age on the synthetic isochrones tracks as a function of age is between 8.9 ang 13 Gyr.

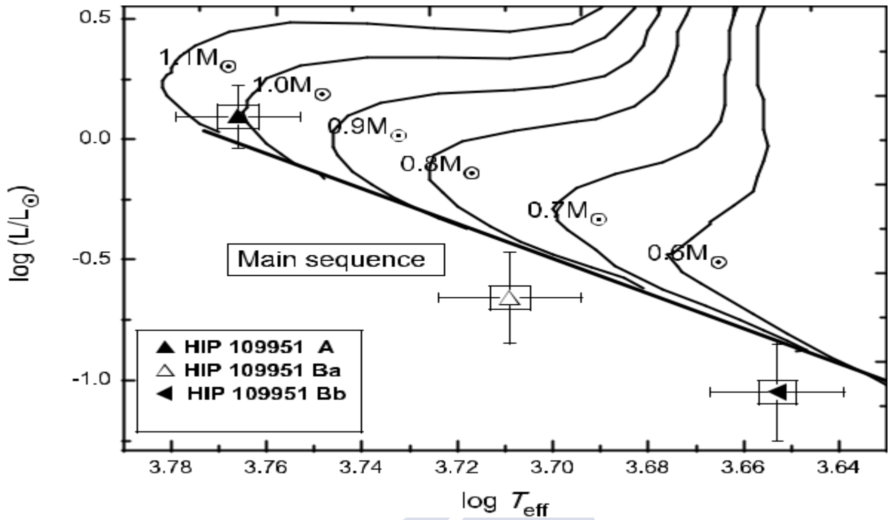


Figure 2-29 The Evolutionary tracks of the components of HIP 109951 on the H-R diagram of masses (0.6, 0.8, ..., 〖1.1M〗_Θ).

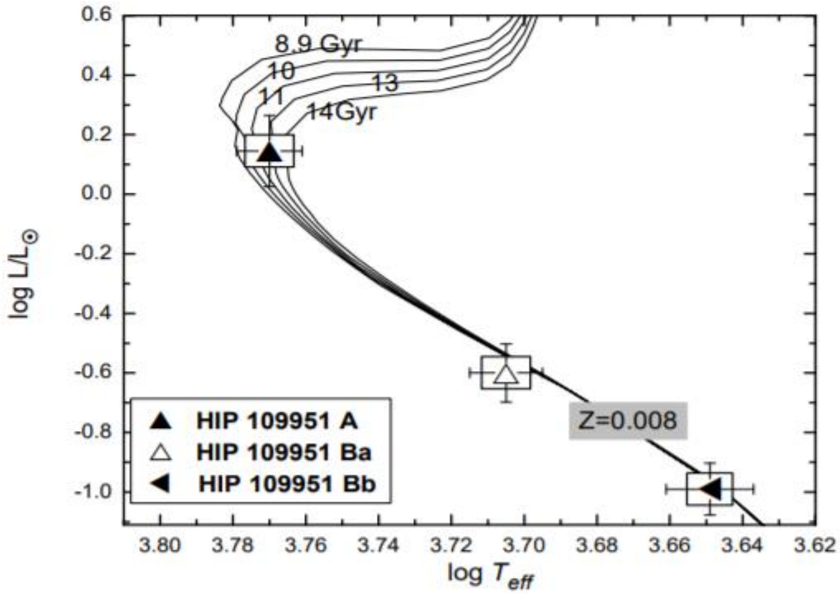


Figure 2-30 The isochrones for the components of HIP 109951 on the H-R diagram for low- and intermediate-mass ranges: from 0.15 to 7 M (and for the composite [Z = 0.008, Y = 0.25] stars of different metallicities). The isochrones were taken from [285].

2.4.2.3. Synthetic Photometry of the System HIP 109951 System

Synthetic photometry is used to estimate the stellar parameters more accurately with the color indices. It is a quantitative analysis for the synthetic SED of a binary system which is used to modify stellar parameters such that the predicted magnitudes fit the observed ones. It is predominantly based on the following equation [311], which is crucial for calculating the total and the individual synthetic magnitudes and color indices of the stars:

$$m_p[F_{\lambda,s}(\lambda)] = -2.5\log\frac{\int P_p(\lambda)F_{\lambda,s}\lambda d\lambda}{\int P_p(\lambda)F_{\lambda,r}\lambda d\lambda} + \mathrm{Z}P_p \qquad (14)$$

where m_p is the synthetic magnitude of the p passband, $P_p(\lambda)$ is the dimensionless sensitivity function of the passband p, $F_{\lambda,s}(\lambda)$: is the synthetic SED of the object, and $F_{\lambda,r}(\lambda)$ is the SED of reference star (Vega). Here, zero point, $\mathrm{Z}P_p$, were adopted from (318).

The result of applying equation (14) to the estimated synthetic SED should be consistent with the observational values in Table 2-3, otherwise, a new set of parameters should be applied. Derived with equation (14), the calculated magnitude and color indices within three different photometric systems: Johnson-Cousins: $(U, B, V, R, U-B, B-V, V-R)$, Strömgren $(u, v, b, y, u-v, v-b, b-y)$, and Tycho $(B_T, V_T, B_T - V_T)$ of component A and component B of the entire system $A-B$ are shown in Table 2-7, while those of the Ba and Bb component of the sub-system $Bb-B$a with entire system B are presented in Table 3-8.

Table 2-7 Magnitudes and color indices of the composed synthetic spectrum and individual component A and entire of the sub-system B of HIP 109951

System	Filter	Entire Synthetic $\sigma = \pm 0.03$	HIP109951	
			A	B
Johnson-Cousins	U	9.67	9.76	12.43
	B	9.43	9.57	11.74
	V	8.72	8.90	10.78
	R	8.33	8.54	10.24
	$U-B$	0.24	0.19	0.69
	$B-V$	0.71	0.67	0.96
	$V-R$	0.39	0.39	0.54
Strömgren	u	10.82	10.91	13.63
	v	9.81	9.93	12.29
	b	9.11	9.27	11.28
	y	8.09	8.87	10.72
	$u-v$	1.01	0.98	1.34
	$v-b$	0.70	0.66	1.01
	$b-y$	0.43	0.41	0.55
Tycho	B_T	9.61	9.74	12.00
	V_T	8.80	8.97	10.89
	B_T-V_T	0.81	0.77	1.11

Table 2-8 Magnitudes and color indices of the composed synthetic spectrum and individual component (Ba - Bb) and entire of the sub- system B of HIP 109951

System	Filter	Entire Synthetic $\sigma = \pm 0.03$	HIP109951	
			Ba	Bb
Johnson-Cousins	U	12.41	12.54	14.78
	B	11.74	11.93	13.71
	V	10.78	10.02	12.52
	R	10.23	10.52	11.80
	$U - B$	0.67	0.60	1.07
	$B - V$	0.96	0.91	1.19
	$V - R$	0.55	0.50	0.72
Strömgren	u	13.60	13.71	16.13
	v	12.29	12.45	14.42
	b	11.28	100.50	13.15
	y	10.72	10.97	12.45
	$u - v$	1.32	1.26	1.71
	$v - b$	1.00	0.95	1.27
	$b - y$	0.56	0.53	0.70
Tycho	B_T	12.00	12.19	14.02
	V_T	10.89	11.12	12.67
	$B_T - V_T$	1.11	1.06	1.35

2.4.3. Result and Discussion

Table 2-5 also shows the residuals, $\Delta\theta$ and $\Delta\rho$, and the rms of the system. Our orbital parameters of the visual system are close to that of [284] but the rms in our orbit improved in θ and in ρ more than previous rms. Moreover, the residuals of the radial velocities obtained with these elements and the parallax of Gaia are of the same order as those that Tokovinin [284] determined in the same manner, that is, using Tokovinin’s visual orbit elements.

Table 2-6 summarizes the results of the accurate orbital solution of the HIP 109951 triple system which is plotted in Figure 2-28 using Docobo’s analytic method. Tokovinin has evaluated the orbital parameters of the main A-B binary system and sub-binary Ba-Bb system. Table 2-6 shows the orbital parameters of the main binary system. The sub-binary system has an orbital period approximately of 111 days [287].

Employing magnitude difference measurements of speckle interferometry, the entire observational SED of spectrophotometry along with atmospheric modeling using Al-Wardat’s complex method resulted in a precise determination of the complete set of the physical and geometrical parameters of the main system. These parameters are presented in Table 2-9. Figure 2-27 shows the best fit between the observed and the synthetic spectrum along with three components (A, Ba, and Bb) of the system using a grid of Kurucz solar metallicity models.

In addition, Table 2-10 shows the final results of the calculated magnitudes and color indices within three different photometrical systems: Johnson-Cousins: $(U, B, V, R, U-B, B-V, V-R)$, Strömgren $(u, v, b, y, u-v, v-b, b-y)$, and Tycho (B_T, V_T, B_T-V_T) of the entire system and individual components of the triple system. The apparent magnitudes of the individual components (m_v^A, m_v^{Ba}, and m_v^{Bb}) of the synthetic photometry are found to be similar to those from the observed photometry.

Moreover, the magnitude difference of the sub-binary obtained from the synthetic photometry in Table 2-10 is similar to those from the observed photometry. Table 2-11 summarizes significant results. It shows a comparison between the synthetic magnitudes and color indices and the observational ones. Of course, the upshots and comparison led us to a clear and powerful indication of the reliability of the estimated physical and dynamical parameters of the individual components of the triple system given in Table 2-9.

Figure 2-29 shows the ideal positions of the individual components of the HIP 109951 triple system following theoretical evolutionary tracks of [322] on the H-R diagram. This indicates that component A belongs to the main sequence stars, while the components of the sub-binary system are a bit below the main sequence.

We have computed the total mass of HIP 109951 using two independent methods: Al-Wardat's com-plex method and Docobo's analytical method. The former gave a mass sum of $2.55 \pm 0.38 M_{\odot}$ distributed in the following manner $M_A = 1.05 M_{\odot}$, $M_{Ba} = 0.83\, M_{\odot}$, and $M_{Bb} = 0.67 M_{\odot}$, while the latter gave a mass sum of $2.15 \pm 0.35 M_{\odot}$ using the revised HIPPARCOS parallax. The good agreement in mass sum between the two methods leads to a reliable and accurate analysis of the used methods. Analysis of HIP 109951 showed that the system is a slightly metal-deficient star [Z = 0.008, Y = 0.25] (Figure 2-30) with an age between 8.9 and 13 Gyr.

Table 2-9 The physical parameters of the individual components of the HIP 109951 triple system

Parameters	Units	HIP 109951		
		A	Ba	Bb
$T_{eff} \pm \sigma_{T_{eff}}$	K	5836 ± 80	5115 ± 80	4500 ± 80
$R \pm \sigma_R$	$R_\odot$	1.09 ± 0.039	0.596 ± 0.05	0.49 ± 0.06
$\log_g \pm \sigma_R$	cgs	4.45 ± 0.06	4.60 ± 0.06	4.65 ± 0.06
$L \pm \sigma_L$	$L_\odot$	1.24 ± 0.10	0.22 ± 0.09	0.09 ± 0.05
$M_{bol} \pm \sigma_{bol}$	Mag	4.52 ± 0.08	6.39 ± 0.08	7.36 ± 0.09
$M^a \pm \sigma_M$	$M_\odot$	1.05 ± 0.16	0.83 ± 0.16	0.67 ± 0.16
Sp.$Type^b$		G1.5	K1.5	K7

Table 2-10 Magnitudes and color indices of the composed synthetic spectrum and individual components of HIP 109951 system

System	Filter	Entire Synthetic $\sigma = \pm 0.03$	HIP109951		
			A	Ba	Bb
Johnson-Cousins	U	9.67	9.76	12.43	14.78
	B	9.43	9.57	11.74	13.71
	V	8.72	8.90	10.78	12.52
	R	8.33	8.54	10.24	11.80
	$U-B$	0.24	0.19	0.69	1.07
	$B-V$	0.71	0.67	0.96	1.19
	$V-R$	0.39	0.39	0.54	0.72
Strömgren	u	10.82	10.91	13.63	16.13
	v	9.81	9.93	12.29	14.42
	b	9.11	9.27	11.28	13.15
	y	8.09	8.87	10.72	12.45
	$u-v$	1.01	0.98	1.34	1.71
	$v-b$	0.70	0.66	1.01	1.27
	$b-y$	0.43	0.41	0.55	0.70

Tycho	B_T	9.61	9.74	12.00	14.02
	V_T	8.80	8.97	10.89	12.67
	$B_T - V_T$	0.81	0.77	1.11	1.35

Table 2-11 Comparison between the observational and syn-thetic entire magnitudes and color indices of the HIP 109951 system

Filter	Magnitude	
	Observed	Synthetic (this work)
V_J	8.27	8.72 ± 0.03
B_J	9.43 ± 0.03	9.43 ± 0.03
B_T	9.58 ± 0.03	9.61 ± 0.03
V_T	8.82 ± 0.02	8.80 ± 0.03
$(B-V)_J$	0.71 ± 0.002	0.71 ± 0.003
$(u-v)_s$	0.96 ± 0.003	1.01 ± 0.003
$(v-b)_s$	0.68 ± 0.003	0.70 ± 0.003
$(b-y)_s$	0.44 ± 0.003	0.43 ± 0.003
Δm_{A-B}	1.88 ± 0.003	1.88 ± 0.003
Δm_{Ba-Bb}	1.50	1.50 ± 0.003

Finally, we conclude that regarding the physical and dynamical parameters of the HIP 109951 system, we concluded that our calculation yielded the most accurate elements to date of the studied this triple system with the reliability of the parallaxes in both methods. The total dynamical masses were ($\sum M =$

$2.59 \pm 0.40\ M_\odot$) and ($\sum M = 2.51 \pm 0.35\ M_\odot$) using Docobo's method based on the Gaia parallax and the revised HIPPARCOS parallax, respectively. The total mass of the three components of the system were ($\sum M = 2.55 \pm 0.38\ M_\odot$) using Al-Wardat's method. In addition, the best match between the observed and synthetic photometry of the magnitudes and color indices in different photometric systems (Johnson: $B, V, B-V$; Strömgren: $u-v, v-b, b-y$; and Tycho: B_T, V_T) of the entire system was accurately achieved.

2.5. CONCLUSIONS

This part of our research is designed to foster scientific knowledge about the history of double and multiple stars and the essential role played by OARMA members under the direction of Prof. Docobo. In fact, the theme of double and multiple stars has been part of astronomical research for more than two and a half centuries. This subject will be important in astronomical and astrophysical studies for many years because their formation, evolution, detection, and termination are relevant to current "hot topics" including exoplanets, X-ray sources, black holes, and galactic evolution. On the other hand, the combination of Docobo's analytical method for orbit calculation with Al-Wardat's method to determine the star parameters resulted very useful in order to achieve a complete study of the binaries.

At the moment, OARMA is obtaining observation time on very large telescopes that is fundamental to perform astrometric data and differential photometry of binaries. Nevertheless, Prof. Docobo maintain collaboration agreements with several world-class observatories in order to enable Docobo's research group to use very large telescopes as well as other cutting-edge facilities in these centers. Prof. Docobo, the Director of this Dissertation announced: " I personally believe that binary and multiple stars will be the subject of research for a long time to come, from both the astrodynamical and the astrophysical points of view". He also continued: " I am certain that the talented young researchers of tomorrow will dedicate themselves to this topic, following in the footsteps of renowned prominent astronomers in this area of research".

For the past years, the OARMA team has collaborated on a global level with many world-class observatories. In fact, Prof. Docobo aspires to establish new cooperation agreements in the near future in order to create new opportunities for his research group to develop their research skills as well as their scientific production. Recently, J. A. Docobo has had professional contacts with different groups in the USA, Germany, Belgium, France, UK, Russia, and Chile.

According to him, the future efforts of OARMA research in the coming years will be focused on: 1- Speckle Interferometry measurements using OARMA's ICCD and EMCCD cameras on class-edge telescopes in order to obtain noteworthy results, 2- the calculation of binary orbits for systems of special interest, 3- the study of late-type binaries with variable components using UBVR photometry and spectroscopy, 4- the discovery of new Flare Stars, 5- the possible detection of orbital subcomponents (including giant exoplanets), 6- the use of the Altair spectrograph to perform radial velocities in order to monitor some binaries of special interest, 7- the investigation of the stable orbits and dynamics of exoplanets and exomoons in binaries, and 8- the maintenance of OARMA as a Center of Interpretation of the Cosmos in Spain, in general, and Galicia, in particular. Regarding this last issue, it is important to highlight the different programs of diffusion promoted by the Director of this Doctoral Dissertation: PECAS (Programa de Extensión Cultural de AStronomía since 1997), TODOCOSMOS (La Astronomía al alcance de todos: colaboración Universidad-Ayuntamientos-Organismos Públicos y Empresas since 2013) with activities in 50 Galician localities, CYCLE 4, Astronomic Disclosure Activities in Galicia from 1997, O Camiño das estrelas, etc. Figure 2-31 shows some of the different activities of the programs of diffusion proposed and promoted by Prof. J. A. Docobo and carried out in Galicia in the by OARMA.

One of the most important collaborations to enhance astronomical research and thought in Jordan is being provided by OARMA. The Observatory will continue to provide facilities and equipment for scientific partnerships with research groups in Jordan for the development of scientific research in Astronomy and Astrophysics in cooperation with Professor Mashhoor Al-Wardat. In order to strengthen and develop these fields in Jordan as well as the rest of the Arab countries, Prof. Docobo has recently directed and carried out research in the fields of Astrophysics, Astronomy, and the History of Science and Astronomy in the Arab world, in general, and Jordan, in particular. In fact, this vital collaboration is based on the vision of OARMA for the enrichment of scientific knowledge and thought in Astronomy in developing countries.

Figure 2-31 Public astronomical activities carried out by OARMA (Credit:OARMA)

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3. CHAPTER 3: ASTRONOMY IN ARAB WORLD IN ANCIENT AND MEDIEVAL TIMES

3.1. INTRODUCTION

In Arabic, “Ilm al−Hai’a or ‘Ilm al−Falak” means Astronomy [1], [2]. It is an old science and has been essential since the earliest times. Astronomy has been an important specialty in Arabic society since the eighth century. The effective utilization of this science has served many religious and scientific purposes. It was used to develop an accurate lunar calendar, prayer times, and the direction of Qibla towards Mecca in Saudia Arabia (the Holy City of Moslems). Accurate calendars were required in order to determine religious celebrations such as the time of fasting known as “Ramadan” and the Pilgrimage period [3]. The term “Arab Astronomy” describes the product of many scholars within the Arab world. During the Medieval era, it was more accurately named “Arab-Islamic Astronomy” [4], [5].

Since 4000 BC, Astronomy was well known in ancient Arab world civilization such as Mesopotamia and old Egypt. Ancient Arab cultures left their mark on Astronomy and Astrology. Mesopotamian history covers many cultural periods such as the Sumerian, the Akkadian, the Assyrian, and the Babylonian. As in most ancient cultures, Astronomy in Mesopotamia was actually practiced as Astrology [6]. Mesopotamia provided numerous contributions in Astronomy, produced rich astronomical diaries and observational texts in cuneiform tablets, identified the planets (Mercury, Venus, Mars, Jupiter, and Saturn), and invented the astrological constellations that are still accepted today (Leo, Taurus, Scorpius, Auriga, Gemini, Capricorn, and Sagittarius). The orientation of the constellations was used for agricultural reasons. The Babylonians divided the sky into three parts and created a Zodiac. Astronomers in Mesopotamia were able to foresee lunar eclipses as they followed the heavenly bodies to enable prediction of their position in the future. The most significant achievement of Mesopotamian Astronomy was the improvement of the mathematical hypothesis of Astronomy [7].

The ancient Egyptian civilization made great strides in Astronomy by developing sophisticated time-keeping tables and producing a luni-stellar calendar. They invented the Star Clock to follow the position and motion of the celestial bodies, dividing the day into 24 hours. Ancient Egyptian Astronomy was fundamentally linked to the many important aspects of the community such as social, economic, political, and religious [8].

The Arabic and Islamic empires in the Medieval Era ruled a vast realm that spread from Asia to Europe. This empire reached its peak in all areas of science, in general, and particularly in Astronomy, between the eighth and seventeenth centuries AD. Arab contributions to Astronomy were significant during the Medieval period. Since the eighth century, Arab scholars and astronomers have translated many Greek scientific manuscripts and other works into the Arabic language. Many theories in Spherical Astronomy and Mathematics were produced and several observatories were established, numerous astronomical instruments were invented and improved, Ptolemy's theories and hypotheses were questioned and refined, and Astronomy was separated from Astrology. In addition, several sophisticated astronomical models and techniques were presented.

Many factors encouraged the growth of Arab Astronomy in the Middle Ages. One element was a geographic closeness to the ancient world, another was a tolerance for scholars of other faiths. Arabic and Islamic leaders in those times provided financial support and infrastructures. After the fifteenth century, Astronomy and other sciences fell from positions of importance and prestige and then gradually vanished. Several surveys and books have been published on the history of Arab Astronomy [9, 10, 11, 12, 13, 14].

This work is designed to demonstrate how Arabic Astronomy in ancient and medieval eras may have contributed to the historical progression of scientific and philosophic concepts of Astronomy and played a valuable role in transferring and shielding ancient scientific knowledge for posterity. It is necessary to provide a suitable review and attempt to illuminate the scientific impact of the ancient Arab realm on Astronomy and the great effort of Arab scholars and astronomers. The main objective of our study is to recognize and review the contribution of the Arab and Muslim scholars in antiquity to the sciences of Astronomy. Ultimately, the goal is to provide a new view of the history of Astronomy in order to launch and support a renaissance in Astronomy in the Arab world today.

In the following section (Section Two), we describe Arab Astronomy throughout the ancient eras. In Section Three and Section Four, we describe Arab and Islamic Astronomy including Observatories, Astronomical books, pioneering Arab and Muslim astronomers and their astronomical contributions, and astronomical instruments through the Medieval Eras. We draw conclusions and offer guidance for future work in the last section.

3.2. ARAB ASTRONOMY IN ANCIENT ERAS

As we know, humans have studied the sky in order to attempt to explain natural phenomena. Astronomy strongly impacted ancient cultures and drove essential contributions to science and knowledge throughout history. There were various significant reasons why ancient civilizations examined and used Astronomy such as the development of more advanced forms of agriculture (the accurate times of farming or crop harvest), the improvement of calendar and time-keeping methods and devices, navigation, religious, and political goals.

3.2.1. Astronomy in Mesopotamian Era

Mesopotamia is a Greek expression meaning “Land between the Rivers”. The term represents the civilization between the Euphrates and Tigris Rivers, in what is now known as Iraq. Ancient Mesopotamia civilization involved many cultures with ethnic names as follows: the Sumerian period (3500 - 2300 and 2094- 1755 BC), the Akkadian period (2275- 2094 BC), the Babylonian (1850-539 BC), and the

Assyrian period (1300 - 612 BC) [15] . This civilization was concerned with Astronomy for religious and agricultural reasons. Mesopotamia is the origin of ancient civilizations and was one of the most advanced civilizations to study Astronomy. Astronomers of that period relied on philosophical and mathematical approaches in the study of Astronomy. Furthermore, the Mesopotamian astronomers used and developed advanced arithmetical methods to study the heavens. Astronomy in the Mesopotamian civilization began during the Sumerian period with the invention the writing [16].

The main sources of our knowledge about Astronomy in Mesopotamia are the astronomical cuneiform texts and clay tablets. These astronomical texts are commonly separated into two classes: mathematical texts which combine theoretical schemes and calculated predictions and non-mathematical texts which cover observations and empirical predictions derived from these observations [17],[18]. In this study, astronomical texts from ancient Mesopotamia are divided into four categories following the classifications first proposed by J. Steels [19], 1- periodic reports about detected astronomical phenomena and their explanation as heavenly omens, 2- " Astronomical Diaries", these diaries contain a wealth of astronomical information concerning lunar phenomena, planetary phenomena, the Sirius phenomena, solstices, equinoxes, meteors, comets and weather. The most common observation recorded in the astronomical Diaries is the position of the Moon relative to a reference star which known by modern scholar as “Normal Stars”, 3- texts are known as " Almanacs" and "Normal Star Almanacs" describe astronomical phenomena for a singular year prophesy by non-mathematical period schemes, 4- Mathematical Astronomy texts including explanatory texts detailing to compute Ephemerides.

The most important sources about Astronomy in the Mesopotamian era come from Enuma-Anu-Enlil and MUL.APIN compendium clay tablets represent an astronomical compendium in cuneiform [20], [21]. These astronomical cuneiform texts are the earliest written records of the interest in heavenly bodies. Enuma-Anu-Enlil consists of 70 tablets and represents a vast collection of astronomical records and celestial omens from all periods of

Mesopotamian civilization. These series of astronomical texts are arranged as follows: tablets 1 to 13 concern the daily appearance of the Moon and the Moon's relation to planets and stars. The tablet 14 implement a mathematical system for predicting the visibility of the Moon. Tablets 15 to 22 focus on lunar eclipses. The movement of the Sun is presented in the tablets 23 to 29. Solar eclipses are specifically presented in tablets 30 to 39. Tablets 40 to 49 concern weather phenomena as well as earthquakes. The last twenty-odd tablets deal with the movements of planets, stars, and stellar astronomy. The sixty-third tablet concerns the position and motion of Venus [21]. MUL.APIN consist of 2 tablets, the first tablet includes six lists of fixed stars and constellations and the second tablet presents data for the identification of the astronomical phenomena. Moreover, these texts provide information about the scientific method of astronomical observation and record-keeping. And considerable shed light the astronomical knowledge in Mesopotamia [22].

Many discoveries and significant achievements there were in Astronomy in Mesopotamia during the Babylonian period. The Babylonian astronomers identified and classified stars into three catalogs of stars and constellations and they also used astronomical instruments like the Sundial and the Water Clock to measure time [23]. The Babylonians were the first to understand that astronomical phenomena are periodic and, moreover, apply mathematics to their predictions. Babylonian mathematical Astronomy began when Babylonian astronomers produced the Zodiac by dividing the path of the Sun, the Moon, and the planets into 12 equal sections [24]. This invented system became a central portion of mathematical Astronomy for estimating positions of the Moon, the Sun, and the planets. Times and positions of the same lunar and planetary phenomena identified from the diaries were predicted with Babylonian mathematical algorithms. The goal of Babylonian Mathematical Astronomy was the computation of ephemerides for the Moon and planets estimating, the main reason of astronomer to the concern of mathematical methods because the ancient astronomical and observational instruments are not inaccurate, using mathematical knowledge to enhancement and improvement the result. The largest and most highly developed part of

Theoretical and Mathematical Astronomy occurred during the Seleucid period [25] .

Babylonian astronomers followed two approaches to estimate and measure the position of heavenly bodies, first depending on the direction along the Zodiac and, second, the direction of the motion of the planets. The Babylonian astronomers adopted a more scientific approach to calendar issues. The Babylonians used a luni-solar calendar and the month started with the first sighting of the Crescent Moon. The month began after sunset on the evening when the lunar crescent became visible for the first time after conjunction. Each month contains either 29 or 30 days. The dates of eclipses as well as the calculus of cycles of eclipses were accurately determined.

Recent research has shown that Babylonian Astronomy was not merely a simple observation of the stars. The German scientist, Mathieu Ossenderjver, aimed to illustrate some of the foremost concepts and techniques of Babylonian Mathematical Astronomy by studying cuneiform tablets and the astronomical Diaries that represent observation evidence for hundreds of years. He analyzed these mathematical data to estimate the speed of Jupiter [26].

3.2.2. Astronomy in the Ancient Egyptian Era

The ancient Egyptian civilization was centered on the banks of the Nile River in what is now known as Egypt. Astronomy was extremely relevant to the ancient Egyptians who were interested in astronomical knowledge mainly for practical and religious purposes and they highly regarded for their knowledge of the heavens. The Astronomy of ancient Egypt is distinguished for its useful application to time measurement particularly at night. Astronomers in ancient Egypt used groups of stars called “decans” (because a new one appeared over the horizon every ten days) as early Hour-Markers, acting as a system of determining time during the night. These decans were thirty-six individual stars or constellations that rose and set at varying times of the year [27, pp. 65–67], [28, pp. 1–3]. The success of the ancient Egyptian civilization was derived from the ability to adapt to the conditions of the Nile River valley where all of the elements of agriculture were available and

Astronomy assisted with the correct prediction of the seasons and the dates of flooding [29].

The ancient Egyptians developed sophisticated calendars based on astronomical observation. The first Egyptian calendar produced was the lunar calendar or "Ecclesiological calendar". The lunar month of the first Egyptian calendar did not begin with the first appearance of the new crescent Moon but with the old crescent of the waning Moon. This calendar naturally divided the year into three seasons: four months when the Nile River flooded, four months of planting and growth, and four months of harvest and low water. Later, that Egyptian astronomers provide a 365-day calendar or “civil calendar” and the Egyptian year started with the time of the Nile flooding and was marked by the heliacal rising of Sirius. This was evidence of the commencement of the agricultural year in old Egypt. The year was divided into 12 months and each month had 30 days. The remaining five days were feast days and were called the "Epagomenal Days". These ”Epagomenal Days” did not belong to a particular month. They were added at the end of the year and marked a string of extraordinary holidays. Furthermore, the year was categorized into three seasons recognized by the early Egyptians, as follows: Akhet "inundation", the season of Nile flooding; Peret "going forth", the season for planting; and Shomu "deficiency", the season of the harvest [30], [31].

Egyptian astronomers used several instruments for observing the sky, such as many distinct types of Sundials (L-Shape, Sloping, Semicircular, Concave, and Miscellaneous Sundials), water clock, and the Merkhet (Merkhet is an ancient Egyptian astronomical instrument used for timekeeping and telling time at night [32]. Egyptian Star Clocks (Diagonal, Transit, and Ramesside) are tables of astronomical data presented as diagrams of the positions of stars relative to the overhead meridian at thirteen positions on twenty-four dates during the year, infrequently detected in ancient Egyptian temples. Moreover, S. Symons argued that the importance of study and analysis of the Egyptian Star Clocks point to an exceptional understanding of ancient Egyptian Astronomy [33].

Despite the scarcity of any recovered scripts or artifacts related to Egyptian Astronomy, the available data suggests that simple systemic observations were the foundation of their approach to astronomical knowledge. This knowledge was reflected in both social and religious life of ancient Egypt [27]. The ingenuity of ancient Egyptians in Astronomy helped them to construct great monuments. There are 81 monuments concerned with Astronomy, such as the pyramids of Giza and the Temple of Abu Simbel. A recent study showed that the Fall Equinox was used to accurately align the Great Pyramid of Giza with the cardinal points by using a vertical rod to track the movement of the Sun on the Equinox. On the other hand, Rameses II built the massive Temple of Abu Simbel in a manner assuring that the sunlight can only penetrate the inner sanctum and illuminate the sculptures on the back wall, on the King's birthday and coronation day [34], [35].

In Ptolemaic Egypt, following the conquests of Alexander the Great the Egyptian traditions of Astronomy were joined with other traditions from nations including Babylonia and Greece. Eratosthenes of Cyrene (c. 276-195 BCE), the Chief Librarian at the Library of Alexandria known for calculating the circumference of the Earth, was the greatest astronomer of this era. The well-known astronomer, Ptolemy (90-168 CE), wrote the Almagest following the Roman conquest of Egypt in which he explained a method for predicting the behavior of the planets by using the equant, a mathematical concept. The Zodiac was apparently introduced into Egypt in the Ptolemaic era [36], [37].

3.3. ARAB AND ISLAMIC ASTRONOMY THROUGH MEDIEVAL ERAS (THE GOLDEN AGE PERIOD)

In 611 AD, the Islamic Empire began on the Arabian Peninsula. In 622 AD, after Mohammed the Prophet migrated to the city of Madinah (Saudi Arabia), the Islamic state was established and expanded rapidly to encompass wide areas on the three continents of Asia, Africa, and Europe which were all under Islamic role from the seventh century.

Sometimes it is confusing to try to distinguish between the two terms: Arab and Islamic astronomers. Usually this term indicates astronomers in the Islamic empire. The Islamic and Arabic scientific community was united by the Arabic language and diverse in religions (Christians, Jewish, Sabian), sorted ethnically and geographically (Persian, Turks, Indian, Berbers). Not every Arab is Muslim and not every Muslim is Arab [38].

The time between the seventh to the fifteenth century was deemed as the "Golden Age of Arab and Islamic Civilization" in the Medieval or Islamic Renaissance eras. During these periods, there was an enormous emphasis on the pursuit of knowledge. At that time Islam was not just a set of religious beliefs, but a set of ideas, ethics, and ideals encompassing all aspects of human life. This resulted in the establishment of the Islamic civilization. Thus, the motivating force of this civilization was its Islamic faith and its language was Arabic.

Donald. R. Hill split Arab-Islamic Astronomy during the Golden Age into the four following distinct time periods [39]: Translation period (700 – 825 AD), Investigating Astronomy directly (825 -1025 AD), Doubts regarding theory and the geocentric model (1025 -1450 AD), and the stagnation or declination period (450- 1900 AD). There are many issues facing us while studying and classifying Arabic and Islamic Astronomy during the Medieval eras. Most astronomical scholars have made other contributions to other branches of knowledge including Mathematics, Optics, Medicine, and Philosophy. In order to get a position for work and funding support for more research, many astronomers in the Arabic empire moved to different areas. It seems difficult to link them to a particular time and certain places. To overcome these issues, we propose the classification of Arab and Islamic Astronomy in the Medieval eras into five epochs. Since the emergence of the Arabic and Islamic empire until the decline of the Arabic and Islamic civilization in the sixteenth century. Table 3-1 illustrate this classification as follows [44, pp. 104–140].

Table 3-1 The classification of Arab and Islamic Astronomy in the Medieval Eras

The Epochs	**The Name of the Epoch**	**The Time Span of the Epoch**
The First Epoch	Astronomy in Early Islam and first Umayyad Caliphate period	(611 - 662 AD) and (662 - 750 AD)
The Second Epoch	Astronomy in the Abbasid Caliphate period	(750 - 1258 AD)
The Third Epoch	Astronomy in the Fatimid Caliphate period	(909 - 1171 AD)
The Fourth Epoch	Astronomy in the Ayyubids Caliphate period and the Mamluks Caliphate period	(1164 – 1250 AD) and (1261– 1517 AD)
The Fifth Epoch	Astronomy in the Andalusian period “the second Umayyad Caliphate “	(756- 1492 AD)

In the following section, we attempt to illustrate and summarize the Arab-Islamic Astronomy picture in all of these epochs as well as the chief astronomical contributions that were accomplished, including astronomical instruments, astronomical books or manuscripts, Observatories, and pioneer astronomers and scholars in the field of Astronomy.

3.3.1. Astronomy in Early Islam (611 – 662 AD) and the first Umayyad Caliphate period (662 -750 AD)

The Arab region at that time used simple astronomical knowledge of a particular nature for distinguishing the directions while traveling, farming, harvesting crops, studying climate, and an interest in divination. They were familiar with the Sun's movement through the Zodiac, they adopted an accurate lunar calendar, they produced "Anwaa'" that ultimately became associated with 28 lunar mansions or houses[7], and they used the rising and setting times of certain specific stars to predict seasonal and meteorological phenomena. More than twenty compilations of astronomical information are found in Arabic sources of folklore, poetry, and literary texts as compiled by the Arabic scholar named Ibn Qutayba [43].

Since the mid-seventh century, Islam promoted a concern for science. The Holy Quran was the main, rich source of the verses related to Astronomy and Cosmology and 1160 verses in the Glorious Quran involve Astronomy, Cosmology, and Natural Sciences and several verses mention the Sun, Moon, and stars [44], [45].

In 638 AD, during the second Islamic Caliphate rule, Omar Bin al-Khattab, was the first to launch an Islamic calendar known as the "Hijri calendar". It was completely based on lunar phases. The Hijri calendar was adopted for the Islamic society which began on 15 July 622 and is still used for religious matters. The concern for Astronomy began at the end of the Umayyad Caliphate, the only contribution was a book on Astrology that was translated from Greek into Arabic, Kitab 'ard miftah al-nujum, which is attributed to the Greek scholar, Hermes in 743 AD [46]. The first century of Islamic rule was not fruitful for astronomical achievement for many reasons such as concern for religious studies and the struggle to expand the Islamic state [47].

[7] For more information about Lunar Mansion [41], [42]

3.3.2. Astronomy in the Abbasid Caliphate period (750 – 1258 AD)

After the overthrow of the Umayyad Caliphate in 750 AD by Abbasid, the control and the center of the Islamic empire shifted from Damascus to Baghdad. The Abbasid played a mighty and significant role in the development of science because they supported scientific learning and decided to establish reliable robust practices in the Islamic world. Astronomy and other developed rapidly during the Abbasid Caliphate from the eighth to the thirteenth century. Moreover, a diverse scientific heritage was acquired from ancient cultures.

Abbasid caliphs began to be interested in Science and especially Astronomy and they began to invite astronomers such as Nabukhat and his sons, al-Fazari, Ali al-Istrlabi, and al-Tabari. Abbasid caliphs, especially Harun-al-Rashid and al-Mamun, realized the truth that the actual happiness of the people is based on knowledge and that education means to search for facts. The first scientific academy was known as Bayt al-Hikmah (House of Wisdom) and it was an important research center, library, and a translation center [48]. That translation department was a revolutionary development where Greek, Persian, and Indian scientific and literary work were translated into Arabic by many scholars. Scientists translated books and manuscripts in different branches of Sciences, in order to gather the cumulative scientific knowledge into the Arabic language which was the formal language in the Islamic empire during that time. The most significant potential appeared on the works were those such as Sassanid's (Zij i-Shai), Ptolemy's (al-Majjast), and Brahmagupta (SindHind) that were collected by translation scholars such as Hanayn bin Ishaq, al-Tamimi, al-Balkhi, and al-Fazri [49].

During al-Mamun, a renaissance in all Sciences began, mainly in Astronomy. The al-Mamun program took the initiative to develop Astronomy as well as to study scientific and accurate scholarly observation in those fields relative to ancient astronomical work. Two observatories were built (in Baghdad and in Damascus) to conduct observations of the Sun and Moon. All of this data was accumulated and published on a book known as, al-Zij al-Mumtiihan (the verified tables) which was compiled by Yahya ibn Abi al-Mansur between (813-833AD)[50].

With extraordinary support from Abbasid Caliphate rulers, Arab and Muslim astronomers switched from translation to research in Astronomy and they established a new era in scientific astronomical knowledge in the Islamic empire. That time was known as a period of doubt when they verified astronomical theories, compared Ptolemy's hypothesis depending on accurate observation results obtained by Islamic astronomers, and improved geometrical models which were acquired from past civilizations. Within that period, numerous astronomers began to rectify doubts regarding some of the most conspicuous obstacles in the Ptolemaic astronomical approaches, planetary models, and theories. They began to modify and correct those geometrical models. The Arab and Muslim astronomers took observation to a new advanced level monitoring the heaven and they obtained high quality observations from the information which were established at several places throughout the Islamic realm. They recorded those observation results and created into tables known as the (al-Zijes) [51].

The scholars and astronomers during the Abbasid rule made sophisticated contributions in the field of Astronomy. Those achievements included updating new methods and developing advanced techniques to calculate the position and motion of heavenly bodies, producing a recording of timekeeping tables and accurately fixing the solar year to be (365 days, 5 hours, 46 min. and 24 sec.). Moreover, they used Spherical and Mathematical Astronomy methods to resolve problems such as spherical trigonometry and introduced the secant as well as the tangent in astronomical observation, invented several astronomical instruments, and studied Optics and atmospheric effects by observing the Sky. Astronomy began in the Islamic realm during the Abbasid rule, the most intellectual and scientifically productive age in the Arabic and Islamic Golden era [52]. We will discuss later the Observatories, Astronomy scholars, astronomical books and manuscripts, astronomical instrumentation and tools during all epochs above-mentioned in this section.

3.3.3. Astronomy in the Fatimid Caliphate period (909 - 1171 AD)

Great achievements in Astronomy were accomplished during the Fatimid rule. The Fatimid Caliphs were celebrated for institutional research and for building the al-Azhar Mosque as the first university of world civilization (founded in 970 AD), the Dar al-Ilm (House of Knowledge), and the public libraries such as the Khizanat al-Kutub (the Books Stores) and the al-Azhar library [53]. They also encouraged intellectual scientific research in Astronomy and other sciences. Astronomical observatories including al-Jayushi Observatory which was established above the al-Muqaṭṭam mountain, al-Mamun's Observatory, and the Observatory in Dar al-Ilm were built.

Astronomer in the Fatimid era, Ibn Yunus (950-1009 AD), produced many works concerning the correction and improvement of Ptolemy's Astronomy and he also used the institutional facilities and observatories to accurately measure astronomical parameters. He described 40 planetary conjunctions and more than 30 lunar eclipses[54], [55]. Many contributions to timekeeping tables by al-Hasan Ibn al-Haytham (965 – 1038 AD) offered significant advancements in Optics, Mathematics, and Astronomy, the nature of light, and vision. He also invented Camera Obscura or the Dark Chamber[8] which is a device that forms the basis of photography. Although records show that Ibn al-Haytham wrote more than one hundred manuscripts, many have not survived and today he is mainly known for his writings on Geometrical Optics, Astronomy, and Mathematics. However, the main work of Ibn al-Haytham, the Kitab al-Manazir (Book of Optics), consists of a landmark seven-volumes, published sometime between 1028 and 1038 AD[58], [59].

One of the most famous Arab astronomers of this period was Ali bin Radwan (998 - 1061/9 AD) who specifically commented distinct on Galen and Hippocrates Astronomy. He announced observing a

[8] Ibn al-Haytham employed the camera obscura to explaine how the image of the Sun could be projected through a hole in the wall of a room onto a wall opposite during an eclipse. By using this concept, the light rays must travel along straight lines and the object is inverted in the image plane[56], [57].

supernova in 1006 AD, as the most illustrious stellar event ever recorded at that time occurred known now SN 1006[60]. He reported his observation in detail in his famous book al-Arba' (Quarters), an extensive astronomical reference in Europe.

3.3.4. Astronomy in the Ayyubid Caliphate period (1164 – 1250 AD) and the Mamluk Caliphate period (1261 – 1517 AD)

The Ayyubid Caliphate dynasty ruled from 1164 to 1250 AD in Egypt and Syria. The Ayyubid dynasty was split apart due to the struggle between members of the family. In 1250 AD, the Mamluks then took full and complete control of the Islamic empire until 1517 AD. In our work, we combine both epochs. A few studies have spoken about science and Astronomy in the Ayyubid period. Under the Mamluk, the revival of Astronomy was a direct consequence of the interest of Mamluk leaders. In this period, both Cairo and Damascus flourished as intellectual centers in all sciences and several astronomical schools and observatories were constructed.

Many of the astronomers in this period had worked in computational Astronomy and timekeeping tables (Mawaqqit): such as al-zij al-Mustlah, al-Zij al-Jadid,al-Zij al-Maghrabi, al-Zij Ilkhani, Ulug Beg Zij and Athir Zij, and the Zijes contain astrological materials and several manuscripts in theoretical and spherical Astronomy [51]. Two new creative mathematical theorems were identified, the al-Tusi Couple and the al-Urdi Lemma, which played a significant role in the development of Mathematical Astronomy via Mu'ayed al-Din al-Urdi and Nass al-Din al-Tusi [61], [62]. Moreover, the astronomer Ulug Beg at that time afforded an advanced catalog of stars [63]. The astronomer Ibn al-Shater studied those theorems to development theoretical planetary models to overcome and correct issues in Ptolemaic Astronomy before Copernicus astronomical works [64], [65].

The Maragha school and Observatory which were founded in 1259 AD and indicate an important role of the History of Astronomy in the Islamic Empire. More than 100 scholars from different countries worked concurrently at the Observatory at various times. A new set of astronomical tables named the al- Ilkhanin Tables provided a better geometrical model for the movement of celestial bodies under the direction of Nasir al-din al-Tusi. The Maragha Observatory at that time contained high-quality astronomical instruments and a huge library with more than 400.000 books and manuscripts [66], [67],[68].

3.3.5. Astronomy in Andalucía period “the Second Umayyad Caliphate" (756 - 1492 AD)

The Arabs and Muslims ruled the Iberian Peninsula (Spain and Portugal) beginning in 711 AD [69]. This marked a new era that revealed role central in the history of Spain, in general, and of Andalusia specifically. Under the rule of the Arab and Islamic in Al-Andalus a high-quality infrastructure was established including the court of Cordoba, many libraries, research institutions, and several observatories in several places that developed many astronomical instruments of high accuracy in order to make scientific observations [70], [71]. Therefore, many scientific scholars and philosophers migrated to Spain to join the development of the learned and scientific base in Andalucia.

Astronomers in Andalucía conducted research and elaborated the Arabic translation of ancient eras such as Ptolemy's book and his hypotheses and corrected many earlier astronomical table issues. The precise and perfect astronomical Toledan tables assembled by Al-Zarqali and others [72]. Al-Zarqali was the first astronomer to detect and describe the Solar apogee concerning stars and separate it from the equinoxes, designed precision instruments for astronomical application and built the water clocks of Toledo [73]. Ibn Baso, another important Andalusian astronomer, developed several novel astronomical instruments, he was a mathematician, astronomer, and supervisor of the timekeeping program in the Granada mosque. He made several astronomical instruments and produced many of the astronomical treatises like Risalat al-Safiha al-Muyayyaba Dat al-Awtar or Treatise on the Use of the Plate of Sines implemented with chords, it has not yet been studied. He also wrote a monograph on the use of a device that he called al-Safiha al-Jami'a li-Jaml' al-Uriid or Genera Plate for all Latitudes [74]. The Andalusian astronomer, al-Majriti, wrote manuscripts in Mathematical Astronomy. Throughout the tenth until the fifteenth century in Spain, the transmission of Astronomy and Mathematics continued with the establishment of an Arabic-Latin translation program [75], [76]. Ibn Rushd, one of the greatest-known Arabic philosophers and astronomers, rejected Ptolemy's astronomical method of the philosophical approach and established theoretical contributions to the Andalusian criticisms regarding Greek Astronomy [77].

3.4. OBSERVATORIES, IMPORTANT BOOKS AND MANUSCRIPTS, AMPORTANT ASTRONOMERS, AND ASTRONOMICAL INSTRUMNETATION DURING THE ARAB AND ISLAMIC MEDIEVAL ERA

3.4.1. Observatories during the Arab and Islamic Medieval Era

Observatories in the Medieval Islamic era were very efficient and used astronomical instruments such as astrolabes, sextants, and armillary spheres. The chief structural feature of the Islamic observatories was the meridian quadrant which measured the planets' elevations as they passed the meridian

The construction of observatories in the Islamic empire began in the eighth century of the Abbasid Caliph al-Mamun era and they were used for specific research programs [78]. The foremost objective of the astronomers who worked at these early observatories was to draw up astronomical tables based on recent observations of the Sun and the Moon. The primary objective of those observatories was to draw up new astronomical tables of all of the planets based on the multiple fresh observations. They also produced astronomical ephemerides of the Sun, Moon, and planets, and also the possible compilation of a star catalog [79], [80]. In modern times, Aydin Sayili presented an important traditional book concerning the History of the observatories in Islam [81]. In Table 3-2, we provide a summary of the most important observatories during the Medieval Islam Era.

Table 3-2 The most important observatories during the Medieval Islam Era

Observatory	Year of establish	Built by	Location
Al-Shammasiyah	828 AD	Caliph al-Mamun	Baghdad -Iraq
Mount of Qasiyun	830-831 AD	Caliph al-Mamun	Damascus-Syria
Sharaf al-Dawla (Bayt al-Rased)	982 - 989 AD	Caliph Sharaf al-Dawla	Baghdad-Iraq
Banu Musa Brother (Samarra)	9th century	Banu Musa Brother	Baghdad-Iraq
Al-Jayushi (Mount of Mokkatam	1074 – 1088 AD	Badir al-Din al-Jamaly	Cairo -Egypt
Al-Mamun (Dar-al-Rasd)	996 – 1021 AD	Al-Hakim bi Amirllah	Cairo -Egypt
Hamadan	1023 AD	Ala al-Dawla	Hamadan city-Iran
Malik Shah	1072-1092 AD	Seljuk Sultan Malik Shah and directed by Omar al-al-Khayyam	Neyshabur -Iran
Maragha	1256 AD	Nasr al-Din al-Tusi	Maragha city-Azarbaijan
Samerkand	1424 AD	Prince Ulug Beg	Uzbekistan
Tower of Seville (Grialda Tower)	1172-1197 AD	Jabir bin Aflah	Seville -Spain
Istanbul	1577 AD	Taqi al-Din Ibn Mauruf (al-Rased)	Istanbul – Turkey

3.4.2. Astronomical books and manuscripts during the Arab and Islamic Medieval Era

An enormous number of books and manuscripts in Astronomy were written during the Golden Age of Arab and Islamic cultures and can still be found in libraries and museums throughout the world. A huge number were destroyed in the thirteenth century and later when the Mongol aggression against the Islamic empire took place in 1258 AD.

In 1956, E.S. Kennedy compiled and issued translations and commentaries about 125 Islamic Zijes [82]. Another German scholar, Benno van Dalen, translated 250 [83]. Many scholars in the field of the History of Sciences have studied Arabic and Islamic astronomical manuscripts such as Henrich Suter, George Sarton, Bockelmann, and Sezgin [84], [85]. Others have made essential contributions and provided good summaries in this area such as L.A. Sedillot [86], Nallino [1], [47], David King[51], [86], [88], Julio Samso [88], George Saliba [9], [10], Roshdi Rashid [89], [90], Kunitzsch [91], Regis Morelon [11], [12], and Sayili [81].

The Islamic Scientific Manuscripts Initiative (ISMI) is a collaborative effort linking the Institute of Islamic Studies (IIS) at McGill University in Montreal, Canada and the Max Planck Institute for the History of Science (MPIWG) in Berlin, Germany. ISMI was created to rationalize the cataloging of both metadata (standard bio-bibliographical information) and content data for all manuscripts in the Mathematical Sciences (broadly conceived). In the beginning, the focus was on astronomical manuscripts. Later, the database also included Science and Philosophy manuscripts. The ultimate objectives are to classify all Islamic astronomical, mathematical, and related manuscripts in a database, to register paleographic, content, and user information collected from these manuscripts, and to set up a suitable means to access this information [92]. In Table 3-3, we provide a summary of the most important books and manuscripts in Astronomy during the Medieval Islam Era.

Table 3-3 Some Important Books and Manuscripts in Astronomy of the Medieval Arabic and Islamic Eras.

Arabic Name	English Name	Author/s	Classification
Kitab al-Arba’	Book of Quarters	Ali bin Radwan	Astronomy
Kitab al-Manazer	Book of Optics or Book of Vision	Ibn al-Haytham	Optics
Kitab Daw al-Qamar	On the light of the Moon	Ibn al-Haytham	Optics and Astronomy
Kitab al-Hāla wa-qaws quzaḥ	On the Halo and the Rainbow	Ibn al-Haytham	Optics and Astronomy
Kitab Ḥall shukuk fi Kitab Uqlidis	Solution of the Difficulties of Euclid’s Elements	Ibn al-Haytham	Astronomy and Mathematics
Kitab Hayʾat al-a'lam	On the Configuration of the World	Ibn al-Haytham	Astronomy

Kitab Adwa al-Kawakib	The Light of the Planets	Ibn al-Haytham	Astronomy
Kitab al-Shukuk ala Batlaymos	Doubts concerning Ptolemy's work	Ibn al-Haytham	Astronomy
Surat al-Kusuf	On the Shape of an Eclipse	Ibn al-Haytham	Astronomy
Zij al-Sindhind	Al-Sindhind Table	Al- Khwarizmi	Astronomy
Kitab fi Jawami ilm al- Nujum	Compendium of the Star Science	Al-Farhgani	Astronomy
Al-madkhal ila ilm hayat al-falak wa harakat al-nujum	Introduction to the Science of Astronomy and Star Motion	Al-Farhgani	Astronomy
Al-Istdrak ala Batlamyus	A Recapitulation regarding Ptolemy	Anonyous author	Astronomy
Kitab abta' al-harakat fi falak al-buruj	On Slow Movement in the Orbit of the Zodiac	Thabit bin Qurah	Astronomy
Kitab Tarkib al-Aflak	The Construction of Orbits	Thabit bin Qurah	Astronomy
Al-Mughni fi ahkam al-Nujum	The Complete Book on Astrology	Ibn Hibinta	Astrology
al-Tadhkira fi c ilm al-hay'a	Memory on Astronomy	al-Tusi	Astronomy
Tarik al-Aflak	The Road of Orbits	Abu Ubayd al - Juzjani	Astronomy
Toledan Tables	Toledan Tables	Al-Zarqali	Astronomy
Zij al-Dimashaqi	Damascus Table	Habash al-Hasib	Astronomy
Zij al-Mumtahan	Tesed Tables	Yahia bin Abi Mansour	Astronomy
Zij al-Sabi	al-Sabi Table	Al-Battani	Astronomy
Kitab ma'rifat matali al-Buruj fi ma bayna arba' al-Falak	On the Ascension of the Zodical signs between the Quadrants of the Celestial Sphere	Al-Battani	Astronomy and Spherical Astronomy
Kitab al-Rasad	Book of Observations	Al-Dinawari	Astronomy
Kitab Nihaya al-Tuhfat al-Shahyya	A Completely Satisfactory Planetary Model	Qutb al-din al-Shirazi	Astronomy and Mathematic
Athiri Zik	The Athiri Table	Athir al-Din al-Maghrabi	Astronomy

Zij al-Jadid	New Table	Ibn al-Shatir	Astronomy
kitab nihayat al-sul fi tashih al-usul	A final inquiry concerning the rectification of planetary theory	Ibn al-Shatir	Astronomy
Ilkhani Zij	The Ilkhani Table	Shihab al-Din al-Halabi	Astronomy
Ulugh Beg Zij	The Ulugh Beg Table	Prince Ulugh Beg	Astronomy
Kitab al-Mabadi wa l-ghayat fi ilm al-miqat	A Complete Survey of Spherical Astronomy	Abu Ali al-Marrakushi	Spherical Astronomy
Kitab fi Sanat al-Shams	Solar Year Notes	Thabi bin Quara	Spherical Astronomy
Kitab suwar al-kawakib al-thabita	Book of the Images of the Fixed Stars	Al-Sufi	Astronomy
Al-Qanun al-Masudi	The al-Masudi Law	Al-Biruni	Astronomy and Mathematics
Hisab al-jabr w-'al-muqabala	Algebra	Al-Khwarizmi	Mathematics
Nihayat al-idrāk fī dirāyat al-aflāk	The Highest Level of Comprehension of the Orbits	Qutb al-Din al-Shirazi	Astronomy
Kitab al- Ajram wa-al-Abaad	Book of Bodies and Distances	Habash al-Hasib	Astronomy
Kitab Maqalid ilm al-Haya ma yahduth fi busit al-kora	The Book of the Keys to Astronomy and What Occurs upon the Surface of the Sphere	Al-Biruni	Astronomy and Spherical Astronomy
Kitab fi ‘ilm al-hayʾah	The Book on the Science of the Heavenly Configuration	Ali ibn Aḥmad al-Balkhi	Astronomy and Astrology
al-Falak wa-al-manazil	Astronomy and Houses	Ibn Sina	Astronomy
Mudhakarat fi'Ilm an-Nujum	Dialogues on Astrology	Abu Mashor Umar al-Balkhi	Astrology
Kitab al-Madkhal al- Kabir Fi ʿilm Ahkam al-Noudjoum	The Great Introduction to Astrology	Abu Mashor Umar al-Balkhi	Astrology

3.4.3. Outstanding Astronomers during the Arab and Islamic medieval era

The contributions of Arab and Muslim scholars in Astronomy reached its peak in the Islamic Medieval Golden period, between the eighth and fifteenth centuries, when the Islamic realm was the center of scientific breakthroughs. Many of the most fundamental assumptions and theories of contemporary Astronomy were either developed directly by Muslim astronomers or came about due to their high impact on following generations of astronomers.

In the early times of the Islamic empire, the Muslim scholars considered Astronomy to be one of the mathematical sciences. Ancient astronomical manuscripts were translated into Arabic from ancient Greek, Sasanian, and Indian cultures. They then undertook observations to verify the calculations in these scientific works. Here, we attempt to provide a concise biographical list of the Arab and Muslim astronomer scholars and their significant contributions to Sciences. Arab and Muslim astronomers took account of both the theoretical and practical aspects of Astronomy research and viewed them as related and interdependent. In Table 4-4, we provide a summary of the most important astronomers and their contributions in Astronomy during the Medieval Islam Era.

Table 3-4 Important Arab and Muslim Astronomers and their Contributions in the Medieval Arab Era.

Scholar	Lifetime	Scientific fields	Greatest Contributions
Abu Mashor Umar al-Balkhi	787 – 886 AD Born in Afghanistan and died in Iraq	Astronomy, Philosophy, and Astrology	- Establishment of Astrology by sufficient arguments and proofs [93]. -Many manuscripts on Historical Astrology.
Yahya ibn Abi al-Mansur	Died in 830 AD Died in Aleppo Syria	Astronomy and Astrology	- In the beginning, he conducted the earliest systematic methodical astronomical observations in the Islamic world [94]. -Astronomical Handbook, *al-Zij al-Mumtaḥan or Verified Zij*
Al-Khwarizmi Known as The Father of Algebra	780 – 850 AD Place of death unknown	Mathematics, Algebra, Geometry, Astronomy, and Geography	-The founder of Algebra (Kitab al-Jabr w al-Muqabala or The Book of Restoring and Balancing). -Mathematical studies in a compilation of astronomical tables [95]. - He was part of a team of astronomers that measured the length of one degree along with a meridian. - Creation of the Arabic number system. - Created an accurate map of the known important sites of the ancient world, this map included the latitudes and longitudes [96].
Ishaq ibn Hunayan al-Ibadi	808 – 873 AD Born and died in Iraq	Astronomy and Translation from Greek into Arabic language	- The leading translator in the House of Wisdom at one of the most remarkable times of Mathematical Astronomy. - He translated the significant works and Greek texts of Plato, Aristotle, Galen, Hippocrates, and the Neoplatonists into Arabic [97] .
Al-Battani	858 – 929 AD Died in Iraq	Mathematics and Astronomy	-He had made astronomical observations for more than forty years. Moreover, from this data, he obtained accurate actual values for the solar year (365 days, 5 hours, 46 minutes, and 24 seconds). -He made some corrections of Ptolemy's works. - He was the first one to explore the Zenith and Nadir and determine these points in the sky [98]. - Wrote a book known as al-Zij al-Sabi [99].
Abd al-Rahman al-Sufi (Azophi)	903 - 986 AD	Astronomy	-The Book of the Fixed Stars is a masterwork on Stellar Astronomy and provides historical information of studies of proper motion and long-period variables[38]. - He was the first astronomer to characterize the 'nebulosity' of the nebula in Andromeda as the concept of galaxy[100]. - He named the southern group of stars al-Baqar al-Abyad which means 'White Bull'. - A catalog of 1,025 stars giving their approximate positions, magnitudes, and colors was presented by him [101].
Ali bin Ridwan	988 – 1067-68 AD	Physics, Astrology, Astronomy, and Medicine.	-The common specific classification of the supernova now known as SN 1006, the brightest stellar event in recorded history[60].

			-A commentator on Greek medicine as well as a commentary on Ptolemy's Tetrabiblos. -The discovered motion of apogee of the Sun (the direction in which the Sun appears when it is furthest from the Earth).
Ali bin Yunus	950 – 1009 AD Died in Fustat -Egypt	Astronomy, Astrology Mathematics, and Trigonometry Science.	-Described 40 planetary conjunctions accurately and 30 lunar eclipses[54]. - Made advanced trigonometrical and astronomical tables to solve calendar and timekeeping issues. -Used accurate astronomical observation to write Zij al-Hakimi [55].
Al-Hasan Ibn al-Haytham (Al Hazen) Known as the Father of Optics	965 - 1040 AD	Optics, Astronomy, Philosophy, Theology, and Medicine.	-Made significant contributions to the principles of optics and visual perception, in particular [59]. - Wrote Kitab al-Manazer (Book of Optics). -Doubts Concerning Ptolemy and produced Model of the Motions of each of the Seven Planets[102]. - Invented the concept of a pinhole camera or dark camera. - Separated Astrology and Astronomy and argued to reject Astrology as a science. - He concluded that the planets must obey the laws of Physics and discussed a theory of attraction between physical masses [89].
Yaqub bin Ishaq al-Kindi known as the Philosopher of the Arabs	800- 873 AD Died in Baghdad -Iraq	Philosophy, Cosmology, Mathematics, Optics and Medicine.	-Wrote more than two hundred forty books, including sixteen books in Astronomy, twelve in Physics, thirty-two in Geometry, and eleven in Arithmetic [103]. -He founded the philosophical program of study centering on the works of Aristotle [104]. - He performed a great contribution in Spherical Geometry with astronomical studies. - Wrote monographs covering astronomical instruments.
Abu Naser al-Farabi	(870 – 950) Born in Turkmenistan and died in Damascus -Syria	Philosophy, Logic, Astronomy, and Astrology	- Created the al-Farabi Method of Astronomy. Implemented a new astronomical methodology by studying infrequently used texts to address pivotal issues in Astronomy and the techniques utilized to obtain the fundamental postulates of Astronomy [105]. -Commentary on Ptolemy's Almagest. - Contributed to Philosophical Cosmology and Methods of Astronomy [106].
Banu Musa brothers: * Jafar Muhammad ibn Musa ibn Shakir * Ahmad ibn Musa ibn Shakir * al-Hasan ibn Musa ibn Shakir	 *Born about 800 AD and died after 873 AD *Born about 805 AD and died after 873 AD *Born about 810 AD and died after 873 AD	Astronomy, Mathematics, and Geometry	- Organized specialists to translate numerous Greek scientific texts into Arabic. -The first group of mathematicians to extend the mathematical developments begun by the ancient Greeks -Wrote the Kitab marifat masakhat al-ashkal (The Book of the Measurement of the Plane and Spherical Figures). -Measured degrees of latitude and made measurements in the desert of northern Mesopotamia[107], [108].

Omar al-Khayyam	1048 – 1131 AD Born and died in Iran	Mathematics and Astronomy	- Measured the period of the solar year as 365.24219858156 days while now it is 365.242190 days[109]. - Set up an Observatory (Malik -Shah) in Esfahan.
Nasir al-Din al-Tusi	1201 – 1274 AD Born in Iran and died in Iraq	Astronomy, Philosophy, Physics, Mathematics, and Medicine.	-Astronomical treatise: al-Tadhkira fi Ilm Al-Haya (Memory on Astronomy) [110] - Created the al-Tusi - Couple theorem. The al-Tusi Couple was the first new mathematical model for planetary motion since the time of Ptolemy [61]. -Offered numerous notable developments of Ptolemy's model of the planetary system. -Introduced Trigonometry as a mathematical discipline (not only as a tool for astronomical applications)[111], [112].
Ibn al-Shatir	1304 – 1375 AD Born and died in Damascus -Syria	Astronomy, Mathematics, and Engineering	- Invented the astrolabe clock. -Compiled a set of tables representing the values of specific spherical astronomical functions relating to the times of prayer. - Designed and constructed a magnificent horizontal astronomical instrument known as the sundial. - Ibn al-Shatir marked a turning point in Astronomy and created the earliest model of the Cosmos in which physical theory, mathematical models, and empirical observations were in agreement [113]. - Made sophisticated contributions to Astronomy in the field of planetary theory [114]. -Used combinations of al-Tusi couples to reject both the eccentrics and the equant use of some epicycles for planets [115].
Mu'ayyad al-Din al-Urdi	1200 -1266 AD Born in Syria and died in Iran	Astronomy, Mathematics, Architecture, and Engineering.	- Wrote a critique of Ptolemy's Almagest and his Planetary Hypotheses [62]. - Created the al-Urdi Lemma Theorem, a new theorem provided with a full formal mathematical proof [116]. - Presented a rich and informative treatise on observational instruments (Urdi's Risala fi Kayfiyyat al-arsad) [117].
Qutb al-Din al-Shirazi	1236 -1311 AD	Astronomy, Mathematics, Medicine, Physics, and Philosophy	- Devised a geometrical model for planetary longitudes that involved a minimum of rotating vectors. -Wrote three major works in Theoretical Astronomy known as the Nihayat al-idrak fi dirayat al-aflak (The highest attainment in comprehending the orbs) [118].
Thabit Bin Qurrah	936 -901 AD Died in Baghdad-Iraq	Astronomy, Algebra, Geometry, and Translation	-A pioneer who extended the concept of traditional Geometry to Geometrical Algebra and advanced theories that led to the improvement of Non-Euclidean Geometry and Spherical Trigonometry [119]. -Analyzed infrequent problems on the movements of the Sun and the Moon and wrote treatises on sundials [120].

Ulugh Beg	1393 – 1449 AD Died in Samarqand	Mathematics and Astronomy	-Built an observatory at Samarkand in 1428. -Ulugh Beg's Catalogue of the Stars, the first comprehensive stellar catalog since that of Ptolemy. It gives the positions of 992 stars published in 1437 [121], [63].
Nur al-Din al-Batraji also known as (Alpetragius)	Unknown birth date -1204 AD Born in Morocco and died in al-Andalus-Spain	Astronomy	-The first astronomer after Ptolomy to present a non-Ptolemaic astronomical system as an alternative to Ptolemy's models. Another original aspect of his system was that he proposed a physical cause of celestial motions [122].
ibn Kathir al-Farghani	800/805-870 AD	Astronomy	-Wrote the book on celestial motion and thorough science of the stars known as (A Compendium of the Science of the Stars or Elements of Astronomy on the Celestial Motions [123].
Habash al-Hasib	766 – 870 AD	Astronomy and Mathematics	- Developed a method for the exact calculation of celestial distance. - The Book of Bodies and Distance [124]. - Calculated tables of sines, tangents, and standard astronomical functions [125]. - Obtained mathematical formulas for estimating the positions and orbits of heavenly bodies that go beyond the Ptolemaic theory [124].
Ibrahim al-Fazari	Unknown birth date and Died in 796 or 806 AD	Mathematics, Philosophy, and Astronomy	- Translated Indian astronomical texts by Brahmagupta into Arabic. - He was the first Muslim astronomer to create an astrolabe in the Arabic and Islamic region [126].
Al-Zarqali	1029 – 1087 AD	Astronomy, Mechanical Engineering, and Instrument Maker.	- Invented and wrote al-Safiha al-Zarqaliya, a treatise on the universal astrolabe, used to solve all the problems of Spherical Astronomy for any latitude developed later. - Constructed the most sophisticated and precise astrolabe ever and built the famed clocks of Toledo. -Contributed to several aspects of Astronomy, determined the correct ascensions, the equation of the Sun, Moon, and planets, ascendant, parallax, eclipses, the setting of planets, theory of trepidation, tables of stellar positions, and trigonometrical tables [73].

3.4.4. Astronomical instrumentation in the Arab and Islamic Medieval Era

Astronomical instrumentation flourished in the Islamic empire from the eighth through the fifteenth century. Moreover, observational and non-observational instruments were classified on two distinct levels. There are more than 1000 astronomical instruments preserved in libraries and museum around the world. Several treatises on the construction and application of these instruments remain unpublished. Unfortunately, many of these astronomical instruments have not yet been constructed and offered yet [127].

The most substantial contributions to instrumentation were done by individuals working separately. Meanwhile, several academies of instrument making were established in Baghdad, Damascus, Cairo, Aleppo, Asfahan,Toledo, and Marrakesh. Many scholars specialized in astronomical instrumentations such as Ibn al-Razaz al-JAzari, Ibn al-Shatir, Habash al-Hasib, al-Zarqalli, and others. An extraordinary work in astronomical instrumentation was compiled between 1276 - 1282 AD by Abu Ali al-Marrakushi in his famous book known as (Jami al-Mabadi wa al-Ghayat fi Ilm al-Miqat or A Collection of the Principles and Objectives in the Science of Timekeeping) [128], a very comprehensive compendium on Spherical Astronomy and astronomical instruments in the Islamic empire. The first Muslim astronomer to create astronomical instruments was al-Fazari. In Table 3-5, we provide a summary of the most important astronomical instruments during the Medieval Islam Era.

Table 3-5Most Important Astronomical Instruments in the Medieval Islam Era

Instrument	Summary
- Astrolabes	The astrolabe is an ancient astronomical device or tool for solving issues relating to timekeeping and the position of the Sun and stars in the sky (Spherical Astronomy). Several types of astrolabes have been made. The Muslim astronomers inherited the astrolabe from ancient Greek and Egypt. It consists of two main parts, one "celestial" and the other "terrestrial"[129]. There are many types of astrolabes (Planispheric astrolabe, spherical astrolab, and linear astrolabes). Astrolabes were further developed and enhanced in the Medieval Islamic world where Muslim astronomers created spherical astrolabes and linear astrolabes. They also introduced angular scales to the design, adding circles indicating azimuths on the horizon. The first Muslim astronomer who made astrolabes was al-Fazari in the tenth century. Another important improvement in the astrolabe occurred in Andalucía in eleventh century by al-Zarqalli called “Shakkaziyya”[130]. al-Khujandi designed a new kind of astrolabe in the late tenth century called Splendid Astrolabes [131].
Quadrant	The quadrant is an observational instrument utilized to measure the angle or altitude of a celestial object. The quadrant is classified into four categories, each were designed by Muslim astronomers: 1. The sine quadrant: for resolving numerical problems of Trigonometry, usually those obtained from Spherical Astronomy. 2. The horary quadrant: for calculating time by the Sun. 3. The astrolabic or almucantar quadrant: developed from the astrolabe. 4. The universal quadrant: for solving problems of Spherical Astronomy for any latitude [132].
Armillary sphere (Dhat al-Halaq or The Instrument with the Rings)	The armillary sphere was a model applied to demonstrate the movements of the celestial sphere (stars) and the annual path of the Sun (the ecliptic). It was also used to demonstrate the seasons and the path of the Sun in the sky for any day of the year. Armillary spheres known as Dhat al-Halaq or the instrument with rings. The astronomer al-Fazari wrote a treatise on the armillary sphere [130].

Celestial Globes	The celestial globe, known as al-Kurah or Dhat al-kursi in the Arab world, which was designed to follow the position and movement of constellations and other celestial bodies relative to given terrestrial latitudes [133].
The Equatorium	A mechanical device used for finding the longitude and position of the Moon, the Sun, and planets, was invented in al-Andalus in nearly the 11th century. It used a geometrical representation of the heavens to avoid difficult calculations [134, pp. 448–480].
Miscellaneous devices	-Magnetic compass and qibla – direction, a modified compass used by Muslims to indicate the direction of Mecca in Saudi Arabia. - Astronomical Compendia is a mathematical instrument which has a range of astronomical functions incorporated into a single small device. Muslim astronomers produced compendia throughout the fourteenth and fifteenth centuries. Ibn al-Shatir devised an important compendium in the form of a box [135].
Sundial	A sundial is an instrument particularly invented for estimating the time of day by projecting the Sun's shadow or a pinhole image on a set of hour lines. The history of the sundial spreads far back into antiquity and early descriptions and examples date from the Egyptian Period (around 1500 B.C.) as well as from ancient Greece and Babylonian eras. In the Islamic world, the concern for observing the daily prayer times, a number of which are mathematically determined by proscribed altitudes of the Sun above the horizon, further stimulated the expansion of instruments for observing the time from the Sun's altitude [136]. The Umayyad Caliph in 718 AD used the sundial to determine the time of prayers. The astronomer al-Khwarizmi wrote a manuscript on the sundial configuration by using polar coordinates[137]. Thabit bin Qurrah had written a treatise on sundial theory and explained the production of a sundial in any plane. Also, Ibn al-Shattir explained the shadow trace of the equinoxes and solstices. Sundials were found in most of the main mosques throughout the Islamic World [138].

3.5. CONCLUSIONS

The Arab world has a long history of Astronomy beginning with ancient civilizations in Mesopotamia, Babylon, and Egypt and continuing throughout the Medieval period known as the “Golden Era" between the eighth to the fifteenth century. Arab culture in the Near and Middle East was influenced by Astronomy due to its practical applications as well as its philosophical and religious implications. This is reflected in calendars, particularly the lunar calendar (the Hijra months), mythology, and a variety of art forms. Dating back 4000 years, Astronomy was well established in Mesopotamia and Egypt where science and technology flourished in continuous interplay with religion, substantially influencing the course of history [9].

Between the 8th and 15th centuries, Arab Astronomy attained great heights which resulted in important achievements and greatly influenced other sciences. It produced a wealth of sophisticated astronomical work. Mainly through the Ptolemaic framework, they improved and refined Ptolemy's work, compiled and edited better tables, and invented and developed astronomical instruments that improved their ability to carry out observations. The extensive contributions of Arab and Islamic Astronomy also exposed some weaknesses in the Ptolemaic and Aristotelian systems. In fact, Arab astronomers and their discoveries in the field of solar system and planetary theories generated various constructions of geometric models that represented the modern concept of the celestial spheres and planets. This was a very important period in terms of the History of Sciences, and it has been extensively studied [10] [47].

Arab and Muslim astronomers at that time began to focus on the Science of Astronomy by translating astronomical manuscripts into Arabic. Astronomy was an essential discipline in ancient Arabia and many important books were produced. They contained extensive tables and explanatory texts concerning chronology, trigonometry, celestial object motion, and Spherical and Mathematical Astronomy. Many astronomers at that time composed the astronomical table, "al-Zij", which presented extensive calculations of the position and motion of stars and other celestial objects [51]. Furthermore, several Arab scholars worked on refining and rejecting some of the Ptolemaic planetary hypotheses, such as, al-Tusi and Ibn al-Shatir. They offered many innovations of astronomical theories that developed and promoted Astronomy and they organized the field into several branches such as Mathematical Astronomy, Planetary Theory, Spherical Astronomy, and Timekeeping Tables [61].

Throughout this period, Arab and Muslim astronomers built many observatories in the Arab and Islamic empires which included several astronomical instruments and facilities. The most significant contributions occurred during the thirteenth century. Since the sixteenth century, Arab science in general and particularly Astronomy declined and fell. Nearly 200 constellations of stars have the Arabic name of Arab and Islamic astronomers who made important astronomical contributions. On the surface of the Moon, there are twenty-four craters named after Muslim astronomers who paved the way for modern Astronomy [139].

Finally, this quick survey of Astronomy in the Arab world during ancient times reviews the highlights of their astronomical contributions. The reader can become familiar with the gradual improvement of Astronomy in the Arab World over the ages and its progressive development and contribution to Astronomy today.

3.6. REFERENCES

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4. CHAPTER 4: ARAB ASTRONOMY AND SPACE SCIENCE IN MODERN TIMES: ACTIVITIES AND ORGANIZATIONS

4.1. INTRODUCTION

Astronomy and Space Sciences A&SS have developed quickly during the last two centuries. Many scientific, technological, educational, and cultural reasons have played a part [1], [2]. Actually, these sciences are directly related to many natural sciences and technologies such as Physics, Agriculture, Biology, Geology, Climatology, Chemistry, Computer Science, Energy, Engineering, Mathematics, Medicine, Military, Meteorology, and Space Telecommunications [3]. At the end of the thirteenth century, the Arab sciences, in general, and Astronomy, in particular, began to decline until they faded due to many political, economic, social and religious factors [4]–[7].

Today, A&SS research and studies in the Arab are poorly funded [8]. The increase of attention and aspiration in modern A&SS is a current matter in Arab societies. Major scientific progress in A&SS has led to the creation of a genuine revolution in knowledge and our understanding of the Universe. Unfortunately, the Arab countries are lagging in these scientific fields, and there is serious deficiency as compared to the rest of the world. Tremendous efforts and clear steps are required in order to bridge this gap and begin a real revolution in these sectors. This should be done by emphasizing the importance of teaching A&SS in elementary schools through university with the objective of increasing public awareness of the importance of A&SS.

The Arab countries are situated on two continents, Asia and Africa. These nations combined have a total area of over 5 million square miles and the entire population of all countries is 423 million across 22 countries [9]. Young people mastering the fastest-growing segment. More than 60% of the population is under 25 years old, with an average age of 22 years as compared to a global average of 28, making it one of the most youthful areas in the world. This group has been driving change in scientific and social values in the region [10]. Arab countries have marvelous potential in terms of natural, cultural, economic, and human resources for scientific research.

On the other hand, a few studies have been dedicated to highlighting and explaining A&SS in the Arab nations throughout the last two centuries. In 2011, Hamid Al-Naimy presented two studies covering the A&SS in many of the Arabic countries [11], [12]. Nidhal Guessoum also contributed another study published in 2013 [8]. Moreover, some studies have presented summaries of astronomical activities in specific Arabic country [13]–[20]. In 2018, Jörg Matthias Determann wrote a valuable book on the history of Arab Space Science during the last two centuries. Determann presented the reader with a highly readable and well-documented survey in A&SS in the Arab world. He described the discoveries and scientific collaborations that occurred in the last two hundred years, incorporating the most significant activities of individuals, institutions, and the national effort of Arab astronomers and researchers in recent times [21]. In our study, we provide review of A&SS in current times and we attempt to illustrate the history of A&SS in Arabic countries since the twentieth century till now, by following developments in A&SS that have occurred in the Arab countries since the twentieth century onward in order to critically assess the reality of A&SS in the modern Arab world.

Arab Astronomy in the modern era began in the nineteenth century and was linked to the existence of astronomical observatories. In Egypt, it began in 1839 with the work of the first modern Egyptian astronomers such as Ibrahim Bin Hasan "Shihab a-Din" and Mahmoud al-khudari EI-Falaky in the late of Ottoman Empire [22]. The Khedivial Observatory was built at Abbasiya, north-east of Cairo, in 1868 [23]. In 1903, it was moved to a new site at Helwan and renamed the Helwan Observatory [19], [24]. The Department of Astronomy was established in Egypt in 1937 at Cairo University and later that in Al-Azhar Islamic University. Astronomy in Lebanon was historically related to the Lee Observatory and Ksara Observatory which were established in 1873 and 1906 respectively [15]. Astronomy in Algeria was beginning since the Bouzareah Observatory (Algiers Observatory) was built in 1890 [16]. Iraq had an ambitious program in A&SS in the last century and witnessed tremendous development in Astronomy and Space Science, building astronomical observatories and research centers for A&SSs [18], [25]. Unfortunately, after 1980, this program was destroyed after difficult years following the First and Second Gulf War [26]. Qatar, the United Arab Emirates, and Saudi Arabia making advanced in the development of A&SS during the last two decades, implementing many pioneer projects in these sectors as well as strengthening interest in scientific research and education in these sectors. Moreover, Morocco, Sudan, Libya, Tunisia, Syria, and Jordan have developed these sectors and various achievements in A&SS have been accomplished [11]. The rest of the Arab countries have not yet taken significant steps to progress in these sectors.

The Space Science era was set up in 1957 which led to the creation of a real revolution in knowledge about the universe. Many Arabic countries turned their attention to Space Science and Technology for both scientific and educational purposes. Egypt took the first steps to create an integrated Space Science program in 1960 and several satellites were launched after 1998 [27]. The Lebanese Space Program was initiated in 1960 [28]. Recently, the United Arab Emirate, Saudi Arabia, and Qatar have been pioneers in the development in Space Science and Technology sectors. Morocco, Algeria, Sudan, Jordan, and Lebanon joined to develop Space Science program in recent years

[21]. The need to build home-grown capacity in Space Science and Technology in the Arab world is important and for this reason, common cooperation between Arab nations to establish "Arab Nations Space Agency" is necessary [12].

The Arab Union for Astronomy and Space Science (AUASS) was established in 1998. In order to raise the level of A&SS in Arab society [11], [14]. The Arab Astronomical Society (ArAS) was also established in 2016 with the aim to bridge the gap in scientific research between the Arab societies and global A&SS research [29]. In addition, there are three space agencies in the Arab region, the UAE Space Agency established in 2015, the Egyptian Space Agency founded in 2018, and the Algerian Space Agency created in 2002. In 2019, Saudi Arabia announced plans to set up the National Saudi Space Agency [30].

The International Astronomical Union (IAU) has played an essential role in developing and strengthening A&SS in the Arab countries with the collaboration and partnership between IAU members of different countries in the world, in order to establish scientific relations in A&SS between Arab societies and the rest of the world. Egypt was the first Arab country to join the IAU in 1925, Lebanon in 1954, Iraq in 1976. And Algeria, Morocco, and Saudi Arabia in 1988 [31]. Recently,the United Arab Emirate, Jordan, and Syria joined in 2018.

In March 2019, during the second "World Space Congress" hosted by the Emirates Space Agency, it was announced that 11 Arab countries with an initial membership (Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Morocco, Oman, Saudi Arabia, Sudan, and the United Arab Emirates) signed the charter to establish the first Arab Group for Space Collaboration in order to advance the developments in the Arab space sector [32]. The first outline will be the construction of a satellite by Arab specialists named the satellite “813” which will be launched within three years. That name contains the date of the beginning of accomplishment for the House of Wisdom in Baghdad during the Golden era. The satellite will be designed and produced at the United Arab Emirates facilities [33, p. 813].

Research in A&SS plays an essential role in a country's economic evolution to reach sustainable development [34]. It is important to note that, during the past century, Arab states lagged behind other nations regarding research in the fields of A&SS [8]. Scientific research in A&SS is inferior in Arab nations for many reasons such as the lack of advanced research skills an poor research infrastructure and equipment, political conflicts in many of the Arab countries, limited freedom and democracy, a brain-drain situations, the absence of financial support, and deficient publishing in high impact journals [35], [36]. In spite of the fact that A&SS research in Arab countries has increased throughout the past decade, it is still behind in terms world of global contributions in these fields. There is a serious need that the Arab countries maintain the amount and upgrade the quality of scientific production in A&SSs.

At present, A&SS education at all levels, from schools to universities in the Arab countries is weak. The educational curricula at the primary and secondary levels do not introduce topics in these sciences and only a minimal part of these educational curricula focus on some preliminary topics toward A&SS [37]. A few Arab universities grant a Bachelor degree program in A&SS as well as postgraduate studies [8], but it is necessary now serious enhance A&SS education. Qualitative changes in the educational systems must occur in order to establish an Arab generation with new opportunities in the global scenario.

On the other hand, the main obstacles to the development and strengthen of A&SS in the Arab region are multiple political conflicts. The Arab region was affected by the First and Second Gulf Wars at the end of the last century. Those wars destroyed infrastructure and caused the emigration of scientists from Iraq. At the beginning of the present century, the Arab Spring began to affect some Arab countries like Egypt, Libya, Tunisia, Yemen, Syria, and Iraq. It stunted the growth of A&SS in some of those countries and led to a halt in common joint projects in A&SS between some of the Arab nations. The Arab Spring caused many highly qualified Arab scholars to move abroad in order to develop their research projects and achieve their scientific and intellectual objectives [38], [39].

We have divided this work into two parts. In Part A, we will present a summary regarding activities and organizations involving A&SSs. In Part B, we will present a brief summary regarding Scientific Research, Future Outstanding Projects, and Pioneer Arab Scientists in A&SS. In the following section (Section Two), we describe the state of activities and organizations of A&SS in the Arab World as well as future projects. We draw conclusions and offer guidance for future work in the last section.

4.2. ASTRONOMY AND SPACE SCIENCE IN ARAB WORLD IN PRESENT AND FUTURE

In recent years, there has been a remarkable development of A&SS in several Arab countries. This growth is characterized by an important increase as compared to other fields of scientific research. Nowadays, they have many strategic plans to accomplish priority of enhancing the scientific activities related to strengthen knowledge and technology in A&SS. This expansion meets the new commitments of some Arabic governments to develop these sectors. In order to accelerate the growth rates in these sectors, some Arab countries like the United Arab Emirates UAE, Qatar, Saudi Arabia, Egypt, Morocco, Algeria, Lebanon, and Jordan, are making positive steps towards a crucial renaissance and revolution in A&SS. The presence of an extensive community of astronomers and scholars in these fields operating diligently within a flourishing economy and a peaceful setting is required.

As we have commented in the introduction, the astronomical communities of Arabic countries lack qualified human capacity as well as research infrastructures for A&SS. These communities at present include astrophysicists, astronomers, amateurs, specialist academic staff members from Arabic universities, and postgraduates' students. Lately, some Arab countries have addressed the lack of competent human capacity problems by providing scholarships to send several students abroad on scientific missions in order to acquire advanced knowledge in these scientific areas.

In the following subsection, we will present a brief summary of the most significant astronomical activities and organizations regarding A&SS in the Arab world in recent times.

4.2.1. Astronomy and Space Sciences in Jordan

Jordan has taken steps toward developing A&SS over the last years that involve efforts by formal and informal societies to strengthen these sectors. Modern Astronomy in Jordan is linked to 1987, the year when the Jordanian Astronomy Society JAS was established [14]. There are many local institutions and universities which have been participating and assisting with the development A&SS in Jordan. They include the Arab Union for Astronomy and Space Science (AUASS), the Arab Regional Office of Astronomy for Development (AW-ROAD), the Royal Jordanian Geographic Centre (RJGC), the Al al-Bayt University (AABU), the Jordan Meteorological Department (JMD), the Higher Council for Science and Technology (HCST), the Jordan University of Science and Technology (JUST), the University of Jordan (UJ), the Al-Balqa Applied University (BAU), and the Regional Centre for Space Science and Technology Education for Western Asia (RCSSTE-WE). Furthermore, Jordan has played an essential role in furthering and growing the A&SS sector in the Arab world, by supporting and hosting several organizations and initiatives that focused on the promotion of A&SS in the Arab region such as AUASS, AW-ROAD, and RCSSTE-WE [12].

The future of these areas in Jordan is linked to Jordanian Strategic Plan to develop the A&SS sector. This plan has objectives to carry out outstanding projects as a tool for the expansion of research and education in the country in the coming years. As commented by Dr. Awni Al-Khasawneh, the Secretary-General of the AUASS, Chairman of the Royal Jordanian Geographic Center, and Director of RCSSTE, there is a set of suggested projects and programs to attain these goals which includes: 1- The establishment of a Jordanian Space Agency, 2- The construction of an astronomical camp including Jordan Telescope with an 80cm- diameter in Jerash city, 3- The installation of a latest generation telescope at the University of Jordan with a diameter of 50 cm dedicated to educational and research purposes, 4- The establishment of the King Abdullah II City for Space Sciences and Astronomy, 5- The installation of a 10-meter Radio Telescope at the Al al-Bayt University. (Figure 4-1)

Next, we present a summary of the most important A&SS communities and institutes in Jordan.

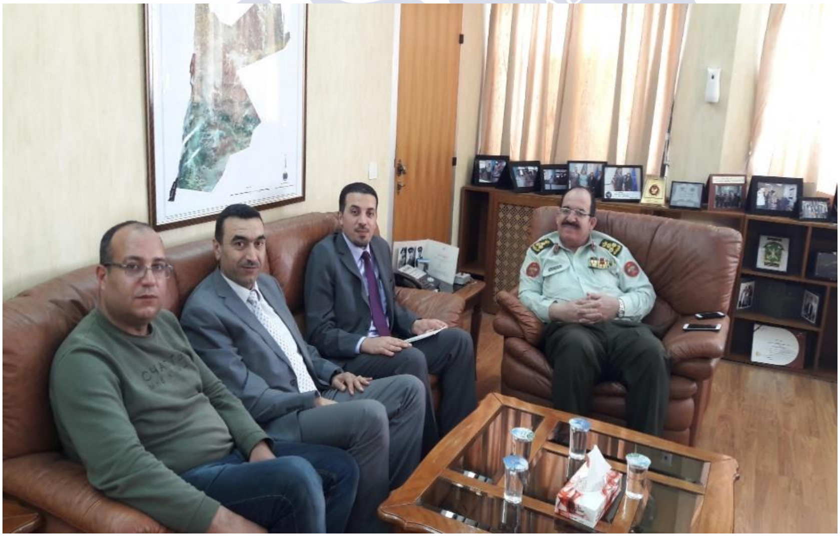

Figure 4-1 From right to left Dr. Awni Al-Khasawneh (the Secretary- General of the AUASS, and Director of the RCSSTE), Dr. Ali Taani (Professor of Astronomy and member in AUASS), Prof. Mashhoor Al-Wardat (Professor of Astrophysics, IAU active member, and AUASS

4.2.1.1. The Jordanian Astronomical Society (JAS)

The JAS (www.jas.org.jo), previously known as "The Jordanian Amateur Astronomers Society" was established in 1987. It is a public organization dedicated to spreading awareness about A&SS throughout Jordan and the whole of the Arab World. The main aim of the JAS is to promote A&SS education and research from amateur to expert levels as well as cooperation with many research centers and institutes in Arab and foreign countries. The JAS has three observatories [14].

4.2.1.2. The Institute of Astronomy and Space Science at Al al-Bayt University (IASS)

The IASS (https://web2.aabu.edu.jo/faculties_site/index.jsp?site_no=100080), was founded in 1994 at the Al al-Bayt University. The main aims of the IASS are to build national capabilities in A&SS sectors. The IASS consists of the Department of Astronomy and the Department of Space Science and has offered a B.Sc and a M.Sc. degree in Astronomy, Astrophysics, and Space Science technology disciplines for more than 15 years. Unfortunately, these programs were closed in 2012 [8] due to a lack of financial support as well a reluctance from the Physics and Science graduates to pursue studies in a field without future employment opportunities.

The main part of IASS is the Maragha Observatory (https://web2.aabu.edu.jo/faculties_site/index.jsp?menu_id=1&site_no=100080&col_id=80&dept_id=0). It contains a 40-cm diameter Meade LX200 telescope with a Schmidt-Cassegrain optical design with a focal length of 4064mm, and a CCD camera (size 1563 x 1024 pixels) which is controlled by a 440 BX computer, including high-accuracy astronomical and imaging software [14]. (Figure 4-2).

4.2.1.3. The Arab Regional Office of Astronomy for Development (AW-ROAD)

In 2018, the AW-ROAD (http://awroad.net) was officially established in Amman, Jordan with the support of the IAU to develop A&SS in Arab countries. The AW-ROAD is supervised and operated by many Jordanian astronomical institutions and organizations such as: 1- the AUASS, 2-the RCSSTE-WE, 3- the RJGC, and 4-the JAS. The objective of the AW-ROAD is to encourage the practice of A&SS as a tool for development by preparing qualified human capacity in the Arab region and by providing scientific, technological, and cultural requirements to enhance A&SS sectors. The AW-ROAD is a common project involving the following Arab countries: Jordan, Palestine, Lebanon, Syria, Iraq, the United Arab Emirates, Bahrain, Egypt, Libya, Algeria, Morocco, Qatar, Bahrain, and Somalia.

4.2.1.4. The Arab Union for Astronomy and Space Science (AUASS)

The AUASS (http://auass.com) was founded in 1998 and it is located in Amman, Jordan. The AUASS is an Arab regional organization composed of both professional and amateur astronomers. The main purposes of the AUASS are to develop and promote A&SS across the Arab countries, in order to advance the Arab nations scientifically and technically. AUASS focuses on increasing public awareness regarding research and education. Furthermore, strengthening the collaboration and partnership between Arabic countries is fundamental for achieving cooperative projects between the Arab institutes and observatories.

The other objectives of the AUASS are summarized as follow: 1- The establishment of the Arab Space Agency, 2- The construction of a high-quality observatory to house the largest telescope in the Arabic region, 3- The linking the recent A&SS activities of the Arab communities with its cultural, historical, and intellectual origins to enable it to restore its scientific and knowledge status and direct it to renaissance in A&SS disciplines, 4- The highlighting of the scientific research and activities in A&SS in the Arab world, 5- The establishment of specialized scientific networks of A&SS, 6- The completion of several outstanding projects in A&SS, 7- The unification of scientific terminology in A&SS within the Arabic language, and 8- The provision of sufficient opportunities for training Arab astronomers in advanced research methods in A&SS [12], [14].

4.2.1.5. The Regional Centre for Space Science and Technology for Western Asia (RCSSEWA)

RCSSEWA (http://rcsste.edu.jo) was established in 2012 in Amman, Jordan as one of five specialized centers in A&SS worldwide based on United Nations initiatives and support programs. The membership of RCSSEWA includes Jordan (host country), Libya, Lebanon, Syria, Iraq, Kuwait, Egypt, Sudan, Yemen, Palestine, Qatar, United Arab Emirate, and Oman. RCSSE aims to develop A&SS and technology in Western Asia countries in order to contribute actively to the sustainable development of natural resources through education, advanced research, and continuous training. RCSSE offers and grants a Master degree in several disciplines in the fields of Astronomy, Space Science, Remote Sensing, Atmospheric Science, and Information Systems.

In addition, in order to strengthen cooperation and provide new opportunities in these fields of research and scientific-technological cooperation, the RCSSTEWA has signed agreements and collaborations with several astronomical institutes and agencies such as: the Arab Union for Space Science and Astronomy, the Pakistan Space Agency, the Islamic Network for Science and Technology (ISNET), and the Institute of Malaysian Space Science. (Figure 4-3).

4.2.1.6. The Sky Gate Telescope Observatory Project

In 2013, the Sky Gate Telescope Observatory project (http://www.rumskygate.jo/en), was founded in Wadi Rum, Jordan. It is unique and possesses the first public telescope of its kind in the Middle East. It is location in Wadi Rum is due to tourism and it is free of light pollution which allows to the visitors and tourists to view the stars in the sky desert. The main objective of the Sky Gate Telescope Observatory is to increase astronomical knowledge for scientists, students, and tourists. This installation provides a sophisticated opportunity for visitors to look up at the sky to monitor and discover astronomical phenomena, and to enhance astronomical knowledge. (Figure 4-4).

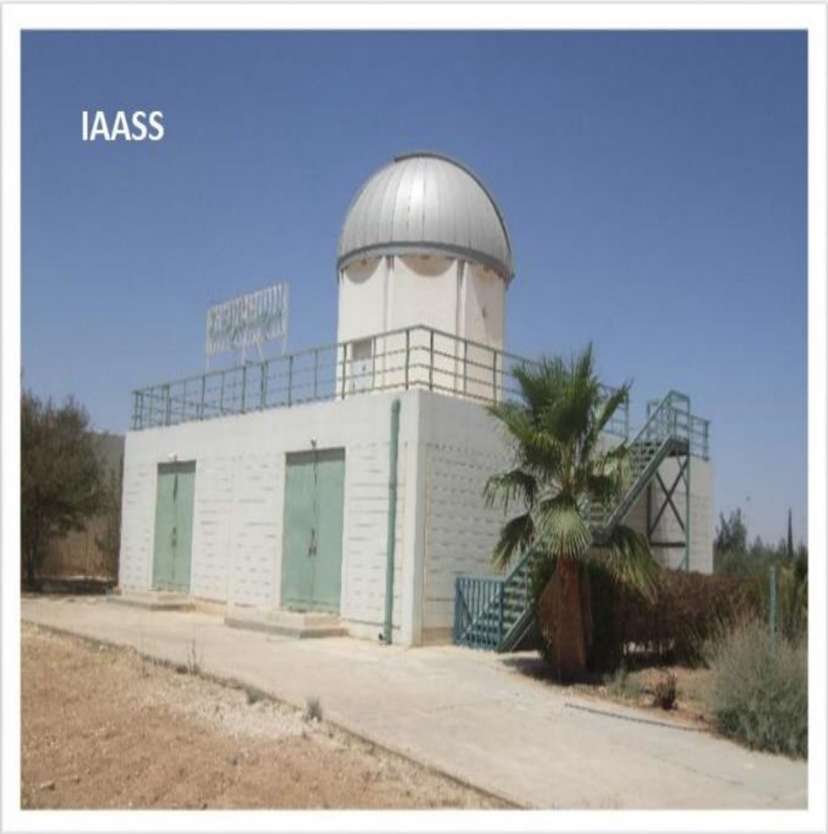

Figure 4-2 Maragha Observatory at Al-al-Bayt University (Credit: Al-al-Bayt University)

Figure 4-3 Regional Centre for Space Science and Technology for Western Asia RCSSEWA (Credit: RCSSEWA)

Figure 4-4 Sky Gate Telescope (Source: https://www.jordangrouptours.com/tourism-news/sky-gate-telescope-in-wadi-rum)

4.2.2. Astronomy and Space Sciences in the United Arabs Emirates (UAE)

At present, UAE is one of the foremost Arab countries to devote prominent attention to A&SSs. With a clear vision to build a solid technical and scientific foundation within the UAE that will ensure a knowledge-based economy for the UAE Space Sector in the country and the entire Arab region, the UAE has taken serious steps towards strengthening these sciences in order to reach a knowledge-based economy and achieve sustainable development in the country. Intending to achieve these goals, the UAE provides all available facilities and financial support for the establishment of infrastructure in this field, sending students to complete their studies abroad and to bring back the class edge technology [40], in order to prepare new generations of highly skilled researchers in astronomical and space research.

A few years ago, the UAE was beginning to achieve its operating ambitions for A&SS with the motto, "Our space is a source of pride and joy to humanity". To promote those sectors as a vital economic industry, the Government of the UAE has provided excellent financial resources and considerable investment in development. The UAE Space Agency has established [40] implementing pioneer projects such as the Emirate Mars Mission EMM [41], [42] constructing appropriate infrastructure as well as specialized research centers to increase well-educated human capacity. They, look proudly to "the future of the UAE s a chief player in A&SS race before 2021" [43].

In the next section, we will cover all astronomical activities, institutions, and organizations including the most crucial initiatives undertaken by the UAE to develop these scientific sectors.

4.2.2.1. The UAE Space Agency (UAESA)

The UAESA (https://www.space.gov.ae/) was founded in 2014 with the main mission to establish, manage, promote, and sustain technological advance in A&SS sectors, focused on the growth of social capabilities and the utilization of space technology in the UAE. Moreover, the establishment of international contacts in these areas, such as in 2015, created a partnership with the National Center of Space Studies of France and the United

Kingdom. The UAESA supervises and directs many of the practical projects listed below.

4.2.2.1.1. The Emirates Space Innovation Group (ESIG)

The ESIG is a part of the UAESA that was established in early 2016 and represents an essential tool for forming synergies and developing expertise and resources to create a stable environment for peaceful space utilization technology around the world. The ESIG also aims to consolidate efforts to develop space technology by planning and prioritizing future Space Technology activities. The dissemination of the UAESA Programs is designed to implement missions and projects in A&SS and their technologies that were funded by UAESA. The ESIG is made up of the UAESA, UAE universities, space technology manufactories, and research centers everywhere in the UAE. The ESIG has developed many laboratories in UAE universities and research institutes, such as the Radio Astronomy Research Laboratory, Ultra-Low Power Radiation Space Detectors, the Lab to Develop the Hyperspectral Data Processing Catalogue, and Next-Generation Lithium-Ion Space Battery Development.

4.2.2.1.2. The Hope Probe Project or Emirates Mars Mission (EMM)

The EMM is the first Arab mission to study Mars. In 2014, UAE's staff announced that the EMM will send an unmanned satellite in 2020 with the objective to reach Mars orbit insertion in 2021 that will correspond with the UAE's 50th-anniversary independence foundation [40], [44]. This mission has the objective to develop the contribution of UAE's scientific capabilities in A&SS, and to raise the UAE's scientific contribution in the fields of the global space community. EMM will be a sophisticated mission and has a solid potential to provide new knowledge about Mars. An Emirati researchers team executes the planning, supervision, and implementation of the probe project. The program is fully financed and controlled by the

UAESA while the probe is being developed as a common project between the UAEAS and the Mohammed bin Rashid Space Centre (MBRSC). In the part B of our study, we will present more details concerning the EMM.

4.2.2.1.3. The UAE Astronomical Cameras Network (UACN)

The UACN conduct video monitoring of the night sky of the UAE for meteor observation. The UACN is a common project performed in cooperation between the UAESA and the International Astronomical Center (IAC) at UAE. The UACN consists of three different stations in three locations across the country: Al-Sharjah city, Liwa city, and Al-Ain city in order to designate astronomical events in the UAE skies. (Figure 4-5 and 4-6). Each Station implemented by sky-pointed astronomical cameras positioned on varying specks in the UAE. Every station has 17 cameras operate as the Fly's Eye Camera System [45] that employed a multiple-passband full-sky surveying instrument to covers many astronomical phenomena. These cameras are working as part of the Cameras for the All-Sky Meteor Surveillance (CAMS) project. The 17th camera has a wide-angle lens to include the entire sky above 20 degrees altitude in one image. The cameras automatically record a video file once a meteor is identified. In addition, the UACN worked as a part of the Cameras for Allsky Meteor Surveillance project[46] and the data acquired will be submitted to the IAU Meteor Data Center, to use this data in future work [47].

4.2.2.1.4. Mezn-Sat 3U Cube Satellite Project (Mezn-Sat)

Mezn-Sat is a new innovative project, implement and funded by the UAESA with the participation of the Khalifa University and the American University of Ras Al-Khaimah. Mezn-Sat has both educational and scientific objectives for enhancing space technology capabilities in the UAE. Mezn-Sat will be developed, built and tested primarily by university students in order to grant the graduates of the UAE universities qualified training in these sectors. The scientific objective of Mezn-Sat project is to detect Green-House Gas (GHG) concentrations as well as breaking new ground for more and advanced space-oriented research relevant to the UAE [48].

4.2.2.1.5. The UAE Mini Satellite Challenge Project

UAESA in partnerships with the Khalifa University and the Boeing Corporation announced the release of "The UAE Mini Satellite Challenge Project Competition". This competition has an educational objective which is to design, manufacture, and operate a mini satellite by UAE universities students in order to allow those students interested in all fields of space technology and engineering to foster creativity and collaboration, seeking the application of new technologies for the advancement of research and development in A&SS sectors.

Recently, nanosatellites are widely used in space technology not only due to their small size, but for the ease deployment and a relatively short development period. This competition provides motivations for universities students to engage in the space-technology community regarding scientific issues in Earth Observation, Space Science, Cosmic Radiation, Astrophysics, Planetary Observation, Microgravity Measurement, Solar Cell Technology, and Space Communications.

4.2.2.1.6. The National Space Science and Technology Center (NSSTC)

The NSSTC (https://www.uaeu.ac.ae/en/dvcrgs/research/centers/nsstc/) was founded in 2015 at the United Arab Emirate University (UAEU) in Al-Ain city and it is a common project between the UAEU, the UAESA and the Telecommunications Regulatory Authority. The main objectives of the NSSTC are the development of advanced research in A&SS sectors, the improvement of education at all teaching levels, and the increase in community outreach. The NSSTC is focused on three opportunities priorities: Excellence in Space Science, the UAE leadership in Space Technology and the provision of innovative solutions to social challenges.

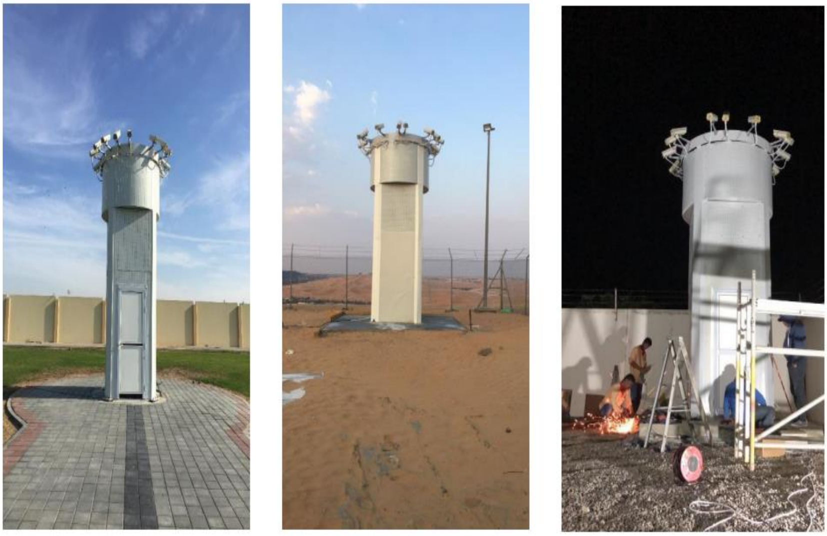

Figure 4-5 The Illustrated Meteor Monitoring Network in UAE. From left to right: (Al-Sharjah, Liwa, and Al-Ain respectively) (Credit: UAESA)

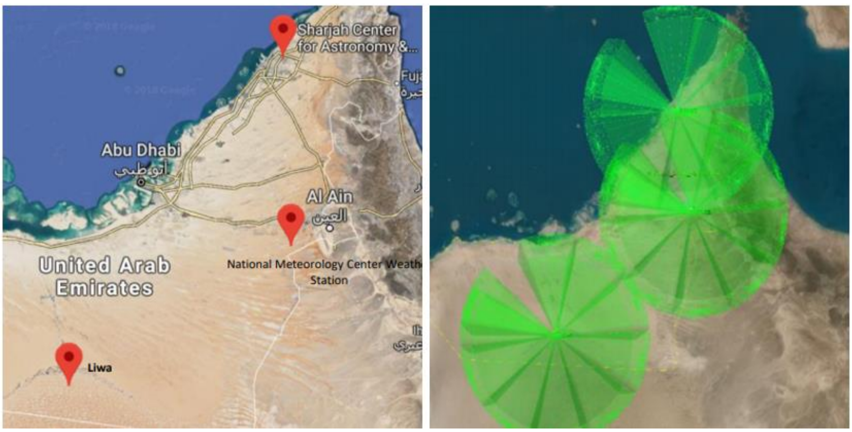

Figure 4-6 Three Location in the UAE area (Credit: UAESA)

4.2.2.2. Mohammed bin Rashid Space Centre (MBRSC)

The MBRSC (https://mbrsc.ae/en) was established in 2015, and it was created to replace the Emirates Institution for Advanced Science and Technology (EIAST) which was founded in 2006. The MBRSC was primarily intended to work as an incubator for A&SS research, development, and innovation in the UAE and the Arab region. It is supervised by the Dubai government in cooperation with all organizations and centers administering the UAE Space Program. In addition, the leaders in the UAE aspire to establish the UAE space program as a hub of superiority in the field of space science and technology innovation.

The MBRSC works in partnership with the UAESA to design, manufacture, and launch the "Hope probe" or the "Emirate Mars mission". Other objectives are to launch and implement advanced nano-satellites projects, prepare a future generation of well-trained Emirati scientists and workforce to support the UAE's ambitious space exploration missions and to build a sustainable Science and Technology sector that contributes to the national knowledge-based economy. The MBRSC with all of its formidable views and ideas, its robust infrastructure, and its advanced laboratories, provides a platform for the UAE's renowned professional engineering to exploit cutting-edge technologies that will strengthen A&SS sectors within the vision of the UAE's to become a global leader in A&SS.

The MBRSC has four main areas of A&SS research: the investigation of outer space, the global satellite industry and operating systems, Earth controlling and observation, and ground station assistance to promote other satellites and communications. Also working with the Airbus DS company, the Advanced Aerial program was designed to launch High-Altitude Pseudo-Satellite HAPS project [49]. HAPS will provide information about several scientific issues regarding the Earth atmosphere, climate change, marine environment, emergency management, security, etc.

The MBRSC launched several Remote Sensing Minisatellites during the past years, the first, the DubaiSat-1 was launched on July 2009 from the Baikonur Launch site in Kazakhstan and the second, the DubaiSat-2 was launched on November 2013 from the Yasny Launch Base in Russia. The third one is the Nayif-1 which occurred in February 2017 on the Indian Space Research Organization PSLV-C37 launch vehicle. For the Nayif-1 project, the MBRSC set up a partnership with the American University of Sharjah, to provide a rich experience for students of engineering in order to acquire a high level of experience in satellite manufacturing, testing, and operations[43]. Khalifa-Sat is the fourth satellite and it was scheduled for launch in 2018. This satellite is the commencement of manufacturing with national hands from the United Arab Emirates engineers only and applied cutting-edge technology.

4.2.2.3. The Sharjah Center for Astronomy and Space Sciences (SCASS)

The SCASS (http://scass.sharjah.ac.ae/en/Pages/default.asp) was founded in 2015 and located at the University of Sharjah in the UAE. The SCASS is one of the essential research centers established to strengthen new A&SS programs of the University of Sharjah, and works in parallel with other research centers spread across the UAE to develop these sectors [50]. The main aim of the SCASS is to develop and increase education and research in A&SS in the Arab World, in general, and the UAE, in particular. The design of the SCASS is based on the solar system and the planetarium building has a golden ceramic roof that represents the Sun and is surrounded by the planets.

The SCASS has numerous show halls to highlight the contributions of Arabs and Muslims to Astronomy, the story of telescopes, satellites, and space exploration [50]. In the SCASS, many research groups which investigate active galactic nuclei, star formation, neutron stars, and pulsars as well as theoretical studies on dark matter, early Universe cosmology, general relativity, and the analysis of measurements of the cosmic microwave background and large-scale structure.

In order to develop the research in A&SS, the center set up five research laboratories running to develop the scientific output, namely 1- the GIS and Remote Sensing Center, 2- the Meteorite Center, 3- the Radio Astronomy Laboratory, 4-the Ionospheric Laboratory, and 5- the CubeSat Laboratory [51]. Recently, the SCASS began to install Space Weather Laboratory.

In addition, the SCASS consists of three parts to promote A&SS knowledge with a view to encouraging the general public and school students. (Figure 4-7).

4.2.2.3.1. The Planetarium Theater

The Planetarium affords an excellent opportunity to approach the simulated universe, grant a trip to the stars and their constellations, and to provide information about the essential requirements to launch a rocket into space. Located at the heart of the center, the massive and sophisticated planetarium includes a semi-circle 18 meters diameter that fixes screen at an angle of 10° which displays high-definition images using an advanced digital display system consisting of seven (7) high-performance light-display channels. The Planetarium Theatre has a 209 seats capacity with seats distributed at extremely calculated angles. It also contains a large star display (Star Ball - 10 million stars) located in the heart of the celestial dome theatre. The Planetarium is the most significant digital and hybrid planetarium in the Arab region[51].

4.2.2.3.2. The Exhibitions Halls

The SCASS has wonderful exhibitions halls that are split into four zones which provide a unique trip concerning the topics of A&SS, the early understanding of light behavior and spectra, the formation of the universe, and space exploration. It contains of 12 exhibition halls as follow: the Blue Galaxy, the Green Galaxy, the

Red Galaxy, the Orange Galaxy, the Air-Powered Rocket Challenge, the Fan-Powered Engines or Rockets, the Docking Maneuver, the Moon Landing Challenge, the International Space Station (ISS), the Graphical Story of the Universe, the Graphic Book of Space Technology, and the Universe in the Holy Qur'an Exhibition. Every one of these exhibitions provides scientific simulations of A&SS for visitors with infinite pathways of astronomical and space knowledge [50].

4.2.2.3.3. The Sharjah Astronomy Observatory

The Sharjah Observatory was established at the University of Sharjah campus for educational and research purposes. The Observatory is equipped with three telescopes as well as other cutting-edge observational instruments such as the SBIG STX16803 CCD camera and an Echelle Compact Spectrograph (BACHES). The Observatory provides an academic role in teaching A&SS to the University of Sharjah students. The Observatory also used for the religious issues regarding observing the Lunar crescent to determine the Islamic calendar [51].

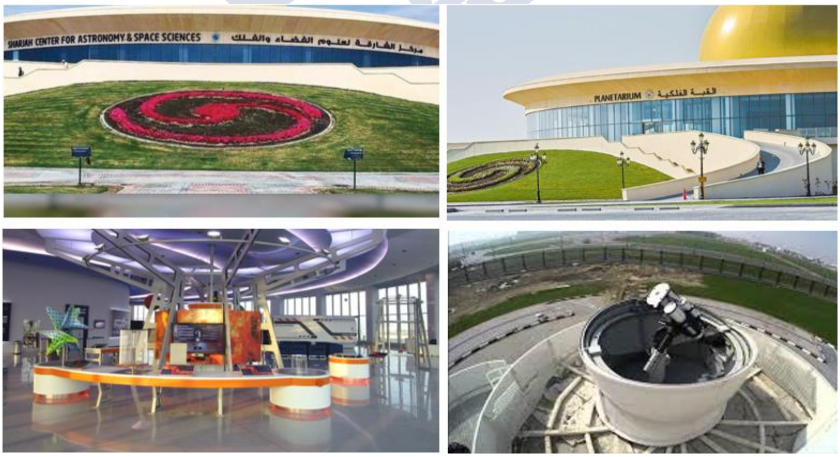

Figure 4-7 Top right, The Sharjah Center for Astronomy and Space Sciences (SCASS). Top left: The Planetarium Theater. Bottom left: The Exhibitions Halls. Bottom right: the Sharjah Observatory Telescope (Credit: The Sharjah Center for Astronomy and Space Sciences)

4.2.2.4. The International Astronomical Center (IAC)

The IAC (http://www.astronomycenter.net) was established in Abu Dhabi, the United Arab Emirate. The IAC also plays a significant role in religious issues regarding observing the Lunar crescent to set the provisions of the Islamic calendar in Arabic and Islamic countries and spread the correct astronomical awareness regarding these issues. According to the s0trategy work of the IAC, it requires many members from different countries over the world to participate in providing the information required in common activities and projects implemented by the IAC [52].

The IAC operates various extra activities locally and internationally. The main projects conducted are summarized below.

4.2.2.4.1. The Islamic Crescents Observation Project (ICOP)

The ICOP (http://www.icoproject.org/iac.html) was instituted in 1998 as an international project and directed by the IAC. The ICOP is one of the most important projects for of all Arabic and Islamic societies regarding the Lunar-sighting issue, the Islamic Calendars, and the Qiblah direction. At the same time, it provided support to develop an accurate crescent observation such as observation instruments, telescope tracking, accurate mathematical calculations software, and professional training for observers. In the ICOP work observers and specialists' members in astronomical matters related to Islamic applications. Those Groups of researchers are positioned all over the world to observe the crescent every month and send observation results to the ICOP team in order to publish the data on the ICOP website after a verification process. New criteria for Lunar crescent visibility were published by the ICOP members as a reference in all Islamic countries [52].

4.2.2.4.2. The Satellite Reentry Watch Program (SRW)

The SRW (http://www.icoproject.org/srw/index.html) is a sophisticated initiative to follow the space debris which falls continuously from the sky. The SRW objective is mainly an educational one as it is designed to spread awareness on this matter to the UAE public. The SRW is a cooperative platform for global specialists in the field of artificial satellites as well as the IAC members.

4.2.2.4.3. The Al Sadeem Astronomy Observatory

The Al Sadeem Astronomy Observatory was officially opened in 2007 at Abu Dhabi city for educational objectives directed to school students and the public. The Observatory is equipped with a 16-inch Meade LX850 telescope as well as other types of astronomical equipment.

4.2.2.4.4. The Astronomical Media Network (AMN)

The AMN is a network administrated and operated by the IAC and it works as a bridge between journalism and media staff who are interested in astronomical issues in order to provide and update them with astronomical information and statements, for publication and distribution to the general public when astronomical phenomena or others events occur.

4.2.3. Astronomy and Space Sciences in Egypt

Egypt is the largest of the Arab countries in population [53]. Astronomy in Egypt has been practiced since the ancient era and it is well known that the Egyptian ancient era provided significant contributions in the science of Astronomy. Modern Egyptian Astronomy began in the nineteenth century by early modern

Egyptian astronomers like Ibrahim Bin Hasan "Shihab a-Din" and Mahmoud al-khudari EI-Falaky in the late Ottoman Empire. Ibrahim Bin Hasan and Mahmoud al-khudari EI-Falaky provided an amazing manuscript called " Commentary on the Brilliancy of the Solutions of Seven Planets" [22]. In 1868, under the direction of Mahmoud al-khudari EI-Falaky during the Ottman period, the Khedivial Observatory was built, for astronomical and meteorological objectives [23]. In 1903, the Observatory was moved to a new site at Helwan, south of Cairo, where it was renamed as the Helwan Observatory. It was equipped with a 30-inch Reynolds's reflector telescope. The facilities in Helwan Observatory were updated since 1904 until the present [19]. In the early twentieth century, many astronomers worked in the Observatory [54].

Today, Egypt has great infrastructure in the field of A&SS, as well as highly educated human resources. The Kottamia Astronomical Observatory, as an extension of the Helwan observatory, was established in 1903 and has the largest telescope in the Arab world (a 87-inch telescope) [19]. Several research centers and laboratories are equipped with the latest generation instruments and technology at the National Research Institute of Astronomy and Geophysics (NRIAG) and the National Authority for Remote Sensing & Space Sciences (NARSS). Egypt was an effective member of the International Astronomical Union (IAU) since 1925, and in1937, Departments of Astronomy were established at Cairo University. Furthermore, the Astronomical Observatory at the American University in Cairo offers a telescope for observations of celestial phenomena and professional analysis of modern issues of A&SS, including the observation of the crescent moon. Recently, the Department of Navigation Sciences and Space Technology was established at Beni Suef University in 2019 as the first department in this field in the Arab countries. A&SS education and research are flourishing in Egypt during recent years. According to the QS Universities Ranking in the 2019 report recently published in Physics and Astronomy, the Arab universities hold sixth position from the top one thousand across the world. Egyptian universities inter to this rank in two universities from top ten Cairo University with rank (351-400) and Ain Shams University with rank (501-550) [55].

The Egyptian government has decided on a plan to launch a pioneer project known as the Egyptian Large Optical Telescope (ELOT) within the next 10 years, with the largest telescope in the Arab region in order to support and develop astronomical and space research in Egypt and the Arab world. In order to construct the ELOT with the highest advanced technology, Egypt cooperated with many high technological countries such as China, Japan, Italy, France, the United States, and Germany [56].

Egypt entered the Space era in 1960 and has taken steps to generate an integrated Space Science program through the construction of facilities for the space sector industry, to enhance Egyptian human resource capabilities for space research, and to develop cooperation between the country's research centers and international research centers in these field of technology. The main objective of the Egyptian Space Program was to join the space technology race. For that reason, Egypt sought to establish an Egyptian Space Agency which approved by the Government in 2018. Moreover, Egypt hosts the African Space Agency [56].

Egypt was the first Arab country to launch a satellite, the ¨Nile-Sat 101”, which was manufactured by the British-French company, Matra Marconi Space. That satellite was followed in 2000 by the "Nile-sat 102” and both are telecommunications satellites. In 2007, Egypt launched the Egypt-Sat-1 which became the first Egyptian remote-sensing satellite and was manufactured with cooperation between Egypt’s National Authority for Remote Sensing and Space Sciences and Ukraine’s Yuzhnoye State Design Office. In April 2014, Egypt launched the "Egypt-Sat-2", which was it second Earth observation satellite manufactured by the Russian firm RSC Energia, for operation by the National Authority for Remote Sensing and Space Sciences NARSS. Subsequently, in February 2019, Egypt launched the "Egypt-Sat A", a remote-sensing satellite, from the Russian Baikonur Cosmodrome, a spaceport in Kazakhstan leased to Russia [57].

In the following section, we summarize the most important organizations, centers, and projects in Astronomy and Space Science in Egypt.

4.2.3.1. The National Research Institute of Astronomy and Geophysics (NRIAG)

The NRIAG (http://www.nriag.sci.eg/) was established in 1903 as a part of the Helwan Observatory. The NRIAG has a very long history of astronomical and geophysical observation, making it the oldest research institute in the Arabic world as well as one of the World Heritage sites in Science and Technology. The main objectives of NARS are: 1- Promoting advanced research and studies in A&SS and Geophysics in Egypt and the Arabic countries, 2- Disseminating research and innovative results in high impact scientific journals, and 3- Strengthening scientific collaboration and partnership with research institutions and bodies of common interest at local and international levels.

Since its inception, NARIAG has witnessed tremendous development in all branches of Astronomy and Geophysics. The research facilities of NRIAG are spread all over Egypt, powered by more than 300 specialist researchers, with cutting-edge laboratories and instruments. The NRIAG includes six scientific divisions and institutes covering all fields of Astronomy and Geophysics that are listed below.

1- Astronomy Department: The Astronomy Department at NRIAG has the largest scientific collection in Astronomy in Egypt and the Arab World. The Astronomy Department consists of three laboratories and research areas, as follows: The Stellar Laboratory, the Galaxy Laboratory, and the Theoretical Astronomy and High-Energy Laboratory.

2- Geomagnetic and Geoelectric Department: This department consists of three laboratories: the Geoelectric and Geothermal Laboratory, the Geomagnetic Laboratory, and the Geomagnetic Observatory.

3- Geodynamic Department: This is one of the most recent departments at NRIAG. The department consists of two main laboratories: The Crustal Movement Laboratory and the Gravity Laboratory.

4- The Solar and Space Research Department: This Solar and Space Research Department has two laboratories, the Solar Research Laboratory and the Space Research Laboratory. Each of them operates many of the scientific research areas.

5- Seismology Department: This department has two laboratories, the National Seismic Network Laboratory and the General Seismological Laboratory. Each of them works in many scientific investigation areas.

6- National Data Center Department: This recently established Department at NRIAG is charged with the chief task of department monitoring and tracking satellites in order to receive and manage data information which comes from space satellites.

NRIAG released a peer-reviewed scientific Journal of Astronomy and Geophysics (NRIAG-JAG published by Elsevier on behalf of the NRIAG, Egypt, which were annually issued. Since 2002, NRIAG has organized bi-annual conference called "The Arab Conference on Astronomy and Geophysics" under the supervision of the League of Arab States. The main aim of the meeting is to foster, deepen, and strengthen the link between Arab astronomers and scholars through joint research and current projects as well as cooperation with other scientists around the world.

4.2.3.2. The Kottamia Astronomical Observatory (KAO)

The establishment of KAO has a long history [58]. In 1840, an astronomical observatory was built at Boulac site, West Cairo, for meteorological objectives. Unfortunately, the observatory was closed in 1860. The observatory was built once again at new location in Abbasya, east of Cairo, in 1868 and named the " Khedivial Observatory" [23]. (Figure 4-8). In 1903, the Khedivial

Observatory was moved to a new location at Helwan city that afforded more than 200 clear nights for astronomical observation. The observatory was renamed to the Helwan Observatory and it began operations on 1 January 1904, equipped with a 30-inch Reynolds Reflector telescope as well as other astronomical instrumentations [54]. (Figure 4-9). In 1948, the Egyptian Government placed an order to upgrade to a 87-inch telescope, equipped with advanced astronomical instrument like the Cassergian and Coude´ Spectrograph [59]. After some difficult issues, a new modern observatory was established in the Kottamia desert, 70 km northeast Cairo, and named the "Kottamia Astronomical Observatory". The new site is located at 485m above sea- level [59], far away from light pollution. The 74-inch telescope at Kottamia is the largest telescope in the Arab World, North Africa, and the Middle East. KAO now works under the direction of NRIAG [19]. A wide variety of astronomical and scientific programs are implemented by KAO [24], [59], [60]. Several studies have described the past, current, and future status of KAO instrumentation [19], [54], [59], [61]. (Figure 4-10). KAO administers and directs two activities of research, summarized as follows.

Figure 4-8 The original Khedivial Observatory at the Abbasiya (Source: Harold Knox-Shaw and the Helwan Observatory by Jeremy Shears and A. A. Shaker)

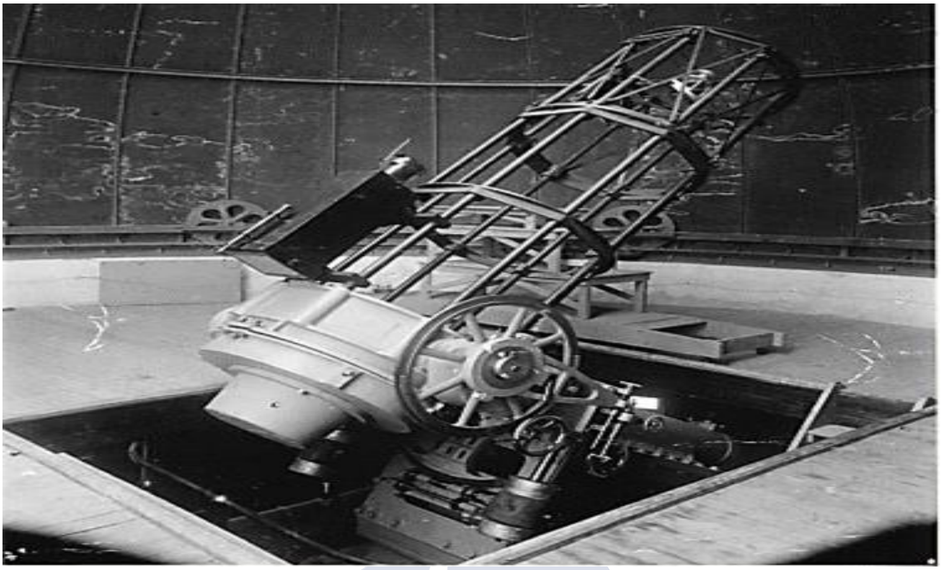

Figure 4-9 The 30-inch Reynolds Telescope at Helwan (Source: Harold Knox-Shaw and the Helwan Observatory by Jeremy Shears and A. A. Shaker)

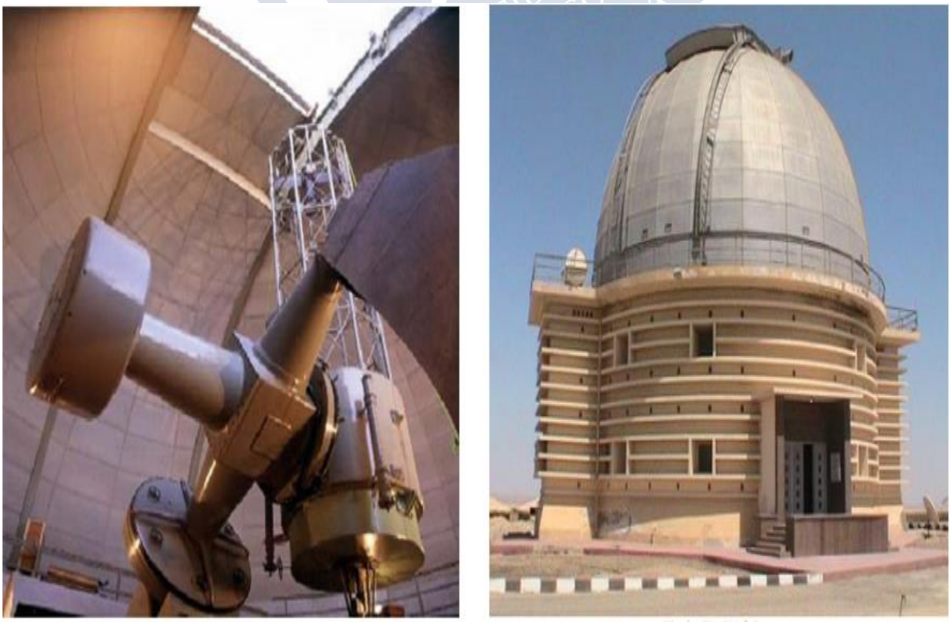

Figure 4-10 Right the Kottamia 74-inch telescope and Left The dome of the Kottamia Observatory telescope (Credit: KAO)

4.2.3.2.1. The Kottamia Center of Scientific Excellence of Astronomy and Space Sciences (KCSCE)

The KCSCE (http://www.kcsce.com) located at KAO[56] aims to develop the observatory infrastructure capabilities to implement superior modern research in A&SSs. The other objectives for KCSCE are to strengthen the cooperation between the KAO and other international observatories in order to rank more highly among international modern observatories, to install a center for the detection of extrasolar planets to establish a center for observational data analysis, and to establish a pioneer training center for young Arabic Astronomers.

4.2.3.2.2. The Egyptian Virtual Observatory (EVO)

The EVO will be the first created in Africa and Arabic countries [56], a very significant project which necessitates significant funding and a long term plan. EVO is an international astronomical cooperation-based initiative develop A&SS in Africa and the Arabic region. EVO has the significant scientific objective to provide free electronic access to the available astronomical data of Space and Ground-based Observatories in order to develop modern research in A&SS such as study of the complete electromagnetic bands, X-ray binary stars, CV variable stars, and exoplanets [62].

4.2.3.3. The National Authority for Remote Sensing and Space Sciences (NARSS)

The NARSS (http://www.narss.sci.eg) is the most effective research center in the field of A&SS and Remote Sensing in Egypt and the Arab region. NARSS was established in 1991 as a National Authority for Remote Sensing and is part of the Ministry of Scientific Research in Egypt. The objectives of NARSS include new leading-edge technology in the fields of remote sensing and the peaceful application of A&SS [63].

The NARSS consists of eight scientific divisions covering various scientific disciplines related to A&SS and Remote Sensing. They are: 1- Geological applications and Mineral Resources, 2-Agricultural Applications, Soil, and Marine Sciences, 3- Engineering Applications and Water Resources, 4-Environmental Studies and Land Use, 5-Data Reception, Analysis, and Receiving Station Affairs, 6- Aerial Photography and Aviation, 7- Space Sciences and Strategic Studies, and 8-Scientific Training and Continuous Studies.

The NARSS is intended to become one of the top scientific institutes in directing research and providing infrastructure in these fields and employs more than 150 specialists, experts, and engineers with prominent research capacities. In addition, NARSS pays major attention to collaboration with both regional and international countries. This is accomplished by participating in conferences, signing scientific partnerships agreements in order to exchange experience with scientists worldwide, and taking part in international projects for A&SS and Remote Sensing research and technology. NARSS has signed scientific agreements with more than 44 institutions worldwide and is involved in partnerships and collaboration with some regional/international space agencies to foster technological development.

4.2.3.4. The Aerospace Engineering Department at Cairo University (AEDCU)

The AEDCU (http://aer.eng.cu.edu.eg) was established in 1953, at Cairo University. The main objective of the Department is to provide high-quality Aerospace teaching and research for Egyptian and Arabic students by creating a sophisticated research environment that is necessary in order to develop a dynamic Arab generation in this sector and construct a world-class community of Aerospace engineers capable of accommodating the subsequent generation of modern aerospace systems.

4.2.3.5. The Faculty of Navigation Science and Space Technology at Beni Suef University (NSSTBSU)

In 2019, Beni Suef University (BSU) established the Faculty NSSTBSU (http://www.spacescien.bsu.edu.eg) the first Egyptian and Arab faculty specialized in the field of space navigation and the applications and uses of space technology. The NSSTBSU has three divisions: Space Navigation, Space Communications, and Space Science. Furthermore, to develop education and scientific research in these fields, six leading-edge laboratories were established. The NSSTBSU offers Bachelor, Master, and Ph.D. degrees in Navigation Sciences and Space Technology at the local, continental, and Arab country levels. The aim is to offer an integrated scientific base and create specialized training centers and laboratories for the purpose of contributing effectively to the Egyptian Space Program.

4.2.4. Astronomy and Space Sciences in the Kingdom of Saudi Arabia (KSA)

The importance of A&SS in KSA is closely related to several Islamic religious matters [13]. In the last decades, KSA began to pay attention in A&SS and to develop and strengthen research and education for A&SS sectors in order to enhance and stimulate the scientific position of the KSA in these sectors. Astronomy education in primary and secondary schools and KSA universities flourished in the last decade. To enhance astronomical knowledge in school curricula, several astronomical topics were introduced into primary and secondary schools. Astronomy has been taught in Saudi Arabian universities, offering degree at the Bachelor, Master, and Ph.D. levels e.g., in the King Abdulaziz University since 1958 and the King Saud University since 1976 [16].

In the Space Science and Technology area, KSA has ambitious plans and is making great effort to transfer and localize Space Science and Technology. KSA has established an advanced infrastructure to support and sustain a space industry in the country, signed several cooperation agreements in the field of outer space technology and its applications, developed a sustainable program for satellite technology and applications, and provided excellent training of Saudi scientists in those sectors. In 2010, the KSA Government published "Saudi Arabia Space Program" between 2010 until 2025, in order to accomplish the long-term vision to transform KSA into a knowledge-based economy, joining advanced industrial countries. The Saudi Satellite Program began in 1998 and has succeeded in launching 16 Saudi satellites, for Telecommunications, Remote Sensing, and Scientific Research.

4.2.4.1. The King Abdulaziz City for Science and Technology (KACST)

The KACST (https://www.kacst.edu.sa) was established in 1977 to replace the Saudi Arabian National Center for Science & Technology (SANCST). KACST is an autonomous scientific organization that aims to formulate science and technology policies, promote advanced scientific research, and sponsor research activities across Saudi Arabia [64].

KACST plays an important role in the development of A&SS in KSA and the Arab world. In order to conduct a world-class scientific research and technological development, KACST has 18 research centers covering all field of sciences. In A&SS, some of the research centers are: the National Center for Astronomy (NCA), the Center of Excellence for Aeronautics and Astronautics (CEAA), the Center of Excellence for Earth and Space Science (CE2S2), the Space and Aeronautics Research Institute (SARI), and the Saudi Center for Remote Sensing and GIS Centers (SCRS). Moreover, various programs have been established under KACST targeting A&SS and their technologies. KACST coordinates, implements, and supervises several pioneer projects such as the Saudi Satellite Program and the Saudi Arabian Space Geodesy Program.

In order to focus on A&SS scientific research, the KACST signed international collaboration and partnership agreements with the leading space agencies. Finally, the KACST has seven observatories for astronomical needs. These observatories are located in different areas of KSA, specifically, the Umm Al Qura Observatory with a 16-inch telescope, the Tabuk Observatory with a 16-inch telescope, and the Alwajeh Observatory with a 16-inch telescope.

Next, we present a brief summary of research centers and programs in A&SS provided by the KACST.

4.2.4.1.1. The National Center for Astronomy (NCA)

NCA is one part of KCSAT. The main goal of NCA is to satisfy the demands of the KSA concerning research, studies, and applications in Astronomy. The most important activities implemented by NCA are related to Islamic religious issues, agriculture, military applications, and astronomical studies in order to enhance the scientific position of the KSA and to stimulate interest in A&SS. NCA academic staff are qualified and highly trained specialists in the field of Astronomy.

4.2.4.1.2. The Center of Excellence for Earth and Space Science (CE2S2)

CE2S2 (https://www.kacst.edu.sa/eng/RD/pages/content.aspx?dID=81) was recently established under the supervision and operation of KACST, with a partnership and collaboration between KACST and the California Institute of Technology (Caltech) of the National Aeronautics and Space Administration (NASA). This scientific project concentrates on collaboration between the Department of Geological and Astronomical Studies at Caltech and CE2S2 [64, p. 2].

The ultimate goal of CE2S2 is the advancement of new methods to develop space missions. The Center advances research in Saudi Arabia by creating and managing laboratory space, preparing major infrastructure grant applications, organizing research seminars, and providing administrative support. The objective is to promote attention and research regarding the following key issues: earth crust deformations and tectonic movements, sand dune movement and impacts, flood pools, and dynamics of groundwater reservoirs.

4.2.4.1.3. The Center of Excellence for Aeronautics and Astronautics (CEAA)

CEAA was established as a part of KACST. The center is intended to localize and strengthen Saudi Arabian capabilities to perform scientific research and advanced space technology development, as well as to improv educational infrastructure in Aerospace physics. CEAA was founded as a direct result of common cooperation efforts between KACST and Stanford University. Several research projects and programs were operated under the direction of CEAA in many research areas such as Advanced Space Technology Development, Satellite Performance Improvement, Astrophysics, Autonomous Flight for Unmanned Aerial Vehicles, and Green Environmental Propellants. Moreover, it operates to develop qualified Saudi human capacity staffs and to build a new generation of researchers in this area in order to move forward in the evolution of the future of Space and Aeronautic ins the country and the Arab region.

4.2.4.1.4. The Space and Aeronautical Institute (SARI)

SARI (https://www.kacst.edu.sa/eng/RD/SARI/Pages/AboutSARI.aspx) is one of the main institutions located at KACST. SARI provides a pivotal springboard towards the development of the space and aeronautical future in Saudi Arabia. SARI works on the reinforcement of the Saudi Arabian position in Space and Aeronautical Technologies for peaceful use. The main objectives of SARI include the localization and development of space research and technology, the significant enhancement of the GIS capabilities, the implementation of an advanced Earth observation satellite system, and the creation of a thriving common commercial program for executing cutting-edge technology in Space and Aeronautics sector.

4.2.4.1.5. The Saudi Center for Remote Sensing and GIS Center (SCRS)

Remote sensing technology plays an important role in Saudi Arabia. For this reason, SCRS (https://www.kacst.edu.sa/eng/RD/pages/content.aspx?dID=66) was established in 1988 at KACST. The main goals of the Center are to transfer and adapt advanced technologies in the field of remote sensing and to conduct scientific research in the field of remote sensing techniques and spatial information. SCRS focuses on the following areas of scientific research and application: Data from Satellites, Atmospheric Detection and Monitoring, Natural Hazards, National Spatial Data Infrastructure, Urban Development, Vegetation, and Natural Disaster Management [63].

4.2.4.2. The Saudi Satellite Program (SSP)

Today satellites and their technology play an important role in fulfilling the strategic needs of nations. Saudi Arabia seek to possessing satellite technologies in order to strengthen the local capability to transfer and localize these sectors in the country.

KACST leads the national strategy of localizing the satellite industry and carries out a number of programs to locally manufacture satellites and to oversee major national satellite programs in collaboration with global organizations and institutes.

SSP is well-established with scientific and technological purposes. It was initiated in 1998 and, in 2007, renamed as the National Satellite Technology Program. This program is the most advanced satellite program in the Arab region. Table 4-1 illustrates the SSP.

Table 4-1 A summary of the Saudi Satellite.

Satellites	Launch Date	Mission	Highlights
Saudi-sat 1 A	2000	Data Communications	Opened for Amateurs
Saudi-sat 1 B	2000	Data Communications	Opened for Amateurs
Saudi-sat 1 C	2002	Data Communications	First Video Imaging
Saudi-sat 2	2004	Remote Sensing	HR Video Imaging
Saudi-comsat 1	2004	Data Communications	Commercial Applications
Saudicomsat 2	2004	Data Communications	Commercial Applications
Saudicomsat 3	2007	Data Communications	Commercial Applications
Saudi-comsat 4	2007	Data Communications	Commercial Applications
Saudicomsat 5	2007	Data Communications	Commercial Applications
Saudicomsat 6	2007	Data Communications	Commercial Applications

Saudicomsat 7	2007	Data Communications	Commercial Applications
Saudisat 3	2007	Remote Sensing	Commercial RS – 2.5 m Pan
Saudi-sat 4	2014	Technology Verification in Space	Amateur Radio Satellite
Saudi Sat-5b	2018	High-Accuracy Remote-Sensing Satellite	High-resolution images, Urban planning, Monitoring changes on the Earth's surface
Saudi Sat-5a	2018	High-Accuracy Remote-Sensing Satellite	High-resolution images, Urban planning, Monitoring changes on the Earth's surface
SaudiGeoSat-1 SGS -1 /HellasSat-4	2019	Telecommunications and Remote Sensing	Remote Sensing, Television, Radio, Internet, and Mobile Communications
Arab-sat 6A	2019	Telecommunications Satellite	Television, Radio, Internet, and Mobile Communications

4.2.4.3. The Saudi Arabian Space Geodesy Program (SASGP)

Due to Space Technology priority needs in Saudi Arabia, KACST launched SASGP with the objective to provide high-accuracy information to Saudi scientific researchers for the exploration and study of Planetary Geodynamics, Earth Atmosphere, Oceans, and Geospatial Analysis. The SASGP project instruments network was installed in six sites in Saudi Arabia. Many factors were taken into consideration in order to suitable sites for the network. The SASGP consists of the following geodetic instruments: Lunar Laser Ranging – LLR, Satellite Laser Ranging – SLR, Space Debris Tracking – SDT, Global Positioning System – GPS, Very Long Baseline Interferometry – VLBI, and Continuous Operating GNSS Network– COGNET [65].

4.2.4.4. The Cosmic Ray Detectors Outreach Programs in Saudi Arabia

Astronomical observation of the Sun, Moon, and planets is the most vital research in Saudi Arabia. Current research focuses on Cosmic Ray detection and monitoring in the Saudi scientific community. KACST launched Cosmic Ray Studies as a new field of research in 2000 in collaboration with the High Energy Astrophysics group at the University of Adelaide, Australia. The project has been begun for aiming to establish a Radiation Detector Laboratory at KACST. The main objective of this project is to provide advanced technology in A&SS to Saudi scholars [66].

The future long-term plan for the Cosmic Ray Program in Saudi Arabia is summarized as follows: 1- To study the cosmic ray modulation on different timescales as well as their effect on the Saudi community, 2- To studying the effect of cosmic ray variations during harsh environmental conditions, 3- To provide advanced training and qualified staff regarding the handling and analysis of cosmic ray data and to conduct theoretical simulations using the relevant software, and 4- To secure scientific cooperation with regional and international organizations and research centers around the world [66], [67].

4.2.4.5. Astronomy and Space Science in Saudi Arabia universities

A&SS education in Saudi Arabia began in 1958 at the Physics and Astronomy Department of the King Saud University (KSU) [13]. This Department is the oldest department in Saudi Arabia, as well as the department includes a14-inch Clestran telescope, advanced solar laboratory, a 3-m Radio telescope, and a planetarium with more than 100 seats, equipped with astronomical measurement instruments. Moreover, the Physics and Astronomy Department afforded B.Sc., M.Sc, and Ph.D. programs in Physics and Astronomy. The Astronomy Department at the King Abdulaziz University (KAU) was established in 1976, as the first Astronomy program in Saudi Arabia. The Bachelor degree program in Astronomy began in 1976, a Master degree program in 2004, and a Ph.D. degree in 2016. KAU has a 45-cm Rich-Chriterian double telescope and a 24-cm Schmidt telescope, as well as other tools and instruments.

According to the QS Universities Ranking in Physics and Astronomy published in 2019, the Saudi universities took fourth position in Arab world university rankings in the fields of Physics and Astronomy. The King Abdulaziz University KAU ranked (301 - 350) as the first universty in the Arab region. The King Abdullah University of Science and Technology ranked (351 - 400), the King Fahd University of Petroleum and Minerals ranked (401 - 450), and the King Saud University ranked (551 - 600) [68].

4.2.5. Astronomy and Space Sciences in Morocco

Recently, A&SS research and education has been growing strongly in Morocco compared to other fields of sciences [17]. Astronomy began in Morocco when the Oukaïmeden Observatory was built in 1988 as the first professional observatory in Morocco [17]. Astronomy education in Moroccan universities have gegun the graduate program in A&SS, for example, the Abdelmalek Essaadi University, the Ain Chock

University, the Alakhawayn University, the Chouaib Doukkali University, the Universite Mohammed II, and the Cadi Ayyad University. A few programs are directed to masters and doctoral studies in A&SS [69]. Moreover, the High Energy Physics and Astrophysics Laboratory at Cadi Ayyad University was installed in 1999 and, later, the Royal Centre for Remote Sensing. There are more than twenty Astronomical societies and clubs in Morocco. In 2004, an innovative project for promoting Astronomy education in high schools in Morocco was accomplished, implemented by the Al Akhawayn University founded by a grant from International Astronomical Union (IAU), to support the continued, long-term development of A&SS in Morocco [69].

In Space Science and Technology sectors, Morocco has joined the space race in order to strengthen the role of space technology as related to the socio-economic development as a whole in the country. Morocco launched the Moroccan Space Program in 2013 with a vision to establish the Space Science and Technology Center in Morocco. Morocco's first Earth observation satellite, called "Mohammed VI-A," was launched in 2017 [56]. The second Earth observation satellite, called "Mohammed VI-B" was launched in 2018 [70]. Both satellites were launched from the Vega Launch Complex in Kourou, French Guyana. Furthermore, the Mohammed VI-A and Mohammed VI-B satellites were equipped with latest generation technological capabilities which include high-resolution images capability. The two satellites run under the authority and direction of the Royal Center for Remote Sensing Space (CRTS), as well as operated by Moroccan engineers and scholars. In the following section, we present a brief summary of the most important A&SS activities and organizations in Morocco.

4.2.5.1. The Oukaïmeden Observatory

The Oukaïmeden Observatory was established in 1988, located in the High Atlas Mountains at an elevation of 2750m and 50km south of Marrakech, Morocco [17]. In 2009, the

Oukaïmeden Observatory was recognized as the Research Institute at the Cadi Ayad University. The Observatory site is located in a semi-desert area with a median seeing of 1 arcsec and more than 200 days with clear nights. The Observatory is equipped with a 50-cm diameter telescope known as the Morocco Oukaïmeden Sky Survey (MOSS) telescope. This telescope is operated via remote control by three teams at the Marrakech Cadi Ayyad University, in France, and in Switzerland. A 50-cm robotic telescope has been operating since 2011 and it provides a large field of view and is somewhat devoted to asteroid search [17], [71]. (Figure 4-11).

As it well known, the stellar images created by a telescope is distorted by atmospheric turbulence. In order to minimize that negative effect, the Differential Image Motion Monitor of Marrakesh (DIMMAR) was installed [72]. In addition, the Oukaïmeden Observatory carried out an essential role in the extraordinary discovery of the seven planetary systems orbiting TRAPPIST-1. Recently, MOSS has become one of the most productive telescopes in the world regarding findings of small bodies in the Solar System which has led to promoting the international reputation of the Observatory staff and facilities[17], [73].

Figure 4-11 The Oukaïmeden Observatory (Credit: the Oukaïmeden Observatory)

4.2.5.2. The Arab Astronomical Society (ArAS)

The ArAS (http://ar-as.org/index.php) was established in 2016 in Morocco and it serve as the second organization responsible for A&SS in the Arab world [29]. The ArAS is formed of both Arab scholars and students who are working in the A&SS disciplines across the Arab nations. The main objectives of ArAs are to strengthen, raise, and improve research in A&SS in the Arabic region.

The ArAS has a strategic plan aimed at developing two sectors, human capacity resource and scientific research in fields of Astronomy and Astrophysics. This plan is classified into three parts, as follows, 1- Short-Term (2015 - 2016), the essential objective as to establish the ArAS and to announce its legal recognitive. 2- Medium-Term (2015 - 2020): at this stage, the main objective is to spread and develop the A&SS educational program in Arab universities at all degree levels. 3- Long-Term (2020 - 2025): at this stage, the principal objective will be to present well-educated Arab specialist in A&SS with high-quality research capabilities in order to play an essential role in igniting the Arab Scientific revolution in these fields of research.

To sustain and encourage Arab researchers and students in the field of Astrophysics, ArAs has implemented several initiatives and activities summarized below.

4.2.5.2.1. The Arab Winter School for Astrophysics (AWSA)

AWSA began in 2016 as the first, major, and unique initiative provided by ArAs in the Arabic region [29]. AWSA is a collaborative project between the Harvard-Smithsonian Center for Astrophysics and the Cadi Ayyad University at Morocco, supported by the Office of Astronomy for Development (OAD) of the International Astronomical Union (IAU) [29]. The AWSA aims to provide a good opportunity for the sharing of Astrophysics knowledge among Arab astronomers and astrophysicists in order to build an influential acknowledgeable Arab community in the field. The AWSA took place with the cooperation of the Cadi Ayyad University, Marrakesh, Morocco in 2016 and the second version of the school was hosted at Al Akhawayn University in Ifrane, Morocco, in 2017. The third version of the school was held in Beirut, Lebanon in 2018 and the fourth version will be held at the Kottamia Astronomical Observatory, Egypt in 2019.

4.2.5.2.2. The ArAS Mobile Observatory (ArAS-MO)

The ArAS-MO is intended to afford an excellent opportunity for Arab researchers and students in different Arab countries, especially those where there are no advanced telescopes Because it provides high level training in order to develop professional and technical skills in the utilization of telescopes. Moreover, it provides useful data and studies conducted by users in the Arab world to determine the best places to build astronomical observatories in the Arab world [29].

4.2.5.3. The Royal Centre for Remote Sensing (CRTS)

The CRTS (https://www.crts.gov.ma) was established in 1989. The main objective of the CRTS to increase the exploitation and improvement of Remote Sensing Applications in Morocco by acquiring, archiving, and diffusing data and images, observing Earth, completing projects [74]. The CRTS provides training and education opportunities in Space and Remote Sensing technologies, affords advanced tools and methodologies in space technologies, and supports partnerships and cooperation for research activities and programs with universities and research institutions. Moreover, CRTS is supervised by the Morocco Space Program and the Satellites Program [75].

4.2.5.4. The Sahara Sky Astronomical Observatory Hotel

The Sahara Sky Astronomical Observatory (http://www.saharasky.com/saharasky) the Arab world is first privately astronomical observatory, established in 2004. The aim is to support astronomical tourism in Morocco, offering a comfortable opportunity for amateur astronomers to monitor the sky with suitable observation conditions. The Observatory location is equipped with advanced astronomical instruments including several telescopes, binoculars, Astro imagers, astronomical software, and other astronomical tools.

4.2.5.5. The Atlas Dark Sky Project (ADSM)

The ADSM (https://atlasdarksky.com/) is an amazing project, operated and directed by the Oukaimeden Observatory team. The aim of the ADSM is to create a global starry sky reserve in Morocco as the first unique project in the Arab countries and Africa. The ADSM site provides a sky of exceptional quality and is protected in order to several scientific, educational, cultural goals related to the protection of the night environment and the study of the effects of light pollution on dark skies through environmentally responsible outdoor lighting.

4.2.6. Astronomy and Space Sciences in Algeria

Algeria is one of the Arab countries that has paid increasing attention in A&SS throughout the last years. The history of Astronomy in Algeria is linked to the Algeria Observatory or known today as the Bouzaréah Observatory that was established in 1980 [16]. In 1962, the astronomical activities in the Observatory were ceased after the French astronomers left Algeria. Following that, the Observatory lacked scientific direction. The Observatory was scientifically recuperated when the Observatory was put under the direction of the Astrophysics and Geophysics Astrophysics Research Center [16]. Recently, Algeria has taken serious steps to construct a new leading astronomical observatory in the Aures Mountains, known as "the Aures Observatory" in order to provide new research facilities to the Algerian astronomical community as well as cooperation on international A&SS projects [76]. Astronomy in Algeria entered a new era when The Center for Research in Astronomy, Astrophysics, and Geophysics (CRAAG) was established in 1985. CRAAG consists of three scientific divisions: Astronomy, Astrophysics, and Geophysical research. A new Space Weather Observatory will be established in the coming years at Tamanrasset, in southern Algeria [56]. Astronomy education in Algeria is poor and is not included in school curricula nor at the universities level [76].

To develop Space Science and Technology sectors, Algeria established the Algerian Space Agency (ASAL) in 2002 with the main objective to develop and strengthen the Space Science and Technology sector in Algeria. The ASAL supervised the Algerian Satellites Project by administering the launching of four satellites: Alsat-1, Alsat-1B, Alsat-2A, and Alsat-2B. The Graduate School of Technology and Space Applications at the Oran University Sciences and Technology Department performed the first Algerian educational CubeSat called ¨ALCUBESAT-1¨ [77].

Next, we present a brief summary of the most important activities and organizations in field of Astronomy and Space Science in Algeria.

4.2.6.1. The Algiers Observatory or Bouzareah Observatory

Algiers Observatory or Bouzareah Observatory was built in 1890 during the French occupation of Algeria. The Observatory played a major role in the development and implementation of astronomical activities in Algeria until 1962 under the operation of French Astronomers. In 1962, Algeria become independent from the French colonization and all of the French scholars left Algeria. After that, the Observatory lacked scientific direction because of the lack of Algerian astronomers. The Observatory was scientifically and physically recuperated after almost twenty years when the Observatory was incorporated under the administration of the Astrophysics and Geophysics Astrophysics Research Center [16]. (Figure 4-12).

Figure 4-12 The Algiers Observatory or The Bouzareah Observatory (Credit: CRAAG)

4.2.6.2. The Center for Research in Astronomy, Astrophysics, and Geophysics (CRAAG)

The CRAAG one of the most extensive scientific and technological research centers for Astronomy, Astrophysics, and Geophysics in Algeria. CRAAG was established in 1985 as the result of the merging of the Institute of Physics of the Globe of Algiers (IMPGA) which was founded in 1931 and the National Center for Astrophysical Astrophysics and Geophysics (NCAAG) which was founded in 1980. CRAAG aims to promote and support those fields of research in order to ensure the perm anent follow-up of the natural geophysical and astronomical phenomena throughout the Algerian territory.

The present structure of the CRAAG consists of several scientific divisions, to advancing research in Astronomy, Astrophysics, Geophysics, and Seismology. The CRAAG has two research areas: Solar Astrophysics and Stellar and High-Energy and provides high-quality capabilities and tools as well as two superior laboratories, the Stellar and the second Astronomy Laboratory and the Astrophysics Laboratory. In order to enhance scientific research in A&SS in Algeria and the Arab nations, CRAAG organizes the Algerian Conference on Astronomy and Astrophysics every year [78].

4.2.6.3. The Algerian Space Agency (ASAL)

The ASAL (http://www.asal.dz/index.php) was established in 2002 to replace of the National Center for Space Technology (CNTS) which was founded in 1987. ASAL is the instrument of the government's space policy to be used as a tool for space and technology development in Algeria. The main target of ASAL is to administrate and implement the Algerian Space Program which is concentrated on four priorities to enhance research areas in A&SS as follows: 1- Implementation of the Earth observation and telecommunications satellite. 2- Construction of cutting-edge space ground infrastructures in order to enhance national capabilities in these sectors. 3- Provision of excellent education and training for the Algerian scientific community. 4- Establishment of international cooperation and partnerships in the space sector at regional, continental, and international levels. Under the direction of ASAL, Algeria launched six satellites for scientific and commercial objectives: Alsat-1 in 2002, Alsat-2A in 2010, Alsat-1B in 2016, Alsat-2B in 2016, Alsat-1N in 2016, and Alcomsat-1 in 2017 [79], [80]. Moreover, ASAL has a future plan to put four satellites into orbit [77].

4.2.6.4. The National Aures Observatory

Due to the fact that there is one observatory in Algeria at the current time. And the Algerian astronomical community has grown, the Algerian Government has taken a decision to construct a new astronomical observatory in the Aliness region in the Aures Mountains in upcoming years [76]. The new candidate site for the Observatory provides the optimal criteria for astronomical observations, located at some 1800m above sea level, and the number of cloudless nights is very satisfactory (72.5‘% of total nights with more than 6 hours of clearness and 78.8% with more than 4.5 hours of clearness). The Aures Observatory has both scientific and educational objectives. The scientific objectives within current astronomical research include multi-messenger Astronomy and the educational objectives are to strengthen the astronomical knowledge of students, amateurs, and the general public in Algeria. The first step to the realization of this pioneering project is to test the site and the second phase involves the installation of cutting-edge instruments. The Observatory will be operational in 2021 [76], [81].

4.2.6.5. The Sirius Astronomy Association (SAA)

The SAA (https://www.siriusalgeria.net) was established in 1996 at Constantine, Algeria. The main objectives of SAA are to promot, encourage, and disseminate A&SS knowledge in the Algerian community. Every year, SAA are organizing and implementing astronomical activities in Algeria. One of the most satisfactory activities is as known ¨ Astronomers as Society Science Relays¨ that aims to spread the astronomical scientific culture in Algeria and is directed toward school and university student sas well as the public community. The main initiative supervised and developed by SAA is APODAR (http://www.apodar.com/about-us/). APODAR is an acronym for Astronomy Picture of the Day in the Arabic language and its purpose is to provide a new picture every day of the universe, accompanied by a simple commentary description in Arabic in order to enhance and enrich the astronomical content in the Arabic language with the goal of making this human scientific knowledge accessible to the Arabic community.

4.2.7. Astronomy and Space Sciences in Qatar

Qatar has recently risen to make its way diligently to the vanguard in the pioneer countries of A&SS research. This research is mainly focused on two areas, space and satellite technology and the discovery of exoplanets. In the last decade, Qatar started the first actual steps to developing and instituting effective A&SS research. Since 2010, Qatar launched the Qatar Exoplanet Survey QES [82] with the objective to discover exoplanets, researchers in Qatar have identified ten exoplanets: Qatar-1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, and 10b [83]–[87]. According to Qatar's National Vision 2030, Qatar aims to provide advanced satellite services and technology and to be a leader and world-class operator of these sectors. Qatar launched two satellite: Es'hail-1 satellite was launched in 2013 and Es'hail-2 was launched in 2018.

In the follow section, we present the astronomical organizations and projects in Qatar.

4.2.7.1. Qatar Exoplanet Survey QES

In order to make a positive impact on the development of A&SS research and education in Qatar, the Qatar Environment and Energy Research Institute (QEERI), in collaboration with the Hamad Bin Khalifa University and the Qatar National Research Fund, launched the QES (http://www.qatarexoplanet.org/). This project is designed to search and detect new extrasolar planets by using the transit method. The QES is worthwhile in terms of inspiring new generations of Arab scholars regarding extrasolar planets as well as providing a new methodology for extracting physical and dynamical knowledge from information provided by QES telescopes. The QES uses innovative space exploration technology to detect exoplanets with telescope in three places around the world, New Mexico (USA), Tenerife (Spain), and Urumqi (China). Since 2010 until today, ten new exoplanets have been discovered and named as follows Qatar-1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, and 10b. In the next chapter of our study, we present more details about the project.

4.2.7.2. The Qatar Astronomical Center (QAC)

QAC (http://qatar-falak.com) is a scientific center established in 2007. The main objectives of the Center include the dissemination of A&SS in Qatar at every level, the introduction of A&SS curricula in all academic stages at schools and universities, and the construction of an astronomical observatory of the Center to provide scientific research opportunities, equipped with high-quality instruments. QAC supervises the preparation of an Arabic Dictionary for Astronomical and Space Science and an Astronomical Encyclopedia in the Arabic version.

4.2.7.3. Al Thuraya Planetarium

The Al Thuraya Planetarium is located at the Cultural Village Foundation (KATARA) (http://www.katara.net). The Planetarium provides visitors a unique tour around the galaxies of the universe in a simplified manner that is appropriate for children and adults in two languages, English and Arabic. It affords a rare experience to visitors, especially students, families, and Astronomy enthusiasts, blending education and entertainment, in order to increasing teaching for new generations in different fields Astronomy and Space Science knowledge and awareness. The Planetarium consists of a hall exhibition with a seating capacity of more than 200 people, a 22 -meter FHD screen, and state-of-the-art digital projectors for 3D and 4K tutorial shows. The Planetarium displayes information about more than 200 data sets classified into five categories: Astronomy, Space Science, Atmosphere, Geology, and Earth Science. (Figure 4-13).

Figure 4-13 Left, Al Thuraya Planetarium Hall. Right, Al Thuraya Planetarium Internad Design (Credit: https://www.katara.net/en/communities/al-thuraya-planetarium)

4.2.8. Astronomy and Space Sciences in Iraq

Iraq witnessed revolution in A&SS until the 1980s in all aspects, as compared with other Arabic countries. After the 1970s, A&SS in Iraq grew significantly and A&SS was popularized through the introduction of the subject in both schools and university curricula [25]. The Iraqi National Observatory at Mount Korek in Iraqi Kurdistan was established in 1981, equipped with 3.5-m and 1.25-m optical telescopes, as well as a 30-m radio telescope. After difficult years following the 1980s, the A&SS programs and facilities in Iraq were truly collapsed almost to zero [18]. A&SS education in Iraqi universities is poor, there is only one university in Iraq has an Astronomy department (the University of Baghdad) and the rest of Iraqi universities offer A&SS courses through the Physics Departments, as an elective course.

The main reason for the collapse of A&SS in Iraq has been political conflict and crises. The Iraq-Iran war in 1980, the First Gulf War 1991, and the Second Gulf War 2003 destroyed all astronomical facilities in Iraq. The majority of the Iraqi scholars and astronomers left the country after that time [25].

A brief summary of the most important activities and organizations in field of Astronomy and Space Science in Iraq follows.

4.2.8.1. The Iraqi National Astronomical Observatory (INAO) (Erbil Observatory at presente)

The Observatory INAO or what is known today as the Erbil Observatory was established in 1981 at Mount Korek in Erbil city in the north of Iraq at an altitude 2127m above sea level. The Observatory has three telescopes: a 3.5-meter optical telescope, a 1.25-meter optical telescope, and a 30-meter millimeter wavelength radio telescope. Furthermore, the Observatory has additional astronomical observing instrumentation such as different kind of photometers and different types of spectrographs [88]. (Figure 4-14).

Unfortunately, the Observatory was damaged for the first time in the Iran-Iraq war and then again destroyed during the Second Gulf war by the US Air Force. The International Astronomical Union (IAU) and many Observatories worldwide have given support to assist in the revival of the Observatory, both physically and scientifically. Many plans have been submitted for the renewal and development of the Observatory, promoting education and research, working together with further plans to assist Iraqi astronomers through the IAU [25].

Figure 4-14 Left, the Iraqi National Astronomical Observatory (Erbil Observatory) and Right, a 30-meter Radio Telescope (Source:http://www.poyntsource.com/Richard/IOTAMeeting2011.htm)

4.2.8.2. The Department of Astronomy and Space at the University of Baghdad

The Department of Astronomy and Space at the University of Baghdad was established in 1998 as the only department involved in this specialization in Iraq. The vision of the Department is to prepare new generations of students to be highly qualified in A&SS and the Department of Astronomy has begun to award the Bachelor, Master, and Doctorate degrees in different disciplines in the field of A&SS. The University of Baghdad constructed astronomical Observatory for educational goals, equipped with different observation instruments including two small reflector telescopes with diameters of 40cm and 20 cm respectively.

4.2.9. Astronomy and Space Sciences in Lebanon

Recently, A&SS research and education in Lebanon is on the rise due mainly to the great effort of Lebanon's A&SS community. Astronomy in Lebanon appeared in the nineteenth century and its development is linked to the Lee Observatory and the Ksara Observatory. The Lee Observatory was established in 1873 at the American University of Beirut and the Ksara Observatory was established in 1906 or 1907 at Santi-Joseph University [15]. Due to the increase of the astronomical society in Lebanon, the Farid and Moussa Raphael Observatory (FMRO) was constructed in 2013 at Notre Dame University Louaize (NDU). Those three observatories have scientific and educational objectives [89]. In 1997, the Lebanese Government decided to the introduce subjects A&SS in schools and universities [15]. A&SS is part of the Physics Curriculum in some Lebanese universities for the Bachelor degree and Notre Dame University-Louaize (NDU) and Universite St-Joseph (USJ) offer a Master degree in A&SS. The American University of Beirut (AUB) has begun a Ph.D. program in A&SS as a part of the Ph.D. in the Theoretical Physics Program.

Lebanon has participated in the ´´space race´´ since 1960. The Lebanese Rocket Society was founded by Manoug Manougian in1960. He is considered to be the father of the Lebanese space program, unfortunately, the Lebanese space project came to an end, for political reasons [90]. Lebanon has launched a new project to manufacture nanosatellites that are called Lebanese Cube Satellites, to be used in scientific and educational goals for sustainable development in Lebanon. The Lebanese Cube Satellite is the first Lebanese satellite and is under the direction of the National Council for Scientific Research [91].

A brief summary of the most important activities and organizations in field of Astronomy and Space Science in Lebanon follows.

4.2.9.1. The Lee Observatory

The Lee Observatory is the first and the oldest astronomical observatory in the Middle East, established in 1873 at the campus of the American University of Beirut. The Observatory functioned for sky viewing and meteorological forecasting for the Middle East. The Observatory is equipped with a 12 inch refractor telescope installed in 1892, a 7 inch photographic doublet in 1906, and a Spectro-helioscope instrument installed in 1927. The Lee Observatory served for religious, educational, and scientific purposes. Unfortunately, after the Lebanon war in 1979, the Observatory closed and all activities were discontinued [15]. (Figure 4-15).

Figure 4-15 The Lee Observatory (Credit: http://ddc.aub.edu.lb/projects/tour/nojava/b12.html)

4.2.9.2. The Ksara Observatory

The Ksara Observatory (http://www.ksara.com.lb) was founded in 1902 at the Santi-Joseph University in Ksara city, south of Lebanon. For main purpose of resolving meteorological and seismological issues. The facilities included an 8-inch refractor telescope, a spectrometer, a microphotometer. The Ksara Observatory was used for astronomical interests such as star observation as well as Telluric Bands measurements, however, it was closed in 1979 after the Lebanon Civil War (Figure 4-16) [15].

Figure 4-16 The Ksara Observatory (Credit: http://www.ksara.com.lb)

4.2.9.3. The Farid and Moussa Raphael Observatory (FMRO)

The FMRO was established in 2013 on the campus of the Notre Dame University-Louaize (NDU) in Beirut. The Observatory was constructed for a Master degree program in Astronomy and Astrophysics with collaboration between the Notre Dame University-Louaize and the University Santi-Joseph to provide high-quality facilities for astronomical research projects in Lebanon. The FMRO instruments include a 61-cm Dale-Kirkham Astrograph telescope and many astronomical instruments such as Photometry, two Photometric Filters, a Littrow high-resolution Spectrograph, cutting-edge camera system, and Spectroscopy. Since the FMRO was founded, the Observatory provides satisfactory opportunities for researchers and students by providing high-quality research in Astronomy and Astrophysics (Figure 4-17) [89].

Figure 4-17 Left, The Farid and Moussa Raphael Observatory. Right, the Farid and Moussa Raphael Dale-Kirkham Astrograph Telescope (Credit: the Farid and Moussa Raphael Observatory by R. Hajjar)

4.2.10. Astronomy and Space Sciences in Sudan

In Sudan, like many of the developing countries facing economic and political issues, interest in A&SS has recently emerged. There are only two universities offering a program in Astronomy: the Islamic University of Omdurman established in 2009 and the University of Khartoum. Other universities in Sudan offer A&SS as part of the Physics curriculum for a Bachelor degree. Sudan lacks astronomical facilities, there are no observatories nor telescopes nor governmental A&SS outreach programs for the public. The most active non-government society for A&SS in Sudan territory is the Sudanese Society for Astronomy and Space Science (SSASS) which offers several activities in A&SS events now and then for the Sudanese public.

The Institute of Space Research and Aerospace (ISRA) was established in 2013 for developing various fields of research in A&SS disciplines [56]. Furthermore, the Space Research Center was established in 2014 at the University of Khartoum as an umbrella for all entities that conduct well-established research in A&SS activities as well as strengthen new A&SS research to be initiated in Sudan in the coming years. In 2011, the University of Khartoum launched the first project to manufacture the Cube Satellite in Sudan following the international standards of CubeSat designation. The National Remote Sensing Authority was instituted in 1977 and renamed as the Sudanese Remote Sensing Authority (RSA) in 1996, affiliated with the National Council for Research. The main objectives of the RSA are to propose and coordinate Space Science and Technology policies for the Sudanese government. Finally, the Sudan government has a strategy plan for the establishment of the Sudan Space Agency as a first significant step toward effectively participating in sustainable development in Sudan.

A brief summary of the most important activities and organizations in field of Astronomy and Space Science in Sudan follows.

4.2.10.1. The Institute of Space Research and Aerospace (ISRA)

The ISRA (http://www.isra.sd) was founded in 2013, affiliated with National Center of Research (NCR). The ISRA is the first research institute that aims to transfer and develop Space and Aerospace Technologies sectors in Sudan, to nationalize the research and development of A&SS and technology in Sudan and to organize and implement the Sudan National Space Program which was begun in 2012. The Sudan National Space Program was launched to boost the development of space activities intended to contribute to the economy and scientific development of Sudan. The ISRA includes five research Departments, as follows: Communication Systems, Electronic Systems, Aerospace Engineering, Astronomy and Physical Science, and Applied Programming.

At present, the ISRA provides training for all A&SS communities in Sudan in order to improve research in these areas. ISRA was initiated to implement two main projects in the cube-satellite programs known as ISRASAT-1 and ISRAHAB-1 which are an educational projects for designing and manufacturing nanosatellites [92], [93]. ISRA has future plans to develop A&SS sectors in Sudan, with partnerships and cooperation Cube-Satellite Project of the University of Khartoum (UofK) and the Sudanese Remote Sensing Authority (RSA) in order to implement the following projects: 1- Establishment of the Satellite Ground Station, 2- Launch of the QB50 Educational Satellite, 3- Design of the Aerial Surveillance System, 4- Establishment of the Astronomical Exploration, and the Center and Ground Telescope [56].

4.2.10.2. The Space Research Centre at the University of Khartoum.

The Space Research Centre (http://staffpages.uofk.edu/space-research-centre-4/) was instituted in 2014 at the University of Khartoum UofK. The UofK Space Research Center provides cutting-edge infrastructures in space and technology for all Sudanese researchers in order to conduct research in the space technologies and satellite telecommunications and to cooperate with all possible local and international space research centers to develop research in A&SS.

In addition, the UofK Space Research Centre developed and implemented a Cube-Satellite project as the first satellite project in all Sudanese universities following the international standards of Cube-Satellite designation. In addition, the Center installed a fully functional educational ground station in order to track and command Cube-Satellite project [94]. The UofK Space Research Center launched the initiative called Space Technology for Sustainable Development in Sudan as an ambitious venture by young scientists in A&SS to strengthen and reinforce A&SS and technologies utilization in Sudan. The initiative is to draw attention and to increase awareness of the role of the capabilities of A&SS for developing countries to attain sustainable development.

4.2.10.3. The Sudanese Remote Sensing and Seismology Authority (SRSSA)

In order to develop Remote Sensing, GIS, and GPS applications as advanced technologies in Sudan, the National Remote Sensing Center NRSC was established in 1977 [95]. The NRSC was renamed as the Sudanese Remote Sensing Authority (RSA) in 1996. In 2013, it was renamed as the Remote Sensing and Seismology Authority (RSSA,http://rssa.gov.sd) to cover seismological research activities. RSSA training is offered by seven sections and units as follows: 1- the Natural Resources Mapping Department, 2-the Early Warning and Disaster Management Department, 3- the Seismology Department, 4-the Space Technologies Department, 5- the Geophysics and Geologic Formation Department, 6- the Seismology data and information unit, and 7- the Training unit. The RSSA programs are oriented toward sustainable development in Sudan and offer effective programs for human and institutional capacity building in the country. The future perspectives of the RSSA include the establishment of long-term training programs in space technology as well as the installation of a ground receiving station Sudan Earth Observation Satellite (SEOS) [96].

4.2.11. Astronomy and Space Sciences in Tunisia

Tunisia lacks astronomical facilities and there is no observatory nor professional telescope in Tunisia [56]. Astronomy is widely practiced by young amateurs and astronomical outreach activities are organized under the direction of non-governmental institutions in Tunisia like the City of Science of Tunis, the City of Science of Tataouine, the National Institute of Meteorology, and the Palace of Science in Monastir. There are three nongovernmental astronomical societies that popularize knowledge on A&SS among the general public in Tunisia: The Astronomical Society of Tunisia (SAT), the

Tunisian Space Agency Society (TSA), and the Youth Science Association of Tunisia (AJST). Unfortunately, A&SS in Tunisia is rare, there are no University courses in A&SS disciplines and A&SS is taught at a very basic level in school curricula. Presently, the Youth Tunisian Astronomical Association launched the Astro-Camping Tourism Project in Djerba as the first step to developing Astronomy in Tunisia [97].

Tunisia joined in the peaceful use of Space Science and Technology in the 1980s. Seeking the development of these sectors, the Tunisian government established the National Commission for Outer Space Affairs (CNEEA) in 1984 and the National Center for Cartography and Remote Sensing (CNCT) was established in 1988. Recently, other organizations have begun working to develop Space Science in Tunisia, e.g., the Research and Studies Communication Centre (CERT), the Center for Research in Microelectronics and Nanotechnology (CRMN), and the National Institute of Meteorology. All of those organizations oversee and develop Space Science and Technology in Tunisia. Tunisia hosts international centers in Space and Technology fields such as the North African Center for Remote Sensing (CRTEAN), the Arab ICT Organization (AICTO), and the African Association for Geospatial Development [98]. In 2019, the Tunisian TELNET Group Company announced the launch of the first Tunisian satellite in 2020 which will be called “Challenge 1 " with the cooperation of a Russian operator of commercial launches of Soyuz-2 rockets, GK Launch [99].

A brief summary of the most important activities and organizations in field of Astronomy and Space Science in Tunisia follows.

4.2.11.1. The National Commission for Outer Space Affairs (CNEEA)

The CNEEA was established in 1984. The main objective of CNEEA on promoting Space and Technology areas in Tunisia

[100]. The CNEEA is involved in programs and activities that include project studies, human capacity building, and awareness-raising in Tunisian scientific community.

4.2.11.2. The National Center for Cartography and Remote Sensing (CNCT)

The CNT was founded in 1988, aiming for promoting remote sensing, research, and training for Tunisian scientific community[98]. In 2009, the CNT was renamed as the National Center of Cartography and of Remote Sensing (CNCT) (http://www.cnct.defense.tn/). CNCT missions were expanded to cover Cartography, Geodesy, Topography, Photogrammetry, and Gravimetry. The CNCT has established several cooperation and partnerships agreements with research centers and laboratories in national, regional, and international. These agreements are focused on the realization of common scientific research projects through the programs of scientific and technical collaboration.

4.2.11.3. The North African Center for Remote Sensing (CRTEAN)

The CRTEAN was created in 1990 at Tunisia as a regional center in the field of Remote Sensing research cooperation. CRTEAN member states Algeria, Egypt, Libya, Morocco, Mauritania, Sudan, and Tunisia. The main goal of the CRTEAN is to advance, encourage, and harmonize the plans of the member countries in the fields of Remote Sensing, Geographic Information Systems, and Cartography [101].

4.2.11.4. The Astronomical Society of Tunisia (SAT)

The SAT (http://www.sat.tn/) is a non-official scientific organization that was established in 1990. The SAT was initiated by the personal effort of some amateur astronomers in Tunisia with the objective of popularizing A&SS knowledge in Tunisian society. The strategy of the SAT include many aspects such as adding the study of Astronomy in school curricula as well as the university level, directing astronomical academic research for students, providing the required human and material resources for academic research, establishing A&SS clubs in the Tunisian territory, organizing diverse scientific conferences and workshops, translating and publishing valuable astronomical scientific documents in the Arabic language. Since 2010, SAT has annually published the Tunisian Astronomical Ephemeris book, "Ezzij Ettounissi", in Arabic. This book offers simple astronomical knowledge to the public in order to develop astronomical culture in the Tunisian society, in particular, and the Arab society, in general [102].

4.2.11.5. The Tunisian Space Agency (TSA)

The TSA (http://tunispacedays.com/) is a non-governmental scientific association established in 2012 with the objective of promoting and developing A&SS fields in Tunisia. The main goal of the TSA is to create and organize a scientific society of young people in the field of A&SS and their technologies, as well as to enrich the scientific scene in Tunisia by supporting and producing high-quality studies and research in these fields.

4.2.11.6. The Astronomical Planetarium at Tunis Science City

The Science City of Tunis (http://www.cst.rnu.tn/en/accueil) was established in 1992 as an institution dedicated to disseminating scientific culture throughout the Tunisian society. In A&SS fields, the Tunis Science City provides several initiatives directed to school students and the public. The Astronomical Planetarium at Tunis Science City's opened in 2002 and includes several Exhibitions Halls equipped with world-class tools including a full-dome HD projection system that provides the public with the opportunity to interest themselves in the phenomena of the cosmos, to discover colored stars, giant planets, and how to navigate their way through space.

Furthermore, Tunic Science City publishes an annual Magazine known as "El Madar" in the Arabic. El Madar encompasses the texts of all the scientific Astronomy topics and highlights the role of Information Technologies in developing A&SS research.

4.2.12. Astronomy and Space Sciences in Syria

A&SS research and education in Syria is weak due to the lack of astronomical facilities. No observatory nor professional telescopes exist. Modern Astronomy appeared in Syria in 1997, the moment of the of launch the International Network of Oriental Robotic Telescope Project (NORT). The major aim of the NORT is to enhance and develop research in A&SS in Syria as well as in developing countries [103], [104]. The General Organization of Remote Sensing (GORS) was established in 1986, aiming to develop studies and projects in Remote Sensing applications. Recently, the GORS announced the establishment of an office for astronomical studies in order to strengthen and develop A&SS activities in Syria [105]. The Syrian Astronomical Association (SAA) was established in 2004, aiming to disseminate astronomical knowledge in the Syrian community. A&SS education and research in Syria is not functioning well. There are no A&SS Departments in Syrian universities, however, a few topics of A&SS levels were introduced at school curricula. In addition, the national Syrian committee for developing A&SS was established recently in order to implement and develop astronomical activities in Syria [104].

Regarding Space Science and Technology, the Syrian government announced in 2014 the launch of the Syrian Space Program which includes the construction of the Syrian Space Agency as well as the Syrian Satellite Project. In addition, since the Syrian civil war began in 2011, that led to the emigration of the majority of Syrian scientists abroad due to fear of war. Various programs for the development of the Space Technology sector were also delayed.

Next, we present a brief summary of the most important activities and organizations in field of Astronomy and Space Science in Syria.

4.2.12.1. The Network of Oriental Robotic Telescope (NORT)

The NORT project is international. It began in 1997 in order to establish a series of robotic telescope networks on high mountain peaks around the Tropic of Cancer, from Morocco in the West to the desert of China in the East. The NORT is supported by United Nations and European Space Agency to enhance A&SS research and education in developing Arabic countries. NORT plays an important role in the development of both scientific and educational A&SS fields in Syria. The main scientific and educational objectives of the NORT are summarized as follows: 1- Improving A&SS research by means of partnerships in different projects; 2- Establishing an astronomical database platform by utilizing interferometry and photometry for the variable stars; 3- Providing new advanced research techniques in A&SS in the Arab astronomical communities, 4- Participating in, the preparation, of A&SS curricula at all levels of universities and school study, and 5- Collaborating in astronomical summer schools and camps [103], [104].

4.2.12.2. The General Organization of Remote Sensing (GORS)

The National Remote Sensing Center was established in 1980, and renamed as the General Organization of Remote Sensing (GORS) (http://www.gors.sy/home-en/) in 1986. The main objective of the GORS is to carry out Aerospace and Land Surveying using Remote Sensing Technology in order to utilize this information in exploring and exploiting natural resources in Syria [105]. Recently, GORS has taken serious steps to establish an office for astronomical studies, aiming to administrate and promote A&SS activities carried out by GORS. The astronomical studies office has three sections at the GORS campus: the Observatory, the Planetarium department, and the coordination and astronomical data exchange department. Furthermore, GORS has carried out a significant study to select the best location for the robotic telescopes in Syria within the NORT project by using Remote Sensing techniques [104].

4.2.12.3. The Syrian Astronomical Association (SAA)

The SAA (http://www.saaa-sy.org) is a non-governmental organization established in 2004, previously known the Syrian Amateur Astronomers Association. The main objective of the SAA is to broaden astronomical knowledge among different social levels, by implemented different astronomical scientific activities. The SAA has other objectives that we summarize as follows: 1- Providing Astronomy education to the Syrian society, 2- Rekindling the Arabic historical heritage in Astronomy, 3- Inserting A&SS topics in school curricula in Syria as obligatory subjects, and 4- Implementing diverse astronomical activities like Observations nights and astronomical camps. In 2017, the SAA constructed a new observatory including two telescopes: a 14-inch Dobsonian Telescope and a Celestron computerized telescope, as well as the establishment of a Planetarium and Exhibitions Halls.

4.2.13. Astronomy and Space Sciences in Libya

A&SS in Libya is limited due to lack of astronomical facilities or observatories. The most important astronomical initiatives in Libya are observation and astrophotography as well as monitoring eclipses and comets. To renew interest in A&SS research, the Libyan government signed a memorandum of understanding with a French company to build a 2-meter robotic telescope [11]. Unfortunately, this project canceled because of political conflict. The Libyan Center for Remote Sensing and Space Science (LCRSSS) was established in 1989 as a governmental institute specialized for research in Remote Sensing, Space Technology, Seismology, and Astronomy [106, pp. 213–215]. In Space Technology, Libya is classified a country with al ow rating in this field. The political turmoil and conflicts in Libya have led to the complete cessation of the scientific movement in A&SS as well as other sciences in Libya.

Next, we present a brief summary of the most important activities and organizations in field of Astronomy and Space Science in Libya.

4.2.13.1. The Libyan Center for Remote Sensing and Space Science (LCRSSS)

The LCRSSS (http://www.lcrsss.ly) is a governmental research institution founded in 1989 and headquartered in Tripoli, with branches in different regions of Libyan territory. The Center is directed to several scientific sectors, as follows: Space Science Technology, Astronomy, Remote Sensing, and Seismology. The main objectives of the LCRSSS are to contribute to the achievement of sustainable development through the establishment of a fruitful collaboration between different scientific disciplines in Libya in order to provide high-quality training of national cadres conducting world-class scientific research in these fields. The LCRSSS includes several Centers, one is the Center of Astronomy and Observatories. The aims of this Center are to provision the facilities to investigate the motion of heavenly bodies using high-quality astronomical tools in order to analyze data and to investigate astronomical phenomena such as solar activity and its effects on the atmosphere, as well as to determine and furnish prayer times and astronomical calendars [106, pp. 213–215].

4.2.14. Astronomy and Space Sciences in Kuwait

Over the previous years, there has been some interest in A&SS in Kuwait. Modern Astronomy was introduced in Kuwait by Dr. Saleh Al-Ojeiri who is known as a father of Kuwait Astronomy [107]. Al-Ojeiri has made a great effort in building an astronomical community in Kuwait. He built the Al-Ojeiri

Observatory in 1977 which was the first observatory in the country [108]. Kuwait National Radio Observatory (KNRO) was established in 2009, aiming to carry out a long-term research program of investigating the Milky Way Galaxy. Several non-governmental astronomical societies like the Kuwait Astronomical Society which established in 2015, the Al-Merzem Astro-Team Society, and the Astronomy Department at Kuwait Science Club have the objective to play a prominent role of the invigoration and development of A&SS throughout the country, as well as to integrate A&SS in the academic field. No Kuwaiti universities provide A&SS education at all levels; some Physics Department afford elective course curricula in A&SS disciplines. Furthermore, A&SS topics in school education are limited and not well-established. A few astronomical themes were mentioned in science curricula, yet it must be modernized and developed. Unfortunately, Kuwait has not yet established a Space program.

Next, we present a brief summary of the most important activities and organizations in field of Astronomy and Space Science in Kuwait.

4.2.14.1. The Kuwait National Radio Observatory (KNRO)

KNRO (http://astronomy.ksclub.org/) was established in 2009 as the first research-grade Radio Observatory of its kind in the Middle East. KNOR construction is divided into several stages. The primary phase involves the building a 5-meter radio telescope, including proper observational instruments as well as high-performance software in order to allow for perpetual study of the origins and the evolution of galaxies, in general, and the Milky Way galaxy, in particular. This step was designed and manufactured by national cadres. The Observatory has a strategy for the development of national technology in the area of Astronomy facilities in order to provide scientific opportunities for academic research in the field of Astronomy and Space Science.

4.2.14.2. The Al-Ojairi Observatory

The Al-Ojairi Observatory established in 1977 in Kuwait City with an individual prominent effort by Dr. Al-Ojairi. The Observatory is equipped with several telescopes, cameras, and other types of astronomical equipment. The main instrument in the Observatory is a 50-cm Reflector Schmidt-Cassegrain telescope that is used for monitoring the distnat planets and celestial bodies as well as astronomical imaging. Moreover, the Observatory has three 6-inch telescopes to track the sun, solar activity, and photograph the Moon and bright planets. Since 2007, the Al-Ojairi Observatory has installed latest generation instruments in order to be recognized center of astronomical research in Kuwait. It has a robotic system capable of tracking faint heavenly particles with the accuracy of less than one arc minutes and both the telescope and the dome move automatically when the telescope moves to its target.

4.2.14.3. The Kuwait Astronomical Society

The Kuwait Astronomical Society in Kuwait was established in 2015 as the first astronomical organization in Kuwait. The main objective of the society is to disseminate astronomical knowledge to the general public in Kuwait as well as to enhance astronomical research and education in their universities. The society implements several initiatives such as the Astronomical Summer School and training.

4.2.15. Astronomy and Space Sciences in Oman

Oman has lacked on astronomical professional infrastructure, but they have begun to be concerned about A&SS for religious issues and have established the Department of Astronomical Affairs in the Ministry of Endowments and Religious Affairs. No Omani universities taught on A&SS program. The Physics

Department at the Sultan Qaboos University afforded 18 credits in Astronomy. The A&SS topics are not well-established in school curricula which must be updated and developed. The Oman Astronomical Society (OAS) is the only organization in Oman that deals with astronomical activities. The OAS is trying to manufacture a small satellite called ´´Inspire Sat-1´´, the project of the first Omani satellite which will be launched into space by 2019 [109].

Next, we present a brief summary of the most important activities and organizations in field of Astronomy and Space Science in Oman.

4.2.15.1. The Oman Astronomical Society (OAS)

The OAS (http://www.falakoman.org) is a non-governmental and non-profit organization established in 2004. The OAS was serves as an umbrella for astronomical activities in Oman. The essential aim of the OAS is to disseminate astronomical knowledge to the public through the implementation of a series conferences, seminars, lectures, and exhibitions relating to A&SS. The OAS is mainly focused on areas such as space-based earth observations and monitoring, participation in A&SS education, astronomical projects and observatories, youth and amateur astronomy research projects, the peaceful usage of Outer Space Technology, and solar activities. The OAS is involved with the development of A&SS through four programs, as follows: 1- Hosting the Mars simulation project (Mars Analogue Mission (AMADEE-18)) in partnership with the Austrian Space Forum [110], 2- The Space Oasis Hall, 3- Participation in the development of the Oman Space Program, and 4- Implementation of the first Omani cubic satellite. Recently, under the supervision of the OAS, the first Omani satellite, Inspire Sat-1, will be launched in 2019. In addition, in order to help raise awareness and knowledge of Astronomy across the country, the OAS with collaboration in Petroleum Development-Oman (PDO) will construct a Mobile Planetarium. The Mobile Planetarium is a valuable educational and entertainment tool for promotion of the understanding of astronomical phenomena and the Cosmos [111].

4.2.15.2. The Department of Astronomical Affairs

The Department of Astronomical Affairs at the Ministry of Endowments and Religious Affairs was established in recent times and was created for religious issues that are related to Astronomy. The Department consists of three Division: The Department of Monitoring the Crescents, the Department of Astronomical Observatories and Telescopes, and the Department of Islamic Calendar and Astronomical Reports. The objective of the three departments is to supervise all Islamic religious issues that depend on Astronomy [112].

4.2.16. Astronomy and Space Sciences in Bahrain

A&SS in Bahrain is limited due to insufficient and inadequate astronomical facilities. Bahraini universities do not provide or teach Astronomy program at all levels. The Physics Department at Bahrain University affords elective courses in A&SS. A&SS in school education must be updated and strengthened. The Bahrain Astronomical Society is the only organization in Bahrain that is concerned with the astronomical activities across Bahrain. The Center for the Care of Talented Students in the Ministry of Education has plans to offer a program in the field of Astronomy and Space Science under the name of "Falak" in collaboration with the University of Bahrain. The program is oriented to increase awareness in these fields and address a variety of topics including the history of Astronomy, the contributions of Arabs and Muslims in Astronomy, the importance of Astronomy in recent times, and the astronomical instruments for observing the skies.

With reference to Space Science and Technology, Bahrain announced the launch of their National Space Science Agency.

The main objective of the new agency are to set up a cutting-edge infrastructure for the observation of outer space and the Earth in order to advance the methodology of scientific research and to encourage technical innovation in A&SS [113].

4.2.17. Astronomy and Space Sciences in Yemen, Mauritania, Palestine, Somalia, Djibouti, and Comoros

Unfortunately, we could not cover the rest of the Arab countries, e.g., Yemen, Mauritania, Palestine, Somalia, Djibouti, and Comoros in our work. The main reason for that was the lack of information about the reality of A&SS in those countries, in addition, to the fact that most of them are political challenges such as civil war, political conflicts, and crises. These factors have led to the decline of all sciences, in general, including A&SSs. Throughout partnerships and collaborations with the Arab Union for Astronomy and Space Sciences, the Arab Regional Office of Astronomy for Development (AW-ROAD), Regional Centre for Space Science and Technology for Western Asia, and the Arab Astronomical Society the expectation is to develop A&SS sector in these Arabic countries in the future.

4.3. CONCLUSIONS

A&SS is considered to be a very important field of science with a large budget, massive instrumentation, and crucial scientific research. However, major investment in A&SS is also necessary to advance discoveries in science and technology that can be applied to improve our life on Earth [1]. Innovations from A&SS technologies have reshaped our contemporary society by instituting and elaborating human capacity in these sectors and enriching academic knowledge and innovative research. The intention is to apply creativity to knowledge in these areas of sciences in order to construct a knowledge-based economy. Groundbreaking changes and revolution arising from technological development have become indispensable to A&SS [3].

. Therefore, it is critically necessary for the Arab countries to establish themselves in A&SS and their technologies for the 21st century, strengthening the relevance of leading-edge technologies and research which will be pivotal to addressing the essential problems facing Arab societies [11] [12].

In line with the vision of various Arab countries regarding the development of A&SS, many Arab countries have witnessed remarkable activity during the last two decades in the establishment of A&SS facilities and expert research centers. Several A&SS projects were initiated at that time and are still in development now in the Arab countries. There is a lack of latest generation observatories and telescopes [8]. Throughout the Arab region, the largest is a 1.88 m diameter telescope at Kottamia Observatory, Egypt [19]. On the other hand, a few telescopes have been constructed in the Arab region in the past years, however, those astronomical observatories did not provide the desired development of A&SS research. Nowadays, it will be necessary to establish an Extremely Large Telescope (ELT) as a common project in the Arab region and many studies were carred out in order to choose a suitable site for the location [114], [115]. ELT is considered to be one of the highest priorities in the establishment of ground-based Astronomy and will immensely advance A&SS knowledge, allowing Arab researchers to advance research in A&SS [8].

As a result of the recent increase in A&SS-related activities, many Arab countries have shown interest in investing in these vital sectors which are now widely regarded as some of the most important emerging economic areas worldwide. The Arab nations have already begun to take serious steps in the race toward investment in space science and related scientific research which reflects the importance of this sector regarding economic development and human progress [40] [50] [82]. Opportunities in the A&SS sectors are more easily available today in the Arab countries with more access to knowledge sharing that helps in creating an integrated A&SS ecosystem. The current objective is to utilize the available potentials within international and regional cooperation to develop an integrated, comprehensive A&SS ecology [29]. The A&SS sectors work as a motivational wheel to develop other sectors such as education, communications, transportation, health, research, and industry which will, in turn, enhance the quality, precision, and creativity of Arab human resources capacity.

A&SS education in both schools and universities is poor and only a few A&SS topics are taught in school curricula in the Arab countries [37]. Several of the Arab universities offer multidisciplinary A&SS at all levels of study. Some of the universities in Egypt, Saudi Arabia, Morocco, Algeria, Iraq, Jordan, and Lebanon grant a B.S, M.S, and a Ph.D. degree in A&SS. To increase the awareness in A&SS education, it will be necessary to establish A&SS as a fundamental component of the curricula in schools as well as to establish compulsory A&SS courses at the university level [8].

Today, it is important to prepare a future strategic plan for A&SS development in the Arab world that can be used to address, strengthen, and improve these sectors. This plan illustrates how A&SS training equips scientists with interdisciplinary technological and scientific skills essential for the rapid and full development of A&SS in the Arab nations [8] [11].

Recently, the resolution to develop competence in Space Science Technology has been underscored by increasing interest by some Arab countries to make Space Technology part of the overall development strategy, in view of its invaluable benefits, and to contribute to its own development and knowledge globally. The United Arab Emirates, Saudi Arabia, Egypt, and Qatar have begun the establishment of leading projects in this field. Space technology offers a wide range of innovative and cost-effective solutions to the challenges of development arising from the need for geospatial data acquisition and critical communication infrastructures.

Satellites and Cube-Satellites are widely utilized in Telecommunications, Remote Sensing, and scientific research in the Arab region. Several Arab countries have considerable projects for satellite programs, such as Saudi Arabia, the United Arab Emirates, Egypt, Algeria, Morocco, Qatar, Sudan, Lebanon, and Jordan have successfully launched satellites in low orbits of the Earth. Saudi Arabia is considered to be at the forefront in this field having launched sixteenth satellites to date [70] [91] [75].

This work aims to highlight modern A&SS in the Arab world. We have divided this work into two parts in order to provide comprehensive coverage. In Part A, we will present a summary regarding activities and organizations involving A&SS. In Part B, we will present a brief summary regarding Scientific Research, Future Outstanding Projects, and Pioneer Arab Scientists in A&SS.

Finally, in this study, we found a great gap between Arabic countries and most of the other developed countries in these fields of research and knowledge, not to mention that this gap is widening every day. We have concluded that it is crucial to make every possible effort in order to narrow this gap and to try to catch up with the global progression in these branches of science.

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5. CHAPTER 5: EDUCATION, SCIENTIFIC RESEARCH, AND FUTURE OUTSTANDING PROJECTS IN ARAB ASTRONOMY

5.1. INTRODUCTION

Astronomy and Space Sciences (A&SS) has become a significant field of study that combines knowledge and technology. Therefore, A&SS can play a central role in promoting education, building human capacity, and furthering sustainable development in the Arab world [1]. Hence, this work presents the second part related to Education, Scientific Research, Future Outstanding Project, and Pioneer Arab Scientists in A&SS to highlight the contemporary development of A&SS in the Arab world. Furthermore, a roadmap for the development of A&SS in the Arab countries is presented.

Currently, educational systems in Arab countries do not align with the significance of A&SS compared to developed countries. Mostly, A&SS is taught as a part of the General Science, Geology, and Geography curricula for primary, preparatory, and secondary levels in Arabic education systems [2]. Ministries of Education and Higher Education in Arab countries need to reform their educational system to consider A&SS as an important and mandatory field of study for curricula at all levels (i.e. schools and universities). Also, they need to provide academic or training programs for teachers of different educational stages. Unfortunately, at the University level, a few A&SS departments are established in public and private universities [3], [4].

Apparently, scientific research on A&SS faces critical challenges in the Arab world [4]. The lack of infrastructure, financial funding, qualified human capacity, and the availability of access to reliable journal and databases, as well as political crises (i.e. Arab Spring) in some Arab countries [5]. In addition, social, economic, and political factors challenge progressive A&SS research. The output of Arab countries has increased during the past decade, however, contributions lag behind the international average in these Fields [6],[7].

In Arab countries, most scientific research in A&SS is carried out in public and private universities and some research is conducted by specialized research centers and observatories. However, Arab countries need to take serious steps to maintain support in order to enhance the quality of A&SS research. Over the past few years, some of the Arab countries have grown considerably and massive changes in the development of A&SS research has occurred, especially in Saudi Arabia, the United Arab Emirates, Egypt, Morocco, Algeria, and Qatar. However, educational policies in Arab countries have failed to improve productive scientific research in A&SS [8], [9]. Thus, it must be noted that the importance of international partnerships between researchers in Arab countries and international organizations are a key strategy to improve their A&SS research productivity [10]. Moreover, continuous regional cooperation between Arabic states is efficient and constructive for the long-term development of A&SS. The regional cooperation between Arabic states is easy and efficient because Arabic countries are neighbors and tend to share a common culture and language.

Recently, A&SS has played a key role in economic advances and the prosperity and revitalization of modern societies. A&SS technology contributes to steady economic growth and sustainable development activities in all countries [11]. The economic impacts within the framework of A&SS provide a wide area for future investment, such as Satellite Launching, Space Tourism, Information and Internet Technology, Energy from Space, Mars and Lunar Exploration, Discovering Exoplanets, and other fields. Therefore, Arab countries should utilize A&SS research as a powerful tool for social and economic development.

Investment in A&SS requires large budgets, bulky instrumentation, and qualified human capacity. However, the establishment of significant projects in A&SS is required for the Arab countries to participate in advanced discoveries in science and technology that can improve future life. Unfortunately, Arab countries failed in setting any prominent projects in A&SS until recently. The United Arab Emirates and Qatar have generously begun to invest in space exploration. In 2014, the United Arab Emirates launched the Hope Probe Project or Emirates Mars Mission Project (EMM). The EMM is a project to send an unmanned probe to Mars by 2021 as the first space mission in the Arab world to discover another planet [12-14]. Furthermore, Qatar launched the Qatar Exoplanet Survey Project (QES) in 2010 to detect new extra solar planets. Hence, this study focuses on these two unique and outstanding projects [15]. In addition, Saudi Arabia has launched 16 satellites [16] and the United Arab Emirates has several operating satellites such as the Dubai-Sat, Yah-Sat and Khalifa-Sat series [17]. Algeria, Morocco, Sudan, Lebanon, and lately Jordan have launched A&SS projects. This attention has stressed the importance of offering priority to educational, scientific, and technological goals in any space program in the Arab regions. Thus, Arab governments should review and estimate the scientific goals for all proposed common projects.

In the Medieval Arab astronomers provided significant contributions in Astronomy. Their research constituted the modern European Renaissance in the field of Astronomy [18], [19]. Unfortunately, the achievements of very few Arab scientists in A&SS have been mentioned and they have failed to convert advanced research in these fields to date. Currently, Farouk El-Baz, Hamid Al-Naimiy, Noureddine Melikechi, ZouhairBenkhaldoun, Khalid Al Subai and Essam Heggy are the world's most prominent Arab scholars in these fields. There are a few Arab women scientists in the field of A&SS, for example, Maha Ashour-Abdalla, Merieme Chadid, Rim Turkmani, and Laila Abdulatif. In addition, we attempt to present a biographical summary of the most prominent Arab researchers in the fields of A&SS as our idea is to provide convenient access and communication to support future cooperation between Arab scientists in these fields. Therefore, we conducted a comprehensive biographical survey on SCOPUS free database to address their contributions in A&SS.

Finally, A&SS research is a highly ambitious endeavor in which excellence and curiosity are crucial for further progress and success. Success demands dedicated and innovative personalities provided within a suitable Arabic-frame in which talents can be developed in the Arab community. Therefore, our roadmap for the development of A&SS in Arab states aims to provide a framework that points out the strength of the system and provides detailed recommendations for further improvement in its coherence and impact. In addition, the need of such a roadmap for A&SS stresses the need for several activities to be completed by Arabic governments for several intents, which can list as follows.

1- Provide a blueprint for a fruitful investment and research projects in A&SS, as well as establish long lasting infrastructures.

2- Determine priorities for the future directions and facilities for Arabian organizations and universities interested in A&SS.

3- Provide an input to the Arabian vision for A&SS.

4- Coordinate activities in education and awareness of the importance of A&SS among all the Arab countries.

5- Provide regional long-term strategies of A&SS for decisions- makers in the Arab world.

In section two, we described the reality of education and scientific research in A&SS in the Arab World. In section three, we illustrate the present and future outstanding projects of A&SS in the Arab World. In section four, we provide biographies of some recent Arabic exemplary scholars in A&SS. Section five presents the roadmap for the development of A&SS in the Arab World in order to ignite the Arab scientific future revolution in A&SS. In the last section, we draw conclusions and provide guidance for future work.

5.2. A&SS Education and Scientific Research in Arab Countries

5.2.1. A&SS Education in Arab Countries

Recently, A&SS has become one of the critical multidisciplinary disciplines which plays a focal role in the fundamental sciences including Physics, Mathematics, Chemistry, Biology, Telecommunication, and the Geosciences. A&SS involves important cultural and philosophical contents. Therefore, A&SS teaching can play a key role for understanding physical laws, conveying the fundamentals of the scientific method, and demonstrating philosophical thought concerning the origin and evolution of the Universe.

Despite of the importance of A&SS, the teaching of A&SS in Arabian primary and secondary schools is insufficient [2]. Indeed, some Arab countries don't offer A&SS classes or curricula or, at the most, at a very simple level. However, some A&SS elements are included in the Science, Geology, and Geography curricula at all school levels. The mission behind A&SS education is to create student awareness of the Cosmos and the importance of its exploration. Thus, developing A&SS curricula becomes a necessary step for a new Arabic generation aware of the importance of A&SS.

In order to ensure the advancement of A&SS education in the Arabi region, primary and secondary teachers of Physics, Mathematics, Earth Sciences, or Geography should be taught and trained to conduct research in A&SS during their university courses. They should be instructed in scientific topics as well as in new educational techniques. In addition, the establishment of an Arab Organization for Astronomy and Space Science Education is an important step for both school and university teaching, aiming to develop, strengthen, and enrich the A&SS curricula. At the University level, there are a few A&SS departments in public and private universities. Most of the Arab universities offer Astronomy courses in Physics departments. In addition, some universities in the Arab states provide elective courses for university students. Table 5-1 shows the Arab universities that have programs in multi disciplines of A&SS for all degrees [3], [4], [10], [20], [21]. However, it should be a top priority to modernize the curricula of Arab region universities in A&SS and their technologies in collaboration with famous scientists from the USA and the Europe countries.

Table 5-1 Academic programs, and degree offered by Arab universities for A&SS disciplines

University	Country	Bachelor	Master	Ph.D.
King Abduaziz University \ Department of Astronomy	Saudi Arabia	Yes	Yes	Yes
King Saud University \ Department of Astronomy	Saudi Arabia	Yes	Yes	Yes
Cairo University \ Department of Astronomy and Meteorology	Egypt	Yes	Yes	Yes
Al-Azhar University \ Department of Astronomy and Meteorology	Egypt	Yes	Yes	Yes
Beni Suef University \ Faculty of Navigation Science and Space Technology	Egypt	Yes	Yes	Yes
University of Baghdad \ Department of Astronomy and Space	Iraq	Yes	Yes	Yes
University of Blida \ Institute of Aeronautics and Space Studies	Algeria	Yes	No	No
Al al-Bayt University \ Institute of Astronomy and Space Science	Jordan	No	Yes	No
Notre Dame University-Louaize \ Department of Physics	Lebanon	No	Yes	Yes
Universite St-Joseph \ Department of Physics	Lebanon	No	Yes	Yes

5.2.2. Research in A&SS at Arab Countries

High-level research in A&SS plays a vital role in a nation's economic growth, long-term sustainable development, and improvement in the standards of living and quality of life. Despite the fact that the A&SS research productivity of Arab countries has risen during the past decades, it is still developing as compared with the rest of the world. The current reality of Arab world research in A&SS is below expectations. Arab countries contribute very few original research publications in top journals and with low citation frequency. For instance, Guessoum (2014) presented the only study regarding A&SS research in the Arab countries as a biometric study. He used the Thomson Reuters Web of Science to extract publication data for Astronomy, Astrophysics, and Space Science manuscripts for each Arab country. He deduced that the number of Astronomy papers as a proportion of scientific papers for the Arab world is 3 per 1,000 publications regarding Astronomy and Astrophysics research articles in Arabic countries from 1 January 2000 to 31 December 2009 [4].

In Arab countries, most research in A&SS is carried out within public and private universities with some executed by specialized research centers and observatories. There are several reasons for the low production in A&SS research in Arab countries. These reasons can be summarized as follows: political instability in some Arabic countries, regional conflicts, the lack of adequate research infrastructure and facilities, the brain drain of qualified Arab scientists, a shortage of financial support, and the difficulty of publishing in high impact journals.

A&SS research must be supported by a business view to investment research areas which would lead to a more beneficial outcome in the Arab communities. This would help boost the competition for the quality but not the quantity of research. Once the aforementioned occurs, scientific research in A&SS in the Arab world would be able to contribute to the development of sustainable economies.

To assess the global recognition and acceptance of the Arab world universities based on the recent QS Universities ranking in 2019, there are only six Arab universities in the top 1000 universities in the fields of Physics and Astronomy. Saudi Arabian universities dominated as compared with other the Arab world universities, taking four of the top six places in this field. Egyptian universities took two of the top six. Table 6-2 lists the top ranked universities in the Arab world in the field of Physics and Astronomy [22].

Table 5-2 Top Arab Universities in Physics and Astronomy-QS Ranking

QS Rank	University	Country	2019
1	King Abdulaziz University (KAU)	Saudi Arabia	301 - 350
2	King Abdullah University of Science and Technology	Saudi Arabia	351 - 400
3	Cairo University	Egypt	351 - 400
4	King Fahd University of Petroleum and Minerals	Saudi Arabia	401 - 450
5	Ain Shams University	Egypt	501 - 550
6	King Saud University	Saudi Arabia	551 - 600

5.2.2.1. 2.1.1 Method

Bibliometric analysis is one of the most large-scale extensive techniques that is used to estimate scientific research output in many specific fields of research. This tool utilizes statistical indices and quantitative analyses to assess organizations, individuals, and countries in terms of their research output as well as the contribution for offering accurate evaluations of scientific research productivity [23], [24]. With the aim to assess the output of the Arab world in A&SS research, their contributions have been examined by the SCImago Journal & Country Rank SJR.

SJR is an openly accessible portal journals and scientific indicators based on the Scopus ® database (Elsevier B.V.). SJR classifies 27 main subject areas including 313 subjects, categories, and performance metrics from 239 countries regarding research output [25-27].

Additionally, the SCImago Journal & Country Rank SJR web site provides lists of country ranking based on 6 individual features: the number of documents, citable documents total citations, self-citations, citations per document, and H-index [25]. Herein, SJR was searched in September 2019 using the indicator or key word of “Physics and Astronomy” for the main subject area, “Astronomy and Astrophysics” for a specific subject category dated from 1996 -2018, and for the “Middle East” and “Africa” regions in order to extract information about 22 Arab countries.

The main objective of this inquiry was to assess the status of A&SS scientific research based on the research productivity in the A&SS subject. Table 6-3 lists the number of published articles along with some extra bibliometric parameters in Arab countries based on the 6 individual features mentioned above [28].

In addition, the amount of research productivity in A&SS areas from the Arab world has significantly increased in the last ten years. To trace this growth of scientific research production in A&SS in each Arab country over the last ten years (2009 – 2018), we used the same methodology as that used for preparing Table 6-3; the only difference is the estimated research output every year from 2009 to 2018. Table 6-4 presents the published research documents in A&SS in last ten years according to SJR SCIMAGO LAB powered by the Scopus database in all Arab world countries [28].

At present, three significant factors are utilized to assess researcher productivity: the number of publications, the impact factor of those journals [29], and the H-index factor [30], [31]. Bibliometric inquiries are conducted with a standard method using one of the public database libraries such as Google Scholar, PubMed, Web of Science, ResearchGate, and Scopus [32]. In this part of our work, we have chosen to utilize Scopus in order to extract the required data for this analysis. Scopus delivers the most more flexible summary regarding the scientific research production at global levels in all of, the science realms [33 - 35]. Table 5 shows the most prolific Arab scholars in publishing in A&SS research who are affiliated with institutions in Arab countries or across the world.

Moreover, Table 5-4 lists research production in A&SS for each Arab country listed within the last ten years according to the SJR SCIMAGO LAB powered by the Scopus database.

The number of publications linked to the most prolific articles is cited. Table 5-5 shows the most prolific Arab authors indexed by the Scopus database and SJR.

Table 5-3 List of Arab Country Research Production in A&SS Fields from 2008 - 2018 according to the SJR SCIMAGO LAB powered by the Scopus database

Country	Document	Citable documents	Citations	Self-Citations	Citations per Document	H index
Egypt	745	738	5506	1436	7.39	33
Saudi Arabia	636	619	7016	1059	11.03	39
United Arab Emirates	337	336	3402	428	10.09	28
Algeria	273	270	3874	427	14.19	26
Morocco	187	186	2944	364	15.74	29
Qatar	120	117	1561	233	13.01	22
Tunisia	100	98	545	159	5.45	13
Lebanon	89	87	2584	114	29.03	19
Jordan	75	74	389	128	5.19	10
Iraq	53	53	222	55	4.19	8
Kuwait	44	44	292	67	6.64	9
Oman	39	39	151	29	3.87	7
Sudan	25	24	96	17	3.84	5

Mauritius	19	19	58	19	3.05	3
Palestine	15	15	64	29	4.27	5
Syria	11	11	16	6	1.45	2
Libya	10	10	58	6	5.8	4
Bahrain	8	8	41	6	5.13	3
Yemen	8	8	110	5	13.75	3
Somalia	0	0	0	0	0	0
Djibouti	0	0	0	0	0	0
Comoros	0	0	0	0	0	0

Table 5-4 Research production on A&SS for each Arab by Scopus database

Country	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	Total Doc.
Saudi Arabia	57	64	62	75	88	71	63	36	15	7	538
Egypt	57	54	71	64	67	39	45	33	29	26	485
United Arab Emirates	67	74	66	22	26	8	13	5	3	7	291
Algeria	27	22	14	17	29	29	28	16	11	6	199
Morocco	17	18	15	10	10	7	7	4	6	1	95
Qatar	5	8	24	20	21	23	13	4	0	0	118
Tunisia	12	14	5	5	6	8	12	8	8	4	82
Lebanon	6	10	13	8	5	9	2	2	2	7	64
Jordan	9	8	6	1	4	1	4	1	4	3	41
Iraq	8	12	6	8	8	5	1	2	2	0	52
Kuwait	5	7	8	2	4	0	0	2	2	5	35
Oman	6	1	6	4	3	2	2	1	2	2	29
Sudan	4	3	0	1	0	2	1	0	1	3	15
Palestine	2	0	2	0	0	1	0	3	1	1	10
Mauritius	0	0	2	0	0	0	0	0	2	0	4

Syria	0	1	2	0	0	0	0	0	1	0	4
Libya	0	0	0	0	0	0	0	1	0	2	3
Bahrain	0	0	1	1	2	1	0	1	1	2	9
Yemen	2	0	0	0	2	0	0	0	0	0	4
Somalia	0	0	0	0	0	0	0	0	0	0	0
Djibouti	0	0	0	0	0	0	0	0	0	0	0
Comoros	0	0	0	0	0	0	0	0	0	0	0

Table 5-5 The most prolific Arab authors in A&SS research

Author Name	Number of Documents	Subject Research Area	Affiliation Country	Nationality	H-index
Maha Ashour-Abdalla	159	Astrophysics and Space Plasma Physics	University of California, Los Angeles, Los Angeles, United States	Egyptian\American	30
Noureddine Melikechi	120	Atomic, Molecular, and Optical Physics. Photo-sensing, Biomarkers, and Astronomical Data Analytics	University of Massachusetts, Lowell and Delaware States University\ United States.	Algerian \American	23
Farouk El-Baz	103	Space Science, Remote Sensing, Orbital Science Photography, and Astronomy	Boston University\ United States	Egyptian\American	18
Benkhaldoun Zouhair	81	Astronomy, Astrophysics, and Astronomical Instrumentation	Université Cadi Ayyad	Moroccan	13
Khalid Alsubai	67	Astrophysics, Exoplanet Detection, and Photometric Observations	Qatar Environment and Energy Research Institute\ Qatar	Qatari	19

EssamHeggy	65	Space Science, Planetary Science, Hydrogeology, Remote Sensing, Electromagnetic Theory, and Radar Technology	Jet Propulsion Laboratory, California Institute of Technology\ United States	Egyptian	18
Mohammed Adel Sharaf	65	Mathematical Astronomy, Celestial Mechanics, Theoretical Astrophysics, and Stellar Atmosphere	Cairo Universit\ Egypt	Egyptian	8
Merieme Chadid	60	Early Star Formation, Stellar Evolution, Very Large Telescope Implementation	Universite Nice Sophia Antipolis\ France	Moroccan/ French	16
Nidhal Guessom	54	Astronomy, Astrophysics (Gamma-Ray), Theoretical Astrophysics, History of Islamic and Arabic Astronomy, and Philosophy of Astronomy and Science	American University of Sharjah\ United Arab Emirates	Moroccan	13

Shawqi Al-Dallal	47	Astronomy, Astrophysics, Supermassive Black Holes, Dark Matter, Superconductivity, Spin Glass, Laser, and Nanotechnology	Ahlia University\Bahrain	Iraqi	7
Nabil Ben Nessib	34	Plasma Spectroscopy and Stellar Plasmas	King Saud University\ Saudi Arabia	Tunisian	9
Mounib El-Eid	34	Astronomy, Astrophysics, Space Sciences, Cosmology, the Galaxy, Stars, Astronomical Computational Physics, and Complex Systems	American University of Beirut\ Lebanon	Lebanon	10
Marwan Gebran	34	Astrophysics, Astronomy, Model Atmospheres, Chemical Abundances, and Peculiar Stars	Notre Dame University \ Lebanon	Lebanon	14

George Saliba	30	History of Arabic Astronomy, History of Arabic Science, History of Islamic Astronomy, and History of Ancient Astronomy	Columbia University in the City of New York, Harvard University, University of Arizona, and University of Maryland School of Medicine\ United States. Learning Institute for Health Care Professionals \ Malta	Lebanon \ American	13
Abouelmagd Elbaz	31	Celestial mechanics, Astrodynamics, Space dynamics, Non-linear systems, Spacecraft Flying Formation	National Research Institute of Astronomy and Geophysics, Egypt	Egyptian	13
Magdy Sanad	30	Astronomical Instrumentation, Space Vehicles, Astronomical Data Processing, Astrometry, Celestial Mechanics, Galaxy Formation, Stars, and Cosmology	National Research Institute of Astronomy and Geophysics, Egypt	Egyptian	2

Hamid Al-Naimiy	28	Astronomy, Astrophysics, Space Science and Technology, Space Physics, Binary Star, Galaxy Formation, Remote Sensing, Celestial Mechanics, History of Arab and Islamic Astronomy, and Astronomy Education	University of Sharjah\ United Arab Emirates.	Iraqi	6
Raid Suleiman	31	Solar Physics, Stellar Physics, Coronal Mass Ejections, Atmospheric Composition, Imaging Processing, and Planetary Sciences	Harvard-Smithsonian Center for Astrophysics, BBN Technologies, Cambridge \United States		16

Mohamed Ibrahim Nouh	32	Astronomy, Theoretical Astrophysics, Stellar Astrophysics, Stars, Stellar Evolution Rotation, Stellar Physics, Stellar Nucleosynthesis, Massive Stars, and Variable Stars	Northern Border University \ Saudi Arabia National Research Institute of Astronomy andGeophysics, Cairo-Egypt.	Egyptian	5
Somaya Saad	26	Astrophysics, Stellar Spectroscopy, Variable Stars, Exoplanets, Systems, Astronomy Education, and Astrometry	National Research Institute of Astronomy and Geophysics, Egypt.	Egyptian	6
Sayed Robaa	26	Meteorology, Atmospheric Science, Astronomy, and Environmental Science	Cairo University Faculty of Science, Egypt	Egyptian	9

Mashhoor Al-wardat	22	Astronomy, Theoretical Astrophysics, Physical and Geometrical Parameters of Stars, Spectrophotometry of Stars, Speckle Interferometry, Scalar Field Theory, Atmospheric Modeling, Spectral Energy Distributions of the Stars System, and Astronomical Site Selection and Testing	Al Al-Bayt University	Jordanian	6
Ashraf Latif Tadross	22	Astrophysics, Astronomy, Observational Astronomy, Extragalactic Astronomy, Star Clusters, Galactic Structure, and Galaxy Evolution	National Research Institute of Astronomy and Geophysics, Egypt.	Egyptian	9

Magdy Amin	22	Atmospheric Physics, Extragalactic Astronomy, Photometry, Star Formation, Theoretical Astrophysics, and Optical Astronomy	Cairo University \ Egypt. Majmaah University \ Saudi Arabia.	Egyptian	4
Abouazza Elmhamdi	22	Space Science, Solar Physics, Stellar Astrophysics, Supernovae, and Observational Astronomy	King Saud University, Saudi Arabia.	Saudi Arabia	7
Ali Taani	21	Formation and Evolution of Binary Stellar Systems, Single and Binary Star Evolution, White Dwarfs, Neutron Stars, Normal and binary Millisecond Pulsars, Core-Collapse Supernovae, Binary Stars, and Astronomy for Development.	Al-Balqa Applied University \ Jordan. National Astronomical Observatories The Chinese Academy of Sciences and Shandong University \ China.	Jordanian	4

Ahmed Essam	20	Photometry, Star Formation, Optical Astronomy, Stellar Astrophysics, Stellar Evolution, Stellar Physics, and Variable Stars	National Research Institute of Astronomy and Geophysics, Cairo, Egypt	Egyptian	5
Hasnaa Chennaoui	20	Astrophysics, Astronomy, Meteoritics, Planetary Sciences, and Geochemistry	Hassan II University of Casablanca Morocco	Moroccan	9
Essam Ghamry	19	Space Physics, Space Environment, Space Plasma Physics, Solar Activity, Exploration Geophysics, Earth Sciences, and Geophysics	National Research Institute of Astronomy and Geophysics \ Egypt	Egyptian	7
Issa Ali Issa	19	Astrophysics, Astronomy, Observational Astronomy, and Astrobiology	National Research Institute of Astronomy and Geophysics \ Egypt	Egyptian	4
Ahmed El-Sayed Ghitas	18	Space Weather, Solar Cell, and Ultraviolet Solar Variability	National Research Institute of Astronomy and Geophysics \ Egypt	Egyptian	7

Abdel Naby Saad	18	Perturbation Theory, Space Dynamics, Dynamics of Natural and Artificial Satellites, Stellar Dynamic	National Research Institute of Astronomy and Geophysics / Egypt	Egyptian	3
Ayman S. Kordi	18	Astrophysics, Observation Astronomy, and Galaxy Formation	King Saud University, Saudi Arabia	Saudi Arabian	4
Joseph Mikhail	18	Galactic Extragalactic Photoelectric Observations, Crescent Visibility, Planetary Systems, History of Astronomy	National Research Institute of Astronomy and Geophysics, Cairo, Egypt	Egyptian	3
Shahinaz Yousef	16	Astronomy, Space Science Technology, Solar Eclipse, Dark Energy, and Quantum Entanglement	Cairo University, Faculty of Science, Cairo, Egypt	Egyptian	3

5.2.2.1. Results and Discussion

The importance of the scientific research production of any country can be deemed as the most appropriate index to measure this progress as linked with economic growth. Assessing the scientific research in the Arab countries, in both quantity and quality can assist in the evaluation of attempts of the Arab region relative to achieving the objectives of sustainable development and the constructing knowledge-based economy. Current years have witnessed the increased interest to Arab researchers in the A&SS field which is apparently shown by the dramatic growth in the number of scientific productions in these areas.

As stated in Table 5-3, the Arab countries along with their bibliometric indicators of research productivity in A&SS yield different bibliometric indicators. We focus only on one indicator that represents the research of Arab countries over a time period (1996 - 2018). Based on the above statistics on Table 3, the highest rate of research production in A&SS was from Egypt and Saudi Arabia. Egypt produced 745 papers and Saudi Arabia published 636 documents. Furthermore, the United Arab Emirates, Algeria, Morocco, and Qatar have good productivity in research which is relatively better than the rest of the Arab countries. Also, statistics in Table 5-3 show that three Arab countries (Somalia, Djibouti, and Comoros) did not have any research contribution in A&SS. (Figure 5-1).

Available data in Table 5-4 show a considerable disparity between the Arab countries concerning the growth of research on A&SS over the last ten years (2009 - 2018). The largest number of publications in the Arab world was from Saudi Arabia (538), followed by Egypt (485), the United Arab Emirates (291), Algeria (199), Qatar (118), and Morocco (95). Moreover, this analysis shows better productivity in the United Arab Emirates in these fields during the last three years (2016 - 2018). Qatar research productivity in these fields between 2013 and 2016 has dramatically increased. However, a few Arab countries

(Comoros, Djibouti, and Somalia) did not have any contribution in A&SS research.

Table 5-5 shows statistics concerning 35 multidisciplinary Arab scholars in the fields of A&SS. Statistics provide six indicators relevant to the most prominent Arab scholars in A&SS. Results rank scholars in descending order (from the highest to lowest) based only on the number of published articles according to the Scopus database. Additionally, this information provides a clear vision to precisely understanding the present situation of A&SS research productivity in order to provide new insight and demand for increased collaboration and partnership in research activities among the Arab scholars in upcoming years.

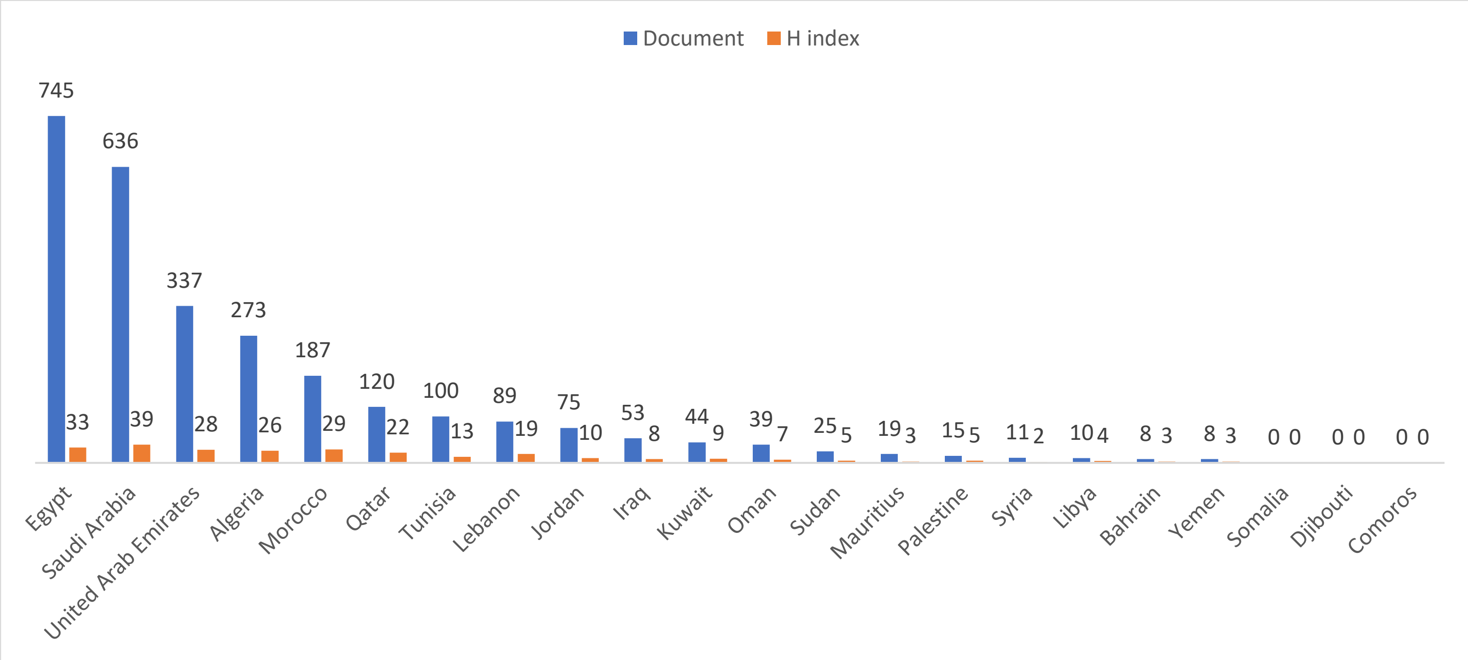

Figure 5-1 Ranking of Arab Countries-Published Papers (1996 - 2018) and the H-Index, SJR

5.2.3. Outstanding Pioneer Projects in Astronomy and Space Science in the Arab Countries in the Present and Future

Some of the Arab countries are entering a new phase of economic development with an emphasis on the crucial role of A&SS and technology in promoting sustainable development and closing the gap with the rest of the world as quickly as possible. Despite some important developments in the field of the A&SS, there are still significant challenges facing the Arab countries in order to outstanding projects in A&SS and technology. The United Arab Emirates and Qatar have entered a new age of excellence and uniqueness in the Arab world and have joined in the space exploration race. In 2014 the United Arab Emirates announced an explorer project known as The Emirates Mars Mission (EMM). In 2010, Qatar launched an explorer project known as the Qatar Exoplanet Survey (QES) to detect exoplanets in the Cosmos. These two projects have opened the door and given a chance to scholars from the United Arab Emirates and Qatar to excel in the field of A&SS engineering as well as A&SS technologies. In the following segment, we mainly focus on these two projects, the Emirates Mars Mission EMM and the Qatar Exoplanet Survey (QES).

5.2.3.1. The Emirates Mars Mission (EMM)

The Emirates Mars Mission (EMM) also called "The Hope Mars Mission", is the most ambitious program in A&SS which has been launched by the United Arab Emirates government EMM is the first Arab mission exploring planets, in general, and Mars, in particular. The EMM project demonstrates the capabilities of Arab scholars as influential contributors to humankind and civilization in modern times. EMM is a major pillar in the UAE government’s Space strategy as well as being a turning point in the country’s progress to establish the Space technology industry as a key in upcoming years to attain sustainable economic development. The EMM was announced by the UAE Government in 2014, launching an unmanned spacecraft called the "Hope Probe" to Mars orbiter on a seven-year journey. EMM completes orbiting Mars in 2021. Table 5-6 shows the scheduled time for this mission.

EMM is designed, directed, and executed by an Emirati team. This team is divided into seven groups as follows, the Hope Spacecraft Group, the Science and Research Group, the Mission Operation Group, the Product Assurance Group, the Ground Station Group, the Strategic Planning Group, and the Launch Vehicle Group. All phases of this project were manufactured, built, and assembled within the UAE. The technical knowledge was developed in the UAE and transferred through collaboration to regional and global partners. More than 150 Emirati scientists and engineers are working on this project. After the data obtained from the probe, Emirati scientists and engineers continue to work together with more than 200 academic and scientific institutions throughout the world with the objective of sharing free information.

Table 5-6 The schedule timeline of the EMM mission

Phase Description	**Time Schedule**
Agreement signed to implement the EMM Project	July2014
Release Mission Concept	2015
Structure and Basic Design	Mid-2015 to mid-2017
Assembly and Build	Mid-2017 to July 2020
Launch Date	July or August 2020
The Probe enters the orbit of Mars (Mars Orbit Insertion)	First Quarter 2021
Scientific Operation and Data Acquisition (Science operation begins)	Mid-2021 to 2023
Extended Scientific operation and investigation	2023 2025

5.2.3.1.1. Strategic and Scientific Objectives of the EMM mission

The EMM mission has strategic and scientific objectives. The strategic goals include building Emirati technical and intellectual capabilities in the fields of Aerospace, Space Technology, and Space Exploration in order to make use of these sectors in a way that enhances the country's development plans. The EMM enriches Emirati capabilities as well as increases human knowledge about Mars and distant planets.

The main scientific objective of the EMM is to explore the dynamics of the atmosphere of Mars as well as the study of climate change on the Red Planet. In order to more deeply understand the Martian atmosphere science issues, the EMM has three specific scientific objectives summarized as follows: characterize the state of the Martian lower atmosphere on global scales and its geographic, daily, and seasonal variability, correlate rates of thermal and photochemical atmospheric escape with conditions in the Martian atmosphere, and characterize the spatial structure and variability of the Martian exosphere [12], [14]. The EMM have created the first integrated model of the atmosphere of the planet, Mars, as well as the study of its climate change. This model may benefit the global Mars science community in order to unlock more mysteries of the Red Planet. Moreover, the study of the climate of mars helps specialists to understand changes in the climate of the Earth.

5.2.3.1.2. The EMM Spacecraft (Probe) Spacecraft Overview

The EMM spacecraft is designed with a hexagonal section shape that carries three cutting-edge scientific instruments and probes. Figure 5-2 shows the EMM spacecraft design.

The EMM spacecraft is linked with a supercomputer equipped with advanced software tools that can manage the mission into the Mars orbit, without human instruction from Earth. In addition, the spacecraft is designed for a three Earth-years lifetime [36]. A summary of the facts about the EMM spacecraft is shown in Table 5-7.

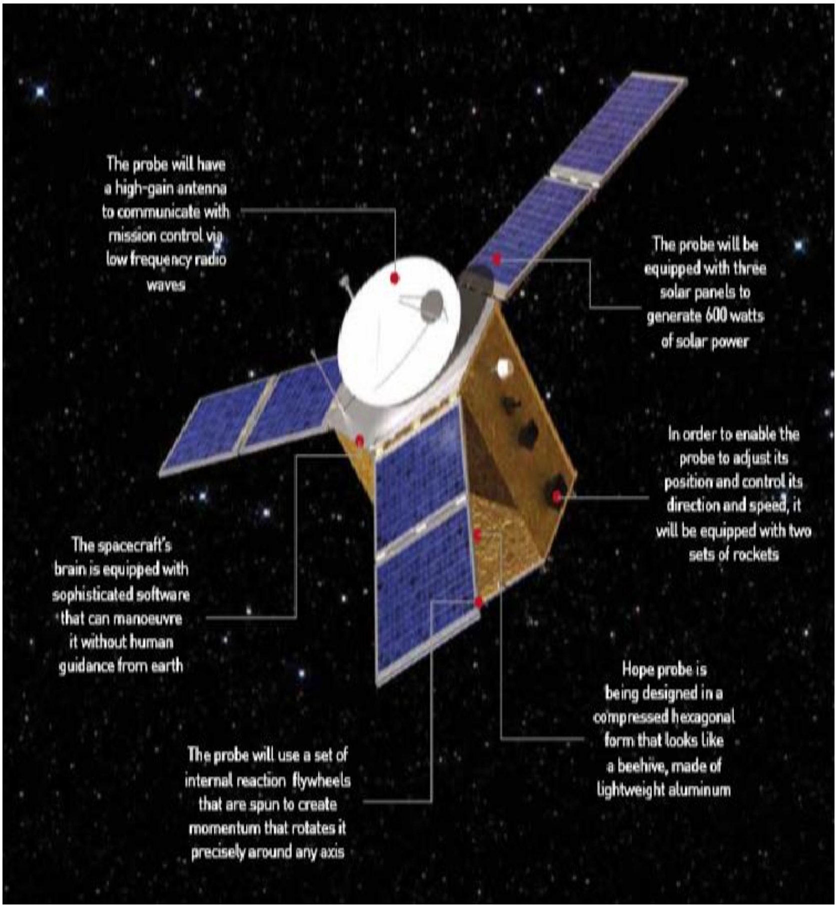

Figure 5-2 The EMM Spacecraft Design and Parts

Table 5-7 A Summary of the facts about the EMM spacecraft

Weight	1,500 kg including fuel
Dimensions	2.37m wide, 2.90m tall (excluding solar panels)
Structure	Aluminum frame with lightweight aluminum honeycomb panels
Solar panels	Three extendable 600W solar panels
Antennae	High-gain (directional) antenna with 1.5m dish with additional non-directional low-gain antennas
Data bandwidth	1.6 mbps at Mars's closest point to earth
Navigation sensors	Star trackers, Sun sensors
Thrusters	Four to six large 120-Newton thrusters for acceleration and braking, Eight to twelve small 5-Newton thrusters for delicate maneuvering
Positioning	Set of internal Reaction Wheels to rotate the probe around three axes

5.2.3.1.1. The EMM Scientific Instruments Overview

The spacecraft carries three science instruments for a mission to study the Martian atmosphere: the Emirates exploration Imager (EXI), the Emirates Mars Infrared Spectrometer (EMIRS), and the Emirates Mars Ultraviolet Spectrometer (EMUS) [36]. A summary of these instruments is shown in Table 5-8.

Table 5-8 Summary of the EXI, EMIRS, and EMUS Instruments

Instrument	Capability	Supplier	Task	Spectral range
EXI	Ultraviolet visible camera	LASP and MBRSC	Measure the optical depths of dust and water ice in the Martian atmosphere at 220 nm and 320 nm	205-235nm 245-275nm 305-335nm 405-469nm 506-586nm 620-650nm
EMIRS	Fourier transformation infared Spectrometer	ASU and MBRSC	Measure the global distribution of key atmospheric parameters over the Martian diurnal cycle and year, including dust, water ice (clouds), water vapor and temperature profiles	6-40 microns

EMUS	Ultraviolet Imaging Spectrograph	LASP and MBRSC	Measure relative changes in the thermo-sphere and the structure radial extent and scale height of both the hydrogen and oxygen exospheres	100 -170 nm

5.2.3.2. The Qatar Exoplanet Survey (QES)

The Qatar Exoplanet Survey Project (QES) is an extensive project with the objective of discovering new extrasolar planets. The QES was launched in 2010 under the direction of the Qatar Environment and Energy Research Institute (QEERI) at Hamad Bin Khalifa University (HBKU) in Doha, Qatar. The QES project is operated by a Qatari research team in collaboration with scientists from the United Kingdom and the United States. The QES aims to detect new exoplanets by a transit method in which inquiring exoplanets help and provide more information about how our solar system was formed. Exoplanet science projects are always beneficial in terms of inspiring new generations of scientists and driving potent new ways of extracting astronomical scientific knowledge from large observation datasets [15].

The QES telescopes sites, are strategically oriented to provide better temporal coverage of northern and equatorial stars. These sites are located in three different geographic locations, as follows: New Mexico (USA), the Canary Islands (Spain), and Urumqi (China)[15].Every site has eight telescopes including a cutting-edge robotic wide-field camera system which allows the scientists to monitor the sky over a 24-hour period. All of the received data from these stations are processed at QEERI at the Hamad Bin Khalifa University. The QES team developed a new algorithm known as the Doha algorithm for data reduction techniques and spectra extraction [37].

Since 2010, the Qatari team discovered ten new exoplanets called Qatar-1b, Qatar -2b, Qatar -3b, Qatar -4b, Qatar -5b, Qatar -6b, Qatar -7b, Qatar -8b, Qatar -9b, and Qatar -10b. All those planets are classified as heavy hot Jupiter family gas giants that are not suitable for life. Table 5-9 presents a summary of some physical and geometrical parameters for the Qatar Series Exoplanets [38-43].

The future goal of the QES project is to expand its capabilities by establishing more observing sites in locations around the world in order to contribute to more discoveries of extrasolar planets. The QES will improve Qatar's A&SS research profile across the scientific world community. In addition, the QES team plans to automate and simplify the techniques for reliable detection of exoplanets using Earth-based small telescopes in order to facilitate the participation of a larger number of scientists and amateur astronomers around the world and improve and accelerate the detection of exoplanets.

Table 5-9 Geometrical and physical parameters of discovered Exoplanets.

Planet	**Mass** M_J: **Jupiter's mass**	**Radius** R_J: **Jupiter's Radius**	**Orbital period**
Qatar -1b	1.09 ±0.08 M_J	1.16 ±0.05 R_J	1.42 days
Qatar -2b	2.487 ±0.0.086 M_J	1.144 ±0.035 R_J	1.337 days
Qatar -3b	4.31 ±0.47 M_J	1.096 ±0.14 R_J	2.5079 days
Qatar -4b	6.1 ±0.54 M_J	1.135 ±0.11 R_J	1.8054 days
Qatar -5b	4.32 ±0.11 M_J	1.107 ±0.064 R_J	2.87925 days
Qatar -6b	0.67 ±0.070 M_J	1.06 ± 0.07 R_J	3.506 days
Qatar -7b	2.03 ± 0.250 M_J	1.70 ± 0.03 R_J	2.0321 days
Qatar -8b	0.371 ± 0.062 M_J	1.285 ± 0.022 R_J	3.715 days
Qatar -9b	1.19 ± 0.16 M_J	1.009 ± 0.014 R_J	1.540 days
Qatar -10b	0.736 ± 0.090 M_J	1.54371 ± 0.040 R_J	1.645 days

5.2.4. A RoadMap for Development of A&SS in the Arab World

Based on the extensive review, many questions have risen about A&SS in the Arab world such as what is the position of the Arab world in the great A&SS revolution during current times? What are the plans and programs required to bridge the gap between the Arab world and developed countries in A&SS fields? Is it possible for the Arab world to keep up with superior technology in A&SS areas?

This is the time for the Arab countries to generate a new scientific revolution in all aspects of the A&SS fields. In pursuit of a distinct Arab renaissance in these fields, we present our recommendations as a roadmap for the development of A&SS in the Arab world. This roadmap is designed to develop strategic plans (short, medium, and long term plans) aimed at providing a framework in which A&SS can best evolve by providing detailed recommendations to further improve their progress and impact in the Arab region, as follows.

1- Establish the Arab Space Agency. The first step to the development of A & SS in the Arab region is the establishment of the Arab Space Agency under the supervision of the Arab League. The establishment of the Arab Space Agency is one of the major dreams and aspirations of all astronomers and scientists in the Arab world, due to its important role in the promotion and development of A&SS in the future. The Agency should be the sole umbrella organization to organize and direct all A&S SS activities, projects, and initiatives across the Arab world. The Agency's financial support can be based on a financial contribution from all Arab countries, according to the GNP of each.

2- Build a world-class Ground-Base Observatory including an Extremely Large Telescope (ELT) as well as accelerate the effort to establish high-class observatories in several countries, including specialized analysis tools needed to deal with big datasets.

In the Arab regions, there are several excellent observation sites that to meet international standards to distinguish the construction of the observatory site. In 2014, Guessoum presented a theoretical study of the preliminary search for suitable sites for the construction of astronomical observatories in the Arab region through the use of international standards to determine the observatory's location in the world. Abdul Aziz (2017), in collaboration with the Sorbonne University in France and the American University of Sharjah in the United Arab Emirates, presented another study to investigate the best astronomical observatory in the Arab world, using satellite measurements. These studies provide valuable information for the construction of future astronomical observatories. Table 5-10 presents the most cited astronomical observatories in the Arab region according to previous studies.

3- Nevertheless, educational policies in Arab countries have failed to effectively catalyze education in the fields of A&SS. Therefore, it is necessary to re-orient their education system towards innovation and entrepreneurship. Hence, establishing the Arab Organization for Astronomy and Space Science Educations (AOASSE) is a first step to develop and encourage A&SS education at all levels. The organization strategy plan may have three central themes in A&SS: academic training, scientific research, and regional scientific collaboration. The AOASSE must work for the following objectives.

I. Promote a greater interest and awareness of A&SS education.

II. Augment the A&SS content in both primary and secondary school curriculums.
III. Increase the effectiveness of A&SS education at all levels through research and the exchange of information and experience between Arab countries.
IV. Establish A&SS programs in all public and private universities.
V. Set exchange agreements with global international institutions.
VI. Fund Arab students to pursue postgraduate programs at universities abroad.

4- Financial support should be made available for small to medium-size research projects that will be carried out by Arab scientists in the future at the level of individual research groups or through regional and international collaborations.
5- Establish a robust and well-coordinated research programs between Arab scientists who are concerned with the following active research topics: Planetary Exploration and Exoplanets, Stars and Stellar Systems, Gravitational Wave Astronomy, Computational and Theoretical Astrophysics, Galaxies and Cosmology, High Energy and Particle Astrophysics, Space Physics and Space Weather, Galaxy Formation and Evolution, Dark Matter, Astrobiology, and the Philosophy and History of Astronomy.

6- Additional investment in launching Earth Observation Satellites and Communication Satellites to contribute to Earth stewardship and sustainable development where Earth observation satellites are used to monitor the land surface, oceans, and Earth atmosphere. Images of Earth from space are an indispensable tool to manage and protect the Earth's resources and environment. Moreover, communications satellites have played an important role in accelerating the development of the modern information society.

7- Enrich the Arab content on internet web pages in A&SS subjects as well as translate significant books on Astronomy, Astrophysics, Space Science into the Arab language to enhancing self-learning in these fields for the public.
8- Enhance the electronic Arabic content of A&SS which is are in web pages.
9- Recruit and provide job opportunities for A&SS graduates in order to encourage the Arab youth to study these sectors.

Table 5-10 A summary of the major astronomical observatories sites in the Arab region

Location	Country	Altitude (m)	Light pollution	Percentage of clear nights	Relative Humidity (%)	Diurnal temperature
South Sinai	Egypt	2629	Medium	82%	H (45 -74) L (16 – 33)	12.08
Hejaz Mountains	KSA	2100	Very low	80%	H (42 -77) L (10 – 32)	13.67
Wadi Rum	Jordan	1845	Medium	72%	H (84 -93) L (41 – 58)	9.33
Marrah Mountains	Sudan	3042	Very Low	60%	H (45 -97) L (11 – 63)	16.95
Ahagger Mountains	Oman and UAE	2980	High	57%	H (24 -50) L (10 – 20)	15.08
Cheekha Dar	Iraq	3611	High	56%	H (73 -94) L (26 – 67)	13.04
Aures Mountains	Algeria	2300	Low	55%	H (67 - 91) L (18 – 51)	12.34
Atlas Mountains	Morocco	4165	Low	55%	H (81 -94) L (21 – 42)	12.67

5.3. CONCLUSIONS

Apparently, attention to A&SS research and investment are critical to bridge the gap between Arabic countries and the rest of the world. Nevertheless, the most important issue seems to be the reform of the education system in Arab nations where they need to entrench systematic research methodology in the mindset of the succeeding generations and increase interest in A&SS scientific research, particularly in school teaching.

Despite the attempts to improve research in A&SS in the Arab region, the responsibilities to support research activities provided by governments are limited and not sufficient. This responsibility should be followed by initiatives to sustain cooperation between universities and research centers in the Arab world and institutions. They should offer a substantial investment in A&SS research as a priority to reach sustainable economic development.

Investment in A&SS research in the Arab world is minimal as compared to other sciences. Investment promotion is essential to fruitful scientific research that could lead to better developments in Arab communities. It can address the fundamental issues that face Arab countries including risk management, security, energy provision, desertification, and contamination of the environment. Therefore, Arab researchers have to be supported for rendering advanced research in A&SS and focusing the efforts directed towards strengthening research centers through various partnerships that would increase their contributions to their community needs. This can then be supported by the creation of scientific journals that are translated into all languages in the world to increase the contribution of Arab scientific research in various scientific areas of A&SS.

The United Arab Emirates, Saudi Arabia, Egypt, Algeria, Morocco, and Qatar are the leading Arab countries in this field of research and they should address the difficulties that are facing the advancement of scientific research in A&SS as well as collaborate with other Arab countries for future investments in technological innovations in all fields of A&SS. Furthermore, educational policies in Arab countries have failed to consolidate science policies in A&SS which would bolster economic and social development; however, the Arab countries possess all the human and financial resources necessary to promote A&SS research. Therefore, Arab region needs to improve its capabilities to enhance higher education and promote A&SS research in the region.

Our study findings imply that in order to improve research and education in A&SS policies in the Arab countries, the educational system must be reformed at both school and university levels and focus on A&SS and related technological topics, offering further financial support for advanced research as well as building capabilities as well as enhancing scientists and engineers in these fields. Arab countries must encourage the private sector to invest in A&SS research. The Arab countries need to benefit from the useful lessons and experiences of developed countries to promote education and research in A&SS.

In the Arab region, we think it is very important to establish the AOASSE. The AOASSE would be oriented towards strengthening education and research in A&SS at universities and schools levels and would focus on providing the Arab general public with inspiration and awareness of the importance of A&SS science and technology on their own lives and especially in the lives of their children, encouraging younger students towards enrolling in a study of A&SS fields.

Finally, this work is helpful in identifying the status of research originated from the Arab world in A&SS. Furthermore, it is useful as an informative study to assist decision-makers and researchers in Arab states to estimate the performance indicators of research activities for the future vision of A&SS in this region.

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6. GENERAL CONCLUSIONS

This Doctoral Dissertation was written by Hatem Abdullah Al-Ameryeen under the direction of José Ángel Docobo, Full Professor of Astronomy and Director of the Ramón María Aller Astronomical Observatory (OARMA) at the University of Santiago de Compostela, Galicia, Spain. This study attempts to achieve several objectives in the field of scientific thought and is framed within the lines of research of Philosophy and the History of Science. Following the research objectives suggested by Prof. Docobo, the author has conducted research to accomplish the tasks that were proposed. The three objectives of the tasks are stated below.

1- Explain and describe the extraordinary advances of human scientific knowledge and thinking with respect to the Universe that was achieved due to the evolution of optical instrumentation and, more recently, laser technology.
2- Demonstrate the current influence and historical value of OARMA in binary studies worldwide. Binary stars play a vital role and the study of all of their types provides access to essential information on basic stellar parameters such as masses, distances to these stars, their sizes, their orbits, etc. This promotes scientific progress and advances human thought regarding the Universe we inhabit.
3- Highlight and analyze the contributions of the Arab world to Astronomy from ancient times to the present in order to explain the value of their fundamental contributions of

antiquity that promoted Astronomy as a science. Follow the historical trajectory in order to demonstrate the actual research, teaching, and diffusion of Astronomy in the different Arab countries as well as their proposals for a promising immediate future.

Our conclusions regarding follow the aforementioned objectives.

1- Since the telescope was invented at the beginning of the 17th century, the evolution of astronomical instruments and astronomical techniques have revolutionized the way we think about systems within the Universe and have changed our essential understanding of the Universe.
2- The advances in optical astronomical instruments have allowed for prominent scientific discoveries as well as unprecedented scientific opportunities for astronomical research and education. For example, Adaptive Optics and Laser Technology enhance and improve the performance of new generation ground and space telescopes.
3- Binary stars play an important role in Astronomy research today.
4- Thanks to its multiple diffusion activities, OARMA plays a vital role in the enrichment of scientific knowledge and thought in Astronomy. Moreover, in the last decades, with the scientific direction of Professor Docobo, OARMA has become an international reference in double and multiple stars.
5- The combination of Docobo's analytic method for orbit calculation with Al-Wardat's method to determine the stellar parameters resulted in very usefully for achieving a complete understanding of these systems.
6- Astronomy was an essential discipline in ancient and medieval Arabia and many important books were

produced with extensive tables and explanatory texts concerning the chronology, trigonometry, celestial object motion, and spherical and mathematical Astronomy. However, Arab science, in general, Astronomy, in particular, has significantly declined since the 16^{th} century.

7- Investment in A&SS research in the Arab world is minimal as compared to other sciences in 20^{th} century. Nevertheless, many Arab countries have witnessed remarkable activity during the last two decades in the establishment of Astronomy and Space Sciences (A&SS) facilities and expert research centers as well as several A&SS projects initiated such as the Qatar Exoplanet Survey (QES) and the Emirates Mars Mission (EMM).
8- Egypt, Saudi Arabia, the United Arab Emirates, Algeria, Morocco, and Qatar are the leading Arab countries in A&SS scientific research productivity in recent times.
9- In order to improve research and education in A&SS policies in Arab countries, we consider that the educational system must be reformed and improved at both school and university levels and must focus on A&SS and related technological topics.
10- As a result of the elaboration of this Doctoral Dissertation, in our opinion it is important that the History of Science and its relationship with the evolution of human thought play a significant curricular role.

Professor José Ángel Docobo (right), and Hatem A. Al-Ameryeen (left) at OARMA's Library