



# THE EVOLUTION OF TELESCOPIC OBSERVATION FROM PAST, PRESENT, AND FUTURE: A REVIEW FOR HIGH SCHOOL STUDENTS

<sup>1</sup>Saatvick Saxena, <sup>2</sup>Hardeep Singh Manhas\*

<sup>1</sup>High School Student, <sup>2</sup>PhD Scholar

<sup>1</sup>12<sup>th</sup> Grade

<sup>1</sup>Navy Children School, Chanakyapuri, Delhi, India

## Abstract

This review article provides a comprehensive exploration of the evolution and future trajectory of telescopes for astronomical observation. Beginning with the fundamental principles of optics governing telescope functionality, the discussion navigates through the categorization of telescopes based on electromagnetic waves and operational strategies, highlighting their diverse roles in space and on Earth. The journey spans from the pioneering work of Hans Lippershey and Galileo Galilei to the rich tapestry of optical, radio, gamma, x-ray, infrared, and ultraviolet telescopes over the past century. The narrative seamlessly transitions to the future, outlining upcoming missions like the expansion of the Event Horizon Telescope, exoplanet surveys, and ventures into dark matter and dark energy realms. Concluding with an inspiring vision, the article underscores the pivotal role telescopes play in unlocking the universe's enigmas, setting the stage for remarkable scientific exploration and discovery. As humanity peers into the cosmic unknown, telescopes stand as beacons illuminating the path to extraordinary revelations.

**Keywords:** Telescopes, Astronomical Observation, Optics, Electromagnetic Spectrum, Space Exploration, Dark Matter

## I. Introduction:

In the grand tapestry of scientific exploration, telescopes emerge as the indispensable lenses through which humanity peers into the vast cosmic expanse. The pivotal role of telescopes in astronomical observation cannot be overstated. As we gaze skyward, these instruments become our eyes, revealing the secrets of distant galaxies, unveiling the birth and death of stars, and tracing the contours of the cosmos itself. Understanding the evolution of telescopic technology becomes not merely a historical pursuit but a key to unlocking the mysteries that continue to captivate astronomers and stargazers alike. This review embarks on a journey spanning the past, present, and future of telescopic technology, unravelling the intricate threads of optics, classification, historical milestones, and the promising frontiers that await us in the celestial realms.

Our exploration unfolds on a dual axis: Optics and Categorization. The first section on Optics delves into the fundamental principles governing telescope design. From the refraction of lenses in refracting telescopes to the reflection of mirrors in reflecting telescopes, we unravel the intricate dance of light gathering and image formation. It's a journey into the physics of telescopes, where the magic of distant celestial bodies converges onto our lenses. Categorization, the second pillar of our review, serves as a roadmap through the diverse landscape of telescopic observation. We navigate through the vast array of telescopes, classified based on the electromagnetic waves they capture and the operational realms they inhabit. From the ground-based observatories that dot our planet to the space-based sentinels orbiting high above, we explore the telescopic universe's different dimensions.

The chronological exploration in the "Timeline of Telescopes for Astronomical Observation" serves as our temporal guide. We traverse the epochs, from the inception marked by Hans Lippershey's pioneering work, through Galileo Galilei's revolutionary observations, to Isaac Newton's groundbreaking contributions with reflecting telescopes. The journey extends into the last century, witnessing the emergence of optical giants and the birth of cosmic, gamma, X-ray, ultraviolet, infrared, and radio telescopes, each opening new windows to the universe. Peering into the future, our focus shifts to the "Future of Telescopes." Near-future missions beckon, promising an expansion of the Event Horizon Telescope's reach, ongoing exoplanet surveys, and groundbreaking advancements in Dark Matter and Dark Energy Observations. Casting our gaze further, we venture into the speculative realm of far-future missions, contemplating technologies that might revolutionize our understanding of the cosmos.

However, this review is not merely a documentation of technological evolution; it is a call to envision the future. As we recapitulate the profound impact of telescopic observation on our understanding of the universe, we emphasize their role in unlocking cosmic mysteries. This work, like the telescopes it envisions, challenges us to dream big, to reach beyond the stars, and to continue our quest to understand the cosmos and our place within it.

## II. Optics: Physics of Telescopes

### Principles of Telescope Optics

The Principles of Telescope Optics encompass the fundamental concepts guiding refracting telescopes, utilizing lenses, and reflecting telescopes, and employing mirrors, each contributing distinctively to astronomical observation. Refracting telescopes, historically referred to as the "spyglass," are foundational to telescopic technology, relying on the fundamental principle of light refraction through lenses.<sup>[1]</sup> The inception in 1608, marked by Hans Lippershey's patent application, paved the way for Galileo Galilei's subsequent improvements, culminating in the Galilean telescope.<sup>[2][3]</sup>



Fig. 1. Legendries of Telescopic History, Hans Lippershey, Galileo Galilei and Sir Isaac Newton (From Left to Right). [Taken from Wikimedia images]

This design, incorporating a convex objective lens and a concave eyepiece, achieved a magnification of up to three times. The elegance of refracting telescopes lies in the simple yet effective bending of light as it passes through the lens, converging to create a focused image<sup>[4]</sup>. In a paradigm shift introduced by Sir Isaac Newton, reflecting telescopes utilize mirrors instead of lenses for light gathering and focusing<sup>[5]</sup>. Newton's design, exemplified in the Newtonian telescope, features a concave primary mirror gathering light and a flat secondary mirror directing it to an eyepiece or camera. Reflecting telescopes offer a distinct advantage by eliminating chromatic aberration, a colour distortion inherent in refracting telescopes due to lens curvature. The application of reflective surfaces empowers astronomers to overcome this limitation, thereby opening new vistas for astronomical observation.

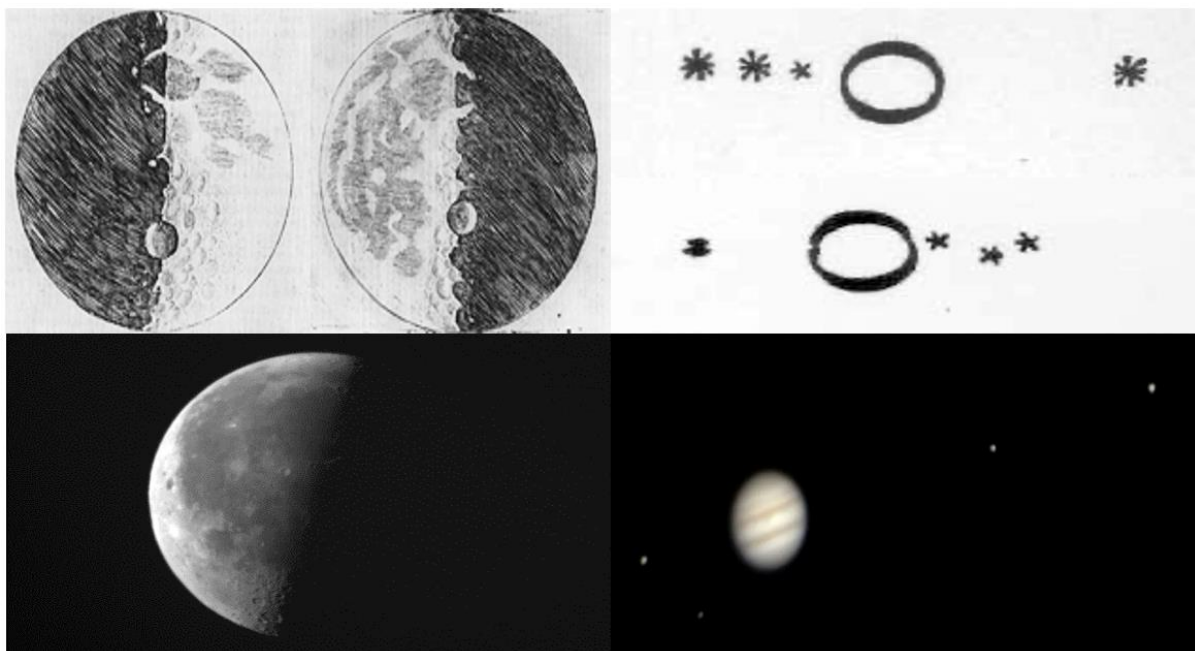


Fig. 2. Top: The drawings of the Lunar Moon (Left) and Jupiter with its four Moons (Right) by Galileo Galilei during his astronomical observation in 1609<sup>[6]</sup>, and Bottom: The images of the Lunar Moon (Left), and Jupiter with its four Moons (Right) captured using a small optical telescope.<sup>[7]</sup>

### Working Mechanism of Telescopes

The Working Mechanism of Telescopes is intricately linked to the vital processes of Gathering and Focusing Light. In both refracting and reflecting telescopes, the fundamental objective is to collect and concentrate light from distant celestial objects. Refracting telescopes achieve this through the curvature of lenses, bending and focusing incoming light rays. <sup>[4]</sup> Conversely, reflecting telescopes utilize mirrors for capturing and converging light, ensuring a more nuanced and accurate observation. <sup>[8]</sup> The effectiveness of telescopes in forming discernible images is crucial for astronomical analysis. Chromatic aberration, a challenge in refracting telescopes, causing colour dispersion, is addressed by reflecting telescopes employing mirrors. Modern telescopes often incorporate additional lenses or corrective measures to refine image clarity, providing a foundation for detailed astronomical exploration and unveiling the mysteries of the cosmos.



Fig. 2. Painting of Galileo displaying his telescope to Leonardo Donato in 1609 (Left) <sup>[9]</sup> and Replica of Newton's telescope of 1672 (Right) <sup>[2]</sup>

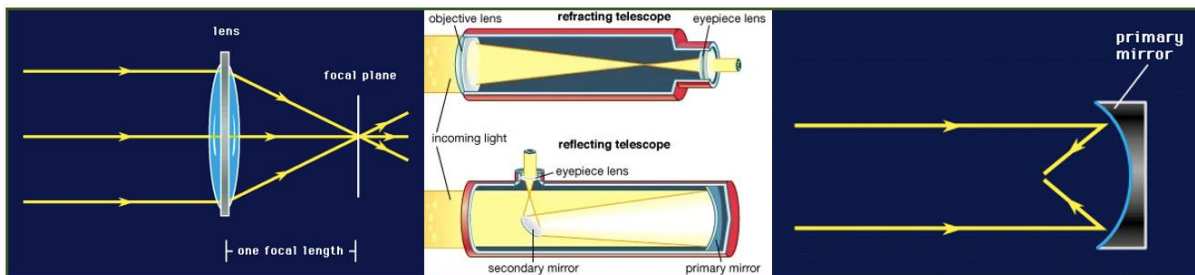


Fig.3. Optics of Telescopes as applicable in Refracting type telescope using Lenses (Left) and Reflecting type telescope using Mirrors (Right). <sup>[10]</sup>

In summary, the principles of telescope optics, whether relying on lenses in refracting telescopes or mirrors in reflecting telescopes, exemplify the ingenuity of astronomical instrumentation. From the early innovations of Lippershey and Galileo to the optical advancements of Newton, the quest for clearer, more detailed observations has driven the evolution of telescope design and optics.

### III. Categorization of Telescopes

#### Categorization of Telescopes Based on Electromagnetic Wave Observation

Telescopes are pivotal instruments in the realm of astronomical observation, each type uniquely designed to capture different wavelengths, unravelling distinct facets of the cosmos. In the optical spectrum, optical telescopes, encompassing refracting and reflecting variations, have played a historical role since the contributions of pioneers like Hans Lippershey, Galileo Galilei, and Isaac Newton. Galileo's ground-breaking use of a refracting telescope allowed detailed examinations of celestial bodies in visible light. Contemporary optical telescopes leverage advanced technologies, including adaptive optics, to compensate for atmospheric distortions, ensuring unprecedented clarity in observations. The Hubble Space Telescope (HST), a beacon in optical astronomy, has made significant contributions, including determining the rate of expansion of the universe and providing profound insights into the cosmos. [9]

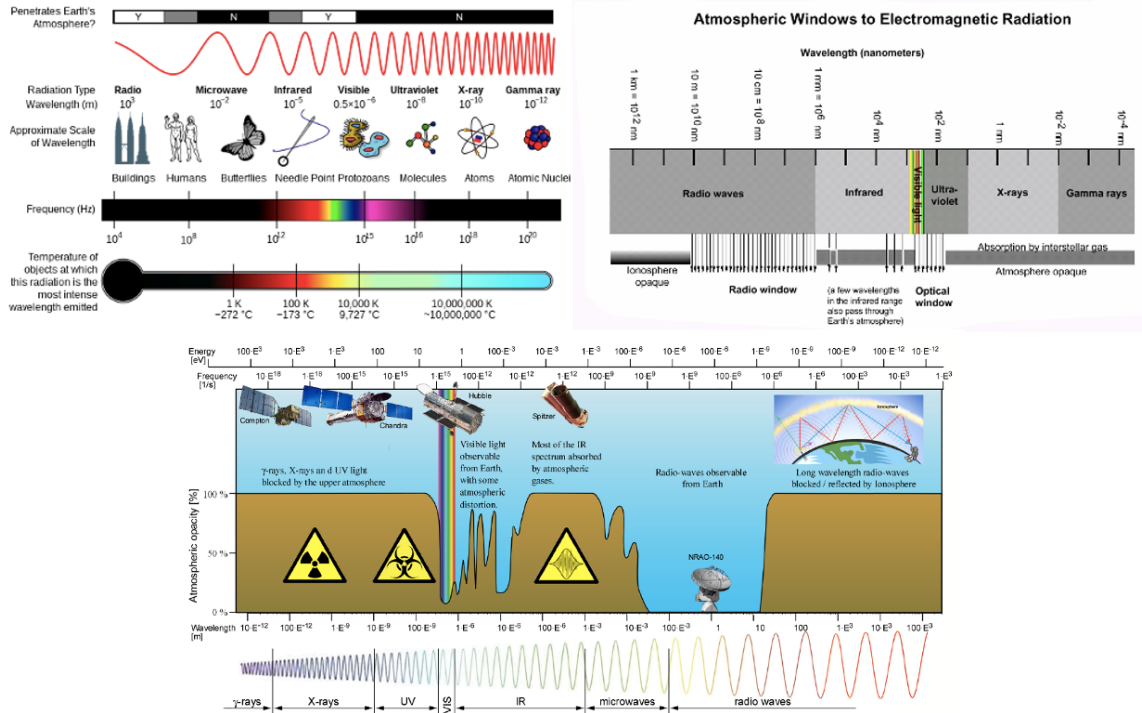


Fig. 4. Milton spectrum, showing the type of electromagnetic radiation and its characteristics (Left)<sup>[12]</sup>, the effect of the atmosphere on electromagnetic radiation (Right).<sup>[13]</sup>, and possible spectrum windows for various telescopes in astronomical observations, explaining the reason only visible and radio telescopes can work on Earth's surface.<sup>[14]</sup> [NASA Images]

The advent of radio telescopes in the early 20th century marked a technological leap, enabling the observation of radio waves emitted by celestial sources. George Ellery Hale's foundational work set the stage for solar dynamics studies. [15]

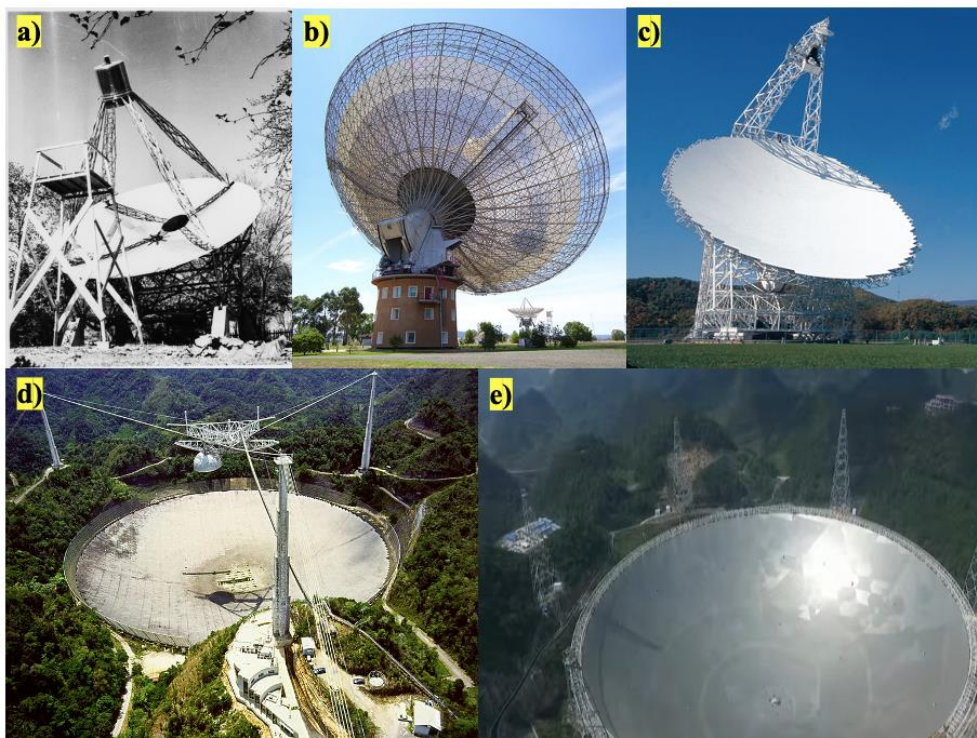


Fig. 5. Famous radio telescopes in the world, a) 9 metre Reber Radio Telescope in the US, b) 64 metres Parkes Telescope in Australia, c) 100 metres Green Bank Telescope in the US, d) 305 metre Arecibo Telescope in the US, and e) 500 metres FAST telescope in China. [Taken from Wikimedia images]

Notable examples include the Lovell telescope at Jodrell Bank Observatory in England <sup>[16]</sup> and Parkes Observatory in Australia <sup>[17]</sup> among the initial ones, and the Effelsberg telescope in Germany <sup>[18]</sup> and the Green Bank telescope in the USA <sup>[19]</sup> among the largest ones. The Five-hundred-meter Aperture Spherical Telescope (FAST) <sup>[20]</sup>, the world's largest telescope with a diameter of 500 meters, is located in China. Also, among the world-famous are the South Pole Telescope (SPT) <sup>[21]</sup> in Antarctica, the Submillimetre Array <sup>[22]</sup> in the US and the Square Kilometre Array Pathfinder in Australia <sup>[23]</sup>, showcasing the capabilities of radio telescopes in unravelling the mysteries of distant galaxies and cosmic microwave background radiation. Often deployed in arrays, radio telescopes offer high-resolution imaging and detailed maps of radio-emitting celestial objects. The Arecibo Observatory <sup>[24]</sup>, with its colossal radio dish, confirmed Einstein's theory of relativity, conducted radar mapping of planets, detected exoplanets, and played a pivotal role in the Search for Extra-terrestrial Intelligence (SETI) <sup>[25]</sup>, leaving an indelible mark on astronomy <sup>[26]</sup>.

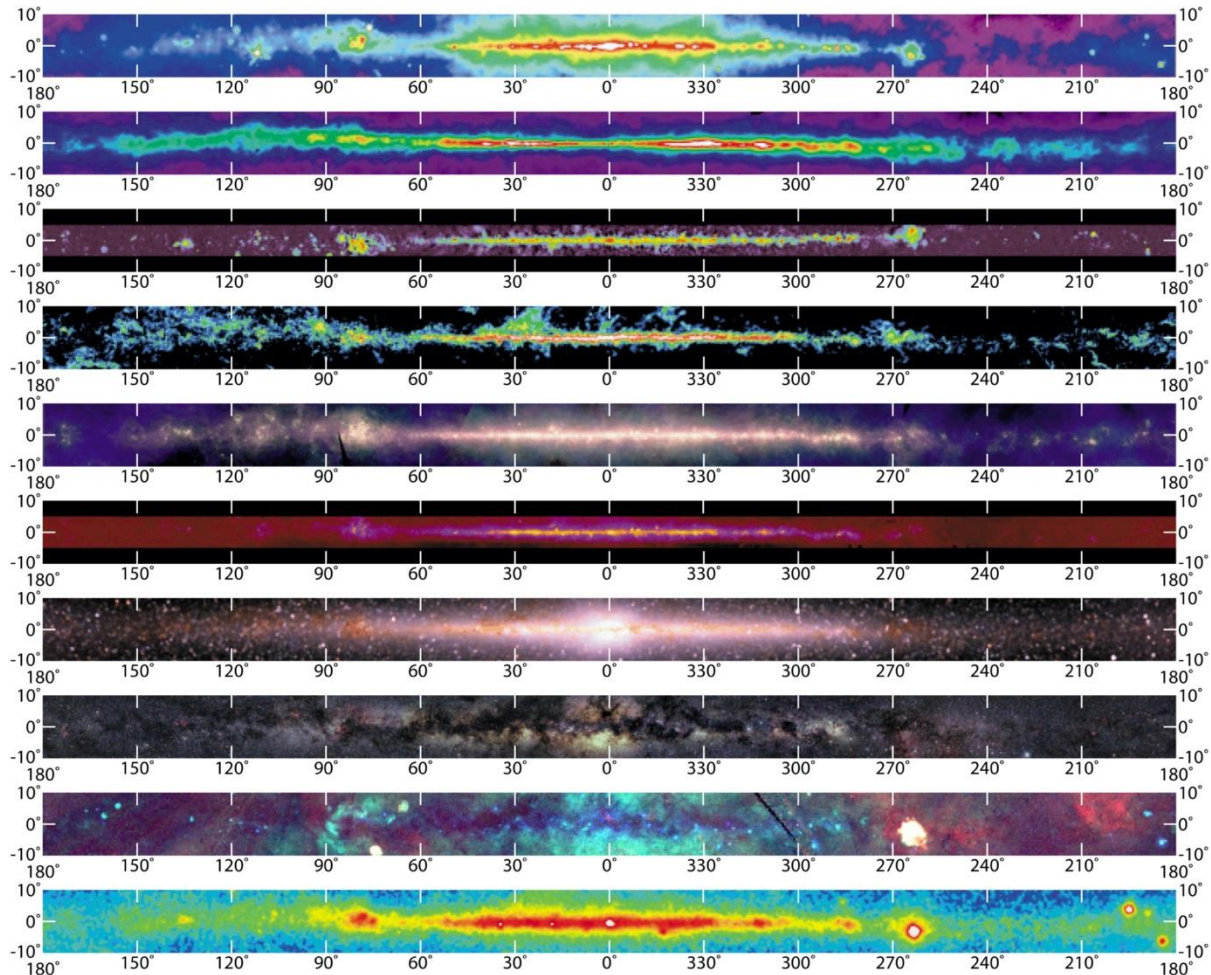


Fig. 6. Maps of the Milky Way galaxy at ten wavelength regions, involving Radio Continuum (408 MHz), Atomic Hydrogen, Radio Continuum (2.4 - 2.7 GHz), Molecular Hydrogen, Mid Infrared, Mid Infrared, Near Infrared, Optical, X-Ray, Gamma Ray, from top to bottom. [NASA Images]

Beyond the visible spectrum, infrared and ultraviolet telescopes extend our observational reach. The James Clerk Maxwell Telescope (JCMT) <sup>[27]</sup> in Hawaii and the Hubble Space Telescope (HST) <sup>[28]</sup> in orbit exemplify advancements in these categories. HST, with its ability to capture detailed ultraviolet images, revolutionized our understanding of distant galaxies <sup>[28]</sup>. Infrared telescopes, such as the Spitzer Space Telescope <sup>[29]</sup>, unveil the cool, dust-obscured regions of the universe, shedding light on star formation and planetary systems. The Spitzer Space Telescope launched in 2003, studied a wide range of astronomical phenomena, from the formation of stars and planetary systems to distant galaxies and exoplanets. <sup>[30]</sup> X-ray and gamma-ray telescopes delve into the high-energy domains, uncovering extreme cosmic phenomena like black holes and supernovae. <sup>[31][32]</sup> The Chandra X-Ray Observatory <sup>[30]</sup>, launched by NASA in 1999, delves into high-energy processes, studying phenomena like black holes and supernova remnants. Chandra's accomplishments include research on supernova remnants, black hole studies, galaxy clusters' mass estimation, and the study of stellar winds and coronal emissions <sup>[33]</sup>. Gamma-ray telescopes, overcoming challenges in detection, explore the highest-energy photons. Instruments like the Fermi Gamma-Ray Space Telescope <sup>[34]</sup>, launched in 2008, contribute to the discovery of pulsars, identification of gamma-ray bursts, and studies of active galactic nuclei <sup>[35]</sup>. Cosmic ray telescopes, typified by the Pierre Auger Observatory in Argentina <sup>[36]</sup>, detect high-energy particles from space, contributing essential data for astrophysical and particle physics research. Studying the arrival directions and energies of cosmic rays, these telescopes offer valuable insights into the origin and impact of these elusive particles <sup>[37]</sup>. Each type of telescope plays a crucial role in advancing our understanding of the universe, contributing to significant discoveries and unveiling the mysteries hidden within the cosmic spectrum.

## Categorization of Telescopes Based on Operational Location and Surface Characteristics

Telescopes can be categorized not only based on the electromagnetic spectrum they observe but also by their operational location, a distinction critical for optimizing observational capabilities. This categorization considers both the surface on which the telescope operates and its location, either on Earth or in space.<sup>[38]</sup> The Earth's atmosphere poses a unique challenge to certain wavelengths of electromagnetic radiation. For instance, the atmosphere is opaque to many wavelengths of ultraviolet and X-ray radiation, necessitating the placement of telescopes observing these spectra in space. The atmosphere's absorption and emission of infrared radiation also impact ground-based observations in this spectrum, leading to the deployment of infrared telescopes in space.<sup>[39]</sup> This categorization by operation location ensures that telescopes can overcome atmospheric limitations and capture a broader range of celestial phenomena.



Fig. 7. Most important observatories for astronomy, showing 10m Twin Keck telescopes two Optical and Near Infrared telescopes in Hawaii US, James Clerk Maxwell Telescope a submillimetre radio telescope in Hawaii US, and Pierre Auger Observatory an international cosmic ray observatory in Argentina (From Left to Right, Source: Wikimedia)

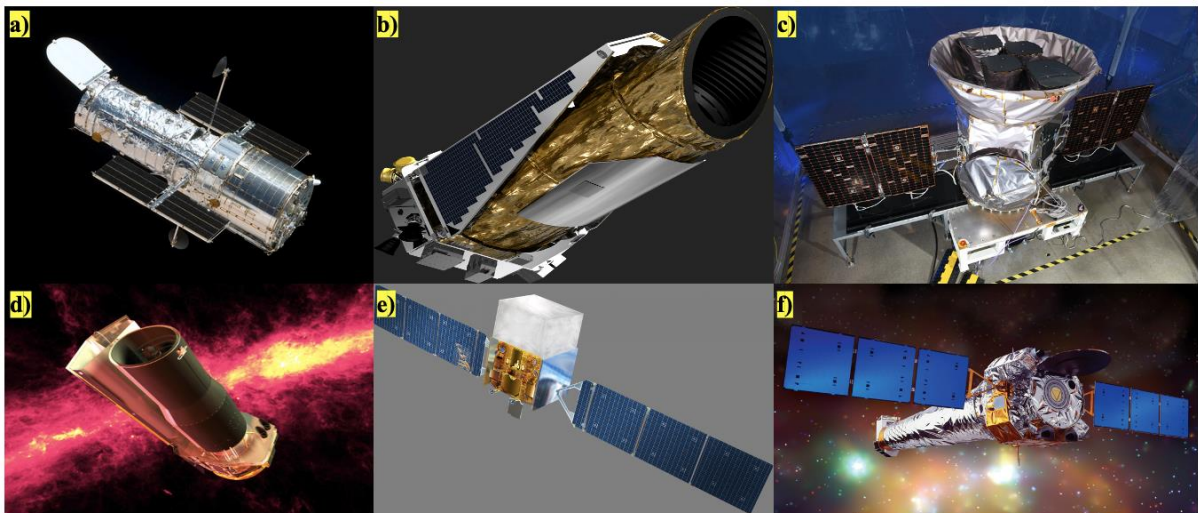


Fig. 8. Some prominent Space Telescopes, a) Hubble Space Telescope for deep space observations, b) Kepler Space Telescope for exoplanet survey, c) Transiting Exoplanet Survey Satellite (TESS) for exoplanet survey, d) Spitzer Space Telescope for Infrared observations, e) Fermi Gamma Ray telescope for Gamma Observations, and f) Chandra X-Ray Observatory for X-ray observations. [Wikimedia Images]

Ground-based telescopes, situated on Earth's surface, include optical and radio telescopes. Optical telescopes take advantage of the relatively transparent windows in the atmosphere to observe visible light. The Gran Telescopio Canarias, also known as GranTeCan or GTC, is a reflective telescope with a diameter of 10.4 meters (410 inches). Situated at the Roque de los Muchachos Observatory on La Palma, part of the Canary Islands in Spain, it holds the distinction of being the largest optical telescope with a single aperture in the world.<sup>[40]</sup> The Mauna Kea Observatories in Hawaii, with their high-altitude location, exemplify the advantages of ground-based optical telescopes.<sup>[41]</sup> In contrast, radio telescopes, such as the Karl G. Jansky Very Large Array (VLA)<sup>[42]</sup> in New Mexico, are strategically located to minimize electromagnetic interference from human-made sources. On the other side, Space-based telescopes, like the Hubble Space Telescope (HST), operate above Earth's atmosphere, avoiding atmospheric distortions and enabling clear observations across the ultraviolet, visible, and near-infrared spectra. The Chandra X-ray Observatory, another space-based telescope, captures X-rays unhindered by atmospheric absorption. The spatial placement of these telescopes ensures optimal data collection and enhances our ability to explore the universe across a wide range of wavelengths.<sup>[43]</sup>

Moreover, the surface characteristics of telescopes play a vital role in their functionality. Optical telescopes as discussed earlier, are classified based on the type of principle used for observation, such as reflecting or refracting. Reflecting telescopes, like the Large Binocular Telescope (LBT)<sup>[44]</sup> in Arizona, utilize mirrors to gather and focus light, while refracting telescopes, exemplified by the Gran Telescopio Canarias (GTC)<sup>[45]</sup> in Spain, employ lenses for this purpose. The strategic placement and design considerations associated with ground-based and space-based telescopes underscore their collective impact on shaping our comprehension of the universe.

IV. Timeline of Telescopes for Astronomical Observation

The Past/History of Telescopes (Up to 1923)

The historical journey of telescopic technology traces its roots back to the early 17th century, marked by pivotal figures and groundbreaking innovations. Hans Lippershey, in 1608, stands at the forefront of this narrative with his foundational contributions to the inception of telescopic technology.<sup>[46]</sup> His patent application marked the beginning of a revolutionary era in observational astronomy. However, it was the profound insights of Galileo Galilei that truly propelled telescopic observation to new heights.

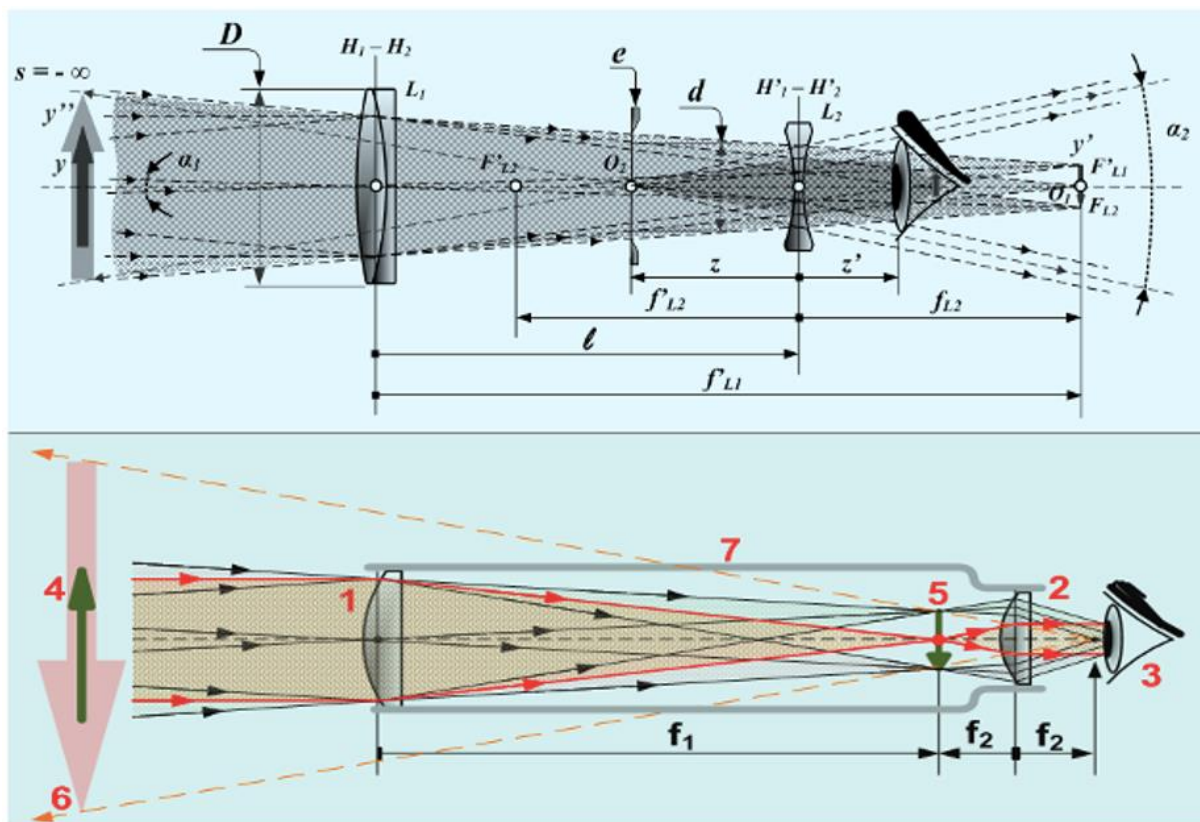


Fig. 9. Top: Galilean optical refracting telescope ( $y$  –Object;  $y'$  – Real image;  $y''$  – Magnified virtual image;  $D$  –Pupil diameter on entry;  $d$  –Pupil diameter on exit;  $L_1$  – Objective lens;  $L_2$  – Eyepiece lens;  $e$  – Virtual exit pupil), Bottom: Keplerian optical refracting telescope ( $f$ -focal length)

Galileo's pioneering observations in the early 17th century were transformative. Using a refracting telescope, he scrutinized the night sky and made unprecedented revelations, such as the discovery of Jupiter's moons, the phases of Venus, and the observation of sunspots.<sup>[47]</sup> Galileo's work laid the groundwork for a more profound understanding of the celestial realm. The 17th century also witnessed the advent of the reflecting telescope, a paradigm shift introduced by Isaac Newton. Newton's innovative design, featuring a concave primary mirror, not only mitigated chromatic aberration but also opened a new chapter in observational astronomy.<sup>[48]</sup> The reflecting telescope, with its improved image clarity, became a cornerstone for future astronomical discoveries. This historical journey, up to a century back from now, reflects the collaborative efforts of these visionaries, each contributing a crucial piece to the evolving puzzle of telescopic observation.

**The Past to Present Journey (1923-2023): 100 Years of Observation**

The timeline of telescopic observation from a century unfolds as a rich tapestry of scientific exploration, marked by major milestones and paradigm-shifting discoveries that have reshaped our understanding of the cosmos.

Table 1. Important Eras in astronomical observation with the kind of telescopic observations.

Era	Explanation	Key Advancements & Discoveries
Ancient Era	Silhouettes of stargazers using gnomons and astrolabes against a starry sky.	Tracking celestial movements, predicting seasons and eclipses.
Galileo's Era	A telescope pointing towards the Moon, with Jupiter's moons and Venus phases in the background.	Telescope invention, observations of Moon's craters, Jupiter's moons, Venus phases, phases of the Sun.
Newton's Era	A reflecting telescope reflecting sunlight, revealing hidden celestial details.	Reflecting telescope design, improved light-gathering power, observations of nebulae, double stars.
Herschel's Era	A telescope aiming at Uranus, with a trail of other planets signifying its ground breaking discovery.	Discovery of Uranus, systematic sky surveys, classification of nebulae.
Photographic Era	A camera capturing the faint glow of a nebula, symbolizing the dawn of astronomical photography.	Recording celestial objects, spectral analysis of stars, discovery of invisible phenomena.
Giant Telescope Era	A silhouette of a massive telescope dome reaching towards the cosmos, representing the pursuit of deeper observations.	Large telescopes like Lick and Yerkes, increased resolution and light-gathering power, detailed studies of stars and galaxies.
Space Telescope Era	A satellite telescope orbiting Earth, sending back images of distant galaxies and planets.	Observations beyond Earth's atmosphere, Hubble Space Telescope's revolutionary images, discoveries of exoplanets, deep field observations.
Modern Era	A montage of diverse telescopes – ground-based, space-based, radio, and optical – working together to paint a comprehensive picture of the universe.	Diverse array of telescopes, multi-wavelength observations, studies of black holes, gravitational waves, dark matter and energy.
Future Era	A silhouette of a futuristic telescope pointed towards a swirling nebula, hinting at the endless possibilities for future discoveries.	Next-generation telescopes like James Webb and ELT, pushing the boundaries of observation, exploring the origins of the universe, searching for habitable worlds.

The pioneering years, spanning from 1923 to 1940, witnessed the foundational work of George Ellery Hale <sup>[15]</sup>, leading to the completion of the 200-inch Hale Telescope at Palomar Observatory <sup>[49]</sup> in 1948. This colossal instrument, often referred to as the Palomar Observatory Hale Telescope, became the largest optical telescope of its time, signalling a new era in observational astronomy. The post-war period, particularly the 1950s and 1960s, saw the emergence of radio astronomy. <sup>[50]</sup> The launch of Sputnik 1 in 1957 unintentionally opened the door to radio observations of Earth's ionosphere. <sup>[51]</sup> Notable contributions include the Green Bank Telescope (GBT), operational since 2000, standing as a testament to the evolution of radio astronomy. <sup>[19]</sup> The 1960s also saw the establishment of the Arecibo Observatory in Puerto Rico, a colossal radio telescope that played a pivotal role in confirming Einstein's theory of relativity, mapping planets, detecting exoplanets, and contributing to the Search for Extraterrestrial Intelligence (SETI). <sup>[26]</sup> The late 20<sup>th</sup> century decades brought forth a new horizon in space with the launch of the Hubble Space Telescope (HST) in 1990. <sup>[52]</sup> This transformative observatory, positioned above Earth's atmosphere, delivered unprecedented optical clarity. Its contributions encompass determining the rate of expansion of the universe, discovering exoplanets, and capturing captivating images of distant galaxies. Advancements in infrared astronomy took centre stage in the 1980s and 1990s. The launch of the Infrared Astronomical Satellite (IRAS) <sup>[53]</sup> in 1983 marked a pivotal moment, providing the first comprehensive survey of the entire sky in infrared wavelengths. <sup>[54]</sup> Subsequent missions, including the Spitzer Space Telescope and the James Clerk Maxwell Telescope (JCMT), further expanded our understanding of star formation and the composition of interstellar dust. <sup>[55][56]</sup> The new millennium ushered in revelations in X-ray astronomy with the Chandra X-ray Observatory entering service in 1999. <sup>[57]</sup> This observatory, with

its high-resolution imaging capabilities, delved into the dynamics of galaxy clusters, explored the remnants of exploded stars, and provided insights into the behaviour of black holes.<sup>[58]</sup>

Table 2. Timelines of famous telescopes and major milestones in Astronomical Observation during the last 100 years.

Year	Name of Telescope/Observatory	Location
1930	First radio telescope Jansky	New Jersey
1934	First 14-inch Schmidt optical reflecting telescope	Palomar, California
1936	18-inch Schmidt optical reflecting telescope	Palomar, California
1937	31-feet radio telescope Reber	Wheaton, Illinois
1947	Jodrell Bank 218-foot radio telescope	Cheshire, England
1949	Palomar 48-inch and 200-inch telescopes	Palomar, California
1956	Dwingeloo Radio Observatory 25 m telescope	Netherlands
1957	Jodrell Bank 250-foot steerable radio telescope	Cheshire, England
1959	Shane 120-inch Telescope	San Jose, California
1961	Parkes 64-metre radio telescope	Australia
1962	Founding of European Southern Observatory	Headquarters Munich, Germany
1962	Green Bank 90m radio telescope	West Virginia, United States
1963	Arecibo 300-meter radio telescope	Puerto Rico
1967	First VLBI images produced	International Collaborations
1969	Founding of Las Campanas Observatory	Atacama Desert of northern Chile.
1970	Kitt Peak 158-inch telescopes, & Launch of Uhuru x-ray telescope satellite	Tucson, Arizona
1972	100 m Effelsberg radio telescope	Bonn, Germany
1978	International Ultraviolet Explorer and Einstein High Energy Astronomy Observatory	United States (NASA), and Europe (ESA)
1980	Very Large Array	Socorro, New Mexico
1983	Infrared Astronomical Satellite (IRAS)	United States (NASA), Netherlands (NIVR), and United Kingdom (SERC)
1984	IRAM 30-m telescope	Pico Veleta, Spain
1987	James Clerk Maxwell	Mauna Kea Observatory, Hawaii
1987	Swedish-ESO Submillimetre Telescopes	ESO La Silla Observatory in Chile
1988	Australia Telescope Compact Array	Narrabri, Australia

1989	Cosmic Background Explorer (COBE) satellite	United States (NASA)
1990	Hubble Space Telescope	United States (NASA), and Europe (ESA)
1991	Compton Gamma Ray Observatory satellite	United States (NASA)
1993	Keck 10-meter telescope and Very Long Baseline Array	Mauna Kea Observatory, Hawaii
1995	Cambridge Optical Aperture Synthesis Telescope	Cambridge, England
1995	Giant Metrewave Radio Telescope	Pune, India
1996	Keck 2 10-meter telescope	Mauna Kea Observatory, Hawaii
2001	First light at Keck Interferometer and VLTI interferometry array	Mauna Kea Observatory, Hawaii
2005	South African Large Telescope	Northern Cape of South Africa
2007	Gran Telescopio de Canarias largest optical telescope	Canary Islands of Spain
2016	Five-hundred-meter Aperture Spherical Telescope (FAST)	Pingtang County, China
2021	James Webb Space Telescope	United States (NASA), European Space Agency (ESA), and the Canadian Space Agency (CSA)
2023	Euclid and XRISM satellites	Japan (JAXA), United States (NASA), Europe (ESA)

The 2010s witnessed a paradigm shift with the advent of multimessenger astronomy. <sup>[59]</sup> In 2015, the detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory (LIGO) <sup>[60]</sup> confirmed a prediction by Albert Einstein a century earlier, opening a new window to the universe. <sup>[61]</sup> This groundbreaking discovery allowed scientists to observe cataclysmic events such as neutron star mergers. <sup>[62]</sup> In 2019, the Event Horizon Telescope (EHT) <sup>[63]</sup> achieved a historic milestone by capturing the first-ever image of a black hole in the centre of the galaxy M87. <sup>[64]</sup> This monumental achievement provided visual confirmation of a theoretical prediction and offered profound insights into the nature of these enigmatic cosmic entities. EHT also provided an image of Sagittarius A black hole in 2022. <sup>[65]</sup>

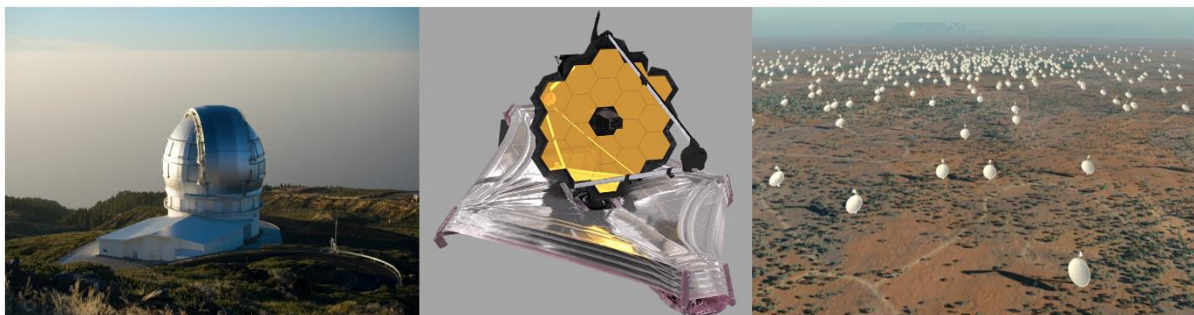


Fig.11. Largest Milestones achieved in Astronomical Instrumentations with the largest single-aperture surface telescope Gran Telescopio Canarias in Spain (Left), the largest space telescope James Webb (Mid), and under construction intergovernmental international radio telescope Square Kilometre Array in Australia and Africa (Right). [Wikimedia Images]

The recent launch of the James Webb Space Telescope (JWST) <sup>[66]</sup>, is poised to push the boundaries of infrared observation. This next-generation telescope will enable astronomers to peer into the early universe and study the atmospheres of exoplanets. <sup>[67]</sup> Additionally, the under-construction Square Kilometre Array (SKA) <sup>[68]</sup> in Australia, an ambitious radio telescope project, aims to revolutionize our understanding of the cosmos by offering unprecedented sensitivity and survey speed. Various Very Long Baseline Interferometry (VLBI) arrays worldwide, including those in Europe, Canada, the United States, Chile, Russia, China, South Korea, Japan, Mexico, Australia, and Thailand, contribute to high-sensitivity observations. <sup>[69]</sup> The European VLBI Network (EVN) stands out as the most sensitive, uniting major European radio telescopes for weeklong sessions, with data processed at the Joint Institute

for VLBI in Europe (JIVE).<sup>[70]</sup> The Very Long Baseline Array (VLBA) in the US, with ten 25-meter telescopes spanning 5351 miles, operates year-round as a versatile astronomical and geodesy instrument.<sup>[71]</sup> Combining EVN and VLBA forms the Global VLBI, achieving unparalleled resolution when supplemented by space-based antennas like HALCA or Spektr-R.

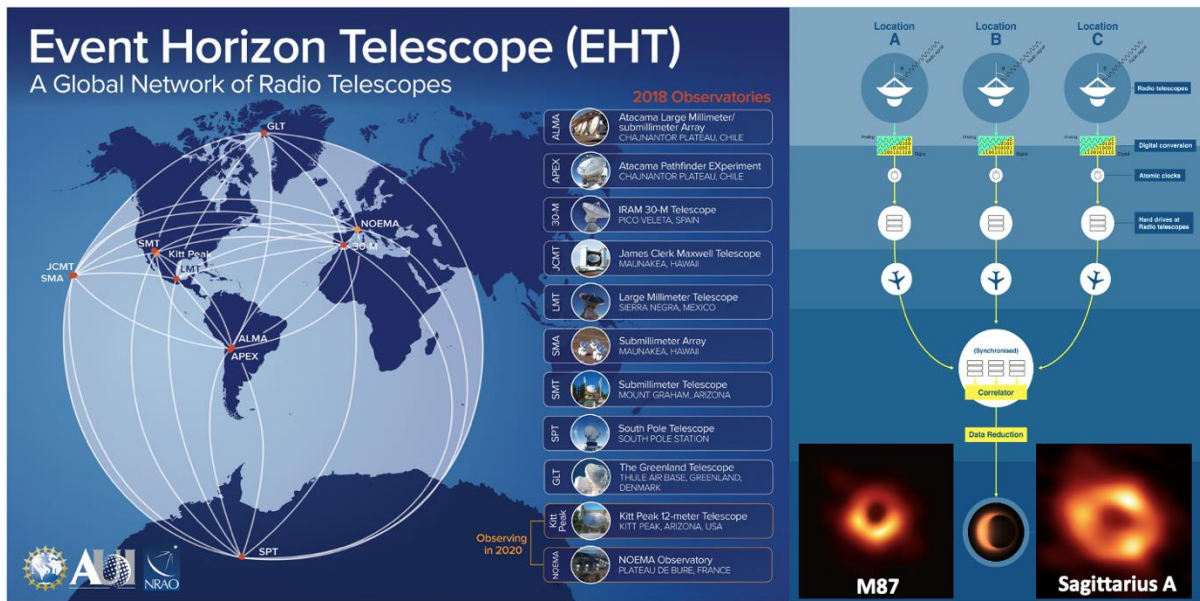


Fig. 12. The network of Event Horizon Telescope with major telescopes partnered for deep and complex astronomical observations (Left), and Diagram depicting the working of ETH network interferometry to produce complex results such as images of black holes, two shown below M87 and Sagittarius A. [Wikimedia Images]

This global collaboration, exemplified in the 1976 joint observation of hydroxyl-maser sources, remains crucial, notably in projects like the Event Horizon Telescope, focused on imaging supermassive black holes as published in recent years and also for future observations.<sup>[72]</sup> From George Ellery Hale's pioneering efforts to the emerging frontiers with JWST, SKA, FAST and the monumental discoveries of black hole images by EHT, each era has added layers to the narrative of humanity's quest to explore the cosmos, with milestones marked by groundbreaking discoveries and technological advancements. The next chapters in this cosmic saga promise even more profound insights as we continue to unravel the mysteries of the universe.

**The Future of Telescopes and Astronomical Observation**

As we stand on the precipice of the next frontier in astronomical observation, the future of telescopes unfolds with promising prospects and ground breaking missions. The Event Horizon Telescope (EHT), having etched its name in history by capturing the first-ever image of a black hole, is poised for expansion.<sup>[69][73]</sup> Beyond black holes, the cosmic quest extends to the exploration of exoplanets, a burgeoning field propelled by ongoing and upcoming surveys. Telescopes dedicated to exoplanet observation are set to usher in a new era of discovery, probing distant worlds for signs of habitability and potential extraterrestrial life.<sup>[74]</sup> The advancements in exoplanet surveys hold the promise of transforming our understanding of the vast cosmic landscape, bringing us closer to answering the age-old question of whether we are alone in the universe.<sup>[75][76]</sup> Simultaneously, the horizon of observational astronomy widens with strides in understanding the elusive realms of dark matter and dark energy. Telescopes equipped with cutting-edge technologies are at the forefront of this quest, poised to delve deeper into the cosmic fabric and decipher the fundamental forces shaping the universe. The interplay of gravitational forces and the cosmic dance of invisible matter are poised to be illuminated, offering profound insights into the very essence of our cosmic existence.<sup>[77]</sup>

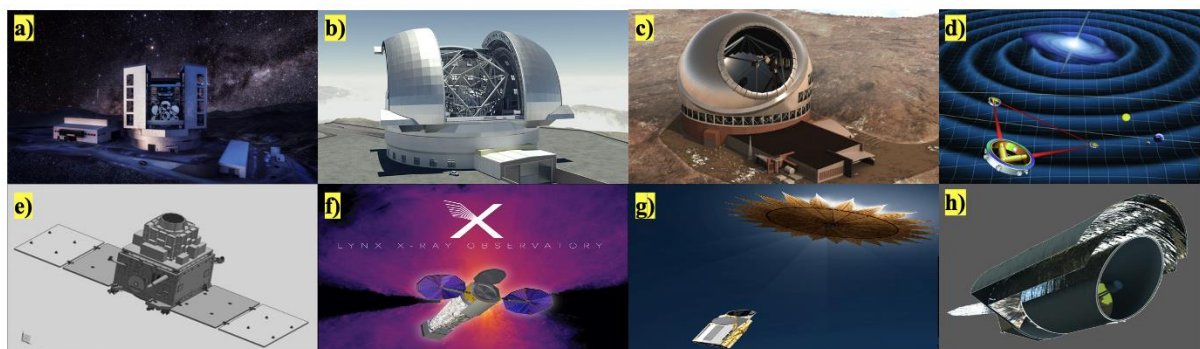


Fig. 13. Some major observatories planned for the future, a) GMT Giant Magellan Telescope 25.4-meter ground-based telescope in Chile (LCO-2025), b) ELT Extremely Large Telescope optical/near-infrared telescope in Chile (ESO-2025), c) TMT Thirty Meter Telescope in the island of Hawaii, d) LISA Laser Interferometer Space Antenna (ESA-2037) for Gravitational waves, e) XpoSat X-ray Polarimeter Satellite to study polarisation of cosmic X-rays (ISRO-2023/24), f) Lynx X-ray Observatory (NASA-2036), g) Habitable Exoplanet Observatory for image Earth-size habitable exoplanets (NASA-), and h) Origins Space Telescope for far-infrared observations (NASA-2035)

Moving further, the trajectory of far-future missions is veiled in the potential for unprecedented advancements, both in instrumental capabilities and conceptual frameworks. Speculation on revolutionary technologies opens avenues for envisioning telescopes equipped with quantum sensors, advanced AI-driven data processing, and possibly even the deployment of telescopes on extraterrestrial bodies or within intricate orbital networks.<sup>[78]</sup> Moreover, the potential for game-changing discoveries looms large on the cosmic horizon. Imagine telescopes with the capability to discern the signatures of extraterrestrial life or unravel the mysteries of cosmic phenomena such as dark energy in ways previously deemed unattainable. A NASA Space telescope named The Dark Universe Observatory (DUO) is also planned which will conduct X-ray observations of galaxy clusters to find data related to dark matter and dark energy.<sup>[79]</sup> The Artemis program, set to return humans to the Moon, introduces the concept of in-space telescope assembly within lunar craters, promising interference-free observations and revolutionizing astronomical research.<sup>[80]</sup> Collaboration between the Lunar Crater Radio Telescope (LCRT) and Artemis envisions a lunar-based radio telescope, shielding it from Earth's interference and potentially revolutionizing radio astronomy.<sup>[81]</sup> Advances in optical surfacing technologies further enhance large optics manufacturing, offering precision and cost-effectiveness.<sup>[82]</sup> Looking ahead, the Moon emerges as a hub for telescope megaprojects, boasting low gravity and minimal atmospheric disturbances. The Artemis-LCRT collaboration outlines shared lunar infrastructure, power, communication, and resource-sharing possibilities, aligning lunar exploration with astronomical pursuits.<sup>[81]</sup> The Event Horizon Telescope (EHT), a global endeavour capturing the first black hole image, exemplifies collaborative success. The network includes observatories like Submillimetre Array (SMA), Atacama Large Millimetre/sub-millimetre Array (ALMA), South Pole Telescope (SPT), IRAM 30-metre Telescope, and James Clerk Maxwell Telescope (JCMT).<sup>[83]</sup> Future telescopic missions promise expansion of EHT, exoplanet surveys, and advances in dark matter and dark energy observations. The interplay of imagination and scientific inquiry becomes the guiding force, leading us into a cosmic odyssey that transcends the limits of our current comprehension.

### Discussion: Challenges and Possibilities in Telescopic Observation

Telescopic technology, from its inception to the present, has undergone transformative innovations that redefined our cosmic perspective. Atmospheric turbulence remains a persistent challenge, distorting celestial images and limiting observational clarity.<sup>[84]</sup> Technological advancements, including adaptive optics and sophisticated image correction algorithms, are pivotal in mitigating these effects.<sup>[85]</sup> These innovations enable telescopes to dynamically adjust to atmospheric conditions, enhancing resolution and unveiling celestial details with unprecedented precision. Despite technological strides, challenges persist due to environmental factors such as daylight, weather conditions, and geographical constraints. Daylight restrictions necessitate nocturnal observations, and adverse weather conditions impede data collection. Geographical limitations further confine certain observatories to specific latitudes, impacting comprehensive sky coverage. Limited observation windows pose substantial implications for astronomical research, constraining the availability of critical data for comprehensive cosmic studies.

The financial investments and international collaboration essential for large-scale telescopes underscore a potential divide in access, particularly affecting researchers from developing nations. The considerable costs associated with constructing and maintaining cutting-edge observatories may limit participation, hindering the inclusivity of astronomical exploration. Balancing financial considerations with a commitment to global collaboration is crucial for fostering a more equitable distribution of observational resources. Collaboration emerges as a key theme, both in addressing challenges and advancing cosmic exploration. Ongoing and potential collaborations among different space missions amplify observational capabilities. Sharing resources, expertise, and infrastructures, these collaborations synergize efforts to tackle complex cosmic inquiries. The interplay between space missions, like the collaboration between the Lunar Crater Radio Telescope and the Artemis program, exemplifies how joint initiatives can broaden the scope of astronomical research.

Reflecting on possibilities, the future holds promises of major discoveries. Telescopic advancements, coupled with AI integration, offer a comprehensive approach to exploring elusive phenomena. The pursuit of understanding dark matter, deciphering the enigma of dark energy, and unveiling the secrets of black holes stands as a testament to the relentless quest for cosmic knowledge. As technology evolves and observational capacities continue to expand, telescopes remain dynamic instruments propelling humanity toward ever-deeper cosmic insights.

### Summary and Conclusion

This comprehensive review of the evolution of telescopic observation holds profound relevance for astronomers, researchers, and educators alike. For astronomers, it serves as a detailed exploration of the diverse types of telescopes across the electromagnetic spectrum, providing insights into their historical significance and contemporary advancements. Researchers benefit from a nuanced understanding of how innovations, from adaptive optics to advanced data analysis techniques, shape the course of telescopic technology. Moreover, the categorization of telescopes based on electromagnetic observation widens the scope of possibilities for future research directions. Educators find valuable material to inspire the next generation of astronomers, offering a rich tapestry of historical milestones and contemporary breakthroughs. Overall, this review stands as a resourceful compendium, bridging the past, present, and future of telescopic observation.

In conclusion, this review illuminates the transformative role telescopes play in unravelling the mysteries of the universe. From the pioneering observations of Galileo to the cutting-edge technologies of today's space-based observatories, telescopes have continually reshaped our cosmic perspective. The discussion on ongoing and future missions, collaborations, and innovations underscores the dynamic nature of telescopic technology. As telescopes continue to push the boundaries of exploration, encouraging advancements in understanding dark matter, dark energy, and celestial phenomena, their significance cannot be overstated. The transformative power of telescopes lies not only in their ability to capture distant cosmic wonders but also in inspiring curiosity, sparking scientific endeavours, and fostering a collective vision for unravelling the secrets of the cosmos. This review serves as both a reflection on the monumental strides we've made and a call to embrace the ongoing journey of exploration and innovation in telescopic technology.

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