Principle and Applications of Telescopes: Refracting, Reflecting and Catadioptric Telescopes

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Keywords: Refractor Telescope, Reflecting Telescope, Catadioptric Telescope, JWST.

Abstract: As a matter of fact, telescopes play the most vital role in astrophysics and cosmology observations, which are the key facilities for recording the spectrum as well as intensity information. In recent years, thousands large telescopes have been built and some amazing observations have been achieved based on the advanced telescopes (e.g., black holes recording from EHT and galaxy formation by JWST). With this in mind, the passage mainly introduces three types of frequently used telescope, i.e., refractor, reflecting, and catadioptric telescopes. At the same time, their recent developing results in astronomy fields such as discoveries of extraterrestrial as well as blackbody are discussed. The consisting of the facilities as well as the detection parameters and categories are also summarized and evaluated. According to the analysis, their limitations such as the change in atmosphere directions and prospect in the future are clarified and demonstrated. Overall, these results pave a path for further investigation of telescopes and cosmology observations.

1 INTRODUCTION

A telescope improves eyesight by magnifying far-off objects and making them seem closer to the observer (Ryan, 2024; Taylor, 2004). Mostly used in astronomy to let people explore the universe, the telescope is a priceless and indispensable scientific tool. A telescope is a device used to gather visible light or at different wavelengths emitted radiation. Big telescopes can catch far lighter than the human eye can, much as a garbage can hold onto more rainfall than a coffee cup. Scientists today are unsure of exactly who the first individual to design the telescope was. Still, historical records show that a Dutch sight producer openly announced in the seventeenth century the creation of a new optical tool allowing amplification of far-off objects. This is the first known account of the telescope's invention.

Still, Galileo Galilei is recognized as having greatly advanced astronomical telescope use. After erecting his own telescope in 1609, Galileo produced some significant discoveries including lunar surface research, identification of Jupiter's moons, and viewing of Venus's phases. These findings validated Copernicus's heliocentric view and disproved the geocentric model of the universe. Telescope technology developed still throughout the next centuries. It was very amazing how Isaac Newton invented the reflecting telescope in 1668. By means of mirrors rather of lenses, Newton's discovery eliminated chromatic aberration and made it possible to build larger telescopes. Development of big refracting telescopes made considerable advancement in the 19th century (Mountain & Gillett, 1998). Among such well-known examples are the 40-inch telescope at Yerkes Observatory, considered as the largest refractor ever constructed. The 20th century brought fresh ideas and more successes. Radio telescopes provide the vision of astronomical objects radiologically active. Several amazing discoveries made possible by this scientific development were the identification of cosmic microwave background radiation and pulsars.

Space observatories have reached incredible resolution by avoiding air distortion—that of the Hubble Space Telescope launched in 1990. The Hubble telescope reveals among the most important facts the fast expansion of the universe. One of the most far-off galaxies yet discovered, JADES-GS-z14-0 has been located and studied using the James Webb Space Telescope (JWST). This galaxy, 13.4 billion light-years distant, lived at the era of just 350 million years old for the universe. This outcome describes the conditions of the universe just following the Big Bang and the initial phases of galaxy

Hu, X.
Principle and Applications of Telescopes: Refracting, Reflecting and Catadioptric Telescopes.
DOI: 10.5220/0013075500004601

In *Proceedings of the 1st International Conference on Innovations in Applied Mathematics, Physics and Astronomy (IAMPA 2024)*, pages 307-312
ISBN: 978-989-758-722-1

development. One significant discovery is about GN-z11, a young galaxy surviving 430 million years after the Big Bang. Notable discovery made by James Webb Space Telescope (JWST) researchers is that this galaxy harbours a supermassive black hole presently accreting matter. GN-z11 is the galaxy currently possessing the furthest known black hole distance. This outcome offers important new insights on the evolution of black holes in the early universe. Moreover, exposed by JWST spectroscopic data are ionized chemical constituents of GN-z11 (Bunker et al., 2023)

This outcome suggests that, even in the early periods, intricate processes involving elements with high atomic numbers were happening, which is crucial to grasp the chemical backdrop of galaxies. The results reveal how well JWST can probe far-off areas of the cosmos and offer unparalleled insight into the early universe, therefore advancing the knowledge of black hole development, galaxy creation, and the evolution of the universe.

2 GOALS AND FRAMEWORK FOR STATE-OF-ART FACILITIES

From Galileo's day, telescopes have been absolutely vital in helping to grasp the universe. telescopic technology is driven ahead by the search to comprehend the universe and therefore learn more. Appreciating the relevance of telescopes in the evolution of science and technology calls for a complete awareness of the basic principles and practical uses of them. The potential of telescopes to increase human vision beyond the boundaries of natural eyesight drives most of the research on their ideas and applications. By means of far-off celestial object analysis, telescopes expose the secrets of planets, stars, galaxies, and other cosmic happenings. Analyzing the universe satisfies the innate curiosity and clarifies basic issues like its evolution, composition, and genesis.

In addition, numerous useful applications call for telescopes. Fundamental tools for black hole research, exoplanet finding, and cosmic microwave background radiation study in astronomy are telescopes. Essential instruments for tracking weather patterns, viewing and evaluating environmental changes, and maintaining national security by means of remote sensing and surveillance are telescopes. If one is to make good use of telescopes in both theoretical and practical environments, one must have a firm awareness of the fundamental notions of optical design, light collecting, and resolution. Since it presents potential for new discoveries, the study of telescopes is essential and fascinating as technology progresses.

The essay consists in three main parts: principles of telescopes, applications in astronomy, and applications in other fields. It reviews basic ideas in telescopes as well as useful applications. Reflectors and refractors are two main types of telescopes; taken together, they account for six basic shapes. In charge of light collection, the objective tells exactly the kind of telescope to be utilized. The main objective of a refractor telescope is formed by a glass lens. The light bends as it passes the glass lens at front of the telescope. A reflector telescope's main optical component is a mirror. Strikes produce reflection of light in the mirror facing the rear of the telescope. A Catadioptric Telescope, which combines mirrors and lenses, is another kind of telescope used to exploit the benefits of both systems. Made expressly to fix optical defects, these flexible devices produce high-quality images with little chromatic and spherical aberrations.

The first type of telescope this study will introduce in this passage is catadioptric telescopes. These optical instruments are designed especially to obtain photographs of far-off objects. This approach uses reflective optics—like mirrors—and refractive optics—like lenses—to clearly integrate mirror and lens optics, hence improving performance and manufacturing process efficiency. Combining the words "dioptric," which defines a system utilizing lenses, with "catoptric," which specifies an optical system using curved mirrors, produces the phrase "catadioptric," a gadget that catches clean, high-quality images suited for both direct viewing as well as shooting astronomical objects. Professionals, teachers, and amateur astronomers find these tools particularly enticing since they mix the optical benefits of the reflecting and refracting designs (Bahrami & Goncharov, 2010).

Usually featuring apertures between 90 mm (3.5 inches) and 355 mm (14 inches), consumer-grade devices Whereas Schmidt-Cosegrain telescopes usually have focal lengths between 1000 mm and 3000 mm, Maksutov-Cassegrain telescopes usually have standard ranges from 1000 mm to 2000 mm. Although Maksutov-Cassegrain telescopes typically have focal ratios between f/12 and f/15, Schmidt-Cassegrain telescopes typically have focal ratios between f/10 and f/2.3. Furthermore, catadioptric telescopes are typically mounted equatorial or altazimuth depending on whether they are used for visual observation or astrophotography. Smaller models of consumer-grade catadioptric telescopes can weigh few kg, whereas bigger aperture models can weigh more than twenty kg. The weight of the object determines its mobility and simplicity of setup and transportation. The manufacturer and the specific type of catadioptric telescope can affect the specified exact values. Professional and observatory-grade telescopes usually have longer focal lengths, larger apertures, and more complex optical systems than consumer-grade telescopes. Mostly employed for the detection of gravitational waves is the catadioptric telescope. Catadioptric telescopes help detect and analyze gravitational waves even though they are not directly visible with optical telescopes. Telescopes are indispensable for multi-messenger astronomy by means of electromagnetic emissions, such as those of gamma-ray bursts or kilonovae since they enable exact location identification of gravitational wave occurrences. Additionally, this requires much effort in public outreach and astrophotography. Catadioptric telescopes are regularly used to capture amazing images of celestial objects in public outreach campaigns and amateur astronomy. These pictures are meant to inspire and enlighten the people on the beauties of space.

Second type telescopes, known as refractors, collect more light than the human eye could detect. Through concentration of light, they raise the visibility, clarity, and size of far-off things. Usually speaking, refracting telescopes have two main lenses. Generally speaking, the larger lens is known as the objective lens; the smaller lens used for seeing is termed the eyepiece lens. The objective lens lets the eyepiece lens operate as a magnifying glass, showing a magnified version of the image generated by the objective lens by generating a precise and small image of the object. To enable more exact and clear observation of far-off astronomical objects such stars, planets, galaxies, and nebulae, a refractor telescope gathers and concentrates light emitted by them. Refractor telescopes mostly serve to view celestial objects in the night sky. Usually made of glass, refractor telescopes gather and concentrate light using an objective lens to produce an image at the eyepikey or camera sensor. The capacity to capture exact and well-defined images of celestial objects is one benefit these telescopes give aficioners and amateur astronomers. Viewers may study the Moon's craters, planets in the solar system, star clusters, nebulae, and far-off galaxies. Reflector telescopes are often used in astrophotography, the technique of photographing astronomical objects by mounting cameras on telescopes. For in-depth studies of planets, galaxies, and nebulae, their ability to create clear, accurate images with obvious brightness variances makes them perfect (Onah & Ogudo, 2014).

Usually running from 50 mm (2 inches) to more than 150 mm (6 inches), an amateur refractor telescope has a focal length. Wider apertures catch more light, resulting in crisper, more brilliant photos. Usually ranging in focal lengths between 400 and 2000 mm, refractor telescopes may include even larger spans. For close examination of minute details in celestial objects, longer focal lengths produce better magnification and narrower fields of view. The degree of magnification might vary greatly depending on the exact mix of the focal length of the eyepiece being used with the focal length of the telescope. For a telescope with a 1000 mm focal length and a 20 mm eyepiece, for example, the magnification that results will be 50x (obtained by dividing 1000 mm by 20 mm). Excellent contrast, reduced chromatic aberration, and great optical accuracy define refractor telescopes of top quality. Quality is affected by lens grinding, coating technology, general design, and degree of accuracy in all three. Reflector telescope focal ratios usually fall between f/5 and f/15 or above. In astrophotography, a telescope with a smaller f-number—say, f/5—has faster exposure time and a higher light-gathering capacity. The dimensions of the telescope tube may change greatly based on the aperture and focal length. Tubes can have lengths between 500 mm and more 2000 mm and diameters between a few inches and several inches. The exact kind and intended use of a refractor telescope can produce significant changes in its values. Usually preferred by amateur astronomers are telescopes with apertures between 70 and 120 mm and focal lengths between 600 and 1200 mm. These decisions provide excellent optical performance and portability, therefore creating a nice balance. Longer focal lengths and much wider apertures of professional-grade reflector telescopes help to enable more exact observations and photographs.

The most current update from January 2022 states that refractor telescopes have been crucial for many recent observations and discoveries. Reflector telescopes have made it feasible in great part to find exoplanets orbiting stars outside of the solar system. Often included in these discoveries are exact measurements of a star's brightness over a certain period of time since they verify the presence of planets in orbit. Reflectors have tremendously helped to find and analyze supernovae, the violent death of large stars. These facts help astronomers to better understand the mechanics of explosions, the process of star evolution, and the resulting debris. Moreover, refractor telescopes actively participate in large-scale studies aiming at map the geographical distribution of galaxies and galaxy clusters over the universe. Surveys offer crucial data on the structure of the cosmos, dark matter distribution, and galaxy evolution across cosmic time.

The third type of telescope is the reflecting telescope, utilizing the phenomenon of light reflection (Mullaney, 2014). A far-off object's light enters the telescope and interacts with the main mirror—a large concave mirror at the rear of the device. This mirror precisely reflects and focuses light. Usually, a reflecting telescope uses a secondary mirror to deflect light from the main mirror as it gets near its point of convergence. The primary use of this secondary mirror is to divert light toward an eyepiece or camera. The eyepiece magnificuates the focussed light, therefore providing the spectator with a crisper, more detailed picture of the far-off object. The main purposes of a reflecting telescope are to effectively gather light from a far-off object and focus it precisely to generate a detailed and clear image. Larger main mirrors in telescopes help them to gather more light, therefore enabling them to view objects fainter and further away. Since the former allows the use of bigger apertures and improves light gathering capabilities, constructing gigantic mirrors is a more sensible and affordable choice than making huge lenses. Reflecting telescopes can be made in a range of configurations including Newtonian, Cassegrain, and Dobsonian to meet several observational needs.

The distance separating the main mirror's focus point from each other. The ratio of the focal length to the aperture decides the field of vision and the telescope's light collecting capability. An auxiliary mirror helps to focus light from the main mirror toward the eyepiece or camera. The James Webb Space Telescope (JWST) has been able to throw light on the early phases of the cosmos by effectively photographing galaxies that developed soon following the Big Bang (Rigby et al., 2023). The telescope also now searches for elements like water vapor and studies extraterrestrial atmospheres. This study helps to better grasp the possibilities of extraterrestrial life. A sketch of JWST is presented in Fig. 1 (Greenhouse, 2016).

The Event Horizon Telescope (EHT), a worldwide network of radio telescopes running as a single telescope with Earth-sized proportions, has achieved a major milestone. Released in April 2019 by the EHT project, the first-ever picture of a black hole at the core of the M87 galaxy This amazing achievement has confirmed Einstein's general theory of relativity and yielded unequivocal, visible evidence of black holes (Gold et al. 2020; Ramakrishnan et al., 2022). Restraints and Prospectives, A sketch for the facility is shown in Fig. 2 (Event Horizon Telescope Collaboration. 2019).

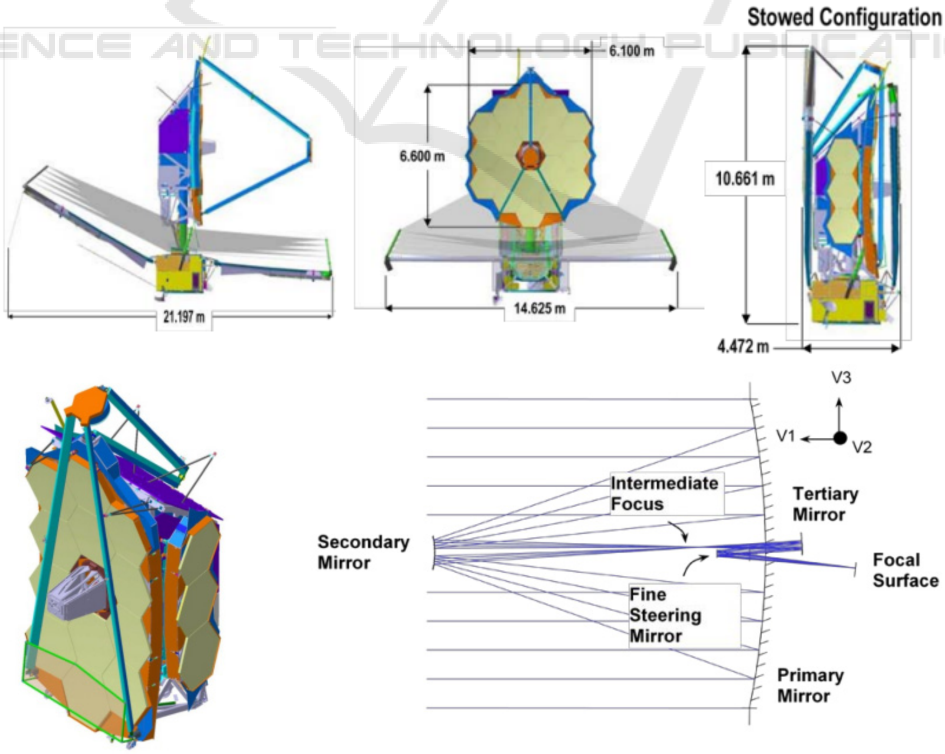

Figure 1: A sketch of JWST (Greenhouse, 2016).

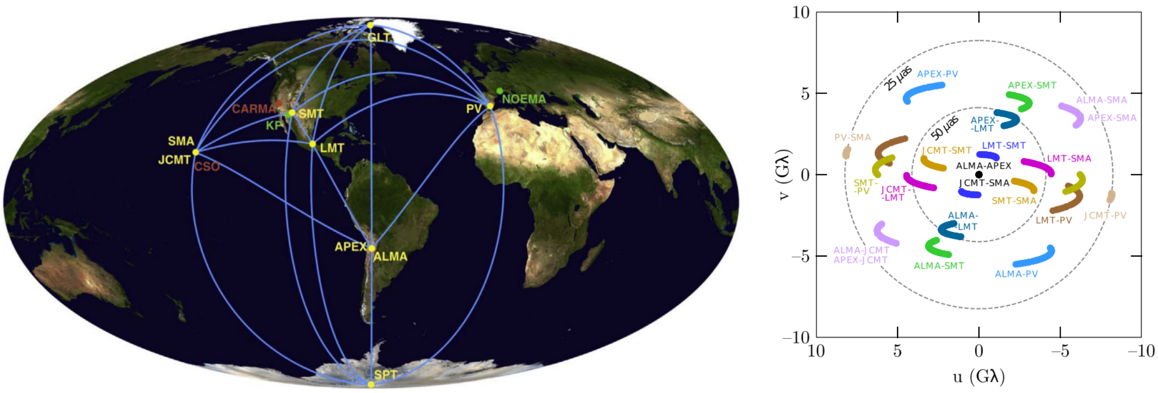

Figure 2: A sketch of EHT (Event Horizon Telescope Collaboration. 2019).

3 LIMITATIONS AND PROSPECTS

Because the atmosphere of the Earth can change the direction of arriving light, images can get distorted. Sometimes known as air turbulence, this phenomenon limits the degree of detail ground-based telescopes can gather. Furthermore, adaptive optics systems can minimize some air distortion; yet, their efficiency relies on the wavelength and their complex construction. Furthermore, providing better sharpness and collecting more light are larger mirrors. They do, however, also have the disadvantage of being more substantial and challenging to build and strengthen structurally.

As the JWST shows, the application of mitigating measures entails the combination of lightweight materials with cutting-edge technologies, such segmented mirrors. Still, engineers still find great challenges from these components' weight and bulk. Operating outside the atmosphere of Earth, the James Webb Space Telescope and the Hubble Space Telescope stop light pollution and atmospheric distortion. Future satellite telescopes will be able to record even higher degrees of detail and resolution. Starting in the middle of the 2020s, the Nancy Grace Roman Space Telescope will look at dark energy and problems associated to exoplanets. Ground-based telescopes will be able to more precisely lower atmospheric turbulence and approach space telescopes in terms of image clarity as adaptive optics technology develops. Modern adaptive optics technology will enable the Extremely Large Telescope (ELT) under construction in Chile to reach unheard-of clarity. Using segmented mirrors makes larger main mirrors that would not be feasible to build as a single piece possible. This method allows one to build larger and more sophisticated telescopes. The seven 8.4-meter Giant Magellan Telescope (GMT) components taken together have an aperture size of 24.5 meters. Reflecting telescopes point to a bright future full of fascinating new discoveries right around the horizon. These advances will keep expanding the boundaries of the knowledge about the universe.

4 CONCLUSIONS

To sum up, telescopes have profoundly transformed the comprehension of the cosmos, each with benefits and challenges, the understanding of the universe has changed significantly. Simple and robust devices using lenses, refracting telescopes are well-known. They are vulnerable to chromatic aberration, though, and have restrictions in size. Because of their mirror-based architecture, which also enables excellent resolution free from chromatic aberration, reflecting telescopes are better in gathering light. They must nevertheless be kept more regularly. Catadioptric telescopes mix lenses and mirrors to offer a compromise between portability and flexibility, even if they are more costly and complex. Future telescopes seem bright with advances in segmented mirrors, adaptive optics, and space-based observatories outside human reach. Using artificial intelligence-powered data processing and interferometry will help to explore far-off and dim celestial objects. These developments will help to better understand the universe and enable important discoveries as well as a clearer knowledge of its fundamental components.

REFERENCES

Bahrami, M., Goncharov, A. V. 2010. *All-spherical catadioptric telescope design for wide-field imaging*. Applied optics, 49(30), 5705-5712.

Bunker, A. J., Saxena, A., Cameron, A. J., et al. 2023. *JADES NIRSpec Spectroscopy of GN-z11: Lyman-α emission and possible enhanced nitrogen abundance in az= 10.60 luminous galaxy*. Astronomy & Astrophysics, 677, A88.

Event Horizon Telescope Collaboration. 2019. *First M87 event horizon telescope results. II. Array and instrumentation*. arxiv preprint arxiv:1906.11239.

Gold, R., Broderick, A. E., Younsi, Z., et al. 2020. *Verification of radiative transfer schemes for the EHT.* The Astrophysical Journal, 897(2), 148.

Greenhouse, M. A. 2016. *The JWST science instrument payload: mission context and status.* Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 904, 20-32.

Mountain, C. M., Gillett, F. C. 1998. *The revolution in telescope aperture*. Nature, 395(6701), A23-A29.

Mullaney, J. 2014. *Reflecting Telescopes.* A Buyer's and User's Guide to Astronomical Telescopes and Binoculars, 35-46.

Onah, C. I., Ogudo, C. M. 2014. *Design and construction of a refracting telescope.* International Journal of Astrophysics and Space Science, 13(1), 56-65.

Ramakrishnan, V., Savolainen, T., Event Horizon Telescope Collaboration. 2022. *First Sagittarius A* Event Horizon Telescope results. II. EHT and multiwavelength observations, data processing, and calibration*. Astrophysical Journal Letters, 930(2), L13.

Rigby, J., Perrin, M., McElwain, M., et al. 2023. *The science performance of JWST as characterized in commissioning.* Publications of the Astronomical Society of the Pacific, 135(1046), 048001.

Ryan, S. G. 2024. Visual Astronomy with a Small Telescope. CRC Press.

Taylor, C. 2004. *Reflecting Telescopes and Double-Star Astronomy*. In Observing and Measuring Visual Double Stars (pp. 97-136). Springer, London.