Analysis and Evaluations for the Detection Results of the Advanced Telescopes

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Keywords: Space Telescopes, Telescope’s Mission, Astrophysics Observations.

Abstract: As a matter of fact, telescopes are the most widely adopted facilities to realize the intensity distribution as well as spectra emitted or reflected by celestials for cosmology and astrophysics observations. With the development of the state-of-art techniques in optics and data analysing, it is available to achieve more accuracy observations (e.g., black hole photographing). With this in mind, this paper will be discussing about the fundamental idea of space telescopes, including different types of telescopes and the corresponding methods telescopes use for detecting celestial objects. To be specific, this study will discuss three telescopes in detail, with the instruments each carries, their capability, the process of detection, the telescope’s mission, and recent scientific discoveries and their significance. According to the analysis, this study will discuss the limitations and prospects of space telescopes at the current time. Overall, these results pave a path and offer suggestions for future telescopes designs and construction.

1 INTRODUCTION

After the invention of optics, Galileo invented a telescope in the 17th century using lenses. Before that time, people used naked eyes and other instruments to study astronomy, telescope was a new method for people to study the sky above them. (King, 2003)

Telescopes for space observation have rapidly developed ever since, people have invented more advanced telescopes for astronomical observations, and the understanding of the universe has increased quickly. During this process, the telescope serves as the most fundamental tool to learn about the universe. Observing and detecting all sorts of phenomena in the universe helped us discover many things, and concluded formulas and theories from the observational results. A unique property of light, or electromagnetic radiation gives us the chance to peek back to the past of the universe. Taking a look deeper into the universe means to look further backward, Humans get to study the evolution of this space lived in, all relying on the help of these space telescopes.

More recently, some of the most powerful telescopes in the world have brought new and significant discoveries that will tell us about the universe. With strong spectroscopy capability, the James Webb Space Telescope (JWST) was able to learn more about the planets with high redshift. By studying the planet’s composition, JWST acquired new information about the composition of a few of the earliest stars in the observable universe (Carnall et al., 2022). Similarly, the ground telescope Gran Telescopic Canarias has also broken the traditional understanding of ring dynamics, having an unusual finding in the solar system, creating a blindspot on the current comprehension of rings (Morgado et al., 2023). Moving to other parts of the electromagnetic spectrum, the Chandra X-ray observatory has detected x-ray emissions from neutron stars emerging and collision, exploring possibilities of multi-messenger events (Troja et al., 2017).

The role of space telescopes is only to collect information emitted from space in the form of electromagnetic radiation on or near Earth, which are limited to observing, collecting as much of this radiation as possible with greater accuracy and sensitivity (Bely, 2003).

Two types of telescopes in modern times are known as space-based and ground-based telescopes. Space-based telescopes can be further sorted into telescopes carrying instruments that collect information from different frequencies. Frequencies of gamma-ray, x-ray, ultraviolet, visible, infrared, microwave, and radio differentiate space telescopes in their use and observation targets.

Yang, T.
Analysis and Evaluations for the Detection Results of the Advanced Telescopes.
DOI: 10.5220/0013077800004601

In *Proceedings of the 1st International Conference on Innovations in Applied Mathematics, Physics and Astronomy (IAMPA 2024)*, pages 343-351
ISBN: 978-989-758-722-1

Ground-based telescopes have three major categories which are divided based on observation methods: reflecting telescope, refracting telescope, and catadioptric telescopes. These types of telescopes are differentiated by methods of light collecting, further by aperture. Additionally, the effectiveness of telescopes is determined by the light-gathering power of the optical system. With a higher aperture, telescopes can produce a higher resolution of detected results, thus allowing the analysis to be more in-depth and detailed. The need for a space-based telescope is due to the presence of the atmosphere. Earth's atmosphere constantly changes, and ground-based observation often encounters turbulence in the atmosphere. Thus, resulting in an inconsistent performance of the telescope, further causing the observed image to be blurred and unclear. Furthermore, another property of Earth's atmosphere blocks off some electromagnetic radiation wavelengths. Short wavelengths of radiation are dangerous to human health but crucial in helping to shape a better understanding of the universe.

Figure 1 shows a spectrograph of electromagnetic radiation in different wavelengths getting blocked by Earth's atmosphere. The graph below includes the elements within the atmosphere blocking the corresponding wavelength of radiation, as well as the percentages of blockage. Capturing these specific wavelengths of electromagnetic radiation would require us to send telescopes outside of the Earth's atmosphere. This creates space-based telescopes to better detect these radiation wavelengths in a more stable environment relative to Earth. Nevertheless, the cost of space-based telescopes is significantly more than ground-based telescopes. Once sent out into space, maintenance and servicing would be difficult to conduct, thus limiting the capabilities of space-based telescopes.

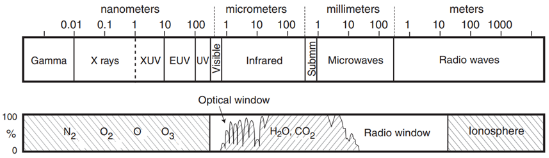

Figure 1: Spectrograph of electromagnetic radiation (Bely, 2003).

2 M DESCRIPTION OF TELESCOPES

Both types of telescopes consist of primary and secondary mirrors but ground-based ones are significantly larger than space-based telescopes for the following reasons. Without considering sending the telescopes to a specific orbit, the weight limitations that the rockets can carry, in comparison with space-based telescopes, gound-based optical telescopes are typically equipped with a larger primary and secondary mirror. Slow gains in resolution have been made by employing better and larger optics, by moving to better sites, and, more recently, by compensating for atmospheric turbulence and going into space (Bely, 2003). As mentioned, atmosphere turbulence is the most dominant obstacle for ground-based telescopes, hence affecting observation efficiency and clarity.

Ground-based reflecting type optical telescopes can capture electromagnetic radiation using their parabolic-shaped primary mirror, with specialized designed shape, material used, and placements. For ground-based telescopes to work most effectively, they also have strict limitations regarding their location. Since telescopes are extremely sensitive to the electromagnetic radiation they receive, ensuring the best observation result, telescopes need to be far away from city lights or any other possible bright light sources. Possible light pollution glows up its surrounding environment and atmosphere, bright light from other light sources nearby telescopes will dim or disrupt celestial light, even covering up the light emitted by celestial objects.

Most ground-based telescopes are located in high altitudes to avoid atmosphere turbulence (Steiner, 1966). Earth's atmosphere is not a uniform medium, rather it has different densities and compositions in distinct areas. In addition, turbulence in the atmosphere lowers the resolution of observations. To avoid that, setting up an observatory at a high altitude may be essential. Higher altitudes also provide a thinner atmosphere layer, producing a clearer, unobstructed view of the universe. Due to the thinner atmosphere layer allowing infrared radiation to penetrate through more easily, it thus helps with infrared detection. In many locations of ground-based optical telescopes scattered worldwide, most are owned by a national government or government-funded institution, carrying out their mission.

Refractor telescopes use the objective lens at the tip to focus all incoming light. By accurate high-precision polishing, the converging lens with its curved surface refracts all the incoming light into an angle, allowing light to meet up at one focal point onto an eyepiece or instrument for observation. Telescopes using this method have limitations since the light is being refracted at an angle, for the light going through the center of the lens can pass right down to the instrument. However, the light going through the lens at the edge has to be refracted at an angle to gather into a focal point, telescopes would have required distance for refracted light to travel, to meet up with the rest of the light into the instrument equipped by the telescope, making the tube of refractor telescope significantly longer than other two methods. Still, both the manufacturer's difficulty and cost of this telescope substantially increase as its size and resolution increase. This is due to the difficulty of producing large and high-precision lenses without any defects since the edge of the lens is extremely fragile. Another problem that refractor telescopes commonly encounter is the chromatic aberration caused by different indices of refraction for each wavelength of light. Chromatic aberration can be calibrated by using a second carefully designed lens mounted behind the main objective lens of the telescope to compensate for the chromatic aberration and cause two wavelengths to focus at the same point.

An example of a refractor telescope is the Yerkes Observatory Refractor. The Yerkes 40-inch was the largest refracting-type telescope in the world when it was completed in 1897. Research conducted at Yerkes in the last decade includes work on the interstellar medium, globular cluster formation, infrared astronomy, and near-Earth objects. Another type of telescope is the catadioptric telescope, which has an optical system of combination refraction and reflection. The catadioptric telescope consists of both lenses and mirrors to form images, utilize the benefits, and minimize the disadvantages of each. Incoming light first passes through a corrector lens, which effectively helps reduce the telescope's optical aberration. The light then passes down to the primary mirror at the bottom of the tube, which then reflects all the light onto the secondary mirror, allowing the secondary mirror to reflect concentrated light into the instrument. Catadioptric telescopes typically have two branches, being Schmidt-Cassegrain Telescopes and Maksutov-Cassegrain Telescopes. Although both have similar structures, Maksutov-Cassegrain Telescopes equip a thin, meniscus-shaped corrector lens. In contrast, Schmidt-Cassegrain Telescopes equip a thin, aspherical lens, and corrector lens lenses to correct optical aberration. In comparison, the Maksutov-Cassegrain telescope works better due to its thin lens, providing better correction to optical aberration, and resulting in a higher price.

The last and most common type of ground-based telescope is the reflecting telescope. The telescope's primary mirror can concentrate as much light as possible into one focal point. Afterward, the secondary mirror reflects all the captured light in the focal point onto the instrument for observation. The primary mirror on the telescopes is adjustable using the optic system, allowing it to change the angle and direction it faces. This is to collect radiation more effectively and to avoid turbulence in the atmosphere. Large mirrors are easier to manufacture than lenses, making reflecting telescopes the most common type for ground-based observation. Additionally, a reflecting telescope wouldn't experience chromatic aberration since light isn't going to be dispersed through lenses during the process,

Earth's atmosphere is transparent for radiations in the radio frequency, making ground-based observation possible. Radio telescopes are one of them, literally collecting radio waves emitted by the universe. Unlike optical telescopes that use a lens or mirror, radio telescopes equip a large parabolic-shaped metal dish with an antenna in the middle. However, similar to optical telescopes, the dish can reflect and concentrate all the radiation into the feed horn in the middle. This will then direct all the focused radiation to the receiver that amplifies these weak signals for recording. Radio telescopes usually scatter many dishes in a region, and with precise placements, many dishes can serve as a radio telescope that covers the whole area. This method is known as interferometry, providing excellent observation for a low budget.

Similar to ground-based optical telescopes, space-based optical telescopes target the visible wavelength and are equipped with a primary mirror and secondary mirror to capture and concentrate light. On top of that, they also have a guidance control system, and a communication system to keep in contact with the earth. In certain situations, some telescopes will have specialized equipment for their unique scientific goal of detection. The Hubble space telescope is a perfect example of a space-based optical telescope, by collecting visible celestial lights using mirrors, while the HST orbits around Earth, its observation isn't affected by the atmosphere's turbulence and captures images with higher resolution. Although the telescope is located in space, astronauts can service it in orbit, extending its lifespan from 15 years to now, which is already 34 years. Its main missions included studying the formation and evolution of galaxies and stars, studying and mapping dark matter, investigating black holes, and more.

Infrared space-based telescopes focus on the infrared wavelength of the electromagnetic spectrum, which is typically emitted by hot objects in the universe that can penetrate through space dust clouds, making it extremely useful for studying the universe. Heated objects emit thermal radiations that consist of various wavelengths of radiation, infrared wavelength being the most dominant. From a design level, infrared telescopes are like optical visible wavelength telescopes, using mirrors made out of materials most effective in reflecting infrared radiation to collect incoming infrared radiations and focus them into the instrument. One key difference is the requirement of a cooling system for infrared telescopes. As mentioned, infrared telescopes observe thermal radiation, and their instrument is sensitive to any thermal radiation source, including the telescope itself. The cooling system on the telescope is to lower the noise caused by thermal radiation emitted by the telescope itself. Such thermal emission can be caused by exposure to the sun or even its optics and electronics. Therefore infrared detection is best done in space rather than on Earth. Not only does the atmosphere have turbulence and absorb some of the radiation, but objects on Earth potentially release too much heat that interferes with the telescope.

X-ray is another type of electromagnetic radiation blocked by Earth's atmosphere, requiring an observatory to be located in space. X-ray radiation has short wavelengths and high energy, giving it the ability to penetrate through materials easily. Therefore, X-ray telescopes don't work the way telescopes in longer wavelengths usually work. Due to high penetration power, x-ray telescopes usually use smooth surfaces to reflect X-rays at a shallow angle, making radiations ricochet off the reflective surface, into the instrument. Gamma-ray is the shortest wavelength of radiation on the electromagnetic spectrum, it easily penetrates through most objects, except for the earth's atmosphere. Space-based gamma-ray telescopes do not use reflective mirrors, because gamma-ray penetrates right through. Hence, unlike x-ray telescopes, gamma-ray telescopes typically don't equip reflective mirrors, but rather detection methods that interact with gamma rays each time radiation strikes them.

3 JAMES WEBB SPACE TELESCOPE (JWST)

JWST is a space telescope that mainly focuses on the infrared observation of the universe. The James Webb Space Telescope was launched on December 25, 2021, and in January of 2022 it arrived at its observing orbit, L2 Lagrange point 2. L2 Lagrange allows the JWST to maintain the same orbiting speed as Earth concerning the sun, offering stable communication with the Earth, additionally, being on the same side of the Earth and moon blocks some thermal radiation from the sun. The telescope is equipped with 6.5 meters, 18 segments of the hexagonal-shaped primary mirror, providing a much wider view than the Hubble space telescope's 2.4 meters diameter mirror, capable of higher resolution observation (McElwain et al., 2023). JWST equips four high-precision near-infrared observational instruments. NIRSPec, NIRCam, MIRI and FGS/NIRISS.

NIRCam, as an infrared imager, provides a range of observational wavelengths, covering from visible light 0.6 µm to the near-infrared 5 µm, allowing it to capture lights from the earliest galaxies and stars formed in the universe. The NIRSpec is a spectrograph that provides observation from 0.6-5.3 µm infrared wavelength with 3 different resolutions, with the lowest resolution at $R \simeq 100$ mode, intended for obtaining exploratory continuum spectra and redshifts of remote galaxies. The intermediate resolution $R \simeq 1000$ mode is designed to accurately measure their nebular emission lines, and the higher resolution $R \simeq 2700$ mode performs kinematic studies using these emission lines (Jakobsen et al., 2022). With the emission lines captured, the data can be analyzed to determine different properties of the observation target, such as the target's temperature, mass, and chemical composition.

MIRI stands for mid-infrared instruments, it focuses on a different wavelength, from 5 to 27 µm. MIRI includes both a camera and a spectrometer for mid-infrared range observation. Lastly, FGS/NIRISS stands for Fine Guidance Sensor, Near Infrared Imager, and Slitless Spectrograph, it is used to stabilize the telescope during observation, and correctly adjust and maintain the telescope's line of sight. As mentioned earlier, infrared telescopes are extremely sensitive to thermal radiations, such a principle applies to JWST as well.

OTE optics must be below 55K to function properly, the NIRISS must be below 45K, and the MIRI must be cooled to 6K. In addition, a cooling system is attached to instruments to reduce temperature passively. JWST provides a 15-meter wide and 21-meter-long, 5-layer sun shield that effectively reduces other thermal radiation that creates noises for the observation (Menzel et al., 2023). JWST has four main missions during its operation: finding light from the earliest star formed in the universe and studying the formation and evolution of galaxies. Third, understanding the formation of stars and planets and studying planetary formation and origin of life.

During the operation of JWST, one got to discover much older galaxies thanks to NIR instruments. Before JWST was in operation, the latest galaxies one discovered using Hubble and Spitzer space telescope was the GN−z11galaxy with redshift $z \approx 11.09$. JWST allowed us to not only study more galaxies from $5 < z < 9$ redshifts and even more galaxies with redshift $z > 10$ were detected, such as the CEERS (Cosmic Evolution Early Release Science) project, which has detected galaxies with redshift $z > 15$, studying the evolution of these galaxies.

Figure 2 was formed by NIRSpec, providing spectrographs for galaxies that were difficult to capture and study before. The bottom row of the graph shows galaxies with a redshift of 5~9. According to past research with ground-based telescopes and Hubble space telescopes, there was not enough evidence to support the claim that early galaxies in the observable universe contain heavy elements (Carnall et al. 2022). JWST is capable of capturing and analyzing the results of these high redshift galaxies. Spectrograph evidence shows oxygen's presence in these galaxies, changing the understanding of the early galaxies and that they are only composed of light elements, such as hydrogen and helium. However, through observation, heavier elements usually produced by nuclear fusion are present in high redshift galaxies as well, renewing the understanding of the evolution and formation of early galaxies.

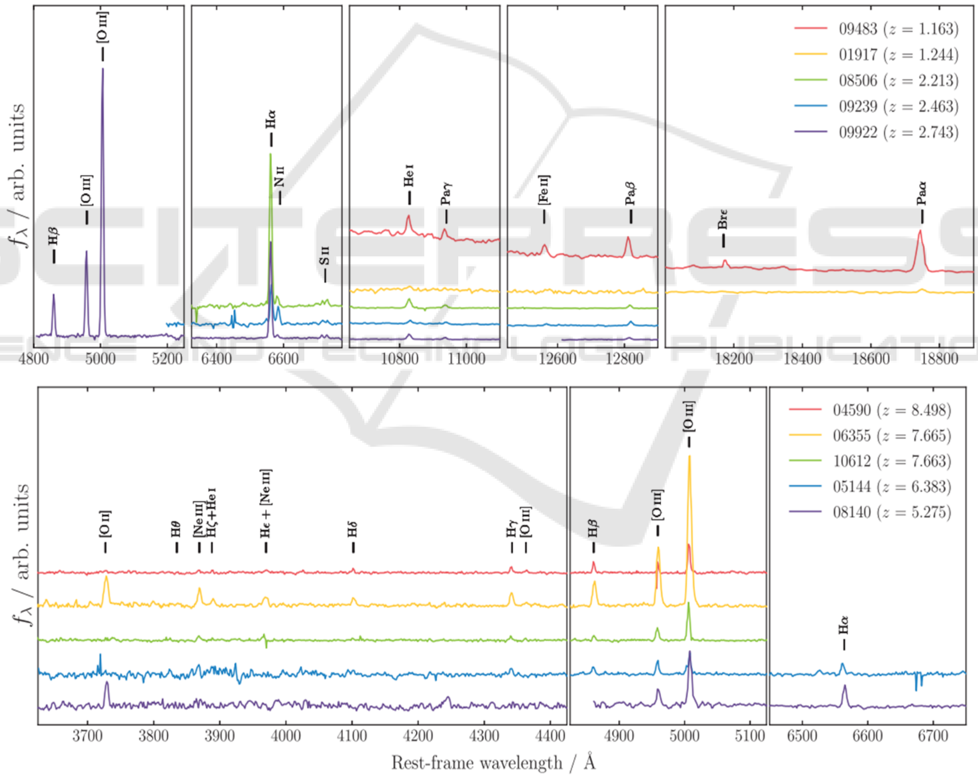

Figure 2: Spectrographs for galaxies formed by NIRSpec (Carnall et al. 2022).

4 GRAN TELESCOPIO CANARIAS (GTC)

Gran Telescopio Canarias (GTC) is a ground-reflecting optical telescope located in Roque de los Muchachos Observatory on the island of La Palma, in the Canary Islands, Spain. It's known as the world's largest single-aperture telescope, with 36 hexagonal segments that work together to form a single, unbroken surface of the primary mirror 10.4 meters in diameter. Since the island is located at an altitude of approximately 2,396 meters, the telescope avoids surrounding light pollution, and atmospheric turbulence gets significantly reduced, providing a clearer view. However, the remote location also caused the shipment and assembly of the telescope to be delayed, as well as its date of operation and first light being pushed backward. The first light of this telescope was achieved on 13 July 2007, and it was put on a mission in 2009. GTC doesn't have main missions that it focuses on, however, organizations send proposals to assign GTC observation targets. Due to its strong near-infrared and mid-infrared wavelength observation technologies, it has advantages in detecting and studying exoplanets, studying dark matter, and observing astronomical events such as supernova explosions. GTC equips 5 main instruments, they are the following OSIRIS, EMIR, MEGARA, HiPERCAM, and CanariCam. Among them, OSIRIS, EMIR, and MEGARA equip adaptive optics enhancing their imaging ability, and encountering atmosphere turbulence, making it essential for near-infrared instruments.

OSIRIS and MEGARA are both visible light wavelength spectrographic instruments. OSIRIS (Optical System for Imaging and low-resolution Integrated Spectroscopy) is an imager and spectrograph covering wavelengths from 0.365 to 1 μm. With a wide field of view (FOV) of 7 × 7 arcmin, direct imaging, and 8 arcmin × 5.2 arcmin for low-resolution spectroscopy (Cepa J. et al, 2003), although it has low resolution, its FOV can capture a large area of space. Additionally, it can provide spectrographs that can be used for broad analysis of multiple targets such as stellar population.

MEGARA (Multi-Espectrografo en GTC de Alta Resolucion para Astronomia) is also a multi-target spectrograph with an observation wavelength from 0.365 to 0.97 μm, with a FOV of 3.5 arcmin x 3.5 arcmin. The main difference between it and OSIRIS is that MEGARA offers a high-resolution imager, giving a more detailed spectrograph great for deep analysis of the speed and composition of targets (de Paz, 2014).

MERI (Espectrógrafo Multiobjeto Infra-Rojo) is a near-infrared wide-field imager and medium-resolution multi-object spectrograph, working with wavelength 0.9 - 2.5 μm and FOV of 6.67 arcmin x 6.67 arcmin. It serves a similar purpose to MEGARA and OSIRIS, on top of that, it can form images rapidly, specializing in capturing more drastically changing phenomena with high frame rates, such as exploring exoplanets and recording supernovae explosions.

HiPERCAM is another instrument specialized in high frame rate observation, capable of observing transiting stars and supernovae explosions, high frame rates allow it to capture the light curves of fast-changing phenomena, complementing MERI's mid resolution, providing further detail for in-depth study.

CanariCam is capable of performing imaging, spectroscopy, polarimetry, and coronography in the 10 and 20 μm atmospheric windows. It mainly focused on 7.5 and 25 μm of mid-infrared observation, capturing high-resolution images in 3 arcmin x 3 arcmin resolution. Still, compared to other instruments on the telescope, CanariCam focuses on warmer objects emitting mid-infrared wavelengths of light, such as star-forming regions, evolved stars, and planetary atmospheres.

GTC has recently discovered a dwarf planet with a ring outside its Roche limit through the stellar occultation method. The dwarf planet called Quaoar is located in the Kuiper Belt, within the solar system. GTC has recorded the light curves of occultation stars, with the HiPERCAM instrument, using a four-band system with 0.40–0.55 μm, 0.550-0.69 μm, 0.69–0.82 μm, and 0.82–1.00 μm filters, such precise and high framerate photometry instrument on GTC was able to capture Quaoar and its ring. According to the Roche limit, the celestial object can maintain its shape and should not be broken down by the tidal force exerted by the planet, but this discovery didn't follow the Roche limit, such significant finding changes the understanding of the ring system, indicating the potential changes of Roche limit and ring dynamics in distant places (Morgado et al., 2023). Figure. 3 shows the light curve observed by HiPERCAM in 0.69–0.82 μm wavelength, the blue highlighted area in Figure A is enlarged and shown in Figures B and C. The changes in flux indicate the ring of Quaoar.

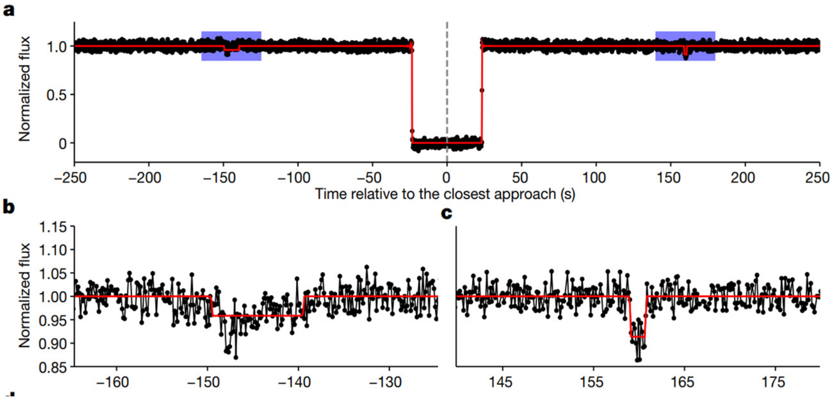

Figure 3: The light curve observed by HiPERCAM in 0.69–0.82 μm wavelength (Morgado et al., 2023).

5 CHANDRA X-RAY OBSERVATORY

Chandra X-ray Observatory is a space-based telescope. Chandra was launched in July 1999 by National Aeronautics and Space Administration (NASA), and the first picture by Chandra was taken just a month afterward. The telescope was planned to operate the mission for about 5-10 years, but by then the mission had far exceeded expectations, Chandra has operated until today, for more than two decades. The observatory has an extremely elliptical orbit, with a Perigee altitude of 14,307.9 km and an Apogee altitude of 134,527.6 km. An elliptical orbit like this allows Chandra to utilize about 70% of its 63.5 hours of orbital rotation to continuously make observations. (Weisskopf et al., 2000). X-ray assembly is the high-resolution mirror assembly, with extreme smoothness, and carefully assembled mirror with accuracy to just a few micrometers, which allows Chandra to reflect high-energy X-rays into the instruments.

Chandra has 5 main instruments, being ACIS, HRC, LEGT, and HEGT. ACIS stands for Advanced CCD Imaging Spectrometer with FOV or 8.4 arcmin x 8.4 arcmin. It is a high-resolution imaging and spectroscopy instrument on board, it can translate the x-ray it receives into electrical signals using Charge-Coupled Devices (CCDs), making information readable. HETG and LETG stand for low and high-energy transmission grating. They are similar in their function, both are designed for high-resolution spectroscopy and work together with ACIS. HETG aims for higher energy x-rays for a wavelength range from 1.2 to 31 Å (0.12 to 3.1 nm) while LETG aims for a wavelength from 5 to 175 Å (0.5 to 17.5 nm), providing a spectrum of observed targets for further analysis. Lastly, HRC stands for High-Resolution Camera, it provides highly detailed imaging power for the telescope with a wide FOV of 31 arcmin x 31 arcmin. HRC has a resolution exceeding ACIS, high-resolution imaging is crucial for high-energy observation, capturing the faintest detail in the universe. In 2017, during the gravitational wave event GW170817, X-ray emission was captured by Chandra X-ray Observatory along with the gravitational wave caused by merging and collision between two neutron stars. Event GW170817 being a binary neutron star system, and the discovery of X-rays with gravitational waves is seen as confirmation of multi-messenger astronomy, with both gravitational wave and electromagnetic types of information, it gives scientists better insight into events like neutron star collision, such multi-messenger has never happened before. The author suspects either a kilonova afterglow or an accretion disk around the newly formed black hole after the collision. Kilonova afterglow represents the collision between two neutron stars, a shock wave releasing energy and heavier elements. When elements are released, they interact with the surrounding environment and produce light across the electromagnetic spectrum including X-ray. Yet today, it wasn't settled on a hypothesis, but one has been monitoring multi-messenger events like this, specific to gravitational wave events, other wavelengths of electromagnetic radiations have been detected (Troja et al., 2017). Figure 4 shows the telescope capturing the x-ray emission from event GW170817, Chandra along with many other telescope's missions to capture the fading glow of the blast's expanding debris.

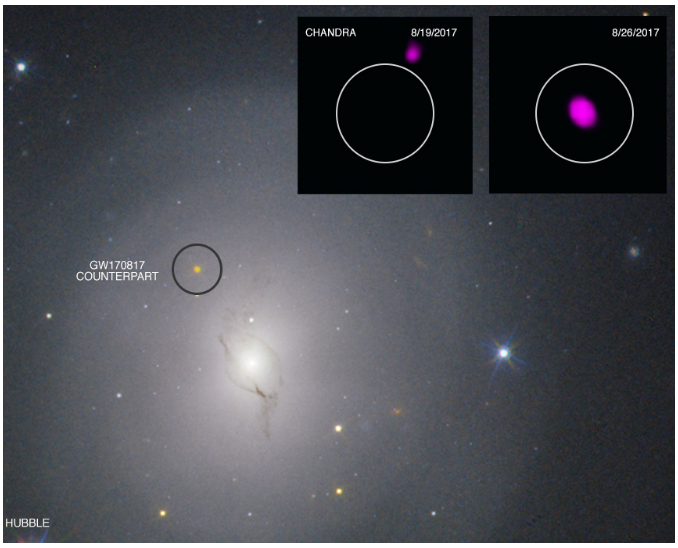

Figure 4: The telescope capturing the x-ray emission from event GW170817 (NASA, 2021).

6 LIMITATIONS AND PROSPECTS

Currently, one has large amounts of space telescopes whether in space or on the ground, each observing for its unique targets and making new scientific breakthroughs. However, many factors have limited the efforts in figuring out all the unsolved questions in the universe. Economical limitations are the most obvious obstacle right now, to the government and organizations, telescopes are costly. James Webb Space Telescope has cost NASA $9.7 billion over 24 years, including development, deployment, etc. Tremendous costs for space telescopes are inevitable, such might cause government-owned organizations to get reduced funding, which is what NASA faces in 2024, and with no choice, some telescopes in operation such as the Chandra X-ray Observatory need to be shut down. Same with ground-based telescopes, including maintenance, telescopes require a scary amount of funding. Another aspect of limitation is technological limitation, which is highly related to economic limitation. Although telescopes have high resolution and wide FOV instruments that can detect objects millions of lightyears away, which was unheard of just a few decades ago, observation on faint targets can take a ridiculously long period. Lastly, nature can also be a great obstacle to telescopes that one can’t deal with, including atmospheric turbulence for ground-based telescopes and solar interference on space telescopes.

In the future, new telescopes are still in development, such as the Nancy Grace Roman Space Telescope (NGRST) and the European Extremely Large Telescope (E-ELT). NGRST has a FOV about 100 times bigger than the Hubble space telescope. E-ELT is a ground-based telescope that has a 39-meter primary mirror, making it the largest optical/near-infrared telescope in the world after construction. New telescopes will provide highly detailed and high-resolution images that can study the universe better. As technologies keep improving, the world will undoubtedly see further and clearer, with unprecedented discoveries and solved questions.

7 CONCLUSIONS

To sum up, this study has briefly discussed the history of telescopes and introduced the functions and categories of telescopes, including methods of observation. In-depth detail about three telescopes, their instrument's capability, and recent discoveries. According to the analysis, the current drawbacks are discussed and future development trends are clarified. Overall, this study serves the purpose of a brief introduction to various kinds of space telescopes, shedding light on guiding further exploration of telescopes.

REFERENCES

Bely, P., 2003. *The design and construction of large optical telescopes.* Springer.

Carnall, A. C., McLure, R. J., Dunlop, J. S., et al., 2022. *The stellar metallicities of massive quiescent galaxies at 1.0< z< 1.3 from KMOS+ VANDELS*. The Astrophysical Journal, 929(2), 131.

de Paz, A. G., Carrasco, E., Gallego, J., et al., 2018. *First scientific observations with MEGARA at GTC.* In Ground-based and Airborne Instrumentation for Astronomy VII 10702, 351-370.

Jakobsen, P., Ferruit, P., de Oliveira, C. A., et al., 2022. *The near-infrared spectrograph (nirspec) on the james webb space telescope-i. overview of the instrument and its capabilities*. Astronomy & Astrophysics, 661, A80.

King, H. C., 2003. *The history of the telescope*. Courier Corporation.

McElwain, M. W., Feinberg, L. D., Perrin, M. D., et al., 2023. *The James Webb Space Telescope mission: optical telescope element design, development, and performance*. Publications of the Astronomical Society of the Pacific, 135(1047), 058001.

Menzel, M., Davis, M., Parrish, K., et al., 2023. *The design, verification, and performance of the James Webb Space Telescope.* Publications of the Astronomical Society of the Pacific, 135(1047), 058002.

Morgado, B. E., Sicardy, B., Braga-Ribas, F., et al., 2023. *A dense ring of the trans-Neptunian object Quaoar outside its Roche limit*. Nature, 614(7947), 239-243.

NASA. Recent results for GW170817, 2021 Retrieved from: https://ntrs.nasa.gov/citations/20210014082

Steiner, R., 1966. *A review of NASA high-altitude clear air turbulence sampling programs*. Journal of Aircraft, 3(1), 48-52.

Troja, E., Piro, L., Van Eerten, H., et al., 2017. *The X-ray counterpart to the gravitational-wave event GW170817*. Nature, 551(7678), 71-74.

Weisskopf, M. C., Tananbaum, H. D., Van Speybroeck, L. P., O'Dell, S. L., 2000. *Chandra X-ray Observatory (CXO): overview.* X-ray optics, instruments, and missions iii, 4012, 2-16.