Analysis of the detection principle and state-of-art results for FAST

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Abstract. Universe has always been mysterious and attractive for human beings. In the early stage of human civilization, plenty of hypothesis were made by people according to the daily observation of the sky. Ancient people discovered the rules for measuring time, weather, climate and even orbiting by seeing how the appearance of sky changed. However, these discoveries largely depend on the naked eye ability and wisdom of ancient people. The invention of the astronomical telescope helped people to observe the space directly by enlarging the image of the celestial body. Since then, people received a more comprehensive information about the universe and a more accurate universe cognition. This paper will discuss the FAST telescope located in China. There will be an introduction of the structure, ability, use, limitation and future outlook of the FAST telescope. It is concluded that FAST is a multifunctional telescope based on the detection of radio. There are many advantages yet a few places still have room to improve. Some outstanding detection outcomes were achieved by FAST. This article mainly analyzes the structure and use of FAST and will also point out the aspects which can be improved on the structure. These results shed light on guiding further exploration of telescope.

Keywords: FAST; Observation; Mirrors.

1. Introduction

Astronomical observation has its root deep in remote antiquity [1]. The long history of the development of astronomical telescope has begun since seventeen centry. It is generally acknowledged that the first telescope in the world was invented by an eyewear manufacturer, Hans Lippershey, in 1608. However, this kind of telescope has a magnification of only threefold enlarge and we are not entirely sure about the design used by the Lippershey telescope-there are two possible lens configuration [2]. The first astronomical telescope is said to be invented by Galileo in 1609, with the ability to magnify 32 times. Through this telescope, Galileo was able to observe the surface of moon, and even discovered the Saturn's rings, Sunspot and etc. Since then, astronomy has entered from the era of naked eye observation to observation by telescope. In 1611, German scientist Kepler invented The Kepler Telescope. The image formed by this telescope is upside down, left and right. All the telescopes mentioned above have a long focal length and they are all belong to the refracting telescope. In 1663, the first kind of reflecting telescope was invented by Gregory, a mathematician in Scottish. Compared to the refracting telescope, the reflecting telescope has the advantage of achromatic. And in 1668, the great England scientist Isaac Newton invented the Newton Telescope which is also a reflecting telescope. The design used in the Newton Telescope enabled it to magnify the objects several times bigger than using the lens. In the design of small telescopes, Newton type reflecting telescope is the one being the most commonly used. The reflecting Cassegrain Telescope was invented in 1672 by Cassegrain. Its design was based on the star camera of Bernhard Schmidt and it improved the plan of Newton Telescope.

The Cassegrain system was commonly used in the modern optical telescope. In 1789, the England astronomers Friedrich Wilhelm Herschel completed his huge telescope with mirror made by reflective metal. However, this telescope is hard to activate as its focal length is 12 meters long. During 1845, Ireland astronomers William Parsons, using the metal mirror, produced a large Newton type reflecting telescope. He discovered the vortex structure Nebula by using this telescope. In 1888, refracting telescope James Lick Telescope was built. It was the largest refracting telescope in the world at that time. German scientist Schmidt invented the Schmidt telescope which contains both the refracting devices and reflecting devices in 1931. This was commonly used in activities of imaging and astronomical science. During 1948, the Hale telescope was invented. It remained the largest telescope in the world before the invention of BTA-6 in 1975. However, the analytic ability of the Hale telescope was not surpassed until the Keck telescope appeared in 1993. In 1990, the Hubble Space Telescope was sent into the orbit. The FAST telescope was first started to build in 2011 and eventually be used in 2020.

FAST is a giant radio telescope with a new working mode and is working in the mountainous environment and complex climate conditions in Guizhou. During a specific issue, Qian et al., which is the first pulsar discovered by the radio astronomical equipment built in China, described the first pulsar discovered by FAST, which became a milestone of FAST [3]. Recently, the FAST telescope have discovered the first persistent active fast radio burst.

The motivation of this essay is to analyze the working principle and theory optical knowledge used in the design of FAST, as well as some latest observations conducted by the FAST telescope. Firstly, there will be a brief introduction about the telescope's principle. Then, the components of FAST will be described in the passage. Performances and new detection results will also be discussed in the following part. Limitations and future outlooks will be mentioned at the final part and a conclusion will be made at the end of the essay.

2. Principle of telescope

Telescope is made up of all kinds of lens and mirrors. It is an optical devices which can be used to detect objects that are very far away from us by using the suitable lens or reflecting mirrors. There are two types of telescope, the optical telescope and the radio telescope. FAST, whose full name is Five-hundred-meter Aperture Spherical radio Telescope, belongs to the radio telescope. For the Optical telescope, it is very common and can usually be seen by people.

Optical telescope can be divided into three types, i.e., the reflecting type, the refracting type and the catadioptric telescope. The reflecting type telescope often involves a concave parabolic mirror or a spherical reflector to reflect the light which has been gathered to a plane mirror located in front of the lens cone. Subsequently. the plane mirror will reflect the light to the eye lens outside the lens cone, enabling us to observe the space. As this reflecting system do not have any special request on the optical property of the glass material, the light does not need to cross through the material itself. Less weight and none chromatic are the main advantages of the reflecting telescope. The refracting telescope at present uses the convex lens as the eye lens of the telescope. Since it can gather the light coming from the objects in order to form a real image. After the light coming through the lens, the light will be focused on the focal point, and be sent out to the eye lens of the telescope, forming an image.

However, as the lens has different refractive index towards different colors of light, aberration can be made. Catadioptric telescope involves both the reflecting system and the refracting system. Thus, the light from the celestial body will go through reflection and refraction. The light is first refracted by a lens. The reflecting devices are mainly responsible for the focal power of light. As a result, after the refraction of light, the light is reflected and focused at the same time by the reflecting mirror. This kind of system has the benefit of the correction for off-axis aberrations. Radio telescope like FAST belongs to a parabolic telescope. The way it collects information is through parabolic reflection. The surface of the parabolic is able to reflect the parallel electromagnetic wave to the parabolic focus. This can be achiveved easier by using the paraboloid of revolution. The radial waves emitted by the asters which will be gathered at the telescope's focal point have to reach a certain power level to be detected by the receiver.

3. Components and descriptions of FAST

The FAST Telescope is located at remote mountain area in Guizhou province in China. It is the world's largest single caliber radio telescope. The real-time monitoring and early warning of the construction process and operating situations provided by the structural health supervision system is indispensable. One of the core components of the FAST health monitoring system is FAST health monitoring data management and integration system. They play a link between the past and the future in the whole health monitoring system [4]. FAST equipped with active reflecting surface and has a ball coronary appearance. Its reflecting surface is a part of the civil engineering. The sphere within a three-hundred-meter aperture match and form a parabolic surface in real-time while working. Thus, the working condition of FAST telescope structure is a changing process [5]. The active reflecting surface of FAST is mainly made of reflective surface unit panel, reflective surface unit back frame, network cable, ring beam, latticed column, and actuator. The feed source supportive system of FAST is mainly made of the feed tank, cabin docking platform, feed support tower and line drive [6].

The area of the reflective surface is one main standard to measure the property of the radio telescope. Only a larger receptor area can allow telescope to detect more and further asters [7]. The reflective surface of FAST has the aperture of five-hundred-meter and area of two hundred and five thousand square meters. There is a significance number of reflective surfaces which are able to form instantaneous parabolic surface. This makes it to be capable of gaining the signal from different parts of the sky through small feed units.

The sketch and structure of the FAST is presented in Figs. 1 and 2. Three major independent technological innovations are used in the design of FAST. The first one is the natural spherical feature of the Karst giant pit topography in Guizhou. By making full use of the hollow pit, many construction projects are saved. In addition, a good electromagnetism environment provides a nice detecting condition for the FAST Telescope. The second one is the active reflecting surface technology. It turns the sphere to a paraboloid to conduct the collection of signals. The third one is the independently developed lightweight cable-driven feed platform and parallel robot, in which fulfill a highly accurate trace record of receptor. The construction team of FAST has set their sights on the structure of network cable. They use tens of thousands of cables to knit a network cable hanging on the ring beam. 4450 reflective surface units are installed on the network cable. In addition, below the 2000 and more nodes of the network cable connects the lasso and the actuator. The whole reflective surface units will experience the shape change and form a paraboloid in the observing direction, eventually gathering the radial waves to the focal point.

Fig. 1 A sketch of the FAST.

Fig. 2 The structure of the FAST.

4. Performances and the state-of-the-art detection results

Although FAST were officially put into use in 2020, observations have been accomplished by FAST since 2018. On April 14th in 2018, the millisecond pulsar discovered by FAST has gained the international recognition. This millisecond pulsar was initially found in 2018, February 27th by tracking the gamma ray point source 3FGL J0318.1+0252 as illustrated in the Fig. 3. The discovery was confirmed through FAST's cooperation with the Fermi-LAT. This new discovered millisecond pulsar J0318+0253 has a rotation period of 5.19 millisecond, and according to the dispersion the distance between the pulsar and the Earth was estimated to be approximately 4000 light years.

FAST used its ultra-wideband receiver to conduct a tracking work which has lasted for an hour to discover the pulsar, and this pulsar was regarded as one of the high energy millisecond pulsars with the weakest radial flux [8]. On 2019 January the 24th , the FAST telescope accomplished the very first cooperation with the Tianma telescope, and together obtained the very-long-baseline interferometry (VLBI) interference fringe.

Scholars used both of the telescopes to carry out a fringe interference experiment, successfully observing the compact radio source 3C454.3. As the develop performance of commissioning work being perfected , the first acquisition of the VLBI interference fringe marked that the FAST telescope has equipped with the ability to participate in the united observation of the VLBI net [9]. During May 2022, the FAST telescope detected the extreme turbulence phenomenon of plasma within the dense binary system, providing new clue to the 'Black Widow' pulsar's eclipse mechanism. Based on FAST's ultra high sensitivity data, the radio pulse scattered phenomenon around the eclipse area of 'Black Widow' pulsar B1957+20 was observed for the first time.

It also showed that going deeper into the eclipse centre means that the radio pulse outline emitted by the pulsar would become wider and its scattering ability would become stronger, which was up to 0.2 second. Fast radio bursts are the lightest radio outbreak in the universe. It can release the same amount of power which the sun emits for a year in just one millisecond. In June 2022, the FAST telescope discovered the first continuous active fast radio bursts. With regard to the speech given by the researcher of Chinese Academy of Sciences national astronomical observatories, Li Di, the continuous active radio pulsar discovered showed special feature, i.e., the short signals sent to the

FAST by the pulsar happened repeatedly, about 3 to 4 explosions in an hour. The explosions usually lasted for a few thousandths of a second [10].

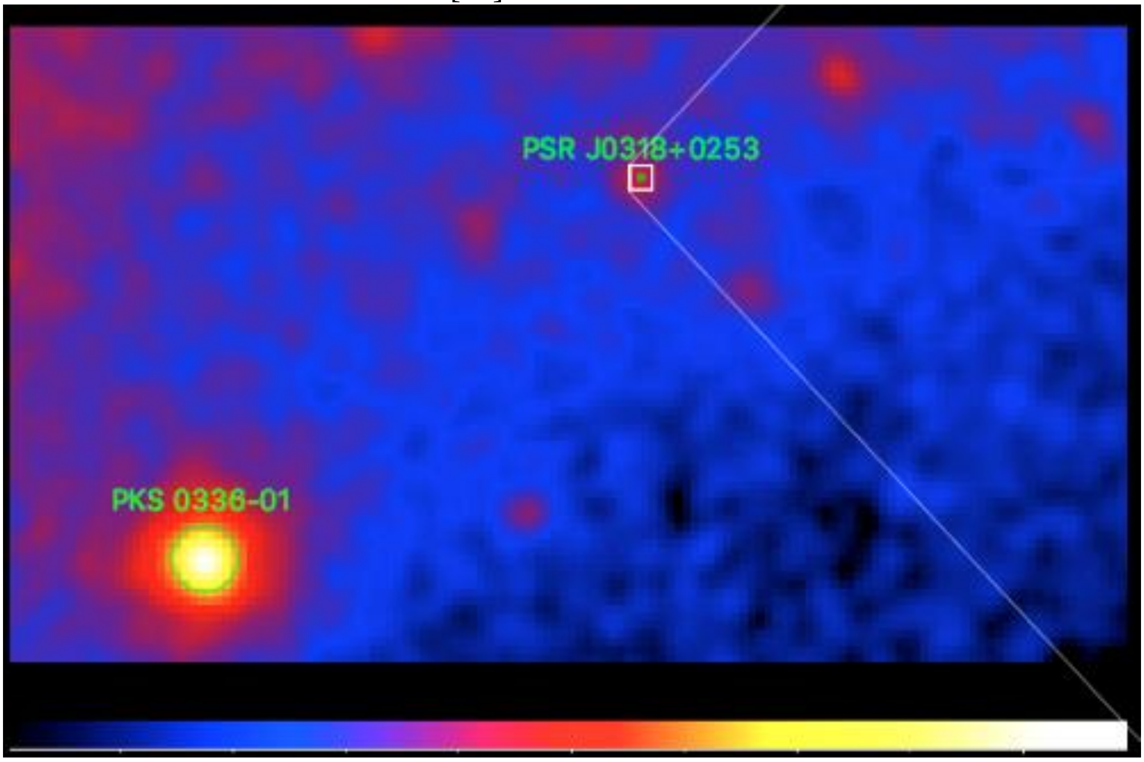

Fig. 3 The observation results of J0318+0253.

5. Limitations & Prospects

The FAST telescope allows us to know the universe more clearly. It has an important meaning to humans. However, there is a limited zenith coverage angle in the design of FAST. The observation range as a result is also very limited. In addition, in the early tests of use of the FAST telescope, the signals were actually extremely unstable. This was partly ascribed to the burden added by the activation of industrious air conditioner, by which the current intensity of the receiver amplifier varied too much.

After controlling the activate conditions of the air conditioner, the problem was eased. FAST is the only 300 meters class antenna in the world. It has Square Kilometre Array (SKA) receiving area of around 10%. Compared to the SKA receiving area of SKA1, FAST will be about 10 years ahead of the world. As the full-scale deployment of SKA1 continue to develop as expected, its comprehensive performance will surpass that of FAST. Even though, FAST will still possess its own unique discovery space. In the radio frequency band, FAST telescope is now the largest, the most sensitive device. Its working frequencies cover 70 MHZ to 3000 MHZ, which means that among the frequency bands humans are often exposed to, a new and more alert device is added. The FAST telescope, as a basic investigating platform for several subjects, is capable of extending the neutral hydrogen observation to the boundary of universe, observing the dark matter and dark energy while seeking for the first celestial bodies. Moreover, it can also be used to search and identify the possible universe communication signals and extraterrestrial civilizations.

6. Summary

In conclusion, this paper discusses from the basic design and structure of FAST telescope to the performance and use of FAST telescope. Each part of the use is extended from the relating local design. As what is mentioned above, the FAST telescope is equipped with a large number of functions. For example, the detection of pulsars, finding the fast radio bursts, receiving the space signals etc.

Owing to a good deal of reflecting mirrors installed on the surface, the FAST telescope is relatively sensitive, especially when catching the light. This makes its functions to be carried out on a more efficient and accurate base. Specifically, the engineering needed in the designing process of FAST is very complicated and time-consuming. The reason is that a suitable surrounding and location are needed and many precise calculations have to be made to ensure its working quality and accuracy. It took 22 years to complete the project. According to the analysis, the operation of FAST telescope is on account of a large number of light principles, including reflection and refraction, that according to the type of telescopes. In addition, FAST produced many advanced observations such as the latest continuously active fast radio burst discovered. Nevertheless, there is limitation on the observation range of FAST. The whole detecting system is not seriously affected by this. In the future, the FAST telescope will be continued to point its finger of the universe, seeking new clues and scene, devoting itself to the astronomical field. Overall, these results offer a guideline for the basic operation of FAST and the area where it can still be improved.

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