Twenty years of the Gunma Astronomical Observatory, experimental trials of how to use a 1.5-m telescope at a public observatory

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Abstract. Gunma Astronomical Observatory (GAO) is regarded as a pioneer of the public observatories equipped with a large telescope of far beyond one meter class. It was established in 1999 by Gunma prefecture local government. Its main telescope is a 150-cm reflector which has an eyepiece system for the star gazing by public people in addition to advanced measuring instruments such as a very powerful high resolution spectrograph for the scientific research. Using this telescope we have carried out a number of activities and studies in the fields of scientific research, education and public outreach. Many of them were kinds of experimental trials of how to use such a telescope at a public observatory. We present some examples of our experiences in these two decades.

Keywords: 1.5-m telescope and Gunma Astronomical Observatory

1. Introduction

In 1999 Gunma Astronomical Observatory (hereafter GAO) was established in Takayama village in Gunma prefecture which is about 120 km north-west of Tokyo (N 36° 35' 47", E 138° 58' 22") as a public observatory aiming at effective education and outreach of astronomy and astrophysics for all kinds of people from young children to professional researchers [1,2]. It was build by the local government of Gunma prefecture. GAO is operated by the board of education of the Gunma prefecture without belonging to any universities and other institutions. There are a number of telescopes with aperture sizes from 10-cm to 150-cm at GAO. All of them are mainly prepared for the public activities as GAO is a public observatory. Even its main telescope with a primary mirror as large as 150-cm in diameter is equipped with an eyepiece system for the star gazing as seen in Fig.1. GAO can be regarded as a pioneer of the public observatories equipped with such a large telescope that is sufficiently powerful also for the scientific observation by the professional researchers.

The 150-cm reflector of the GAO main telescope was the second largest telescope in Japan when it was built, following the largest one of the 188-cm reflector at the Okayama Astrophysical Observatory, National Astronomical Observatory of Japan (OAO, NAOJ) which was designed and used only for the scientific studies by professional researchers. The GAO 150-cm reflector was the world largest telescope at that time far beyond the second one with which people can watch stars by their own eye through its large aperture. In order to utilize the full capability of the telescope for the scientific observations of high standard in addition to the public services, some powerful measuring instruments have been designed and made for the GAO 150-cm reflector as seen in Fig.2. The largest and the most
A powerful instrument is the Gunma Astronomical Observatory Echelle Spectrograph (GAOES) [3,4], that is a high resolution echelle spectrograph set at the Nasmyth platform. It makes us possible to carry out very detailed studies of stellar astrophysics through the spectra of extremely high spectral resolution up to $R = \lambda/\delta\lambda \sim 10^5$. The Gunma Infra-Red Camera and Spectrograph (GIRCS) at the Cassegrain focus [5] and the Gunma LOW resolution Spectrograph (GLOWS) at the bent-Cassegrain focus are very powerful as well. Using those instruments on the 150-cm telescope we have carried out a lot of scientific observations. Thanks to the high sensitivity of modern detector devices, telescopes with an aperture size about two meters can be very useful and powerful tools for the studies of astrophysics. In particular, there are a lot of interesting stars which are bright and suitable enough for the detailed studies using the telescopes of such a scale.

![Image](image_url)

**Figure 1.** The 150-cm telescope of GAO [1,2]. It has a star gazing optic at a Nasmyth focus.

2. **Strategy for scientific observations**

In order to make full use of the observational performance given to the GAO 150-cm telescope, it is essentially important to choose the most suitable observation methods focusing on the most suitable scientific subjects. Spectroscopic study of stellar objects is one of the most suitable ways in practice. There are a lot of stars which are bright enough to be observed very precisely by the 150-cm telescope, while it is much smaller than the world largest telescopes of 8 – 10-m class.

In addition, we must take into account the observation condition at the site where the telescope is located. Usually the world largest telescopes are located in the sites ideal for the observations, where the sky is dark and clear, and the atmosphere is extremely stable with a number of clear nights, such as at the top of Mt. Mauna Kea in Hawaii. It is somewhat unfortunate that GAO may not be located in such an ideal place. However, spectroscopic observations with a sufficiently high spectral resolution can overcome the less ideal observation condition of us. Since the photons coming into a spectrograph...
are divided into a number of pixels on the detector of different wavelengths, the number of photons from the city lights becomes very small at each pixel. Thus, the light pollution does not affect the astronomical measurements so seriously in the spectroscopic observations.

Poor seeing which makes the stellar image larger at GAO does not matter extremely much either for the spectroscopic observations as long as a slit width can be made wide enough against the size of stellar image. Generally speaking, any spectrographs for a big telescope at a poor seeing condition necessarily become very large in order to realize good observation efficiency because the size of a spectrograph is proportional to the aperture size of telescope, spectral resolution and the size of stellar image caused by the seeing condition in principle. On the other hand, it also means that it is much easier to realize a spectrograph of a reasonable size with sufficiently good observation efficiency and high spectral resolution for the smaller telescopes even if somewhat poorer seeing condition is taken into account.

**Figure 2.** Observation instruments on the GAO 150-cm telescopes [2].

It is not always easy to get much observation time of the world largest telescopes. It is very rare in practice that observations for a long period are carried out by some of the world largest gigantic telescopes. On the other hand, we can easily expect more observation time for smaller telescopes. With a number of observations for longer periods by middle class telescopes like the GAO 150-cm telescope, we can obtain statistically valuable data of large samples, or time dependent information of a number of variable events for long periods. It is no doubt that the spectroscopic observations with a middle class telescope can provide unique and promising opportunities for the scientific studies.

It is noted that GAO is operated independently. We can use all the observation times of our telescopes flexibly based on our own decision. It allows us to make ourselves focus on a limited number of specific scientific subjects. GAO has definite advantages in making the best use of our telescopes for the scientific researches of astrophysics. A number of unique observational studies can
be carried out with the use of our 150-cm telescope and its measuring instruments. In practice this telescope has published a number of papers based on its own observations.

3. Scientific researches by the GAO 150-cm telescope

Spectroscopic study of the chemical abundances in the Pleiades open cluster M45 [6] is a good example of the scientific research which was carried out based on a large sample obtained by the middle class telescopes. We could ensure the homogeneity of chemical abundance in M45 by the high resolution spectroscopic observations of a number of stars in the cluster using GAOES on the 150-cm telescope. There were few observational evidences definitive enough to confirm the homogeneous metalicity in the clusters, while such a result had been expected from the view point of cluster evolution since it was believed that all the stars in a cluster were born from the same interstellar matter of homogeneous chemical composition. Chemical abundances measured for a number of stars in a large sample also provide some important suggestions about stellar evolution in the Galaxy. We found that chemical abundances of carbon and oxygen of field stars nearby the Sun are significantly different from those of the stars in some open clusters. It indicates their evolutions are not the same and they have evolved in different manner at the different places in the Galaxy [7].

Our observation system of the GAO 150-cm telescope is more effective and useful in the observational studies of time dependent phenomena of variable targets. For instance, some details of the dynamic structure of an X-ray emitting binary system consists of a hot star and an evolved compact neutron star have been made clear by the continuous repetition of high resolution spectroscopic observations by GAOES for a long period. We detected direct evidences of the non-axisymmetric features of an eccentric disc around one star in the system [8,9,10]. Also, we have made a significant contribution by the GAOES observations for several years to solve some enigmas of a strange eclipsing binary system of ε Aurigae which is well known by its very long variation period of about 27 years. Our observation results indicate a complex structure of the rotating disc around the visibly unseen secondary star [11]. As the most recent study of us, we have been observing a unique binary system of α Aurigae (Capella) which consists of two G-type giant stars [12]. One is a normal G-type giant star while the secondary is a rapid rotating G giant. Using the high resolution spectra obtained by the GAOES for a period of several months, individual spectra of those two stars were clearly separated by the spectrum disentangling technique [13]. It is found that more careful treatment of chromospheric effect is necessary for the abundance analysis of the fast rotating giant stars of high activity as the conventional model atmosphere analysis does not work well any longer.

Transient phenomena such as novae, supernovae, gamma-ray bursters are also very suitable targets for the middle size telescopes since rapid responses by the flexible operation and time dependent continuous follow up observations for certain periods are essentially important for the studies of them. We have made a number of observations of such transient targets using the GAO 150-cm telescope. Many observation reports have been published in addition to the usual papers in journals. It is noted in particular that cooperative observations with various telescopes and observatories are essentially effective for the studies of such time varying transient objects. It is not only useful to avoid bad weather condition at each individual observation site but makes us possible to get more observation points in time for a longer period with higher density. In practice, most of our studies of the transient and variable targets have been carried out as collaboration works with various telescopes at various observatories in the world. While many of them are international collaborations, GAO has been intensively contributing to the Japanese collaboration network the Optical and Infrared Synergetic for Education and Research (OISTER) [14] in the observations of the transient events. After the first detection of the gravitation waves from stars [15], quick response and follow up of the very transient phenomena caused in the sources of gravitation waves have become more and more important in order to solve a number of essential enigmas of universe such as the origin of heavy elements and the universe itself.
4. Education and outreach

Basically, GAO is a public observatory which has a mission of education and outreach for various kinds of public people while its main telescope is very powerful for the scientific research. Star gazing events to the public people using the telescopes at the observatory are the most important activities of us in the aspects of education and the public outreach.

However, the telescopes with an aperture size much larger than one meter are not always very useful and suitable for providing beautiful clear images of high spatial resolution for the human eyes in the case of star gazing since the seeing effect by the atmosphere of the earth works. As the larger aperture gathers lights coming through the more distant air in the sky, the image quality is affected much more seriously by the seeing condition. For example, Saturn may not be seen more beautiful than by a smaller telescope in many cases.

On the other hand, light collecting power of the telescopes always works well almost regardless of the seeing condition. We can always expect brighter images by the larger telescope. A lot of photons gathered by the telescope with a sufficiently large aperture can provide good opportunities to see the interesting aspects of the astrophysics in the stellar light even by a human eye which is not very sensitive to the faint light. In addition to the differences of colors from star to star, it is quite impressive that various features in the stellar spectra can also be directly seen through the large telescopes if a suitable spectroscope is used.

Based on such experiences of us at GAO as a public observatory we have proposed and developed a unique spectroscopic eyepiece system for the GAO 150-cm telescope [1,16]. It provides a direct image and a spectrum of target star at two separate viewing points simultaneously. Observers using this newly developed instrument should be able to understand the physical meanings of the spectrum and the color of the observing target much easier by direct comparison between them.

![Figure 3](image.png)

**Figure 3.** The spectroscopic eyepiece system set on the star gazing optics at the Nasmyth focus of the GAO 150-cm reflector [2,4]. Its right viewing point provides a direct image of the target star on the slit of the spectroscope as the observers can see the color of the target. The vertical gap in the stellar image is made by the slit. The left one shows a spectral image of the target star at the same time.
Figure 3 shows the spectroscopic eyepiece system set at the star gazing focus of the GAO 150-cm telescope. It is made as small and light as it can be easily used instead of a usual 50.8-mm eyepiece used for the star gazing. It has two viewing points. One provides a direct image on the slit of the spectroscope where the stellar image is divided into two parts by a gap caused by the slit as seen in the right-bottom panel in Fig.3. It makes observers easy to see the color of the target because all the photons gathered by the telescope are focused at the direct image on the slit. The light coming into the slit is processed to show the spectrum of the target at the other viewing point. Observers can compare the color and spectrum directly at the same time. We have been investigating some applications of this unique instrument in the education programs of astronomy and astrophysics using the 150-cm telescope at GAO. It is found that the direct comparison of the stellar spectrum and color is quite effective in practice for understanding the physical meanings of them intuitively.

![Figure 4](image.png)

Figure 4. Spectral images of the Moon, Jupiter, Mars and a carbon star V460 Cygni taken by the GAO 150-cm telescope.

For example, we can easily see the difference of spectra between Mars and the red giant stars, even though their red colors in the direct images seem very similar for human eyes. Figure 4 shows images of spectra of Moon, Jupiter and Mars in addition to the spectrum of a carbon star V466 Cygni. All the spectra of Moon and planets Jupiter and Mars seems almost the same as the solar spectrum which is often observed as a rainbow. It is quite natural since those solar system bodies are not shining by themselves but just reflecting the lights coming from the Sun. We can easily understand such a basic fact directly from the comparison of those spectra.

On the other hand, the spectrum of the carbon star, which is a kind of red giant star, in the bottom panel of Fig. 4 is completely different from that of Mars. It indicates that the carbon star is not reflecting solar light but shining by itself. Further, we can estimate its surface temperature as about 2500 K from its spectrum. Some structures in the spectrum such as absorption features indicate the chemical characteristics of the stellar atmosphere as well. We can see the existence of a lot of carbon molecules in this star even though we can never touch the stellar body directly. Through our experimental trials of the education and outreach using our 150-cm telescope we have learned an interesting fact. Most students and peoples are impressed and activated very much by knowing that the telescope and instruments
in front of them are really used and active in the real scientific research on the cutting edge. It is essentially important for the effective education and outreach to make full use of the telescopes also for the scientific research in practice.

5. Summary
Gunma Astronomical Observatory (GAO) can be regarded as a pioneer of public observatory equipped with a telescope of 2-m class, which is sufficiently powerful for the scientific research on the cutting edge by professional researchers. With the use of the 150-cm telescope, GAO has been carrying out a number of scientific studies. Many of them are studies of stellar astrophysics based on the large samples of observation data or focusing on the time variation of the targets for long periods or quick response to the transient phenomena. Such observations are the most suitable in general for the middle size telescopes, since it is not usually easy to occupy some of the world largest telescopes for long periods focusing on a limited number of scientific subjects. Collaborations with various observatories make it more effective to get more data and cover more observation points in time for longer periods. It is not only limited in the optical wavelengths but collaborative observations covering various wavelengths from gamma rays to radio wavelengths make the studies more fruitful. Moreover, since the first detection of the gravitation waves from the merging black holes [15], cooperative observations of transient phenomena using various media other than electromagnetic waves are getting more and more important. The middle size telescopes under a sufficiently flexible operation are really suitable for such collaboration studies so called as “multi-messenger observations”.

It is proved through our experimental trials at GAO using the 150-cm telescope that the middle size telescopes are also useful for the education and outreach activities both for the students and public people. It can provide some unique opportunities of effective studies of astronomy and astrophysics by taking the advantage of the strong light gathering power of the telescopes. It is noted that the students and all the people are much impressed and activated through their own experiences using the real facilities and instruments which are really used for the active research of science as well. It is essentially important for the effective education and outreach to make full use of the telescopes also for the scientific research in practice. All the telescopes with an aperture size around 2-m must be the very powerful tools for any of the astronomical research, education and outreach. We expect Lampung Astronomical Observatory in Sumatera which will be equipped with a telescope of such a scale should work well.

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