Optical Follow-up Observations of Transient Sources at Gunma Astronomical Observatory

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Abstract

Gunma Astronomical Observatory (GAO) is a public observational facility founded in 1999 by Gunma Prefecture local government. GAO has a 1.5-m reflector, a 65-cm reflector, and other small telescopes. Moreover, there are some powerful instruments prepared for the 150 cm telescope such as a near infrared camera/spectrograph, a high resolution spectrograph and a low resolution spectrograph and imager for optical wavelength. The observatory is designed for both astronomical research and public use. We can flexibly operate it as an independent observatory, allowing us to observe time-limited transient sources. We proceed with optical follow-up observations of gamma-ray bursts, supernovae, and other variable objects and cooperate with some multi-wavelength observation campaigns of SS 433, GRS 1915+105 and so on. We introduce some GAO facilities and some scientific results from the optical follow-up observations of transient sources. We can carry out follow-up observations for new transient sources discovered by MAXI.

Key words: telescopes: instruments — transients: optical — follow-up

1. Gunma Astronomical Observatory and Its Facilities

Gunma Astronomical Observatory (GAO) was established by Gunma Prefectual local government in 1999. It is located in Takayama village about 140 km northwest of Tokyo (Lat. 36° 35′ 37″ N, Long. 138° 58′ 35″ E, and Alt. 885 m). It has many fine days in winter, but not so good in summer season. This observatory is designed for both astronomical research and public use. We have a 1.5-m reflector as its main telescope, as well as a 65-cm reflector and other small telescopes. Moreover, some powerful observational instruments are equipped on the telescopes. Characteristics of the telescopes and the instruments are summarized below.

1.1. 1.5-m telescope and its instruments

The main telescope of GAO is a 1.5-m reflector on an alt-azimuth mounting which provides pointing and tracking accuracies about 3.0" and 0.7", respectively. The telescope is the Ritchy-Chritien type reflector with F-ratio of 12.2. There are some powerful instruments attached to the telescopes, such as Gunma Infrared Camera and Spectrograph (GIRCS), GAO Echelle Spectrograph (GAOES) and Gunma LOW resolution Spectrograph and imager (GLOWS).

GIRCS is an infrared camera and spectrograph attached on the Cassegrain focus of the 1.5-m telescope. With an 1,024 × 1,024 pixels HgCdTe array (HAWAII), it covers a field of 6.8′ × 6.8′ with a spatial resolution of 0.4 "/pixel. The limiting magnitudes are 17.7 mag in J, 16.9 mag in H, and 16.3 mag in K_s with S/N=10 at 9 min exposure. A spectrograph mode with grisms can be used for J, H, K-bands with a spectral resolution of about 1,000.

GAOES is a high resolution spectrograph with an echelle grating set on the Nasmyth focus of the telescope. It provides an optical spectrum with spectral resolution up to 100,000 for a wavelength coverage of 360–1,000 nm. The whole optical system is enclosed in a vacuum chamber in order to avoid thermal instability and air turbulence in the optical system. The limiting magnitude is about 10 mag which is limitted by slit-viewer of GAOES.

GLOWS is an optical low-resolution spectrograph and imager on the bent-Cassegrain focus. It covers a field of 10.7′ × 11.7′ with a resolution of 0.56"/pixel using Andor DW432, an 1,152 × 1,250 pixels back-illuminated CCD camera, which cools down to − 70 degC controlled by electronics. It can be used as a grism spectrograph with a spectral resolution of 400-500 for wavelengths of 400-800 nm. Limiting magnitude of the spectrograph is about 17 mag with S/N=30 at 30 minutes exposure. It is useful for quick or time-critical observations of transient objects such as gamma-ray bursts (GRBs), supernovae (SNe), and novae.

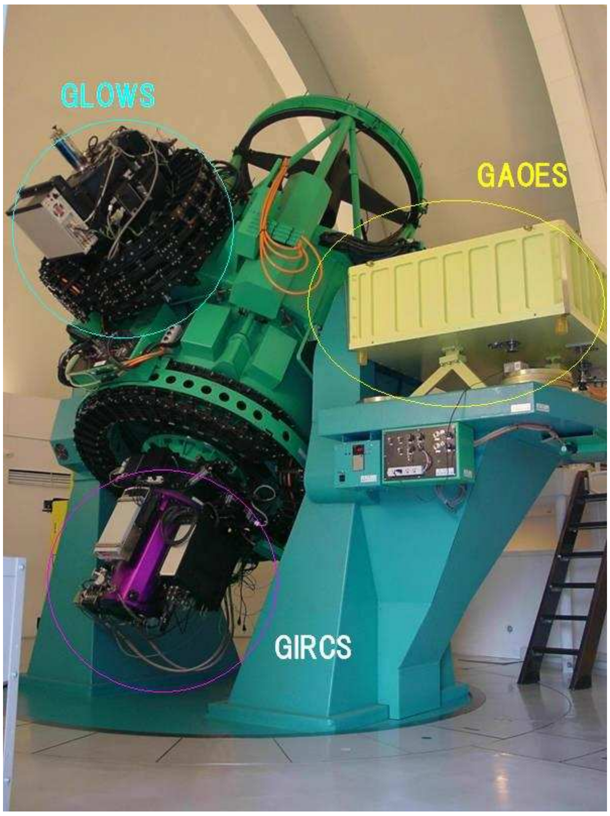

Fig. 1. 1.5-m reflector of GAO

1.2. 65-cm telescope and GETS telescope

Besides the 1.5-m telescope, we have a 65-cm telescope and other small telescopes.

The 65-cm telescope is the Cassegrain type reflector with F-ratio of 12. Some instruments can be attached on the classical Cassegrain focus of the telescope. One of them is Gunma Compact Spectrograph (GCS), which is an optical low-resolution spectrograph with a resolution of 500 or 2000. Others are optical imaging CCD cameras, such as Apogee Alta U6, which covers a field of $10' \times 10'$.

GETS (Gunma Experiment of optical Transient Search) is a robotic system which consists of a 25-cm robotic telescope and its enclosure. It can automatically point the telescope at GRBs following GCN (GRB Coordinate Network) alerts. The telescope is Meade LX200, a Schmidt-Cassegrain type with F-ratio of 6.3. Using CCD camera Apogee Alta U6, it covers a field of $50' \times 50'$. It mainly provides with sequential optical photometry for GRBs, dwarf novae, and so on.

There are other small telescopes with a diameter of 25-30 cm settled in sliding roof, which are mainly used by amateur astronomers.

Fig. 2. GETS consists of a 25 cm Schmidt-Cassegrain telescope and its enclosure.

2. Optical Follow-up Observations

GAO is designed not only for an astronomical research but also public education and popularization for astronomy. On the basis of the latter point of view, we must spare machine time of the telescopes for public star gazing in the evening. On the other hand, there are some definite advantages as well in the view of scientific research. Since GAO is operated independently from open use, we can make a flexible time allocation for ourselves to focus original scientific subjects. Take advantages of this point, we can carry out "time-critical" observations for transient sources. In this section, we describe some results from optical follow-up observations at GAO.

2.1. Gamma-ray bursts

We proceed with follow-up observations of GRB afterglows with a trigger of GCN alerts from Swift and INTEGRAL satellites. We mainly perform optical or infrared photometric observations with GETS and the 1.5-m telescope equipped with GLOWS or GIRCS. At first, we tried to observe an afterglow of GRB 011212. Since then, we have reported 21 observation results in GCN Circulars.

For GRB 030329, the monster GRB associated SN 2003dh, we intensively performed the follow-up observations with many instruments of GAO under a poor weather condition. We carried out infrared photometry with the 1.5-m telescope and GIRCS, optical photometry with GETS, and optical spectroscopy with the 65-cm telescope and GCS. As the results, we obtained optical-infrared light curve and SED in the early phase (Torii et al. 2003; Nishihara et al. in prep.). Early SED evolution of GRB 030329 is shown in figure 3.

For GRB 041006, we performed optical and infrared photometry with GETS and the 1.5-m telescope equipped with GIRCS. Obtained early optical and in-

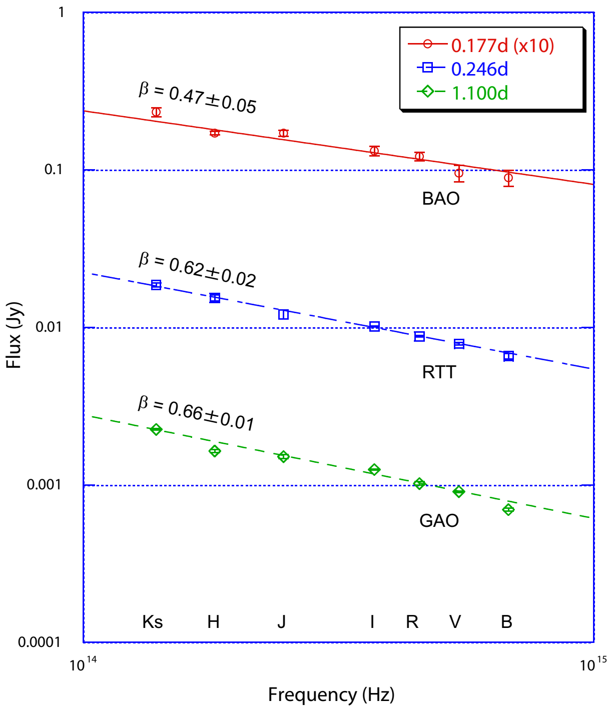

Fig. 3. The early Opt.-IR SED of GRB 030329 obtained with GAO, Bisei Astronomical Observatory, and RTT150 (Burenin et al. 2003).

frared light curve is shown in figure 4.

Moreover, we caught an optical afterglow of GRB 060927, which is the second highest redshift GRB ever discovered (z∼5.47; Ruiz-Velasco et al. 2007). We started about 37 minutes after the burst with GLOWS attached on the 1.5-m telescope and detected it to be R∼ 20 mag. Even the high redshift GRB can be detected with small to middle-size telescopes if we can observe soon after the burst.

2.2. Supernovae

We proceed with the earliest spectroscopy program of relatively bright supernovae with GLOWS attached on the 1.5-m telescope and GCS on the 65-cm telescope. The objective is the early identification of the important events such as hypernovae according to spectroscopic observations to follow the discovery reports of IAU circular (IAUC) and CBET. We have reported 11 earliest observation results on the IAUC/CBET. If the target is important and enough bright to observe with our facilities, we will carry out continuous spectroscopic observations to trace the SN evolutions.

For example, we tried spectroscopic observations for SN 2002ap, which is a broad line SN Ic, so called hypernovae, with the 65-cm telescope and GCS to follow the discovery report (Nakano et al. 2002). We found a broad-line SN Ic feature from the obtained spectrum and reported these results as soon as possible (Kinugasa et al.

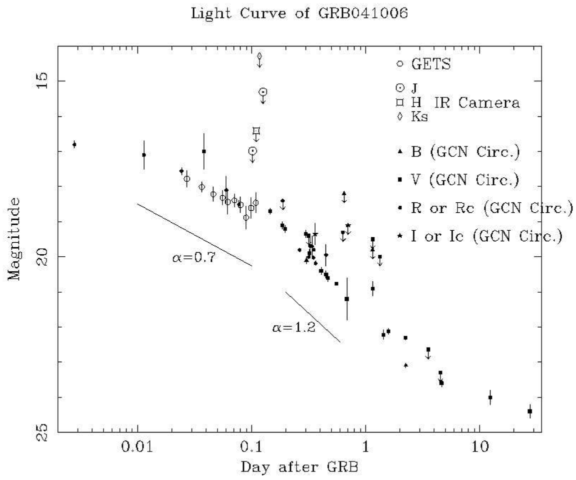

Fig. 4. The early light curve of GRB 041006 obtained with GAO and GCN Circ.

Fig. 5. M74 images before (left panel) and after (right panel) the appearance of SN 2002ap. The SN is marked with a dash line on light panel.

2002a). Our report was a trigger of much observations with larger telescopes in the world. As the results, many observation reports has been published so far. Therefore, SN 2002ap could be a very important event to study a connection between SN and GRB, although it was not accompanied with GRB. Moreover, the following sequential spectroscopic observations at GAO could reveal the early evolution and a variety of hypernovae (Kinugasa et al. 2002b). The image and spectral evolution of SN 2002ap in the early phase are shown in figure 5 and 6, respectively.

2.3. Novae and Dwarf Novae

In the same way as SNe, spectroscopic observations of novae and dwarf novae, have been performed to follow IAUC, CBET and VSNET. We can confirm and determine whether an observed object is a nova or a dwarf nova, and whether it is a FeII type or a He/N type nova.

Especially, we pay attention for WZ Sge-type dwarf novae, which is a subclass of SU UMa type. Their features are the large outburst amplitude over 6 mag, and

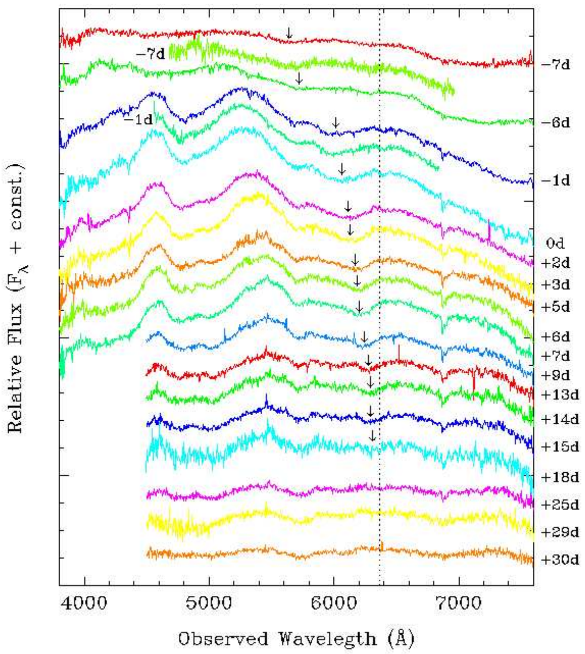

Fig. 6. Spectral evolution of SN 2002ap from -7 to +30 days relative to B-maximum. Arrows mark the absorption minima of SiII 6355. Dot line marks the rest wavelength of SiII (Kinugasa et al. 2002b).

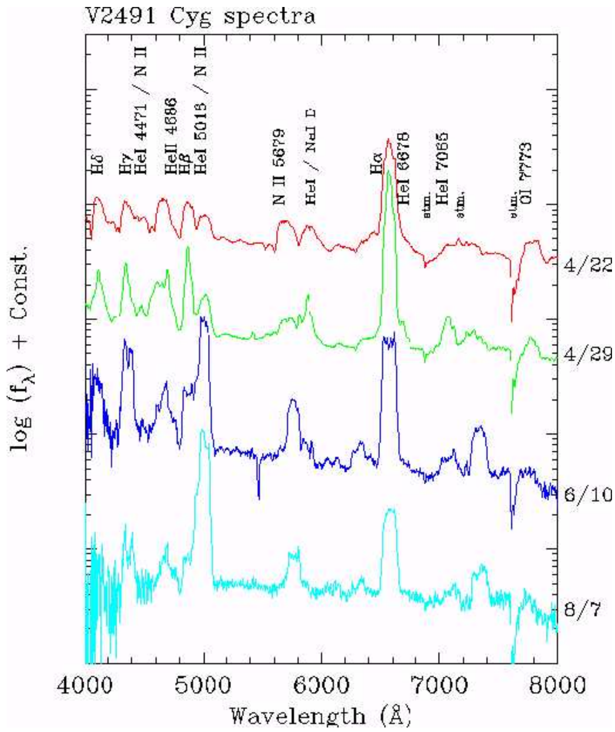

Fig. 7. Optical spectral evolution of V2491 Cyg in April to August 2008. Line identification and observed date are also shown.

the long recurrence cycle of the superoutburst (several year or more), and no (or few) normal outburst. These peculiar mechanisms are still in debate. We performed spectroscopic observations of two WZ Sge-type dwarf novae, GW Lib and V455 And, during their superoutbursts in 2007 (Nogami et al. 2008).

Recently, we also have interested in novae as soft X-ray emitters since these events sometimes has been observed by X-ray observatories, such as Swift and Suzaku. For example, we carried out the spectroscopic observations for V2491 Cyg, which was discovered in April 2008 (Nakano et al. 2008) and observed by Swift and Suzaku many times. These optical spectra obtained at GAO are shown in figure 7. The spectra clearly show prominent He emission lines at early phase. It is a He/N type nova.

We expect that SXC on board MAXI can discover these classical novae as soft X-ray emitters such as super soft sources. We will be able to perform spectroscopic observation of these targets with GLOWS attached on the 1.5-m telescope. These sources newly discovered by MAXI may be a new class of nova.

3. Cooperative Observations

Taking advantages of capability of the flexible time allocation from GAO operation, we can carry out not only follow-up observations but also some cooperative observations along with other facilities such as X-ray satellites.

3.1. SS 433

SS 433 is a microquasar with a precessing bipolar continuous jet with a velocity of 0.26c. Simultaneous optical spectroscopic observations along with X-ray satellites provide a precise direction of jets on the obtained X-ray data sets. Since it is important to study the jet physics, we performed spectroscopic observations when X-ray satellites observed SS 433 for several times.

So far, we carried out simultaneous observations along with ASCA in March – April 2000, Chandra in May and October 2001 (Namiki et al. 2003), and Suzaku in April 2006 (Kubota 2007). Moreover, in a flare of SS 433, the similar cooperative observations with XTE and RATAN-600 in November 2001 (Kotani et al. 2006) and December 2006 (Kotani et al. in prep.). The spectral variation of SS 433 during Suzaku observation campaign 2006 is shown in figure 8. These spectra clearly show moving Hα emissions labeled r (red) and b (blue), which represent directions of two jets.

3.2. GRS 1915+105 and other sources

We tried to investigate the correlation of multi-wavelength light-curve of GRS 1915+105 from simultaneous infrared photometric observations along with INTEGRAL in March 2003 and Suzaku October 2006. However, we could not observe due to bad weather con-

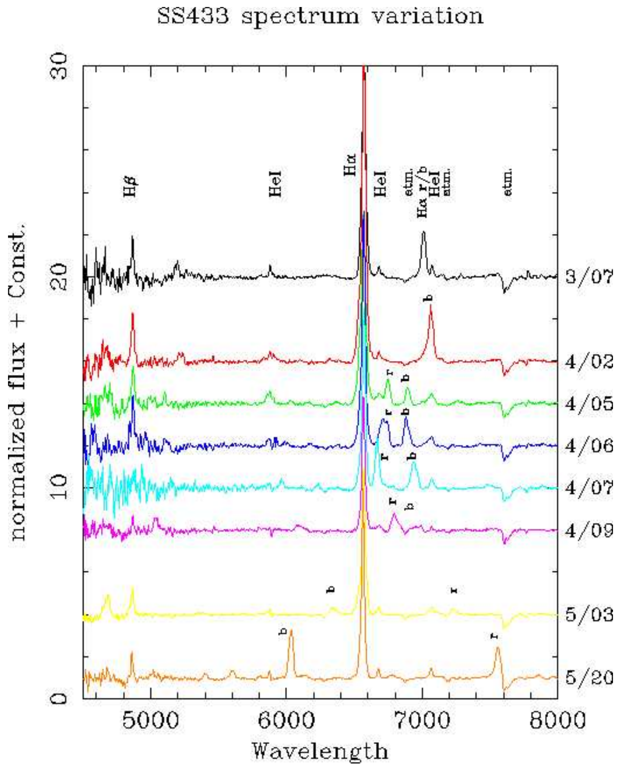

Fig. 8. Optical spectral variation of SS 433 during Suzaku observation campaign 2006. Two moving Hα emissions labeled r (red) and b (blue), represent the direction of each jet.

ditions.

Moreover, we sometimes carry out the cooperative observations of interesting variable stars along with other facilities. For example, low-resolution sequential spectroscopic observations along with other observatories were performed for Tago event, which is a nearby gravitational microlensing event, since discovery (Fukui et al.2007). A high resolution spectroscopy was performed for ζ Oph with MOST satellite to study the line-profile variations (Koubsky et al. 2007).

4. Summary

GAO is a public observational facility founded in 1999. GAO has a 1.5-m reflector, a 65-cm reflector, and other small telescopes. Moreover, there are some powerful instruments attached on the telescopes. The observatory is designed for both astronomical research and public use. Since GAO is operated independently from open use, we can make a flexible time allocation for ourselves to focus original scientific subjects. Take advantages of this point, we can carry out "time-critical" observations for transient sources. We proceed with optical follow-up observations of GRBs, SNe, and other variable objects and with cooperative observations such as multi-wavelength observation campaigns. Especially, we expect the first frequent soft X-ray survey by SXC on board MAXI can discover soft X-ray novae such as super soft sources. Although these sources may include classical novae, these will be a new class of novae. We will be able to carry out the follow-up observations for new transient sources discovered by MAXI.

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