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OPTICAL-INFRARED AND HIGH-ENERGY ASTRONOMY COLLABORATION AT HIROSHIMA ASTROPHYSICAL SCIENCE CENTER

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ABSTRACT

The Hiroshima Astrophysical Science Center (HASC) was founded in 2004 at Hiroshima University, Japan. The main mission of this institute is the observational study of various transient objects including gamma-ray bursts, supernovae, novae, cataclysmic variables, and active galactic nuclei by means of multi-wavelength observations. HASC consists of three divisions; the optical-infrared astronomy division, high-energy astronomy division, and theoretical astronomy division. HASC is operating the 1.5m optical-infrared telescope Kanata, which is dedicated to follow-up and monitoring observations of transient objects. The high-energy division is the key operation center for the Fermi gamma-ray space telescope. HASC and the high-energy astronomy group in the department of physical science at Hiroshima University are closely collaborating with each other to promote multi-wavelength time-domain astronomy. We report the recent activities of HASC and some science topics pursued by this multi-wavelength collaboration.

Key words: telescopes

1. INTRODUCTION

The Hiroshima Astrophysical Science Center (HASC) was founded in 2004 at Hiroshima University. HASC consists of three divisions: the optical-infrared astronomy division, high-energy astronomy division, and theoretical astronomy division. One of the main research interests in HASC is high-energy astronomical phenomena, which occasionally originate from variable and/or transient sources. The high-energy astronomy group of HASC has joined the Fermi collaboration, as well as the Suzaku and Astro-H teams. The aim of HASC is multi-wavelength studies of high-energy and time-variable sources. For this aim, we developed a 1.5-m telescope, named "Kanata", in 2006.

Figure 1 is a picture of "Kanata". The telescope is a Ritchey-Chretien telescope having three focal points: one Cassegrain and two Nasmyth. In 2014, the instrument, "HONIR" was attached to the Cassegrain focus (Akitaya et al., 2014). HONIR contains one optical CCD and one HgCdTe array detector (VIRGO) for near-infrared (NIR) light. It enables the taking of simultaneous optical and NIR data using a beam-splitter. HONIR offers four observation modes: imaging, imaging-polarimetry, spectroscopy, spectropolarimetry. The instrument, "HOWPol" is attached to one of the Nasmyth foci (Kawabata et al., 2014). It contains a double-Wollaston prism, with which we can measure a set of linear polarizations (I, Q, U) in on one exposure. We also have the "High-speed imaging spectrograph" which is installed at the other Nasmyth focus. It takes optical images with a maximum rate of 33 Hz.

As mentioned above, the characteristics of the Kanata instruments can be summarized by two points: polarization and simultaneous optical-NIR observations. Both observation modes can provide useful data for transients, especially on short time-scales. Furthermore, the driving speed of the telescope is so high ($5^\circ\ s^{-1}$ in Alt. $2^\circ\ s^{-1}$ in Az.) that the telescope can reveal unseen features of short time-scale phenomena, for example, polarization variations in gamma-ray bursts (GRB). This article reviews our recent work obtained by the Kanata telescope.

2. JET SOURCES AND POLARIMETRIC OBSERVATIONS

Relativistic jets are common phenomena associated with the accretion process onto compact objects. It is believed that magnetic fields play an important role in collimating and maintaining the jet structure and its variability. Issues regarding the structure of the magnetic field in jets have been discussed: random or ordered, helical structure, and amplification caused by the compres-

Figure 1. The Kanata telescope.

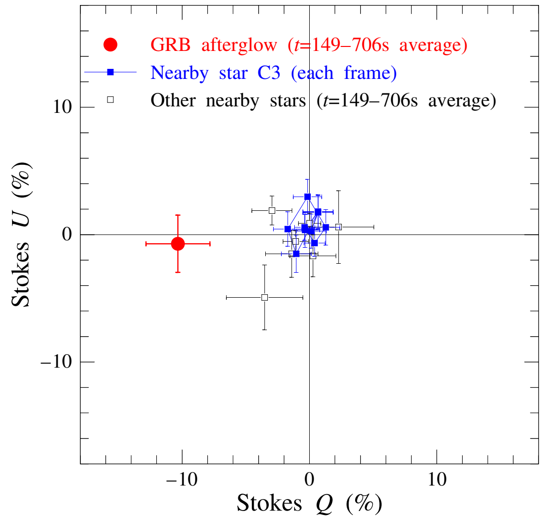

Figure 2. Stokes QU diagram of the afterglow of GRB 091208B. The red, blue, and open circles indicate the GRB afterglow, comparison star, and other nearby stars, respectively. A significant polarization of the afterglow is clearly seen (Uehara et al., 2012).

sion in shocked regions (Laing , 1980; Sari , 1999; Gruzinov & Waxman, 1999; Marscher et al., 2008). However, it is hard to directly observe the magnetic field structure. Polarimetric observations give us a chance to see its signature. Synchrotron emission can be dominant in the optical–NIR region when the jet is a dominant source. We focus on short-term polarization variations in GRBs and blazars.

Owing to the high driving-speed of Kanata, we can start polarimetric observations of GRBs with HOWPol within a minute of their triggering. In 2008–2014, we succeeded in obtaining polarimetric data of six GRB afterglows in their early phases. Figure 2 shows an example. It shows the Stokes QU diagram of the GRB 091208B afterglow (Uehara et al., 2012). Compared with the field stars, it is clear that the emission of the object is significantly polarized, having a polarization degree of ~ 10 % around 300 s after the GRB trigger. Other GRBs that we have observed show only low polarization even in their early phase, except for one object showing violent variations. Those observations suggest that there are diversities in polarization in GRB afterglows, and more observations are required to establish a unified view of the GRB polarization.

Blazars form a subclass of active galactic nuclei, in which the jet axis is directed toward us. Along with GRBs, blazars are good targets to study jets because their emission is amplified by the relativistic beaming effect. One of the characteristics of blazar variability is a wide range of time-scales from minutes to decades. Hence, monitoring with a high cadence and a long period is required. Since 2007, we have monitored 42 blazars. We detected several rotation episodes of polarization. Figure 3 shows an example in the case of PKS 1510−089 (Ikejiri et al., 2011). As shown in panel (c), the polarization angle gradually increased, associated with the active phase. We also found that the behavior of the polarization can apparently change if multiple polarization components are present. Panel (d) shows a polarization angle whose origin is set to the mean of the observed QU. The increase in the polarization angle is still seen, while the period of the episode is shorter than that shown in panel (c). This demonstrates that the component separation is important to study the blazar polarization (Uemura et al., 2010).

3. SIMULTANEOUS MULTI-BAND OBSERVATIONS

Short-term transient variations having time-scales of minutes to hours have been studied in terms of the structure of their power-spectra or periodicity. On the other hand, their color variations have not been well studied because this requires multiple telescopes or instruments. Recently, such studies can be readily performed using instruments with beam-splitters, or dichroic mirrors (Watanabe et al., 2005). Simultaneous multi-band observations offer a chance to reveal the variation in spectra of short-term events.

Figure 4 shows the light curve of early superhumps observed in the dwarf nova, V455 And (Matsui et al., 2009). The period of the humps is about 78 min. We obtained simultaneous g, V, R_c, I_c, and J band light curves. Using those observations, we found that the amplitude was larger in longer wave-bands. This supports the previously proposed idea that the early superhump is caused by the geometrical effect of a non-axisymmetric accretion disk (Kato et al., 2002). The color variation enables us to reconstruct the geometrical structure of the accretion disk using a tomography technique. Figure 5 shows the height structure of the ac-

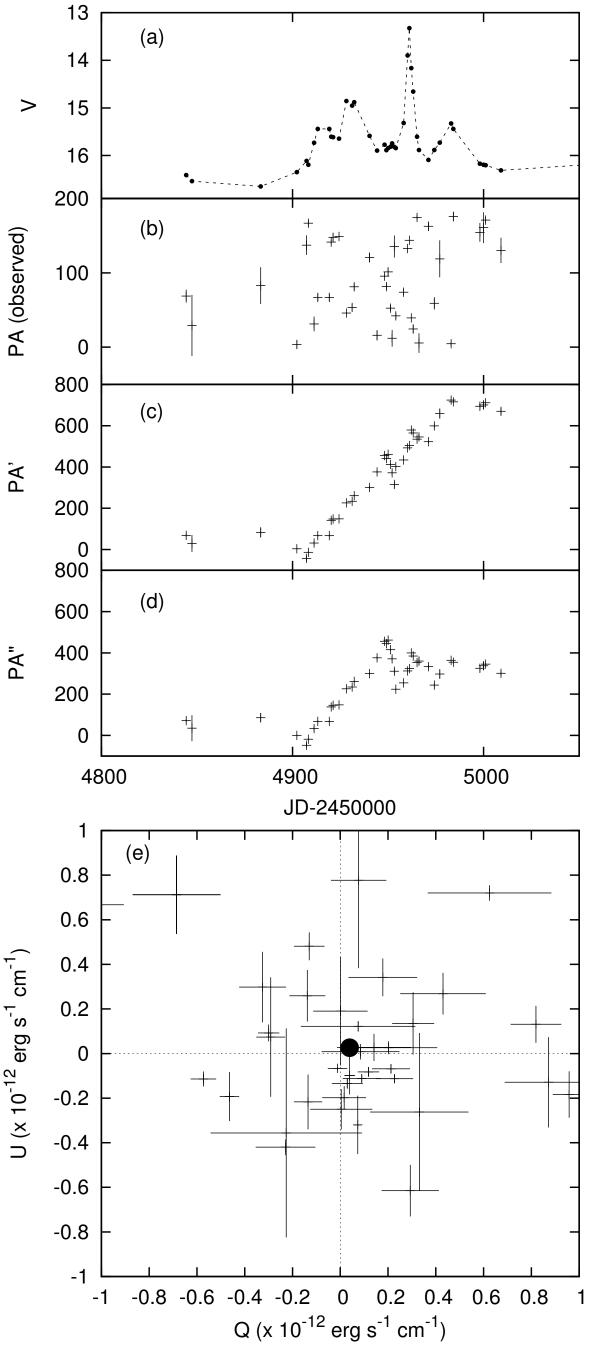

Figure 3. Polarization variations in the blazar, PKS 1510−089 (Ikejiri et al., 2011). From top to bottom, (a) the V-band light curve, (b) observed polarization angle (PA), (c) 180°-ambiguity corrected PA, (d) QU-center corrected PA, and (e) Stokes QU diagram.

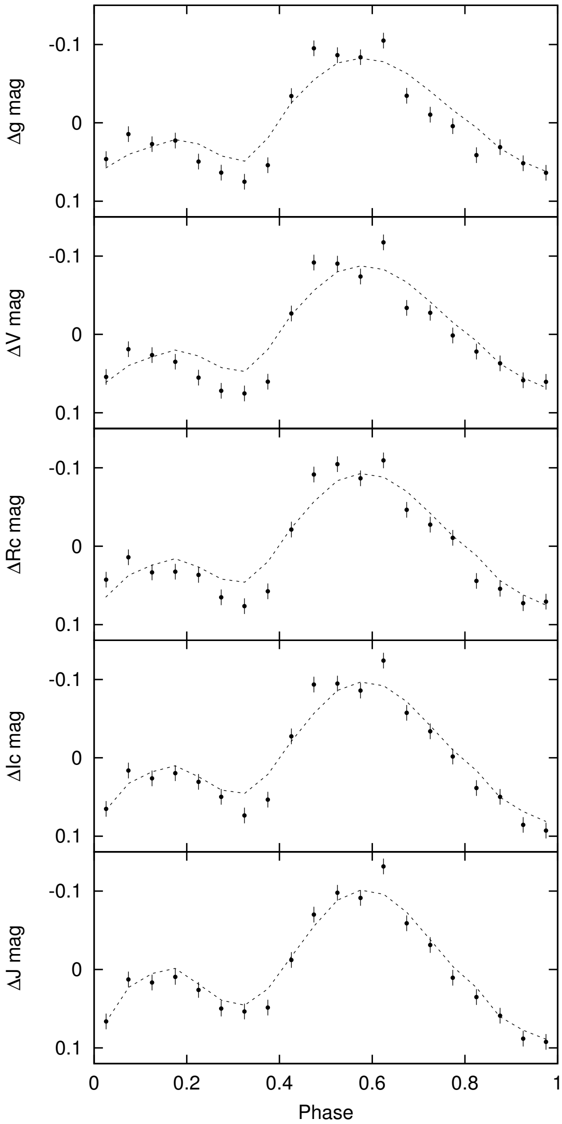

Figure 4. g, V, R_c, I_c, and J band light curves of early superhumps in the dwarf nova, V455 And (Uemura et al., 2012). The dotted lines indicate the model light curve.

cretion disk that is reconstructed from the light curves in Figure 4 (Uemura et al., 2012). The humps mainly originate in the two outermost flaring regions. We can also see the inner arm-like structures. This study is based on the simultaneous multi-band observations of short-term variations, and may open a new window for the study of accretion disks.

4. SUMMARY

In this article, we introduced our research on astronomical transients using the "Kanata" telescope of Hiroshima University. We focus on two topics; polarimetry and simultaneous multi-band observations of variable sources. We also have future projects that expand beyond our current time-domain astronomy. HinOTORI is a project for follow-up optical observations of gravitational wave

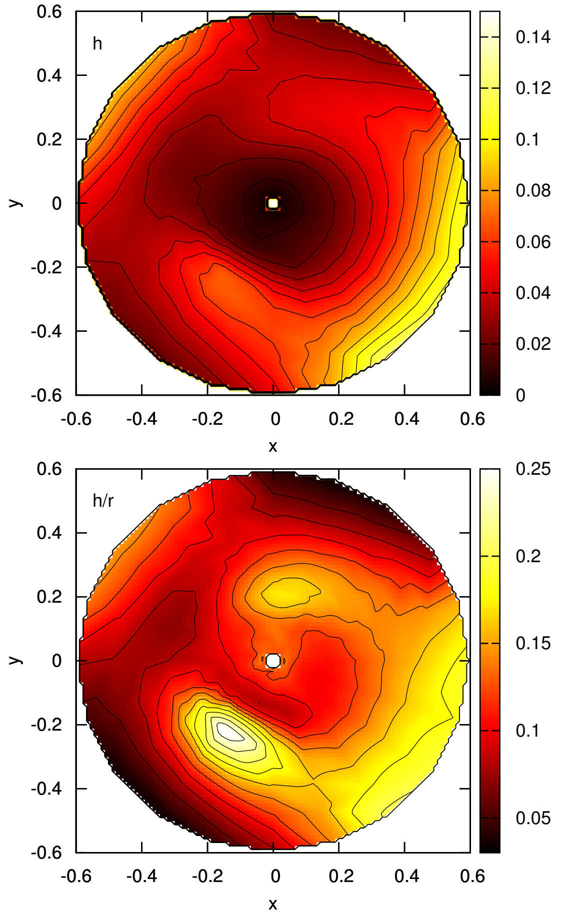

Figure 5. The height structure of the accretion disk in V455 And (Uemura et al., 2012). The upper and lower panels show the height and the ratio of height to radius, respectively.

events. We plan to develop a new observatory with a 50-cm telescope in Tibet (http://hinotori.hiroshima-u.ac.jp/). SGMAP is a survey project to measure linear polarization of all stars brighter than 13 mag visible from Hiroshima. For this survey, we plans to install a new 2-m telescope next to the Kanata telescope.

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