DENSE OPTICAL AND NEAR-INFRARED MONITORING OF CTA 102 DURING HIGH STATE IN 2012 WITH OISSTER: DETECTION OF INTRA-NIGHT “ORPHAN POLARIZED FLUX FLARE”

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ABSTRACT

CTA 102, classified as a flat spectrum radio quasar at \(z = 1.037\), produced an exceptionally bright optical flare in 2012 September. Following the Fermi Large Area Telescope detection of enhanced \(\gamma\)-ray activity, we closely monitored this source in the optical and near-infrared bands for the 10 subsequent nights using 12 telescopes in Japan and South Africa. On MJD 56197 (2012 September 27, four to five days after the peak of bright \(\gamma\)-ray flare), polarized flux showed a transient increase, while total flux and polarization angle (PA) remained almost constant during the “orphan polarized-flux flare.” We also detected an intra-night and prominent flare on MJD 56202. The total and polarized fluxes showed several similar temporal variations, but the PA again remained constant during the flare. Interestingly, the PAs during the two flares were significantly different from the jet direction. The emergence of a new emission component with a high polarization degree (PD) up to 40% would be responsible for the observed two flares, and such a high PD indicates the presence of a highly ordered magnetic field at the emission site. We argue that the well-ordered magnetic field and even the observed directions of the PA, which is grossly perpendicular to the jet, are reasonably accounted for by transverse shock(s) propagating down the jet.

Key word: galaxies: jets

1. INTRODUCTION

Blazars are highly variable active galactic nuclei (AGNs) emitting radiation at all wavelengths from radio to \(\gamma\)-rays. They have strong relativistic jets aligned with the observer’s line of sight and are apparently bright due to relativistic beaming. Their emission typically consists of two spectral components. One is attributed to synchrotron radiation at lower energies peaking in the radio through optical bands, and the other is inverse Compton scattering peaking in the \(\gamma\)-ray bands. Outstanding characteristics of blazars are their rapid and high-amplitude intensity variations or flares. These variations are observed in various wavelengths and timescales. Microvariability (intraday variability) of flux in the optical band has also been detected on timescales as short as minutes to hours (e.g., Racine 1970; Miller & Noble 1996). It is important to measure the timescales of microvariability because it provides limits on the size and location of the emitting regions.

Polarized radiation is one piece of evidence of synchrotron origin in low energies and it also varies drastically. Therefore, optical polarimetric observations also provide a strong tool to probe jet structures (e.g., Marscher et al. 2008; Abdo et al. 2010a). Nevertheless, simultaneous short-term (intraday) observations of flux, color, and polarization have been performed only in a few blazars (e.g., Andrucovich et al. 2003, 2011; Cellone et al. 2007; Sasada et al. 2008; Hagen-Thorn et al. 2008), and hence the origin of microvariability is still unclear.

CTA 102 (also known as PKS J2232+1143, R.A. = \(22^\text{h}32^\text{m}36^\text{s}\), decl. = \(+11^\circ43'50''\)), J2000, \(z = 1.037\); Hewitt & Burbridge 1989) was first identified as a strong radio source (Harris & Roberts 1960) and classified as a flat spectrum radio quasar (Abdo et al. 2010b) from multi-wavelength observations. CTA 102 showed microvariability of optical flux and color in the 2004 flare (Osterman Meyer et al. 2009). In this flare, the “redder when brighter” trend was reported and was explained by the superposition of the variable synchrotron...
component from the radio to optical bands and the non-variable “blue bump” component which is thought to be thermal disk radiation connecting to the UV band.

Recently, CTA 102 showed extreme activity in the optical and GeV $\gamma$-ray bands in 2012 September (Larionov et al. 2012; Orienti & D’Ammando 2012). In this Letter, we present the results of high-temporal-density monitoring observations of CTA 102 just after the 2012 September $\gamma$-ray flare.

2. OBSERVATION

Observations were carried out as a Target of Opportunity (ToO) program of Optical and Infrared Synergetic Telescopes for Education and Research (OISTER). OISTER is a global observing network that organically links many ground-based small telescopes in Japan, South Africa, and Chile under a Japanese interuniversity cooperation regime. OISTER aims to investigate potential transient sources ($\gamma$-ray bursts, AGNs, supernovae, cataclysmic variables, etc.). The largest advantage of OISTER is its capability to perform continuous and high-temporal-density monitoring in many bands extending to as long a wavelength as $K_s$. The ToO observation of CTA 102 with OISTER was conducted from September 23 to October 3 in 2012, following the bright GeV $\gamma$-ray flare. We obtained the $B, V, g', r', R_C, I_C, i', z', J, H, K'$ and $K_s$-band photometric and the $R_C$-band polarimetry data with OISTER and also with other collaborative telescopes. The telescopes and instruments used for this observation are listed in Table 1. Note that we treated the $r'$- and $K'$-band data as the $R_C$- and $K_s$-band data, respectively. Reductions of optical and near-infrared (NIR) data were performed under the standard procedure of CCD photometry. The position of the comparison star is R.A. = 22h32m41.5s, decl. = +11°43'14.1" (J2000). The magnitudes in the optical bands were obtained differentially with nearby comparison stars that have been calibrated with the photometric standard stars in Landolt fields (Landolt 1992) observed on clear and stable nights. The same comparison stars are used also in NIR bands, where the magnitude is given in the Two Micron All Sky Survey catalog (Skrutskie et al. 2006). We corrected the data for the Galactic extinction (e.g., $A_V = 0.233$; Schlafly & Finkbeiner 2011, NASA/IPAC Extragalactic Database (NED) Database19). There were small systematic differences in photometric system among observatories and instruments; the standard deviations of the magnitudes of the comparison star during the observation period were $\Delta R_C \sim 0.02$ mag ($\sim$2% of flux) and $\Delta K_s \sim 0.06$ mag ($\sim$5% of flux). These values were added to the photometric errors of CTA 102 in each band.

The polarimetric observations were performed with HOWPol installed on the Kanata Telescope located on Higashi-Hiroshima Observatory (Kawabata et al. 2008). A unit of the observing sequence consisted of successive exposures at four position angles of a half-wave plate; 0°, 45°, 22.5°, and 67.5°. Polarimetry with HOWPol suffers from large instrumental polarization ($\Delta p \sim 4\%$) produced by the reflection of the incident light on the tertiary mirror of the telescope. The instrumental polarization was modeled as a function of the declination of the object and the hour angle at the observation, and we subtracted it from the observation. We estimated that the error in this instrumental polarization correction is smaller than 0.5% from many observations for unpolarized standard stars. The polarization angle (PA) is defined in the standard manner as measured from north to east. The PA was calibrated with two polarized stars, HD183143 and HD204827 (Schulz & Lenzen 1983). Because the PA has an ambiguity of $\pm 180° \times n$ (where $n$ is an integer), we selected $n$ which gives the least angle difference from the previous data, assuming that the PA would change smoothly. The error of the PA was estimated to be smaller than 2° from observations of the polarized stars.

The radio data were obtained from September 26 to 28 using the Hitachi 32 m telescope of the Mizusawa very long baseline interferometry (VLBI) Observatory, NAOJ, which is operated by Ibaraki University. The front end was a cooled HEMT receiver, and a typical system temperature was 25 K including the atmosphere toward the zenith. Since the beam switching system is not equipped, we rapidly scanned the antenna around the target CTA 102 in azimuth and elevation direction, while recording the total power. As a result, the fluctuation of the observed power

\begin{table}[h]
\centering
\caption{Observatories, Telescopes, and Instruments}
\begin{tabular}{|c|c|c|c|}
\hline
Observatory/Telescope & Diameter$^a$ & Instrument & Filters \\
\hline
Nayoro Observatory/Pirk & 160 cm & MSI$^1$ & $V, R_C$ \\
Akeno Observatory/MITSuME$^2$ & 50 cm & g', $R_C, I_C$ & \\
Kyoto University/- & 40 cm & $R_C$ & \\
Koyama Astronomical Observatory/Araki & 130 cm & ADLER & $B, g', V, I_C, i', z'$ \\
Nishi-Harima Astronomical Observatory/Nayuta & 200 cm & NIC & $K_s$ \\
Bisei Spaceguard Center/- & 100 cm & Volante & $r'$ \\
Okayama Astronomical Observatory/- & 188 cm & ISLE$^{1,4}$ & $J, H, K_s$ \\
Okayama Astronomical Observatory/MITSuME$^2$ & 50 cm & g', $R_C, I_C$ & \\
Higashi-Hiroshima Observatory/Kanata & 150 cm & HOWPol$^2$ & $V, R_C, R_C$-Pol. \\
Iriki Observatory/- & 100 cm & Infrared Camera & $J, H, K'$ \\
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Opt/NIR in South Africa & & & \\
South African Astronomical Observatory/IRSF & 140 cm & SIRIUS & $J, H, K_s$ \\
Radio Observatory & & & \\
Mizusawa VLBI Observatory/Hitachi 32 m Telescope & 32 m & 8.4 GHz & \\
\hline
\end{tabular}
\end{table}

Notes. $^a$ Size of primary mirror.

References. (1) Watanabe et al. 2012; (2) Kotani et al. 2005; (3) Yanagisawa et al. 2006; (4) Yanagisawa et al. 2008; (5) Kawabata et al. 2008.

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Ks-band flux

[10-11erg/cm2/s]

RC band flux

[10-11erg/cm2/s]

Polarized Flux

[10-11erg/cm2/s]

Polarization Degree

[%]

Polarization Angle

[deg]

due to the atmosphere can be minimized and the pointing error can disappear. The accuracy of the calibration was estimated to be 10%.

3. RESULTS

Figure 1 shows temporal variations of the optical $R_C$ band and NIR $K_s$-band total fluxes, as well as those of the $R_C$-band polarization degree (PD) and PA during our dense monitoring of CTA 102, following the intense $\gamma$-ray flare detected by Fermi Large Area Telescope (LAT). In the third panel of Figure 1, we also show a light curve of $R_C$-band polarized flux (PF), which was calculated by

$$PF = \frac{PD \times F_{R_C}}{100},$$

where PD and $F_{R_C}$ are the measured polarization degree in units of % and total flux in the $R_C$ band. Except for some nights with bad weather, we were able to monitor CTA 102 continuously. We note that, although not shown here, the light curves in other bands exhibited quite similar temporal variations to those in the $R_C$ and $K_s$ bands.

First, the light curves in the $R_C$ and $K_s$ bands showed a clear decay on MJD 56194. Given that Fermi-LAT detected a strong $\gamma$-ray flare on MJD 56189, the observed declining profile likely corresponds to the decay phase of the bright $\gamma$-ray flare. After that, both of the light curves showed a mild and symmetrical enhancement peaking around MJD 56198 until the end of this follow-up observation, except an intra-night strong flare on MJD 56202. In addition, we can clearly see some remarkable features in the daily polarimetric data. Namely, possible PA swings from $\sim 0^\circ$ to $\sim 100^\circ$ were observed on MJD 56195 and 56196. To check the temporal evolution of the PA, we plotted the Stokes parameters $Q$ and $U$ observed during these nights in Figure 2, together with those of other nights. Again, a gradual rotation of the PA was obviously seen, confirming the PA swing by $\sim 100^\circ$ during those two nights.

The continuous PA rotation was terminated by a sudden jump to $\sim 50^\circ$ on MJD 56197. More strikingly, the PF rapidly increased by three times from $\sim 0.1 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ to $\sim 0.3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ without an apparent increase of the total flux during the night. This is the first clear detection of a short-term (hour-scale) PF flare without corresponding total flux enhancement. Another interesting feature is a strong intra-night flare detected on MJD 56202. The isolated flare showed smooth and symmetrical profile peaking around 13 UT, and the total and polarized fluxes increased by factors of $\sim 1.5$ and $\sim 2.0$, respectively. Notably, the PD evolved in a quite similar way as the total flux, while the PA remained almost steady during the flare (see also Figures 1 and 2). The PA measured on MJD 56202

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Figure 1. Multi-wavelength light curves of CTA 102 from 2012 September 24 to October 3. Top panel: NIR ($K_s$-band) flux. Second panel: optical ($R_C$-band) flux. Third panel: polarized flux (PF) in the $R_C$ band. Fourth panel: polarization degree (PD) in the $R_C$ band. Bottom panel: polarization angle in the $R_C$ band.
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is orthogonal to the jet direction observed from the Very Long Baseline Array (VLBA) (Fromm et al. 2013). This is in contrast with the case of AO 0235+164, in which the optical PA aligned nearly the same direction as the jet during the flare in 2006 December (Hagen-Thorn et al. 2008).

To see spectral evolution in the optical and NIR bands, we plotted $R_C - K_s$ color against $R_C$-band magnitude in Figure 3. As reported in Osterman Meyer et al. (2009), a “redder when brighter” trend is expected in microvariability. As a result, however, there is no clear correlation between $R_C - K_s$ color and $R_C$-band magnitude for a whole data. Looking at the colors measured during our observation other than MJD 56197 and 56202, the source showed a hint of the “redder when brighter” trend, as reported previously by Osterman Meyer et al. (2009).

On the other hand, radio fluxes were almost constant within 10% during our monitoring and were comparable to that measured in the quiescent state (Stanghellini et al. 1998). This is because the emission region would be optically thick at 8.4 GHz. Actually, the constant radio flux during the optical and γ-ray flare was previously observed for CTA 102 in 2006 (Fromm et al. 2011).

### 4. DISCUSSION

On MJD 56197, a transient PF flare without significant increase of the total flux was observed. This “orphan PF flare” is interesting and can be explained in such a way that a new emission component that is less luminous but possesses extremely high PD with respect to the long-term baseline component might have emerged suddenly. The large discrepancy in PA between MJD 56196 and 56197 (∼100° to ∼45°) supports the emergence of the new component. A careful inspection of the light curve showed that the source brightened only by ∼10% in the total flux (which corresponds to $0.2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$) during the intra-night increase of PF from $0.1 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ to $0.3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$, implying that the new component has a PD of ∼100%. To overcome this unrealistic situation, we must consider that the decrease of the total flux of the long-term component occurred simultaneously with the emergence of the highly polarized new emission component and weakened increase of the total flux. In this case, the PD of the new component depends on how much total flux the long-term component decreases. For example, we assume that the gradual decrease of the total flux of the long-term component by $0.2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ occurred simultaneously with the gradual increase of the new component by $0.4 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. Then, the PD of the new component can be estimated as 50%, which seems reasonable compared to the above ∼100% PD scenario, though it is still very high. We note that some blazars such as OJ 287 and BL Lac exhibited similar orphan PF flares in longer day–month timescales (Ikejiri et al. 2011). It is currently unclear whether the same mechanism is responsible for such a similar phenomenon with a longer timescale. Anyway, our observation presented here is the first measurement of an orphan PF flare on a much shorter (intra-night) timescale, and further theoretical study is needed.

The smooth and continuous change of PAs from ∼0° to ∼100° observed on MJD 56195 and 56196 suggests either the presence of a helical magnetic field inside a jet (Marscher et al. 2008) or the global bending of a jet (Abdo et al. 2010a). Note that the PD remained constant at ∼3° during the PA swing, which was also observed in both scenarios from BL Lac (helical magnetic field) and 3C 279 (bent jet). The observed large PA swing rate of ∼50° day$^{-1}$ is similar to the case of BL Lac and four times larger than that of 3C 279, implying that the helical magnetic field scenario might be preferred. On the other hand, if PA swing in the opposite direction is observed, the bent jet scenario would be validated.

Current VLBI polarization observation is now feasible to examine the magnetic field structure of the parsec-scale jet. Especially, measurement of Faraday rotation is recognized as a powerful tool to manifest the presence of helical magnetic field. When polarized radiation propagates within a magnetized plasma, the plane of linear polarization rotates and the rotation measure (RM, rotation of the PA) depends on the line-of-sight component of the magnetic field (see, e.g., Chen 1974). Hence, if helical magnetic field is surrounding the jet, the RM gradient across the jet should be observed (e.g., Blandford 1993). Indeed, several authors (e.g., Gabuzda et al. 2004) claimed detection of RM gradient transverse to the VLBI jet in various blazars since the first discovery from 3C 273 by Asada et al. (2002),
although the significance of these detections is still controversial (Taylor & Zavala 2010). Importantly, recent VLBA observation detected significant RM gradient from CTA 102 (Hovatta et al. 2012). The presence of a helical magnetic field is consistent with our observation of relatively fast PA swing over the two nights on MJD 56195 and 56196. Thus, optical polarimetry provides another powerful tool to claim the presence of a helical magnetic field.

A prominent brightening was observed on MJD 56202, as is evident from the light curves of both the total flux and PF, with an almost constant PA of $\sim 70^\circ$ (see Figure 1). This could again be explained by the emergence of a new bright component with high PD with respect to the long-term baseline emission component. Comparison of the total and polarized fluxes between the beginning and peak of the flare allows us to estimate the PD of the new component. Namely, ratio of the PF increase by $\sim 0.35 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ with respect to the total-flux increase by $\sim 1.0 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ leads to a PD of $\sim 30\% - 40\%$ for the new emission component. Such a high PD indicates the presence of a highly ordered magnetic field at the emission site, which might be generated through compression of turbulent magnetic field by shocks inside a jet as advocated by previous papers (e.g., Hagen-Thorn et al. 2008).

The optical PAs measured during the two flares on MJD 56197 and 56202 were $\sim 45^\circ$ and $\sim 70^\circ$, respectively. Compared to the VLBA jet image (see, e.g., Figure A.15 of Fromm et al. 2013 for the jet image), we found that they are nearly orthogonal to the jet direction. Since the magnetic field direction is in principle assumed to be perpendicular to the PA, the measured PAs result in a claim of magnetic field orientation aligned with the jet. How is the highly ordered magnetic field aligned with the jet generated? At first glance, the shock-in-jet scenario considered above seems unreasonable because the magnetic field compressed by shocks propagating down the jet is aligned with a direction transverse to the jet. It should be noted that here the magnetic field direction is inferred based on the assumption that it is orthogonal to the observed PA, but recent theoretical work suggests that such an assumption is not correct for relativistically moving sources like AGN jets (Lyutikov et al. 2005). In particular, Lyutikov et al. (2005) pointed out that a toroidally dominated magnetic field is observed as poloidal in the observer’s (rest) frame when an ultra-relativistic jet with $\Gamma \gg 1$ is viewed at a small angle to the line of sight ($\Gamma$ is bulk Lorentz factor of the jet). Given this complicated situation, the measured EVPAs that are significantly different from the jet direction can still be accounted for by the “shock-in-jet” scenario.

It is interesting to compare the PAs observed during the two flares on MJD 56197 and 56202 with past observations, although only one observation by Hagen-Thorn et al. (2008) is found in the literature. Those authors reported an hour-scale short-timescale polarimetric variability from the BL Lac object AO 0235+164 during an outburst in 2006 December and found that the PAs tend to align with the jet direction around the maximum PD (see Figure 4 of Hagen-Thorn et al. 2008). This is quite different from our observation of perpendicular EVPAs to the jet direction. If the relativistic effect hypothesis is true, a uniform distribution of EVPAs with respect to the jet direction would be found for hour-scale flares. In any case, the current samples are only two and further optical polarimetric observation is most certainly needed.

To summarize, we performed dense optical/IR photometric and polarimetric monitoring of CTA 102 following a strong $y$-ray flare in 2012 September with the OISTER program. We found (1) smooth and gradual PA swing by $\sim 100^\circ$ over the two nights on MJD 56195 and 56196, (2) an orphan PF flare on MJD 56197, (3) significant brightening on MJD 56202, and (4) grossly perpendicular PAs to the jet direction during the two flares. Combined with the recent VLBA detection of a RM gradient across the jet, we infer that a helical magnetic field would be present at the emission region responsible for the long-term baseline component. The observed two flares can be explained by the emergence of a new emission component which possesses a highly ordered magnetic field. Such a magnetic field configuration would be generated through compression by shocks propagating down the jet. The observed EVPAs perpendicular to the jet direction are not unreasonable given the effect of a relativistically moving radiation source.

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REFERENCES

Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010a, Natur, 463, 919
Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010b, ApJ, 722, 520
Andruchow, I., Cellone, S. A., Romero, G. E., Dominici, T. F., & Abrahm, Z. 2003, A&A, 409, 857
Andruchow, I., Combi, J. A., Muñoz-Arjoniella, A. J., et al. 2011, A&A, 531, A38
Asada, K., Inoue, M., Uchida, Y., et al. 2002, PASJ, 54, L39
Blandford, R. 1993, in Astrophysics and Space Science Library, Vol. 103 (Cambridge: Cambridge Univ. Press), 15
Cellone, S. A., Romero, G. E., Combi, J. A., & Marti, J. 2007, MNRAS, 381, L60
Chen, F. F. 1974, Introduction to Plasma Physics (New York: Plenum)
Fromm, C. M., Perucho, M., Ros, E., et al. 2011, A&A, 531, A95
Fromm, C. M., Ros, E., Perucho, M., et al. 2013, A&A, 551, A32
Gabuzda, D. C., Murray, E., & Cronin, P. 2004, MNRAS, 351, L89
Hagen-Thorn, V. A., Larionov, V. M., Jordstad, S. G., et al. 2008, ApJ, 672, 40
Harris, D. E., & Roberts, J. A. 1960, PASP, 72, 237
Hewitt, A., & Burbidge, G. 1989, ApJS, 69, 1
Hovatta, T., Lister, M. L., Aller, M. F., et al. 2012, AJ, 144, 105
Ikejiri, Y., Uemura, M., Sasada, M., et al. 2011, PASJ, 63, 639
Kawabata, K. S., Nagae, O., Chiyonobu, S., et al. 2008, Proc. SPIE, 7014, 7014J
Kotani, T., Kawai, N., Yangisawa, K., et al. 2005, NCimC, 28, 755
Landolt, A. U. 1992, AJ, 104, 340
Larionov, V., Blinov, D., & Jordstad, S. 2012, Atel, 4397, 1
Lyutikov, M., Pariev, V. I., & Gabuzda, D. C. 2005, MNRAS, 360, 869
Marscher, A. P., Jordstad, S. G., D’Arcangelo, F. D., et al. 2008, Natur, 452, 966
Miller, H. R., & Noble, J. C. 1996, in ASP Conf. Ser. 110, Blazar Continuum Variability, ed. H. R. Miller, J. R. Webb, & J. C. Noble (San Francisco, CA: ASP), 17
Orienti, M., & D’Ammando, F. 2012, Atel, 4409, 1
Osterman Meyer, A., Miller, H. R., Marshall, K., et al. 2009, AJ, 138, 1902
Racine, R. 1970, ApJL, 159, L99
Sasada, M., Uemura, M., Arai, A., et al. 2008, PASJ, 60, L37
Schlafly, E. F., & Finkbeiner, D. P. 2011, ApJ, 737, 103
Schulz, A., & Lenzen, R. 1983, A&A, 121, 158
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Stanghellini, C., O’Dea, C. P., Dallacasa, D., et al. 1998, A&AS, 131, 303
Taylor, G. B., & Zavala, R. 2010, ApJL, 722, L183
Watanabe, M., Takahashi, Y., Sato, M., et al. 2012, Proc. SPIE, 8446, 84462O
Yangisawa, K., Okita, K., Shimizu, Y., et al. 2008, Proc. SPIE, 7014, 7014J7
Yangisawa, K., Shimizu, Y., Okita, K., et al. 2006, Proc. SPIE, 6269, 6269JQ