P1-59

Optical Monitoring of Blazars by the MITSuME Telescope

Yuki A.Mori[1] (ymori@hp.phys.titech.ac.jp), N.Kawai[1], M.Yoshida[2], Y.Yatsu[1], T.Shimokawabe[1]
H.Nakajima[1], A.Endou[1], on behalf of the MITSuME Team

1. Department of Physics, Tokyo Institute of Technology, Ookayama, Meguro-ku, Tokyo 152-8551, Japan
2. Okayama Astrophysical Observatory, National Astronomical Observatory of Japan, Asakuchi, Okayama 719-0232, Japan

Summary : We present the optical light curves of ∼50 blazars obtained by monitoring for 20 months with the 50 cm MITSuME telescope, and discuss their correlation with the gamma-ray light curves.

Abstract : We are performing automatic optical monitoring of blazars using the MITSuME Telescope, a 50 cm optical telescope equipped with a tricolor camera capable of simultaneous imaging in g´, R_c and I_c bands. We have been conducting a monitoring program since January 2008, and have obtained light curves of ∼50 blazars, Among them 32 are listed in the Fermi Bright Source List. In 2009, we detected optical brightening of some sources, such as S5 0716+71, DA 055, and 3C 454.3. The high flux state of these blazars were also detected by Fermi. For these sources, we compared the optical light curves with the publicly released Fermi light curves. We find strong correlation between optical and gamma-ray light curves for a flat spectrum radio quasar 3C 454.3, and two Low frequency peak BL Lacs (LBLs) AO 0235+16 and S5 0716+71. Furthermore, we find that the amplitudes of optical variability of FRQSs tend to be larger than those of High frequency peak BL Lacs (HBLs) .

MITSuME Telescope

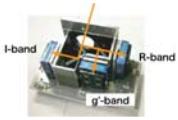
- MITSuME: Multicolor Imaging Telescopes for Survey and Monstrous Explosions
- ICRR Akeno Observatory, Yamanashi, Japan
- a diameter 50cm
- 28 arcmin ×28 arcmin
- remote observation

MITSuME Akeno telescope observe ∼ 15 blazars in a good night

MITSuME Akeno 50cm

The monitoring system starts automatically at twilight. The targets are selected by their current elevations and pre-defined "weights," and images are in tricolors.

Tricolor Camera



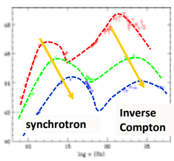
g´ band (480nm)
R_c band (650nm)
I_c band (800nm)
Tricolor photometry possible.

Blazar

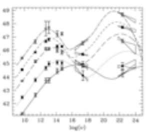
- direction from observer $\theta \sim 1/\Gamma_{BLK} \sim 5^\circ$
- relativistic beaming effect
- Luminosity $L_{obs} \propto \nu t^{-1} d\Omega^{-1} \propto \delta^4 \sim 10{,}000!$

radiation process

- Synchrotron Radiation + Inverse Compton Scattering
- Blazar Sequence
- Synchrotron Self Compton, External Compton
- Thermal emission from accretion disk and Broad Line Region



Kubo+ 98, Fossati+ 98, JK 02

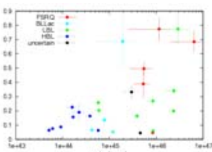


Fossati et al.1998

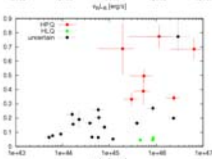
Optical Variability and Fluxes

The fluxes in R_c band were corrected the galactic extinction using Schlegel et al. 1998, and subtracted the estimated host galaxy fluxes using Nilsson et al. 2008.

F_{var} versus averaged flux in R_c band

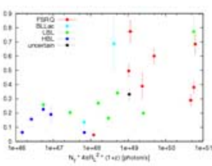


- The variability of HBLs tends to be small (<0.3), on the other hand, three FSRQs have large variability that are all HPQs
- The only FSRQ that has small variability is LPQ

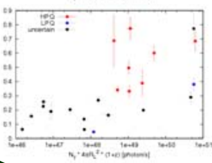


- The variability of HPQs are larger than LPQs

F_{var} versus gamma-ray flux



- N_γ is the gamma-ray flux [photon/cm²/s] of 1 - 100 GeV
- The fluxes of HBLs tend to be smaller than FSRQs
- The fluxes of the high optical variability blazars tend to be larger than low optical variability blazars.



- The blazars that have high variability in optical are comparatively bright in gamma-ray

Samples of Observation Targets

Name	z	Class *1	Average Flux (R_c) [erg/cm²/s]	F_{var} *2 (R_c)
1ES 0033+595	0.086	HBL	1.35e-11 ± 4.0e-12	0.190
GC 0109+224	-	BLLac	1.95e-11 ± 4.2e-12	0.209
3C 66A	0.444	LBL	3.47e-11 ± 6.9e-12	0.199
AO 235+16	0.94	LBL	6.85e-12 ± 5.4e-12	0.773
S5 0716+71	0.30	LBL, HPQ	8.86e-11 ± 3.0e-11	0.341
PKS 0735+17	0.424	LBL	6.36e-12 ± 1.1e-12	0.164
1ES 0806+524	0.138	BLLac	9.01e-12 ± 8.2e-13	0.066
Q 0827+243	0.94	LPQ	2.01e-12 ± 1.6e-13	0.060
OJ 287	0.306	LBL	2.99e-11 ± 8.1e-12	0.269
1ES 1011+496	0.200	BLLac	1.02e-11 ± 7.6e-13	0.063
1ES 1028+511	0.36	BLLac	2.87e-12 ± 1.9e-13	0.052
Mrk 421	0.031	HBL	7.93e-11 ± 1.9e-11	0.226
4C 29.45	0.729	FSRQ, HPQ	5.05e-12 ± 4.0e-12	0.774
B2 1215+30	0.13	BLLac	1.87e-11 ± 2.9e-12	0.136
1ES 1218+304	0.182	HBL	4.40e-12 ± 7.7e-13	0.164
W Com (ON 231)	0.102	LBL	2.38e-11 ± 5.0e-12	0.203
PG 1222+216	0.432	LPQ	7.14e-12 ± 4.7e-13	0.045
3C 273	0.158	FSRQ, LPQ	1.30e-10 ± 6.6e-12	0.046
3C 279	0.538	FSRQ, HPQ	4.93e-12 ± 2.0e-12	0.389
PG 1424+240	-	BLLac	3.19e-11 ± 1.7e-12	0.030
PKS 1510-08	0.361	FSRQ, HPQ	1.32e-11 ± 6.7e-12	0.496
3C 345	0.593	HPQ	2.17e-12 ± 7.3e-13	0.332
Mrk 501	0.034	HBL	2.13e-11 ± 3.2e-12	0.064
IZW 187	0.055	BLLac	9.13e-12 ± 7.1e-13	0.076
OT 081	0.322	BLLac, HPQ	6.05e-12 ± 4.3e-12	0.688
1ES 1959+650	0.047	HBL	3.58e-11 ± 5.8e-12	0.157
BL Lac	0.069	LBL	5.63e-11 ± 1.5e-11	0.258
CTA 102	1.037	HPQ	2.73e-12 ± 2.6e-13	0.065
3C 454.3	0.859	FSRQ, HPQ	1.89e-11 ± 1.3e-11	0.685
1ES 2344+514	0.044	HBL	2.29e-11 ± 2.4e-12	0.087

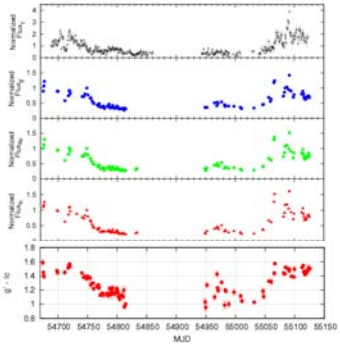
*1 The classification refers to NED, Ghisellini et al. 1998b, Celotti et al. 2008, Abdo et al. 2009
*2 F_{var} : the fractional root mean square (rms) variability amplitude of optical fluxes (Vaughan et al. 2003)

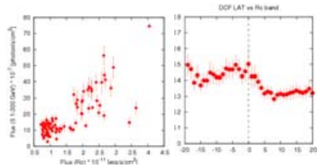
$$F_{var} = \sqrt{\frac{S^2 - \overline{\sigma^2_{err}}}{\bar{x}^2}}, \quad \overline{\sigma^2_{err}} = \frac{1}{N}\sum_{i=1}^{N} \sigma^2_{err,i}.$$

Correlation between Optical and Gamma-ray Light curve

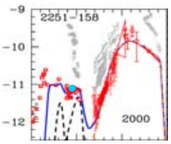
3C 454.3

- Right Panel : optical light curves (blue points = g´ (SDSS); green points = R_c; red points = I_c band) and gamma-ray light curve (black points) of Fermi public data from July 2008 to October 2009
- The light curves are normalized in flux at MJD=54748
- Right bottom panel : color index of g´ – I_c
- Fine correlation between optical and gamma-ray light curve
- When the optical fluxes are low (F_R<1.5*10^-11 [erg/cm²/s]), the color index of g´ – I_c decrease (∼1.1)
  → Increased of ratio of UV component is implied
  → Thermal emission from the accretion disk becomes comparable to synchrotron emission





- Left Panel : the gamma-ray flux measured by Fermi LAT versus the optical (R_c) flux obtained by MITSuME
- Right Panel : Discrete Correlation Function (DCF) between optical (R_c) and gamma-ray
- the relative peak on the DCF is located between 0 ∼ -4
  → Possibility of delay of the optical with respect to the gamma-ray

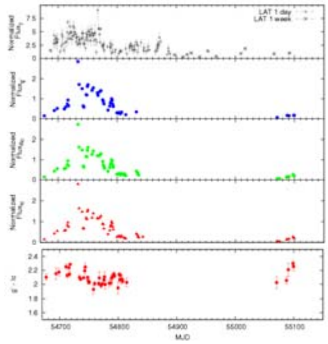


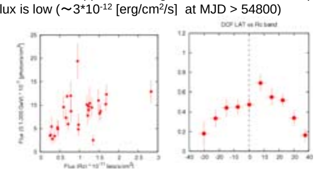
Ghisellini et al., 2009b

- SED of 3C 454.3 in 2000 (Ghisellini et al. 2009b)
- the low state flux F_R = 9.7e-12 (MJD=54800) is indicated by the light blue circle in the SED
- the low state flux obtained by our observation as small as fluxes in 2000

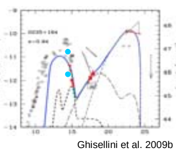
AO 0235+16

- Right Panel : optical light curves (blue points = g´ (SDSS); green points = R_c; red points = I_c band) and gamma-ray light curve (black points) of Fermi public data from July 08 to October 09
- The light curves are normalized in flux at MJD=54790
- Right Bottom Panel : color index of g´ – I_c
- Correlation between optical and gamma-ray light curve
- The optical magnitude reached R = 14.4 at MJD=54733, however, there is no counterpart in gamma-ray light curve
- there are no apparent changes of color index when optical flux is low (∼3*10^-12 [erg/cm²/s] at MJD > 54800)





- Left Panel : the gamma-ray flux measured by Fermi LAT versus the optical (R_c) flux obtained by MITSuME on the assumption of a 8 day delay of gamma-ray with respect to the optical
- Right Panel : Discrete Correlation Function between optical (R_c) and gamma-ray with bin size of 7 days
- The relative peak of the DCF is around ∼ 7.5 ± 3.5
  → gamma-ray delayed compared to optical



Ghisellini et al. 2009b

- SED of AO 0235+16 (Ghisellini et al. 2009b)
- is indicated by light blue circle in the SED
- the peak flux F_R = 2.8e-11e-12 (MJD=54733) and the low state flux F_R = 3.2e-12 (MJD=54801) are indicated by light blue circles in SED

Conclusion

- We succeeded in obtaining optical light curves of ∼ 50 blazars by MITSuME Telescope from January 2008
- There is a tendency that the optical variability of HBLs is smaller than that of FSRQs
- The only FSRQ that has small optical variability is a LPQ; other FSRQs are HPQs
- The gamma-ray luminosity of HBLs tends to be smaller than that of FRSQs and LBLs
- We found that the color index (g´ – I_c) of 3C 454.3 is low when the optical flux is faint. It suggests the increase of the ratio of UV components at F_R<1.5*10^-11 (erg/cm²/s)
- The optical fluxes of AO 0235+16 peak at MJD=54733, however, peaks do not appear in the gamma-ray light curve
- Gamma-rays appear to be delayed with respect to the optical emission of AO 0235+16