The Variability and Periods in the BL Lac AO 0235+164

J.H. Fan[1,2], O. Kurtanidze[3,4], Y. Liu[1,2], X. Liu[5], H. T. Wang[6], W. Cai[1,2],
H. B. Xiao[1,2], D. X. Wu[1,2], Z.Y. Pei[1,2], S. Mahito[7]

[1]Center for Astrophysics, Guangzhou University, Guangzhou 510006, China
[2]Astronomy Science and Technology Research Laboratory of Department of Education of Guangdong Province, Guangzhou 510006, China
[3]Abastumani Observatory, Mt. Kanobili, 0301 Abastumani, Georgia
[4]Engelhardt Astronomical Observatory, Kazan Federal University, Tatarstan, Russia
[5]Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, China
[6]Faculty of Physics and Electronic Information, LangFang Teacher's College, China
[7]Department of Astronomy, Kyoto University, Japan

Abstract

Variability is one of the extreme observational properties of BL Lacertae objects. AO 0235+164 is a well studied BL Lac through the whole electro-magnetic wavebands, it is violently variable in the optical bands. In the present work, we show its optical R band photometric observations carried out during the period of Nov, 2006 to Dec. 2012 using the Ap6E CCD camera attached to the primary focus of the 70 cm meniscus telescope at Abastumani Observatory, Georgia. It shows a large variation of $\triangle R$ = 4.88 mag (14.20 - 19.08 mag) during our monitoring period. During the period of Dec. 2006 to Nov. 2009, we made radio observations of the source, it shows also two outbursts with peak flux densities at JD 54266.92 and JD 54778.80 at an interval of 513 days. During the period, there are two optical peaks at the R band. When we adopted a DCF method to the optical and radio bands, we found that there is a time lag of 21.7±10.2 days or 55±51 days with optical leading the radio emissions. When periodicity analysis methods are adopted to its R observations from our Abastumani monitoring programme and those in the literatures, the signs of some periods, P_1 = 8.26 yr, P_2 = 0.54 yr, P_3 = 0.85 yr, P_4 = 1.99 yr, and P_5 = 0.56 yr are found.

Keywords. Galaxies: BL Lacertae Objects: individual (AO 0235+164): photometry: Variability

Introducture

One of the most important results of the Fermi/LAT is the discovery of blazars (i.e., flat-spectrum radio quasars–(FSRQs) and BL Lac objects), which emit most of their bolometric luminosity in the high energy range γ-rays (0.1 $\sim$ 100 GeV) (Abdo et al. 2010b; Ackermann et al. 2011; Nolan et al. 2012; 3FGL ; Fan et al. 2014b). The γ-rays are found to maybe strongly beamed(Kovalev et al. 2009; Hovatta et al. 2010; Savolainen et al. 2010; Ackermann et al. 2011; Giroletti et al. 2012; Massaro et al. 2013a,b; Giovannini et al. 2014; Fan et al. 2014a).

The BL Lac AO 0235+164, located at z_{em} = 0.94 (Cohen et al. 1987), is a well studied object. It is observed from radio to X-rays bands, and even high energetic γ-ray regions. It shows variability timescale from a few days to several years (Webb et al. 1998; Romero et al. 1997, 2000; Fan et al. 2002; Ackermann et al. 2012; Wang et al. 2014; Vol'vach et al. 2015). Its historic optical variation is over 5 magnitudes (Rieke et al. 1976). In our previous paper, variations in the UBVRI are $\Delta U = 4.26$, $\Delta B = 5.47$, $\Delta V = 4.74$, $\Delta R = 4.18$, and $\Delta I = 3.85$ (Fan & Lin. 2000). The degree of polarization varies between 35% and 13% on the nightly scale (Larionov et al. 2015). The highest degree of polarization has been reported to be 43.9 % (Impey et al. 1982). Raiteri et al.(2001) analyzed about 25 years of the observational data in optical and radio bands during the period of from 1975 to 2000, found a quasi-periodicity of the main radio (and optical) outbursts on 5.7 years time scale. A period of 5.87±1.3 years was found in our pervious paper based on 16 years of optical observations (Fan et al. 2002). It perhaps suggests existence of a binary black hole system at its center (Romero et al. 2003; Ostorero et al. 2004). Very recent analysis based on the long term multiwavelength observations suggests AO 0235+164 is a close binary with SMBHs with similar masses of the order of $10^{10} M_{\odot}$ (Vol'vach et al. 2015).

AO 0235+164 is one of the monitoring objects in our monitoring programme at Abastumani Observatory, Gorgia (Kurtanidze et al. 2007; Kurtanidze et al. 2009; Nikolashvili & Kurtanidze. 2007; Fan et al. 2014b).

Observations and Results

Optical Observations and Data Reduction

Abastumani Observatory is located at the top of the Mountain Kanobili in the South-Western part of Georgia. Mt. Kanobili is about 1,700 meters above the sea level with a latitude of $41^{\circ}.8051$ and a longitude of $42^{\circ}.8254$ respectively. The weather and seeing conditions are excellent (about $1/3$ clear nights per year with seeing ≤ 1 arcsec). The mean values of the night sky brightness are $B = 22.0$, $V = 21.2$, $R = 20.6$, and $I = 19.8$ magnitude.

Radio Observations and Data Reduction

The flux density monitoring observations of AO 0235+164 were carried out at an about monthly time sampling at 4.8 GHz from Dec. 2006 to Nov. 2009 with the Urumqi 25 m radio telescope, with the central frequency of 4.8 GHz and bandwidth of 600 MHz. The typical system temperature is 24 K in clear weather, and the antenna sensitivity is ~0.12 K/Jy.

Results and Analysis

Results

The optical R photometry and radio observation results are shown in the upper and middle panles of Fig. 1. which indicates a largest variation of $\triangle$ R = 4.88 mag from R = 14.20 to R = 19.08 mag, and a largest radio variability of $\triangle f$ = 4.5 mJy from 0.86 mJy to 5.36 mJy.

Discrete Correlation Function–DCF

When DCF are applied to the optical R and the radio data as shown in Fig. 1, the resulting DCF result is obtained and shown in Fig. 1. For optical and radio variation, there is a very weak correlation with the optical variation leading radio variation by days. For comparison, the DCF results for radio bands are also calculated and shown in Fig. 1.

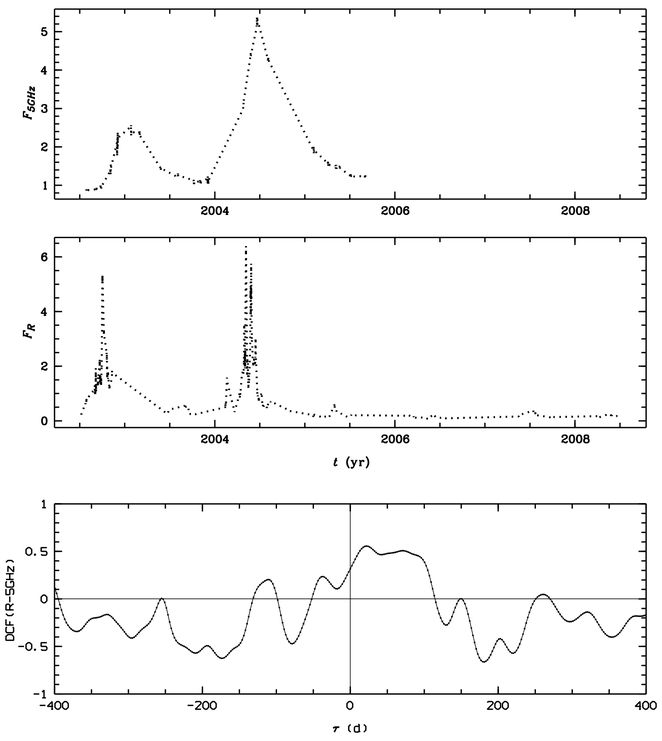

Figure 1: Optical (upper panel) and Radio (middle panel) Observations (upper panel), and DCF result (lower panel) for optical and radio light curves for 0235+164.

Period Analysis

Optical Light Curve: For AO 0235+164, we compiled the optical data from the literatures as listed in our previous work Wang (2014) and shew them in Fig. 2.

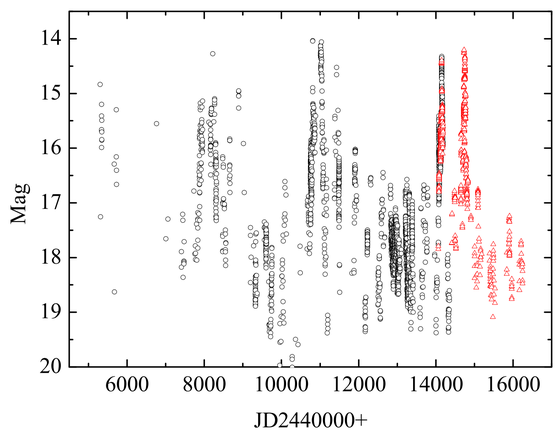

Figure 2: Optical R Photometry Result of 0235+164. The triangles stand for the photometric observations at Abastumani Observatory from 2006 to 2012 while the circles are from the literatures.

Power Spectral Analysis: DCDFT+CLEANest We performed a *Power Spectral Analysis (PSA, or Fourier Analysis, or power-density spectrum analysis)* to detect possible harmonic components, and gives some quantitative criterion for the detection of a possible periodic signal as we did in our previous paper Fan et al. (2006).

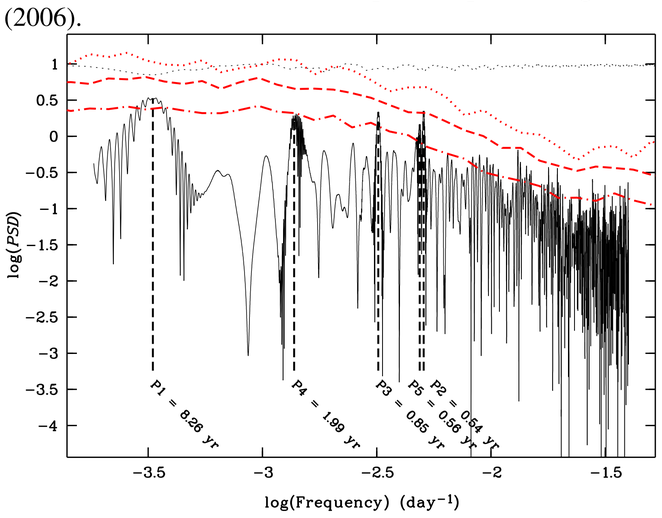

Figure 3: Periodicity analysis results for 0235+164.

We assumed that there are 7 independent frequency components to clean the observation data, the CLEANest spectrum is shown in Fig 3. There are signs of periods, P_1 = 8.26 yr, P_2 = 0.54 yr, P_3 = 0.85 yr, P_4 = 1.99 yr, and P_5 = 0.56 yrs.

acknowledgements

The work is partially supported by the National Natural Science Foundation of China (NSFC 10633010, NSFC 11173009, NSFC11203007,U1431112), Guangdong Province Universities and Colleges Pearl River Scholar Funded Scheme (GDUPS)(2009), Yangcheng Scholar Funded Scheme (10A027S), and supports for Astrophysics Key Subject of both Guangdong province and Guangzhou City.