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Prolonged Intranight Optical Quiescence of the Classical BL Lac Object PKS 0735+178

A. Goyal,[1] Gopal-Krishna,[2] G. C. Anupama,[3] D. K. Sahu,[3] R. Sagar,[1] S. Britzen,[4] M. Karazous,[4] M. F. Aller,[5] and H. D. Aller[5]

[1] *Aryabhatta Research Institute of Observational Sciences (ARIES), India*
[2] *National Centre for Radio Astrophysics, TIFR, India*
[3] *Indian Institute of Astrophysics (IIA), India*
[4] *Max-Planck-Institut für Radioastronomie, Germany*
[5] *Astronomy Department, University of Michigan, USA*

Abstract. We report our extensive intranight optical monitoring of the well known low-energy peaked (LBL) BL Lac object PKS 0735+178. This long-term follow-up consists of R-band monitoring for a minimum duration of ∼ 4 hours, on 17 nights spanning the past 11 years (1998−2008). Intra-night optical variability (INOV) amplitude of ≥ 3% on hour-like time scale was not observed in any of the nights even though the likelihood of seeing such INOV levels in a single session of ≥ 4 hours is known to be high (∼ 50%) for LBLs. Our observations thus establish a peculiar long-term INOV quiescence of this radio-selected BL Lac.

1. Introduction

BL Lac objects are a subset of the *blazar* population for which the dominant source of emission is believed to be a relativistic jet of non-thermal radiation (Urry & Padovani 1995). They are known to frequently exhibit large and rapid flux variations in all wavebands, which are not shown by other classes of active galactic nuclei. A classical radio-selected BL lac object (RBL) is quite likely to show optical variability at the level of a few percent, on hour-like time scale (e.g., Miller, Carini, & Goodrich 1989; Romero, Cellone, & Combi 1999; Romero et al. 2002). More specifically, INOV of amplitude $\psi > 3\%$ is expected to occur in such observations, with a probability (duty cycle: DC) of ∼ 53% (Gopal-Krishna et al. 2003; Stalin et al. 2005). These studies have also shown that large amplitude INOV ($\psi > 3\%$) is displayed exclusively by blazars, associating it primarily with the relativistic jet. Possible mechanisms for INOV include perturbations in the inner jet, caused by shear or relativistic shocks, small-scale inhomogeneities in the magnetic field and instabilities in the particle acceleration mechanism, etc. (e.g., Wiita 1996; Marscher 1996), and also from accretion disk instabilities (Mangalam & Wiita 1993).

PKS 0735+178 has been monitored by us since 1998 every winter [the first 4 years of observations (1998−2001) are reported in Sagar et al. (2004)], except for 2002. Each time the duration of monitoring was longer than ∼ 4 hours and the sensitivity was sufficient to detect INOV down to 1 − 2% level. Here we report these new data and discuss our entire dataset in the broader context of the published multi-wavelength observations of this BL Lac. This object is known to show large variability in both optical and radio bands, (Ciprini et al. 2007; Qian & Tao 2004), being characteristic of blazars, but its X-ray and γ−ray emission was found to be quite steady (Madejski & Schwartz 1988; Nolan et al. 2003).

2. Observations and the INOV Results

Photometric observations were carried out using the 104-cm Sampurnanand telescope (ST) located at ARIES, Naini Tal (India), except on one night when the 201-cm Himalayan Chandra

Table 1. Observation log and the INOV results for PKS 0735+178

Date dd.mm.yy	Teles-copes	Number of points	Duration (hours)	ψ (%)	C_{eff}	Status‡	References
26.12.98	ST	49	7.8	1.8	1.13	N	Sagar et al. (2004)
30.12.99	ST	64	7.4	1.0	0.61	N	Sagar et al. (2004)
25.12.00	ST	42	6.0	1.6	1.02	N	Sagar et al. (2004)
25.12.01	ST	43	7.3	1.0	2.8	V	Sagar et al. (2004)
20.12.03	HCT	36	5.8	1.0	1.78	N	Present work
10.12.04	ST	28	5.8	1.3	3.00	V	Present work
23.12.04	ST	11	5.0	1.2	3.10	V	Present work
02.01.05	ST	20	4.9	0.8	0.97	N	Present work
05.01.05	ST	23	5.8	1.0	2.25	PV	Present work
09.01.05	ST	28	6.7	1.3	3.20	V	Present work
09.11.05	ST	17	3.8	0.7	2.00	PV	Present work
16.11.06	ST	19	4.5	1.1	0.95	N	Present work
29.11.06	ST	26	5.8	1.0	0.83	N	Present work
17.12.06	ST	24	5.6	0.9	1.06	N	Present work
15.12.07	ST	28	6.6	1.9	3.53	V	Present work
16.12.07	ST	27	6.6	1.0	1.45	N	Present work
22.11.08	ST	27	5.6	0.8	0.33	N	Present work

‡V = variable; N = non-variable; PV = probable variable

telescope (HCT), IAO at Hanle (India) was used with CCDs as N-star photometer. All the observations were carried out using *R* filter. Table 1 gives the log of our observations, including those already reported in Sagar et al. (2004). For each session it lists the date, the telescope used, number of data points, duration of monitoring, the quantifiers of INOV, C_{eff} and the amplitude of variability ψ, as well as the INOV status. The data analysis was done using IRAF[1] and the instrumental magnitudes were determined by aperture photometry. The source is termed as intranight variable (V) if $C_{eff} > 2.57$ (Jang & Miller 1997), corresponding to a confidence level of 99%. It is called a 'probable variable' (PV) if C_{eff} is found to be in range of 1.95 to 2.57, corresponding to a confidence level of 95−99%. The INOV amplitude and the duty cycle (DC) was calculated using the definition by Romero et al. (1999) (see Stalin et al. 2005 for details). The DC is found to be ∼ 27%, which increases to ∼ 42% if the two PV cases are also included. The key result, however, is that *large INOV ($\psi \geq 3\%$) was not detected on even one of the 17 nights*, in spite of an adequate data quality.

3. Long-Term Optical and Radio Variability Patterns

In Figure 1, the top panel displays our calibrated R band data points superposed on the existing light curve from Ciprini et al. (2007), after binning the data in 1 year intervals. The 100-year light curve of PKS 0735+178 shows 5 optical outbursts (Ciprini et al. 2007), last one occurred during 2001 February – October.

The UMRAO light curve at 15 GHz is shown in Figure 1b, observed with the 26-metre Michigan dish (Aller et al. 1985). Figure 1c shows the plot of spectral index (defined as $S_\nu \propto \nu^\alpha$). Fig. 1d shows the variation of the percentage (linear) polarization at 15 GHz. Around 1990 and 1992 a pair of large flares ('twin radio flares') was recorded but thereafter only mild variability has been observed. The pattern of the radio light curve is closely mimicked by the run of radio spectral index (α_r). PKS 0735+178 has shown a large long-term variability of optical (linear) polarization, from about 1% to more than 30% (Tommasi et al. 2001) which is

[1] Image Reduction and Analysis Facility

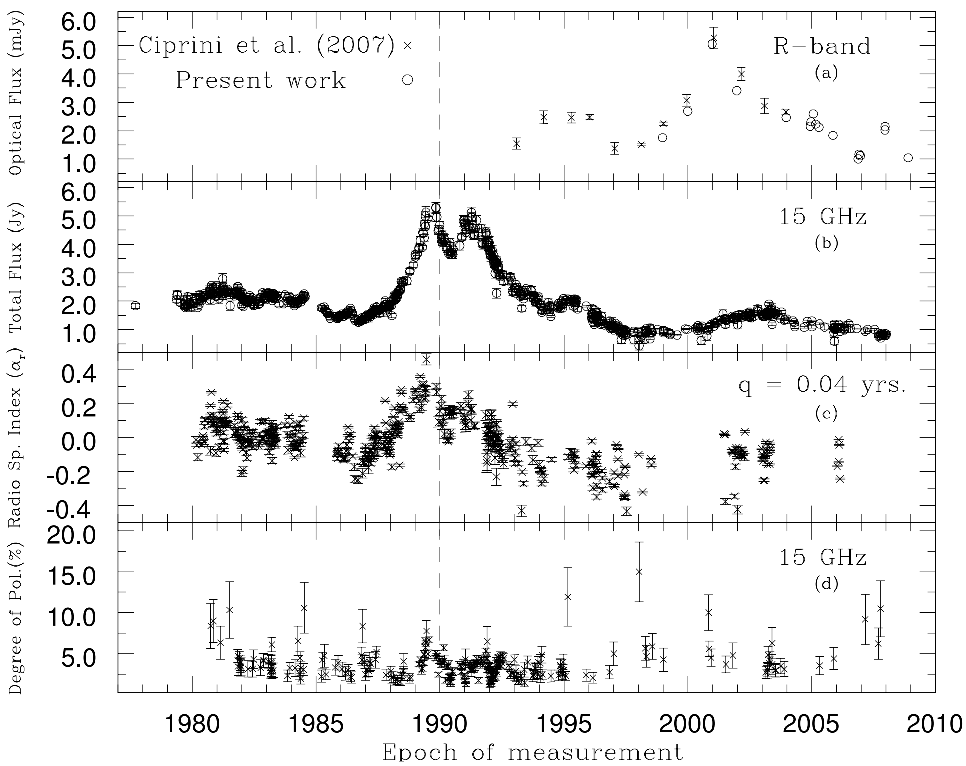

Figure 1. Time series of the radio/optical measurements of PKS 0735+178

a characterstic of BL Lac objects. The integrated radio polarization has remained between 2% and 4% during the entire monitoring period.

4. Discussion

The last variability cycle (1998−2008) witnessed a ten-fold brightening in the optical (synchrotron) flux of PKS 0735+178, but INOV was observed on just 4 out of the total 17 nights, corresponding to a INOV DC of 27%. Interestingly, the nights of INOV detection coincide not with the extrema but with gradients in optical flux.

Thus, we did not find the INOV amplitude of this BL Lac to be > 3%, even though the probability of observing such amplitudes in even a single session lasting $\gtrsim$ 4 hours, is ∼ 50% (section 1). This suggests that PKS 0735+178 has continued to be in an INOV quiescent state since 1998, despite other indications of its returning to an active state, such as: (a) the fairly large variation in its radio and optical synchrotron flux on month/year-like time scale (Figure 1), (b) the return of its VLBI jet to the 'normal' rectilinear shape within the inner 2 milliarcsec from the core, indicating a change in the flow (Gómez et al. 1999; Agudo et al. 2006) and (c) the observed 'normal' degrees of its optical and radio polarization (section 3). Thus, this BL Lac is quite exceptional for its propensity to persist in a state of intranight optical quiescence (i.e., $\psi \leq 3\%$).

We propose to associate the subdued INOV, primarily to the lack of perturbations in the inner jet or the absence of small-scale inhomogeneities in the magnetic field in the parsec-scale jet which is discussed in more detail in our forthcoming paper (Goyal et al. 2009, in preparation).

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