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Long-term optical monitoring of blazars: the case of PKS 0735+178

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Abstract. Data and first results on the optical light curve of the blazar PKS 0735+178 (S3 0735+17, OI 158, DA 237), are presented from the longest continuous *BVRI* observations ever published. The data belong to an optical observing monitoring campaign performed over the last ten years by the Perugia, Torino and Tuorla astronomical observatories.

Key words. BL Lacertae objects: individual: PKS 0735+178 – BL Lacertae objects: individual: PKS 0738+17 – BL Lacertae objects: general – galaxies: photometry

1. Introduction

Rapid and violent optical variability is one of the defining properties of blazars. A well sampled and extended observing monitoring jointly to multiwavelength observations is important to clarify fluctuation modes, typical time scales, variation lags of the flux at different wavelengths, temporal duty cycles and spectral changes. Hence optical variability is able to shed light on the location, size, structure, and dynamics of the emitting regions. The past optical data are rather sparse, but at present dedicated moderate–size telescopes and international collaborations have improved the amount of photometric data and sampling.

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Table 1. The number of final photometric *BVRI* data points of PKS 0735+178 obtained by each observatory.

DATA POINTS PER OBSERVATORY						
Obs.	*B*	*V*	*R*	*I*	Tot.	Period
Perugia	0	226	490	282	998	Feb93-Feb04
Torino	75	38	150	0	263	Dec94-Apr02
Tuorla	0	55	0	0	55	Oct95-Feb01
Shanghai	0	115	52	138	305	Jan95-Dec01
Total	75	434	692	420	1621	

Ten years of optical data on the blazar PKS 0735+178 were acquired by the Perugia University Observatory (Italy), by INAF Torino Observatory (Italy), and by Tuorla Observatory (Finland). Published data from Shanghai Observatory (Qian & Tao 2004) were also added in order to improve the sampling.

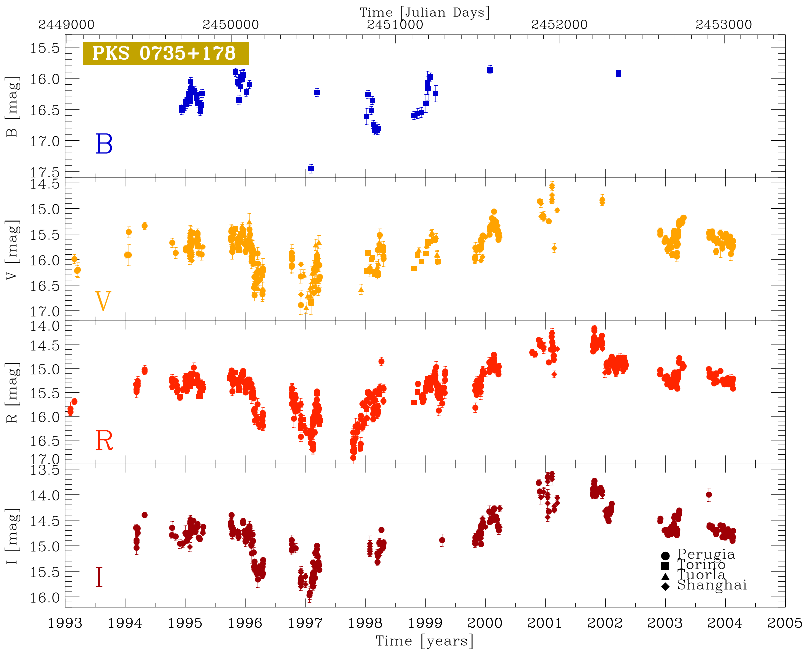

Fig. 1. *BVRI* magnitude light curves of PKS 0735+178 from 1993 to beginning of 2004. Data come from our ten-years observing monitoring programme. Published observations from Shanghai Observatory (Qian & Tao 2004) are added in order to improve the sampling. Data sets from different observatories are in agreement within the uncertainties.

2. The monitoring of PKS 0735+178

The radio source PKS 0735+178 (S3 0735+17, OI 158, DA 237, VRO 17.07.02, RGB J0738+177) was optically identified and classified as a classical BL Lac object by Carswell et al. (1974). This object is both radio and X-ray selected, it was detected as a gamma-ray emitting blazar by EGRET (Nolan et al. 1996) and it was extensively studied in the radio bands. This blazar has one of the most bent radio jets and several moving components were detected in VLBI (see e.g. Kellermann et al. 1998; Gómez et al. 1999, 2001; Homan et al. 2002). Early multifrequency flux density measurements showed a very flat radio spectrum, interpreted as a superposition of incoherent synchrotron radiation from distinct components, each with its own turnover frequency. For this reason the source was termed with the nickname of "cosmic conspiracy" (Marscher 1980; Cotton et al. 1980; Bååth, Zhang, & Chu 1991). The optical spectrum of PKS 0735+178 shows an absorption line due to an intervening system identified with MgII, which gives a redshift limit $z > 0.424$. The host galaxy of PKS 0735+178 remains unresolved in optical imaging (see e.g. Falomo & Ulrich 2000; Pursimo et al. 2002), and the object shows a relatively high level of optical polarization (from about 1% to more than 30%, see e.g. Valtaoja et al. 1993; Tommasi et al. 2001). Several possible periods or recurrent timescales were claimed in literature (Smith, Leacock, & Webb 1988; Webb et al. 1988; Smith & Nair 1995; Fan et al. 1997; Qian & Tao 2004), and now the historical light curve spans over almost 100 years in the optical (Fig. 2), thanks to the data obtained in the last years (1993-2004) by Perugia, Torino and Tuorla observatories.

These observatories took CCD frames, with a first automatic data reduction using batch procedures to correct each raw image for dark and bias signals, performing flat fielding, recognizing the field stars, and deriving instrumental magnitudes via aperture pho-

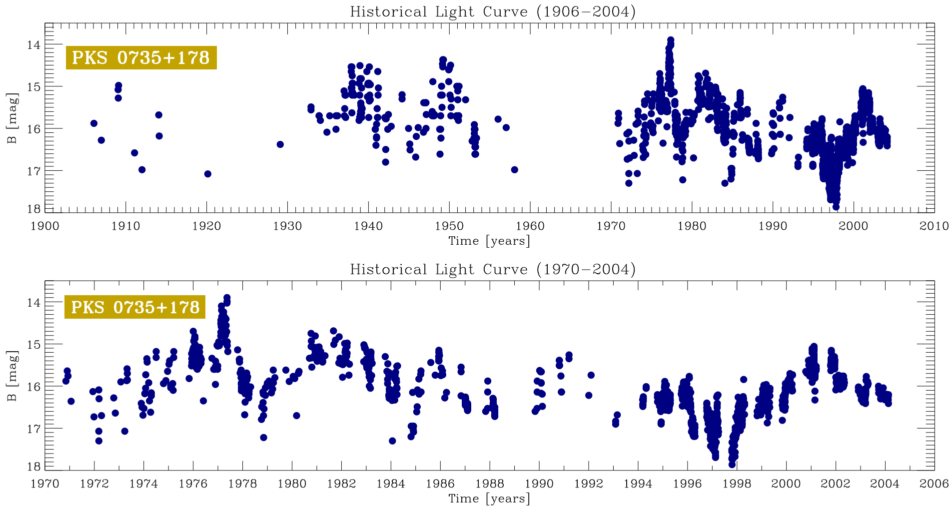

Fig. 2. The historical optical light curve of PKS 0735+178 in magnitude B, reconstructed from literature and including our original B and R-derived observations (magnitudes derived using mean colour index $B - R = 0.993$ for data sets homogeneity; Fan et al. 1997; Qian & Tao 2004). The old photographic magnitudes are converted into B values by $B - m_{pg} = 0.28$ (Kidger 1989).The time series so obtained is composed of 1725 data points. Mean errors for the old historical data and for the derived B magnitudes can be considered no larger than ±0.3 mag (error bars are not represented for clarity).

tometry or Gaussian fitting. The comparison among data obtained with the three different telescopes showed a good agreement without any noticeable offset. Also the comparison with the published data of the Shanghai Observatory (Qian & Tao 2004) is good (in terms of long-term/moderate-precision photometry: discrepancies are around 0.1-0.2 mag). PKS 0735+178 was observed in the B, V, R_c, I_c Johnson-Cousins bands (Bessell 1979) from February 2, 1993 to February 17, 2004 (JD=2449021–2453053, see Table 1). Our improved observing sampling recorded also the faster variations. Magnitude light curves in Fig. 1 show that the source was always in a low brightness state starting from 1993, displaying a flickering variability with moderate flaring and no extraordinary and isolated outburst. From the end of 1997 a slow increase of the average magnitude is observed (Fig. 1). Moreover as the host galaxy of PKS 0735+178 is rather faint, it is reasonable to neglect the interference of the galaxy colour in the observed optical fluxes. The statistical and correlation analysis is ongoing, using methods optimized for discrete unevenly sampled data sets.

In Fig. 3 the periodogram plot (a modified version of the discrete Fourier transform), and the structure function (SF) of the historical light curve (1970 to 2004; from Fig. 2) are reported. The timescale corresponding to the highest peak in the periodogram is about 8.4 ± 0.2 years. Dashed line shows the 1% false alarm significance level, under the hypothesis of fluctuations dominated by Poisson statistics. The spurious peaks around 1 years are due to the periodic windows induced by the observing seasonal interruptions. The slope of the first part of the SF curve gives a power spectral density of the signal characterized by the $1/f^{\alpha}$ trend, with $\alpha = 1.58 \pm 0.9$. This means a "shotted-flickering" behaviour of the optical variability.

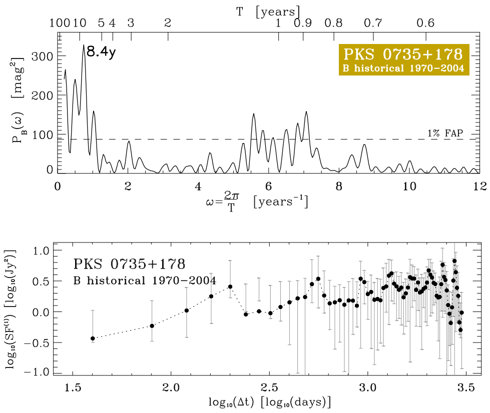

Fig. 3. Upper panel: periodogram plot of the historical blue light curve in the best sampled period (1970-2004). Lower panel: the first order structure function (SF) of the same light curve.

3. Conclusions

Ten years of optical monitoring of the blazar PKS 0735+178, performed with an unprecedented sampling and continuity, have confirmed its rapid and intense variability. In these last years the mode of variability of the source seems to be a flickering with moderate flaring. There are not hints of a periodicity with a single period, but some weak signs of recurrent timescales (on the order of some years) are found. A first look suggests that it will be difficult to correlate this optical behaviour with the recent history in the radio-mm bands.

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