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Optical flux behaviour of a sample of *Fermi* blazars⋆

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ABSTRACT

Aims. We aim at investigating the time-behaviour of a sample of gamma-ray blazars. We present the results from a 13 month-long optical photometry monitoring campaign of the blazars PKS 0048−097, PKS 0754+100, [HB89] 0827+243, PKS 0851+202, PKS 1253−055, PKS 1510−089, PKS 1749+096, PKS 2230+114 and PKS 2251+158.

Methods. We analyse the variability of each object, focusing on different time-scales (long term, short term, and microvariability), in an attempt to achieve a statistical comparison of the results.

Results. After applying a geometric model to explain the variability results, we found that it is possible that a slight change in the direction of the jet generates the variations detected in some objects during this campaign.

Key words. BL Lacertae objects: general

1. Introduction

Blazars are a sub-type of active galactic nuclei (AGN), whose jets axes are extremely close to the line of sight; the electromagnetic (non-thermal) emission from the jet is thus relativistically boosted and dominates along the whole spectrum. These objects often show a flat radio spectrum and apparent superluminal motions at VLBI scales (Urry 1999), while both short- and long-term variations are detected in optical flux (e.g. Miller et al. 1989; Carini et al. 1990, 1992; Romero et al. 2002). Most blazars present microvariability, e.g.: variations over intranight timescales. These changes in brightness can also be detected at other wavelengths, from radio to gamma rays.

Blazars are subclassified as flat spectrum radio quasars (FSRQ) and BL Lac objects (BL Lacs). In the first case, strong emission lines are present in their optical spectra while, in the second, these lines are weak or non-existent. A (possibly) more physically based classification takes into account the position of the synchrotron peak (SP) in the spectral energy distribution (SED): in this way, blazars are classified as high- (HSP), intermediate- (ISP) and low-synchrotron peak (LSP) objects, according to the frequency of the low-energy peak (Abdo et al. 2010b). In most cases, BL Lacs are identified as HSP, while most FSRQs are LSP. However, this differentiation is not clear-cut since there are several transition objects.

Recently, Giommi et al. (2012) studied the difference in the emission properties between these sub-types of blazars. They found that FSRQs maintain their LSP classification, which is the same as Fanaroff-Riley II (FRII) radio-galaxies, according to their ionisation degree. On the other hand, BL Lac objects are a mixture of two intrinsically different sources: FR I objects, with weak or non-existent emission lines, and FR II objects whose lines were diluted by several effects, mainly because of a strong thermal (accretion disk) component. In this sense, the SP classification might be driven by selection effects, while the FR I–FR II division is a classification based on physical properties.

A detailed knowledge of the optical flux properties in blazars is thus relevant to get a clearer picture of the complex interrelations between emission properties at different frequencies. In particular, flux variability studies are important to test the size and location of the emitting region at a given frequency, as well as to give clues on the mechanisms which originate the emission. Variability at the shortest measurable timescales is supposed to provide information on emitting regions at the smallest spatial scales, which can be useful to test any relation with the emission at higher frequencies.

In this work we analyse the optical flux variability in a sample of nine blazars. All these sources were detected at high frequencies by different satellites in X-rays (e.g. Giommi et al. 2012; Cusumano et al. 2010), and by *Fermi*-LAT (Fermi Large Area Telescope) at GeV energies (Abdo et al. 2010a). Some of them were also detected at TeV energies by experiments like HESS and MAGIC. According to Abdo et al. (2010c), all the blazars in our sample show a SED of the LSP class, with the exception of PKS 0048−097, which is classified as ISP.

2. Observations and data reduction

A sample of nine gamma-ray blazars was photometrically followed with high temporal resolution (<1 h), each object being

⋆ Differential photometry results used in the statistical analysis reported in Table 2 are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/591/A21

Table 1. Sample.

Object	Type	$\alpha_{J2000.0}$	$\delta_{J2000.0}$	m_{NED}	z
PKS 0048−090	BL-Lac	00:50:41.3	−09:29:05	17.4	0.634
PKS 0754+100	BL-Lac	07:57:06.6	+09:56:35	14.5	0.266
[HB89] 0827+243	Blazar (LPQ)	08:30:52.1	+24:11:00	17.2	0.940
PKS 0851+202	BL-Lac	08:54:48.8	+20:06:31	14.0	0.306
PKS 1253−055	FSRQ (TeV)	12:56:11.1	−05:47:22	15.2	0.536
PKS 1510−089	QSO (HP+TeV)	15:12:50.5	−09:06:00	18.2	0.360
PKS 1749+096	BL-Lac	17:51:32.8	+09:39:01	16.8	0.320
PKS 2230+114	FSRQ	22:32:36.4	+11:43.50	17.3	1.037
PKS 2251+158	FSRQ	22:53:57.7	+16:08:53	16.1	0.859

Notes. Column 1 is the source name; Col. 2, the type; position is given in Cols. 3 and 4; visual magnitude and redshift (as found in NASA Extragalactic Database – NED) are presented in Cols. 5 and 6, respectively.

observed along 1 to 4 (mostly) consecutive nights. The whole campaign spanned 13 months, from March 2006 to April 2007. The general information on the sources is shown in Table 1. Optical images were obtained using standard V and R Johnson-Kron-Cousins filters with the no longer operating 1.52 m telescope at the Estación de Observación de Calar Alto, part of the National Astronomical Observatory (OAN) of Spain. This telescope was equipped with a 1024 × 1024 pixel CCD, resulting in a field of view (FOV) of 6$'$.9 × 6$'$.9 (i.e., 0.40 arcsec pixel^{-1} scale). Full width at half maximum (FWHM) values varied from 2.3 arcsec to 3.7 arcsec in some of the frames; exposure times ranged from 100 to 840 seconds, depending on the night conditions and the brightness of the source.

All images were de-biased and flat-fielded using the standard IRAF[1] reduction package. The IRAF APPHOT package was used to extract the photometry for all the images, with aperture diameters of 4 arcsec for all objects with the exception of PKS 2230+114 (3.2 arcsec) and 0827+243 (4.8 arcsec). The size of the aperture diameter was chosen according to the stabilisation of the photometric growth curve.

A comparison and a control star were chosen within each field to build the differential light curves. These were statistically analysed to study their variability by means of the F-test. For each light curve, we estimated the F parameter, defined as the ratio of the variance of the object−comparison light curve ($\sigma^2_{\rm o-c}$) to the variance of the control−comparison light curve ($\sigma^2_{\rm k-c}$). If $F = \sigma^2_{\rm o-c}/\sigma^2_{\rm k-c} \geq F^\alpha_n$, the object is said to be variable, being F^α_n a critical value. This critical value is calculated for a set of $n = N-1$ degrees of freedom, where N is the number of points in the light-curve, while α is chosen to determine the desired level of confidence. If $\alpha = 0.01$, then the F test has a 99% confidence level.

In this process, a statistical weight Γ, as introduced by Howell et al. (1988), was adopted for the F test to consider effects caused by the difference in magnitude of the source and the stars. The Γ factor can be derived from measurable quantities from a given observation, such as sky-substracted counts from the object, sky photons, and the read-out noise.

As a result of taking this weight into account, $F = \sigma^2_{\rm o-c}/\left(\Gamma^2\sigma^2_{\rm k-c}\right)$. The importance of this weighting to avoid spurious variability results in differential photometry studies of blazars has been underscored by Cellone et al. (2007).

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

3. Results

In this section we present a brief description of each object and the optical flux variability results that we found.

PKS 0048−097: is a strongly variable BL-Lac object. Its redshift is highly uncertain since its spectrum is basically flat; Stickel et al. (1993) derived a lower limit of $z \geq 0.2$. A tentative value of $z \approx 0.63$ was estimated (Rector & Stocke 2001) and then confirmed at $z = 0.635$ (Landoni et al. 2012). This BL-Lac object, as most of its kind, shows variability at almost every wavelength range, from radio to optical bands (Pica et al. 1988). It has also been detected in X-rays (Brinkmann et al. 2000). On the other hand, several works have found variability in optical polarization, reporting a value of polarization degree $\langle P_V \rangle = 10.6\%$ (Wills et al. 1992). Through a very long campaign (from 1979 to 2004), Kadler et al. (2006) detected evidence for long-term periodicity in radio emission, suggesting a period of ∼450 days for the first half of the 80 s, and a period of almost 600 days for late 80 s and early 90 s (these periods were determined with a very high confidence level). These authors also reported a change of about 90° in the direction of the jet during its propagation from 1995 to 2002. This behaviour implies a strong structural variability, which would deserve further studies. We used the magnitudes of the field stars published in Villata et al. (1998) to estimate the mean standard magnitude for PKS 0048−097 in each filter during our observations; resulting in 15.84 ± 0.05 mag in V, 15.44 ± 0.04 in R band the first night, and 15.89 ± 0.05 mag in V, 15.99 ± 0.05 in R band the second night. These magnitudes are in agreement with those presented by Fan & Lin (2000), who found V = 15.86 and R = 15.40. In the present work, this object showed small amplitude variability in the R band.

PKS 0754+100: is a highly polarized and variable LSP blazar (Ghosh & Soundararajaperumal 1995; Ghosh et al. 2000) of the BL-Lac type (Tapia et al. 1977). Its long-term variability at optical bands can be traced back to 1980 (e.g. Baumert 1980; Pica et al. 1988; Sillanpaa et al. 1991; Katajainen et al. 2000). Infrared variations were detected by Fan & Lin (1999), as well as a radio flare by Nieppola et al. (2009). This object shows a featureless spectrum and its host galaxy can be resolved in the images (Abraham et al. 1991; Falomo 1996), but it is rather faint compared to the AGN. Nilsson et al. (2003) suggest a host magnitude of R = 18.55 mag and $r_{\rm eff}$ = 1.3 arcsec. Carangelo et al. (2003) suggest a redshift $z = 0.266 \pm 0.001$ based on the identification of two faint emission lines. We followed this source during the night of March 24, 2006, in which, the F test results in no variability neither in the V nor in the R bands. Using the comparison stars and standard magnitudes published by Fiorucci et al. (1998), the mean standard magnitudes for PKS 0754+100 are 16.72 ± 0.05 mag in V and 16.22 ± 0.05 mag in R bands. Compared with Fan & Lin (2000), who present mean values of $V = 15.40$ and $R = 14.27$, our observations clearly correspond to a minimum activity state.

[HB89] 0827+243: is classified as a FSRQ (Healey et al. 2007). It is also a gamma-ray bright quasar, with a redshift $z = 0.939$ (Hewett & Wild 2010). Variability on a day-long scale has been detected at B, V, and R optical bands (Villata et al. 1997; Raiteri et al. 1998), as well as long-term variability in the near-infrared J, H, and K' bands (Enya et al. 2002). The jet emerging from the core of 0827+243 has been detected both at X-ray and radio bands, showing an apparent superluminal motion of over $20c$ (Jorstad et al. 2001; Piner et al. 2006). This jet has a highly unusual morphology bending almost 90° at the X-ray band, while in radio only the external 90°-bended section is visible. A swinging-nozzle model has been proposed to explain this unusual jet behaviour (Jorstad & Marscher 2004); this model proposes a scenario in which the jet flow has always been straight, but the AGN smoothly changed its direction, leaving traces of energised matter towards its former direction, and hence the difference both in structure and in emission can be explained. Our data show no intranight variability (both in V and in R bands) during each of the three nights [HB89] 0827+243 was observed. Regarding an internight time-scale, the light-curves analysis detects significant variability.

PKS 0851+202: (also known as OJ 287) is a well known AGN. Its redshift is well-determined at $z = 0.306$ (Nilsson et al. 2010), and it is usually classified as a FSRQ (Healey et al. 2007). OJ 287 shows a periodical behaviour in its optical emission. Analysing its historical light-curve, several studies concluded that it shows a period of ~12 years (Sillanpaa et al. 1988, 1996), explained by a binary black hole system (Sillanpaa et al. 1988; Valtaoja et al. 2000; Valtonen et al. 2008). Variability has also been detected both at radio and X-ray wavelengths (Urry et al. 1996; Hughes et al. 1998; Hovatta et al. 2008). In recent years a host galaxy has been observed for this object. Nilsson et al. (2003) found a diffuse host of $R = 18.9$ mag and $r_e = 1.0$ arcsec, with an upper limit of $M_R > -24.0$. The complex radio structure shown by the jet of this source was reported by Jorstad et al. (2001) and Jorstad et al. (2005). We found this source to display strong activity, resulting variable in both filters (R and V), in each night and when considering two consecutive nights. With the magnitudes given by Fiorucci & Tosti (1996) and González-Pérez et al. (2001), we obtained mean standard estimates of 14.93 ± 0.01 in V and 14.47 ± 0.01 in R the first night, and 14.91 ± 0.01 in V, 14.44 ± 0.01 in R the second night. Fan & Lin (2000) propose a periodic light curve for PKS 0851+202, with a period of 12 years. Our results are in agreement with the magnitudes expected for this periodic variability and with the values observed by Bach et al. (2007).

PKS 1253−055: (also known as 3C 279), at a redshift of $z = 0.538$, was the first blazar detected at γ-rays by the *EGRET* telescope (Hartman et al. 1992), as well as the first superluminal blazar ever detected (Whitney et al. 1971). It is very well known for its variability at every wavelength and also for its γ-ray flares (see Grandi et al. 1996; Wehrle et al. 2001; Böttcher et al. 2007; Giuliani et al. 2009). It seems that some periods of extreme variability could be present in this source, for example, the optical outburst detected during 2001–2002 reported by Kartaltepe & Balonek (2007). Andruchow et al. (2003) found strong microvariability in both optical polarization degree and its position angle, and consequently proposed a jet rotation model to explain the behaviour of the position angle. On the other hand, Nilsson et al. (2009) resolved the host galaxy, reporting an apparent magnitude $m = 18.4 \pm 0.3$ mag in the I band, an effective radius $r_{\rm eff} = 2.7 \pm 1.1$ arcsec, and a luminosity $M_R = -23.8$ mag.

As 3C 279 seems to usually undergo periods of extreme variability in one band together with extremely low variability in another band (see, e.g. Collmar et al. 2010); theories that describe its SED should also consider an anti-correlation in variability states at different wavelengths.

On February 23, 2006, this object was detected by MAGIC at very high energies (VHE), in the TeV range (MAGIC Collaboration 2008). It is interesting to note that 3C 279 is one of the objects with the highest well-determined redshift detected so far at VHE. Observations covering a span of four months beginning in December 2005, reported by Böttcher et al. (2007) and Böttcher & Principe (2009), show that 3C 279 was in a high-brightness state around the date of the γ flare, after which its flux began to decrease at all optical wavelengths. Our observations started less than a month after the end of that campaign. Using the field star magnitudes published by González-Pérez et al. (2001), we obtained mean standard magnitudes of $V = 15.2 \pm 0.03$ and $R = 14.7 \pm 0.02$ mag ($\langle V - R \rangle \simeq 0.5$).

Böttcher et al. (2007) report a strong flux decrease ($\Delta V/\Delta t \approx 0.15$ and $\Delta R/\Delta t \approx 0.10$ mag per day) at the end of the 2005–2006 WEBT[2] campaign on 3C 279.

Our results show that the blazar continued its decreasing flux trend, although either with a smaller slope, or the flux stabilised sometime before the start of our observations. We found some low amplitude activity in both bands during the first night, but no further significant intranight variability. However, we found strong internight variability in both bands.

PKS 1510−089: at a redshift $z = 0.36 \pm 0.002$ (Thompson et al. 1990), is classified as a highly polarized FSRQ (Véron-Cetty & Véron 2001; D'Ammando et al. 2009). Its emission spans from radio wavelengths to gamma-rays, including optical and X-ray bands (Kataoka et al. 2008; Cusumano et al. 2010). This quasar has an extensive history of long and short-term variability at optical bands (see, for example, Liller & Liller 1975; Pica et al. 1988; Villata et al. 1997; Romero et al. 2002; Cellone et al. 2007), with continuous changes in brightness over long periods of time. Moreover, optical polarization has been detected with variability both in P and in position angle θ (Andruchow et al. 2005), as well as a rapid variation in γ-rays (D'Ammando et al. 2009). Simultaneously with this γ-ray flare, these authors also found intense variability at optical and radio wavelengths. Its jet is detected primarily in radio, with superluminal motion (Homan et al. 2001), and also in X-rays (Sambruna et al. 2004) and at infrared wavelengths (Rantakyro et al. 1998), and is described as a rather extended, diffuse, and bended jet (Jorstad et al. 2001). Although there was no detectable activity during the two nights we followed this object, and no internight variability in the R band, we found clear internight variability in the V band. Again, derived from

[2] The Whole Earth Blazar Telescope (http://www.oato.inaf.it/blazars/webt/).

the magnitudes in González-Pérez et al. (2001), we found mean standard magnitudes of 16.79 ± 0.01 in V, 16.33 ± 0.01 in R the first night, 16.73 ± 0.02 in V and 16.26 ± 0.01 in R the second night.

PKS 1749+096: is a BL-Lac object with a redshift $z = 0.32$ according to Stickel et al. (1988) and White et al. (1988). Its radio jet was originally detected by Lobanov et al. (2000). This source presents a history of radio flaring, possibly with a long-term period (Hovatta et al. 2008; Nieppola et al. 2009). Flux variability was also detected at optical (Stickel et al. 1993) and γ-ray frequencies (Abdo et al. 2010a). The optical and infrared polarizations also show variability (Brindle et al. 1986). We found small amplitude activity for this object during one of the nights in the V band. However, at internight scales, this source showed the largest amplitude variability for the whole sample, reaching a change in its differential magnitude of ~0.7 mag. In standard magnitudes, taking mean values and using the magnitudes given by Fiorucci et al. (1998), this detected variation resulted in a decrease in magnitude from 17.94 ± 0.04 mag in V and 17.10 ± 0.05 mag in R the first night to 17.23 ± 0.04 in V and 16.57 ± 0.04 in R the second night. According to the light curve given in Fan & Lin (2000), these values correspond to a minimum of activity.

PKS 2230+114: (also known as CTA 102) is a blazar at $z = 1.037$. Multi-wavelength studies have detected correlated variability, mostly with flares from radio to X-rays, including optical and near IR bands (Bach et al. 2007; Osterman Meyer et al. 2009; Fromm et al. 2011). CTA 102 also shows a jet with superluminal motions of up to 21 c, derived from VLBI observations (see, Jorstad et al. 2001; Rantakyrö et al. 2003; Jorstad et al. 2005). Its history of optical variability can be tracked back to 1973 (Pica et al. 1988), with sporadic detections afterwards (see, for example, Wilkes et al. 1994; Ghosh et al. 2000; Véron-Cetty & Véron 2001; Romero et al. 2002). We report here a clear internight variability in both R and V bands. We also detected one night (over four) with activity, in the V band.

PKS 2251+158: (also known as 3C 454.3) with $z = 0.860$, is one of the most active blazars at high energies (Hartman et al. 1992); during 2005 it underwent a major flaring in almost all energy bands (Giommi et al. 2006). During 2007, a multiwavelength study was carried out by several observatories from radio to γ-rays. In December 12, the flux increased ~1.1 mag in 1.5 h, followed by a decrease of ~1.2 mag in ~1 h at optical wavelengths (Raiteri et al. 2008), being one of the fastest variations ever detected in blazars. A new SED has been determined using *AGILE*/Swift data (Vercellone et al. 2008). Another outburst was detected in 2009, at optical, X-ray and gamma frequencies. This flare was studied by Striani et al. (2010), and its polarization was studied by Sasada et al. (2012); these authors report two distinct rotation events. Because of its frequent outbursts and extreme variability, this object is usually used as an example when studying the validity of the SP classification (Gopal-Krishna et al. 2011; Ghisellini et al. 2011). We report a strong internight variability in the R and V bands. Furthermore, we found microvariability in the R band within one out of three nights we followed this blazar. Taking mean values and using the magnitudes published in González-Pérez et al. (2001) and in Fiorucci et al. (1998), we found mean standard magnitudes of 16.37 ± 0.09 in V, 16.06 ± 0.09 in R (first night), 16.3 ± 0.09 in V, 15.99 ± 0.09 in R (second night), and 16.2 ± 0.09 in V, 15.88 ± 0.09 in R (third night). These values are in agreement with those given in Raiteri et al. (2007), as with the general trend of increasing magnitudes.

The variability results are summarised in Table 2. Column 1 gives the object name with the date, while the following columns give, respectively for V and R: the observational error, σ, obtained from the standard deviation of the control−comparison differential light-curve for each filter; the variability results; the confidence parameter (F); the gamma corrective factor (Γ); the number of points in the light curves; and the corresponding critical value, F' for $n = N - 1$ degrees of freedom, assuming a 99% confidence level. As can be seen, from a total of 60 light curves (each night and all the nights together for each object), 35% resulted variable at the 99% confidence level. If we relax the confidence level to a 95%, this percentage increases up to 47%. In Fig. 1 we show the differential light curves for PKS 1253−055, PKS 1749+096, PKS 2230+114, and PKS 2251+158, as an example for the whole campaign; $m_{\rm BL}$, $m_{\rm c}$, $m_{\rm k}$ are the instrumental magnitudes for the blazar, the comparison star and the control star, respectively. Observations in the R band are represented in red, while observations in the V band are shown in green.

As a check, we re-calculated the variability state of each light curve after exchanging the stars, using the comparison as a control star and vice versa. The results did not change, except for four light curves which changed their variability state. This is an indication that in most cases we were able to choose well behaved stars as comparison and control. Another indirect evidence of this is the fact that $\Gamma \approx 1$ in most cases. In general, σ values were below 0.02 mag with the exception of PKS 0048−090, with $\sigma = 0.04$.

4. Discussion

Internight variability was detected in most of our sample. In particular, results for PKS 1749+096, PKS 1253−055, PKS 2230+114, and PKS 2251+158 show the largest amplitudes. The most notable variation was detected in PKS 1749+096, resulting in an amplitude $\Delta m \sim 0.7$ mag along almost five days.

According to the F test results, the largest short-scale variations were detected for PKS 2230+114 and PKS 2251+158, one in each band, with an amplitude of 0.05 mag in the first case and of 0.02 mag in the second. However, given that the other band shows no signs of variability and that there are few data points, we suggest taking the F-test results with caution (see Zibecchi et al. in prep., for a critical evaluation of the F–test and other statistics as variability indicators).

Different models have been proposed to explain (micro)variability in blazars. In particular, we want to test whether our variability results can be explained by a swinging jet scenario (e.g. Gopal-Krishna & Wiita 1992; Romero et al. 1995; Bachev et al. 2012, and references therein). This means that variability is a consequence of slight deviations of the direction of motion of the emitting particle populations along the relativistic jet, which is close to the line of sight, thus leading to a change in the associated Doppler factor. This, in turn, produces a significant change in the observed magnitude. This is a consequence of relativistic effects in the jet plasma playing an important role by magnifying any perturbation. Since PKS 1749+096 presented the strongest variation measured during our campaign, we show and discuss the application of this model to our results for this specific object. We find a similar result for the remaining objects in our sample.

Table 2. Statistical results for the differential light curves.

UT Date [m/d/y]	σ (mag) V	σ (mag) R	Variable? V	Variable? R	F V	F R	Γ V	Γ R	N V	N R	$F^t_{99\%}$ V	$F^t_{99\%}$ R
PKS 0048-090												
09/26/06	0.050	0.029	NV	NV	2.36	1.49	0.74	0.89	18	19	3.24	3.13
09/27/06	0.030	0.046	NV	NV	2.42	1.29	0.73	0.88	27	31	2.55	2.39
All nights	0.040	0.040	NV	V	1.91	2.13	0.73	0.89	43	49	2.08	1.98
PKS 0754+100												
03/24/07	0.024	0.024	NV	NV	4.35	1.89	1.04	0.99	11	10	4.85	5.35
[HB89] 0827+243												
03/20/07	0.022	0.010	NV	NV	1.12	5.47	1.18	1.21	05	04	15.97	29.44
03/22/07	0.013	0.009	NV	NV	1.24	1.32	1.12	1.14	12	16	4.46	3.52
03/23/07	0.016	0.013	NV	NV	1.45	3.16	1.08	1.12	12	14	4.46	3.90
All nights	0.016	0.013	V	V	6.07	6.86	1.10	1.13	29	33	2.46	2.32
PKS 0851+202												
03/28/06	0.006	0.007	V	V	4.77	5.80	0.98	0.93	31	30	2.39	2.42
03/29/06	0.007	0.007	NV	V	2.73	5.12	0.98	0.91	13	12	4.16	4.46
All nights	0.007	0.007	V	V	6.27	8.58	0.99	0.98	44	42	2.06	2.09
PKS 1253-055												
04/25/06	0.009	0.008	V	V	6.59	7.65	0.67	0.81	15	16	3.70	3.52
04/26/06	0.010	0.008	NV	NV	4.18	2.14	0.68	0.82	10	11	5.35	4.85
04/29/06	0.007	0.009	NV	NV	2.44	2.03	0.66	0.80	12	10	4.46	5.35
All nights	0.008	0.010	V	V	63.05	42.49	0.67	0.81	37	37	2.21	2.21
PKS 1510-089												
06/03/06	0.009	0.025	NV	NV	3.27	1.04	1.02	1.03	08	06	7.00	10.97
06/04/06	0.007	0.018	NV	NV	6.22	1.23	0.97	0.98	08	05	7.00	15.97
All nights	0.009	0.021	V	NV	14.95	3.18	0.97	1.02	13	10	4.16	5.35
PKS 1749+096												
04/26/06	0.018	0.007	NV	NV	11.11	2.45	1.00	0.99	05	04	15.97	29.44
04/30/06	0.006	0.007	V	NV	8.56	4.55	0.68	0.67	07	06	8.47	10.97
All nights	0.011	0.009	V	V	1902.39	1411.39	0.73	0.69	12	10	4.46	5.35
PKS 2230+114												
08/26/06	0.013	0.007	NV	NV	3.70	2.28	1.00	1.08	06	06	10.97	10.97
08/27/06	0.008	0.008	NV	NV	4.95	4.31	0.98	1.07	06	04	10.97	29.44
08/28/06	0.003	0.006	V	NV	46.01	3.23	0.97	1.04	08	05	7.00	16.00
08/30/06	0.010	0.007	NV	NV	1.63	1.97	0.91	0.95	09	06	6.03	10.97
All nights	0.011	0.009	V	V	29.50	62.29	0.95	1.02	29	21	2.46	2.94
PKS 2251+158												
06/22/06	0.015	0.002	NV	V	3.57	37.55	0.79	0.94	07	04	8.47	29.44
06/23/06	0.019	0.008	NV	NV	2.01	3.03	0.74	0.89	09	08	6.03	7.00
06/24/06	0.006	0.011	NV	NV	2.81	1.54	0.71	0.83	10	09	5.35	6.03
All nights	0.011	0.009	V	V	44.68	65.45	0.76	0.89	26	21	2.60	2.94

Following Nesci et al. (2002) the expected temporal change in the observed magnitude of the blazar is related to the temporal change in the jet viewing angle $d\theta/dt_{\rm jet}$ by the expression

$$dm/dt_{\rm obs} = 1.086\,(3+\alpha)\,\beta\,\gamma\,\delta^2\,\sin(\theta)\,(1+z)^{-1}\,(d\theta/dt_{\rm jet}), \quad (1)$$

where α is the spectral index ($F_\nu \propto \nu^{-\alpha}$), β the bulk plasma velocity in the jet in terms of the speed of light, γ is the Lorentz factor, δ is the Doppler factor, and we have included the redshift correction factor. We note that the time interval on the left hand corresponds to the observer's frame, while that on the right hand is in the jet's reference frame.

To calculate $d\theta/dt_{\rm jet}$, we used the parameters reported by Hovatta et al. (2009): a Lorentz factor $\gamma = 7.5$, a Doppler factor $\delta = 12.0$, and a jet angle to the line of sight $\theta = 3.8°$, while we adopted the optical spectral index $\alpha_{VR} = 2.85$ from Ojha et al. (2009).

From the data here reported, we estimated a mean value of $dm/dt_{\rm obs} = -0.16$ mag per day. Calculating the (intrinsic) velocity, $\beta = \sqrt{1-1/\gamma^2} = 0.991$, we then use Eq. (1) to obtain $d\theta/dt_{\rm jet} = -4.69 \times 10^{-4}$ radians per day, i.e., $d\theta/dt_{\rm jet} = -1.6$ arcmin per day.

This procedure was also applied to another blazar not included in this campaign, AO 0235+164 ($z = 0.94$). This object showed a very strong hour-scale variability reported by Romero et al. (2000) and Cellone et al. (2007). In this case, we used the observational data from the night with the highest amplitude ($dm/dt_{\rm obs} = 2.67$ mag per day), and another night with a lower amplitude ($dm/dt_{\rm obs} = 1.96$ mag per day). The relativistic parameters for this blazar are: $\gamma = 12.1$, $\delta = 24.0$, $\theta = 0.4°$ (Hovatta et al. 2009), and $\alpha_{VR} = 2.15$, from Cellone et al. (2007). The results were $d\theta/dt_{\rm jet} = 1.91 \times 10^{-2}$ rad per day, i.e., $d\theta/dt_{\rm jet} = 65.7$ arcmin per day in the first, highly variable night chosen, and $d\theta/dt_{\rm jet} = 1.40 \times 10^{-2}$ rad per day, i.e., $d\theta/dt_{\rm jet} = 48.2$ arcmin per day, in the second case.

However, we note that given a near zero value of θ, such as that reported by Hovatta et al. (2009), the relevant equations

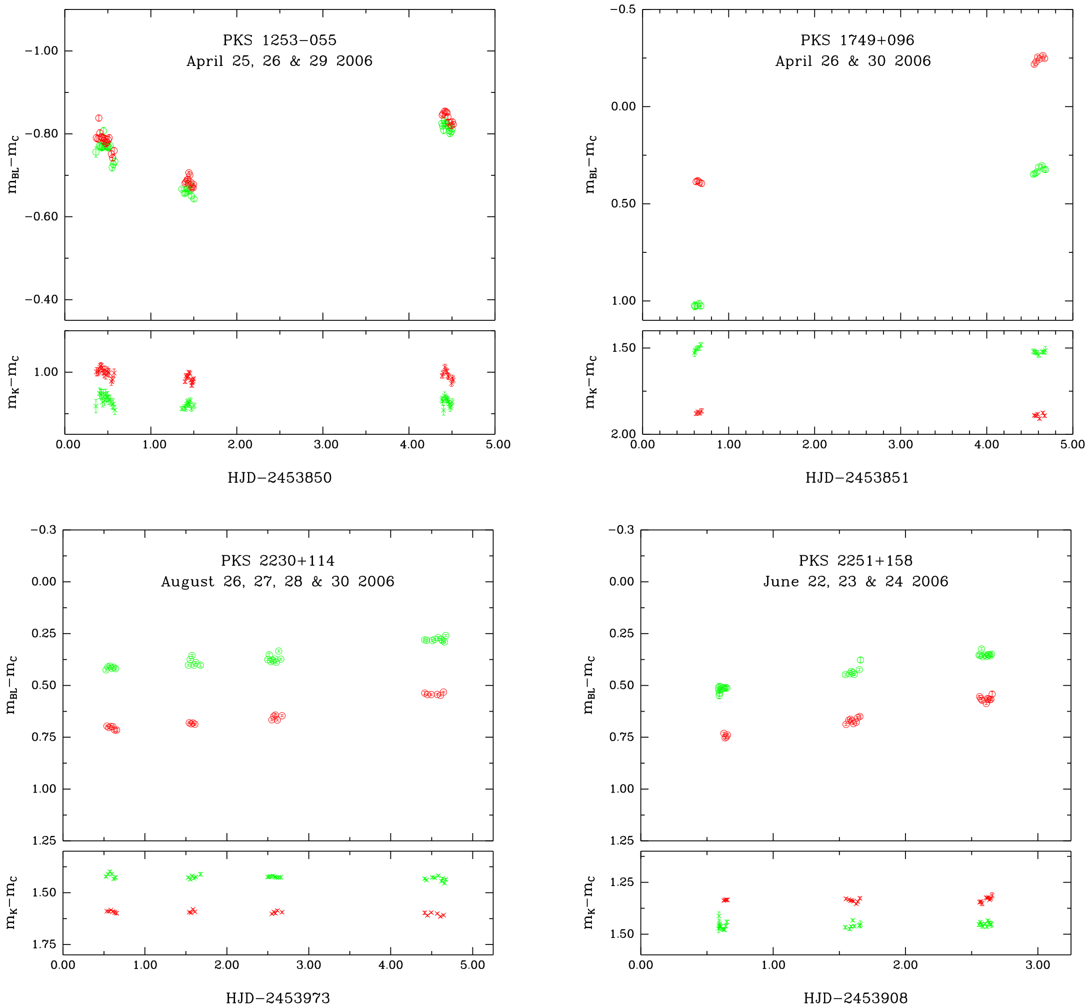

Fig. 1. Examples of differential light curves from our sample. $m_{\rm BL}$, $m_{\rm c}$, $m_{\rm k}$ are the instrumental magnitudes for the blazar, the comparison star and the control star, respectively. *From top to bottom, left to right*: PKS 1253−055, PKS 1749+096, PKS 2230+114, and PKS 2251+158. Data for the *V* filter are shown in green, data for the *R* filter in red. *Upper panels*: object − comparison star differential light curves; *lower panels*: control star − comparison star differential light curves. Note that both panels are shown with the same scale for a given blazar.

rapidly tend to a strongly non-linear behaviour. Thus, we also used the set of parameters inferred from a more realistic SED modelling that was given by Ackermann et al. (2012): $\gamma = \delta = 20$, $\theta = 2.3°$. These resulted in $d\theta/dt_{\rm jet} = 2.89 \times 10^{-3}$ radians per day, i.e., $d\theta/dt_{\rm jet} = 9.9$ arcmin per day in the first night, and $d\theta/dt_{\rm jet} = 2.12 \times 10^{-3}$ radians per day, i.e., $d\theta/dt_{\rm jet} = 7.3$ arcmin per day in the second night.

From these results, it seems that it is possible to understand the origin for the internight variability detected in PKS 1749+096 as a slight change in the direction of the jet-emitting region with respect to the line of sight. On the other hand, for variations as high as those detected in AO 0235+164, faster changes of the viewing angle are required (from a few arcmin up to around a degree, depending on the adopted parameters) to explain the variability reported as that expected as being only due to a swinging jet.

So, a considerable part of the short-term variations usually detected in blazars could be produced by jet wiggles, mainly those sufficiently low to be associated with a wiggle of a few arcseconds or even arcminutes. However, it is more difficult to explain degree-scale changes in the angle of the emitting region in less than a day, as this model would imply for AO 0235+164, especially if a small value of the viewing angle is adopted. On the other hand, AO 0235+164 did present strong changes in its colour index (Romero et al. 2000), thus further disfavouring the wiggling-jet scenario in its case.

To evaluate the rates of change in the viewing angle, we have so far considered time intervals in the jet reference-frame. Thus, our conclusions should be valid for small variations in the direction of the emitting region, propagating down the relativistic jet (e.g. Andruchow et al. 2003). These changes can be the effect of a twisted helical magnetic field component in the inner jet. A helical field is expected beyond the Alfvén radius in most models of jet launching (e.g. Spruit 2010). If we were dealing, instead, with large-scale fluctuations of the angle subtended by the jet itself (such as in a precessing-jet scenario), we should refer the timescales to the galaxy's rest frame, thus dropping one δ factor from Eq. (1). While, in this frame, rates of change in the viewing angle for AO 0235+164 become implausibly high, for PKS 1749+096 we obtain $d\theta/dt_{\rm gal} = -19.3$ arcmin per hour, ruling out any large-scale phenomenon, but still probably allowing for small bendings at a sub-parsec scale (Gopal-Krishna & Wiita 1992).

5. Conclusions

We presented optical differential photometry data for a sample of nine blazars. Only four of them show statistically significant variability: PKS 1253−055, PKS 1749+096, PKS 2230+114 and PKS 2251+158. In the particular case of PKS 1253−055, we found that it was at a flux state consistent with the brightness decreasing trend reported by Böttcher & Principe (2009). Moreover, lower than expected minimum brightness states were detected for PKS 0754+100 and PKS 1749+096.

On the other hand, the variations detected in PKS 1749+096 are quite remarkable: ~0.7 mag in four days, resulting in a very high variability parameter in both bands ($F_V = 1902.39$ and $F_R = 1411.39$).

To explain these variability results, we applied the geometric model as in Nesci et al. (2002), which assumes that the variation in brightness responds to a slight change in the direction of the emitting region with respect to the line of sight. This change in direction, though small, can produce a noticeable change in brightness owing to a relativistic Doppler effect. Using the data given by Hovatta et al. (2009), we found this model can explain our results with jet wiggles of just ∼10 arcmin per day.

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