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# Optical quasi-periodic oscillation and color behavior of blazar PKS 2155–304 *

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**Abstract** PKS 2155−304 is a well studied BL Lac object in the southern sky. The historical optical data during different periods have been collected and compiled. Light curves spanning 35 yr have been constructed. The $R$-band light curve has been analyzed by means of three methods: the epoch folding method, the Jurkevich method and the discrete correlation function method. It is derived that there is an evident periodic component of 317 d (i.e. 0.87 yr) superposed on a long-term trend with large-amplitude variation in the light curve. The variability of this source is accompanied by a slight color variation, and the brightness and color index are correlated with each other. On a long-term time scale, PKS 2155−304 exhibits a tendency of bluer-when-brighter, which means the spectrum becomes flatter when the source brightens.

**Key words:** BL Lacertae objects: general — BL Lacertae objects: individual (PKS 2155−304) — galaxies: active — method: statistical

## 1 INTRODUCTION

Blazars are the most extreme class of active galactic nuclei (AGNs) exhibiting very violent high energy phenomena. The subset of blazars can be grouped into two very different categories: BL Lacertae-type objects (BL Lacs) and flat spectrum radio quasars (FSRQs). They have been observed at all wavelengths from radio through very-high energy (VHE) gamma-rays, and exhibit rapid variability at all wavelengths on various time scales, from years and a few months to even shorter than an hour in some cases. The emission from blazars is thought to be highly beamed through a relativistic jet. Study of flux variation is considered to be a powerful tool for understanding the structure and emission mechanism of AGNs. Periodical variabilities on a wide range of time scales have been reported by some investigations, e.g. Fan & Lin (2000); Xie et al. (2008); King et al. (2013). The most notable case is that of OJ 287, which has an over 120-year-long light curve and a convincing 11–12 yr periodicity (Kidger et al. 1992; Valtonen et al. 2006). However, there is still some debate about whether blazar variability is periodic.

Multi-wavelength observations of blazars have been performed for many years. They can have the general shape of an energy spectrum (i.e. flux versus frequency), which approximately follows a power law. The energy spectrum can provide insight into the nature of the emission process. The low energy component between radio and optical, and even to X-ray frequencies, is mainly attributed

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to synchrotron emission from non-thermal electrons in a relativistic jet. The high energy emission between X-rays and TeV $\gamma$-rays may be due either to the Compton up-scattering of low energy radiation by the synchrotron-emitting electrons (Böttcher 2007) or to hadronic processes initiated by relativistic protons co-accelerated with the electrons (Mücke et al. 2003). Measurements of blazar spectral variability are an important tool in constraining physical models. In the optical domain, the color index is often used to represent a spectral index, and its variation usually accompanies flux variabilities with different behaviors, such as a "bluer when brighter" (BWB) or "redder when brighter" (RWB) trend.

The high-frequency peaked BL Lac PKS 2155−304 with a redshift of $z = 0.116$ is one of the brightest BL Lacs in the X-ray and extreme ultraviolet bands (Giommi et al. 1998). It was classified as a TeV blazar by the detection of VHE gamma rays by the Durham Mark 6 Gamma Ray telescope (Chadwick et al. 1999), and then was confirmed by the H.E.S.S. collaboration with a high significance of $45\sigma$ at energies greater than 160 GeV (Aharonian et al. 2005). This source has been observed on diverse time scales over a wide range of frequencies from radio to VHE gamma-rays, and has shown rapid and strong variability (Dominici et al. 2006; Dolcini et al. 2007; Aharonian et al. 2007; Abramowski et al. 2010; Kastendieck et al. 2011; Abramowski et al. 2012; Aleksić et al. 2012; Barkov et al. 2012). The long-term optical variability of PKS 2155−304 has been studied by some authors (Fan & Lin 2000; Zhang & Xie 1996; Kastendieck et al. 2011). Fan & Lin (2000) investigated the periodic variations in the long-term optical light curves, and found two possible periodicities of 3.7 yr and 7.1 yr. The short-term color varies in complicated ways, and shows different behaviors at different epoches, e.g. Carini & Miller (1992); Pesce et al. (1997); Xie et al. (1999); Dolcini et al. (2007); Bonning et al. (2012).

This research aims to investigate the periodic variations and long-term color behavior with the historical optical light curves of PKS 2155−304. This paper is organized as follows: In Section 2, the optical data are compiled and the historical light curve is constructed; In Section 3, the technique used for searching periodicity is described and the periodic variations are investigated; In Section 4, the long-term color behavior is studied; and then the discussion and conclusions are given in Section 5.

## 2 OPTICAL DATA

All available historical archival data of PKS 2155−304 have been collected from the following literature: Griffiths et al. (1979), Miller & McAlister (1983), Brindle et al. (1986), Hamuy & Maza (1987), Treves et al. (1989), Mead et al. (1990), Smith & Sitko (1991), Carini & Miller (1992), Smith et al. (1992), Jannuzi et al. (1993), Urry et al. (1993), Courvoisier et al. (1995), Xie et al. (1996), Heidt et al. (1997), Pesce et al. (1997), Bai et al. (1998), Xie et al. (1999), Bertone et al. (2000), Tommasi et al. (2001), Xie et al. (2001), Gupta et al. (2002), Dolcini et al. (2007), Osterman (2007) and Kastendieck et al. (2011). Up-to-date SMART optical data (Bonning et al. 2012) have also been collected. In total, 179, 759, 1382, 8674 and 590 data points in the $U$, $B$, $V$, $R$ and $I$ bands have been compiled, respectively. The observations cover the time duration from 1979 to 2013, and the time interval is about 35 yr. The mean magnitudes in the $U$, $B$, $V$, $R$ and $I$ bands are 12.52 $\pm$ 0.39, 13.54 $\pm$ 0.46, 13.04 $\pm$ 0.42, 12.78 $\pm$ 0.40 and 12.23 $\pm$ 0.28, respectively. The source shows violent activity. The amplitudes of the observed variability are $\Delta U$ = 1.50 mag, $\Delta B$ = 2.23 mag, $\Delta V$ = 2.57 mag, $\Delta R$ = 2.40 mag and $\Delta I$ = 2.34 mag, respectively. The variations in different passbands show a similar trend. The light curves are well correlated with each other. The $R$ band light curves are displayed in two panels of Figure 1 in order to exhibit more details.

It is clear that there are more intensive observations after MJD 52500. In Figure 1, one can see that the source exhibited oscillations with $\sim$0.7 mag throughout the duration of MJD 52500–54100, superposed on a general and slowly brightening trend with a total magnitude of $\sim$2. Then the source began to slowly fade till MJD 55200 by a total of $\sim$2 mag, accompanied by some small flickering of

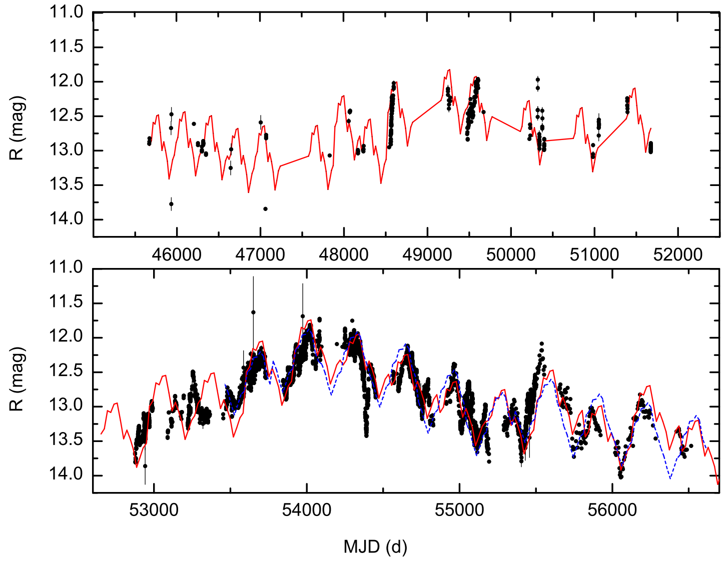


**Fig. 1** The historical optical $R$-band light curve of PKS 2155−304. The solid line and the dashed line are the folded light curves with a 317-day period using all the data and those after MJD 53400, respectively.

∼0.7 mag. Subsequently, a large, sharp outburst appeared from MJD 55200 to 55300, and after that the brightness of the source decreased with some small amplitude fluctuations. It is obvious that the short term variations are superposed on the large, long-term variations.

## 3 PERIODICITY ANALYSIS

To search for periodic variations in the long-term light curve, the epoch-folding technique has been employed. This technique was described by Leahy et al. (1983) and extended by Davies (1990, 1991). It is less affected by harmonics, and more effective for nonsinusoidal modulations than the Fourier transform technique, which is most sensitive to a periodic component with a sinusoidal shape. This method is also well suited for sparse and unevenly sampled data sets. The $N$ data points of a time series are folded on a trial period and binned by phase. For the $i$th of $M$ phase bins, the mean $x_i$ and sample variance $\sigma_i^2$ are computed, as is the overall mean, $\langle x \rangle$. Then the $Q^2$ statistic is computed,

$$Q^2 = \sum_{i=1}^{M} \frac{(x_i - \langle x \rangle)^2}{\sigma_i^2}\,, \tag{1}$$

which is distributed similarly to the $\chi^2$ statistic. Davies (1990) pointed out that the test statistic is only valid for large sample sizes. He proposed an improved method for detecting periodicities based on the $L$-statistic, giving a greater sensitivity when the number of data points is limited. The $L$-statistic is defined as,

$$L = \frac{(N - M)Q^2}{(M - 1)(N - 1) - Q^2}\,, \tag{2}$$

which obeys an $F$ distribution with $M - 1$ and $N - 1$ degrees of freedom. The large value of $L$ means that the corresponding trial period may be a true period in the light curve. It can be tested by calculating the false alarm probability (the confidence with which one can reject the null hypothesis, i.e. no periodic component).

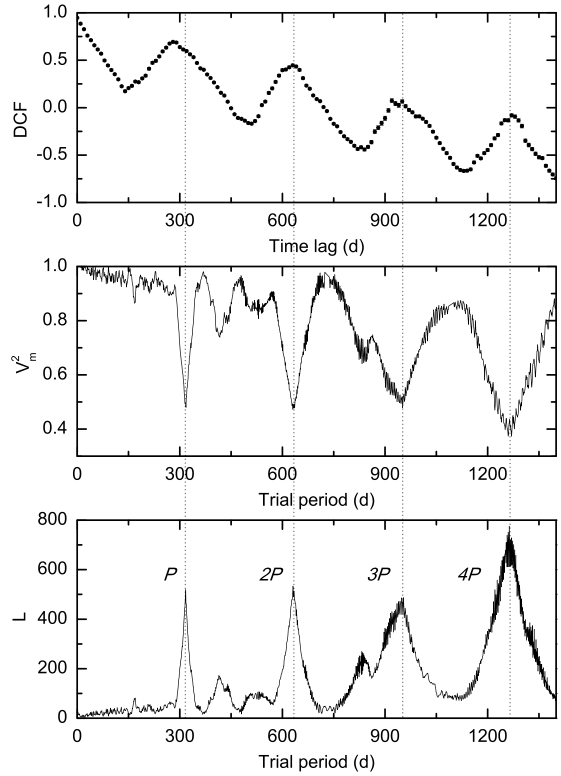


**Fig. 2** *Top*: DCF as a function of time delay, $\tau$; *middle*: $V_m^2$ as a function of trial periods; *bottom*: $L$-statistic as a function of trial periods for the optical $R$-band light curve. The vertical dotted lines are drawn to guide the eyes.

The $R$-band observations are used to search for periodicity because there are more data available in the $R$-band than others. For each trial period, the data are folded into 20 phase bins, and then values of the $L$-statistic are calculated for a range of trial periods from 1 d to 1400 d in steps of 1 d. The $L$ is plotted as a function of the trial period in the lower panel of Figure 2. The strong peak at 317±12 d (i.e. 0.87 yr) is clearly visible (the error corresponds to half of the full width at half maximum (FWHM)), which means the periodicity $P = 317$ d. The integer multiples of this period are also strongly detected at 631, 954 and 1263 d, which correspond to $2P$, $3P$ and $4P$, respectively.

To confirm the periodicity of 317 d, the Jurkevich method (Jurkevich 1971) and the discrete correlation function (DCF) method (Edelson & Krolik 1988) are also applied to search for periodic signals in the light curve. The Jurkevich method adopted the folding technique, and it is based on the expected mean square deviation. The light curve is folded according to test periods and then all data are grouped into 20 phase bins. The sum variance $V_m^2 = \sum_{i=1}^{20} V_i^2$ of all phases are computed and shown in the middle panel of Figure 2. The minimum of $V_m^2$ suggests that the trial period may be true. Obvious dips are located at 318, 630, 951 and 1270 d, which represent the principal period, $P$, and its integer multiples. They are very consistent with those detected by the epoch-folding method.

The DCF method is a useful tool for not only investigating correlations between different light curves but also periodic components in a light curve. For two time series, $a$ and $b$, DCF($\tau$) is defined as the mean of $(a_i - \overline{a})(b_i - \overline{b})/\sigma_a \sigma_b$ for all pairs with $\tau - \Delta\tau/2 \leq t_j - t_i < \tau + \Delta\tau/2$. When $a = b$, the position of the DCF peak gives information about the periodicity in the light curve. The

DCF for the $R$ band is computed and plotted as a function of $\tau$ (the upper panel of Fig. 2). The peak at $P = 280$ d can obviously be seen. It is slightly different from the period of 317 d derived by the epoch-folding technique. The subsequent peaks appear at 630, 920 and 1270 d, which are near the corresponding values detected by the two other methods. The last two peaks are very low, which means that they are modulated by a longer-term trend in variation.

## 4 COLOR BEHAVIOR

The behavior of colors provides a clue for understanding the mechanism of time variations in blazars. Since blazars vary rapidly, the color index should be ideally evaluated using simultaneous observations in different bands. However, there are few exactly simultaneous data. The color indices with quasi-simultaneous data have been calculated. The mean values of color indices are listed in Column (2) of Table 1. The correlation between color and magnitude is investigated.

**Table 1** The Results of Linear Regression Analysis between Color Index and Magnitude

| Color (1) | Mean (2) | Slope (3) | $r$ (4) | Prob. (5) | $N$ (6) |
|---|---|---|---|---|---|
| $B-R$ | $0.67 \pm 0.09$ | $0.066 \pm 0.008$ | 0.33 | $< 10^{-15}$ | 635 |
| $B-V$ | $0.32 \pm 0.08$ | $0.056 \pm 0.007$ | 0.30 | $3.56\times10^{-15}$ | 678 |
| $V-R$ | $0.33 \pm 0.06$ | $0.029 \pm 0.004$ | 0.23 | $2.51\times10^{-11}$ | 837 |

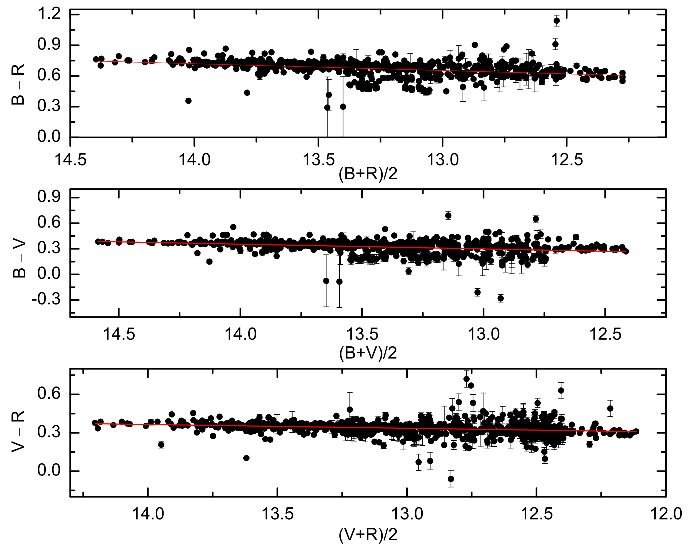


**Fig. 3** Color indices versus magnitude of PKS 2155−304. The solid lines represent the best linear fitting.

Figure 3 displays the color indices versus magnitudes. Linear regression analysis is performed, and the results are listed in Table 1. Columns (3) to (6) list the slope, the correlation coefficient $r$, chance probability Prob. and number $N$, respectively.

According to the results listed in Table 1, one can see that data points in Figure 3 are fitted well by straight lines. The small correlation coefficients suggest that there is a weak correlation between color index and magnitude. There is a general indication that the object becomes bluer when it is brighter.

## 5 DISCUSSION AND CONCLUSIONS

Three methods are applied to search for periodic components in the $R$-band light curve. The results are very consistent with each other. A 317-day (i.e. 0.87 yr) periodic oscillation can be clearly seen. For the periodicity of 317 d, the corresponding $L$ is 519. This means that the chance probability of obtaining such a large value is extremely small. According to the $F$-distribution, the chance probability for the null hypothesis is less than $10^{-20}$. So, 317 d is suggested to be a true periodicity. In addition, this value can be confirmed by the Jurkevich method. Kidger et al. (1992) provided a fraction $f = (1 - V_m^2)/V_m^2$ to assess the significance of the periodicity derived by the Jurkevich method. A value of $f \geq 0.5$ implies a strong periodicity in the light curve. In this analysis, $f = 1.2$ suggests that the 317-day periodicity is true.

In Figure 1, from MJD 53500 forwards, one can see five obvious peaks well separated by nearly 317 d intervals. The data show the average separation among these five peaks is 316 d which are spaced by 321, 314, 325 and 304 d, respectively. Going backwards and forwards from these five peaks, the periodicity seems to disappear. But after MJD 55500, the periodicity appears again with 328-day and 315-day intervals. Sometimes, the positions of the peaks are difficult to identify exactly. So, the folded light curve is calculated with a period of 317 d (Fig. 4), and superimposed on the light curve in Figure 1 (the general shape of the whole light curve is taken into consideration). One can see that, except for the peaks near MJD 53250 and MJD 55060, the folded light curves are very consistent with most of the peaks and the dips in the light curve, but nevertheless, the last three peaks seem to not be in the same periodic sequence as the previous ones. So, 317 d is not a strict and persistent periodicity in the light curve. The variations with time scale longer than 317 d can also be seen in Figure 1. This tells us that in the light curve there may be a longer periodic component, which is difficult to identify at present.

For PKS 2155−304, a 5-day roughly continuous light curve in November 1991 appeared to have a quasi-periodicity of 0.7 day (Urry et al. 1993). However, this periodicity was not confirmed by a more rigorous analysis, although more data covering the whole month of November 1991 were adopted (Edelson et al. 1995). Using the historical data from 1977 to 1994, Fan & Lin (2000)

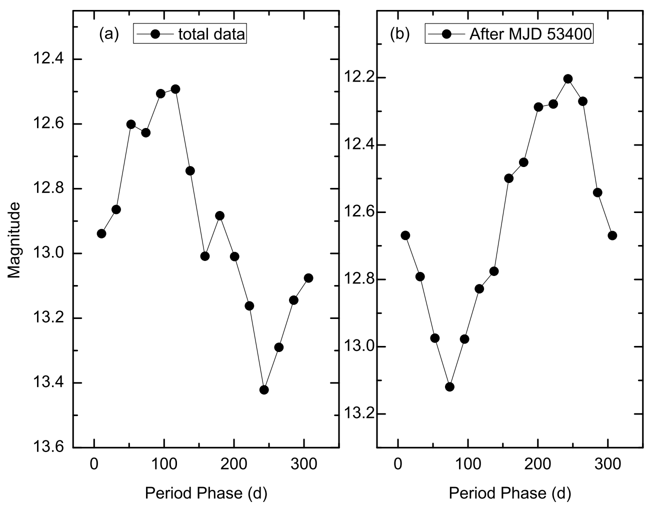


**Fig. 4** The folded light curves with a period of 317 d. (a) All the data are employed; (b) The data after MJD 53 400 are employed. The curves seem to follow the shape of a sinusoidal wave.

found two possible periodicities of 4.16 yr and 7.0 yr in the $V$ band light curve. The two possible periodicities are respectively 5 and 8 times the periodicity (0.87 yr) found in this work. They also pointed out hints of a period less than 4.0 yr which could not be confirmed at that time due to the limited size of the data sample. Kastendieck et al. (2011) characterized the optical behavior of PKS 2155−304 with a long-term light curve, however, they found no clear evidence for periodic behavior on any time scales.

Several models have been developed to explain the periodic variations, for example a supermassive binary black hole model (Valtaoja et al. 2000; Xie et al. 2002) and a helical jet model (see Rani et al. 2009 and references therein). The quasi-periodic variations seem to suggest that there is a supermassive binary black hole system in the center of a source. The periodic fading in brightness is caused by an eclipse that occurs in the system. In the case of PKS 2155−304, the emission is dominated by synchrotron emission and inverse Compton emission which both arise from relativistic jets. The quasi periodic variations are mostly caused by blobs propagating in a helical jet. The effect is similar to that of a jet whose direction changes. When the viewing angle is small, the source is brighter, and vice versa. In this case, one would expect to see a rather exact variability pattern for some periods until the blob vanishes, and then a repetition with a new blob. From Figure 1, the light curve seems to have a possible 5-peak stretch of almost periodic variations with a periodicity of 317 d, a break in the pattern, and then a 3-peak repetition of the 317-day periodicity, again followed by a break. These phenomena are very consistent with the expected behavior.

In general, there are five kinds of color behaviors:

(1) BWB in all the data sets. It is a well-observed feature in blazars, especially in BL Lac objects (Gu et al. 2006; Rani et al. 2010; Zhang et al. 2010; Ikejiri et al. 2011). This trend is generated by a variable component with a constant and relatively blue color and an underlying red component (Ikejiri et al. 2011);
(2) RWB in all the data sets. Most FSRQs follow this RWB tendency, which suggests the presence of a steady blue accretion disk component underlying the more variable jet emission (Rani et al. 2010; Bonning et al. 2012);
(3) cycles or loop-like pattern, e.g. S5 2007+777 and 3C 371 (Xilouris et al. 2006), S5 0716+714 (Wu et al. 2007), and OJ 287 (Bonning et al. 2012), which may be caused by different amplitudes or time delays in different spectral bands;
(4) RWB at the low state and BWB at the high state (RWB to BWB), e.g. AO 0235+164 (Bonning et al. 2012) and PKS 0537−441 (Zhang et al. 2013);
(5) stable when brighter (SWB) or no correlation with brightness in all the data sets (Ikejiri et al. 2011; Gu & Ai 2011).

Since the 1970s, the color of PKS 2155−304 has been investigated by several authors. The color behavior showed very different and complex tendencies on different time scales and during different periods. On short time scales of days to months, during October and December in 1990, PKS 2155−304 showed a tendency to be bluer when the object was brighter (BWB) (Smith & Sitko 1991), but the tendency was not observed in November 1990, and the optical spectral index remained relatively constant even though the object brightened by nearly one magnitude (SWB) (Smith et al. 1992). Observations during November 1991 showed a constant spectral slope in the $U - I$ domain (SWB) (Courvoisier et al. 1995). During the period in 1994, the average colors remained relatively constant, with no correlation in brightness (SWB) and a slight BWB (Pesce et al. 1997). During the campaign in 1995, there was clear evidence of hardening when the source became brighter (BWB) (Paltani et al. 1997). During August-October in 1996, the BWB trend was observed by Xie et al. (1999). From May to December in 2005, no apparent correlation between spectral index and brightness (SWB) was found by Dolcini et al. (2007), but the source exhibited a rather soft spectral shape during its high state (RWB).

On long time scales of years, this source became redder during 1979-1982 as it brightened (RWB) (Miller & McAlister 1983). From 1983 to 1985, it was found that the higher state was harder than the lower one (BWB) (Treves et al. 1989). Zhang & Xie (1996) collected the pre-1994 observations, and found no correlation between brightness and colors (SWB). Between 2001 and 2003, the optical colors showed a BWB phenomenon but opposite behavior in the infrared domain (Dominici et al. 2006). Ikejiri et al. (2011) found that this source exhibited a BWB trend during 2008 and 2010. In observations from 2008 to 2010, the overall trend over several years revealed no strong correlation between color and brightness (SWB) (Bonning et al. 2012). The data from April 2005 to June 2012 observed by the REM telescope showed that the color did not vary with brightness (SWB) (Sandrinelli et al. 2014).

It is clear that PKS 0537−441 exhibited BWB or SWB trends most of the time. In our color-magnitude analysis, the data covering 35 yr are used. On the longest time scale till now, the source shows a clear BWB trend which means the spectrum hardens when the source brightens. Rani et al. (2010) suggested that BWB and RWB can both be accommodated within shock-in-jet models.

In conclusion, the long-term possible periodic variations have been investigated, a 317-day (0.87 yr) periodic component in the light curve has been detected, and it is more convincing. On the whole, the source varies with a 0.87 yr periodicity superposed on a slower long-term trend. PKS 2155−304 shows complex color behavior on different time scales. This analysis suggests a clear BWB chromatism on a long-term time scale.

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## References

Abramowski, A., Acero, F., et al., H.E.S.S. Collaboration, 2010, A&A, 520, A83
Abramowski, A., Acero, F., et al., H.E.S.S. Collaboration, 2012, A&A, 539, A149
Aharonian, F., Akhperjanian, A. G., Aye, K.-M., et al. 2005, A&A, 430, 865
Aharonian, F., Akhperjanian, A. G., Bazer-Bachi, A. R., et al. 2007, ApJL, 664, L71
Aleksić, J., Alvarez, E. A., Antonelli, L. A., et al. 2012, A&A, 544, A75
Bai, J. M., Xie, G. Z., Li, K. H., Zhang, X., & Liu, W. W. 1998, A&AS, 132, 83
Barkov, M. V., Aharonian, F. A., Bogovalov, S. V., Kelner, S. R., & Khangulyan, D. 2012, ApJ, 749, 119
Bertone, E., Tagliaferri, G., Ghisellini, G., et al. 2000, A&A, 356, 1
Bonning, E., Urry, C. M., Bailyn, C., et al. 2012, ApJ, 756, 13
Böttcher, M. 2007, Ap&SS, 309, 95
Brindle, C., Hough, J. H., Bailey, J. A., Axon, D. J., & Hyland, A. R. 1986, MNRAS, 221, 739
Carini, M. T., & Miller, H. R. 1992, ApJ, 385, 146
Chadwick, P. M., Lyons, K., McComb, T. J. L., et al. 1999, ApJ, 513, 161
Courvoisier, T. J.-L., Blecha, A., Bouchet, P., et al. 1995, ApJ, 438, 108
Davies, S. R. 1990, MNRAS, 244, 93
Davies, S. R. 1991, MNRAS, 251, 64P
Dolcini, A., Farfanelli, F., Ciprini, S., et al. 2007, A&A, 469, 503
Dominici, T. P., Abraham, Z., & Galo, A. L. 2006, A&A, 460, 665
Edelson, R., Krolik, J., Madejski, G., et al. 1995, ApJ, 438, 120
Edelson, R. A., & Krolik, J. H. 1988, ApJ, 333, 646
Fan, J. H., & Lin, R. G. 2000, A&A, 355, 880
Giommi, P., Fiore, F., Guainazzi, M., et al. 1998, A&A, 333, L5
Griffiths, R. E., Briel, U., Chaisson, L., & Tapia, S. 1979, ApJ, 234, 810
Gu, M.-F., & Ai, Y. L. 2011, A&A, 528, A95
Gu, M. F., Lee, C.-U., Pak, S., Yim, H. S., & Fletcher, A. B. 2006, A&A, 450, 39

Gupta, A. C., Joshi, U. C., & Fan, J. H. 2002, Ap&SS, 282, 655
Hamuy, M., & Maza, J. 1987, A&AS, 68, 383
Heidt, J., Wagner, S. J., & Wilhelm-Erkens, U. 1997, A&A, 325, 27
Ikejiri, Y., Uemura, M., Sasada, M., et al. 2011, PASJ, 63, 639
Jannuzi, B. T., Smith, P. S., & Elston, R. 1993, ApJS, 85, 265
Jurkevich, I. 1971, Ap&SS, 13, 154
Kastendieck, M. A., Ashley, M. C. B., & Horns, D. 2011, A&A, 531, A123
Kidger, M., Takalo, L., & Sillanpaa, A. 1992, A&A, 264, 32
King, O. G., Hovatta, T., Max-Moerbeck, W., et al. 2013, MNRAS, 436, L114
Leahy, D. A., Elsner, R. F., & Weisskopf, M. C. 1983, ApJ, 272, 256
Mead, A. R. G., Ballard, K. R., Brand, P. W. J. L., et al. 1990, A&AS, 83, 183
Miller, H. R., & McAlister, H. A. 1983, ApJ, 272, 26
Mücke, A., Protheroe, R. J., Engel, R., Rachen, J. P., & Stanev, T. 2003, Astroparticle Physics, 18, 593
Osterman, M. A. 2007, New Multiwavelength Variability and Optical Microvariability Investigations of X-Ray And Radio Selected Blazars, Physics and Astronomy Dissertations. Paper 22. Georgia State University Digital Archive @ GSU
Paltani, S., Courvoisier, T. J.-L., Blecha, A., & Bratschi, P. 1997, A&A, 327, 539
Pesce, J. E., Urry, C. M., Maraschi, L., et al. 1997, ApJ, 486, 770
Rani, B., Gupta, A. C., Strigachev, A., et al. 2010, MNRAS, 404, 1992
Rani, B., Wiita, P. J., & Gupta, A. C. 2009, ApJ, 696, 2170
Sandrinelli, A., Covino, S., & Treves, A. 2014, A&A, 562, A79
Smith, P. S., & Sitko, M. L. 1991, ApJ, 383, 580
Smith, P. S., Hall, P. B., Allen, R. G., & Sitko, M. L. 1992, ApJ, 400, 115
Tommasi, L., Díaz, R., Palazzi, E., et al. 2001, ApJS, 132, 73
Treves, A., Morini, M., Chiappetti, L., et al. 1989, ApJ, 341, 733
Urry, C. M., Maraschi, L., Edelson, R., et al. 1993, ApJ, 411, 614
Valtaoja, E., Teräsranta, H., Tornikoski, M., et al. 2000, ApJ, 531, 744
Valtonen, M. J., Lehto, H. J., Sillanpää, A., et al. 2006, ApJ, 646, 36
Wu, J., Zhou, X., Ma, J., et al. 2007, AJ, 133, 1599
Xie, G. Z., Zhang, Y. H., Li, K. H., et al. 1996, AJ, 111, 1065
Xie, G. Z., Li, K. H., Zhang, X., Bai, J. M., & Liu, W. W. 1999, ApJ, 522, 846
Xie, G. Z., Li, K. H., Bai, J. M., et al. 2001, ApJ, 548, 200
Xie, G. Z., Liang, E. W., Zhou, S. B., et al. 2002, MNRAS, 334, 459
Xie, G. Z., Yi, T. F., Li, H. Z., Zhou, S. B., & Chen, L. E. 2008, AJ, 135, 2212
Xilouris, E. M., Papadakis, I. E., Boumis, P., et al. 2006, A&A, 448, 143
Zhang, B.-K., Dai, B.-Z., Zhang, L., & Cao, Z. 2010, RAA (Research in Astronomy and Astrophysics), 10, 653
Zhang, B.-K., Wang, S., Zhao, X.-Y., Dai, B.-Z., & Zha, M. 2013, MNRAS, 428, 3630
Zhang, Y. H., & Xie, G. Z. 1996, A&AS, 116, 289