# Color Variability of BL Lac objects on Long-term Timescales

**Zhou Li, Wang Lisha, Xu Guangyang, Zhang Yao, Li Xiaopan**

College of Physics and Information Engineering, Zhaotong University, Zhaotong, 657000, China

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**Abstract:** Based on the introduction of blazer, BL Lac object and SMARTS project, this paper briefly analyses the historical optical variation curve and color index change curve of a typical BL Lac object AO 0235+164 band. The results show that the target optical variation activity is intense, and the color index change shows the characteristics of BWB. This paper analyzes the Long-term timescales color change of five BL Lac objects in the SMARTS source. Among them, AO 0235+164, 0531-4827 and OJ 287 exhibited the color change characteristics of BWB, while 2155-304 and PKS 0426-380 did not exhibit color change.

## 1. Introduction

Blazer is a kind of radio noise AGN (AGN) with fast and large optical variations. It is also the most active type of AGN and the most important type of Fermi source. According to the magnitude of blazer variation, short-term optical variations can be roughly divided into small bursts, flashes and flickers. The blazer exhibits extreme physical properties such as dramatic and rapid optical variation, large and varying polarization, superluminal motion and continuous non-thermal radiation. The blazer's radiation covers the entire electromagnetic spectrum and exhibits dramatic changes. Its radiation mainly comes from the jet directed toward the observer, and therefore has a strong relativistic effect. Blazer is usually classified into two subclasses according to whether they have emission lines in optical bands: BL Lac object (BL Lac) and FSRQ (FSRQ). There are many differences between BL Lac object and FSRQ. For example, the emission line of BL Lac object is weak or even has no emission line (equivalent width is less than 0.5nm), while FSRQ has a strong emission line. The BL Lac object has a large amplitude short time scale optical variation, medium time scale optical variation, strong and varying optical polarization (usually the longer the wavelength the greater the degree of polarization). The characteristics of non-thermal continuous radiation from radio band to X-ray and even $\gamma$ band are also discussed in this paper. FSRQ is characterized by fast optical variation, high polarization and radio structure dominated by dense radio nuclei [1, 2]. In addition, the other characteristics are not very different, for example: they are all flat-spectrum radio sources, and they all have strong optical variations and high polarizations and other unique optical spectral characteristics.

BL Lac object is a very important subclass of blazer, which is observable; its shape is similar to fixed star. The main characteristics of BL Lac object are: intense optical variation, high polarization, non-thermal continuous spectrum, no or only very weak emission lines in the spectrum, and only very weak absorption lines, which is also the distinguishing feature of BL Lac object and other celestial body. BL Lac object has always been the focus of celestial body physics research. Since it has been confirmed as an important type of AGN, researchers have taken a variety of detection methods to find new BL Lac objects. The properties of various aspects of BL Lac object are explored and studied, and several theoretical models of the radiation mechanism of BL Lac object are proposed. According to the different peak frequencies of BL Lac object radiation, it is divided into low energy peak BL Lac object (LBL) and high energy peak BL Lac object (HBL). The energy spectrum distribution of Blazer has obvious bimodal structure. The bimodal structure of BL Lac object mainly includes lepton model and baryon model to explain [3]: lepton model thinks that the bimodal structure of BL Lac object is produced by the same particles. The Baryon model believes that its bimodal structure is produced by different particle swarms, and these particle swarms are not necessarily simply related. The basic assumption of the lepton model is that the relativistic electrons

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in the relativistic jet are subjected to a magnetic field to produce synchrotron radiation. The quantum photon produced by synchrotron radiation continues to counteract the Compton process with the relativistic electrons in the jet, resulting in a higher-energy quantum photon, which is also known as the Synchronized Self-Popton Model (SSC). At present, the lepton model and the hadron model are able to adapt to many current limitations, and both can make relatively reasonable explanations of the energy spectrum distribution of some observed sources [4].

## 2. Data reduction

The full name of the SMARTS project is Small and Moderate Aperture Research Telescope System. An important scientific objective of the SMARTS project is to observe Fermiblazer. Data from the SMARTS project are derived from small and medium-caliber telescopes at the Cerro Tololo Interamerican Observatory (CTIO). The SMARTS 1.3m telescope and ANDCAM equipment are used for daily observation of the SMARTS project. ANDICAM is a dual-channel imaging instrument which uses spectroscope to work for optical CCD and infrared imaging instrument. This instrument can obtain observation data from 0.4 to 2.2 micron and quasi-simultaneous observation data at four bands of BVRJK.

The SMARTS project also observes the spectrum of the blazer. Current research shows that many blazers do not have a special spectrum, but some blazers show starting rays (eg 3C 273, 1510-089) and can see changes in the intensity of the emission line. In addition, some blazers without emission lines may also generate emission lines under certain conditions. Therefore, the SMARTS project also looks at the spectra of the brighter sources in the sample. The SMARTS 1.5m telescope allows only one spectral observation on a given night, so the SMARTS program cannot make daily observations. In general, the SMARTS project will get the target star's spectrum every two to four weeks. The SMARTS project quickly releases most of the observed data and streamlined data products in the database within the same 1-2 day time scale of the LAT observation project. In addition, the SMARTS project continues to search for correlations between observations and LAT data, and to change its observation strategy based on interesting results and specific events.

## 3. Light curve and color variability Of AO 0235+164

### 3.1 Optical variation of AO 0235+164

Figure 1 shows BL Lac object AO 0235+164 optical B-band historical optical variation curve from July 15, 2008 to August 31, 2015. There are 221 data points, the abscissa is Julian day (day), and the ordinate is celestial body's brightness (magnitude). From the optical variation curve, we can see that the activity of BL Lac object AO 0235+164 is more intense, and the greater the magnitude, the darker the celestial body; and vice versa. According to the observed data, celestial body is the darkest on November 3, 2014, with a B-band magnitude of 20.765 and the brightest on September 24, 2008, with an magnitude of 15.755.The average magnitude of B band is about 18.878, and the magnitude of the brightest celestial body is 4.591 different from that of the darkest celestial body.

Table 1 gives the statistics of optical variations in B, V, R, J and K bands of BL Lac object AO 0235+164. As shown in the Table, there are 221, 238, 302, 333 and 238 data points in V, R, J and K bands respectively. From the image, it can be seen that each band of celestial body is in a rather drastic change, and there are often large-scale outbreaks in the whole observation range. The curve diagram of optical variation shows that the five bands of B, V, R, J and K all had an obvious outbreak on November 3, 2014, and celestial body reached its brightest on that day. In the multi-band observation data, it can be seen that the changes of the five bands occur almost simultaneously, and of course, there will be cases where the short-wave burst is ahead or behind the long-band.

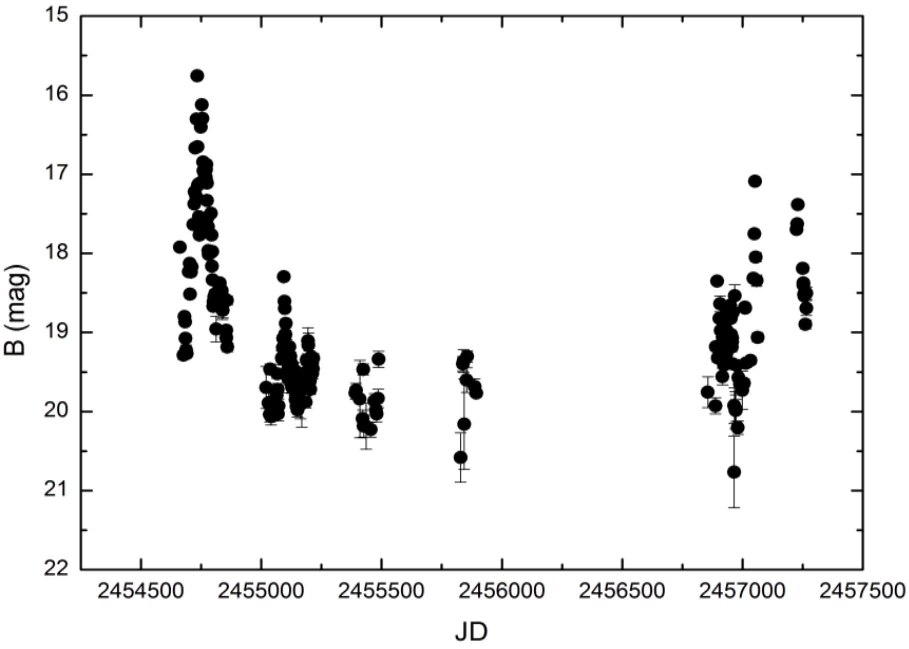


Fig. 1 BL Lac object AO 0235+164 optical B-band historical optical variation curve

Table 1 BL Lac object AO 0235+164 BVRJK band optical variation curve statistics

| Optical waveband | Data point | Maximum magnitude | Minimum magnitude | Average magnitude |
|---|---|---|---|---|
| B | 221 | 20.765 | 15.755 | 18.87766968 |
| V | 238 | 17.602 | 14.86 | 18.05155462 |
| R | 302 | 19.228 | 14.085 | 17.46439735 |
| J | 333 | 17.044 | 11.849 | 15.21837838 |
| K | 238 | 14.581 | 10.498 | 12.92405882 |

### 3.2 Color Change of AO 0235+164

In astronomy, the difference between magnitudes of the same celestial body in any two bands is called colour index. For BL Lac object AO 0235+164, there are various colour indices for stars. In this paper, we use B band and V band to calculate colour index. The colour index curves of AO 0235+164 with abscissa Julian Day (Unit: Day) and ordinate colour index (Unit: magnitude) are shown in Figure 2.

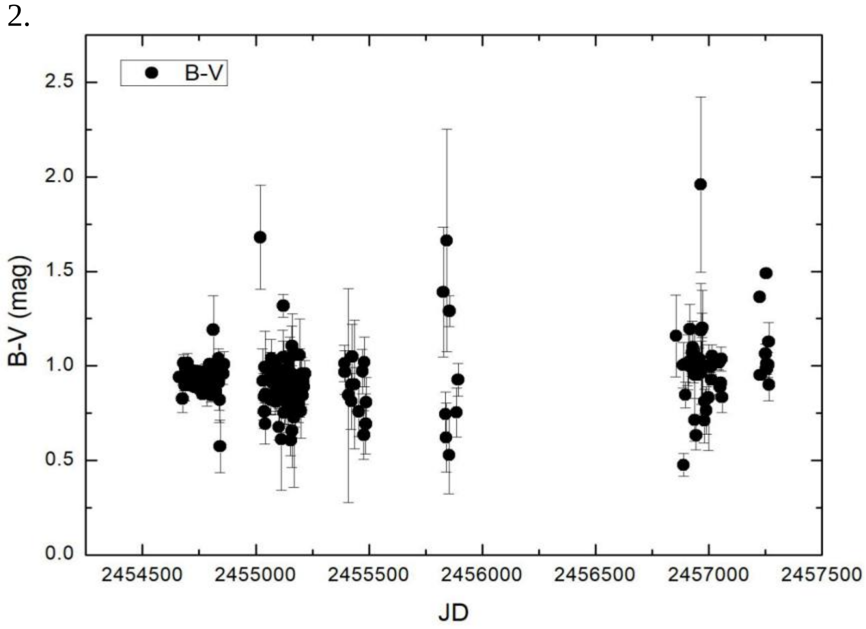


Fig.2 Colour index curve of AO 0235+164

As shown in the figure above, take the data of July 15, 2008 solstice and August 31, 2015 for graphic analysis, the average value of the colour index is 0.94 amount, the standard deviation is 0.17. On August 19, 2014, the colour index reaches the minimum value of 0.476 amount. On November 3, 2014, the colour index reached the maximum amount of 1.96 points. On November 3, 2014, the colour index quickly rose to 1.96magnitude, and this change was the fastest and most violent one in the entire observation process. Observing the curve, it can be found that the color index change amount is 1.484magnitude from July 15, 2008 to August 31, 2015. Observing and comparing the curves of each color index shows that the colour index of AO 0235+164 is in a rapid rise and rapid decline, and the change is very intense.

In order to better understand the optical variations of BL Lac object AO 0235+164, we studied the correlation between the colour index of stars and the corresponding magnitude average. In this paper, the correlation coefficient is greater than 0.2 and the confidence probability is less than 0.01, which indicates that there is a significant positive correlation between colour index and traffic, that is, there is a BWB color characteristic between them [5]. When the correlation coefficient is less than 0.2 and the confidence probability is less than 0.01, it shows that there is a significant negative correlation between colour index and traffic, i.e. there is a color characteristic of RWB between them. In addition, it shows that there is no correlation between them, expressed by NONE. Here, the B-band is plotted on the abscissa and the colour index B-V is plotted on the ordinate. The slope of the fitted line is 0.031±0.0058, the intercept is 0.403±0.09974, the Pearson correlation coefficient is 0.349, and the confidence probability is 3.286E- 7. Therefore, the linear regression equation is B-V=(0.403±0.09974)+V(0.031±0.0058). The color change characteristics of colour index B-V and B magnitude can be obtained as BWB. And the correlation is poor.

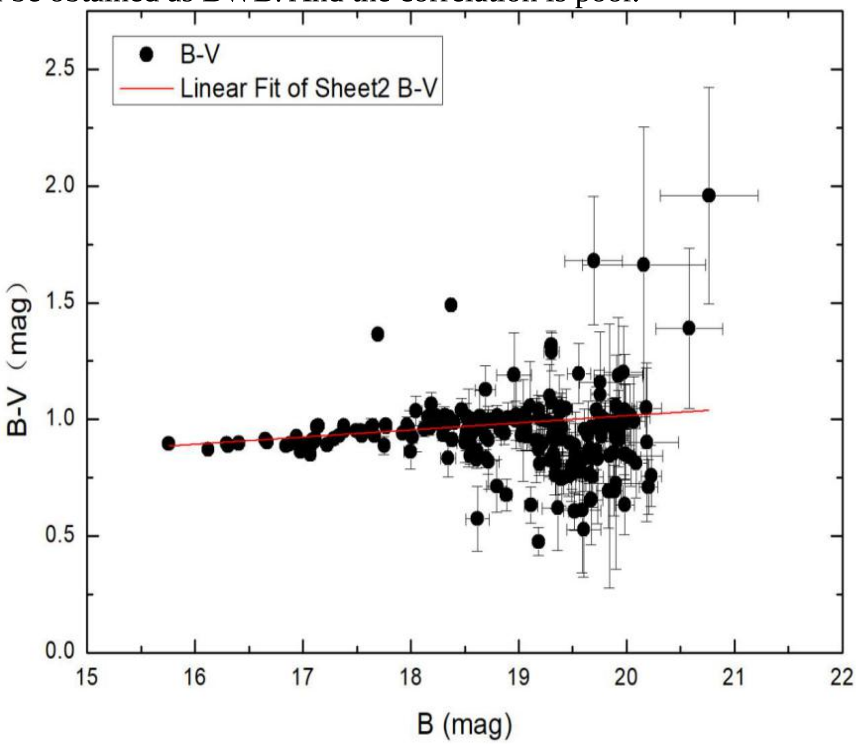


Fig.3 Colur index of AO 0235+164 and correlation analysis of B-band magnitude

The colour index of BL Lac object AO 0235+164 and the corresponding magnitude average were correlated. Using V-band as abscissa and colour index B-V as ordinate as figure 4, the slope of the fitting line is 0.0242+0.00613, the intercept is 0.535+0.0997, the Pearson correlation coefficient is 0.269, and the confidence probability is 1.058E-4. The linear regression equation is B-V=(0.535±0.0997)+V(0.0242±0.00613). It can be seen that there is a significant positive correlation between colour index and flow rate, so the color change characteristics of colour indexB-V and Bmagnitude are BWB. And the correlation is poor.

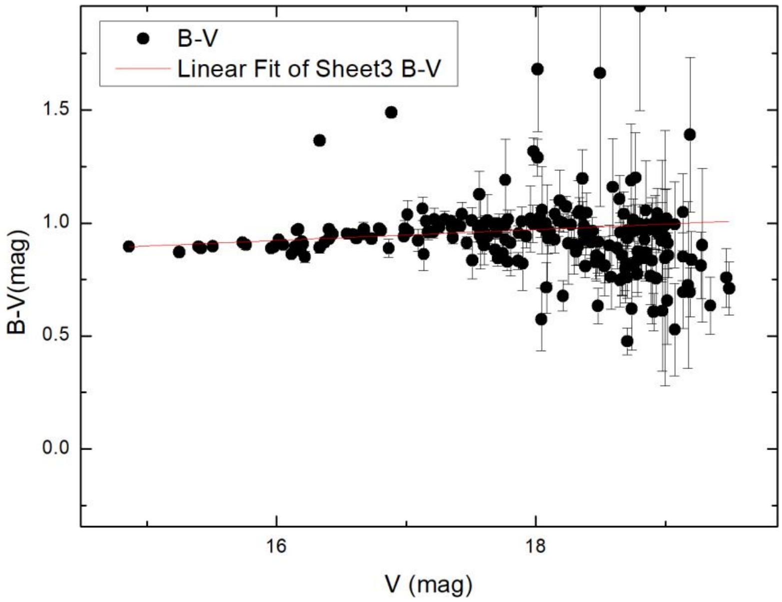


Fig.4 Colur index of AO 0235+164 and correlation analysis of V-band magnitude

The colour index of BL Lac object AO 0235+164 and the corresponding magnitude average were correlated. Using (B+V)/2 magnitude as abscissa and colour index B-V as ordinate as figure 5, the slope of the fitting line is 0.028+0.006, the intercept is 0.468+0.100, the Pearson correlation coefficient is 0.310, and the confidence probability is 6.864E-6. Therefore, the linear regression equation is B-V=(0.468±0.100)+(0.028±0.006)(B+V)/2. It can be seen that there is a significant positive correlation between the colour index and the flow rate, so the color change characteristic of the colour index B-V and (B+V)/2magnitude is BWB.

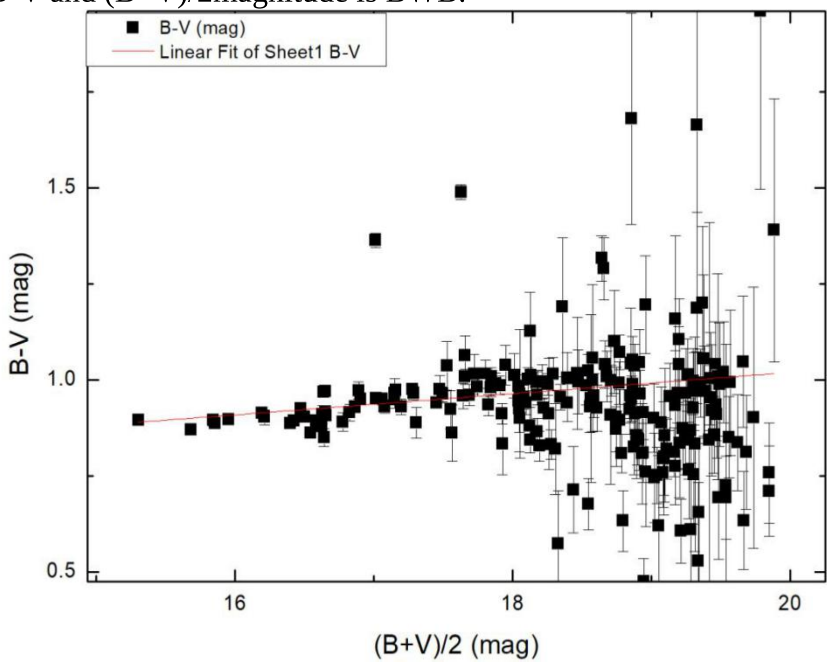


Fig.5 Colur index and (B+V)/2 magnitude analysis of AO 0235+164

## 4. Sample statistical analysis results

Here, we use the same method to analyze the BL Lac objects in SMARTS samples, first calculating the colour indexb-v, and then calculating the correlation between colour indexb-v and (B+V)/2. There are a total of 20 BL Lac objects in SMARTS samples. However, there are no data for 16 target band B and 2 target bands B and V. Therefore, among SMARTS samples, only five BL Lac objects can make correlation analysis for B-V and (B+V)/2. That is (B + V) / 2 magnitude as abscissa and B - V as ordinate. The concrete results are shown in Table 2. In the Table, the first column is the target name, the second column is the average value of colour index B-V, and the third-fifth column is the result of correlation analysis of colour index B-V and (B-V)/2, in order of slope, correlation coefficient and confidence probability. Column 6 is the color characteristics. As can be seen from the Table, in addition to AO 0235+164, there are 0531-4827 and OJ 287 which exhibit a color change and are BWB. The other two targets did not exhibit color changes in the Long-term timescales range, and no targets exhibited RWB color changes.

Table 2 Analysis of BL Lac object B-V and (B+V)/2 correlation in SMARTS samples

| Target name | Average colour index | Slope | Correlation coefficient | Confidence probability | Colour |
|---|---|---|---|---|---|
| 0531-4827 | 0.12 | 0.024±0.005 | 0.343 | 8.402E-7 | BWB |
| 2155-304 | 0.407 | 0.017±0.01 | 0.082 | 0.081 | NONE |
| AO 0235+164 | 0.94 | 0.403±0.0997 | 0.349 | 3.286E-7 | BWB |
| PKS 0426-380 | 0.58 | -0.002±0.051 | -0.004 | 0.976 | NONE |
| OJ 287 | 0.509 | 0.032±0.007 | 0.198 | 8.021E-6 | BWB |

## 5. Conclusion

Optical variation and color change of celestial body are important observational characteristics of FSRQ. The research and analysis of celestial body can deepen our understanding of its energy mechanism and the surrounding environment. BL Lac object AO 0235+164 B, V, R, J, K bands of historical optical variations curve shows that the optical variations of each band of the target are very intense, and the frequency of outbreaks is high. In addition, it can be seen that there is a strong correlation between the bands. Observing and comparing the change index of colour index, we can find that the colour index of BL Lac object AO 0235+164 is in a rapid rise and rapid decline, and the change is very intense. Linear regression analysis of colour index and B-band, V-band and (B+V)/2magnitude revealed that the change in brightness was positively correlated with the correlation of color index change. But its correlation is not too strong and does not reach a high level of credibility. Such a situation reflects the complexity of BL Lac object AO 0235+164optical variation, and the correlation we obtained may be the inherent color variation characteristics of these two targets in different bands, or it may be caused by the impact of the lack of observation data on a single color variation characteristic (BWB or RWB). Finally, the BL Lac object in SMARTS samples is analyzed. There are five targets with B-band and V-band data. There is a significant positive correlation between colour index and flow in each target. Among them, there are three targets with BWB color (AO 0235+164, 0531-4827 and OJ 287). In addition, no target showed RWB color change.

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