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Period of Light Variability in BL Lac ON 231

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Abstract. In this paper, the authors have compiled the data of about 100 years in B-band of the BL Lac ON 231 and used this database to analyze periodicity signals in the optical light curve. Two different methods were applied: the wavelet analysis and the Discrete Correlation Function (DCF) method. We revealed the existence of periods of 13.5 years in the source variability.

Key words. BL Lac object individual: ON 231—period of light variation—methods: wavelet analysis method, DCF analysis method.

1. Introduction

ON 231 is a BL Lac object with large light variations and periodic variability, that can be given some of the parameters within these class objects. Then we can study its internal physical mechanism (Zhang *et al.* 1998). Therefore, there have been strong interest in periodic research. Many have studied the light variation period and achieved a lot. Liu *et al.* (1995) found two periods of 0.981 ± 0.005 yr and 13.6 ± 1.3 yr for explaining the outbursts in the B band in ON 231. After several years, Zhang *et al.* (1998) further analyzed with B band data and confirmed a period of 13.6 ± 1.3 yr (or 26.6 ± 0.8 yr). Fan *et al.* (2002) got a period of 14.85 ± 1.55 yr. However, due to the complex internal structure and violent activities of ON 231, its light curve is very complicated. Because of constraints of other factors such as observation instruments and weather, at present, there is no comprehensive database of long-term sample. On the whole, periodic certification of ON 231 is also clearly more difficult, its long-period light variability may be greater than the current observation history and needs further monitoring certification (Zhang *et al.* 1998).

To establish the real periods of ON 231, we employ wavelet analysis and DCF method to search a periodicity in the light curves.

2. Periodicity analysis of ON231

2.1 *Light curve of ON 231*

We have compiled its B-band optical data on ON 231 from 1898 to 2005 to find its long-term variability period. These data are from 22 literatures (see Xu *et al.* 2010).

The light curve is shown in Fig. 1. As can be seen from Fig. 1, ON 231 is a highly active object, its magnitude $m_B = 13.1$ mag when it was brightest in 1998 and $m_B = 17.8$ mag when it was darkest in 1984, and the magnitude variation reached 6 mag. There were no observed data before 1930, while we have abundant data of the bursts in 1940 and 1968.

2.2 *Wavelet analysis method*

Wavelet analysis is a good tool for searching for period in a signal especially in non-steady signal. Relations between Morlet wavelet scale factors a and the period T (Meyers *et al.* 1993) is:

$$T = \frac{4\pi}{\omega + \sqrt{2 + \omega^2}} \times a. \tag{1}$$

We ask for $\omega = 6.2$ so as to acquire $T \approx a$. The discrete forms of the wavelet variance (Collineau & Brunet 1993) was defined as:

$$\mathrm{Var}(a) = \frac{1}{N} \sum_{k=1}^{N} |W_f(a, b_k)|^2 . \tag{2}$$

The period signal may be mixed in the random signal, and we can get the period of the period signal by wavelet variance.

As can be seen from Fig. 2, periods of ON 231 are 13.5 and 26.1 yr. The period of 26.1 yr is likely the harmonics of 13.5 yr, so the possibly significant period is 13.5 yr.

2.3 *DCF analysis method*

The Discrete Correlation Function (DCF) (Edelson & Krolik 1998) method is defined as:

$$\mathrm{UDCF}_{ij} = \frac{(a_i - \overline{a})(b_j - \overline{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}} . \tag{3}$$

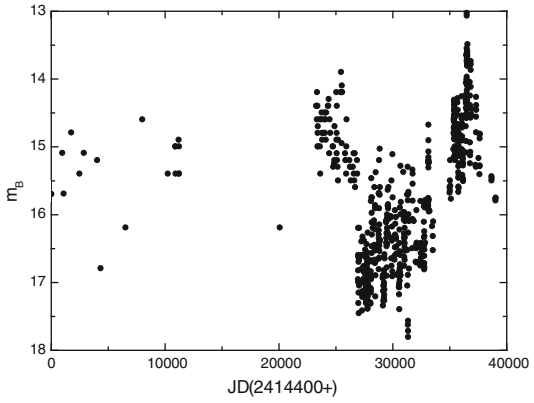

Figure 1. Daily-averaged historical light curve of ON 231 from 1898–2005.

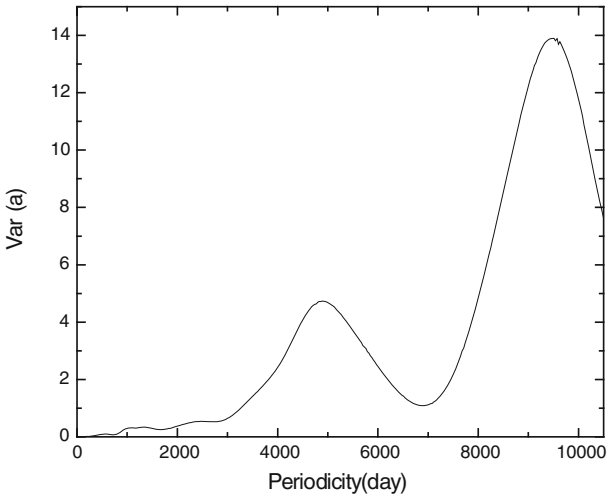

Figure 2. The wavelet variance diagram of transform coefficients, using the data shown in Fig. 1.

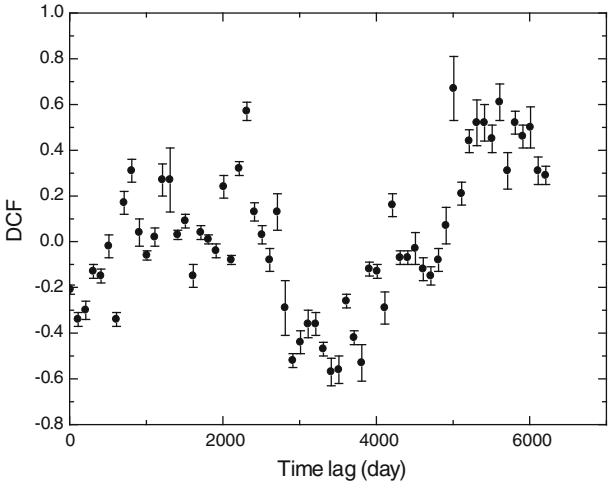

Figure 3. DCF results, using the data shown in Fig. 1.

Here a_i and b_j are the observational magnitude of B-band, e_a and e_b are the mean value of the standard error of the observational magnitude; $\overline{a}$, $\overline{b}$ and σ_a, σ_b are the mean observational magnitudes and their standard deviations, respectively. Binning the result in time directly allows a useful function DCF(τ) to be measured. Averaging over the M pairs for which $\tau - \Delta\tau/2 \leq \tau + \Delta\tau/2$, we have:

$$\mathrm{DCF}(\tau) = \frac{1}{M}\mathrm{UDCF}_{ij}\,. \tag{4}$$

We got two periods of 13.68±0.14 and 6.42±0.04 yr from Fig. 3. The period is equal with other results.

3. Discussion and conclusion

We use two different methods to search for the periodicity in the light curve of ON 231 and obtain the same results as other authors. Period of 13.5 yrs should be a basically stable periodicity. We believe that the variability in the time-scale of a few years may be due to instability of accretion disks around black holes and the usual center in the active galactic nuclei, especially the thermal instability of thin disk may lead to the type oscillator of outbreak (Fan *et al.* 2001); binary black hole model is not the best model for explaining long-term optical variability of BL Lac objects, its outbreaks can not be completely derived from binary black holes.

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