Research in Astron. Astrophys. **2010** Vol. **10** No. **11**, 1100–1108
*http://www.raa-journal.org* *http://www.iop.org/journals/raa*

*Research in Astronomy and Astrophysics*

# Long-term variation time scales in OJ 287 *

Jun-Hui Fan[1,2], Yi Liu[1,2], Bo-Chun Qian[3,4], Jun Tao[3,4], Zhi-Qiang Shen[3,4], Jiang-Shui Zhang[1,2], Yong Huang[1,2] and Jin Wang[1,2]

[1] Center for Astrophysics, Guangzhou University, Guangzhou 510400, China; *jhfan_cn@yahoo.com.cn*
[2] Astronomy Science and Technology Research Laboratory of Department of Education of Guangdong Province, Guangzhou 510006, China
[3] Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China
[4] Joint Institute for Galaxy and Cosmology, ShAO and USTC, Chinese Academy of Sciences, China

Received 2010 February 25; accepted 2010 June 12

**Abstract** The light curve data from 1894 to 2008 are compiled for the BL Lacertae object OJ 287 from the available literature. Periodicity analysis methods (the Discrete Correlation Function-DCF, the Jurkevich method, the power spectral (Fourier) analysis, and the CLEANest method) are performed to search for possible periodicites in the light curve of OJ 287. Significance levels are given for the possible periods. The analysis results confirm the existence of the $12.2 \pm 0.6$ yr time scale and show a hint of a $\sim$53 yr time scale. The $12.2 \pm 0.6$ yr period is used as the orbital period to investigate the supermassive binary black hole system parameters.

**Key words:** galaxies: active — galaxies: general — methods: data analysis — galaxies: individual (OJ 287)

## 1 INTRODUCTION

The nature of blazars is an interesting topic. Blazars' light curves were generated by using the data from their monitoring programs and have yielded very valuable information about the mechanisms operating in these sources. Light curves are important for their implications for quasar modeling (Fan et al. 1998a). The observation data of blazars show that they vary over different time scales, which can be roughly divided into three classes: intra-day variability (IDV) or micro-variability, short term outbursts and long term trends (Fan 2005). Variability of blazars in radio to optical bands on diverse time scales have been reported in a large number of papers (see Fan 2005; Takalo et al. 2008; Heidt & Wagner 1996; Sillanpää et al. 1996a,b; Bai et al. 1999; Fan et al. 1998a, 2007, 2009a,b; Qian et al. 2000, 2002, 2004; Aller et al. 2003; Tao et al. 2008; Romero et al. 2002; Xie et al. 2002a,b; Gupta et al. 2008a,b; Cellone et al. 2007; Ciprini et al. 2007; Kurtanidze 2008; Raiteri et al. 2008; Villata et al. 2008; Valtonen et al 2008; Dai et al. 2001, 2009; Fidelis et al. 2009; Boettcher et al. 2009 and references therein). The variability time scale of years gives the long term variation information and even some information about the central structure of the source.

* Supported by the National Natural Science Foundation of China.

OJ 287 (0851+202), located at redshift $z = 0.306$, is one of the most extensively observed and best studied BL Lac objects for variability studies. OJ 287 is also one of the very few AGNs for which optical light curve data spanning more than a century are available, which provide us with a very good historical light curve of the source (Abraham 2000; Fan et al. 1998b, 2002; Hudec et al. 2001; Sillanpää et al. 1988). In 1972, it reached maximum brightness, with $V \sim 12$ (see Fan et al. 1998b and reference therein). Zheng et al. (2008) presented evidence for long-term optical spectral index variability behavior for the source. Its $\sim$12 yr period, confirmed by the OJ-94 program (Sillanpää et al. 1996a) and the 2005–2007 observations of the blazar, was explained by a binary black hole model (Valtonen et al. 2008). OJ 287 is the blazar used to test the general theory of relativity (Valtonen et al. 2008). In its radio bands, light curves were also investigated (e.g Tateyama et al. 1999; Venturi et al. 2001; Fan et al. 2007).

It is one of the blazars monitored in our program with the 1.56-m telescope at Sheshan station, Shanghai Astronomical Observatory (ShAO), China (Qian et al. 2002, Qian & Tao 2003, 2004; Tao et al. 2004; Fan et al. 2009).

In the paper, we collected the historical light curves combined with our monitoring data (Qian & Tao 2003; Fan et al. 2009), and applied the periodicity analysis methods to the light curve. Sections 2 and 3 present the details about our periodicity analysis methods and the results, and in Section 4 our discussions and conclusions are given.

## 2 DATA

OJ 287 was observed more than 100 yr ago starting in 1894 (Visvanathan & Elliot 1973; Takalo 1994). The data used in the present paper are from the following literature (Kurochkin 1971a,b; Tsessevich 1972; Miller et al. 1976; Pollock et al. 1979; Smith et al. 1982; Lloyd 1984; Sillanpää et al. 1996a), the compiled data (Fan et al. 1998b, Fan & Lin 2000) and our monitoring results (Qian & Tao 2003; Fan et al. 2009a). The data are shown in Figure 1. Here the figure is for the flux density using $F_V(\mathrm{mJy}) = 3.68 \times 10^{6-0.4\,m_V}$ (Mead et al. 1990).

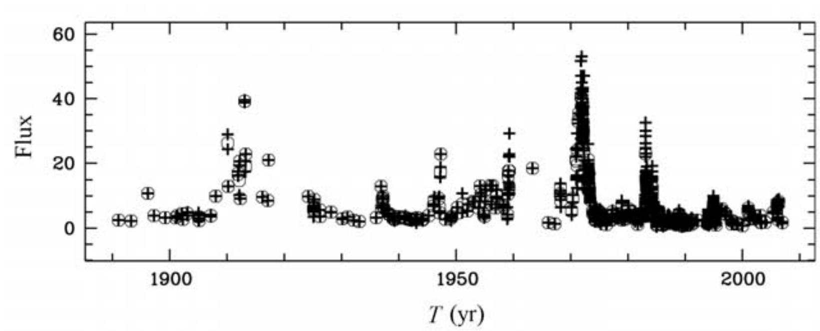


**Fig. 1** Light curve of OJ 287 from 1894 to 2007. The observed times (in units of year) are on the abscissa, and the fluxes are on the ordinate.

## 3 PERIODICITY ANALYSIS

There are many methods that can be applied to time series data analysis. However, the special characteristic of astronomical observations, namely that the data are not evenly sampled, puts some constraints on the available analysis methods. In this paper, we have used the discrete correlation function, the Jurkevich method, the power spectral (Fourier) analysis, and the CLEANest method to search for periodicity in the light curve of OJ 287.

### 3.1 Discrete Correlation Function Method

The Discrete Correlation Function (DCF) method is intended for analysis of the correlation of two data sets. It is described in detail by Edelson & Krolik (1988). This method can indicate the correlation of two variable temporal series with a time lag, and can be applied to the periodicity analysis of a unique temporal data set, as we did in our previous papers (Fan et al. 1998b, 2002). If there is a period, $P$, in the light curve, then the DCF should clearly show whether the data set is positively correlated with itself with time lags of $\tau = 0$ and $\tau = P$. We have implemented the method as follows.

From a paper by Edelson & Krolik (1988), we calculated the set of Unbinned Discrete Correlation Functions (UDCFs) between data points in the two data streams $a$ and $b$, i.e.

$$\mathrm{UDCF}_{ij} = \frac{(a_i - \bar{a}) \times (b_j - \bar{b})}{\sqrt{\sigma_a^2 \times \sigma_b^2}}, \tag{1}$$

where $a_i$ and $b_j$ are points in the data sets, $\bar{a}$ and $\bar{b}$ are the average values of the data sets, and $\sigma_a$ and $\sigma_b$ are the corresponding standard deviations. Secondly, we have averaged the points sharing the same time lag by binning the $\mathrm{UDCF}_{ij}$ in suitably sized time-bins in order to get the DCF for each time lag $\tau$

$$\mathrm{DCF}(\tau) = \frac{1}{M}\Sigma\ \mathrm{UDCF}_{ij}(\tau), \tag{2}$$

where $M$ is the total number of pairs. The standard error for each bin is

$$\sigma(\tau) = \frac{1}{M-1}\{\Sigma\ [\mathrm{UDCF}_{ij} - \mathrm{DCF}(\tau)]^2\}^{0.5}. \tag{3}$$

The DCF is performed for the light curve; results are obtained and shown in Figure 2. Positive correlations are found with time lags of $P_1 = 12.1 \pm 1.0$ (DCF$= 0.28$), $P_2 = 24.6 \pm 0.4$ (DCF$= 0.20$), $P_3 = 46.1 \pm 0.3$ (DCF$= 0.19$) and $P_4 = 54.6 \pm 0.7$ (DCF$= 0.39$) yr.

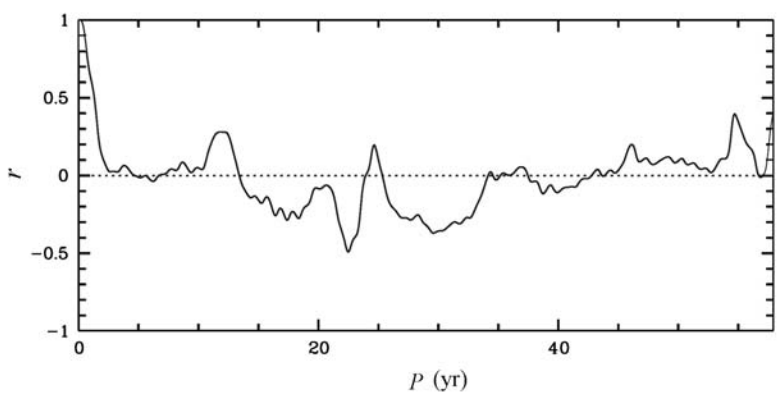


**Fig. 2** Analysis results obtained by using the DCF method. DCFs are plotted against the time lags (in units of year).

### 3.2 Jurkevich Method

The Jurkevich method (Jurkevich 1971, also see Kidger et al. 1992, Liu et al. 1995; Fan et al. 1998a, 2002; Fan 1999) is based on the expected mean square deviation from a mean curve, and it is less inclined to generate spurious periodicity than the Fourier analysis.

This method tests a run of trial periods around which the data are folded. All data are assigned to $m$ groups according to their phases around each trial period. The variance $V_i^2$ for each group and the sum $V_m^2$ of all groups are then computed. If a trial period equals the true one, then $V_m^2$ reaches its minimum. So, a "good" period will give a much reduced variance relative to those given by other false trial periods and which have almost constant values.

A further test is the relationship between the depth of the minimum and the noise in the "flat" section of the $V_m^2$ curve close to the adopted period. If the absolute value of the relative change of the minimum in the "flat" section is large enough compared with the standard error of this "flat" section (say, five times), the periodicity in the data can be considered as significant and the minimum as highly reliable (Kidger et al. 1992; Fan et al. 1998a; Fan 1999). We think the test is not good enough to give a quantitative criterion. Therefore, we adopted the *False Alarm Probability* (FAP, Horne & Baliunas 1986) to give a quantitative criterion for the detection of a minimum. Horne & Baliunas (1986) introduced the False Alarm Probability to deal with the modified periodogram. In fact, the FAP can deal with all kinds of periodicity analysis methods if the variations (mainly) consist of randomly distributed noise.

Supposing that $z$ is the lowest minimum in a Jurkevich periodogram of a random unevenly sampled time series, and that the probability that every minimum is higher than $z$ is FAP($z$), we can obtain FAP by a simple Monte Carlo method.

We have applied the Jurkevich's method to the OJ 287 light curve, and the results are shown in Figure 3. This figure shows several minima, and various FAP levels are also marked. We found possible periods of $P_1 = 52.0 \pm 9.0$ ($V_m^2 = 0.86$) and $12.1 \pm 0.9$ ($V_m^2 = 0.78$) yr, both with FAP $\ll 0.01$.

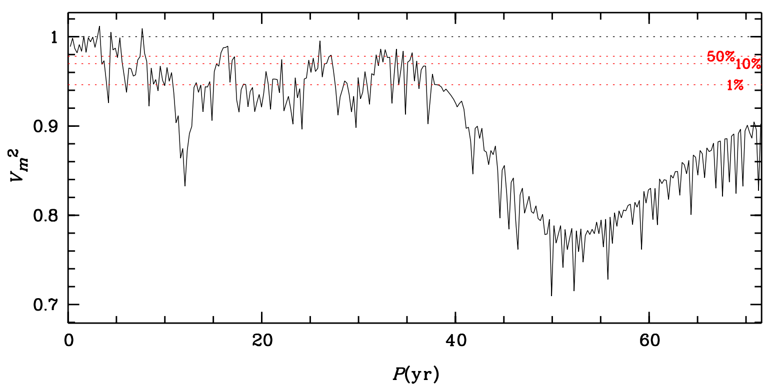


**Fig. 3** Analysis results obtained using the Jurkevich method. $V_m^2$ is plotted against the trial periods in units of year. Various FAP levels are marked.

### 3.3 Power Spectral (Fourier) Analysis

We also used a power spectral (Fourier) analysis because it is a common (well-studied) method to detect periodic signals, and gives some quantitative criteria for the detection of a periodic signal. We used a Fourier analysis technique named *Date-Compensated Discrete Fourier Transform*, or DCDFT (Ferraz-Mello 1981; Foster 1995).

Then we applied the CLEANest algorithm (Foster 1995) to the OJ 287 data. The CLEANest algorithm is a method for removing false peaks from a power spectrum. It is an effective technique for detecting and describing multi-periodic signals.

### *3.3.1 Fourier analysis (*DCDFT*)*

In the case that the data are unevenly spaced in time, many attempts of power spectral analysis have been made. In widespread use by astronomers is the *modified periodogram* (Scargle 1982; Horne & Baliunas 1986), which is based on a least squares regression onto the two trial functions, $\sin(\omega t)$ and $\cos(\omega t)$. A superior technique is the DCDFT (Ferraz-Mello 1981; Foster 1995), a least-squares regression onto $\sin(\omega t)$, $\cos(\omega t)$ and a constant. The DCDFT is a more powerful method than the *modified periodogram* for unevenly spaced data, so we applied it to the $V$ light curve, which can be done as Foster (1995) described.

We also adopted the FAP (Horne & Baliunas, 1986) to give a quantitative criterion of the detection of a periodic signal derived by DCDFT. The FAPs are obtained by a simple Monte Carlo method.

The DCDFT power spectral analysis is applied to the light curve; the resulting DCDFT is shown in the upper panel of Figure 4. In the periodogram, various FAP levels are marked. The highest peak is at $T = 50.1 \pm 8.0$ yr. The second highest one is at $T = 12.2 \pm 0.6$ yr. All the FAPs of these peaks are lower than 1%.

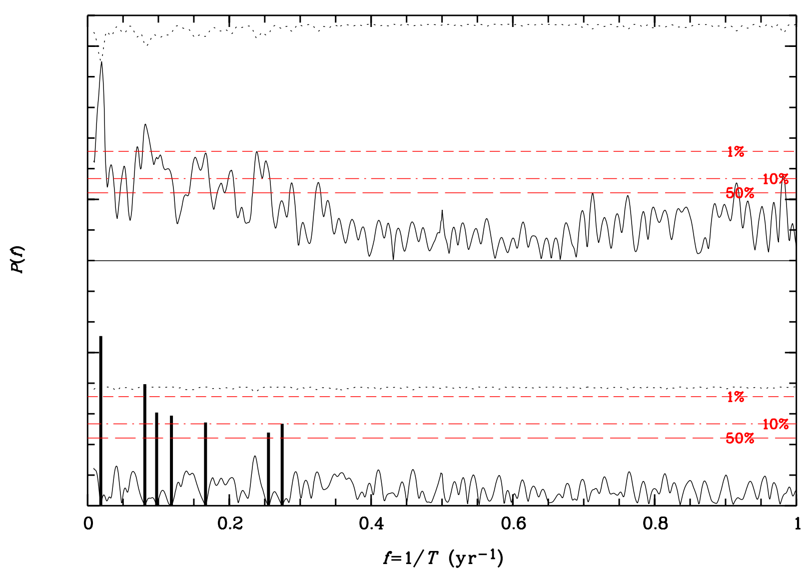


**Fig. 4** Fourier analysis and the CLEANest spectrum for the light curve. The upper panel is the Fourier analysis of the light curve while the lower panel is the CLEANest spectrum from the same light curve. In the lower panel, seven CLEANest frequency components (*rough lines*) and the residual spectrum are shown. Various FAP levels are marked.

### 3.3.2 CLEANest analysis

In the case of an unevenly sampled time series analysis, irregular spacing introduces a myriad of complications into the Fourier transform. It can alter the peak frequency (slightly) and amplitude (greatly), and even introduce extremely large false peaks.

Foster (1995) proposed using the CLEANest analysis to clean false periodicity. We also tried to use the CLEANest analysis method. The CLEANest algorithm can remove false peaks. First, the strongest single peak and corresponding false components are subtracted from the original spectrum, then the residual spectrum is scanned to determine whether the strongest remaining peak is statistically significant. If so, then the original data are analyzed to find the pair of frequencies which best model the data, these two peaks and corresponding false components are subtracted, and the residual spectrum is scanned. The process continues, producing the CLEANest spectrum, until all statistically significant frequencies are included. We assume that there are seven independent frequency components to clean observational data; the CLEANest spectrum is shown in Figure 4, and the results are listed in Table 1.

**Table 1** Seven CLEANest Frequency Components for OJ 287

| | Period (yr) | Amp. | FAP |
|---|---|---|---|
| $P_1$ | $53.4 \pm 7.0$ | 5.54 | $\ll 1$ |
| $P_2$ | $12.4 \pm 2.0$ | 3.97 | $< 1$ |
| $P_3$ | $10.3 \pm 1.4$ | 3.04 | 5 |
| $P_4$ | $8.5 \pm 0.9$ | 2.94 | 7 |
| $P_5$ | $6.0 \pm 0.5$ | 2.72 | 9 |
| $P_6$ | $3.9 \pm 0.29$ | 2.39 | 40 |
| $P_7$ | $3.6 \pm 0.2$ | 2.68 | 11 |

The variance of a frequency Var($\omega$) and the variance of the amplitude of the given frequency Var($P$) can be estimated by Foster (1996).

$$\mathrm{Var}(\omega) = \frac{24\sigma_{\mathrm{res}}^2}{NA^2T^2}, \quad (4)$$

$$\mathrm{Var}(P) = \frac{2\sigma_{\mathrm{res}}^2}{N}, \quad (5)$$

where $\sigma_{\mathrm{res}}$ is the variance of the residual data, $A$ is the amplitude of the given frequency and $T$ is the total time span. The $\sigma_{\mathrm{res}}^2$ is estimated by

$$\sigma_{\mathrm{res}}^2 = \frac{NV_{\mathrm{res}}}{N - 3f - 1}, \quad (6)$$

where $V_{\mathrm{res}}$ is the variance of residual data, $V_{\mathrm{res}} = \langle \mathrm{res}|\mathrm{res}\rangle - \langle 1|\mathrm{res}\rangle$, and $f$ is the number of discrete frequencies.

We also introduce the False Alarm Probability to deal with CLEANest frequency components, because of the same definition of amplitude. FAP are also listed in Table 1. The strongest component is at $T = 53.4 \pm 7.0$ yr, with an amplitude of $5.54 \pm 0.83$ and a false probability of FAP$\ll 1\%$; the second strongest one is at $T = 12.4 \pm 2.0$ yr, with an amplitude of $3.97 \pm 0.83$ and a false probability of FAP$< 1\%$. The false probabilities of other components and the residual spectrum are higher than $5\%$. Notably, FAP means a strong enough signal with a small probability of being false.

For illustration, we present the analysis results in Figure 4 for the strong sign of periods in the light curve.

### 3.4 Results

From the analyses of the results given above, we find two timescales in Table 2. However, as discussed below, the reality of the longer period still remains in question.

**Table 2** Periodicity Analysis Results

| | $P_1$ (yr) | $P_2$ (yr) |
|---|---|---|
| DCF | $54.6 \pm 0.7$ | $12.1 \pm 1.0$ |
| JV | $52.0 \pm 9.0$ | $12.1 \pm 0.9$ |
| DCDFT | $50.1 \pm 8.0$ | $12.2 \pm 0.6$ |
| CLEANest | $53.4 \pm 7.0$ | $12.4 \pm 2.0$ |

## 4 DISCUSSION AND CONCLUSIONS

Variation is one of the main observational properties of blazars and they are variable over the whole range of electromagnetic wavelengths. Optical photometry has been available for some blazars for about a century (Fan 2005), which is long enough for us to investigate the long-term period in the light curve.

Periodicity analysis has been performed on the light curve of OJ 287 by many authors: Sillanpää et al. (1988) reported an 11.65 yr period in the optical light curve. Kidger et al. (1992) used the Jurkevich method to analyze the periodicity in the light curve and found a period of $11.6 \pm 0.5$ yr. They also found some evidence of a period of $55 \pm 3$ yr. We also performed period analysis for the source and found periods of $5.53 \pm 0.15$ and $11.75 \pm 0.5$ yr in our previous paper (Fan et al. 2002). However, the radio light curve shows periods of $8.8 \pm 1.0$ yr in 4.8 GHz with FAP = 0.445 and $9.4 \pm 0.6$ yr in 8 GHz with FAP = 0.266 (Fan et al. 2007), which are very different from the reported optical periods.

In the present paper, we used several methods for the periodicity analysis and adopted FAP for the significance level of the obtained period.

DCF analysis shows possible periods of $P_1 = 12.1 \pm 1.0$ (DCF = 0.28), $P_2 = 24.6 \pm 0.4$ (DCF = 0.20), $P_3 = 46.1 \pm 0.3$ (DCF = 0.19) and $P_4 = 54.6 \pm 0.7$ (DCF = 0.39) yr. It is interesting to notice that the period $P_2 = 24.6$ yr is twice as long as the period of $P_1 = 12.1$ yr. We think that they both have the same origin, with the latter being a harmonic of the former. The $12.1 \pm 1.0$ yr period is consistent with the 11.65 yr period by Sillanpää et al. (1988) and the $11.6 \pm 0.5$ yr period by Kidger et al. (1992), while the $54.6 \pm 0.7$ value is consistent with the result of $55 \pm 3$ yr obtained by Kidger et al. (1992).

The Jurkevich method shows possible periods of $P_1 = 52.0 \pm 9.0$ ($V_m^2 = 0.86$) and $12.1 \pm 0.9$ ($V_m^2 = 0.78$) yr, both with FAP $\ll 0.01$. The two periods are also quite consistent with the result of $55 \pm 3$ yr and $11.6 \pm 0.5$ yr obtained by Kidger et al. (1992) and that of 11.65 yr by Sillanpää et al. (1988).

Power spectral (Fourier) analysis shows that the strongest component is $T = 53.4 \pm 7.0$ yr, with an amplitude of $5.54 \pm 0.83$ and a false probability of FAP$\ll 1\%$; the second strongest one is $T = 12.4 \pm 2.0$ yr, with an amplitude of $3.97 \pm 0.83$ and a false probability of FAP $< 1\%$.

All the analysis confirms the existence of a $\sim$ 12.0 yr time scale in the optical light curve. Also, a hint of a $\sim$ 53 yr time scale shows up in our analysis.

However, one should keep in mind that the light curve coverage is only twice as long as the $\sim$ 53 yr time scale, although its FAP is $\ll 0.01$. It is interesting that the $\sim$ 53 yr time scale is about four times larger than the confirmed $\sim$ 12 yr time scale. In this sense, it is possibly a harmonic of the $\sim$ 12 yr time scale. In addition, the long time scale is close to the time between the $\sim$ 1913 and

$\sim$ 1971 outbursts. In any case, the authenticity of the $\sim$ 53 yr time scale should be confirmed with more observations. We can regard the $\sim$ 12.0 yr period as physically significant.

For AGNs, the variability mechanism is not yet well understood. Some models have been proposed to explain the possible optical long-term periodic variations: the binary black hole model, the thermal instability model, and the perturbation model (Fan 2005). The promising models are the binary black hole model and the perturbation model. The helical jet related to the binary black holes have been used to explain the optical variability behavior for the objects (3C 345, OJ 287, BL Lacertae and PKS 0735+178).

For a binary black hole pair with semi-major axes $a_1$ and $a_2$, the value of $a_1 + a_2$ can be estimated by Kepler's law,

$$P^2 = \frac{4\pi^2(a_1 + a_2)^3}{G(M + m)}, \tag{7}$$

which can be written in the form

$$P \sim 1.72 M_8^{-1/2} r_{16}^{3/2} \left(1 + \frac{m}{M}\right)^{-1/2} \text{ yr}, \tag{8}$$

where $M$ and $m$ are the primary and the secondary black hole masses, $P$ is the orbital periodicity, $G$ is the gravitational constant, $M_8$ is the mass of the primary black hole in units of $10^8 M_\odot$, and $r_{16} = a_1 + a_2$, which is given in units of $10^{16}$ cm. From a work by Sillanpää et al. (1988), $r \sim 0.1$ pc; if we take $\frac{m}{M} \ll 1$, then the obtained $12.2 \pm 0.6$ yr period, namely $9.34 \pm 0.46$ yr in the source frame ($z = 0.306$), suggests that the primary black hole mass is $M_8 = 31.5$, namely, $M = 3.15 \times 10^9 M_\odot$. From our recent work, we obtained $m \sim 3 \times 10^7 M_\odot$ (Fan et al. 2009). In this sense, the ratio of $\frac{m}{M} \sim 0.01$.

In this work, we adopted the Discrete Correlation Function (DCF), the Jurkevich method, the power spectral (Fourier) analysis, and the CLEANest method to search for periodicity in the light curve of OJ 287, and confirmed the period of $12.2 \pm 0.6$ yr. In addition, we also found a hint of a period of $\sim$ 53.0 yr. The 12.2 yr period suggests that there is a binary system with a mass ratio of $\sim$ 0.01 in the binary black hole system at the center of OJ 287.

**Acknowledgements** The work is partially supported by the National Natural Science Foundation of China (Grant No. 10633010), the 973 program (2007CB815405) and the Bureau of Education of Guangzhou Municipality.

## References


Abraham, Z. 2000, A&A, 355, 915
Aller M.F., Aller, H. D., & Hughes, P. A. 2003, ApJ, 586, 33
Bai, J. M., Xie, G. Z., Li, K. H., et al. 1999, A&AS, 136, 455
Boettcher, M., Fultz, K., Aller, H. D., et al. 2009, ApJ, 694, 174
Cellone, S. A., Romero, G. E., Combi, J. A., & Martí, J. 2007, MNRAS, 381, L60
Ciprini, S., Takalo, L. O., & Tosti, G. 2007, A&A, 467, 465
Dai, B. Z., Xie, G. Z., Li, K. H., et al. 2001, AJ, 122, 2901
Dai, B. Z., Li, X. H., Liu, Z. M., et al. 2009, MNRAS, 392, 1181
Edelson, R. A., & Krolik, J. H. 1988, ApJ, 333, 646
Fan, J. H. 1999, MNRAS, 308, 1032
Fan, J. H. 2005, ChJAA (Chin. J. Astron. Astrophys.), 5S, 213
Fan, J. H., Xie, G. Z., Pecontal, E., et al. 1998a, ApJ, 507, 173
Fan, J. H., Adam, G., Xie, G. Z., et al. 1998b, A&AS, 133, 163
Fan, J. H., & Lin, R. G. 2000, ApJ, 537, 101
Fan, J. H., Lin, R. G., Xie, G. Z., et al. 2002, A&A, 381, 1

Fan, J. H., Liu, Y., Yuan, Y. H., et al. 2007, A&A, 462, 547
Fan, J. H., Zhang, Y. W., Qian, B. C., et al. 2009a, ApJS, 181, 466
Fan, J. H., et al. 2009b, RAA (Research in Astronomy and Astrophysics), 9, 751
Ferraz-Mello, S. 1981, AJ, 86, 619
Fidelis, V. V., Yakubovskyi, D. A., & Voytkova, Y. V. 2009, Astronomy Lett., 35, 579
Foster, G. 1995, AJ, 109, 1889
Foster, G. 1996, AJ, 111, 541
Gupta, A. C., Cha, S.-M., Lee, S., et al. 2008a, AJ, 136, 2359
Gupta, A. C., Deng, W. G., Joshi, U. C., Bai, J. M., & Lee, M. G. 2008b, New Astronomy, 13, 375
Heidt, J., & Wagner, S. J. 1996, A&A, 305, 42
Horne, J., & Baliunas, S. 1986, ApJ, 302, 757
Hudec, R., Hudec, L., Sillanpää A., Takalo, L., & Kroll, P. 2001, ESASP, 459, 295
Jurkevich, I. 1971, Ap&SS 13, 154
Kidger, M. R., Takalo, L., & Sillanpää, A. 1992, A&A, 264, 32
Kurochkin, N. E. 1971a, Astr. Tsirk, 654, 1
Kurochkin, N. E. 1971b, Astr. Tsirk, 654, 7
Kurtanidze, O. 2008, The Starburst-AGN Connection Conference, Oct. 27–31, 2008 Shanghai, China
Liu, F. K., Xie, G. Z., & Bai, J. M. 1995, A&A, 295, 1
Lloyd, C. 1984, MNRAS, 209, 697
Mead, A. R. G., Ballard, K. R., Brand, P. W. J. L., et al. 1990, A&AS, 83, 183
Miller, H. R., Wingert, D. W., McGimsey, B. Q., et al. 1976, AJ, 81, 298
Pollock, J. T., Pica, A. J., Smith, A. G., et al. 1979, AJ, 84, 1658
Qian, B. C., & Tao, J. 2003, PASP, 115, 490
Qian, B. C., & Tao, J. 2004, PASP, 116, 161
Qian, B. C., Tao, J., & Fan, J. H. 2002, AJ, 123, 678
Qian, B., Tao, J., & Fan, J. 2000, PASJ, 52, 1075
Raiteri, C. M., Villata, M., Larionov, V. M., et al. 2008, A&A, 480, 339
Romero, G. E., Cellone, S. A., & Combi, J. A., & Andrcuhow, I. 2002, A&A, 390, 431
Scargle, J. 1982, ApJ, 263, 835
Sillanpää, A., Haarala, S., Valtonen, M. J., et al. 1988, ApJ, 325, 628
Sillanpää, A., Takalo, L. O, Pursimo, T., et al. 1996a, A&A, 305, L17
Sillanpää, A., Takalo, L. O, Pursimo, T., et al. 1996b, A&A, 315, L13
Smith, A. G., et al. 1982, in Low Frequency Variability of Extragalactic Radio Sources, eds. W. D. Cotton, & S. R. Spangler (NRAO: Green Bank), 55
Takalo, L. O., 1994, Vistas in Astron., 38, 77
Takalo, L. O., Nilsson, K., Lindfors, E., et al. 2008, in AIP Conf. Ser. 1085, 705
Tao, J., Qian, B. C., & Fan, J. H. 2004, PASP, 116, 634
Tao, J., Fan, J. H., Qian, B. C., & Liu, Y. 2008, AJ, 135, 737
Tateyama, C. E., Kingham, K. A., Kaufmann, P., et al. 1999, ApJ, 520, 627
Tsesevich, V. P. 1972, Astr. Tsirk, 688, 7
Valtonen, M., Kidger, M., Lehto, H., & Poyner, G. 2008, A&A, 477, 407
Venturi, T., Dallacasa, D., Orfei, A., et al. 2001, A&A, 379, 755
Villata, M., Raiteri, C. M., Larionov, V. M., et al. 2008, A&A, 481, L79
Visvanathan, N., & Elliot, J. L. 1973, ApJ, 179, 721
Xie, G. Z., Zhou, S. B., Dai, B. Z., et al. 2002a, MNRAS, 329, 689
Xie, G. Z., Liang, E. W., Xie, Z. H., & Dai, B. Z. 2002b, AJ, 123, 2352
Zheng, Y. G., Zhang, X., Bi, X. W., Hao, J. M., & Zhang, H. J. 2008, MNRAS, 385, 823