ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **133**, 163–169 (1998)

The infrared and optical variability of OJ 287

J.H. Fan[1,2,3], G. Adam[1], G.Z. Xie[4], S.L. Cao[5], R.G. Lin[2], Y.P. Qin[4], Y. Copin[1], J.M. Bai[4], X. Zhang[4], and K.H. Li[4]

[1] CRAL Observatoire de Lyon, 9 avenue Charles André, 69563 Saint-Genis-Laval Cedex, France
[2] Center for Astrophysics, Guangzhou Normal University, Guangzhou 510400, China
e-mail: jhfan@guangztc.edu.cn
[3] Joint Laboratory for Optical Astronomy, Chinese Academy of Sciences, China
[4] Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011, China
[5] Department of Astronomy, Beijing Normal University, Beijing, China

Received March 19; accepted May 25, 1998

Abstract. In this paper, the long-term historical optical ($UBVRI$) and near-infrared (JHK) data are presented with some new observations in the optical (February 1994-January 1995) and near-infrared (November 1995) bands included for BL Lac object OJ 287. The new optical data in V-band are in agreement with the results reported by other authors (Sillanpaa et al. 1996a; Arimoto et al. 1997), a close correlation between the color index of $B-V$ and the magnitude V has been obtained from our new observations. The new infrared observations presented here indicate that the source was at a high level in the infrared band during the observation period. From the available literature, we have got that the largest variations for $UBVRIJHK$ bands are respectively: $\Delta U = 4\overset{\rm m}{.}72$; $\Delta B = 5\overset{\rm m}{.}93$; $\Delta V = 5\overset{\rm m}{.}18$; $\Delta R = 4\overset{\rm m}{.}45$; $\Delta I = 4\overset{\rm m}{.}07$; $\Delta J = 3\overset{\rm m}{.}87$; $\Delta H = 3\overset{\rm m}{.}78$; $\Delta K = 3\overset{\rm m}{.}54$. A strong correlation is found between the optical and near-infrared bands when the DCF method is used, which suggests that these two bands have the same emission mechanism.

Key words: BL Lacertae objects: individual: OJ 287; general — infrared: galaxies

1. Introduction

BL Lac objects are a special subclass of active galactic nuclei (AGNs), which show some extreme properties: rapid and large variability, high and variable polarization, no or only weak emission lines in its classical definition.

BL Lac objects are variable not only in the optical band, but also in radio, infrared, X-ray, and even γ-ray bands. Some BL Lac objects show strongly correlated variation between radio and optical emissions with some delay (e.g. Tornikoski et al. 1994). Some BL Lac objects show that the spectral indices change with the brightness of the sources (Bertaud et al. 1973; Brown et al. 1989; Fan 1993), generally, the spectrum flattens when the source brightens, but different phenomenon has also been observed, from 3C 66A for instance (see De Diego et al. 1997).

The nature of AGNs is still an open problem; the study of AGNs variability can yield valuable information about their nature, and the implications for quasars modeling are extremely important (Blandford 1996). From the telescopes in China (the optical telescopes: 1-m telescope at Yunnan Observatory, the 1.56-m telescope at Shanghai Observatory, and the 2.16-m telescope at Beijing Observatory; and the 1.26 m infrared telescope at Beijing observatory), we have monitored dozens of AGNs, including BL Lac objects, quasars, and Seyfert galaxies (Xie et al. 1987, 1988a,b, 1990, 1991, 1992, 1994; Fan et al. 1997; Bai et al. 1998; Xie et al. 1998).

OJ 287 (VRO 20.08.1) was discovered in radio observation by Dickel et al. (1967) and in the optical band by Thompson et al. (1968). Spectroscopic observations of Miller et al. (1978) showed a weak [O_{III}] spectral feature with a redshift of 0.306, which was confirmed by later observation of Sitko & Junkkarinen (1985) and Stickel et al. (1989). Early observations indicated that it was variable in the radio (Blake 1970) and optical bands (Kinmin & Conkin 1971). It was observed to show only continuum emission (Adam et al. 1972) and high linear polarization (Kinman & Conkin 1971; Nordsiek 1972). It has been observed extensively since.

OJ 287 is one of the very few AGNs for which continuous light curve over more than one hundred years has been observed. Its observational properties from radio to X-ray have been reviewed by Takalo (1994). The light curve in optical band shows the strong signature of an outburst that occurs with a period of 12 years. Models including binary black hole can explain these variations (Sillanpaa et al. 1988a). The outburst predicted to occur in the fall of 1994 confirmed the 12-year period (Sillanpaa et al. 1996b,c).

Besides the long-term large outburst, OJ 287 has also shown some interesting fluctuations of brightness on times ranging from less than 1 hour (Visvanathan et al. 1973; Veron & Veron 1975; Carrasco et al. 1985) to about a week (Kinman et al. 1974). It is one of the objects in our optical monitoring program (see Xie et al. 1994; Bai et al. 1998).

Large infrared variations have been seen in the source. Variations of 0.3 to 0.5 magnitudes in the near-infrared bands over a time scale of one day have been reported during its outburst by Holmes et al. (1984a) and during its low state by Wolstencroft et al. (1982) and Impey et al. (1984). Lorenzetti et al. (1989) reported variations of $0\overset{m}{.}3$ over a time scale of 3 hours and $0\overset{m}{.}5$ over a day and $\langle J-H\rangle = 0.83$, $\langle H-K\rangle = 0.91$. As reported in the optical band (Takalo & Sillanpaa 1989), a correlation between color index and magnitude has been found in the infrared band: Gear et al. (1986a) found a correlation between the infrared spectral index and the J band flux from data covering the period February 1983 to February 1986 after the 1983 outburst. Kidger et al. (1994) and Zhang & Xie (1996) also found the correlation. But no such significant correlation was found in the data of 1986 February through 1987 December (Lorenzetti et al. 1989). In November 1995, it was detected in our observation program at Xinglong station of Beijing Observatory (see Xie et al. 1998 for detail).

In this paper, we will present both historical and new data in the optical and infrared bands, and deal with them by means of the DCF method. The paper has been arranged as follows: In Sect. 2, we will present the observations; in Sect. 3, the correlation analysis method (DCF); in Sect. 4, we will discuss our results; and in Sect. 5, we will give a brief conclusion.

2. Observations

2.1. New observation

During 1994 and 1995, OJ 287 was observed with the 1-m RRC telescope at Yunnan Observatory, which is equipped with a direct CCD camera at the Cassegrain focus, and the 1.26-m Infrared telescope at Xinglong station of Beijing Observatory. The daily averaged magnitudes are presented in Tables 1 and 2. The data reduction and the detailed magnitudes will appear in separate papers altogether with other BL Lac objects observed during the same period (Bai et al. 1998, for the optical data and Xie et al. 1998, for infrared data).

Table 1. Daily averaged magnitudes of OJ 287

Date	B	V
94-02-07	16.07(0.03)	
94-02-08		15.62(0.03)
94-04-18	15.96(0.01)	
94-12-04	15.52(0.01)	15.04(0.01)
94-12-05	15.75(0.05)	15.08(0.04)
94-12-06	15.49(0.08)	14.85(0.04)
95-01-23	15.55(0.09)	15.15(0.07)
95-01-24	15.57(0.07)	15.35(0.07)
95-01-25	15.78(0.08)	15.49(0.07)
95-01-26	15.53(0.08)	15.20(0.05)
95-01-27		15.32(0.05)
95-01-28	15.66(0.08)	15.28(0.05)

Table 2. Daily averaged magnitudes of OJ 287

Date	J	H	K
95-11-16	10.19(0.16)	10.45(0.17)	9.40(0.14)
95-11-17	9.91(0.26)	9.78(0.38)	9.13(0.13)
95-11-18	11.13(0.31)	10.83(0.40)	9.67(0.38)

2.2. Historic observations

Since no infrared observation is available before 1971, and in order to compare the optical data with the infrared data, only the observations in optical band after 1971 have been compiled (Martynov 1971; Huruhata 1971; Burkhead 1971; Locher 1972; Strittmatter et al. 1972; Craine & Warner 1973; Goldsmith & Weistrop 1973; Visvanathan 1973; Frohlich et al. 1974; Selmes et al. 1975; Veron & Veron 1975; Kikuchi et al. 1976; O'Dell et al. 1978a,b; Usher 1979; Hagen-Thorn et al. 1980; Pushell & Stein 1980; Shaefer 1980; Gaida & Roser 1982; Takalo 1982; Haarala et al. 1983; Bortle 1983a,b; Sitko et al. 1983; Corso et al. 1984, 1986, 1988; Holmes et al. 1984a; Moles et al. 1984, 1985; Sillanpaa et al. 1985; Sitko et al. 1985; Sitko & Junkkarinen 1985; Brindle et al. 1986; Cayatte et al. 1986; Miller 1987; Monella 1987; Monella & Verdenet 1987; Sillanpaa 1987; Smith et al. 1987; Xie et al. 1987, 1988a,b, 1989, 1990, 1991, 1992, 1994; Sillanpaa 1988a,b; Webb et al. 1988; Brown et al. 1989; Takalo 1989; Mead et al. 1990; Takalo et al. 1990; Sillanpaa et al. 1991a,b; Sitko & Sitko 1991; Takalo 1991; Takalo et al. 1992a; Valtaoja et al. 1991; Carini et al. 1992; Kidger & Takalo 1993; Okyudo 1993; Smith et al. 1993; Fiorucci & Tosti 1994a,b; Meusinger 1994a,b; Vanmunster & Cautern 1994; Kidger 1995; Arimoto et al. 1997). All those data and the data presented in Table 1 are used in our analysis. The data in $UBVRI$ bands are shown in Figs. 1a–e.

The infrared (JHK) are from Epstein et al. (1972), Rieke et al. (1977), O'Dell et al. (1977, 1978a), Pushell & Stein (1980), Allen et al. (1982), Wolstencroft et al. (1982), Impey et al. (1982, 1984), Sitko et al. (1983), Holmes et al. (1984a,b), Brindle et al. (1986), Gear et al. (1986a,b), Landau et al. (1986), Roelling et al. (1986), Smith et al. (1987), Impey & Neugebauer (1988), Brown et al. (1988),

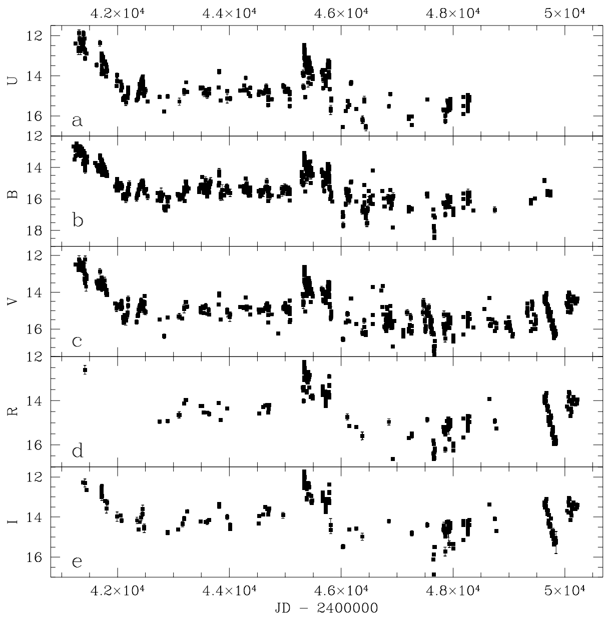

Fig. 1. a) The long-term U light curve of OJ 287 covering the period 1971–1991, there are no new data available in the literature after 1991. **b)** The long-term B light curve of OJ 287 from 1971 to 1995. **c)** The long-term V light curve of OJ 287 from 1971 to 1996. **d)** The long-term R light curve of OJ 287 from 1972 to 1996. **e)** The long-term I light curve of OJ 287 from 1972 to 1996

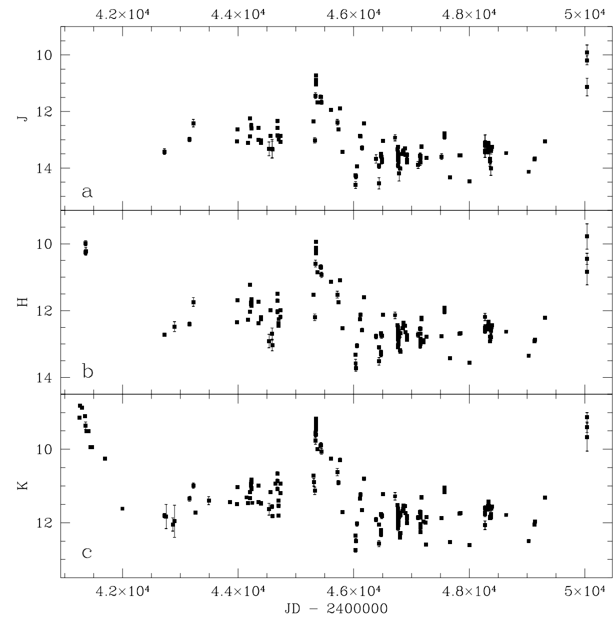

Fig. 2. a) The long-term J light curve of OJ 287 in covering a period of 1975 through 1995, the discontinuity of the light curve is due to the lack of observation in this band. **b)** The long-term H light curve of OJ 287 covering a period of 1972 through 1995, the discontinuity of the light curve is due to the lack of observation in this band. **c)** The long-term K light curve of OJ 287 covering a period of 1971 through 1995, the discontinuity of the light curve is due to the lack of observation in this band

Lorenzetti et al. (1989), Mead et al. (1990), Takalo et al. (1992b), Bersanelli et al. (1992), Sitko & Sitko (1991), Gear (1993), Kidger et al. (1994), Litchfield et al. (1994). Some early data are derived from the figure of Soifer & Neugebauer (1980). The infrared (JHK) data are shown in Figs. 2a–c.

2.3. Variations

From the available literature, we found that the variations in the $UBVRIJHK$ bands are: $\Delta U = 4\overset{\mathrm{m}}{.}72(11\overset{\mathrm{m}}{.}86-16\overset{\mathrm{m}}{.}58)$; $\Delta B = 5\overset{\mathrm{m}}{.}93(12\overset{\mathrm{m}}{.}47-18\overset{\mathrm{m}}{.}40)$; $\Delta V = 5\overset{\mathrm{m}}{.}18(12\overset{\mathrm{m}}{.}22-17\overset{\mathrm{m}}{.}40)$; $\Delta R = 4\overset{\mathrm{m}}{.}45(12\overset{\mathrm{m}}{.}25-16\overset{\mathrm{m}}{.}70)$; $\Delta I = 4\overset{\mathrm{m}}{.}07(11\overset{\mathrm{m}}{.}73-15\overset{\mathrm{m}}{.}80)$; $\Delta J = 3\overset{\mathrm{m}}{.}87(10\overset{\mathrm{m}}{.}73-14\overset{\mathrm{m}}{.}60)$; $\Delta H = 3\overset{\mathrm{m}}{.}78(9\overset{\mathrm{m}}{.}94-13\overset{\mathrm{m}}{.}73)$; $\Delta K = 3\overset{\mathrm{m}}{.}54(8\overset{\mathrm{m}}{.}81-12\overset{\mathrm{m}}{.}75)$. The color indices are respectively: $U-B=-0.60\pm0.14$ ($N=391$ pairs); $B-V=0.46\pm0.17$ ($N=470$ pairs); $B-I=1.42\pm0.25$ ($N=186$ pairs); $V-R=0.48\pm0.14$ ($N=243$ pairs); $V-I=0.98\pm0.22$ ($N=235$ pairs); $R-I=0.56\pm0.12$ ($N=198$ pairs); $J-H=0.82\pm0.16$ ($N=173$ pairs); $H-K=0.88\pm0.14$ ($N=193$ pairs); $J-K=1.70\pm0.19$ ($N=173$ pairs).

From our observations presented in Table 1, a correlation has been found for $B-V$ and V (see Fig. 3): $V=-(1.02\pm0.08)(B-V)+(15.61\pm0.01)$ with a correlation coefficient $r=-0.831$. This correlation means that the spectrum flattens when the source brightens.

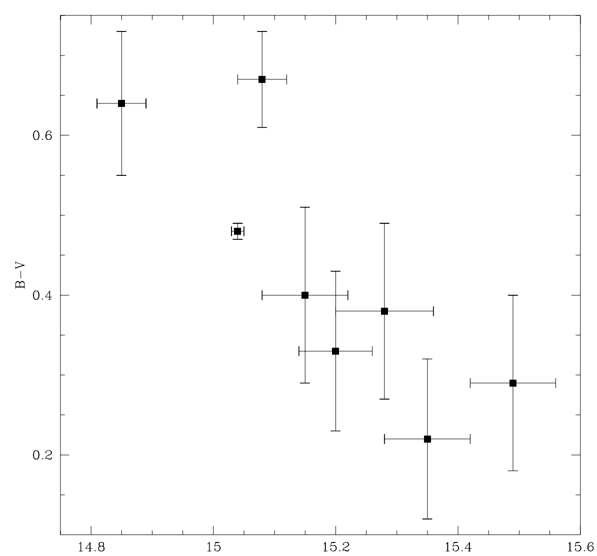

Fig. 3. Color index–($B-V$) versus against V magnitude. The relation suggests that the spectrum changes with the brightness of the source

3. Correlation analysis of variations

3.1. DCF method

OJ 287 is violently variable in the optical and infrared bands. We want to investigate whether the variations in these two bands are correlated or not. To do so, we use the DCF method described by Edelson & Krolik (1988) and generalized by Hufnagel & Bregman (1992) which is suitable for data sets which are not sampled evenly or at the same density.

Following Edelson & Krolik (1988) and Hufnagel & Bregman (1992) (see also Tornikoski et al. 1994), we have calculated the DCF. Firstly, we have calculated the set of unbinned correlation (UDCF) between data points in the two data streams a and b

$$UDCF_{ij} = \frac{(a_i - \bar{a}) \times (b_j - \bar{b})}{\sqrt{\sigma_a^2 \times \sigma_b^2}} \quad (1)$$

where a_i and b_j are points in the data sets, $\bar{a}$ and $\bar{b}$ are the means in the data sets, and σ_a and σ_b are the standard deviations of each data sets. Secondly, we have averaged the points sharing the same time lag by binning the $UDCF_{ij}$ in suitably sized time-bins to get the DCF for each time lag τ

$$DCF(\tau) = \frac{1}{M}\Sigma UDCF_{ij}(\tau) \quad (2)$$

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

$$\sigma(\tau) = \frac{1}{M-1}\{\Sigma[UDCF_{ij} - DCF(\tau)]^2\}^{0.5}. \quad (3)$$

3.2. Correlation between optical and infrared bands

From the light curve, we know that there are more observations in the K band for the infrared data and in the V band for the optical data. So, we use the V and K bands to investigate the correlation between optical and infrared emissions. The results are shown in Fig. 4 (a: for bin = 30 days and b: for bin = 50 days). It is clear that the peak in DCF corresponds to "zero" point suggesting that the two bands are correlated with almost no time delay.

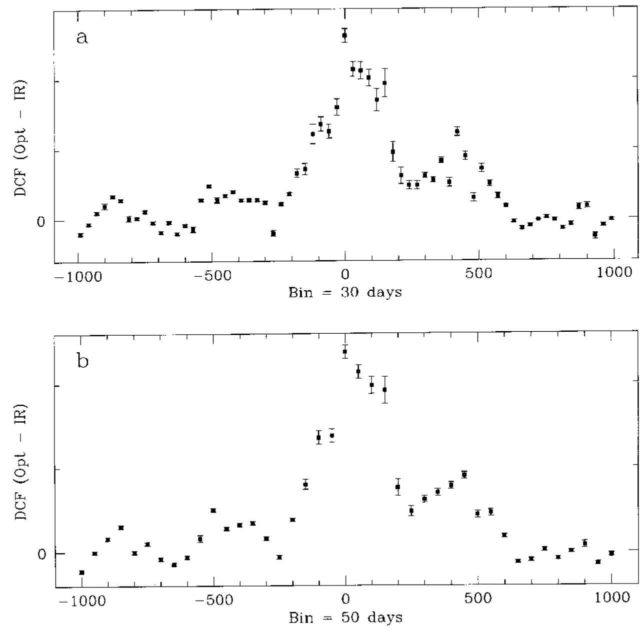

Fig. 4. a) DCF between B and K bands with bin = 30 days. **b)** DCF between B and K bands with bin = 50 days

4. Discussion

OJ 287 is one of the most extensively studied objects. Its optical light curve covers a period starting at the end of last century, and shows obviously the outbursts with a period of 12 years, which has been explained by the double black hole model (Sillanpaa et al. 1988a). The detail detection from the OJ-94 project also show clearly the double peak structure of the outburst, tentatively explained by Lehto & Valtonen (1996) and Sillanpaa et al. (1996a). Besides, the observations from the OJ-94 project has aroused much interest in the light curve explanation (Lehto 1996; Sadun 1996; Valtonen et al. 1996; Sundelius et al. 1996; Sillanpaa et al. 1996a). During the project OJ 287 was detected for the first time by EGRET (Pian et al. 1996; Webb et al. 1996), but its radio emission was in a low state during the first optical burst (Valtaoja et al. 1996).

4.1. Spectral index

OJ 287 is violently variable in spectral indices as well as in the flux in the optical and infrared bands. The long-term analysis of this object showed that the spectra steepened after 1971 in the optical bands (Takalo & Sillanpaa 1989) and the infrared spectra steepened during the 1975 to 1990 period (Zhang & Xie 1996). Its spectral indices changed with the brightness of the source. Takalo & Sillanpaa (1989) found a strong association between $B - V$ and V magnitude using the available optical data, but not for $U - B$ and V. In the present paper, we did not find correlation for $U - B$ and V either. There is no correlation for $B - V$ and $U - B$, or $V - I$ and I.

For infrared data, Gear et al. (1986a) and Kidger et al. (1994) found a correlation between $J - K$ and J based on the limited data, this tendency has also been reported by Zhang & Xie (1996). But during the OJ-94 project, the optical spectral index kept unchanged even during the outburst period (Sillanpaa et al. 1996a), the color indices also stayed constant during the observations of Arimoto et al. (1997). It maybe that the correlation between the brightness and the spectral index does not hold during bursts. From our limited observation, there is a close

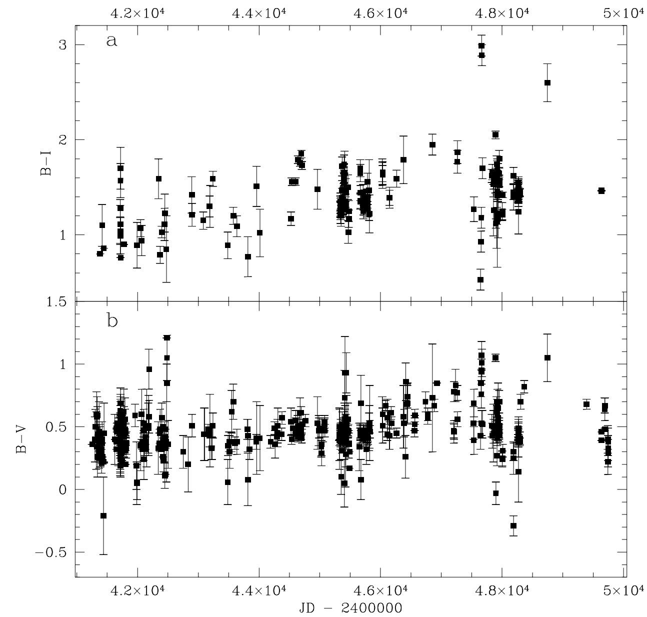

Fig. 5. a) Evolution of color index of $B-V$. **b)** Evolution of color index of $B-I$

correlation between $B-V$ and V (see Fig. 3). From the available data, $B-V$ and $B-I$ show the indications of a decrease of spectral index with the time after the 1972 burst; color indices show that the spectrum flattened during the 1983/1984 outbursts. But it is interesting to note that there is also clear spectral flattening during the time of about JD 2448000 when there was no large outburst (see Fig. 5).

4.2. Comparison of observations

In Autumn 1994, Fioruci & Tosti (1994a,b) announced that OJ 287 was at its high level. Arimoto et al. (1997) also obtained its optical data in the V, R and I bands covering a period of October 13, 1994 through May 25, 1996. They obtained that the object was at its high level of $V = 14\overset{\mathrm{m}}{.}03$ in the first half of November 1994 and fainted out to $V = 16\overset{\mathrm{m}}{.}5$ within 150 days. Comparing our data with theirs, we can see clearly that our data of $V = 14\overset{\mathrm{m}}{.}85 \pm 0.09$ on Dec. 6 of 1994 is in agreement with their result of $V = 14\overset{\mathrm{m}}{.}84 \pm 0.03$ on Dec. 6.79 of 1994, and our data of $V = 15\overset{\mathrm{m}}{.}32 \pm 0.05$ on January 27 of 1995 is also in agreement with their result of $V = 15\overset{\mathrm{m}}{.}50 \pm 0.04$ on January 26.72 of 1995. For other data we can not compare with theirs, because they got one point every week. During our observation, V changed from $15\overset{\mathrm{m}}{.}62$ (Feb. 8, 1994) to $14\overset{\mathrm{m}}{.}85$ (Dec. 6, 1995), which is also in good agreement with the results obtained by Sillanpaa et al. (1996a), who showed that the range of V was from $14\overset{\mathrm{m}}{.}0$ to $16\overset{\mathrm{m}}{.}5$. But there are no observations reported in the B band in other literature for the outburst. For our observations, the B magnitudes changed from $16\overset{\mathrm{m}}{.}07$ (Feb. 7, 1994) to $15\overset{\mathrm{m}}{.}49$ (Jan. 01, 1995). From Fig. 1 it is clear that the 1994 optical outburst was fainter than the previous two (1972, 1983). But in infrared bands, the peaks for the three (1972, 1983, 1995) outbursts are comparable. Comparing the peaks in the light curve of OJ 287 in the paper of Sillanpaa et al. (1996a), we can see that the peak in the 1910s is comparable with the peaks in the 1980s, and the peak in the 1920s is comparable with the peaks in the 1990s. So, we might have missed a large peak in the 1900s which should be comparable with the peaks of the 1970s. If this is true, then there should be a slow variation over about 70 years and we would expect that the following outburst (in 2006) should be brighter than the 1990s outburst.

4.3. Infrared observations

There is no report in the infrared bands from the object during the OJ-94 project. We had the opportunity to observe it with the 1.26-m infrared telescope during the middle of November 1995. The data shown in Table 2 indicate that the infrared emission of the source was at a high level with $K = 9\overset{\mathrm{m}}{.}13 \pm 0\overset{\mathrm{m}}{.}13$ on Nov. 17, 1995. It is comparable with the previous observation obtained during the optical outbursts: $K = 8\overset{\mathrm{m}}{.}8$ in 1972 (Soifer & Neugebauer 1980) and $K = 9\overset{\mathrm{m}}{.}25 \pm 0\overset{\mathrm{m}}{.}03$ in 1983 (Holmes et al. 1984a). From the three peaks, we can get that the intervals between the successive peaks is about 12.0 years, which is consistent with the period derived from the optical light curves (Sillanpaa et al. 1988a). From the figure in the paper of Sillanpaa et al. (1996a) it is clear that our infrared observations correspond to the second peak during the outburst of OJ 287. So, there should be a missed peak which occurred in the end of 1994!

4.4. Variability correlation

In order to investigate the emission mechanism from OJ 287, variations in the radio, optical and infrared bands have been discussed. Kinman et al. (1974) reported that there are some indications of a radio flux increase after the optical and infrared outburst, O'Dell et al. (1978) also reported that the 3 mm flux was related with that in the optical and infrared. But it is strange that no corresponding outburst was observed in radio band during OJ-94 project optical outburst. When it was at high level in optical band its radio emission was in a low state (Valtaoja et al. 1996). For the optical and infrared bands, a good correlation was obtained between the optical flux and that at 10 μm (Rieke & Kinman 1974) based on the limited data over limited period. The results shown in this paper indicate that the two bands are strongly correlated with almost no time delay. The reason for that the peak in the DCF is not so sharp is from the fact that the infrared data are fewer than the optical ones and that the clear double-peak in the optical is missed in the infrared observations.

5. Conclusion

In the present paper, the post-1971 infrared and optical data have been compiled and dealt with by means of the DCF method, the result indicates a strong correlation between these two bands, which suggests that the emission mechanisms in the optical and infrared bands are the same. The color index and brightness association is found from our new optical data. The time-dependent decreasing color indices post large outburst are also presented in the paper.

Acknowledgements. The authors thank the referee Dr. L. Takalo's comments. This work is supported by the National Scientific Foundation of China (the ninth-year important project) and the National Pandeng Project of China.

References

Adam G., Floquet M., Marchal J., Schneider M., 1972, C. R. Acad. Sci. Ser. B. 274, 201
Allen D.A., Ward M.J., Hyland A.R., 1982, MNRAS 199, 969
Arimoto J., Sadakano K., Honda S., Tanake K., 1997, PASP 109, 300
Bai J.M., Xie G.Z., Li K.H., et al., 1998 (in preparation)
Bersannelli M., Banchet P., Falomo R., Tanzi E.G., 1992, AJ 104, 28
Bertaud G.W., Wlericck G., Veron P., et al., 1970, ApL 6, 201
Blandford R.D., 1996, in "Blazar Continuum Variability" Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 475
Bortle J.E., 1983a, IAU Circ. 3780
Bortle J.E., 1983b, IAU Circ. 3792
Brindle C., Hough J.H., Bailey J.A., Axon D.J., Hyland A.R., 1986, MNRAS 221, 739
Brown L.M.J., Robson E.I., Gear W.K., Smith M.G., 1989, ApJ 340, 150
Burkhead M.S., 1971, IAU Circ. 2366
Craine E.R., Warner J.W., 1973, ApJ 179, L53
Carini M.T., Miller H.R., Noble J.C., Goodrich B.D., 1992, AJ 104, 15
Carrasco L., Dultzin-Hacyan D., Cruz-Gonzalez I., 1985, Nat 314, 146
Cayatte V., Chevreton M., Herpe G., Vanderriest C., Moles M., 1986, IAU Circ. 4208
Cohen M.H., Cannon W., Purcell G.H., et al., 1971, ApJ 170, 207
Corsco G.J., Ringwald F.A., Purchell B., 1988, PASP 100, 70
Corsco G.J., Schultz J., Dey A., 1986, PASP 98, 1287
Corsco G.J., Purchell B., Giroux M., Schultz J., 1984, PASP 96, 705
De Diego J.A., Kidger M.R., Gonzales, 1997, A&A 318, 331
Dickel J.R., Yang K.S., McVittie G.C., Swenson G.W., 1967, AJ 72, 757
Edelson R.A., Krolik J.H., 1988, ApJ 333, 646
Epstein E.E., Fogarty W.G., Hackney H.R., et al., 1972, ApJ 178, L51
Fan J.H., Xie G.Z., Lin R.G., et al., 1997, A&AS 125, 525
Fan J.H., 1993, Ph.D. Thesis, Yunnan Astronomic Observatory, Chinese Academy of Sciences
Fiorucci M., Tosti G., 1994a, IAU Circ. 6095
Fiorucci M., Tosti G., 1994b, IAU Circ. 6104
Frohlich A., Goldsmith S., Weistrop D., 1974, MNRAS 168, 417
Gaida G., Roser H.J., 1982, A&A 105, 362
Gear W.K., 1993, MNRAS 264, 919
Gear W.K., Roboson E.I., Brown L.M.J., 1986a, Nat 324, 546
Gear W.K., Brown L.M.J., Robson E.I., et al., 1986b, ApJ 304, 295
Goldsmith S., Weistrop D., 1973, ApJ 180, 661
Haarala S., Korhonen T., Sillanpaa A., Salonen E., 1983, IAU Circ, 3764
Hagen-Thorn V.A., 1980, ApSS 73, 263
Holmes P.A., Brand P.W.J.L., Wolstencroft R.D., Williams P.M., 1984b, MNRAS 210, 961
Holmes P.A., Brand P.W.J.L., Wolstencroft R.D., et al., 1984a, MNRAS 211, 497
Hufnagel B.R., Bregman J.N., 1992, ApJ 386, 473
Huruhata M., 1971, IAU Circ. 2366
Impey C.D., Neugebauer G., 1988, AJ 95, 307
Impey C.D., Brand P.W.J.L., Wolstencroft R.D., Williams P.M., 1984, MNRAS 209, 245
Impey C.D., Brand P.W.J.L., Wolstencroft R.D., Williams P.M., 1982, MNRAS 200, 19
Kidger M.R., 1995, IAU Circ. 6271
Kidger M.R., Takalo L.O., de Diego J.A., 1994, A&A 282, 369
Kidger M.R., Takalo L.O., 1993, IAU Circ. 5909
Kikuchi S., Mikami Y., Konno M., Inoue, 1976, PASJ 28, 117
Kinman T.D., Wardle J.F.G., Conklin E.K., et al., 1974, AJ 79, 349
Kinman T.D., Conkin E.K., 1971, ApL 9, 147
Landau R., Golish B., Jones T.J., et al., 1986, ApJ 308, 78
Lehto H., 1996, in "Blazar Continuum Variability" Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 80
Lehto H., Valtonen M.J., 1996, ApJ 460, 207
Litchfield S.L., Robson E.I., Stevens J.A., 1994, MNRAS 270, 341
Locher K., 1972, IAU Circ. 2380
Lorenzetti D., Massaro E., Ferola G.C., Spinoglio L., 1989, ApJS 71, 175
Martynov D.Ya, 1971, IAU Circ. 3365
Mead A.R.G., Ballard K.R., Brand P.W.J.L., et al., 1990, A&AS 83, 183
Meusinger H., 1994a, IAU Circ. 5971
Meusinger H., 1994b, IAU Circ. 5990
Miller H.R., 1987, Active Galactic Nuclei, Lecture Notes in Physics 307, Miller H.R., Wiita P.J. (eds.), p. 146
Miller J.S., French H.B., Hawley S.A., 1978, in "Pittsburg Conf. on BL LAc Objects", Wolf A.M. (ed.), p. 176
Moles M., Garcia-Pelayo J.M., Masegosa J., Aparicio A., 1985, ApJS 58, 255
Moles M., Gasia-Pelayo J., Masegosa J., 1984, MNRAS 211, 621
Monella R., 1987, IAU Circ. 4325
Monella R., Verdenet M., 1987 IAU Circ. 4378

Mutel R.L., Phillips R.B., 1987, in Superluminal Radio Sources, Zensus J.A. & Pearson T.J. (eds.). Cambridge, p. 60
Nordsiek K.H., 1972, ApL 12, 69
O'Dell S.L., Pushell J.J., Stein W.A., 1977, ApJ 213, 351
O'Dell S.L., Pushell J.J., Stein W.A., Warner J.W., 1978a, ApJS 38, 267
O'Dell S.L., Pushell J.J., Stein W.A., et al., 1978b, ApJ 224, 22
Okyudo M., 1993, Annu. Rep; Nishi-Harima, Obs. 3. 1
Pian E., et al., 1996, in "Workshop on Two Year of Intensive Monitoring of OJ 287 & 3C 66A", Takalo L.O. (ed.), Tuorla Observatory Reports 176, 26
Puschell J.J., Stein W.A., 1980, ApJ 237, 331
Quinn J., et al., 1995, in Proc. 24th Int. Cosmic Ray Conf. Room 2, 269
Racine R., 1970, ApJ 159, L99
Rieke G.H., Lebofsky M.L., Kemp J.C., Coyne G.V., Tapia S., 1977, ApJ 218, L37
Rieke G.H., Kinman T.D., 1974, ApJ 192, L115
Roelling T.L., Beckin E.E., Impey C.D., Werner M.W., 1986, ApJ 304, 646
Sadun A., 1996, in "Blazar Continuum Variability" Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 86
Selmes R.A., Tritton K.P., Wordsworth R.W., 1975, MNRAS 170, 15
Shaefer B.E., 1980, PASP 92, 255
Sillanpaa A., Takalo L.O., Pursimo T., 1996a, in "Blazar Continuum Variability", Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 74
Sillanpaa A., Takalo L.O., Pursimo T., et al., 1996b, A&A 305, L17
Sillanpaa A., Takalo L.O., Pursimo T., et al., 1996c, A&A 315, L13
Sillanpaa A., Mikkola S., Valtaoja L., 1991a, A&AS 88, 225
Sillanpaa A., Takalo L.O., Kikuchi S., Kidger M.R., de Diego J.A., 1991b, A&AS 88, 225
Sillanpaa A., Haarala S., Valtonen M.J., et al., 1988a, ApJ 325, 628
Sillanpaa A., Haarala S., Korhonen T., 1988b, A&AS 72, 347
Sillanpaa A., 1987, IAU Circ. 4296
Sillanpaa A., Teerikorpi P., Haarala S., Korhonen T., Efimov Y.S., Shakhovskoy N.M., 1985, A&A 147, 67
Sitko M.L., Sitko A.K., 1991, PASP 103, 160
Sitko M.L., Junkkarinen V.A., 1985, PASP 97, 1158
Sitko M.L., Schmidt G.D., Stein W.A., 1985, ApJS 59, 323
Sitko M.L., Stein W.A., Zhang Y.X., Wisniewski W.Z., 1983, PASP 95, 724
Smith P.S., Allen R.G., Angel J.R.P., 1993, ApJ 415, L83
Smith P.S., Balonek T., Elston R., Heckert P.A., 1987, ApJS 64, 459
Soifer B.T., Neugebauer G., 1980, IAU Symp. 96, 329 1980
Stickel M., Fried J.W., Kuhr H., 1989, A&AS 80, 103
Strittmatter P.A., Serkowski K., Carswell R., et al., 1972, ApJ 175, L7
Sundelius B., Wahde M., Letho H.J., Valtonen M.J., 1996, in "Blazar Continuum Variability", Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 99
Takalo L.O., 1996, in "Blazar Continuum Variability" Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 70
Takalo L.O., 1994, Vistas Astron. 38, 77
Takalo L.O., Sillanpaa A., Nilsson K., Kidger M.R., De Diego J.A., Piirola V., 1992a, AJ 104, 40
Takalo L.O., Kidger M.R., De Diego J.A., Sillanpaa A., Nilsson K., 1992b, AJ 104, 40
Takalo L.O., 1991, A&AS 90, 161
Takalo L.O., Kidger M.R., de Diego J.A., et al., 1990, A&AS 83, 459
Takalo L.O., Sillanpaa A., 1989, A&A 218, 45
Takalo L.O., Kidger M.R., 1989, IAU Circ. 4782
Takalo L.O., 1982, A&A 109, 4
Thompson J.R., Kraus J.D., Andrew B.H., 1968, ApJ 154, L1
Tornikoski M., Valtaoja E., Terasranta H., et al., 1994, A&A 298, 673
Usher P.D., 1979, AJ 84, 1253
Valtaoja E., et al., 1996, in "Workshop on Two Year of Intensive Monitoring of OJ 287 & 3C 66A" Takalo L.O. (ed.), Tuorla Observatory Reports 176, 13
Valtaoja L., Valtaoja E., Shakhovskoy N.M., Efimov Y.S., Sillanpaa A., 1991, AJ 101, 78
Valtonen M., Lehto H., Kokkonen K., Mikkola S., 1996, in "Blazar Continuum Variability", Miller H.R., Webb J.R. and Noble J.C. (eds.), ASP Conf. Ser. 110, 93
Vanmunster T., Cautern P. von, 1994, IAU Circ. 5944
Veron P., Veron-Cetty M.P., 1975, A&A 39, 281
Vermeulen R.C., Ogle P.M., Tran H.D., et al., 1995, ApJ 452, L5
Visvanathan N., 1973, ApJ 185, 145
Webb J., et al., 1996, in "Workshop on Two Year of Intensive Monitoring of OJ 287 & 3C 66A" Takalo L.O. (ed.), Tuorla Observatory Reports 176, 20
Webb J.R., Smith A.G., Leacock R.J., Fitzgibbons G.L., Gombola P.P., Sheppard D.W., 1988, AJ 95, 374
Wolstencroft R.D., Gilmore G., Williams P.M., 1982, MNRAS 201, 479
Xie G.Z., et al., 1998 (in preparation)
Xie G.Z., Li K.H., Zhang Y.H., et al., 1994, A&AS 106, 361
Xie G.Z., Li K.H., Liu F.K., et al., 1992, ApJS 80, 683
Xie G.Z., Li K.H., Cheng F.Z., et al., 1991, A&AS 87, 961
Xie G.Z., Li K.H., Cheng F.Z., et al., 1990, A&A 229, 329
Xie G.Z., Li K., Zhou Y., Lu R.W., Wang J.C., 1988a, AJ 96, 24
Xie G.Z., Lu R.W., Zhou Y., et al., 1988b, A&AS 72, 163
Xie G.Z., Li K.H., Bao M.X., et al., 1987, A&AS 67, 17
Zhang Y.H., Xie G.Z., 1996, A&AS 119, 199