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Infrared properties of OJ 287

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Abstract. — The paper presents the first evidence for the long-term near-infrared brightness, colour and spectral variability in the BL Lac object OJ 287. It had an infrared outburst of large amplitude during the beginning of 1983. The $J-K$ colour index increased linearly, and infrared spectrum also linearly steepened during the years 1975−1990. After then, both the $J-K$ colour and spectral index began to recover. Both the $J-K$ colour and the near-infrared spectral index shows also a strong correlation with the flux intensity, in the sense that when OJ 287 is fainter, $J-K$ is larger, and the near-infrared spectrum steeper. These properties show a very important similarity with the optical data of OJ 287 from the same time interval (Takalo & Sillanpää 1989). Our results argue that a single variable synchrotron source might be responsible for the photometric behaviour of OJ 287 in the near-infrared and optical regions.

Key words: BL Lac objects: individual: OJ 287 — infrared: galaxies

1. Introduction

OJ 287 is so extensively studied in the optical band that it is unnecessary to list optical properties from its photometric history. Here we only refer to its large flux variations which might show a period of 11.6 yr for the optical outburst (Kidger et al. 1992 and references therein). It is very important to collect historical observational data of BL Lac objects together and to investigate their long-term behaviour in flux, colour and spectral variations in various wavelenghths, because also the long time-scales behaviour help us to understand their physics. Takalo & Sillanpää (1989) had studied the long-term behaviour of OJ 287 in the optical region. BL Lac objects emit the largest part of their total energy budget in the infrared and so one might expect any results to be more pronouced in this region (Gear 1993), therefore, we would like to probe the long-term behaviour of OJ 287 in the near-infrared region.

Large infrared variations have been found for OJ 287 on almost timescales from minutes to years. Wolstencroft et al. (1982) detected 1 mag variation in 50 s and 0.5 mag variation in 30 min during low state. Gear et al. (1986) reported considerable variations in the infrared flux and spectral index and a strong correlation between them during the period 1983−1984. Variations of 0.3 mag in 3 hr and 0.5 mag in one day were found by Lorenzetti et al. (1989), but there were no significant colour variations. Kidger et al. (1994) found a strong correlation between the spectral index and the intensity in the J-band from their five nights of pseudo-simultaneous JHK monitoring of OJ 287 during March 1991.

In all the studies above the results were based on observations taken in a limited time interval and in a limited flux range. In this paper, we shall present, based on the published JHK data, the long-term flux, colour and spectral behaviour of OJ 287 in the near-infrared, where we shall also compare the properties both in the near-infrared and in the optical region.

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2. Observations and results

We have collected all the published JHK observations of OJ 287 together from the literatures since 1972, all of the cited references are as follows in time order: Epstein et al. 1972; Riek et al. 1977; O'Dell et al. 1977; O'Dell et al. 1978; Puschell & Stein 1980; Allen et al. 1982; Wolstencroft et al. 1982; Impey et al. 1982, 1984; Holmes et al. 1984; Gear et al. 1986; Rolling et al. 1986; Laudau et al. 1986; Smith et al. 1987; Brown et al. 1989; Lorenzetti et al. 1989; Mead et al. 1990; Takalo et al. 1992; Bersanelli et al. 1992; Gear 1993; Litchfield et al. 1994; Kidger et al. 1994.

2.1. *Long-term near-infrared variability*

The light curve of K magnitudes based on the above mentioned observations is shown in Fig. 1. Each point in Fig. 1 is a nightly averaged value, and for more than one observations each night, the averaged data are calculated.

Figure 1 clearly shows the outburst in 1983 and the minima in 1975−1976 and 1984−1988. The properties of variations before 1975 is not clear due to only one observation during this period. However, the K=10.51 magnitude in 1972 is obviously brighter than others besides the outburst in 1983, which might indicate the outburst in 1972, but it is little viable. Also noticeable is the fast decline in the source brightness after the 1983 outburst. Variability of about 3.5 mag in *JHK* bands is found from 1972 to 1993. By examining the long-term optical (V magnitude) variability (Takalo & Sillanpää 1989), we find that the long-term variability behaviour in the near-infrared is very similar to the one in the optical. This result shows a strong correlation between the near-infrared and optical emission.

2.2. $J-K$ colour indices

Using the above mentioned observations we calculated the J−K colour indices for OJ 287. They are displayed in Figs. 2 and 3. In Fig. 2 the colour indices are shown against the observing time, nightly and half a year averages are shown in Figs. 2a and 2b, respectively. Because we are mainly interested in the overall colour behaviour of OJ 287, we have not presented the error bars in the figures. Errors in the averages could be quite large, due to the strong and rapid variability of OJ 287 and to the large differences in the number of observations used in calculating the averages, in some cases only one observations can be obtained. As can be seen from Fig. 2, the J−K colour indices have increased linearly during the years 1975−1990. But the J−K colour indices in 1983 departured from the the overall behaviour. After 1990, the J−K began to decrease. The mean range of the J−K colour indices of OJ 287 is 1.5−1.9. The overall behaviour of J−K before 1990 is similar to the one of the B−V of OJ 287 found by Takalo & Sillanpää (1989). We have also found that the B−V of OJ 287 are in the range of 0.40−0.45 after 1990 from the published optical observations (e.g. Takalo et al. 1992; 1994), which is smaller than those before 1990. Therefore, both the infrared and optical colour index have begun to decrease after 1990. However, the J−K colour indices in 1976 and 1972−1974 cannot be obtained, where we cannot compare them with the B−V in the same years. Anyway, the overall behaviour in J−K and B−V of OJ 287 is similar.

In Fig. 3 the J−K colour indices are shown against the J magnitudes, and nightly and half a year averages are shown in Figs. 3a and 3b, respectively. As can be seen from Fig. 3, the J−K colour shows clear depedence on J magnitude; there is a linear dependence of J−K on J from J=11 to J=13.5. After that the dependence is steeper. Gear et al. (1986) and Kidger et al. (1994) reported similar correlations using the limited observations in the limited time. We have also found similar linear dependence of J−K on K and H magnitude. Takalo & Sillanpää (1989) have found a strong correlation between B−V colour and V magnitude using the long-term optical photometric data. From their Fig. 3b, we can see that the linear dependence of B−V on V is not significantly different from the one of J−K on J in this paper.

2.3. *The near-infrared spectral index*

In order to specify the spectral properties, we have also fitted a power law ($F_\nu \propto \nu^\alpha$) to the observed *JHK* data, using a least square fitting method. All of the correlation coefficients for these fits are greater than 0.96, indicating that the power law spectrum is a reasonable model for the near-infrared emission in OJ 287. The nightly and half a year averaged spectral index α are shown against time in Figs. 4a and 4b, respectively. It is evident from the figures, that the observed spectra become linearly steeper from 1975 to 1990, but begin to flatten from 1991. Also the spectrum in 1983 depatures from the overall behaviour due to the outburst. Takalo & Sillanpää (1989) analysed the yearly averaged optical spectral indices, also showing that the optical spectrum steepened during the years 1971−1988. Also in 1976 (minimum) the optical index was much different from the ones in 1975 and 1977, and prominent is the sharp steepening of the optical spectrum after the 1983 outburst. We cannot compare the near-infrared spectra in 1972−1974 and 1976 with the optical ones in the same period due to lack of the near-infrared data. We also find that the optical spectra flattened after 1991 (see Takalo et al. 1992; 1994). Anyway, the near-infrared and optical spetra show overall similar behaviour in such a long period. We also found nearly identical spectral indices for the infrared and optical emission, indicating that the emission spetrum shows insignificant curve from the infrared to optical wavelengths.

In Figs. 5a and 5b we show the nightly and half a year averaged near-infrared spectral index against the flux in the J band. A correlation between α and the J flux is obvious, similar to the one found in the optical by Takalo & Sillanpää (1989). We have also noticed that the averaged spectra in the near-infrared seem to be flatter during 1970s than 1980s, it is also similar to the ones seen in the optical (Takalo & Sillanpää 1989; see their Fig. 5)

3. Discussion

We have collected all available *JHK* data of the classic BL Lac object OJ 287 together to investigate the long-term near-infrared brightness, colour and spectral index behaviour. We have also compared the long-term behaviour in the near-infrared presented by this paper with the optical one presented by Takalo & Sillanpää (1989). We list our main results briefly:

1. Large and rapid variability are shown in both the near-infrared and optical region. An important property is a tight similarity in the long-term behaviour of variability in these two wavebands. This could indicate a similar

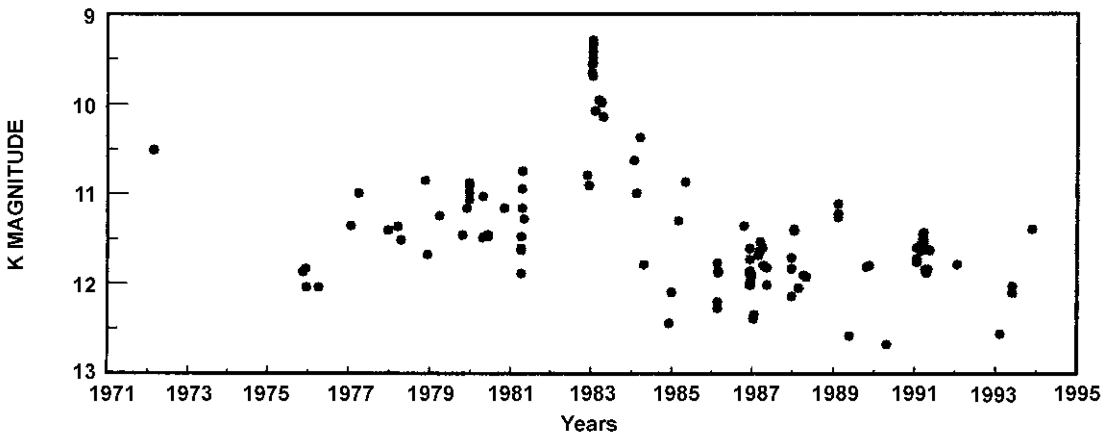

Fig. 1. K magnitude light curve of OJ 287 since 1972, based on data from the references in the text. The points are K magnitudes nightly averaged

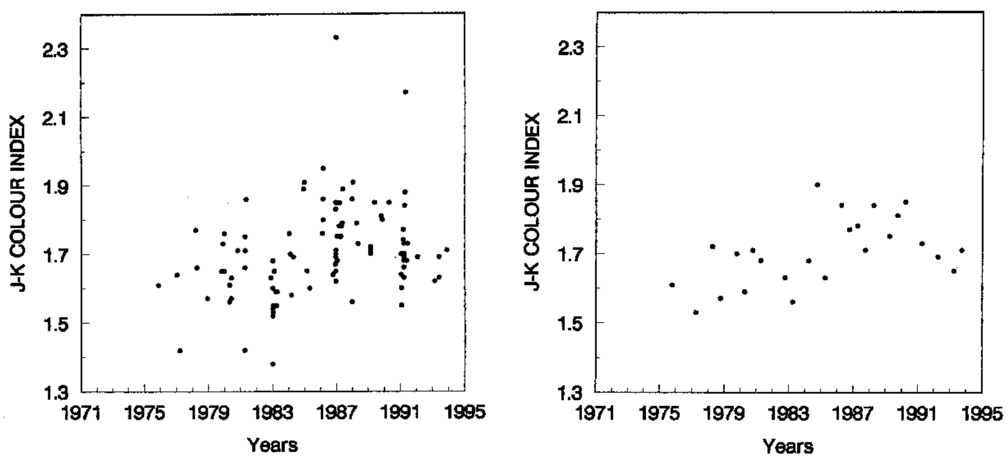

Fig. 2. Time evolution for the $J-K$ colour indices of OJ 287 since 1972. **a)** nightly averaged $J-K$ colour indices; **b)** half a year averaged ones

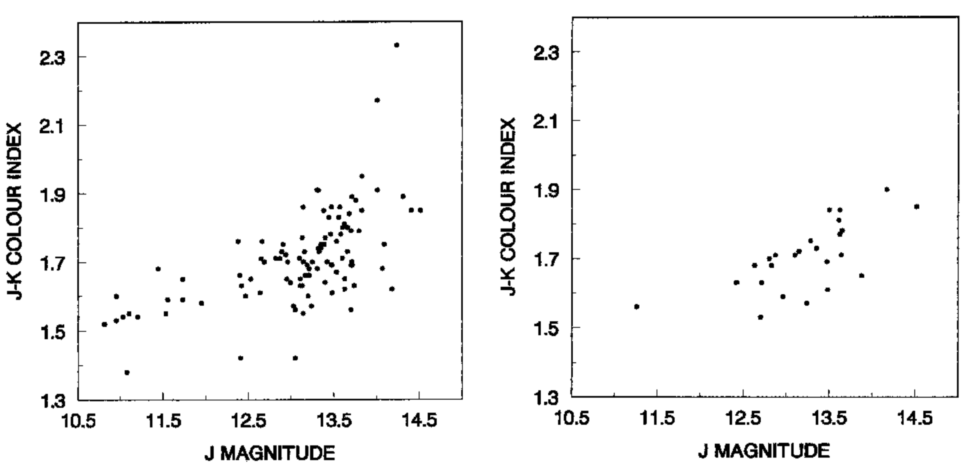

Fig. 3. $J-K$ colour indices versus J magnitude, showing a strong correlation. **a)** points are nightly averaged values; **b)** half a year averages

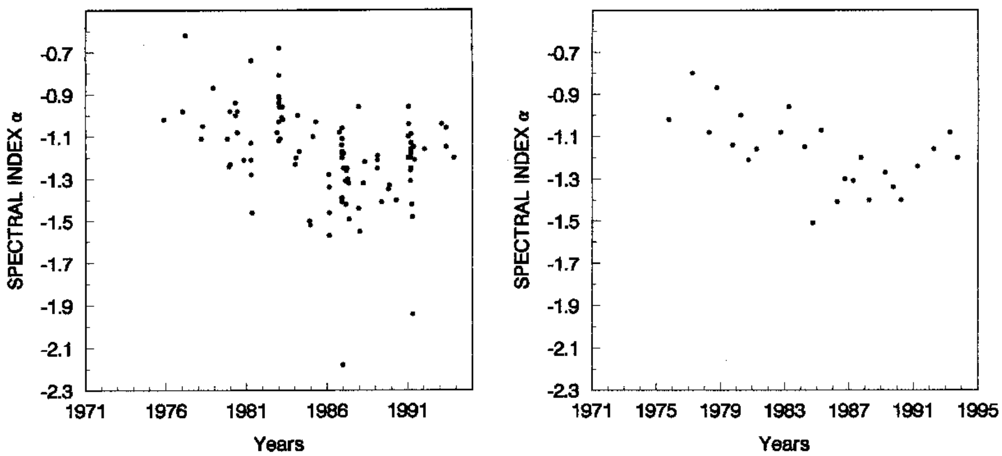

Fig. 4. Time evolution for the near-infrared spectral indices of OJ 287 since 1972. **a)** Nightly averaged spectral indices; **b)** half a year averaged ones

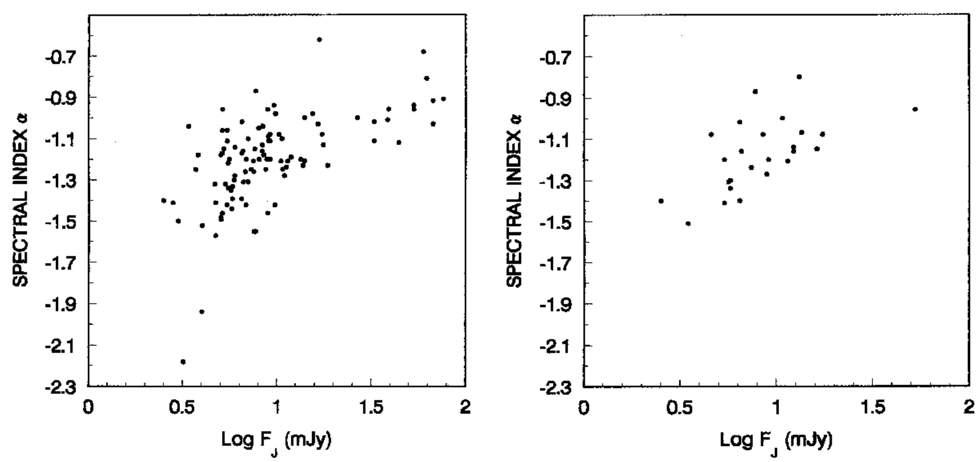

Fig. 5. The near-infrared spectral indices versus the fluxes in J band, showing a correlation. **a)** Nightly averages; **b)** half a year averages

period for the outburst and a correlation for emission in these two bands of OJ 287.

2. Both the infrared and optical spectrum of OJ 287 had steepened during the years 1972−1990, after that, the spectrum begun to flatten in these two regions.

3. The J–K and B–V colour index behaves also similarly, they had increased linearly during the years 1972−1990, after that, begun to decrease.

4. The spectral and colour index shows also clear correlation with the flux and magnitude, which is very similar for both the near-infrared and optical region.

5. The emission from the near-infrared and optical region can be resonablely represented by a power law, respectively, with identical spectral index. Hence, the spectrum does not curve obviously from the near-infrared to optical region, and can be represented by a power law with a single spectral index.

Anyway, the long-term behaviour in brightness, colour and spectral variability and their correlations is very similar for both the near-infrared and optical emission of OJ 287. Our results argue that a single variable sychrotron source might be responsible for the emission from OJ 287 in the near-infrared and optical wavelengths. Using a various method, Hagen-Thorn et al. (1994) also argued a single variable synchrotron source responsible for the photometric behaviour of OJ 287 in the IR-optical-UV region.

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