PROCEEDINGS OF SCIENCE

The OJ 287 colors during a multiwavelength campaign

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In 2005 the blazar OJ 287 exhibited an interesting variable behavior in the optical band. An optical outburst was observed in the period Oct.-Nov. 2005, and two XMM-Newton X-ray observations were performed in correspondence with two active optical states of the source (an intermediate flare and such claimed outburst). These satellite pointings triggered and invited observations by several radio, mm, near-IR, and optical ground-based observatories. During an intensive WEBT campaign coordinated with the satellite observations, and longer-term monitoring observations, a rather good set of multi-band optical and near-IR photometric data was collected. Such multi-color data of OJ 287 are briefly introduced.

Workshop on Blazar Variability across the Electromagnetic Spectrum
April 22-25, 2008
Palaiseau, France

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PoS(BLAZARS2008)030

1. Introduction

The high-energy and variable flux, the broad-band synchrotron and inverse Compton (possibly connected) emission components, make blazars ideal targets for multiwavelength campaigns, engaging space-borne observatories and ground-based facilities.

In particular the blazar OJ 287 (PG 0851+202, 1ES 0851+203, 3EG J0853+1941, $z = 0.306$) is an optically highly-variable (> 3 mag variations) and low/intermediate-energy peaked BL Lac object (LBL/IBL), very interesting for a twofold reason. First, this source is historically among the best observed AGN in the optical/radio bands, having a very good database of observations (for example [10, 14]), allowing therefore a more significant statistical investigation, and a wider study of the parameter space of variability. Secondly it is one of the very few extragalactic sources, where a major periodical or quasi-periodical signature is claimed, because quite similar optical outbursts occurred at approximately 12 yr intervals since the early 1900s. More information and details on the long-term historical observations, predictions and dynamical modelling can be found in [9, 10, 12, 13, 14, 15, 16, 17, 18, 19]. Moreover the search for supermassive binary black holes should become a major research field in the next years, because of the next completion of the first gravitational waves observatories, and the future developments in multi-messenger astro-particle physics. The modelling of the supposed optical cyclic activity seems to confirm the binary nature of the system, providing evidence for the loss of orbital energy in agreement with the emission of gravitational waves from the system [16].

2. Brief résumé of the campaign

In this section only a short summary of the multiwaveband campaign is reported. Some details are described also in the captions of the figures reported here.

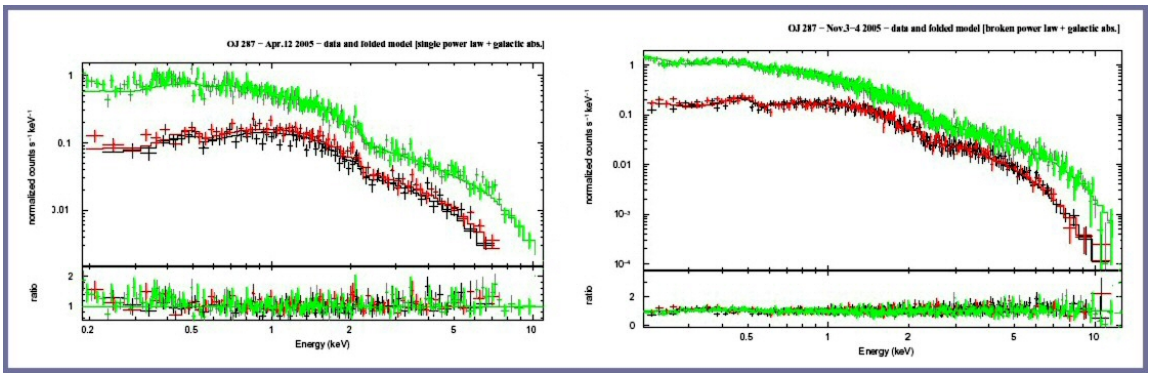

Figure 1: XMM-Newton combined EPIC (pn, MOS1 and MOS2 detectors) X-ray spectra of OJ 287, belonging to the two observations performed on Apr.12, and Nov.3-4, 2005. *Left panel*: the Apr.12 spectrum can be described by a simple power-law plus galactic absorption, $N_H = 3.09 \times 10^{20}$ cm^{-2}, $\Gamma = 1.63 \pm 0.02$, $\chi^2_r = 1.03$ $d.o.f. = 367$, $F_{2-10\mathrm{KeV}} = (2.5 \pm 0.8) \times 10^{-12}$ erg s^{-1} cm^{-2}. *Right panel:* the Nov.3-4 spectrum can be described by a broken power-law plus galactic absorption, $N_H = 3.09 \times 10^{20}$ cm^{-2}, $\Gamma_1 = 2.65^{+0.12}_{-0.07}$, $\Gamma_2 = 1.79 \pm 0.02$, $E_{br} = 0.69^{+0.04}_{-0.05}$ keV, $\chi^2_r = 1.03$ $d.o.f. = 927$, $F_{2-10\mathrm{keV}} = (1.82 \pm 0.07) \times 10^{-12}$ erg s^{-1} cm^{-2}.

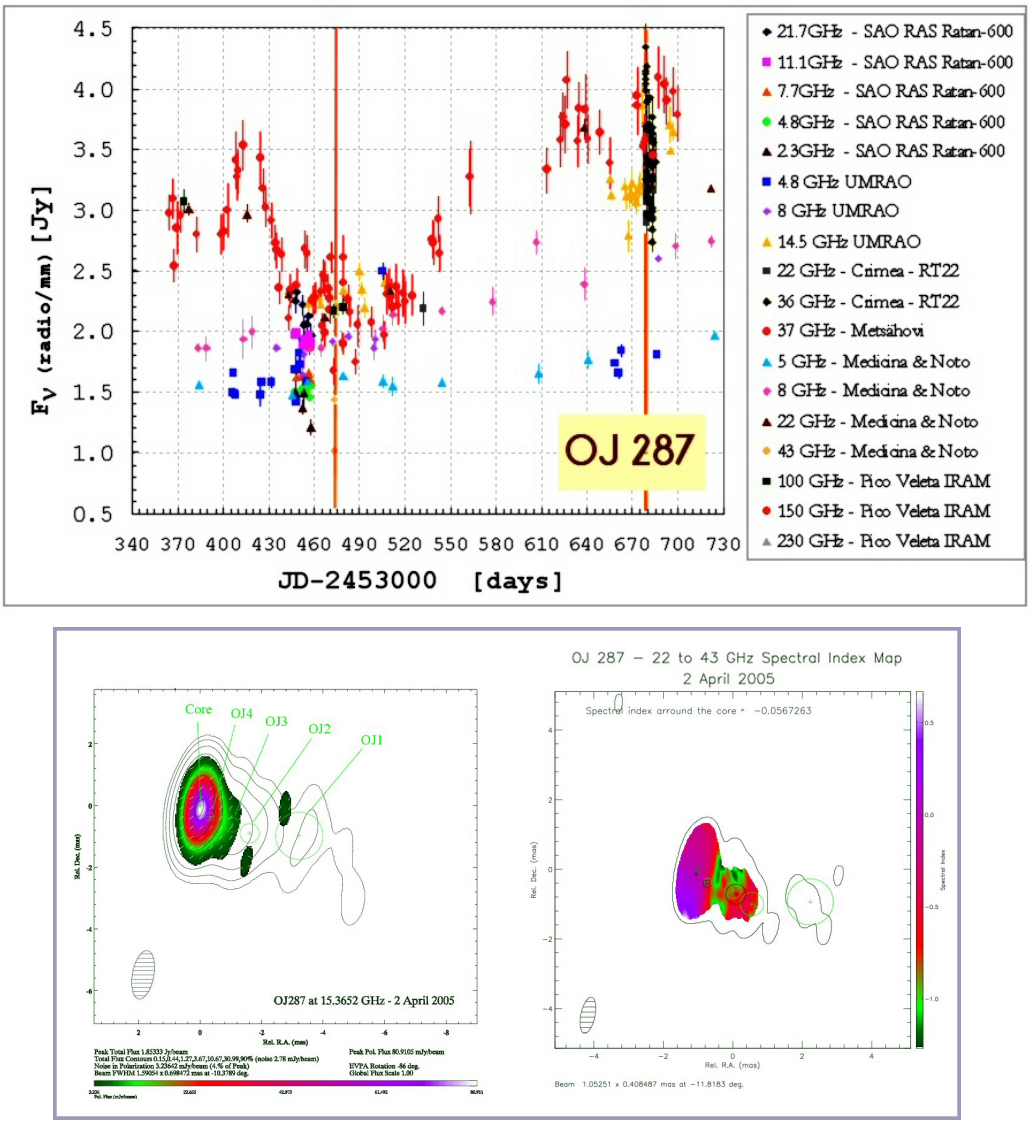

Figure 2: *Upper panel*: The Nov.2004-Dec.2005 multiband light curves of the radio/mm fluxes of OJ 287 (observing bands span from 2.3 to 230 GHz), obtained during the extended campaign. *Lower panel*: 22 GHz VLBA intensity-polarization image of OJ 287 obtained in Apr.02, 2005 (left) and map of the spectral index of the jet from 22 GHz to 43 GHz (right). Contours in the left map represent the total intensity, the colour scale the polarized intensity, and the superimposed sticks the orientation of the polarization electric vectors.

Two X-ray snapshots of OJ 287 by the XMM-Newton satellite, based on our GO run, were performed in Apr.12, 2005 and Nov.3-4, 2005 together with radio, mm, near-IR, and optical data obtained by a ground-based and coordinated WEBT campaign, and by longer-term observations obtained within the ENIGMA Network. Moreover, data of OJ 287 obtained from further independent observing programs (like the program at VLBA) were also collected.

The whole dataset of radio, mm, near-IR, and multiband optical observations has been collected by more than 30 ground-based observatories. The intensive coordinated WEBT campaign

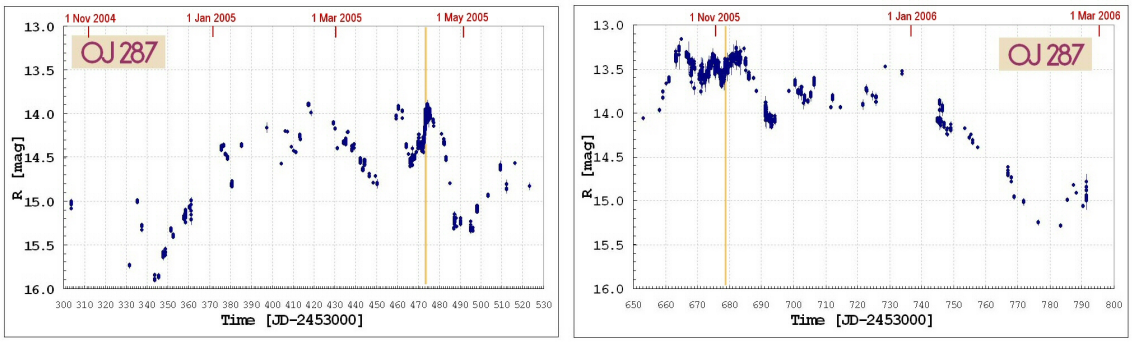

Figure 3: Optical (*R*-band magnitude) light curve obtained during the coordinated, intensive and short MW campaign by the Whole Earth Blazar Telescope (WEBT) consortium, and during longer-term monitoring observations (ENIGMA network observatories, plus other independent programmes and observatories), invited and triggered by the two XMM-Newton pointings in 2005. This light curve covers two optical observing seasons for the blazar (Oct.2004 - Mar.2006). The XMM-Newton space observatory pointed OJ 287 twice (Apr.12 and Nov.3-4, 2005, vertical lines in the figs.) following our granted GO AO-4 proposal. X-ray observations were coincident with two main active stages in the optical band (a mild flare in Apr. and an outburst in Oct.-Nov.). The second X-ray observation was performed during an optical enduring ($\sim$ 20 days) and time-structured (3 major symmetric wiggles) outburst.

covers a period of about 1 week around the first XMM-Newton pointing in Apr.2005, and about 1 month around the second pointing of Nov.2005.

About the high energy data of OJ 287, we can mention that past X-ray observations of OJ 287 were performed by ASCA [5, 7, 6] and *Beppo*-SAX [8], while very recent X-ray observations have been obtained with the Suzaku satellite [11].

The X-ray spectra obtained by the EPIC camera (pn-MOS1 and MOS2 detectors) on board of XMM-Newton; the radio data obtained in several bands; and the long-term optical light curve in the best sampled *R*-band collected are all reported and described concisely in Fig.1, 2 and 3.

Among the most interesting results we can mention:

- (i) an enduring, symmetrical, and time structured optical outburst discovered, and intensively monitored in the period Oct.-Nov. 2005;
- (ii) rather good evidence of a broken power-law X-ray spectrum (i.e. a two-component, synchrotron plus IC spectrum, typical signature of intermediate blazars, or a thermal tail end) discovered by the EPIC instrument on Nov.3-4;
- (iii) a clear frequency dependence of the mean structural position angle of the radio-jet in VLBA maps, consistent with a ballistic jet precession model, and a polarization structure mostly concentrated on the emission core.
- (iv) an evidence for intra-day variability at radio-bands [4].

Some of these results are anticipated and introduced in [2, 3] while a more detailed and complete presentation of data and results will appear in [1].

3. The colors of OJ 287

The whole optical and near-infrared dataset of the coordinated and extended campaign on OJ 287 is reported in Fig.4, while a zoom on it is displayed in Fig.5. This "multicolor" light curve reports observations in 8 spectral bands (i.e. the *UBVRI* optical bands and *JHK* near-infrared bands) and was obtained by the collaboration of more than 30 ground-based (professional and amateur) observatories. Such multi-band data allows to calculate spectral indexes, when simultaneous observations are available (frames spread in about less than half hour). In Fig.4 (lower panel) the whole temporal light curve of the optical *BVRI* spectral index is shown, while in Fig. 6 is displayed the scatter plot between the optical *BVRI* spectral index and the *R*-band flux. A spectral flattening during the flares is evident in both the plots. We remember that the whole period covered by the light curve reported in Fig.4 and Fig.5 is October 2004 - April 2006. The WEBT intensive-observations (about 1 week around the first satellite pointing date in Apr.2005, and about 20 days around the second satellite pointing date in Nov.2005), provided a good record of the temporal shapes and multi-color behavior during the April flare and the October-November outburst. More details on

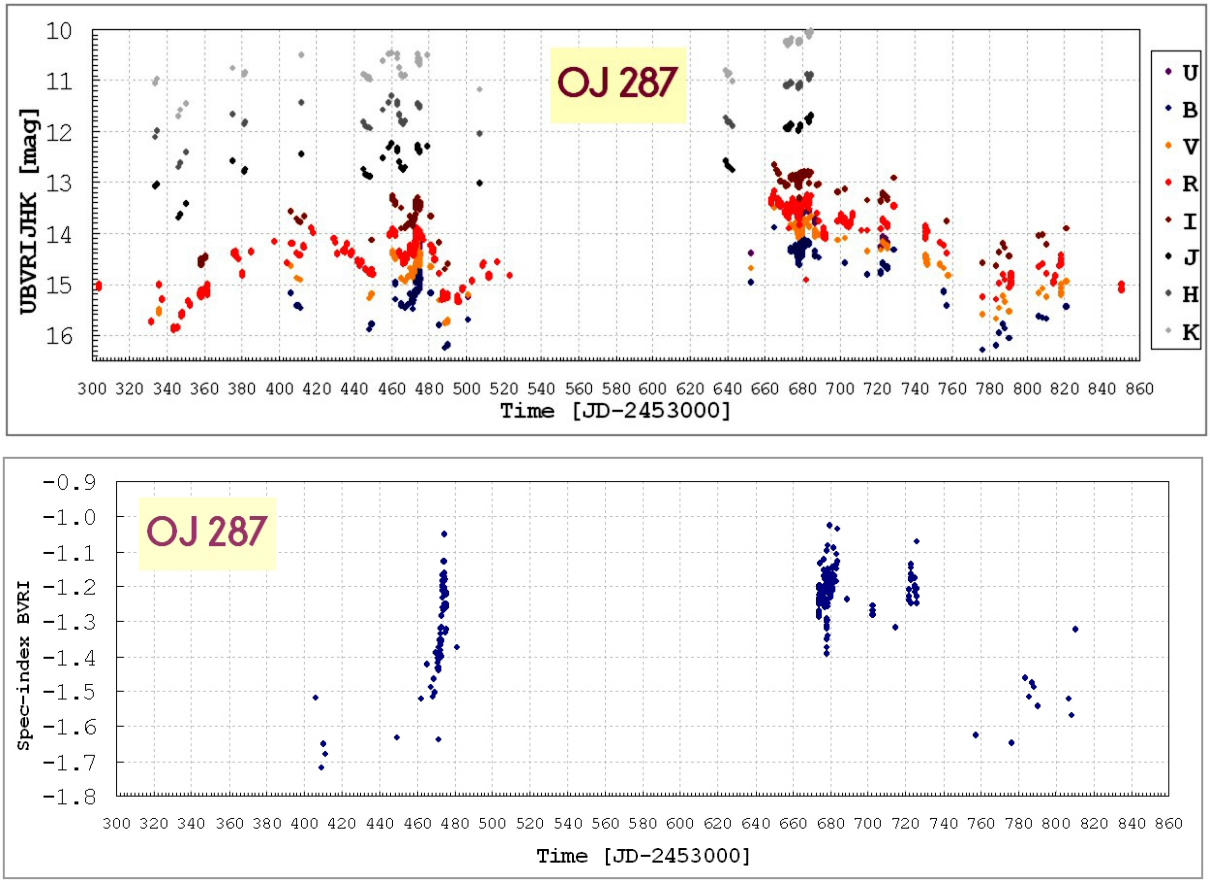

Figure 4: *Upper panel:* the whole optical and near-infrared light curves of the coordinated and extended campaign on OJ 287. This "multicolour" data set covers the period October 2004 - April 2006. *Lower panel:* the corresponding temporal light curve of the optical *BVRI* spectral index, calculated with simultaneous data in the four optical filters, when available. A spectral flattening during the flares is evident.

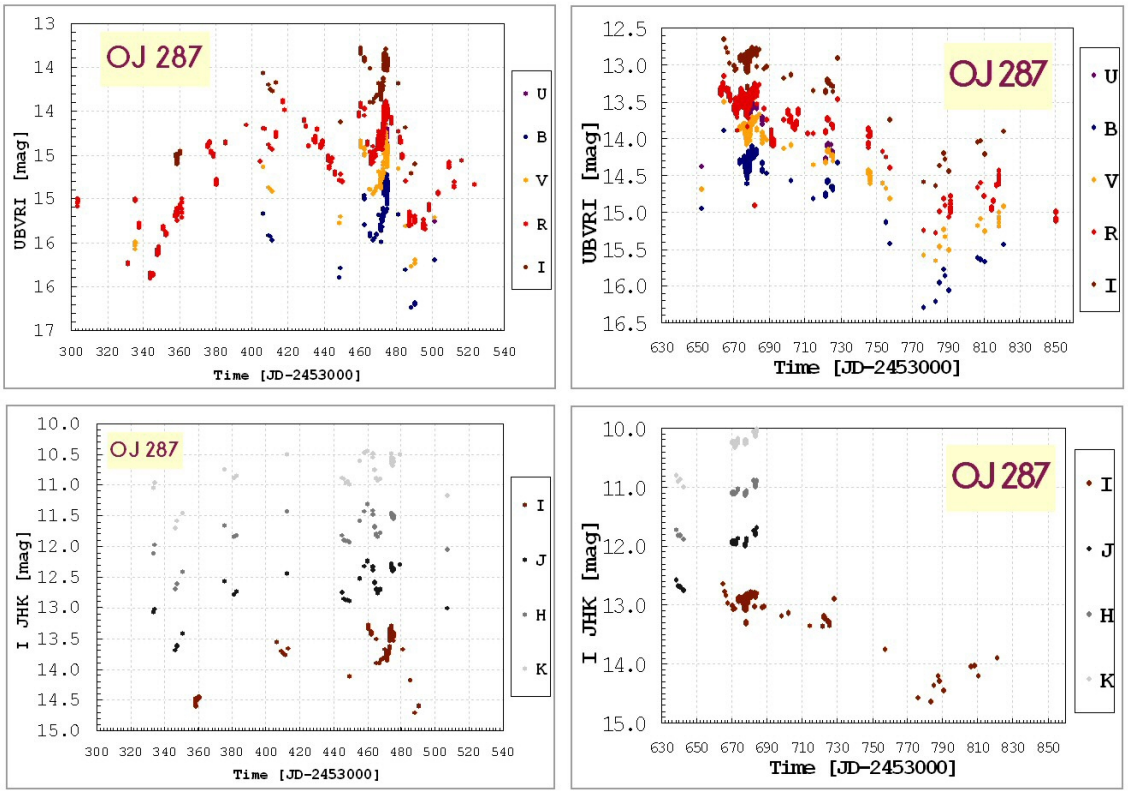

Figure 5: More detailed zooms on the optical *UBVRI* and near-IR *JHK* multi-color light curves reported in the previous Figure. The *I*-band light curve is shown here on both the optical and near-IR panels for comparison.

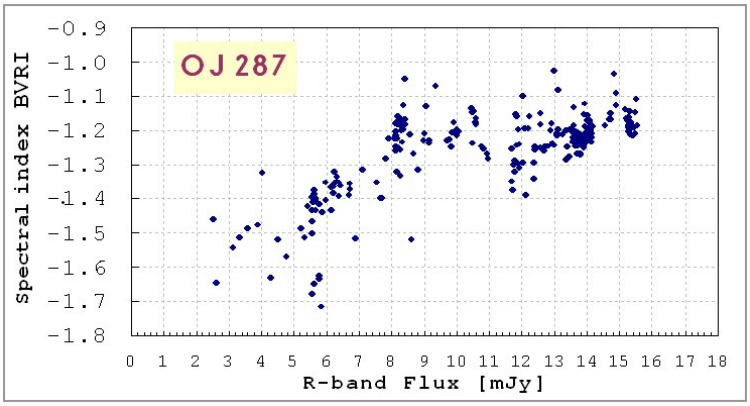

Figure 6: The scatter plot between the optical *BVRI* spectral index and the *R*-band flux exhibits again, in general, a flattening of the optical spectrum when the flux intensity increases.

data and results can be found in [1].

This appreciable observing effort on OJ 287 is still ongoing joined with further parallel/multi-monitoring observing programs devoted to follow this interesting blazar.

Acknowledgments

Based on data taken and assembled by the WEBT collaboration. Based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and NASA. The teams belonged to the former Research Training Network ENIGMA, acknowledge the funding by European Community's Human Potential Programme under contract HPRN-CT-2002-00321.

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