How much red may a Blazar be ?

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Abstract

We present the first results of a search for BL Lac objects having the synchrotron peak at frequencies lower than the optical-NIR ones. Simultaneous optical-NIR observations combined with radio data collected from literature allowed us to evaluate the frequency of the synchrotron peak of a set of 11 sources: we found a correlation between this frequency and the radio-optical spectral index. We found a marked optical variability in our set of sources but did not detect appreciable colour variations.

1 Introduction

The first samples of BL Lac objects, selected on the basis of their radio or X-ray emissions, showed an apparent dichotomy between sources with Spectral Energy Distribution (SED) peaked in the infrared (LBL) and sources peaked in the UV or even X-rays (HBL) (Padovani and Giommi 1995, ApJ 444, 567).

Further studies filled in the gap (e.g. the DXRBS, RGB, 200 mJy samples) with sources having intermediate characteristics and the term IBL (Intermediate BL Lac) was used to indicate them, but up to now it is not clear how much far the peak frequency of the SED of a BL Lac can go into the IR or the X-ray bands.

Sources peaking far in the IR (lower than 10^{13} Hz) have been called Very Low-energy Peaked BL Lac (shortly VLBL) by Anton et al. (2004, MNRAS 356, 225). Such sources should have a large ratio between radio and optical fluxes and, according to the standard scenario of synchrotron emission process, one would expect for such sources a steep spectrum in the optical-NIR and a variability in the optical band comparable to, or even higher than, that of the LBL sources.

In order to study in a systematic way the properties of the VLBL sources, we selected 11 "VLBL candidate" from literature data and started a multiwavelength observational campaign in the B (Johnson), V (Johnson), R (Cousins), I (Cousins), J, H and K bands.

We also analysed all the historical images available on-line (scanned plates from POSS I and POSS II Surveys and UK-Schmidt Survey) with the aim to inspect the optical variability of our set of sources on long time scales.

2 Selection of "VLBL candidates"

The selection of our 11 "VLBL candidates" (see Table 1) was based on literature data following the criteria listed below:

- BL Lac classification from a featureless optical spectrum;
- radio flux at 5 GHz higher than 200 mJy;
- V magnitude, corrected for the intestellar absorption, higher than 17.0;
- spectral index α_{ro} higher than 0.6.

Moreover, we preferred to select sources at high Declination ($> +50°$) to have the possibility to observe them during the entire year.

Being optically faint, none of our objects is included in the 200 mJy sample (Anton et al. 2004, MNRAS 352, 688).

Data from the Sloan Digital Sky Survey (SDSS) are available for four sources: an optical spectral index α_{SDSS} in Table 1 was evaluated from their u, g, r, i, z magnitudes.

3 Observations

The data used in this work were collected in several runs from January 2005 to March 2006. Photometric observations were performed in the B, V, R, I band with the telescopes of Loiano (1.5m) and Asiago (1.8m) both equipped with liquid nitrogen cooled CCD cameras.

In a few nights (3) we carried out simultaneous observations in the J, H and K band with the AZT24 telescope of Campo Imperatore (1.1m) equipped with an infrared CCD camera.

The exposure times depended upon the brightness of the source, the telescope and the wheater conditions but they typically were in the range of 5-10 minutes for R and I filters, 15-20 minutes for B and V filters and 2-3 minutes for J, H and K filters.

4 Data reduction

Bias and flat field corrections of the frames were performed with IRAF [1] tasks and aperture photometry was carried out using the DAOPHOT routine of the IRAF package. For each frame a photometric radius equal to the average FWHM of the measurable stars was used.

The preliminary analysis of the data showed that the nights were not photometrical so the standardization of our fields was not possible: it was deferred to further data.

To study the variability of our sources we selected therefore in each field 5 stars with B and R magnitudes listed in the GSC2 catalogue and J, H, K magnitudes listed in the 2MASS catalogue. Some stars were choosen nearly as faint as the target, to estimate the actual photometric accuracy achievable, while the others were choosen substantially brighter and were used to put on a common scale the instrumental magnitudes from different runs. The zero point of the magnitudes for each field was established adopting the GSC2 or 2MASS magnitude for the brightest reference star.

Figure 1 illustrates the magnitude dispersion of all the reference stars plotted as a function of B (lower panel) and R (upper panel) magnitudes: in both panels the dispersion of the data is smaller than 0.05 magnitudes for almost all the stars, so we assume 0.05 mag as typical magnitude uncertainty in the B and R band.

5 The evaluation of the peak frequency

By means of our simultaneous optical-NIR observations and data at 5 GHz and 1.4 GHz collected from radio catalogues we estimated the frequency of the synchrotron peak in the SED of our "VLBL candidates" fitting the data with a parabola in the plane $\text{Log}(\nu)$ *vs* $\text{Log}(\nu F_\nu)$ (see Table 1). An example of such fit is shown in Figure 2 for the source 0749+54.

For comparison, we estimated in the same way the frequency of the synchrotron peak in the SED of 6 well known LBL and IBL sources (see Table 2), for which we

[1] Image Reduction and Analysis Facility, distributed by NOAO, operated by AURA, Inc. under agreement with the US NSF.

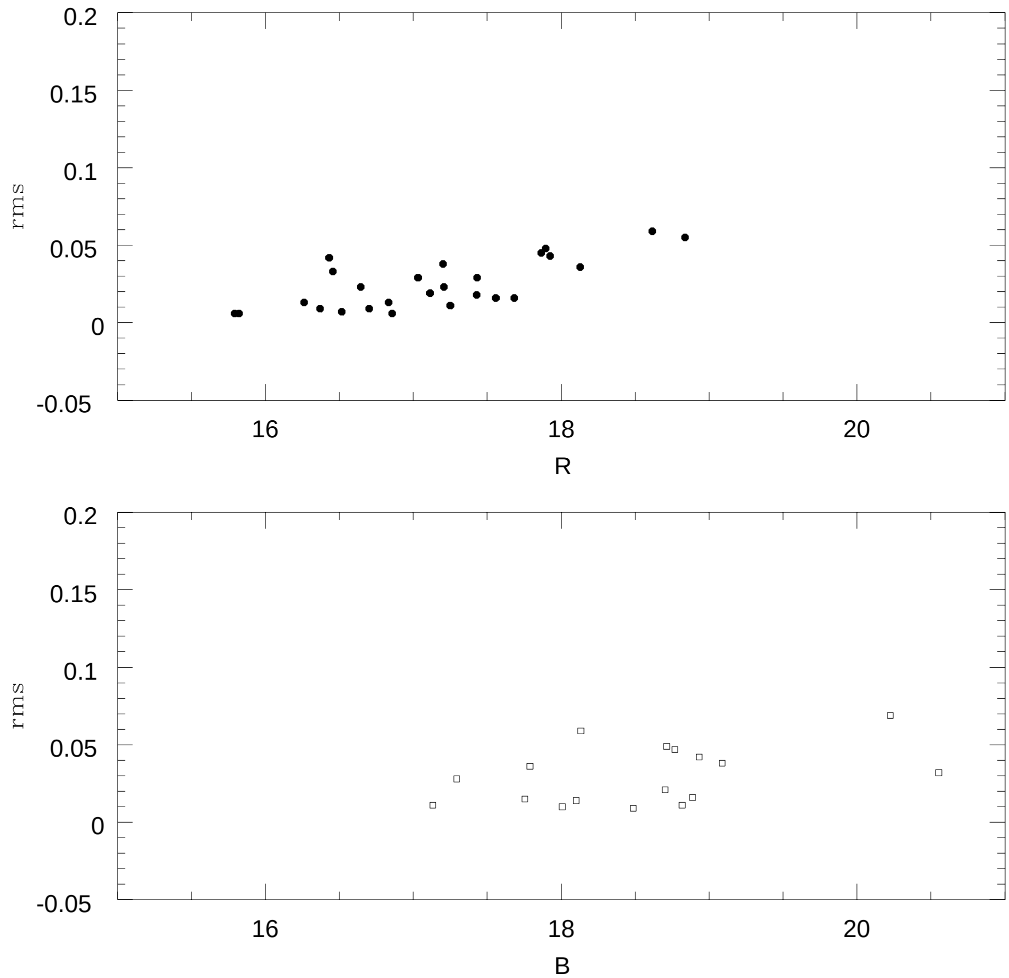

Figure 1: Magnitude dispersion of all the reference stars plotted as a function of B (lower panel) and R (upper panel) magnitudes.

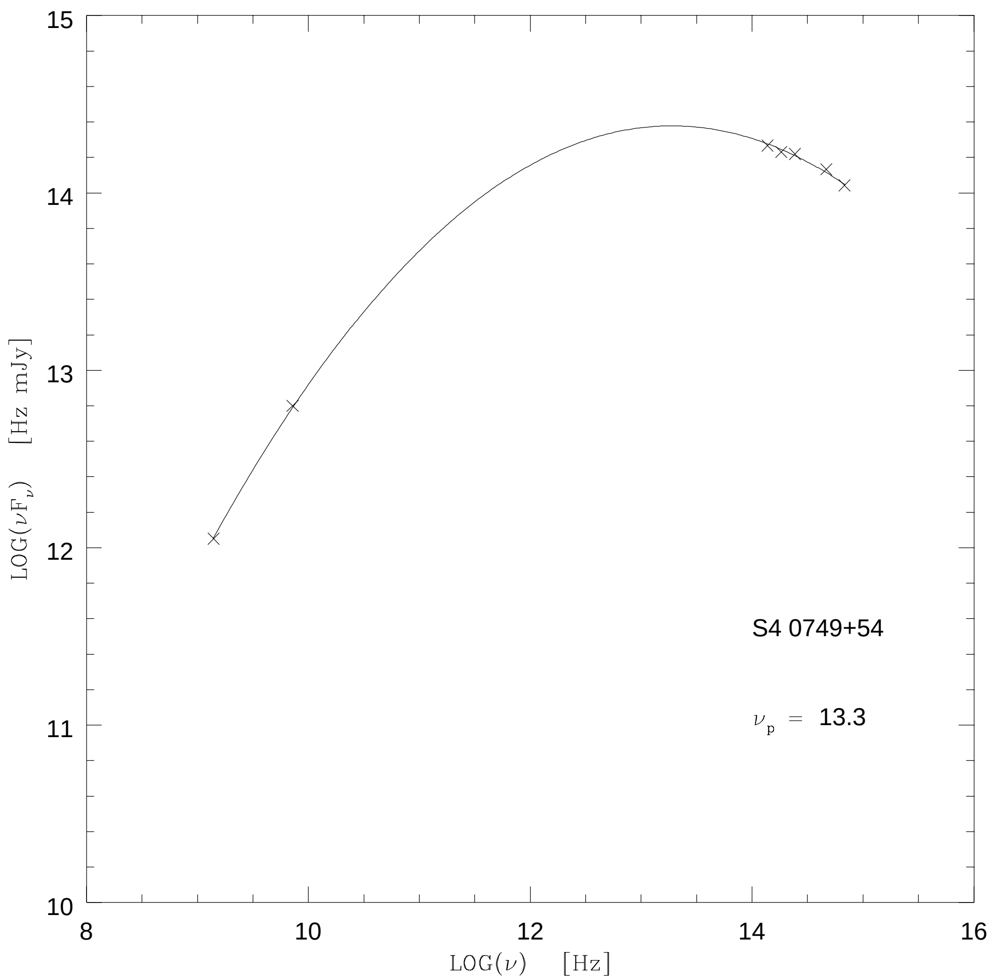

Figure 2: SED of the source 0749 and estimation of ν_p with a parabola.

have simultaneous optical-NIR data ("SCAE sources") from previous observations (Nesci et al. 2003, Mem. SAIt 74, 169).

Figure 3 shows the presence of a correlation between the radio-optical spectral index α_{ro} and the synchrotron peak frequency ν_p: low values of the peak frequency ν_p correspond to high values of the spectral index α_{ro}. The majority of the "VLBL candidates" lies in the region of the plot characterized by low values of ν_p and high values of α_{ro}: it means that the radio-optical spectral index is a good tool to search for "VLBL candidates".

In Figure 3 we can also see that 2 of our "VLBL candidates" (1557 and 1902) actually have α_{ro} lower than 0.6 and ν_p higher than 10^{14} Hz and so they belong to the LBL objects more than to the VLBL ones. Moreover we could think of other 2 sources (1250 and 1926) as "border-line" objects, having α_{ro} around 0.6 and ν_p around 10^{14} Hz.

Our simultaneous optical-NIR data show that the peak frequency ν_p of a source, observed at different epochs and luminosity levels, can shift up to a decade (see 1557 and 1902 in Table 1, ON231 and BLLac in Table 2 and Figure 3). It is therefore necessary to collect simultaneous data at the different frequencies if one wants to obtain a meaningful value of the peak position.

6 The optical and infrared spectral indices

In the optical-NIR band the flux distribution of a BL Lac can be modelled as $F_\nu = A\nu^\alpha$. The spectral indices α derived from our data are collected in Table 1 and Table 2: they are the optical one α_{BR} (column 5), the infrared one α_{JHK} (column 4) and the optical-infrared α_{BRJHK} (column 3).

Two major points come out from these Tables:

- the spectral indexes for our "VLBL candidates" are not very different from those of the control sample, so the optical-NIR spectral index is not well correlated with the peak frequency;
- there is a good agreement between our optical-NIR spectral index α_{BRJHK} and the spectral index derived from the Sloan Digital Sky Survey photometry α_{SDSS}, when available.

7 Short term variability: observations in 2005-2006

The light curves of our "VLBL candidates", built with data from January 2005 to March 2006, showed that the change in brightness of these sources were:

- higher than 1 magnitude in 2 cases;
- between 0.5 and 1 magnitude in 5 cases;
- lower than 0.5 magnitudes in 4 cases.

On the contrary no significant variability was detected for the colour index $B-R$: see for example Figure 4 in which the B and R magnitudes of the source 0828+493 show a variation of more than 1 magnitude in about 15 month (January 2005 – March 2006) but the colour index $B - R$ remains in the range of the evaluated uncertainty.

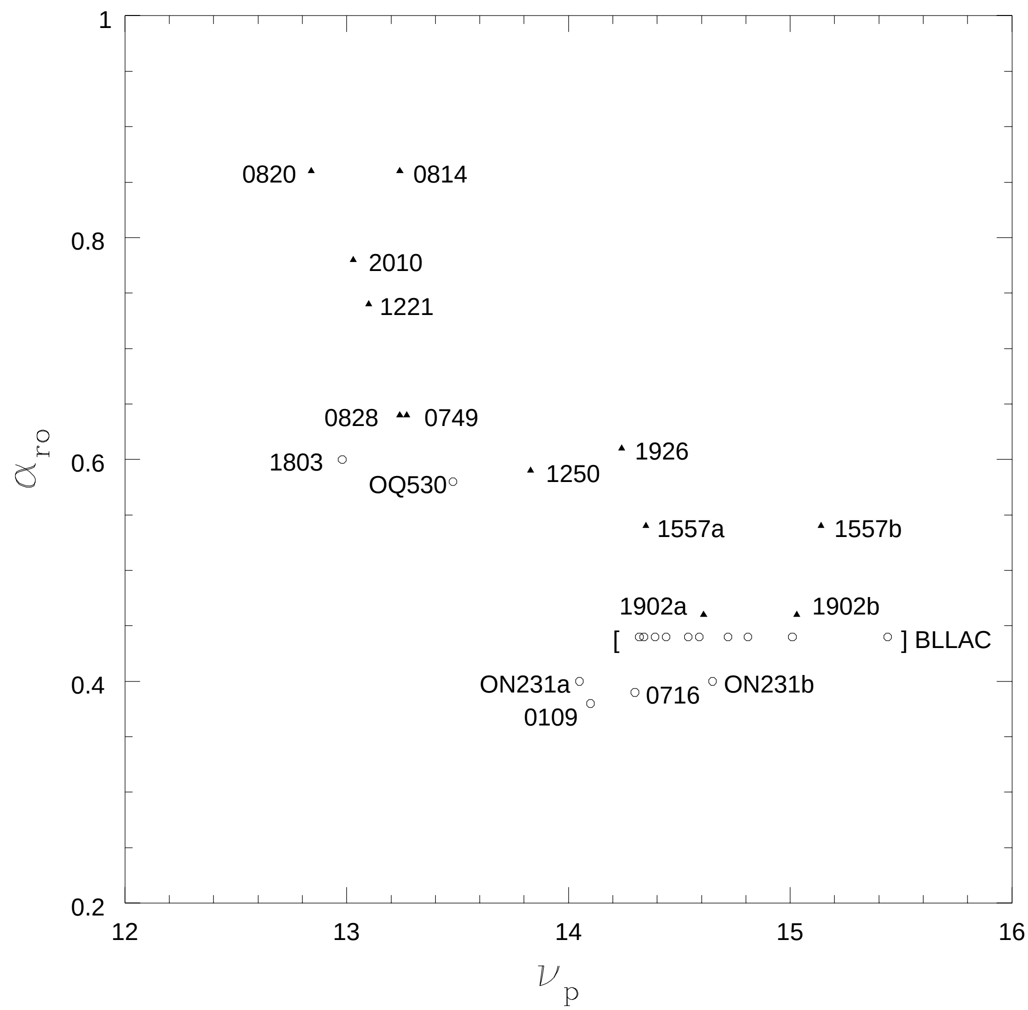

Figure 3: Spectral index α_{ro} between the radio and optical bands *vs* peak frequency ν_p of the synchrotron emission: filled triangles are the "VLBL candidates" and empty circles are the "SCAE sources". The squared brackets emphasizes the shift of the peak frequency of BL Lacertae in different states of luminosity.

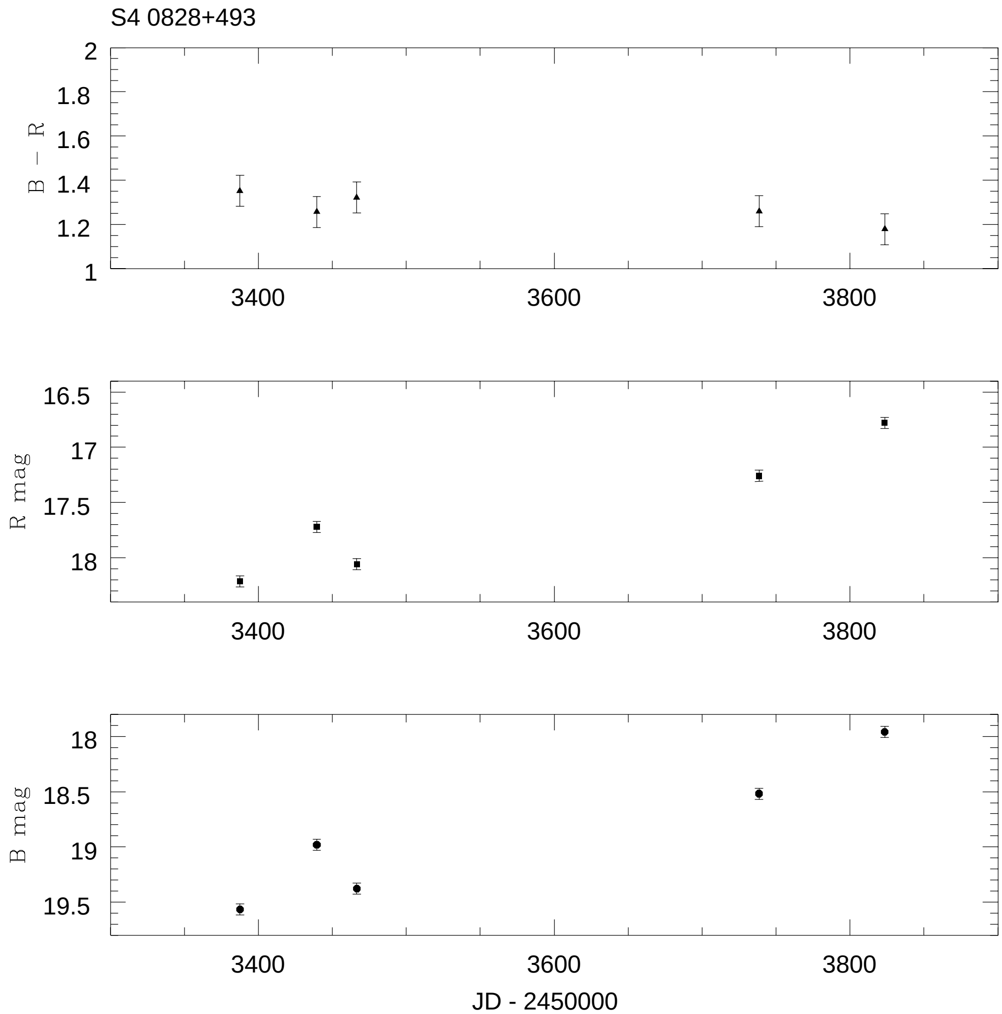

Figure 4: Source 0828+493 : abscissa is in Julian Date−2450000 while ordinate shows B magnitude (lower panel), R magnitude (middle panel) and colour index $B-R$ (upper panel). The observations span the period January 2005 – March 2006.

8 Historic photographic data

To further explore the characteristics of the "VLBL candidates" we performed a search for their historic optical variability: for each object we retrieved all the scanned images available on-line from the POSS I and POSS II Surveys and the UK-Schmidt plates in the red (E or F emulsion) and blue (J emulsion) bands.

Differential aperture photometry of the "VLBL candidates" was made with the DAOPHOT routine of the IRAF package, using the same reference stars selected for the CCD frames: the photometric radius was taken equal to the average FWHM of the bright reference stars. Conversion from photographic magnitudes to our CCD magnitude scale was made building a calibration curve for each image by means of the reference stars: the CCD magnitude of our target was determined by interpolation with an uncertainty of about 0.2 magnitudes.

The detected variations are reported in Table 1 (column 7).

9 Long term source variability

The analysis of the historic light curves points out that in a time interval of about 50 years the change in brightness of our set of 11 "VLBL candidates" were about 1 magnitude. In details the variations were:

- larger than 1.5 magnitude in 4 cases;
- between 1.5 mag and 1.0 mag in 5 cases;
- between 1.0 mag and 0.8 mag in 2 cases.

The few simultaneous B and R plates referring to the same object gave $B-R$ values in good agreement with those obtained from our CCD observations: it confirms that also on long time scales our "VLBL candidates" showed no valuable colour effects.

10 Conclusions

- Our "VLBL candidates" show a marked optical variability as expected for objects belonging to the subclass of the Low Energy Peaked BL Lac objects.
- There is a correlation between the radio-optical spectral index α_{ro} and the synchrotron peak frequency ν_p: therefore α_{ro} may be a good tool to select "VLBL candidates".
- No clear variability of the spectral slope with the luminosity level of the source was detected, at variance with the "bluer when brighter" behaviour shown by several LBL-IBL sources.
- Simultaneous multifrequency data, covering a large frequency interval, are required to locate with good accuracy the peak frequency ν_p.

We plan to continue the multifrequency study of our VLBL candidates and to extend the sample to obtain a better definition of their statistical properties.

"VLBL candidates"

(1) Source	(2) α_{SDSS}	(3) α_{BRJHK}	(4) α_{JHK}	(5) α_{BR}	(6) ΔR_{CCD}	(7) ΔR_L	(8) α_{ro}	(9) α_{ox}	(10) Log ν_p
S4 0749+54	—	-1.3	-1.2	-1.5	0.64	0.9	0.6	1.3	13.3
S4 0814+425	-1.5	-1.2	-1.5	-0.8	1.27	1.9	0.9	1.1	13.2
PKS 0820+225	-1.6	-1.5	-1.9	-1.8	0.32	0.8	0.9	1.1	12.8
S4 0828+493	-1.9	-1.5	-1.4	-2.2	1.45	0.7	0.6	1.3	13.2
S5 0916+86	—	—	-1.4	—	0.79	1.3	0.6	1.3	—
S5 1221+80	—	-1.5	-1.8	-2.1	0.85	0.2	0.7	1.2	13.1
S4 1250+53	-1.4	-1.3	-1.2	-1.1	0.89	0.7	0.6	1.3	13.9
MYC 1557+566	—	-1.1	-1.3	-0.8	0.35	0.7	0.5	1.4	14.3
		-0.9	-0.7	-0.5					15.1
87GB 1902+553	—	-0.9	-0.8	-1.4	0.49	0.8	0.5	1.3	15.0
		-1.0	-1.1	-1.4					14.6
S4 1926+61	—	-0.9	-1.4	-0.2	0.11	0.9	0.6	1.4	14.2
S5 2010+72	—	-1.4	-1.2	—	0.20	1.5	0.8	—	13.0

Table 1: "VLBL candidates". The columns give: (1) source name; (2) optical spectral index α_{SDSS} obtained from SDSS data in the u,g,r,i,z band; (3) optical spectral index α_{BRJHK} obtained from simultaneous observations in the B,R,J,H,K band; (4) NIR spectral index α_{JHK} obtained from simultaneous observations in the J,H,K band; (5) optical spectral index α_{BR} obtained from simultaneous observations in the B and R band; (6) change in the R magnitude ΔR_{CCD} of the source during our monitoring period (CCD frames); (7) change in the R magnitude ΔR_L of the source obtained from the historical plates; (8) radio-optical spectral index α_{ro} (obtained from simultaneous optical-NIR data joint with radio data available in literature); (9) optical-X spectral index α_{ox} (obtained from simultaneous optical-NIR data joint with X-ray data available in literature); (10) logarithm Log ν_p of the peak frequency ν_p (obtained from simultaneous optical-NIR data joint with radio data available in literature).

"SCAE sources"

(1) Source	(2) α_{SDSS}	(3) α_{BRJHK}	(4) α_{JHK}	(5) α_{BR}	(6) ΔR_{CCD}	(7) α_{ro}	(8) α_{ox}	(9) Log ν_p
GC 0109+224	—	-1.4	-1.3	-1.5	2.91	0.4	1.3	14.1
S5 0716+71	—	-1.3	-1.4	-1.4	2.23	0.4	1.4	14.3
ON 231	—	-1.2	-0.9	-1.2	2.82	0.4	1.5	14.1
		-1.0	-0.9	-1.2				14.7
OQ 530	-1.3	-1.3	-1.4	-1.5	1.42	0.6	1.3	13.5
S5 1803+78	—	-1.6	-1.6	-1.8	3.40	0.6	1.5	13.0
BL Lac	—	-1.2	-0.9	-1.4	2.82	0.4	1.7	14.8
		-1.0	-0.9	-1.5				15.0
		-1.2	-1.0	-1.7				14.4
		-1.2	-0.9	-1.8				14.3
		-1.2	-1.0	-1.7				14.3
		-1.2	-1.0	-1.7				14.6
		-1.2	-0.9	-1.7				14.4
		-1.2	-1.0	-1.8				14.5
		-0.9	-0.8	-1.5				15.4
		-1.2	-0.9	-1.6				14.7

Table 2: "SCAE sources". The columns give: (1) source name; (2) optical spectral index α_{SDSS} obtained from SDSS data in the u,g,r,i,z band; (3) optical spectral index α_{BRJHK} obtained from simultaneous observations in the B,R,J,H,K band; (4) NIR spectral index α_{JHK} obtained from simultaneous observations in the J,H,K band; (5) optical spectral index α_{BR} obtained from simultaneous observations in the B and R band; (6) change in the R magnitude ΔR_{CCD} of the source (CCD frames belonging to the SCAE database in the period from 1994 to 2005); (7) radio-optical spectral index α_{ro} (obtained from simultaneous optical-NIR data joint with radio data available in literature); (8) optical-X spectral index α_{ox} (obtained from simultaneous optical-NIR data joint with X-ray data available in literature); (9) logarithm Log ν_p of the peak frequency ν_p (obtained from simultaneous optical-NIR data joint with radio data available in literature).