Blazar Demographics and Physics
ASP Conference Series, Vol. 227, 2001
Paolo Padovani and C. Megan Urry, eds.

Simultaneous Optical and X-Ray Observations of BL Lacertae

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Abstract. We present the results of simultaneous X-ray and optical observations of BL Lacertae performed in the periods 1999, June 5–7 and December 5–6. The *Beppo*SAX satellite (0.2–100 keV) and the WEBT (Whole Earth Blazar Telescope) collaboration (B,V,R,I bands) were involved in this campaign. During the first observation the optical behavior of the source showed an oscillating pattern with a total observed amplitude of ~ 0.5 mag. A marked variability was detected on hour time scale in the soft X-rays. Two power-law components were required to fit the X-ray spectrum, which we interpret as the Synchrotron (soft) and the Inverse Compton (hard) components. During the second run only the Inverse Compton component was detected in the X-rays, without appreciable variability neither in the X-rays nor in the optical.

1. Introduction

Simultaneous multiband observations of blazars are a key way to better understand the physical processes responsible for the emission of these puzzling objects. According to our current knowledge there are two main processes at work:

a) Synchrotron emission by relativistic electrons in a somewhat ordered magnetic field, mainly parallel to the relativistic jet, which is responsible for the emission from radio (8 GHz) to soft X-rays (2 keV);

b) Inverse Compton emission from upscattered low-energy photons, either coming from the above mentioned Synchrotron process (Self Compton) or from external origin.

A very effective way to recognize if the X-ray emission is just a tail of the Synchrotron process responsible for the optical one, or is produced by a different mechanism, is to check for its variability simultaneously with the optical emission.

With this purpose in mind, at the IAU General Assembly at Kyoto in 1997 the Whole Earth Blazar Telescope (WEBT) collaboration was started, including several observers scattered all over the world, aiming at performing a 24 hours coverage of some BL Lac objects simultaneously with X-ray or γ-ray observations.

The observations presented in this paper are the result of the interaction between an X-ray team (P.I. G. Tagliaferri) using the *Beppo*SAX satellite and the WEBT collaboration, coordinated in this occasion by R. Nesci.

The first satellite pointing was made on July 5–7 1999, and a second one was performed five months later on December 5–6.

2. Optical Observations

In the first campaign, useful observations were collected by the following groups: Roma University, Abastumani Observatory, Foggy Bottom Observatory (Colgate University), Lowell Observatory (Western Kentucky University), Kyoto University and Perugia Observatory. In the second campaign data were obtained by the groups of Roma, Abastumani, Kyoto, Perugia, and also by the Catania Astrophysical Observatory, while bad weather conditions prevented any contribution from the USA. Photometric observations were performed in the standard bandpasses U, B, V (Johnson) and R, I (Cousins). A list of the involved telescopes and filters is given in Table 1. Magnitudes were evaluated using IRAF (Roma, Abastumani, Foggy Bottom, Lowell) or locally developed codes (Catania, Kyoto, Perugia).

Table 1. WEBT Optical Telescopes

Group	Bands	telescope	detector
Abastumani	B,V,R,I	70 cm	Texas TC241
W. Kentucky (Lowell)	V, I	180 cm	SITe 501A
Catania	U,B,V	91 cm	EMI 9893QA/350 photomultiplier
Foggy Bottom	R,I,V	40 cm	CCD
Kyoto	R	25 cm	Kodak KAF 400
Perugia	R, I	40 cm	Texas TC211
Roma (Vallinfreda)	V	50 cm	Texas TC241
Roma (Greve)	I	35 cm	SITe 501A

Each optical group performed differential photometry of BL Lac with respect to 4 nearby reference stars (Bertaud et al. 1969; Fiorucci and Tosti 1996). The data, sent to the campaign coordinator, were then checked for systematic differences in the instrumental magnitudes of the reference stars; a general light curve of BL Lac was obtained and the color indices were computed when possible.

Since not all the involved observers could use the same filters (see Table 1), to build an optical light curve as complete as possible in time coverage, conversions to the same I band were made using appropriate color indices for each Observatory (typical V−I = 1.3). The resulting light curve is plotted in Fig. 1 (lower panel) for comparison with the X-ray one (upper panel).

It is apparent from Fig. 1 that BL Lac varied continuously during the *Beppo*SAX pointing with an overall amplitude of 0.55 mag. After the maximum at 1334.8, followed by a decay of about 0.4 mag in less than 10 hours, the source behavior was characterized by an increasing trend for about one day, superposed onto small oscillations; the brightness then decreased down to I = 13. These data show how important is the availability of several observers distributed in longitude to achieve a good coverage of the light curve. Indeed, given the shortness of the night near the summer solstice, each telescope could monitor BL Lac only for a few hours.

A color change with the source luminosity (0.06 in V−I for a change of 0.2 R mag) was clearly detected in the Abastumani data set, which provided nearly simultaneous BVRI photometry for June 6, but it is not critical for the transformation of the observed magnitudes from the other bands into the I band,

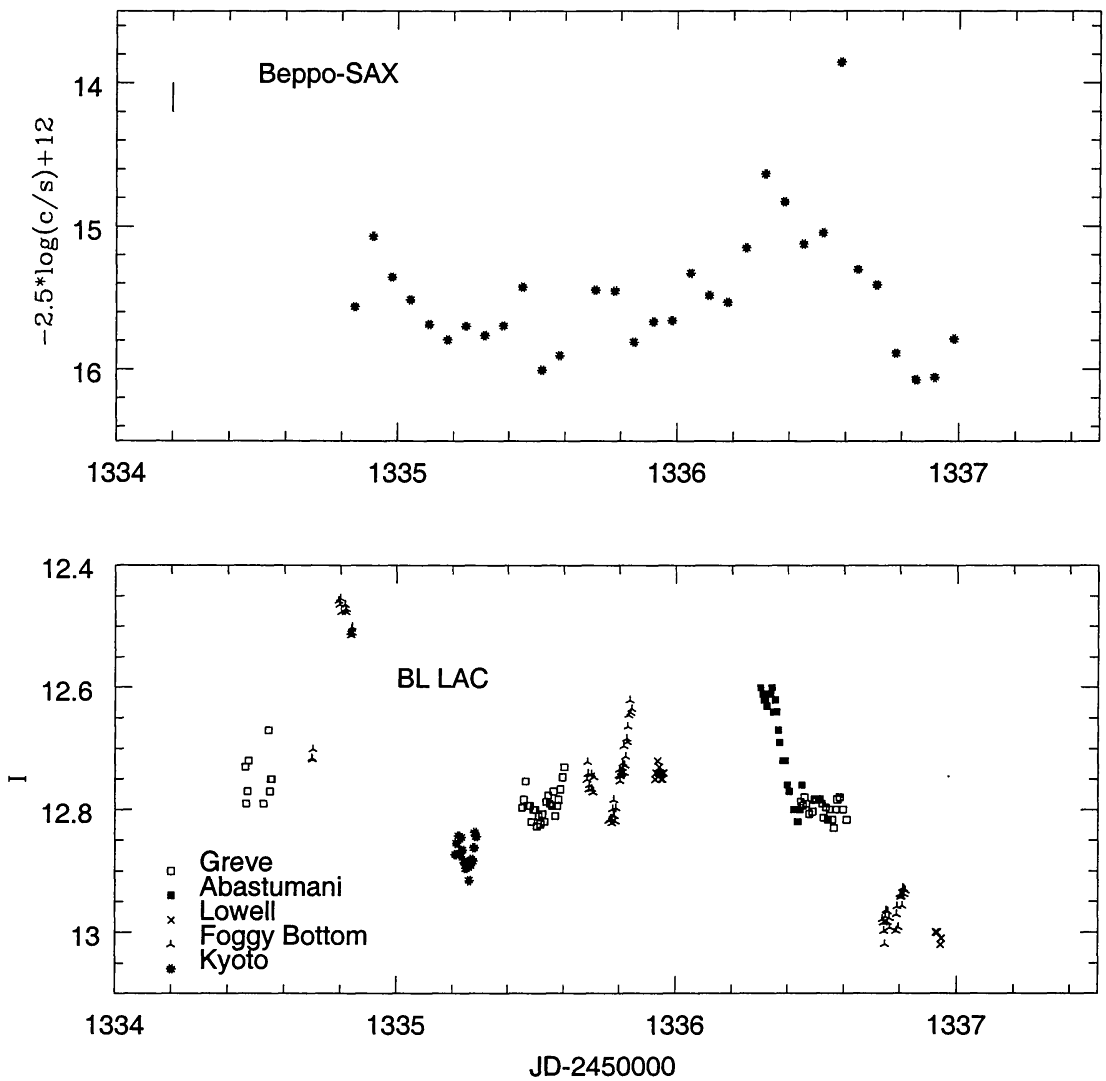

Figure 1. Composite optical I-band light curve (lower panel) and LECS x-ray light curve averaged over 30 m intervals (upper panel), for the June pointing. Notice that the ordinates are in magnitudes for both plots. The typical x-ray error bar is shown at the upper left corner. Perugia data, not plotted for sake of clarity, overlap some Greve points.

so that the long-term behavior of the source during the run shown in Fig. 1 is reliable.

The second run (December) was less lucky from the meteorological point of view, so coverage from the ground was less complete. The source showed an overall variation of only ~ 0.2 mag. The (V−I) color index was about 1.6, substantially steeper than in June, while the average flux level in the I band (12.6) was about the same at both epochs.

3. X-ray Observations

The observations were made with the *Beppo*SAX satellite, using the LECS, MECS and PDS instruments, as part of a ToO program. The first pointing was on June 5, 1999, starting at 08:05 UT and lasted 52 hours; the second one started on December 5, 1999 at 11:06 and lasted 30.5 hours.

Table 2. X-ray Fluxes and Energy Spectral Indices

Date	α_1 (energy)	α_2 (energy)	$F_{2-10keV}$ (erg/cm^2/s)	I (mag)	α_{opt}
5–7 June	1.6 ± 0.25	0.15 ± 0.22	0.6×10^{-11}	12.7	1.4
5–6 Dec.	—	0.60 ± 0.05	1.2×10^{-11}	12.6	1.9

The source flux showed a large variability in the soft X-rays, as apparent from the light curve plotted in the upper panel of Fig. 1; a logarithmic scale, magnitude like, was used for a better comparison with the optical one. No flux variations were detected at energies above 4 keV on the day time-scale. Two main episodes of variation, a smaller one around JD 1336.3 and a larger one, around JD 1336.6, were detected; the latter, in particular was quite fast having a total duration of about 20 minutes only. Despite the much larger amplitude of the X-ray variations, it is apparent a fair match of the overall optical and X-ray trends until JD 1336.4, while the large X-ray outburst has no optical counterpart. This outburst, however, was real because it was detected both by the LECS and the MECS instruments and the image analysis showed that the photons' coordinates were fully compatible with the position of BL Lac. A spectral fit to the LECS, MECS and PDS data required a two-power-law model ($F_\nu = A_1\nu^{-\alpha_1} + A_2\nu^{-\alpha_2}$), with a steep low energy component and a much harder one above about 3 kev, to give a satisfactory χ^2. The best-fit value of the (energy) indices are given in Table 2.

In the second run (December) only the hard component was detected at a level (in the 2–10 keV range) brighter than in June (see Table 2); no significant variability was observed.

4. Conclusions

The main results of this campaign may be summarized as follows:

a) The optical data are well fitted by a single power law, while two power laws are necessary for the X-ray data, at least for the June observations, with a spectral slope of the hard X-ray component flatter than the optical one, indicating that different radiation processes are involved.

b) Variability on intraday time scale was detected both in the optical and in the soft X-rays in June and the variations were fairly correlated, while the hard X-ray flux was stable on this time scale. This result supports the conclusion, derived from the spectral slopes, of the existence of two physical processes responsible for the emission.

c) On a several months time scale the X-ray flux of the hard component was different by a factor ~ 2, while the optical flux in the I band was practically unchanged.

d) The optical spectrum in the December observation was steeper than in June, consistently with the non detection of the soft X-ray component.

The most straightforward interpretation of all these findings is that the soft X-ray flux observed in June is essentially the high energy tail of the Synchrotron emission, having the peak of its spectral energy distribution in the optical. The hard X-ray flux is likely due to the Inverse Compton process, but the lack of variability on intraday time scale suggests that the seed photons of this component are not the optical ones. The upscattered photons could either have a much lower frequency (from the far IR or millimetric range), where the emission is expected to be less variable than around the peak, or be originated in a region external to the jet.

We remark that BL Lac is the third case, after ON 231 (Tagliaferri et al. 2000), and S5 0716+714 (Giommi et al. 1999), of a *Beppo*SAX detection of the emission from both Synchrotron and Inverse Compton processes in a BL Lac object.

Some observational points however still requires a deeper understanding:

a) Despite the source was at the same optical level in the two runs, both the optical and the X-ray spectral slopes were different. Therefore there is not a simple relation between the flux level and the spectral shape when different episodes of variation are considered, while a fair correlation is present within a single episode.

b) The nature of the large and fast burst detected in the soft X-rays during the June observation without an optical counterpart is unclear. It is the only episode of this type observed so far. Further simultaneous observational campaigns in the optical and X-rays are therefore necessary to search for other similar events.

References

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