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Optical Spectral Variability of Blazars

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Abstract. It is well established that blazars show flux variations in the complete electromagnetic (EM) spectrum on all possible time scales ranging from a few tens of minutes to several years. Here, we report the review of optical flux and spectral variability properties of different classes of blazars on IDV and STV time-scales. Our analysis show HSPs are less variable in optical bands as compared to LSPs. Also, we investigated the spectral slope variability and found that the average spectral slopes of LSPs showed a good agreement with the synchrotron self-Compton loss-dominated model. However, spectra of the HSPs and FSRQs have significant additional emission components. In general, spectra of BL Lacs get flatter when they become brighter, while for FSRQs the opposite trend appears to hold.

Key words. Galaxies: active—galaxies: quasars: blazars: blazar.

1. Introduction

Blazars constitute an enigmatic subclass of radio-loud Active Galactic Nuclei (AGNs). Blazars include BL Lacertae (BL Lac) objects and Flat Spectrum Radio Quasars (FSRQs), as both are characterized by strong and rapid flux variability across the entire electromagnetic spectrum. Blazars exhibit variability at all wavelengths on various time scales.

The Spectral Energy Distributions (SEDs) of blazars have a double-peaked structure (e.g., Giommi *et al* 1995; Ghisellini *et al* 1997). The first component peaks in the near-infrared/optical for LBLs and in the UV or X-rays for HBLs, while the second component usually peaks at GeV energies for LBLs and at TeV energies for HBLs. Nieppola *et al.* (2006) classified over 300 BL Lacs and suggested that blazars with energy peak frequency, $\nu_{\rm peak} \sim 10^{13-14}$ Hz are LSPs, those with $\nu_{\rm peak} \sim 10^{15-16}$ Hz are ISPs and those with $\nu_{\rm peak} \sim 10^{17-18}$ Hz are HSPs. Recently, Abdo *et al.* (2010) extended the definition to all types of non-thermal dominated AGNs depending on the peak frequency of their synchrotron hump, $\nu_{\rm peak}$, and suggested the following classification: Low Synchrotron Peaked (LSP) sources with $\nu_{\rm peak} \leq 10^{14}$ Hz, Intermediate Synchrotron Peaked (ISP) sources with $10^{14} < \nu_{\rm peak} < 10^{15}$ Hz, and High Synchrotron Peaked (HSP) sources with $\nu_{\rm peak} \geq 10^{15}$ Hz. However, we have used the broader definition of ISPs put forward by Nieppola *et al.* (2006).

Blazar variability can be broadly divided into 3 classes. Significant variations in brightness may occur over the course of less than a day, often called micro-variability, intra-night variability or Intra-Day Variability (IDV) (Wagner & Witzel 1995). Short Term Variability (STV) can range from days to few months and Long Term Variability (LTV) can have time scales of several months to several years (Gupta *et al.* 2004).

In the present paper, we reviewed optical variability studies done for a sample of blazars to search for possible differences in optical IDV of HSPs and LSPs, STV search for blazars as it can help in deciding the blazar state (outburst, pre/post outburst and low state), to search for correlation between flux and colour and to study optical spectral variations of different classes of blazars.

The paper is structured as follows: in section 2, we report the important optical flux variability results of blazars and spectral variability results of different classes of blazars and in section 3, we report the main conclusion of the present work.

2. Results

In this work, we observed a sample of 14 blazars during the period 2009–2011. We have measured the multiband optical flux and colour variations on intra-day and short-term time-scales. Results are summarized below:

2.1 *Intra-day variability of blazars*

We present our results of quasi-simultaneous (B and R pass-bands) and dense temporal observations of five HSPs: Mrk 421, 1ES 1426 + 428, 1ES 1553 + 113, 1ES 1959 + 650 and 1ES 2344 + 514 and of three LSPs: S5 0716 + 714, OJ 287 and 3C 454.3 during the observing season 2009–2011 (Gaur *et al* 2012a, b, c). These are the first extensive observations of HSPs and thus adds to a rather small amount of data on HSP micro-variability. We have observed the sources Mrk 421, 1ES 1553 + 113, 1ES 1959 + 650 and 1ES 2344 + 514 on 9, 6, 24 and 19 nights, respectively, but no significant IDV was observed during any nights for these four targets. But for 1ES 1426 + 428, we found genuine IDV in 2 nights out of 4 nights of observations. Totally we observed HSPs for 62 nights and got genuine IDV in 2 nights. However LBLs were observed for a total of 15 nights and we got IDV in 6 nights. This very less detection of IDV of HSPs are in agreement with previous observational results which indicated that HSPs show a statistically lesser amount of optical variability than LSPs. But, we still need more optical observations to firmly conclude this statement.

2.2 *Short-term variability of blazars*

We performed photometric observations of a sample of blazars in the BVRI passbands during our observing run covering the period 2009–2011. Comparisons of our observations with earlier measurements of the same sources indicated that the blazars 3C 66A, S5 0716 + 714, OJ 287, Mrk 421, 1ES 1553 + 113, 1ES 1959 + 650 and 3C 454.3 were probably in high states; blazars AO 0235 + 164, ON 231 and BL Lac were apparently in faint states and 3C 279 was in a pre- or post-outburst state. In the last decade, the source 1ES 1426 + 426 has only varied between 15.7–16.1 mag. So, this source in our observation also shows a similar state. Similarly, 1ES 1218 + 304 has varied between 16.3–15.4 mag and in our observations it showed an average R band magnitude of 15.7 mag. We cannot attempt to classify 1ES 2344 + 514 in this fashion because it has never shown a large amount of optical activity (Gaur *et al.* 2012b). We found significant flux variations in all the sources except for 1ES 1218 + 304 and 1ES 1553 + 113 on short-term time-scales. These flux variations can be reasonably explained by models involving relativistic shocks propagating outwards (e.g. Marscher & Gear 1985; Marscher 1996).

2.3 *Colour variations of blazars*

We report the search for variations in colour with time for time-periods corresponding to STV in a sample of blazars. Out of the fourteen blazars we have newly observed only five (AO 0235 + 164, S5 0716 + 714, 1ES 1426 + 421, 1ES 1959 + 650 and 3C 454.3) that have shown significant colour variations on short time scales. In the case of BL Lacs, any accretion disc radiation is always overwhelmed by that from the jet, and therefore jet models that can produce different fluctuations in different colours are most likely to be able to explain the colour variations we have detected.

2.4 *Relation between colour index and flux variations*

We have investigated the relationship between spectral changes and flux variations on STV time-scales. Out of the fourteen blazars, six (S5 0716 + 714, OJ 287, Mrk 421, ON 231, 1ES 1426 + 428 and 1ES 1959 + 650) have shown significant positive correlation between colour and magnitude, one (AO 0235 + 164) has shown a very weak positive correlation, while six (3C 66A, 1ES 1218 + 304, 3C 279, BL Lac, 1ES 1553 + 113 and 1ES 2344 + 514) lacked any correlation. No significant negative correlation was found for any BL Lac which reflects the common trend for this class that they become bluer when they brighten (Ghisellini *et al.* 1997; Fan *et al.* 1998; Ghosh *et al.* 2000; Villata *et al.* 2002; Gu *et al.* 2006).

2.5 *Spectral variations of blazars in optical bands*

We have combined the optical data in the B, V, R and I bands from our optical observations for our sample of blazars. As the radiation of these blazars can be adequately described by a single power law $F_\nu = A\nu^{-\alpha}$ in the optical band, where α is the spectral slope which is obtained by using the linear least square fitting between log F_ν and log ν. Spectral variations of these classes of blazars are discussed below:

2.5.1 *LSPs*.

BL Lacs: For LSPs, we expect optical spectral indices $\alpha_{\rm ave} > 1$ due to their being on the descending part of the first bump of the SED. The distribution of spectral indices in the optical clustered around 1.5. Chiang and Böttcher (2002) demonstrate that for a broad range of particle injection distributions, SSC-loss-dominated synchrotron emission exhibits exactly this kind of spectral slope. Hence, SSC model fit the optical emission for LSPs very well.

FSRQs: Since FSRQs are a subclass of LSPs, we expect the optical spectral index also to be greater than 1. However, FSRQs show strong emission lines and a thermal contribution that may be comparable to the synchrotron emission in the optical spectral region. For two sources, 3C 454.3 and 3C 279, the spectral slopes are 1.47 and

1.13 respectively. This indicates that the optical spectra of 3C 454.3 is likely dominated by the synchrotron component. This interpretation is supported by the fact that 3C 454.3 shows strong variability in our observations and was in very high state (Gaur *et al.* 2012a). But during our observations 3C 279 seems to be in intermediate state and thermal component also plays a role in synchrotron component.

2.5.1 *ISPs.* For the BL Lacs showing intermediate behaviour, we expect $\alpha_{\rm ave} \geq 1$. We have 11 ISP sources, and the average of their spectral indices is 1.19. This supports the hypothesis that synchrotron emission dominates the optical band of these sources too.

2.5.2 *HSPs.* The spectral slopes of the HSPs scatter in the range between 0.5 and 1.8, while the predicted spectral slope under simple pure synchrotron emission models should be less than or equal to 0.75 or 0.80, corresponding to the spectral index of optically thin synchrotron emitting plasma, $\alpha_{\rm thin}$ (Urry & Padovani 1995). *s* indicates that the optical emission of HSPs is contaminated by other components, such as thermal contribution from the accretion disc or host galaxy, or else significant amounts of non-thermal emission originating from different regions of the relativistic jets. For nearby blazars, the host galaxy contribution is probably important (Pian *et al.* 1994). For Mrk 421, α is found to be 1.08 and 0.619 before and after the host galaxy contribution, respectively and for 1ES 1959 + 650, α is found to be 1.03 and 0.67 before and after the host galaxy contribution is removed. Now we can say that there is certainly a large deformation of the optical spectra of these HSPs due to thermal contribution from the host galaxies.

3. Conclusion

- HSPs are intrinsically less variable on IDV time scales in optical bands and is in agreement with previous studies but still we need more optical observations of HSPs to conclude this statement.
- Blazars are variable on STV time scales and can be explained by jet-based models.
- Blazars sometimes show colour variations on STV time scales and can be attributed to models involving shock propagating down the jets.
- BL Lacs show bluer-when-brighter trend whereas FSRQs show redder-when-brighter trend.
- Average of optical spectra of LSPs is 1.5 and is in agreement with synchrotron-self-Compton model.
- Optical spectra of FSRQs probably have a contribution from thermal bump that noticeably contaminate the synchrotron component.
- Optical spectra of HSPs indicate that in addition to synchrotron component, they have contributions by thermal and non-thermal components.

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