

Variability of Spectral Energy Distribution of Blazar S5 0716+714

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Abstract. The emission from blazars is known to be variable at all wavelengths. The flux variability is often accompanied by spectral changes. Spectral energy distribution (SED) changes must be associated with changes in the spectra of emitting electrons and/or the physical parameters of the jet. Meaningful modeling of blazar broadband spectra is required to understand the extreme conditions within the emission region. Not only is the broadband SED crucial, but also information about its variability is needed to understand how the highest states of emission occur and how they differ from the low states. This may help in discriminating between models. Here we present the results of our SED modeling of the blazar S5 0716+714 during various phases of its activity. The SEDs are classified into different bins depending on the optical brightness state of the source.

Key words. Galaxies: active—galaxies: quasars: individual: S5 0716+714.

1. Introduction

S5 0716+714 is a bright, high declination BL Lac object at a redshift, $z = 0.31 \pm 0.08$ (Nilsson *et al.* 2008). This source has been extensively studied across the whole electromagnetic spectrum and exhibits strong variability on a wide range of time scales, ranging from minutes to years (e.g., Wagner *et al.* 1990; Heidt & Wagner 1996; Villata *et al.* 2000; Raiteri *et al.* 2003; Montagni *et al.* 2006; Ostorero *et al.* 2006; Gupta *et al.* 2008a, 2008b, 2009 and references therein). Nearly periodic oscillations of ~ 15 min in the optical R band were detected in this source (Rani *et al.* 2010). The optical duty cycle of S5 0716+714 is nearly unity, indicating that the source is always in an active state in the visible region (Wagner & Witzel 1995). This blazar was recently shown to be a strong source in the high energy gamma-ray band by Fermi-LAT (Abdo *et al.* 2009).

2. Multi-frequency data

We carried out this study of the SEDs of the BL Lac object S5 0716+714 using high quality multifrequency data in the literature. The data cover radio to optical energy bands. The optical U, B, V, R and I fluxes were collected from Raiteri *et al.* (2003);

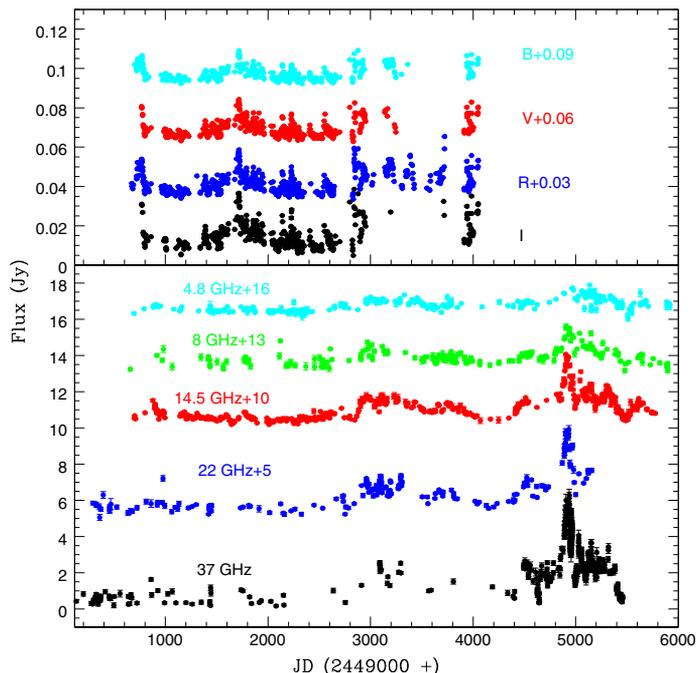


Figure 1. The multi-frequency radio and optical data of the BL Lac object S5 0716+714.

Montagni *et al.* (2006); Villata *et al.* (2000); Ostorero *et al.* (2006); and Gu *et al.* (2006). The data at radio frequencies of 22 and 37 GHz were taken from Salonen *et al.* (1987) and Teräsranta *et al.* (1992, 1998, 2004, 2005). The UMRAO¹ (University of Michigan Radio Astronomy Observatory) data at 4.8, 8 and 14.5 GHz frequencies was provided by Margo Aller. The data at optical frequencies spans over a period from November 1994 through April 2004 while the radio data cover a time period from September 1991 to May 2005 (Fig. 1).

We model the SEDs of S5 0716+714 using the above radio to optical frequency data. The long term data allow us to obtain six different mean SEDs of the source corresponding to different phases of its activity (Fig. 2). These six different SEDs are characterized by different optical outburst phases and the radio data is averaged over the same time periods.

3. Analysis and results

3.1 SED modelling

We use a homogeneous synchrotron self-Compton model (SSC) with a broken power law (BPL) to fit the lower energy part of the observed spectra which are characterized by synchrotron emission. The SED model fitting is achieved by using a SED code

¹<http://www.astro.lsa.umich.edu/obs/radiotel/umrao.php>

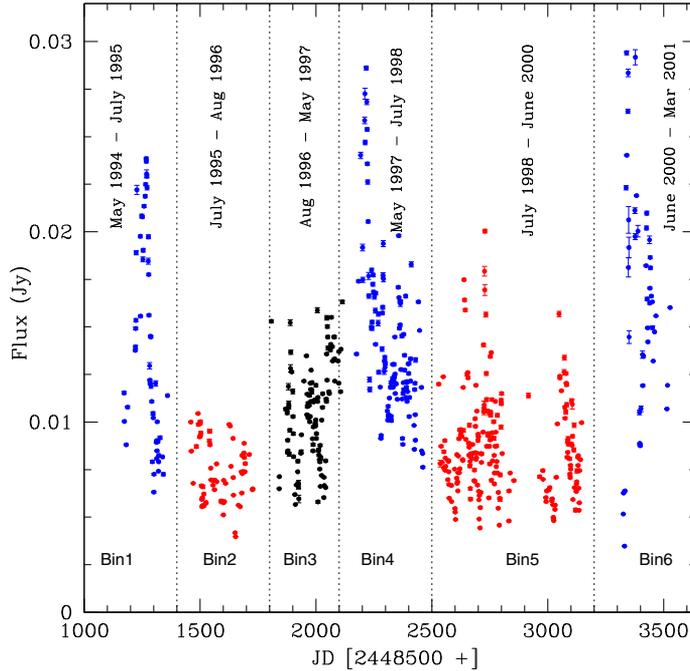


Figure 2. The optical R passband flux of S5 0716+714 divided into six different bins on the basis of its optical activity. Bin 1, Bin 4 and Bin 6 represent the optical outburst phases while Bin 2, Bin 3 and Bin 5 represent dimmer phases of the source.

available on-line.² The best fit model was obtained by varying the parameters of a numerical SSC code (Tramacere *et al.* 2007, 2009). The model assumes that radiation is produced within a single zone of jet (\sim radius R), moving relativistically at a small angle to the line of sight of the observer. The observed radiation is amplified via the boosting factor $\delta = [\Gamma(1 - \beta \cos \theta)]^{-1}$.

Below and above the peaks, the spectrum can be approximated with power law profiles with indices α_1 and α_2 , respectively. The power law spectra in AGNs are naturally produced if the emitting electron follow a power-law distribution in energy. We approximate this behaviour with a broken power law (BPL) with indices n_1 and n_2 , respectively below and above the break energy $\Gamma_b m_e c^2$:

$$P(\gamma) = \begin{cases} N\Gamma^{-n_1}, & \text{if } \Gamma < \Gamma_b, \\ N\Gamma_b^{n_2-n_1}\Gamma^{-n_2}, & \text{if } \Gamma > \Gamma_b. \end{cases} \quad (1)$$

With these approximations, we can completely specify the model with the following parameters: magnetic field intensity (B), size of emission region (R), Doppler boosting factor (δ), power-law indices (n_1 , n_2), number density of emitting electrons (N) and Lorentz factor of the electrons at the break energy (Γ_b). The values of all these fitted parameters for different SEDs are listed in Table 1.

²<http://tools.asdc.asi.it/>

Table 1. Fitted parameters of SED model.

	$\log R$ (cm)	B (Gauss)	δ	N (cm^{-3})	$\log \Gamma_{\min}$	$\log \Gamma_{\max}$	n_1	n_2	$\log \Gamma_b$	$\log \nu_{\text{peak}}$ (Hz)	$\log \nu F_{\nu_{\text{peak}}}$ ($\text{erg cm}^{-2} \text{s}^{-1}$)
Bin 1	16.8	0.4	12.8	25	0.2	6	0.4	4.5	3.20	13.76	-9.69
Bin 2	16.8	0.4	11.5	30	0.2	6	0.6	4.1	3.14	13.61	-10.01
Bin 3	16.8	0.4	11.0	30	0.2	6	0.5	4.0	3.18	13.75	-9.92
Bin 4	16.8	0.4	12.5	25	0.2	6	0.3	4.5	3.20	13.76	-9.67
Bin 5	16.8	0.4	11.0	30	0.2	6	0.6	4.0	3.18	13.72	-9.99
Bin 6	16.8	0.4	16.0	25	0.2	6	0.2	4.9	3.20	13.64	-9.42

R : Size of emitting region; B : Magnetic field; δ : Doppler boosting factor; N : Number density of emitting electrons; Γ_{\min} , Γ_{\max} : Minimum and maximum values of Lorentz factor; Γ_b : Lorentz factor corresponding to break energy of electrons; n_1 , n_2 : Power law indices; and ν_{peak} : Synchrotron peak frequency.

4. Discussion and conclusions

4.1 Limitations to the model

Although, as seen in Fig. 3, we were able to achieve reasonably good fits of the synchrotron emission for all six SEDs of the source, one should bear in mind that the one-zone BPL model is over-simplified in accounting for the radio-optical blazar emission. The applicability of a single-zone emitting region has been questioned by a number of authors (e.g., Vittorini *et al.* 2009; Raiteri *et al.* 2010). They showed that the BL Lac SED can be more successfully modelled with two synchrotron components (two different emitting populations).

Furthermore, unfortunately, we do not have synchrotron peak measurements for the source, which would significantly help in constraining the model. Another limitation to the model is that we do not correct our optical measurements for any possible host galaxy contribution. Some objects, such as BL Lac itself, have a significant contribution from starlight to the optical bands, which will modify the calculated synchrotron emission in this region, especially during the low states. We also do not make any corrections for galaxy or internal absorption, which may again slightly affect the optical-UV part of the spectra. Last, but not the least, we stress that our data is not strictly simultaneous but has been averaged over a period of months. As blazars are highly variable over time scales of a day or less, the time differences and averaging might have compromised the modelling.

4.2 Spectral energy distribution variation

To attempt a study of how the physical parameters related to emission region and synchrotron emission are changed when the BL Lac S5 0716+714 goes through various phases of its activity we used the simplest approach by fitting a single-zone SSC model. The observed results can be summarized as:

- No change between the R and B in the modelled SED are seen during different phases of activity.
- The Doppler boosting factor δ is higher during the optically bright states of the source compared to the dimmer phases of activity.
- The number density (N) of electrons emitting synchrotron photons is larger when the source is in lower states.

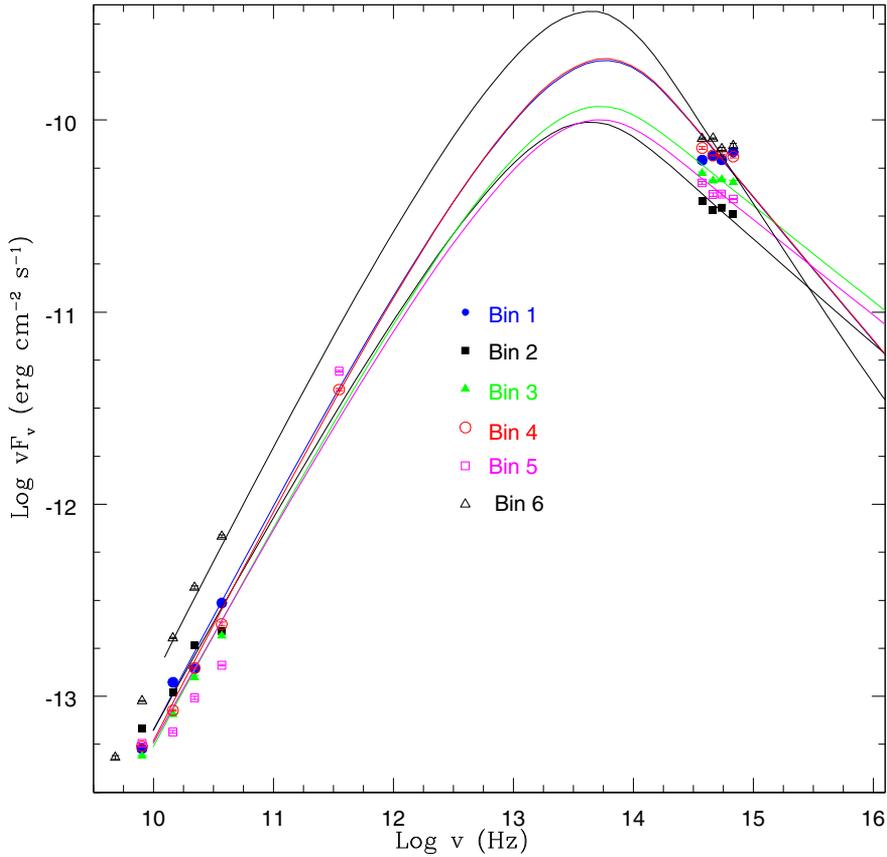


Figure 3. The SSC modeled SEDs of the source corresponding to six different bins.

- The synchrotron peak frequency (ν_{peak}) and peak intensity ($\nu F_{\nu\text{peak}}$) are comparatively higher during the optical outburst phases of the BL Lac object.

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