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BEST FITS OF SIMULTANEOUS BLAZAR SPECTRAL ENERGY DISTRIBUTIONS

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We report about recent progress in the first numerical implementations of spectral energy distribution (SED) fits to estimate synchrotron-self Compton (SSC) model parameters. Using two well observed objects, Markarian 421 and Markarian 501, we highlight the strength of the method, as well as plans for future improvements.

Keywords: BL Lacertae objects – diffuse radiation – gamma rays: galaxies

In the last decades we have witnessed a formidable improvement in the quantity and quality of observational data for many astrophysical phenomena. In this contribution we will concentrate our attention on the possibility to study BL Lacertae objects (BL Lacs) using simultaneous multiwavelength observations of their spectral energy distribution (SED). In particular, we will present a discussion of recent results for two specific sources, Markarian 421 (Mrk 421,[1] redshift $z = 0.030$) and Markarian 501 (Mrk 501,[2] redshift $z = 0.034$), obtained by a numeric χ^2-minimization procedure. BL Lacs are a particular class of *blazars*, i.e. active galactic nuclei (AGNs) characterized by two jets shooting, with relativistic speed, at opposite sides of a supermassive central object and pointing directly in our direction[a]. Within this class, BL Lacs are radio loud objects featuring a broad spectrum ranging from radio to gamma rays: emission lines are absent, variability is marked and optical polarization is strong. BL Lac SEDs show two peaks: the first one is in the infrared or in the X-ray part of the spectrum, and it is generally agreed that it is the result of synchrotron emission; the second peak is instead around GeV or Tev frequencies, correspondingly. *Leptonic models* relate the very high energy γ-ray emission to Compton scattering of photons by relativistic electron/positron populations: when the photons are the synchrotron photons produced by the very same population of electrons that also up-scatters them, we have the so called synchrotron-self-Compton (SSC) models. Alternatively, the scattered photons could be ambient photons, in which case we have external inverse Compton (EIC) models. *Hadronic models* consider instead a proton component in the jets: the higher energy peak is thus produced by interaction of matter and/or photons from the environment with the accelerated protons. It could be reasonable to imagine models where these effects could

[a] For a concise review and an essential bibliography, please see Ref. 3 and references therein.

co-exists, although this possibilities clearly presents additional and more complex challenges. For this reason, in what follows we will restrict ourselves to a specific one-zone[b] SSC model.[4,5] The emission region is considered to be a sphere with radius R that moves with a bulk Lorentz factor Γ in the beam. The beam itself forms a small angle θ with the direction of observation, and special relativistic effects (including relativistic beaming) can be all taken into account with a single parameter $\delta = (\Gamma(1 - \beta \cos\theta))^{-1}$, where β is the speed of the emitting region (having electron density $n_{\rm e}$ and immersed in a magnetic field of uniform intensity B) in units of the speed of light. In the model that we are considering the spectrum of the emitting electrons is phenomenologically taken as a broken power-law in the Lorentz factor of the electrons, γ; this means that spectral indices n_1 and n_2 characterize the spectrum for $\gamma_{\rm min} < \gamma < \gamma_{\rm br}$ and $\gamma_{\rm br} < \gamma < \gamma_{\rm max}$, respectively.

From the literature we could build nine Mrk 421 datasets, and eight Mrk 501 datasets corresponding to simultaneous multiwavelength observations of these sources in different activity states. These datasets have been fitted against the one zone synchrotron-self-Compton model briefly outlined above and, described in more detail in Ref. 3–5. The best fit parameters, the corresponding uncertainties, and the related reduced χ^2 are reported in Tab. 1. The Mrk 421 symmetric uncertainties have been calculated in the canonical way. For the Mrk 501 analysis, we instead calculated non-symmetric uncertainties by searching the χ^2 parameters space along each parameter direction for the points around the minimum at which the χ^2 was bigger than the minimum by the amount required to have a 99% confidence level. Performing a Kolmogorov-Smirnov test for the normality of the residuals, we see that at the 5% significance level normality of the residuals is always rejected. For some datasets normality can not be rejected at the 10% confidence level. This shows that existing multiwavelength data, although in some cases cannot allow for determination of parameters with sufficient accuracy, already suggests that improvements to AGN emission models might be required. This and other aspects, including an independent implementation of SSC models with improved features, will be discussed elsewhere.[6]

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[b]This means that we consider the emission as coming from a single region within the jet.

	state	1	2	3	4	5	6	7	8	9
Markarian 421	n_e	1300^{1500}_{1500}	1000^{3000}_{3000}	5000^{5000}_{5000}	2000^{5000}_{5000}	2000^{5000}_{5000}	4000^{4000}_{4000}	1000^{7000}_{7000}	4000^{9000}_{9000}	1000^{7000}_{7000}
	$\gamma_{\rm min}$	1	1	1	1	1	1	1	1	1
	$\gamma_{\rm br}$	$2.6^{0.9}_{0.9}$	$2.4^{0.9}_{0.9}$	7^{3}_{3}	4^{2}_{2}	$4.5^{1.9}_{1.9}$	$1.9^{0.6}_{0.6}$	8^{6}_{6}	5^{2}_{2}	$8.0^{0.9}_{0.9}$
	$\gamma_{\rm max}$	$1.05^{0.18}_{0.18}$	$4.1^{1.1}_{1.1}$	7^{5}_{5}	$8.2^{1.7}_{1.7}$	$2.4^{0.3}_{0.3}$	$1.8^{0.4}_{0.4}$	7^{2}_{2}	$1.6^{0.4}_{0.4}$	$1.1^{0.4}_{0.4}$
	n_1	$1.49^{0.19}_{0.19}$	$1.5^{0.3}_{0.3}$	$2.05^{0.10}_{0.10}$	$1.8^{0.3}_{0.3}$	$1.7^{0.3}_{0.3}$	$1.54^{0.11}_{0.11}$	$1.7^{0.4}_{0.4}$	$1.5^{0.2}_{0.2}$	$1.6^{0.5}_{0.5}$
	n_2	$3.77^{0.11}_{0.11}$	$3.62^{0.14}_{0.14}$	$4.8^{0.3}_{0.3}$	$4.11^{0.13}_{0.13}$	$4.30^{0.18}_{0.18}$	$4.37^{0.09}_{0.09}$	$4.23^{0.20}_{0.20}$	$4.22^{0.14}_{0.14}$	$3.9^{0.2}_{0.2}$
	B	90^{30}_{30}	80^{60}_{60}	6^{6}_{6}	$12.1^{1.6}_{1.6}$	19^{13}_{13}	100^{70}_{70}	4^{3}_{3}	6^{3}_{3}	4^{3}_{3}
	R	$0.09^{0.04}_{0.04}$	$0.08^{0.04}_{0.04}$	$0.20^{0.15}_{0.004}$	$0.11^{0.13}_{0.13}$	$0.010^{0.004}_{0.004}$	$0.06^{0.03}_{0.03}$	$0.2^{0.5}_{0.5}$	$0.20^{0.18}_{0.18}$	$0.20^{0.40}_{0.40}$
	δ	20^{5}_{5}	27^{11}_{11}	100^{50}_{50}	80^{60}_{60}	70^{50}_{50}	28^{11}_{11}	80^{70}_{70}	110^{40}_{40}	120^{100}_{100}
	$\tilde{\chi}^2$	0.84	1.86	0.91	0.89	0.67	1.39	1.61	0.60	0.85
Markarian 501	n_e	$68.9^{0.2}_{0.2}$	234^{2}_{2}	254^{2}_{2}	153^{1}_{1}	456^{4}_{4}	94^{1}_{1}	165^{1}_{1}	465^{4}_{4}	*Markarian 421/Markarian 501 best fit parameters*
	$\gamma_{\rm min}$	1	1	1	1	1	1	1	1	
	$\gamma_{\rm br}$	$8.02^{0.01}_{0.01}$	$4.88^{0.03}_{0.03}$	$5.60^{0.02}_{0.02}$	$2.67^{0.02}_{0.02}$	$1.03^{0.01}_{0.01}$	$26.72^{0.02}_{0.02}$	$30.64^{34.9}_{30.0}$	$55.5^{2.1}_{1.9}$	
	$\gamma_{\rm max}$	$1.86^{0.04}_{0.03}$	$2.12^{0.06}_{0.05}$	$1.61^{0.22}_{0.15}$	$2.67^{0.08}_{0.07}$	$3.62^{0.06}_{0.06}$	$12.73^{0.05}_{0.05}$	$13.53^{13.3}_{3.3}$	$8.85^{0.36}_{0.30}$	
	n_1	$1.73^{0.00}_{0.00}$	$1.79^{0.00}_{0.00}$	$1.78^{0.00}_{0.00}$	$1.73^{0.00}_{0.00}$	$1.64^{0.00}_{0.00}$	$1.65^{0.00}_{0.00}$	$1.70^{0.00}_{0.00}$	$1.73^{0.00}_{0.00}$	
	n_2	$3.38^{0.00}_{0.00}$	$3.16^{0.00}_{0.00}$	$3.61^{0.00}_{0.00}$	$3.05^{0.00}_{0.00}$	$2.25^{0.02}_{0.02}$	$3.00^{0.01}_{0.01}$	$2.80^{0.00}_{0.00}$	$2.11^{0.01}_{0.01}$	
	B	$2.098^{0.002}_{0.002}$	$1.530^{0.006}_{0.006}$	$5.58^{0.02}_{0.01}$	$1.513^{0.005}_{0.005}$	$1.126^{0.006}_{0.006}$	$3.60^{0.02}_{0.02}$	$1.799^{0.009}_{0.008}$	$1.043^{0.006}_{0.005}$	
	R	$2.332^{0.002}_{0.002}$	$1.909^{0.006}_{0.006}$	$1.620^{0.004}_{0.004}$	$1.985^{0.005}_{0.005}$	$1.742^{0.006}_{0.006}$	$0.925^{0.003}_{0.003}$	$1.202^{0.004}_{0.003}$	$1.627^{0.004}_{0.004}$	
	δ	$19.13^{0.01}_{0.01}$	$24.40^{0.05}_{0.05}$	$15.12^{0.02}_{0.02}$	$25.24^{0.05}_{0.05}$	$12.85^{0.03}_{0.03}$	$16.43^{0.04}_{0.04}$	$17.53^{0.04}_{0.04}$	$13.89^{0.03}_{0.03}$	
	$\tilde{\chi}^2$	0.76	1.72	0.54	0.55	0.47	1.14	1.04	1.18	

Table 1: Best fit parameters for nine Mrk 421 and eight Mrk 501 states. B is given in units of 10^{-6} T, R in units of 10^{14} m, $n_{\rm e}$ in units of $10^6\,{\rm m}^{-3}$, $\gamma_{\rm br}$ in units of 10^4, $\gamma_{\rm max}$ in units of 10^6. In the fits $\gamma_{\rm min}$ has been kept fixed to 1.