Challenges in modeling the high-energy emission in the BL Lac object S5 0716+714

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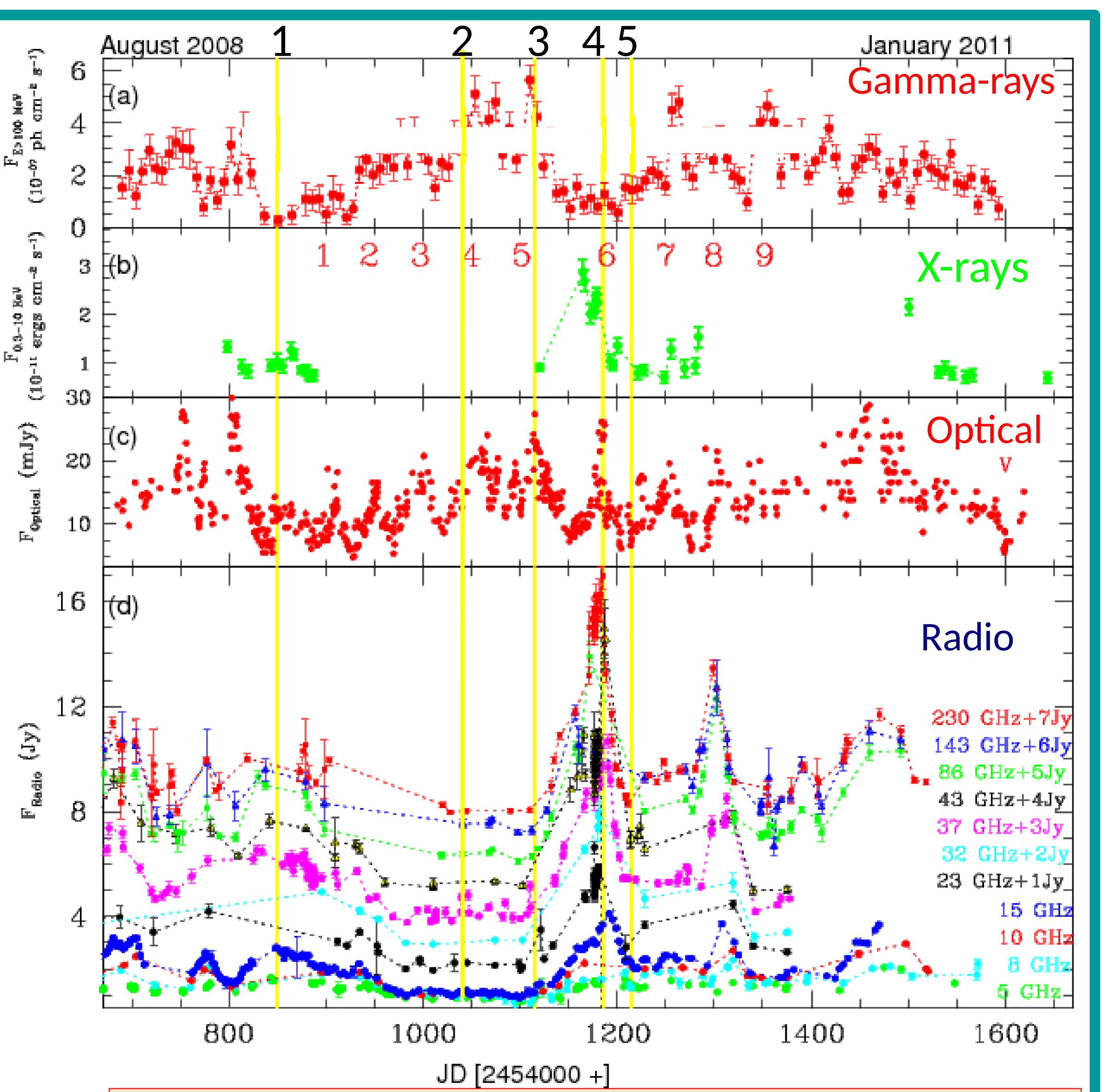
Objective of the project

The origin of the high-energy radiation from bright *Fermi* blazars has always been a key question in AGN physics. In particular, the location and the mechanism responsible for the high-energy emission and the relation between the variability at different wavelengths are not yet well understood. Therefore, it is important to investigate whether a correlation exists between optical and radio emissions, which are both ascribed to synchrotron radiation from relativistic electrons in a plasma jet. If the same photons are up-scattered to high energies, simultaneous variability features could be expected at optical – γ-ray frequencies. The external seed photons also have significant contribution in the origin of high-energy emission. But the observed flux variability often challenges such scenarios. We take the advantage of the broadband variability of the **BL Lac object S5 0716+714** over a time period of April 2007 to January 2011 to explore the physics of radiation mechanisms in the vicinity of the central black hole. The multi-frequency observations comprise monitoring gamma-rays by ***FERMI*-LAT**, X-rays by ***Swift*/XRT**, as well as optical and radio monitoring by several ground based telescopes. We found that the high-energy spectrum, especially in gamma-ray flaring states, in the source cannot be explained by using a one-zone synchrotron self-Compton (SSC) model; a model including external Compton component generally does a better job in reproducing the entire spectral energy distribution SED (including the gamma-ray spectrum), if one uses an external radiation field dominated by Lyman-alpha emission from a putative broad-line region (BLR). The radiation field energy density of this external field varies between 10^{-6} to 10^{-5} erg cm^{-3} , which is a factor of ~1000 lower than expected for a typical quasar. This is a reasonable value for a BL Lac like S5 0716+714, which is known to have a featureless spectrum (no prominent BLR). The combination of non-simultaneous GeV-TeV spectrum of the source shows absorption-like feature between 10-100 GeV (Senturk et al., 2011), and its origin is still an open question.

Broadband Flux Variability

The source exhibits multi-flaring behavior (shown in the Figure) across the whole electromagnetic spectrum over this period. Flares appear on a timescale of ~60-70 days at optical and gamma-rays, which is followed by two major radio flares. An orphan X-ray flare is observed at X-rays during our observations.

The yellow lines in the Figure, represent the different modes of flaring activity for which we construct the broadband spectrum of the source (Time Bin 1 to 5).



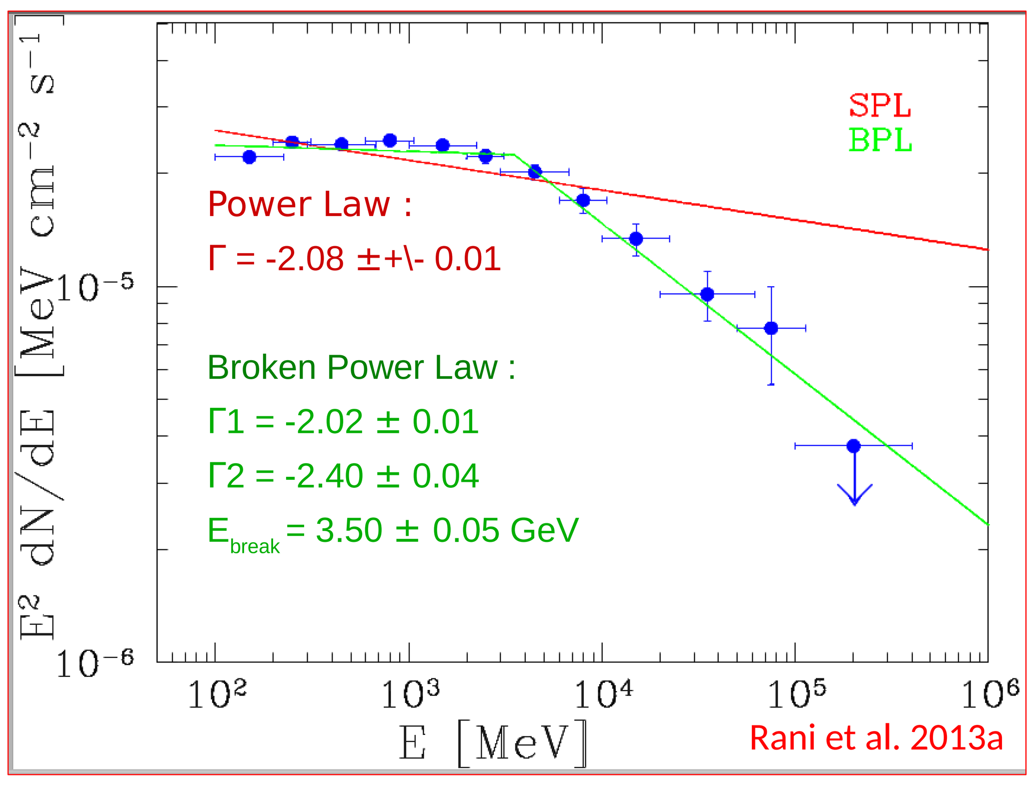
Multi-frequency light curves of BL Lac S5 0716+714

Gamma-ray Spectrum

Gamma-ray spectrum of the source during the past 3.8 years of *Fermi*-LAT monitoring. The red curve represents the best fitted simple power law, while broken power law is in green.

PowerLaw simple power law
$N(E) = N_0 (E/E_0)^{\Gamma}$
N_0 :Prefactor, Γ:spectral index
E_0:energy scale

BrokenPowerLaw two component power law
$N(E) = N_0 (E/E_b)^{\Gamma 1+1}$ E<Eb
$= N_0 (E/Eb)^{\Gamma 2+1}$ E>Eb
N_0 :Prefactor Γ1:low energy spectral index Γ2:high energy spectral index
Eb:break energy



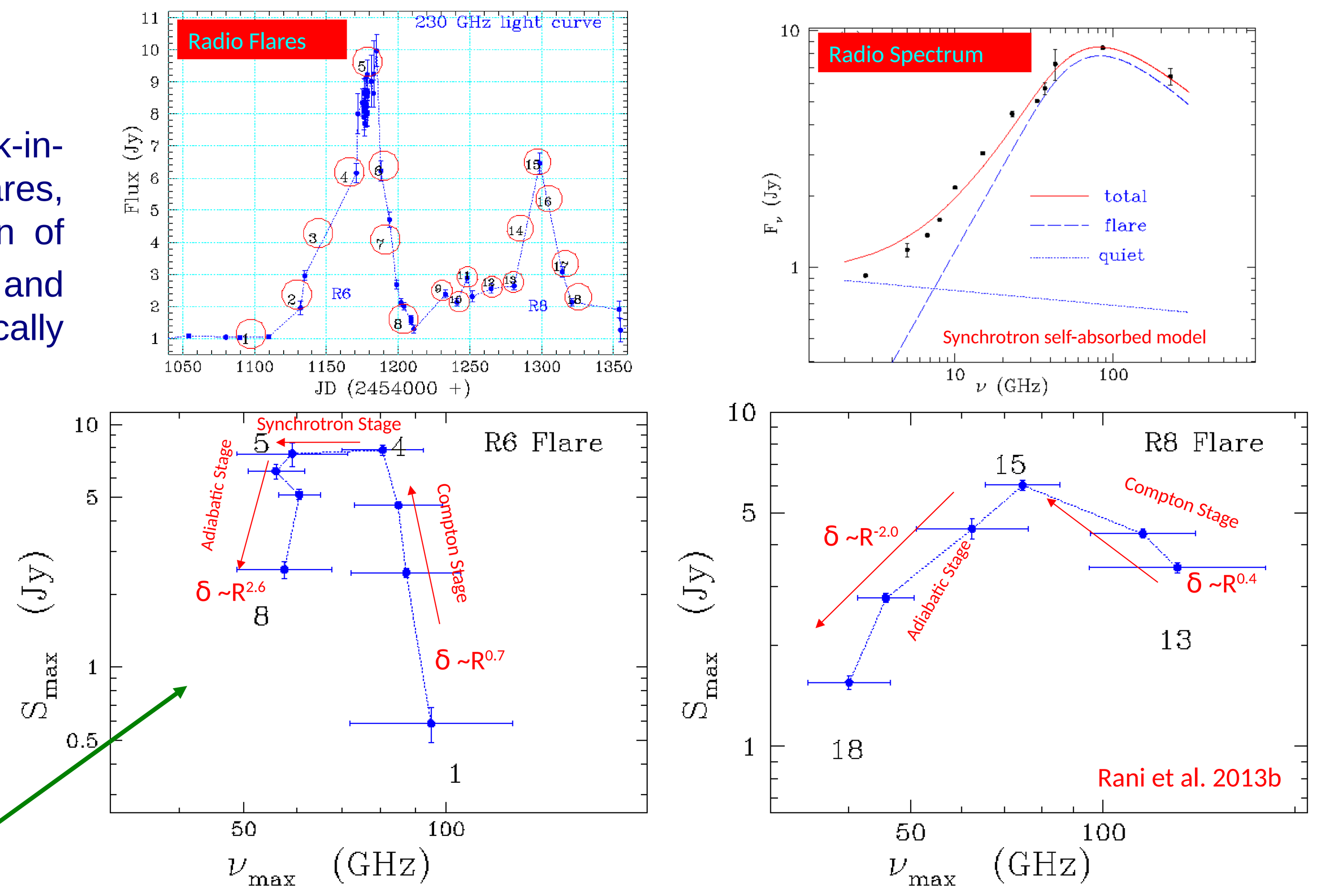
A broken power law model well describes the shape of the gamma-ray spectrum above 100 MeV with a break energy ~**3.5 GeV**. The observed change in spectral slope above and below the break energy is ~**0.38**.

Evolution of Radio Spectra

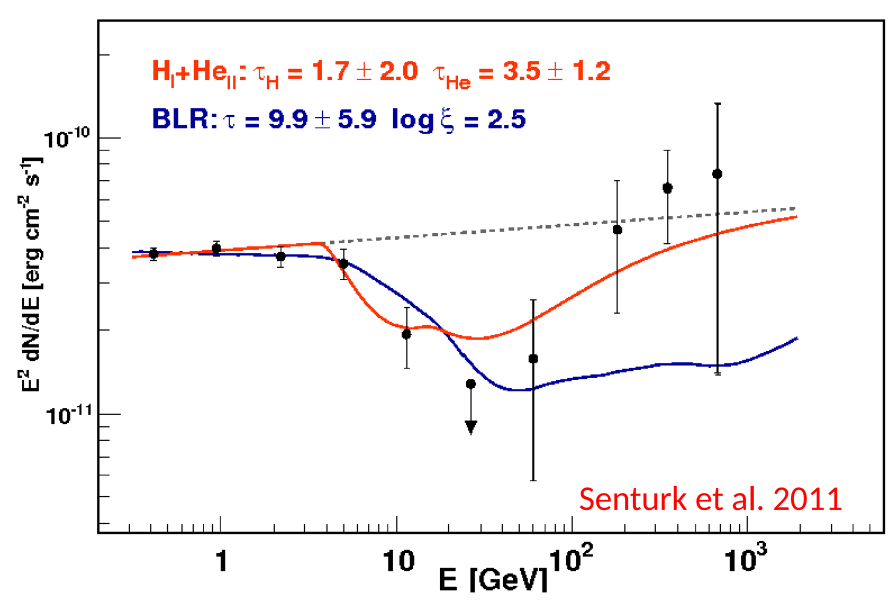
The evolution of the radio flares is tested in context of the shock-in-jet model (Marscher & Gear (1985). For the shock-induced flares, $S_{max} \sim \nu_{max}^{\varepsilon}$, where the ε value depends upon the variation of physical quantities i.e. magnetic field (B), Doppler factor (δ) and energy of relativistic electrons. A comparison of the theoretically expected and our estimated values is given in the table below :

Flare	Stage	$\varepsilon_{Calculated}$	$\varepsilon_{Expected}$
R6	Compton	-7	-2.5
	Synchrotron	0	0
	Adiabatic	10	0.7
R8	Compton	-0.9	-2.5
	Adiabatic	1.8	0.7

The rapid rise and decay of flares in S_{max} vs ν_{max} plane rule out the simple assumptions of a standard shock-in-jet model considered by **Marscher & Gear (1985)** with a constant Doppler factor (δ). For the two flares, we found that δ changes as a function of jet radius.



Curvature in the GeV-TeV Spectrum

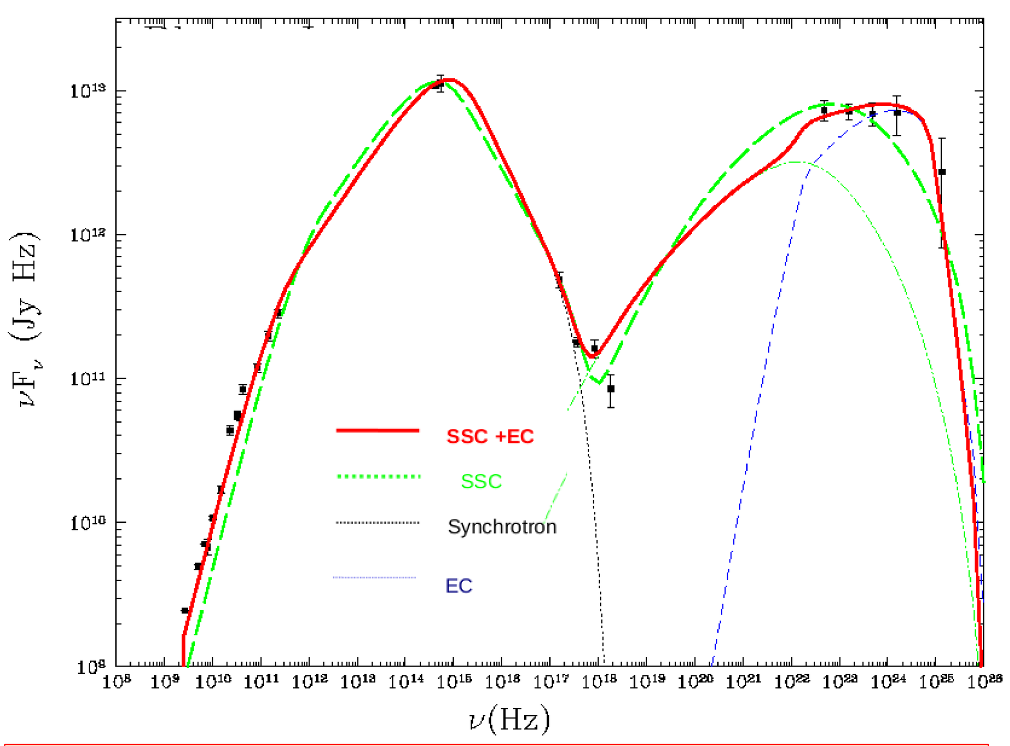


Fermi high-state + MAGIC spectrum for the LBL S5 0617+714. The red curve represents H I + He II absorption and the blue one the full BLR absorption.

Broadband Spectral Modeling

The Figure shows the best fitted spectrum. SSC model is shown as a dashed curve; the combined model is the thick solid curves; the synchrotron component is dotted, the SSC component is dot-dashed, and the EC components is shown by a thin dashed curve.

A combined one-zone **synchrotron self-Compton (SSC) model and a hybrid SSC plus external Compton model** (Böttcher & Chiang 2002) better explains the broadband spectrum of the source. The external radiation field is found to be dominated by Ly-α from a putative broad line region (BLR) with an external field energy density ~10^{-5} ergs cm^{-3}.



Quasi-simultaneous broad band spectrum of the BL Lac object S5 0716+714 observed on October 10, 2009 (Bin 3). (*Rani et al. 2013*).

Summary

➔ The evolution of the flares show a very steep rise and decay over the Compton and adiabatic stages with a slope too high to be expected from intrinsic variations, requiring an additional Doppler factor variation along the jet.

➔ The low activity states of the source are well described by a pure SSC model, while, an EC contribution is required to reproduce the SEDs for high states.

➔ An orphan X-ray flare challenges the one-zone emission models, rendering them too simple. We found that this flare has equal contributions from both the synchrotron and the high-energy (inverse Compton in a leptonic model interpretation) emission mechanisms.

Open Questions

BLR vs MT ?

GeV spectral breaks (~3.5 GeV) favor location of emission within the broad-line region (BLR).
The broadband spectral modeling reveals that the external radiation field is dominated by **Ly-α emission** from the broad-line region.
The detection of 0716+714 at **TeV energies** favors external-Comptonization of molecular torus photons (MT).

The lack of detection of the thermal emission from BLR and/or MT challenges both of the above scenarios.

References

1. Böttcher, M. & Chiang, J. 2002, ApJ, 581, 127
2. Rani B., Lott B., Krichbaum, T. P. et al. 2013A, ASR, 51, 235
3. Rani B., Krichbaum, T. P., L. Fuhrmann et al. 2013B, A&A, 552, 11
4. Senturk, G.D., Errando, M., Boettcher, M., et al. 2011 [arXiv:1111.0378]