Characterizing Multiwavelength Outbursts of Blazars

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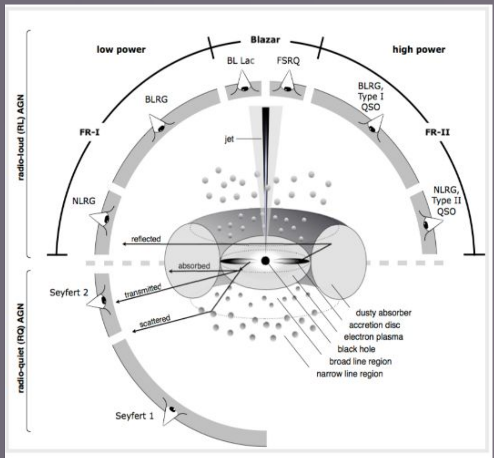
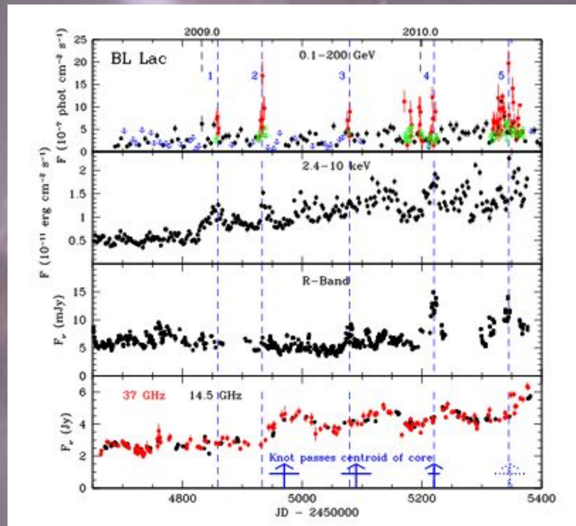
What is a blazar?



Beckmann & Schrader

The centres of all galaxies contain a supermassive blackhole which can accrete matter from its surroundings and can become extremely bright. Such objects are known as active galactic nuclei (AGN). A schematic diagram of an AGN is shown in this image. Some AGNs are known to possess large scale jet like structures. When such jets are pointed along our line of sight, the emission is dominated by the relativistic jet due to Doppler boosting effects and such objects are known as Blazars. Blazars are bright γ-ray sources and dominate the GeV sky.

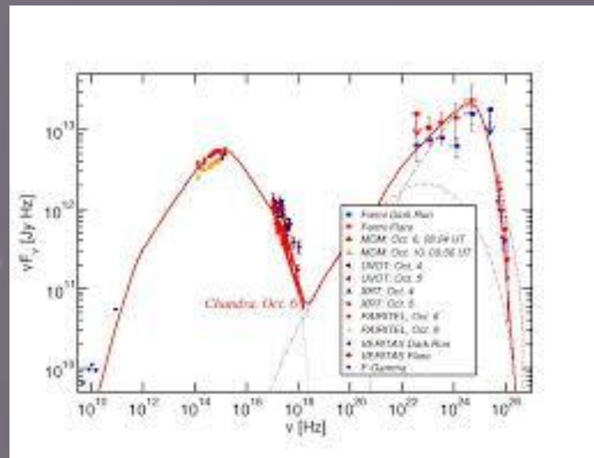
Blazar characteristics



Marscher et al. (2011) 2011JApA...32..233M

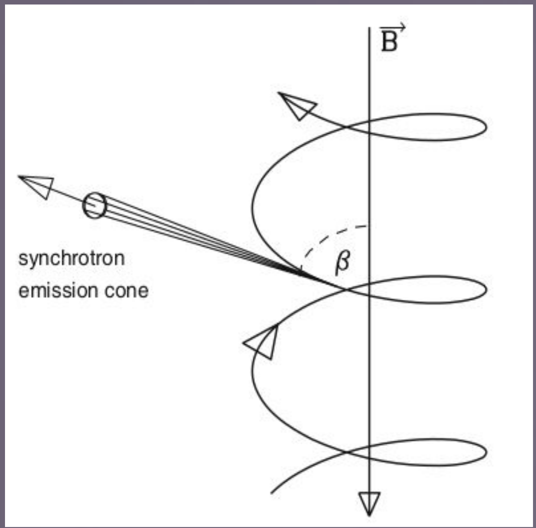
- Blazars are characterized by correlated multiwavelength variability
- Variability timescales range from hours to month scales
- Outbursts appear to be correlated with appearance of new radio 'knots' observed using VLBI as can be seen in the figure on the left.

- Double humped Spectral Energy Distribution (SED)
- Lower energy peak is due to synchrotron emission from electrons in jet
- Higher energy peak is due to Inverse Compton emission from the same electron population in the leptonic model



Abdo et al. 2010 2010ApJ...716...30A)

Emission mechanisms in jet



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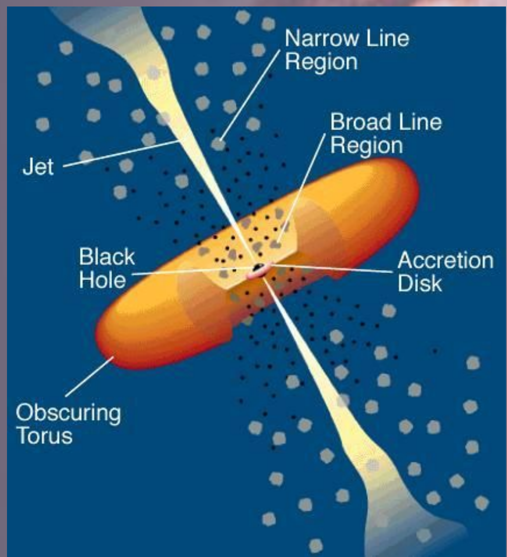
- In the presence of strong magnetic fields relativistic electrons gyrate along magnetic field lines producing electromagnetic radiation called synchrotron emission
- Presence of magnetic fields within jets can be established from polarization measurements
- An electron distribution in the presence of magnetic fields gives rise to the lower energy 'bump' in the blazar SED

- Low energy seed photons could be upscattered by relativistic electrons to very high energies.
- This process is called Inverse Compton scattering (IC). This process is responsible for the high energy 'bump' in the blazar SED
- Seed photons are generated from the synchrotron photons or injected externaly (eg from the BLR or dusty torus)



Urry and Padovani (1995)
1995PASP..107..803U

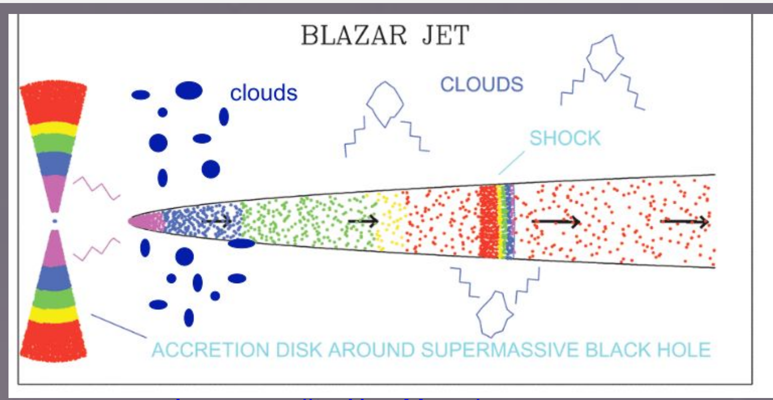
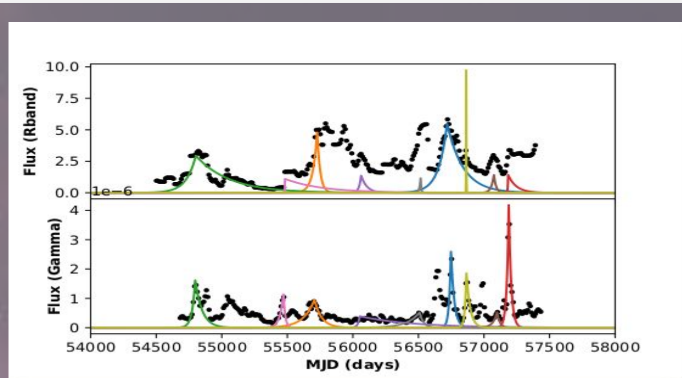


Image credit : Alan Marscher

The production of relativistic electrons in the jet is explained by the Internal Shock model. Standing shocks can be produced within the jet due to collision of plasma blobs moving down the jet. Originally quiscent electrons may be accelerated to relativistic energies by a passing shock front. As these energized electrons move downstream they are cooled by emitting radiation via the synchrotron and Inverse Compton mechanisms. The flares seen in the light curves of blazars is a manifestation of this energizing and cooling of the electron population



The above figure shows simulataneous optical and GeV lightcurves of the blazar 3C 279. 'Flare pairs' are defined as simulataneous outbursts in multiple bands. The identified flare pairs in the lightcurves of 3C 279 are marked with same colours in the upper and lower panels. Flare pairs are believed to be associated to the same event in the jet.

The FERMI telescope observes the GeV sky from 0.1-200 GeV.

FERMI has observed several bright blazars. The SMARTS programme monitored the FERMI detected blazars at optical-near IR wavelengths during 2008-2017 with the goal of multiwavelength studies of blazars. We use well sampled light curves of 10 bright blazars observed over a period of 10 years by FERMI and SMARTS.

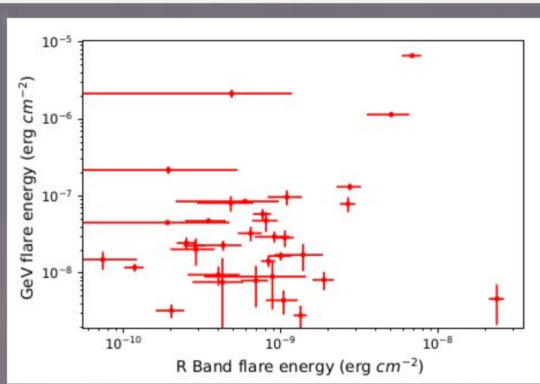


Figure 2a

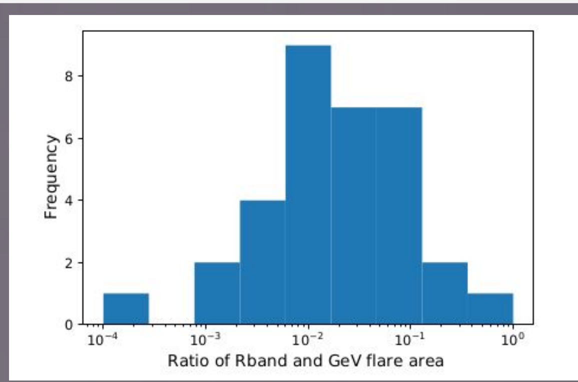


Figure 2b

Figure a shows the correlation plot between energy dissipated in the GeV versus the energy dissipated in the optical outbursts for the identified flare pairs in our sample. Figure b shows the distribution of the ratio of energies dissipated in the optical and GeV flares. The GeV flares are more energetic compared to the optical flares and the peak of the energy ratio distribution lies around 10^{-2}.

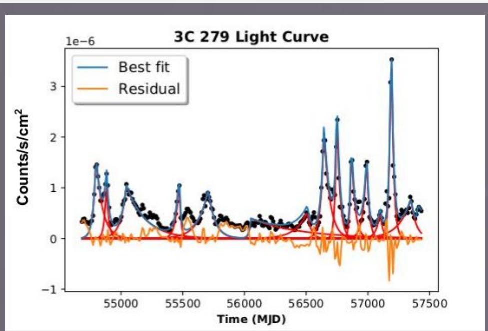


Figure 1a

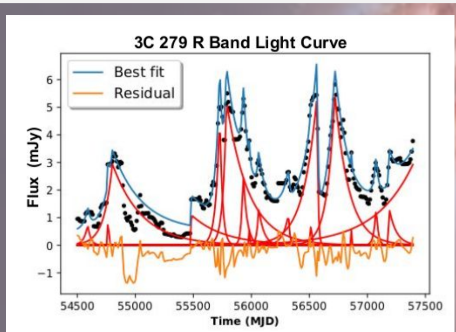


Figure 1b

Figure a and b show the 10 years GeV and R-Band lightcurves of the blazar 3C 279. The red curves are the individual flares modelled using a double exponential function as shown below. The blue curve is the sum of all the fitted flares and the orange line is the residual. From these simultaneous lightcurves we identify the flare pairs. We repeat this process for all 10 blazars.

$$f(t)= A_0 \exp((t-t_0))/t_{rise} \quad t<t_0$$

$$f(t)= A_0 \exp((t_0-t))/t_{fall} \quad t>t_0$$

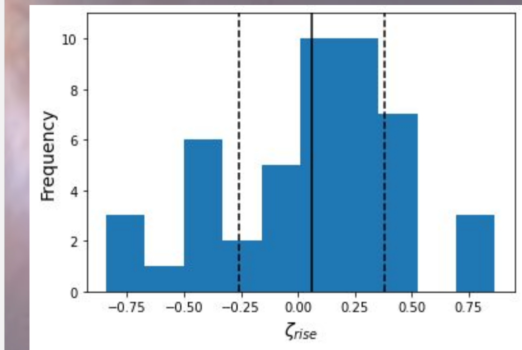


Figure 3a

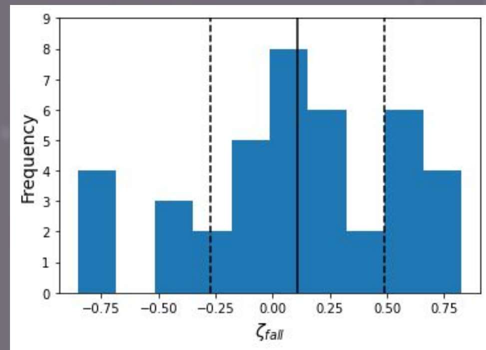
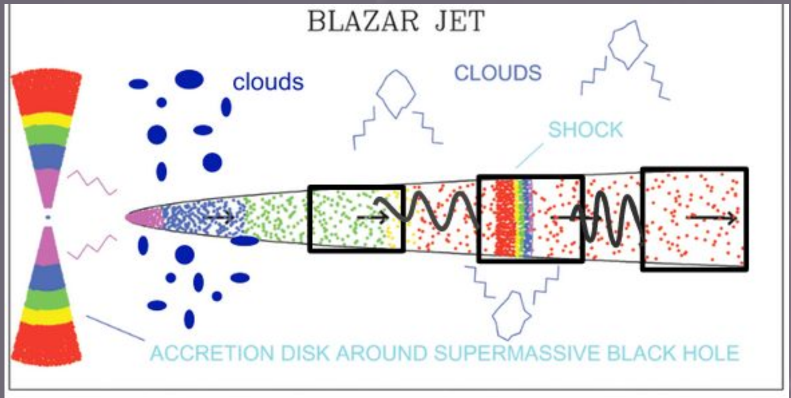


Figure 3b

Figure a and Figure b show the distributions of asymmetry parameter between the rise and fall timescales of the GeV and R-Band flares respectively. Asymmetry parameter is defined below. The rise and fall timescale distribution peaks are consistent with 0. This is expected because we are looking at month timescale flares which are related to the shock crossing timescales in jets

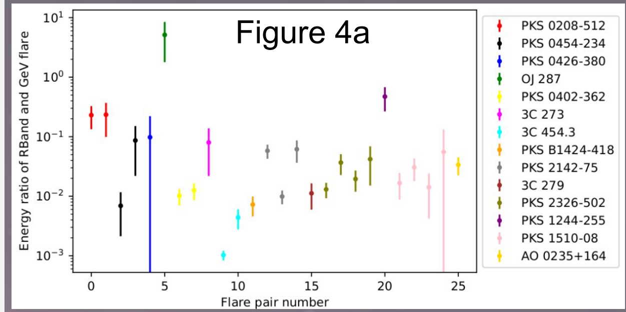
$$\zeta=(t_\gamma-t_{opt})/(t_\gamma+t_{opt})$$

Jet emission model



We model the blazar emission region with cylindrical symmetry and it is divided into multiple cells as shown in the schematic figure above. Each cell consists of its independent electron population and the magnetic field decreases from base to end of emission region. The electrons in a cell are instantly energized into a powerlaw distribution when the cell encounters a shockfront and the electrons are subsequently cooled by the emission of synchrotron and inverse compton radiation. The seed photons for the inverse compton can be generated from the synchrotron photons produced within the jet and this process is called synchrotron self-Compton (SSC), or could be of external origin like the broad line region (BLR) and the dusty torus. For SSC seed photons, light travel times have been taken into account. The BLR is assumed to be located at 0.9 pc and the torus is assumed to be located at 10pc from the central engine and we assume that the BLR and torus emission is a line emission at UV and infrared frequencies respectively for the sake of simplicity. Multiple shocks are sent down the jet during the course of the simulation. The simulation parameters include maximum energy of injected electron population (γ_{max}), bulk Lorentz factor of jet (Γ_{jet}), location of emission region (r_{ems}), magnetic field strength as base and tip of jet (B_0 , B_1).

Constraining the location of the emission region in blazars



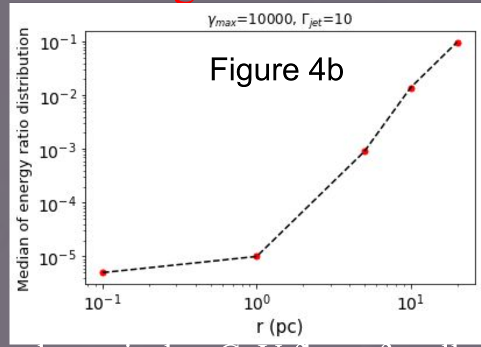
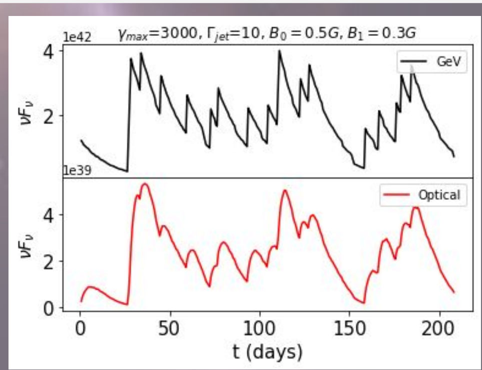


Figure a shows the ratio of energy dissipated in the optical to GeV flares for all the flare pairs in our sample. We expect the energy ratio to be strongly dependent on the location of the emission region and the energy of the shock front which is represented by γ_{max}. We take the case of the blazar PKS 2326-502 and from its observed SED (Dutka et al. 2016) we simulated its lightcurves by fixing γ_{max}=10000. Figure b shows the median of the energy ratio distribution for each simulation run as a function of the emission region location. We can conclude that the best fit location for the GeV emission region is around the 10 pc zone i.e the GeV emission region is in the vicinity of the dusty torus and far away from the BLR. Physically this means that the high energy GeV photons are mostly generated due to IC from BLR seed photons and as we go farther away from the BLR the GeV flare intensities also decline.



Simultaneous GeV and optical lightcurves generated using our simulation. The input parameters of the simulation have been indicated on the top of the figure.

Conclusion

Locating the GeV emission region is an important challenge for the blazar physics community. Several authors have proposed parsec scale GeV emission regions by studying day scale flares (eg see Dotson et al. 2015, Saito et al. 2013). We have reconfirmed the same proposal independently by studying month scale flares.