Impact of MHD Instabilities on the Non-thermal Emission Signatures of Blazar Jets

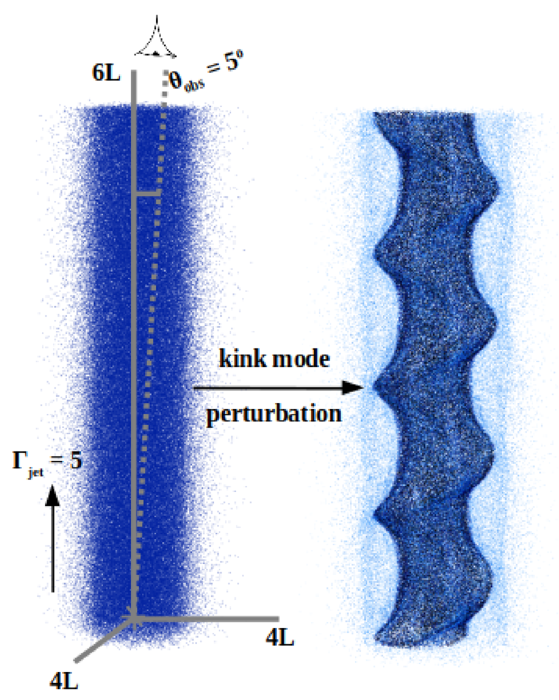
Sriyasriti Acharya[1,2]

[1]Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, 21029 Hamburg, Germany
[2]Department of Astronomy, Astrophysics & Space Engineering, IIT Indore, M.P. - 452020, India
Email: *sriyasriti.acharya@uni-hamburg.de, sriya.acharya@gmail.com*

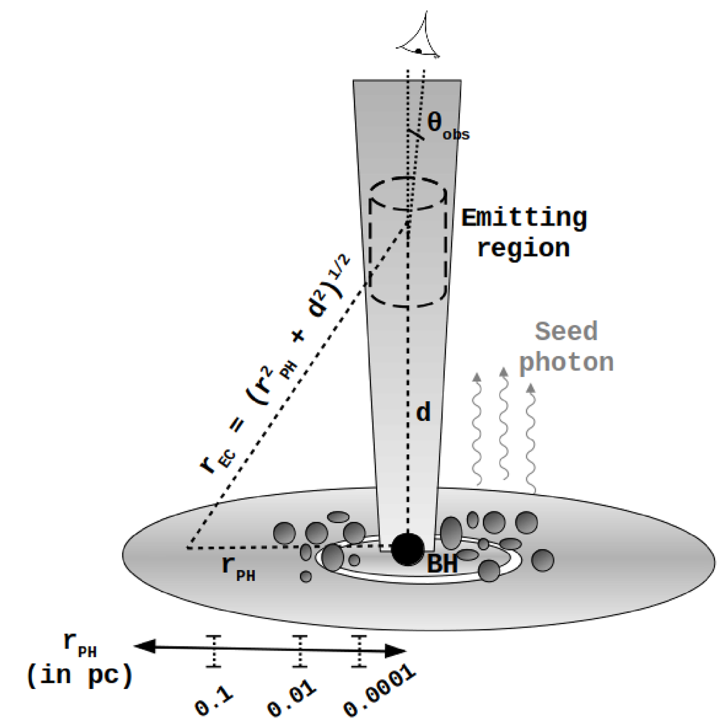
– Context –

Blazars, a subclass of active galaxies with relativistic, collimated plasma jets pointing in the direction of the observer, are prone to a variety of magneto-hydrodynamic (MHD) instabilities. These instabilities play a major role in governing the dynamics and observed signatures of blazar emissions. Several studies indicate that jets are not straight and stable in structure. Indeed, instabilities can cause the jet to bend. The goal of this work is to investigate the interplay of the dynamics of the jet with radiation and particle acceleration mechanisms in regulating the multi-band emission, variability, and polarization features through numerical analysis. For this purpose, we performed simulations of a representative section of a blazar jet perturbed with kink instability. We found that with the evolution of kink instability, the plasma column bends and gets turbulent in nature, generating localized shocks. These shocks give rise to flaring signatures in the high-energy band and also result in instantaneous flattening of the synchrotron component of the SEDs. Further, our results may provide a possible explanation for the observed uncorrelated variation of optical flux and polarization degree.

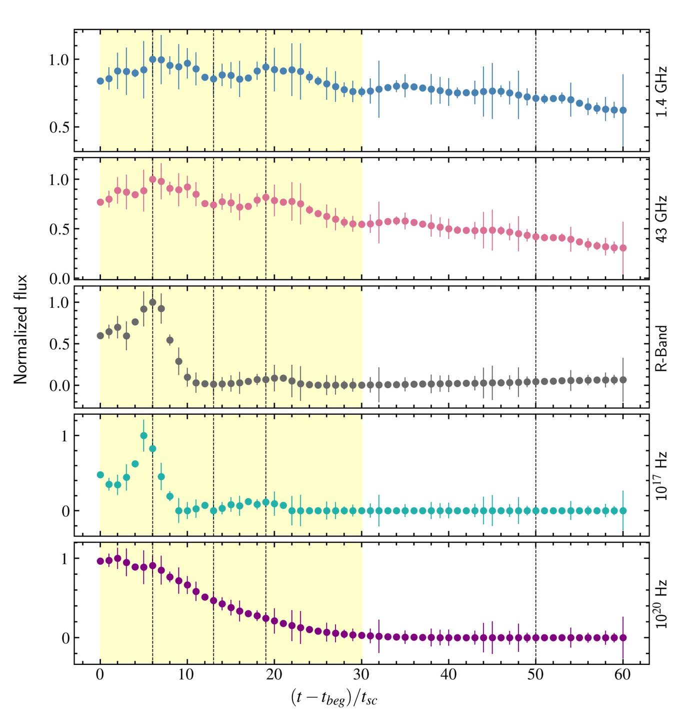
Initial Conditions: Dynamics & Emission



- RMHD module of the PLUTO code (Mignone 2007)
- Plasma column is about a few 10s of pc away from the central engine and hence magnetically dominated with magnetization parameter σ = 10 *(Acharya 2021)*
- Lighter jet compared to the ambient medium (Walg 2013)
- Toroidal + poloidal magnetic field (Mizuno 2011)
- Used Hybrid framework of the PLUTO code (Vaidya 2018, Mukherjee 2021)
- Radiation Processes: Synchrotron, *External Compton (Acharya 2023)*
- Power-law particle spectra with initial power-law index p = 6, $\gamma_{min} = 10^2$, $\gamma_{max} = 10^8$
- Target photon source: T = 5000 K, $r_{PH} \approx$ 0.01-0.1 pc (outer region of accretion disk)



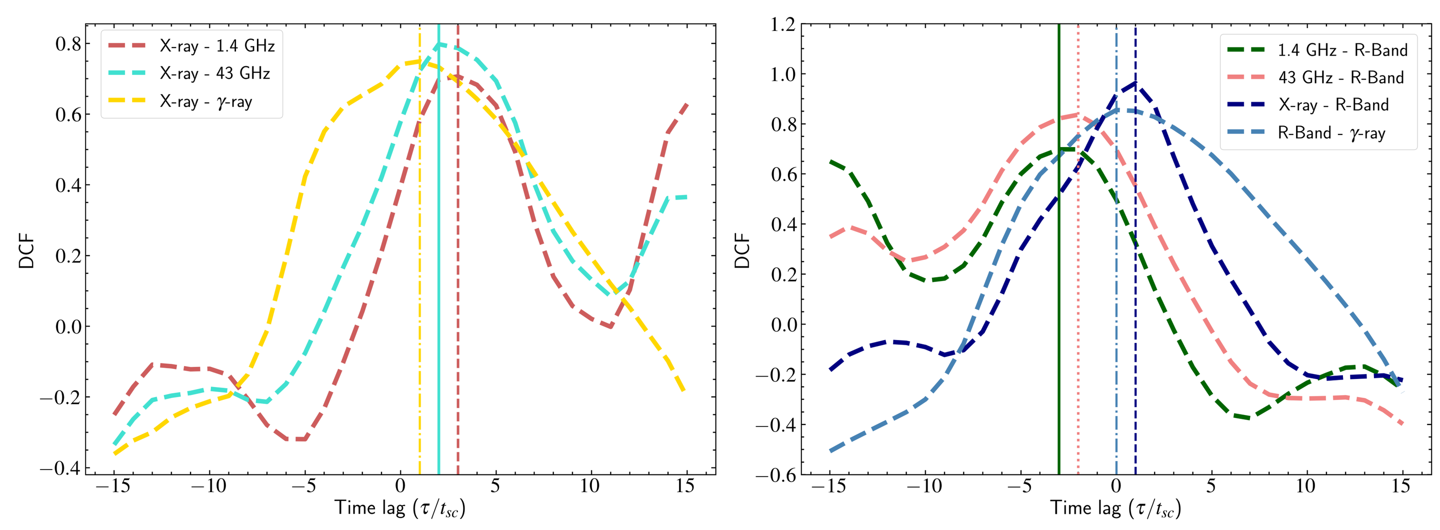
Multi-band Variability Study



Here, t_{sc} = 0.32 years with $t_{beg} = 20\ t_{sc}$.

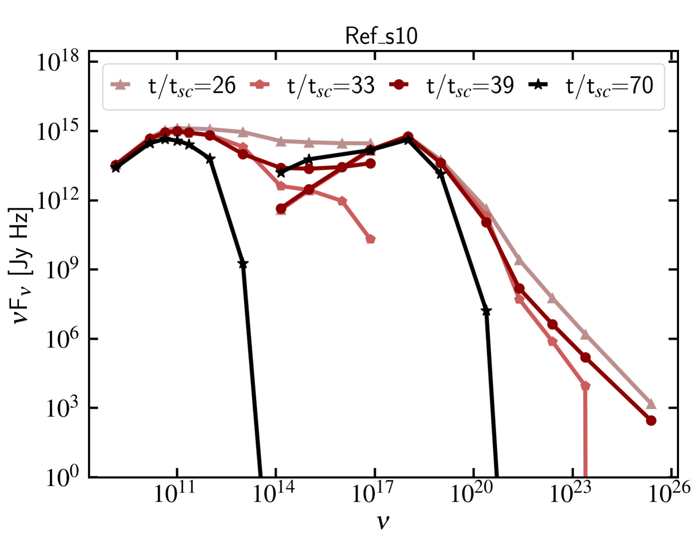
- Flux values are normalized to their maximum values and provided in the units of erg s^{-1} cm^{-2} Hz^{-1}
- Radio: moderately variable emission
- R-band & 10^{17} Hz: characteristic transient feature at t/t_{sc} = 26
  - Min. variability timescales: $\approx 0.75 t_{sc}$
  - Size of emitting region: ≈ 30 number of grid cells out of (160 × 160 × 240)
- Statistical estimates such as relative variability amplitude (RVA) suggest the presence of long-term variability in each band for nearly 20 years

Discrete Correlation Function



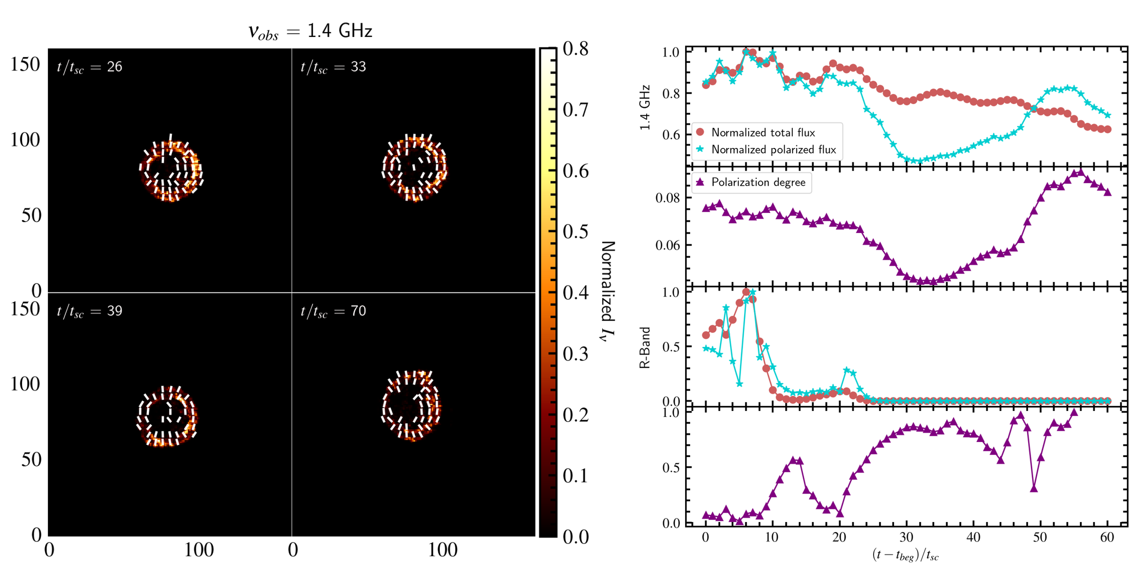
- Radio emissions show a strong correlation with zero time lag suggesting co-spatial emitting regions within that period
- Rise in R-Band & 10^{17} Hz fluxes are followed by the radio and γ-ray emissions

Spectral Analysis



- During the transient event, flatter spectra are observed
- As the transient activity dissipates, the spectra become steeper
- Generation of localized shocks in addition to dynamics of plasma column, results in the flattening of Synchrotron spectra at t/t_{sc} = 26
- Both components of SED behave in a similar way, as the same electron population responsible for both
- Also, each component gets broadened owing to the different losses of emitting particles

Polarization Activity [*PRELIMINARY RESULTS*]



- Magnetic field lines follow the evolution of the column
- Polarized flux variation correlates with synchrotron flux in both bands
- Optical flux and polarization degree are uncorrelated with each other

Summary

- Combination of geometry and growth of MHD instabilities lead to the generation of localized shocks, resulting in the acceleration of particles up to very high energies.
- Impact of such localized shocks is manifested in multi-band light curves and SEDs, as we find evidence of flattening during the transient activity phase.
- Multi-band correlation study suggests highly energetic shocked particles lose energy due to radiative cooling and emit in the lower energy bands via the synchrotron process. Further, these lower energy particles get up-scattered and emit γ-ray via EC process.
- Uncorrelated uncorrelated behavior of optical flux and polarization degree may favor the geometrical model in the presence of shocks.

[Find me here]