Angle- and Polarization-dependent Synchrotron and SSC blazar model

Motseothata Tisang
Prof. Markus Böttcher

Center for Space Research
North-West University

tisangtms@gmail.com

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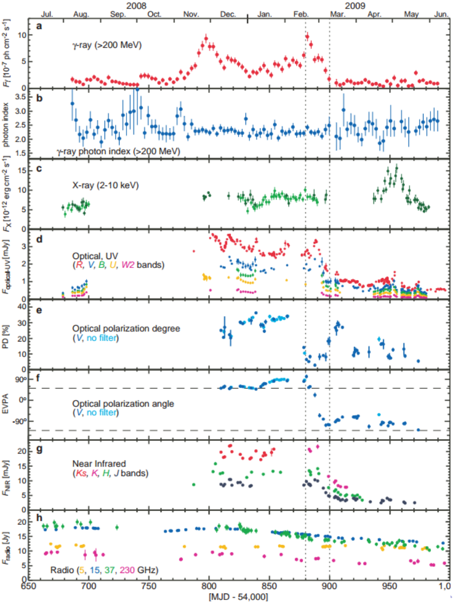
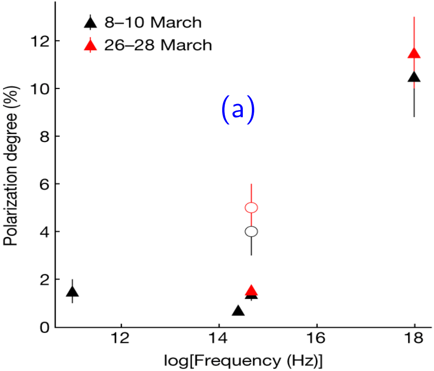
Multiwavelength Polarization of Blazars

- Blazars exhibit polarization in radio-optical bands and X-rays (in some cases).
- Multi-band polarimetry effectively probes the jet magnetic field and emitting regions.
- Blazar polarization (PD and PA) can change with time (see the right plot, from Abdo et al., 2010 - 3C 279).
- Optical-radio polarimetry effectively probes less active jet regions.



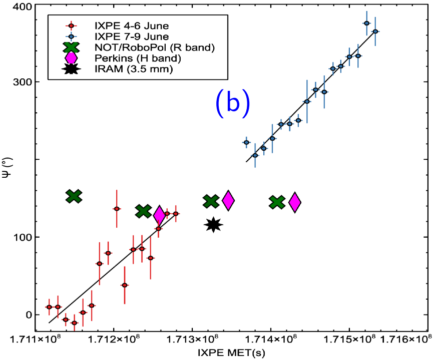
IXPE Observation Results

Mrk 501



Liodakis et al. (2022)

Mrk 421



Di Gesu et al. (2023)

Related Conducted Work

- Lyutikov et al. (2005) reviewed synchrotron polarization properties with purely helical B-fields.
- Jamil & Böttcher (2012) studied the angle-dependent S+SSC blazar emission with partially ordered B-fields.
- Zhang & Böttcher (2013) analyzed the expected SSC polarization signatures of blazars in a perfectly ordered B-field.
- Joshi et al. (2020) explored the effects of the magnetic field orientation on the SEDs of a typical blazar.

So, the fully angle- and polarization-dependent S+SSC blazar emission has never been explored.

Research Aims

- To develop a comprehensive, fully angle- and polarization-dependent synchrotron and SSC blazar model.
- Explore the SED and linear PD variations when the magnetic field is oriented perpendicular, obliquely, and toroidally relative to the jet axis.
- Conducted in the emission frame moving along the jet $\rightarrow$ no Doppler boosting effects into the observer's frame.
- LoS, jet axis $||$ z-axis.

Model (Synchrotron Radiation)

Synchrotron polarization and emissivity (Rybicki & Lightman, 1979):

$$\Pi_\nu^{\text{syn}}(\varphi) = \frac{\langle G(x)\rangle}{\langle F(x)\rangle} = \frac{\int n_e(\gamma)G(x)d\gamma}{\int n_e(\gamma)F(x)d\gamma}, \quad (1)$$

$$j_\nu^{\text{syn}}(\varphi) \propto \sin(\varphi)\int n_e(\gamma)F(x)d\gamma, \quad (2)$$

where

$$F_{\text{exact}}(x) = x\int_x^\infty K_{5/3}(\xi)d\xi, \ \ F_{\text{approx}}(x) = 1.42\sqrt{\frac{\pi}{2}}x^{3/10}e^{-x} \quad (3)$$

$$G(x) = xK_{2/3}(x), \quad (4)$$

$$x = \frac{\nu}{\nu_\varphi(\gamma)}, \quad (5)$$

$$\nu_\varphi(\gamma) \approx 4.2\times 10^6 B\gamma^2 \sin\varphi \ \ [\text{Hz}], \quad (6)$$

$$n_e(\gamma) = n_0\gamma^{-p} \ \ \text{for} \ \ (\gamma_1 \le \gamma \le \gamma_2). \quad (7)$$

Model (Synchrotron Self-Compton Process)

SSC emissivity (Böttcher et al., 2012):

$$j^{SSC}(\epsilon_s, \Omega_s) = \frac{hc\epsilon_s}{4\pi} \int_1^{\infty} n_e(\gamma) d\gamma \int_{-1}^{+1} d\eta_{ph} \int_0^{2\pi} d\phi_{ph} \int_0^{\infty} n_{ph}(\epsilon, \Omega_{ph})(1-\beta\mu) \frac{d\sigma_C}{d\epsilon_s} d\epsilon. \tag{8}$$

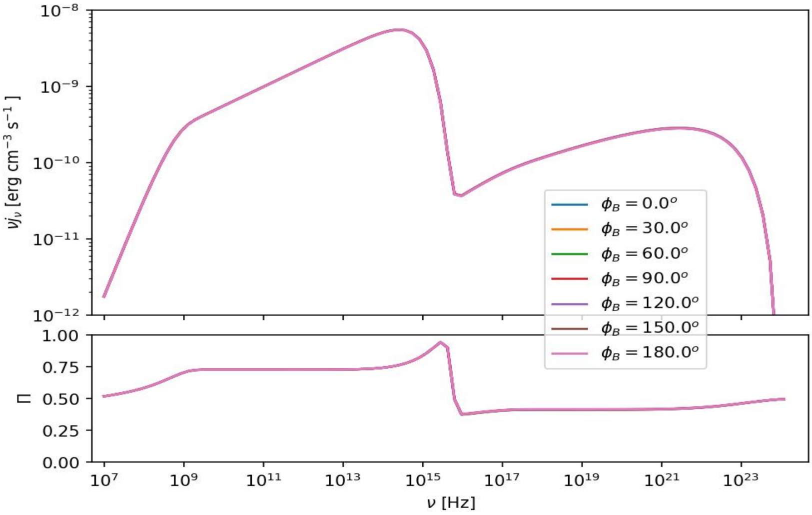
SSC Polarization (Bonometto & Saggion, 1973):

$$\Pi_\nu^{SSC} = \frac{P_\perp^{SSC} - P_{||}^{SSC}}{P_\perp^{SSC} + P_{||}^{SSC}} \tag{9}$$

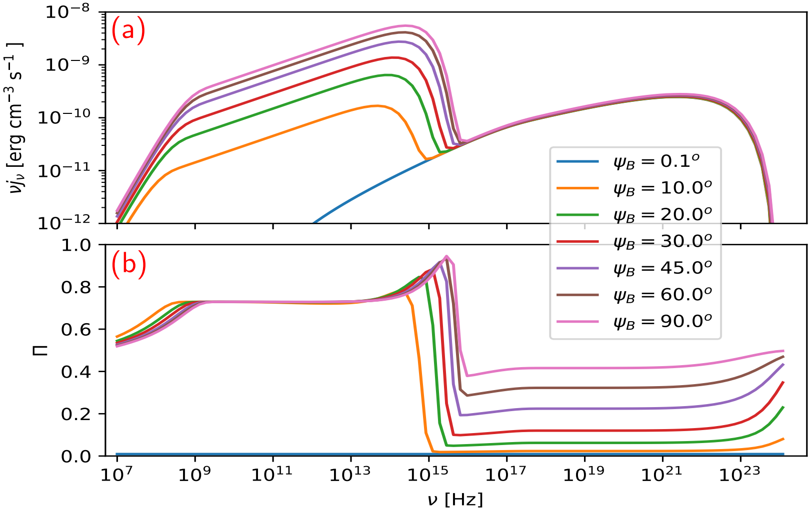
Total Polarization:

$$\Pi_\nu^{Total} = \frac{\Pi_\nu^{Syn} \cdot j_\nu^{Syn} + \Pi_\nu^{SSC} \cdot j_\nu^{SSC}}{j_\nu^{Syn} + j_\nu^{SSC}} \tag{10}$$

Results (SED and Total Polarization)

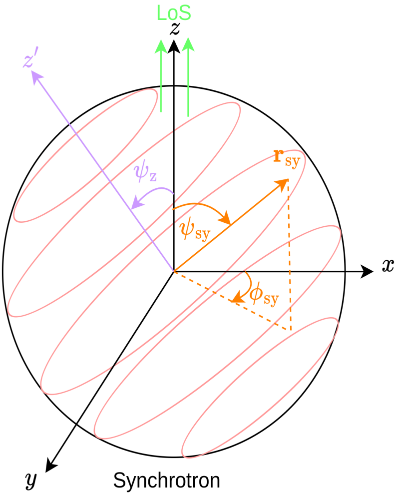


Results (cont...)

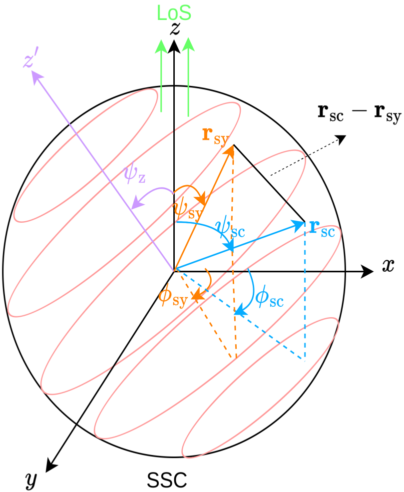


Currently → Toroidal Field

- Exploring the toroidal (and eventually, helical) magnetic field structures.



Synchrotron



SSC

Summary and Outlook

- We developed an angle- and polarization-dependent S+SSC blazar model.
- New aspect was to treat the anisotropy of the radiation produced and the polarization in the treatment of the synchrotron and SSC mechanisms.
- Synchrotron SED component and SSC PD depend strongly on the $B-$field polar angle compared to the synchrotron PD and SSC SED component.
- First step in the development of a comprehensive, fully angle- and polarization-dependent blazar radiation transfer code.
- Future work: We will also consider more complex $B-$field geometries (such as helical) and the effects of SSA and gamma-ray absorption.