Tenth International Fermi Symposium

9th-15th October 2022

Modeling the Multi-wavelength Polarization and Spectral Energy Distributions of Blazars

Hester Schutte

Supervisor: Markus Böttcher

Collaborators: Joleen Barnard, Justin Cooper, Brian van Soelen, Anton Dmytriiev, Amanpreet Kaur, Abe Falcone, Fabrizio Tavecchio, Marco Landoni, Michela Negro, Haocheng Zhang and David Buckley

schuttehester1@gmail.com

Collaborators

- *Southern African Large Telescope* (SALT) - Robert Stobie Spectrograph (RSS):
  - Proposal "Observing the Transient Universe"; PI: David A. H. Buckley
  - Data reduction: Joleen Barnard and Justin Cooper with supervision from Brian van Soelen
- Optical photometry from the *Las Cumbres Observatory* (LCO) and the Steward Observatory: Joleen Barnard and Brian van Soelen (PI of LCO proposal)
- Archival data: Hester Schutte
- *Swift*-XRT: Abe Falcone and Amanpreet Kaur
- *Fermi*-LAT: Anton Dmytriiev
- *IXPE*: Michela Negro
- Modeling: Hester Schutte, Markus Böttcher, Marco Landoni, Fabrizio Tavecchio, Haocheng Zhang

Motivation and Aim

Motivation: The synchrotron (non-thermal) continuum produced by relativistic electrons in the jet is expected to have a high polarization degree

- Low degree of linearly polarized light $\Rightarrow$ can be explained by a disordered magnetic field.
  $\Rightarrow$ Polarimetry is useful to probe the inner structure of jets.
- Unpolarized light from stars in host galaxy, dusty torus and accretion disk (thermal). $\Rightarrow$ Decreases the net degree of polarization measured.

The *IXPE* started observing 3C 273 and 3C 279 in June 2022.

Aim: Construct the SED and multi-wavelength polarization model for these sources (incl. 4C+01.02) by including the unpolarized thermal components and the magnetic field geometry downstream from the shock in the jet.

Observations

The SALT ToO Program "Observing the Transient Universe" (PI: D.A.H. Buckley) conducts spectropolarimetry and spectroscopy observations of blazars and contemporaneous observations are included from the LCO (PI: Brian van Soelen) and the Steward Observatory, *Fermi*-LAT and the *Swift*-XRT (when available).

- 20 blazars observed (16 FSRQ, 3 BL Lacs, 1 blazar candidate of unidentified classification)
- redshifts of 0.1 to 2.1
- Multi-epoch observations for 10 blazars
- Polarization degrees of 0 to $\sim$ 30 %

In this presentation we will be focussing on: 4C+01.02, 3C 273 and 3C 279

One Zone Leptonic Model: Low-Energy Components

ELECTRON DISTRIBUTION

Broken power-law with exponential cut-off

$\rightarrow$ Synchrotron radiation

SHAKURA AND SUNYAEV (1973) ACCRETION DISK

Assuming a thin disk ($L_d < 0.3 L_{Edd}$) and non-rotating BH.

The peak of the accretion disk component corresponds to the maximum disk temperature at the inner disk radius:

$$\nu^d(T^{max}) \propto M_{BH}^{-1/4}$$

BLR EMISSION LINES

- Approximated as Gaussians.
- Flux heights (independent of the continuum flux) relative to each other (Francis et al., 1991).

SYNCHROTRON POLARIZATION

According to Rybicki and Lightman (1979):

$$\Pi^{sy} = F_B \cdot \frac{<G(x)>}{<F(x)>}$$

$$<G(x)> = \int N_e(\gamma) x(\gamma) K_{2/3}(x(\gamma)) d\gamma$$

$$<F(x)> = \int N_e(\gamma) x(\gamma) \int_{x(\gamma)}^{\infty} K_{5/3}(x(\psi)) d\psi d\gamma$$

One Zone Leptonic Model: High-Energy Components

INVERSE COMPTON RADIATION (Böttcher et al., 2012):

$$j_\nu^{\mathrm{head-on}}(\epsilon_s, \Omega_s) \propto \int d\gamma n_e(\gamma) \int d\Omega_{ph} \int d\epsilon n_{ph}(\epsilon, \Omega_{ph}) \frac{d\sigma_C}{d\epsilon_s}$$

BLR SEED PHOTONS (Böttcher et al., 2013): Modeled as an isotropic thermal photon field in the AGN rest frame.

ACCRETION DISK PHOTON DISTRIBUTION (Böttcher et al., 1997): depends on disk intensity and angle at which photon travels from disk.

EC emission is expected to be unpolarised due to the approximate azimuthal symmetry and unpolarised target photons.

SSC POLARIZATION (Bonometto and Saggion, 1973):

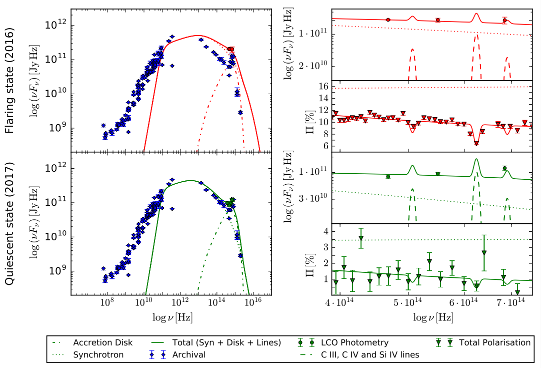
$$\Pi_\omega^{SSC} = \frac{P_\omega^{SSC,\perp} - P_\omega^{SSC,\parallel}}{P_\omega^{SSC,\perp} + P_\omega^{SSC,\parallel}}$$

TOTAL DEGREE OF POLARIZATION:

$$\Pi_\nu = \frac{\Pi_\nu^{sy} \cdot F_\nu^{sy} + \Pi_\nu^{SSC} \cdot F_\nu^{SSC}}{F_\nu^{sy} + F_\nu^{SSC} + F_\nu^{d} + F_\nu^{lines} + F_\nu^{EC}}.$$

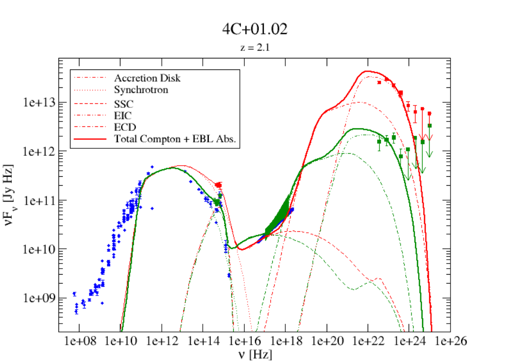
One Zone Leptonic Model for 4C+01.02

Polarization diluted by thermal components: accretion disk and BLR

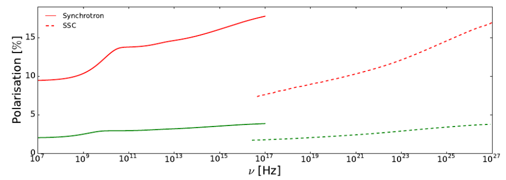


Constrains $F_B < 1$ (compared to prev. work $F_B = 1$ by Zhang & Böttcher 2013): $F_B^{\mathrm{flare}} = 0.2$, $F_B^{\mathrm{quies}} = 0.04$ and $M_{BH} = 5 \times 10^9 \mathrm{M}_\odot$.

Schutte et al. (2022)



Code of Böttcher et al. 2013 (Schutte et al., 2022)

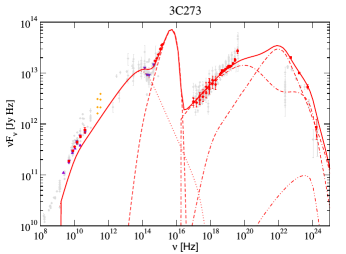


SSC polarization - code of Zhang and Böttcher (2013)

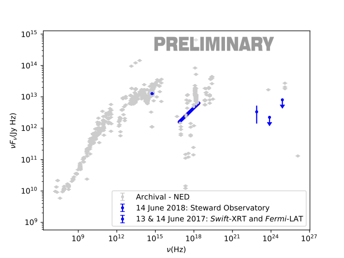
Observations: 3C 273

Optical flux is dominated by the accretion disk →

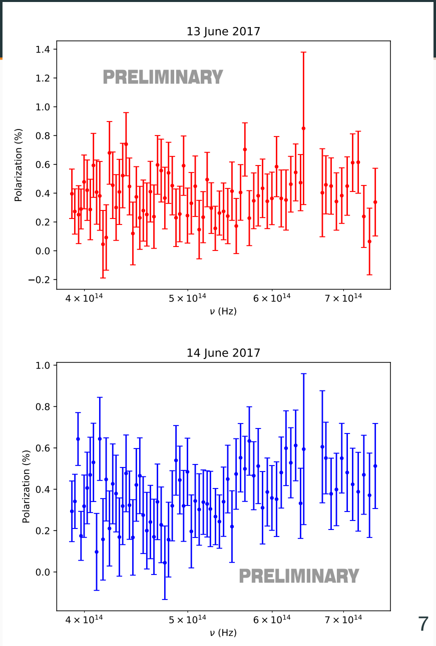
Polarization observed in the spectropolarimetry might be from the accretion disk (not seen perfectly face-on) or ISM.



Böttcher et al. (2013)



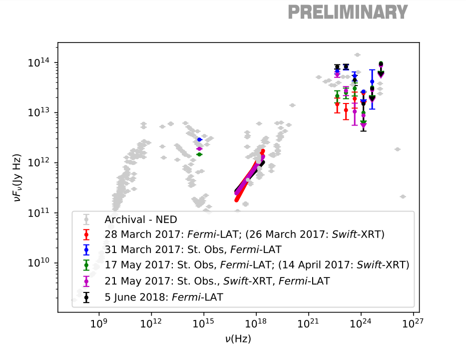
Our collected data.



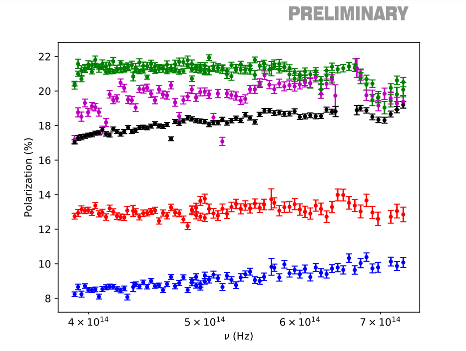
No increase in the polarization towards the red end:

→ Can only derive an upper limit on the synchrotron contribution in the optical regime.

Observations: 3C 279

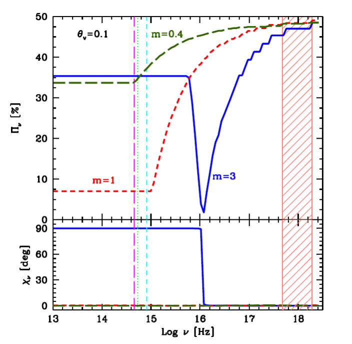


SED

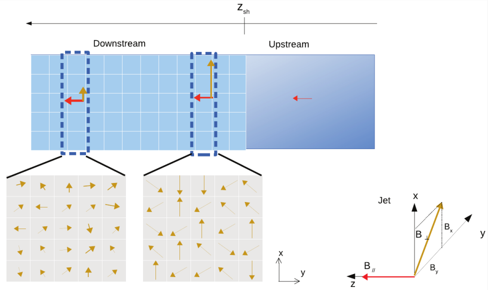


SALT Spectropolarimetry

Shock-in-Jet Model (time-independent)



Tavecchio et al. (2018)



Setup

- Jet divided into domains along its radius and downstream region.
- The maximum Lorentz factor $\gamma_{\max}(z)$ and maximum perpendicular field component $B_{\perp,\max}(z)$ decreases along the distance z of the jet:

$$\gamma_{\max}(z) = \left[\gamma_{\max,\,0}^{-1} + \frac{4}{3}\sigma_T \frac{1}{mc}\frac{1}{v_{\rm adv}}\frac{1}{8\pi}\int_{z_{\rm sh}}^{z} B(z)^2 dz\right]^{-1}.$$

$$B_{\perp,\,\max}(z) = B_{\perp,\,0}(z/z_{sh})^{-m}$$

Total synchrotron polarization degree:

$$\Pi_\nu = \sqrt{Q_\nu^2 + U_\nu^2}/I_\nu$$

with $U_\nu = \sum U_{\nu,\,i}$, $Q_\nu = \sum Q_{\nu,\,i}$
and $I_\nu = \sum I_{\nu,\,i}$, by knowing the B-field
in each domain i.

Current work:

Constructing the model that combines the thermal components with the polarization calculated by the shock-in-jet model to calculate the total polarization degree:

$$\Pi_\nu = \frac{\Pi_\nu^{sy} \cdot F_\nu^{sy} + \Pi_\nu^{SSC} \cdot F_\nu^{SSC}}{F_\nu^{sy} + F_\nu^{SSC} + F_\nu^{d} + F_\nu^{lines} + F_\nu^{EC}}.$$

Fit to the observations of 3C 273, 3C 279 and 4C+01.02.

Summary

- **Degree of polarization decreasing towards optical-UV frequencies:** Can be described by a one zone leptonic model wherein thermal components dilute non-thermal synchrotron polarization. However, according to the shock in jet model, magnetic field ordering decreases along the downstream jet:
- **Degree of polarization increasing towards optical-UV frequencies** wherein we expect well-defined polarization close to the shock regime (high $B_{\perp}$) - electrons emitting at X-ray energies. At lower (optical-IR) frequencies, lower energy electrons experience a less ordered magnetic field, yielding the lower polarization degree observed in the optical regime.

Spectropolarimetry allows for disentanglement of radiation components (thermal vs. non-thermal) and understanding the ordering of the magnetic field along the jet, thereby, enabling the constrainment of SSC polarization to model IXPE observations. This can also contribute to distinguish between leptonic and hadronic models.

Tenth International Fermi Symposium

9th-15th October 2022

Thank you for your attention!

Hester Schutte

National Research Foundation

NWU

schuttehester1@gmail.com