Connection between optical polarization plane rotations and gamma-ray flares in blazars

Ioannis Myserllis
Max-Planck-Institut für Radioastronomie

on behalf of the RoboPol Collaboration
U. Crete/FORTH-MPIfR-Caltech-IUCAA-NCU

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Blazars

- Beamed & boosted
- Fast variability
- Superluminal motions
- High apparent luminosity
- High-energy emission
Optical polarization encodes information about:
- **geometry** of magnetic field in emission region
- **number** of emitting cells along line of sight
- degree to which magnetic field is **ordered**

Optical polarization in blazars is **variable**
Blazar optical polarization swings

3C279

Polarization rotation

Abdo et al. (2010)
Many interpretations

- A wealth of theoretical ideas:
  - A multitude of phenomenological possibilities.
    - Large rotations, small rotations, rotations of all sizes
    - All blazars, many blazars, only few blazars do it
    - Happens only during flares, happens all the time

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**Propagation of shock along jet B-field**
cartoon from Zhang, Deng, Li & Boettcher 2016

**Precessing jet**
Blandford et al.
cartoon from Heinz & Sunyaev 2002

**Turbulent plasma crossing standing shock**
Marscher et al.
cartoon from Marscher 2014

**Propagation through jet bend**
Nalewajko et al.
cartoon from Young 2010
The RoboPol Program

- Observe large, well-defined sample of blazars in optical linear polarization with high cadence
- Identify rotations with uniform criteria
- Systematically answer questions regarding optopolarimetric properties of blazars:
  -- Are $\gamma$-ray—loud and $\gamma$-ray—quiet blazars different in optical polarization?
  -- Do all blazars exhibit polarization rotations?
  -- Are polarization rotations related to $\gamma$-ray flares?
The RoboPol polarimeter

No moving parts, low systematics, high sensitivity

The Project

Our approach:
- a lot of telescope time (4 nights / week) for 3 years
- a dedicated instrument (no moving parts)
- well defined sample of blazars (~100 sources)
- automated operation
- adaptive observing strategy
- broadband data (+ radio and gamma)

OVRO, Effelsberg, Torun


1.3 m Skinakas observatory
1750 m.a.s.l.
Median seeing 0.7'' (DIMM)
Program Features

- Low-systematics, high-sensitivity polarimeter

- **Ample telescope time:** 4 nights/week for 3 years at Skinakas 1.3 m telescope (1750m, median seeing 0.6 arcsec)

- Statistically robust sample

- Unbiased observing strategy
The Sample

✓ **Main**: 62 γ-ray – loud blazars, $R<17.5^m$

✓ **Control**: 15 γ-ray – quiet blazars, similar in radio flux, spectra, variability with main

Pavlidou et al. 2014
RoboPol Rotation Definition

- Continuous EVPA change > 90°
- Comprised by ≥ 4 measurements with significant swings between them
- Start/End points defined by x5 change in slope OR change in slope sign

Blinov et al. 2015
RoboPol Rotations

CTA 102

3C 454.3
γ-loud vs γ-quiet blazars

Median $p$ of γ-loud blazars almost $\times3$ median $p$ of γ-quiet blazars

Median $p$, γ-loud: 0.074
Median $p$, γ-quiet: 0.025

different at $>4\sigma$

Angelakis et al. 2016
Do all blazars rotate?

Prior to RoboPol: 16 rotations in 10 blazars
3 years of RoboPol: + 40 rotations in 24 blazars

1. Avg. frequency of rotations slower than $7^\circ$ per day:
   $0.32$/blazar-yr
   Chance to find rotations of that avg frequency only in those blazars that did rotate: $10^{-7}$

2. Rotators have different γ-ray properties than non-rotators

rotators are: more luminous  more variable

Blinov et al. 2016
Rotations related to $\gamma$-activity?

Lags too small to be random
Rotations related to $\gamma$-activity?

Blinov 2017

all lags consistent with zero
\( \gamma \)-flaring/rotations: timescales correlation

Blinov 2017
Rotations Summary

Are γ-ray—loud and γ-ray quiet blazars different in optical polarization?  
**YES.** γ-loud blazars are significantly more polarized

Do all blazars exhibit polarization rotations?  
**NO.** Introducing the “rotator class of blazars”: rotates its polarization plane, brighter in γ-rays, more variable

Are polarization rotations related to γ-ray flares?  
**YES.** Time lags with γ-flares too small for random associations. Durations of rotations and nearest gamma-flares are correlated.