RoboPol: the optical polarisation of gamma-ray-loud and gamma-ray-quiet blazars

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and the RoboPol collaboration
EVPA rotations and high energy activity

Marscher et al. 2008, Nature 452, 966

Abdo et al. 2010, Nature 463, 919
the RoboPol approach:

- 4 nights / week for 3 years (2013-2015)
- cadence: 3 — 0.3 nights
- $\rho$ uncertainty < 0.01, $\chi$ uncertainty: 1-2 deg

- select and unbiased sample:
  - 62 gamma-ray loud “GL” from 2FGL $F (> 100$ MeV $) > 2 \times 10^{-8}$ cm$^{-2}$ s$^{-1}$
  - 15 gamma-ray quiet “GQ”: from OVRO
RoboPol EVPA rotations:

- 2013-2015: 40 rotations in 24 blazars
  (before RoboPol: 16 rotations in 10 blazars)
  Blinov et al. 2015, MNRAS.453.1669B;

- any class can “rotate” (HSP/LSP, FSRQs/BL Lacs, TeV/non-TeV)

- rotation rate can vary a lot in the same source

- both senses allowed in the same source
EVPA rotations and $\gamma$-ray activity:

- data suggest:
  - all "rotators" are GL: physical relation between $\gamma$-ray loudness and optical polarisation
  - we find no rotation that is not associated with a gamma-ray flare within the uncertainties
  - all lags consistent with zero
EVPA rotations and $\gamma$-ray activity:

- rotators are more luminous and more variable in $\gamma$ rays

![Image of EVPA rotations and $\gamma$-ray activity](image-url)
optical polarisation and γ-ray loudness:

- “GL” more polarised than “GQ”.

assuming a power law distribution:

- **GL**: \( \langle p_0 \rangle \sim 0.092 \pm 0.008 \)
- **GQ**: \( \langle p_0 \rangle \sim 0.031 \pm 0.008 \)

Angelakis et al. 2016, MNRAS.463.3365A
Pavlidou et al. 2014, MNRAS.442.1693P

\[
\text{PDF}(p; \alpha, \beta) = \frac{p^{\alpha-1} (1-p)^{\beta-1}}{B(\alpha,\beta)}
\]

\[p_0 = \frac{\alpha}{\alpha + \beta}\]

and

\[m_p = \frac{\sqrt{\text{Var}}}{{p_0}} = \frac{\alpha + \beta}{\alpha} \cdot \sqrt{\frac{\alpha \beta}{(\alpha + \beta)^2}} \cdot \sqrt{\frac{1}{\alpha + \beta + 1}}.
\]
explaining the dichotomy between “GL” and “GQ”:

**GL:** highly variable, strong jet dominance due to high degree of Doppler boosting  

- frequent impulsive events of particle acceleration
- optical from smaller volumes hence higher polarisation

**GQ:** objects with:
- less extreme Doppler boosting or
- less efficient impulsive episodes,
- not accelerating particles to energies needed for γ-ray production at measurable levels
- optical from larger volumes hence lower polarisation

Angelakis et al. 2016, *MNRAS.463.3365A*
polarisation vs synchrotron peak frequency:

- **mean** polarisation and its **spread decreases** with **synchrotron peak** frequency

for BL Lac GL only: $\varphi = -0.5$ (p-value: $7 \times 10^{-6}$)

Angelakis et al. 2016, MNRAS.463.3365A
high energy $e^-$, small volume, less cells:
→ high polarisation
→ more variable polarisation

low energy $e^-$, large volume, more cells:
→ low polarisation
→ less variable polarisation
→ lower variability amplitudes
→ longer variability time scales
→ a stable EVPA component dominates

Angelakis et al. 2016, MNRAS.463.3365A
Angelakis et al. 2016, MNRAS.463.3365A

- **Smaller region**
  - More variable EVPA
  - Smaller variability amplitudes
  - Longer variability time scales

- **Larger region**
  - Less variable EVPA
  - Stable B-field component dominant

Log($\nu_s$/Hz) vs. EVPA “stability”
Angelakis et al. 2016, MNRAS.463.3365A

- **smaller region**
  - smaller variability amplitudes
  - longer variability time scales

- **larger region**
  - more variable EVPA
  - less variable EVPA

- **stable B-field component dominant**
The optical polarization of GL and GQ blazars may play a significant role in determining the degree of polarization and variability in the optical regime. The polarization variability amplitude at 15 GHz from the optical modulation indices may be associated with stronger variability in either the optical or radio emission. Nevertheless, despite the evidence for a helical structure of the magnetic field, the degree of polarization relates to the degree of variability in the light curves.

In §2, we plot the median polarization fraction versus the radio modulation index for GL and GQ sources. The distribution of EVPA for a close-to-uniform case (highly polarized) is compared to the distribution of EVPA for a case where the EVPA is more likely to have a preferred and less variable EVPA than LSP sources. The EVPA of HSP sources is considered to be more variable and less likely to have a preferred EVPA.

The distribution of EVPA for a close-to-uniform case (highly polarized) is shown as a green dashed line, which gives a significant slope of χ^2 ≈ 31 with a p-value of 10^−4. Despite the higher variability in optical polarization, the Spearman's test results indicate a comparable correlation. Similarly, in the lower panel, we show the maximum EVPA for a source to be considered ISP if 14 ≤ Log(ν_s/Hz) ≤ 15, respectively. Then we see that the EVPA of ISP sources are systematically less polarized on average than those of GL sources with comparable radio modulation indices as it was already found by Richards et al. (2011, 2016, MNRAS.463.3365A). As it is seen there, the two are correlated with a significance of p-value 10^−3, where including both GL and GQ sources, is indicated around 0.4. Again, GQ sources have average polarization fractions that are comparable to GL sources with higher modulation indices as it was already found by Richards et al.

We conclude that the variability amplitude, in both radio and optical bands, is increased by around 0.3 in ISP sources compared to GL sources with comparable radio modulation indices. Spearman's test to be giving a positive correlation. Similarly, in the lower panel, we show the maximum EVPA for a source to be considered ISP if 14 ≤ Log(ν_s/Hz) ≤ 15, respectively. Then we see that the EVPA of ISP sources are systematically less polarized on average than those of GL sources with comparable radio modulation indices.
alignment of the EVPA and jet in high-energy BL Lac objects (TeV):

- sample: 32 TeV and 19 non-TeV
- TeV show preferred orientations of the EVPA
- for most sources the EVPA and jet are aligned to less than 20° implying a B-field perpendicular to the jet direction
conclusions:

- all classes rotate; different sense allowed; rates can vary
- non all blazars rotate; there are rotators are more luminous and more variable in gamma-rays than non-rotators
- no evidence that rotations are not associate with gamma-ray flares
- GL are more polarised than GQ sources
- the dichotomy disappears fro the polarisation variability amplitude
- the mean $p$ and its spread depend on the synchrotron peak
- the EVPA clearly shows a preferred direction for HSP sources
- A jet
  - populated by a helical field
  - impulsive events of particle acceleration (e.g. Diffusive Shock Acceleration)
- can provide a natural explanation of all the above
Angelakis et al. 2016, MNRAS.463.3365A
Pavlidou et al. 2014, MNRAS.442.1693P
Blinov et al. 2015, MNRAS.453.1669B;

http://robopol.org

Thank you!

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