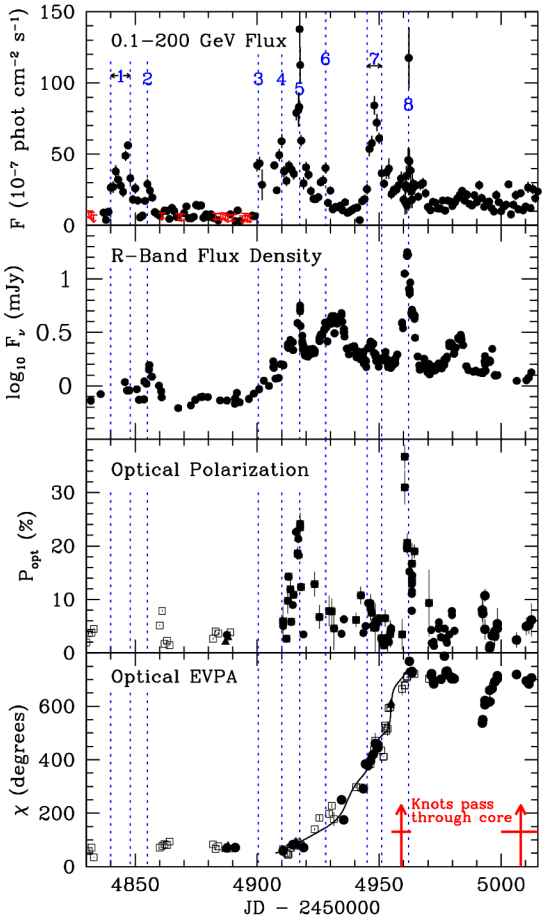
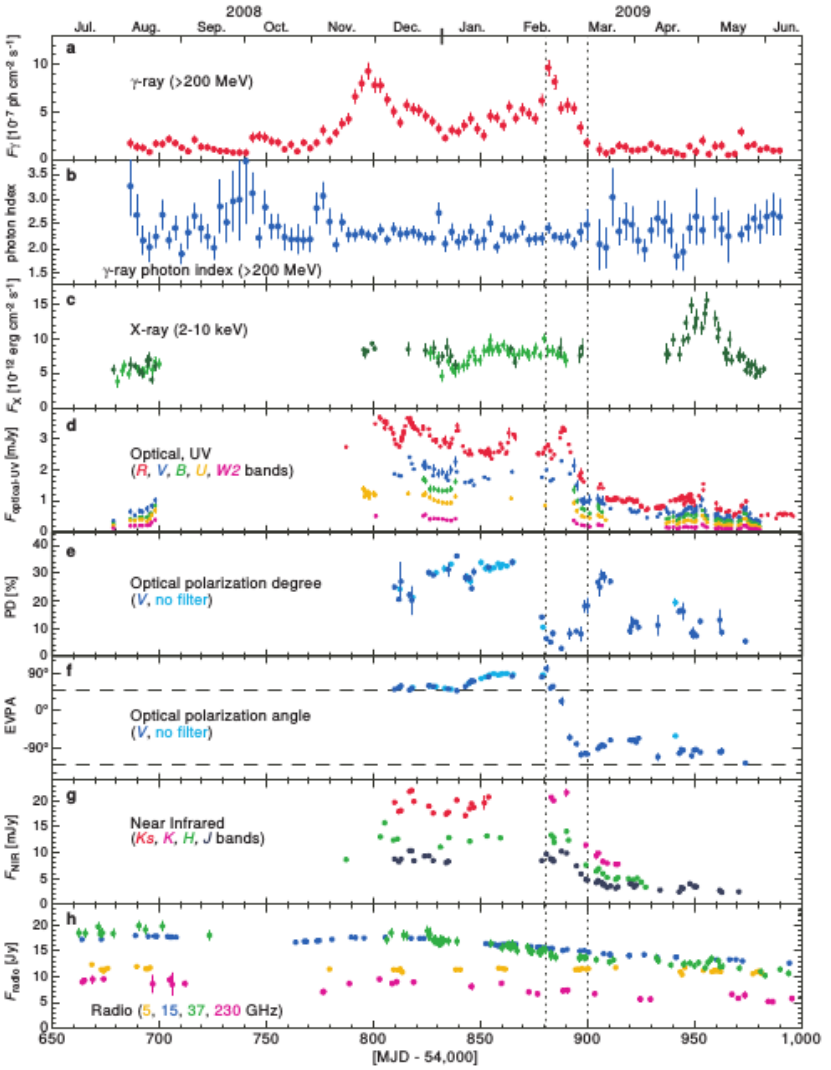
Do all blazars rotate optical polarization planes?

Dmitry Blinov on behalf of the RoboPol collaboration
University of Crete/FORTH, Greece
St. Petersburg university, Russia

Optical EVPA rotations



Marscher et al., ApJ 710, L126 (2010)



Abdo et al., Nature 463, 919 (2010)

First optical reported in Kikuchi et al., A&A, 190, L8 (1988)

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The RoboPol project

Goals:

- Observe a large, well-defined sample of blazars in linear polarization with high cadence
- Apply rigorous statistical methods to identify rotation events and study correlations with γ-ray, optical and radio flares

Caltech, USA: M. Baloković, O. G. King, A. Mahabal, T. J. Pearson, A. C. S. Readhead,

U. of Crete/FORTH, Greece: D. Blinov, N. Kylafis, I. Liodakis, G. V. Panopoulou, I. Papadakis, I. Papamastorakis, V. Pavlidou, P. Reig, K. Tassis

IUCAA, India: V. Joshi, S. Prabhudesai, A. Ramaprakash

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+ T. Hovatta, S. Kiehlmann (Aalto University, Metsähovi Radio Observatory, Finland)

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RoboPol

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

King et al., MNRAS 445, L114 (2014)

1.3 m Skinakas observatory
1750 m.a.s.l.

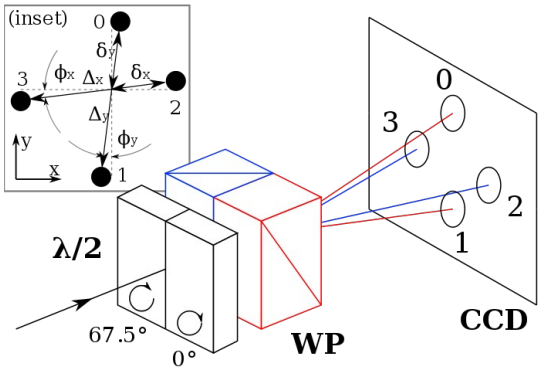
The Sample

Main: 62 γ-ray–loud blazars (2FGL) R<17.5^{m}

Control: 15 γ-ray–quiet blazars (CGRaBS\2FGL)

+24 additional active objects

Pavlidou et al., MNRAS, 442, 1693 (2014)



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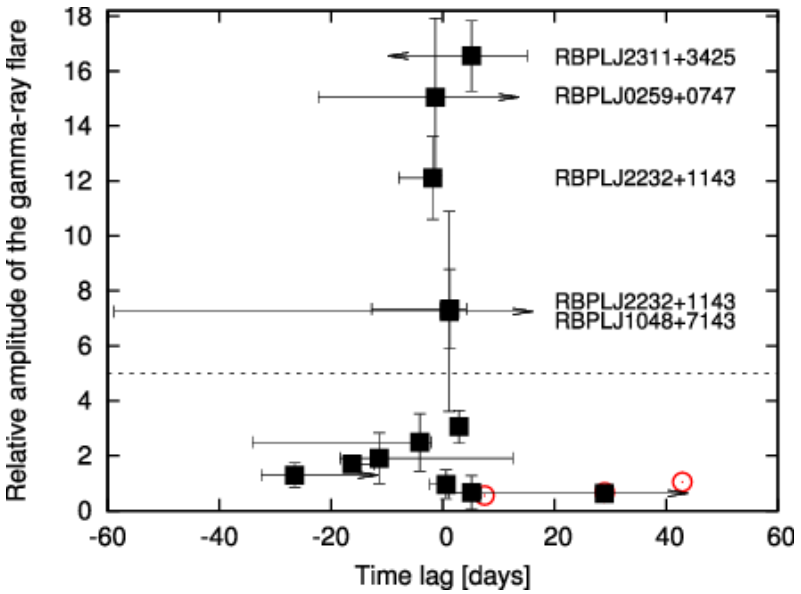
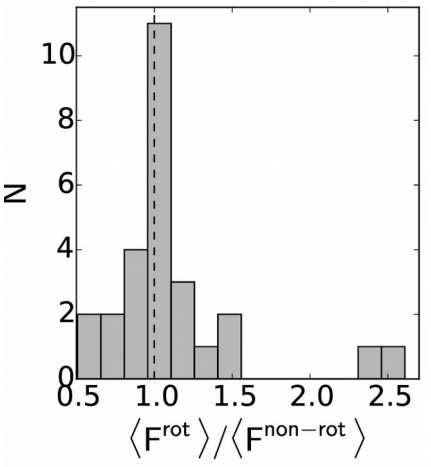
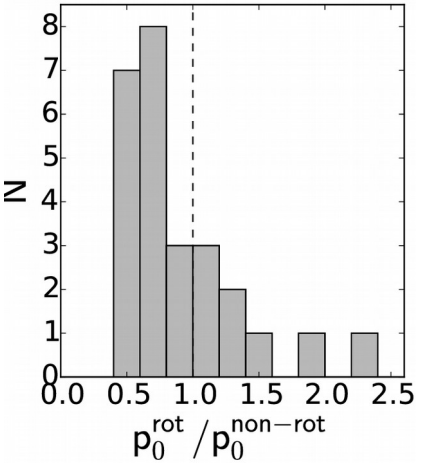
Some results from RoboPol







- At least some EVPA rotations must be connected to γ-ray flares
- It is unlikely that all rotations are random walks
- There is a sign of two separate types of rotations (see also Kiehlmann et al., A&A, 590, 20 (2016))

Blinov et al., MNRAS 453, 1669 (2015)

- there is no statistical association of rotations with contemporaneous optical flares
- average fractional polarization during rotations tends to be lower than that in a non-rotating state

Blinov et al., MNRAS 457, 2252 (2016)

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EVPA rotations

- Total amplitude $\Delta\theta \geqslant 90°$
- At least 3 significant swings (4 points)

$$|\theta_{n+1} - \theta_n| \geq \sqrt{\sigma(\theta_{n+1})^2 + \sigma(\theta_n)^2}$$

- No large changes in the rate

$$\frac{1}{5}\frac{\Delta\theta_n}{\Delta T_n} \leq \frac{\Delta\theta_{n+1}}{\Delta T_{n+1}} \leq 5\frac{\Delta\theta_n}{\Delta T_n}$$

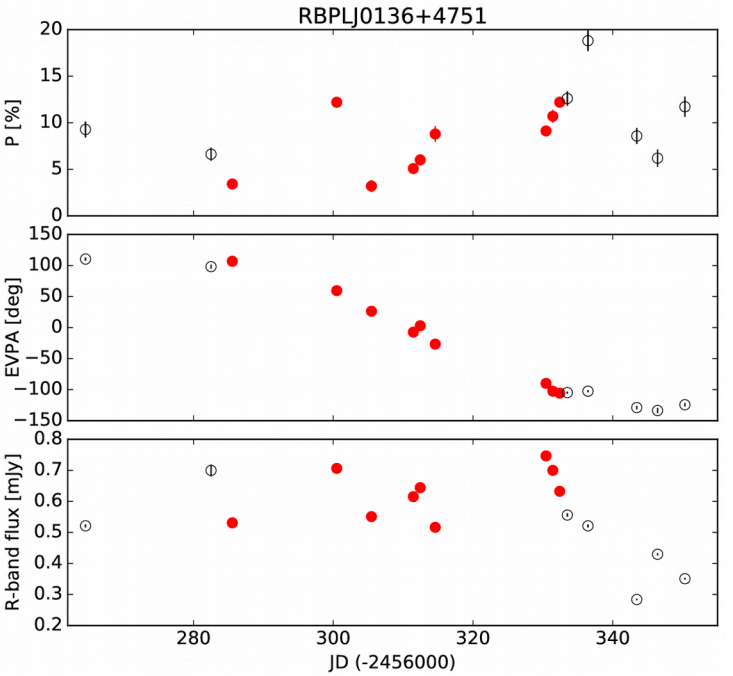
2013 – 2015:

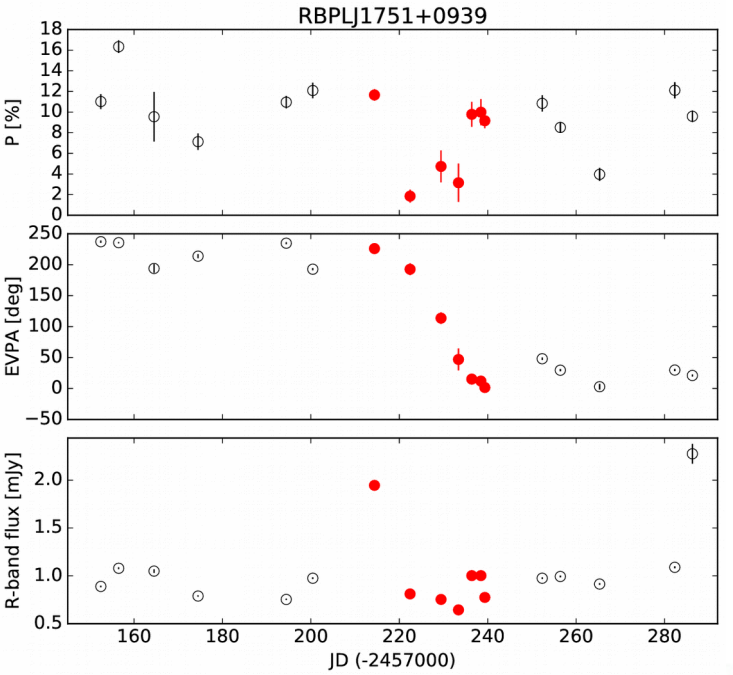
Total

40 rotations in 24 blazars

Used in statistical analysis

36 rotations in 22 blazars





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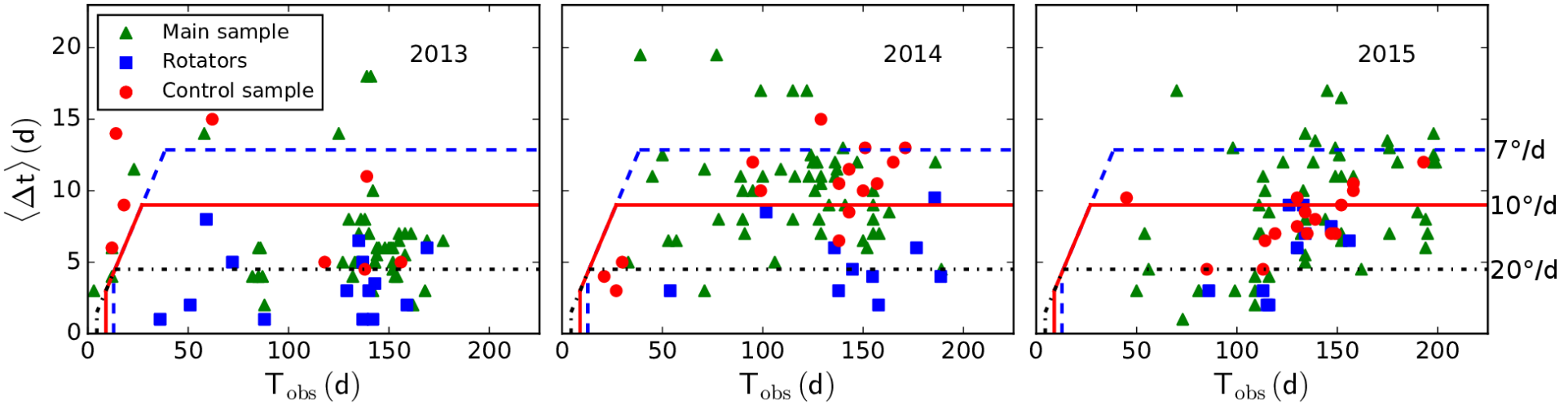
Frequency of EVPA rotations



	N_{rot}	T_{obs} (d)	λ (d^{-1})	$\mathcal{P}$
		≤ 7 deg d^{-1}		
all:	22	24584	8.9×10^{-4}	-
rotators:	22	6296	(3.5×10^{-3})	1×10^{-7}
non-rotators:	0	18288	$(< 5.5 \times 10^{-5})$	9×10^{-8}
		≤ 10 deg d^{-1}		
all:	24	17820	1.4×10^{-3}	-
rotators:	24	5847	(4.1×10^{-3})	4×10^{-6}
non-rotators:	0	11973	$(< 8.4 \times 10^{-5})$	5×10^{-8}
		≤ 20 deg d^{-1}		
all:	20	5412	3.7×10^{-3}	-
rotators:	20	2224	(9.0×10^{-3})	2×10^{-4}
non-rotators:	0	3188	$(< 3.1 \times 10^{-4})$	8×10^{-6}

$$\mathcal{P}(n,t,\lambda) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

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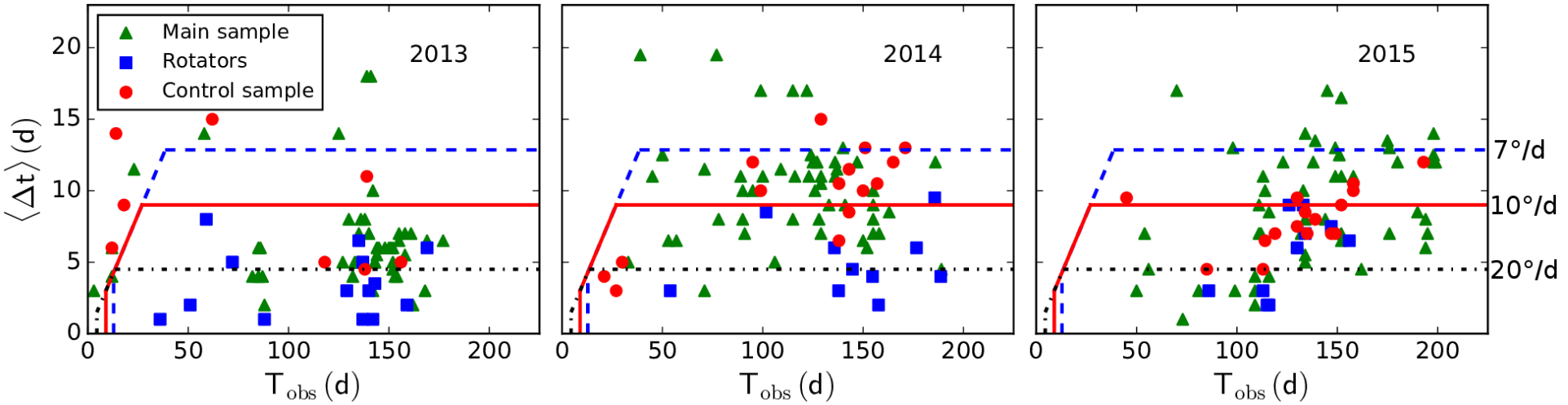
Frequency of EVPA rotations



	N_{rot}	T_{obs} (d)	λ (d^{-1})
0 rotations	0	12978	$< 7.7 \times 10^{-5}$
1 rotation	12	4462	2.7×10^{-3}
2 rotations	6	1246	4.8×10^{-3}
3 rotations	6	885	6.8×10^{-3}
4 rotations	12	1054	1.1×10^{-2}
all rotators:	36	7647	4.7×10^{-3}
total:	36	20625	1.8×10^{-3}

$$\mathcal{P}(n,t,\lambda) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

If all rotators have equal λ:

$$\mathcal{P}(12, 1054, 4.7 \times 10^{-3}) = 0.3\%$$

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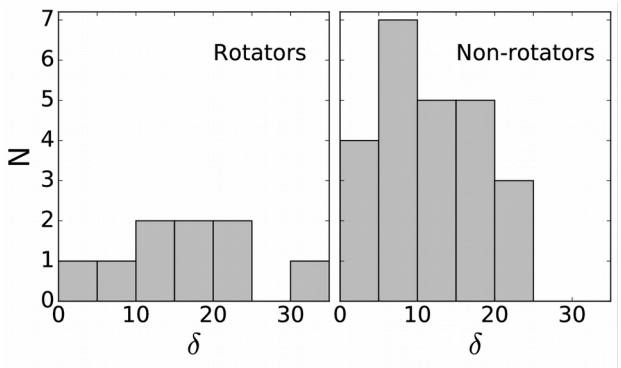
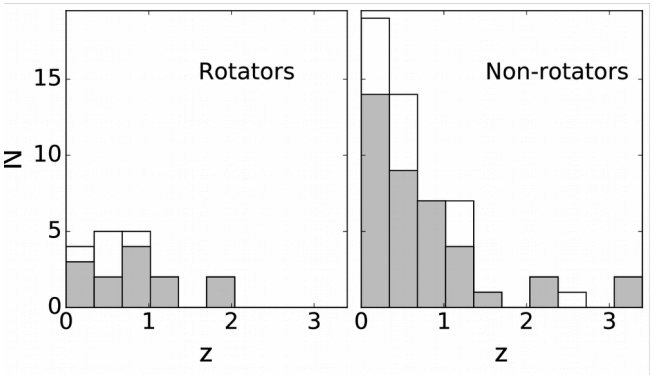
Why the frequency is different?

Rest frame timescale differences: $\Delta T^{\rm jet} = \Delta T^{\rm obs}\delta/(1+z)$

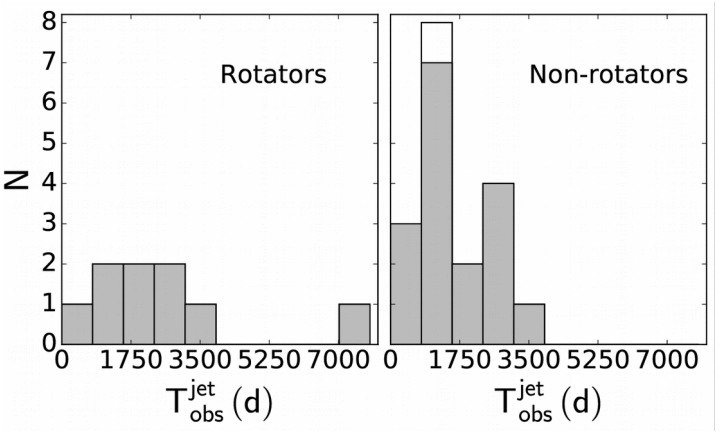


K-S test p-value= 0.62



Spectroscopic: p-value= 0.48
All estimates: p-value= 0.54

For rotations within the 7°/d detection box



Spectroscopic z: p-value= 0.27
All z estimates: p-value= 0.25

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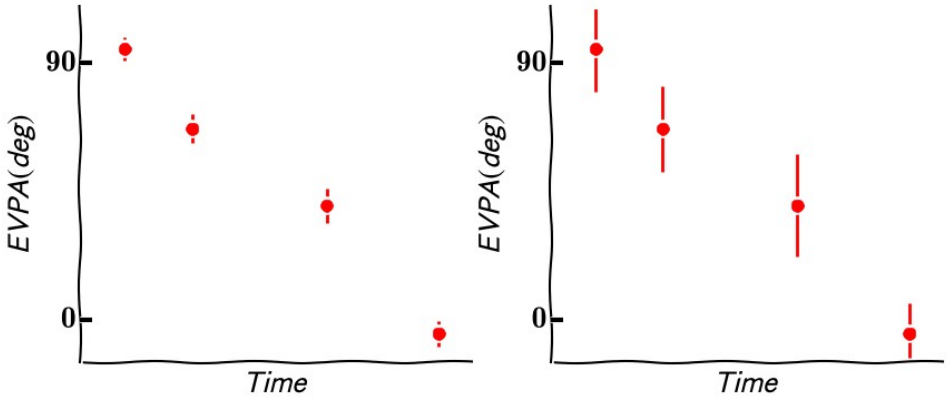
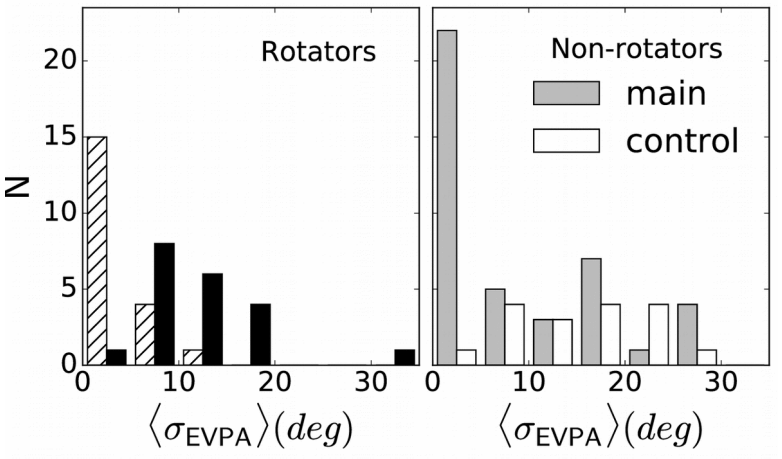
Why the frequency is different?

Differences in accuracy of EVPA measurements:



$$\sigma_{EVPA} \sim \frac{\sigma_P}{P}$$



When σEVPA of rotators is increased by a factor of 3:

- Distributions of <σEVPA> become indistinguishable (p-value = 0.03)

- 14 rotations out of 36 are lost

- remaining 22 rotations still give significant difference in the frequency
E.g. for the 7°/d detection box:

$$\begin{aligned} \mathcal{P}(\mathrm{rot}) &= 10^{-7} \\ \mathcal{P}(\mathrm{no-rot}) &= 2 \times 10^{-5} \end{aligned}$$

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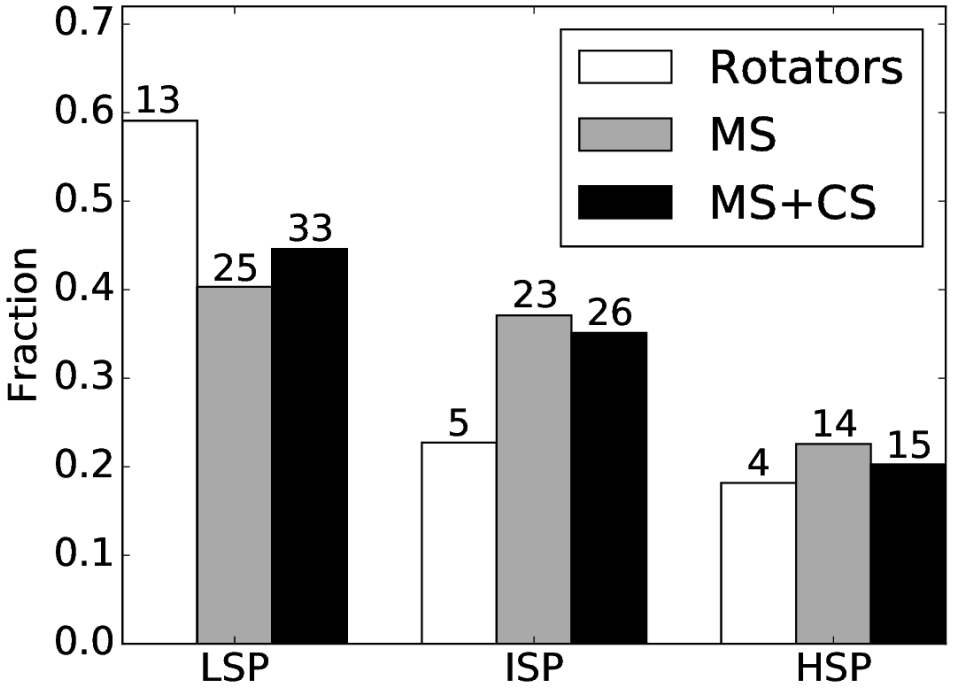
EVPA rotations in blazars of different classes



rotators are randomly drawn from the Main + Control samples:

$$\mathcal{P} = \frac{C_{33}^{13} C_{26}^{5} C_{15}^{4}}{C_{74}^{22}} = 0.014$$

rotators are randomly drawn from the Main sample:

$$\mathcal{P} = \frac{C_{25}^{13} C_{23}^{5} C_{14}^{4}}{C_{62}^{22}} = 0.005$$

EVPA is more stable in HSP
Hovatta et al. (submitted)
Angelakis et al. (submitted)

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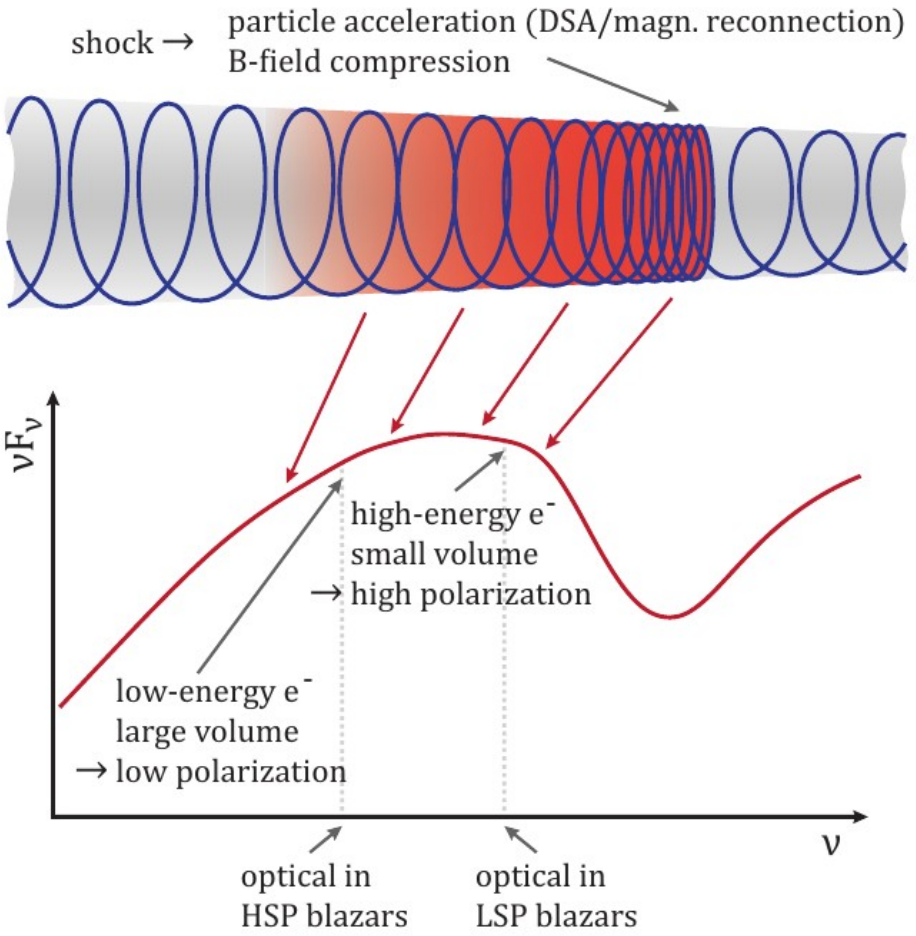
Interpretation



Angelakis et al. (submitted)

Explains

- Higher polarization in LSP sources

- Preference of rotations to occur in LSP sources

- Deterministic rotations associated with strong γ-ray flares in LSP sources

Prediction

HSP blazars must exhibit EVPA rotations in UV/X-ray bands approximately as frequent as LSP sources in optical

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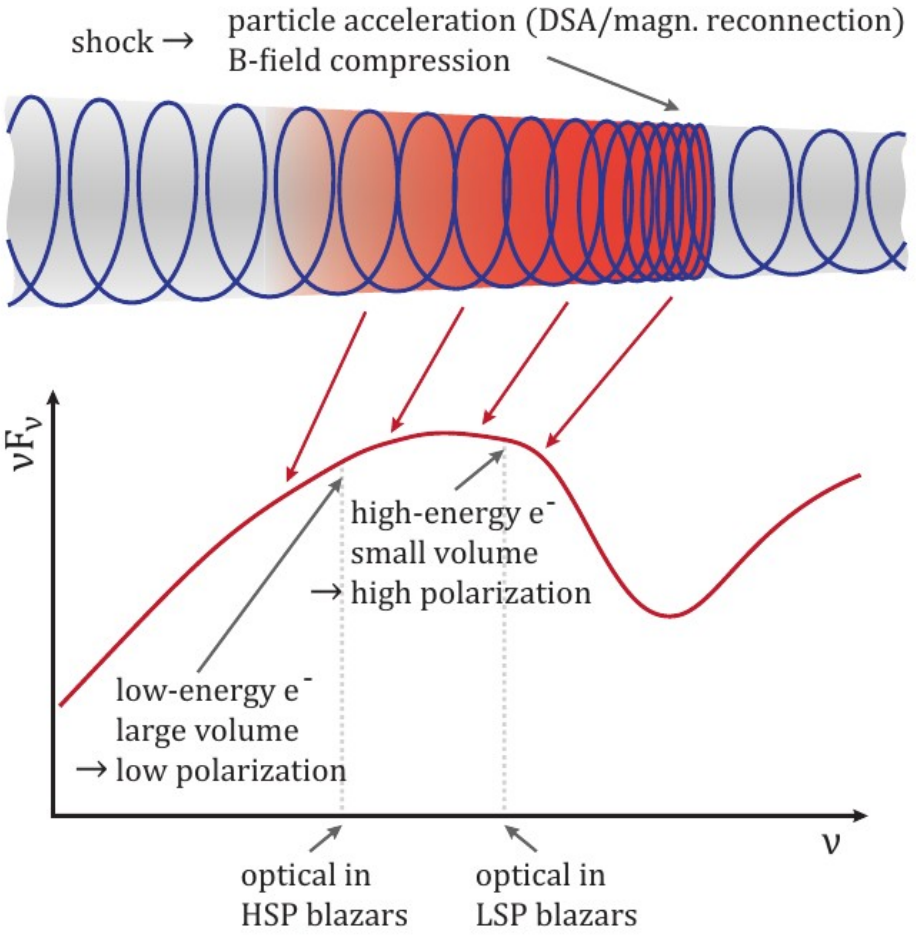
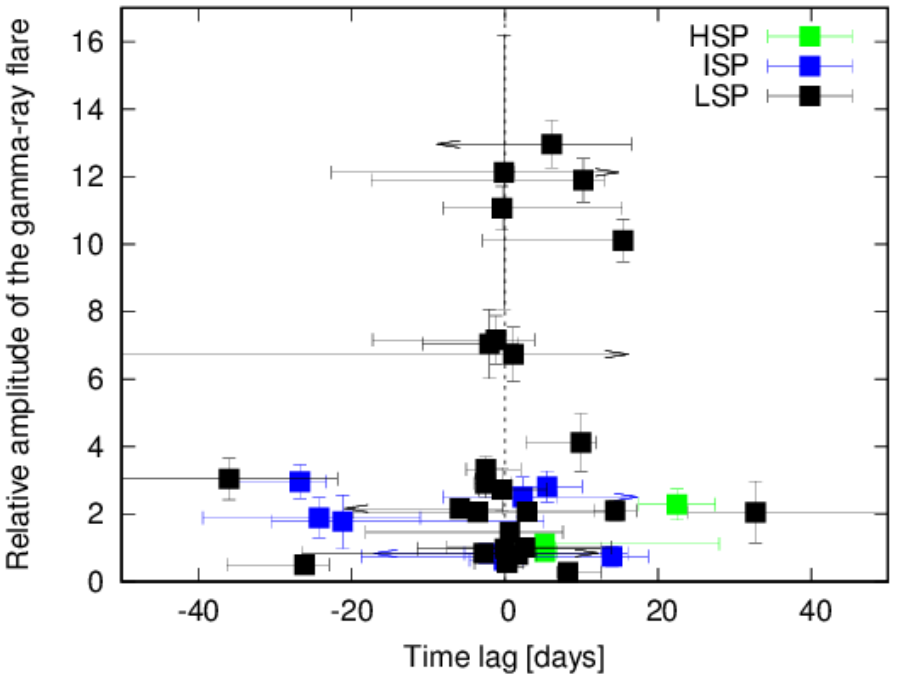
Interpretation





Angelakis et al. (submitted)

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Conclusions

- Blazars exhibit EVPA rotations in the optical band with significantly different frequency
  - ~28% of blazars exhibit rotations with rates $\leqslant 20°/d$ with average frequency 1/230 d^{-1}
  - remaining 72% do not show rotations or show them with frequency < 1/3200 d^{-1}
- EVPA rotations in the optical band tend to occur more frequently in LSP blazars

http://robopol.org

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