Rotations of optical polarization plane in blazars as seen by RoboPol

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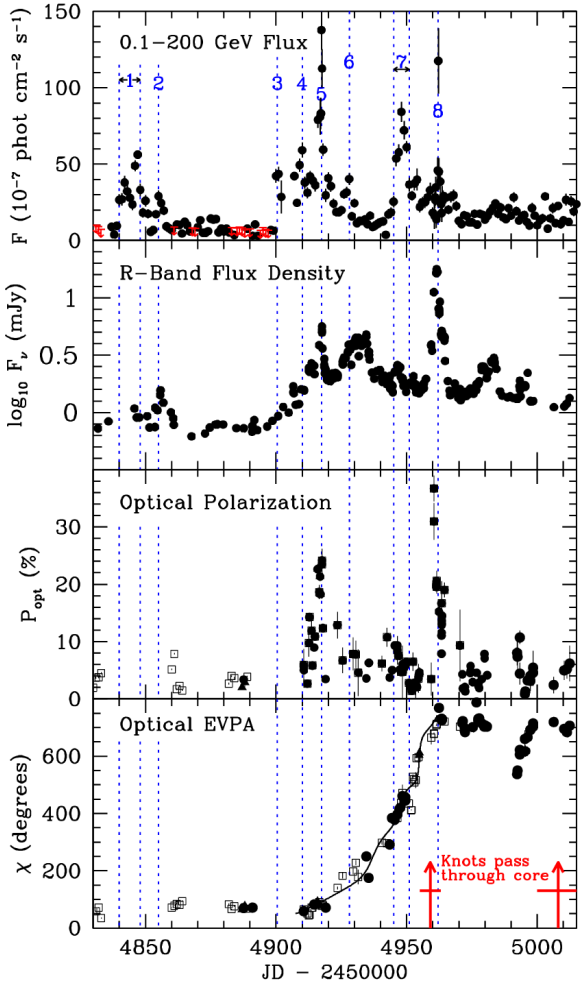
Rotations of the EVPA

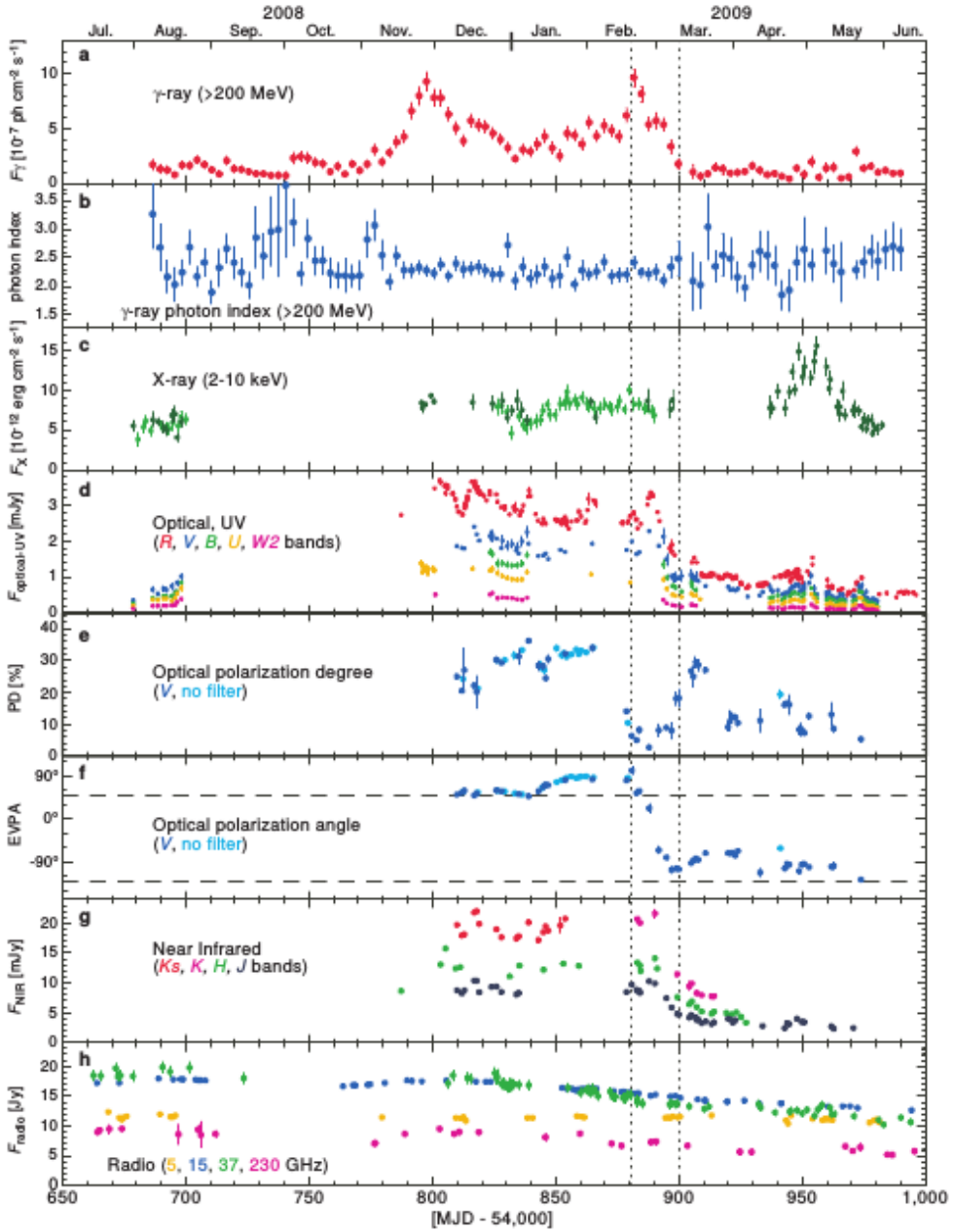
Kikuchi et al. 1988, A&A, 190, L8

PKS 1510-089

Marscher et al. 2010, ApJ 710, L126



3C 279 Abdo et al. 2010, Nature 463, 919



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The RoboPol collaboration

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: O. King, M. Baloković, T. Hovatta, T. Pearson, A. Readhead, A. Mahabal

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

IUCAA, India: A. Ramaprakash, P. Khodade, C. Rajarshi, R. Rouneq

MPIfR, Germany: E. Angelakis, I. Myserlis, L. Fuhrmann, S. Kiehlmann, J. A. Zensus

N.C.U., Poland: A. Kus, R. Feiler, B. Pazderska, E. Pazderski

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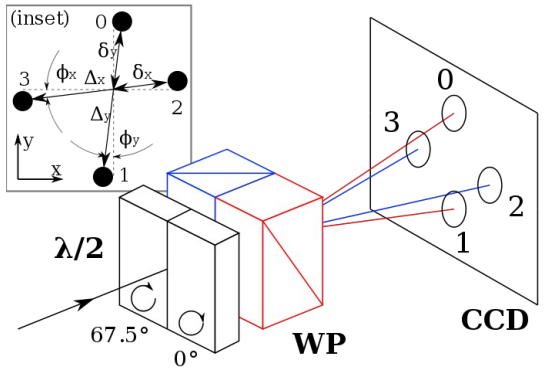
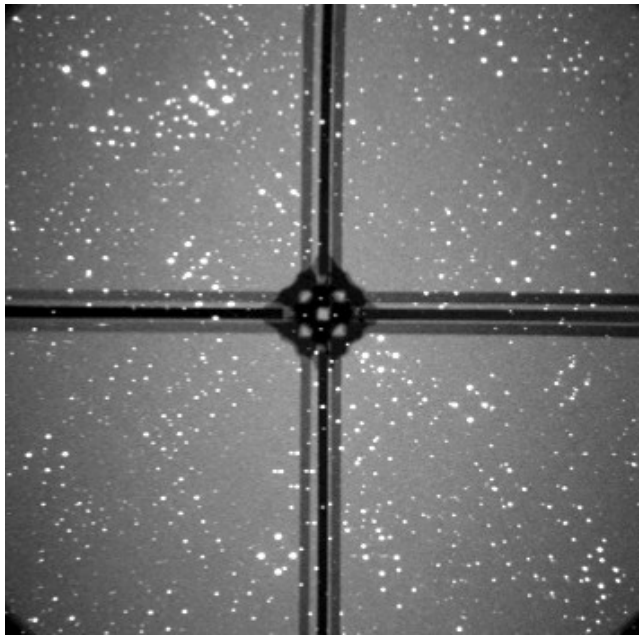
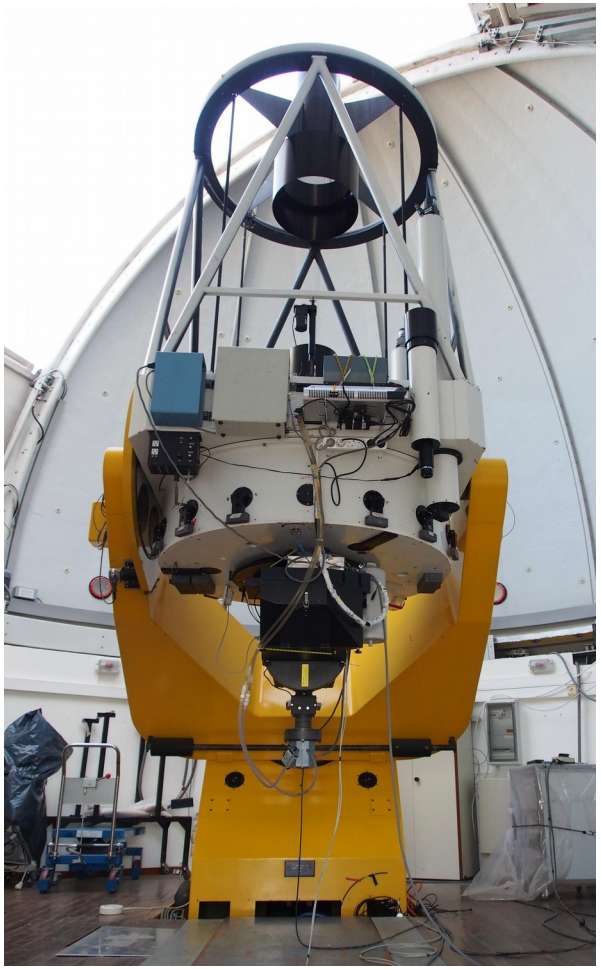
The Project

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

King et al. 2014, MNRAS 445, L114







1.3 m Skinakas observatory
1750 m.a.s.l.
Median seeing 0.7" (DIMM)

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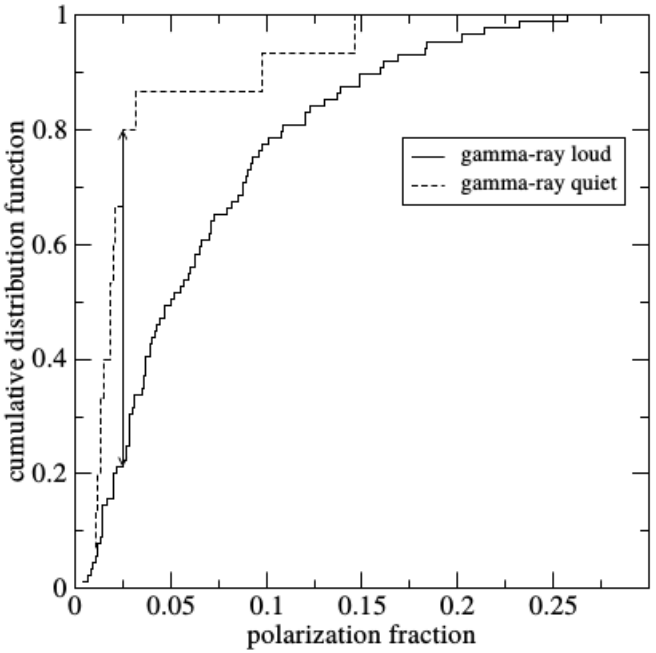
The Sample

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

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

24 additional interesting objects



Polarization fraction follows exponential distribution, for both γ-ray–loud and γ-ray–quiet

Mean p = 6.4% γ-ray–loud
Mean p = 3.2% γ-ray–quiet
different at ~3.5 σ (K-S test)

Pavlidou et al. 2014, MNRAS 442, 1693

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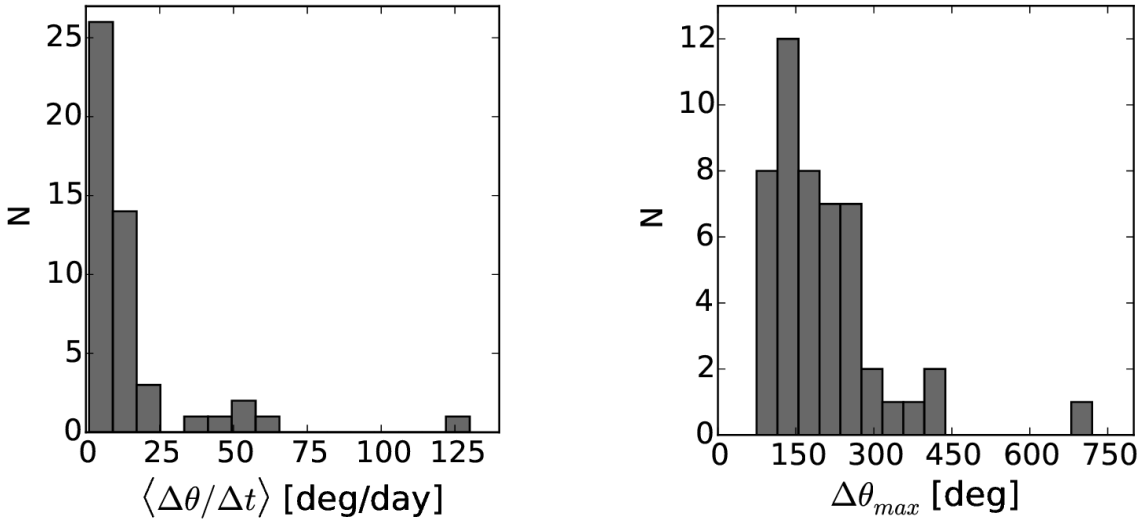
EVPA rotations

Prior to RoboPol: 16 rotations in 10 blazars were know
RoboPol has added 34 in two seasons



Observed frequency:
γ-ray–loud blazars show 1 rotation with $\Delta\theta/\Delta t < 10^{0}$/day every 730 days

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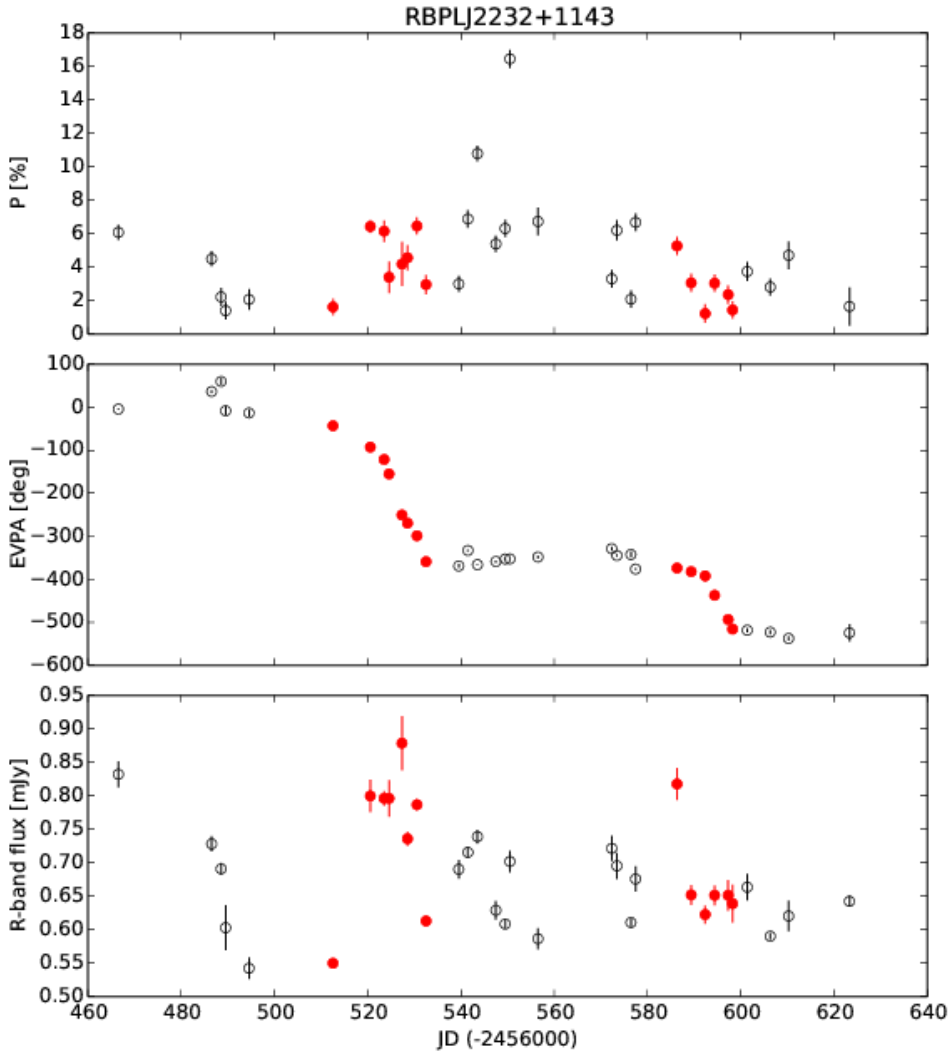
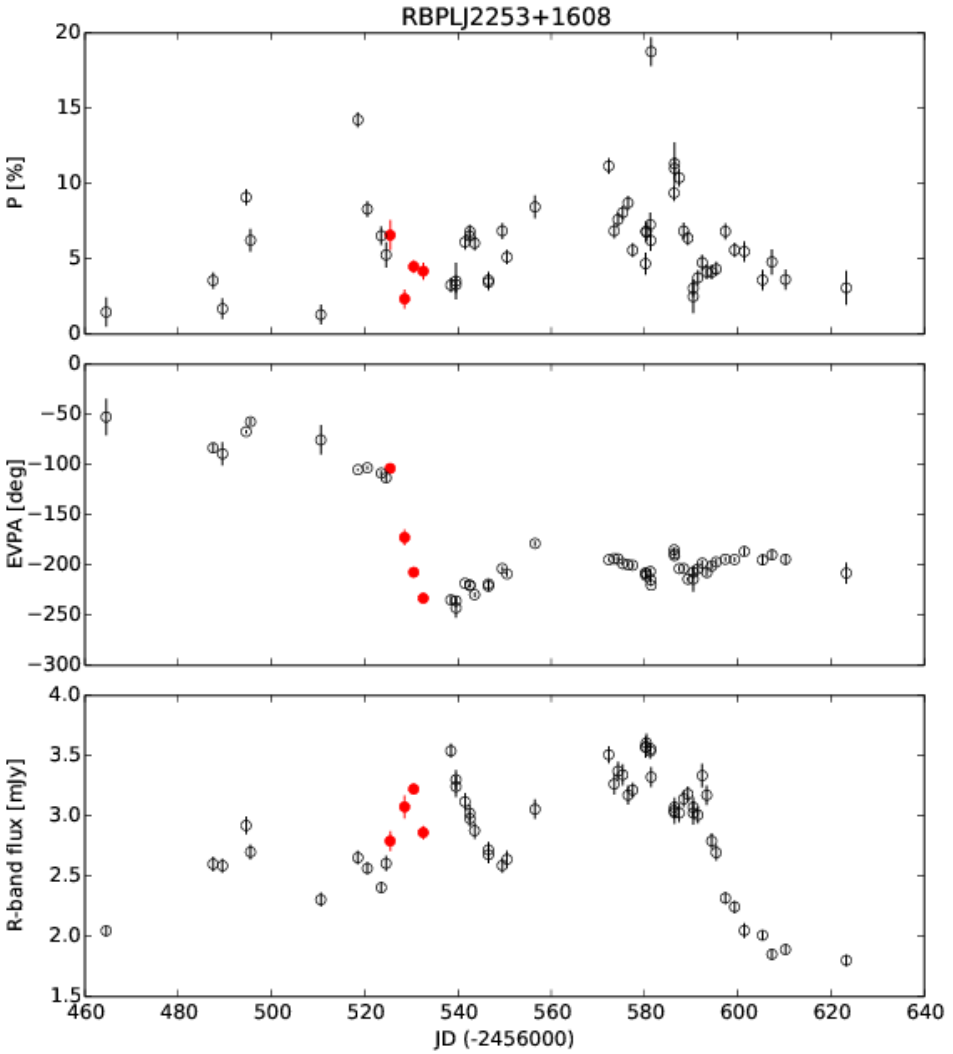
EVPA rotations

CTA 102



3C 454.3



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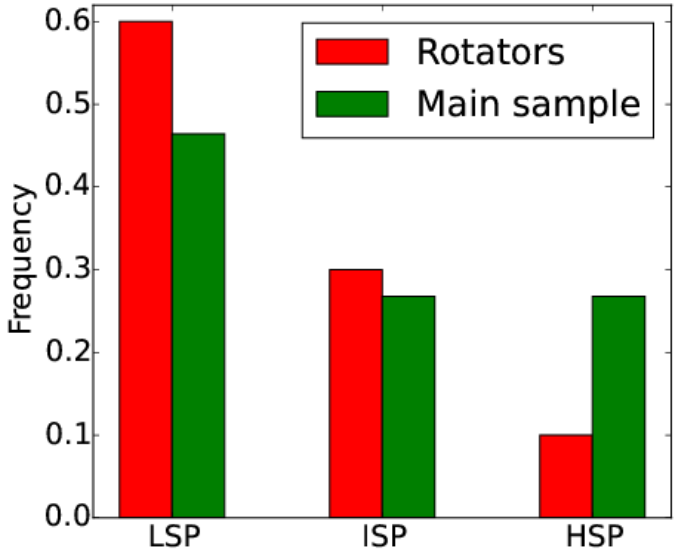
EVPA rotations

- All known rotators are γ-ray—loud sources
- All subclasses show rotations: high and low synchrotron peaked blazars, FSRQs and BL Lacs, detected and non-detected in TeV
- A single blazar can show rotations in both directions
- Rotations seen in a single source can be of significantly different rates



P = 0.7%

Tend to occur in sources with low synchrotron peak

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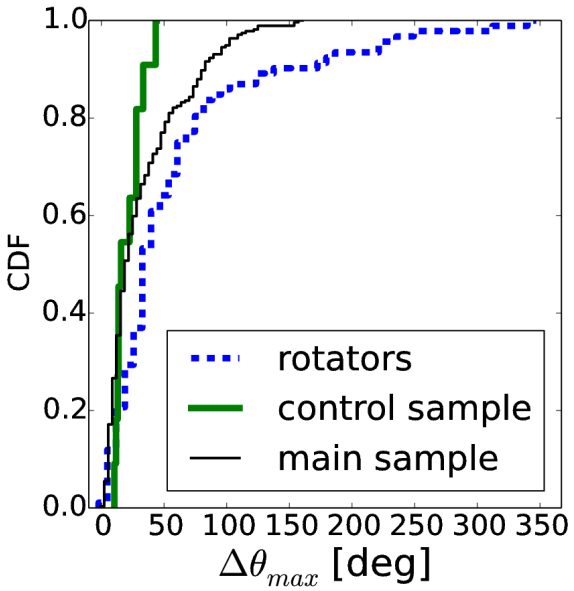
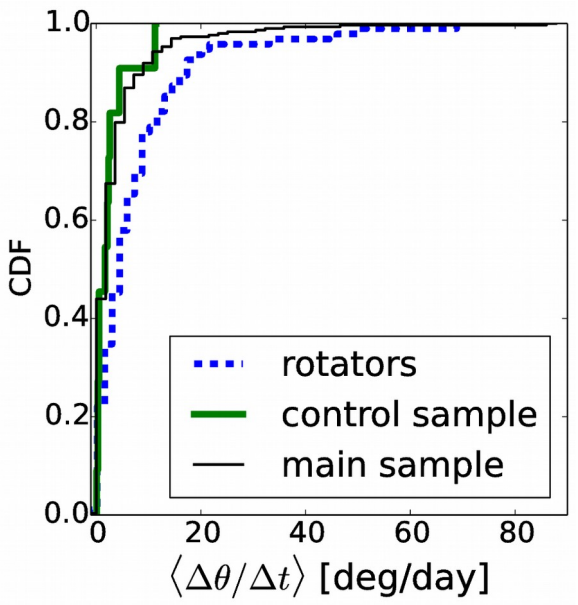
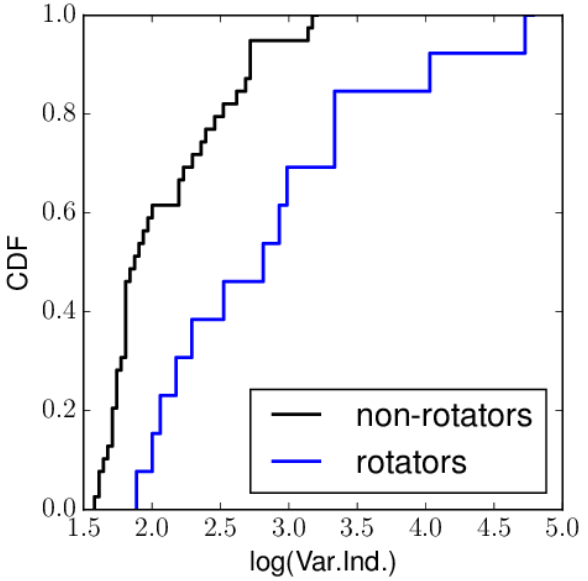
Variability of rotators and non-rotators







Rotators vs. non-rotators:
- Δθ/Δt K-S p-value = 1.4×10^{-6}
- Δθ K-S p-value = 2×10^{-3}

K-S p-value = 4×10^{-3}

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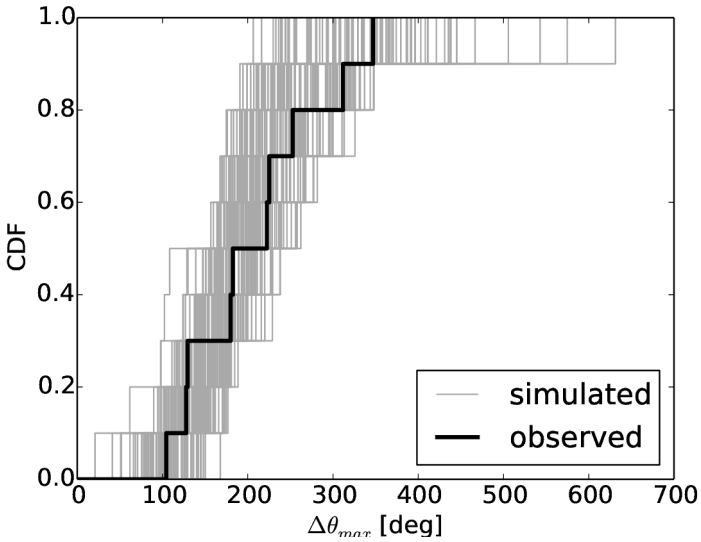
Are they random walks?

MC simulations following
Kiehlmann et al. 2013

$$\overline{P} \approx \frac{P_{\max}}{\sqrt{N}}$$

$$N_{var}(\Delta t_i) = \frac{\Delta t_i}{\overline{\Delta t}} \frac{\sigma(P)}{\overline{P}} N$$

Blazar	T_{occ} [days]	P(RW)
RBPLJ0136+4751	505	0.11
RBPLJ0259+0747	151	0.48
RBPLJ0721+7120	325	0.28
RBPLJ0854+2006	142	0.36
RBPLJ1048+7143	180	0.79
RBPLJ1555+1111	128	1.00
RBPLJ1558+5625	266	0.51
RBPLJ1806+6949	965	0.15
RBPLJ1806+6949	259	0.55
RBPLJ1927+6117	137	0.98
RBPLJ2202+4216	633	0.21
RBPLJ2232+1143	1557	0.09
RBPLJ2232+1143	178	0.87
RBPLJ2243+2021	183	0.92
RBPLJ2253+1608	184	0.86
RBPLJ2311+3425	61	0.74



Similar simulations:
Jones et al. 1985, ApJ 290, 627
D'Arcangelo et al. 2007, ApJL 659, L107

All together are RW with
P = 1.5%

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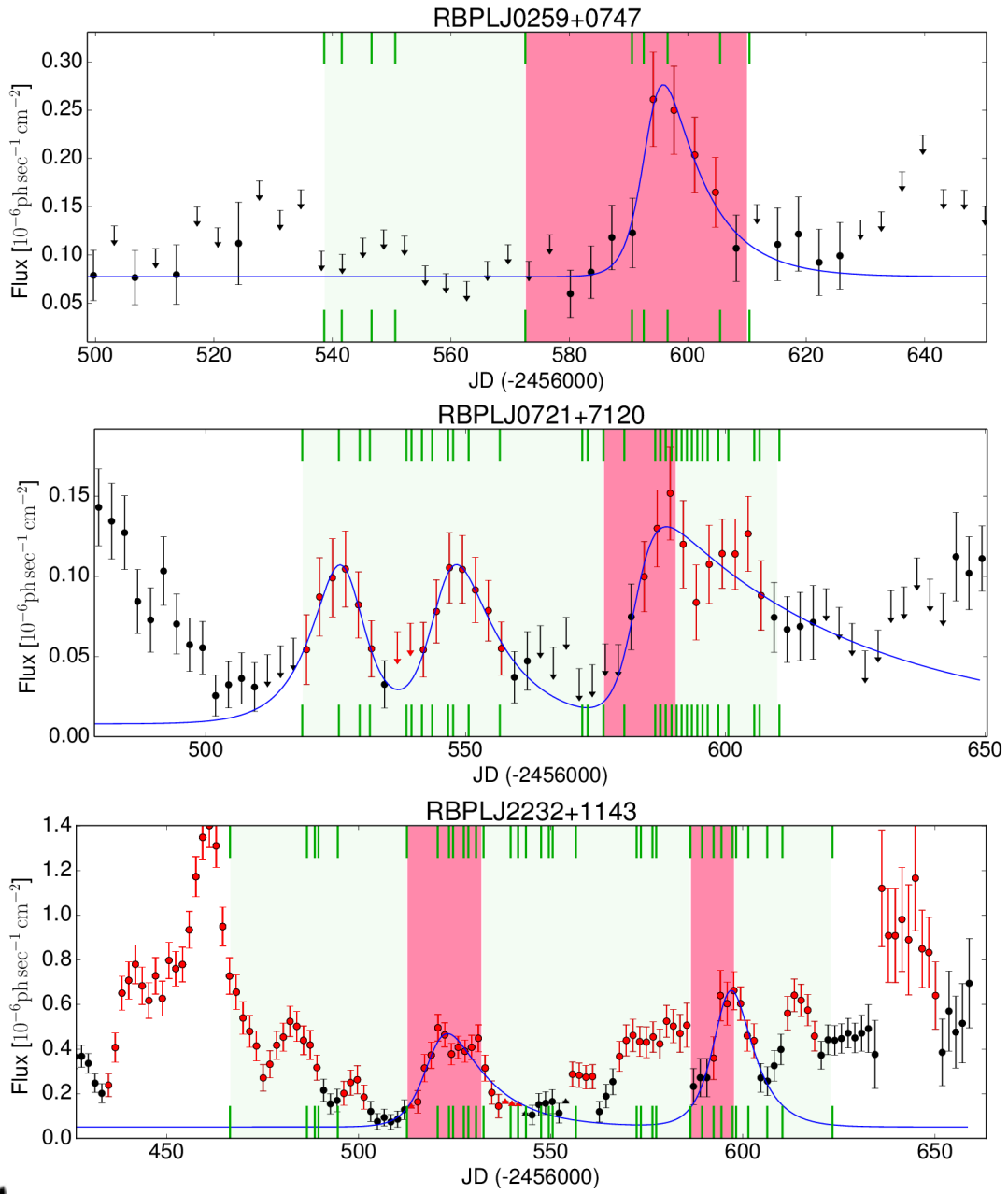
Association with γ-ray flares



Flare:
contiguous period in which flux exceeds factor x=0.5 of the corresponding peak
Nalewajko 2013, MNRAS 430, 1324

$$F(t) = F_{\rm c} + F_{\rm p}\left(e^{\frac{t_{\rm p}-t}{T^r}} + e^{\frac{t-t_{\rm p}}{T^d}}\right)^{-1}$$

$$\tau_{\rm obs} = \overline{T^{\rm rot}} - t_{\rm p}$$

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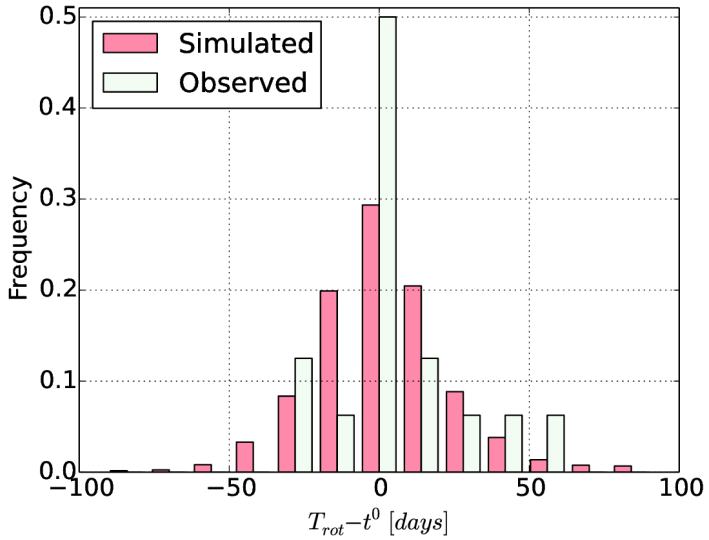
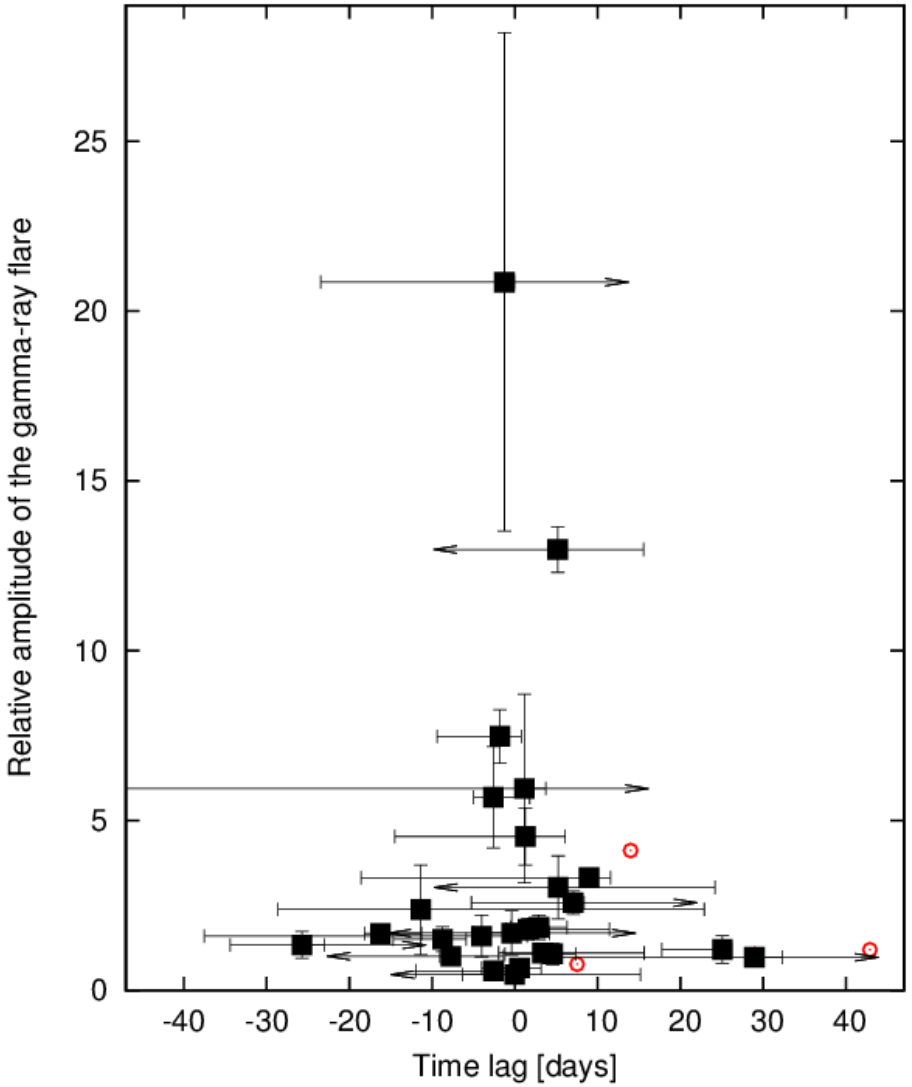
Association with γ-ray flares





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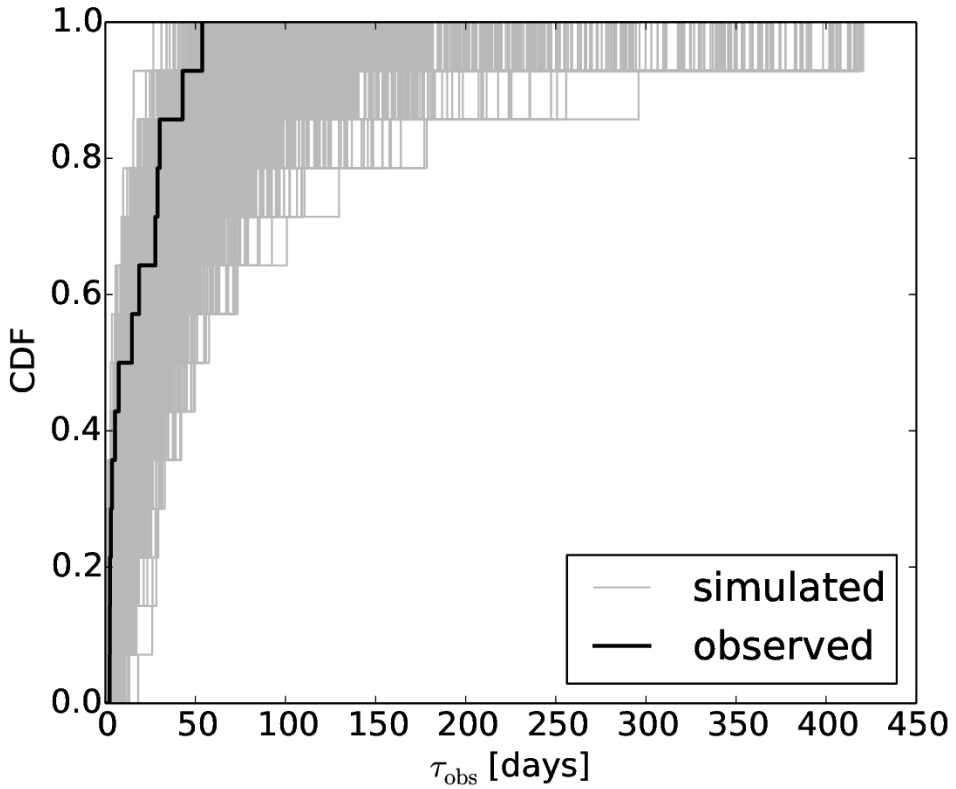
Association with γ-ray flares

Blazar	$P(\tau_{obs})$
RBPLJ0136+4751	0.75
RBPLJ0259+0747	0.03
RBPLJ0721+7120	0.04
RBPLJ0854+2006	0.23
RBPLJ1048+7143	0.14
RBPLJ1555+1111	0.72
RBPLJ1558+5625	0.20
RBPLJ1806+6949	0.10
RBPLJ1806+6949	0.49
RBPLJ1927+6117	0.08
RBPLJ2202+4216	0.21
RBPLJ2232+1143	0.14
RBPLJ2232+1143	0.19
RBPLJ2243+2021	0.48
RBPLJ2253+1608	0.78
RBPLJ2311+3425	0.56



Simulations give a set

$\tau_{sim} \leq \tau_{obs}$

with probability 5×10^{-5}

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Conclusions

- Blazars exhibiting rotations have longer and faster EVPA variations and more variable in γ-rays when compared to non-rotators

- Every single EVPA rotation can be produced by a random walk of the polarization vector, however it is unlikely ($<1.5 \times 10^{-2}$) that *all* rotations observed by RoboPol in 2013 are random

- It is very unlikely ($\sim 5 \times 10^{-5}$) that none of the rotations is physically related with γ-ray activity

- The brightest gamma-ray flares tend to be located closer in time to rotation event, which may be an indication of two separate mechanisms responsible for the rotations

P.S. Have a look at our poster about Polaroastrometry and two possible types of EVPA rotations

http://robopol.org

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