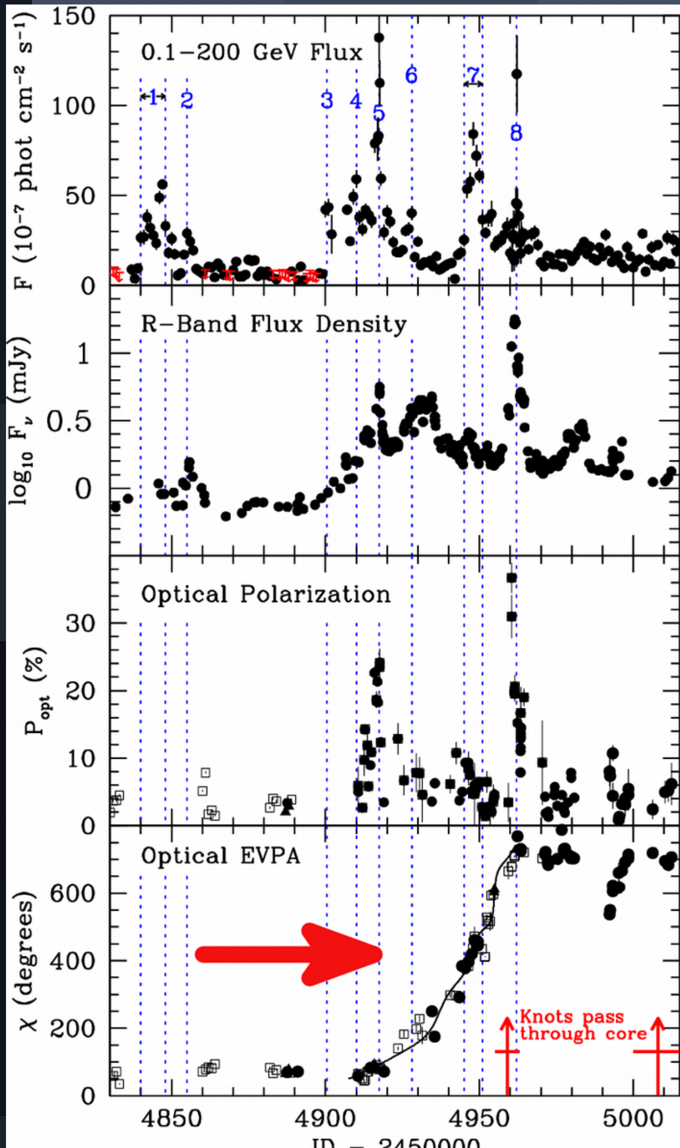
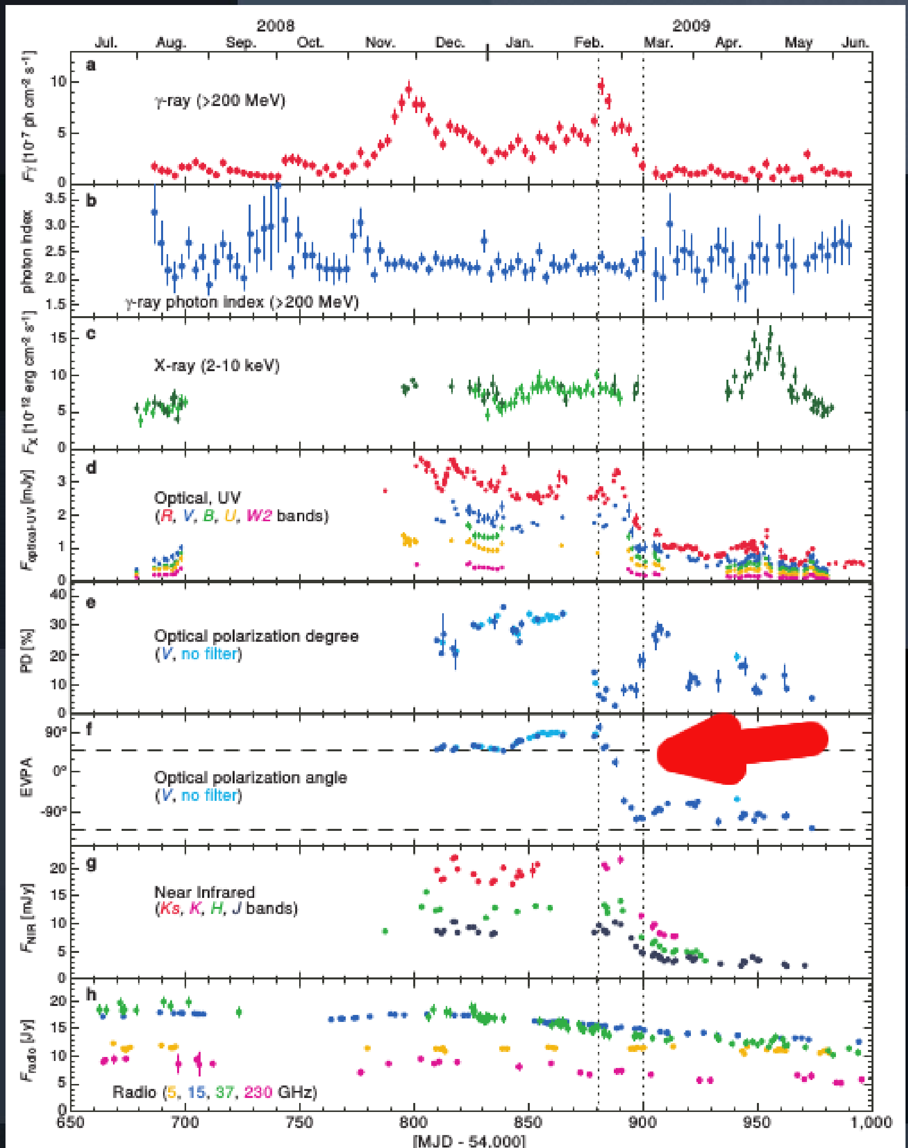
RoboPol: connection between optical polarization plane rotations and γ-ray flares in blazars

Vasiliki Pavlidou for the RoboPol collaboration
University of Crete, Greece





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

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

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

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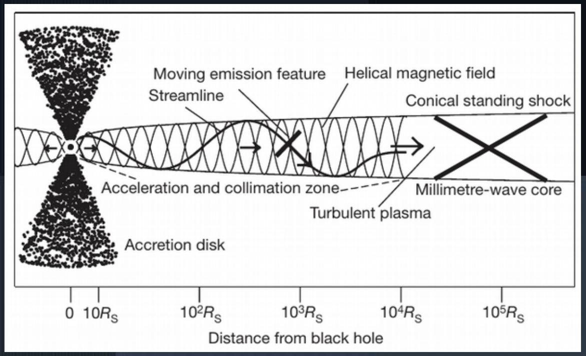
Many interpretations

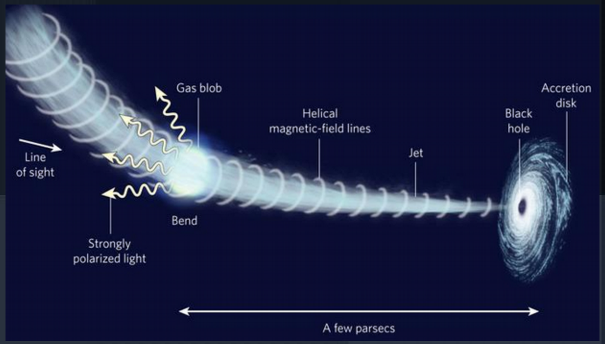
Propagation through helical trajectory



Marscher et al. 2008, Nature, 452, 966
Marscher et al. 2010, ApJ, 452, 966

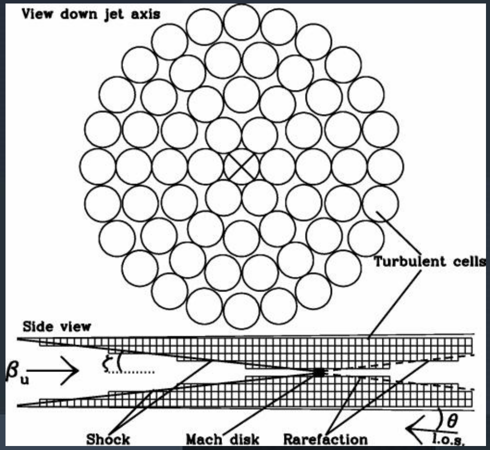
All are single event studies
Statistical approach is needed

Propagation through jet bend



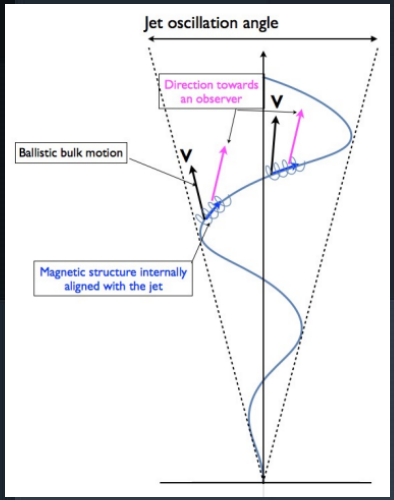
Abdo et al. 2010, Nature, 463, 919
Nalewajko 2010, Int. J. Mod. Phys. D, 19, 701

Stochastic variations in turbulent plasma



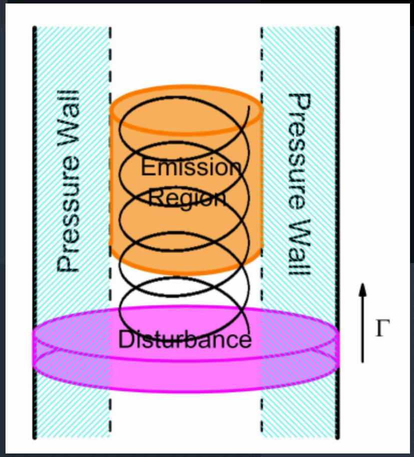
Marscher 2014, ApJ, 780, 87

Precessing jet



Lyutikov & Kravchenko 2017,MNRAS, 467, 3876

Modification of B-field by propagating shock



Zhang et al. 2016, ApJ, 817, 63

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

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N.C.U., Poland: A. Kus, A. Marecki, E. Pazderski

+ T. Hovatta, (University of Turku, 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

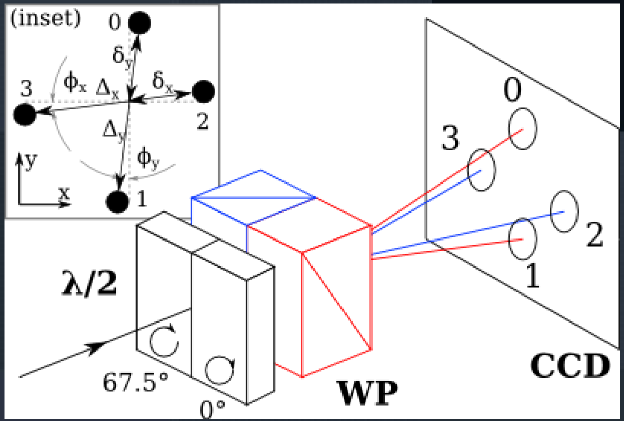
King et al., MNRAS 445, L114 (2014)

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

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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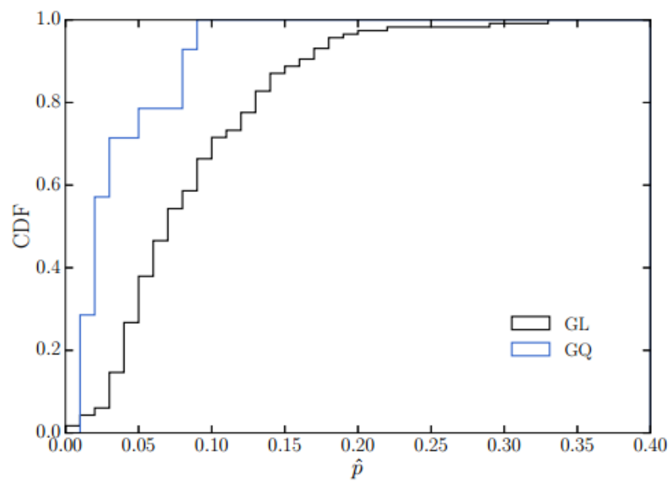
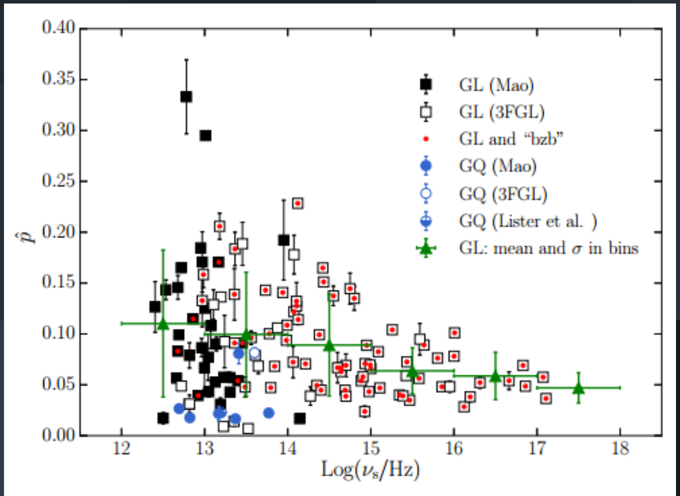
Polarization of γ-loud vs γ-quiet





Median p of γ-loud blazars
Is **3 x** median p of γ-quiet

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

Different at >4σ

Polarization depends on the synchrotron peak position

Angelakis et al., 2016

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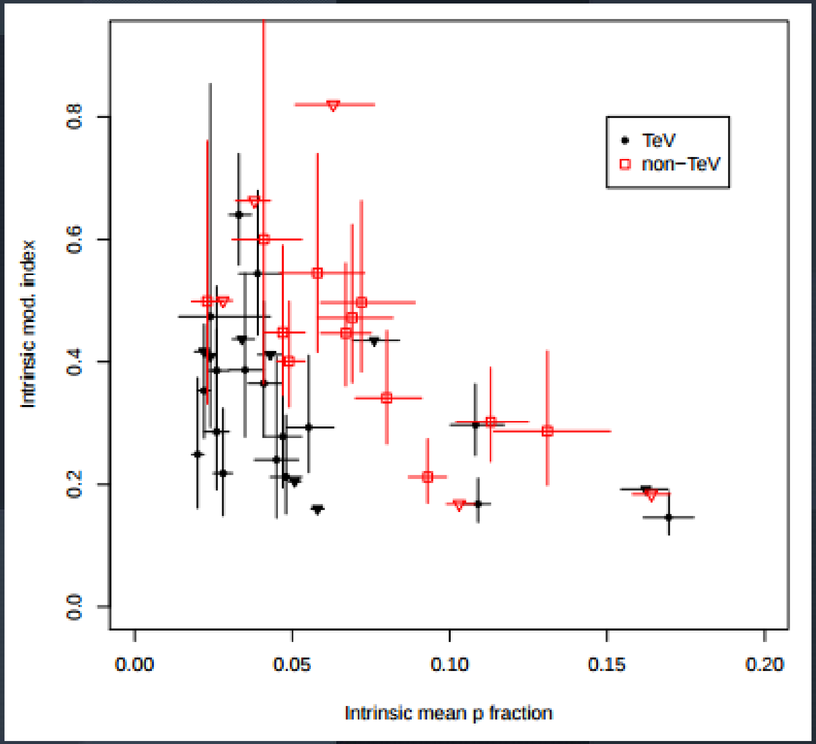
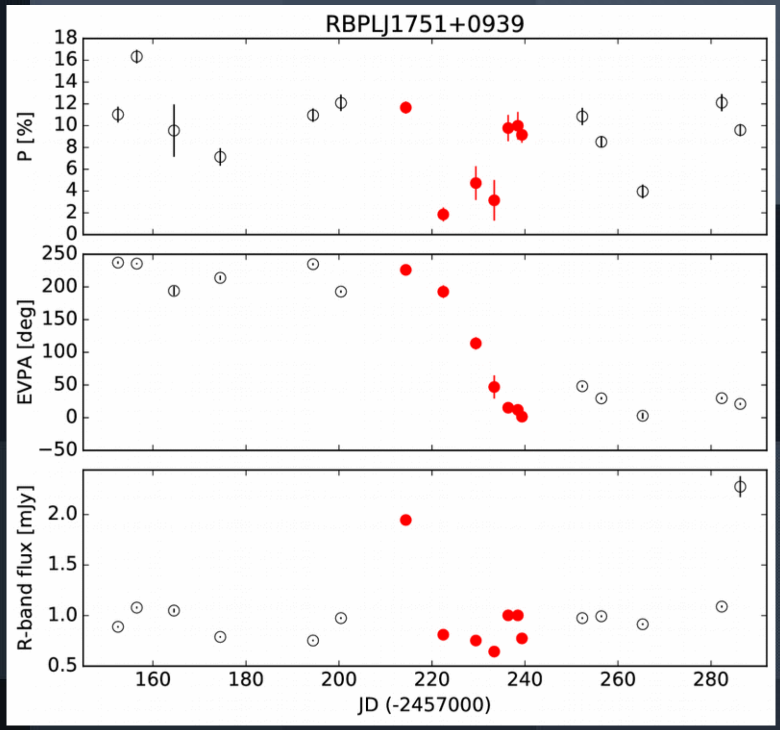
Polarization and TeV emission

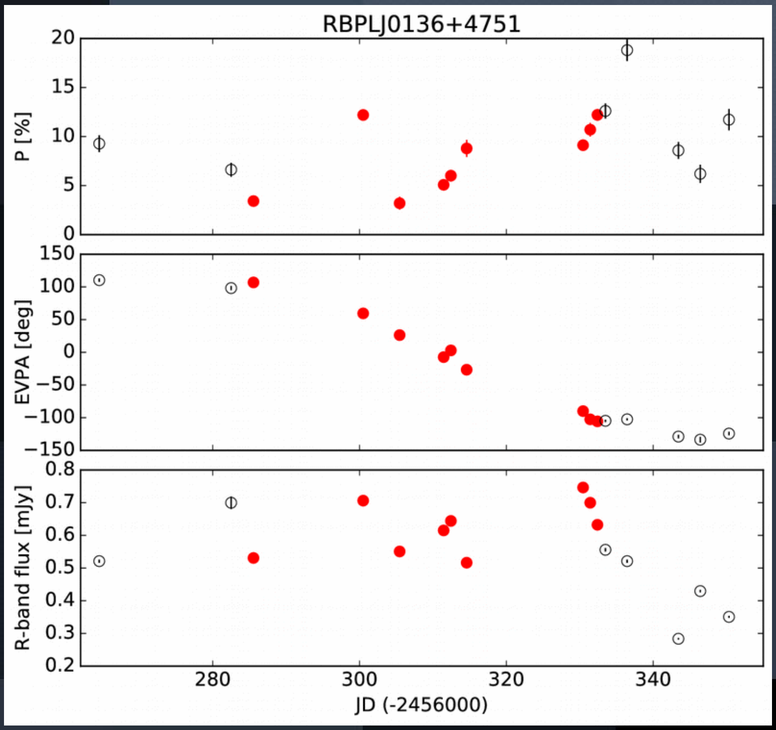
No difference in polarization properties between TeV-detected and TeV-non-detected
Both samples include rotators

Likely good news for future TeV surveys:
All HSPs may be detectable (if z is small enough)



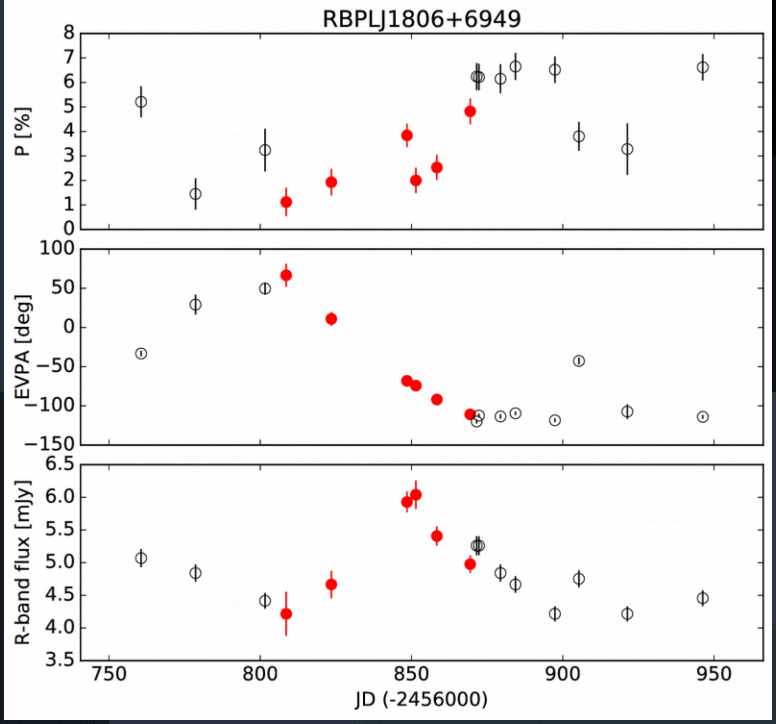
Hovatta et al., 2016





16 EVPA rotations prior to RoboPol
(1988 - 2013)

RoboPol 3 years monitoring:
40 EVPA rotations in 24 blazars



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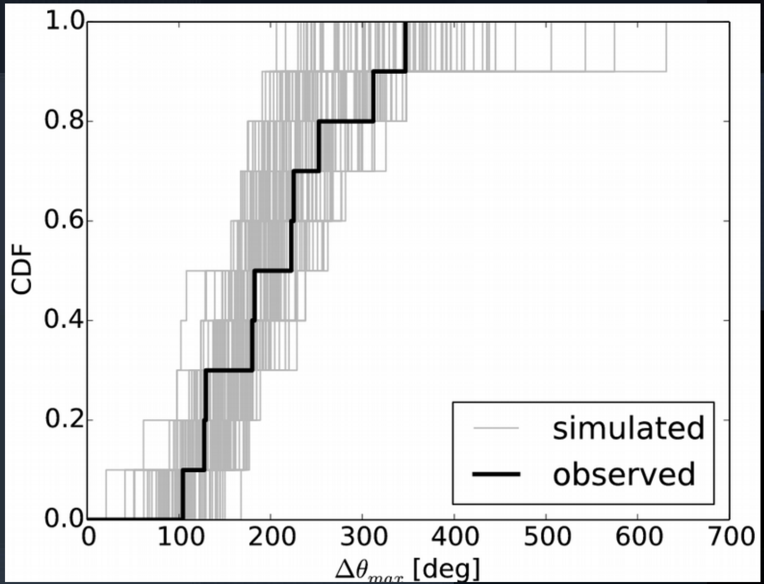
Are all EVPA rotations stochastic?

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 ID	$T_{\rm occ}$ (d)	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 for a single rotation:
D'Arcangelo et al. 2007

Chance that all 1st season rotations are Random walks < 0.5%

Blinov et al. 2015
+ Kiehlmann et al. submitted

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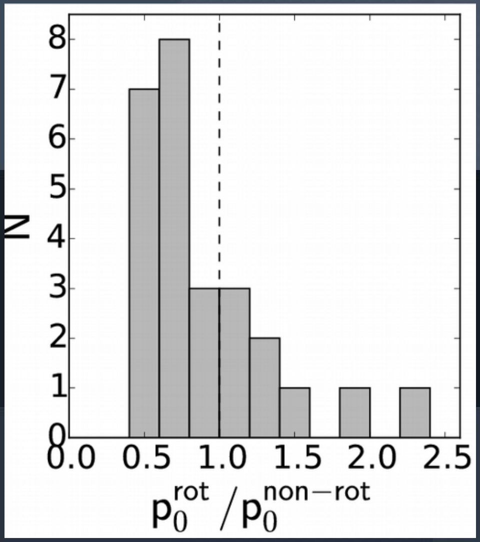
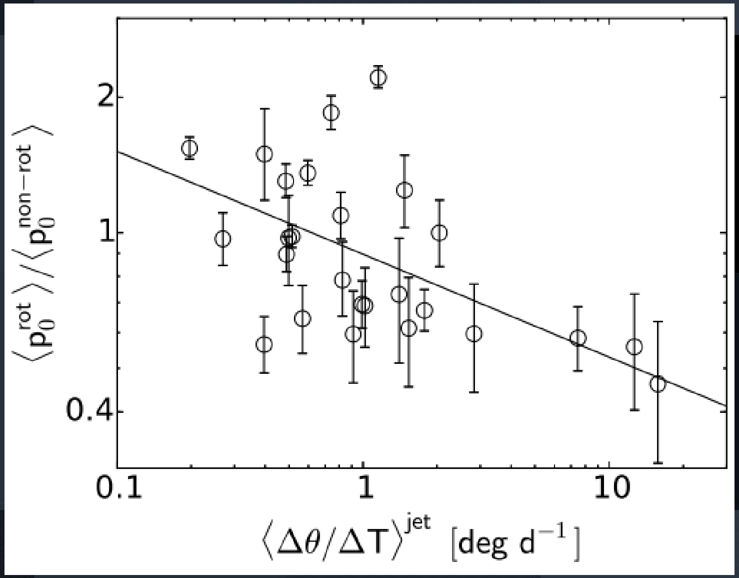
- Polarization is usually lower during rotations than in non-rotating periods



- Change of polarization during rotations depends on the rotation rate



Blinov et al. 2016a

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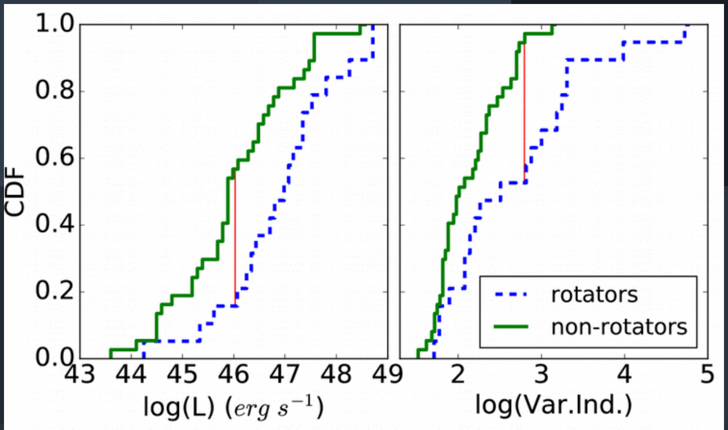
Do all blazars rotate EVPA?

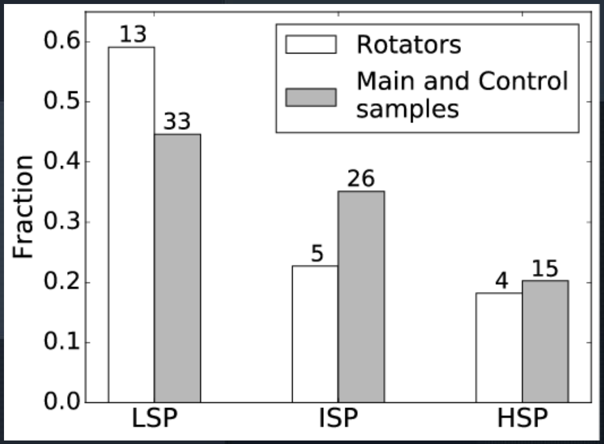
1. Average frequency of rotations varies significantly among blazars
   28% blazars in both samples rotate EVPA every 232 days
   remaining 72% either do not rotate or rotate with frequency 1/3230 d^{-1}

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



Rotators are
more luminous
and more variable

3. Rotations tend to happen in LSP sources rather than HSP



Blinov et al., 2016b

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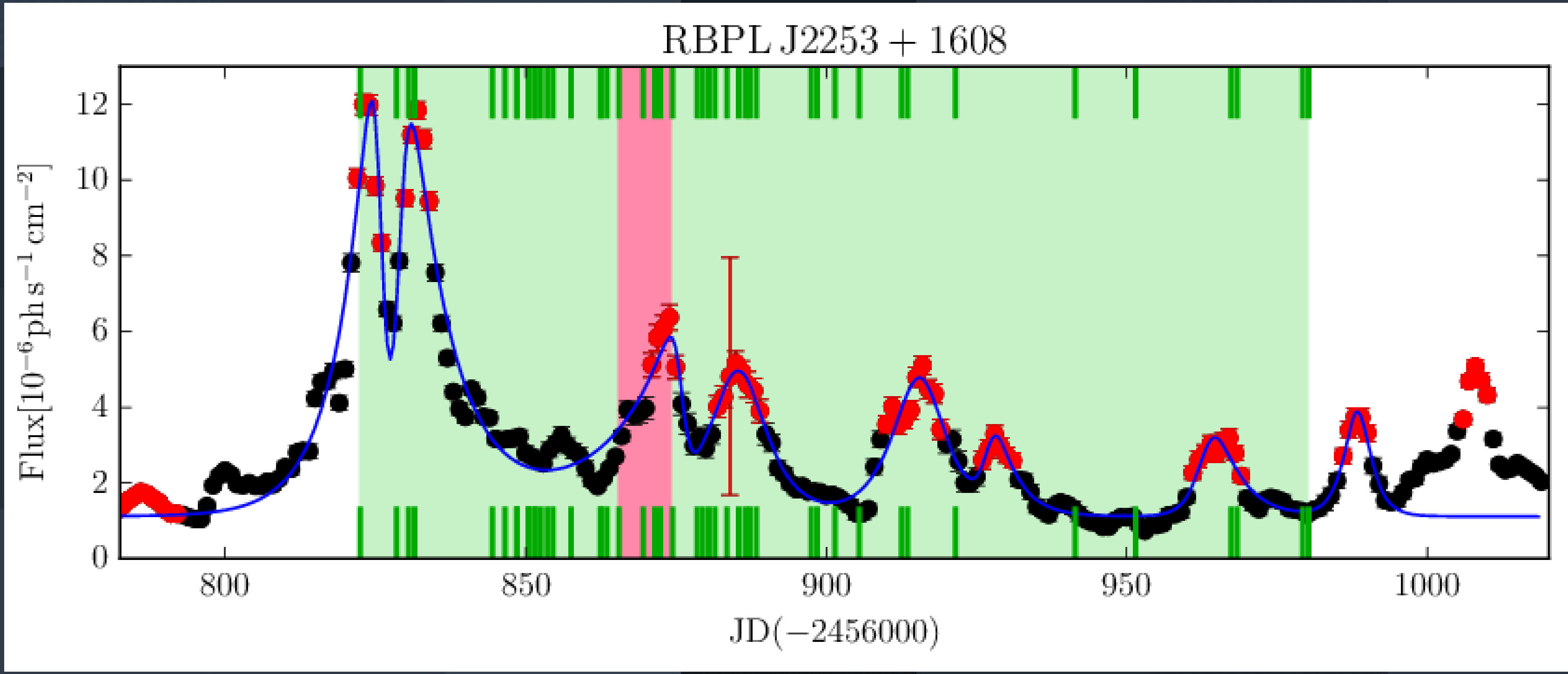
Are EVPA rotations related to γ-ray flares?

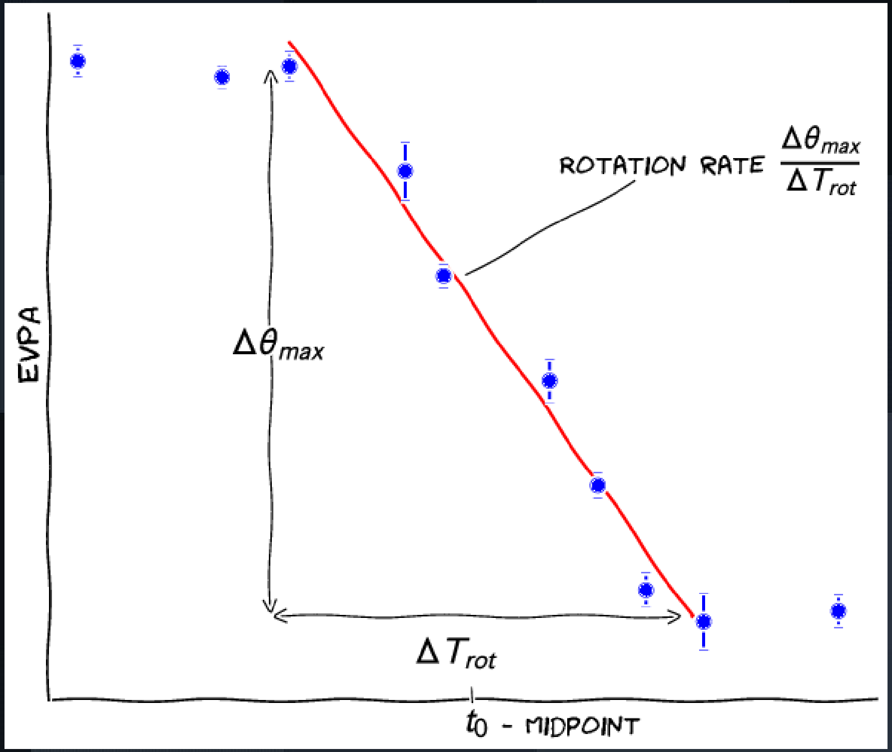
3 seasons data

40 EVPA rotations in 24 blazars

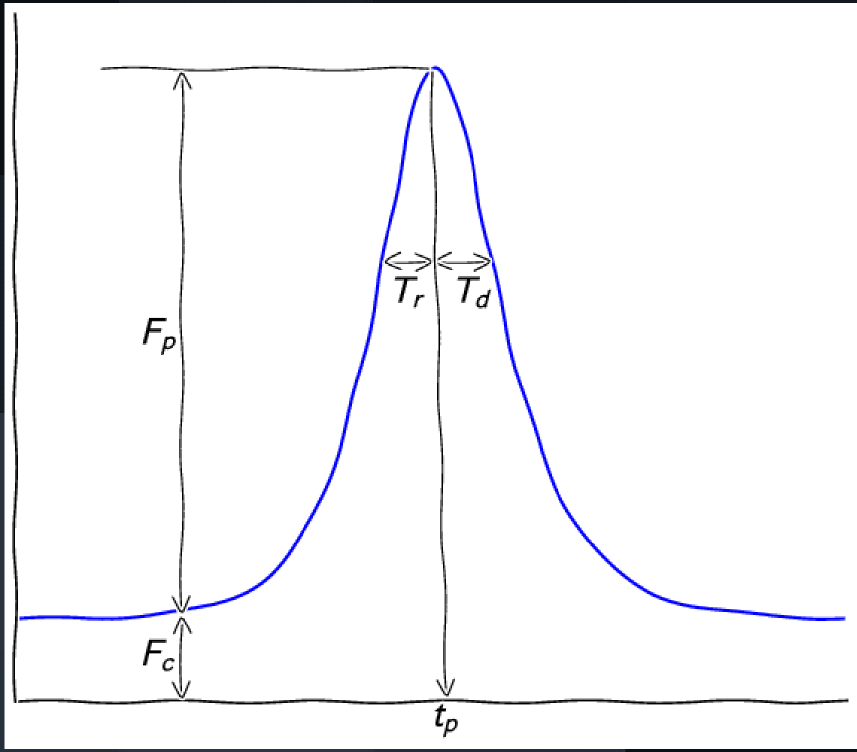
- identified flares
- fitted flares => F_0, t_p, F_p, T_r, T_d



EVPA rotation



γ-ray flare



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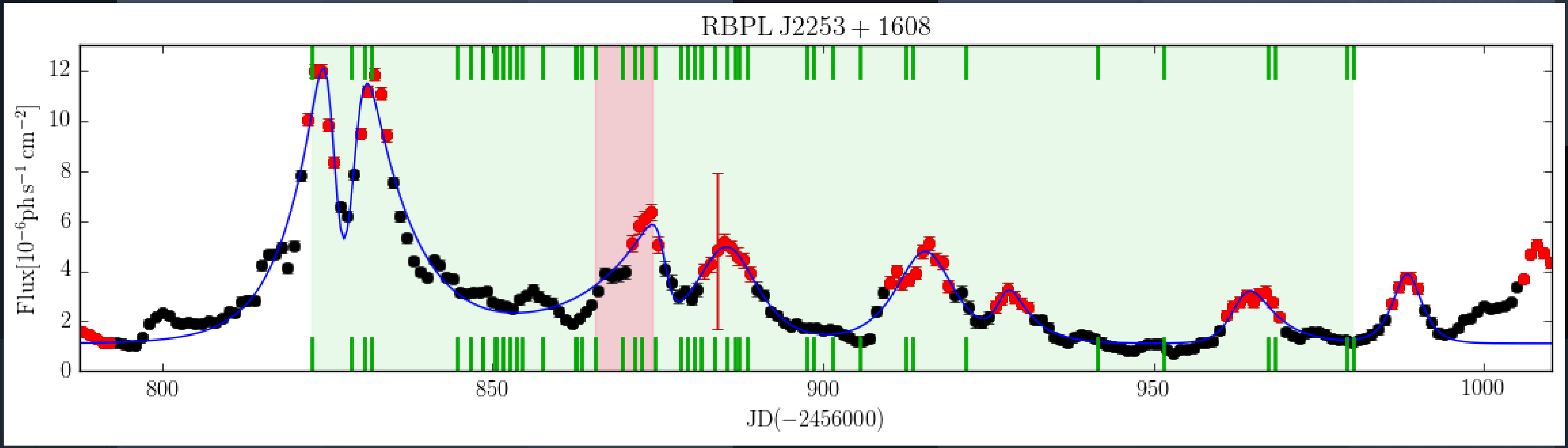
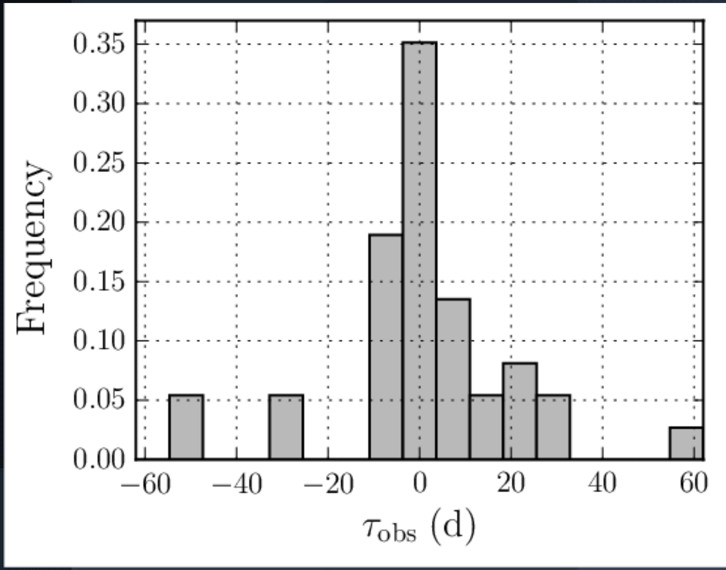
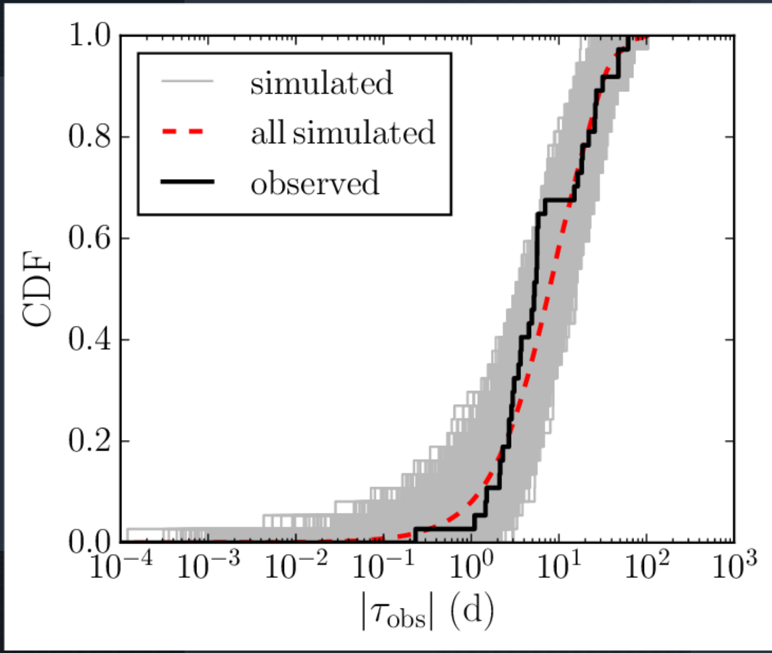
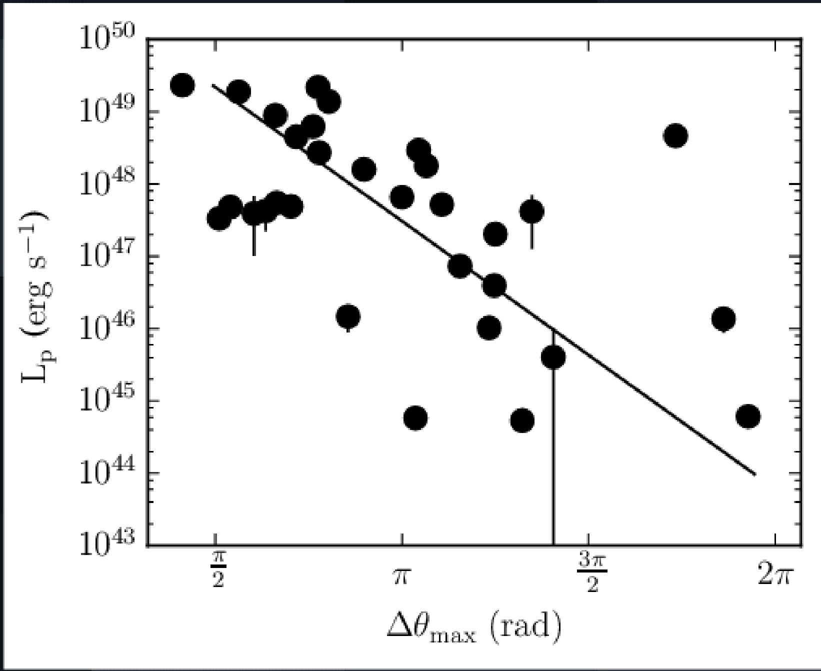


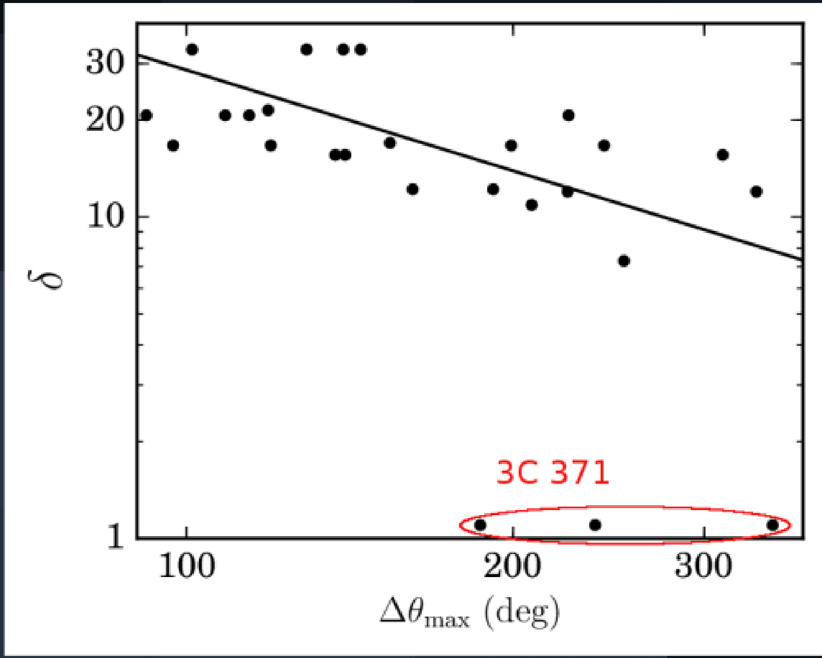




Such small time lags can be produced accidentally with $p = 7 \times 10^{-5}$

Rotation amplitude vs flare luminosity





r=-0.58 (p-value=$7x10^{-4}$)
slope=-1.18±0.08

r=-0.57 (p-value=0.005)
slope=-1.04±0.03

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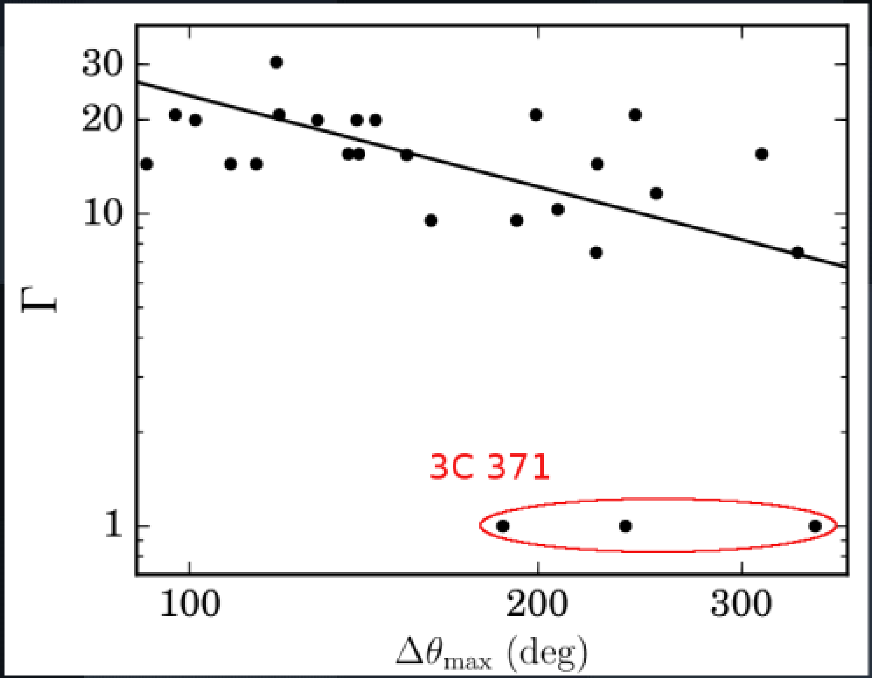
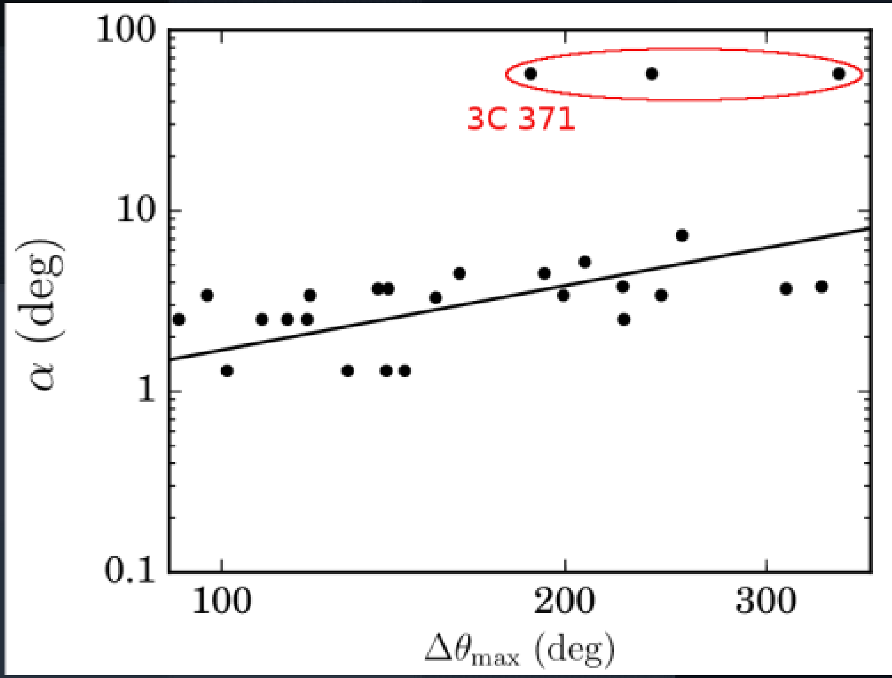
Amplitude vs jet parameters

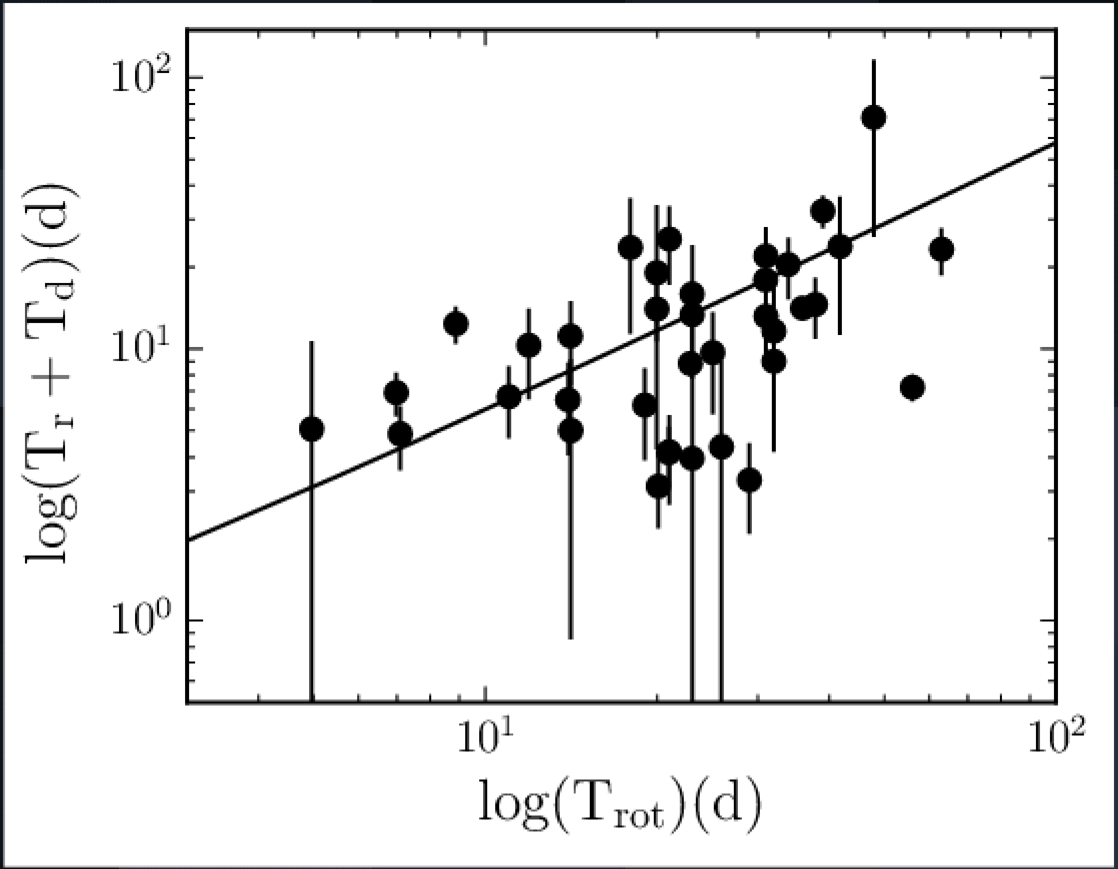




r=-0.51 (p-value=0.01)
slope=-0.97±0.01

r=0.51 (p-value=0.01)
slope=1.19±0.04

Rotation duration vs flare duration



r=0.37 (p-value=0.02)

Slope=0.57±0.19

Slope ≠ 0 at 2.8σ level

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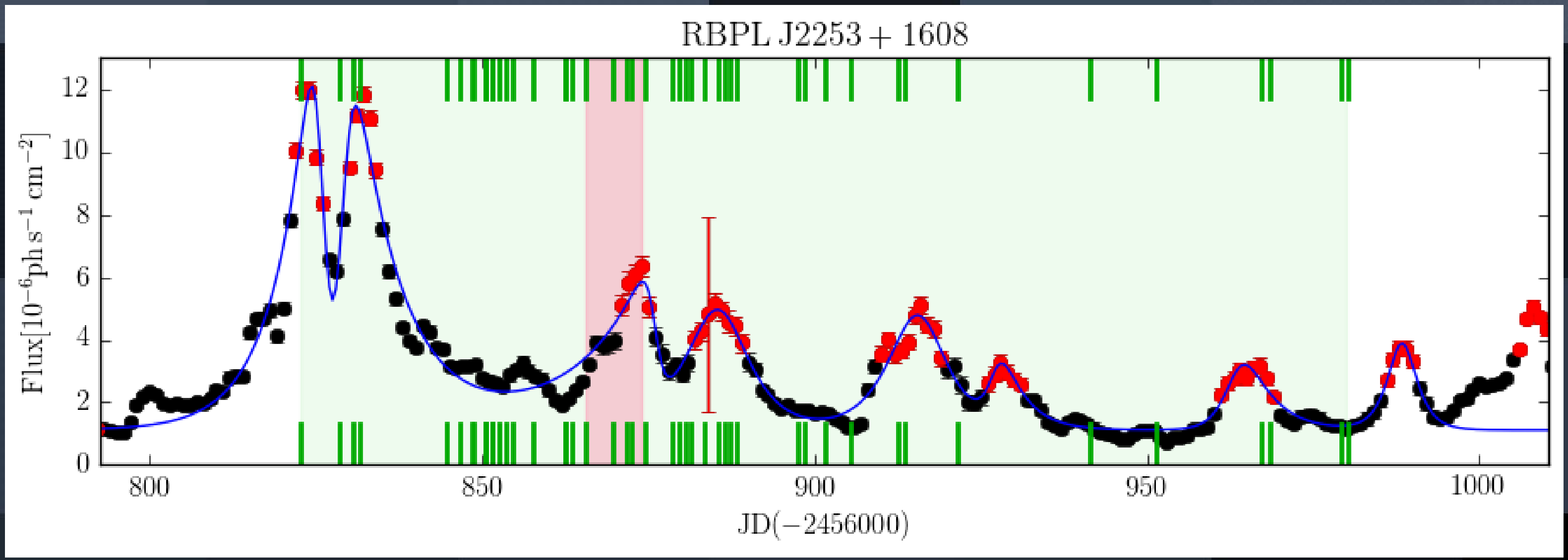
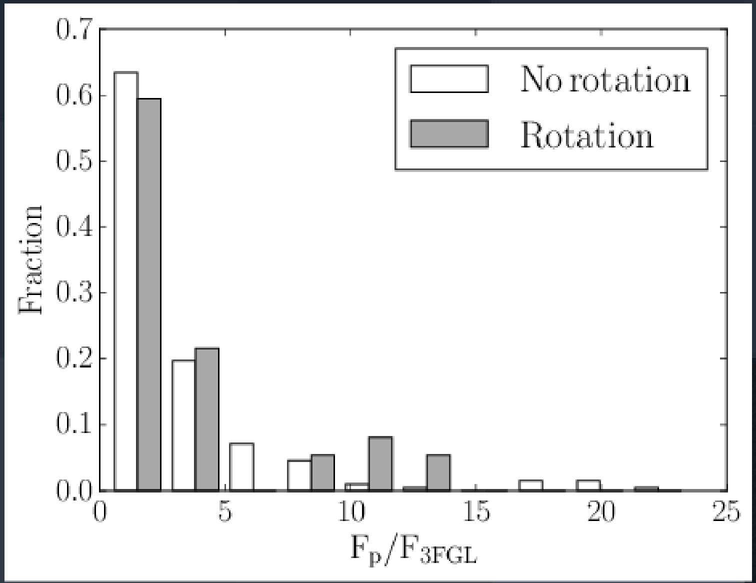
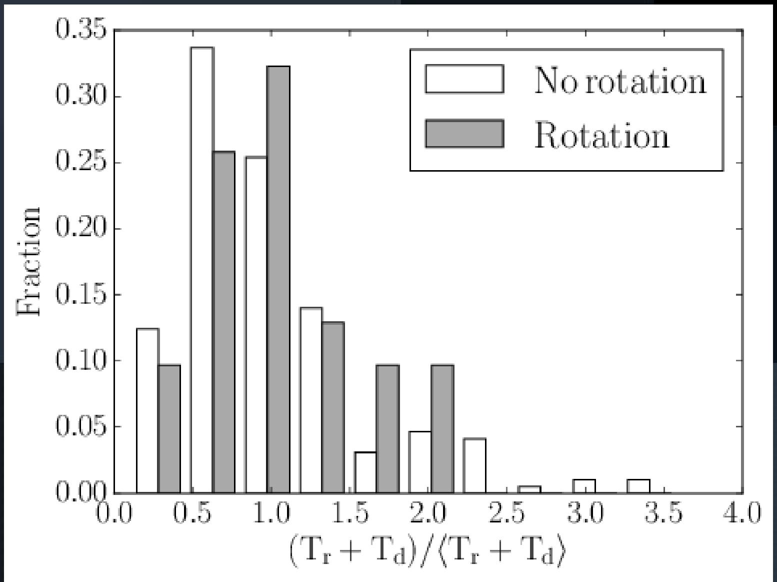
Are these flares special?







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Conclusions

- There is no evidence for non-zero time lags
- Time lags are so small that they cannot **all** be accidental
- Amplitudes of the rotations are anticorrelated with luminosities of the flares
- Amplitudes of the rotations are correlated with the jet properties (Γ and the viewing angle)
- Durations of the flares and rotations are marginally correlated
- Majority of EVPA rotations must be deterministic, however, some of them can be produced by random walks – see the next talk

http://robopol.org

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EVPA rotations

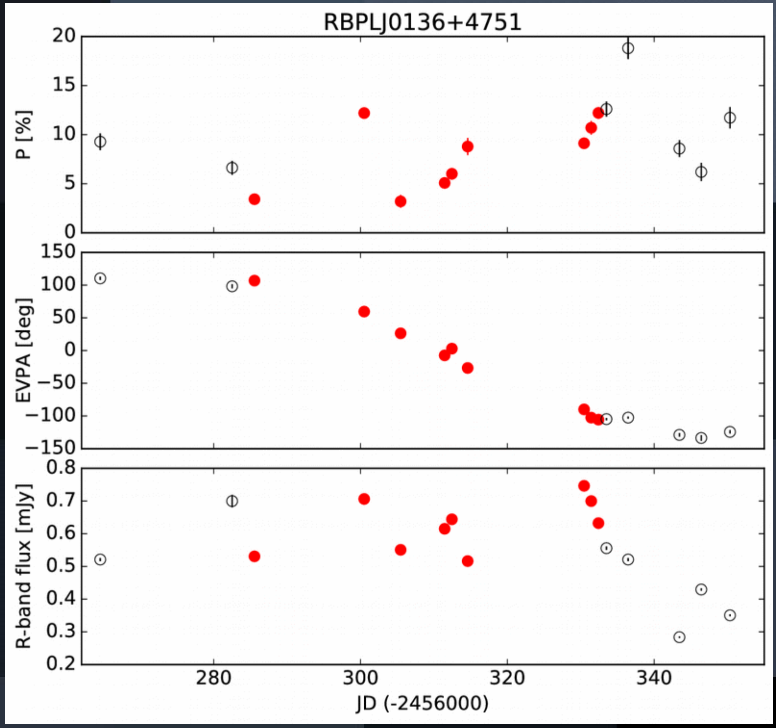
- Total amplitude Δθ ⩾ 90°

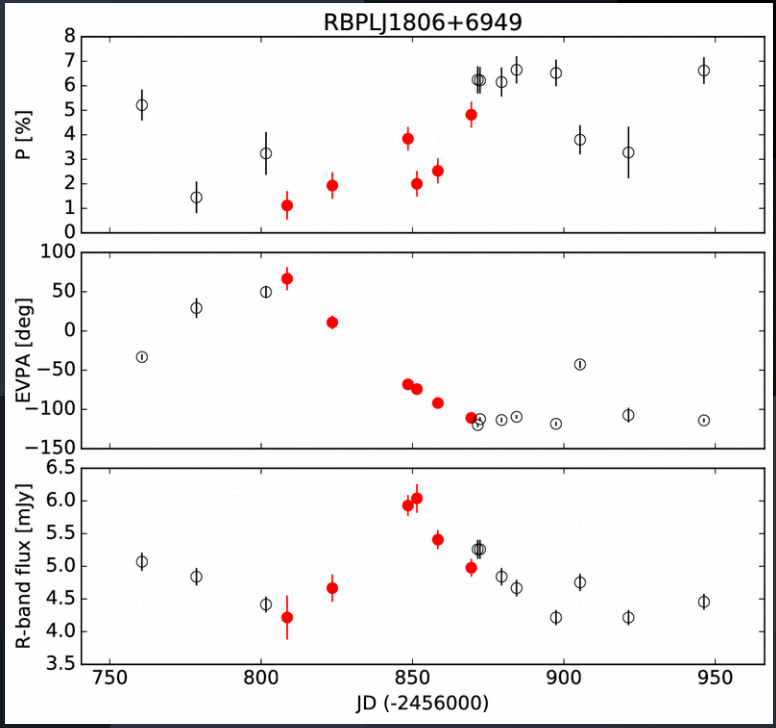
- At least 3 significant swings (4 points)

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

- No large changes in the rate

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





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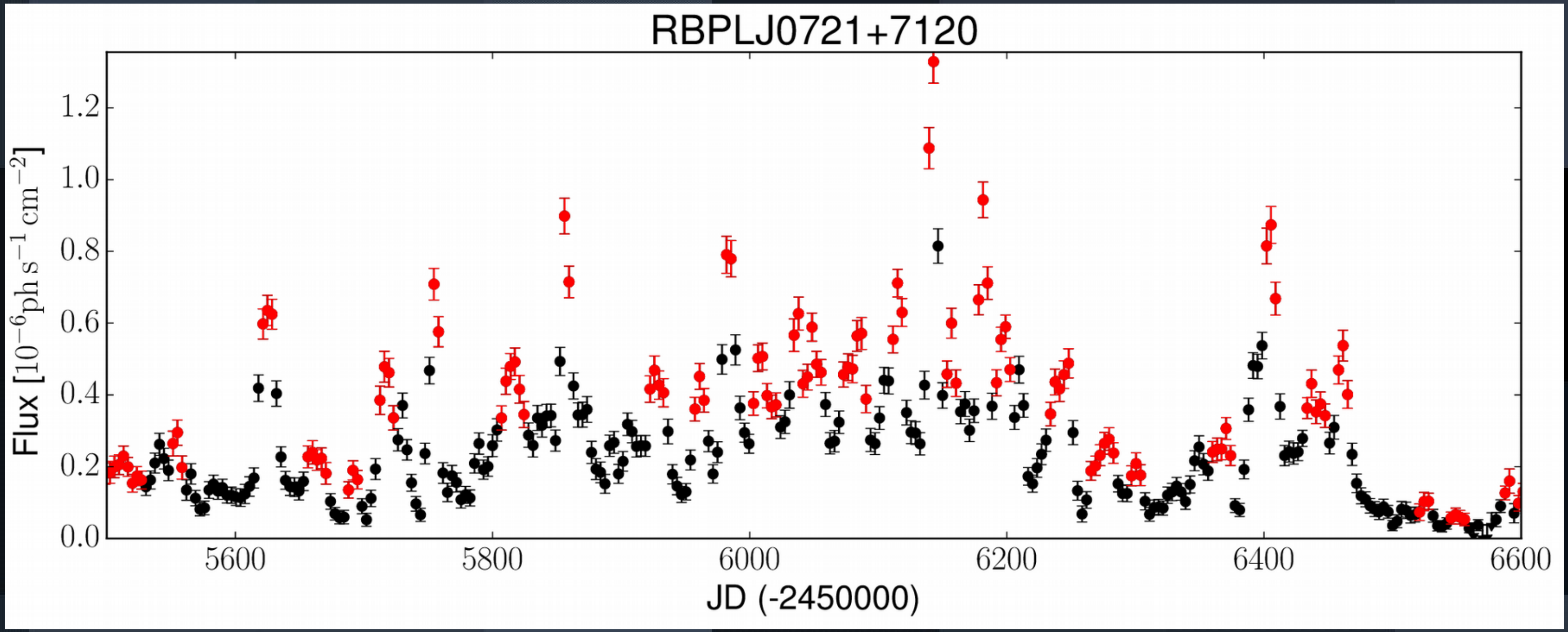
γ-ray flare

Definition by Nalewajko (2013): „a flare is a contiguous period of time, associated with a given photon flux peak, during which the photon flux exceeds 2/3 of the peak value, and this lower limit is attained exactly twice – at the start and at the end of the flare”



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