The RoboPol Optical Polarization Monitoring Program

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

Polarised Emission from Astrophysical Jets – Ierapetra, 12-16 Jun 2017

Max-Planck-Institut
für Radioastronomie

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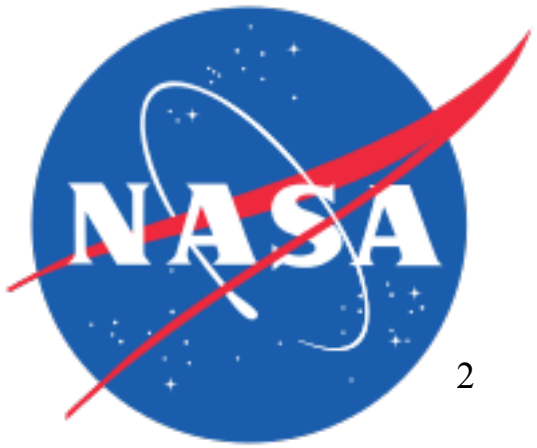
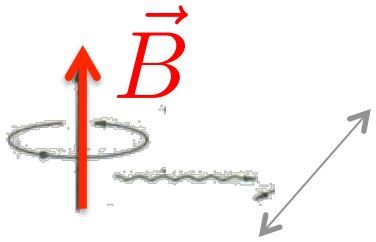


In brief:

Using a ***unique instrument*** and ***ample observation time***,
we took ***rotations of the optical polarization plane of blazars***
from “novelty” class of events
to a well-studied class with robust statistics,
ready for detailed modeling

Optical Polarization in Blazars

Blazars: Optical = optically thin Synchrotron:



highly linearly polarized
polarization direction $\perp \vec{B}$

contribution from all emitting regions
along line of sight

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

robopol

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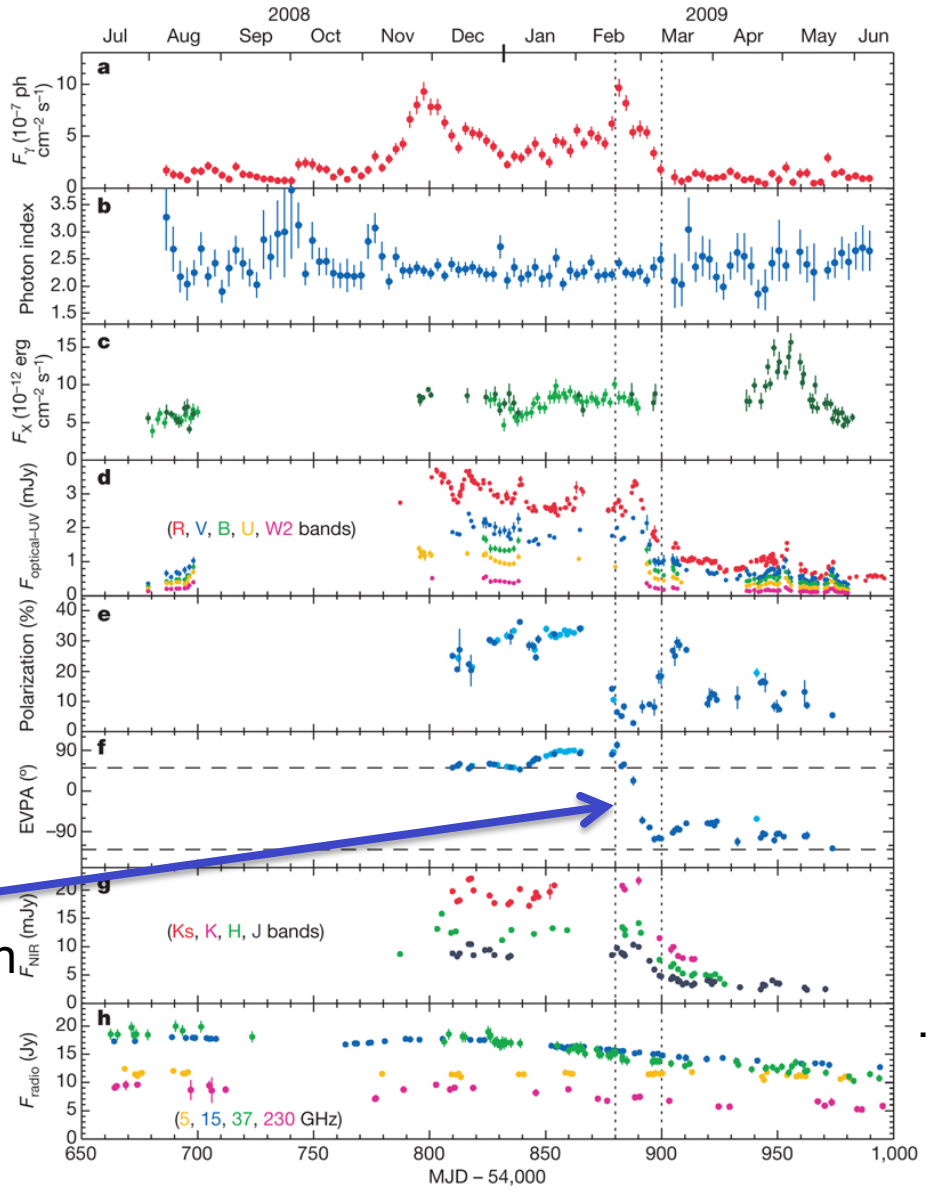
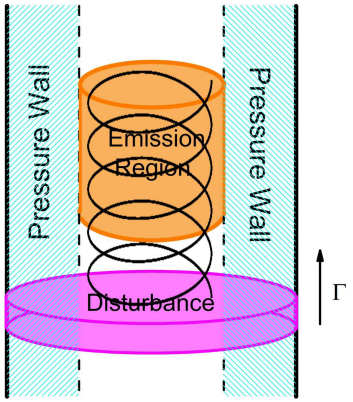


Polarization rotation

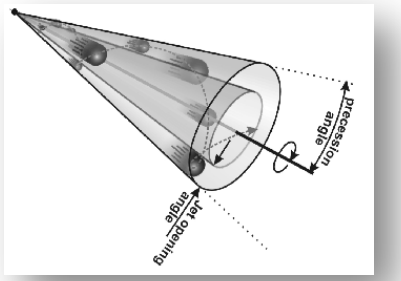
. Abdo et al. (2010)

Many interpretations

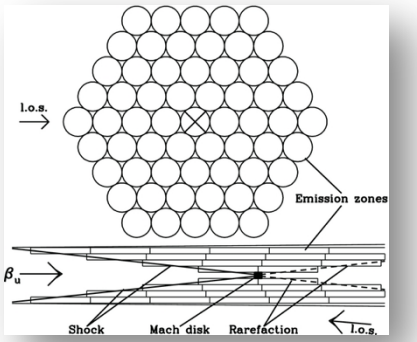
- A wealth of theoretical ideas:



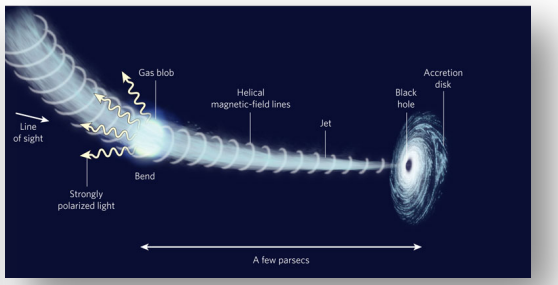
Propagation of shock along jet B-field
cartoon from Zhang, Deng, Li & Boettcher 2016



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

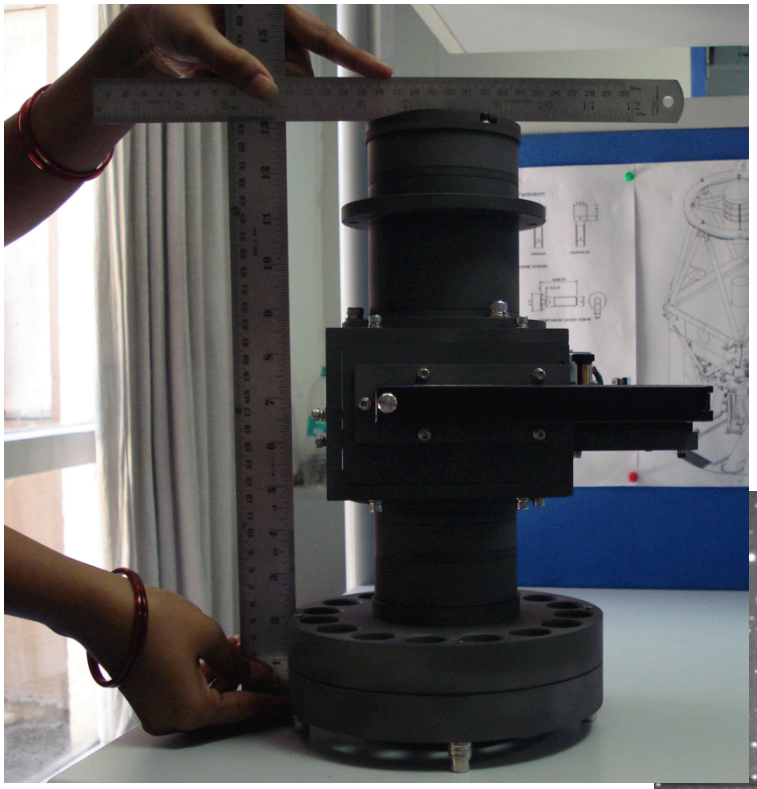
- A multitude of phenomenological possibilities.
  - ✓ large rotations, small rotations, rotations of all sizes
  - ✓ all blazars, many blazars, only few blazars do it
  - ✓ happens only during flares, happens all the time

The RoboPol Program

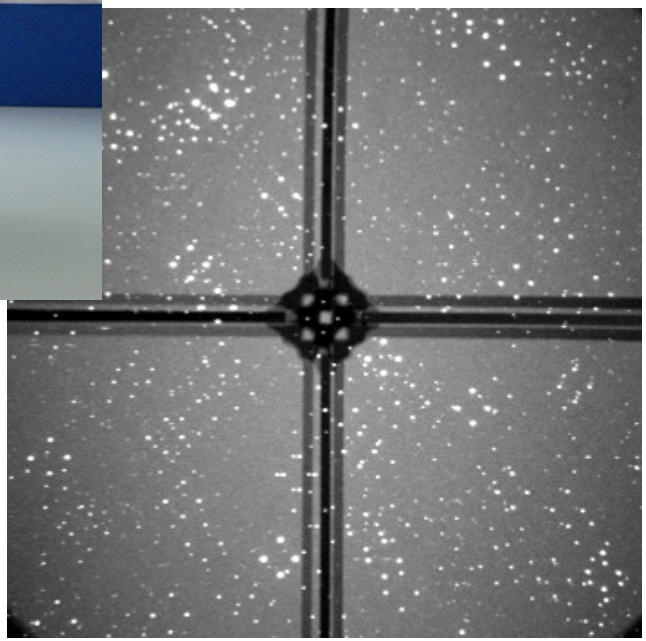
- ✓ Observe large, well-defined sample of blazars in optical linear polarization with high cadence
- ✓ Identify rotations with uniform criteria
- ✓ Systematically answer questions regarding optopolarimetric properties of blazars:

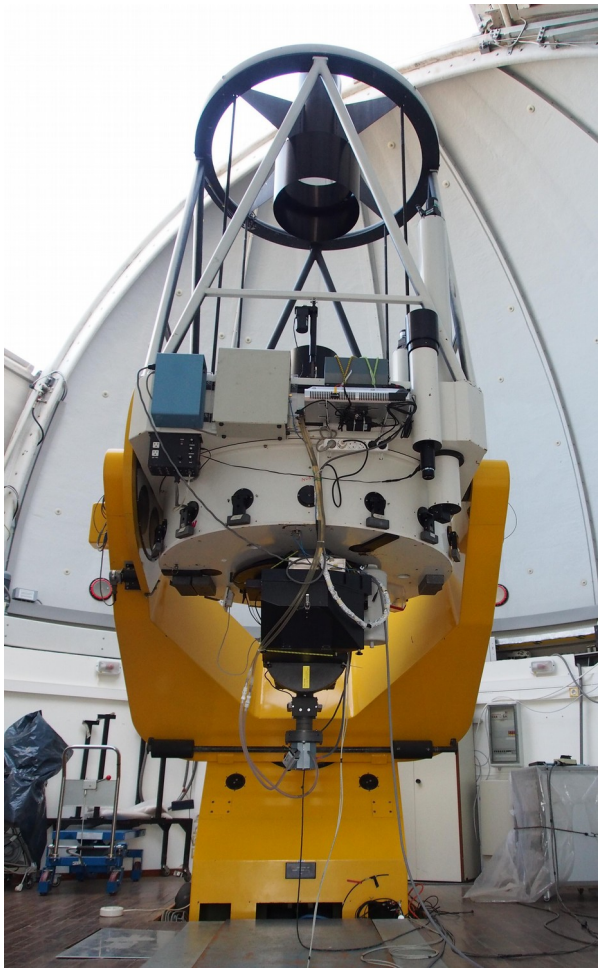
-- **Are γ-ray—loud and γ-ray—quiet blazars different in optical polarization?**
-- **Do all blazars exhibit polarization rotations?**
-- **Are polarization rotations coherent events?**
-- **Are polarization rotations related to γ-ray flares?**

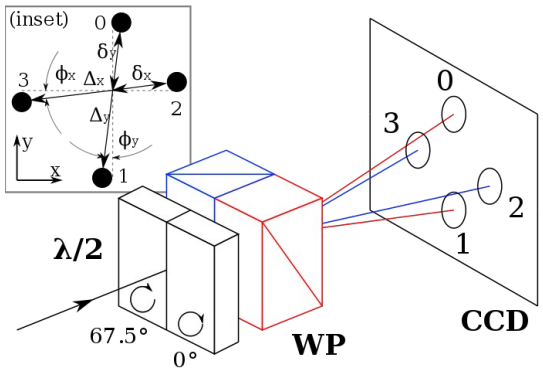
The RoboPol polarimeter



No moving parts,
low systematics,
high sensitivity







Program Features

- ✓ **Low-systematics, high-sensitivity polarimeter**
- ✓ **Ample telescope time:** 4 nighs/week for 3 years at Skinakas 1.3 m telescope (1750m, median seeing 0.53 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
- ✓ 24 additional interesting objects (dropped in 3rd season to increase cadence)

Pavlidou et al. 2014

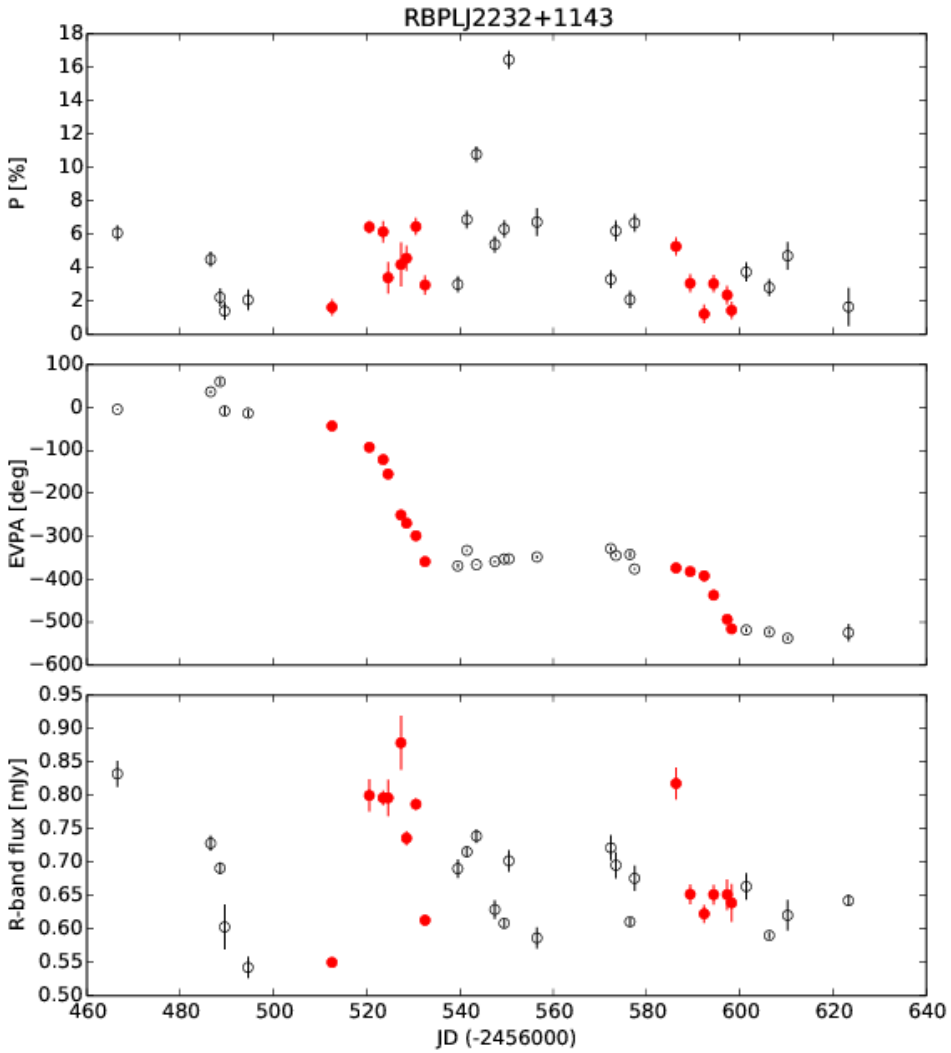
RoboPol Rotation Definition

- ✓ **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



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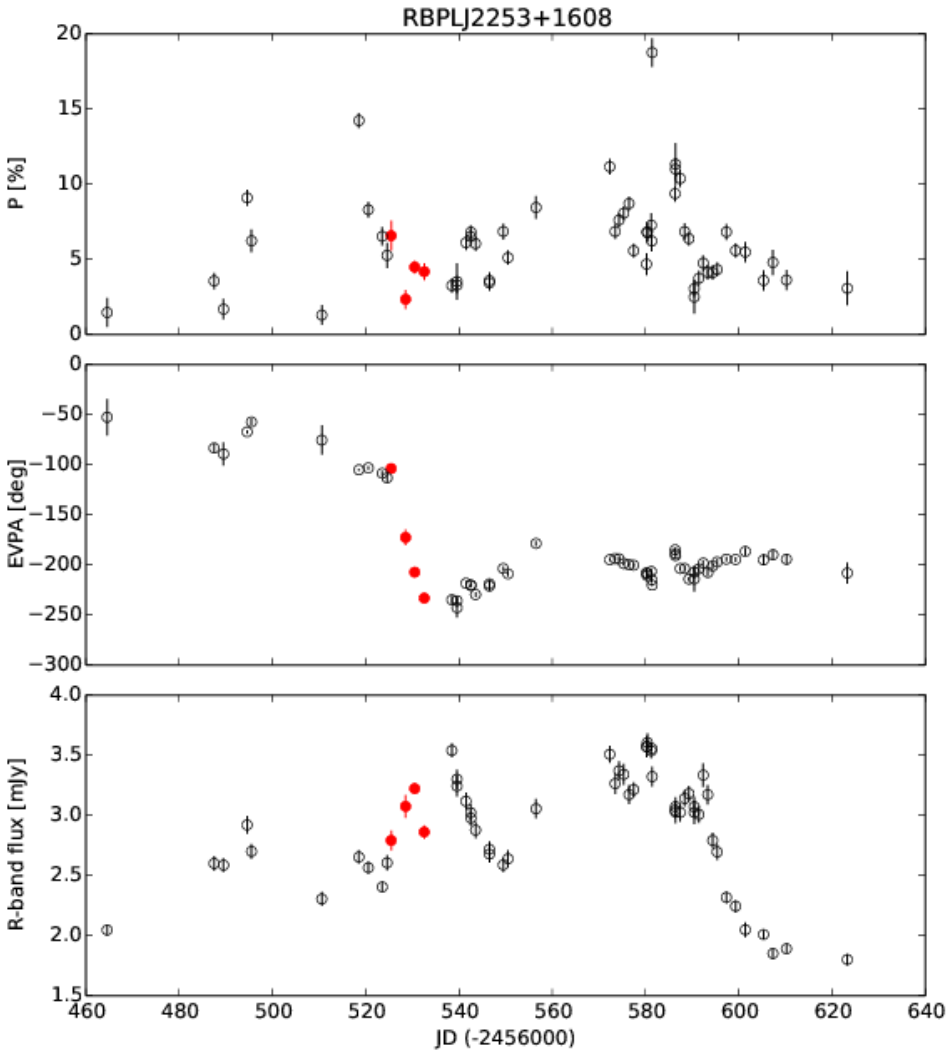
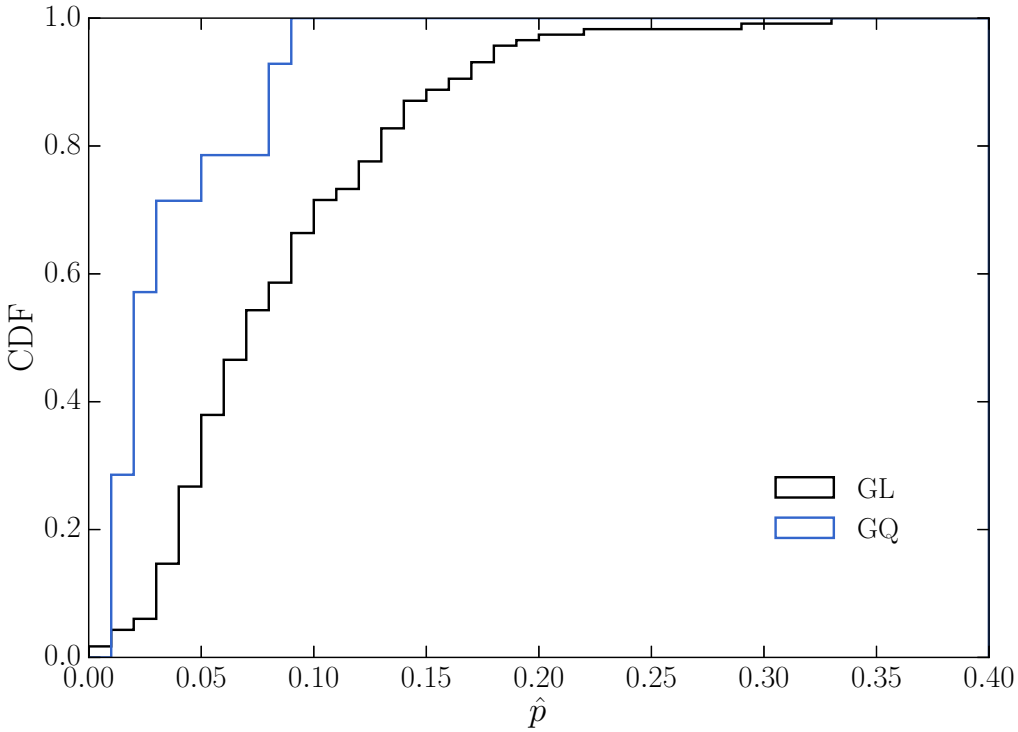


γ-loud vs γ-quiet



Median p of γ-loud blazars almost **x3** median p of γ-quiet blazars

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

different at >4σ

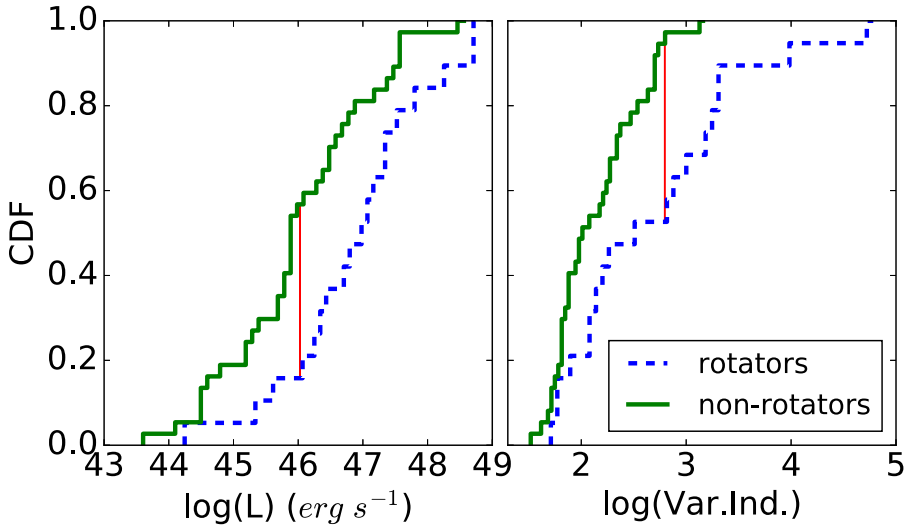
Angelakis et al. 2016

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° 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



Blinov et al. 2016

rotators are: **more luminous more variable**

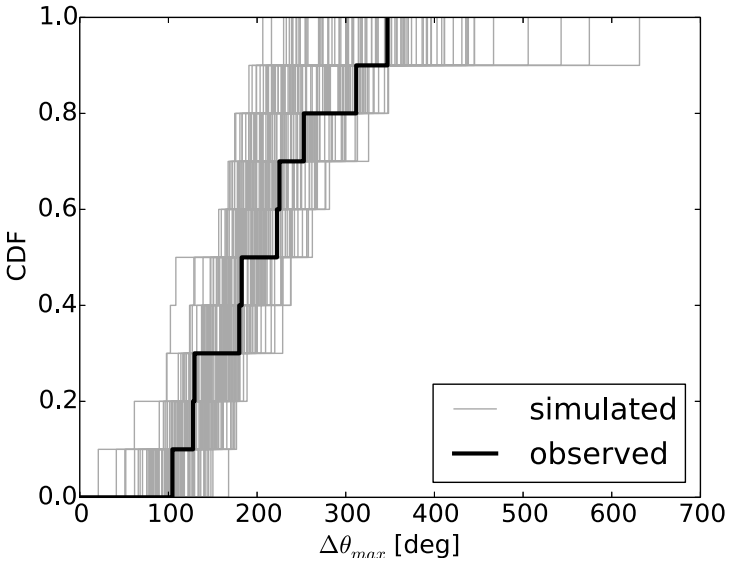
Are rotations coherent?

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

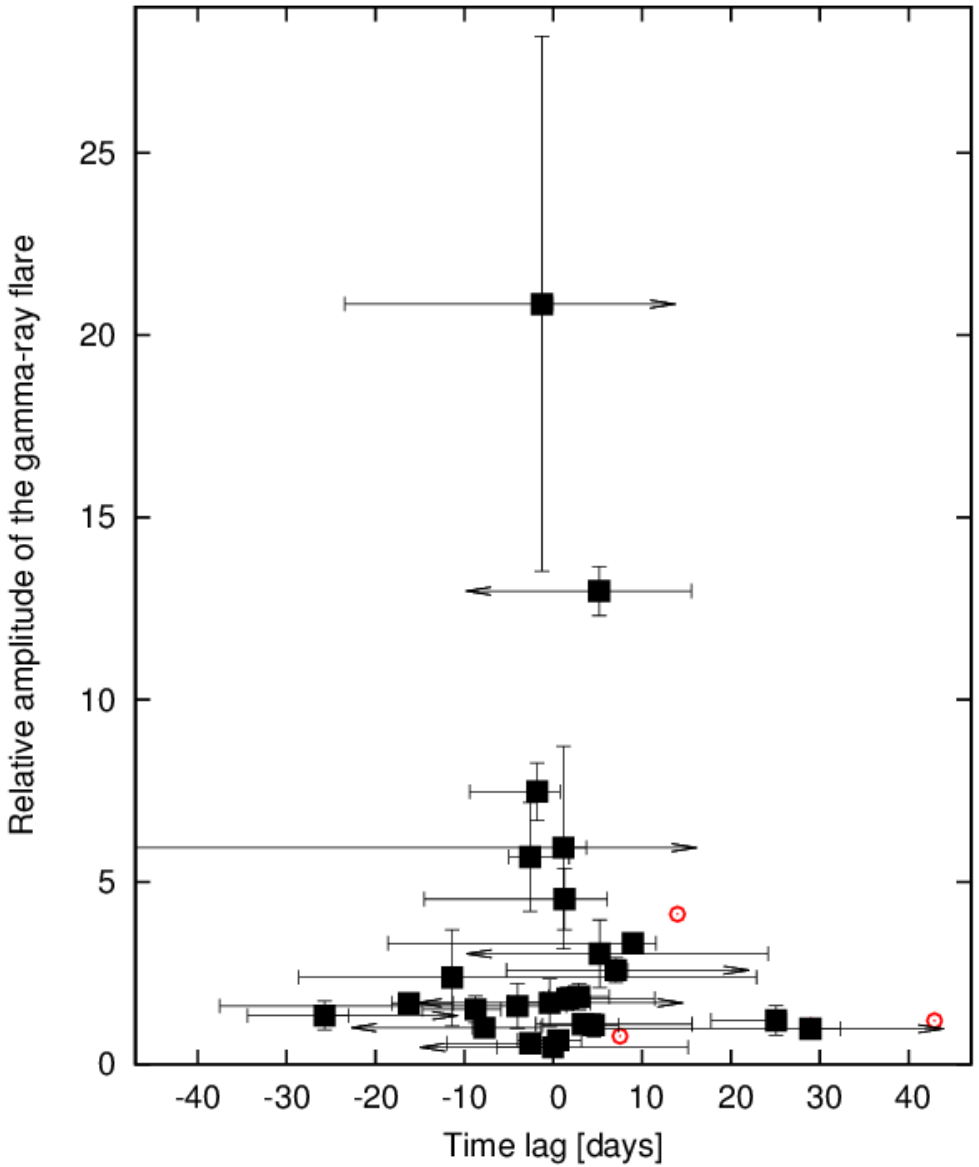


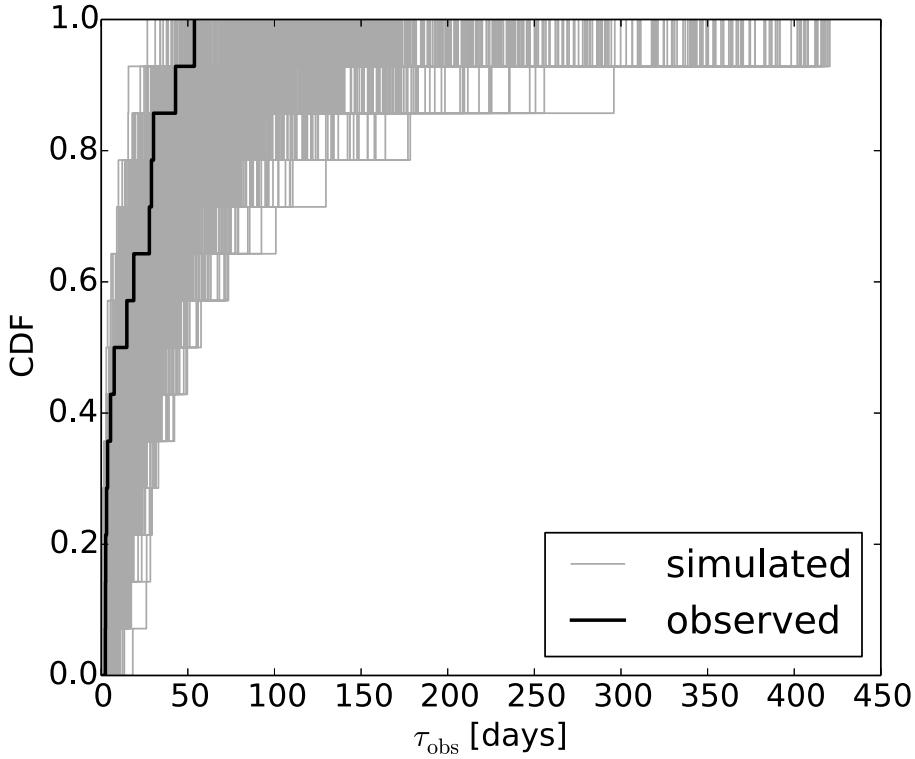
Similar simulations:
Jones et al. 1985, ApJ 290, 627
D'Arcangelo et al. 2007, ApJL 659, L107

Chance that **all** 1st season rotations are RW: <0.5%

Blinov et al. 2016

Rotations related to γ-activity?





$P=2x10^{-4}$

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 coherent events?
SOME. Robopol data inconsistent with ALL rotations being RW.

Are polarization rotations related to γ-ray flares?
YES. Time lags with γ-flares too small for random associations

Bonus: Polarization & TeV

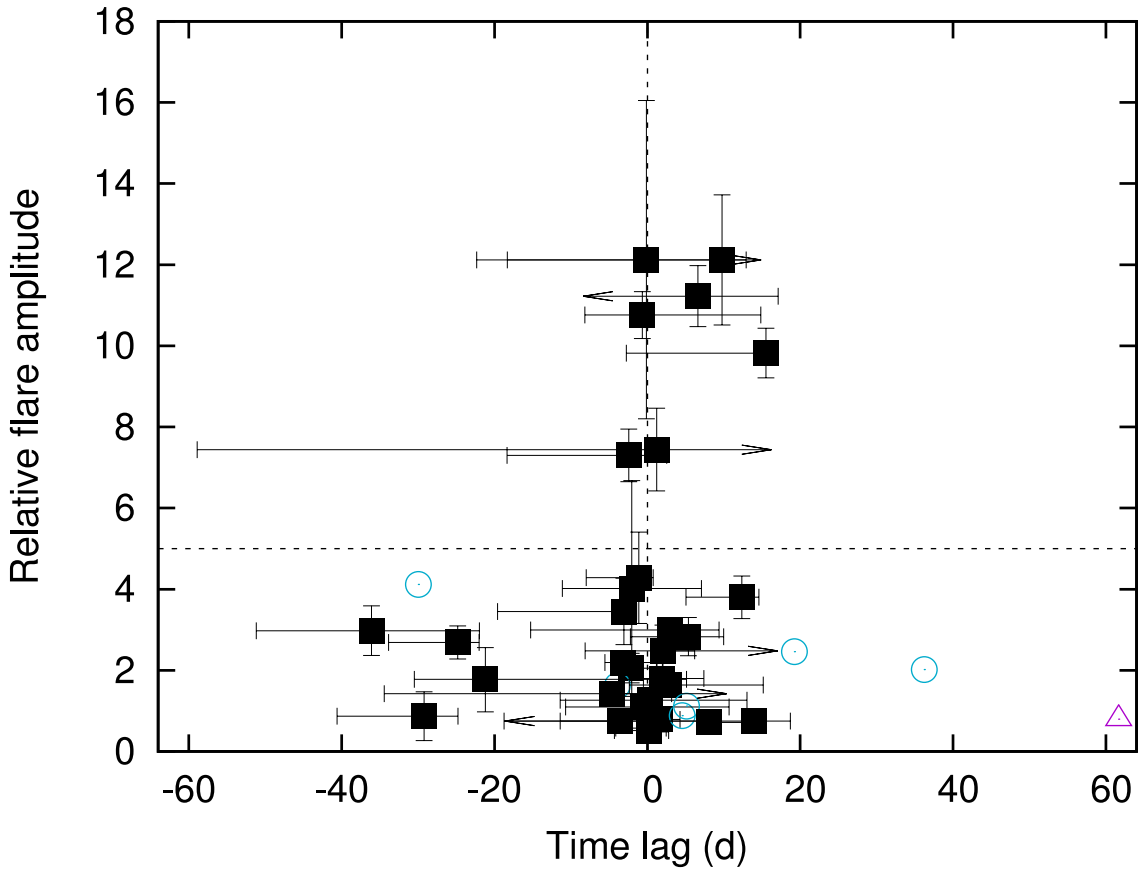
No difference in polarization properties between TeV-detected and TeV-non-detected, Fermi 71- 585 GeV non-detected blazars

Both samples include rotators

Likely good news for future TeV surveys:
All HSPs may be detectable (redshift-permitting)
if they flare enough

Hovatta et al. 2016

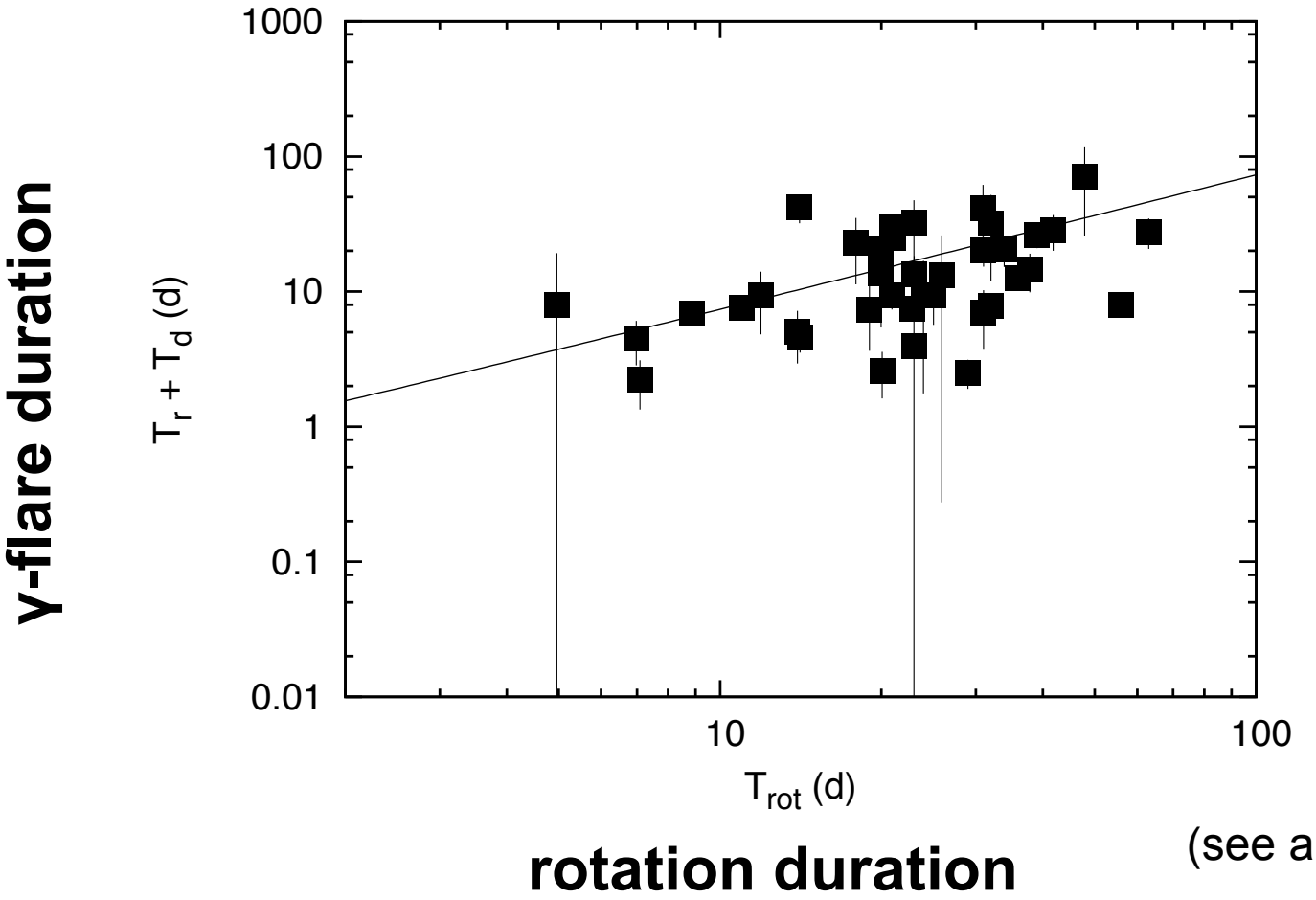
Bonus: 3 seasons update on γ-flaring/rotation connection



Blinov talk!

all lags consistent with zero

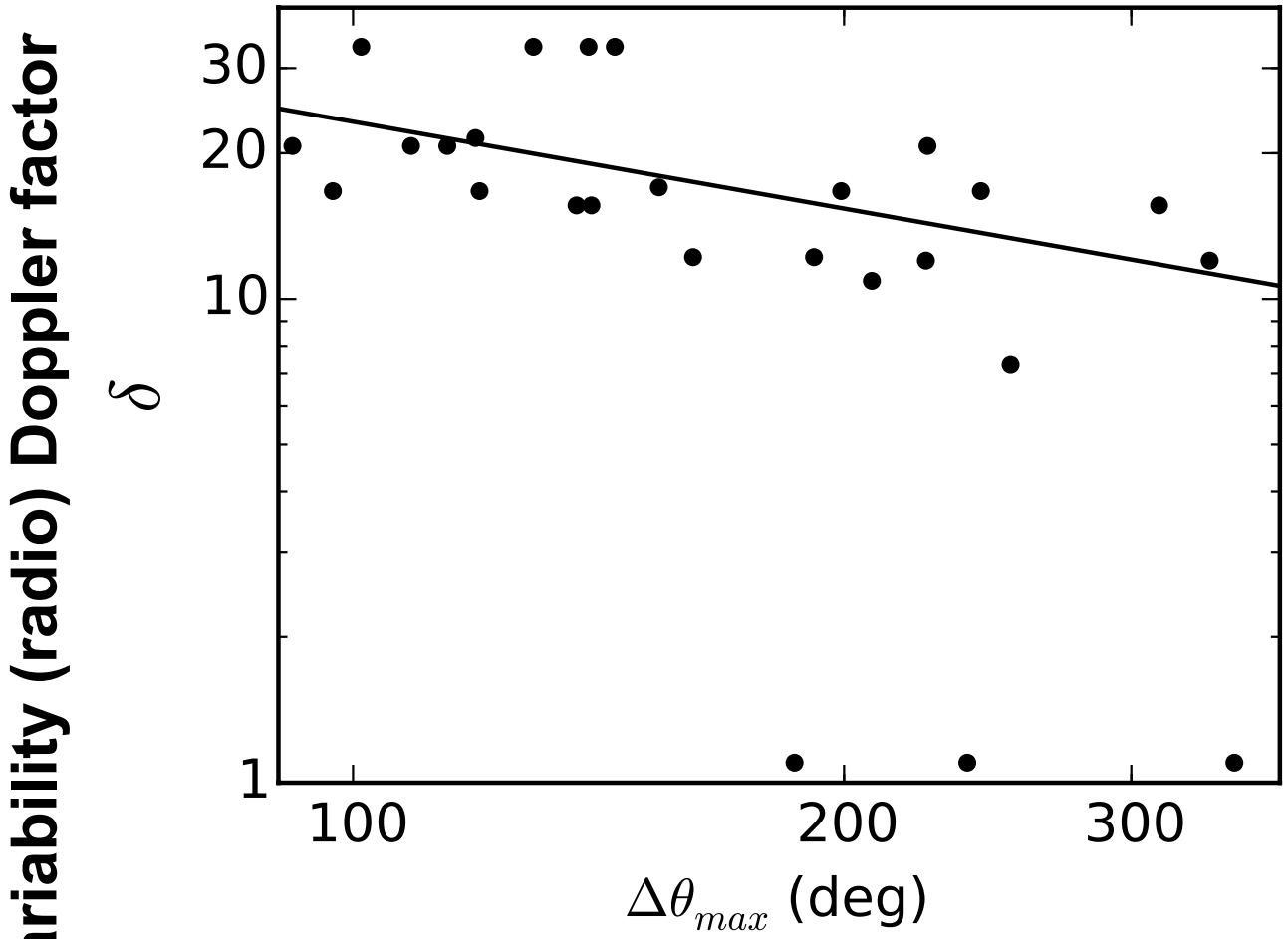
Bonus: γ-flaring/rotations: timescales correlation



(see also Liodakis talk)

Blinov talk!

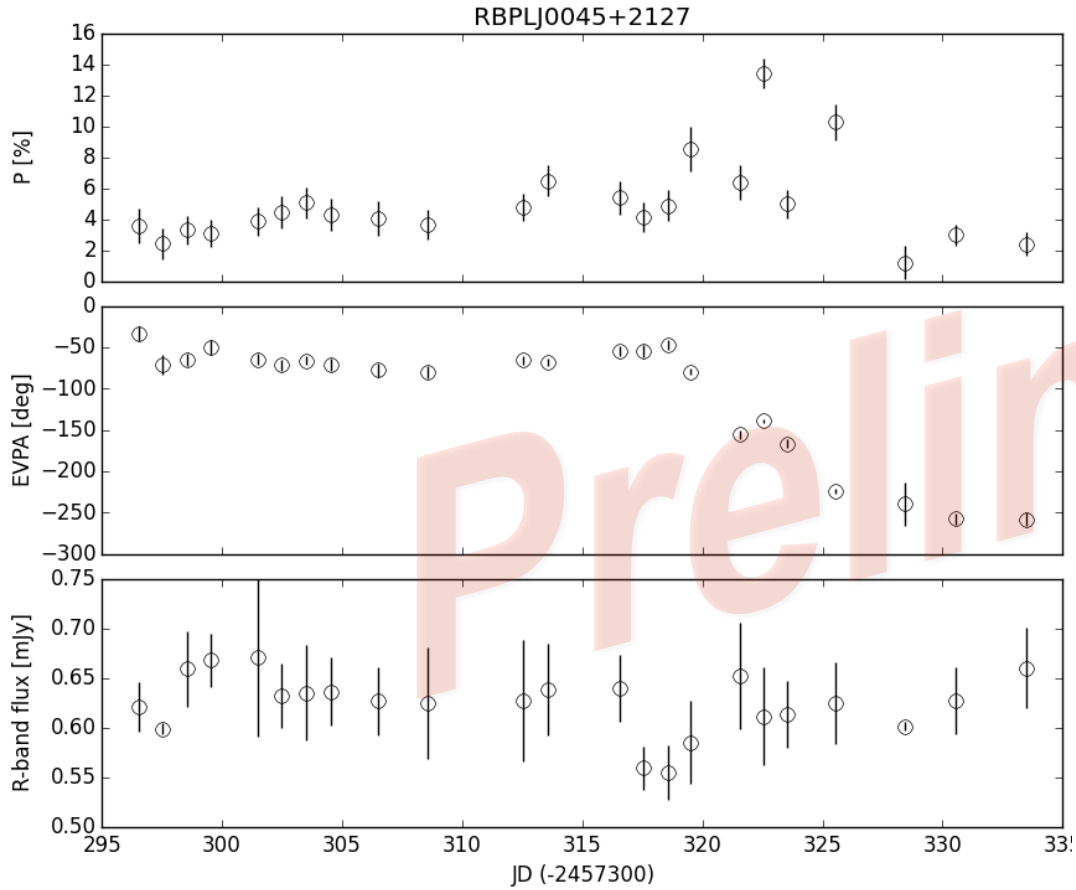
Bonus: Correlation of rotation amplitude with jet parameters

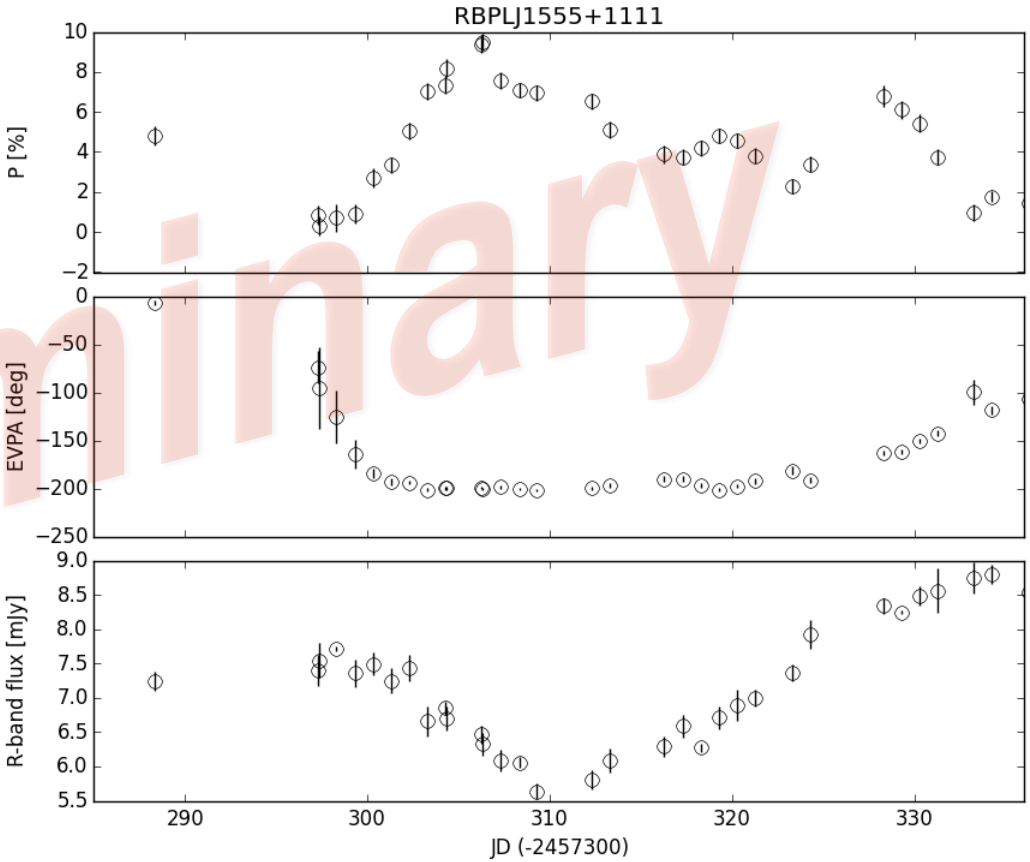


rotation amplitude (total EVPA change)

Blinov talk!

Bonus: High-cadence results





Preliminary

What comes next

- ✓ Blinov et al.
  3-seasons paper on γ-activity / rotations connection
  -- Blinov talk!

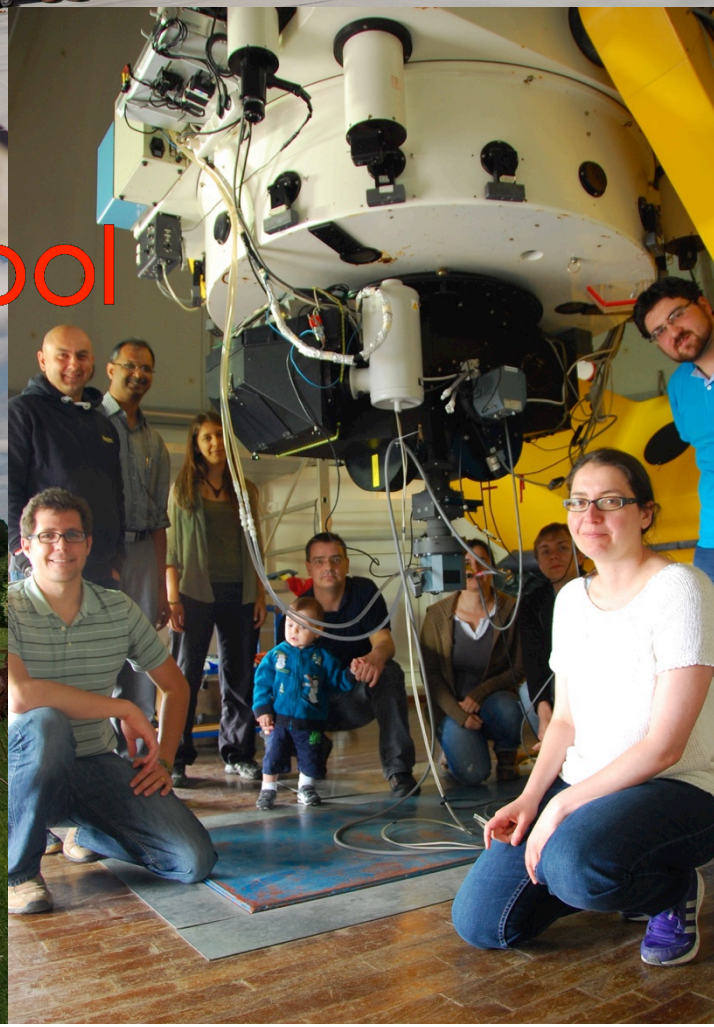
- ✓ Analysis of individual events
  -- Liodakis talk!

- ✓ Kiehlmann et al. updated analysis on possible stochastic origin of rotations
  -- Kiehlmann talk!

- ✓ analysis of 4^{th} season high-cadence results

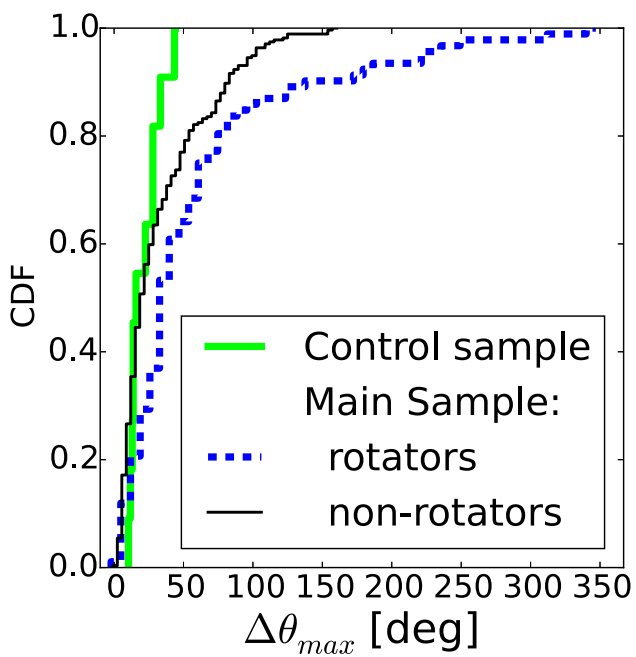
- ✓ **first 2 seasons full data release**

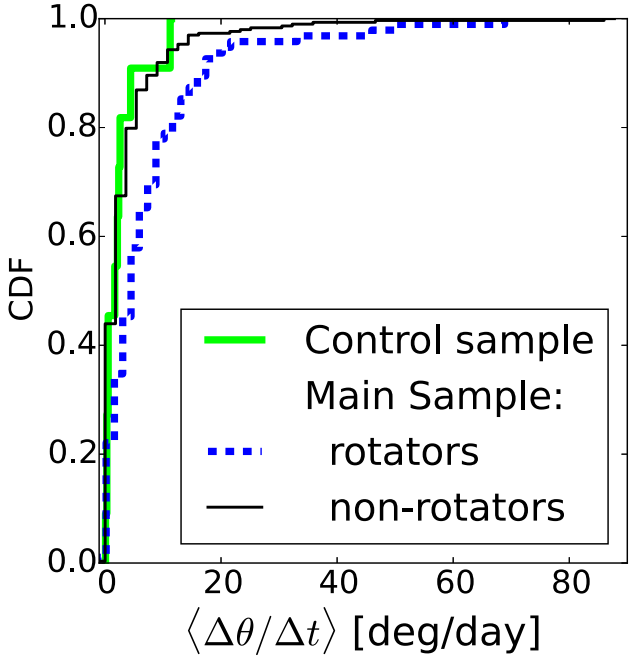
robopol



V. Pavlidou

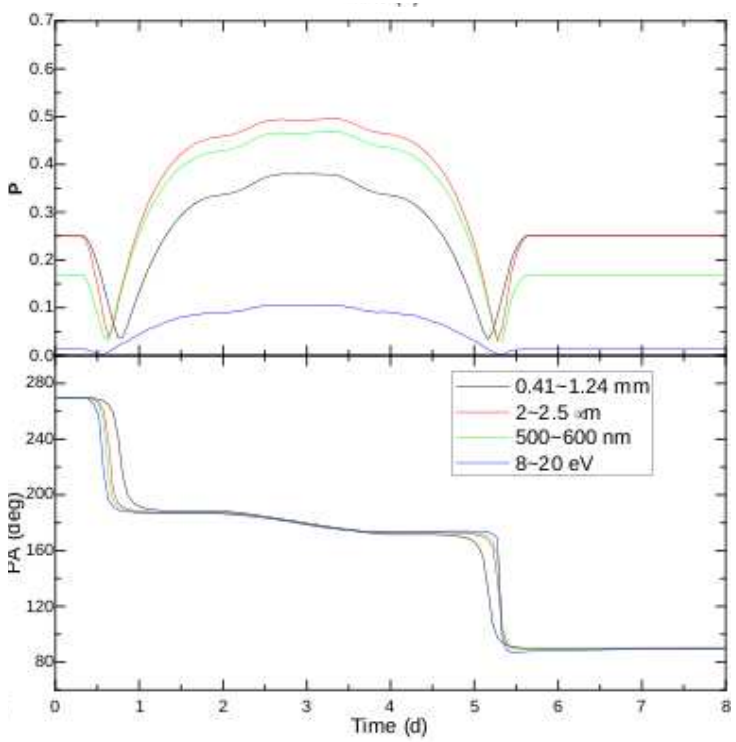
Rotators vs non-rotators





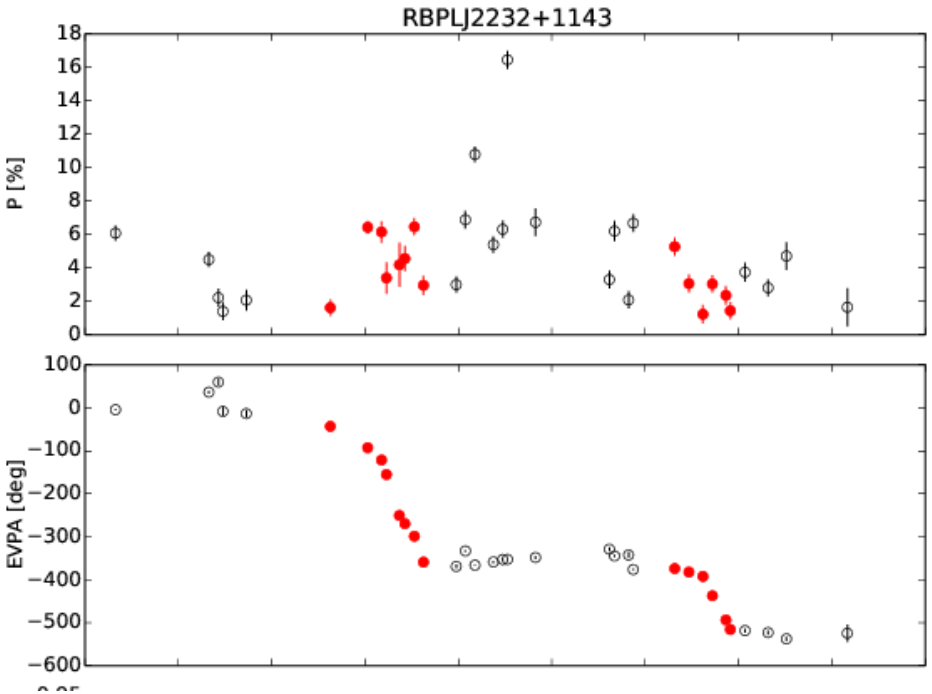
Rotators vs. non-rotators:

- $\Delta\theta/\Delta t$ K-S p-value = 1.4×10^{-6}
- $\Delta\theta$ K-S p-value = 2×10^{-3}



Zhang, Chen & Boettcher 2014

CTA 102



Blinov et al. 2015