RoboPol:
Rotations of Optical Polarization Plane in Blazars

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

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NCU/Torun:

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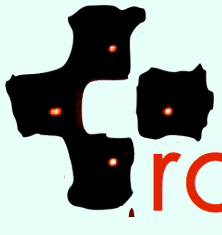
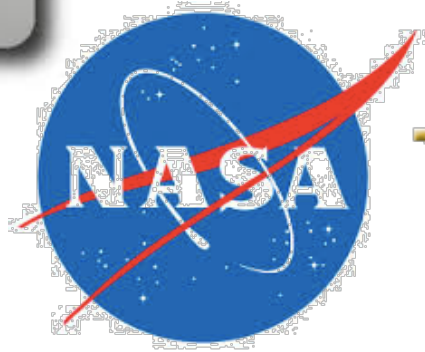
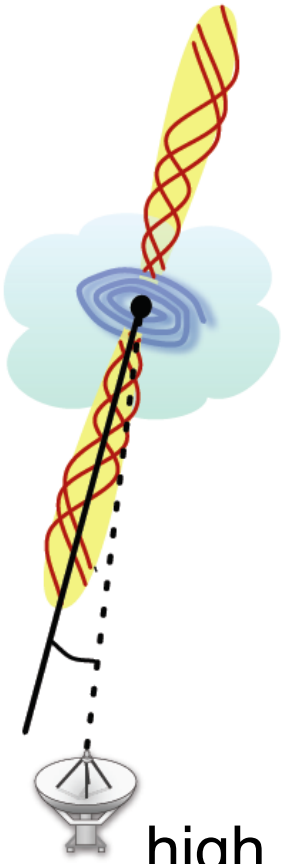
A nod to our sponsors

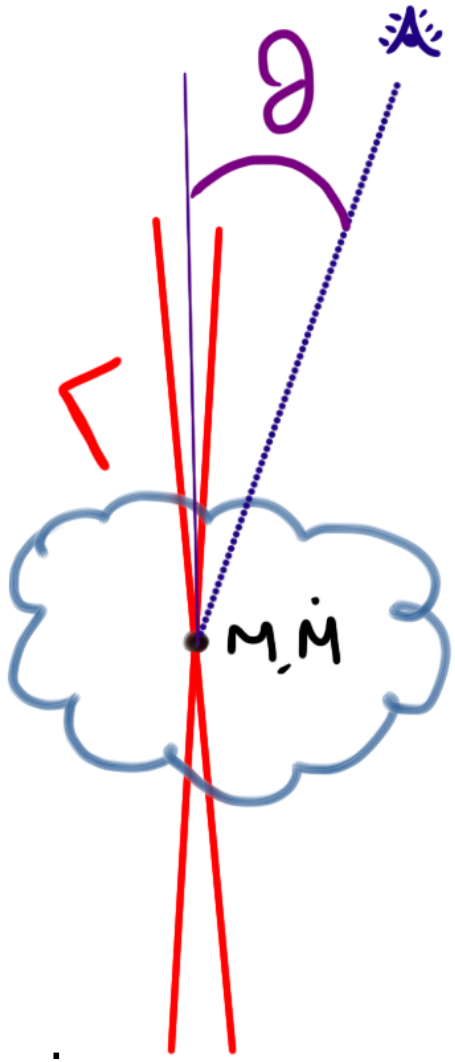


Co- financed by Greece and the European Union



Blazars

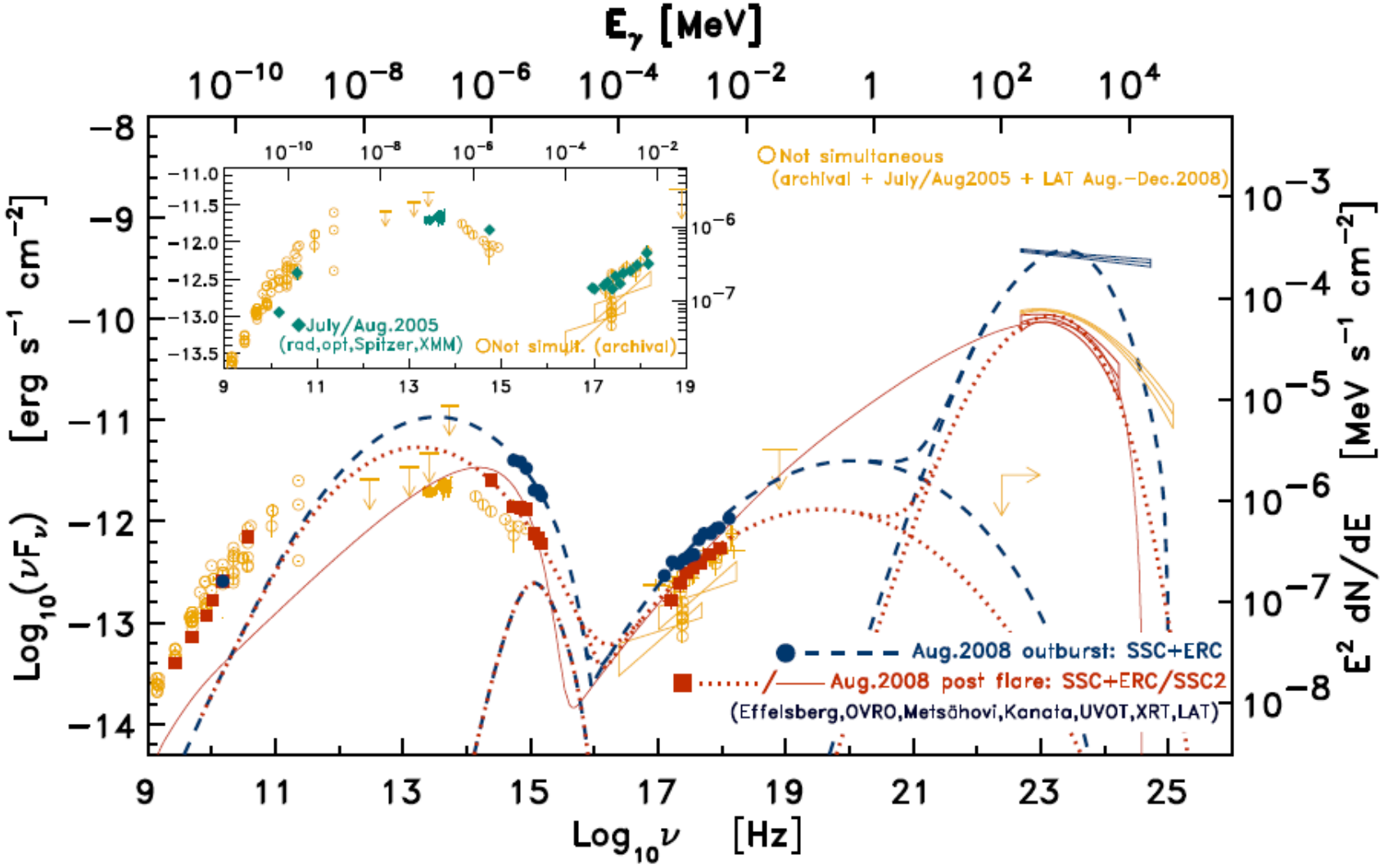




beamed & boosted

- fast variability
- superluminal motions
- high apparent luminosity
- high-energy emission

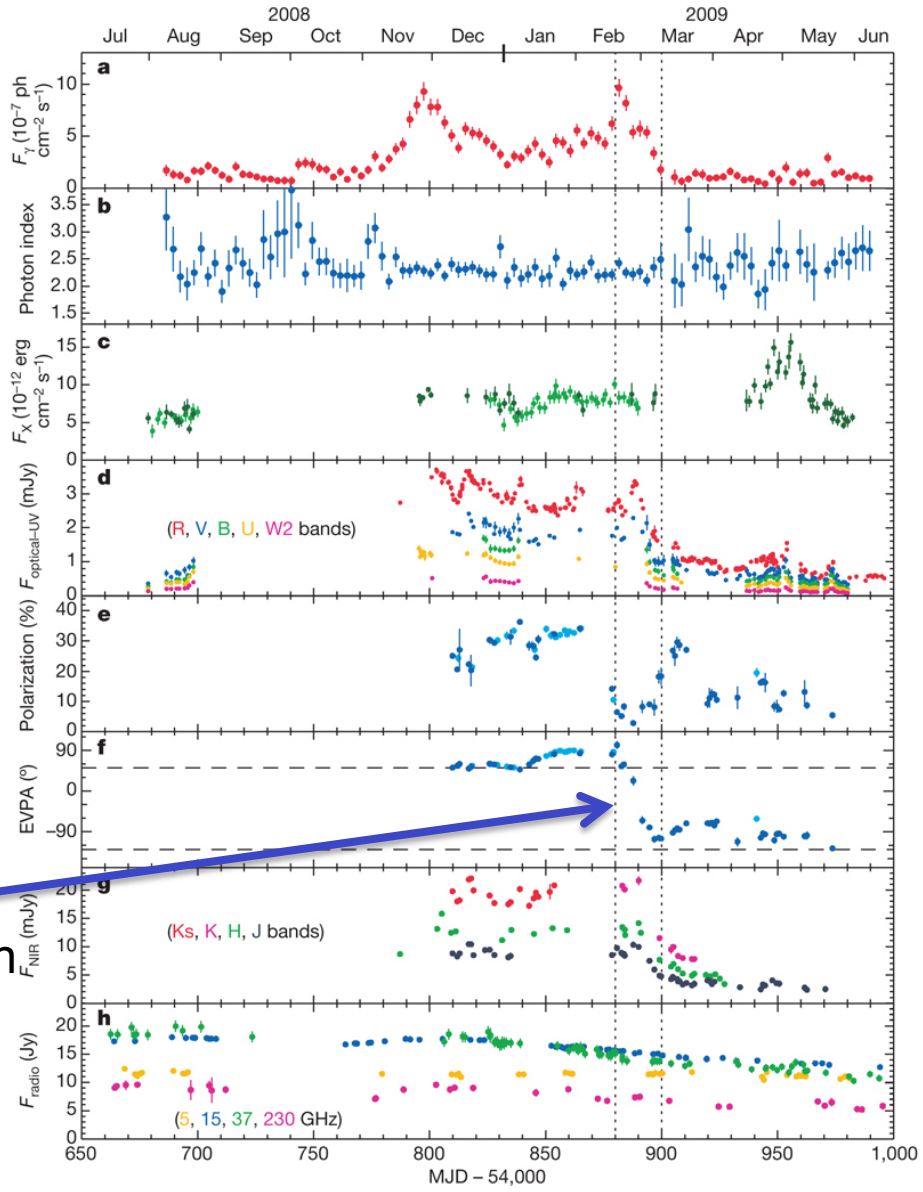
Blazar Spectra



PKS 1502+106, Abdo et al. 2010

Blazar Variability

3C279

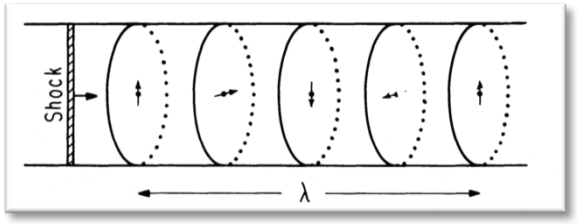


Polarization rotation

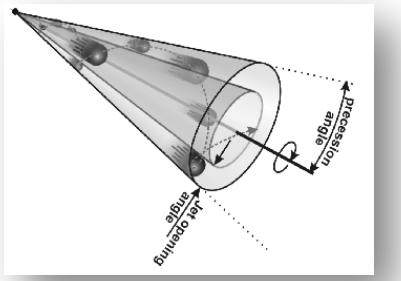
A. Abdo et al. (2010)

robopol Many interpretations

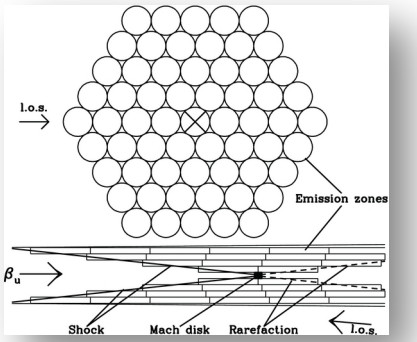
- A wealth of theoretical ideas:



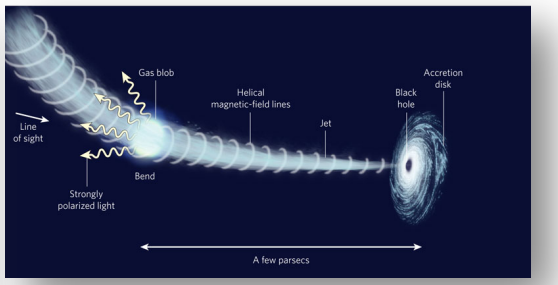
Propagation of shock along jet B-field
Konigl et al.
cartoon from Konigl & Choudhuri 1985!



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

robopol The RoboPol Program

- ✓ Observe large, well-defined sample of blazars in optical linear polarization with high cadence

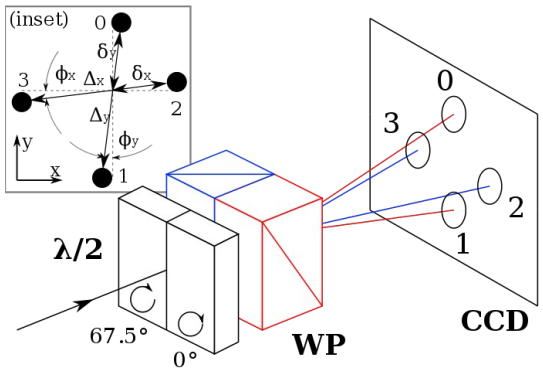
- ✓ Identify rotations with uniform criteria

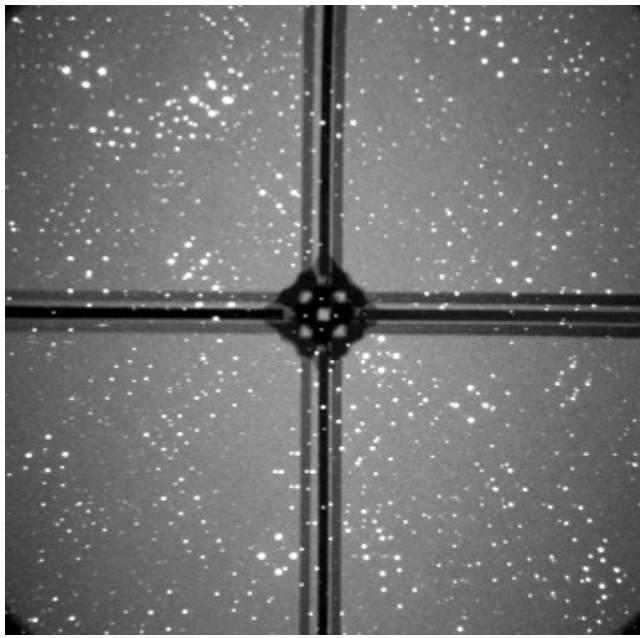
- ✓ Systematically answer questions regarding optopolarimetric properties of blazars:

  -- Are γ-ray—loud and γ-ray quiet blazars different in optical polarization?
  -- Do all blazars exhibit polarization rotations?
  -- Are polarization rotations coherent events or the result of random walks in polarization angle?
  -- Are polarization rotations related to γ-ray flares?

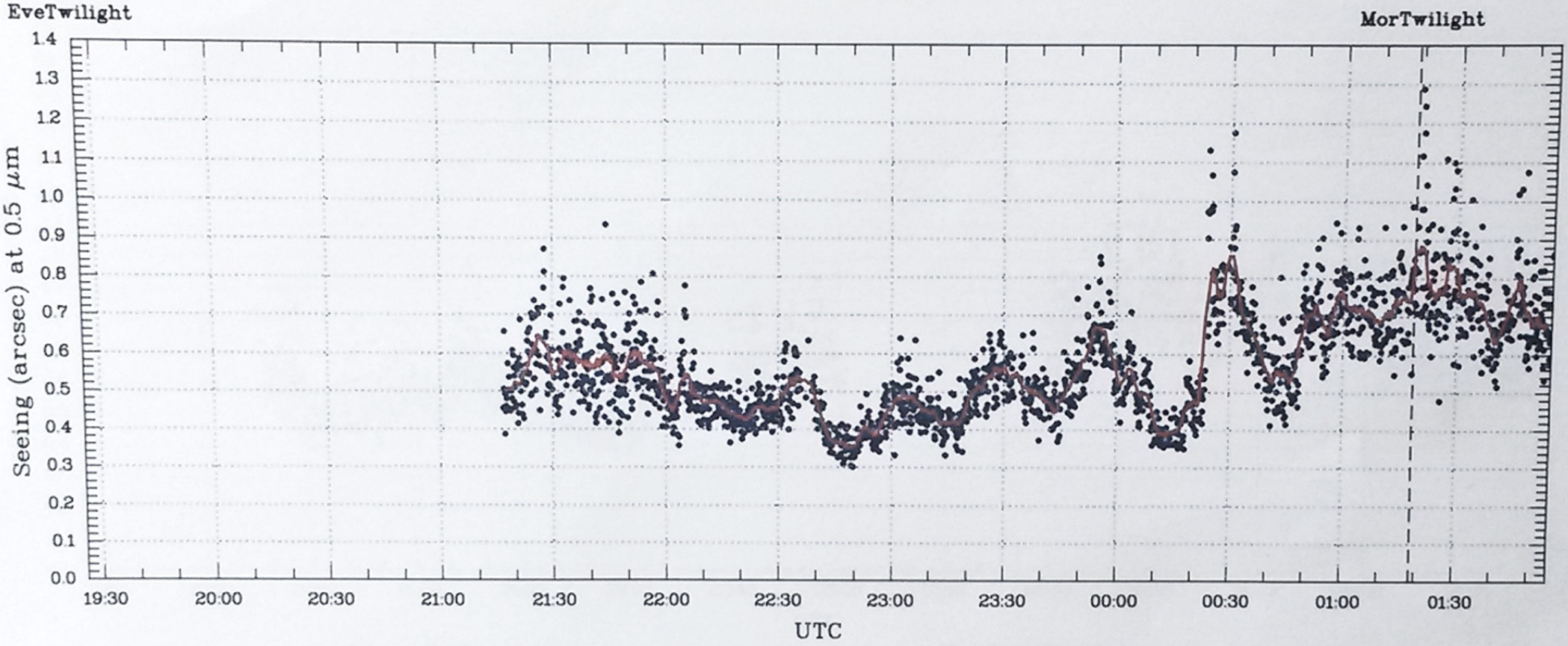
Program Features

- ✓ **RoboPol polarimeter:** unique design, no moving parts, low systematics, high sensitivity
- ✓ **Telescope time:** 4 nighs/week for 3 years at Skinakas 1.3 m telescope (1750m, median seeing 0.53 arcsec)
- ✓ **Observing strategy:** adaptive, self-triggering.

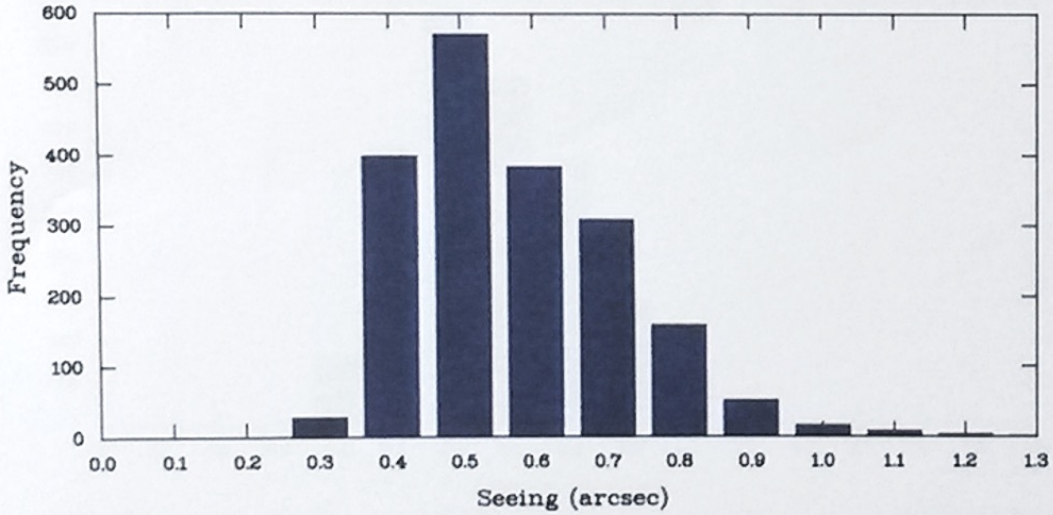




Skinakas Observatory Seeing Measurements
For the night of: Sun, 21 Jun 2015 ---> Mon, 22 Jun 2015



Seeing Histogram



Seeing Statistics

Number of measurements: 1923

Single measurement mean duration: 7.99 ± 0.12 seconds

Average Seeing: 0.57 ± 0.15 arcseconds

Minimum: 0.30 Maximum: 1.29

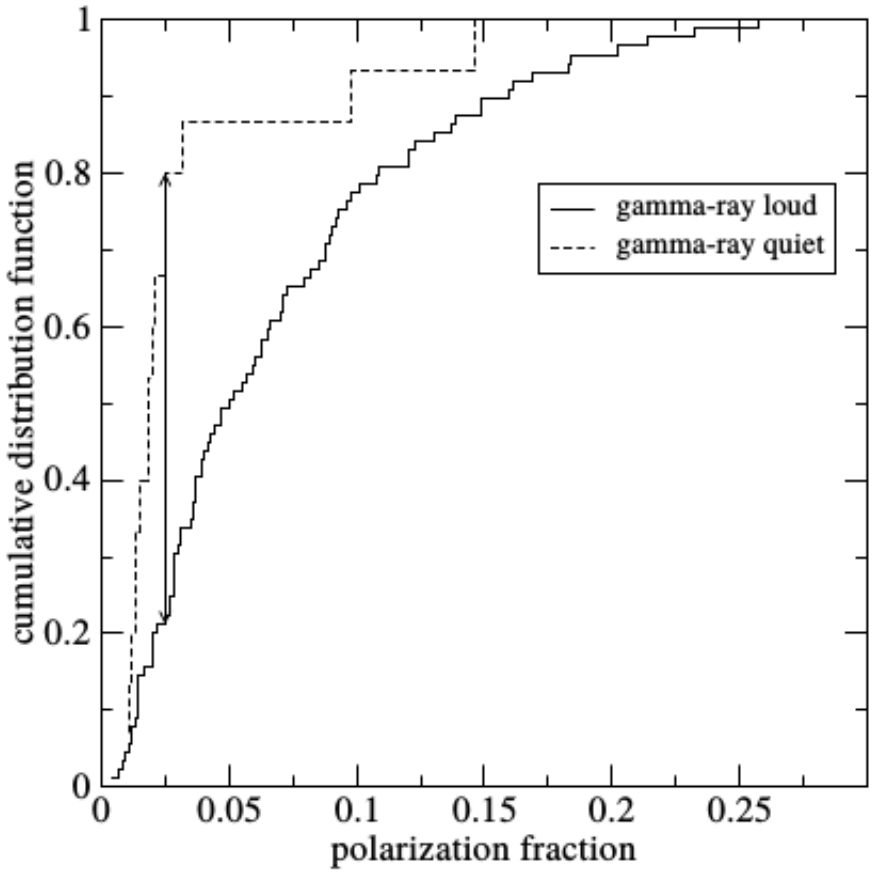
Median: 0.53 Lower Quartile: 0.45 Upper Quartile: 0.66

Mode: 0.46

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

γ-loud vs γ-quiet



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

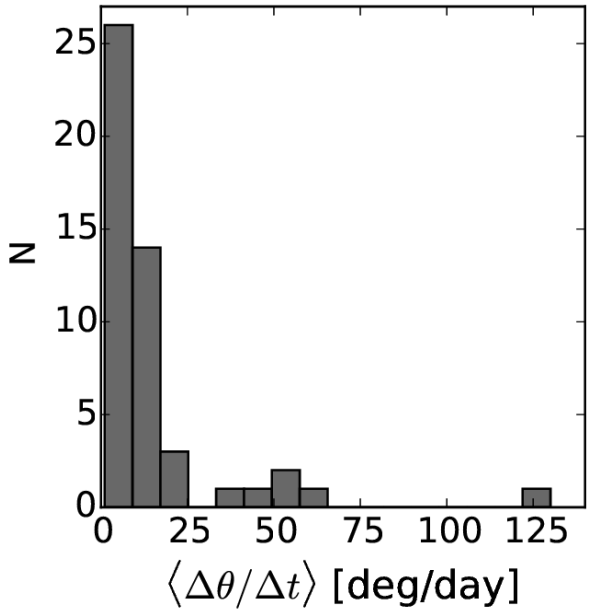
Mean p = 6.4% γ-ray–loud
Mean p = 3.2% γ-ray–quiet
different at ~3.5 σ (K-S test)

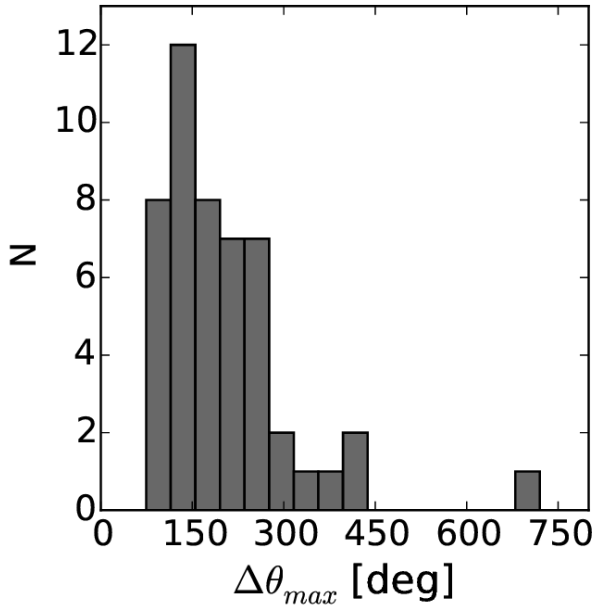
Pavlidou et al. 2014, MNRAS 442, 1693

No rotations seen in γ-ray quiet blazars

Detected Rotations

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





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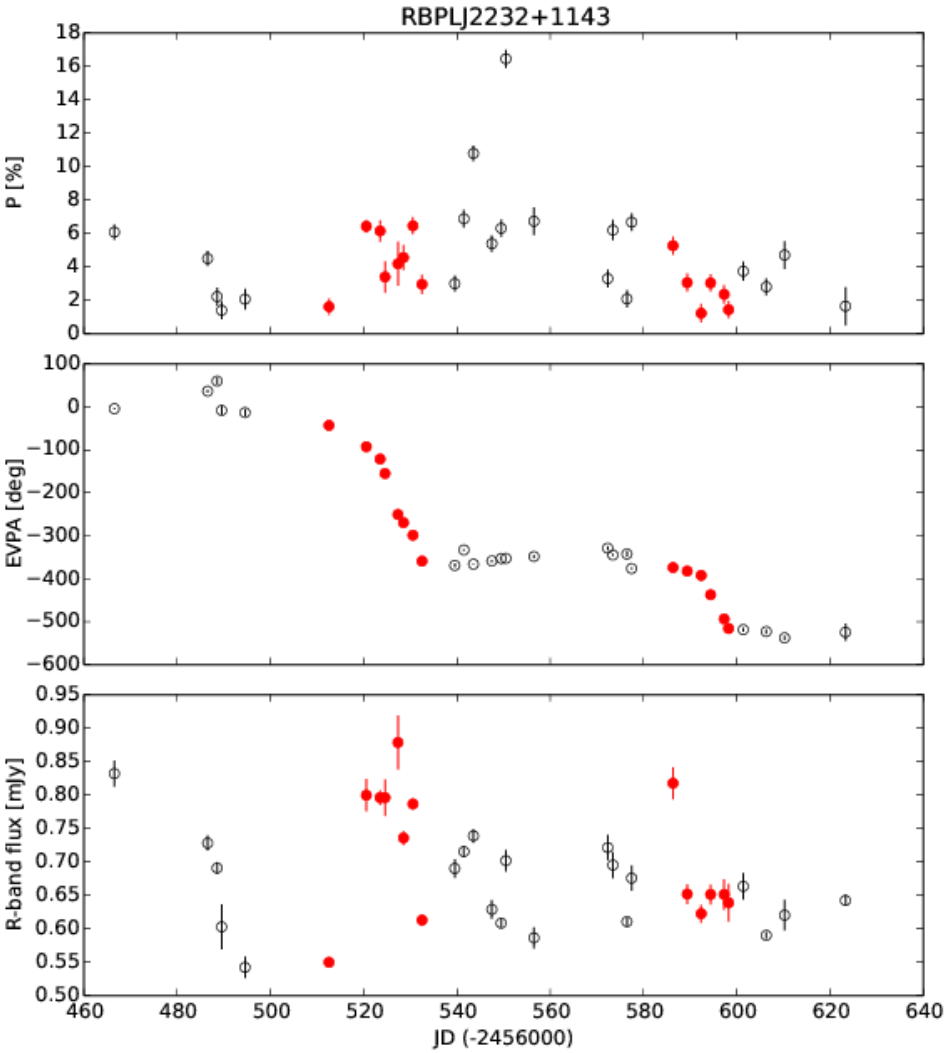

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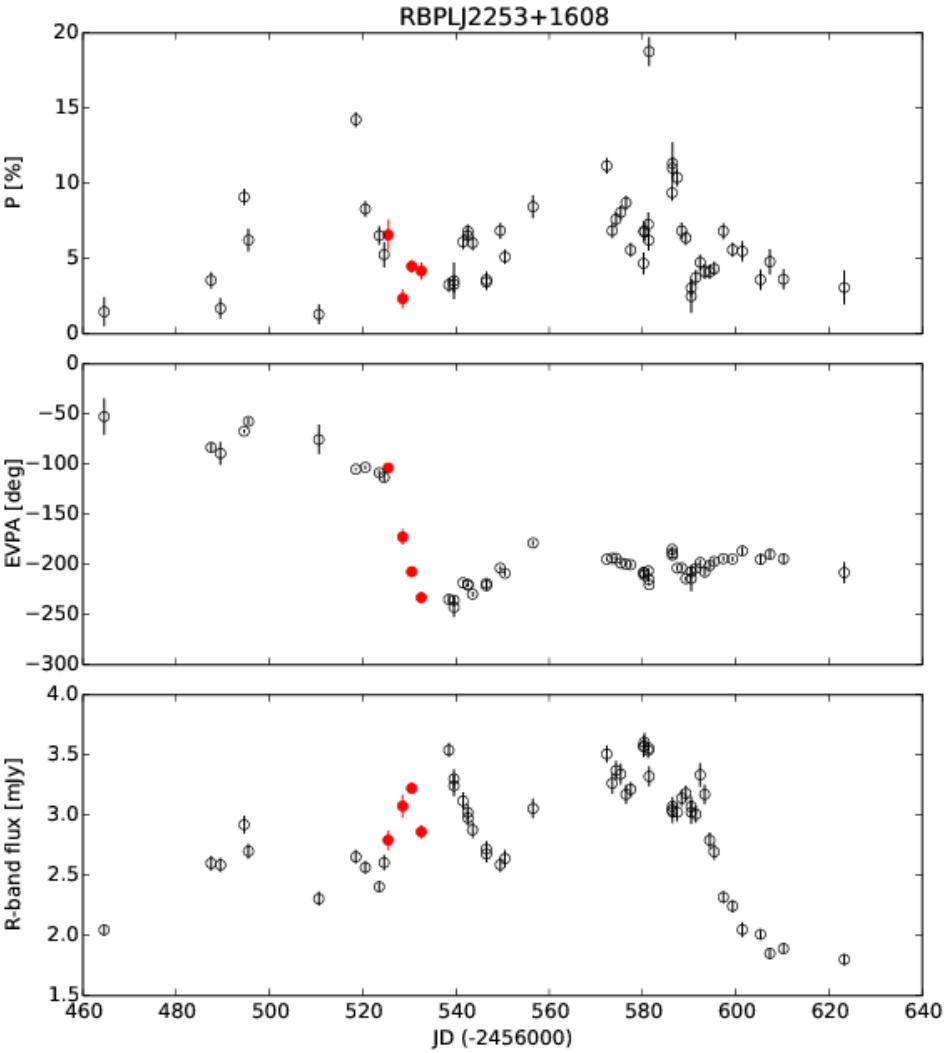
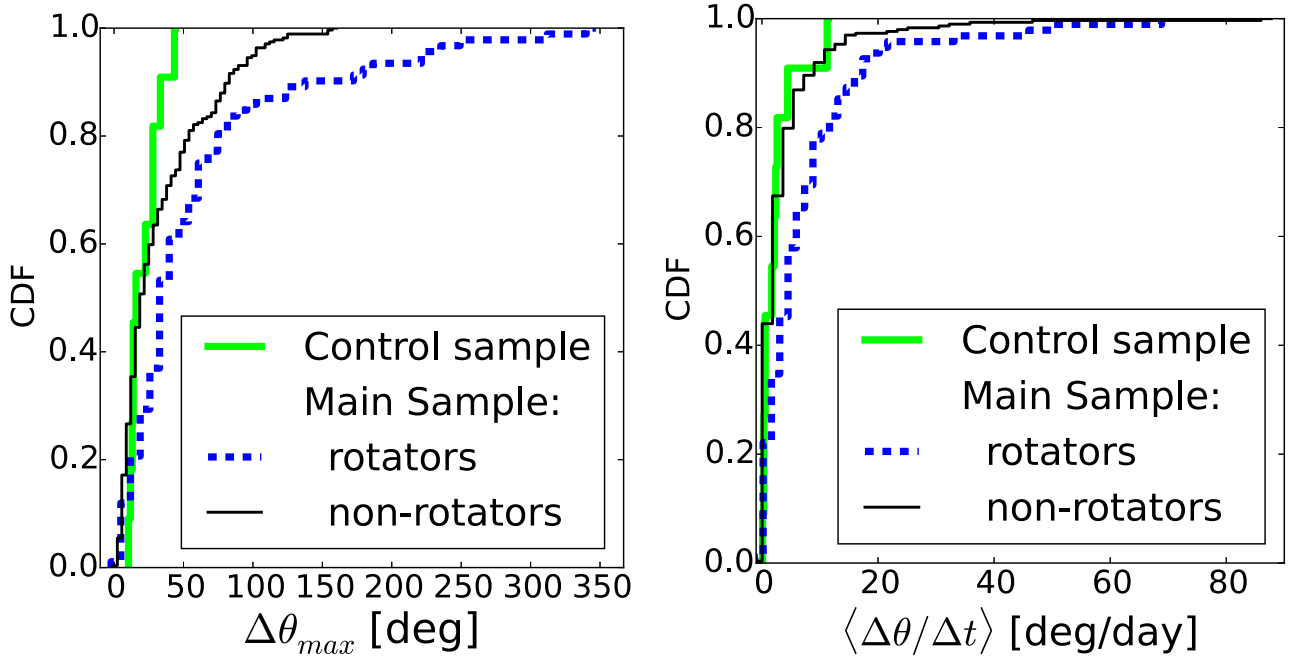


robopol Rotators / Non-rotators



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}

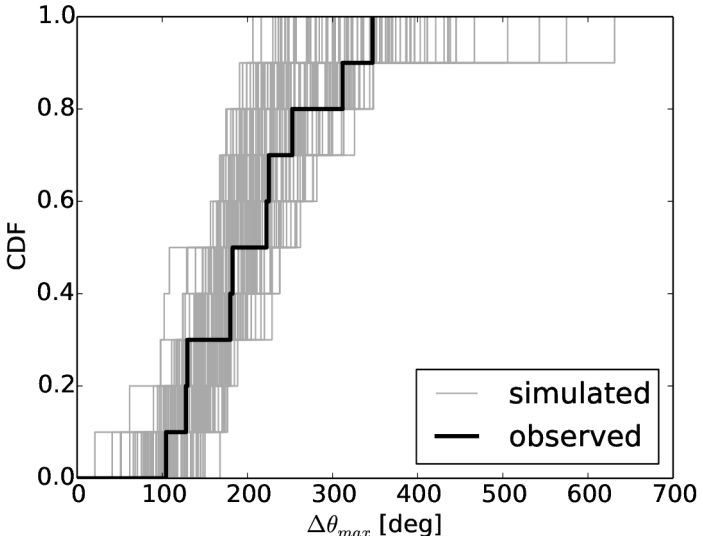
robopol Random walk in EVPA?

MC simulations following
Kiehlmann et al. 2013

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

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

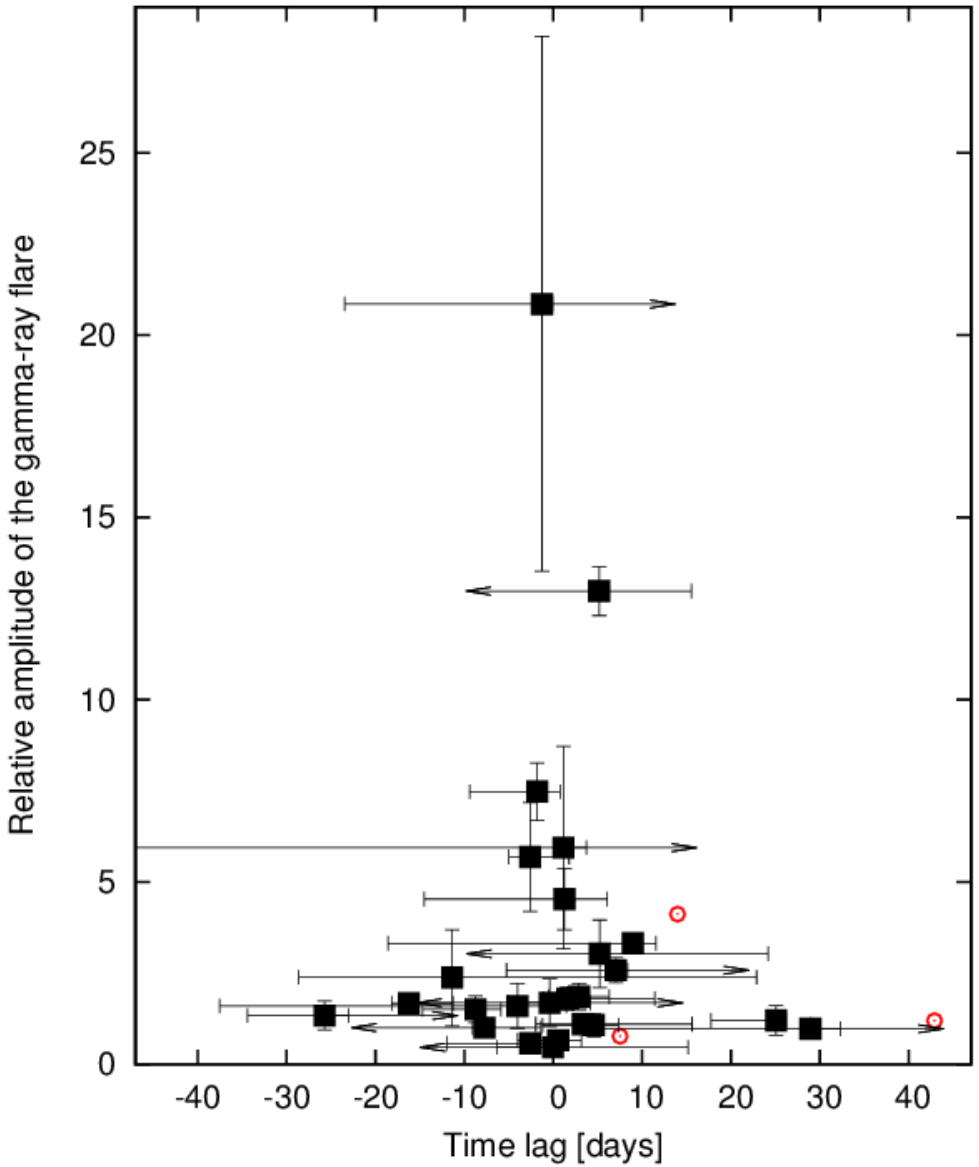
Blazar	T_{occ} [days]	P(RW)
RBPLJ0136+4751	505	0.11
RBPLJ0259+0747	151	0.48
RBPLJ0721+7120	325	0.28
RBPLJ0854+2006	142	0.36
RBPLJ1048+7143	180	0.79
RBPLJ1555+1111	128	1.00
RBPLJ1558+5625	266	0.51
RBPLJ1806+6949	965	0.15
RBPLJ1806+6949	259	0.55
RBPLJ1927+6117	137	0.98
RBPLJ2202+4216	633	0.21
RBPLJ2232+1143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

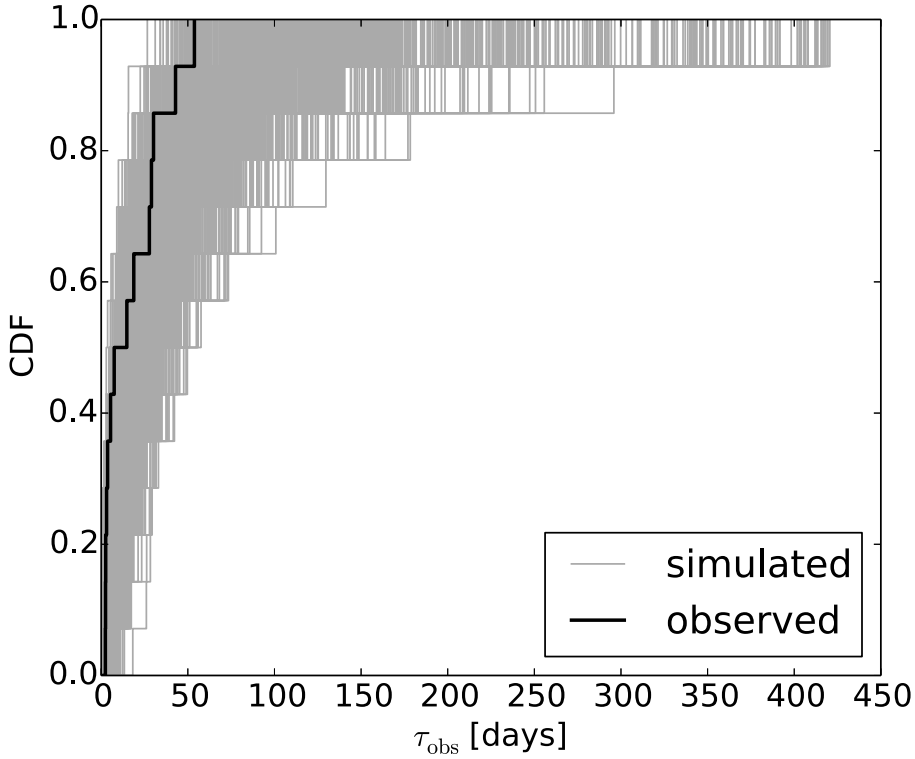


Similar simulations:
Jones et al. 1985, ApJ 290, 627
D'Arcangelo et al. 2007, ApJL 659, L107

All together are RW with
P = 1.5%

γ-ray – related?





$P=2\times10^{-4}$

Rotations Summary

- ✓ In two seasons, RoboPol has > TRIPLED the number of observed polarization rotations in blazars

- ✓ With one season rotations only:

Are γ-ray—loud and γ-ray quiet blazars different in optical polarization?

YES
γ-ray—loud are more polarized
all rotators are γ-ray—loud

Do all blazars exhibit polarization rotations? NO

Are polarization rotations coherent events? SOME

Are polarization rotations related to γ-ray flares? **YES**

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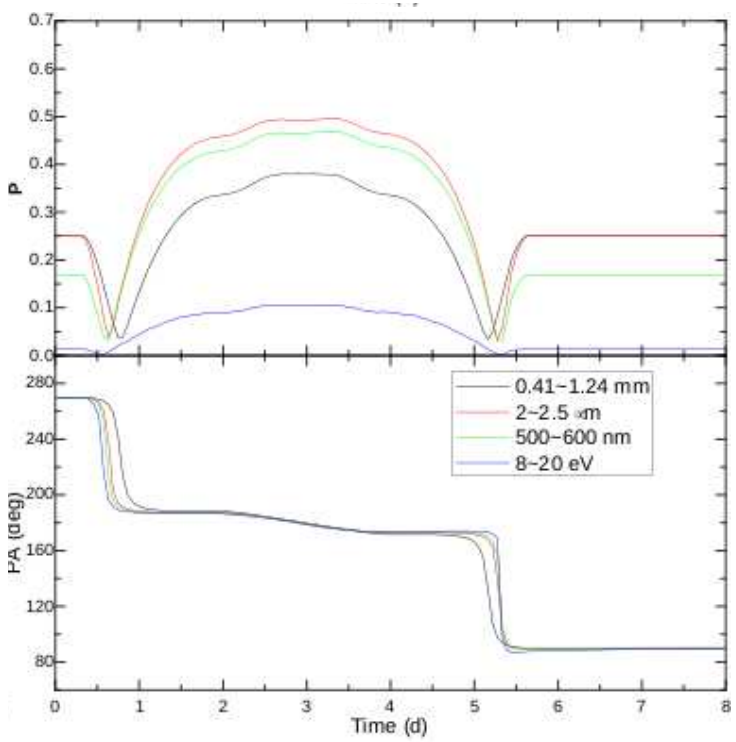
Outlook

- ✓ DATA: 3rd year of monitoring under way, expect > 50 rotations total
- ✓ ANALYSIS: 2nd year rotations analysis under way, confirm / strengthen 1st season results, additional analyses
- ✓ INTERPRETATION: full dataset public soon for theorists to tackle



Zhang, Chen & Boettcher 2014

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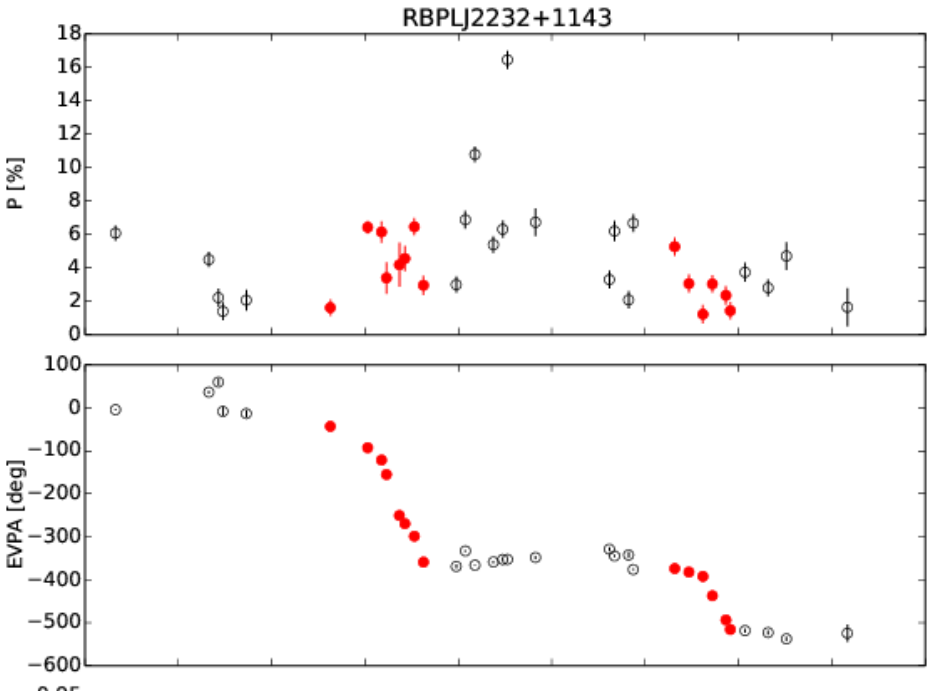

Blinov et al. 2015

Other science

A lot of other exciting science underway with RoboPol:

Mapping B-field in ISM cloud envelopes (Tassis talk, Psaradaki poster)

GRB followup (King et al. 2014)

Highest-polarization ever Be/X-ray binary (Reig et al. 2014)

Inflationary B-modes: foreground removal! (talk to Tassis)

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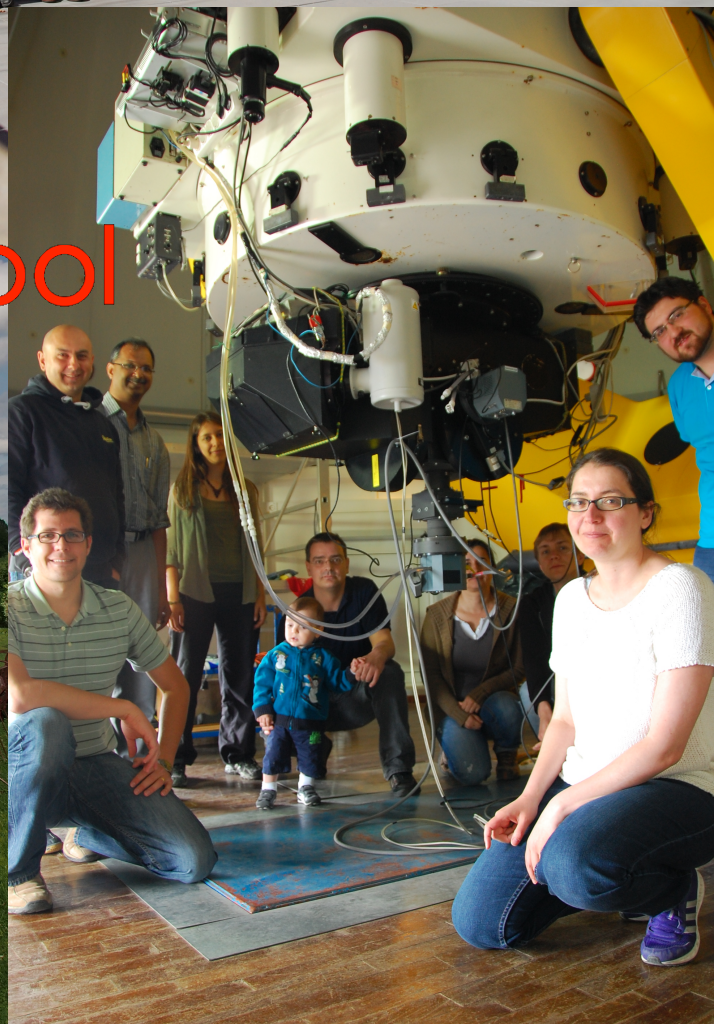

V. Pavlidou