Observational view of magnetic fields in AGN jets

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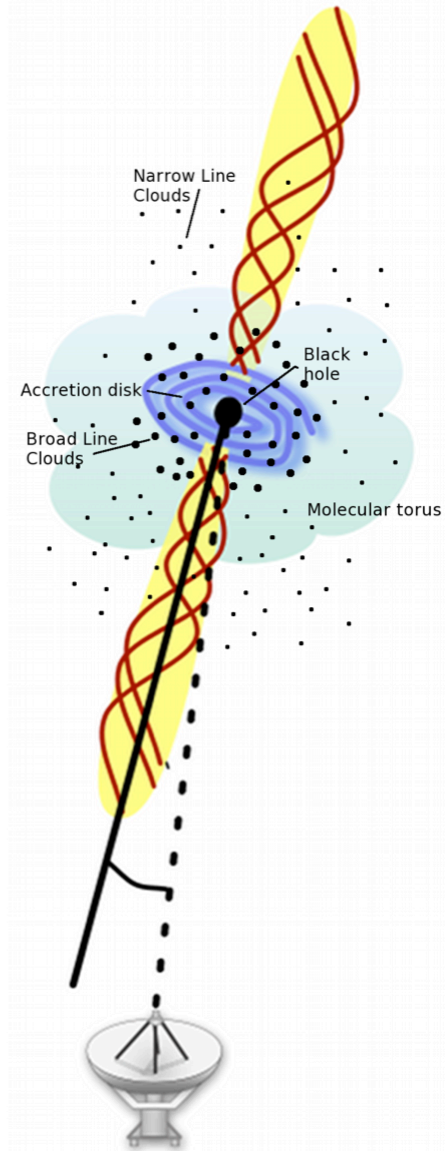
Outline

- Motivation
- How to observe magnetic fields
- Blazar emission modeling through:
  - Radio polarization
  - Optical Polarization
  - Observations of 3D magnetic field structure
- Future prospectives



Credit: V. Pavlidou

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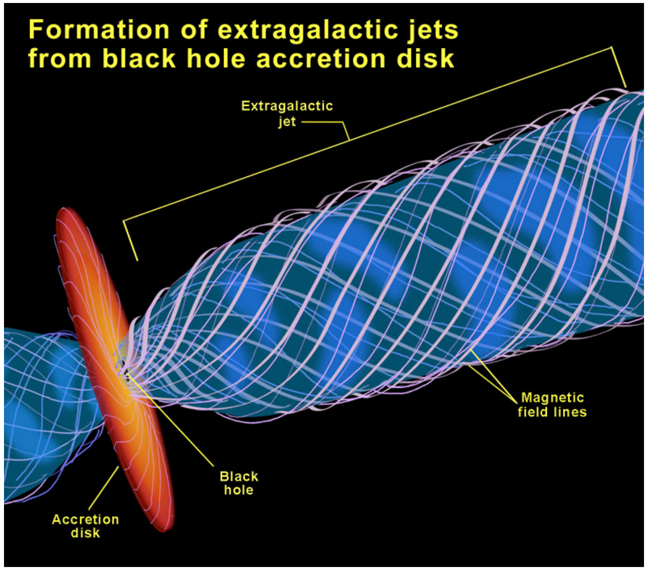
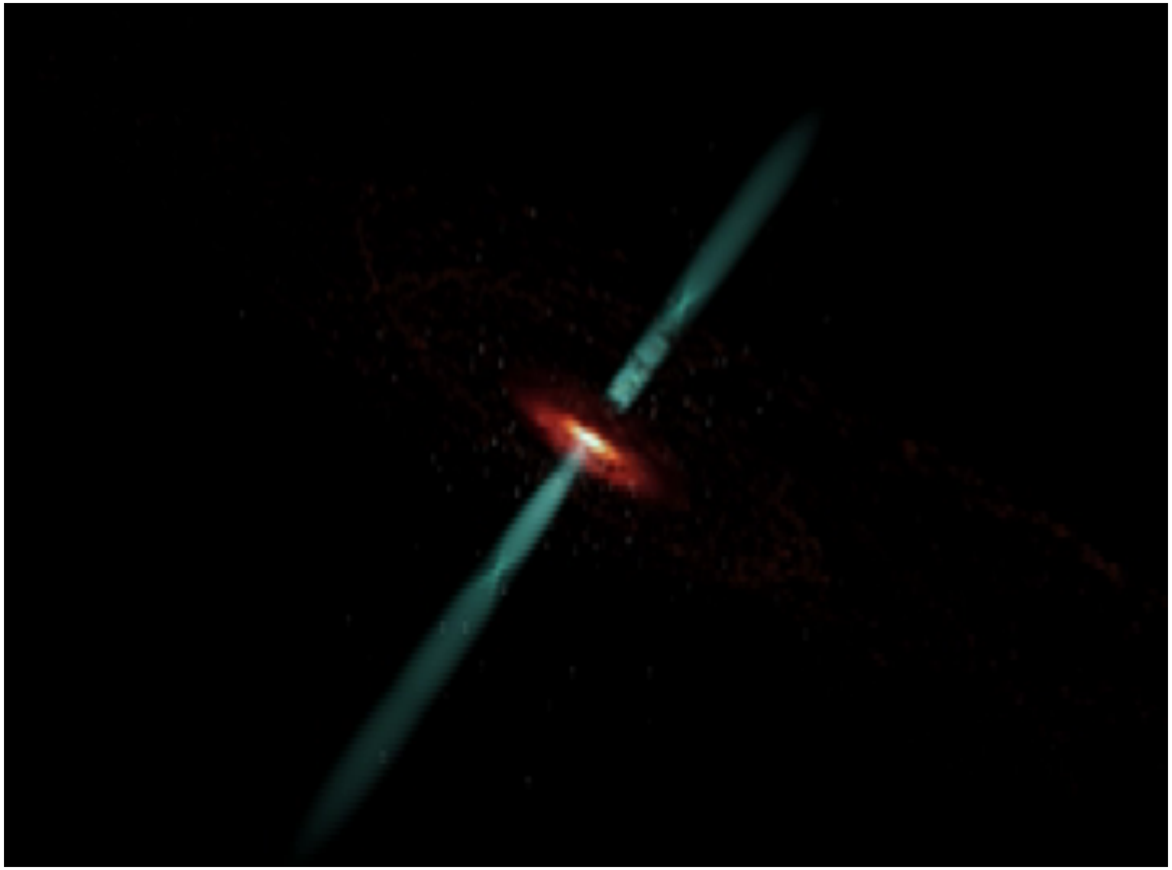
Role of magnetic fields in jet emission



Credit: NASA and Ann Field (Space Telescope Science Institute)



Movie credit: Cosmovision

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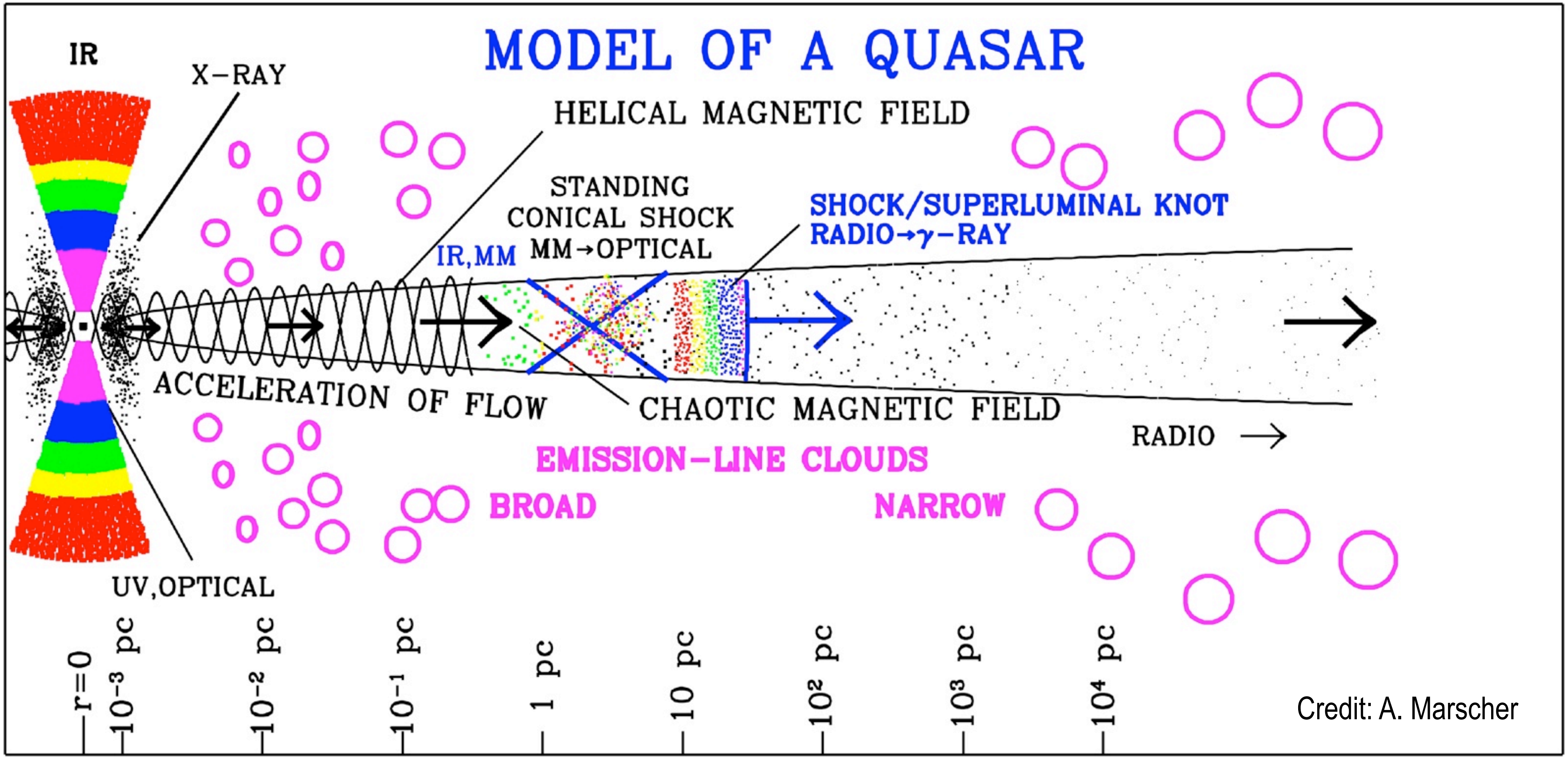
Schematic model of a blazar



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Some open questions

- Are the jets magnetized?
  - What is the emission mechanism?
    - Shocks vs. reconnection?
- What is the magnetic field structure near the base of the jet
  - Helical as in simulations? How to observe it?
- Is the magnetic field order the same near the base of the jet as in the observable pc-scales?
  - Does a standing shock destroy the ordered field component?
- What is the connection to high-energy emission?
- Are there differences among different blazar types?

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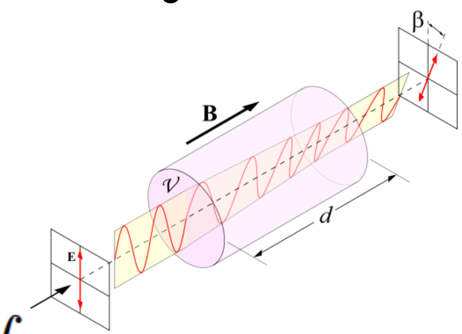
Polarization as a probe of magnetic fields

- Synchrotron emission produced by relativistic electrons spiraling in a magnetic field
- Intrinsically highly polarized (70%) in a uniform magnetic field
- Can be expressed with 4 Stokes parameters, I, Q, U and V
  - In an optically thin source, the EVPA is perpendicular to the magnetic field
- 3D polarization structure through Faraday rotation



Linear polarization fraction

$$P = (Q^2 + U^2)^{1/2}$$

$$m_c = P/I,$$

Faraday Rotation

$$\chi_{\rm obs} = \chi_0 + 0.81 \int n_e \mathbf{B} \cdot \mathrm{d}\mathbf{l} = \chi_0 + \mathrm{RM}\lambda^2$$

Electric Vector position angle (EVPA)

$$\chi = (1/2) \arctan(U/Q)$$

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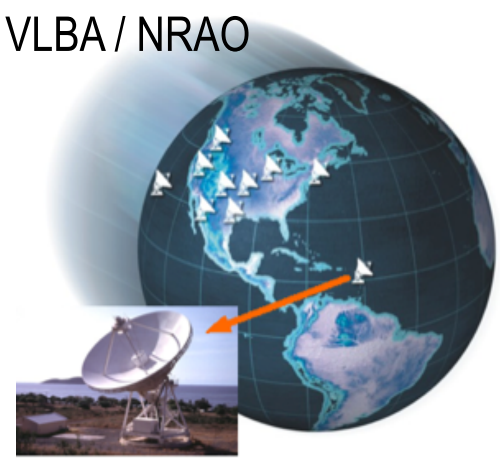
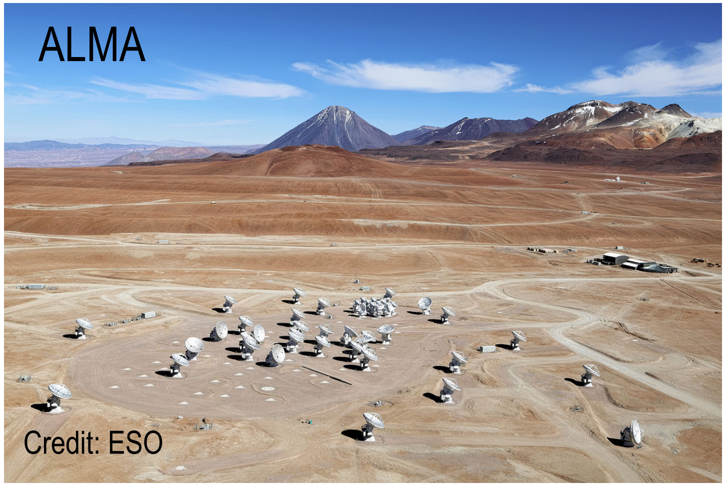
Some blazar emission models

1. Turbulence (Jones et al. 1985, Marscher, 2014)
2. Shock in a jet (Hughes, Aller & Aller 1985, 2015)
3. Emission in a helical field (Marscher et al. 2008,2010, Zhang et al. 2014, 2015)
4. Magnetic reconnection (e.g., Giannios et al. 2009)





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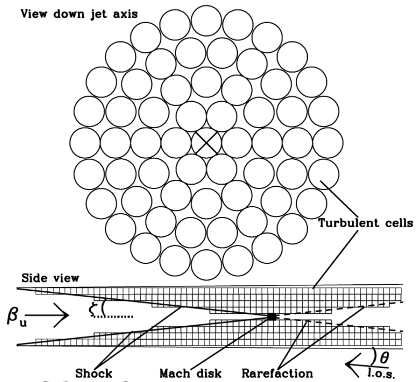
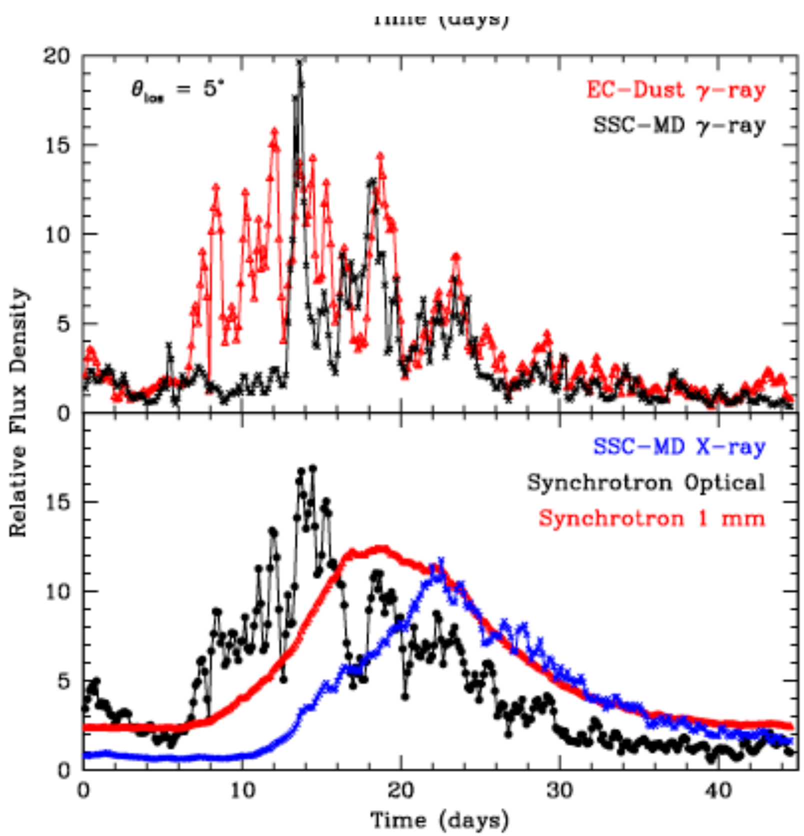
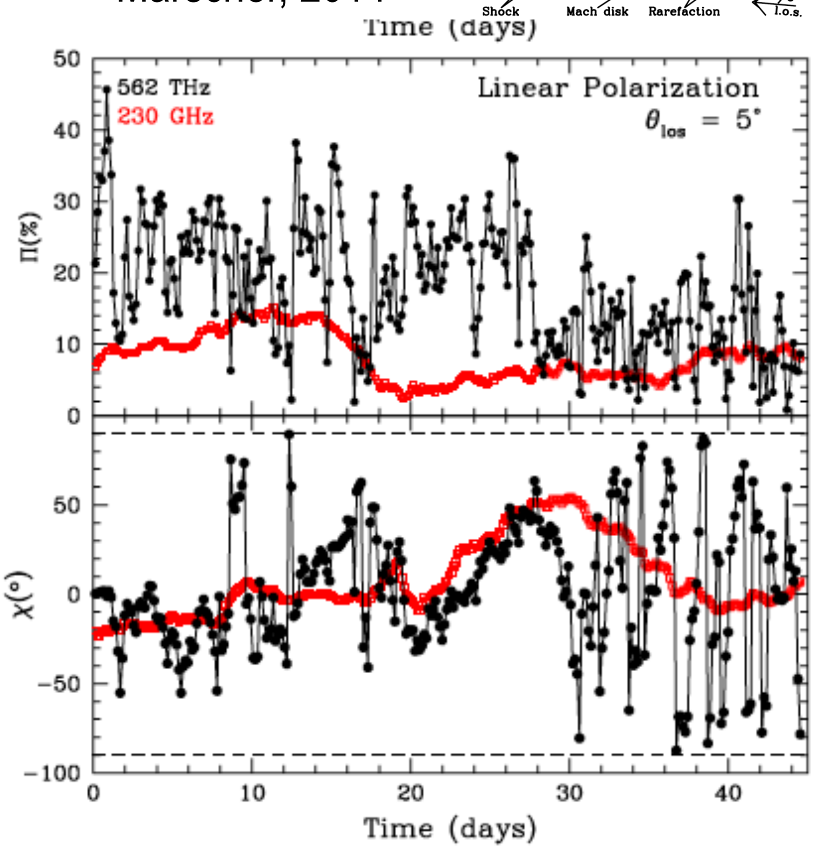
1) Turbulent cells in a jet

- Requires statistical comparisons = long-term monitoring!



Marscher, 2014





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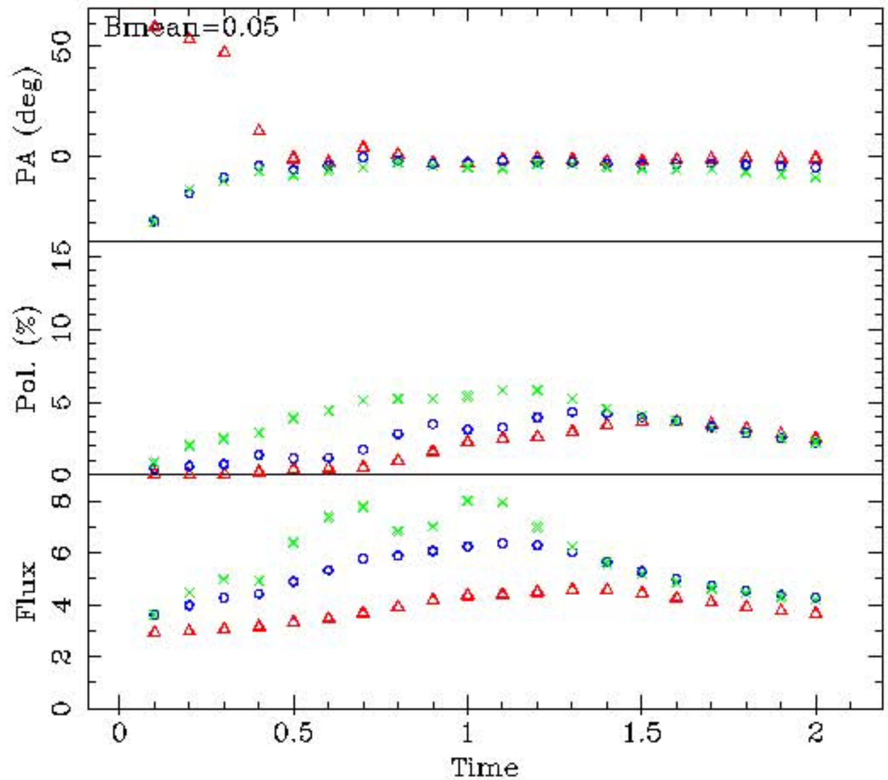
2) Shock in a jet

- Radiative transfer modeling by Hughes, Aller & Aller, 2015
- Three radio frequencies (4.8,8, 14.5 GHz)

Parameter	Constraint
Low energy cutoff (γ_i)	EVPA spectral behavior
Axial B field (**B**z)	EVPA and P%
Bulk Lorentz Factor (γ_f)	P%
Viewing Angle (θ)	P%
Shock obliquity (η)	ΔEVPA
Shock sense (F or R)	Doppler Factor and β_{app}
Shock length (l)	duration of flare in S
Shock Compression (κ)	ΔS and P%
Shock onset (t_0)	start of flare in S or P

Courtesy of M. Aller

Simulation of different amount of axial B-field



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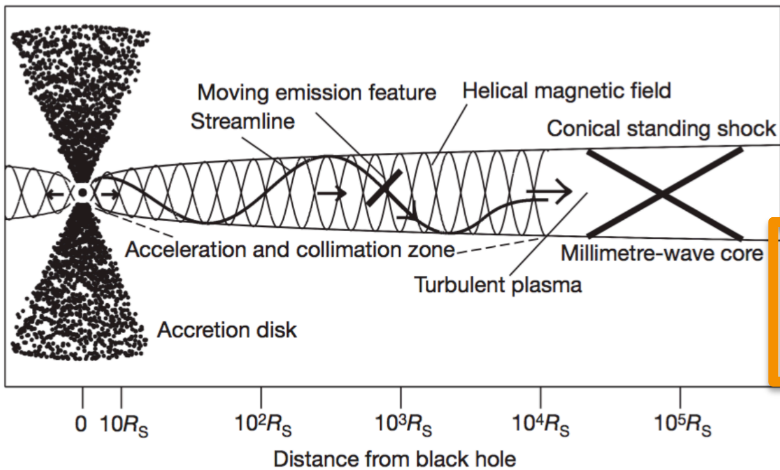
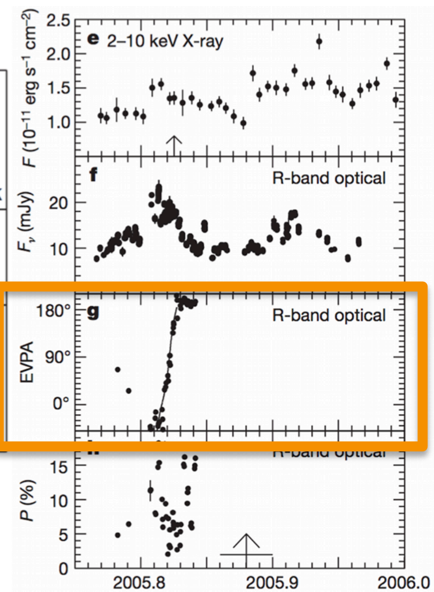
3) Emission in a helical field

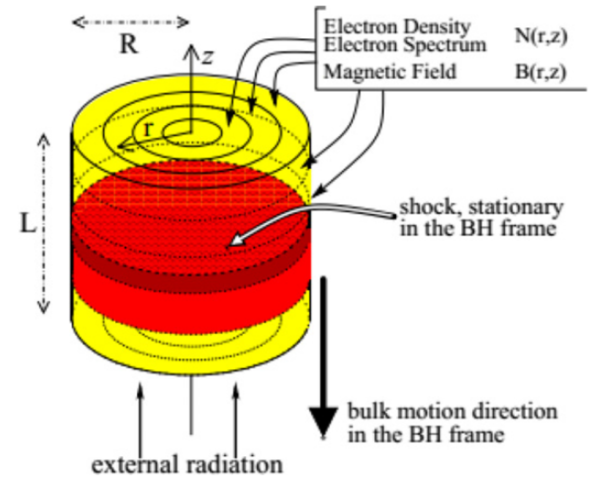
- Characteristic signature is a rotation in optical EVPA

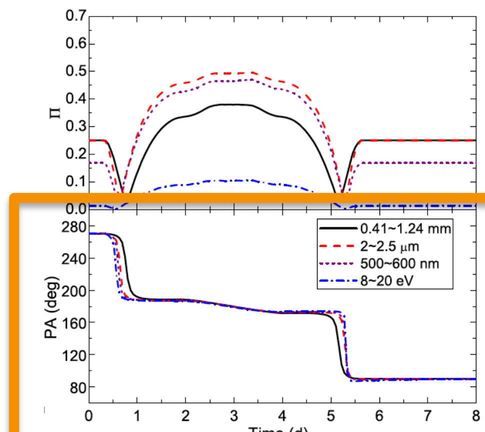
Marscher et al. 2010





Zhang et al. 2014





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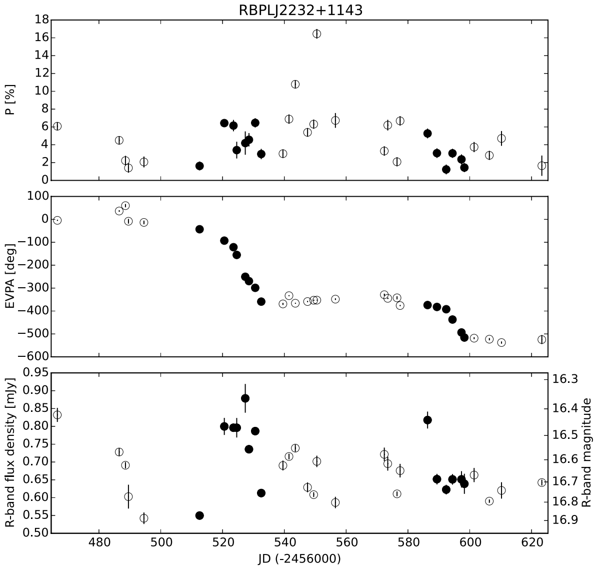
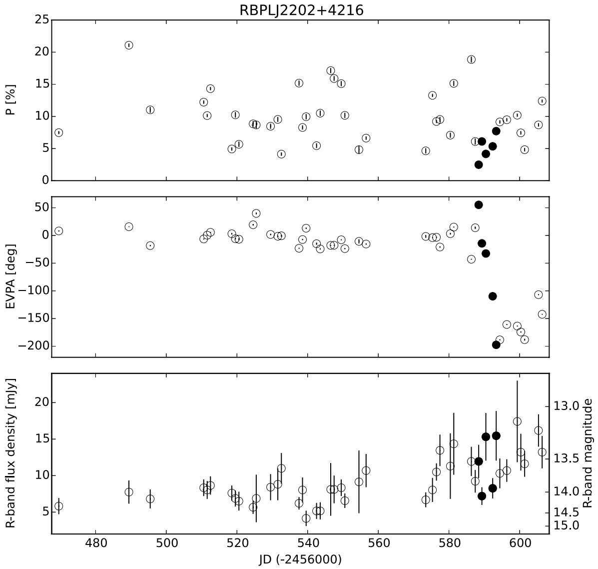
RoboPol

- Sample of ~ 100 blazars
- Optical R-band monitoring twice per week between April and November in 2013-2015
  - 2016 fast-cadence monitoring of 27 sources for 50 nights
- In 2013-2015 detected 40 EVPA rotations in 24 blazars

http://robopol.org/





Blinov et al. 2015

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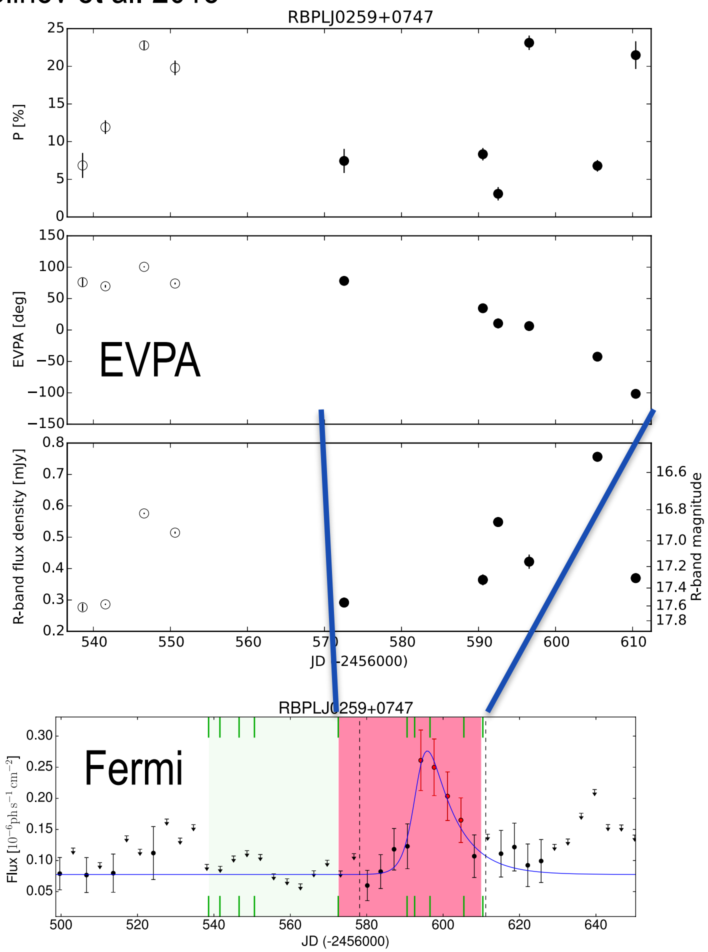
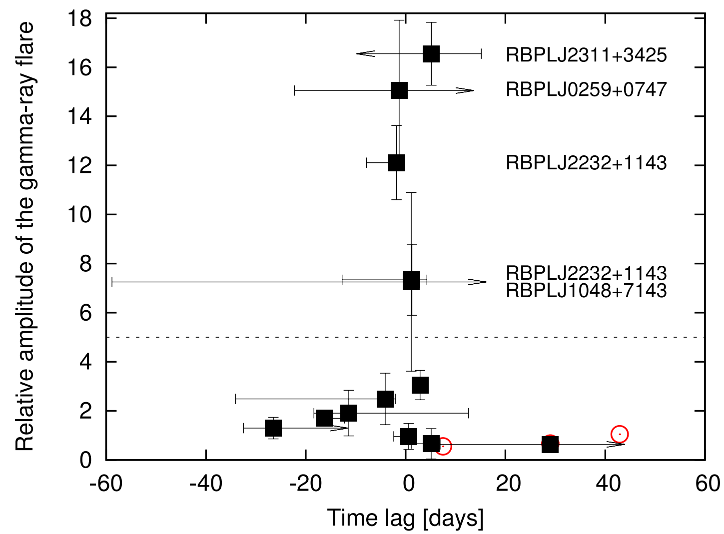
RoboPol: High-energy connection

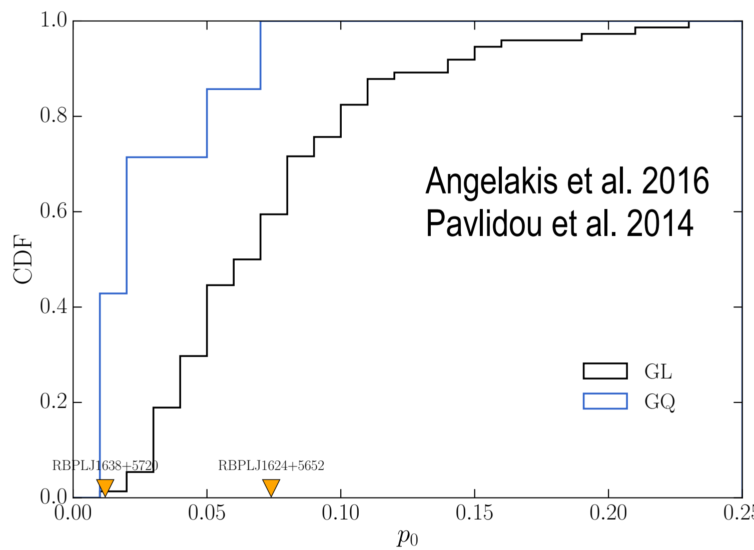
Blinov et al. 2015





Rotations are coincident in time with large gamma-ray flares

Blinov et al. 2015



Angelakis et al. 2016
Pavlidou et al. 2014

Gamma-ray loud sources are more polarized than non-detected

See also Jermak et al. 2016

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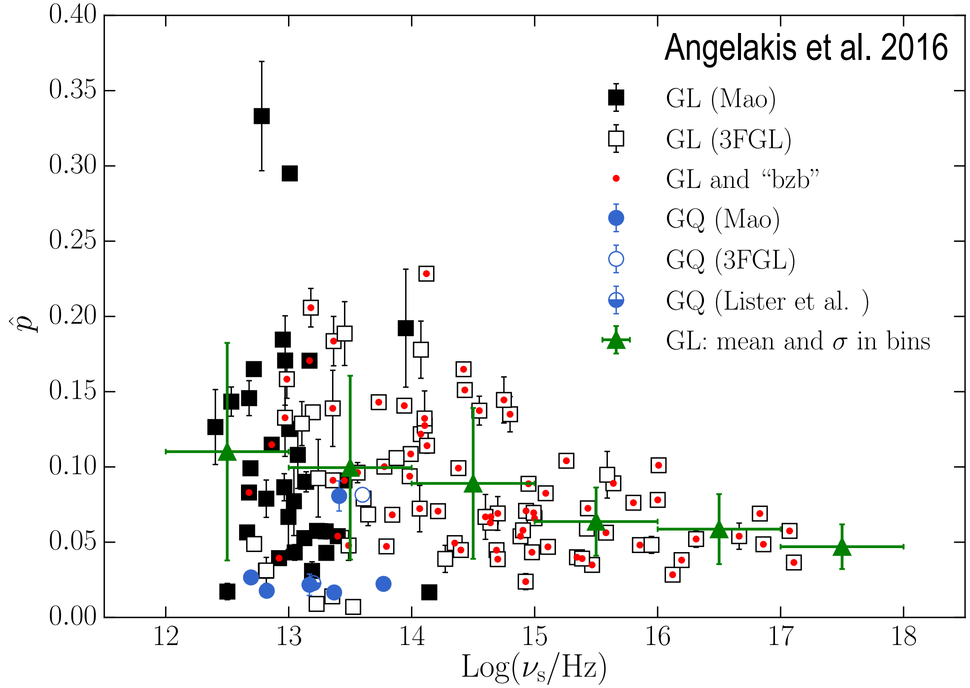
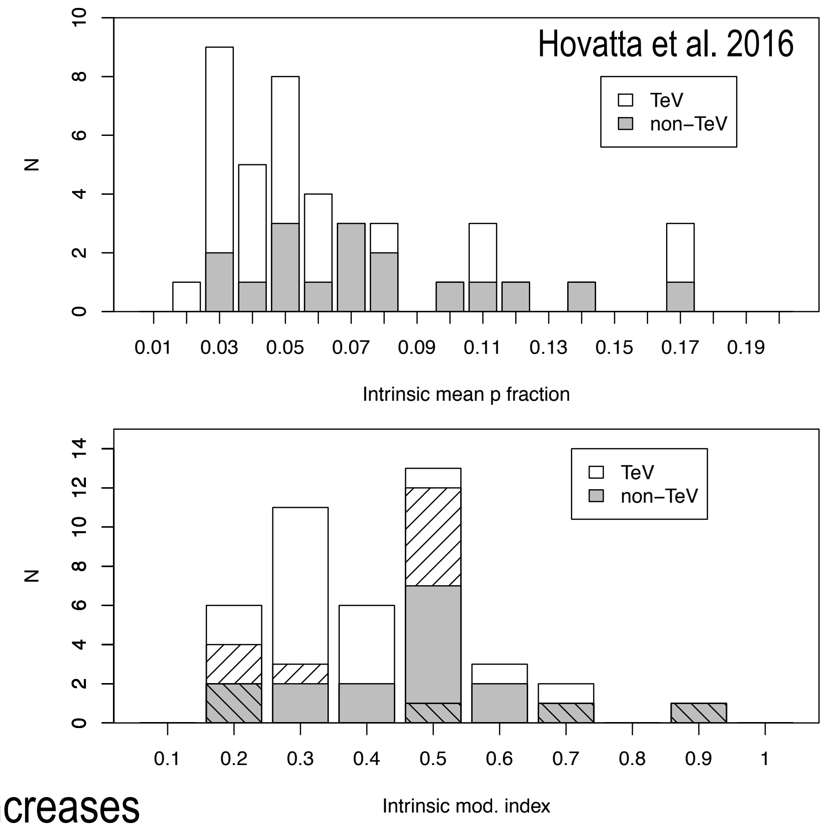
RoboPol: Differences among blazar classes

Polarization as a function of SED peak frequency



Polarization in TeV vs. non-TeV BL Lacs



- Polarization decreases when SED peak frequency increases
- There are no differences in the polarization properties of TeV-detected vs. non-detected BL Lac objects

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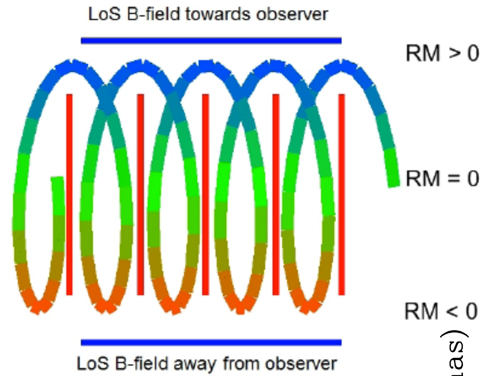
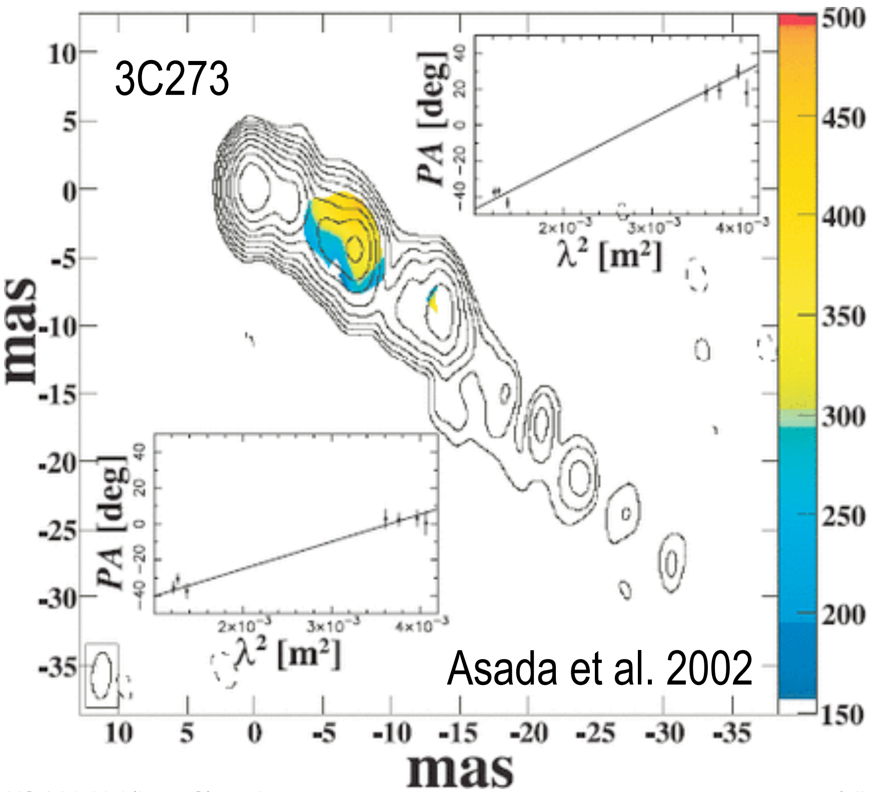
Is the magnetic field helical (on pc scales)?

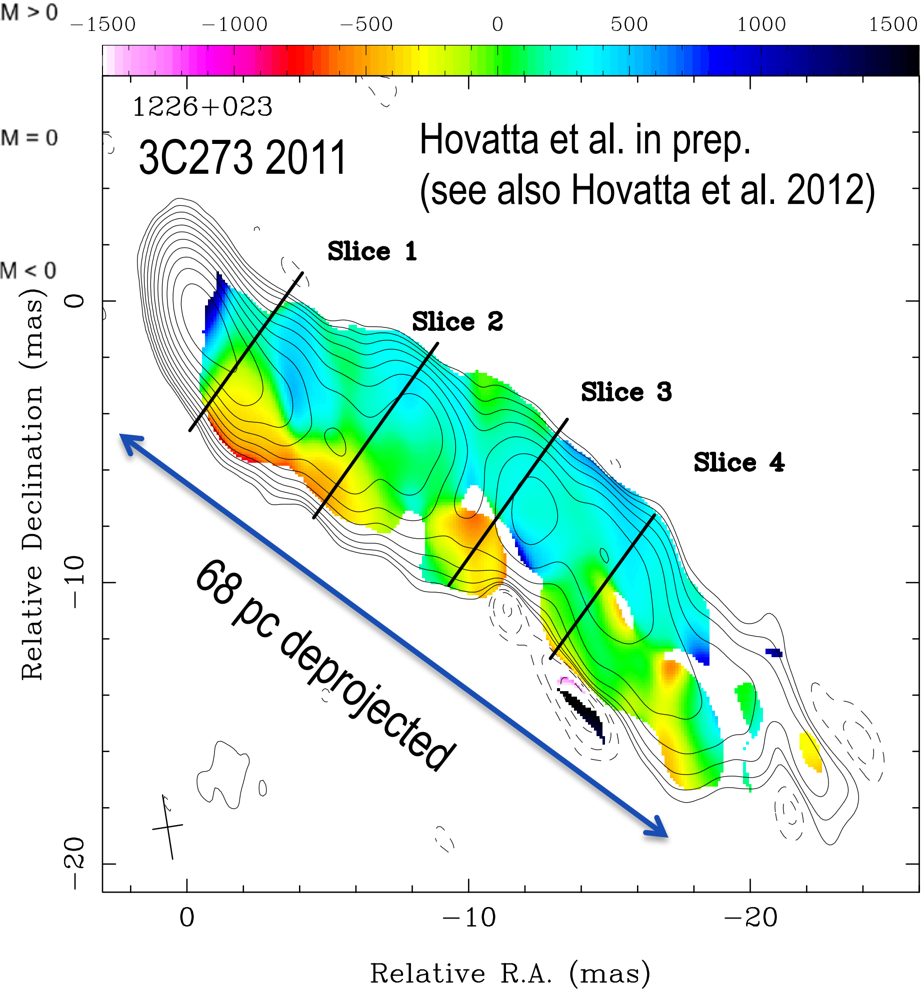
- Helical field could show up as a Faraday rotation gradient
- Lots of caveats!!!



Reichstein & Gabuzda 2011



Asada et al. 2002



Hovatta et al. in prep.
(see also Hovatta et al. 2012)

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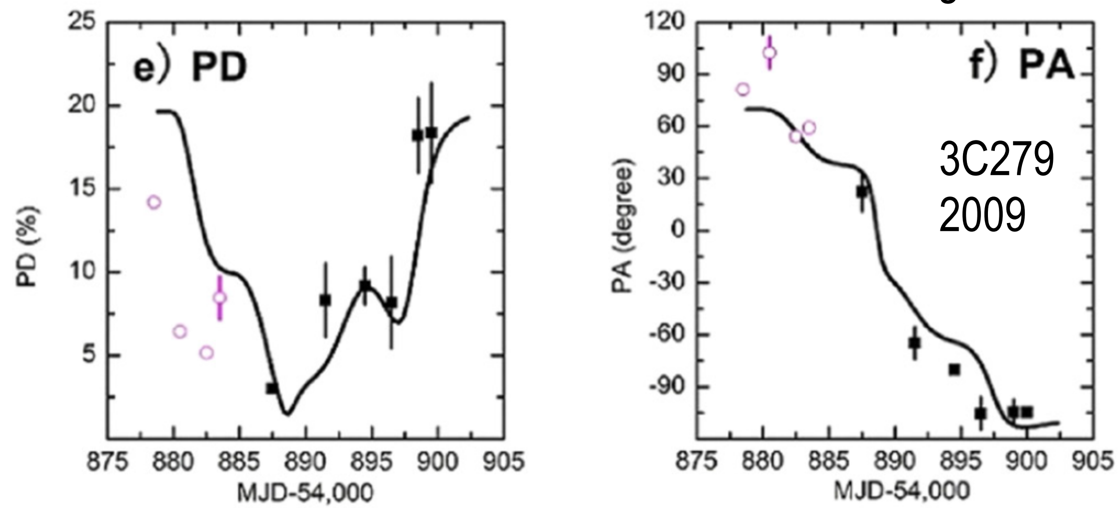
4) Magnetic reconnection

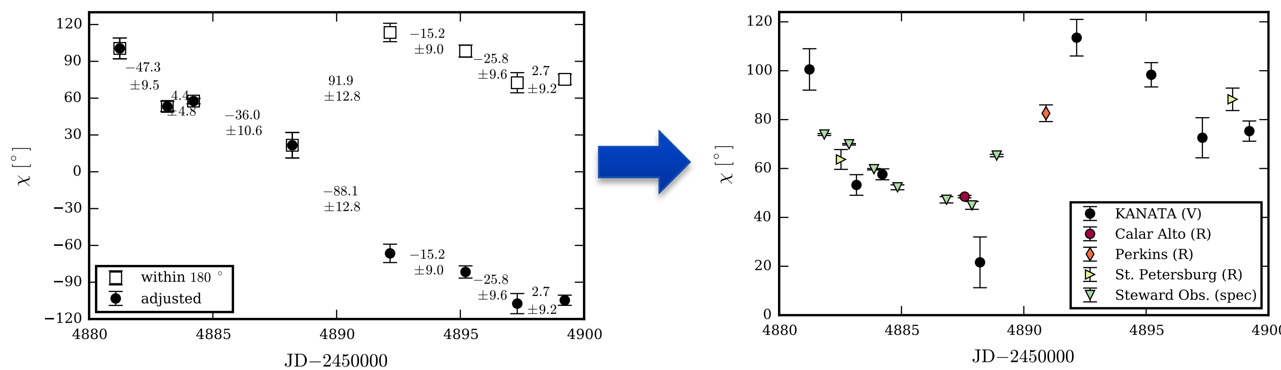
- There are no explicit polarization predictions yet
  - Swing in 3C279 reproduced by a model which favors "magnetic energy dissipation process during the flare"
  - Caveat when interpreting polarization data

- Essential question: Are the jets magnetized?

Zhang et al. 2015



CAVEAT!!!!



Kiehlmann et al. 2016

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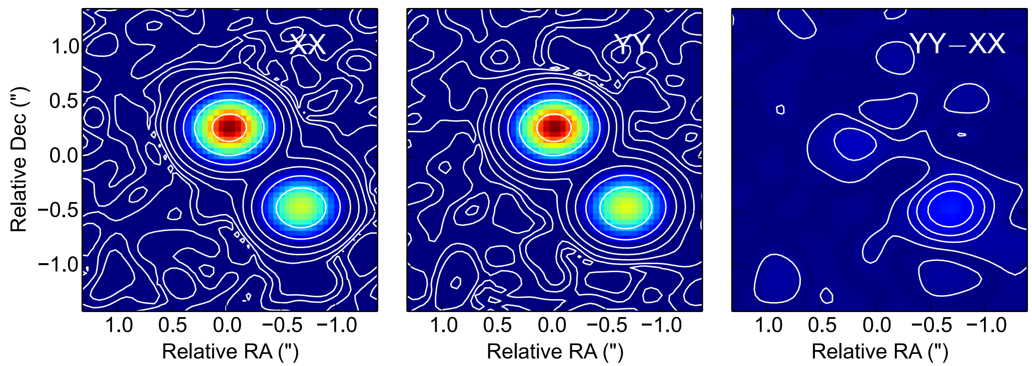
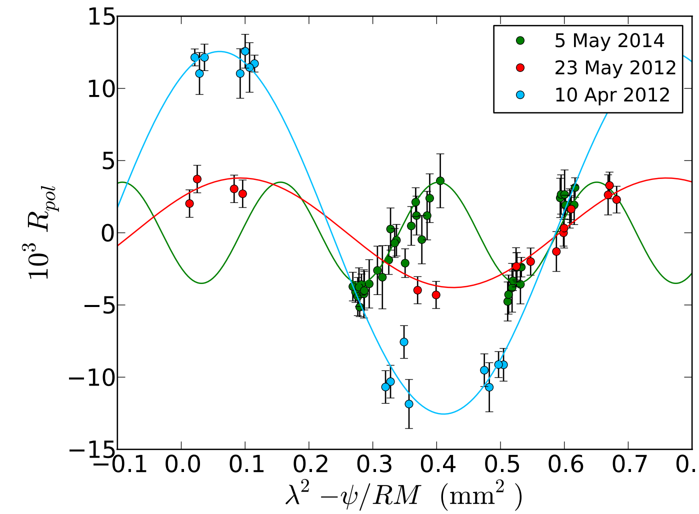
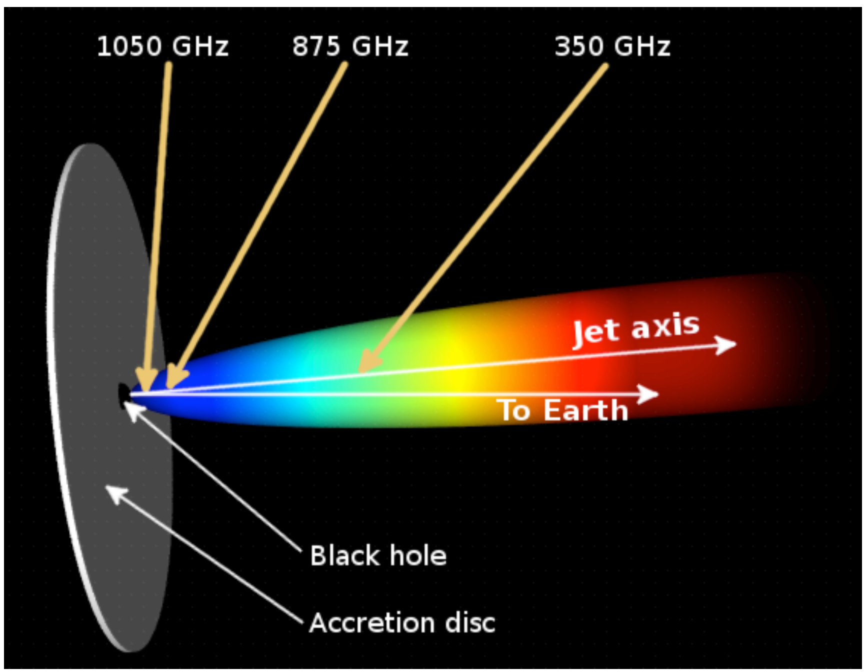
ALMA polarization observations

Marti-Vidal et al. 2015 PKS 1830-211







- Rotation measure of 10^8 rad/m^2 in source frame (z=2.5 lensed source)
- Implies extreme B-field at the jet base or high electron density -> Could be a sign that jets are magnetized

Cycle 4 observations of 3C273 have been approved

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Future: 1mm / 3mm polarization monitoring

- Using 2-3 of the old CARMA dishes relocated to the valley floor at Owens Valley Radio Observatory (OVRO) in California
- Extension of the MARMOT program http://www.astro.caltech.edu/marmot/
- Would provide a statistical approach
- Currently seeking funding

MARMOT

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Summary

- Radio and optical polarization observations can be used to probe the magnetic fields in AGN jets
  - 3D structure through Faraday rotation observations
- There are several emission models with observational predictions
  - Polarization signatures of reconnection still missing
  - Statistical studies needed to distinguish between the models
- mm-band polarization can possibly be used to constrain jet magnetization

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