Magnetic fields in blazar jets

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In collaboration with MOJAVE and RoboPol teams +
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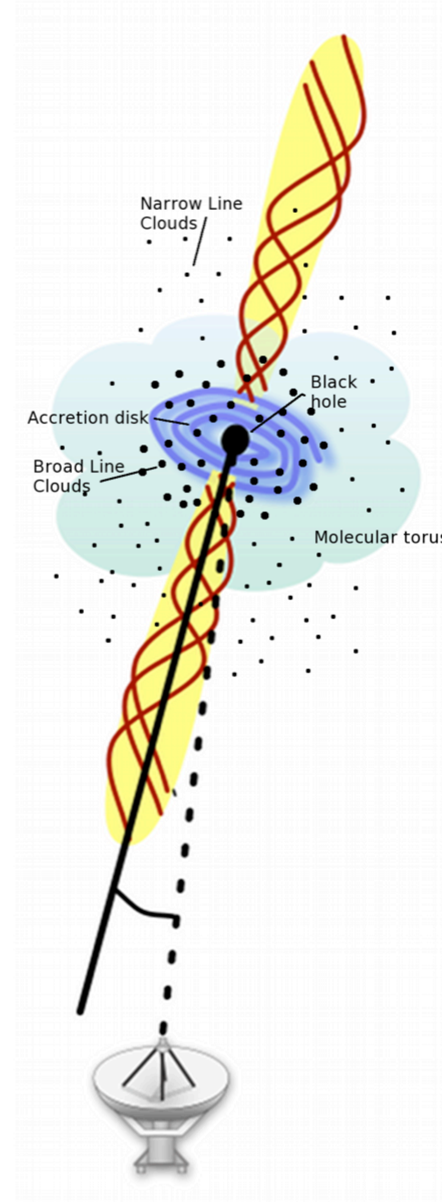
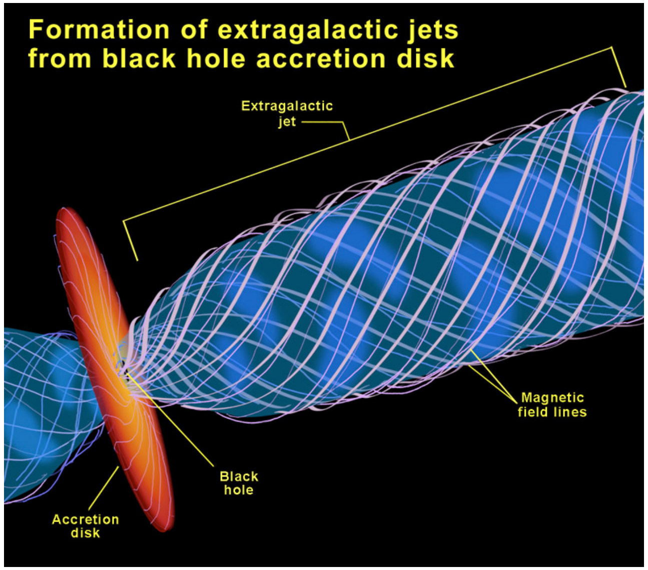


Credit: V. Pavlidou

Outline

- Motivation
- How to observe magnetic fields
- ALMA observations of 3C273
- Statistical studies on magnetic fields in radio and optical bands
- Conclusions

Role of magnetic fields in jet launching and emission



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

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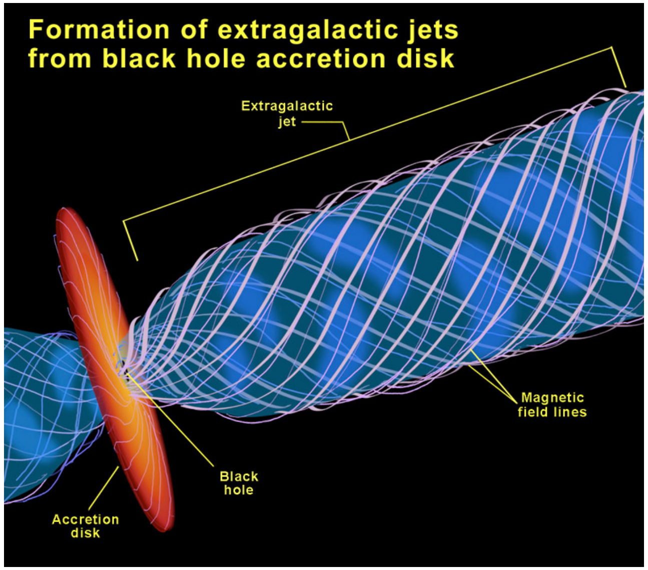
Role of magnetic fields in jet launching and emission



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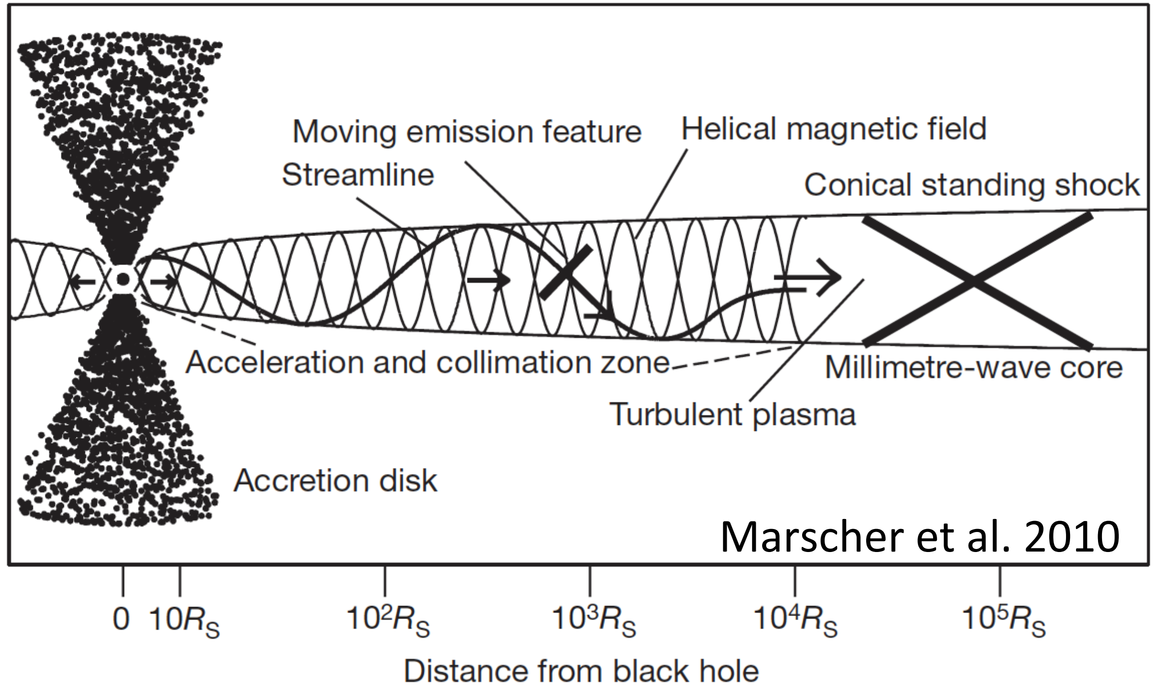

Open questions

1. What is the magnetic field structure near the base of the jet?
   - Helical as in simulations?
   - How to observe it?
   - Can we use observations to constrain the simulations?

2. What is the connection between magnetic fields and emission?
   - Is there a connection between magnetic fields and high-energy emission?
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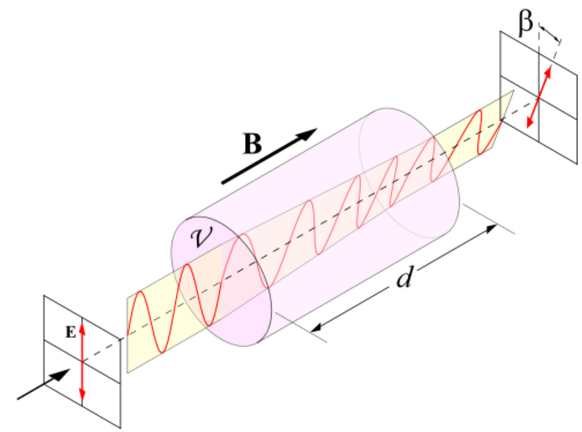
Polarization as a probe of magnetic fields

- Synchrotron emission is 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 (nonrelativistic) 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

Electric Vector position angle (EVPA)

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

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

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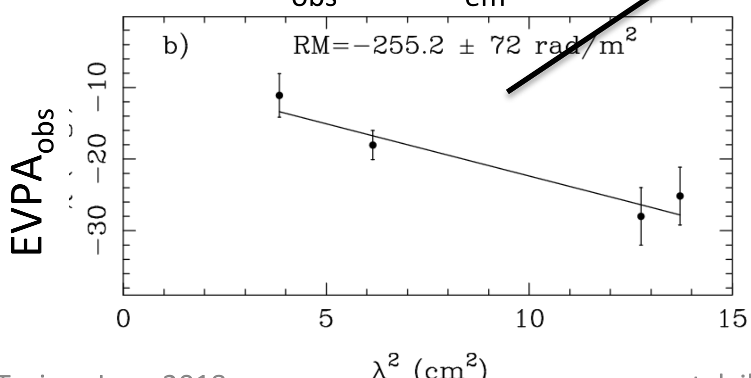
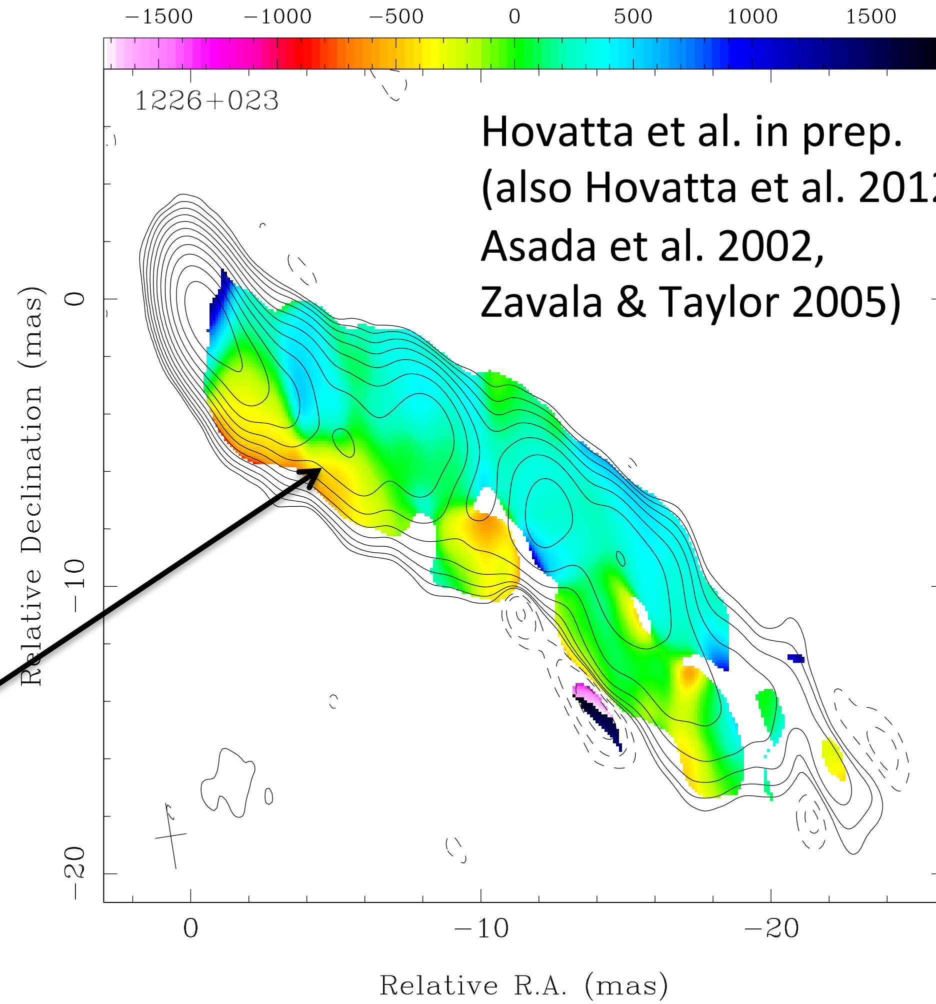
Is the magnetic field helical?

- Best evidence from Faraday rotation observations of 3C273
- Helical (or toroidal) field could show up as a gradient in the Faraday rotation measure
    - RM is positive when the field is towards the observer, negative when going away

$EVPA_{obs}=EVPA_{em} + RM\lambda^2$



VLBA observations at 8-15 GHz



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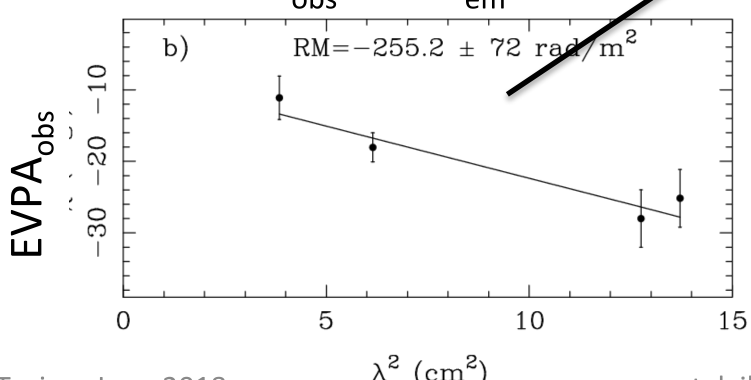

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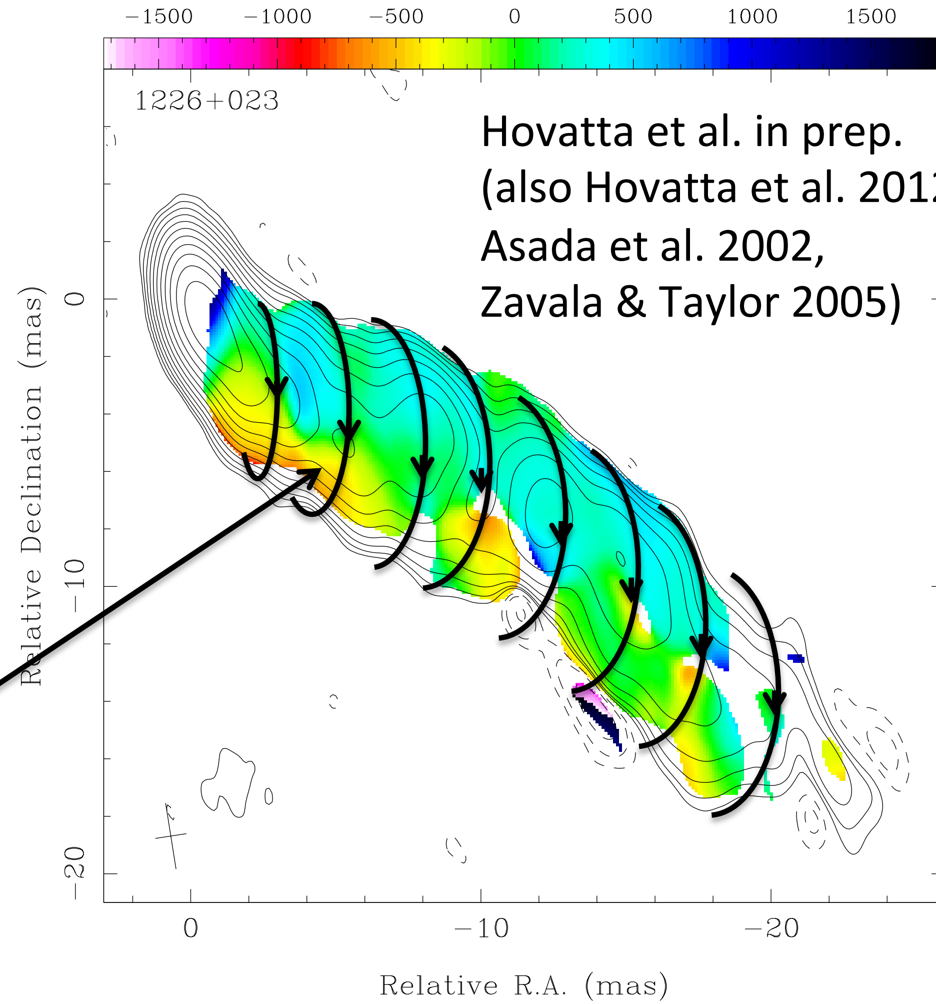

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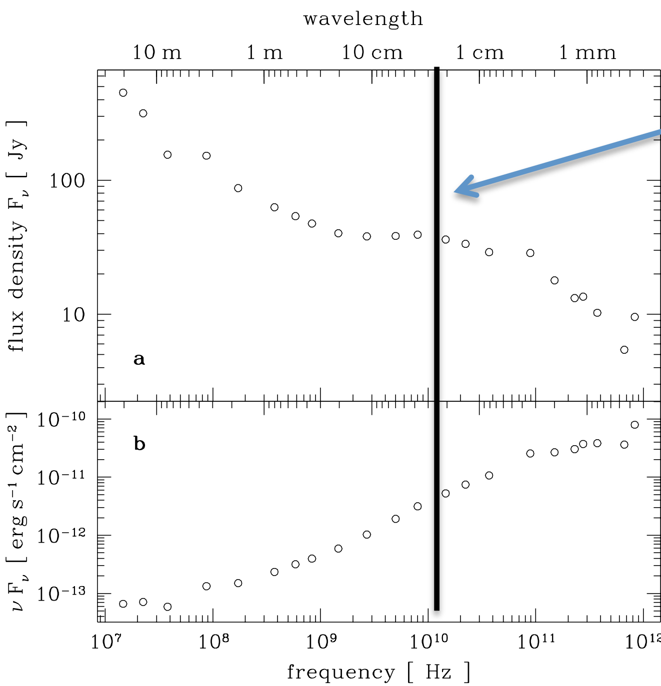
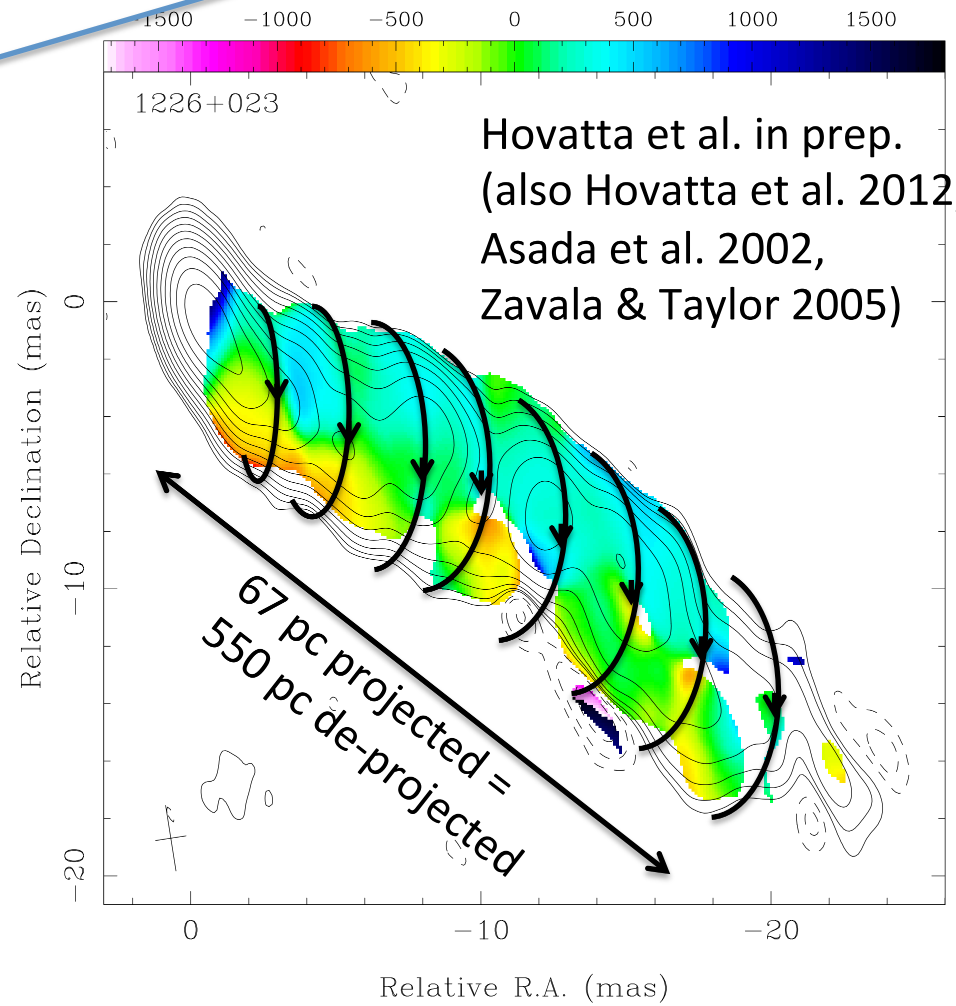
VLBA observations at 8-15 GHz





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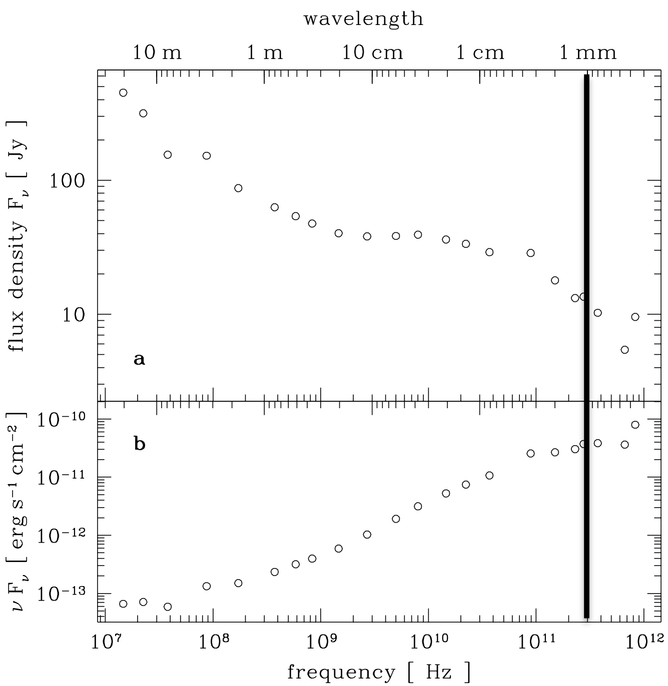

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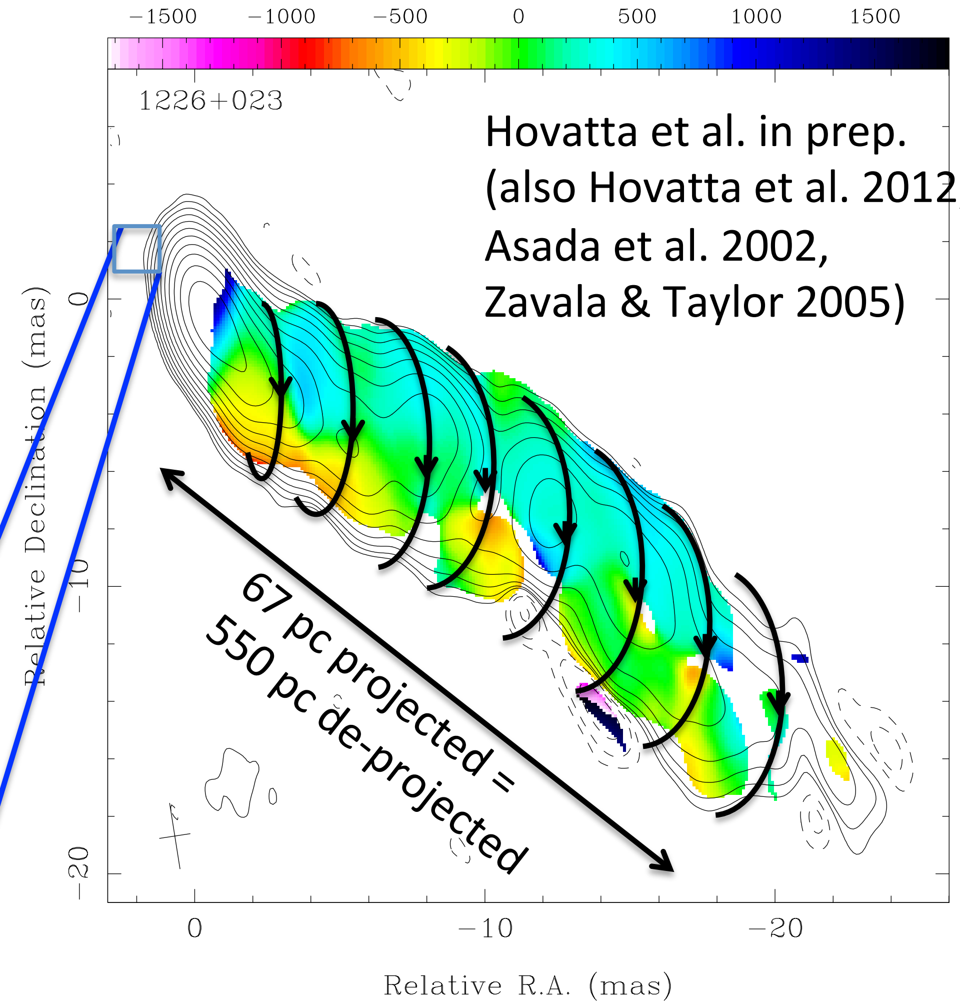

ALMA 1mm polarization observations probe the optically thin emission somewhere near the black hole

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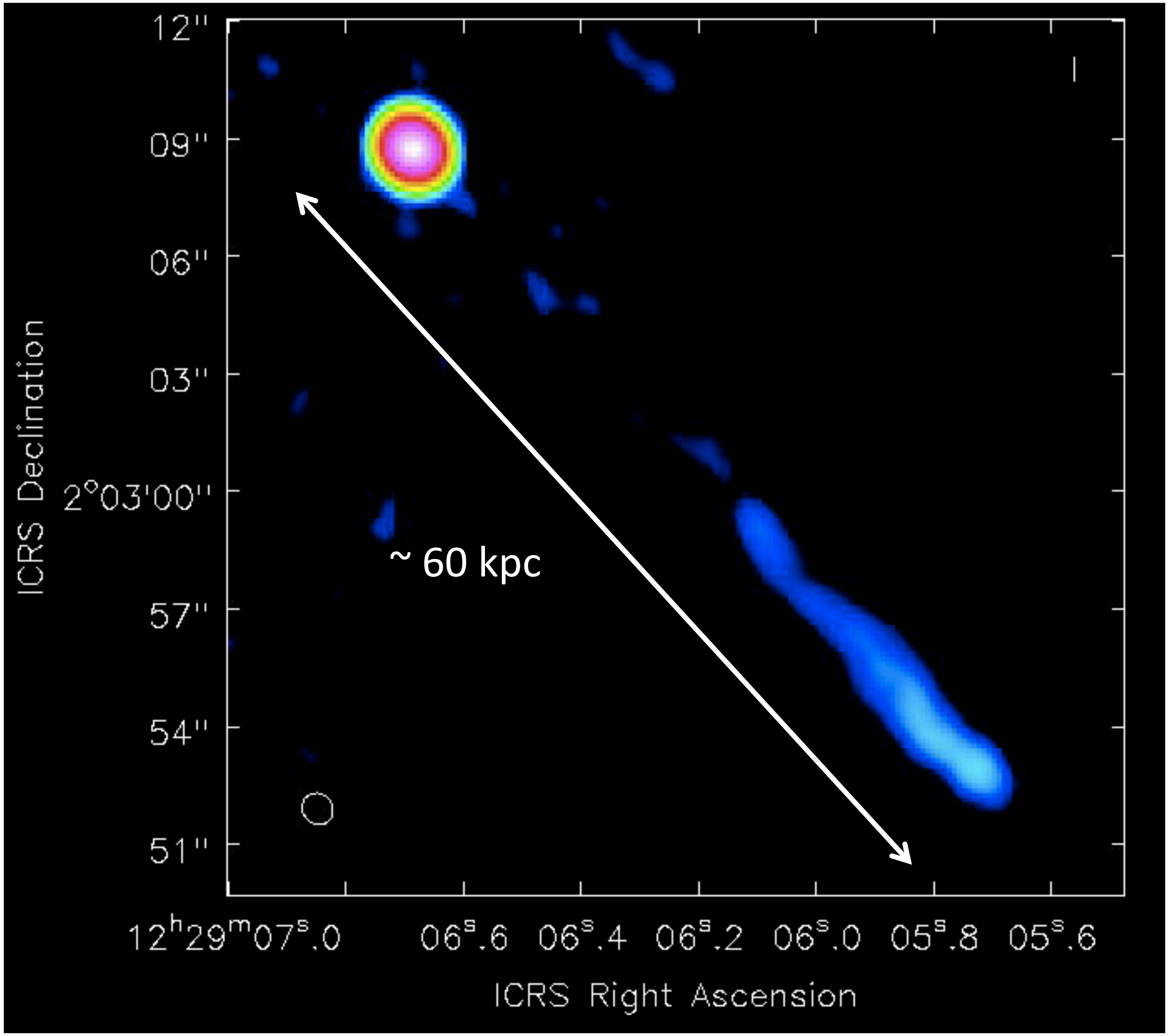
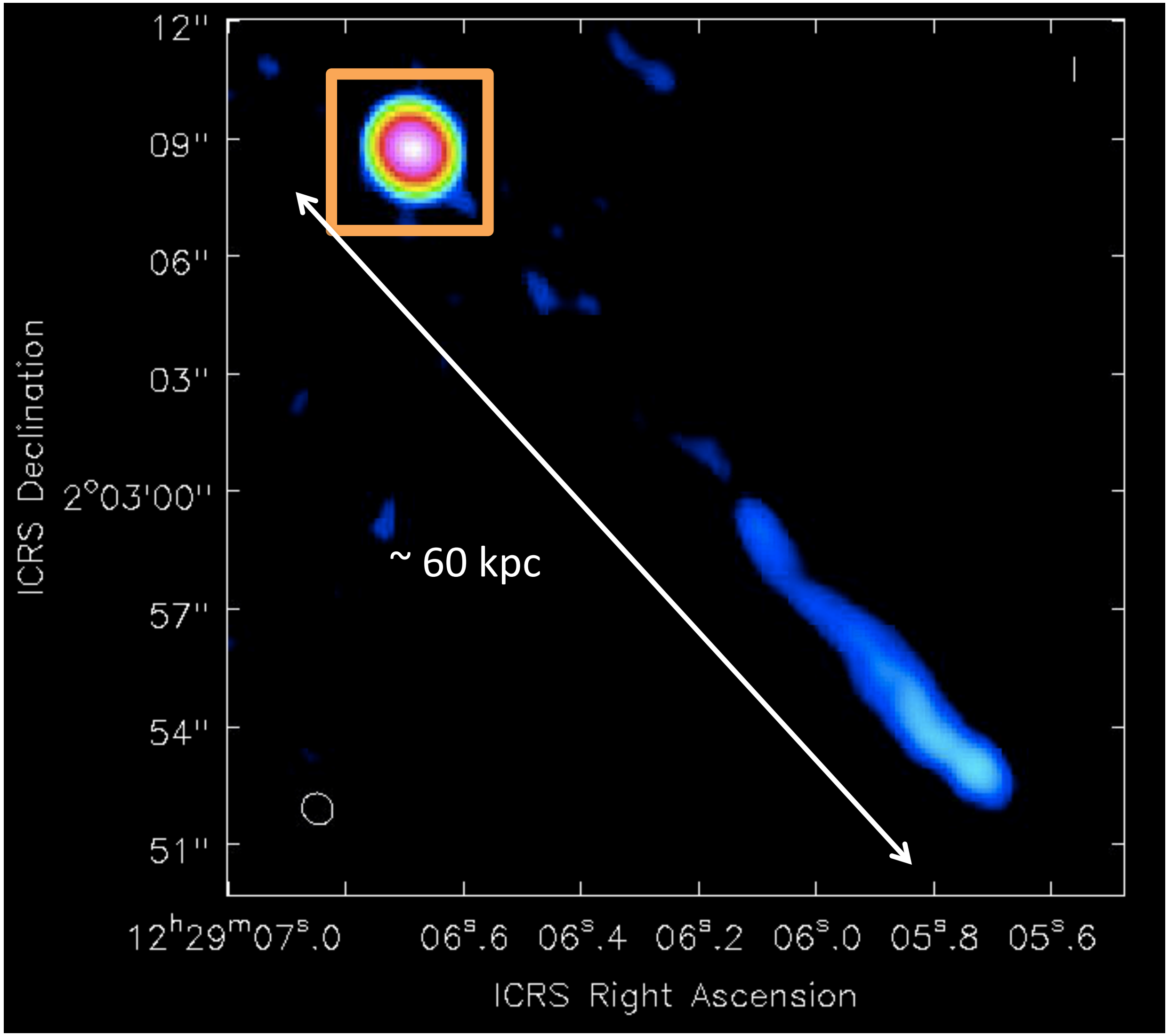
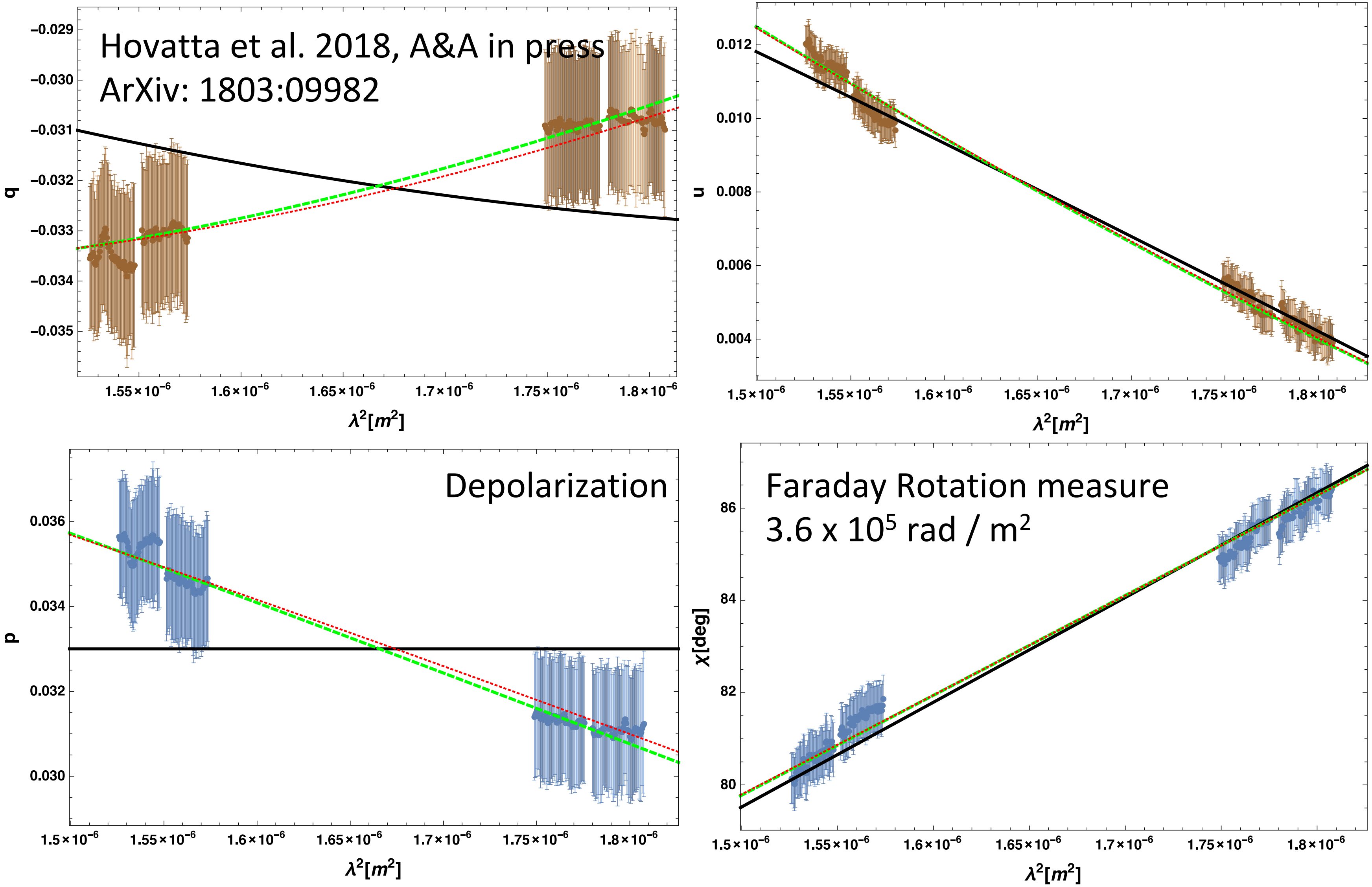
3C273 with ALMA at 1mm



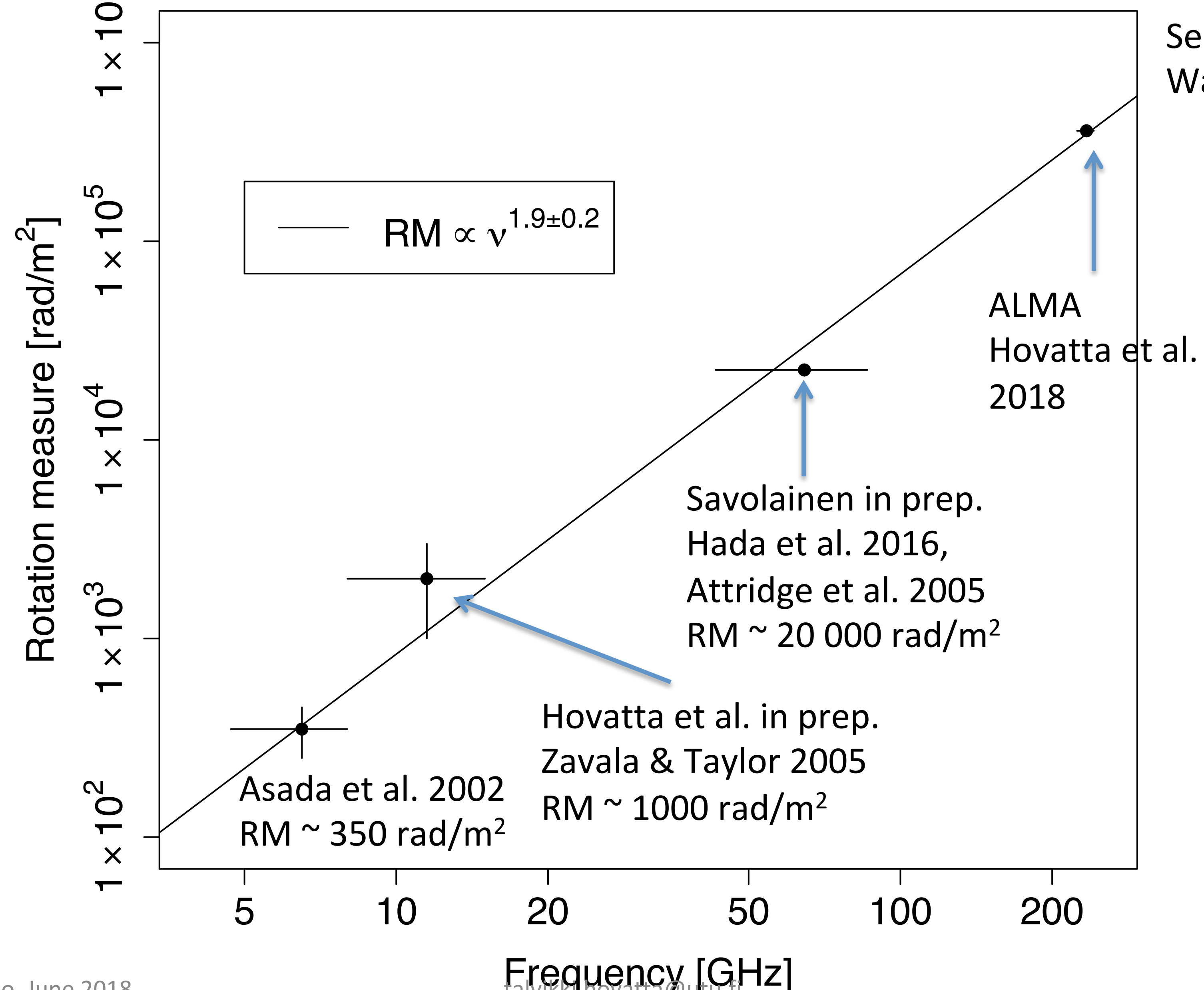
3C273 with ALMA at 1mm



Polarization spectrum in the ALMA observations between 224-242 GHz



Frequency-dependence of RM in 3C273



See also
Wardle 2018

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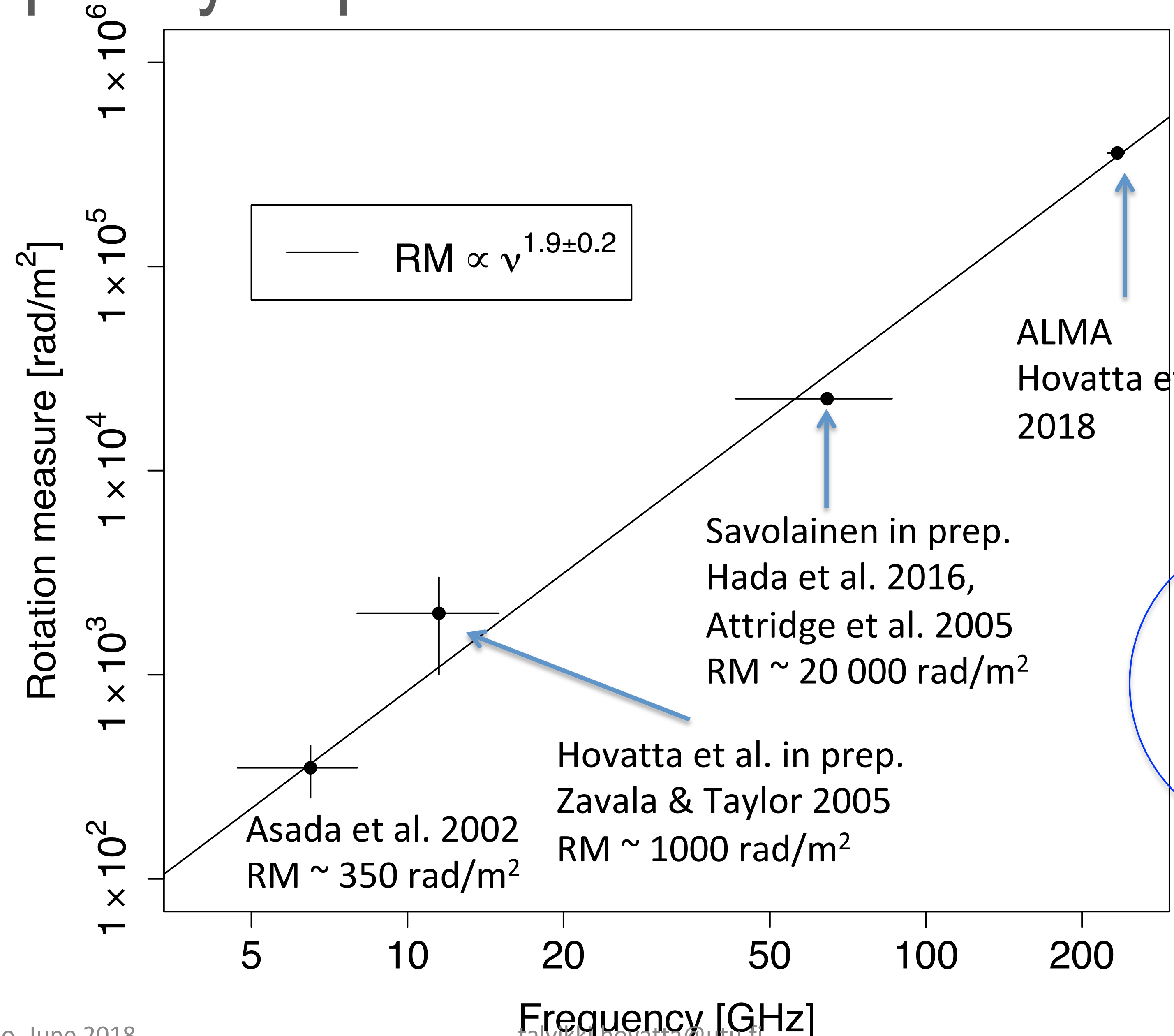
Frequency-dependence of RM in 3C273



See also Wardle 2018

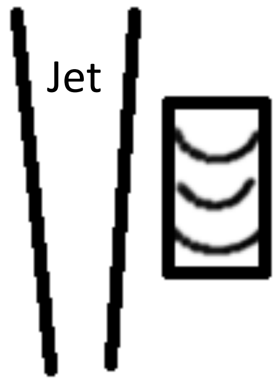
Consistent with a conically expanding jet surrounded by a sheath

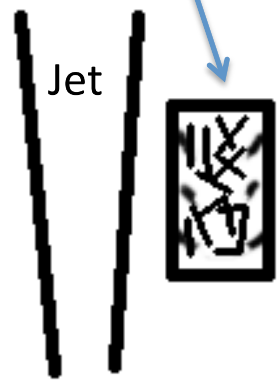
Two plausible models that explain the Q/U behavior and depolarization

External screen

Ordered external screen:

- Requires a rotation measure gradient ΔRM of ~ 9 x 10^5 rad/m^2





Turbulent external screen:

- Requires the Faraday dispersion of the RM screen to be ~ 2.7 x 10^5 rad/m^2

$$P = p_0 \,\mathrm{sinc}(\Delta \mathrm{RM}\lambda^2)\; e^{2i(\Psi_0+\mathrm{RM}\lambda^2)}$$

$$P = p_0 e^{-2\sigma^2_{\mathrm{RM}}\lambda^4} e^{2i(\Psi_0+\mathrm{RM}\lambda^2)}$$

Sokoloff et al. 1998, O'Sullivan et al. 2017

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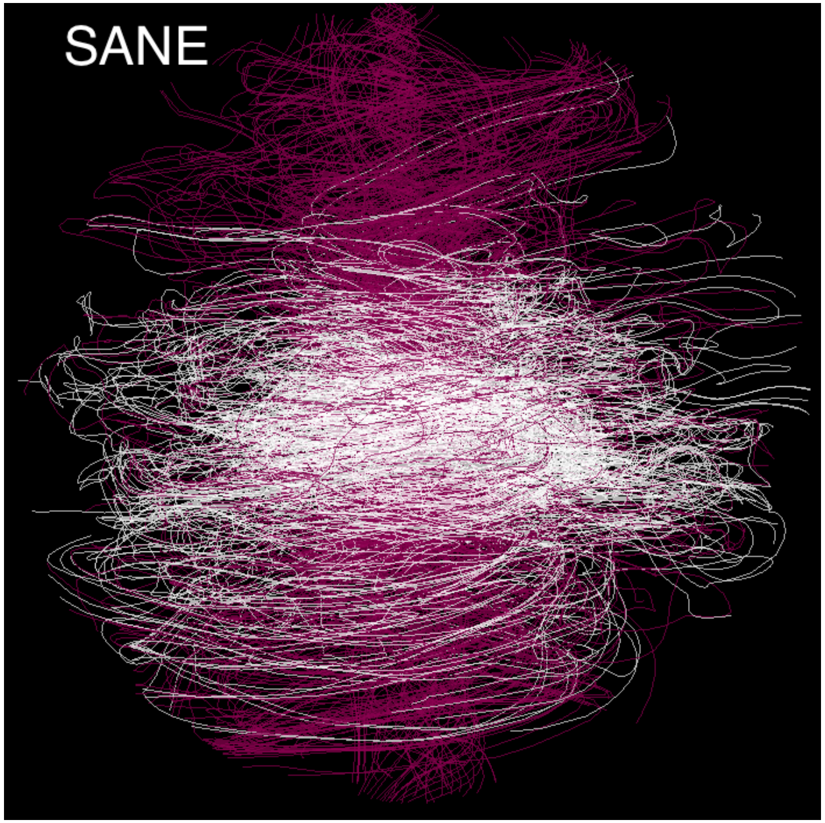
Comparison to jet formation simulations will allow us to connect observations and theory

Magnetically arrested disk
(large-scale magnetic field)

Standard and Normal Evolution
(no large-scale poloidal field needed)



Foucart et al. (2017)

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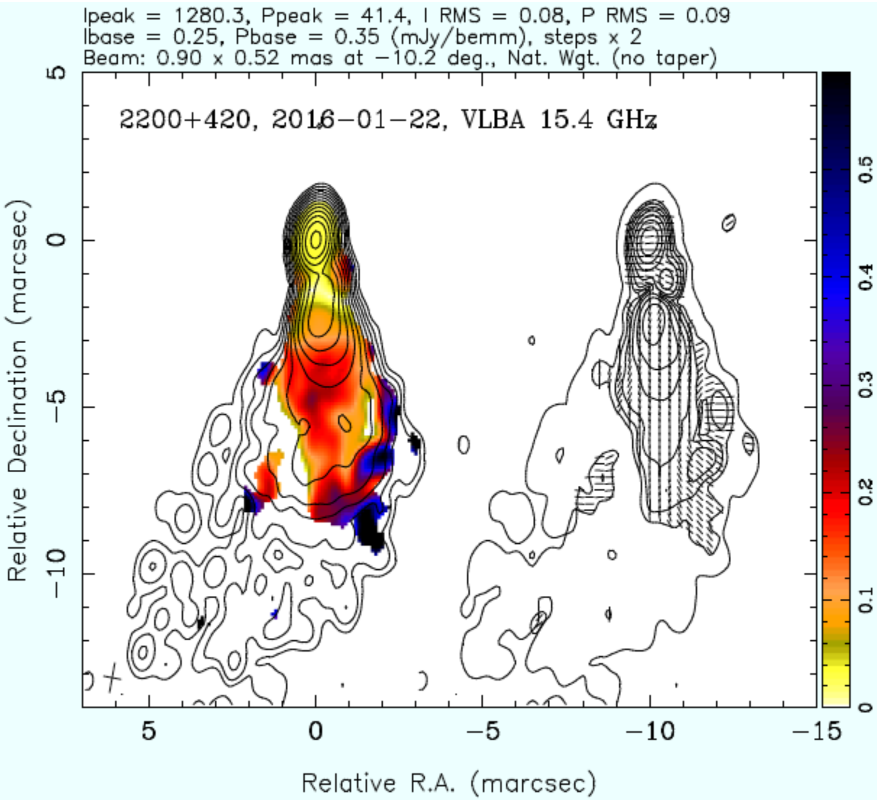
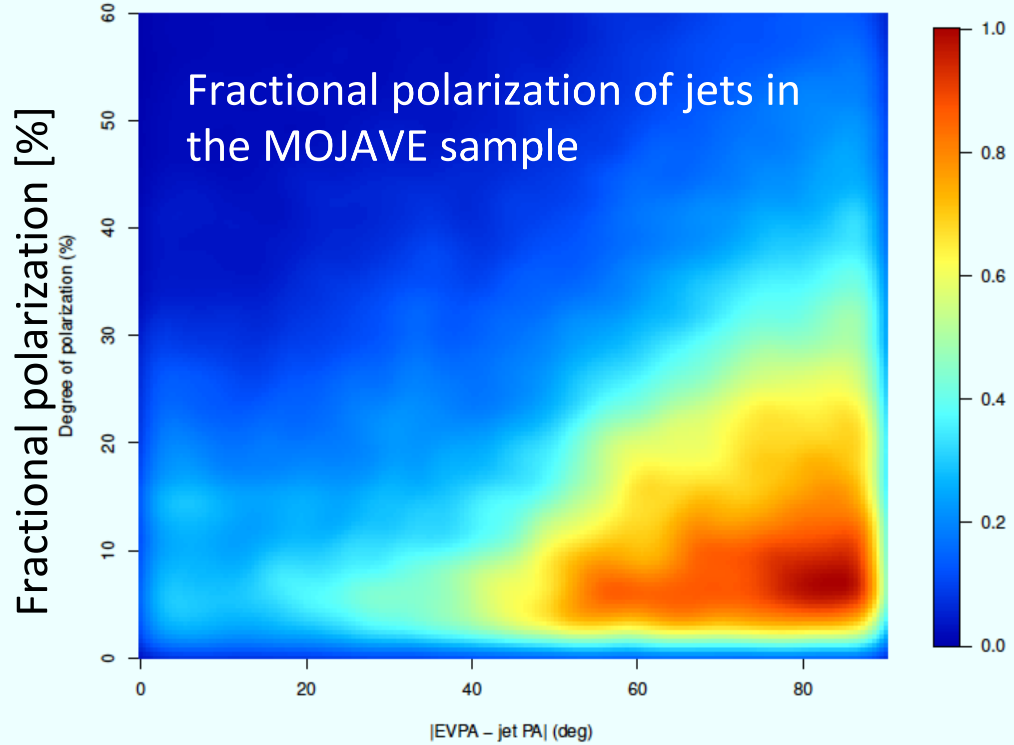
Evidence for a longitudinal magnetic field in the sheath layer on pc scales

Poster by A. Pushkarev





EVPA – jet position angle

Fig. 2. VLBA maps BL Lac at 15 GHz. Degree of polarization is depicted by color and overlaid with I contours (left panel). Stiks show EVPAs overlaid with P contours (right panel). The western jet edge shows a sheath of longitudinal magnetic field.

Fig. 3. 2D histogram of fractional polarization vs EVPA deviation from the local jet direction beyond 1.5 beam offset from the jet ridgeline. EVPA is predominantly transverse to the jet indicating a presence of a sheath of the longitudinal B-field.

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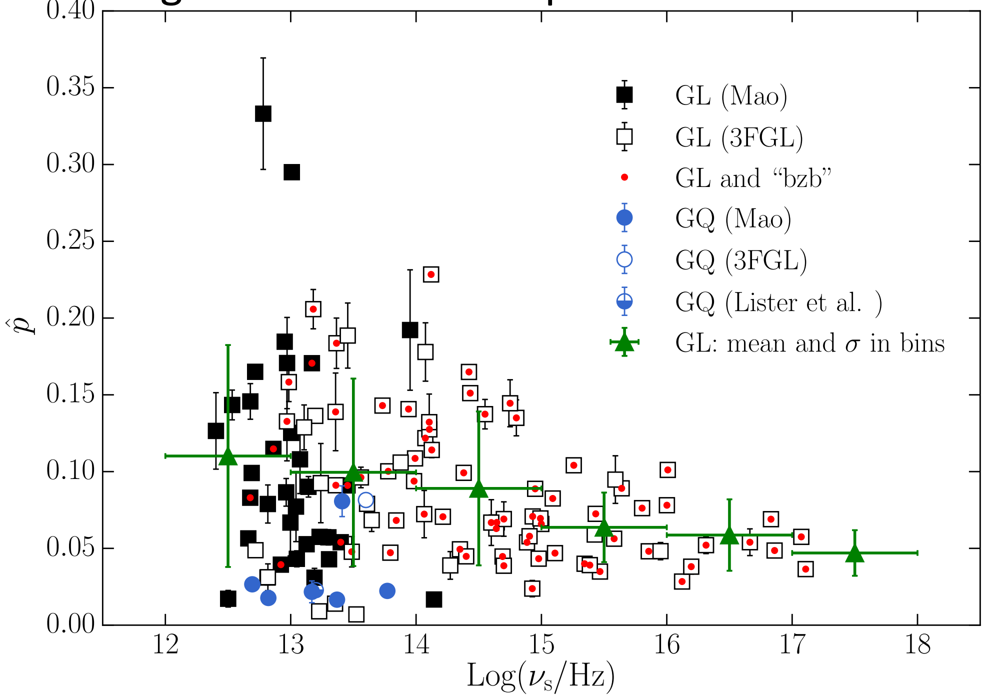
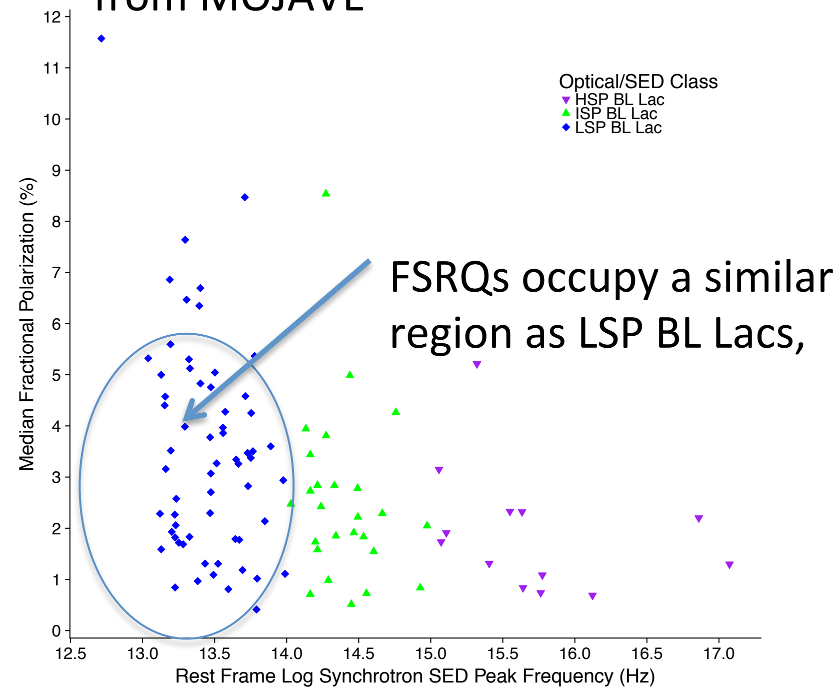
Fractional polarization as a function of SED peak

Poster by E. Angelakis

Angelakis et al. 2016 optical from RoboPol



Hodge et al. 2018 (MOJAVE XVI) 15 GHz from MOJAVE



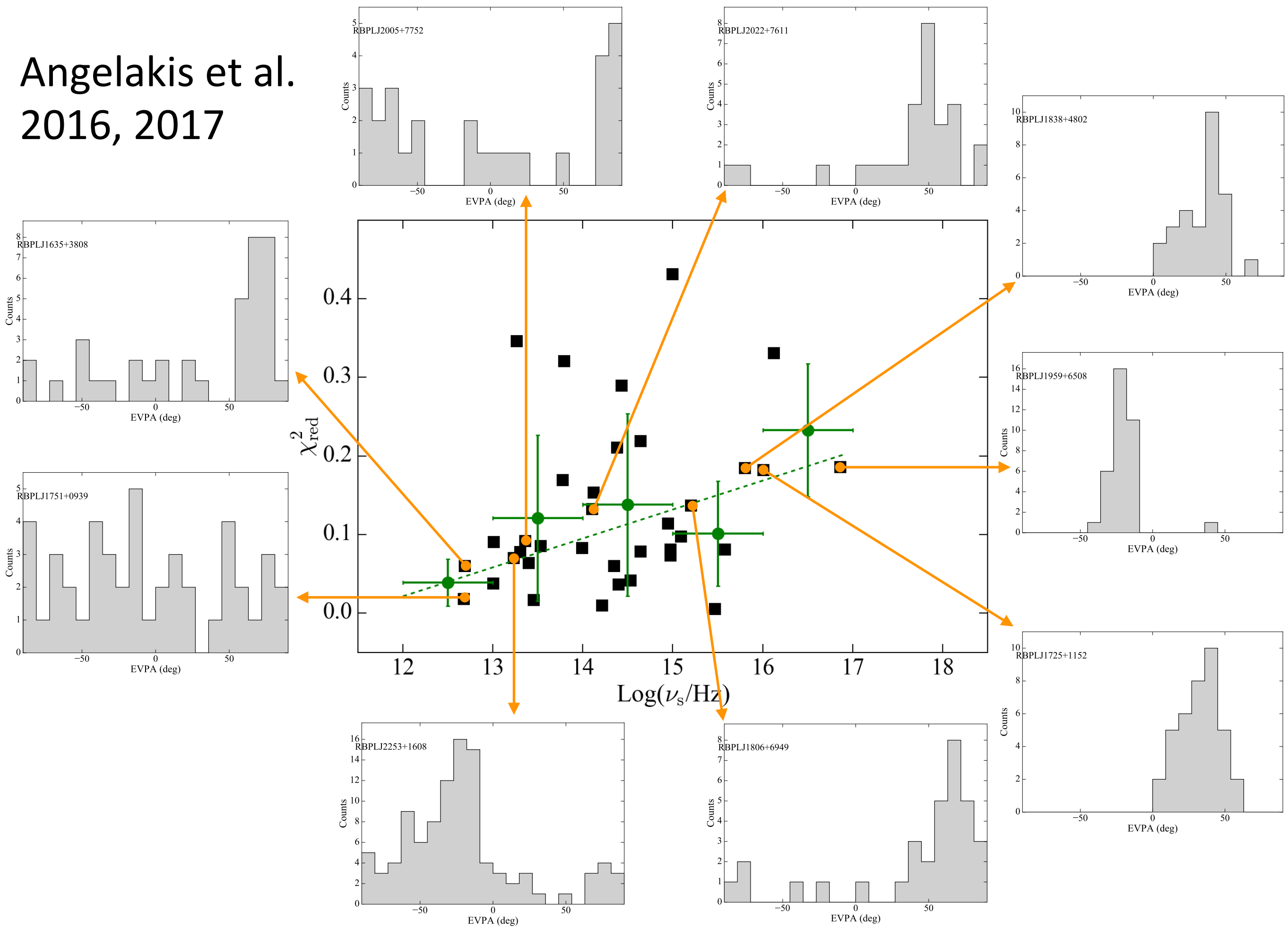
HSP sources seem to form their own low polarization tail both in radio and optical observations

Note the resemblance to the luminosity and speed plots in Lister's talk on Monday!

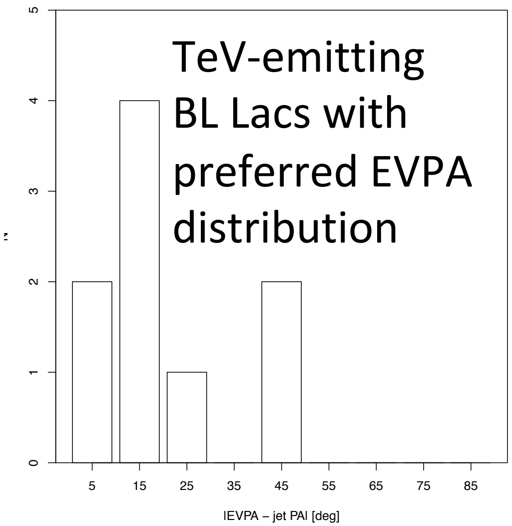
In the optical band sources with higher synchrotron peak seem to have more stable EVPAs

EVPA distribution as a function of SED peak in RoboPol sources

Angelakis et al. 2016, 2017



Hovatta et al. 2016



EVPA – jet PA

See also Angel et al. 1978, Jannuzi et al. 1994, Lister & Smith 2000, Jorstad et al. 2007

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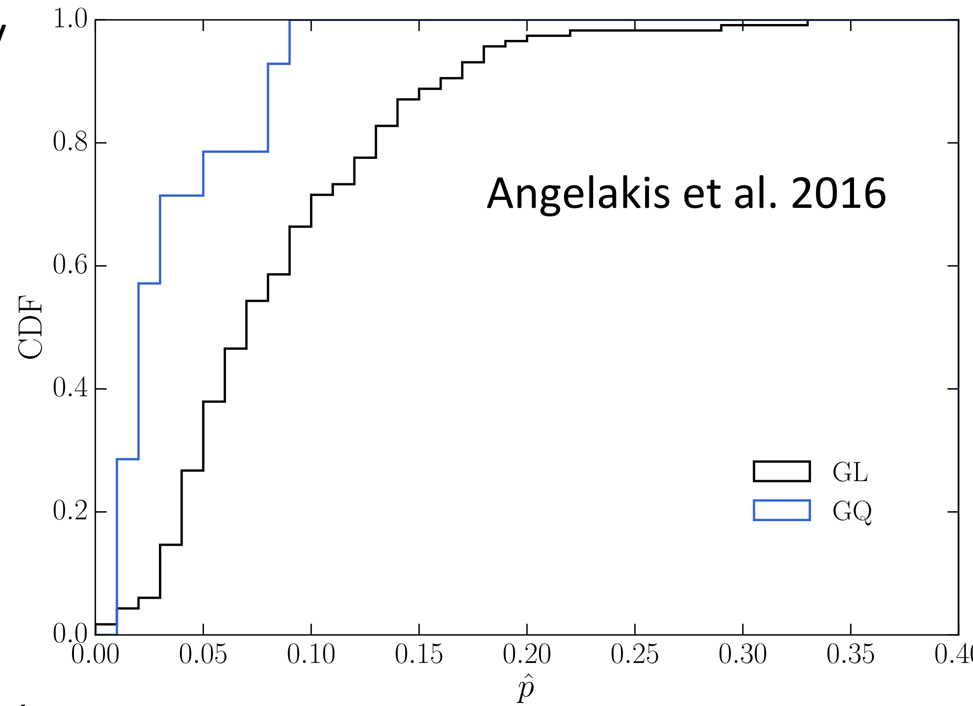
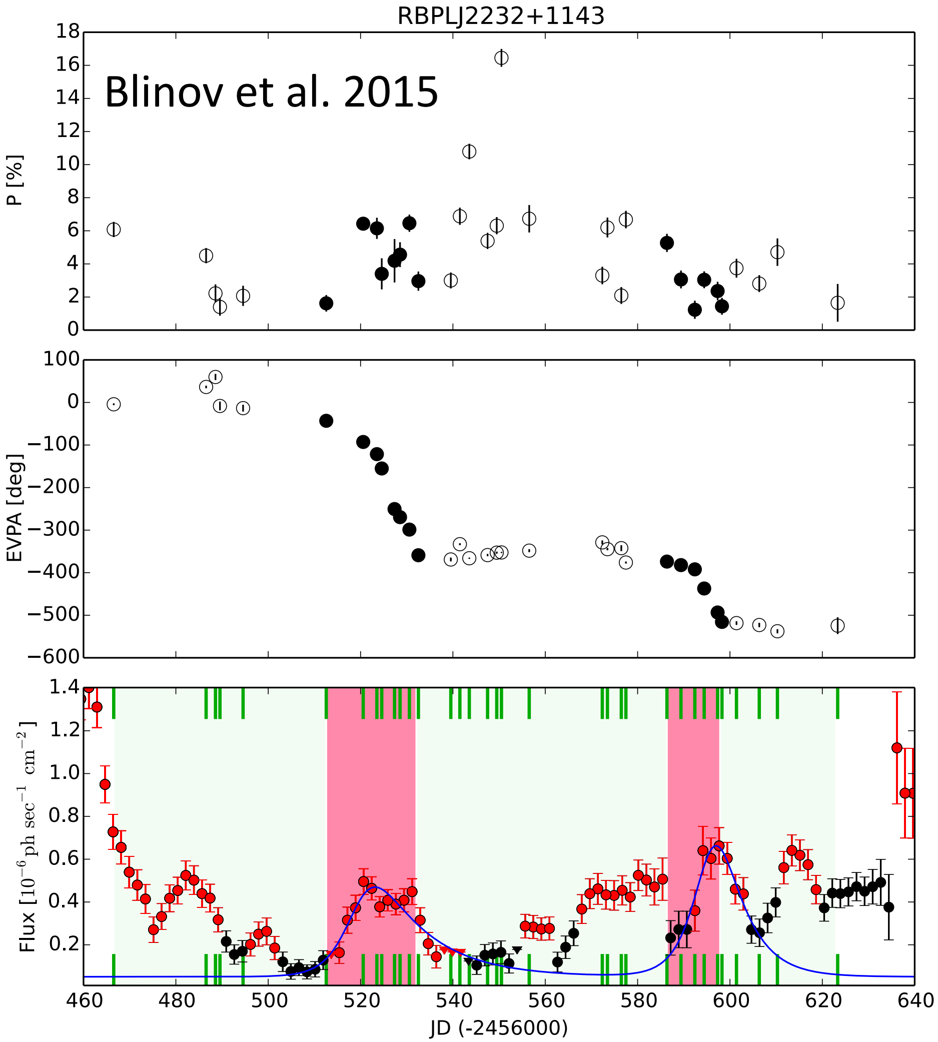
Connection between magnetic fields and high-energy emission

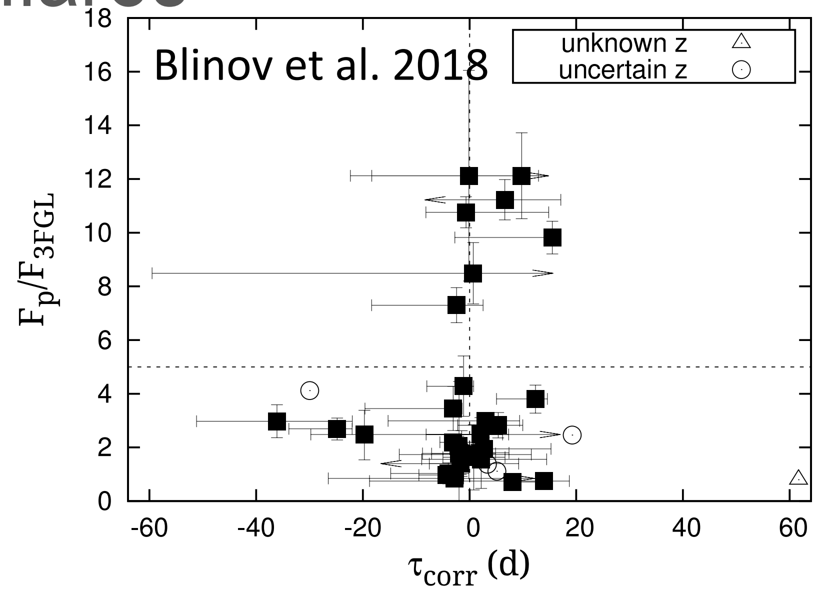
- In the optical band, the gamma-ray loud objects are seen to be more polarized
  - Perhaps a more ordered field, or connection to flaring?

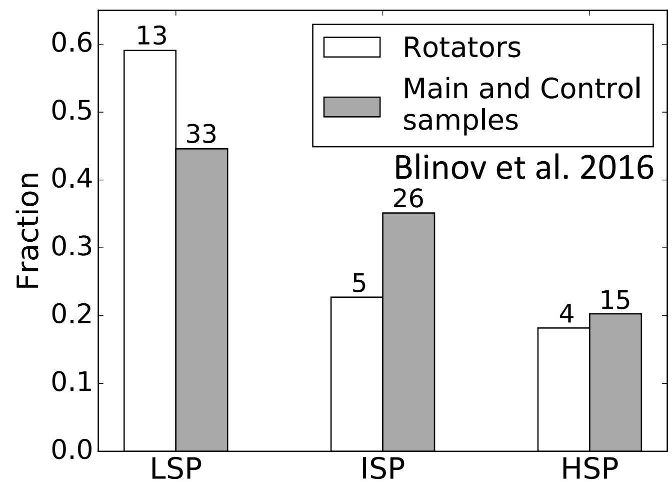
- In the radio the connection is not as clear
  - Hovatta et al. 2010 showed higher polarization fraction in Fermi-detected sources
  - This trend is not seen in the analysis of Hodge et al. 2018 when 3FGL detections are used
  - Should be tested with gamma-ray luminosities



Polarization angle rotations are statistically always coincident with gamma-ray flares







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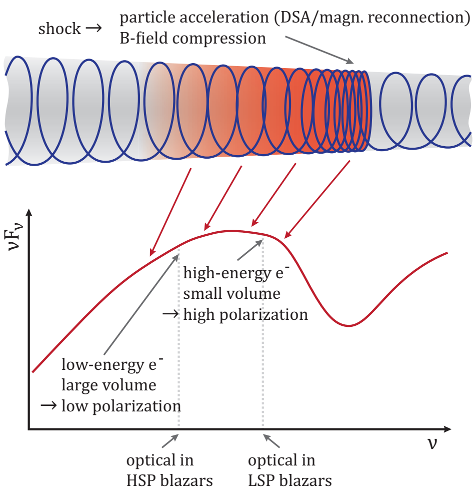
What models can explain the trends?

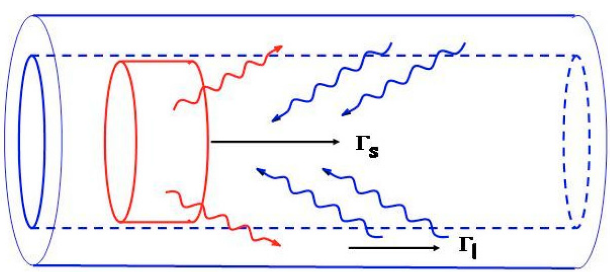
Angelakis et al. 2016



Shock in a helical field

- Lower polarization in HSPs because of a larger emitting volume
- Preferred angle in HSPs due to the dominance of the toroidal / helical magnetic field component
- Gamma-ray emission more likely to be produced when field is more compressed and particles accelerate to higher energies

Ghisellini et al. 2005



Spine-sheath structures

- Sheath with a helical (or toroidal) field dominates the radio / optical emission in HSP sources, resulting in a preferred EVPA
- Consistent with slow HBL speeds (see Piner & Edwards 2018 for a model description)

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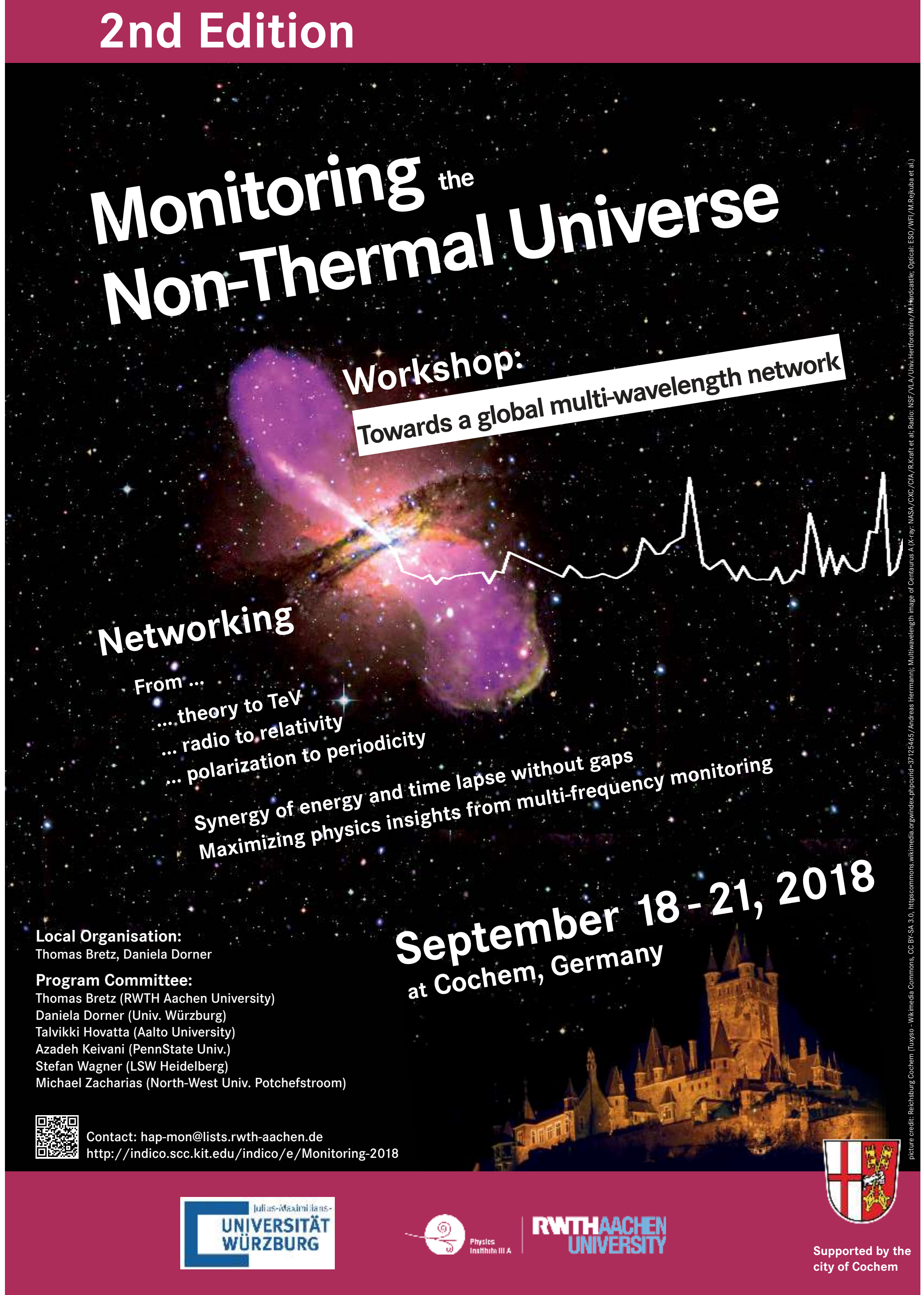
Conclusions

- ALMA has opened a new window for studying Faraday rotation at the base of blazar jets
  - A very high RM of ~4×10^5 rad/m^2 is seen in 3C273
  - Consistent with a sheath surrounding a conically expanding flow
- Statistical studies of polarization in the jets in both radio and optical bands reveal trends as a function of SED peak and class
  - HSP BL Lacs show more often a preferred EVPA parallel to the direction of the jet position angle
    - toroidal field component? Dominance of a sheath layer?
- Optical polarization fraction and EVPA rotations seem to be connected to gamma-ray flaring
  - Connection to particle acceleration mechanism?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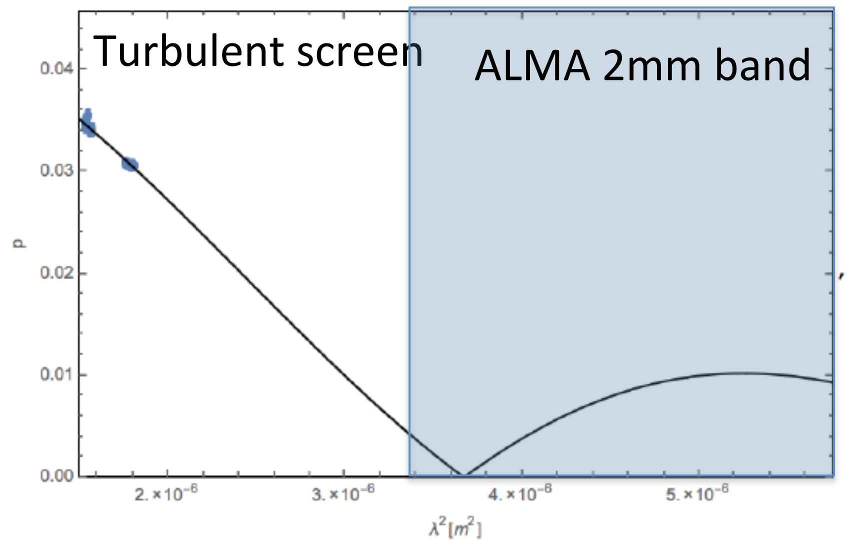
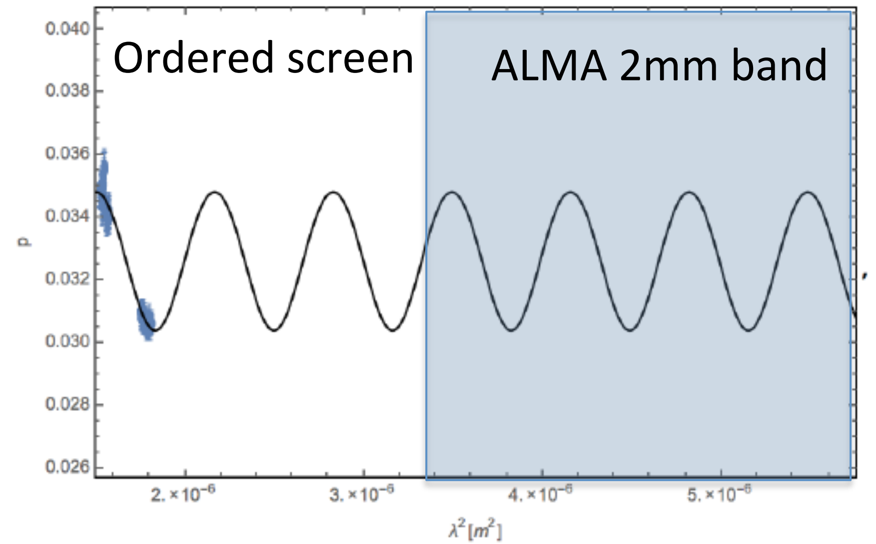
backup slides

Wider frequency coverage will help as the expected depolarization signal is very different





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