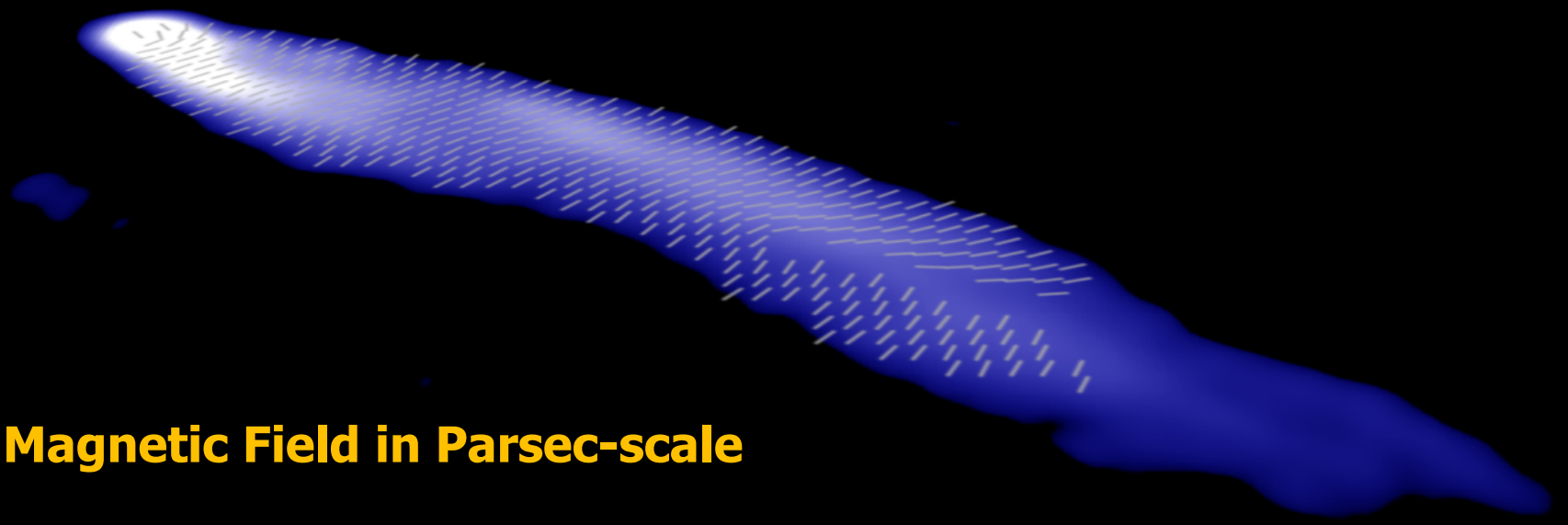

Persistent Structure of Magnetic Field in Parsec-scale AGN jets

Alexander Pushkarev

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Ilya Pashchenko, Tuomas Savolainen, Daria Zobnina

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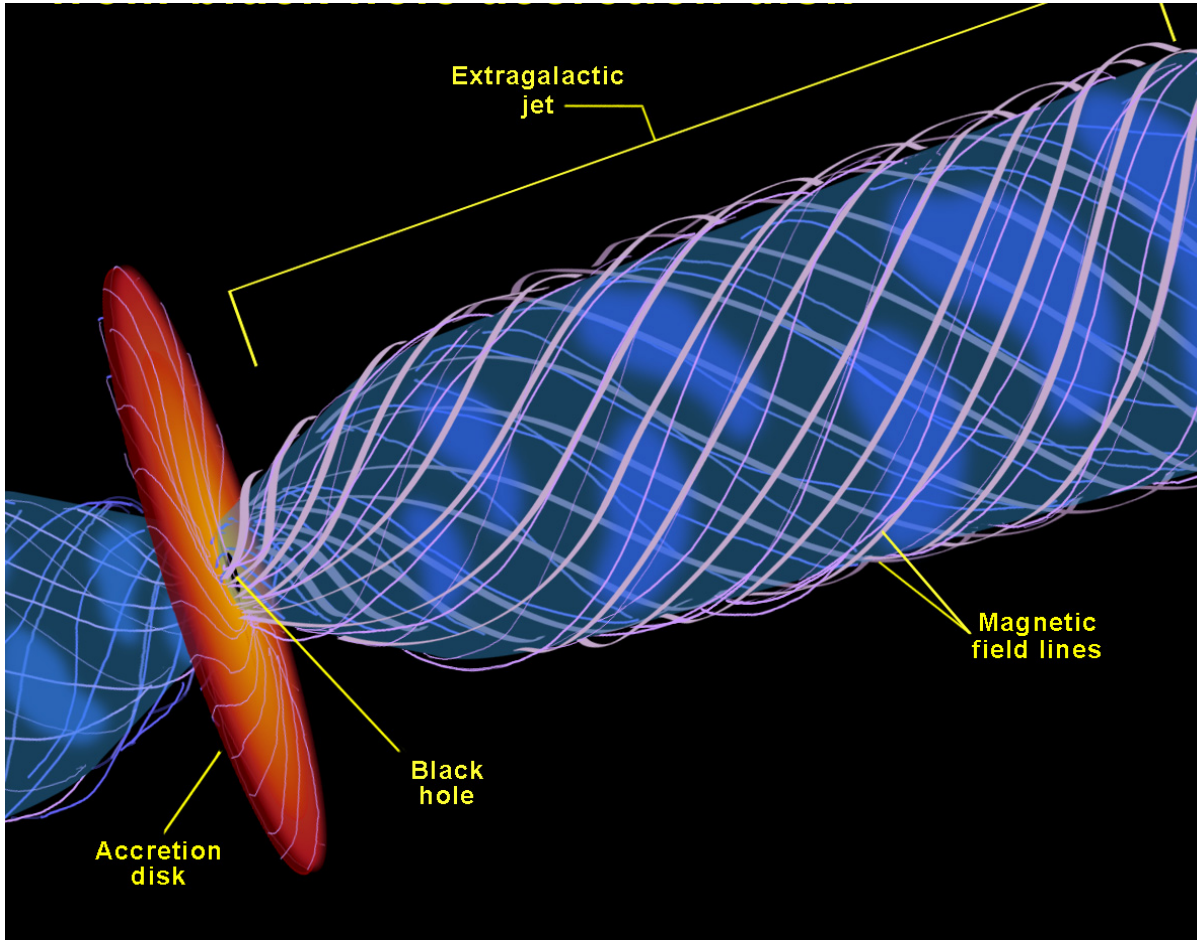
Motivation

- The role of magnetic field in AGN jet physics
  - launching, acceleration, collimation

- Aim: B-filed configuration and regularity
  (along & across the jet)

- Method: Stacking over epochs of P-sensitive obs.
  - to reveal stable B-field configuration and wash out short-term variations
  - to gain sensitivity
  - to fill out the entire outflow cross-section



Observations & Source Sample

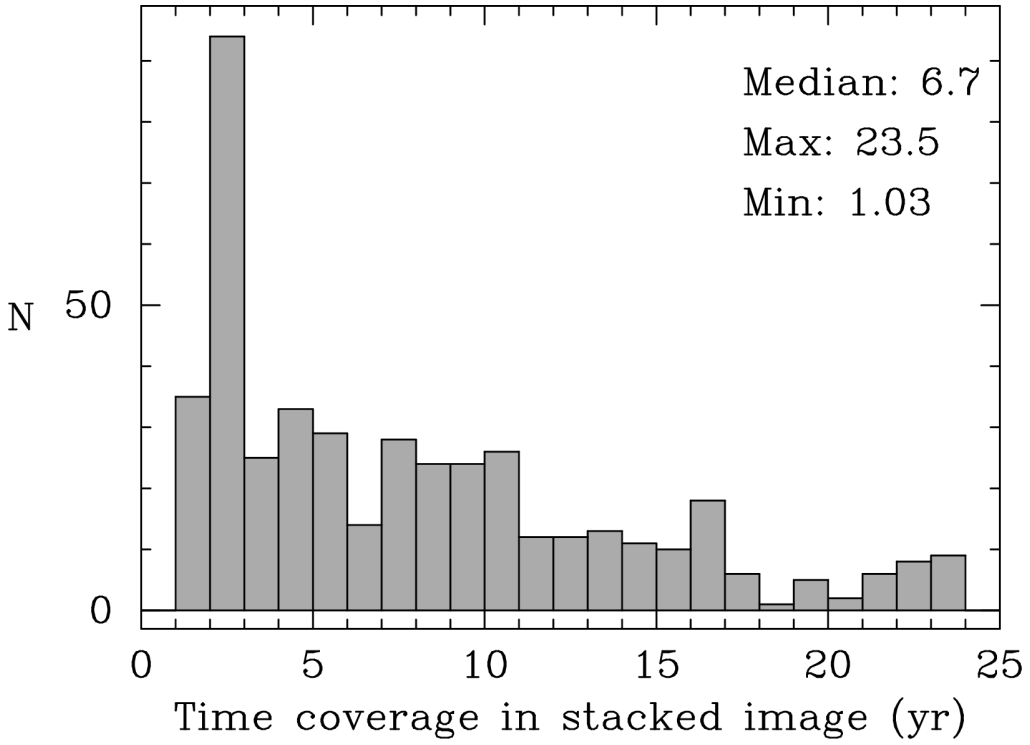
Very Long Baseline Array

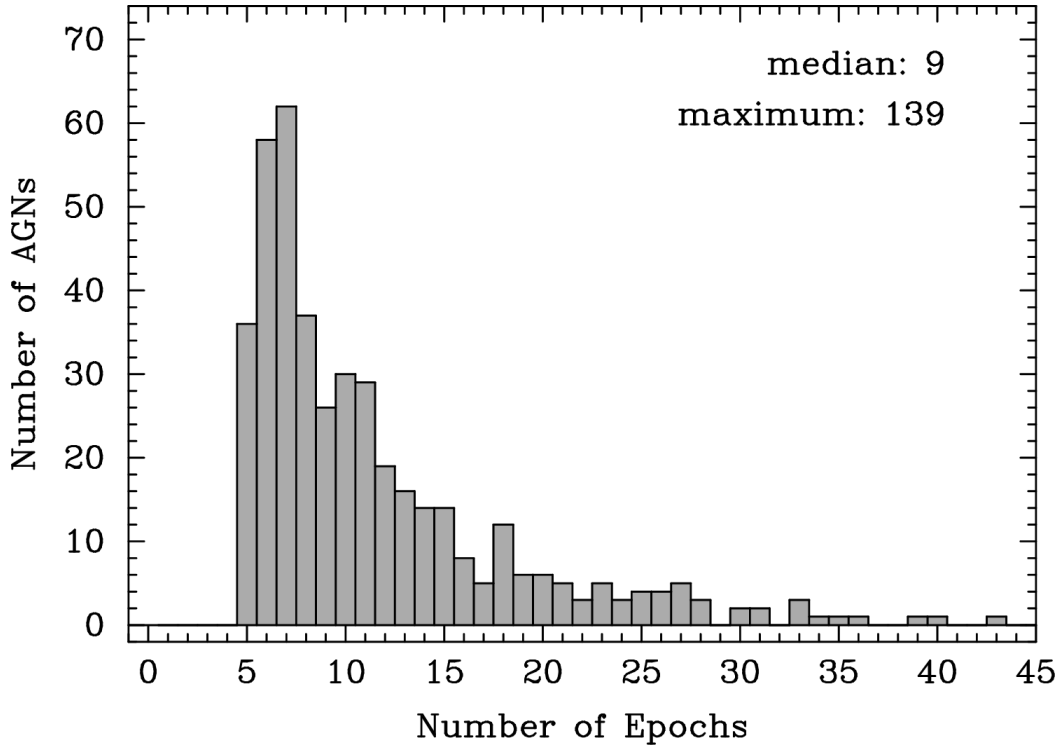
- At least 5 epochs from the long-term MOJAVE program or archival full Stokes obs. at 15 GHz with VLBA

➔ 437 sources (60% - quasars, 30% - BL Lacs, 4% - RG)

➔ 368 unique epochs (90% from MOJAVE) from 1996 to 2019

➔ 5983 single-epoch maps





Methods of Polarization Stacking

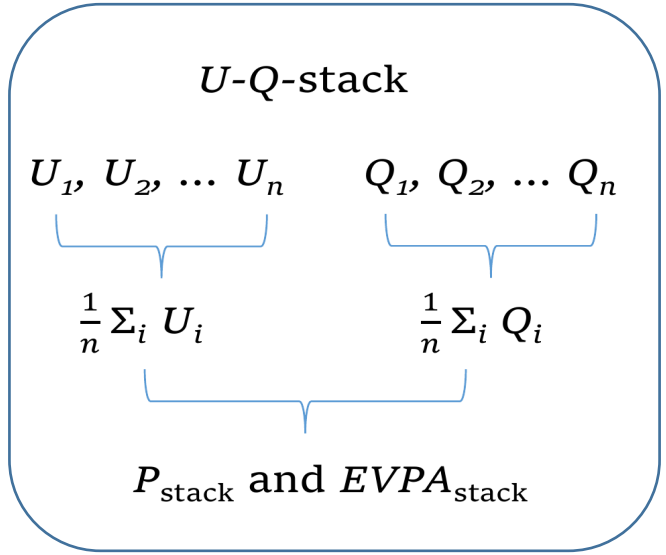
Procedure
- Convolve Stokes I, Q, U single-epoch maps with a circular beam
- Align by the core position
- Filter out noisy epochs (rms > 3 rms_med)
- Produce stacked I maps

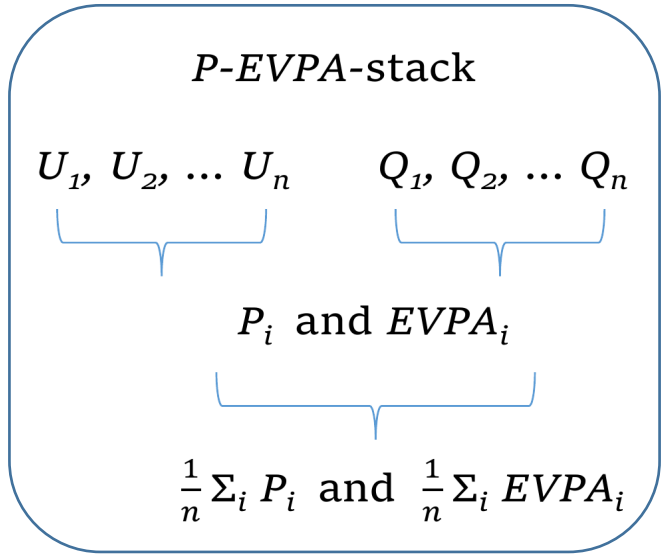
Approach 1
- Produce stacked Q, U maps ➔ stacked P, EVPA, m maps
- Correction for Ricean (Wardle & Kronberg, 1974) and CLEAN biases

➔ Deeper P-images (σ_p, m, EVPA ~ $1/\sqrt{N}$)

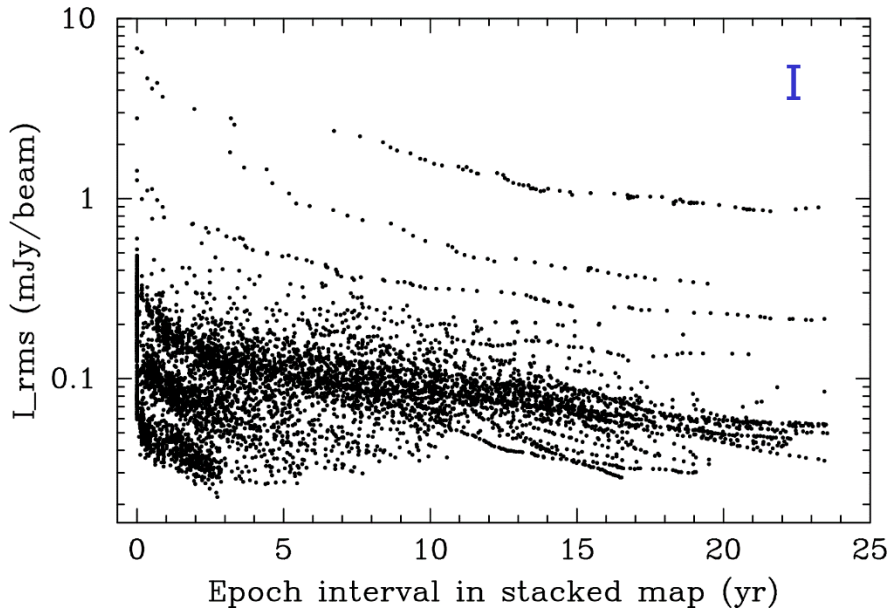
Approach 2
- Produce single-epoch P, EVPA, m maps ➔ stacked P, EVPA, m maps
- No gain in sensitivity (averaging P>0 signal)

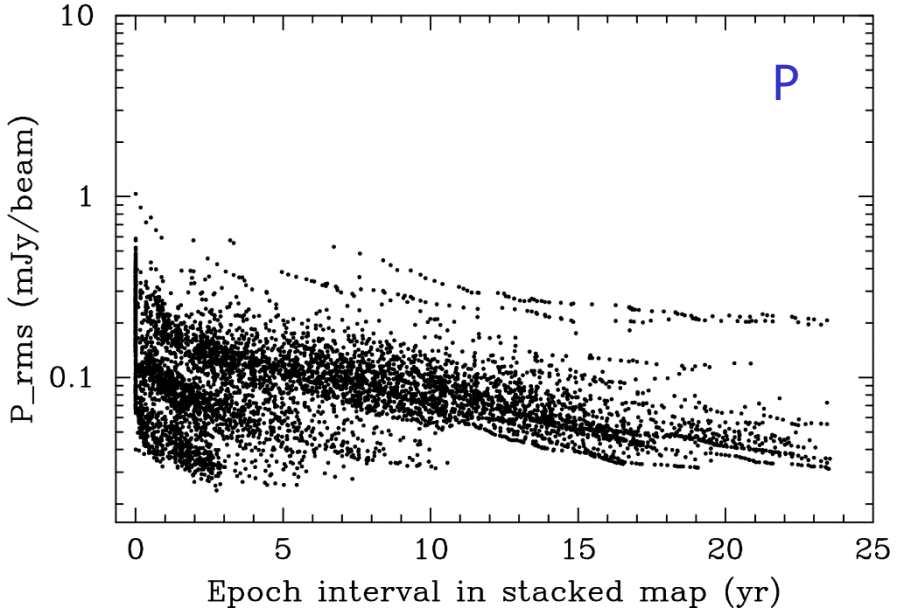
➔ Allows to study variability (D. Zobnina talk)

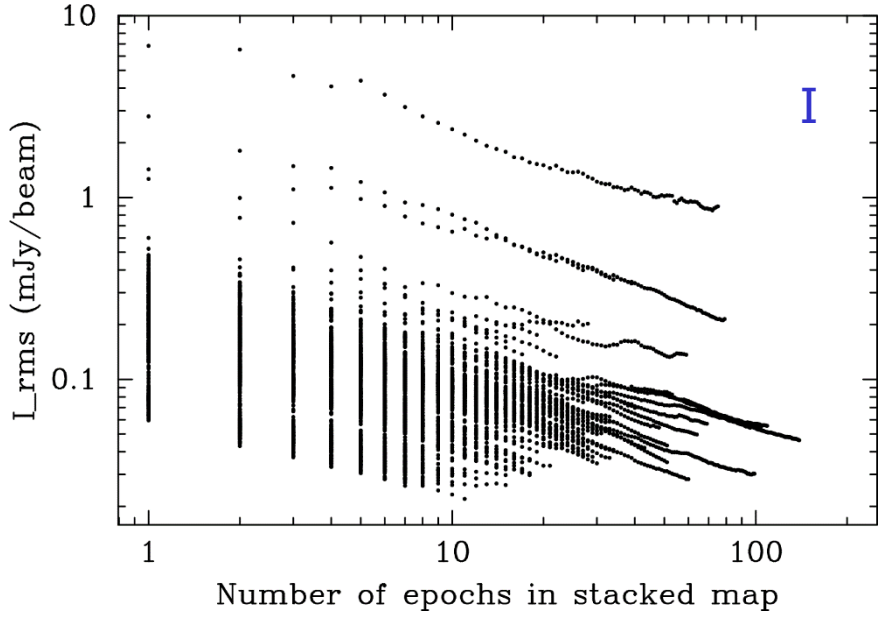


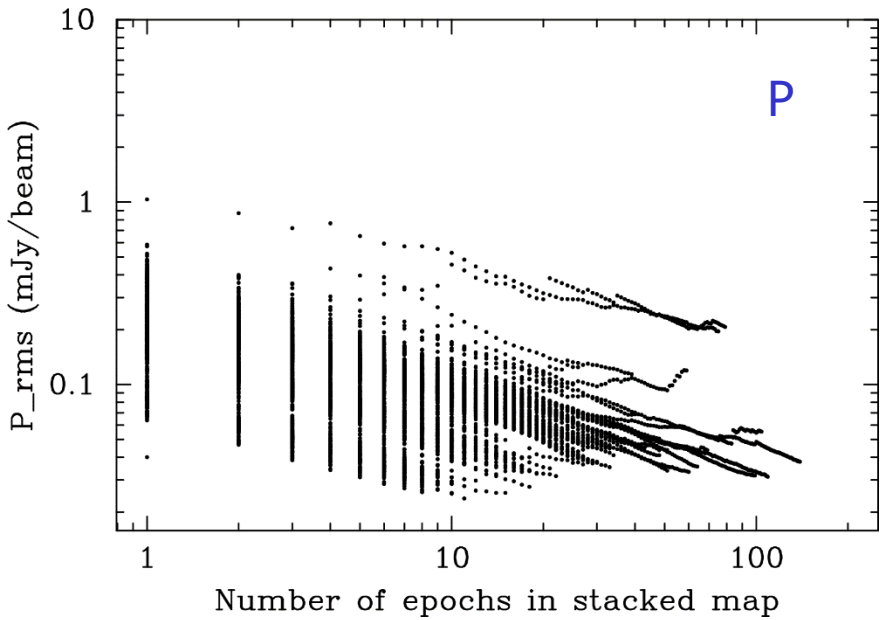


Stacking & Sensitivity

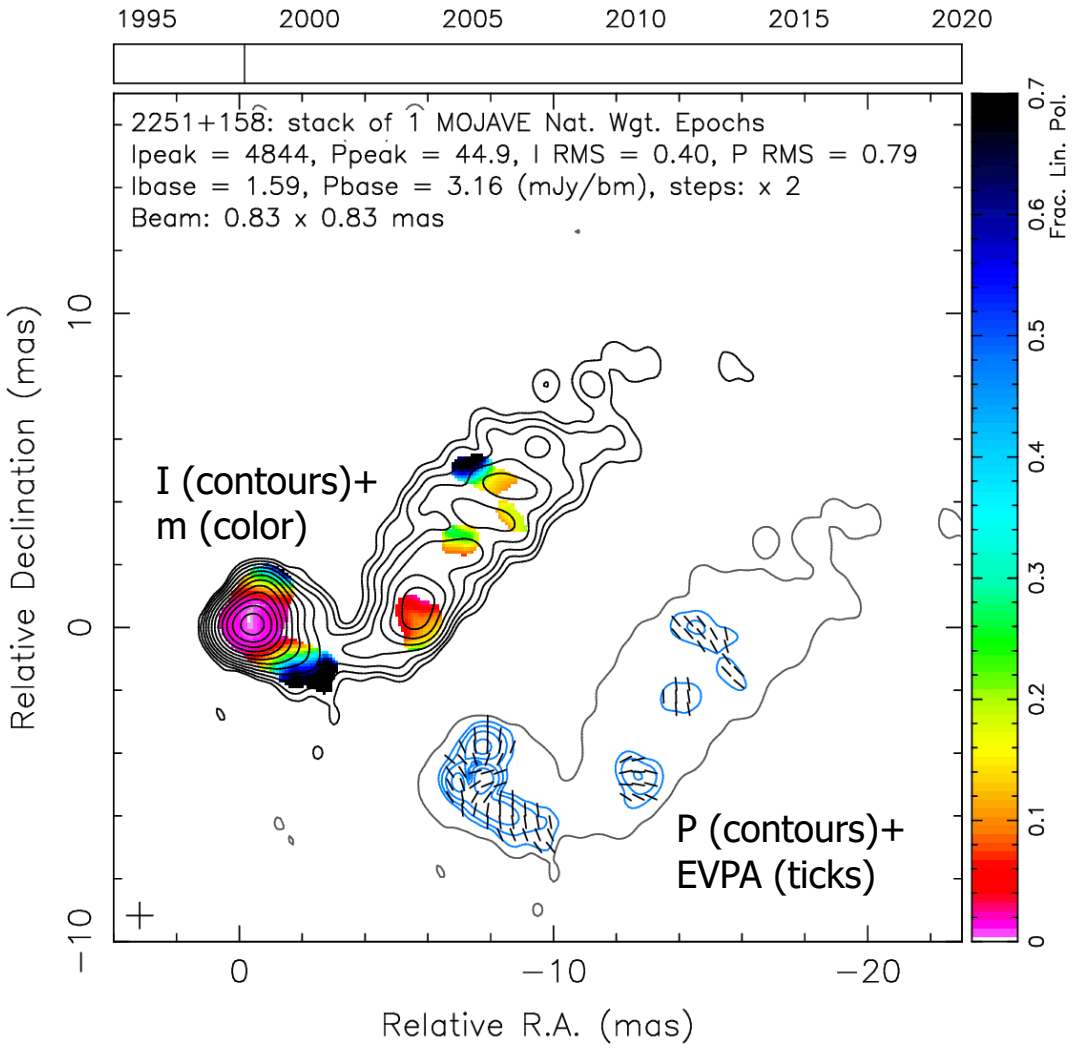


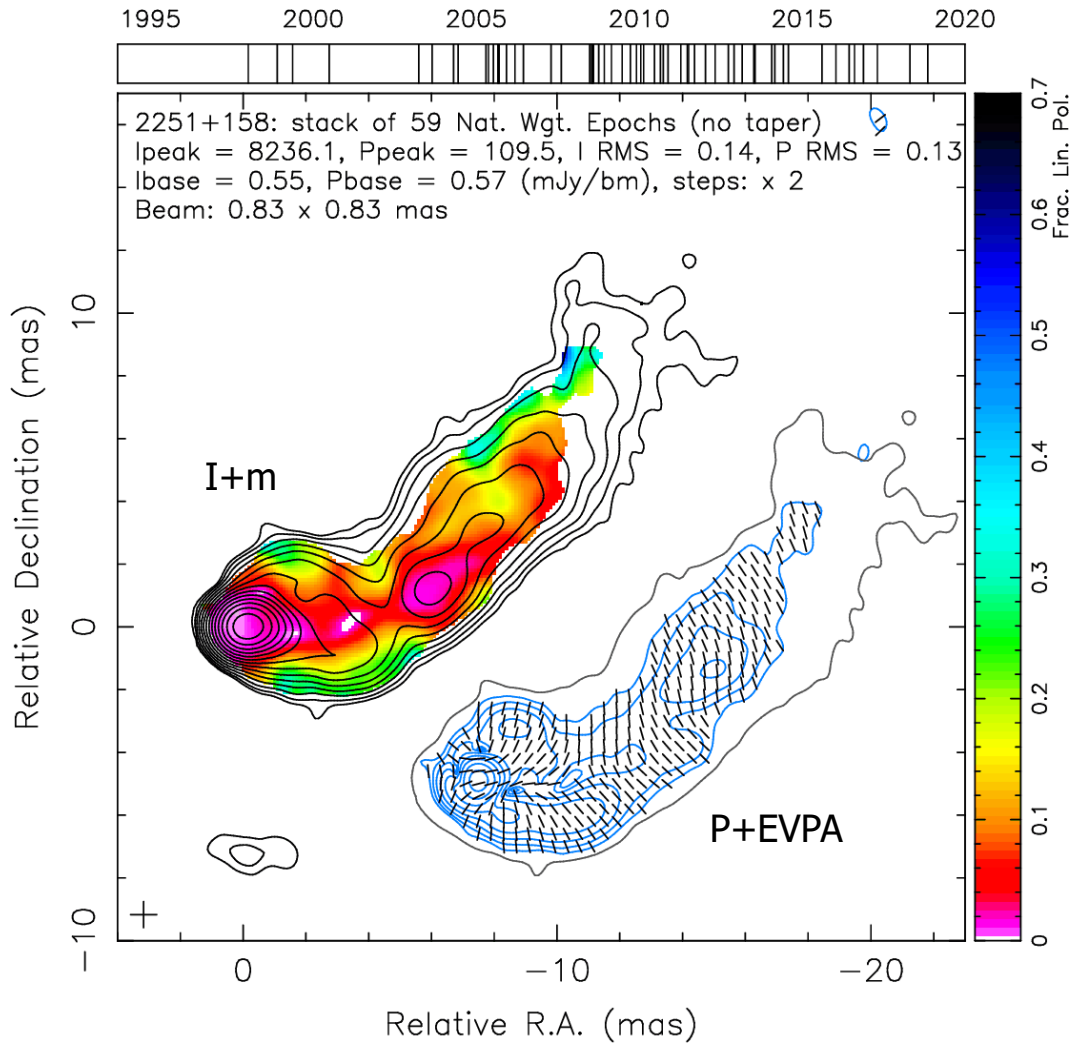






Polarization Stacking Example: 3C454.3

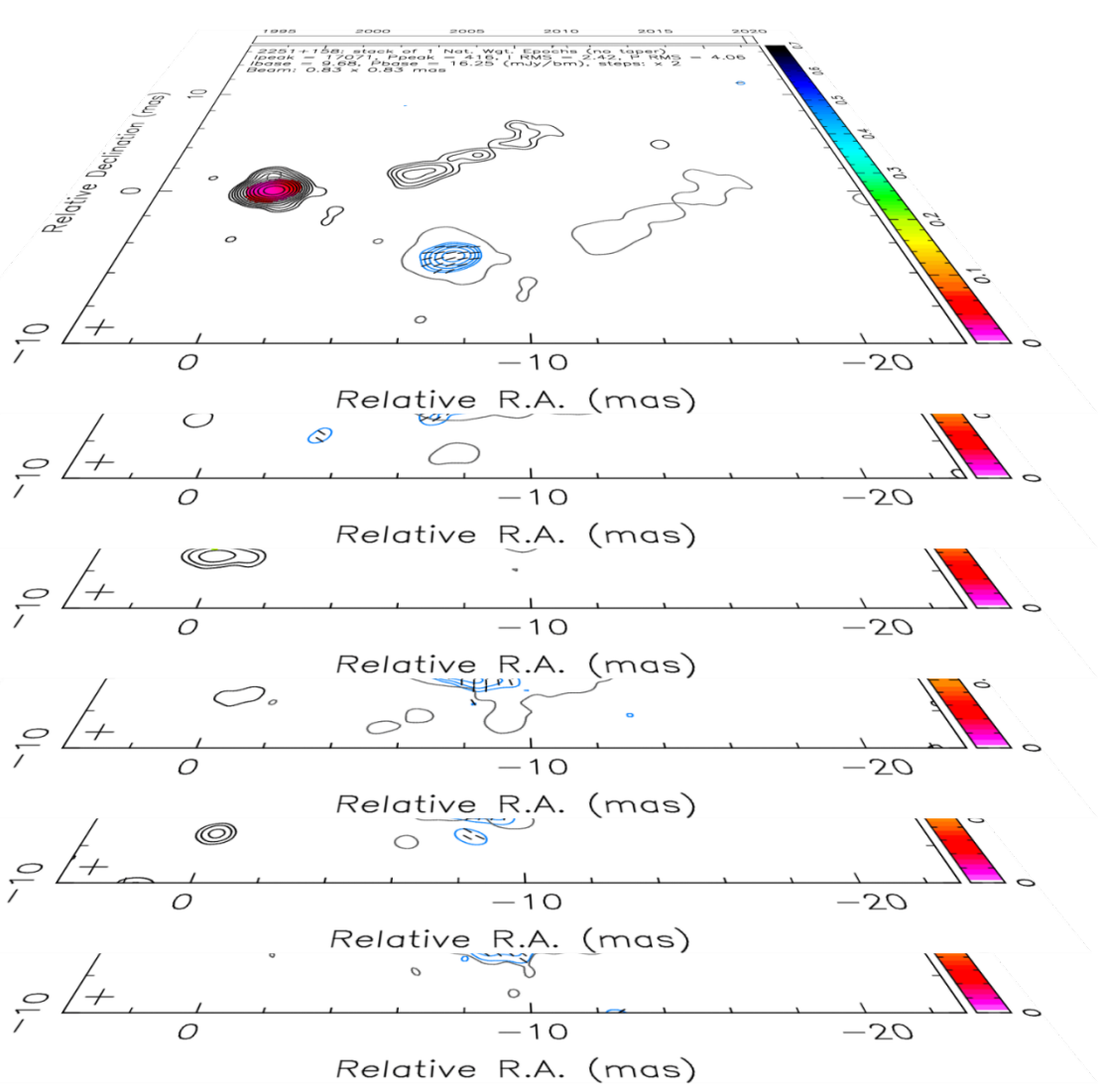




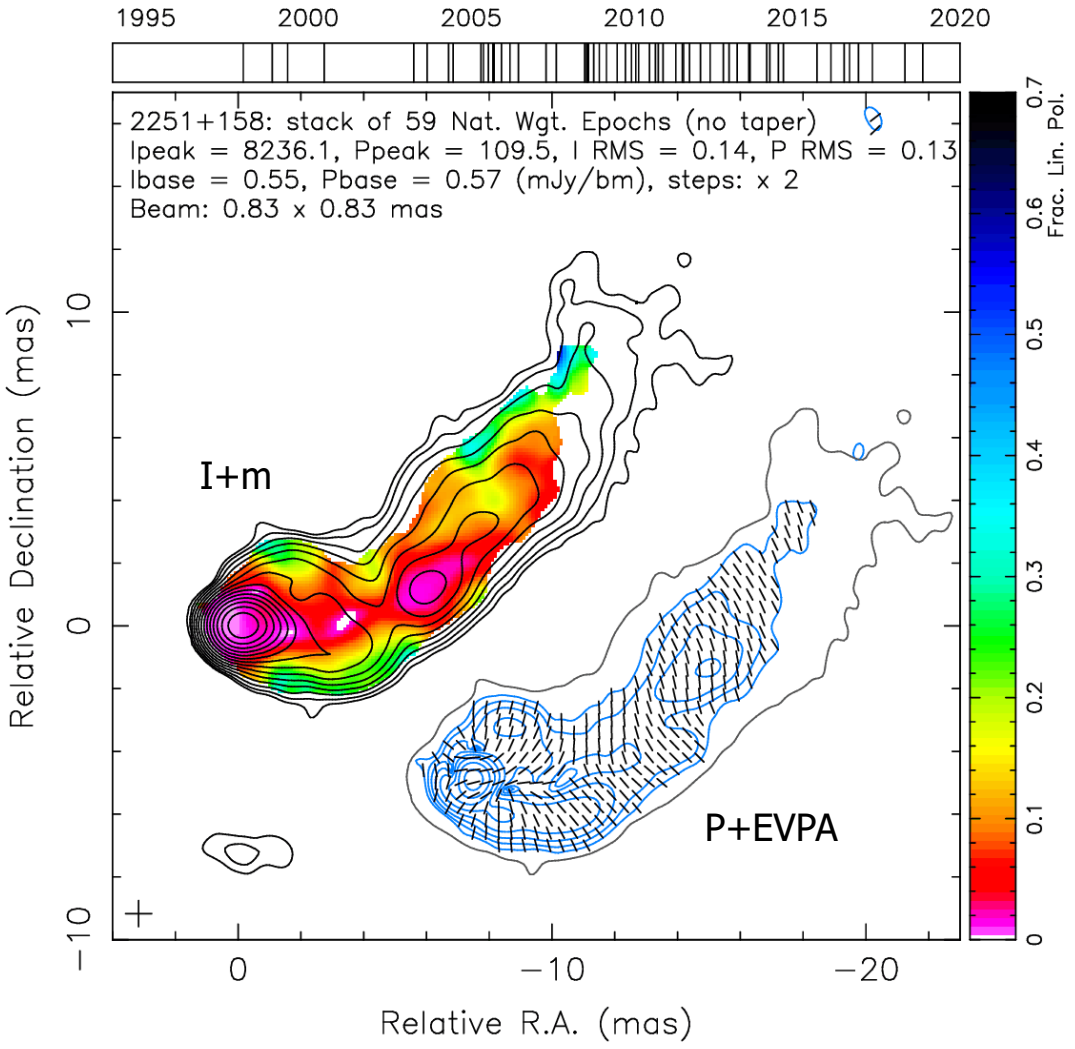
Single-epoch map: patchy P detection

Stacked map: complete in P; delineates stable B-field comp.

Polarization Stacking Example: 3C454.3

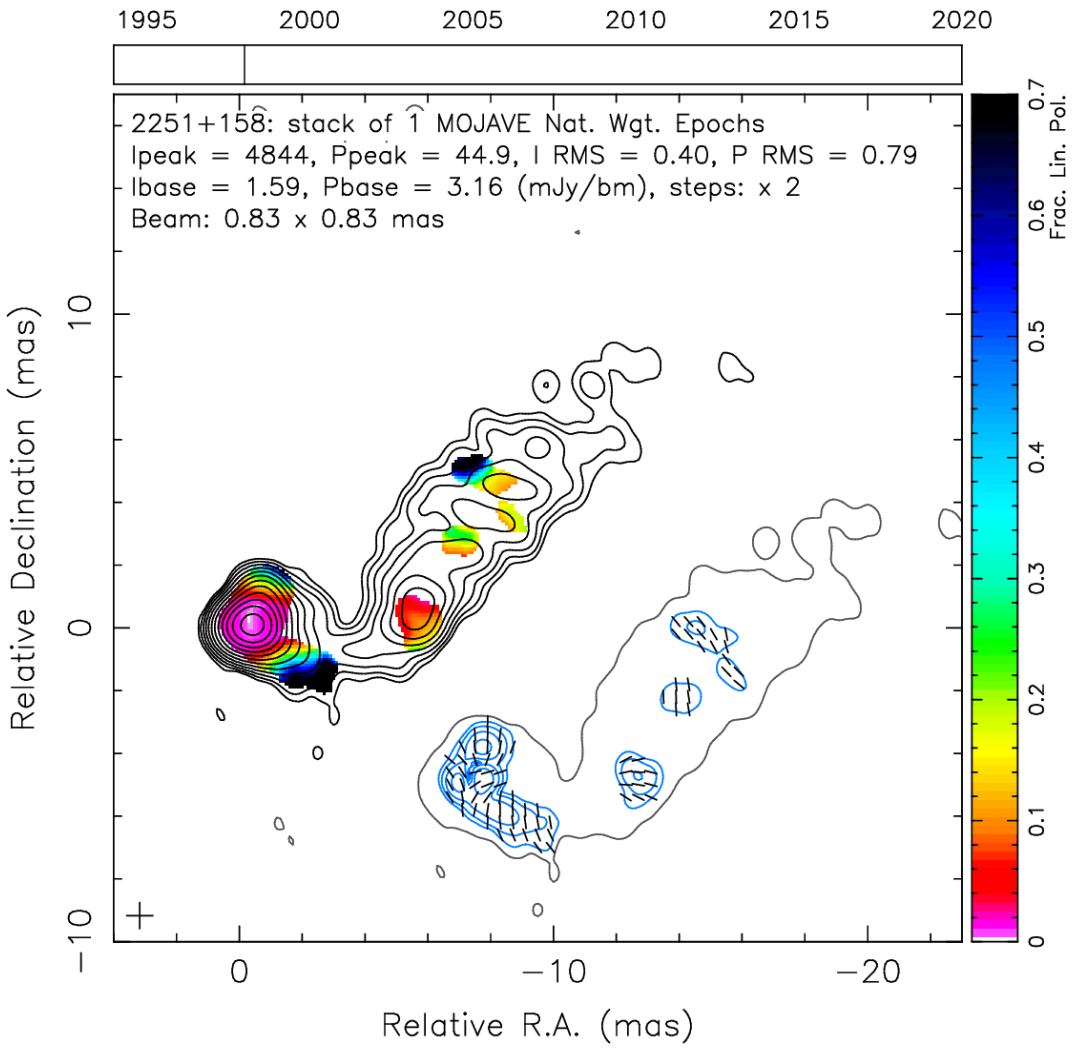


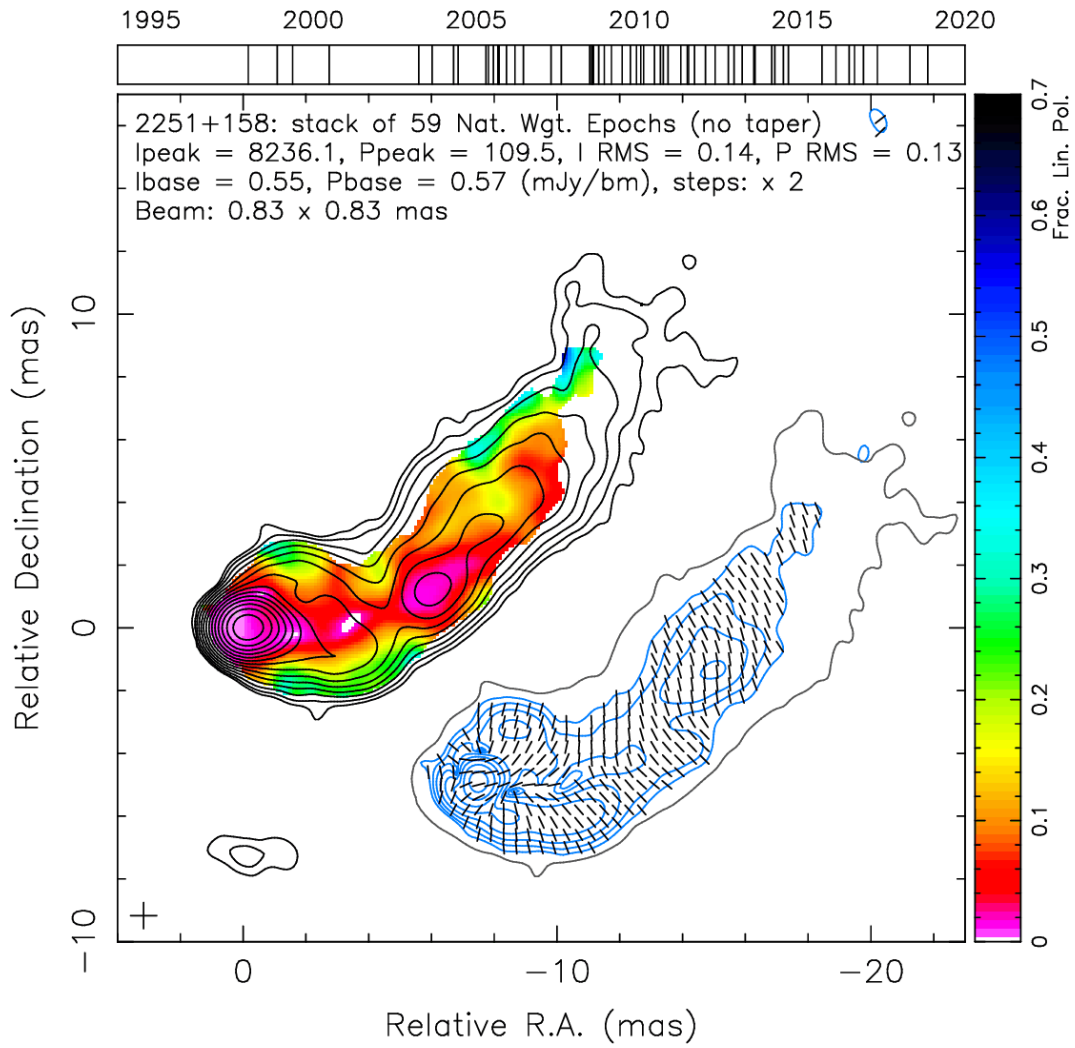
Single-epoch map: patchy P detection



Stacked map

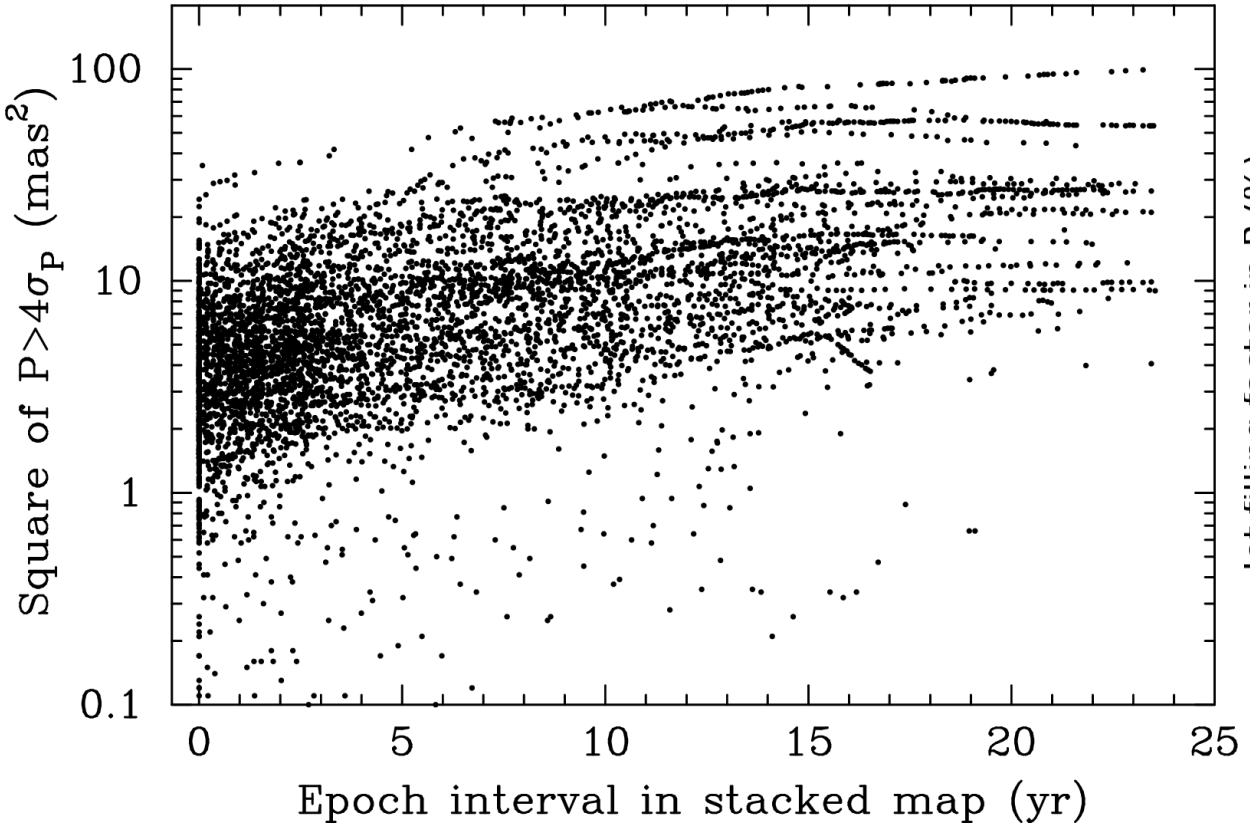
Cumulative Stacking Example: 3C454.3



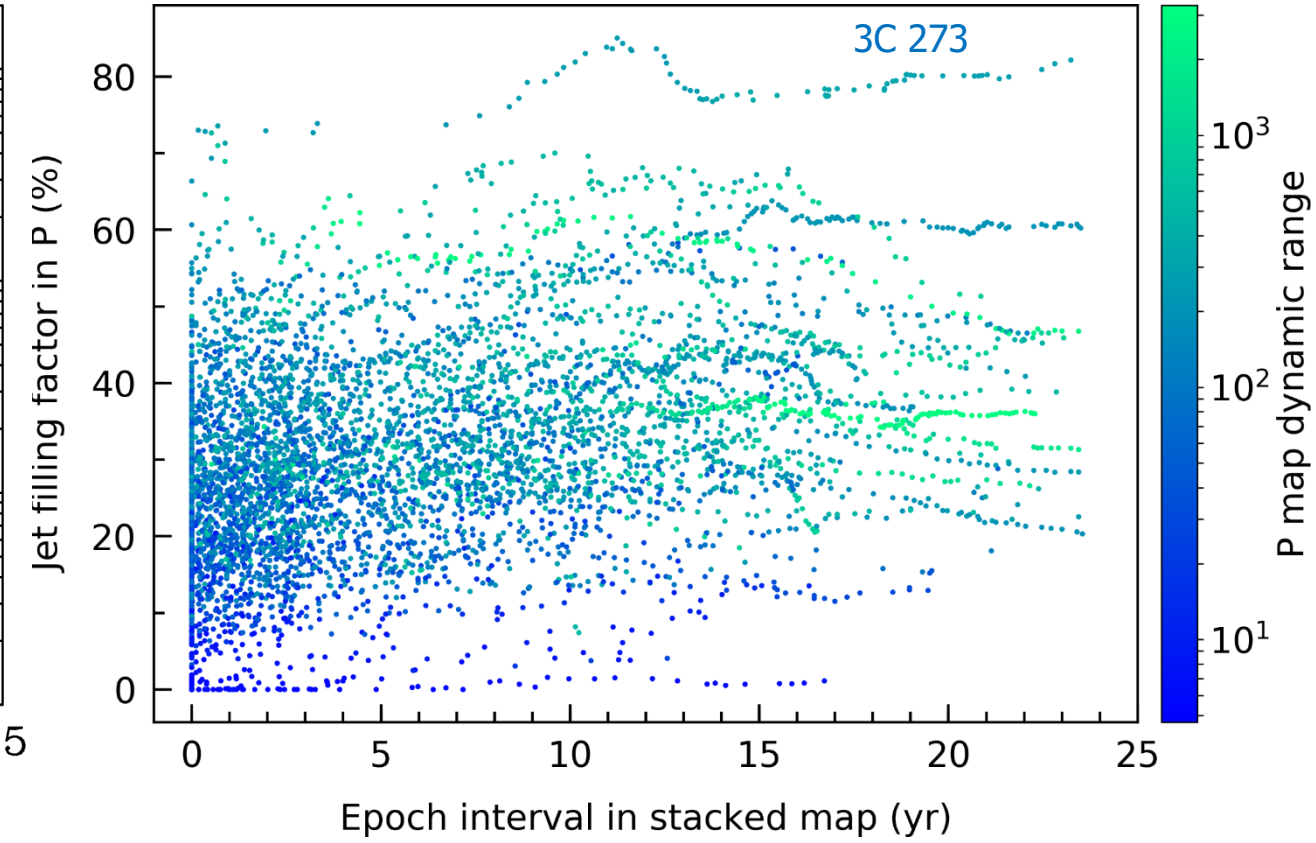


It takes ~ 10 years to fill out jet cross-section in P

Filling out jet cross-section in P

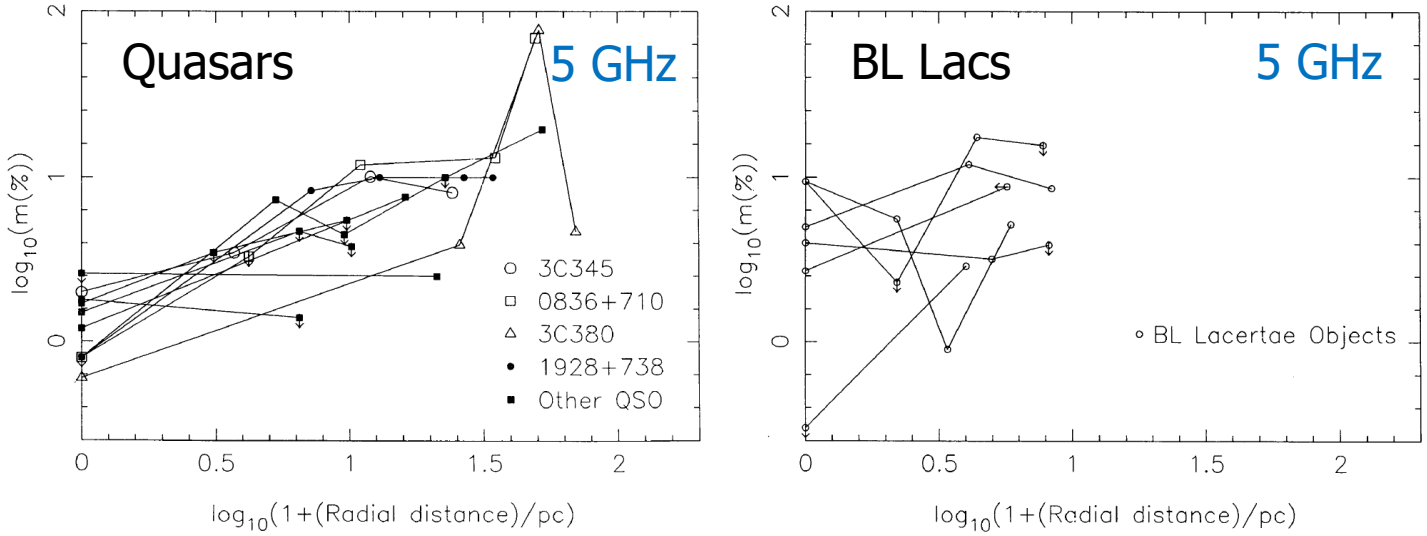


Filling factor = S_P/S_I * 100%

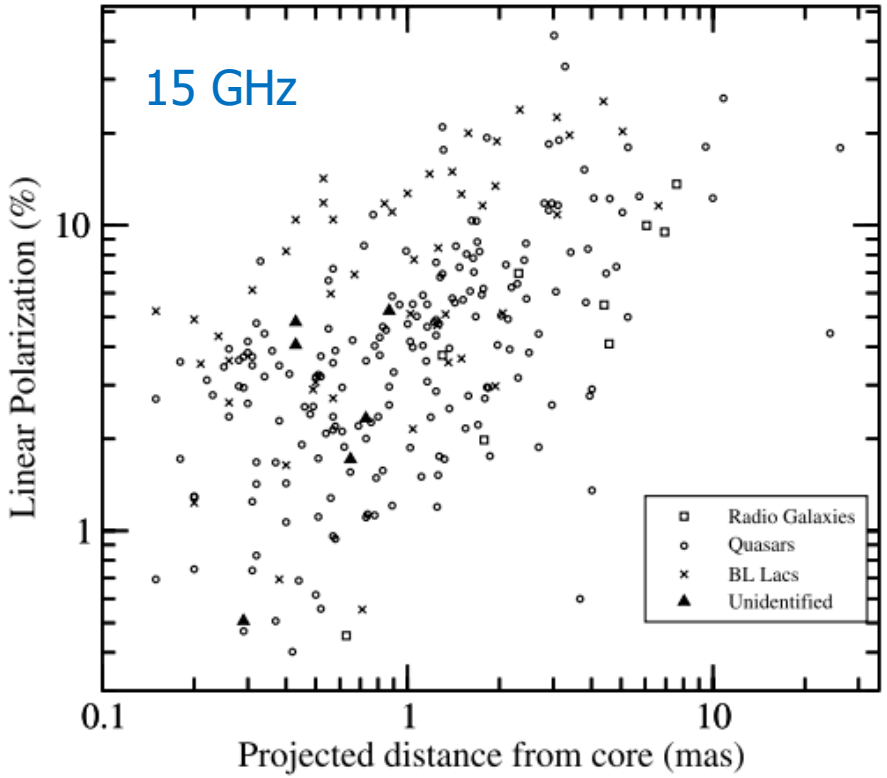


It takes ~ 10 years to fill out jet cross-section in P

Polarization degree along the jet: early studies



24 sources from the Pearson-Readhead sample (Cawthorne et al. 1993)

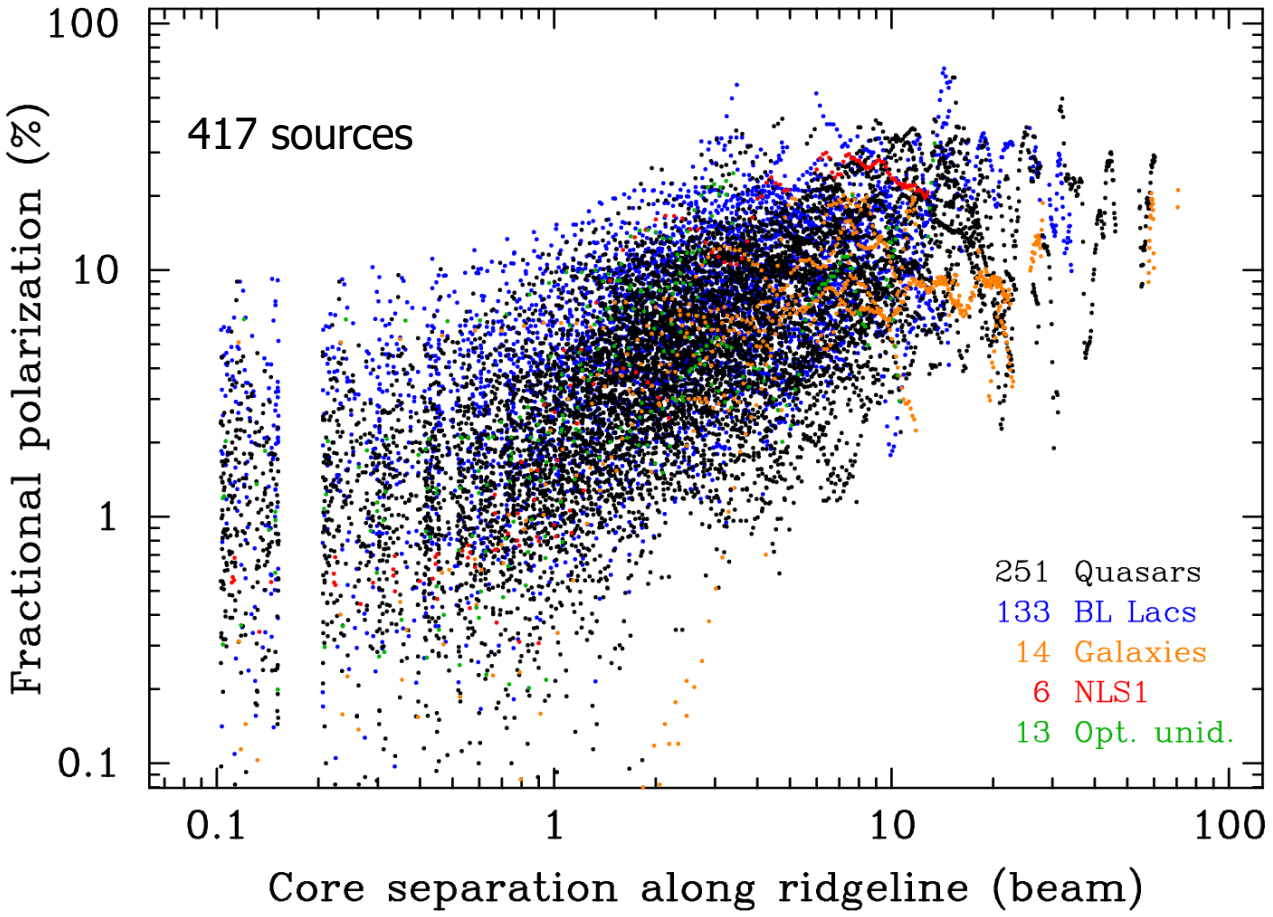


First-epoch of 133 MOJAVE sources (Lister & Homan, 2005)

B-field decreases down the jet as $B \sim r^{-2}$ but becomes more ordered

Polarization degree along the jet

Degree of polarization



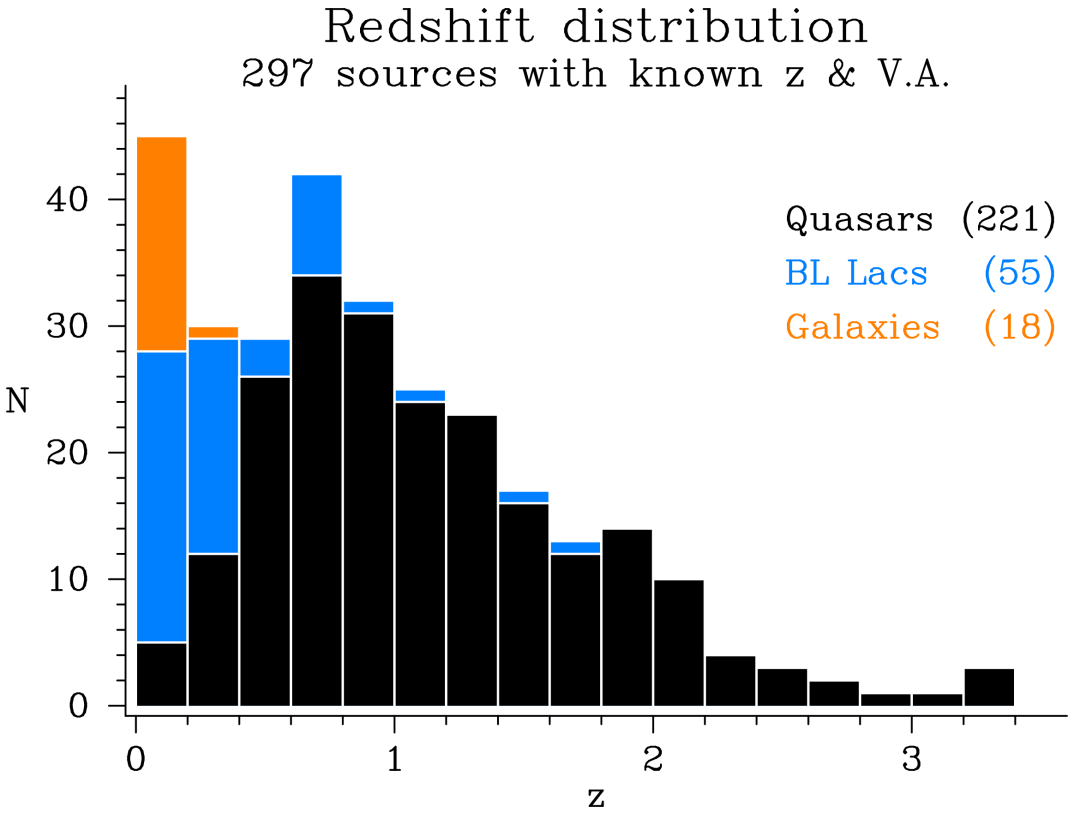
- constant within the core, m_med ~ 1%, m < 10%
  - opacity & Faraday effects (Gabuzda et al. 2018)
  - in-beam depolarization

- increases down the jet reaching 10-30% due to
  - decreasing opacity

    (synchrotron emission becomes optically thin)
  - spectral aging

    ($\Delta\alpha \approx -0.6$; Kardashev 1962; Hovatta et al. 2014; Pushkarev & Kovalev 2012)
  - turbulence weakening (Marscher 2014)
  - pitch-angle decrease (Porth et al. 2011)

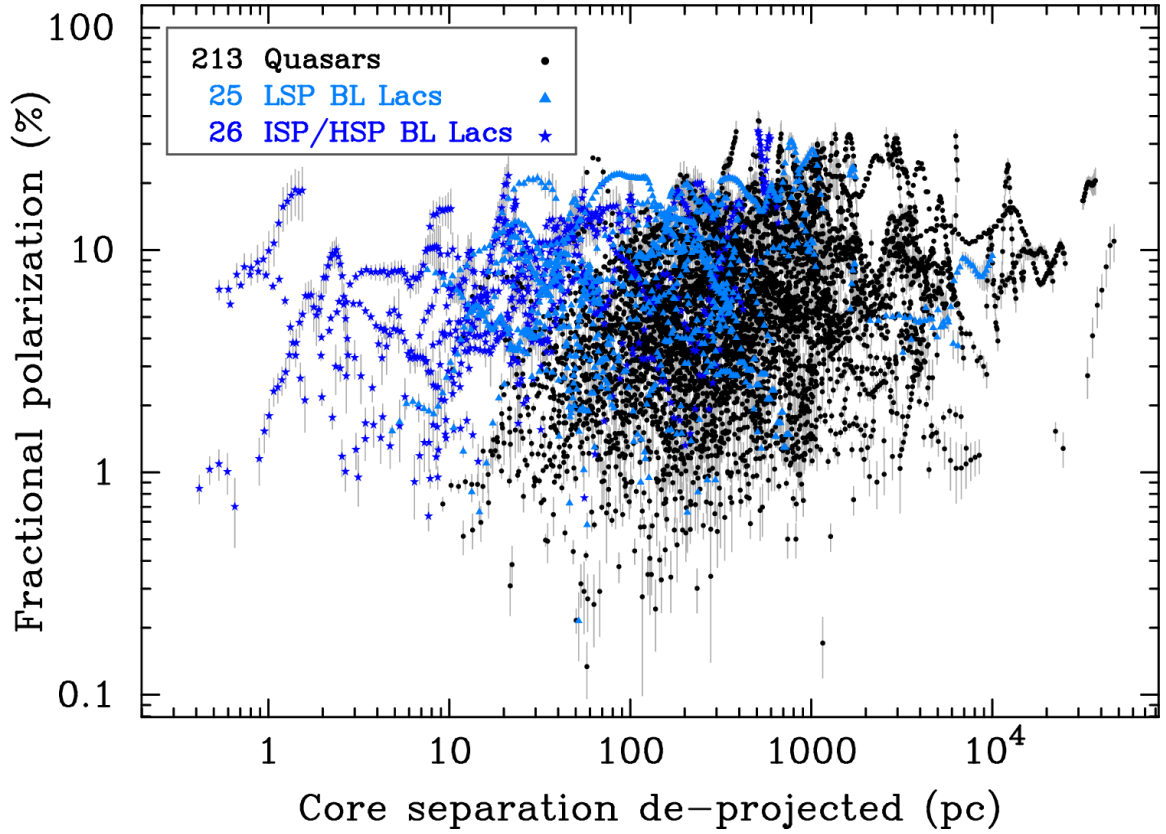
Polarization degree along the jet: BL Lac vs quasars



$$\theta = \arctan \frac{2\beta_{\rm app}}{\beta_{\rm app}^2 + \delta_{\rm var}^2 - 1} \qquad \delta = T_{\rm b,obs}/T_{\rm b,int}$$

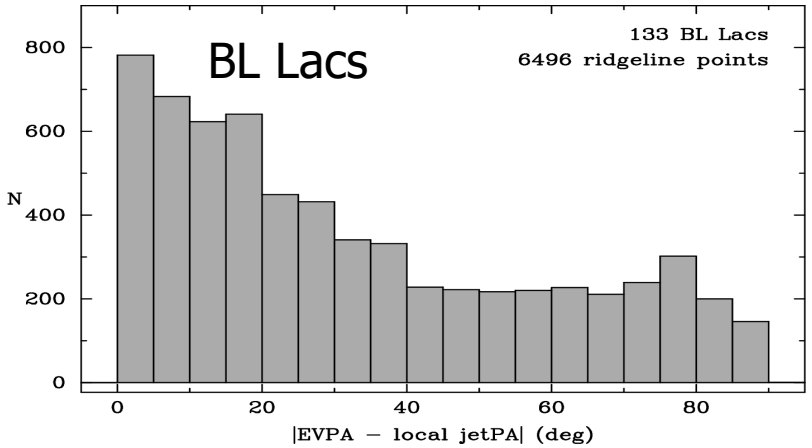
Apparent speeds (Lister+ 2021)

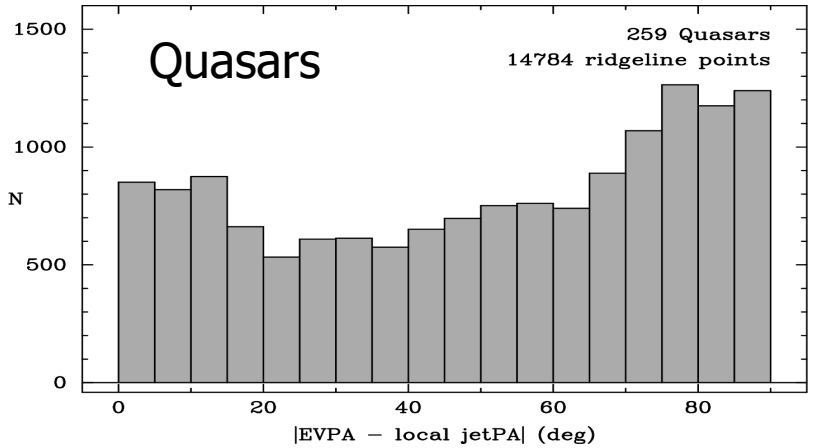
Viewing angles & Doppler-factors (Homan+2021)

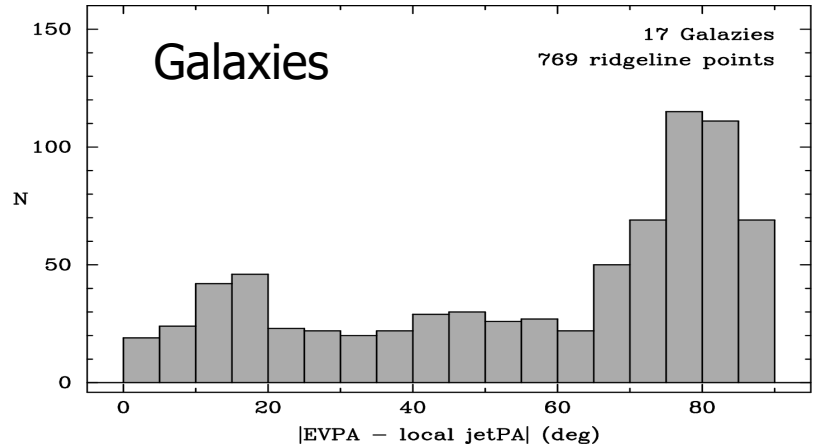


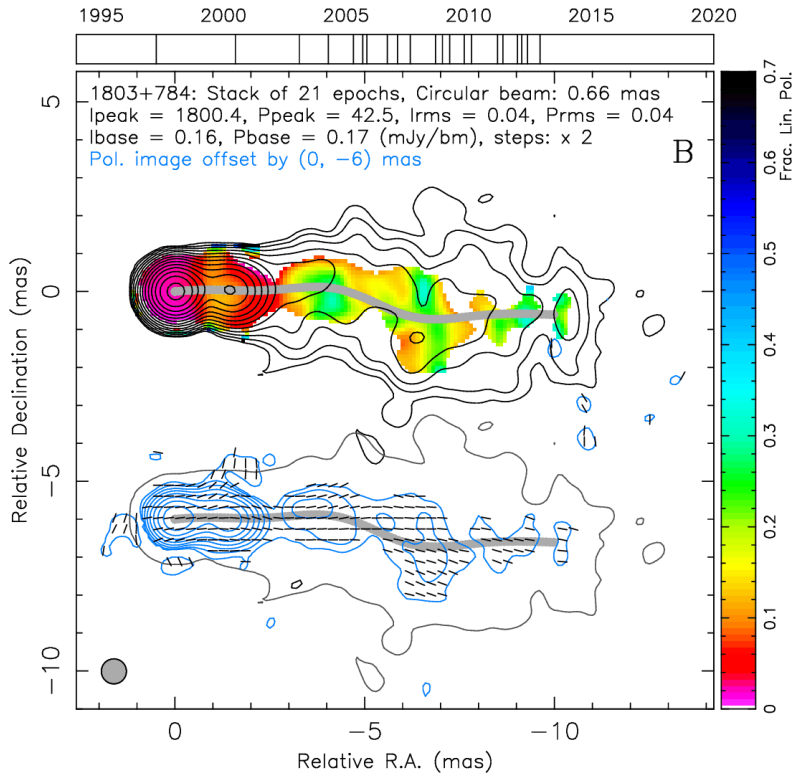
- Up to deca-parsec scales BL Lacs have higher m-values in their jets (mostly ISP/HSP)
- Starting from hecto-parsec scales BL Lacs (mainly LSP) and quasars show comparable fractional polarizations

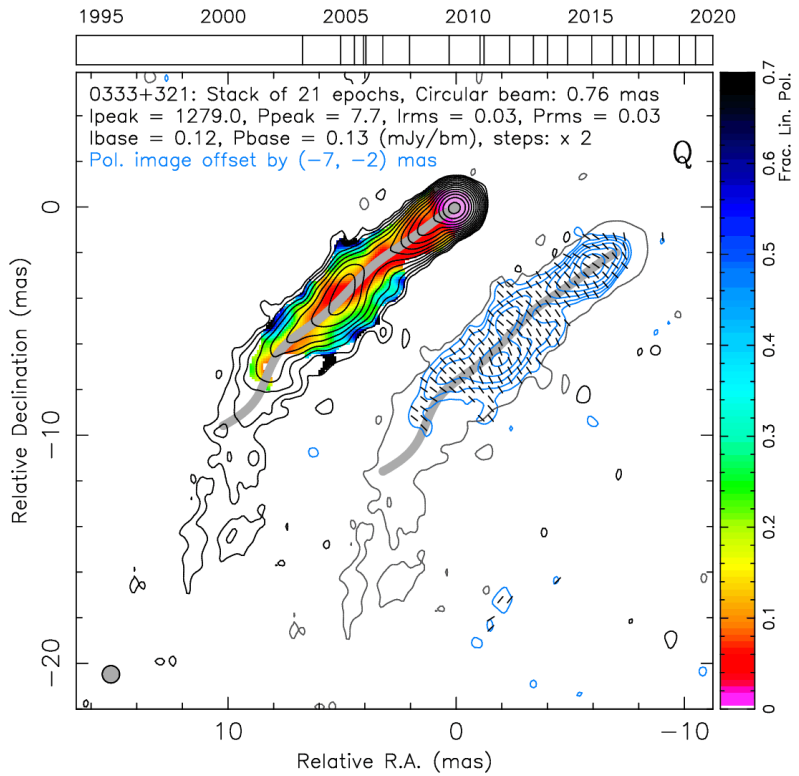
EVPA along the jet

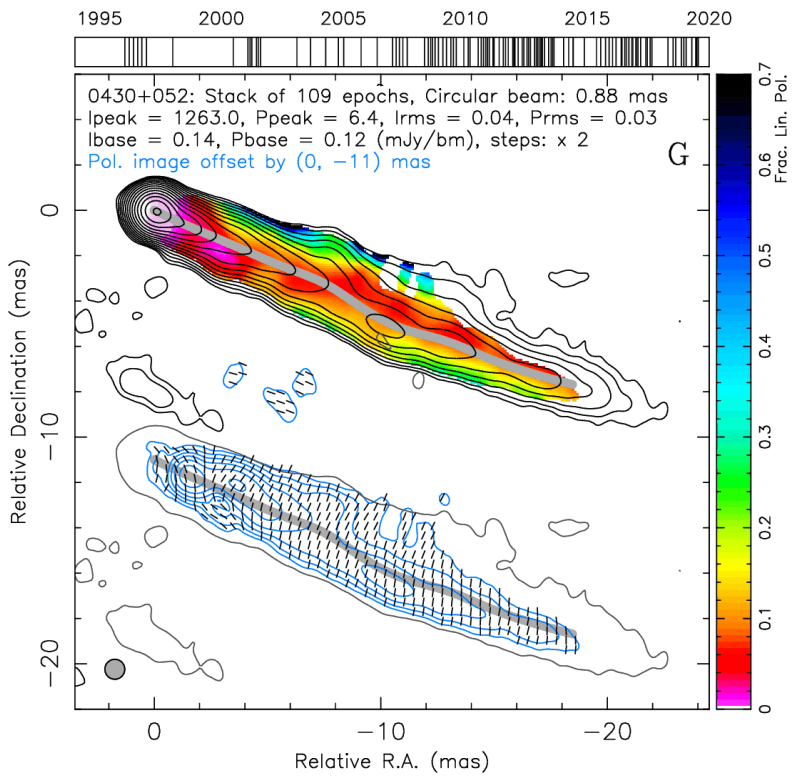




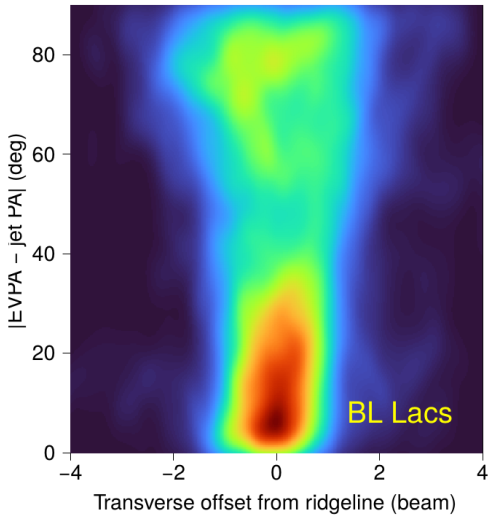






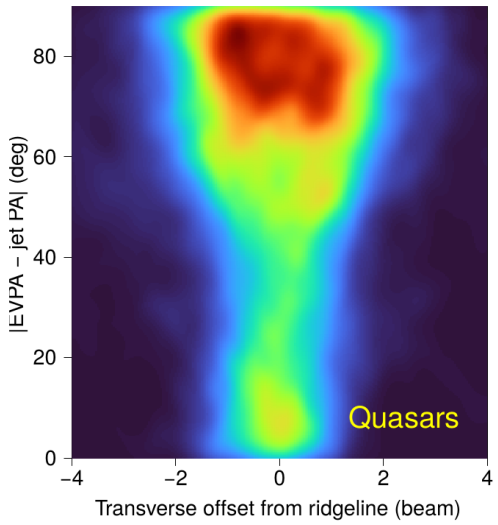


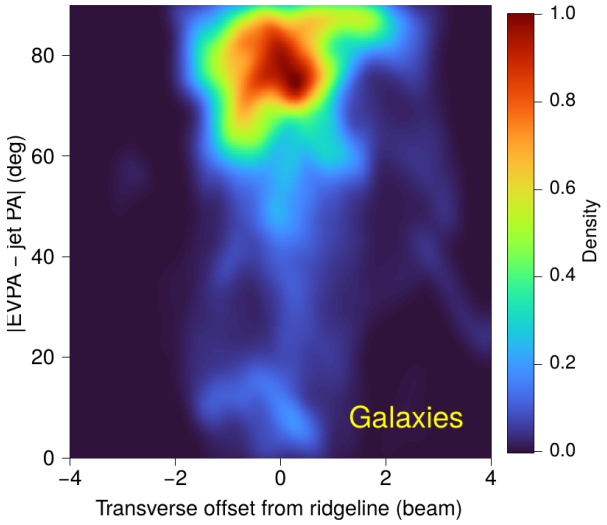
|EVPA – jet PA| vs ridgeline offset

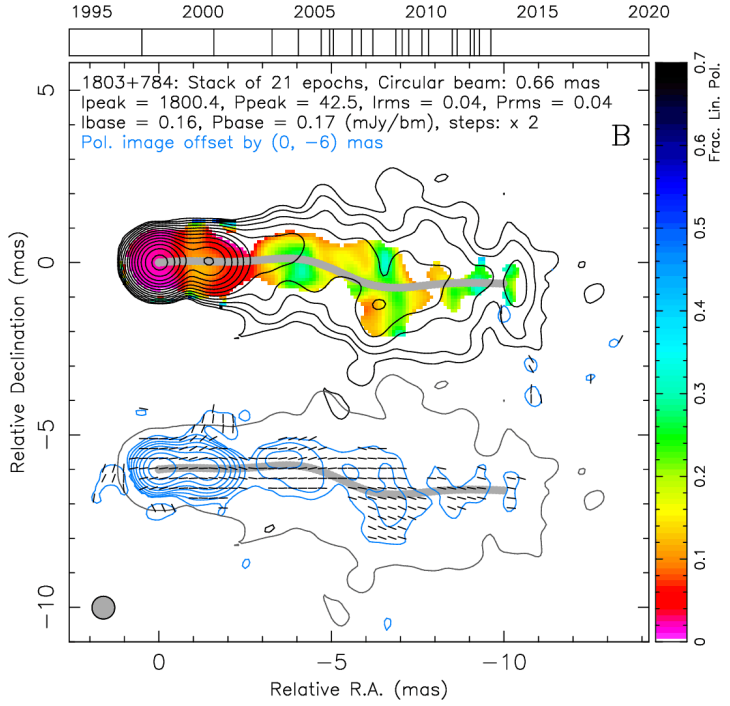


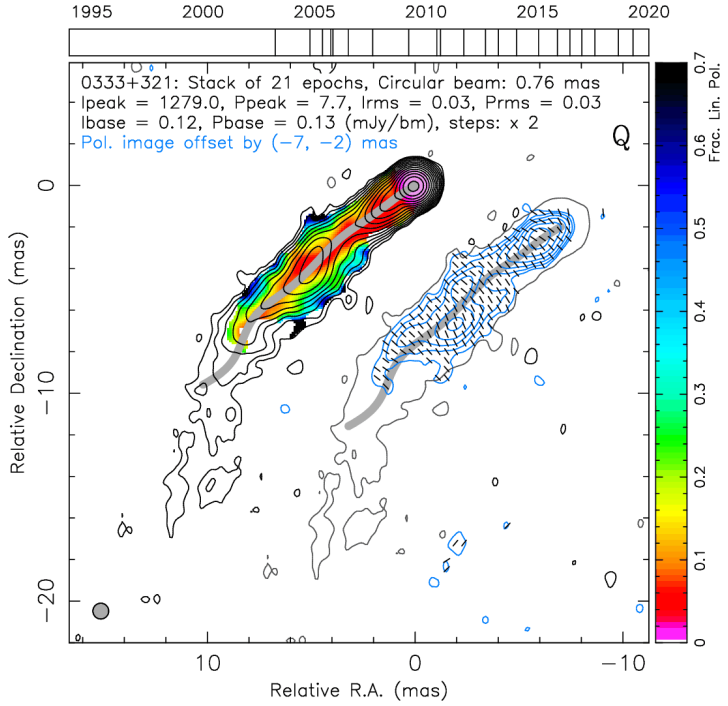
2d histograms: EVPA vs ridgeline Offset

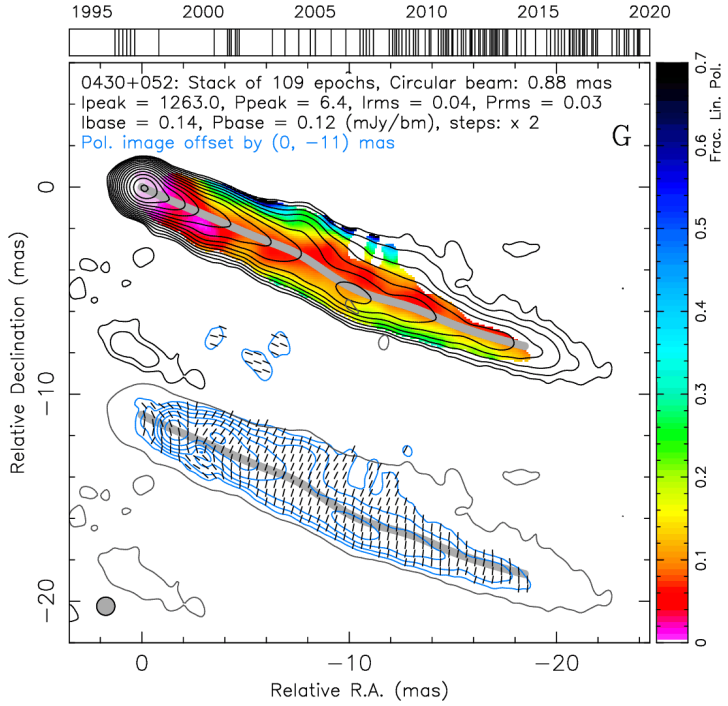
EVPA-jetPA as a FSRQ/BL Lac discriminator (D. Gabuzda)



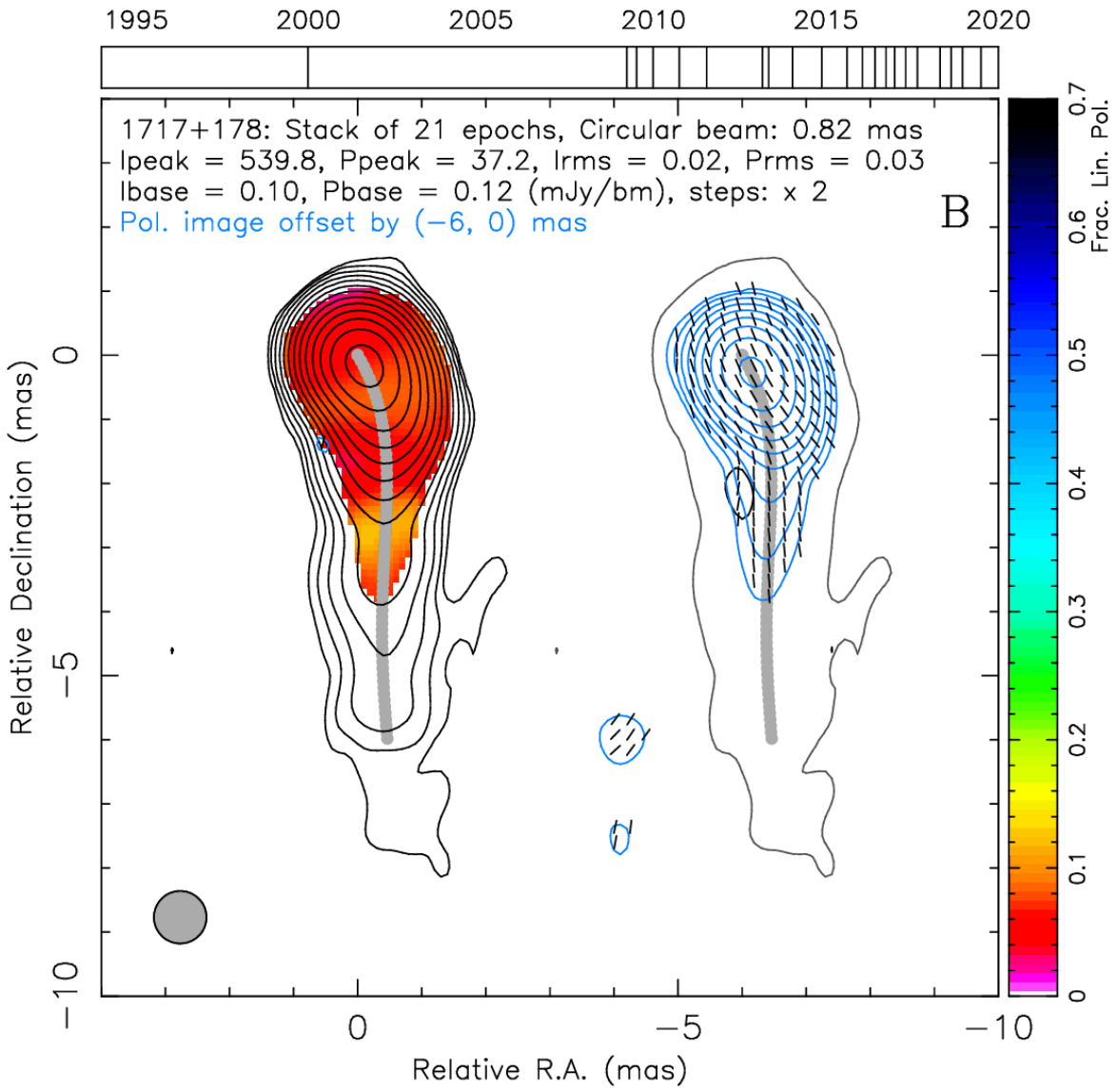




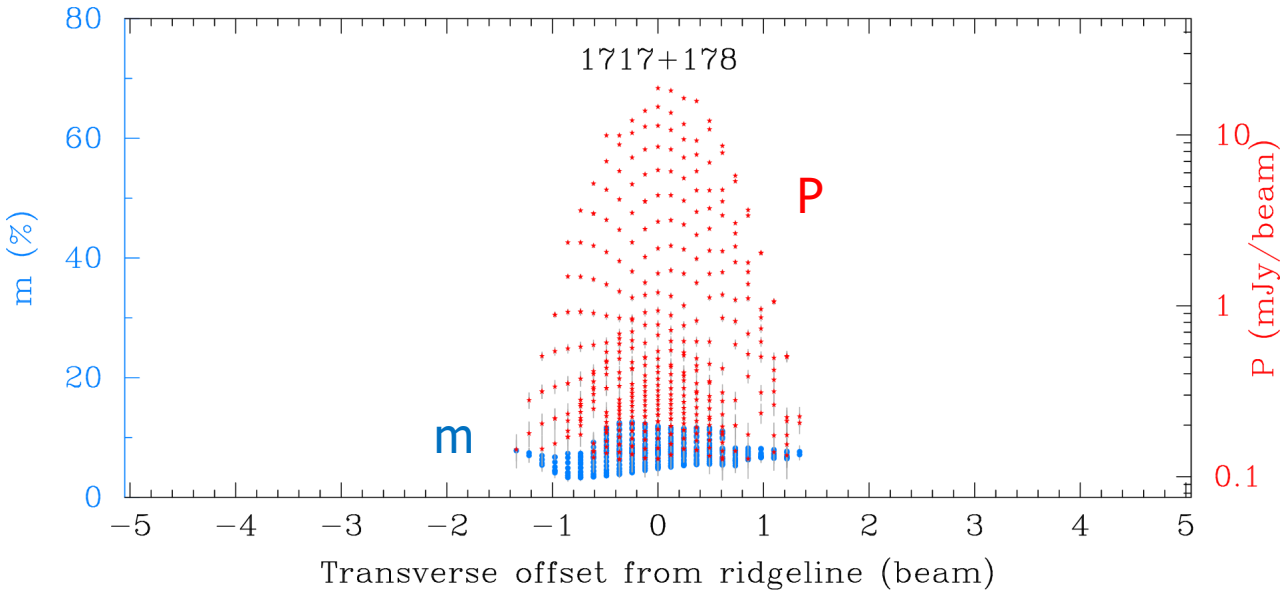




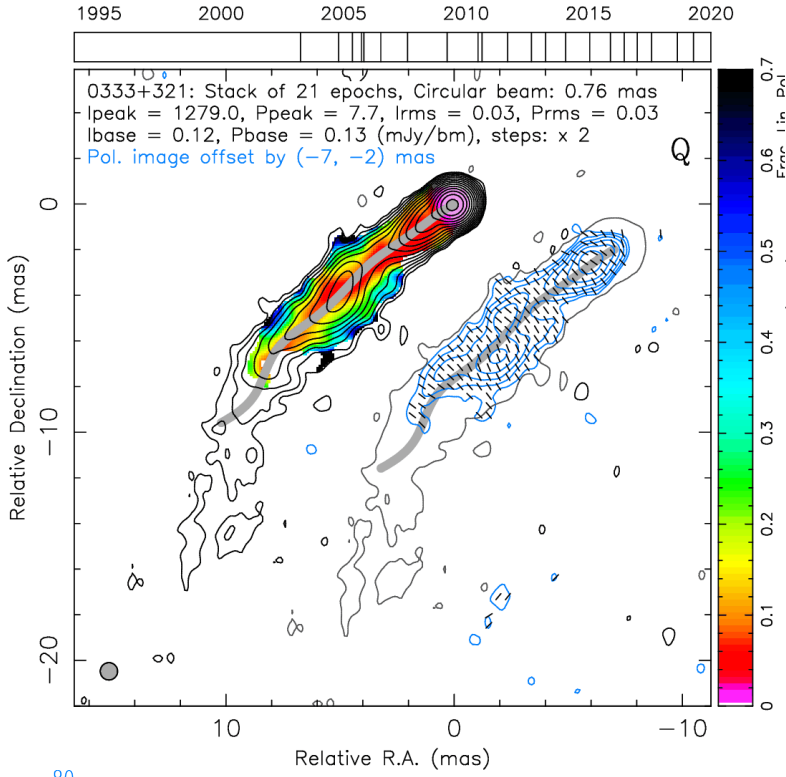
Polarization degree across the jet: flat m-cuts

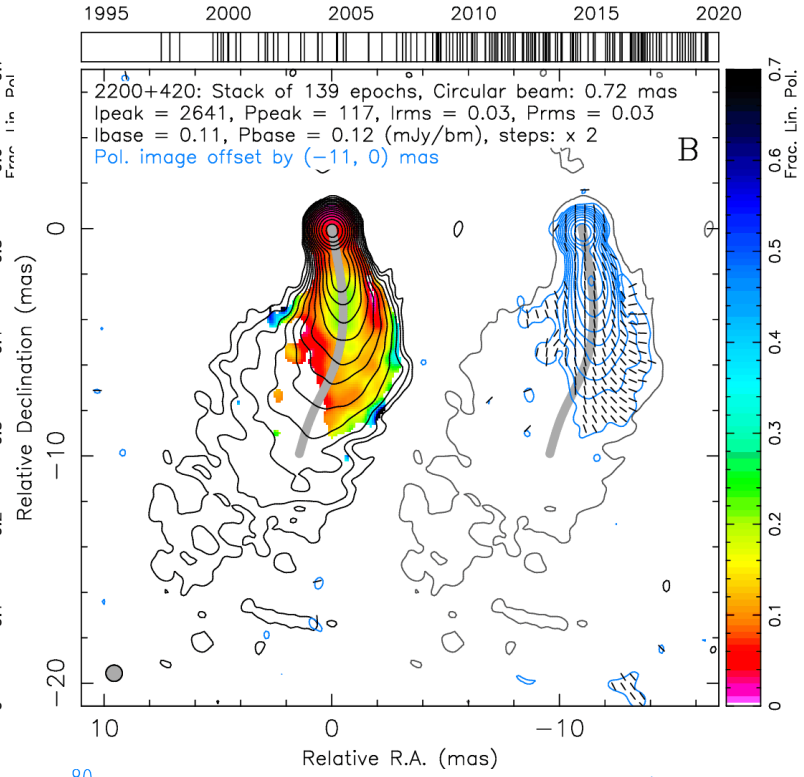


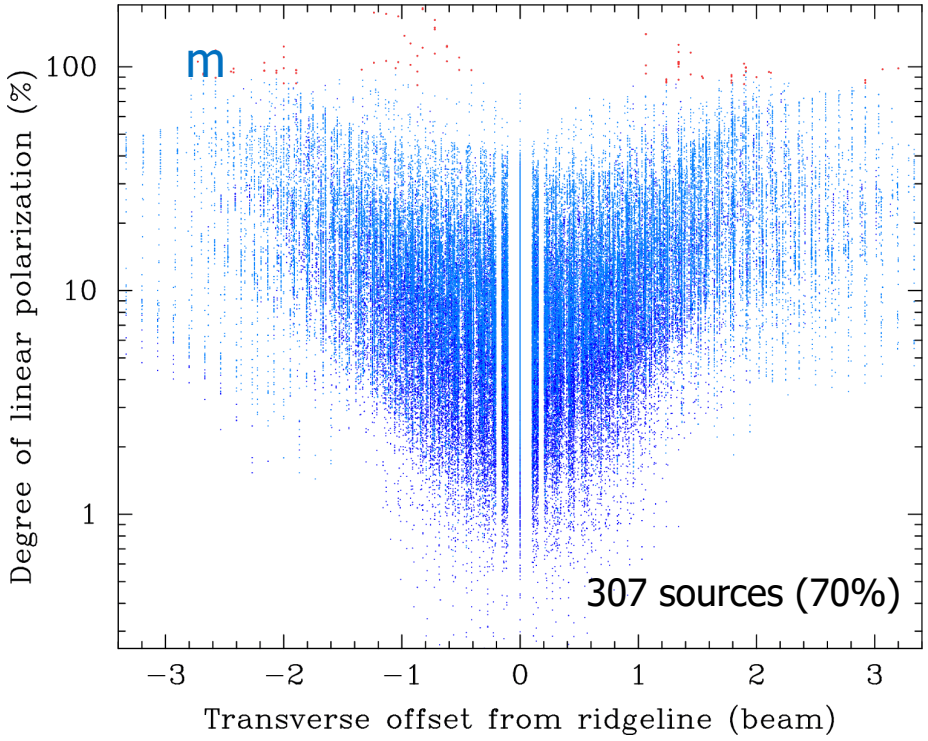
- m-cuts: quasi-constant (13% of sources)
- Mainly observed in: BL Lacs
- EVPA pattern: aligned with local jet direction
- P-profiles: one-peaked & symmetric
- P-signal location: close to ridge, never at edges

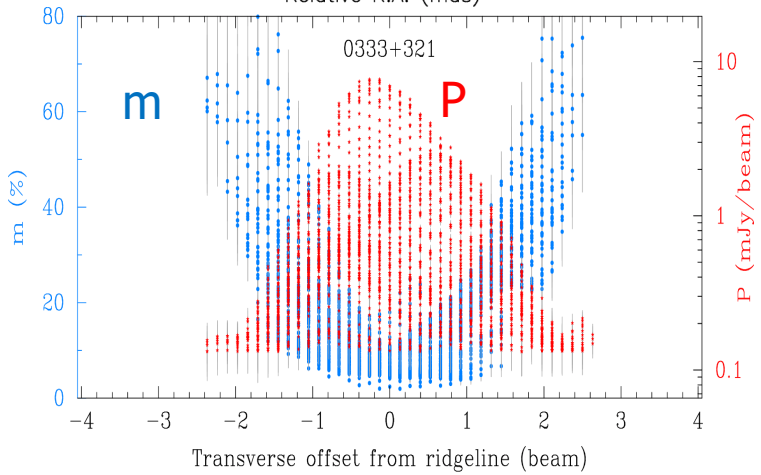


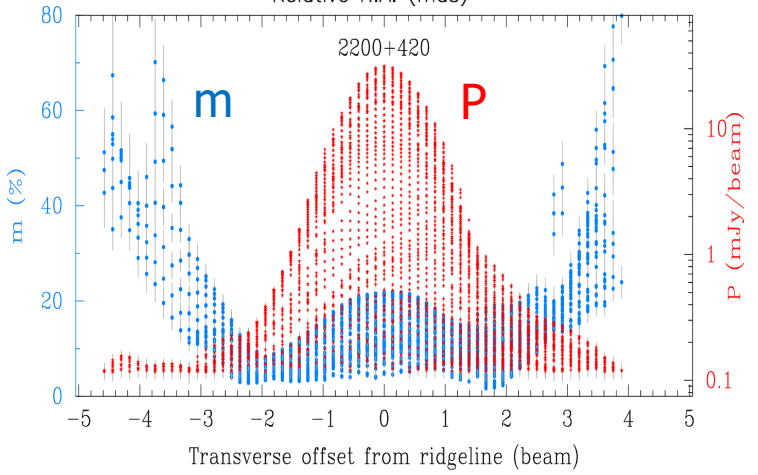
Polarization degree across the jet: U / W m-cuts











- U/W-shaped transverse profile of m
- not fully symmetric

➔ evidence for a helical B-field

– superposition of P-emission from regions with different EVPA

Summary

- Stacked P-images delineate the long-term persistent configuration of B-field
  - about 10 yrs to fill out jet cross-section in P (~5 yrs for I)

- B-field becomes more regular down the jet (m reaches up to ~20%)
  - opacity decreasing
  - spectral aging
  - turbulence weakening
  - pitch-angle decreasing

- Degree of polarization increases towards the jet edges
  - U/W-shaped profiles
  - helical field, asymmetric profiles
  - spine-sheath structure (shear layer)

- m_BL Lacs > m_quasars in the core and inner jets, and become comparable on hecto-parsec scales and beyond