Magnetic fields of parsec-scale AGN jets from multi-epoch VLBA linear polarization imaging

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Observations & Source Sample

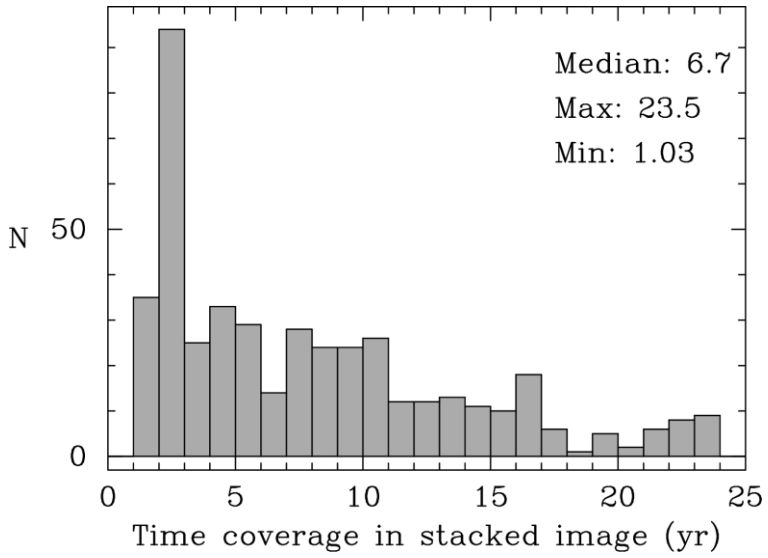
- At least 5 epochs from MOJAVE (**M**onitoring **O**f **J**ets in **A**ctive galactic nuclei with **V**LBA **E**xperiments) or archival full Stokes obs. at 15 GHz

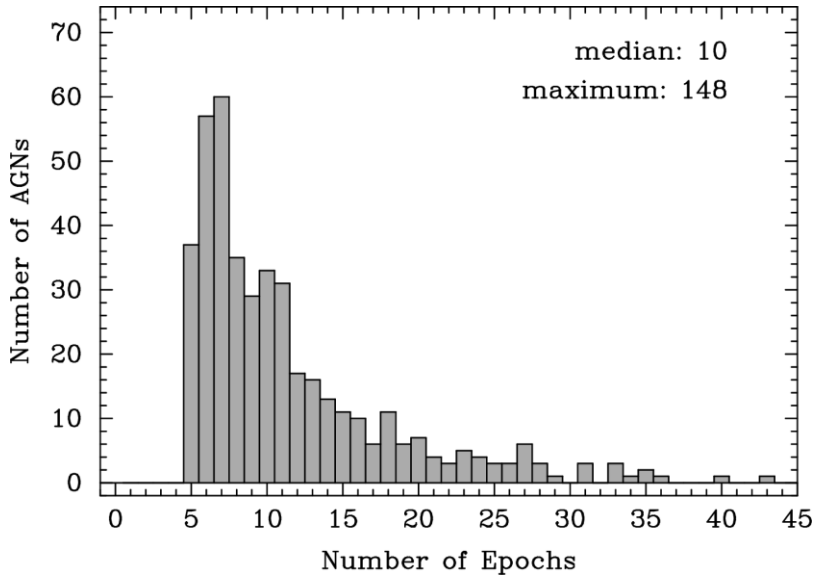
➔ 438 sources (60% - quasars, 30% - BL Lacs, 4% - RG)

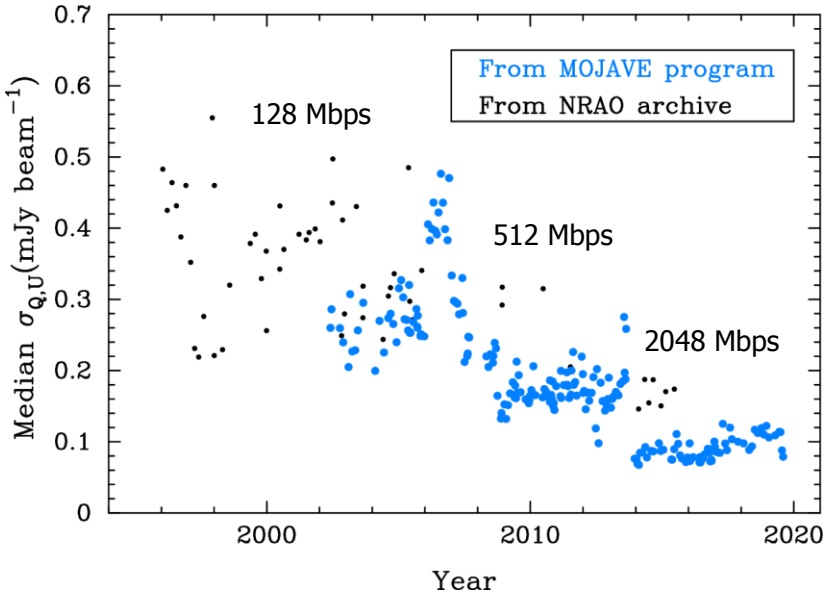
➔ 278 unique epochs (80% MOJAVE) from 1996 to 2019

➔ 5918 single-epoch images

Very Long Baseline Array







Method of Polarization Stacking

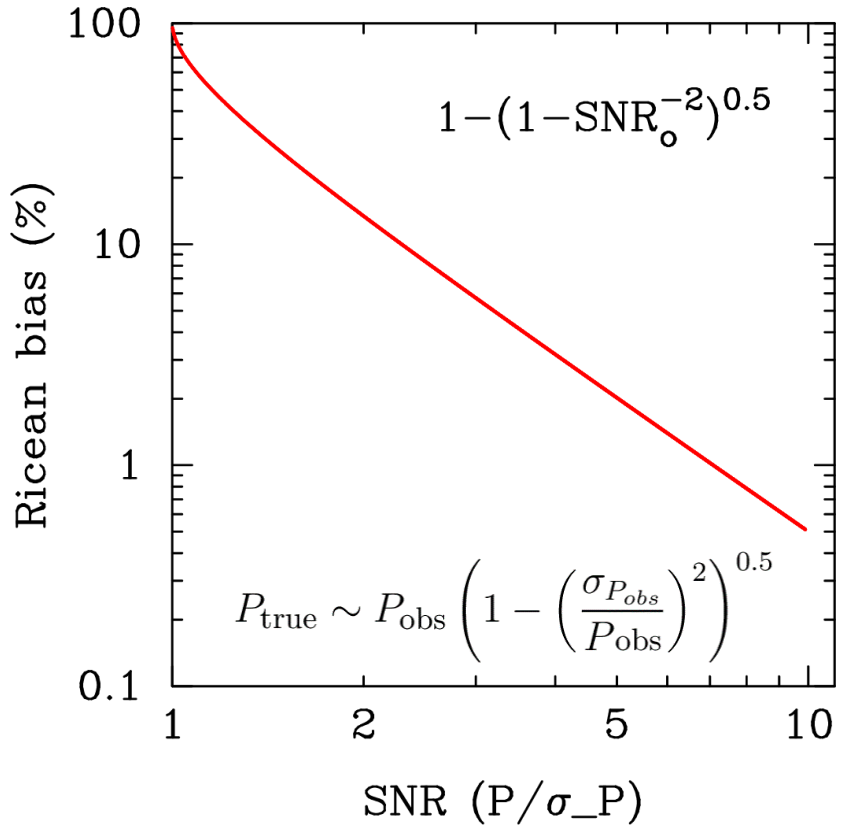
$$P = \sqrt{Q^2 + U^2} \qquad m = P/I \qquad \chi = 0.5\,\mathrm{atan}(U/Q)$$

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

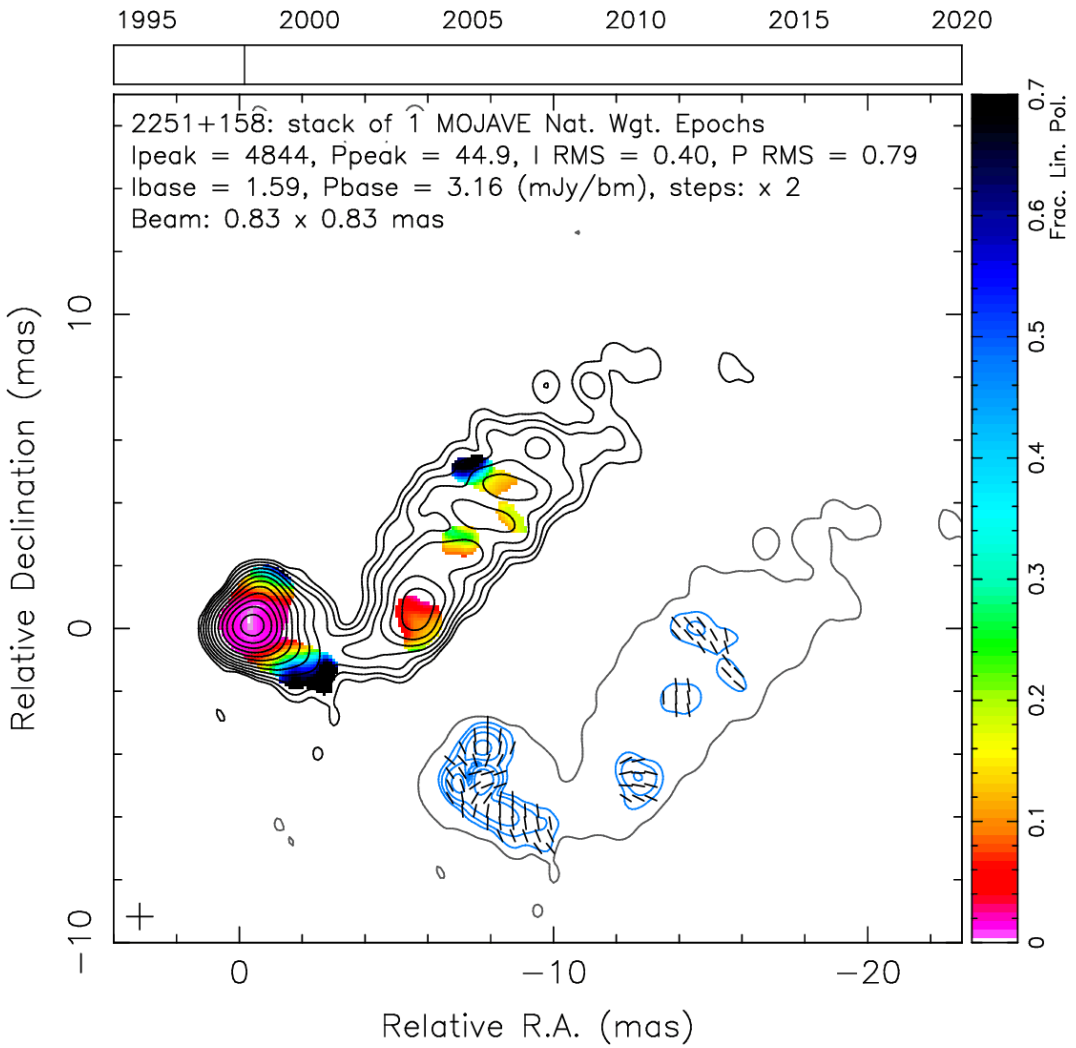
Approach 1
- Produce stacked Q, U maps ➔ stacked P, EVPA, m maps
- Correction for Ricean (Wardle & Kronberg, 1974) and CLEAN biases

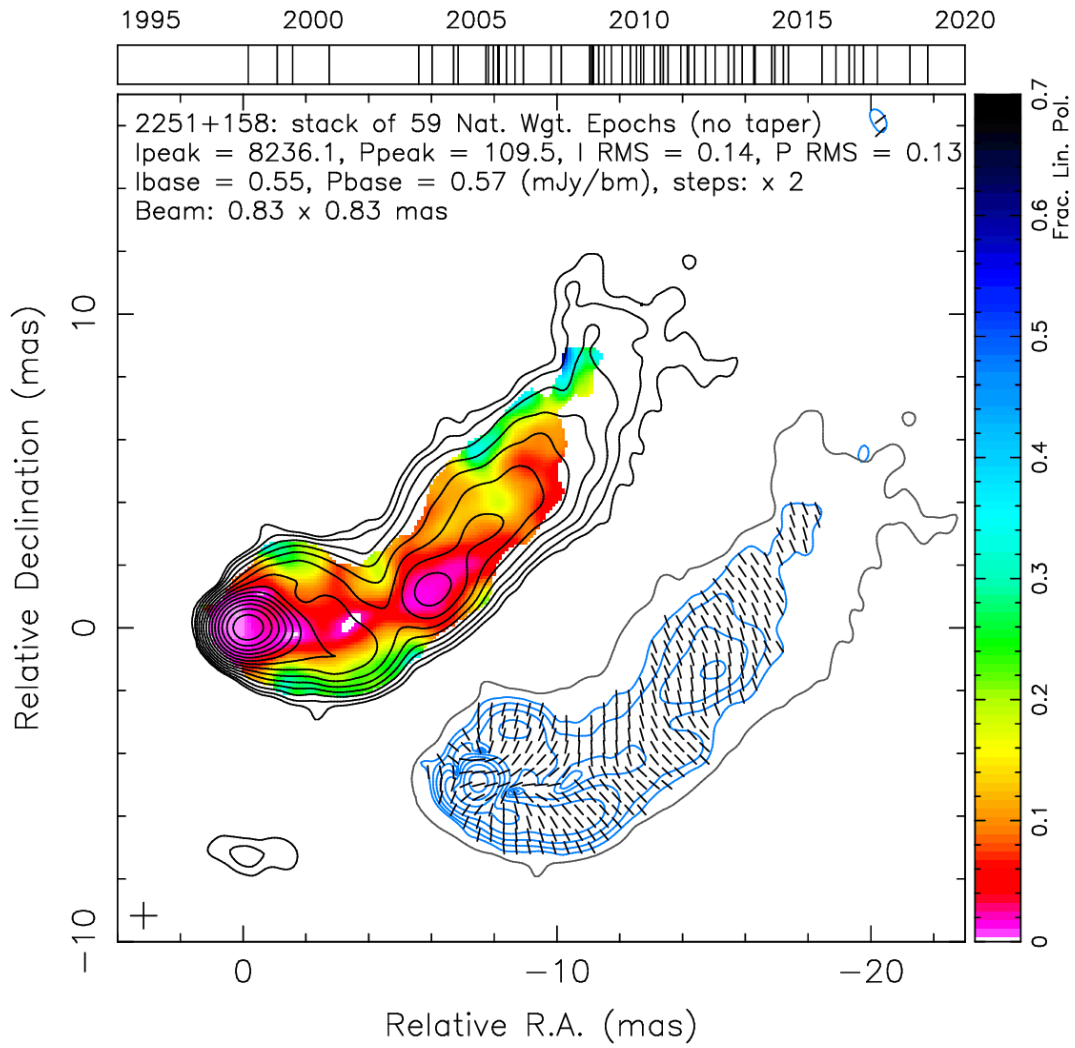
➔ Deeper P-images (sigma_p, m, EVPA ~ 1/sqrt(N))

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 (see poster by Daria Zobnina et al.)



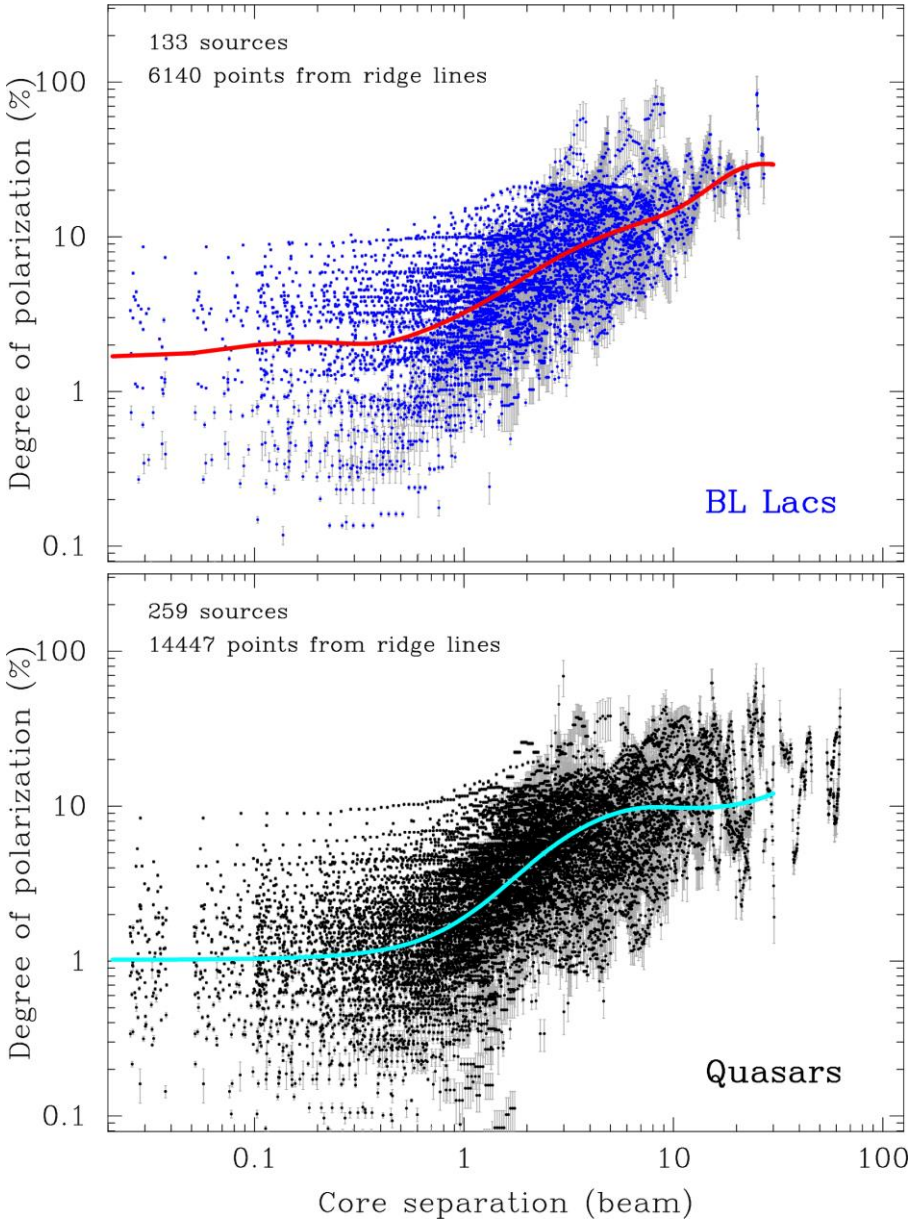
Polarization Stacking Example: 3C454.3





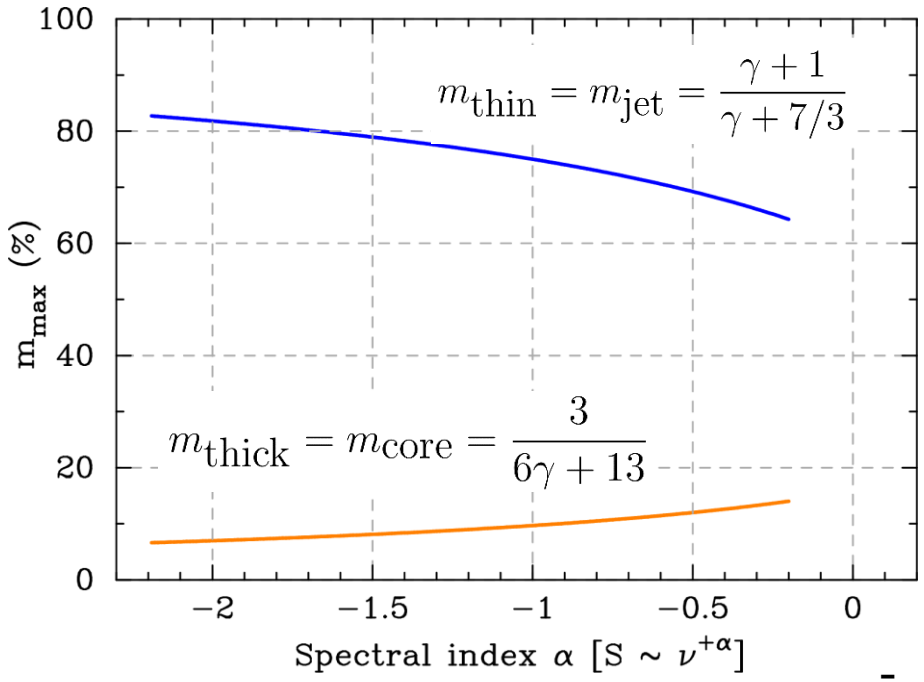
It takes ~ 10 years to fill out jet cross-section in P

Polarization degree along the jet



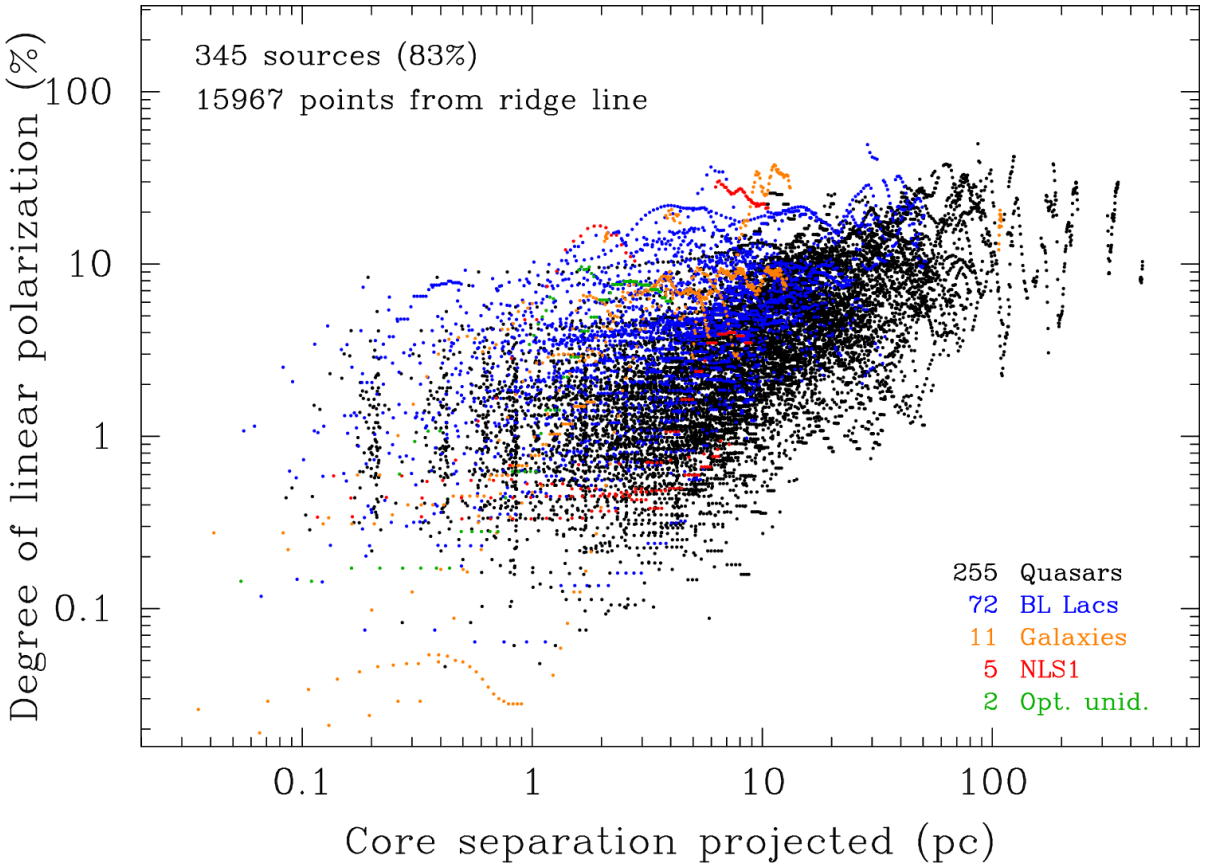
$$dE\, N(E) \propto E^{-\gamma}\, dE$$

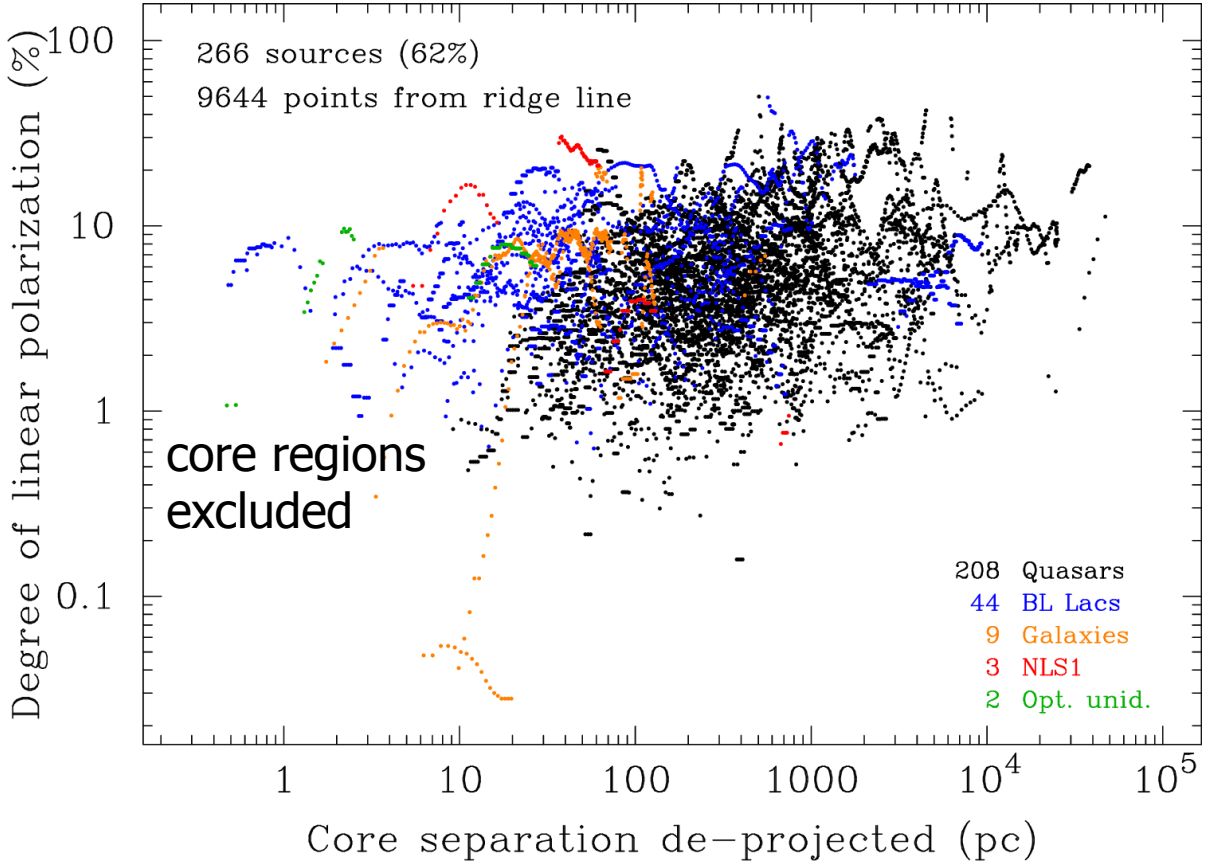
$$S \propto \nu^{+\alpha}, \quad \gamma = 1 - 2\alpha$$



- Degree of polarization
  - constant within the core region, m_med ~ 1%, m < 10%
  - increases down the jet reaching 10% - 30% due to
    - spectral aging ($\Delta\alpha \approx -0.6$; *Kardashev 1962; Hovatta et al. 2014*)
    - turbulence weakening and/or pitch-angle decrease
- BL Lacs are more polarized with EVPA parallel to jet axis
- Radio galaxies are weakly polarized in their cores

Polarization degree along the jet



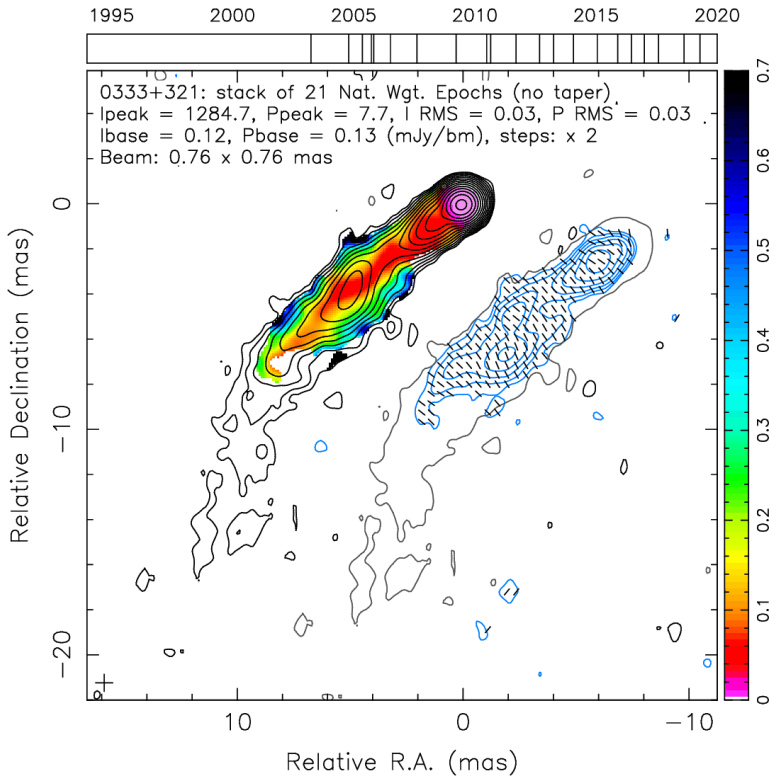


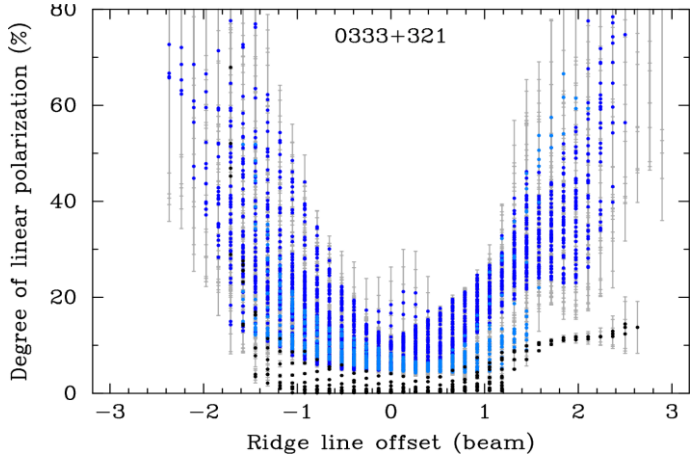
- Quasars are less polarized than BL Lacs in their inner jets
- m-values become comparable at larger (kpc) scales
- Steeper spectra: $\alpha\_q \sim -1.1$ vs $\alpha\_bl \sim -0.8$ (*Hovatta et al. 2014*)

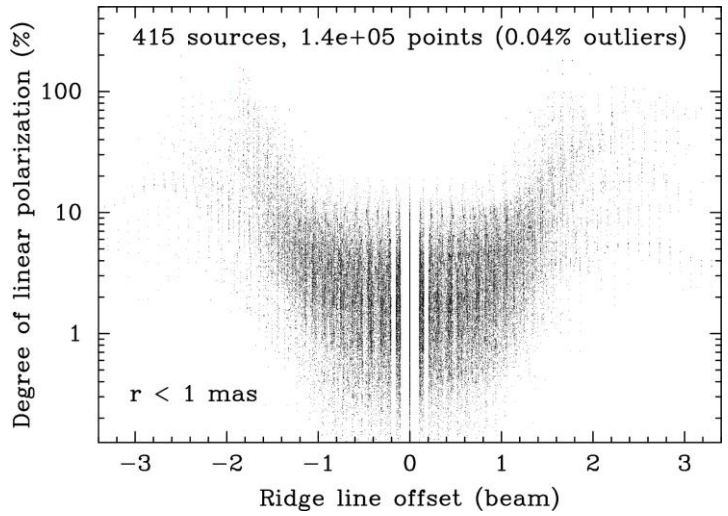
$$\theta = \arctan \frac{2\beta_{\rm app}}{\beta_{\rm app}^2 + \delta_{\rm var}^2 - 1}$$

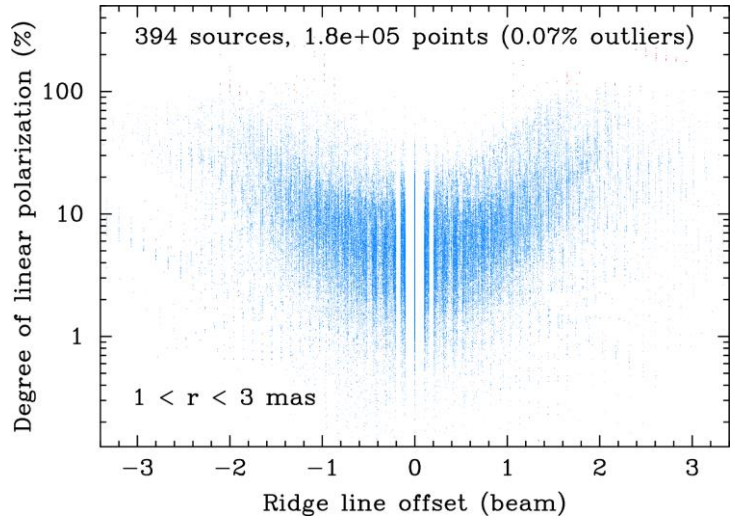
Apparent speeds (*Lister et al. in prep.*)
Doppler-factors (*Homan et al., in prep.*)

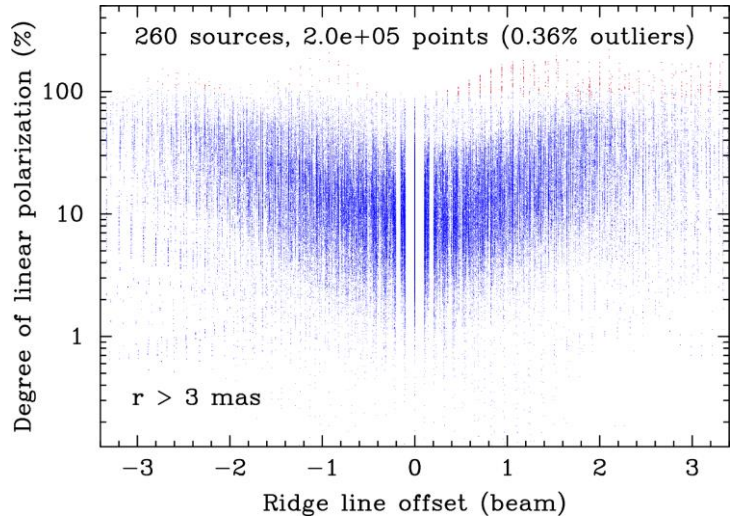
Polarization degree across the jet











- U-shaped transverse profile of m
- becomes seen beyond the core

➔ 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%)
  - spectral aging
  - turbulence weakening
  - pitch-angle decreasing
- Degree of polarization increases towards the jet edges
  - U-shaped profile
  - helical field
  - spine-sheath structure
- On average, BL Lacs are more polarized than quasars on pc-scales