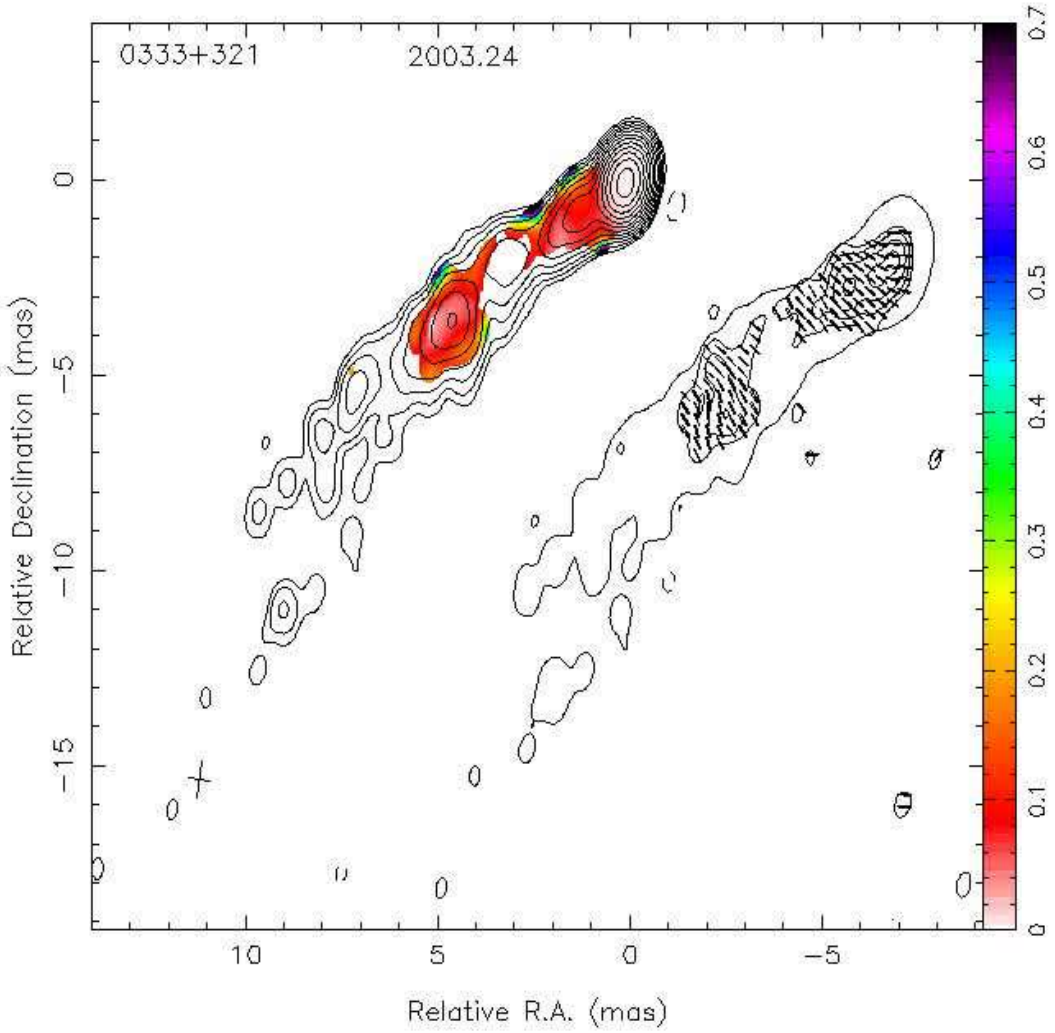
Polarization Evolution of Parsec-Scale Jets in Active Galactic Nuclei



Matt Lister

Dept. of Physics & Astronomy

Purdue University

MOJAVE Collaboration

M. Lister (P.I.), M. Hodge, E. Stanley (Purdue, USA)

M. and H. Aller (U. Michigan, USA)

M. Cohen, J. Richards (Caltech, USA)

D. Homan (Denison, USA)

M. Kadler, J. Trüstedt (U. Wurzburg, Germany)

K. Kellermann (NRAO, USA)

Y. Y. Kovalev (ASC Lebedev, Russia)

J. A. Zensus (MPIfR, Germany)

A. Pushkarev (Crimean Observatory)

E. Ros (MPIfR, Germany & U. Valencia, Spain)

T. Savolainen, T. Hovatta (Metsähovi Obs., Finland)

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Monitoring

Of

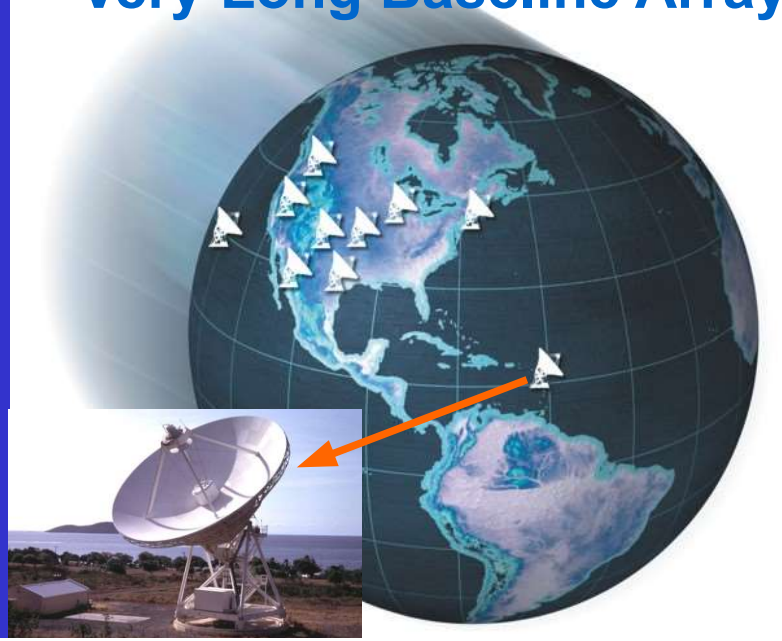
Jets in

Active Galaxies with

VLBA

Experiments

Very Long Baseline Array

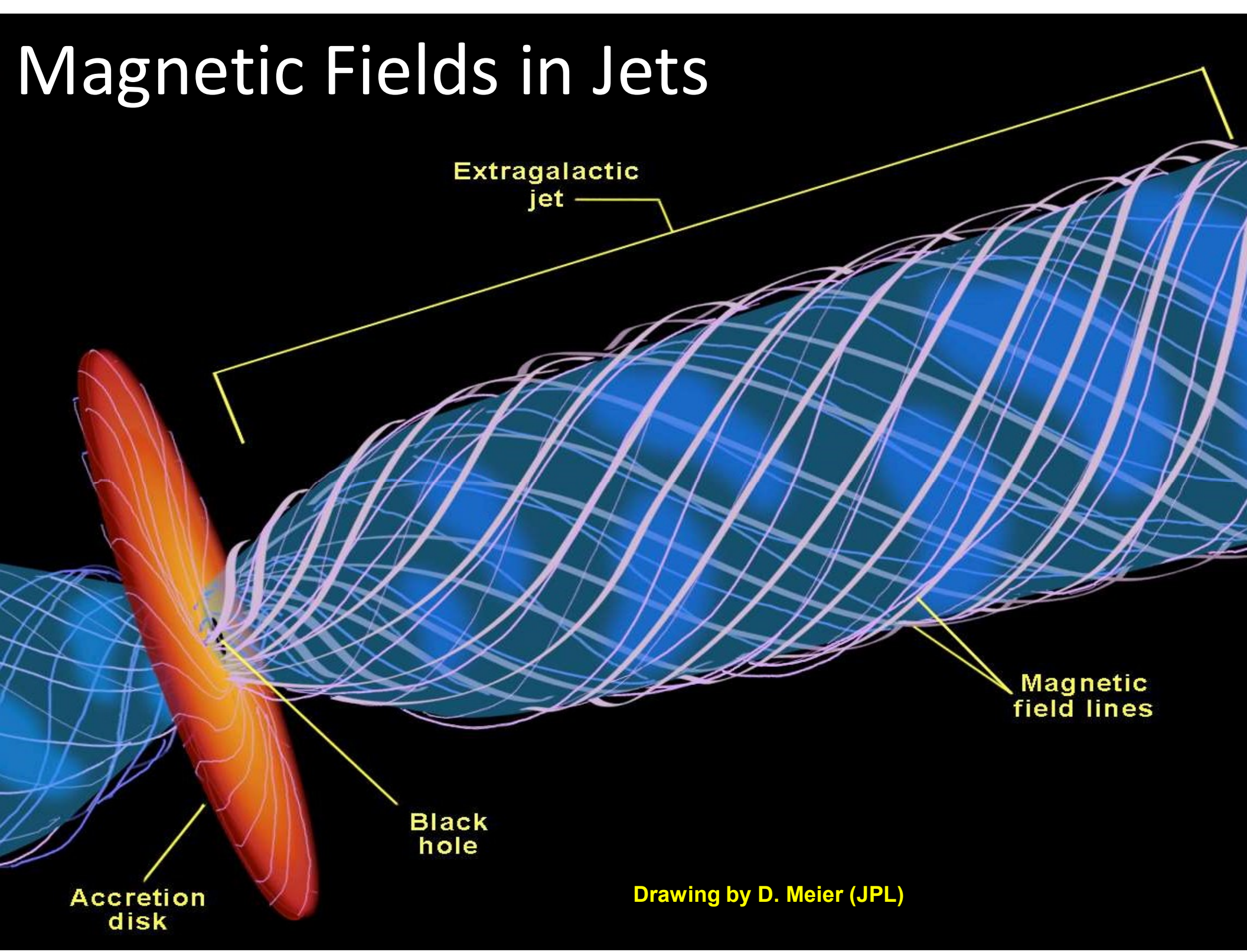


- AGN jets are the most powerful, long-lived phenomena in the Universe.
- Probes of supermassive black hole environments out to high redshift.
- Play a central role in regulating galaxy formation via feedback mechanisms.

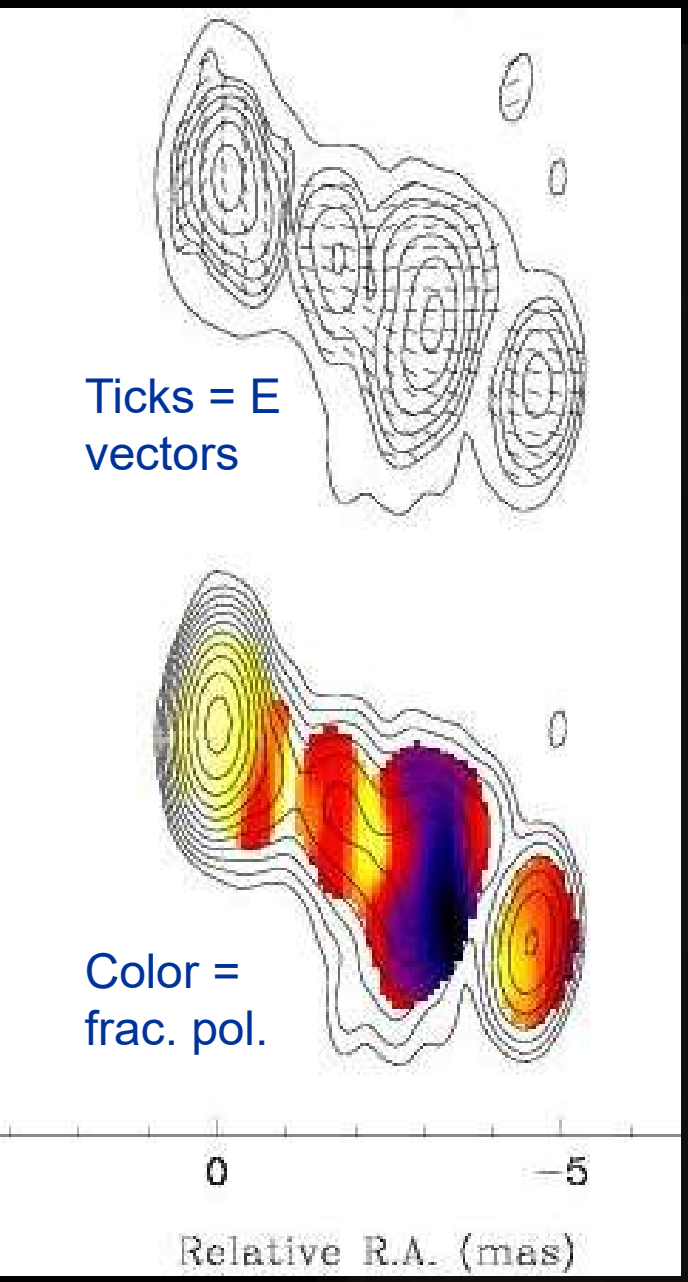
X-ray image of Perseus A (Fabian et al. 2006)

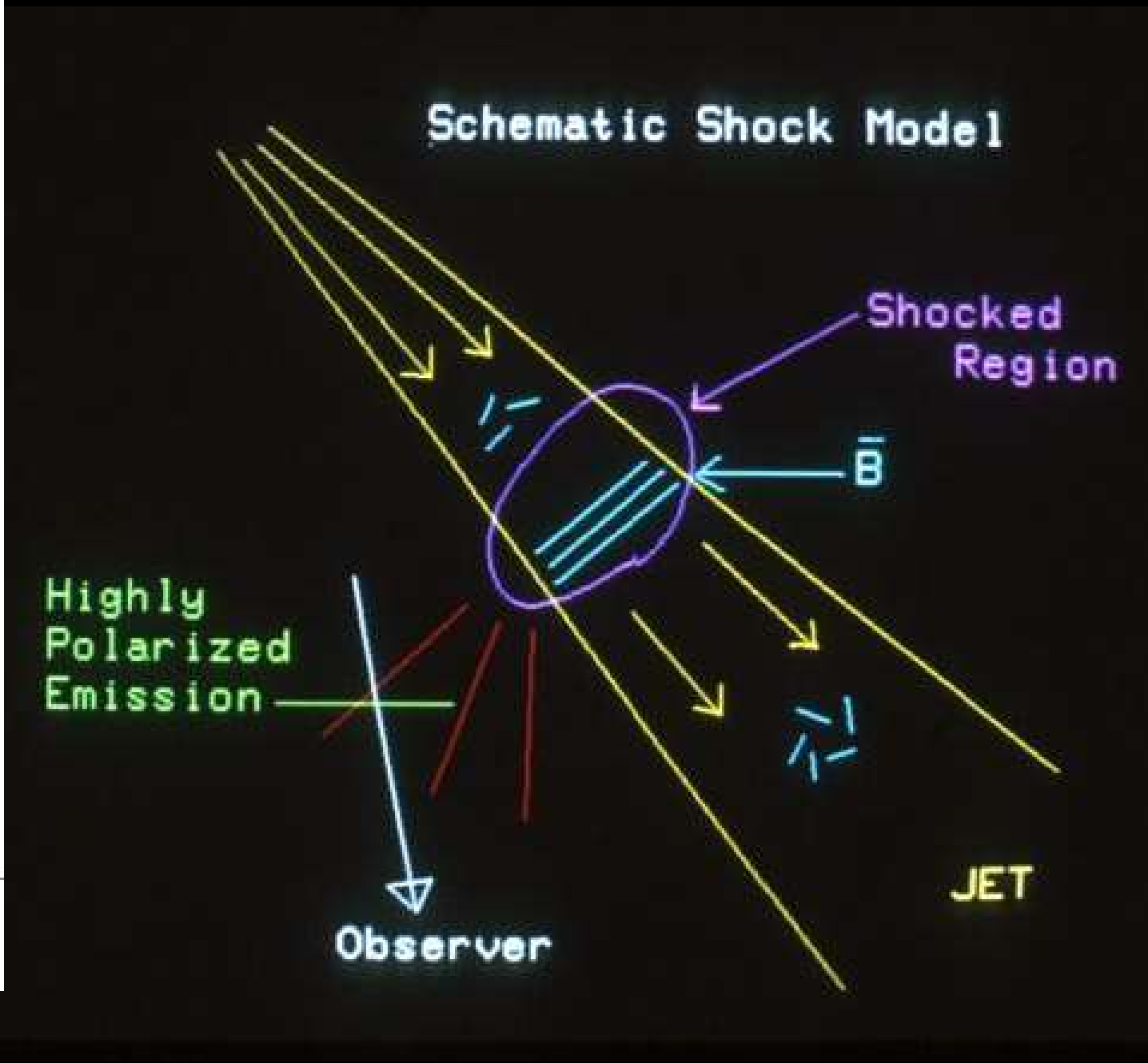
Artist Rendering: JPL/Caltech

Magnetic Fields in Jets



Transverse shock model for linear polarization



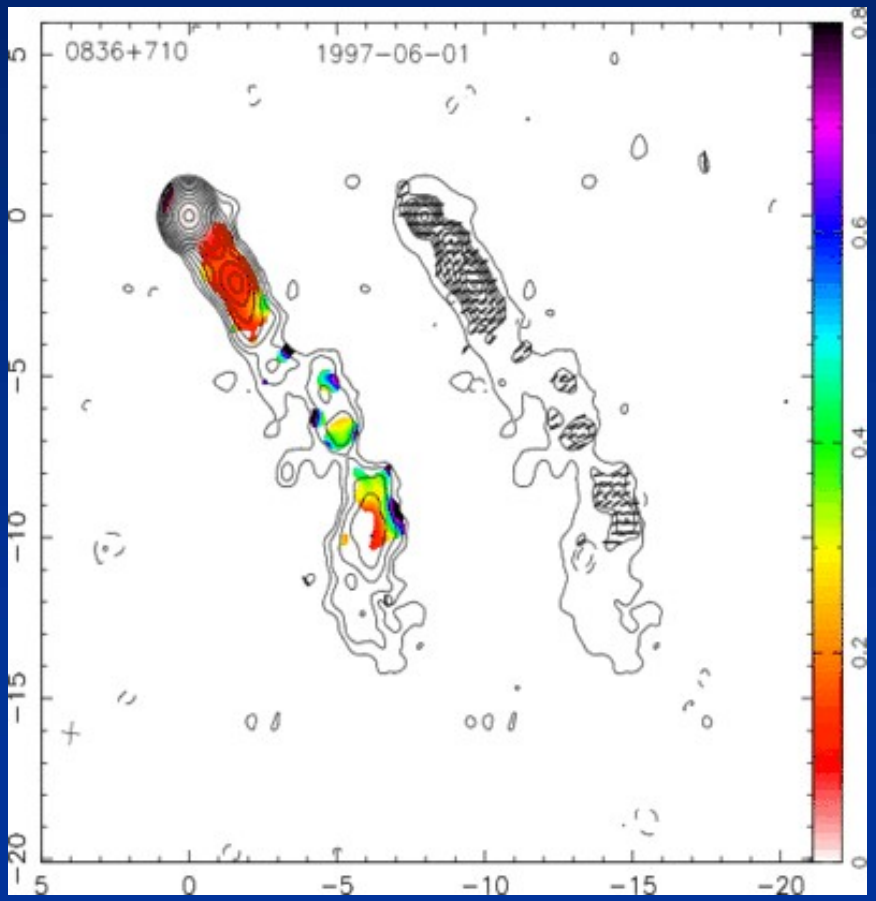


Aller et al. 1985

AGN Jets and the VLBA

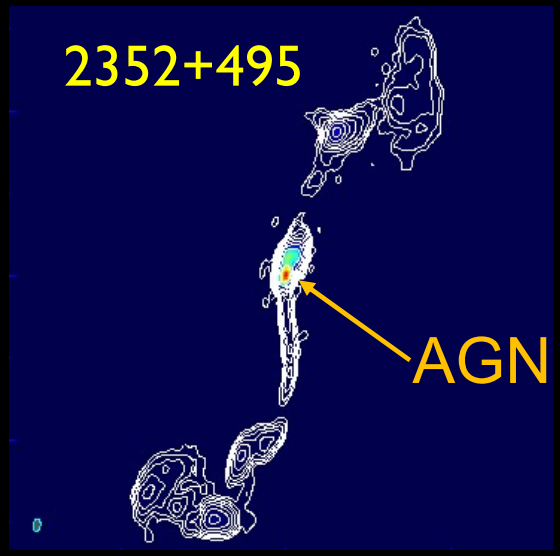
Only instrument capable of full polarization time lapse imaging on milliarcsecond (parsec) scales.

Polarization images probe the degree of magnetic field order and its orientation in the jet, as well as plasma properties.



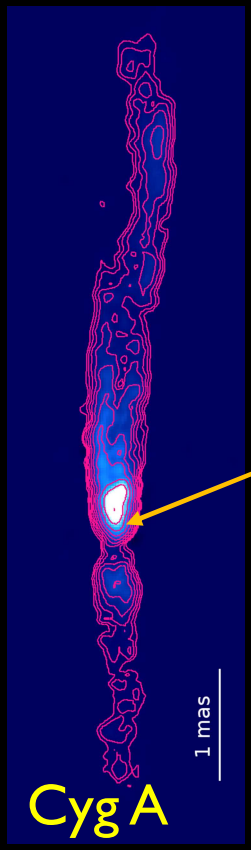
AGN Jets on Parsec Scales

Young Radio Source



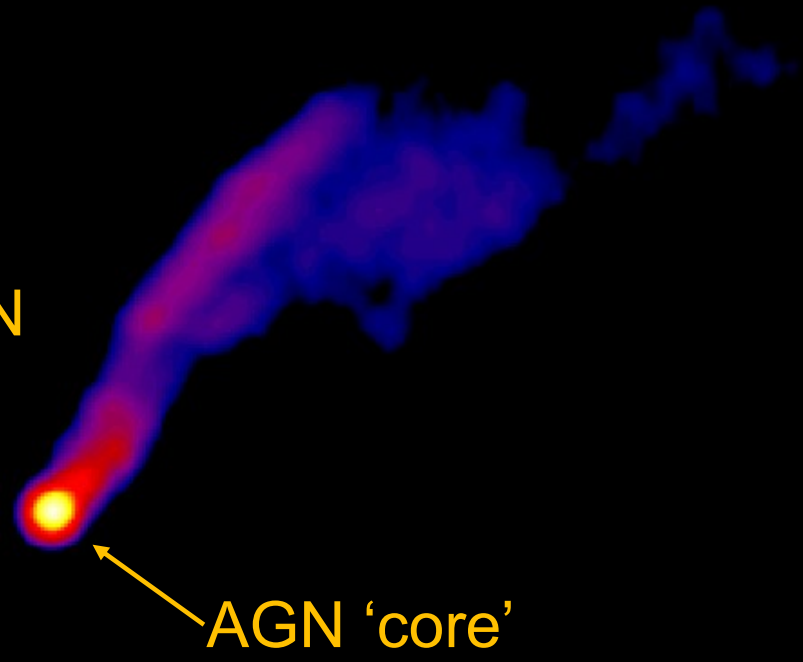
- Recently active jets
- Strongly emitting lobes
- Slow advance speeds
- Usually depolarized

Radio Galaxy



- Two-sided jets
- Slow speeds
- Strongly depolarized

Blazar

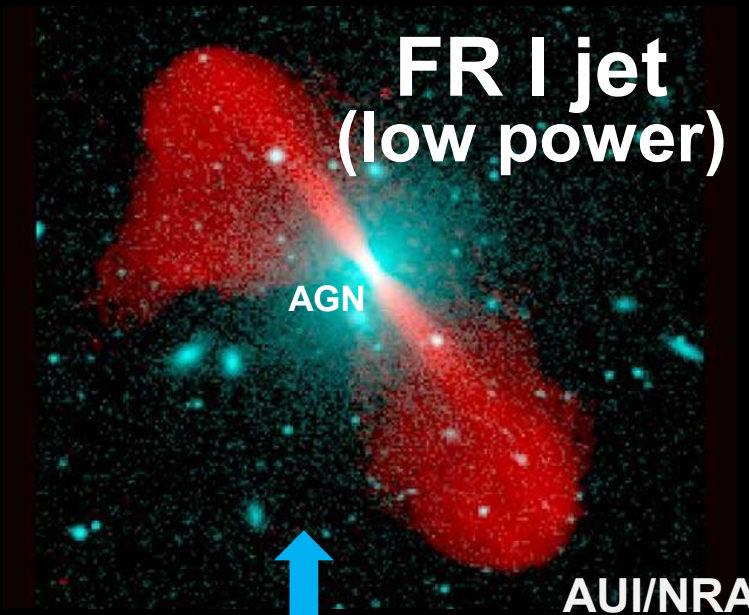


- De-boosted counterjet
- Polarized (lin. and circ.)
- Very compact core ($T_b > 10^{12}$ K) and speeds > c
- Common γ-ray emitters

Blazar Flavors: Quasars and BL Lacs

Quasars:

- broad optical emission lines
- high power jets seen end-on

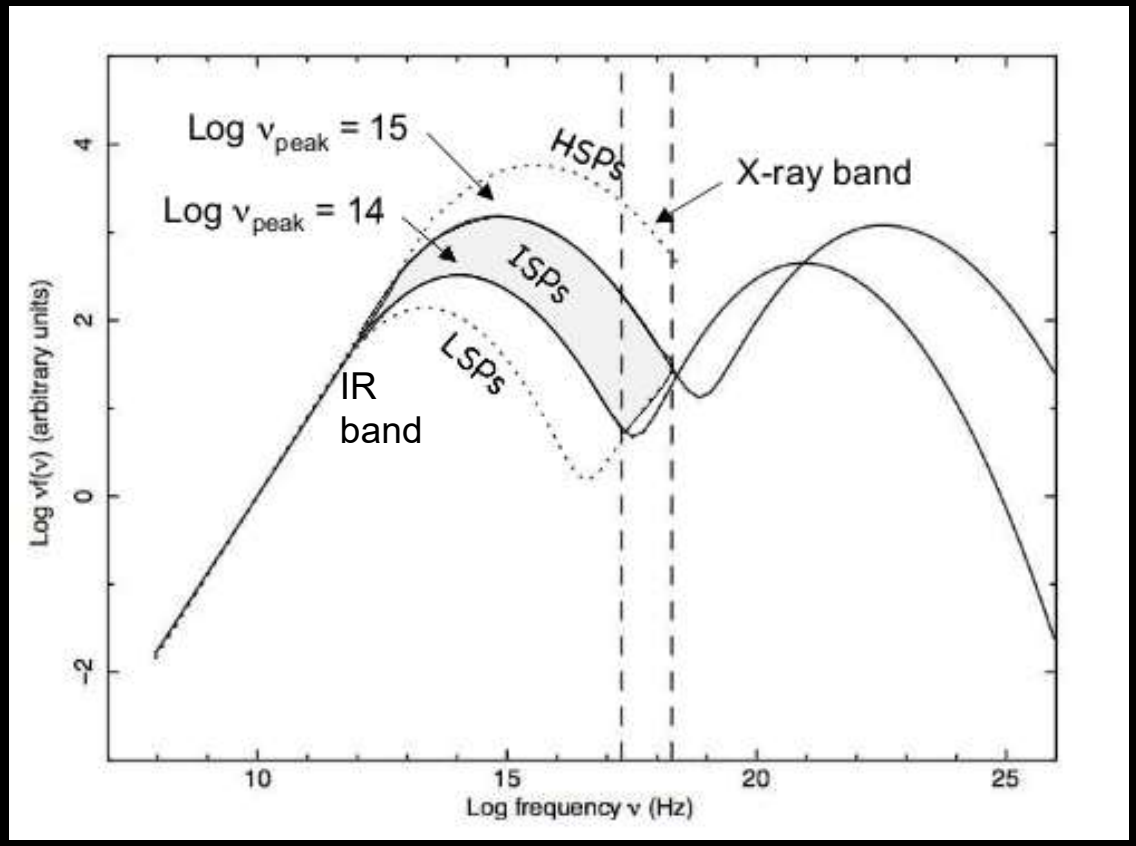


BL Lacertae objects:

- weak/absent broad emission lines
- low power jets seen end-on

Classifying Beamed Jets

- Only BL Lacs have synchrotron peaks above 10^{14} Hz:
- Low rate, inefficiently radiating accretion flow, thus no optically thick accretion disk or broad line region.
- Broad line photons in quasars are responsible for Compton cooling of synchrotron electrons.
- GeV and TeV gamma-ray catalogs are heavily dominated by HSP BL Lacs

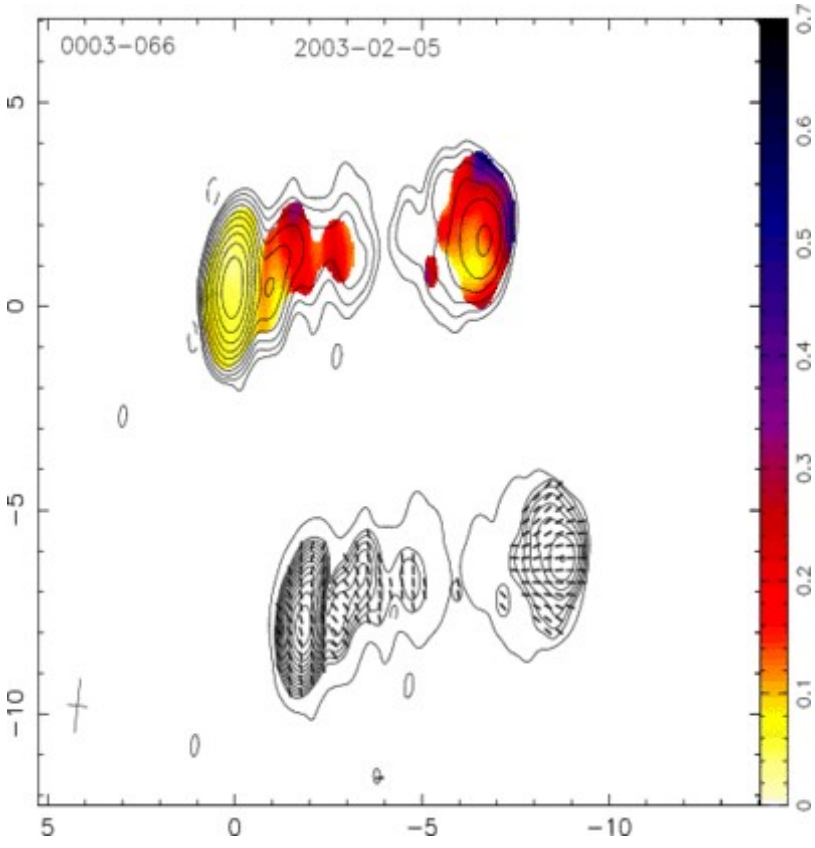


- The VLBA has identified fundamental differences in the jets of quasars and (LSP, ISP, HSP) BL Lacs.

MOJAVE VLBA Program

- Regular observations of radio-bright AGN
  - ~100 currently monitored
- Milliarcsec-resolution images at 15 GHz
  - continuous time baselines on many sources back to 1994
  - full polarization since 2002
  - 8000 images of over 400 AGN in on-line archive:

www.physics.purdue.edu/astro/MOJAVE

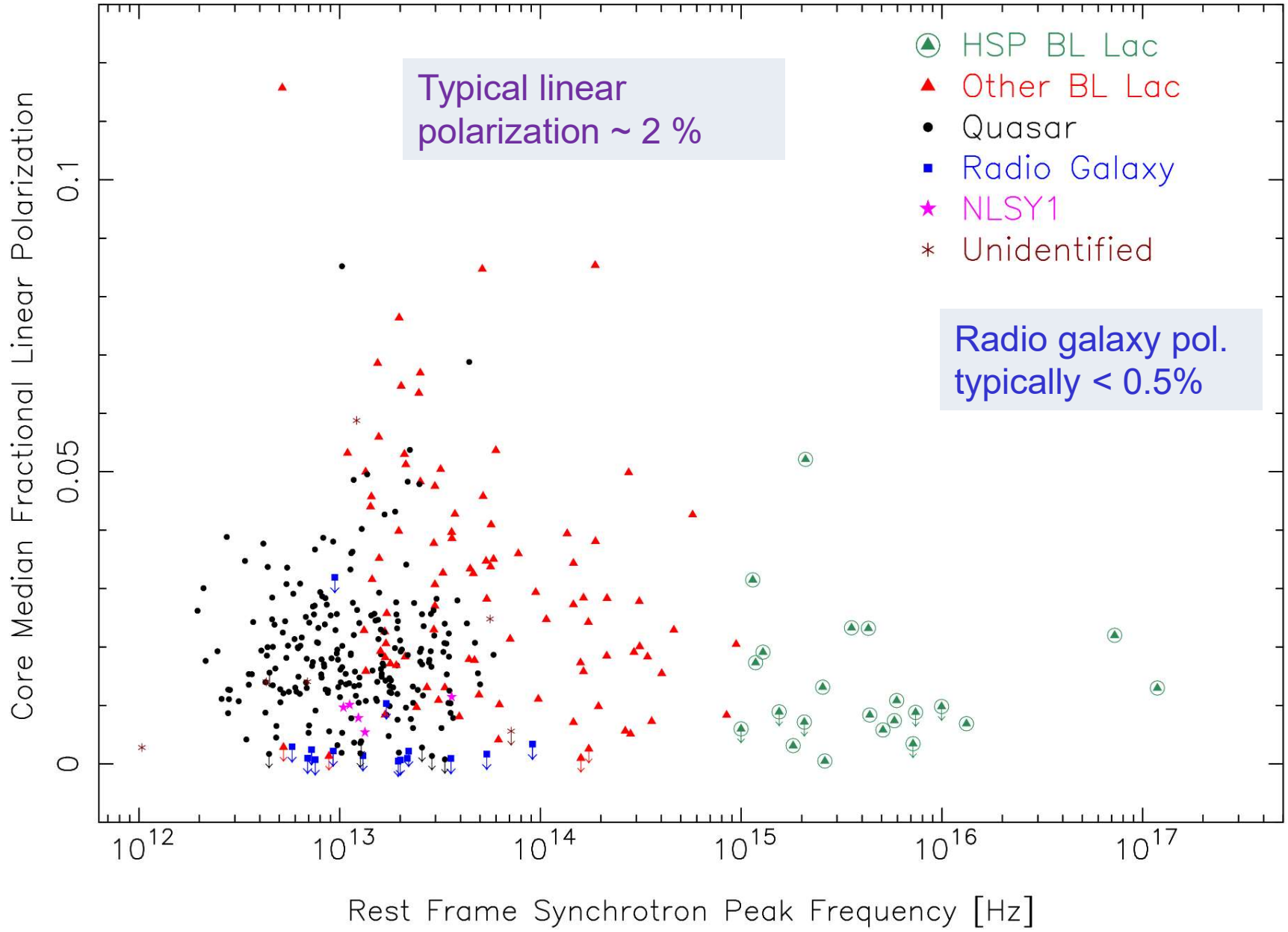


Blazar 0003-066 at 15 GHz

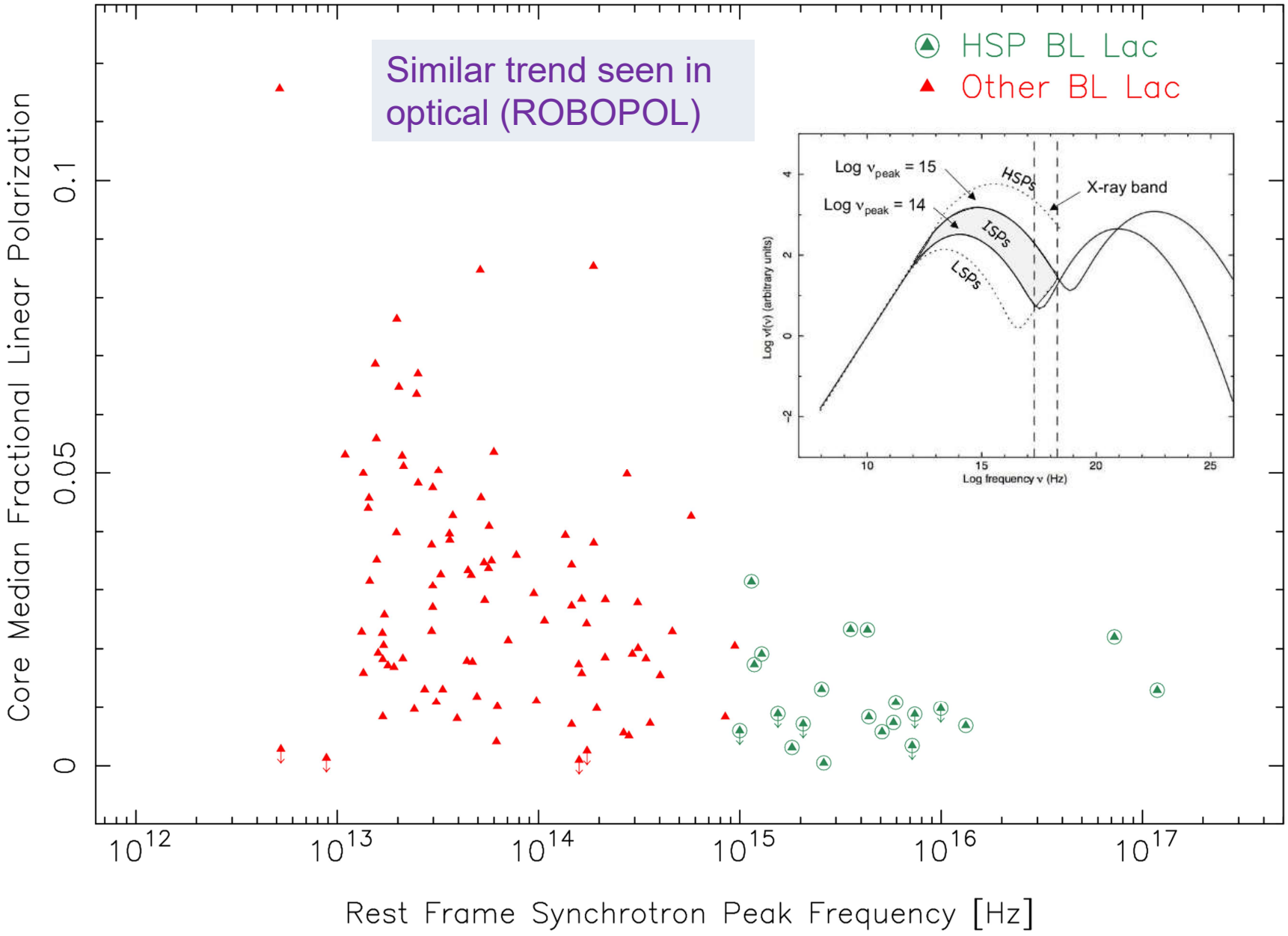
Colors: fractional linear polarization

Statistical Trends: AGN Jet Cores

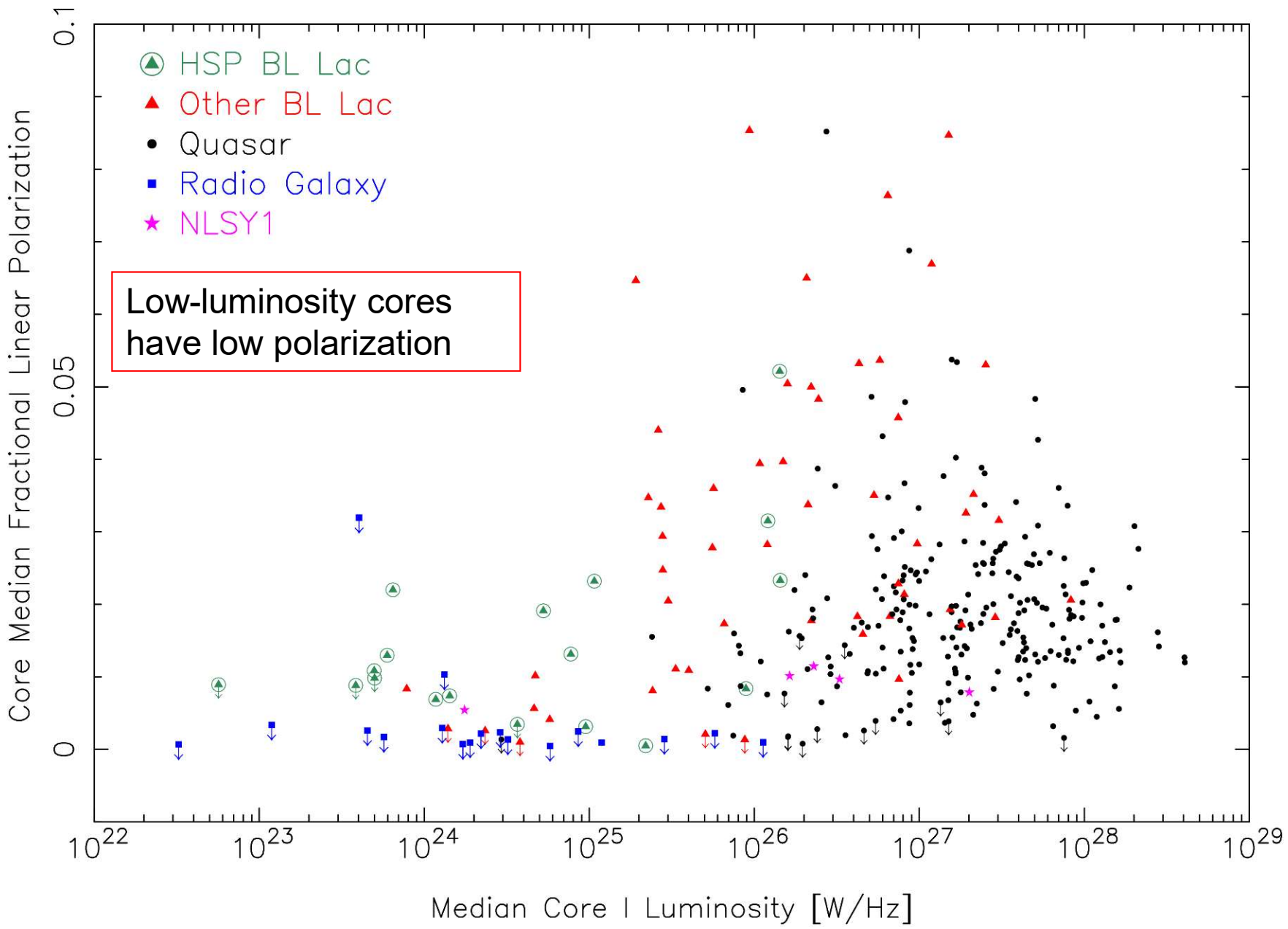
Fractional Linear Polarization of AGN Cores



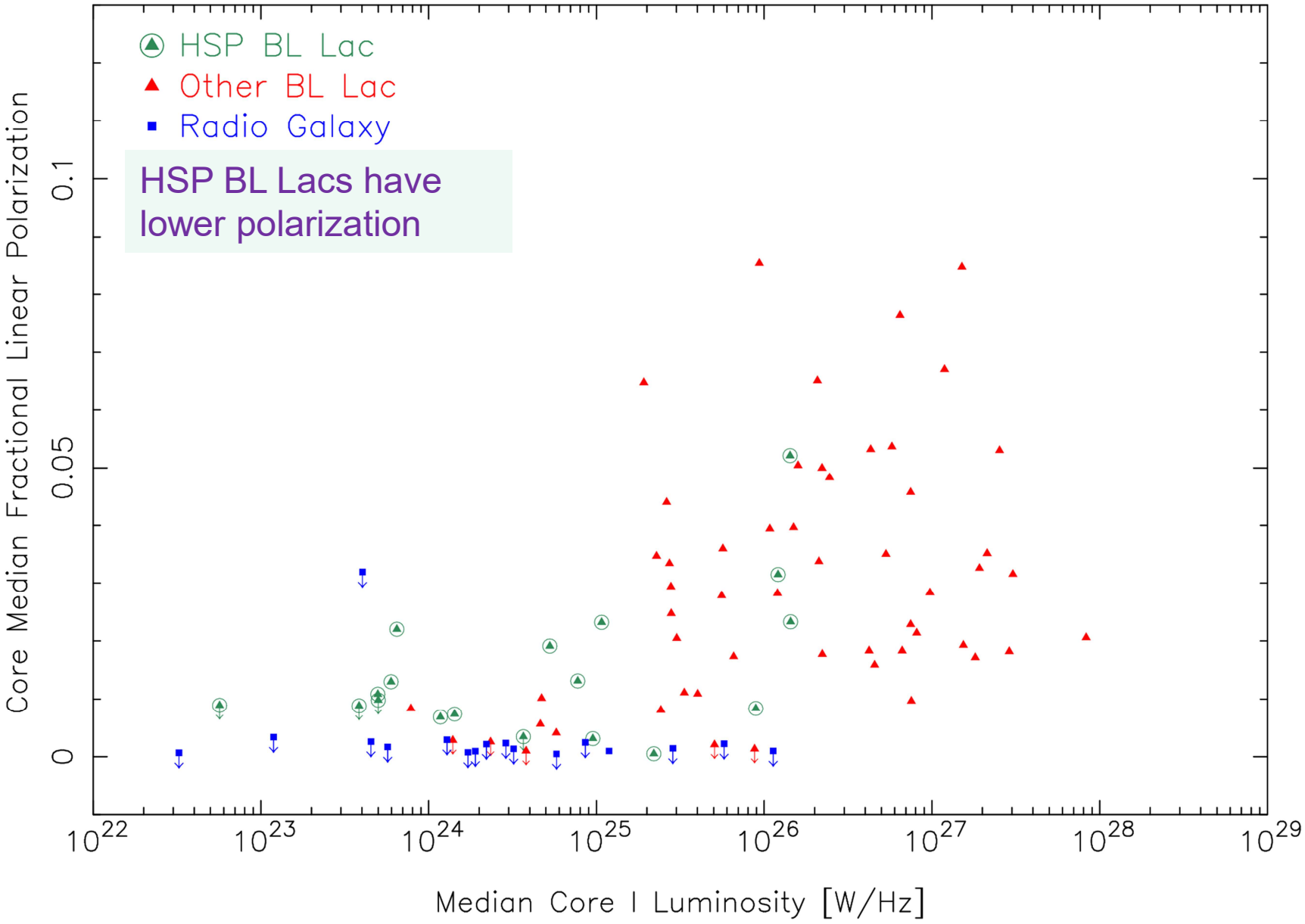
Fractional Linear Polarization of AGN Cores



Core Polarization vs. Luminosity

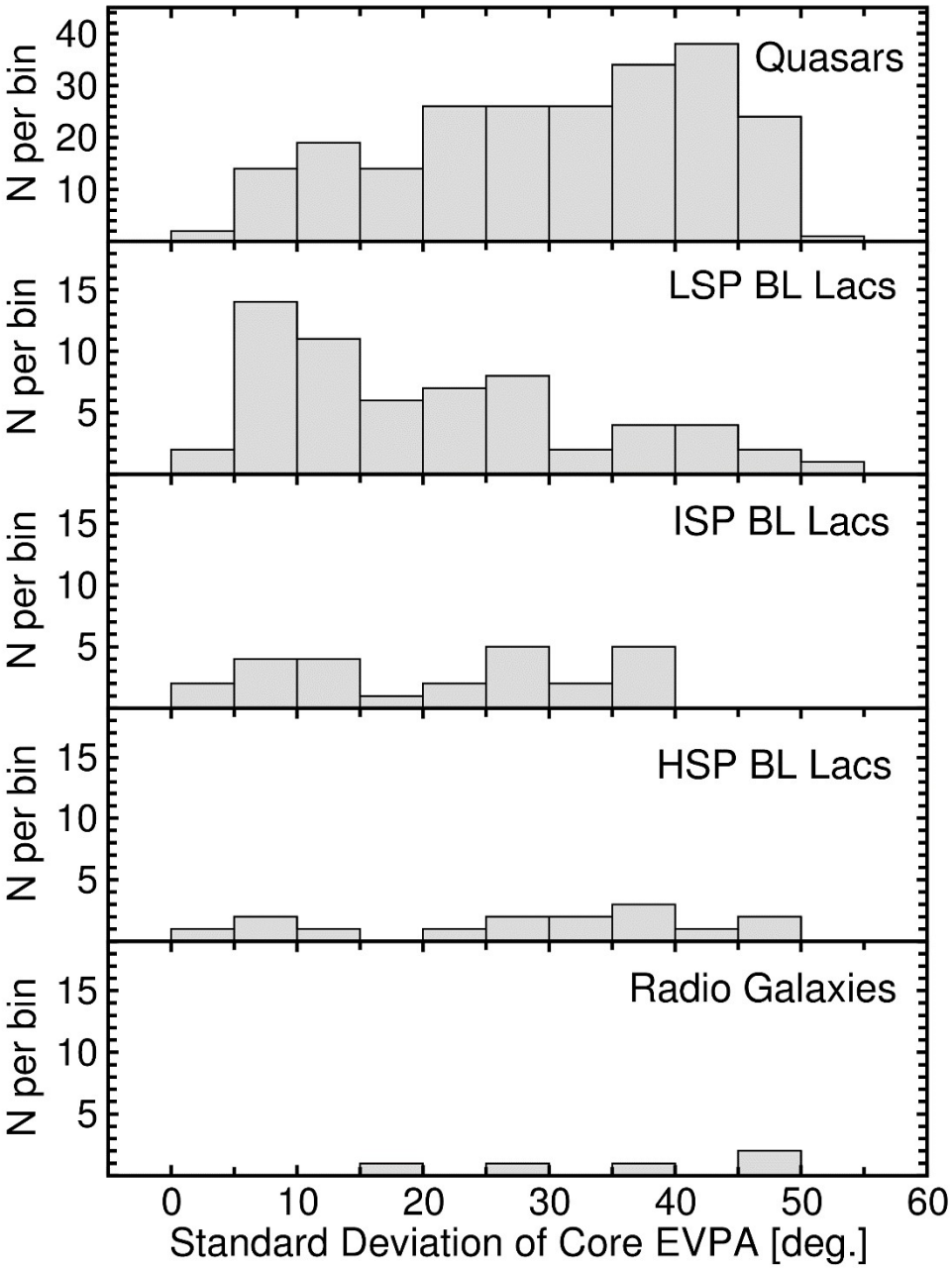


Core Polarization vs. Luminosity

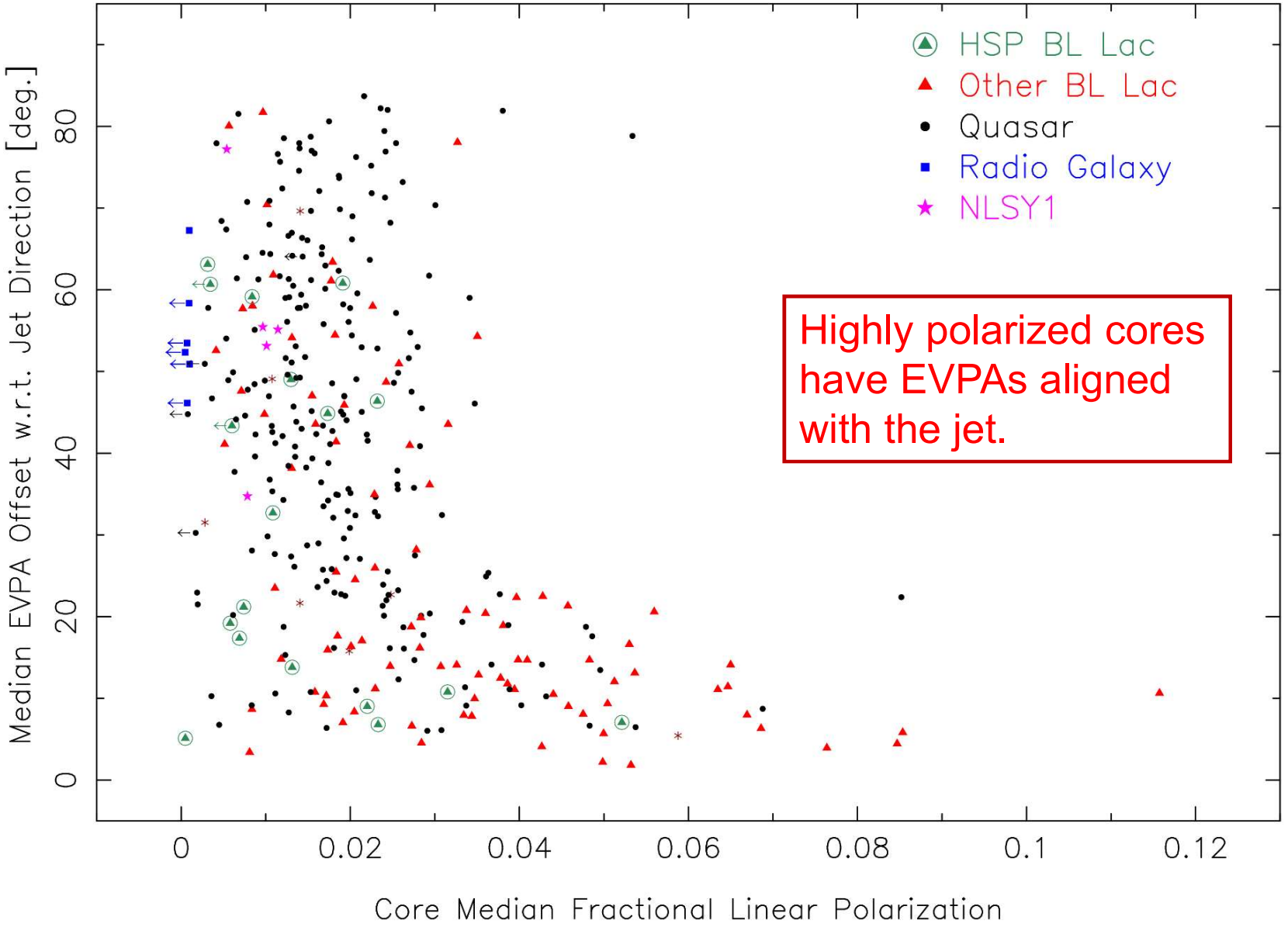


Stability of Core EVPAs

- 47% of the AGN jet cores have at least half their electric vector position angle (EVPA) measurements within ± 10° of a preferred direction.
- Occasional large changes in EVPA, perhaps associated with rotation events.
- LSP BL Lacs have more stable EVPAs than quasars.
- All of the most highly polarized cores have stable EVPAs.

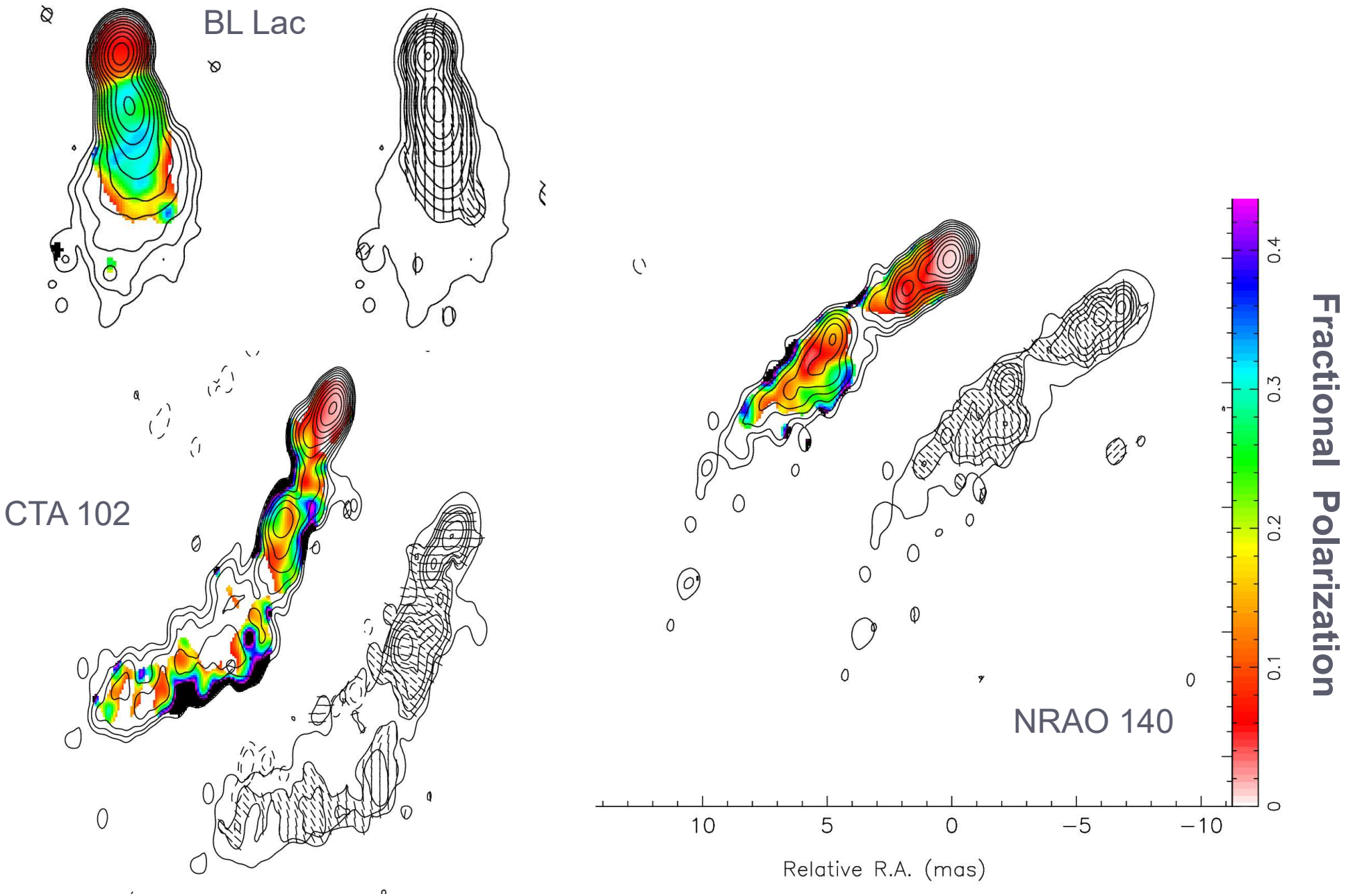


Electric Vector Direction and the Jet

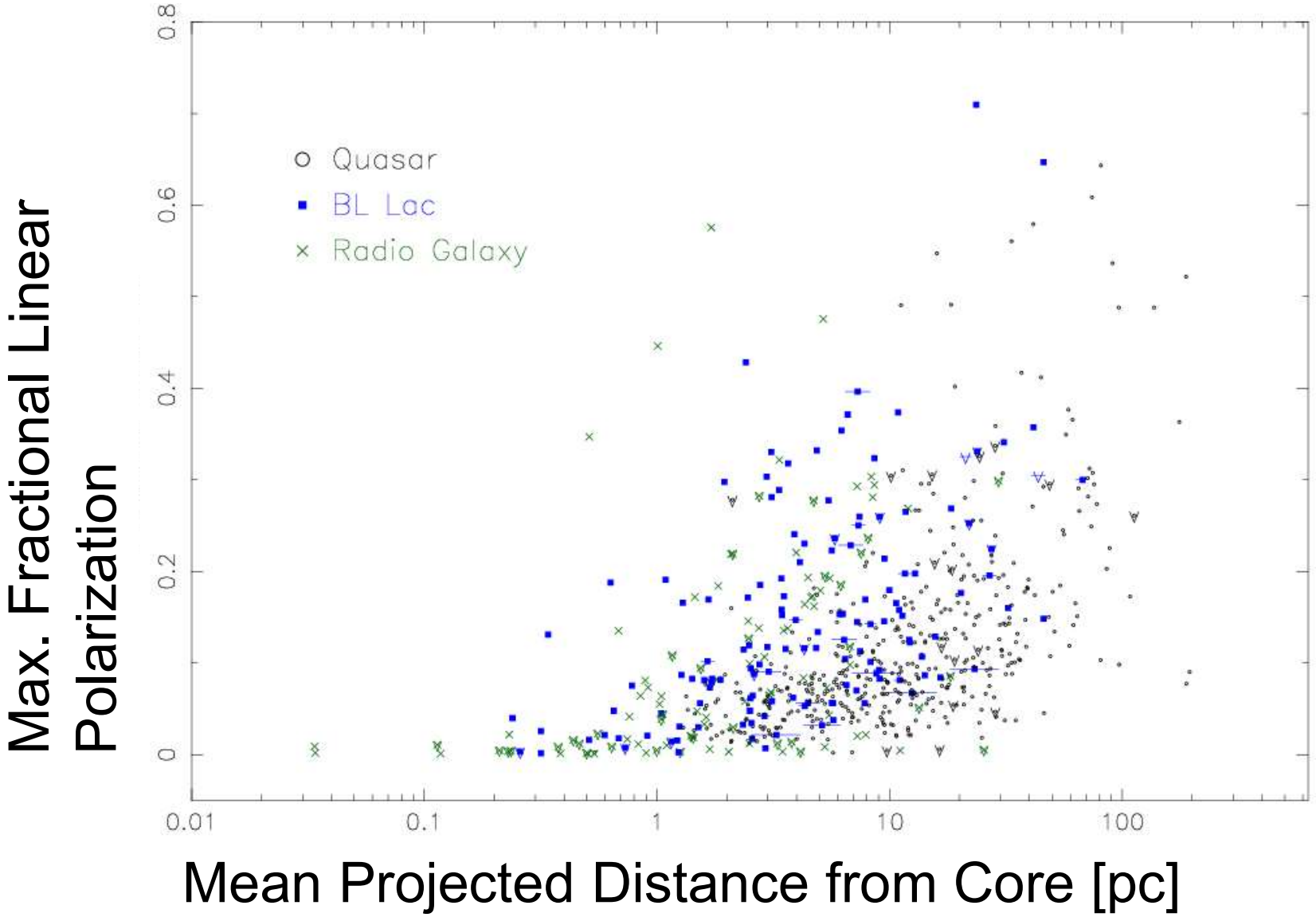


Statistical Trends: Downstream Jet Features

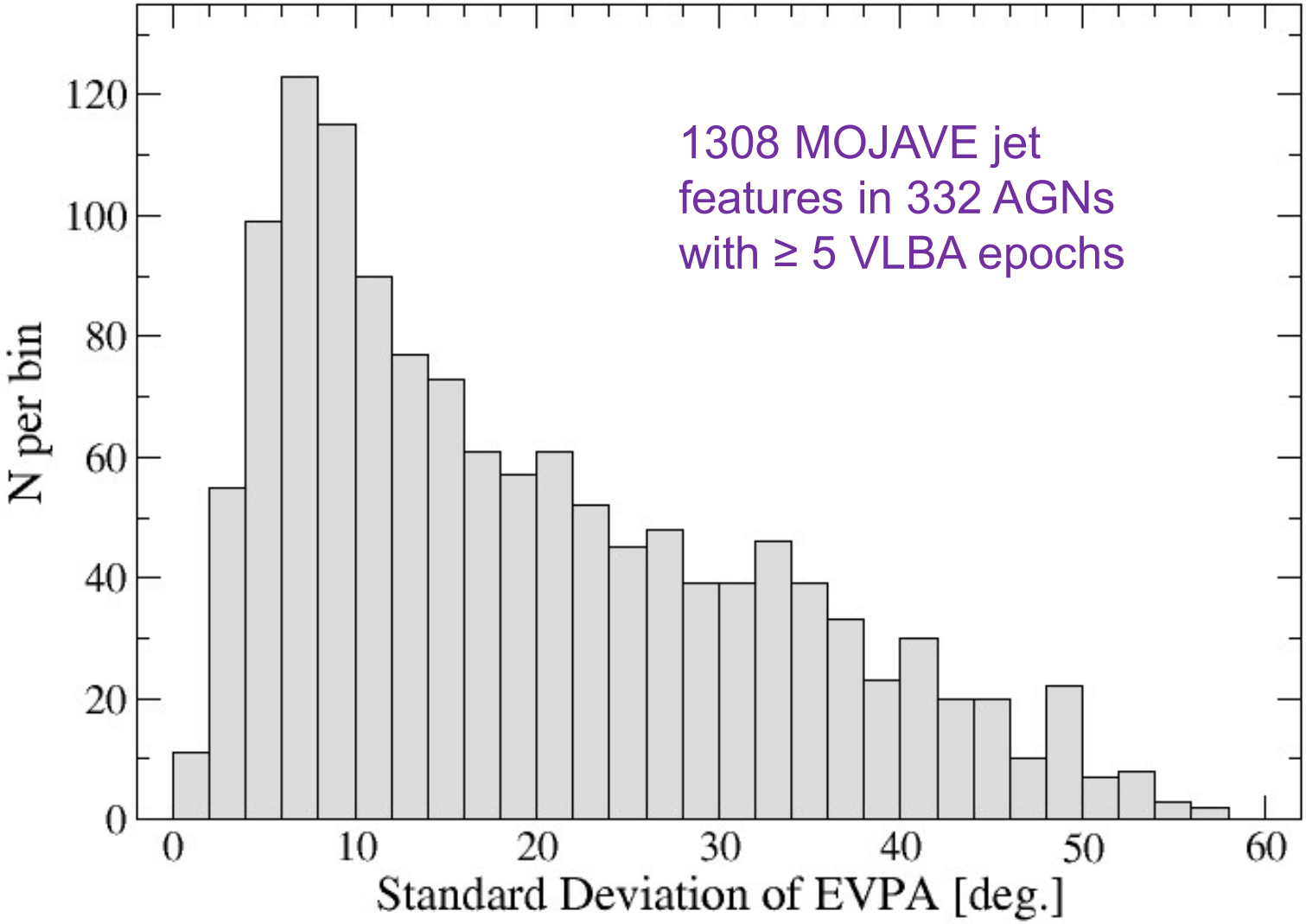
Increasing Field Order Downstream

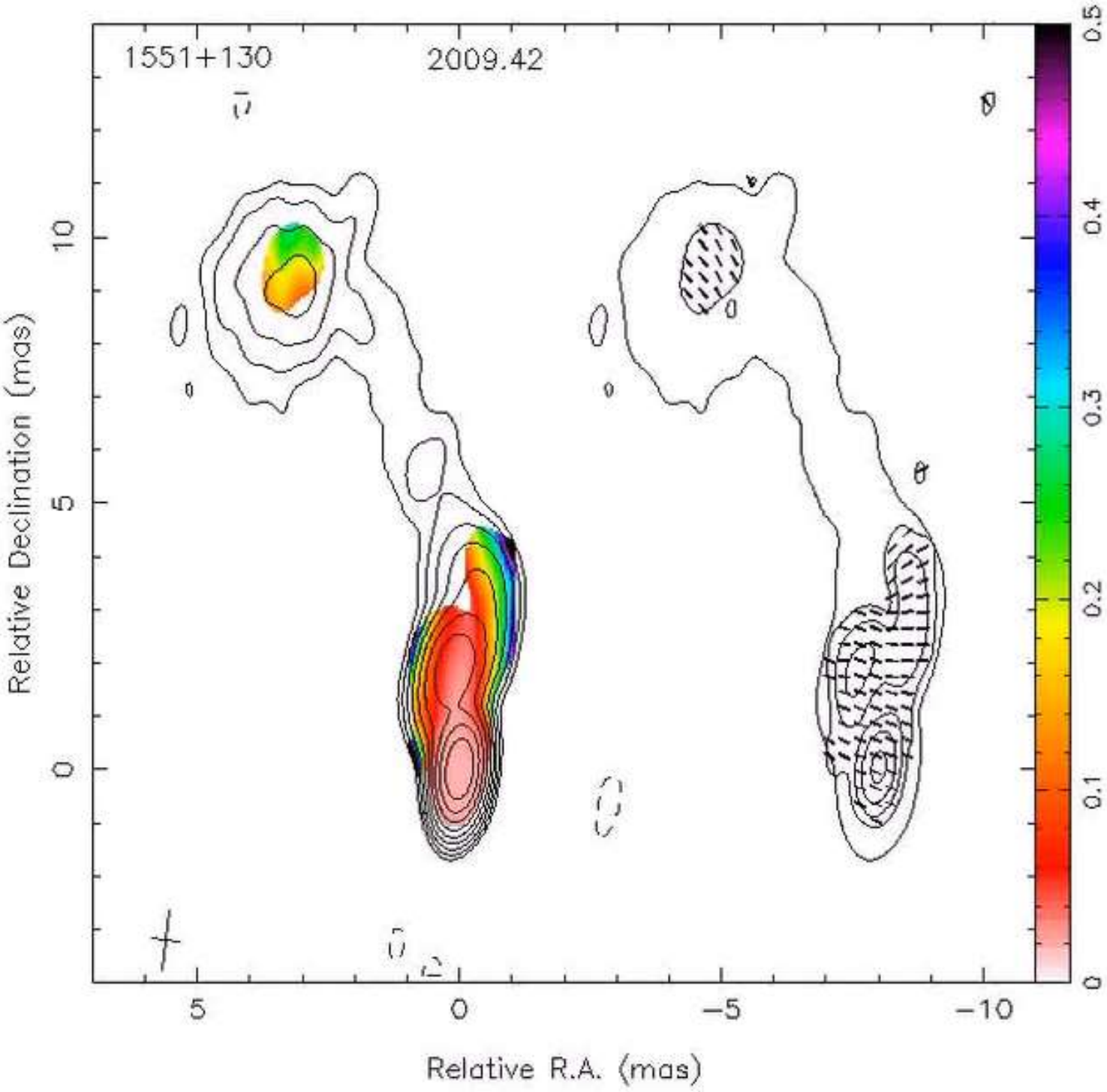


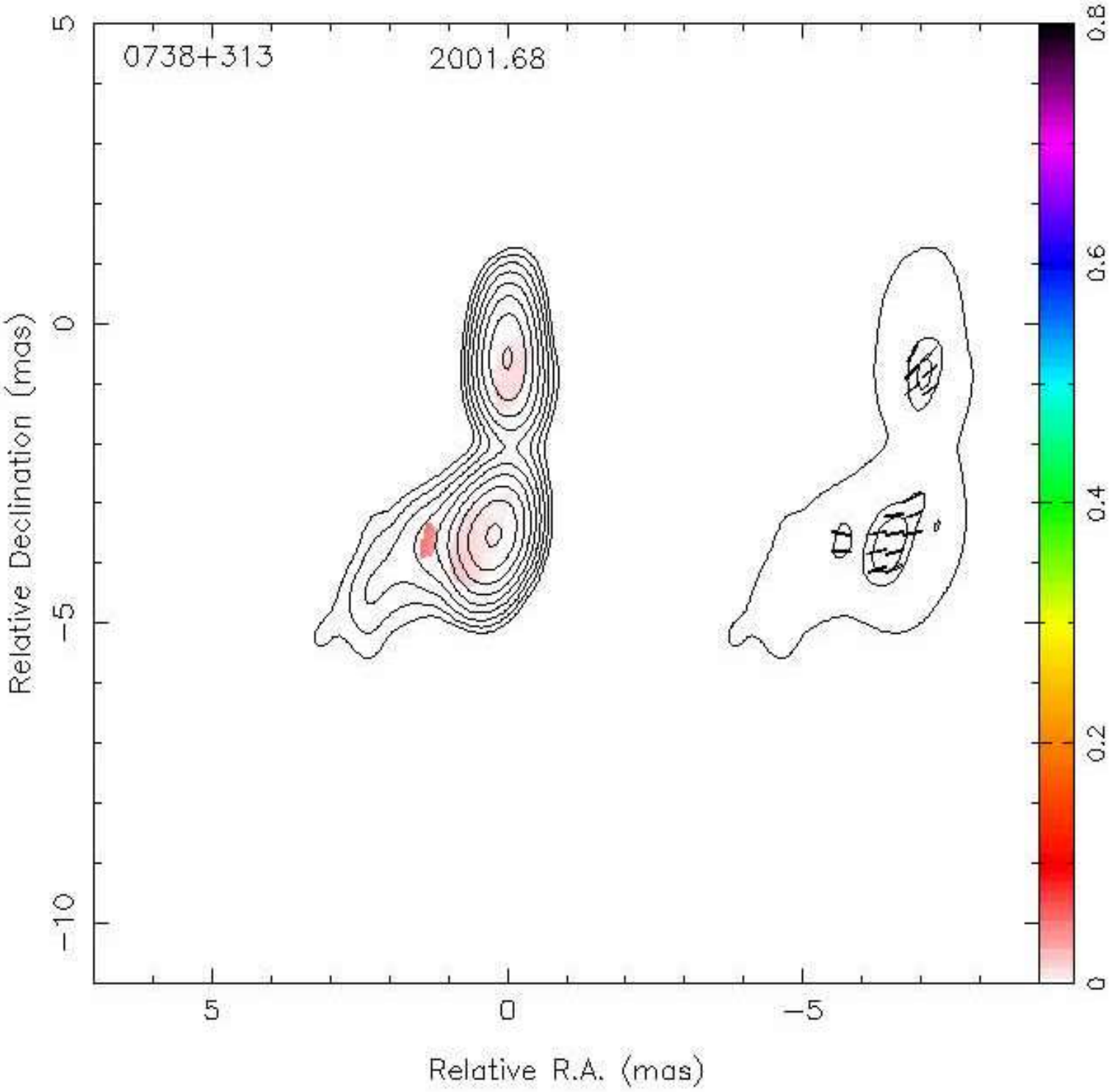
Evolution of Magnetic Field Order



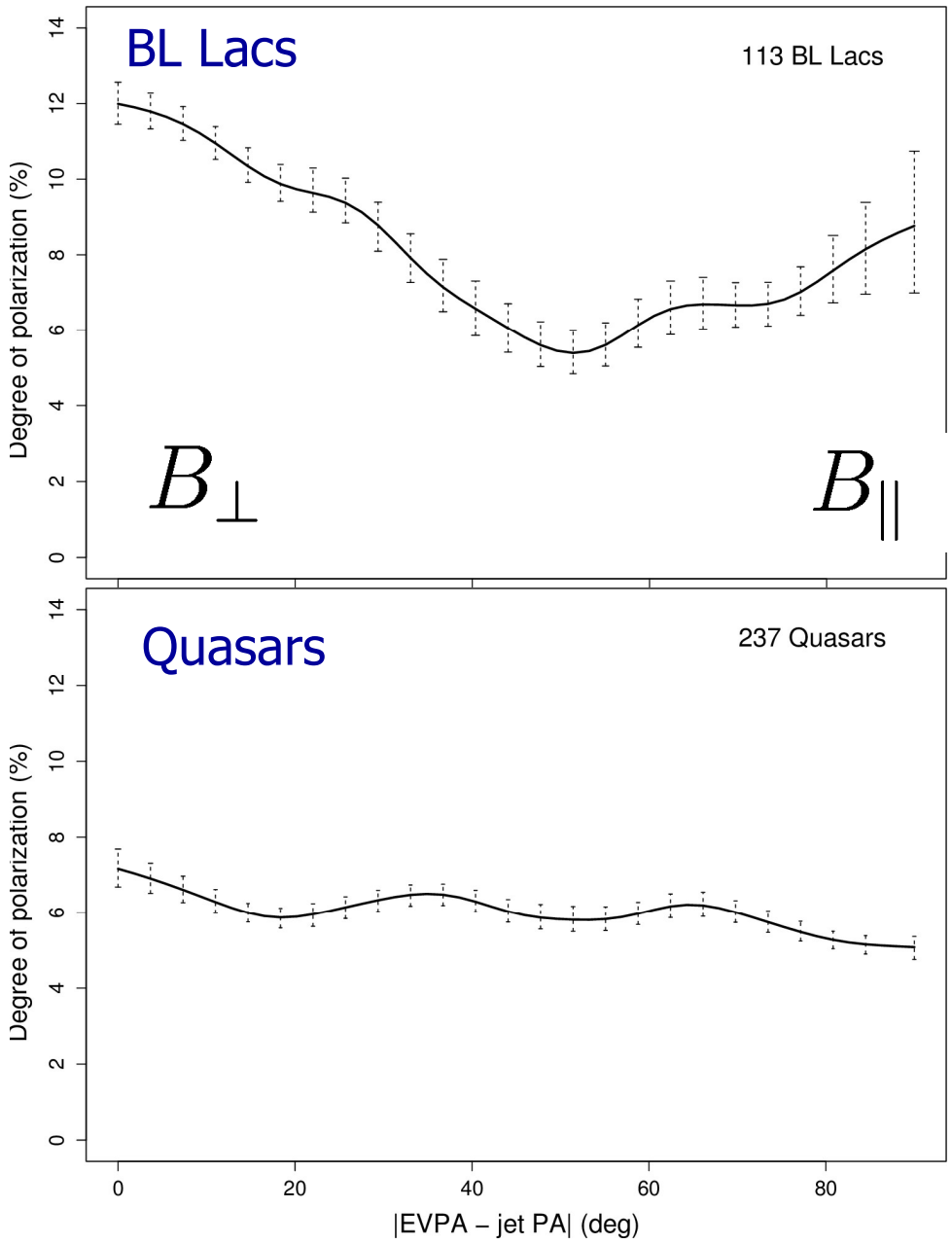
Stability of Downstream EVPAs




1551+130
2009.42
Relative Declination (mas)
Relative R.A. (mas)
10
5
0
5
0
−5
−10
0.5
0.4
0.3
0.2
0.1
0

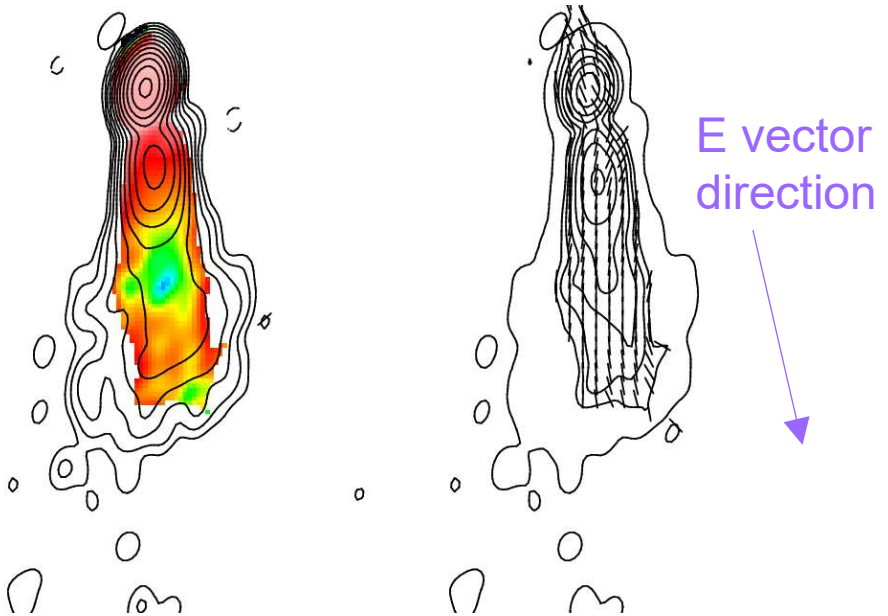

0738+313
2001.68
Relative Declination (mas)
Relative R.A. (mas)
5
0
−5
−10
0.8
0.6
0.4
0.2
0

Downstream EVPA w.r.t. Jet



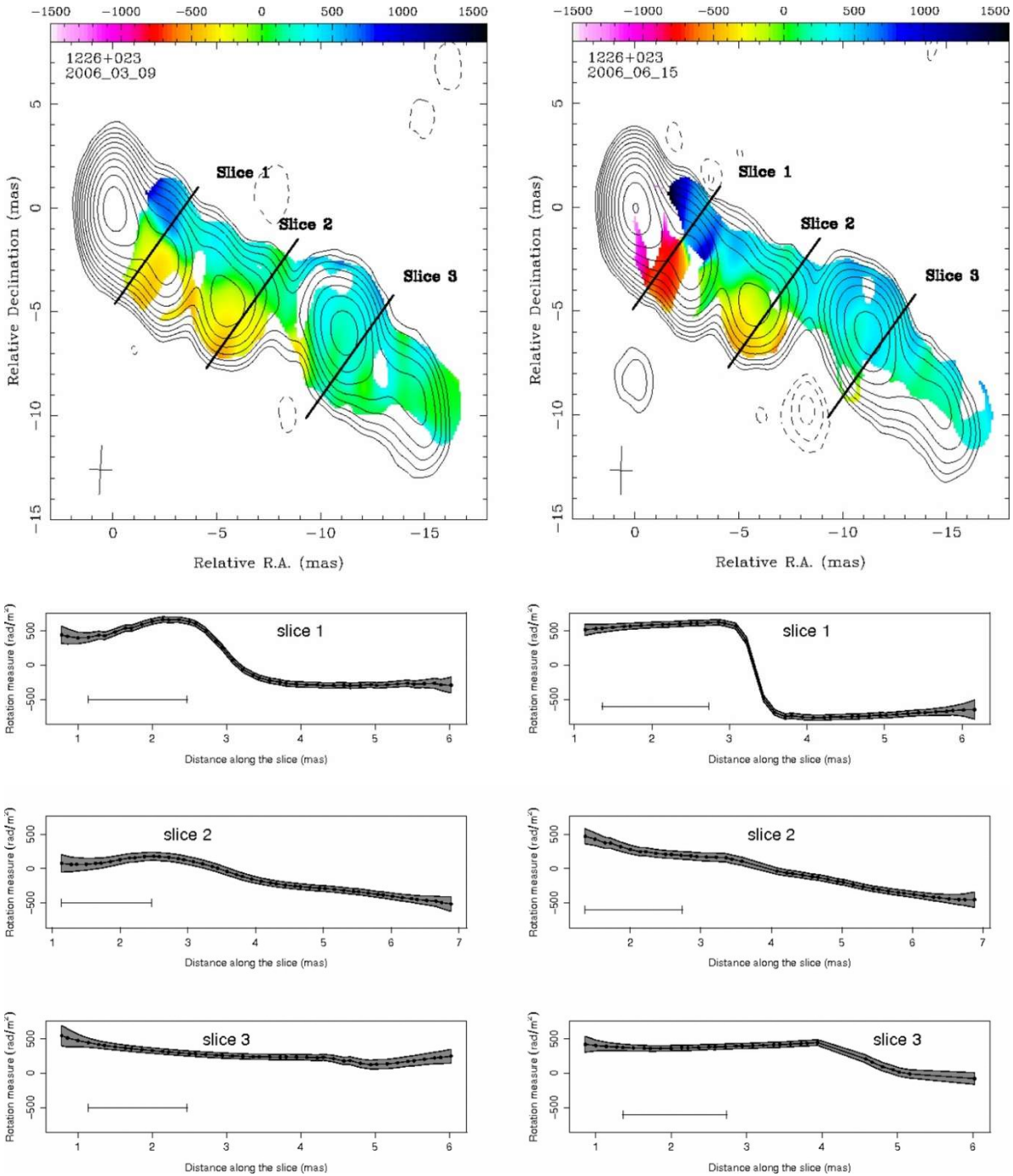
Different optical classes show different behavior:

- stronger $B_\perp$ for BL Lacs
- no preference for Quasars



Helical B Fields

- Time-variable helical field signatures found in transverse Faraday rotation measure gradients (e.g., Hovatta et al. 2012; Asada et al. 2002)
- Predicted in some numerical jet production models invoving initially Poynting-dominated flows that show efficient conversion to kinetic energy flux (Vlahakis & Konigl 2004, Kommissarov et al. 2007, Lyubarsky 2009)



Circular Polarization

- Single dish studies indicate CP levels only of a few per cent.

- MOJAVE VLBA studies (Homan et al. 2006, 2017):
  - Typically at 0.3 – 0.7 % level, only in bright core feature
  - Only 1/3 of sample have CP detections
  - Large majority show a preferred CP sign over time – indicative of field helicity/geometry?

- Production mechanisms:
  - intrinsic synchrotron CP (low since $\propto 1/\gamma_e$)
  - Faraday conversion by emitting or intervening plasma
  - interstellar scintillation

- Only a few strong AGN studied in CP: e.g., 3C 279, 3C 84, PKS 2126-158; no consensus on dominant mechanism(s).

Summary

The VLBA is the only instrument capable of regular magnetic field studies of AGN jets on parsec scales.

- MOJAVE program spans 20 years and over 400 AGN.

Near the jet base:

→ magnetic fields are less ordered, with low linear polarization (~ 2 %) and circular polarization (< 1%).

→ electric vectors show preferred direction ~50% of the time.

→ rapid changes in electric vector angle can occur.

Downstream, field order increases (to 20 - 40% linear pol.):

→ electric vectors more stable and in BL Lacs, are generally aligned with jet

Helical field and transverse shock interpretations are both viable.