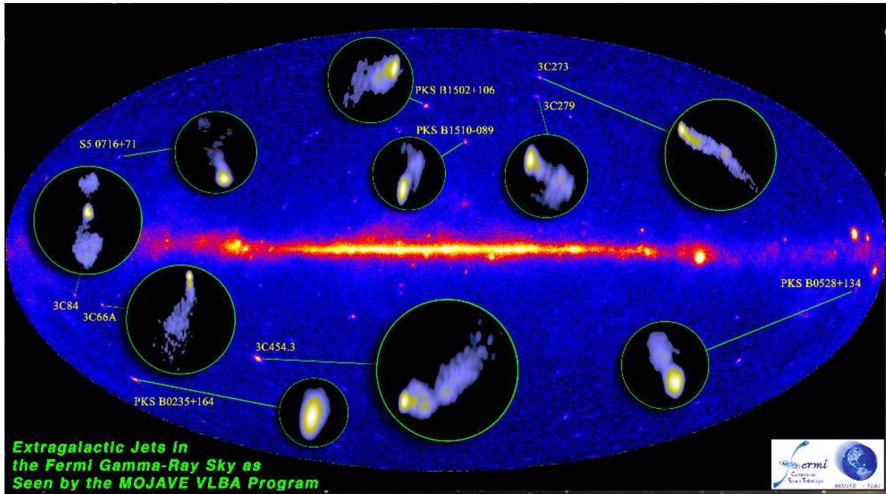
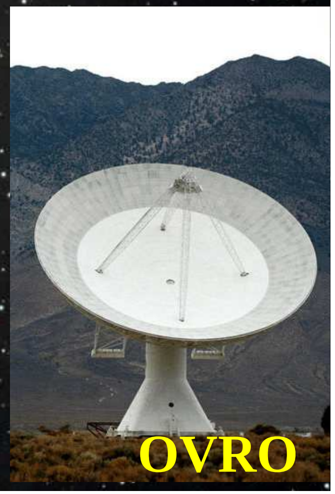


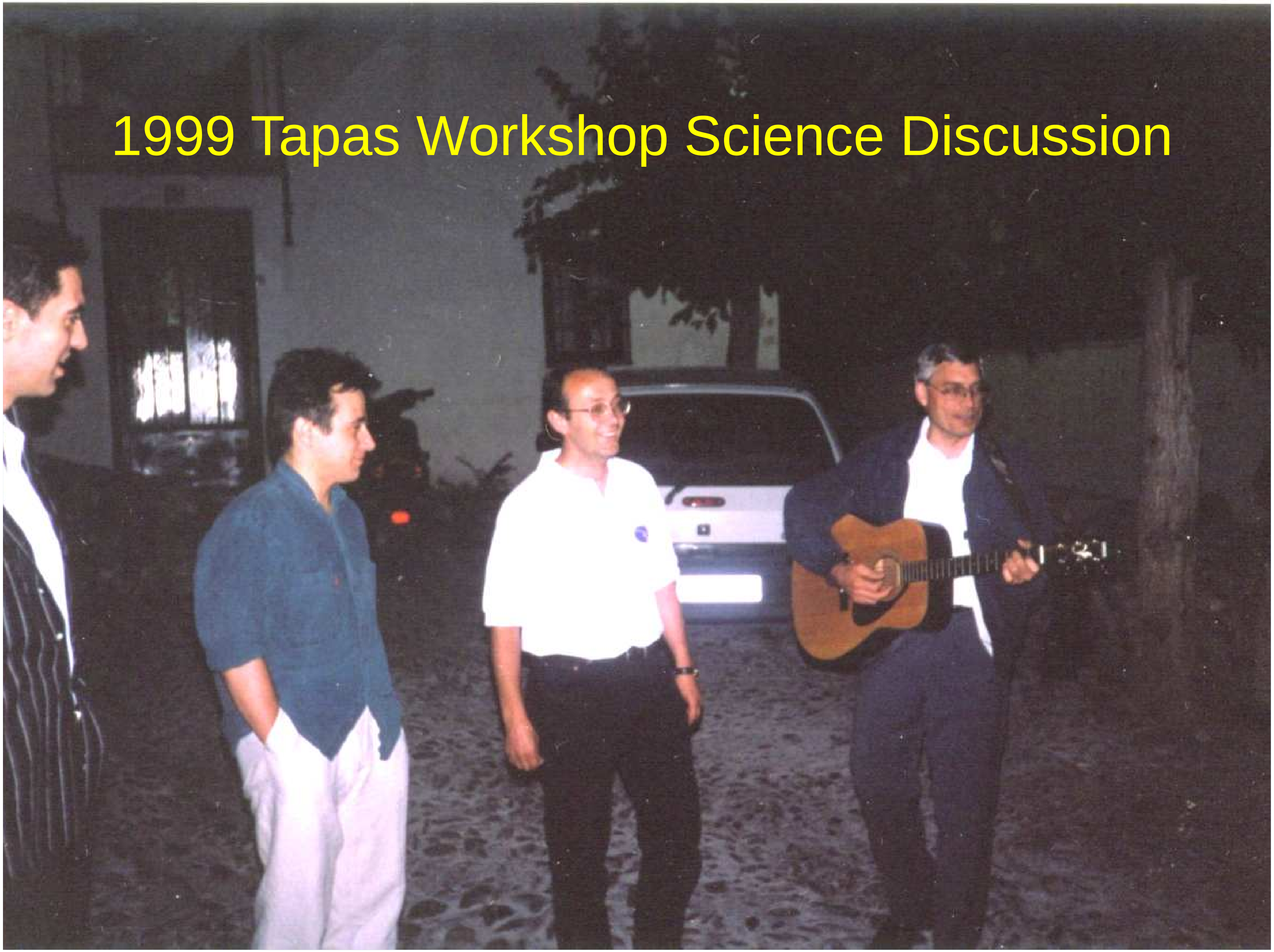
Parsec-Scale Kinematic and Polarization Characteristics of MOJAVE AGN Jets

Matt Lister

Purdue University



1999 Tapas Workshop Science Discussion



Outline

- Description of MOJAVE program
- Kinematics Analysis of Data 1994-2011.5 (Lister et al., AJ submitted)
- (Very) Preliminary polarization results
- Upcoming changes to MOJAVE program

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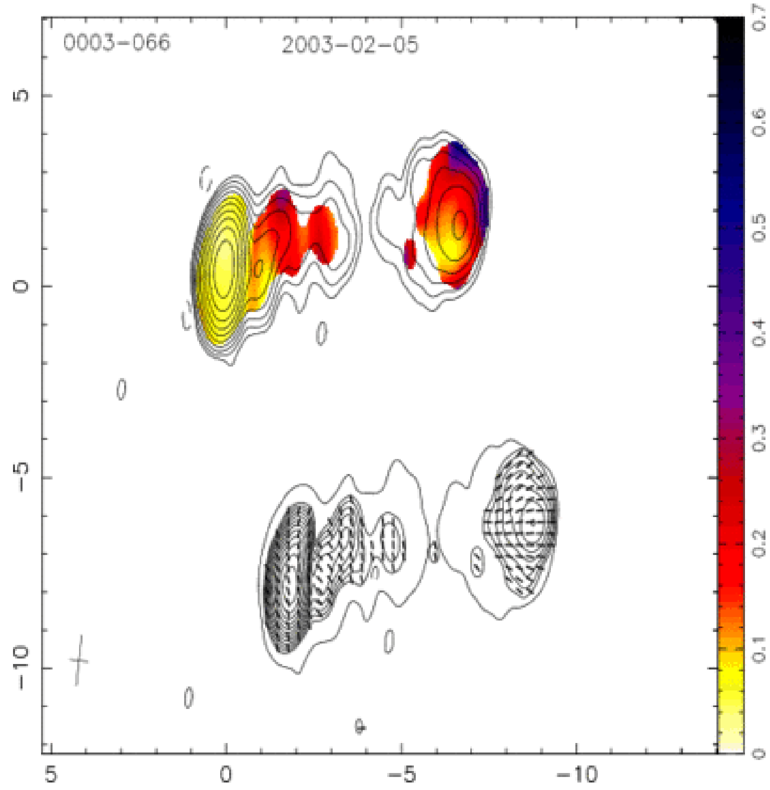
Monitoring
Of
Jets in
Active Galaxies with
VLBA
Experiments

Very Long Baseline Array

MOJAVE VLBA Program

- Regular observations of radio-bright AGNs
  - NRAO VLBA Key Science project
- 24 hr observing session every 3 weeks
  - cadence tailored to individual jets: once every 3 weeks to once every 3 years
- mas-resolution images at 15 GHz
  - continuous time baselines on many sources back to 1994
  - full polarization since 2002



MOJAVE images of 0003-066

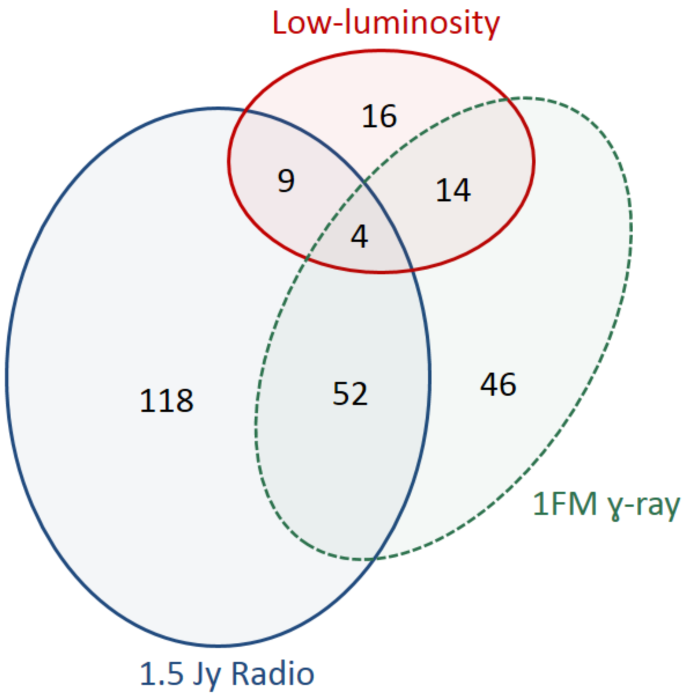
Colors: fractional linear polarization

MOJAVE AGN Samples (δ > -30°)

- **1.5 Jy Radio: Complete radio-selected sample with VLBA 15 GHz flux density exceeding 1.5 Jy at any epoch during 1994.0-2010.0**

- **1FM γ-ray: Complete *Fermi*-selected AGN sample above 100 MeV (Lister et al. 2011, ApJ 742,27)**

- **Low-luminosity: Representative sample of 43 AGNs with 15 GHz luminosity below 10^{26} W/Hz selected from the Radio Fundamental Catalog.**



	1.5 Jy Radio	1FM γ-ray	Low-Luminosity
Quasars	142	72	7
BL Lacs	29	42	20
Radio Galaxies	8	1	16
Narrow-line Seyfert 1s	0	1	0
Unidentified	4	0	0
Total	183	116	43

Observational Data Set

- **4366 VLBA 15 GHz epochs of 200 AGNs from 1994 Sep - 2011 May.**
- **Gaussian models fit to visibilities at each epoch.**
- **Image restoring beam:**

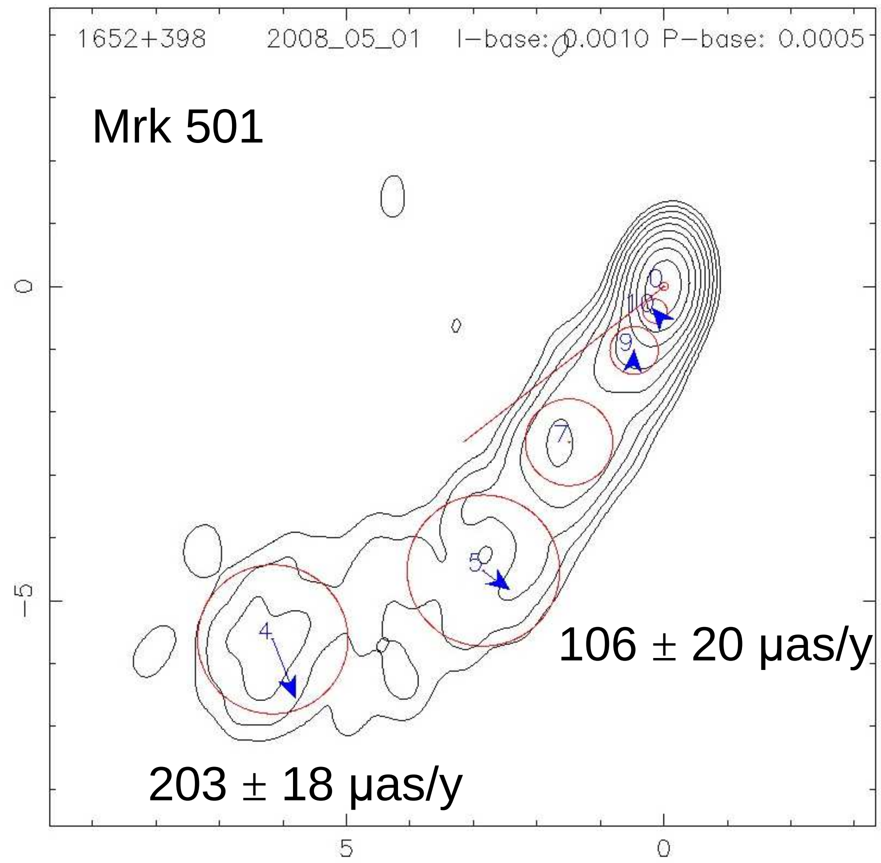
  ~0.5 to 1 mas

- **Image sensitivity:**

  0.1 - 0.3 mJy/beam

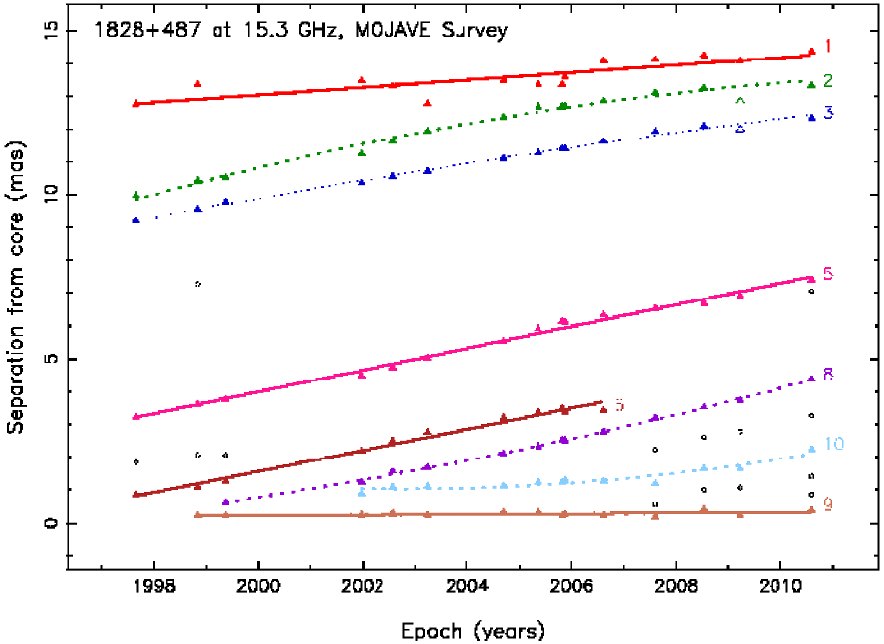
- **Positional accuracy:**

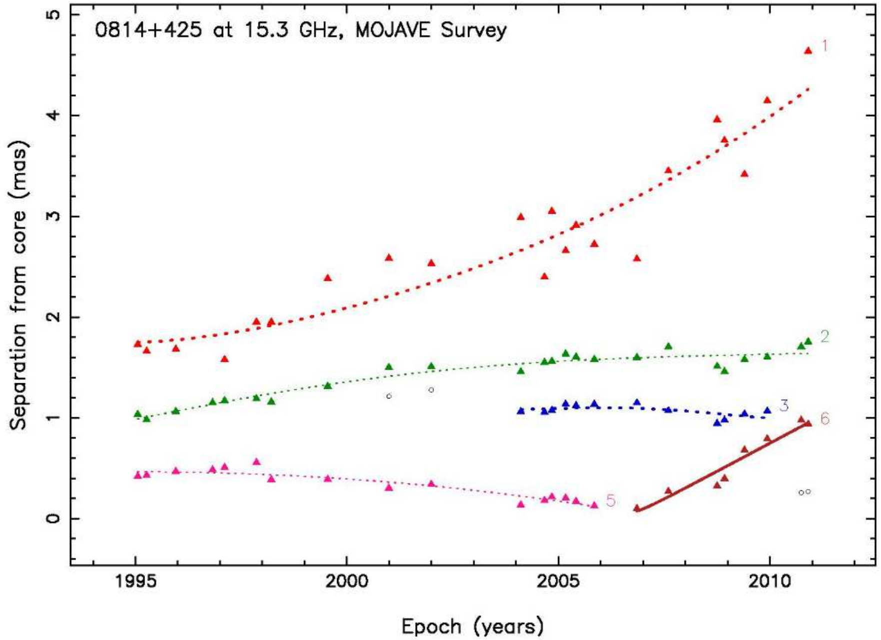
  0.05 - 0.1 mas



Probe of jet kinematics and polarization in region 10-1000 pc (de-projected) from central engine.

Kinematic Fits

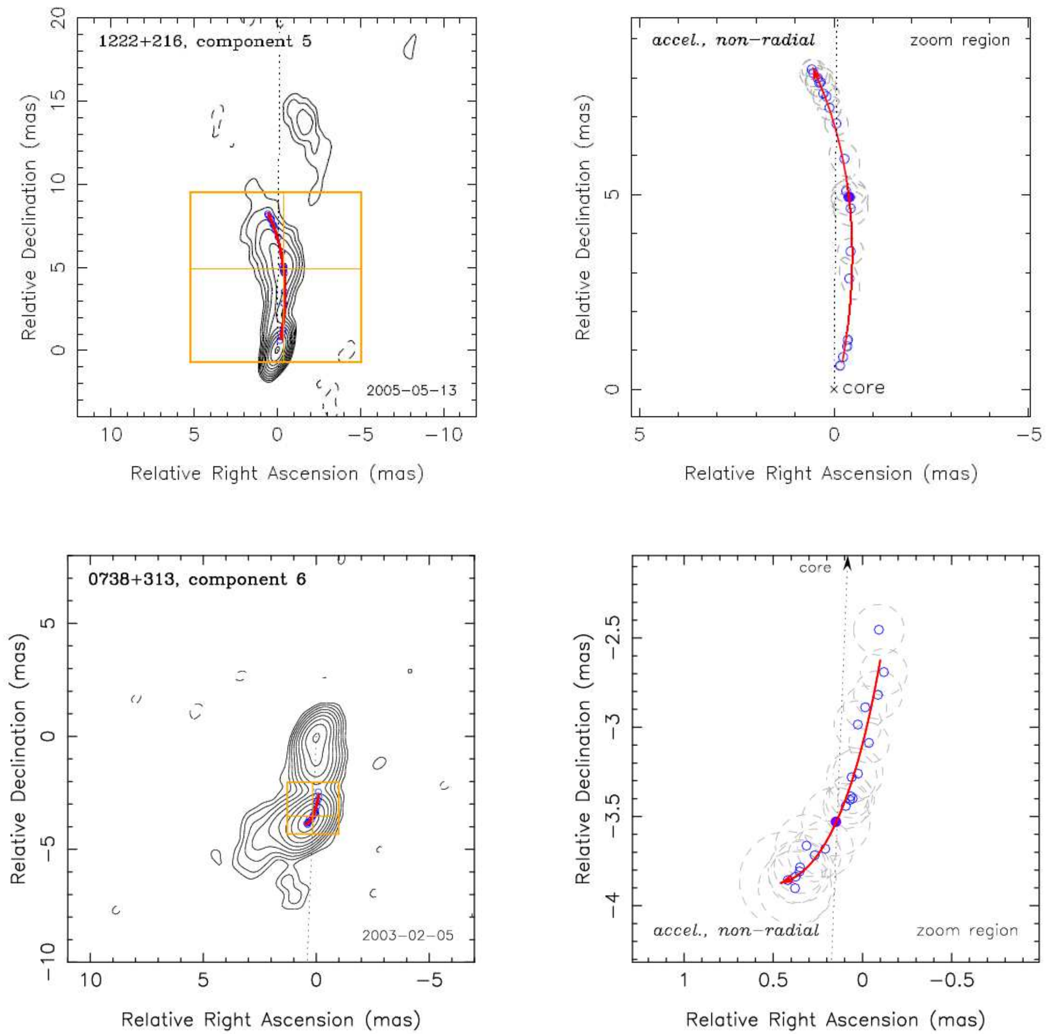




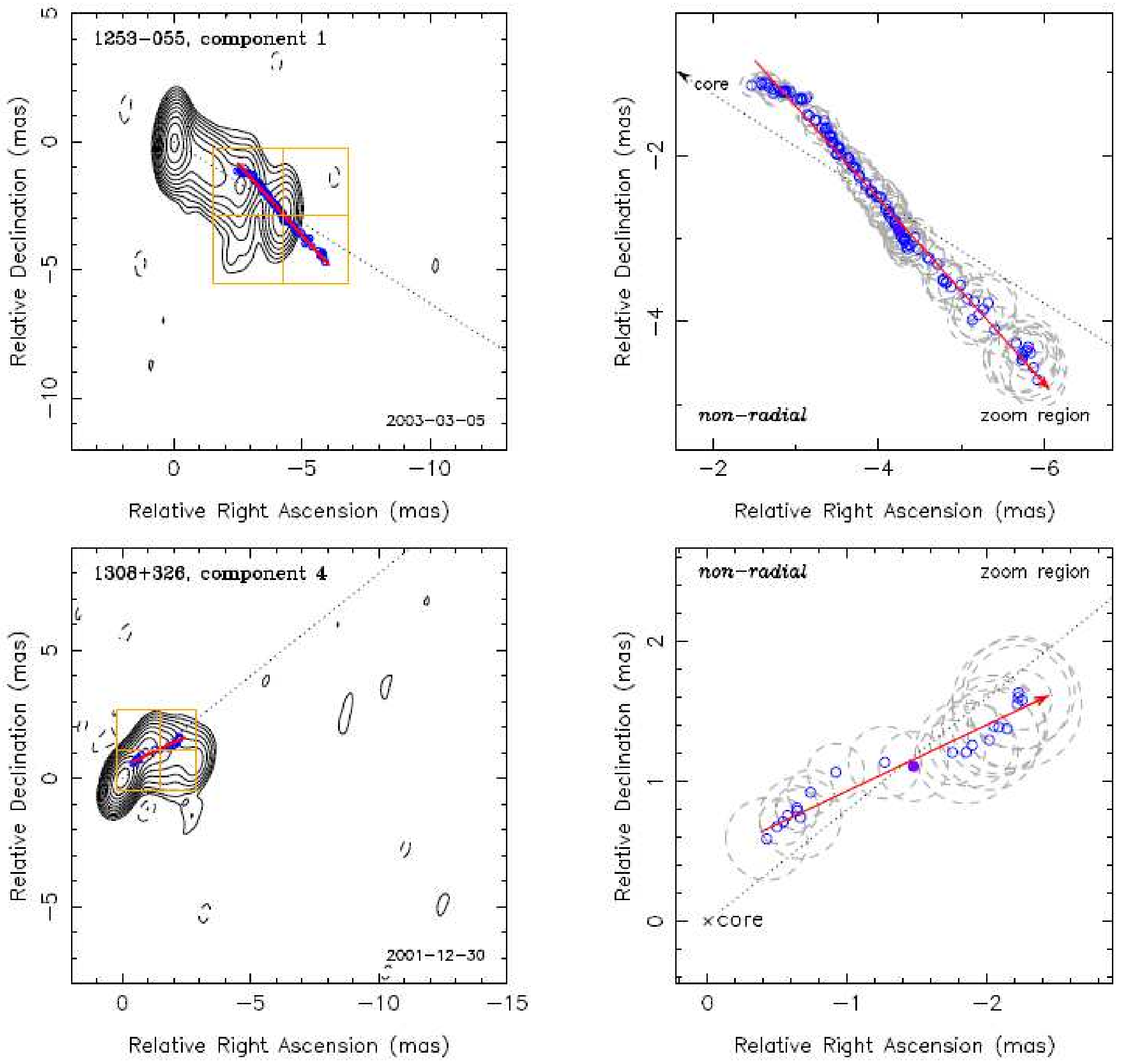
- Two-dimensional sky vector motion fits were made to 887 features in 200 AGN jets which had 5 or more epochs.

  --- many features tracked for 10+ years

- Constant acceleration fits were made to 557 features with 10 or more epochs.



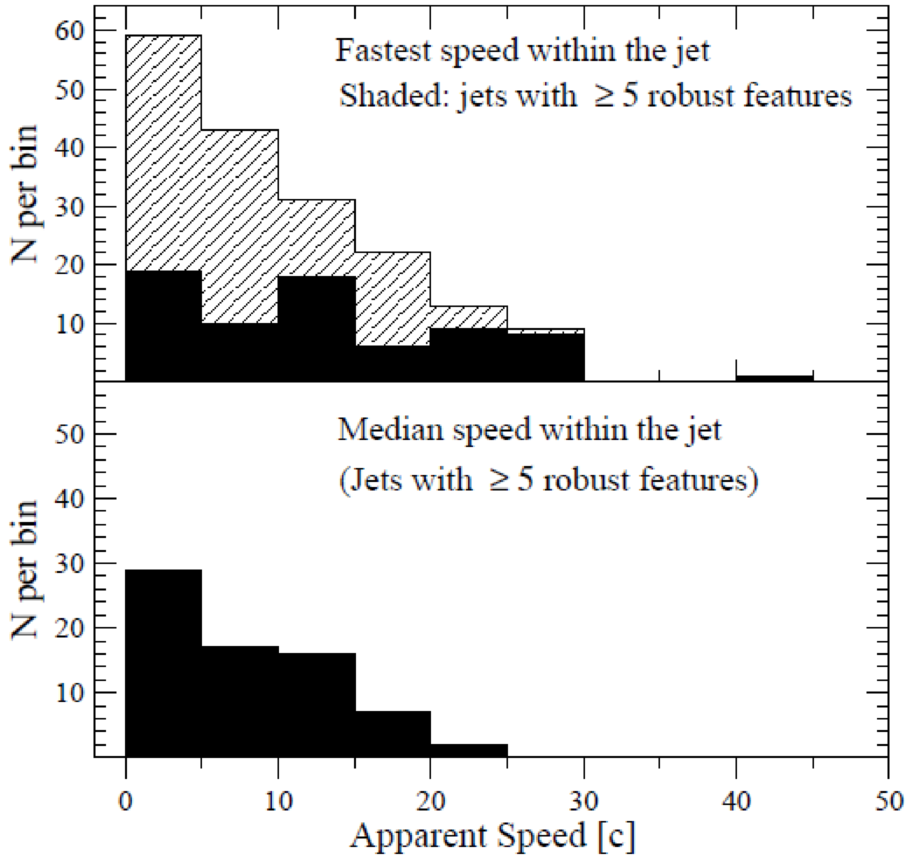
- In most cases a constant acceleration model provides a good fit to the observed motions



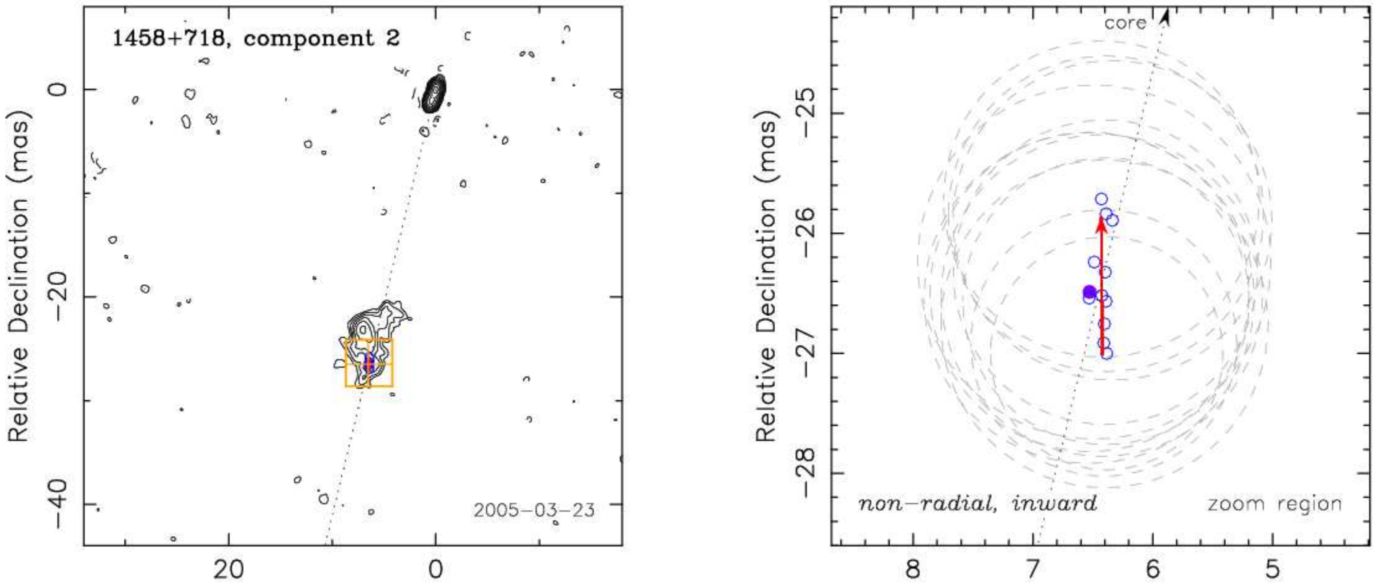
- Some features show variable acceleration

Kinematics Summary

- 98% of motions are outward from core
- 38% have non-radial motions
- 39% have >3σ accelerations
- All told, 70% of motions are non-ballistic
- Speed distribution:
  - peaked at low values
  - only 2 jets with $\beta_{app} > 30$
  - high Γ jets are very rare in blazar parent population



Apparent Inward Motions

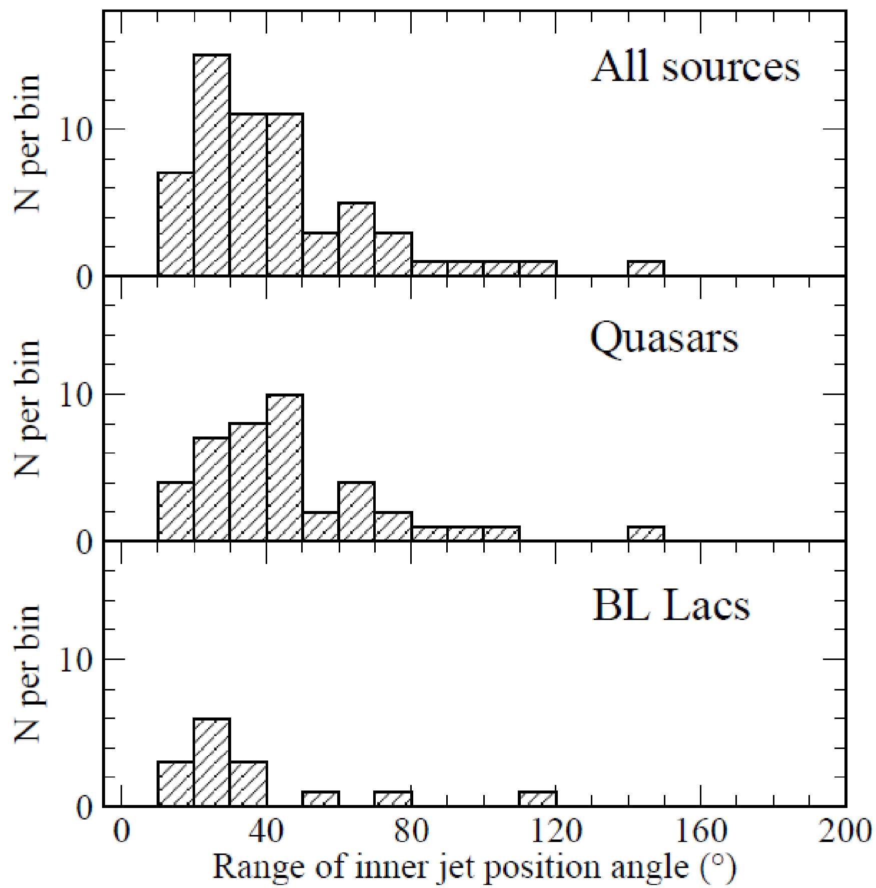


- Statistics:
  - Rare: only 2% of all moving features
  - seen in only 10 of 200 jets
  - More prevalent in BL Lacs (6 of 10 AGNs)

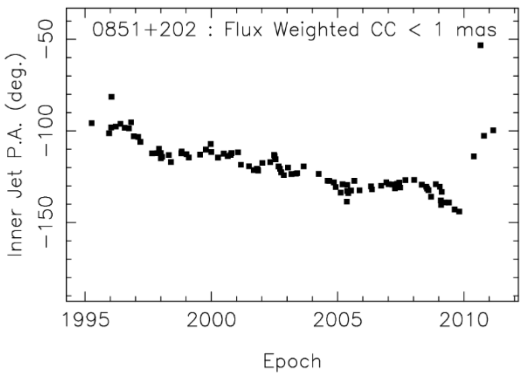
- Possible causes:
  - Accelerated motion across the line of sight
  - Inward pattern speed (e.g., reverse shock)
  - Misidentification of true core feature

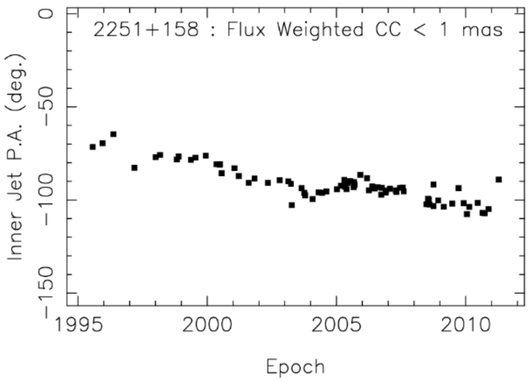
Inner Jet Orientation Variations

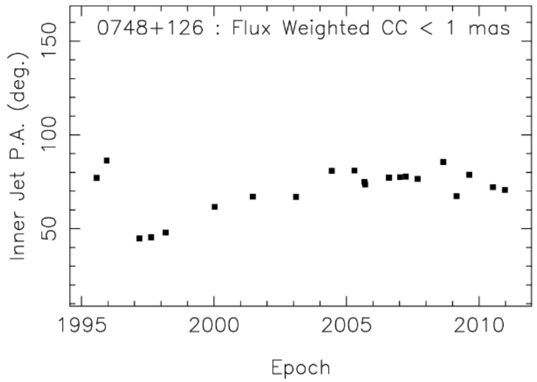
- Analyzed 60 jets with 12-15 years of VLBA coverage
- Determined inner jet orientation based on flux-weighted average of clean components from 0.15 to 1 mas of the core.
- Most jets show significant changes in inner jet position angle, large jumps also occur
- BL Lac jets typically show smaller variations than quasar jets

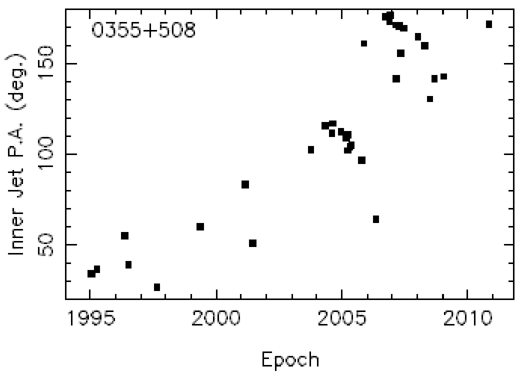


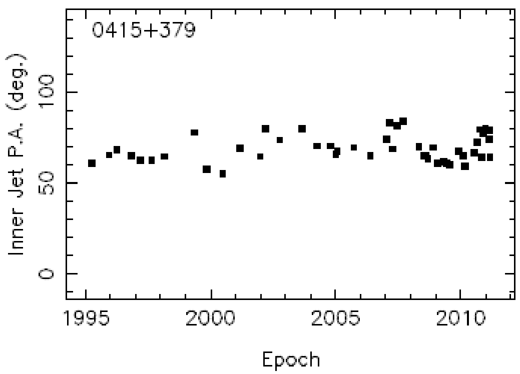
- 50% show no trend with time
- 43% have monotonic swings in position angle
  - Typically 1 to 3 degrees per year
  - Fastest: NRAO 150 (9.8 ± 1˚ per y)

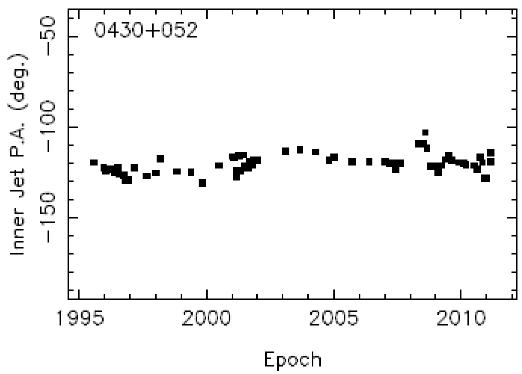




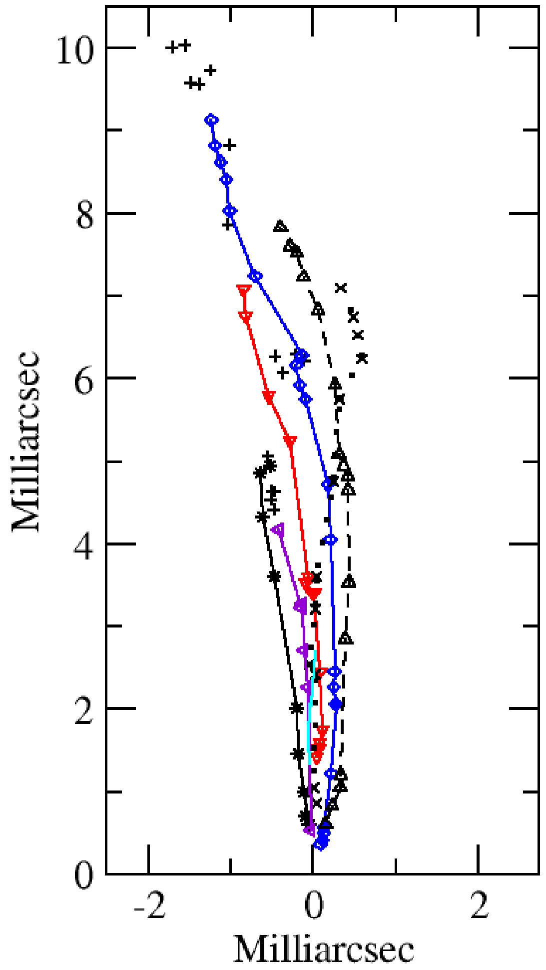


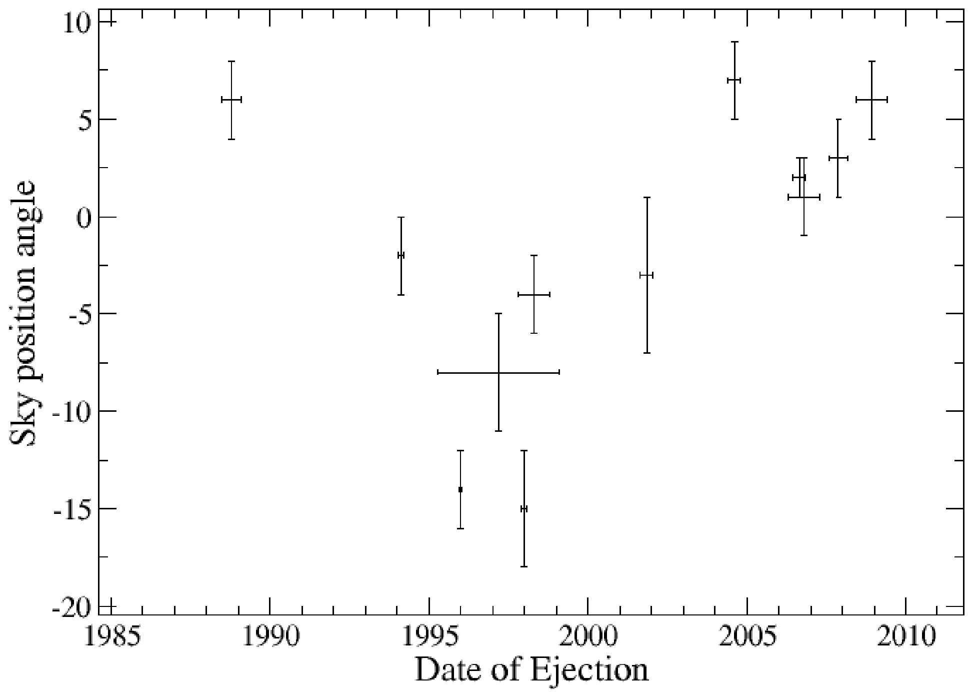






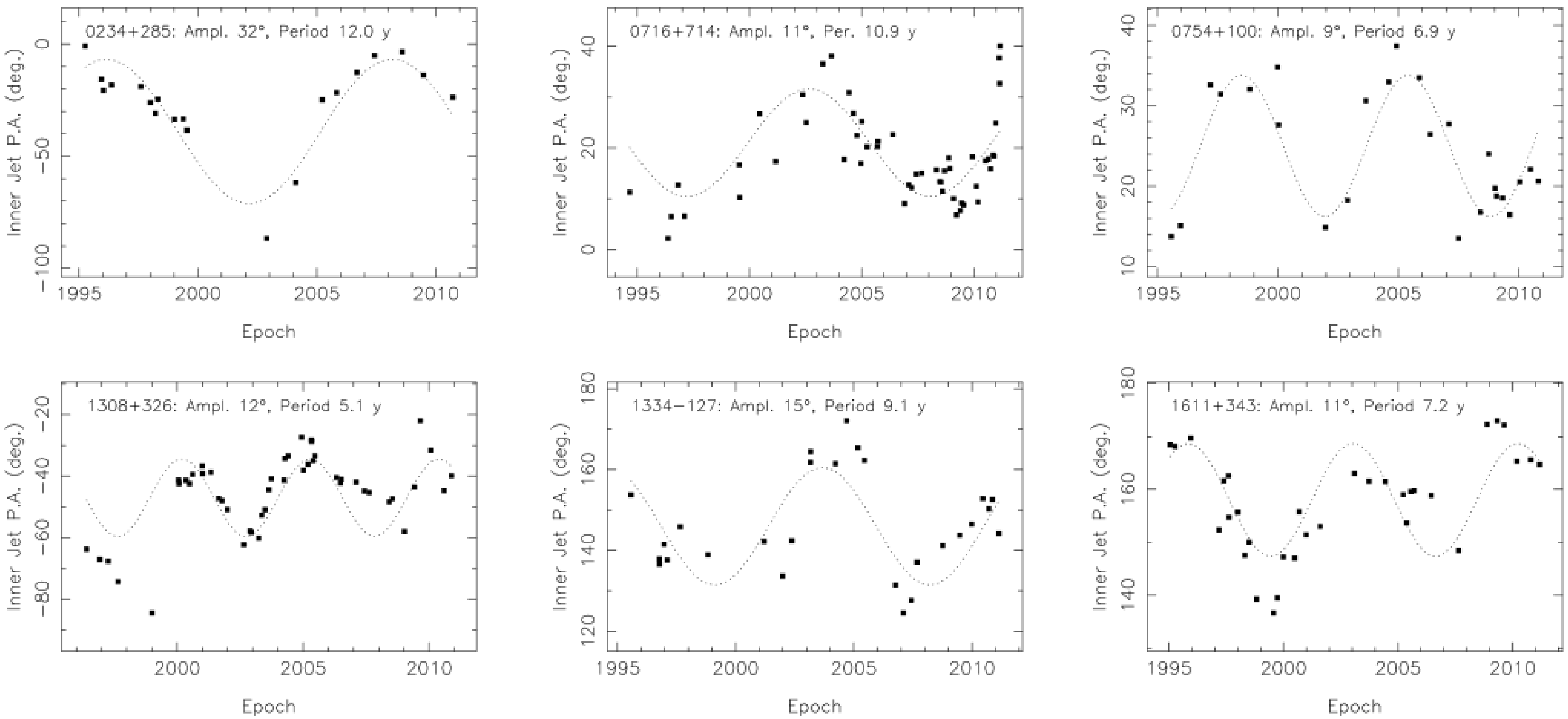
Jet P.A. changes are primarily driven by emergence of new features



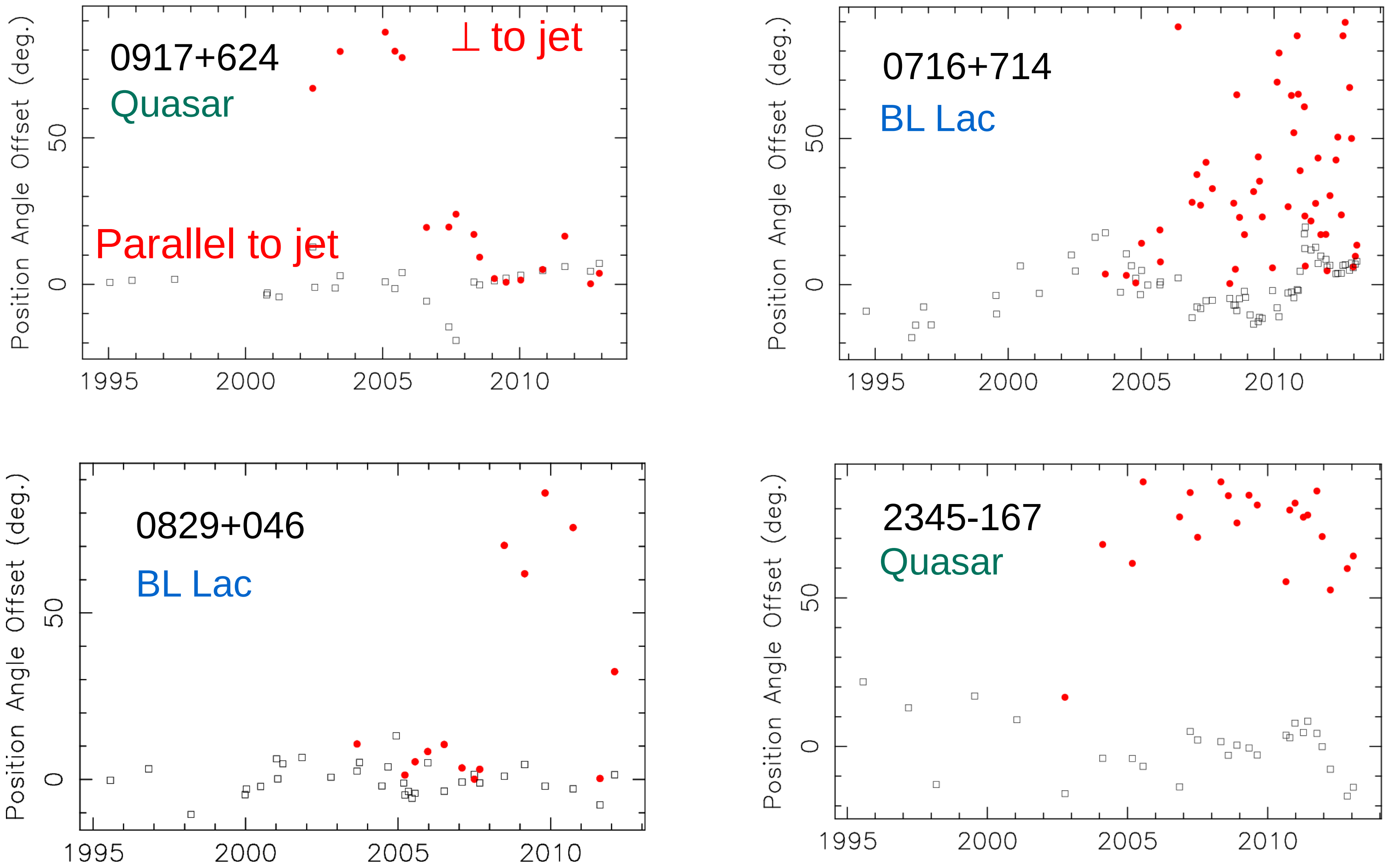


Quasar 1222+216

- Sinusoid-like PA variations in 20% of jets
- Variations are too slow to establish periodicity

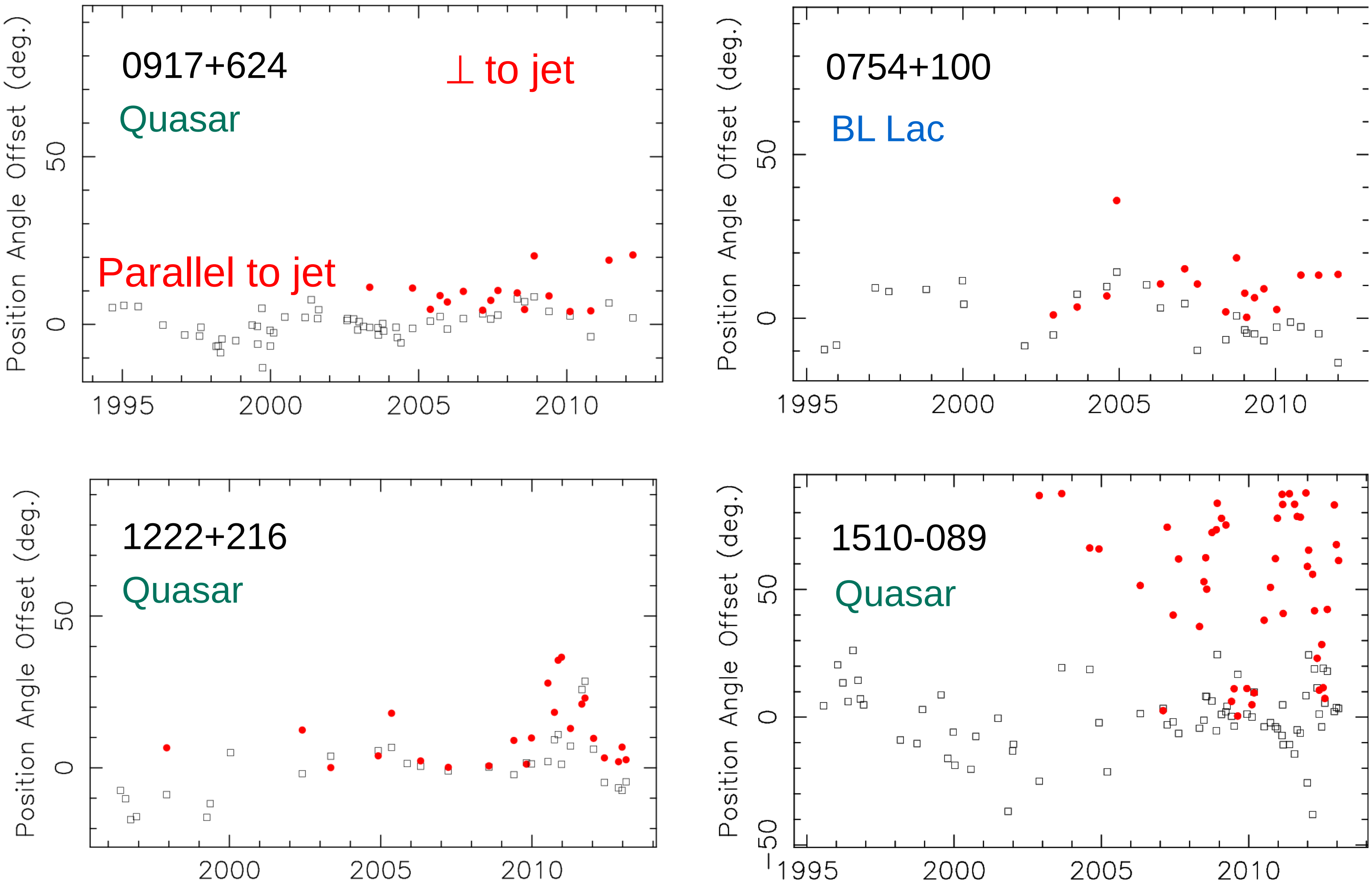


Core electric vector polarization changes over time



Typical core Faraday rotation corrections at 15 GHz: ~ 10 deg (MOJAVE paper VIII)

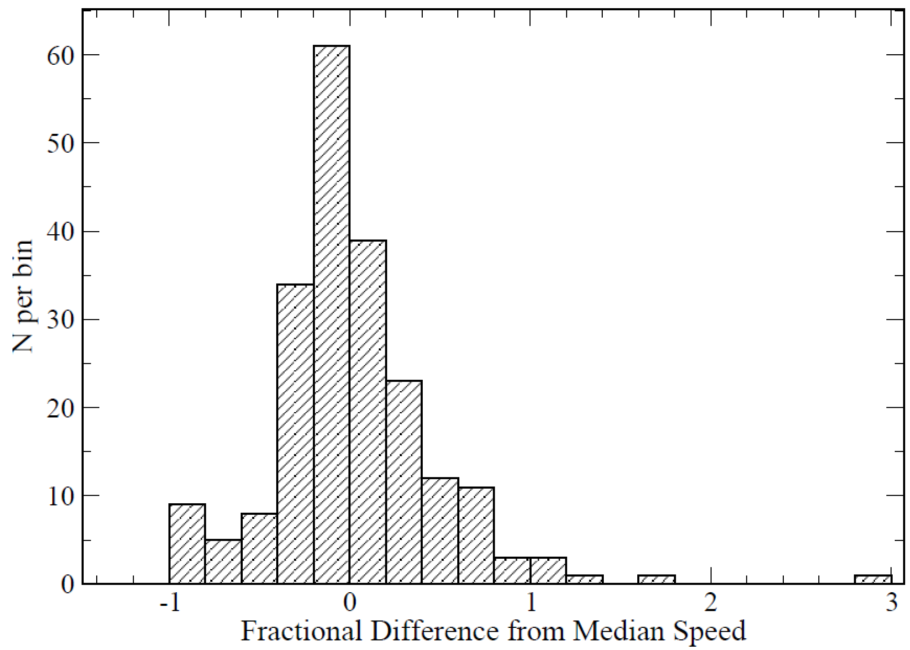
Wide range of core EVPA behavior



Speed Dispersion Within the Jet

- Typically wide range of speed within a jet, but clustered around a characteristic value

- Inner jet P.A. variations are insufficient to wholly account for the speed dispersion



Normalized speed distribution within 12 jets with at least 10 moving features

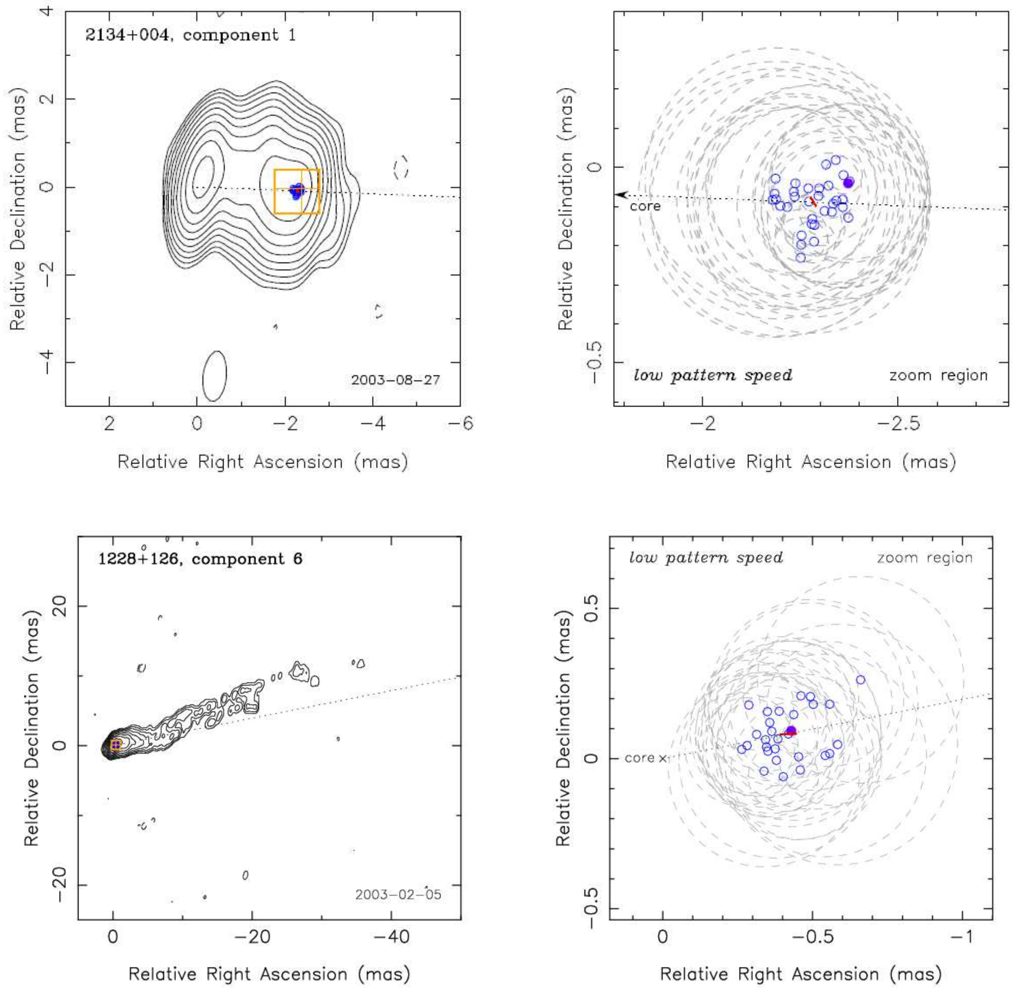
AGN jets typically contain features with a range of bulk Lorentz factor and/or pattern speed

Slow Pattern Speeds

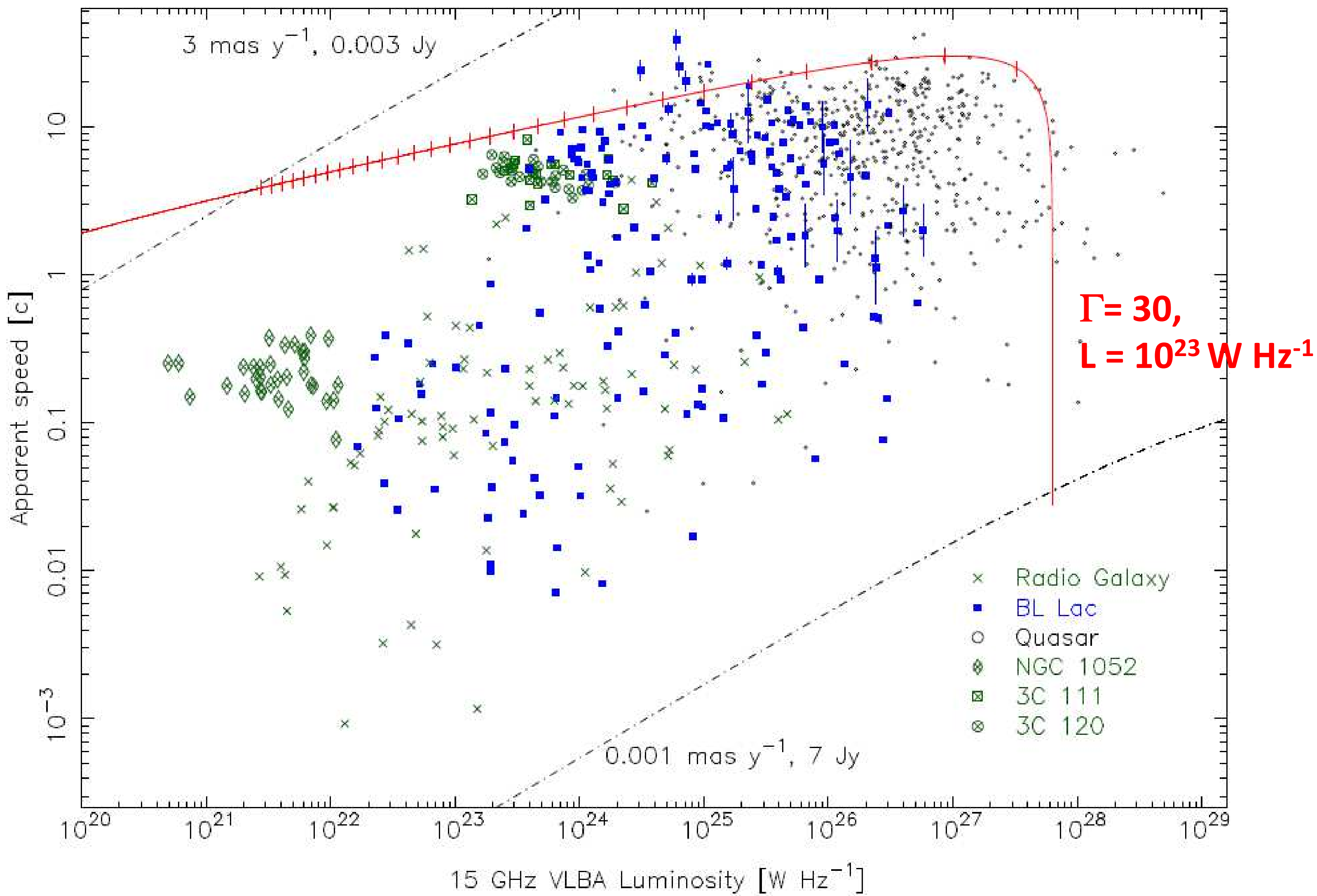
- Defined as:
  a) < 20 μas/y ,
  b) non-accelerating ,
  c) < 1/10th of max speed.

- Only 4% of all features

- Less common in high-luminosity/quasar jets

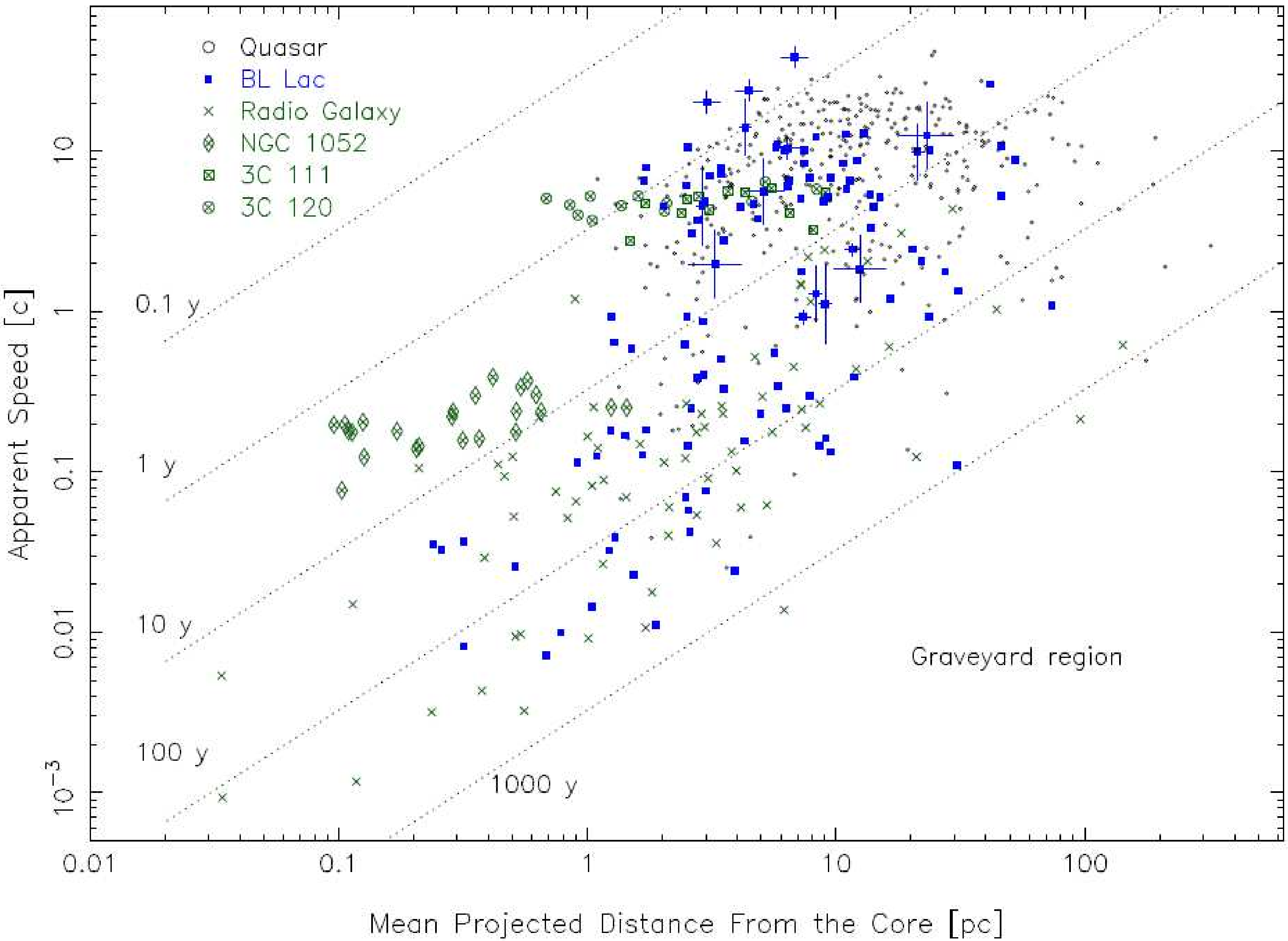


Statistical Trends

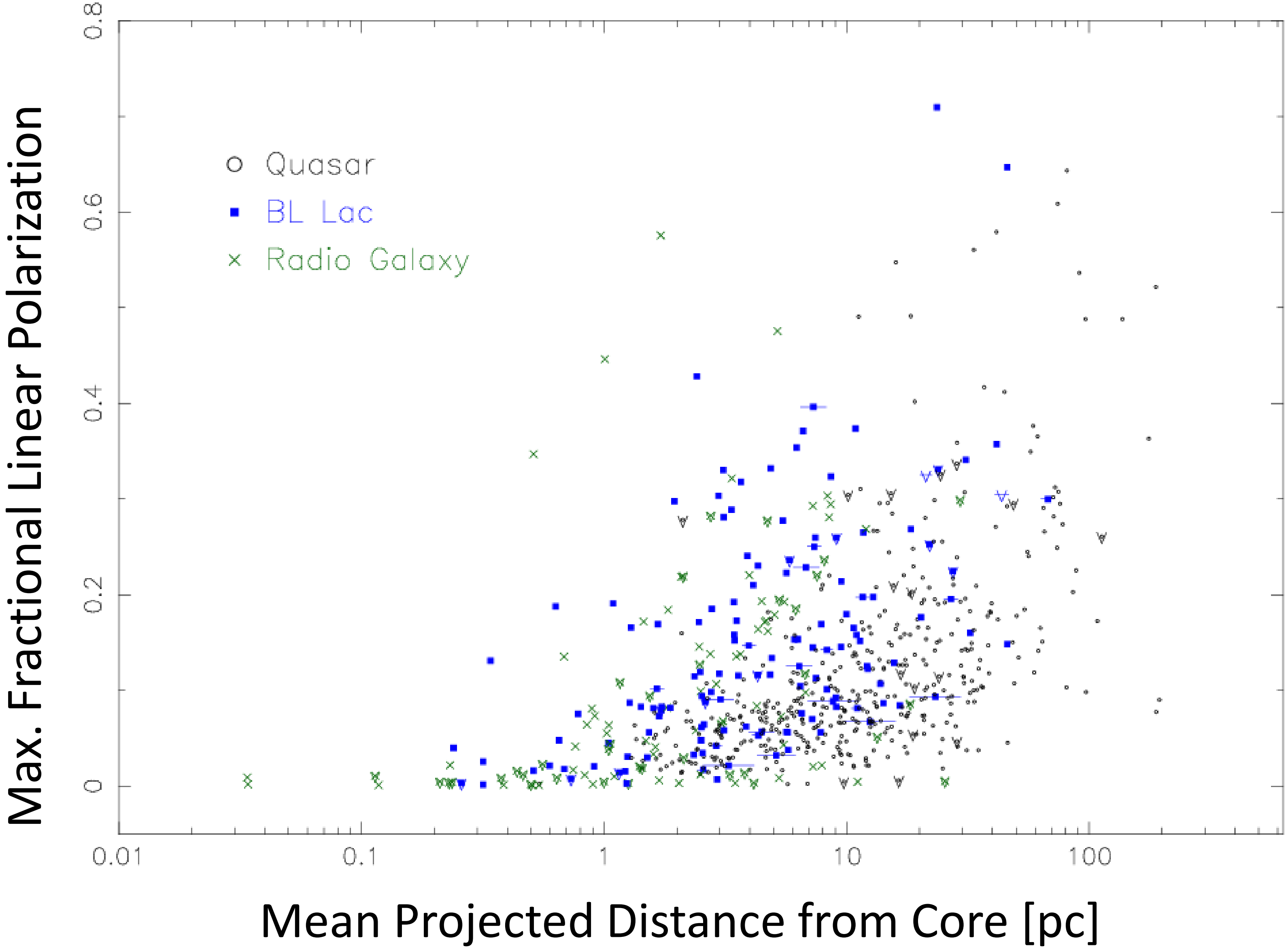


- Absence of fast features with low synchrotron luminosity
- The most powerful blazar jets have a wide range of Lorentz factors up to ~40
- Weaker AGN jets have Lorentz factors of only ~ a few

Trends Down the Jet



- Increase in mean apparent speed downstream for BL Lacs and radio galaxy jets

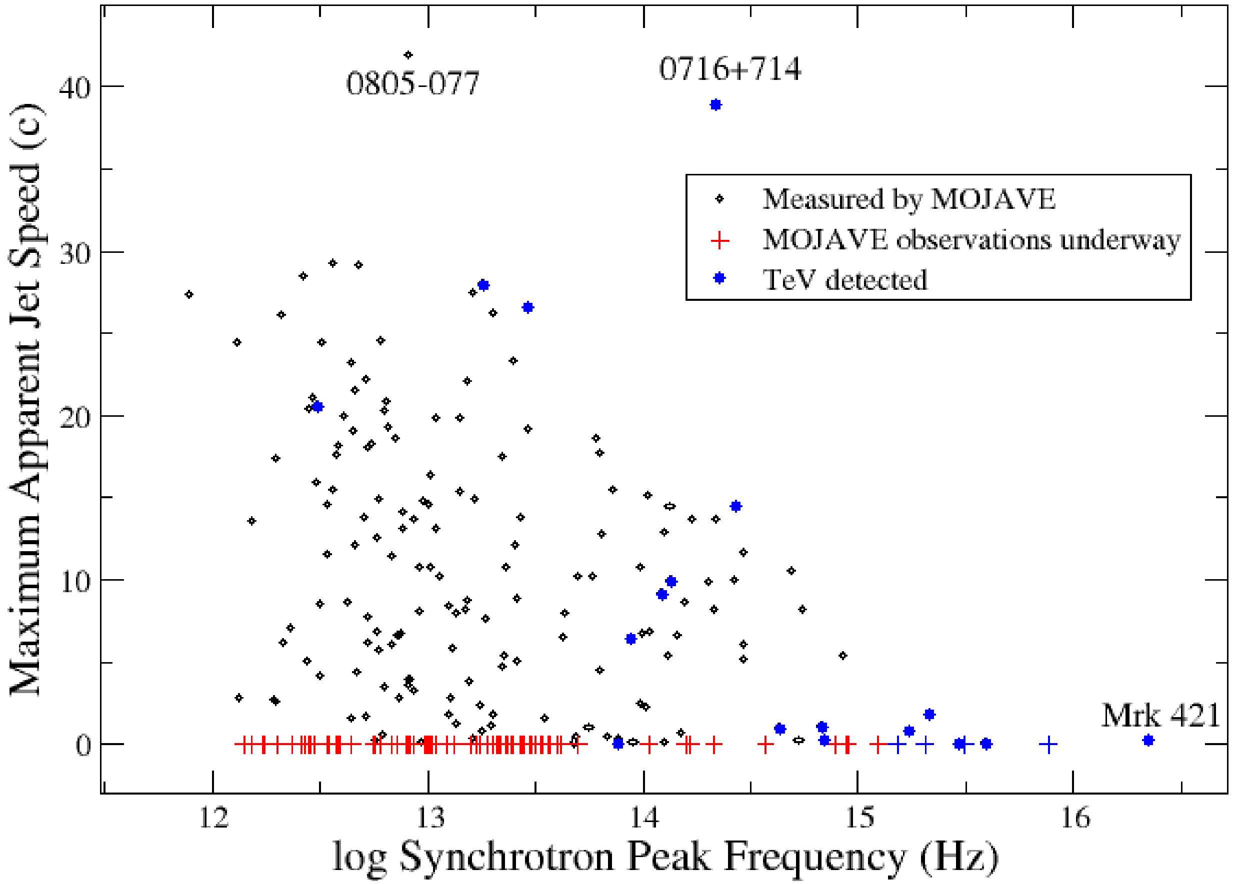


- Increase in magnetic field order down the jet

  (confirms 2005 MOJAVE Paper I single-epoch findings)

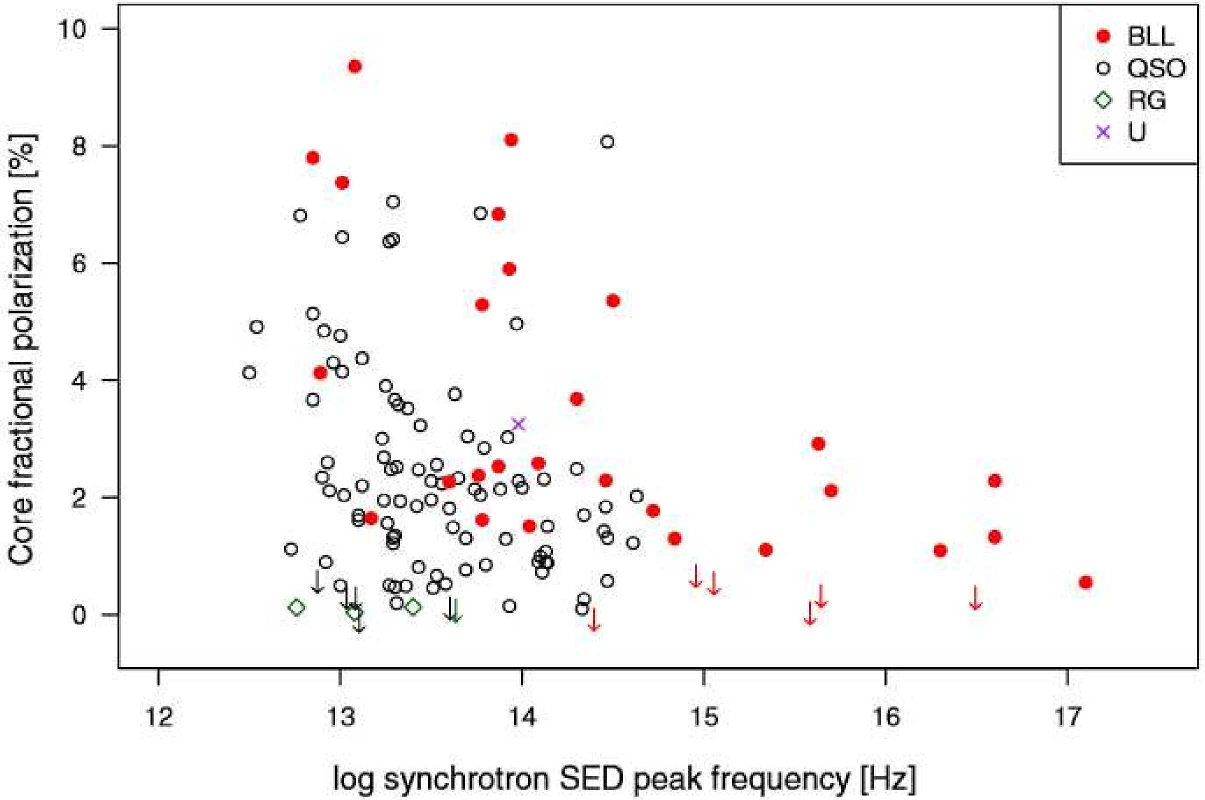
Trends with SED Peak Location

Max. Jet Speed vs. SED peak



- LSPs have larger range of speed
- Currently gathering final multi-epoch VLBA data

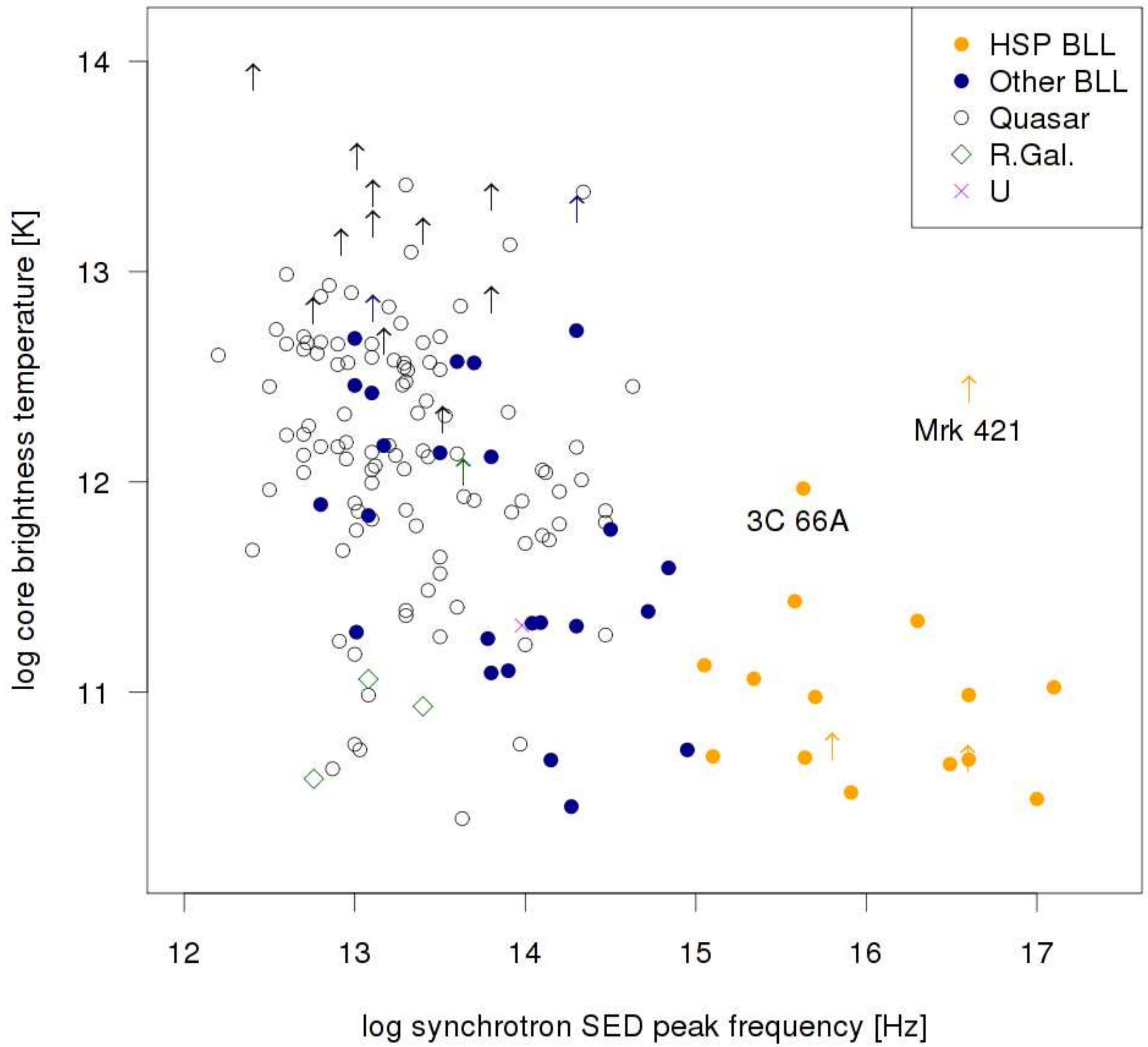
Core polarization vs. SED peak



- Single epoch result from Lister et al. 2011, ApJ 742,27
- Currently gathering final multi-epoch VLBA data

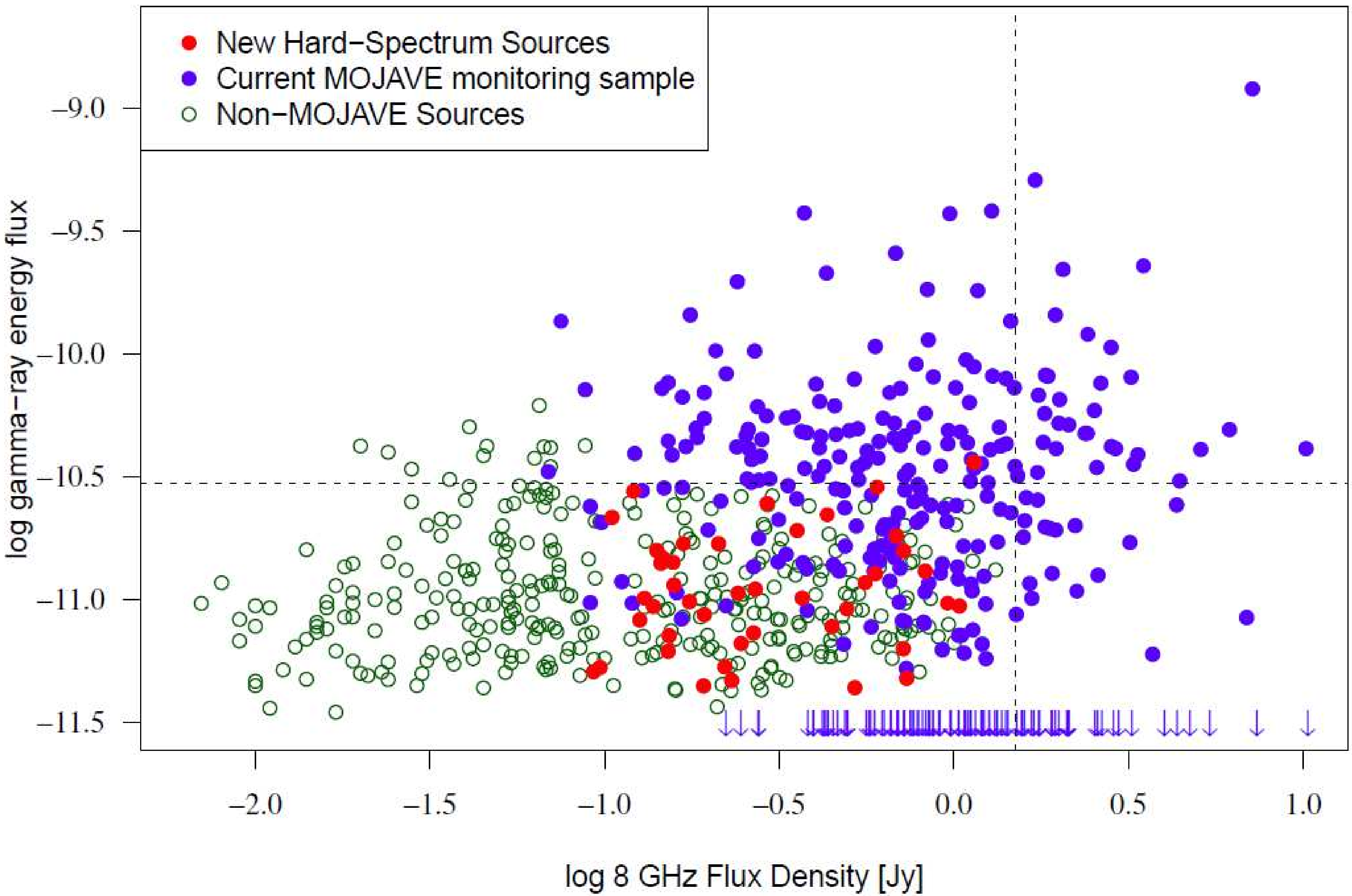
Core Brightness Temp. vs. SED peak

- **Lower radio compactness and variability of HSP radio cores is indicative of lower Doppler beaming factors than LSPs**



Upcoming Changes to MOJAVE Program

- Starting Sept 2013, shift of focus from complete AGN samples to selected sample of:
  - 27 jets that have shown significant accelerations and/or inner jet position angle changes over time
  - 83 high-spectral peaked 2LAC Fermi AGNs above declination -20 deg. with mean >100 MeV spectral index harder than 2.1.
- Thirteen 24 hour long VLBA sessions per year have been approved by NRAO
- More details are available on MOJAVE website


New Hard−Spectrum Sources
Current MOJAVE monitoring sample
Non−MOJAVE Sources
log gamma−ray energy flux
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
log 8 GHz Flux Density [Jy]

Take-Home Points

- Pc-scale AGN jets produce long-lived, accelerating features with a range of position angle and characteristic speed
  - inner jet position angle often swings 1 to 10 deg. per year on sky
- Bright features do not fill the entire jet cross-section, and have a range of intrinsic Lorentz factor and/or pattern speed
  - very slow pattern speeds (‘stationary features’) are rare
- The most powerful blazar jets have a wide range of Lorentz factors up to ~40; weaker AGN jets have Lorentz factors of ~a few.
- B field order increases down the jet, & highest SED spectral-peaked blazar cores all have weak degree of polarization.
- Core electric polarization vectors exhibit wide range of behavior over time and among optical classes.

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