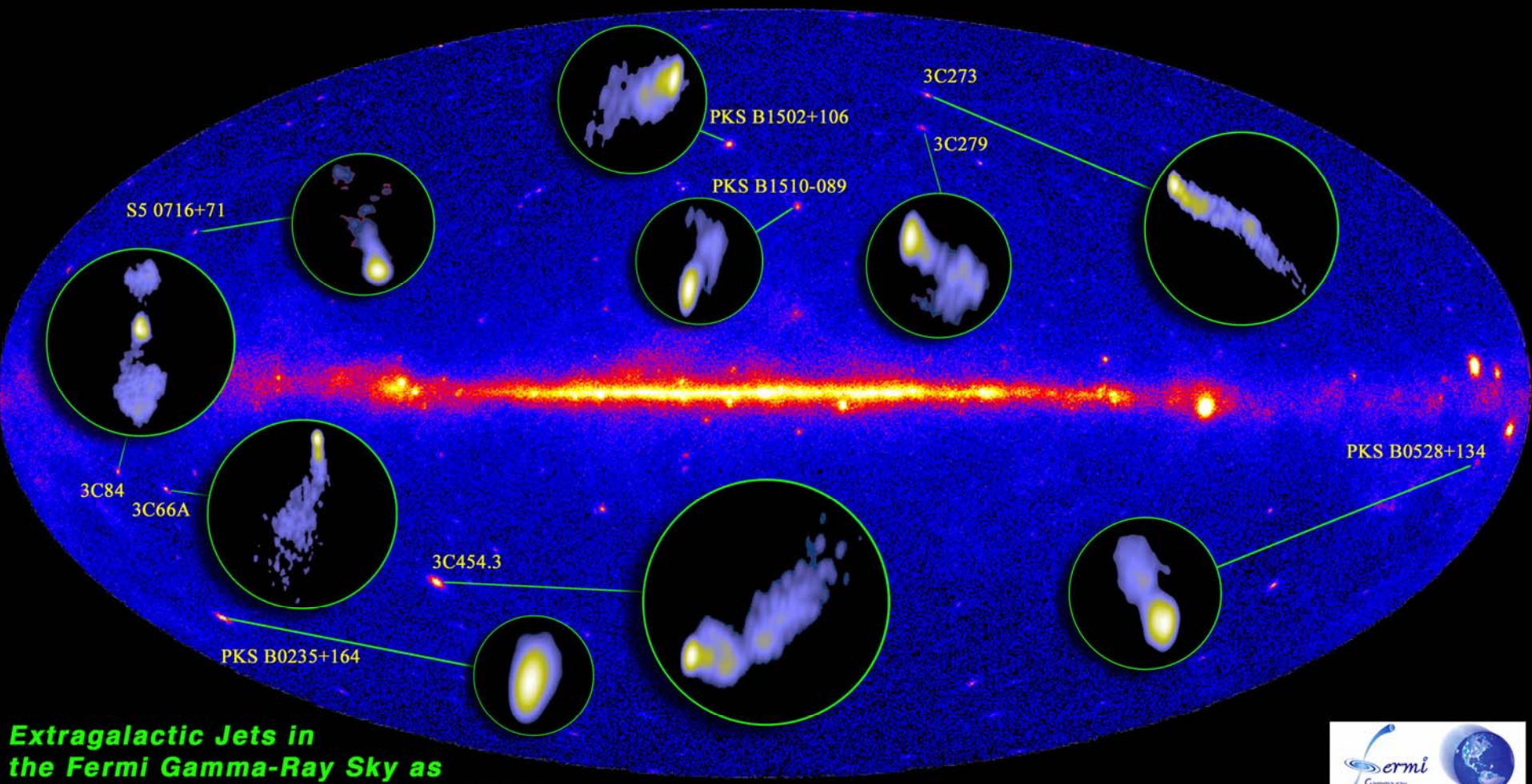
The MOJAVE Program: Investigating the Parsec-Scale Jet Properties of Gamma-Ray Blazars

Matthew Lister (Purdue) for the MOJAVE Team



MOJAVE Collaboration

Monitoring
Of
Jets in
Active Galaxies with
VLBA
Experiments

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- M. and H. Aller (Michigan)
- M. Cohen (Caltech)
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- K. Kellermann (NRAO)
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We thank the LAT team for providing preliminary 1st LAT catalog data

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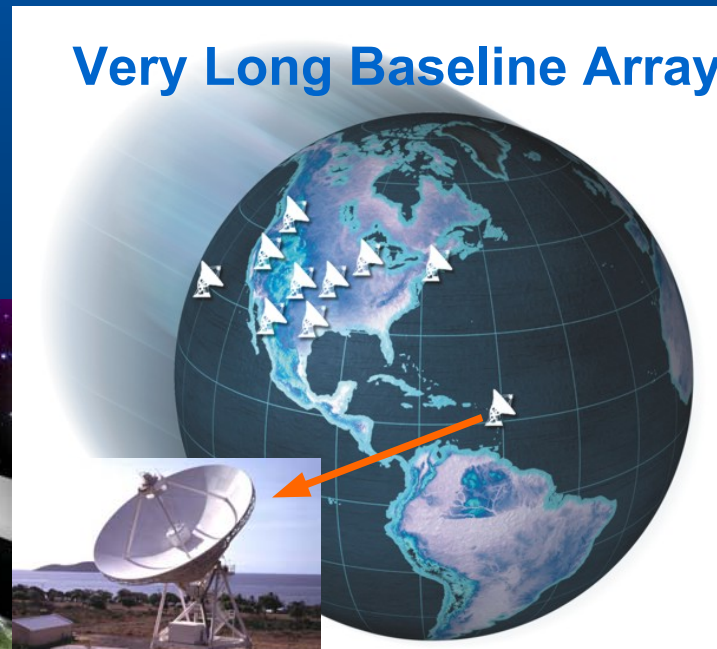
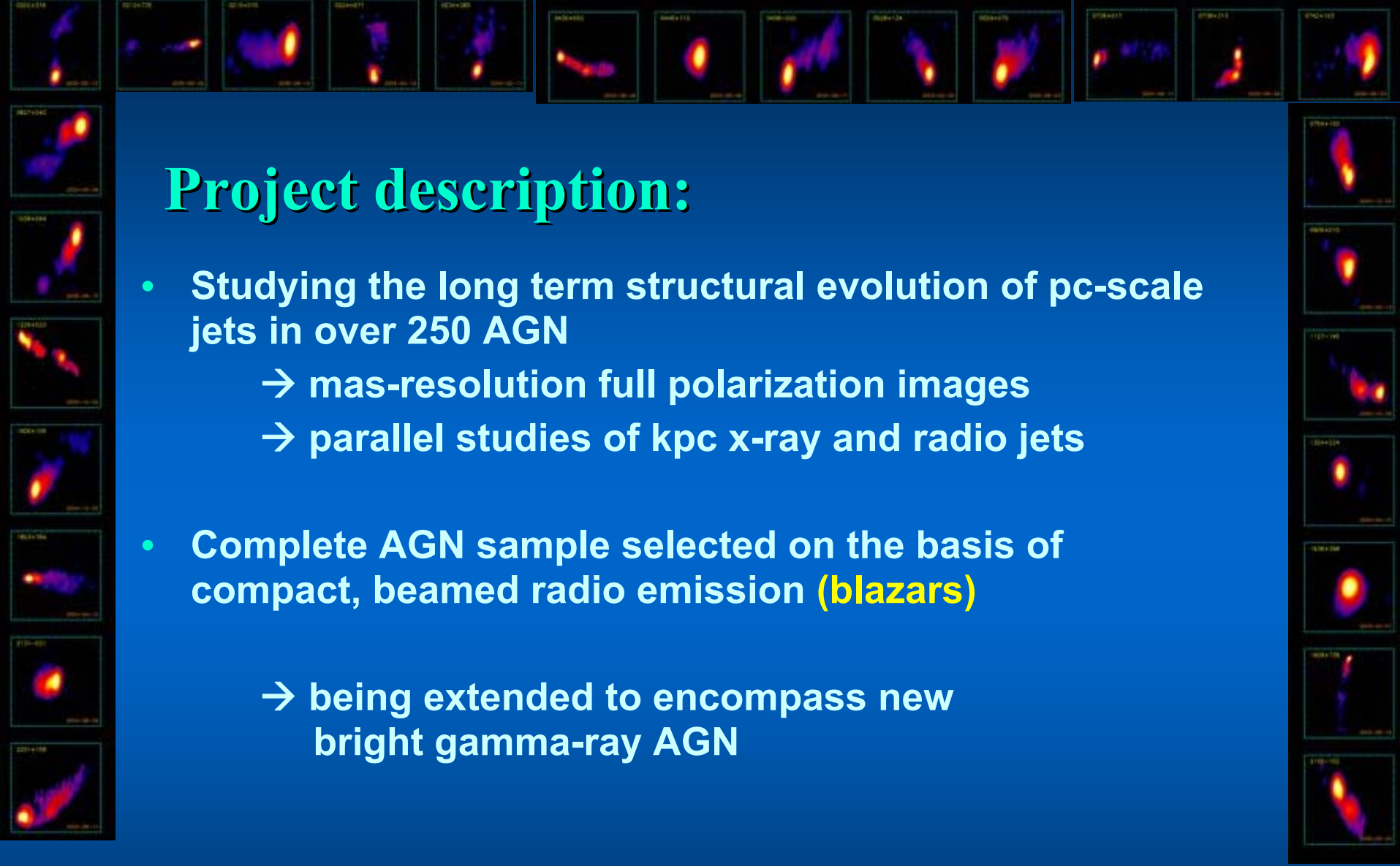
Very Long Baseline Array





Project description:

- Studying the long term structural evolution of pc-scale jets in over 250 AGN
  - → mas-resolution full polarization images
  - → parallel studies of kpc x-ray and radio jets
- Complete AGN sample selected on the basis of compact, beamed radio emission (blazars)
  - → being extended to encompass new bright gamma-ray AGN

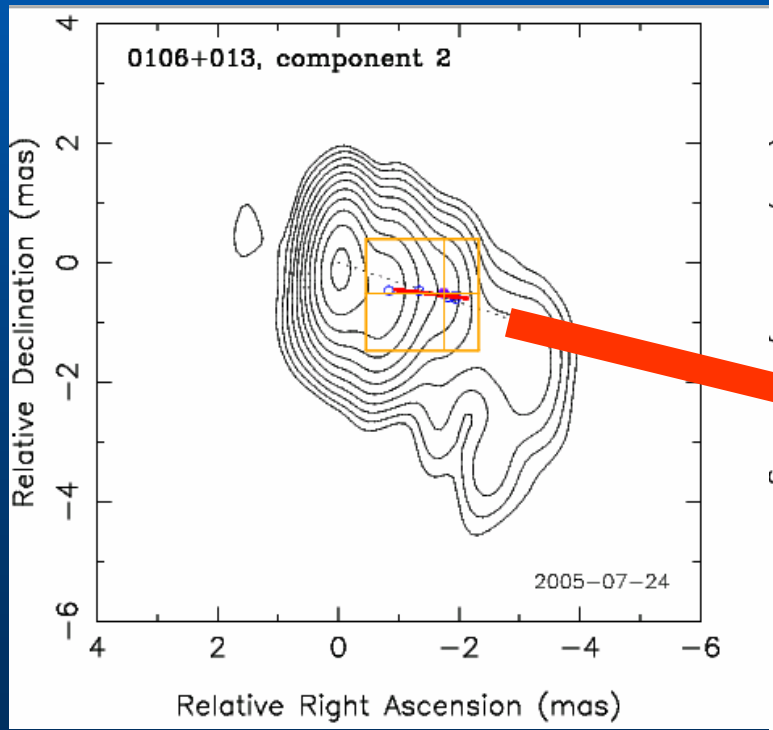
http://www.physics.purdue.edu/MOJAVE

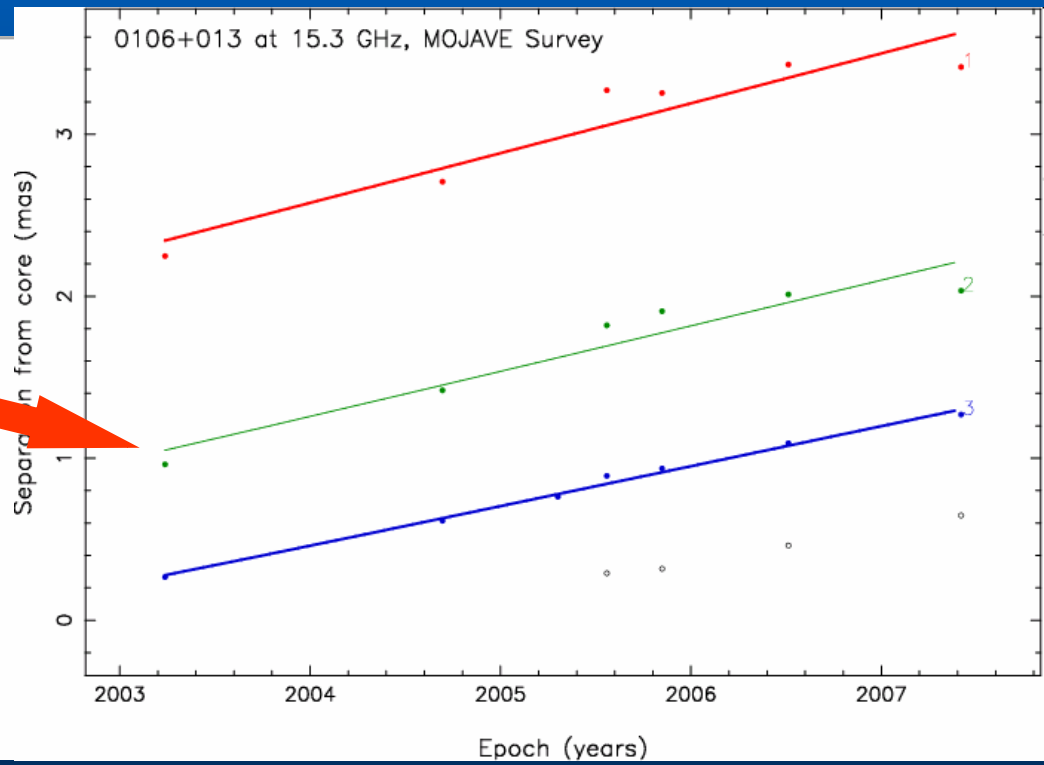
Lister et al., 2009, AJ, 137, 3718

Recent findings (526 features in 127 AGN jets):

- **Superluminal motions are the norm in radio-selected blazar jets**
  - typically ~10c, broad range up to 50 c: (PKS 0805-077)
  - motions are related to underlying flow
  - caveat: in rare cases stationary bright features are seen near the base of the jet

- **Bright features within a single jet typically move with similar characteristic speed**

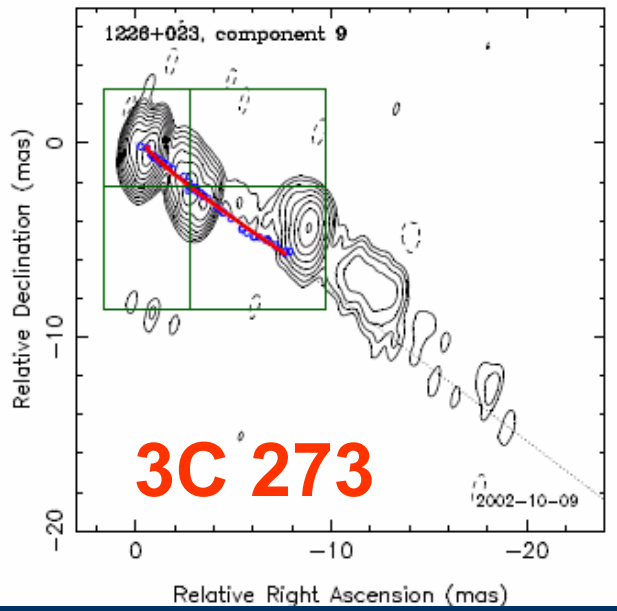


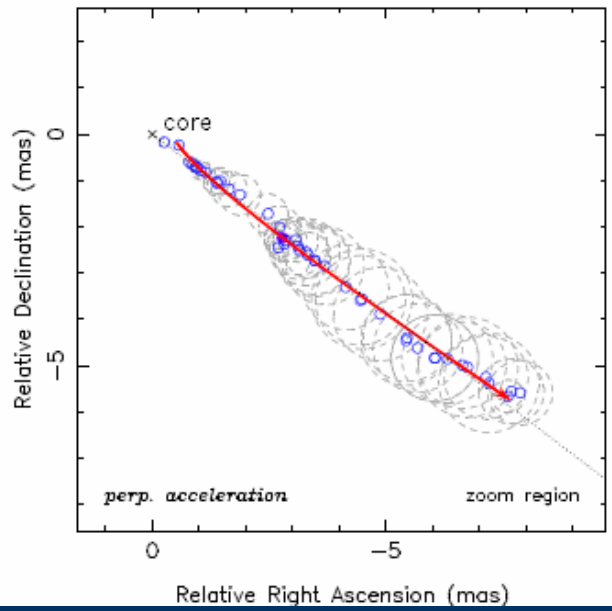


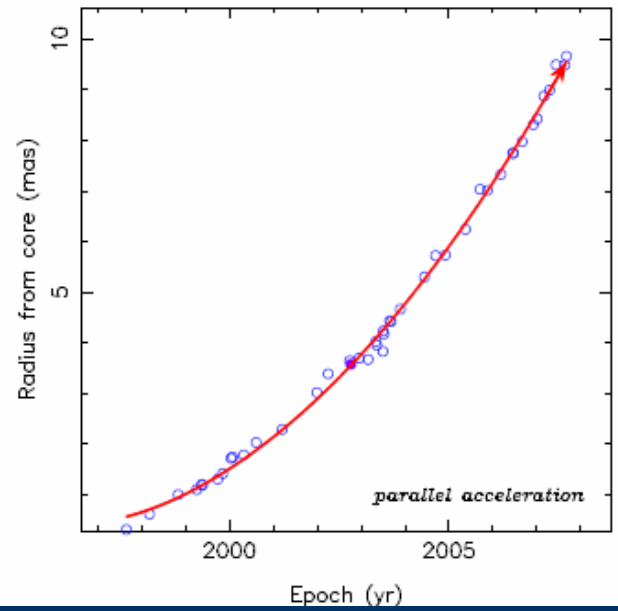
Lister et al., 2009, AJ, (arXiv 0909.5100)

Recent findings:

- Over 1/3 of bright jet features are accelerating
  - creates the illusion of 'bent jets' in single epoch VLBA images
  - changes in speed are more common than changes in direction
- Positive (speeding up) accelerations are more prevalent close to the base of the jet
  → flows are still becoming organized on pc scales

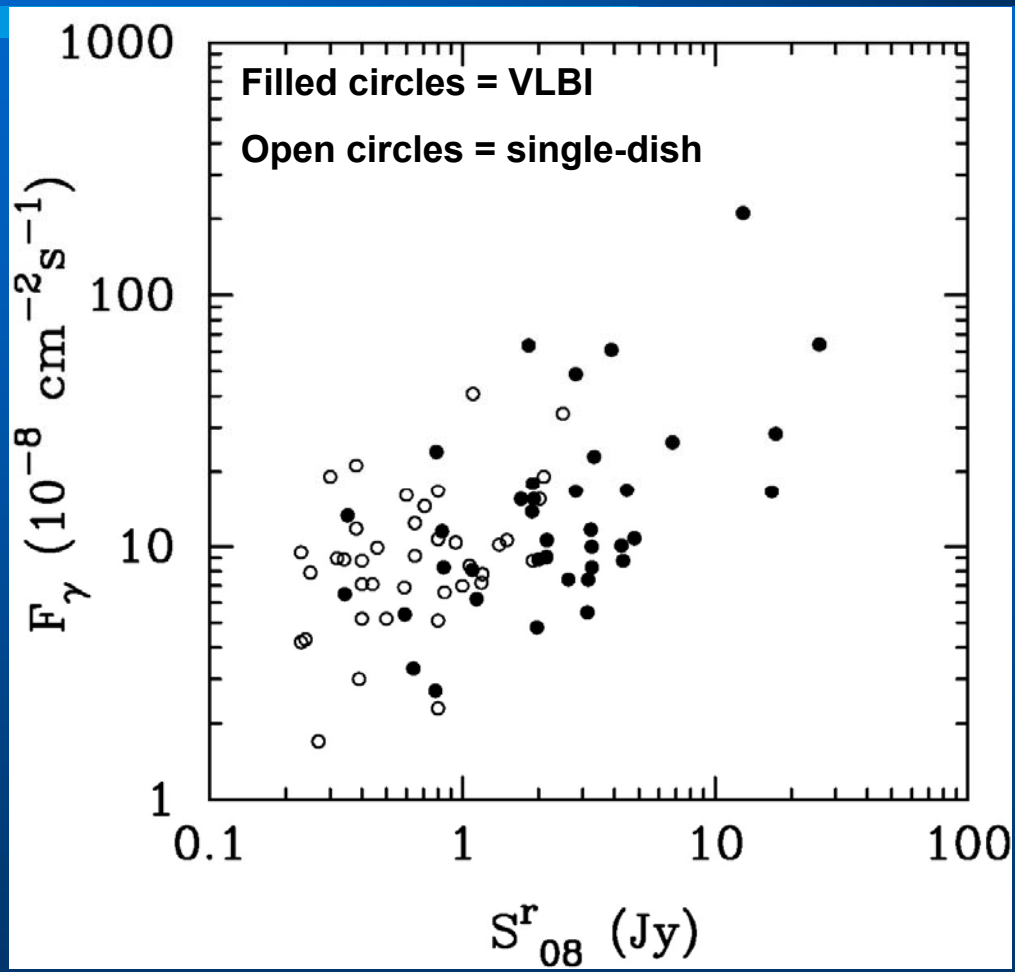






Homan et al., 2009, ApJ, (arXiv 0909.5102)

Recent findings:

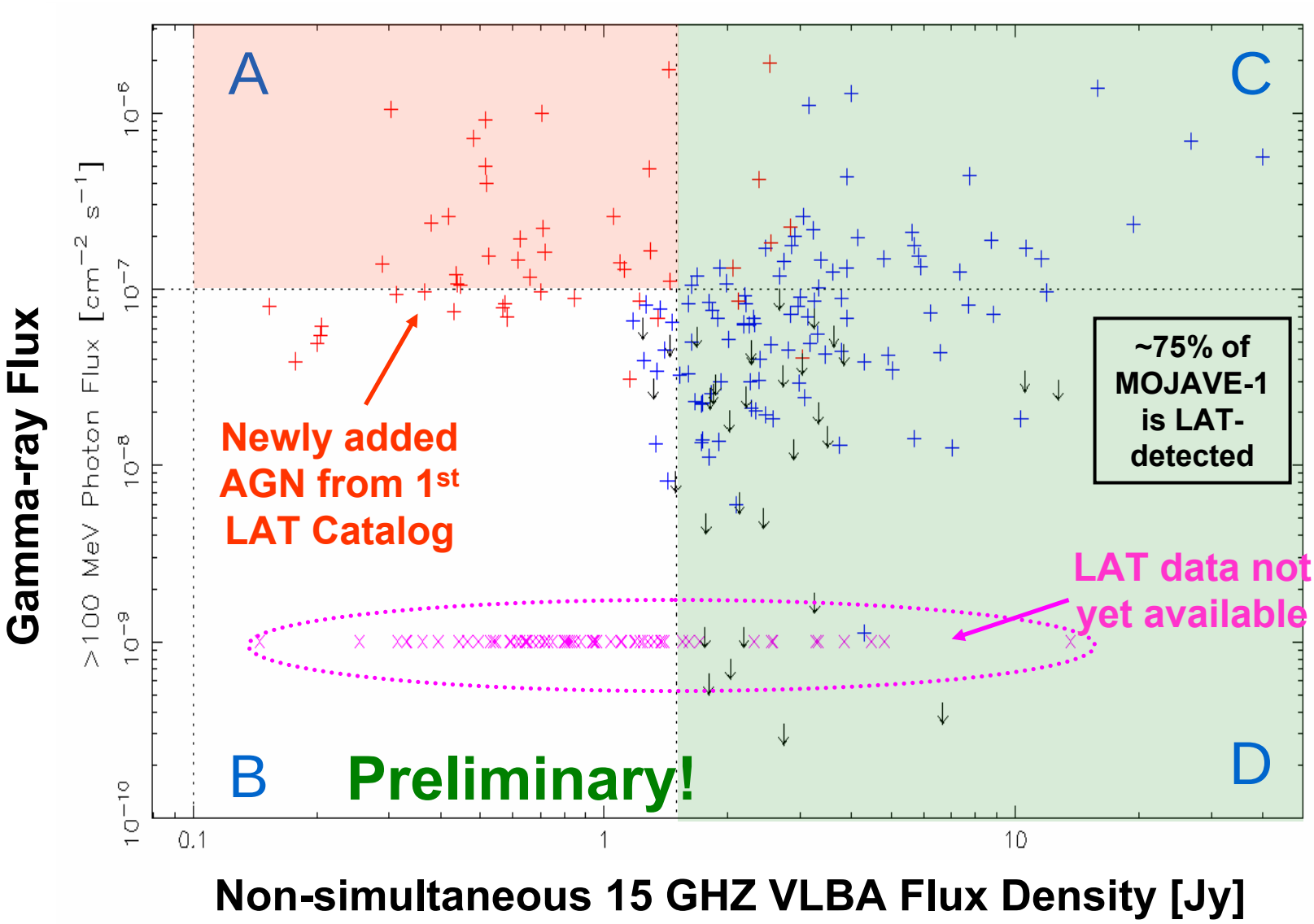


Kovalev et al. 2009, ApJ 696, L17

(see poster P1-19 by Kovalev et al.)

Good correlation between Fermi LAT γ-ray photon flux and the quasi-simultaneously measured compact radio flux density.

Fermi+VLBA=Killer Combination for Blazar Science



What makes an AGN γ–ray bright?

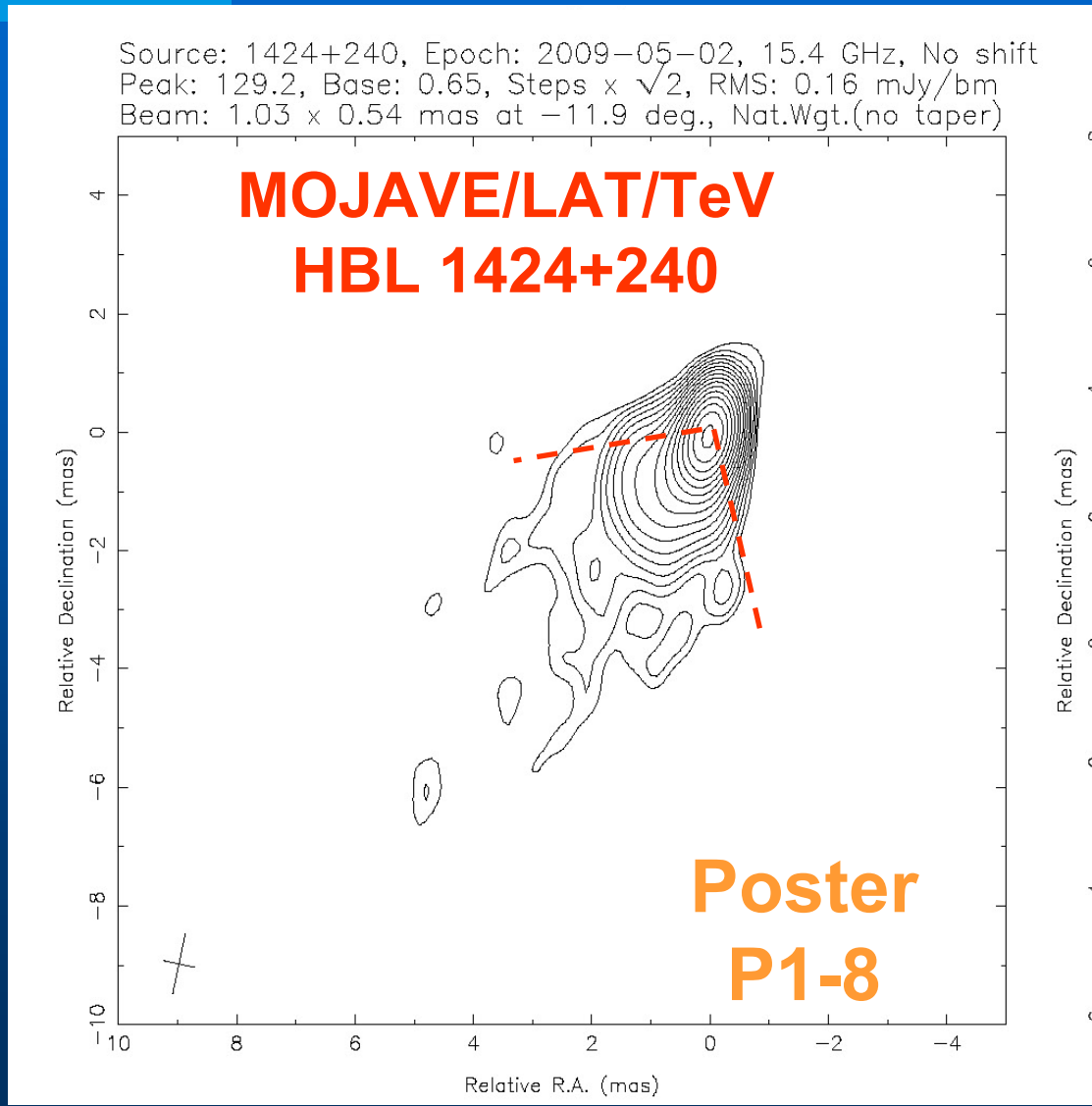
Complex combination of:

1. Preferred viewing angle
2. High jet Lorentz factor
3. High current activity state
4. High-peaked spectral energy distribution

Apparent Jet Opening Angles

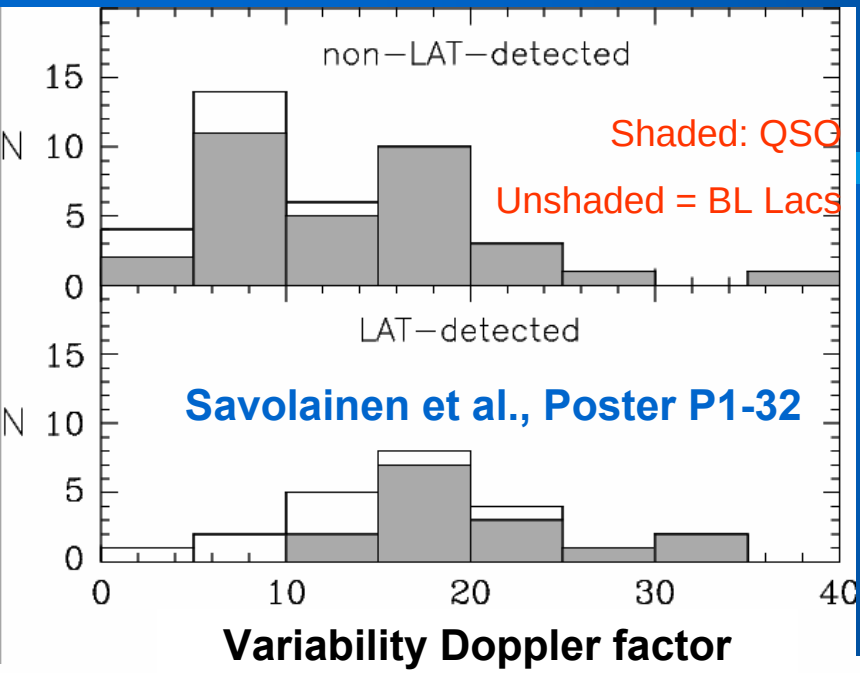
- 3month MOJAVE-LAT generally have broader **apparent** opening angles than non-LAT
- Overall ***intrinsic*** opening angle distributions are similar

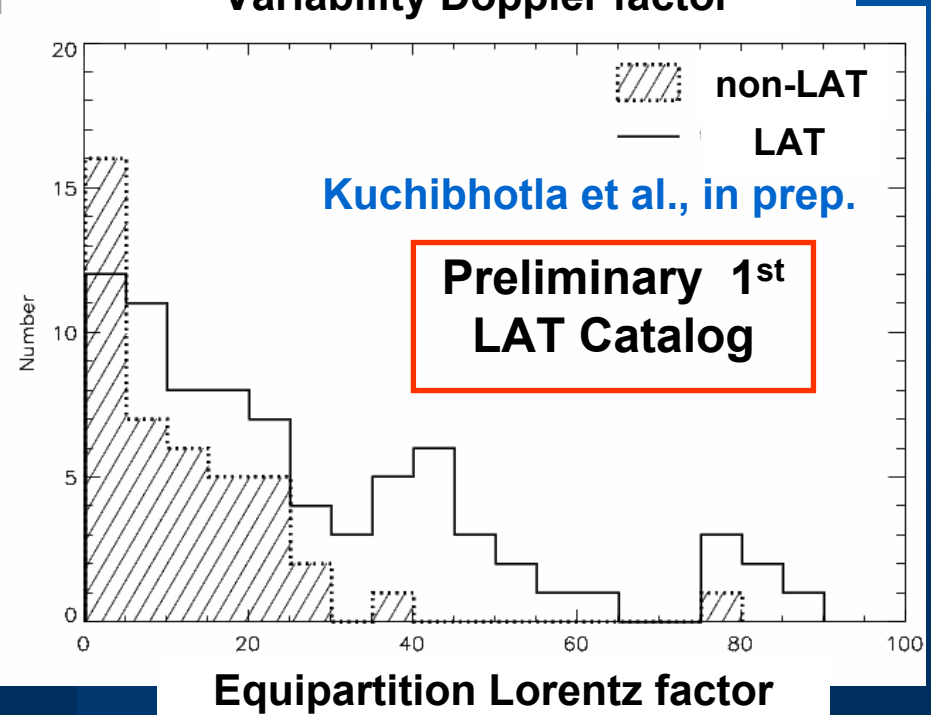
→The bright LAT blazar jets are typically viewed closer to the line of sight



Pushkarev et al., arXiv/0910.1813

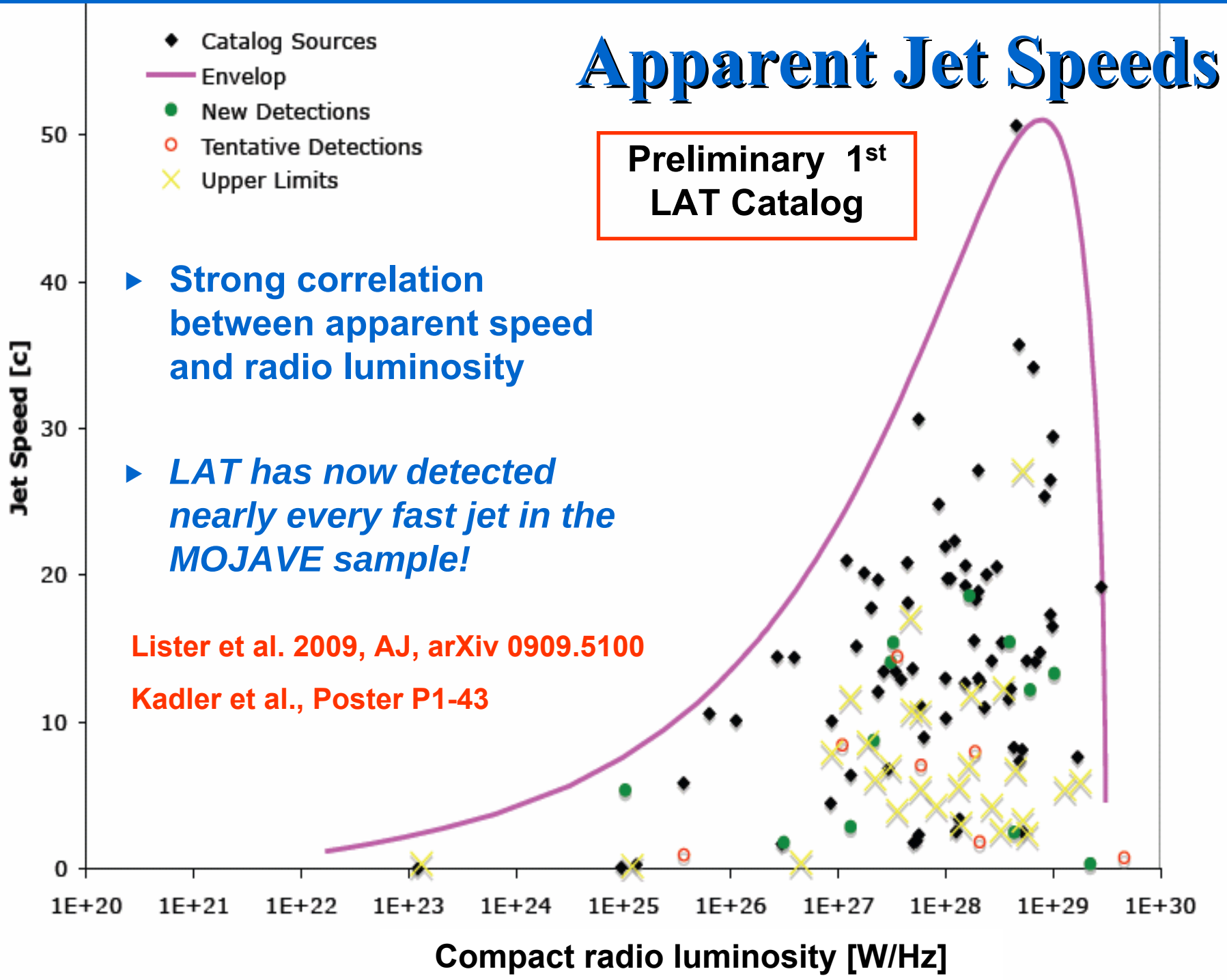
Doppler Factors





- MOJAVE-LAT AGN jets have significantly higher Doppler factors than MOJAVE non-LAT
- Constrains viewing angle: $\theta < \sin^{-1}(\delta^{-1})$
- Anisotropy of gamma-ray emission may also influence viewing angle range – see Savolainen et al. poster P1-32

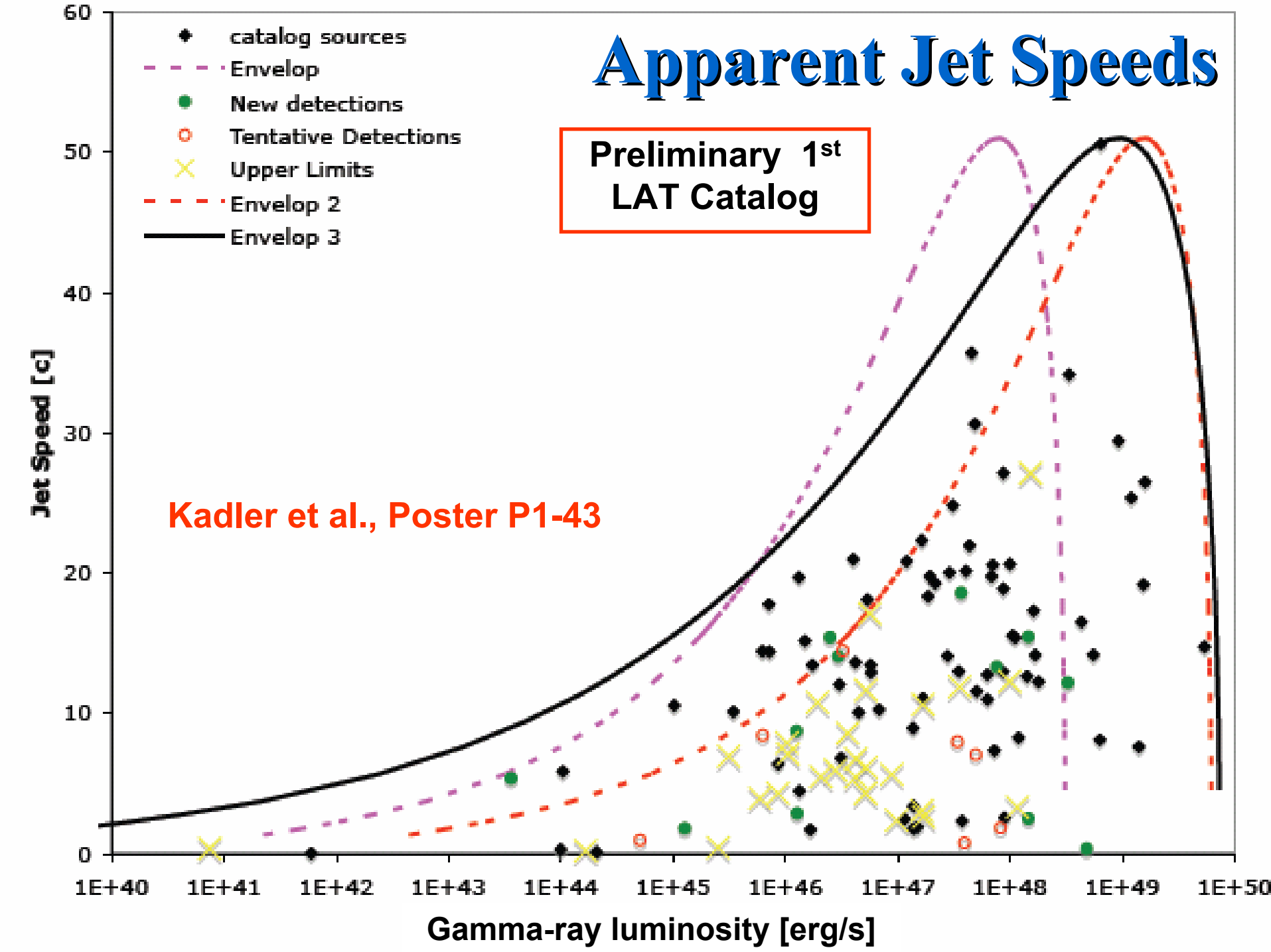
Apparent Jet Speeds



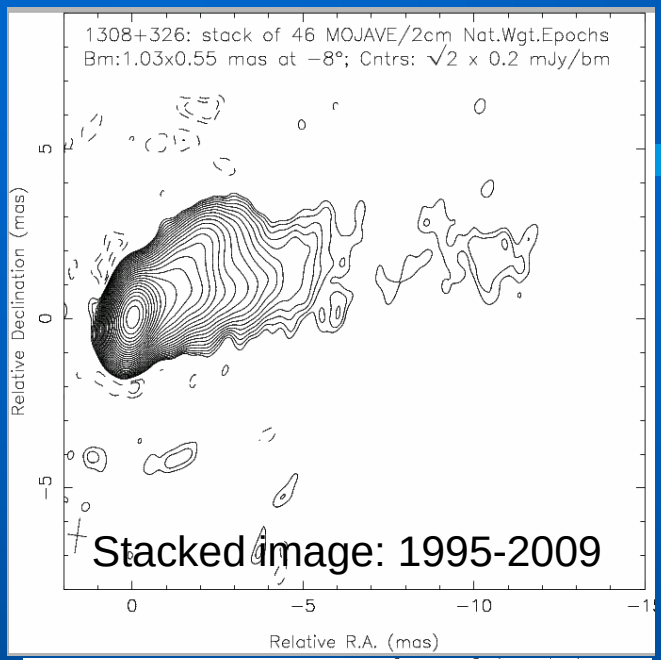
- **Strong correlation between apparent speed and radio luminosity**
- ***LAT has now detected nearly every fast jet in the MOJAVE sample!***

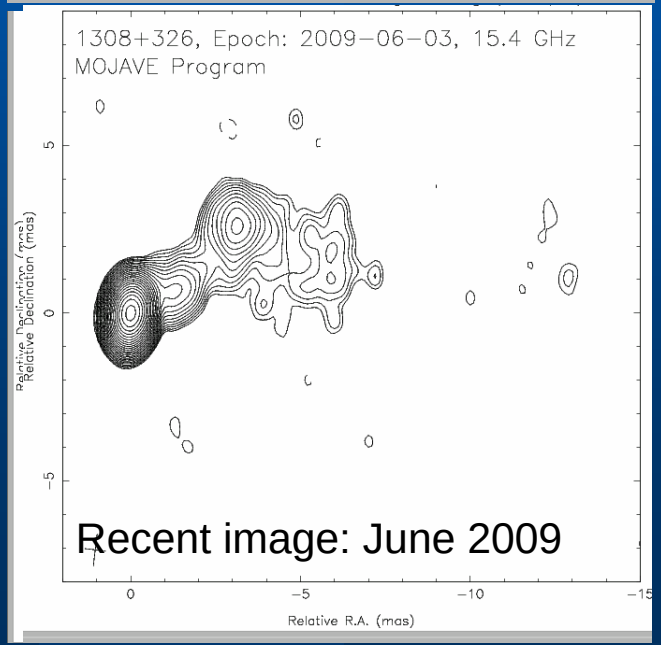
Lister et al. 2009, AJ, arXiv 0909.5100

Kadler et al., Poster P1-43


Apparent Jet Speeds
Preliminary 1st LAT Catalog
catalog sources
Envelop
New detections
Tentative Detections
Upper Limits
Envelop 2
Envelop 3
Kadler et al., Poster P1-43
Jet Speed [c]
Gamma-ray luminosity [erg/s]
0
10
20
30
40
50
60
1E+40
1E+41
1E+42
1E+43
1E+44
1E+45
1E+46
1E+47
1E+48
1E+49
1E+50

Jet Activity States



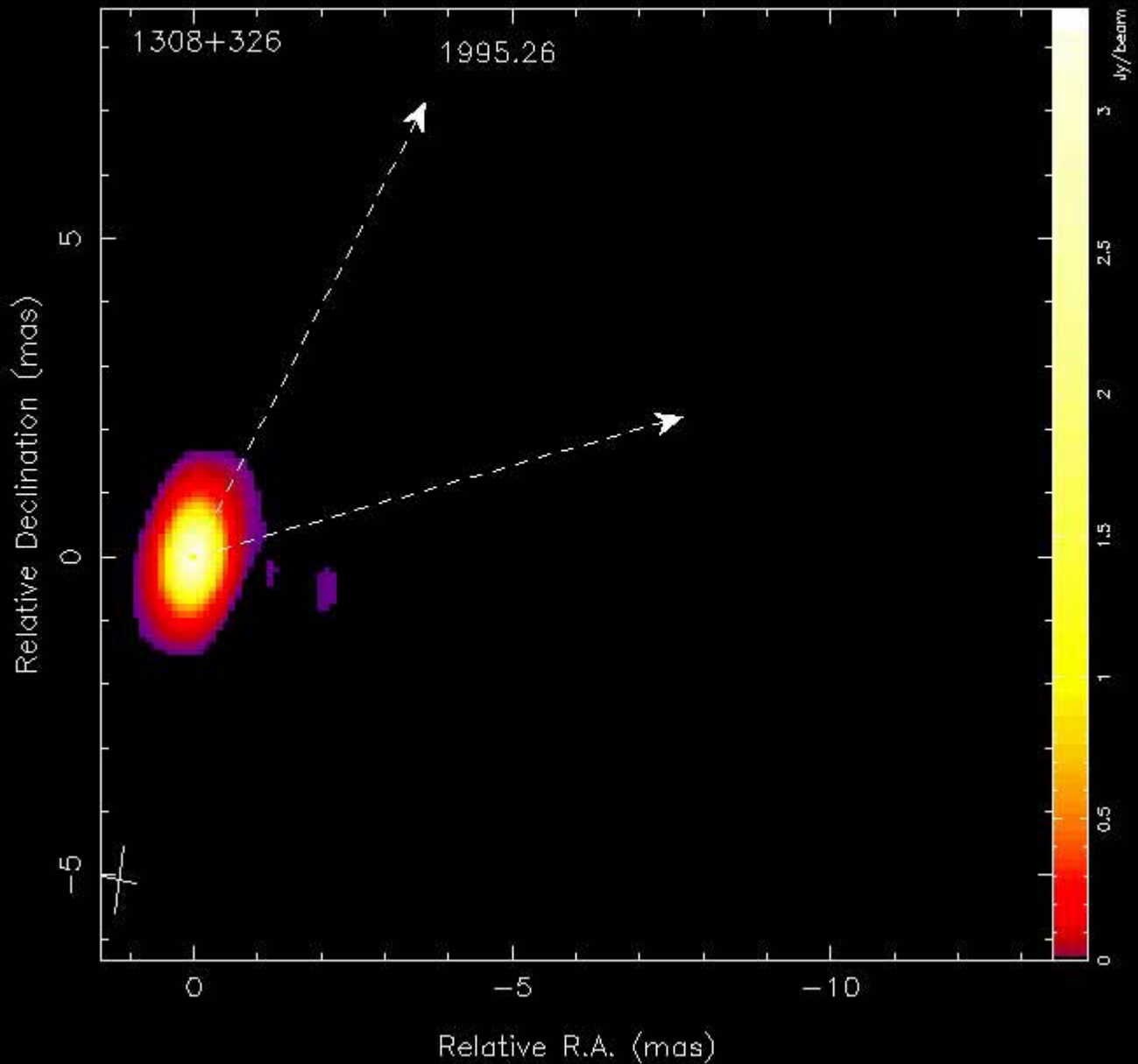


Lister et al., 2009, AJ, 137, 3718

- ***At any given time, only the energized portion of a broader jet is visible***
- **Activity states of AGN jets evolve over time**
  - **long quiescent periods of no blob ejection are seen**
  - **new blobs ejected at new position angles**
  - **only 30% of the 3 month LAT AGN were detected by EGRET**

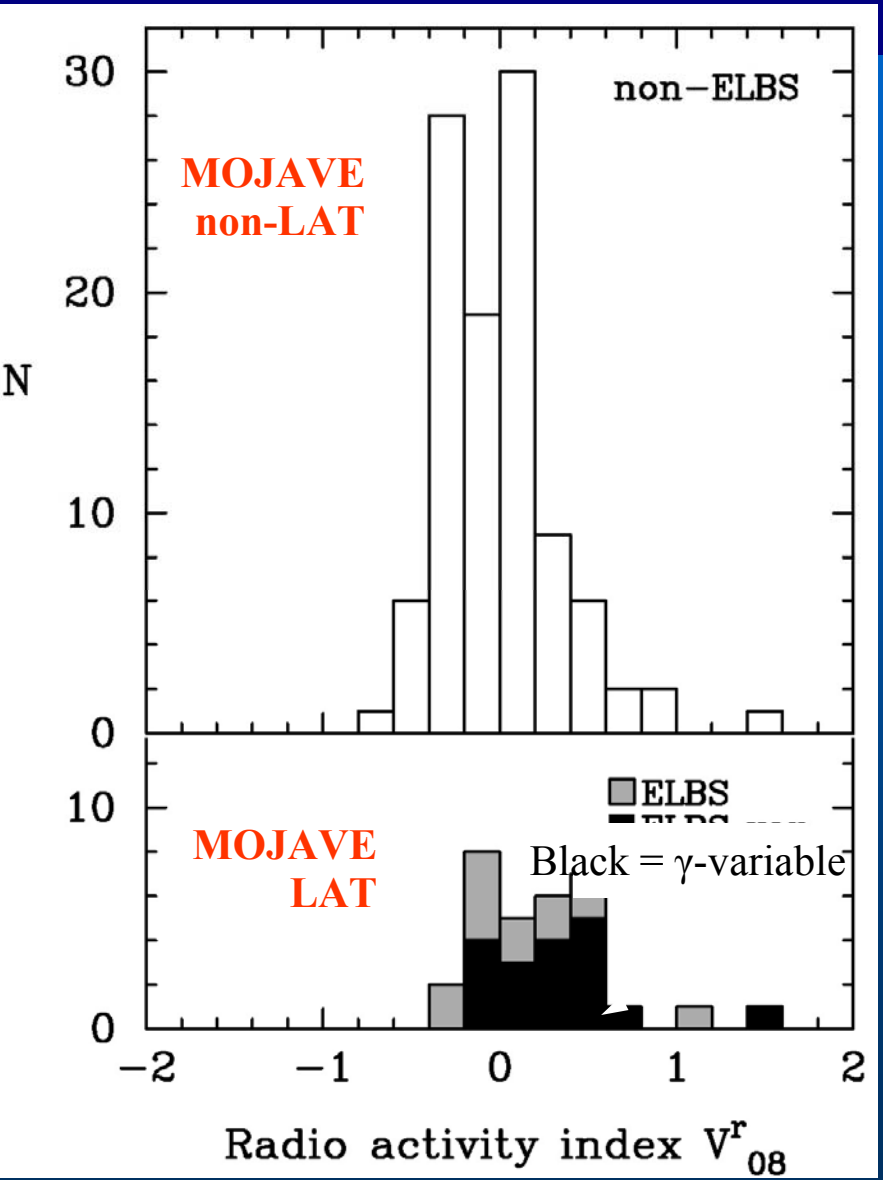
→Are changes in pc-radio jet morphology reflected in the gamma-ray activity? YES – see poster by Jorstad et al.

1308+326: BL Lac at z = 1



40 pc

MOJAVE complete sample activity in 2008



Kovalev et al., 2009, ApJ, (arXiv 0902.2085)

Activity index in radio band:
$V=(S_{2008}-S_{1999-2007})/S_{1999-2009}$

Statistical conclusions:

1. MOJAVE-LAT AGN are in a high activity state, both in total intensity, and polarization (Kovalev P1-19, Hovatta P1-36, Aller P1-3)

2. Flares in radio and γ-ray domain happen within a typical apparent time separation of a few months

Does the jet beaming factor change with activity state?

MOJAVE-LAT Summary

- **Blazar gamma-ray emission originates on pc-scales in relativistically moving plasma – likely shock fronts.**

- **Compared to other radio blazars, LAT-detected jets are:**
  - **faster and more highly beamed**
  - **more highly polarized and in a high active state in the radio**

  → SED peak location plays a key role in BL Lac LAT detections (see posters P1-21, P1-42, P1-43)

- **VLBA+Fermi is a fantastic tool for nailing down where the gamma-rays are being produced within the jet.**