Gamma-Ray Properties of Extragalactic Jets from the TANAMI and MOJAVE Samples

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On behalf of the LAT, MOJAVE & TANAMI Collaborations

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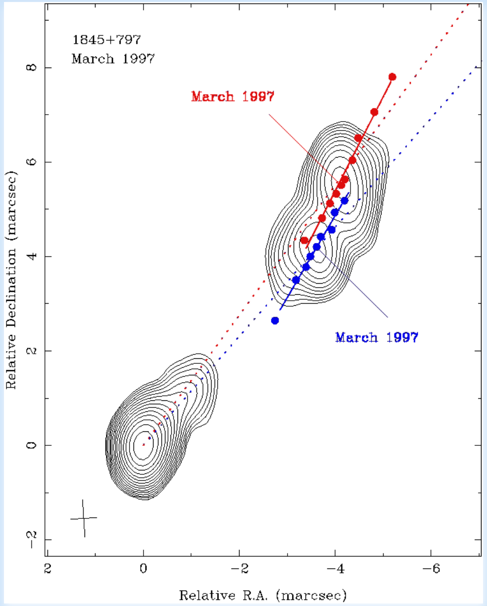
2011 Fermi Symposium

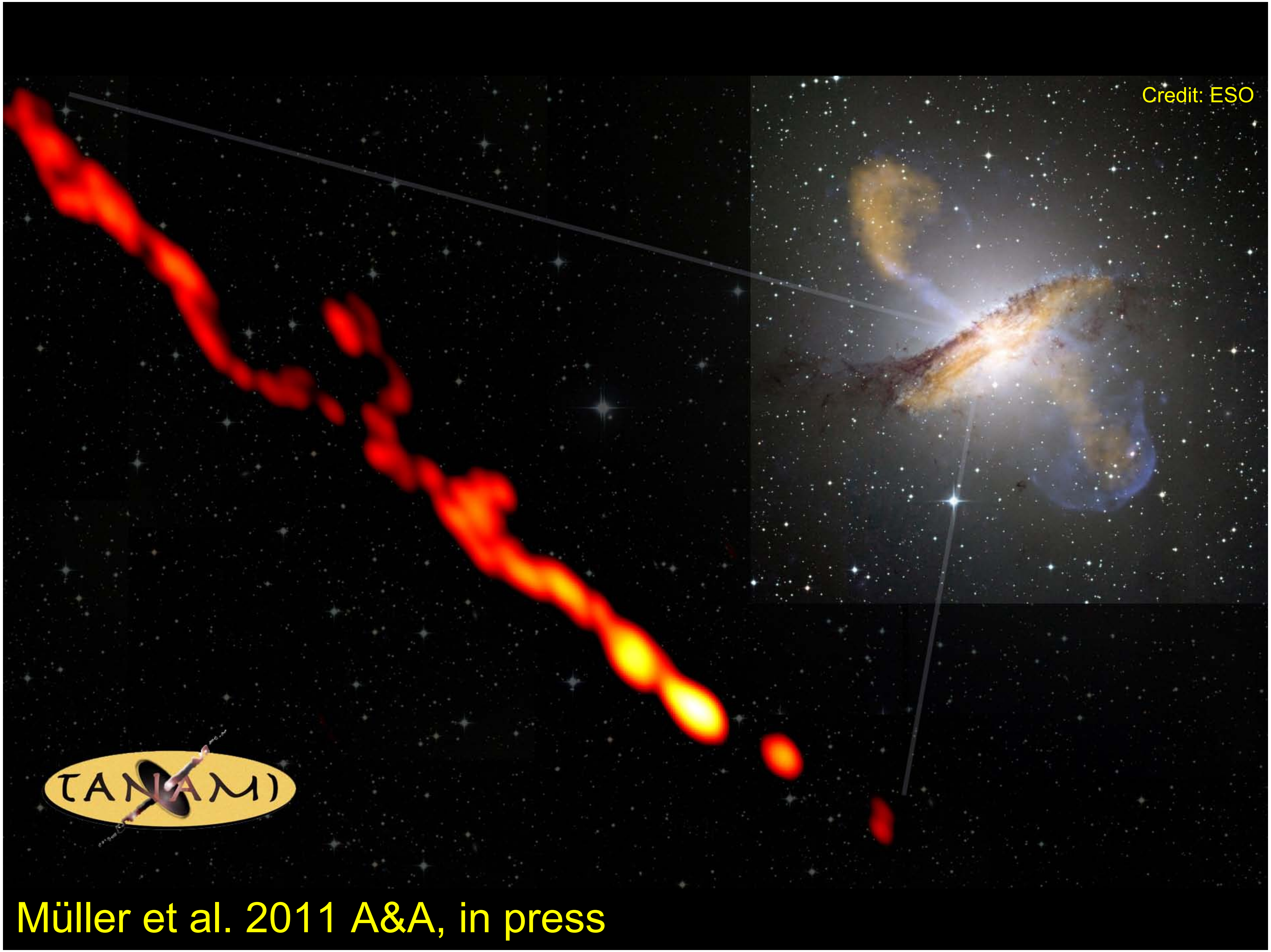
What VLBI brings to the table…

- Very Long Baseline Interferometry
  - ~10000km baselines, GHz frequencies
  - ⇒ Milliarcsecond Resolution
- Only direct imaging of blazar jets
- Only direct measure of intrinsic jet parameters
  - ✓ jet speeds
  - ✓ Doppler factor
  - ✓ inclination
  - ✓ opening angle
- Identify location and extent of emission regions


VLBA-NRAO



Kellermann et al. 2004

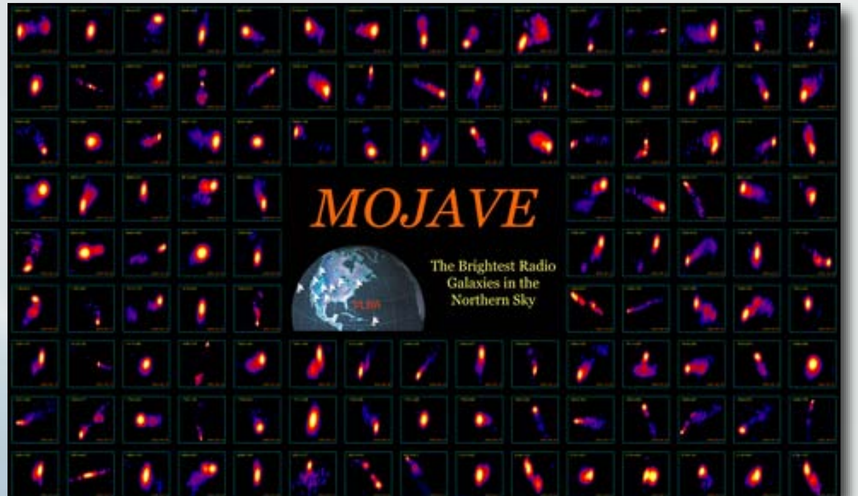

Credit: ESO
TANAMI
Müller et al. 2011 A&A, in press

MOJAVE

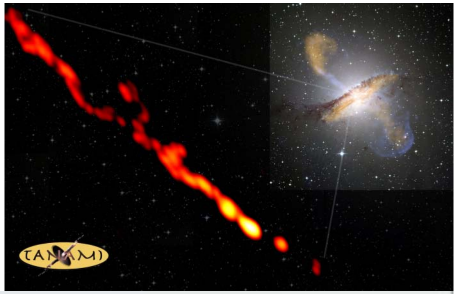
www.physics.purdue.edu/astro/MOJAVE/

- Monitoring of a sample of >300 targets using the VLBA at ν=15 GHz (λ=2 cm) since 1995
- Statistically complete Sample
    - Strong sources: $S_{15\ GHz}$>1.5 Jy
    - Flat Spectrum: α>-0.5 for $S \propto \nu^{\alpha}$

- Contains also a complete gamma-ray flux limited subsample of 116 AGN
    - Dec > -30, |b| > 10
    - $S_{median,100MeV} > 3 \times 10^{-11}$ MeV/cm^2/s
- plus a matching radio sample for LAT era
- Supported through a NASA Fermi grant



pulsar.sternwarte.uni-erlangen.de/tanami



Tracking **A**ctive galactic **N**uclei with **A**ustral **M**illiarcsecond **I**nterferometry

Hybrid radio and gamma-ray selected sample south of -30 deg declination

1) Flat spectrum sources with $S_{5GHz} > 2$ Jy

2) Known Gamma-Ray Blazars

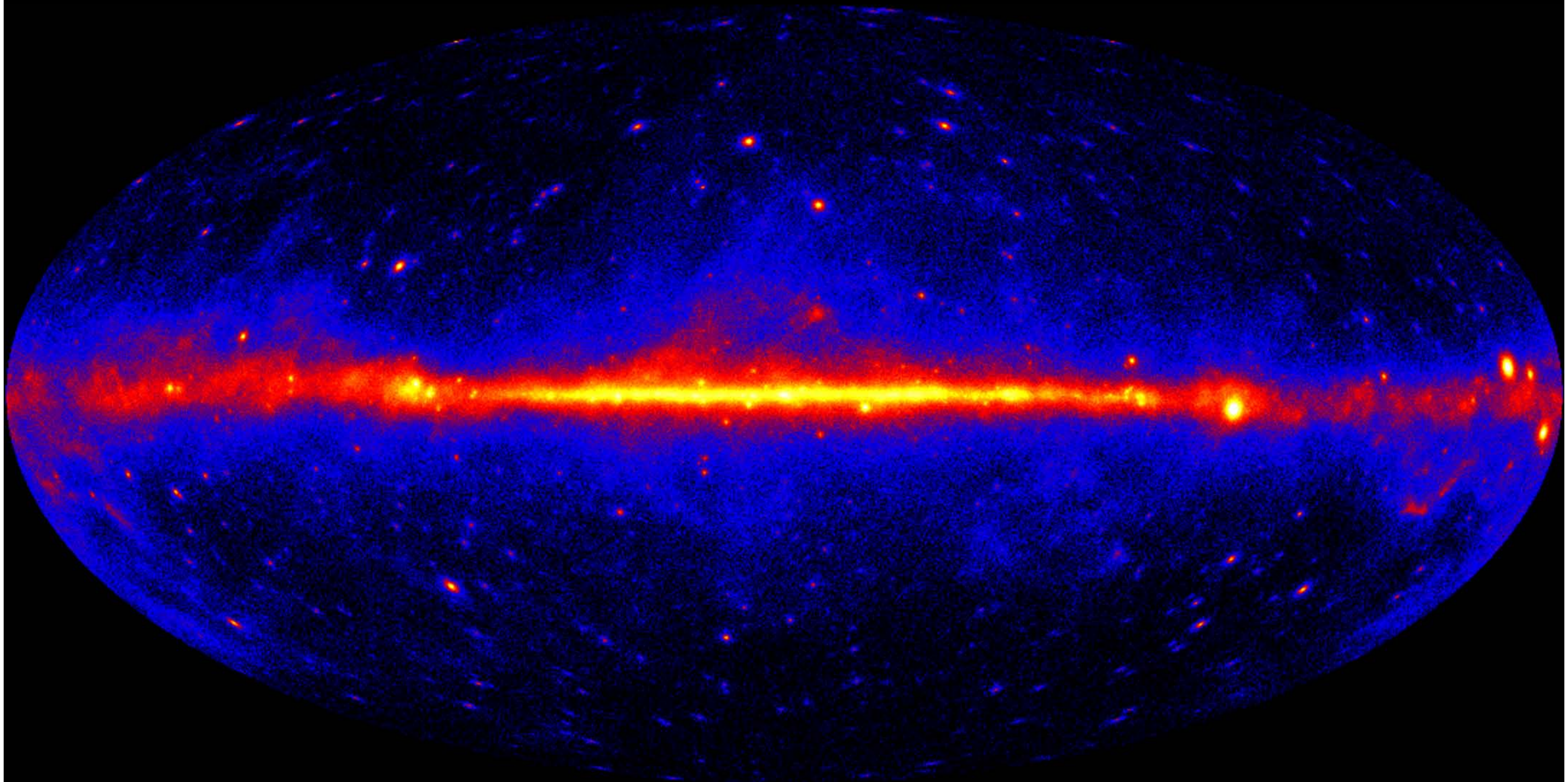
3) Typical sources of a class IDVs, GPS sources, radio galaxies

Initially 43 sources. Now including *Fermi*-detected gamma-loud AGN (mostly without previous VLBI observations)

Total: 75 sources

- Dual-frequency Observations at 8.4 and 22GHz
- Sampling once every ~2 months
- Supported through NASA Fermi Grants

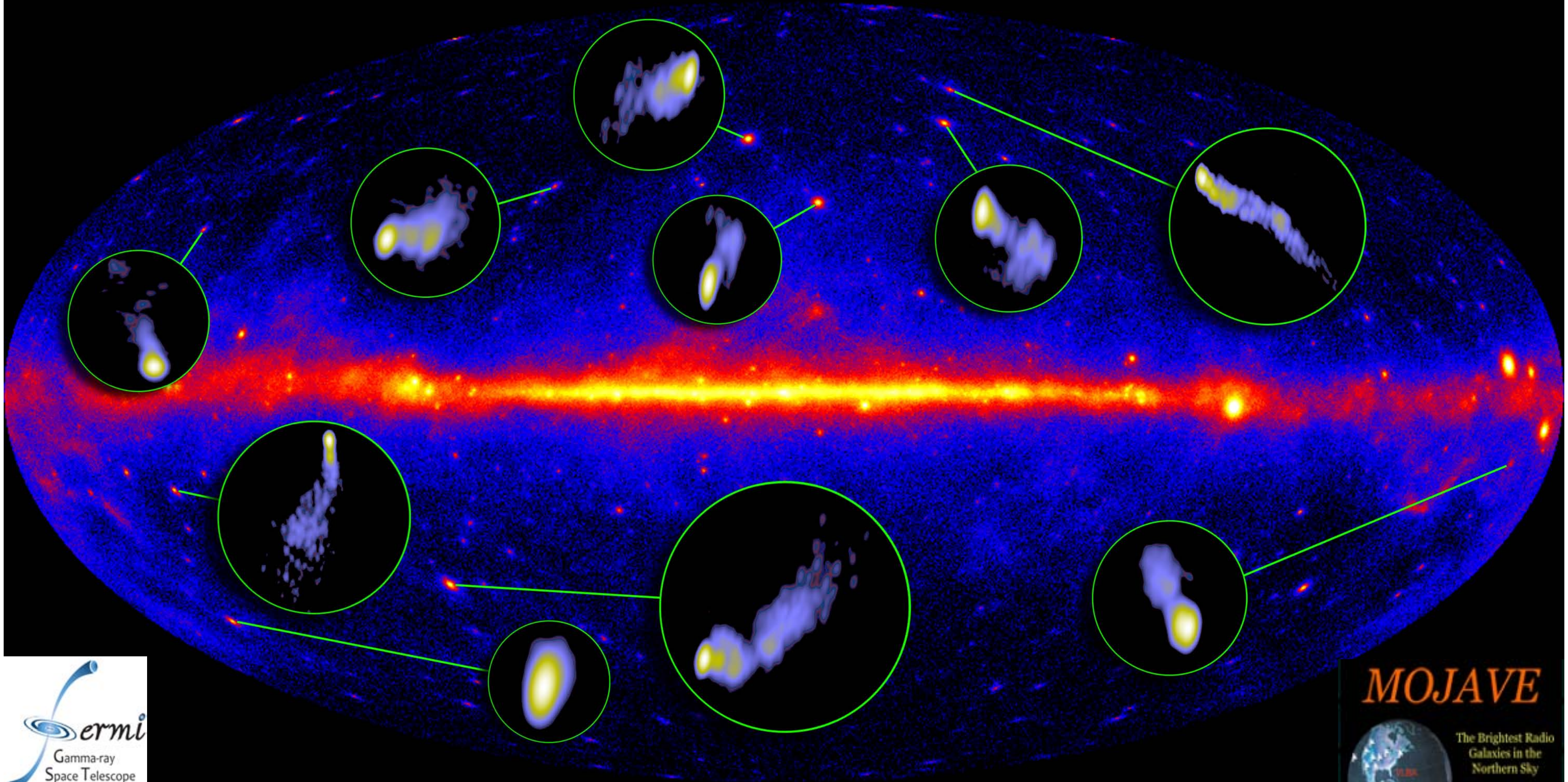
The Gamma-Ray Sky (11 months)



NASA-DOE-Fermi LAT Kollaboration

Radio-Gamma Jets of the Northern Hemisphere

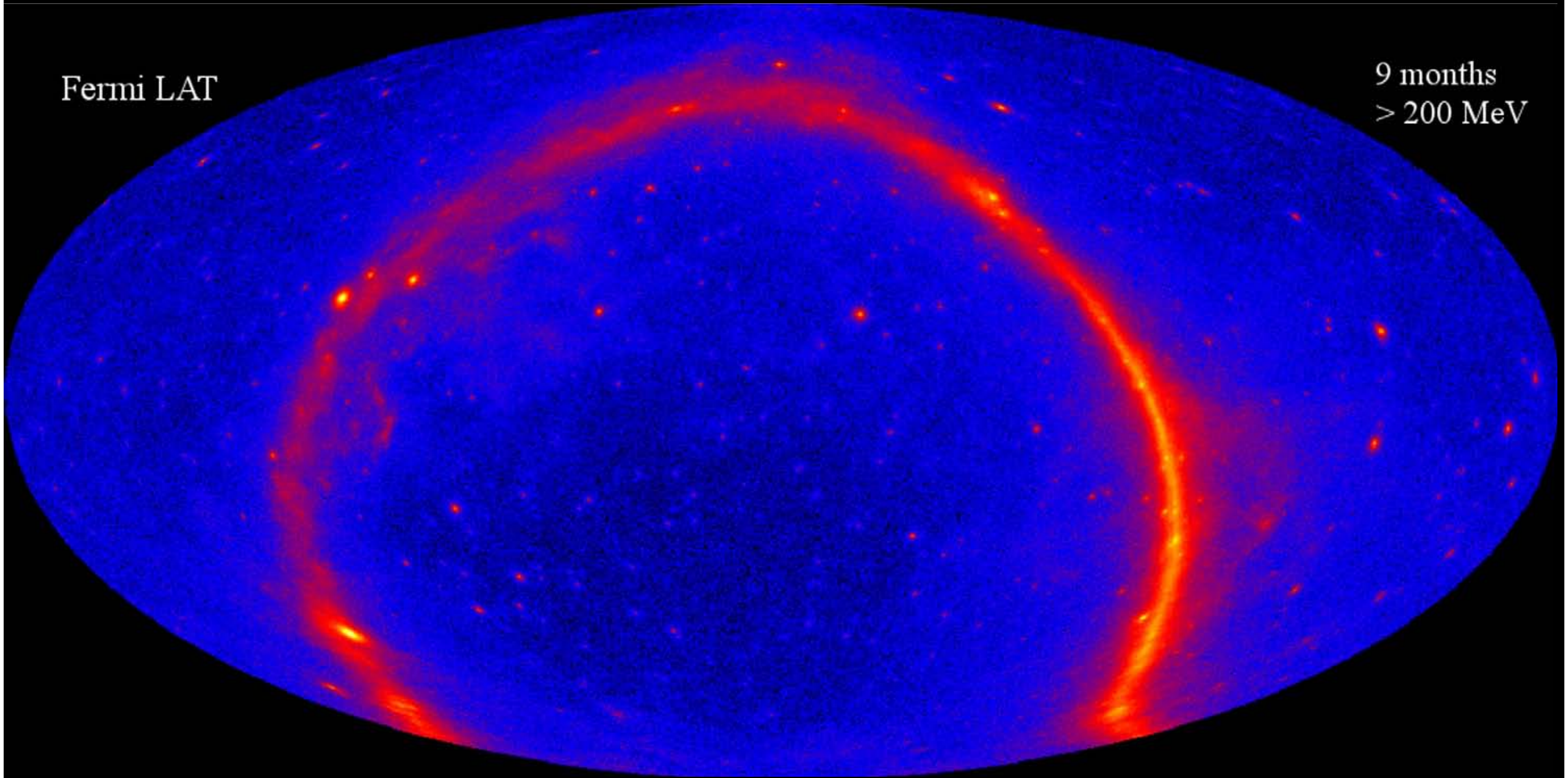
LAT & MOJAVE Collaborations; M. Kadler



Fermi
Gamma-ray
Space Telescope

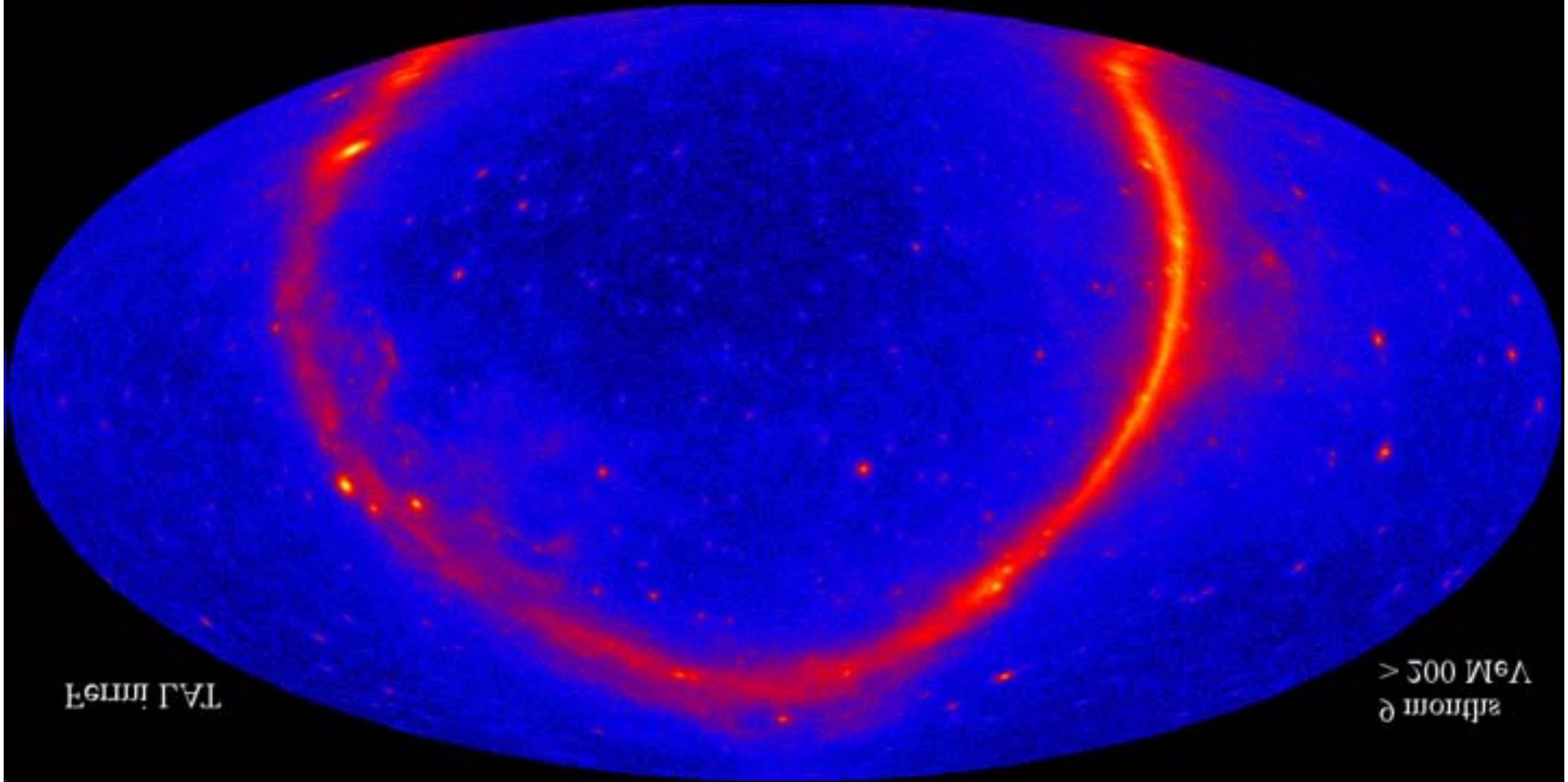
MOJAVE
The Brightest Radio Galaxies in the Northern Sky

Gamma-Ray Sky in Equatorial Coordinates



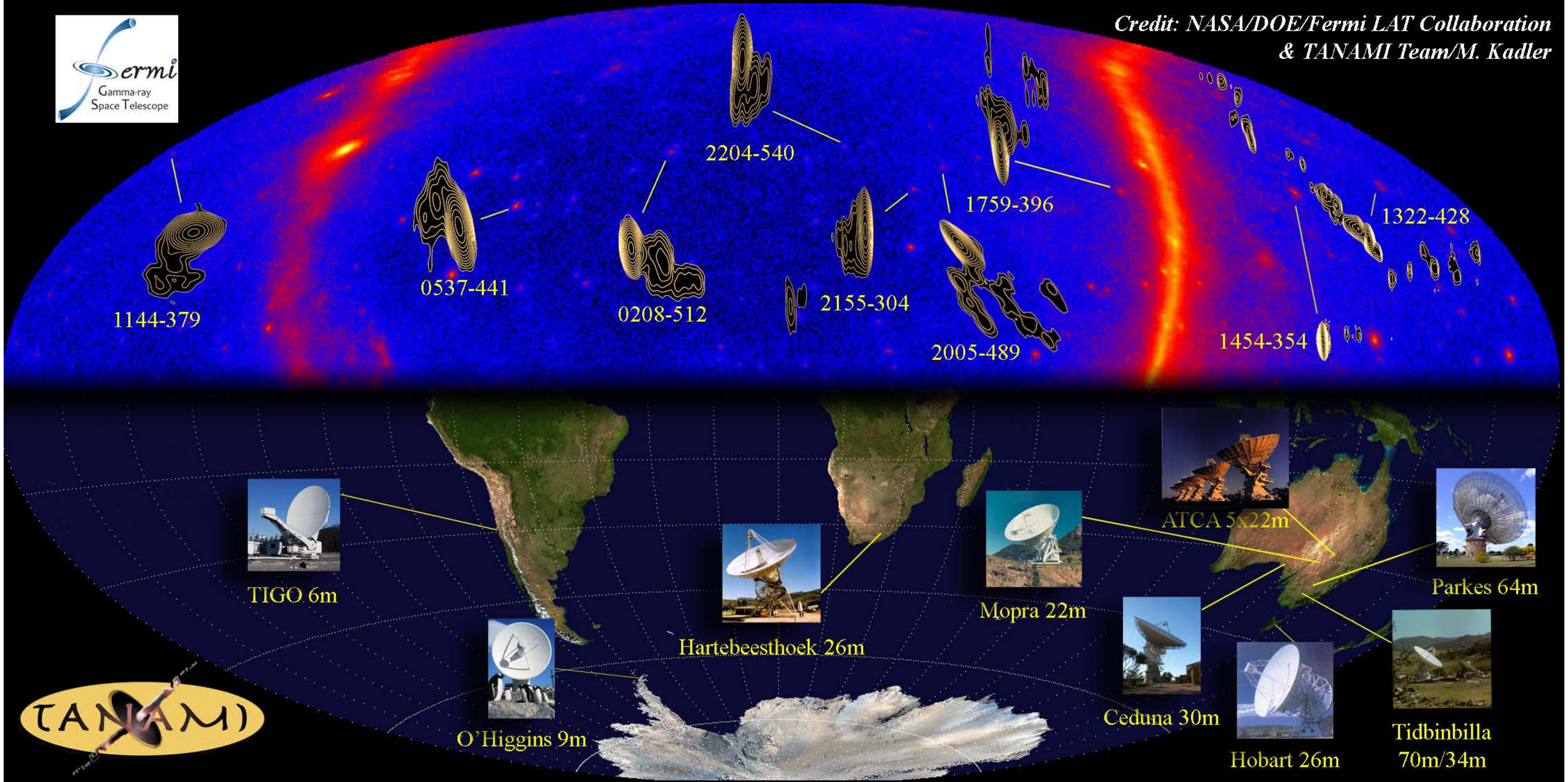
NASA-DOE-Fermi LAT Kollaboration

The Austral Point of View…



NASA-DOE-Fermi LAT Kollaboration

Radio-Gamma Jets of the Southern Hemisphere

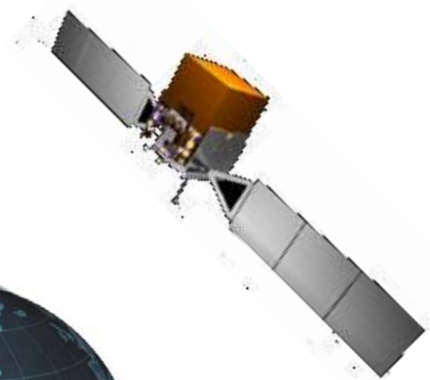


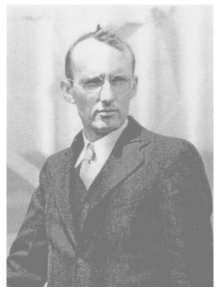
Selected MOJAVE/TANAMI LAT Results

(mostly based on 3-month data)

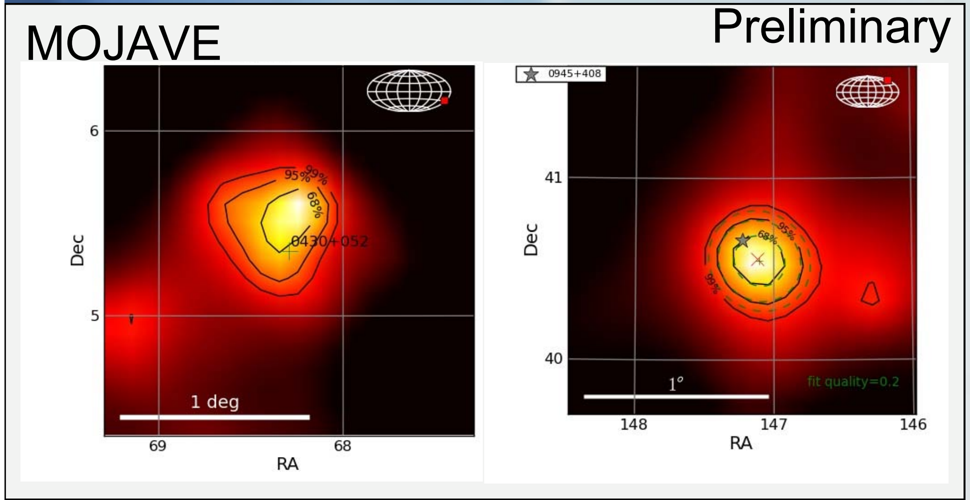
- Gamma-bright jets are faster
- Gamma-variable jets are faster than non-variable sources
- Gamma-bright jets have higher Doppler-factors
- Gamma-bright jets tend to be in an active radio state
- Gamma-bright jets have larger apparent opening angles
- Radio/Gamma-ray Time Delay
- EVPA swing in 1502+106
- Parsec scale structure of PKS1454-354
- Radio core spectra for SED catalog
- Sub-parsec scale radio spectra of candidate gamma-ray regions in CenA
- Activity region in NGC1275
- Parsec-scale structure of LAT-detected RLNLSy1s

Lister et al. 2009, Kovalev et al. 2009, Savolainen et al. 2010, Pushkarev et al. 2010, 2010b, Ojha et al. 2010, Müller et al 2011, Abdo et al. 2009a, 2009b, 2009c, 2010a, 2010b, 2010c, 2010d, 2011

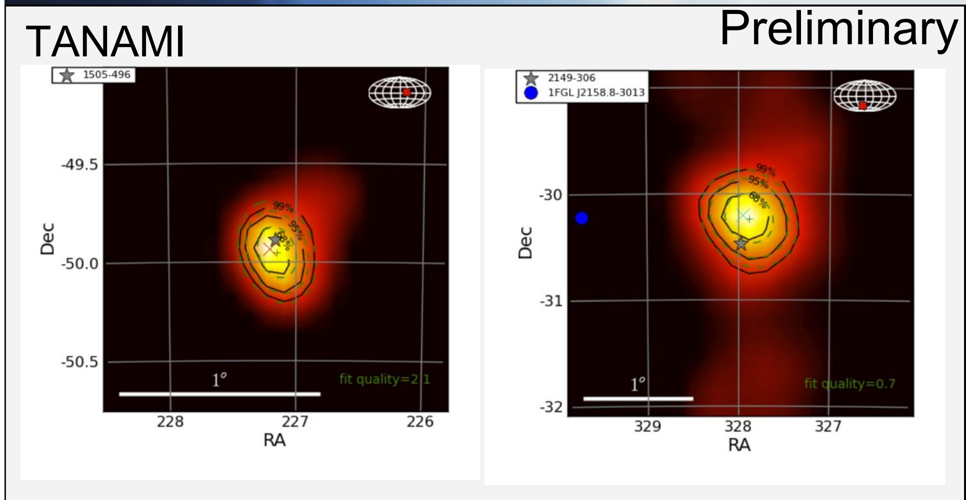




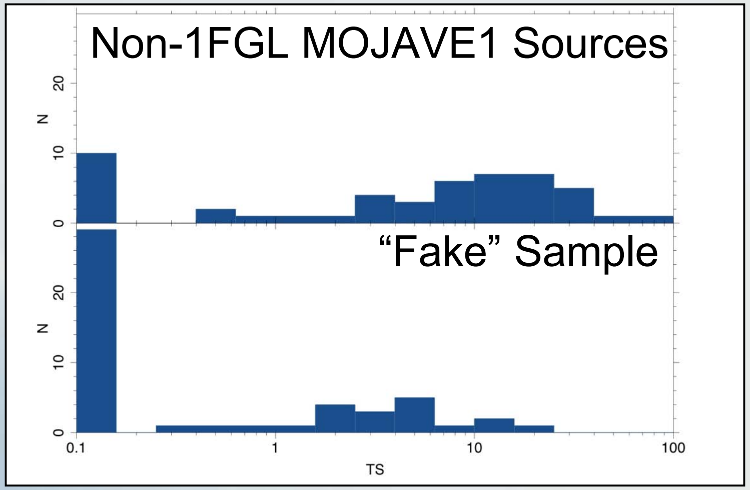
Faint Gamma-Ray Sources



- Targeted search – Gamma-Ray detections beyond 1FGL:
  - MOJAVE: 6
  - TANAMI: 2
- Plus many additional candidates
- Upper Limits for non-detected sources



Preliminary



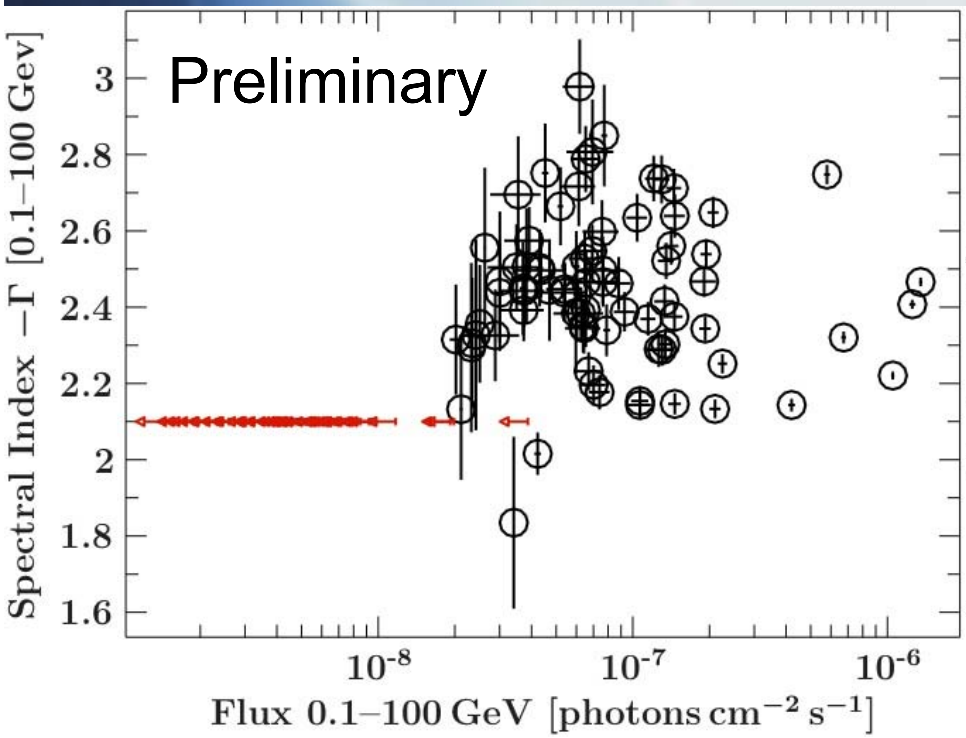
Gamma-Ray Properties

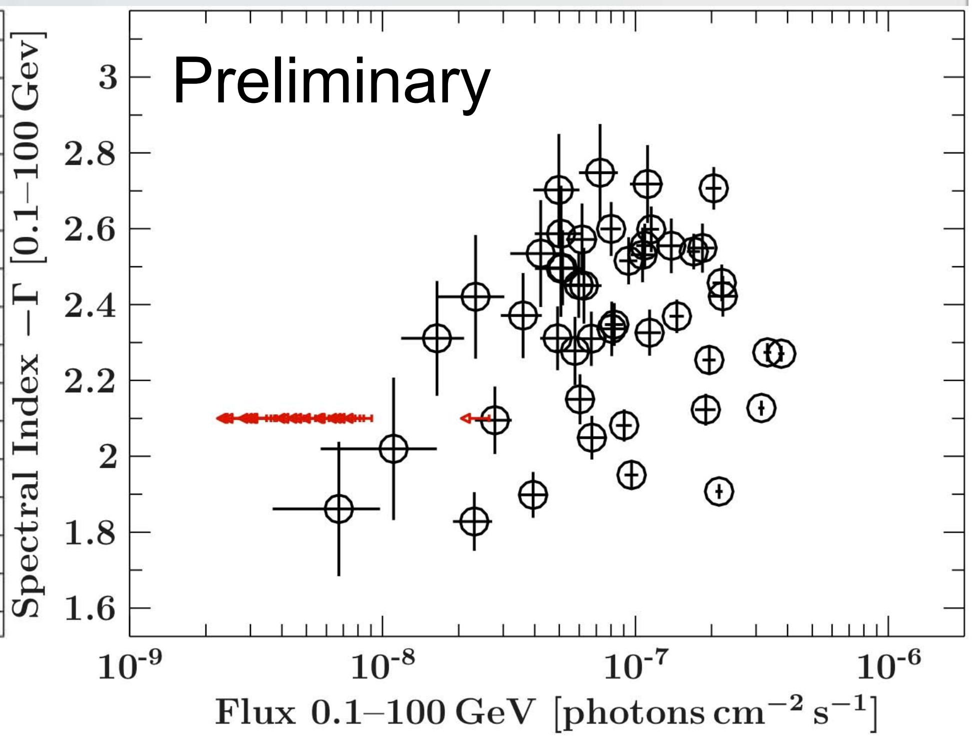
MOJAVE

- 135 sources; complete radio-selected sample (MOJAVE 1)

TANAMI

- 75 sources; 55 LAT-detected (quasi-complete) plus 20 radio-selected (not complete)





Gamma-Ray Flux Distributions

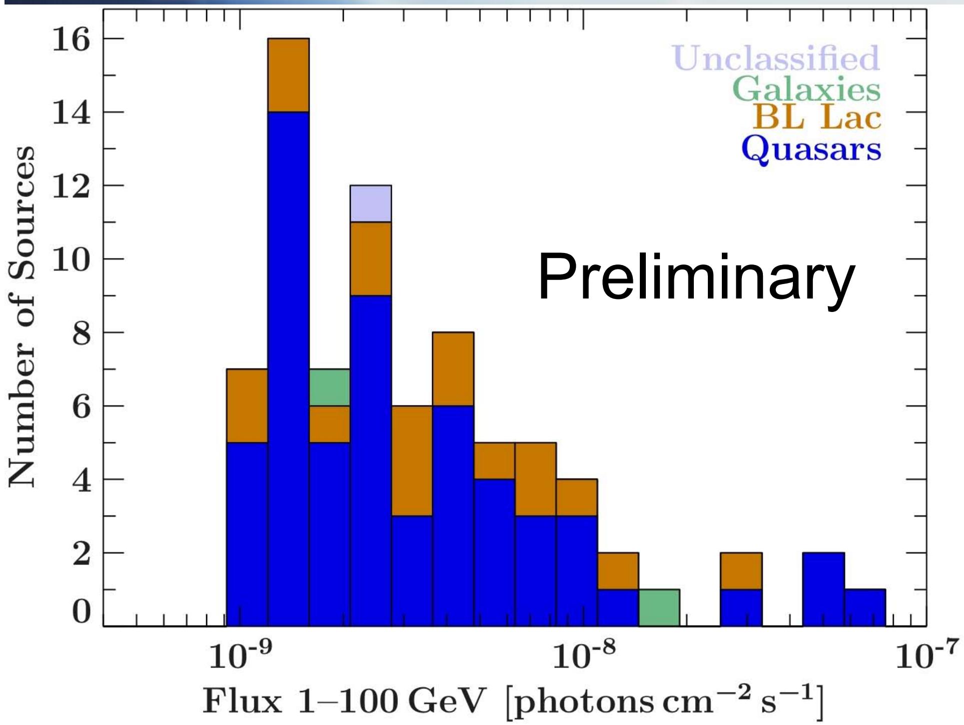
MOJAVE

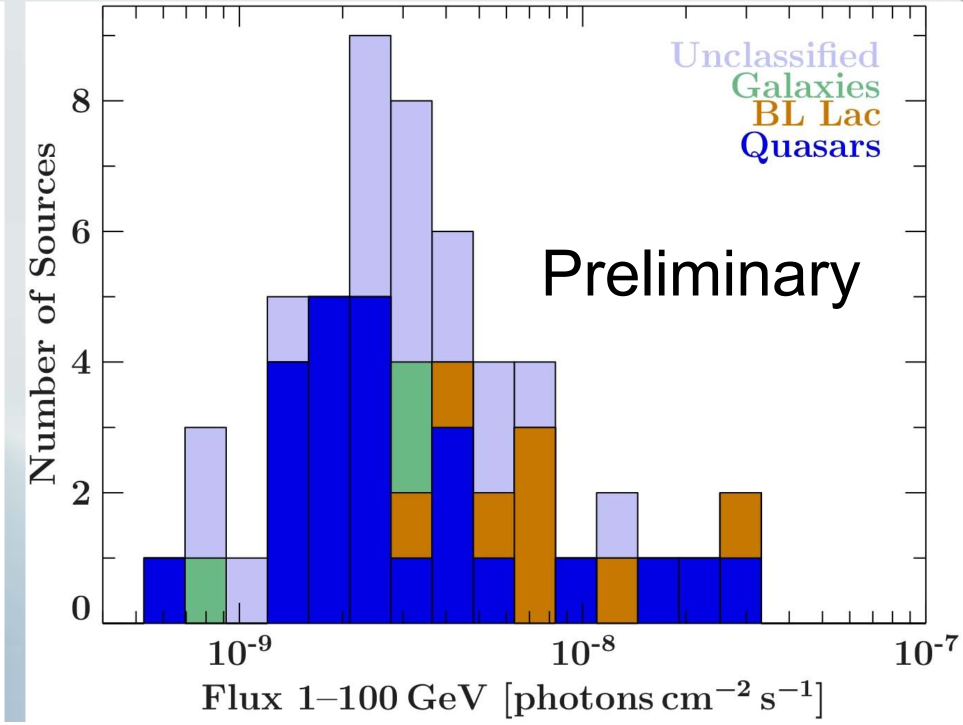
- 85/135 sources LAT detected
  - 19/22 BL Lacs (86%)

  but only
  - 63/101 Quasars (62%)

TANAMI

- 55/75 sources LAT detected
  - All 8 BL Lacs but only
  - 24/32 Quasars (75%)
- More unclassified sources

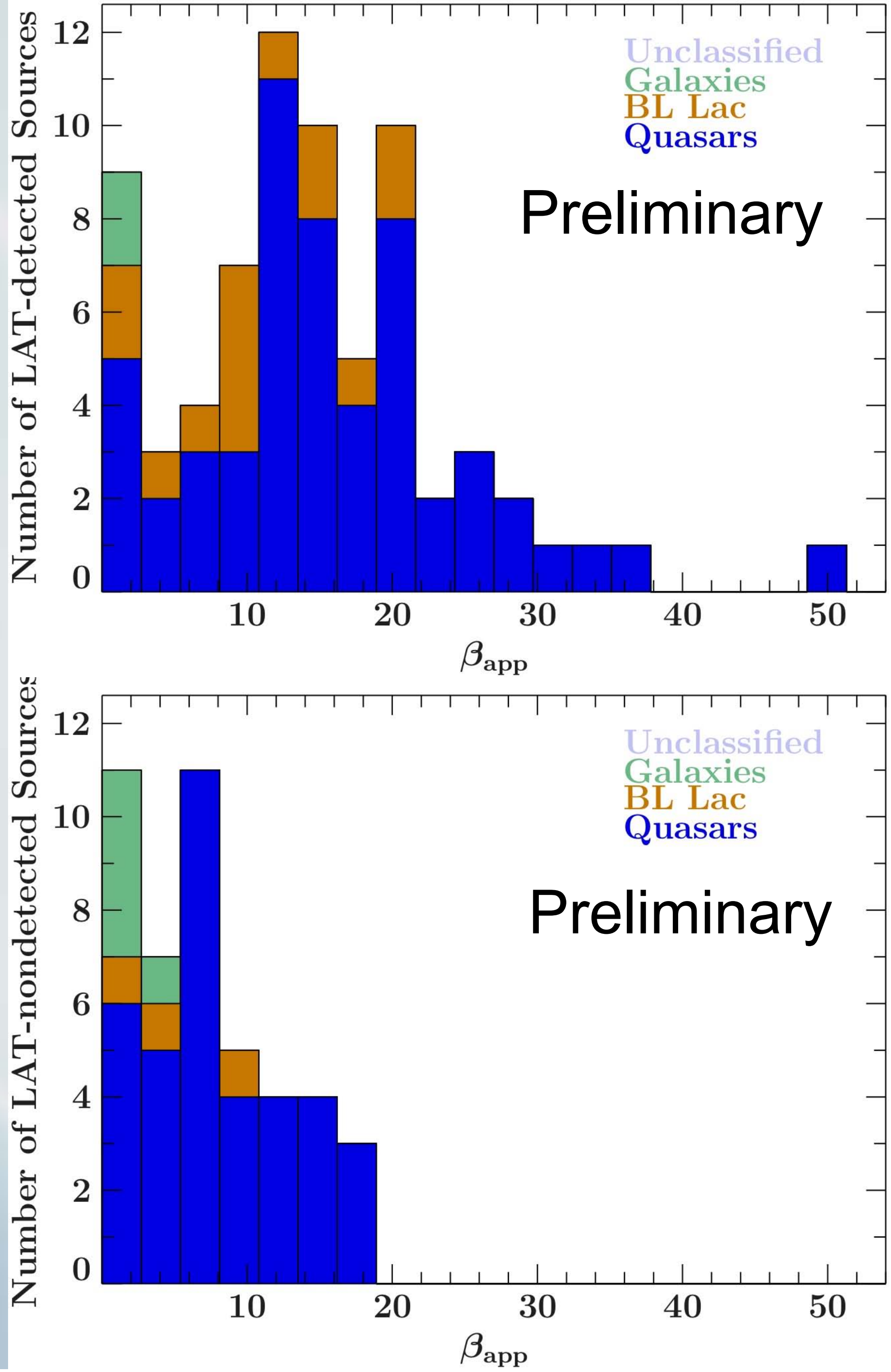




Jet Speeds

MOJAVE

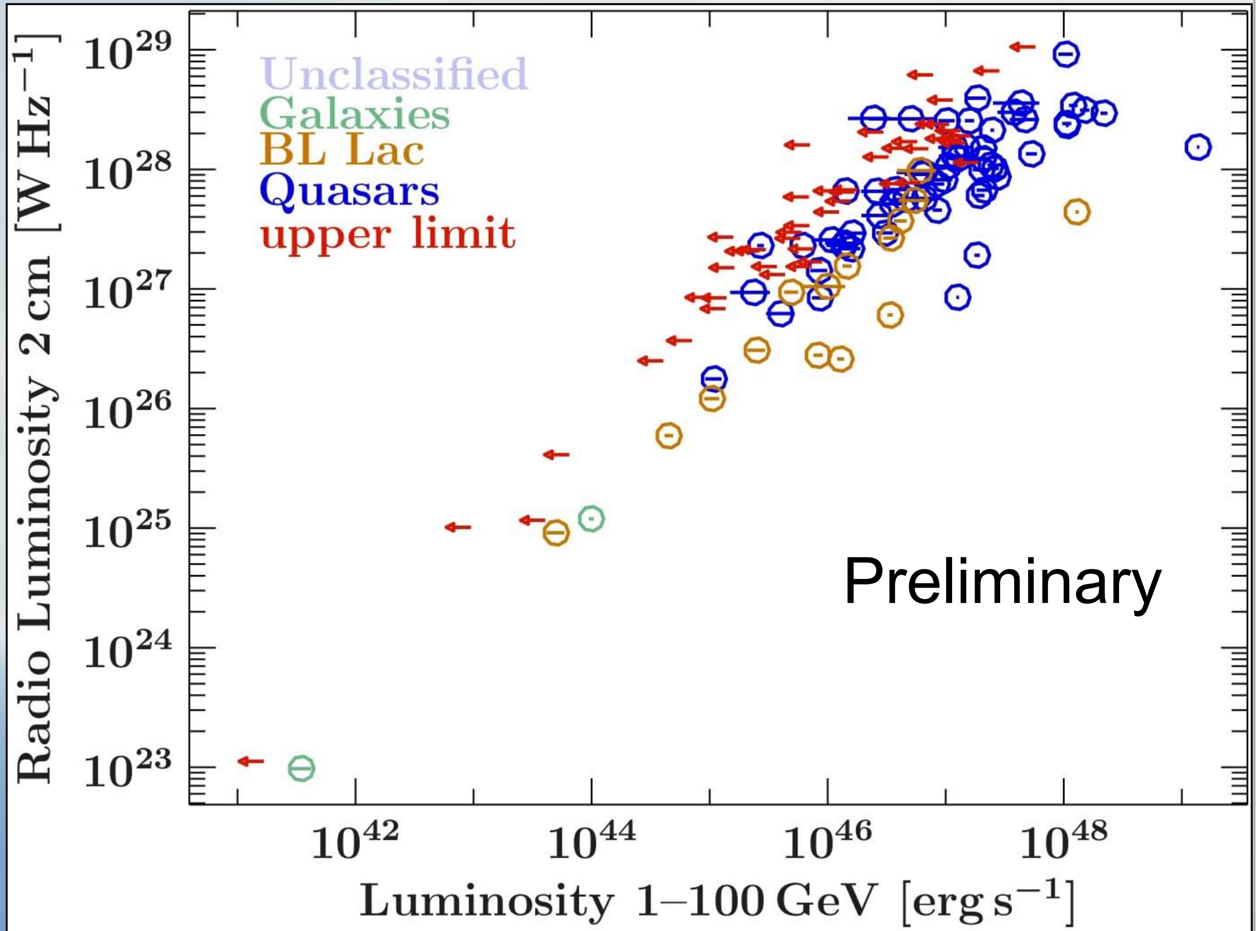
- 3-month result confirmed:
  - Lat-detected sources have higher speeds than non-detected ones
- All jets above 20c are gamma bright
- But also the gamma-faint quasars have fast jets up to 20c, i.e., high Lorentz factors.



Radio vs. Gamma Luminosity

MOJAVE

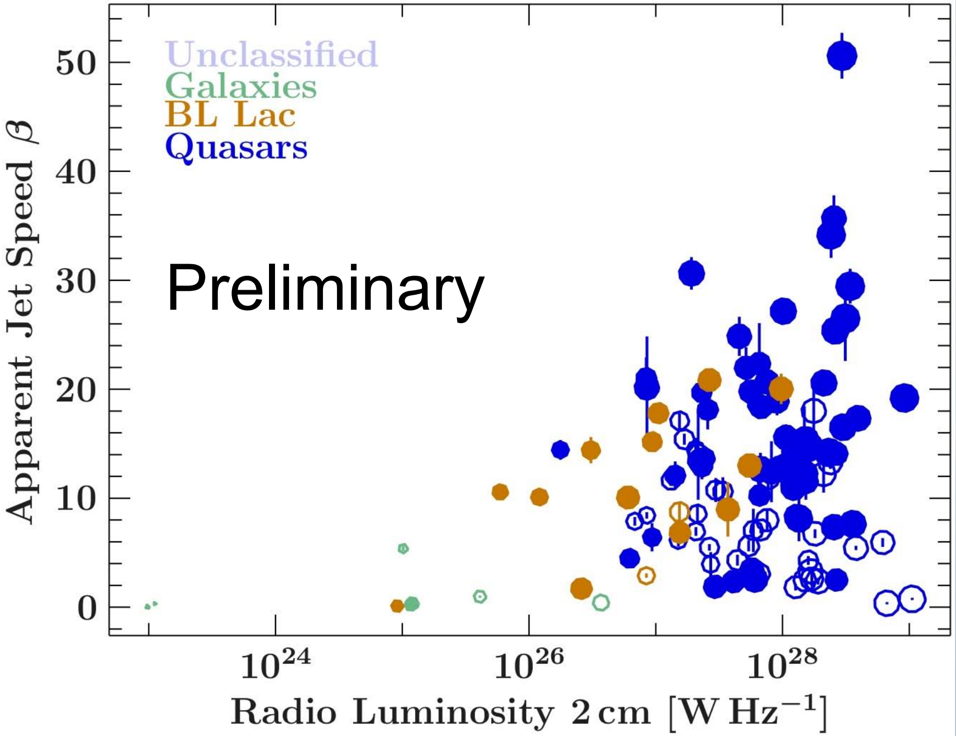
- No simple direct correlation between radio- and gamma-ray luminosity
- Gamma-faint sources over the full range of observed radio luminosities



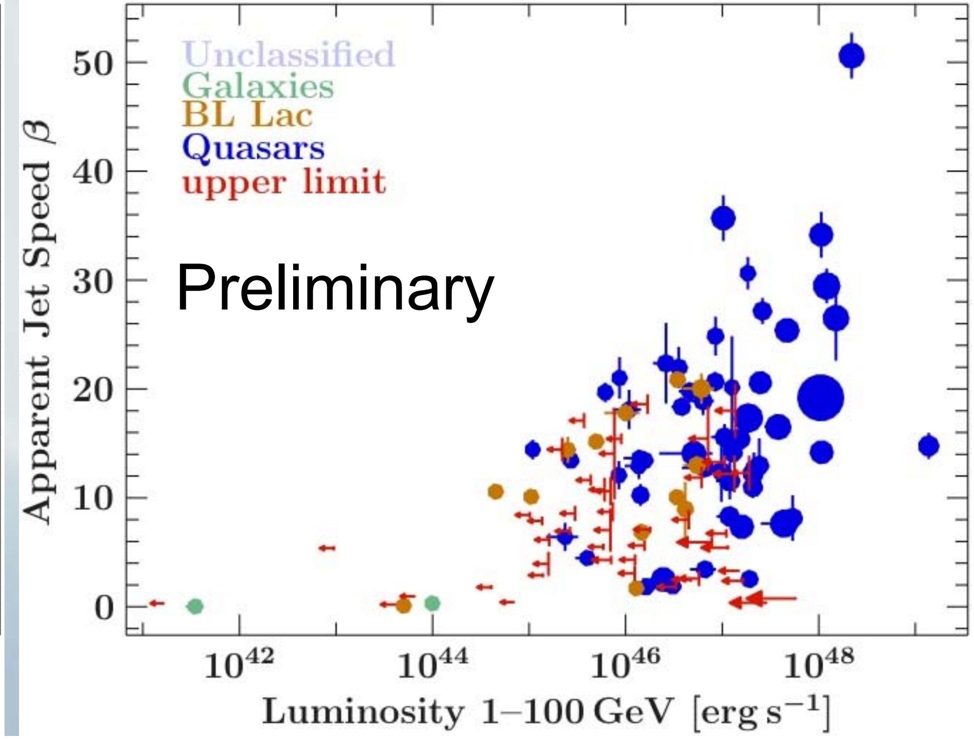
Speed-Luminosity Diagrams

- Well-known envelop in the jet speeds vs observed luminosity plot in the radio domain (Cohen et al. 2007)
- Similar envelop in the gamma-ray domain
  - No low-lum high-speed sources and few high-lum, low-speed sources
  - Maximum Lorentz factor ~50
  - Maximum intrinsic luminosity of ~10^{46} erg s^{-1}

Jet Speed vs. Radio Luminosity

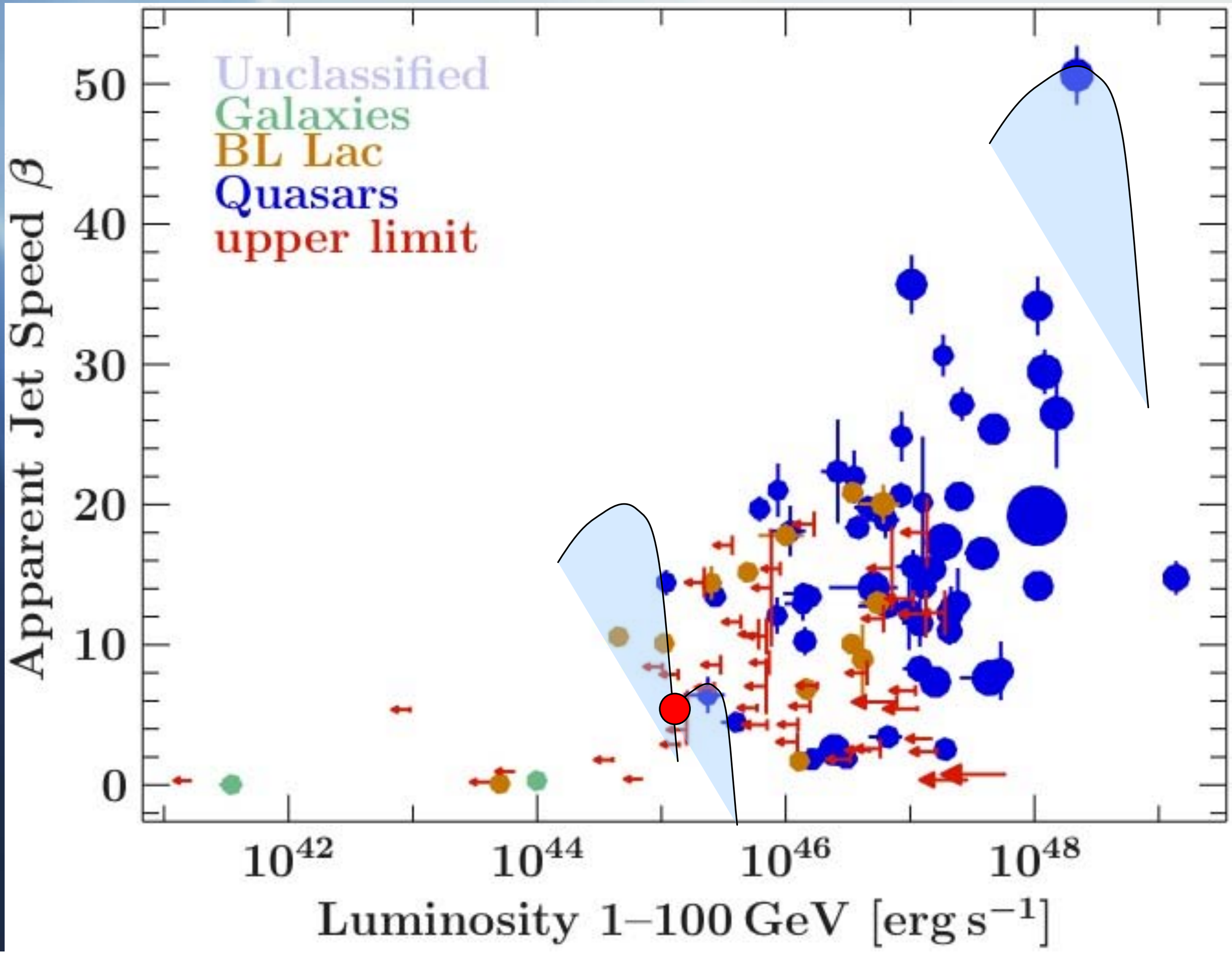


Jet Speed vs. Gamma Luminosity



Summary

- Gamma-ray properties of two radio-selected jet samples MOJAVE1 and TANAMI
- New LAT detections beyond 1FGL from targeted search (exploration of 3-5σ regime)
- Upper limits for gamma-faint sources for statistics
- Gamma-bright sources have faster jets. But gamma-faint sources go up to 20c
- Almost 40% of the radio-brightest quasars remain undetected by LAT
- No simple direct correlation between radio- and gamma-ray luminosity
- Envelop in speed-vs-luminosity diagram in the gamma-ray domain; maximum Lorentz factor ~50; maximum intrinsic luminosity of $\sim 10^{46}$ erg s^{-1}
- More VLBI-LAT correlations under investigation…



Unclassified
Galaxies
BL Lac
Quasars
upper limit
Apparent Jet Speed β
0
10
20
30
40
50
10^42
10^44
10^46
10^48
Luminosity 1–100 GeV [erg s^-1]

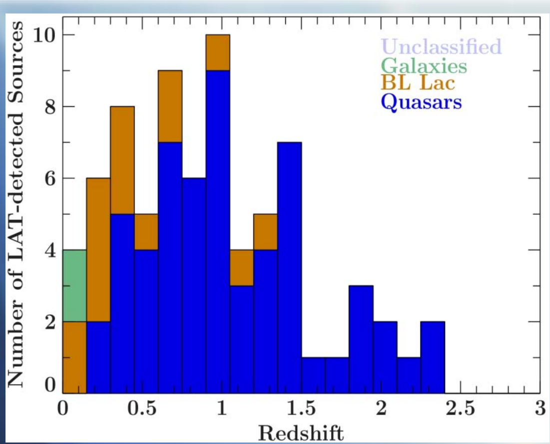
Redshift Distributions

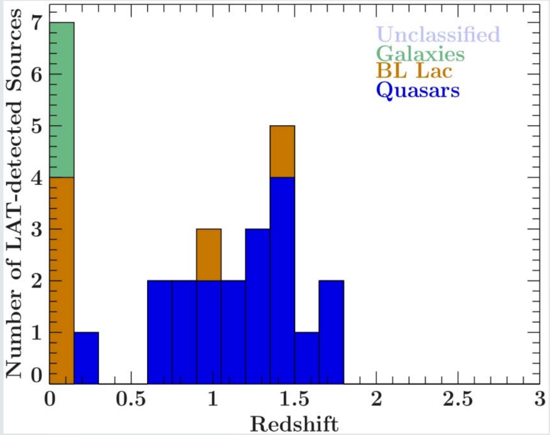
MOJAVE

- No obvious difference in redshift distribution between detected and undetected sources

TANAMI

- Only 5 nearby galaxies and 2 distant Quasars not LAT-detected (plus some unidentified objects)





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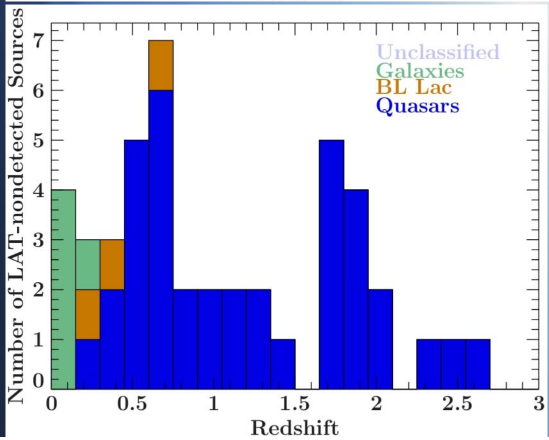

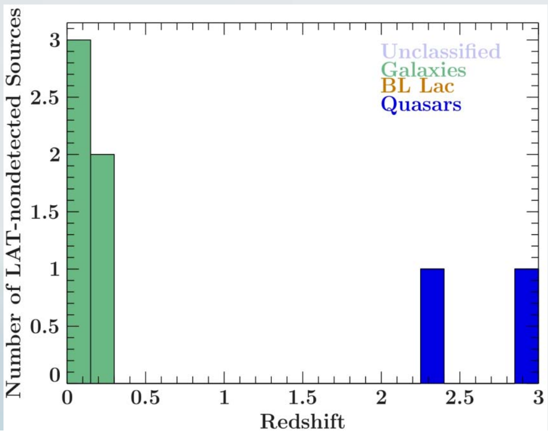

Gamma-Ray Spectra

MOJAVE

- Like in 1FGL: BL Lacs have harder spectra

TANAMI

- Many unclassified sources show BL Lac-like Gamma-Ray spectra