Radio Variability Studies of Gamma-Ray Blazars with the OVRO 40 m Telescope

Joseph L. Richards, Walter Max-Moerbeck, Vasiliki Pavlidou, Anthony C. S. Readhead, Timothy J. Pearson, Oliver G. King, Rodrigo Reeves, Matthew A. Stevenson, Martin C. Shepherd

California Institute of Technology / Owens Valley Radio Observatory

Since late 2007, we have been monitoring a large sample of known and likely gamma-ray-loud blazars at 15 GHz twice per week with the Owens Valley Radio Observatory 40 m Telescope. Our initial sample included the 1158 sources above declination –20° from the Candidate Gamma-Ray Blazar Survey (CGRaBS), and we have since added nearly 400 more sources, including all blazars associated with *Fermi*-LAT detections in the First AGN Catalog (1LAC). Here, we describe the new sample and present results for 2008 through early 2011. Using statistical likelihood analyses, we compare the variability amplitude for various sub-populations within our sample. These include comparisons of gamma-ray-loud versus quiet objects, BL Lac objects versus flat-spectrum radio quasars, and a study of the variability amplitude trend with redshift. We also describe KuPol, the new digital Ku-band receiver being constructed for the 40 m telescope. This new receiver will provide total intensity and linear polarization measurements over the 12–18 GHz band, with 16 MHz spectral resolution.

Scientific Background

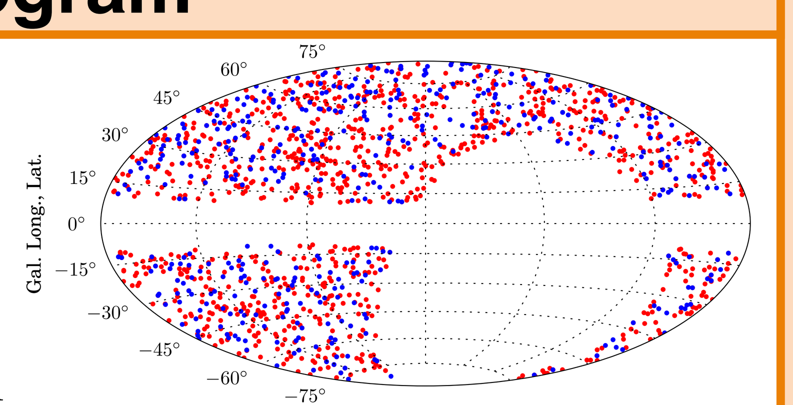
Blazars are the most extreme class of active galactic nuclei (AGN), probably resulting when an AGN is viewed along its relativistic jet axis. Although a variety of models have been proposed, and despite decades of observation, many fundamental questions about blazars and AGN physics remain open. Among them:

- How are jets launched, accelerated, collimated, and confined?
- Of what are the jets composed?
- Where in the jet are the observed photons emitted?
- What are the details of the emission mechanisms?

Gamma-rays are our best tool for probing the most extreme processes within AGN, and coordinated multiwavelength observations are crucial to the interpretation of gamma-ray data.

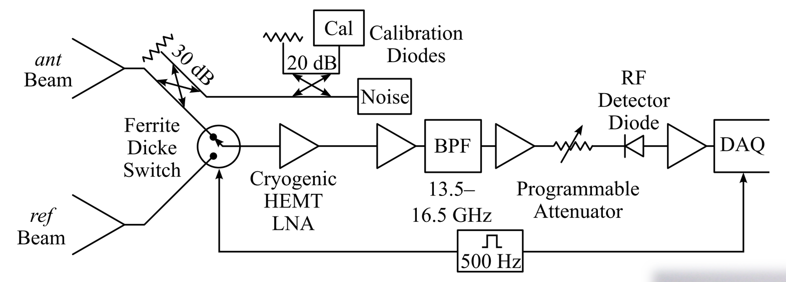
OVRO 40 m Program

- Since late 2007, 2–3× per wk per source
- Initial sample: 1,158 CGRaBS (δ>–20°)
- Now ~1,550 sources, including all 454 "clean" 1LAC sources (δ>–20°)
- 2008–2009 ("2 year") CGRaBS results in press (Richards et al. 2010)
- CGRaBS data available online: http://www.astro.caltech.edu/ovroblazars



CGRaBS (red) and 1LAC clean (blue) sources in the OVRO monitoring program.

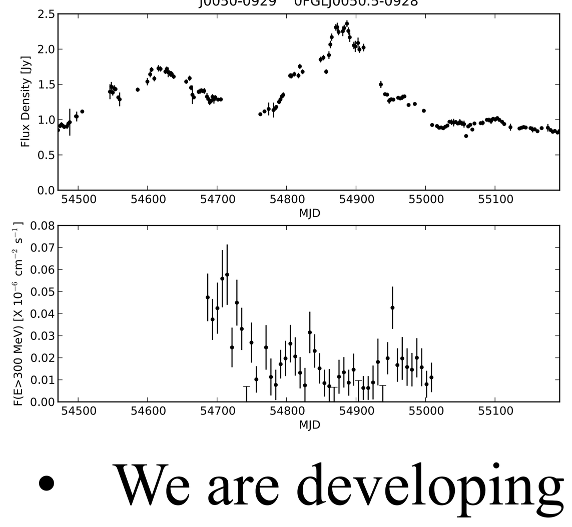
- Instrument: OVRO 40 m telescope
  - 15.0 GHz, 3 GHz bandwidth
  - Cryogenic HEMT receiver
  - Dual beam optics, Dicke switched
  - T_{RX} ~ 29 K, Total T_{sys} ~ 55 K
- 3% typical, 4 mJy minimum uncertainty
- Flux cal: 3C 286 (Baars et al. 1977)



Receiver block diagram for the Ku-band HEMT receiver.

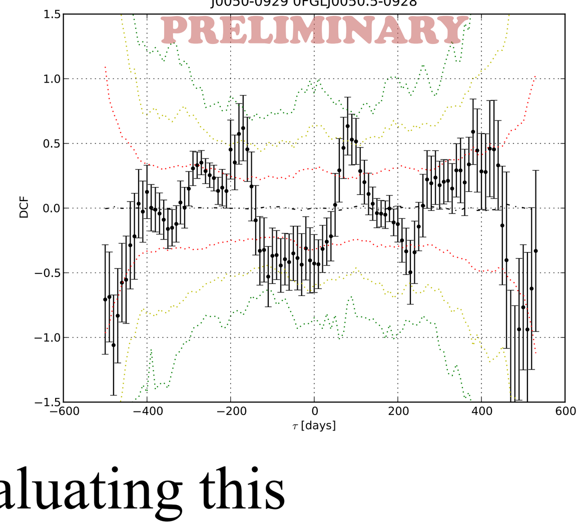
Radio/Gamma-ray Cross-Correlation

- Peaks in radio/gamma-ray cross-correlation function can identify relative locations of emission *if they are physically significant.*



Left: OVRO 15 GHz (top) and *Fermi*-LAT gamma-ray light curves for J0050-0929.

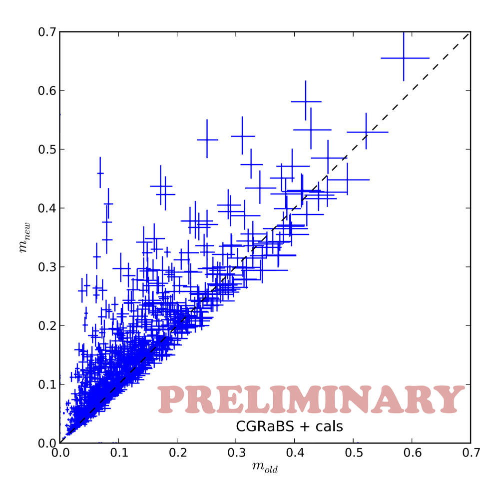
Right: Cross-correlation of the light curves (black) shows several peaks. Colored curves show Monte Carlo-estimated 1σ, 2σ, and 3σ significance contours assuming radio (gamma-ray) noise power spectral indexes of β=2.0 (1.5) (PSD $\propto f^{-\beta}$)



- We are developing a Monte Carlo method for evaluating this significance: see talk by W. Max-Moerbeck for details.

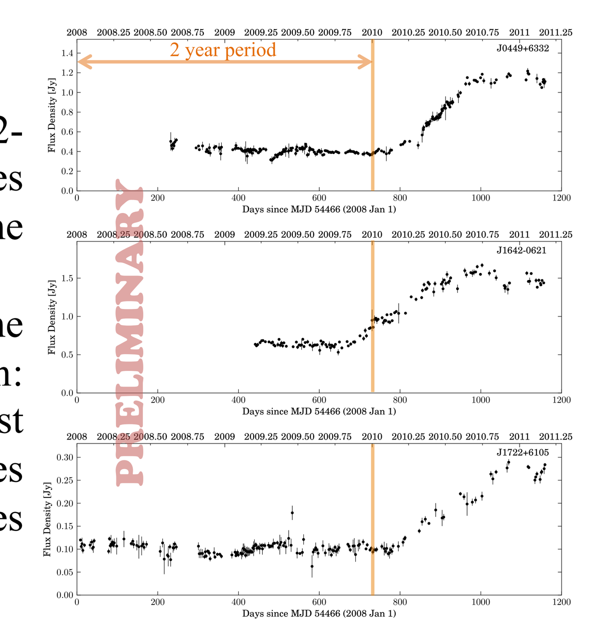
Radio Variability Amplitude Results

- Effect of additional data on modulation indices

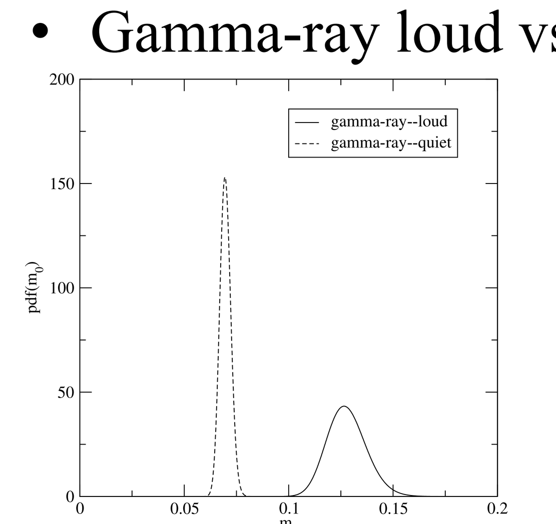


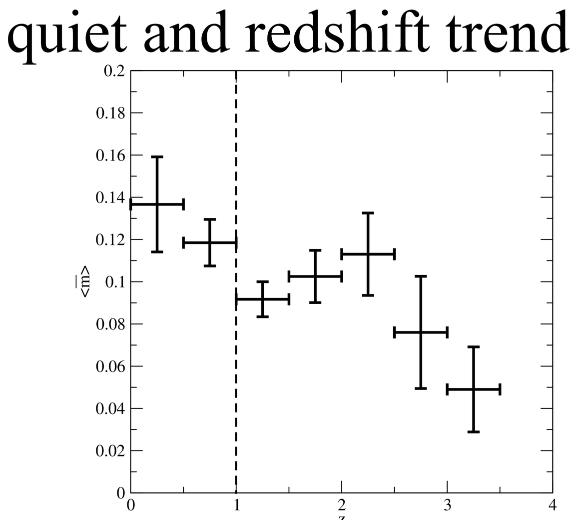
Left: a scatter plot of the 3.2-year against 2-year CGRaBS intrinsic modulation indices shows values to be consistent or larger in the longer data set.

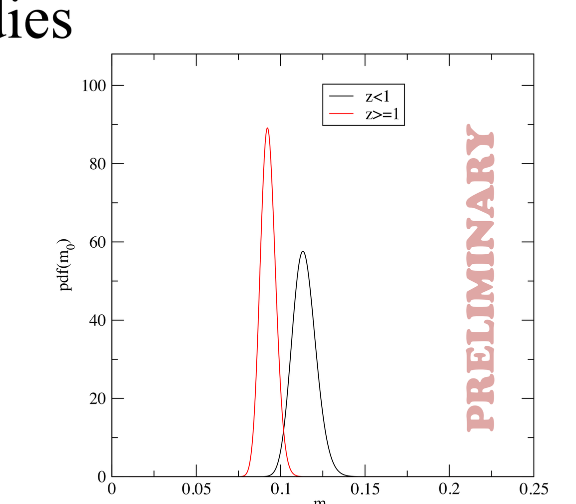
Right: Light curves for the 3 sources with the largest increase suggests an explanation: sources that have not yet "visited" their highest and lowest emission states will show increases in their modulation indices until all those states have been sampled.



- Gamma-ray loud vs. quiet and redshift trend studies

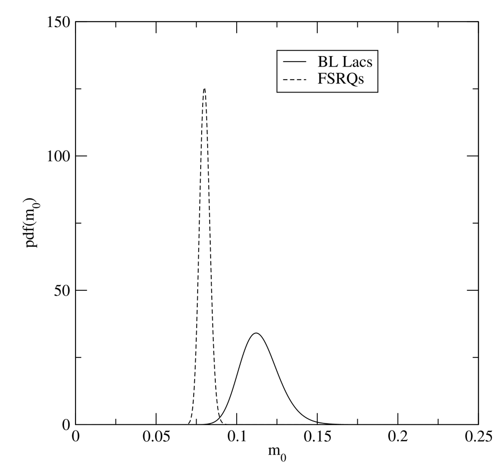






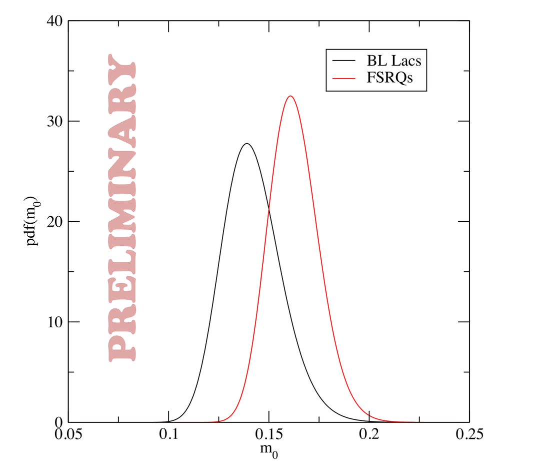
Left: Gamma-ray-loud CGRaBS are more radio variable than gamma-ray-quiet by 5.7% (> 6σ).
Center: CGRaBS FSRQs during 2-year data period show a trend of decreasing intrinsic modulation index with redshift. Right: This trend continues in the 3.2-year period, with low redshift (z<1) FSRQs on average more variable by 2.1% (~2.5 σ significance). A similar study using 1LAC sources finds low redshift (z<1) FSRQs to be 4.7% less variable, but this result is not statistically significant, perhaps due to a smaller sample size.

- BL Lac versus FSRQ sub-populations



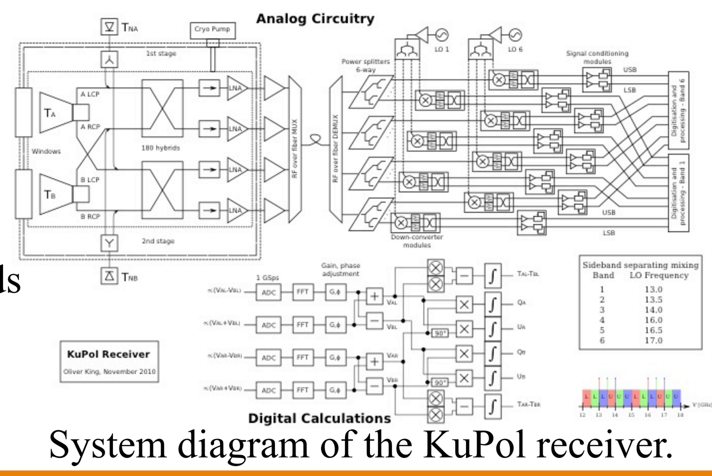
Right: BL Lac vs. FSRQ comparison for 1LAC sources. *FSRQs are more radio variable by 2.2% (<1.5σ, consistent with 0).*

Left: BL Lac vs. FSRQ comparison for OVRO CGRaBS using 2 year data. *BL Lacs are more radio variable by 3.2% (>3σ).*



KuPol Receiver Upgrade

- New Ku-band receiver under construction
  - Beam-differenced total power + linear polarization
  - 12–18 GHz BW, 16 MHz channels
  - Dual-beam optics (2.5 arcmin FWHM, 13 arcmin separation)
  - Digital back-end processing using FPGA-based ROACH boards
  - Target T_{sys} ~ 20 K
- Commissioning Fall 2011!



System diagram of the KuPol receiver.

Conclusions & References

- Radio variability stronger at low redshift
- Gamma-ray loud CGRaBS are more radio variable
- 1LAC BL Lac/FSRQ comparison *not* consistent with CGRaBS result
- Additional year of data increases intrinsic modulation indices

- Abdo et al. 2010, ApJ, 715, 429.
- Baars et al. 1977, A&A, 61, 99.
- Richards et al. 2011, ApJS *in press* (arXiv:1011.3111).
- Healey et al. 2008, ApJS, 175, 97.

This work is supported in part by NASA grants NNX08AW31G and NNG06GG1G and NSF grant AST-0808050.