Multi-Waveband Variability of Eight Blazars in the First Year of Observations with Fermi

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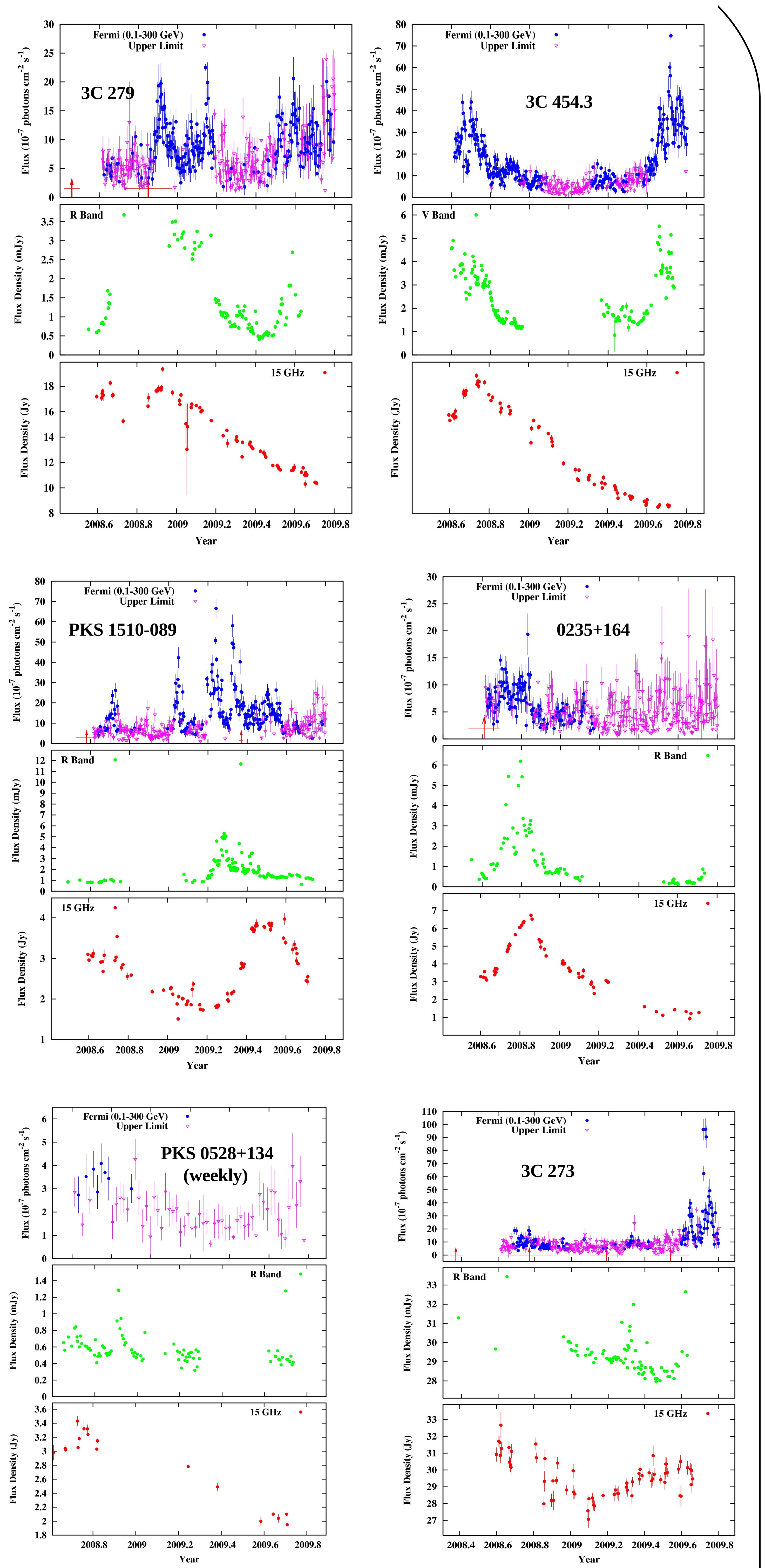
Introduction: A multitude of programs around the world, including SMARTS (optical-IR), UMRAO (15 GHz) and BU blazar group (monthly VLBA; optical and 43 GHz polarization) have started to provide simultaneous multi-wavelength monitoring of many of the blazars that Fermi is regularly observing. The light curves from these lower frequency observing programs are being made accessible to public soon after observation. By combining these data at lower frequencies with the Fermi data and VLBI imaging, stringent tests on models for the nonthermal emission and jet physics in blazars will be possible.

Robust and objective techniques are required for the analysis of the time variability data from Fermi so that the physics extracted from these results is significant and unbiased. We calculate the power-spectral density (PSD) using a Monte-Carlo type approach to study the precise nature of the gamma-ray variability of blazars. We use discrete cross-correlation function (DCCF) to calculate inter-waveband correlation.

Abstract: We present preliminary results from our program to investigate the location and mechanism of high energy emission in eight blazars using multi-waveband time variability. These eight target objects are chosen based on the availability of relevant data from Fermi, SMARTS, and BU blazar group, which are all public databases. Two of these eight objects (1730-130 and OJ 287) were undetected in gamma-rays during most or all of the first yr observations. We have analyzed one-year-long light curves of the other six blazars in gamma-rays (Fermi), optical-IR (SMARTS), and radio (15 GHz; UMRAO) as well as VLBA images (BU blazar group) at 43 GHz. Power spectral densities (PSD) of the gamma-ray variability of 3C 279 and 3C 454.3 can be fit by simple power-laws with negative slopes while that of PKS 1510 can be fit by a broken power-law equally well. In most of these objects, variations in gamma-rays are well-correlated with those in the optical band and in some cases with those in the radio (15 GHz) frequencies as well. Using the results of our analysis we discuss possible location and mechanisms of the time variable emission in these objects.

Gamma-ray, optical and radio light curves of six blazars

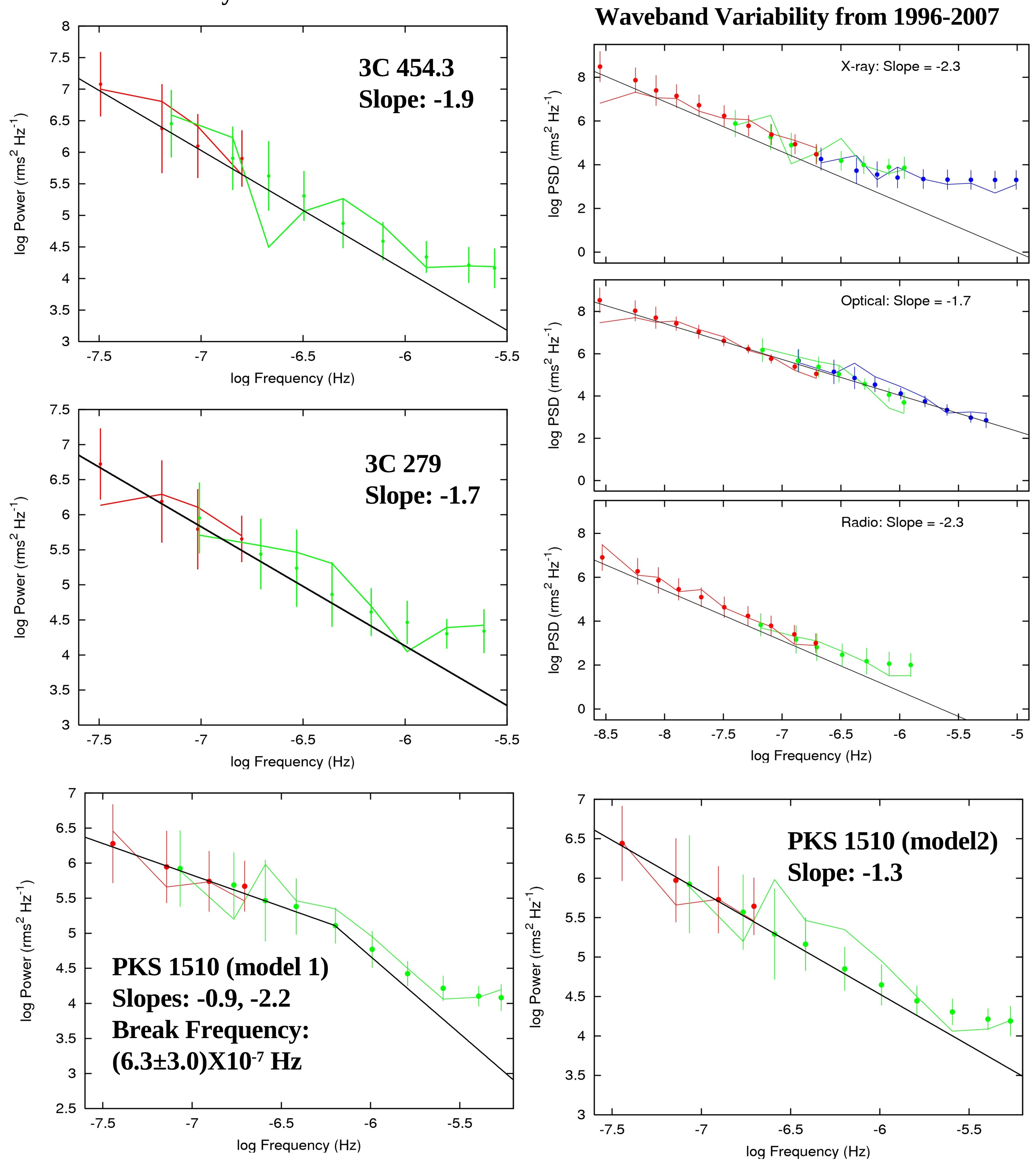


Variation of X-ray flux, optical flux density and radio flux density of 6 blazars in the first year of Fermi observations. In the top panels, the arrows show the times of superluminal ejections in the jet from VLBI observations. The line segments perpendicular to the arrows indicate the uncertainties in the times. Time of "ejection" is defined as the time when a knot starts to move away from the (presumed quasi-stationary) core in the VLBA images

Power spectrum results

Gamma-ray PSD of 3 blazars

3C 279: Broadband PSDs of multi-Waveband Variability from 1996-2007



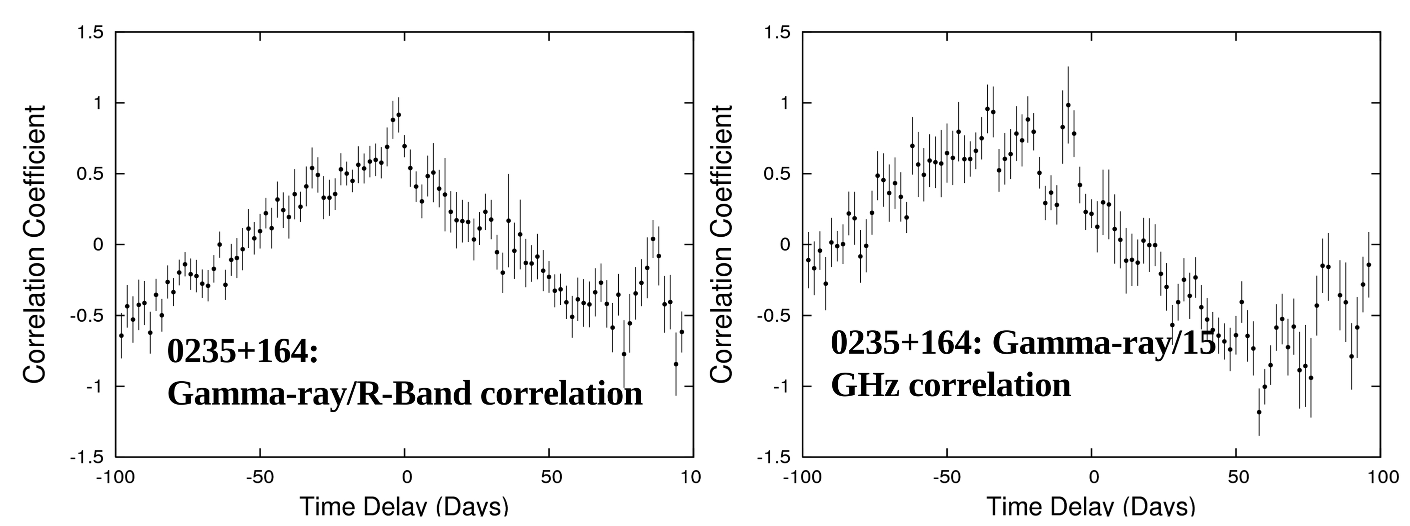
The power spectral density (PSD) of the observed data at high, medium and low frequencies are given by the blue, green and and red jagged lines, respectively, while the underlying power-law model is given by the black line. Points with error bars (blue, green and red for high, medium, and low frequency range, respectively) correspond to the mean value of the PSD simulated from the underlying power-law model. The error bars are the standard deviation of the distribution of simulated PSDs. **Gamma-ray PSD of 3C 279 and 3C 454.3 as well as the broadband X-ray, optical and radio PSD of 3C 279 are best described by a simple power law with slope between -1.3 and -2.3. Gamma-ray PSD of PKS 1510-089 is well fit by a simple as well as a broken power-law model. More data need to be carefully analyzed to confirm the presence of the break and constrain the value of the break-frequency.**

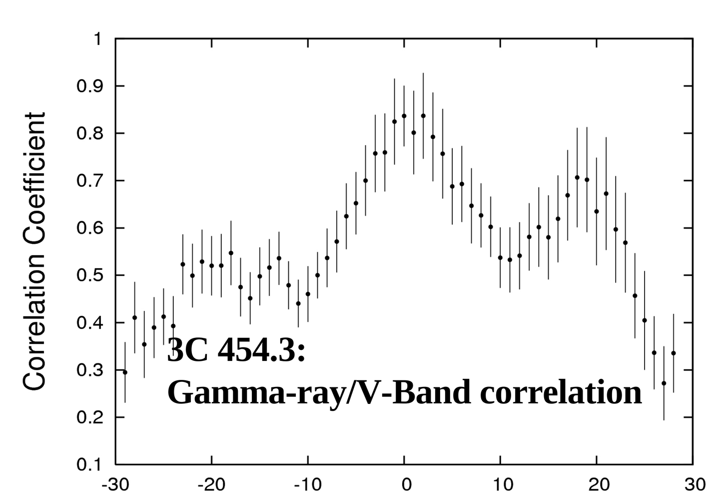
1. See Alan Marscher's talk on Tuesday for a discussion of the physical picture of PKS 1510 as revealed by Fermi and supporting observations.

2. Visit poster P1-1 by Svetlana Jorstad for the connection of gamma-ray variability of blazars with changes in the pc-scale jet observed through VLBA.

3. See Erin Bonning's talk on Wednesday for more details on SMARTS project on optical/IR observations of LAT monitored blazars.

Cross-correlation results





Discrete cross-correlation functions (DCCF) of the gamma-ray and lower frequency (optical, 15 GHz) monitor data. The time delay is defined as positive if the low frequency variations lead those at gamma-rays.

In 3C 454.3, variations in gamma-rays and those in the optical V-band are very well-correlated with zero time lag. There is a secondary peak with the optical variations leading by ~20 days.

In 0235+164, gamma-ray variation is well-correlated with those in the optical (γ-rays lead by few days) and radio (γ-rays lead by ~20 days).

Conclusions:

Expansion of multi-wavelength monitoring of blazars to a wide range of gamma-ray energies (20 MeV to 300 GeV) is now possible through Fermi.

Precise characterization of gamma-ray variability of blazars such as the power spectral density (PSD) is possible using the well-sampled gamma-ray light curves.

Detailed investigation of the relation of variations in gamma-rays to those in the lower frequencies using cross-correlation functions can be carried out with much better time resolution than it was possible in the past.

We draw the following conclusions from the preliminary analysis of the multi-waveband light curves during the first yr of observations:

- **The gamma-ray PSD of 3C 279 and 3C 454.3 can be fit by a simple power-law with a negative slope. This property of these objects is similar to the X-ray, optical and radio variability of 3C 279 determined from 10-yr-long light curves. This result indicates that the mechanism of production and variability of gamma-rays is similar to the emission in lower frequencies. Gamma-rays are also produced in the jet.**
- **Variations in gamma-rays are very well correlated to those in the optical. In some objects, there is a broader 15 GHz flare following a large flare in gamma-ray and optical. This indicates that the same electron distribution is responsible for the production of emission in all three wavebands. Radio and optical through synchrotron and gamma-ray through inverse-Compton scattering of seed photons. More data needs to be carefully analyzed to put stronger constraints on the origin of seed photons and exact location of gamma-ray emission.**

Acknowledgments:

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Optical data is obtained from SMARTS/LAT program which is using ~700 hours per year on three of the telescopes operated by the Small and Moderate Aperture Research Telescope System (SMARTS) at Cerro Tololo Interamerican Observatory (CTIO) in Chile to observe all public Large Area Telescope (LAT) monitored blazars that are accessible from Chile (http://www.astro.yale.edu/smarts/glast/)

VLBA data is from the Boston University blazar group. The VLBA is an instrument of the National Radio Astronomy Observatory (NRAO). NRAO is a facility of the National Science Foundation, operated by Associated Universities Inc.

15 GHZ data is from the University of Michigan Radio Astronomy Observatory (UMRAO) which has been supported by the University of Michigan and by a series of grants from the National Science Foundation, most recently AST-0607523 and NASA Fermi grant NNX09AU16G.