Physical significance of time lags in radio/gamma-ray cross-correlations

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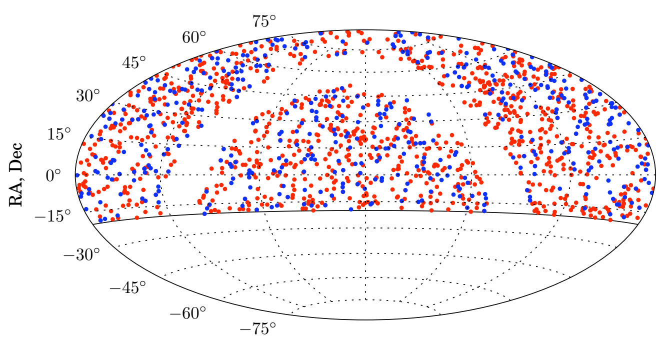
Correlated radio and gamma-ray variability

- Problem:
  - Where does the gamma-ray emission originates in blazars?
    - Various alternatives: e.g. Blandford and Levinson 1995, Marscher et al 2008
- Our strategy:
  - Study radio and gamma-ray light curves for a large number of sources

OVRO 40 m Telescope
Blazar monitoring program

- Monitoring 1550 blazars
- 454 detected by Fermi on 1LAC "clean" sample
- Radio continuum 15 GHz, 3 GHz bandwidth
- 4 mJy thermal noise, ~3% typical uncertainty
- Polarization monitoring by the end of this year



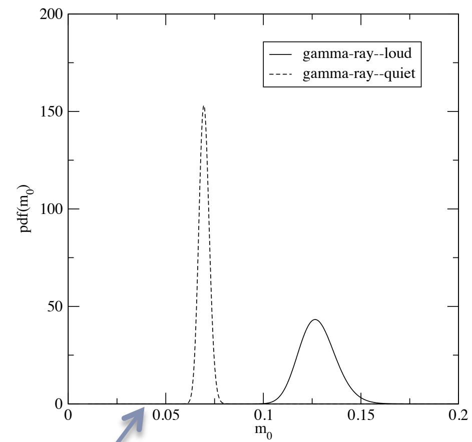
Distribution of CGRaBS sources in equatorial coordinates.
Red circles CGRaBS, Blue circles 1LAC

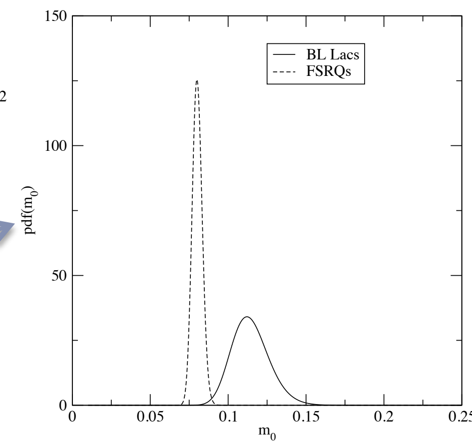
The OVRO 40 m Telescope at night
By Joey Richards

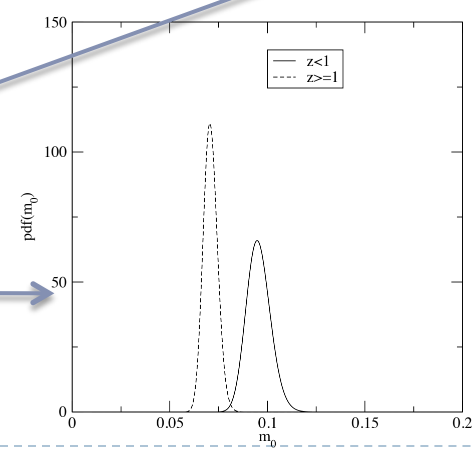
J. Richards poster "Radio Variability Studies of Gamma-ray Blazars with the OVRO 40 m Telescope"

First results of the monitoring program
Richards et al 2011, ApJS in press

- First data release, 2 years of data for original CGRaBS sample
- Radio variability properties studied using "intrinsic modulation index" m = σ / S
  - Gamma-ray detected sources are more variable in radio than non-detected ones
  - BL Lacs are more variable in radio than FSRQs
  - Low redshift FSRQs are more variable than high redshift ones







J. Richards poster "Radio Variability Studies of Gamma-ray Blazars with the OVRO 40 m Telescope"

Correlated radio and gamma-ray variability

- Our approach:
  - Large sample of objects
  - Preselected as gamma-ray candidates
  - Observed independently of gamma-ray state
  - High cadence, observed twice per week
  - Statistical tests for cross-correlations

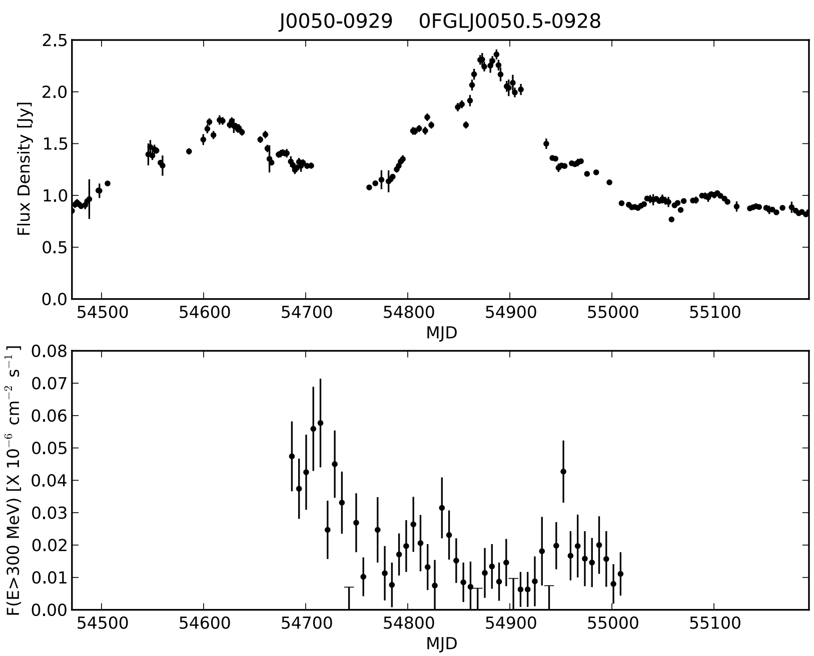
A first look at the radio/gamma-ray cross-correlations

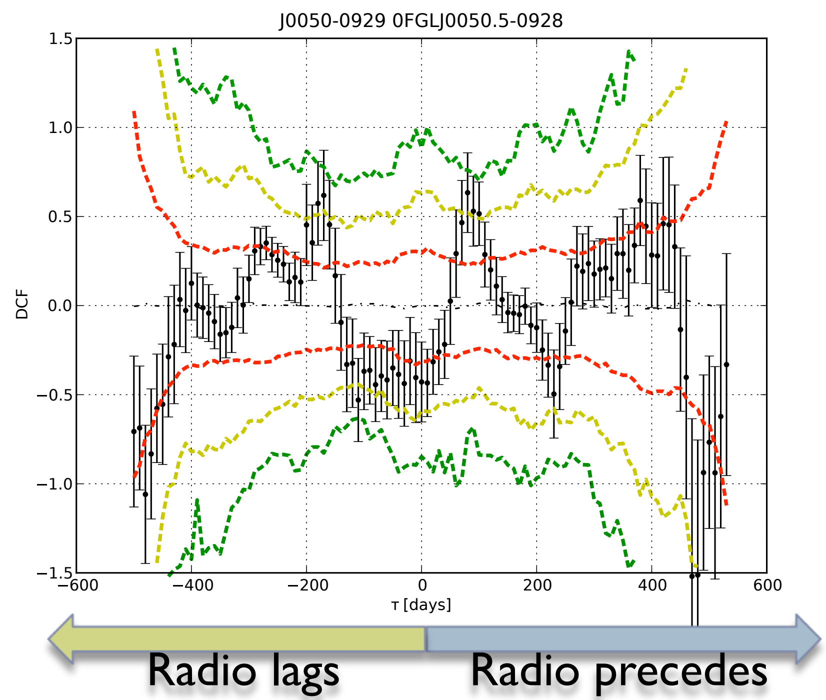
- Radio data
  - 2 year light curves of CGRaBS + a few calibrators
  - Published in Richards et al 2011, ApJS in press, see as arXiv: 1011.3111
- Gamma-ray data
  - Published by Fermi collaboration on blazar variability paper. Abdo et al. 2010, ApJ 722, 520
  - 106 sources
  - 11 month light curves, weekly sampling
  - 52 / 106 are in CGRaBS and have simultaneous radio data

Radio/gamma-ray time lags and their significance

- Example cross-correlation. 3-month Fermi detections, using 11-months of Fermi data and 2 years of radio monitoring

○ Significance evaluated using simulated data with a power-law PSD ~ 1/f^ β $\left\{ \begin{array}{l} \beta\text{\_radio} = 2.0, \\ \beta\text{\_gamma} = 1.5 \end{array} \right.$

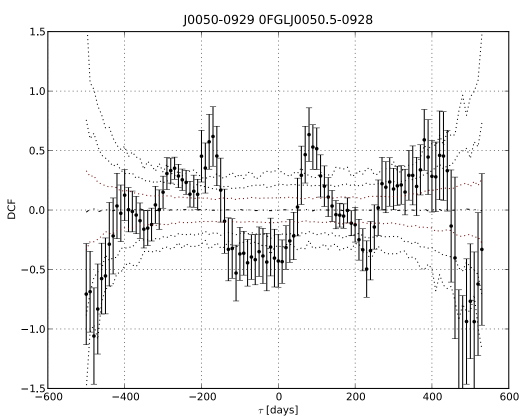




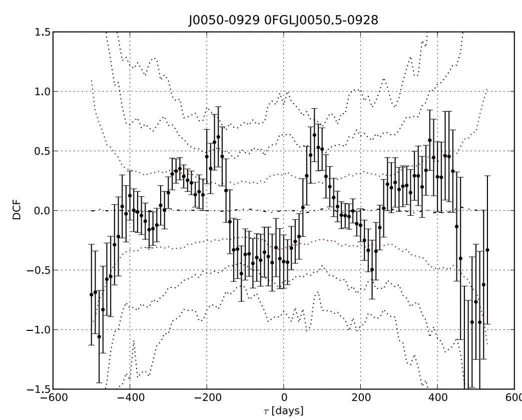
- Using these parameters only 4 out of 52 sources show significant correlations!

Statistical tests for the cross-correlations: Model dependence of the significance

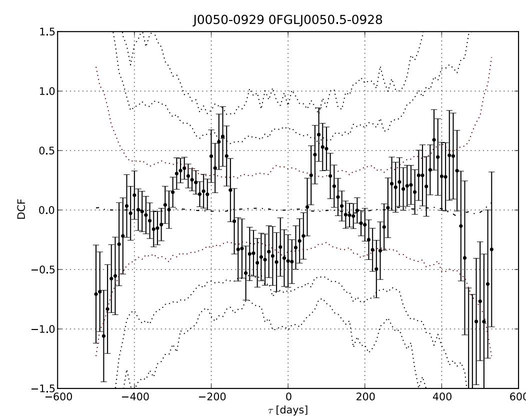
- The significance of the cross-correlation depends on the model used for the light curves
- PSD commonly assumed to be simple power law



$\beta_{radio} = 0.0$ and $\beta_{\gamma} = 0.0$



$\beta_{radio} = 2.0$ and $\beta_{\gamma} = 1.5$



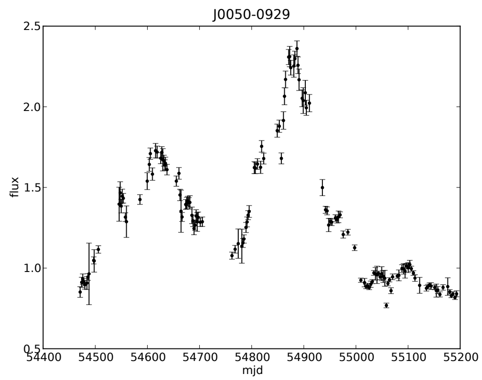
$\beta_{radio} = 2.0$ and $\beta_{\gamma} = 2.0$

Statistical tests for the cross-correlations: Measuring the power spectral density

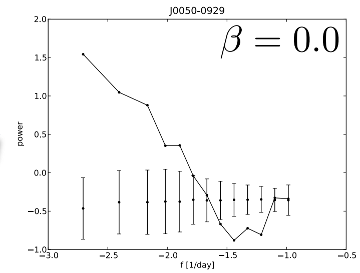
- We need some method to determine the appropriate value
- Uneven sampling complicates model fitting
  - We use the method of Uttley et al 2002, MNRAS 332, 231 with some modifications
  - Basic idea is to simulate data with a given PSD and process it as the data. Mean PSD and deviations are used for model fitting

Measuring the power spectral density

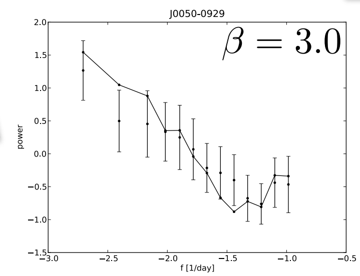
Example radio light curves



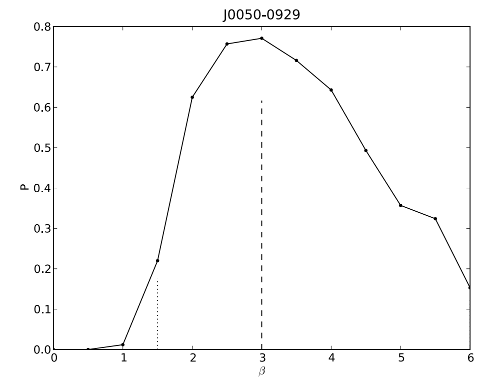
Bad fit



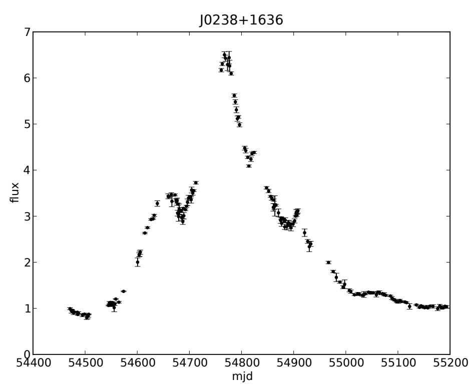
Good fit



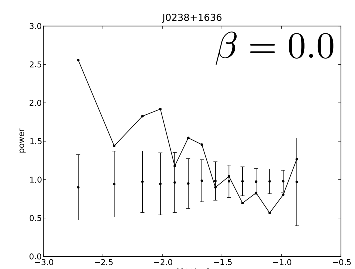
PSD fits



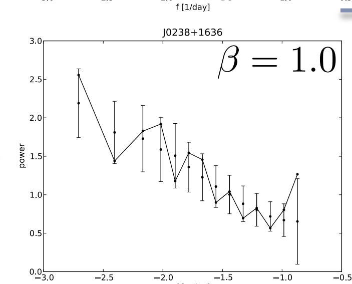
Well constrained for a large fraction of sources

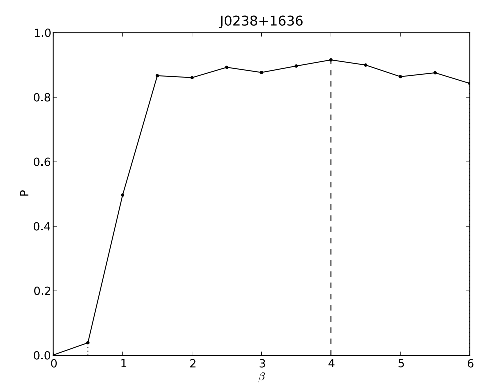


Bad fit



Good fit

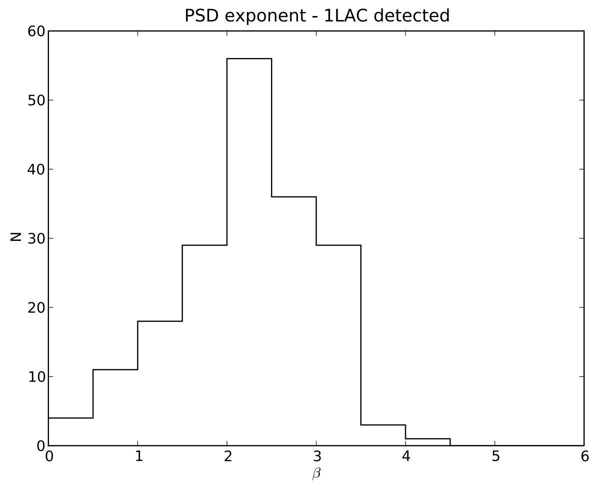


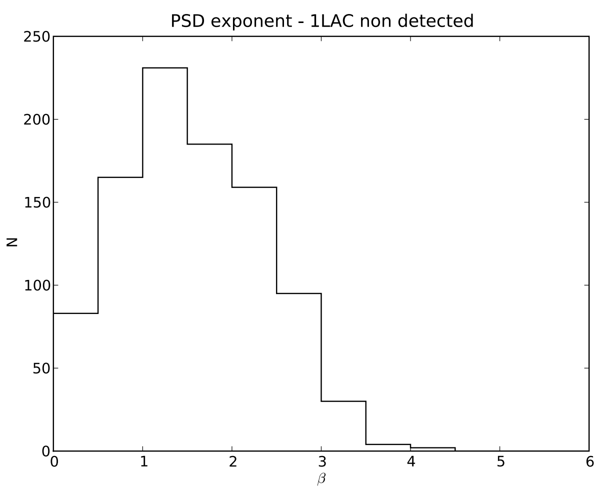


Some are hard to constrain -> we need longer time series

Power spectral densities
First results

Detected vs non-detected

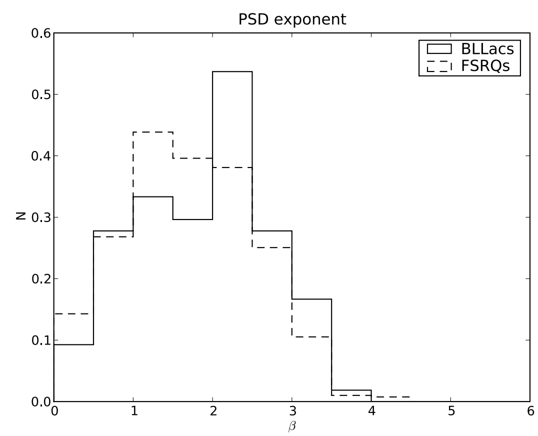




- Gamma-ray detected sources have steeper power spectral densities

- No clear difference for the case of BL Lacs vs FSRQs

BL Lacs vs FSRQs



Summary

- Using high cadence radio and gamma-ray light curves we study the connection between radio and gamma-ray emission in Fermi detected blazars
- A method to estimate the significance is implemented
  - Using typical parameters we find that 4 out of 52 sources have 3σ correlations
- The significance depends on the model for the light curves => a method to characterize them is implemented
  - Gamma-ray detected sources have steeper PSDs
  - Final significance will be computed using these results after separating statistical versus per source variability

Stay tuned!