



Fermi  
Gamma-ray Space Telescope

## *The Fermi LAT view of blazar variability*

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for the Fermi-LAT collaboration

*Shining from the heart of darkness black hole accretion and jets  
Kathmandu, Nepal 16 - 21 October 2016*



*Blazars are AGN with a relativistic jet pointing towards our line of sight*

*Doppler boosting: Bright and rapidly variable*

Boston University  
Blazar Research Group



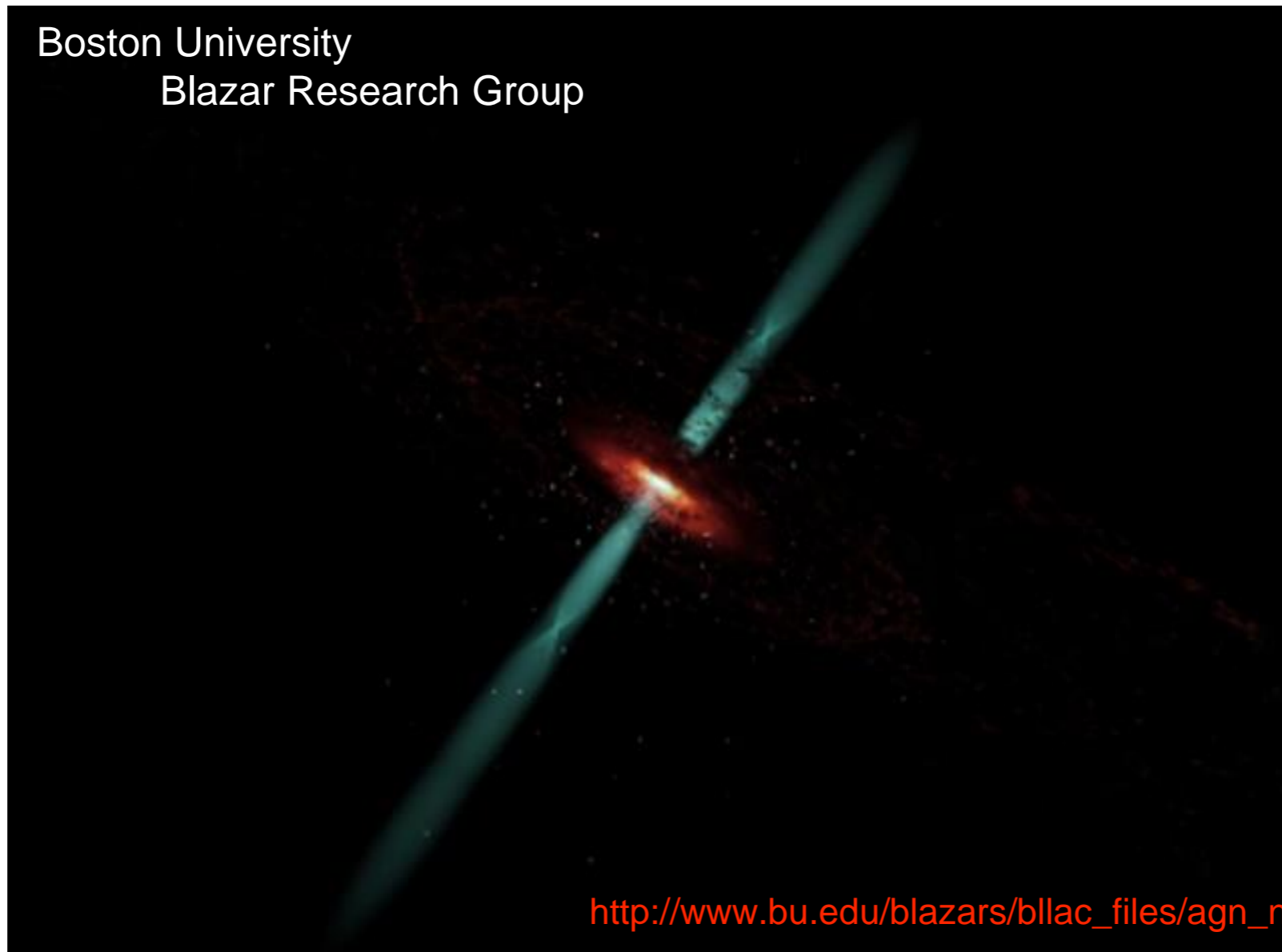
[http://www.bu.edu/blazars/bllac\\_files/agn\\_nature\\_cam3\\_360sqpix.mov](http://www.bu.edu/blazars/bllac_files/agn_nature_cam3_360sqpix.mov)



*Blazars are AGN with a relativistic jet pointing towards our line of sight*

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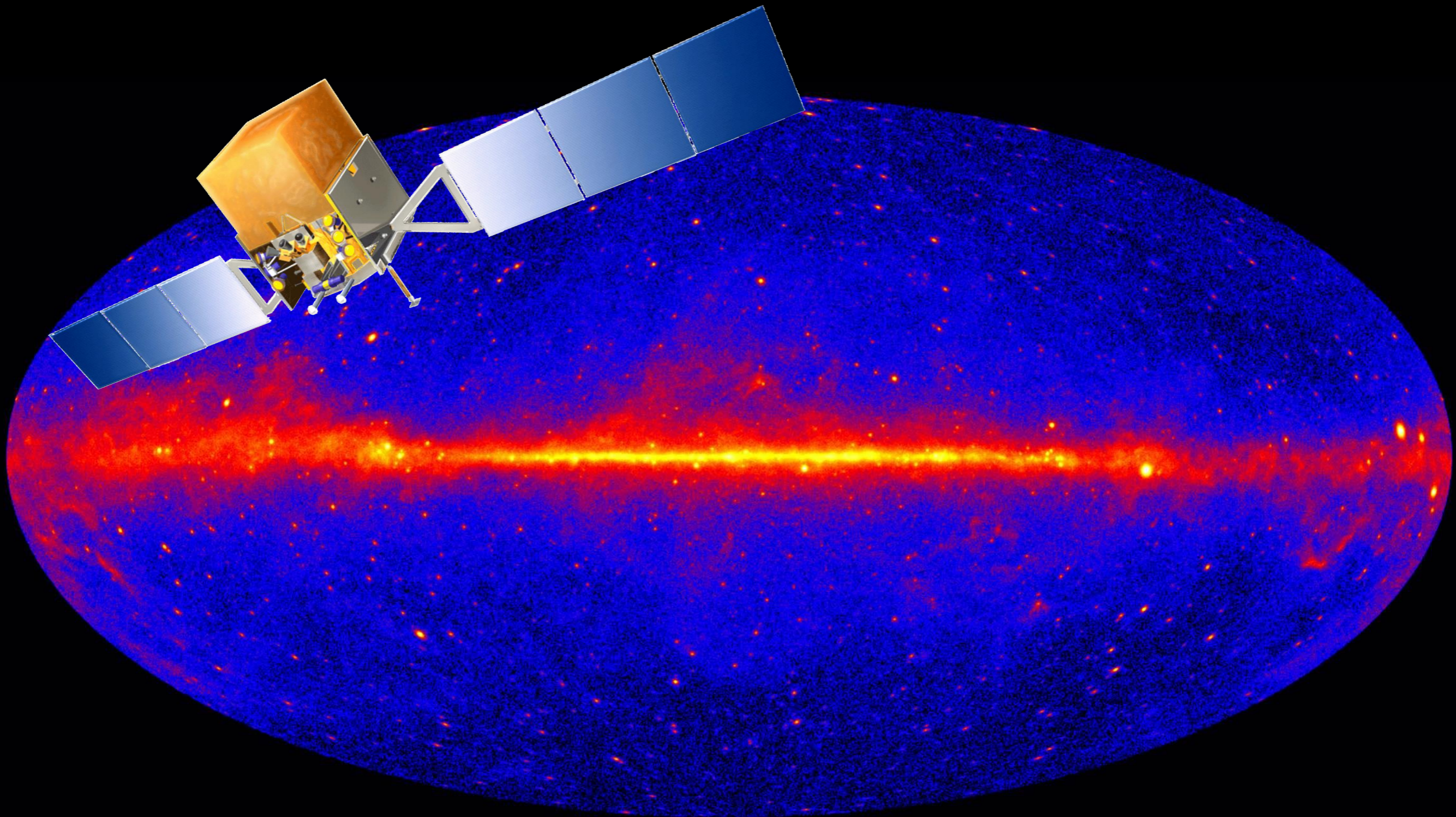
[http://www.bu.edu/blazars/bllac\\_files/agn\\_nature\\_cam3\\_360sqpix.mov](http://www.bu.edu/blazars/bllac_files/agn_nature_cam3_360sqpix.mov)



## *Variability*

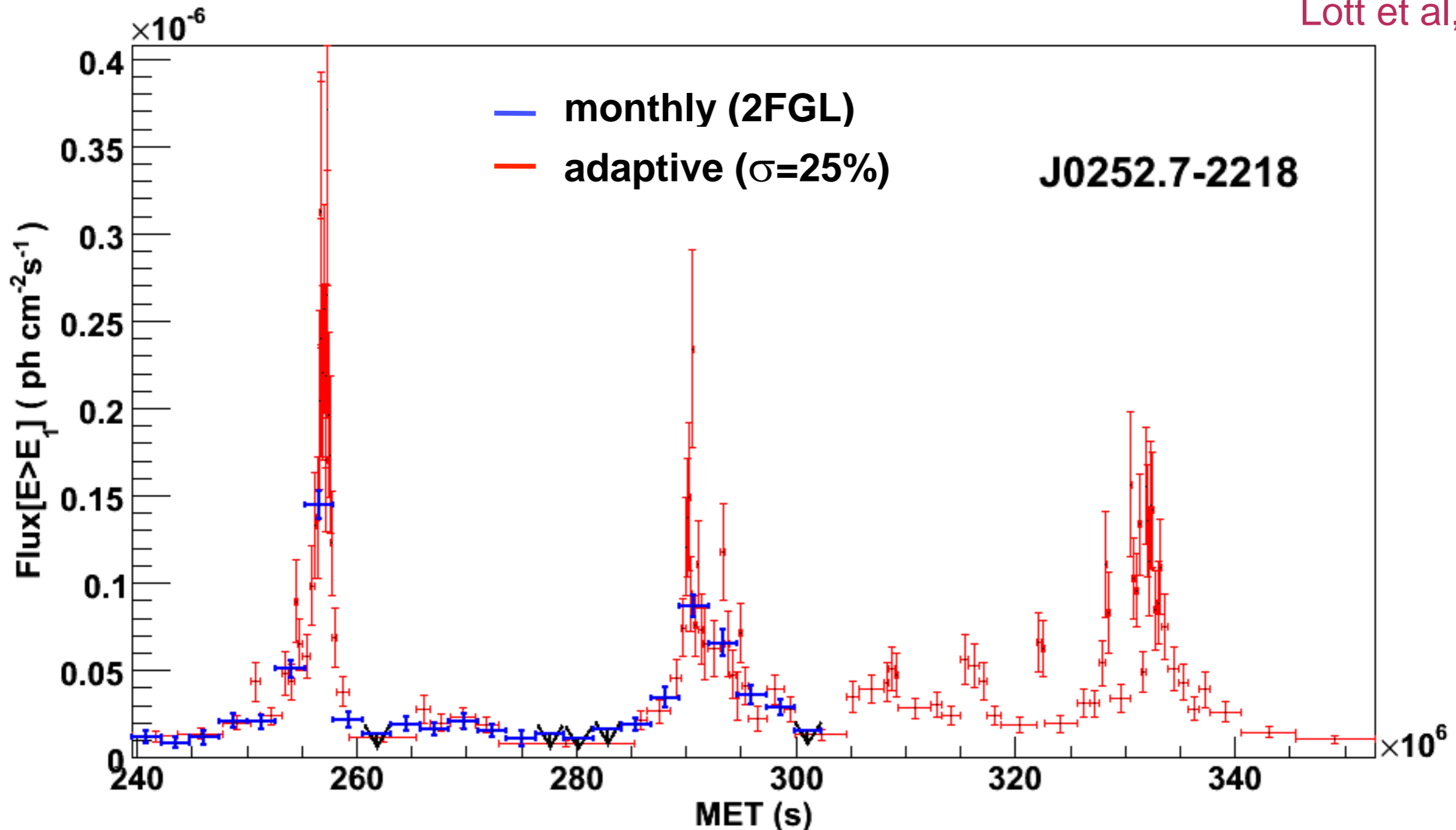
- ◆ How do we characterize blazar variability?  
Duty cycle, time asymmetry, power spectrum etc
- ◆ What characteristics do we see?  
Flares, rms, time scales, (quasi) periods, correlations, time delayed components?
- ◆ How do we interpret these characteristics?  
Stochastic process, brightness states, physical mechanism, localisation...

# Fermi-LAT 5 year sky map ( $>1$ GeV)



**Principle:** adapt the bin widths of a light curve according to a user-defined condition, constant relative uncertainty on flux or constant significance in each bin

Lott et al, 2012

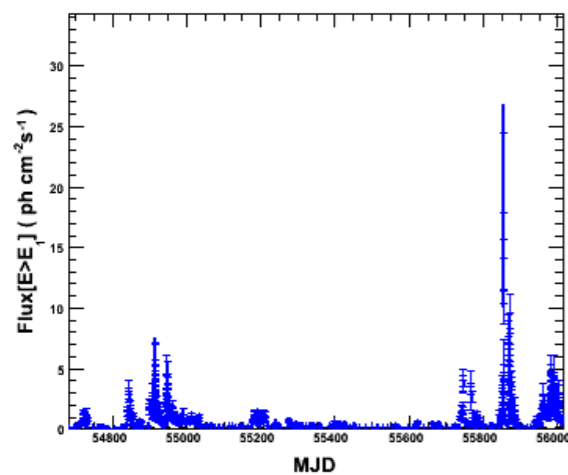


# Flux and spectral variation



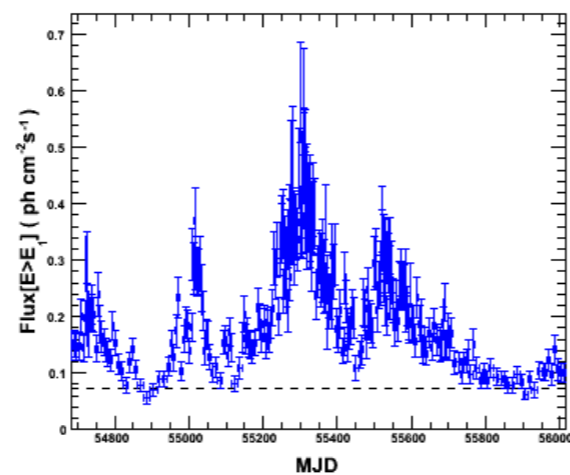
FSRQ

PKS 1510-089



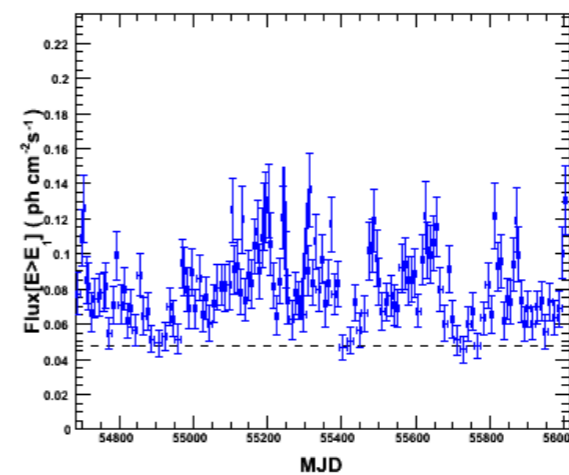
LSP BL Lac

PKS 0537-441



HSP BL Lac

Mrk 421



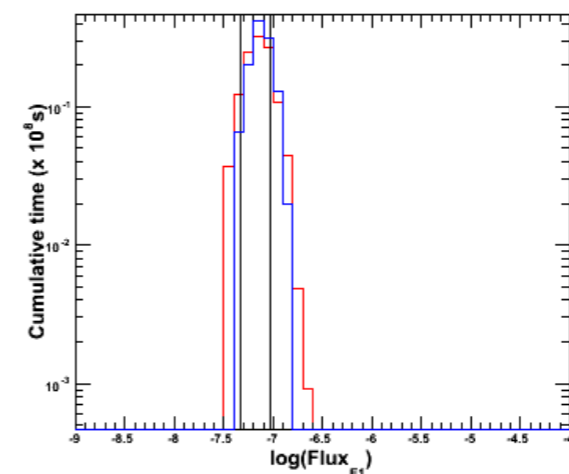
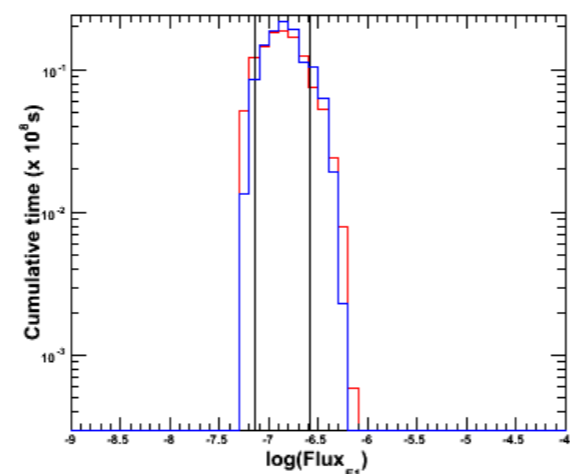
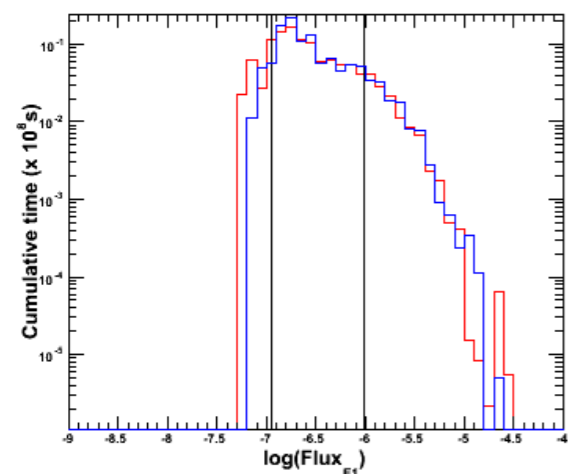
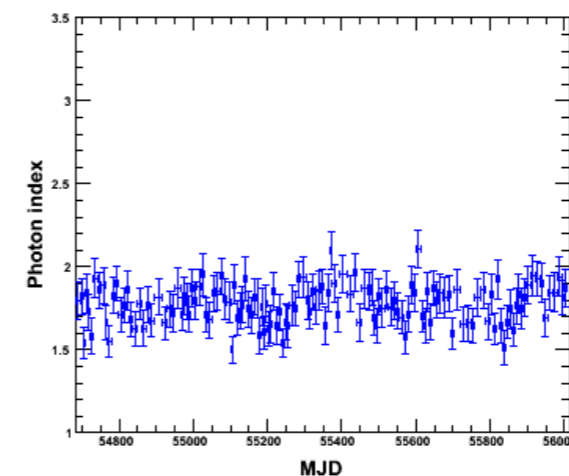
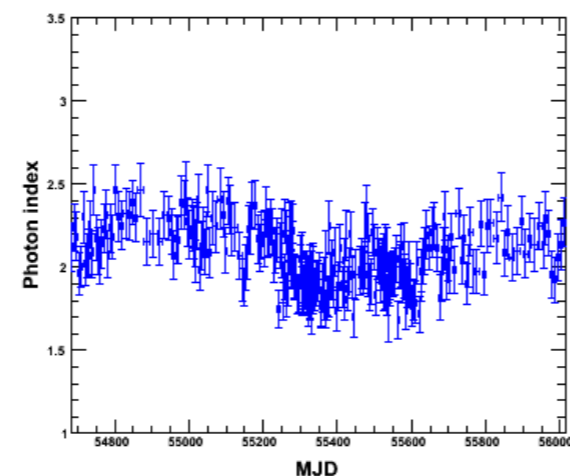
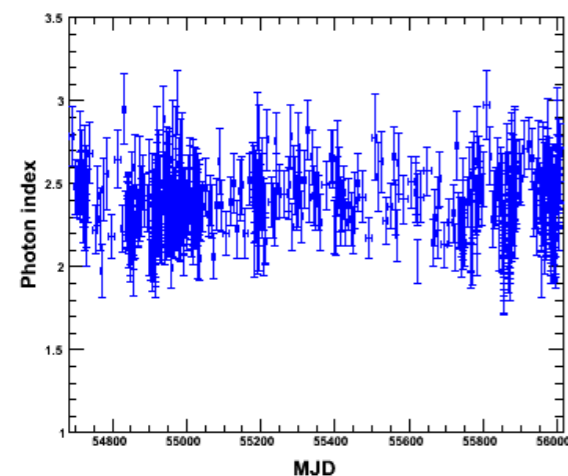
Flux

Photon  
index

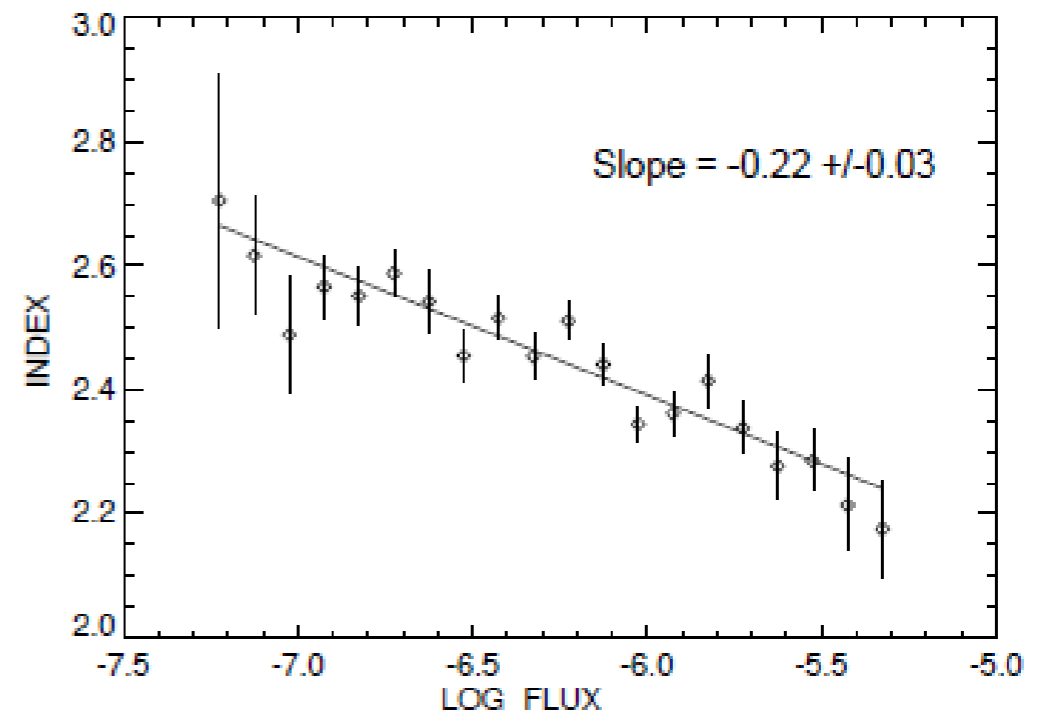
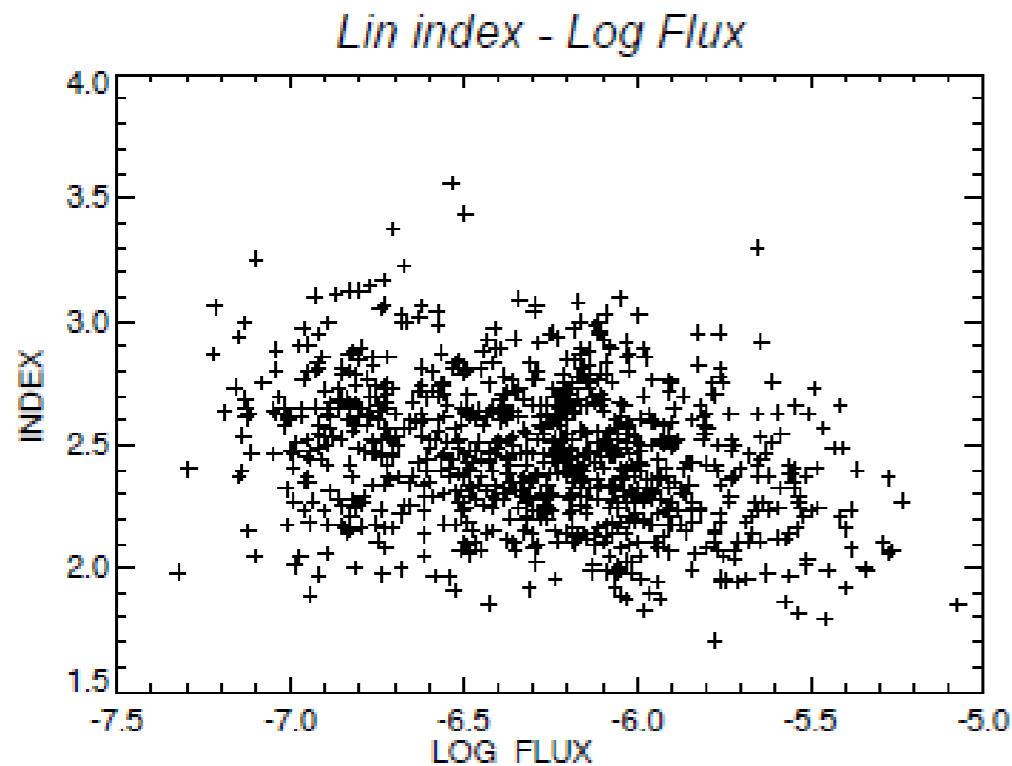
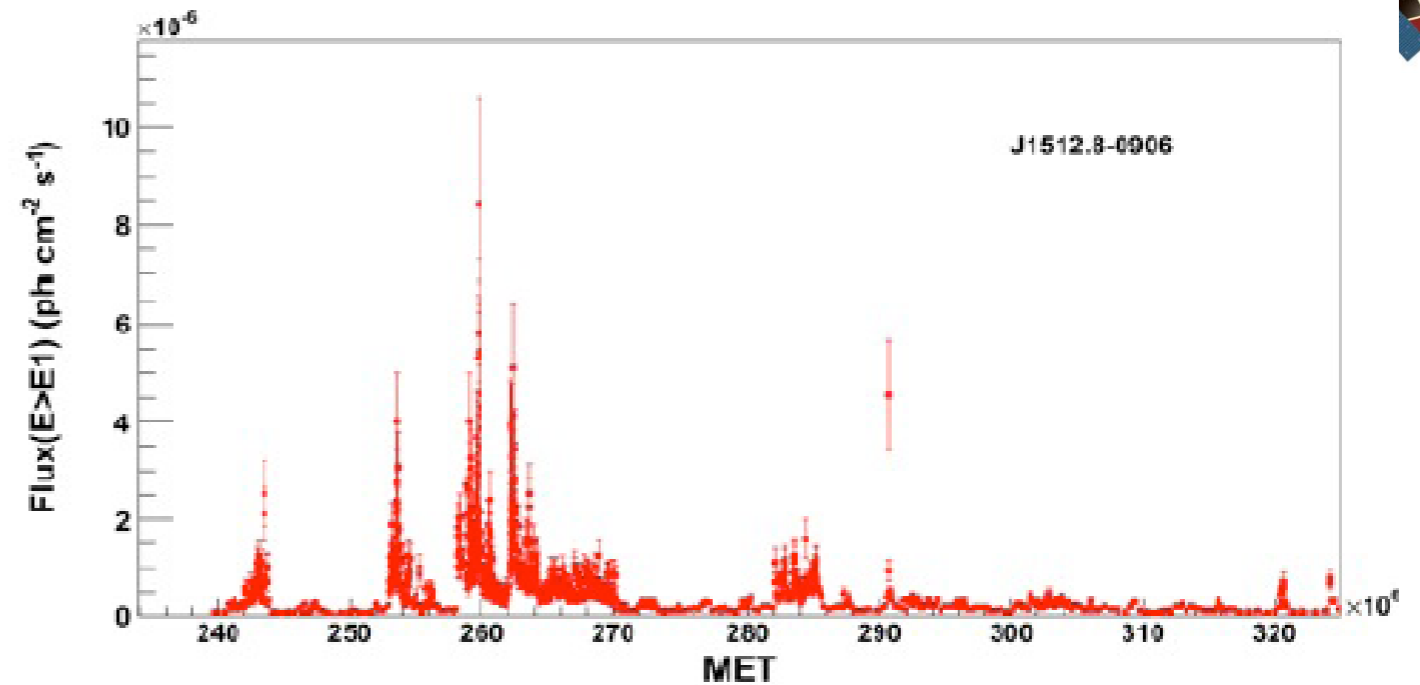
Flux  
distribution

Preliminary

Soft  
↕  
Hard



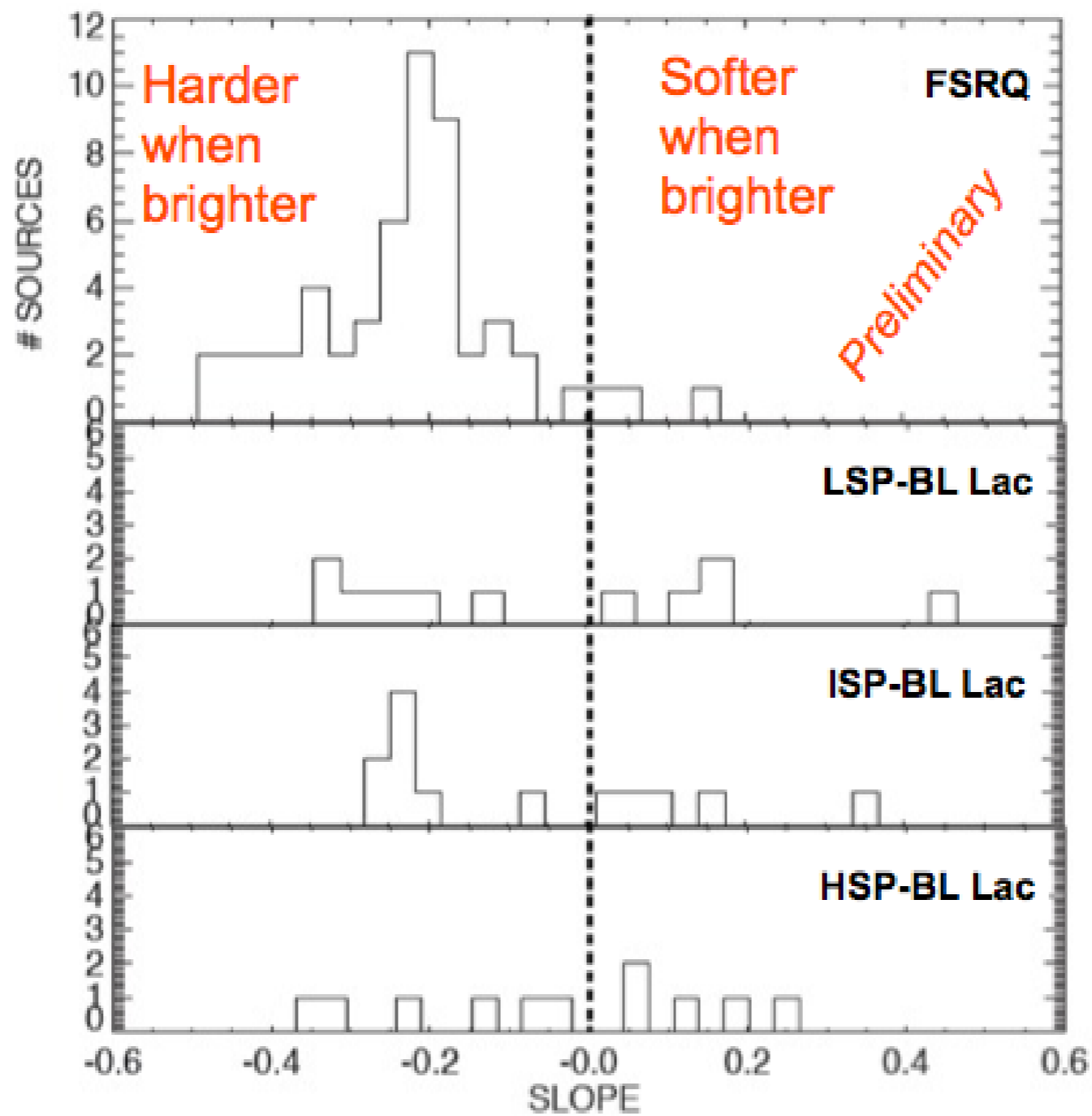
«moderate» spectral variability reported for several individual sources



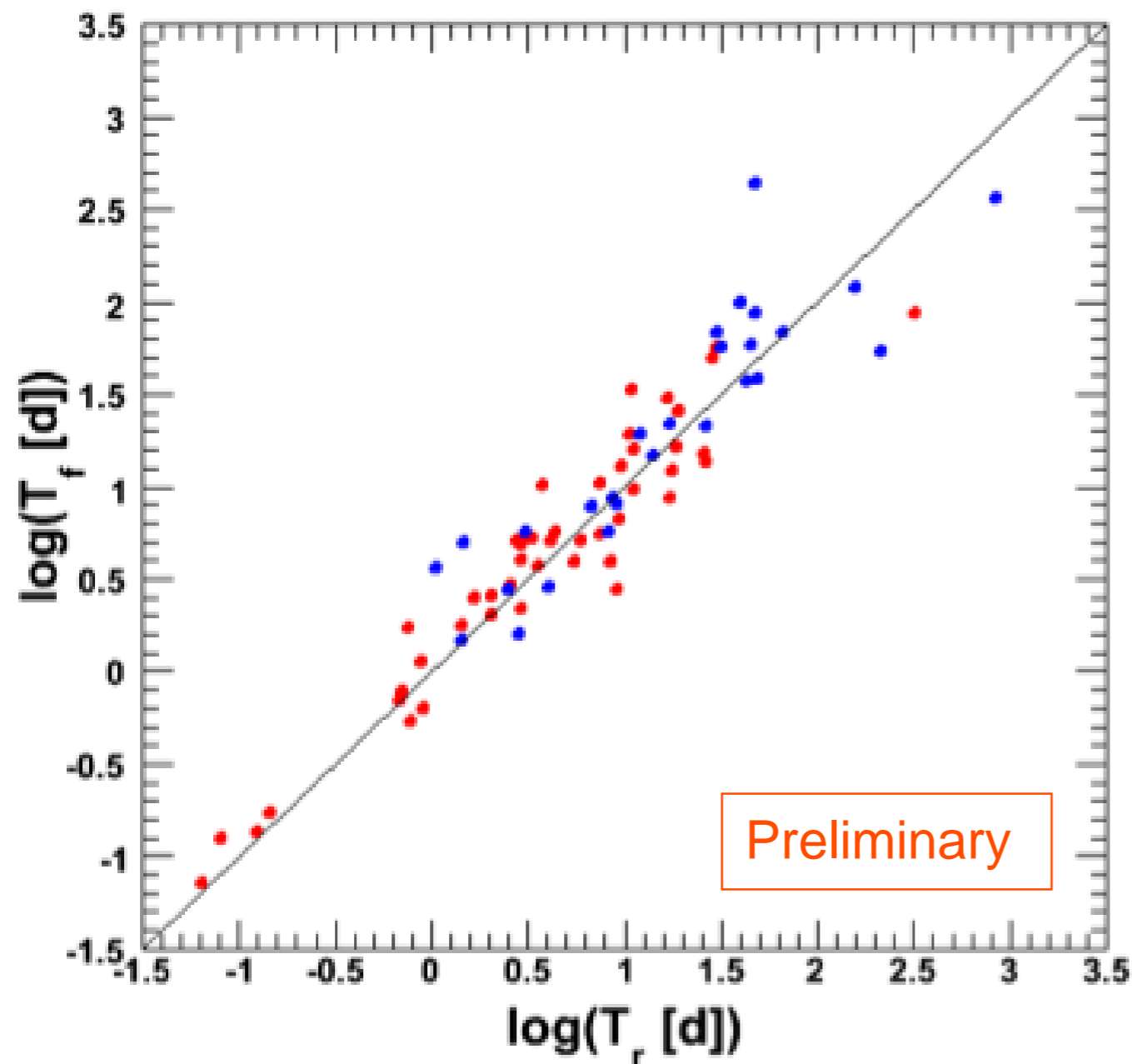
LOG FLUX(ph cm<sup>-2</sup> s<sup>-1</sup>)

Preliminary

# Spectral index vs flux



$R_S/c = 10^4 \text{ s} \sim 0.1 \text{ d}$  for a  $10^9$  solar mass BH



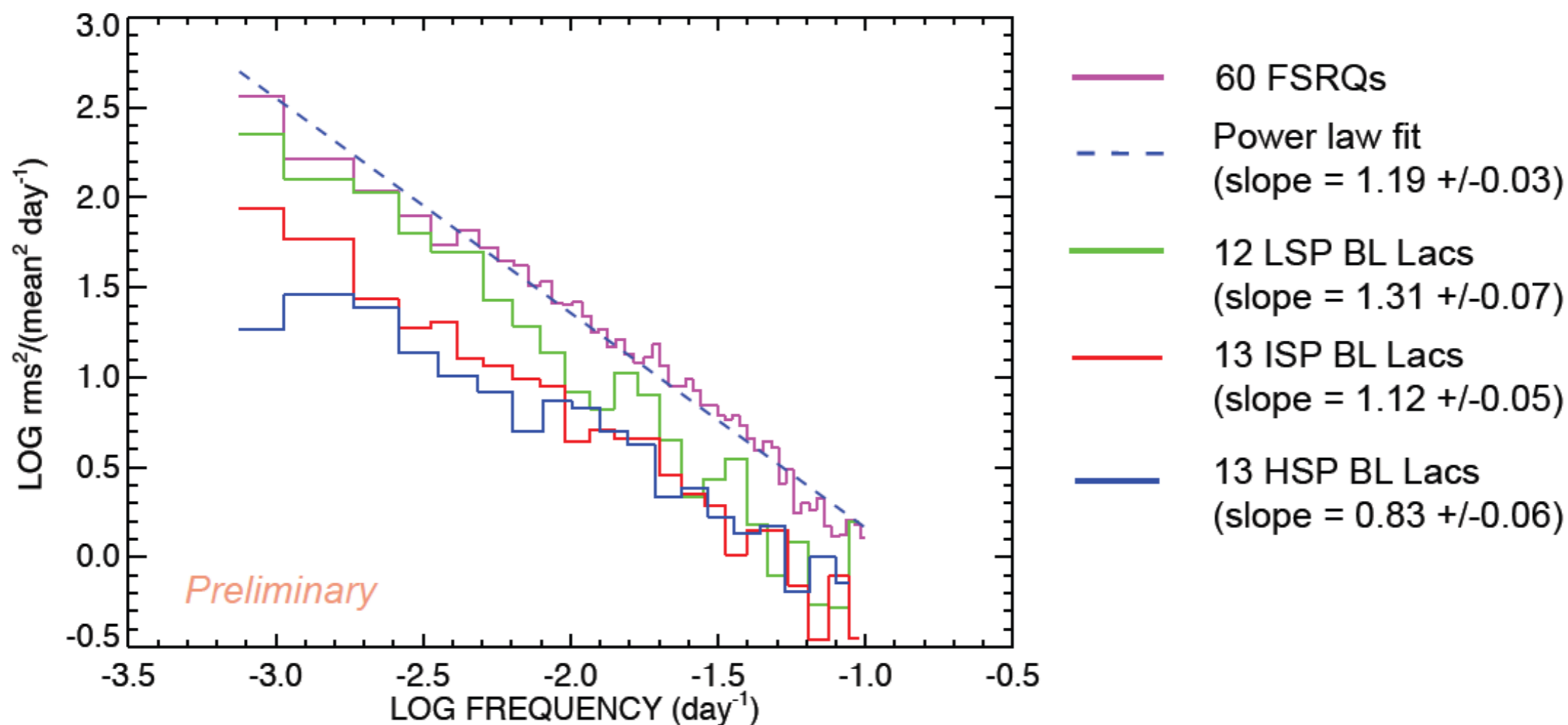
$$R = c T_{\text{var}} \delta / (1+z)$$

Mean ratio  $T_r/T_f = 0.93 \pm 0.37$  for FSRQs  
 $0.91 \pm 0.34$  for BL Lacs

Governed by light crossing time?

$T_r$  = Rise time  
 $T_f$  = Fall time

Averaged Power Density Spectra



No persistent breaks found in  
PDS of individual sources

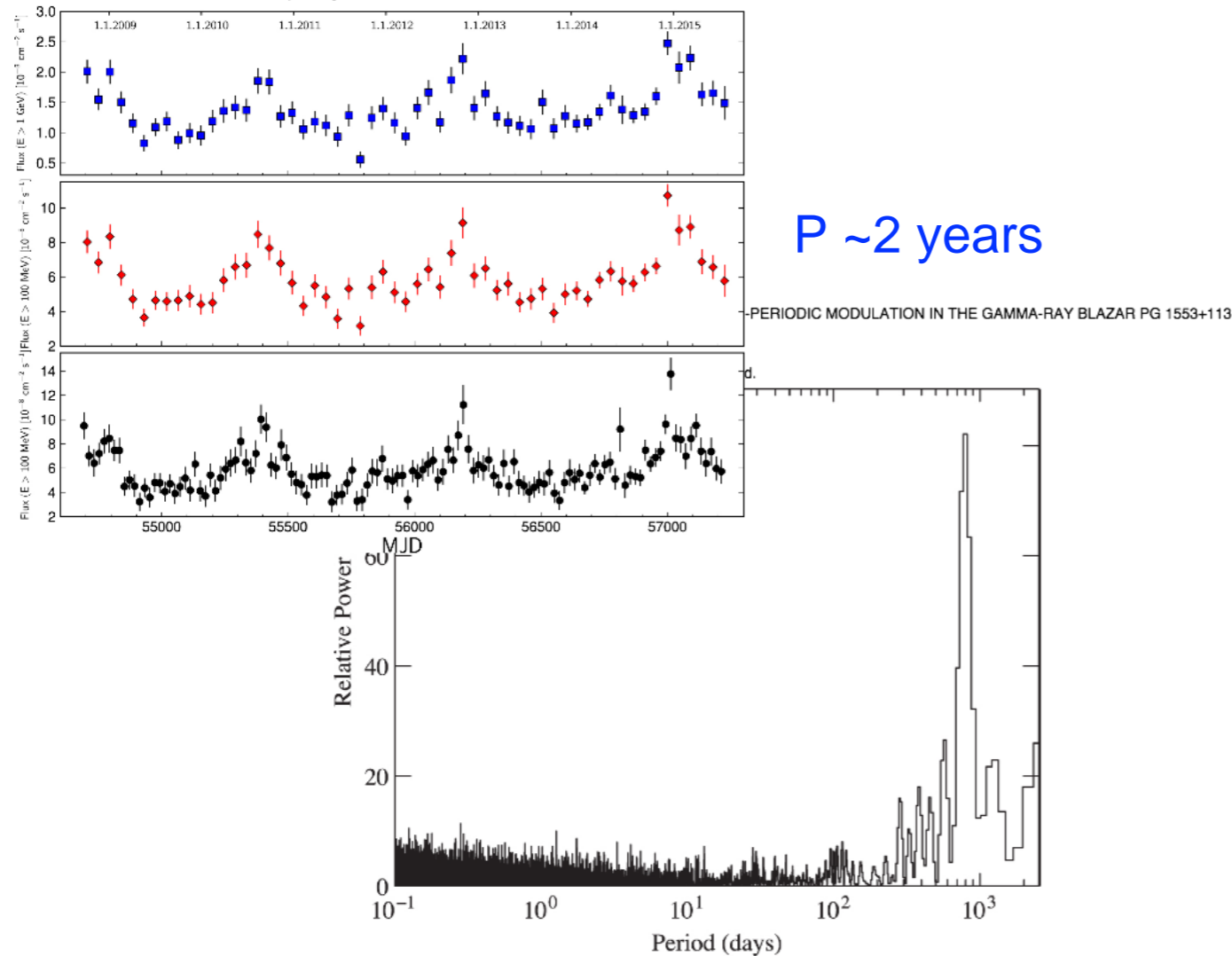
Power Density Spectra  
in radio, optical, X-ray typically  
power-laws with index 1 to 2

# (Quasi) periodicities? Time delays!



PG1553+113: A quasi-periodic flux modulation?  
Ackermann et al 2015 ApJL 813 L41

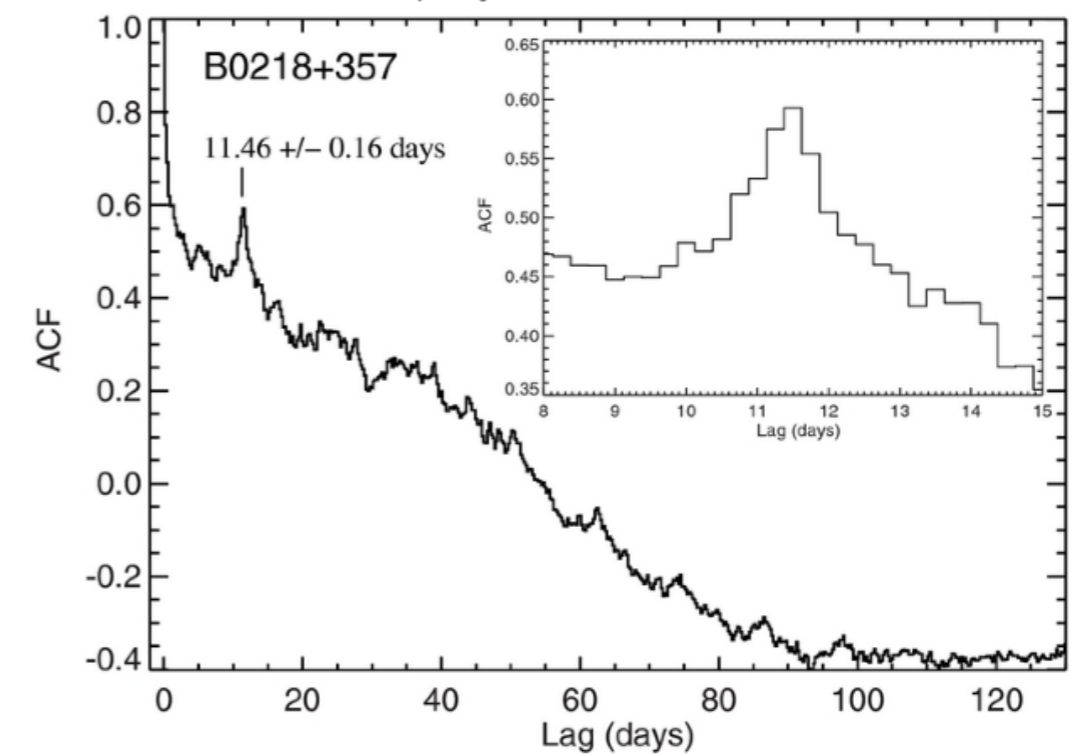
Figure 1. from MULTIWAVELENGTH EVIDENCE FOR QUASI-PERIODIC MODULATION IN THE GAMMA-RAY BLAZAR PG 1553+113  
null 2015 APJL 813 L41 doi:10.1088/2041-8205/813/2/L41  
<http://dx.doi.org/10.1088/2041-8205/813/2/L41>  
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B0218+357: A gravitationally lensed blazar

Cheung et al 2014 ApJL 782 L14

Figure 3. from  
Fermi Large Area Telescope Detection of Gravitational Lens Delayed -Ray Flares from Blazar B0218+357  
Cheung et al. 2014 ApJL 782 L14 doi:10.1088/2041-8205/782/2/L14  
<http://dx.doi.org/10.1088/2041-8205/782/2/L14>  
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# The RMS-Flux relation at gamma-ray energies



Full sample: 127 high significance AGN (3FGL)

This analysis: 16 FSRQs, 6 year light curves (6 day binning)  
for 2 (3C 279 and PKS 1510-089) also  
7 year, 1 day binned light curves.

Method: Compute RMS directly from light curve  
using 20 or 72 day segments  
(sampling time scales: 2-20 days and 12-  
72 days respectively)

Analysis: RMS vs Flux (and RMS/Flux vs Flux)

Questions: Is the RMS-Flux relation linear?

Is it the same over time?

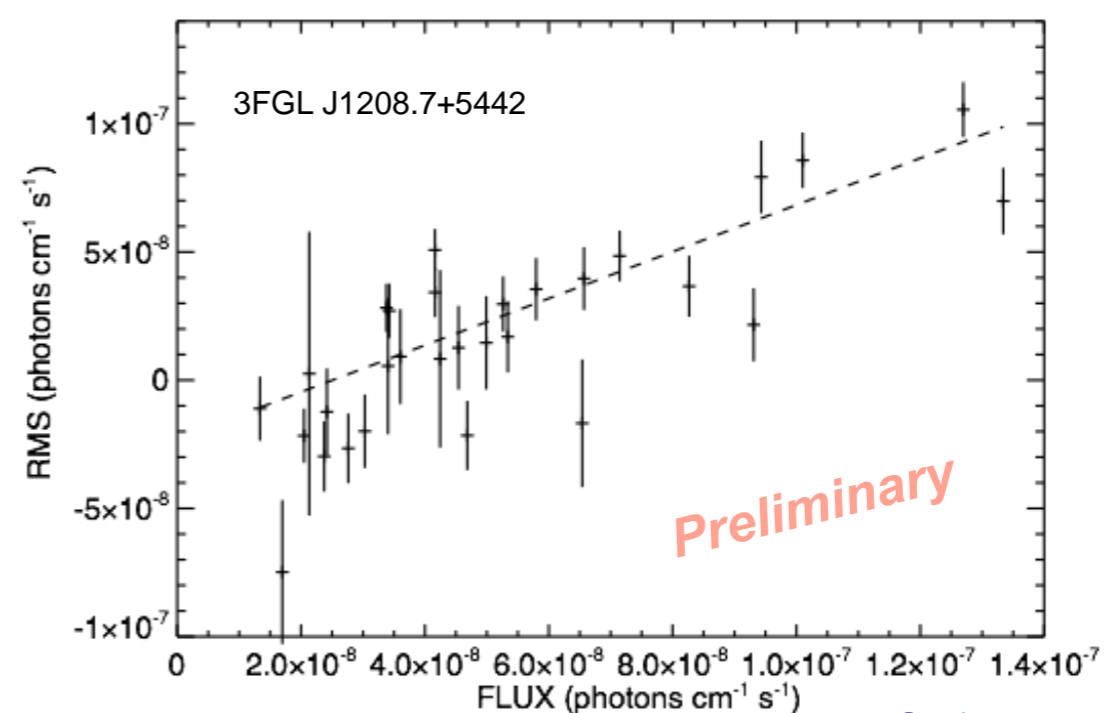
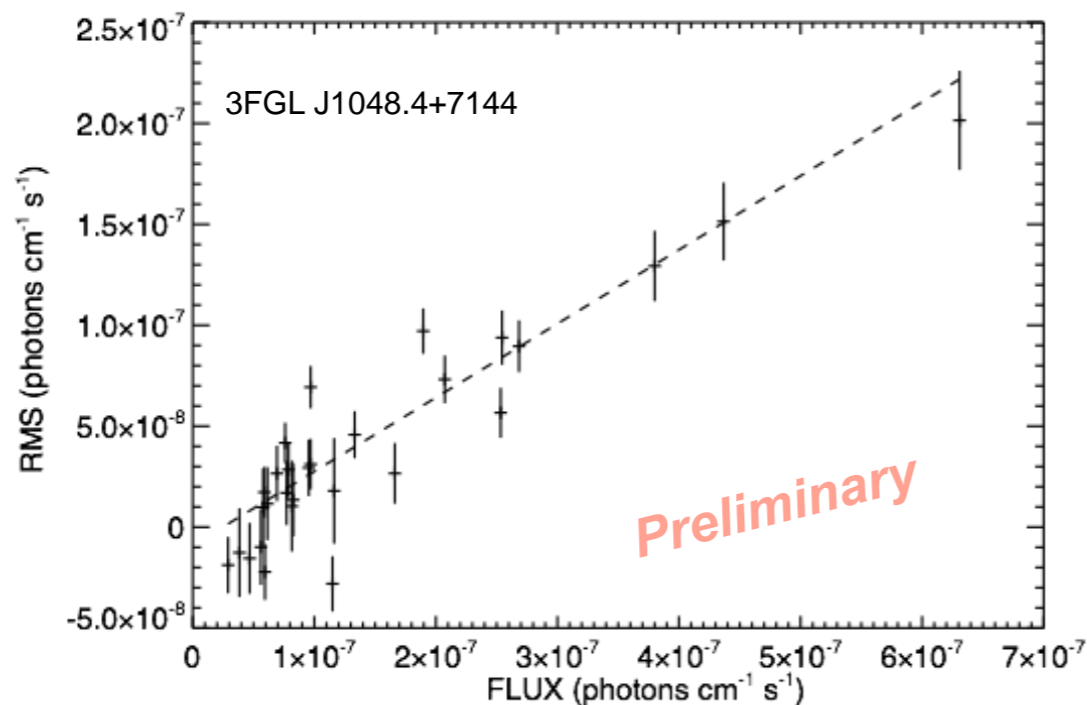
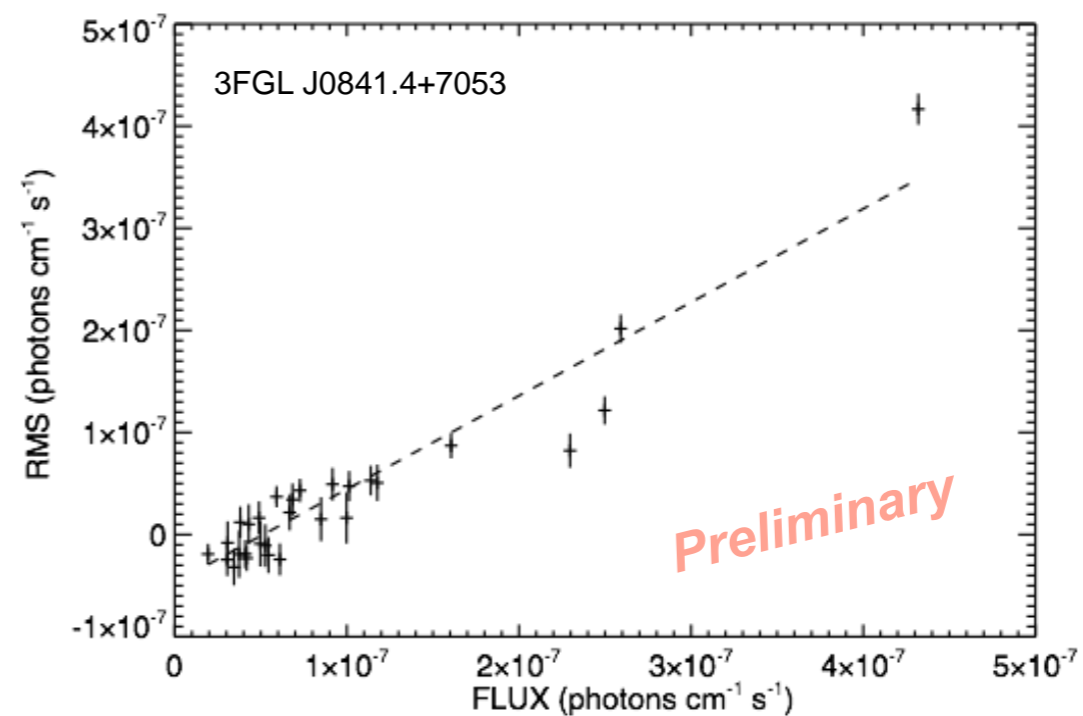
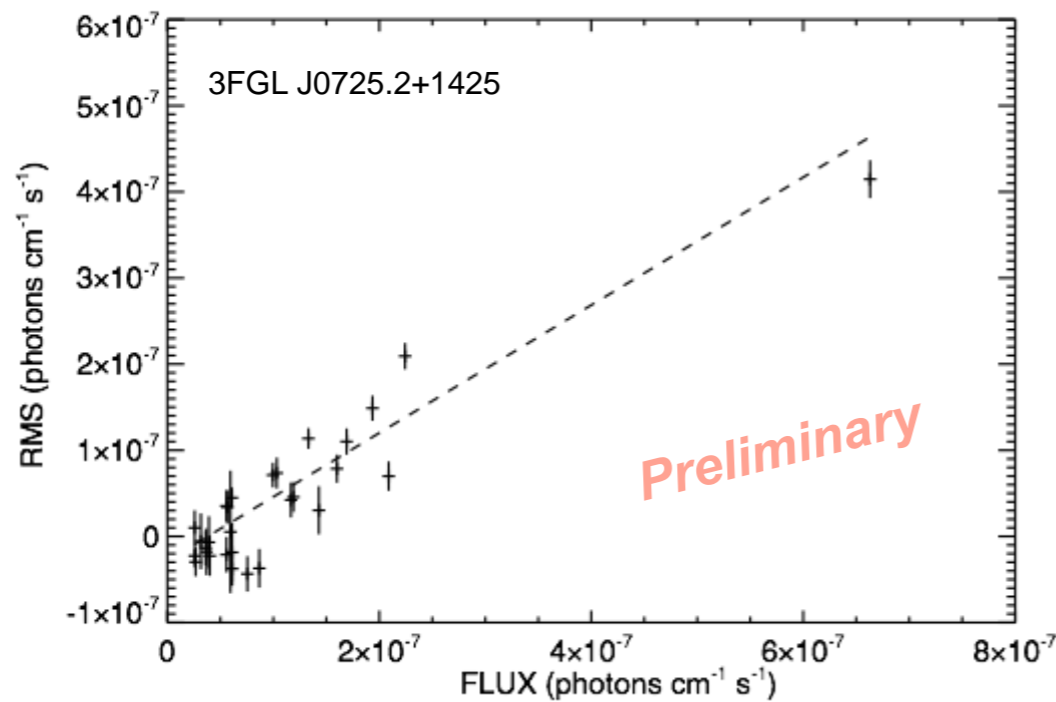
Implications for variability models?

# The RMS-Flux relation at gamma-ray energies

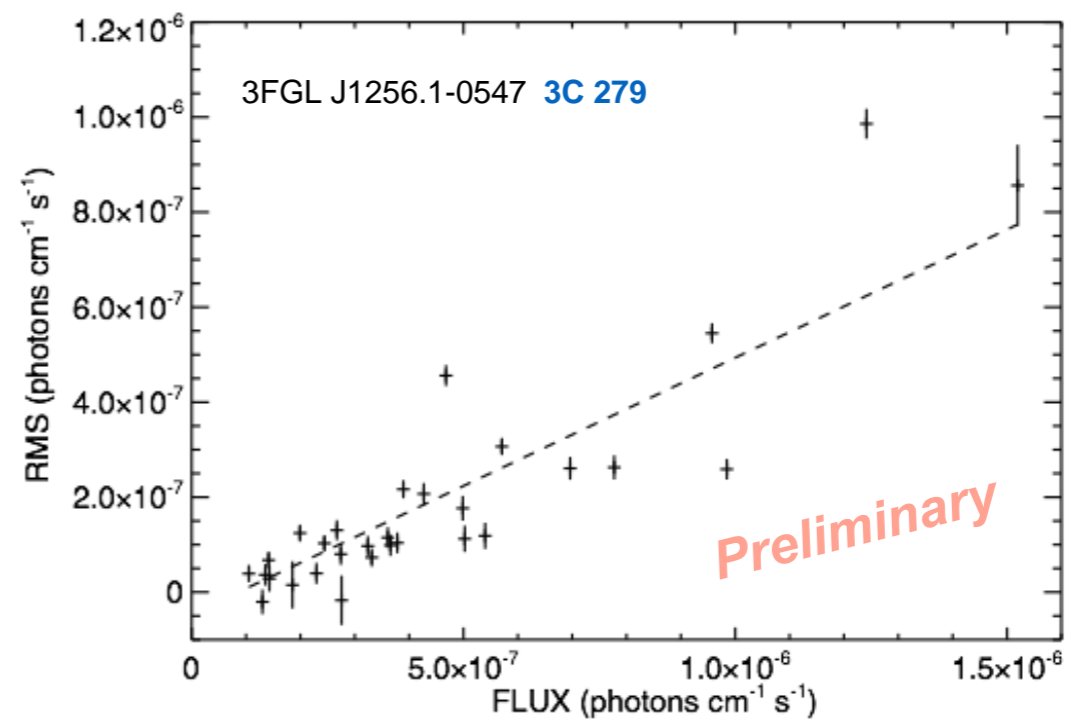
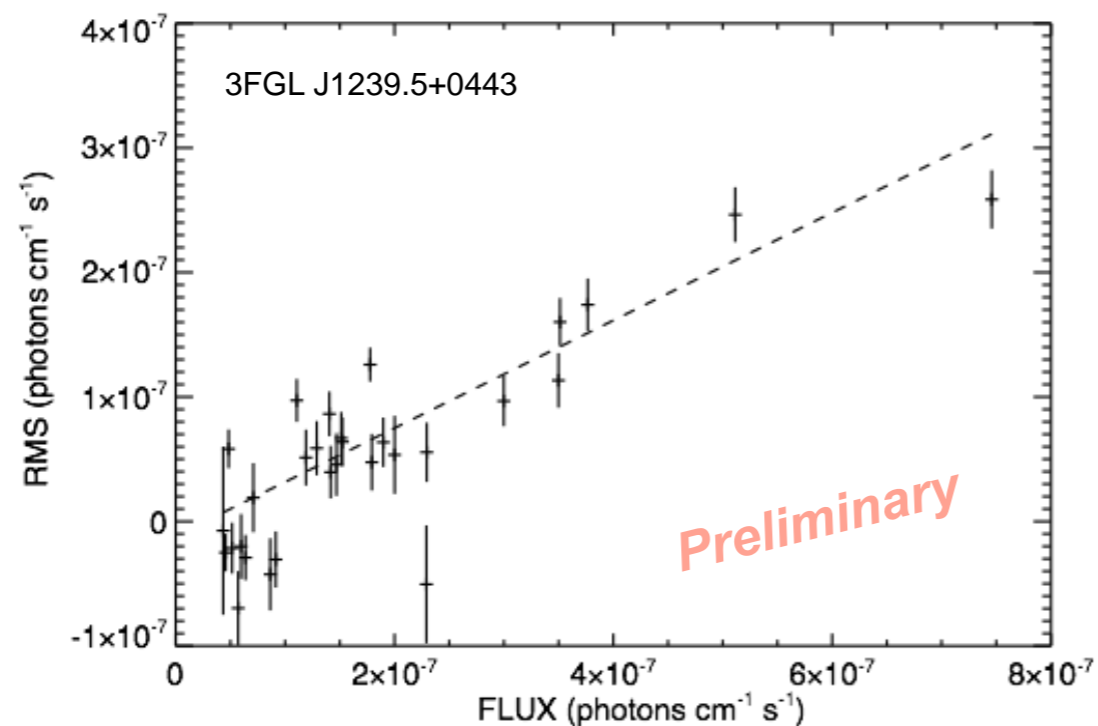
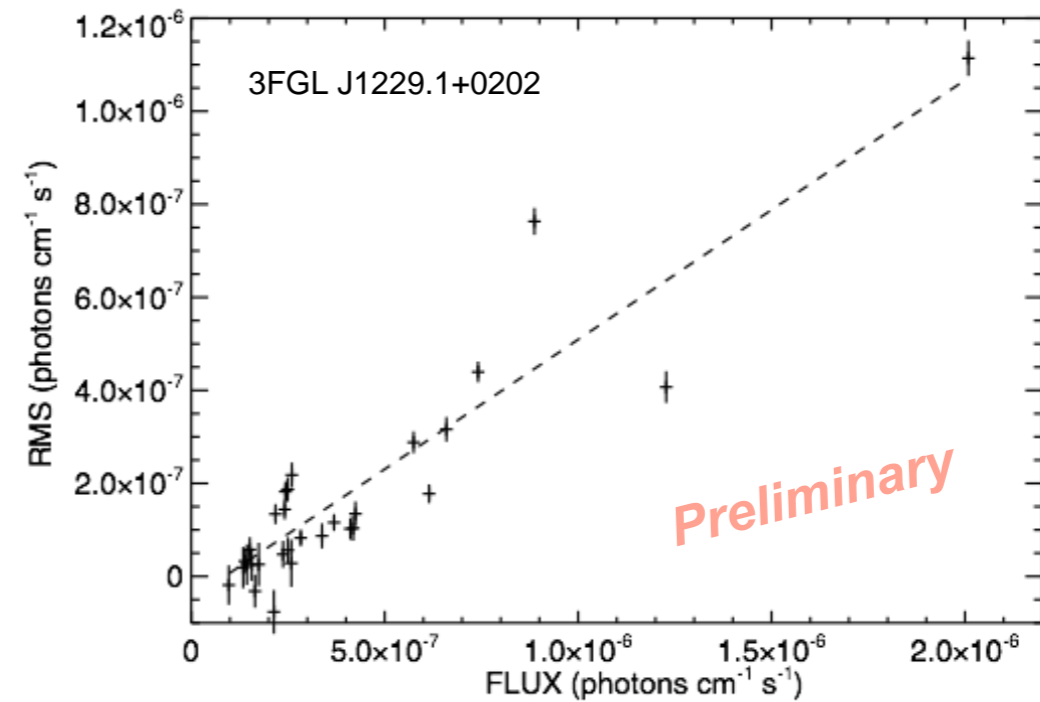
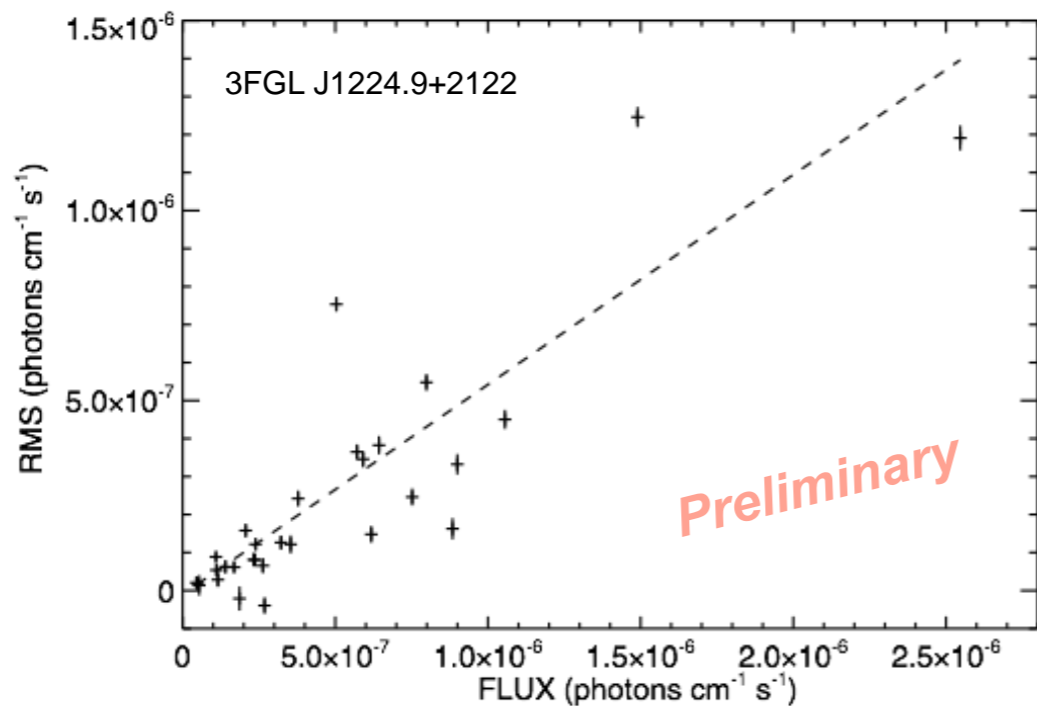


RMS-Flux for 6 year LAT light curves (with 6-day binning)

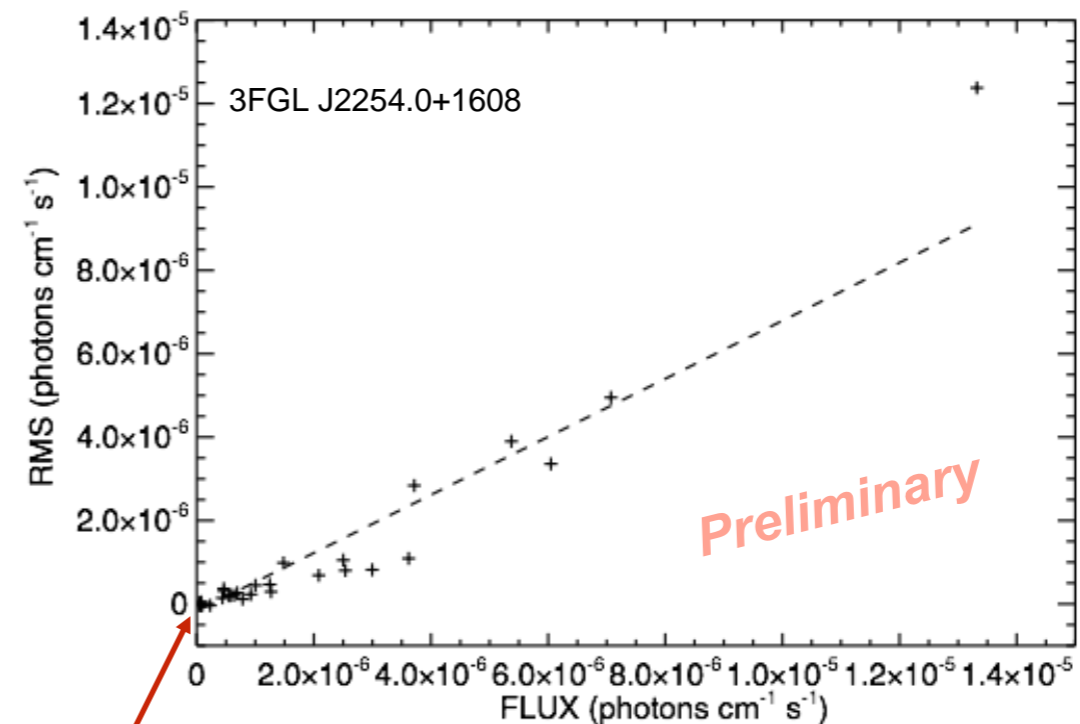
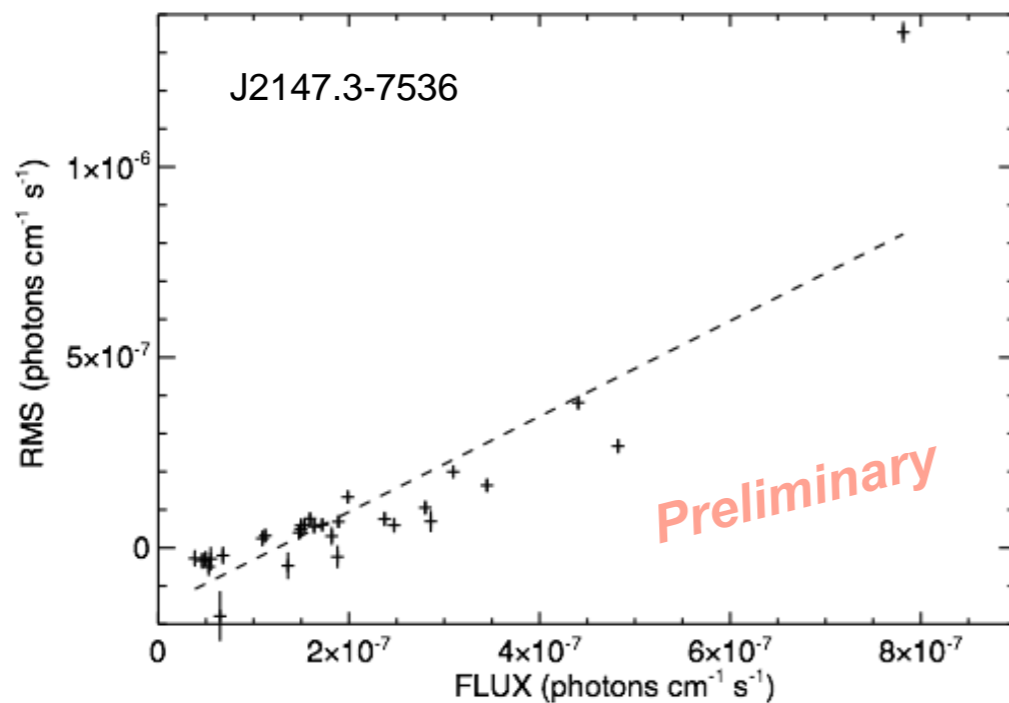
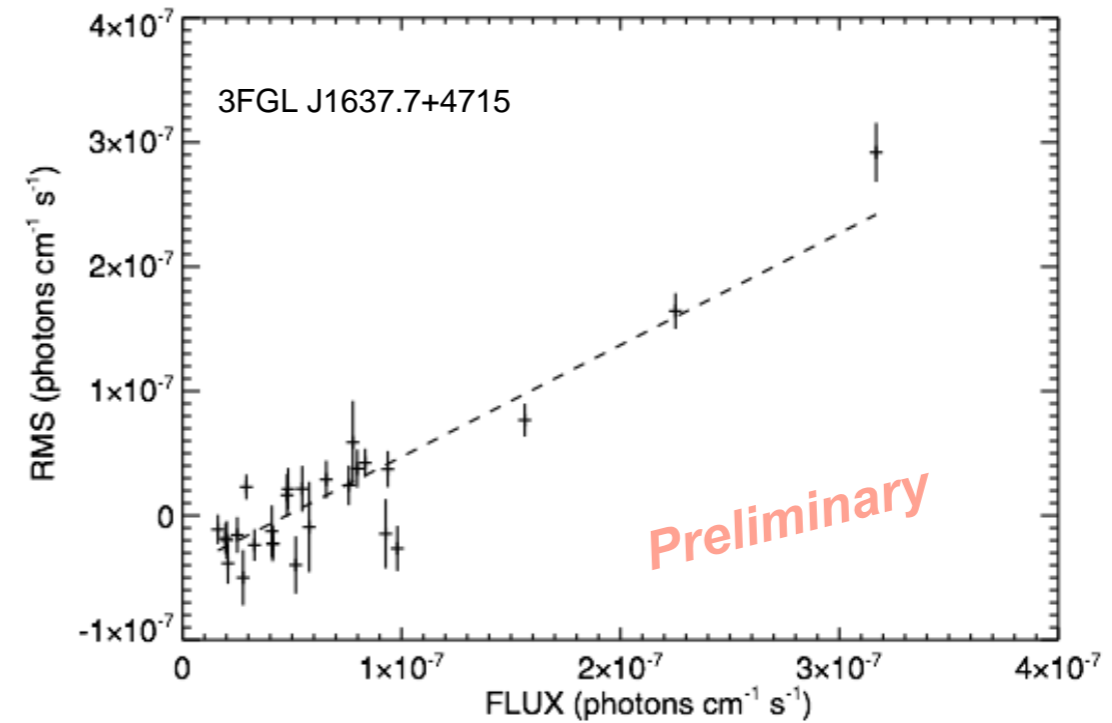
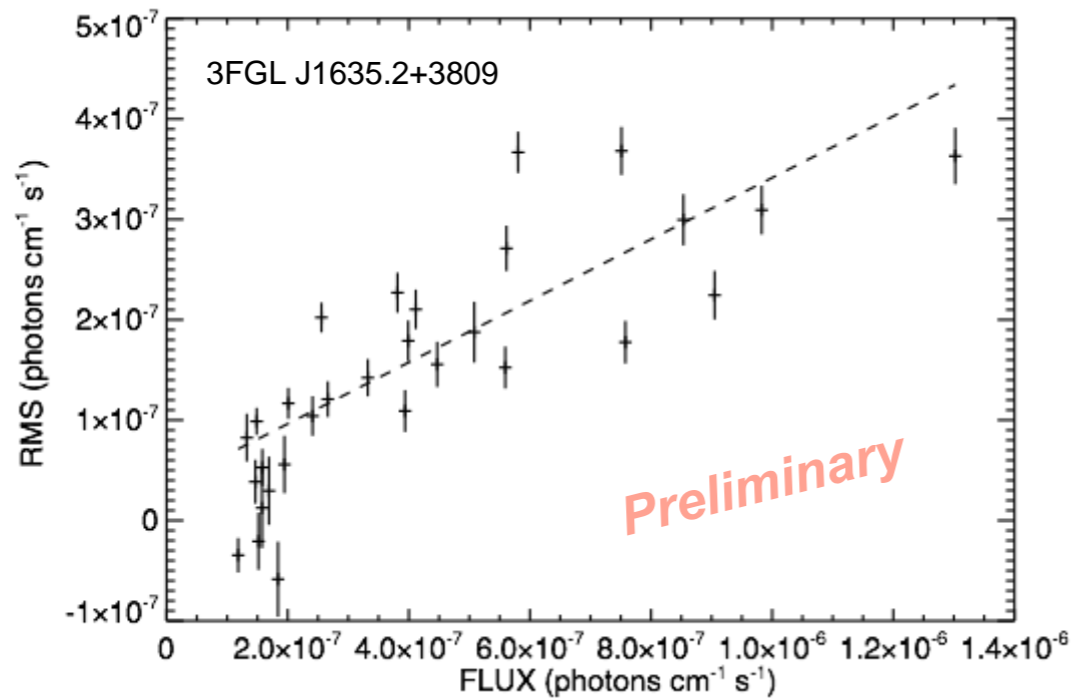
Points are for individual segments (error bars include measurement noise but not red noise)



# The RMS-Flux relation at gamma-ray energies



# The RMS-Flux relation at gamma-ray energies

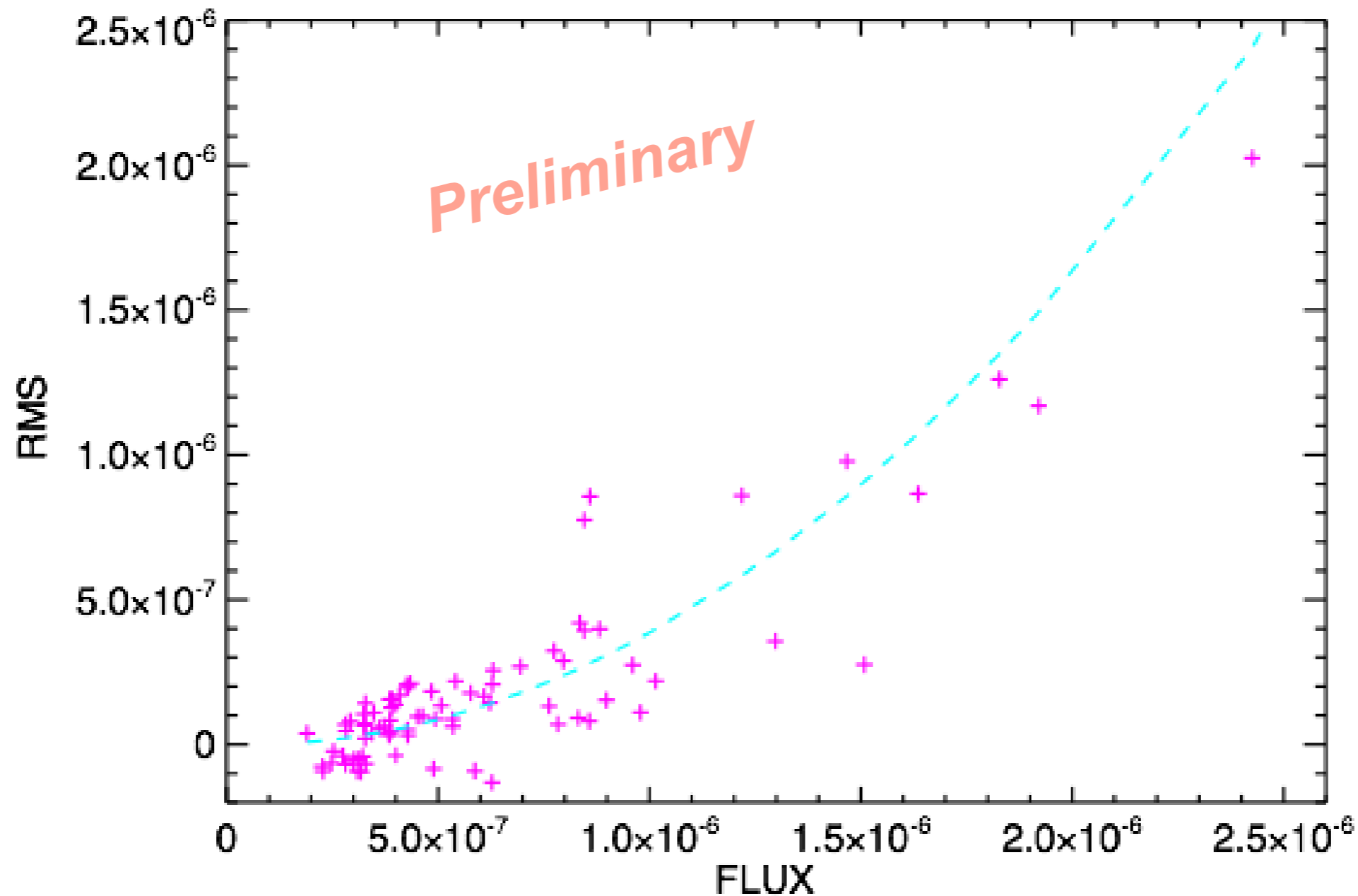


# The RMS-Flux relation at gamma-ray energies

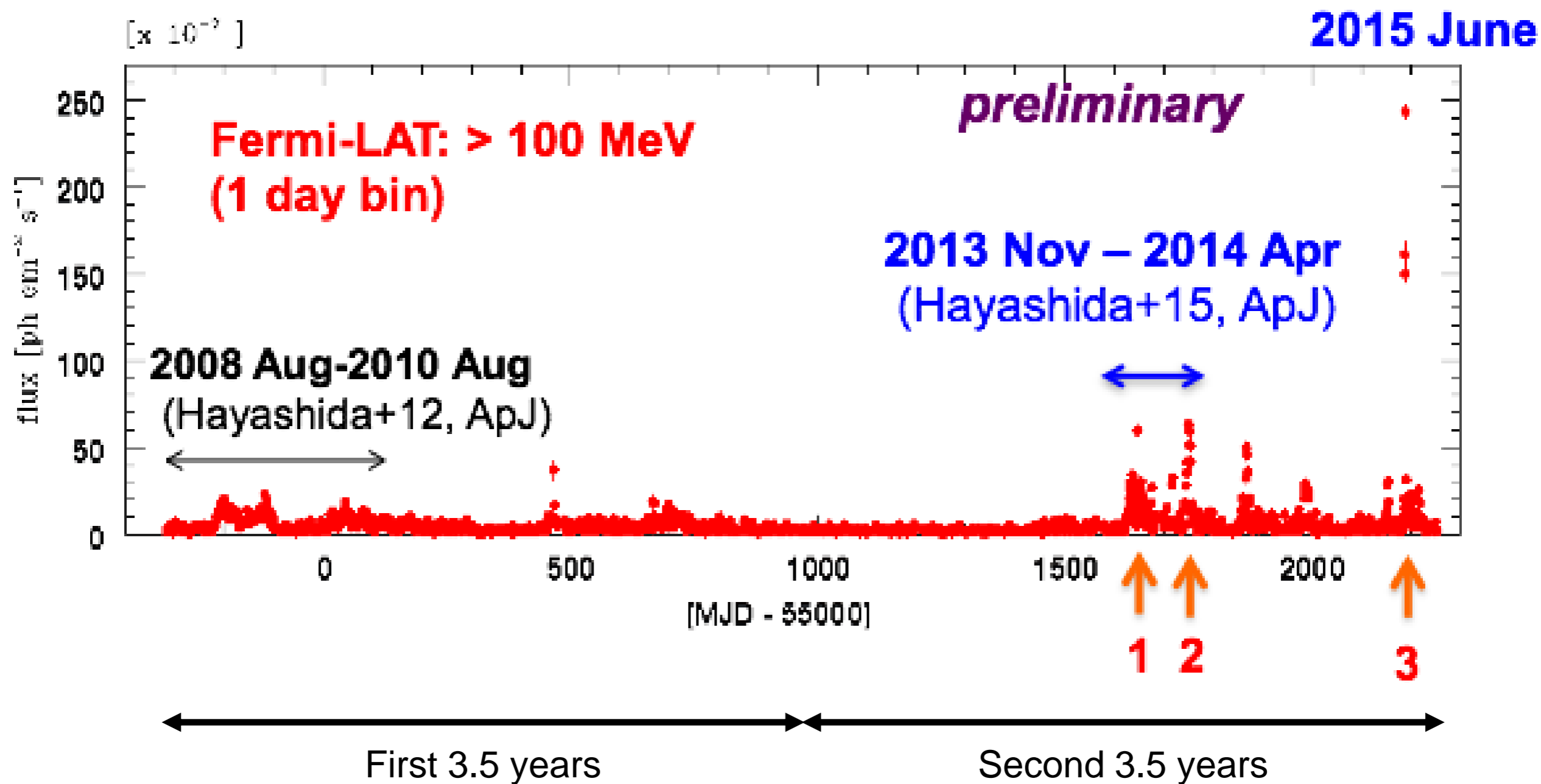


3C 279 RMS-Flux based on 1 day binned Fermi LAT light curve (7 years of data)

*A second order polynomial provides a better fit than a linear relation when all data is used*



# The RMS-Flux relation at gamma-ray energies

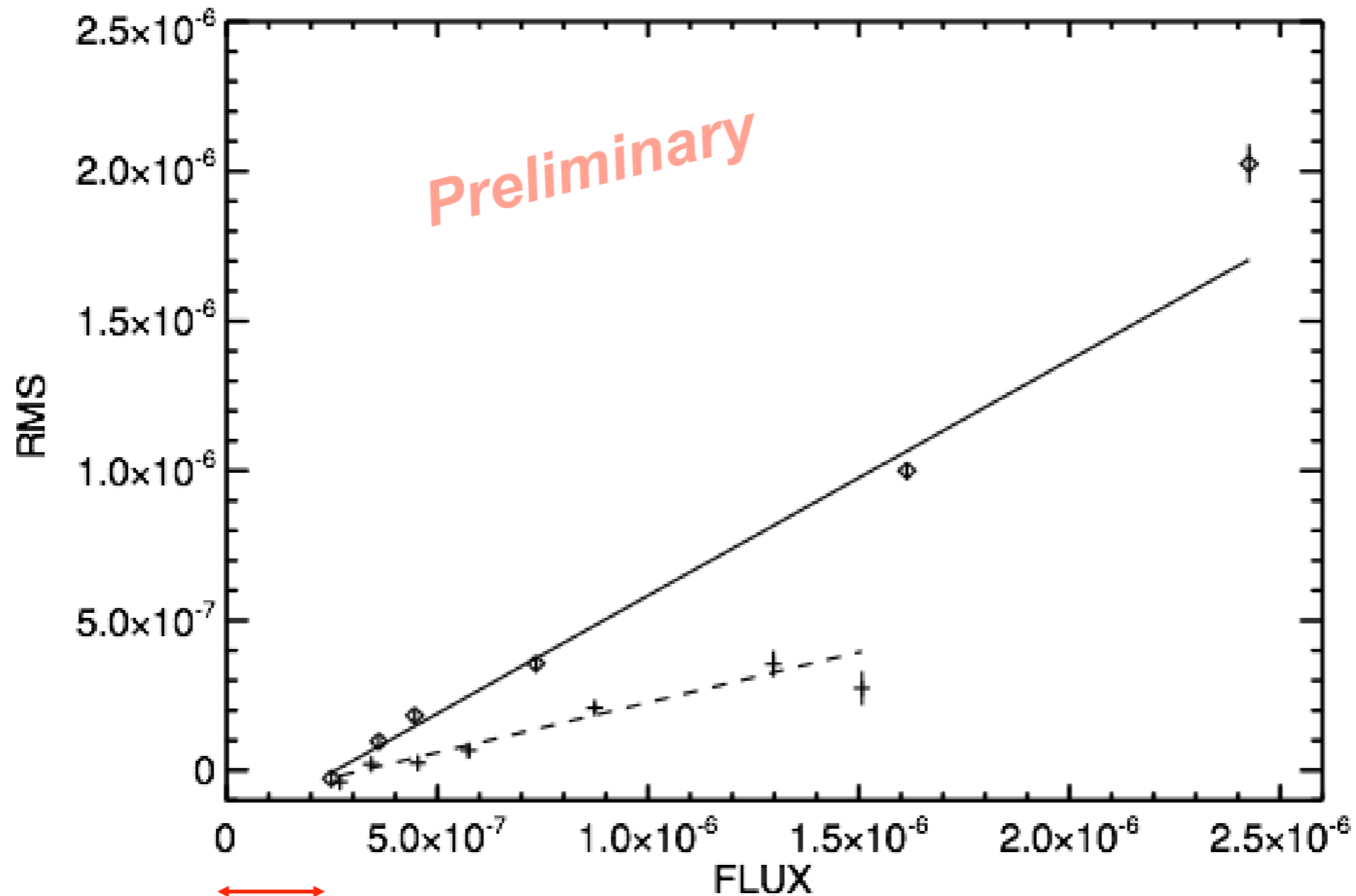


*Ackermann 2016ApJ...824L..20A*

# The RMS-Flux relation at gamma-ray energies



3C 279 RMS-Flux for the first (+) and second (diamonds) 3.5 years of Fermi-LAT observations (flux binned)

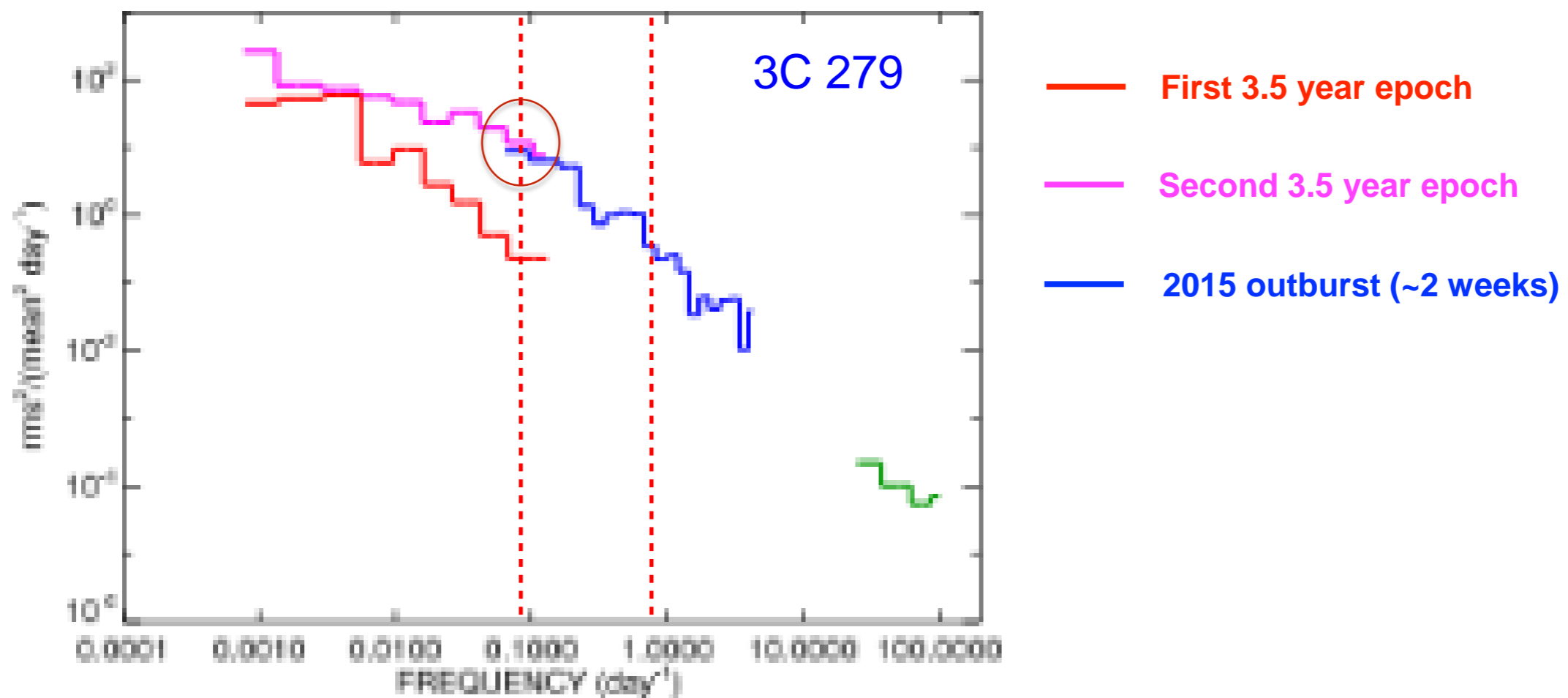


Non/slowly variable component?

# 3C 279 Power Density Spectrum



Also the Power Density Spectrum differ between the two epochs  
(from Ackermann et al 2016, 2016ApJ...824L..20A)



Overlapping PDS is consistent with constant RMS/Flux

*(but for a linear RMS-Flux relation, RMS/Flux will be constant only if the RMS-Flux line goes thorough origo)*



*Larsson et al (in preparation)*

- We have investigated the RMS-Flux relation at gamma-ray energies for 16 FSRQs.
- The RMS-Flux relation is typically linear suggesting a multiplicative rather than additive process.
- A more weakly variable component might be present in some sources but its contribution is typically small.
- A single RMS-Flux relation and a smooth connection of the mean and flaring state PDS suggests that the variability at different brightness levels is driven by the same process.
- In 3C279 a simultaneous change in RMS-Flux relation and PDS shape does imply a change in the variability process.



## Gamma-ray variability:

1. Spectral: Harder-when-brighter (FSRQs) mixed (BL Lacs)
2. Time asymmetry: No
3. PDS: Power law index  $\sim 0.8 - 1.3$   
No persistent break (= characteristic time scale)
4. (Quasi) Periodicity? PG1553+113
5. Time delay? B0218+357 (Gravit. lens)
6. RMS - Flux relation: Linear

## Main conclusion:

Variability at different brightness levels can typically be described by the same stochastic process.