Rapid Gamma-Ray and Optical Variability in Bright Fermi Blazars

P. Coppi, Yale

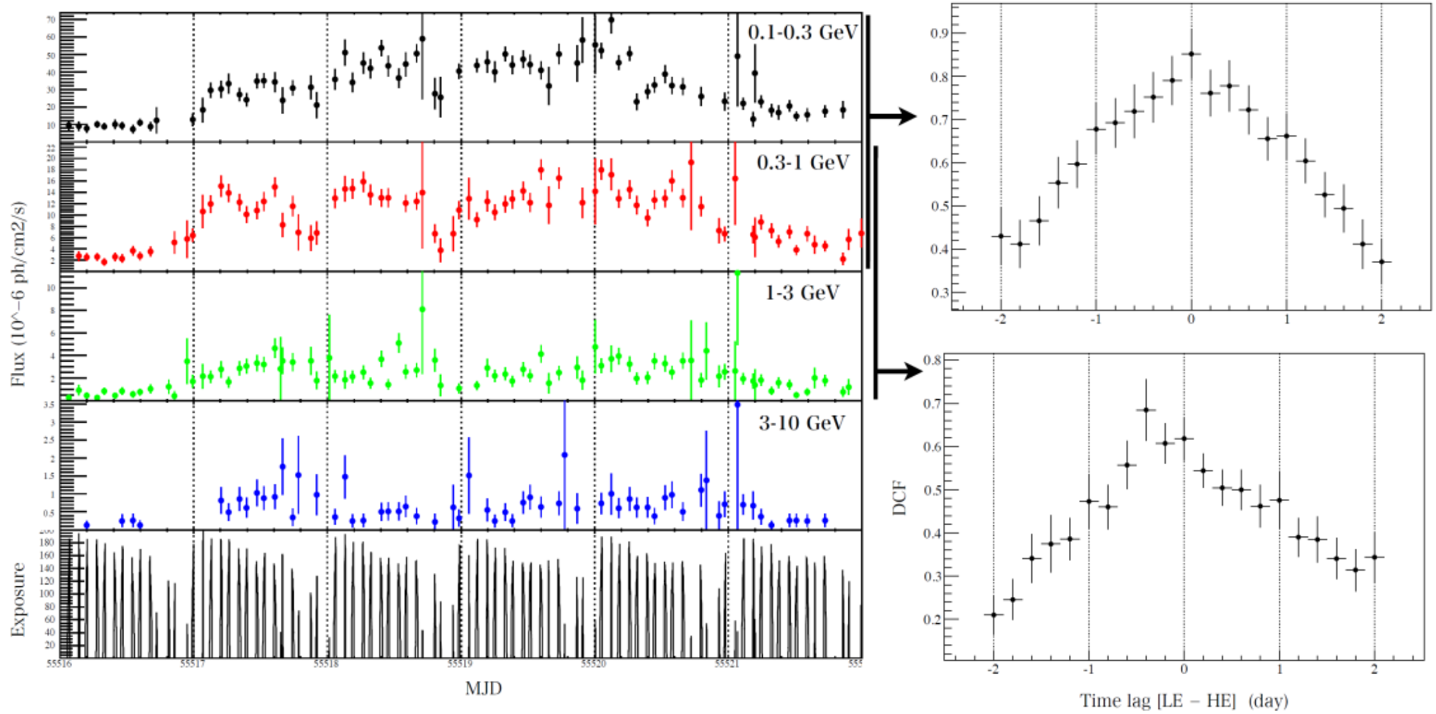
S. Saito, Rikkyo

L. Stawarz, Jagellonian

Using an “aperture photometry" technique to generate Fermi lightcurves on minute timescales, we have carried out a Bayesian Block analysis of the brightest blazar flares to search for variability down to ~15 minute timescales. There is moderate evidence for one such fast flare in PKS 1510-089, but 9 other flare events we examined do not show it, i.e., very rapid variability as found in TeV blazars is probably not common. However, all flare events *do* show evidence strong (factor 2) gamma-ray variability down to ~1 - 2 hour timescales, and we show evidence in 3C 454.3 for spectral evolution on these short timescales. Using SMARTS and optical/NIR data, we are searching for correlated rapid optical variability on similar timescales. While variability on these very short timescales is seen in a few cases, the optical variability amplitude is typically much *smaller* than the gamma-ray one. Interestingly, on ~1-3 day timescales the optical and gamma-ray variability are instead well-correlated and of similar amplitude.

Spectral Evolution on Short Timescales?

3C454.3 2010 flare



TS>10, Γ=2

Fig. 2: ***(left panel)*** Sample light curves from the giant flare of the blazar 3C454.3 in 2010 shown for four different energy bands. The light curve points are obtained by integrating flux over the ~30 minute exposure windows shown in the bottom graph, properly taking into account the variation in exposure during the window. Note that there is clear evidence for fast and repeated variability (greater than factor 2 on ~0.5-1 hour timescales.) ***(right panels)*** Discrete correlation function computed between the 0.1-0.3 and the 0.3-1 GeV energy bands *(top)* and the 1-3 GeV *(bottom)* energy bands as a function of time lag/lead between the bands. Fluxes in the various bands do not behave identically, i.e., there is spectral evolution during the flare, and there is a moderate (~2 sigma) detection of a high-to-low energy lag above ~1 GeV.

3C454.3 2009 flare

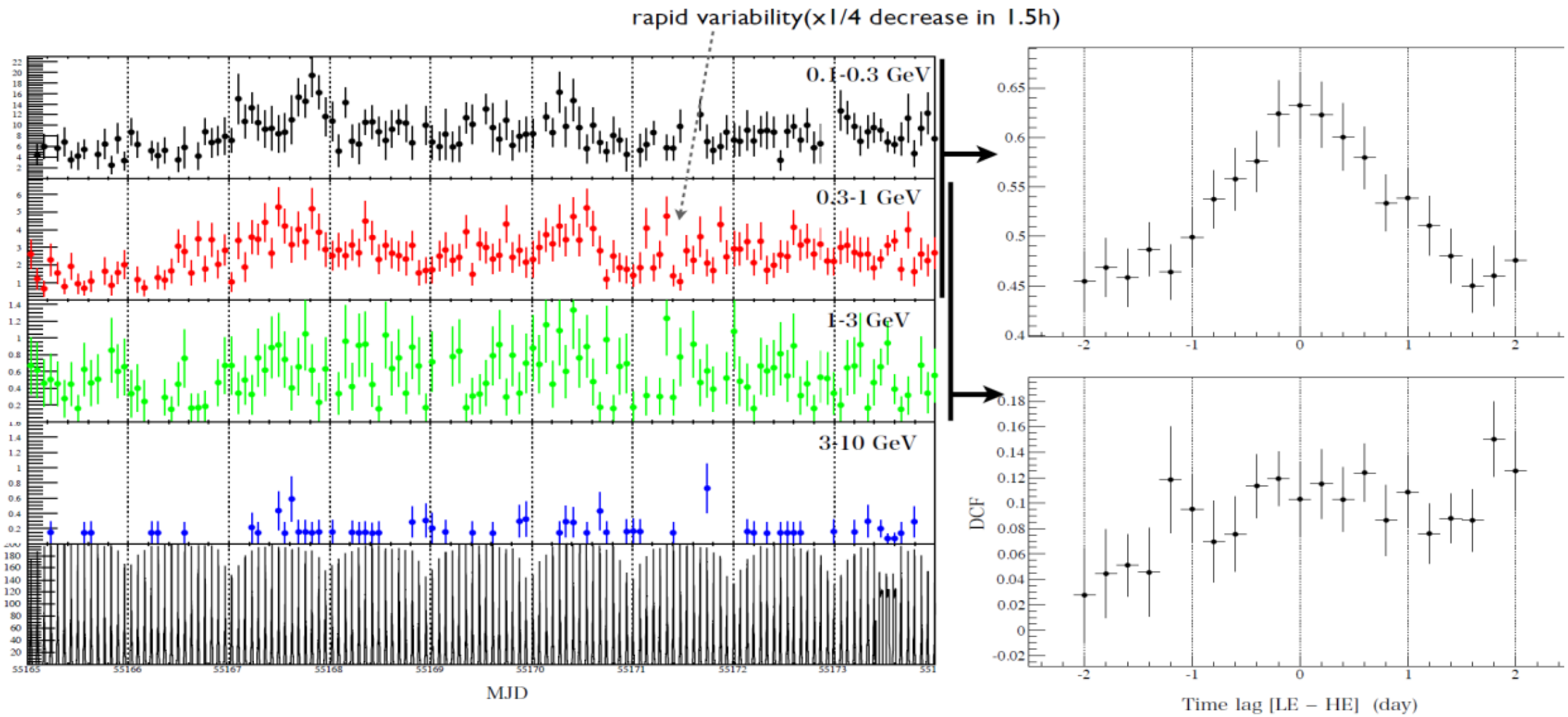


Fig. 3: Similar to Fig. 2, except the data is for the large 3C454.3 in 2009. Interestingly, the short timescale behavior below ~1 GeV is qualitatively similar, but *not* above 1 GeV – compare the 0.3-1 vs 1-3 GeV correlation functions in the lower of the two right panels.

Rapid Variability Example: PKS 1510-089

Using standard daily time bins doesn't tell the whole story …

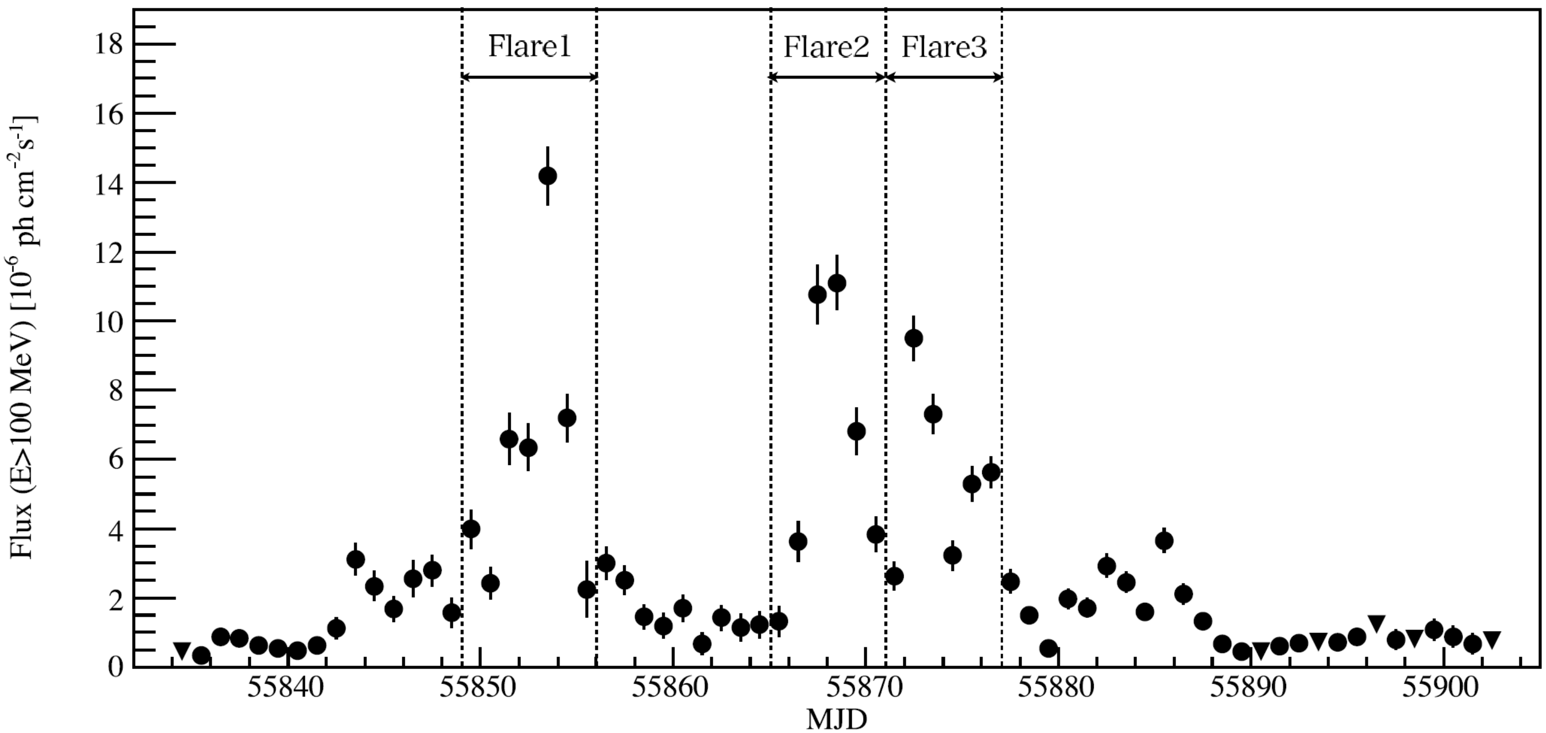
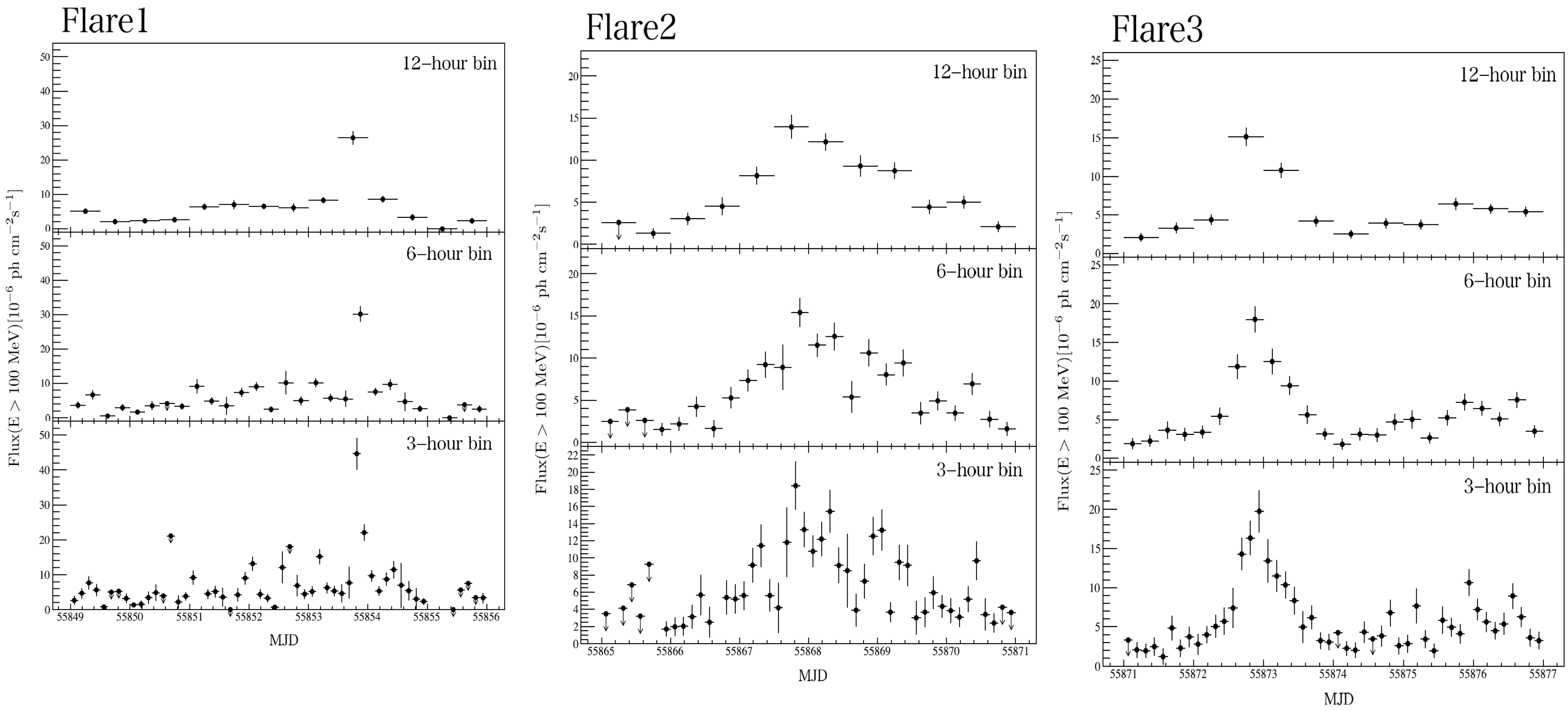


Figure 5.5: Daily γ-ray light curve of PKS 1510−089 during the period MJD 55834–55903 analyzed in this paper. 95% flux upper limits are represented by triangles. Horizontal lines separating the three major flares are chosen arbitrarily just to guide the eye.



- N.B. Amplitudes of flares increases as go to shorter time binning.
- There are >2x flares on even three hour timescales … !

=> DON'T USE DAILY LIGHTCURVES

Bayesian block analysis inside individual Fermi exposure windows, example for PKS 1510-089.

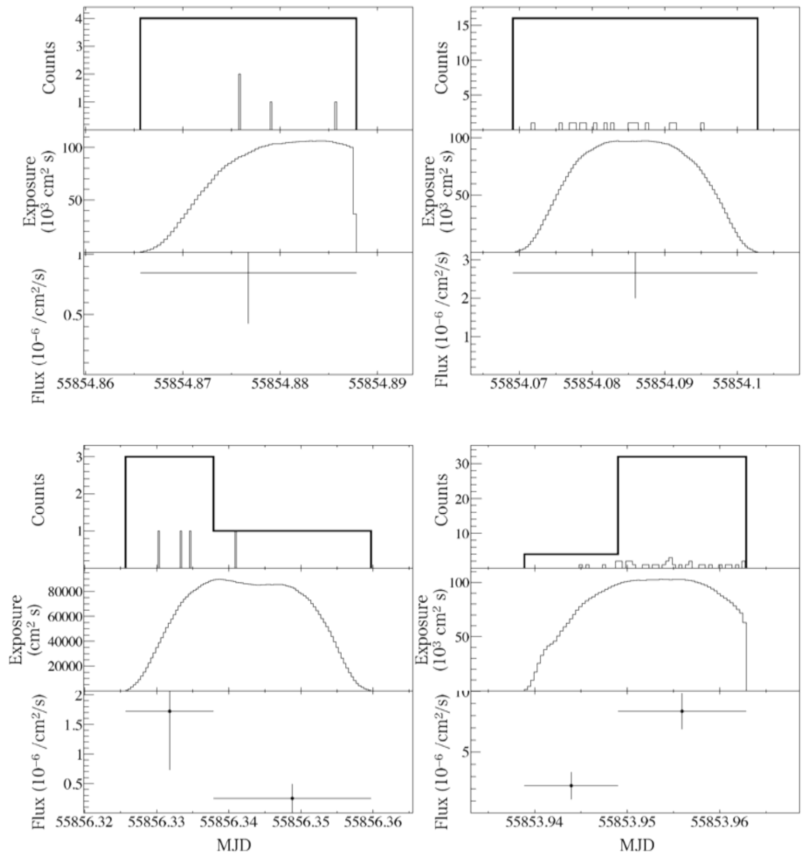
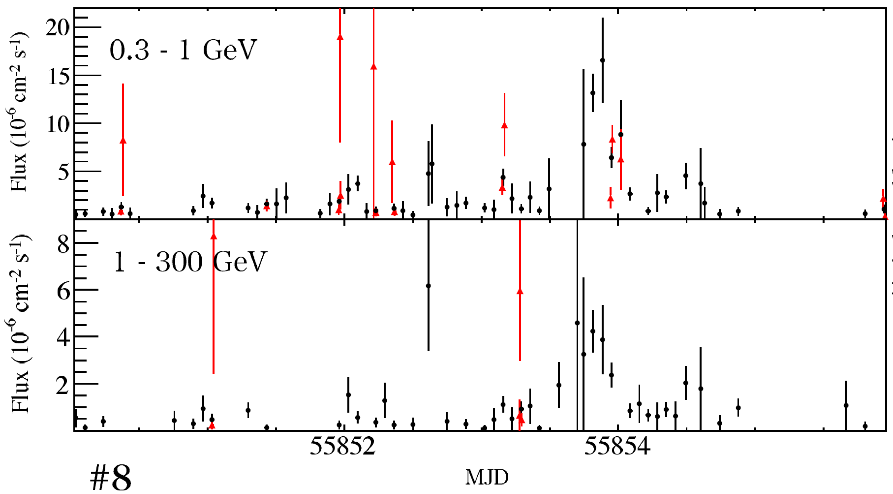


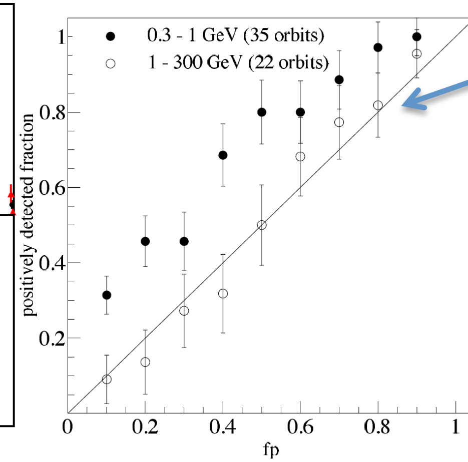
Figure 6.9: Examples illustrating how the *Bayesian block* works to detect sub-orbit variability for different statistics. Four examples of orbits presented were taken from flare #5 in PKS 1510–089, and analysed with $fp = 0.1$. Each exposure typically lasts ∼30 minutes. (*upper panels*) Raw count histogram with piecewise constant blocks obtained with *Bayesian* blocks. (*middle panels*) Exposure variation during a single orbit. (*lower panels*) Flux values calculated by dividing counts by exposure.

Bayesian Block Analysis – PKS 1510-089, Flare 5 shows 3.5 sigma excess of orbits where saw possible flux change (vs. expected number of false positives, solid line in right panels)

Red interval – Bayesian blocks favors 2+ intensity levels during orbit

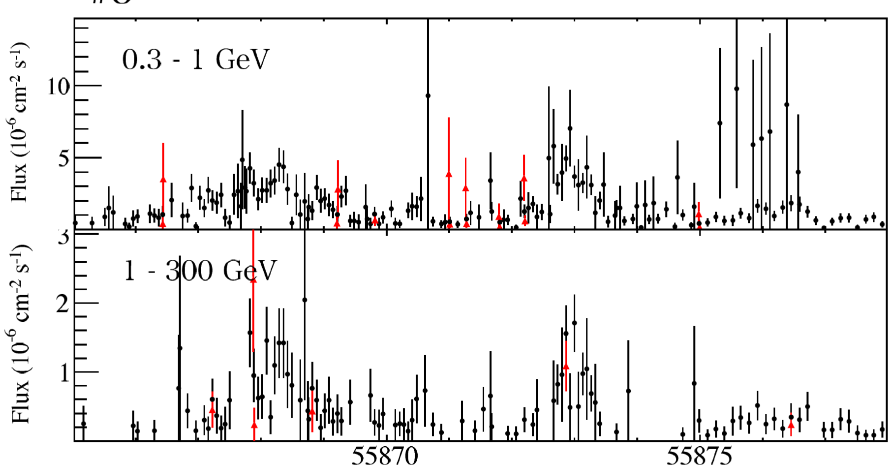
#5

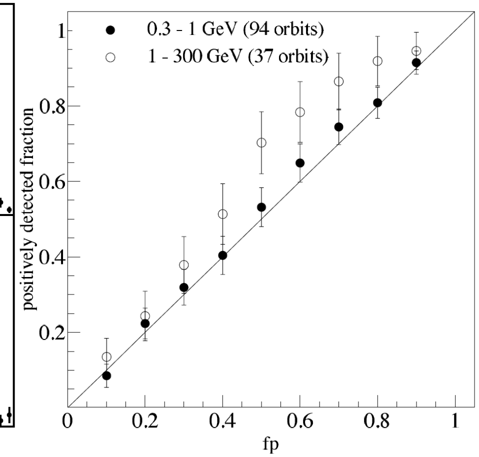




Solid line = Number of expected false positives

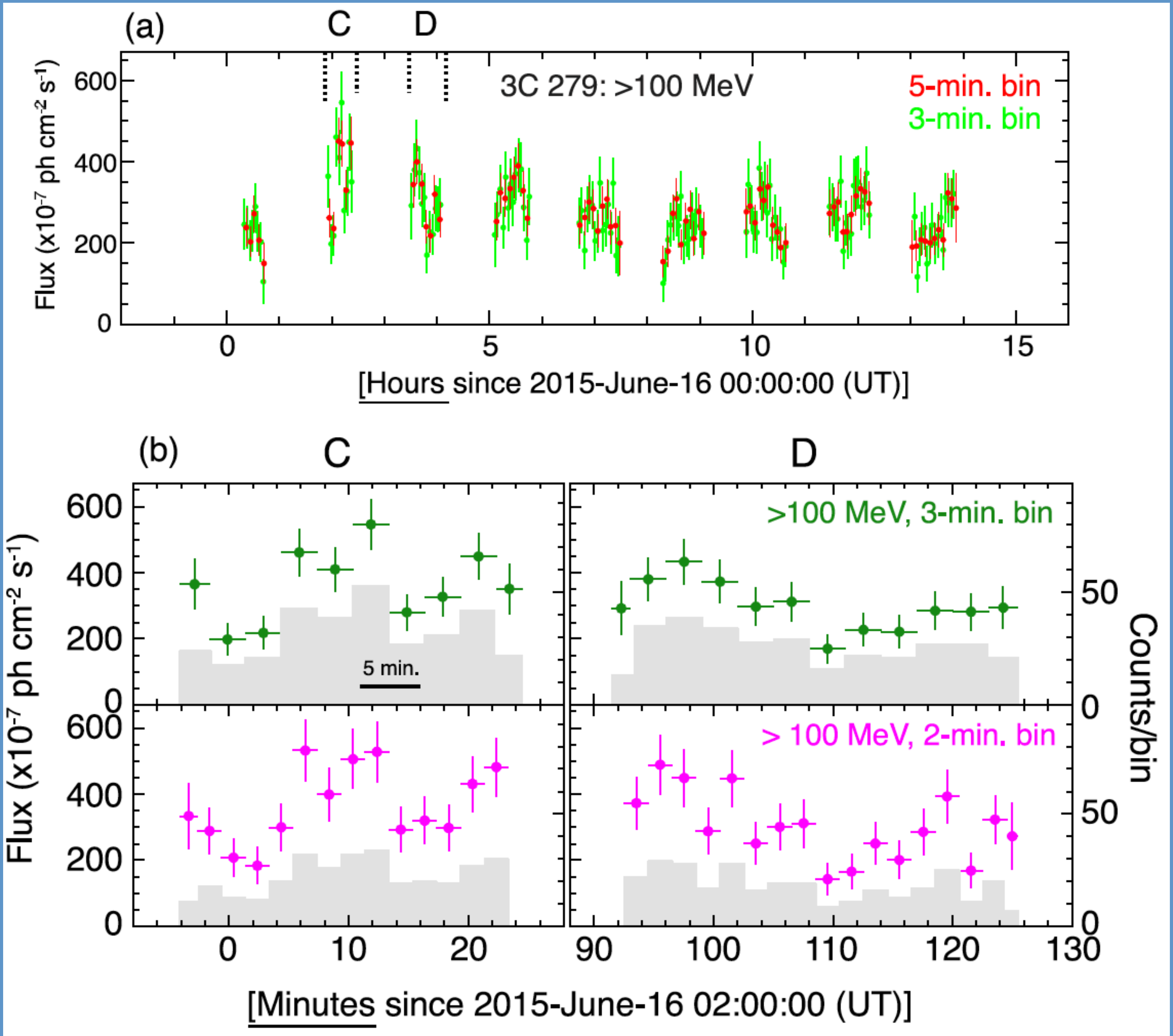
#8

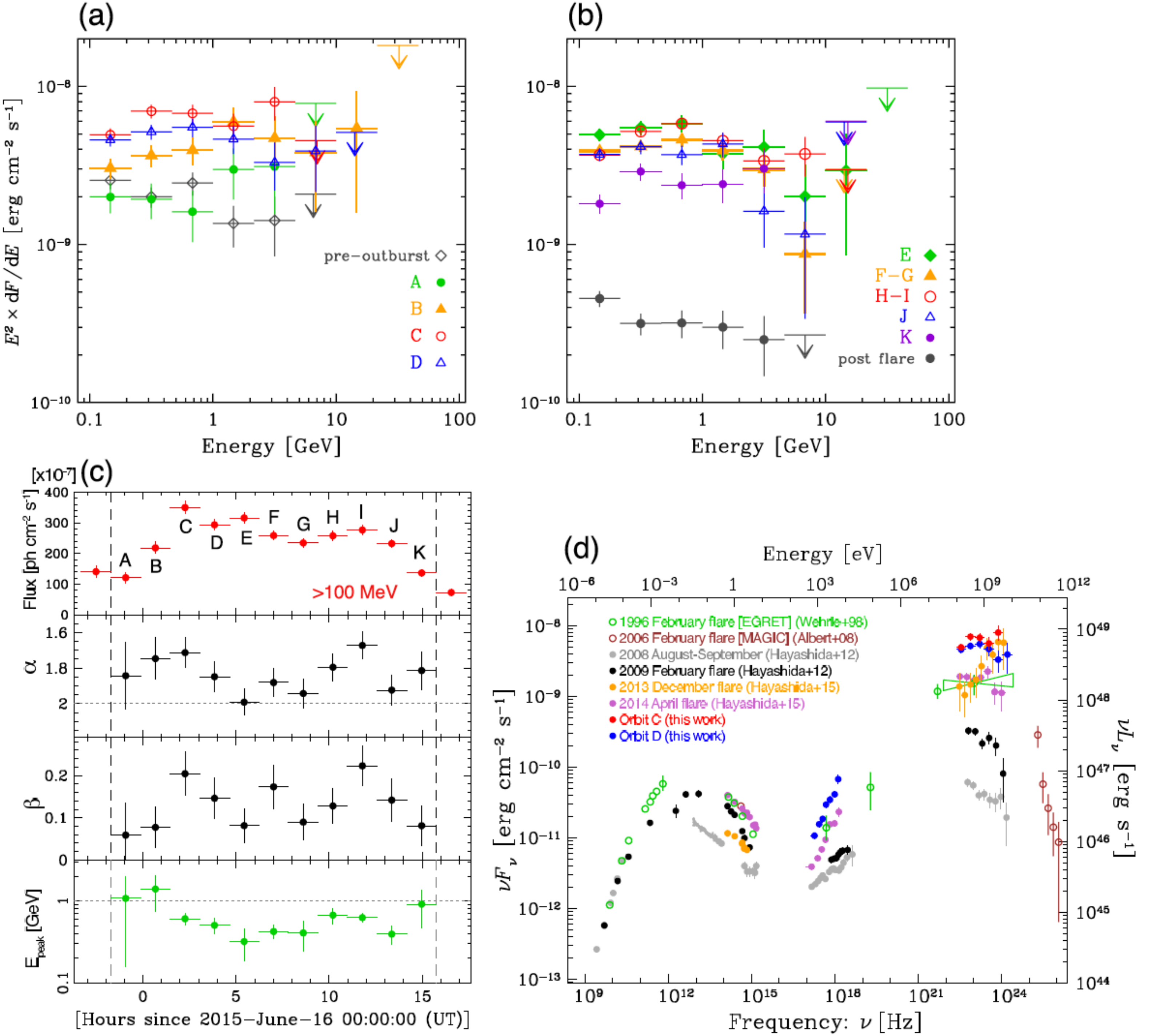




Light curve points shown are averaged over each Fermi exposure window (~30 min long).

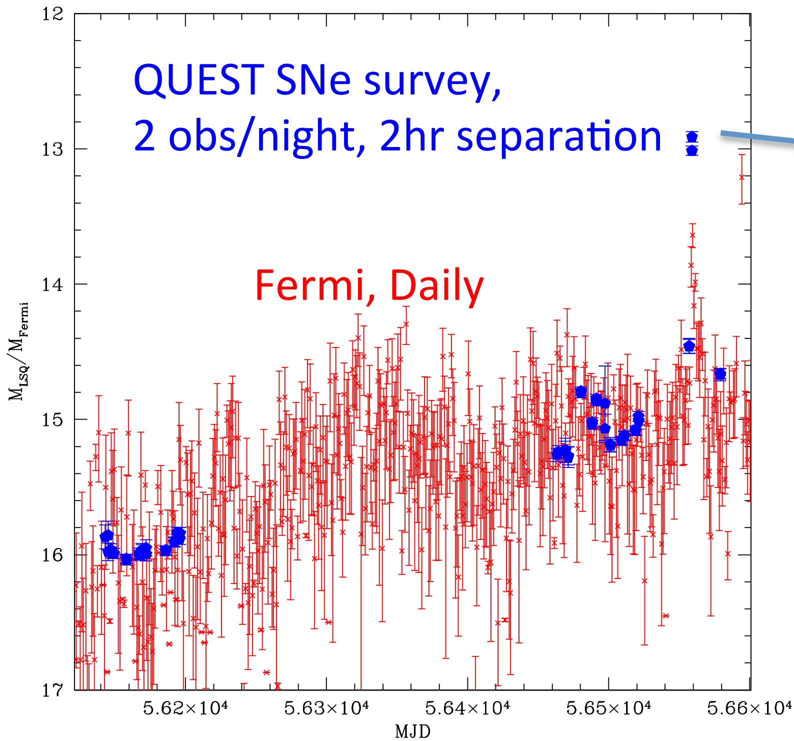
3C 279 in 2015, Fermi, arXiv:1605.05324, Ackerman et al. 2016



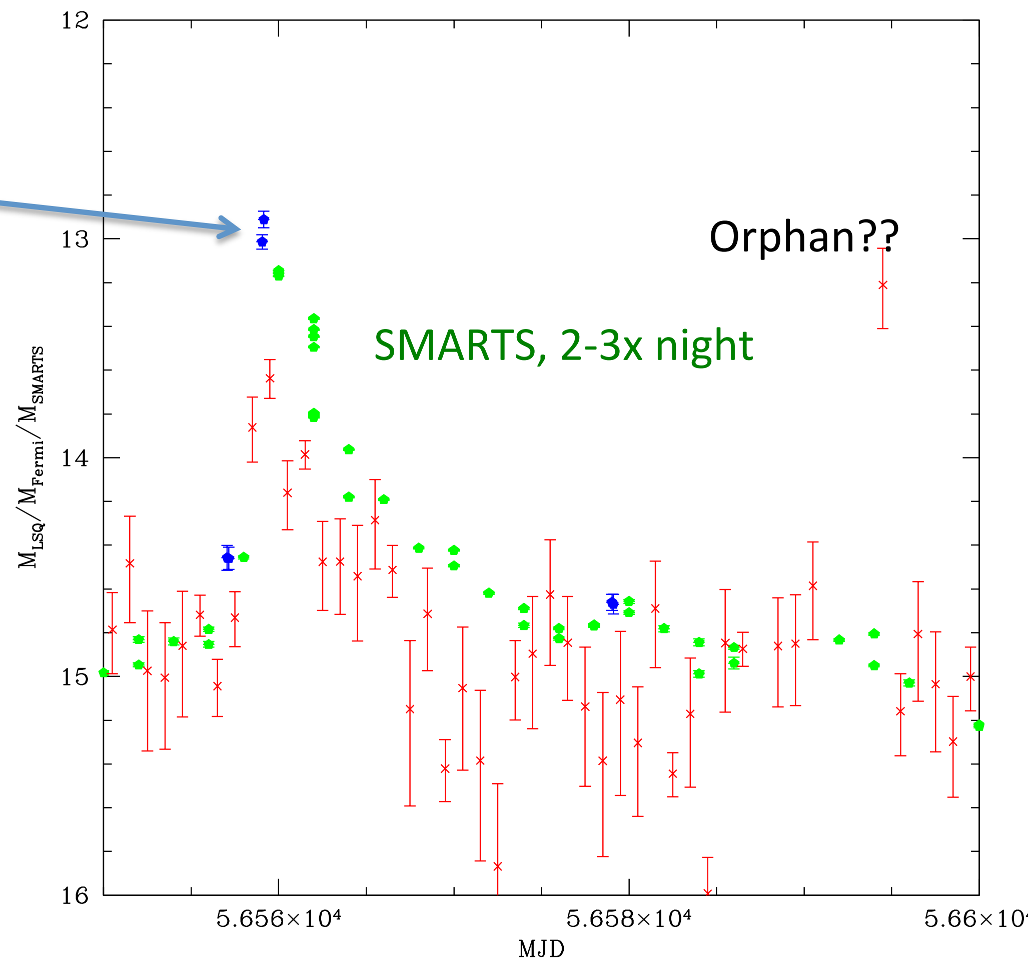


(a)
(b)
(c)
(d)
pre−outburst
A
B
C
D
E
F−G
H−I
J
K
post flare
Energy [GeV]
$E^2 \times dF/dE$ [erg cm^{-2} s^{-1}]
[x10-7]
Flux [ph cm^{-2} s^{-1}]
>100 MeV
α
β
E$_{peak}$ [GeV]
[Hours since 2015−June−16 00:00:00 (UT)]
Energy [eV]
1996 February flare [EGRET] (Wehrle+98)
2006 February flare [MAGIC] (Albert+08)
2008 August-September (Hayashida+12)
2009 February flare (Hayashida+12)
2013 December flare (Hayashida+15)
2014 April flare (Hayashida+15)
Orbit C (this work)
Orbit D (this work)
νF_ν [erg cm^{-2} s^{-1}]
νL_ν [erg s^{-1}]
Frequency: ν [Hz]

Optical vs. Gamma-Ray Variability: recent flare in 3C 454.3



Fermi *daily* lightcurve – red
QUEST lightcurve, V – blue
SMARTs lightcurve, B - green



- If you only had SMARTS and Fermi daily coverage, good luck measuring leads/lags (e.g., SMARTS missed peak).
- On 2hr timescales, QUEST typically sees <10% variability (~15% at flare peak). But if as before (TBD), gamma-rays will have ~2x(+) variability on that timescale!?
- Yet on ~daily timescales, optical and gamma-ray fluxes track well??

Take-Away Points

- In the brightest flares, there is strong evidence for variability on < 3hr timescales, the shortest binning time typically used in Fermi light-curve analysis.
- <30 minutes variability possible, but not so common
- Spectral variability *is* present on these short timescales too.
- => DON'T USE DAILY bins for SED analysis!
- Variability characteristics useful for identifying "states"
- *Pointed mode* Fermi observations + ~*continuous* multi-wavelength coverage (not one or two snapshots per night) are essential for unraveling what's going on.

- Rapid variability is a problem for GeV blazars too…!!

- Connection between optical/NIR and GeV not entirely obvious...