Searching for Sub-hour Gamma-ray Variability in FSRQ Flares with Bayesian Statistics

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Abstract:

We performed a systematic study on sub-hour GeV gamma-ray flux variability during the brightest blazar active periods observed with Fermi-LAT. 3C 454.3, PKS 1510–089, 4C 21.35 and 3C 273 were investigated since they have most prominent GeV flux, which enables a detailed study of short time variability with the best photon statistics. In this work, we utilized Bayesian block method in order to investigate sub-hour variability in the ten brightest active periods of FSRQs. The systematic analysis found no obvious sub-hour variability throughout the selected active intervals, though only a slight indication for sub-hour variability was found in PKS 1510–089.

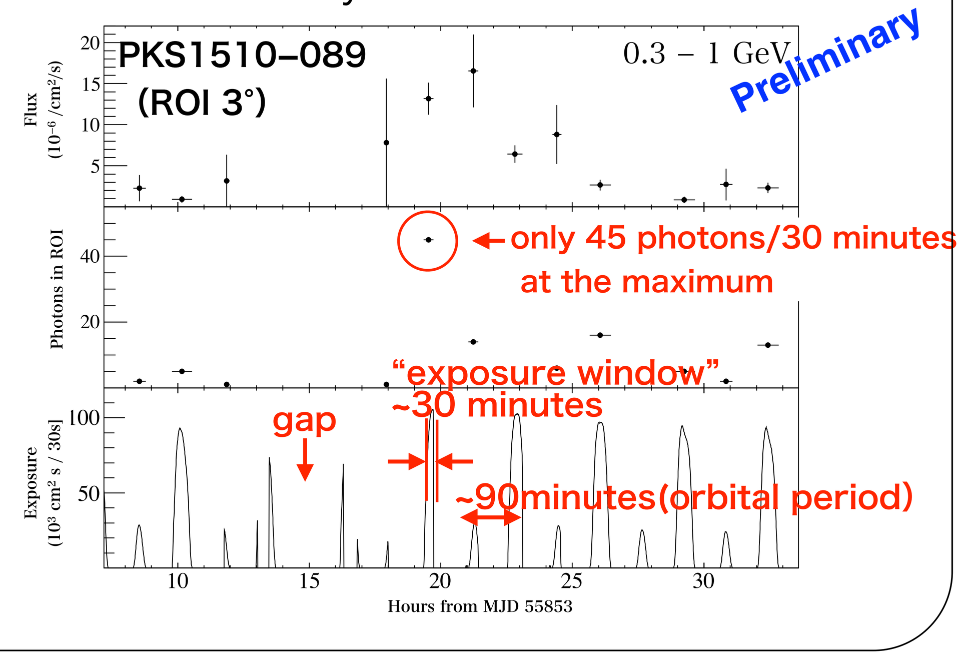
1. Introduction

• Rapid gamma-ray variability in FSRQs

Studying time variability offers an important clue for understanding geometry and location of the gamma-ray emitting zone in blazars. Recent TeV observations found variability timescale of several minutes during FSRQ flares, that indicates an extremely compact emission zone (*Aleksic+11*). On the other hand, in GeV energy range, variability with flux doubling timescales of a few hours, sometimes as short as a hour was found for several flares in PKS 1510–089, 4C 21.35, 3C 273 and 3C 279 (*Foschini+11, Saito+13, Brown+13, Foschini+13, Rani+13, Hayashida+15*).

• Problems in searching for sub-hour variability

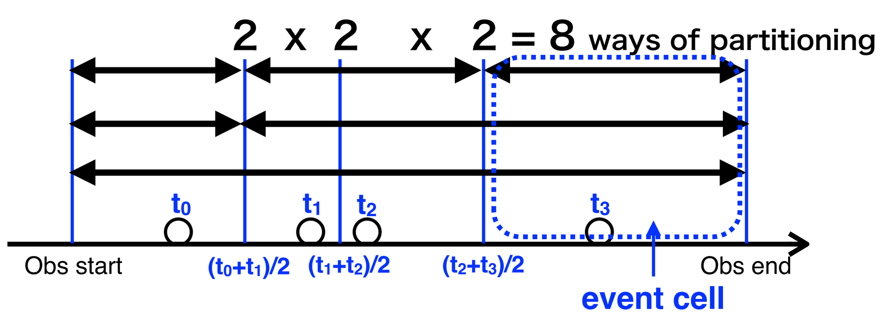
1. **Uneven data sampling**. Surveying all the sky with LAT inevitably brings exposure variation toward any point in the sky, and time intervals when a source is out of LAT FOV make gaps in observations. A point source has been in LAT FOV typically for 30 minutes in every 90 minutes.
2. **Limited photon statistics**. There are tens of photons at most from the target within one LAT orbit even for the brightest blazars. In such a case, arbitrary binning significantly loses information of variability which could potentially lie within the bin width.



2. Bayesian approach

• Bayesian block (Scargle 98, Scargle+13)

"event cell" is defined as a section ($(t_{n-1}+t_n)/2$, $(t_n+t_{n+1})/2$) where t_n is arrival time of each event. Then the best partitioning of event cells (block representation) is found by maximizing modified likelihood function (log L).



$$\log L = \sum_{k \in B} N_k (\log N_k - \log T_k) + N_B \log \psi$$

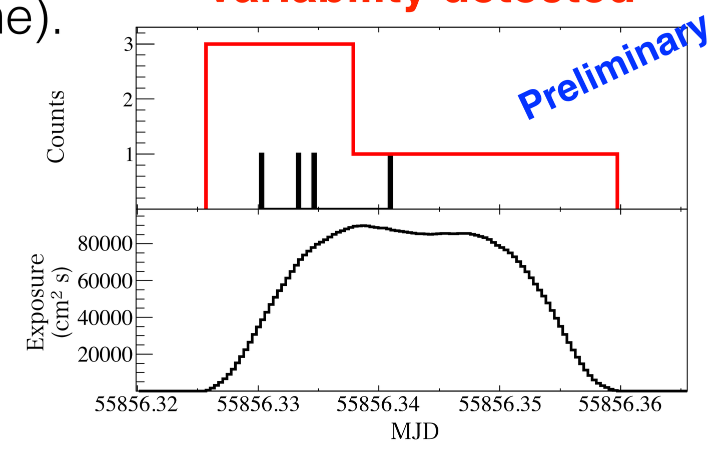
(N_k: number of events in a block, T_k: width of a block, N_B: number of blocks, ψ: prior parameter)

• Example:

In practical, width of each event cell is weighted with exposure (effective area x observation time).

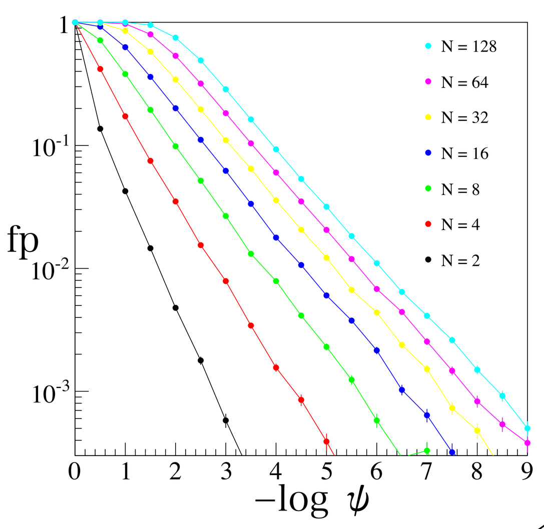
In such a case that we have only four photons (right figure), the Bayesian analysis detected variability (two block representation).

2 blocks
→Variability detected



• Calculating probability of miss detection

false positive probability (fp):
probability that variability was falsely detected under constant flux.
→ fp is obtained as a function of ψ (prior parameter) by simulating events (the number of events: N) subject to constant flux and analysing them with the Bayesian block.

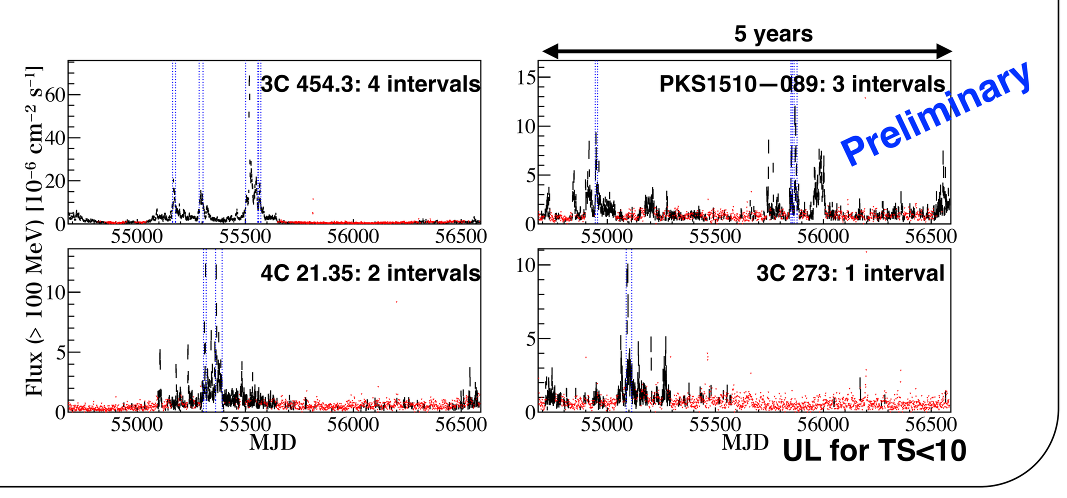


3. Sample selection

We selected blazars whose daily flux (E>0.1 GeV) has exceeded 5x10^{-6} s^{-1}cm^{-2}. Active periods were defined as top 5% intervals of their daily fluxes.Finally we picked up ten intervals according to the peak daily flux.

Selected brightest periods

ID	Source	MJD_{Start}	MJD_{Stop}	$F_{peak}[10^{-6}$ ph s^{-1} $cm^{-2}]$
1	3C 454.3	55501	55558	67.38
2	3C 454.3	55164	55177	20.10
3	3C 454.3	55561	55572	18.39
4	3C 454.3	55287	55305	15.02
5	PKS 1510-089	55850	55856	14.32
6	4C 21.35	55307	55319	11.82
7	4C 21.35	55362	55393	11.69
8	PKS 1510-089	55865	55878	11.27
9	3C 273	55088	55113	9.43
*10	3C 454.3	55304	55307	8.97
*11	3C 454.3	55194	55197	8.79
12	PKS 1510-089	54944	54955	8.73



4. Searching for sub-hour variability in FSRQs

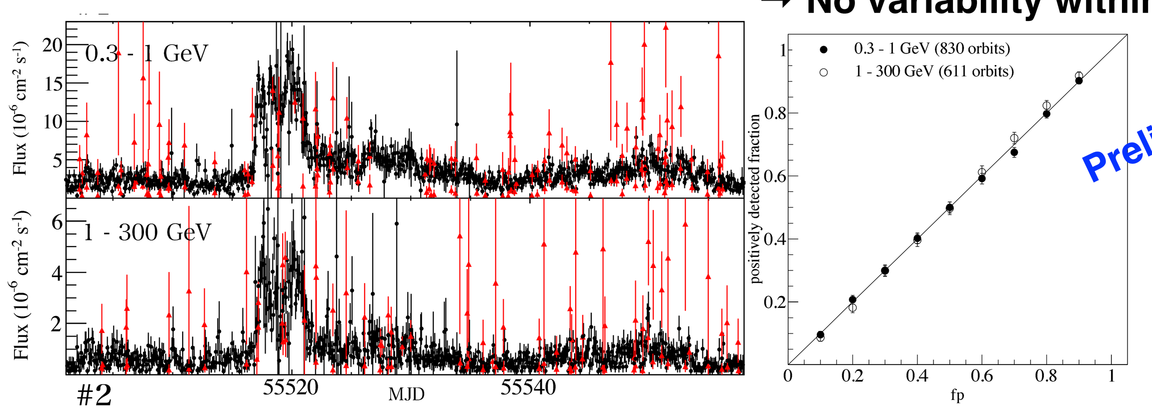
• Application of the Bayesian block to the LAT data

We picked up arrival times of photons within ROI(3°) from the target during the selected intervals, and defined event cells. In the next step, the Bayesian block was applied to every exposure window during the flares individually.

p: fraction of exposure windows detected to be variable

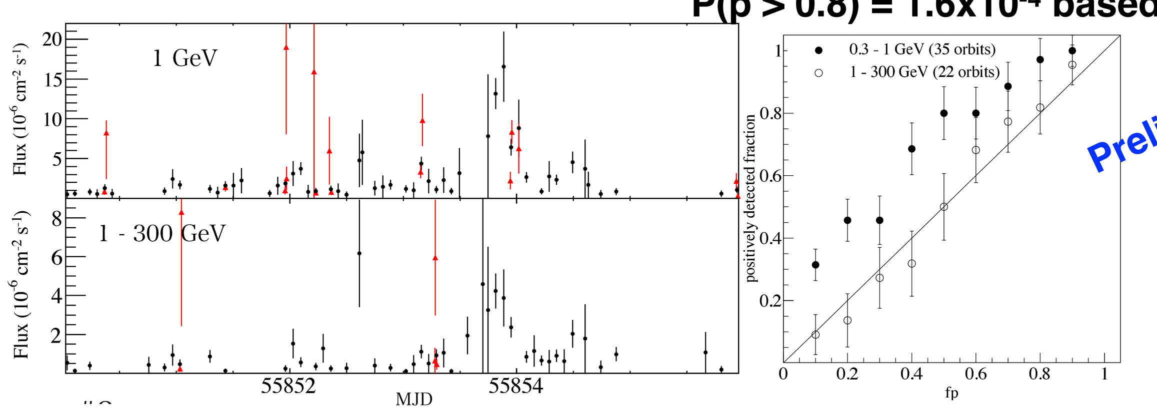
For 9 of the 10 intervals, p ≒ fp
→ No variability within exposure windows

3C454.3



PKS 1510-089

p=0.8 when fp=0.5.
P(p > 0.8) = 1.6x10^{-4} based on binomial distribution



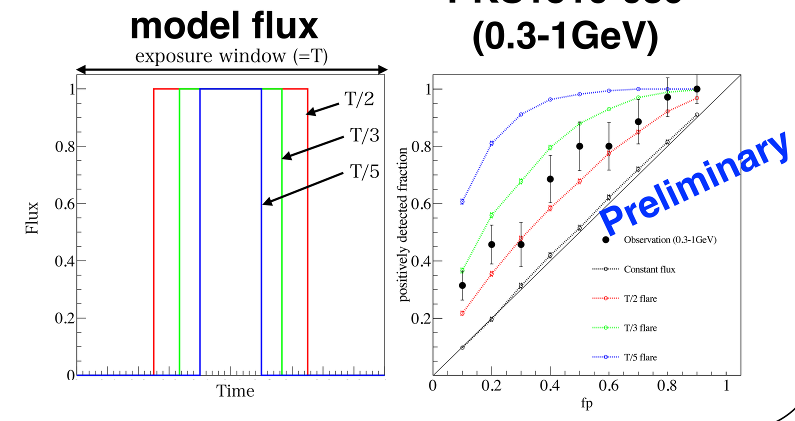
No sub-hour variability was detected for nine of the ten periods, while an indication was found for one period in PKS 1510–089.

•Evaluation of variability amplitude

We simulated events subject to model flux, and applied the Bayesian analysis. Model flux profile: rectangular variability profiles with T/5, T/3, T/2, and T(means constant flux).

model flux

PKS1510-089 (0.3-1GeV)



5. Summary and discussions

We performed Bayesian block analysis to the brightest intervals of FSRQs detected with Fermi-LAT. Among the ten periods selected, only one period in PKS 1510-089 indicated a sub-orbit variability. The results are reasonable considering PKS 1510–089 showed the fastest superluminal motion reaching 45c (*Jorstad+05*), and consistent with a recent study studying gamma-ray sub-hour variability in blazars (*Sobolewska+14*).

On the other hand, the light-crossing time of the black hole's event horizon (tg) is typically tg=100xM/(6x10^{8}M$_\odot$) min for FSRQs studied in this work. The Bayesian analysis in this work focused on timescale of ~ 30 min, and found no significant variability. This supports a hypothesis that tg characterizes the minimum variability timescale of a bulk energy of blazar jet, which was pointed out in *Begelman+08*.

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