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

1. 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 an 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).

2. 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 seen 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

1. Bayesian block (Scargle 98, Scargle+13)

“event cell” is defined as a section (t_i,t_i+1/2, (t_i+t_{i+1/2}) where t_i 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, \psi: 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. 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 \psi (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 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.

4. Searching for sub-hour variability in FSRQs

1. Application of the Bayesian block to the LAT data

We packed 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.

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 (t_g) is typically t_g=100M/\sqrt{G/M_a} 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 t_g characterizes the minimum variability timescale of a bulk energy of blazar jet, which was pointed out in Begelman+88.

References


Acknowledgements

The Fermi-LAT Collaboration acknowledges generous ongoing support from a number of agencies and institutes that have supported both the development and the operation of the LAT as well as scientific data analysis. These include the National Aeronautics and Space Administration and the Department of Energy in the United States, the Commissariat à l’Énergie Atomique and the Centre National de la Recherche Scientifique / Institut National de Physique Nucléaire et de Physique des Particules in France, the Agencia Espacial Italiana and the Istituto Nazionale di Fisica Nucleare in Italy, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), High Energy Accelerator Research Organization (KEK) and Japan Aerospace Exploration Agency (JAXA) in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the Swedish National Space Board in Sweden. Additional support for scientific analysis during the operations phase is gratefully acknowledged from the Istituto Nazionale di Astrofisica in Italy and the Centre National d’Études Spatiales in France.