Waiting Times Between activity peaks of FSRQs

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ABSTRACT

The study of the statistical distribution of waiting times between activity peaks (waiting times are the time intervals between consecutive activity peaks (see, e.g., Wheatland 2002) can give information on the distribution of flaring times, and constrain the physical mechanism responsible for Gamma-ray emission.

Candidate activity peaks are reveled using a photometric unbinned peak detection method (Pacciani 2018); fake flares are removed from the sample by comparing the photometric results with the standard likelihood analysis performed within the identified peak activity period.

We found that the waiting times distribution can be described with a set of overlapping bursts of flares, with an average burst duration ~0.6 year, and with an average burst rate of ~1.3/y.

For short waiting times (below 1 d host frame) we reveal a second population: the blue component with a few tens of short waiting times.

In our analysis, CTA 102 showed the large majority of short waiting times. Interestingly, the period of conspicuous detection of the blue component of waiting times for this source coincides with the crossing time of the superluminal K1 feature with the C1 stationary feature in radio reported in Jorstad 2017 and in Casadio 2019.

The obtained distribution of waiting times between Gamma-ray flares can be interpreted as originating from relativistic plasma moving along the jet for a deprojected length of ~30-60 pc (assuming a bulk Gamma=10), that sporadically produce Gamma-ray flares. Duration and Burst rate is roughly in agreement with distribution of fading time and ejection rate of traveling structures observed with VLBA at 43 GHz.

Method

To reveal flaring episodes of a given gamma-ray source, a general temporal-unbinned method is proposed (Pacciani 2018) to identify flaring periods in time-tagged data and discriminate statistically-significant flares: It consists of an event clustering method in one-dimension to identify flaring episodes, and Scan-statistics (Naus 1965) to evaluate the flare significance within the whole data sample.

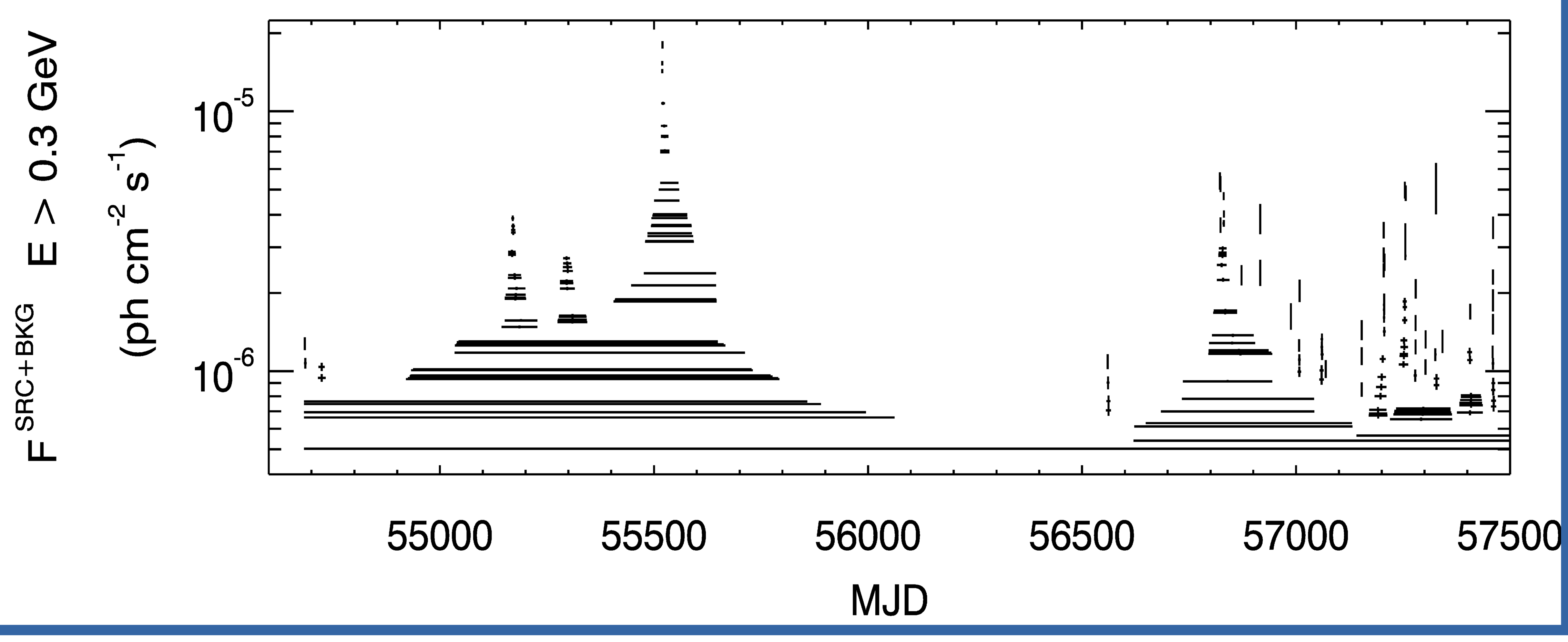
This is a photometric algorithm. The comparison of the photometric results (e.g., photometric flux, gamma-ray spatial distribution) for the identified peaks with the standard likelihood analysis for the same period is mandatory to establish if source-confusion is spoiling results.

The procedure can be applied to reveal flares in any time-tagged data sample. The study of the gamma ray activity of 3C 454.3 and of the fast variability of the Crab Nebula are shown as examples.

The result of the proposed method is similar to a photometric light curve, but peaks are resolved, they are statistically significant within the whole period of investigation, and peak detection capability does not suffer time-binning related issues.

The method can been applied for gamma-ray sources of known celestial position, for example, sources taken from a catalogue. Furthermore the method can be used when it is necessary to assess the statistical significance within the whole period of investigation of a flare from an unknown gamma-ray source.

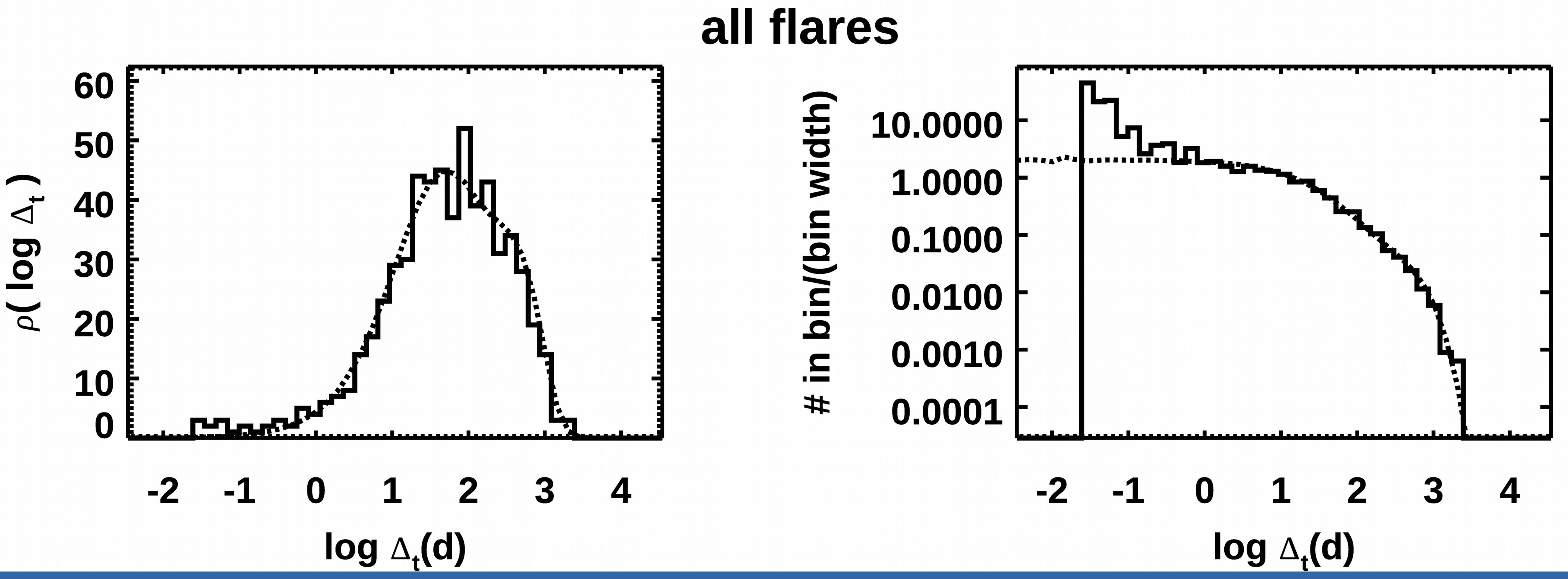
The activity peaks and unbinned light curve of the FSRQ 3C 454.3



Unbinned light curve obtained with N_{tol}=50, E>0.3 GeV, extraction radius corresponding to the containment of 68% of photons from the source. Confidence level is 99.87%.
The unbinned light curve as a whole is a representation of a single-root tree like hierarchy. The bottom segment is the root cluster. Ascending the tree corresponds to go from the bottom up of the plotted diagram of clusters. For each cluster, a parent can be identified (the boundaries of a son cluster are within the boundaries of the parent). All the reported clusters which can be regarded as parents do not describe flat activity periods (the hypothesis that the events within a parent cluster are uniformly distributed is rejected with a confidence level of 99.87%). Clusters and chain of clusters are expected for flaring periods, when the hypothesis of uniformly distributed events is false. Leaves are the activity peaks. Every son cluster is statistically relevant with respect to its parent, according to the chosen confidence level. Therefore the unbinned light curve is a statistically filtered representation of the source activity.

Distribution of Waiting Times between activity peaks

all flares

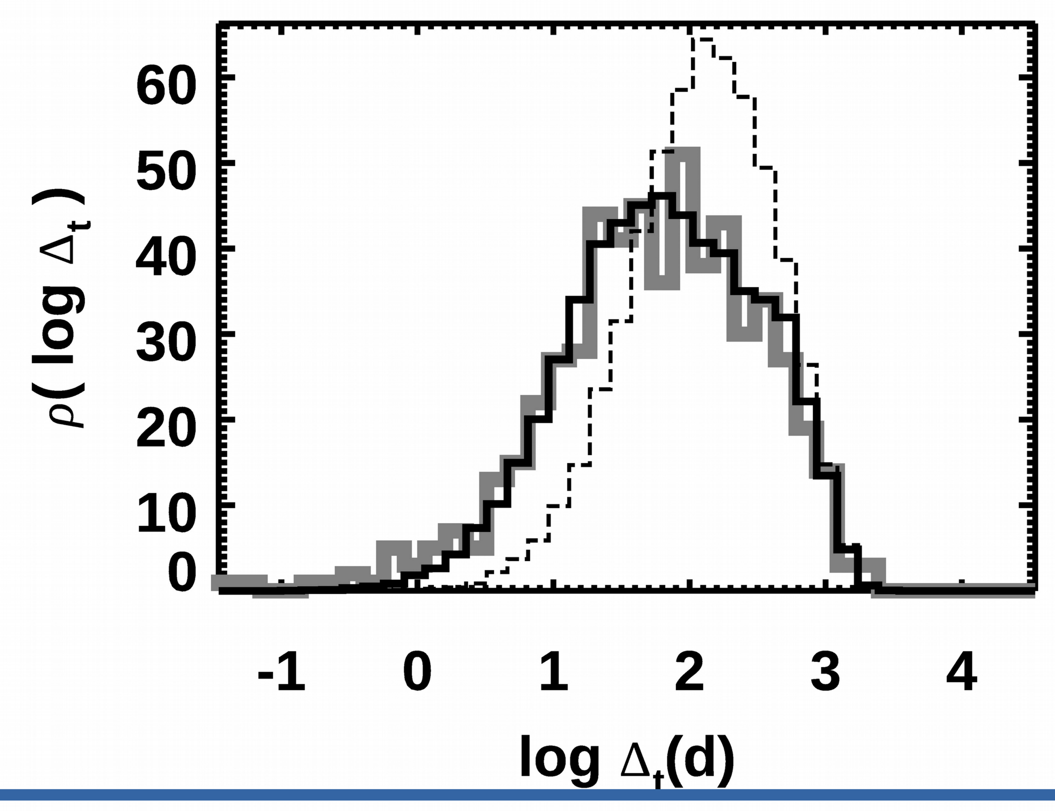


For short waiting time, this distribution follows the typical tail of poissonian processes:
For $\Delta_t \to 0$, the waiting time distribution is proportional to $\exp(-\Delta_t/\tau)$, and the distribution reported on the right tends to be flat.
Superimposed to the poissonian tail, there is an excess of events (the blue component) for $\Delta_t < 1$d.

The obtained distribution can be modeled with the waiting time distribution of an overlapping set of bursts of activity. We fitted the model to the data and obtained that the rate of emission of bursts is ~1.3/y, and the burst duration is ~0.6y.
This model does not take into account for the exposure variation with time.

Detailed simulations

We simulated two physical scenario taking into account of the exposure of the satellite to the source:
a) uniformly distributed flares (dashed lines in the plot),
b) moving emitting regions (knots) that sporadically produce flares before fading. Knots move straight, and their trajectories are randomly extracted within a cone of aperture 1 deg; the observer line of sight is randomly oriented with respect to the jet axis of each source (black line in the plot).
We found that an uniform distribution of flares does not mimic the moving emitting region scenario. Moreover the scenario b) reproduce the data (grey line in the plot) for waiting times larger than several days. Pile-up effect reduce the revealed events for short waiting times.
This scenario resembles shock acceleration models for jets (see, e.g., Sironi, 2015).



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