Flat Spectrum Radio Quasars: ten years of variability in gamma-ray

(a study of waiting time distribution between flares)

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Flare recognition

- With a clustering method applied to gamma-ray collected within a suitable region around the source, we searched for gamma-ray flares of FSRQs in the energy range **0.1-300 GeV**.

- **data set**: $\{X_{(i)}\}$ (gamma-ray events collected within an extraction region)
  where $X_{(i)}$ is the cumulative exposure (from the start of obs) of the collected event i.

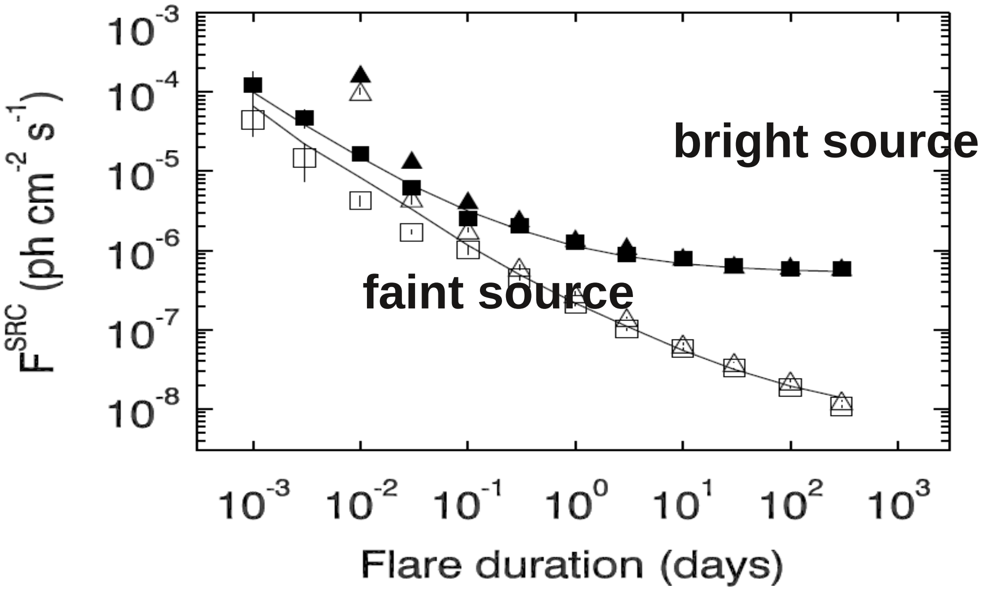
- **clustering law**:

$$\begin{cases} X_{(i+k)} - X_{(i)} < k * \Delta_{thr} & (K < N_{tol}) \\ l \in [i, i+k] & \end{cases}$$

- chance cluster probability is evaluated with a scan-statistic related method (**maximum score scan statistic**, Glaz 2006, **conf. level set to $1*10^{-3}$)**.

iSRS sensitivity

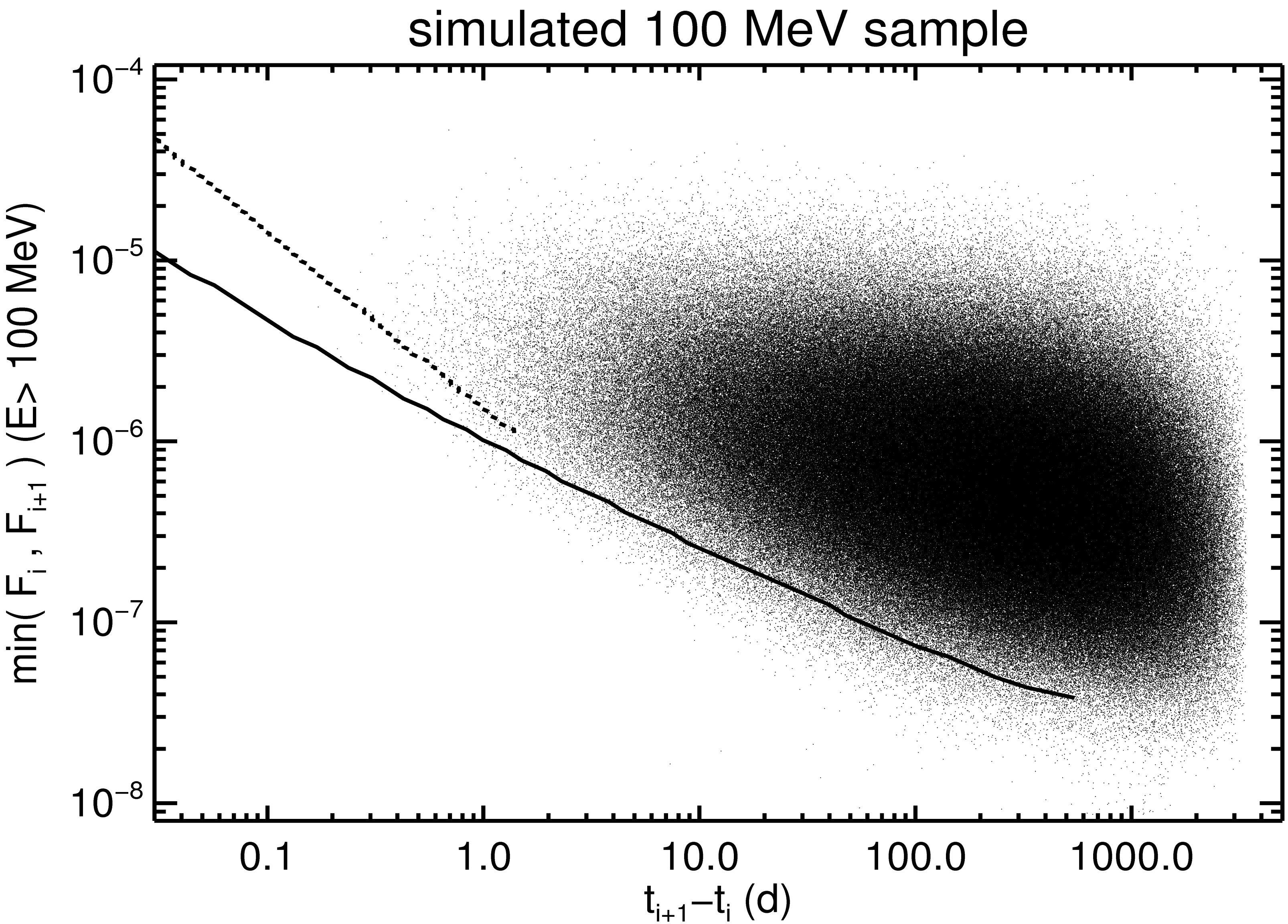
Sensitivity depends on average source flux within the obs period:



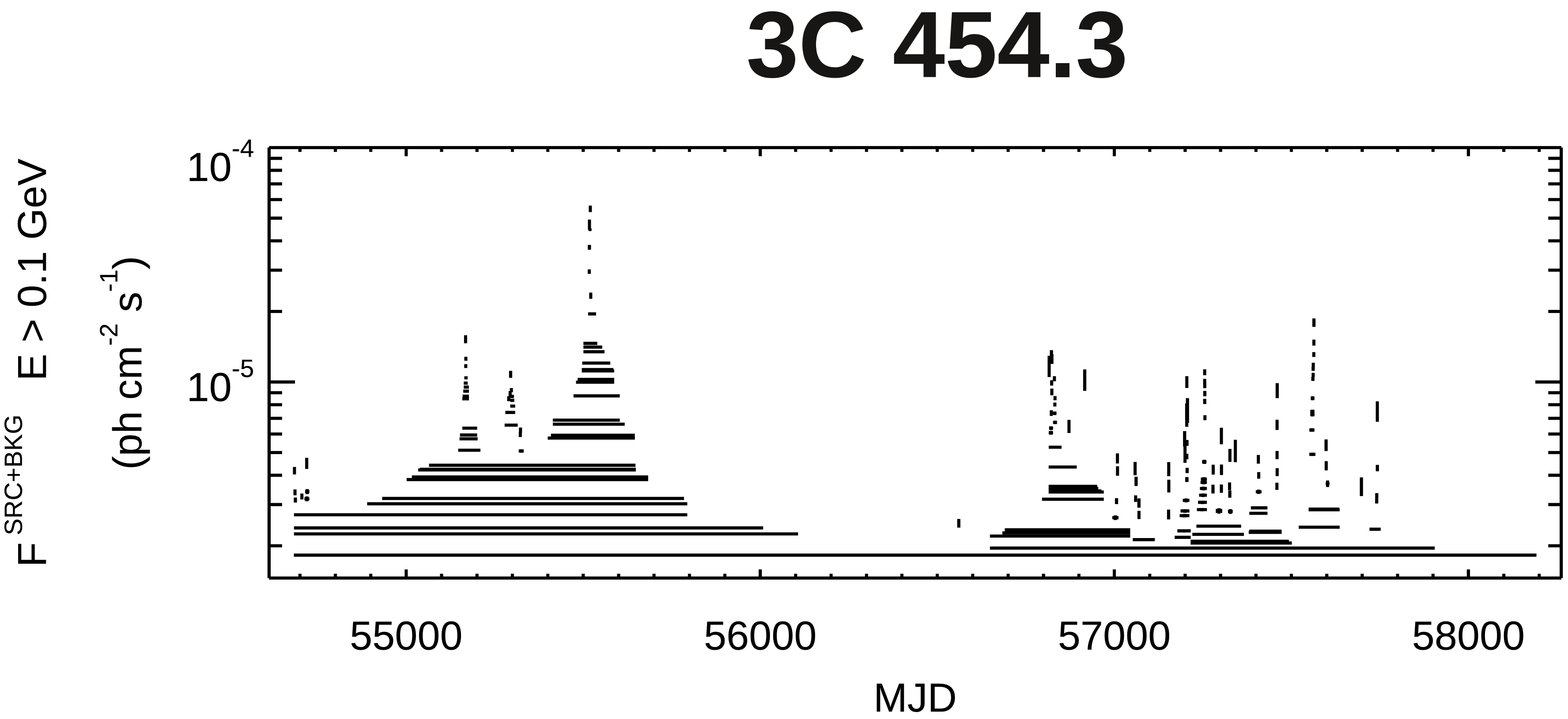
Lines: computed sensitivity assuming constant exposure (no gaps)

Squares and triangles: sensitivity evaluated for simulations and adopting FERMI-LAT real exposures to the sources.
Triangles: 50% of simulated flares are recognized;
Squares: 20% of simulated flares are recognized.

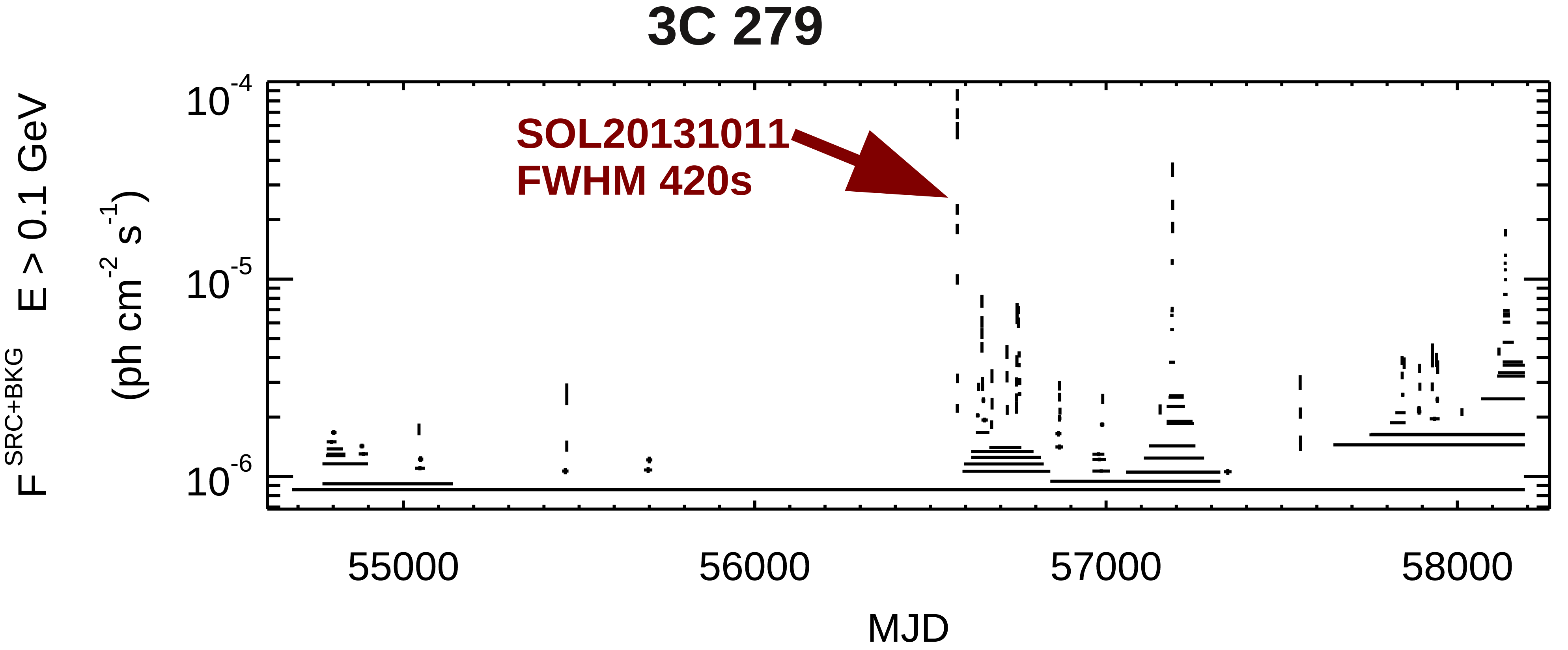
iSRS resolving power



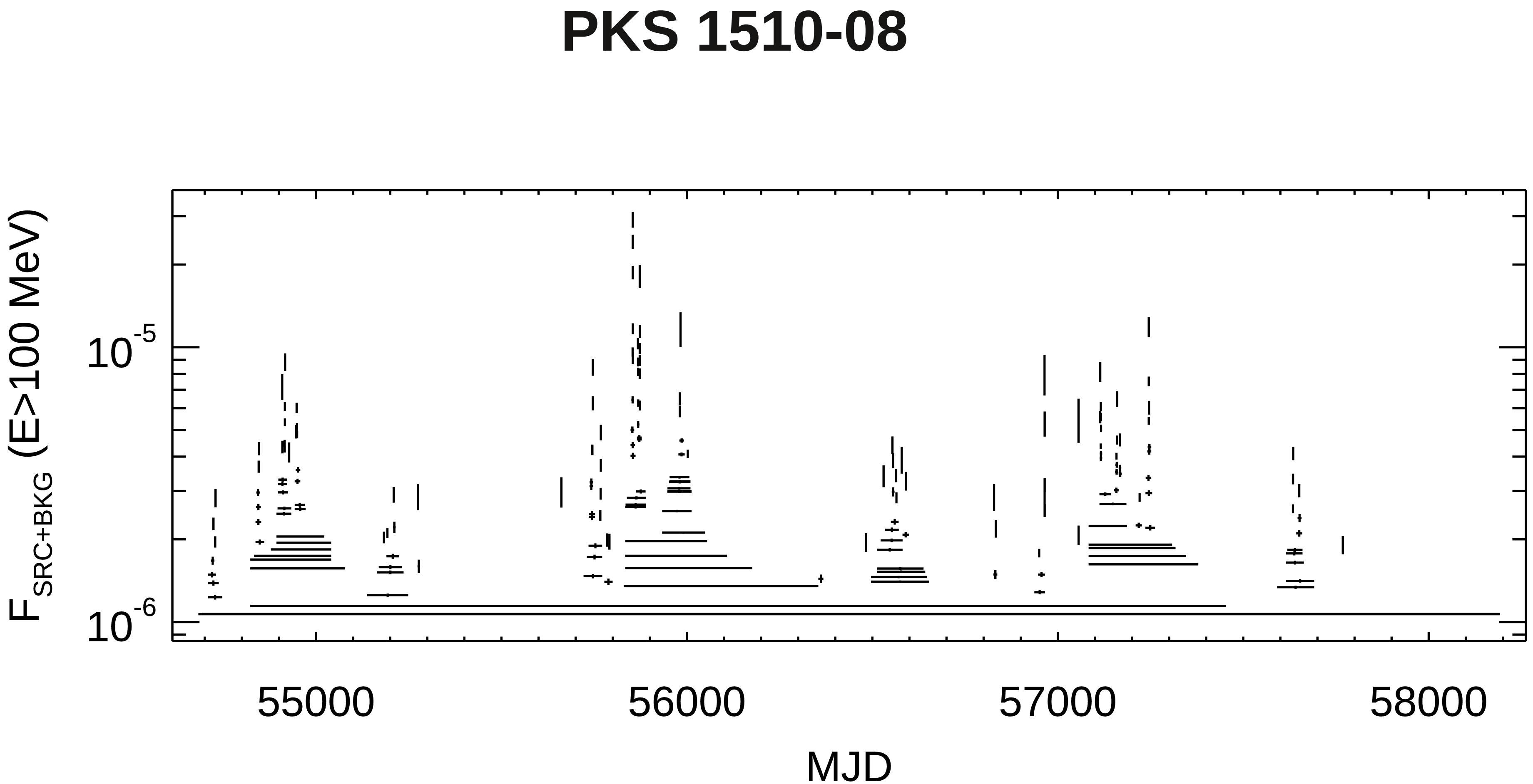
Unbinned light curves (NSIGMA=3)



Unbinned light curves (NSIGMA=3)



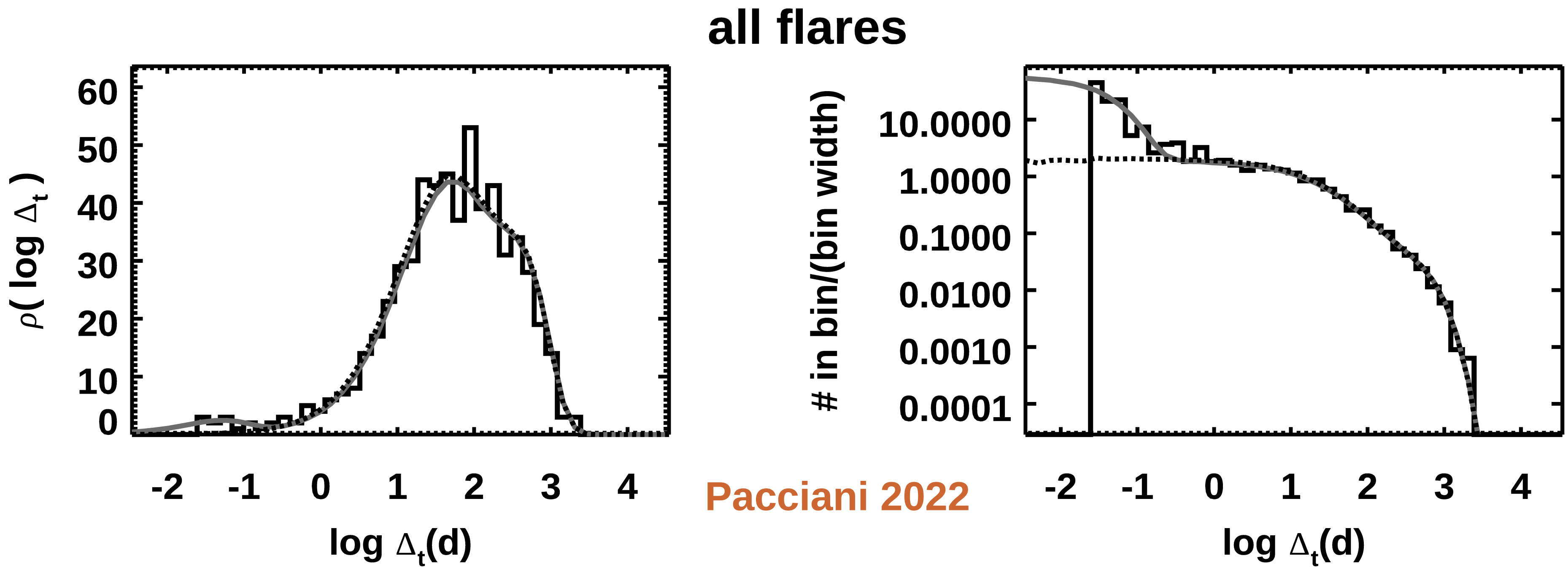
Unbinned light curves (NSIGMA=3)

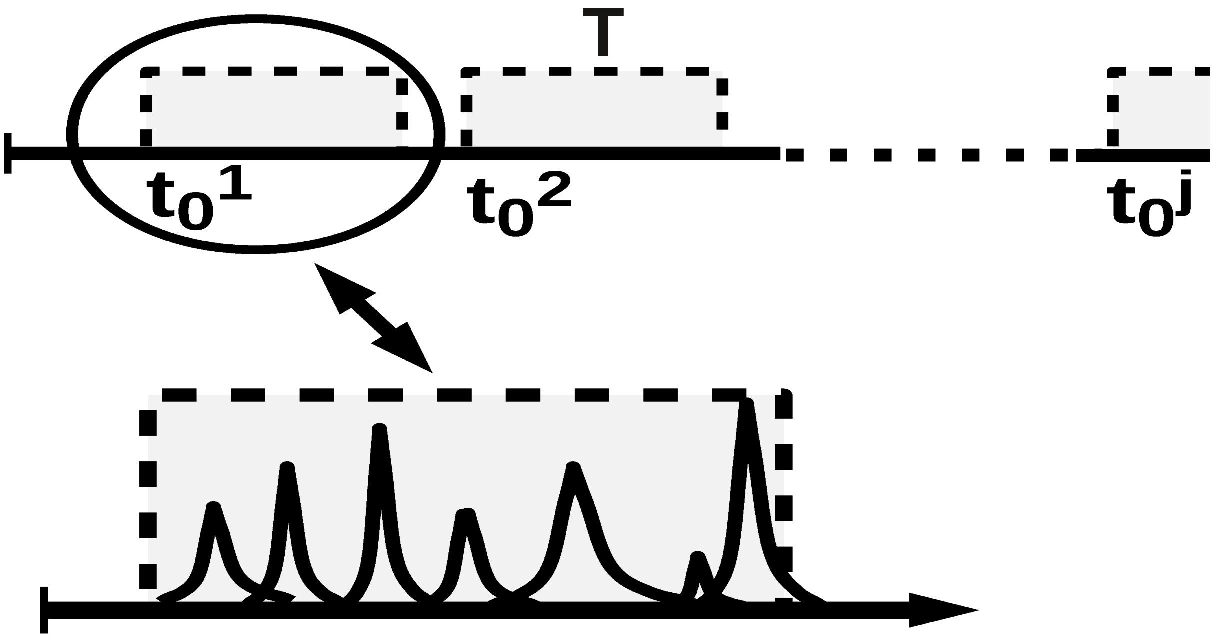


Sample selection

- FSRQs from the 3FGL catalog with TS > 49
- Only sources at least 15^0 above the galactic plane are chosen
- Peak fluxes evaluated with **photometry** are **compared with the full likelihood** analysis, and eventually the photometric flare is validated (TS flare > 9, Ratio of photomeric to likelihood based flare flux < 1.3)
- No other selections applied (e.g., Sun constrain)
- Comparison with simulations of time series taking into account of exposure variation with time
- esposure for each source evaluated with time bins of 1/1000 of a day
- 649 (713) flares from 147 (115) sources for E > 300 MeV (E> 100 MeV)

Waiting time distribution (all flares)

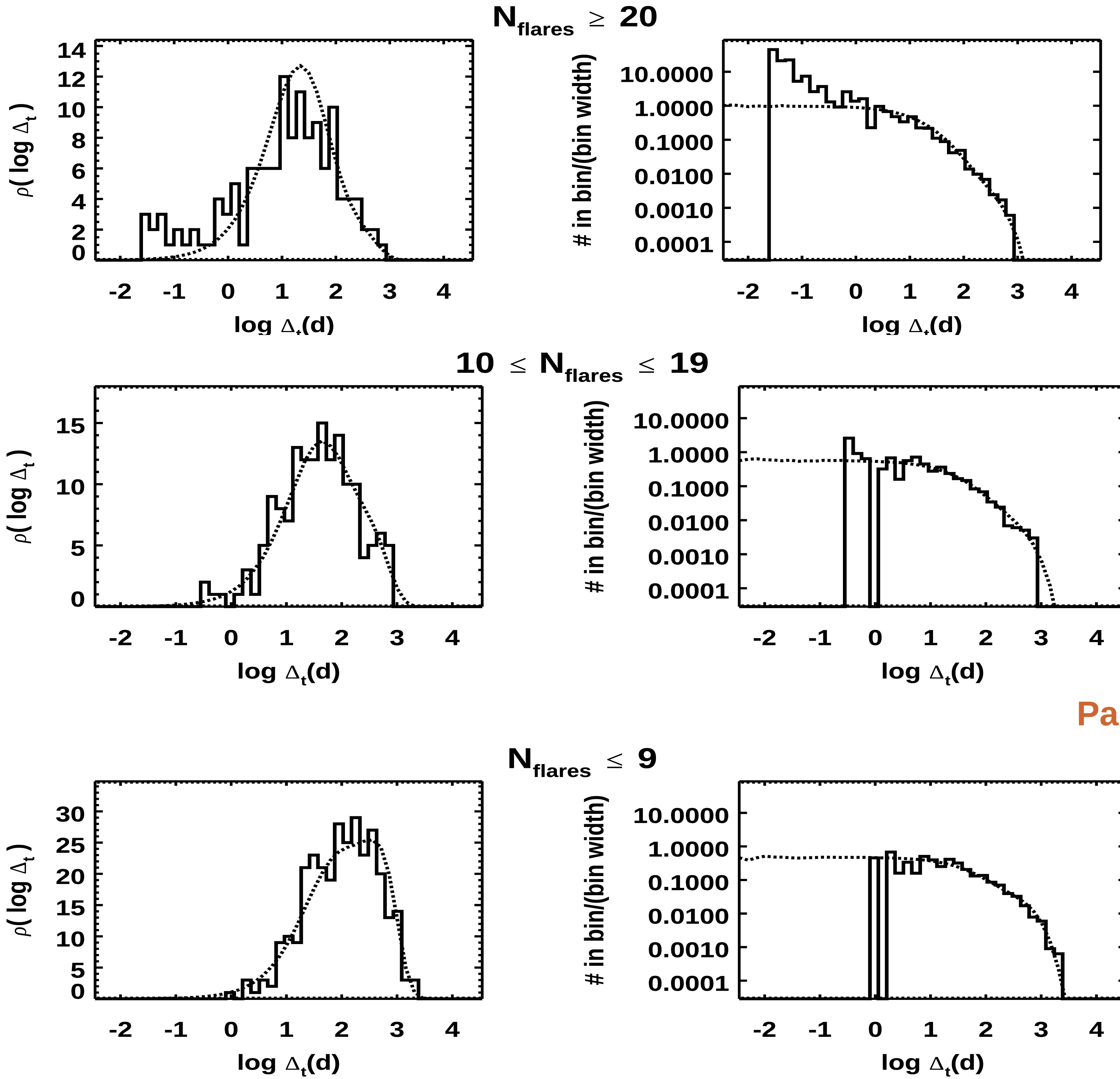




overlapping bursts of flares (multi log-hat distribution) with:

- burst duration T ~0.6y
- burst rate $1.3y^{-1}$
- flares uniformly distributed within the burst

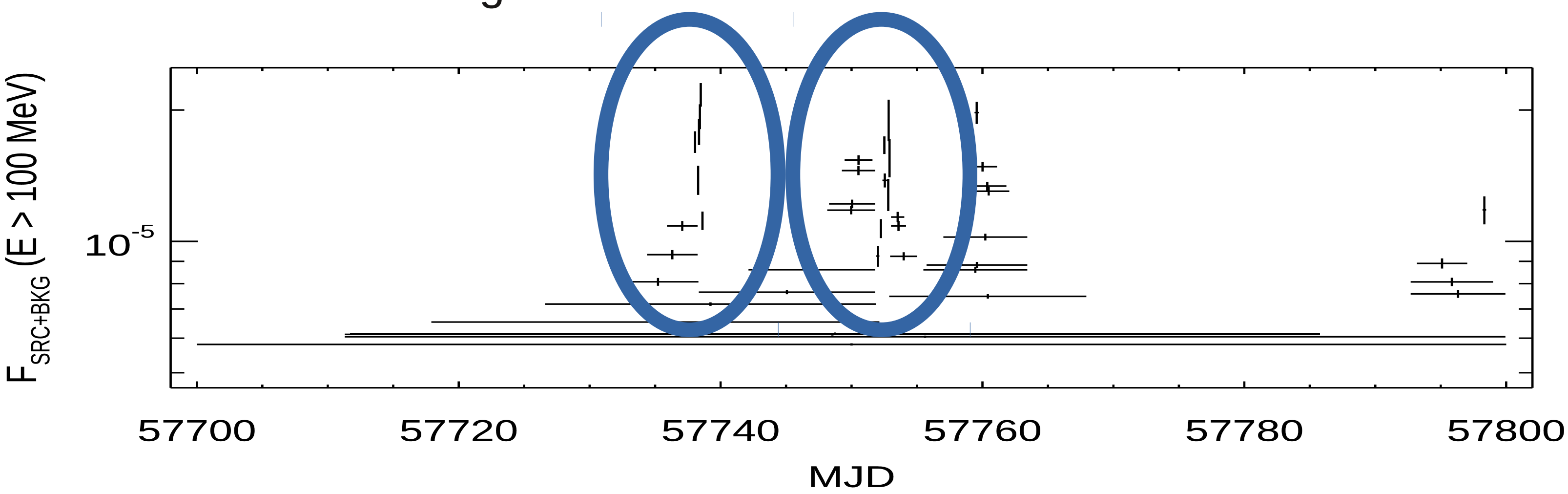
moreover a fast component for Δt<1d



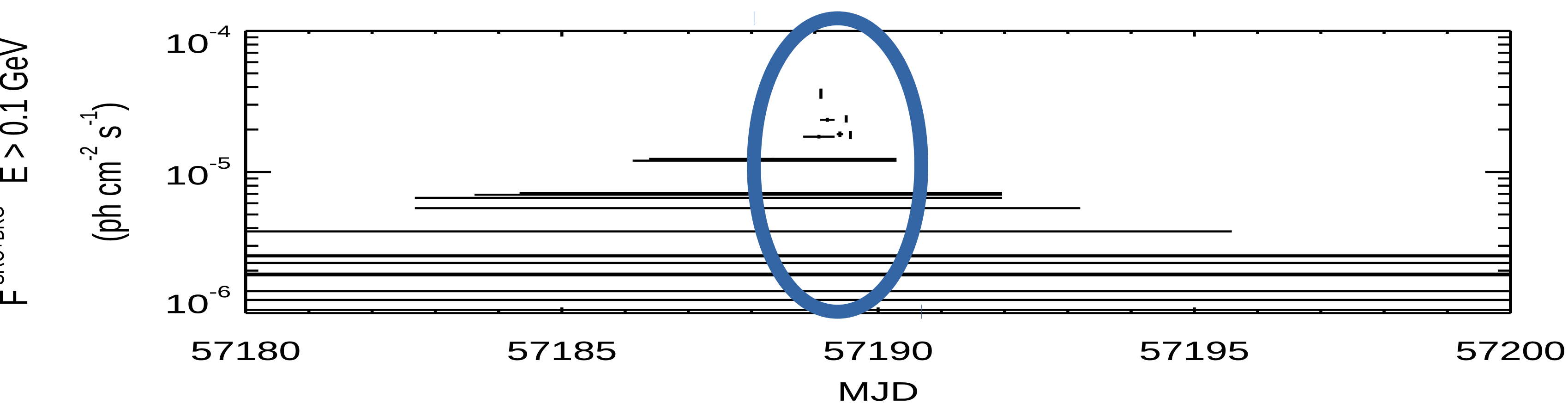
Pacciani 2022

Short Waiting times and Fermi-LAT ToO

Apart from S4 0218+35, FERMI-LAT performed 5 ToO Campaigns on FSRQs during bright flares, and during 3 of theese campaigns we found the large majority of short waiting times:

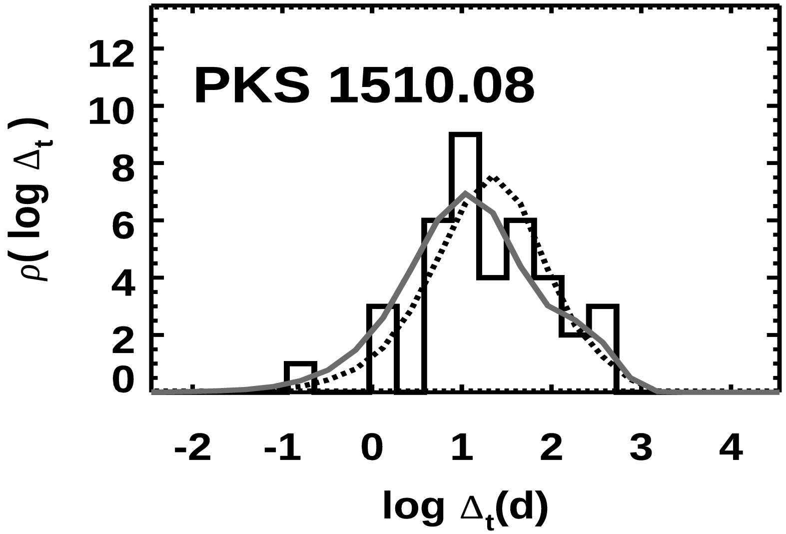


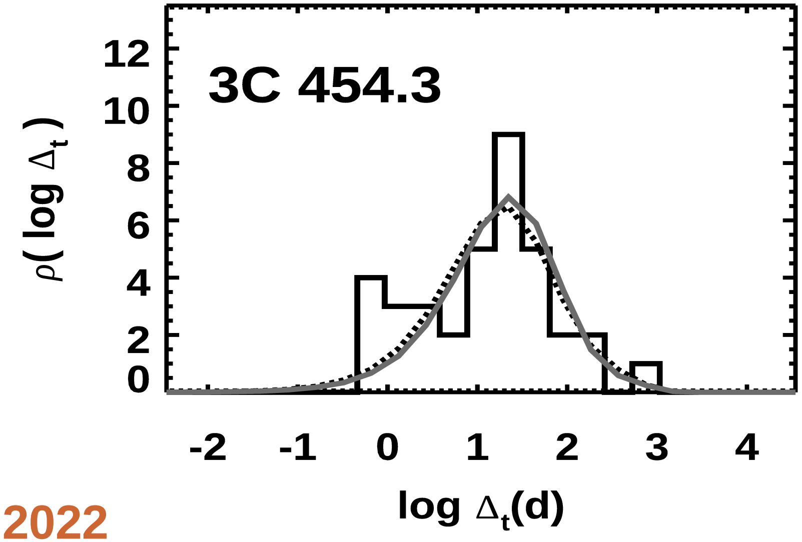
CTA 102



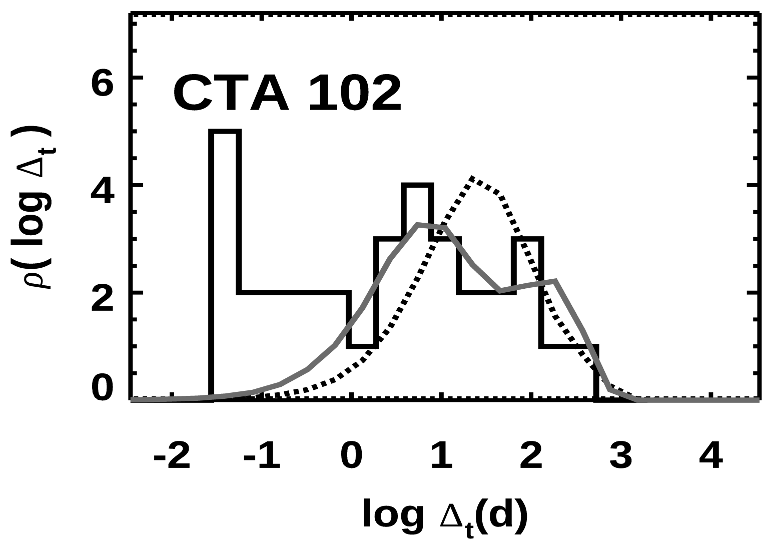
3C 279

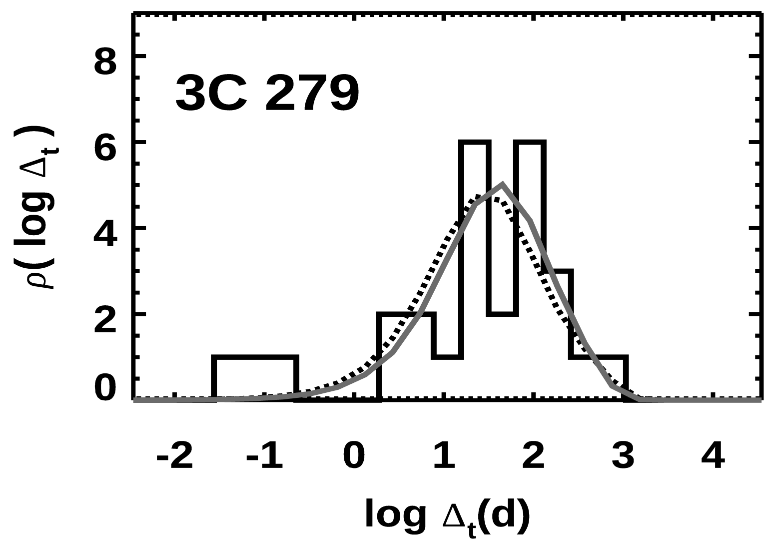
Fit for single sources



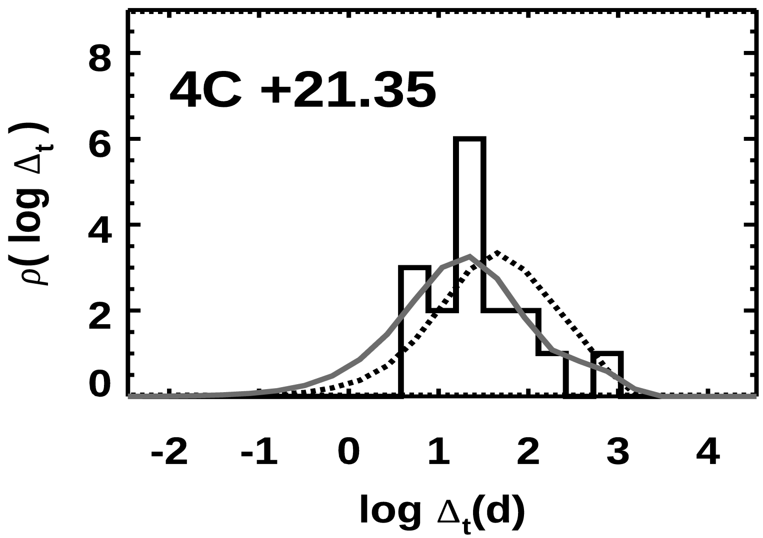


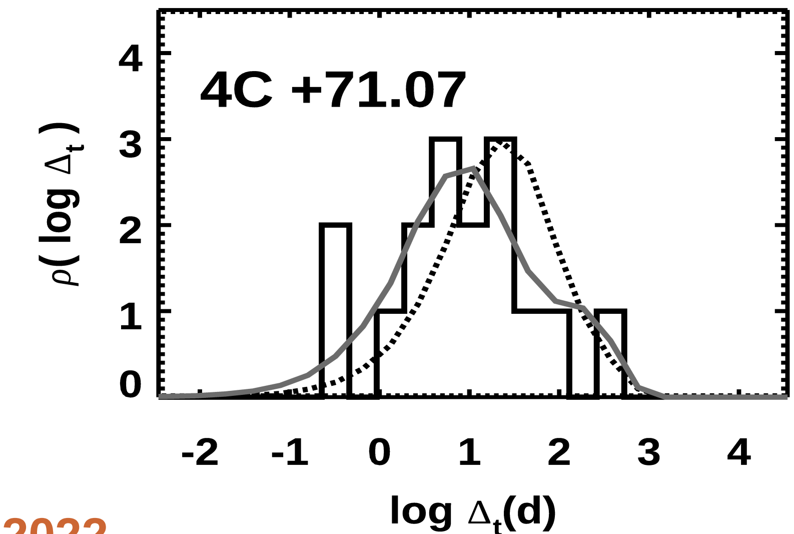
Pacciani 2022



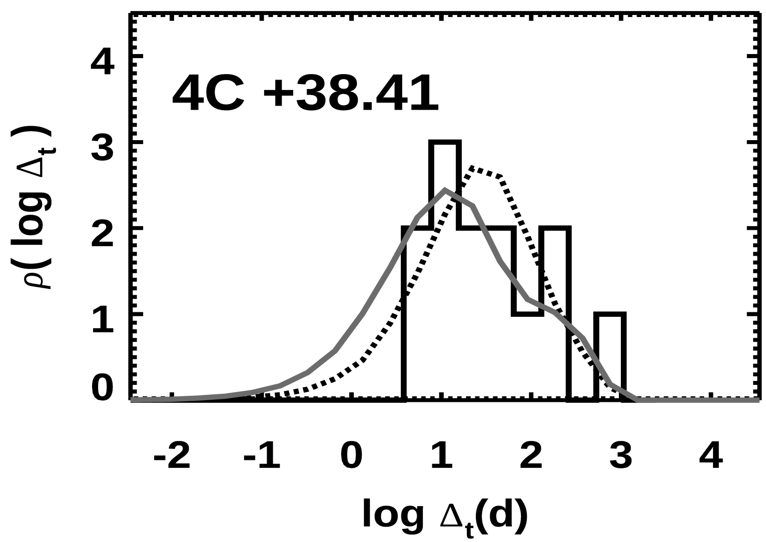


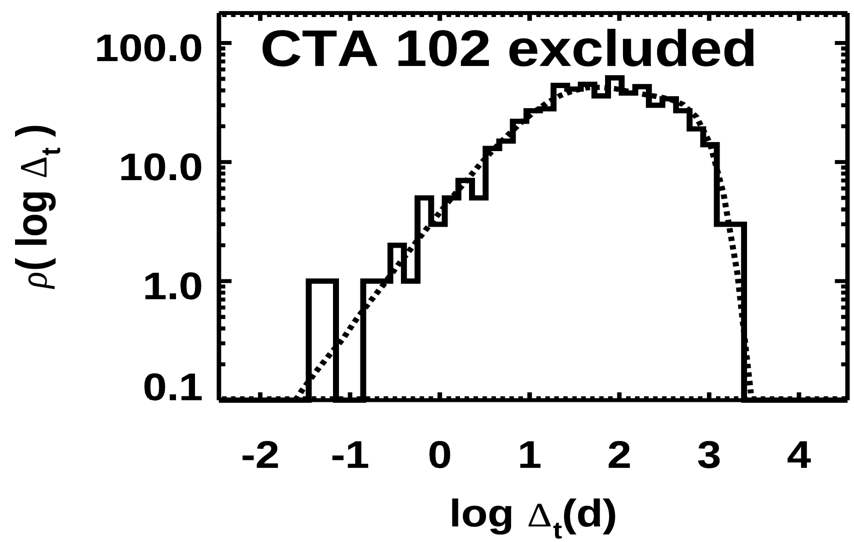
Fit for single sources



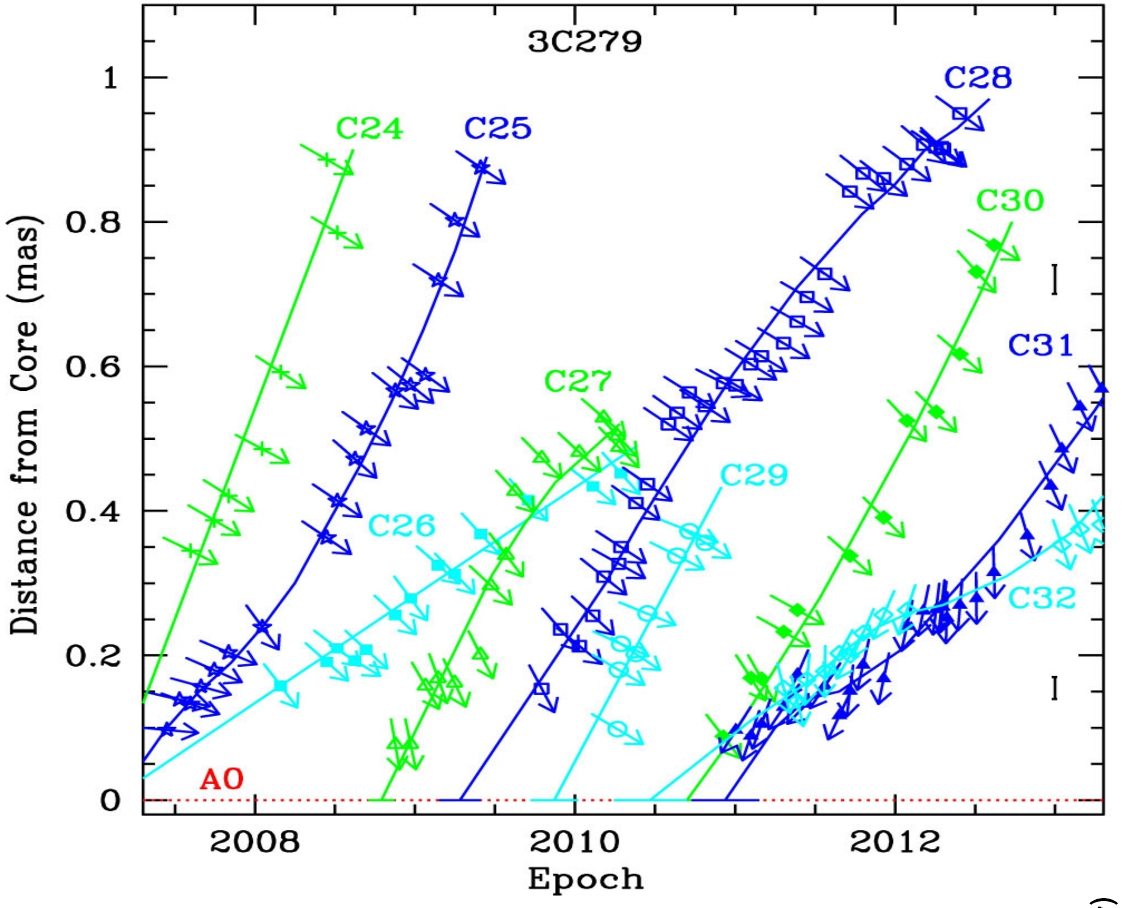


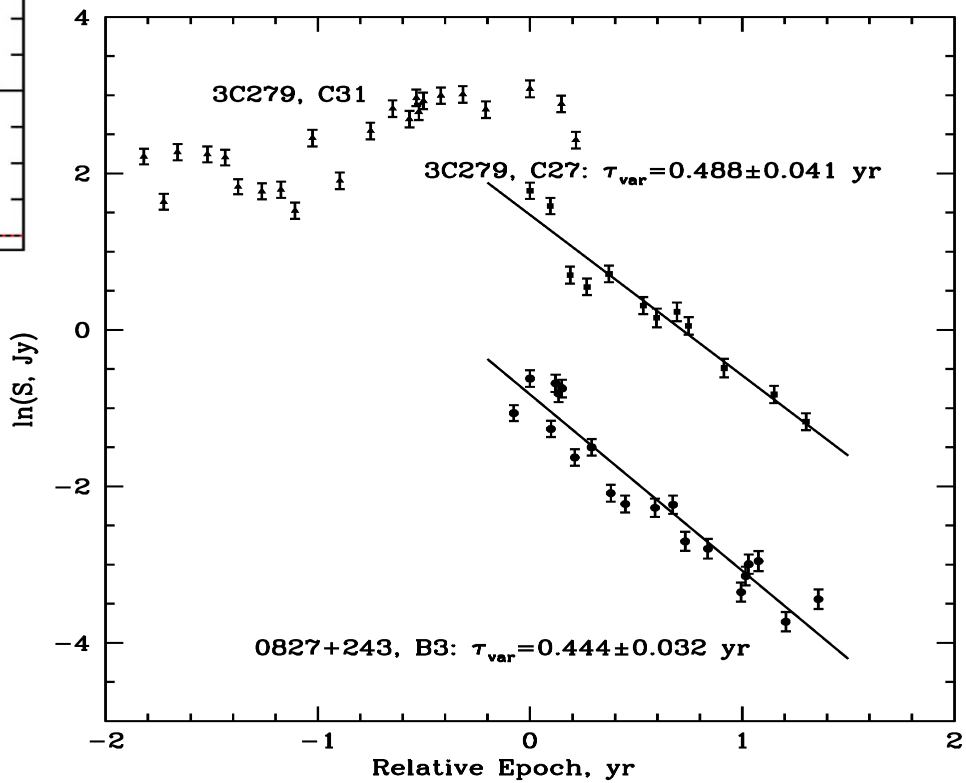
Pacciani 2022





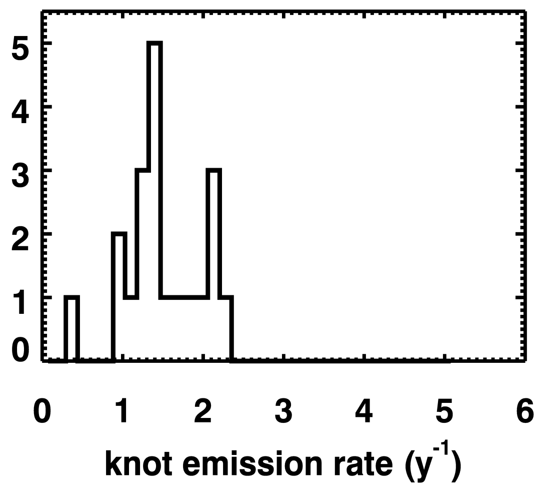
Radio data @ 43 GHz (Jorstad 2017)



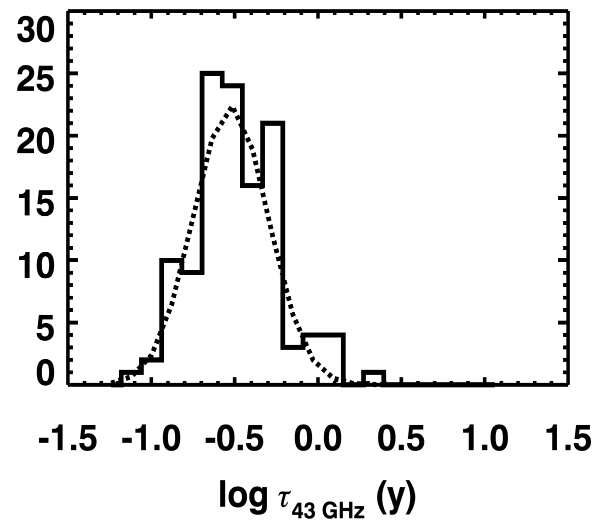


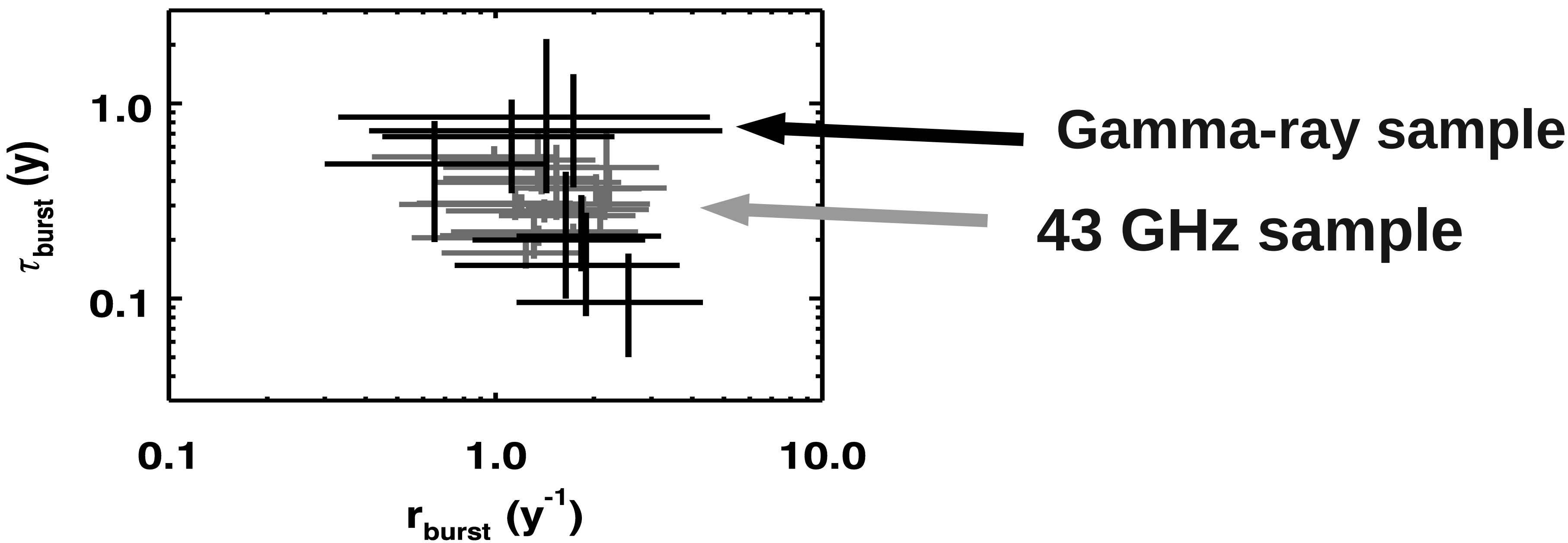
But we expect the synchrotron power to decrease with $1/d^2$. Is the plasma accelerating along its path?

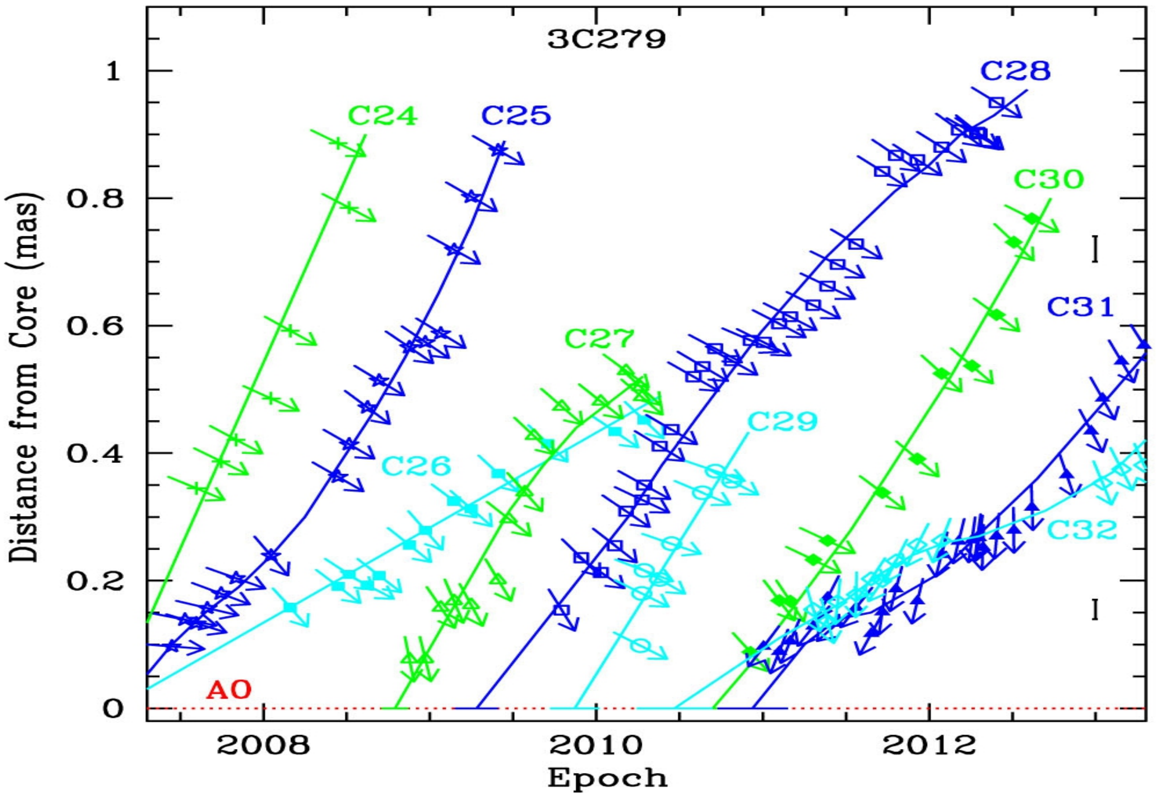
Comparison with Radio data



from Jortad 2017, table 7, and fig. 4

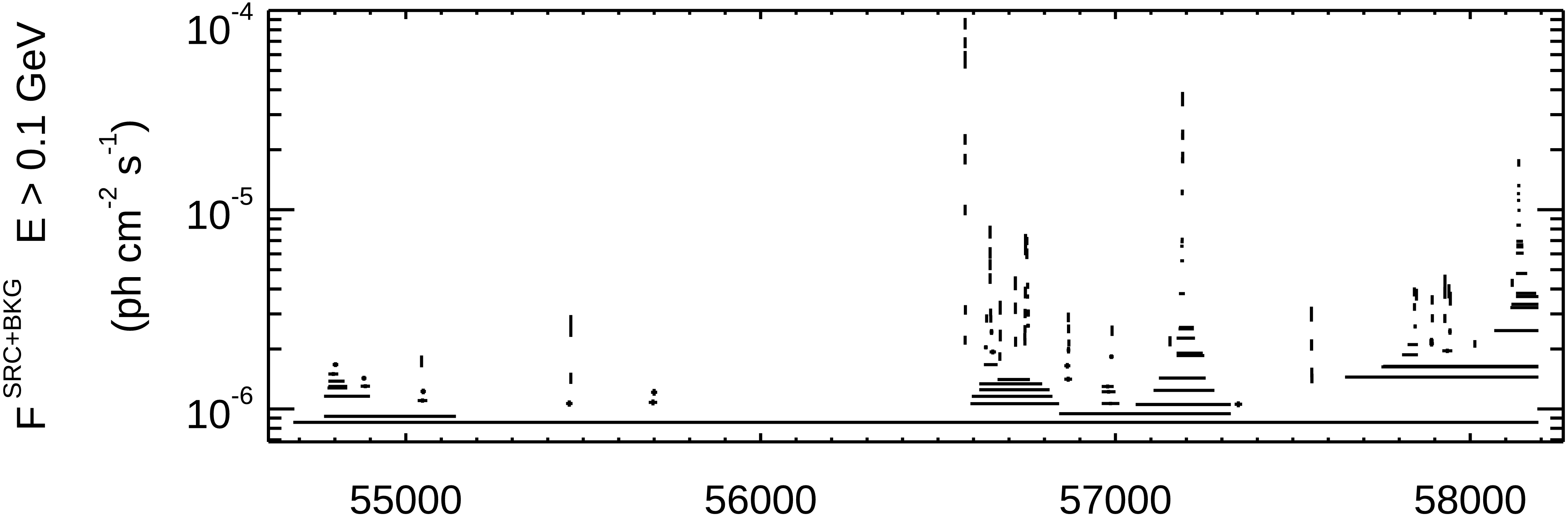


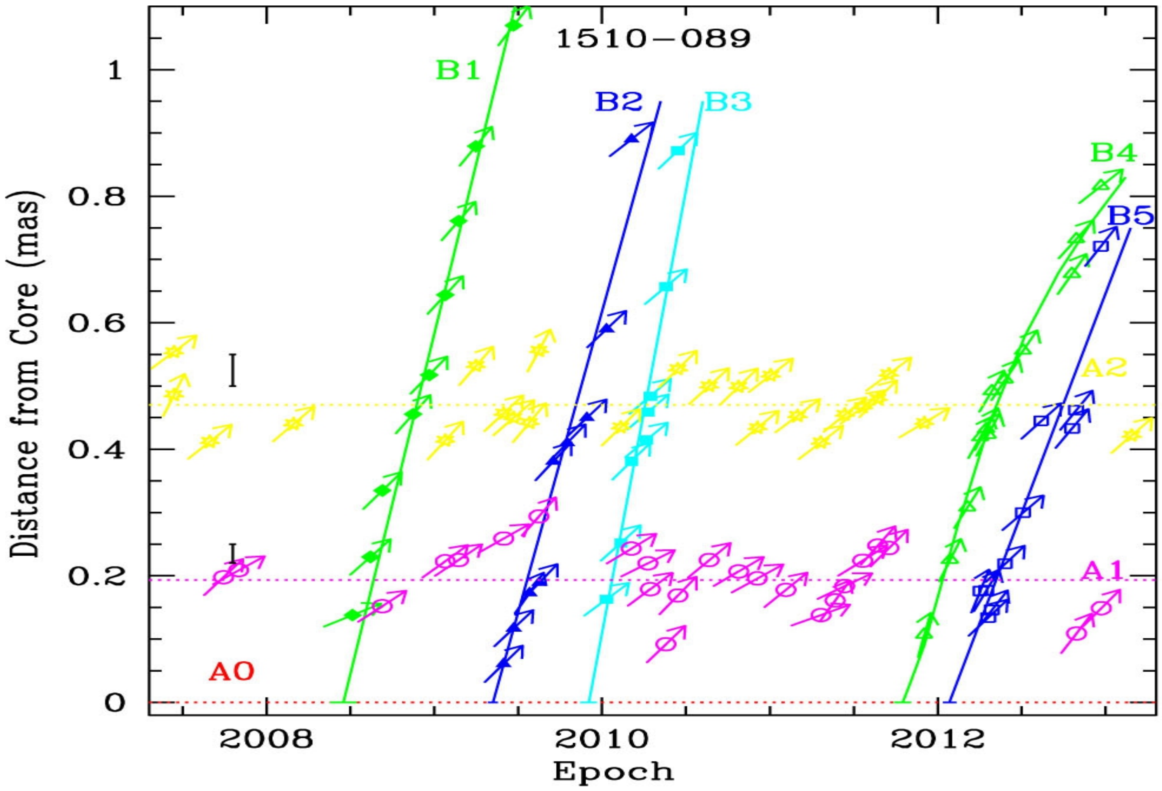




Radio data @ 43 Ghz and Gamma Ray data for 3C 279

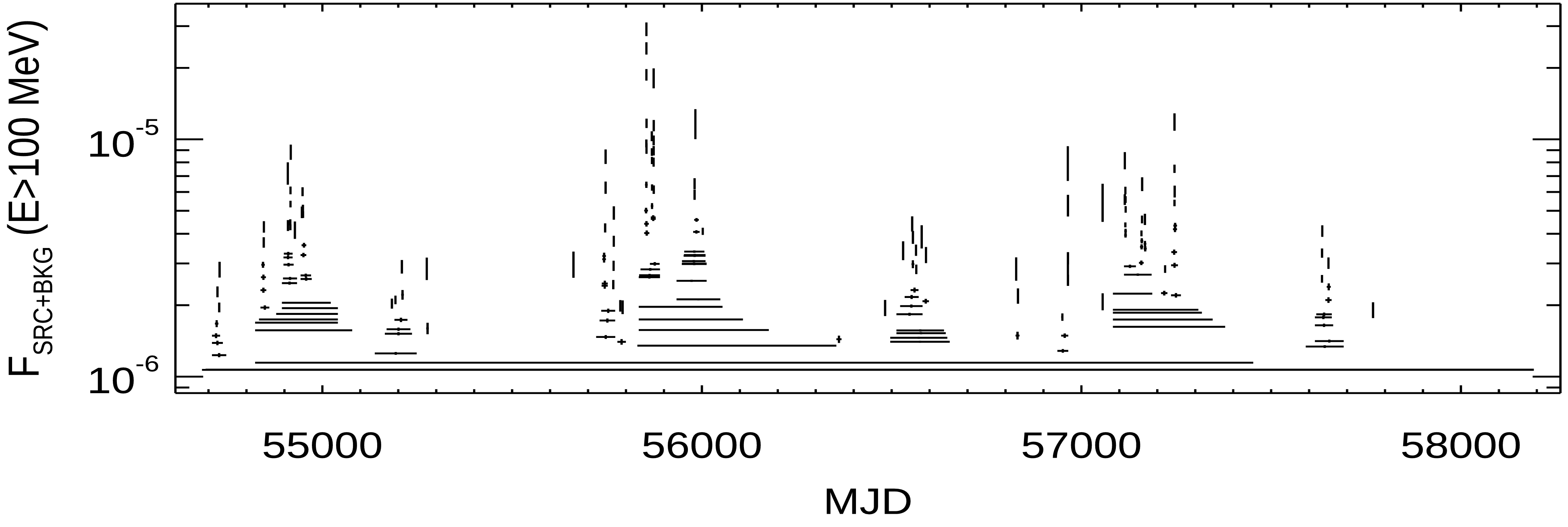
Horizontal scales are aligned in radio and in Gamma-ray



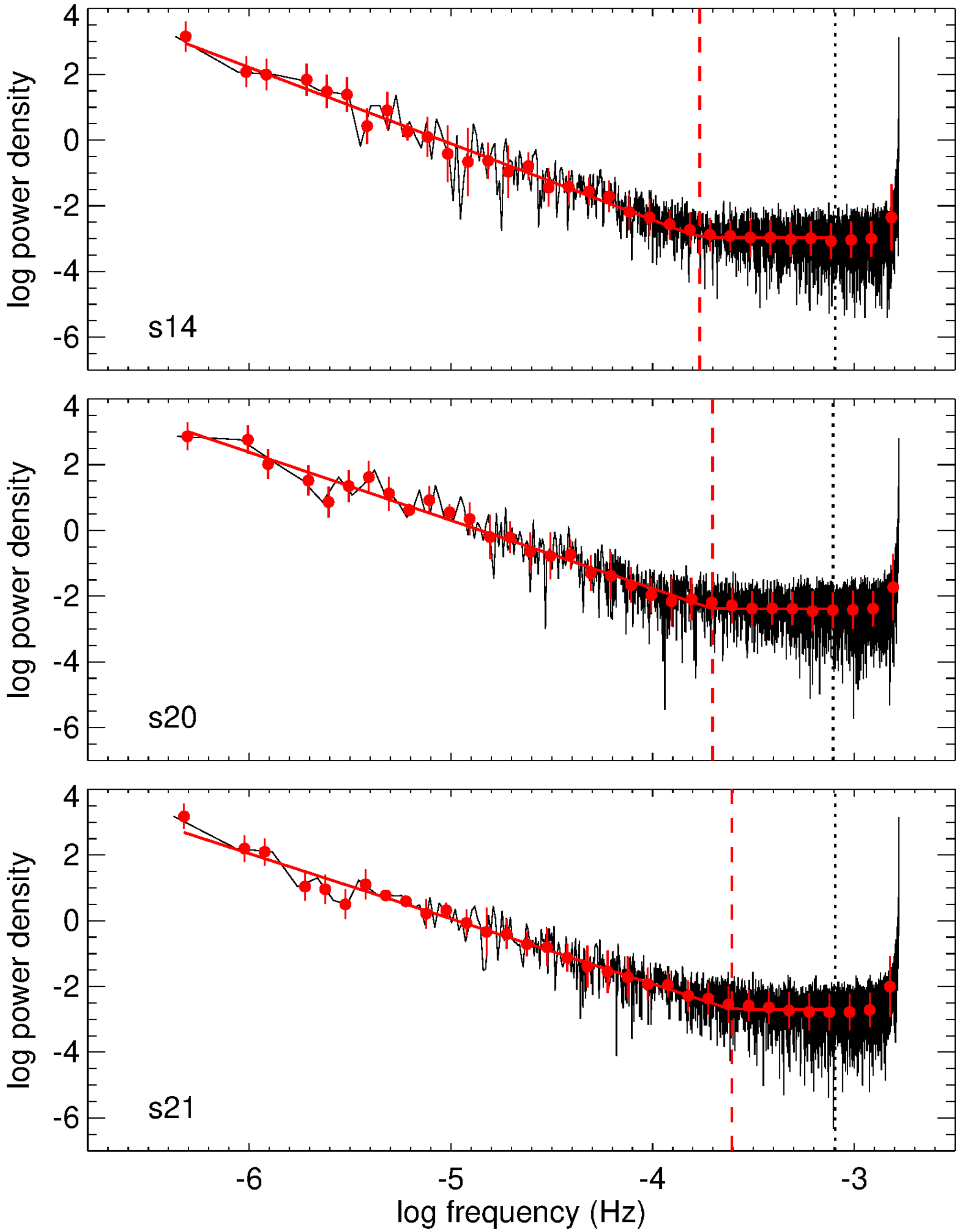


Radio data @ 43 Ghz
and
Gamma Ray data
for PKS 1510-08

Horizontal scales are aligned in radio and in Gamma-ray



comparison with optical

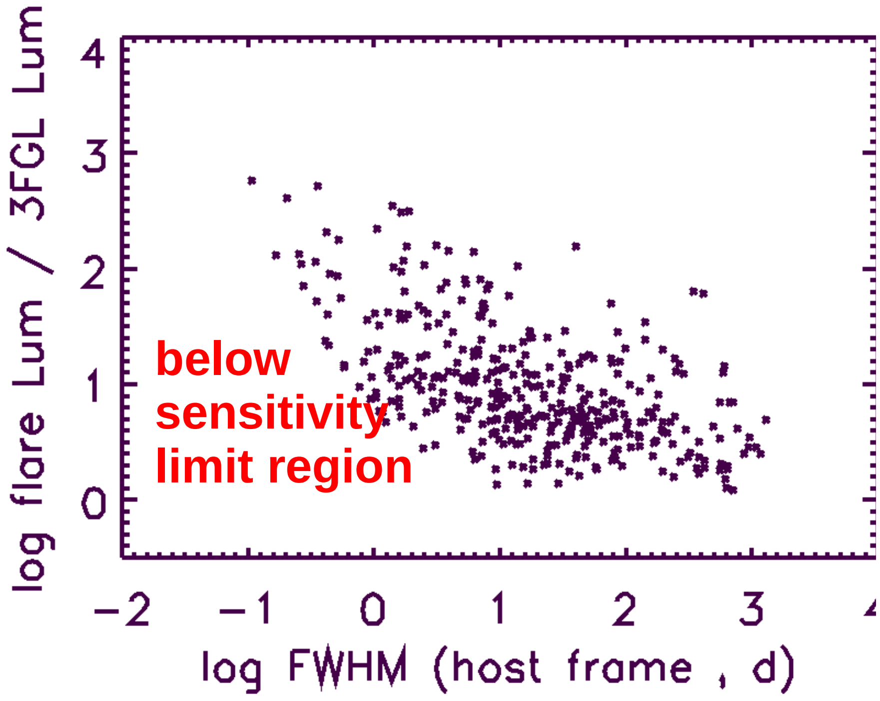


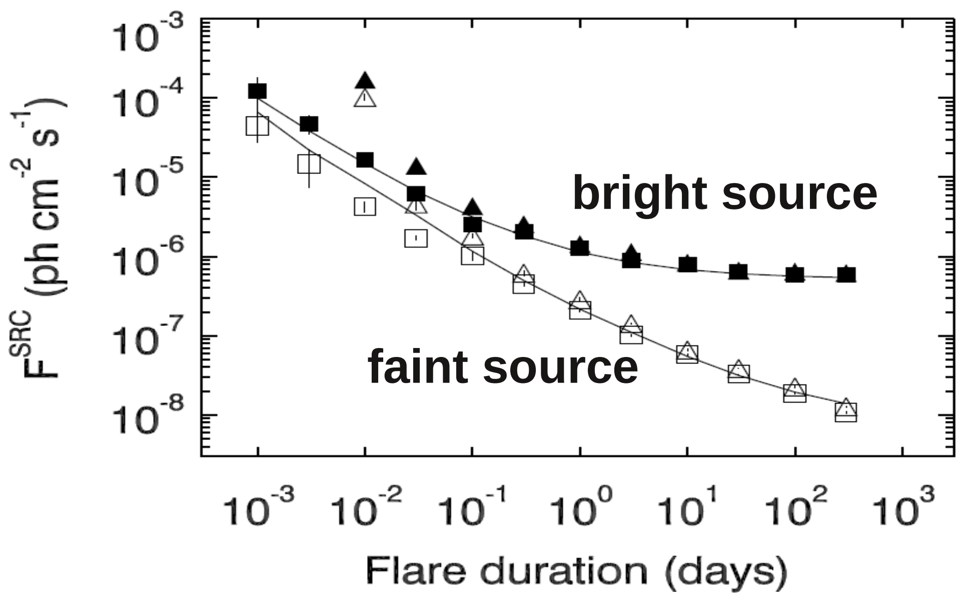
S4 0954+65
(a BL Lac object)
Raiteri 2021

White noise appears for timescales < 1h

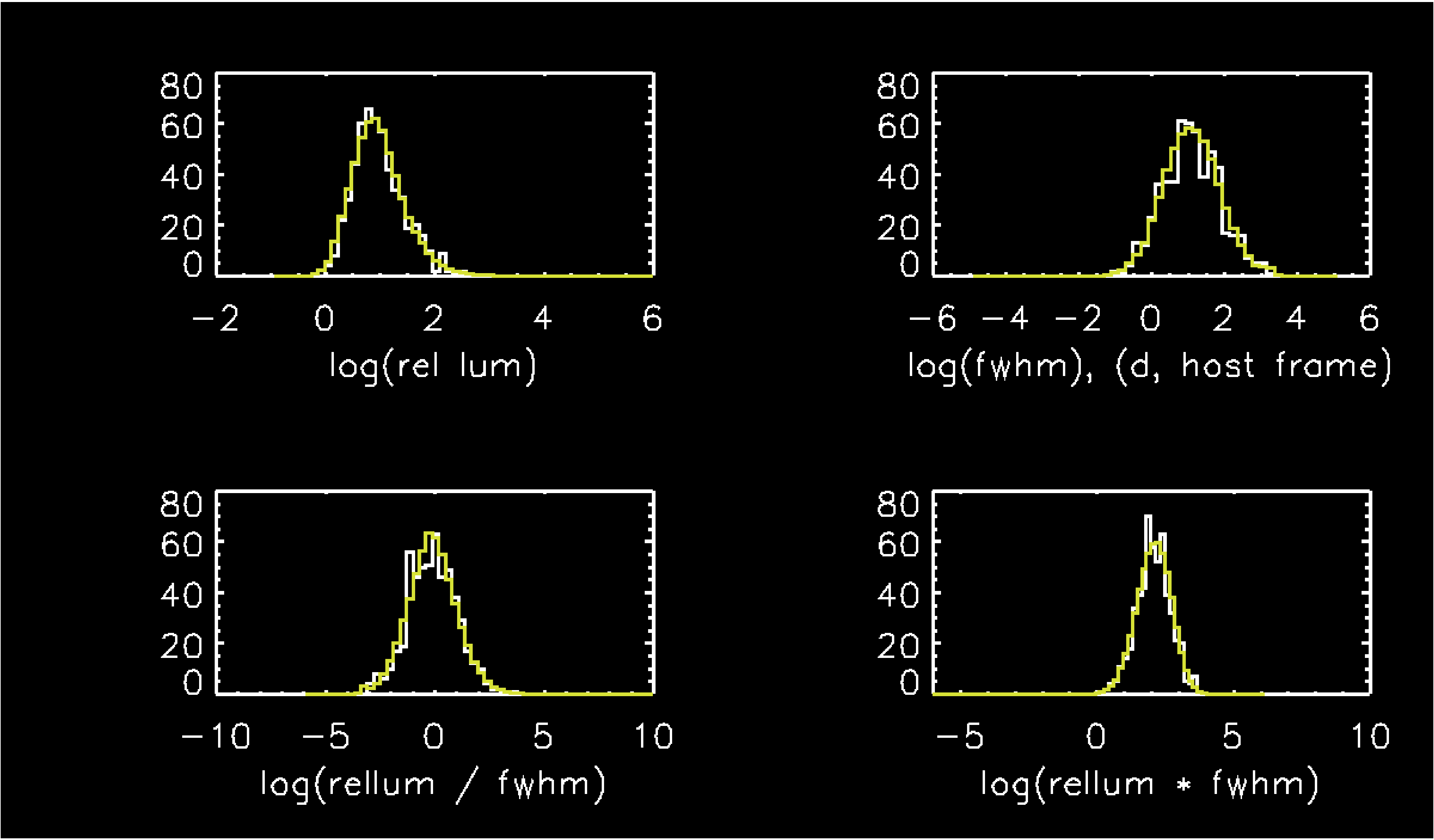
Flaring Luminosity
Vs
flare temporal
FWHM

work in progress

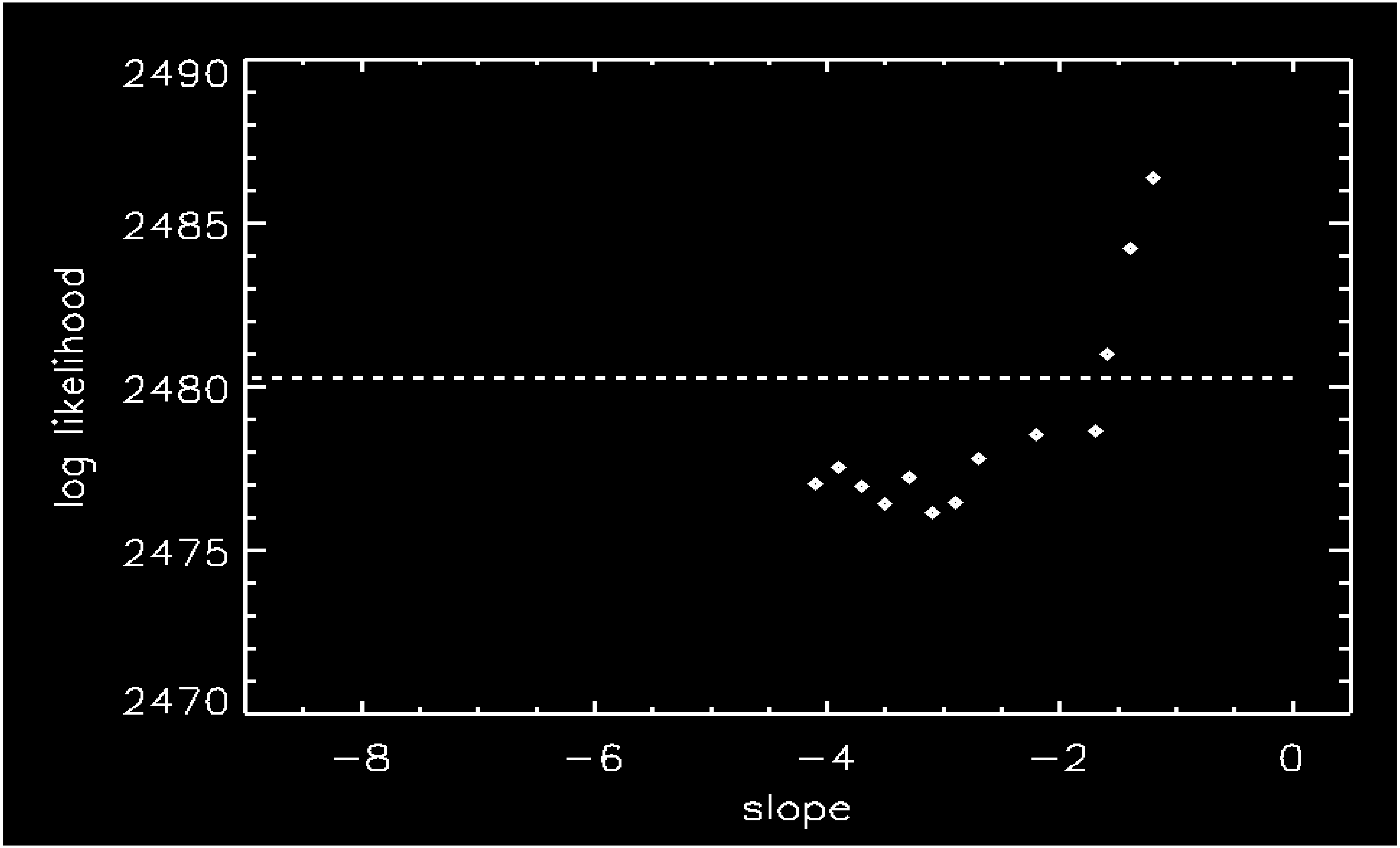




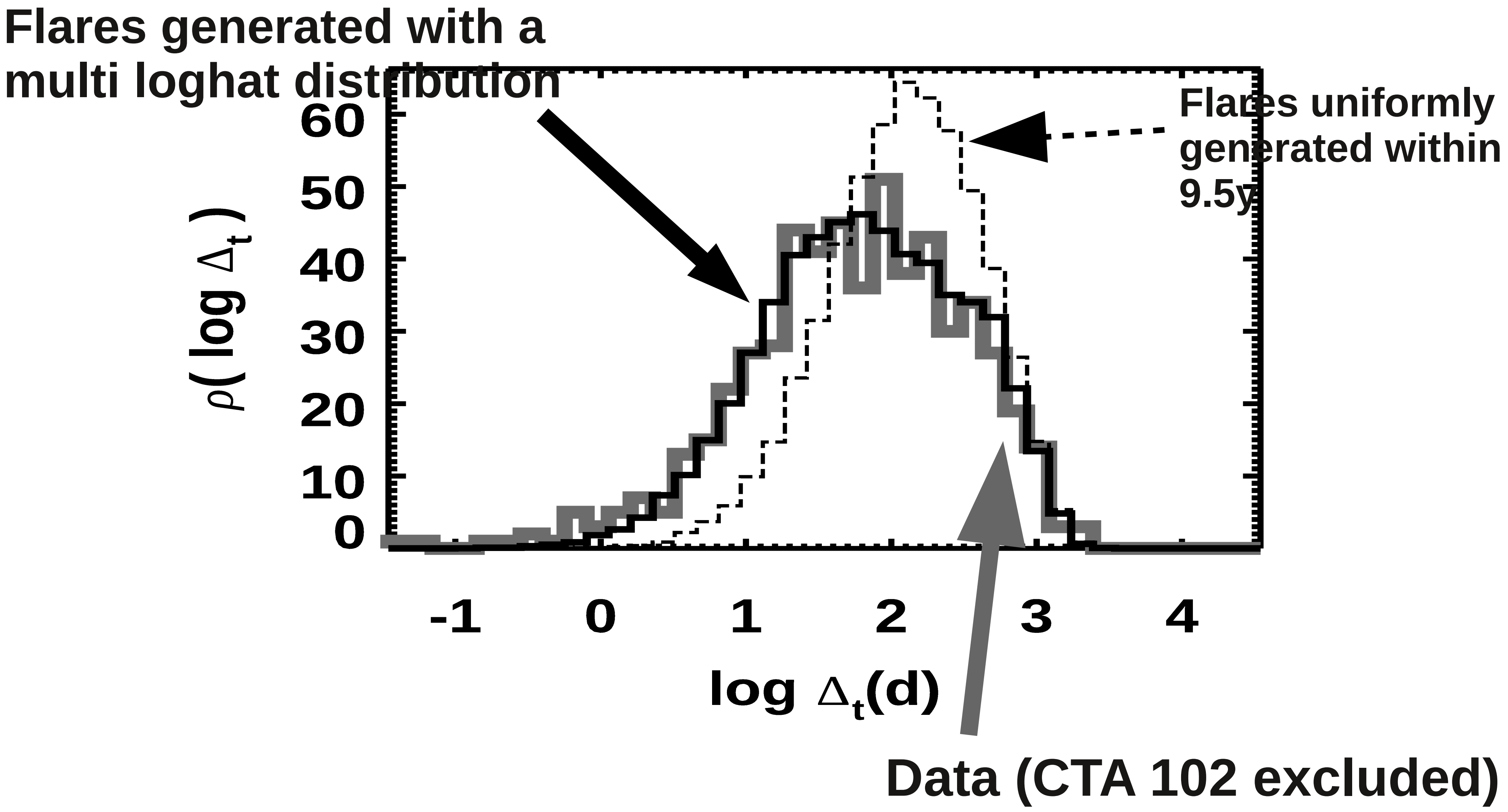
Flare Luminosity and duration distributions (300 MeV sample)



Correlation between luminosity and flare duration (PRELIMINARY)



Fit taking into account for the exposure variation with time and simulating flares



recollimation shock scenario

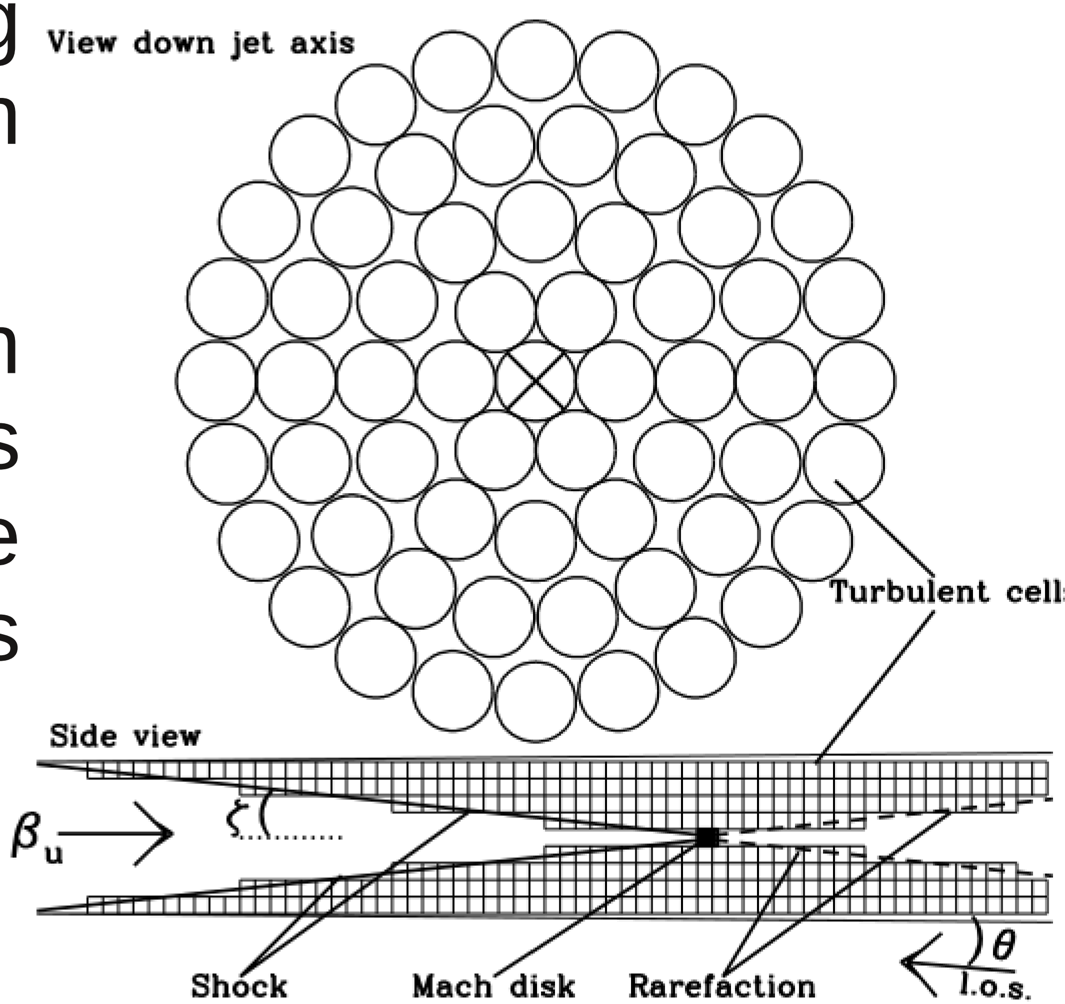
- If gamma-ray flares are produced while the traveling knots cross jet stationary features (recollimation shock scenario, Casadio2015, Casadio2019), from the burst period, knot size along the jet should be ~2pc (knot reference frame).

Turbulence in the jet

electron acceleration is caused by standing conical recollimation shocks.

Flux and polarization variability originates from turbulence in the flow, approximated as cilindrical cells

(Marscher 2014)



Flares emitted along the knot path

- If gamma-ray flares are produced along the path of traveling knots, from the burst duration, the travelled path should be ~30-50pc (assuming a bulk Lorentz factor of 10)
- the energy density of seed photon from BLR, and from the dusty torus should be

  $U_{ext} \sim 1/d^2$

- the magnetic field energy density should be reduced of the same amount
- $U_B \sim 1/d^2$
- Both radio knot emission, both gamma-ray emission should be extremely weak toward the path end
- Could acceleration of superluminal radio features compensate for the decrease of energy density along the path (actually 18% of moving knots observed at 47GHz show acceleration, Weaver 2022)?

Magnetic reconnection scenario

at ~1 TeV:

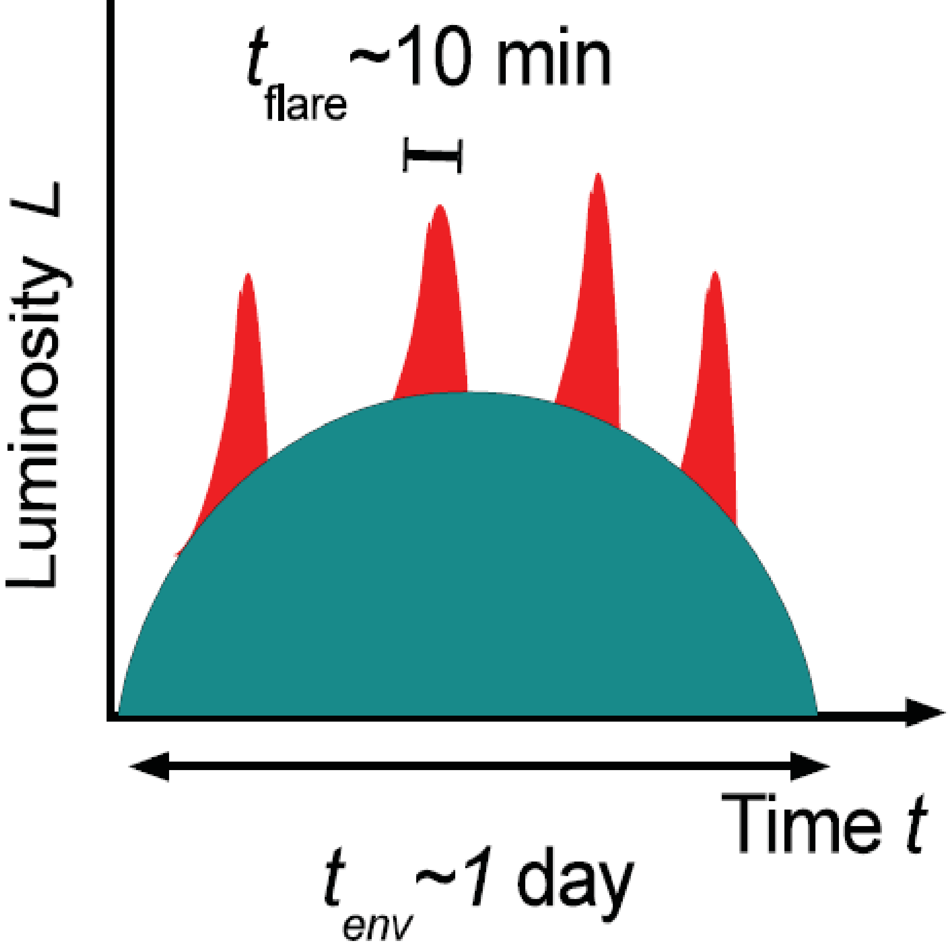


Figure 2. A sketch of the envelope-flare structure of the emission from a reconnection layer. The envelope duration corresponds to that of the reconnection event: $t_{env} = l'/\Gamma_j \epsilon c$. Monster plasmoids power fast flares which show exponential rise and last for $t_{flare} = 0.1 l'/\delta_p c$. For an envelope of $\sim$1 d blazar flaring, the model predicts that monster plasmoids result in $\sim$10-min flares.

Giannios 2013

Recent scenario for magnetic reconnections proposed for strongly magnetized jets (Giannios 2013) includes an envelope emission (lasting ~1 day) powered by plasmoids, together with fast flares (lasting ~10 min) generated by grown "monster plasmoids".

In low magnetized plasma (such as at several parsec), reconnection time scales are longer, and longer flares (days to weeks) could arise (Giannios 2013).

"Monster plasmoids" contain energetic particles freshly injected by the reconnection event (Uzdensky et al. 2010)

Large variability observed when the reconnection layer is aligned with the jet axis and with the observer line of sight (Christie 2019)

Comparison with results for Quasars

- optical variability of quasar can be described wth a damped random walk with $\tau_{damping}$ of the order of several hundread of days (Kelly 2009, Ivezic & McLeod 2013);
- **$\tau_{damping}$ ~110-260 d** for SMBH with mass in the range of 10^8-10^9 (Burke 2021);
- Radio Loud Quasars show **excess white noise** for timescale below 1 day (kelly 2009);

Conclusions

- **Waiting time distribution of FSRQs can be modeled with a set of overlapping bursts of flares with burst duration of ~0.6y, burst rate ~1.3y^{-1} + a fast component (for $\Delta t < 1d$)**

- If flares are generated while the knot is crossing a stationary feature along the jet
  - the knot size along the jet should be ~2pc

- Flares could be generated along the path of superluminal knots traveling for ~30-50pc
  - but both the magnetic field energy density both the external photon energy density decreases with $1/d^2$ (**why do we see those fading radio features?**)
  - Could acceleration of superluminal radio features compensate for the decrease of energy density along the path?

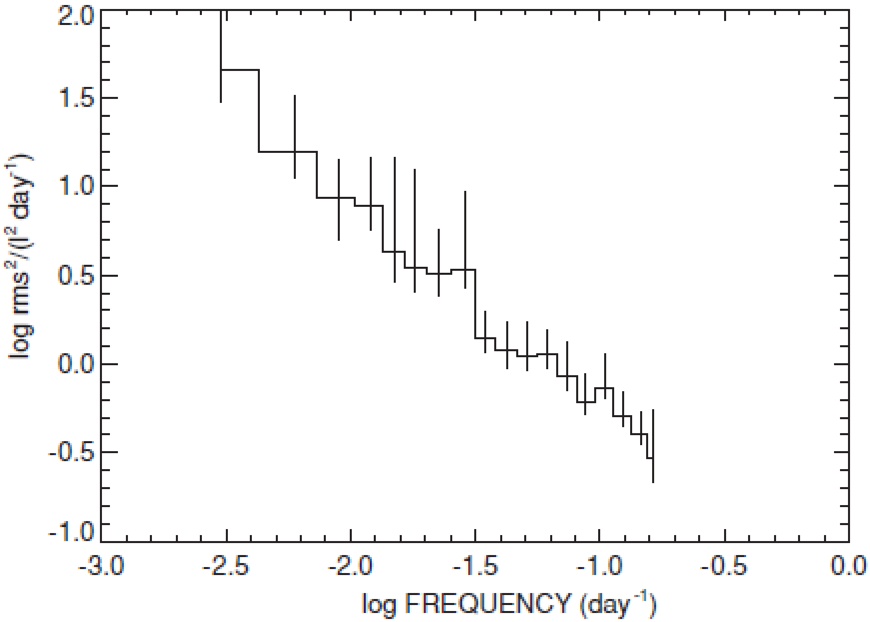
- Magnetic reconnection could account for the observed waiting times if the magnetic field instabilities generating reconnection events (or the duration of plasma injection) lasts 0.6y, and if the generation rate of instabilities (or the rate of sporadic plasma injection) is ~1.3y^{-1}

- Could the waiting time distribution have the same origin that in Quasars?

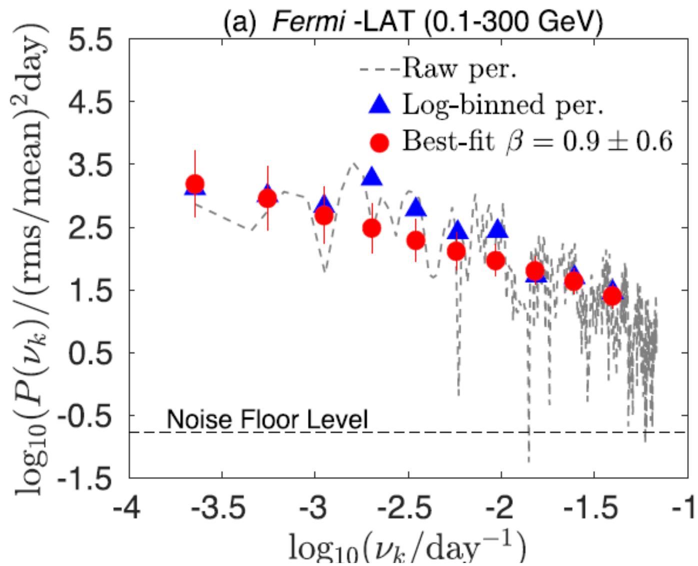
- While the short component represents a small subset of waiting times, it was found during 3/5 Fermi-LAT ToO campaings during bright FSRQs flares. It could witness that **structured flares are not so rare.**

Backup slides

PSD in gamma-rays

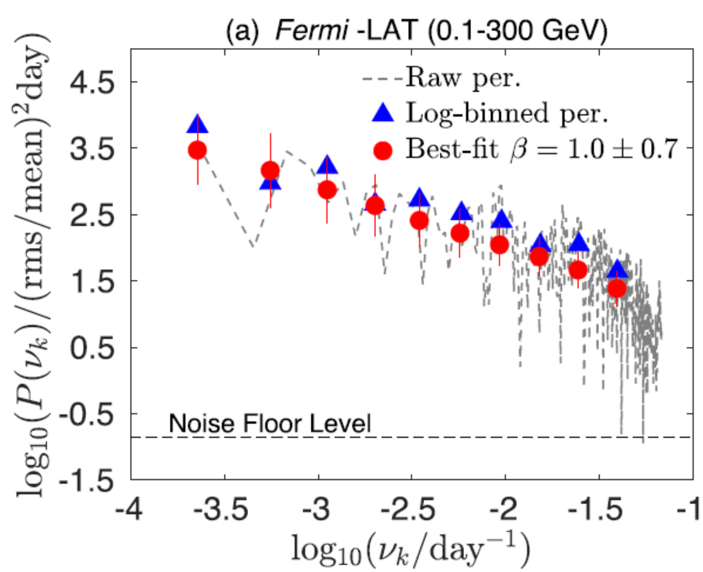


PSD of the 9 brightest FSRQs
slope = 1.4±0.1
(11 months data)
Abdo et Al 2010



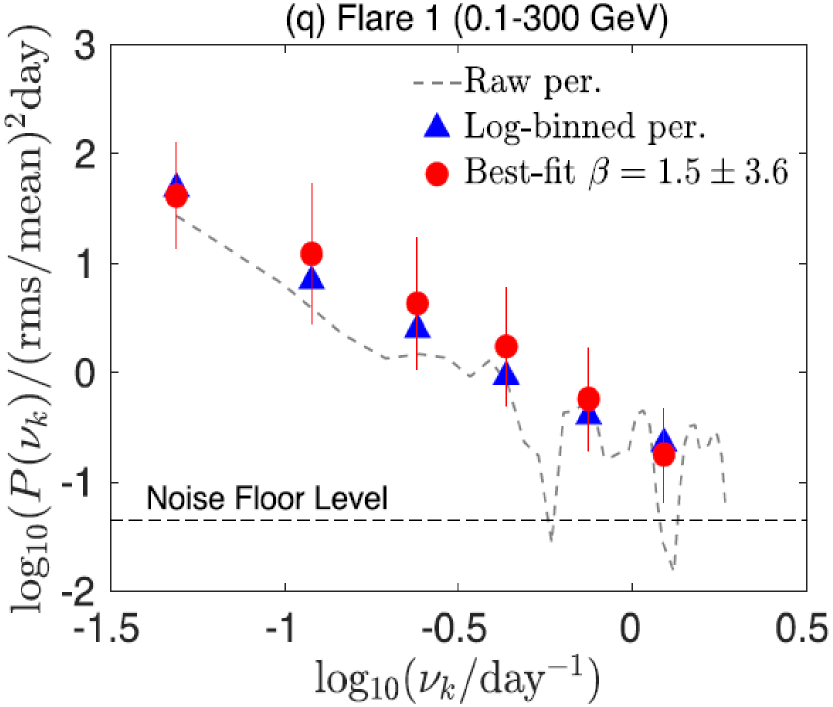
PKS 1510-08

12.1 years
7 days
time binning
(Goyal 2022)



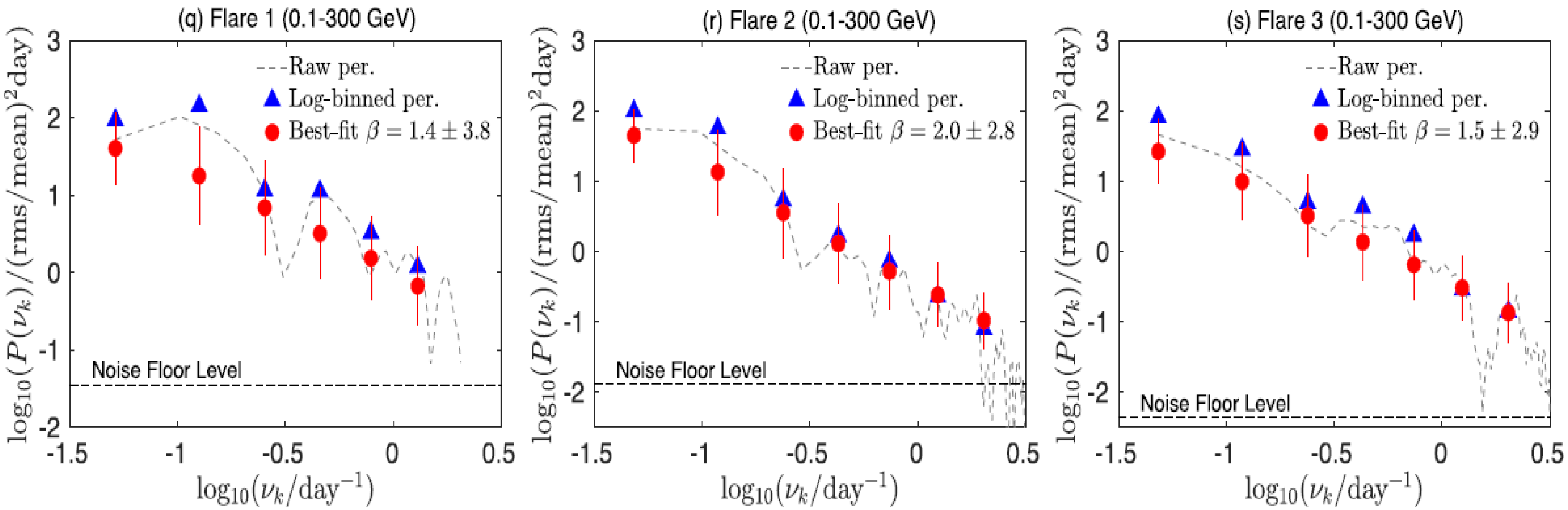
3C 279

PSD in gamma-rays (flares)

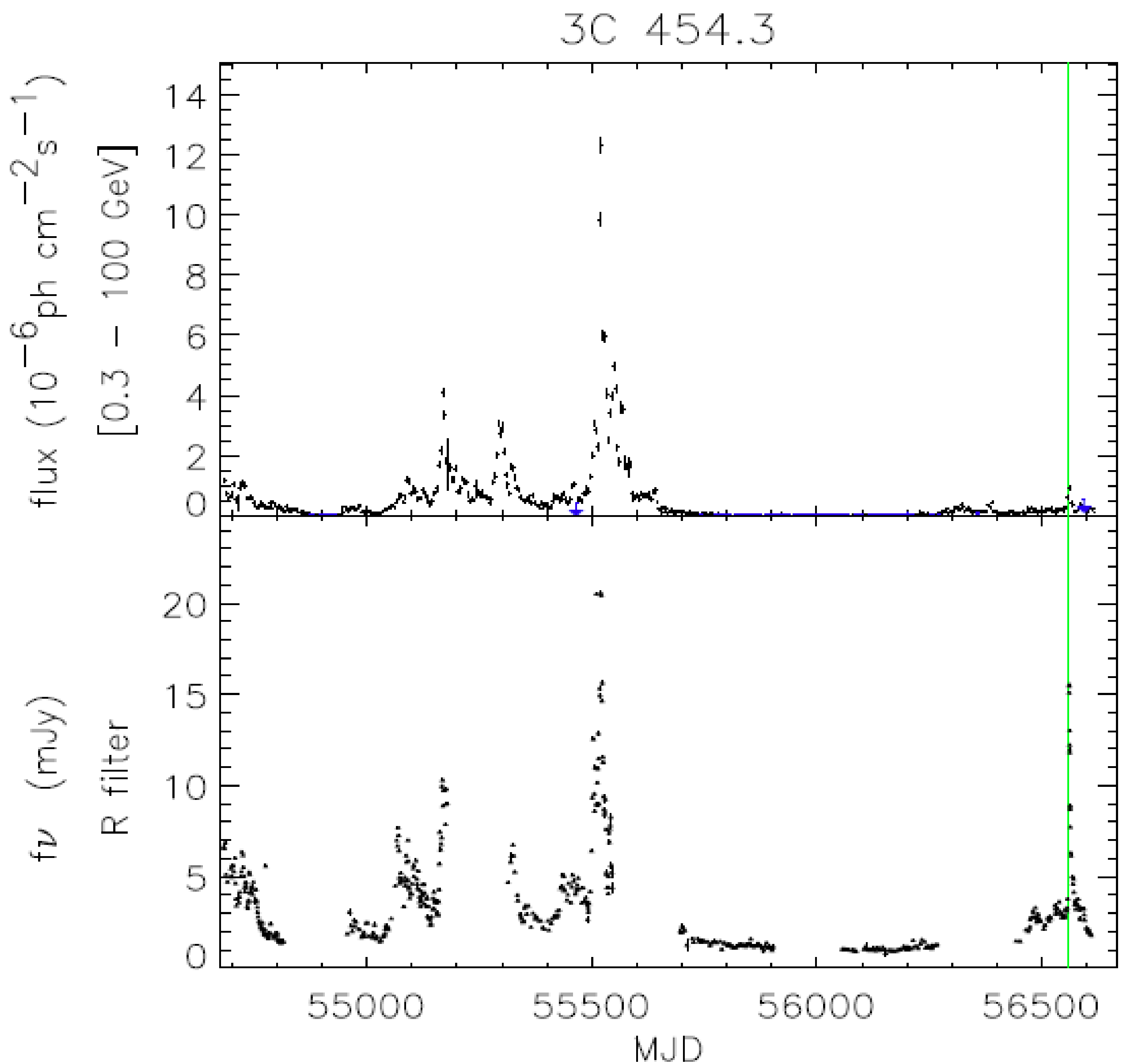


PKS 1510-08

12.1 years
7 days
time binning
Goyal 2022



3C 279


3C 454.3
flux (10^{-6} ph cm^{-2}s^{-1})
[0.3 – 100 GeV]
fν (mJy)
R filter
MJD
0
2
4
6
8
10
12
14
0
5
10
15
20
55000
55500
56000
56500