The observability of plasmoid-powered γ-ray flares w the *Fermi* Large Area Telescope

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Maria Petropoulou

Department of Physics
National & Kapodistrian University of Athens

In collaboration with:

Manuel Meyer (Erlangen Center for Astroparticle Physics)
Ian Christie (Northrop Grumman)

on behalf of the *Fermi*-LAT Collaboration

Blazars

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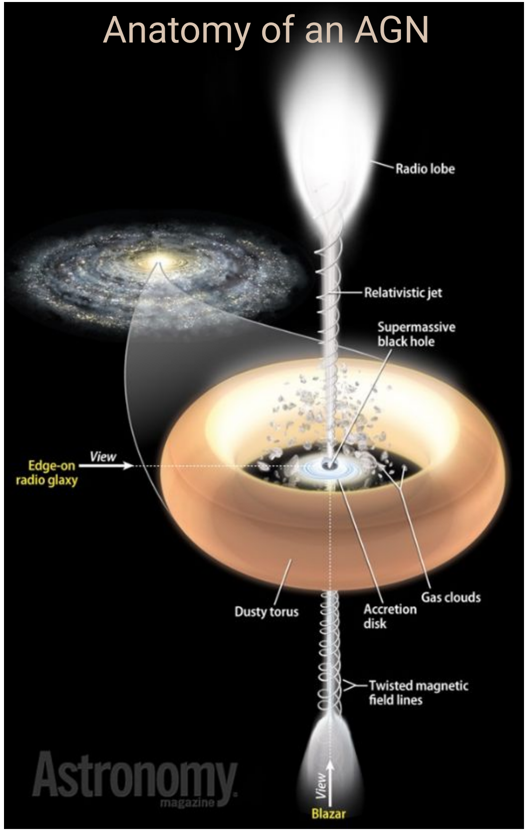
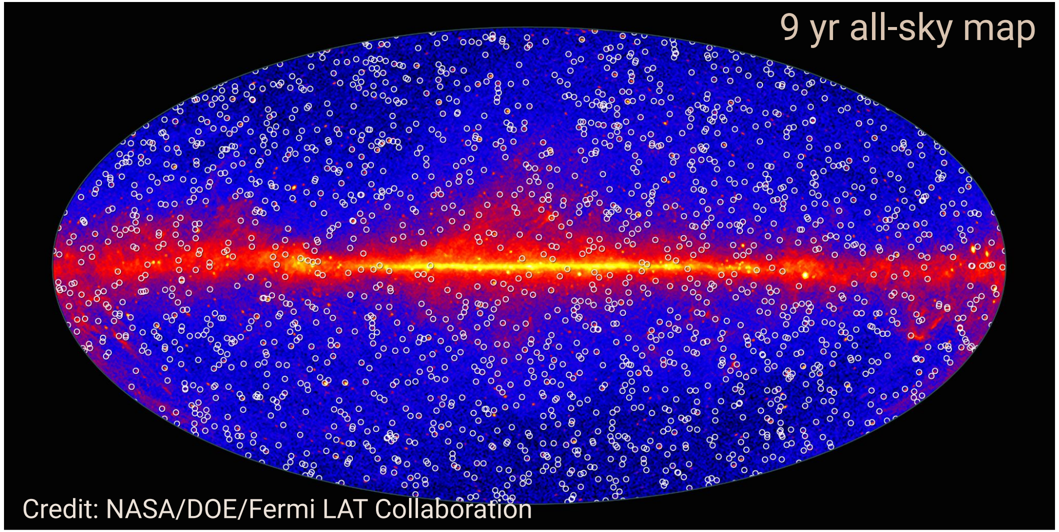


- Most extragalactic γ-ray sources are active galactic nuclei (AGN)
- Blazars are AGN with jets closely aligned to the line of sight



Motivation

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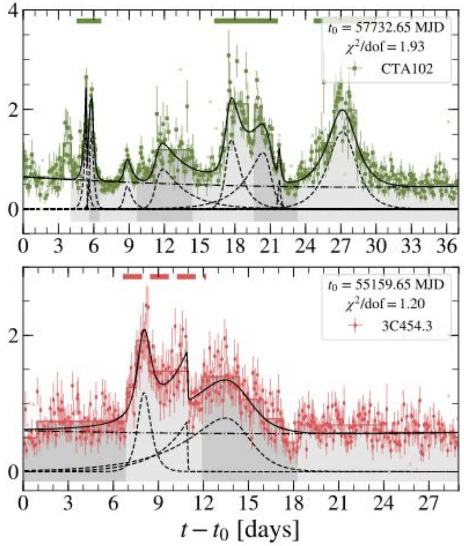
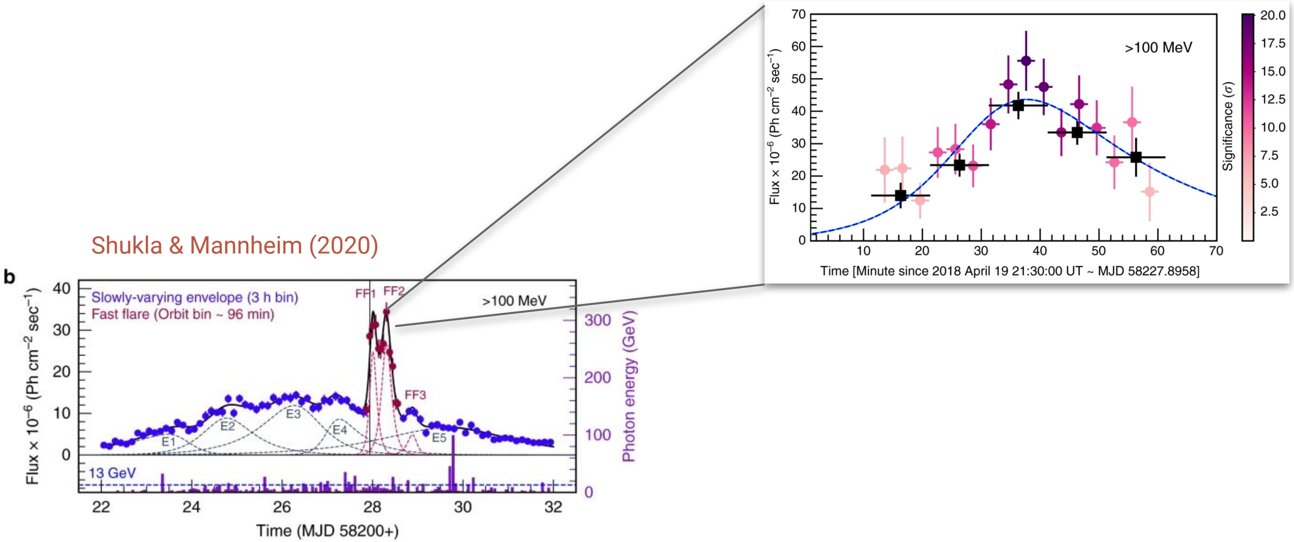
- Blazar γ-ray variability occurs on different timescales (months/weeks to hours/minutes)
- Short-duration flares usually emerge on top of slower varying emission
- Origin of short-duration flares is still a mystery!

Meyer, Scargle, Blandford (2019)



Shukla & Mannheim (2020)



Magnetic reconnection

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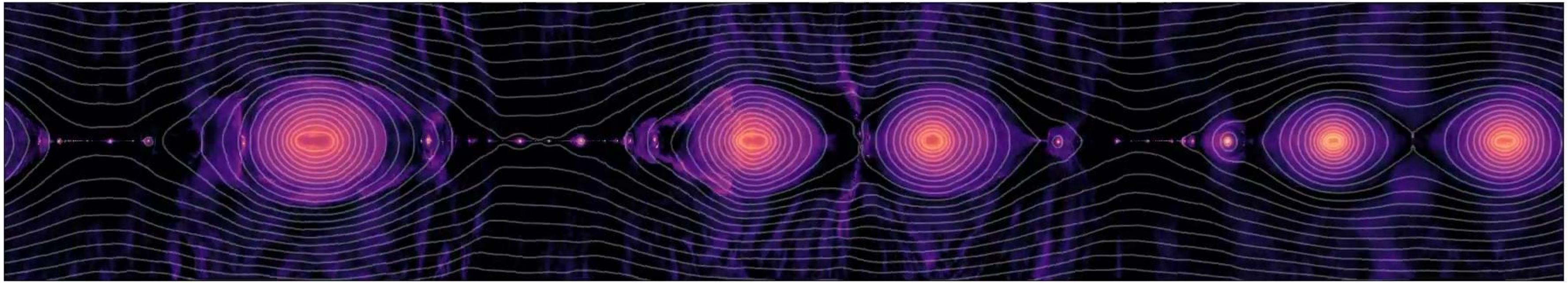

Credit: H. Hakobyan

When?

Magnetic field lines of opposite polarity are brought together by bulk plasma motions

What?

Magnetic energy is transformed to heat, bulk plasma kinetic energy and kinetic energy of relativistic particles

Plasmoids

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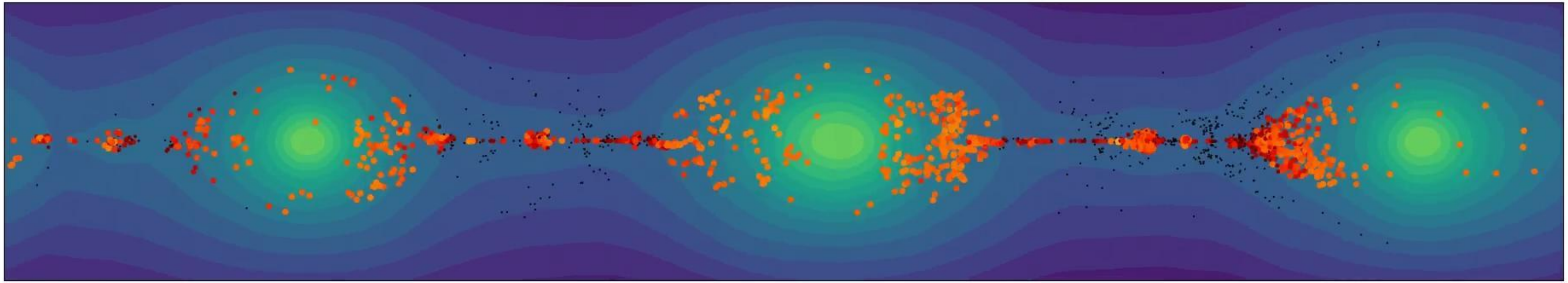

Credit: H. Hakobyan

Current sheet fragments into quasi-spherical plasma structures known as *plasmoids* that

- contain relativistic particles in rough energy equipartition with magnetic fields
- can move along the current sheet with speeds approaching the speed of light
- have a finite lifetime

Each plasmoid produces a flare with characteristic duration and flux !

Model

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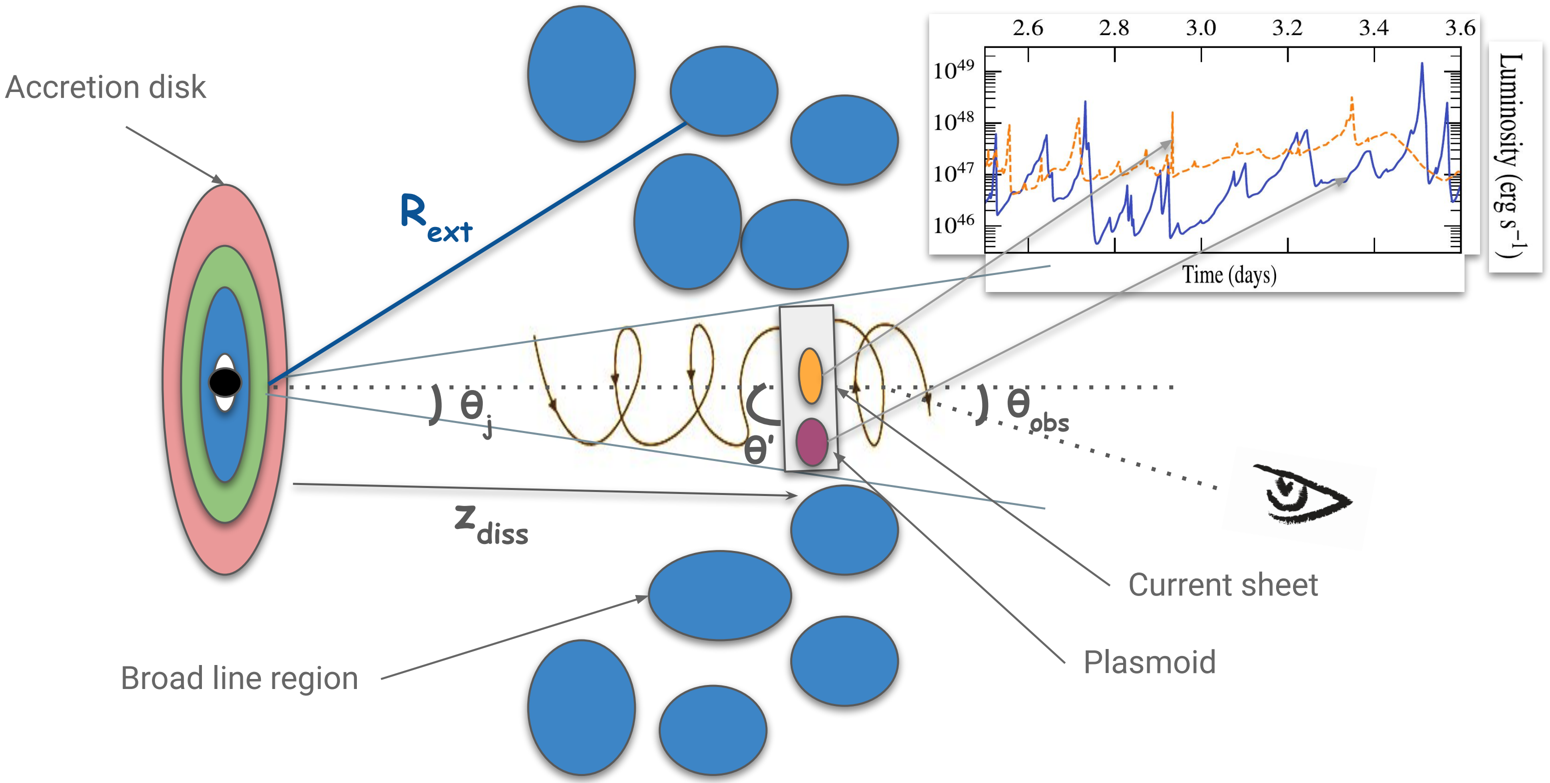

Model parameters

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	Model			
	A	B	C	D
Bulk Lorentz factor, Γ_j	12	24	24	24
Observer's angle, $\theta_{\rm obs}$ (deg)	0	0.2	0	0
Angle between layer and jet axis (in jet frame), θ' (deg)	0	0	30	0
Dissipation distance, $z_{\rm diss}$ (pc)	0.2	0.4	0.4	0.4
Bolometric luminosity of external radiation, $L_{\rm ext}$ (10^{45} erg s^{-1})	4	4	4	10
Luminosity of two-sided jet, $L_{\rm j}$ (10^{47} erg s^{-1})	1	5	5	5
Target blazar	3C 273	3C 273	3C 273	3C 279

Fixed parameters (adopted from Christie et al. 2019)

Half-length of current sheet	Plasma magnetization	Magnetic field strength at z_{diss}	Average co-moving energy density of relativistic pairs	Average minimum Lorentz factor of pairs	Average maximum Lorentz factor of pairs	Power-law slope of pair distribution at injection
5 10^{16} cm	10	5 G	2.2 erg cm^{-3}	94	5000	2.1

Theoretical light curves

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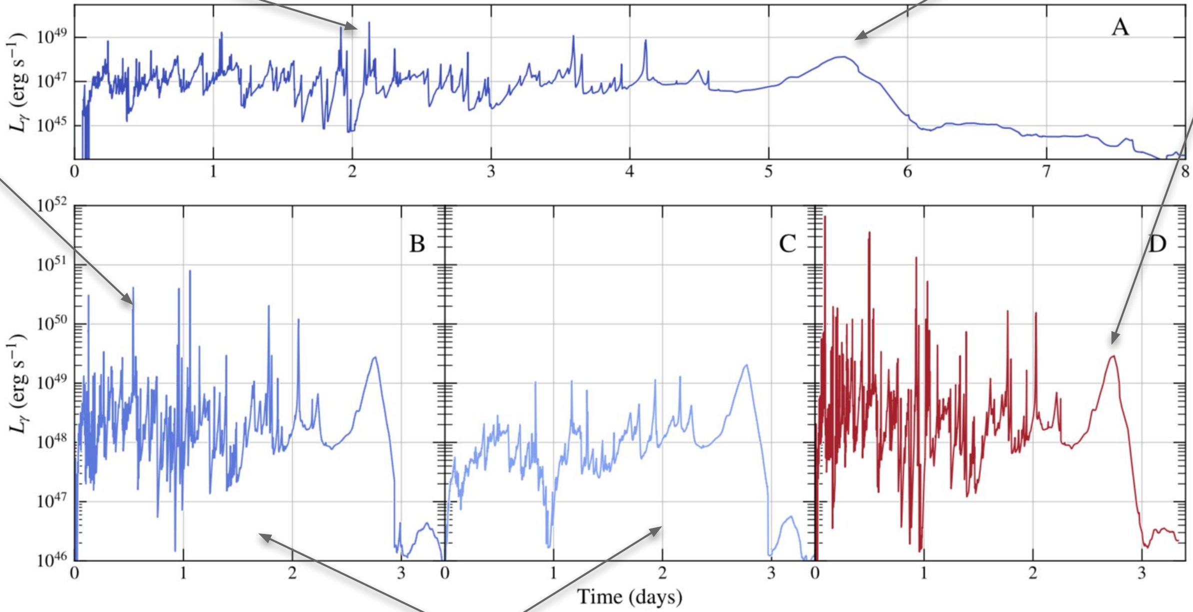
Luminous ultra-rapid flares from fast plasmoids

Long-duration flare from slow "monster" plasmoid



Variability sensitive to orientation of observer and current sheet

Goals

- Evaluate which features of theoretical light curves (e.g. ultra-rapid variability) could be detected with Fermi-LAT

- Check if a quantitative comparison of the model to the data is feasible

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Methods

- Simulate artificial LAT light curves for **3C 273** and **3C 279**

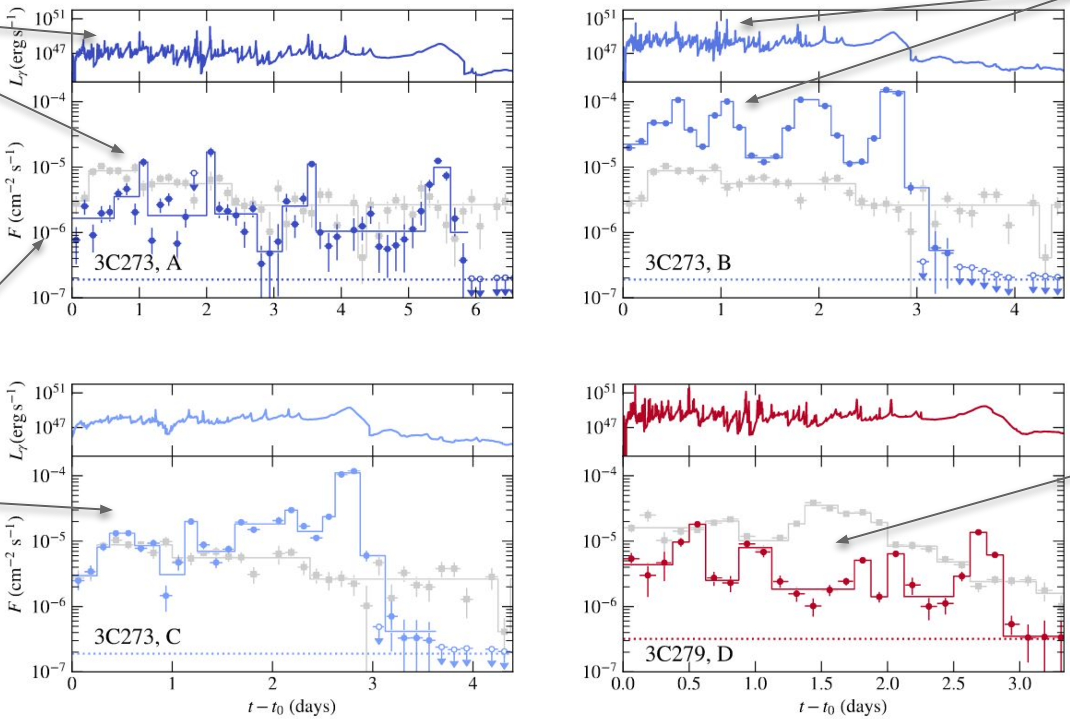
- Simulation and analysis done with `fermipy`:
    - Perform standard analysis for each light curve bin
    - Replace central source of best-fit model of region of interest (ROI) with reconnection model prediction, multiply with EBL and BLR optical depth, add quiescent source flux
    - Re-run simulation of modified ROI and LAT analysis

Artificial LAT light curves

Ultra-rapid flares are washed out due to binning

3 hr binned light curves

Flares in artificial binned light curves are the superposition of many plasmoid flares



Average flux level of bright 3C 273 flares is reproduced

Difficult to match the flux of the brightest flare of 3C 279

Artificial LAT light curves: fast variability

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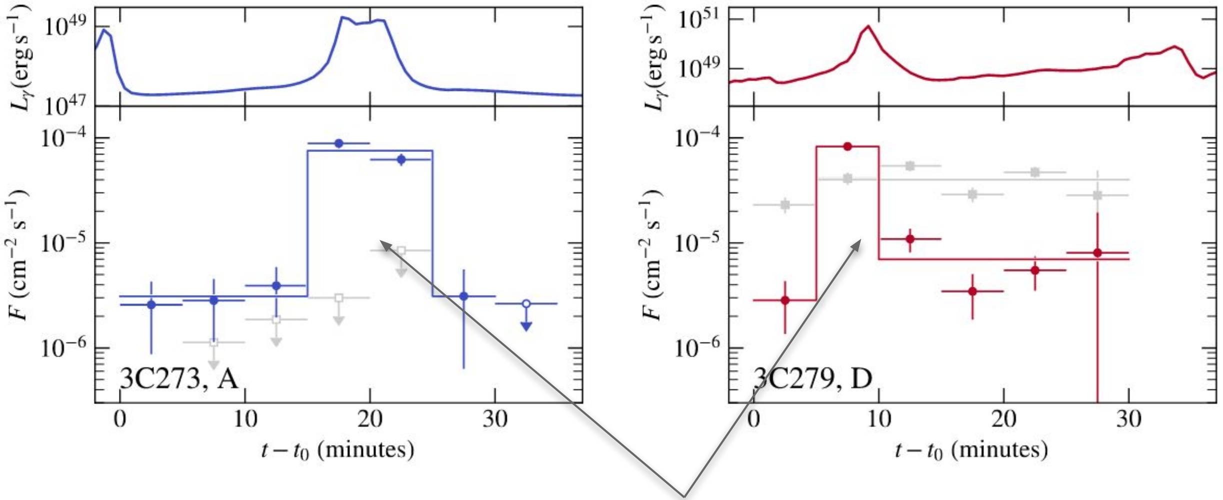
5-min binned light curves



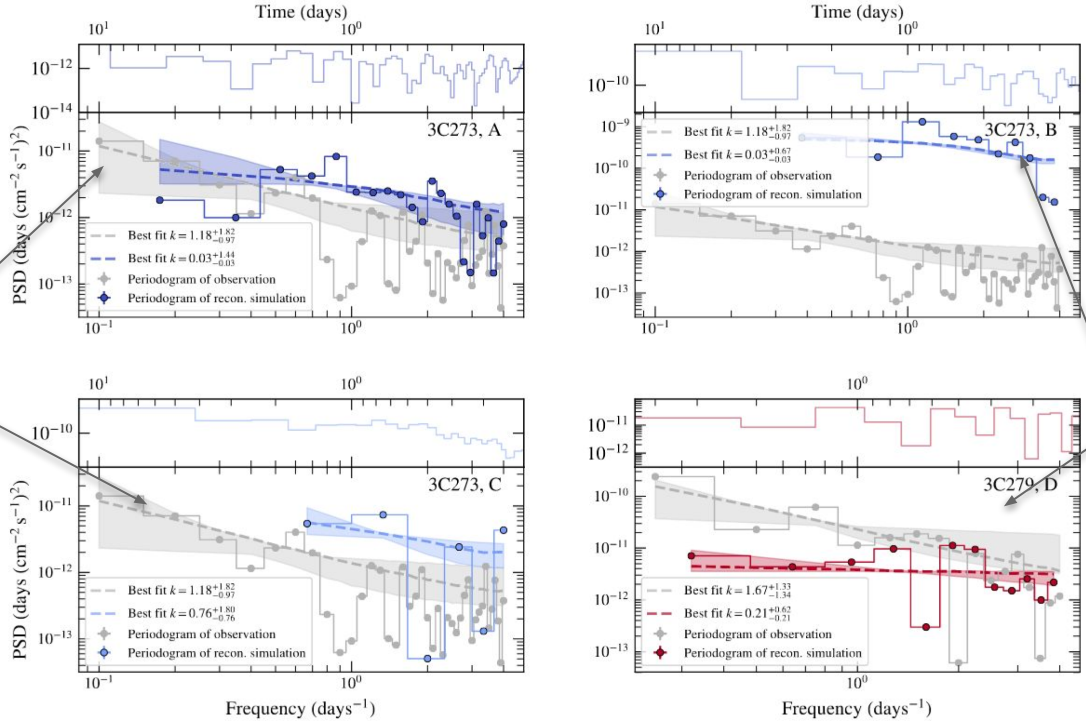
Ultra-rapid flares are detectable, if these occur within GTIs !

Artificial LAT light curves: periodograms

Model	$k_{\rm art}$	$k_{\rm obs}$
A	< 1.47	$1.18^{+1.82}_{-0.97}$
B	< 0.70	$1.18^{+1.82}_{-0.97}$
C	< 2.56	$1.18^{+1.82}_{-0.97}$
D	< 0.83	$1.67^{+1.33}_{-1.34}$

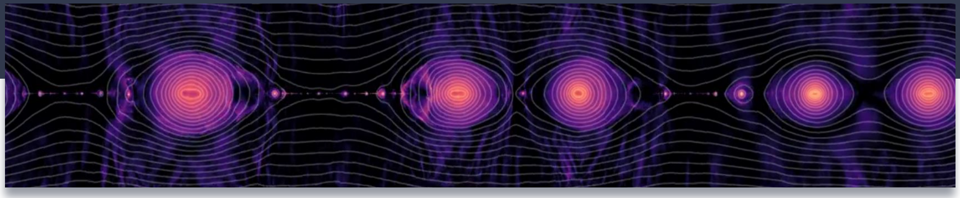
PSD(ν) ~ ν^{-k}

PSD slopes of real & artificial light curves are compatible within errors



Hard PSDs (slope ~0) in probed frequency range

Conclusions



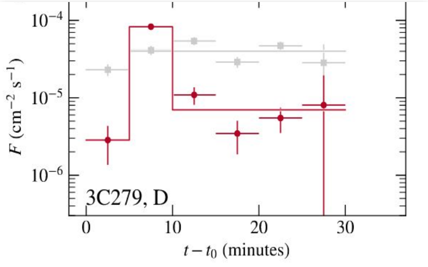
1. First-time simulation of artificial *Fermi*-LAT light curves from magnetic reconnection

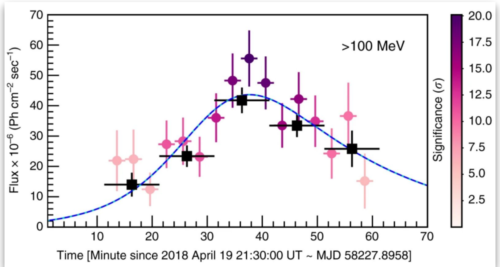
2. General characteristics of real LAT light curves are recovered (average flux and minimum variability timescale)

3. To explain the day-long high flux of the brightest flare of 3C 279 is challenging (high external photon density required)

4. Minute-scale bright flares from fast plasmoids are detectable during GTIs

5. Systematic search of minute-scale flares in LAT data on sub-orbital time scales could serve as a test for magnetic reconnection in blazars





If you would like to learn more, take a look at our paper:
[Meyer, Petropoulou, Christie, 2021, ApJ, 912]

Back-up slides

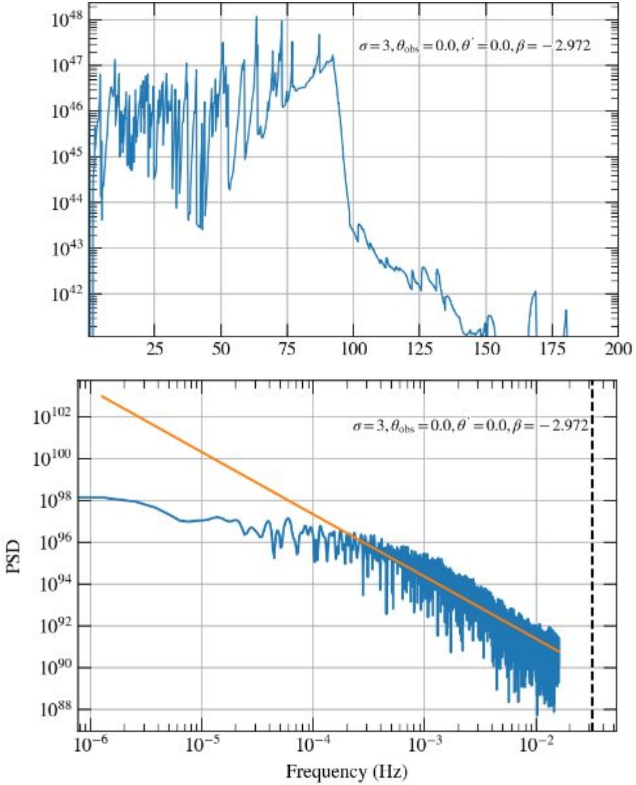
Event selection and ROI optimization

- Normalizations left free to vary for sources within 10 deg, all spectral parameters for sources within 5 deg + additional point sources with TS > 25 added iteratively; central source relocalized → yields smooth residual and TS maps
- For weekly and daily light curves: central source spectral parameters and normalizations of sources within 1 deg + isotropic and galactic diffuse normalizations left free to vary.

Data set	Pass 8R3 V6
Event class	P8R3 SOURCE
Energy range, binning	0.1 - 316 GeV, 8 bins per decade
ROI size, binning	15° x 15°, 0.2º per pixel
Zenith angle	< 90°
Time cuts filter	DATA_QUAL>0 && LAT_CONFIG==1; Additionally bright solar flares and GRBs with TS > 100 excised
Fermi tools version / fermipy version	1.23 / 0.19.0
Catalog/s	4FGL, gll_psc_v18.fit
Galactic diffuse template	gll_iem_v07.fit
Isotropic diffuse templates	iso_P8R3_SOURCE_V2_v1.txt

Theoretical light curves and periodograms for different plasma magnetizations

σ =3



σ =50