THE OBSERVABILITY OF PLASMOID-POWERED GAMMA-RAY FLARES WITH THE FERMI LARGE AREA TELESCOPE

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SUMMARY

Plasmoids – magnetized quasi-circular structures of plasma formed self-consistently in reconnecting current sheets – are ideal candidates for the production of broadband variable non-thermal emission. Using state-of-the-art kinetic simulations of magnetic reconnection and radiative transfer calculations, we generate artificial gamma-ray light curves that would be observed with the Fermi Large Area Telescope (LAT). Our goal is to investigate if characteristic features of the theoretical light curves, such as the ultra-rapid gamma-ray flares predicted by the reconnection model, are detectable with the typical Fermi-LAT observations. A comparison with observed luminous and fast gamma-ray flares from flat spectrum radio quasars (FSRQs) reveals that magnetic reconnection events lead to comparable flux levels and variability patterns, especially when the reconnection layer is slightly misaligned with the line of sight. Emission from fast plasmoids moving close to the line of sight could explain fast variability on the time scales of minutes for which evidence has been found in observations of FSRQs. Our results motivate improvements in the existing reconnection model for blazars as well as dedicated searches for fast variability in LAT data as evidence for magnetic reconnection events.

ARTIFICIAL LAT LIGHT CURVES

By coupling recent two-dimensional particle-in-cell (PIC) simulations of relativistic reconnection with a time-dependent radiative transfer code the authors of Ref. [1] computed the multiwavelength spectra and light curves from a chain of plasmoids formed during a single reconnection event. The geometry of the simulation in the jet of a FSRQ is shown in Fig. 1. Here, we extend previous work [1] by performing simulations for different orientations of the reconnection layer, jet bulk Lorentz factor, viewing angles, dissipation distances, and luminosities of the external photon fields. The parameters of the simulation are shown in Table 1. Other parameters of the simulation are set to the values chosen in [1]. For two models C and D, the resulting simulated light curves are shown in the upper panels of Fig. 2.
We use these simulated light curves to construct artificial *Fermi*-LAT light curves of two well-studied FSRQs, 3C 273 and 3C 279. We conduct a standard LAT analysis (using `fermitools` and `fermipy`, [2]) for time periods of strong gamma-ray activity and extract the light curves, shown as grey markers is the lower panes of Fig. 2. In the best-fit model of the region of interest (ROI), we replace the central FSRQ with the magnetic reconnection model assuming a power law spectrum with index equal to 2 and including absorption on the extragalactic background light and broad line region (BLR). We perform a simulation of this modified ROI and redo the LAT analysis to generate the artificial light curve. The result for two models are shown as blue and red markers in the lower panels of Fig. 2 together with the Bayesian block [3] representation of the light curve.

	Model			
	A	B	C	D
Bulk Lorentz factor	12	24	24	24
θ_{obs} (deg)	0	0.2	0	0
θ' (deg)	0	0	30	0
z_{diss} (10^{18} cm)	0.6	1.2	1.2	1.2
L_{ext} (10^{45} erg s^{-1})	4	4	4	10
L_j (10^{47} erg s^{-1})	1	5	5	5
Blazar	3C 273	3C 273	3C 273	3C 279

Tab. 1: Parameters for the magnetic reconnection simulation models A-D. The luminosity of the external photon field for inverse Compton scattering is given by L_{ext}, the total power of the two-sided jet is denoted with L_j.

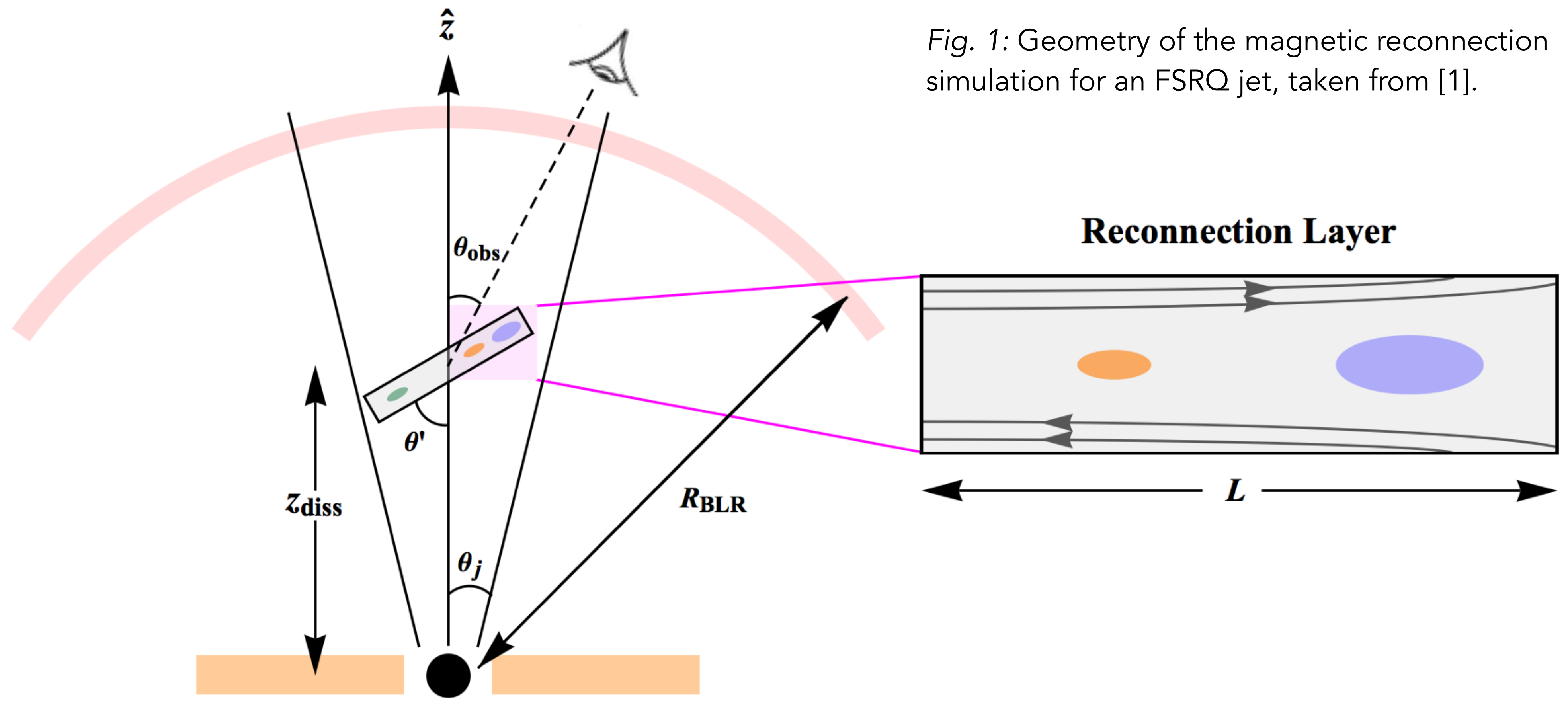

Fig. 1: Geometry of the magnetic reconnection simulation for an FSRQ jet, taken from [1].

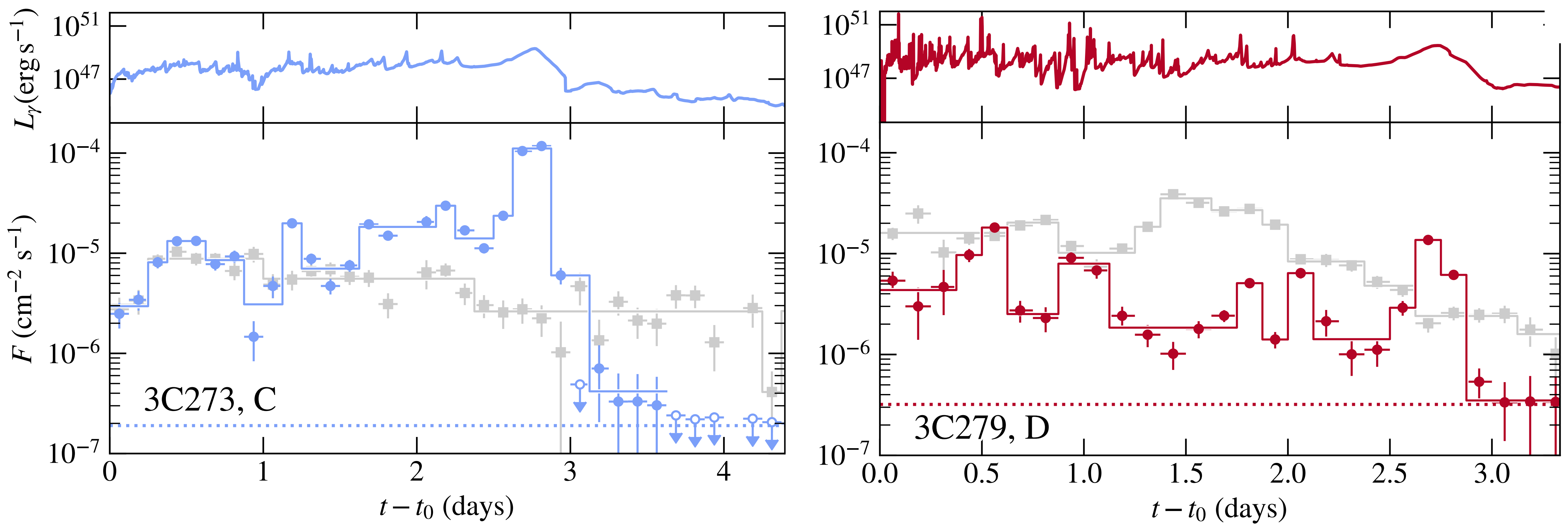

Fig. 2: Theoretical, simulated, and observed γ-ray light curves in the 0.1–300 GeV energy band for theoretical models C and D. The theoretical light curves are shown in the top panels of each figure, while the observed and simulated light curves with 3 hr binning are shown in the bottom panels. The blue (red) points show the simulated light curve as would be observed with Fermi LAT from 3C 273 (3C 279). The gray points show the actually observed light curves. Solid lines show the Bayesian block representation of the light curves

COMPARISON BETWEEN ARTIFICIAL AND OBSERVED LIGHT CURVES

The flux of the artificial light curves in Models C is broadly consistent with the observed flux of the flare under study, whereas the prediction of Model D is not sufficient to reproduce the brightest flare observed from 3C 279. However, the model-predicted fastest and brightest flares (see spikes on top panel) can produce similar levels as the observed flux. As indicated by the Bayesian block representation of the artificial light curves, much of the short time variability that is visible in the theoretical light curves is lost due to the chosen binning (here, 3 hr) and averaging. We also perform a power spectral density (PSD) analysis of the observed and artificial light curves. The artificial light curves show power-law type PSD behavior with slopes < 1 which is smaller than for the observed PSDs. The PSDs are however still compatible within statistical uncertainties.

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SHORT TIME VARIABILITY

We also investigate if the artificial light curves could explain the short variability on time scales of minutes, for which evidence has been reported [e.g., 4]. For this, we assume that one Fermi orbit encompasses one narrow gamma-ray flare predicted in the model and derive an artificial light curve with a binning of 5 minutes (see Fig. 3). Indeed, the artificial light curves lead to similar variability time scales as the observed ones and can also reproduce the high flux levels as observed for the 3C 279. In light of these results, we conclude that magnetic reconnection events are a viable explanation for the observed short time variability reported in FSRQs.

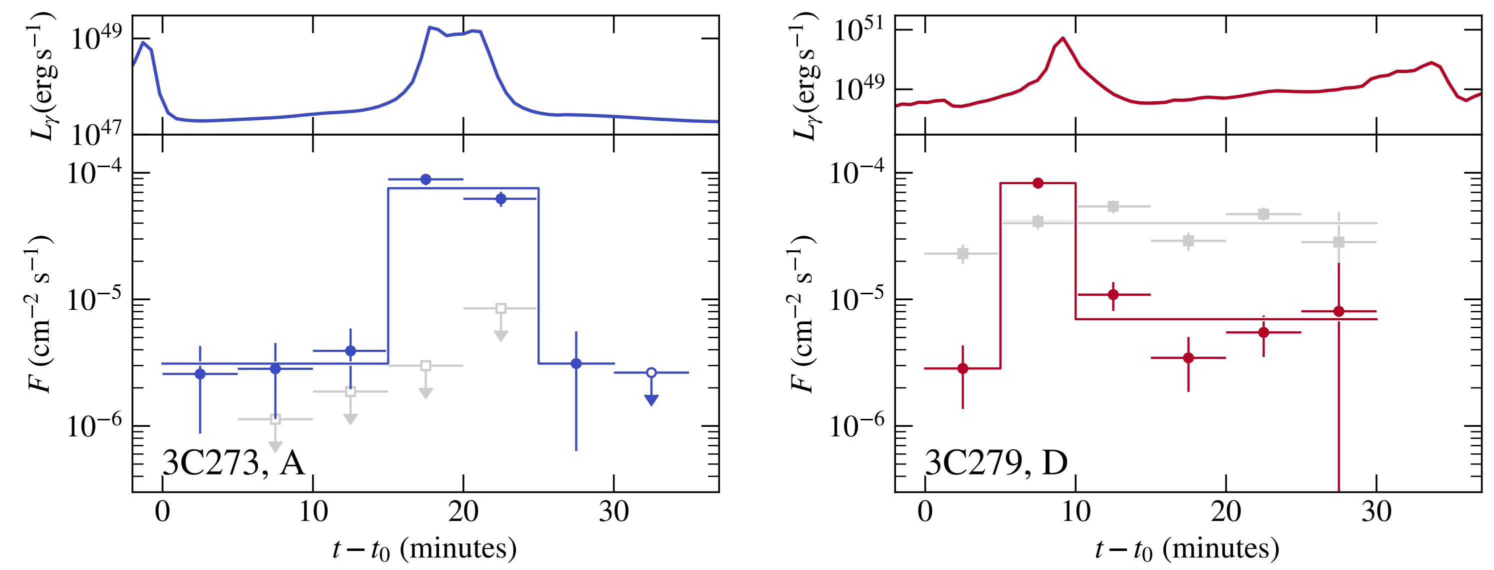

Fig. 3: Theoretical and reconstructed light curves to search for variability on timescales of minutes. Left panels: theoretical (top) and reconstructed light curves (bottom) for Model A and 3C 273. The theoretical light curve is shifted such that one short peak coincides with a GTI. Right panels: same as the upper panels but for Model D and 3C 279.

DISCUSSION

The model-predicted variability is highly dependent upon the orientation of the reconnection layer with respect to the blazar jet axis and to the observer. For optimal orientations, the theoretical light curves exhibit fast and powerful flares powered mostly by small and fast plasmoids (compare Models C and D in Fig. 1). These sharp, spike-like outbursts of emission appear as excesses atop a more slowly evolving envelope produced by the cumulative emission of medium-sized plasmoids. These outbursts can easily explain minute-scale variability in FSRQs and are a clear-cut prediction of our reconnection model (see Fig. 3). A systematic search of minute-scale flares could serve as a test for magnetic reconnection events in blazar jets.
From a theoretical perspective, it is desirable to compute the emission produced from multiple reconnection layers formed at different distances within the jet. Extension of our radiative transfer calculations to times after the plasmoid exit from the layer, where they may undergo adiabatic expansion, would be necessary for computing a likely delayed radio signal following fast gamma-ray flares.

[1] Christie, Petropoulou, Sironi, Giannios (2019), MNRAS, 482, 65
[2] See https://fermi.gsfc.nasa.gov/ssc/ and Wood et al. (2017), arXiv: 1707.09551
[3] Scargle et al. (2013), ApJ, 764, 167
[4] Meyer, Scargle, Blandford (2019), ApJ 877, 39

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