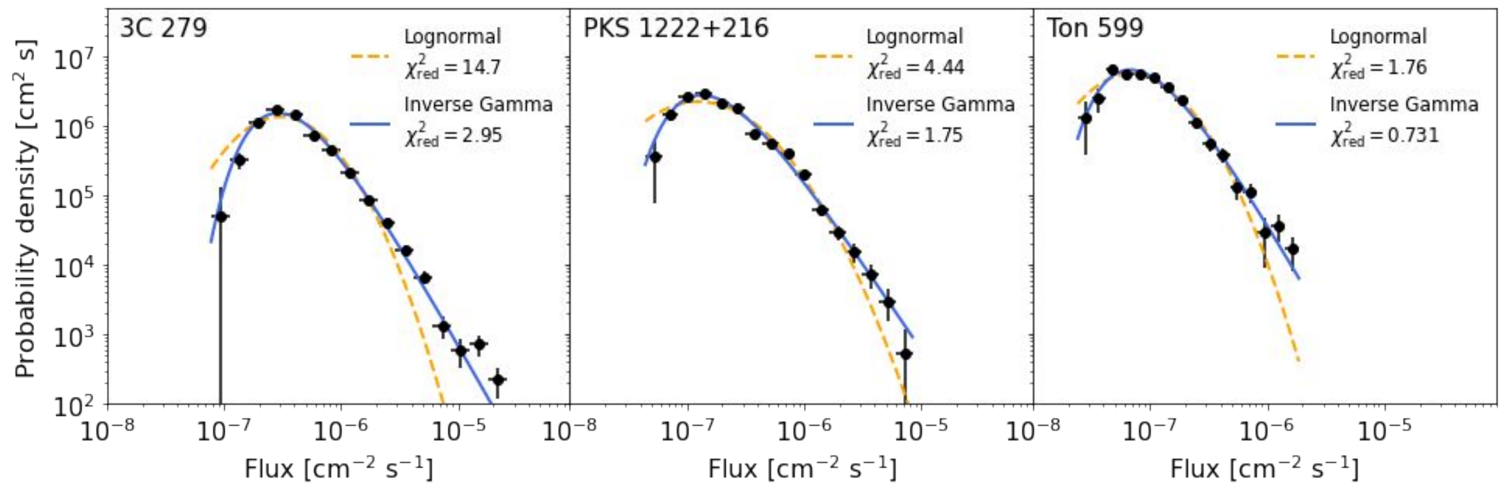
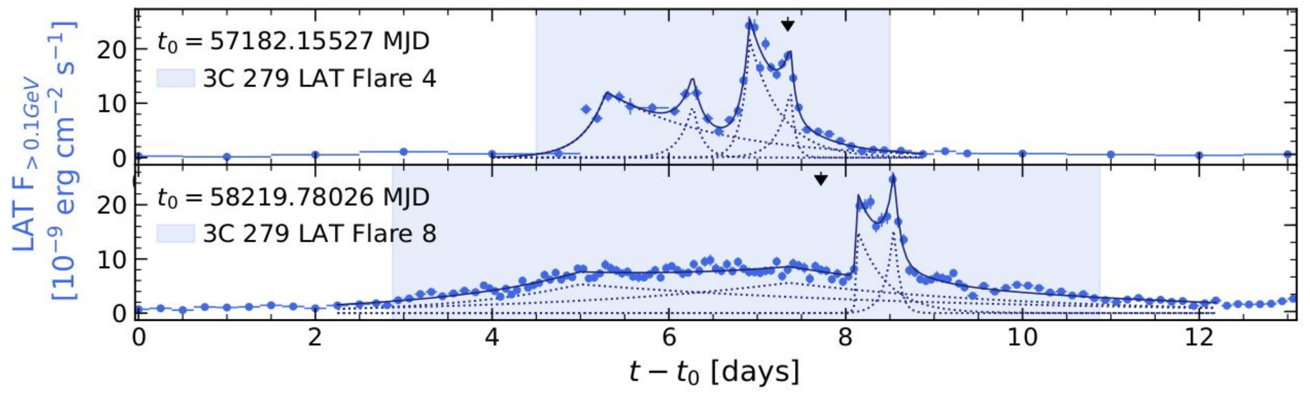
A Novel Model for the Gamma-Ray Variability of Flaring Blazars

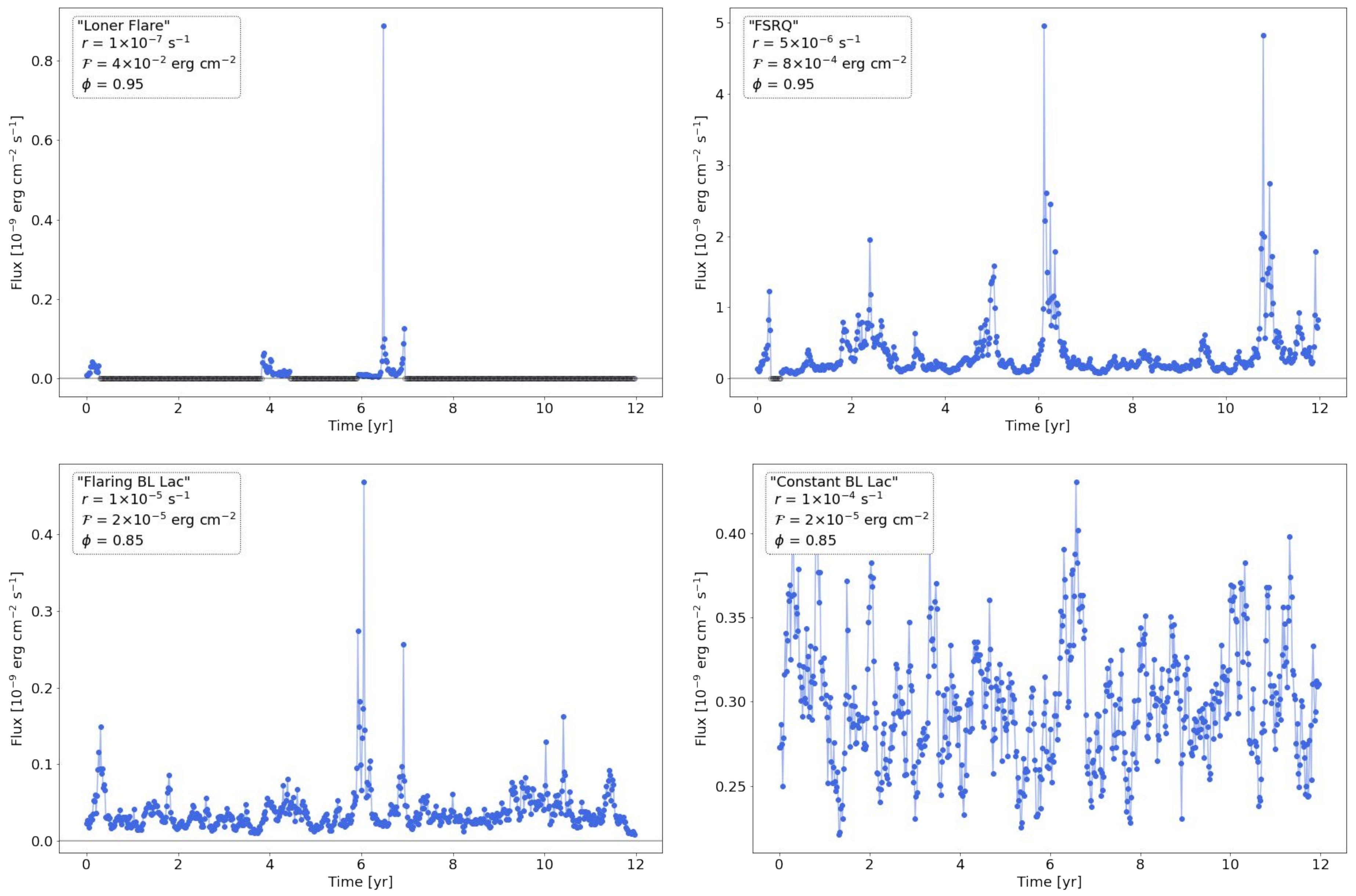
Ari Brill, NASA Postdoctoral Program Fellow, NASA Goddard Space Flight Center, on behalf of the *Fermi*-LAT Collaboration

- What causes blazars' stochastic multiwavelength variability?
- Blazar gamma-ray flux distributions are commonly modeled as lognormal, but those of several flaring flat spectrum radio quasars (FSRQs) are extremely heavy-tailed and better described by the *inverse gamma* distribution.
- An inverse gamma distribution can arise from a shot-noise process where discrete bursts are *individually unresolved* within time bins, as with *Fermi*-LAT data. For many small bursts, the distribution becomes approximately lognormal.
- With simulated light curves, we reproduce different source classes' variability, showing how the model parameters can be extracted and interpreted in terms of physical quantities.

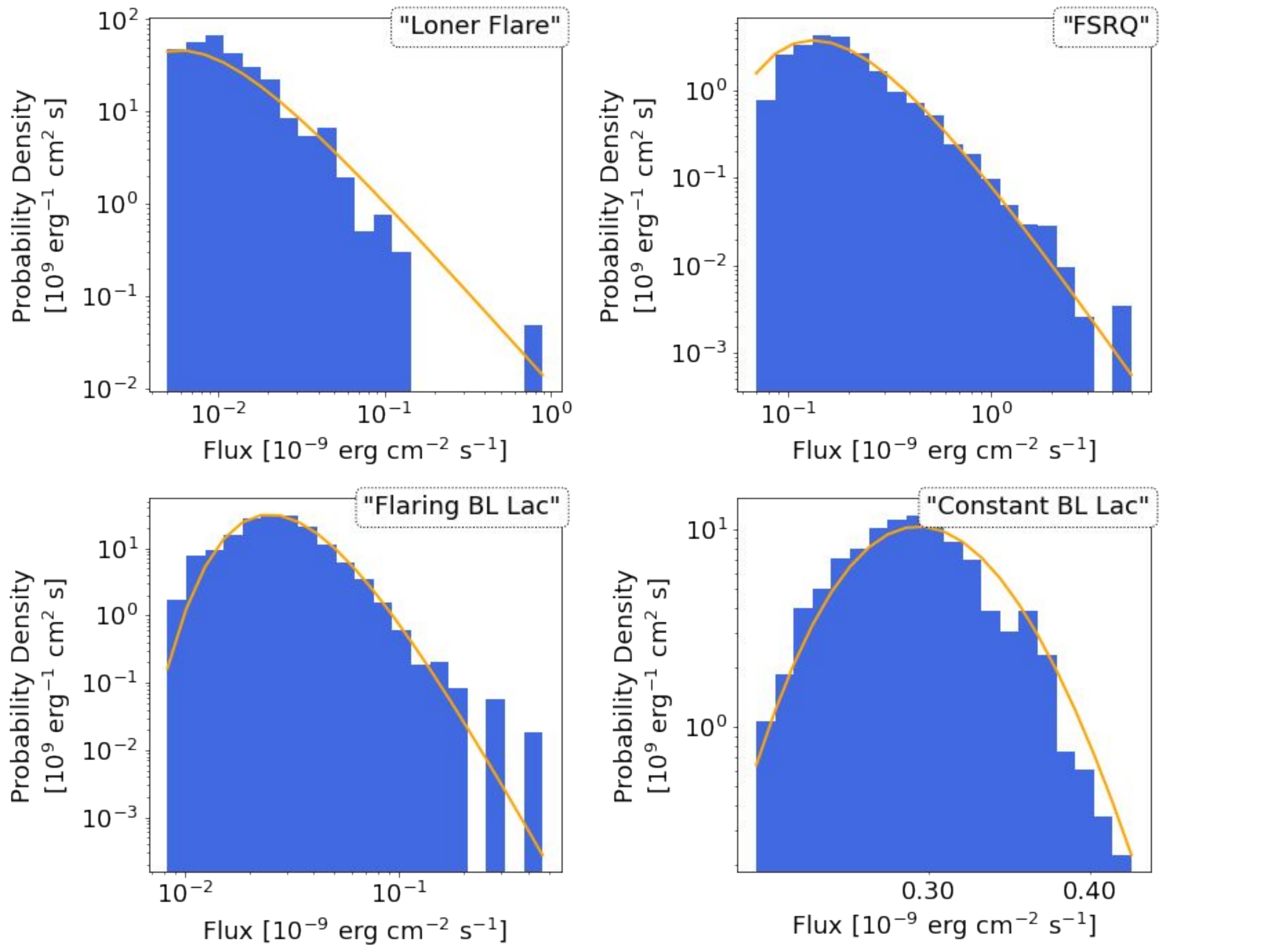




Top: *Fermi*-LAT flux distributions of three FSRQs. An inverse gamma PDF (solid blue) provides a better fit than a lognormal one (dashed orange). *Bottom*: Sub-daily light curves of 3C 279 around selected flaring episodes (light shaded areas), revealing multiple flare components (dotted blue lines). Both figures adapted from [1].



- A light curve is observed in constant time bins ΔT. Gamma rays are emitted in discrete independent bursts of equal fluence $\boldsymbol{F}$ with mean rate r and shape timescales << ΔT. On average, each time bin has $\alpha = r\Delta T$ bursts and flux $\beta = \boldsymbol{F} r\alpha / F_{scale}$ (normalized by flux F_{scale}).
- Each burst's flux ≈ (interarrival time/fluence)$^{-1}$, so each time bin's mean reciprocal flux $F^{-1} \sim$ Gamma(α, β), or flux $F \sim$ InvGamma(α, β).
- We obtain an autoregressive inverse gamma process by modifying the process of [2] so α fluctuates from bin to bin. A bin with no bursts has no flux, yielding an observed flux distribution always with $\alpha \geq 1$.
- The model has 3 free parameters, representing the average burst rate r, the burst fluence $\boldsymbol{F}$, and the autocorrelation parameter ϕ, which can be estimated by fitting the light curve.



Above left: Simulated weekly light curves. The "FSRQ" parameters were estimated from 3C 279 flare observations [1], yielding a realistic light curve. A low burst rate yields a "loner flare" blazar, while larger ones give light curves like BL Lac objects, with weaker flares and ~lognormal flux distributions.

Top: Flux distributions of the simulated light curves; expected PDF in orange.

- Variability modeling can potentially help characterize the relationship between FSRQs and BL Lac objects.
- The parameters can be interpreted physically, e.g. by associating the bursts with plasmoid-powered flares in a magnetic reconnection scenario.
- The short-timescale burst process and long-timescale stochastic variations interact to naturally produce flaring and quiescent emission on weeks-months timescales.
- Inverse gamma variability was also proposed by [3] based on a stochastic differential equation motivated by accretion disk processes. Our model differs by predicting "loner flares" for $\alpha \ll 1$, observable "bursting" at short ΔT, and decreasing fractional variability at long ΔT.

NASA POSTDOCTORAL PROGRAM

Fermi Gamma-ray Space Telescope

Email: aryeh.brill@nasa.gov

[1] Adams et al. (2022), ApJ, 924, 95, arXiv:2110.1318.
[2] Sim (1990), Journal of Applied Probability 27(2), doi:10.2307/3214651.
[3] Tavecchio et al. (2020), MNRAS 497, 1, arXiv:2004.09149.

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