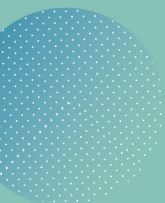




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A morphological search for stable year-scale modulation in gamma-ray blazars

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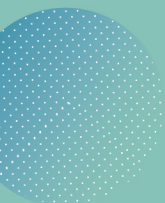
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Abstract

Year-scale quasi-periodic oscillations (QPOs) in blazar gamma-ray light curves have been proposed as signatures of supermassive binary black holes and precessing jets. Red noise can mimic periodicity, and detection does not establish whether modulation is persistent or stable. We develop and calibrate a morphological framework to characterize temporal behavior of year-scale modulations and constrain the incidence of stable modulation in blazars. We analyze 120 Fermi-LAT light curves spanning 18.1 yr. Singular spectrum analysis selects the oscillatory mode and period; weighted wavelet Z-transform ridge tracking on the detrended light curve quantifies strength, persistence, period drift and cycle-to-cycle volatility. Flux randomization, 10,000 red-noise simulations and about 20,000 injections calibrate the classification. Of 97 quality-selected sources, two show persistent, coherent modulation consistent with a stationary period (Rank I: PG 1553+113 and B2 1215+30), six show coherent modulation whose stationarity cannot be established (Rank II), and 89 form a residual Rank III. Neither Rank I nor II significantly exceeds red noise. Injection–recovery tests classify 92% of drifting signals as Rank II, and stationary signals below the period ceiling as Rank I in 63–97% of trials at signal-to-noise ratio 1 and 100% at 2. These results limit stable, approximately sinusoidal 1–3 yr modulation to at most 7% of the sample at signal-to-noise ratio ≥ 1 and 5% at ≥ 2 (95% confidence). PG 1553+113 has the lowest false-alarm probability, 4.7% after trials. Stable year-scale modulation is uncommon, and no individual QPO is established. Calibrated morphology distinguishes persistent, stationary modulation from coherent variability whose period may evolve or fluctuate, but not the physical mechanism. PG 1553+113 and B2 1215+30 merit monitoring and may inform continuous gravitational-wave searches for supermassive binary black holes, although their stability does not establish a binary origin. The six Rank II sources are targets for studying evolving modulation, while a longer baseline is needed to assess the stability of six coherent Rank III features beyond the period ceiling.

