

MULTI-FREQUENCY CHARACTERIZATION OF BLAZAR LIGHT CURVES USING FERMI-LAT AND ALMA OBSERVATIONS



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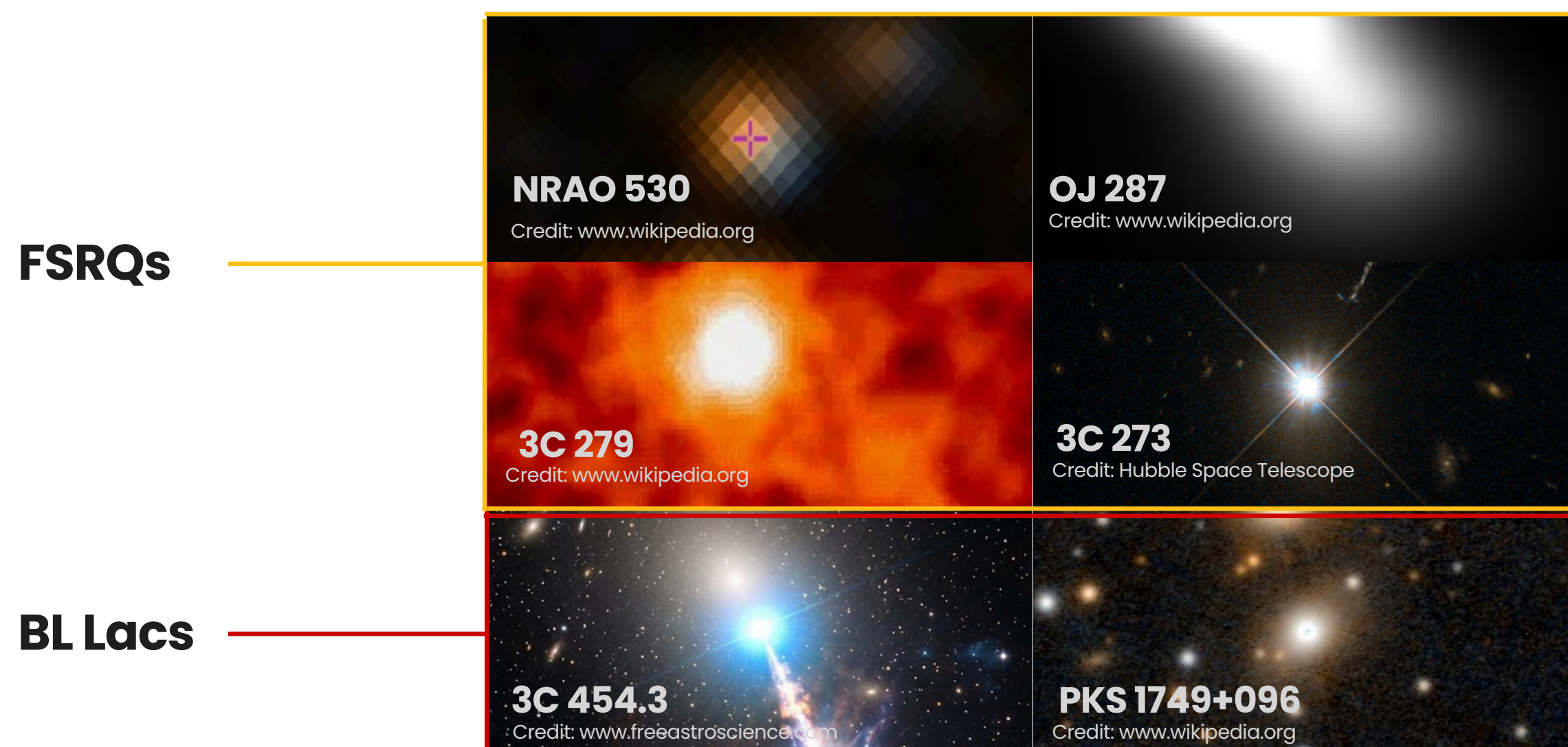
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ABSTRACT

Blazars are the most extreme class of active galactic nuclei (AGN), featuring relativistic jets directed close to our line of sight. Their strong multi-wavelength variability provides valuable probes of jet dynamics, particle acceleration, and non-thermal emission. While Flat Spectrum Radio Quasars (FSRQs) and BL Lacertae objects (BL Lacs) exhibit distinct spectral properties, quantitative differences in their variability and light-curve morphology remain poorly constrained within uniform observational frameworks. This study presents a comparative multi-wavelength analysis of six blazars: four FSRQs (3C 273, 3C 279, 3C 454.3, and NRAO 530) and two BL Lacs (OJ 287 and PKS 1749+096). We combine 16 years of Fermi-LAT γ -ray observations (0.1–300 GeV) at 3-, 7-, and 30-day cadences with 14 years of ALMA millimeter-wave observations (85–373 GHz). Statistical variability metrics and flare properties, including duration, peak amplitude, and rise/decay symmetry, are evaluated, with two-sample Kolmogorov-Smirnov (K-S) tests used to assess differences between FSRQs and BL Lacs across wavebands and time scales. The results establish a multi-wavelength baseline for blazar variability and provide constraints on jet physics and emission geometry, with potential applications to future monitoring by facilities such as H.E.S.S. and the Africa Millimetre Telescope (AMT).

BACKGROUND

SOURCES:



While blazars are known for their extreme variability, the underlying physical processes that drive their variability patterns in their light curves remain weakly understood.

GROUNDWORK FOR THE AFRICA MILLIMETRE TELESCOPE (AMT):

About the AMT:

- Set to be built in Namibia
- 14 m single-dish telescope
- Join the Event Horizon Telescope (EHT) to conduct black hole imaging.

AMT Single-Dish Science [1]:

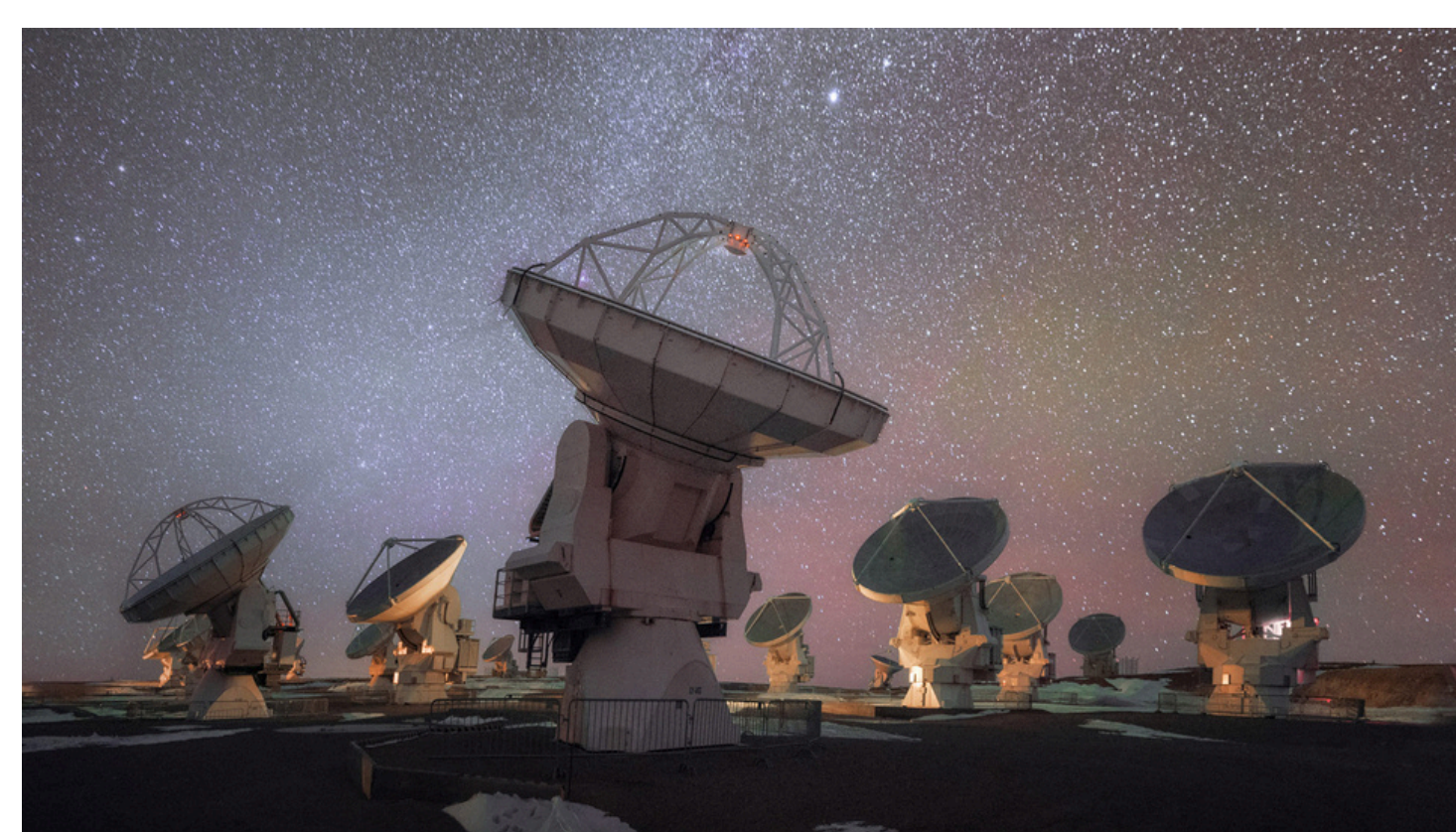
- Long-term monitoring of blazars to fill high-cadence gaps and better understand brightness changes.



[1] Michael Backes, Markus Böttcher, and Heino Falcke. Millimeter-wave monitoring of active galactic nuclei with the africa millimetre telescope. *Galaxies*, 7(2):66, 2019.

METHODOLOGY & SAMPLE SOURCE RESULTS

INSTRUMENTS:



Source: www.innovationnewsnetwork

Atacama Millimeter/submillimeter Array (ALMA):

- 10 receiver bands
- Operates within 35 GHz – 950 GHz
- 66-antenna radio interferometer in northern Chile



Source: www.symmetrymagazine.org/

Fermi Gamma-ray Space Telescope:

- It carries two instruments: the Large Area Telescope (LAT) for high-energy gamma rays and the Gamma-ray Burst Monitor (GBM) for lower-energy bursts.
- The LAT observes from 20 MeV to over 300 GeV, the GBM covers 8 keV – 40 MeV.

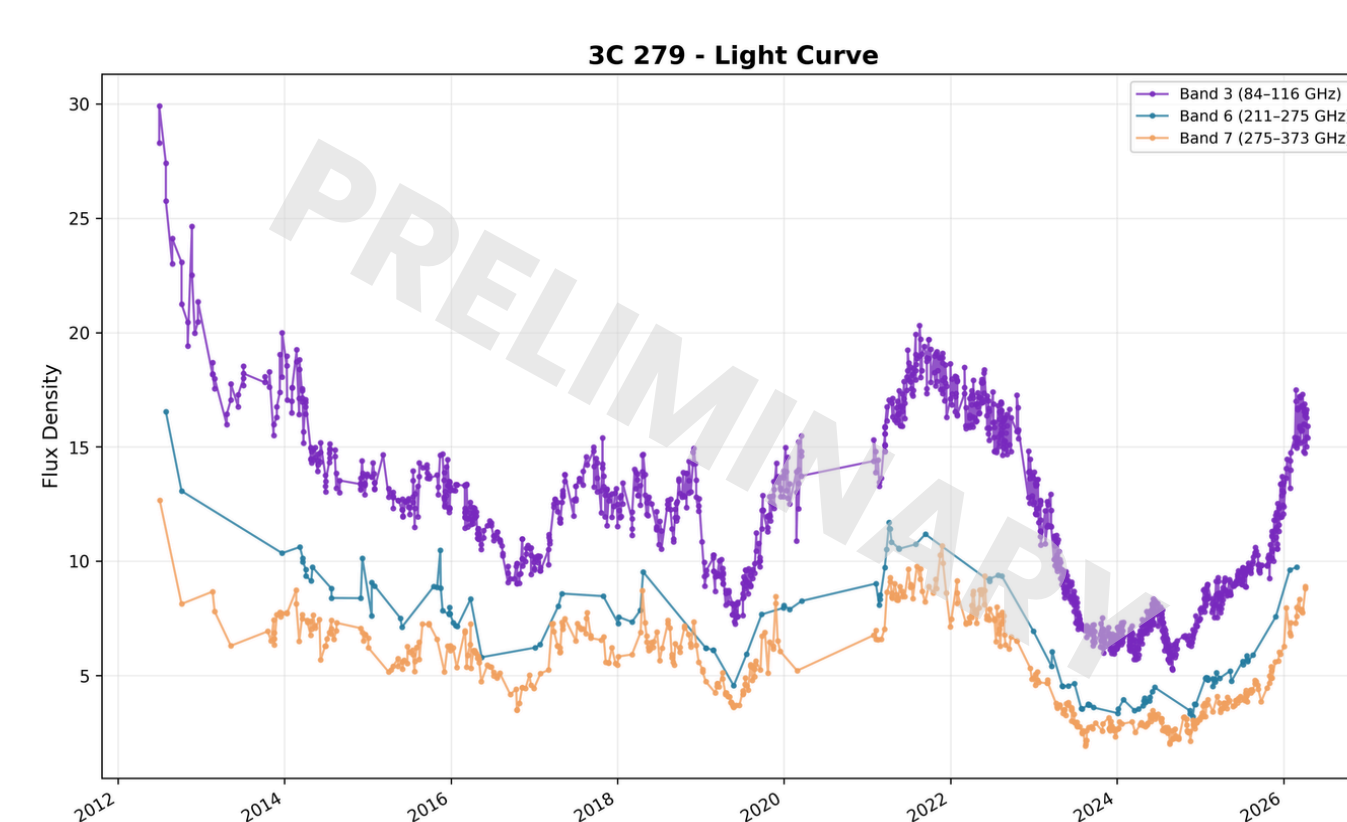


Figure 1: Light Curve – ALMA

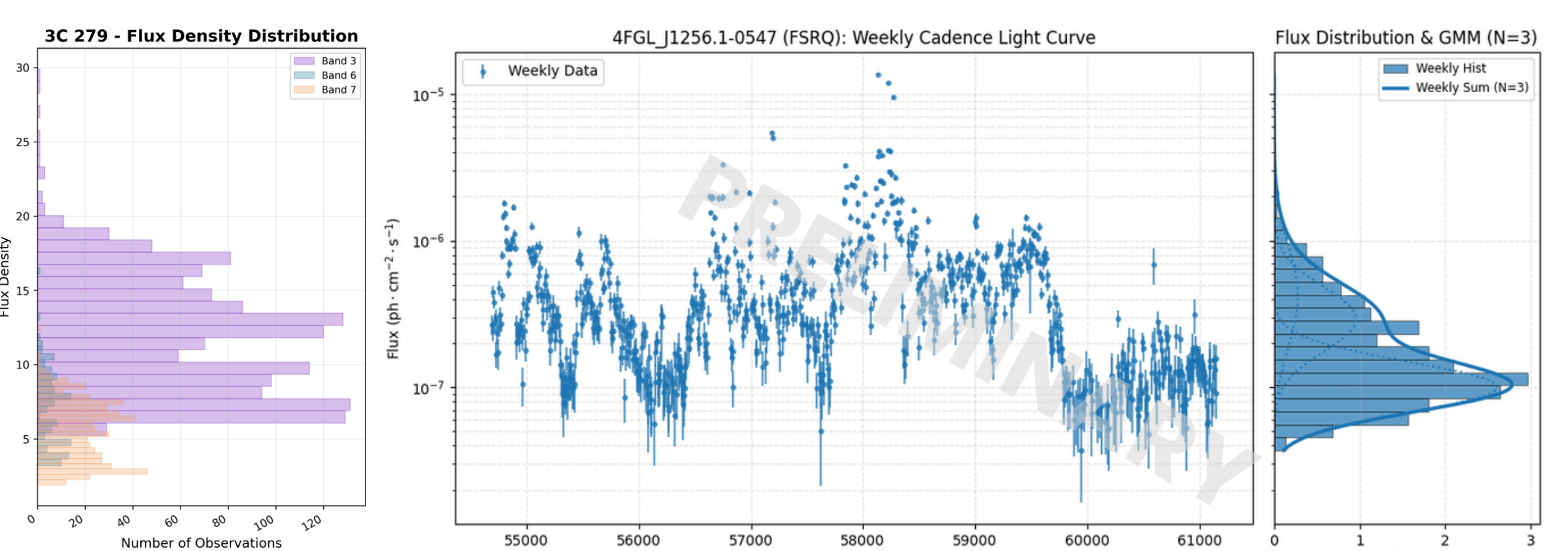


Figure 2: Light Curve – Femi-LAT

STATISTICAL METRICS ON BLAZAR 3C 279 (ALMA) FREQUENCY RANGE: BAND 3, 6 & 7

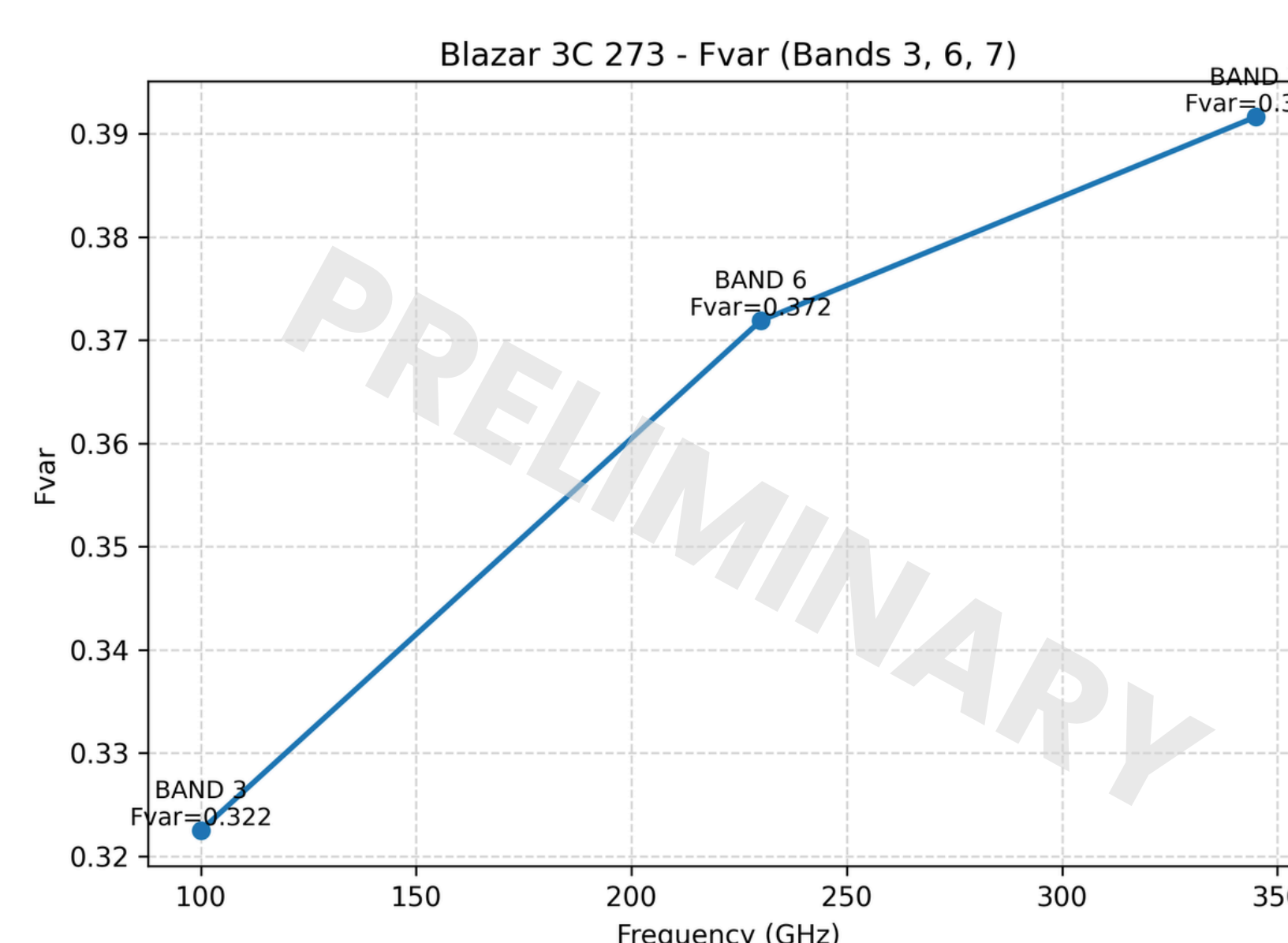


Figure 4: Fractional Variability –ALMA

Fractional Variability (Fvar)– Quantifies intrinsic variability relative to the mean flux.

- Higher values indicate stronger proportional fluctuations.
- Typically increases with frequency in blazars (energetic electrons cool faster)
- FSRQs show higher fractional variability than BL Lacs due to stronger jets and more dramatic proportional changes.

Variability Amplitude (VA) – Measures the peak-to-peak flux change.

- Higher values indicate larger absolute flux swings.
- Tracks the total magnitude of flaring events.
- FSRQs exhibit larger amplitude swings than BL Lacs because their higher-energy jets produce more intense flares.

RMS Scatter – Standard deviation of flux values from the mean.

- Higher values indicate greater dispersion in the data.
- Scales with total flux density (higher at low frequencies).
- FSRQs display higher RMS scatter than BL Lacs, reflecting more dynamic variability with shorter timescales.

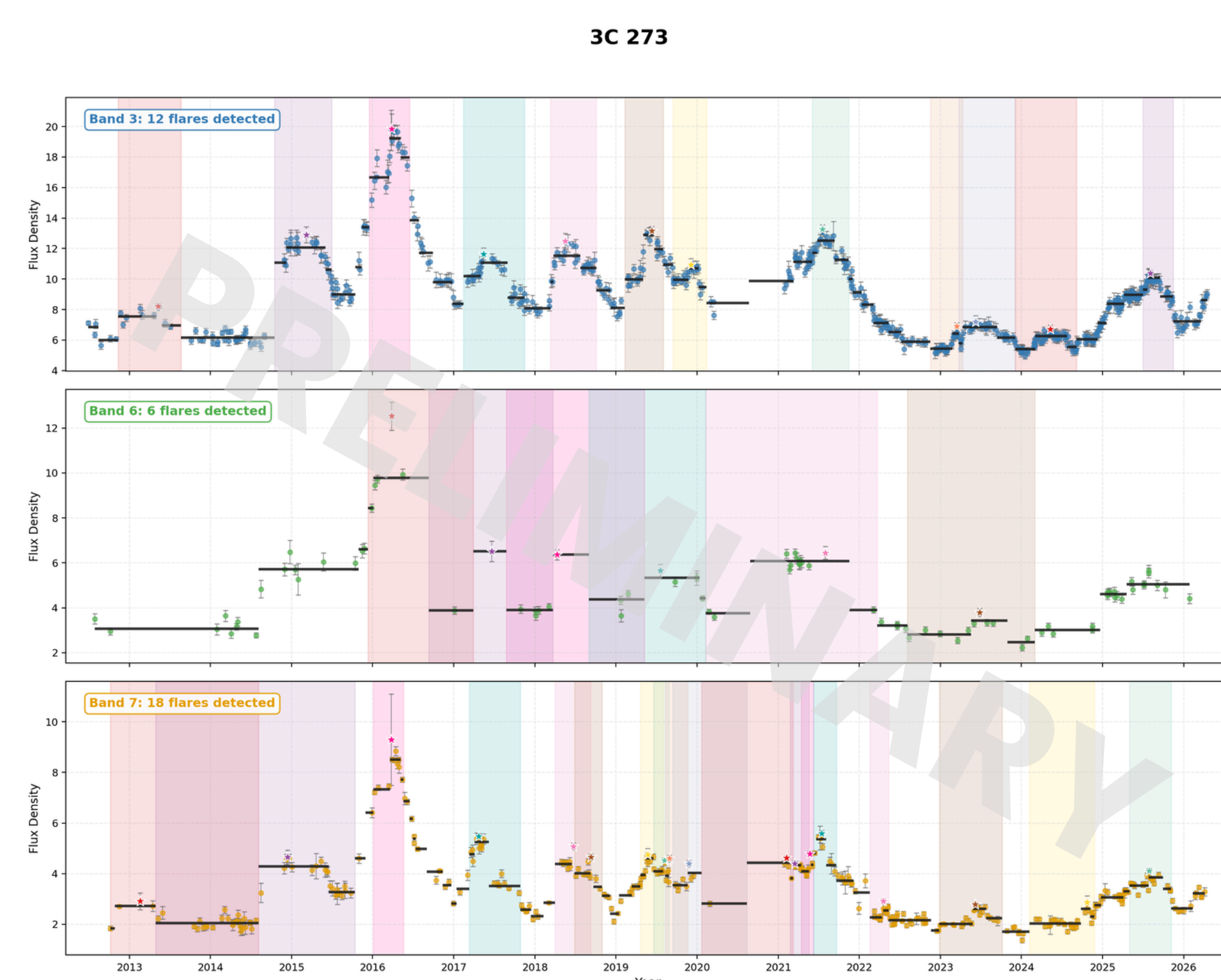


Figure 3: Flare Detection – ALMA

- Identifies significant, transient increases in flux density above quiescent baseline.
- Detects change points without assuming a fixed binning or shape.
- Confirms blazar emission is highly non-uniform and episodic.

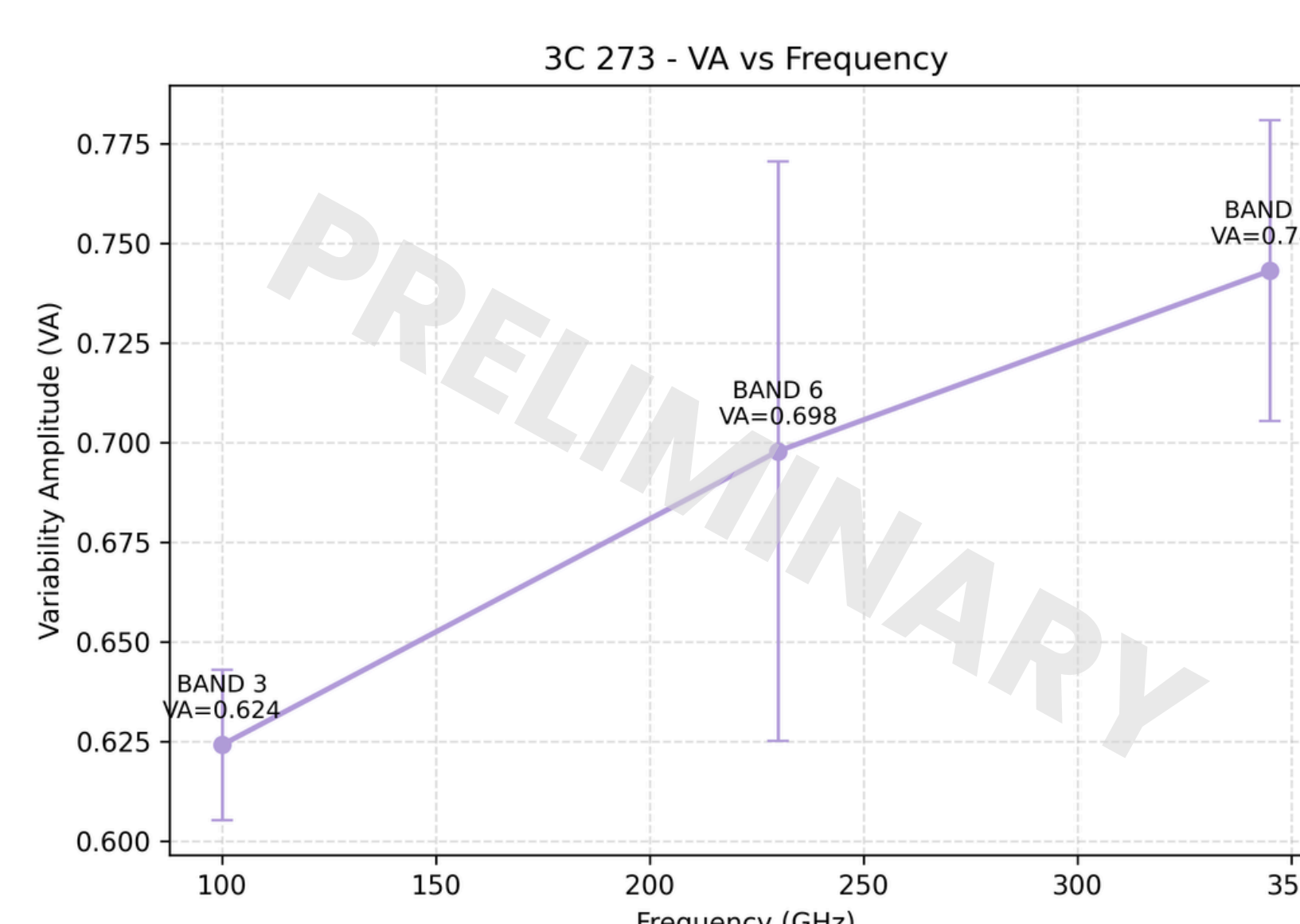


Figure 5: Variability Amplitude – ALMA

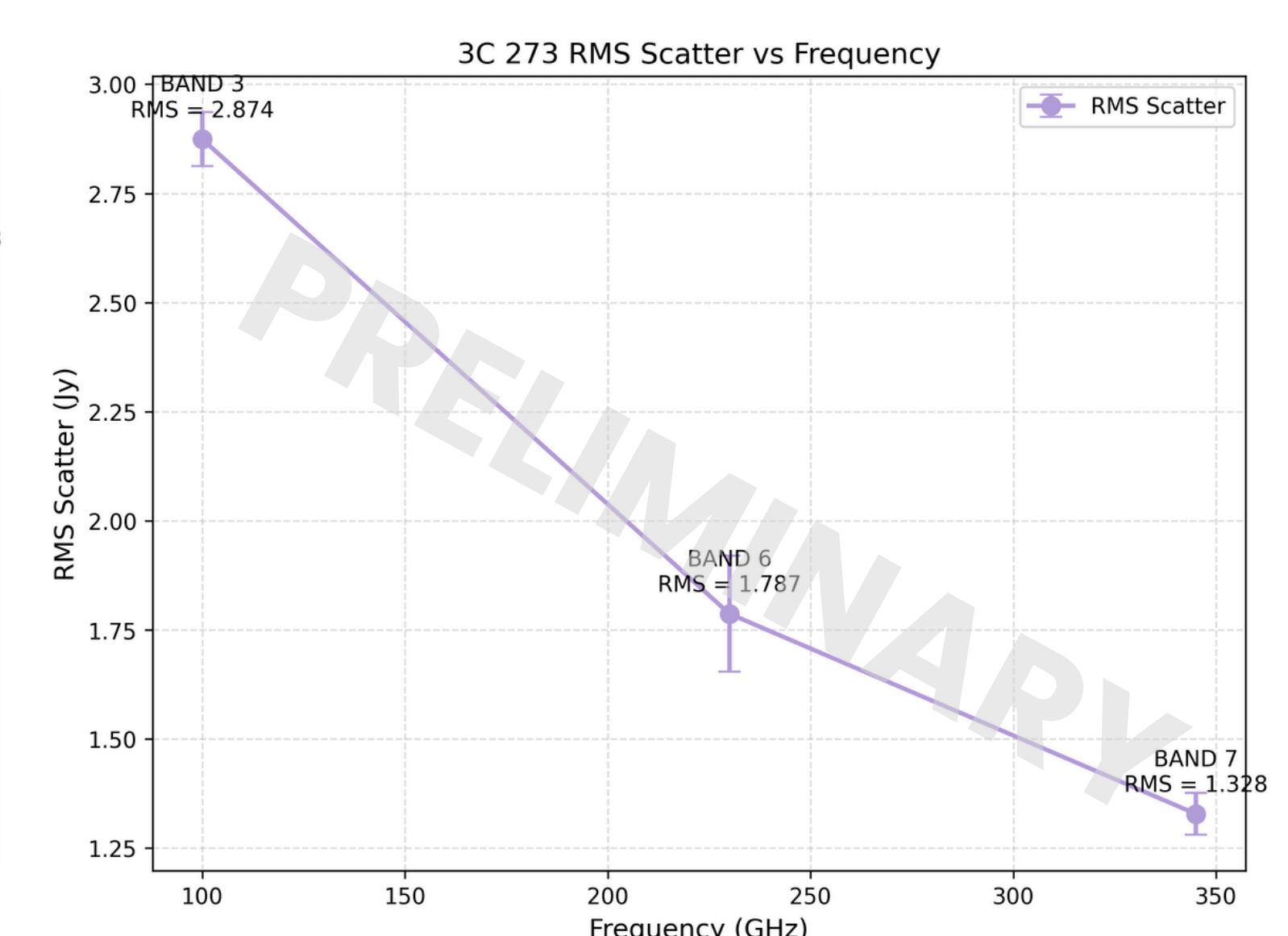


Figure 6: Root-Mean-Square Scatter – ALMA

FSRQS: MORE POWERFUL JETS, PRESENCE OF BRIGHT ACCRETION DISKS AND BROAD-LINE REGIONS, STRONGER AND MORE RAPID VARIABILITY.

BL LACS: RELATIVELY WEAKER JETS, ACCRETION DISKS NOT PROMINENT, SMOOTHER AND SLOWER VARIABILITY.