Mysterious Low-Frequency Variability of PSS

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Spectral variability of radio sources at low frequencies

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Monthly Notices of the Royal Astronomical Society, Volume 501, Issue 4, March 2021, Pages 6139–6155, https://doi.org/10.1093/mnras/staa3795

Published: 11 December 2020 **Article history** ▾

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ABSTRACT

Spectral variability of radio sources encodes information about the conditions of intervening media, source structure, and emission processes. With new low-frequency radio interferometers observing over wide fractional bandwidths, studies of spectral variability for a large population of extragalactic radio sources are now possible. Using two epochs of observations from the GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey that were taken one year apart, we search for spectral variability across 100–230 MHz for 21 558 sources. We present methodologies for detecting variability in the spectrum between epochs and for classifying the type of variability: either as a change in spectral shape or as a uniform change in flux density across the bandwidth. We identify 323 sources with significant spectral variability over a year-long time-scale. Of the 323 variable sources, we classify 51 of these as showing a significant change in spectral shape. Variability is more prevalent in peaked-spectrum sources, analogous to gigahertz-peaked spectrum and compact steep-spectrum sources, compared to typical radio galaxies. We discuss the viability of several potential explanations of the observed spectral variability, such as interstellar scintillation and jet evolution. Our results suggest that the radio sky in the megahertz regime is more dynamic than previously suggested.

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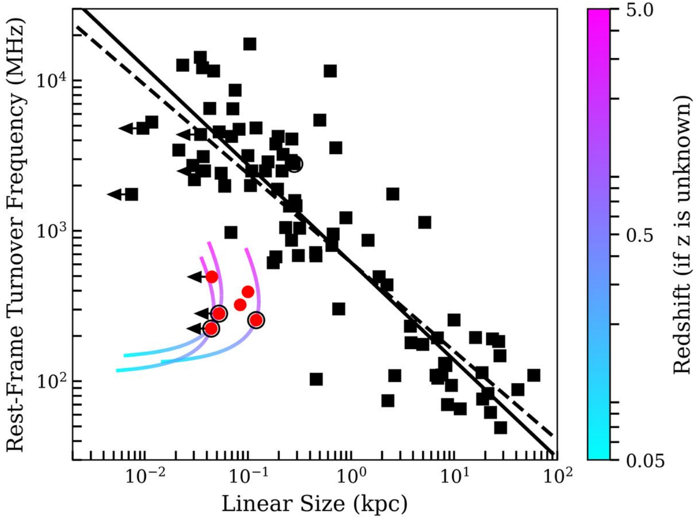
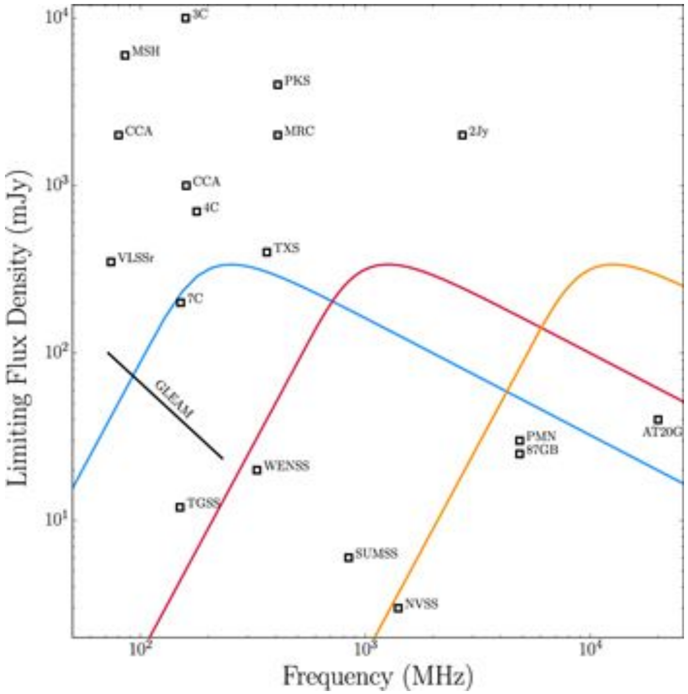
The MHz Regime

- Biased towards PSS with peak in MHz
- Dominated by flux from lobes rather than core
- “Larger” of PSS → ~20kpc



Keim et al. 2017



Callingham et al. 2017

Low-Frequency Variability

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Intrinsic

- Core of jet evolution
- Internal shocks
- Blazar variability
- Changes in optical depth

Extrinsic

- Interplanetary Scintillation
- Refractive Interstellar Scintillation (RISS)

Spectral Variability

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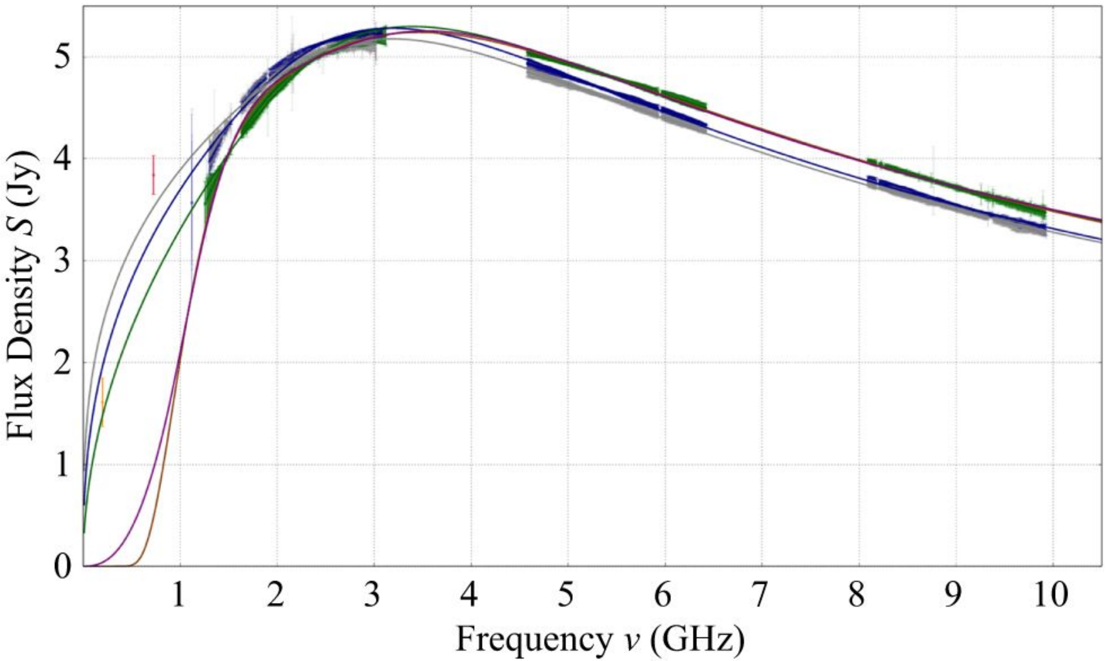
Low Frequency Variability

- Single frequencies
  - Hunstead 1972
  - Fanti 1982
  - Bell 2019
- High frequencies
  - Torniainen 2005
  - Nyland 2021
  - Wolowska 2021
- Limited populations
  - Tingay 2015



Tingay et al. 2017

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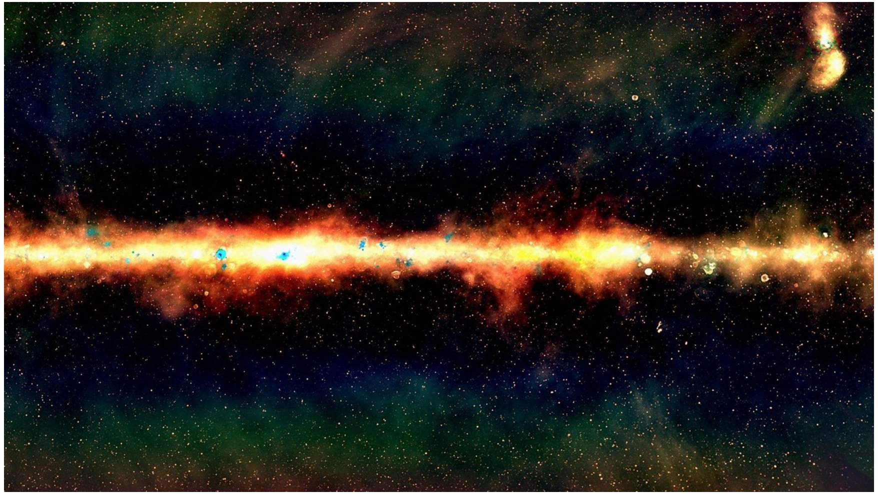
The GLEAM Survey

Galactic and Extragalactic All-Sky MWA Survey

- 8,000 sq deg
- 16 flux density measurements (100-231MHz)
- 2 epochs, ~1 year apart
    - Franzen et al. 2021



GLEAM Team

Our Survey

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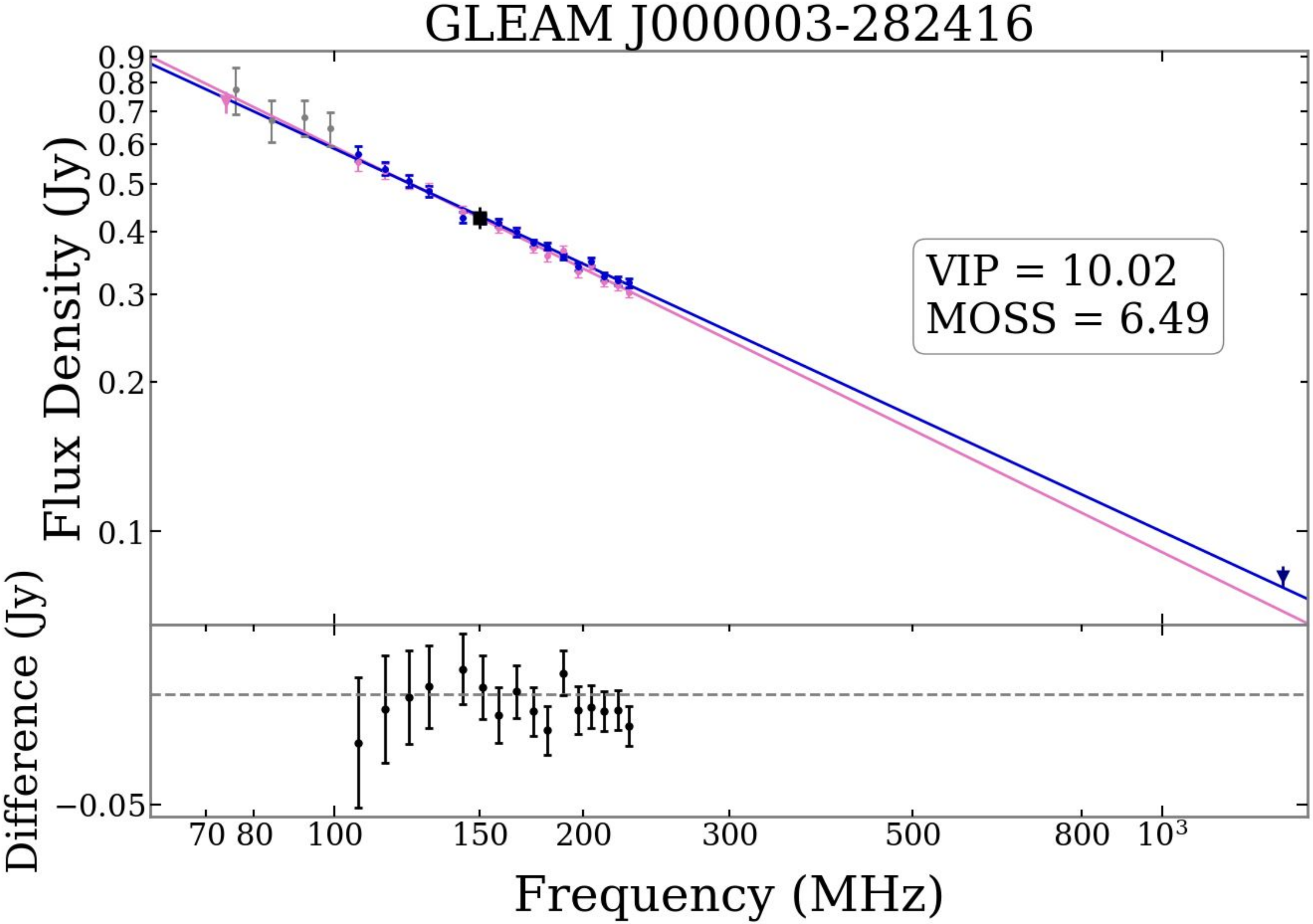
Quality Cut Criteria:

- Unresolved (~<2')
- Bright and high S/N (>160mJy, S/N>3)
- High frequency counterpart (SUMSS or NVSS)

Master population: 21, 558 sources

PSS population: 422 (Callingham et al. 2017)



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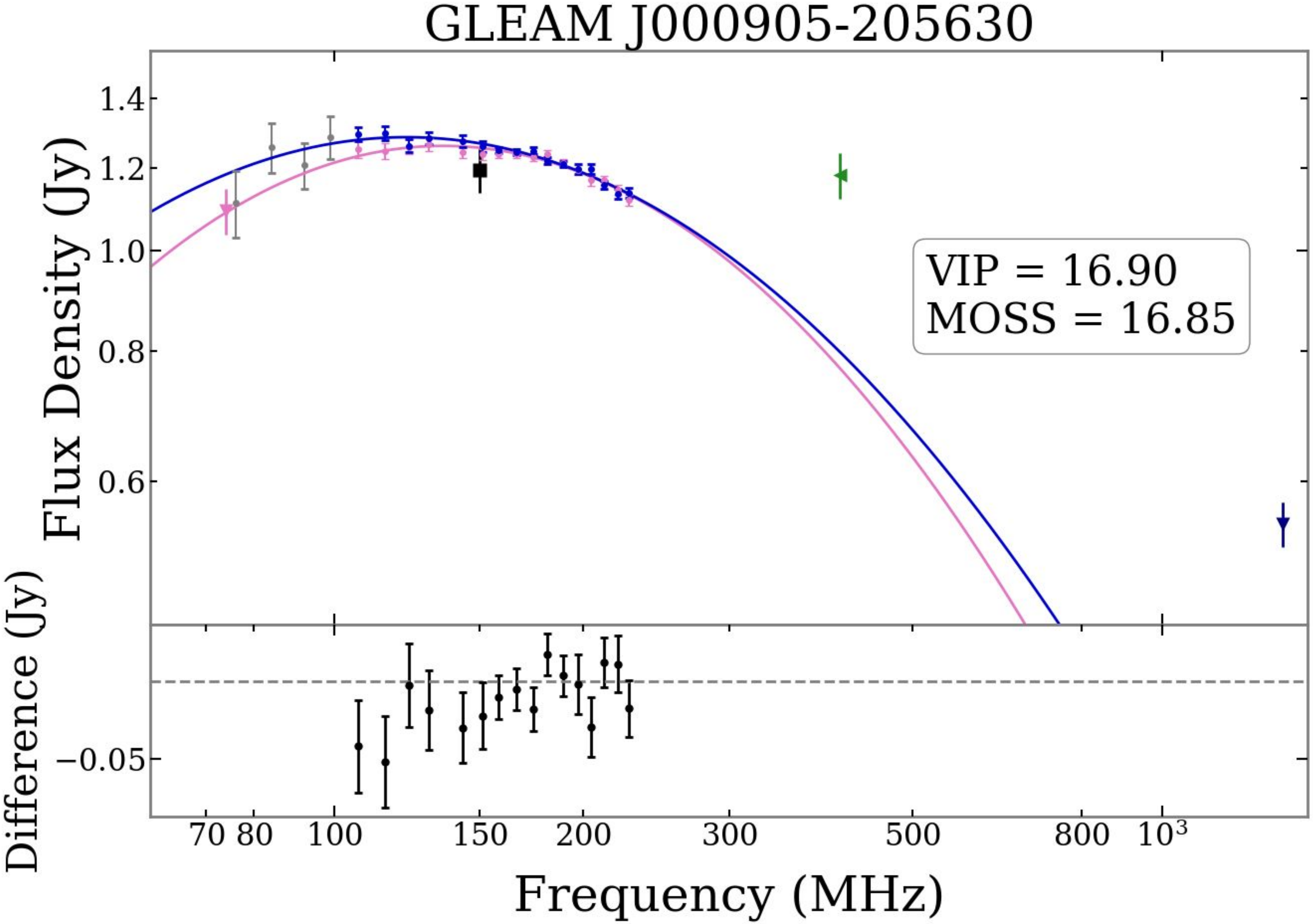

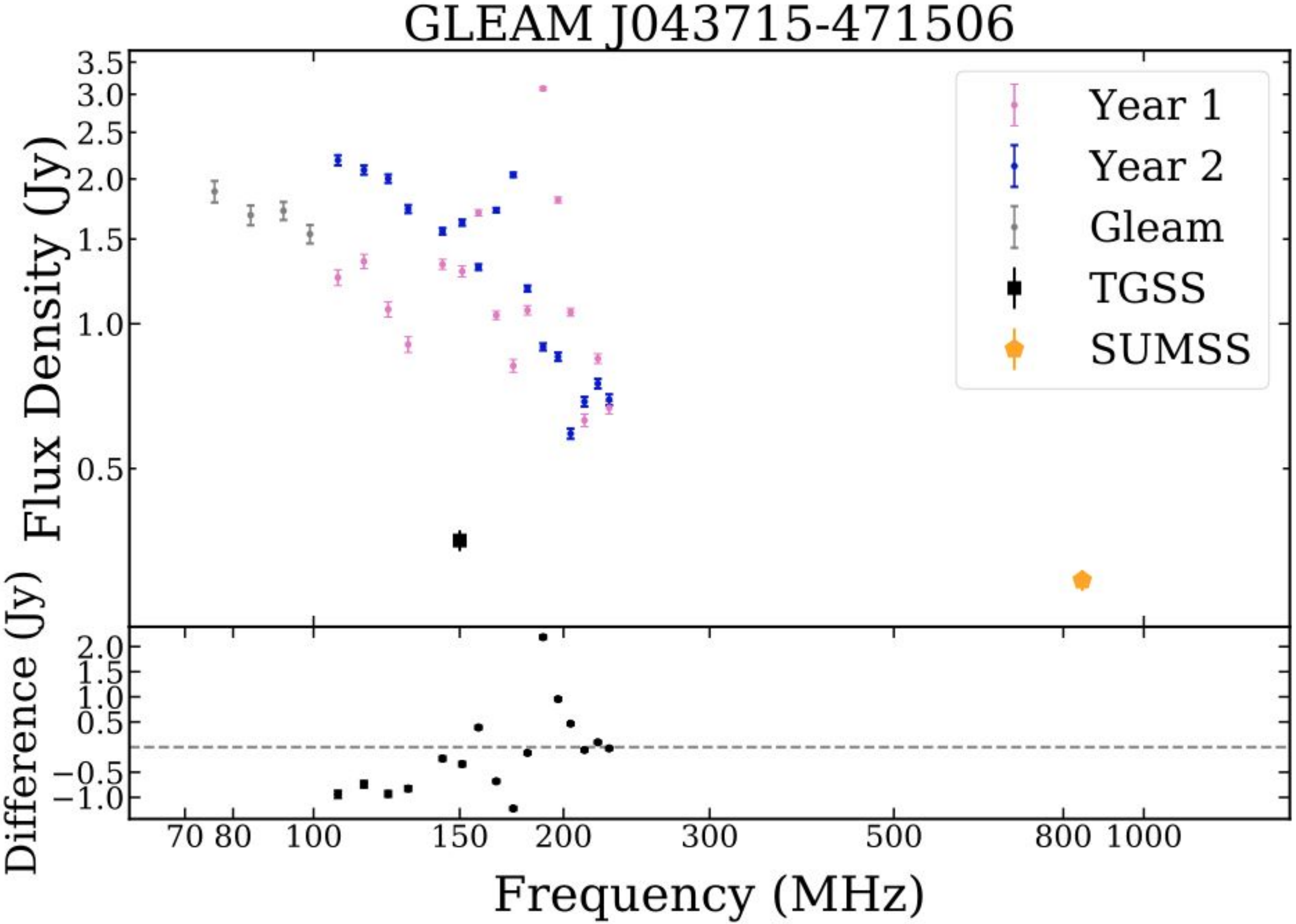

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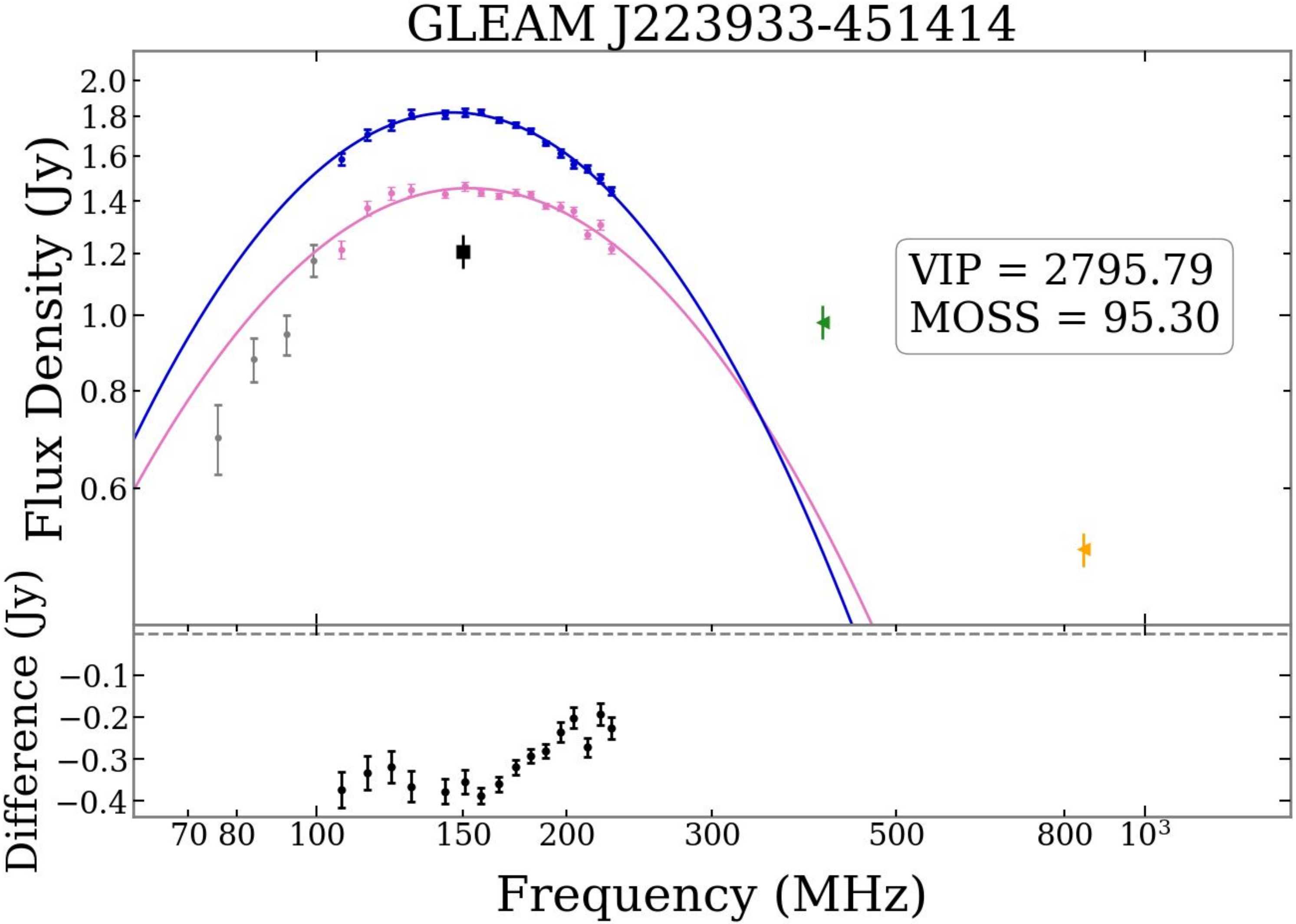

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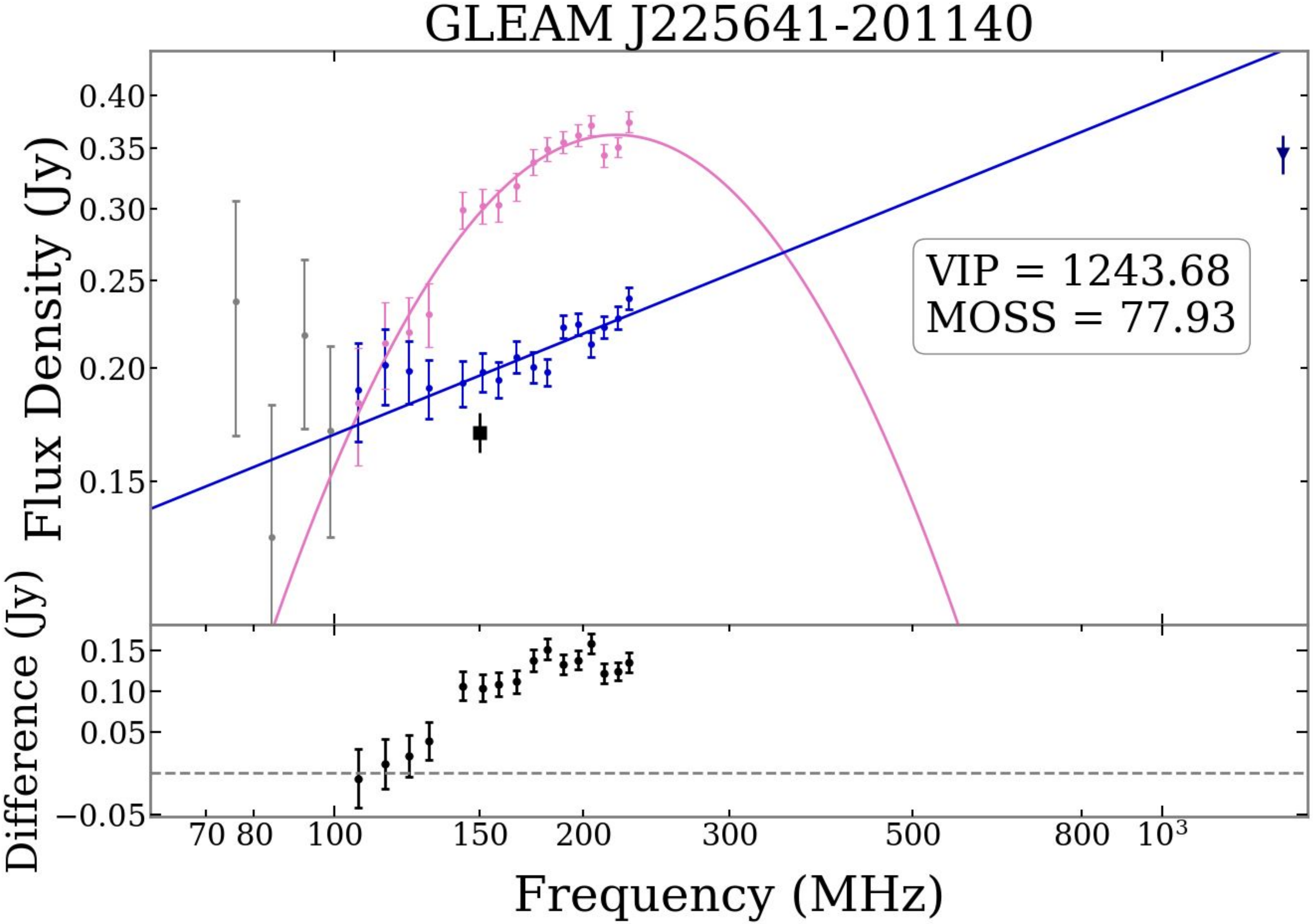

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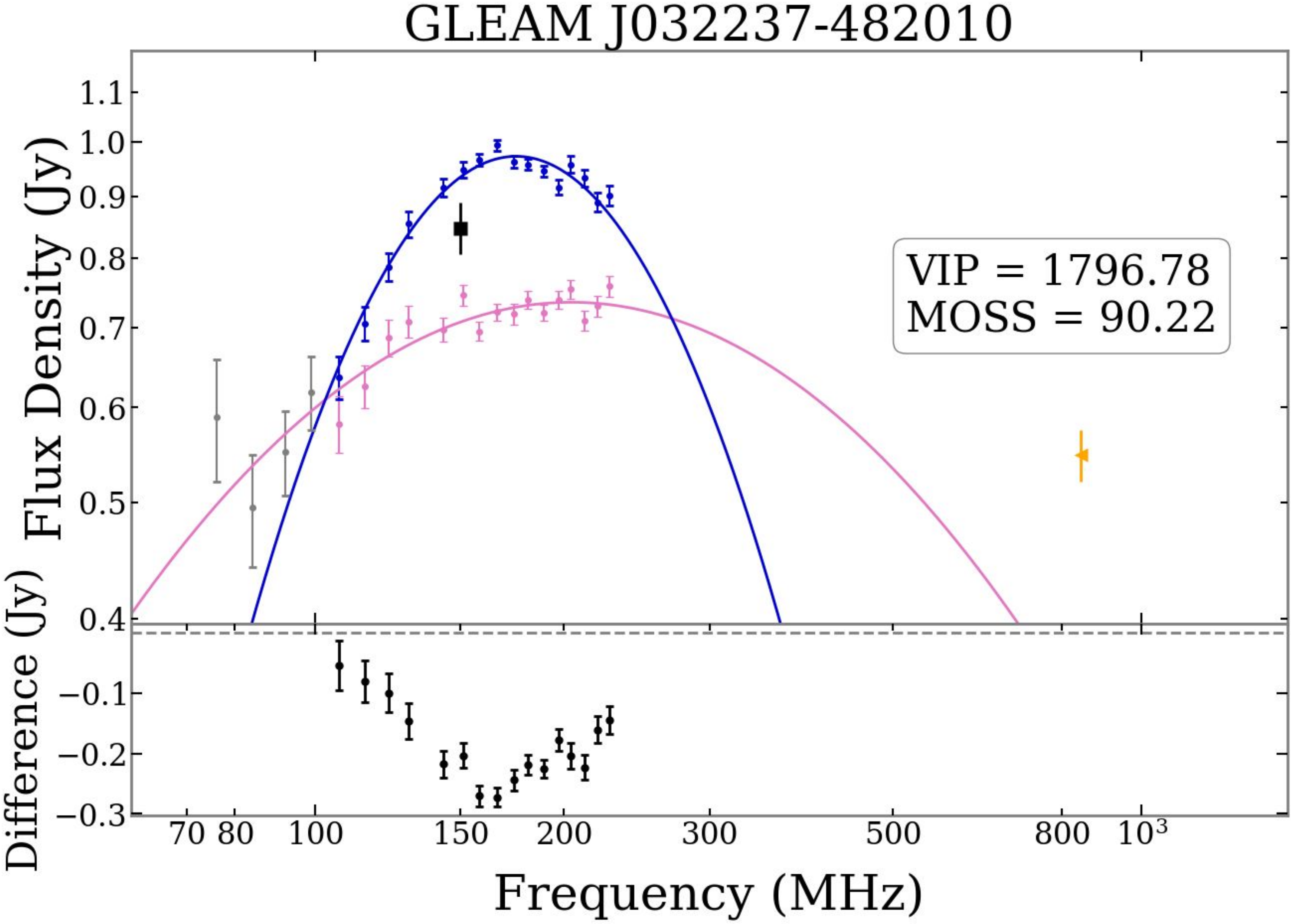

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Stastical Problem??

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1. How do you determine what is variable?
    - 21, 558 sources
    - 16 flux density measurements
    - 2 epochs of observation
2. How do you categorise the *type* of variability?
    - PSS losing classification
    - Sources becoming PSS
    - Changes in spectral index
    - Uniform increase/decrease across the MWA bandwidth

Variability Index Parameter (VIP)

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Based on χ^2 statistic

Uses all 16 individual flux density measurements + errors

Independent of model fitting

$$\mathrm{VIP} = \sum_{i=1}^{n} \frac{\left(S_{\mathrm{yr1}}(i) - S_{\mathrm{yr2}}(i)\right)^2}{\sigma_i^2}$$

Measure of Spectral Shape (MOSS)

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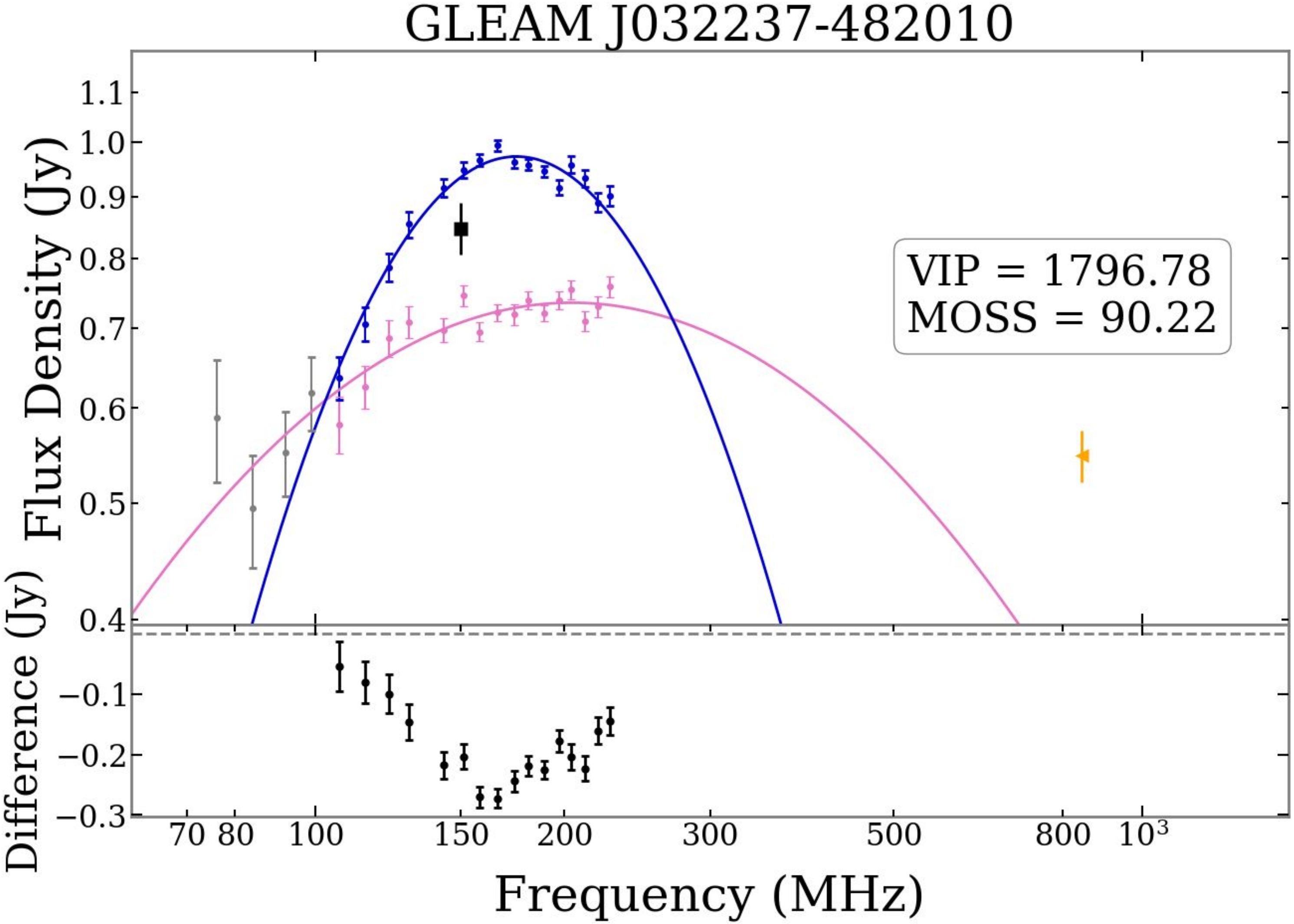
Also based on χ^2 statistic

Uses all 16 measurements of *difference* in flux density

Considers the shape of the difference

Independent of model fitting

$$\text{MOSS} = \sum_{i=1}^{n} \frac{(\widetilde{\text{diff}} - \text{diff}(i))^2}{\sigma_i^2}$$



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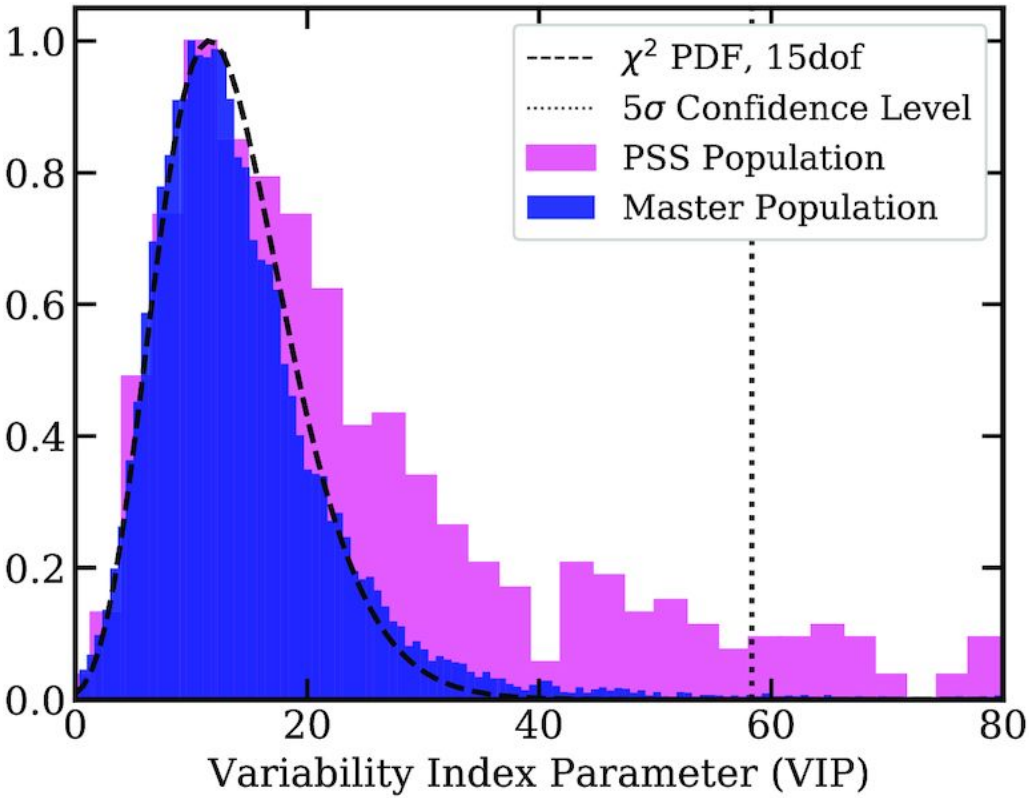

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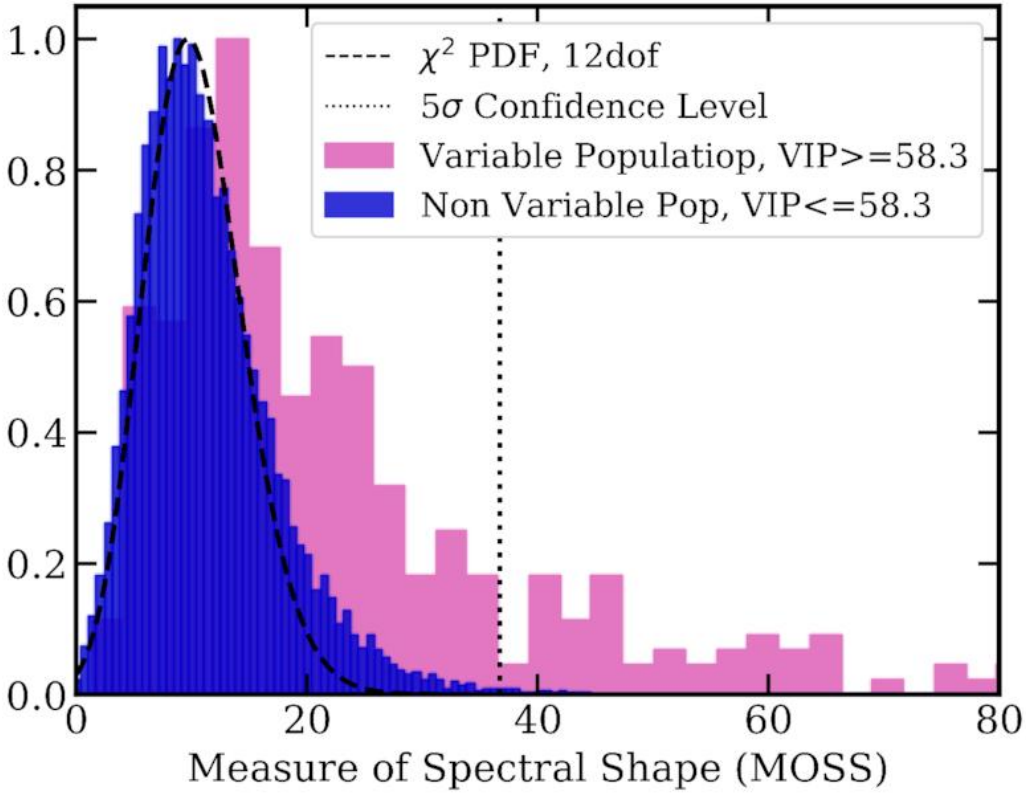

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Stastical Problem??

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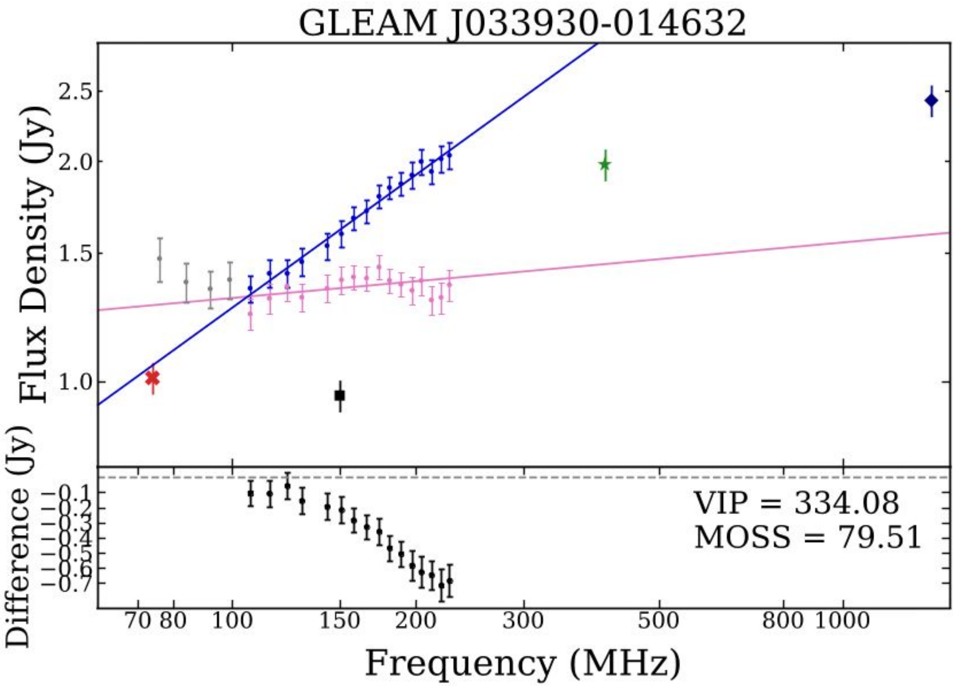
What do we find?

- Identify 323 variable sources (~1%)
- Classify 51 as changing spectral shape (16%)
- 1020 Master pop have AT20G
    - 116 variable sources with AT20G (11%)
    - 24 sources changing spectral shape (21%)
- 295 Master pop known blazars
    - 64 variable sources blazars (22%)
    - 18 sources changing spectral shape (28%)



What do we find? PSS Edition

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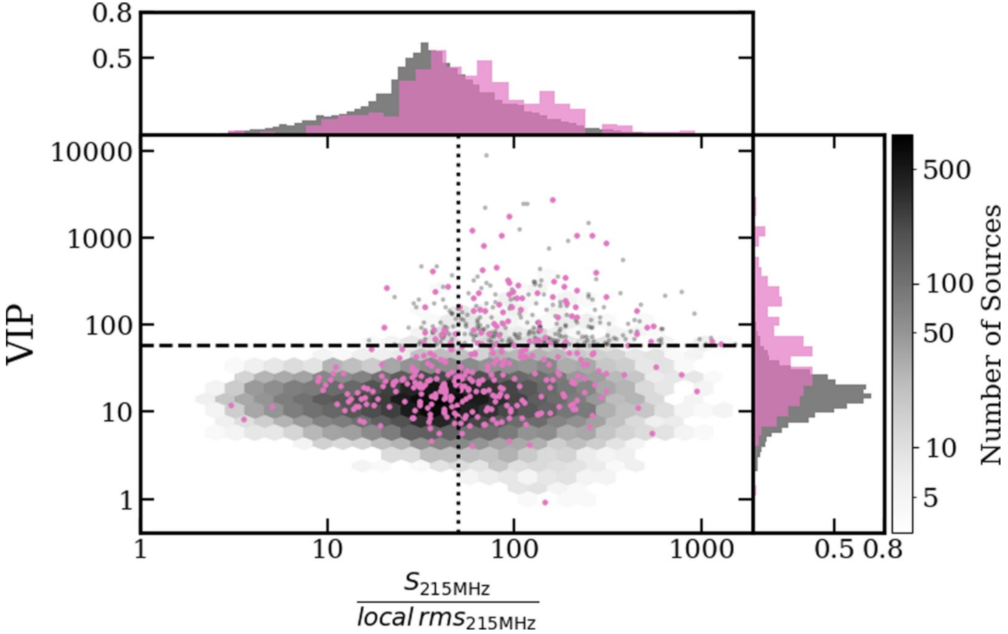
350 master population *maintain* PSS classification (3%)

83 variable sources maintain PSS classification (26%)



3 Main Possibilities

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Scintillation

- RISS is a broadband effect
- Timescale yrs-decades
- Requires compact component <~5mas
    - Keim et al. 2019, Dallacasa et al. 2021

Blazars

- Changing spectral shape previously identified
    - Torniainen et al. 2005
- Changes in flaring state can produce dynamical spectral effects
    - Tatorenko et al. 2019
- Doppler boosting → extreme variability above Compton scattering limit
- Large percentage of variable sources are known blazars already
- Likely compact enough for ISS

Intrinsic source evolution

- Vast possibilities in source evolution
- On these timescales??

What's Next?

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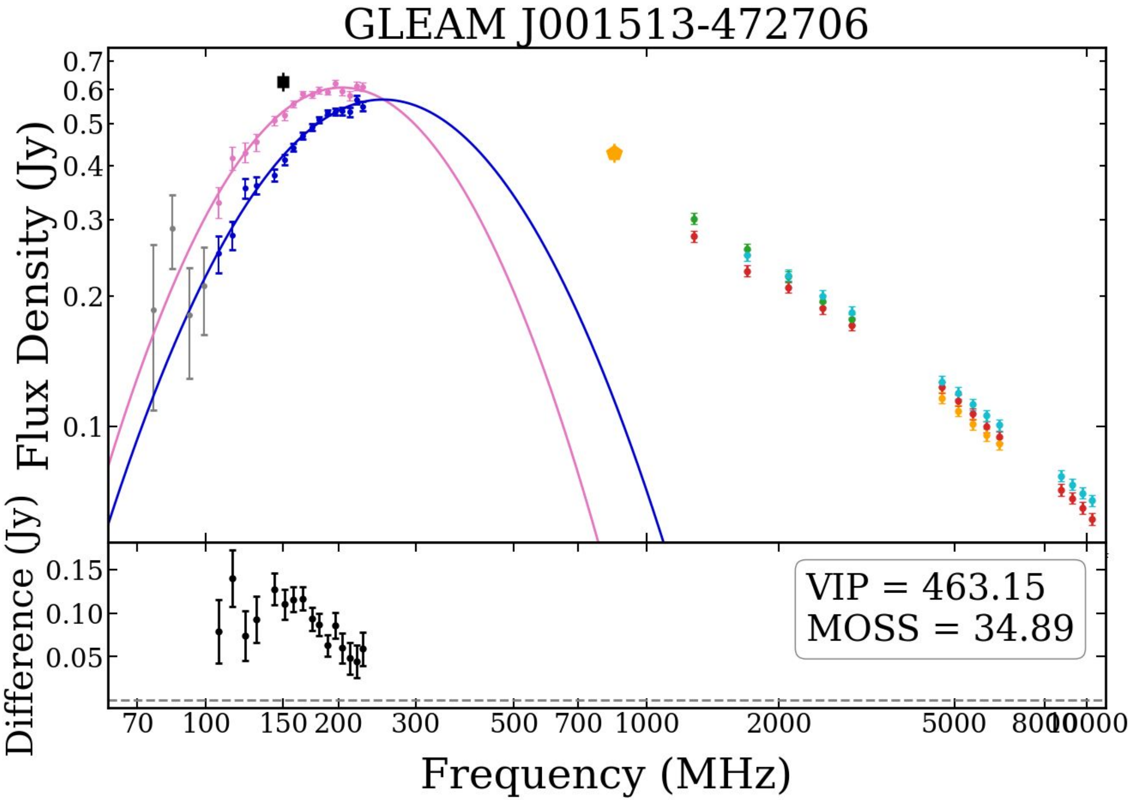

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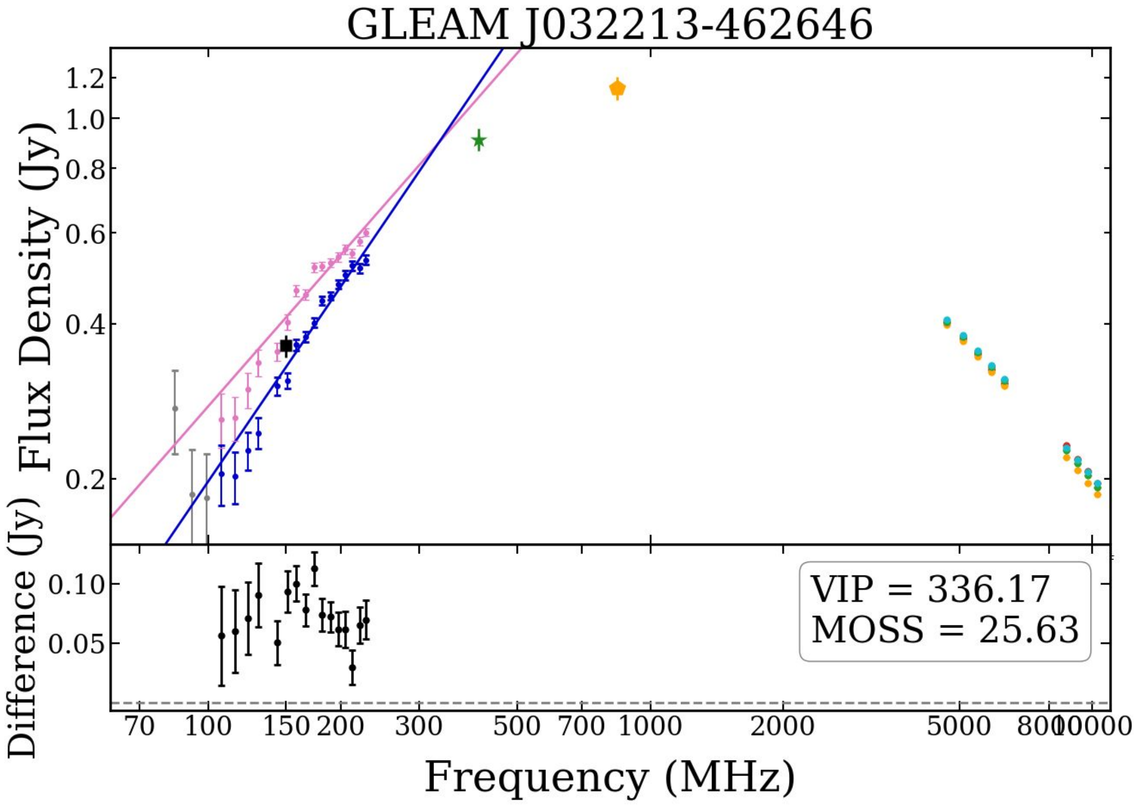

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Conclusion

Largest spectral variability survey to date

- 21,558 sources surveyed, 16 flux density measurements, 323 variable sources

PSS are intrinsically a variable population compared to typical AGN

Present VIP and MOSS as statistical methods to detect and classify spectral variability

MHz sky is far more variable than expected, implications for SKA?

Currently following up with simultaneous ATCA and MWA observations, high resolution LBA