EIGENANALYSIS OF FOREGROUNDS

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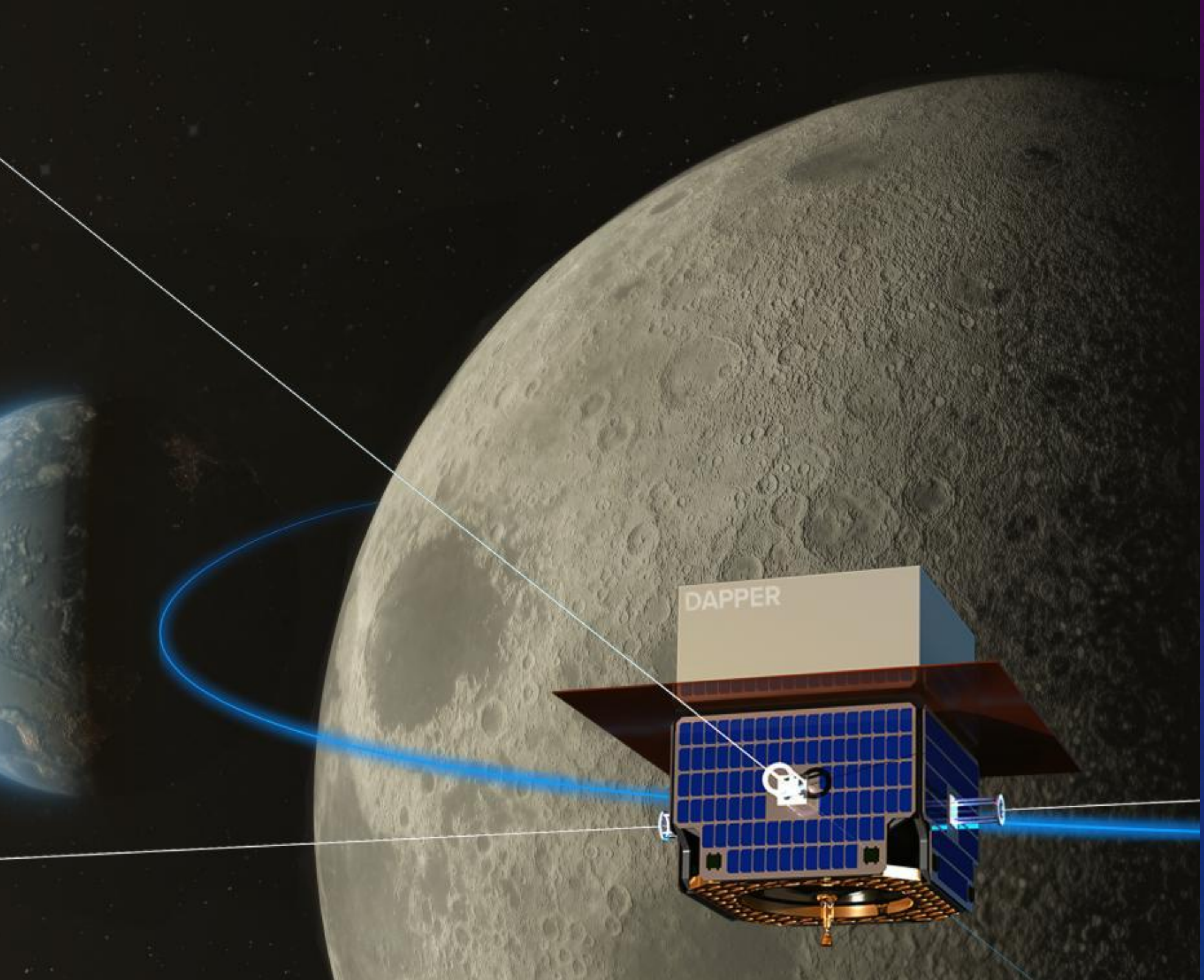
GLOBAL 21-CM SIGNAL PIPELINE

- Three primary challenges must be overcome to measure this signal:
  1. Foreground Brightness
  2. Beam Chromaticity
  3. Earth's RFI and Ionospheric Effects

Graphic from Burns et al. 2019, BAAS; adapted from Djorgovski et al., Caltech.



Graphic taken from: https://www.colorado.edu/ness/dark-ages-polarimeter-pathfinder-dapper

DAPPER

- The lunar farside offers a pristine radio-quiet environment, potentially solving the problems of anthropogenic RFI and the ionosphere.
- The Dark Ages Polarimeter PathfindER (DAPPER) is a NASA-funded mission concept to place a satellite in orbit around the moon to make use of this environment.

PIPELINE REVIEW

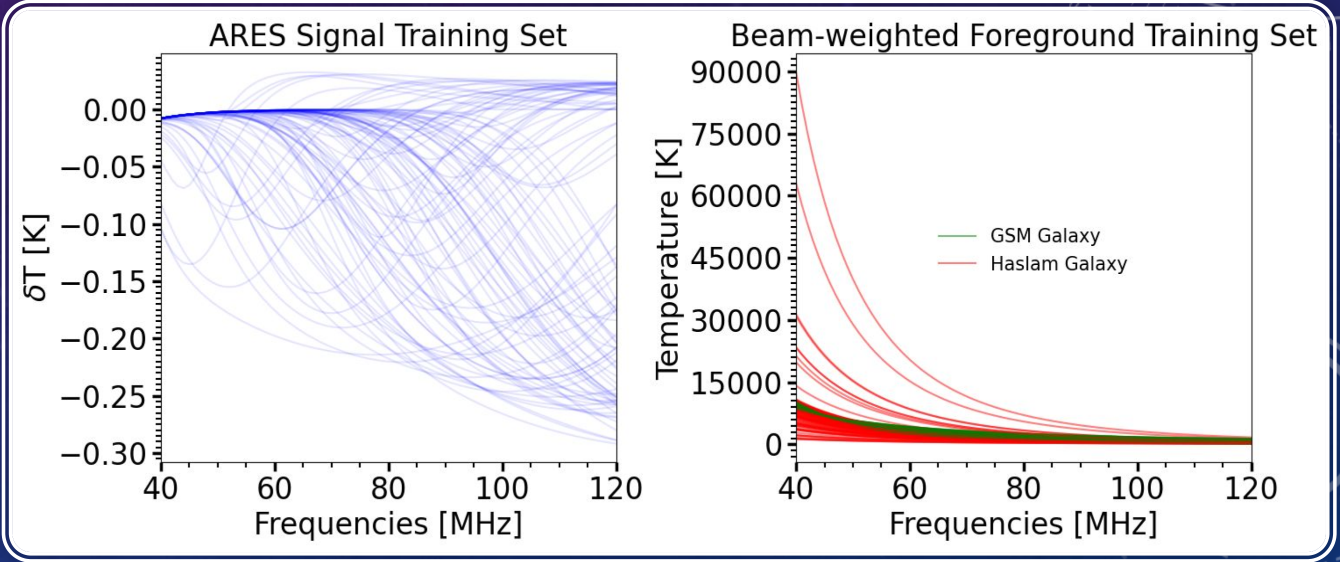
Generate Galaxy Models

Assemble many model fluctuations into a "training set"

Use Singular Value Decomposition (SVD) from *pylinex* (Tauscher et al. 2018) to generate **optimal Eigenmodes** for modelling a particular training set.

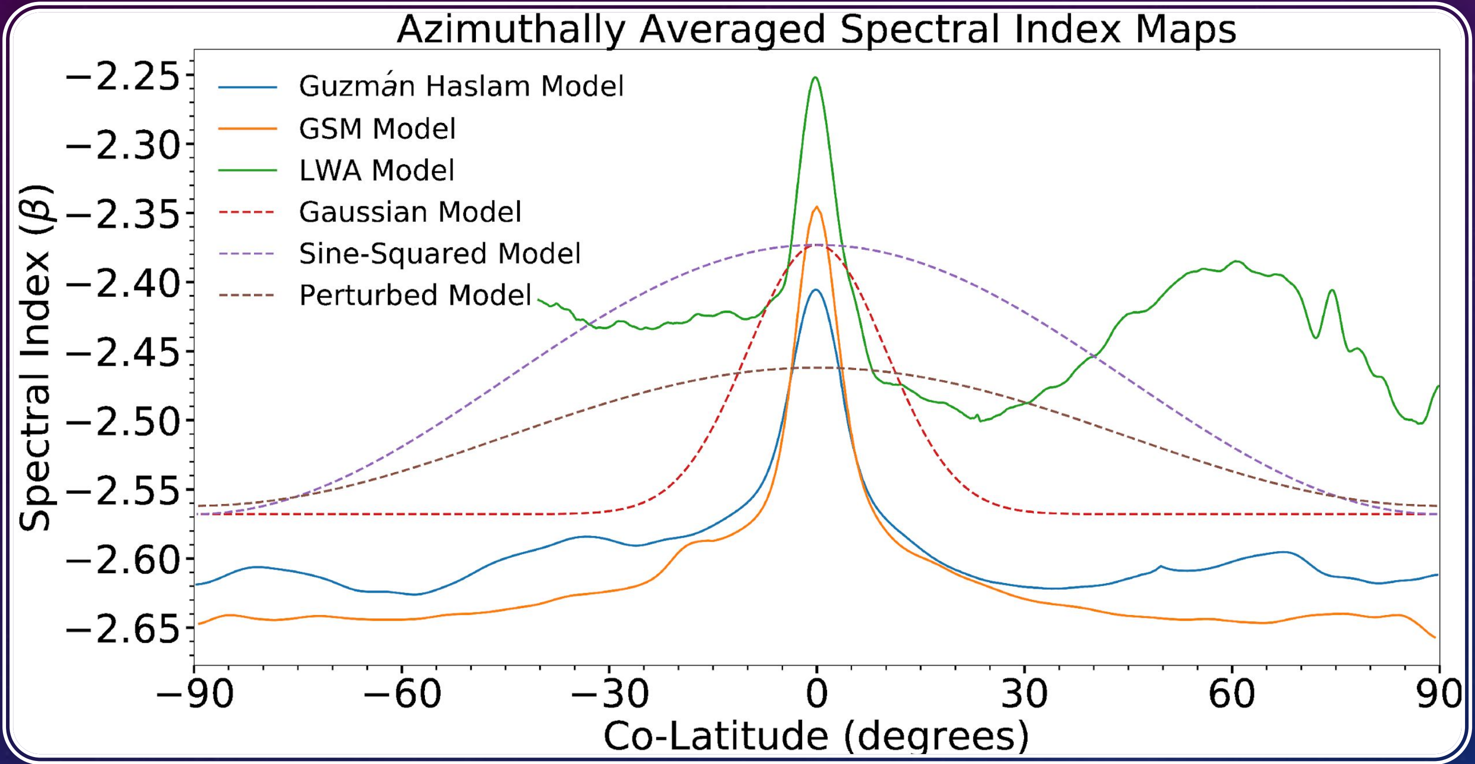
Galaxy Models include:

- Spectral Index Map (spectral variation)
- Sky Brightness Temperature Map (angular variation)
- Beam Simulations



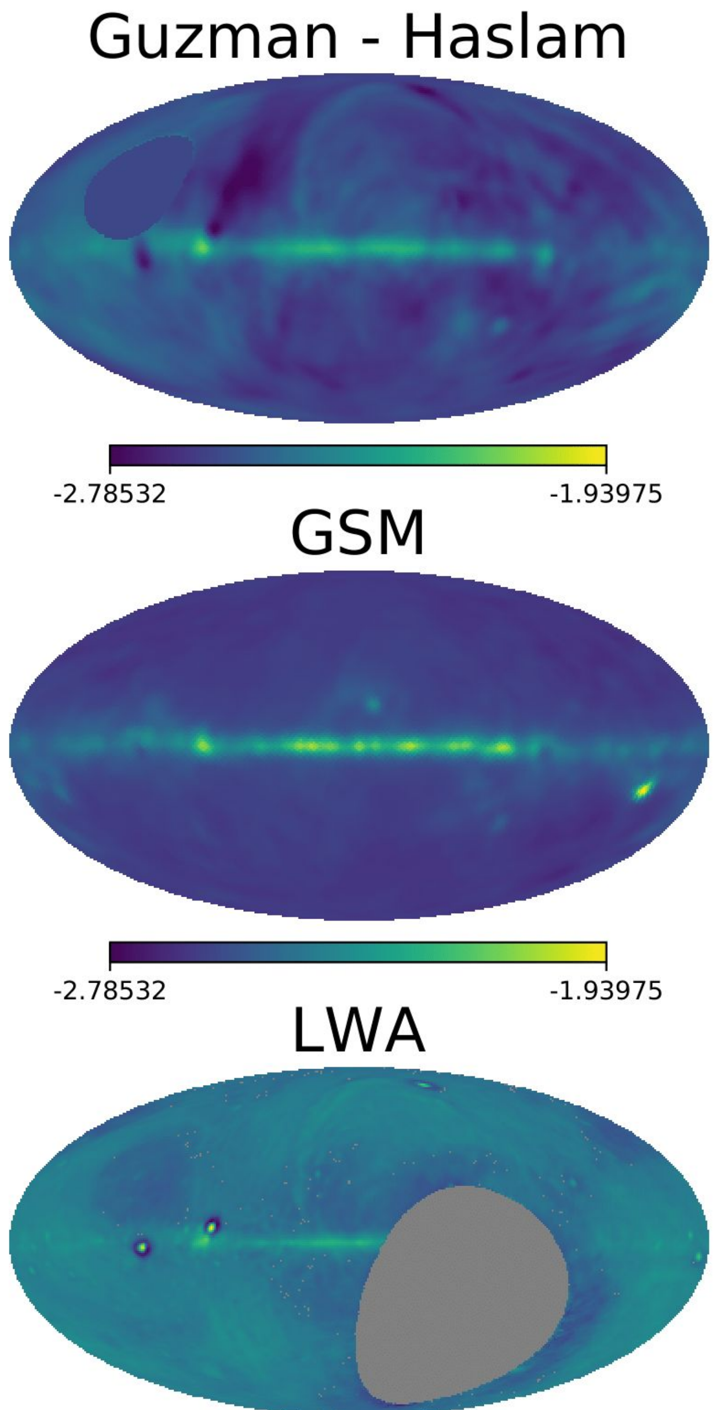
$$B = U\Sigma V^T$$

SPECTRAL INDEX MAPS



All Figures hereafter taken from Hibbard et al. 2020 (accepted by ApJ).

- Determine how spectral index latitude variation and magnitude affect foreground eigenmodes and residuals.
- Analytical maps: Gaussian, Sine-Squared, Perturbed (Noise)
- Interpolated Observational: Guzman-Haslam, GSM, LWA



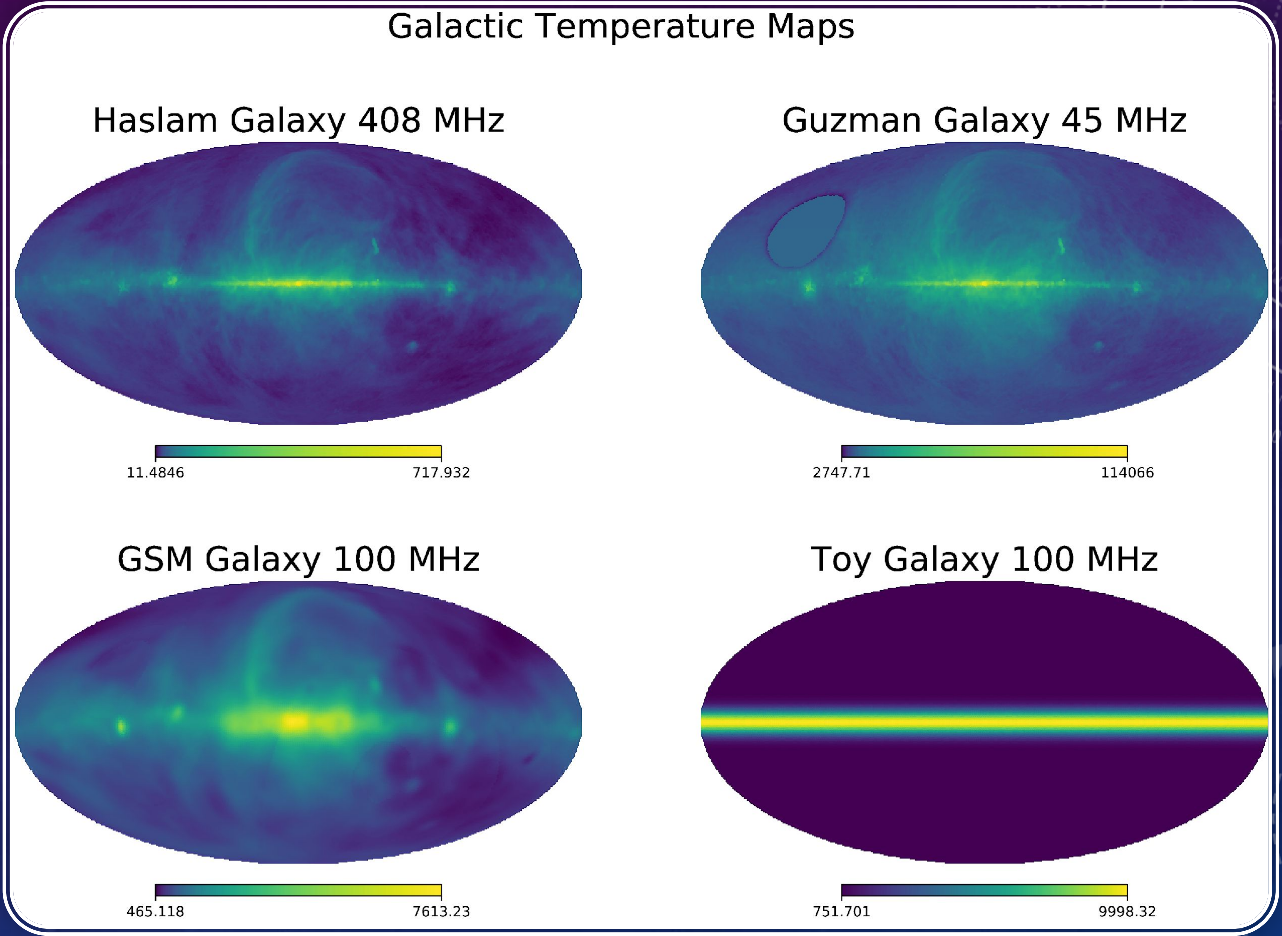
SPECTRAL INDEX MAPS (CONTINUED)

- Mollweide Projection of Interpolated Observational Spectral Index maps.

SKY BRIGHTNESS TEMPERATURE MAPS

- Characterize the spatial distribution of temperature

- Example of various published sky brightness temperature maps, along with a simple Toy Galaxy which includes only the Galactic Plane, with an on-plane and off-plane temperature.



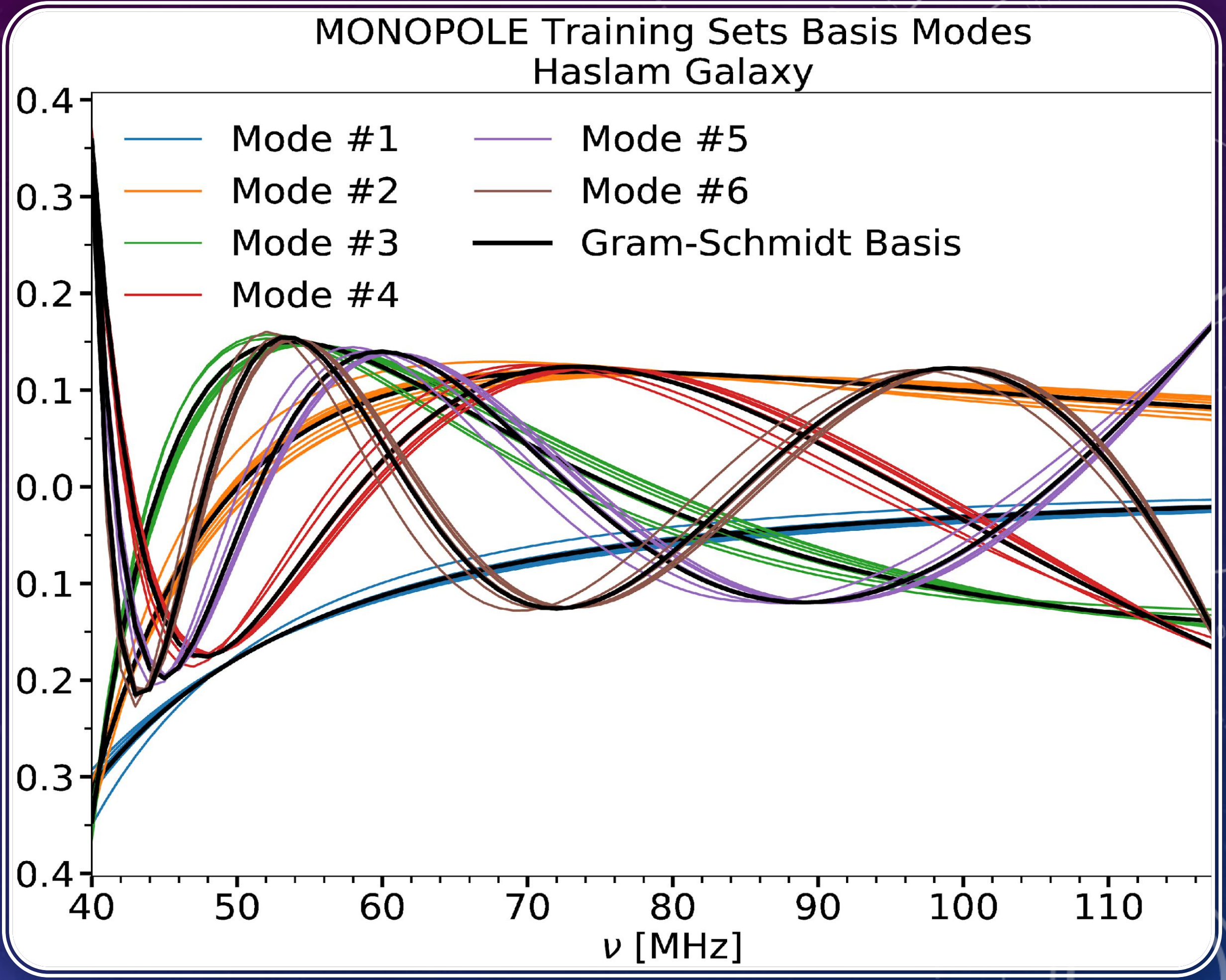
THE MONOPOLE-BEAM FOREGROUND

For comparison with other realistic beams, the Monopole-beam represents an achromatic, isotropic beam, the ideal case.

The graph shows the first 6 SVD Eigenmodes for 11 different spectral index models.

All are well-modelled by a power law times a polynomial in logarithmic frequency space (Lin-Log polynomial).

Beam chromaticity breaks this model degeneracy.



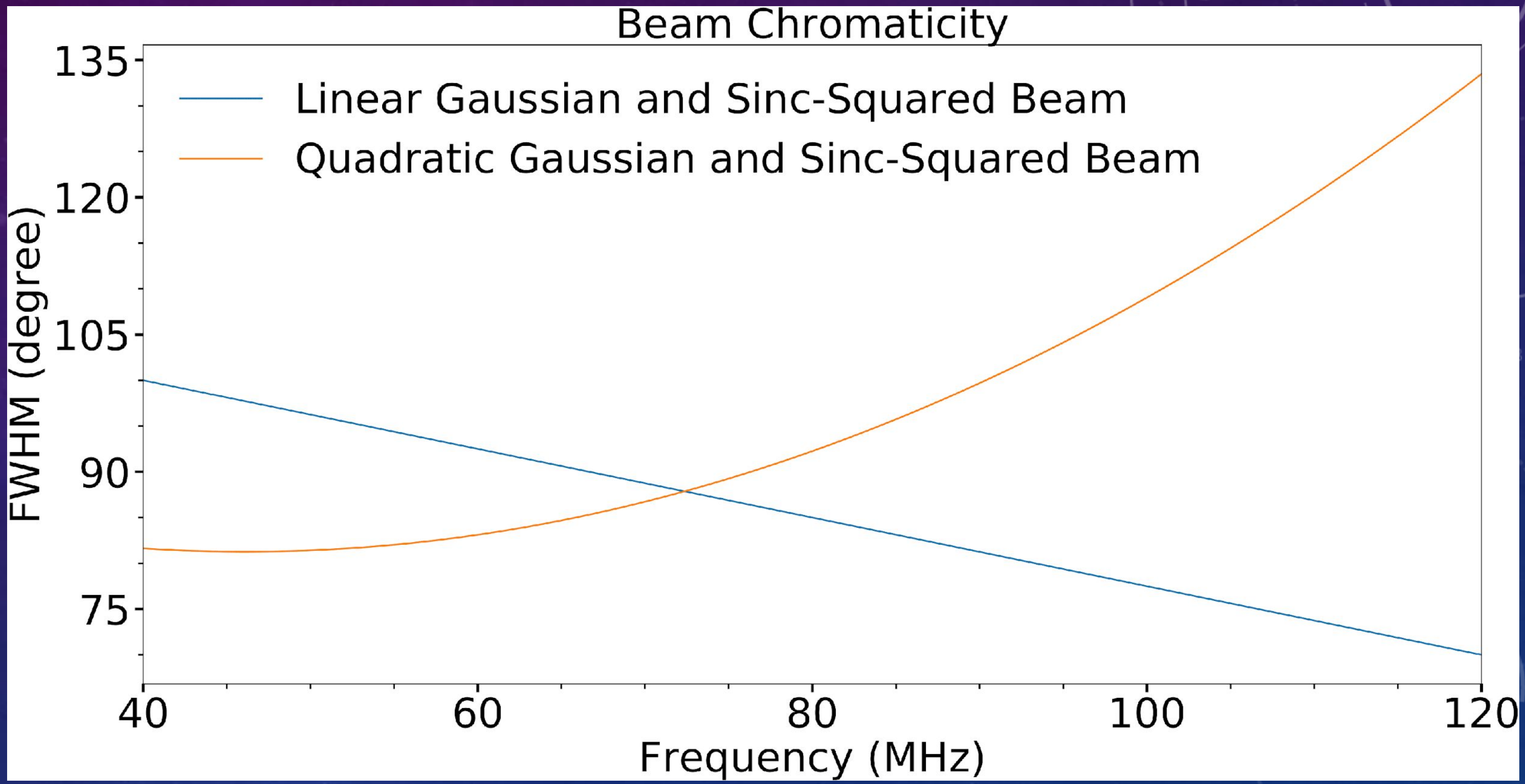
$$T_{mon}(\nu) = \frac{1}{N_{pix}} \left(\frac{\nu}{\nu_o}\right)^{\beta_{ref}} \sum_{i=1}^{N_{pix}} T_{map}(i) \left[1 + \ln\left(\frac{\nu}{\nu_o}\right)\epsilon_i + \frac{1}{2}\ln^2\left(\frac{\nu}{\nu_o}\right)\epsilon_i^2 + \frac{1}{6}\ln^3\left(\frac{\nu}{\nu_o}\right)\epsilon_i^3 + O(\epsilon_i^4)\right].$$

OTHER BEAM-WEIGHTED FOREGROUND SIMULATIONS

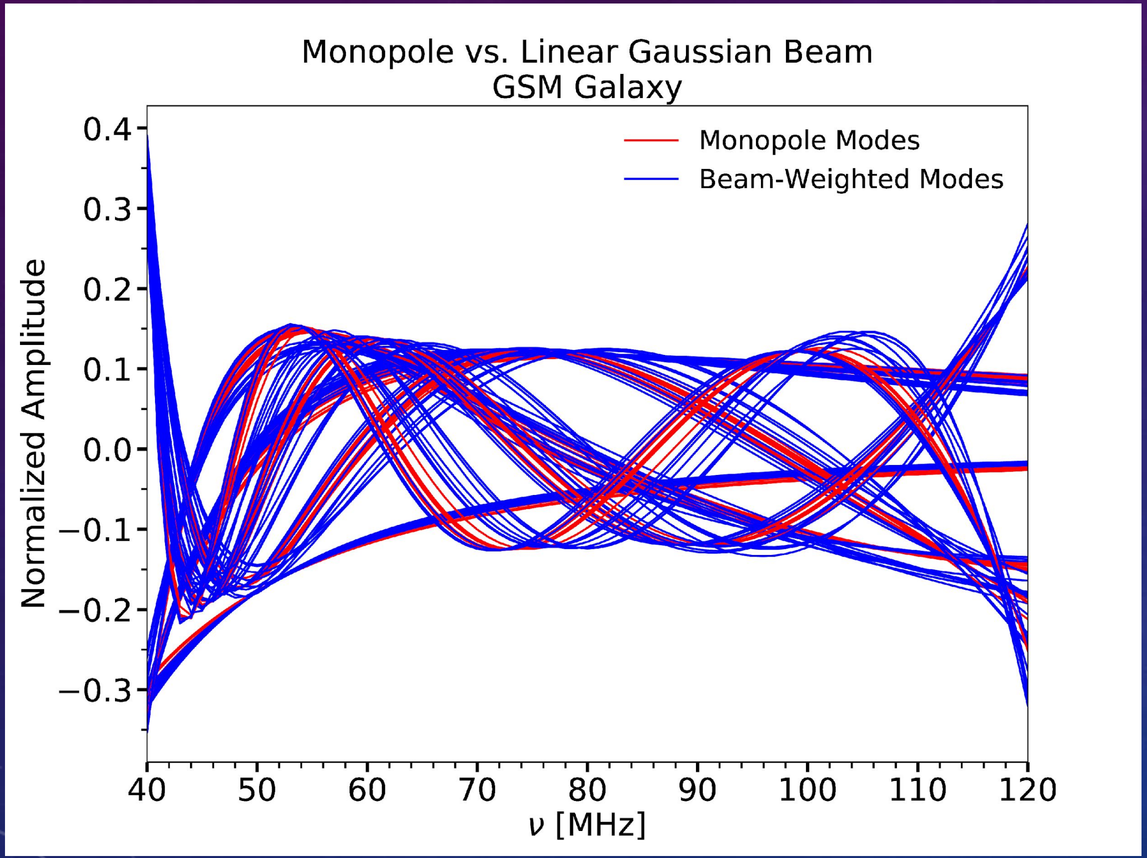
Realistic beams include:

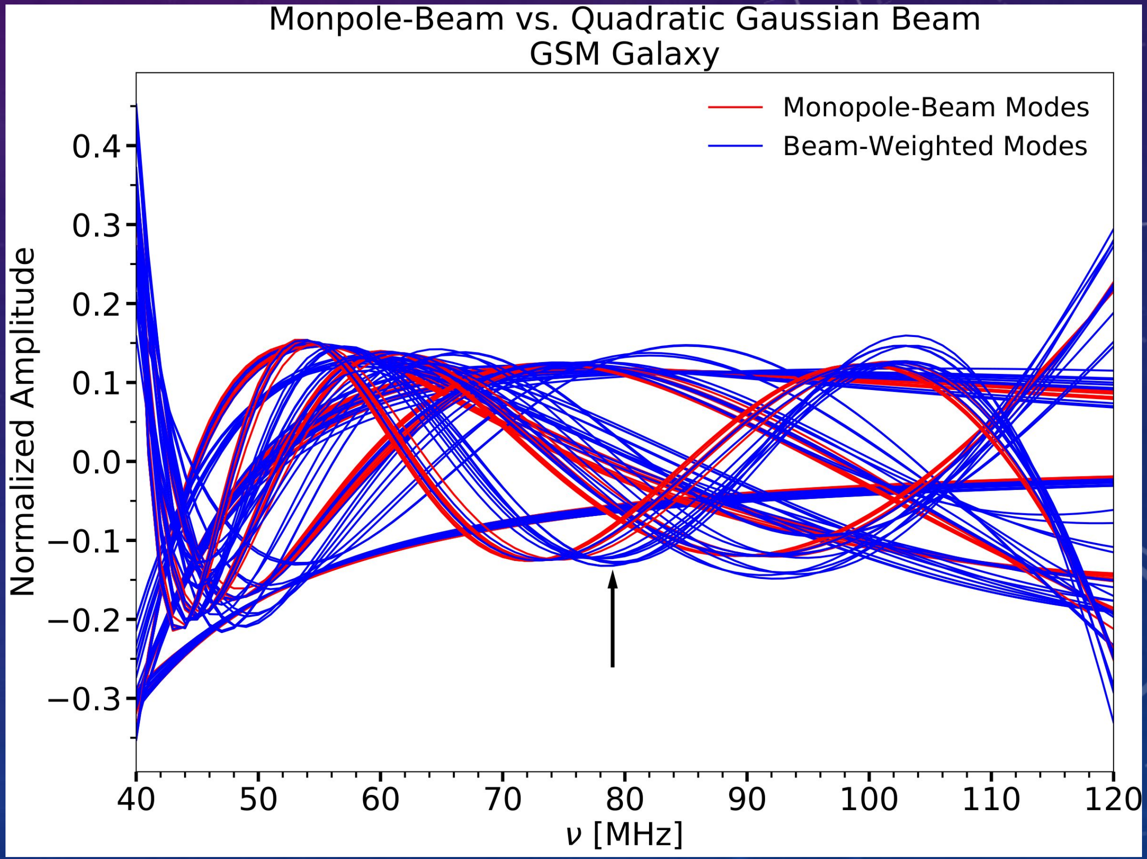
1. Chromaticity (spectral) dependence:
    - Linear vs. Quadratic FWHM function
2. Angular (spatial) dependence:
    - Gaussian vs. Sinc-Squared Beam

Beams see different sources and angular frequency features at each channel.

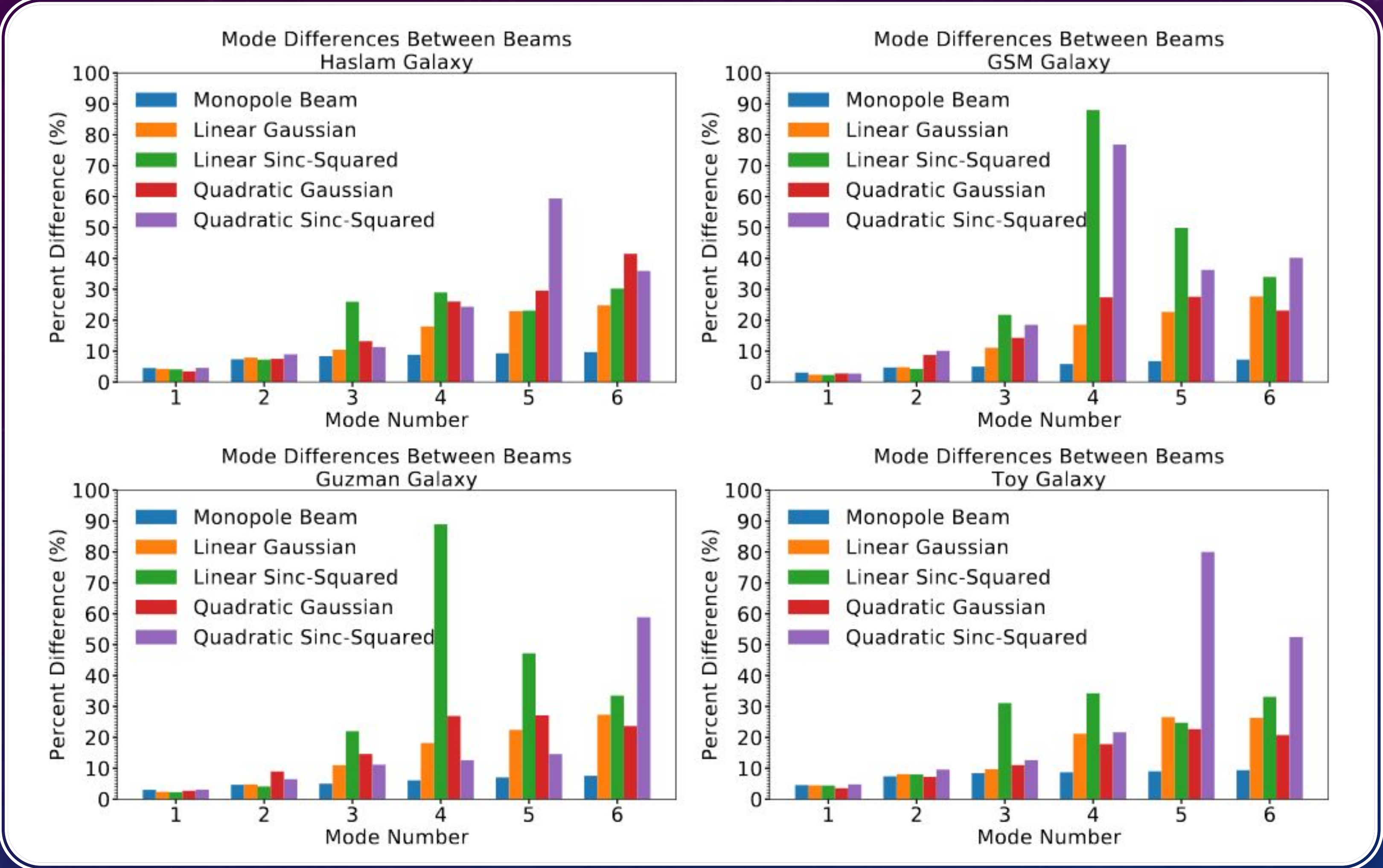


BEAM-WEIGHTED FOREGROUND EIGENMODES



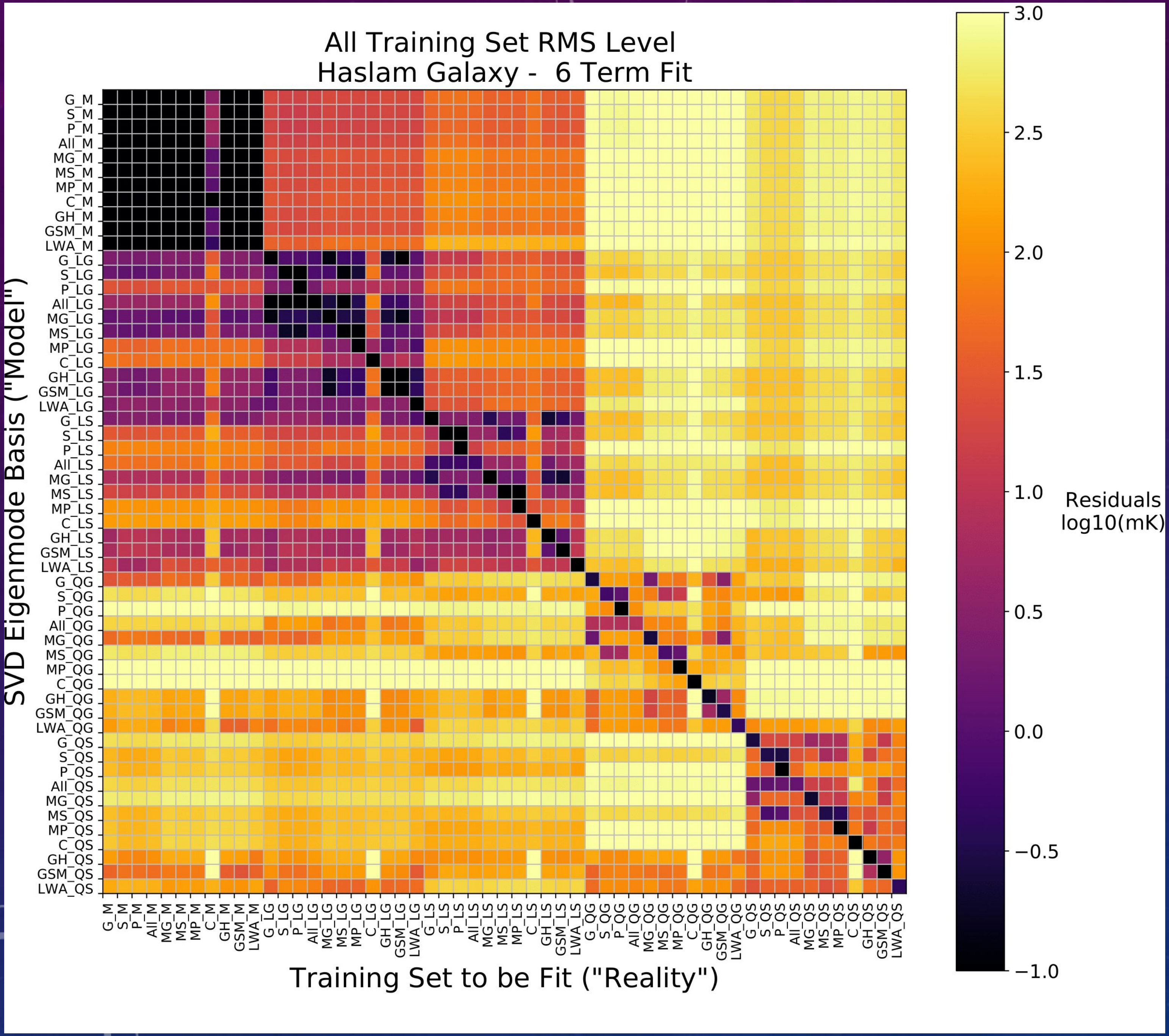


Modes are not only distorted from the Monopole-beam, but now each spectral index model has different optimal modes.



COMPARISON OF BEAMS AND TEMPERATURE MAPS

- Percent Difference per Mode Number RMS'ed across both Spectral Index Model AND Frequency.
- Monopole modes show stability across mode number.
- The QG and SS beams distort the modes most, meaning the optimal modes for modelling the beam-weighted foreground depend intimately now on detailed knowledge of the beam AND the foreground's spatial/spectral structure.



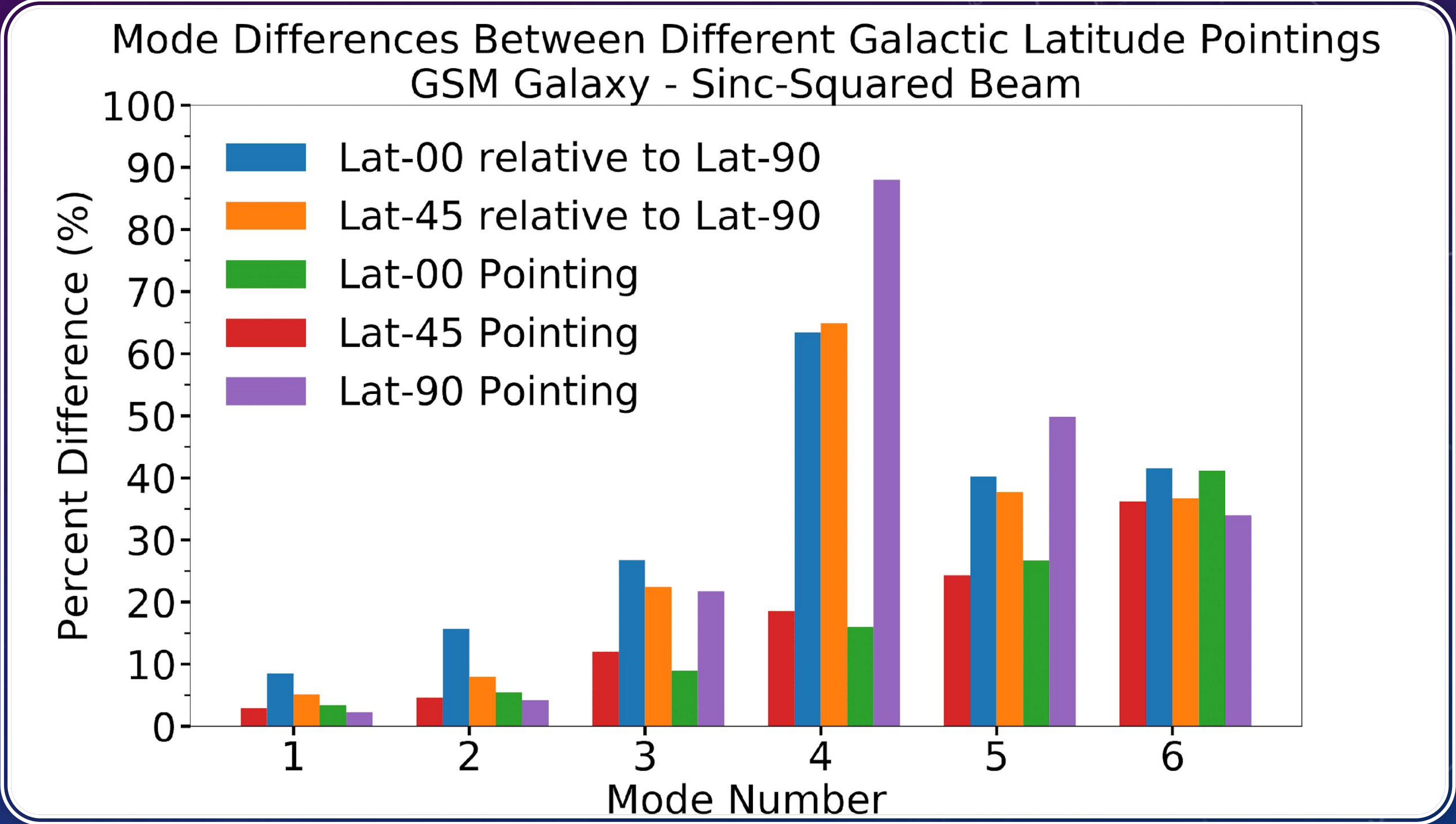
RESIDUAL LEVEL GRIDS

- Y-axis gives the MODEL from which SVD eigenmodes are taken.
- X-axis gives the training set, or REALITY to be fit by the eigenmodes from the y-axis.
- Purple shows the FG noise level of 1 mK.
- First acronym denotes the spectral index model, second denotes the simulated beam (M for Monopole, LG for Linear Gaussian, S for Sinc-Squared, QG for Quadratic Gaussian, and QS for Quadratic Sinc-Squared).
- The BEAM affects the residuals the most, indicated by the “blocky” structure of the grid.

BEAM POINTING

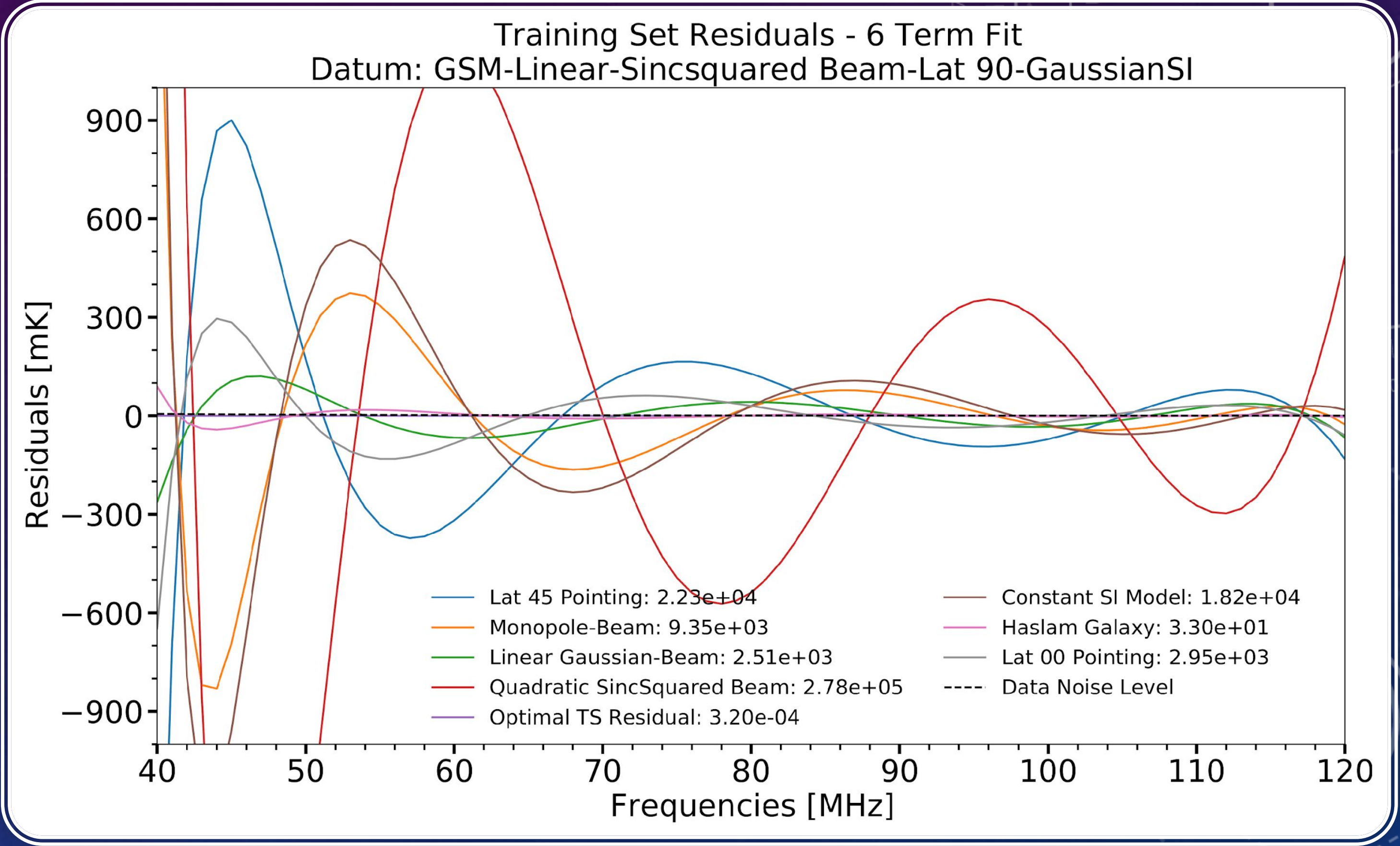
Briefly, the Eigenmodes will also depend upon the position and portion of the galactic plane overhead.

Pointing of the beam (here in Galactic Coordinates) affects the Eigenmodes.



SUMMARY OF BEAM-WEIGHTED FOREGROUND SYSTEMATICS

- Beam-weighted foreground residuals for a 6-term fit of the Datum.
- Each curve represents a Training Set with a single feature changed from the Optimal Training Set.
- Numbers in legend represent the value of Chi-squared from the fit.
- Only the Optimal TS eigenmodes fit the Datum down to the noise-level.



Conclusions

- For any experiment, the BEAM determines the optimal modes for modelling. Its spectral and spatial structure must be well-characterized, including all known fluctuations around the "nominal" beam.
- Through the beam, an exact model of the unweighted Foreground's full spatial and spectral features is required. This includes spectral index maps at the frequency ranges of interest, and sky brightness temperature maps.
- Because of the latter, any model which does not directly incorporate the beam, will be unable to fit the Foreground. Thus, the polynomials which are agnostic of any beam and are commonly used to model the Foreground are insufficient.
- Any experiment must use a Foreground model particular to their own beam, pointing, LST hour or risk unaccounted for beam-weighted foreground systematics.

Acknowledgements: This work was directly supported by the NASA (National Aeronautics and Space Administration) Solar System Exploration Virtual Institute cooperative agreement 80ARC017M0006.