CMB Spectral Distortions:
Forecasting for Future Spectrometer Missions including Galactic and Extragalactic Foregrounds

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CMB Foregrounds for B-mode Studies

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Prospects for measuring cosmic microwave background spectral distortions in the presence of foregrounds.

Abitbol, Chluba, Hill, and Johnson

MNRAS 471, 1 (2017).

Overview

Spectral distortions

- Reveal information about the thermal history of the universe.
- Test cosmological model back to redshift of $z \sim 2 \times 10^6$.

PIXIE and PRISTINE

- Sensitivity and design.

Forecasting

- Parametric models and Fisher Information.
- Detection significance and mission optimization.

Results

- PIXIE and PRISTINE could detect y and relativistic correction.
- Need more low frequency sensitivity or observations to detect μ-distortion.

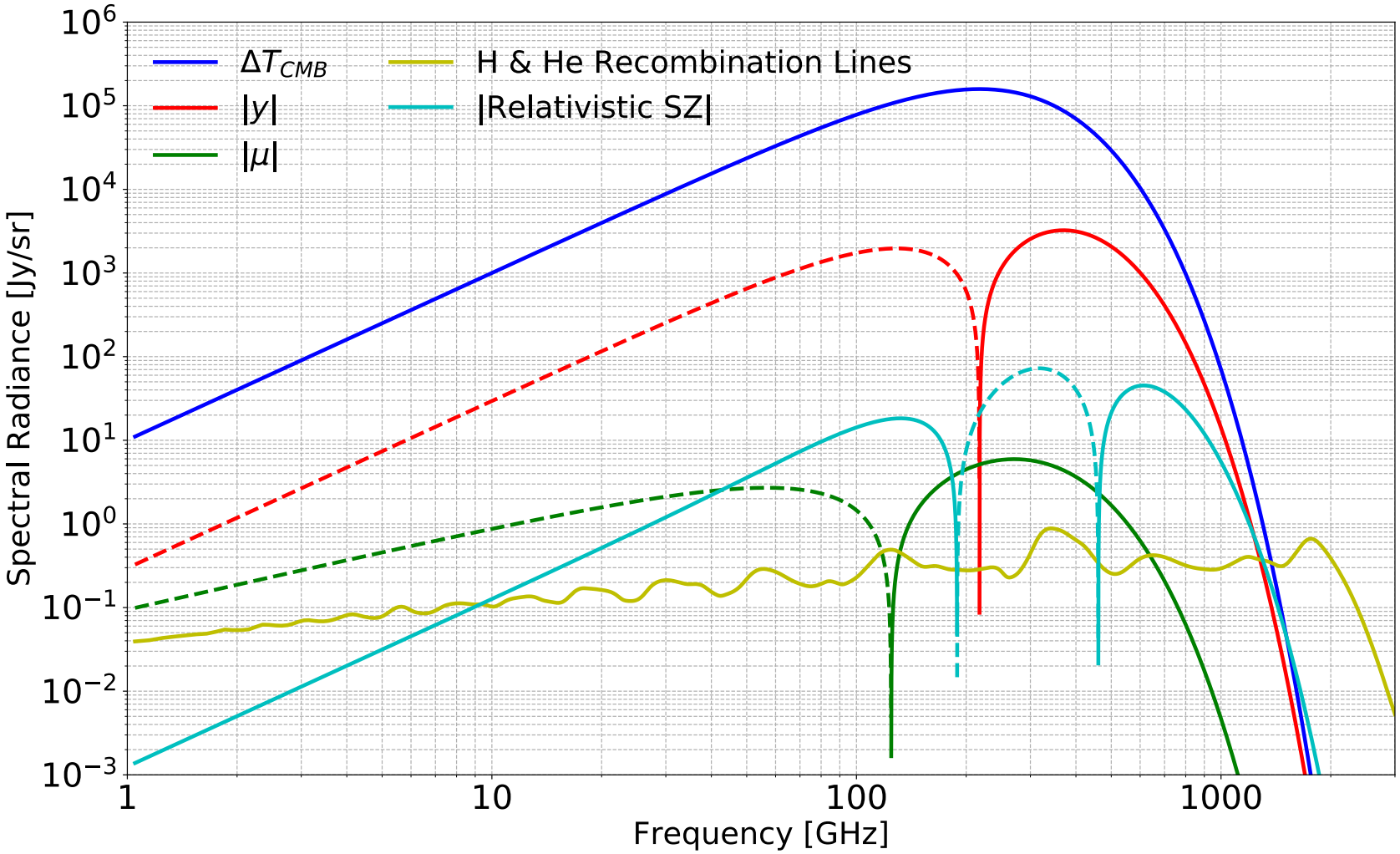
CMB spectral distortions

- Energy released into the CMB produces deviations from the blackbody monopole.
- Compton y distortion created during reionization and by structure formation.
  - Primarily from hot gas in ICM at $z < 2$.
- Measures thermal energy in electrons in the universe.
- Relativistic correction gives electron temperature distribution and thus electron density and baryon density.

CMB spectral distortions

- Chemical potential mu distortion produced by Silk Damping and adiabatic cooling of the CMB during recombination.
  - Up to $z \sim 10^6$
- Also sensitive to non-standard model physics including:
  - axion scenarios, late-time decaying particles, dark matter scenarios, cosmic strings, and primordial black holes.
- Hydrogen and helium recombination lines.

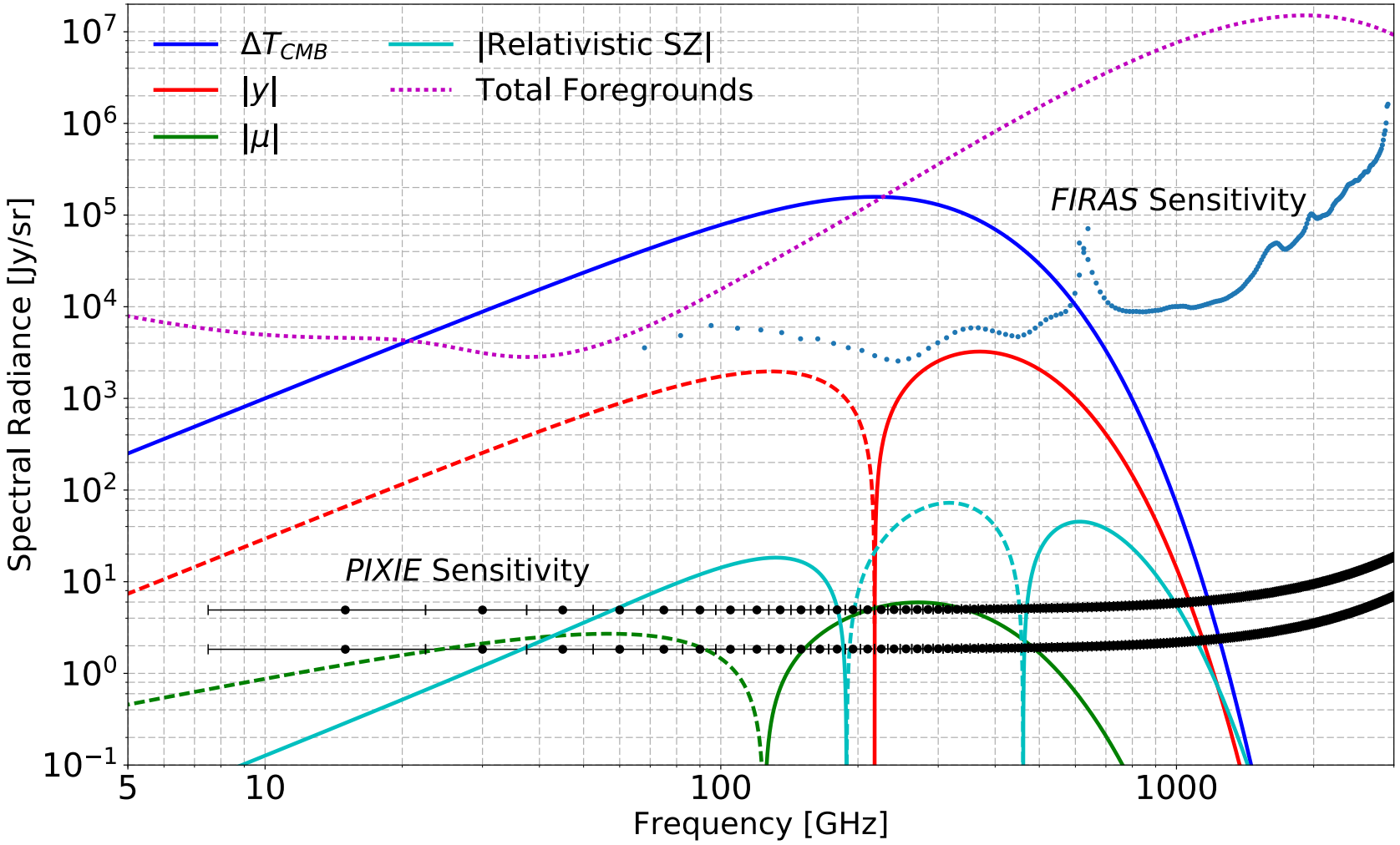
CMB spectral distortion signals



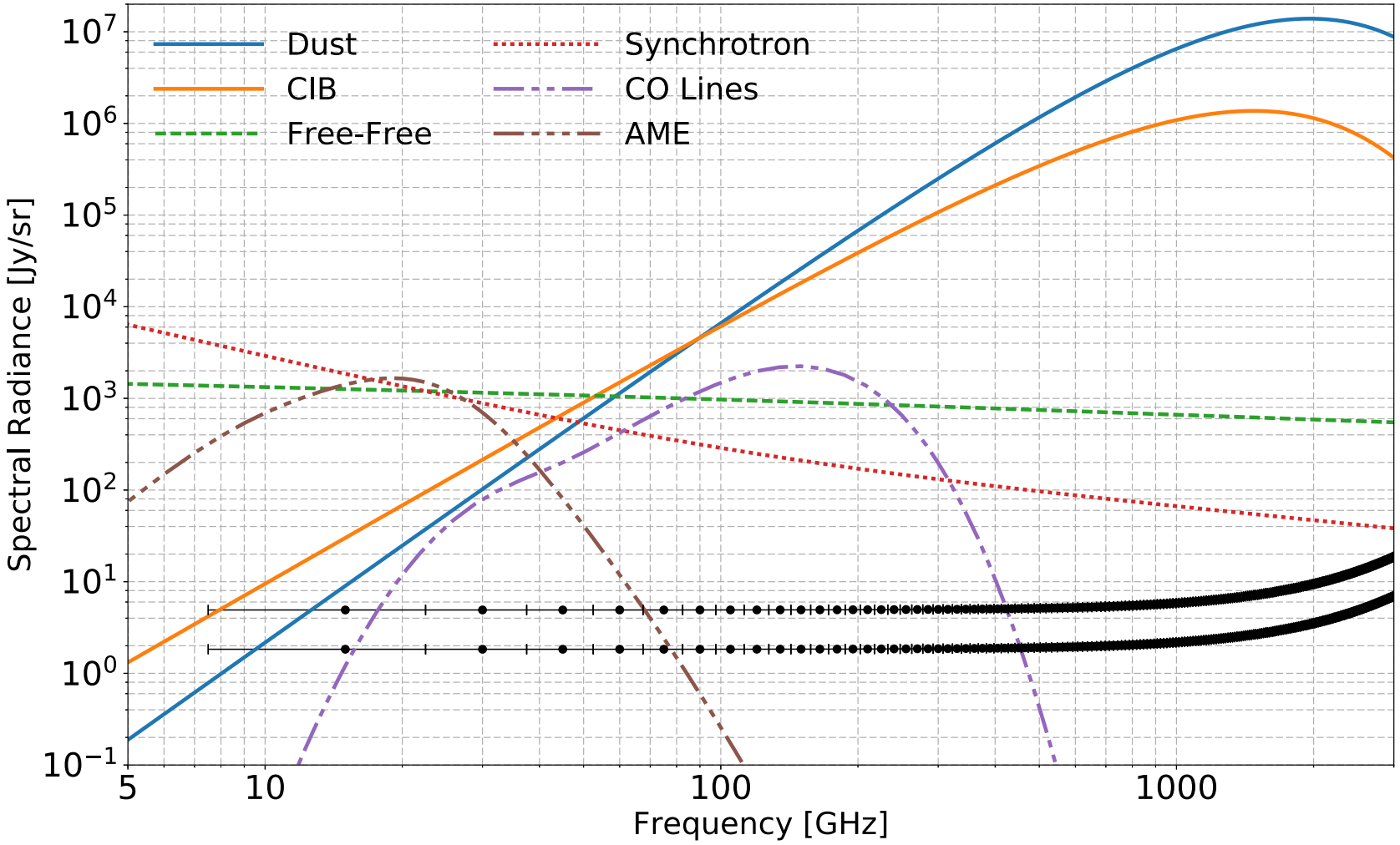
PIXIE Mission

- Space-based, absolutely calibrated Fourier Transform Spectrometer (FTS).
- Similar to COBE FIRAS (1990).
- 15 – 6,000 GHz frequency coverage, 15 GHz channel width.
  - Center Frequencies: 15, 30, 45, 60, …, 6000 GHz.
- Proposed to NASA.

PIXIE sensitivity



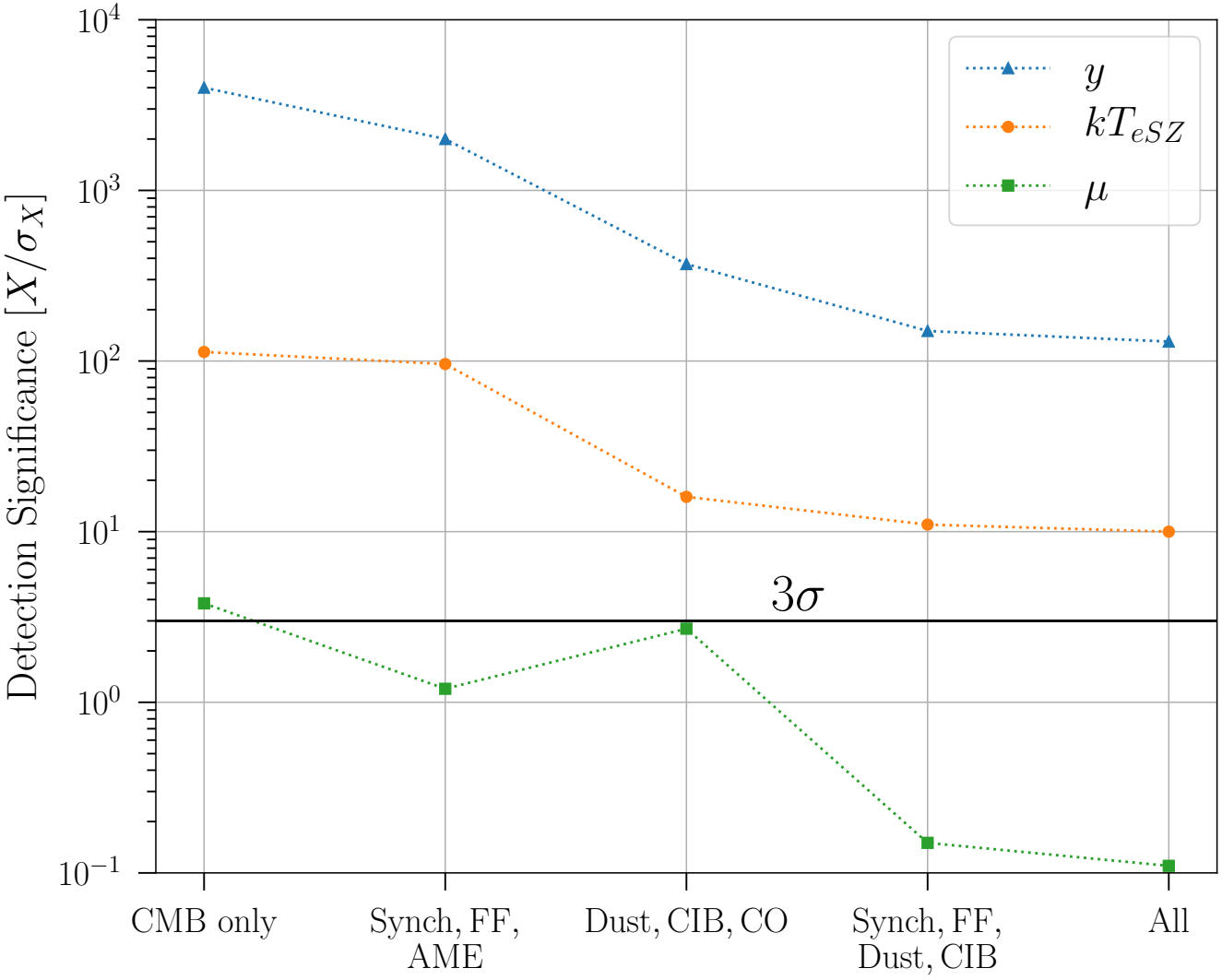
Foregrounds



Fisher uncertainty estimation

- Fisher:
  - Parametric modeling.
  - Turn experiment sensitivity into parameter uncertainties.
  - $$F_{ij} = \sum_{a,b} \frac{\partial(\Delta I_\nu)_a}{\partial p_i} C^{-1}_{ab} \frac{\partial(\Delta I_\nu)_b}{\partial p_j}$$
- CMB Signals:
  - CMB monopole temperature, y distortion, relativistic correction to y distortion, and mu distortion.
- Foregrounds:
  - Thermal dust, cosmic infrared background, synchrotron, free-free, spinning dust, integrated CO.

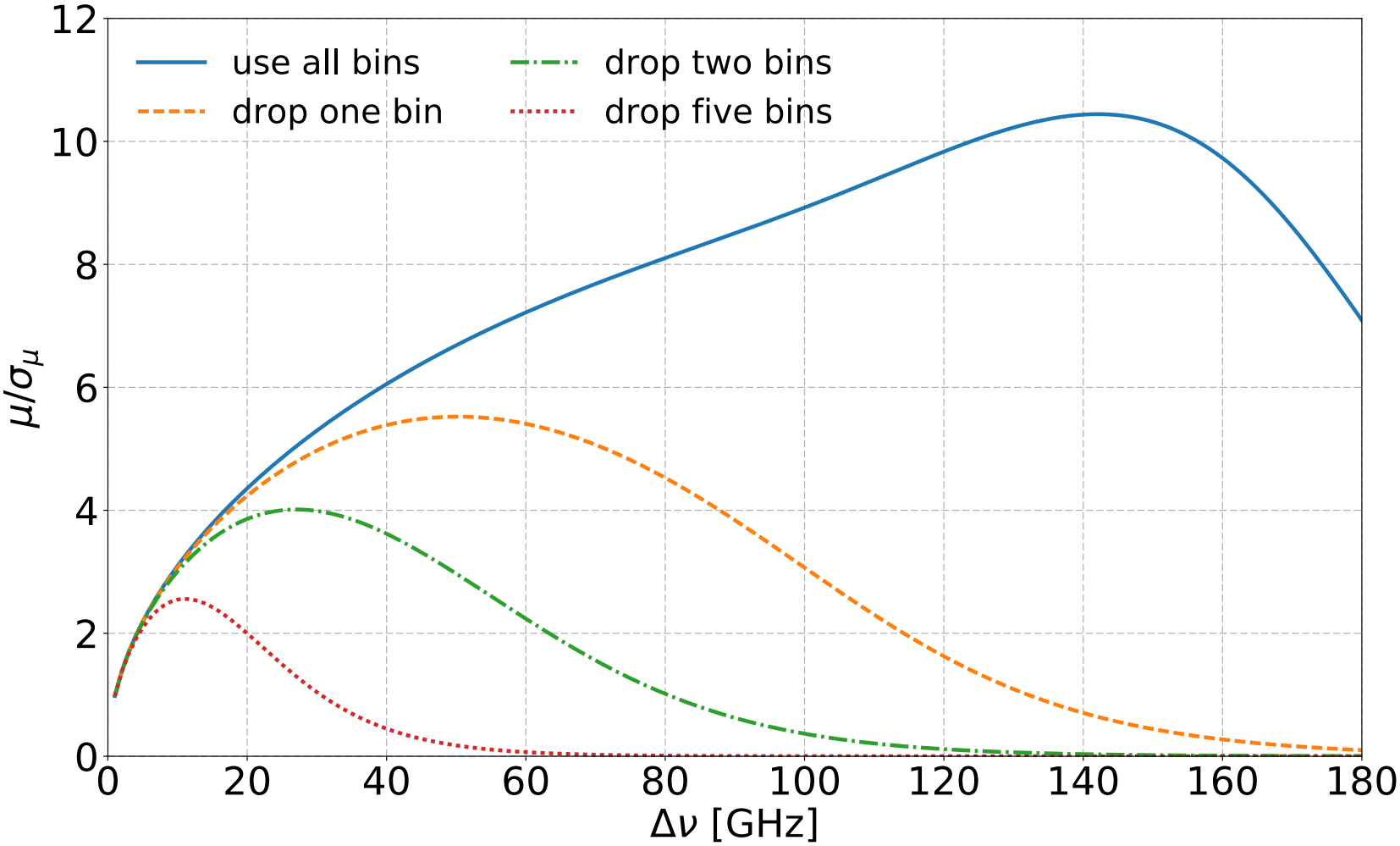
Forecast with foregrounds



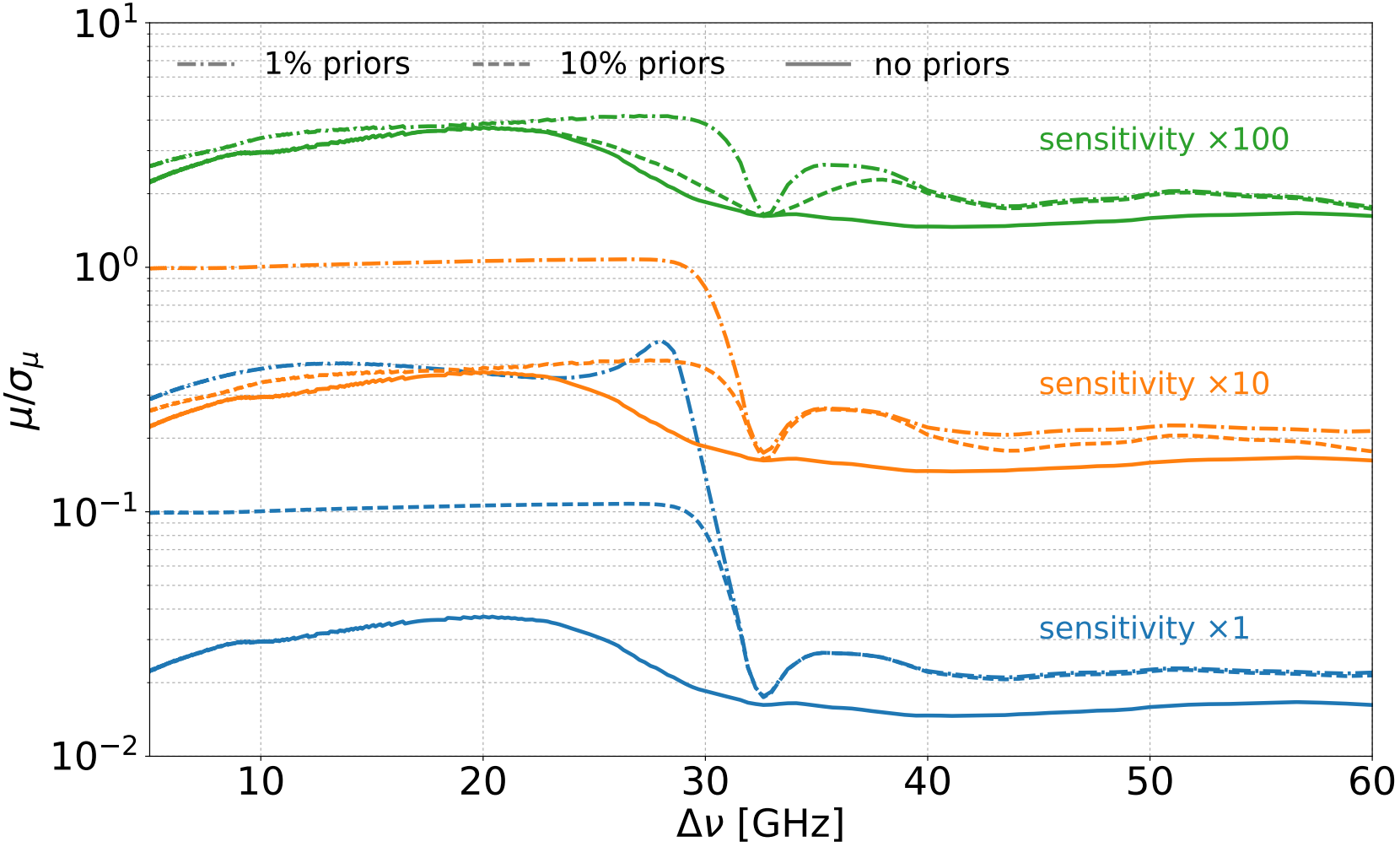
Optimizing the missions

- The main parameter to optimize is the FTS channel width, $\Delta\nu$.
  - Does not require changing instrument size.
  - Changing the channel width changes the sensitivity per bin.
  - The scaling is linear e.g., 5 GHz bins have 3x worse sensitivity than 15 GHz bins.
- Also consider increasing sensitivity.
  - Could change instrument size (e.g. cost).

Mu detection – CMB only



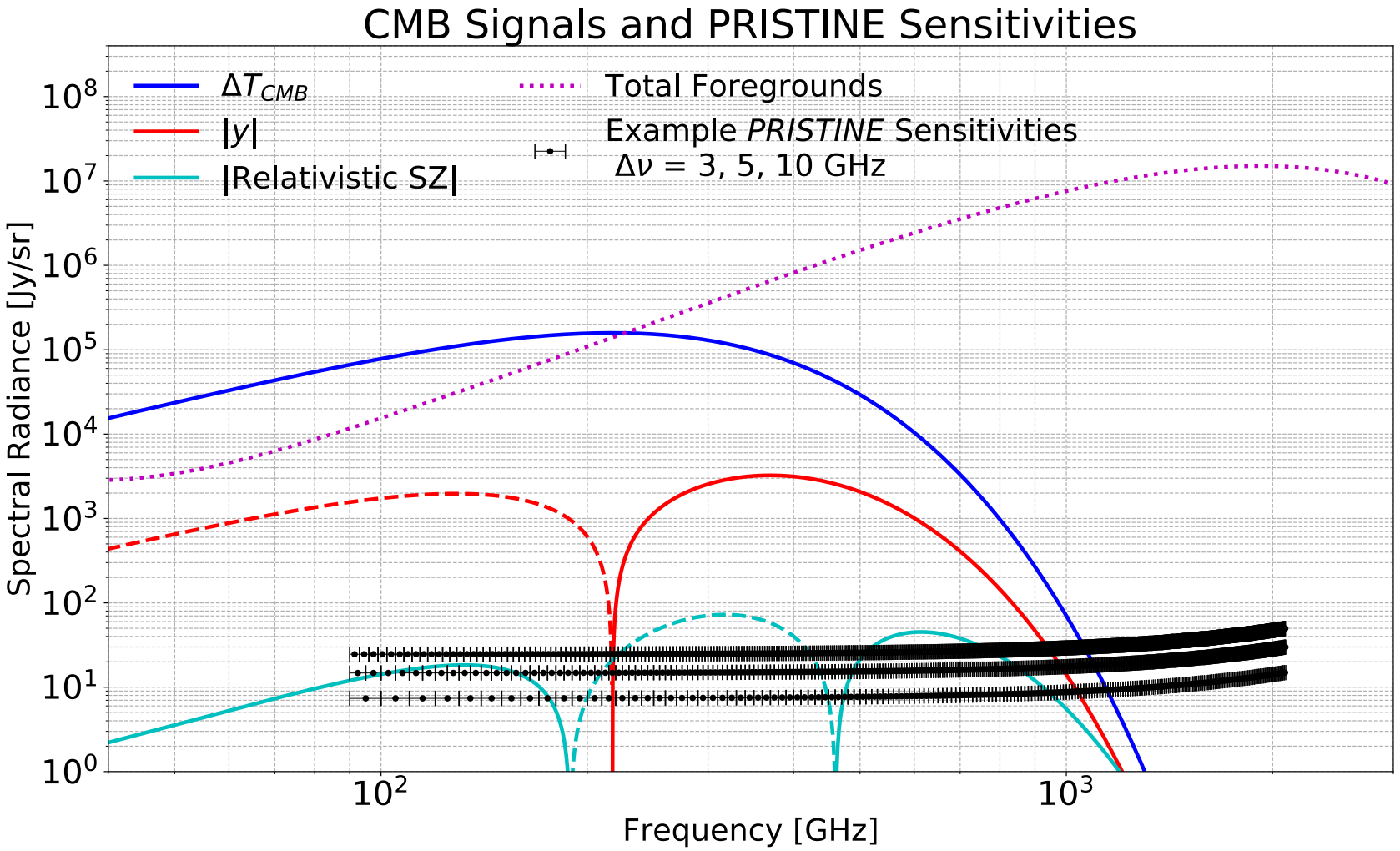
Mu detection with foregrounds



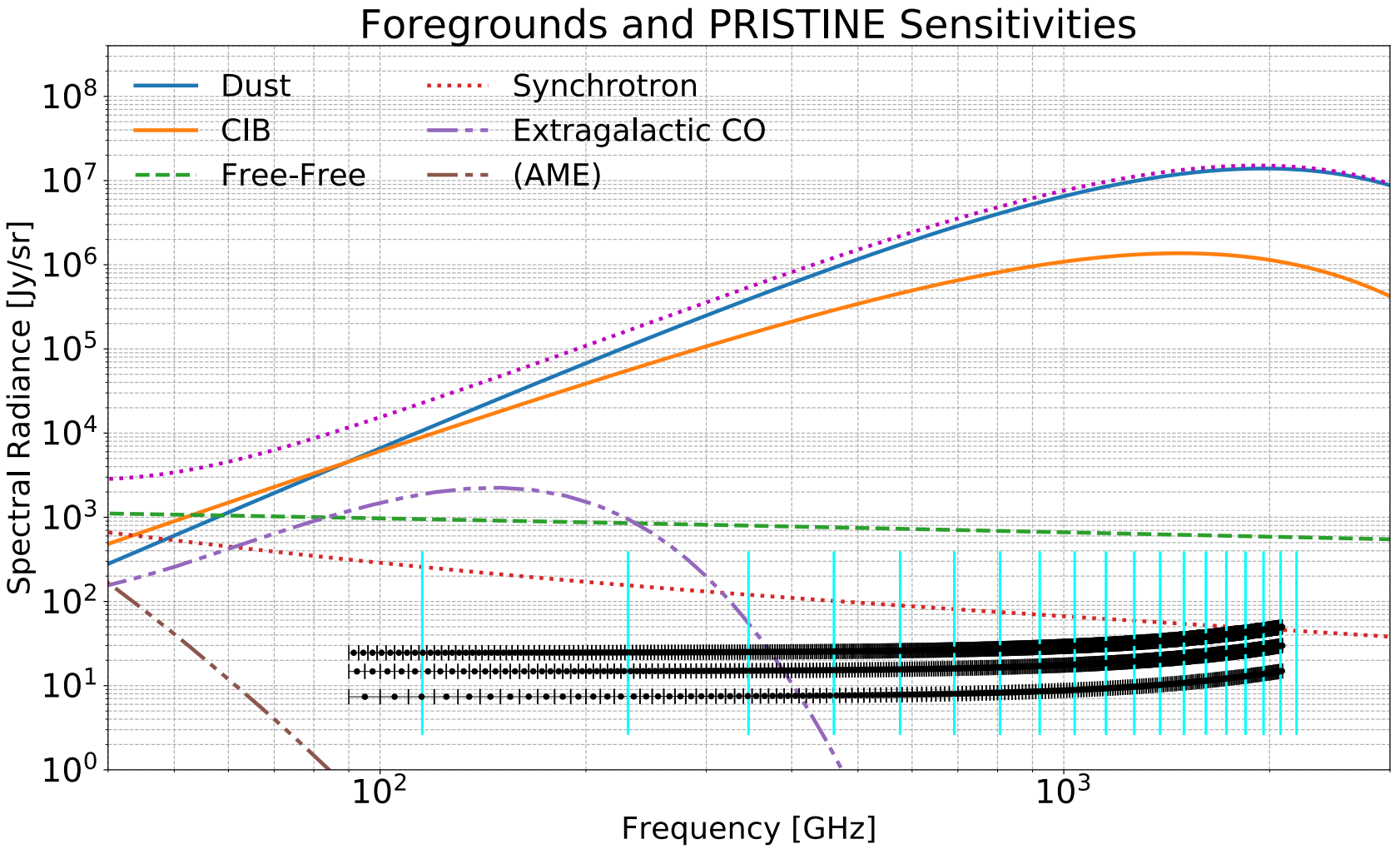
PRISTINE mission

- Frequency range: 90 – 2000 GHz, 5 GHz bins.
- More sensitive than PIXIE by including more detectors and cutoff at 2 THz to reduce detector loading.
- Excluded mu distortion and AME foreground.
- Included Galactic CO lines.
- Proposing to ESA.

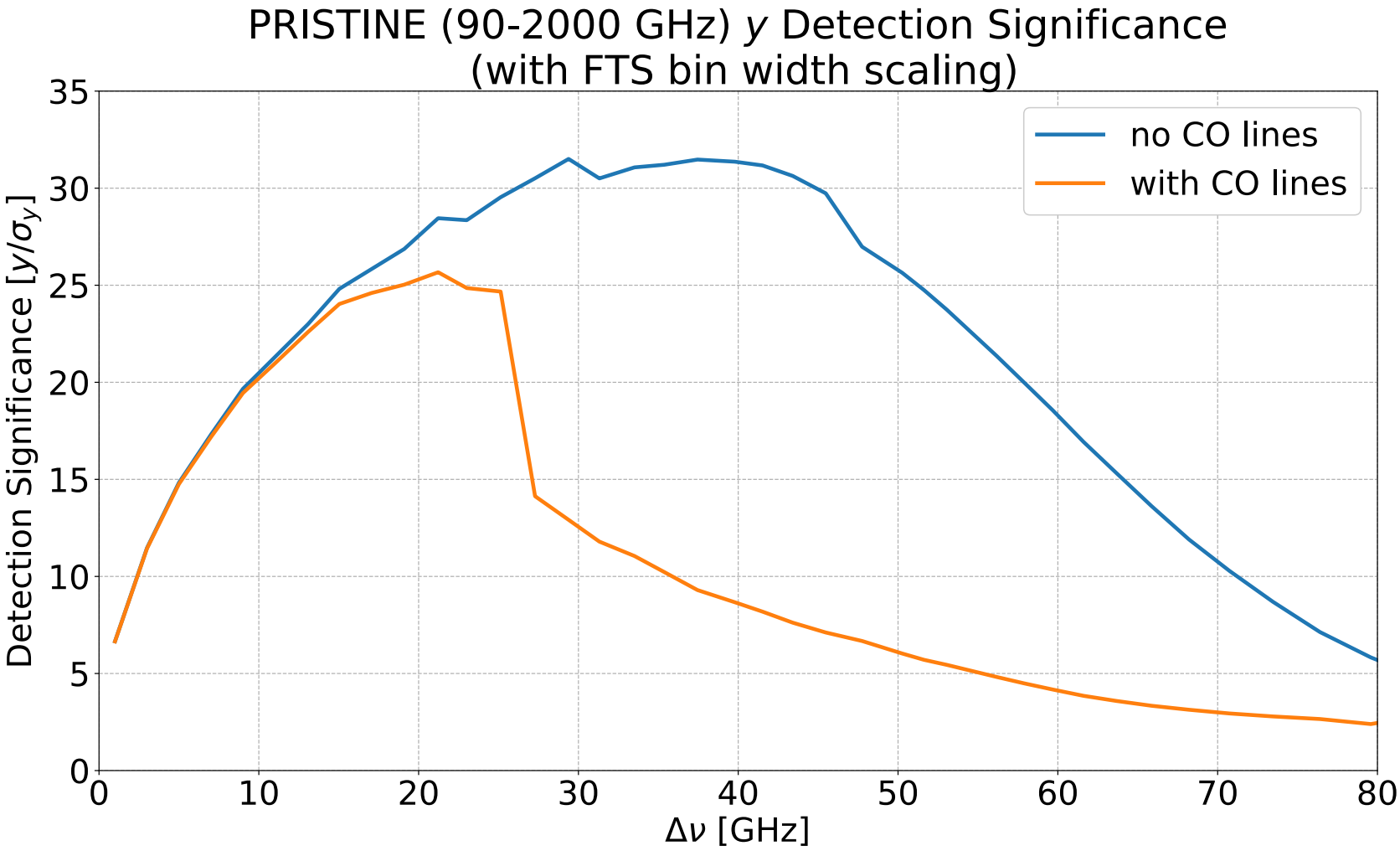
Sky signals – PRISTINE



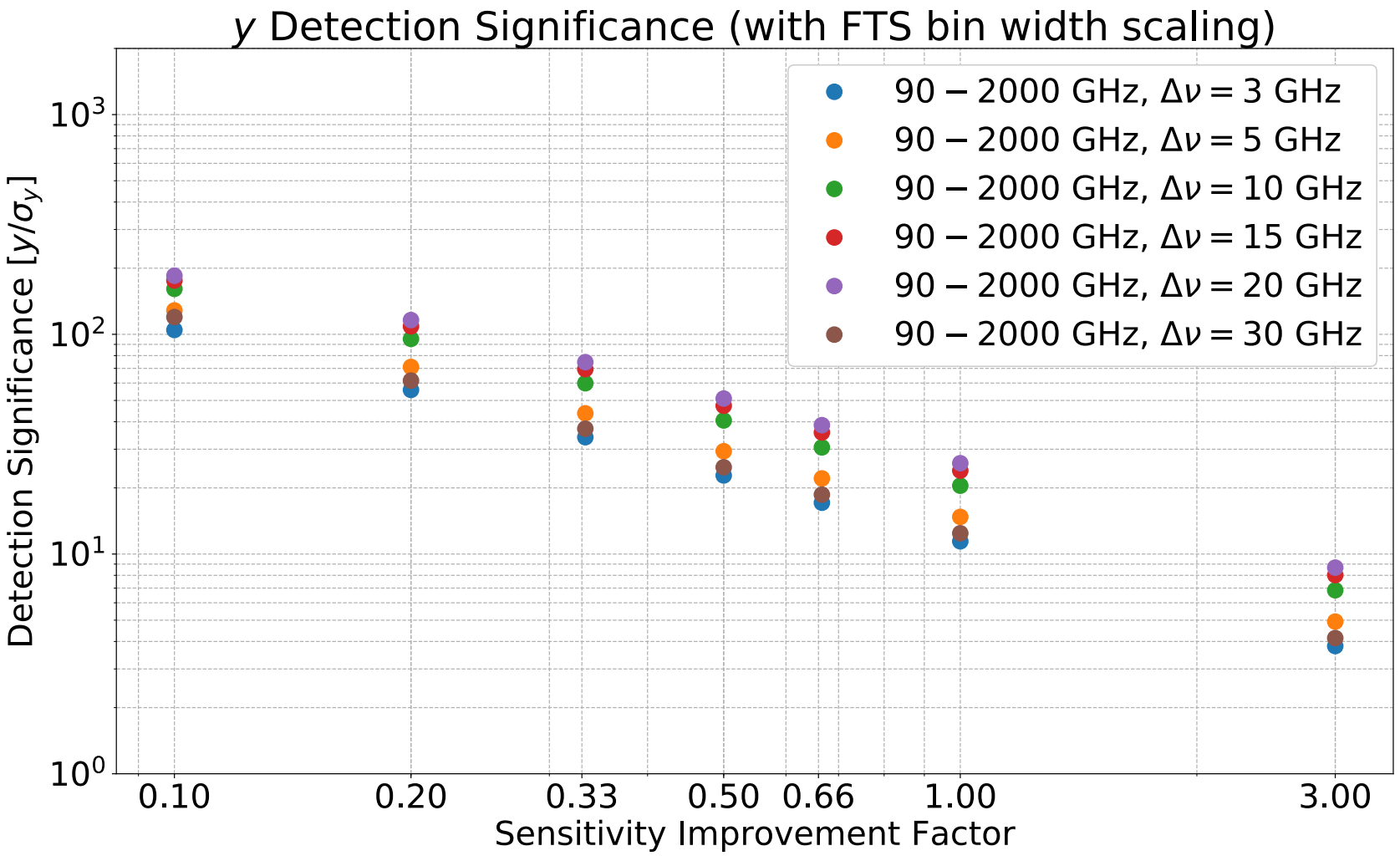
Foregrounds – PRISTINE



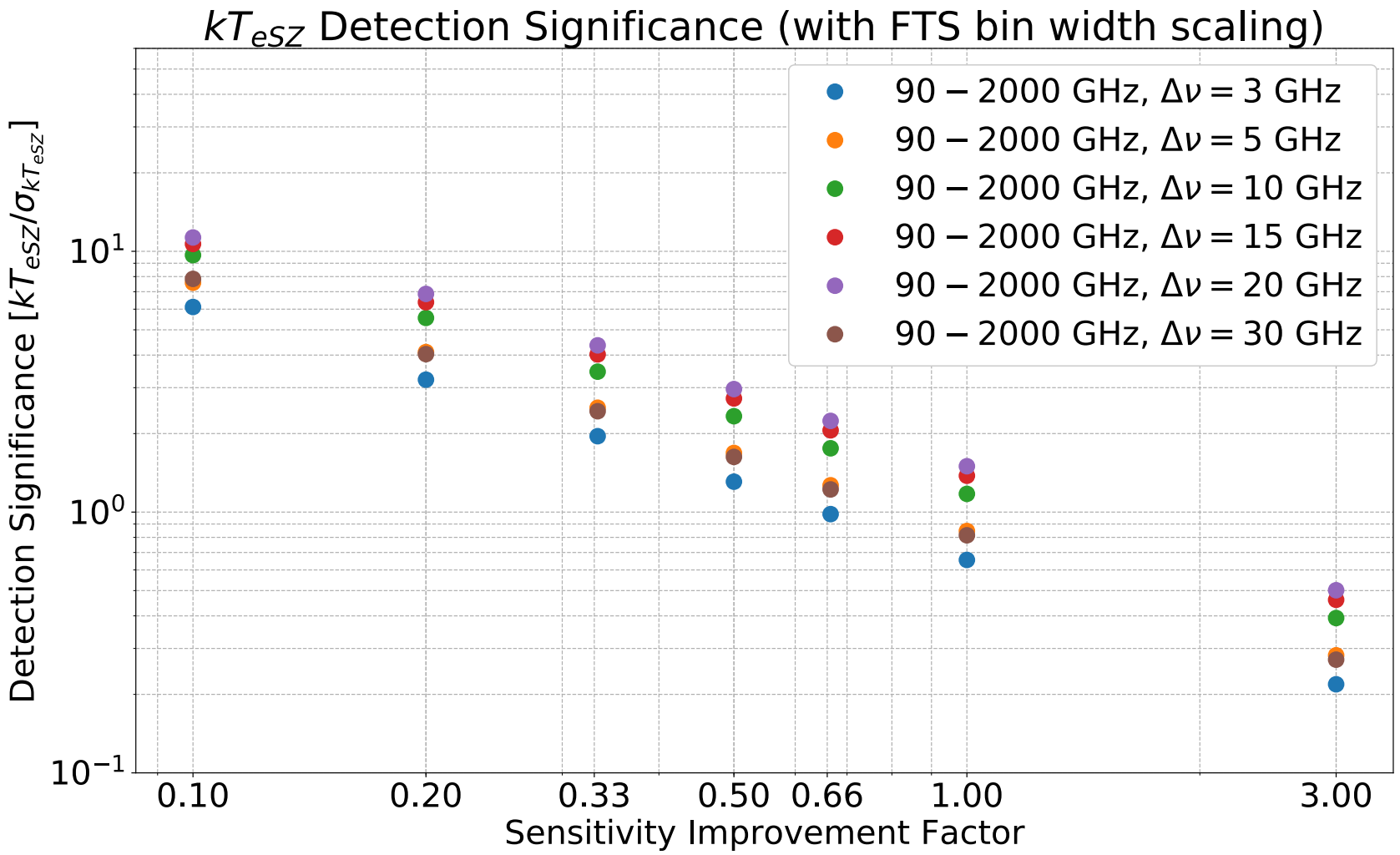
Y detection – PRISTINE



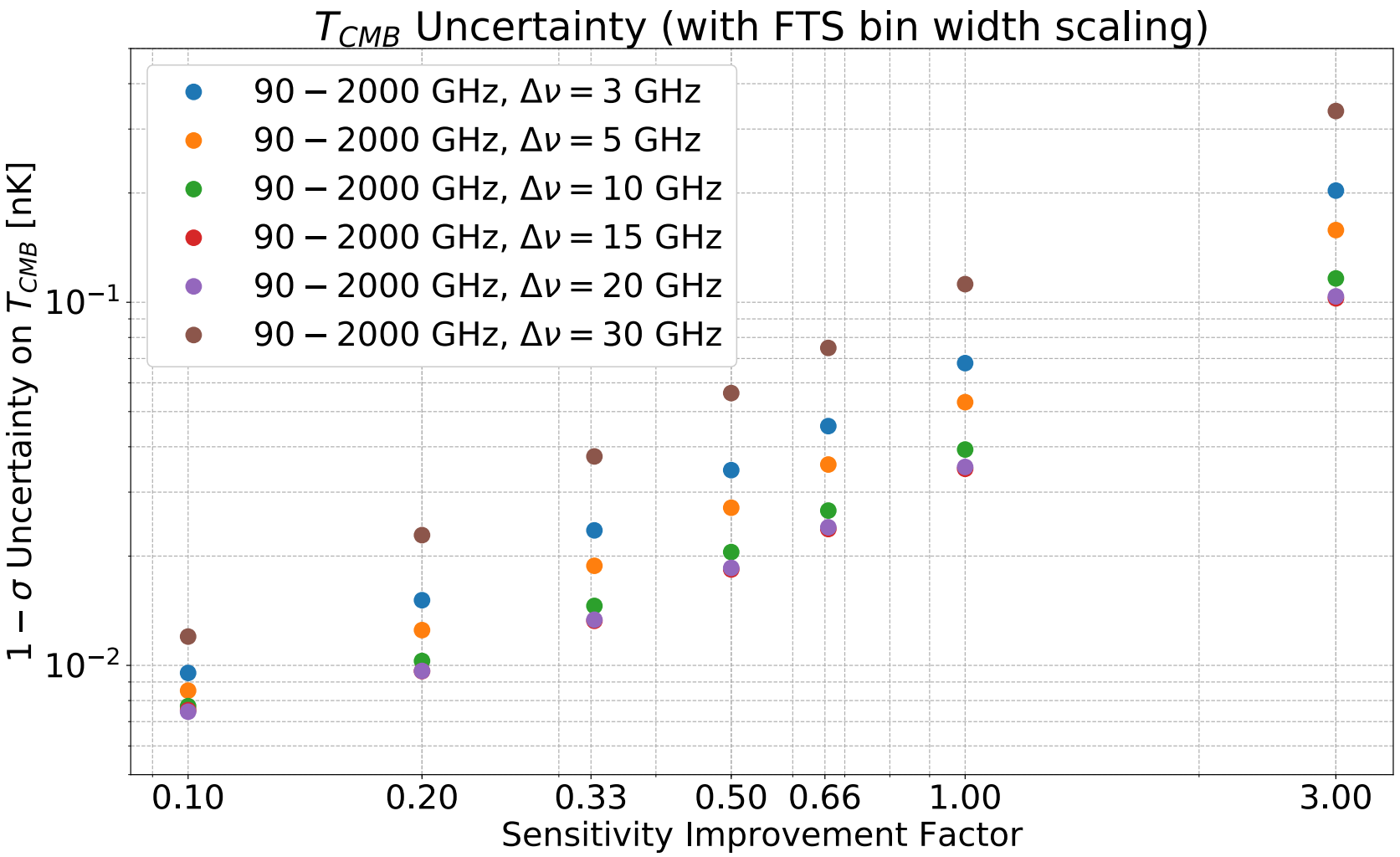
Y detection – PRISTINE



kTeSZ detection – PRISTINE



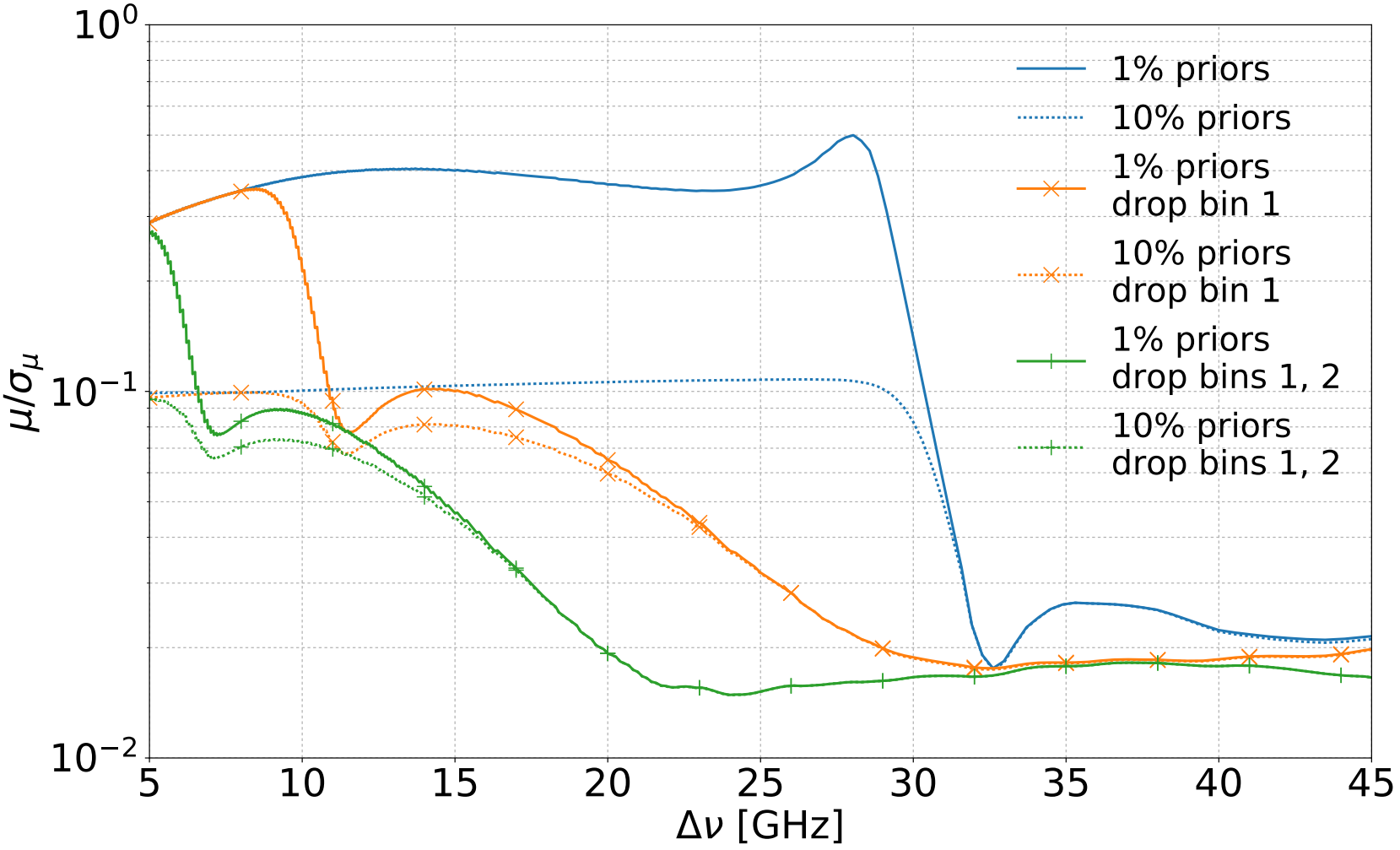
TCMB uncertainty – PRISTINE



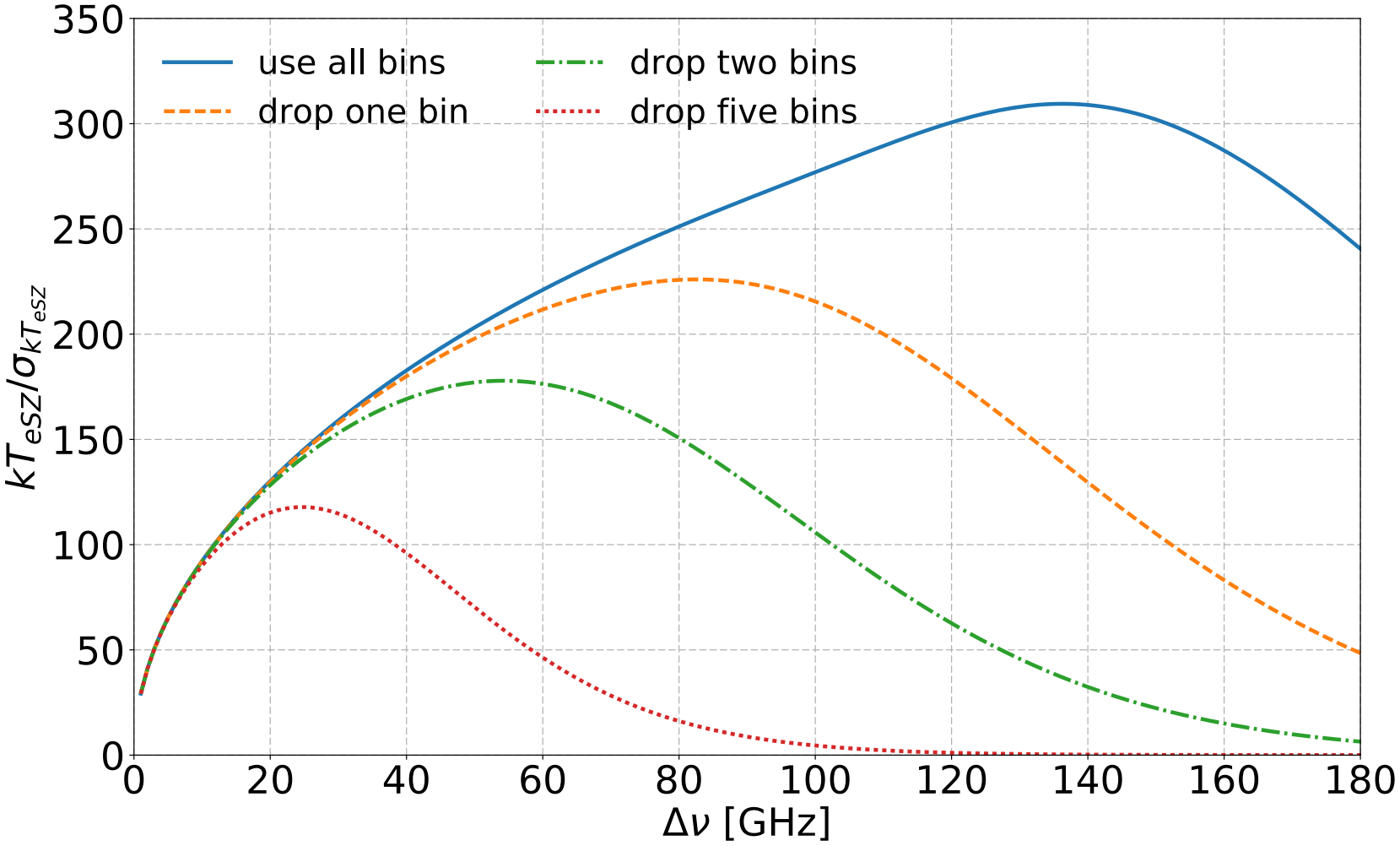
Conclusions

- Foregrounds dominate CMB spectral distortion signals.
  - Low frequency (10 – 100 GHz) sensitivity is important to detect mu.
  - High frequencies (100 GHz – 2 THz) are needed for y and the relativistic correction.
- PRISTINE detects y with high significance even with foregrounds and could potentially detect the relativistic correction.
- Future Work:
  - More general instrument optimization.
  - Super PIXIE could detect mu.
  - Spatial information is not yet included!

Mu detection with foregrounds



Relativistic SZ detection – CMB only



Relativistic SZ detection with foregrounds