Masi et al., 2021, **“The COSmic Monopole Observer (COSMO)”**
https://ui.adsabs.harvard.edu/abs/2021arXiv211012254M/abstract

★ Mele et al., 2022, **“Measuring CMB Spectral Distortions from Antarctica with COSMO: Blackbody Calibrator Design and Performance Forecast”**
https://link.springer.com/article/10.1007/s10909-022-02874-x

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Measuring CMB Spectral Distortions from Antarctica with COSMO: Blackbody Calibrator Design and Performance Forecast

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Abstract
COSMO is a ground-based instrument to measure the spectral distortions (SD) of the Cosmic Microwave Background (CMB). In this paper, we present preliminary results of electromagnetic simulations of its reference blackbody calibrator. *HFSS* simulations provide a calibrator reflection coefficient of $R \sim 10^{-6}$, corresponding to an emissivity $\epsilon = 1 - R = 0.999999$. We also provide a forecast for the instrument performance by using an ILC-based simulation. We show that COSMO can extract the isotropic Comptonization parameter (modeled as $|y| = 1.77 \cdot 10^{-6}$) as $|y| = (1.79 \pm 0.19) \cdot 10^{-6}$, in the presence of the main Galactic foreground (thermal dust) and of CMB anisotropies, and assuming perfect atmospheric emission removal.

Background: CMB spectral distortions

Processes in the thermal history of the universe

- Interaction of CMB photons with plasma
  - Described by Kompaneets eq.

$$\frac{\partial n}{\partial y_\gamma} = \frac{1}{x^2}\frac{\partial}{\partial x}x^4\left(n + n^2 + \frac{T_e}{T}\frac{\partial n}{\partial x}\right),$$

$$y_\gamma(z, z_{\rm max}) = -\int_{z_{\rm max}}^{z} dz \frac{k_B \sigma_T}{m_e c}\frac{n_e T}{H(1+z)}$$ (Sunyaev & Khatri, 2013)

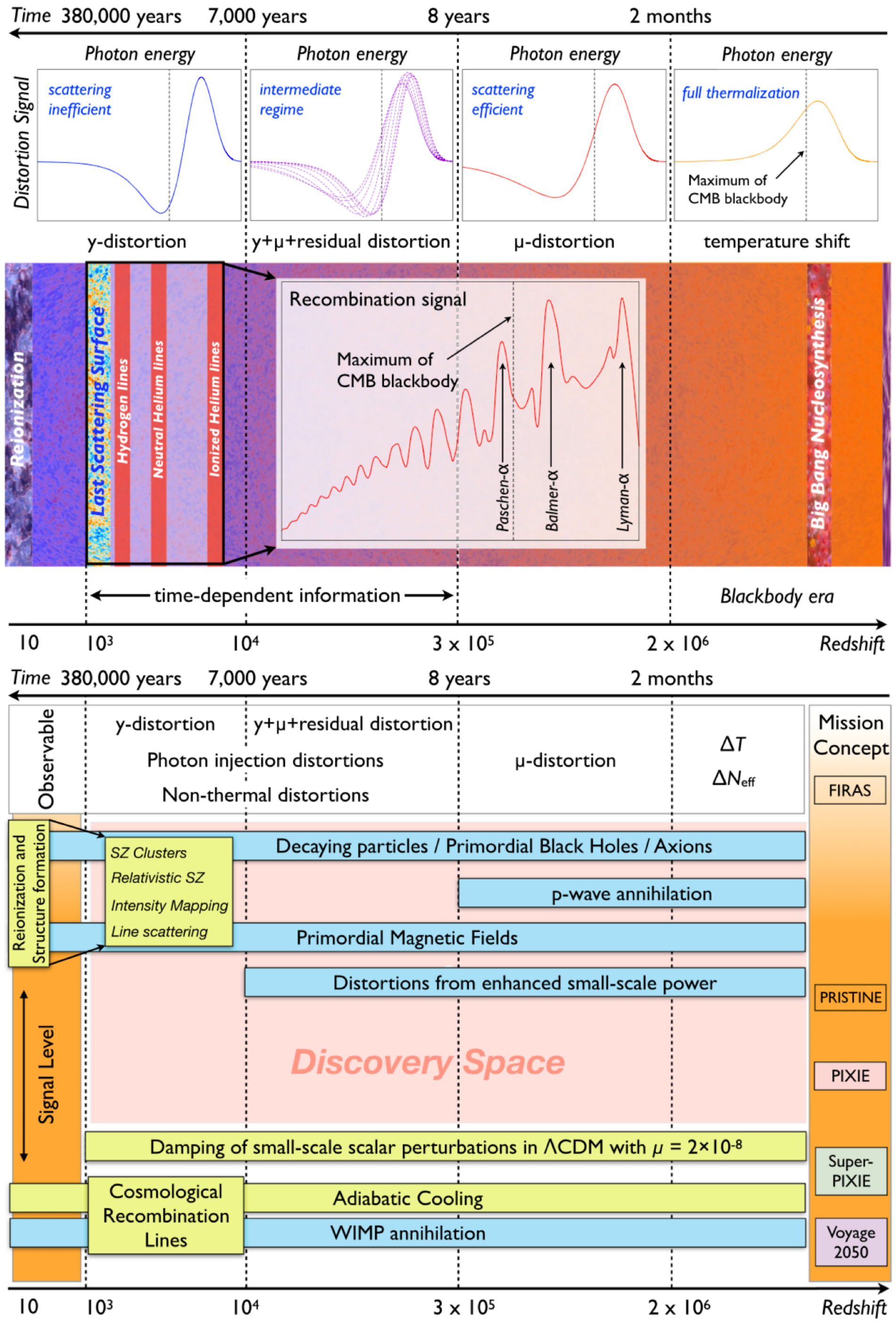
  - y-type distortion: minimal comptonization limit ($y_\gamma \ll 1$)
  - μ-type distortion: saturated comptonization limit ($y_\gamma \gg 1$)
- Cosmological recombination lines of H & He
- etc.

Importance

- Testing the cosmological standard model
- New physics?

Amplitude & its measurements

- Deviations from a perfect BB < 1 ppm
- Best upper limit by COBE/FIRAS (in 1990s!)



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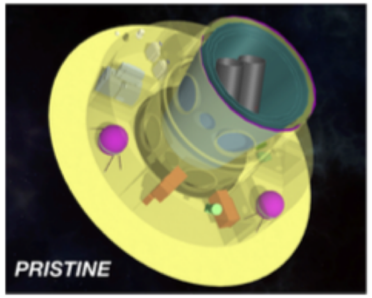
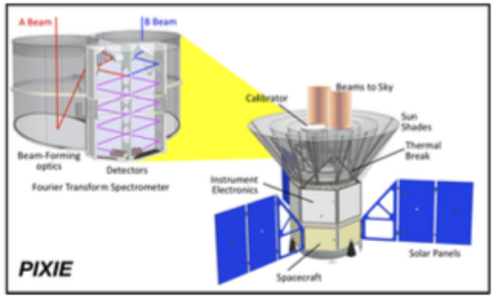
Background: Future observations for CMB spectral distortions

- Future satellite missions
  - [FTS] PIXIE (NASA), PRISTINE (ESA)
  - [Polarimeter] LiteBIRD (JAXA), PICO (NASA), CORE? (ESA)

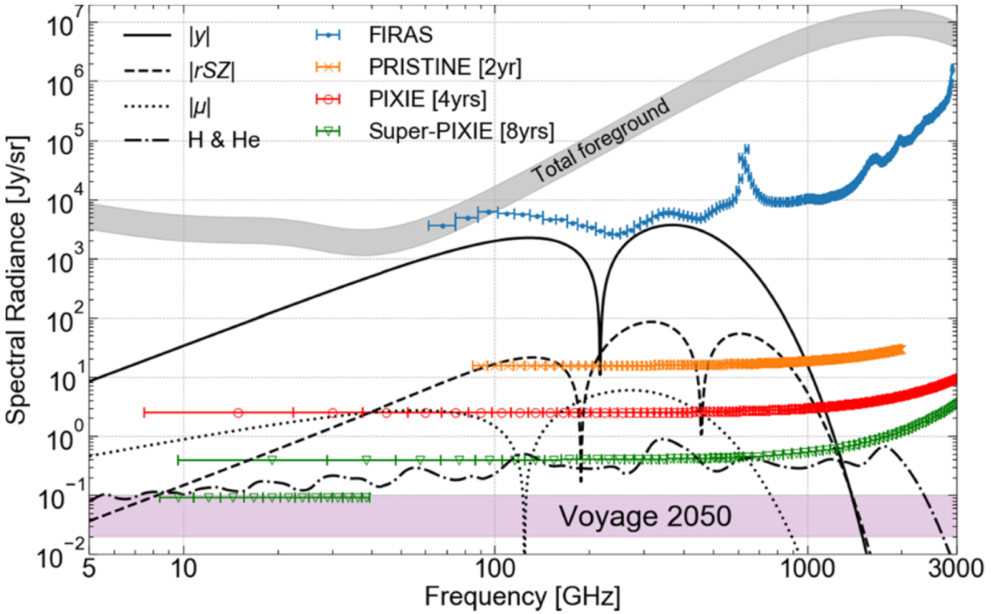
- Why Fourier Transform Spectrometer (FTS)?
  - ✓ Low-resolution spectrometry
  - ✓ Wide frequency coverage
  - ✓ Accurate absolute calibration
  - ✓ Well understood systematics

- While the final measurement must be from space, ground-based/balloon-borne experiments are necessary
  - To test methods
  - Possibly to detect the largest spectral distortions





Estimated sensitivity vs. expected spectral distortions



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COSmic Monopole Observer (COSMO)

- FTS (Martin-Puplett) with resolution of ~ 10 GHz
- Ground-based (Dome-C, Antarctica) or balloon
- Fast elevation scan by the spinning wedge mirror to separate atmospheric emission
- Fast lumped element KID (LEKID) arrays
- 2 focal planes for 110-170, 200-300 GHz

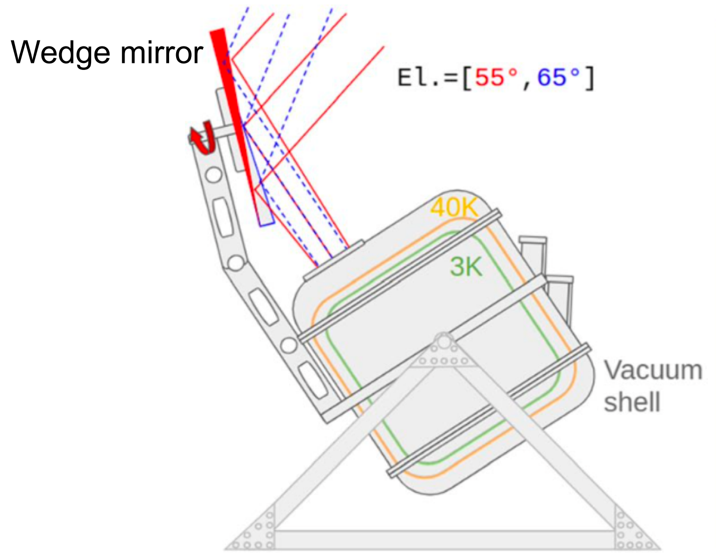


Table 1. Scanning characteristics of the COSMO instrument[a]

circle radius	5	deg
beam FWHM	0.5	deg
wedged mirror spin	600	rpm
time per beam	200	μs
time for one forward plus one reverse sky dip	0.1	s
maximum wavenumber	20	cm^{-1}
sampling step	125	μm
resolution	5-15	GHz
time to complete one interferogram	25.6	s
sky dips per interferogram element	2	

Note: [a]Example of certainly feasible combination of wedge and roof mirror scans; faster scans are currently under consideration.

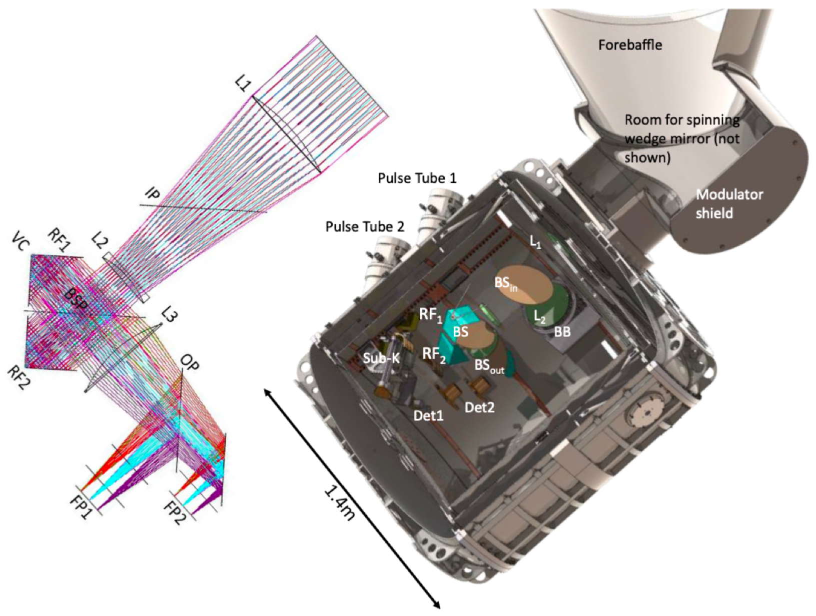
Spinning wedge mirror

FTS
Low spectral resolution

Table 2. Optical parameters of the COSMO instrument.

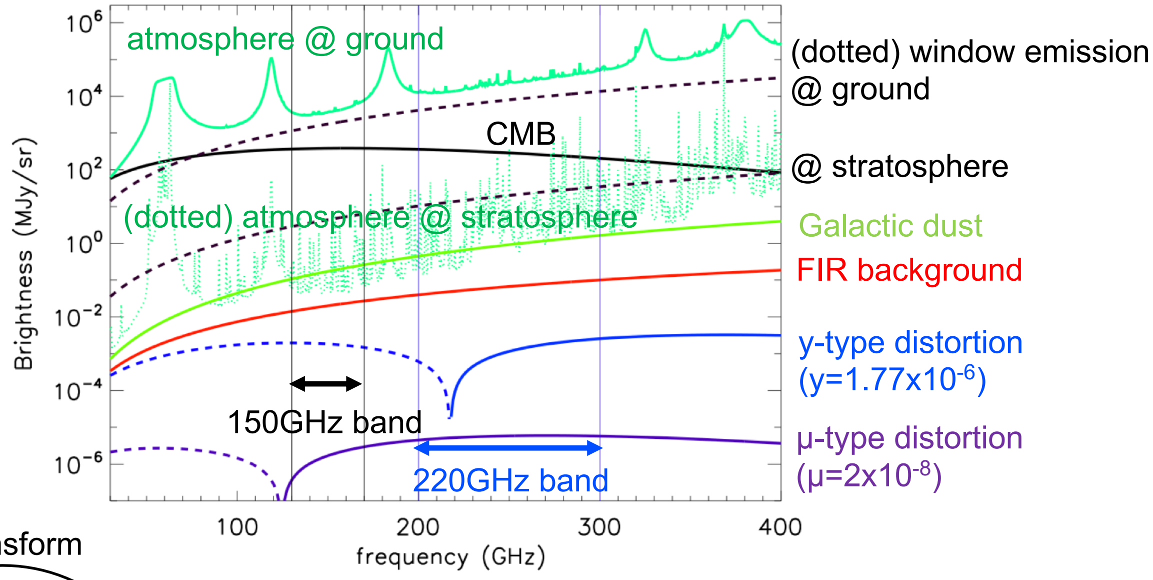
optical aperture diameter	220	mm
effective focal length	726	mm
multimode pixel antenna aperture diameter	20	mm
focal planes	2	
number of detectors per focal plane	9	
projected pixel to pixel distance (x and y)	0.75	deg
beam FWHM	0.75	deg

Small aperture
Low angular resolution

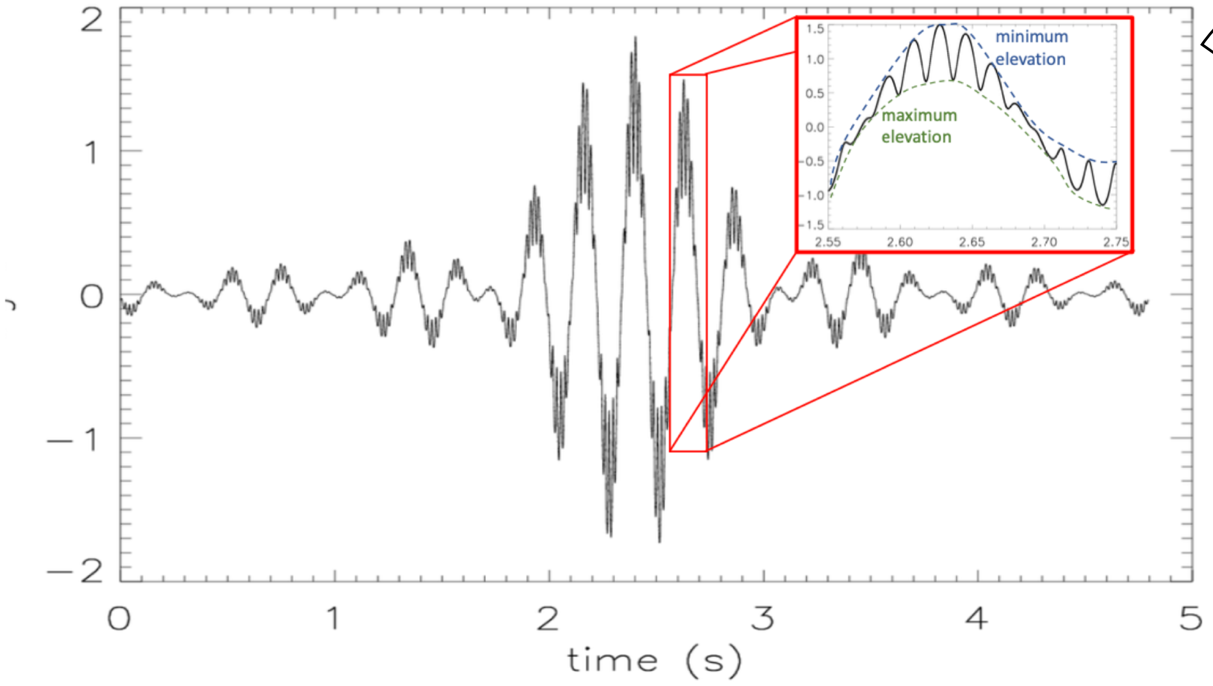


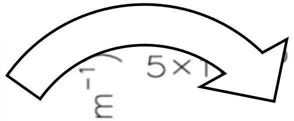
Coping with atmospheric emission

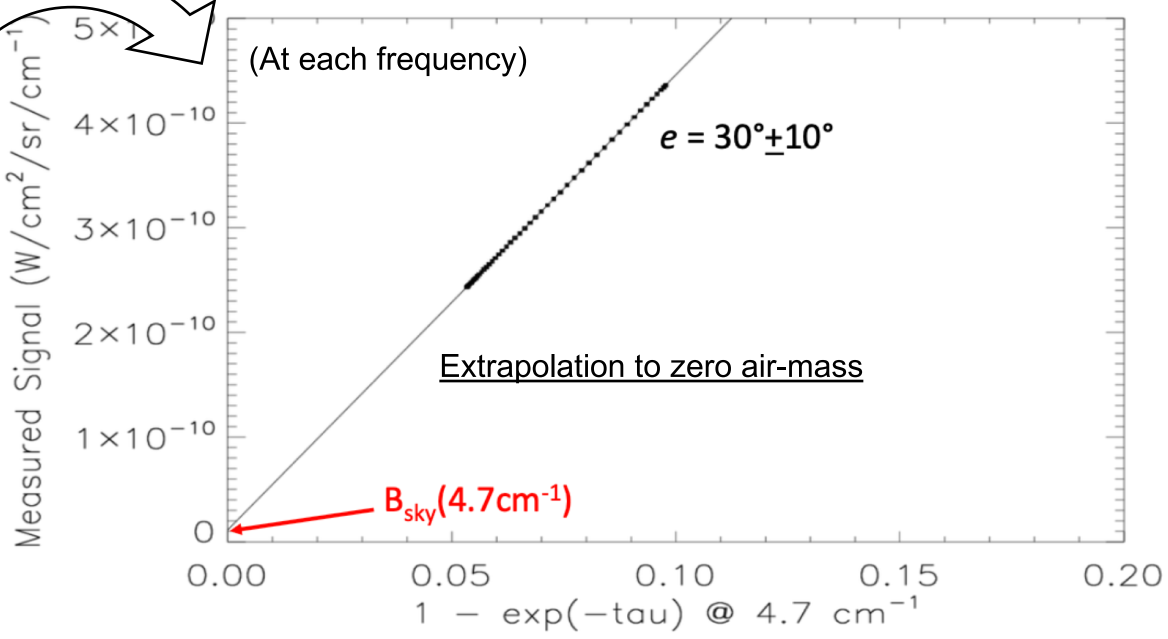
- Selection of the frequency interval
- Modulation by spinning wedge mirror up to 2,500 rpm
- Fast (τ ~ 60 μs) KIDs, ~ 60 kHz readout with FPGA



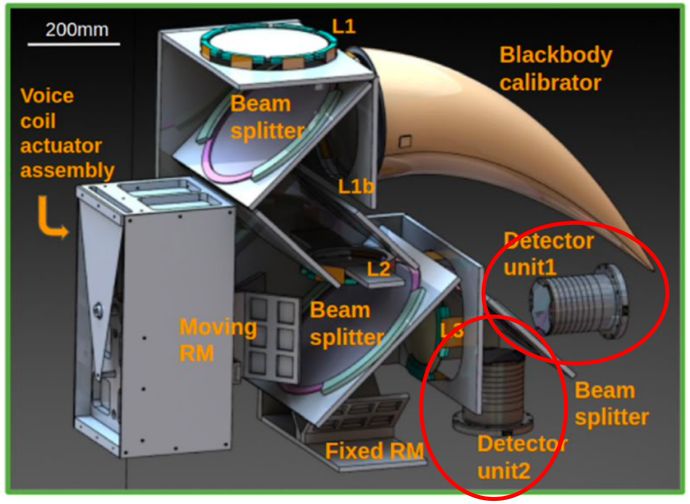
Example of an expected interferogram





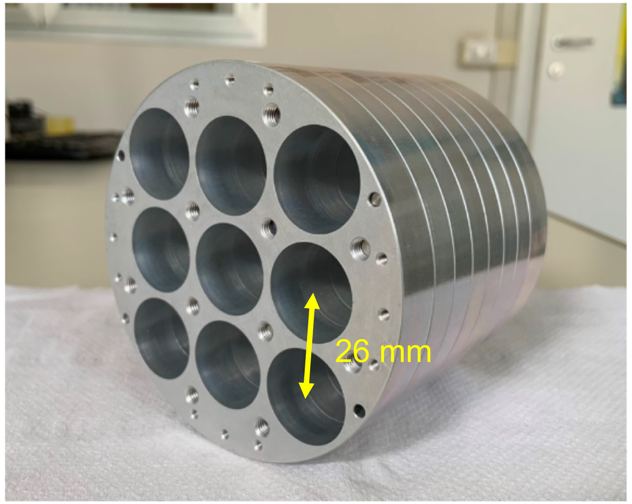


Focal plane arrays

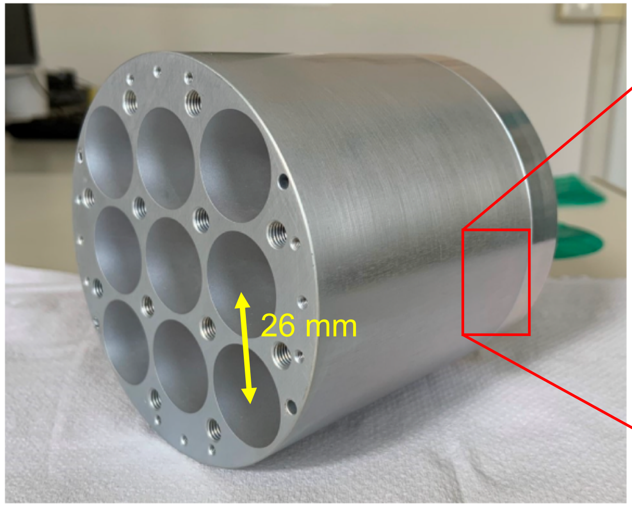


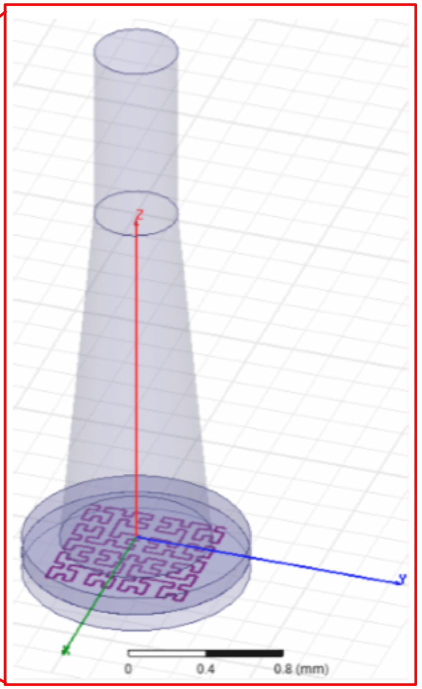
- 2x9 pixels at 300 mK
- LEKID + <u>multimode</u> waveguide/feedhorn for total intensity measurements
  - Absorber area ~ 8 mm x 8 mm
  - WG diameter:
    4.5 mm for LF ➔ 10-19 modes in 120-180 GHz
    4.0 mm for HF ➔ 23-42 modes in 210-300 GHz

LF array (Winston cone antenna)



HF array (conical horn antenna)





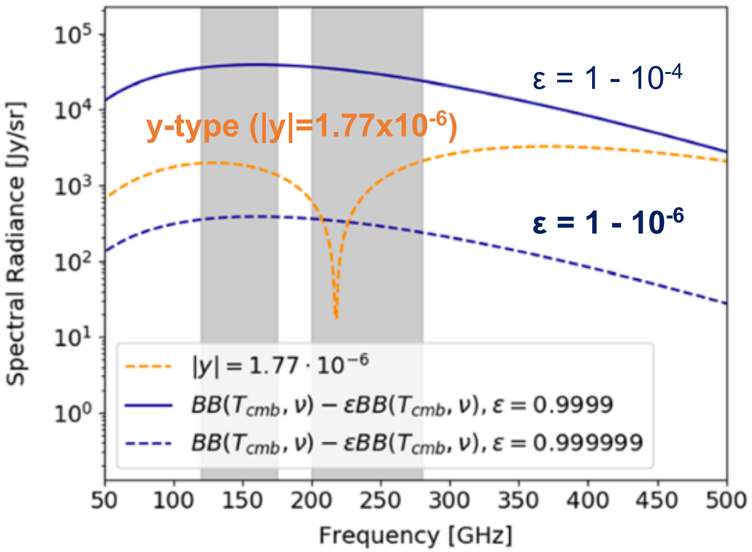
LEKID design
(for OLIMPO, Paiella et al. 2019)

Blackbody calibrator

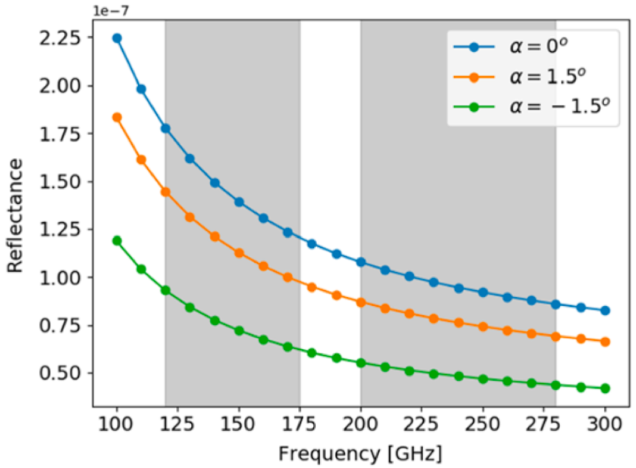
Requirement
- The calibrator needs to be close to a perfect BB
- Goal emissivity **$\varepsilon > 1 - 10^{-6}$** (or $R < 10^{-6}$) to detect the largest distortion signal

Solution: deformed cone cavity
- Number of internal reflections N > 6
- Internal absorber: 10mmt Eccosorb
- External body: copper

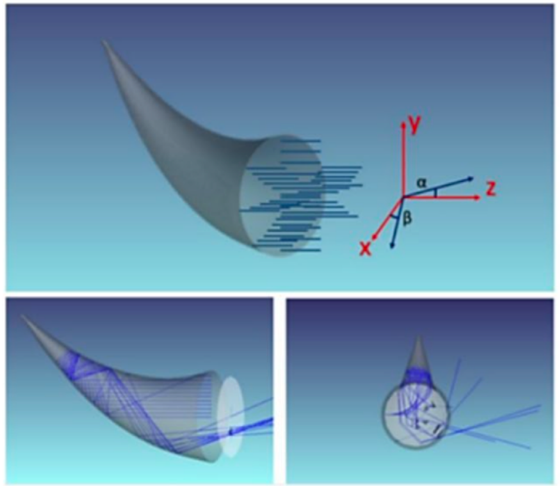
Distortion by non-ideal BB calibrator



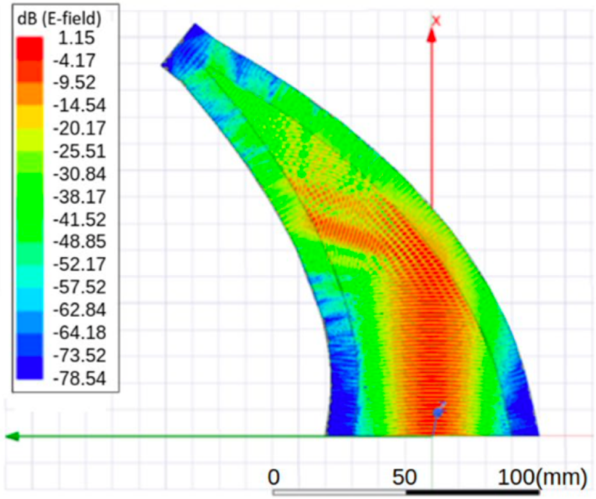
Reflectance for different incident angle α assessed by ray-tracing



Ray-tracing:
R < 10^{-6} over 100-300 GHz



EM sim., slice of the calibrator
R(120GHz) = 3.2×10^{-6}



Performance forecast

Methods
- **"constrained Internal Linear Combination (c-ILC)"** component separation method (Remazeilles et al. 2011)
- Applied to sky map simulated by PySM (Thorne et al. 2017) CMB anisotropies & Galactic thermal dust emission
- Isotropic y-distortion map with $y=1.77 \times 10^{-6}$ is added
- Added photon noise from
  - cryostat window emission (220K, 1% emissivity)
  - atmospheric emission (PWV=0.15mm)
- Assuming a perfect atmospheric emission removal
- Assuming 1 year and 30% time efficiency

Results & discussions
- ✓ Error of 110, 323 Jy/sr for 150, 220 GHz bands, respectively
- ✓ Best estimate $|y| = (1.79 \pm 0.19) \times 10^{-6}$

  ➔ COSMO can extract the isotropic y-type distortion
- ✓ The variance degrades as the higher order dust emission is subtracted
  - Limited by noise level and available frequency coverage