Looking for isotropic spectral distortions of the CMB from Antarctica

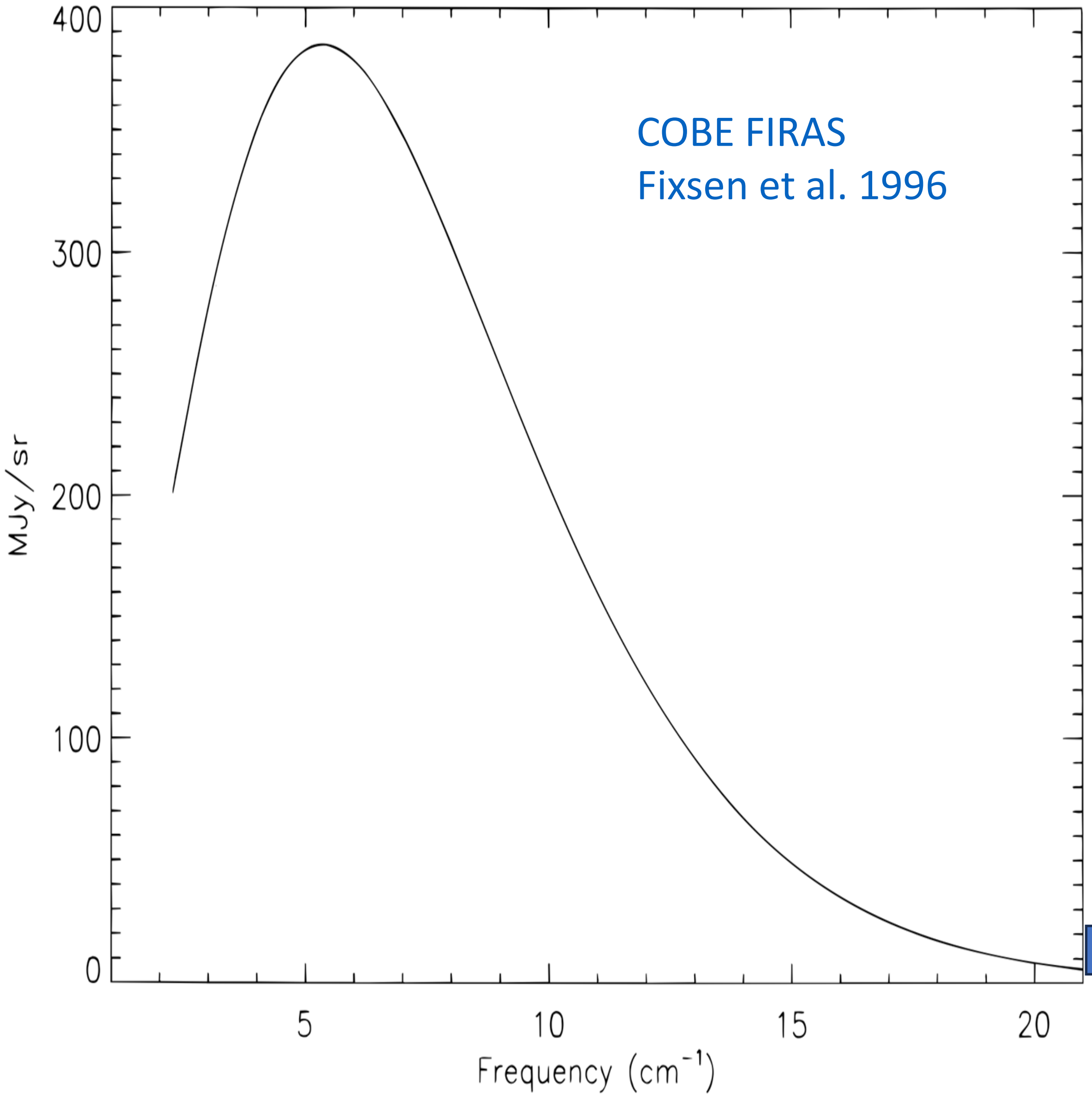
Paolo de Bernardis, for the *COSMO* collaboration

Dipartimento di Fisica, Sapienza Università di Roma

SCAR AAA 2023 meeting

2023/09/21 Longyearbyen

The CMB: an almost perfect blackbody



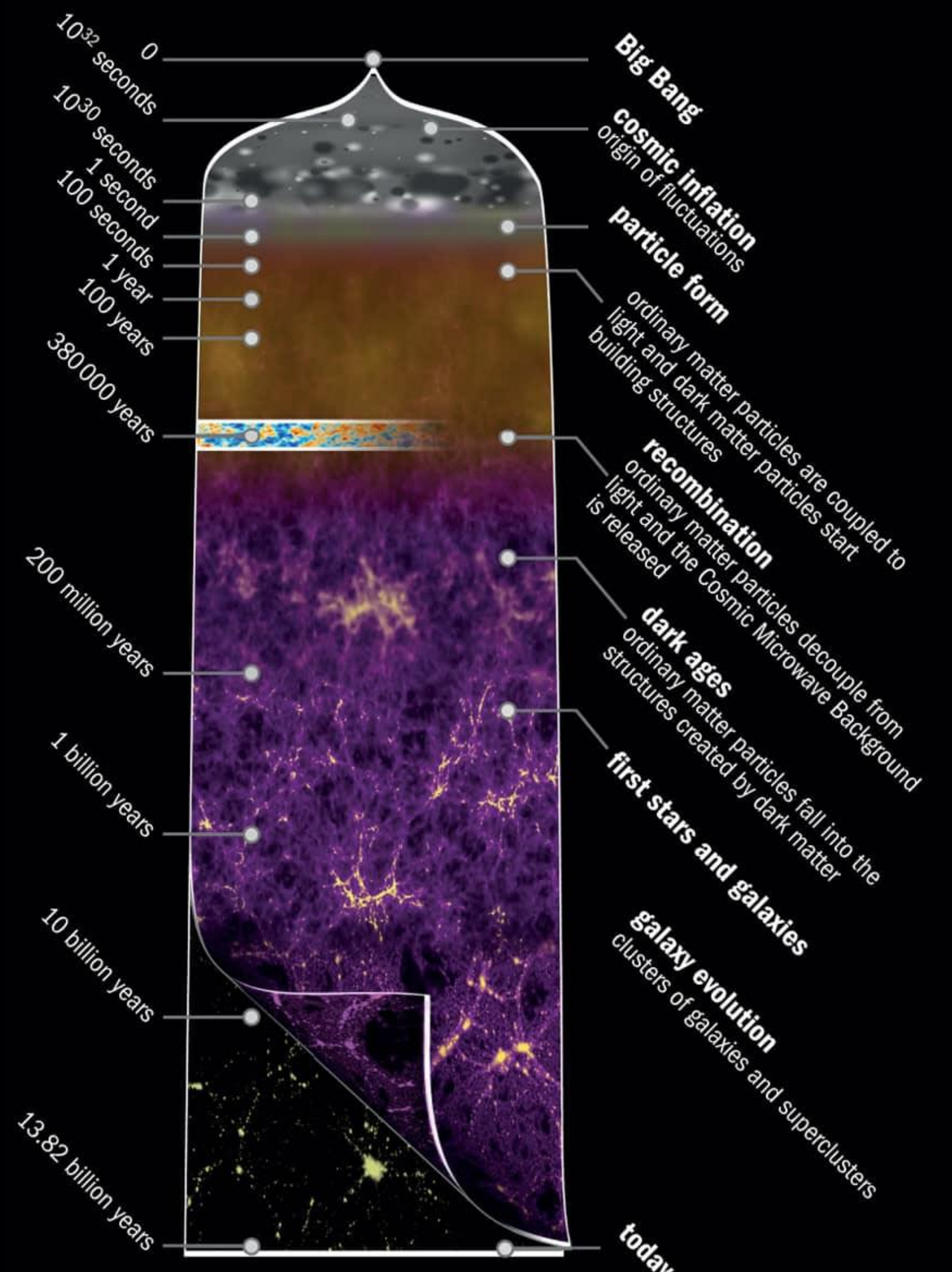
- CMB photons were produced by matter-antimatter annihilation a few μs after the big bang.
- They were then thermalized in the primeval fireball.
- The expansion of the universe redshifted and diluted these photons, maintaining the blackbody spectrum.
- To first order, the CMB must be – and in fact is - a blackbody.

$$B(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}}-1} = \frac{2h\nu^3}{c^2}\frac{1}{e^{x}-1}$$

$$B_{\boldsymbol{\mu}}(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{x+\boldsymbol{\mu}}-1}$$

$$B_{\boldsymbol{y}}(\nu,T) == B(\nu,T)\left\{1+\boldsymbol{y}\frac{xe^x}{e^x-1}\left[x\coth\frac{x}{2}-4\right]\right\}$$

$$y,\mu < 10^{-5}$$



courtesy: ESA/C Carreau

Spectral distortions of the CMB

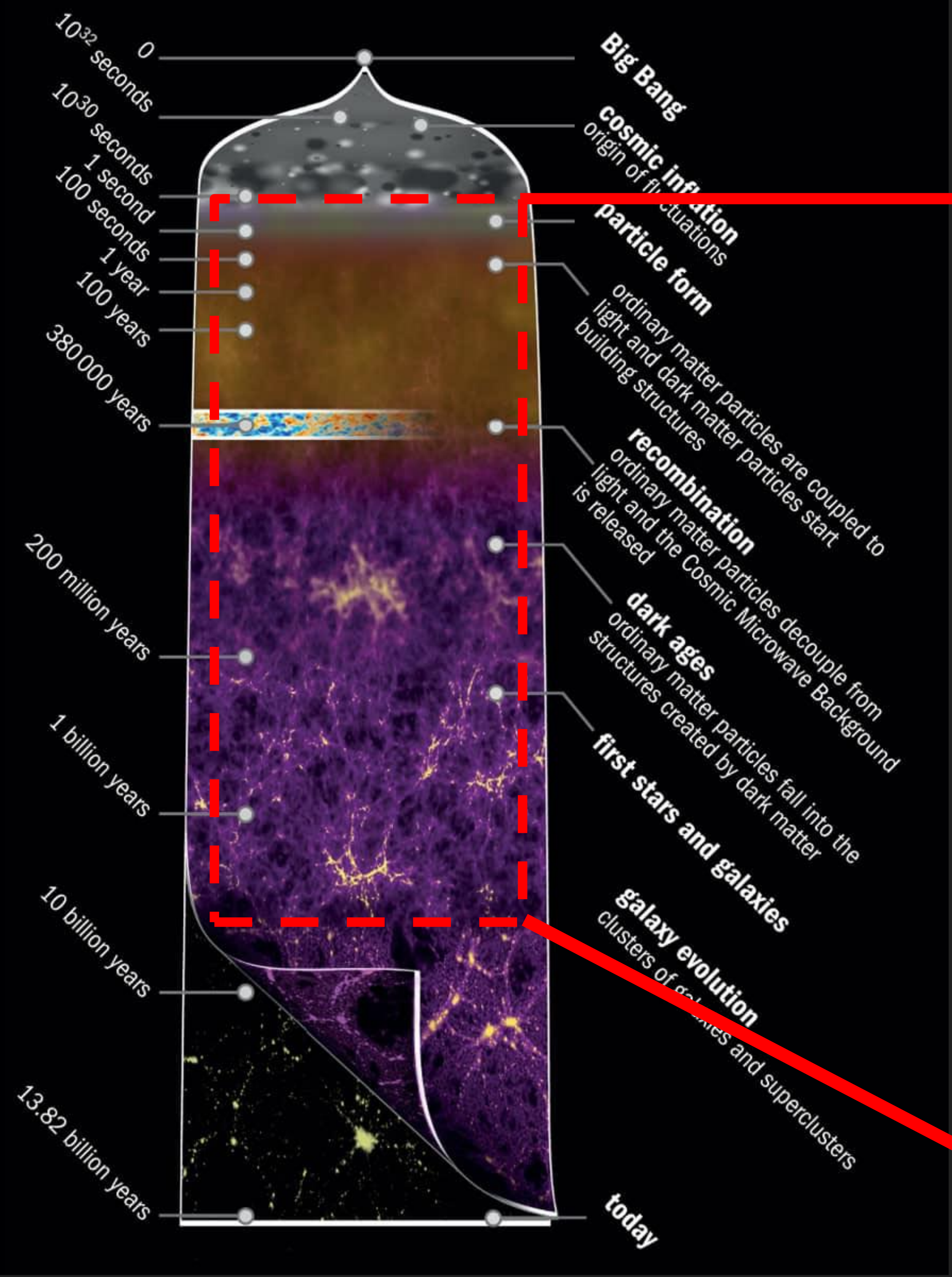
Small departures from a perfect blackbody shape are expected, due to well known as well as exotic physical processes; and can provide information about processes that occurred before and after recombination. See e.g. :

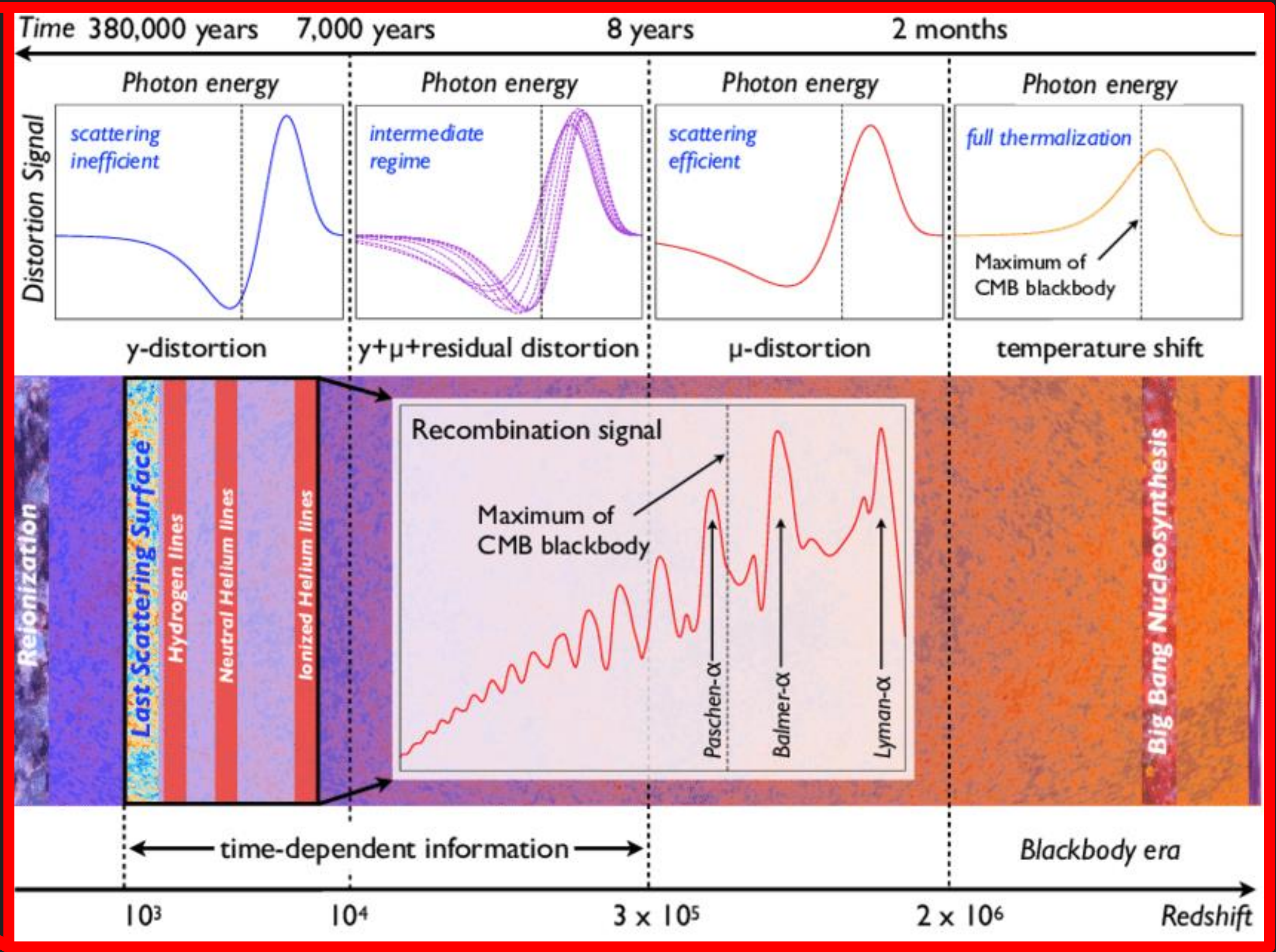
- Reionization and structure formation (De Zotti et al., 2016)
- Adiabatic cooling of baryons and electrons (Chluba and Sunyaev, 2012)
- Damping of small scale acoustic modes -> inflationary power spectra (Chluba et al., 2011)
- Cosmological recombination radiation (Dubrovich, 1975, Sunyaev and Chluba 2008)
- Decaying and annihilating particles (Acharya and Kharti 2019)
- …… and many more

Current upper limits for the comptonization parameter y and for the chemical potential μ are still close to the ones from COBE/FIRAS : $$y, \mu < 10^{-5}$$

Spectral distortions of the CMB

Expected from ΛCDM: $\mu \simeq 2 \times 10^{-8}$ $\quad y \simeq 1.77 \times 10^{-6}$





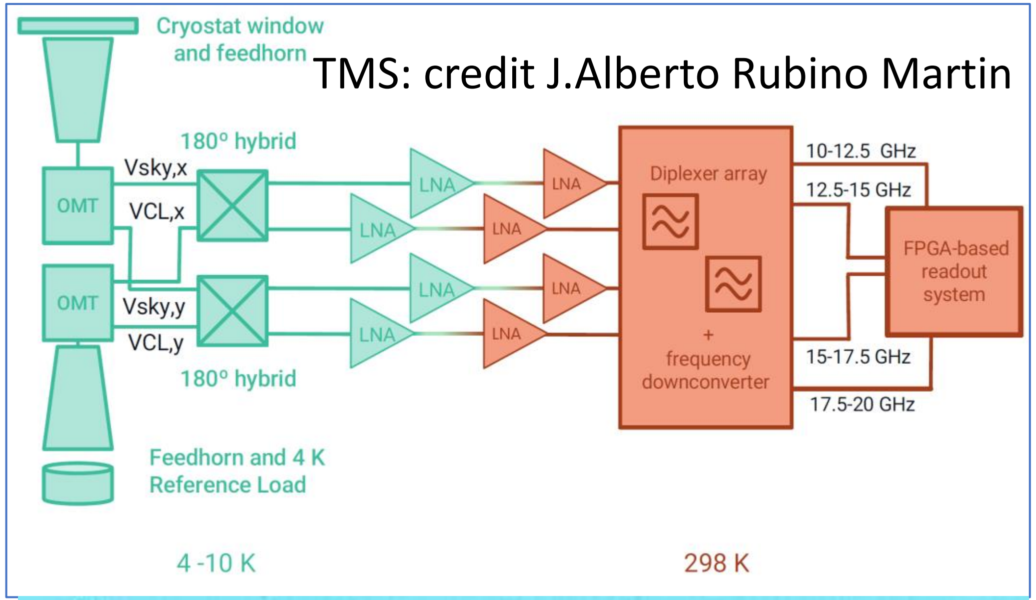
[Chluba et al. 2019]

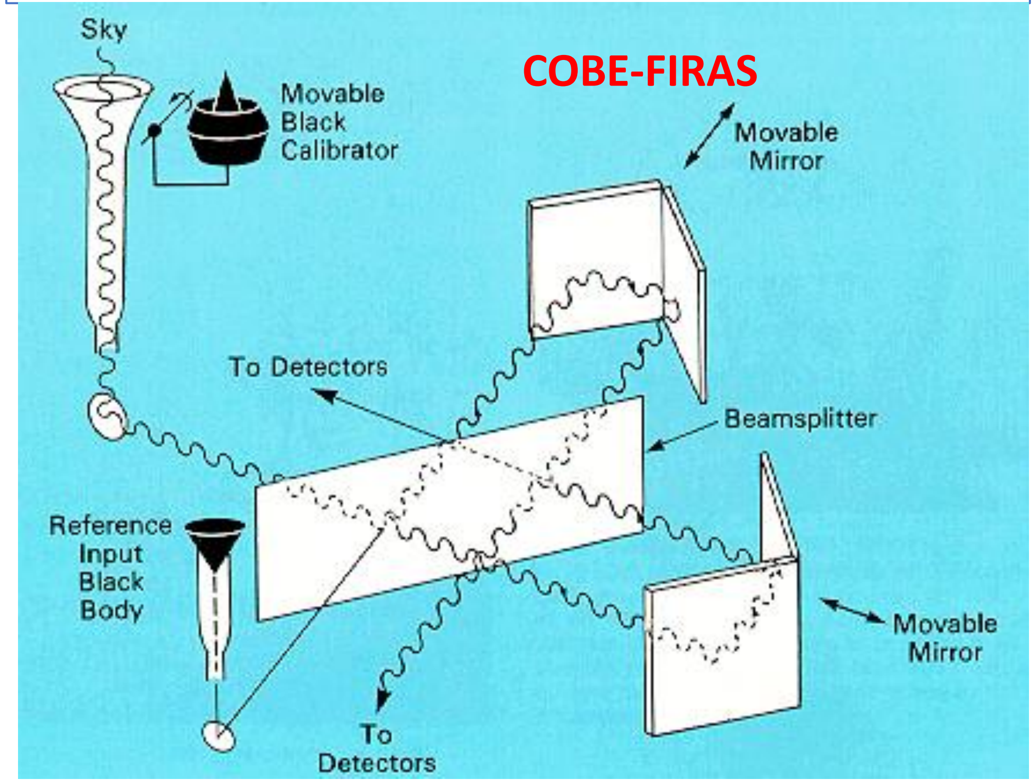
Ground-based spectral distortion measurements

- *Isotropic* spectral distortions of the CMB are extremely faint, when compared to the CMB itself, and even more if compared to room-temperature emissions.
- Ground-based experiments must face:
  - Atmospheric emission
  - Ground emission in the sidelobes
  - Receiver vacuum window emission
  - Electromagnetic interference
- All the above is reduced or absent in space-based instruments, which clearly represent the final approach to obtain high-quality measurements.
- However, ground-based experiments:
  - Are relatively cheap and can be deployed in a reasonable time scale
  - Offer the opportunity to develop, test and optimize iteratively instrument configurations and analysis methods
  - Can detect the largest spectral distortions, still undetected.

Spectrometer concepts

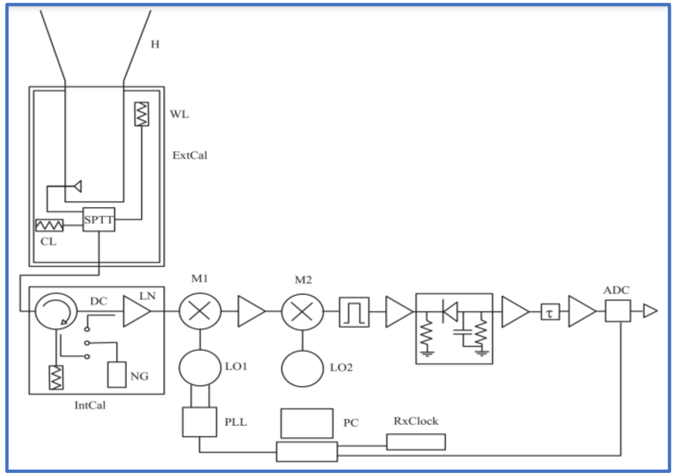
- All current monopole SD experiments make use of a reference load and measure the difference between the sky and the load.
- In the «radio» region antennas, coherent amplifiers, electronic frequency analysis are used, together with a matched resistive load. Either correlation or switch architectures can be used to measure the difference spectrum.
- In the «mm» region quasi optical components with consolidated FTS spectrometers and incoherent detectors (bolometers, KIDs) are used. The FTS is configured as a differential Martin Puplett, comparing the sky to a cryogenic blackbody source.
- «On-chip» differential spectrometers represent a promising technology, starting to be experimented and promising a large gain in terms of instrument size and cost.

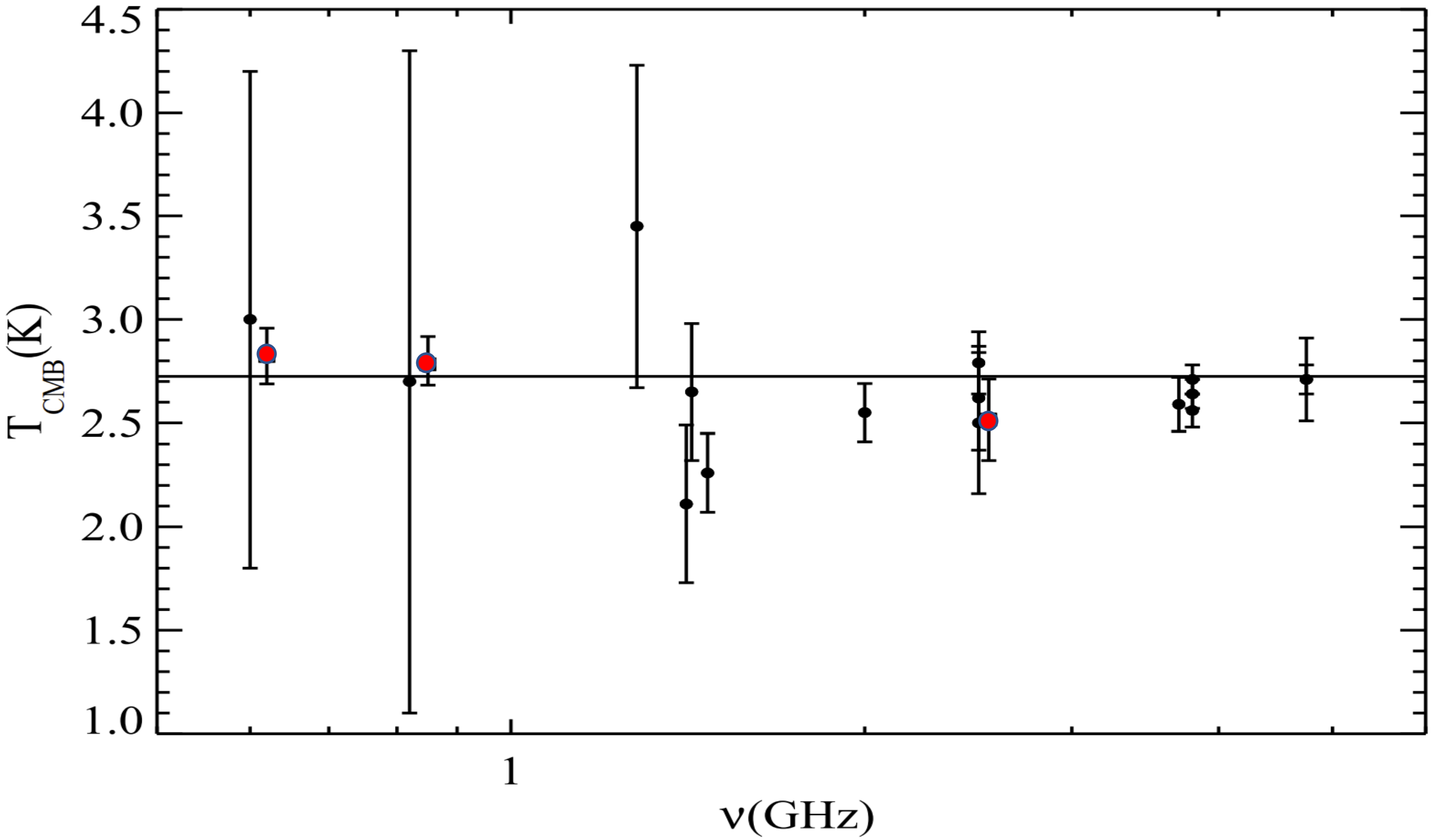




Radiometers

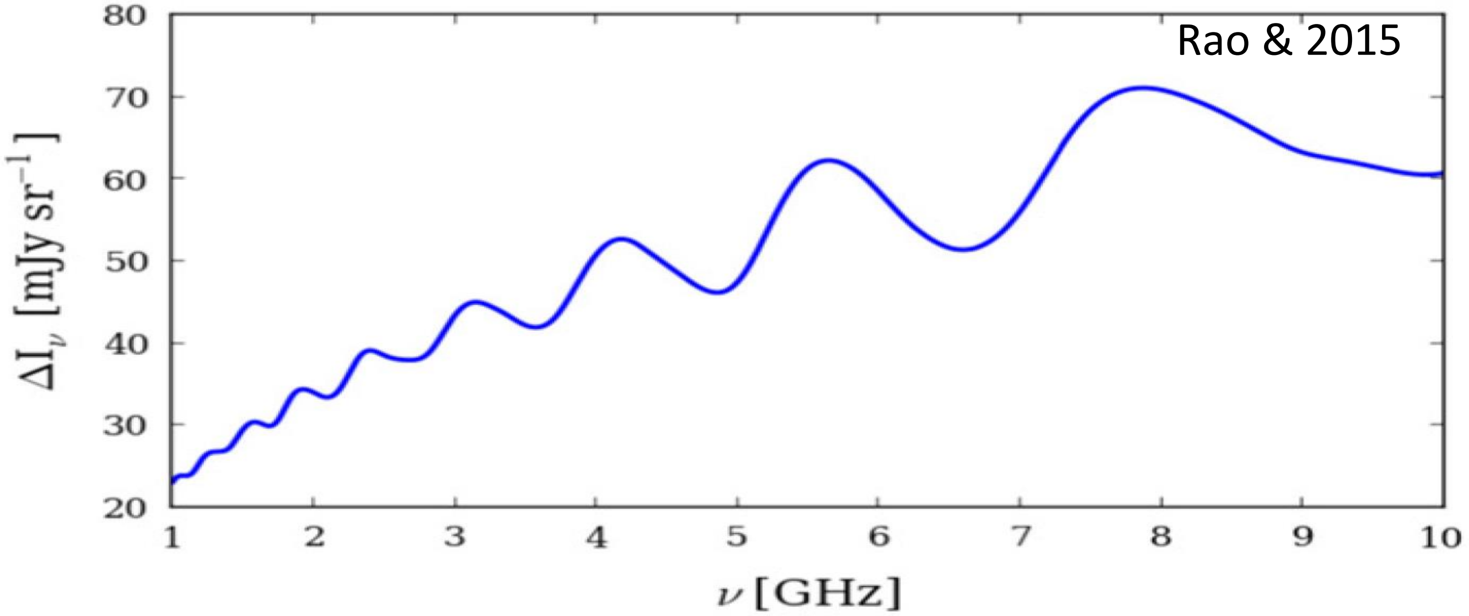
- Ground based radiometers (not really spectrometers) have been used very efficiently (e.g. White Mountain collaboration ..) to measure the spectrum of the CMB at long wavelengths.
- **TRIS** (Milano University: Gervasi&08) was a set of three absolute radiometers at 0.60, 0.82 and 2.5 GHz, installed at Campo Imperatore (2000 m osl) in Italy and operated between 1996 and 2000
- Even with only 3 spectral points at low frequencies, adding them to the FIRAS data, TRIS was able to set a limit $|\mu| < 6 \times 10^{-5}$ at 95% C.L. (with FIRAS)

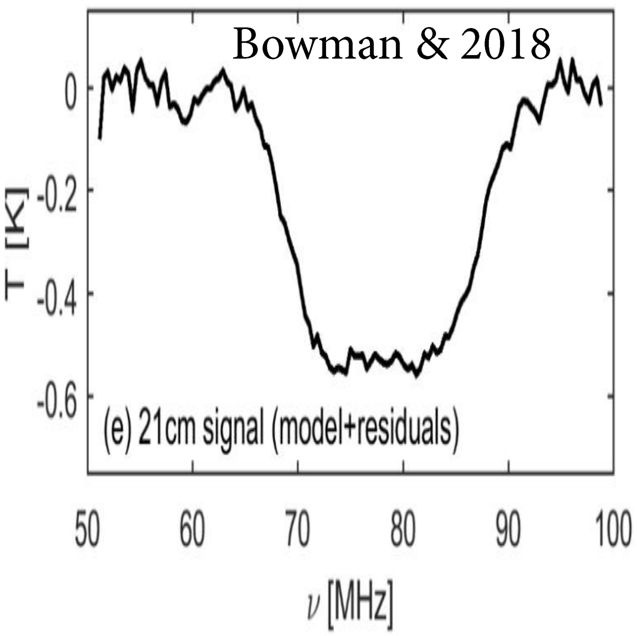


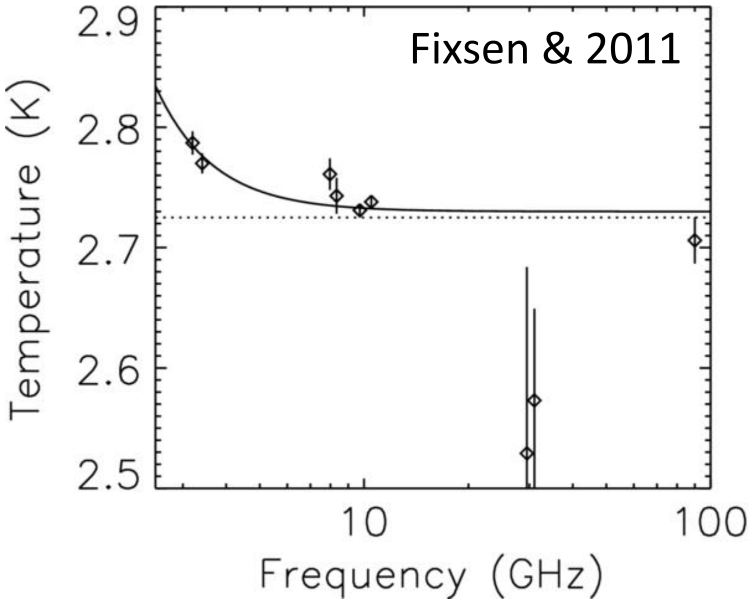


Spectral distortions at radio frequencies

- Important targets for CMB spectral distortions in the radio region (< 10 GHz) are :
  - Recombination lines
    - ripples in the spectrum [Chluba & Sunyaev (2008), Sunyaev & Chluba (2009)]
    - best detection range 2-6 GHz [Rao & 2015], $\pm$**10 nK** amplitude
  - Redshifted 21 cm line
    - features produced by neutral H absorption, determined by the thermal state of the gas during reionization.
    - Detection range in the tens of MHz region, expected ~**100 mK** amplitude
    - EDGES detection (Bowman & 2018), in contrast with SARAS3 data (Singh & 2022)
  - ARCADE excess (Fixsen & 2011, **56 mK** amplitude @3.3 GHz)

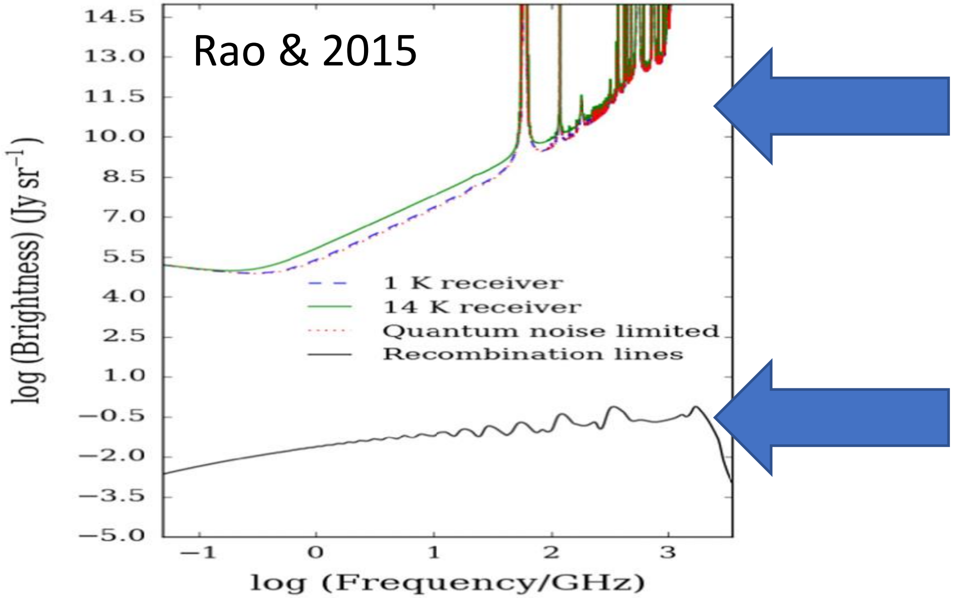






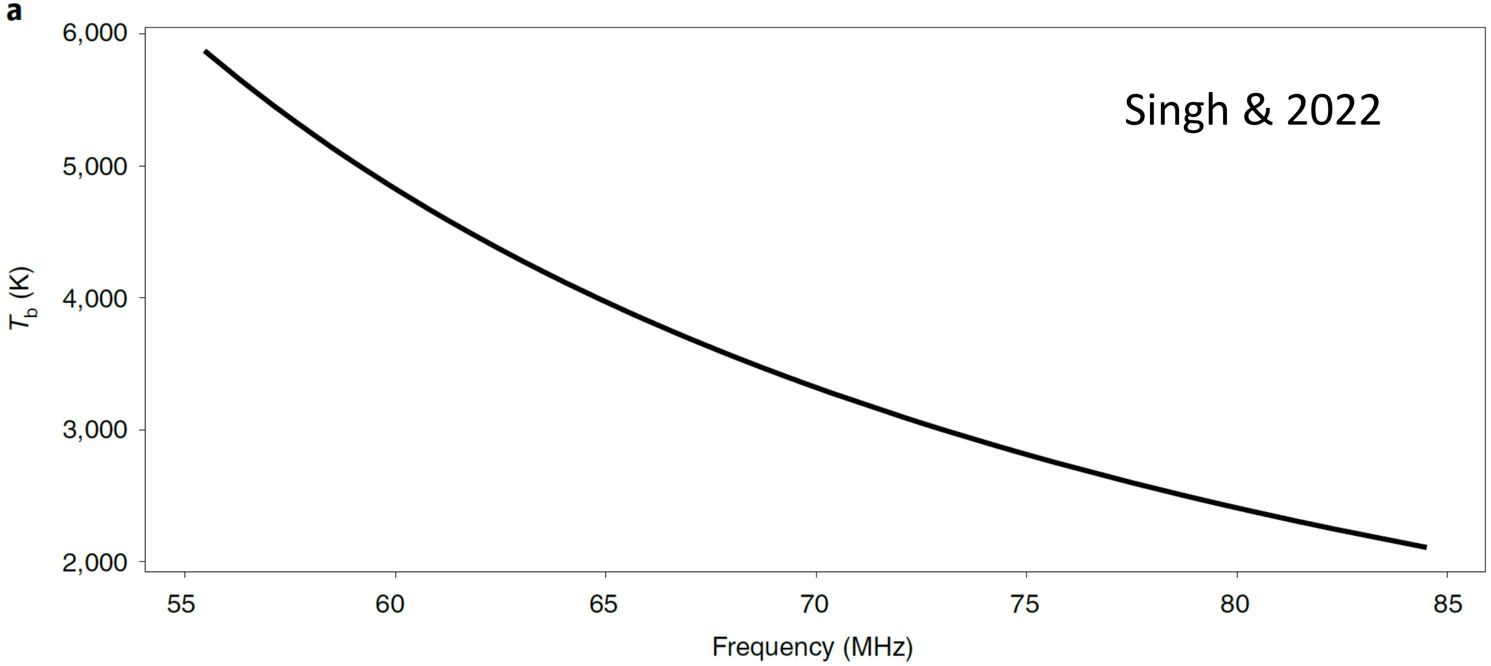
Spectral distortions at radio frequencies

- Recombination lines
  - The expected signal is of the order of 10 ppb (!) of the CMB.
  - Detection method based on smooth nature of the foreground vs. wavy nature of the signal.
  - Detector noise very significant. Long integration time and extreme long term stability of the measurement system required.
- Redshifted 21 cm lines:
  - the foreground is very smooth, and the expected signal is of the order of 20 ppm of it.
  - Better detection likelihood

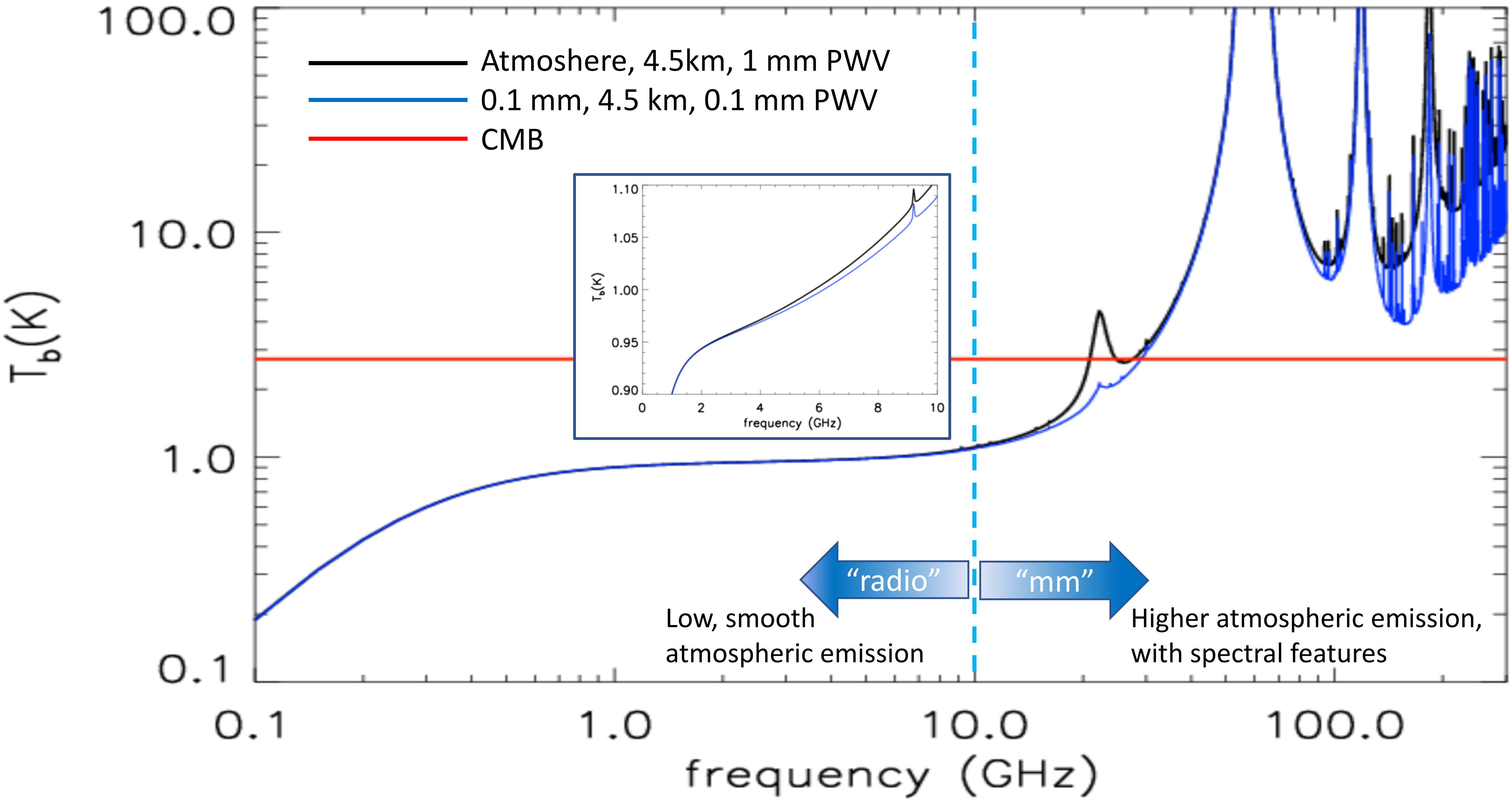


Receiver noise + Atmospheric emission + Galactic foreground

Recombination lines

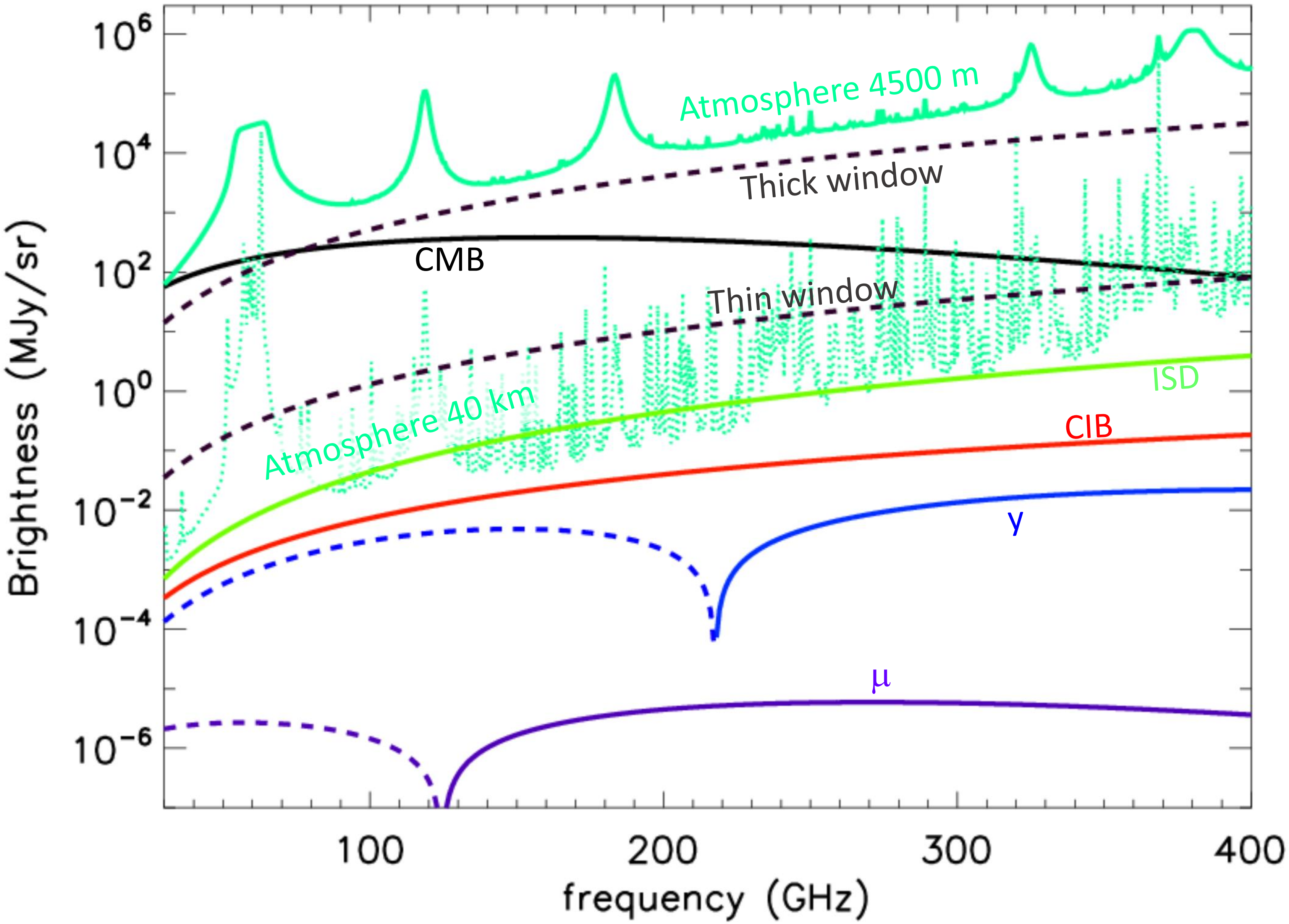


Atmospheric emission (AM)

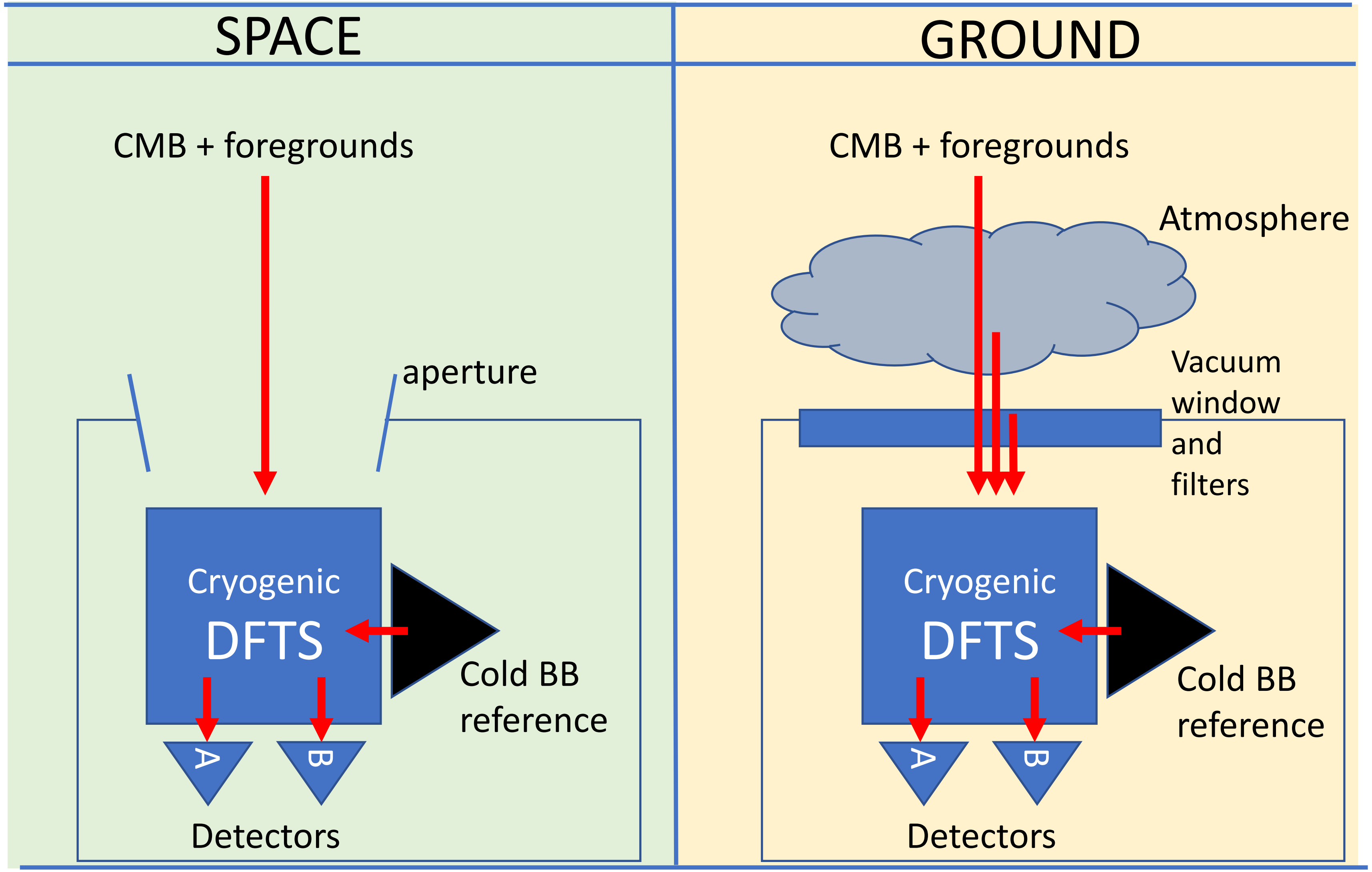


Spectral distortions at mm wavelengths

- y, μ, and mixed distortions.
- Post-recombination y is the strongest distortion at a level $y{\sim}2\times10^{-6}$.
- Pre-recombination y at least 1 order of magnitude smaller.
- μ even smaller.
- Smooth spectra in the mm range, to be compared to complex atmospheric emission spectra.
- Atmospheric and window emissions are the main foregrounds for ground-based experiments.



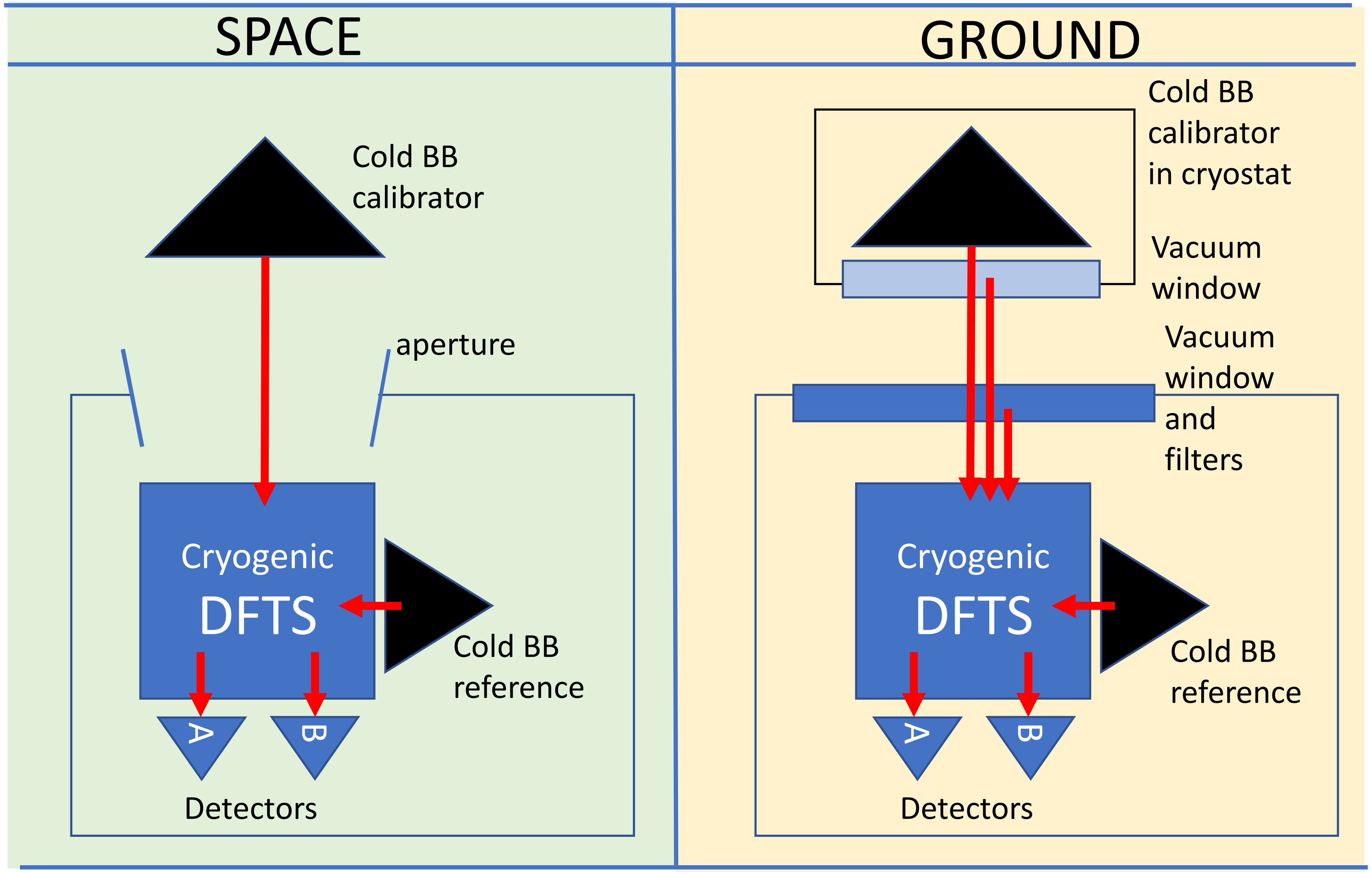
A ground-based measurement ?



In a space-based instrument there is nothing between signal to be measured (CMB + foregrounds) and the DFTS

In a ground-based instrument the signal to be measured (CMB + foregrounds) is dominated by the **emission of the Earth atmosphere and the emission of the warm part of the instrument** (vacuum window & filters). **They must be *minimized* AND *subtracted*.**

A ground-based measurement ?



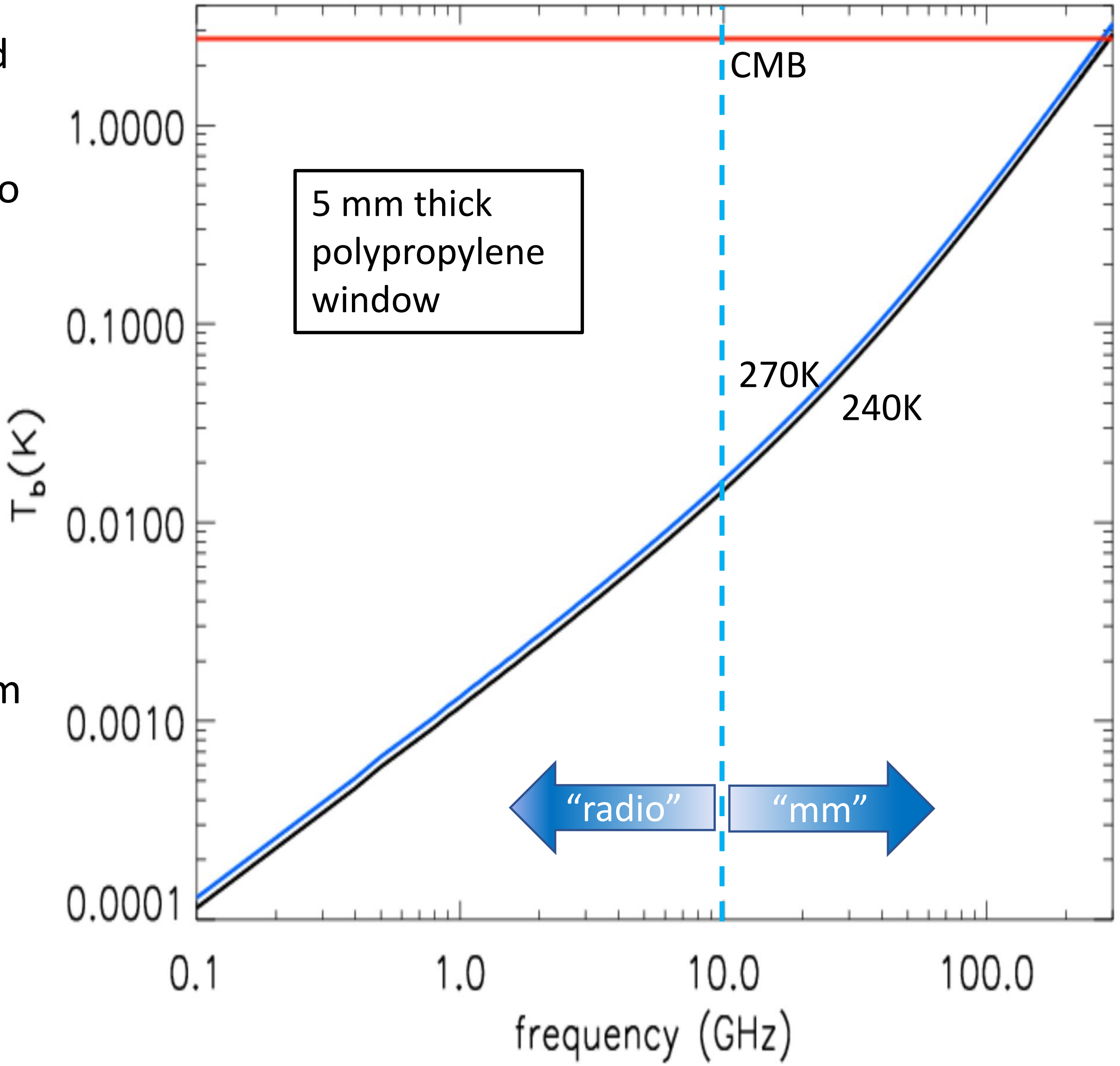
Even the Calibration measurement cannot be carried out on the ground in the same way as is done in space. A vacuum window is necessary to keep the calibrator BB cold. **Its emission must be *minimized* AND *subtracted*.**

Coping with atmospheric emission

- In the “radio” region:
  - atmospheric emission is **smooth**, but still comparable to the CMB (1K vs 3K).
  - quasi-periodic or absorption features in the spectrum can be extracted **assuming maximum smoothness** of the atmospheric and galactic foregrounds.
- In the “mm” region:
  - Atmospheric emission features **strong emission lines and bands** (peak brightness similar or larger than the CMB). Smooth emission (tails of FIR lines) is present between lines.
  - As a consequence, atmospheric emission must be removed using **sky dips** and exploiting the **lack of covariance** between the residuals and **y** or μ distortions (i.e. atmospheric residuals **do not mimic** the largest CMB spectral distortions, relevant in this frequency range).

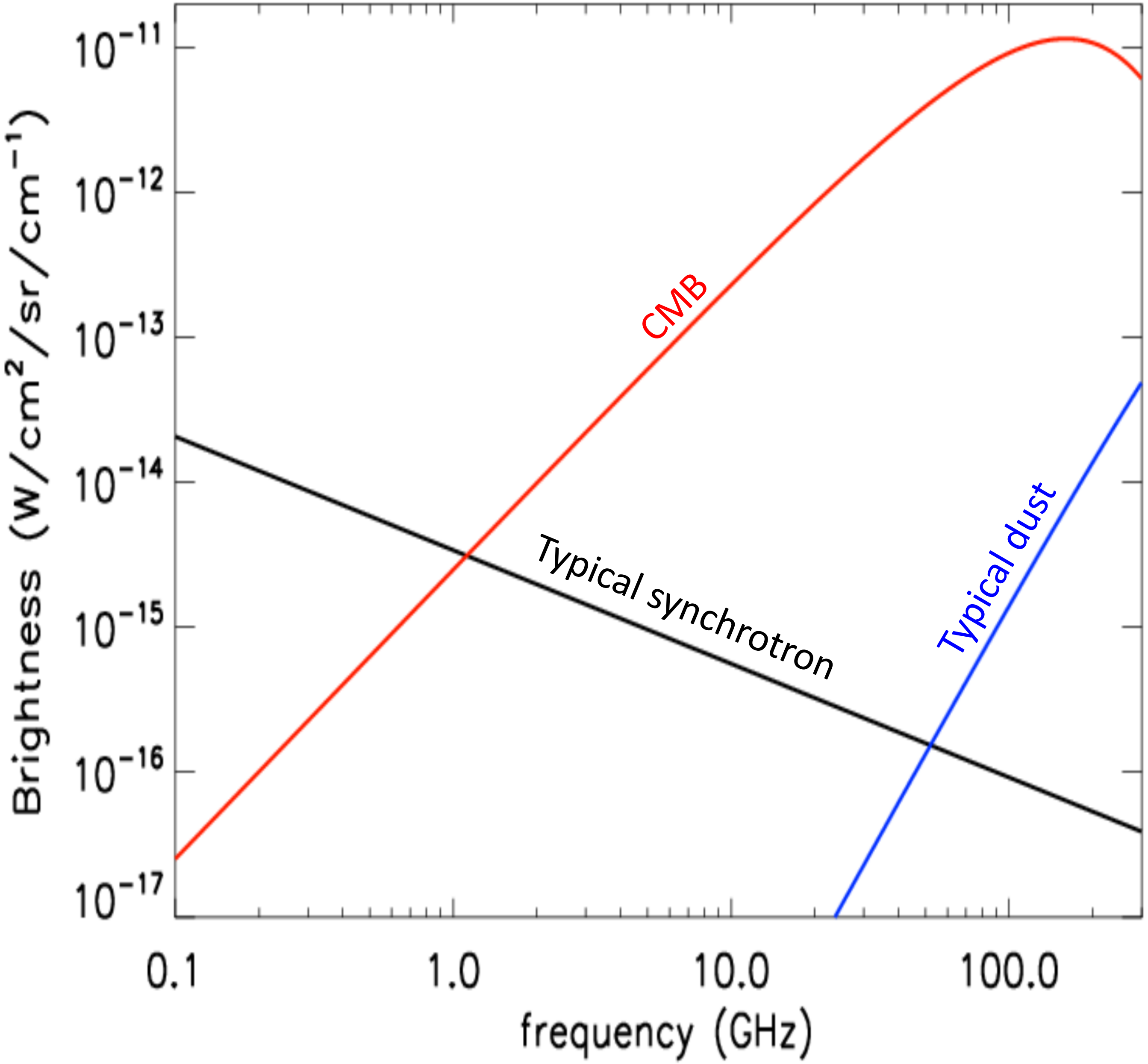
Coping with receiver window emission

- In the "mm" region quasi optical devices are used to collect the radiation to be measured, and very sensitive cryogenic detectors are available.
- Detectors must be cooled at sub-K temperature to achieve detector noise negligible wrt photon noise (NEP ~ aW/Hz$^{1/2}$)
- Quasi optical devices must be cryogenically cooled to make their emission negligible wrt the CMB.
- An optically transparent vacuum window is necessary to separate the cryogenic instrument from the ambient environment.
- This window is made out of low emissivity material at room temperature.
- Its emission can be comparable to the CMB at mm wavelengths.
- Must be subtracted using suitable procedures:
  - Changing (and measuring) the temperature
  - Changing (and measuring) the thickness
- Provided measurement errors are small enough, residuals do not mimic **y** or μ distortions.

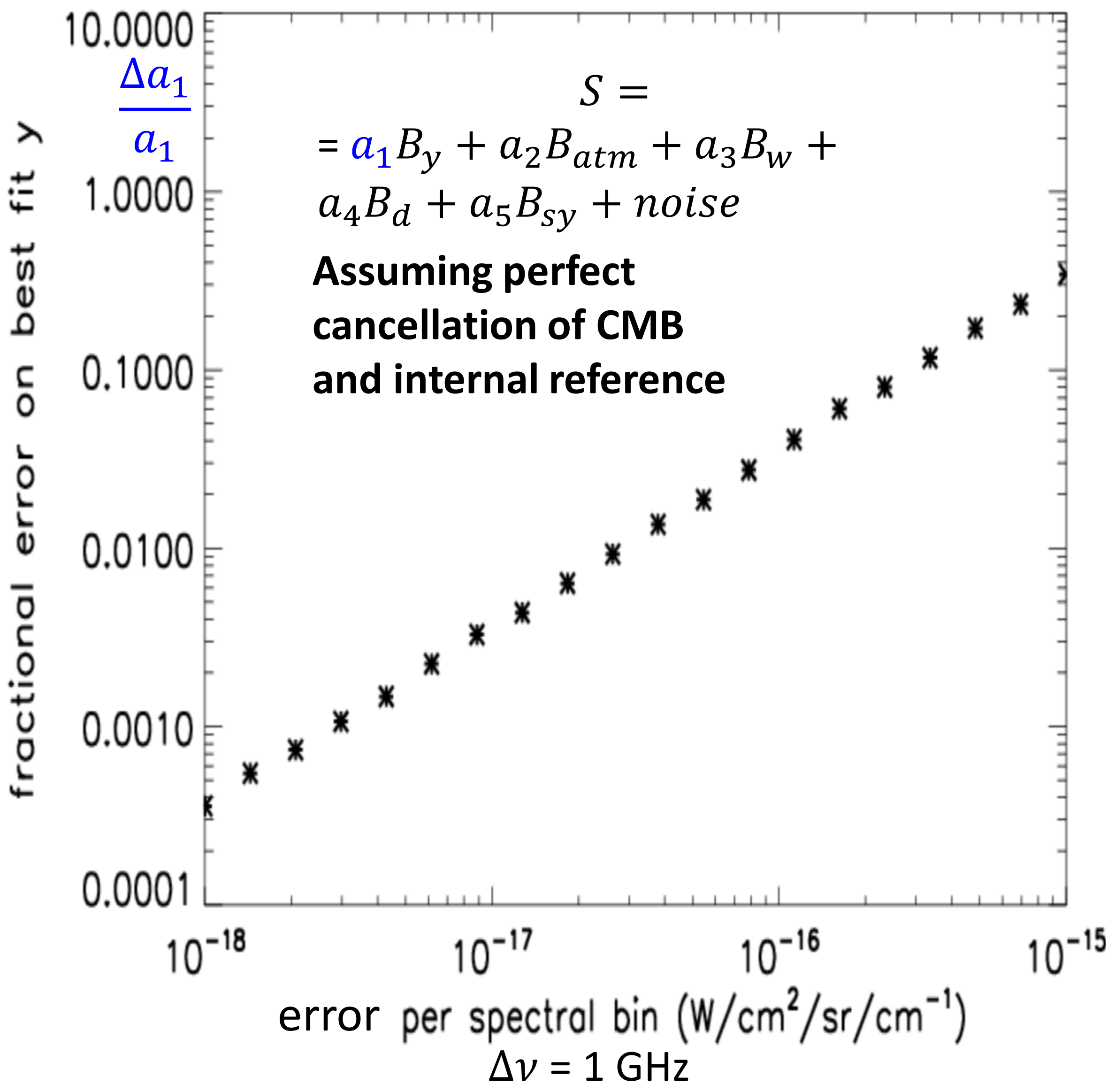


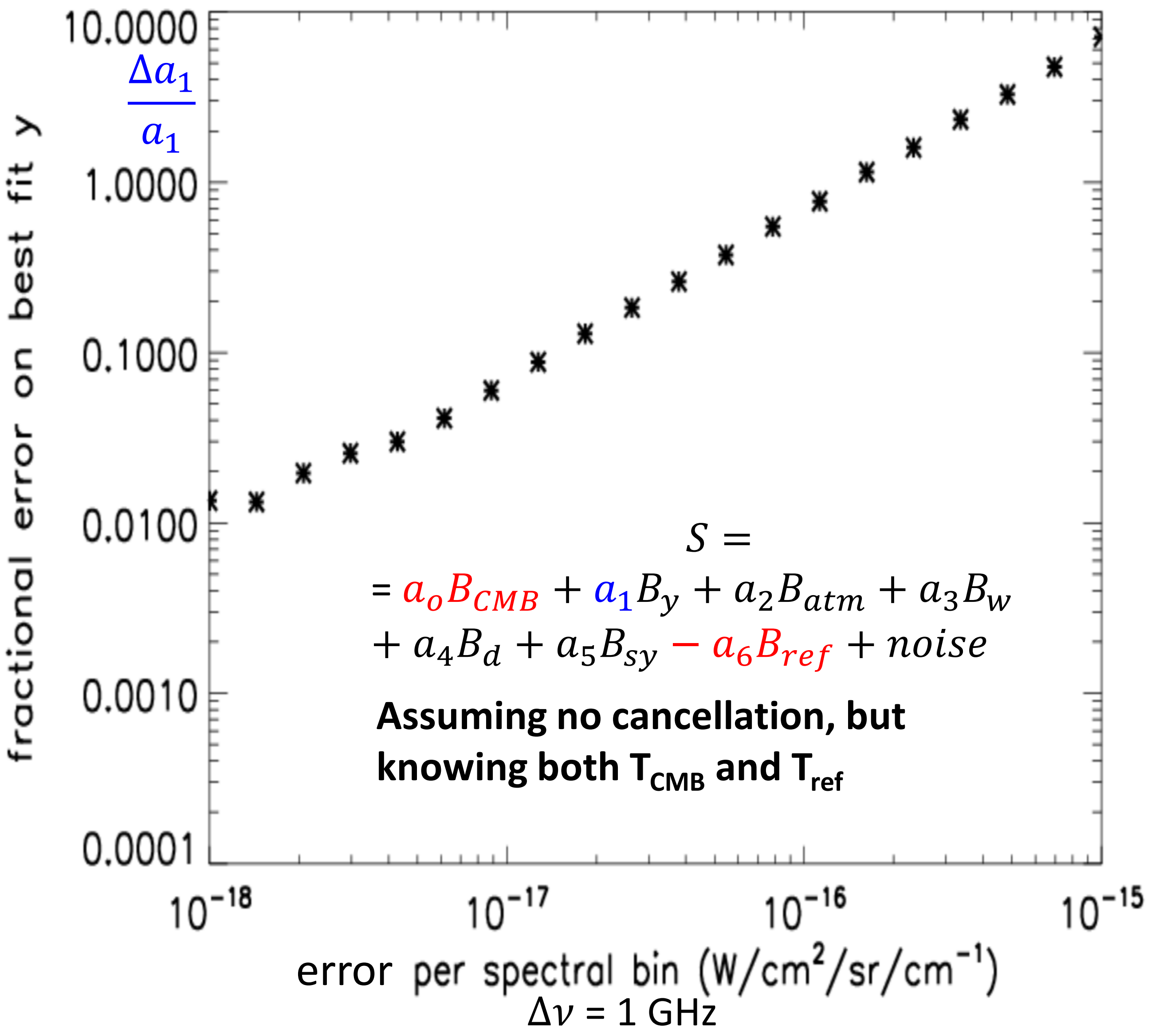
Coping with astrophysical foregrounds

- This problem is common to ground-based and space-borne experiments.
- Main galactic foregrounds
  - Interstellar dust
  - Free-free
  - Synchrotron
- Extragalactic foregrounds
  - Dusty galaxies (CIB)
  - Radio galaxies
- They are expected not to mimic SDs
- Absolute value of the emission not well known, is one of the targets of these experiments.



Naïve simulations



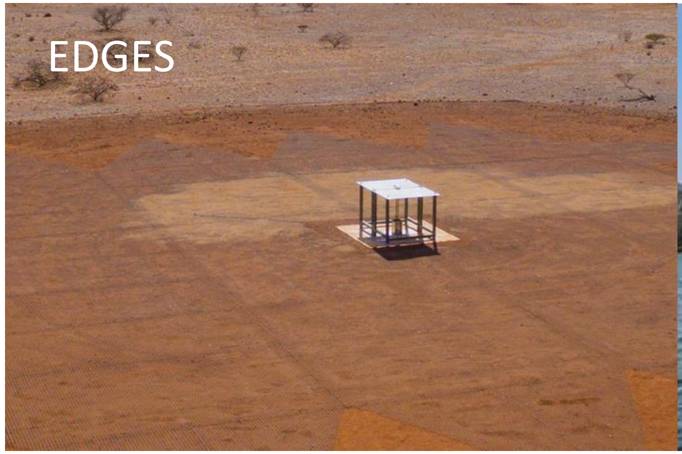


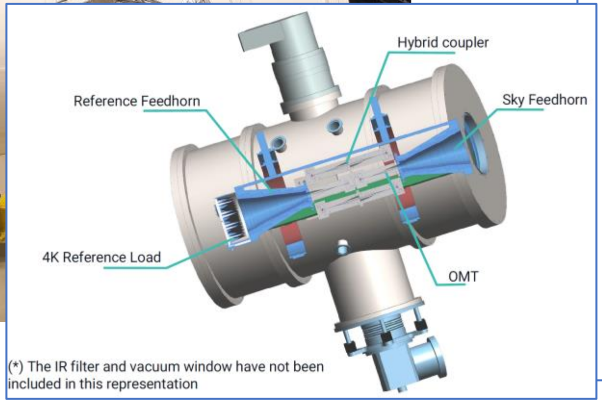
Naïve simulations

- The simulations above are really naïve. Their only purpose is to show that the shapes of the foreground spectra, including the atmospheric emission ones, cannot mimic the *y* spectral distortion (similar results can be found for μ or other distortions).
- If the shapes are perfectly known *and* the measurement errors are small enough, there is the possibility to retrieve the spectral distortion, even if it is orders of magnitude smaller than the foregrounds.
- Since we are focusing on ground-based measurements, we have to cope mainly with window emission and atmospheric emission
- For the emission of the window, the shape of its spectrum is known, and is basically stable, depending only on the temperature, which can be monitored.
- The shape of the atmospheric spectrum is not well known. Composition variations (e.g. PWV changes), or temperature profile variations vary the ***shape*** of the spectrum of the atmosphere, in a way which would require to include a large number of additional free parameters.
- For this reason ground based experiments
  - avoid spectral regions where atmospheric emission and associated noise are strong
  - operate from sites where atmospheric emission is weak (e.g. Antarctica for mm experiments, Tenerife for radio ones)
  - rely on sky dips to remove the effects of atmospheric emission, without having to accurately model it.
- Finally, we have to make sure that the noise levels on the abscissae of the simulation plots can be achieved. This is the final error for each spectral bin, depending on detector noise, RFI, atmospheric noise, integration time, spectral resolution.
- This requires stable atmosphere and signal modulation to avoid 1/f, radio quiet sites, long integration times, and performing detectors.

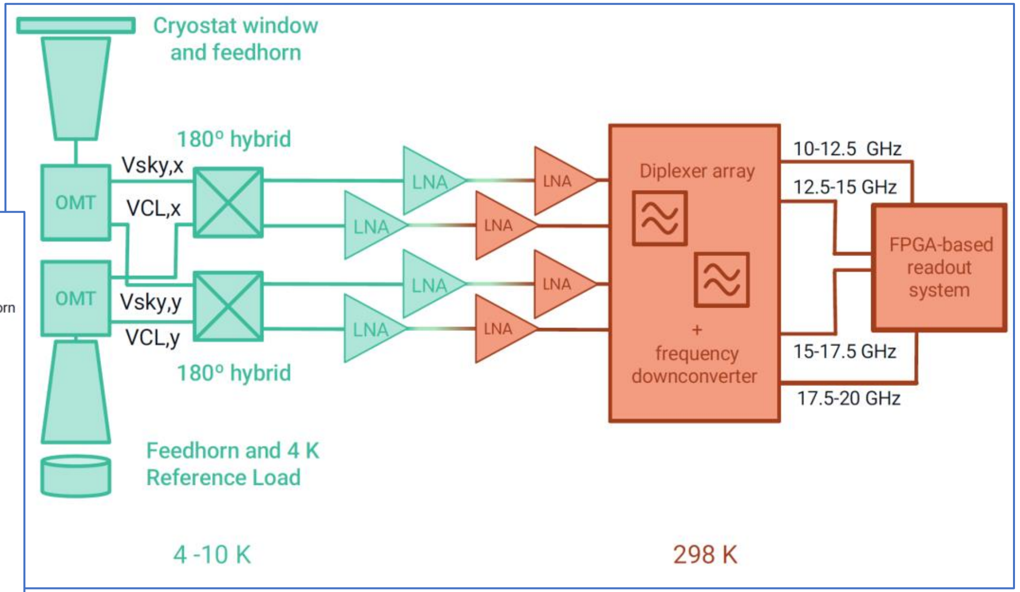
Measurements of monopole SD from the ground

- Wide beam antennas: at low frequencies (**EDGES, SARAS**, **LEDA** …) covering the high z 21 cm features (< 200 MHz). Need large ground planes and radio-quiet sites.
- **APSERa**: Array of 128 Precision radiometers covering 2-6 GHz in a radio-quiet site. Hear Mayuri Rao later.
- Absolute radiometers at intermediate frequencies: **TRIS** (completed), **TMS** - hear Jose Alberto Rubino-Martin later) – covering 10-20 GHz with R=60, 2^{o} beam, NET = 1.5 mK s$^{-1/2}$, survey depth @10 GHz 10 Jy/sr in 100h. Targets: ARCADE excess and post-recombination y.
- Higher frequencies: **COSMO** (100-300 GHz from Dome-C Antarctica). First step of a staged effort – ground/balloon/space. Target: post-recombination y.

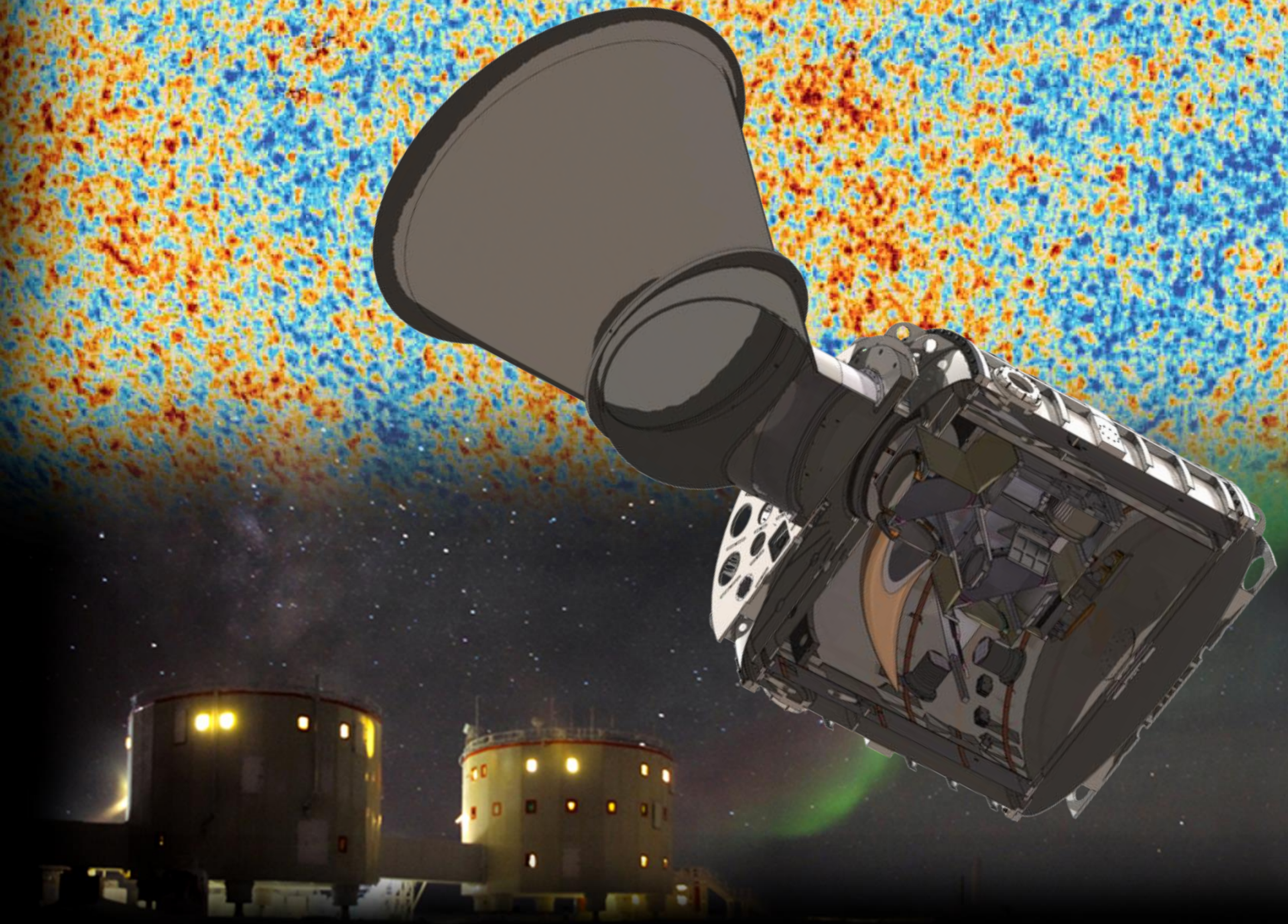




TMS



COSMO (COSmic Monopole Observer)



SAPIENZA UNIVERSITÀ DI ROMA

CNR IFN Istituto di Fotonica e Nanotecnologie

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

UNIVERSITAS STUDIORUM MEDIOLANENSIS

MANCHESTER 1824 The University of Manchester

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

E. Battistelli, P. de Bernardis, F. Cacciotti, S. Cibella, F. Columbro, A. Coppolecchia, M. Bersanelli, G. D'Alessandro, M. De Petris, C. Franceschet, M. Gervasi, A. Limonta, L. Lamagna, E. Manzan, E. Marchitelli, S. Masi, L. Mele, A. Mennella, A. Paiella, G. Pettinari, F. Piacentini, L. Piccirillo, G. Pisano, S. Realini, C. Tucker, M. Zannoni

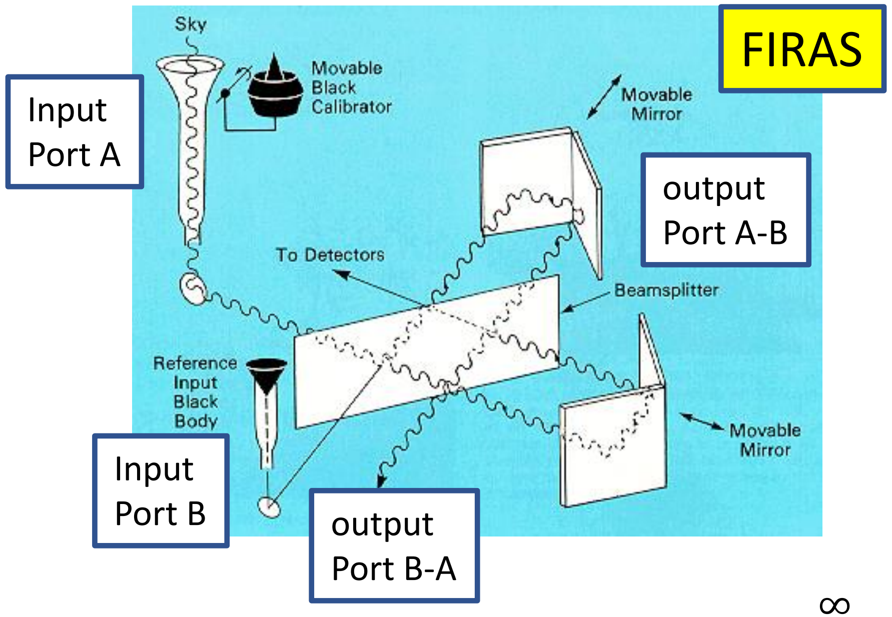
PRIN Programmi di Ricerca Scientifica di Rilevante Interesse Nazionale

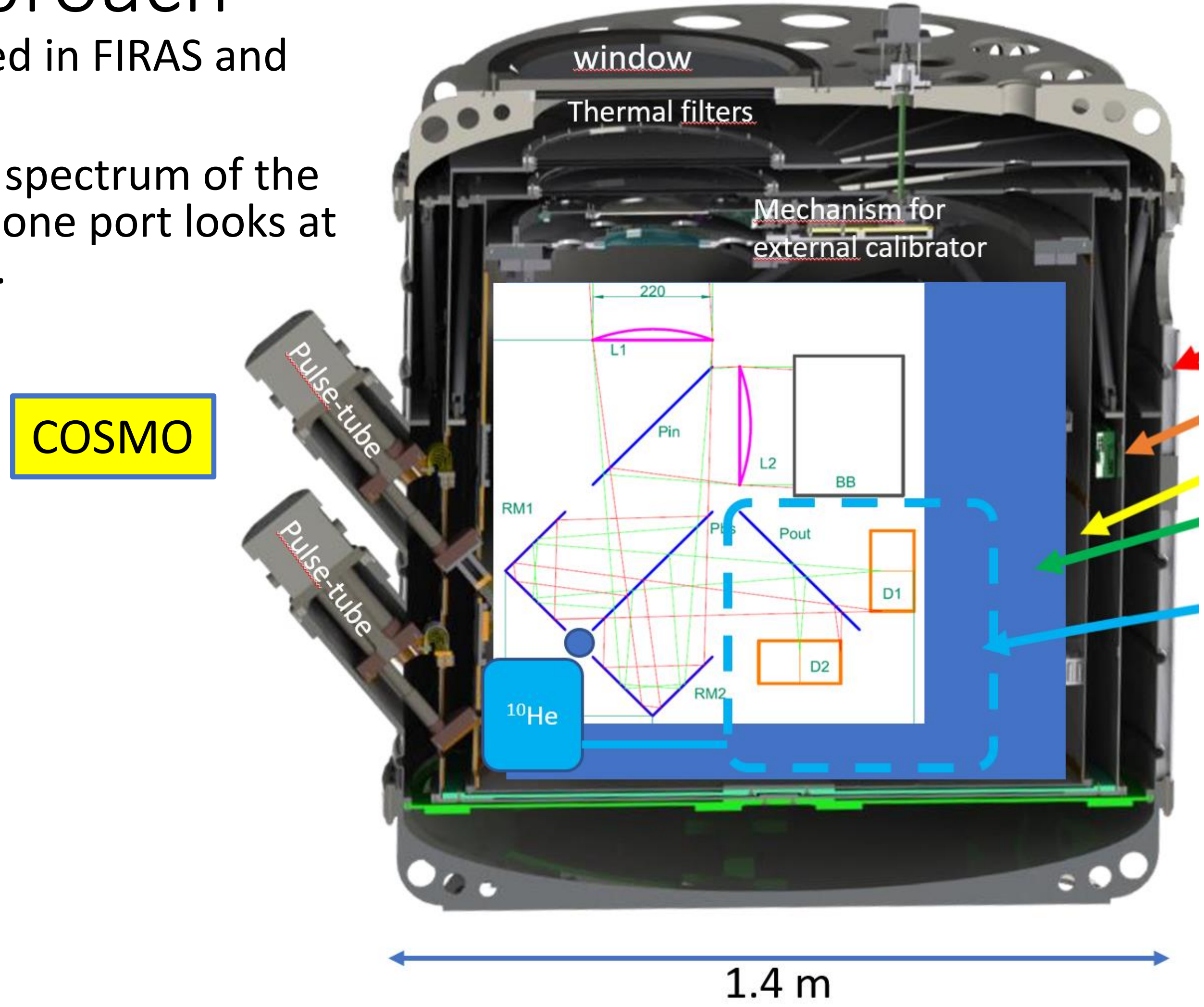
PROGRAMMA NAZIONALE DI RICERCHE IN ANTARTIDE ITALIANTARTIDE

https://cosmo.roma1.infn.it

Absolute measurement approach

- The Martin-Pupplett Fourier Transform Spectrometer used in FIRAS and PIXIE has two input ports.
- The instrument is intrinsically differential, measuring the spectrum of the difference in brightness at the two input ports. Normally one port looks at the sky, the other one at an internal reference blackbody.
- For calibration, a movable blackbody fills the sky port.





Sky measurement

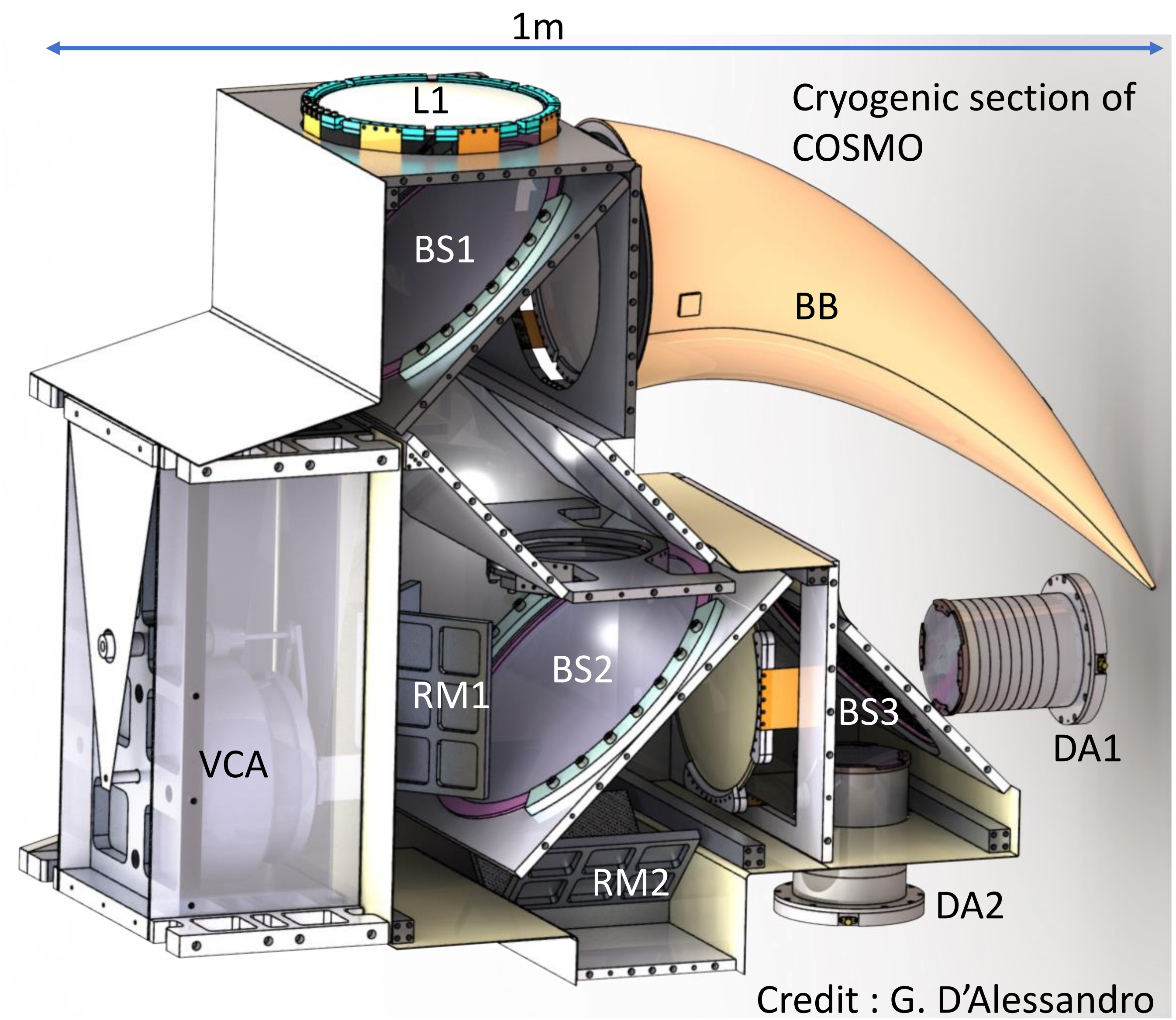
$$I_{SKY}(x) = C\int_0^\infty [S_{SKY}(\sigma) - S_{REF}(\sigma)]rt(\sigma)\{1+\cos[4\pi\sigma x]\}d\sigma$$

Calibration measurement

$$I_{CAL}(x) = C\int_0^\infty [S_{CAL}(\sigma) - S_{REF}(\sigma)]rt(\sigma)\{1+\cos[4\pi\sigma x]\}d\sigma$$

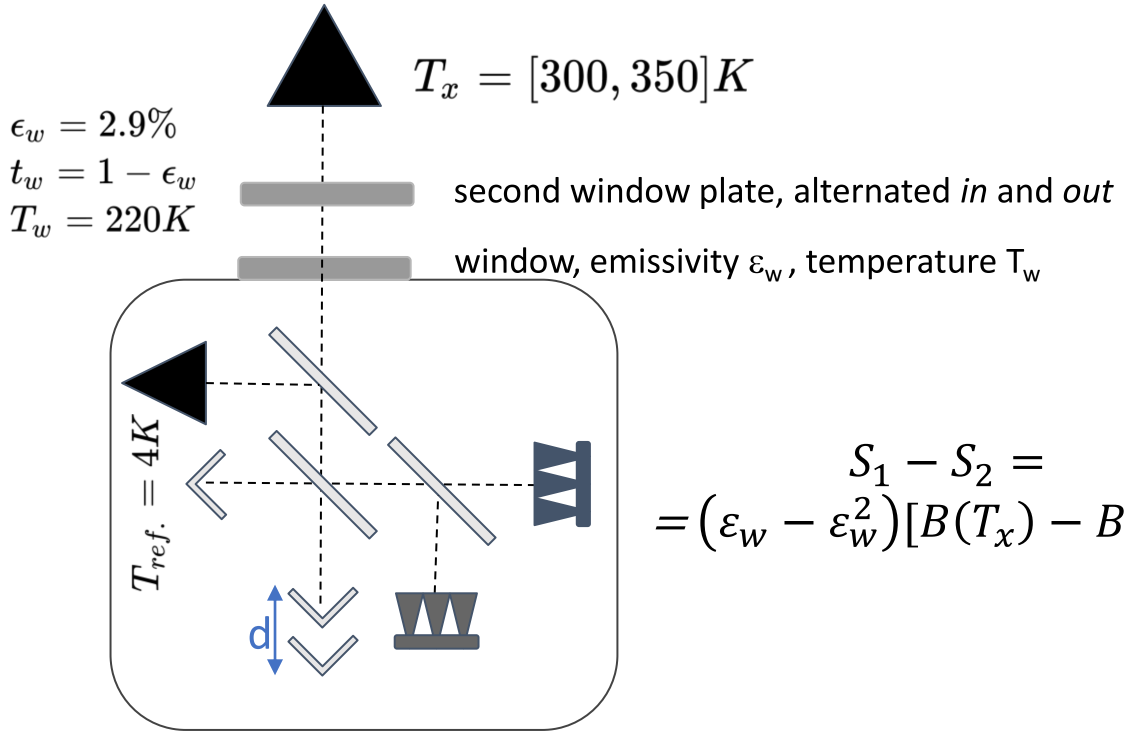
COSMO in a nutshell

- **COSMO** is a pathfinder experiment, ground-based in the first implementation, balloon-borne in its second step.
- A cryogenic **Differential Fourier Transform Spectrometer**, comparing the sky brightness to an internal blackbody (configuration similar to COBE-FIRAS)
- Operation from the Concordia French-Italian base in **Dome-C, Antarctica**. Average PVW of 210µm, T < -60C, stable weather in the winter season (*Tremblin et al. A&A, 2011*). Atmospheric emission strongly reduced wrt mid latitude sites.
- High transmission bands: **125-175 GHz** (ySD<0) and **200-285 GHz** (ySD>0) ~**5 GHz** resolution.
- Uses fast detectors (multi-mode KIDs, τ=60 μs) so that **fast sky-dips** are continuously performed to measure and reject atmospheric emission and its slow fluctuations.
- The FTS is cryogenically cooled @3K;
- The reference blackbody can be tuned to 2.5-4 K;
- A continuous and **fast** (few seconds) **interferogram scan** is achieved via a voice-coil actuator.
- Several **10ºx10º** sky patches are observed with **1º resolution**, in the southern sky and with varying levels of galactic signals.
- In **100 days of integration** in the Antarctic winter, the *y SD* can be detected at **5σ**.

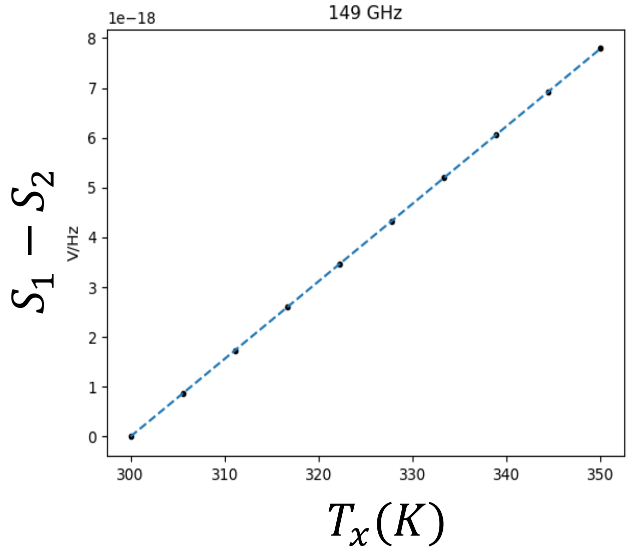


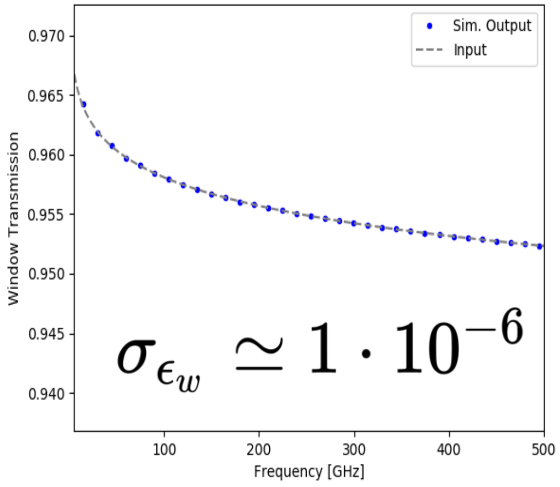
Coping with window emission

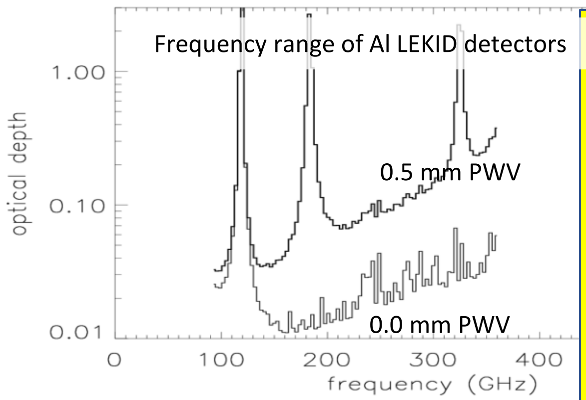
- Window **common mode emission** must be measured and removed with high accuracy.
- A special subtraction procedure, based on the comparison of the emission from 1 or 2 windows stacked and accurate temperature monitoring, has been studied (PhD thesis, Lorenzo Mele)
- **Preliminary results:** The window emission can be subtracted, and the expected residual is smaller than the target distortion (assuming *y* ~ 2x10^{-6}).
- This is relevant for the ground based measurement, where the window is HDPE, ~10 mm thick, to withstand 1 bar of atmospheric pressure.
- For the balloon-borne measurement (3 mbar), the window thickness can be reduced to a few tens of microns, and this issue becomes less important.
- Similar procedures must be carried out for **all other common mode emissions** (the window one is the largest, but we also have a filters chain and a cold lens), which **must be measured in advance vs temperature**, monitored and subtracted.



$$S_1 - S_2 =$$
$$= (\varepsilon_w - \varepsilon_w^2)[B(T_x) - B(T_w)]$$







Coping with atmospheric emission

COSMO will operate from the Concordia French-Italian base in Dome-C (Antarctica) … the best site on Earth, extremely cold and dry ! But still has to cope with some atmospheric emission.

COSMO uses fast detectors (KIDs) and fast elevation scans to separate atmospheric emission and its long-term fluctuations from the monopole of the sky brightness.

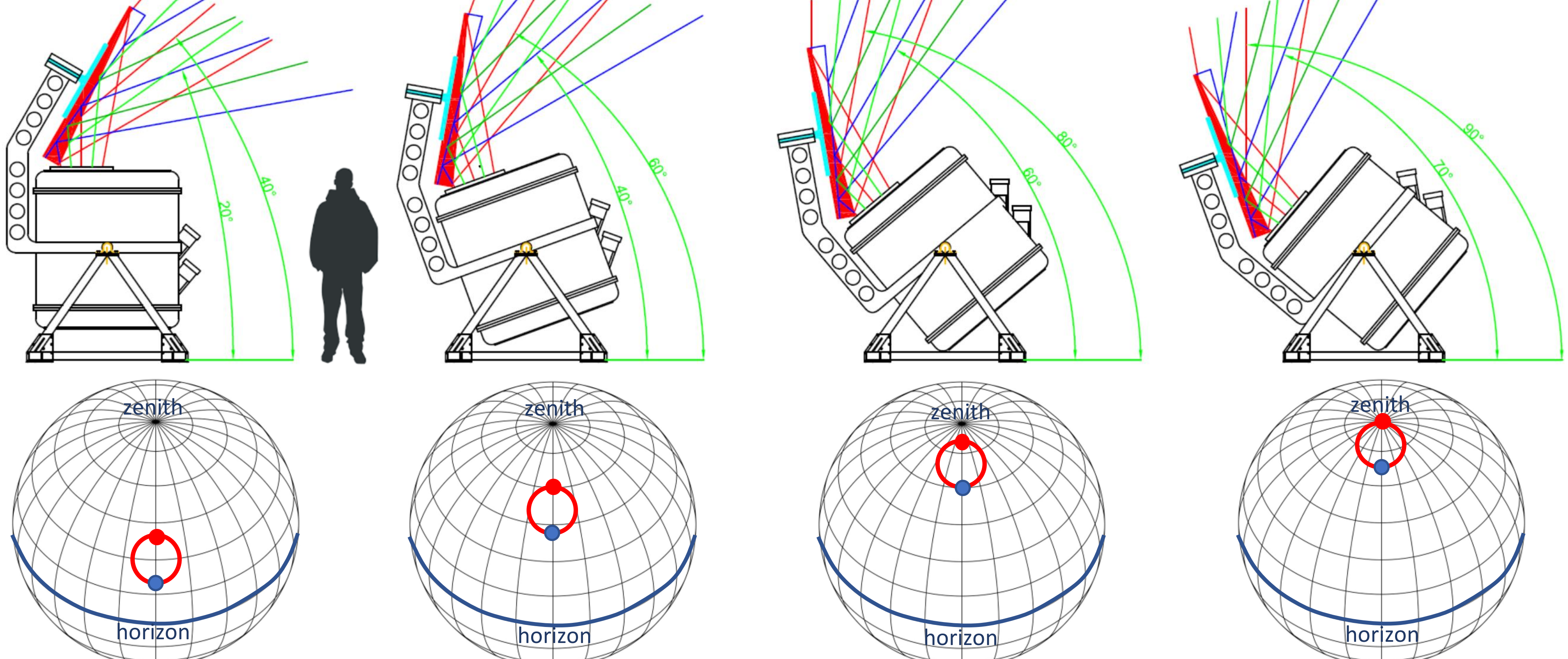
A fast spinning wedge mirror (>1000 rpm!) steers the boresight direction on a circle, 20º in diameter, scanning a range of elevations (and corresponding atmospheric optical depths) while the cryogenic interferometer scans the optical path difference.

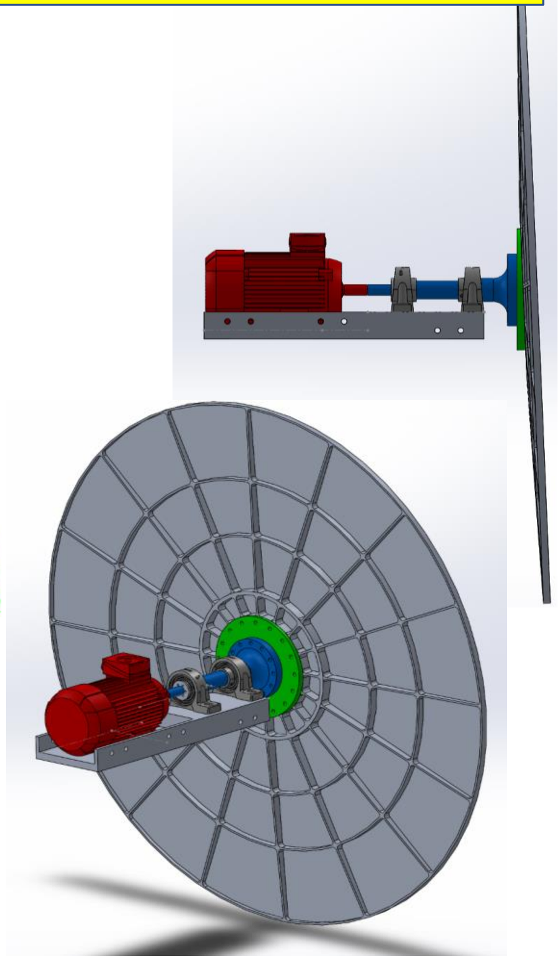
Cryostat tilt = 0º
PT tilt = 40°
Min. elev. = 20°
Max. elev. = 40°

Cryostat tilt = 20º
PT tilt = 20°
Min. elev. = 40°
Max. elev. = 60°

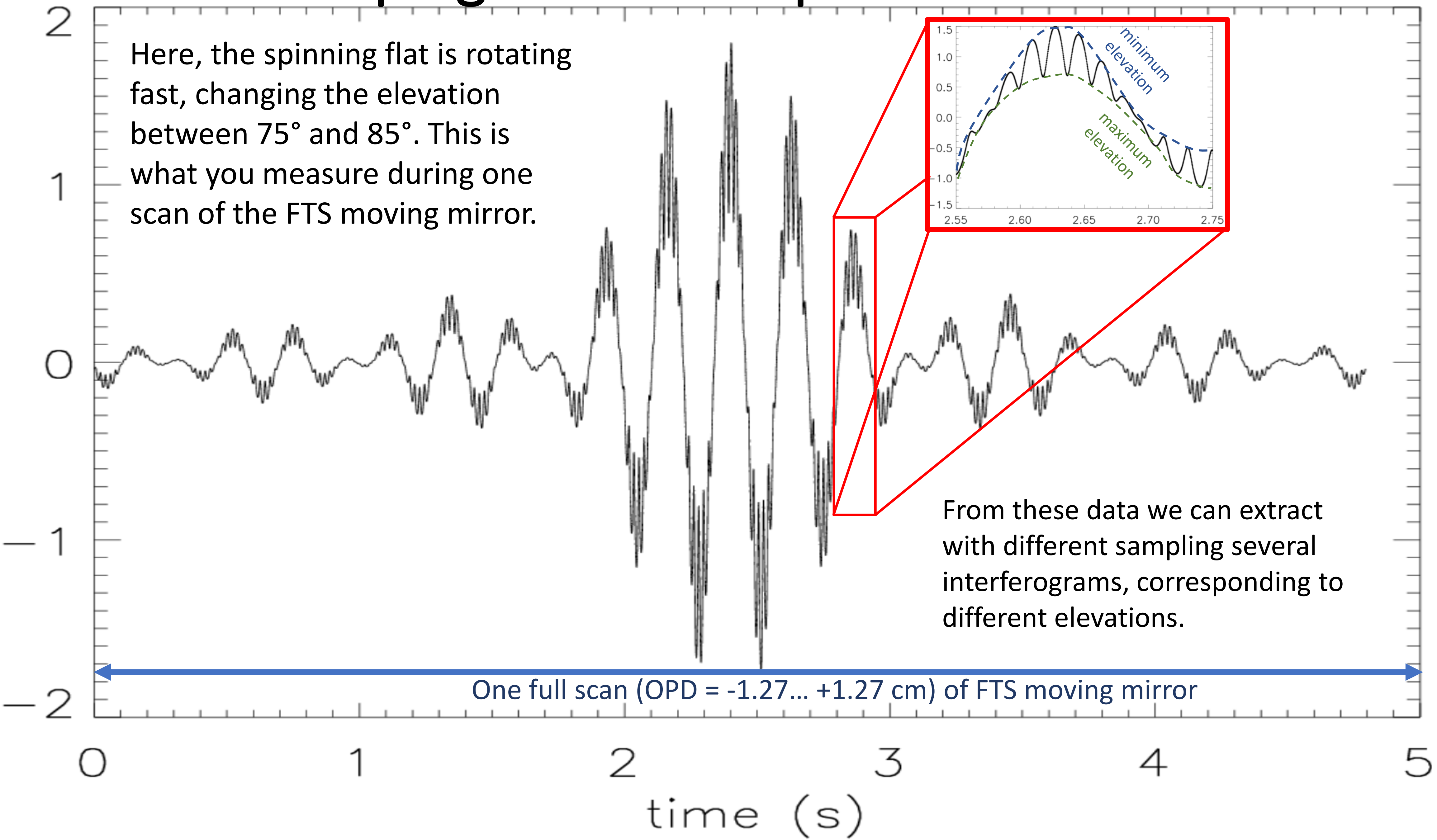
Cryostat tilt = 40º
PT tilt = 0°
Min. elev. = 60°
Max. elev. = 80°

Cryostat tilt = 50º
PT tilt = -10°
Min. elev. = 70°
Max. elev. = 90°





Coping with atmospheric emission



Measurements based on two modulations (optical path difference + fast sky scan)

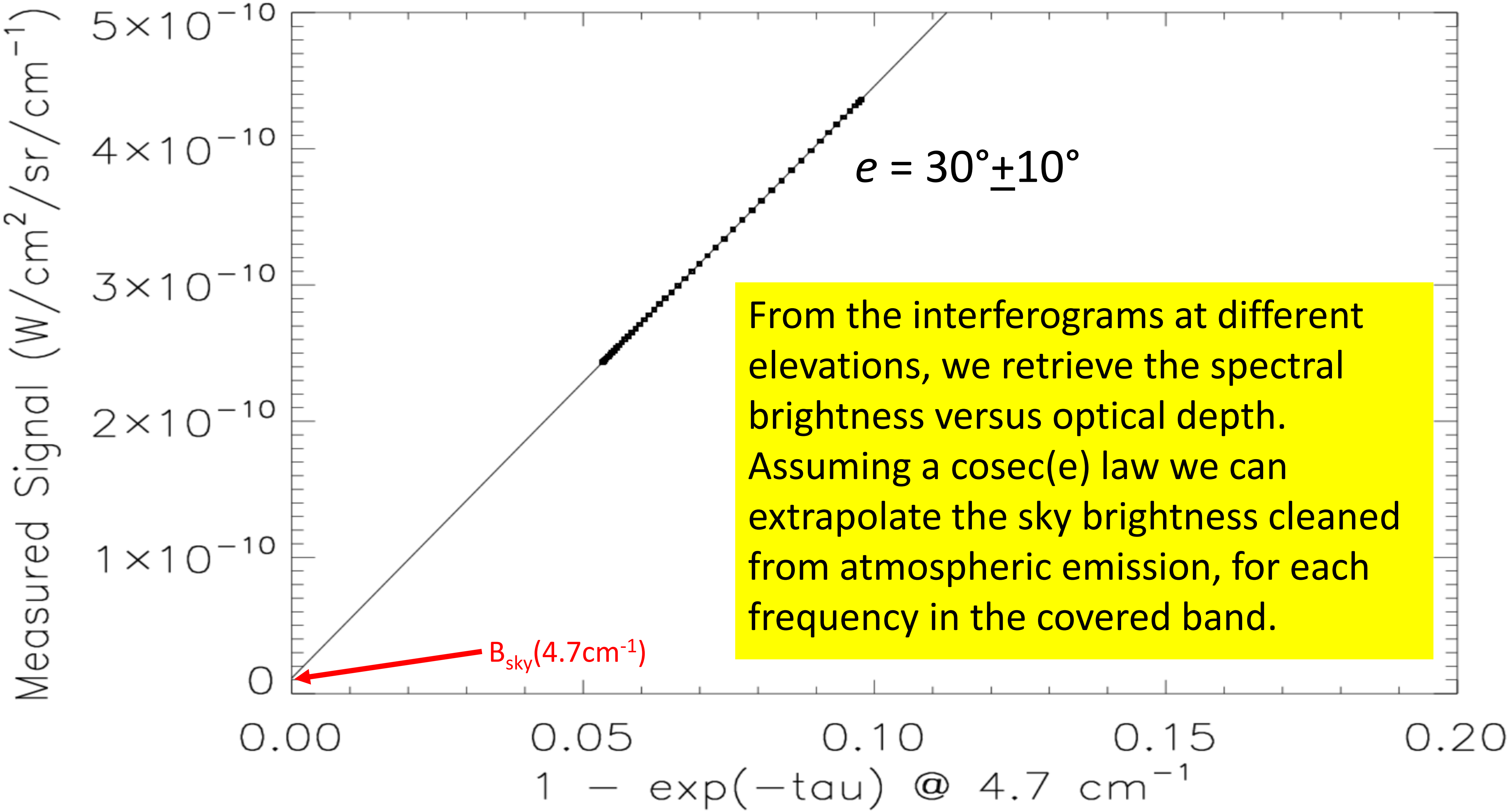
Optimal

sky scan fast		
circle radius	5	deg
circle length	31.4	deg
beam size	1	deg
number of samples per circle (3 per beam)	94	
time per beam	2.50E-04	s
time for 2 sky dips (downwards + upwards)	2.36E-02	s
wedge mirror rotation rate	2546	rpm
interferogram scan slow		
maximum wavenumber (Nyquist)	20	cm-1
sampling step	0.0125	cm
resolution	6	GHz
resolution	0.200	cm-1
number of frequency samples	100	
number of samples in double-sided interferogram	256	
time to complete an interferogram	6.032	s
interferograms per second	0.2	
mirror scan mechanism period	12.06	s
sky stability required for	6.03	s

Certainly Feasible

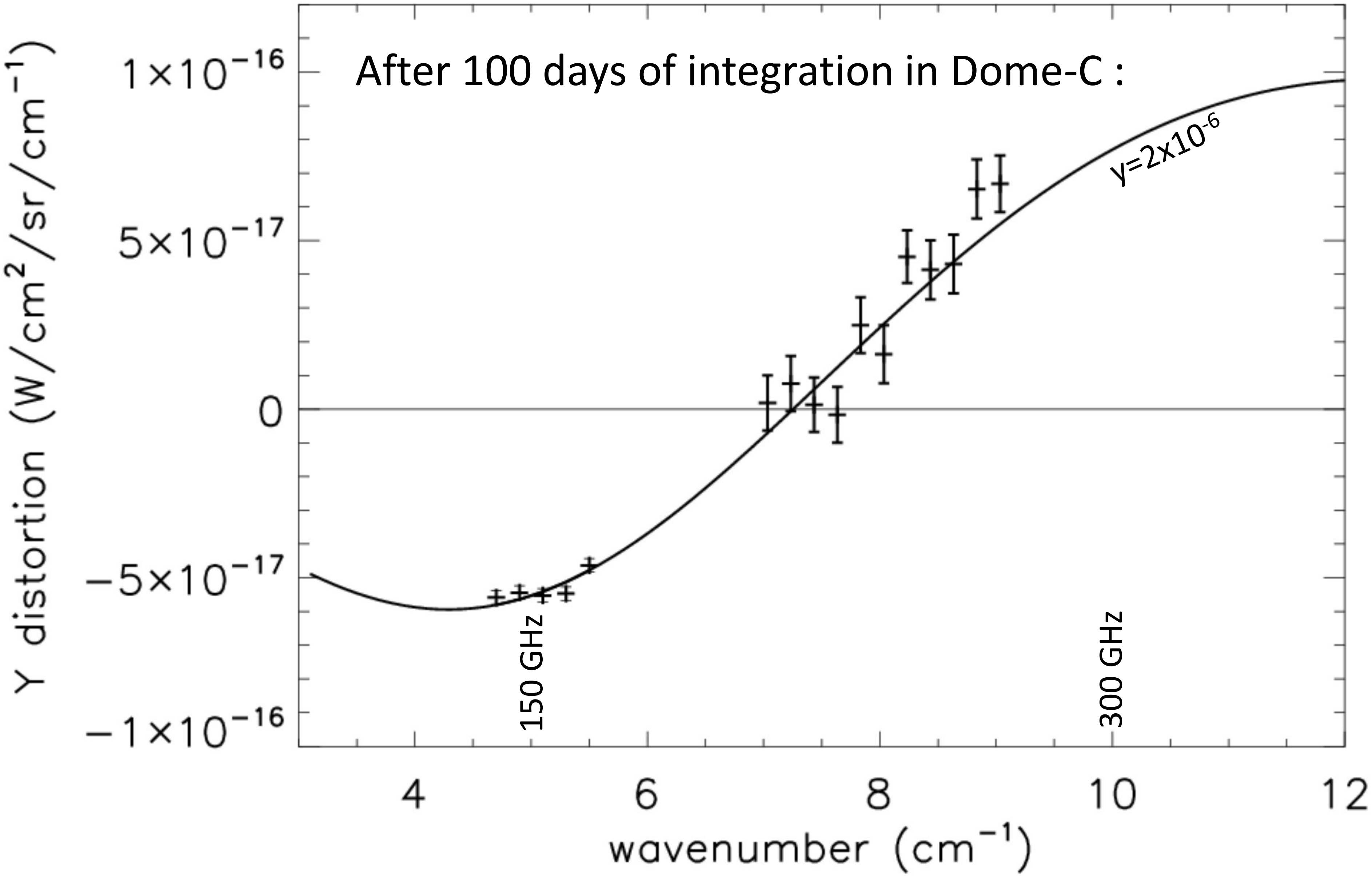
sky scan fast		
circle radius	5	deg
circle length	31.4	deg
beam size	0.5	deg
number of beams per circle	63	
time per beam	2.00E-04	s
time for 2 sky dips (downwards + upwards)	1.00E-01	s
wedge mirror rotation rate	600	rpm
interferogram scan slow		
maximum wavenumber (Nyquist)	20	cm-1
sampling step	0.0125	cm
resolution	6	GHz
resolution	0.200	cm-1
number of frequency samples	100	
number of samples in double-sided interferogram	256	
time to complete an interferogram	25.600	s
interferograms per second	0.0	
mirror scan mechanism period	51.20	s
sky stability required for	25.60	s

Coping with atmospheric emission



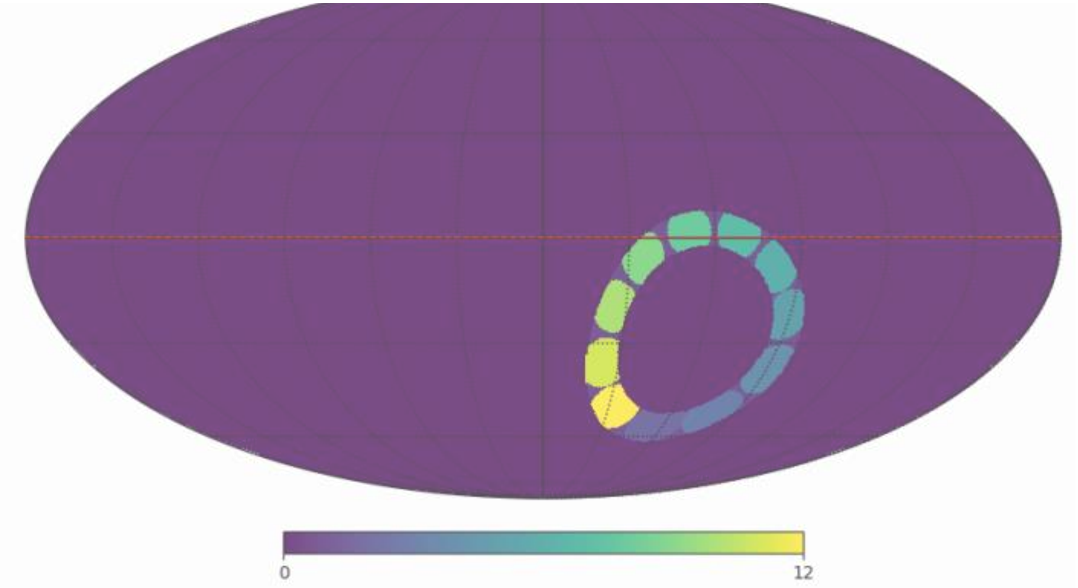
From the interferograms at different elevations, we retrieve the spectral brightness versus optical depth. Assuming a cosec(e) law we can extrapolate the sky brightness cleaned from atmospheric emission, for each frequency in the covered band.

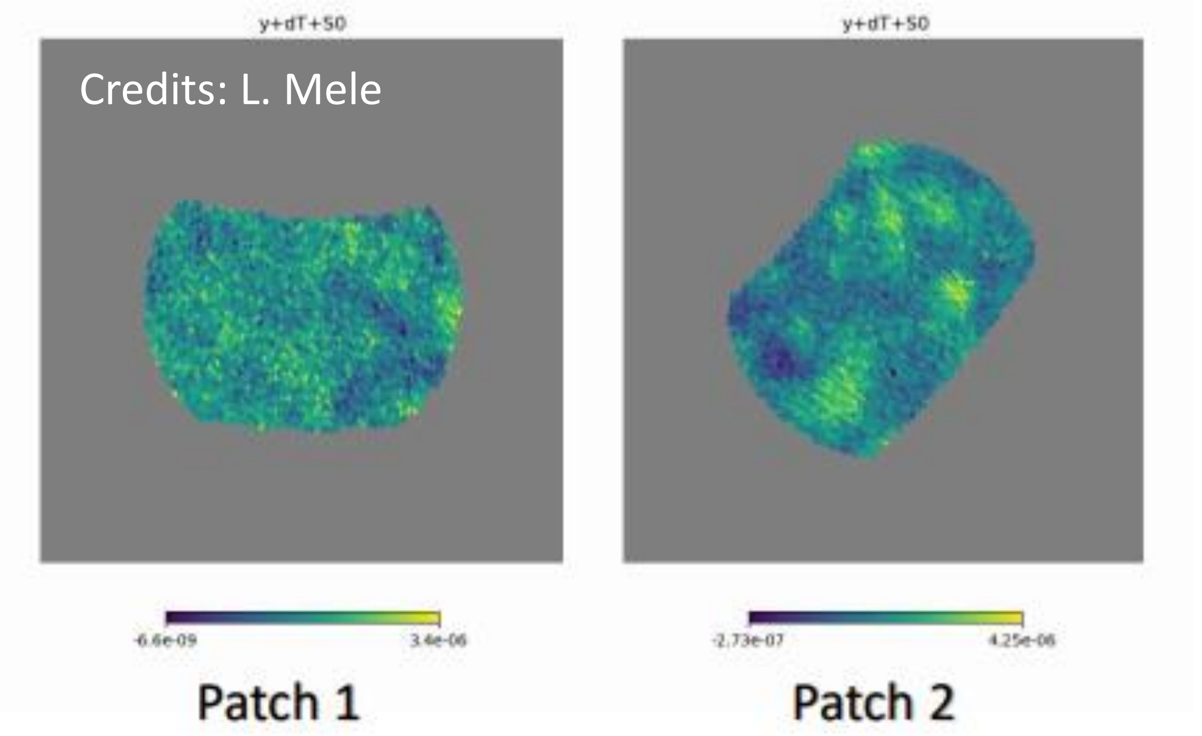
Simplistic Forecast

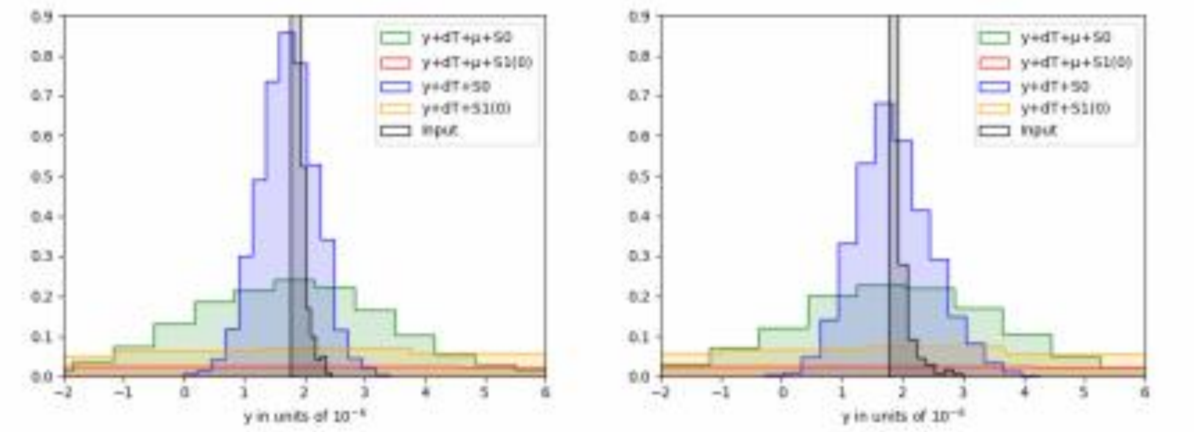


Performance Forecast

- Assuming photon noise limited performance, dominated by the atmospheric emission (AM model) and cryostat window (with $\varepsilon = 1\%$)
- Observing site: Dome-C. Daily coverage of 11 sky patches at high elevation, 100 days of integration.
- ILC-based simulations: COSMO can extract the isotropic comptonization parameter (assumed to be $y = 1.77 \cdot 10^{-6}$) as $y = (1.76 \pm 0.26) \cdot 10^{-6}$ in the presence of the main Galactic foreground (thermal dust) and of CMB anisotropy, and assuming perfect atmospheric emission removal (L. Mele)



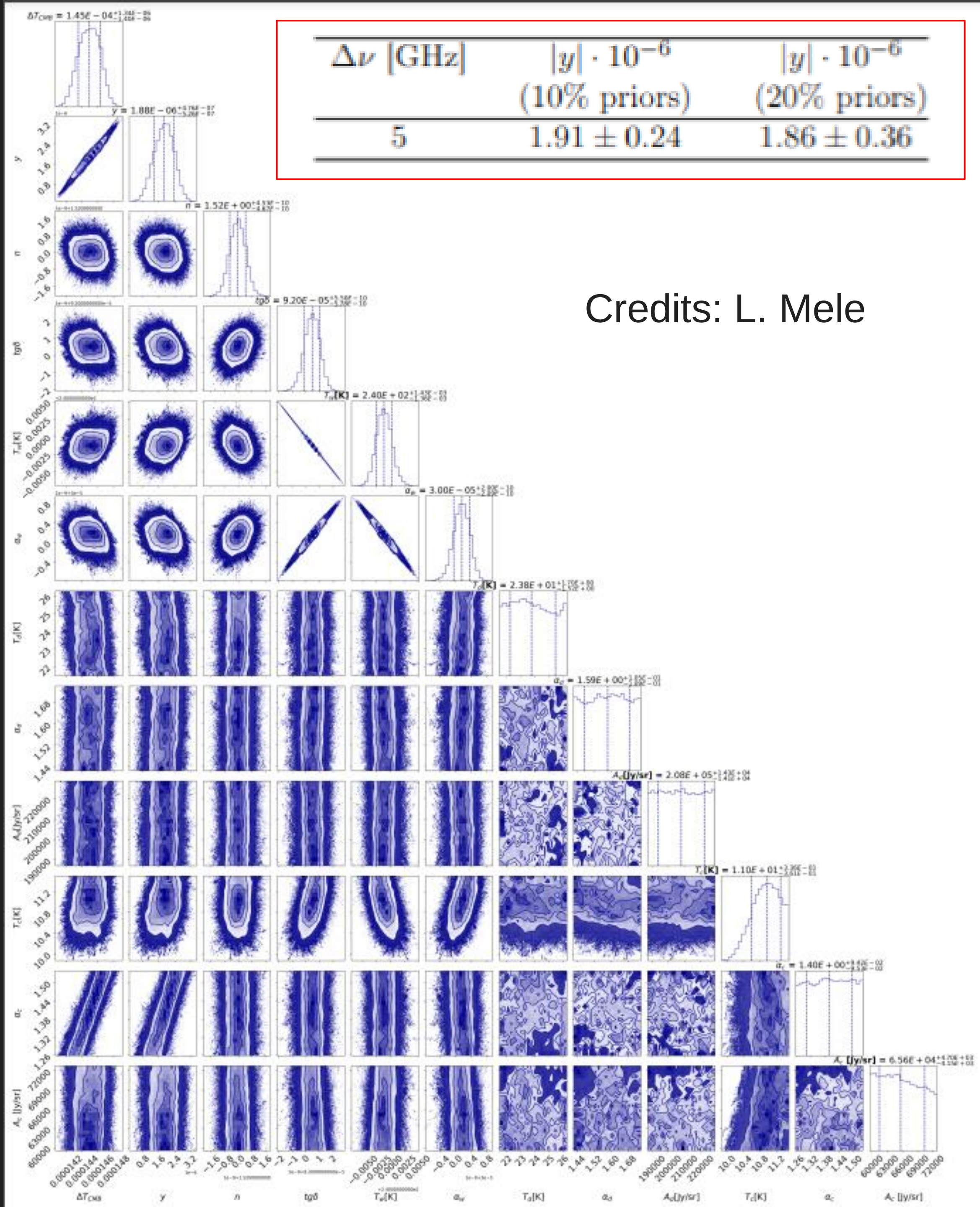




Simulations

- Monte Carlo Markov Chain (MCMC) fitting
- Photon noise limited performance (atmosphere + vacuum window)
- Separation from the Thermal dust emission from the Galaxy and the Cosmic Infrared Background (CIB) as the main foreground emissions
- Input distortion $|y| = 1.77 \cdot 10^{-6}$
- Different priors on foregrounds parameters
- Single sky-patches separation

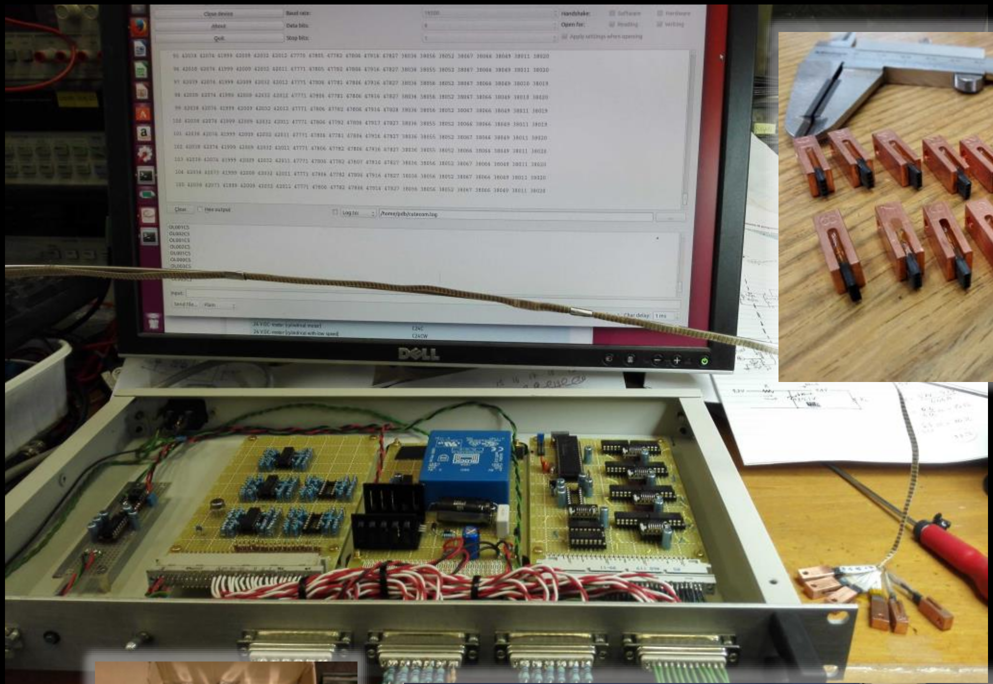
Sky patch #	$\lvert y\rvert \cdot 10^{-6}$ (10% priors on CIB and Dust)	$\lvert y\rvert \cdot 10^{-6}$ (20% priors on CIB and Dust)
1	1.96 ± 0.57	1.99 ± 0.88
2	1.88 ± 0.62	1.59 ± 0.83
3	2.16 ± 0.77	1.95 ± 0.87
4	2.19 ± 2.36	2.62 ± 1.87
5	2.56 ± 2.91	2.94 ± 2.26
6	2.98 ± 3.21	2.66 ± 2.45
7	3.68 ± 2.56	3.29 ± 2.28
8	2.04 ± 1.00	1.76 ± 1.28
9	1.86 ± 0.55	1.90 ± 0.88
10	1.84 ± 0.53	1.93 ± 0.97
11	1.88 ± 0.55	1.87 ± 0.90

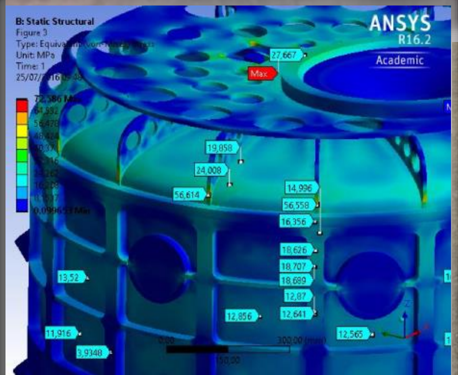


$\Delta\nu$ [GHz]	$\lvert y\rvert \cdot 10^{-6}$ (10% priors)	$\lvert y\rvert \cdot 10^{-6}$ (20% priors)
5	1.91 ± 0.24	1.86 ± 0.36

Credits: L. Mele

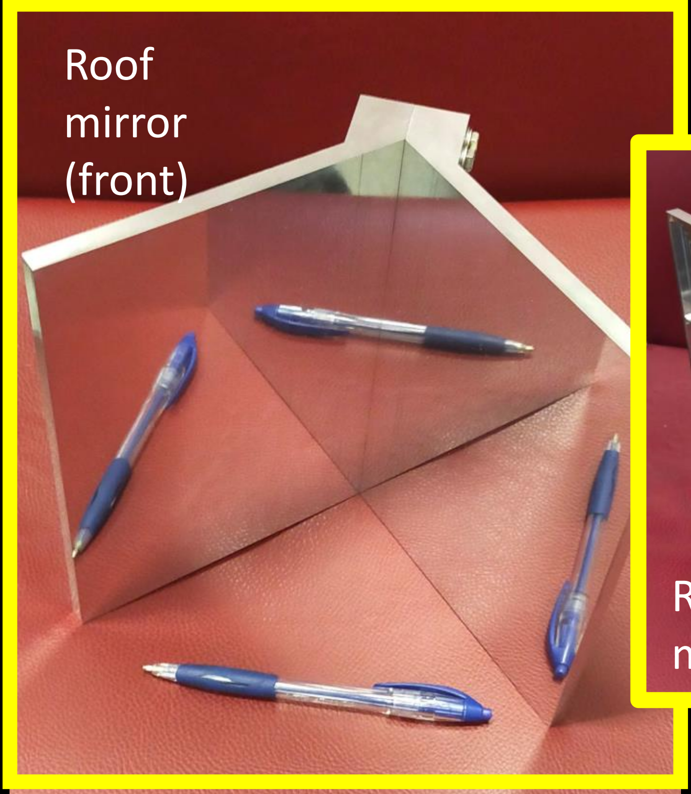
COSMO hardware

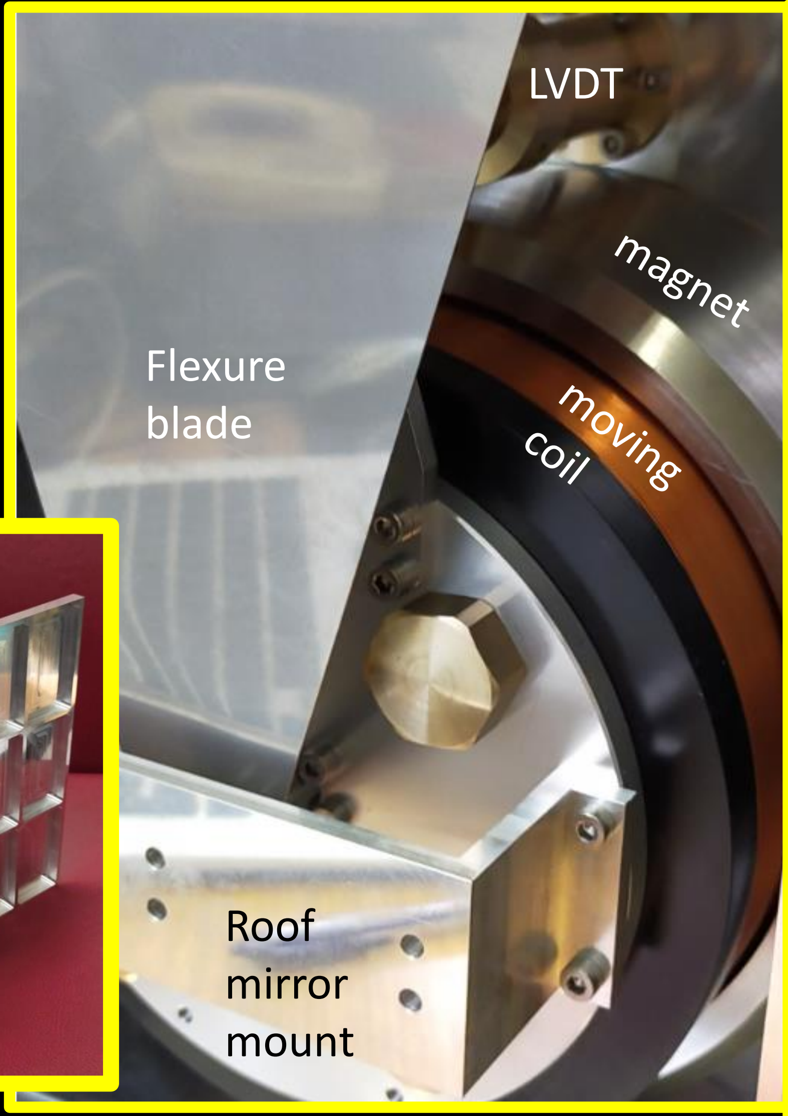


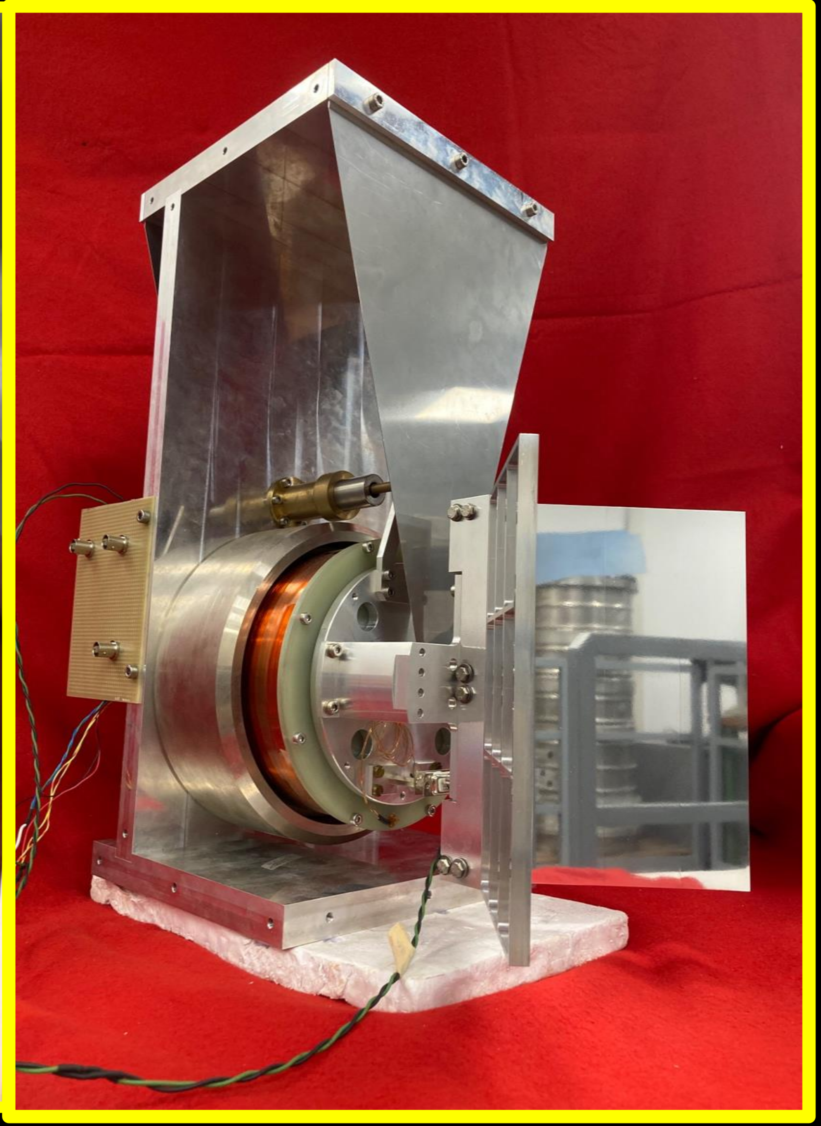


Variable Delay Line for the FTS

- Cryogenic operation – frictionless design to minimize heat load
- Based on a powerful voice coil with steel flexure blades support, to move one roof mirror. up to 0.2 cm/s.
- Voice coil delivered, assembly built.
- Eddy currents in moving coil support minimized by means of a dielectric coil support.
- Electronics developed (E. Marchitelli)

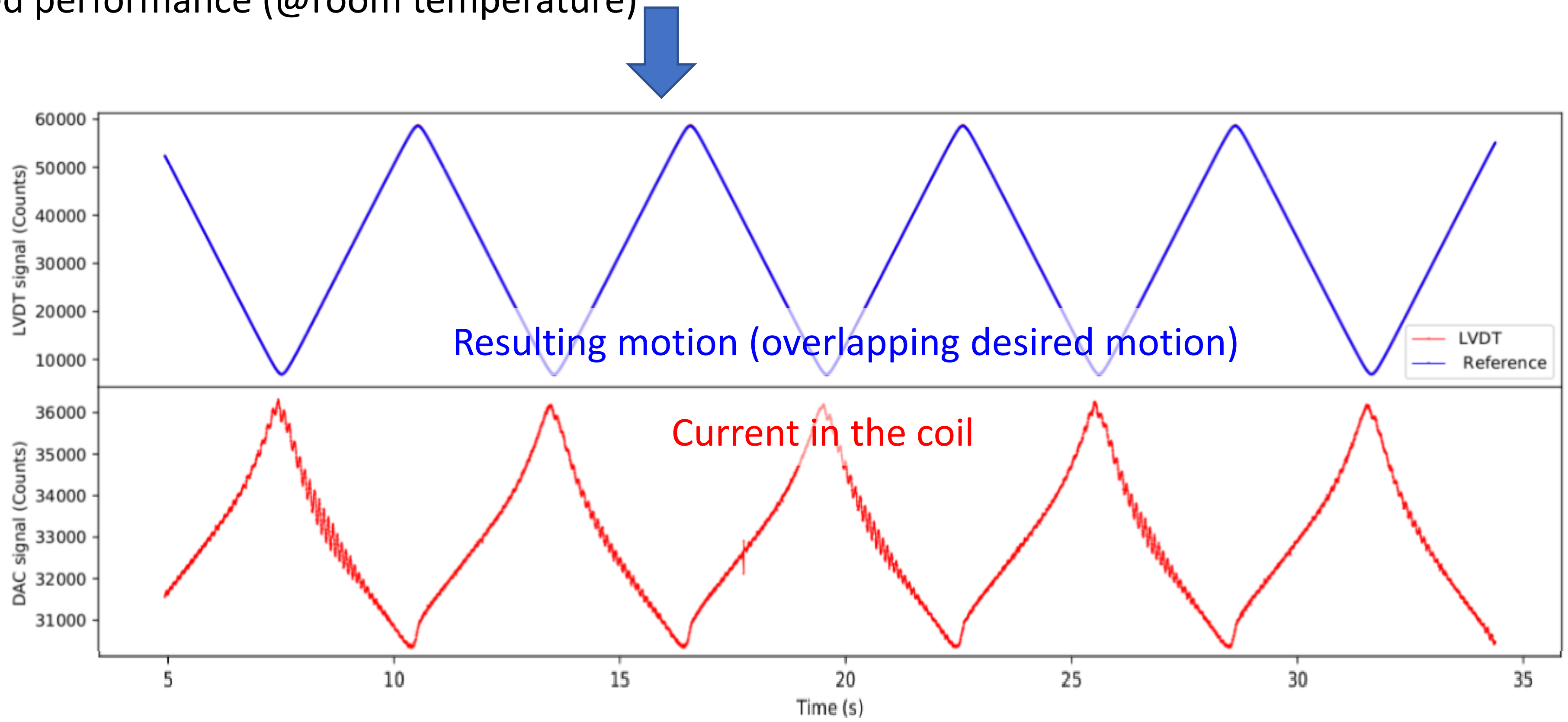






Cryogenic Roof Mirror Transport Mechanism

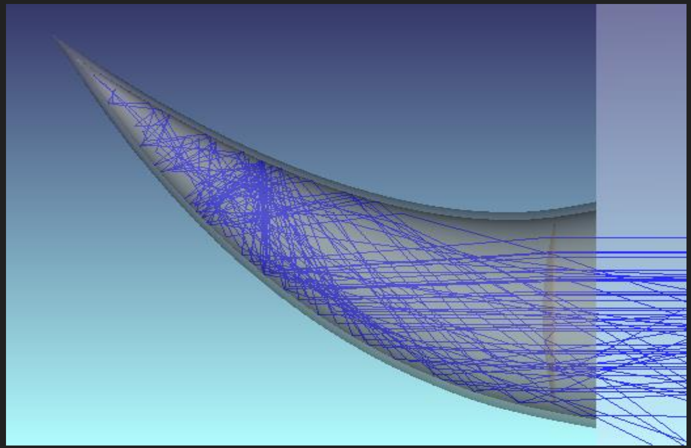
- Based on harmonic steel flexure blades supporting a large voice coil
- Drive electronics based on digital generator, DAC, current pump, coil, LVDT sensor, ADC, digital PID feedback loop.
- Auxiliary NIR FP interferometer for precision position readout (< 1 μm) procured.
- Measured performance (@room temperature)

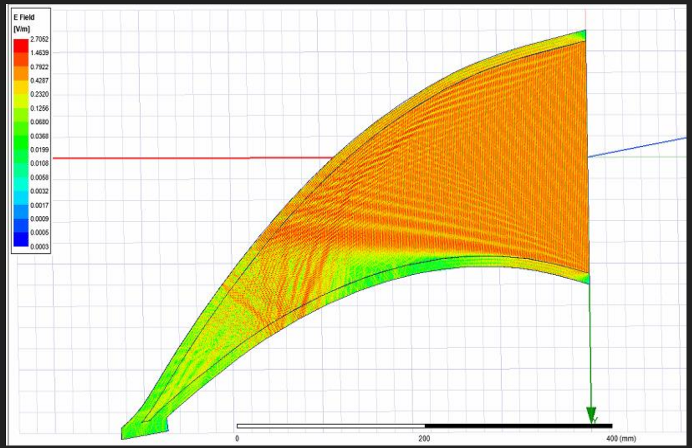


Credits: E. Marchitelli

Reference Blackbody

- A parabolic cavity providing an emissivity very close to unity
- Thermal gradients <1mK (FEM simulation in Comsol Multiphysics, assuming a single compact element)
- Ray-Tracing simulations have been performed to maximize of the # of reflections with the absorbing coating (Emerson & Cuming CR-110)
- HFSS simulations provide a residual reflectance of 1×10^{-6} @ 120 GHz
- A prototype of the calibrator has been assembled





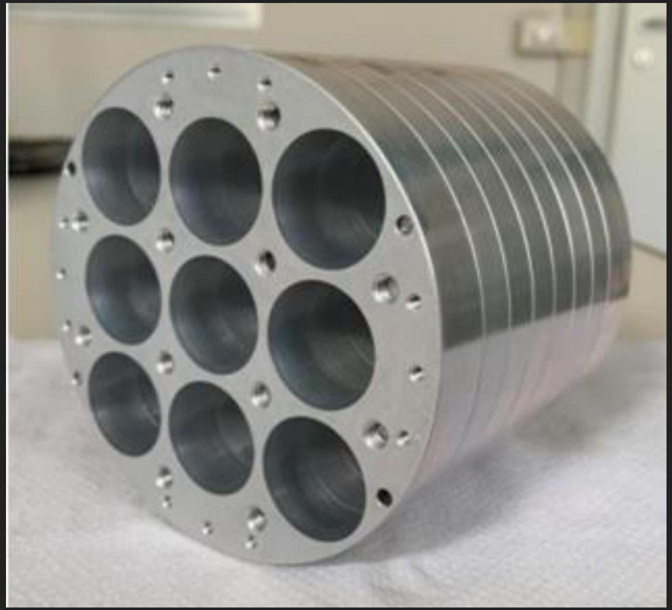
External Al mould

Teflon master mould to shape the absorbing coating

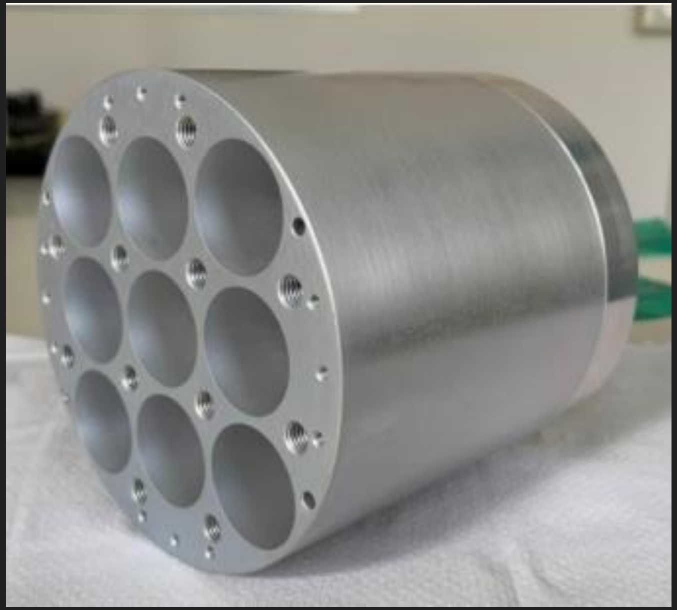
Credit: L.Mele

Feedhorns Arrays

- Multi-mode 3×3 horn antenna arrays feed the multimode KIDs arrays
- Each horn has a 24 mm aperture diameter and a waveguide diameter of 4.5 mm and 4.0 mm for the 150 GHz and the 220 GHz horn-arrays respectively
- The 150 GHz array is made of 7 platelets to build a Winston cone to model a parabolic internal profile
- The 220 GHz horn-array is made of a linear single profile
- Made of aluminum and machined through a CNC milling machine
- Electromagnetic simulations have been carried out to provide the expected performance. From 10 to 19 modes are included for the 150 GHz simulation, and from 23 to 42 modes are included in the 220 GHz simulation



E. Manzan, University of Milan

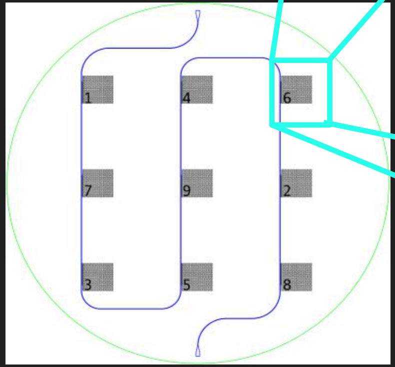


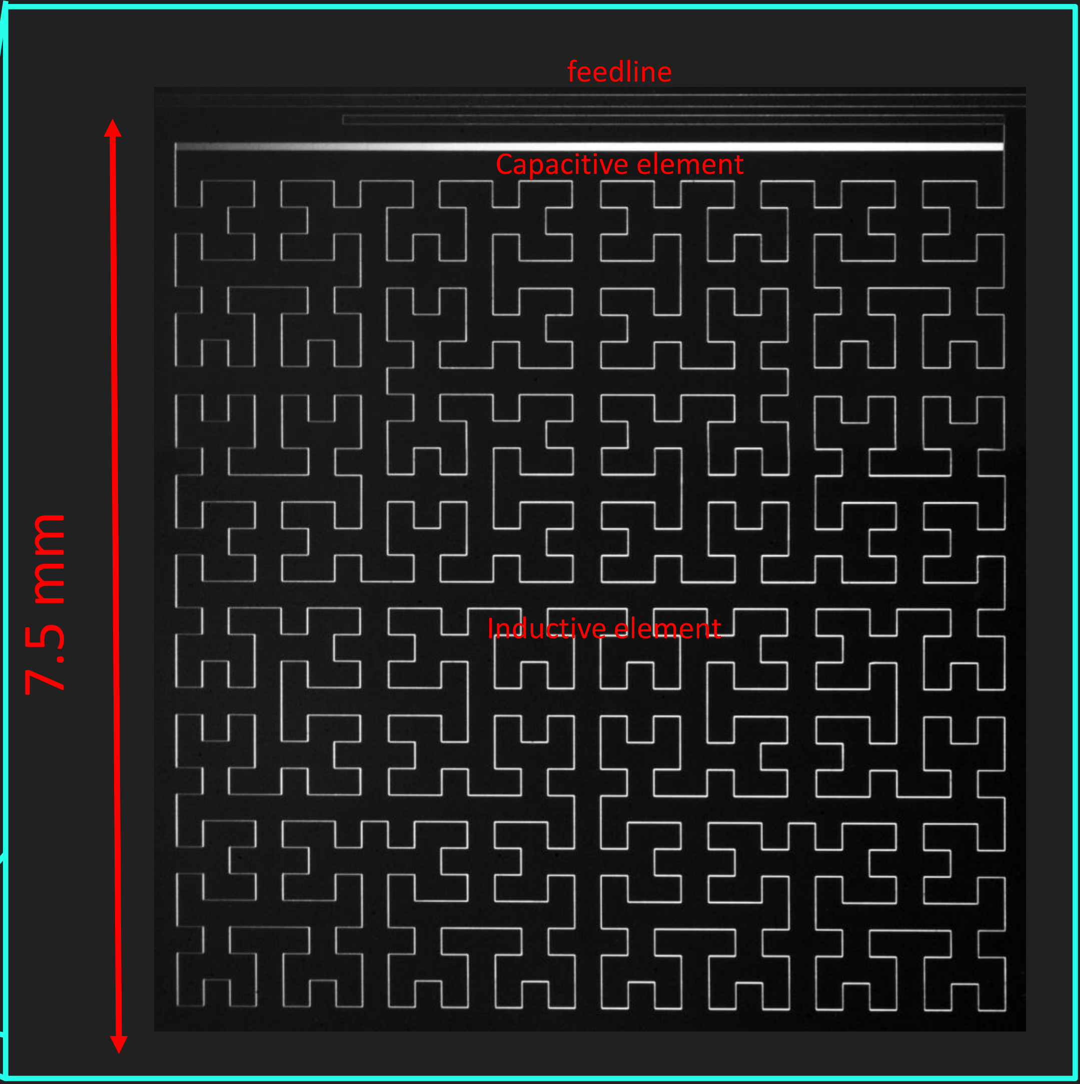
Kinetic Inductance Detector Arrays

- The throughput of the system, which includes the cryogenic differential MPI, is limited by the available room in the cryostat, and the angular resolution required by the measurement is modest (~1°)
- For these reasons the two focal planes, sensitive in the 150GHz and 250GHz bands, are filled with just 9 multimode feed-horns, each feeding one large Kinetic Inductance Detector (KID) fabricated with the same process developed for the OLIMPO ones (Paiella et al. 2019, Masi et al. 2019).
- Nine 7.5mm x 7.5mm pixels accommodated on a 4" Si wafer
- Photon noise limited performance, (scales as $N_{modes}^{1/2}$)
- 150GHz prototype currently under test

Index	n_c	C [pF]	ν_r [MHz]	Q_c
1	16	6.80	85.1	13 700
2	15	6.35	88.1	12 400
3	14	5.89	91.4	11 100
4	13	5.44	95.1	9800
5	12	4.99	99.4	8600
6	11	4.53	104.2	7500
7	10	4.08	109.9	6400
8	9	3.63	116.5	5300
9	8	3.17	124.6	4400

Low resonance frequencies to cope with lumped condition

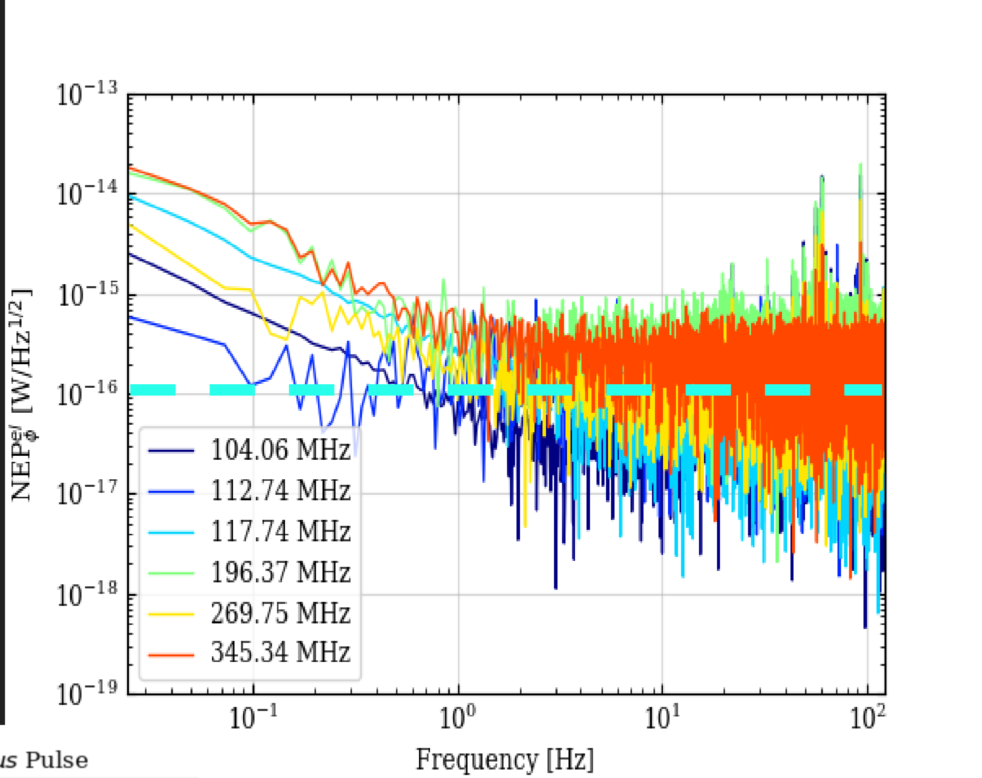


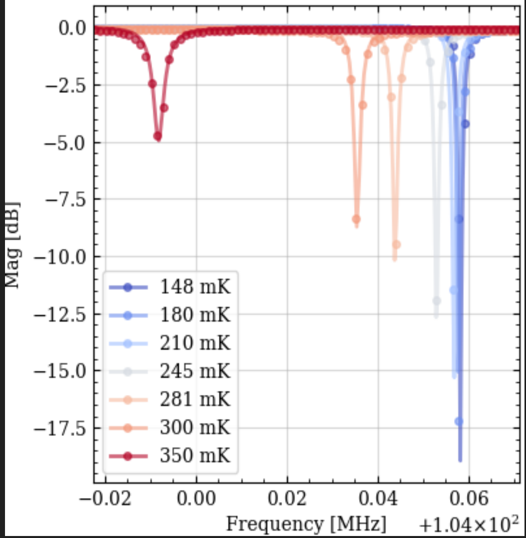


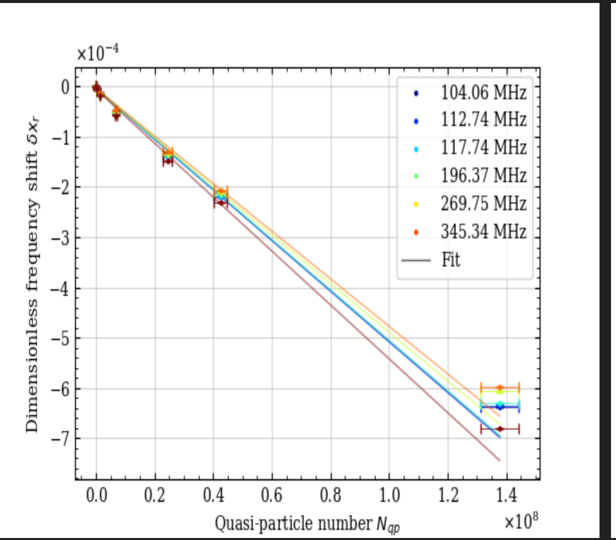
A. Credits: A. Paiella, F. Cacciotti, G. Isopi, E. Marchitelli (Sapienza) G. Pettinari (IFN-CNR)

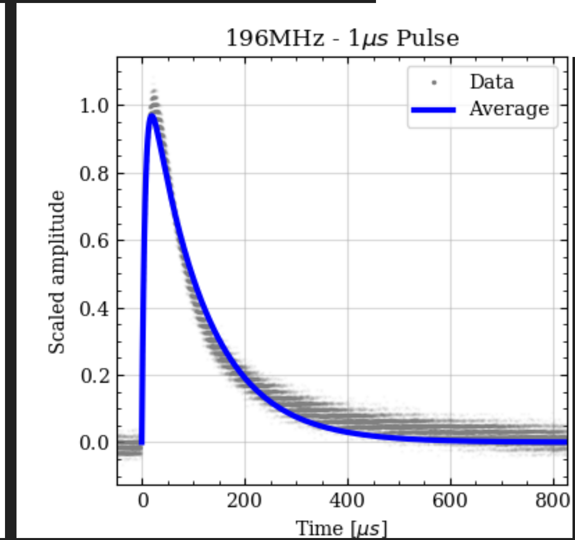
Kinetic Inductance Detector Arrays

- The throughput of the system, which includes the cryogenic differential MPI, is limited by the available room in the cryostat, and the angular resolution required by the measurement is modest (~1°)
- For these reasons the two focal planes, sensitive in the 150GHz and 250GHz bands, are filled with just 9 multimode feed-horns, each feeding one large Kinetic Inductance Detector (KID) fabricated with the same process developed for the OLIMPO ones (Paiella et al. 2019, Masi et al. 2019).
- Nine 7.5mm x 7.5mm pixels accommodated on a 4" Si wafer
- Photon noise limited performance, (scales as $N_{modes}^{1/2}$)
- 150GHz prototype currently under test







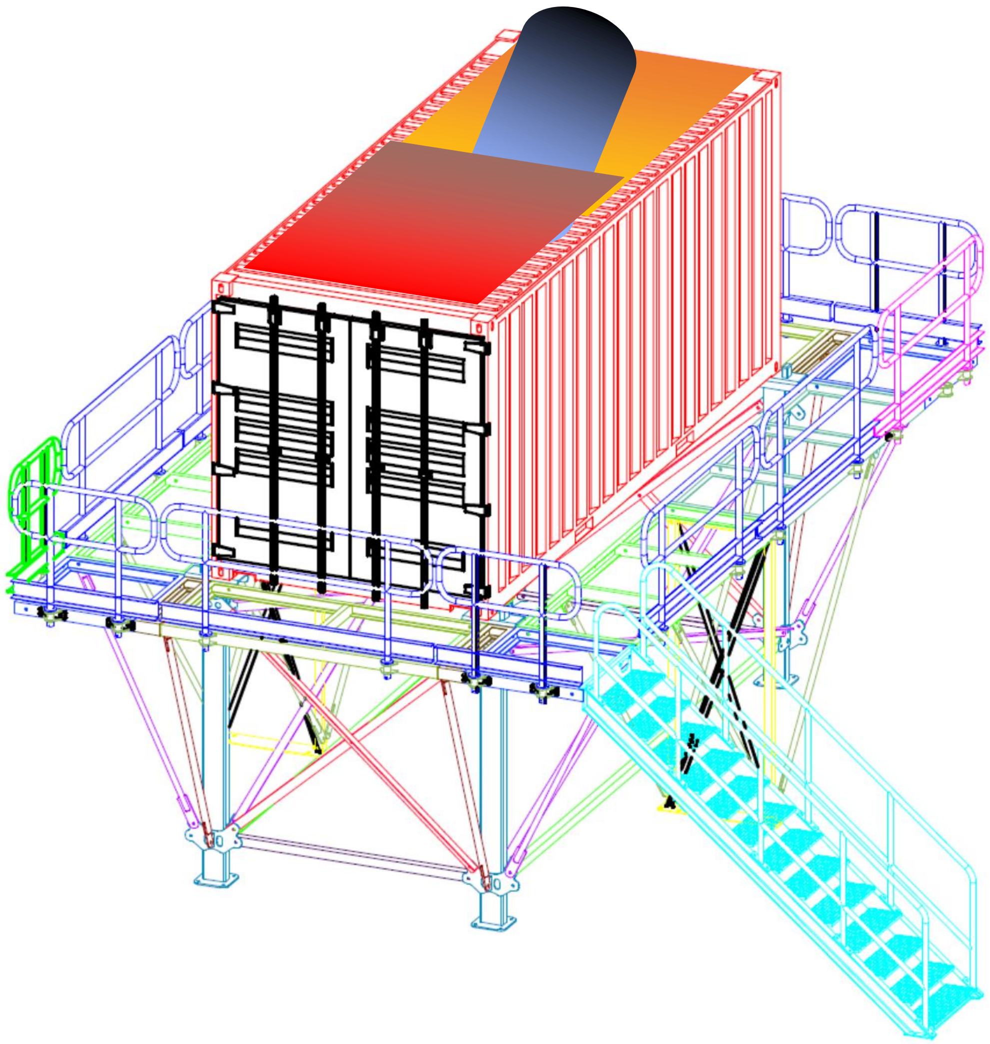


- Non-linearities and harmonics present, due to lumped condition not perfectly met.
- Average performance close or better than photon noise limit (depending on chosen resonance)

Readout Electronics :

hear Mario Zannoni in a while.

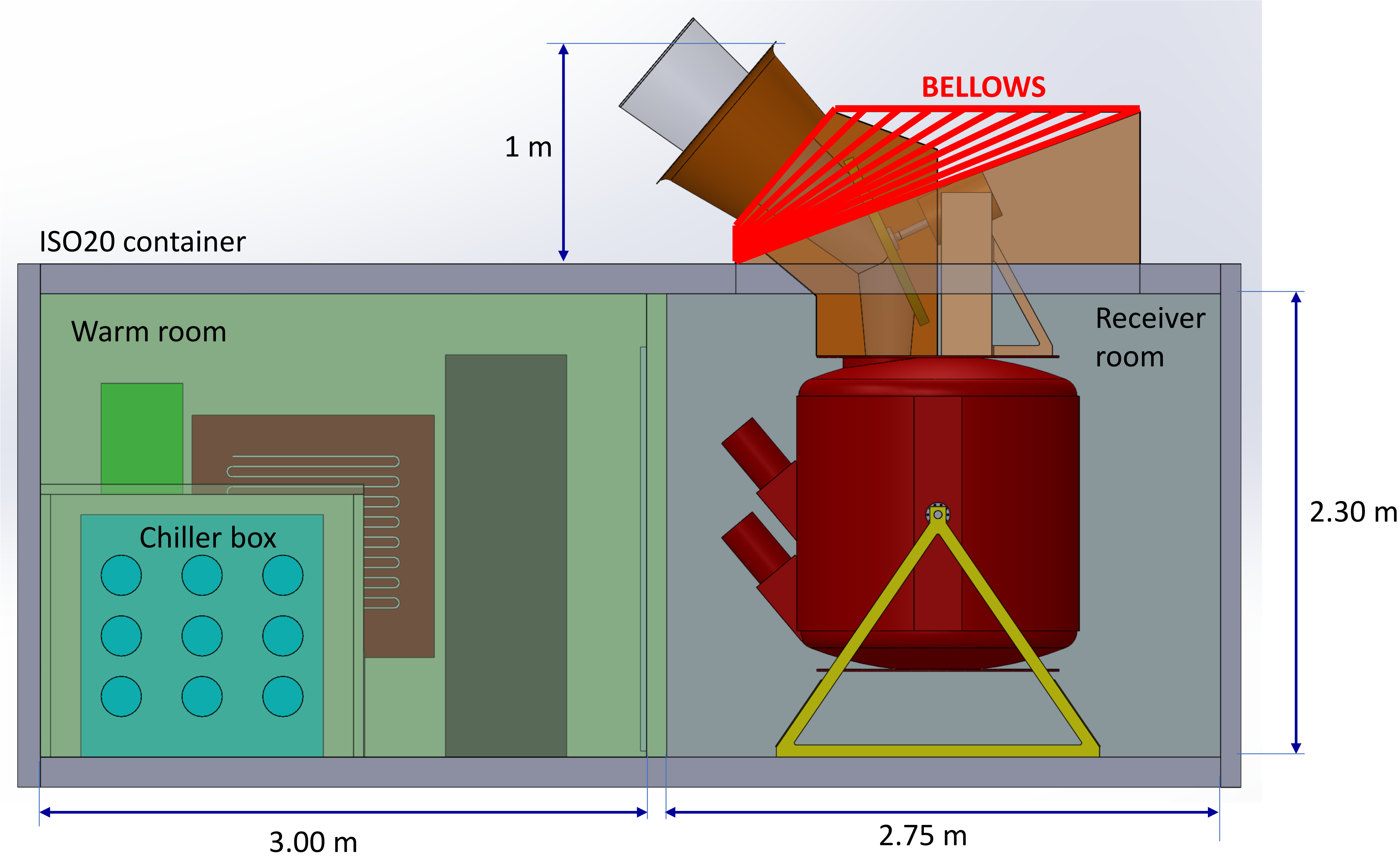
COSMO on-site implementation



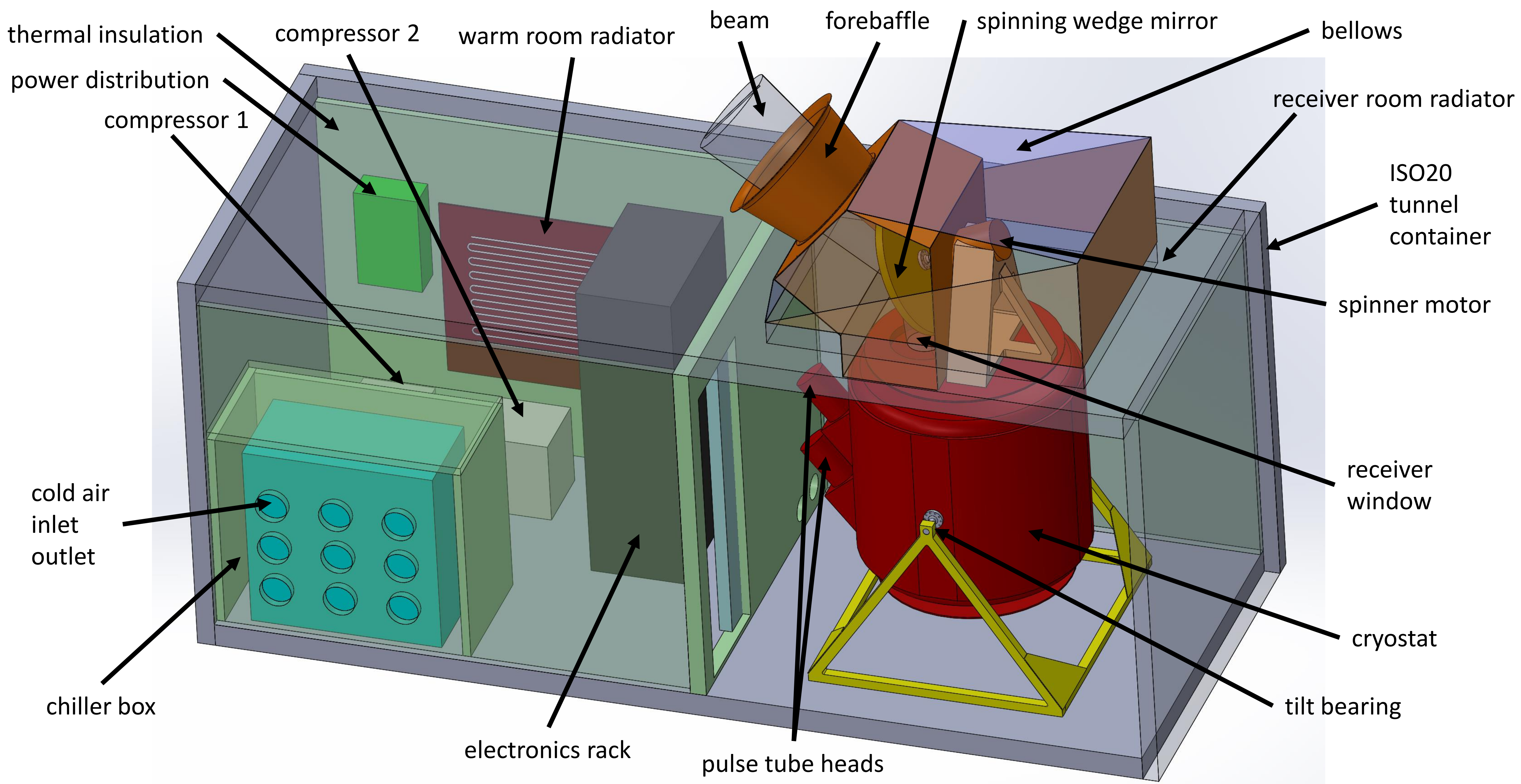
Thanks to Gianluca Bianchi-Fasani for palafitte dwg.

- Experiment in a thermally insulated container
- Warm section with electronics and compressors.
- Cold section with receiver. No window. Shields.
- The same container used for tests and shipment
- Palafitte as usual in Dome-C (e.g. superDARN)
- Installation site: near astronomy lab
- Energy needed: 20 kW for 100 days

COSMO on-site implementation – main concept

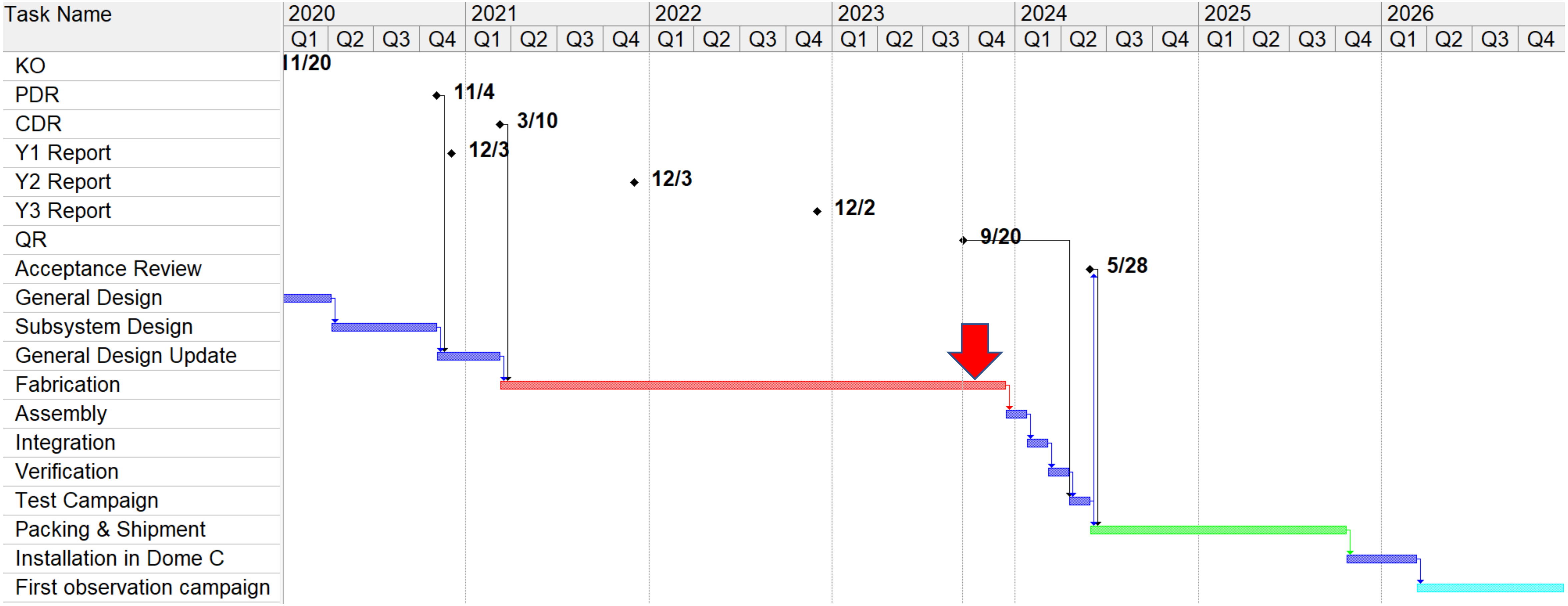


COSMO on-site implementation – location of main components

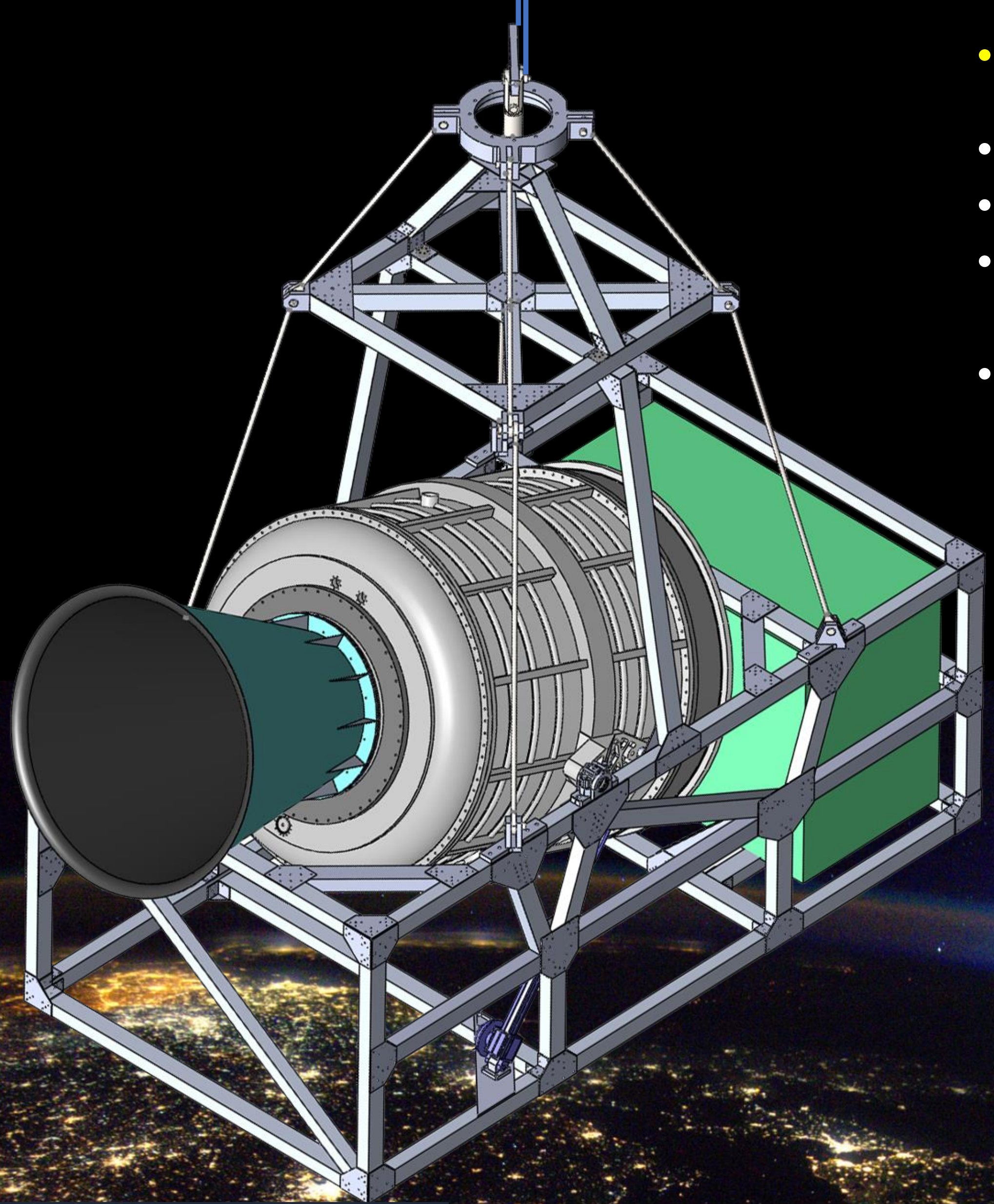


COSMO - Top Level Schedule

- We are currently near the end of the subsystems fabrication phase.
- In the current schedule, the first Antarctic winter observation campaign in Dome-C will be in 2026

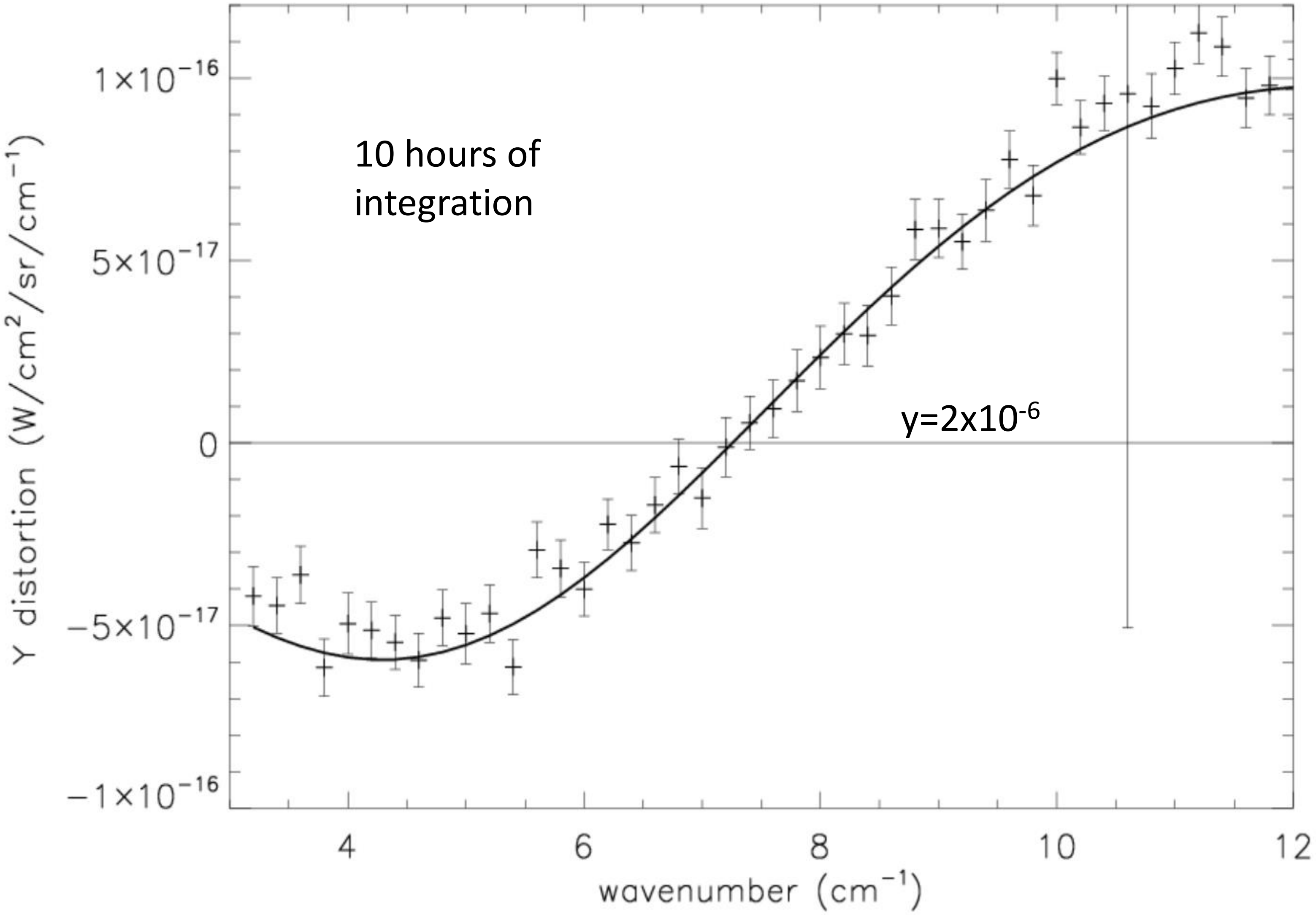


The future of COSMO: a balloon-borne instrument



- **Reuse of LSPE** LDB payload
  http://planck.roma1.infn.it/LSPE
- Works in the polar night
- Suitable cryogenic system
- Possible to add (slower ?) sky modulator, if needed
- Might gain a factor 10.

The future of COSMO: a balloon-borne instrument



Feasibility study carried out with ASI – COSMOS project.
Synergic effort in France (BISOU, see B. Maffei talk)

Cosmic Orbital and Suborbital Microwave ObservationS

Agenzia Spaziale Italiana

Conclusions

- COSMO is a first attempt to measure the spectral distortions of the CMB monopole from the ground.
- It beats atmospheric noise and measures atmospheric emission using fast modulation and detectors.
- If this strategy is effective, the sensitivity is enough to measure the largest spectral distortion, arising from comptonization at recombination / reionization / ionized baryons in the universe.
- It paves the way to more accurate measurements with the same approach, to be carried out with COSMO on a stratospheric balloon (see also the synergic proposal BISOU)
- Synergic to low-frequency *monopole* spectral distortion measurements (e.g. The Tenerife Microwave Spectrometer (TMS) and the Array of Precision Spectrometers for the Epoch of RecombinAtion (APSERa) to enter the detection era of SD.