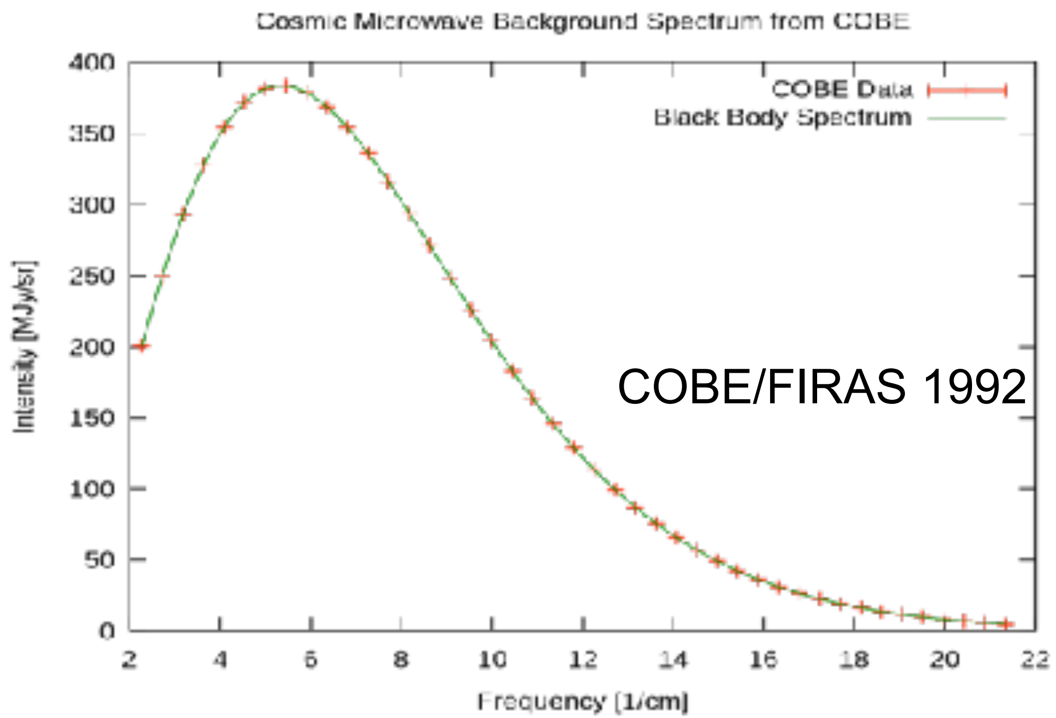
BISOU
A balloon project to measure the CMB spectral distortions

B. Maffei for the BISOU collaboration

CMB-France – Nov 2021

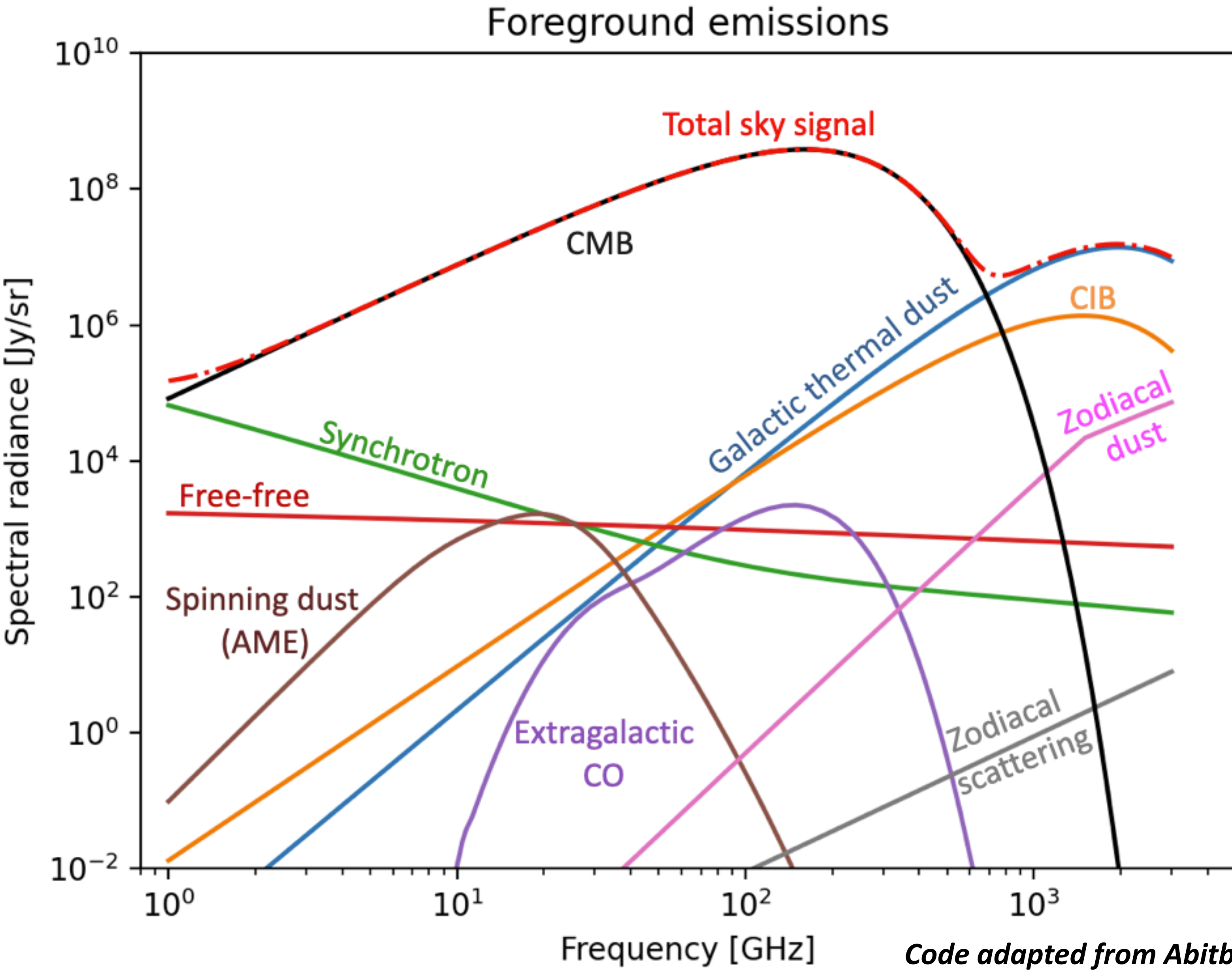
Introduction



- Last measurements of the CMB spectrum: 1992
- Spectral distortions →
  - **Thermal history of the Universe** from inflation to the formation of first stars & galaxies
  - High-redshift, optically thick → chemical potential μ-type distortions
  - Low-redshift, optically thin → Compton interaction y-type distortions (Sunyaev-Zeldovich SZ effect)

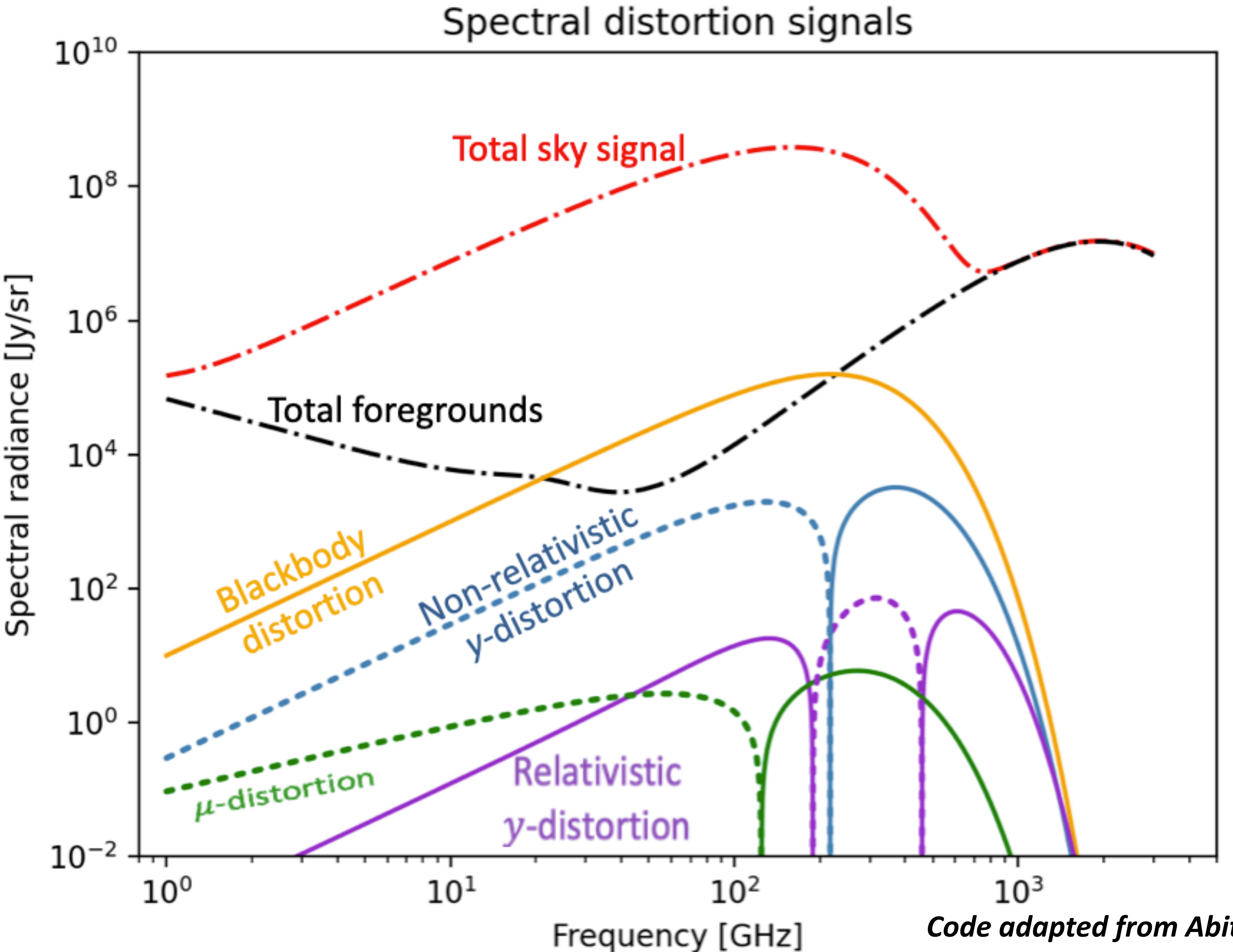
See previous talks

Model of CMB and foreground emissions



Code adapted from Abitbol et al, 2017
See talk by X. Coulon

Estimated emissions of spectral distortions



Code adapted from Abitbol et al, 2017
See talk by X. Coulon

Status of projects for spectral distortions science

- Space missions have been proposed but not selected
  - PIXIE (A. Kogut et al, 2017): NASA medium mission
  - PRISTINE (N. Aghanim et al, 2018): ESA F-mission
- ESA Voyage 2050 (Large missions)
  - White papers: J. Chluba et al, J. Delabrouille et al
  - "New physical probes of the early Universe" and high precision spectroscopy of CMB in particular as one of the 3 chosen themes
- New US Decadal: not really mentioned
- Scope for a pathfinder
  - To improve the maturity of the instrument concept
  - To get a possible detection of y-parameter + "secondary" science
  - To get a better understanding of the associated systematics
- Attempts from the ground:
  - KISS: 80-300 GHz FTS dedicated to S-Z observations (***A. Fasano et al, 2020***)
  - COSMO: 120 - 300 GHz FTS at Dome C (***S. Masi et al, 2021***)
  - TMS: 10-20 GHz Tenerife Microwave Spectrometer ***(J.A. Rubiño Martin)***

➡ **What could be done from a balloon platform?: CNES Phase0**

BISOU

Balloon **I**nterferometer for **S**pectral **O**bservations of the **U**niverse

- Feasibility study of a balloon project (Phase 0):
  - Defining the needs in order to get ***at least*** the following science goals:
    - A detection of the y-type distortions
    - Measurement of the Cosmic Infrared Background
    - Improvement of dust emission knowledge → inputs for future CMB projects
  - Adapting and optimising the instrument concept for a balloon platform
  - Prepare a proposal for a Phase A detailed study

Present Consortium

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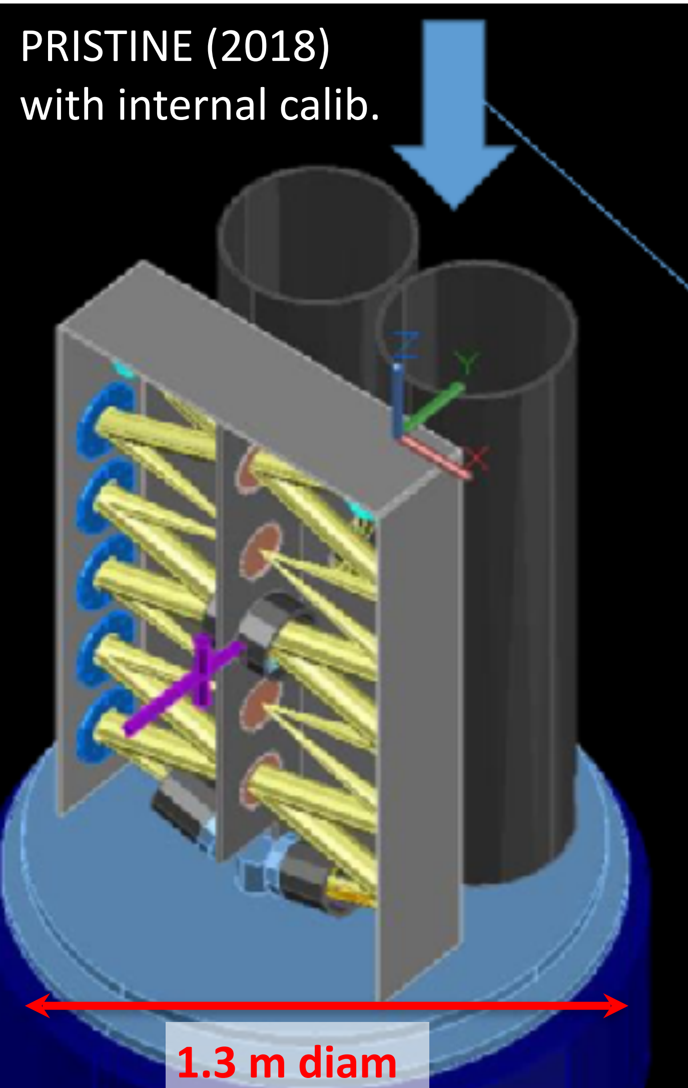
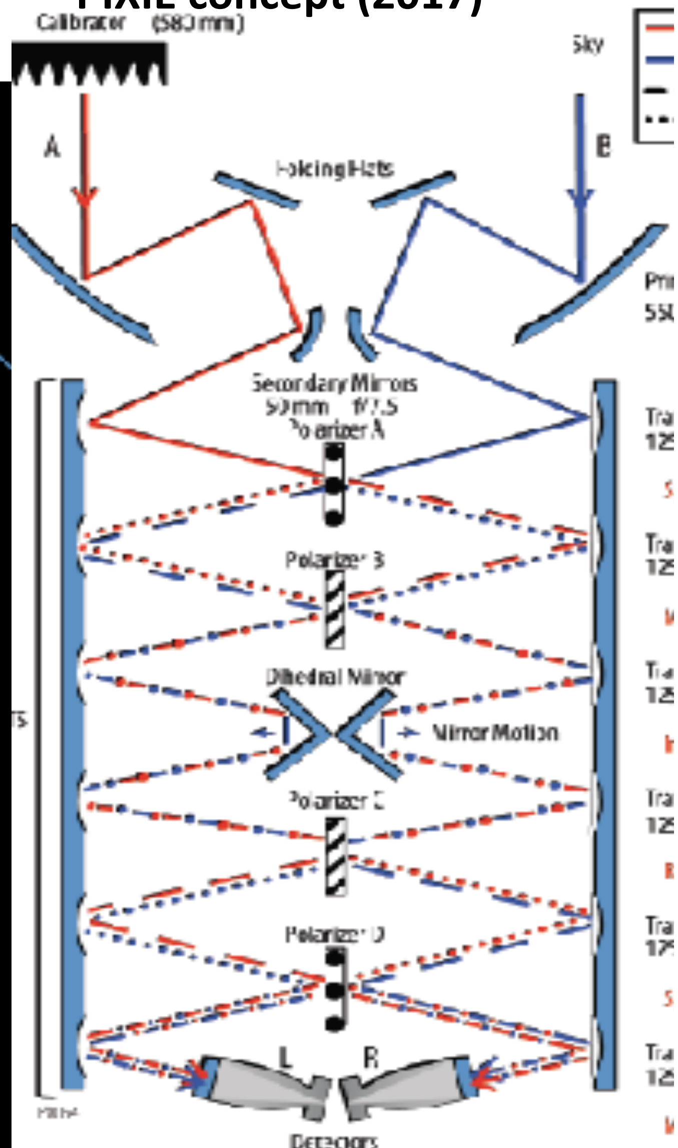
Original concept: PRISTINE / PIXIE



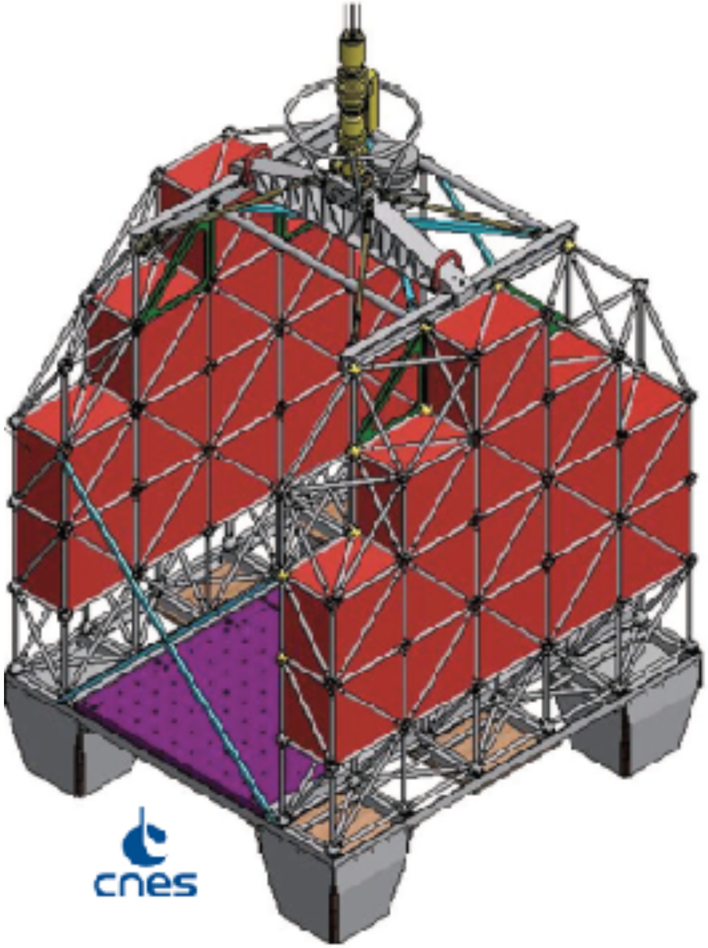
PIXIE concept (2017)



Absolute spectrometers

- FTS
- Two inputs
- Two outputs (Pol)
- Several observation modes
- Need for a cold calibrator
- 60 GHz to 2 / 6THz
- 15 GHz bandwidth
- 100 mK detectors

CNES "CARMEN" gondola



Balloon project constraints

CARMEN Gondola

Overall max mass at take-off: 1030 kg

Gondola mass without equipment nor crash pads: 275 kg.

- ➢ Mass available for payload : 755kg
- ➢ Including instrument, crash pads, ballast, stellar sensor, power (batteries and solar panels), etc…

Max volume for payload ~ 0.9m x 1.8m x 1.6 m

Exemple of CARMEN gondola use: PILOT project

(credits PILOT consortium)

Other constraints vs space include:

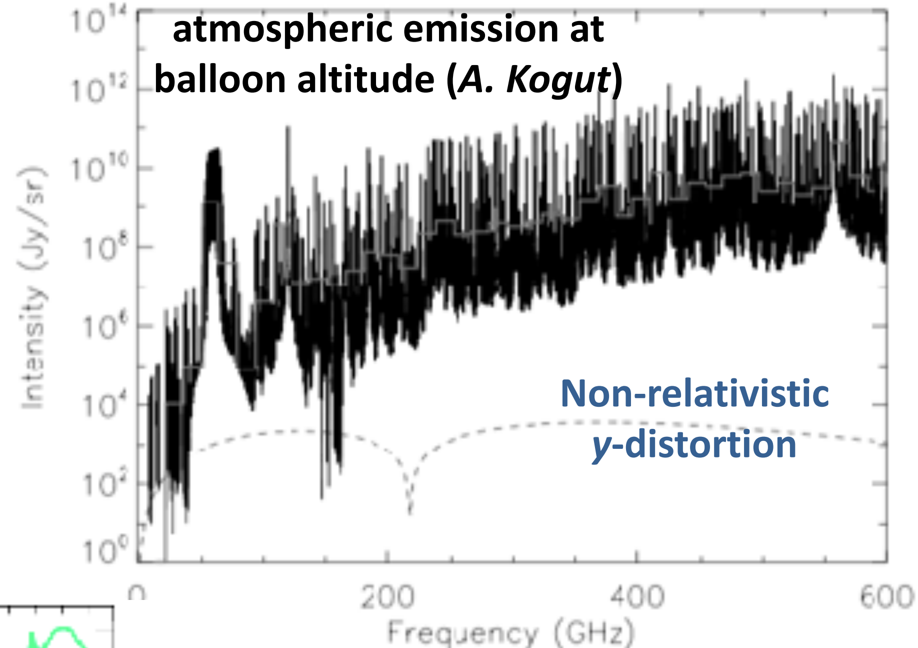
- Limited flight time: up to 5 days (CNES)
- Residual atmosphere:
- Different thermal and straylight environment
- Need for additional spectral filters and window
  - → higher background on detectors

Preliminary Concept considerations

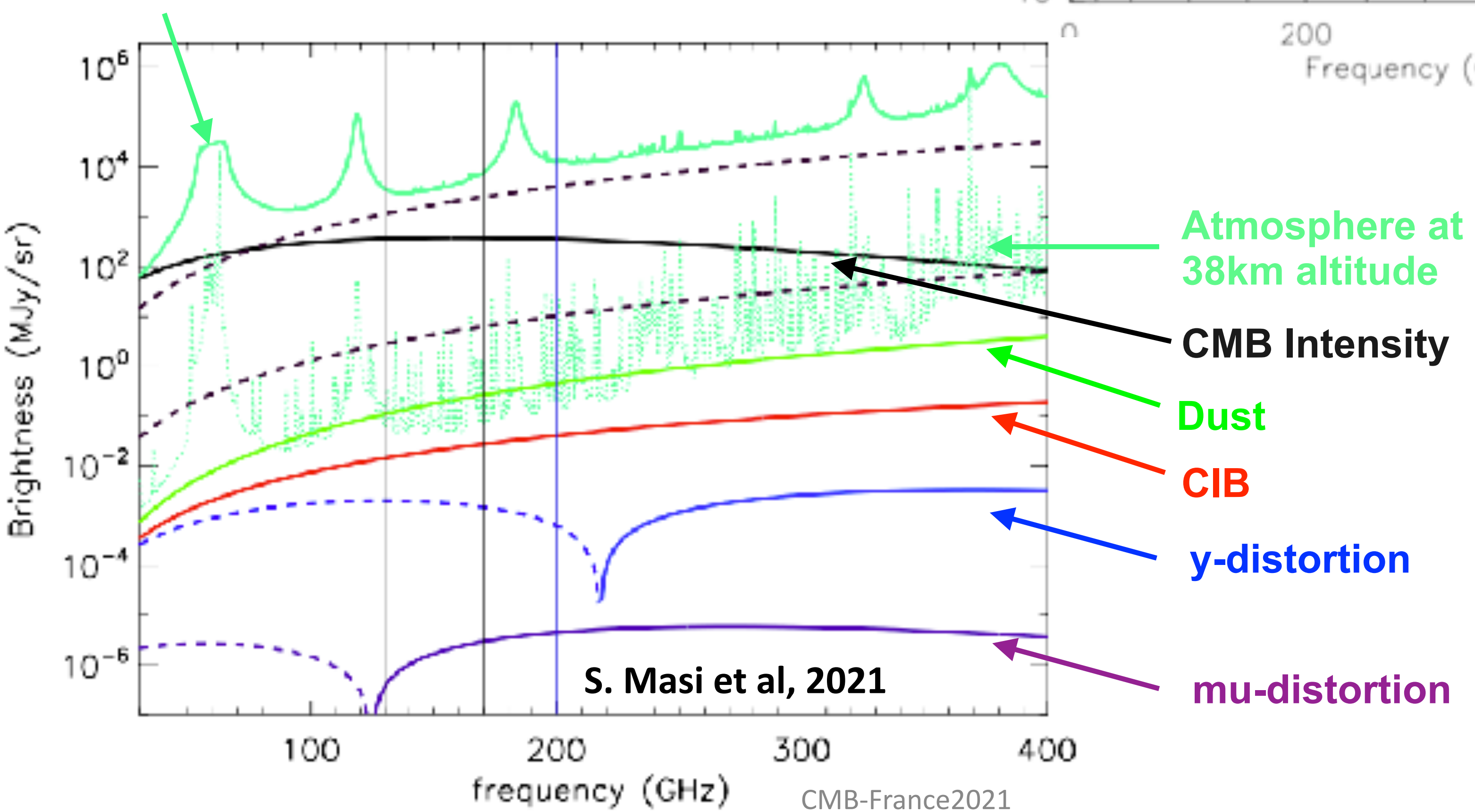
- Focus on spectral distortions
- Simplifying the design ***whenever*** possible
  - Due to mass and volume restriction: will stick to one full cold telescope if possible (while assessing systematics)
  - Internal fixed calibrator
- Sensitivity calculations assume a 5-day flight at an altitude of 38 – 40 kms.
- While most of the parameters are being explored
  - Some are more important (Freq. range for instance)
  - Others can be fixed to start with (spatial and spectral resolutions)
  - dnu=15 GHz, FWHM of the order of 1.5deg
- Need to assess the impact of elements that are specific of balloon:
  - i.e. residual atmosphere, higher background on detectors

The atmosphere

Atmosphere simulations with ***am*** Atmospheric Model
(S. Paine - https://lweb.cfa.harvard.edu/~spaine/am/)

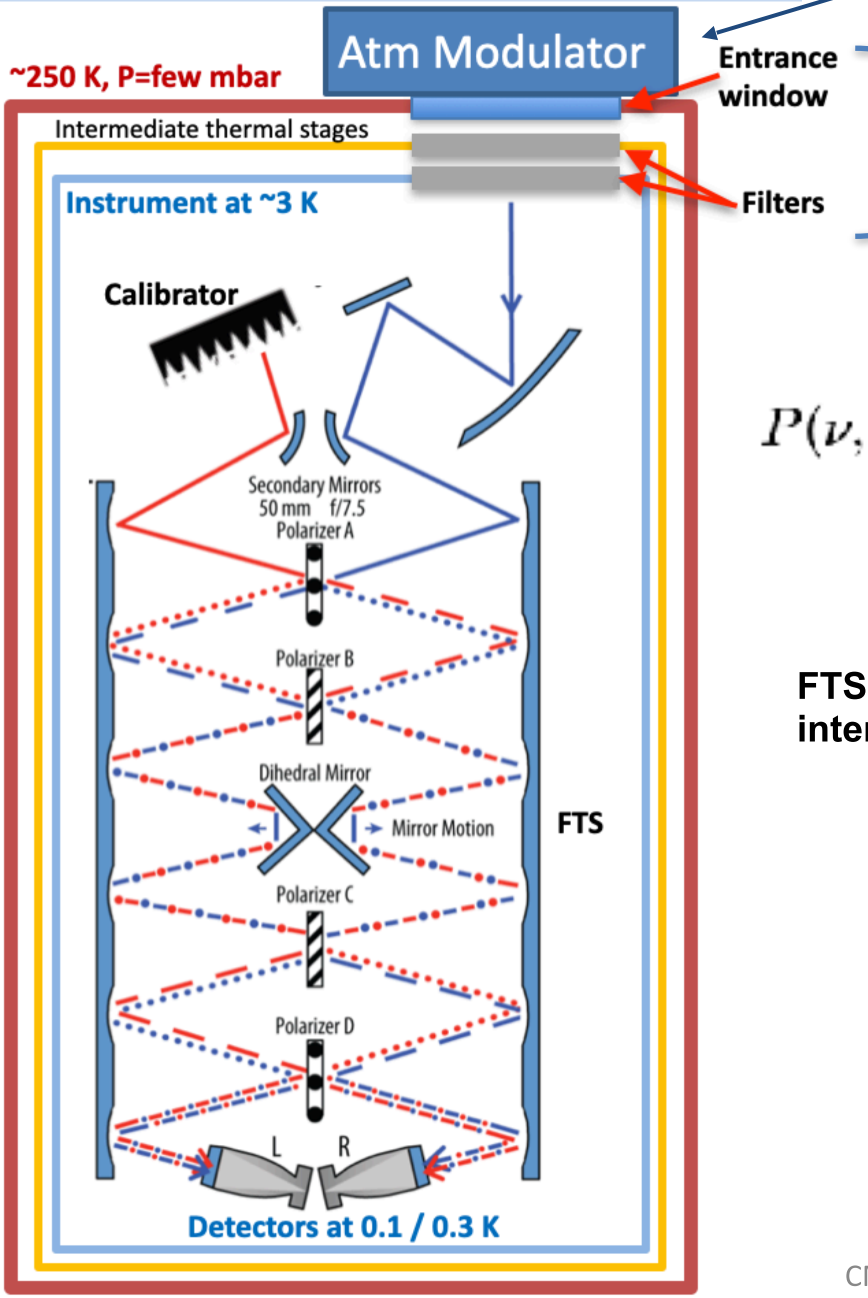


Atmosphere at Dome C



Preliminary concept

Addition of ***atmosphere modulator*** to remove effects (but not background)

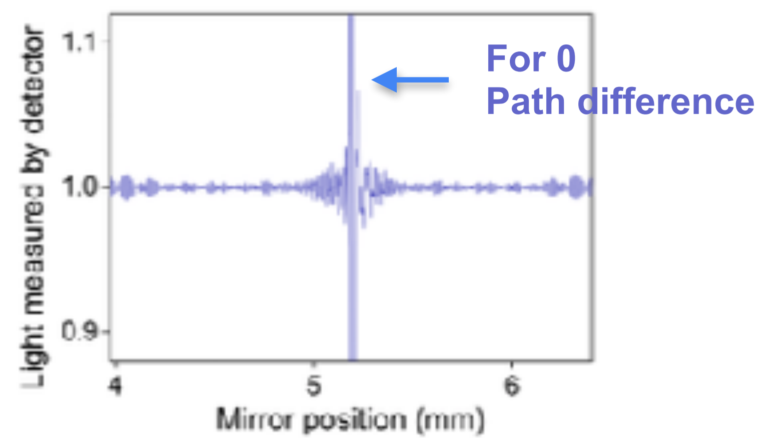


Window and filters:
Extra components vs space mission

For each signal (astro and instrument)

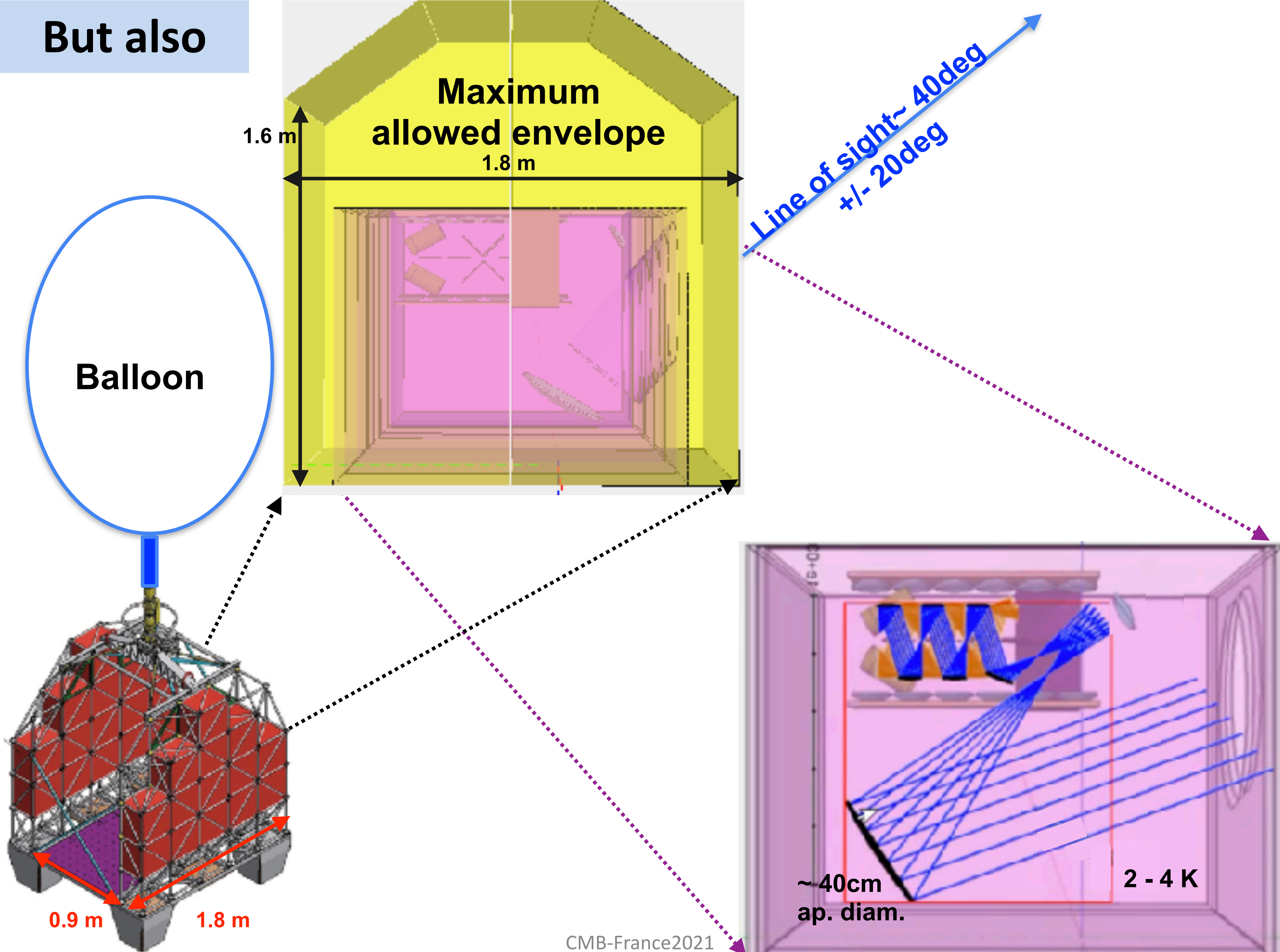
$$P(\nu,T) = \int_{\nu_{min}}^{\nu_{max}} eff(\nu) A\Omega(\nu)\epsilon(\nu,T)B(\nu,T)d\nu$$

FTS interferogramme



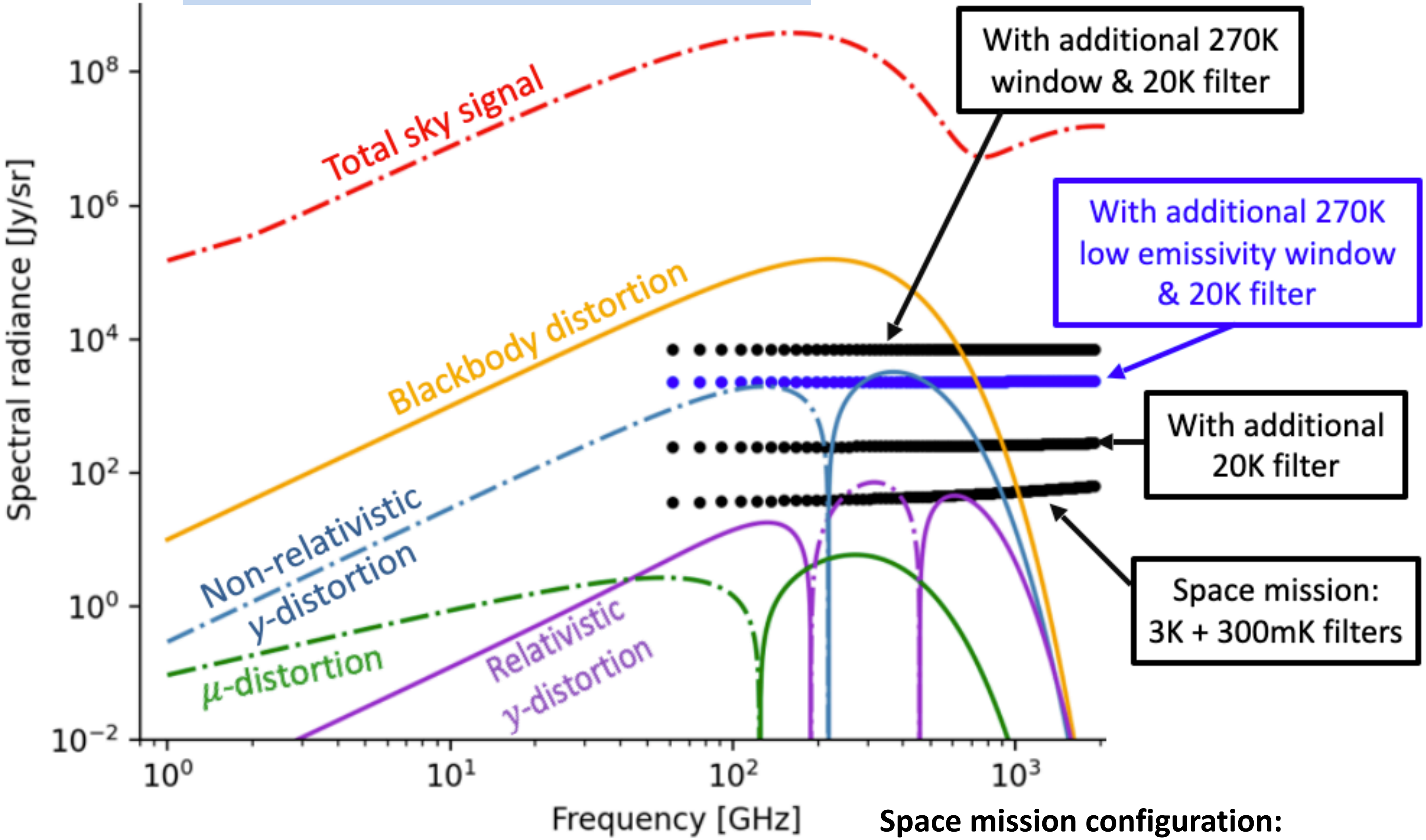
Extra optical components and residual atmosphere:
High frequency background power on detectors is the major issue with an FTS instrument

But also



Maximum
allowed envelope
1.6 m
1.8 m
Line of sight~ 40deg
+/- 20deg
Balloon
0.9 m
1.8 m
~ 40cm
ap. diam.
2 - 4 K

Sensitivity calculations



Space mission configuration:
Freq range: 60 GHz - 2 THz;
5 day flight, 75 % obs efficiency
Low temp filters with 0.1% emission
Tapered filtering from 600 GHz
No Atmosphere

Photon noise on detector →
→ Photon noise limited NEP (Noise Equivalent Power)
→ Sensitivity

See talk by X. Coulon

Sensitivity estimates

- Calculations have been done so far:
  - Simple model of the instrument
  - Atmosphere not taken into account
  - Strongly dependant on some specific parameters (see X. Coulon talk)
    - Frequency range, Filter/window temperature, emissivities, …
- Present sensitivity estimates:
  - S/N ~ 5 for the y-distortions
  - S/N ~ 10 for T_{CIB}
  - S/N ~ 30 for ΔT_{CMB}
- Increase / Optimisation of the sensitivity:
  - Frequency range (very sensitive to max frequency)
    - Adapting filter transmission to decrease the high frequency part
  - Splitting the focal planes (use of dichroic)
  - Increasing number of detectors (one —> 7 per array)
  - Actively cool window / first filter (***R&T proposed to/by CNES***)

On-going and future studies within Phase 0

- Model of atmosphere and assessment of impact
  - How to mitigate the effects?
- Observation strategy
  - Part of the sky to cover, scanning strategy
- Flight plan
  - Launch site, trajectory, day/night flight
    - First 5-day balloon test by CNES in 2024
    - CNES confident that 5-day flight duration available from 2025
    - May-June: Kiruna-North Canada
- Organisation
  - Consortium, costing,…..

Schedule

- Phase 0 until early 2022
- If the study shows that the science goals are achievable (not only a technology demonstrator)
  - Proposal to CNES and other funding agencies in 2022
  - Phase A in 2023
  - Development until 2025
  - First flight in 2026