BISOU

A Balloon-Borne Pathfinder for
CMB Spectral Distortion Measurements

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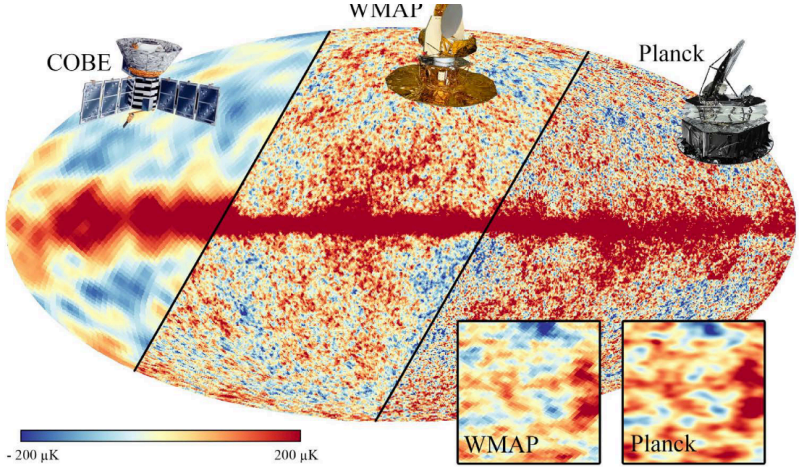
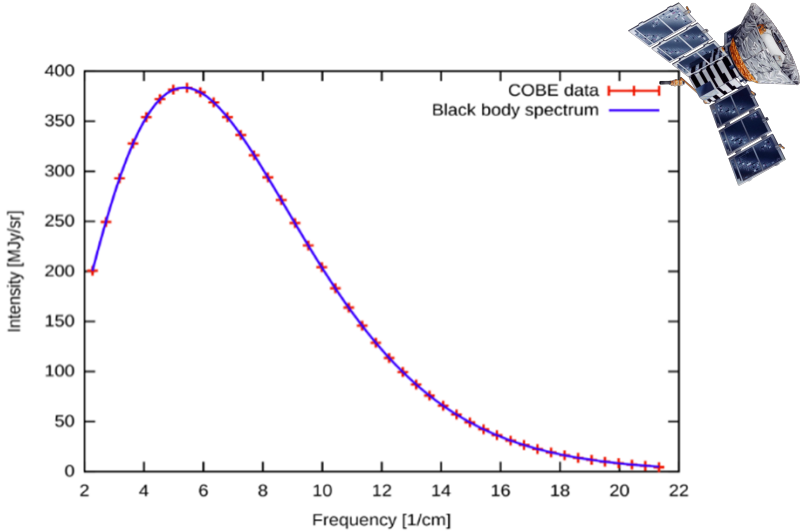
Cosmic Microwave Background Spectrum

CMB past Observations



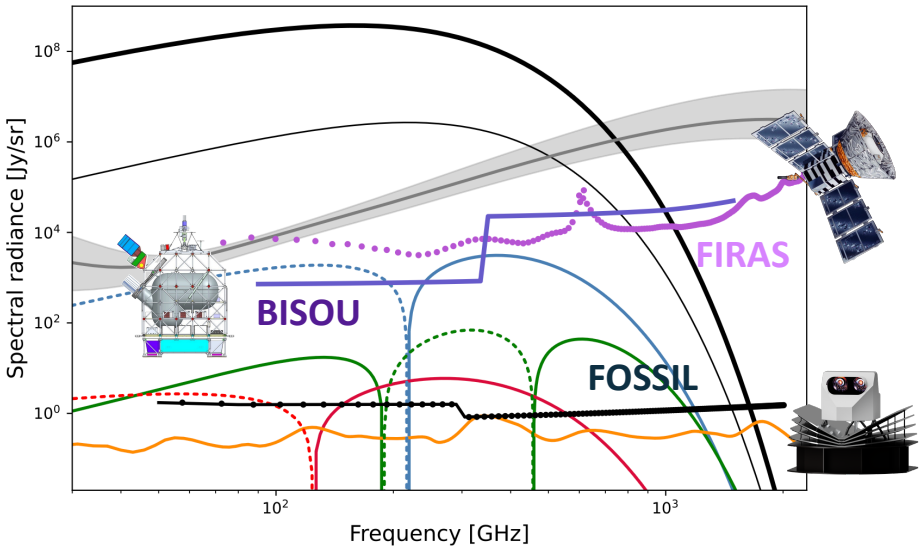
Comparative CMB maps from COBE, WMAP, and Planck missions

The last spectrum measurement : COBE/FIRAS in 1991



BlackBody Spectrum of the CMB by FIRAS, *D.J Fixen et al 1991*

Spectral Distortions : Sensitivity



Sensitivity to Spectral Distortions for different projects X.Coulon

CMB
Average total foregrounds
y-distortion
μ-distortion

FOSSIL

- Frequency range: 50 GHz - 2 THz
- Spectral resolution : $\Delta\nu$ = 15 GHz

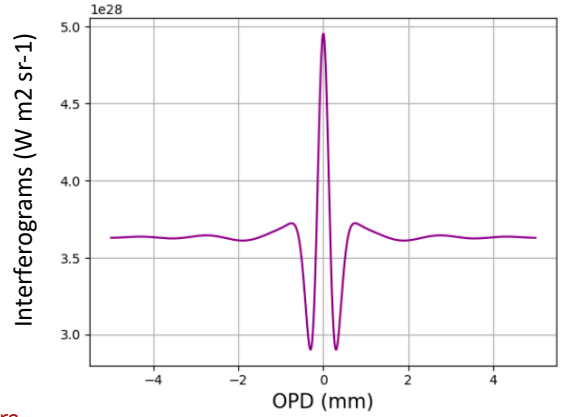
BISOU

- Frequency range: 90 GHz - 1.5 THz
- Spectral resolution : $\Delta\nu$ = 15 GHz

Science goals :

- First y-distortion measurement
- More accurate CIB measurement
- Systematic effects studies

Instrument concept : BISOU & FOSSIL



Power on detectors

$$P_{L_{LF}} = \frac{1}{2}\int_{\nu_{min}}^{\nu_{split}} I_{sky} + I_{BBIR} + \left(I_{sky} - I_{BBIR}\right)\cos\left(\frac{4\pi\delta\nu}{c}\right) d\nu$$

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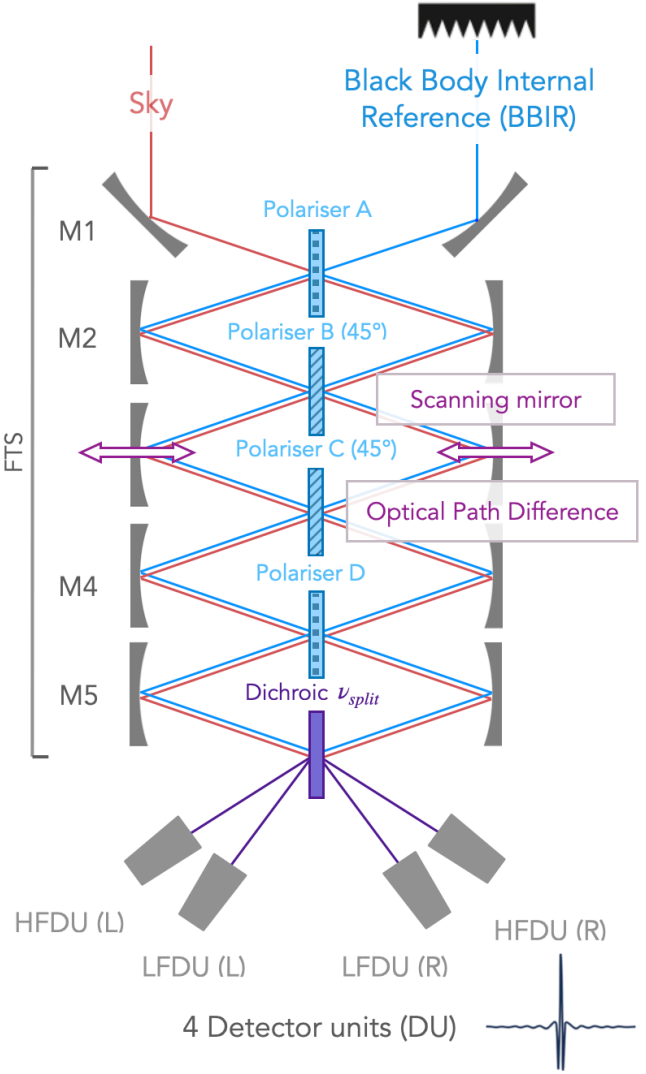
Optical path difference



Instrument concept : BISOU & FOSSIL

Power on detectors

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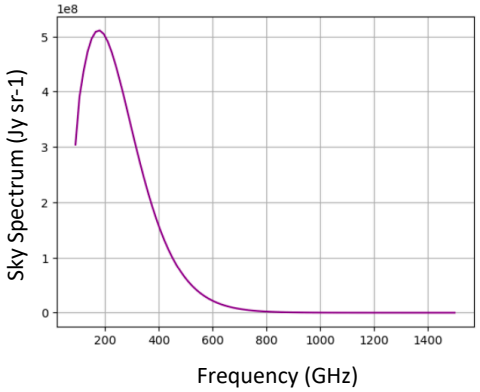
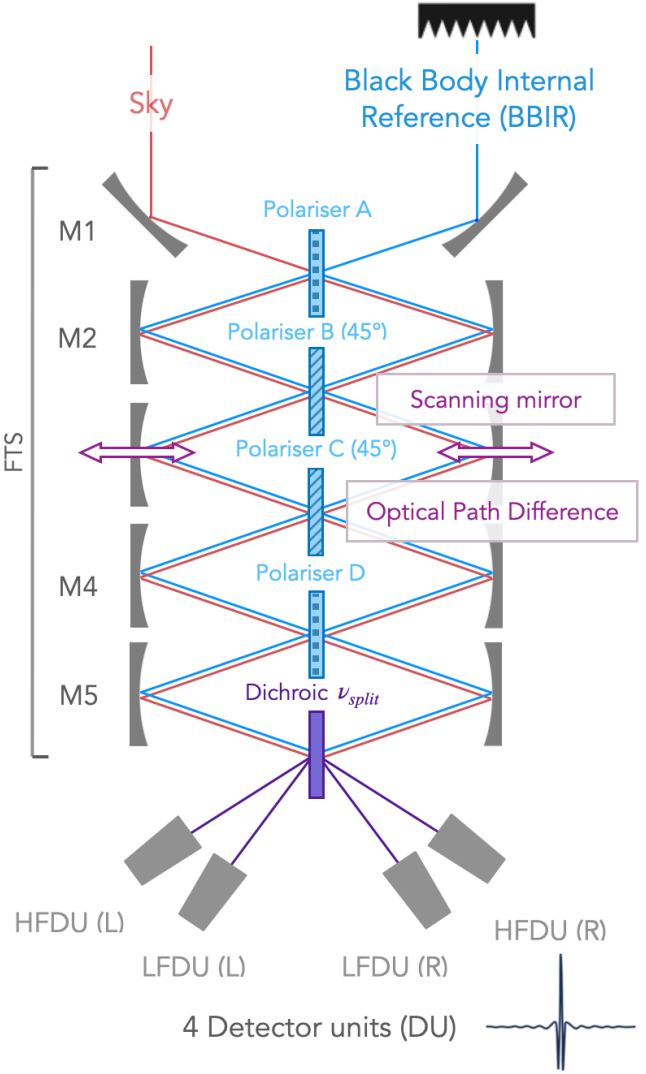
Optical path difference

Fourier Transform

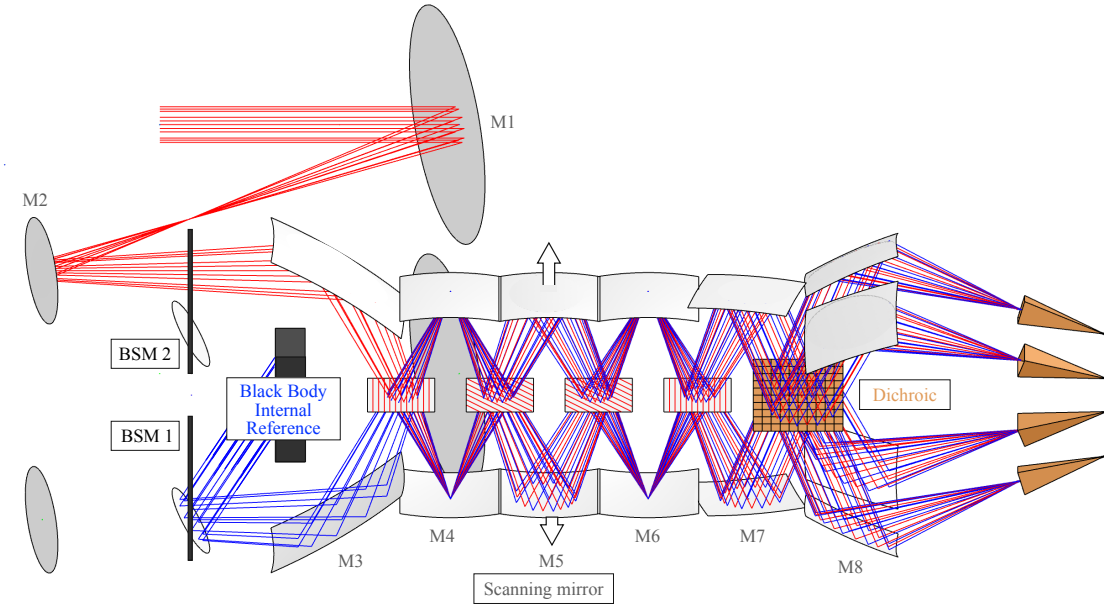
±

BBIR Spectrum

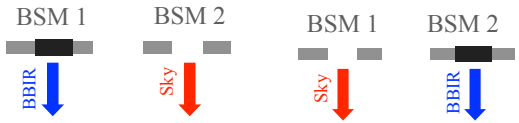




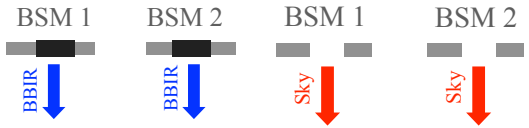
Instrument concept : Application to FOSSIL



Science modes :

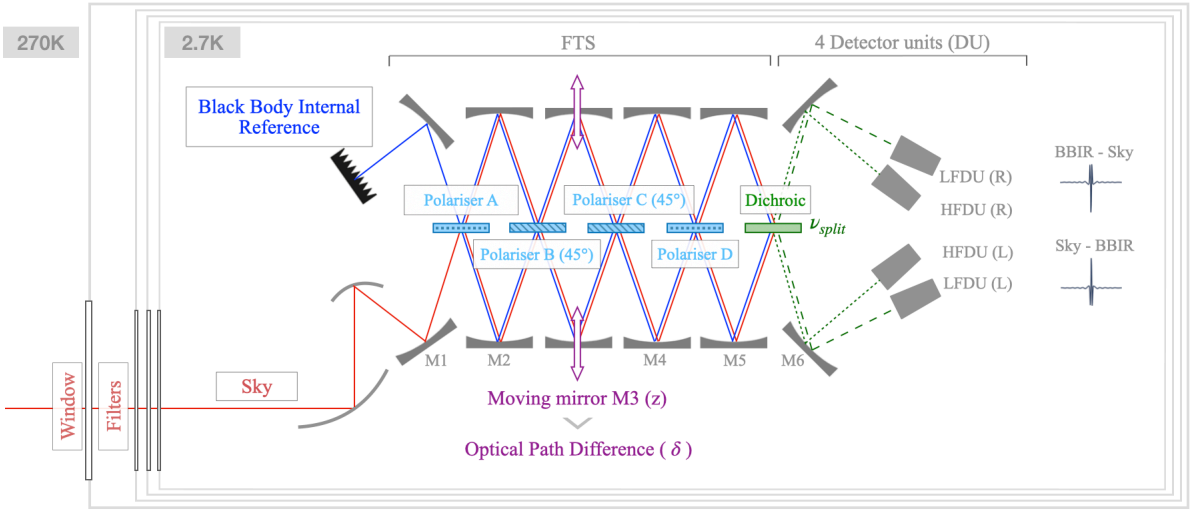


Measurement of mismatches between the two paths :



From FOSSIL step-2 proposal M.LOQUET LE GALL

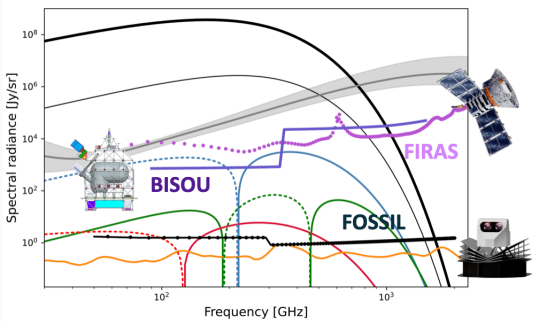
Instrument concept : Application to BISOU



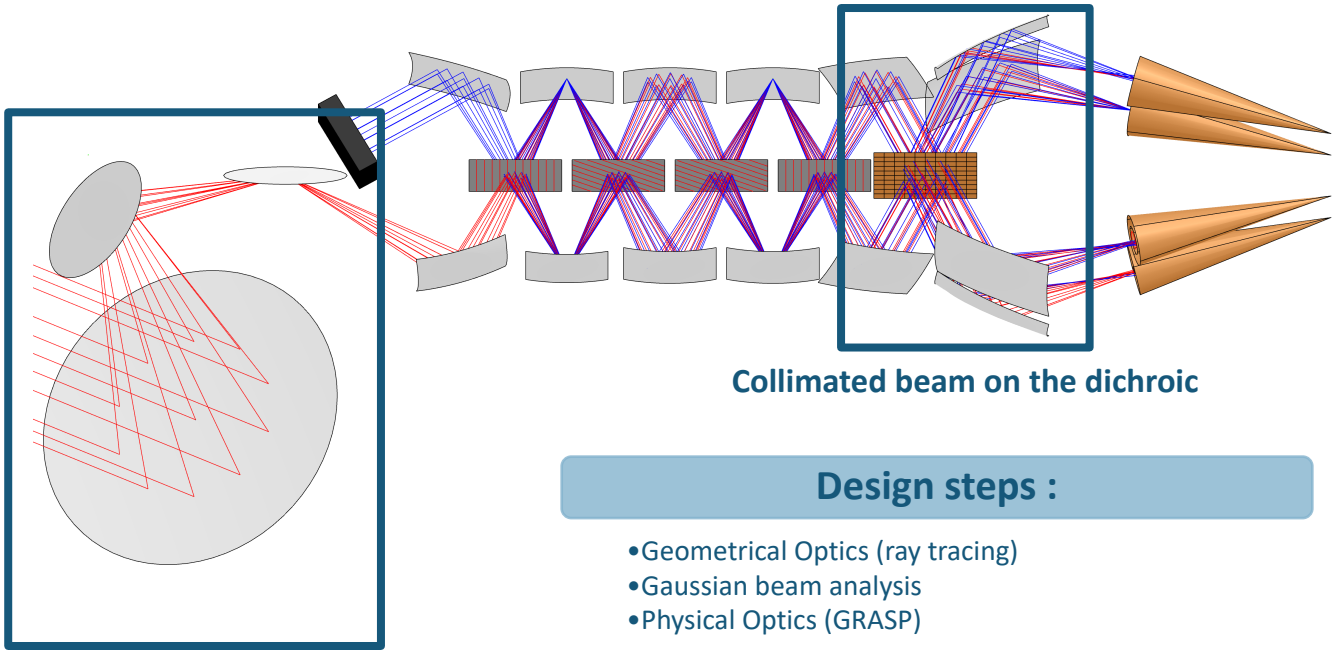
From M. Loquet Le Gall SPIE Optical Design 2026 - submitted

Balloon mission
=
Additional challenges

- Residual atmosphere at 40km
  - Cryogenic enclosure (2.7K)
  - Focal plane at hundreds mK
- Photon noise dominated by :
  - Thermal emission of the atmosphere
  - Hot component (window/filters)



BISOU : Optical Design

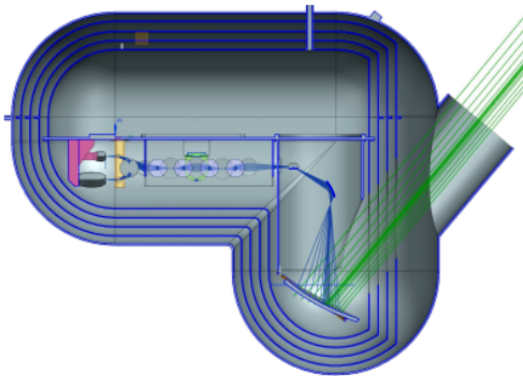


Mizuguchi-Dragone Telescope

Collimated beam on the dichroic

Design steps :

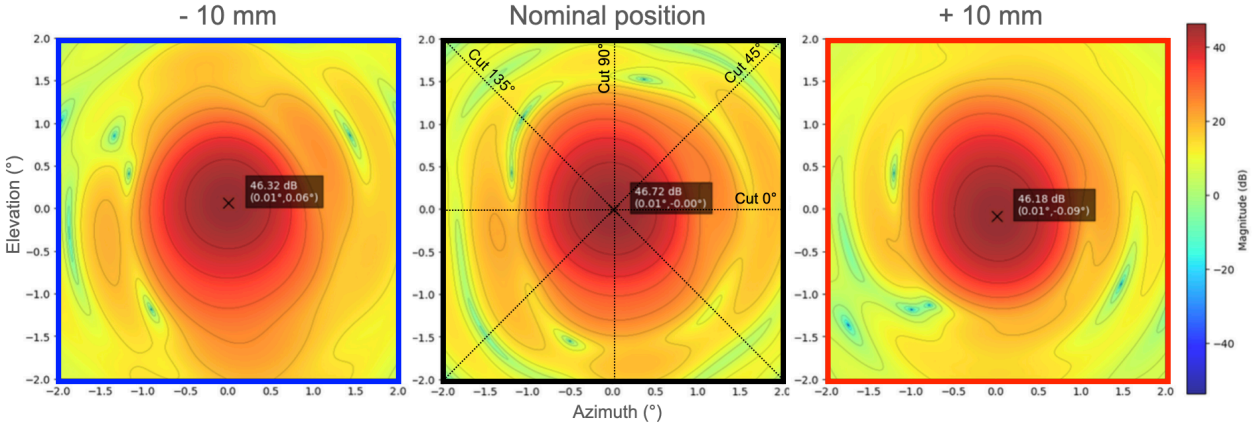
- Geometrical Optics (ray tracing)
- Gaussian beam analysis
- Physical Optics (GRASP)



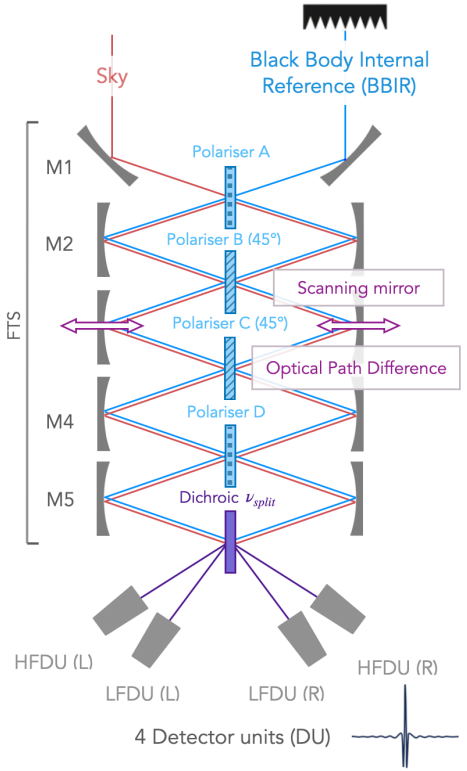
2D cut of the BISOU instrument inside the cryostat environment B. BORGO (IAS)

SPIE Optical Design 2026 - M. Loquet Le Gall - 10.1117/12.3098705

BISOU : Beam modeling



Simulated beam patterns on the sky for three different positions of the moving mirror



M. Loquet Le Gall - 10.1117/12.3098705

BISOU : Status

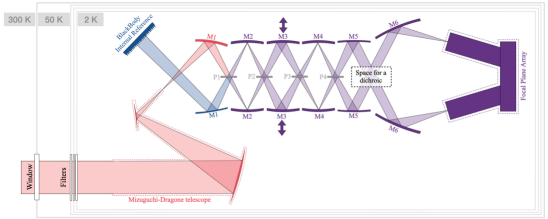
BISOU

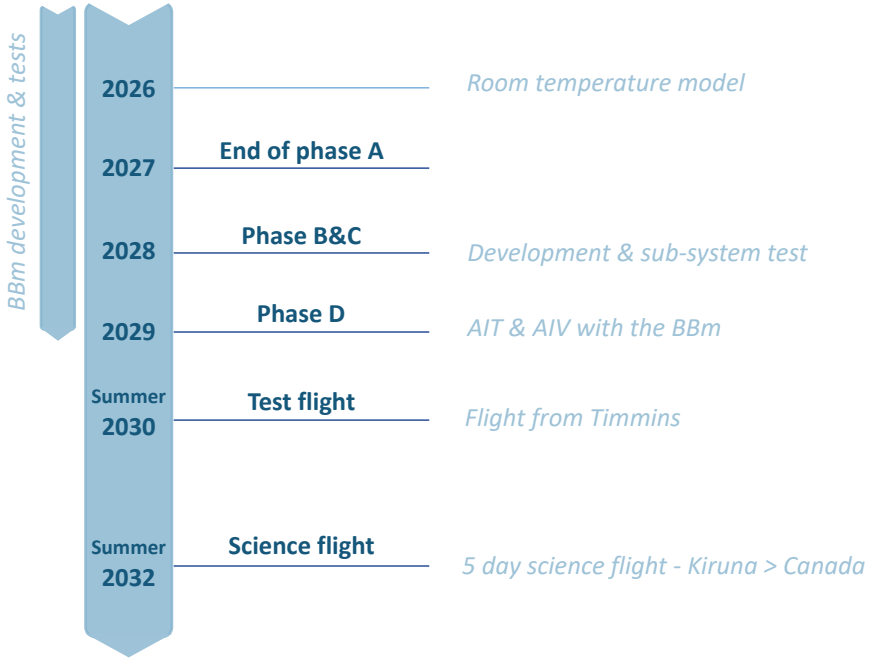
- CNES Phase A : Mission definition & feasibility study
- Test flight (Timmins) : Summer 2030
- Science flight (Kiruna to Canada) : Summer 2032

BISOU BreadBoard Model (BBM)

- Finalisation of the optical design
- Finalisation of the cryogenic facility design
- Room temperature model being built (assembly before winter 2026)

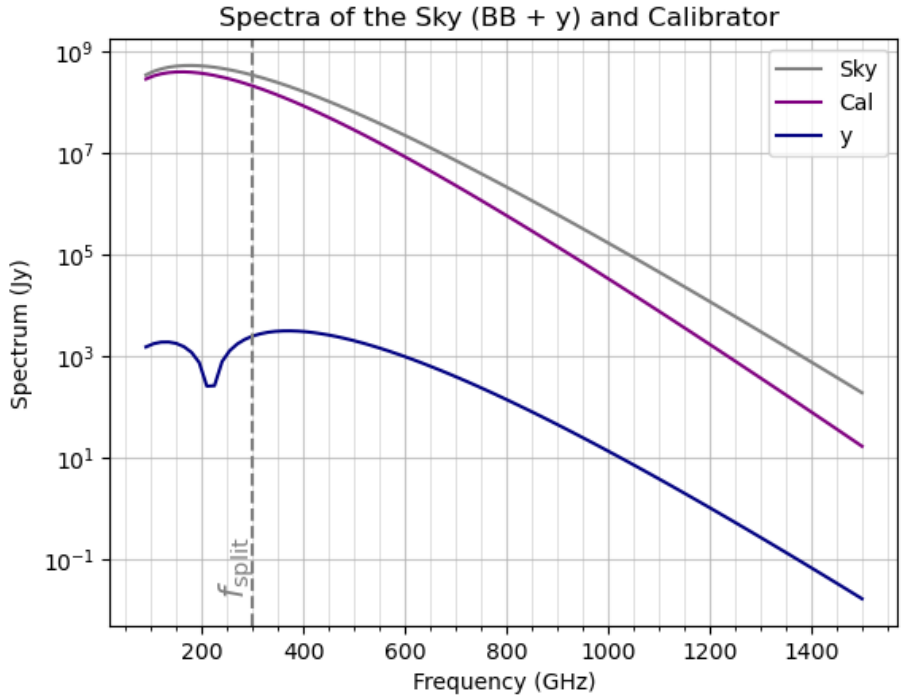
Poster & Proceeding : **SPIE Telescope + Instrumentation 2026**





Studying Systematic effects : instrument simulator

Sky model



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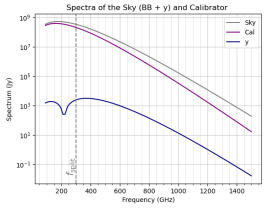

Instrument model

Beam in

Optical element

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

- Transmission profile
- Emissivity
- Temperature
- Frequency split
- …

Beam out

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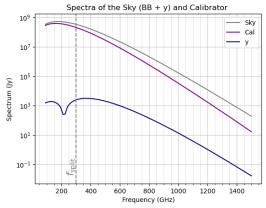

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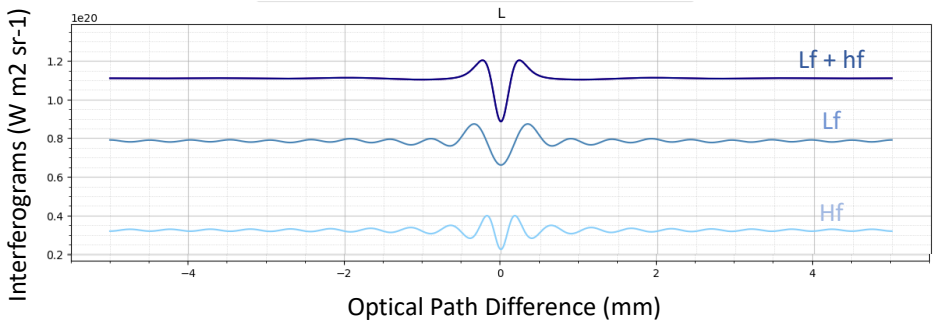
Interferogram



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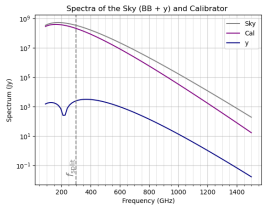

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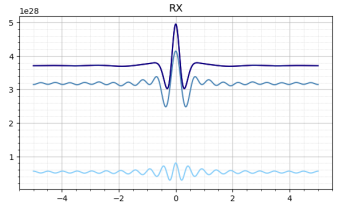
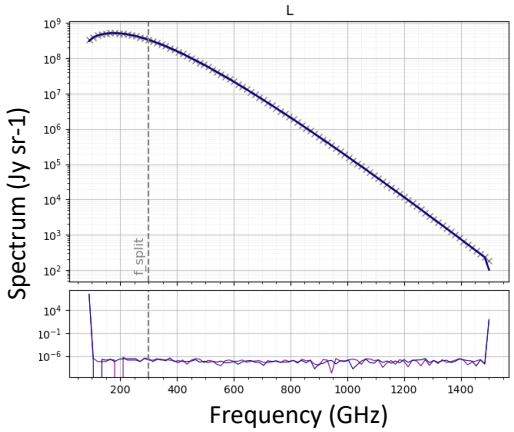


Reconstructed Spectrum



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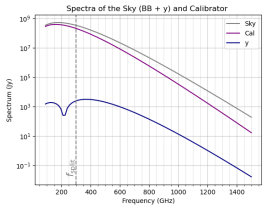

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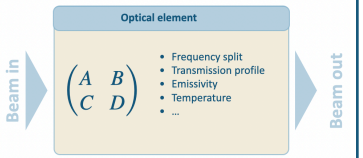

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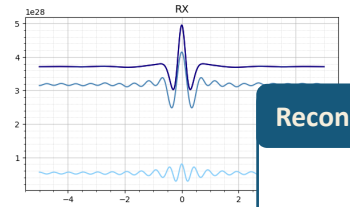

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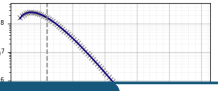
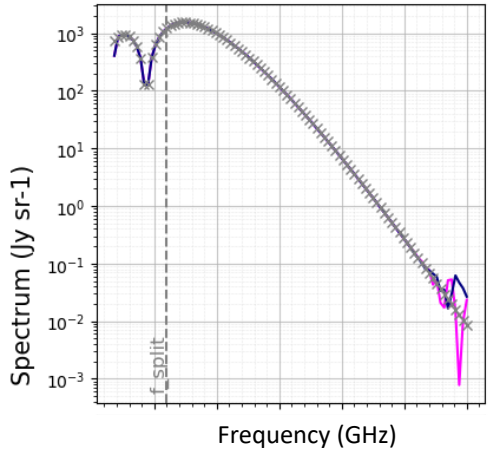


Reconstructed y-distortion



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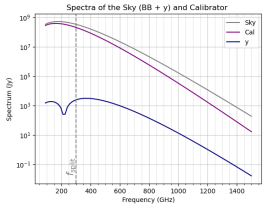

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Beam out

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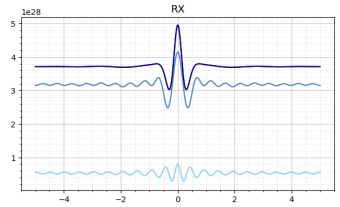

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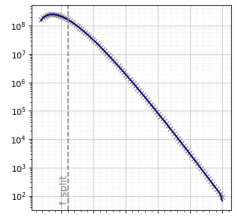

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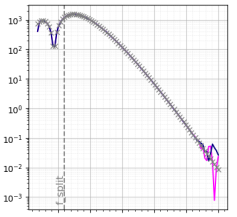


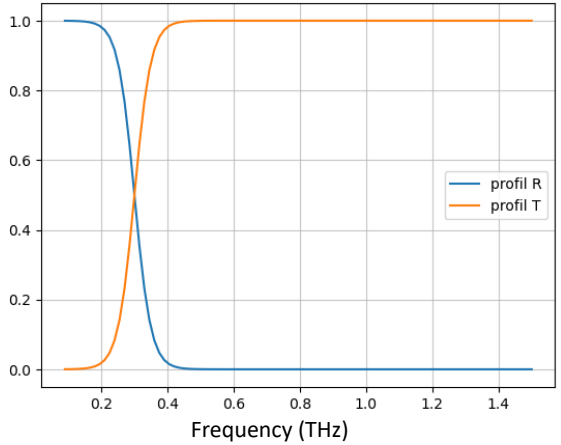
Y parameter & TCMB

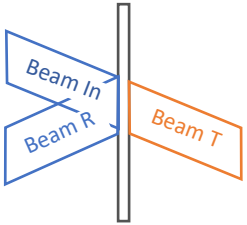
MCMC

Y = 1.70e-6
TCMB = 2.275 K

Effect of the dichroic profile

Transmission/reflection profile





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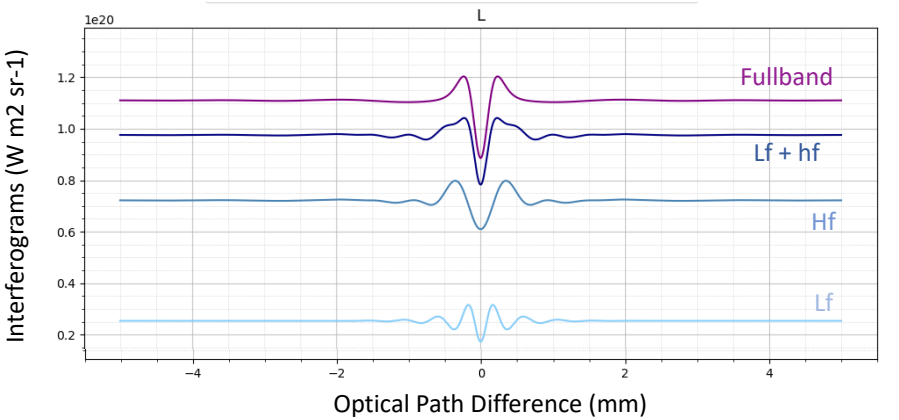
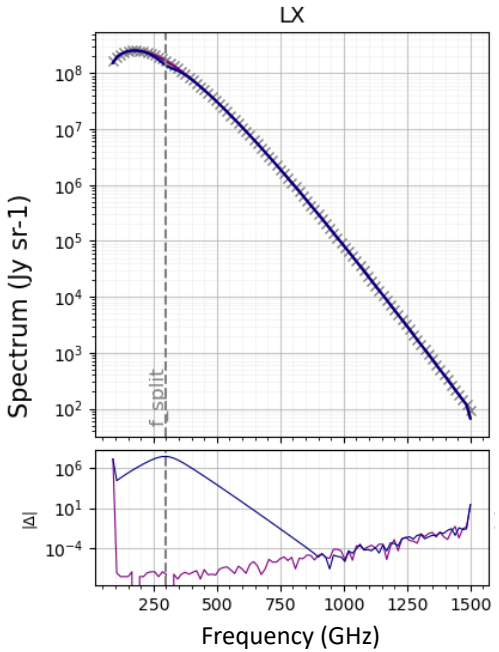


Effect of the dichroic transmission profile

Sky spectrum



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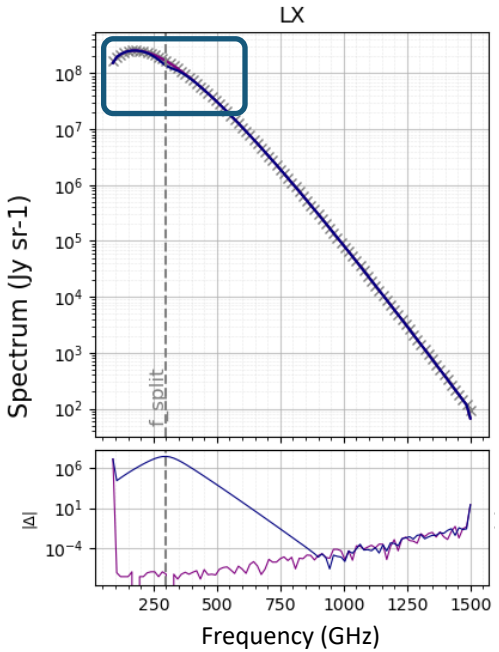

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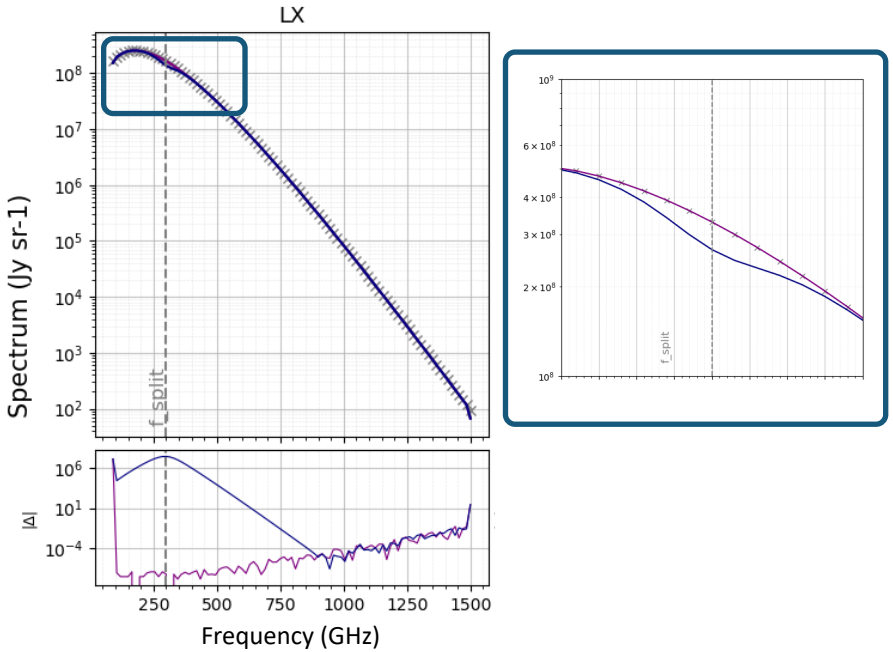

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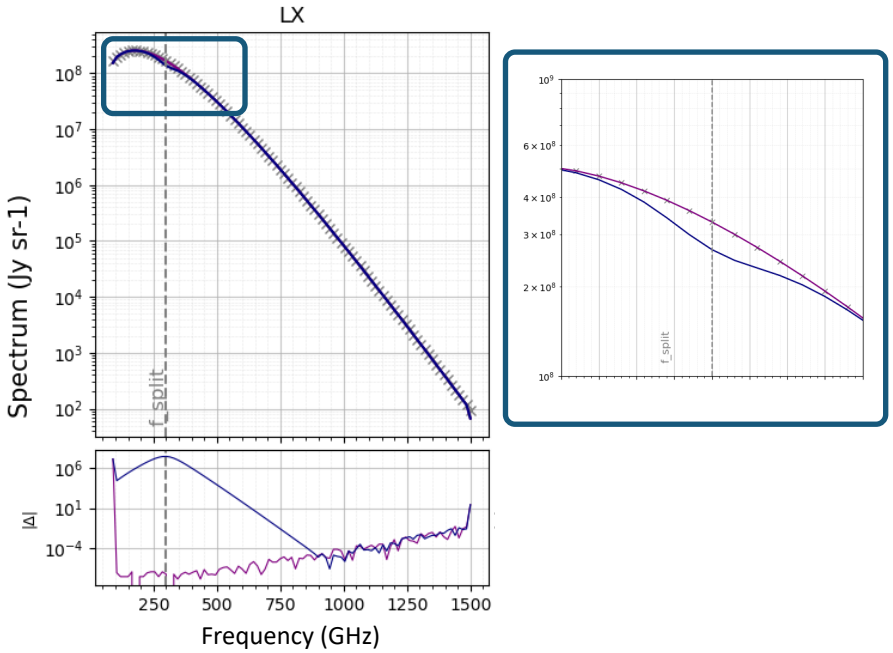
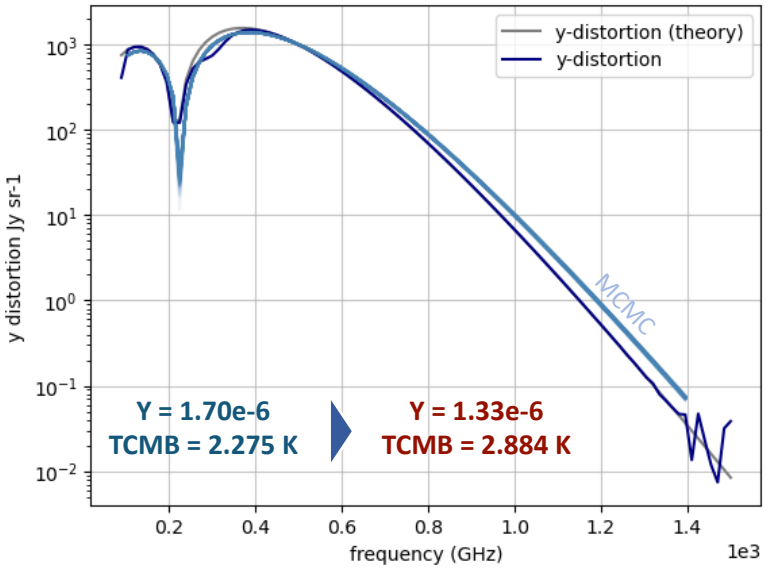


Y-distortion



Studying Systematic effects

Dichroic Transmission profile : a good first example

- “Easy” to model and include in the instrument
- First realistic transmission/reflection profile to be provided soon

  G. Pisano (Sapienza Università di Roma)

- Pipeline preparation
- Requirement on the knowledge of the transmission profile

Ongoing projects

- Work in progress…
  - Adding as many systematics as possible (emissivity, T, window, filters, …)
  - Adding a more accurate sky model
  - Having GRASP simulations as an input (beam, link between mirror displacement and OPD)

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Thanks for your attention :)

- **Contact**: morgane.loquet-le-gall@universite-paris-saclay.fr
- **I will be at :**
  - SPIE Telescope + Instrumentation 2026

    BISOU BBm optical design
  - Global End-to-end Analysis at all frequencies

    Global sky modelling workshop
  - International Conference on Space Optics (ICSO)

    FOSSIL Optical design