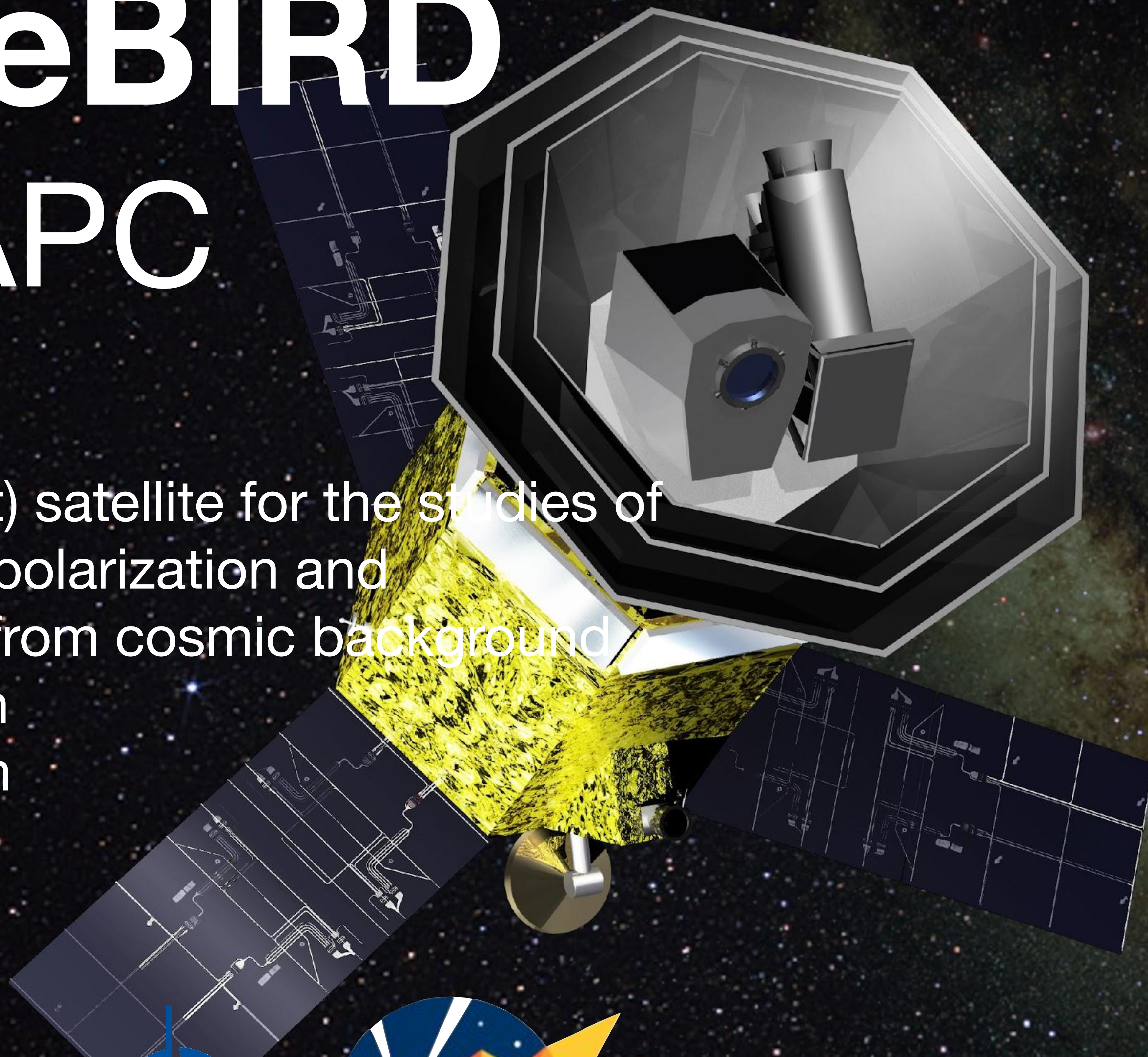
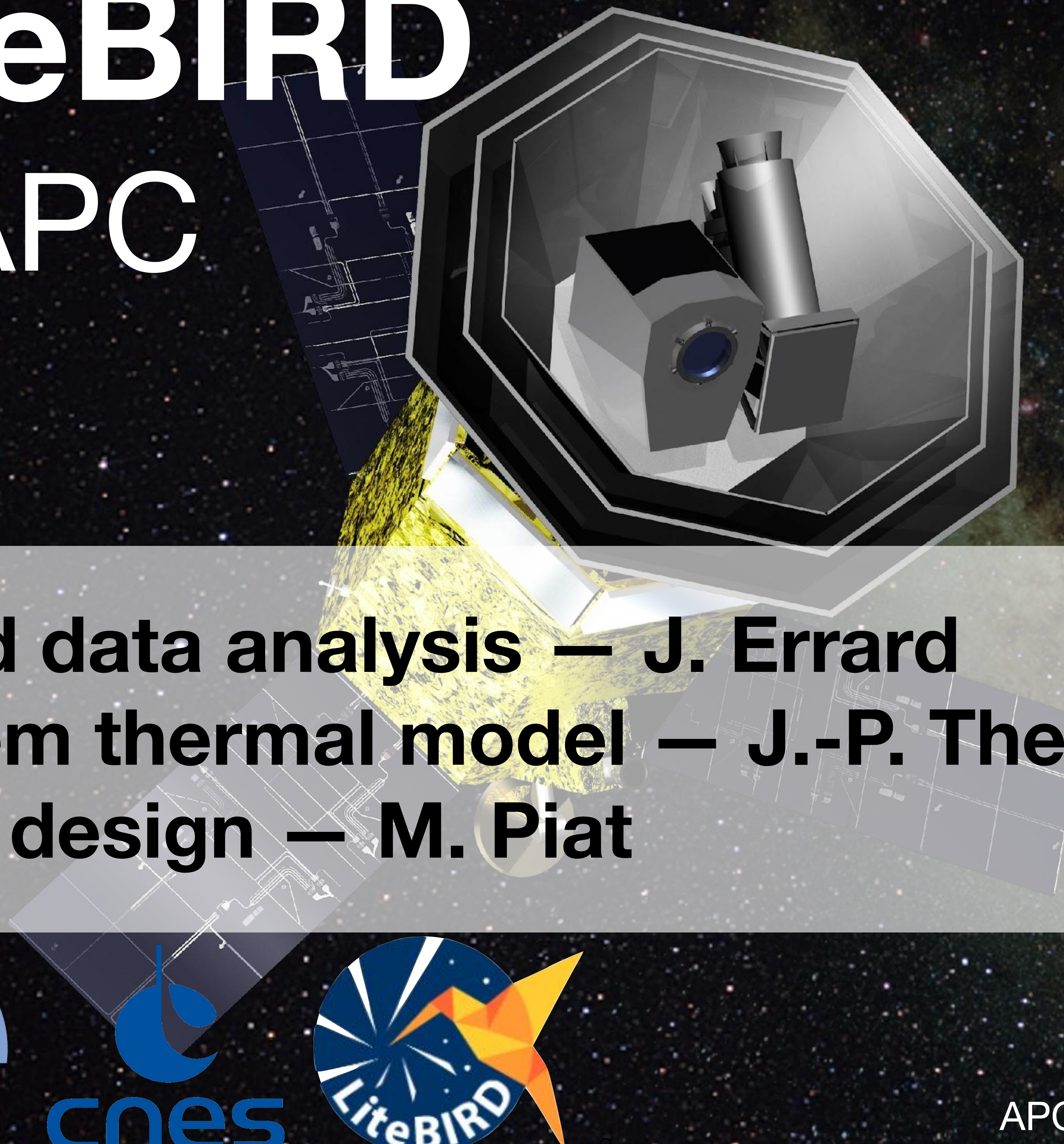
LiteBIRD
@ APC



Lite (light) satellite for the studies of
B-mode polarization and
Inflation from cosmic background
Radiation
Detection

APC, January 2026

LiteBIRD
@ APC



nce and data analysis — J. Errard

T system thermal model — J.-P. Thermeau

plane design — M. Piat

APC, January 2026

- B. Beringue (postdoc, ERC SciPol)
- M. Bucher
- G. Deniel
- J. Errard (*interim – APC point of contact*)
- K. Ganga
- L. Grandsire
- J.-Ch. Hamilton (➔ lab director)
- A. Ilioni
- M. Le Jeune
- W. Kabalan (PhD, ERC SciPol)
- G. Patanchon (*JSG systematics co-convener, IGB, PI of RISE CMB-Inflate*
  ➔ ILANCE/IPMU Tokyo)
- M. Piat (CPB Berkeley ➔ *APC point of contact*)
- R. Stompor (APC)
- J.-P. Thermeau
- S. Biquard (PhD, ERC SciPol + DIM ➔ U. Manchester)
- P. Chanial (IR, ERC SciPol)
- W. Sohn (postdoc, ERC SciPol) ➔ leaving to the UK next Summer
- A. Basyrov (postdoc, ERC SciPol)
- Tran Hoang Viet (PhD)
- M. Citran (PhD)
- Pierre Masson (PhD)
- A. Villarrubia-Aguilar (PhD, UPC, SciPol)
- A. M. Landais (PhD, UPC, SciPol)

NEW!

~ 20 persons involved in LB

data analysis
hardware

→ **FTE / ETP data for the CMB activities @ APC** data analysis @ APC

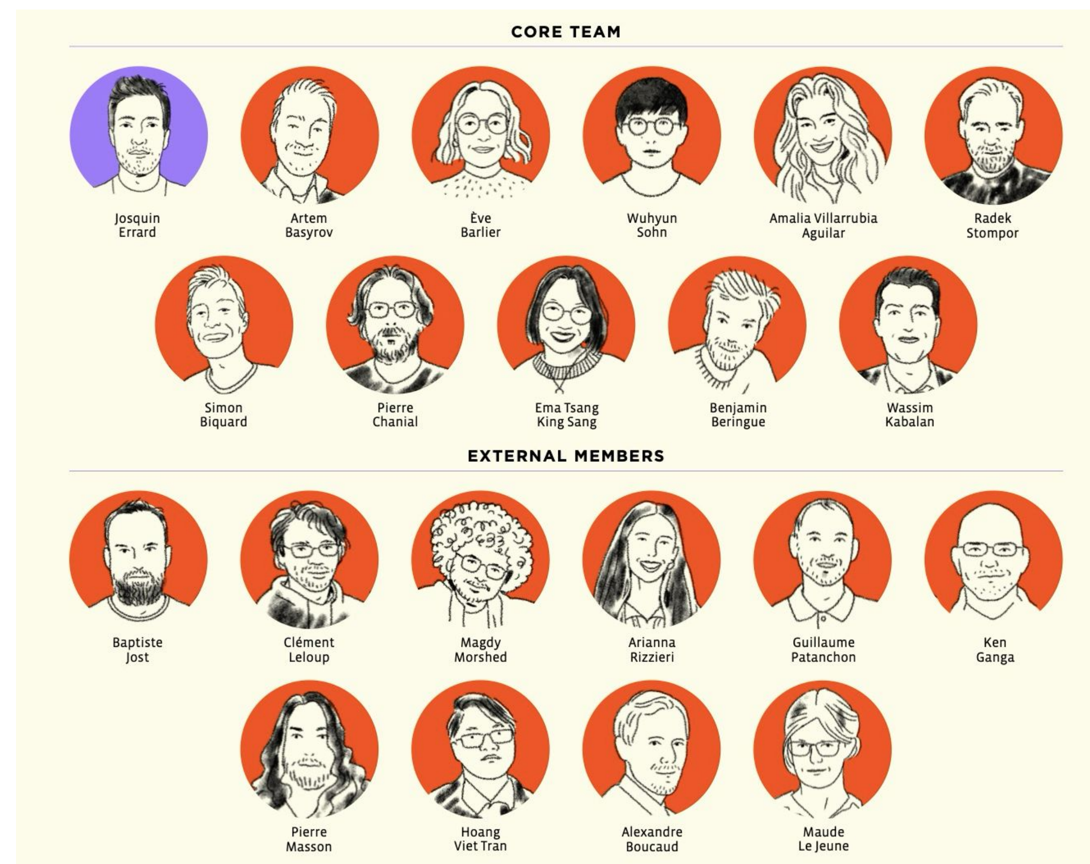
structured by

SciPol (2023-2028)

SciPol

Science from the large scale cosmic microwave background polarization structure

scipol.in2p3.fr

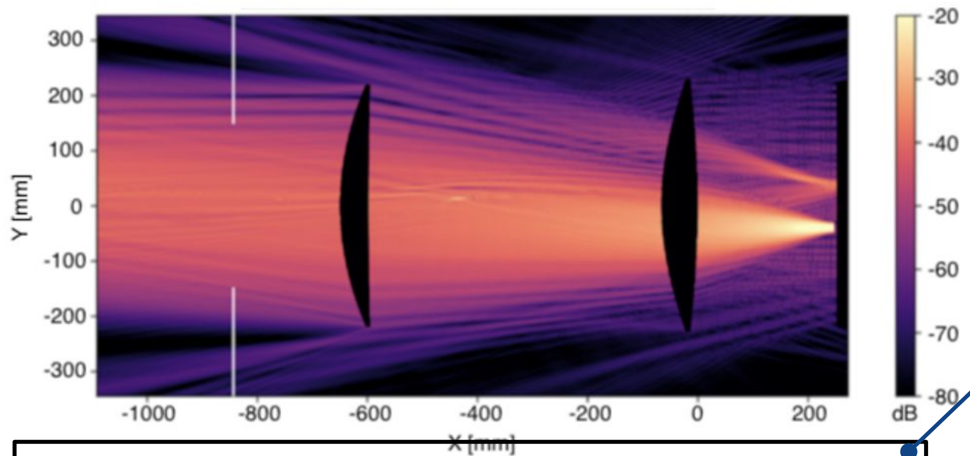


FURAX

a Framework for a Unified and Robust Analysis with JaX

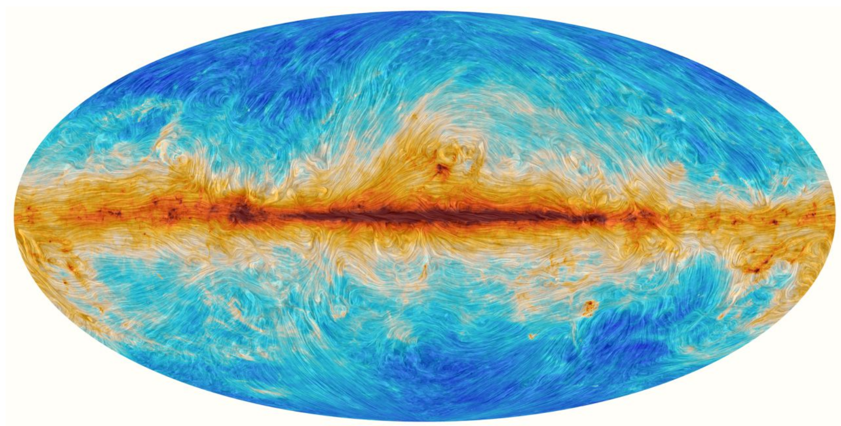
CMB-Inflate

data analysis



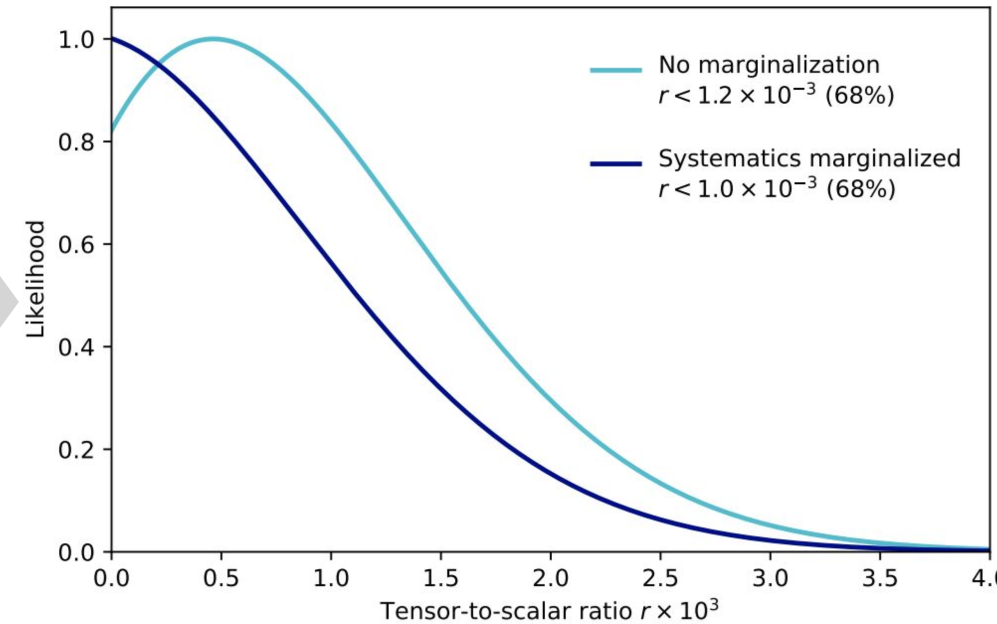
instrumental modeling / simulation

foregrounds modeling / simulation



scientific analysis + forecasting

constraints on large scale CMB polarization



synergies with other CMB projects

* APC led the IN2P3 Planck effort

CNES Phase A (L3) requirements + JAXA MDR

Reformation plan / requirement

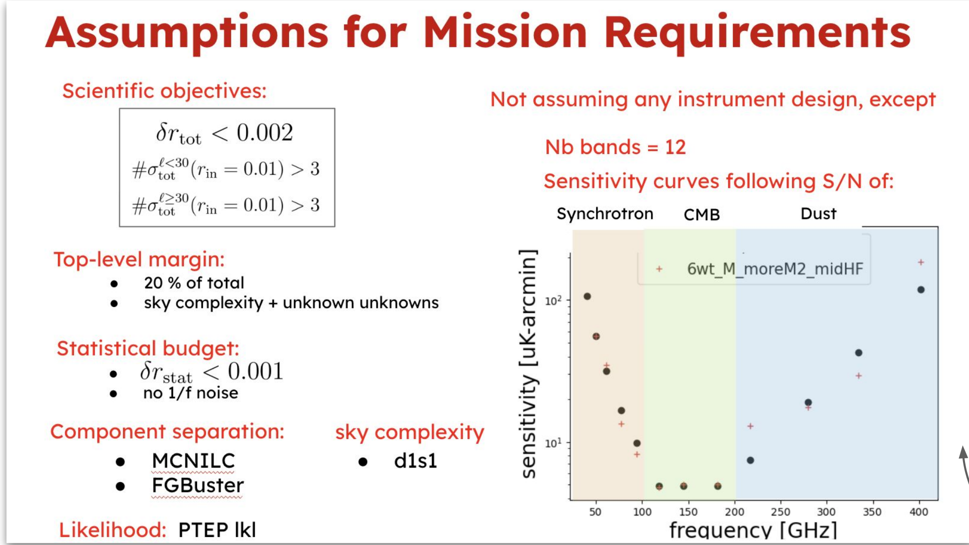
+ scientific publications related to LiteBIRD, led by APC: Leloup et al. (2023); Morshed et al. (2024), Rizzieri et al. (2024); Patanchon et al. (2024); Ganga et al. (2021); Rizzieri et al. (2025)

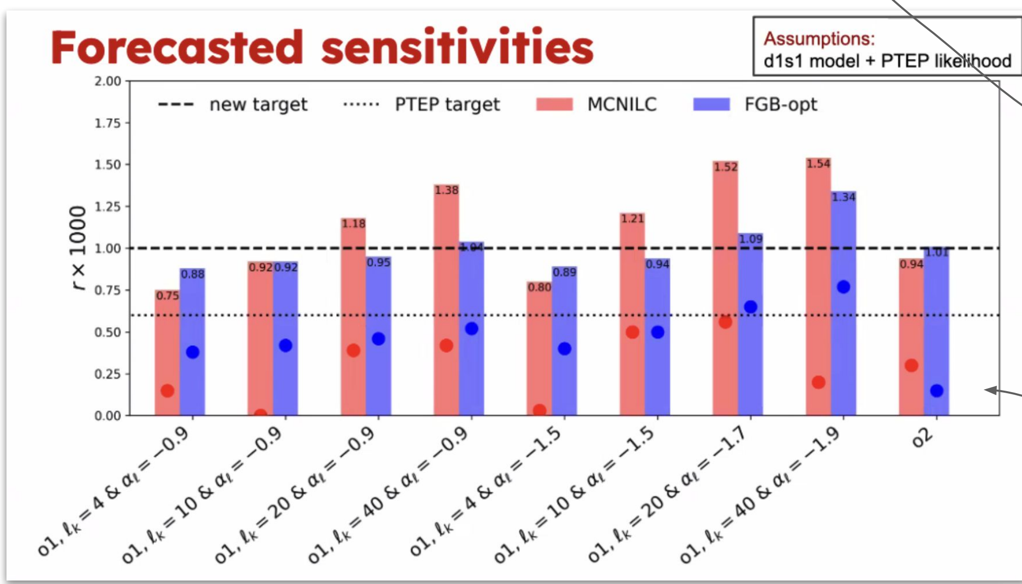
Prog. Theor. Exp. Phys. **2015**, 00000 (155 pages)
DOI: 10.1093/ptep/0000000000

Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey

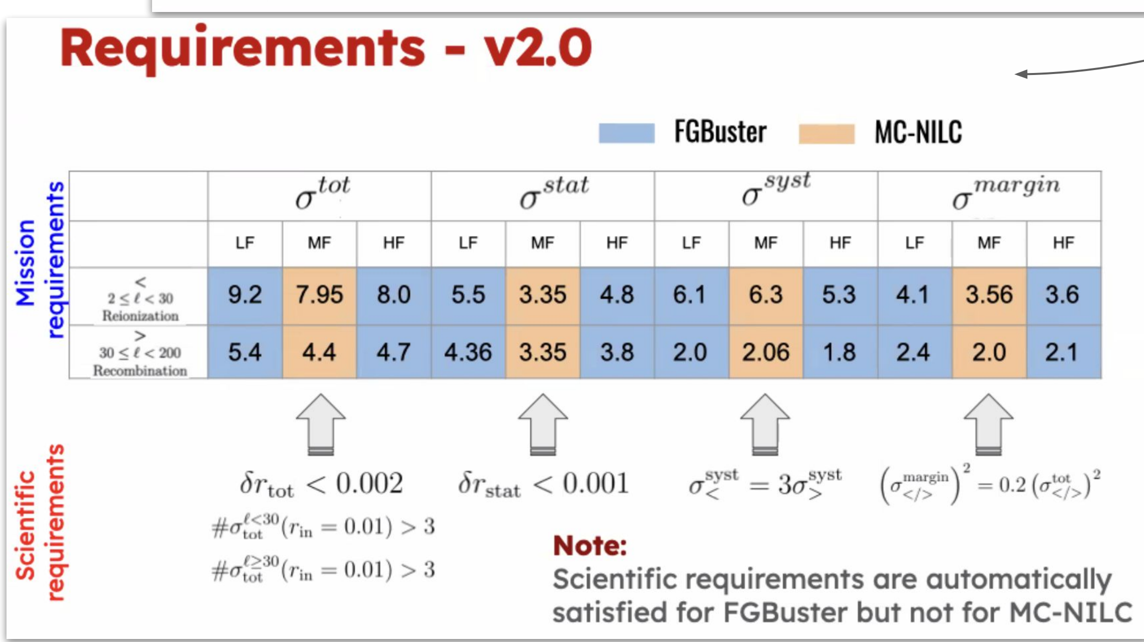
LiteBIRD Collaboration*

from this week's F2F @ IPMU

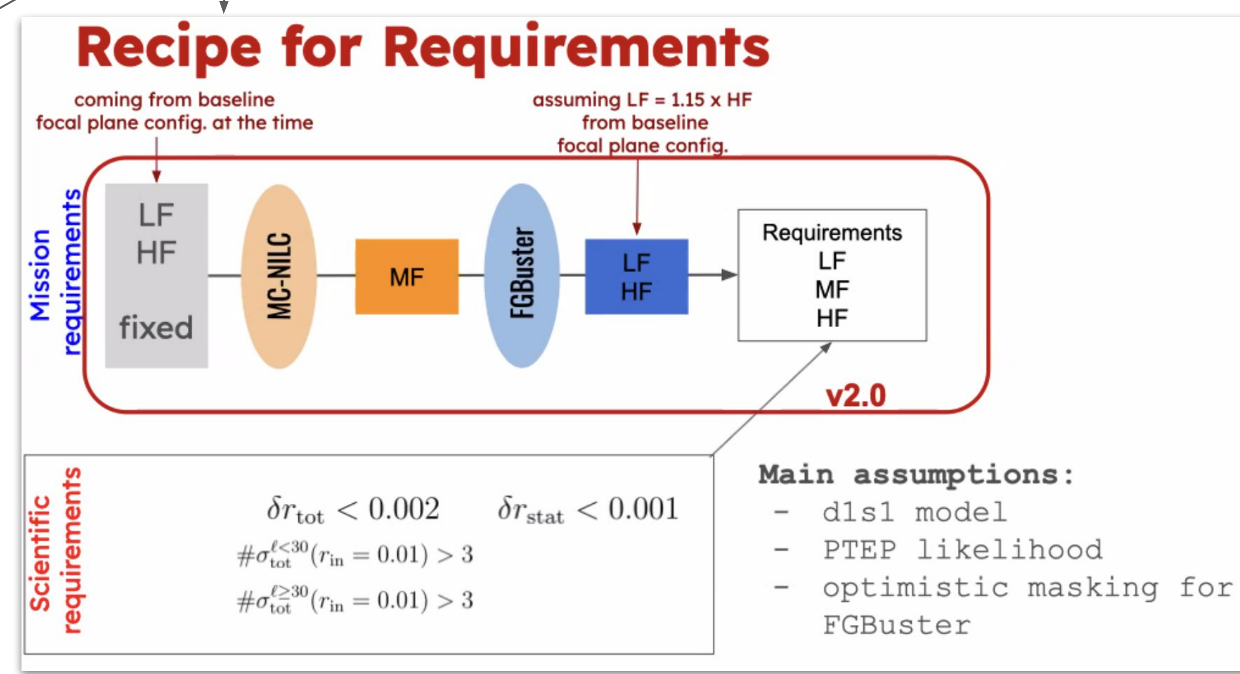




fgbuster



	σ^{tot}			σ^{stat}			σ^{syst}			σ^{margin}		
	LF	MF	HF	LF	MF	HF	LF	MF	HF	LF	MF	HF
< $2 \leq \ell < 30$ Reionization	9.2	7.95	8.0	5.5	3.35	4.8	6.1	6.3	5.3	4.1	3.56	3.6
> $30 \leq \ell < 200$ Recombination	5.4	4.4	4.7	4.36	3.35	3.8	2.0	2.06	1.8	2.4	2.0	2.1



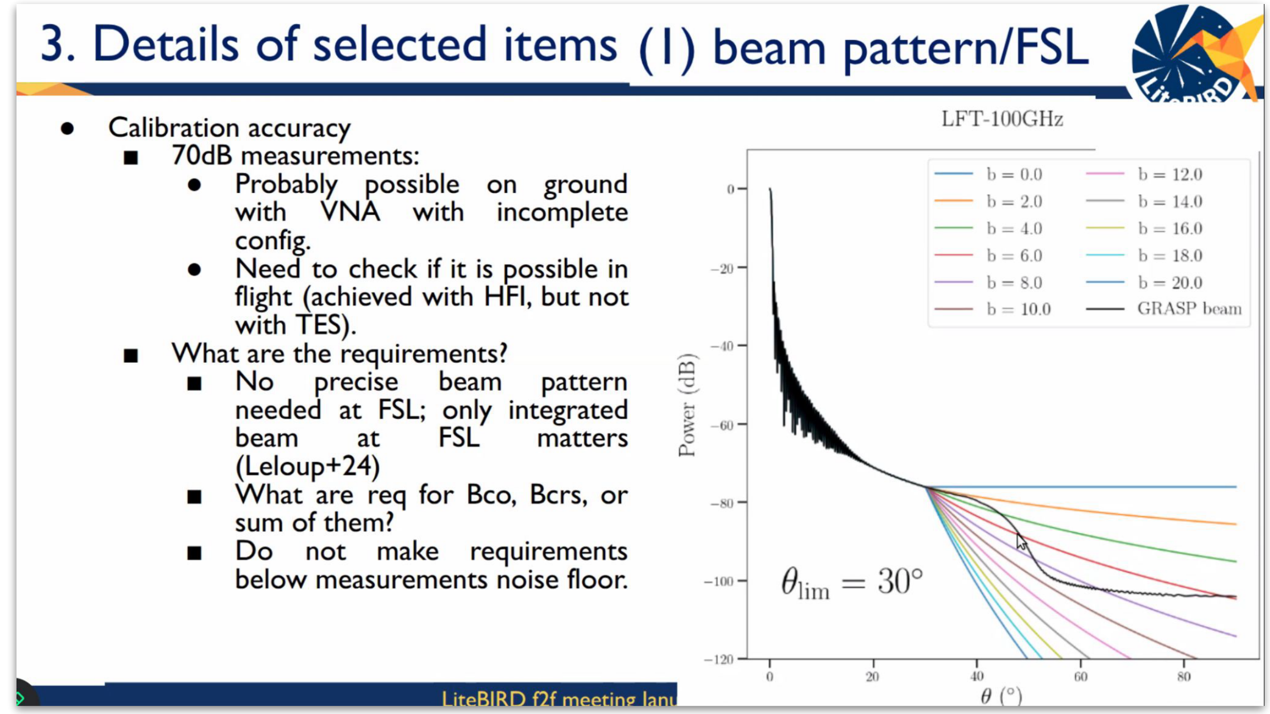
data analysis

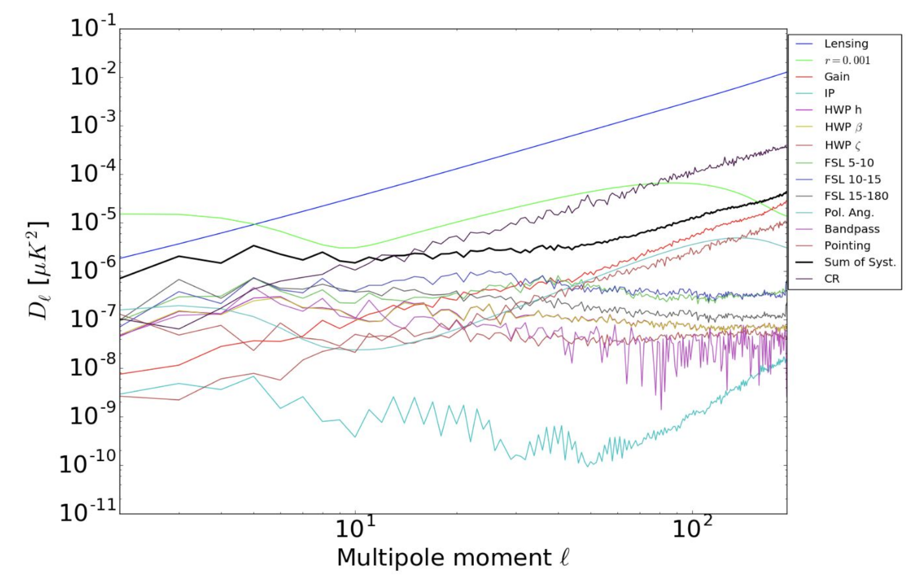
Systematics studies

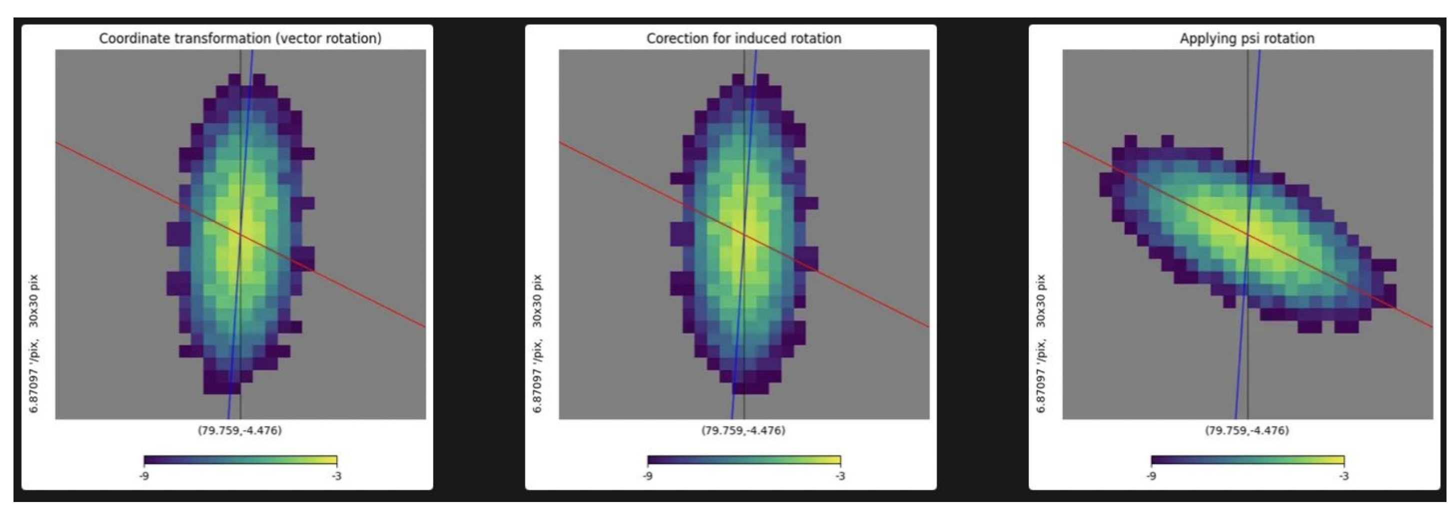
Coordination of systematics studies for the collaboration (G. Patanchon)

Beam sidelobes: W. Wang, C. Leloup (<2023/2024), A. Basyrov (<2027)

HWP imperfections: G. Patanchon E. Tsang King Sang + J. Errard + R. Stompor







HWP systematics

Effect of Instrumental Polarization with a Half-Wave Plate on the B-Mode Signal: Prediction and Correction

Guillaume Patanchon[a] Hiroaki Imada[b] Hirokazu Ishino[c] Tomotake Matsumura[d,e]

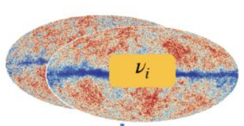
Tsang King Sang et al. (in prep)

Half-wave-plate non idealities propagated to component separated CMB B-modes

Ema Tsang King Sang*, Josquin Errard*, and Radek Stompor*
*Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France
(Dated: January 29, 2026)

We investigate the impact of non-ideal continuously rotating half-wave plates (HWPs) on CMB polarization measurements in experiments such as the Simons Observatory and LiteBIRD. We exploit a frequency-dependent parametric model of multi-layer HWPs using Mueller matrix formalism, which captures the induced mixing of Stokes parameters. Through end-to-end simulations, we propagate these effects into the later stages of CMB data analysis, namely map-making and component separation, and quantify the resulting bias on the B-modes power spectrum and the tensor-to-scalar ratio r. We show that neglecting the frequency dependence of a three layer HWP can produce significant polarization leakage, biasing foreground spectral parameters and eventually leaving residuals in CMB maps corresponding to an effective bias of up to $r \sim 7 \times 10^{-3}$. To address this, we test two corrective data models: an effective model, with fitted parameters at the time-ordered data level, and a full stack model explicitly encoding the instrumental response. While the latter reduces systematics, it may become insufficient for targetted scientific goals of next-generation CMB instruments. We finally suggest a JAX-based component separation method that incorporates the non-ideal HWP response and allows marginalization over hardware uncertainties.

Simulation configuration



HWP modulation
w/ non ideal HWP

Map making

Uncorrected maps
sky reprojection
w/ ideal HWP

Corrected maps
sky reprojection
w/ effective HWP

Component separation
fgbuster

B-mode residual

Q/U single frequency maps:
- PySM templates d0s0 - spatially invariant spectral parameters $\beta_d, \beta_s,$
CMB from Planck 2018
- No noise, r=0 Alens=1 (no delensing)
- Scanning strategy: random hit on SO-SAT like sky patch

FURAX

```
h = pol @ hwp @ mixing_matrix @ sampling
sky_template = ((h.T @ h).I @ h.T)(tod)
```

https://github.com/CMBSciPol

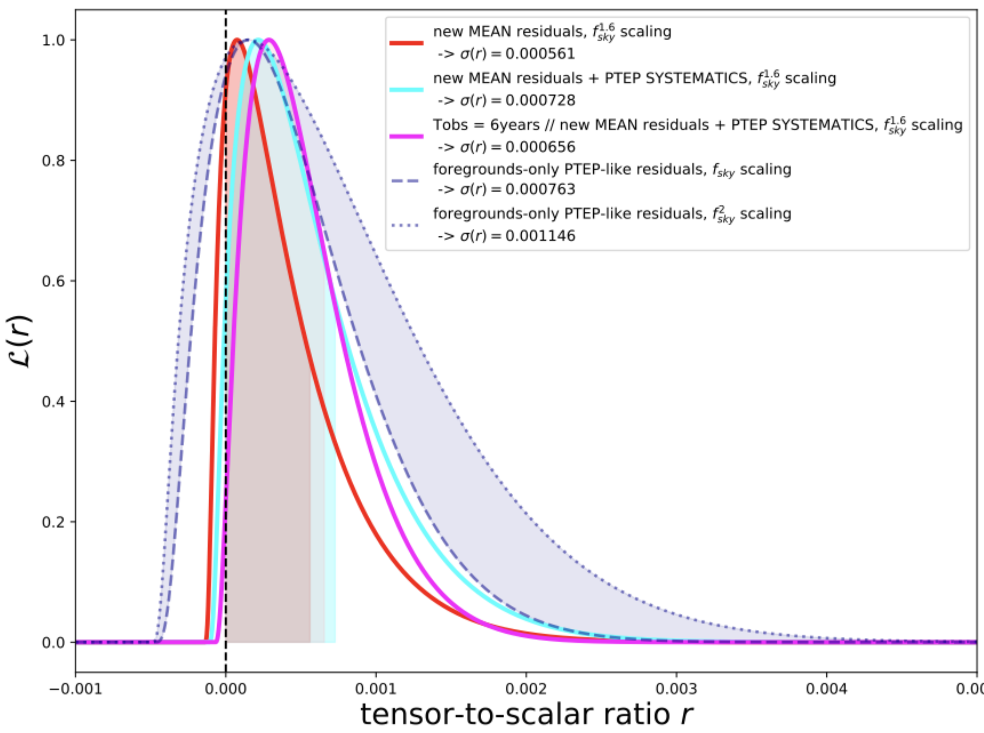
P.Chanial's talk @ IAP https://indico.iap.fr/event/30/
S.Biquard's talk @ CMB France https://indico.in2p3.fr/event/34251/overview

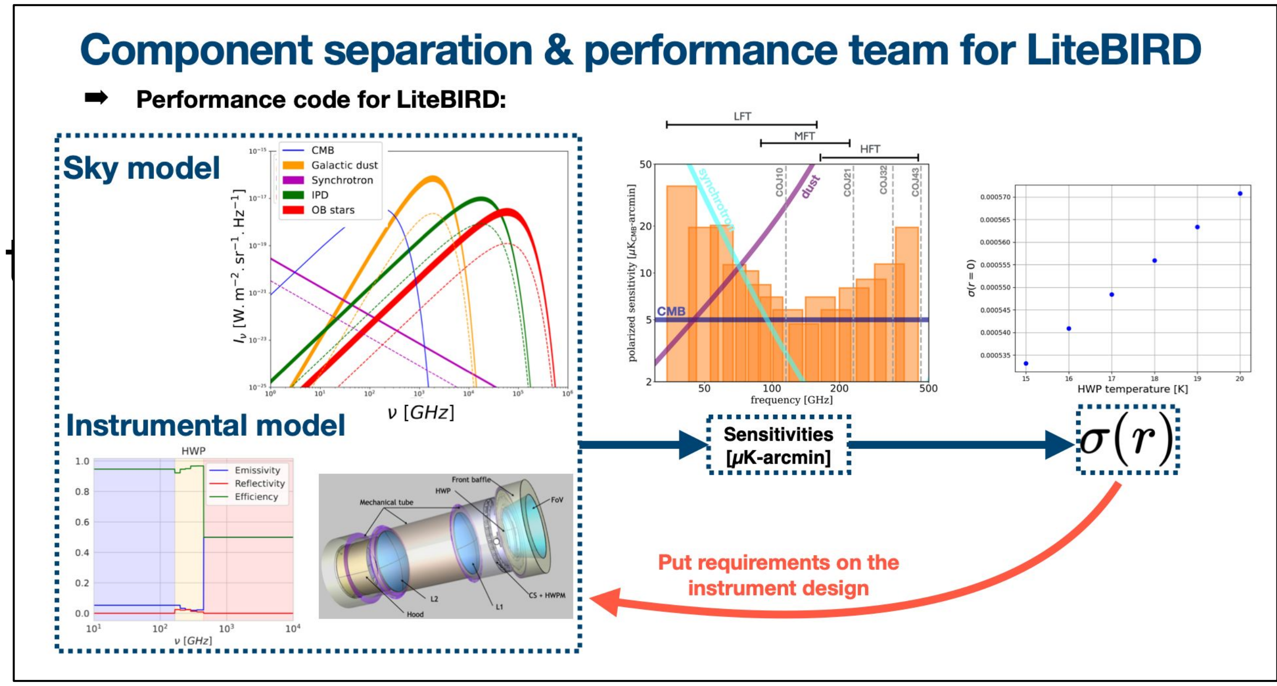
Input maps: no band-pass integration
- Frequency bands: SO SAT
  LF1: 27, LF2: 39, MF1: 92, MF2: 148,UHF1: 225.5, UHF2: 286.5 GHZ
- cmb, dust @ 148 GHz, synchrotron @ 148 GHz

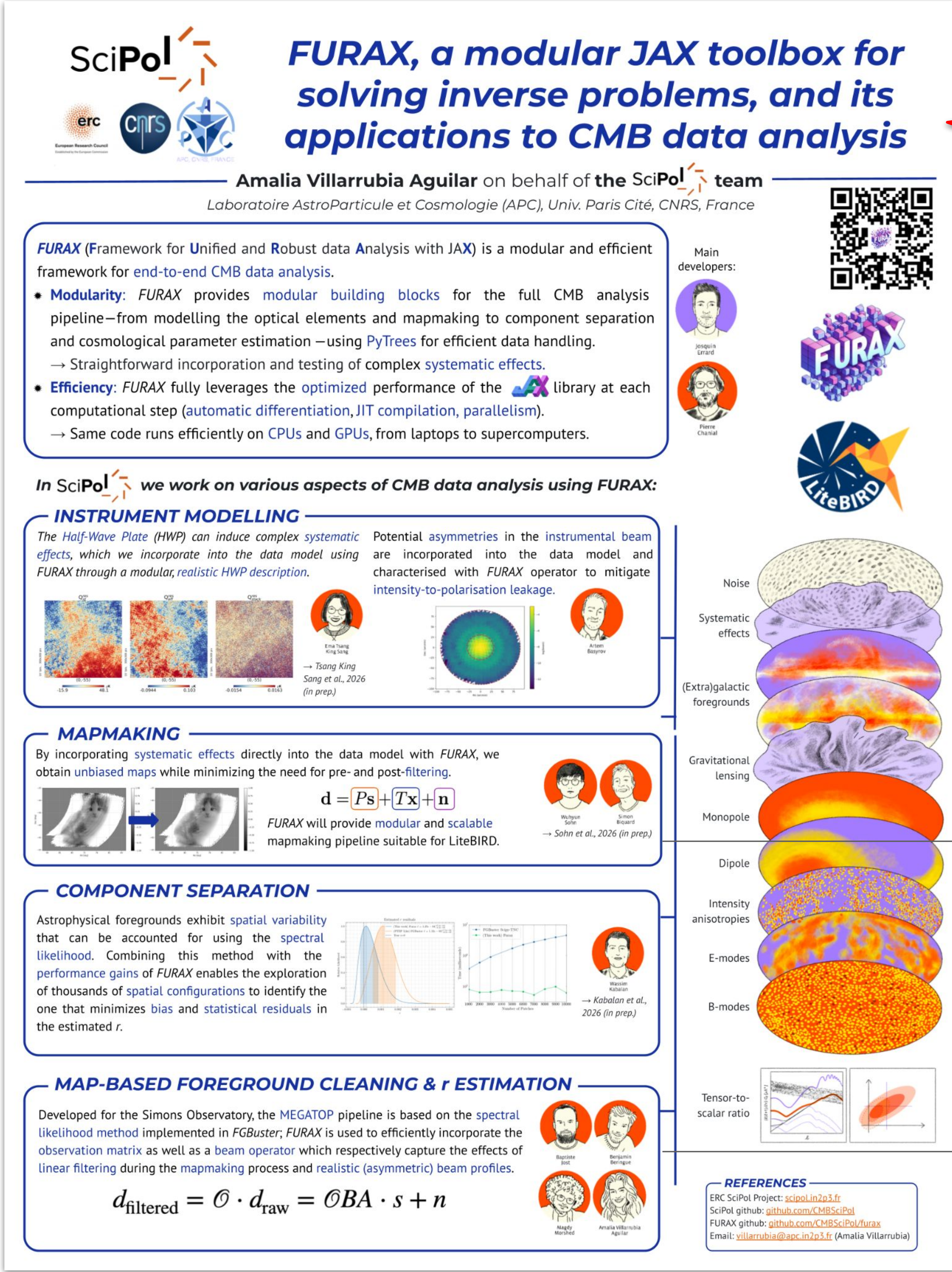
tsang@apc.in2p3.fr 12 CMB B-mode NEXT, KEK Tsukuba 01/2025

Component separation

- improving on PTEP (inclusion of more sky, different splitting of regions to handle **spatial variability** of foreground SEDs) → *Morshed et al. (2024)* + *Rizzieri et al. (2025)* + *Kabalan et al. (2026, in prep)*
- improvement of the component separation by explicitly including **beams** in the parametric component separation → *Rizzieri et al. (2024)*
- exploring **non-parametric** component separation → *Morshed et al. (2024), Leloup et al. (2025)* Tran Hoang Viet + Guillaume Patanchon + Benjamin Beringue working on a novel implementation of SMICA (using FURAX)
- we have been among the main developers of t performance pipeline, **from hardware configuration to constraints on r**





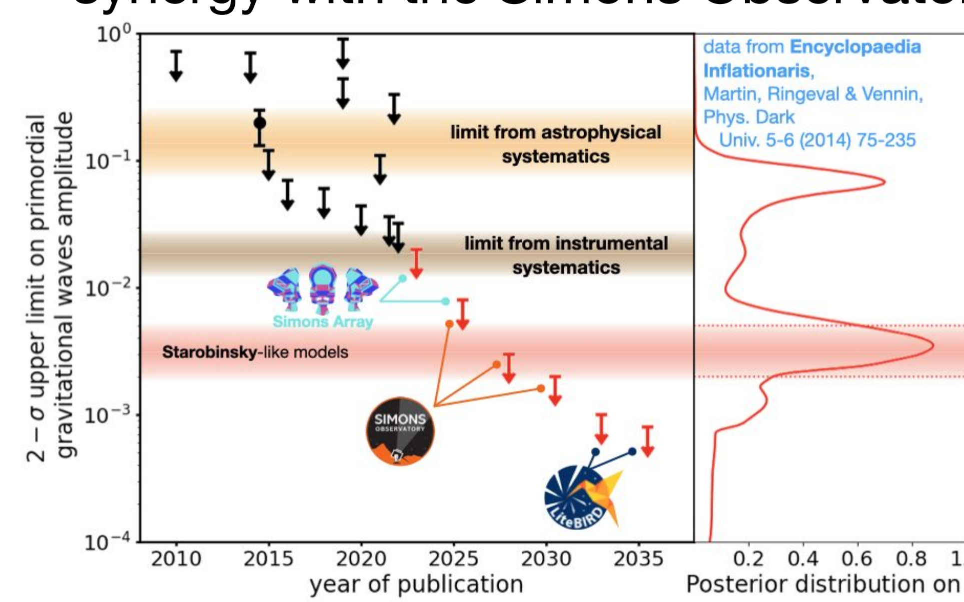


presented this week at the F2F @ IPMU, Tokyo

- + Involvement in the **post PTEP papers**:
  - **Out-of-band rejection requirements for LiteBIRD Medium and High Frequency Telescopes** (**Errard**, **Rizzieri**)**:** Studying the post component separation bias on r – Mousset et al. (in prep, internal review)
  - **E modes from LiteBIRD (Rizzieri)**: *FGBuster component separation*
  - Co-leading of **Cosmic Birefringence group** (**Errard**) – De la Hoz et al. (2025)
  - **Foreground Cleaning & Component Separation** (B-modes paper, **Tran Hoang Viet + Benjamin Beringue**)

NB: FURAX map-maker now interfaced with LiteBIRD-sims

synergy with the Simons Observatory!



Mathias Régnier (currently @ IRAP) applying to CNES postdoctoral fellowship to join APC

- unique expertise in CMB data analysis
- strong understanding of FURAX architecture
- led pioneering work on the modeling and treatment of astrophysical x instrumental systematics
- just attended the LiteBIRD F2F in Tokyo
- key for APC/SciPol to make FURAX a sustainable framework and to fully exploit its capabilities within LiteBIRD.

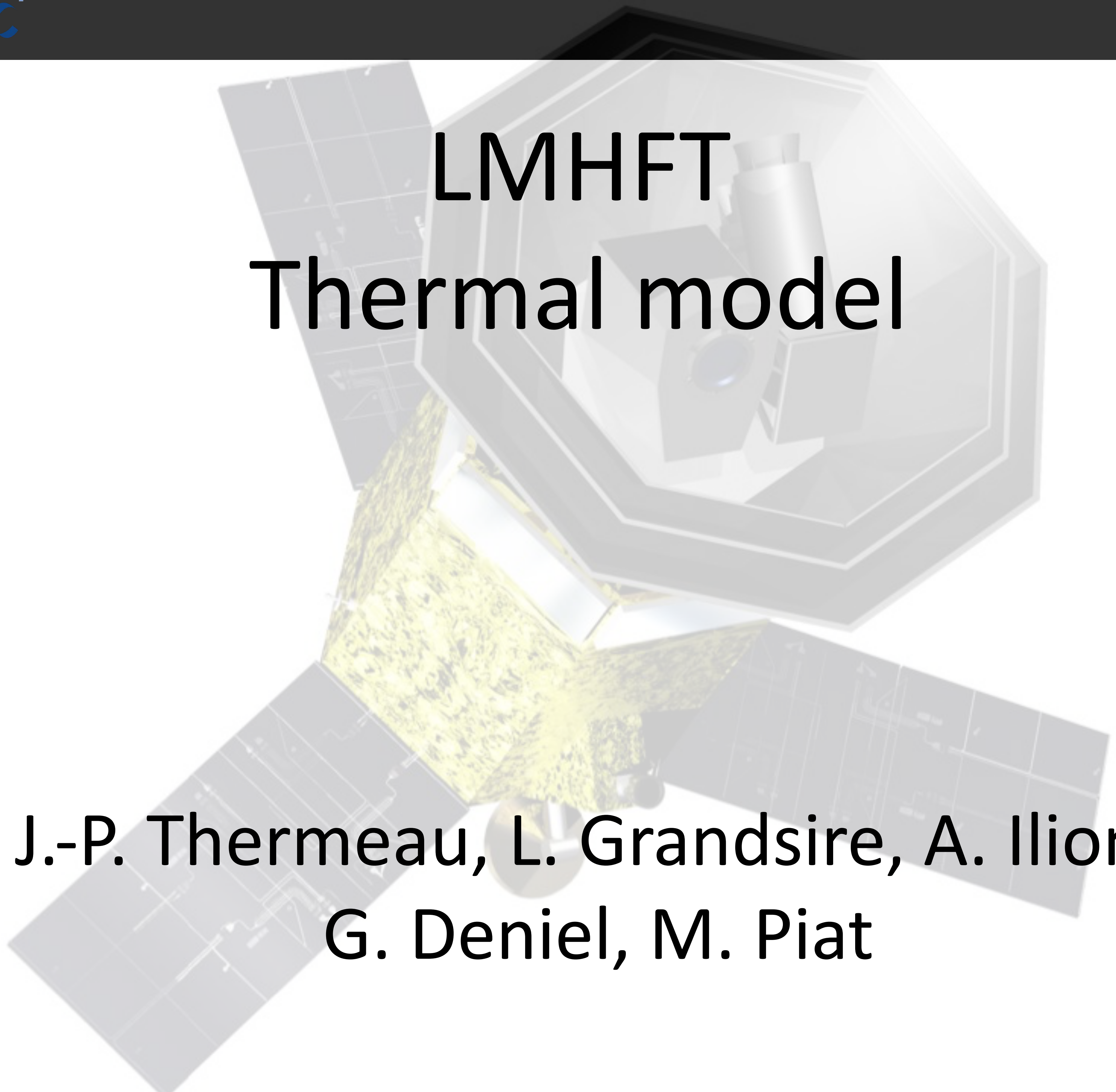
Main results :

Mathias Regnier

- Modeling of **complex beams** for CMB experiment
- Development of parametric and blind **component separation** method directly in the time domain
- Mitigation of i**nstrumental systematics** for CMB experiments using efficient codes
- Currently producing the state-of-the-art model for polarized thermal emission of the dust using realistic galactic magnetic field model

Publications – APR 2026
(>= 2024)

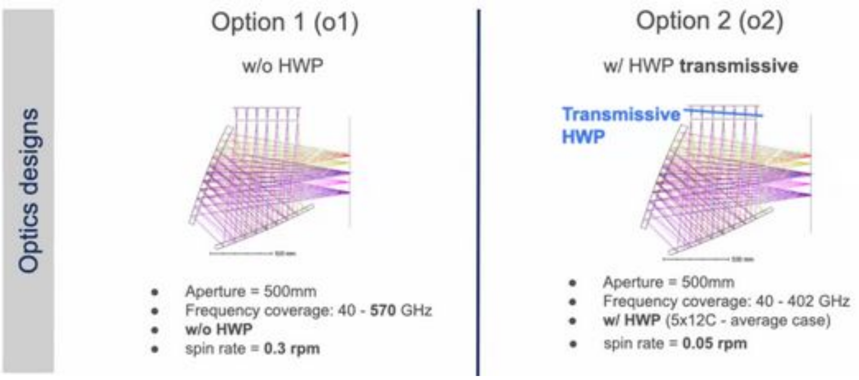
- Patanchon et al. 2024 “Effect of Instrumental Polarization with a Half-Wave Plate on the B-mode Signal: Prediction and Correction
- Leloup, Errard, Stompor, “Non-parametric maximum likelihood component separation for CMB polarization data”, Phys. Rev. D 108, 123547
- Leloup et al., JCAP 06 011 (2024), “Impact of beam far side-libe knowledge in the presence of foregrounds for LiteBIRD”
- Morshed, Rizzieri, Leloup, Errard, Stompor, “Pixel domain implementation of the Minimally Informed CMB MAp foreground Cleaning (MICMAC) method”, arXiv:2405.18365
- Rizzieri, Errard, Stompor, “Main beam treatment in parametric, pixel-based component separation”, arXiv:2409.12944
- Vergès, Errard, Stompor, “Framework for analysis of next generation, polarized CMB data sets in the presence of Galactic foregrounds and systematic effects”, Physical Review D, Volume 103, Issue 6, article id.063507 (2021)
- The LiteBIRD collaboration, “Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey”, eprint arXiv:2202.02773 (Feb 2022), accepted for publication in PTEP, doi:10.1093/ptep/ptac150.
- El Bouhargani et al, “MAPPRAISER: A massively parallel map-making framework for multi-kilo pixel CMB experiments”, accepted for publication in Astronomy and Computing (2022).
- Jost, Errard, Stompor, “Characterising cosmic birefringence in the presence of galactic foregrounds and instrumental systematic effects”, arXiv:2212.08007, submitted to PRD (2023).
- Azzoni et al. “A hybrid map-$C\ell$ component separation method for primordial CMB B-mode searches”, Journal of Cosmology and Astroparticle Physics, Volume 2023, Issue 03, id.035, 28 pp. (2023).
- Giardiello et al. “Detailed study of HWP non-idealities and their impact on future measurements of CMB polarization anisotropies from space”, Astronomy & Astrophysics, Volume 671, id.C1, 3 pp. (2023)
- Leloup et al , “Forecasting the performance of the minimally informed foreground cleaning method for CMB polarization observations”, Phys. Rev. D 112, 043531 (2025)
- A. Rizzieri et al., “Cleaning Galactic foregrounds with spatially varying spectral dependence from CMB observations with FGBuster” in prep. → published
- A. Kabalan, A. Rizzieri et al. “A novel approach to optimize clustering for parametric map-based component separation for upcoming CMB polarization satellites”, in prep.
- G. Sathyanathan, J. Errard and S. Basak, “Parameterizing Noise Covariance in Maximum-Likelihood Component Separation”, in prep.



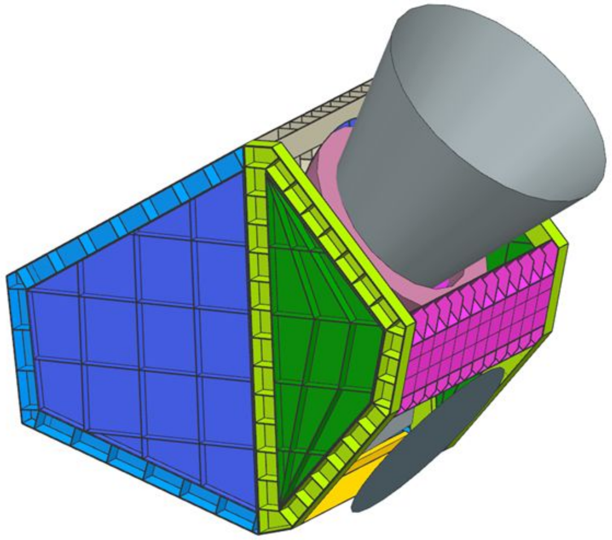
LMHFT
Thermal model

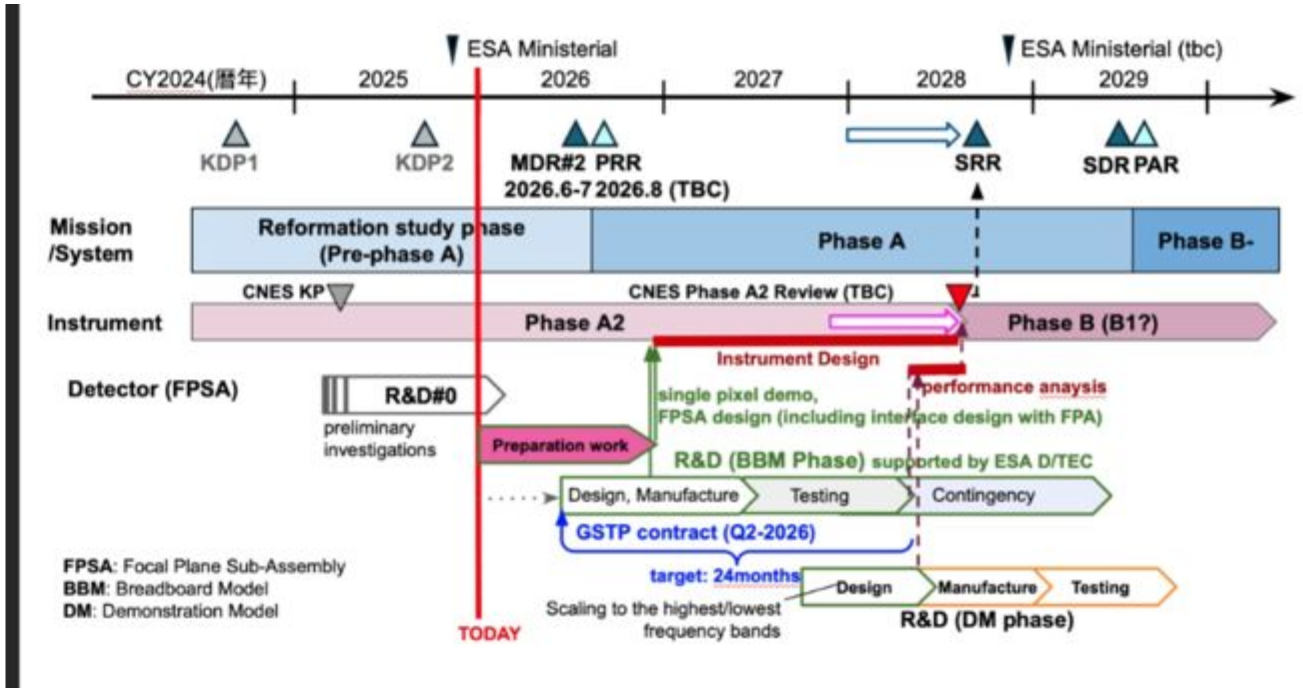
J.-P. Thermeau, L. Grandsire, A. Ilioni,
G. Deniel, M. Piat

- Actuellement en phase de reformation
  - Les trois instruments ont été réunis en un seul → LMHFT
  - Architecture optique : Option #2 est la baseline, Option #1 en back-up
  - Définition du plan focal et fournisseur des détecteurs encore inconnus à ce stade -> R&T TES @ CEA LETI/APC
  - IRAP travaille sur la CAO de l'instrument



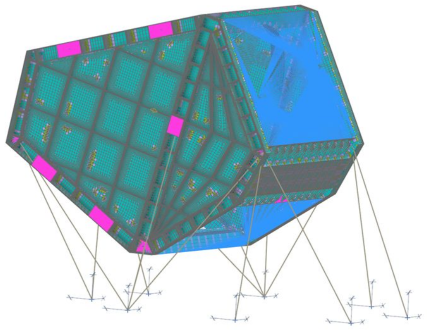
- Statut du projet
  - Objectif actuel : définir en détail la baseline

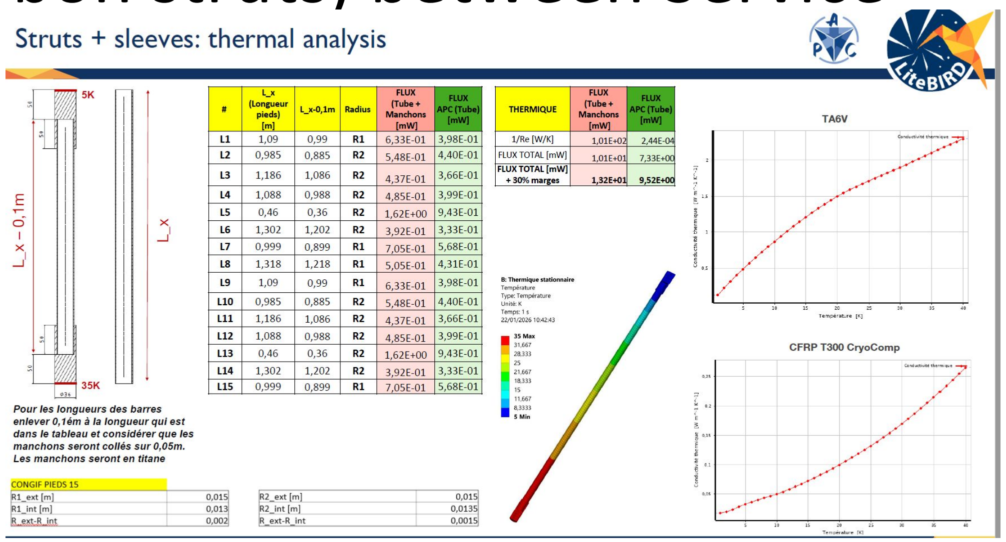




Future plan

- Short term (before JAXA MDR) :
  - Estimate of thermal conduction (via carbon struts) between Service Module and LMHFT





Struts + sleeves: thermal analysis

#	L_x (Longueur pieds) [m]	L_x-0,1m	Radius	FLUX (Tube + Manchons [mW]	FLUX APC (Tube) [mW]
L1	1,09	0,99	R1	6,33E-01	3,98E-01
L2	0,985	0,885	R2	5,48E-01	4,40E-01
L3	1,186	1,086	R2	4,37E-01	3,66E-01
L4	1,088	0,988	R2	4,85E-01	3,99E-01
L5	0,46	0,36	R2	1,62E+00	9,43E-01
L6	1,302	1,202	R2	3,92E-01	3,33E-01
L7	0,999	0,899	R1	7,05E-01	5,68E-01
L8	1,318	1,218	R1	5,05E-01	4,31E-01
L9	1,09	0,99	R1	6,33E-01	3,98E-01
L10	0,985	0,885	R2	5,48E-01	4,40E-01
L11	1,186	1,086	R2	4,37E-01	3,66E-01
L12	1,088	0,988	R2	4,85E-01	3,99E-01
L13	0,46	0,36	R2	1,62E+00	9,43E-01
L14	1,302	1,202	R2	3,92E-01	3,33E-01
L15	0,999	0,899	R1	7,05E-01	5,68E-01

THERMIQUE	FLUX (Tube + Manchons [mW]	FLUX APC (Tube) [mW]
1/Re [W/K]	1,01E+02	2,44E-04
FLUX TOTAL [mW]	1,01E+01	7,33E+00
FLUX TOTAL [mW] + 30% marges	**1,32E+01**	**9,52E+00**

Pour les longueurs des barres enlever 0,1ém à la longueur qui est dans le tableau et considérer que les manchons seront collés sur 0,05m. Les manchons seront en titane

CONGIF PIEDS 15	
R1_ext [m]	0,015
R1_int [m]	0,013
R_ext-R_int	0,002

R2_ext [m]	0,015
R2_int [m]	0,0135
R_ext-R_int	0,0015

- Long term :
  - Nodal global thermal model of LMHFT
  - Steady state results :
    - Thermal loads between nodes
    - Heat loads of each cold stage
  - Transient studies : First results of the cold stage sensitivity to sinusoidal excitations
  - Impact of the sky heat load variation on the cold stages
  - Sensitivity analysis

Prototypage d'une matrice de détecteurs TES pour le plan focal LiteBird

Référence ESA: GT17-818EF – Integrated submillimetre wave antenna-coupled dual-polarization focal plane array and detection chain

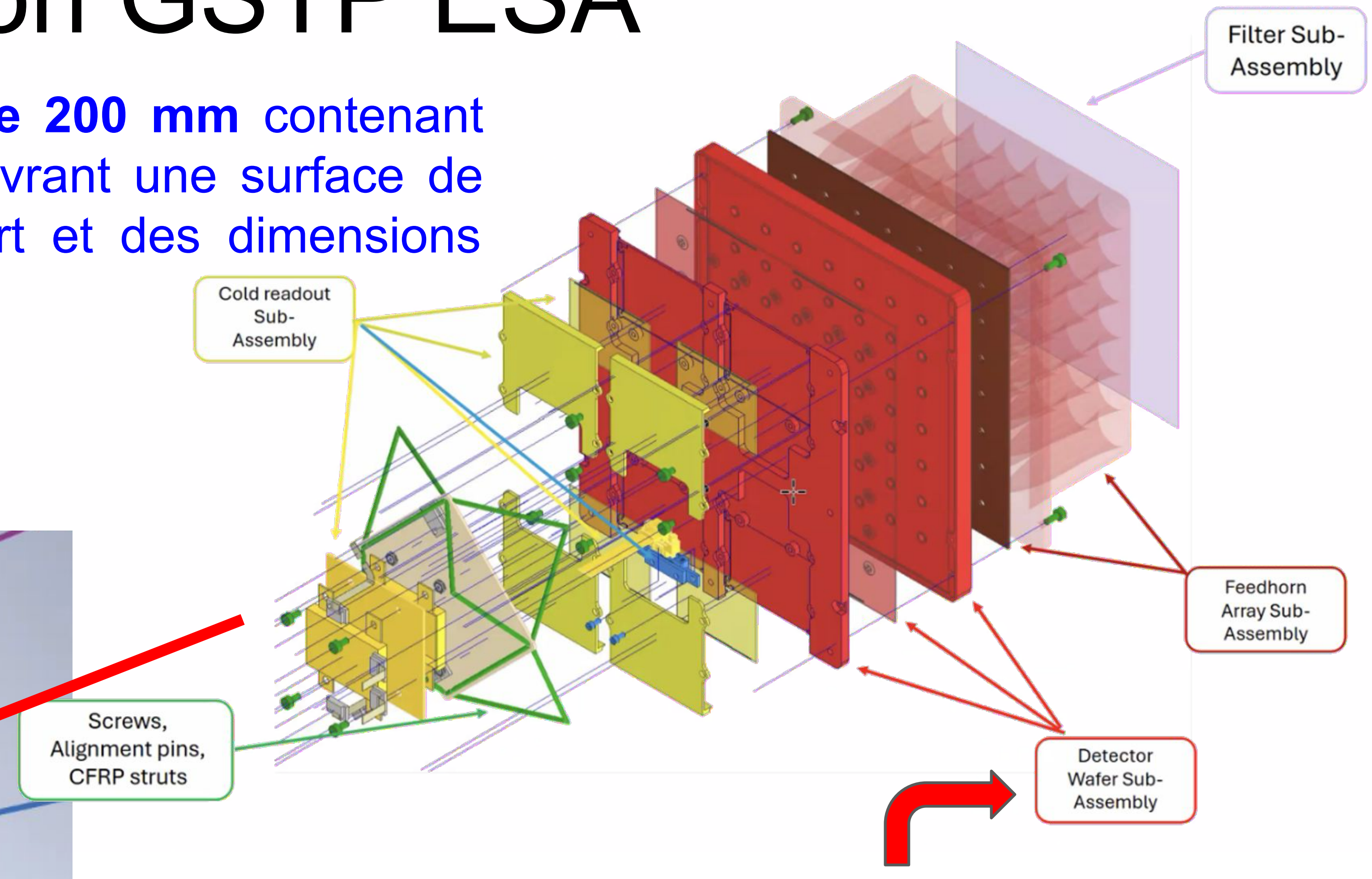
Consortium: CEA-LETI, APC, CEA-IRFU, IRAP, LBNL

Proposition ESA GSTP: TES@LETI

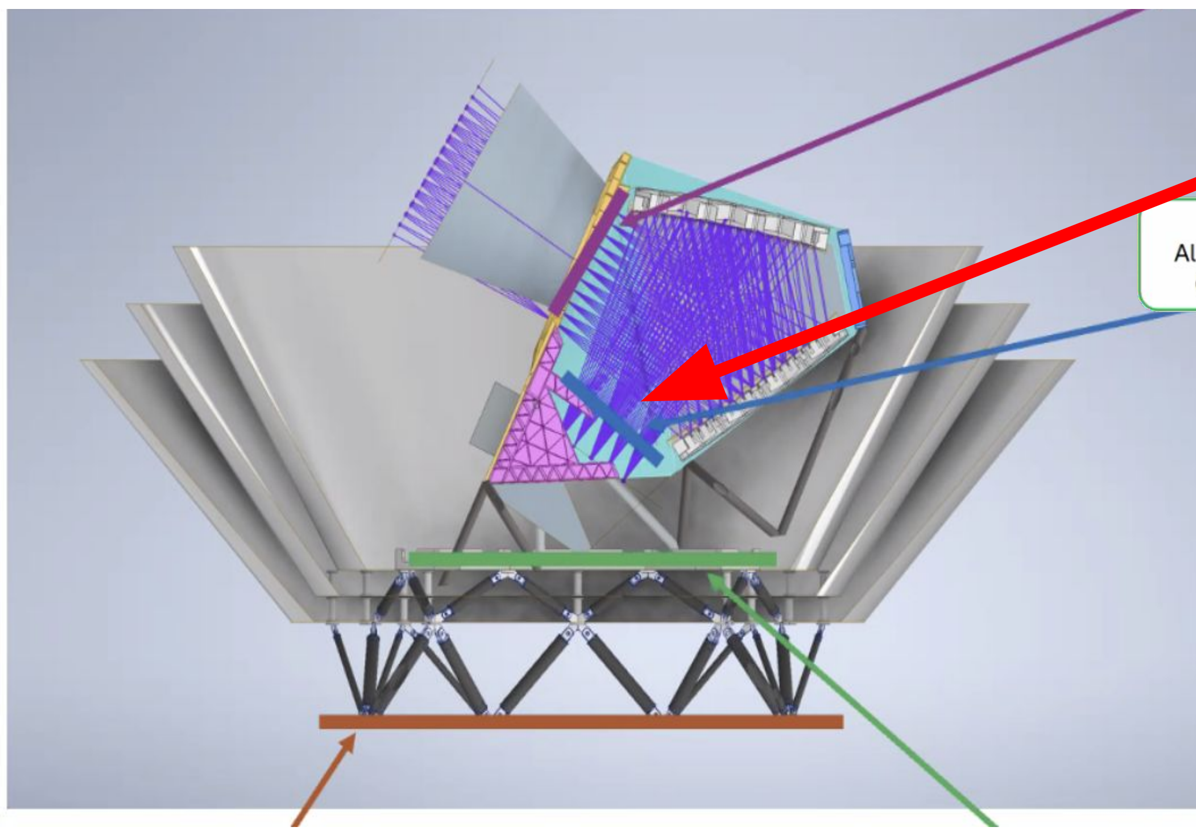
- Consortium INFN-SRON-UK
  - GSTP ESA
  - Proposition de collaboration:
    - Design et fabrication de TES au LETI
    - Gamme de fréquence complémentaire du SRON
    - Permet de paralléliser les développements
    - Liens privilégiés avec Berkeley (détecteurs CMB-S4)
  - **Refus de collaboration!**
    - SRON semi-industriel
- Proposition GSTP indépendante
  - LETI, CEA-IRFU, APC
  - Premiers retours positifs du CNES

Objet de la proposition GSTP ESA

➔ Réalisation d'un ensemble de **wafers de 200 mm** contenant chacun une **matrice de 144 pixels** couvrant une surface de 10^4 mm^2 représentative de l'état de l'art et des dimensions prévues pour LiteBird.



Positionnement du plan focal dans le dispositif optique de LiteBIRD:



➔ Développement de la partie sensible du FPA:

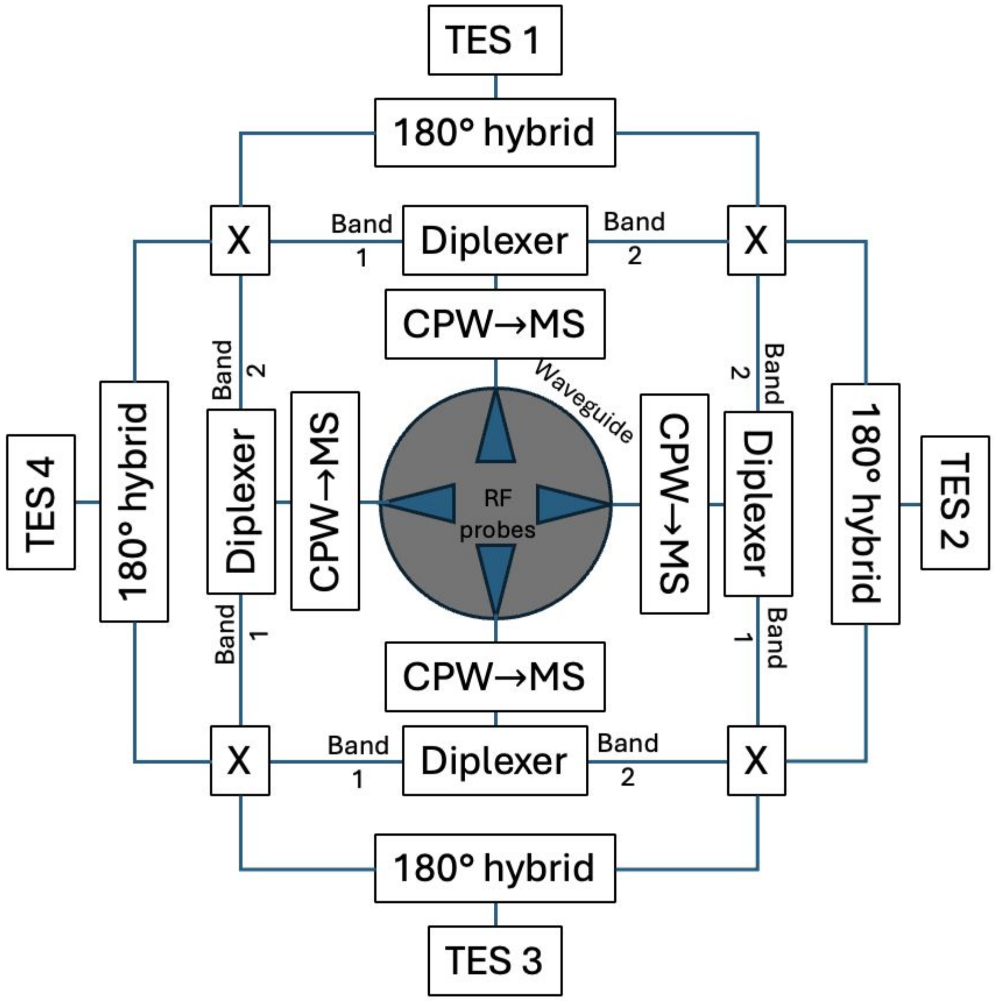
- **Démonstration de faisabilité des procédés critiques**
- **Conception du détecteur complet** (antennes pour mesurer la polarisation, diplexeur pour séparer les bandes, détecteur TES pour mesurer l'intensité du rayonnement et connections entre les fonctions)
- **Caractérisation du détecteur**

➔ Les autres parties du plan focal sont développées dans d'autres laboratoires du consortium LiteBIRD (SRON, U Cardiff, U. Roma, Pise, etc..)

Objectifs techniques

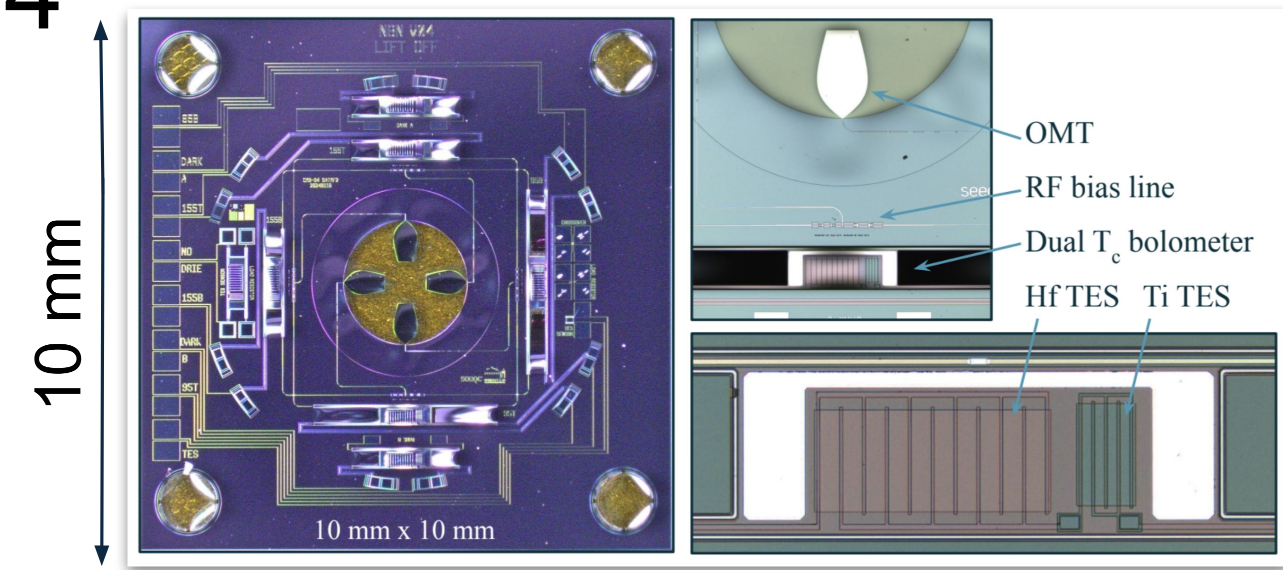
Développer à **TRL5** un prototype de **matrice de détecteurs TES** (Transition Edge Sensors) **double-polarisation double bande** dans le domaine millimétrique pour les futures missions scientifiques telles que LiteBird ou d’autres missions ESA du programme Voyage 2050

- Matrice 12x12 pixels
- Température: 100mK
- Bandes HF1 de Litebird: 217GHz et 334GHz, $\Delta\nu/\nu = 30\%$
- 2 polarisations
- NEP ~ 6.10^{-18} $W.Hz^{-0.5}$

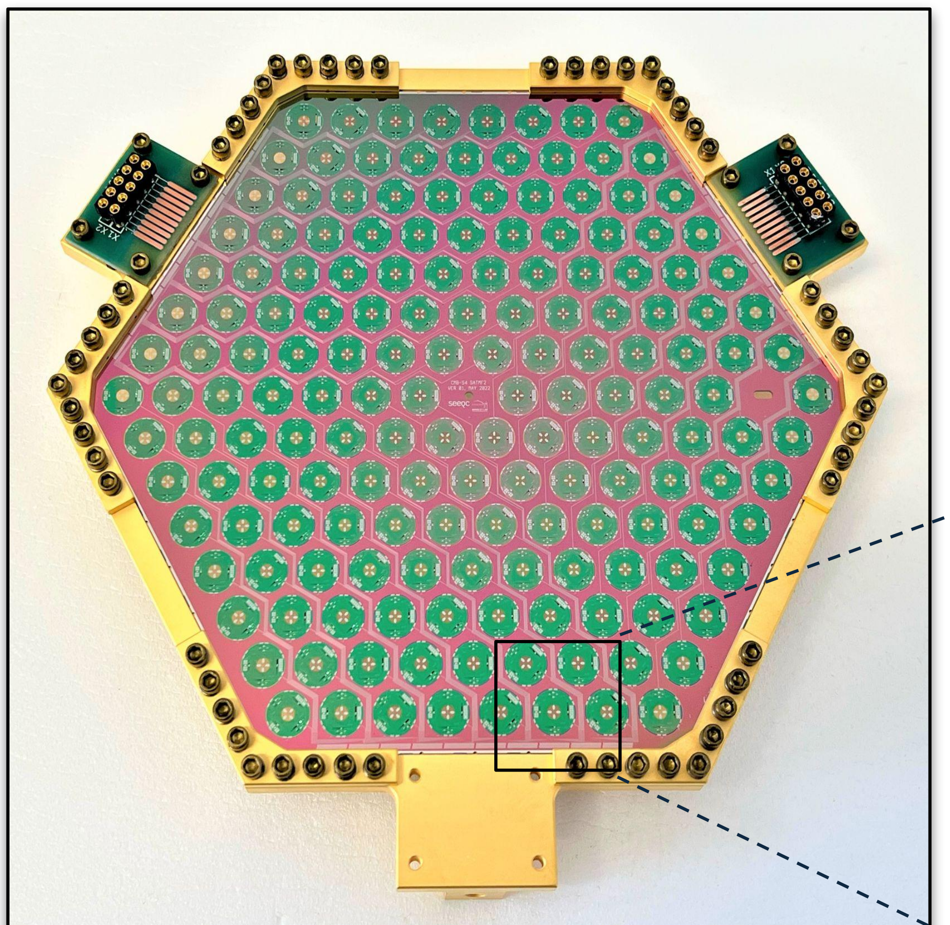


Architecture d’un pixel

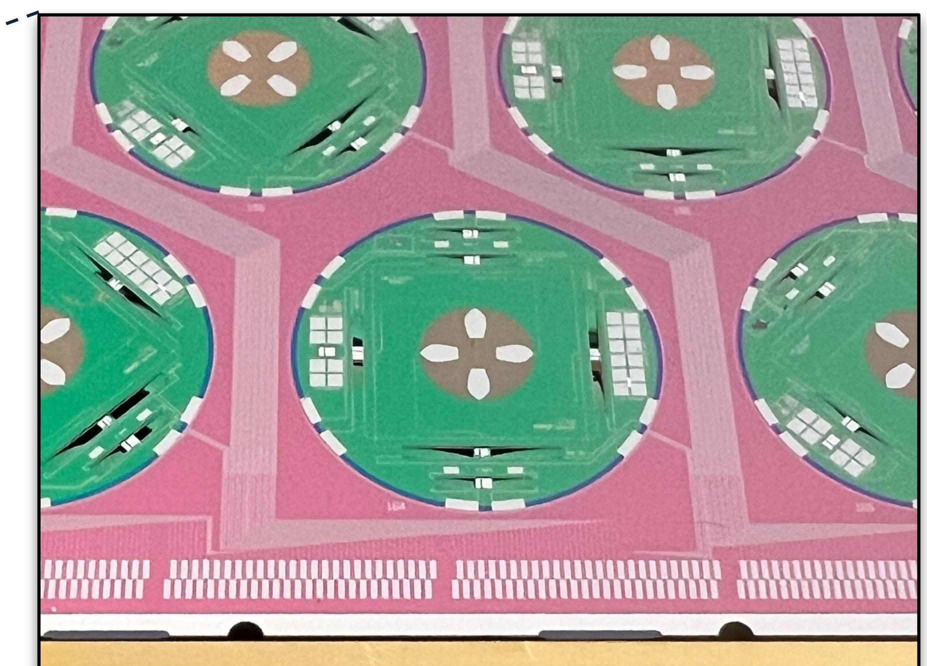
Exemple de matrice CMB-S4 (LBNL, USA)



[Rotermund 2025]



[Suzuki 2024]

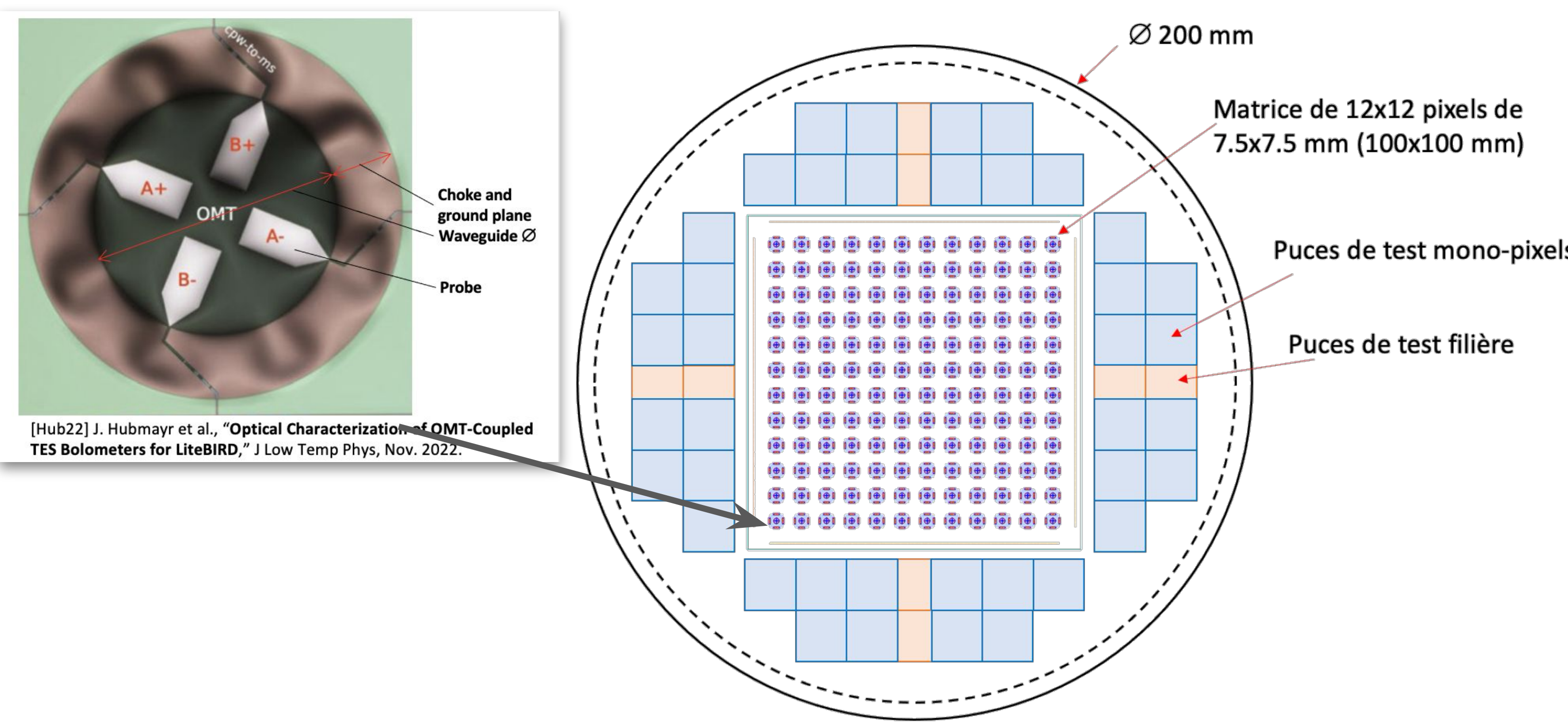


LBNL/Seeqc SAT MF2 (95/155GHz) fabricated prototype detector arrays

- 98.9% electrical yield
- Hafnium TES

Objets livrables

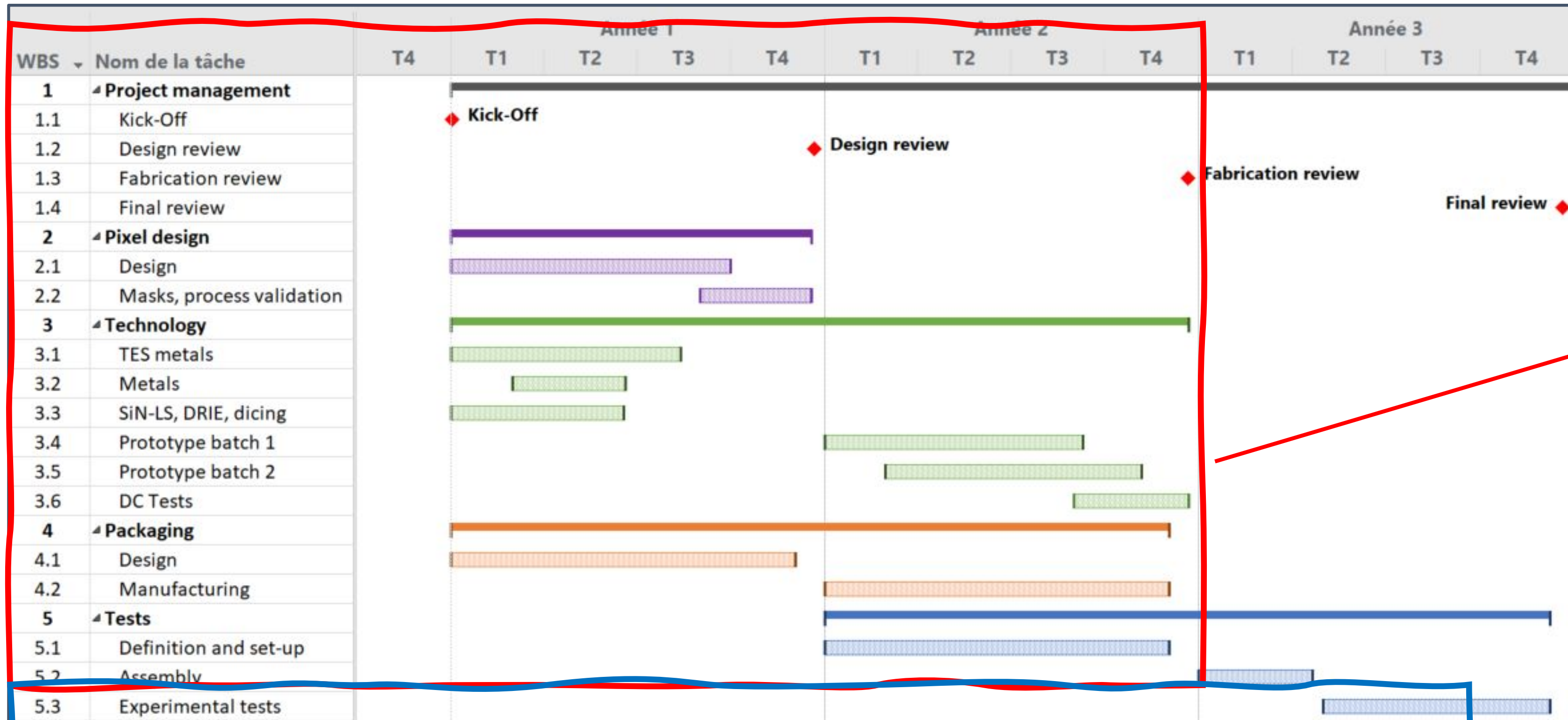
- ➔ **Deux lots de fabrication comprenant 12 wafers** (200 mm) chacun.
- ➔ Sur chaque wafer:
  - ◆ Puces de test filière
  - ◆ **Une matrice de 144 pixels** (100x100 mm^2) au centre
  - ◆ **Une quarantaine de mono-pixels et structures RF** permettant de tester individuellement des variantes technologiques destinées à optimiser/sécuriser le design.



Description préliminaire d'un wafer prototype

- ➔ **Tests au niveau filière de chaque wafer** permettant d'établir un rendement de fabrication (opérabilité)
- ➔ **Tests électriques à 100mK** sur quelques détecteurs: Tc, caractéristiques V(I,T)
- ➔ Mesures optiques: au cours de la 3ème année du développement (hors GSTP) dans les laboratoires techniques concernés APC et DAp

Plan de développement et WBS



<u>Projet proposé</u>

WP1: Management

WP2: Pixel and prototype design

- ➢ **Rapport de conception**

WP3: Technology

- ➢ Année 1: lots d'étude des procédés
- ➢ Année 2:
  - **Deux lots prototypes**
  - Tests DC complets à 300K
  - Premiers tests DC à basse température
  - **Rapport de fabrication et de test DC**

<u>Travaux d'accompagnement avec les partenaires LiteBird</u>

WP4: Packaging

Conception et réalisation des montures, cornets et interfaces de test.

WP5: Tests

Préparation et réalisation des tests optiques à basse température.

APC:

➔ WP2: Design

➔ WP3: Tests DC

APC hors GSTP:

➔ WP4: Packaging

➔ WP5: Tests

Points forts de la proposition GSTP ESA

Visite de Aritoki Suzuki à l'APC de Nov. 2026 à Janvier 2027

- **Héritage US:** accord entre labo français et LBNL pour transfert de compétences et design (technologie type CMB-S4)
- **Compétence française dans le domaine**
    - Centrale technologique LETI 200mm
    - Héritage programme spatial TRL9 (Herschel, Planck)
- **Importance stratégique des développements détecteurs et opportunité**
    - Complémentarité gamme de fréquence SRON (action de forte diminution de risques développement détecteurs)
    - Brique clé qui conforte la position de PIship français
- **Perspective de valorisation**
    - Projet FOSSIL (back-up bolomètres)
    - Line Intensity Mapping: structure à grande échelle et évolution de l'Univers.
    - Technologies quantiques

Demande de financement : **46.2k€** total demandé au CNES au titre de l'APR 2026

- **Vacation** : 10.8k€ → 6k€
  - 16 mois de stage niveau M2 et/ou école ingénieur
- **Missions** : 25k€ → 9k€
  - **Conférences scientifiques** (SPIE 2026, B-modes from space...) : 8 missions (4 à 9 jours)
- **Frais de gestion CNRS / Laboratoire** : 3.4k€

- bon de commande 13k€ au printemps

Justification financement :

- **Vacation** : Nous prévoyons de prendre deux stagiaires école d'ingénieur ou M2 pour travailler sur les effets systématiques/thermiques et sur les aspects analyse de données et un stagiaire école d'ingénieur pour travailler sur les aspects thermiques en régime instationnaire.
- **Missions** : Les réunions de collaborations sont prises en charge par le projet LiteBIRD mais nous demandons ici la participation indispensable à tout travail scientifique à des conférences scientifiques et ateliers internationaux.