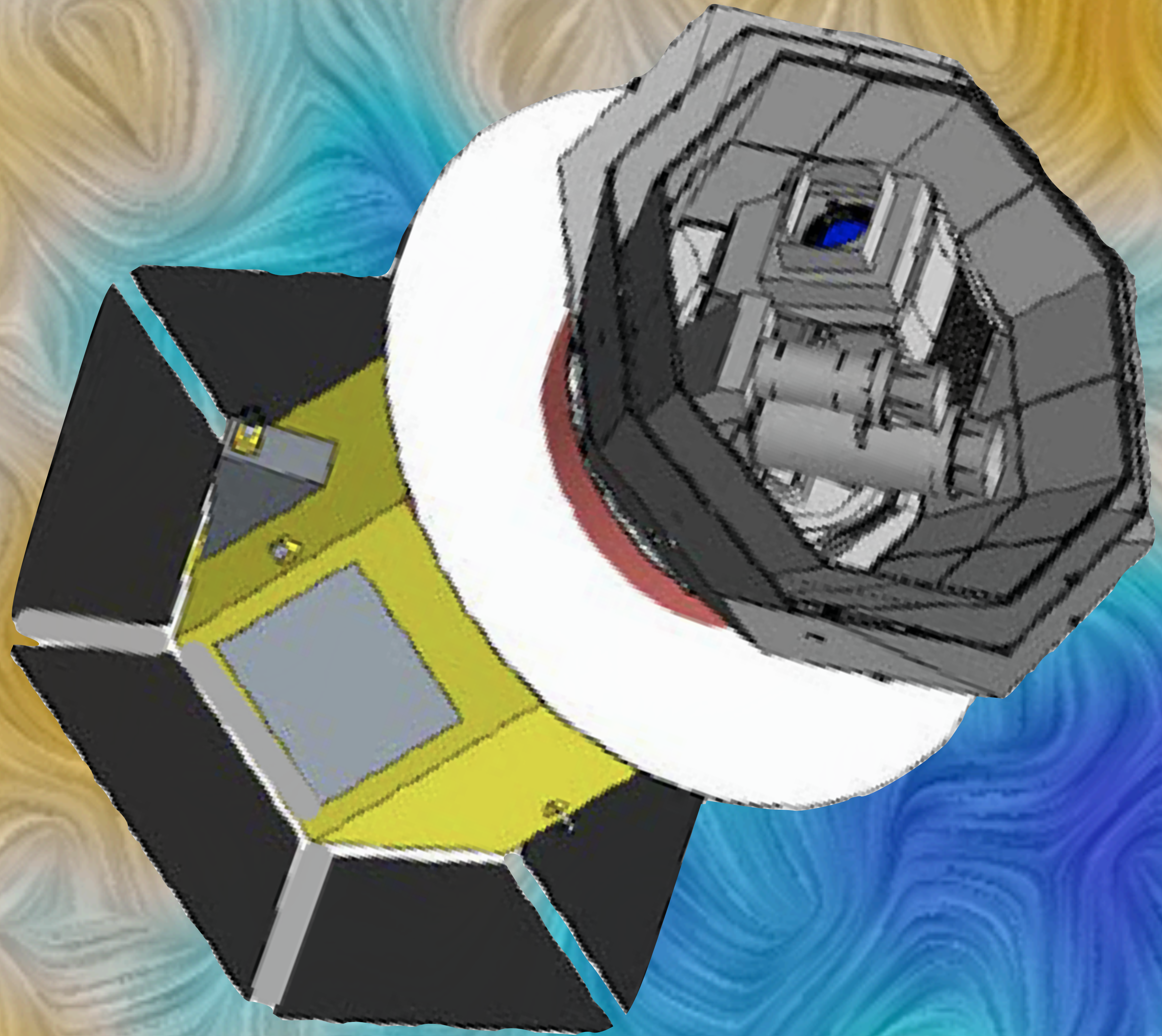
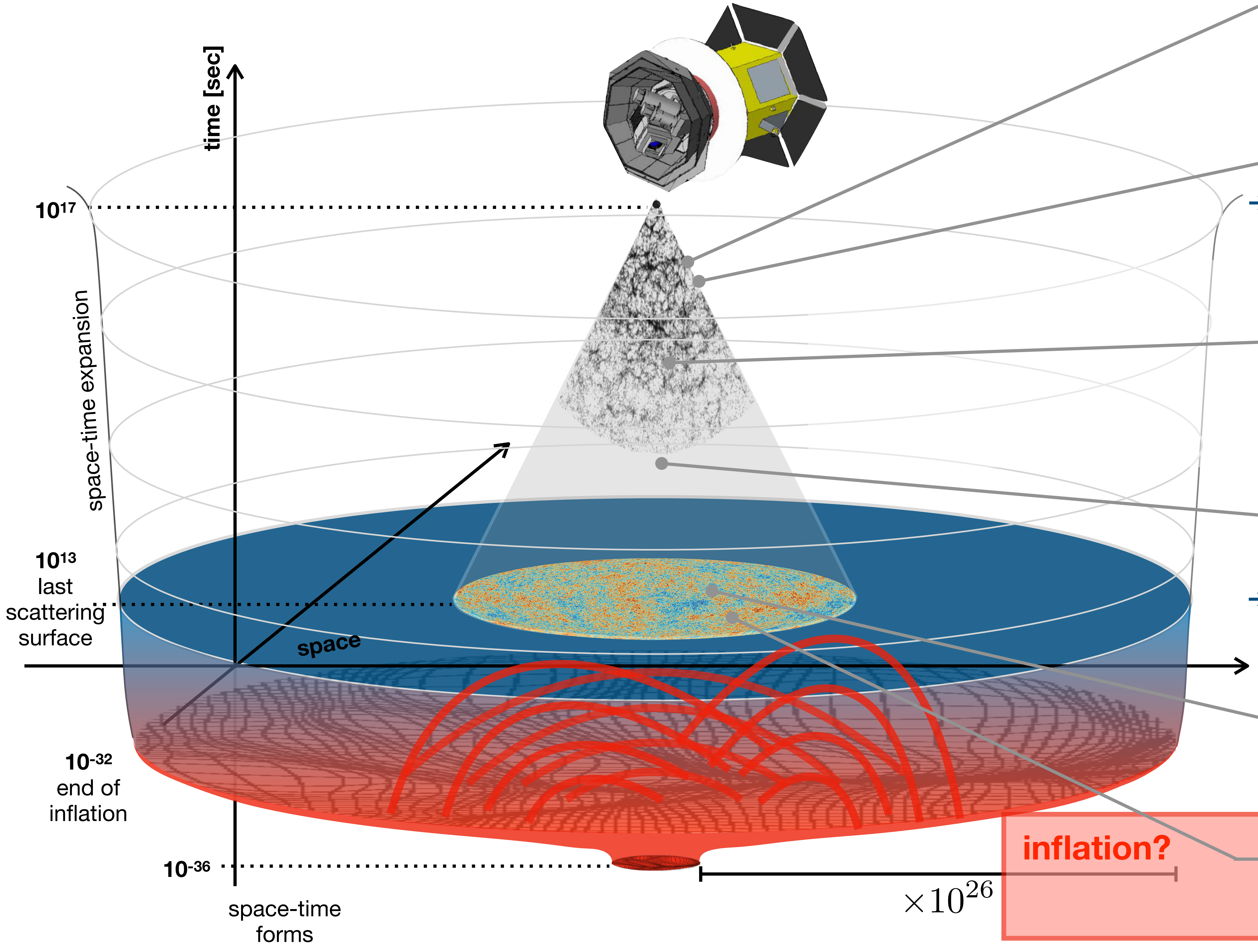
LiteBIRD
&
the quest for the primordial gravitational waves



L. Montier
on behalf of LiteBIRD Collaboration

Looking for Primordial Gravitational Waves



dark energy

tSZ, lensing
→ σ_8 at z=2-3 (lensing, tSZ)
→ growth of structure (kSZ)

galaxy evolution

tSZ, kSZ
→ non-thermal pressure (tSZ+kSZ)
→ feedback efficiency (tSZ+kSZ)

neutrino mass

lensing potential (TT+EB), tSZ
→ Σm_ν

reionization

sources
→ duration of reionization (kSZ)
→ mean free path of photons (kSZ)

relativistic species

damping tail
→ N_{eff} (TE, TT, EE)

inflation? **primordial fluctuations**

large scale B-modes
→ tensor-to-scalar ratio (BB)

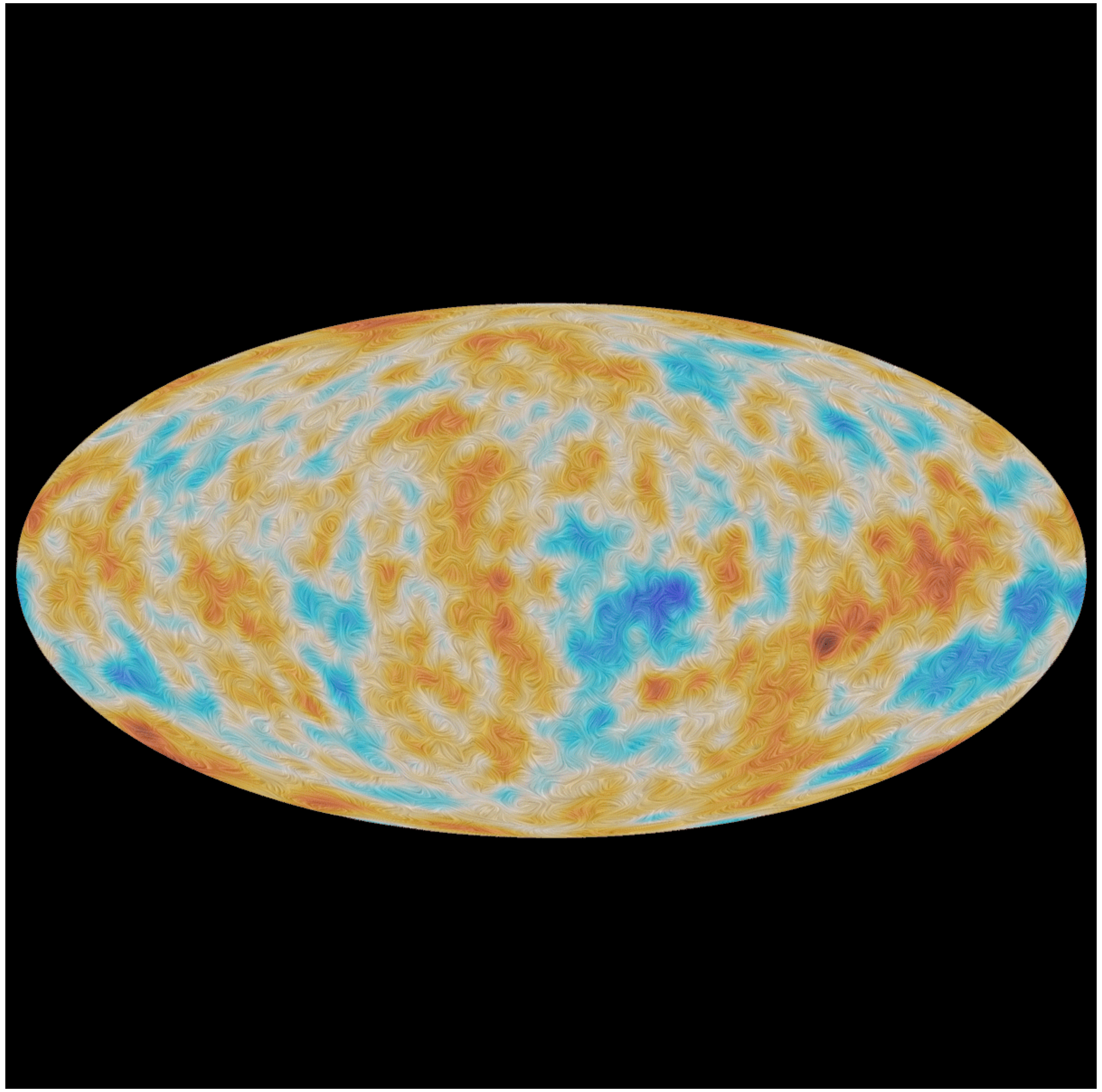
damping tail
→ primordial power on small scales (TE, TT, EE)
→ primordial bispectrum (f_{NL} via TTT,TTE,… + lens/kSZ)

Looking for Primordial Gravitational Waves

The imprints of gravitational waves on CMB polarisation signal

E-Modes

Curl-free



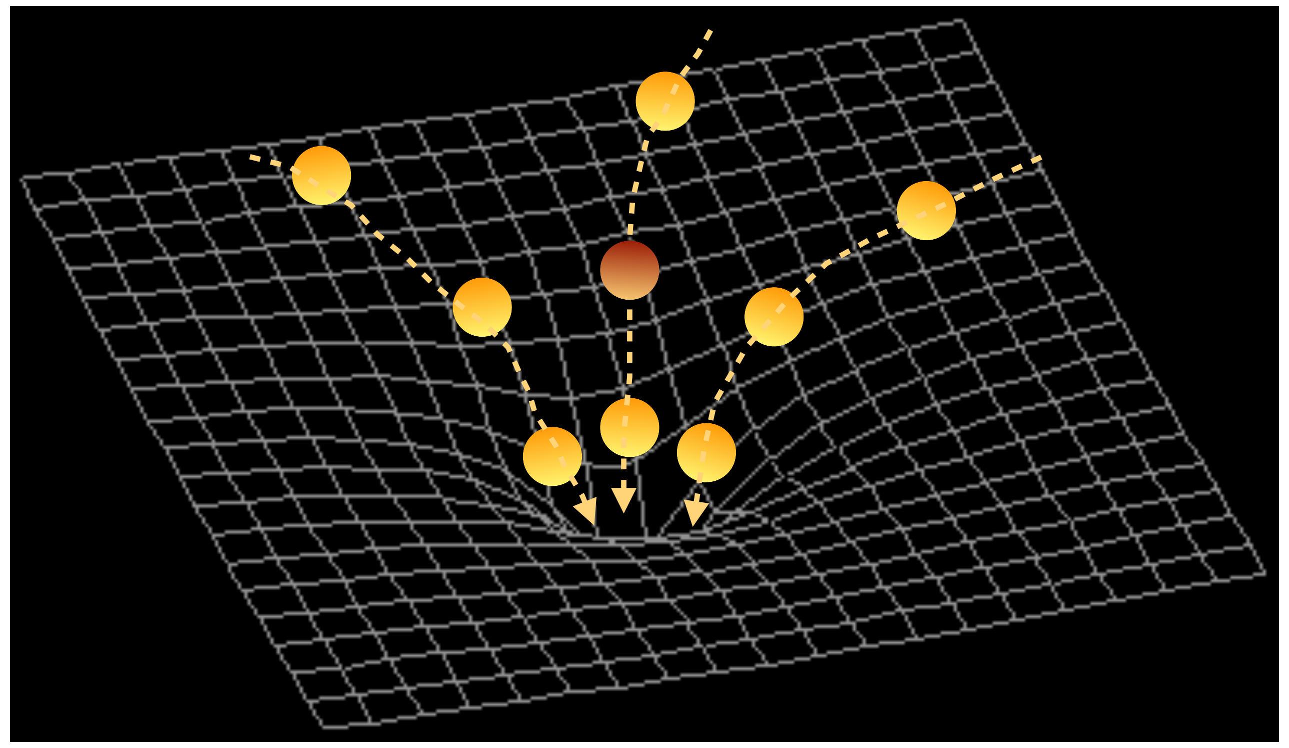
B-Modes

Div-free

Looking for Primordial Gravitational Waves

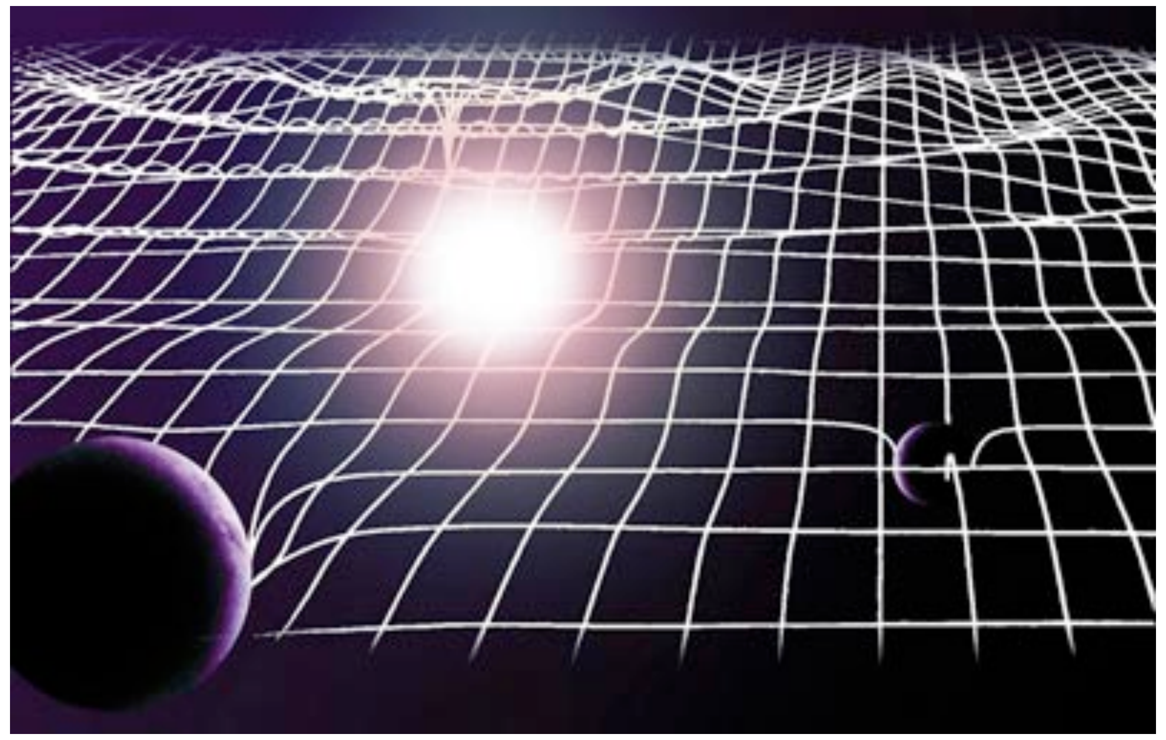
… as tracers of the Inflation period

Density fluctuations

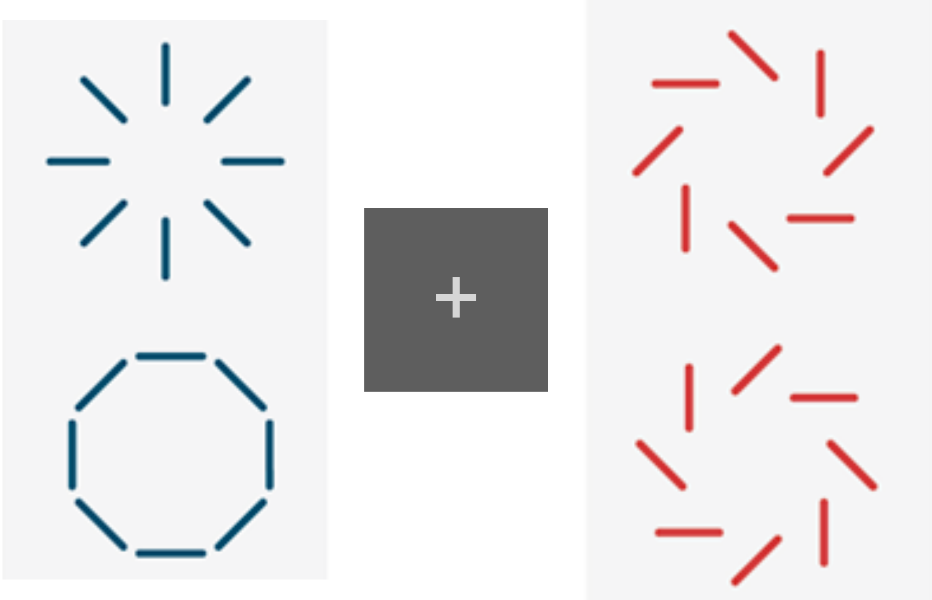


E-Modes

Gravitational waves



E-Modes B-Modes



Inflation

↓

Quantum fluctuations of Spacetime

↓

Primordial Gravitational Waves

↓

Vortex in CMB polarisation map (B-modes)

Opportunity to probe the Cosmic Inflation but also to shed light on GUT-scale physics

Observational test of quantum gravity

Looking for Primordial Gravitational Waves

… as tracers of the Inflation period

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_0}\right)^{n_s-1}$$ scalar

$$\mathcal{P}_{\mathcal{T}}(k) = A_t \left(\frac{k}{k_0}\right)^{n_t}$$ tensor

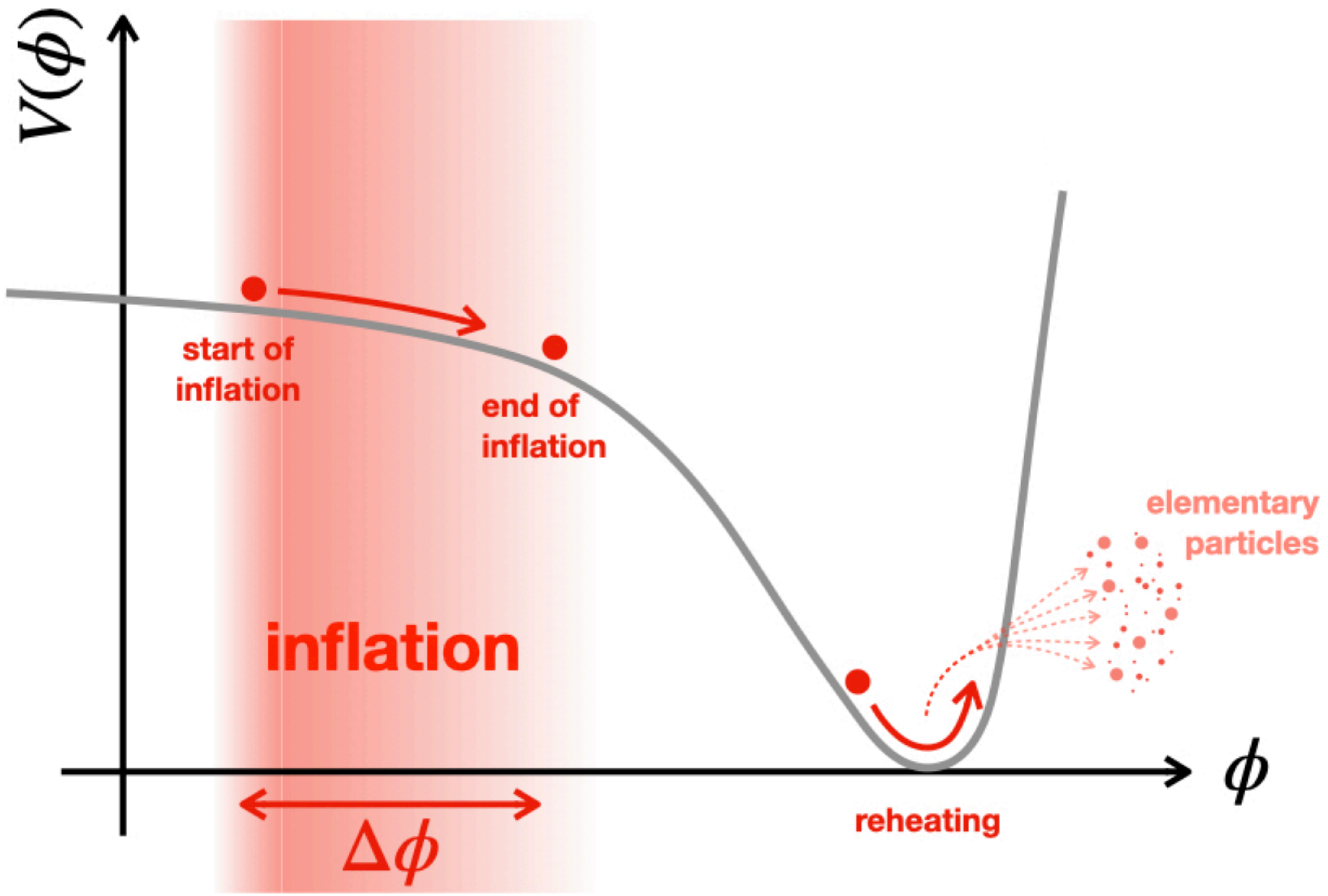
→ $r = A_t/A_s$ gives direct constraints on the shape of the Inflation potential:

Energy scale of inflation: $V^{1/4}(\phi) \simeq 10^{16}\,\mathrm{GeV}\left(\frac{r}{0.01}\right)^{1/4}$

Inflation field excursion: $\frac{\Delta\phi}{M_P} \simeq \mathcal{N}_* \left(\frac{r_*}{8}\right)^{1/2} \simeq \left(\frac{r}{0.001}\right)^{1/2}$

Derivatives of potential: $r = 8M_{\rm Pl}^2\left(\frac{V_\phi}{V}\right)^2$

$$n_s - 1 \equiv \frac{\mathrm{d}\ln\mathcal{P}_\zeta}{\mathrm{d}\ln k} \simeq -3M_{\rm Pl}^2\left(\frac{V_\phi}{V}\right)^2 + 2M_{\rm Pl}^2\frac{V_{\phi\phi}}{V}$$



Many open questions:

Where did field come from ?
Why did the field start in slow-roll ?
Why is the potential so flat ?
How do we convert the field energy into particules ?

Looking for Primordial Gravitational Waves

Looking for Primordial Gravitational Waves

Imprints from Big Bang are really everywhere

Looking for Primordial Gravitational Waves

Imprints from Big Bang are really everywhere

even B-Modes may be detected

The Challenge of detecting the CMB B-Modes

From Shibuya

Looking for Primordial Gravitational Waves

Imprints from Big Bang are really everywhere

even B-Modes may be detected

but you have to deal first with…

Noise

Looking for Primordial Gravitational Waves

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Noise

Instrumental Effects

Looking for Primordial Gravitational Waves

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Noise

Instrumental Effects

Foregrounds

Looking for Primordial Gravitational Waves

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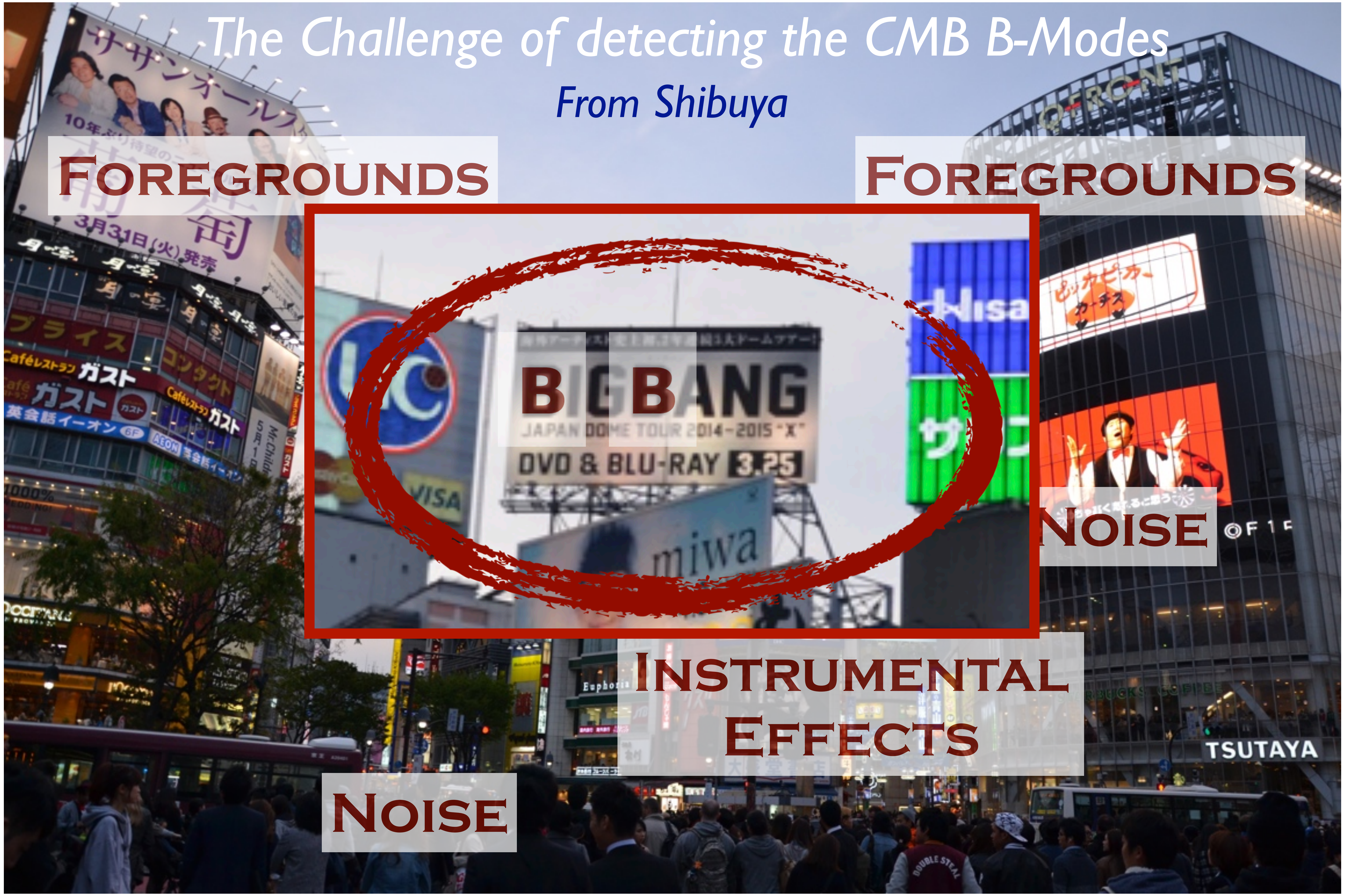

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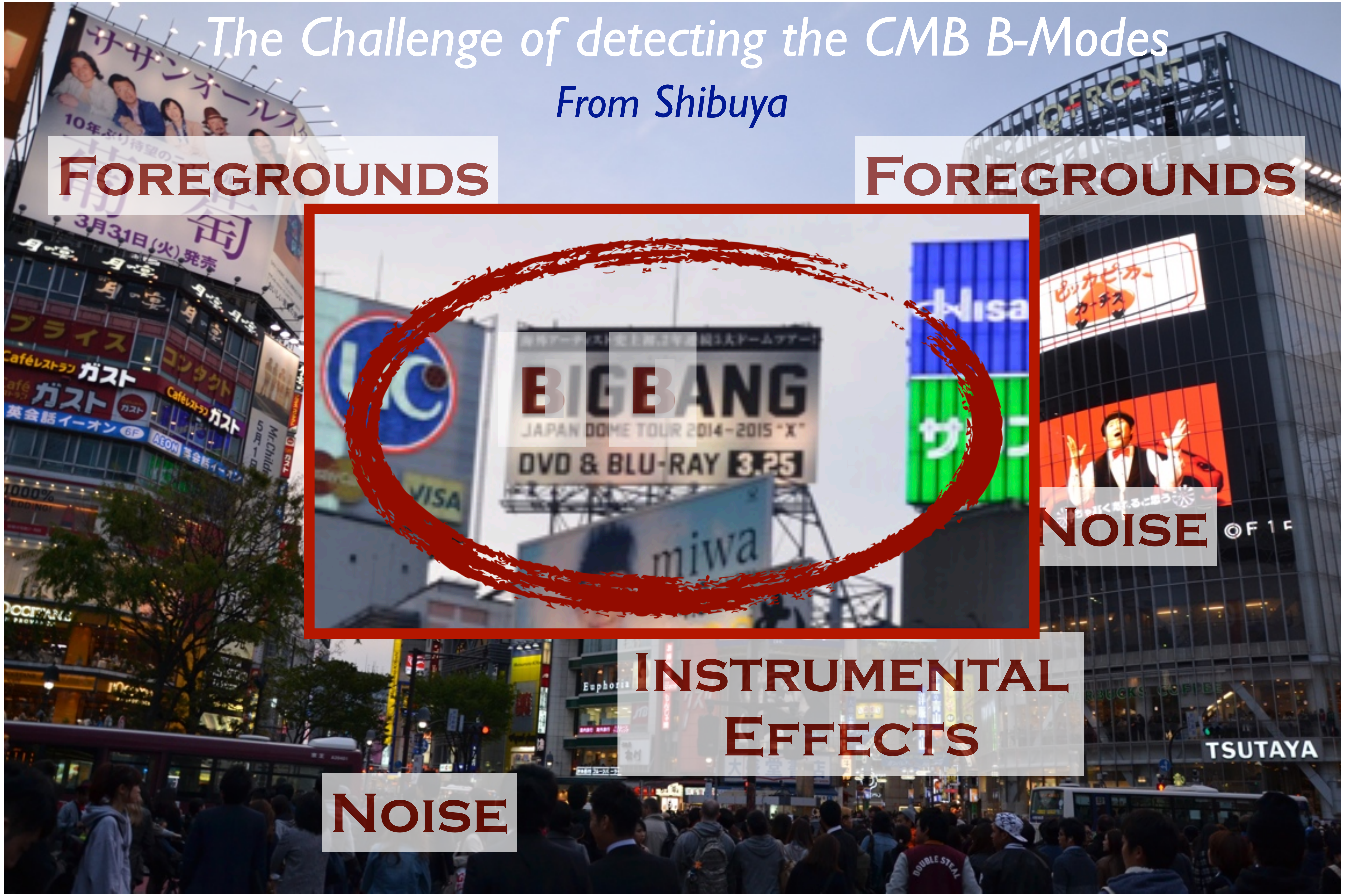


Noise

Instrumental Effects

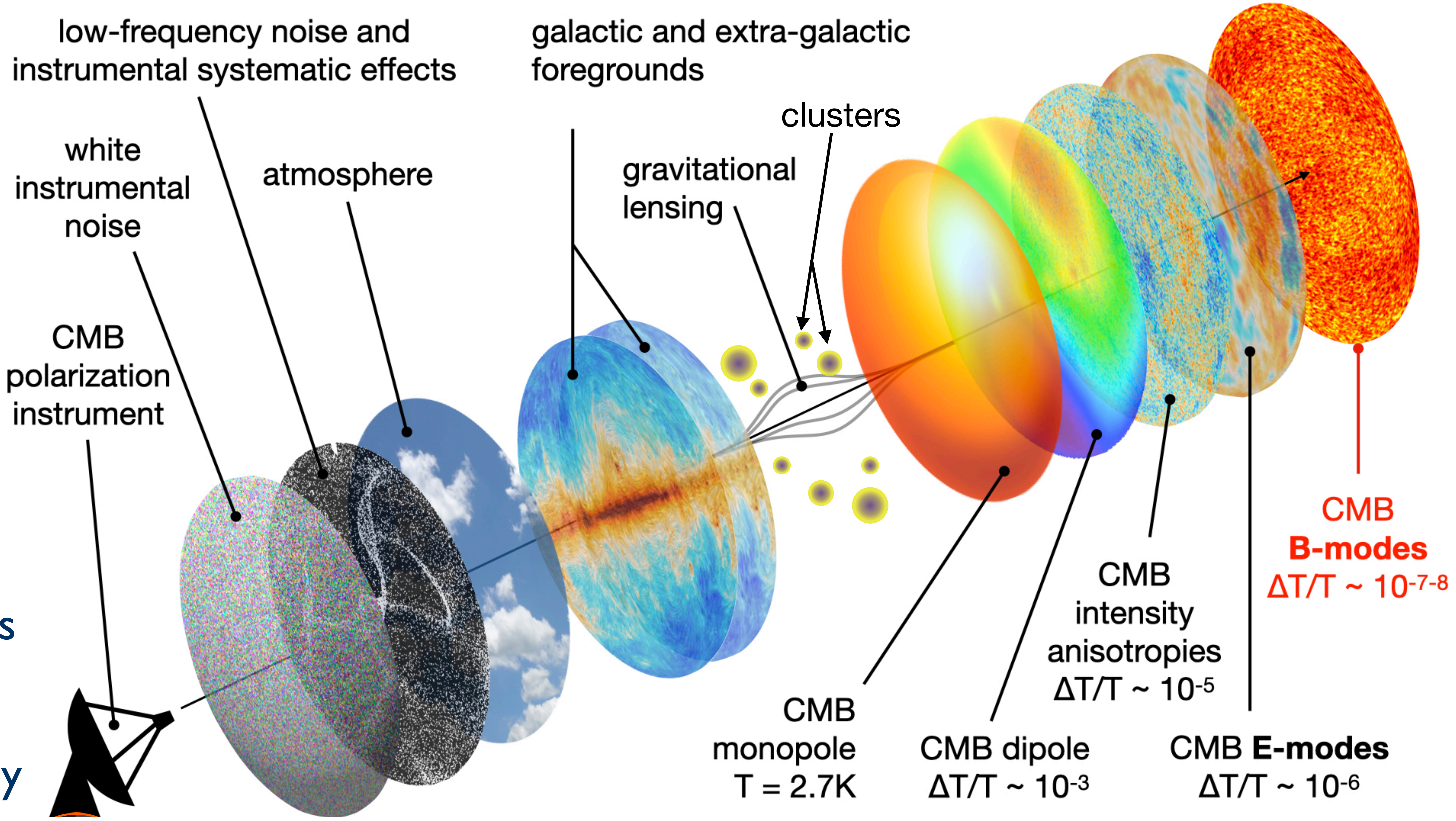
Foregrounds

Lensing E-Modes

Looking for Primordial Gravitational Waves

The Challenge of detecting the CMB B-Modes

- The *B*-mode signal is expected to have an amplitude at least 3 orders of magnitude below the CMB temperature anisotropies
- LiteBIRD is targeting a sensitivity level in polarization ~30 times better than Planck
- This extremely good statistical uncertainty must go in parallel with exquisite control of:
  1. **Instrument systematic** uncertainties
  2. **Galactic foreground** contamination
  3. **"Lensing B-mode signal"** induced by gravitational lensing
  4. Observer biases



Credits: Josquin Errard

Looking for Primordial Gravitational Waves

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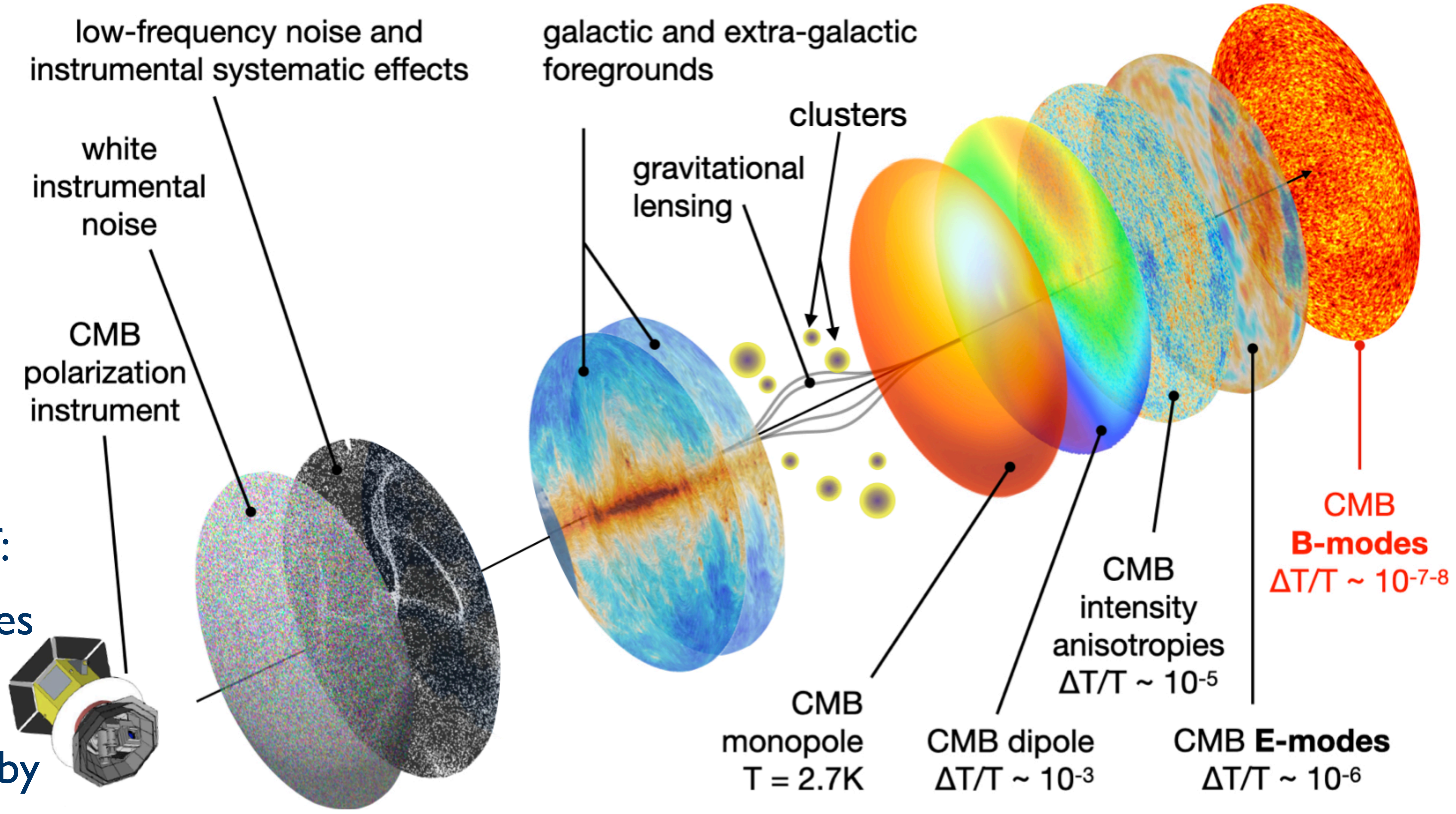
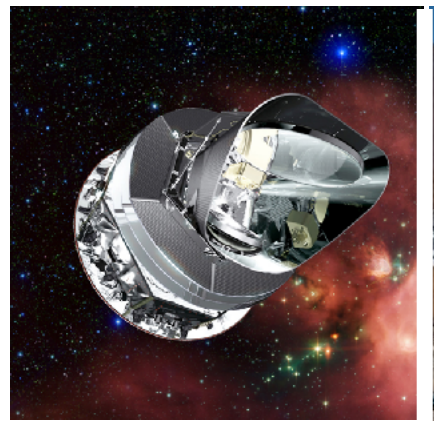


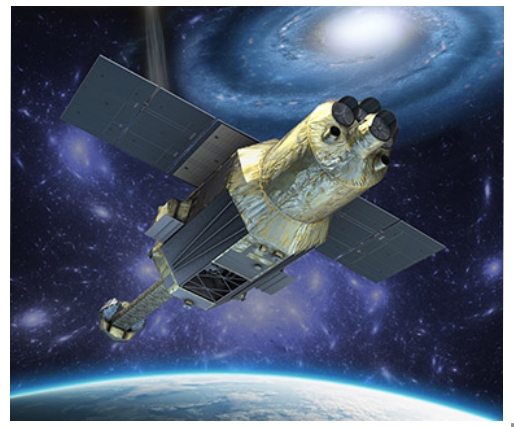
Credits: Josquin Errard

LiteBIRD Joint Study Group

Over 400 researchers from **Japan**, **North America** and **Europe**

Team experience in CMB experiments, X-ray satellites and other large projects (ALMA, HEP experiments, …)



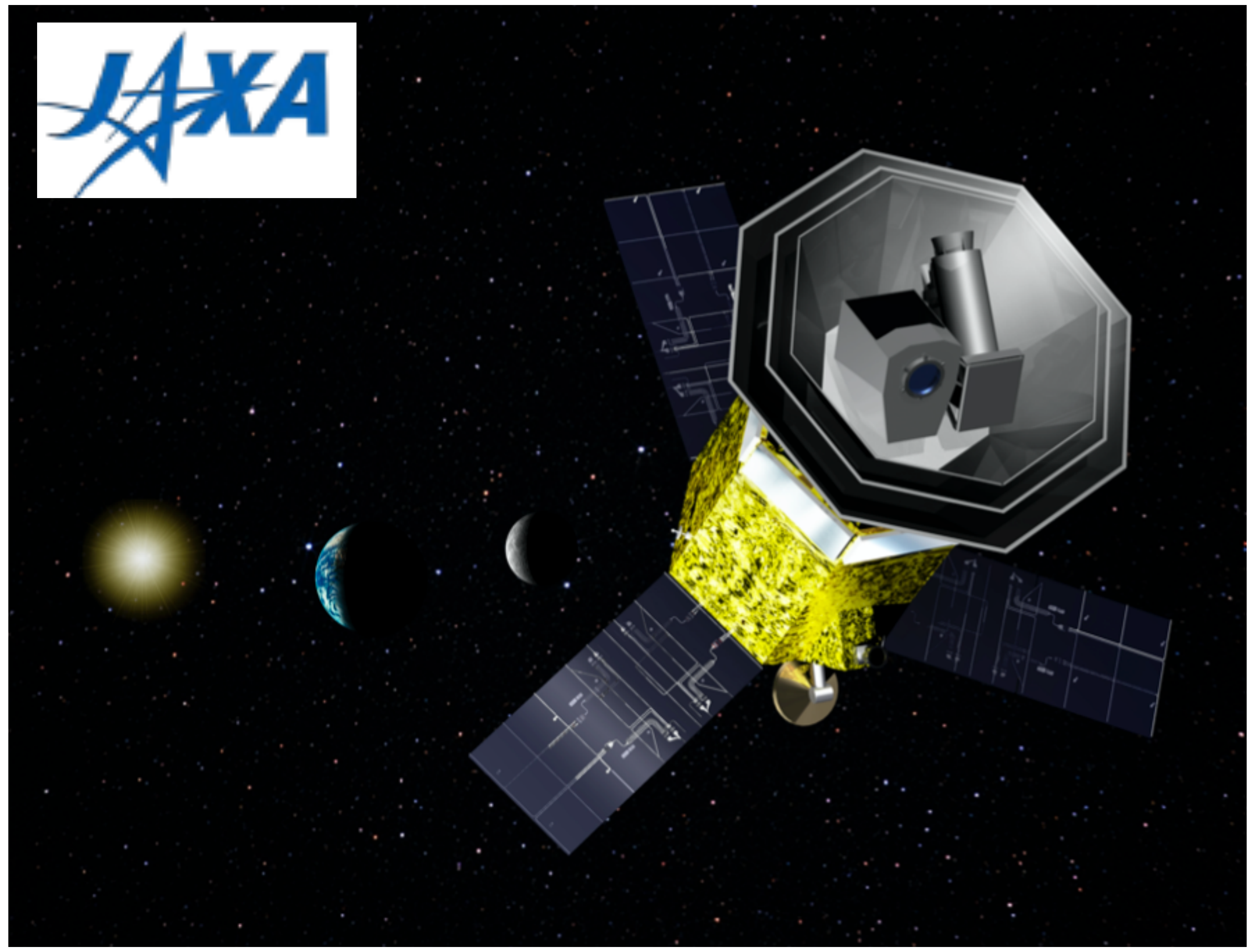


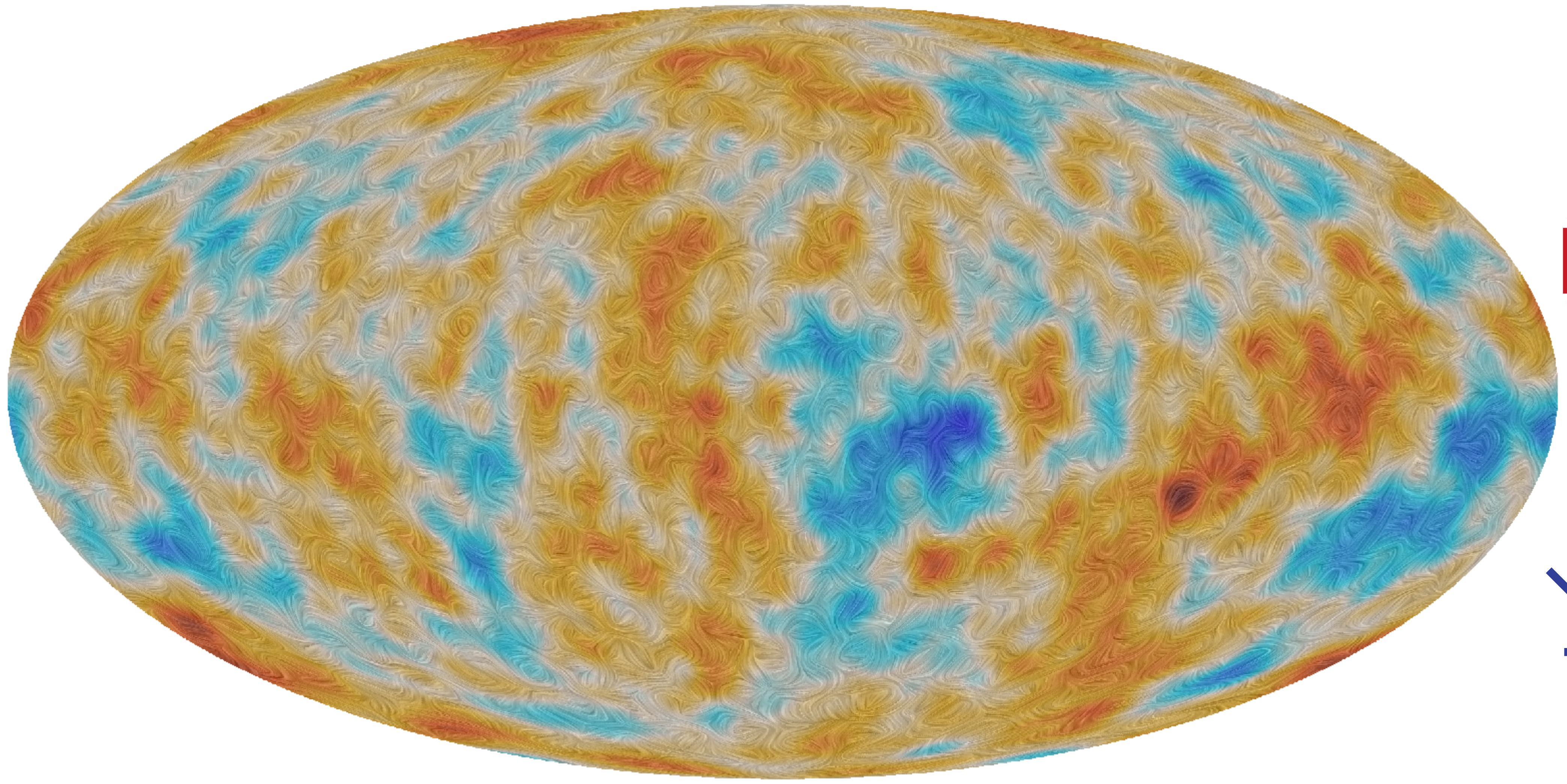
LiteBIRD Global F2F meeting
Sep 28 - Oct 1, 2023 at Elba

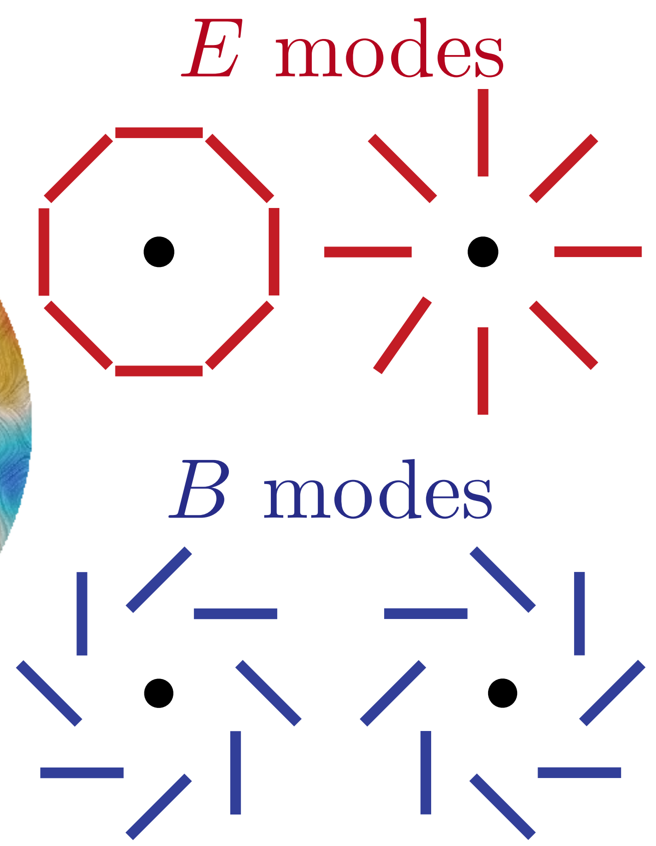
LiteBIRD overview

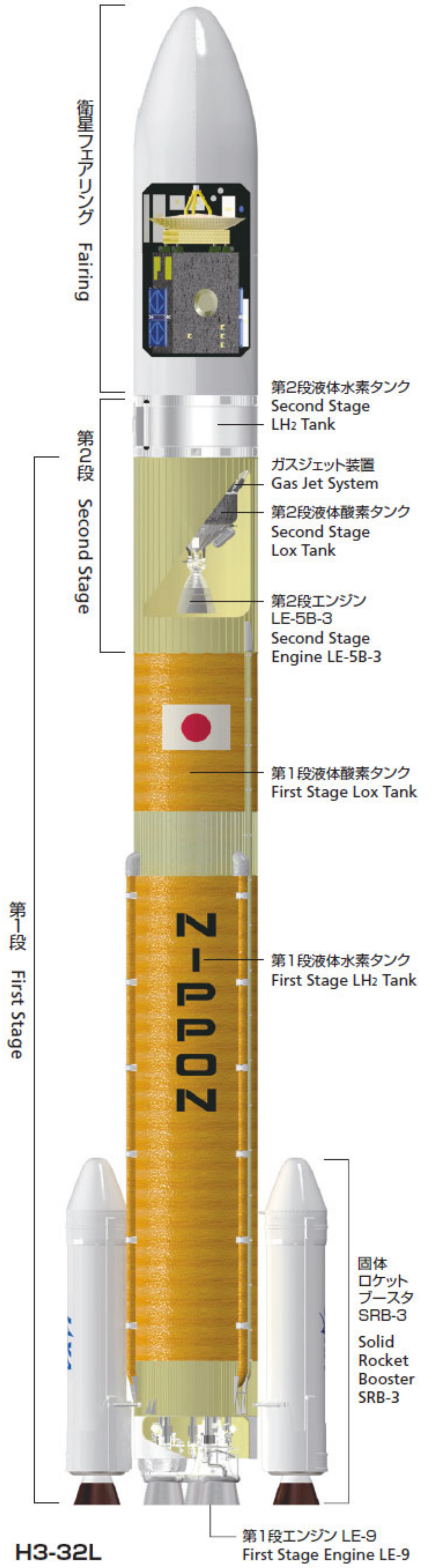
- Lite (Light) spacecraft for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- JAXA's L-class mission was selected in May 2019 to be launched by JAXA's H3 rocket.
- **All-sky 3-year survey**, from Sun-Earth Lagrangian point L2
- Large frequency coverage (**40–402 GHz**, 15 bands) at **70–18 arcmin** angular resolution for precision measurements of the **CMB *B*-modes**
- Final combined sensitivity: **2.2 μK·arcmin**

📖 LiteBIRD collaboration PTEP 2023







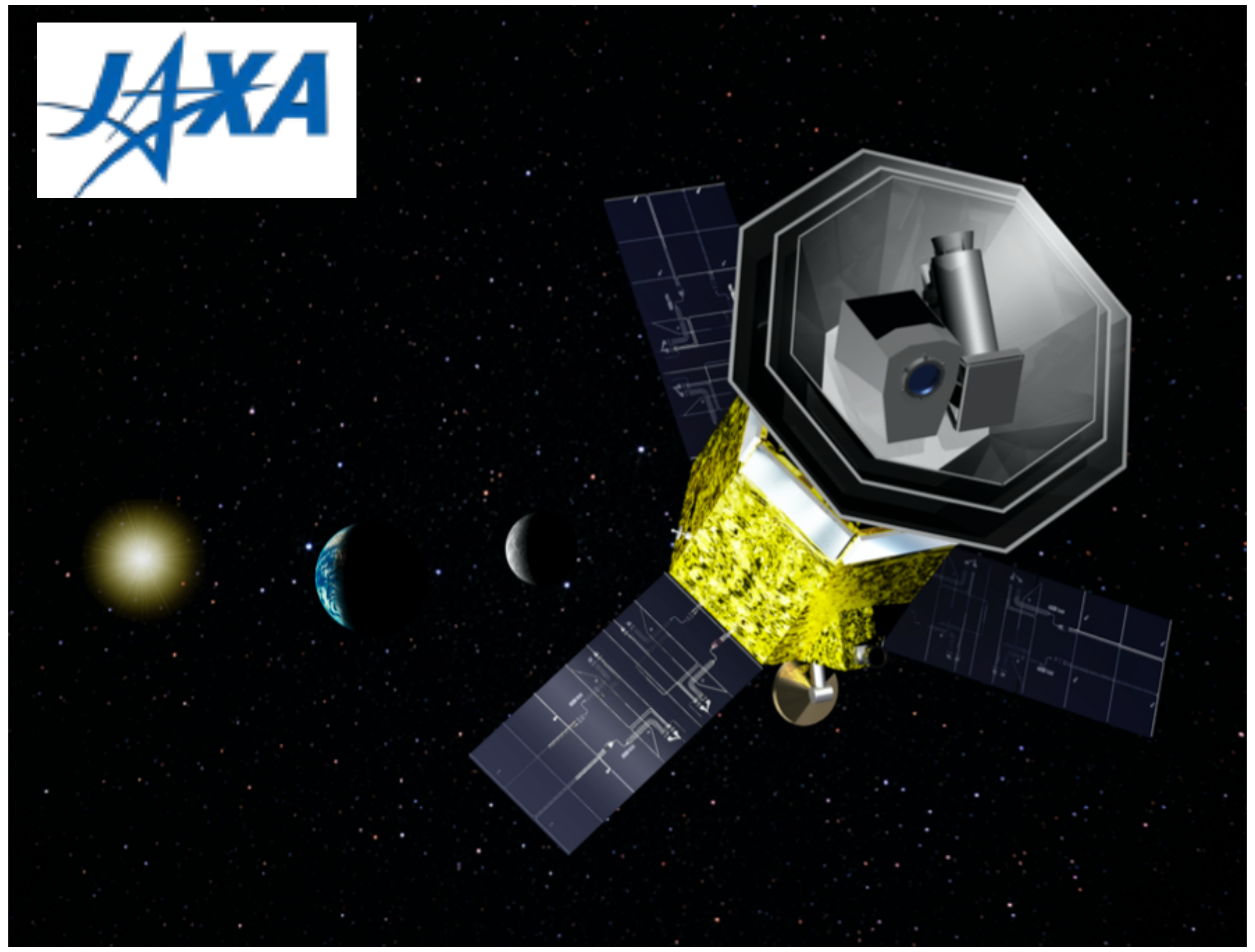


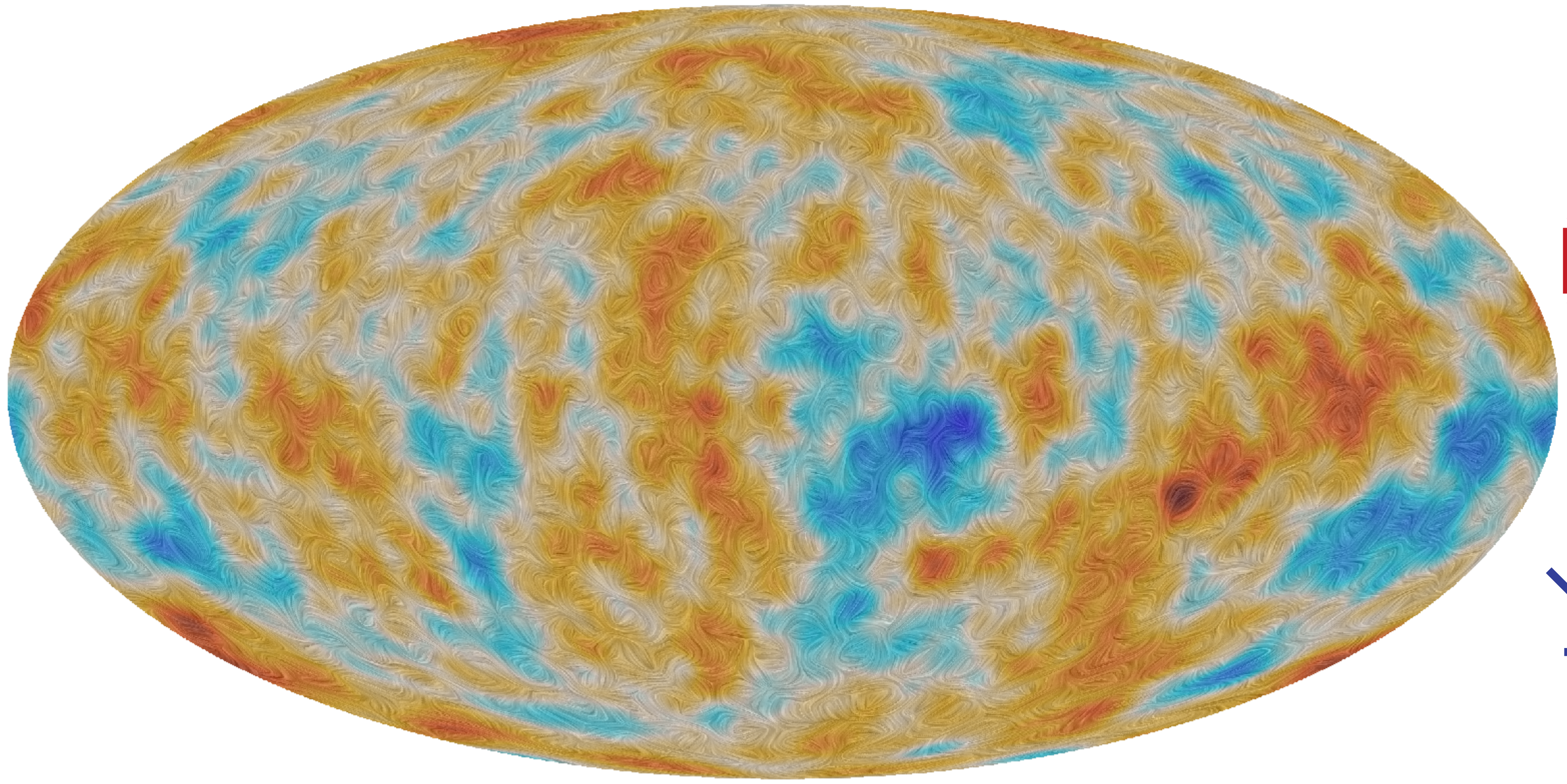
LiteBIRD overview

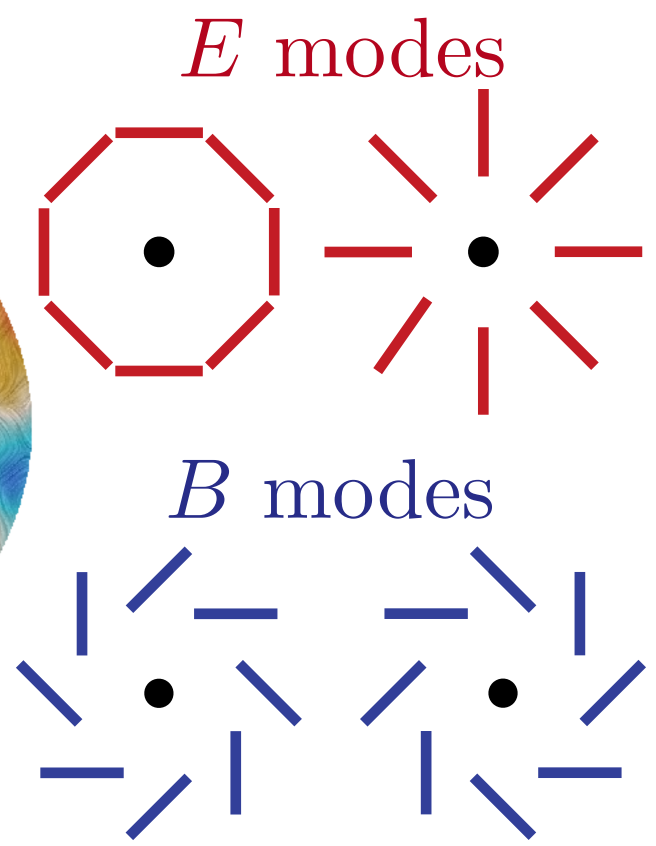
LiteBIRD reformation phase

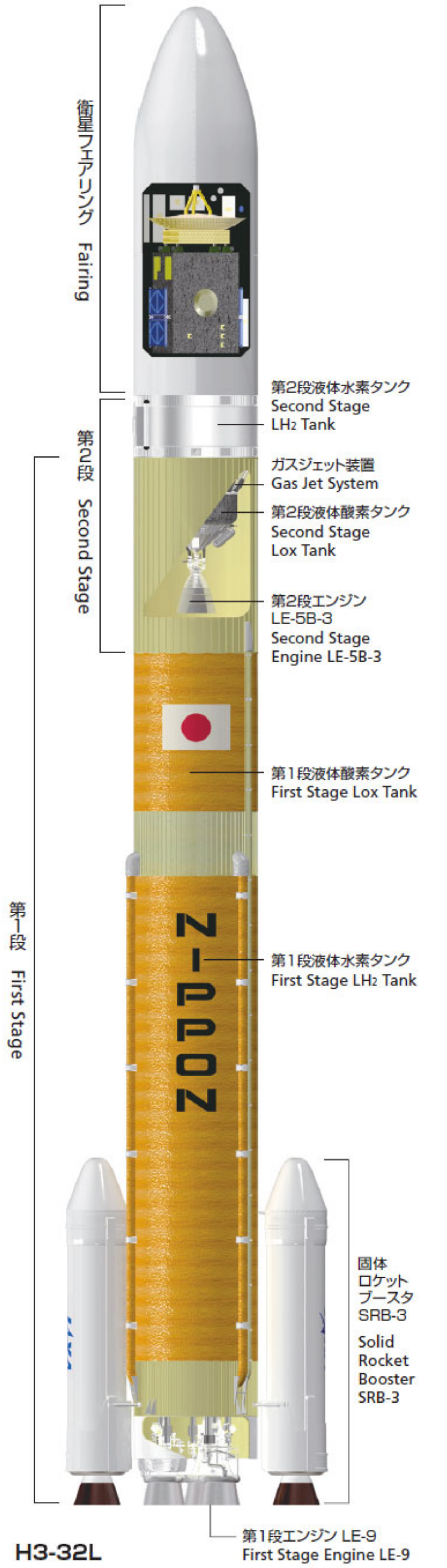
- After the ISAS/JAXA mission definition review, LiteBIRD is under rescope studies to consolidate the mission's feasibility with the same scientific objectives.
- The LiteBIRD collaboration will spend approximately one year (~ late 2025) on the studies of the reformation plan.

📖 LiteBIRD collaboration PTEP 2023





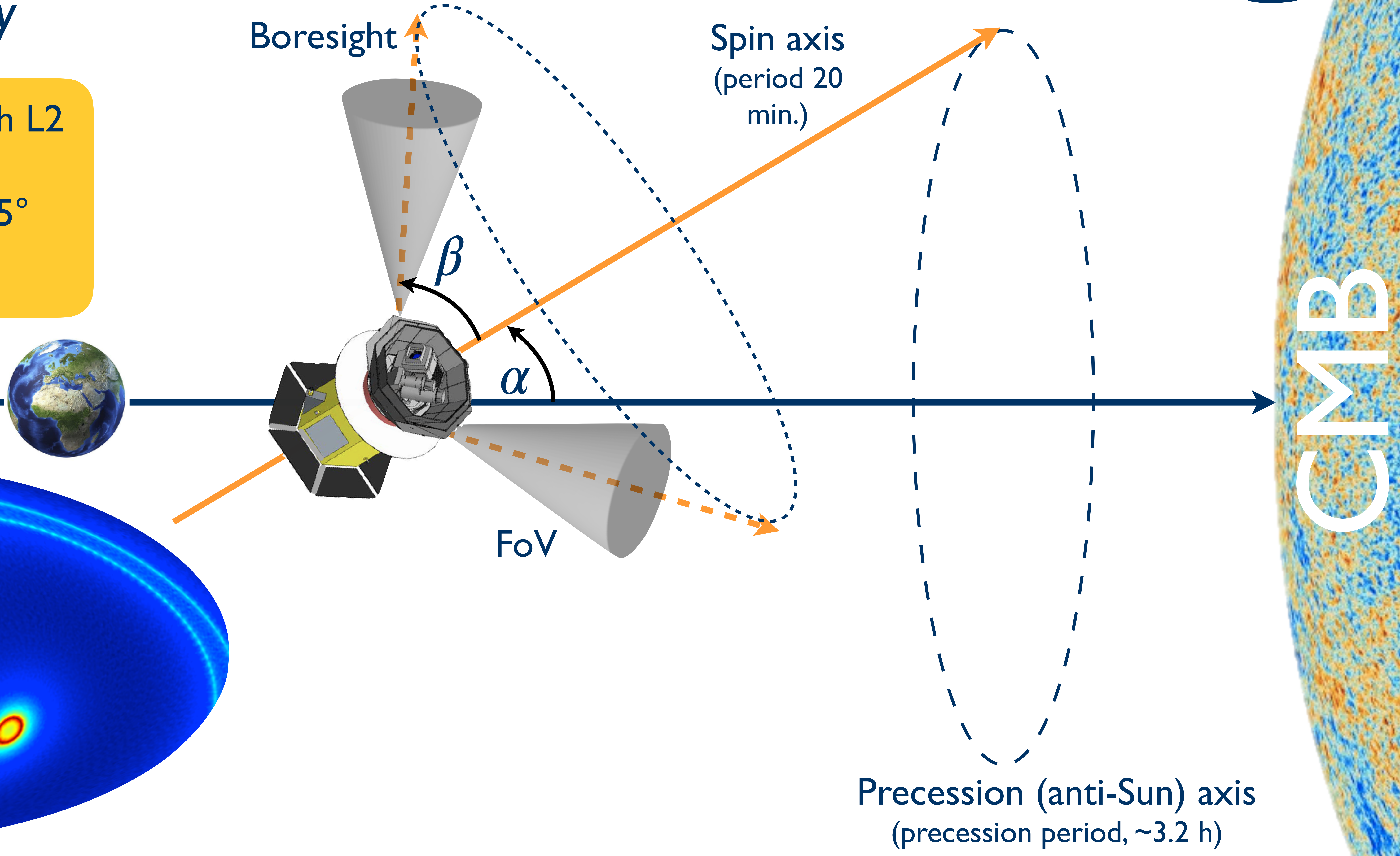


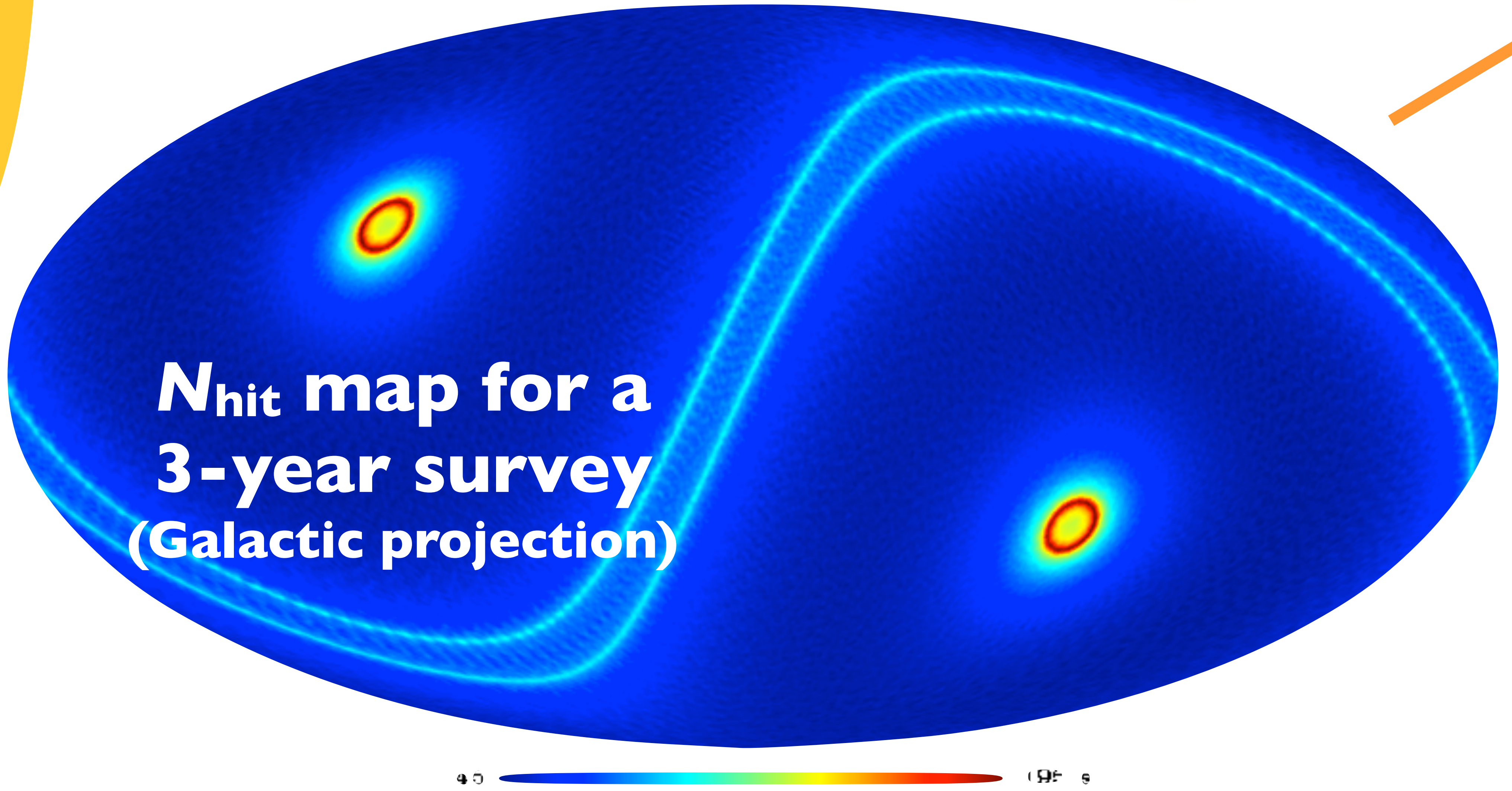


LiteBIRD overview: Technical Challenges

Scanning Strategy

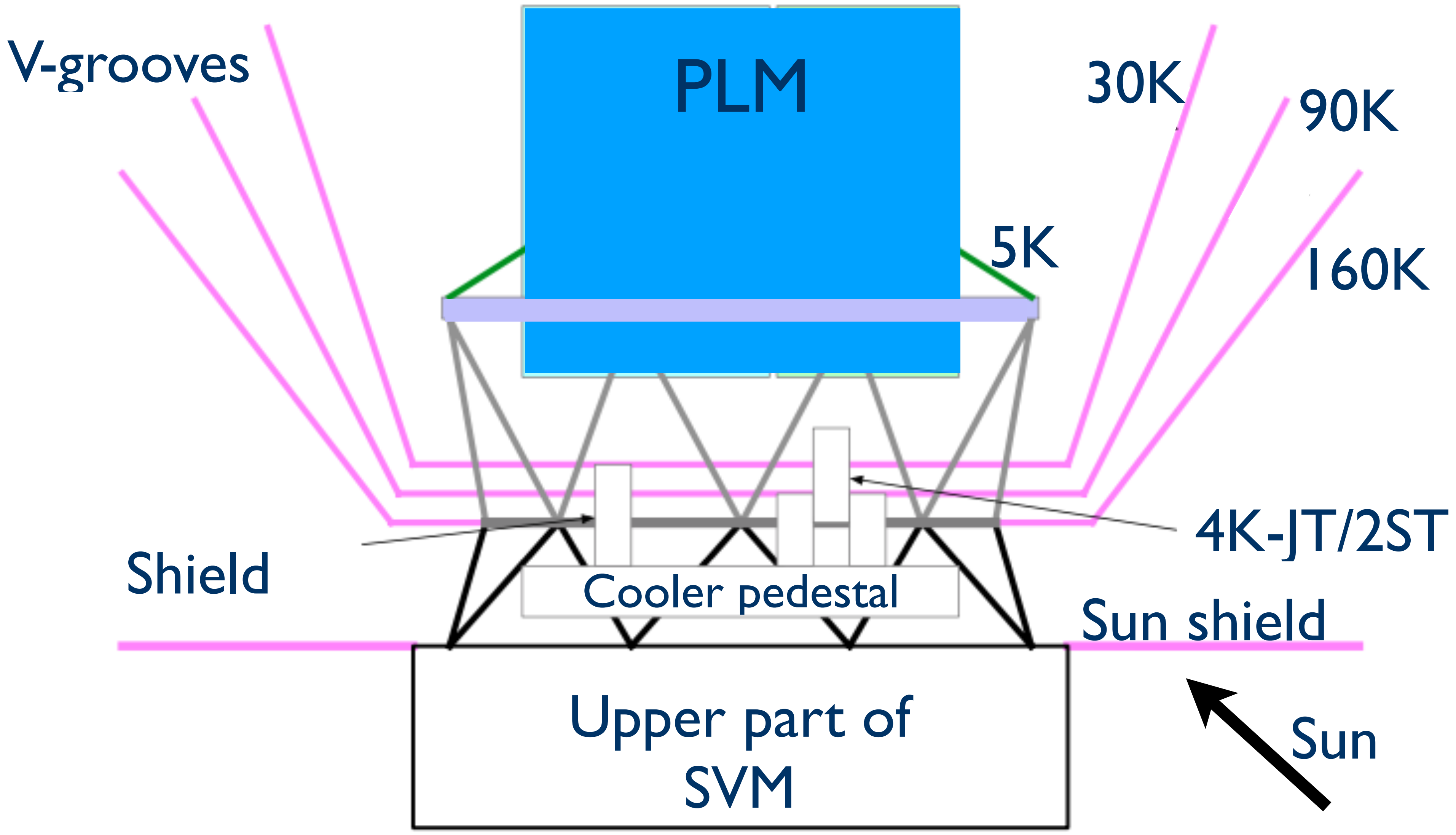
- 3-year survey, Sun-Earth L2 Lissajous orbit
- Precession angle: α = 45°
- Spin angle: β = 50°

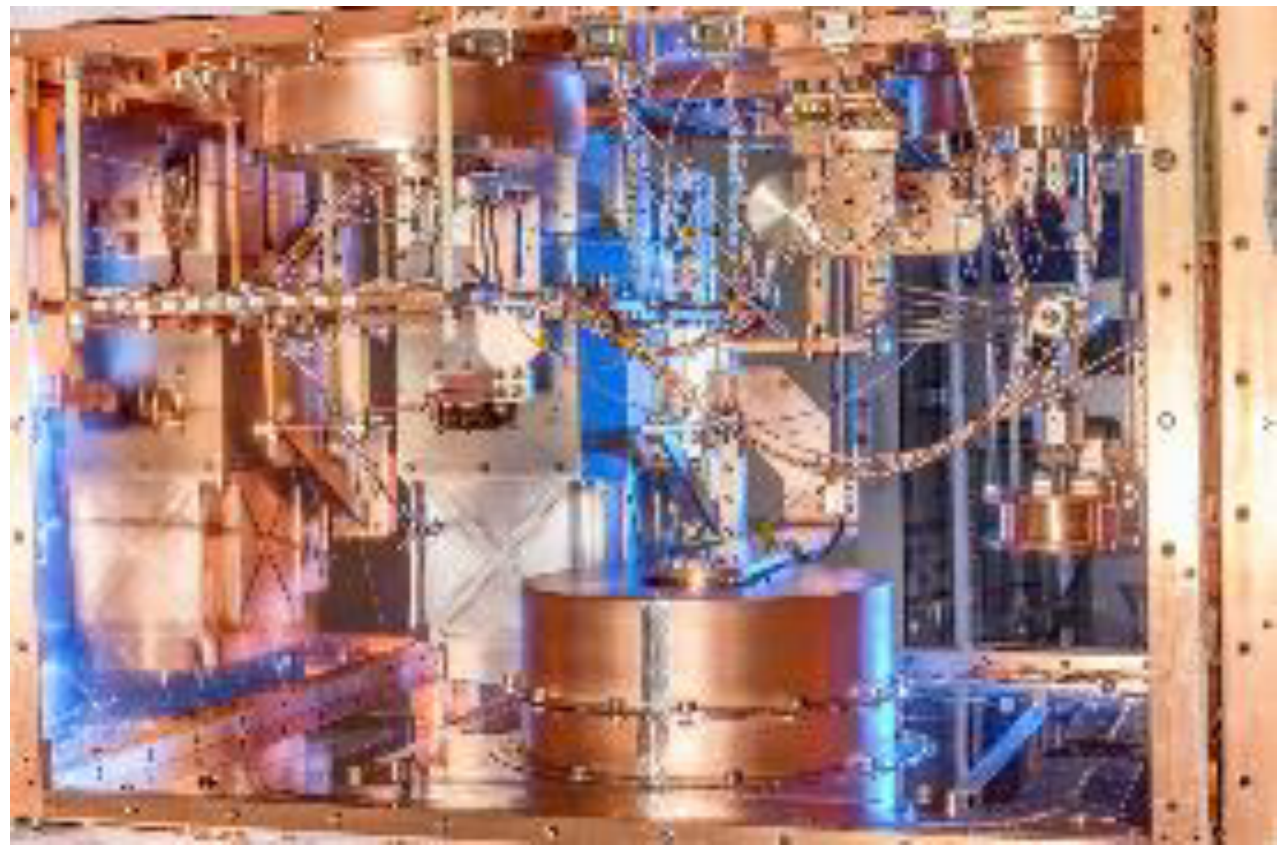


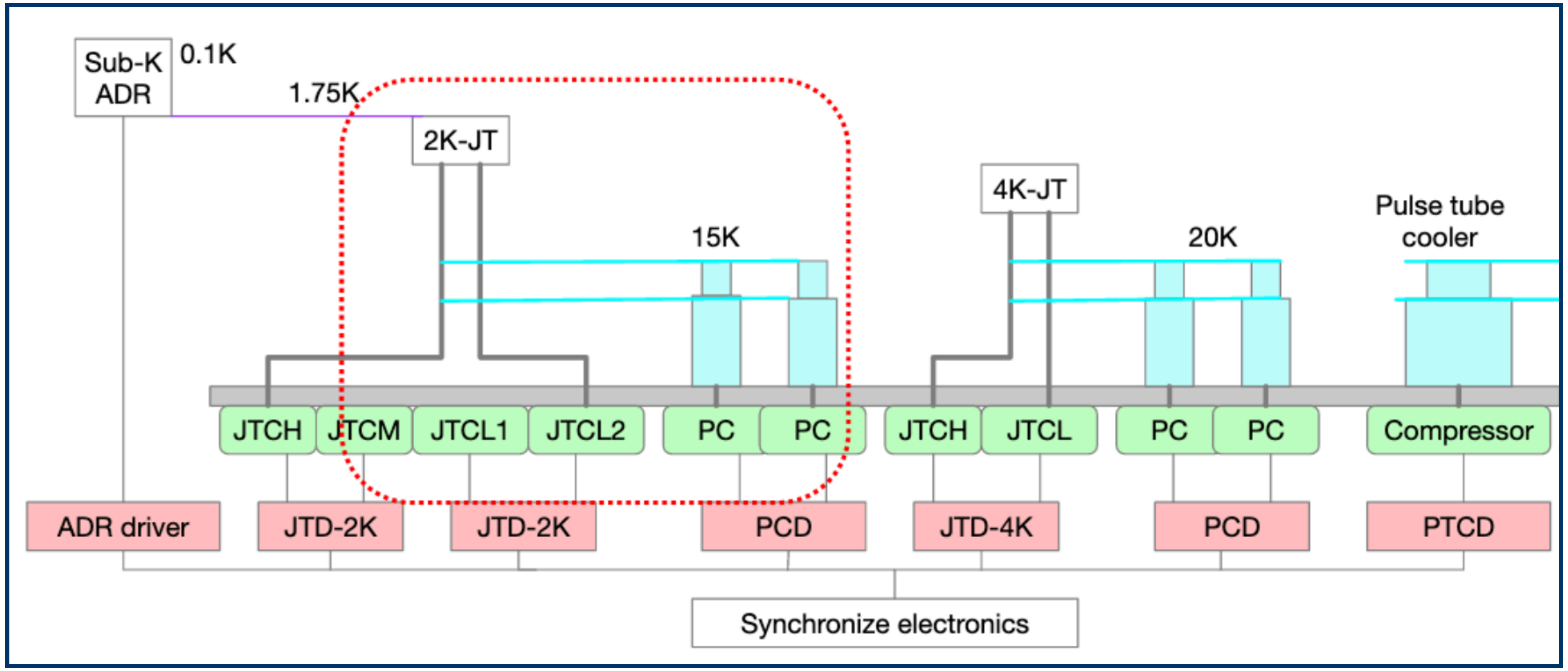


LiteBIRD overview: Technical Challenges

Cryogenic Chain







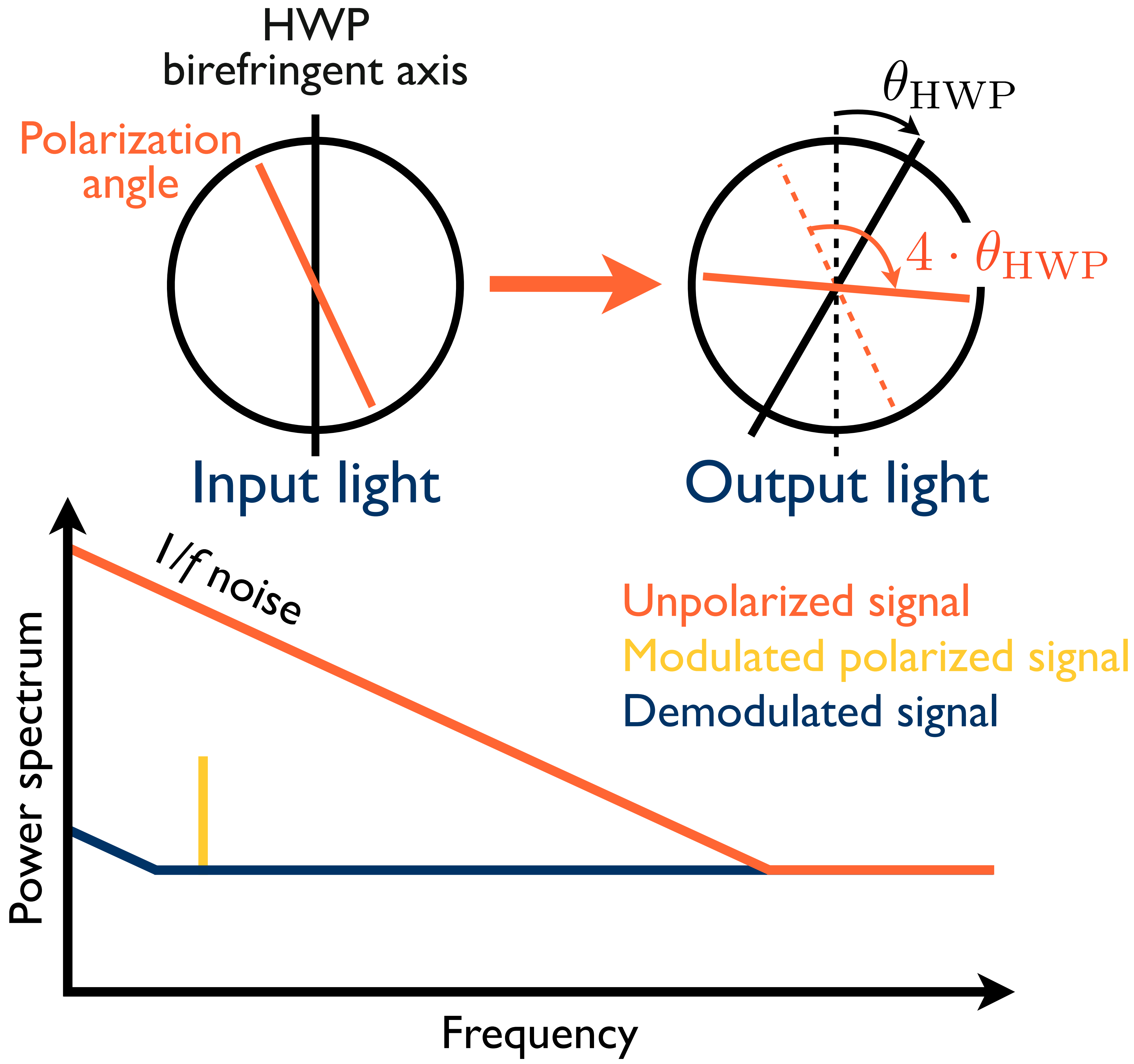
Continuous cooling at 100mK and 350mK

High stability on telescopes at all stages

LiteBIRD overview: Technical Challenges

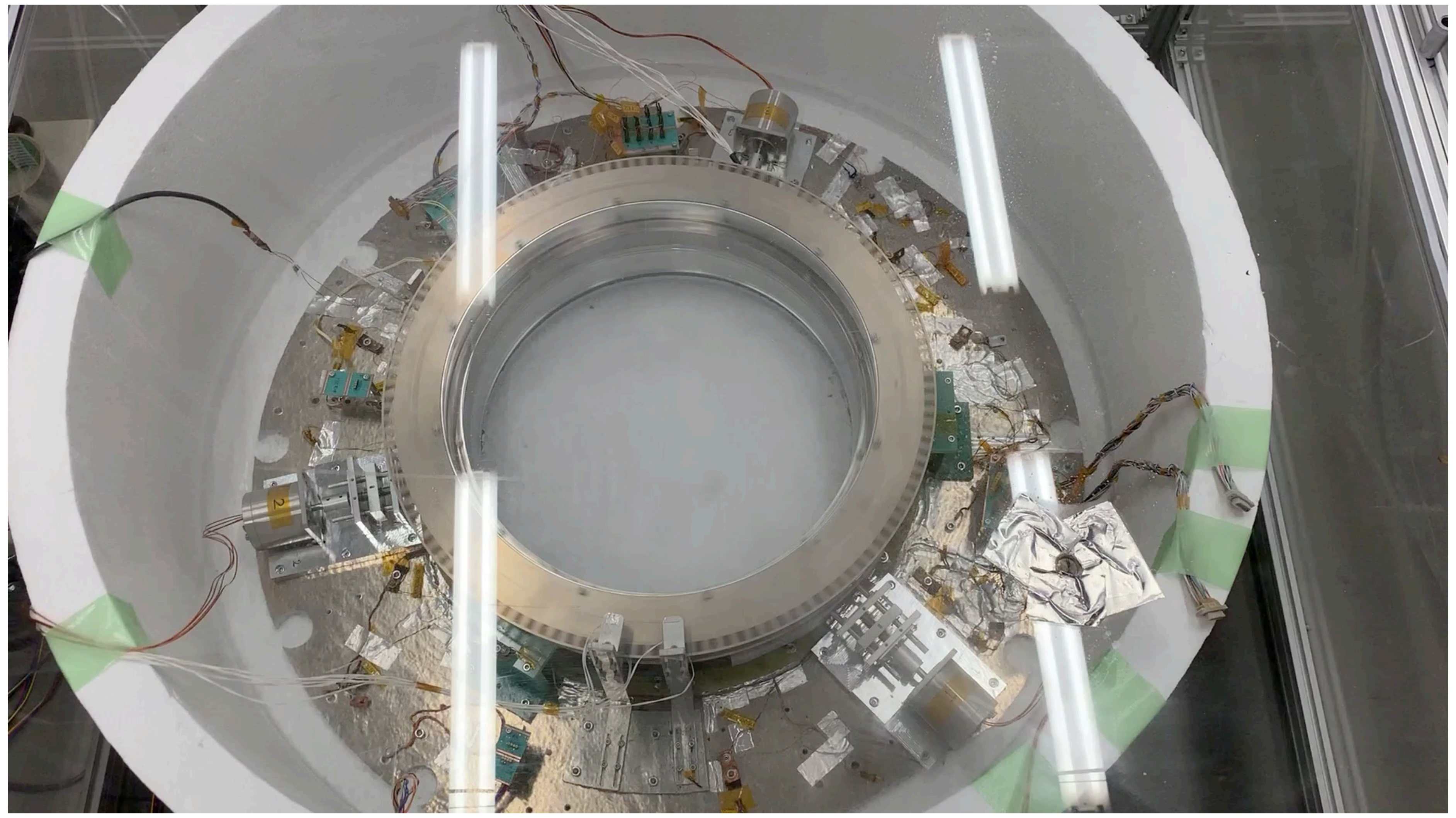
Polarisation Modulation Unit (PMU)

- Rotating a birefringent plate to modulate polarization
- The first sky-side optical element



📖 Sakurai+2020 | 📖 Komatsu+2020 | 📖 Toda+2020 | 📖 Columbro+2020 | 📖 Sugiyama+2020

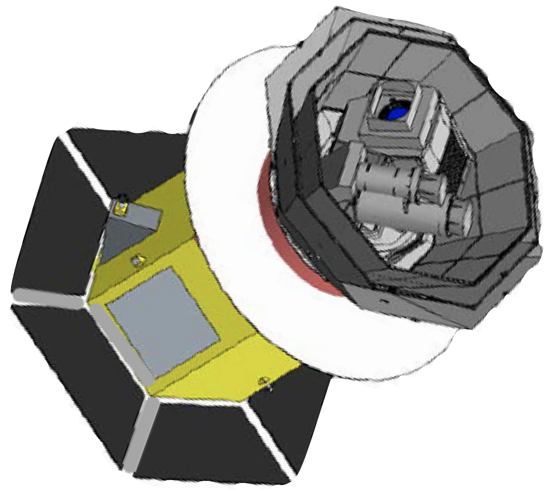
- LFT PMU BBM at Kavli IPMU:



- Rotation test of superconducting magnetic bearing system in the 4K cryostat
- Stable rotation at cryogenic temperature (< 10 K)

LiteBIRD Forecasts

How to extract r from the data ?



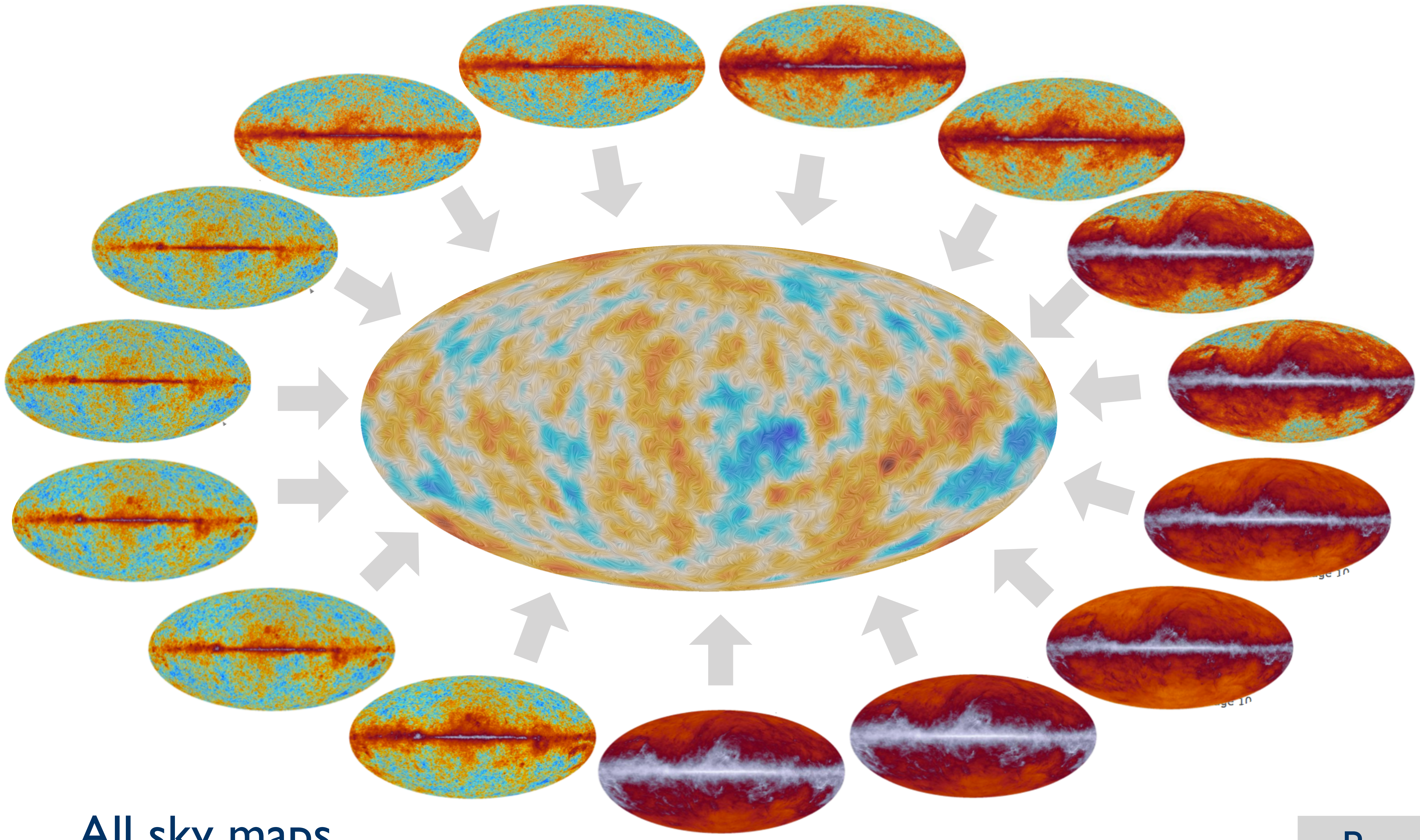
Time Ordered Data (TOD) / detectors

Cleaning from instrumental systematics effects

Cleaned & Calibrated TOD / detectors

Map Making

All sky maps of polarisation in15 bands

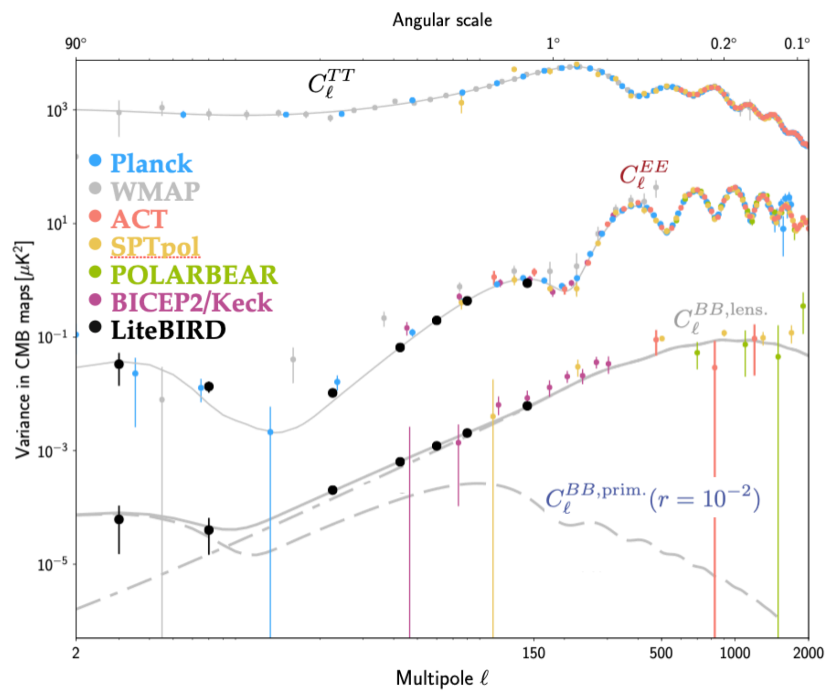


Component Separation

CMB Map

Power Spectrum Estimator

Power Spectrum



Likelihood Estimate

r

tensor-to-scalar ratio estimate

LiteBIRD Forecasts

Foreground Cleaning

Foregrounds modeling

- Synchrotron:

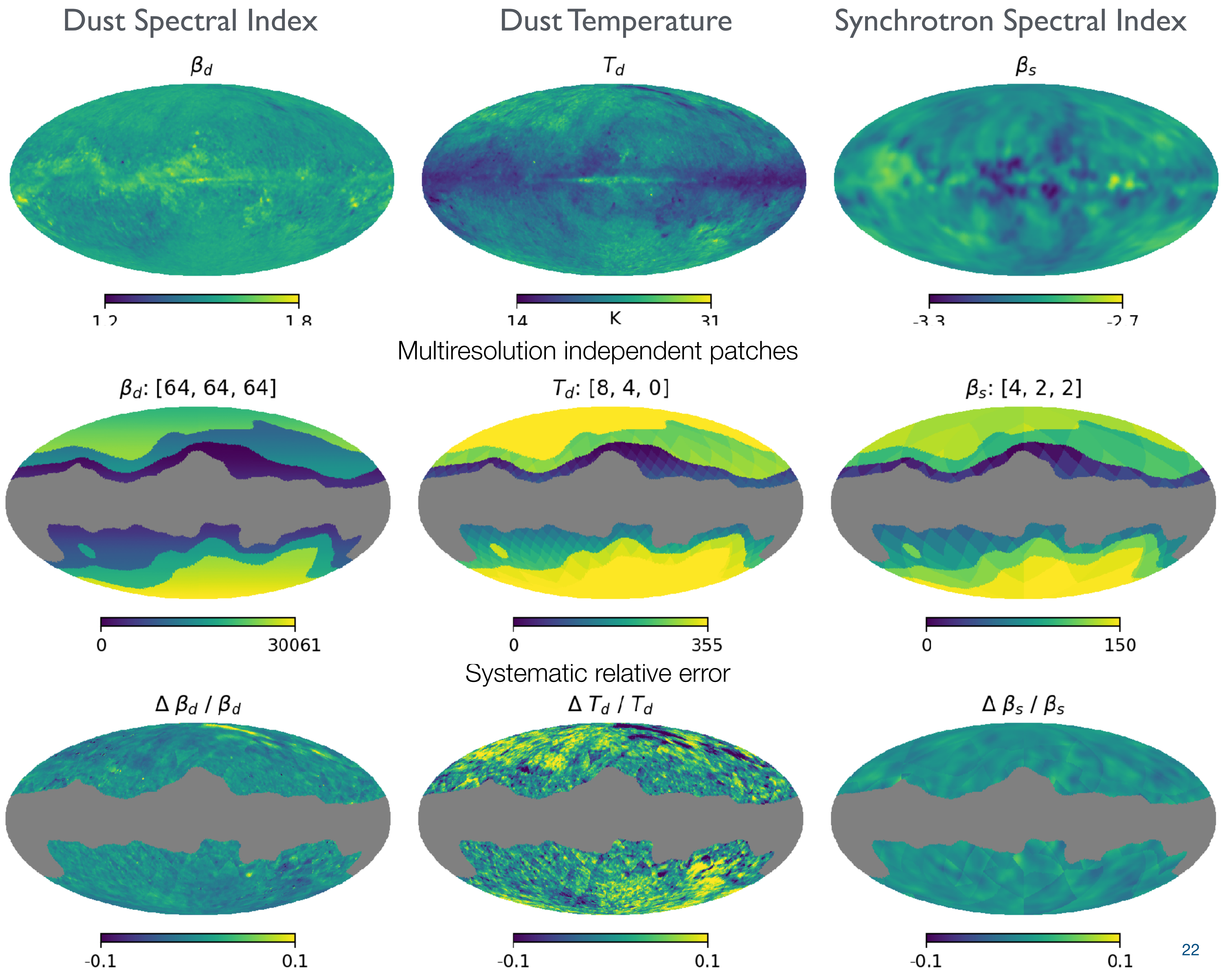
$$[Q_\mathrm{s}, U_\mathrm{s}](\hat{n}, \nu) = [Q_\mathrm{s}, U_\mathrm{s}](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_\mathrm{s}(\hat{n})}$$

- Dust: modified blackbody

$$[Q_\mathrm{d}, U_\mathrm{d}](\hat{n}, \nu) = [Q_\mathrm{d}, U_\mathrm{d}](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_\mathrm{d}(\hat{n})-2} \frac{B_\nu(T_\mathrm{d}(\hat{n}))}{B_{\nu_\star}(T_\mathrm{d}(\hat{n}))}$$

- "Multiresolution technique" (extension of xForecast), to account for spatial variability.
- => Adapt resolution on each patch for each parameter

Resolution	Fit	S/N		
High	Local	Low	→	Statistical Noise
Low	Global	High	→	Systematics Noise



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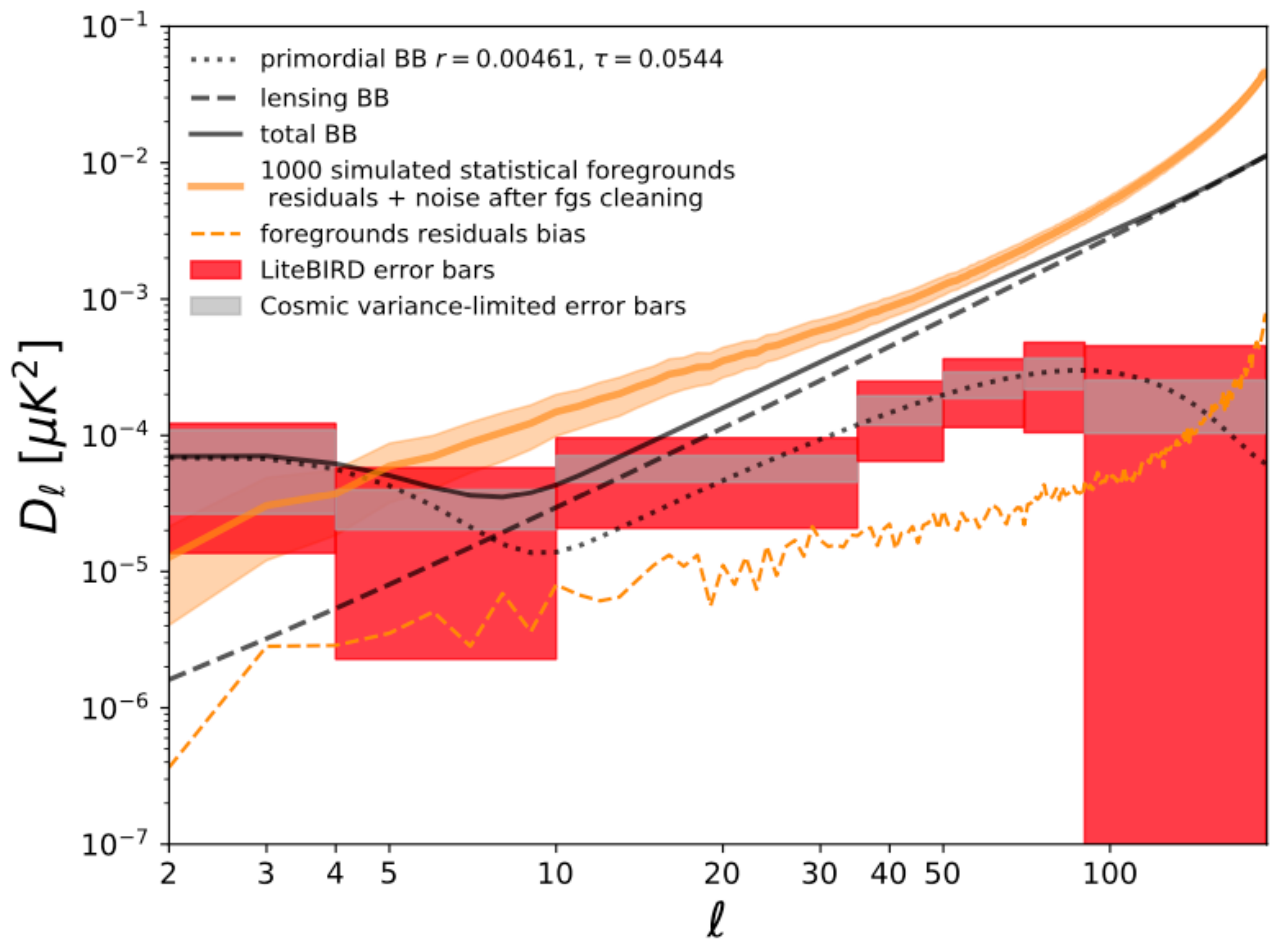
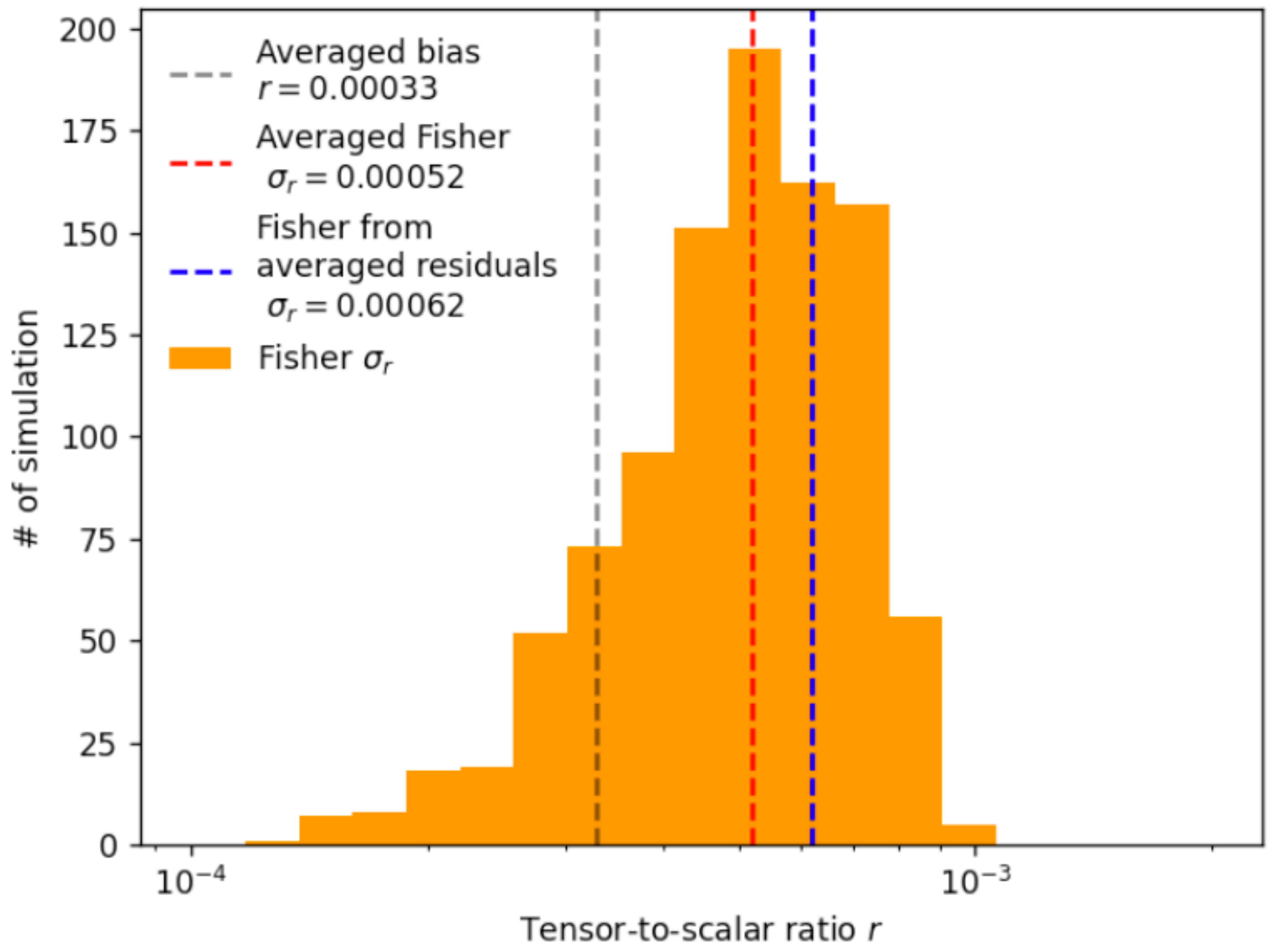
LiteBIRD Forecasts

Impact of Foregrounds

Foregrounds





Final value on statistical uncertainty: **$r = (3.3 \pm 6.2)\times 10^{-4}$**

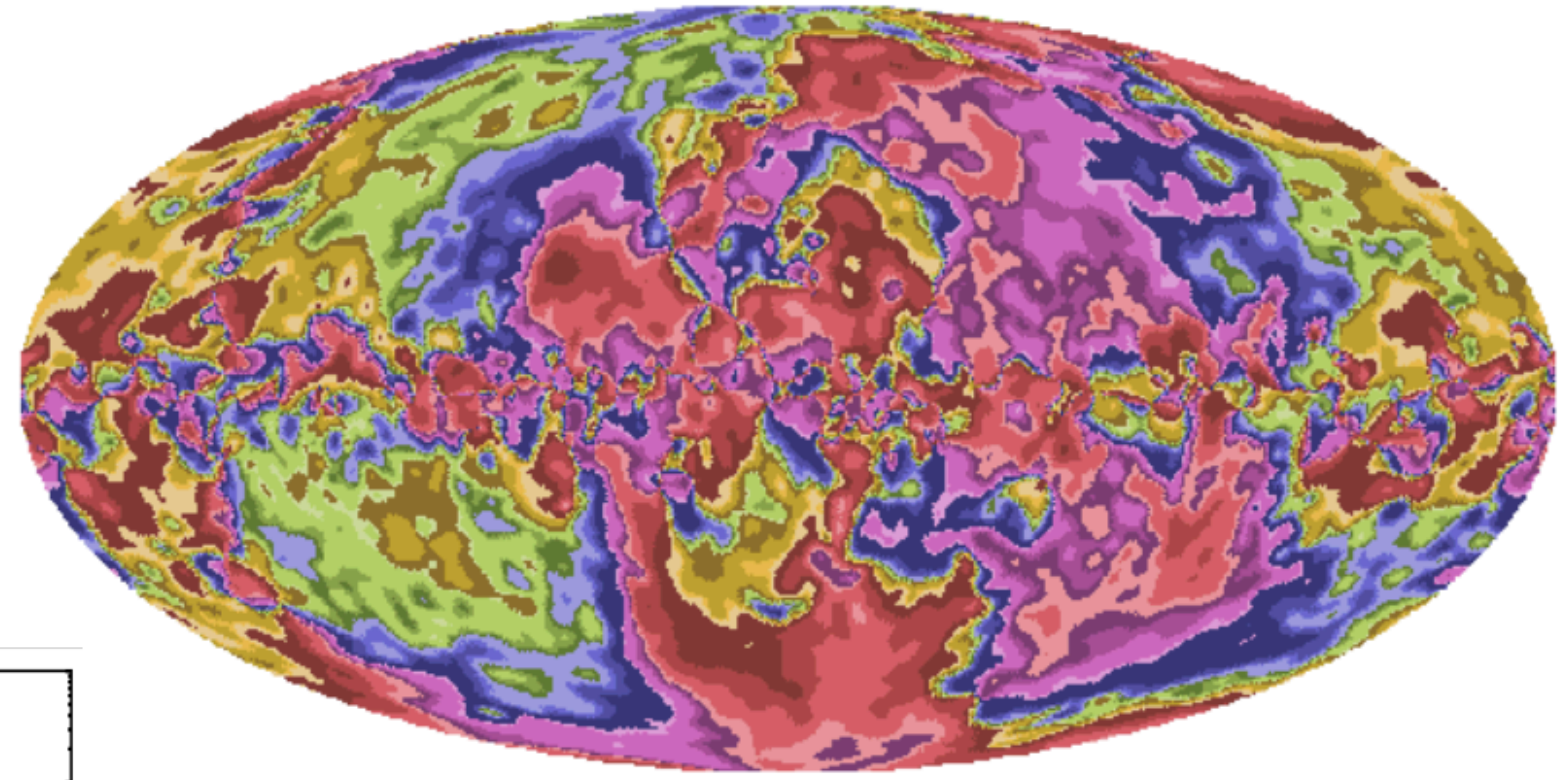
LiteBIRD Forecasts

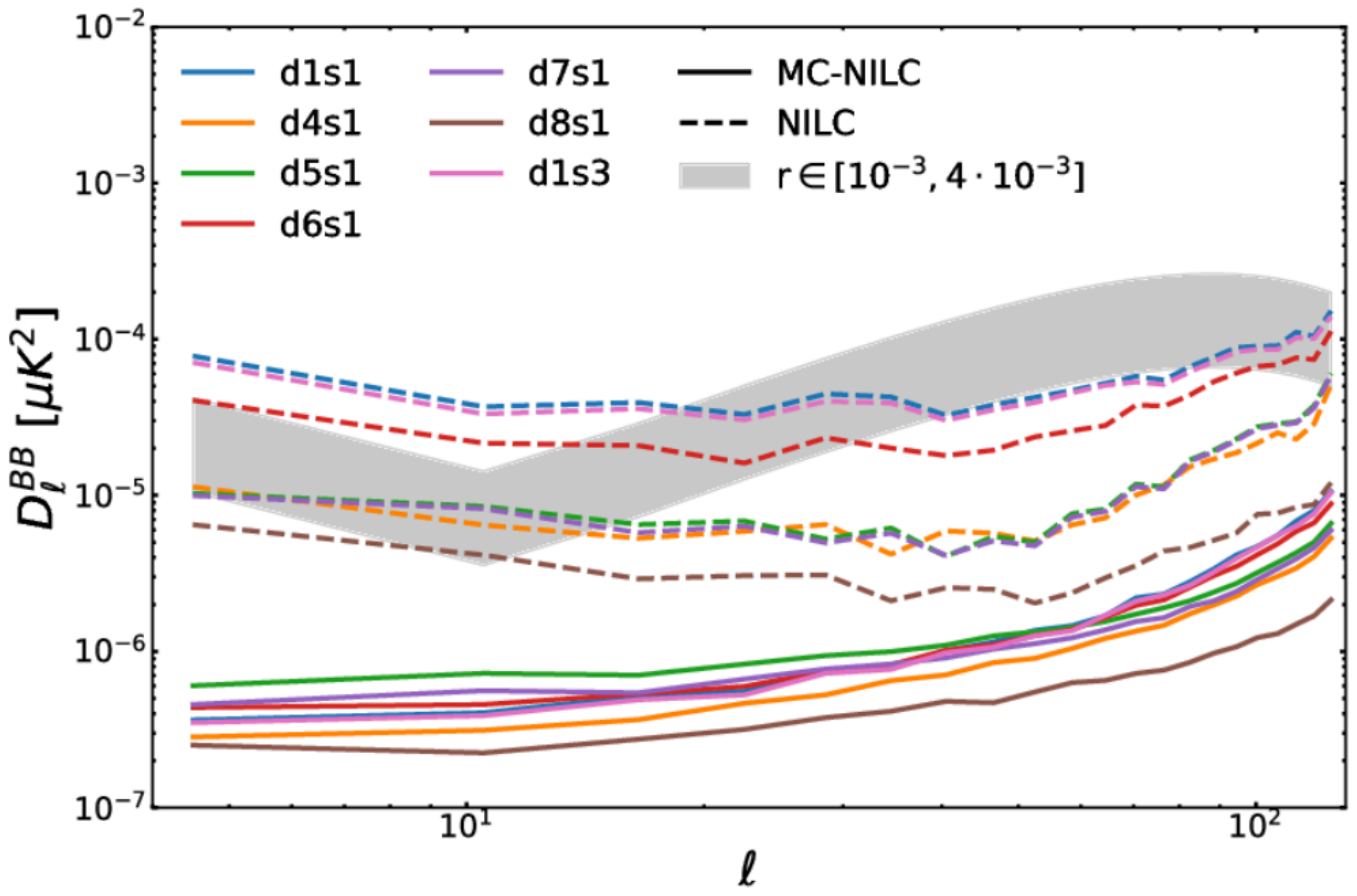
Impact of Foregrounds

- Development of new foreground cleaning methods to handle particularly complex foregrounds:

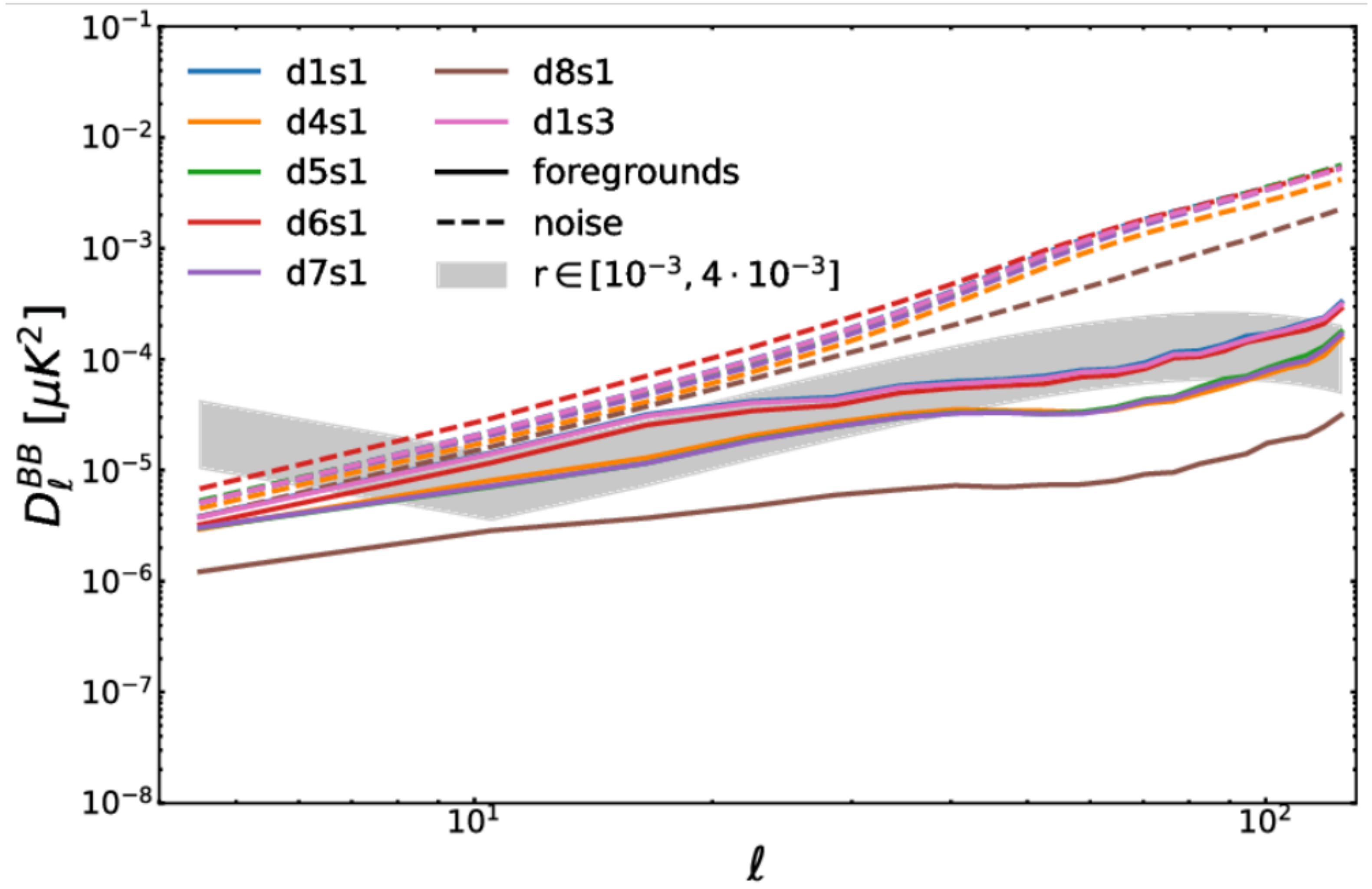
Multi-Clustering Needlet ILC

Foreground cleaning with ILC method in regions of similar foreground characteristics





Ideal case



Realistic case

📖 Carones+2023

LiteBIRD Forecasts

Impact of Foregrounds

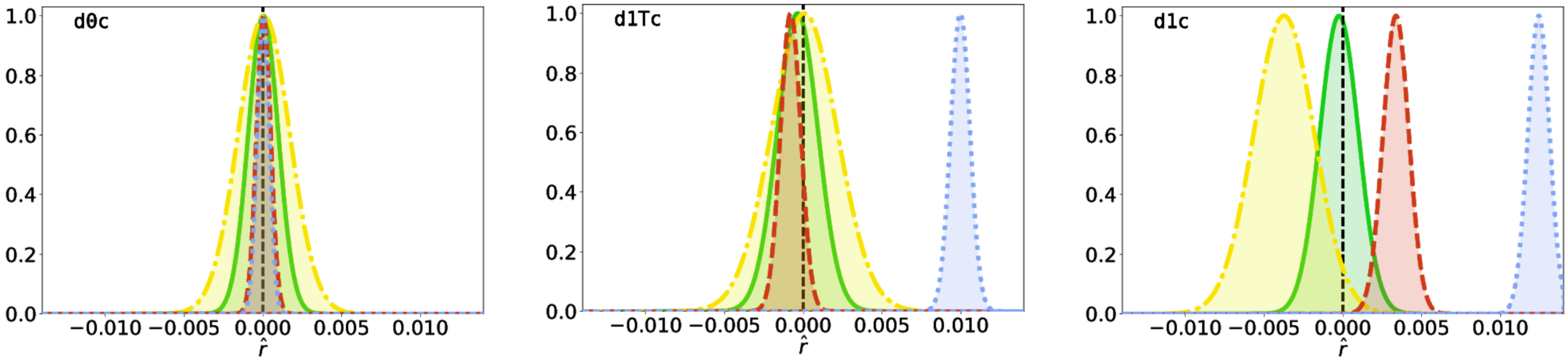
- Development of new foreground cleaning methods to handle particularly complex foregrounds:

📖 Vacher+2022

Moment Expansion

Based on Taylor expansion around the standard SEDs

$$[Q_d, U_d](\hat{n}, \nu) = \left(\frac{\nu}{\nu_*}\right)^{\beta_d - 2} \frac{B_\nu(T_d)}{B_{\nu_*}(T_d)} \left([Q_d, U_d](\hat{n}, \nu_*) + \omega^1(\hat{n}) \ln\left(\frac{\nu}{\nu_*}\right) + \dots\right)$$



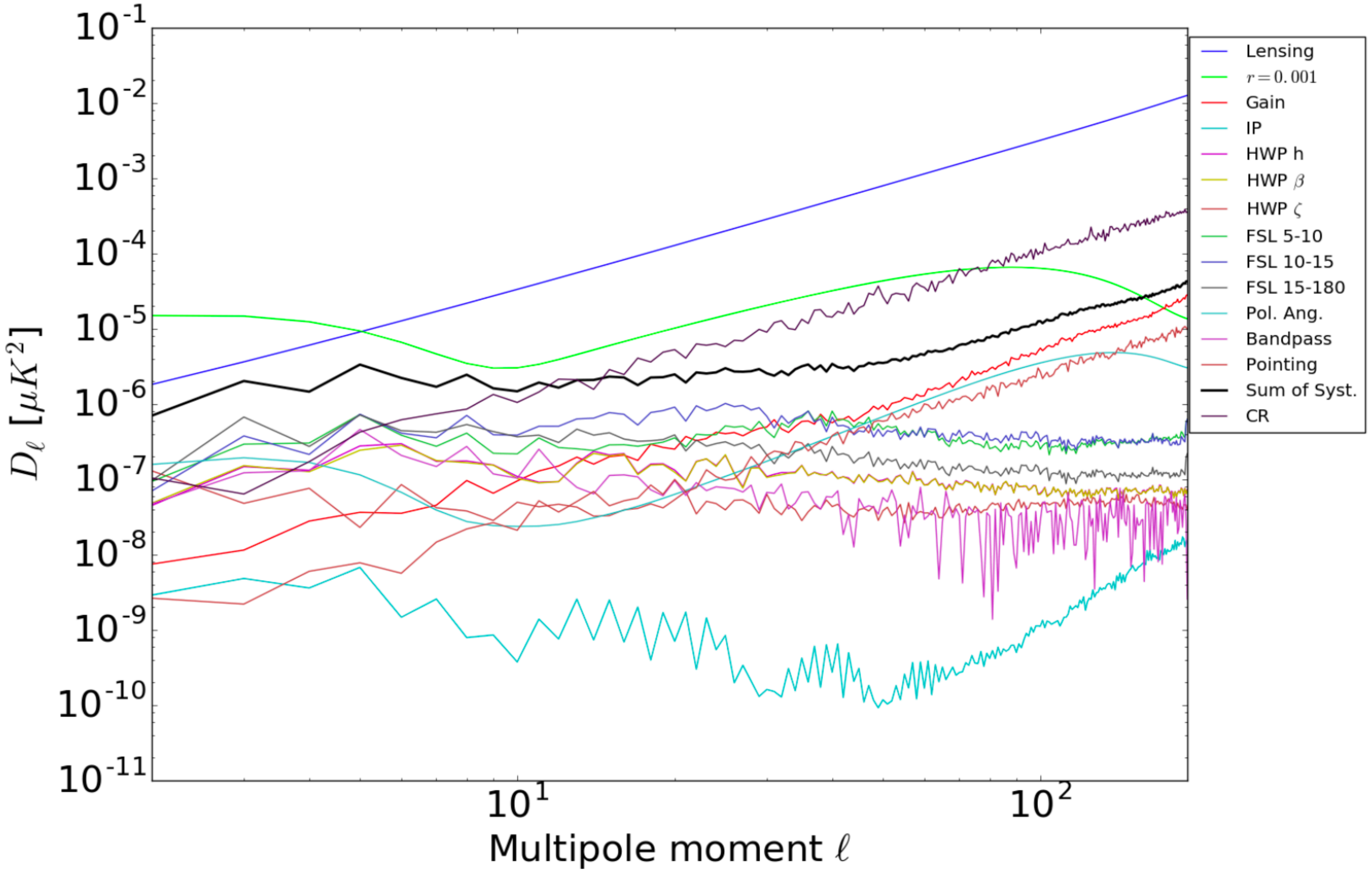
Simple dust → Complex dust

LiteBIRD Forecasts

Impact of Systematics

Instrumental Systematics

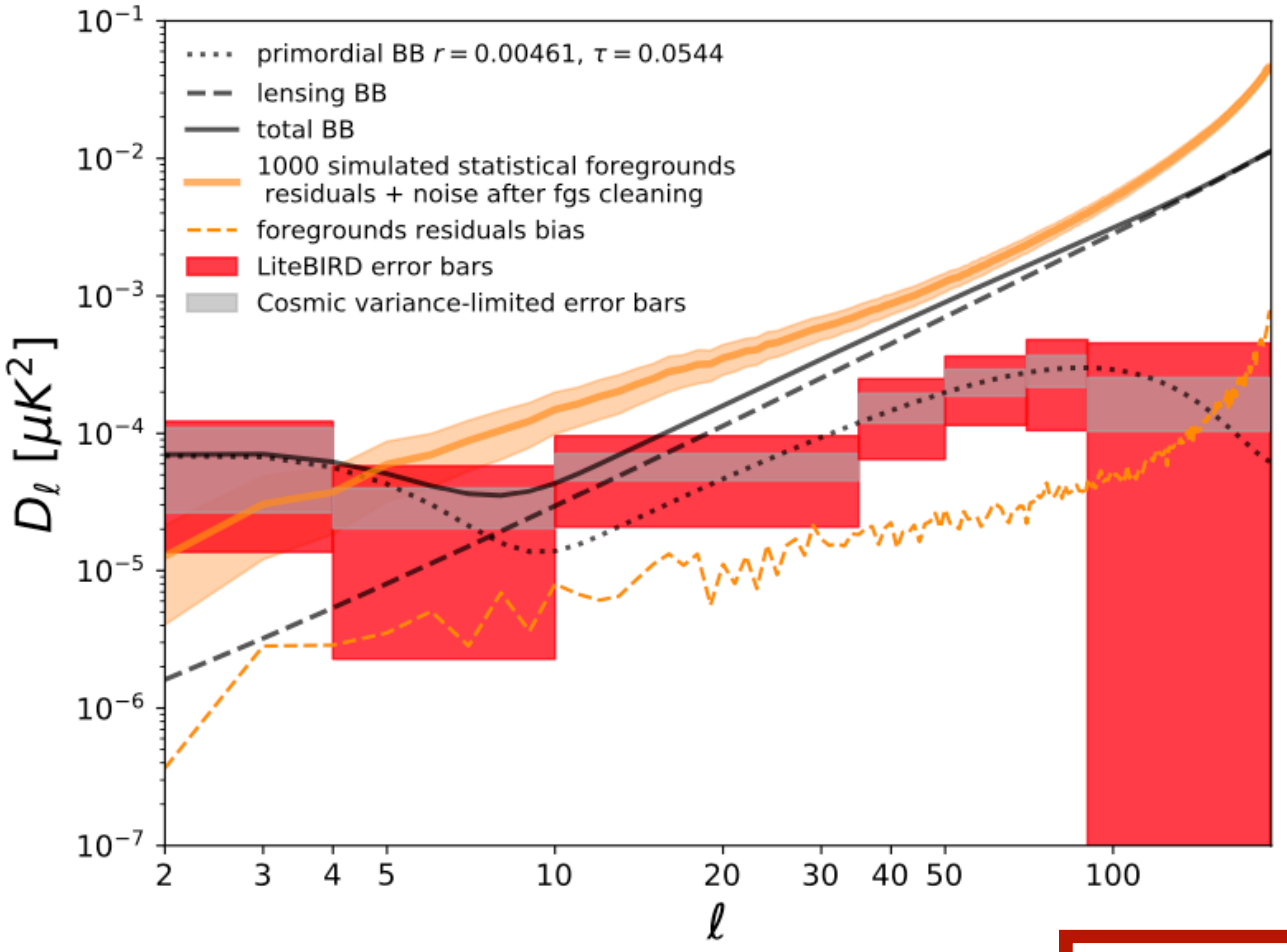
Category	Systematic effect	Type
Beam	Far sidelobes	R
	Near sidelobes	R
	Main lobe	E
	Ghost	R
	Polarization and shape in band	R
Cosmic ray	Cosmic-ray glitches	E
HWP	Instrumental polarization	E
	Transparency in band	R
	Polarization efficiency in band	R
	Polarization angle in band	R
Gain	Relative gain in time	R
	Relative gain in detectors	R
	Absolute gain	E
Polarization angle	Absolute angle	E
	Relative angle	E
	HWP position	E
	Time variation	E
Pol. efficiency	Efficiency	E
Pointing	Offset	R
	Time variation	E
	HWP wedge	R
Bandpass	Bandpass efficiency	R
Transfer function	Crosstalk	R
	Detector time constant knowledge	R



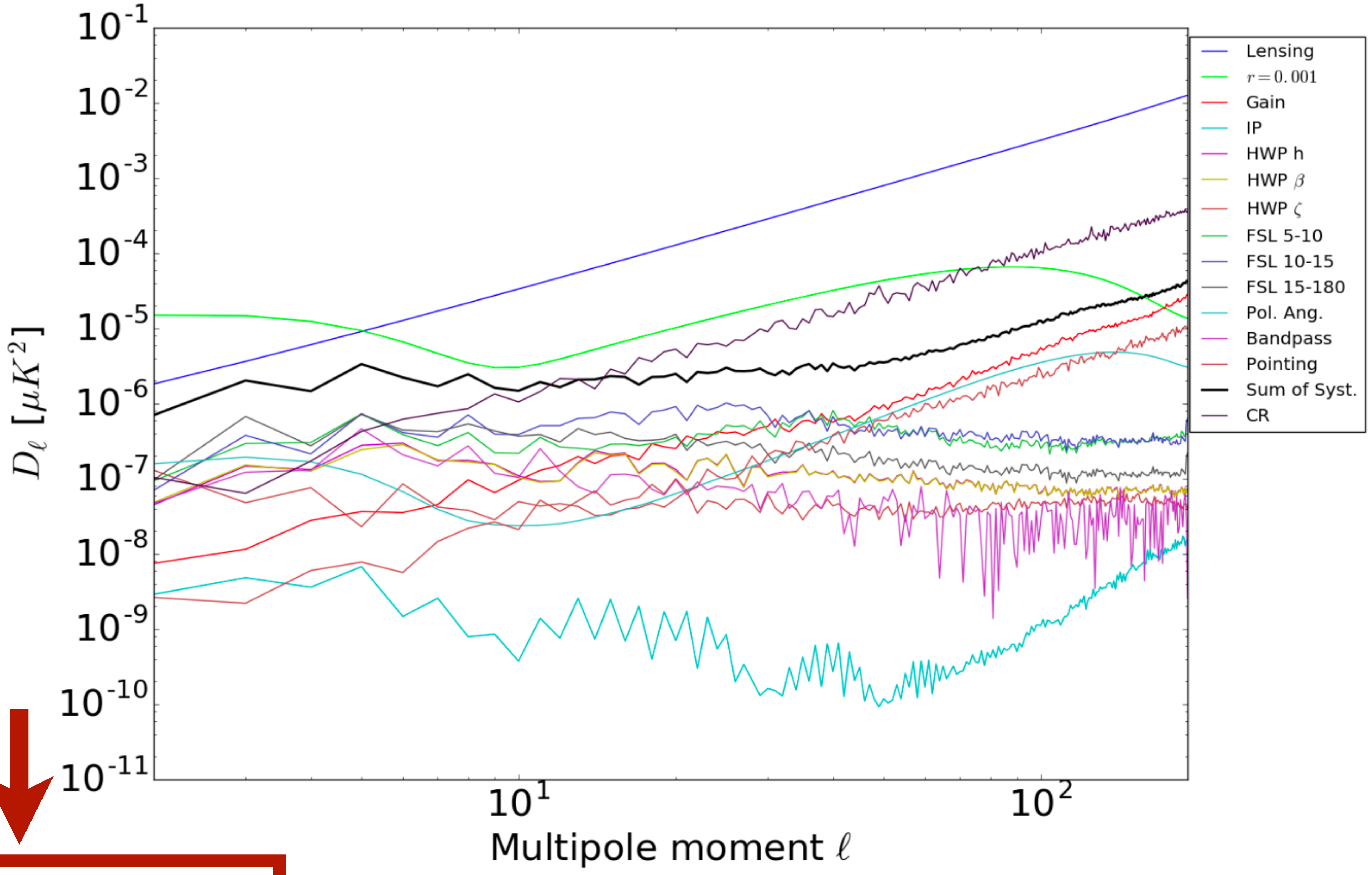
LiteBIRD Forecasts

Impact of Foregrounds and Systematics

Foregrounds



Instrumental Systematics

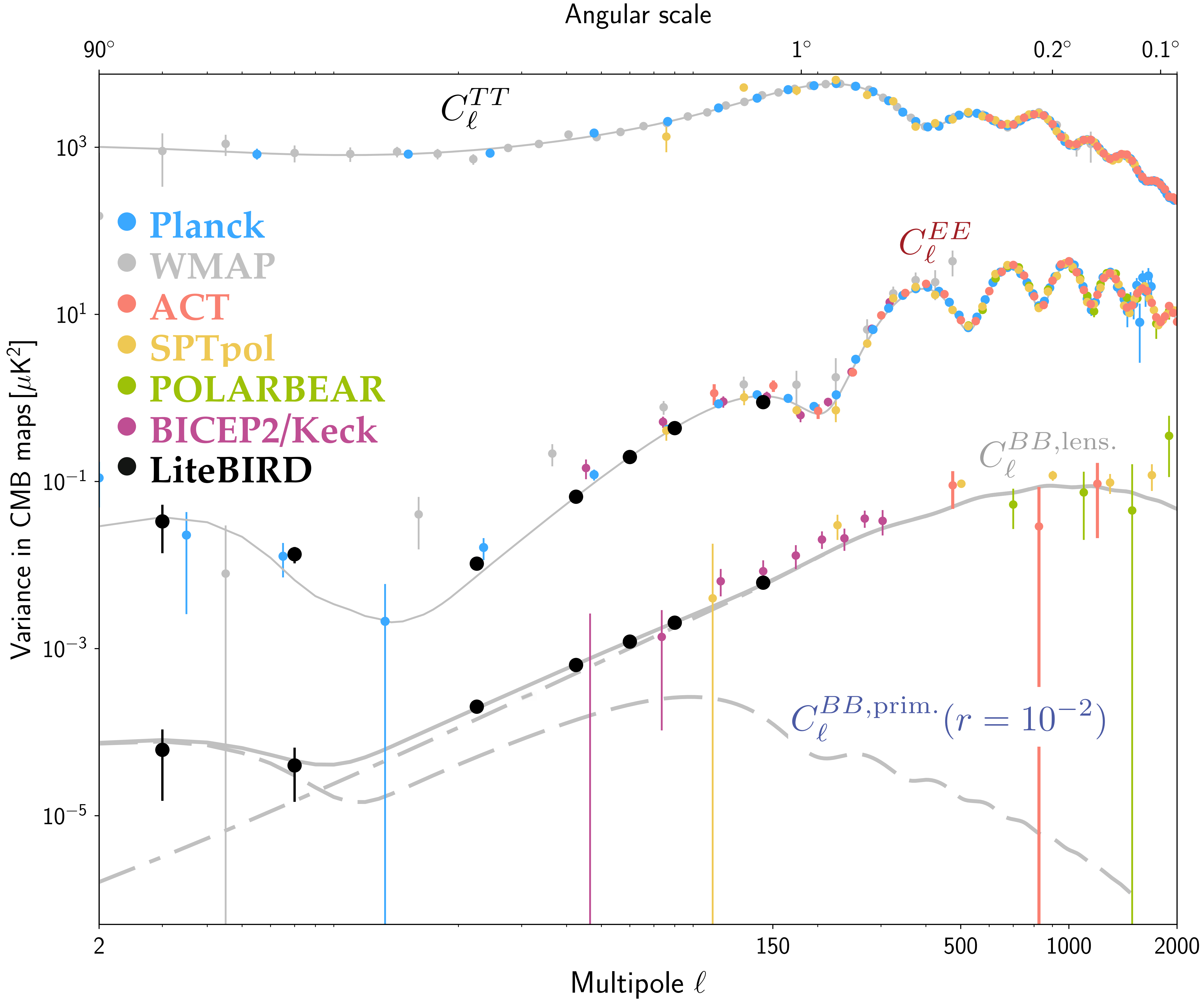


$$\delta r = 1.0 \times 10^{-3}$$

LiteBIRD main scientific objectives

- Definitive search for the ***B*-mode signal** from **cosmic inflation** in the CMB polarization
  - Making a discovery or ruling out well-motivated inflationary models
  - Insight into the quantum nature of gravity
- The inflationary (i.e. primordial) *B*-mode power is proportional to the **tensor-to-scalar ratio, *r***
- Current best constraint: $r < 0.032$ (95% C.L.)
  (📖 Tristram et al. 2022, combining BK18 and Planck PR4)

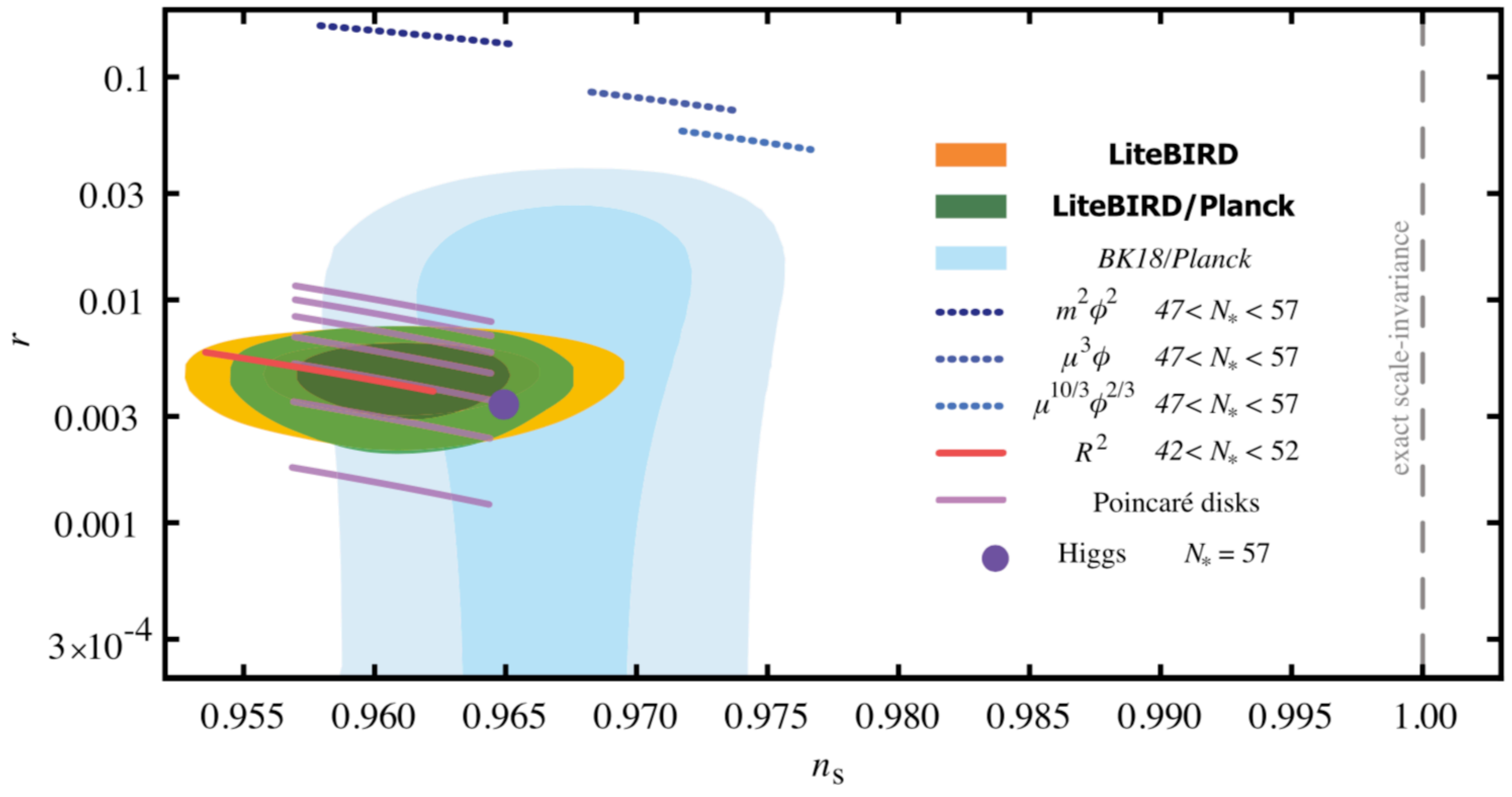
- LiteBIRD will improve current sensitivity on *r* by a factor ~30
- L1-requirements (from PTEP):
  - For $r = 0$, **total uncertainty of $\delta r < 0.001$**
  - For $r = 0.01$, 5-σ detection of the reionization ($2 < \ell < 10$) and recombination ($11 < \ell < 200$) peaks independently

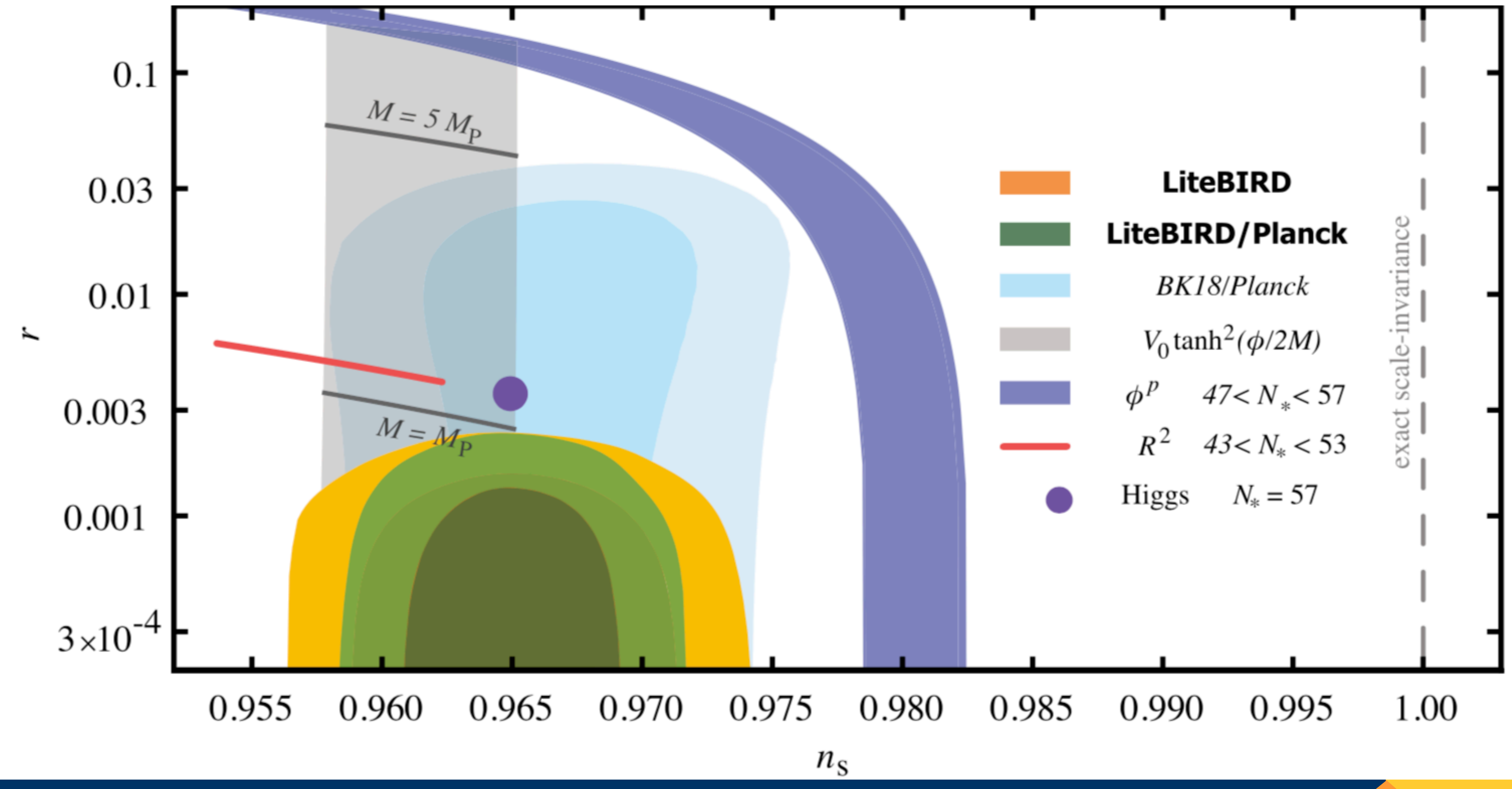


LiteBIRD main scientific objectives

Constraints on Inflation

- Huge discovery impact (evidence for inflation, knowledge of its energy scale, and distance traveled by the inflaton…)
- A detection of B-modes by LiteBIRD with $r > 0.01$ would imply an excursion of the inflation field that exceeds the Planck mass
  - Such a detection would **constrain theories of quantum gravity** such as superstring theories
- An upper limit from LiteBIRD would disfavour the simplest inflationary models, with $M > M_P$
  - This includes the monomial models, α-attractors with a super-Planckian characteristic scale, including the **Starobinsky model** and models that invoke the Higgs field as the inflaton





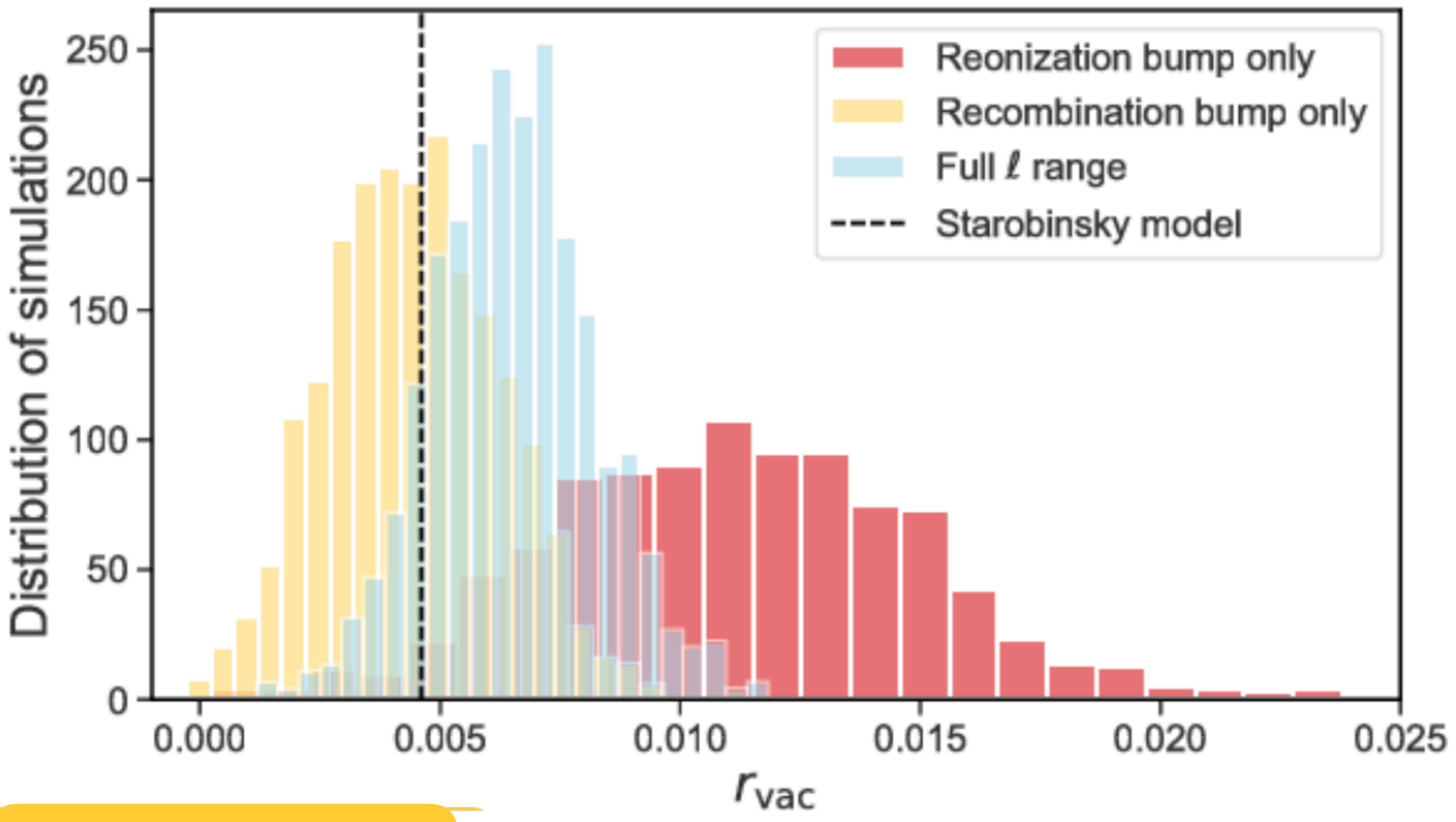
LiteBIRD main scientific objectives

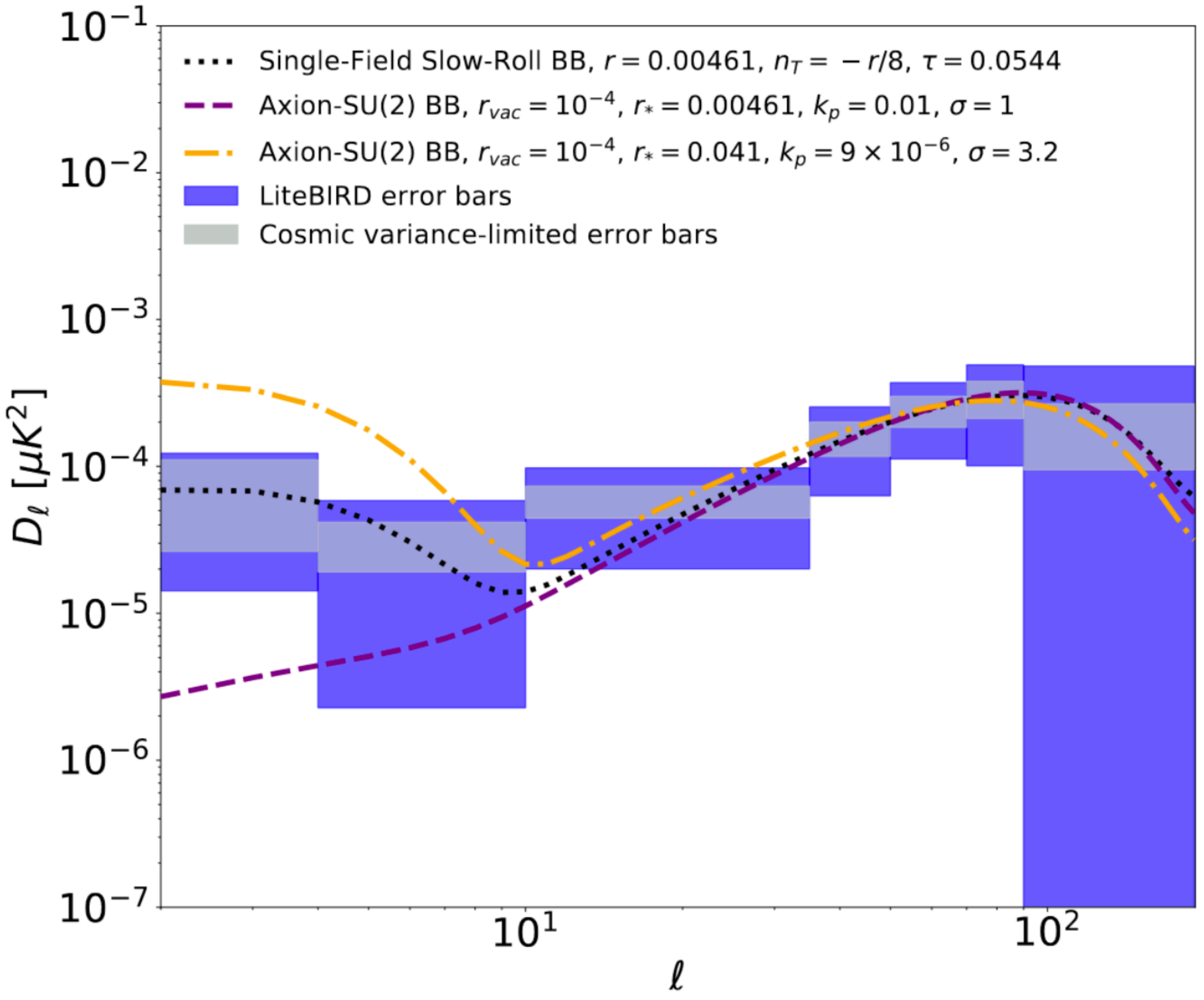
Constraints on Inflation

- Characterize the *B*-mode power spectrum

Ex. Spectator axion-SU(2) gauge field inflation

$$\mathcal{L} = \mathcal{L}_{inf} - \frac{1}{2}(\partial_\mu \chi)^2 - V(\chi) - \frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + \frac{\lambda}{4f}\chi F^a_{\mu\nu}\tilde{F}^{a\mu\nu}$$



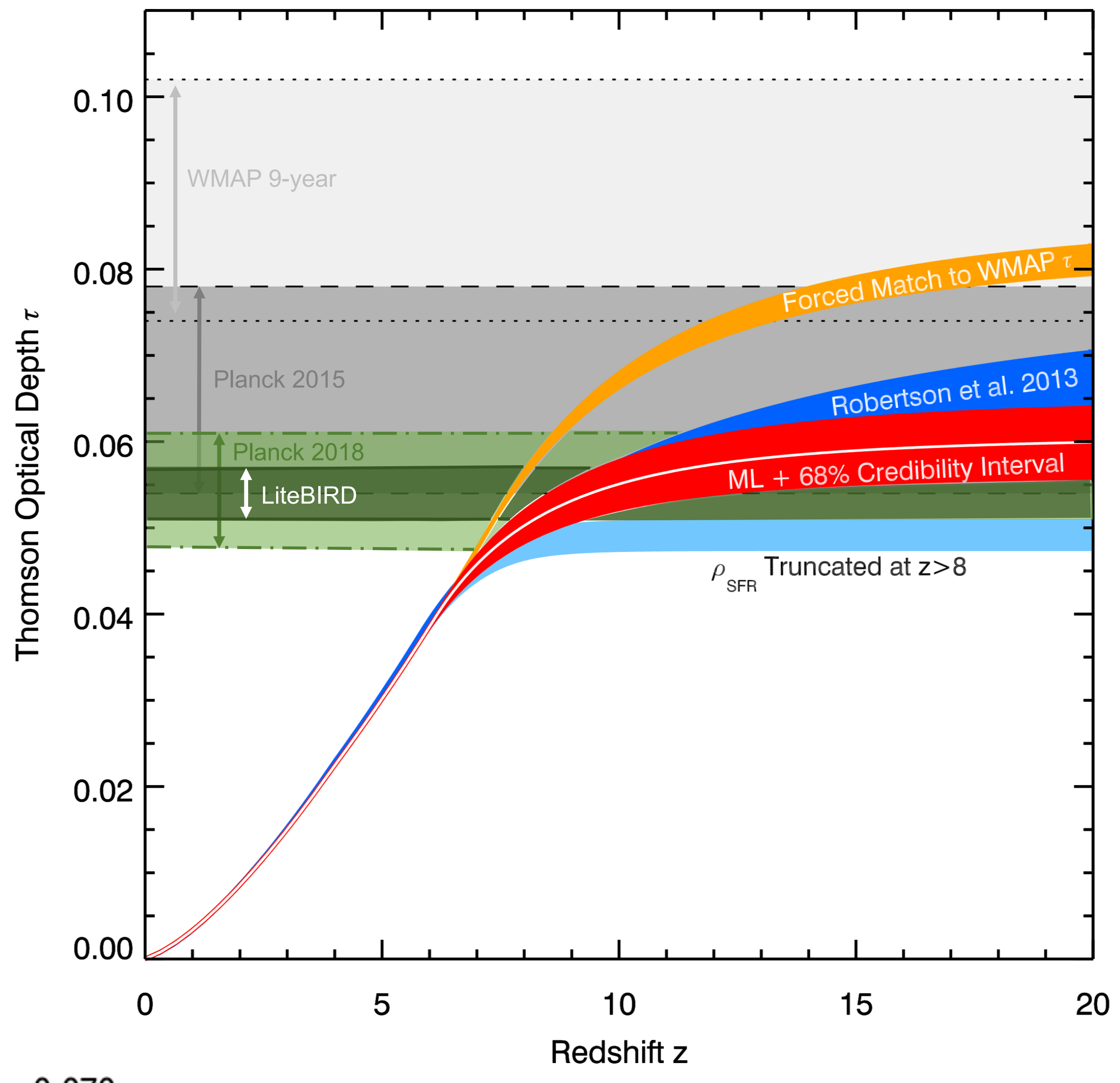


📖 Campeti+2023

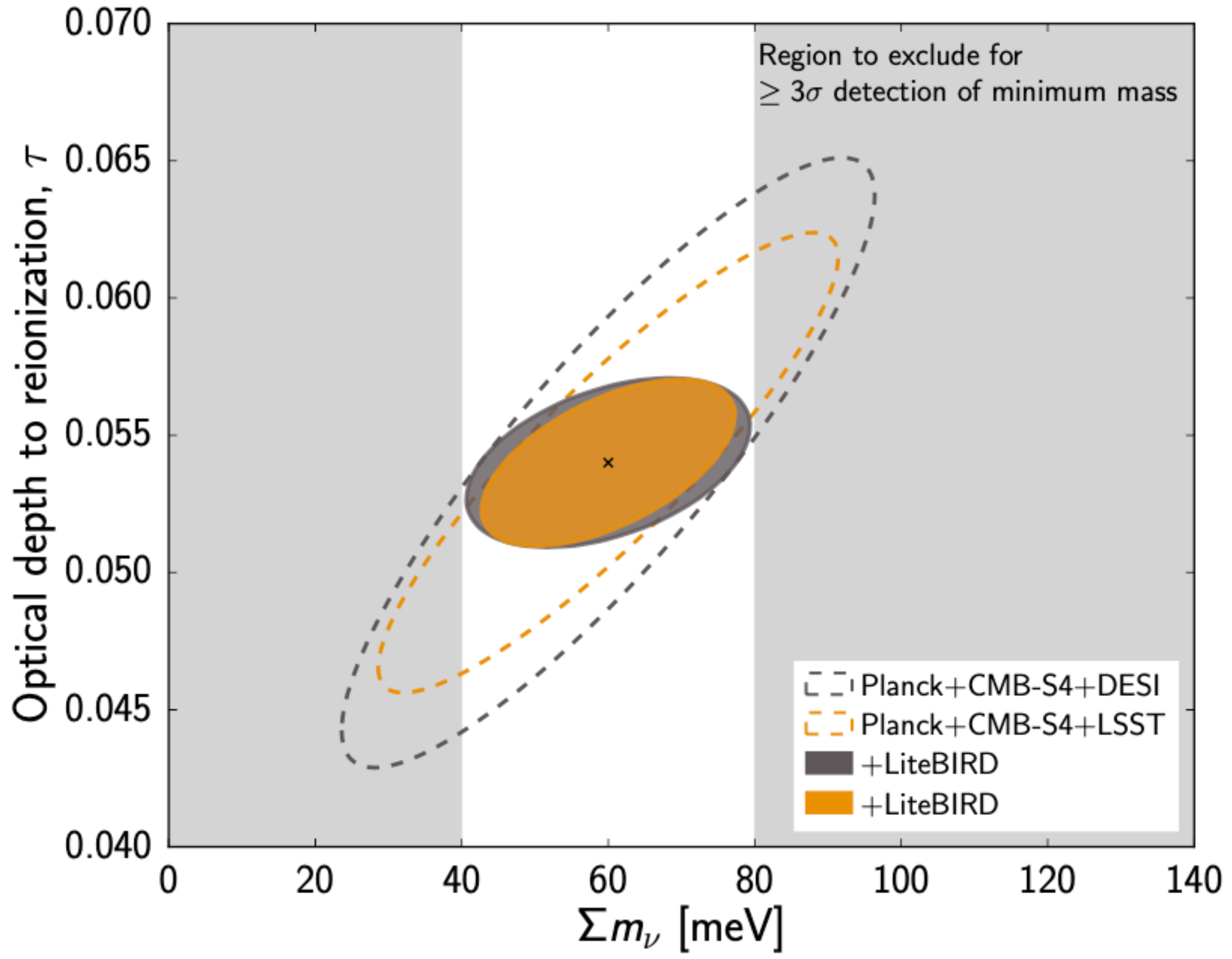
LiteBIRD other science outcomes

Optical depth, deionisation & neutrino masses

- LiteBIRD will provide a cosmic-variance limited measurement of the ***E*-mode** power spectrum at large scales ($2 < \ell < 200$)
- This will lead to improved constraints on:
  - **Reionization**
    - Cosmic-variance measurement of the **optical depth** to reionization ⇒ $\sigma(\tau) \approx 0.002$ ⇒ ×3 improvement with respect to Planck (Planck Int.Res. LVII, 2020)
    - Improved constraints on reionization history models: 35% improvement on the uncertainty of $\Delta(z_{reion})$
  - **Neutrino masses**
    - ×2 improvement on $\sigma(\sum m_\nu)$
    - $\sigma(\sum m_\nu)$ = 12 meV ⇒ 5σ detection for a minimum value of $\sum m_\nu$ = 60 meV (allowed by flavour-oscillation experiments) or larger
    - Potentially allow us to distinguish between the inverted neutrino mass ordering and the normal ordering



📖 adapted from Robertson+2015

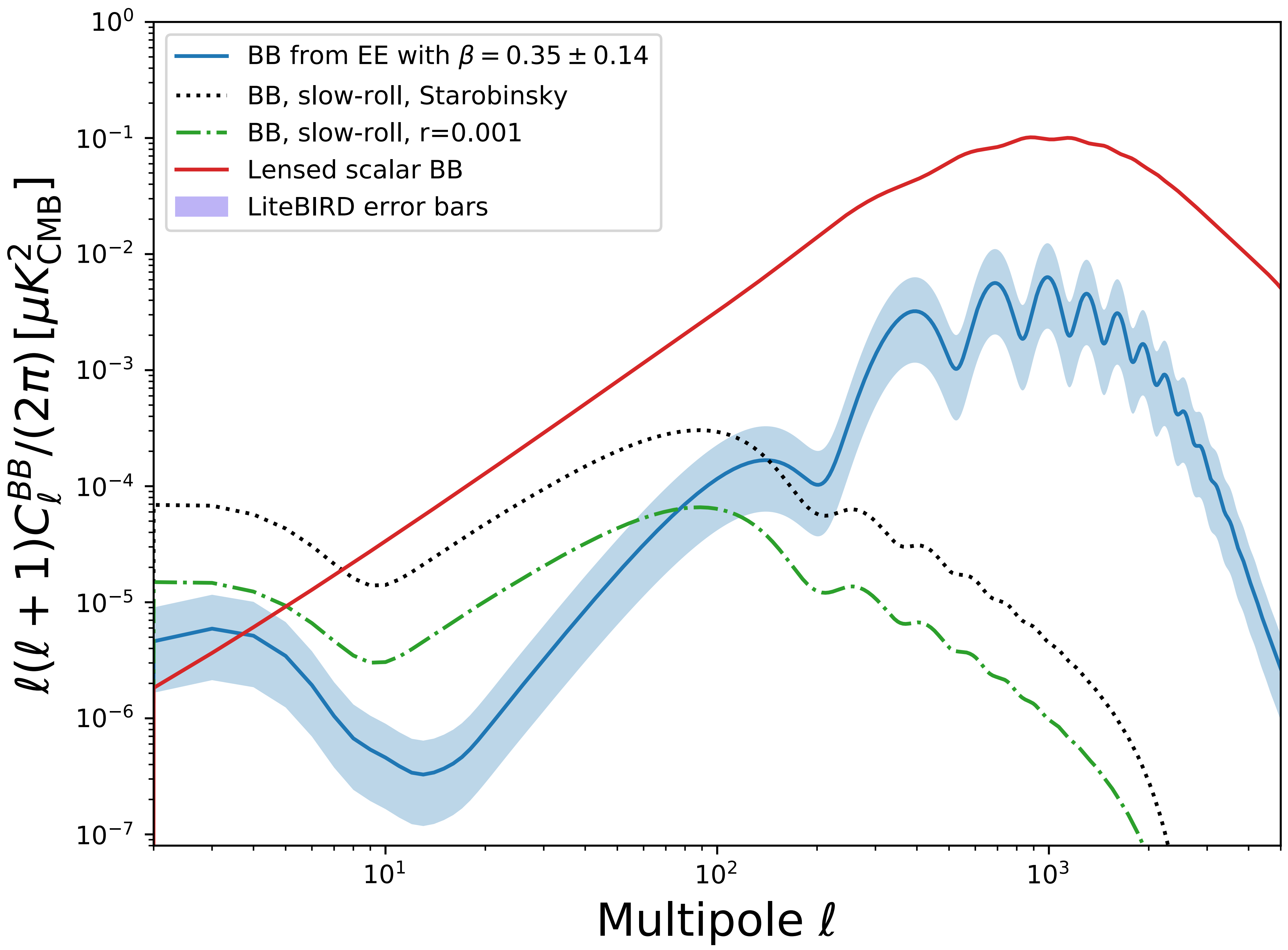


📖 adapted from Calabrese+2017

LiteBIRD other science outcomes

Cosmic Birefringence

- **Cosmic birefringence** could be seeded by parity-violating processes in Universe.
- Could occur if dark matter or dark energy are a pseudo-scalar field coupled to electromagnetism that changes sign under inversion of spatial coordinates.
- Induces non-zero *TB* and *EB* and also a *B*-mode signal
- Constraints from the CMB must account jointly for i) a possible detector angle miscalibration (📖 Minami et al., 2019) and ii) a positive EB signal from Galactic foregrounds (📖 Diego-Palazuelos et al., 2022)
- Recent measurements show a tentative detection of a birefringence angle of **β = (0.34±0.09)°** (📖 Eskilt & Komatsu 2022, from a combination of WMAP and Planck PR4)
- LiteBIRD has the potential to:
  - Reduce the error bar on a global β leading to a **~10-sigma detection**
  - Produce a map of β to test for **cosmic-birefringence anisotropy**

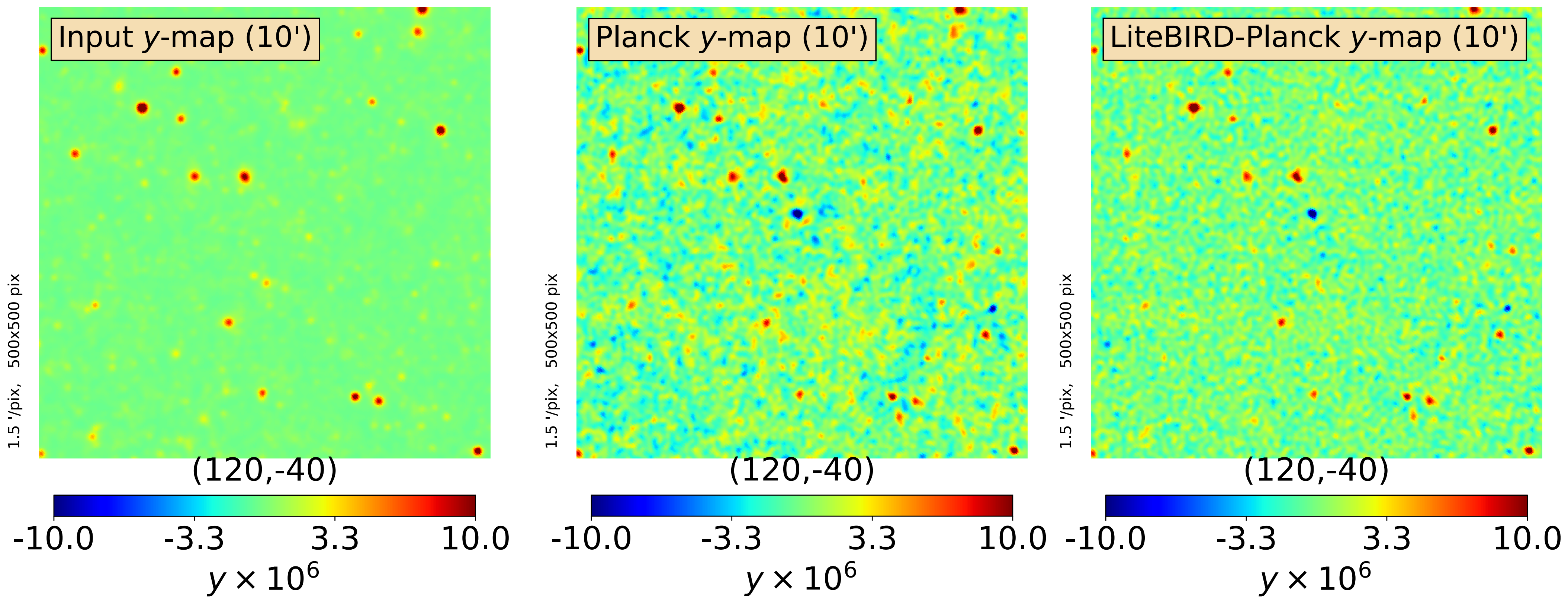


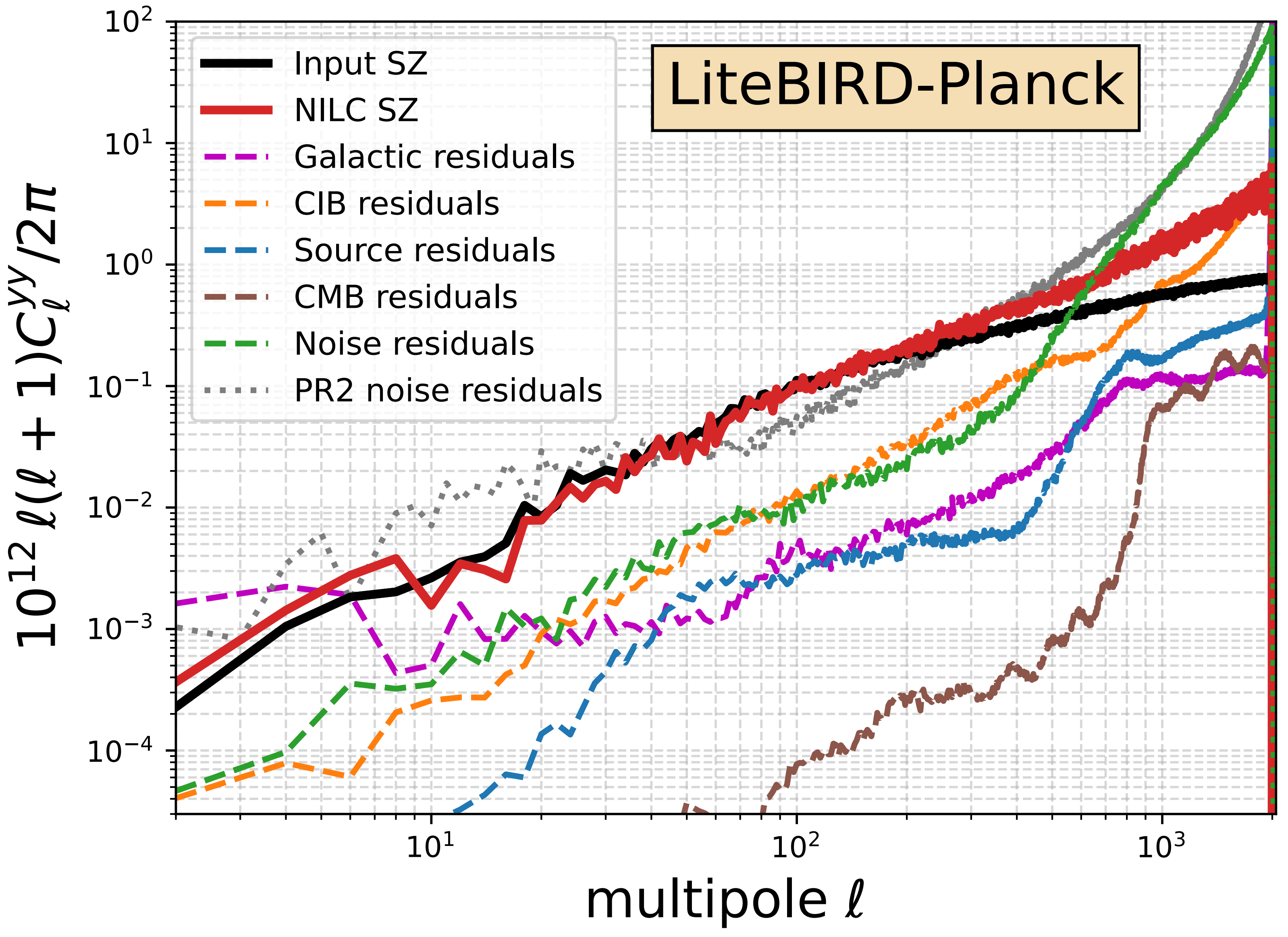
📖 LiteBIRD collaboration PTEP 2023

LiteBIRD other science outcomes

Mapping the hot gas in the Universe

- The **Sunyaev-Zel'dovich** effect provides a mean to map the distribution of hot electrons in the Universe
- Improved sensitivity and frequency coverage of LiteBIRD crucially contributes to improve these studies
- Combination with Planck adds the benefit of angular resolution
- LiteBIRD will **improve ×10 the noise in the SZ map** wrt Planck
- This will allow us to:
    - Produce a high-fidelity SZ map over the full-sky essentially **free of contamination at $\ell < 200$**
    - Test theories of structure formation via **hot-gas tomography** from SZ × galaxy surveys correlations
    - Search form **WHIM** in filaments connecting clusters
    - Study an **inhomogeneous reionization** process via cross-correlations of SZ × CMB optical depth
    - Measure the mean gas T_e via the relativistic SZ
    - Improve constraints on $S_8 = \sigma_8(\Omega_m/0.3)^{0.5}$ by 15%



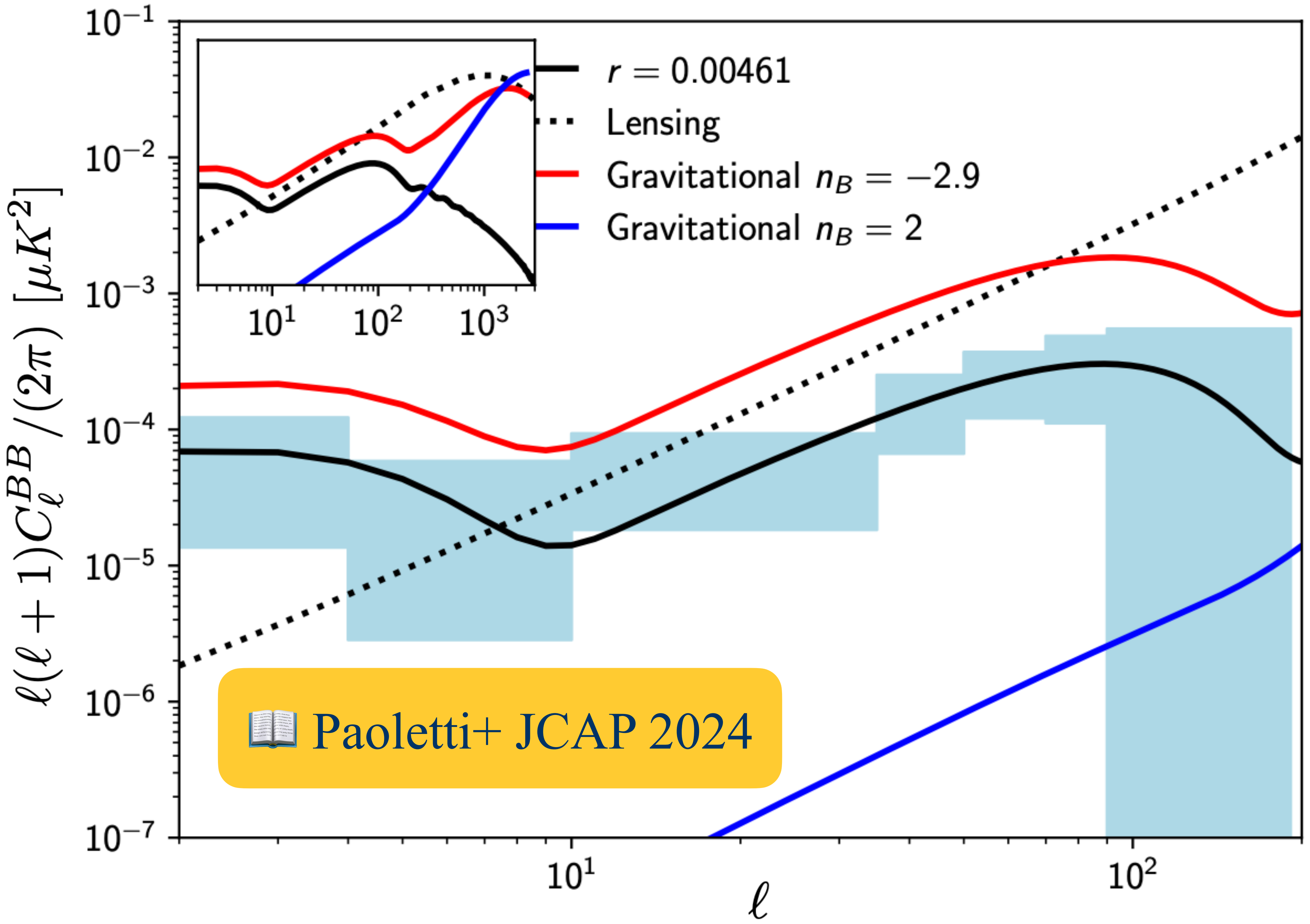


Remazeilles+ JCAP 2024

LiteBIRD other science outcomes

Primordial magnetic fields

- Primordial magnetic fields (PMFs) affect the CMB via different effects:
  - **Gravitational effects** with magnetically-induced perturbations
  - Impact on the **ionization history** of the Universe due to their post-recombination dissipation
  - Induce a **Faraday rotation** of the CMB polarization
  - **Non-Gaussianity** induced in the CMB polarization anisotropies
- LiteBIRD:
  - Is a **sensitive probe** to PMFs through all these effects, thanks mainly to its remarkable sensitivity in polarization
  - Will **break the nG threshold** improving current upper limits by a factor of ~ 3
  - Will be able to **univocally identify the PFMs contribution to CMB** by joining all these effects together
  - Will allow a detection of **nG fields** with high significance

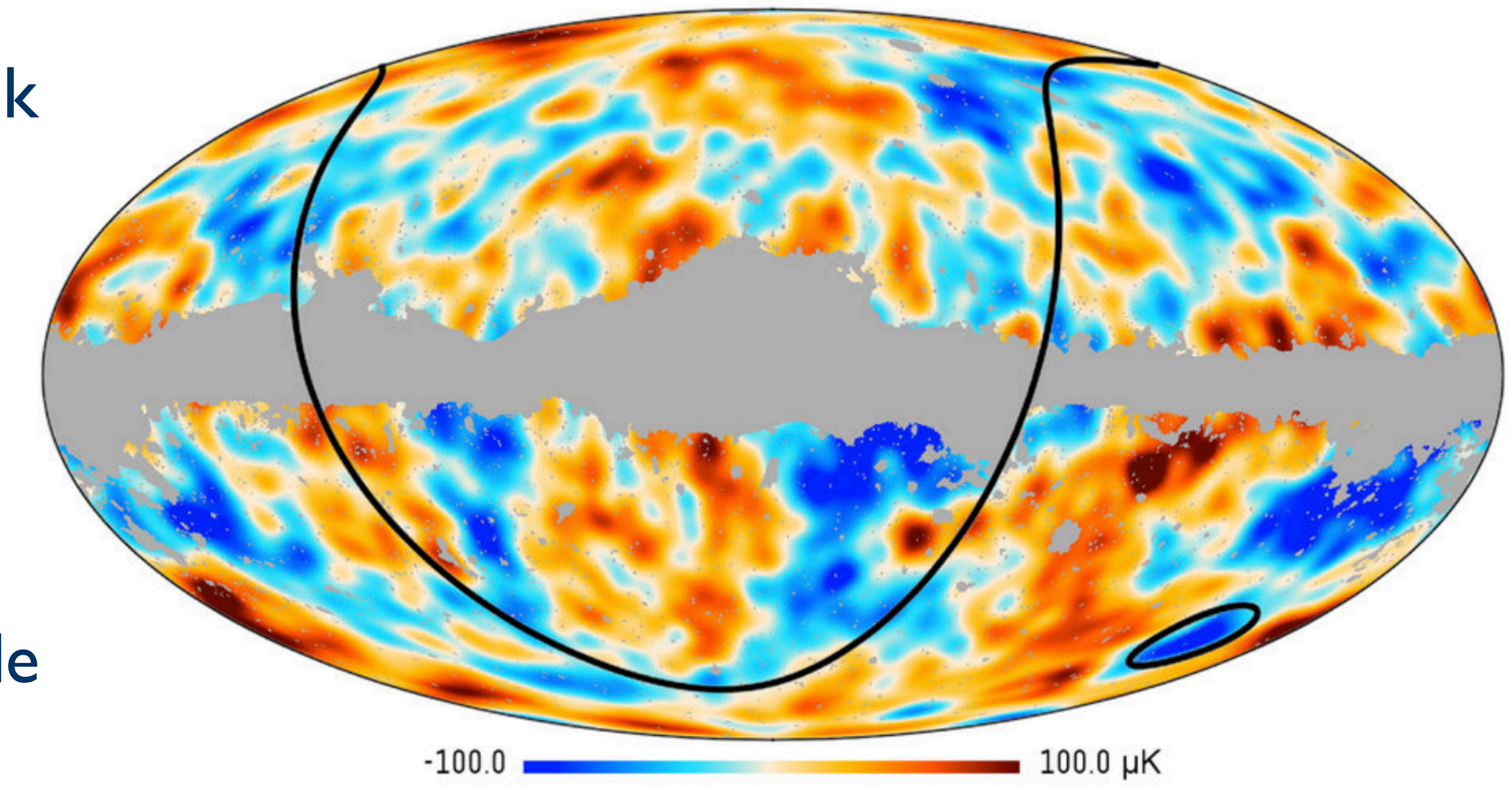


Upper limits on PMF amplitude for n_B = -2.9	
Gravitational effect	$B_{1\mathrm{Mpc}} < 0.8$ nG
Ionization history	$\sqrt{<B^2>} < 0.7$ nG
Faraday rotation	$B_{1\mathrm{Mpc}} < 3.2$ nG
Non-Gaussianities	$B_{1\mathrm{Mpc}} \lesssim 1$ nG

LiteBIRD other science outcomes

Elucidating spatial anomalies with polarisation

- Various so-called anomalies have been found in WMAP and Planck temperature data that exert a mild tension against the ΛCDM cosmological model:
  - a lack of power on large angular scales
  - the alignment of the quadrupole and octopole moments
  - a hemispherical asymmetry in power on the sky
  - a lack of correlation at large angular scales
  - parity asymmetry in the power associated with even/odd mode
  - an anomalous "Cold Spot" on a scale of ~ 10°
  - anomalously low temperature variance
- Given their modest statistical significance, these could simply be statistical flukes
- However, they may also be hints of **new physics** beyond the standard model



Credit ESA/Planck Collaboration

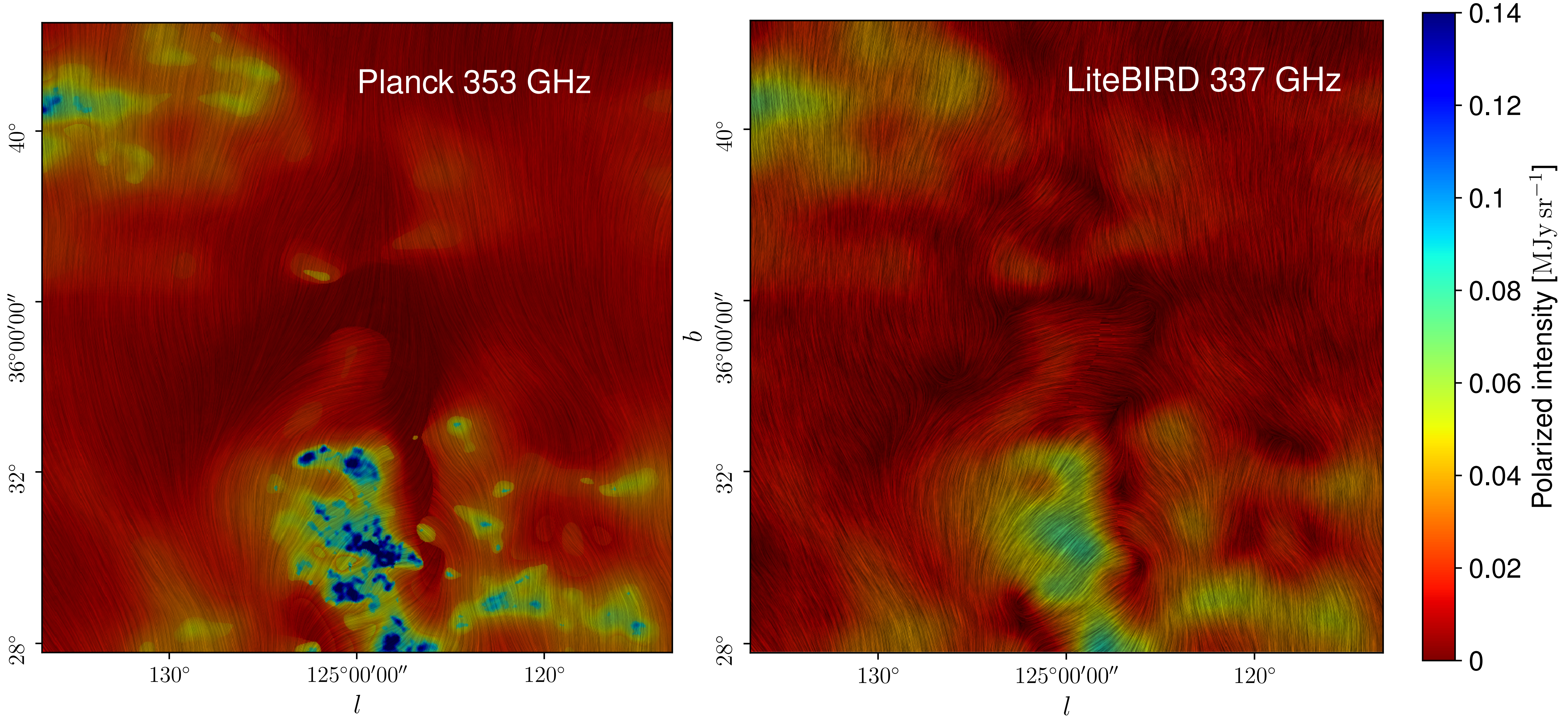
- Polarized CMB anisotropies provide independent information on the fluctuations that source the temperature anisotropy
- **LiteBIRD E-mode polarization sky maps will allow further tests** on the nature of these spatial anomalies at close to the cosmic-variance level of sensitivity

LiteBIRD other science outcomes

Galactic astrophysics

- LiteBIRD will provide 15 high-sensitivity polarization full-sky maps from 40 to 402 GHz
- Sensitivity improved by a factor of 5 at 40 GHz and 10 at 402, with respect to Planck
- Gain in spectral resolution

- **Wealth of Galactic science possible**:
  - Geometry of the Galactic magnetic field
  - Interstellar turbulence
  - Dust composition
  - Grain alignment
  - Cold clumps
  - Geometry of synchrotron-bright loops
  - SED of the synchrotron emission
  - Nature of AME and spectral variations...
  - … and many others!



Take-home Message

The most-mature CMB Space mission in 2020's

Phase-A started in Japan, US, CA and EU

Selected by ISAS / JAXA in May 2019

Launch by beg 2030'

Expected science outcomes

Constraining detection of primordial gravitational waves at a level of r close to 10^{-3}

Including statistical noise, systematic effects and component separation

without de-lensing !

Broad range of science outcomes on top of inflation

International collaboration

Great enthusiasm within this international team with lots of positive diversity !

Looking for more ?

LiteBIRD Overview Paper in Progress of Theoretical and Experimental Physics (PTEP) Journal

Reformation study to be concluded in about 1 year

APC

ASI

Berkeley
UNIVERSITY OF CALIFORNIA

BERKELEY LAB

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

cea

Centre Pierre Binétruy
CNRS • Berkeley

cnes

cnrs

CSA ASC
Canada

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CSL
CENTRE SPATIAL DE LIÈGE

ENS | PSL

erc
European Research Council

EXCELENCIA MARÍA DE MAEZTU

EXCELENCIA SEVERO OCHOA

FAU
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Forskningsrådet
The Research Council of Norway

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

NASA
Goddard Space Flight Center

GSSI
GRAN SASSO SCIENCE INSTITUTE

INSTITUTO DE ASTROFISICA DE CANARIAS IAC

IAP

IAS
Institut d'Astrophysique Spatiale
Orsay

IFCA
Instituto de Física de Cantabria

ifpU

IJCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

INFN

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

IPMU

IPNS
素粒子原子核研究所
Institute of Particle and Nuclear Studies

irap
astrophysique & planétologie

JAXA

NASA
Jet Propulsion Laboratory
California Institute of Technology

NATIONAL INSTITUTE OF TECHNOLOGY KAGAWA COLLEGE
香川高専

KEK

KIPAC
KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS & COSMOLOGY

KMI
Kobayashi-Maskawa Institute
Nagoya University

LMU

LPSC
GRENOBLE | MODANE

LiteBIRD

MAX-PLANCK-INSTITUT FÜR ASTROPHYSIK

McGill

Maynooth University
National University of Ireland Maynooth

名古屋大学
NAGOYA UNIVERSITY

NÉEL institut

NIST

HK
Norwegian Directorate for Higher Education and Skills

OAC

岡山大学
OKAYAMA UNIVERSITY

QUP
International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles

POLITÉCNICA

idr

RWTH AACHEN UNIVERSITY

SAPIENZA
UNIVERSITÀ DI ROMA

SISSA

SORBONNE UNIVERSITÉ

SRON

SSDC
SPACE SCIENCE DATA CENTER

LELAND STANFORD JUNIOR UNIVERSITY
1891

Stockholm University

公立諏訪東京理科大学
Suwa University of Science

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

UCL

UBC
THE UNIVERSITY OF BRITISH COLUMBIA

UC
UNIVERSIDAD DE CANTABRIA

Università di Catania

University of Colorado Boulder

UKRI
Science and Technology Facilities Council

ULB
UNIVERSITÉ LIBRE DE BRUXELLES

Universidad de La Laguna

MANCHESTER 1824
The University of Manchester

UiO : University of Oslo

UNIVERSITY OF OXFORD

UNIVERSITÀ DI PISA

Università degli Studi di Ferrara

UNIVERSITÀ DEGLI STUDI DI MILANO

UNIVERSITÀ DEGLI STUDI DI PADOVA

THE UNIVERSITY OF TOKYO

UNIVERSITY OF TORONTO

Back-up

Back-up

Neutrino Sector

Improvement of Optical depth determination:

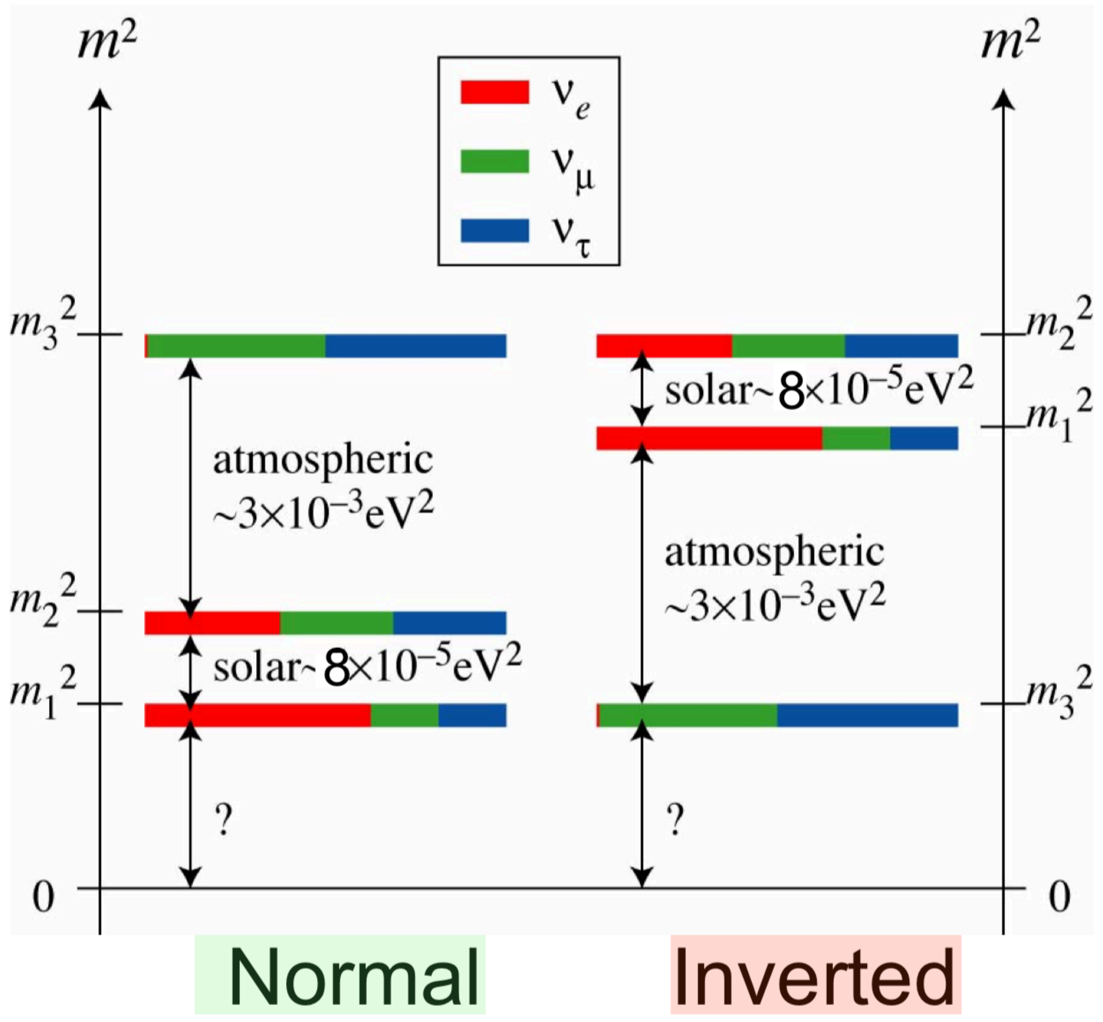
$\sigma(\Sigma m_\nu)$ = 12 meV

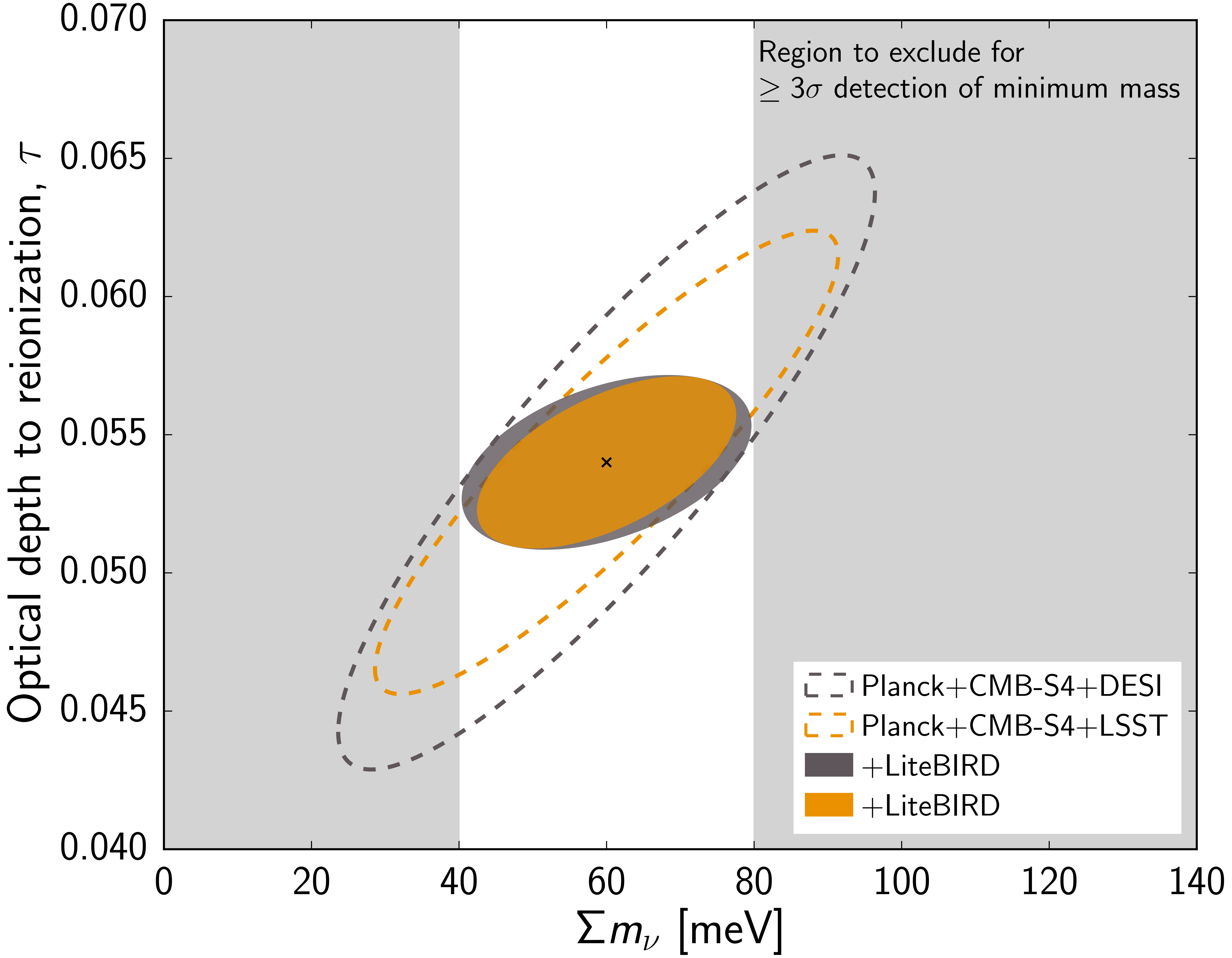
Determination of neutrino hierarchy (normal versus inverted)

Measurement of minimum mass

≥ 3σ detection NH ≥ 5σ detection IH

$\sum m_\nu > 0.06\,\mathrm{eV}$ $\sum m_\nu > 0.10\,\mathrm{eV}$

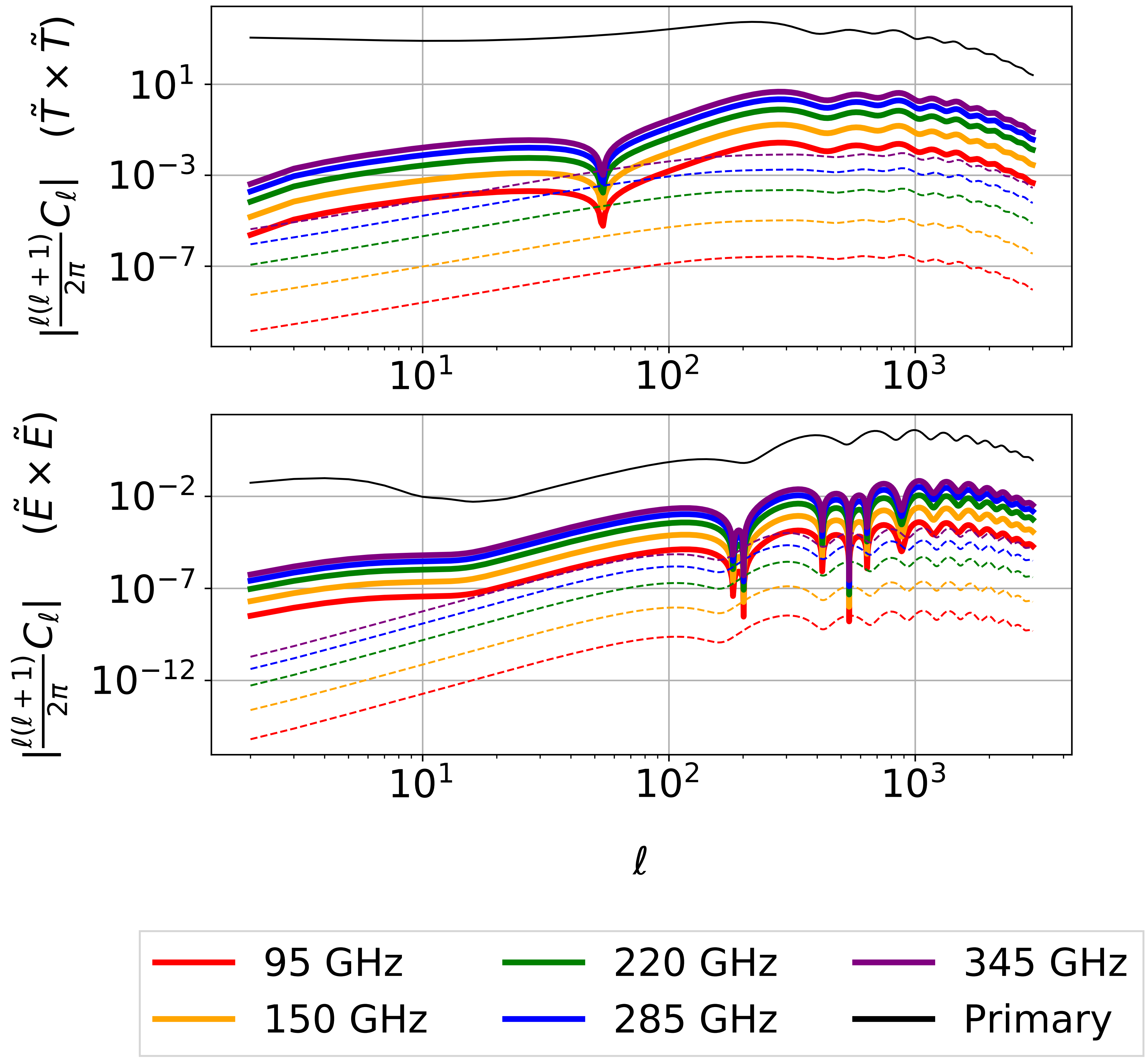




LiteBIRD other science outcomes

Anisotropic CMB spectral distortions

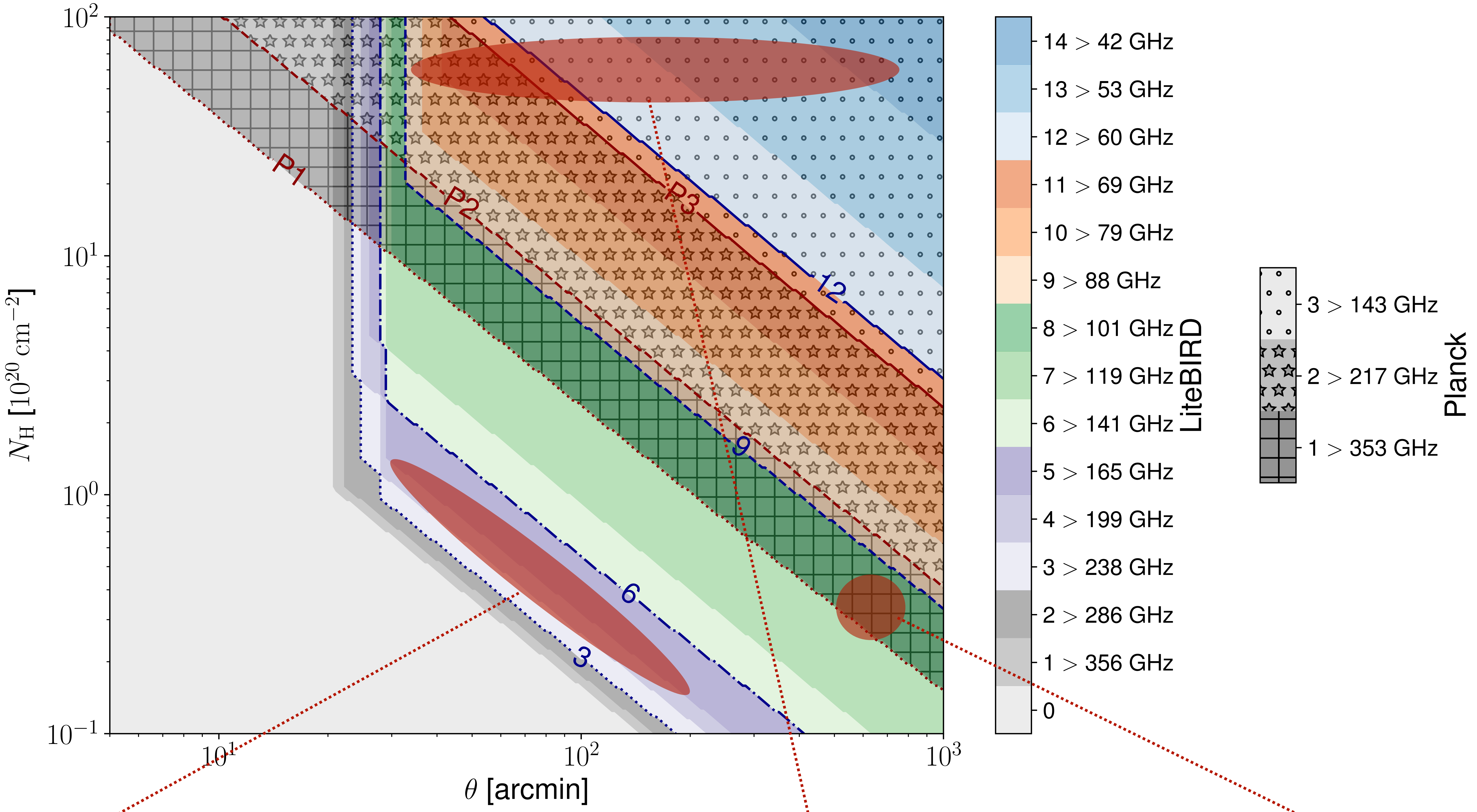
- LiteBIRD will be sensitive to any **spatially-varying CMB spectral distortion**, beyond the SZ effect
  - **Rayleigh scattering**. LiteBIRD will have sensitivity to measure at **25-sigma** (📖 Beringue et al. 2021) the frequency-dependent CMB anisotropies due to Rayleigh scattering by HI at the LSS
    - ➡ Such a detection would allow us to derive improved constraints on N_{eff} and $\sum m_\nu$
  - **μ distortion**. LiteBIRD can detect an anisotropic μ distortion induced by non-Gaussian fluctuations induced during inflation
    - ➡ This would offer a power test of inflation at its onset
  - **Axion decay**. LiteBIRD can look for polarized spectral distortions produced by resonant conversion of axions into photons by the Galactic magnetic field



📖 Dibert+ PhysRevD 2022

LiteBIRD other science outcomes

Galactic astrophysics

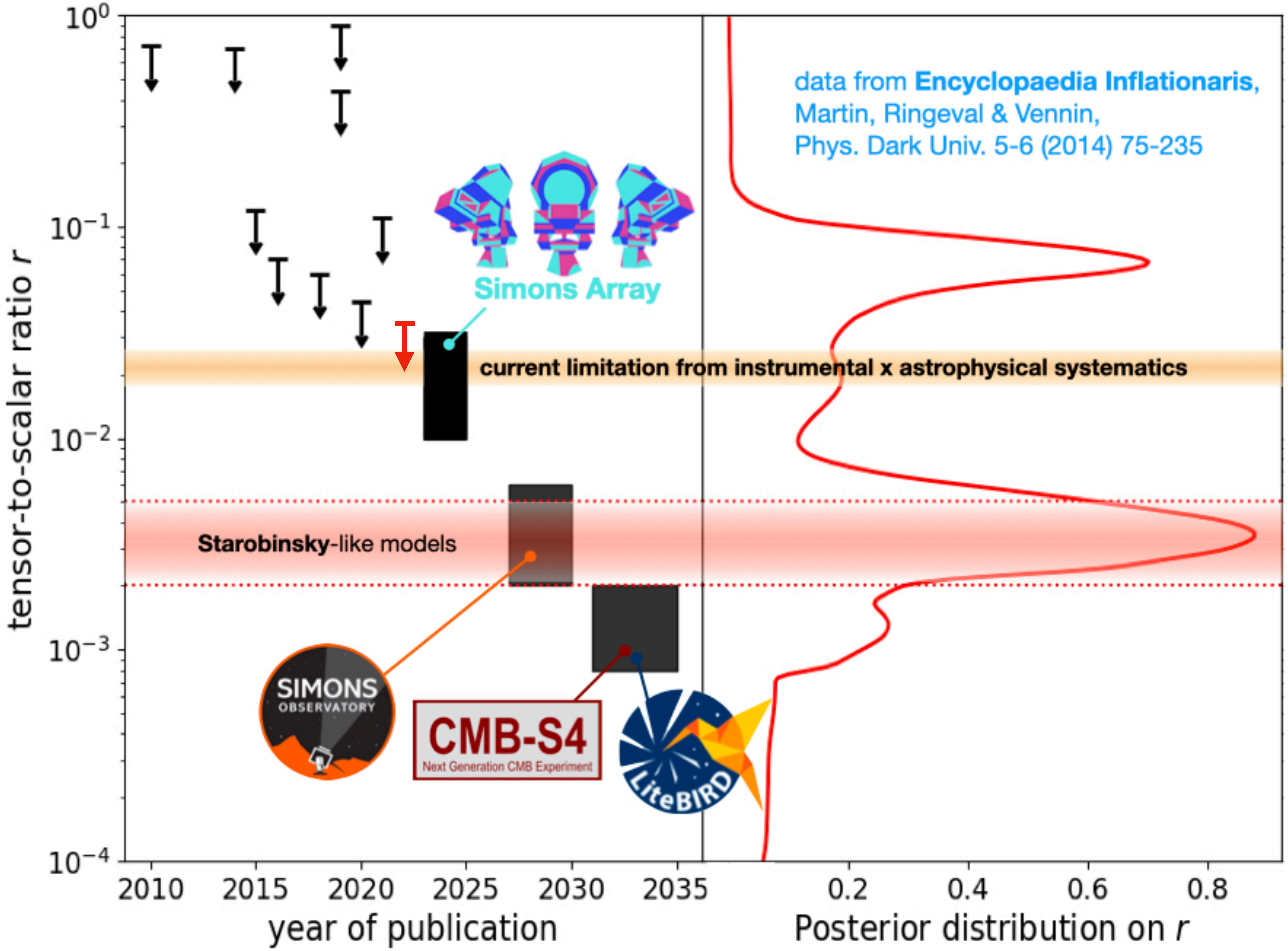


Exploration of diffuse medium @

Broad Multi-Frequency analyses in bright regions @ degree scales

Broad Multi-Frequency analyses in diffuse regions @ larger scales

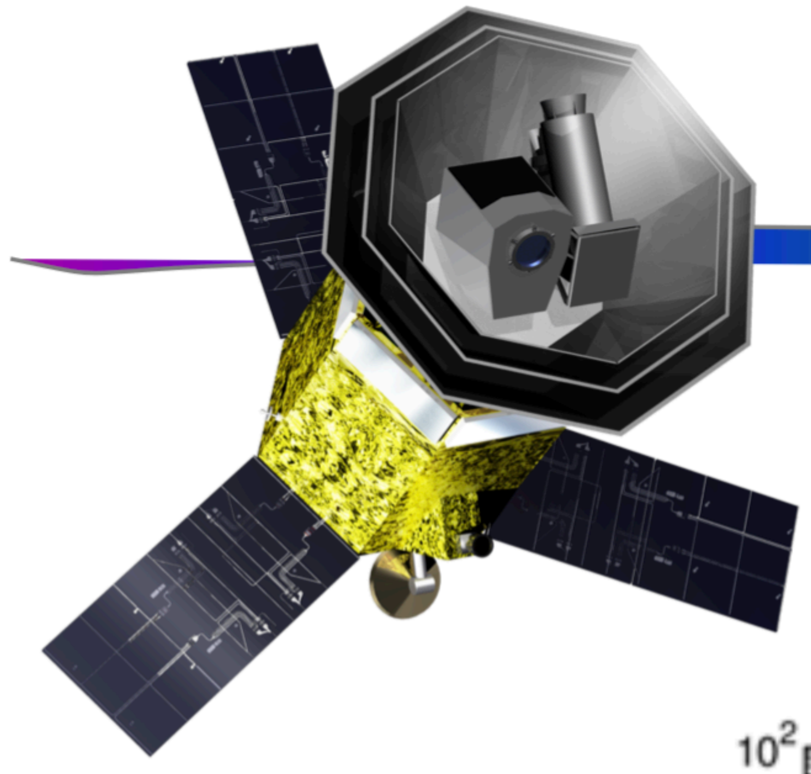
Back-up



tensor-to-scalar ratio r
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
2010 2015 2020 2025 2030 2035
year of publication
0.2 0.4 0.6 0.8
Posterior distribution on r
data from Encyclopaedia Inflationaris,
Martin, Ringeval & Vennin,
Phys. Dark Univ. 5-6 (2014) 75-235
Simons Array
current limitation from instrumental x astrophysical systematics
Starobinsky-like models
SIMONS OBSERVATORY
CMB-S4
Next Generation CMB Experiment
LiteBIRD

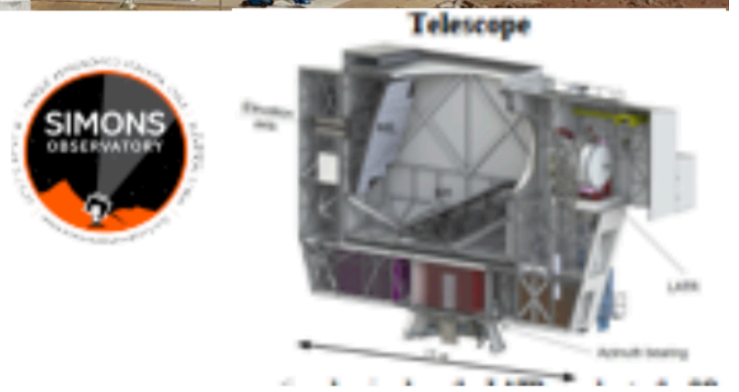
Back-up

Vision for 2020's

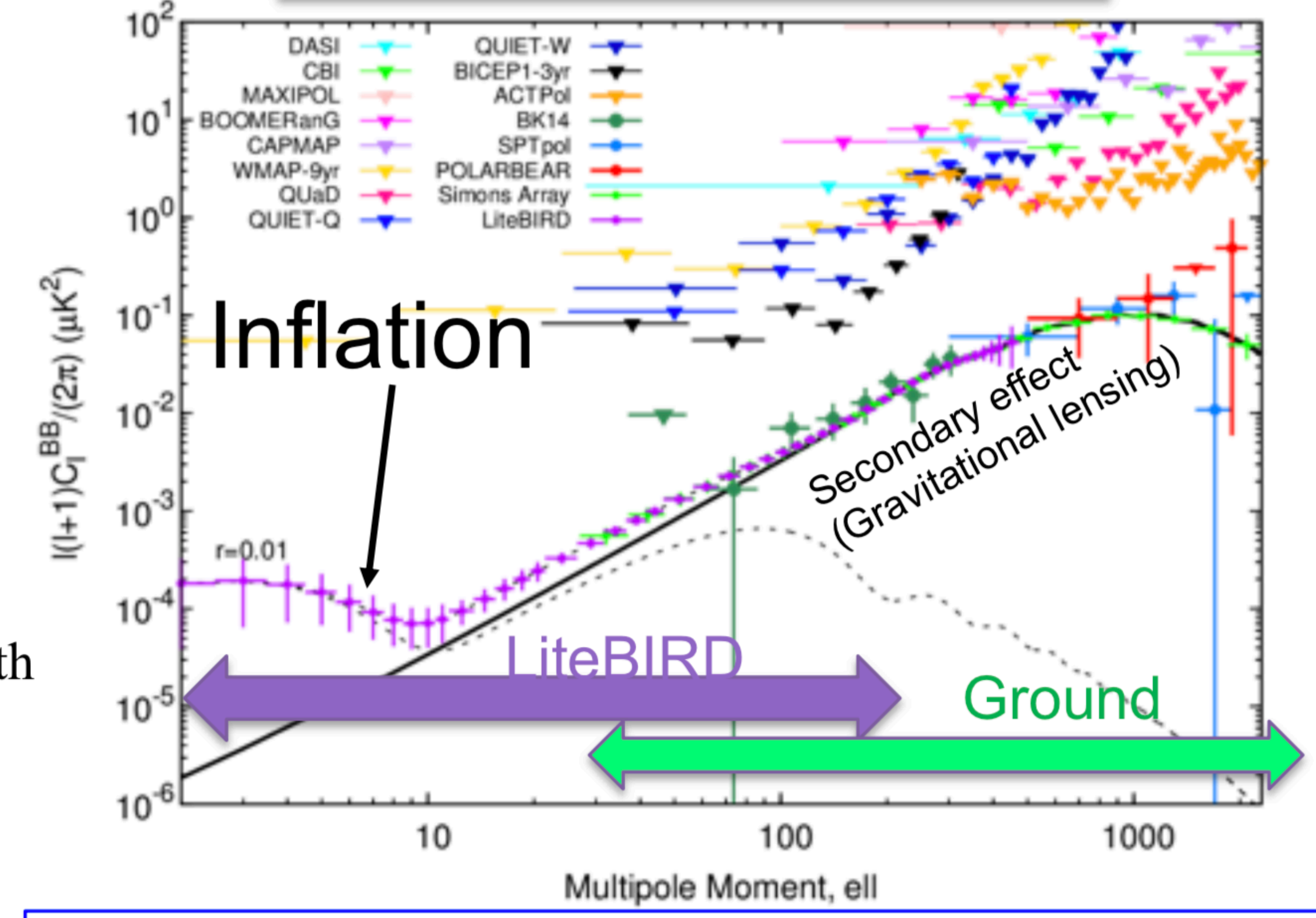


X

Powerful Duo



<u>LiteBIRD</u>
JAXA-led focused mission
σ(r)<0.001
$2 \leq \ell \leq 200$
focused but still with many byproducts

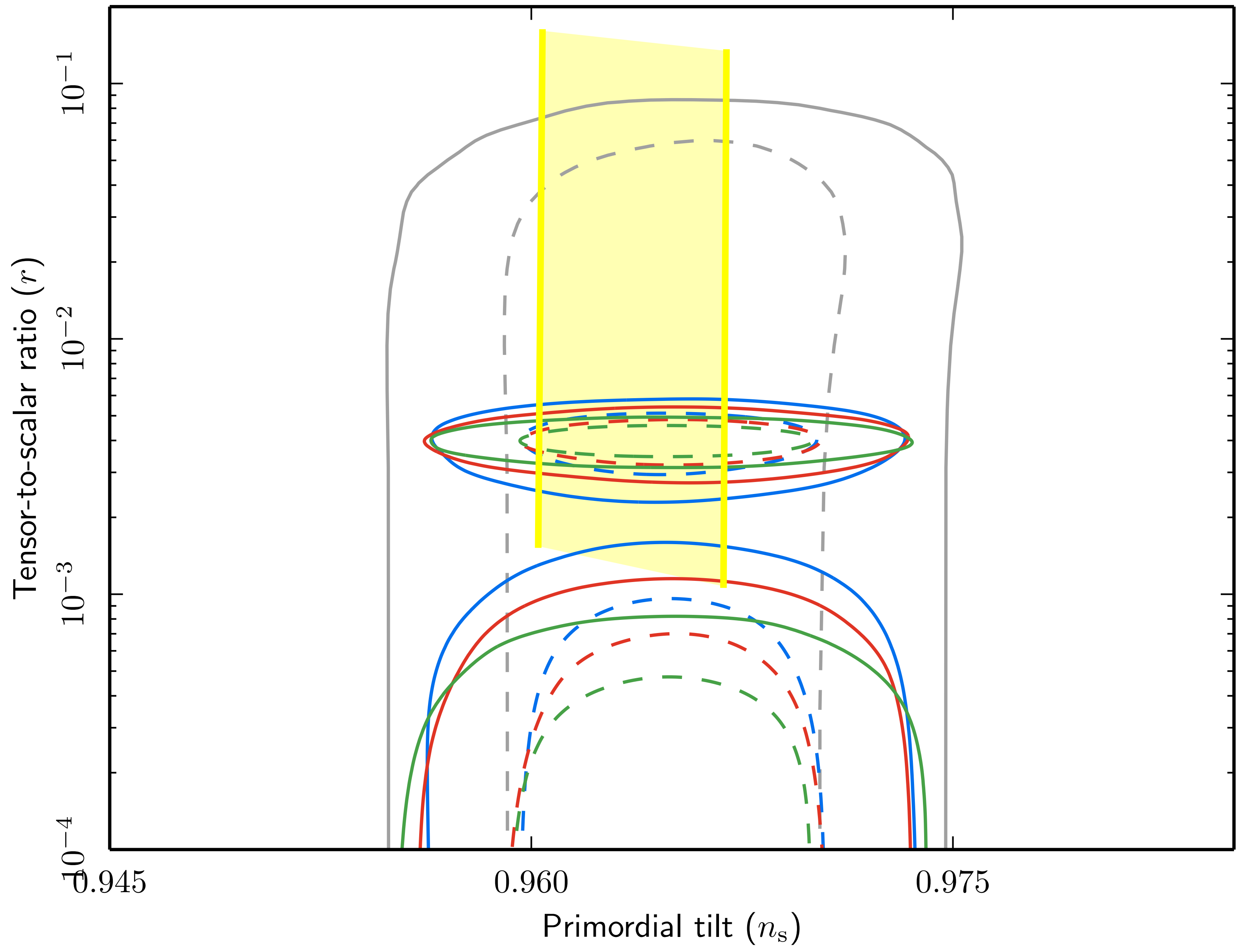


<u>Ground</u>
US-led telescopes on ground
$30 \leq \ell \leq \sim 8000$
e.g. Simons Observatory and CMB-S4

- This powerful duo is the best cost-effective way.
- Great synergy with two projects

Aiming at detection with >5σ in case of Starobinsky model

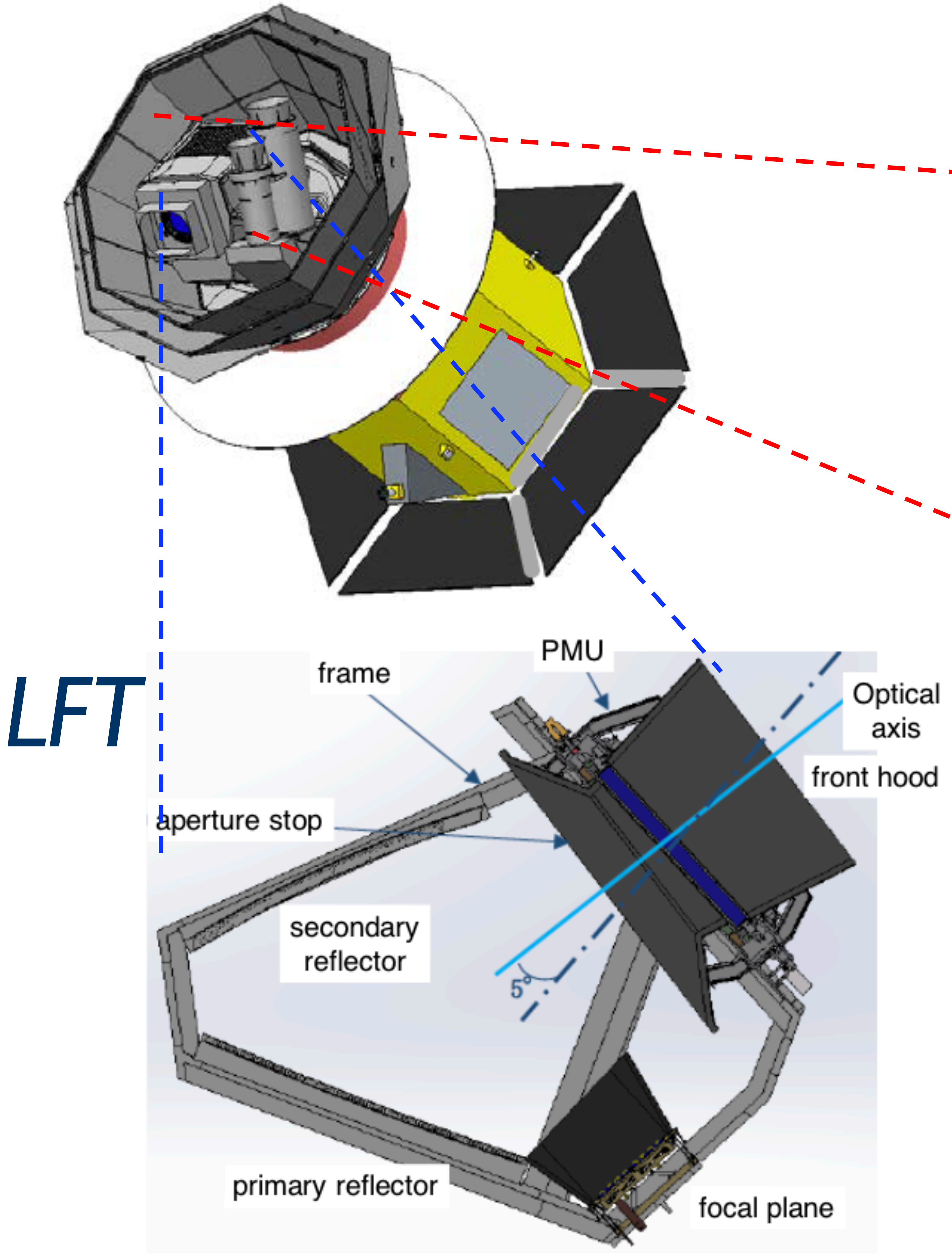
Baseline
+ delensing w/Planck CIB & WISE
+ extra foreground cleaning w/ high-resolution ground CMB data



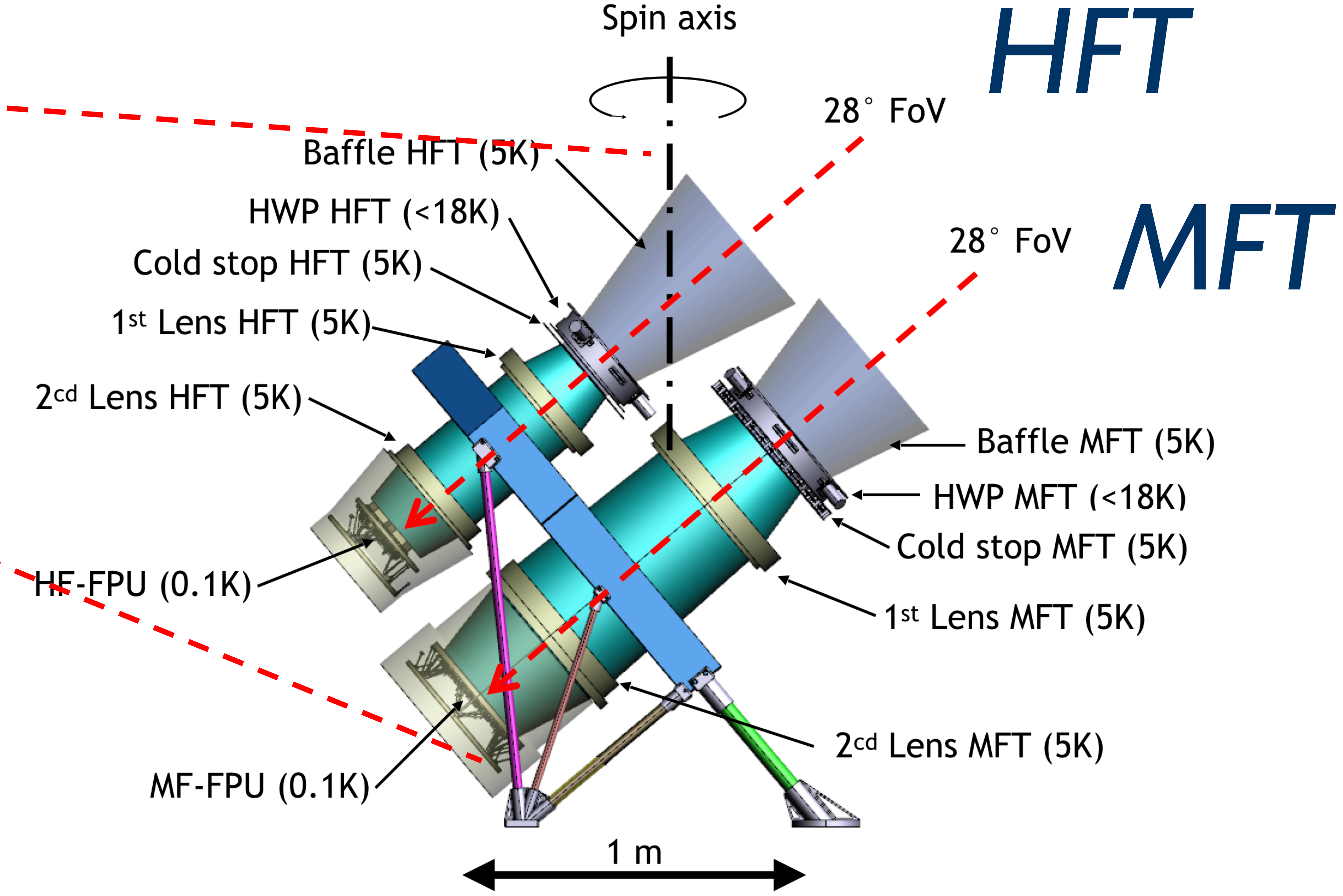
PTEP
Setup

for the record

LiteBIRD: PTEP Setup



The 3 LiteBIRD Eyes

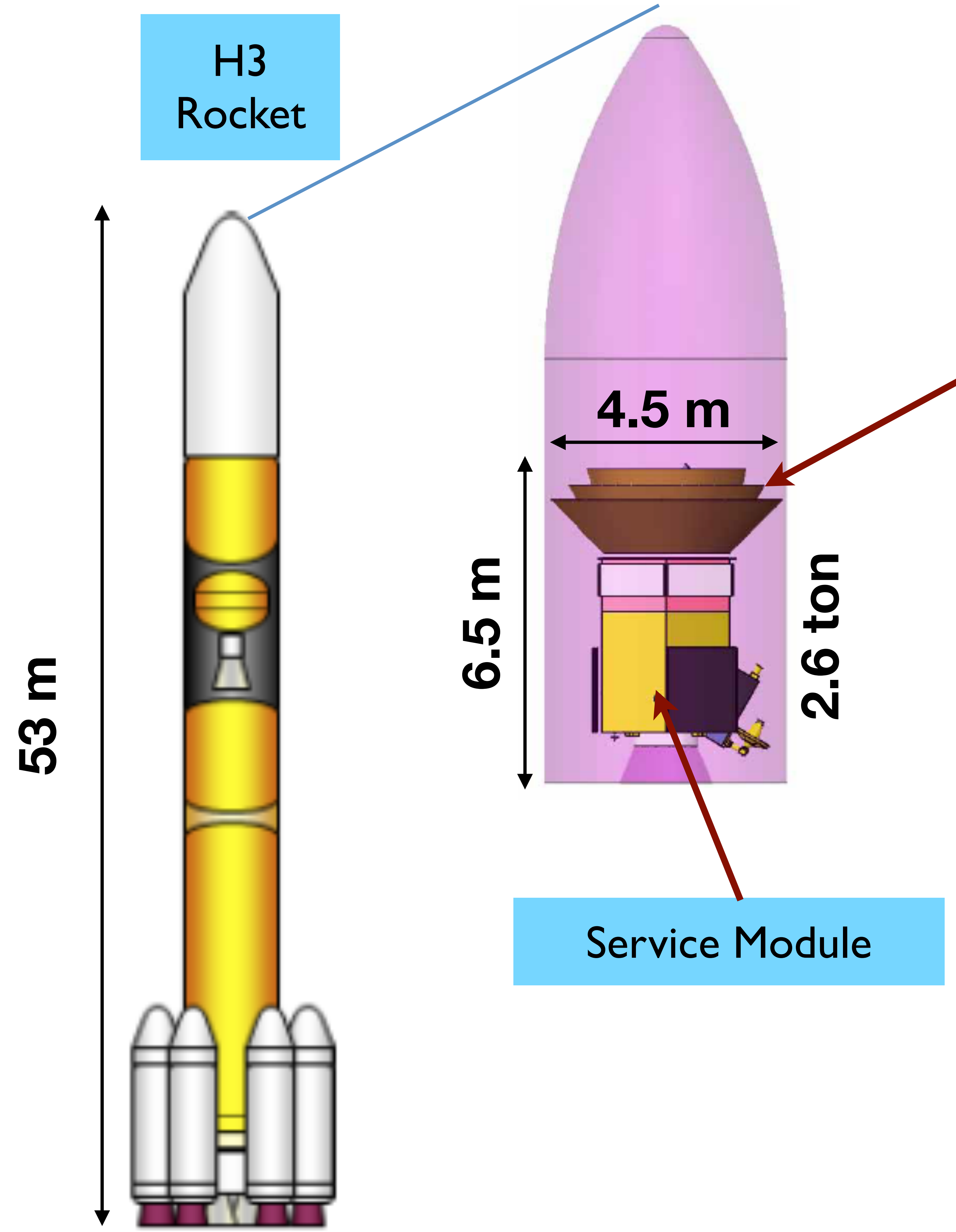


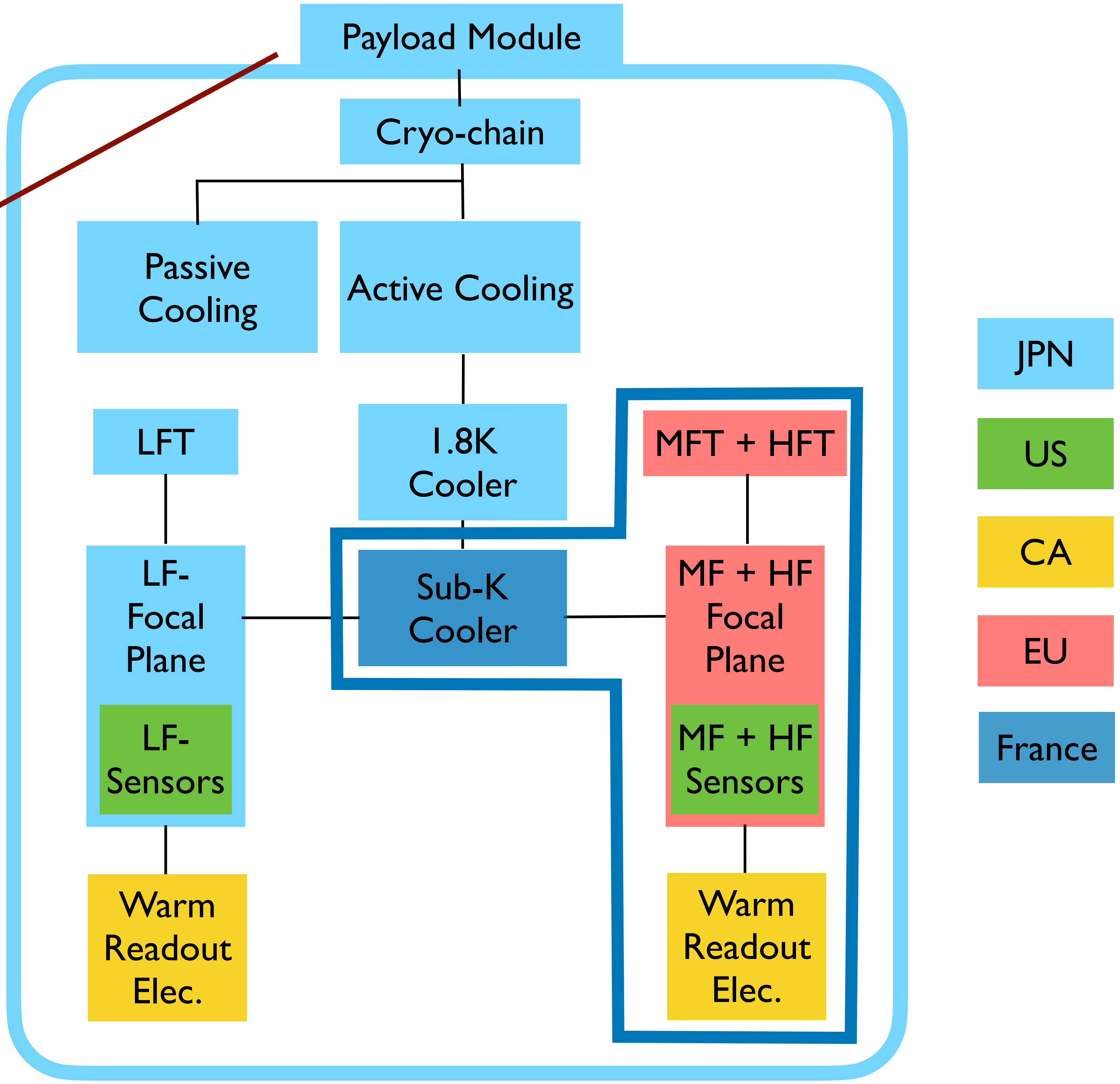
- Mass: 2.6 t
- Power: 3.0 kW
- Data: 17.9 Gb/day

- Multi-chroic transition-edge sensor (TES) **bolometer arrays** cooled to **100 mK**
- Polarization modulation unit (PMU) in each telescope with **rotating half-wave plate** (HWP), for 1/*f* noise and systematics reduction
- Optics cooled to **5 K**

LiteBIRD: PTEP Setup

International Task Sharing



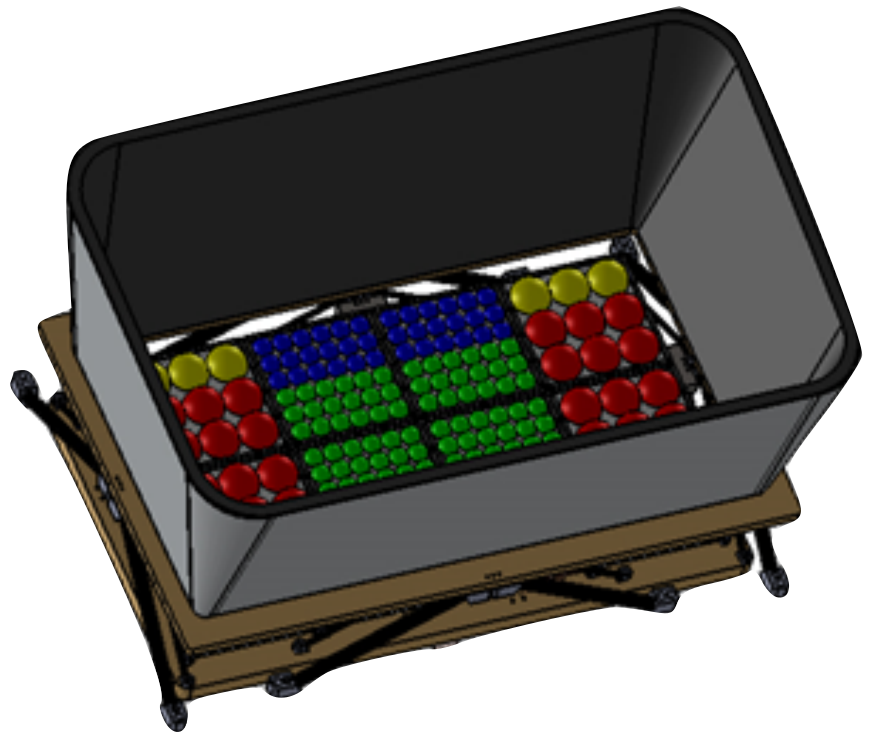


LiteBIRD: PTEP Setup

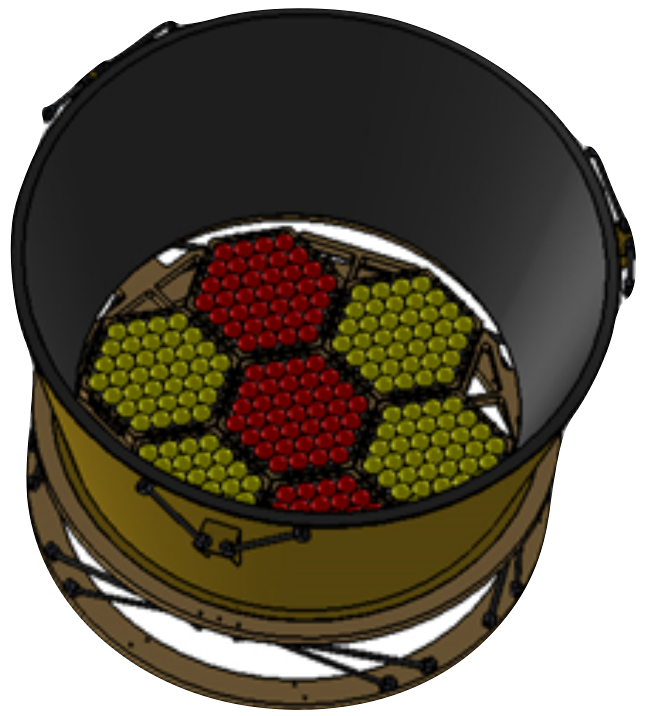
Focal Plane Configuration

- Transition-Edge Sensor (TES) arrays.
- Multichroic detectors.
- Number of sensors: 4508
- 15 bands including overlap between instruments.

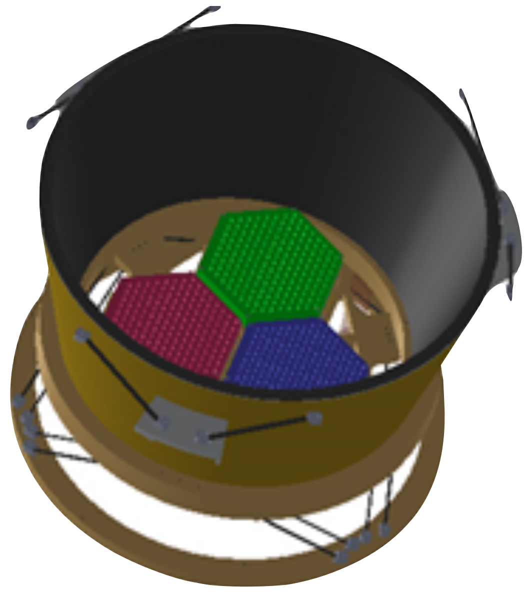
LFT



MFT

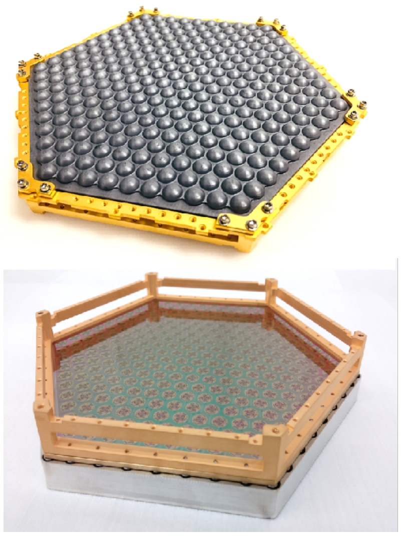


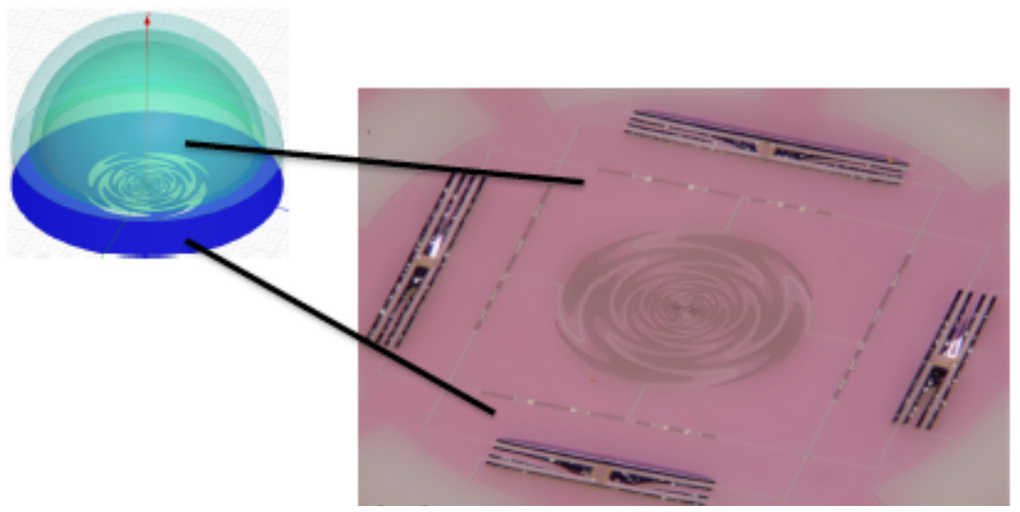
HFT



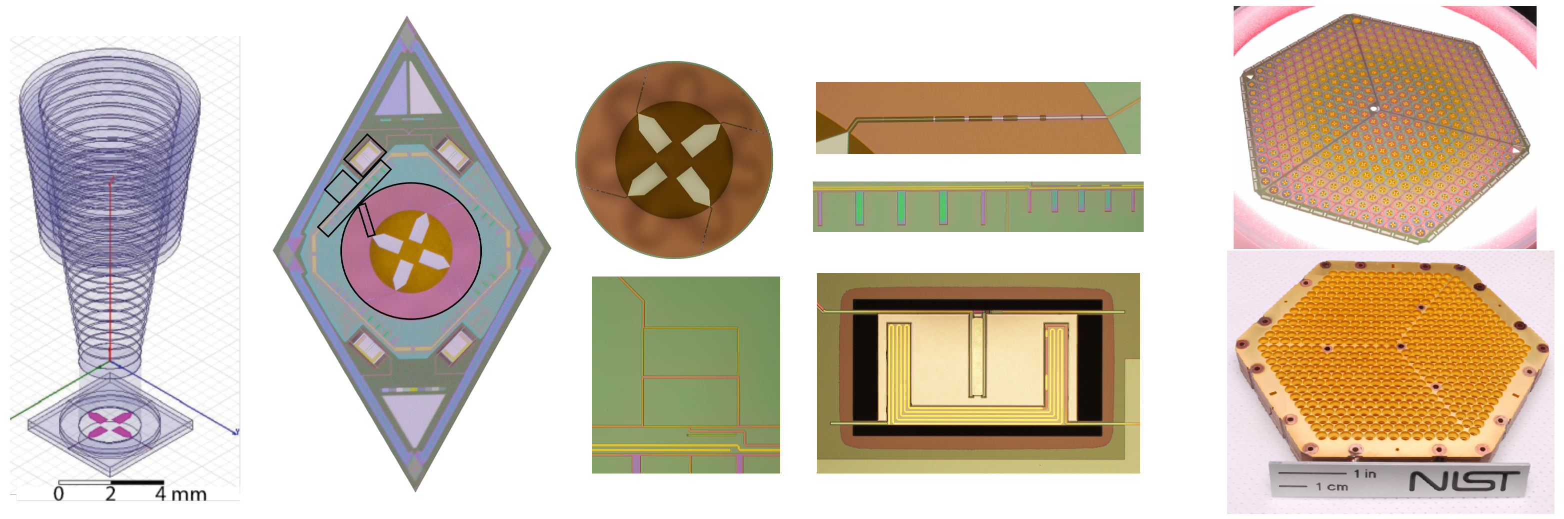
Rule of thumb:
1000 detectors in space
= 100 000 detectors on ground

Lensed coupled detectors
Lenslets





Horn coupled detectors
Platelets



MFT (2.5:1)

89GHz — 225 GHz

2075 detectors
366 Trichroic TES
588 Dichroic TES

100 | 119 | 140 | 166 | 195

LFT (5.7:1)

34GHz — 161 GHz

40 | 50 | 60 | 68 | 78 | 89 | 100 | 119 | 140

68 | 78 | 89

1258 detectors
2 x (65 + 155) Trichroic TES

HFT (2.7:1)

166 GHz — 448 GHz

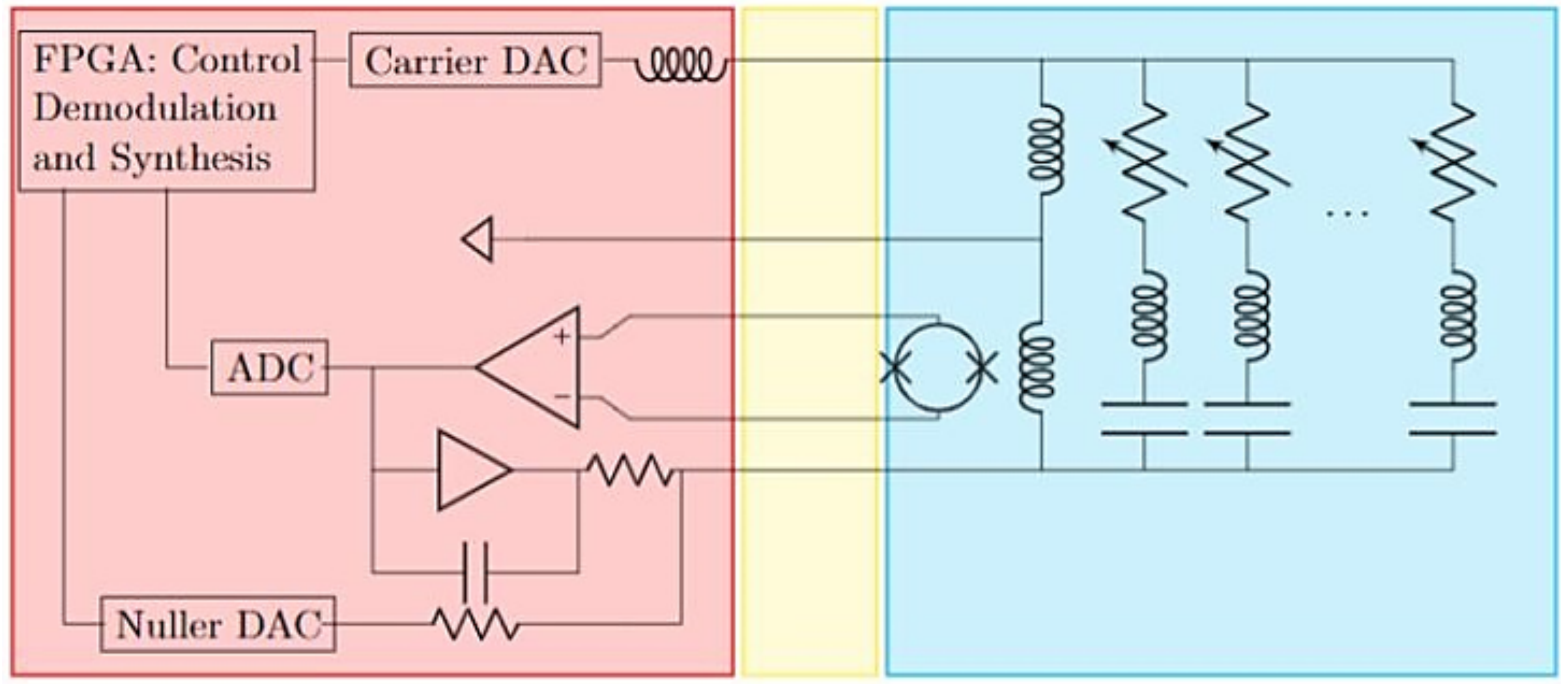
195 | 235 | 280 | 337 | 402

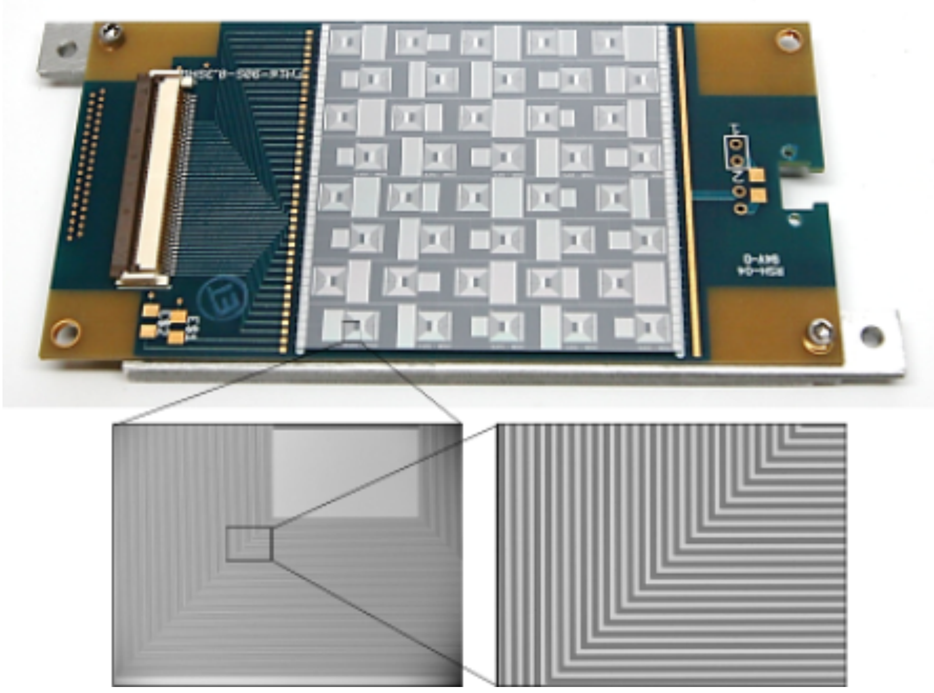
1355 detectors
2 x 255 Dichroic TES
338 Monochromatic TES

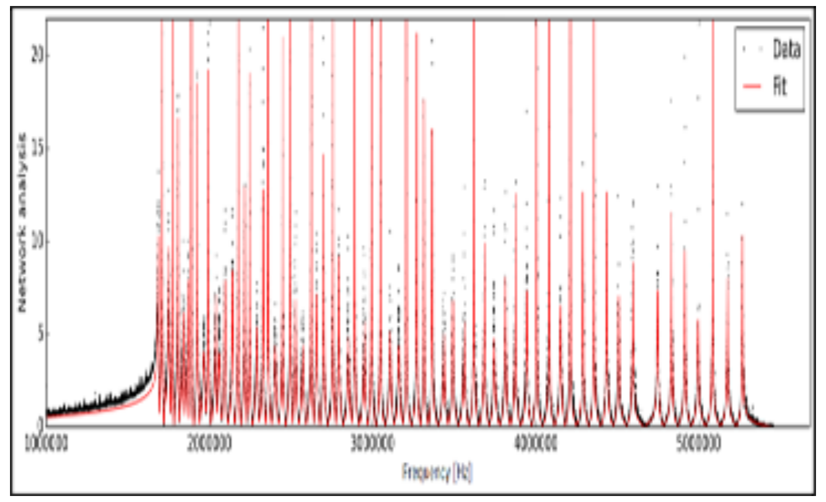
📖 Westbrook+ SPIE 2020

LiteBIRD: PTEP Setup

Readout System



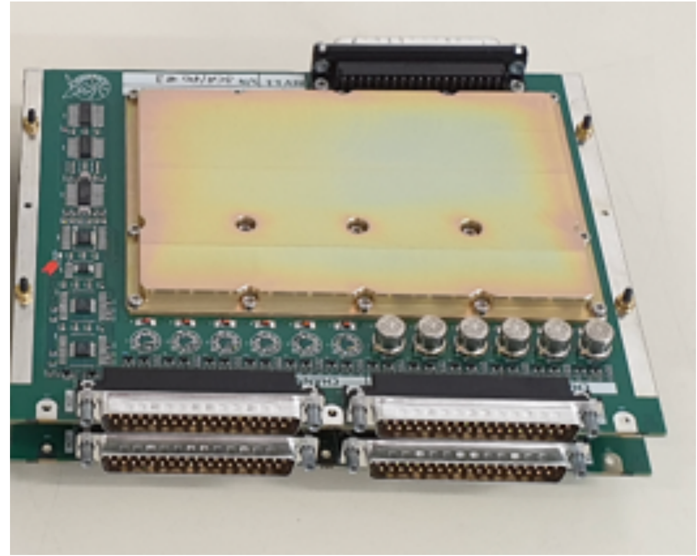




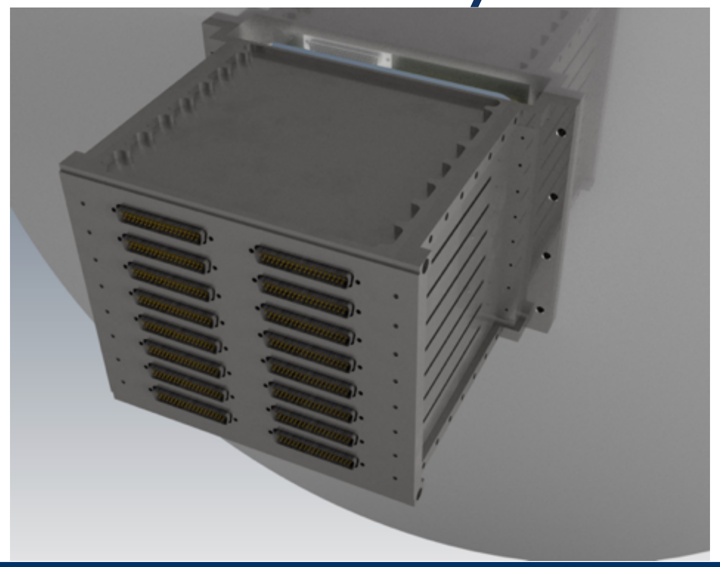
Cold Readout LC filters for MUX

- Frequency multiplexing readout technology to readout multiple TES with less components
- Assign unique frequency channel to TES sensors via superconducting resonators
- Low noise SQUID amplifier and FPGA controller readout the signal
- Saves mass, volume, power consumption and cost
- Heritage from ground based CMB experiments

SQUID controller board



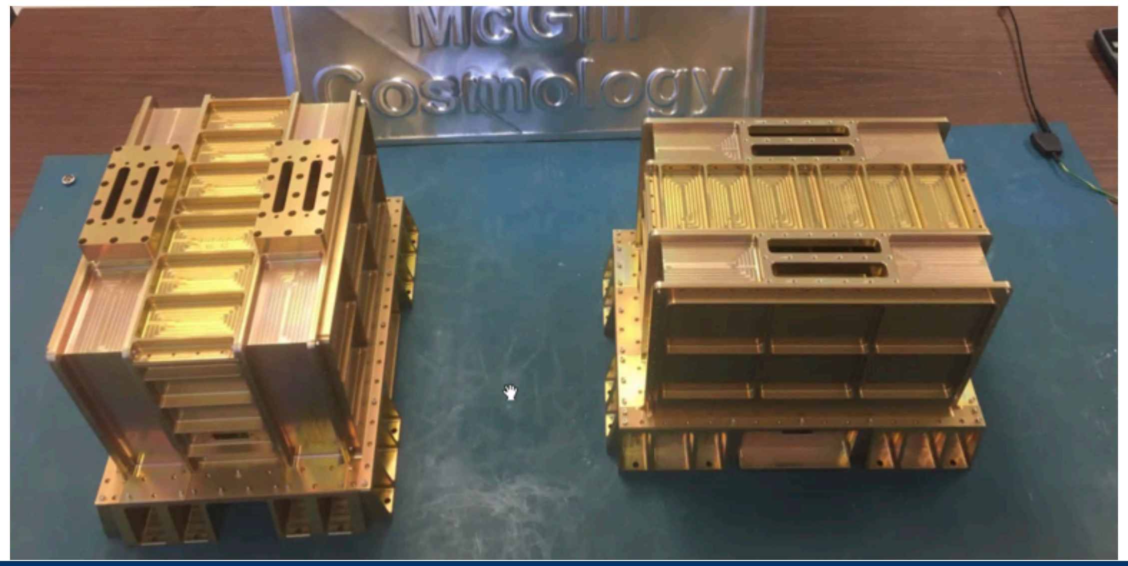
SQUID controller assembly



Digitizer assembly

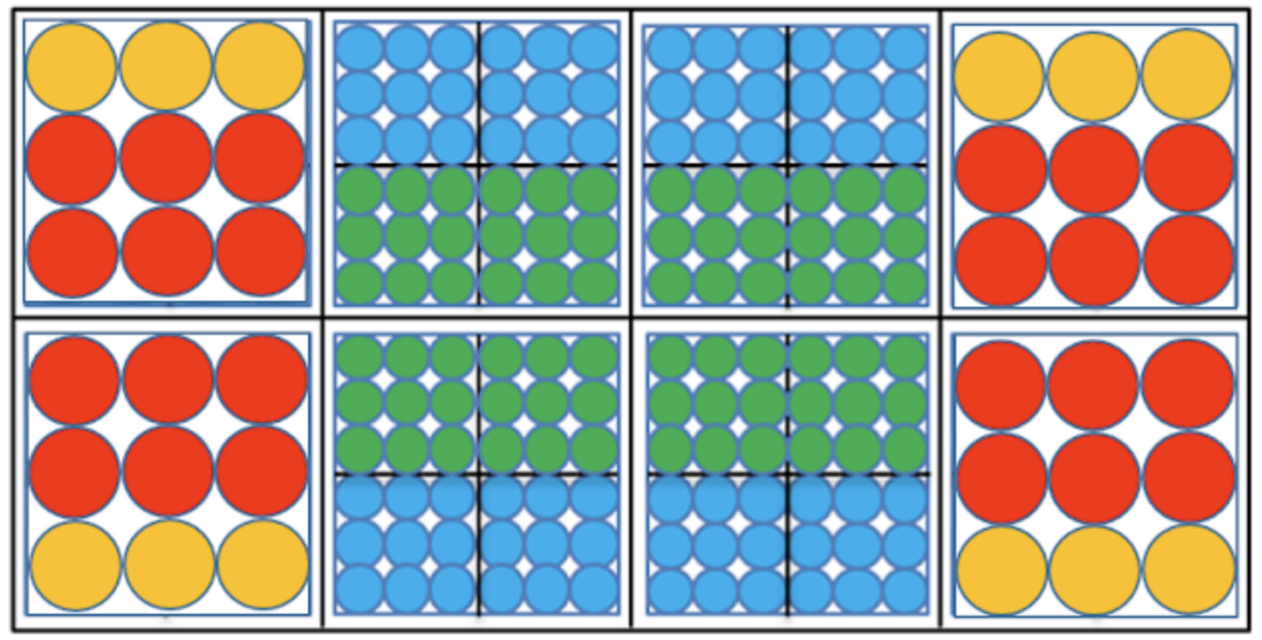
Signal Processing Unit

Digitizer assembly

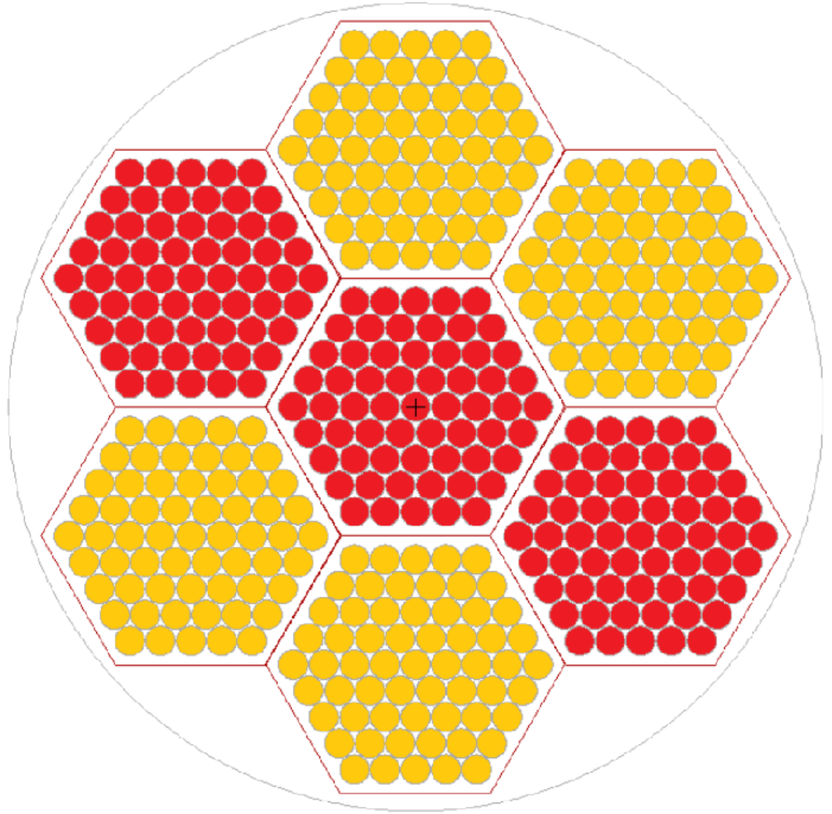


LiteBIRD: PTEP Setup

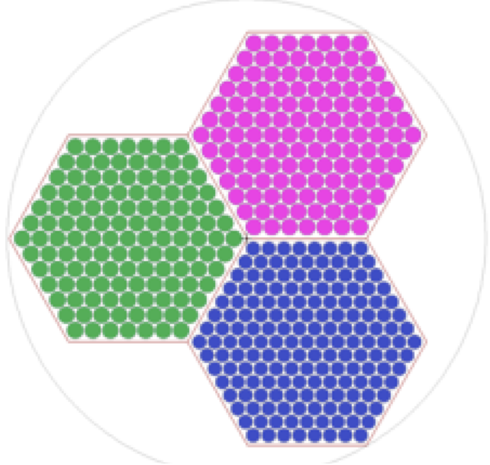
LFT



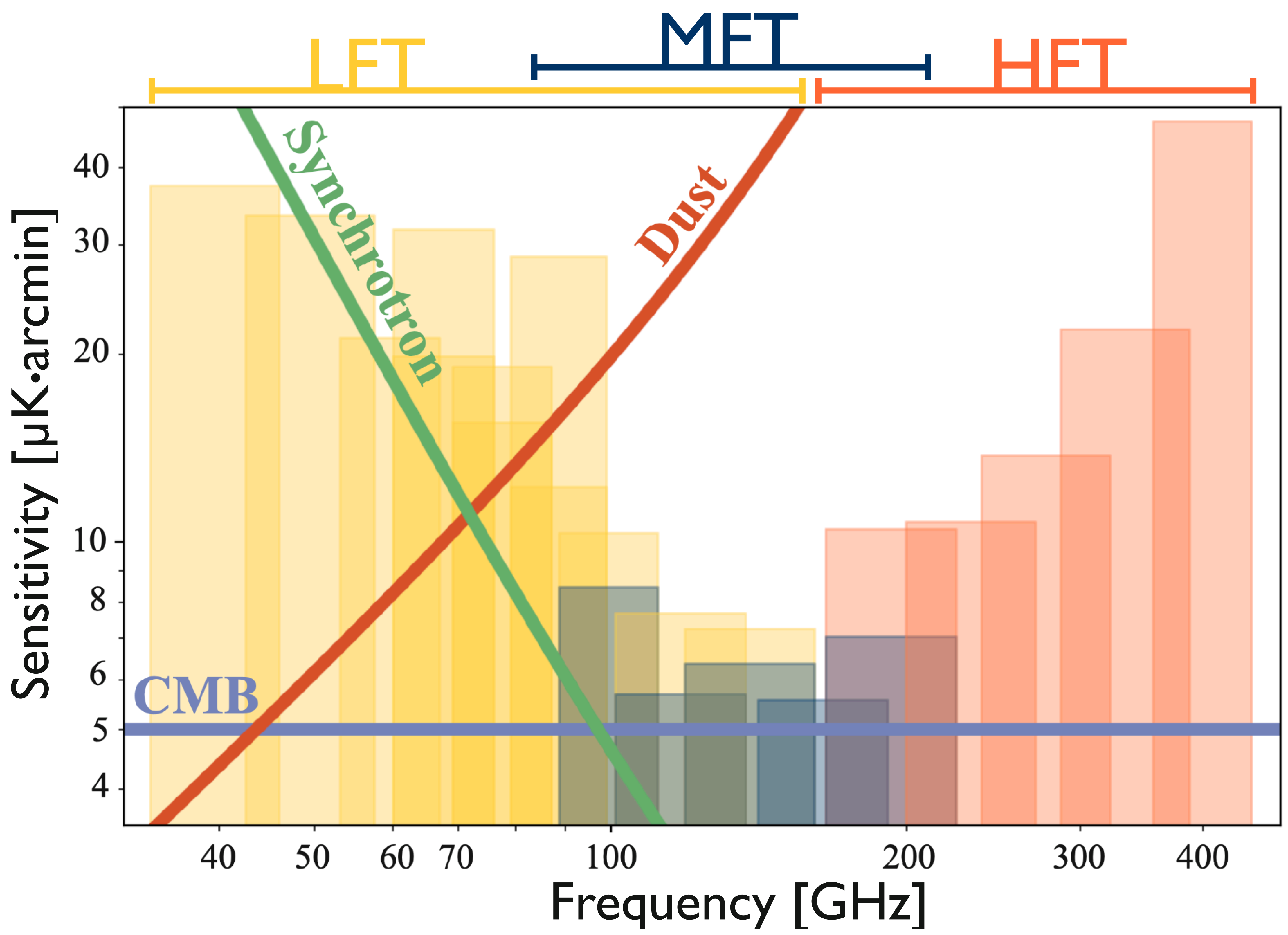
MFT



HFT



Sensitivities

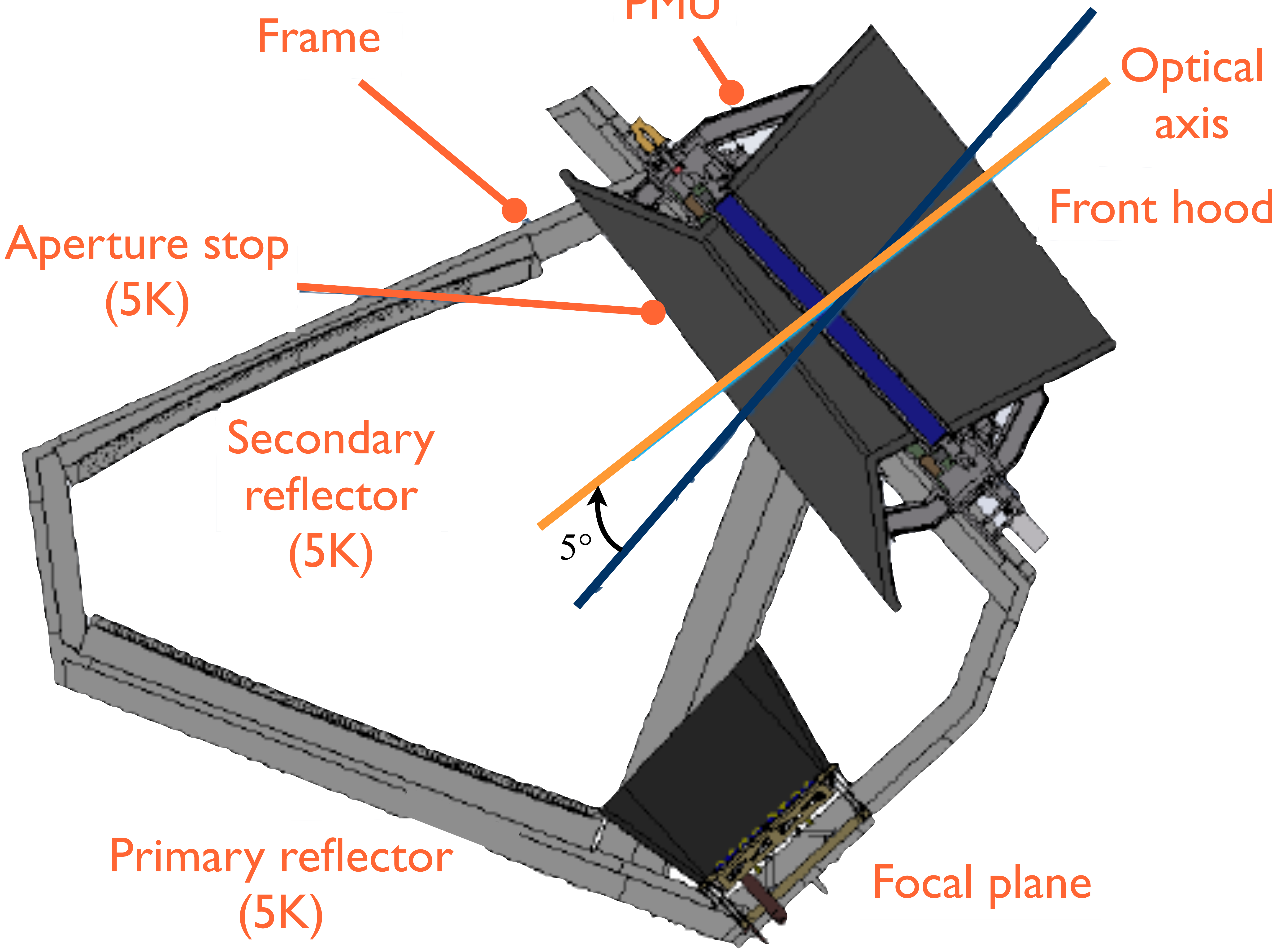


📖 Hazumi+ SPIE 2020

- Projected **polarization sensitivities** for a **3-year full-sky survey**
- Best of 4.3 μK arcmin @ 119 GHz (Hazumi+ 2020)
- Combined sensitivity to primordial CMB anisotropies : **2.2 μK·arcmin**

LiteBIRD: PTEP Setup

Low Frequency Telescope (LFT)



- Polarization Modulation Unit (PMU) as the first sky-side optical element
- **Crossed-Dragone** design
  - Mirrors and aperture stop at **5 K**
  - Made of aluminium
- Field of view: **18° × 9°**
- Strehl ratio > 0.95 (@ 140 GHz)
- Aperture diameter: **400 mm**
- Frequency range: **40-140 GHz**
- Angular resolution: **70-24 arcmin**
- F#3.0 & cross angle of 90°
- Cross-polarization < **-30 dB**
- Rotation of the polarization angle across the FoV < ±1.5°
- Weight < 200 kg

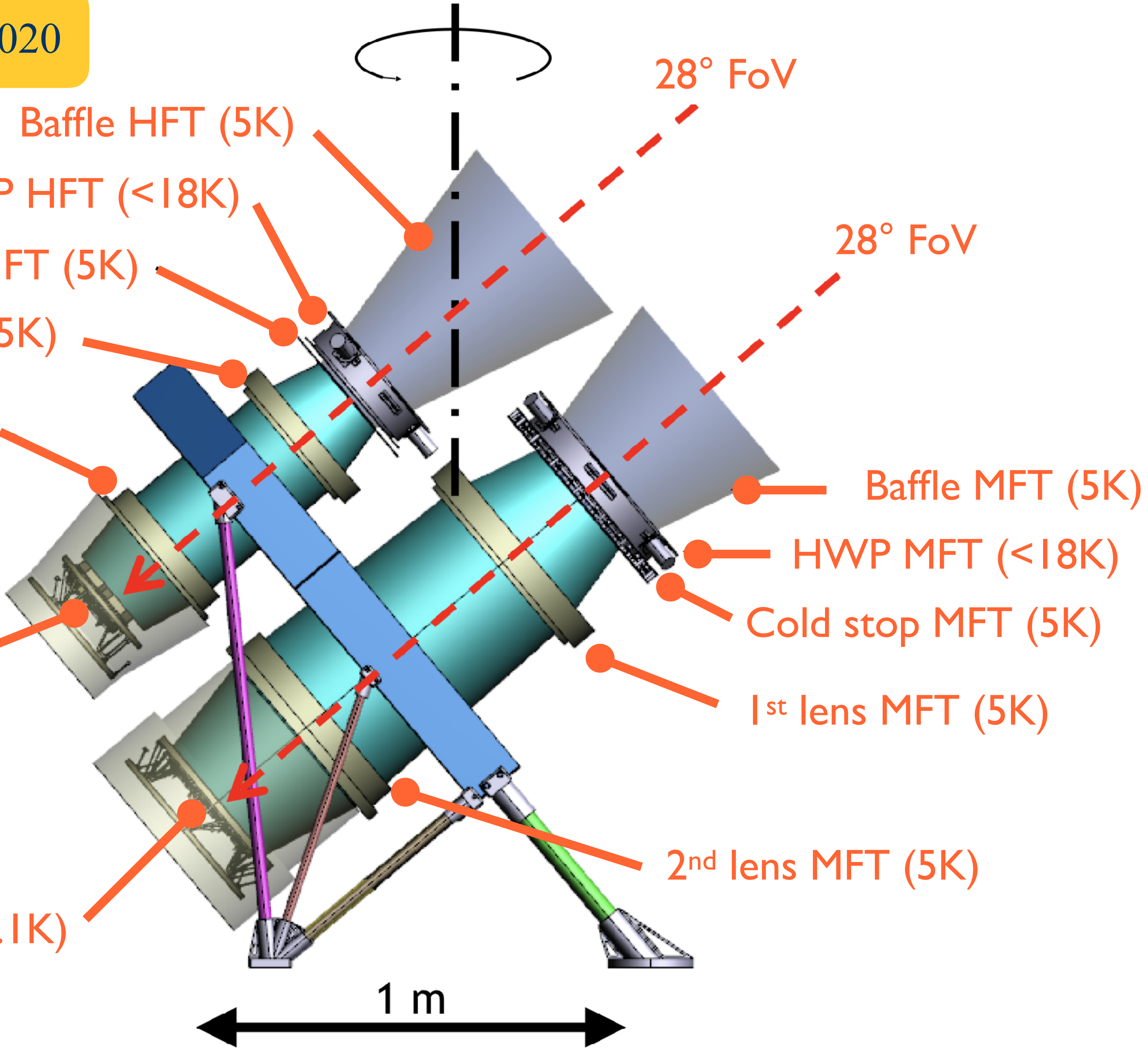
📖 Sekimoto+ SPIE 2020

LiteBIRD: PTEP Setup

Mid-High Frequency Telescopes (MFT / HFT)

📖 Montier+ SPIE 2020

📖 Lamagna+ SPIE 2020



- Refractive optics
- Each telescope has PMU with a half-wave-plate (HWP)
- Optics at **5 K**
- Field of view: **28°**
- Simple and high heritage from ground experiments
- Compact (mass & volume)
- Simplified design for filtering scheme
- PP lenses + ARC
- Weight 180 kg

	MFT	HFT
ν (GHz)	100-195	195-402
Ap. diameter (mm)	300	200
Ang. res. (arcmin)	38-28	29-18