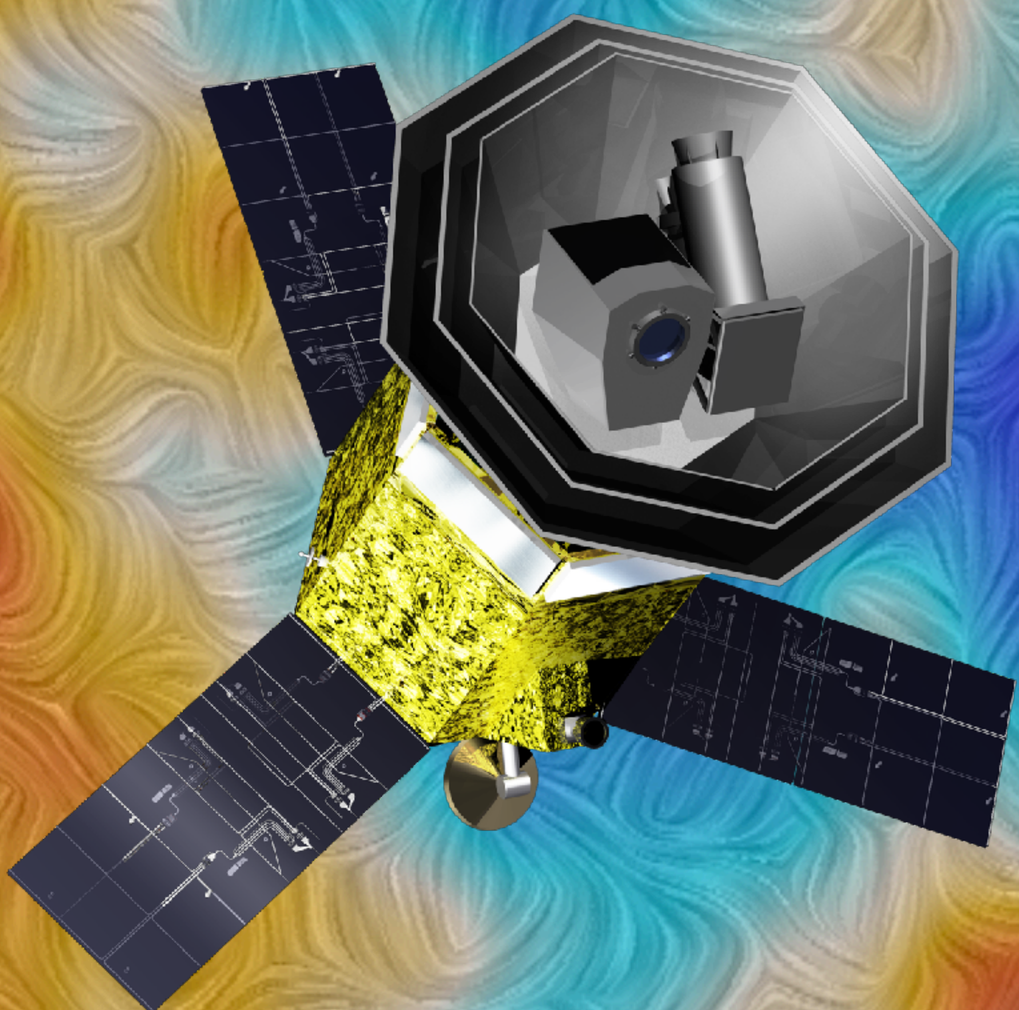


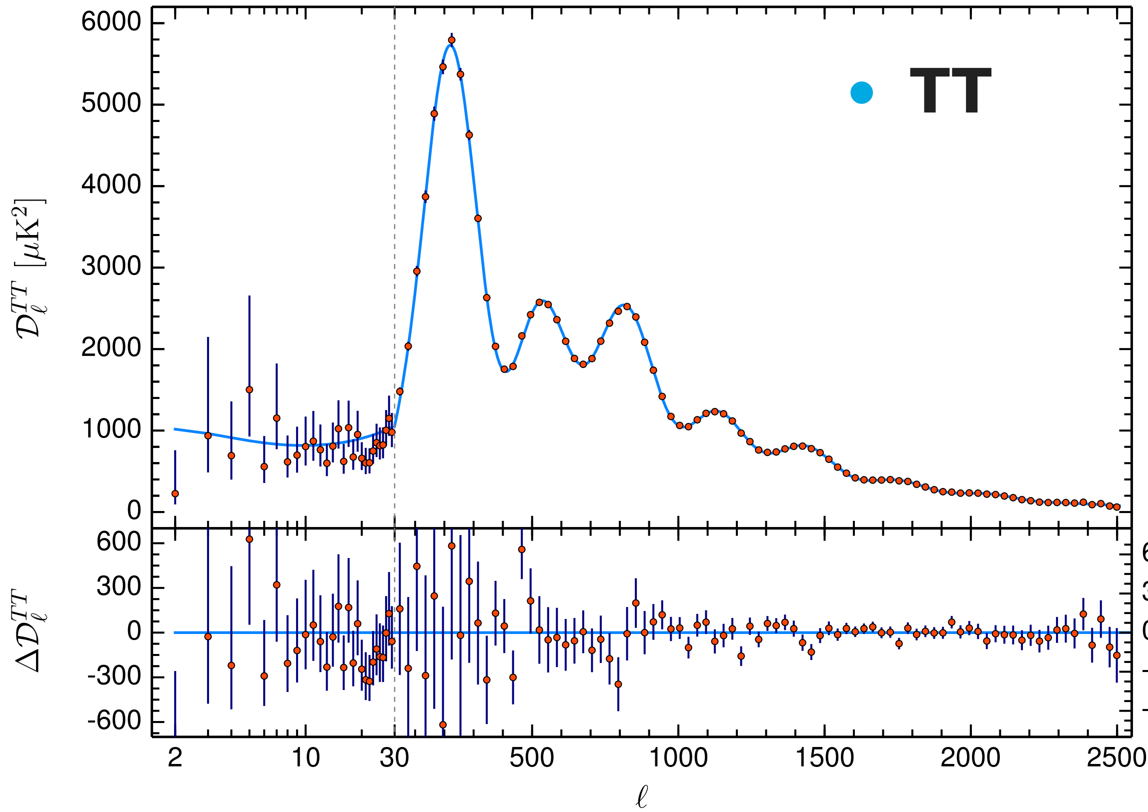
LiteBIRD

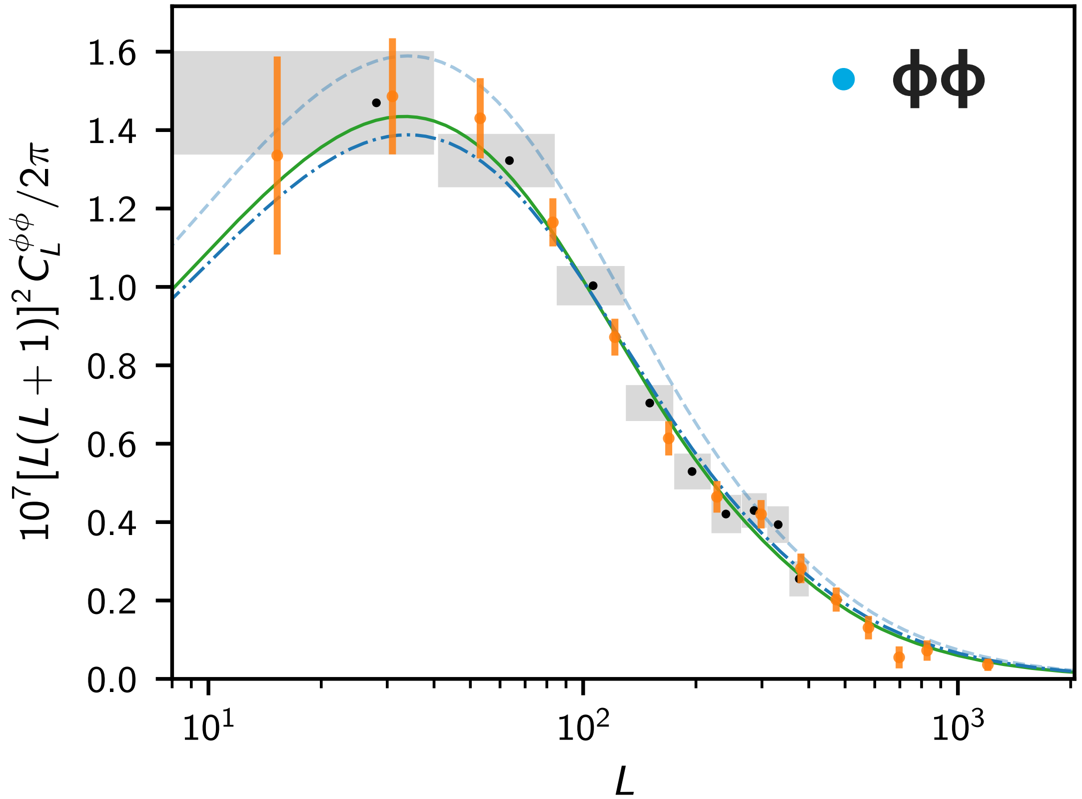
M. Tristram
on behalf of
the LiteBIRD Collaboration

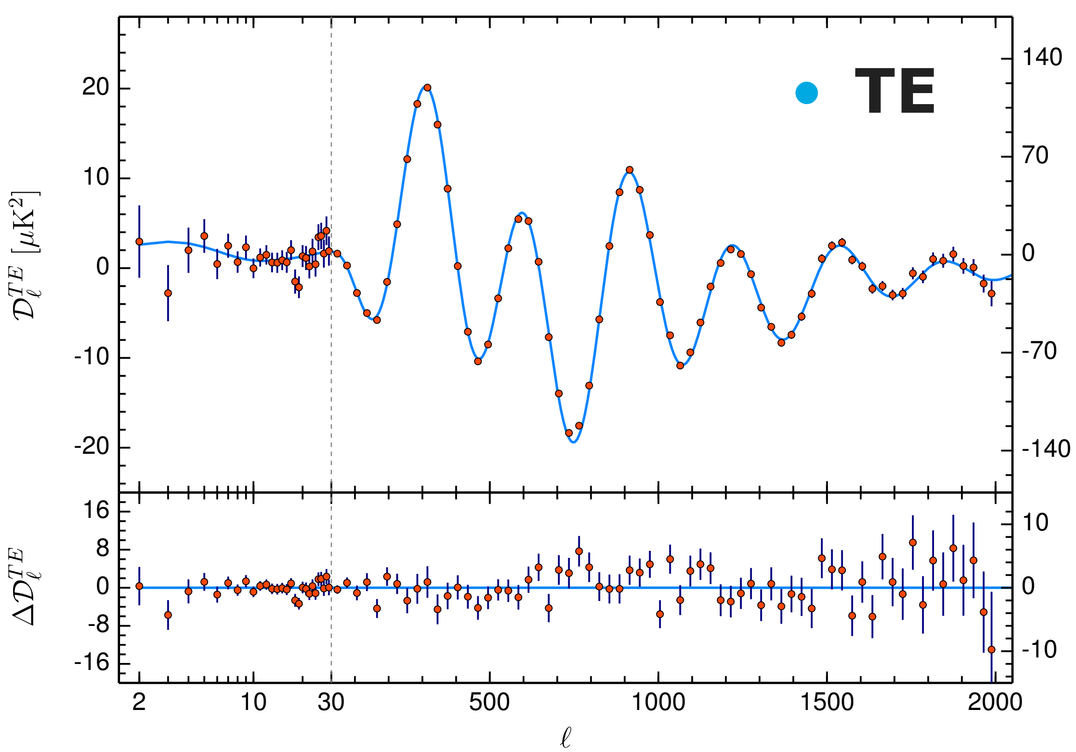
CS IN2P3 (Oct. 2020)

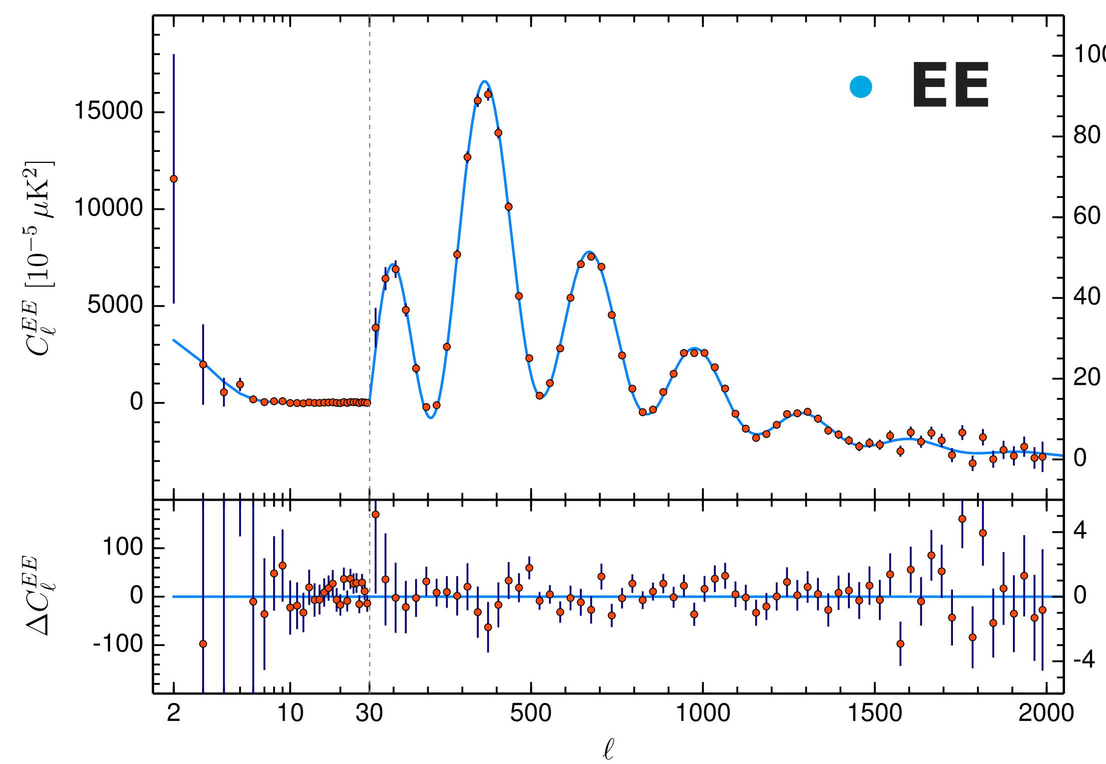
CMB power spectra

[Planck 2018 results. VI]
[Planck 2018 results. VIII]



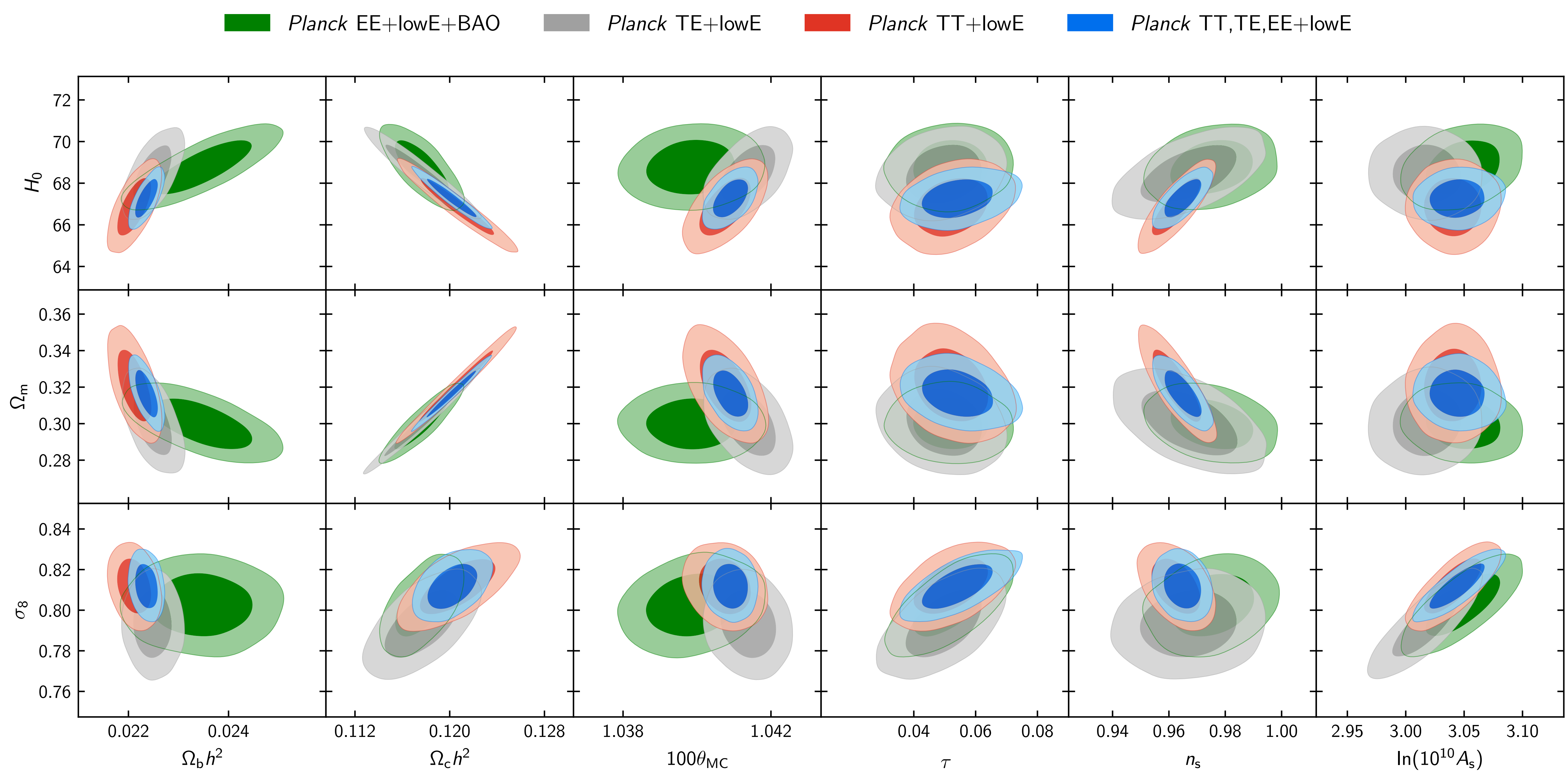






ΛCDM results

[Planck 2018 results. VI]



TE polarization spectra highly consistent with TT spectra

EE spectra also consistent but still noisier

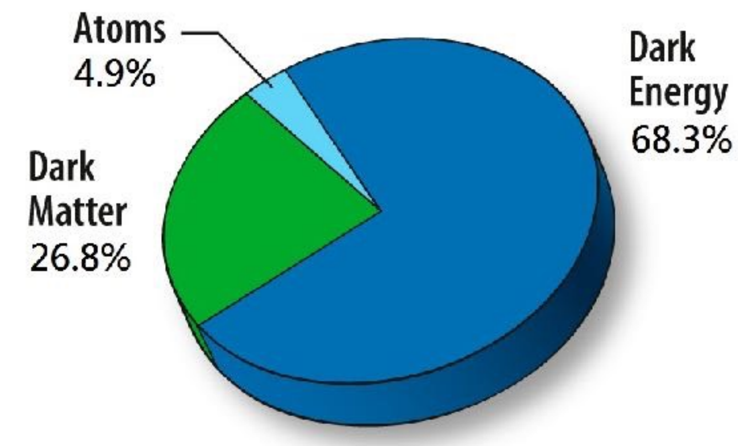
ΛCDM

- **Consistency**
  The **CMB anisotropies** in temperature and polarisation (TT, TE, EE), **CMB lensing** ΦΦ, as well as **BAO**, **BBN**, and **SNIa** measurements are all consistent, among themselves and across experiments, within ΛCDM

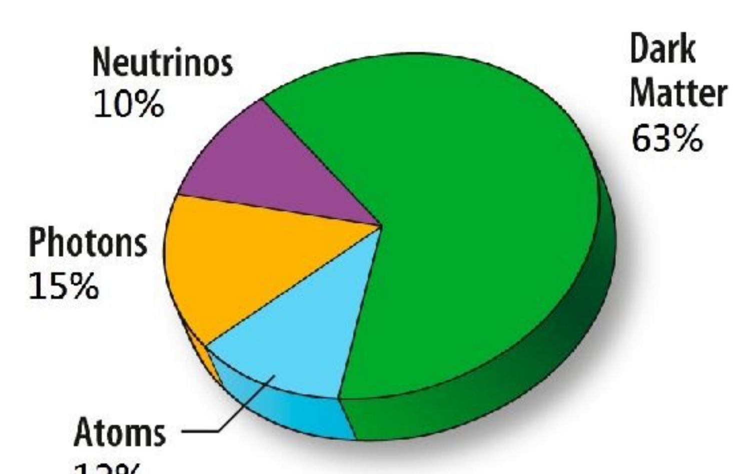
- **Robustness**
  These probes allow many different checks of the robustness for the ΛCDM model and some of its extensions, including **flatness**, sum of **neutrinos masses** and **effective number**, **DM annihilation** limits, **dark energy** equation of state w(z), details of the **recombination** history ($A_{2s\rightarrow 1}$, T_0, and also fundamental constants variation, or any energy input...)

- **Precision**
  This network of consistency tests is passed with **per cent** level precision but for relative **tensions** (including A_L, H_0, S_8)

Parameter	TT,TE,EE+lowE+lensing 68% limits	
$\Omega_b h^2$	0.02237 ± 0.00015	**0.7%**
$\Omega_c h^2$	0.1200 ± 0.0012	**1.0%**
$100\theta_{MC}$	1.04092 ± 0.00031	**0.03%**
τ	0.0544 ± 0.0073	**13%**
$\ln(10^{10} A_s)$	3.044 ± 0.014	**0.5%**
n_s	0.9649 ± 0.0042	**0.4%**



TODAY



13.7 BILLION YEARS AGO
(Universe 380,000 years old)

ΛCDM

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what's next ?

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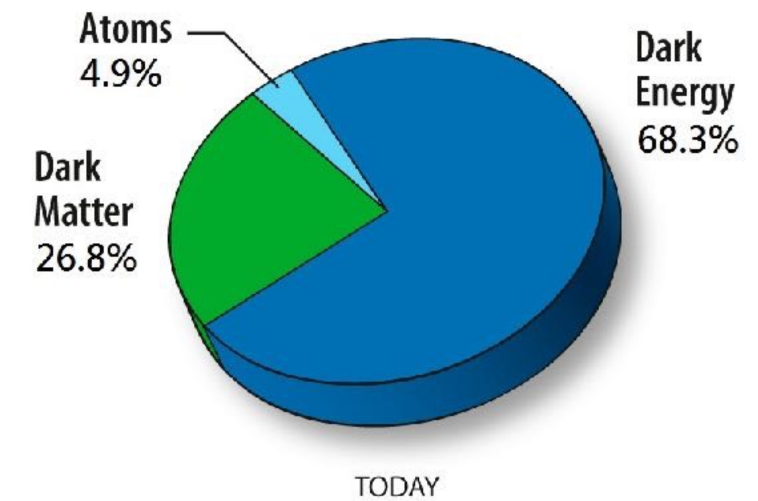
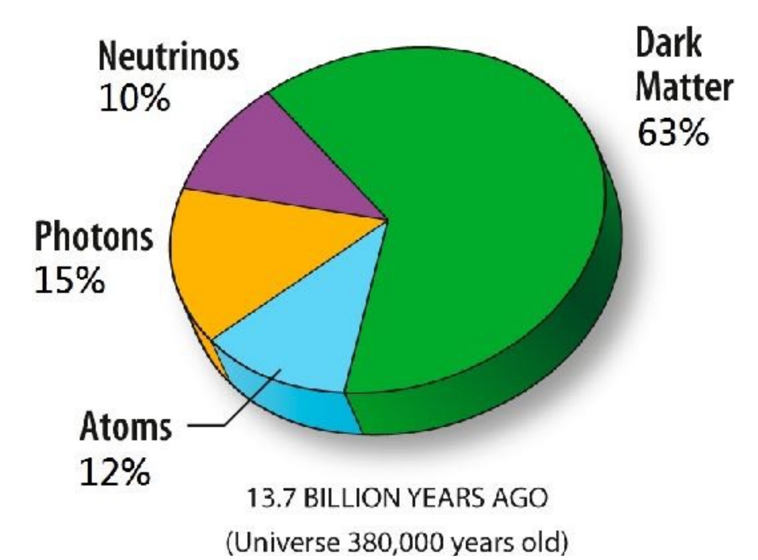
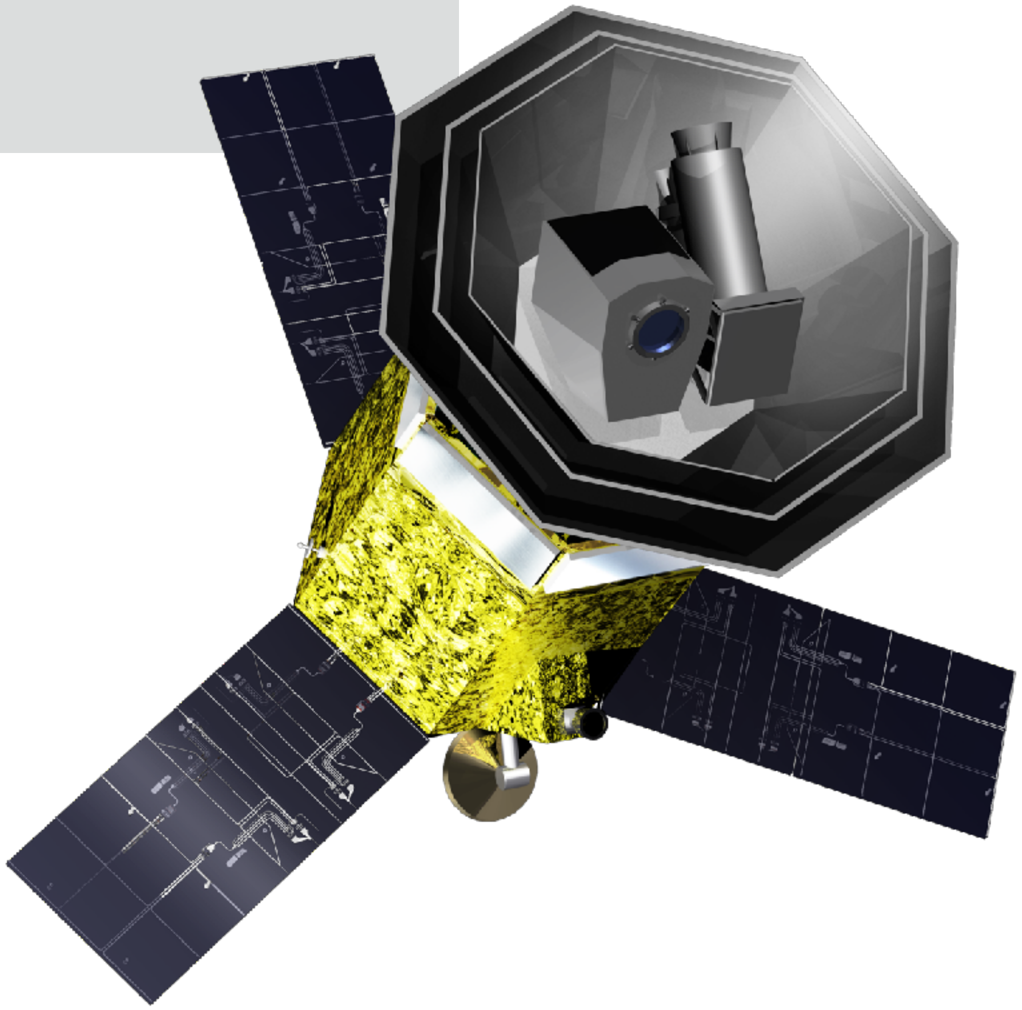




Scientific outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Inflation energy (Full success / Extra success)
  - Constraints on the inflation potential
  - Beyond the B-mode power spectrum



Scientific outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Inflation energy (Full success / Extra success)
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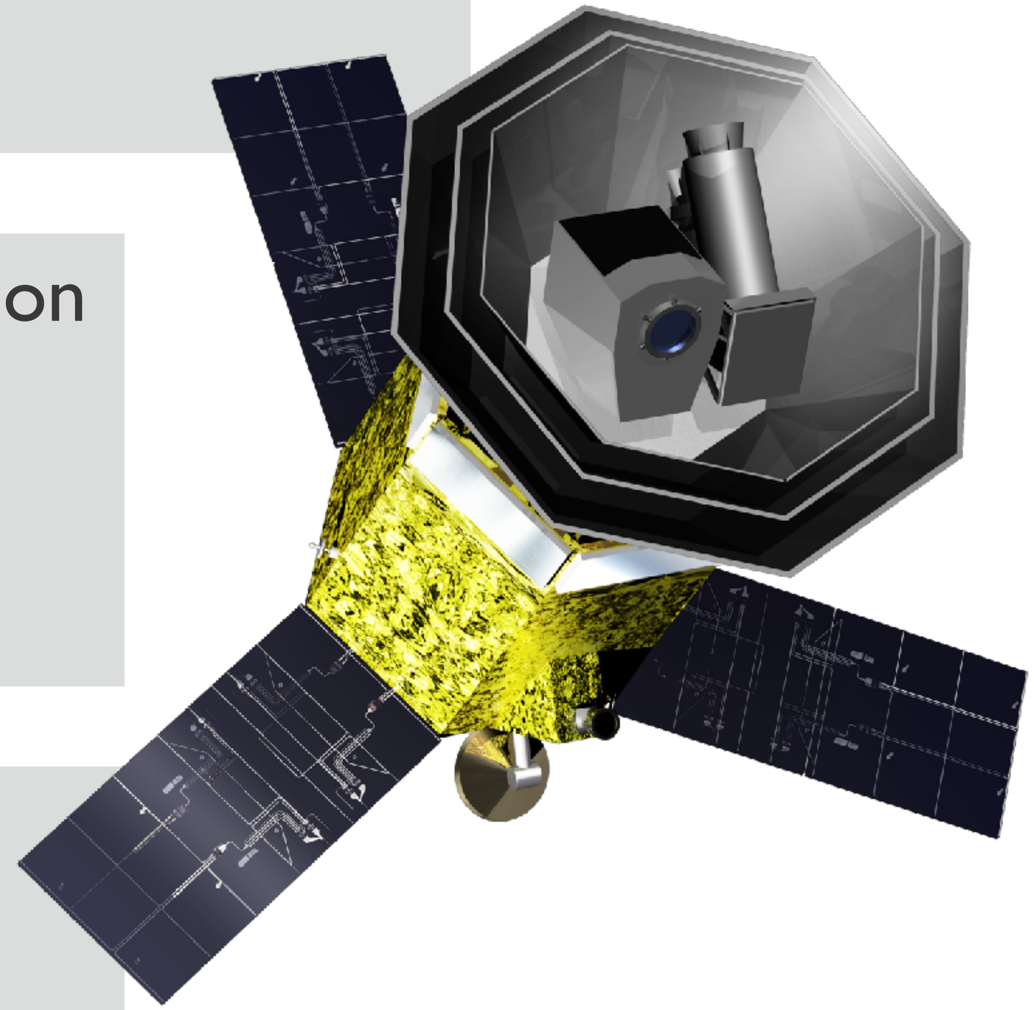
  - Beyond the B-mode power spectrum

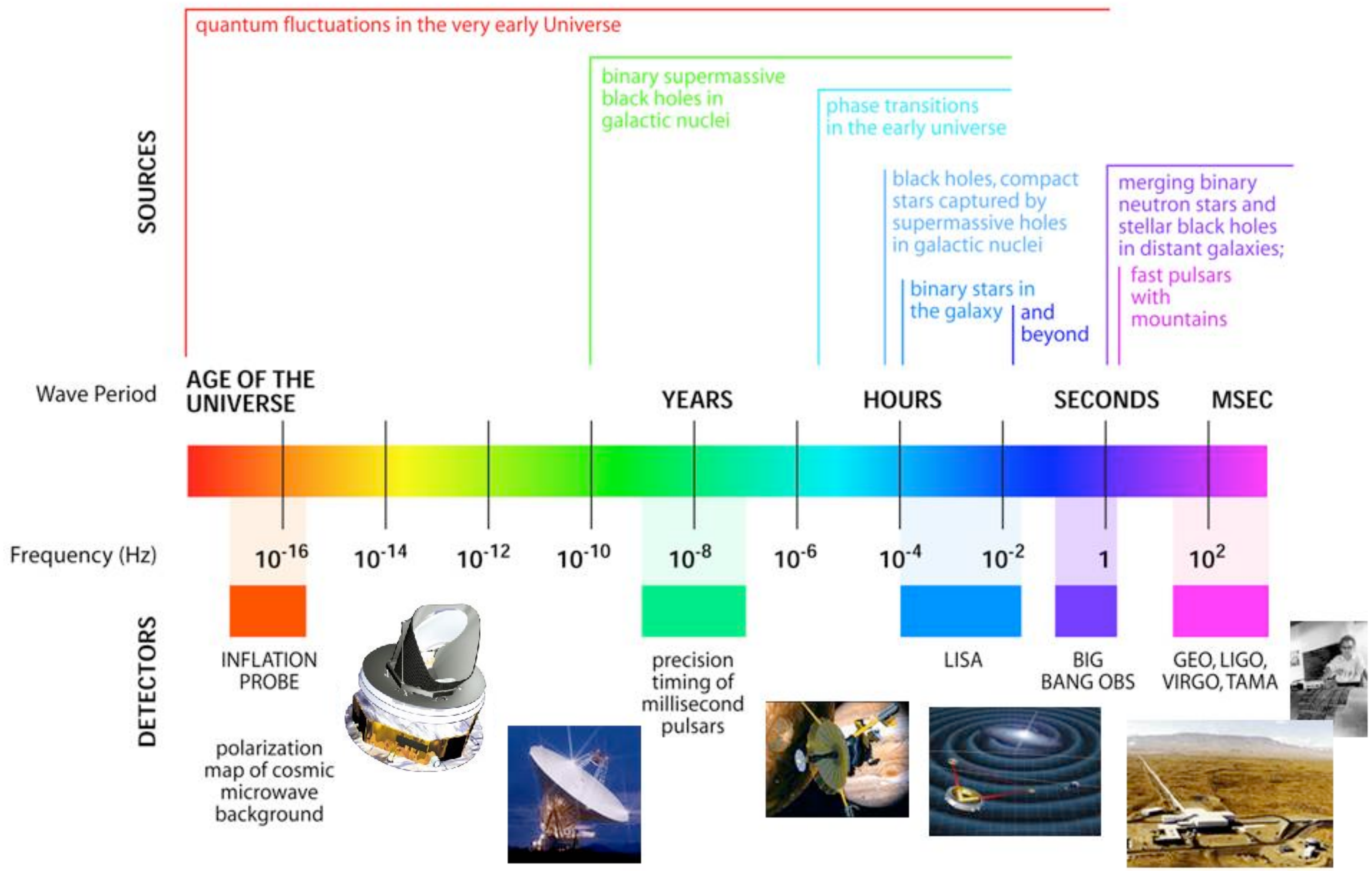
- Cosmological parameters with E polarisation
  - Optical depth and reionization of the Universe
  - Elucidating low-ℓ anomalies with polarization
- Neutrino sector
- Cosmic birefringence

- Anisotropic CMB spectral distortions
- Galactic science
- Mapping the hot gas in the Universe

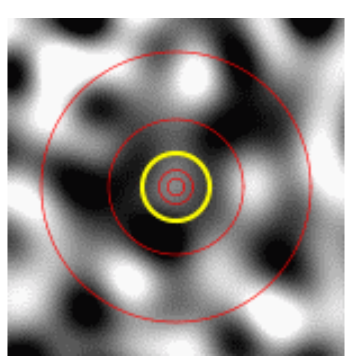


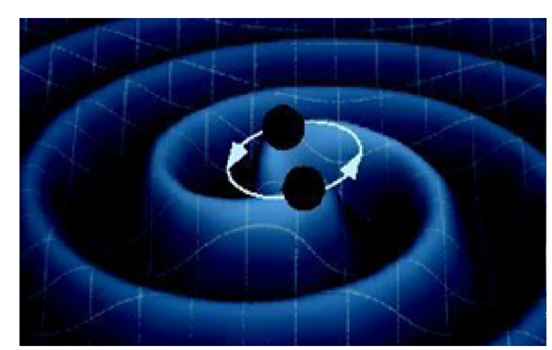
Gravitational waves

Big leap between LISA and LiteBIRD



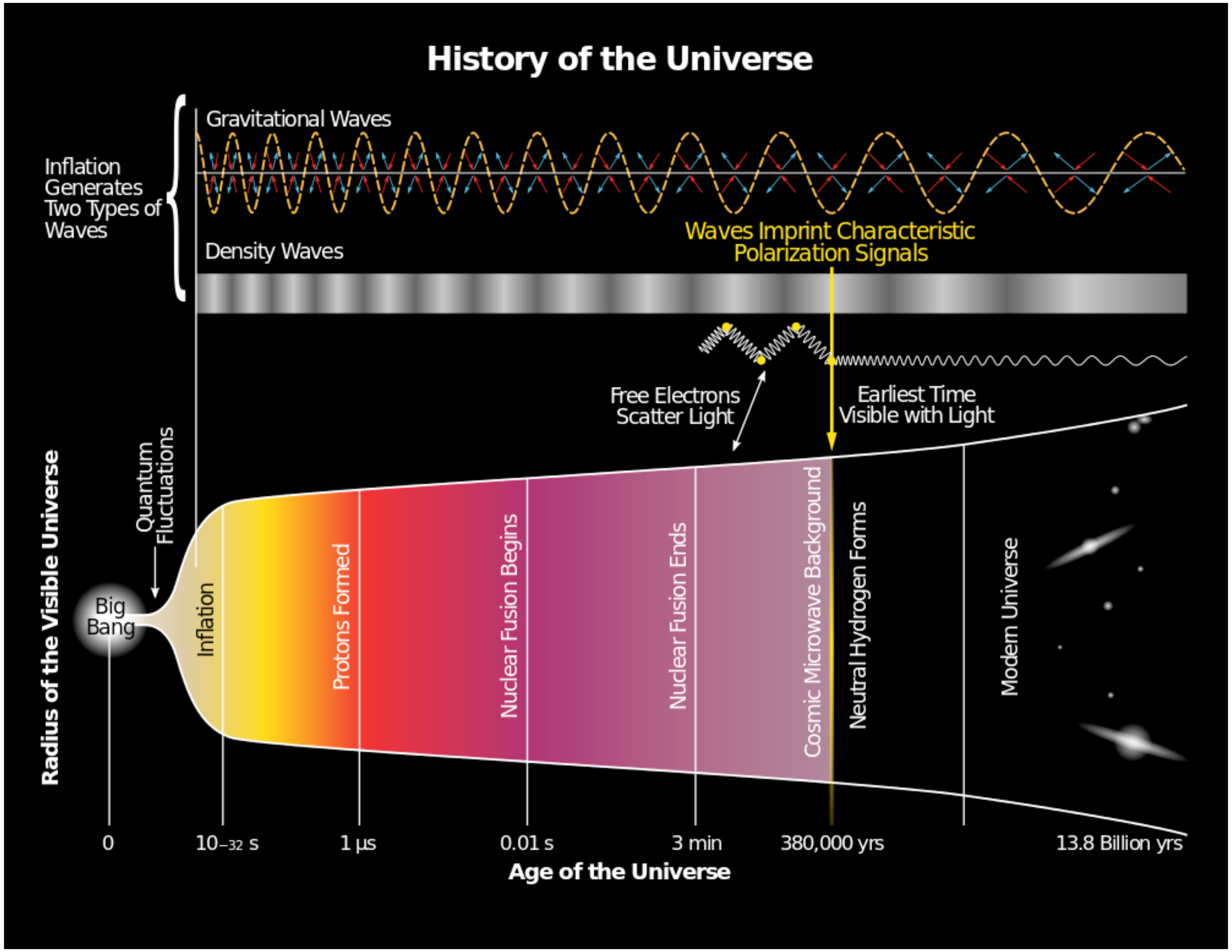
LiteBIRD
Gravitational waves with quantum origin





LISA
Gravitational waves with classical origin

Primordial gravitational waves



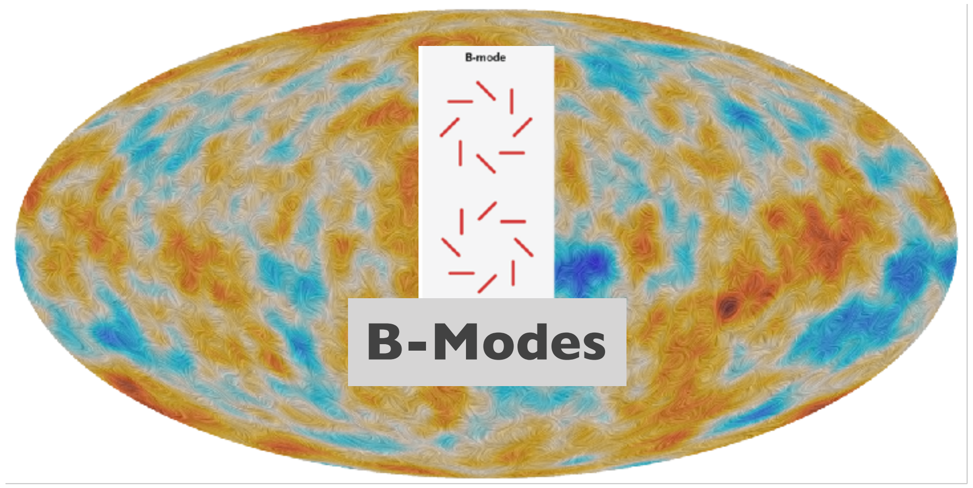
quantum fluctuations of spacetime

⇩ **Inflation**

primordial gravitational waves

⇩

imprints on the CMB
(B-modes: "vortex" in polarization)



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

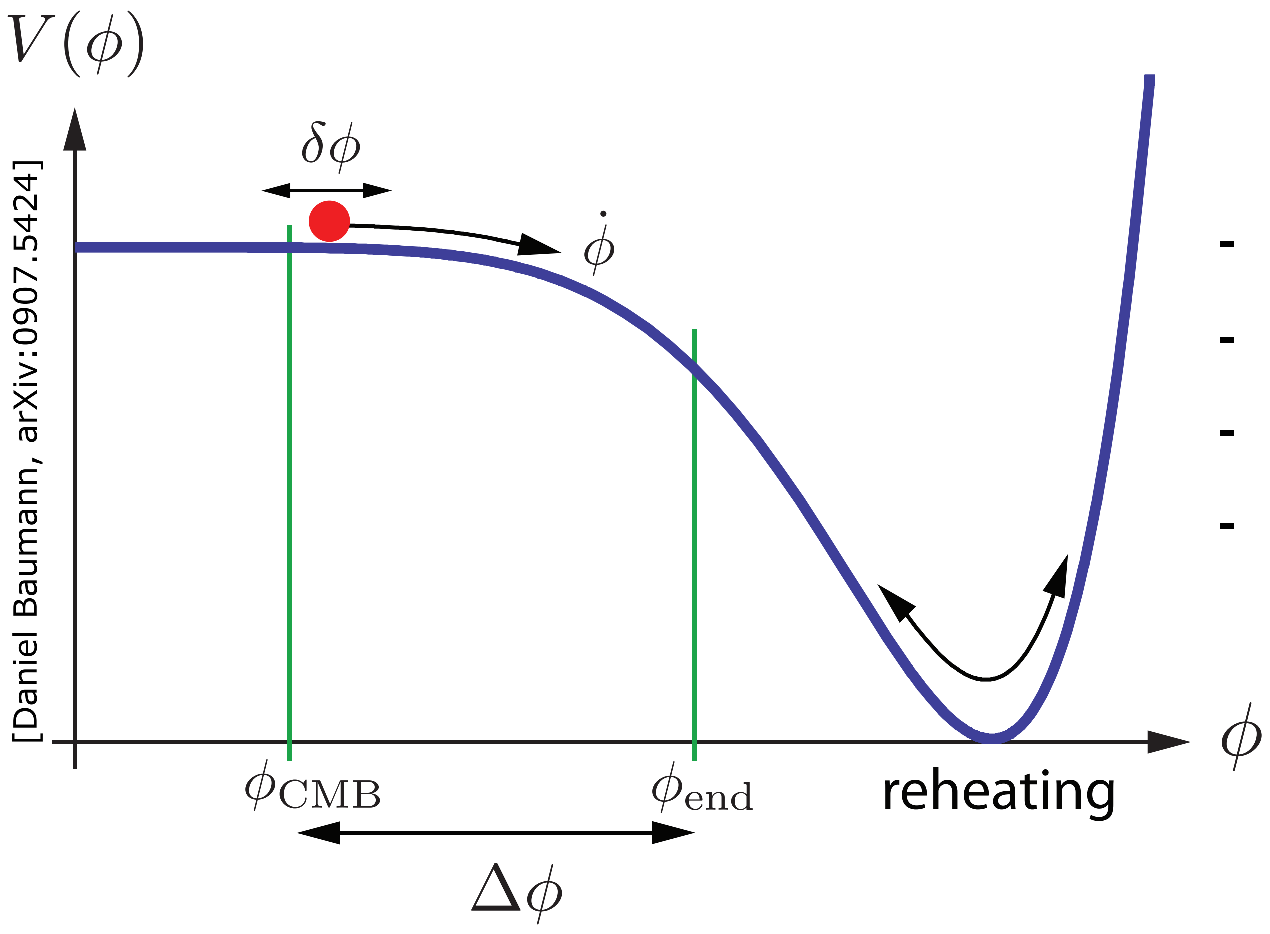
Observational test of quantum gravity

inflation φ

- **dynamics of an homogeneous scalar field in a FRW geometry is given by**

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0 \qquad \text{and} \qquad H^2 = \frac{1}{3}\left(\frac{1}{2}\dot{\phi}^2 + V(\phi)\right)$$

- **inflation happen when potential dominates over kinetic energy (slow-roll)**



- where did **V(Φ) comes from** ?
- why did the field start in **slow-roll** ?
- why is the potential so **flat** ?
- how do we convert the field energy into **particules** ?

matter

- **According to single field, slow-roll inflationary scenario, quantum vacuum fluctuations excite cosmological scalar and tensor perturbations**

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

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

- **with the definition of the tensor-to-scalar ratio "r"** $r = A_t / A_s$

matter

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- **with the definition of the tensor-to-scalar ratio "r"** $r = A_t / A_s$

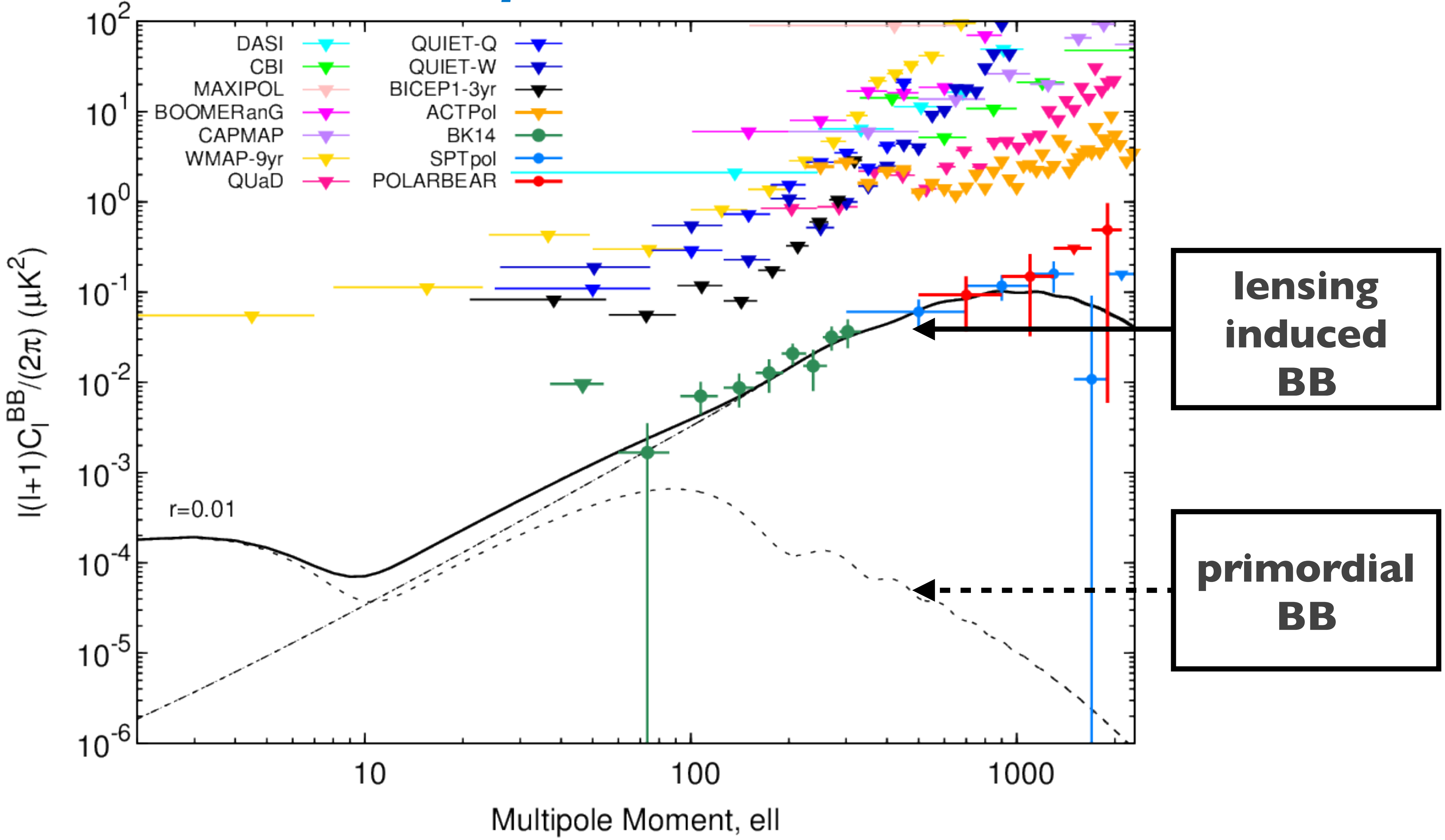
which characterises the amplitude of GW and gives direct constraints on the shape of the potential

- **energy scale of inflation** $V^{1/4}(\phi) \simeq 10^{16}\,\mathrm{GeV} \left(\frac{r}{0.01}\right)^{1/4}$
- **inflaton field excursion** $\frac{\Delta\phi}{M_P} \simeq \mathcal{N}_* \left(\frac{r_*}{8}\right)^{1/2} \simeq \left(\frac{r}{0.001}\right)^{1/2}$
- **derivative of the potential**

$$r = 8M_{\mathrm{Pl}}^2 \left(\frac{V_\phi}{V}\right)^2$$

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

Current status of the B-mode measurements

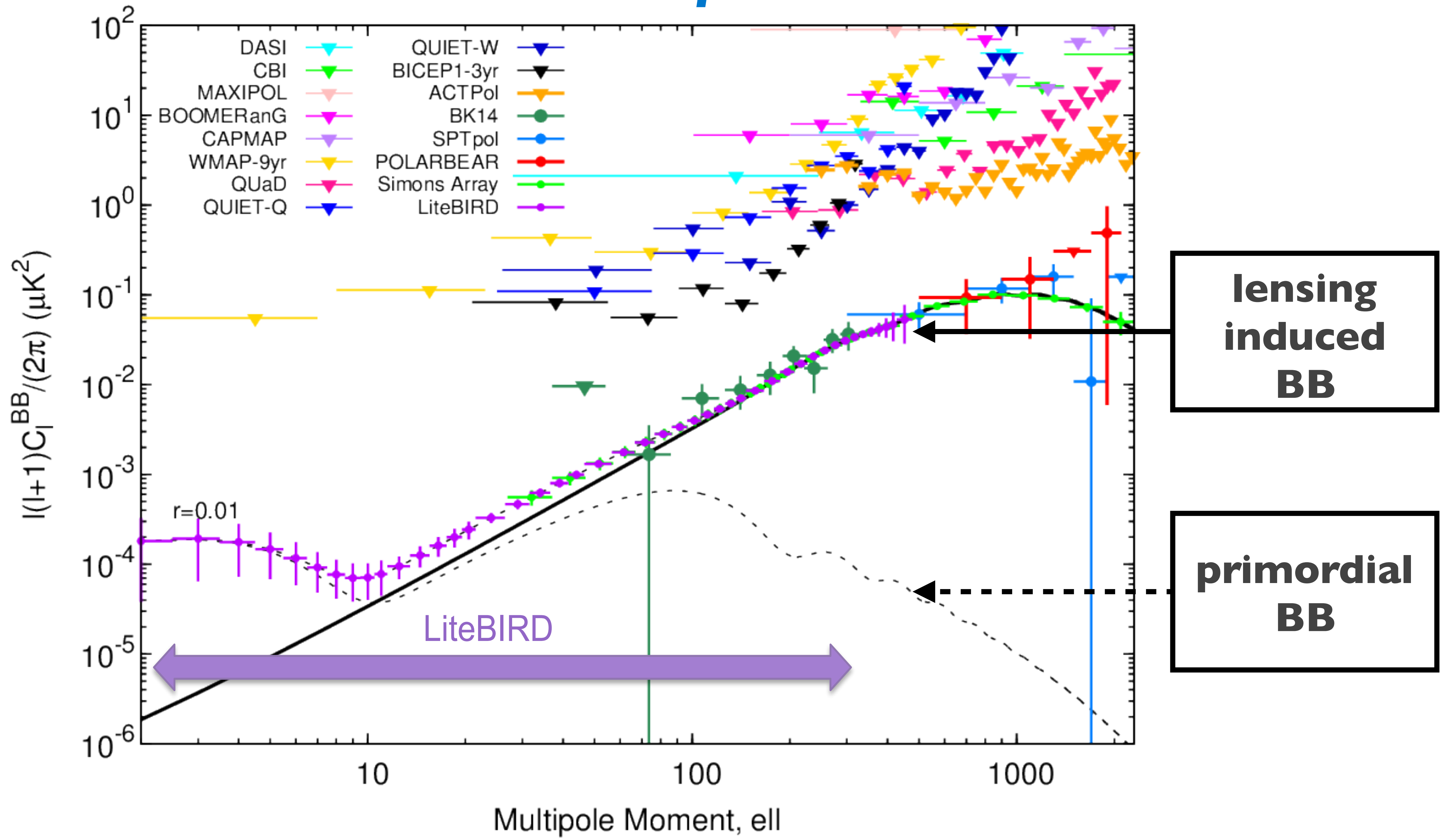


r < 0.07 (95% CL) — BICEP2 [BICEP2 Collaboration 2018]

r < 0.044 (95% CL) — BICEP2+Planck [Tristram et al. 2020]

Primordial gravitational waves

LiteBIRD Expectation



σ_r < 0.001 (for r=0)

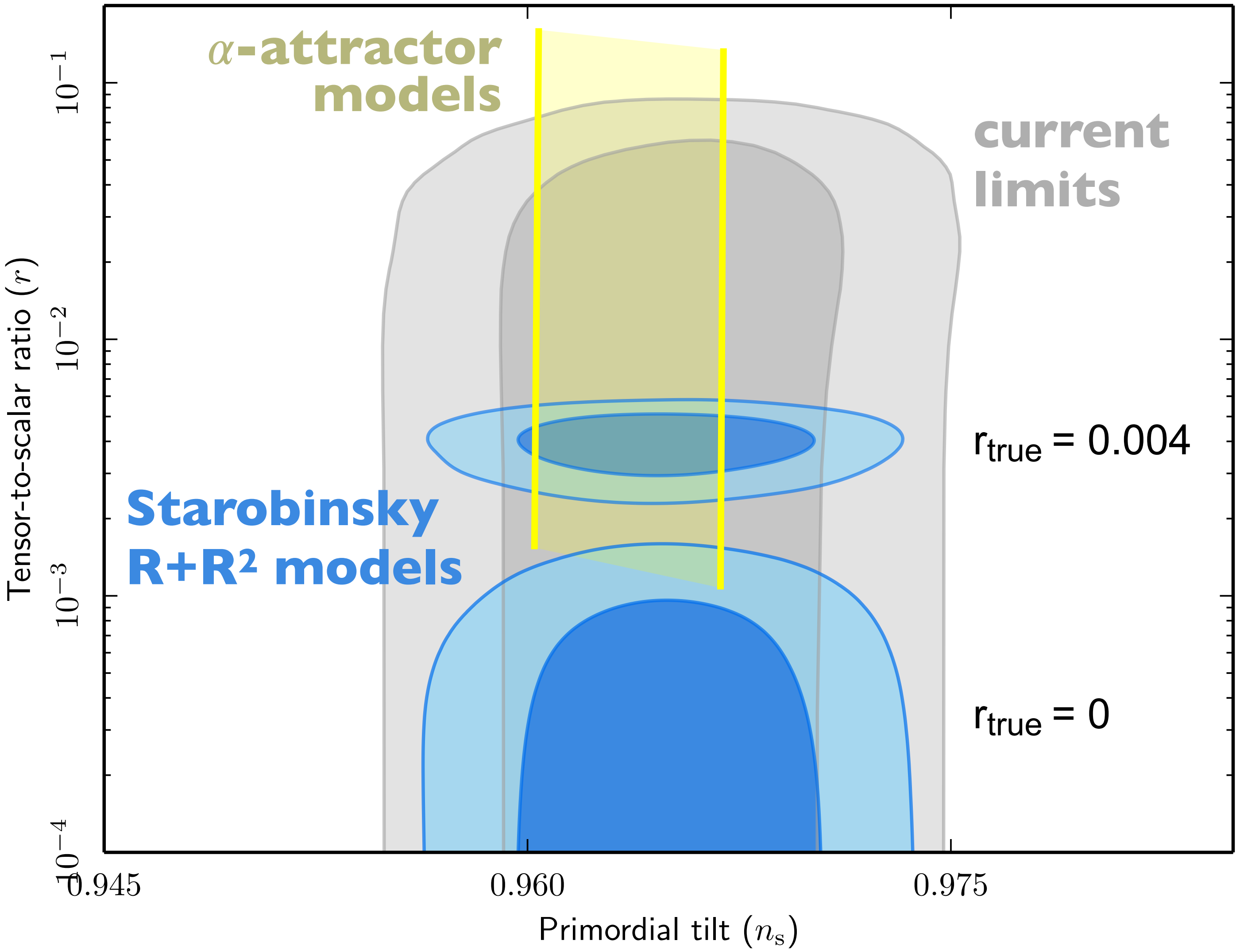
LiteBIRD only (no delensing)

Full Success

- $\sigma(r) < 10^{-3}$ (for r=0, no delensing)
- $>5\sigma$ observation for each bump (for $r \geq 0.01$)

Rationale

- Large discovery potential for $0.005 < r < 0.05$
- Simplest and well-motivated $R+R^2$ "Starobinsky" model will be tested
- Clean sweep of single-field models with characteristic field variation scale of inflaton potential greater than m_{pl} *[Linde, JCAP 1702 (2017) no.02, 006]*



Primordial gravitational waves

Full Success

- $\sigma(r) < 10^{-3}$ (for r=0, no delensing)
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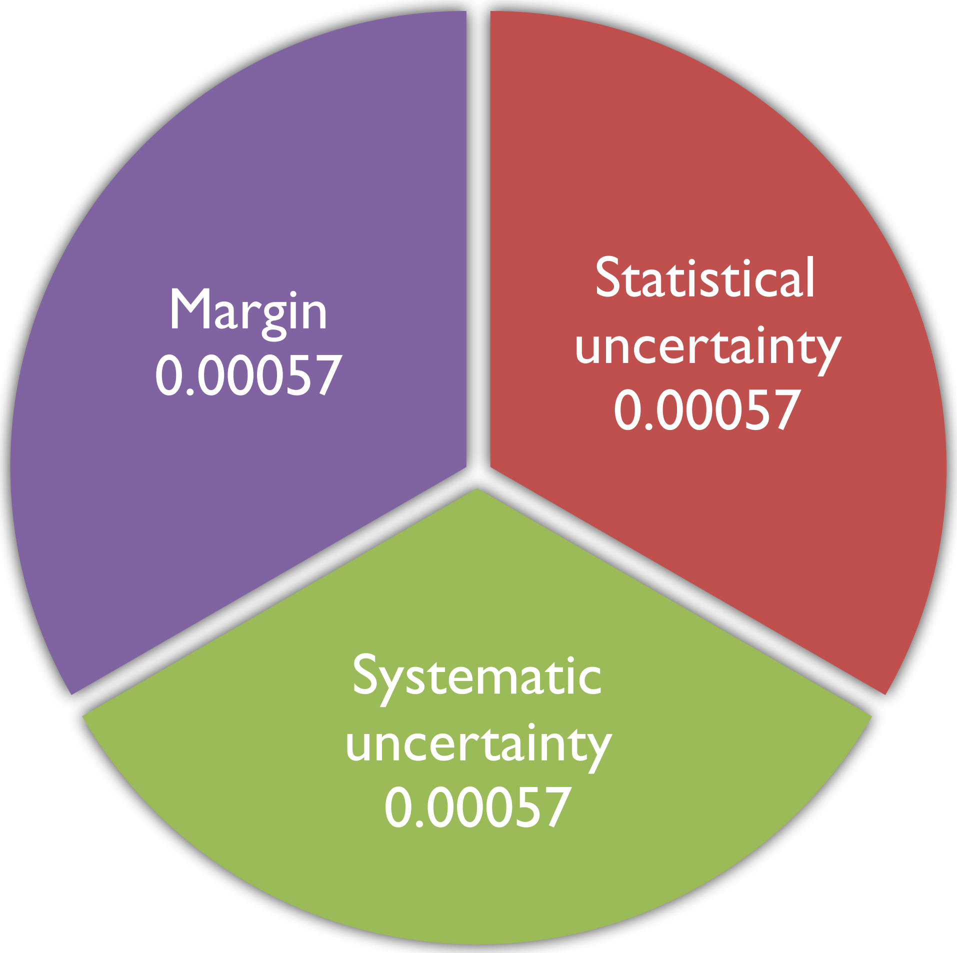
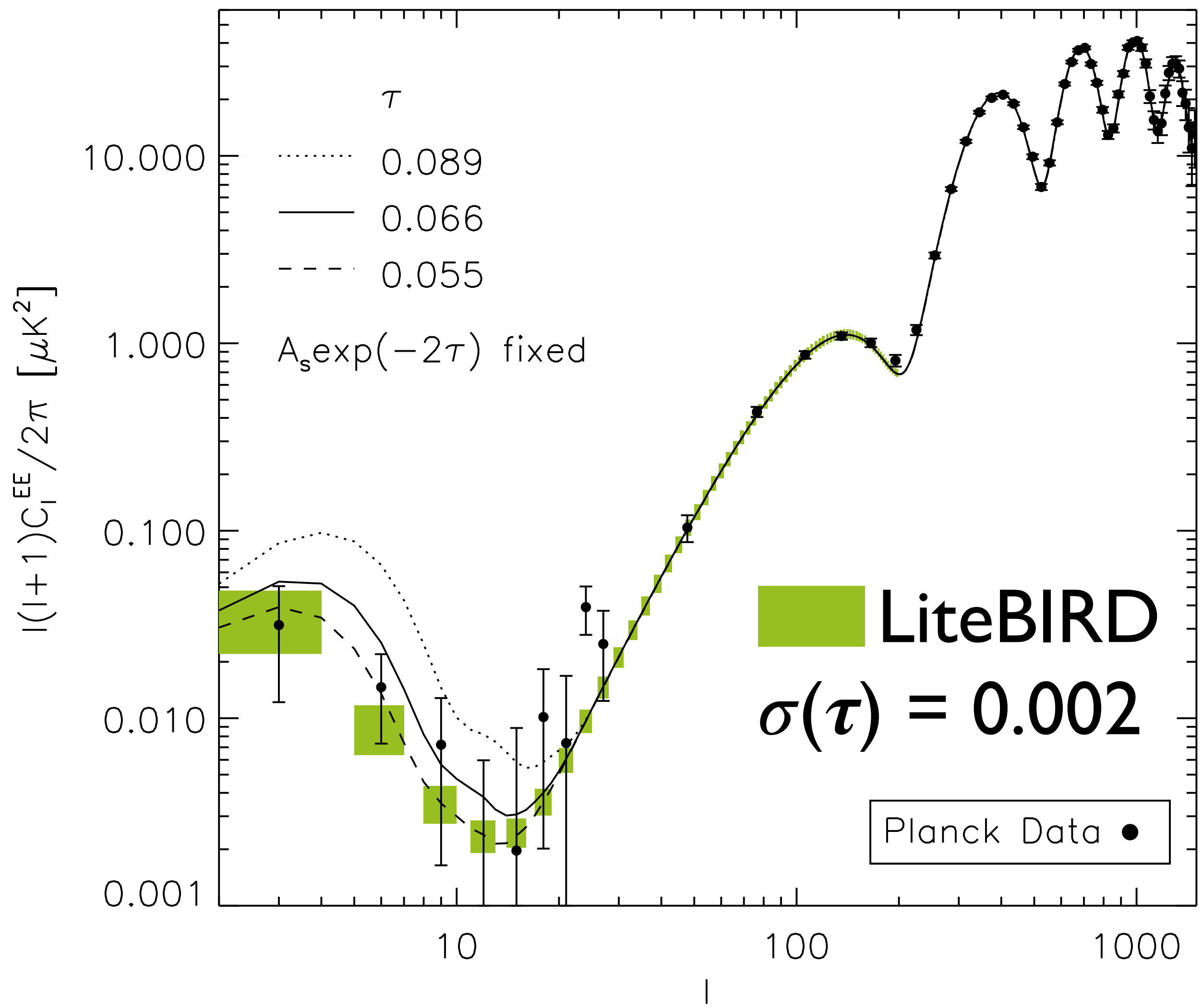
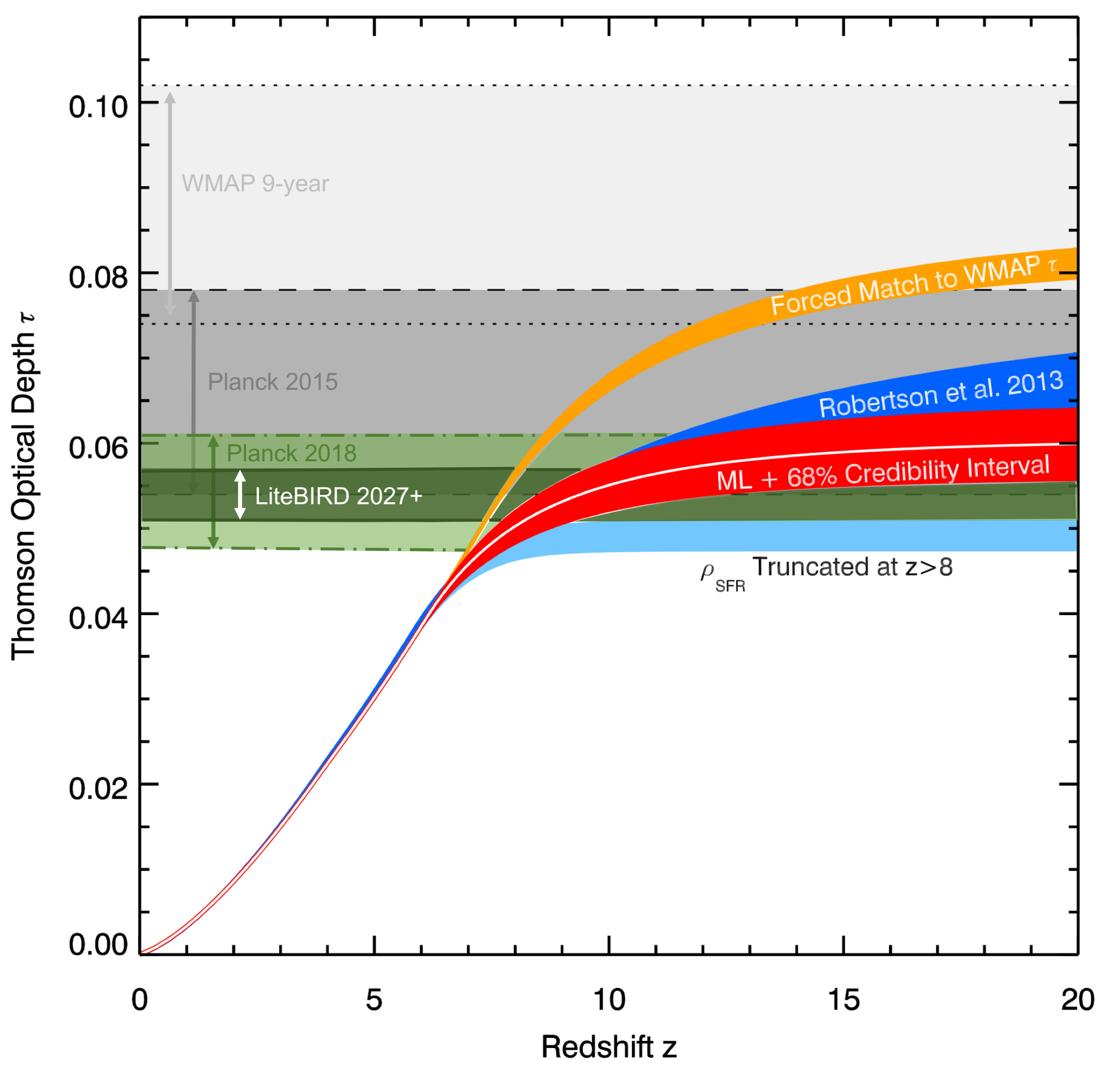


Statistical uncertainty
- foreground cleaning residuals
- lensing B-mode power
- 1/f noise

Systematic uncertainty
- Bias from 1/f noise
- Polarization efficiency & knowledge
- Disturbance to instrument
- Off-boresight pick up
- Calibration accuracy

A **cosmic variance limited** measurement of EE on large angular scales will be an important, and guaranteed, legacy for LiteBIRD



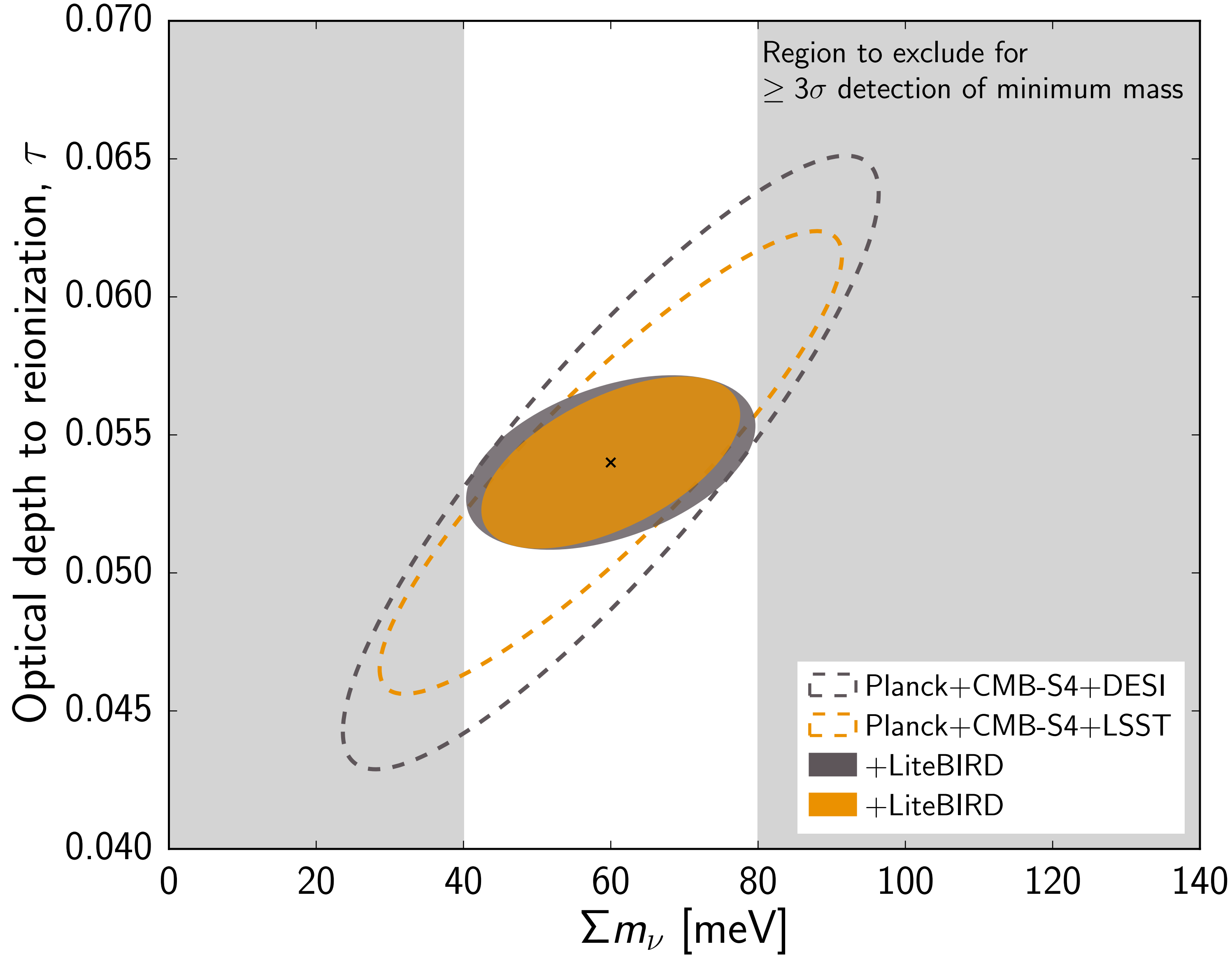


σ(τ) better than current Planck constraints by a factor 2

Neutrino sector

Improvement in **reionization optical depth** measurement implies:

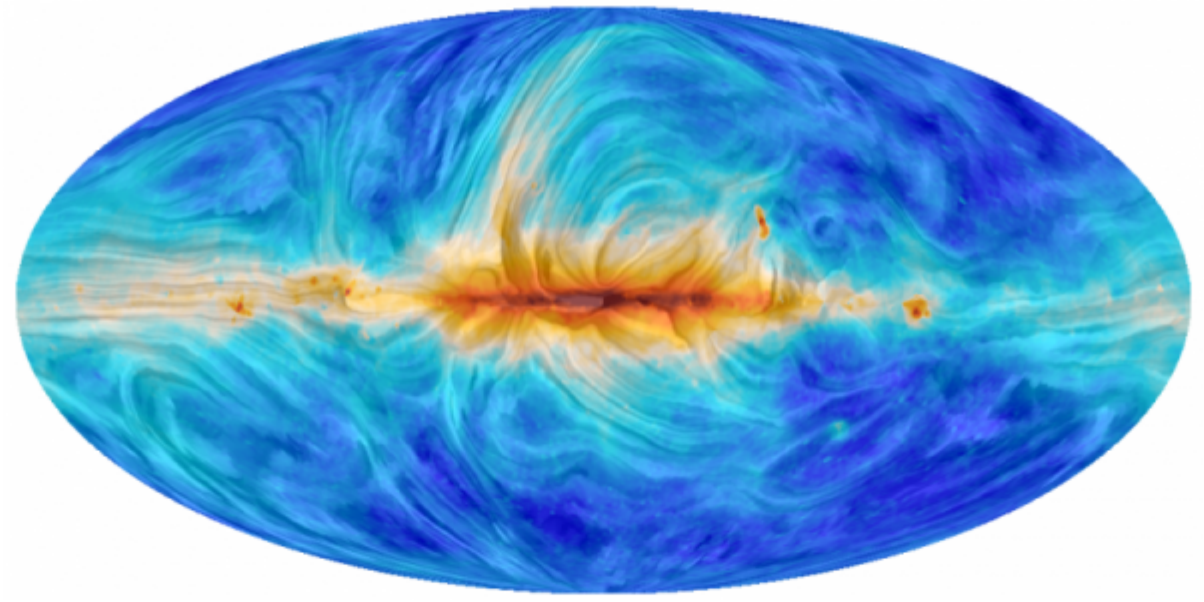
- $\sigma(\Sigma m_\nu)$ = 15 meV
- determine neutrino hierarchy (normal v.s. inverted)
- measurement of minimum mass ($\geq 3\sigma$ detection NH, $\geq 5\sigma$ detection for IH)



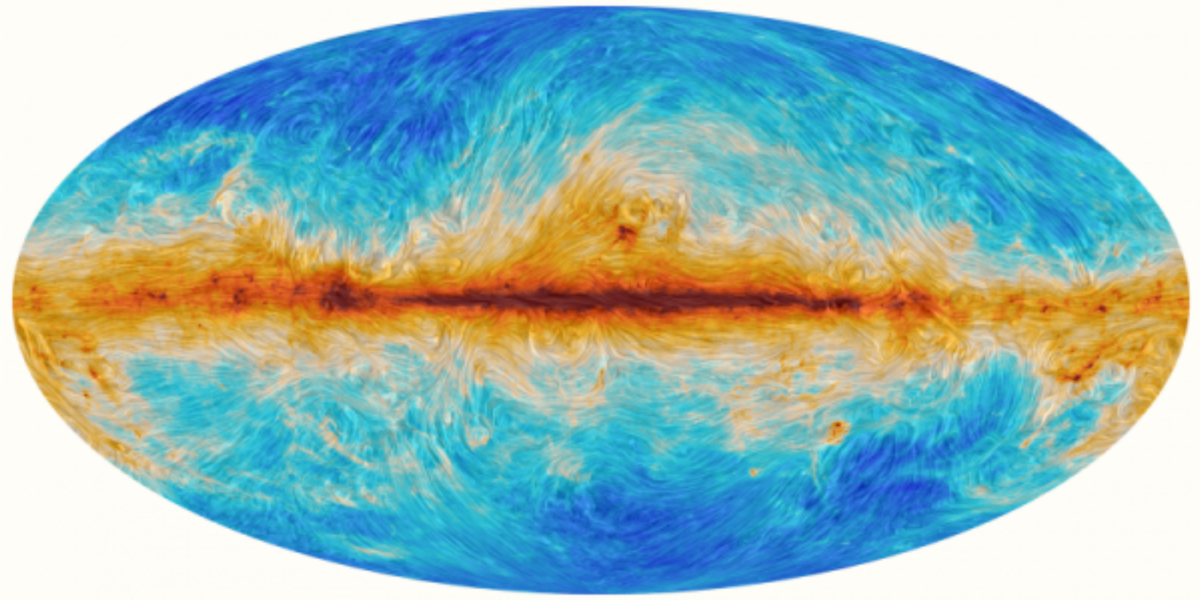
Galactic science

With frequency range from 34 to 448 GHz and access to large scales LiteBIRD will gives constraints on

- Characterisation of the foregrounds SED
- Large scale Galactic magnetic field
- Models of dust polarization grains

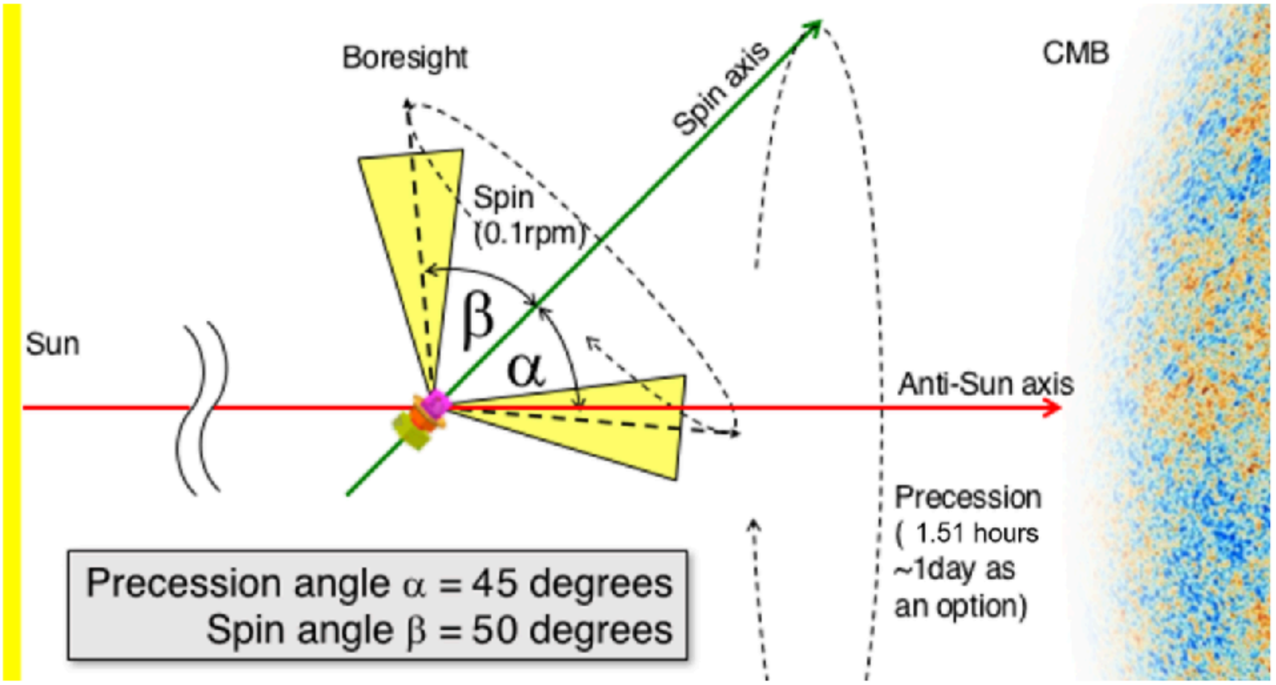


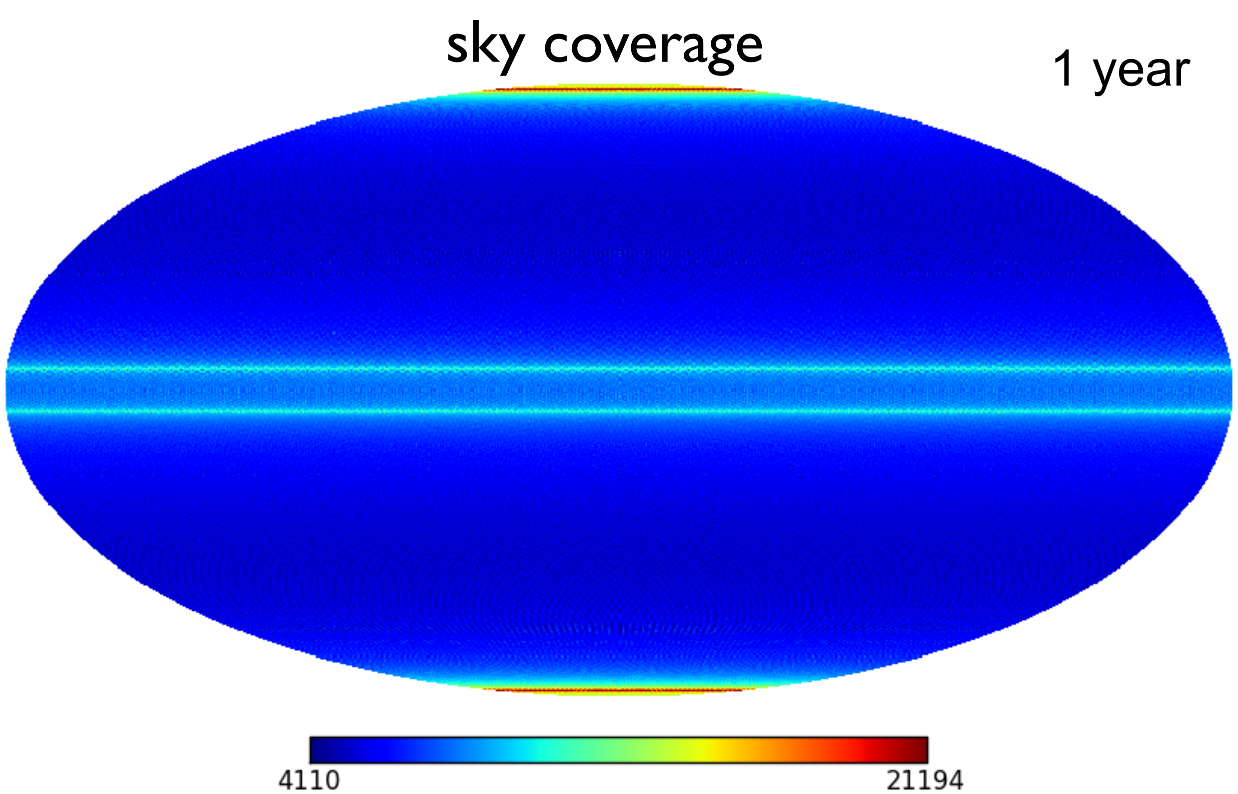
Synchrotron



Dust

LiteBIRD in a nutshell





L-Class JAXA Mission
Selected by JAXA (May 2019)
CNES Phase-A (end 2019)
Launch 2029

L2 orbit

All-sky Survey during 3 years

Large frequency coverage
15 bands 34 - 448 GHz

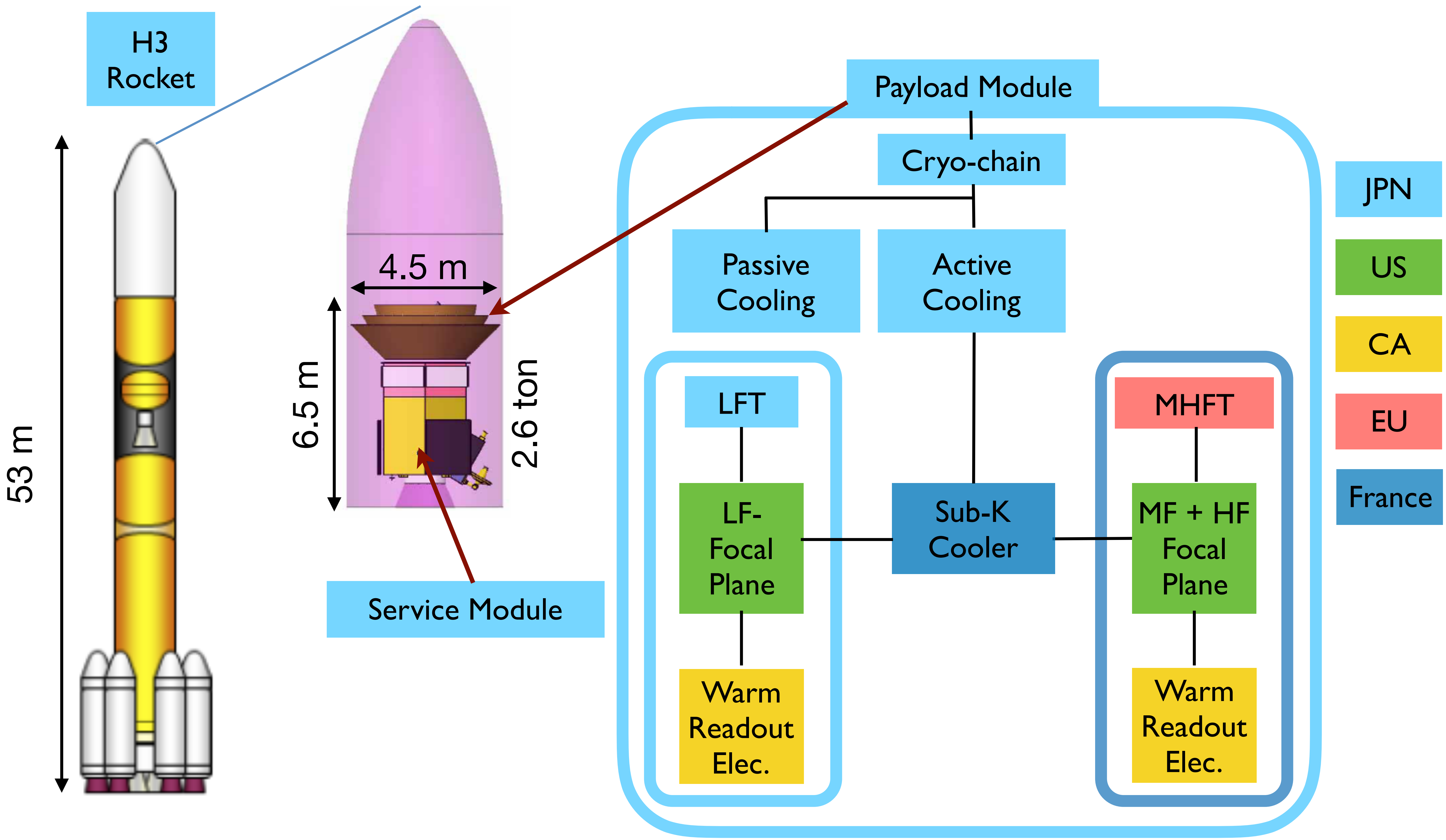
Resolution

LFT	70' - 23.7'
MFT	37.8' - 28.0'
MHFT	28.6' - 17.9'

Sensitivity
2.8 uK.arcmin
after component separation
(more than 100 times better than Planck in P)

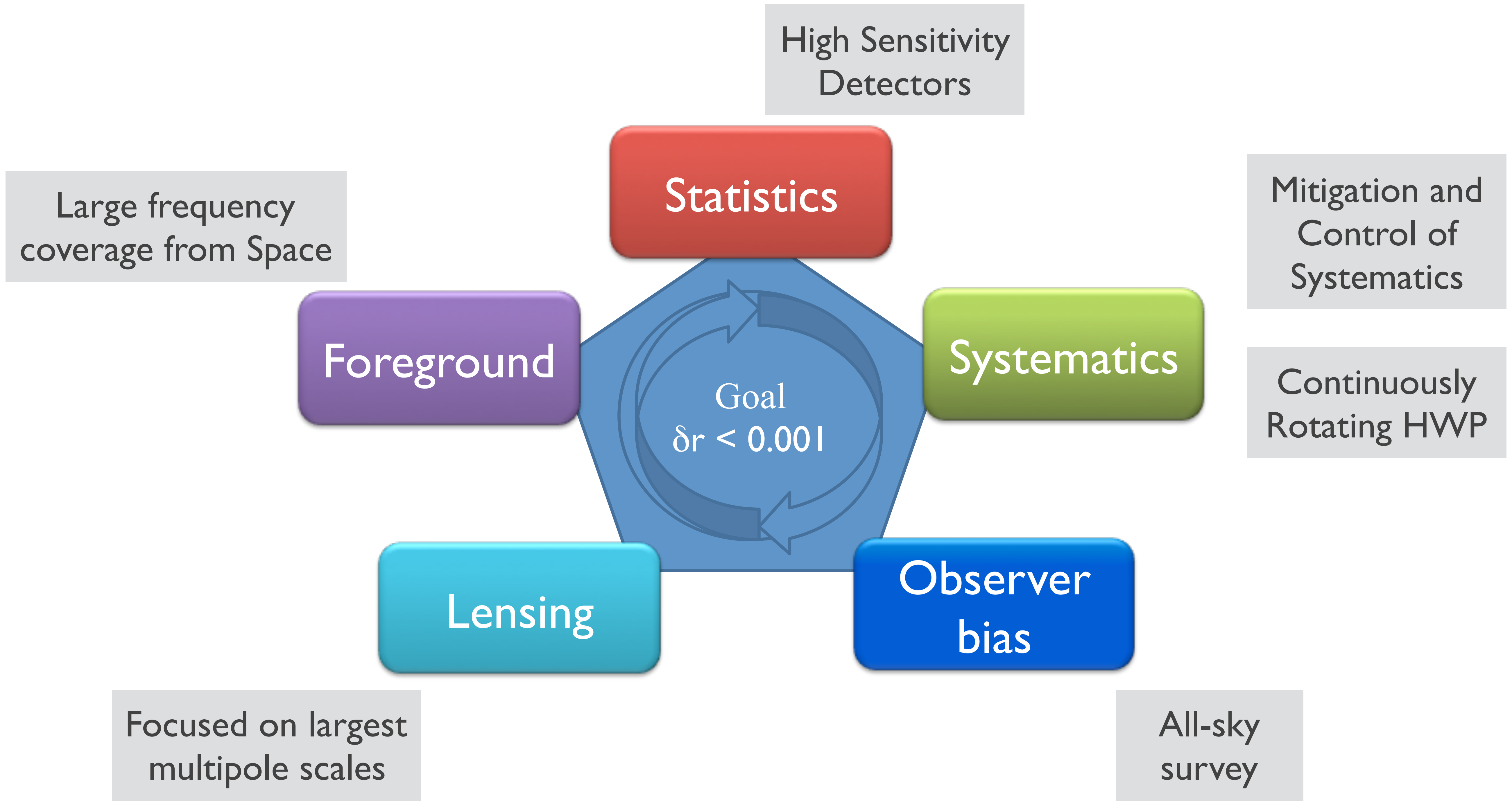
The LiteBIRD mission

Payload



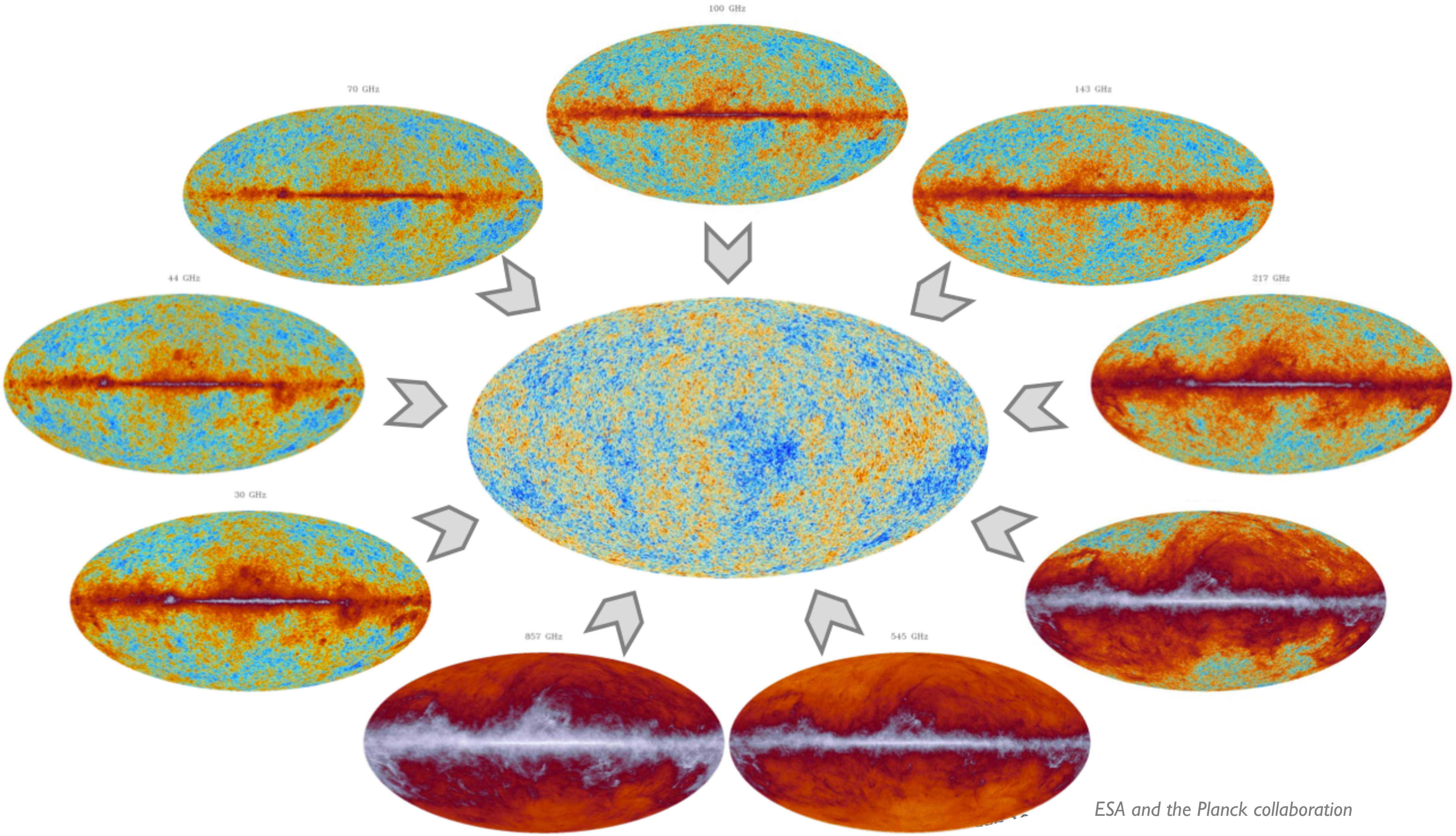
The LiteBIRD mission

Mission Challenges



Mission challenges

foregrounds



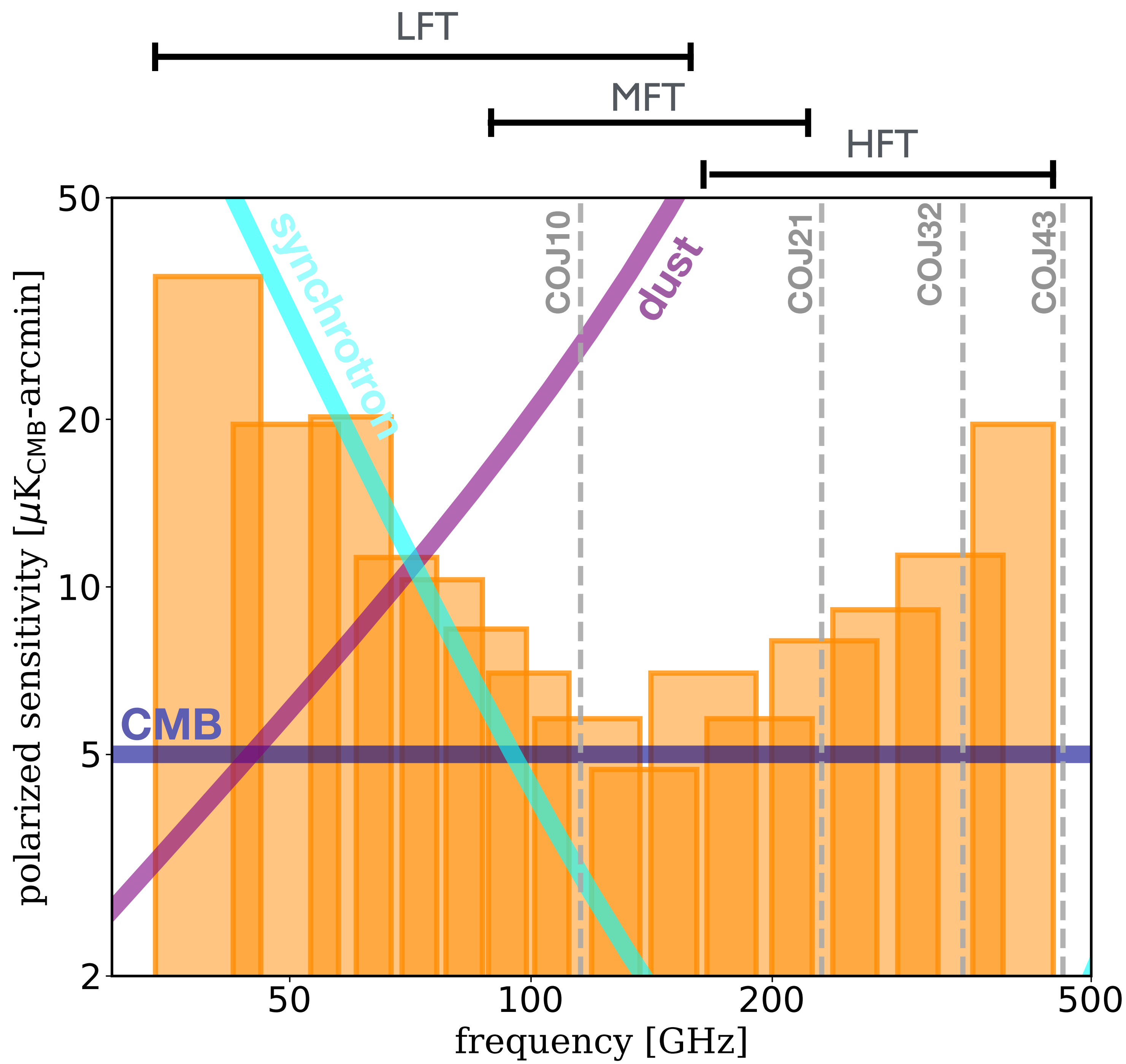
ESA and the Planck collaboration

The LiteBIRD mission

frequency coverage

15 bands
from 34GHz
to 448GHz

4676
detectors



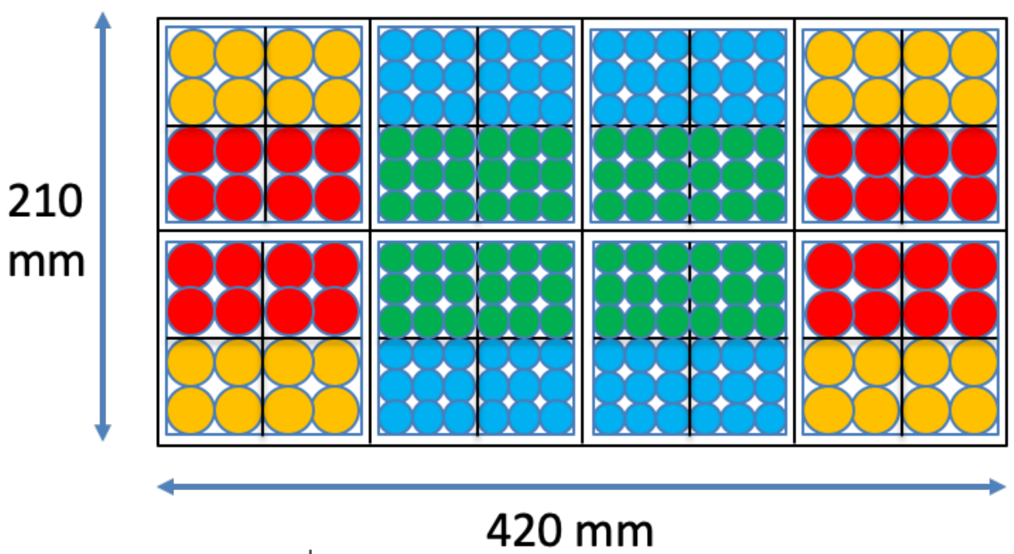
9 bands LFT
5 bands MFT
5 bands HFT

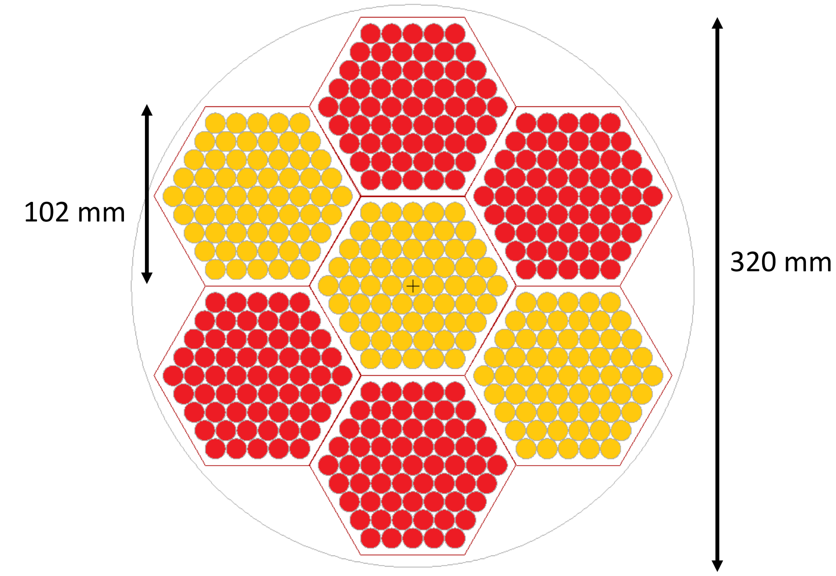
with 4 overlapping bands

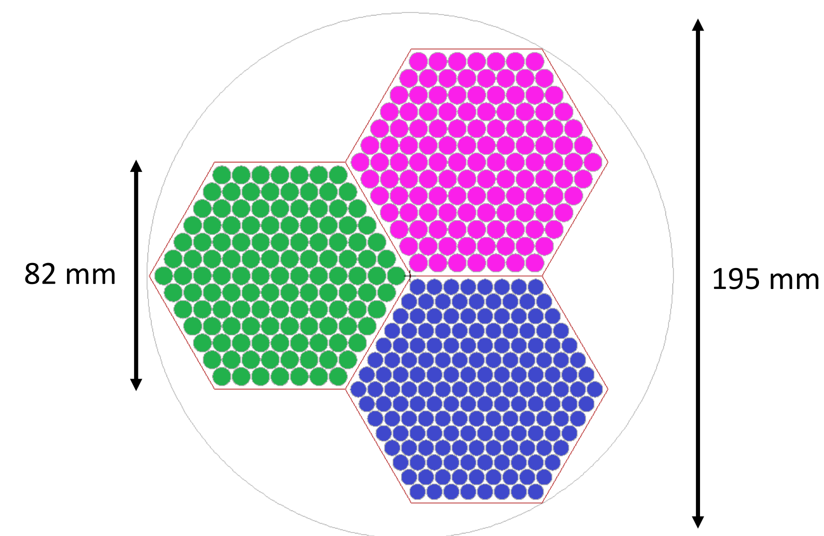
The LiteBIRD mission

Number of detectors: 4676
Overlap between telescopes

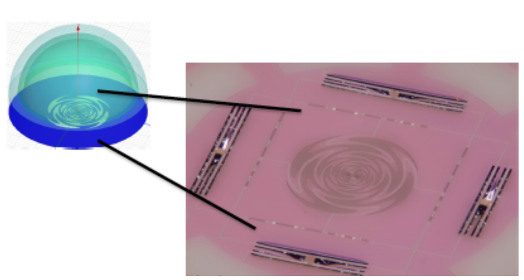
focal plane



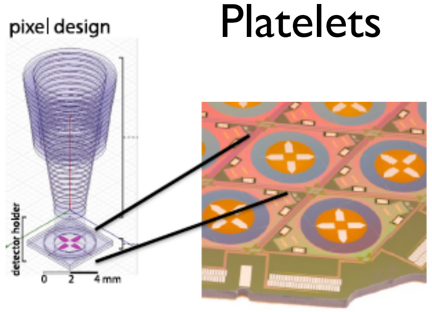




Lenslets



Platelets



MFT (2.5:1)

89GHz — 224 GHz

2075 detectors
366 Trichroic TES
488 Dichroic TES

100 | 119 | 140 | 166 | 195

LFT (4.7:1)

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

1258 detectors
2 x (64 + 155) Trichroic TES

34GHz — 161 GHz

HFT (2.7:1)

195 | 235 | 280 | 337 | 402

1355 detectors
2 x 254 Dichroic TES
338 Monochromatic TES

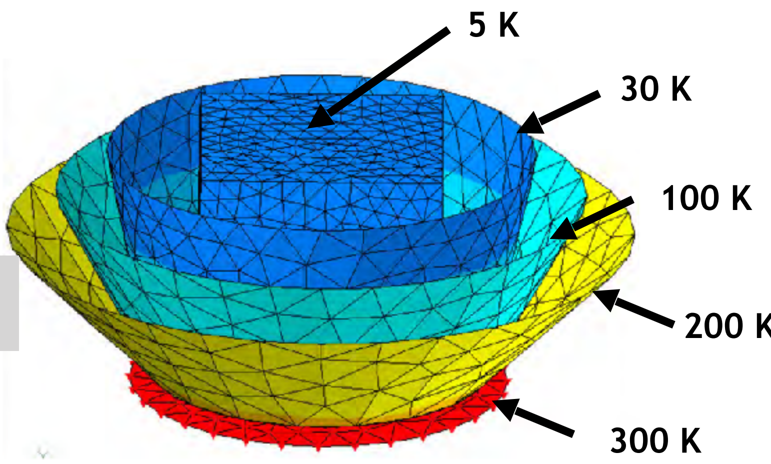
166 GHz — 448 GHz

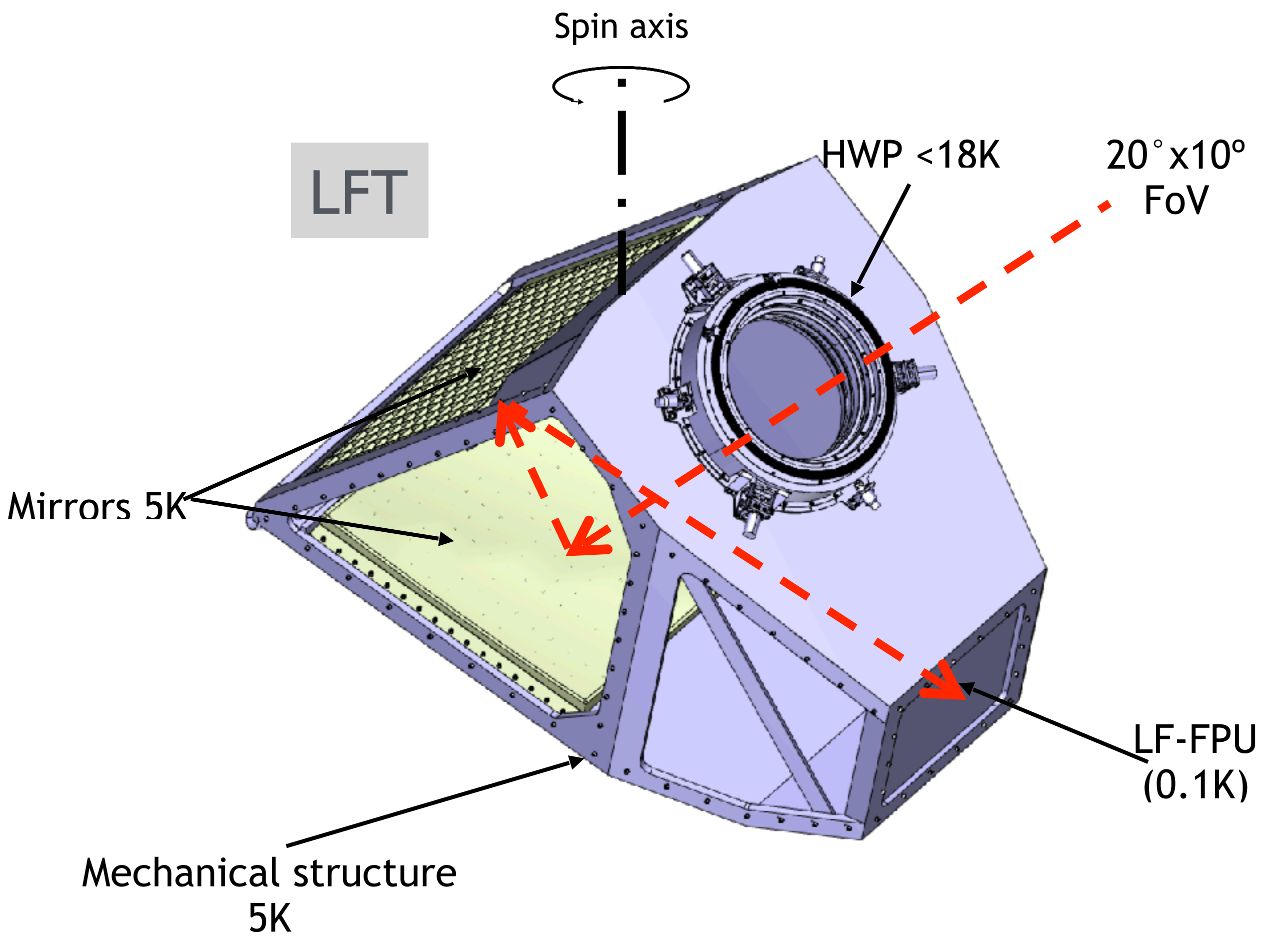
The LiteBIRD mission

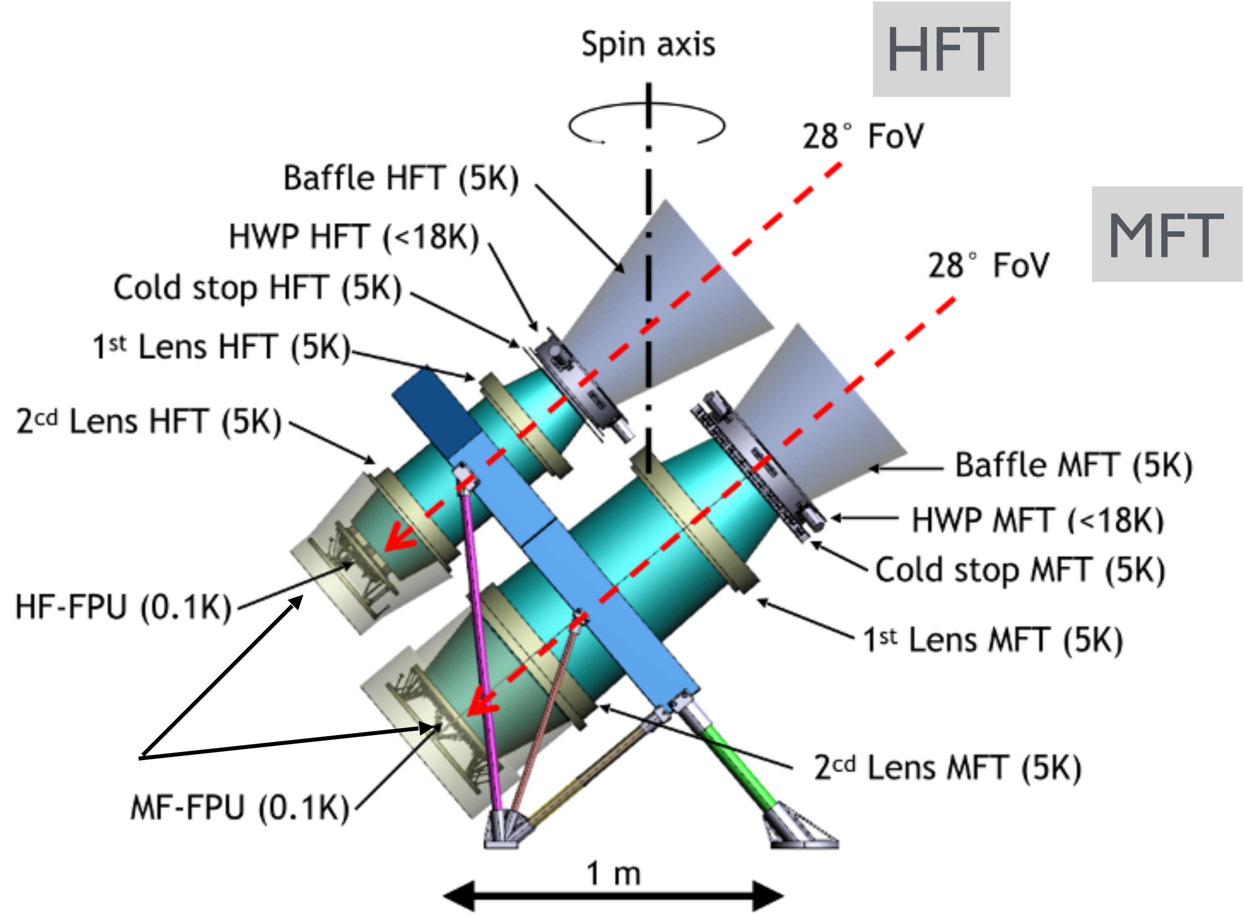
Systematics

telescopes and optics at 5K

continuously Rotating Half-Wave Plates



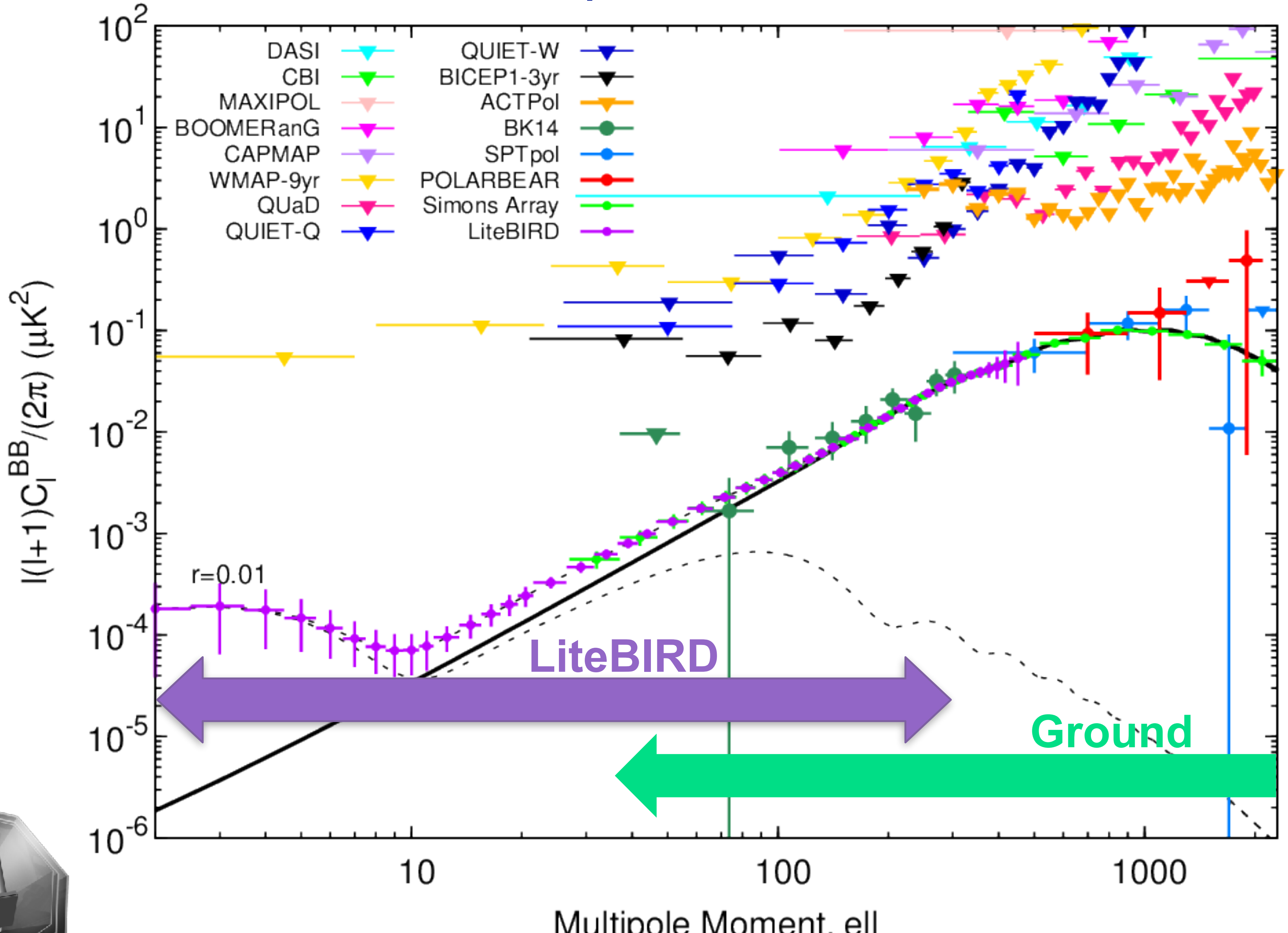




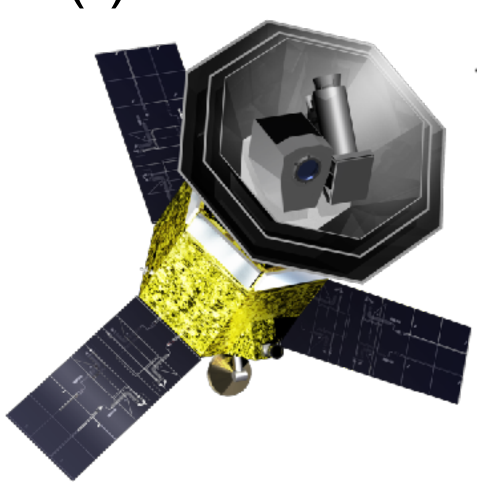
focal planes at 100mK

CMB from space and ground

a powerful duo



LiteBIRD
$2 \leq \ell \leq 300$
$\sigma(r) < 0.001$



Ground telescopes
$30 \leq \ell \leq 8000$

CMB from space and ground

Extra Success

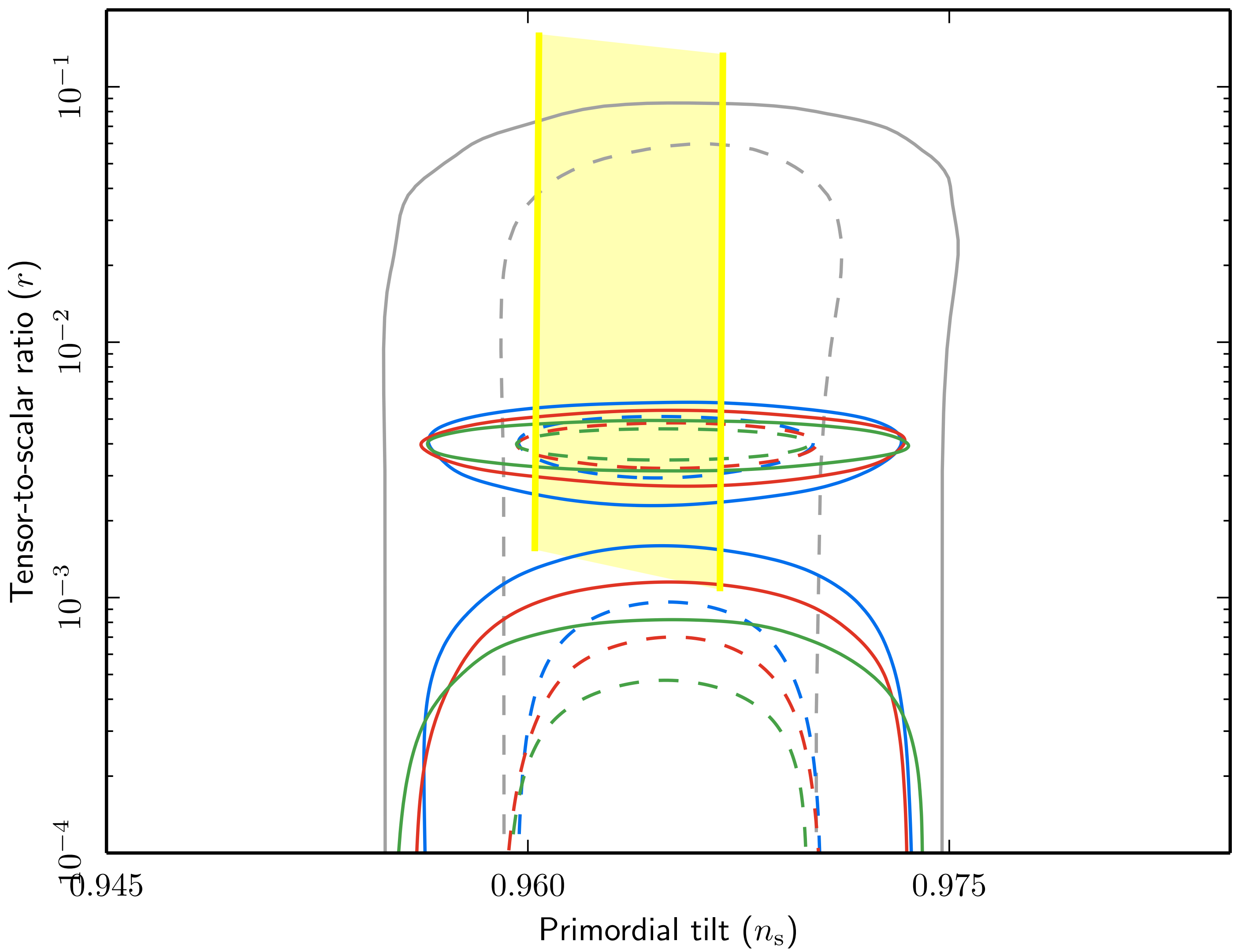
- improve σ(r) with external observations
- delensing improvement to σ(r) can be a factor ≥ 2

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



Synergy with other probes

- Lensing

LiteBIRD E-modes
+
CMB-S4 high-resolution

→ improve our knowledge of the projected gravitational lensing produced by the large-scale structure

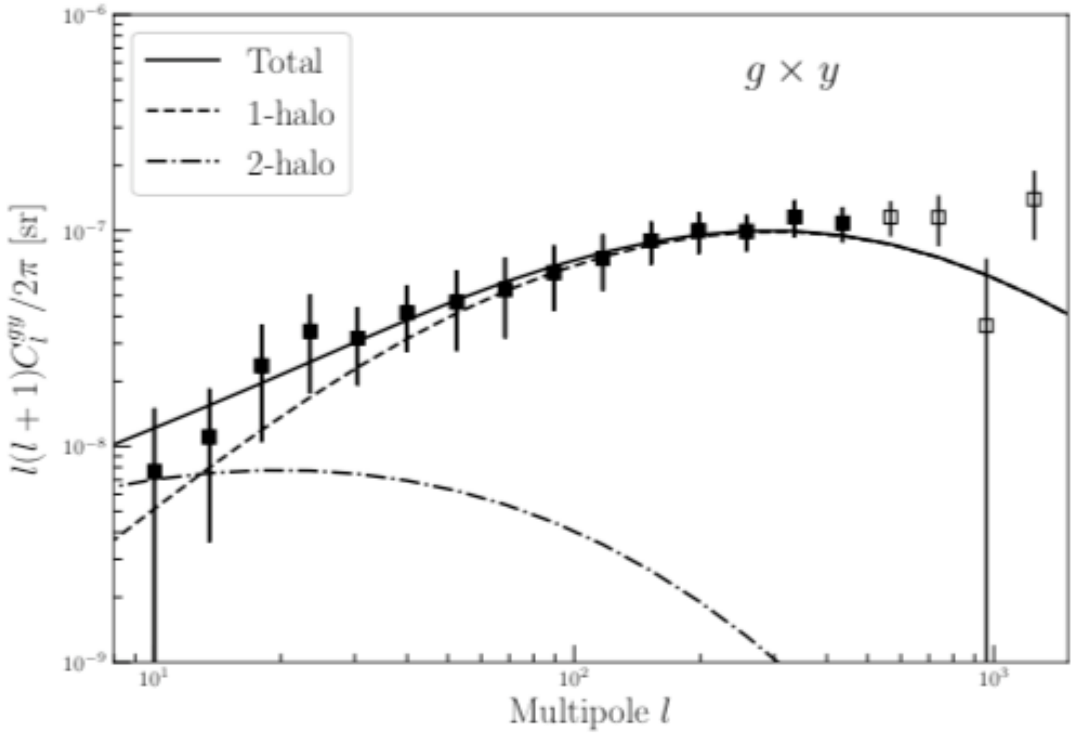
- Integrated Sachs-Wolf effect

improvement on ISW signal (~20%)

- Galaxy surveys

full-sky map of hot gas
(thermal SZE)
⊗
3D distribution of the matter
(galaxy survey)

how gas traces the matter in the Universe



The LiteBIRD Collaboration

An international collaboration

More than 200 researchers from Japan, Europe & North America

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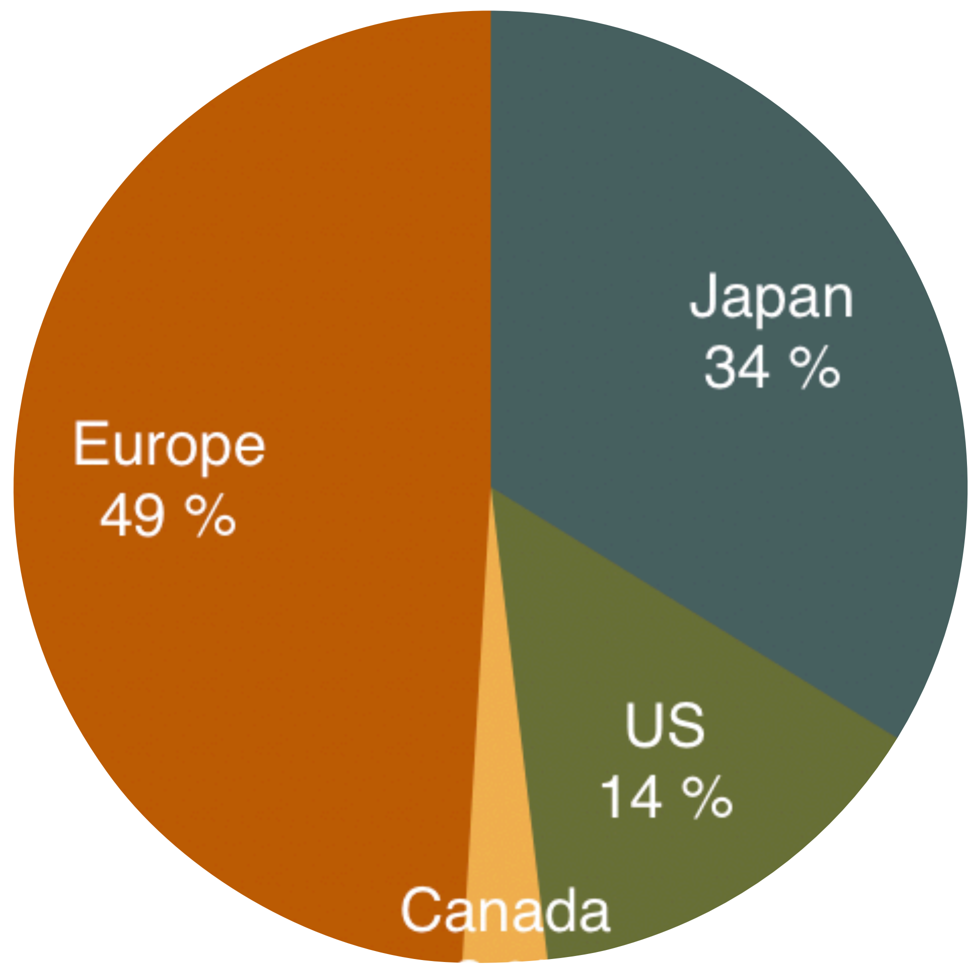

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The LiteBIRD Collaboration

LiteBIRD-Europe

About 100 members, including scientists experts on instrument and data analysis:

France

APC (Paris)
CEA-DAp (Saclay)
CEA-SBT (Grenoble)
ENS-LERMA (Paris)
IAP (Paris)
IAS (Orsay)
IJClab (Orsay)
Institut Néel (Grenoble)
IPAG (Grenoble)
IRAP (Toulouse)
LAM (Marseille)
LESIA (Meudon)
LPSC (Grenoble)

Italy

Università di Roma "Tor Vergata"
Università di Milano
Sapienza Università di Roma
INAF/IASF, Bologna
INAF/OATS, Trieste
Università di Milano-Bicocca
Università di Genova
INFN-Sezione di Pisa
Università di Ferrara
Università di Padova
SISSA – Trieste

UK

Cardiff University
University of Cambridge
Imperial College London
University of Manchester
University College London
University of Oxford
University of Portsmouth
University of Sussex

Germany

Max Planck Society (MPA, MPE, MPIfR)
Ludwig-Maximilians-Universität München
Universität Bonn
RWTH Aachen Universität

Spain

IFCA, IDR/UPM, DICOM/UC
ICCUB, IAC
Universidad de Oviedo
Universidad de Salamanca
Universidad de Granada
CEFCA

Holland

SRON
RuG

Norway

University of Oslo

Sweden

Stockholm University

Ireland

Maynooth

European Meetings

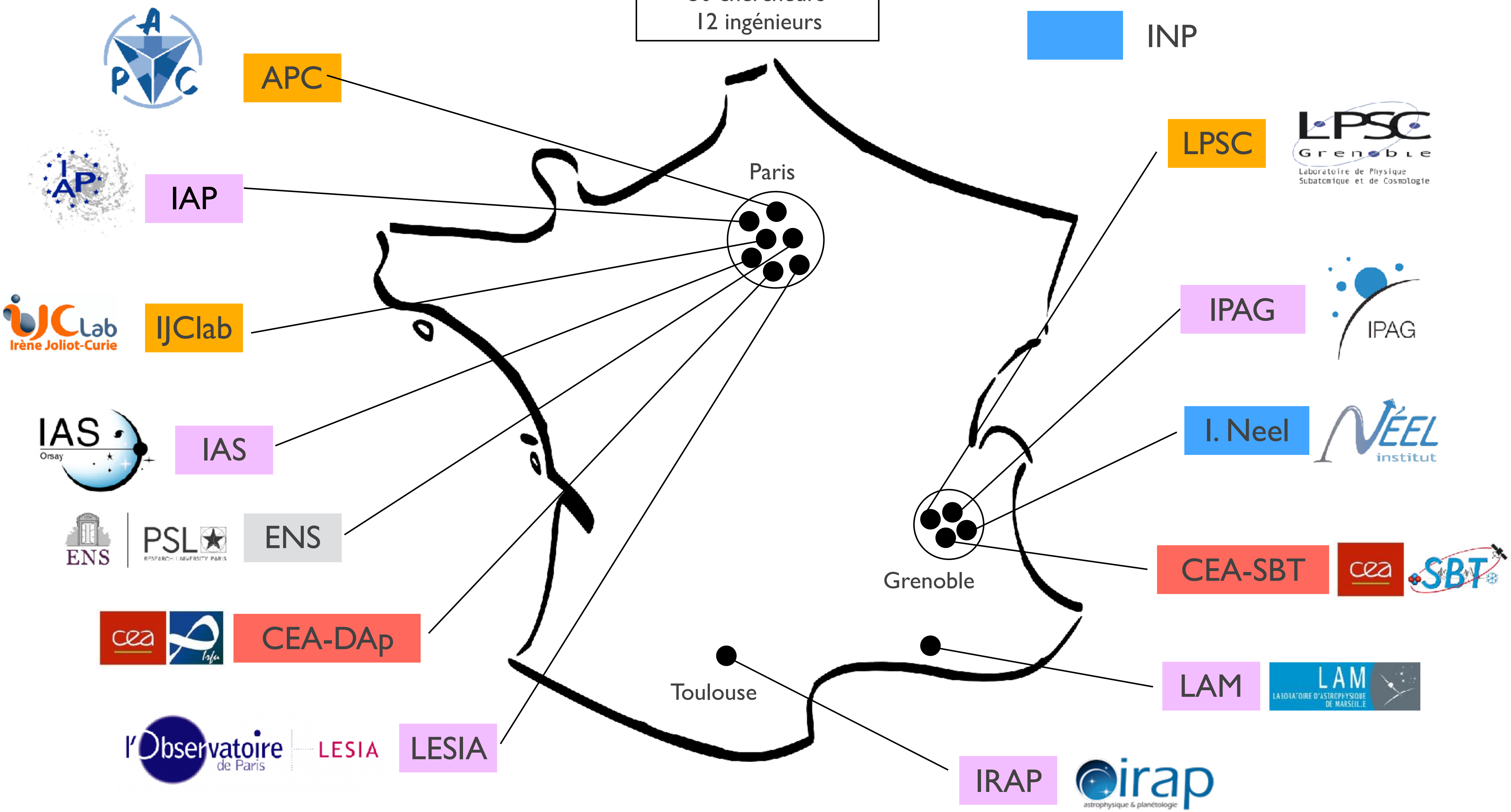
06/19: Toulouse
04/19: Munich
11/18: Cardiff
10/18: Toulouse
04/18: Munich
02/18: Turin
10/17: Paris
07/17: Cardiff

Current French involvement

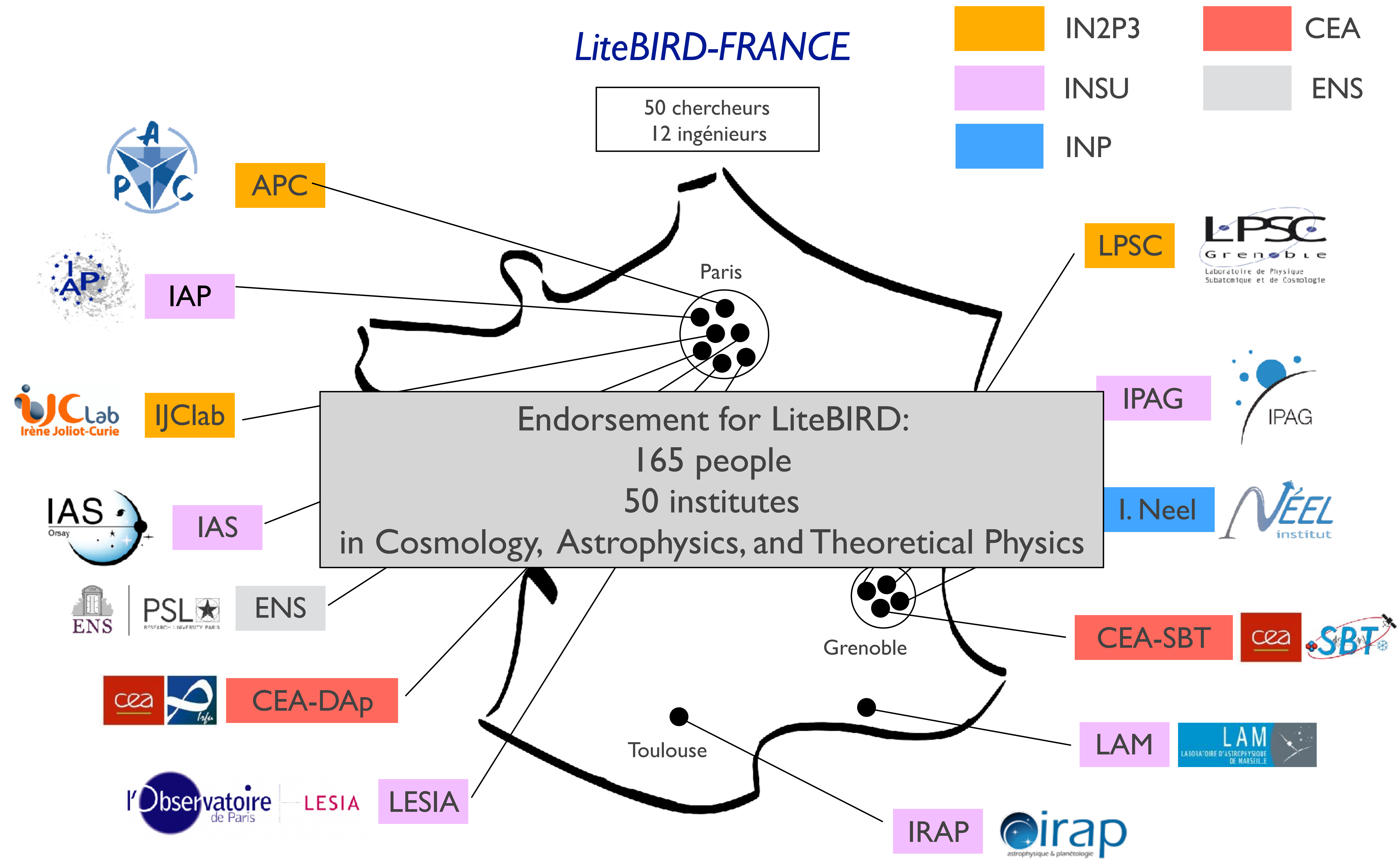
LiteBIRD-FRANCE

50 chercheurs
12 ingénieurs

IN2P3	CEA
INSU	ENS
INP	



Current French involvement



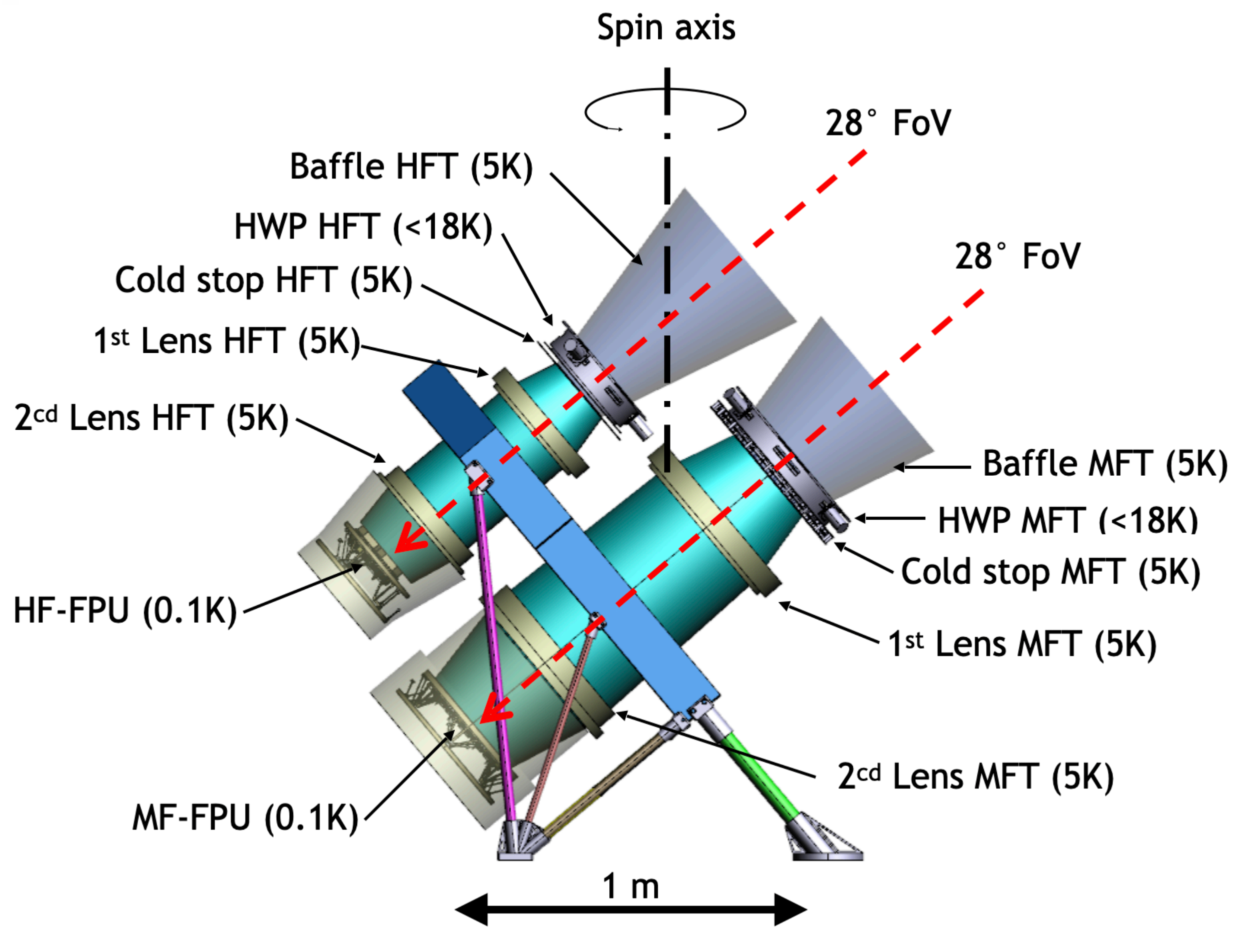
CNES phase A2 (2019-2021)

US
- Focal Plane
- Cold Readout Electronics

Canada
- Warm Readout Electonics

UK
- Optics

Italy
- HWP mechanism



cnes

- Instrument Design & Management — irap, IJCLab, IAS, APC, l'Observatoire de Paris LESIA, LAM, cea SBT
- MHFT Mechanical Structure — IJCLab
- 30K-5K cryo-structure — LAM
- Electronics & on-board software — irap
- Sub-K Cooler (LFT, MFT, HFT) — cea SBT
- Calibration — IJCLab, IAS, LPSC, NÉEL institut, APC, LAM, IPAG, irap

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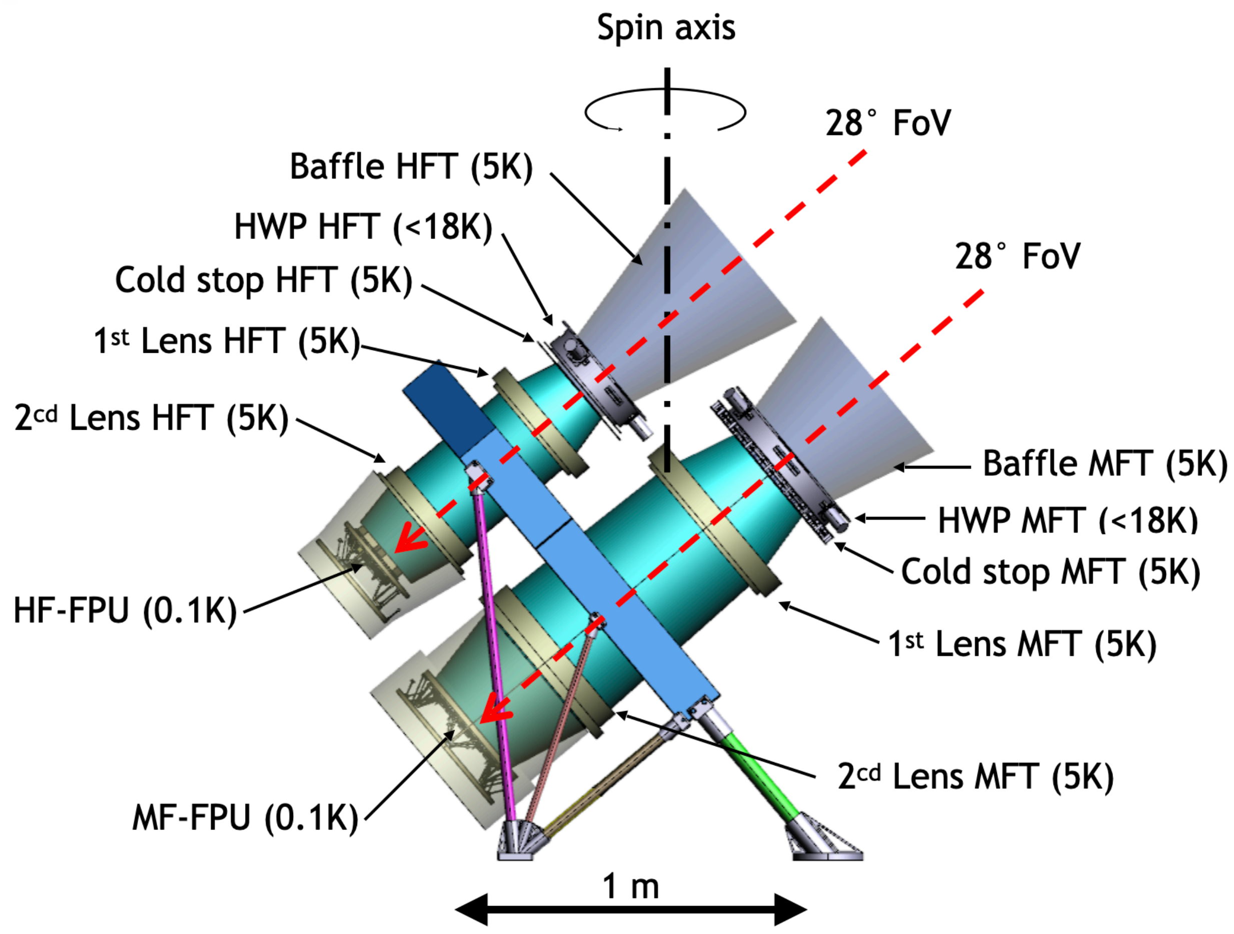


- Instrument Design & Management
- MHFT Mechanical Structure
- 30K-5K cryo-structure
- Electronics & on-board software
- Sub-K Cooler (LFT, MFT, HFT)
- Calibration

LiteBIRD organisation (phase A)

PI: Masashi Hazumi (JPN)
PI-US: Adrian Lee (LBNL)
PI-EU: Ludovic Montier (IRAP)

Interim Governance Board

40 members
(7 French including 4 IN2P3)

Joint Study Groups

systematics	**G. Patanchon (APC)** H. Ishino (IPMU) J. Borrill (LBNL)
foregrounds	N. Katayama (Japan) R. Flauger (US) C. Baccigalupi (Europe)
calibration	T. Matsumura (Japan) K. Arnold (US) **S. Henrot-Versille (IJClab)**
Payload Module	Y. Sekimoto (Japan) K. Thompson (US) **B. Mot (IRAP)**

Performance Team

Takashi Hasebe (Japan)
Josquin Errard (APC)

Data Management Group

Paolo Natoli (Italy)
Matthieu Tristram (IJClab)

- Instrument Model Team
- Simulation Team

- **Science Ground Segment**
  under responsibility of the LiteBIRD international collaboration
- Collaboration **bylaws** for phaseA under validation
  (incl. governance, publication, configuration control, and data policies)

LiteBIRD @ IN2P3

- 3 labs (APC, IJClab, LPSC)
- 13 staff researchers
- 8 engineers

- CNES Task-sharing
  - responsible for the mechanical structure
  - responsible for the ground calibration
- LiteBIRD Management
  - Interim Governance Board (4 members)
  - Joint Study Groups (2 co-lead)
  - Data Management Group (1 co-lead)
- Large implication in science and forecasting studies

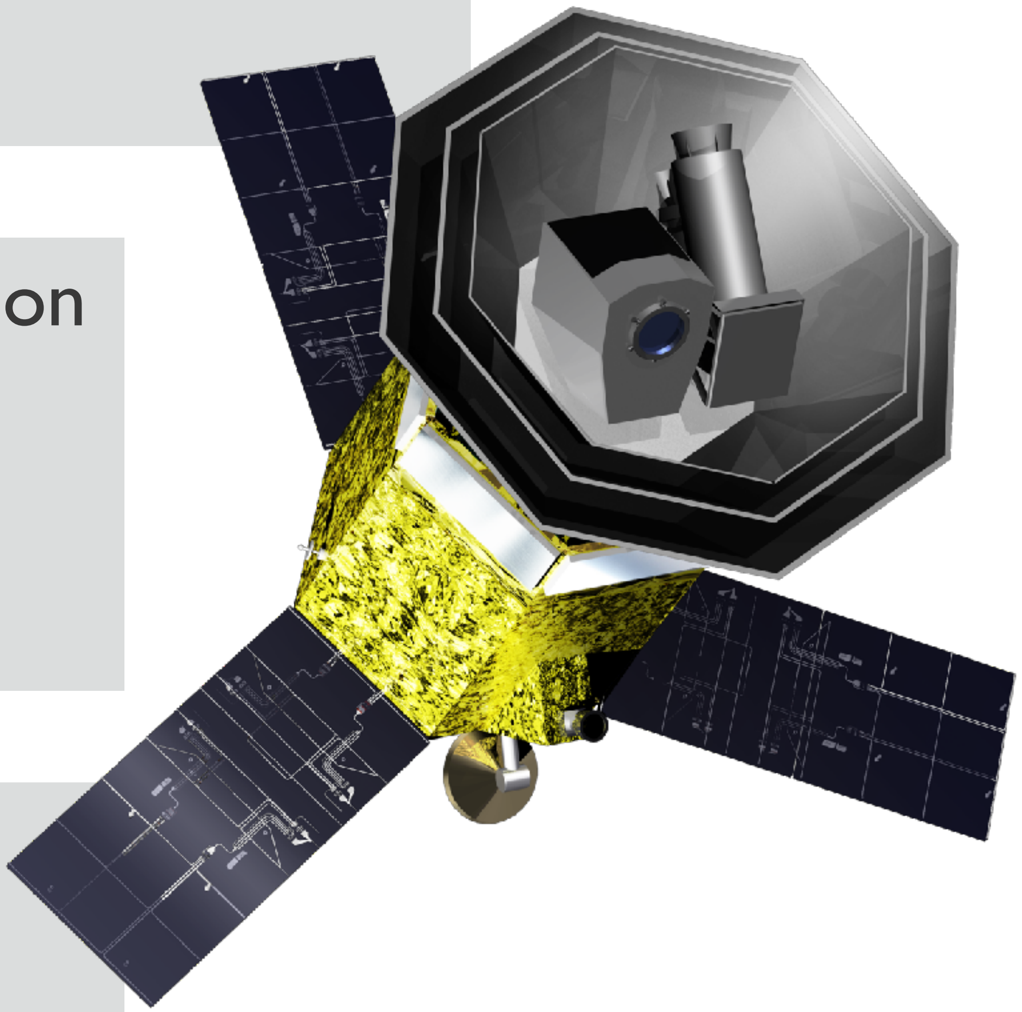
Conclusions

LiteBIRD is targeting one the **biggest discovery** of science in modern cosmology

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Inflation energy (Full success / Extra success)
  - Constraints on the inflation potential
  - Beyond the B-mode power spectrum

- Cosmological parameters with E polarisation
  - Optical depth and reionization of the Universe
  - Elucidating low-ℓ anomalies with polarization
- Neutrino sector
- Cosmic birefringence

- Anisotropic CMB spectral distortions
- Galactic science
- Mapping the hot gas in the Universe



Conclusions

- The telescopes are designed in order to **overcome the challenges** related to the extreme sensitivity (reduction and control of systematics)
- The project is :
  - **selected** by the JAXA as the next Large Scale mission with a launch in early 2029
  - phase A undergoing at JAXA
  - NASA is under technology development. Participation needs to be consolidated
  - phase A is starting at cnes for the study of the Medium and High Frequency Telescopes
  - ASI commitment for a phase A
  - esa is interested. Participation needs to be consolidated in the new context of M5 (SPICA is not selected).

2017 - 2019	JAXA pre-Phase A
May 2019	Class-L Mission Selection
09/2019 - 03/2022	JAXA Phase A1
End 2021	System Requirement Review
03/2022 - 03/2023	JAXA Phase A2
03/2023 - 06/2024	Phase B (Preliminary design)
01/2024 - 09/2025	Phase C (EM development and tests)
09/2025 - 12/2028	Phase D (FM production and tests)
early 2029	Launch
2029 - 2032	Mission Operation

current JAXA calendar

Conclusions

- LiteBIRD at IN2P3
  - Large involvement in the management
  - Responsibilities in the instrument hardware
  - Science Ground Segment: co-lead and need to increase !
  - Forecast and simulation: leader and need to increase !
  - Science Exploitation: expertise and interest in France (and at IN2P3 in particular)

- What we need from IN2P3
  - support: during phase A2 and for further phases (B, C, D)
  - manpower: PhD and Post-doc to increase IN2P3 participation to science and data analysis
  - help to keep the CMB community structured in France (keep expertise, increase scientific impact and relations between instrument/data-analysis/theory, relation with INSU & CEA)