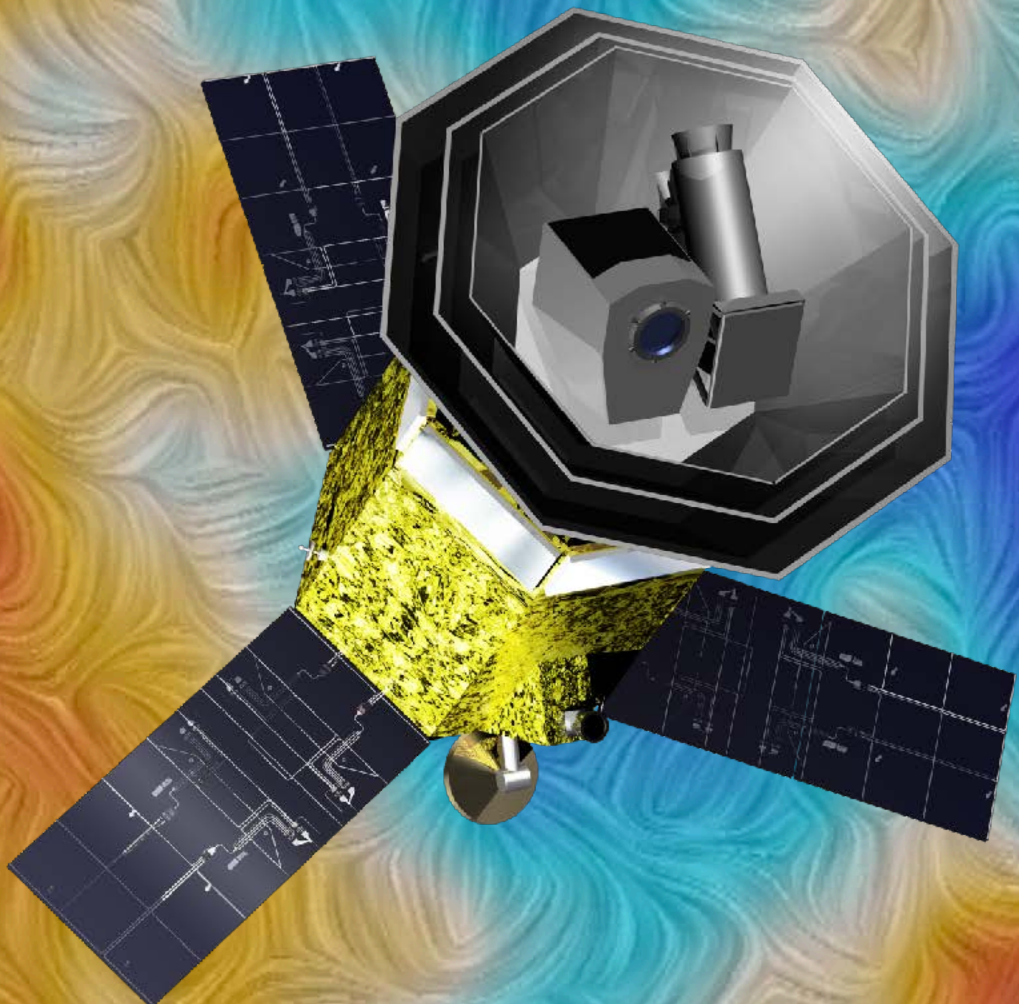


LiteBIRD

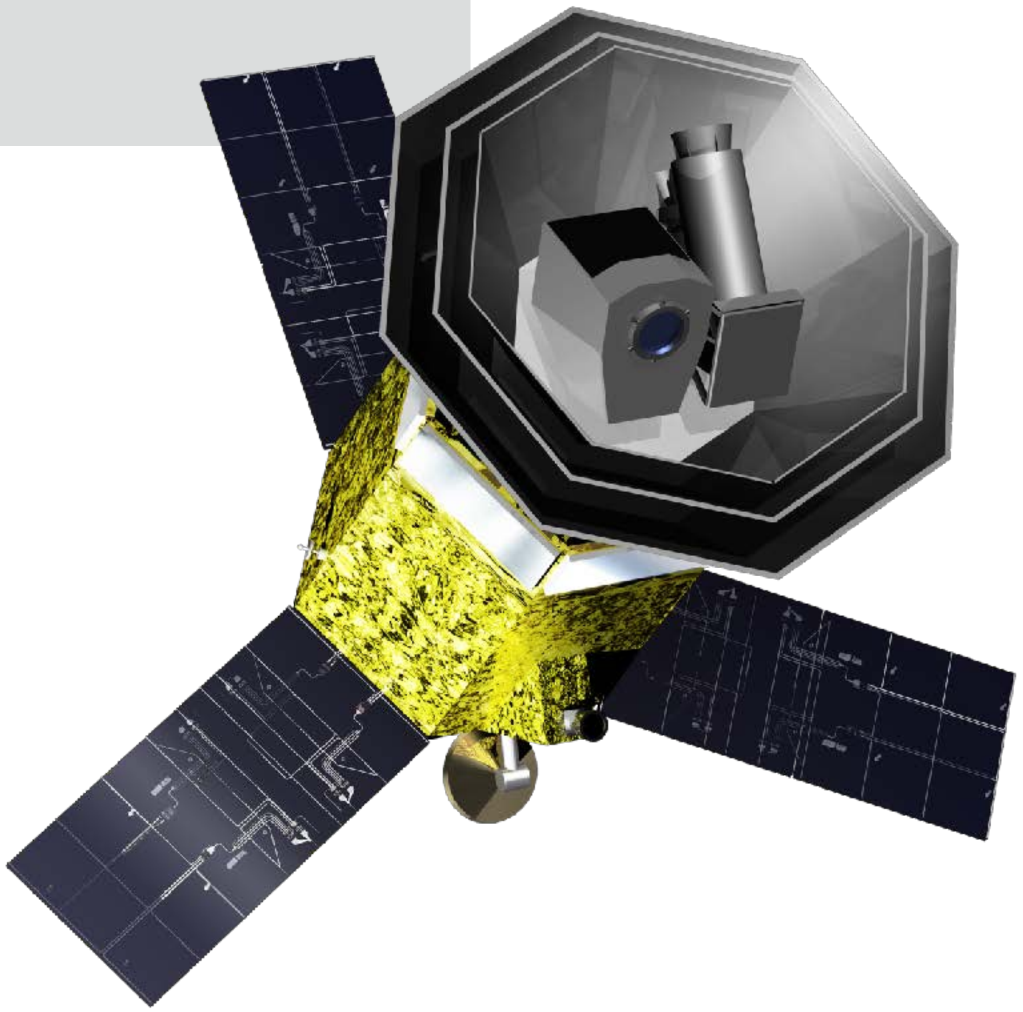
M. Tristram
on behalf of
the LiteBIRD Collaboration

CS IN2P3 (Juillet 2023)

Scientific outcomes

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



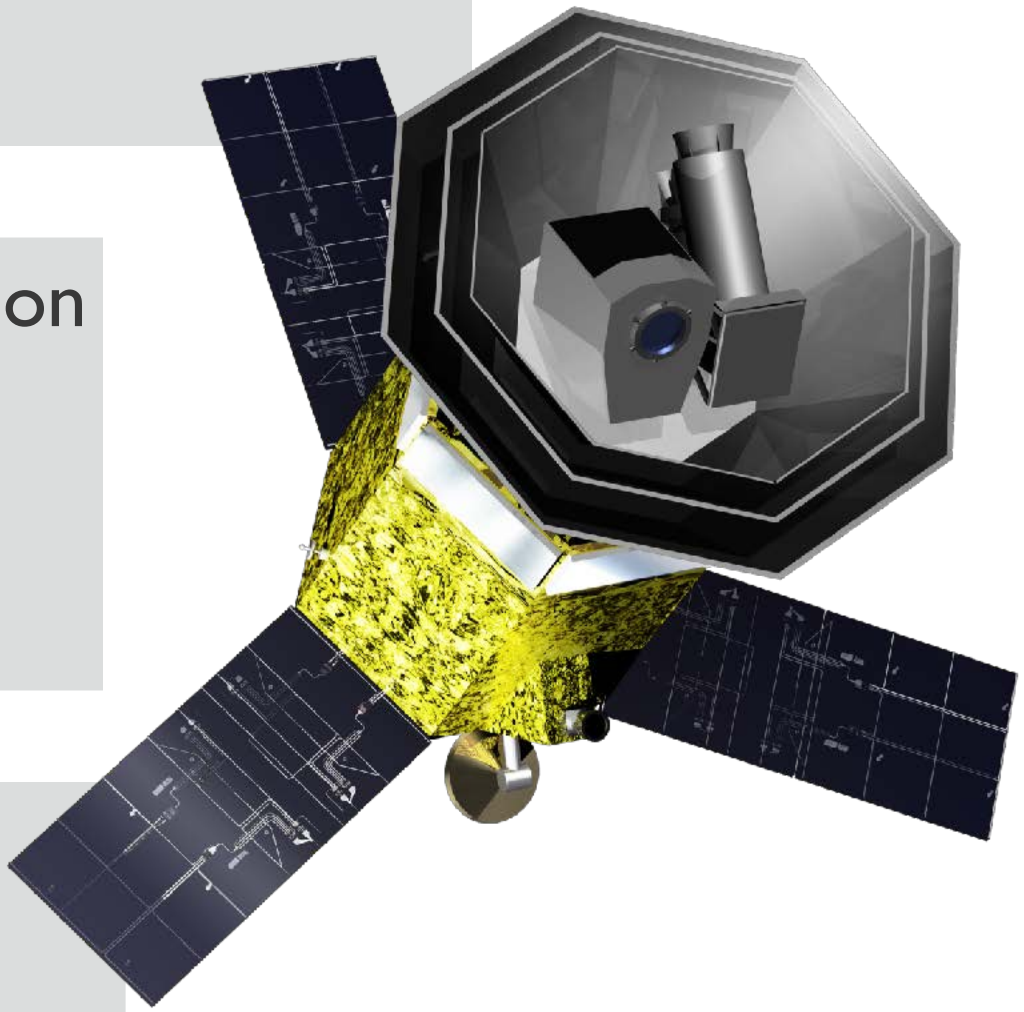
Scientific outcomes

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

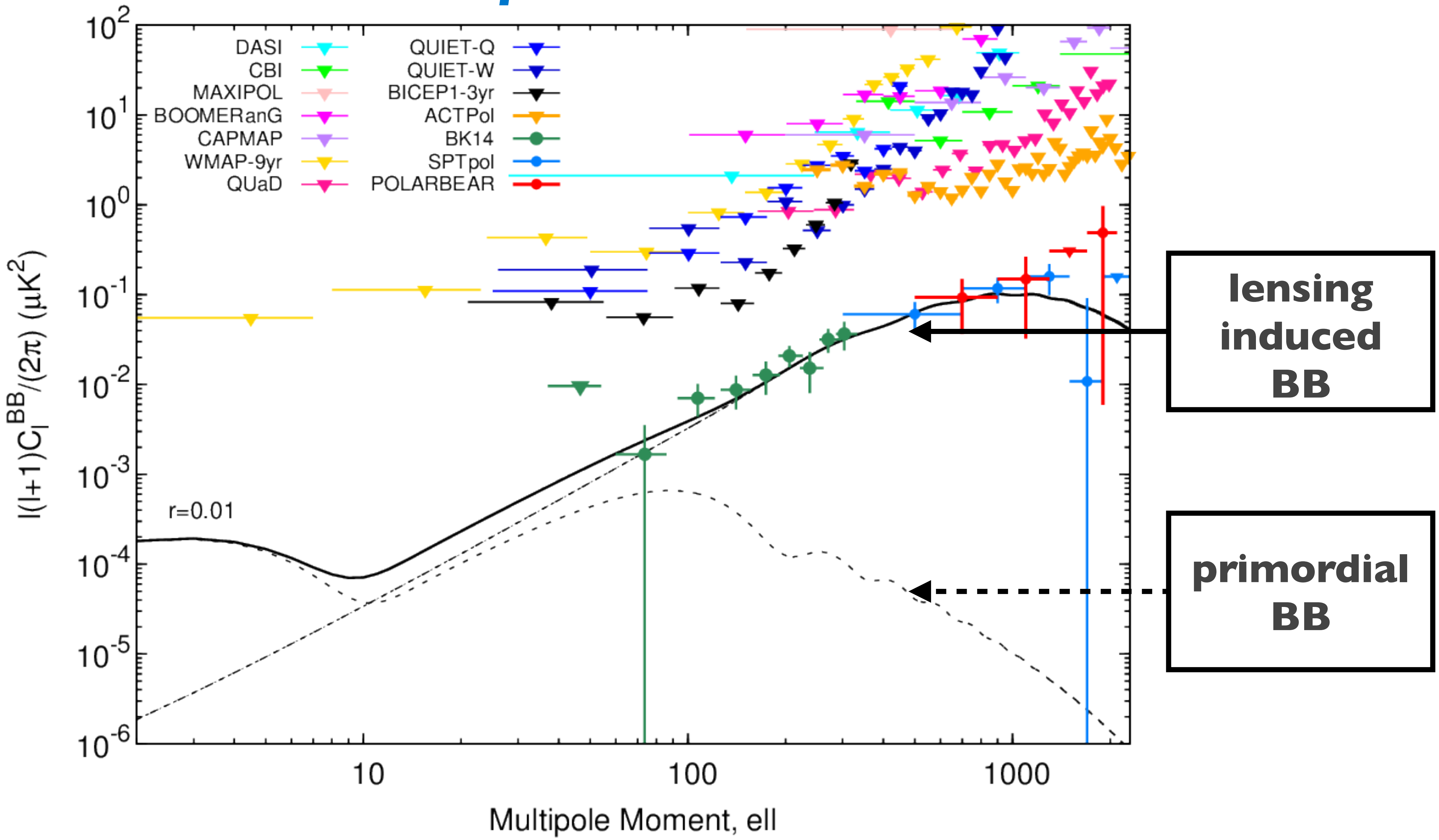
- Cosmological parameters with E polarisation
  - Optical depth and reionization of the Universe
  - Elucidating low-ℓ anomalies with polarization
- Neutrino sector
- Cosmic birefringence

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



Primordial gravitational waves

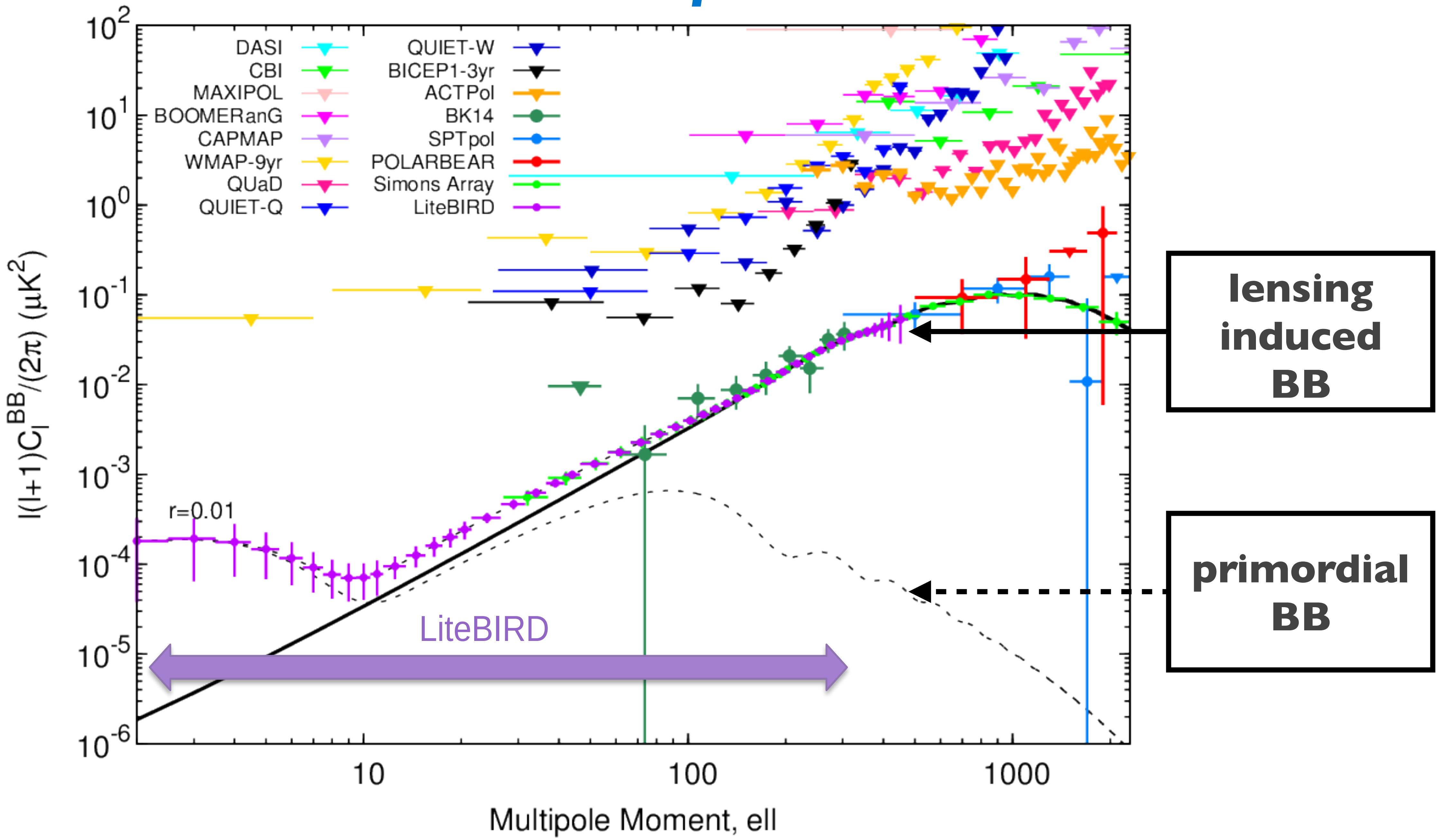
Current status of the B-mode measurements



r < 0.032 (95% CL)

BICEP2+Planck [Tristram et al. 2021]

LiteBIRD Expectation



σ_r < 0.001 (for r=0)

LiteBIRD only (no delensing)

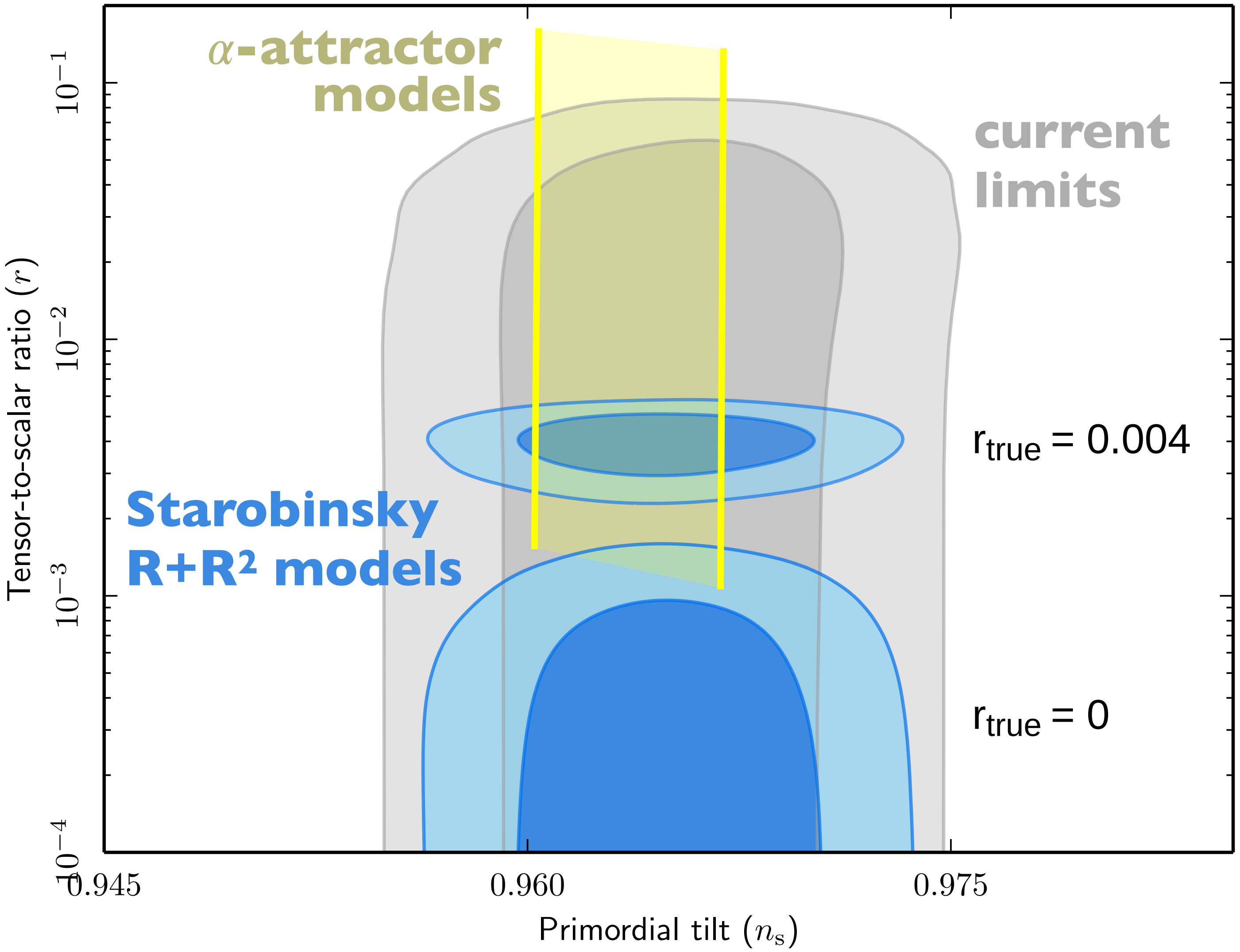
Primordial gravitational waves

Full Success

- $\sigma(r) < 10^{-3}$ (for r=0, no delensing)
- >5σ observation for each bump of the BB spectrum (for r≥0.01)

Rationale

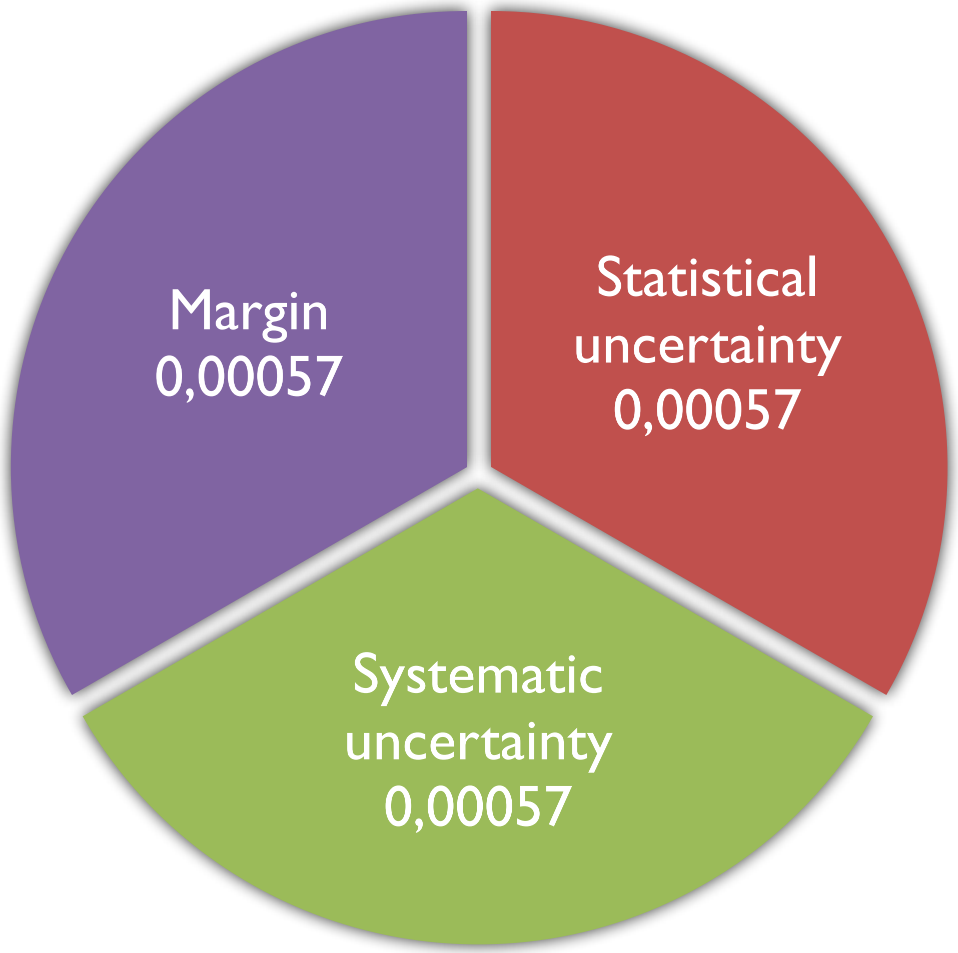
- Large discovery potential for $0.005 < r < 0.05$
- Simplest and well-motivated $R+R^2$ "Starobinsky" model will be tested
- Clean sweep of single-field models with characteristic field variation scale of inflaton potential greater than m_{pl} *[Linde, JCAP 1702 (2017) no.02, 006]*



Primordial gravitational waves

Full Success

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

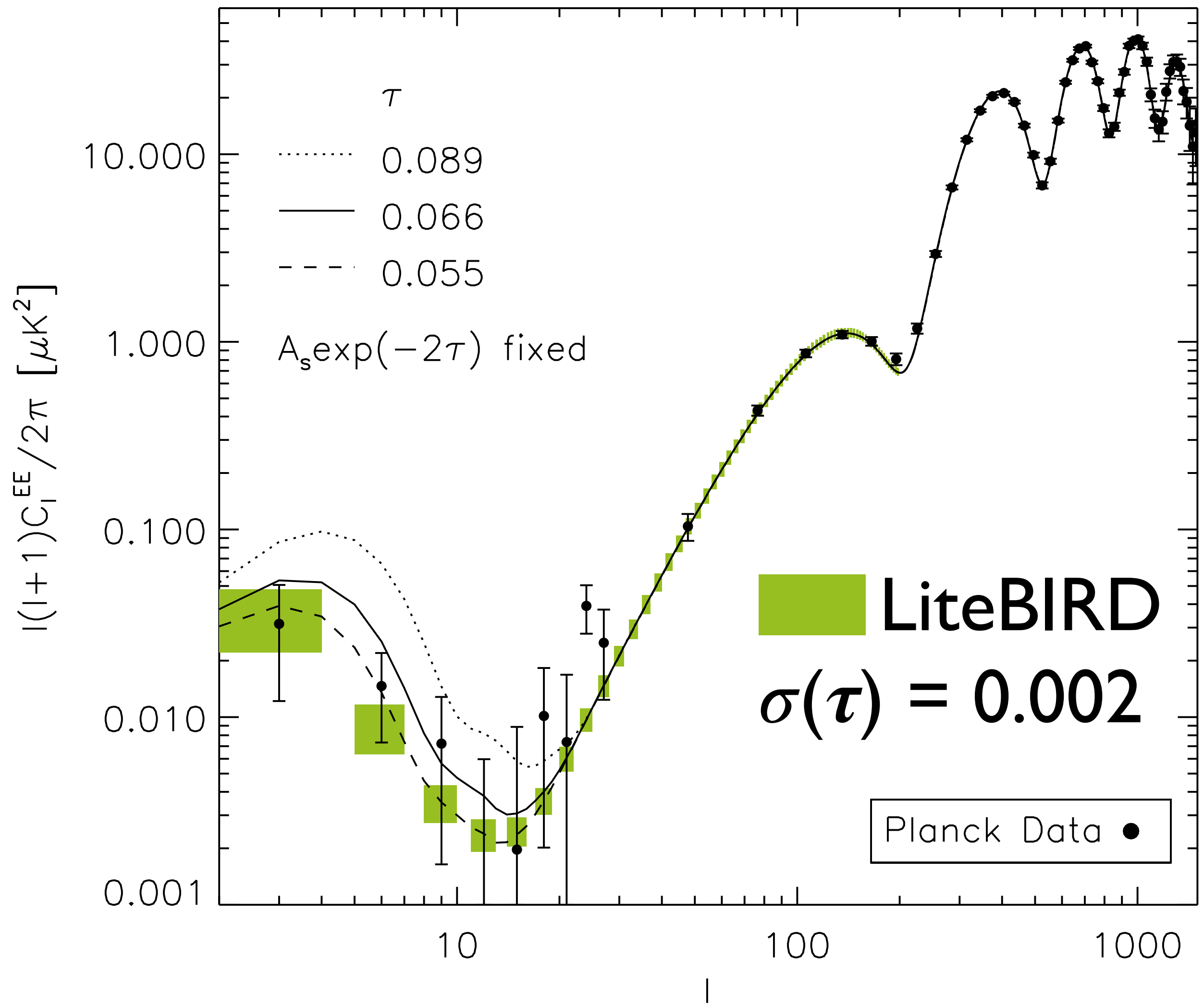


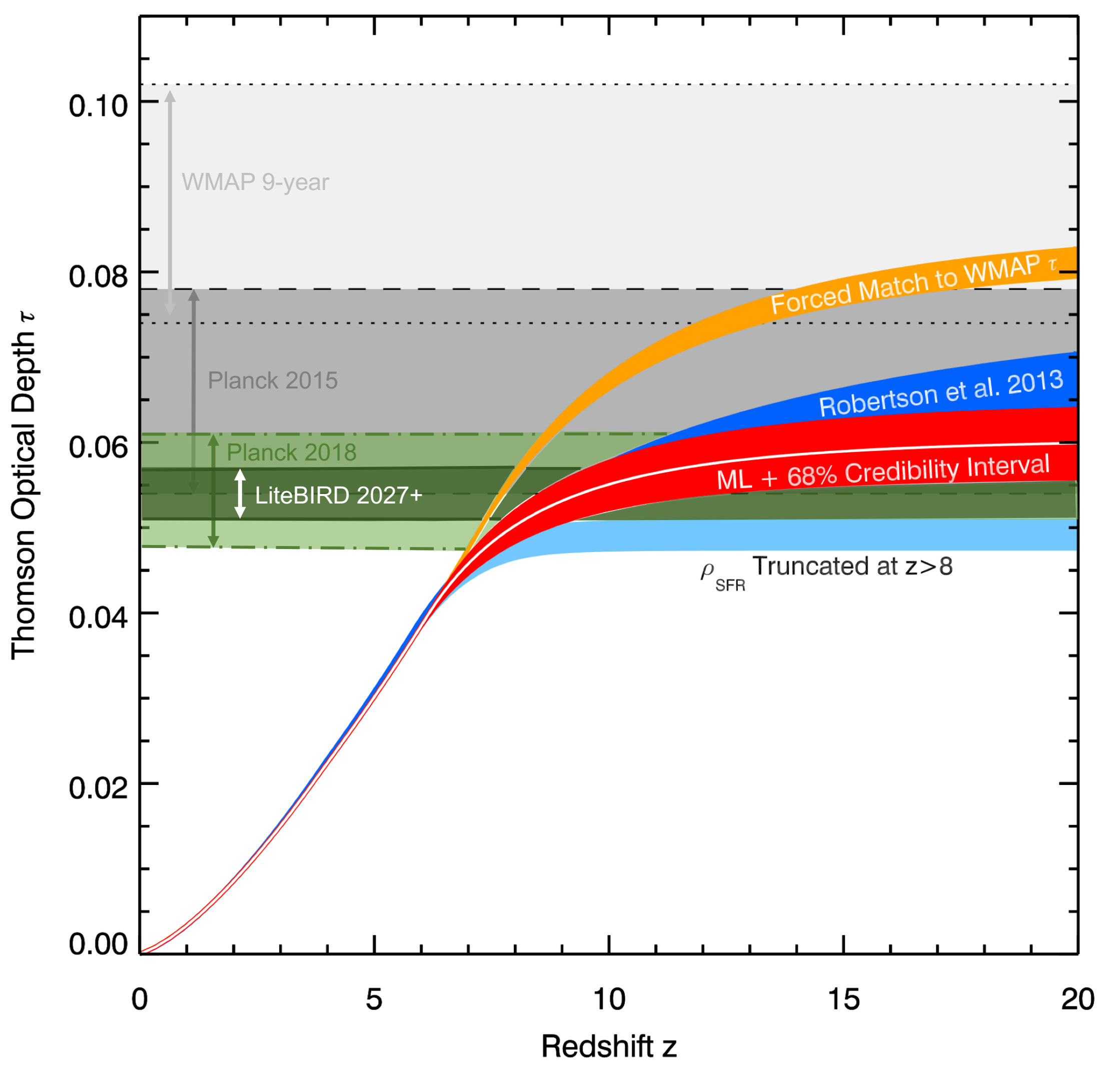
Statistical uncertainty
- foreground cleaning residuals
- lensing B-mode power
- 1/f noise

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

Reionization

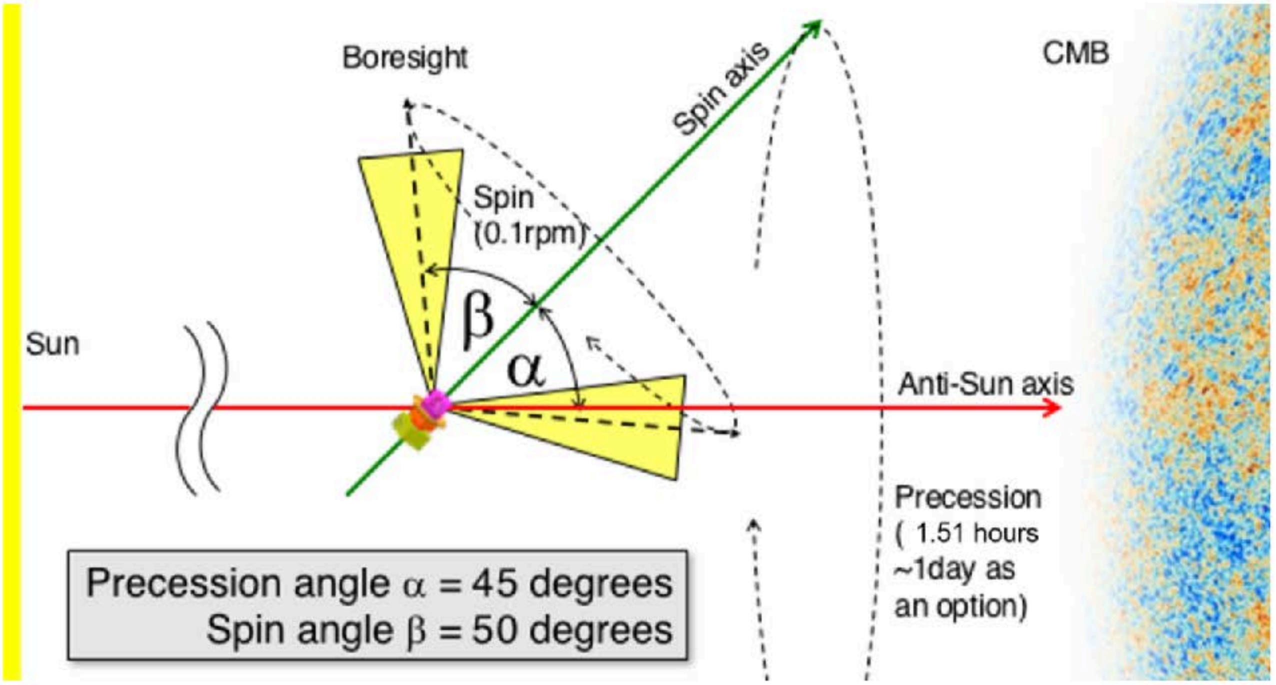
A **cosmic variance limited** measurement of EE on large angular scales will be an important, and guaranteed, legacy for LiteBIRD





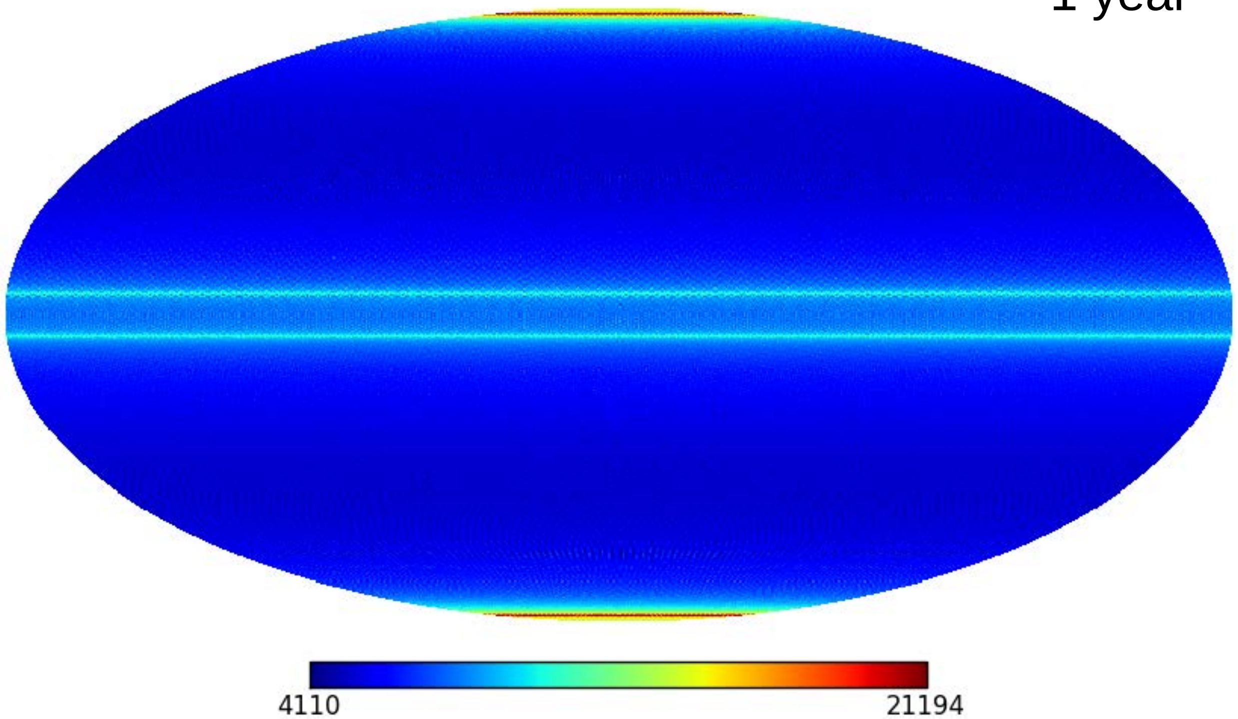
The LiteBIRD mission

LiteBIRD in a nutshell



sky coverage

1 year



L-Class JAXA Mission
Selected by JAXA (May 2019)
CNES Phase-A (end 2023)
Launch 2031

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

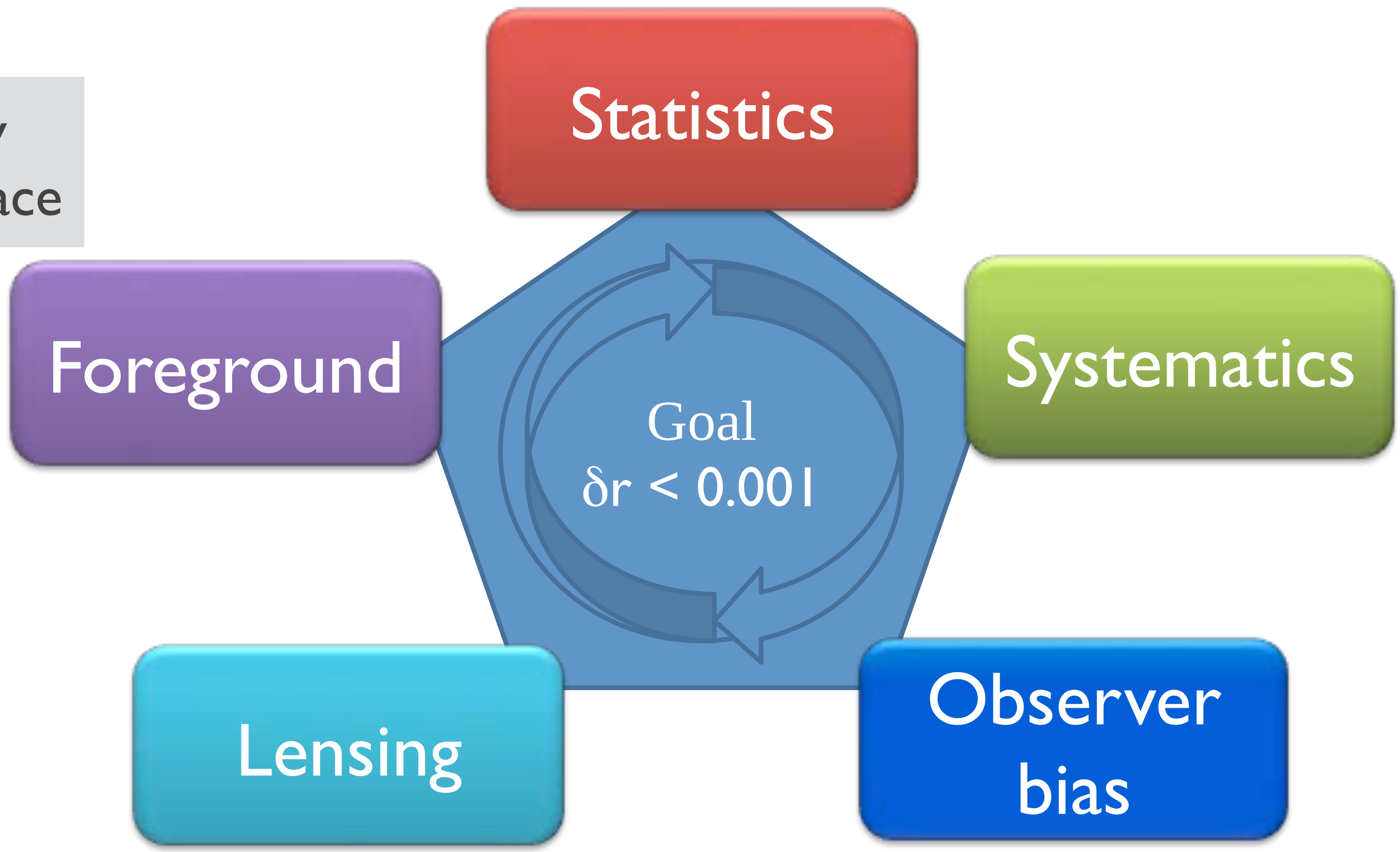
Mission Challenges

High Sensitivity Detectors

Large frequency coverage from Space

Mitigation and Control of Systematics

Continuously Rotating HWP

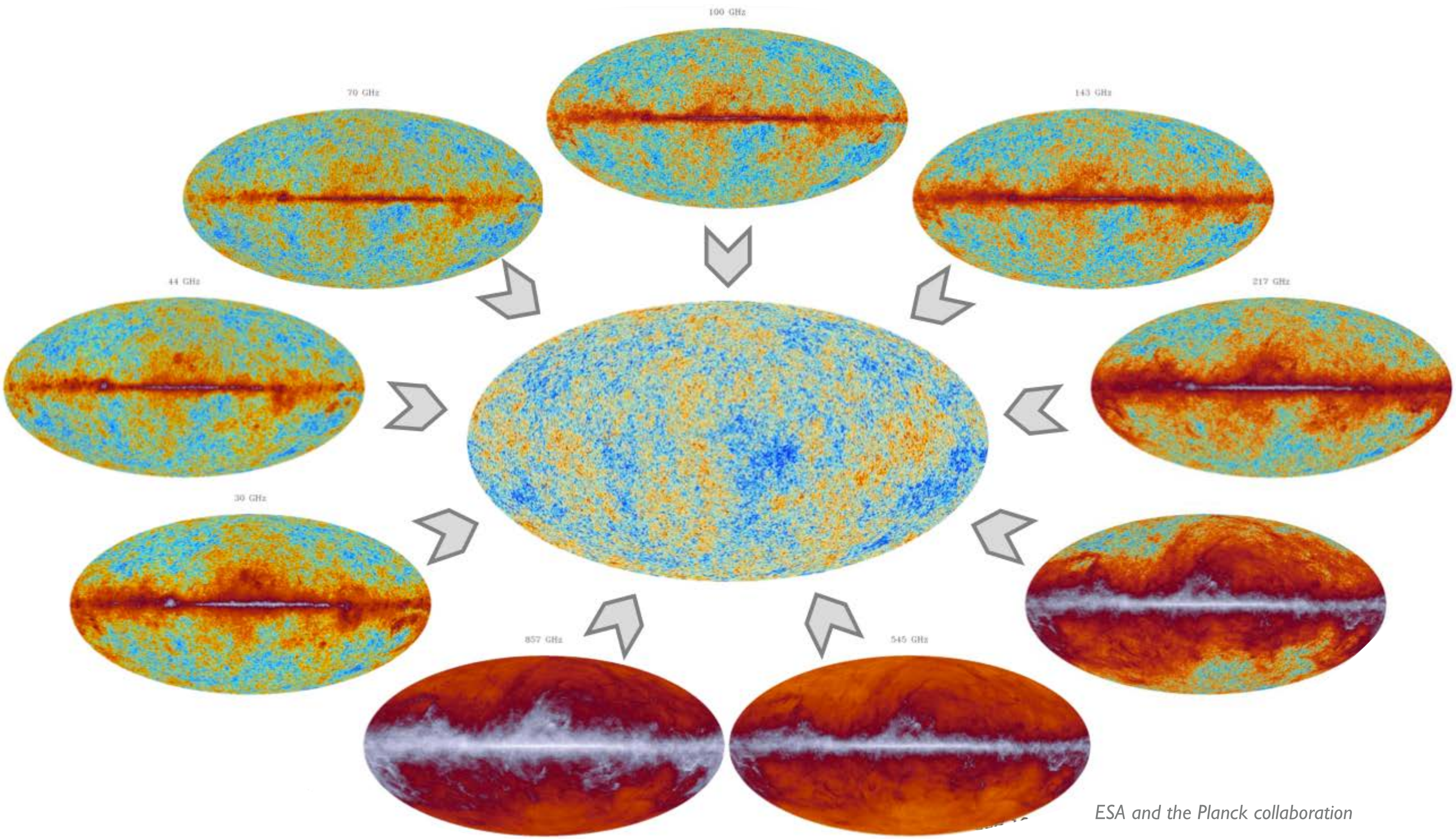


Focused on largest multipole scales

All-sky survey

Mission challenges

foregrounds



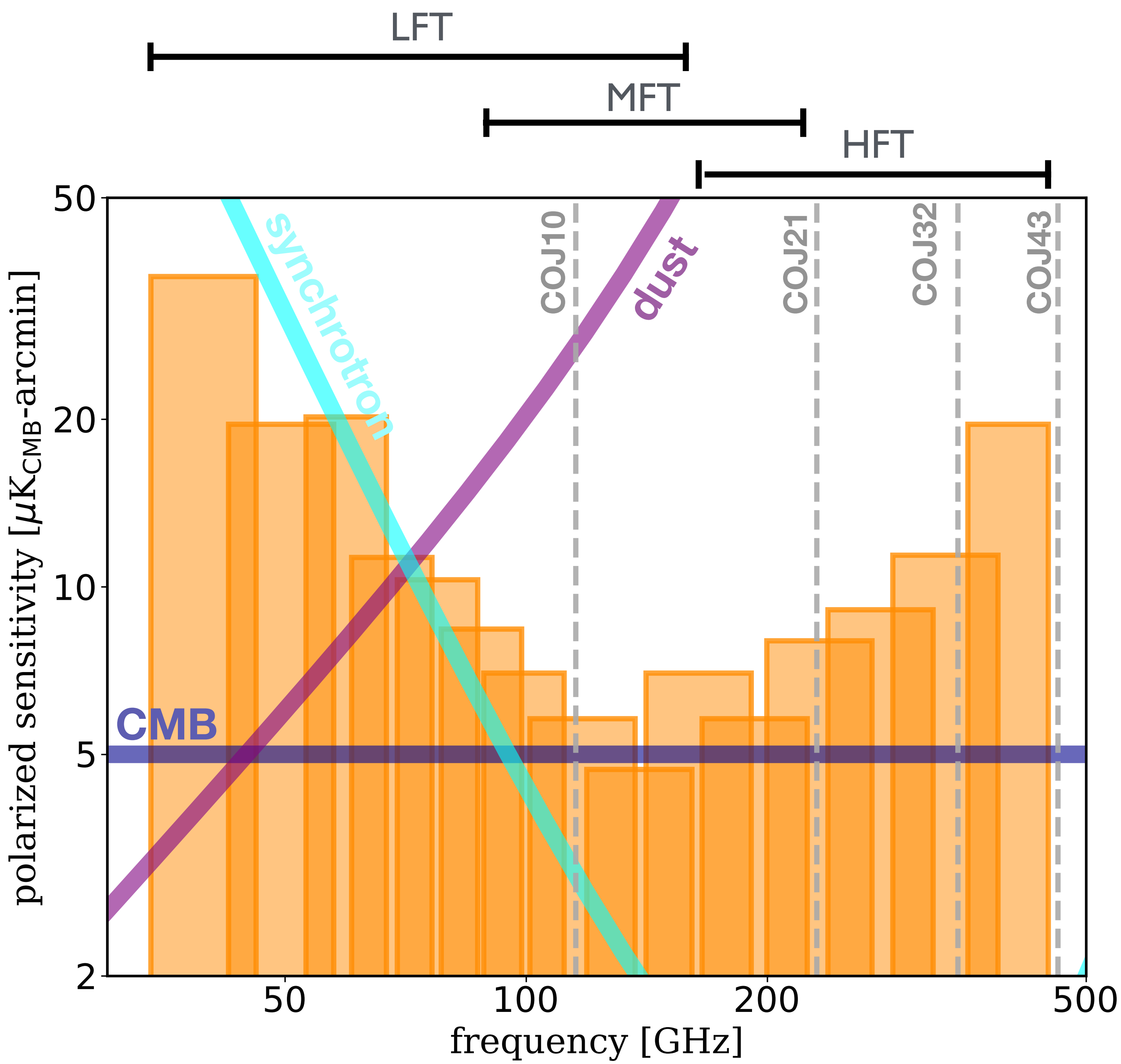
ESA and the Planck collaboration

The LiteBIRD mission

frequency coverage

15 bands
from 34GHz
to 448GHz

4676
detectors

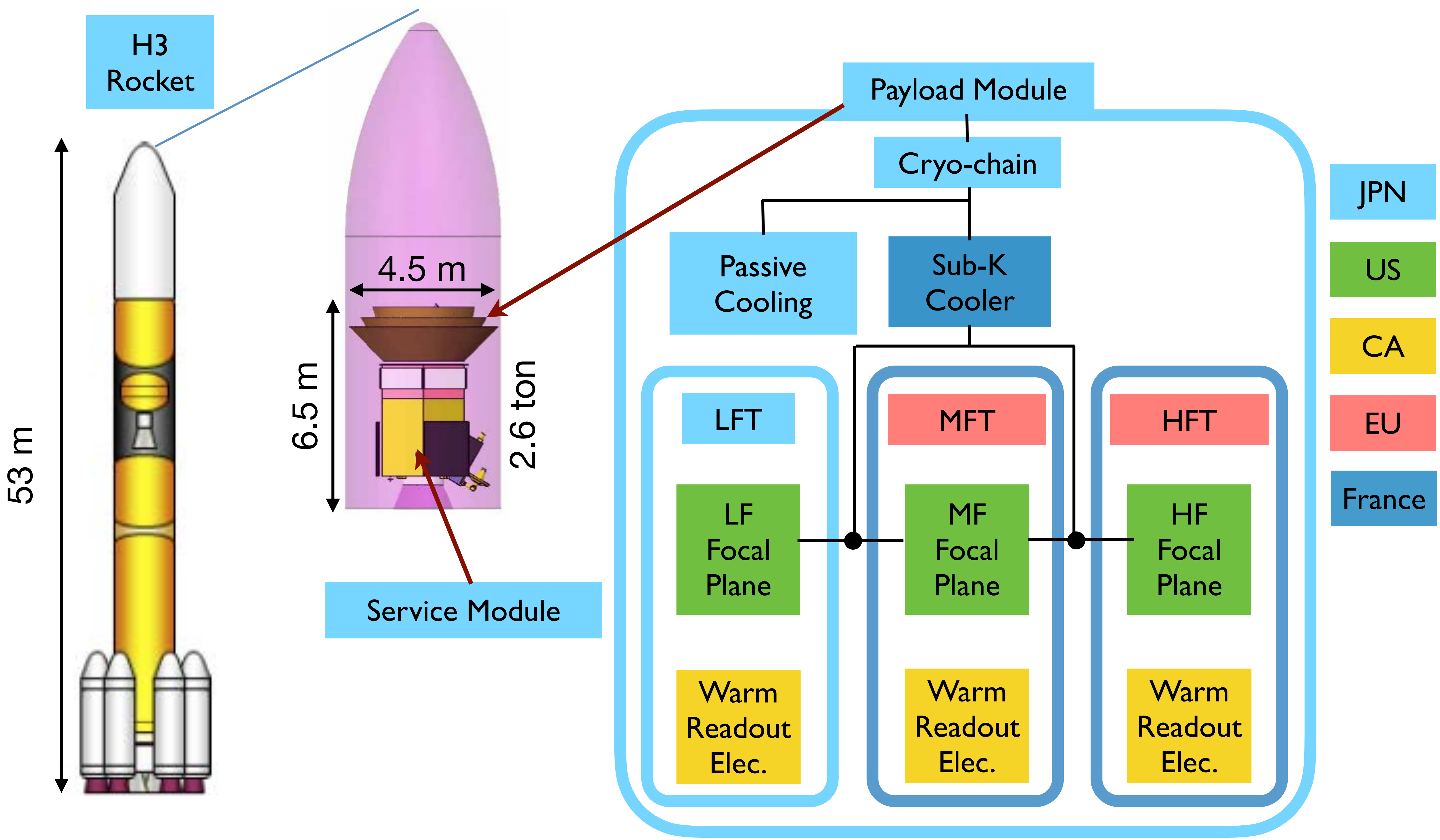


3 telescopes

9 bands LFT
5 bands MFT
5 bands HFT

with 4 overlapping bands

Payload

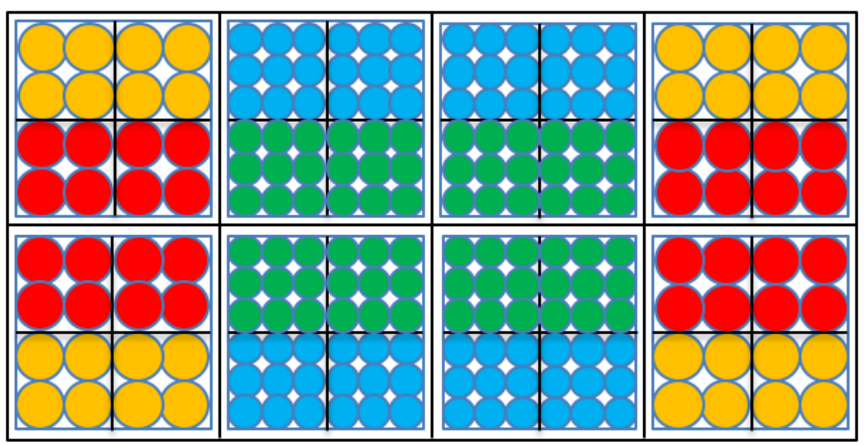


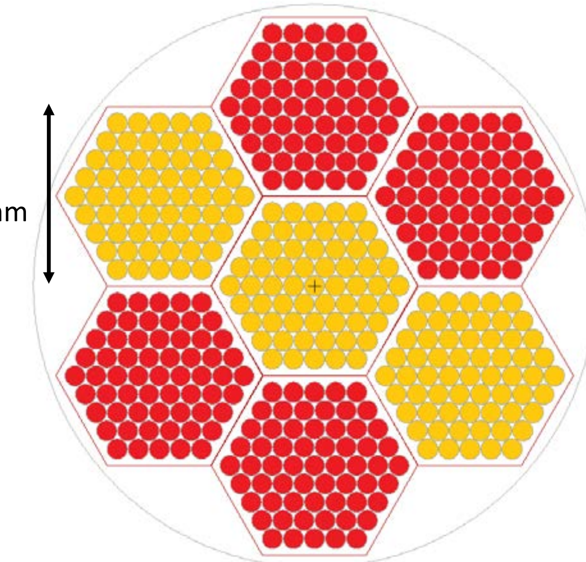
H3
Rocket
53 m
4.5 m
6.5 m
2.6 ton
Service Module
Payload Module
Cryo-chain
Passive
Cooling
Sub-K
Cooler
LFT
LF
Focal
Plane
Warm
Readout
Elec.
MFT
MF
Focal
Plane
Warm
Readout
Elec.
HFT
HF
Focal
Plane
Warm
Readout
Elec.
JPN
US
CA
EU
France

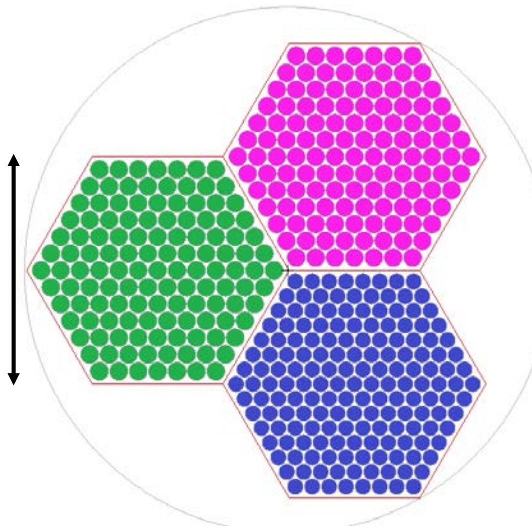
The LiteBIRD mission

Number of detectors: 4676
Overlap between telescopes

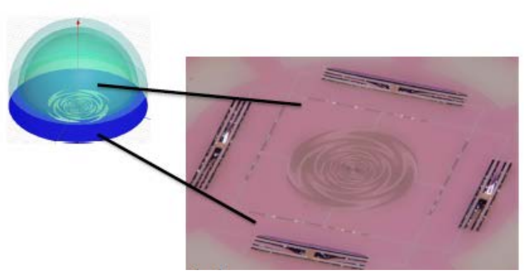
focal plane



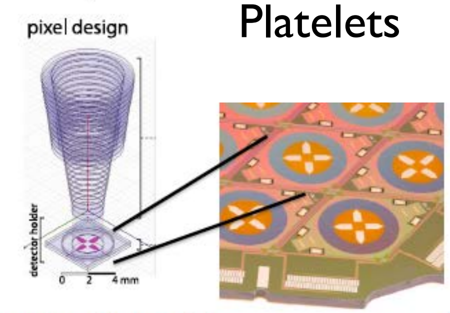




Lenslets



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

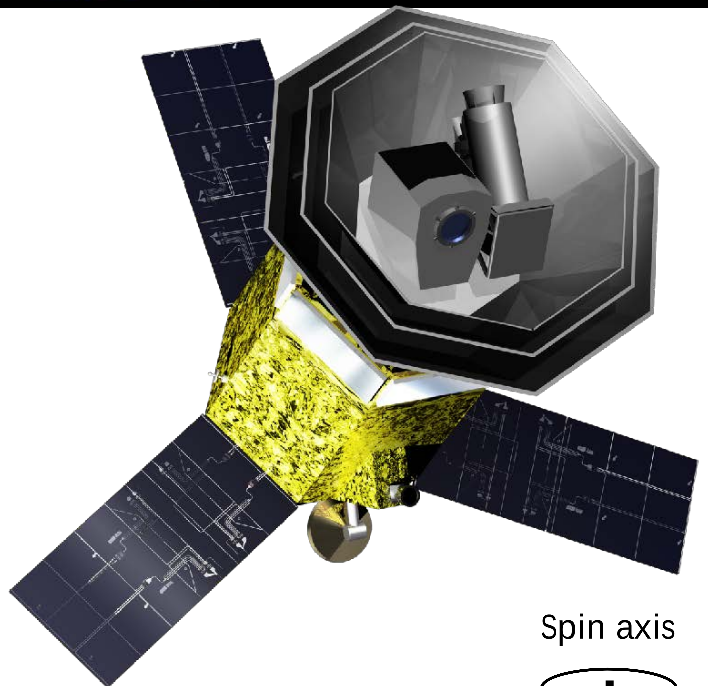
HFT (2.7:1)

195 | 235 | 280 | 337 | 402

1355 detectors
2 x 254 Dichroic TES
338 Monochromatic TES

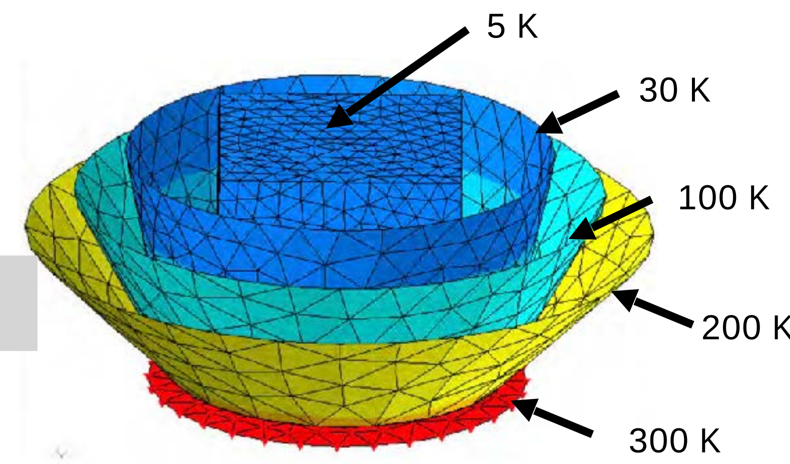
166 GHz — 448 GHz

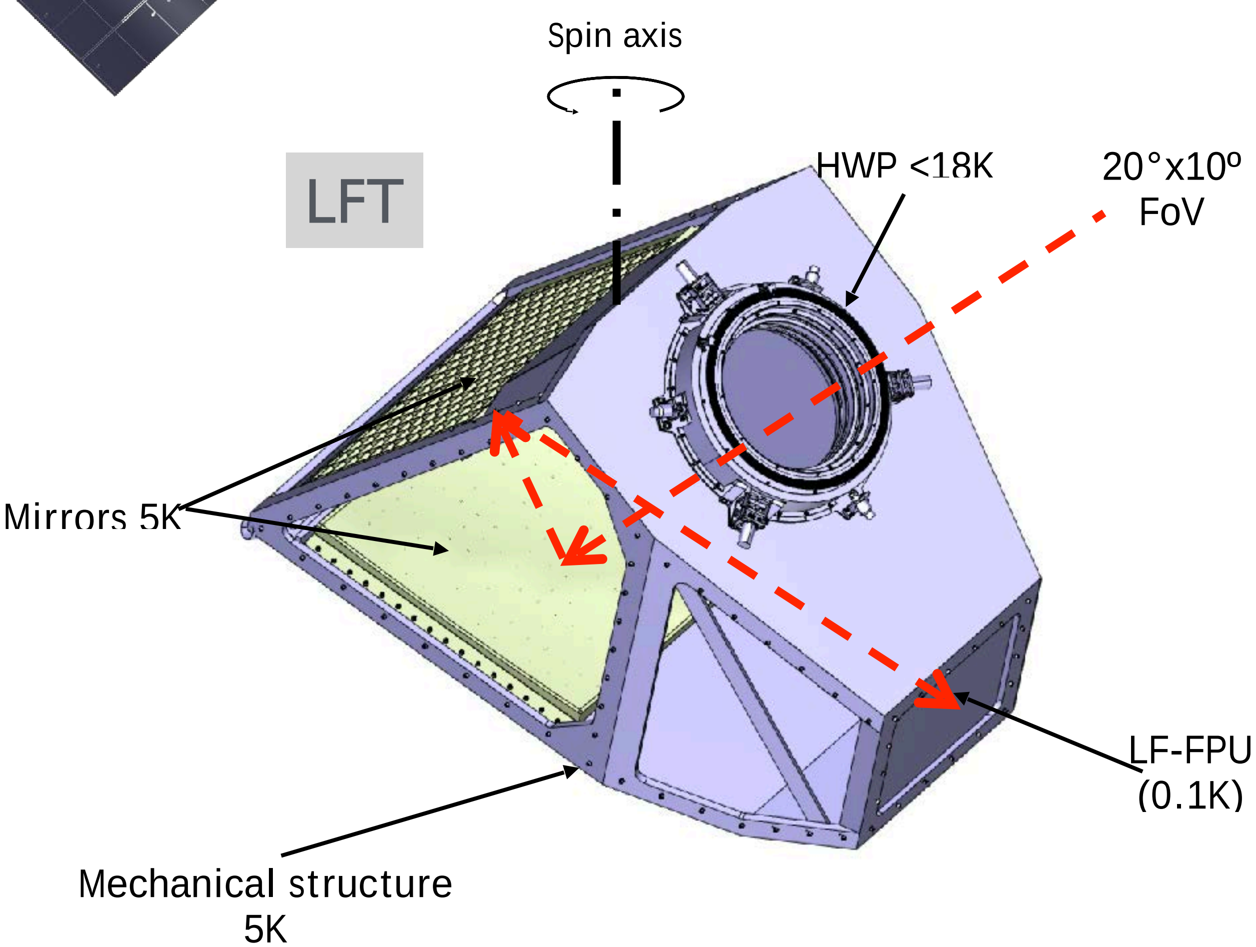
The LiteBIRD mission

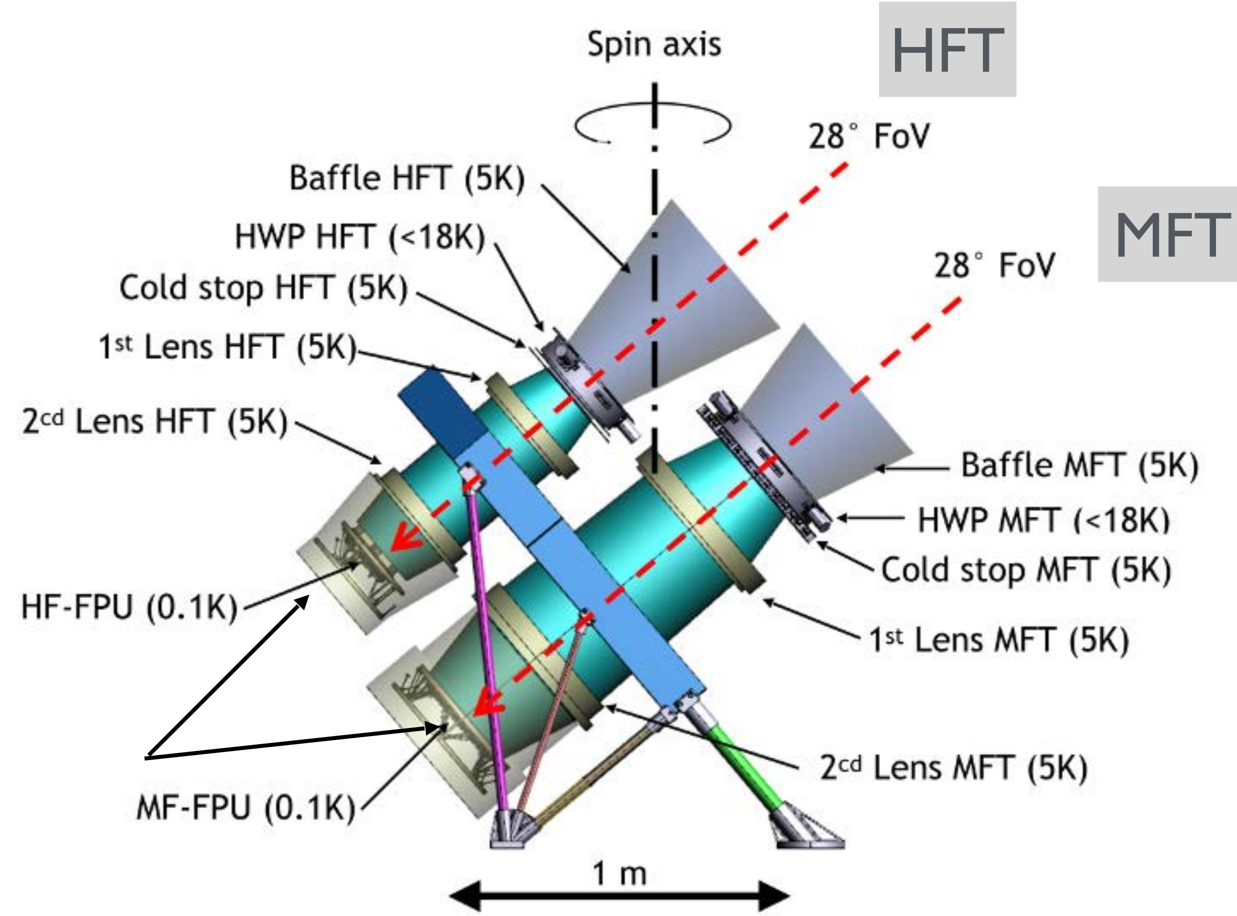


telescopes and optics at 5K

continuously Rotating Half-Wave Plates







focal planes at 100mK

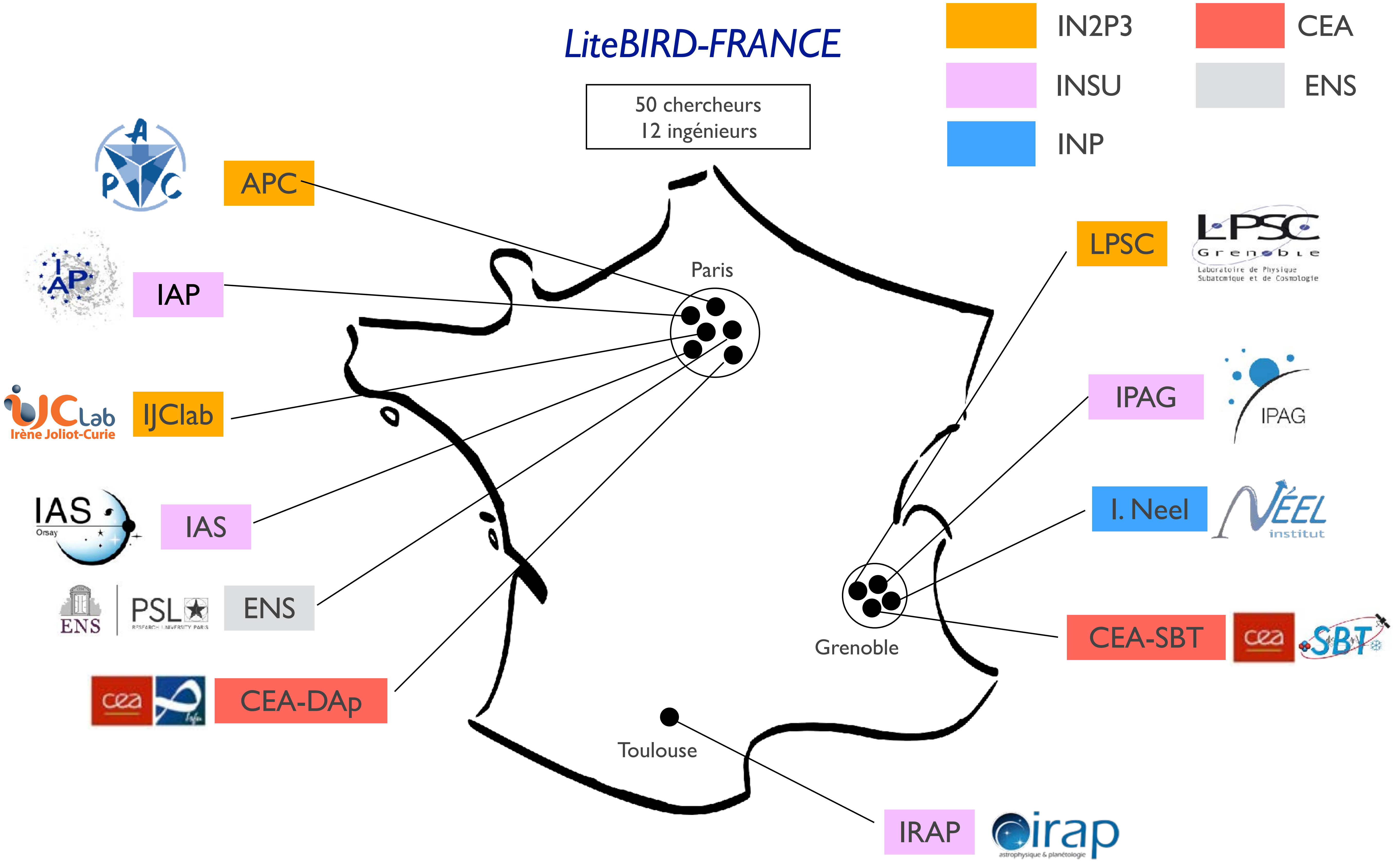
The LiteBIRD Collaboration

An international collaboration

More than 350 researchers from Japan, Europe & North America

E. Allys[1], K. Arnold[2], J. Aumont[3], R. Aurlien[4], S. Azzoni[5,6], C. Baccigalupi[7,8,9], A. J. Banday[3], R. Banerji[4], R. B. Barreiro[10], N. Bartolo[11,12,13], L. Bautista[3], D. Beck[14], S. Beckman[15], M. Bersanelli[16,17], F. Boulanger[1], M. Brilenkov[4], M. Bucher[18], E. Calabrese[19], P. Campeti[20], A. Carones[21,22], F. J. Casas[10], A. Catalano[23], V. Chan[24], K. Cheung[15,25,26], Y. Chinone[27,6], S. E. Clark[14,28], F. Columbro[29,30], G. D'Alessandro[29,30], P. de Bernardis[29,30], T. de Haan[31], E. de la Hoz[10,32], M. De Petris[29,30], S. Della Torre[33], P. Diego-Palazuelos[10,32], M. Dobbs[34], T. Dotani[35,36], J. M. Duval[37], T. Elleflot[38], H. K. Eriksen[4], J. Errard[18], T. Essinger-Hileman[39], F. Finelli[40,41], R. Flauger[2], C. Franceschet[16,17], U. Fuskeland[4], M. Galloway[4], K. Ganga[18], M. Gerbino[42], M. Gervasi[43,33], R. T. Génova-Santos[44,45], T. Ghigna[5,6], S. Giardiello[46], E. Gjerløw[4], J. Grain[47], F. Grupp[48], A. Gruppuso[40,41], J. E. Gudmundsson[49], N. W. Halverson[50], P. Hargrave[19], T. Hasebe[6], M. Hasegawa[51,31,36], M. Hazumi[51,31,35,6,36], S. Henrot-Versillé[52], B. Hensley[53], L. T. Hergt[54], D. Herman[4], E. Hivon[55], R. A. Hlozek[24], A. L. Hornsby[15], Y. Hoshino[56], J. Hubmayr[57], K. Ichiki[58], T. Iida[59], H. Imada[60], H. Ishino[61], G. Jaehnig[50], N. Katayama[6], A. Kato[31], R. Keskitalo[26,15,25], T. Kisner[26], Y. Kobayashi[62], A. Kogut[39], K. Kohri[31], E. Komatsu[20,6], K. Komatsu[61], K. Konishi[63], N. Krachmalnicoff[7,8,9], C. L. Kuo[64,14], L. Lamagna[29,30], M. Lattanzi[42], A. T. Lee[38,15,51], C. Leloup[18], F. Levrier[1], E. Linder[38,25], G. Luzzi[65], J. Macias-Perez[23], T. Maciaszek[66], B. Maffei[47], D. Maino[16], S. Mandelli[16,17], E. Martínez-González[10], S. Masi[29,30], M. Massa[67], S. Matarrese[11,12,13,68], F. T. Matsuda[35], T. Matsumura[6], L. Mele[29,30], M. Migliaccio[21,22], Y. Minami[69], A. Moggi[67], J. Montgomery[34], L. Montier[3], G. Morgante[40], B. Mot[3], Y. Nagano[61], T. Nagasaki[31], R. Nagata[35], R. Nakano[70,35], T. Namikawa[6], F. Nati[43,33], P. Natoli[46,42], S. Nerval[24], F. Noviello[19], K. Odagiri[35], S. Oguri[35], H. Ohsaki[62], L. Pagano[46,42,47], A. Paiella[29,30], D. Paoletti[40,41], A. Passerini[43,33], G. Patanchon[18], F. Piacentini[29,30], M. Piat[18], G. Polenta[65], D. Poletti[43,33], T. Prouvé[37], G. Puglisi[21,26], D. Rambaud[3], C. Raum[15], S. Realini[16], M. Reinecke[20], M. Remazeilles[10,71], A. Ritacco[72,47,1], G. Roudil[3], J. A. Rubino-Martin[44,45], M. Russell[2], H. Sakurai[62], Y. Sakurai[61,6], M. Sasaki[73], D. Scott[54], Y. Sekimoto[35,70,31], K. Shinozaki[74], M. Shiraishi[75], P. Shirron[39], G. Signorelli[67], F. Spinella[67], S. Stever[61,6], R. Stompor[18,77], S. Sugiyama[56], R. M. Sullivan[54], A. Suzuki[26], T. L. Svalheim[4], E. Switzer[39], R. Takaku[78,35], H. Takakura[70,35], Y. Takase[61], A. Tartari[67,79], Y. Terao[62], J. Thermeau[18], H. Thommesen[4], K. L. Thompson[64,14], M. Tomasi[16,17], M. Tominaga[70,35], M. Tristram[52], M. Tsuji[76], M. Tsujimoto[35], L. Vacher[3], P. Vielva[10], N. Vittorio[21,22], W. Wang[18], K. Watanuki[35], I. K. Wehus[4], J. Weller[48], B. Westbrook[15], J. Wilms[73], E. J. Wollack[39], J. Yumoto[62], and M. Zannoni[43,33]

Current French involvement



CNES phase A2 (2019-2023)

US

Focal Plane

Cold Readout Electronics

Canada

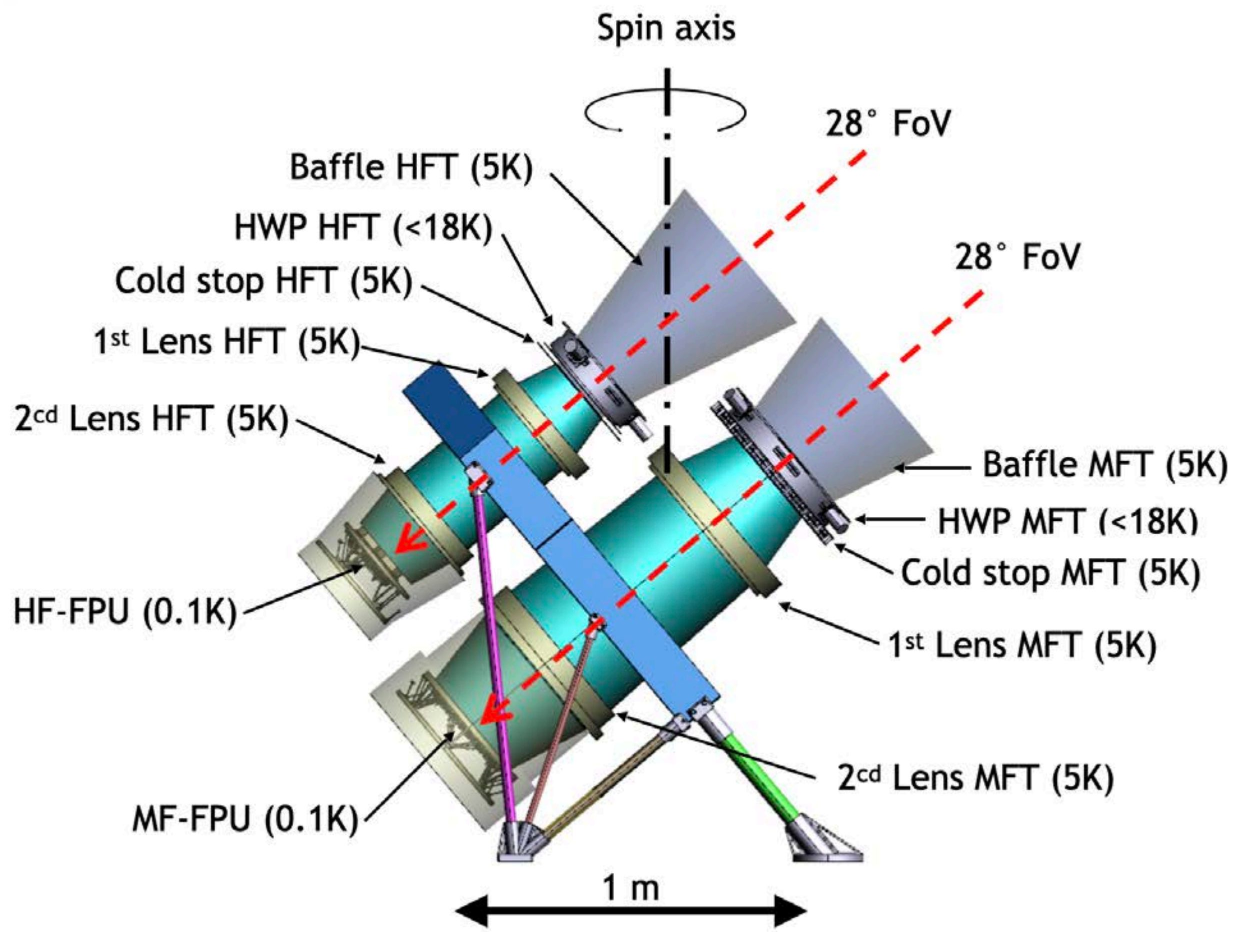
Warm Readout Electonics

UK

Optics

Italy

HWP mechanism



cnes

Instrument Design & Management

MHFT Mechanical Structure

30K-5K cryo-structure

Electronics & on-board software

Sub-K Cooler (LFT, MFT, HFT)

Calibration

MHFT (IN2P3)

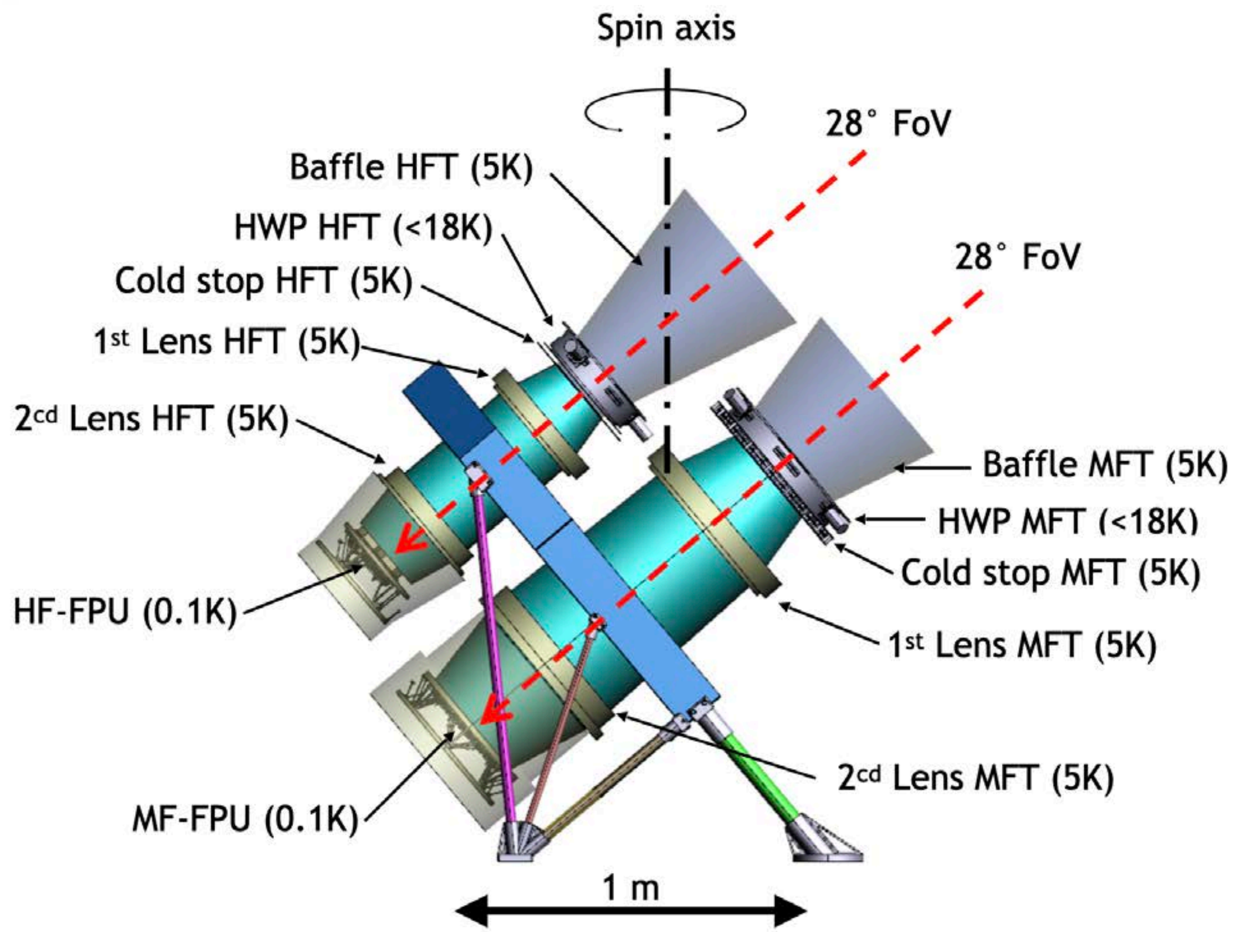
CNES phase A2 (2019-2023)

US
- Focal Plane
- Cold Readout Electronics

Canada
- Warm Readout Electonics

UK
- Optics

Italy
- HWP mechanism



- 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 (**TBD**)
- Collaboration **bylaws** for phaseB (**TBD**)
  (incl. governance, publication, configuration control, and data policies)

LiteBIRD @ IN2P3

- 3 labs (APC, IJClab, LPSC)
- 13 staff researchers
- 7 engineers
- 2 post-docs, 3 PhD

11.25 FTE

- **Hardware task-sharing**
  - responsible for System Thermal Modeling
  - 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**

Status

- The telescopes are designed in order to **overcome the challenges** related to the extreme sensitivity (reduction and control of systematics)
- The project is the following:
  - **selected** by the JAXA as the next Large Scale mission with a launch currently scheduled in 2031
  - pre-phase A undergoing at JAXA
  - phase A is ending at cnes for the study of the Medium and High Frequency Telescopes
  - ASI commitment for a phase A
  - esa is interested. Participation through a **Mission of Opportunity** needs to be consolidated.

News

The MHFT project just went through a Key-Point (may 2023) organised by CNES/JAXA ended up with 5 recommendations for the phase A2.

The review of the end of phase A2 will happen in december 2023.

current JAXA calendar

May 2019	Class-L Mission Selection
2019-2023	pre-phaseA2
mi-2023	Mission Definition Review
mi2023-03/2024	Phase A1
03/2024-03/2025	Phase A2
03/2025-06/2026	Phase B
6/2026-12/2027	Phase C (EM development and tests)
01/2028-12/2029	Phase D (FM production and tests)
01/2031	Launch
2031-2033	Mission Operation

Conclusions

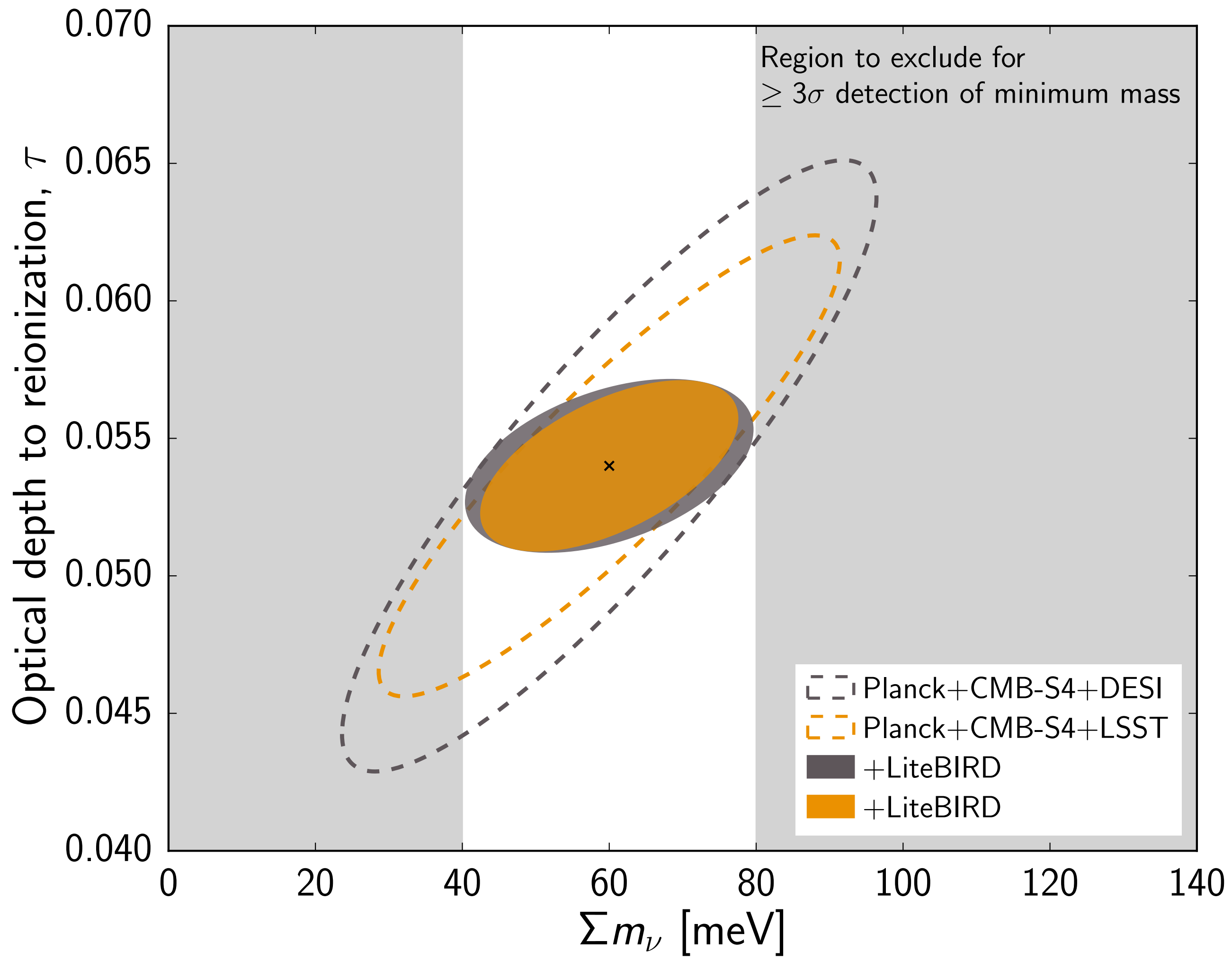
- LiteBIRD at IN2P3
  - Large involvement in the management
  - Responsibilities in the instrument hardware, calibration and systematics studies
  - Science Ground Segment: co-lead and need to increase !
  - Forecast and simulation: leader and need to increase !
  - Science Exploitation: expertise and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

- What we need from IN2P3
  - help to keep the CMB community structured in France (keep expertise, increase scientific impact and relations between instrument/data-analysis/theory, relation with INSU, INP & CEA)
  - support: during phase A2 and, if selected, for further phases (B, C, D)
  - **manpower**: PhD and Post-doc to increase IN2P3 participation to science and data analysis
  - **Permanent position** at IN2P3 (last CMB was in 2017)

Neutrino sector

Improvement in reionization optical depth measurement implies:

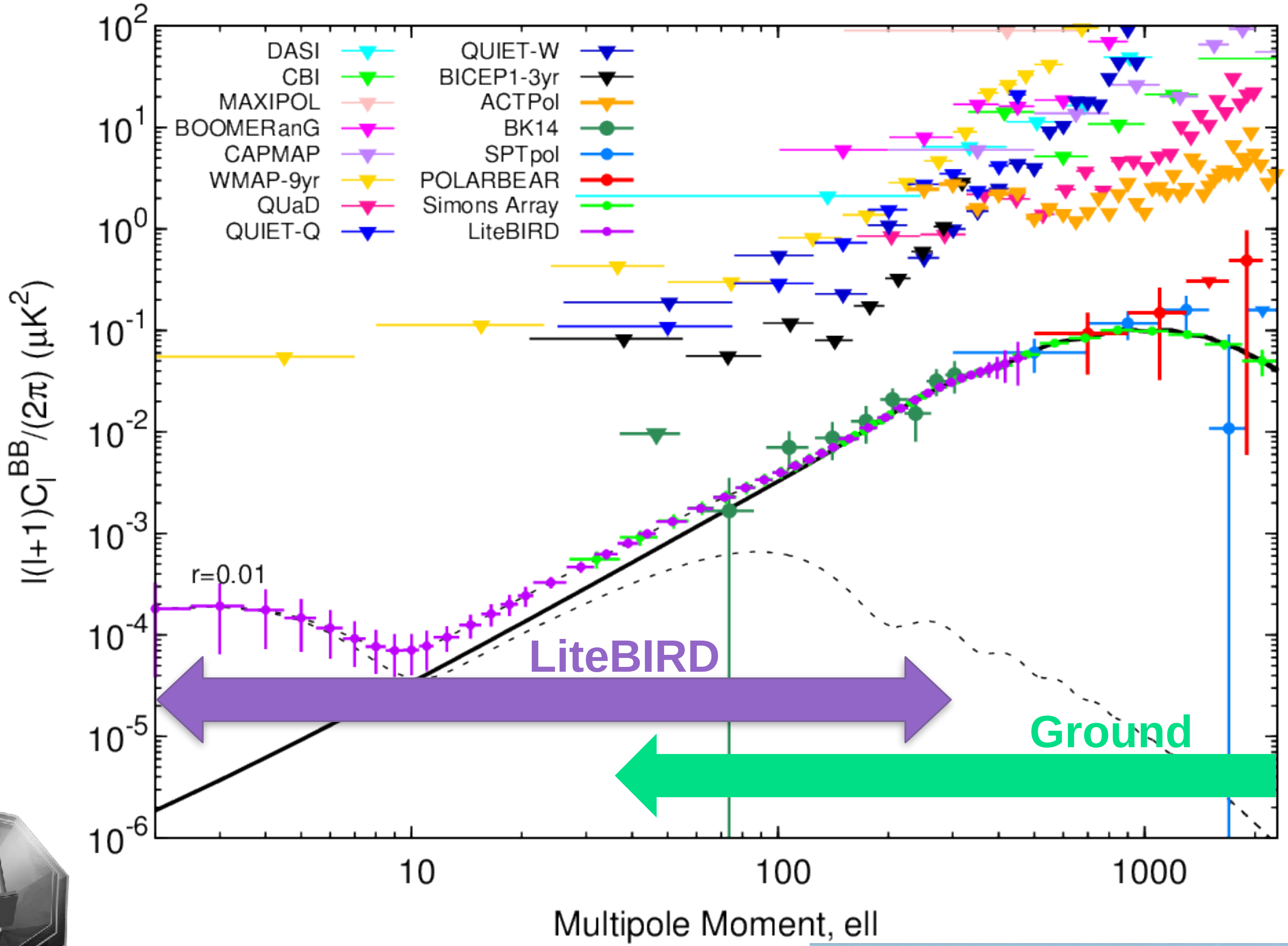
- $\sigma(\Sigma m_\nu)$ = 15 meV
- **determine neutrino hierarchy**
  normal v.s. inverted
- **measurement of minimum mass**
  $\geq 3\sigma$ detection NH,
  $\geq 5\sigma$ detection for IH



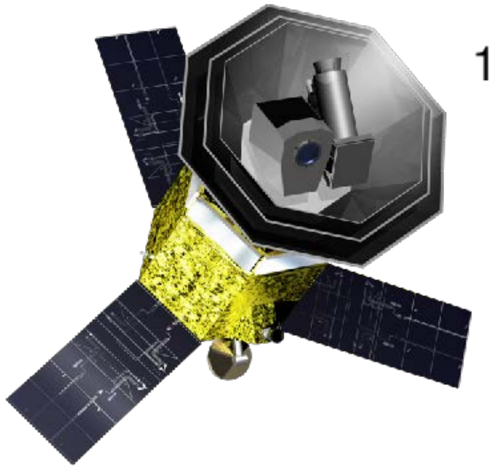
complementarity with ground-based measurements

CMB from space and ground

a powerful duo



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



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

Extra Success

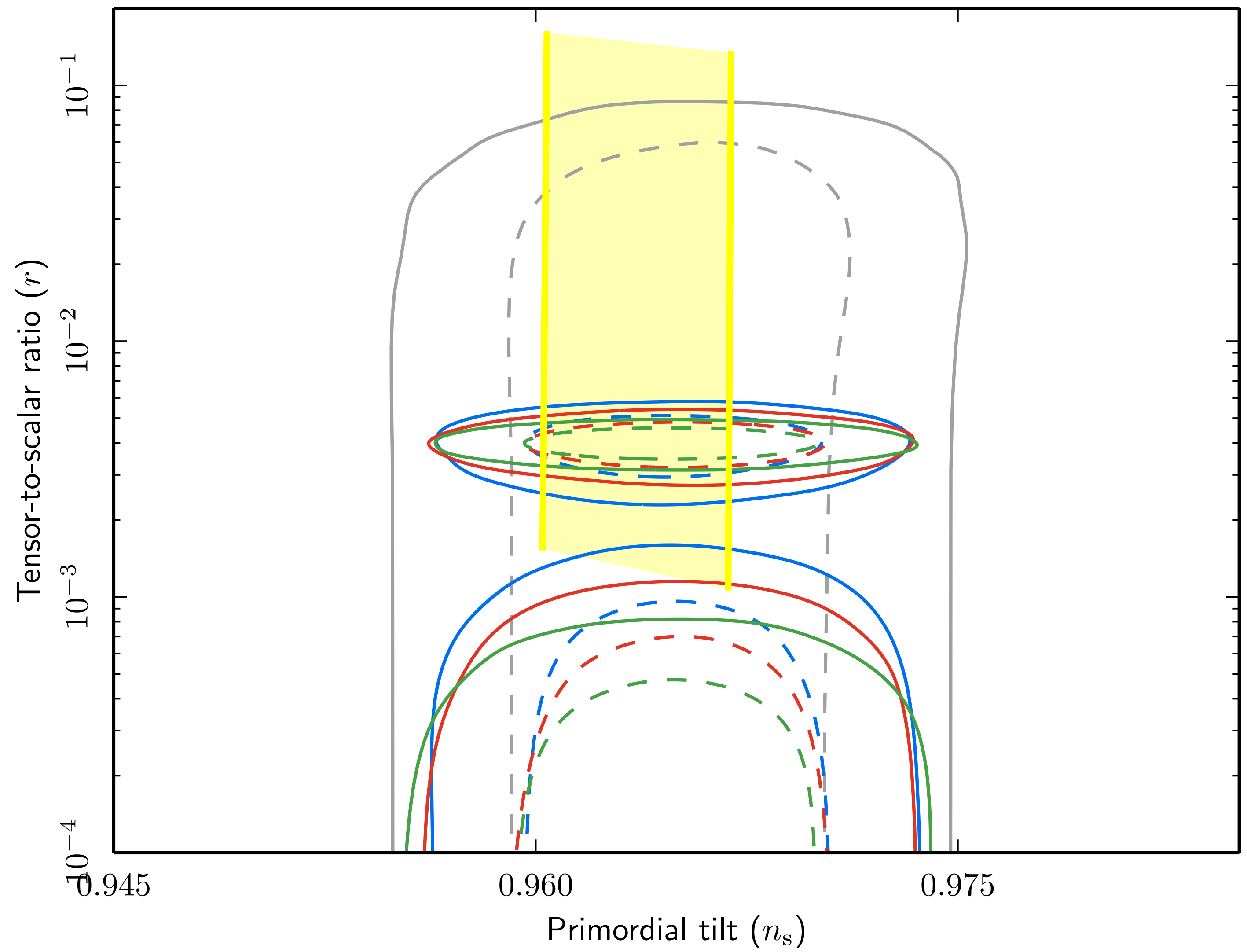
- improve σ(r) with external observations
- delensing improvement to σ(r) can be a factor ≥ 2

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

Baseline

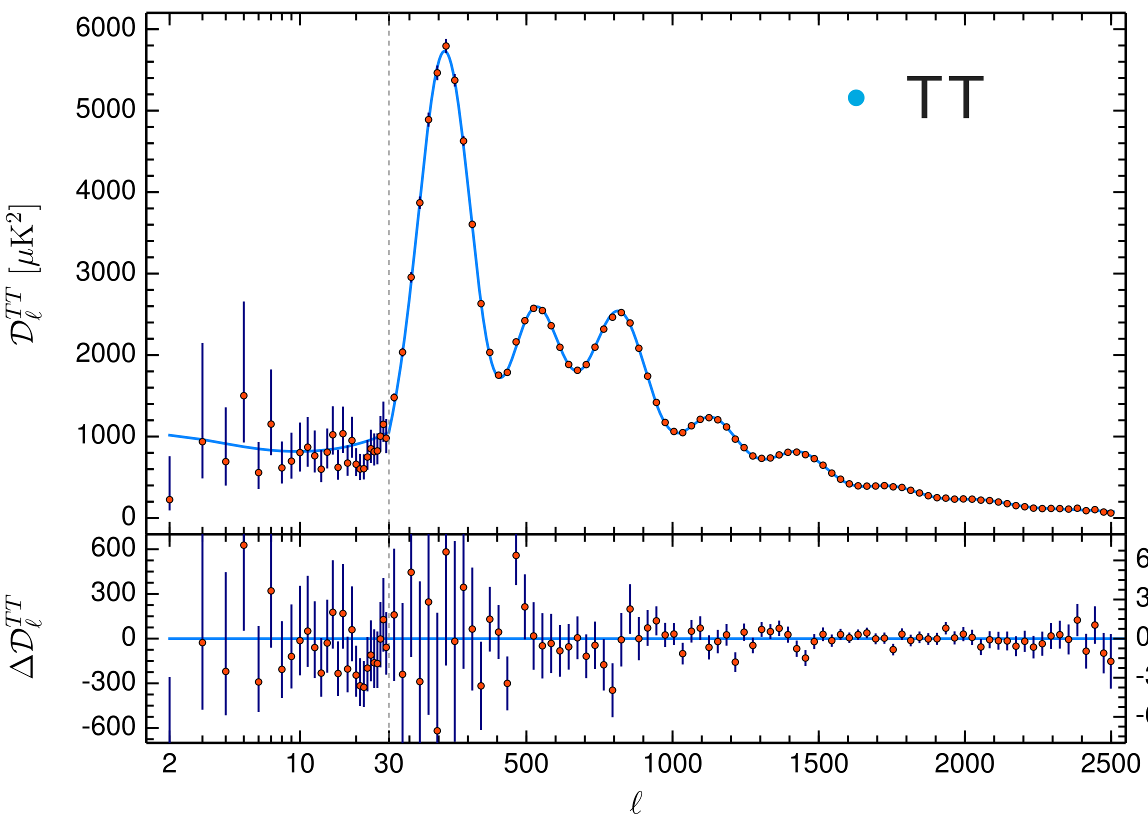
+ delensing w/current external data

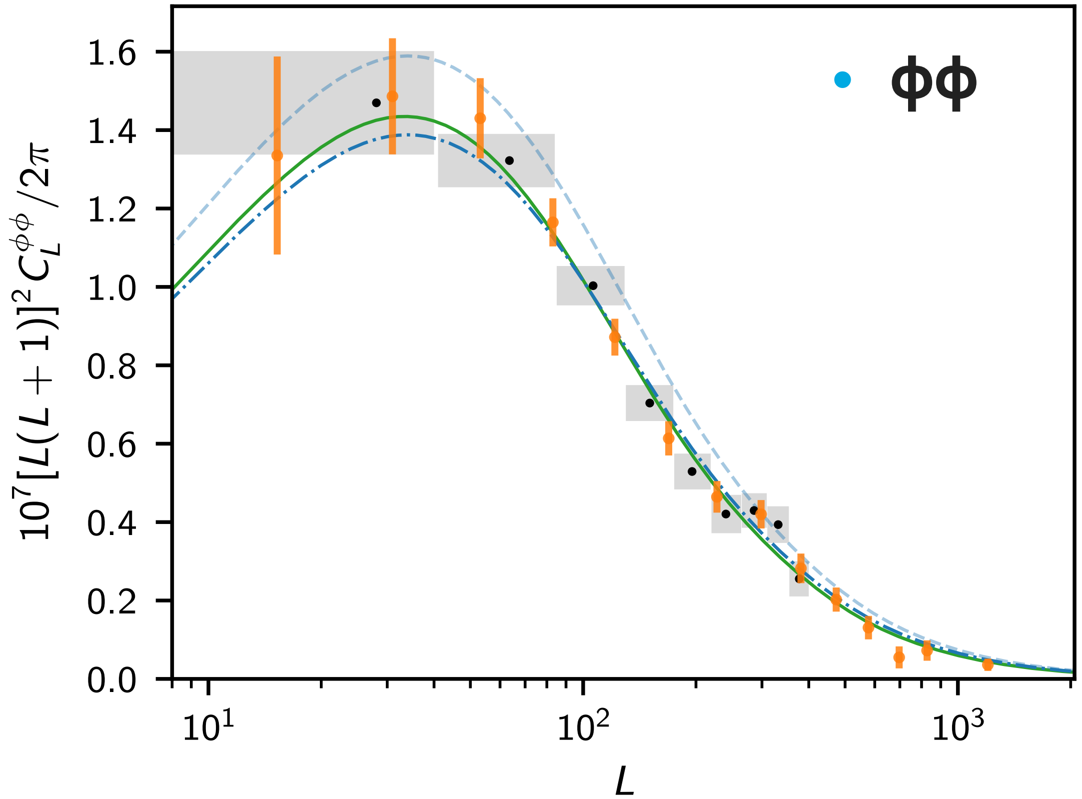
+ extra foreground cleaning w/ high-resolution future ground CMB data

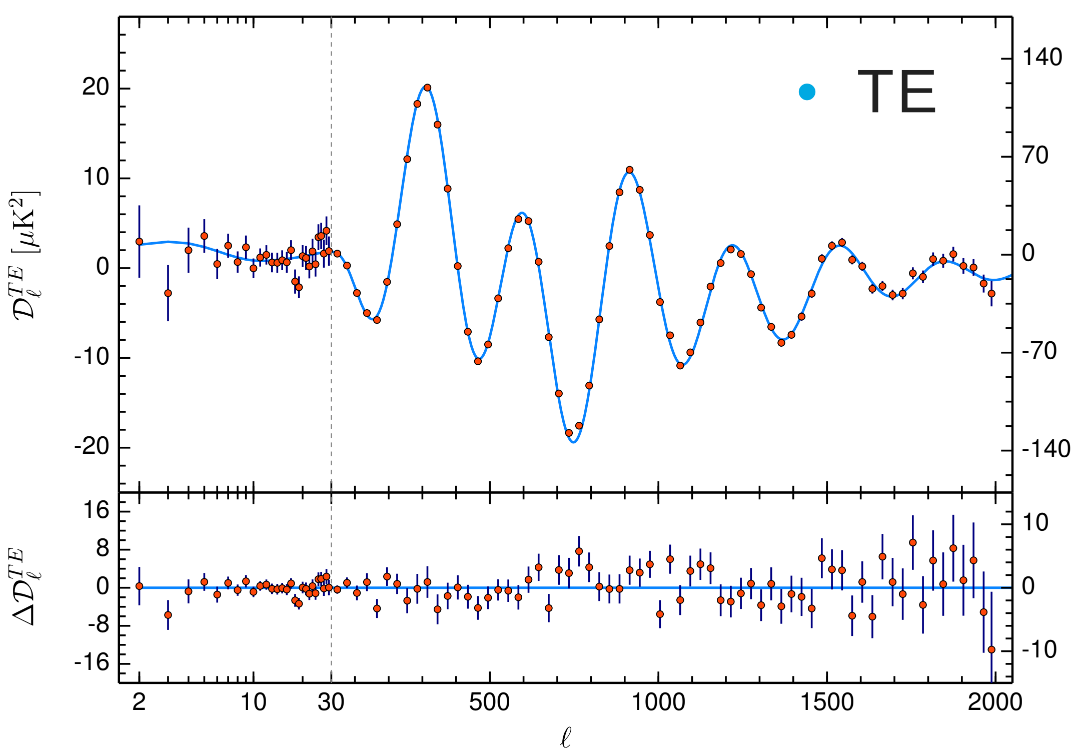


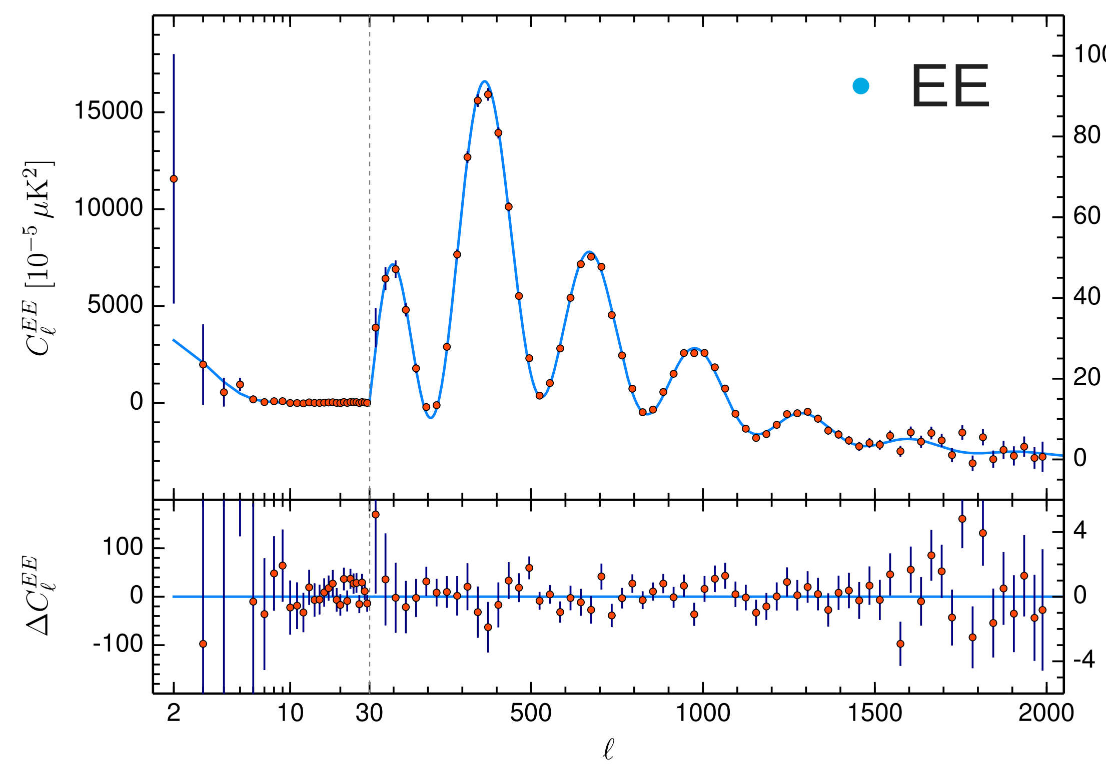
CMB power spectra

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



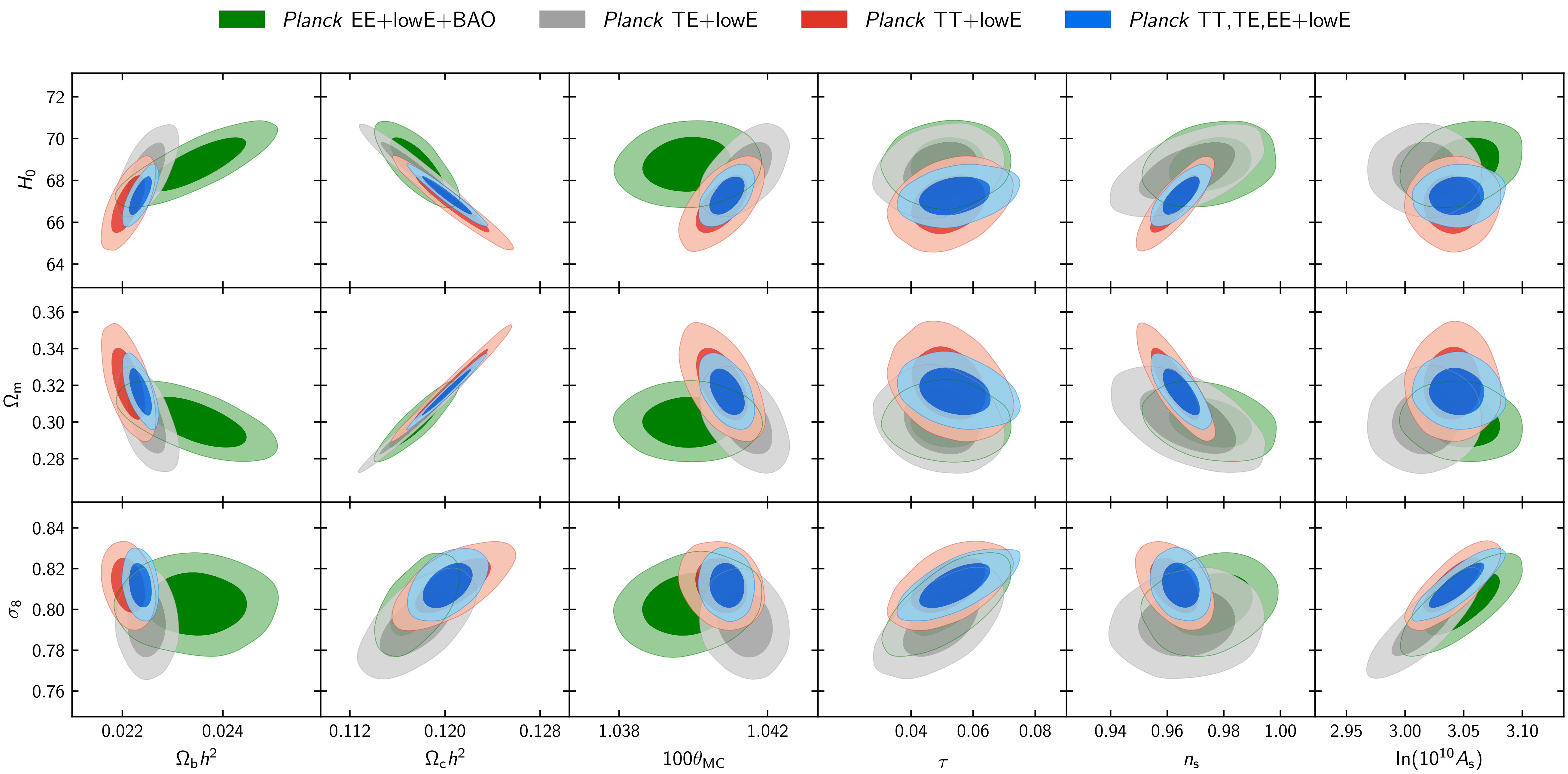






ΛCDM results

[Planck 2018 results. VI]



TE polarization spectra **highly consistent** with TT spectra

EE spectra also consistent but still noisier

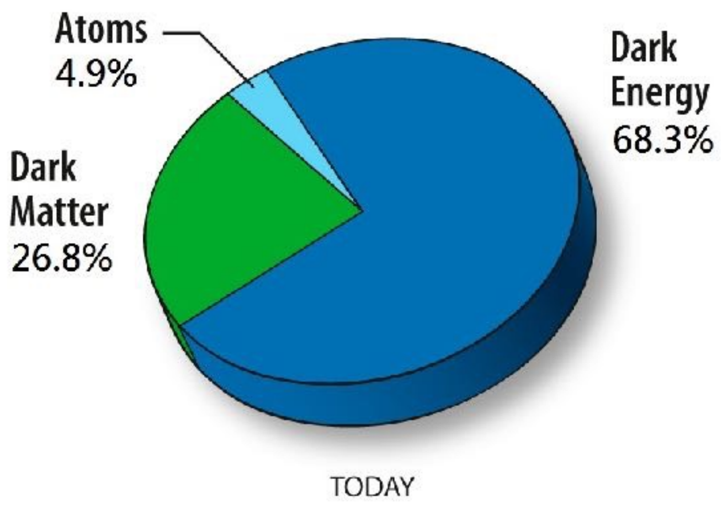
ΛCDM

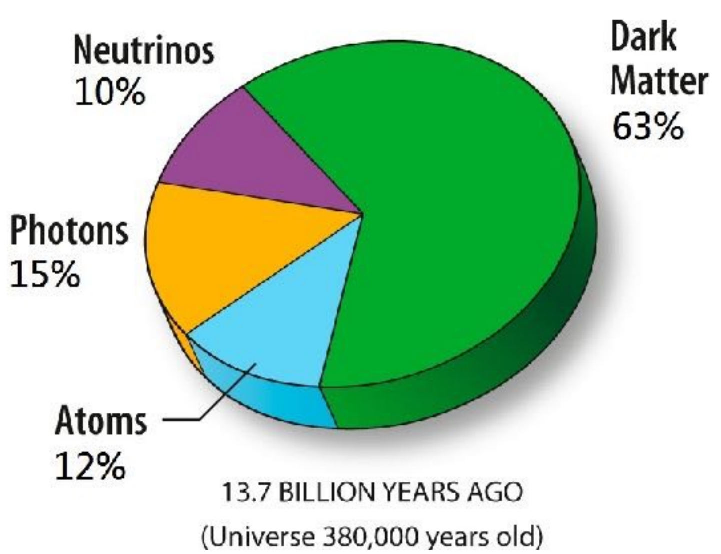
- **Consistency**
  The **CMB anisotropies** in temperature and polarisation (TT, TE, EE), **CMB lensing** ΦΦ, as well as **BAO**, **BBN**, and **SNIa** measurements are all consistent, among themselves and across experiments, within ΛCDM

- **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 ($A_{2s\to 1}$, 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%**





ΛCDM

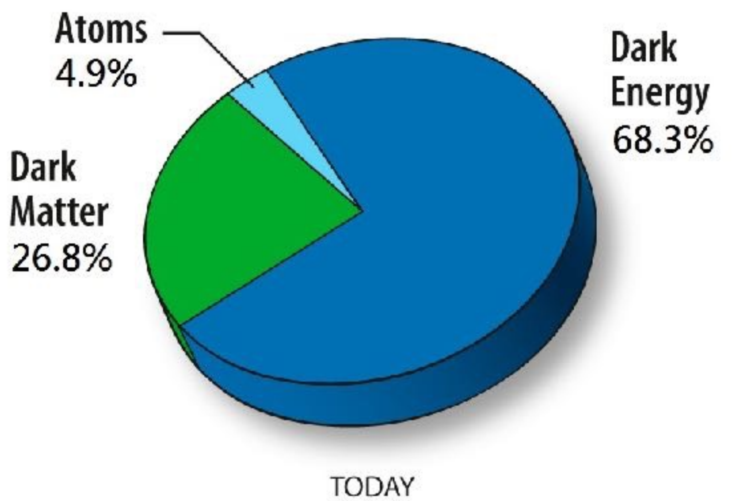
- **Consistency**
  The **CMB anisotropies** in temperature and polarisation (TT, TE, EE), **CMB lensing** ΦΦ, as well as **BAO**, **BBN**, and **SNIa** measurements are all consistent, among themselves and across experiments, within ΛCDM

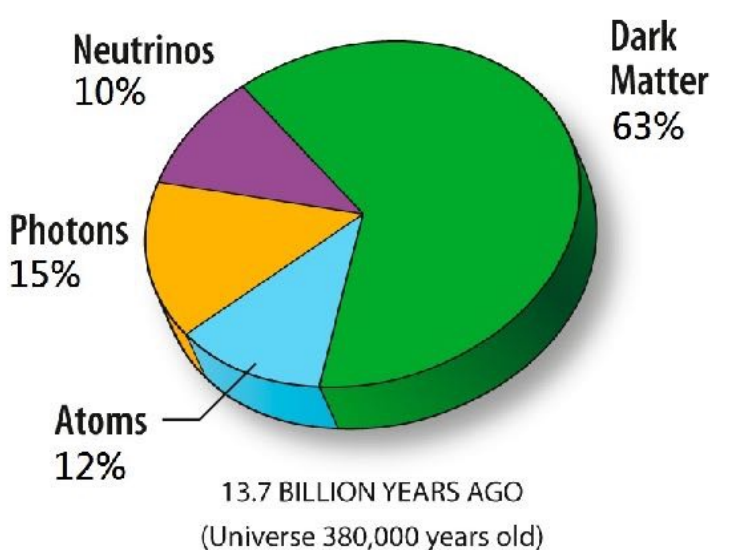
- **Robustness**
  These probes allow many different checks of the robustness for the ΛCDM model and some of its extensions, including **flatness**, sum of **neutrinos masses** and **effective number**, **DM annihilation** limits, **dark energy** equation of state w(z), details of the **recombination** history ($A_{2s\to1}$, 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)

what's next ?

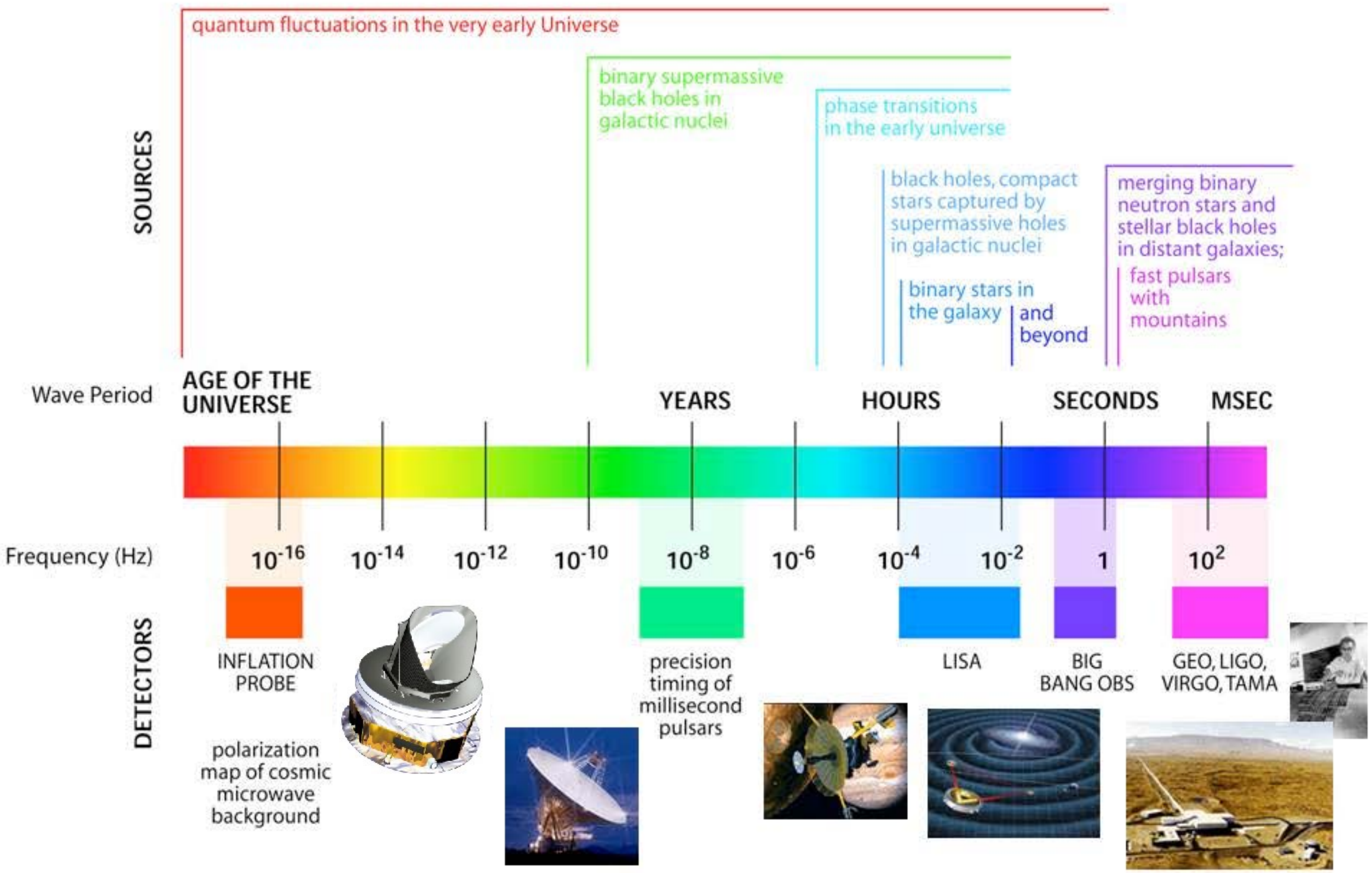
Parameter	TT,TE,EE+lowE+lensing 68% limits	
$\Omega_b h^2$	0.02237 ± 0.00015	**0.7%**
$\Omega_c h^2$	0.1200 ± 0.0012	**1.0%**
$100\theta_{MC}$	1.04092 ± 0.00031	**0.03%**
τ	0.0544 ± 0.0073	**13%**
$\ln(10^{10} A_s)$	3.044 ± 0.014	**0.5%**
n_s	0.9649 ± 0.0042	**0.4%**



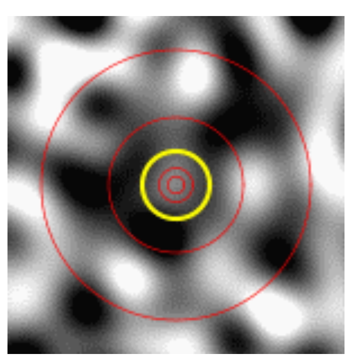


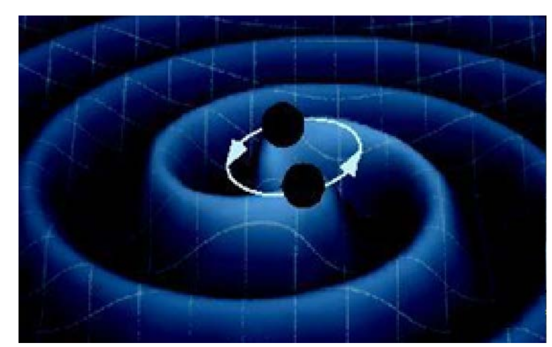
Gravitational waves

Big leap between LISA and LiteBIRD



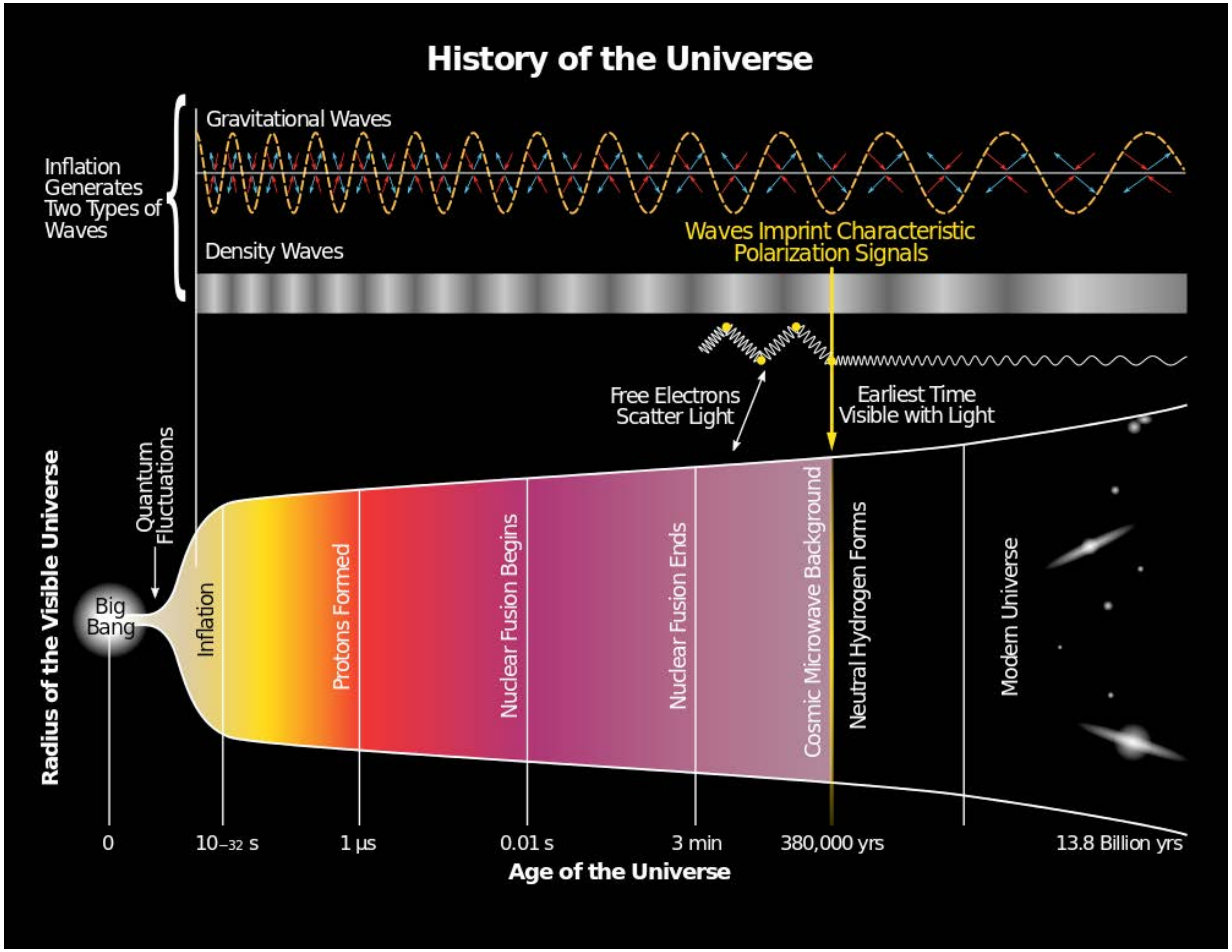
LiteBIRD
Gravitational waves with quantum origin





LISA
Gravitational waves with classical origin

Primordial gravitational waves



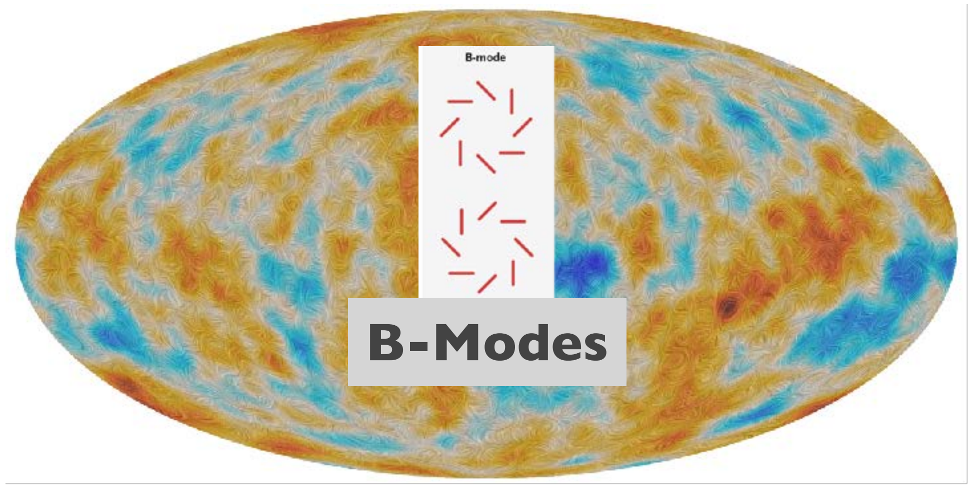
quantum fluctuations of spacetime

⇩ **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

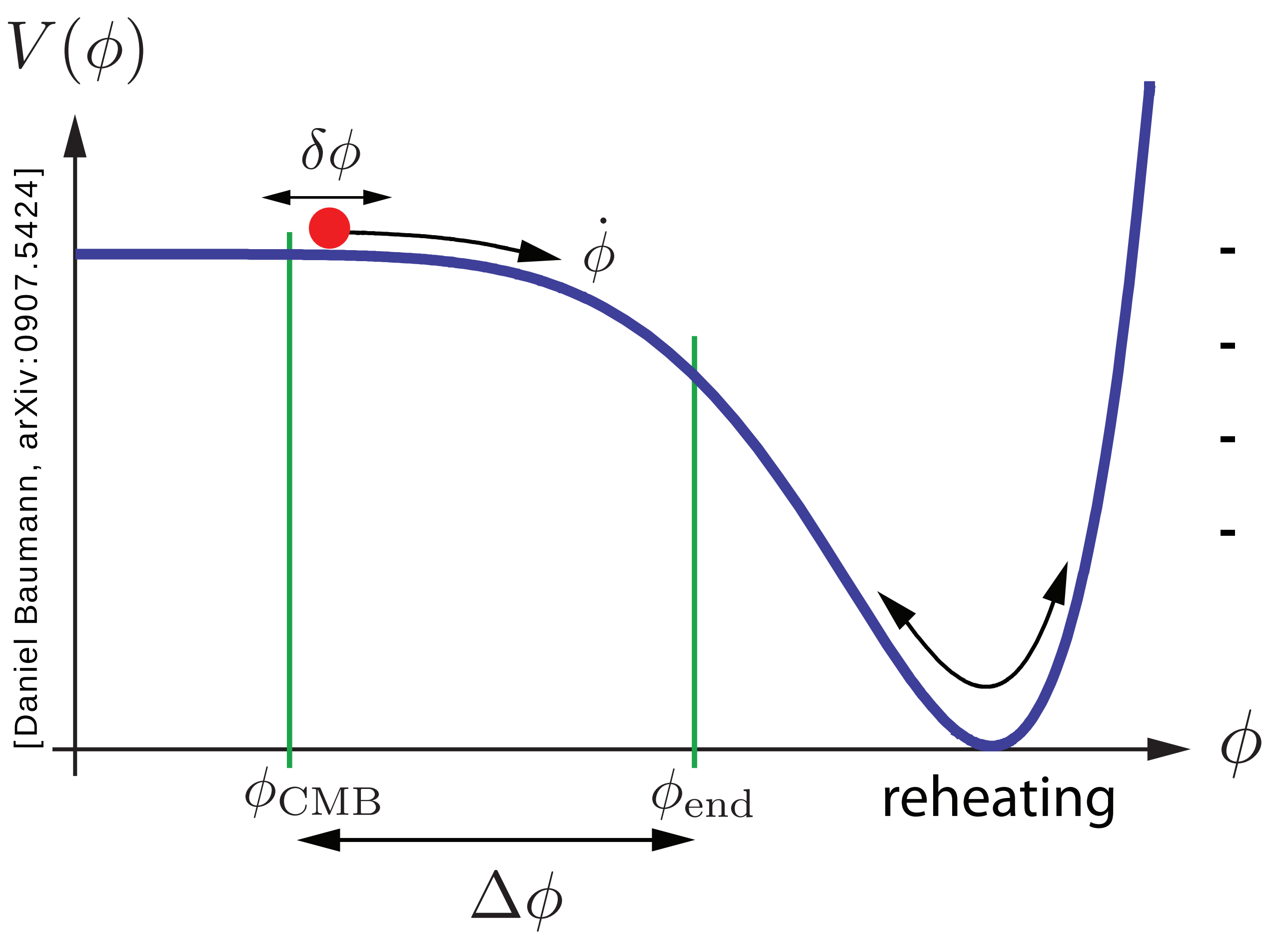
Observational test of quantum gravity

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** ?

Inflation

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

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

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

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

- 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

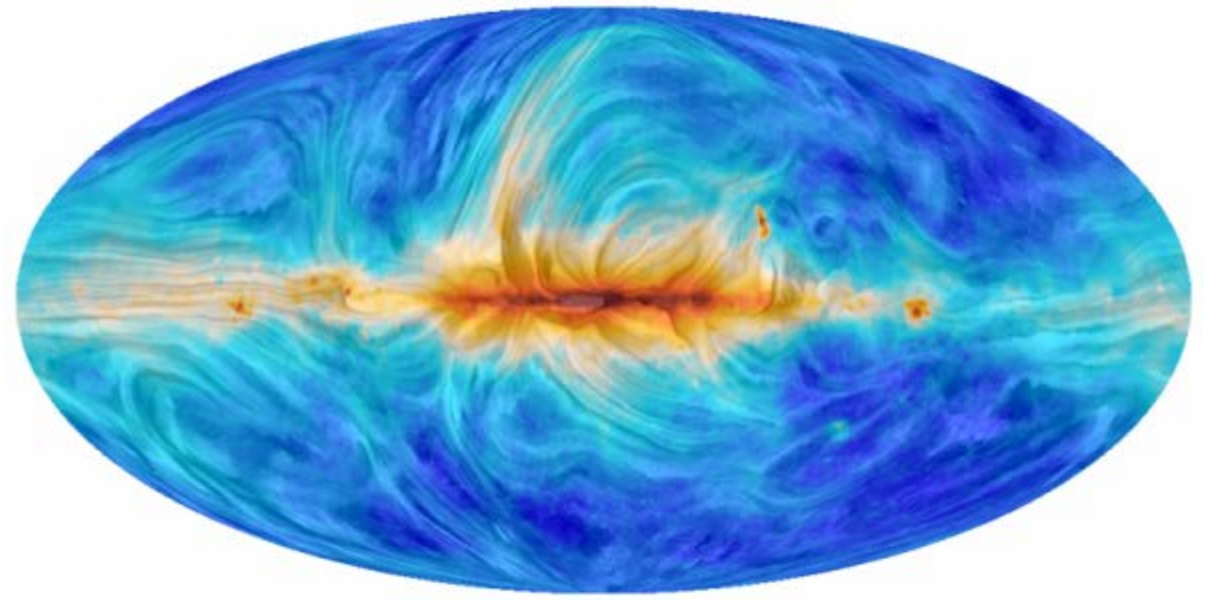
$$r = 8M_{\mathrm{Pl}}^2 \left(\frac{V_\phi}{V}\right)^2$$

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

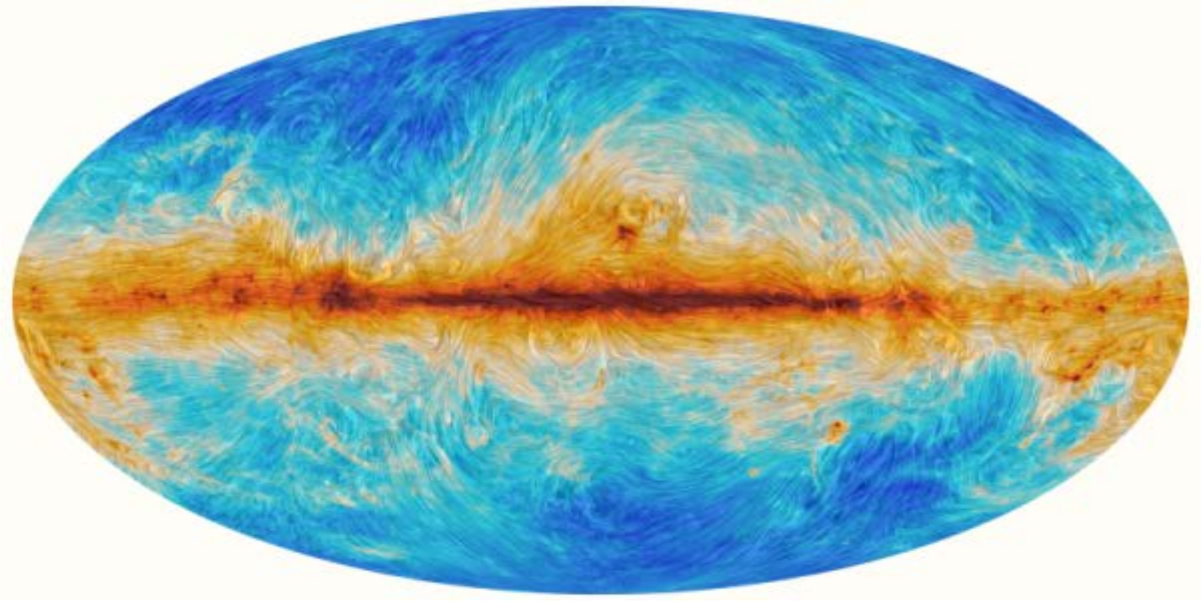
Galactic science

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

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)
$\otimes$
3D distribution of the matter
(galaxy survey)

how gas traces the matter in the Universe