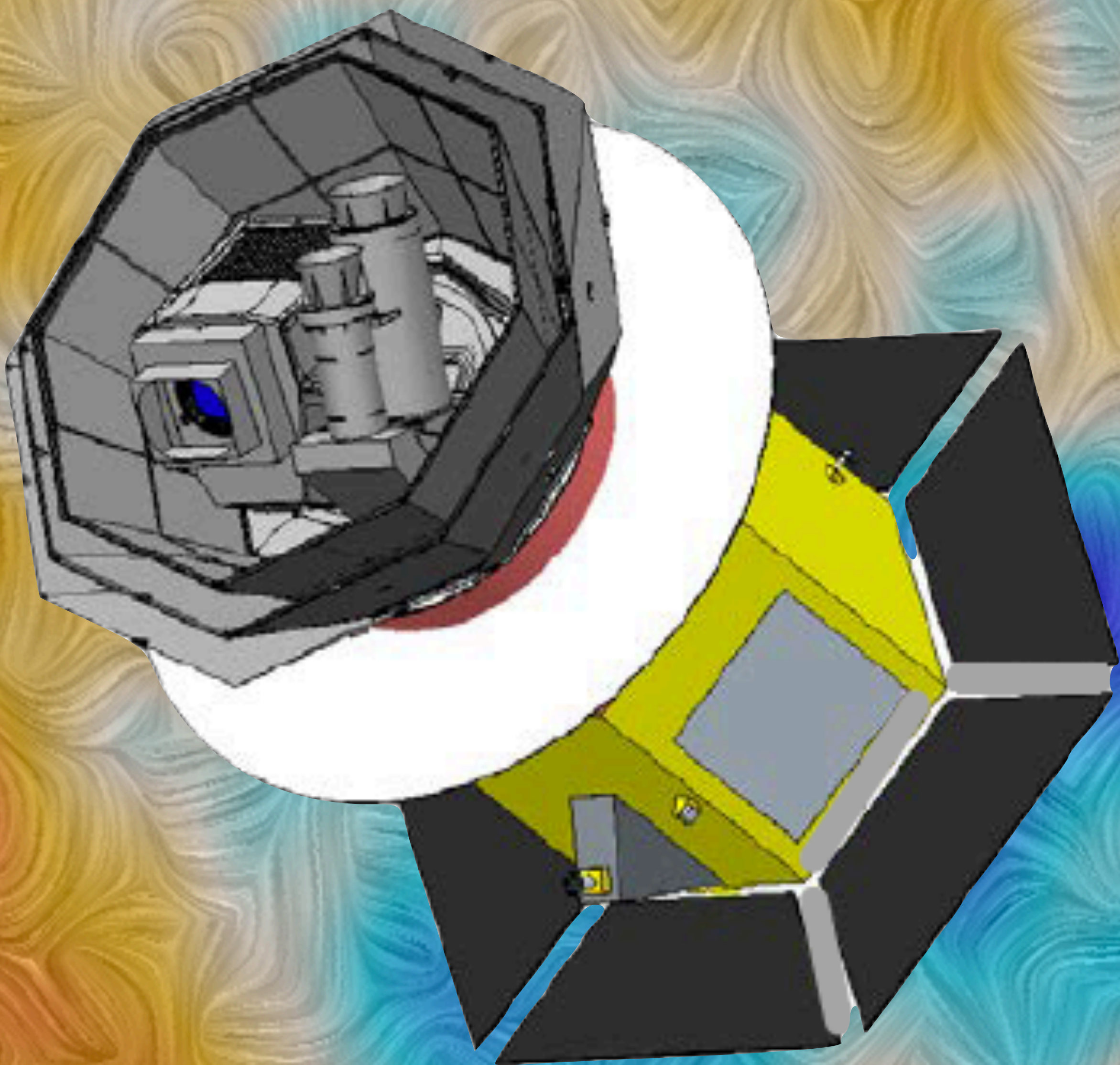
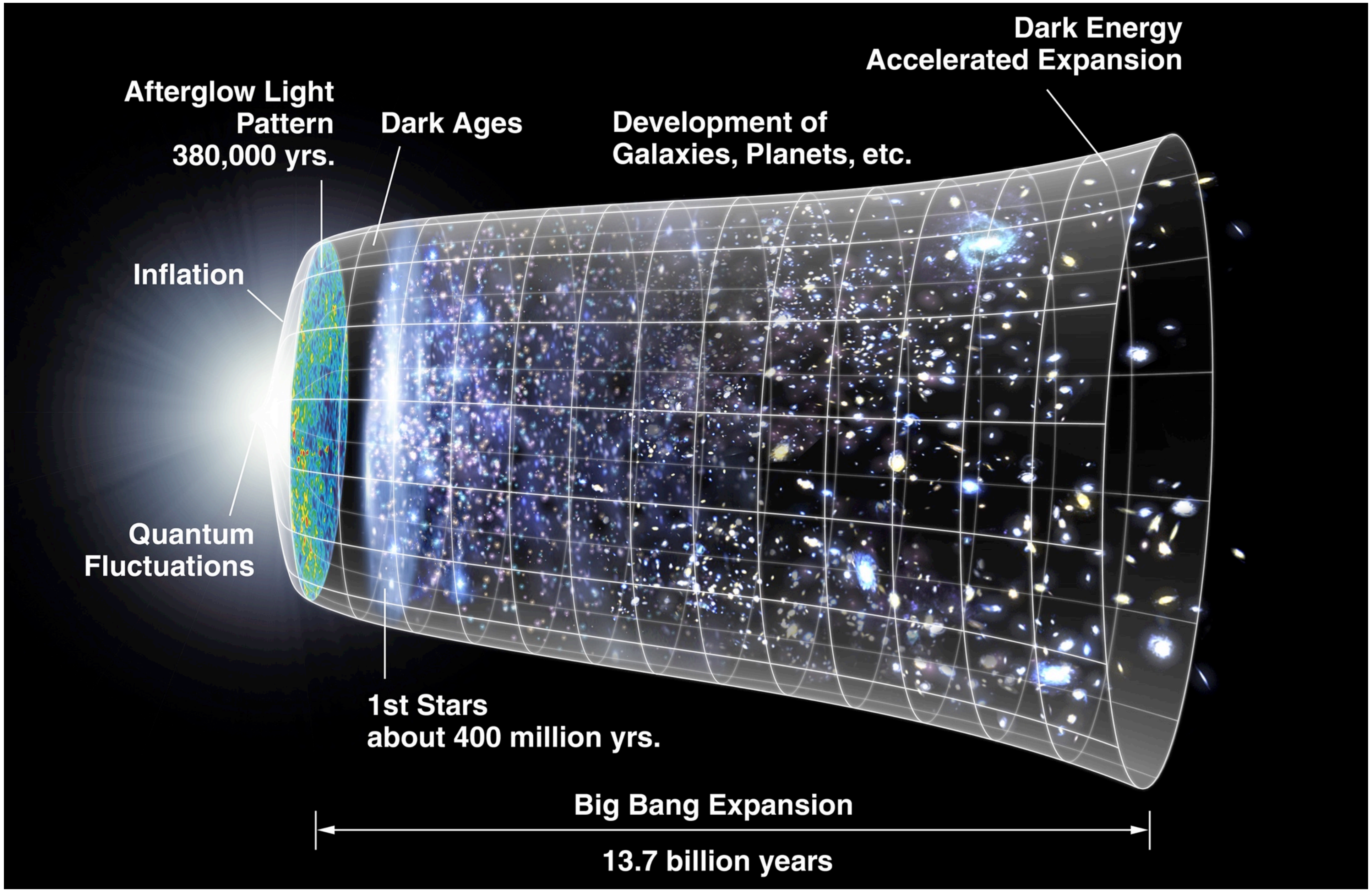


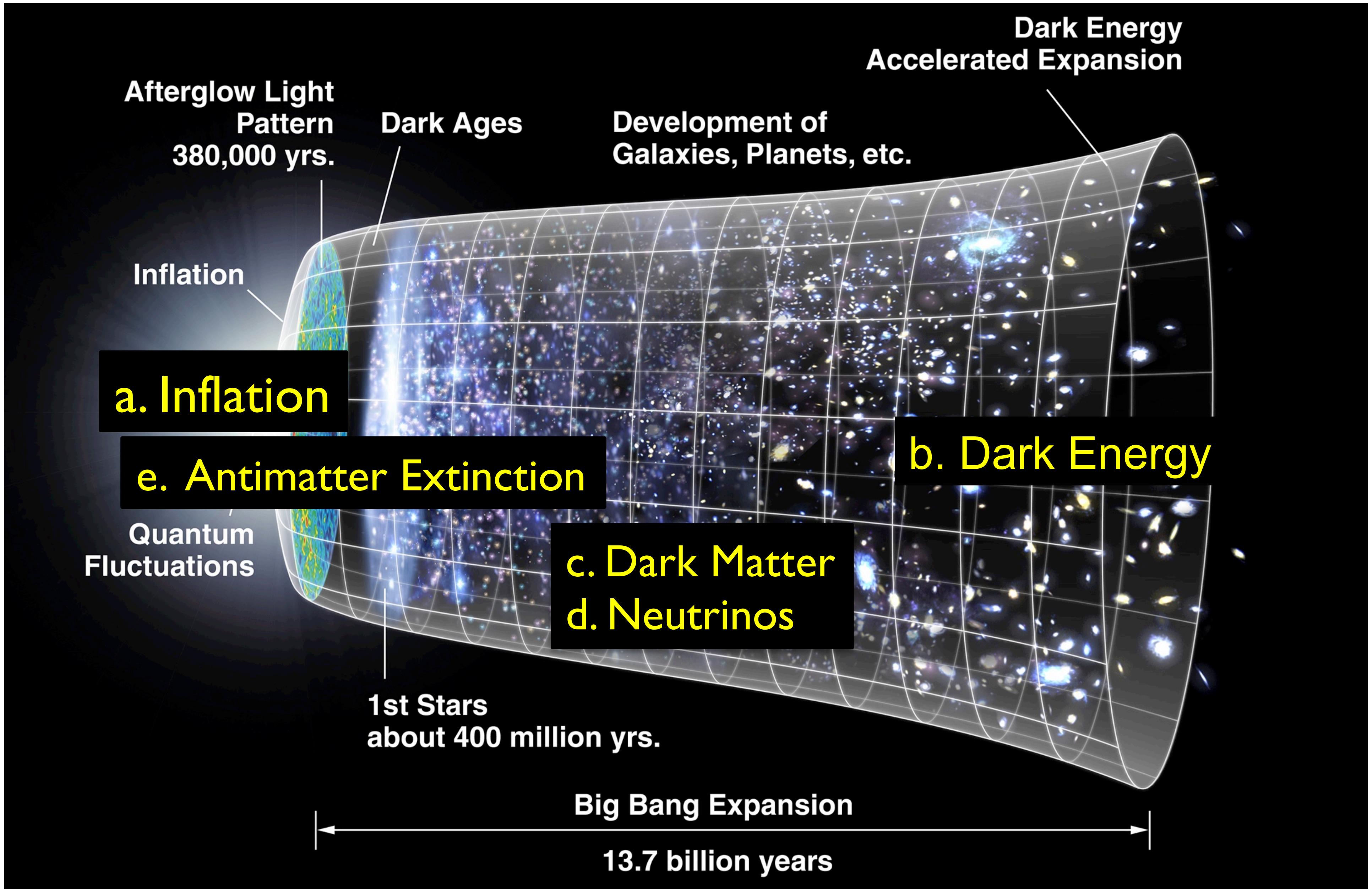
LiteBIRD and the Quest of the Primordial Gravitational Waves

L. Montier
on behalf of LiteBIRD Collaboration

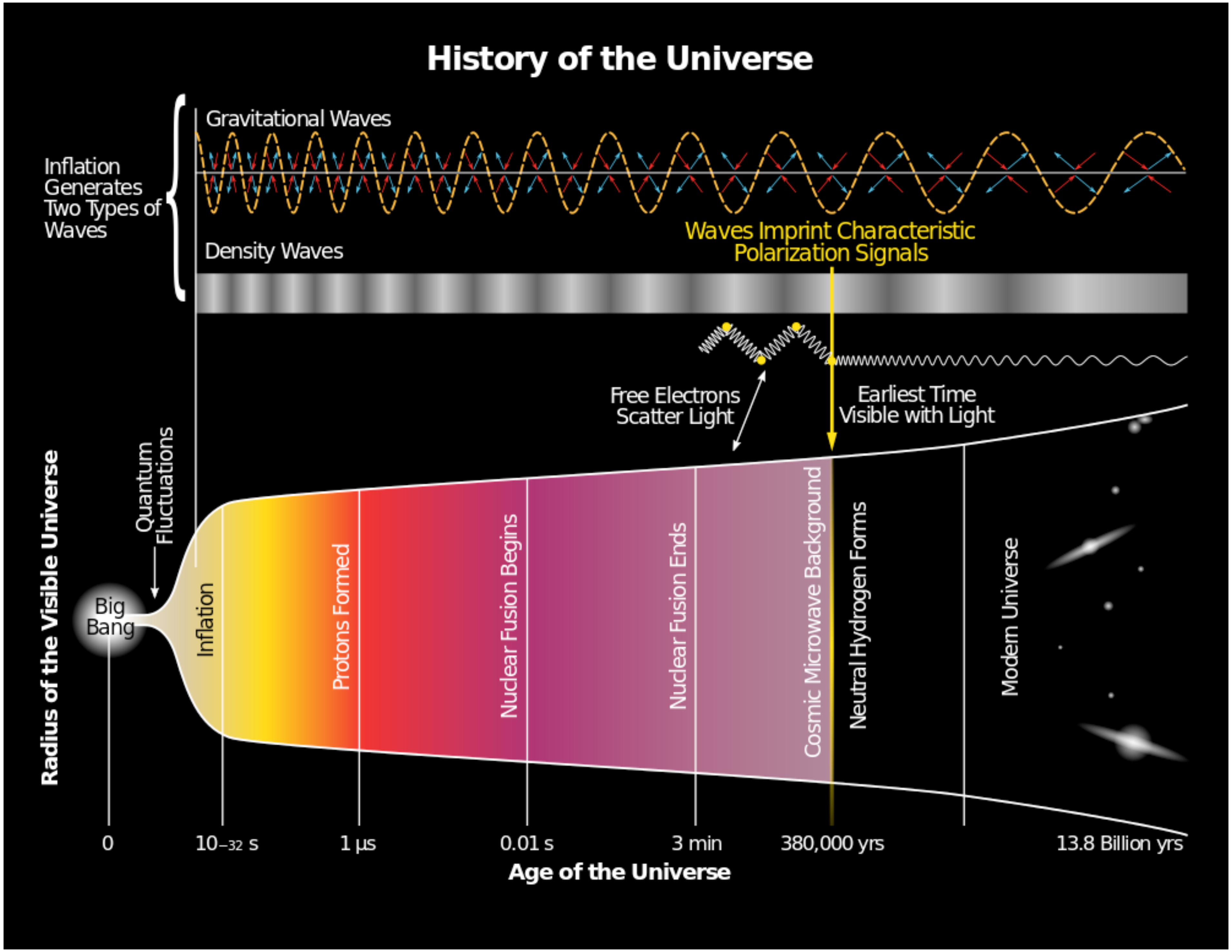
Looking for Primordial Gravitational waves



Looking for Primordial Gravitational waves

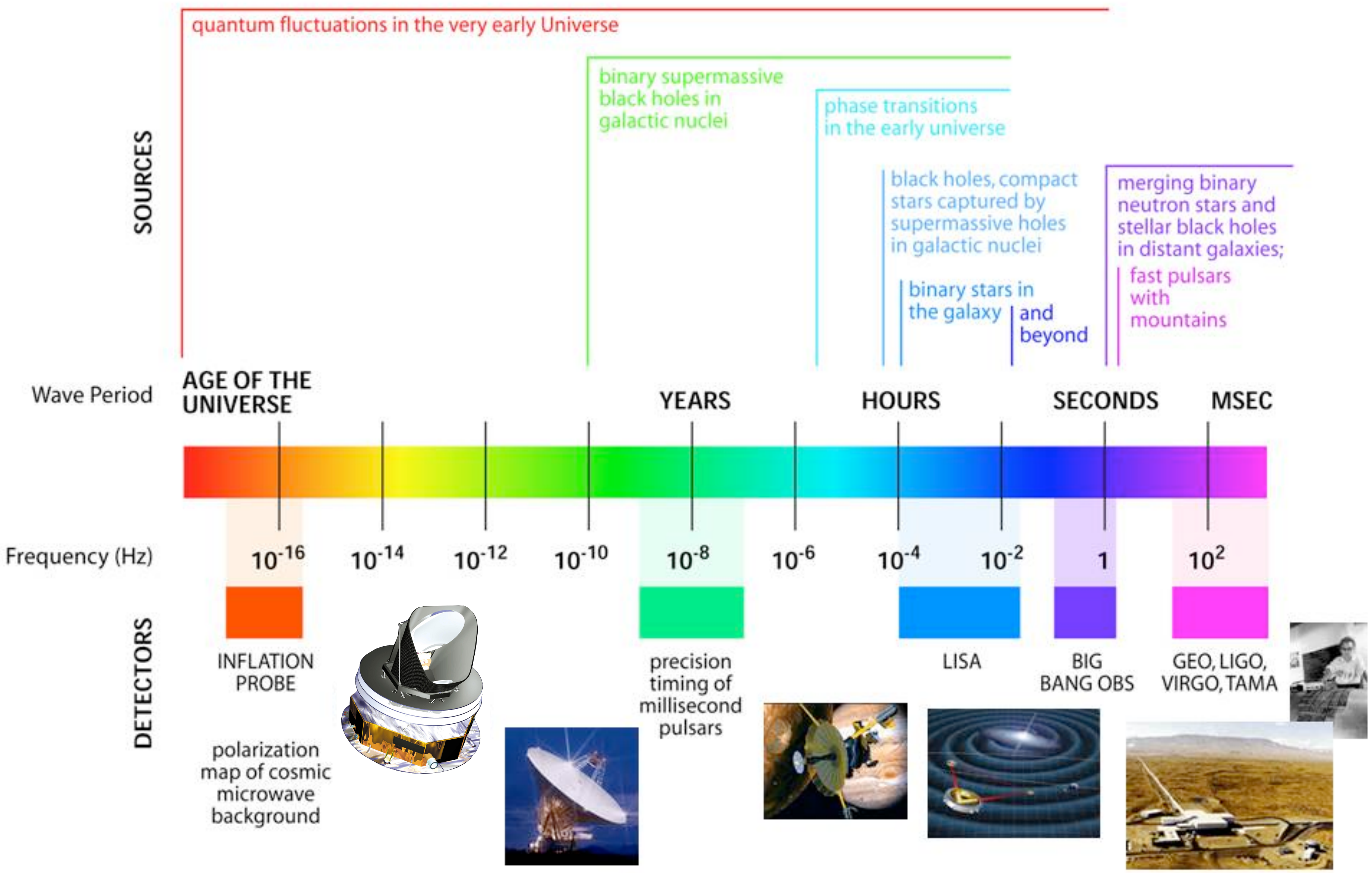


Looking for Primordial Gravitational waves

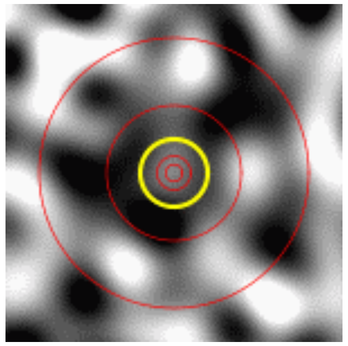


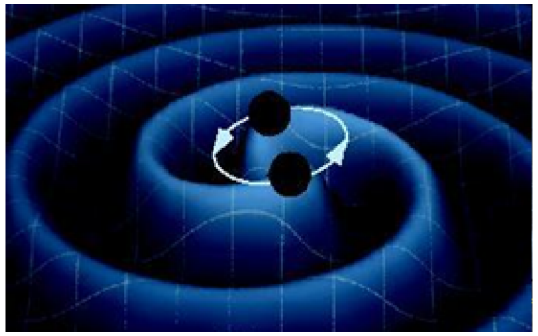
Looking for Primordial Gravitational waves

Big leap between LISA and LiteBIRD



LiteBIRD
Gravitational waves with quantum origin

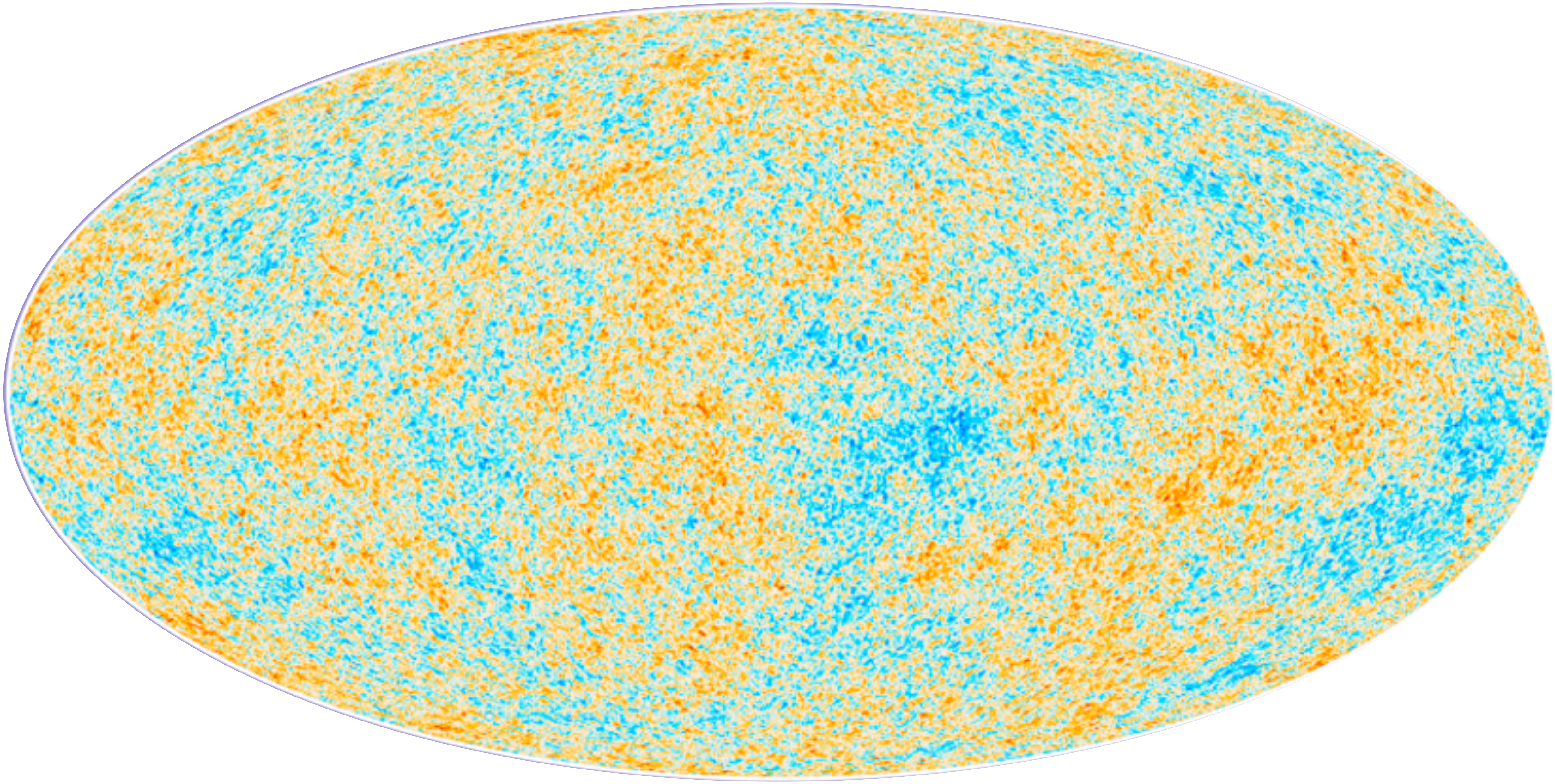




LISA
Gravitational waves with classical origin

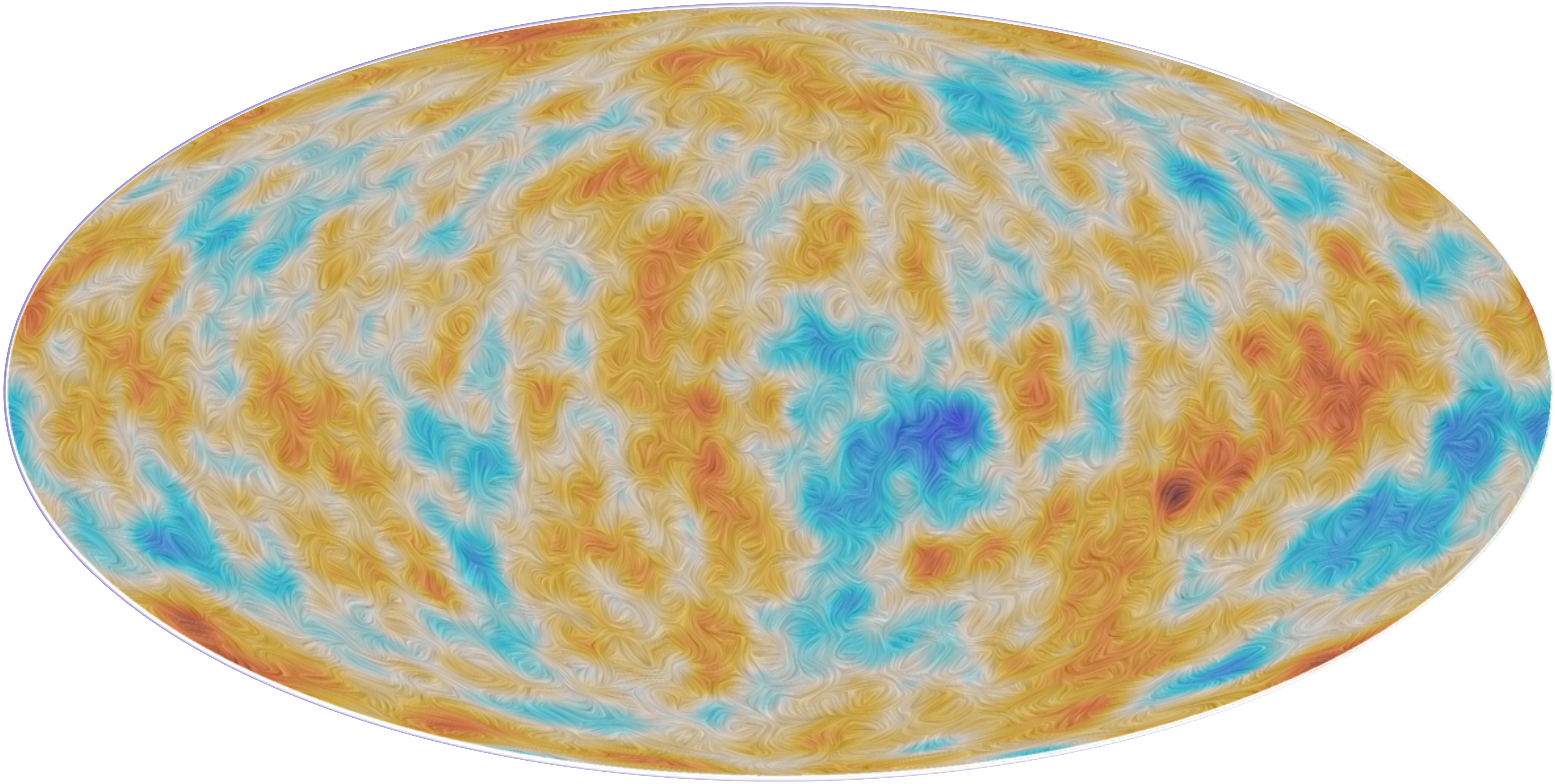
Looking for Primordial Gravitational waves

Emission from CMB measured by Planck Mission



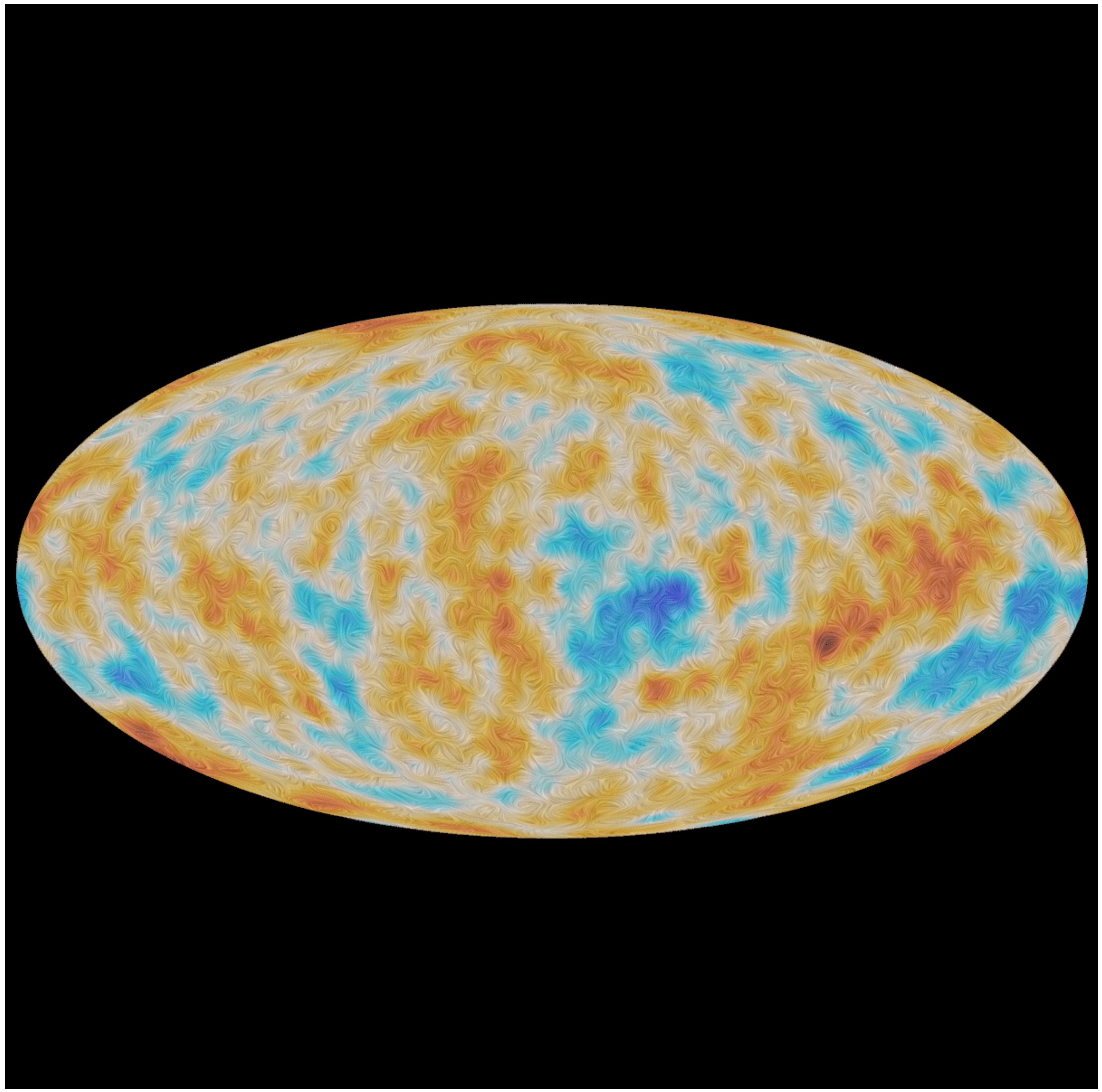
Looking for Primordial Gravitational waves

Polarised emission from CMB measured by Planck Mission



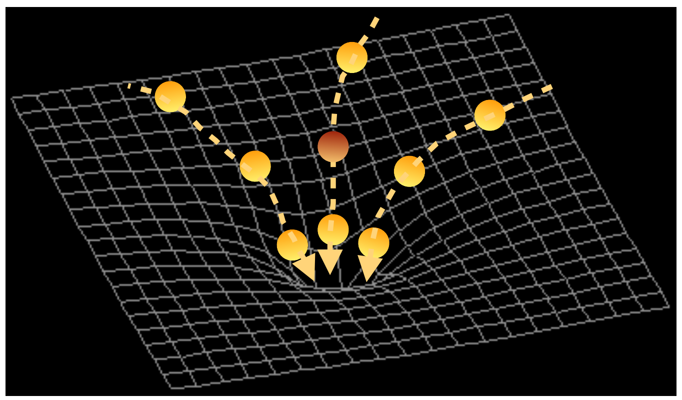
Looking for Primordial Gravitational waves

The imprints of gravitational waves on CMB

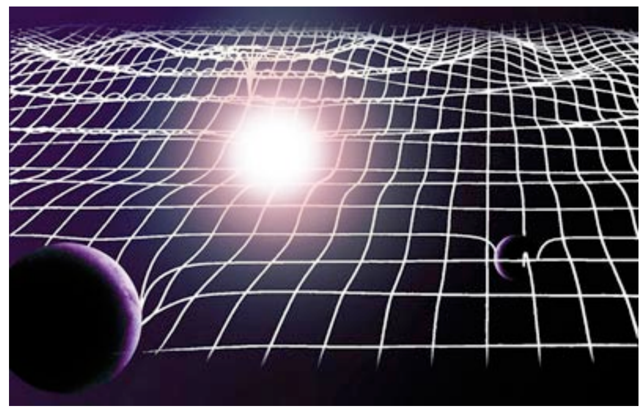


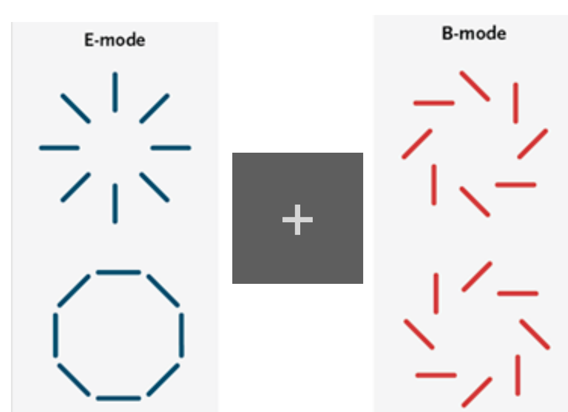
Looking for Primordial Gravitational waves

The imprints of gravitational waves on CMB



Gravitational waves





Inflation

⇩

Quantum fluctuation of spacetime

⇩

Primordial gravitational waves

⇩

"vortex"es in the CMB polarization map (called "B-mode")

Looking for Primordial Gravitational waves

The imprints of gravitational waves on CMB

- **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"** $r = A_t / A_s$

$$V^{1/4} = 1.06 \times 10^{16} \times \left(\frac{r}{0.01}\right)^{1/4} [\text{GeV}]$$

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

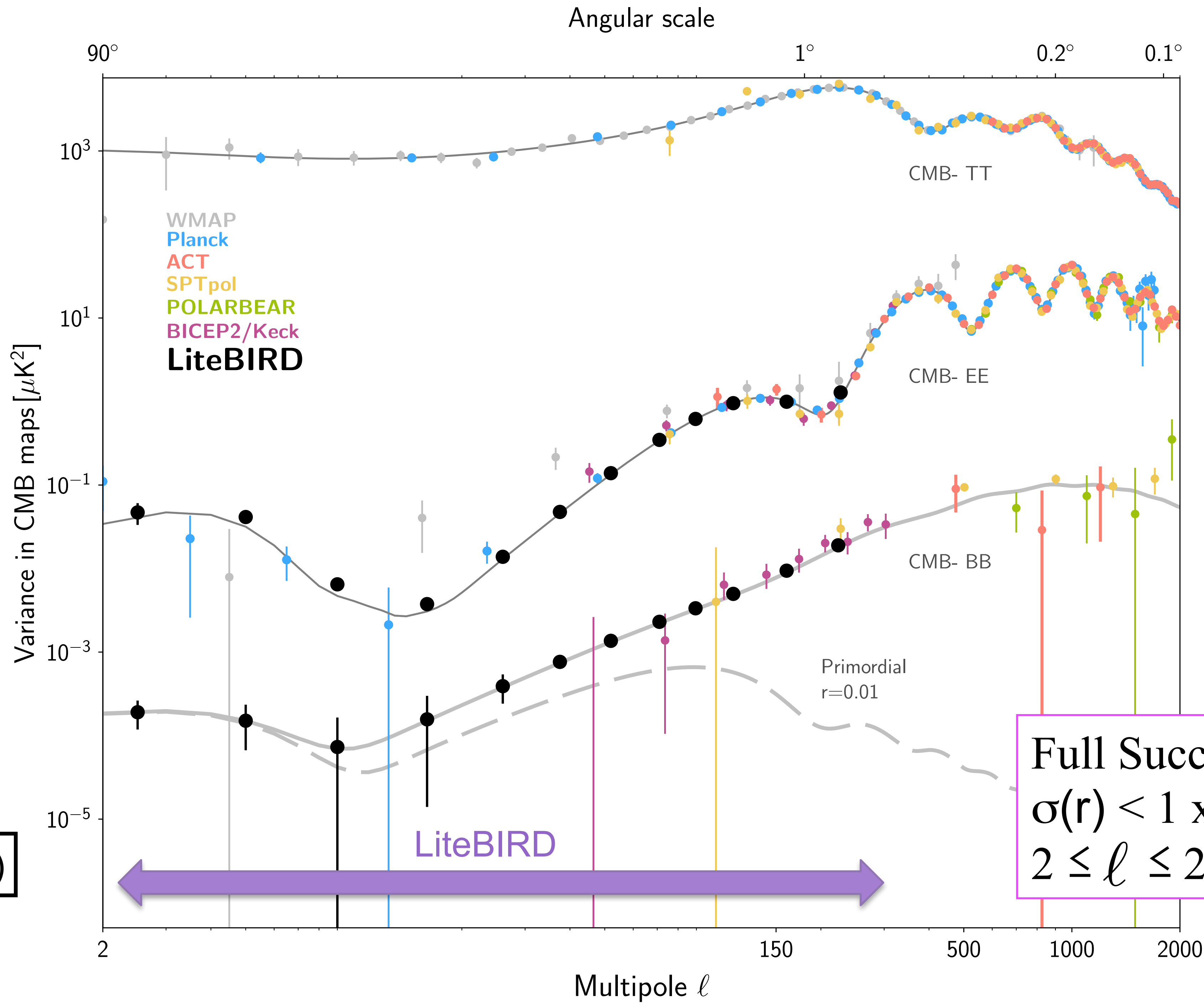
From Shibuya

From Shibuya

Looking for Primordial Gravitational waves

From Shibuya

LiteBIRD Expectation



LiteBIRD only

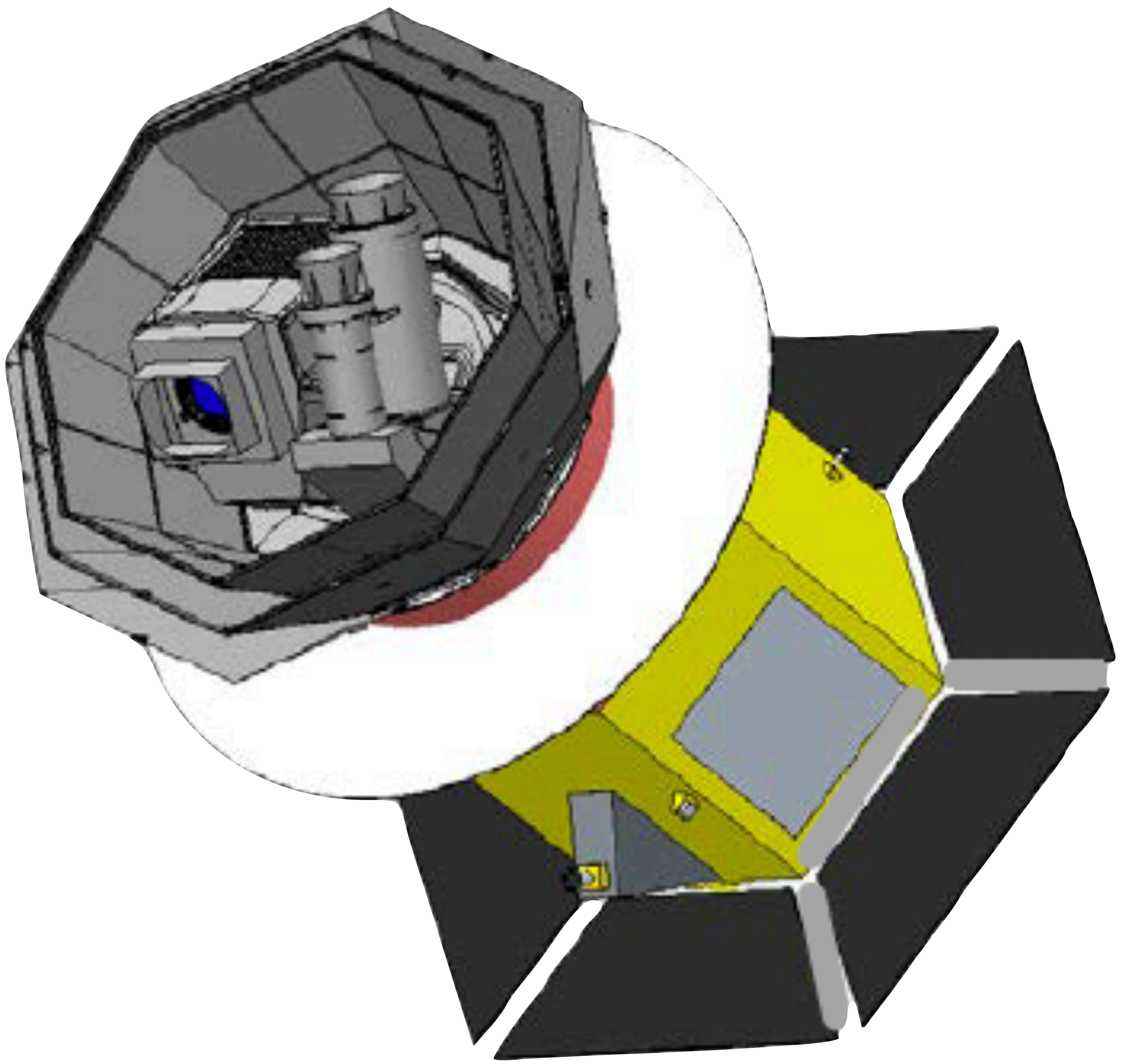
(without de-lensing)

Best upper limit so far

r < 0.044 (95% CL)

Full Success :
$\sigma(r) < 1 \times 10^{-3}$ (for r=0)
$2 \leq \ell \leq 200$

LiteBIRD Mission



L-Class JAXA Mission

Selected by JAXA May 2019

Launch 2029

L2 orbit

All-sky Survey during 3 years

Large frequency coverage
15 bands 34 - 448 GHz

Resolution:

LFT	MFT	HFT
70.5' - 23.7'	37.8' - 28'	28.6' - 17.9'

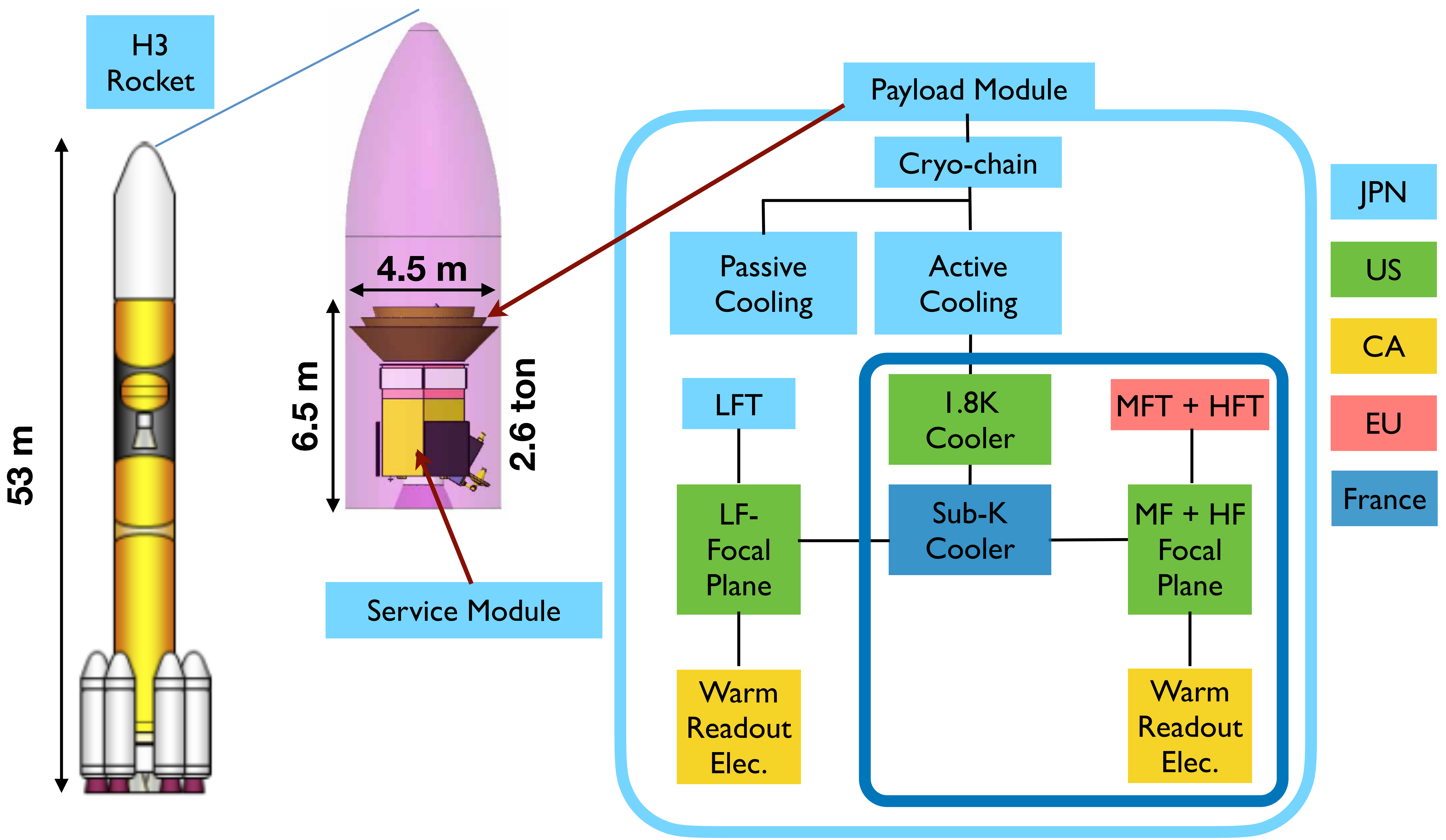
Sensitivity: 2.16 uK.arcmin

after component separation

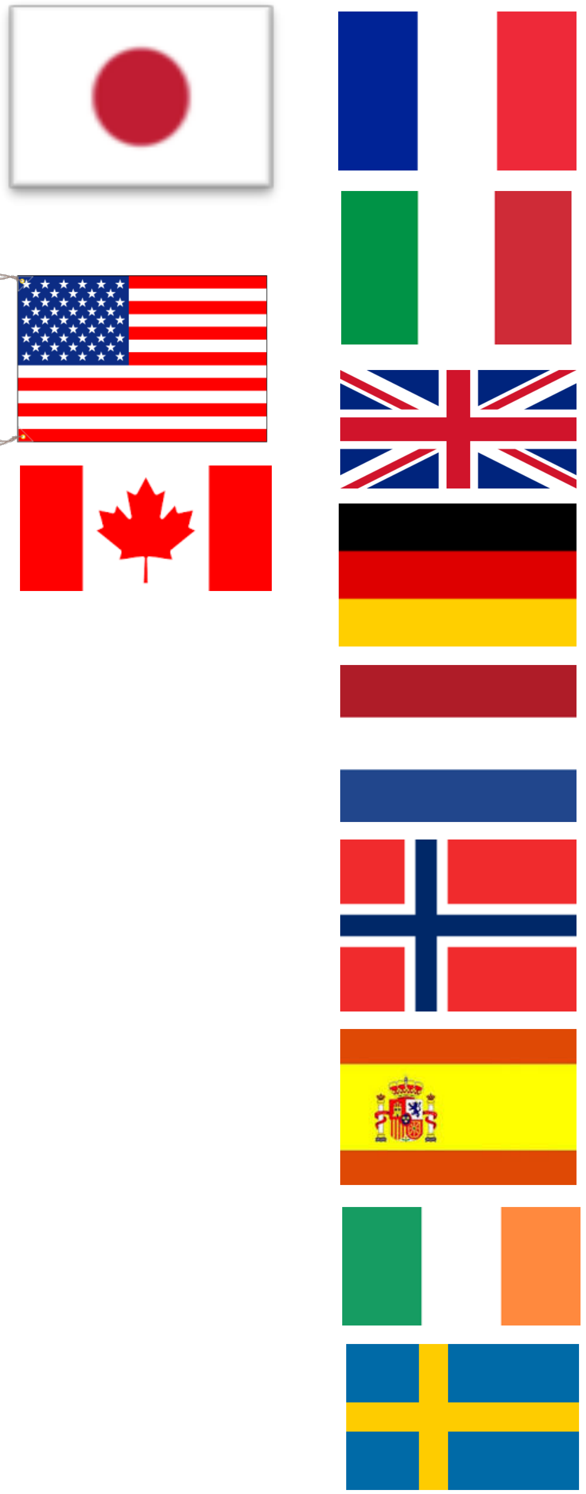
more than 100 times better than Planck/HFI in P

LiteBIRD Mission

Payload

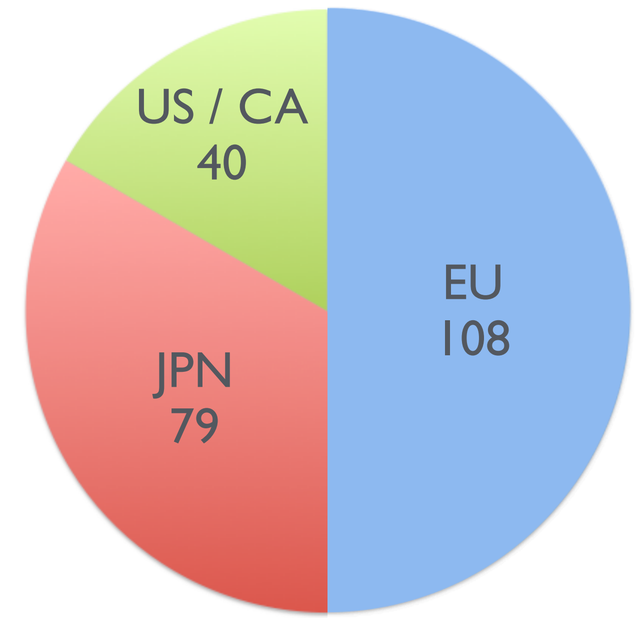


An international collaboration



More than 200 researchers from Japan, Europe & North America

Y. Sekimoto[14,37] , P. Ade[2], K. Arnold[49], J. Aumont[12], J. Austern
A. Banday[12], R. Banerji[56], S. Basak[7,11], S. Beckman[49], M. Be
F. Boulanger[4], M.L. Brown[53], M. Bucher[1], E. Calabrese[2], F.J. Ca
Y. Chinone[16,47], F. Columbro[46], A. Cukierman[47,36], D. Curtis[47],
Petris[46], M. Dobbs[23], T. Dotani[14,37], L. Duband[3], JM. Duval[3], A.
T. Elleflot[49], H. Eriksen[56], J. Errand[1], R. Flauger[49], C. Frances
K. Ganga[1], J.R. Gao[35], T. Ghigna[16,57], J. Grain[9], A. Gruppuso[6], N
T. Hasebe[14], M. Hasegawa[5,37], M. Hattori[42], M. Hazumi[5,14,16,3



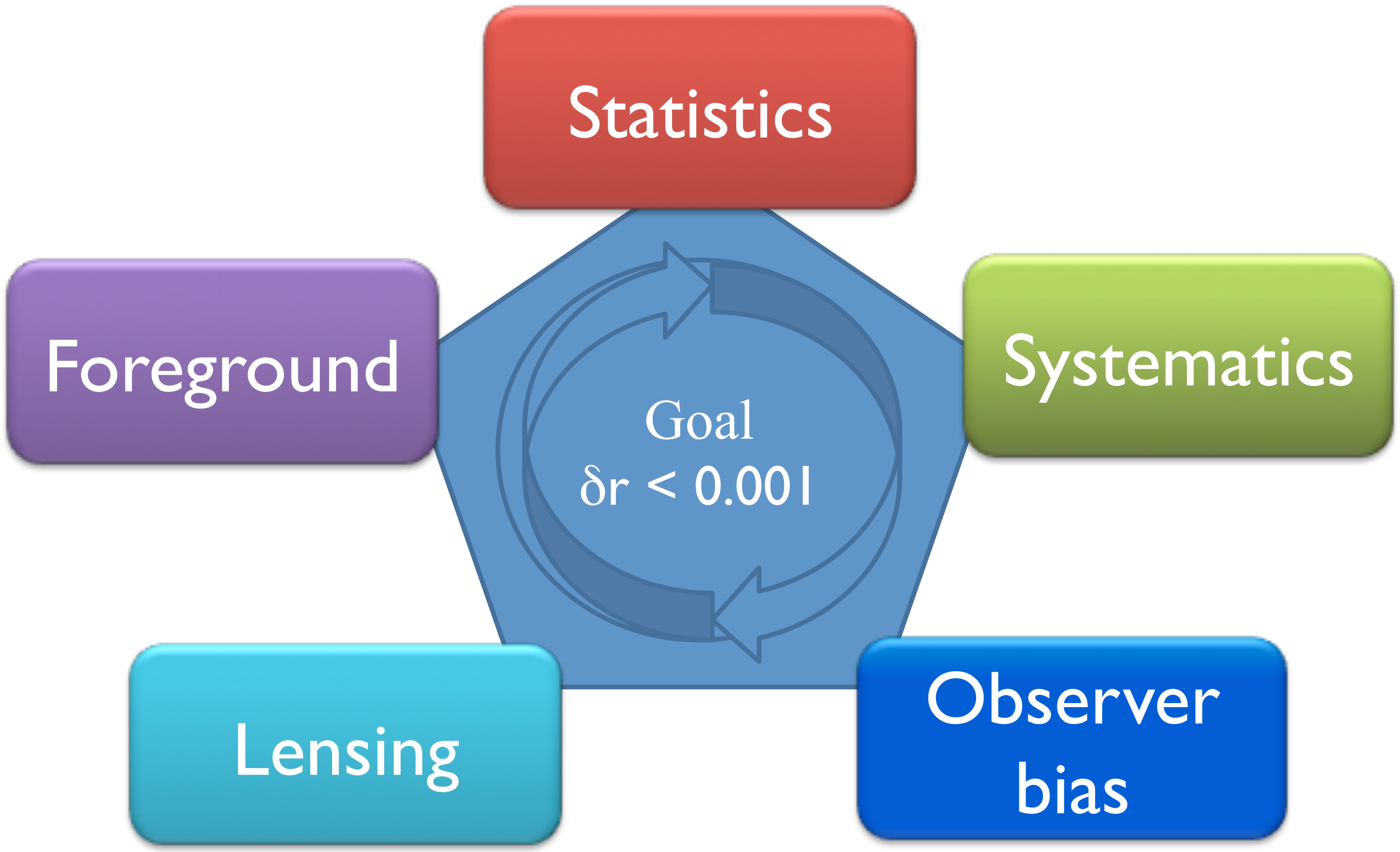
Mission Challenges

High Sensitivity Detectors

Large frequency coverage from Space

Mitigation and Control of Systematics

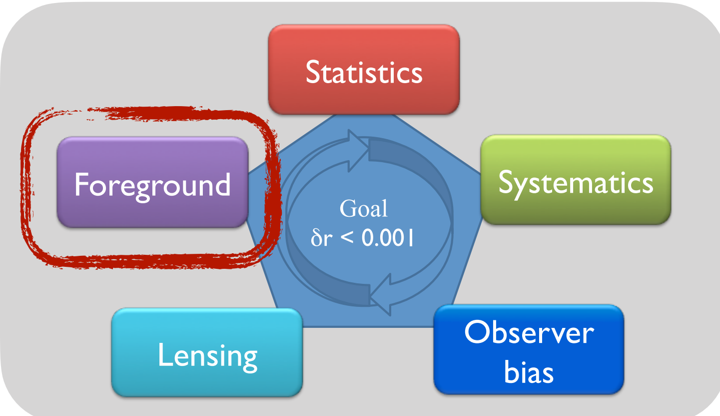
Continuously Rotating HWP



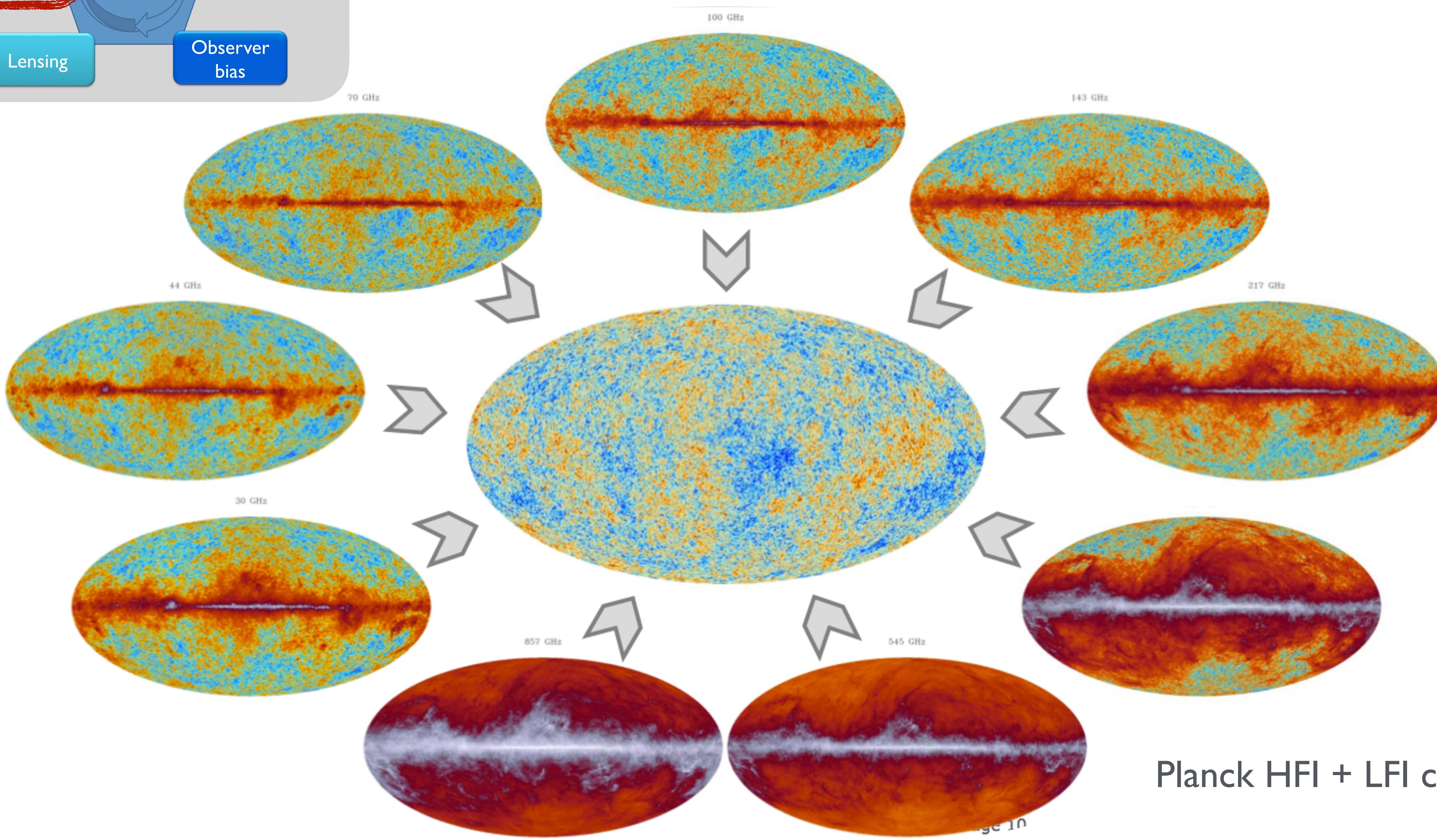
Focused on largest multipole scales

All-sky survey

Mission Challenges

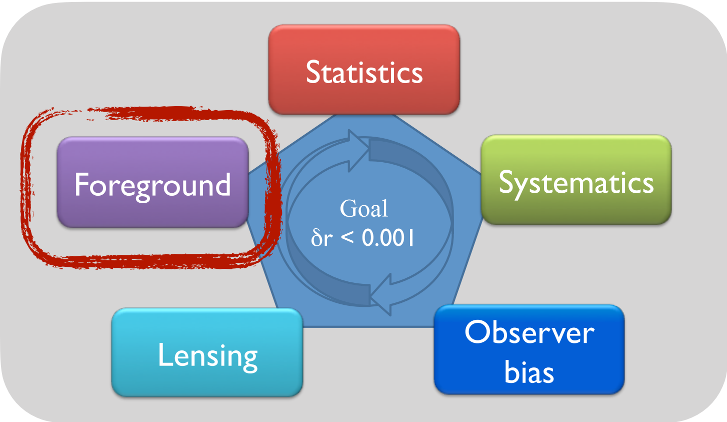


Foregrounds



Planck HFI + LFI case

Mission Challenges

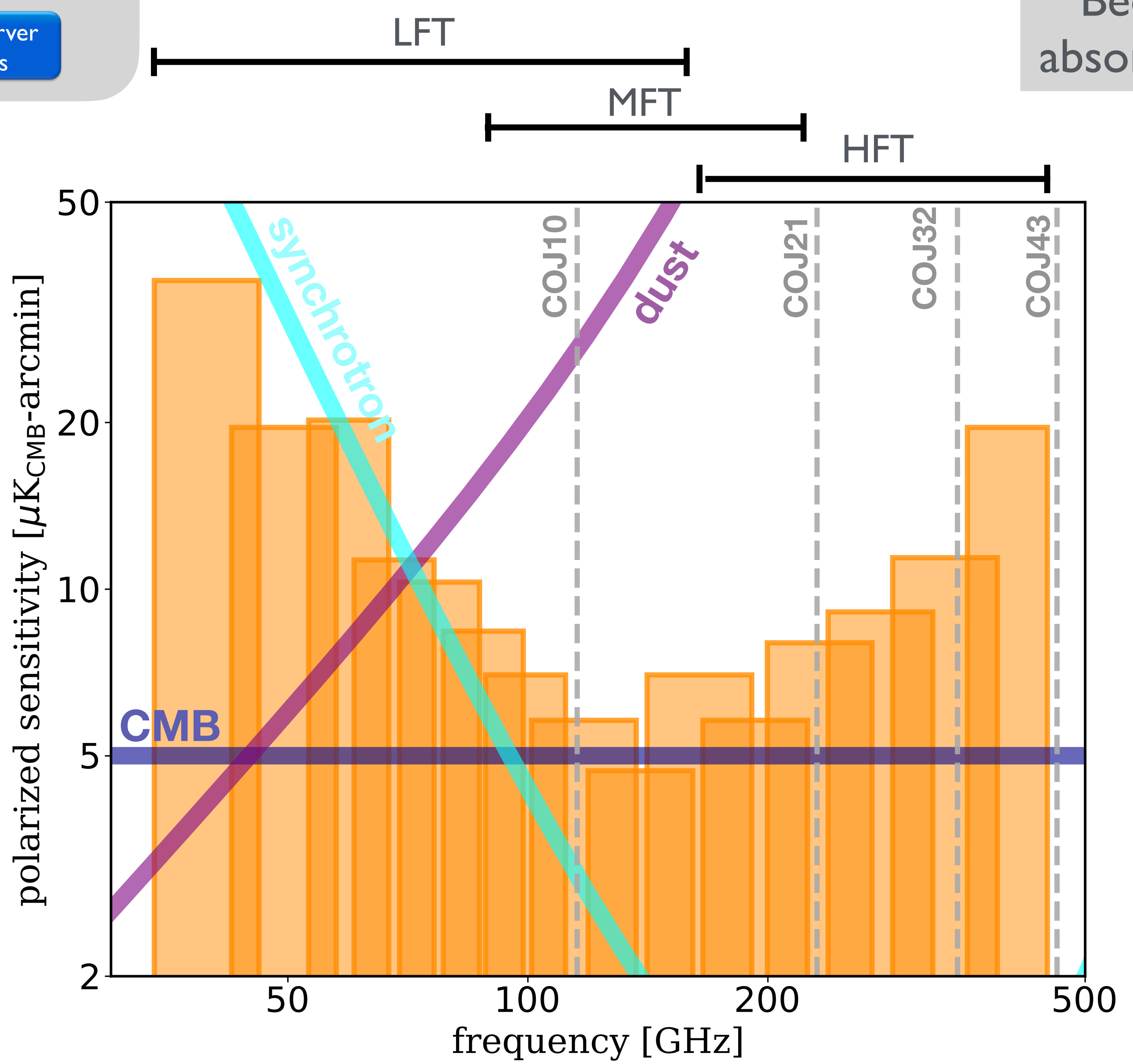


Foregrounds

Possible only from Space !
Because of atmospheric absorption from the ground

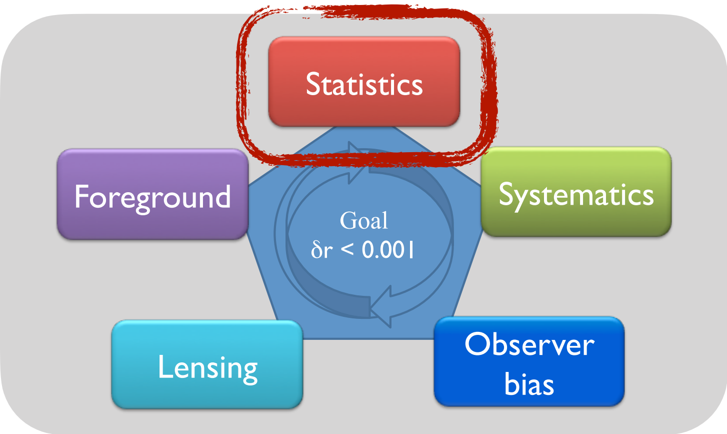
15 bands from 34GHz to 448GHz

+4600 detectors



9 bands LFT
5 bands x 2 MHFT
+
4 bands overlapping

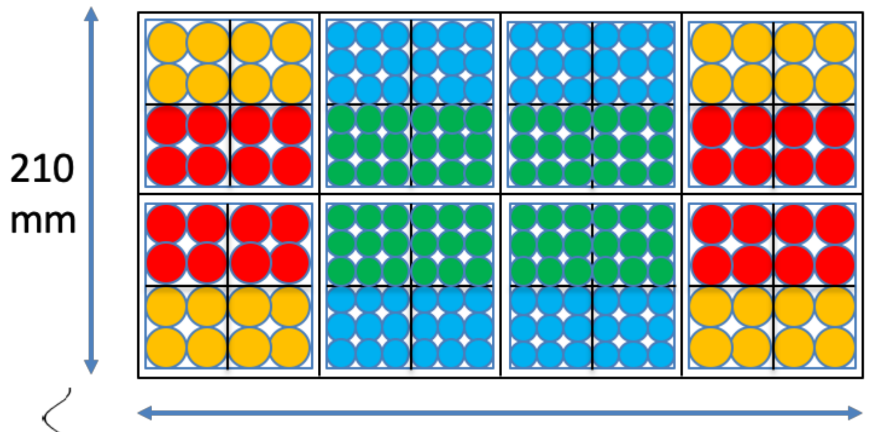
Mission Challenges

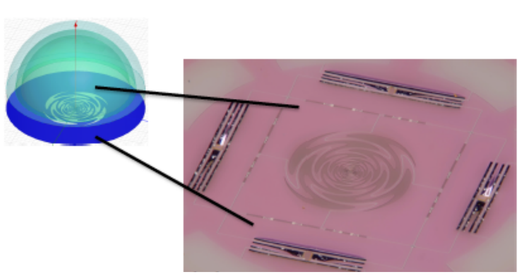


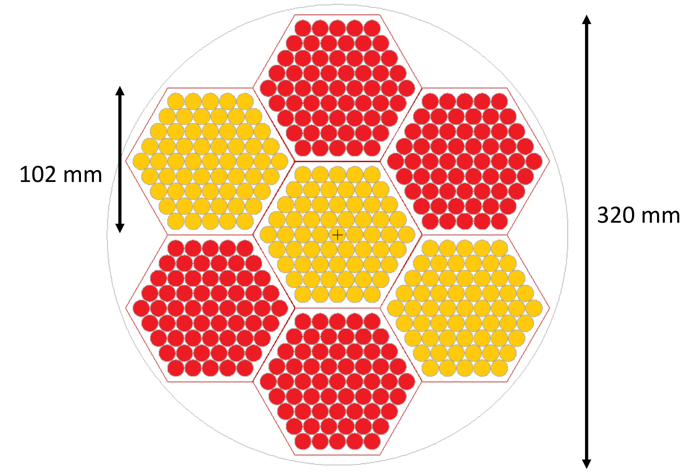
Statistics

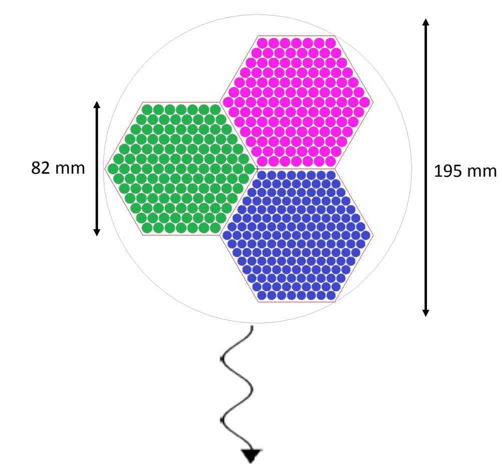
Number of detectors:4676
Overlap between instruments

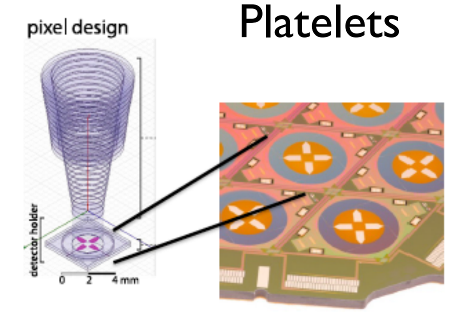
Rule of thumb:
1000 detectors in space = 100 000 detectors on ground











MFT (2.5:1)

89GHz — 225 GHz

2075 detectors
366 Trichroic TES
588 Dichroic TES

100 | 119 | 150 | 166 | 195

LFT (5.7:1)

50 | 50 | 60 | 68 | 78 | 89 | 100 | 119 | 150

1258 detectors
2 x (65 + 155) Trichroic TES

35GHz — 161 GHz

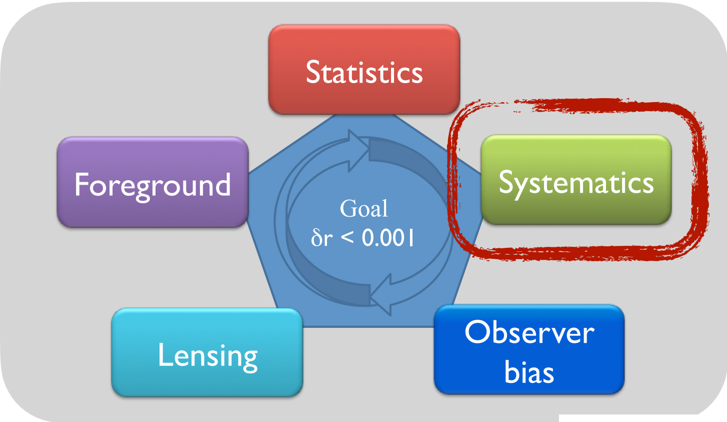
HFT (2.7:1)

195 | 235 | 280 | 337 | 502

1355 detectors
2 x 255 Dichroic TES
338 Monochromatic TES

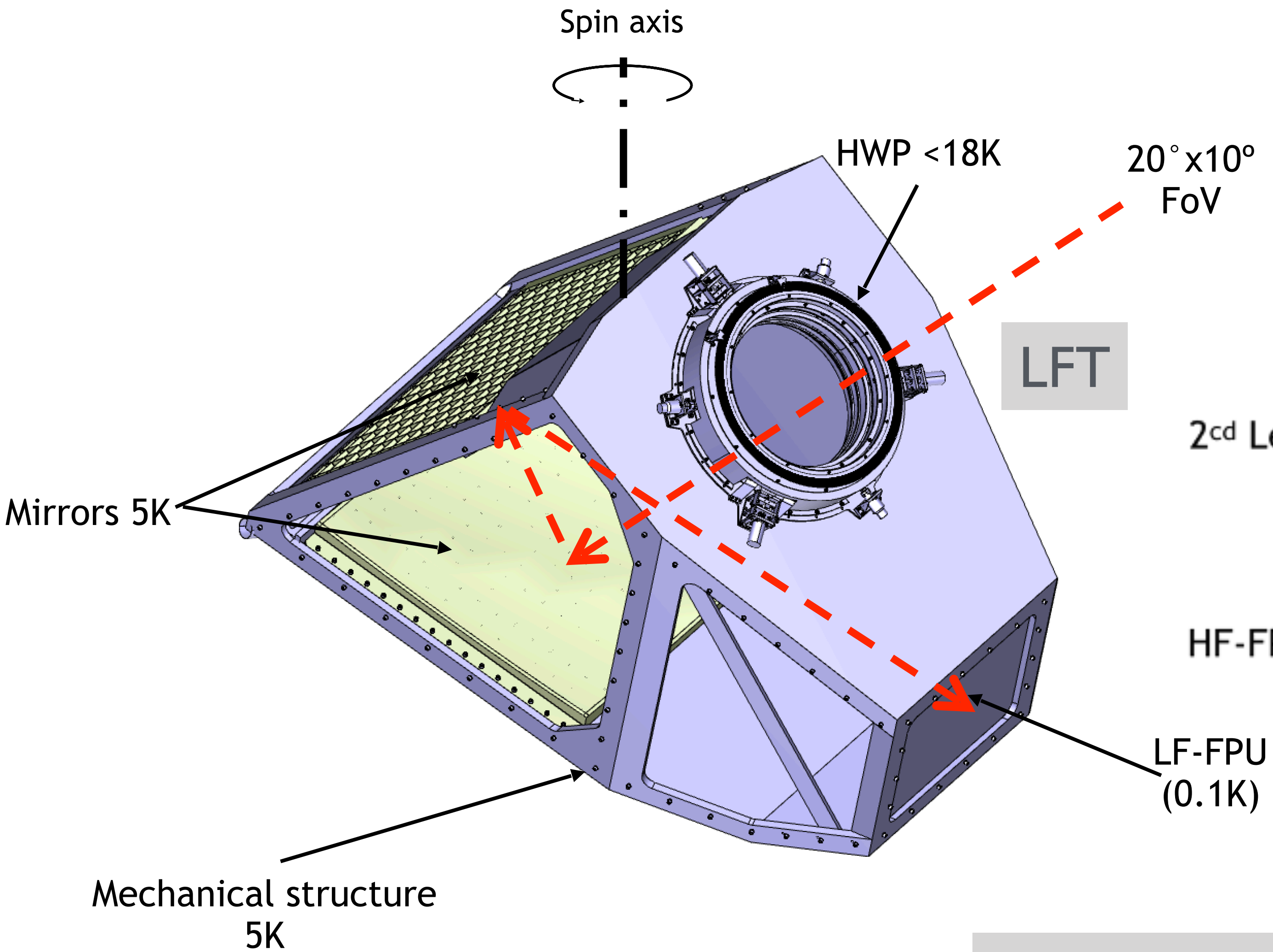
166 GHz — 448 GHz

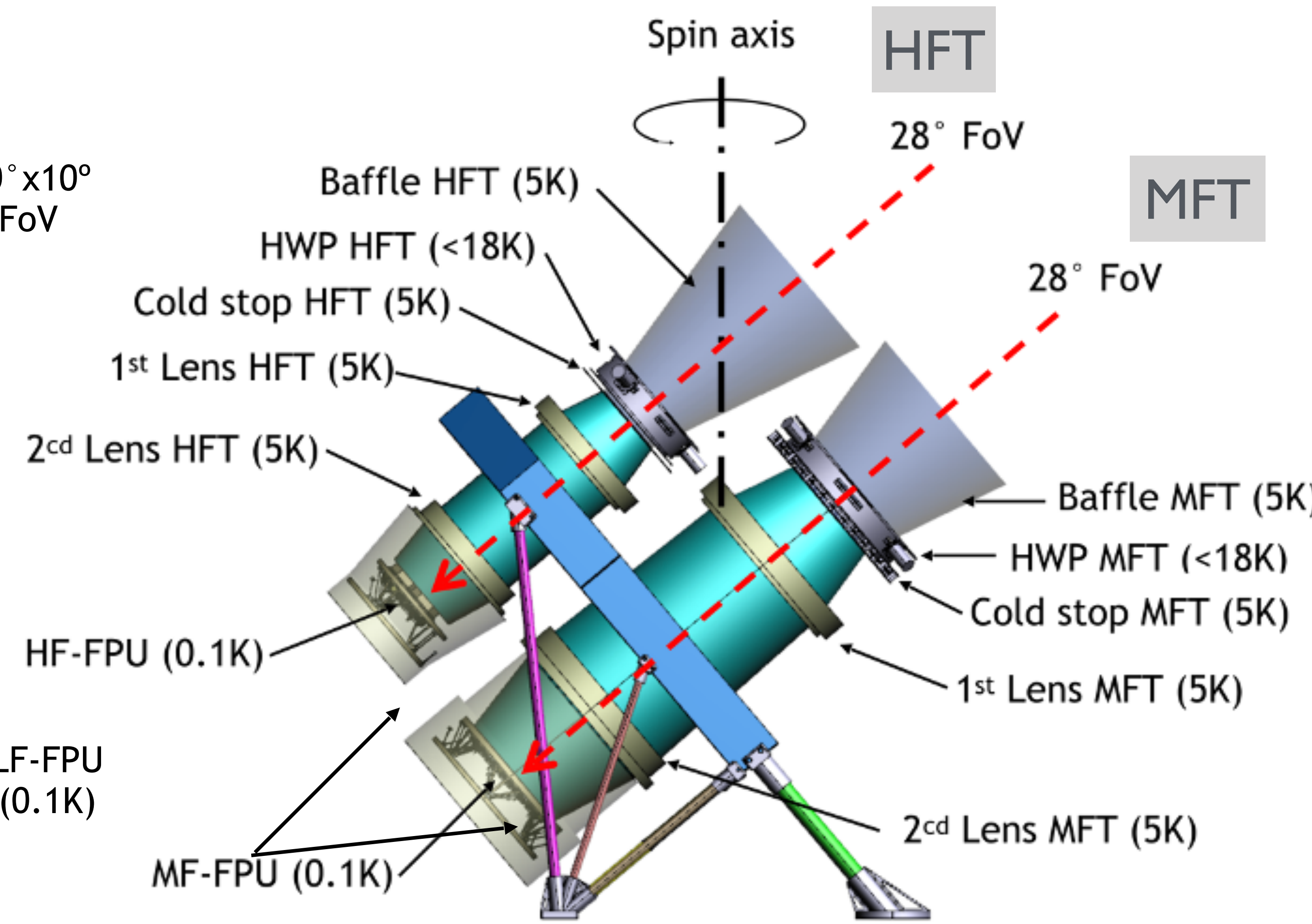
Mission Challenges



Systematics

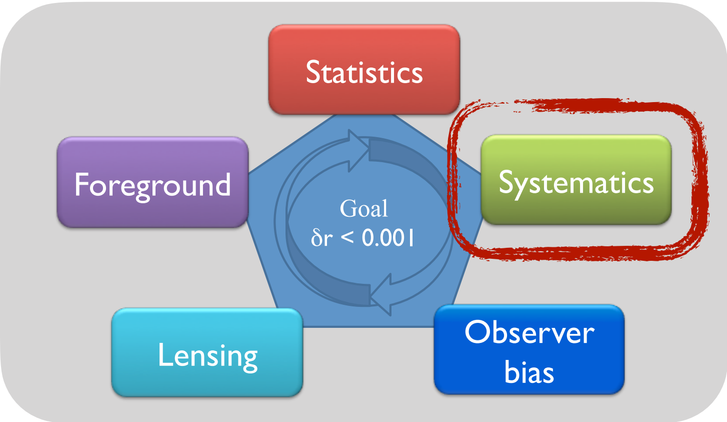
Full instruments and optics at 5K





Focal planes at 100mK

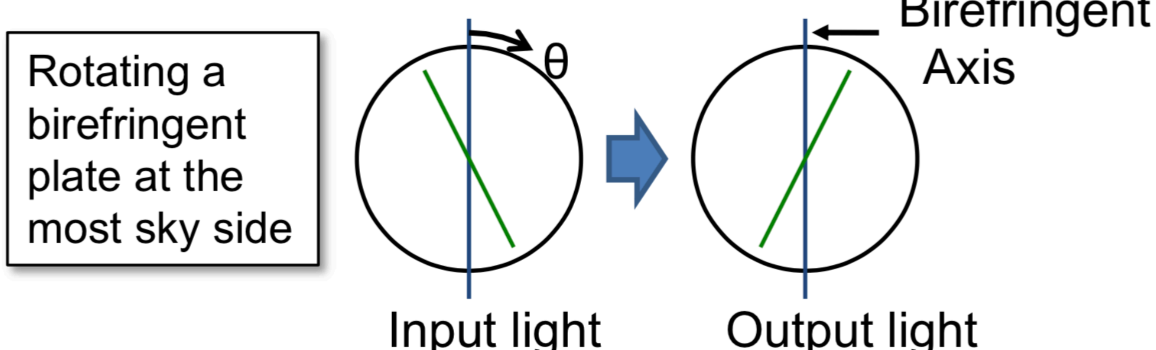
Mission Challenges



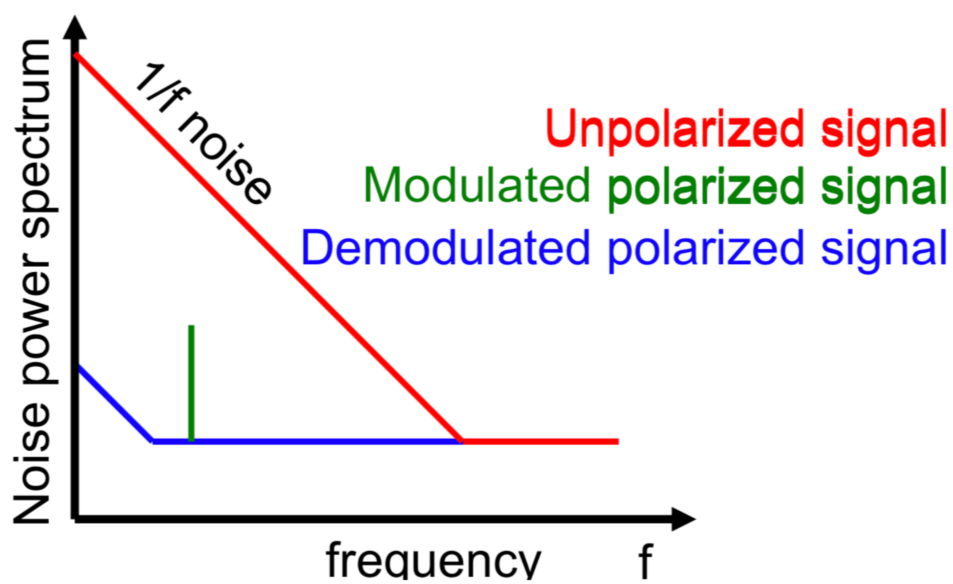
Systematics

Continuously Rotating Half-Wave Plates

2. Polarization modulator with a rotating half-wave plate (HWP) for 1/f noise & systematics reduction

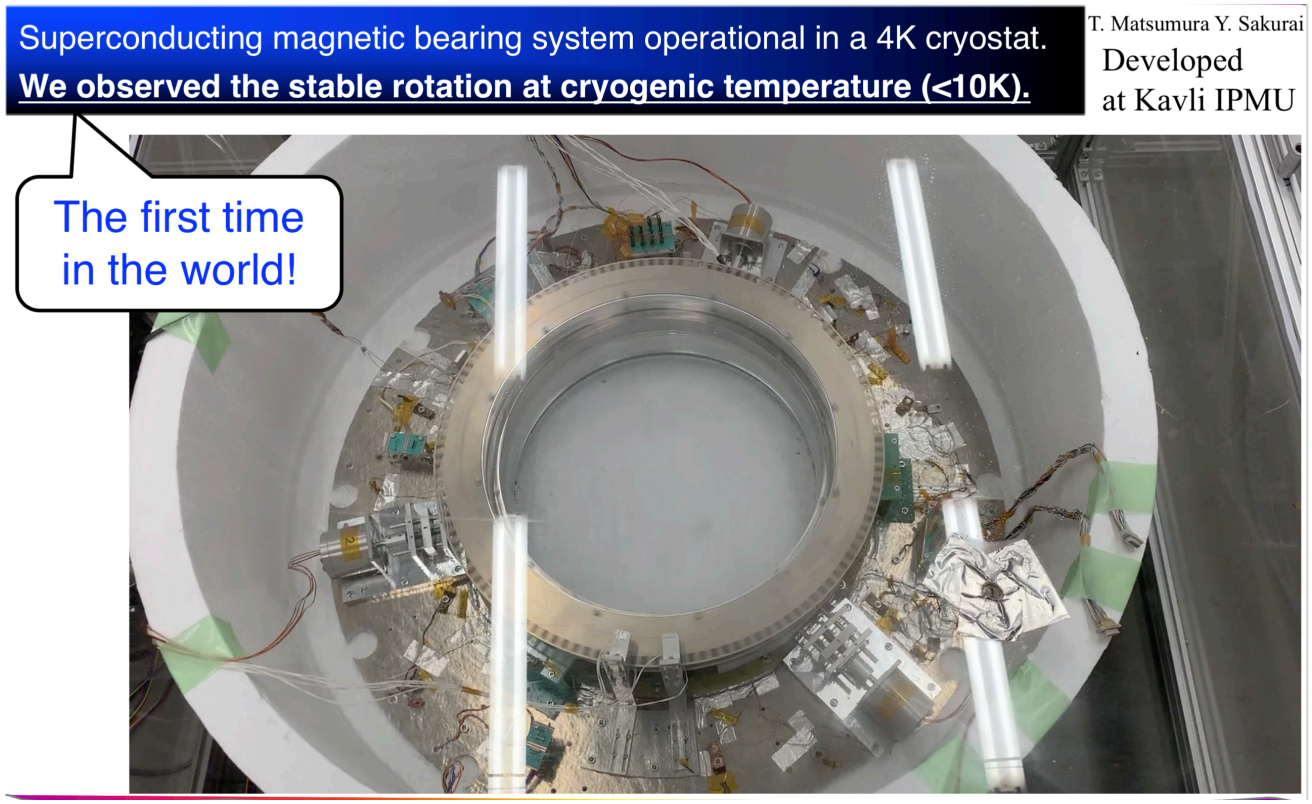


$$I + P\cos 4\theta_{\mathrm{HWP}}$$

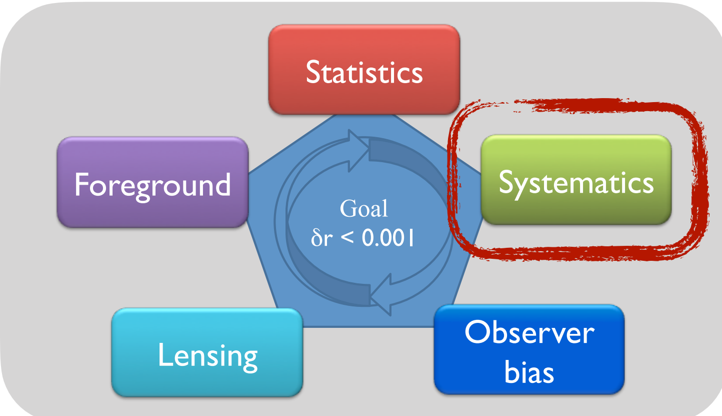


Magnetic sustentation

First prototype in the world developed at IPMU (Tokyo)



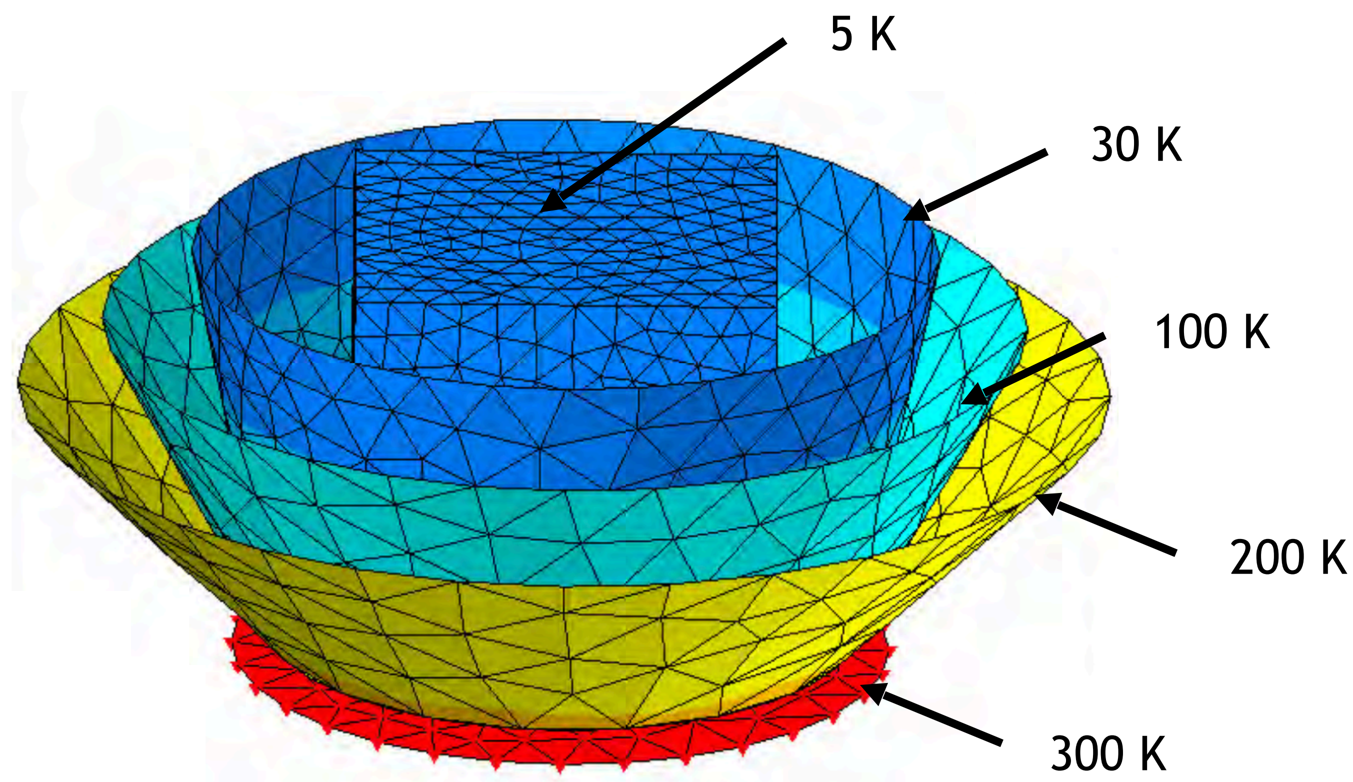
Parallel development in Italy

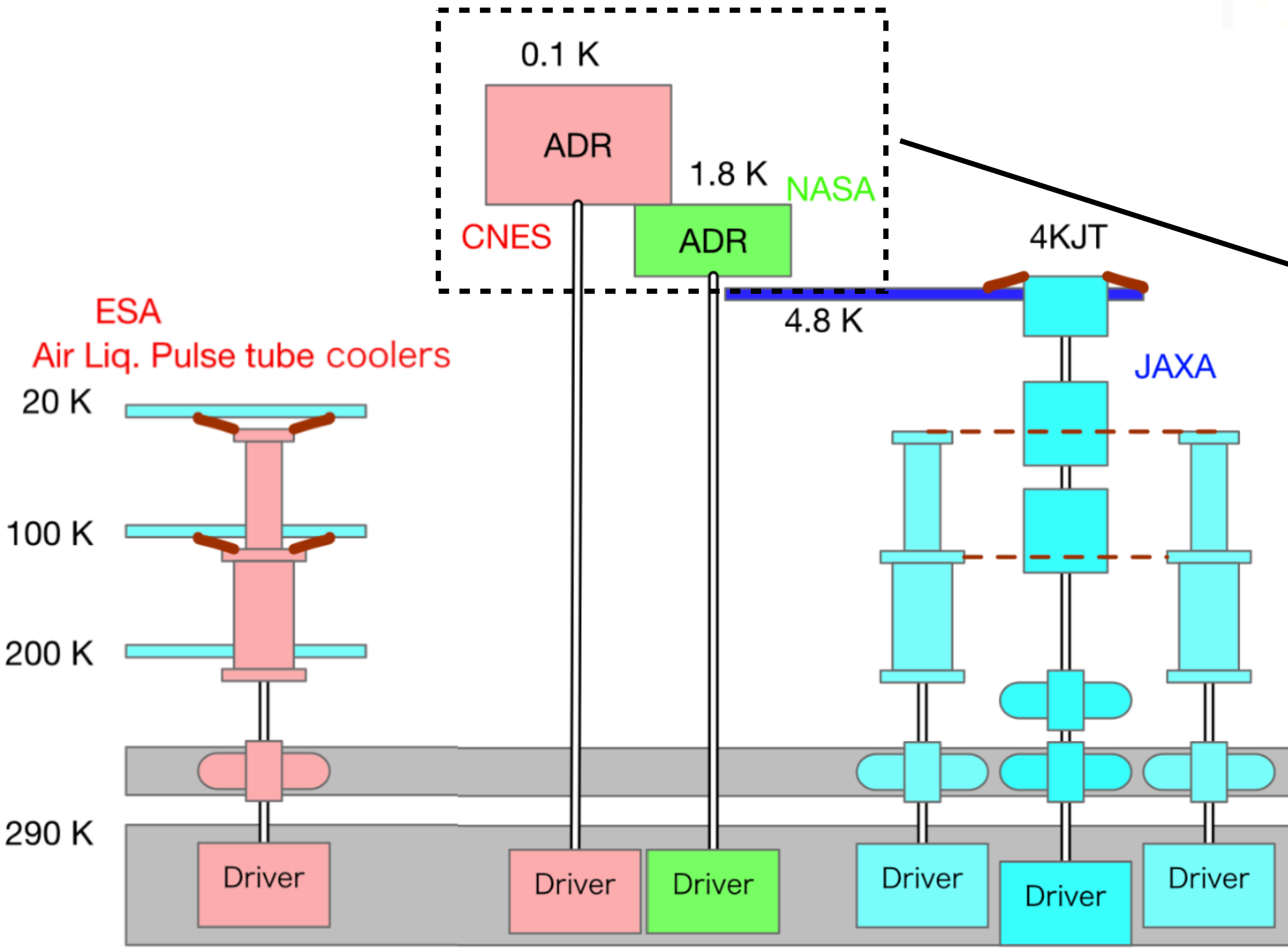


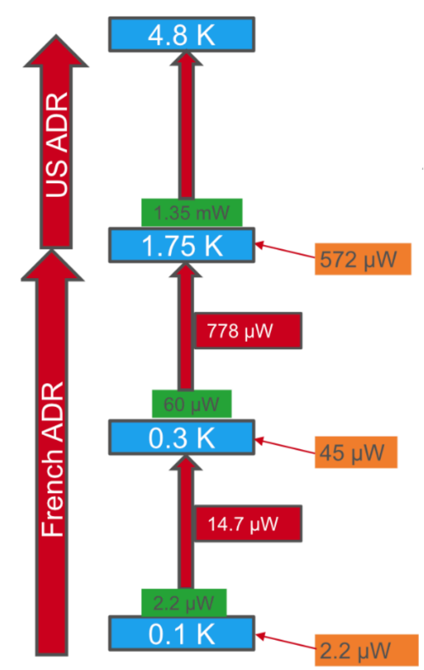
Systematics

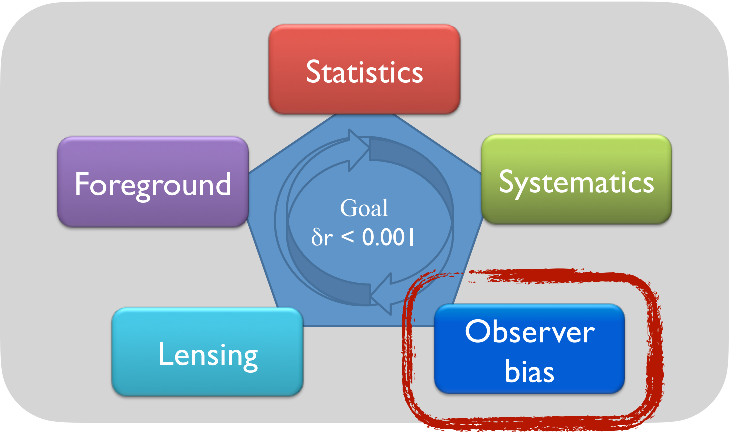
Cryo-chain

Continuous cooling at all stages, down to 0.1K, using multistage ADR



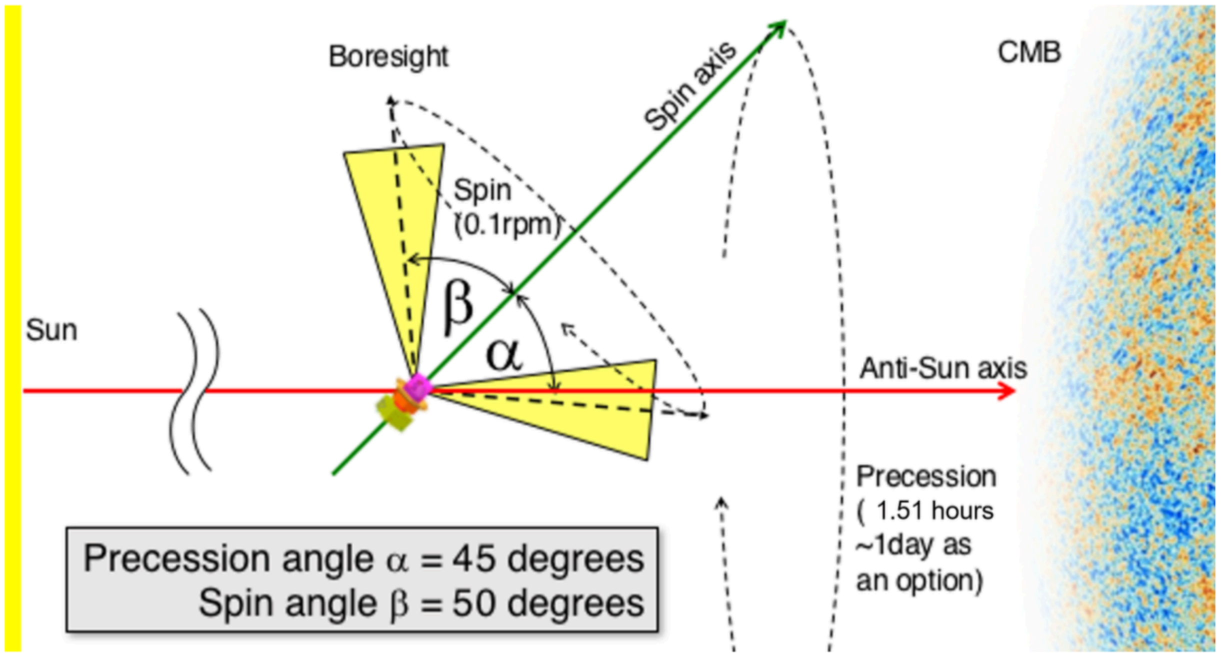


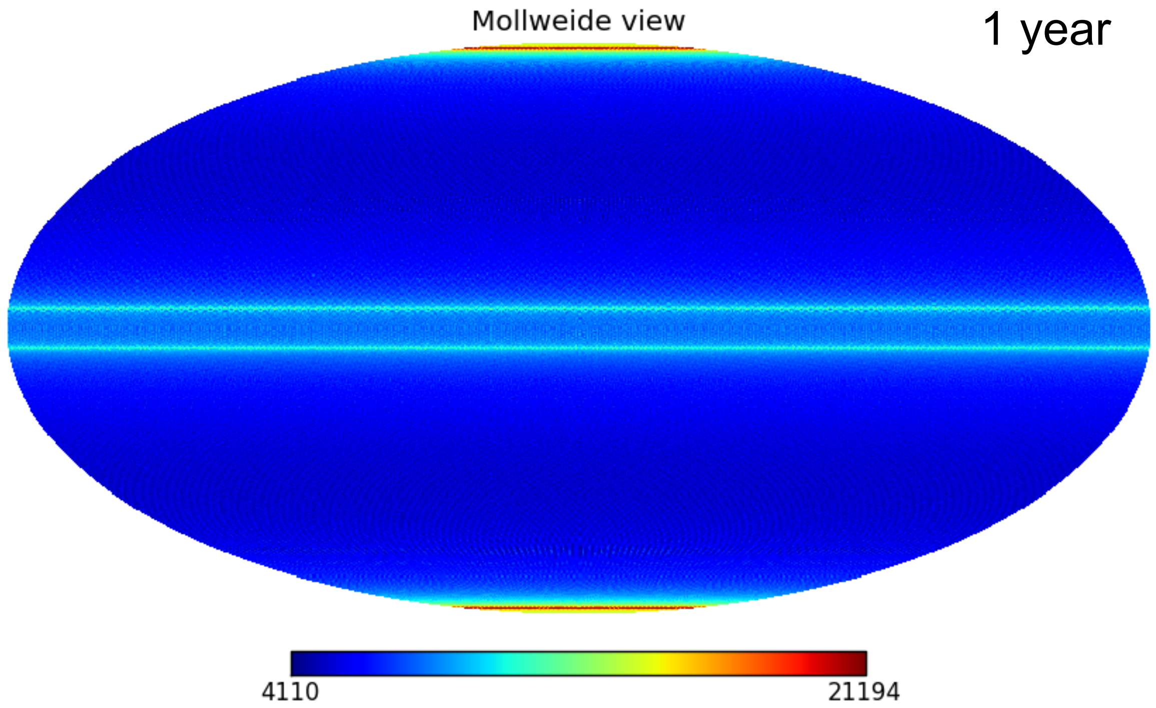




Whole Sky Survey

3 years of continuous all-sky survey

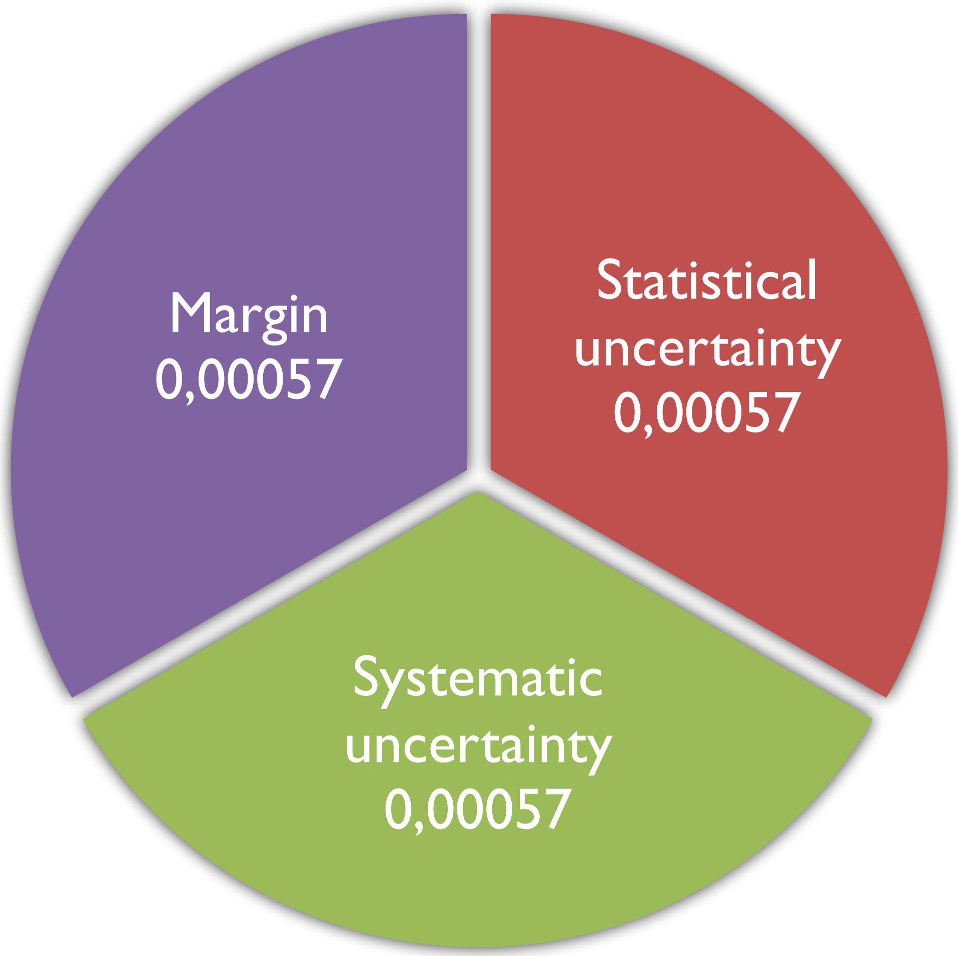




Scientific Outcomes

Full success

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



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

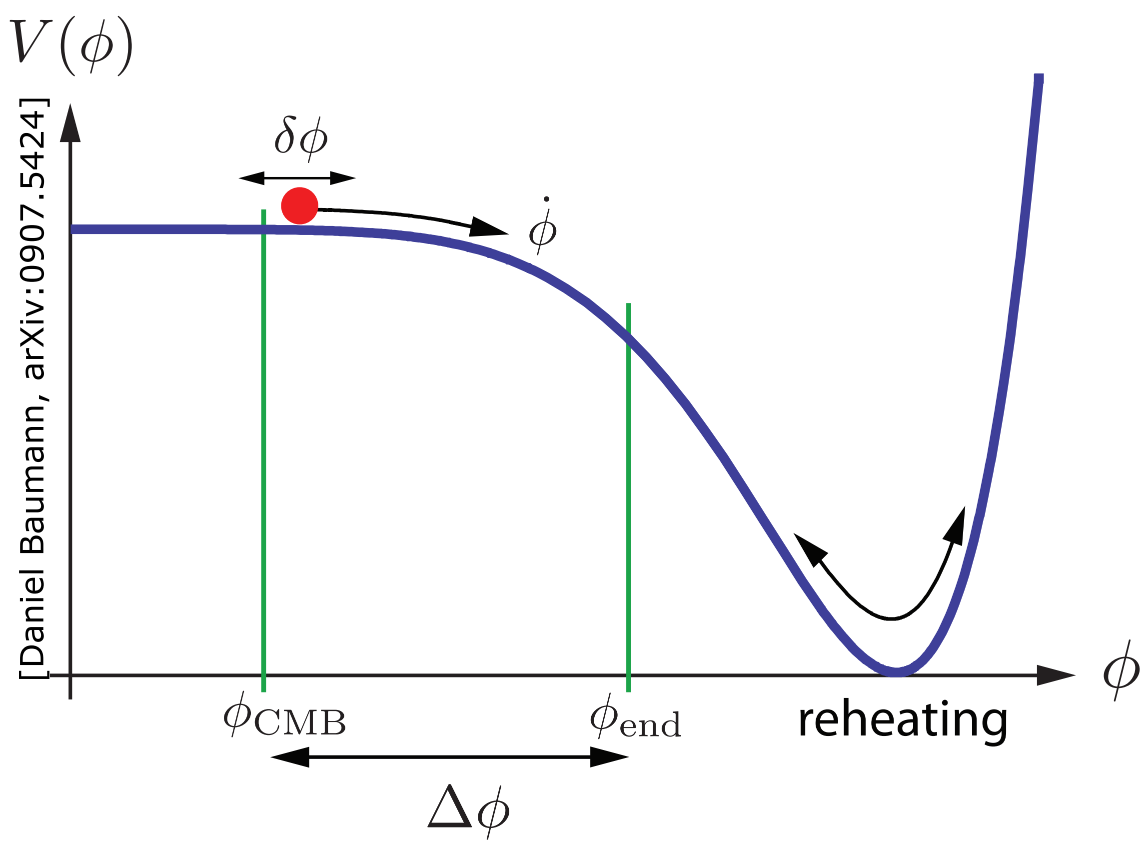
Systematic uncertainty
- Bias from 1/f noise
- Polarization efficiency & knowledge
- Disturbance to instrument
- Off-boresight pick up
- Calibration accuracy

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)**



- **r 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**

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

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

Scientific Outcomes

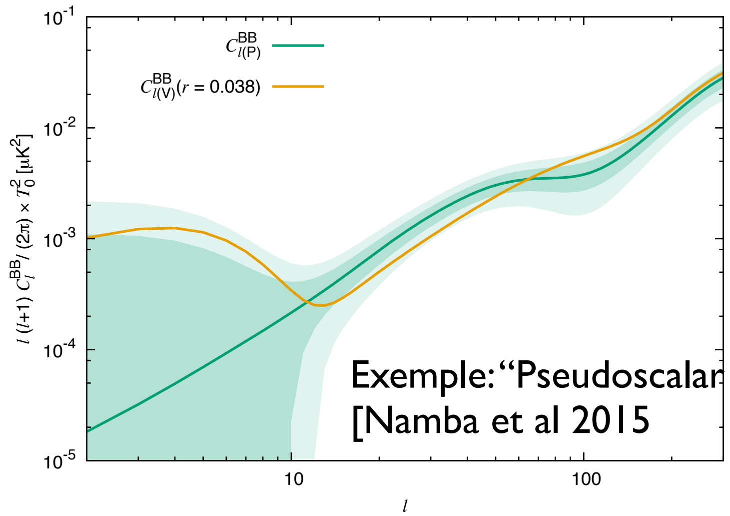
- within single field slow-roll inflation, the tensor perturbation obey the vacuum equation $\Box h_{ij} = 0$
- inducing the following statistical properties
  1. nearly scale invariant power spectrum $n_t = -r/8$
  2. nearly Gaussian probability distribution
  3. parity-conserving probability distribution

tensor tilt n_t

Other mechanism than single-field slow-roll inflation predict deviations from scale-invariant P_k (e.g. gravity inflation, open inflation, SU(2)-axion model, multi-field inflation…)

constraints on the primordial tensor power spectrum can distinguish between inflation models

Non-Gaussianity



Exemple: "Pseudoscalar model" [Namba et al 2015

indistinguishable with BB for ℓ >10 alone

⬇

non-Gaussian features using BBB bi-spectrum

Parity-violating

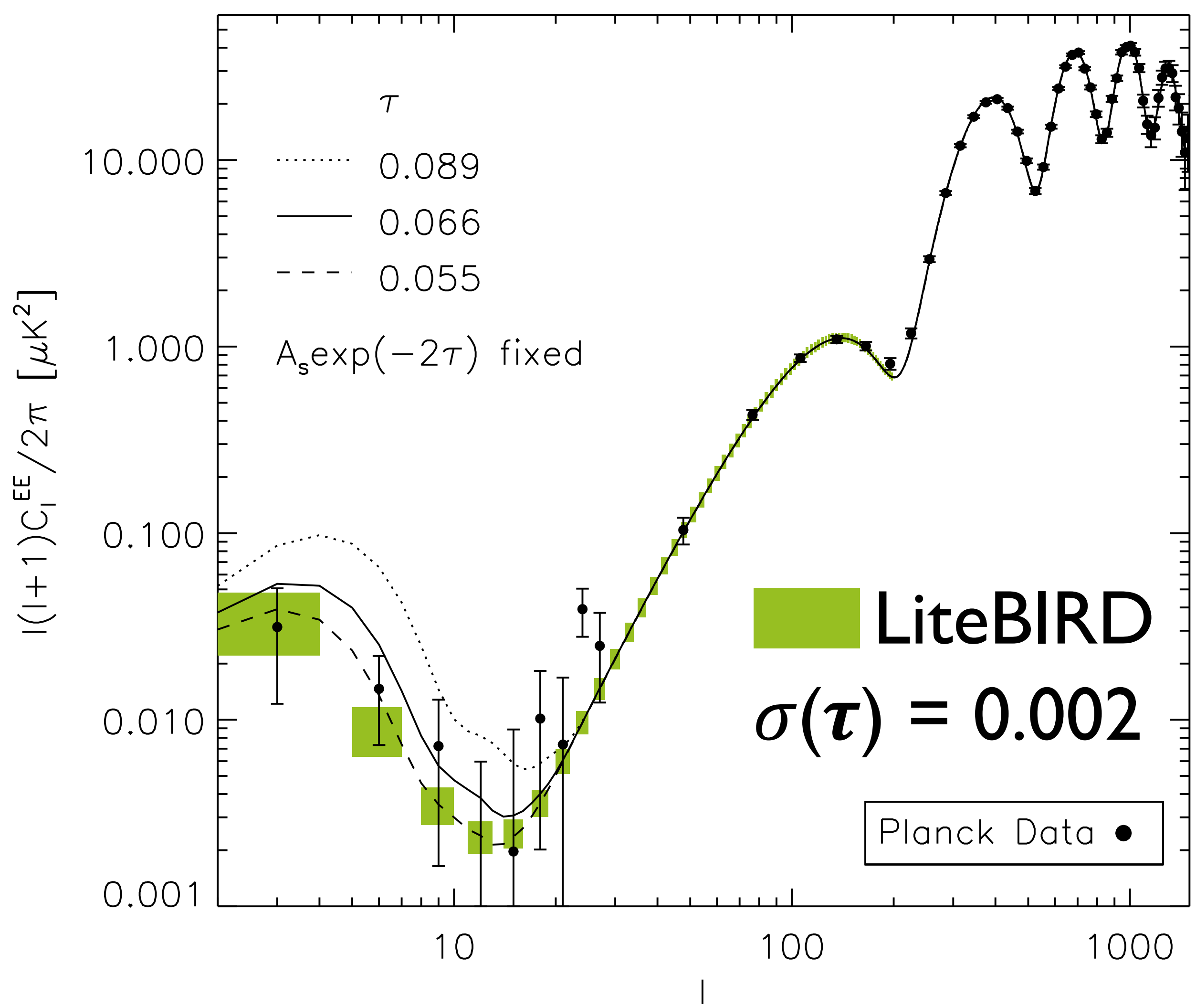
Parity-violating coupling of a scalar field to the electromagnetic tensor induces a rotation of the polarization direction

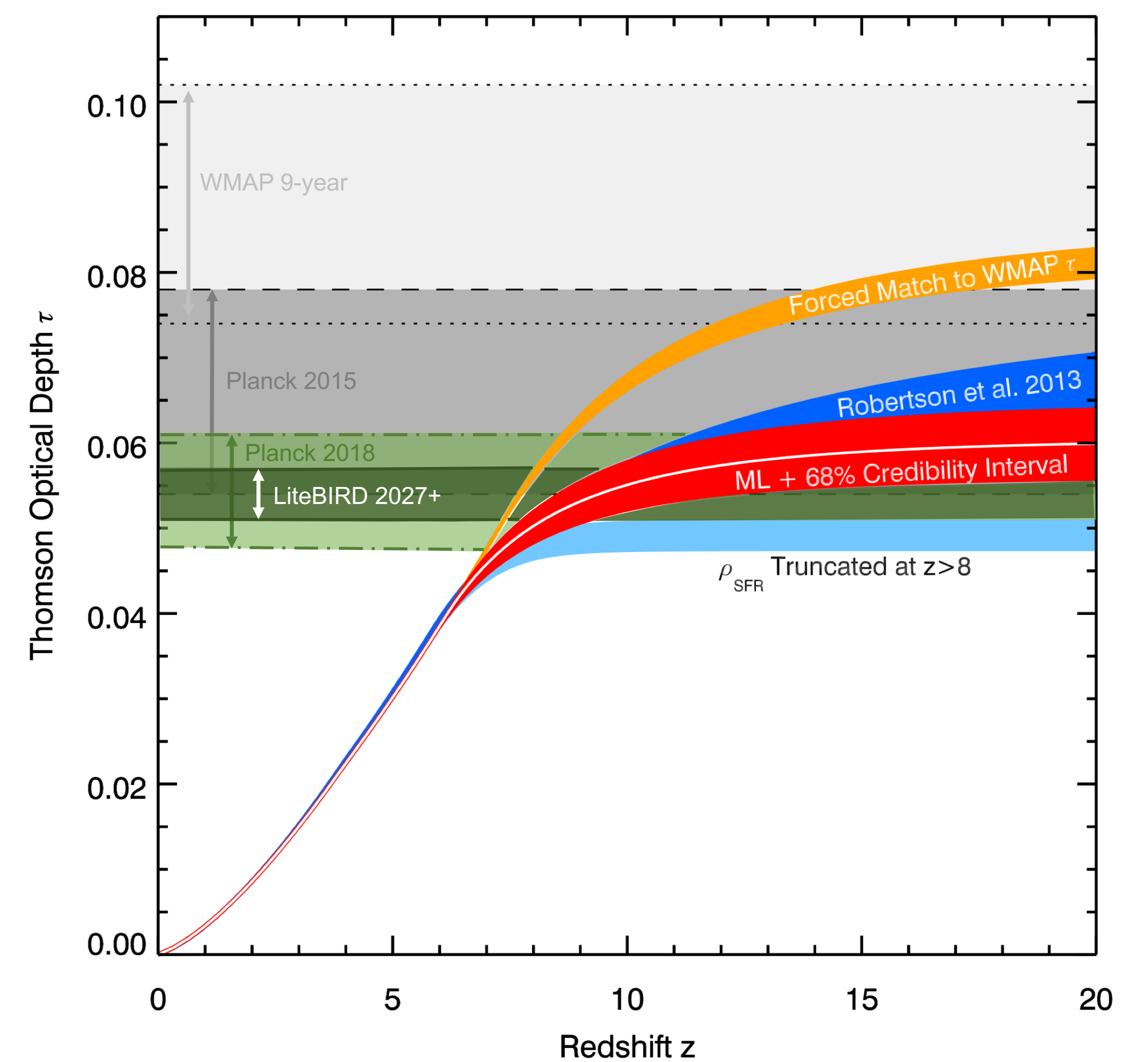
➡ TB and EB non longer zero

Scientific Outcomes

Reionisation

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





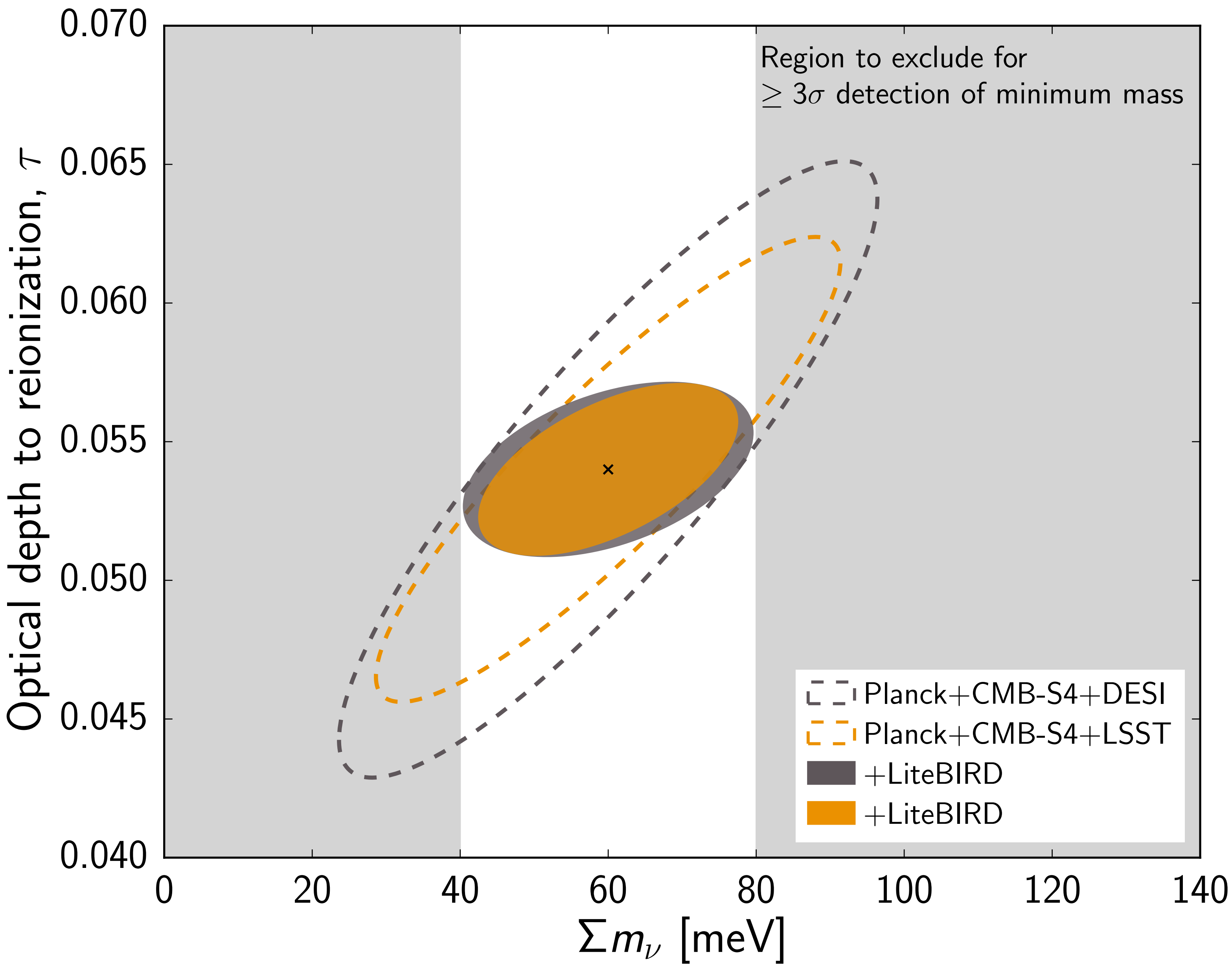
$\sigma(\tau)$ better than current Planck constraints by a factor 2

Scientific Outcomes

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)

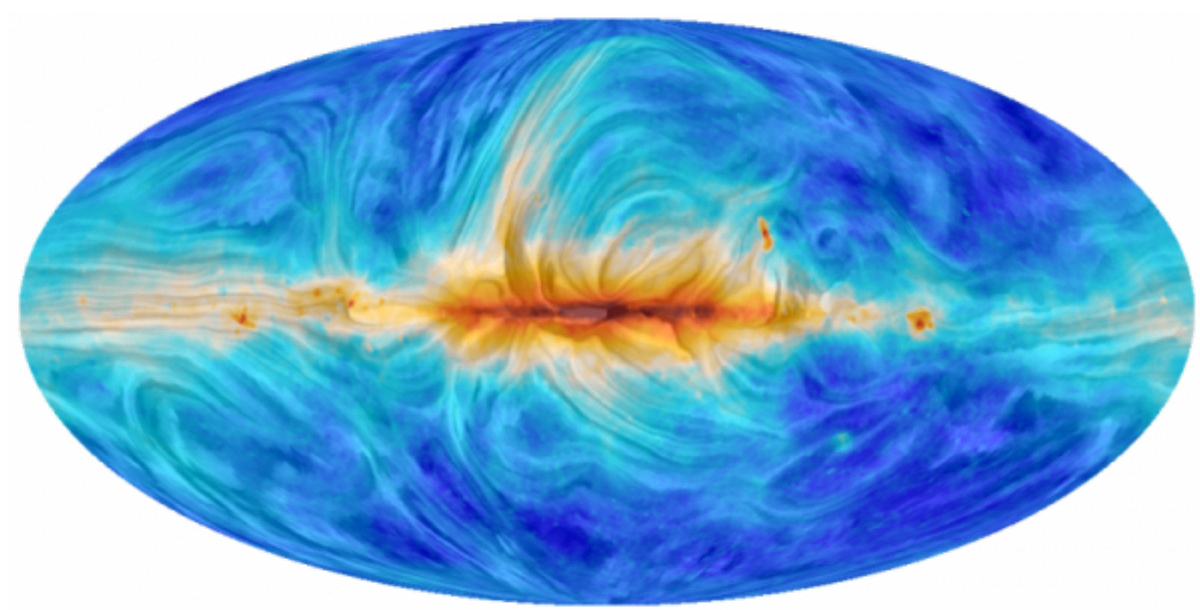


Scientific Outcomes

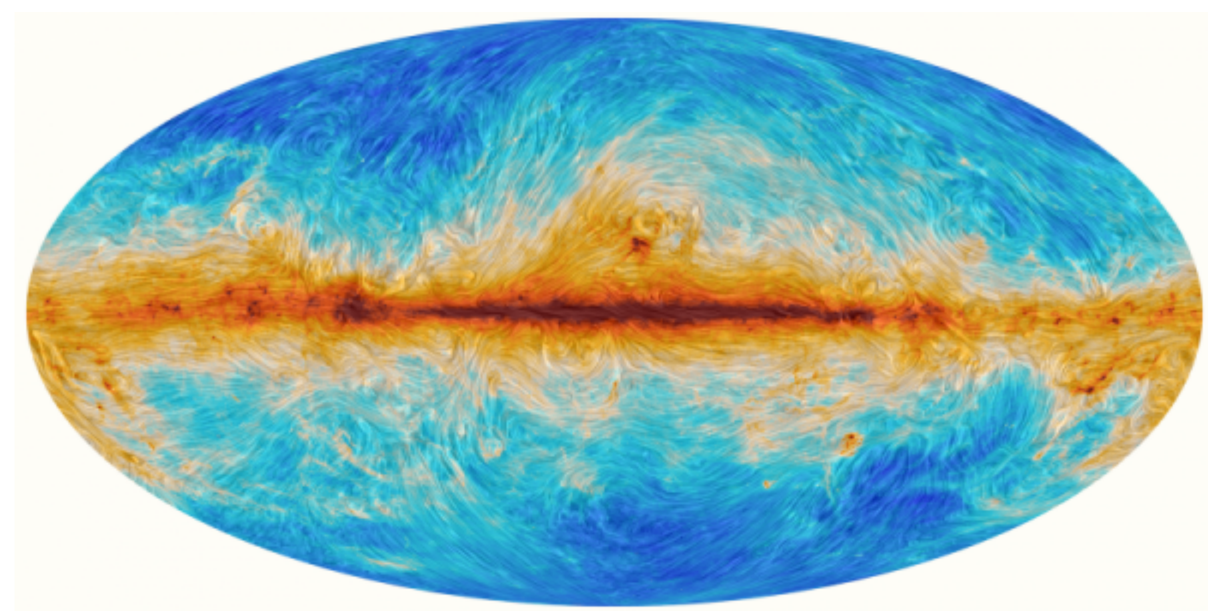
Galactic Science

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

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

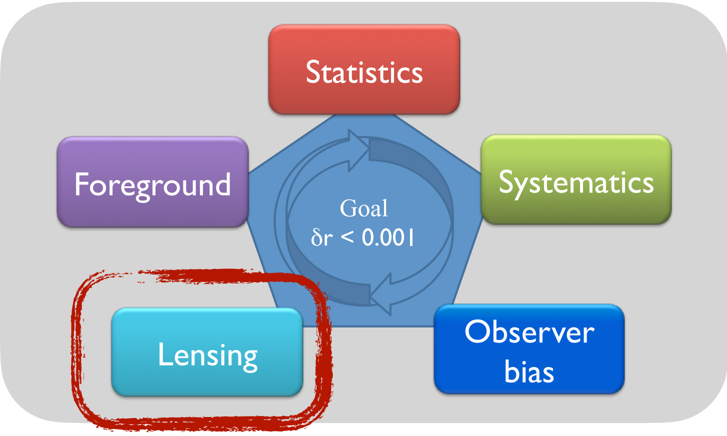


Synchrotron



Dust

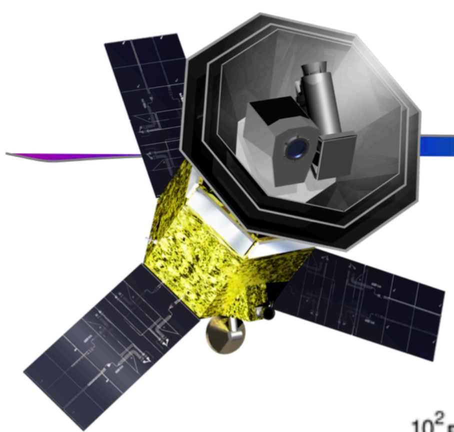
Scientific Outcomes



Extra success

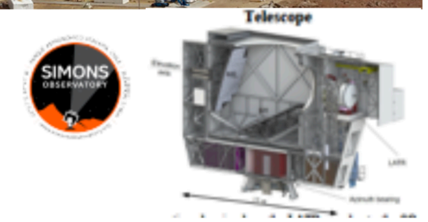
- improve σ(r) with external observations
- delensing improvement to σ(r) can be a factor ≥ 2

Vision for 2020's

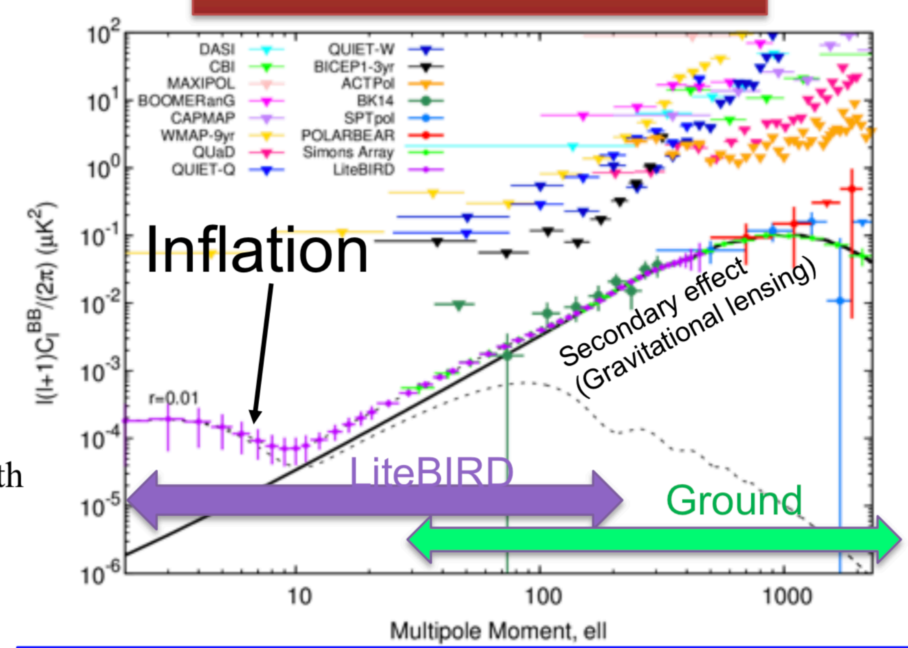


X

Powerful Duo



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



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

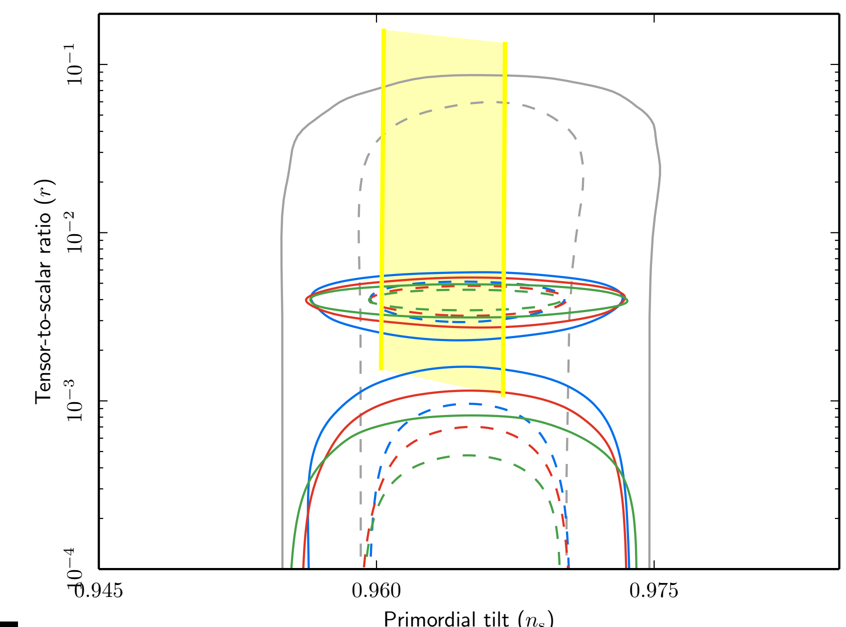
- This powerful duo is the best cost-effective way.
- Great synergy with two projects

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



Scientific Outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Full success
  - Extra success
  - Beyond the B-mode power spectrum

- Galactic science
- Optical depth and reionization of the Universe
- Cosmic birefringence

- Mapping the hot gas in the Universe
- Anisotropic CMB spectral distortions
- Elucidating anomalies with polarization
- Correlation with other data sets

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 2029

Expected sensitivity on r

Full Success :
$\sigma(r) < 1 \times 10^{-3}$ (for r=0)
$2 \leq \ell \leq 200$

without de-lensing !

Could gain a factor of 2 or more
when combining with other data

with de-lensing

International collaboration

Strong European involvement