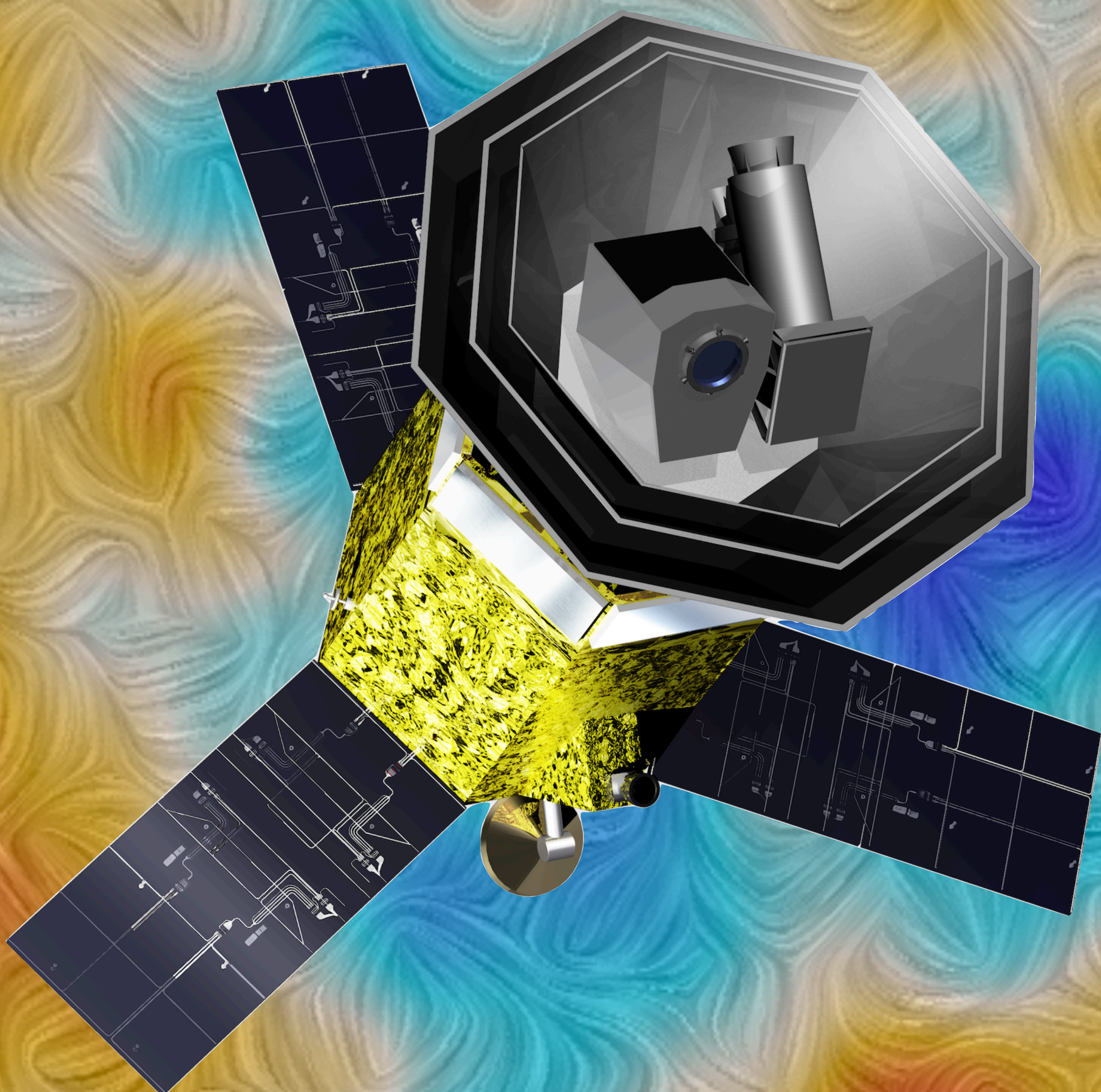
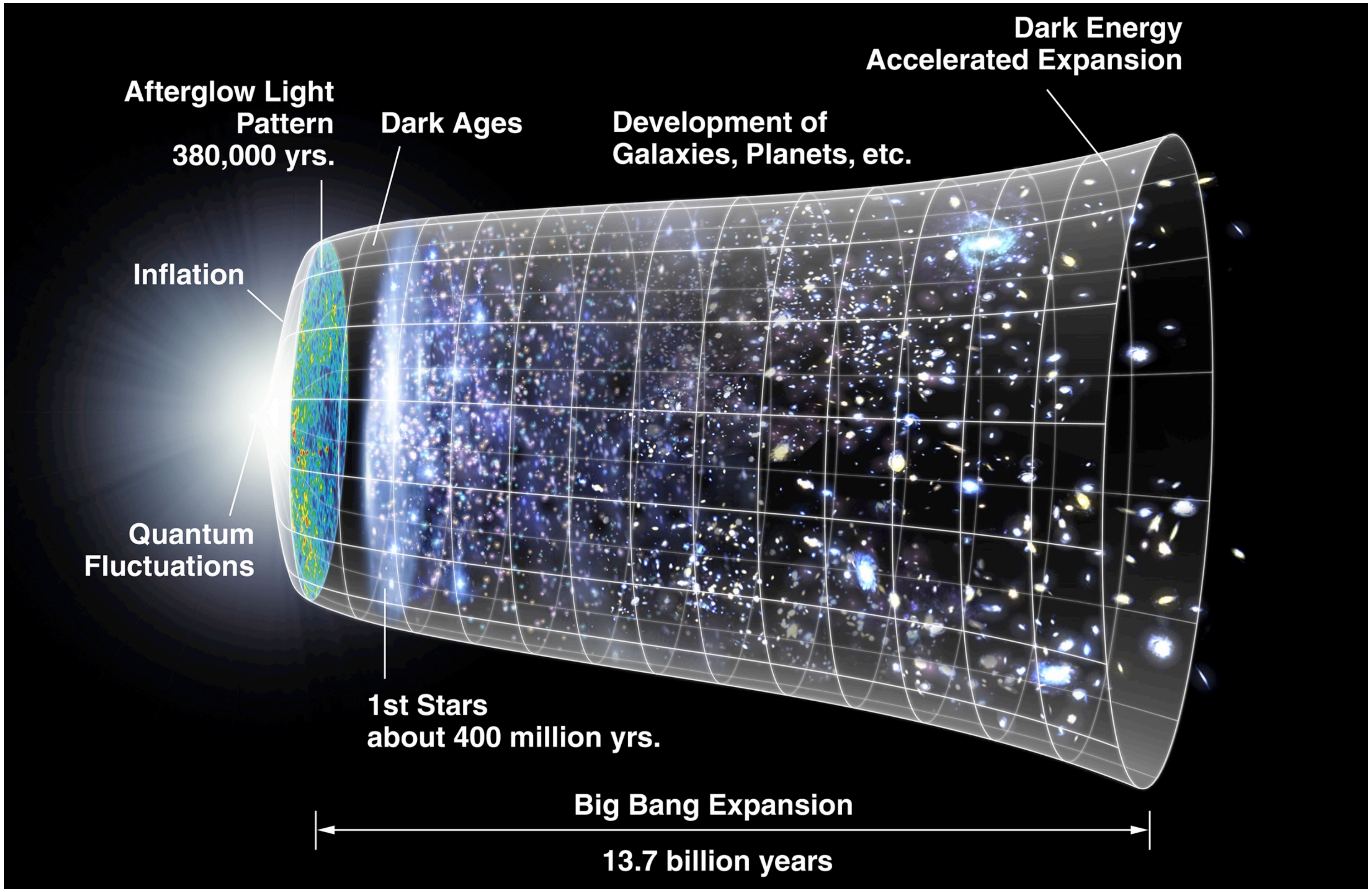
LiteBIRD and the Quest of the Primordial Gravitational Waves

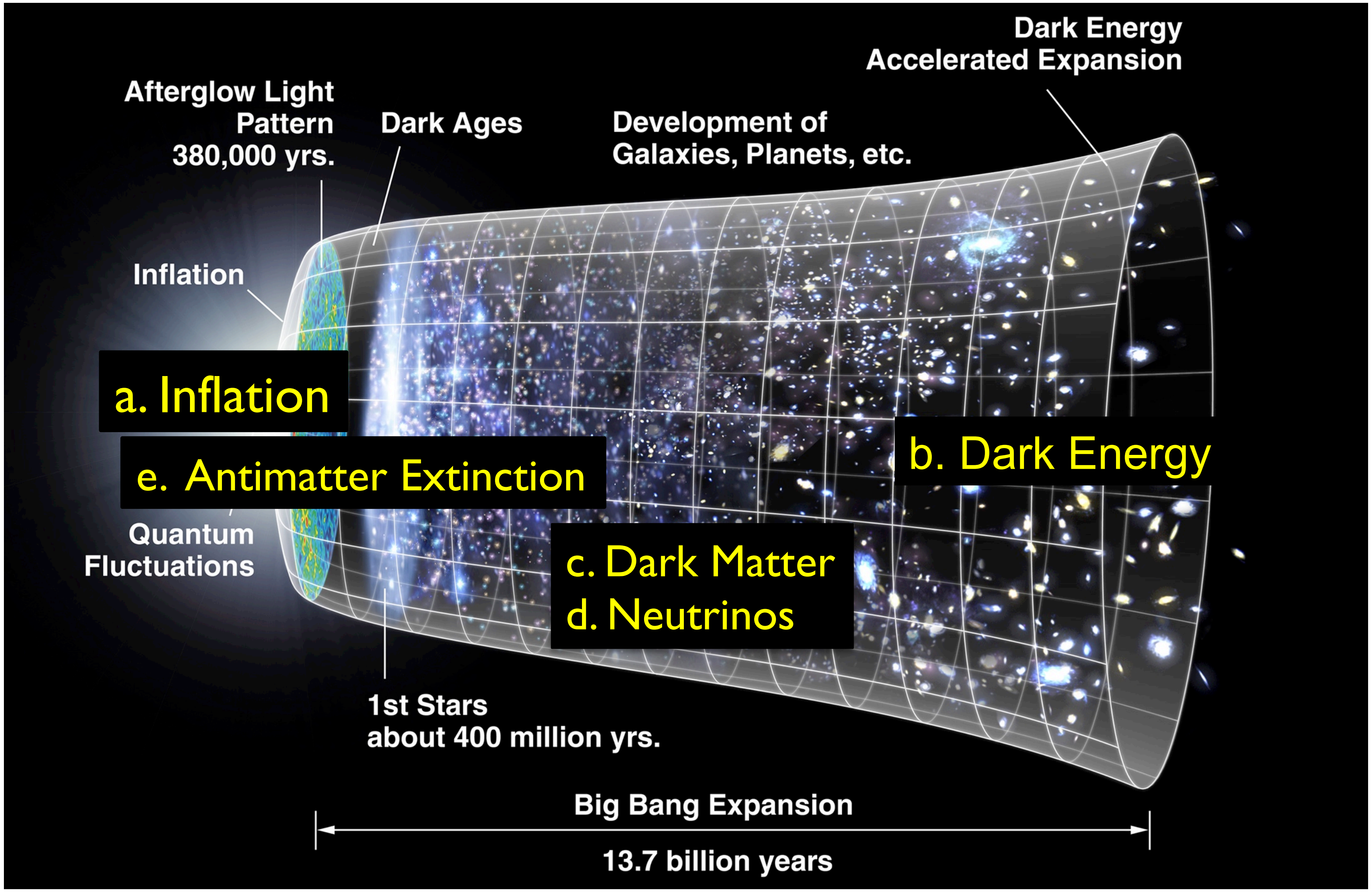


L. Montier
on behalf of LiteBIRD Collaboration

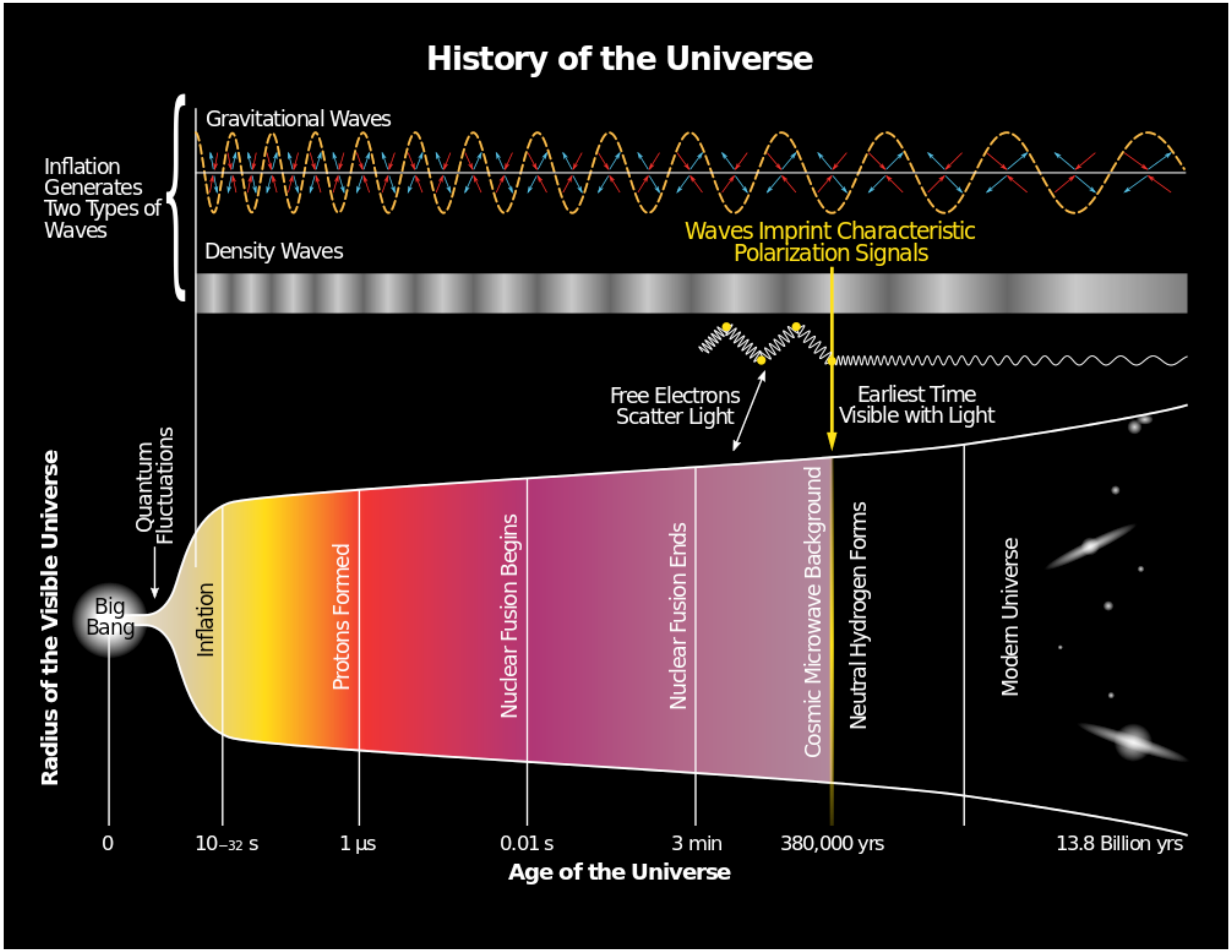
Looking for Primordial Gravitational waves



Looking for Primordial Gravitational waves

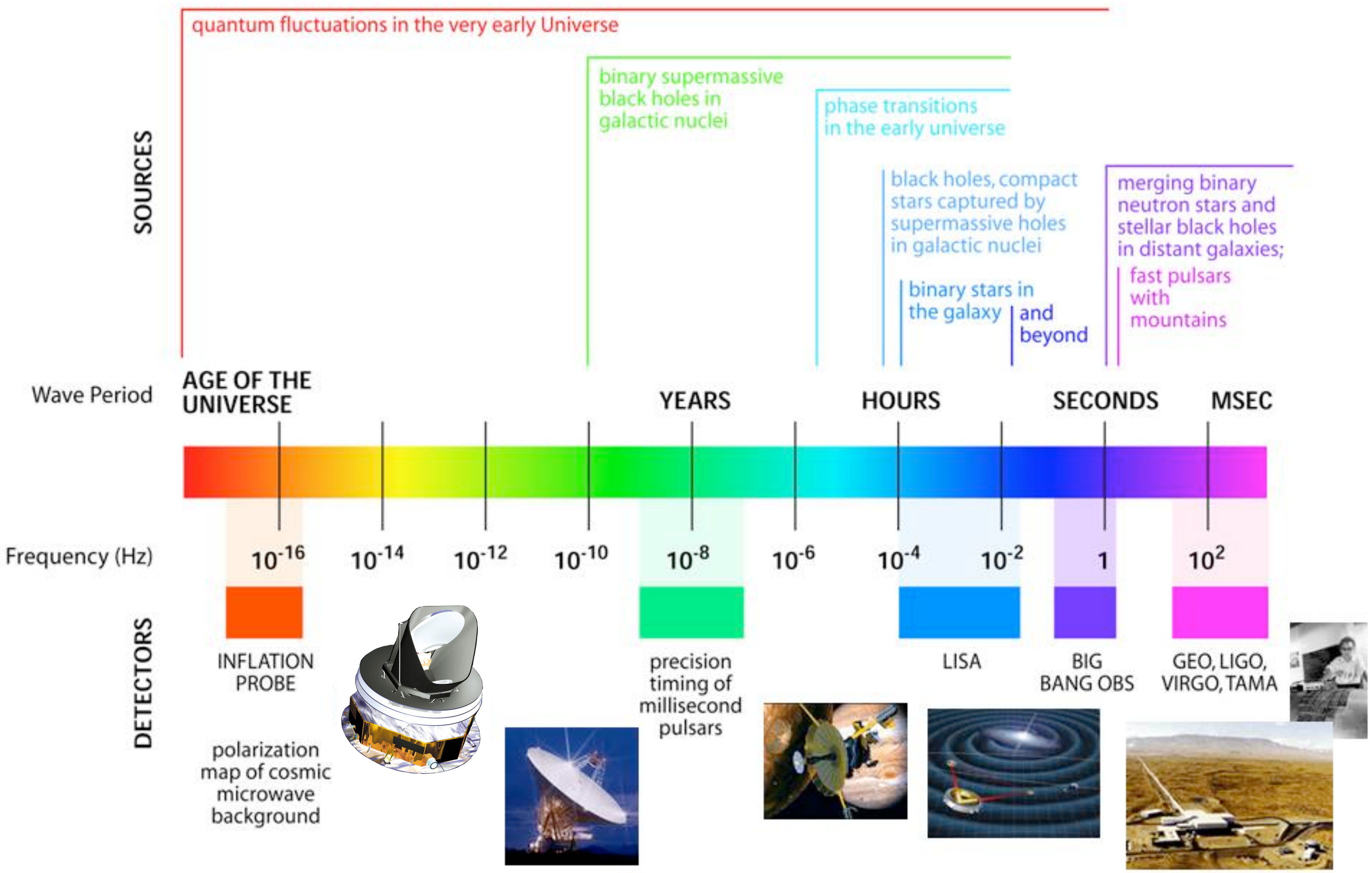


Looking for Primordial Gravitational waves

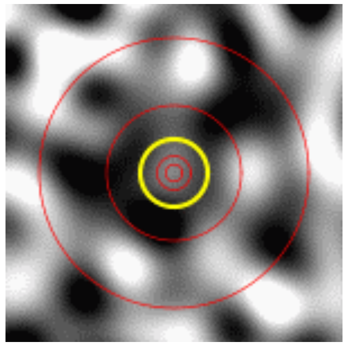


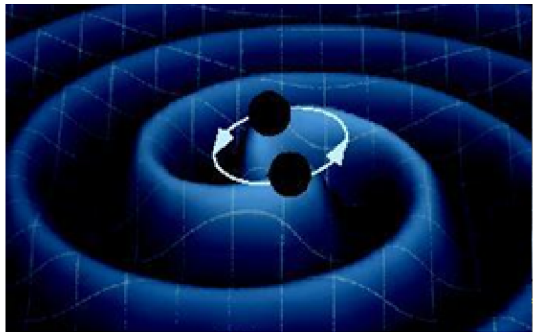
Looking for Primordial Gravitational waves

Big leap between LISA and LiteBIRD



LiteBIRD
Gravitational waves with quantum origin

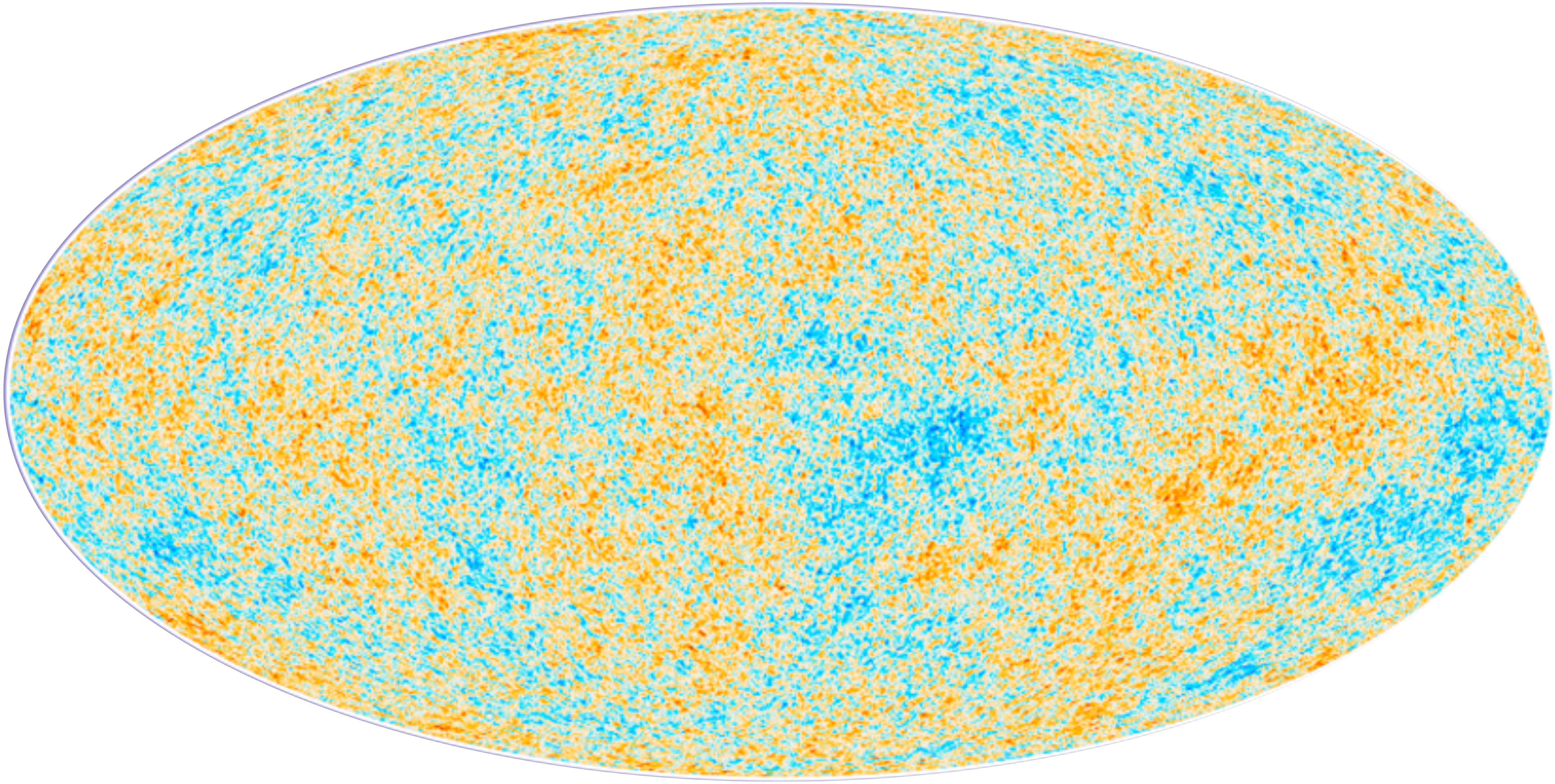




LISA
Gravitational waves with classical origin

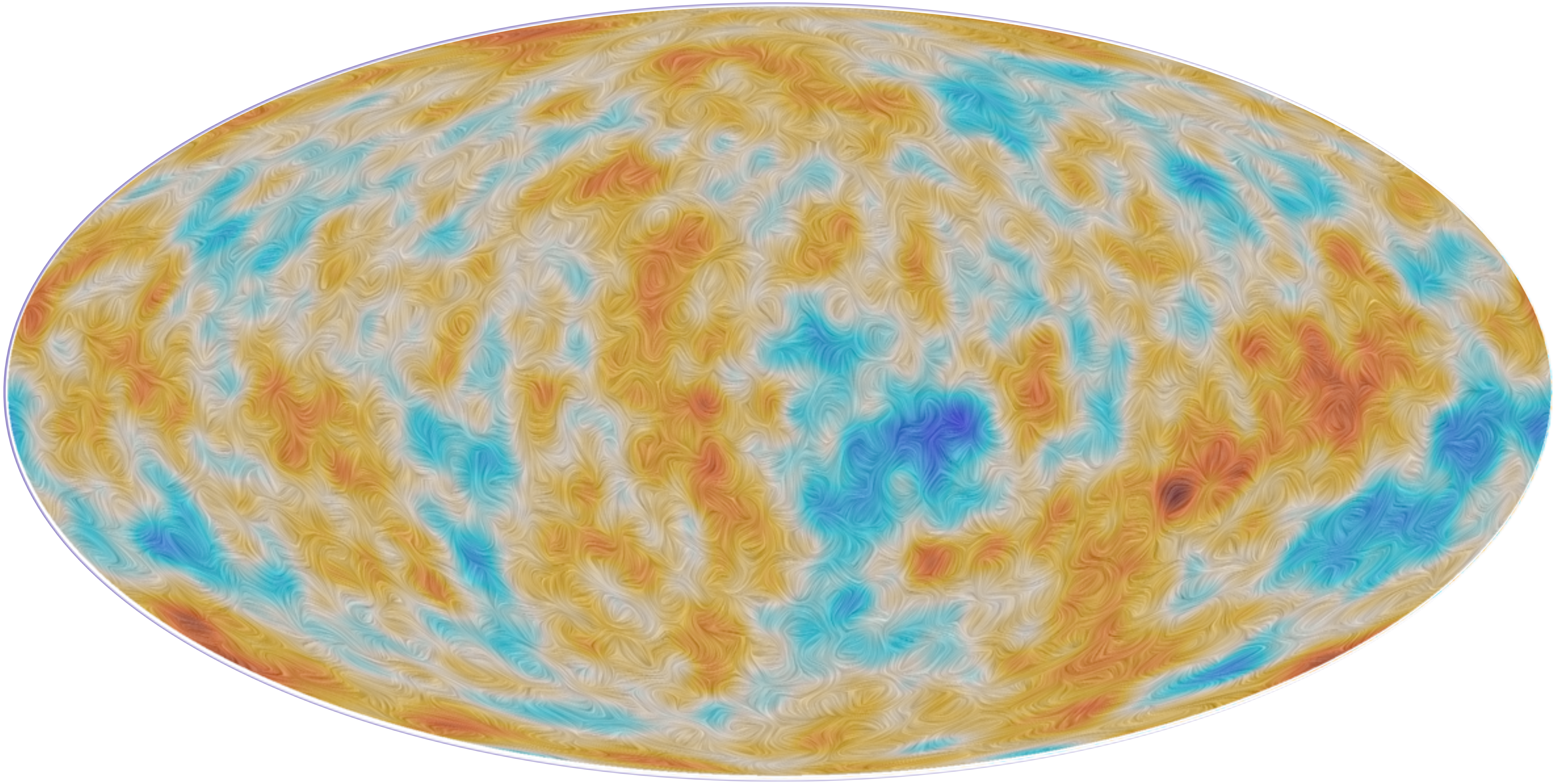
Looking for Primordial Gravitational waves

Emission from CMB measured by Planck Mission



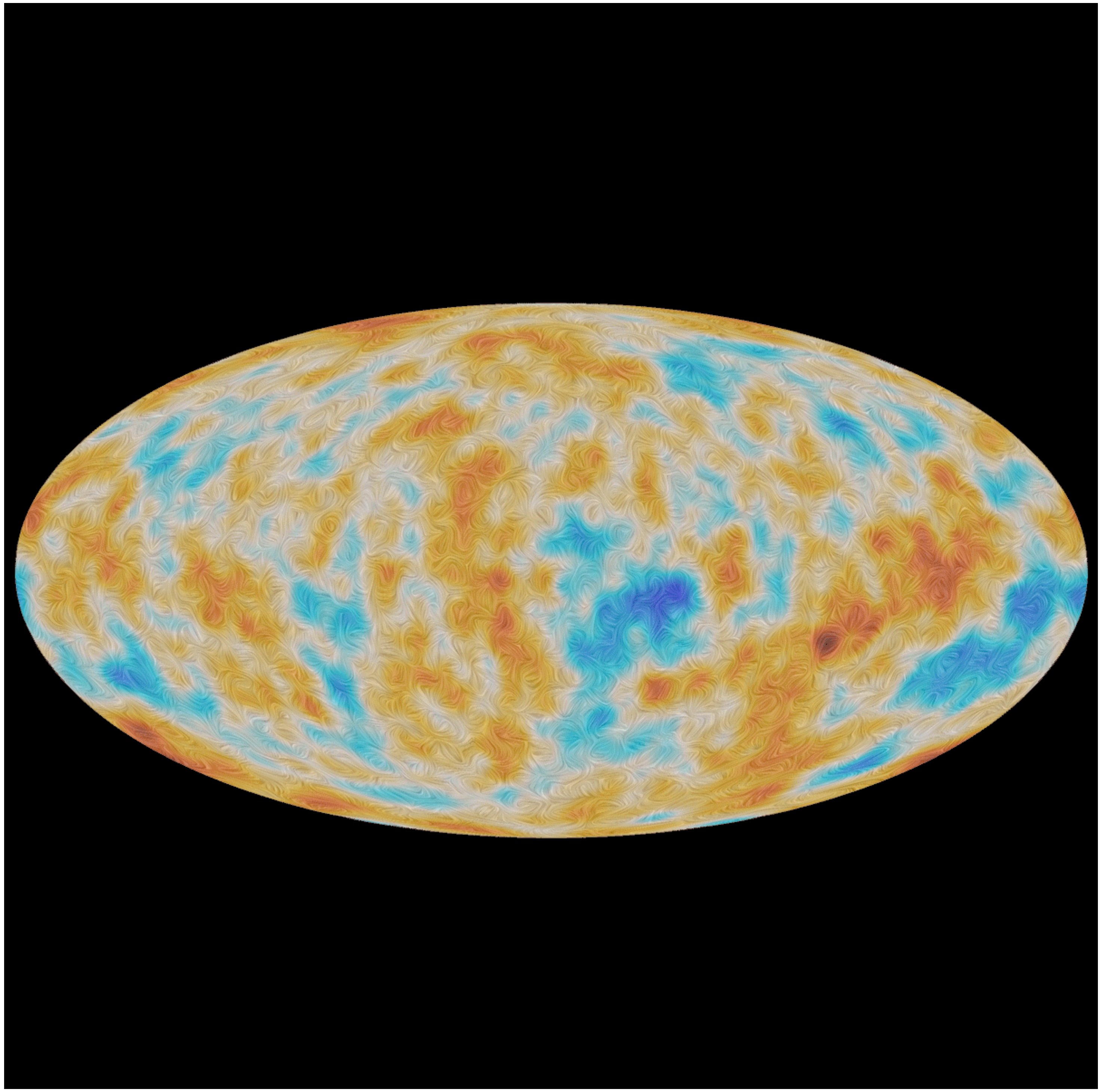
Looking for Primordial Gravitational waves

Polarised emission from CMB measured by Planck Mission



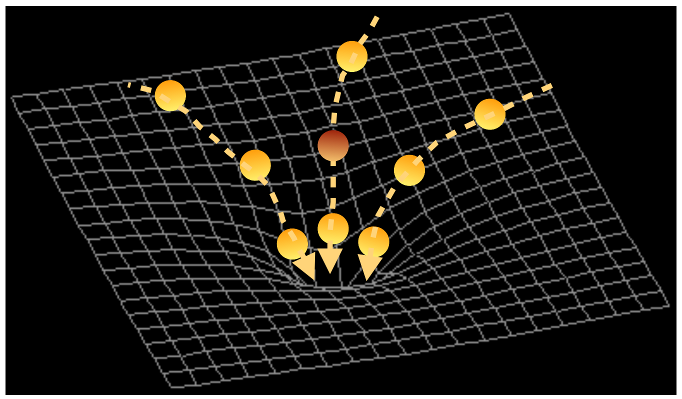
Looking for Primordial Gravitational waves

The imprints of gravitational waves on CMB

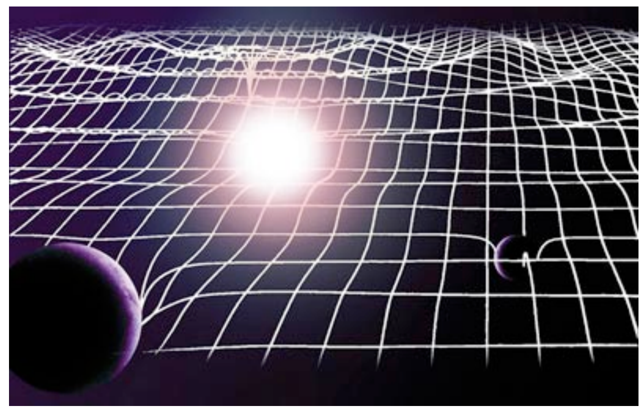


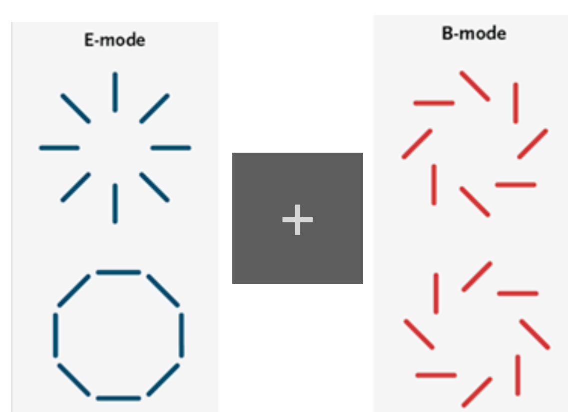
Looking for Primordial Gravitational waves

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**

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

$$r = A_t / A_s$$

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

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

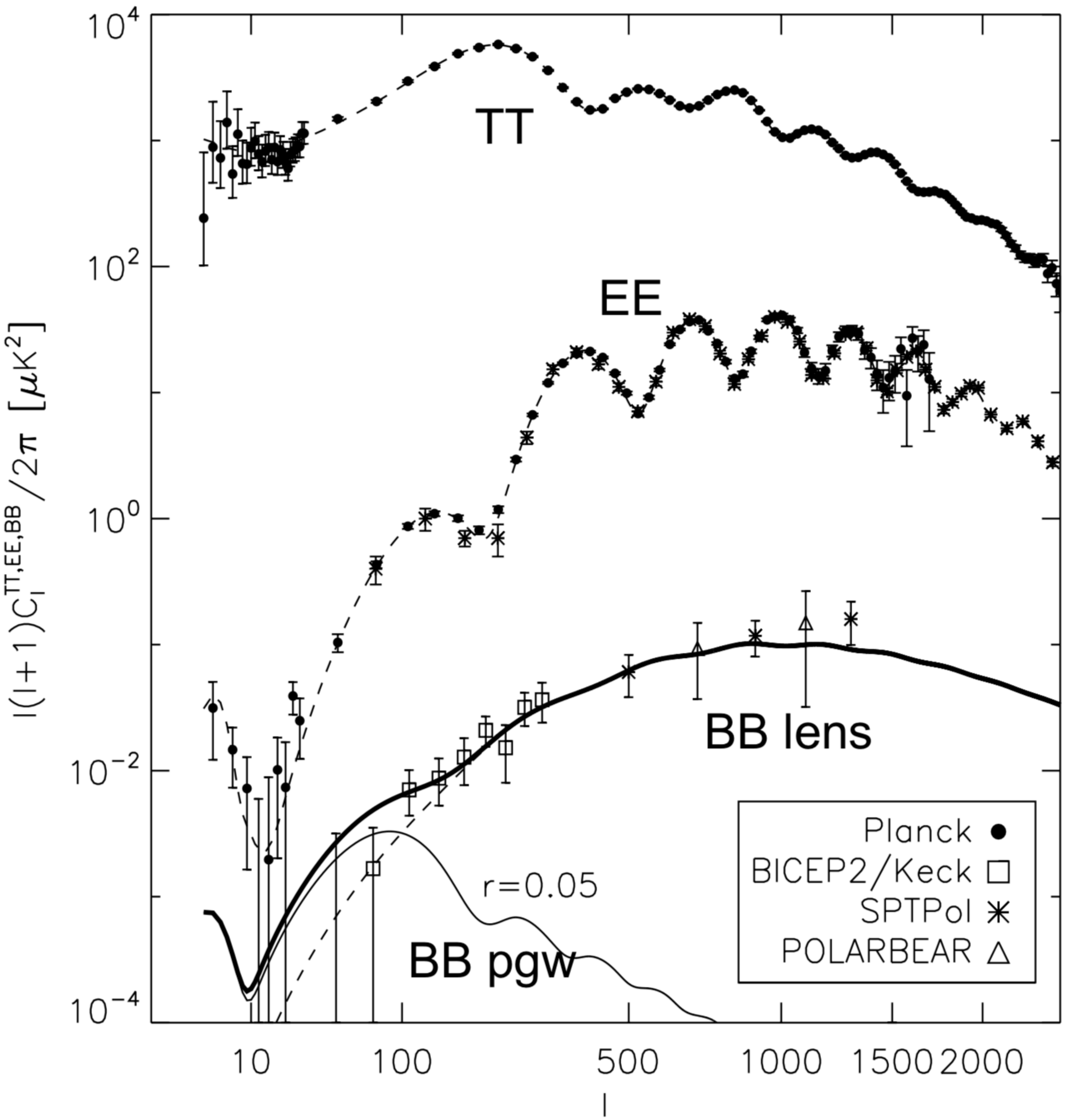
From Shibuya

Looking for Primordial Gravitational waves

From Shibuya

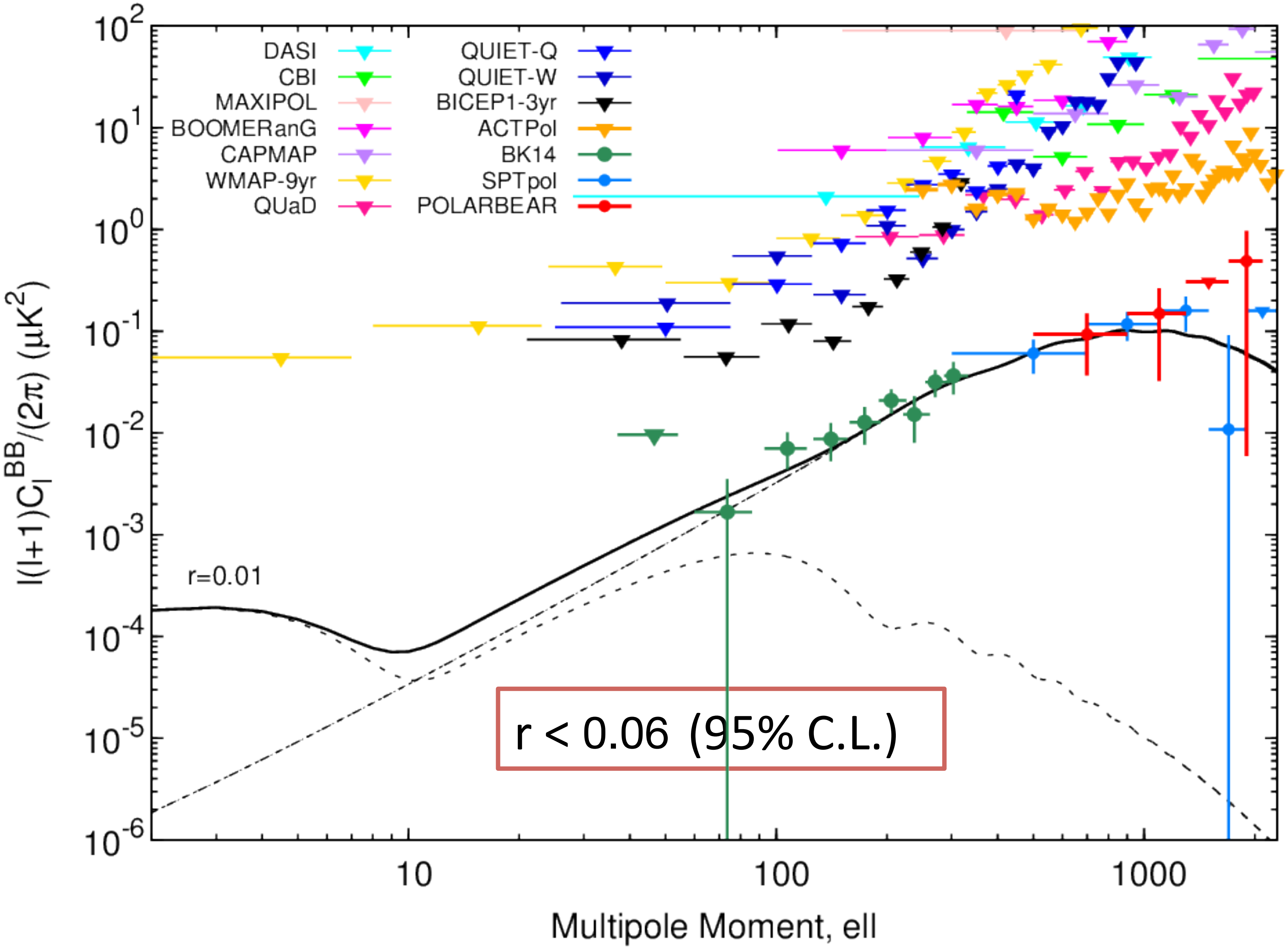
Looking for Primordial Gravitational waves

CMB Power Spectrum



Looking for Primordial Gravitational waves

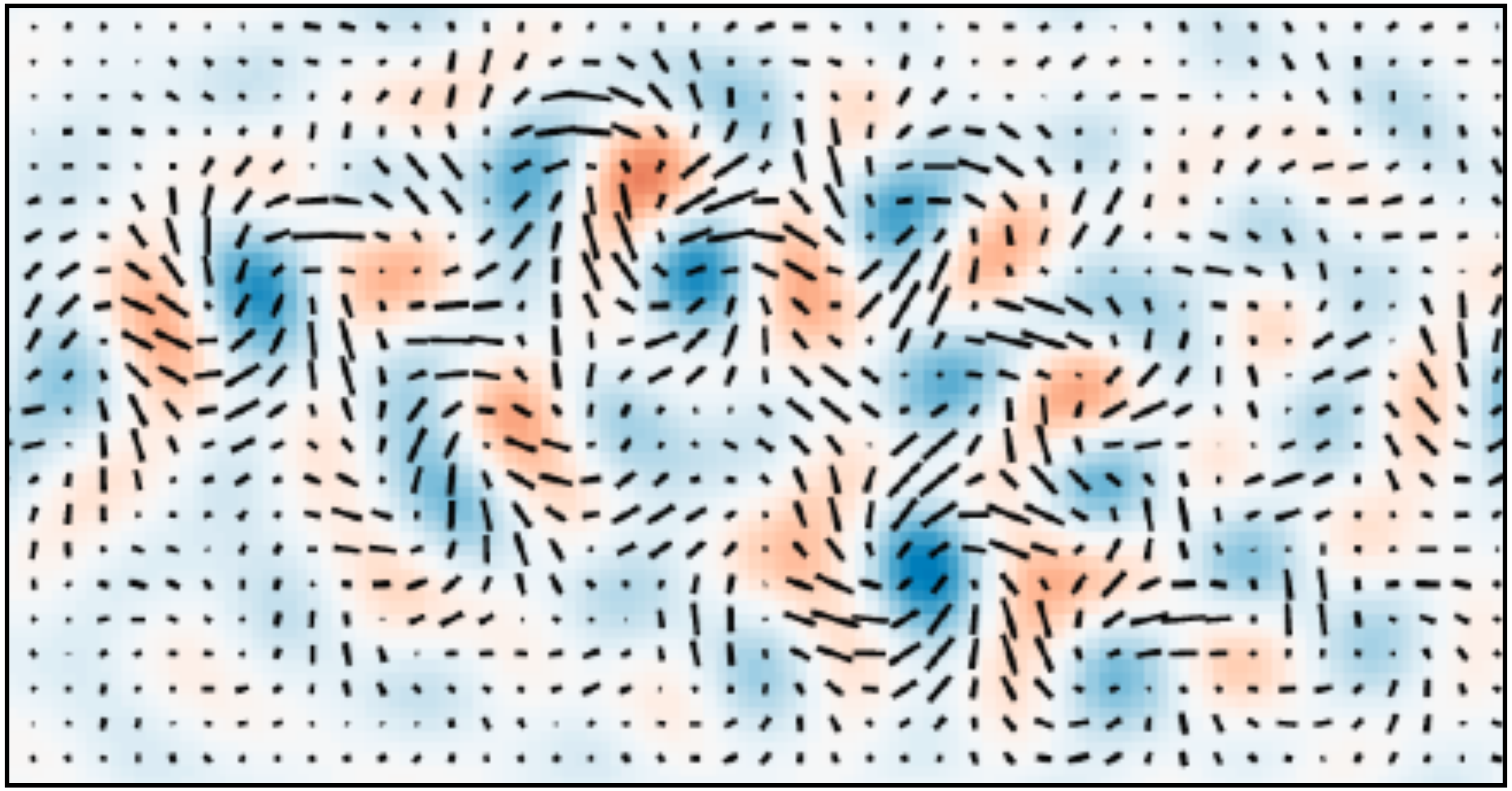
Current status of the B-mode measurements



Looking for Primordial Gravitational waves

Detection by BICEP2 in 2014

Carte BICEP2 B-Mode



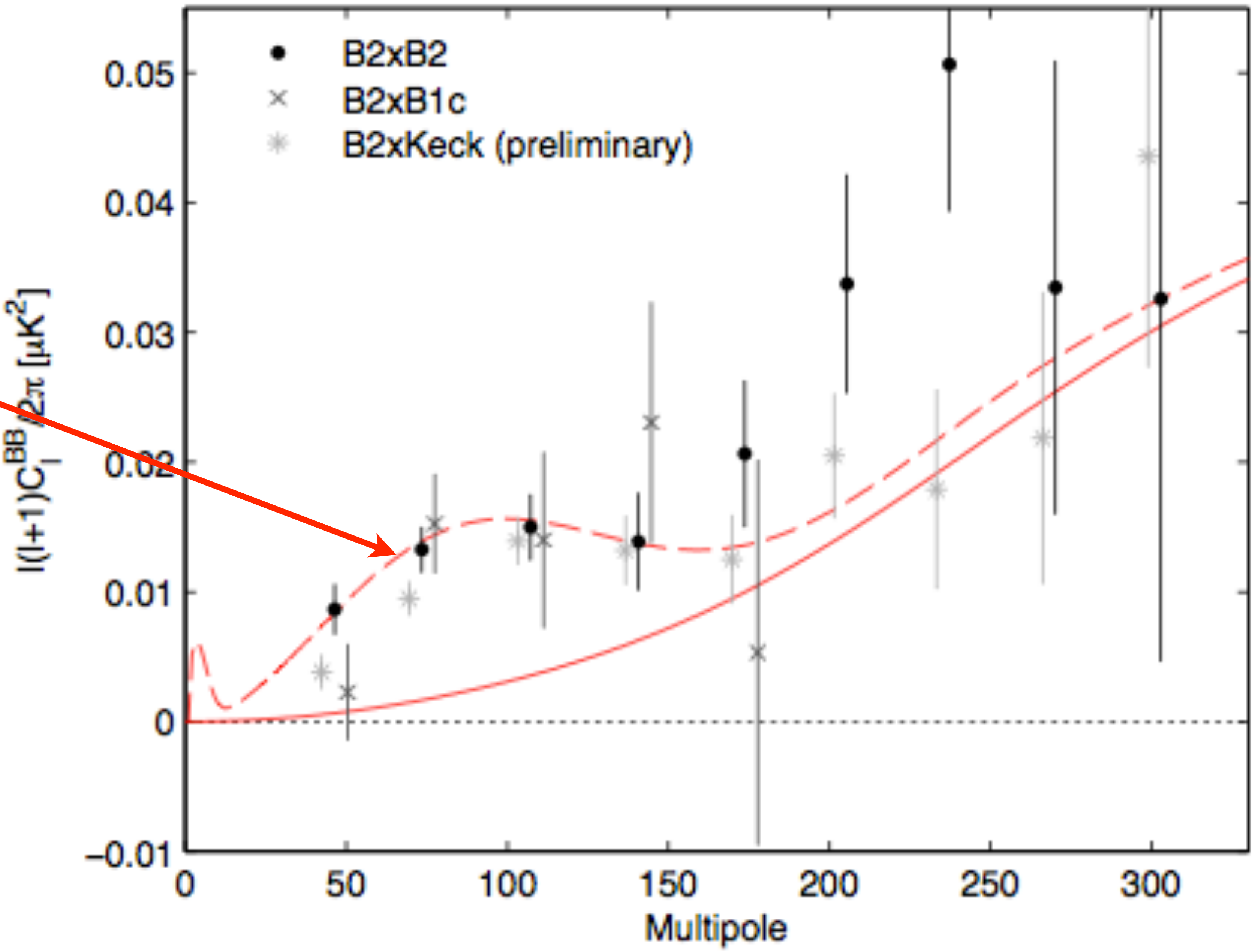
150 GHz

BICEP2 collaboration 2014

Looking for Primordial Gravitational waves

BICEP2 Results

Bump
due to
Gravitational
waves ?

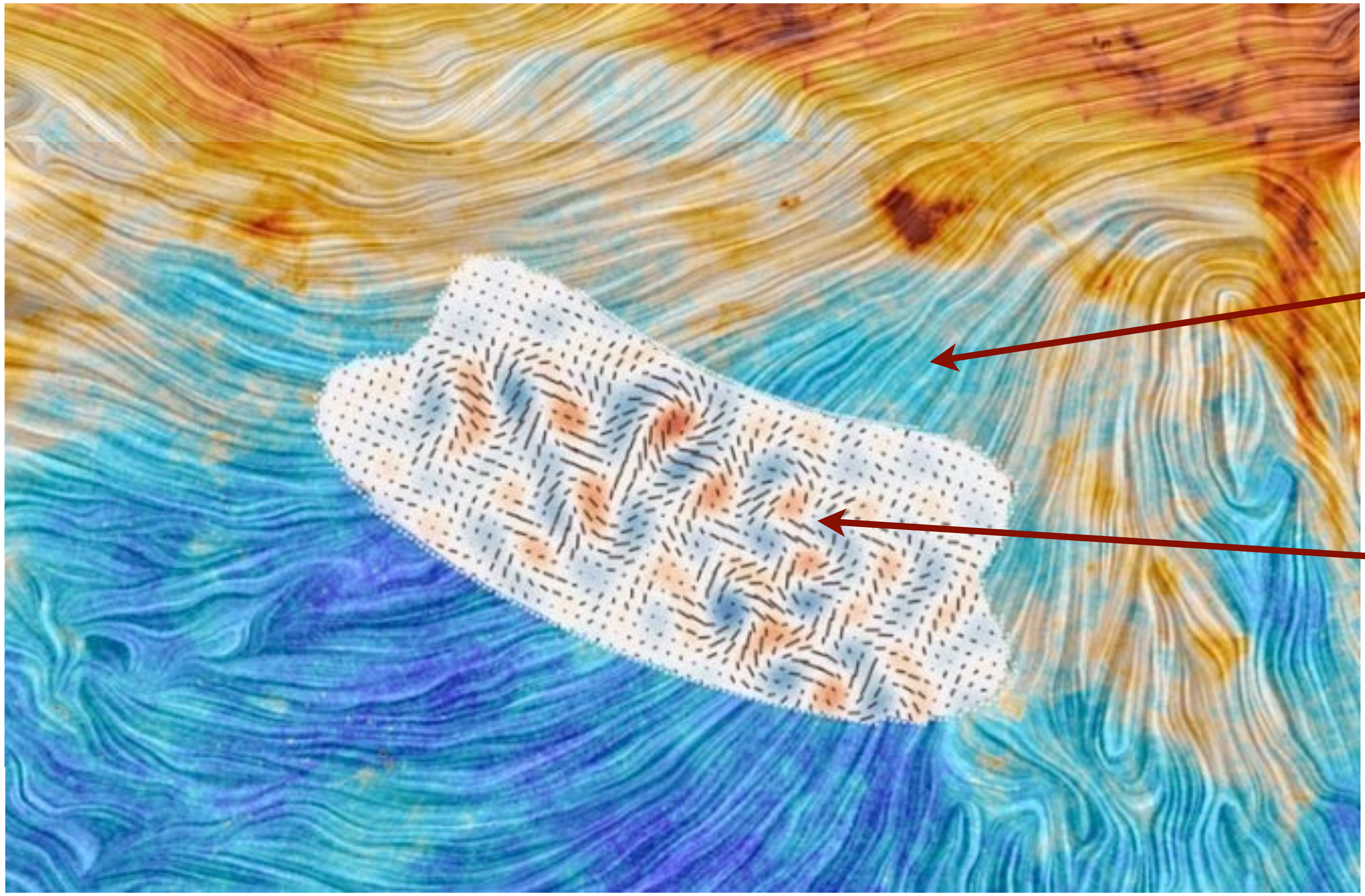


Evidence of
the Inflation ?

r=0.2 !

Looking for Primordial Gravitational waves

Warning : Galactic Foregrounds

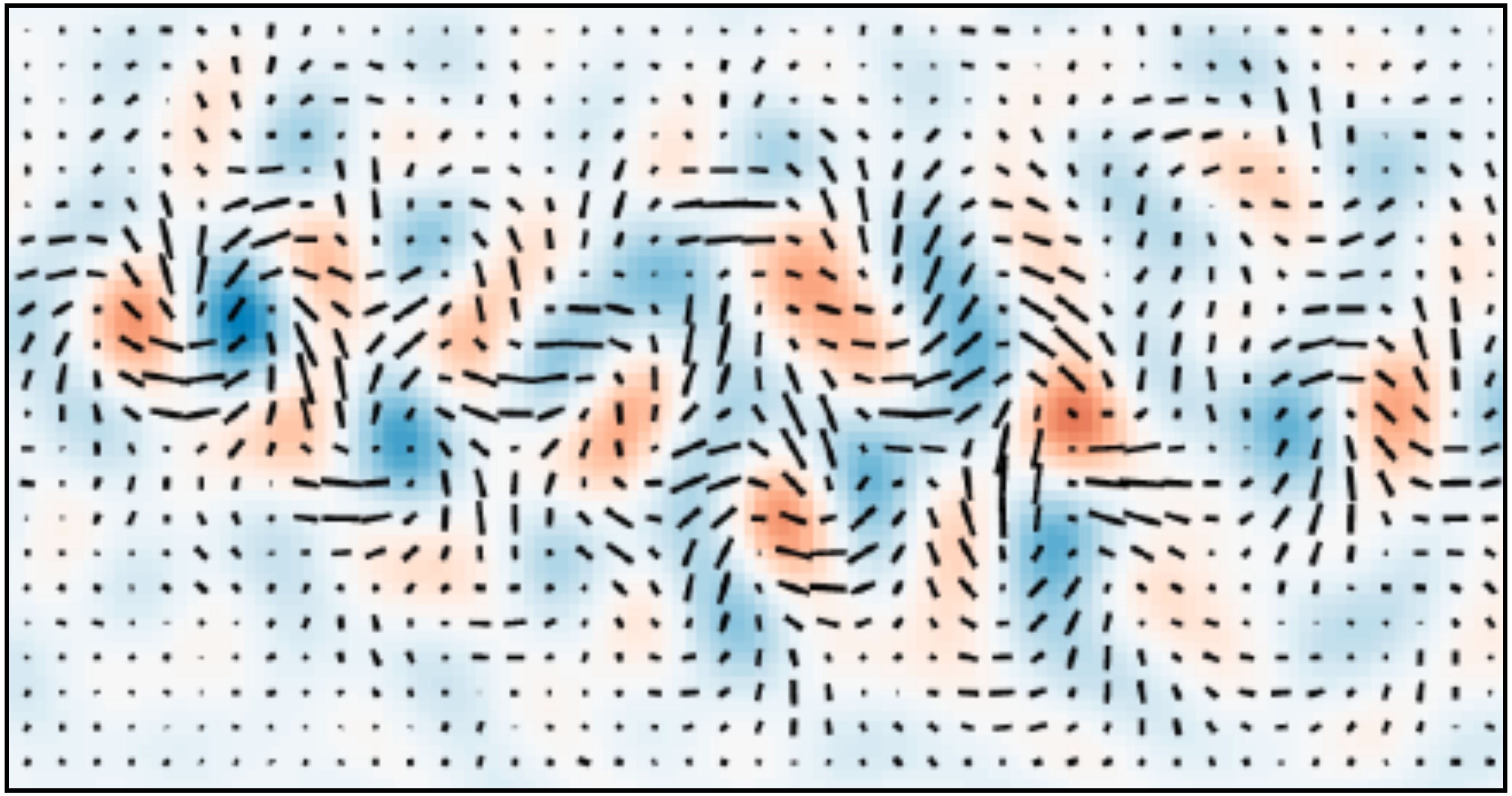


353 GHz

150 GHz

Combined Analysis Planck + BICEP2

Planck B-Mode map of the Galactic Dust

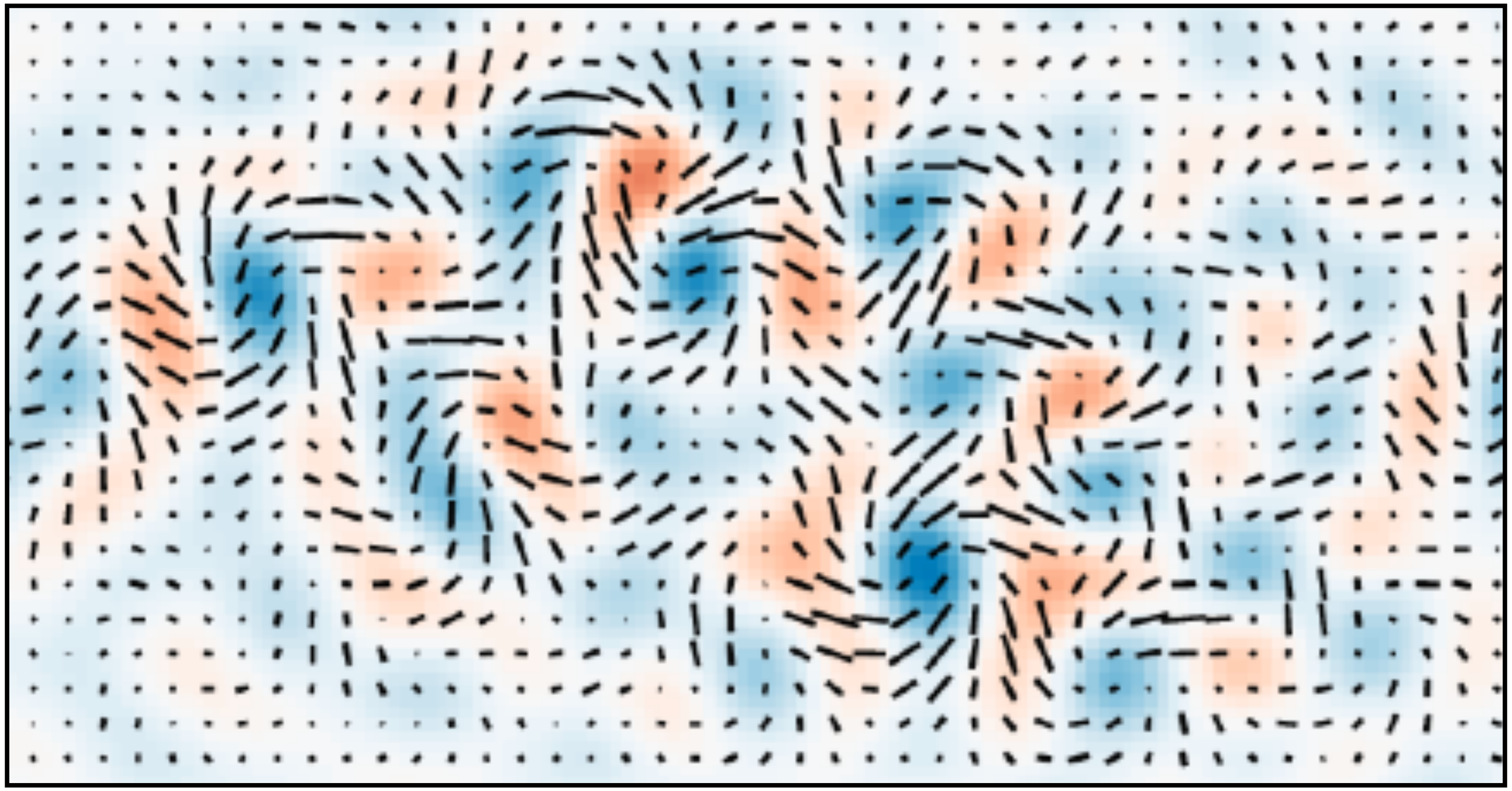


353 GHz

Looking for Primordial Gravitational waves

Combined Analysis Planck + BICEP2

BICEP2 B-Mode map

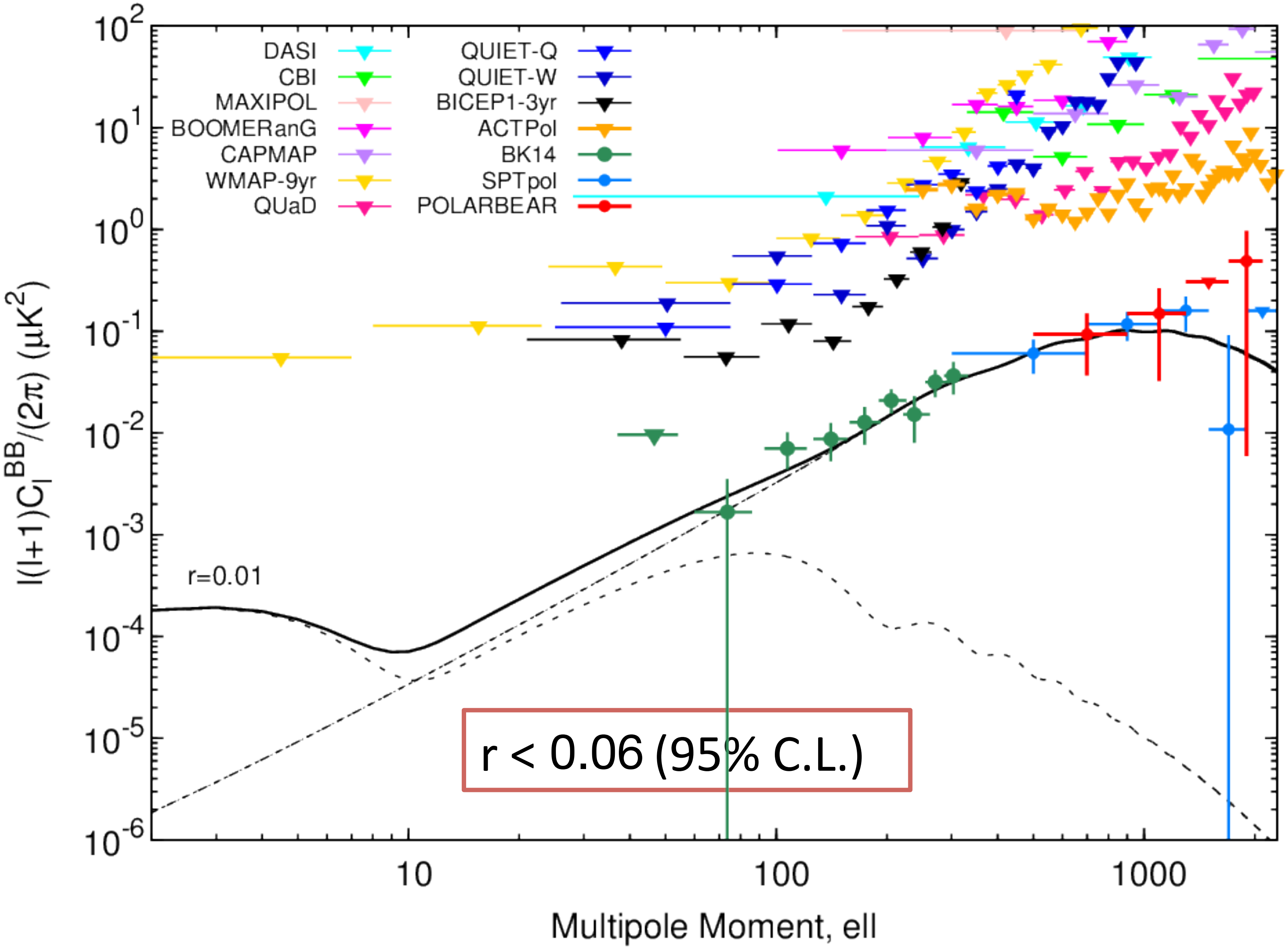


150 GHz

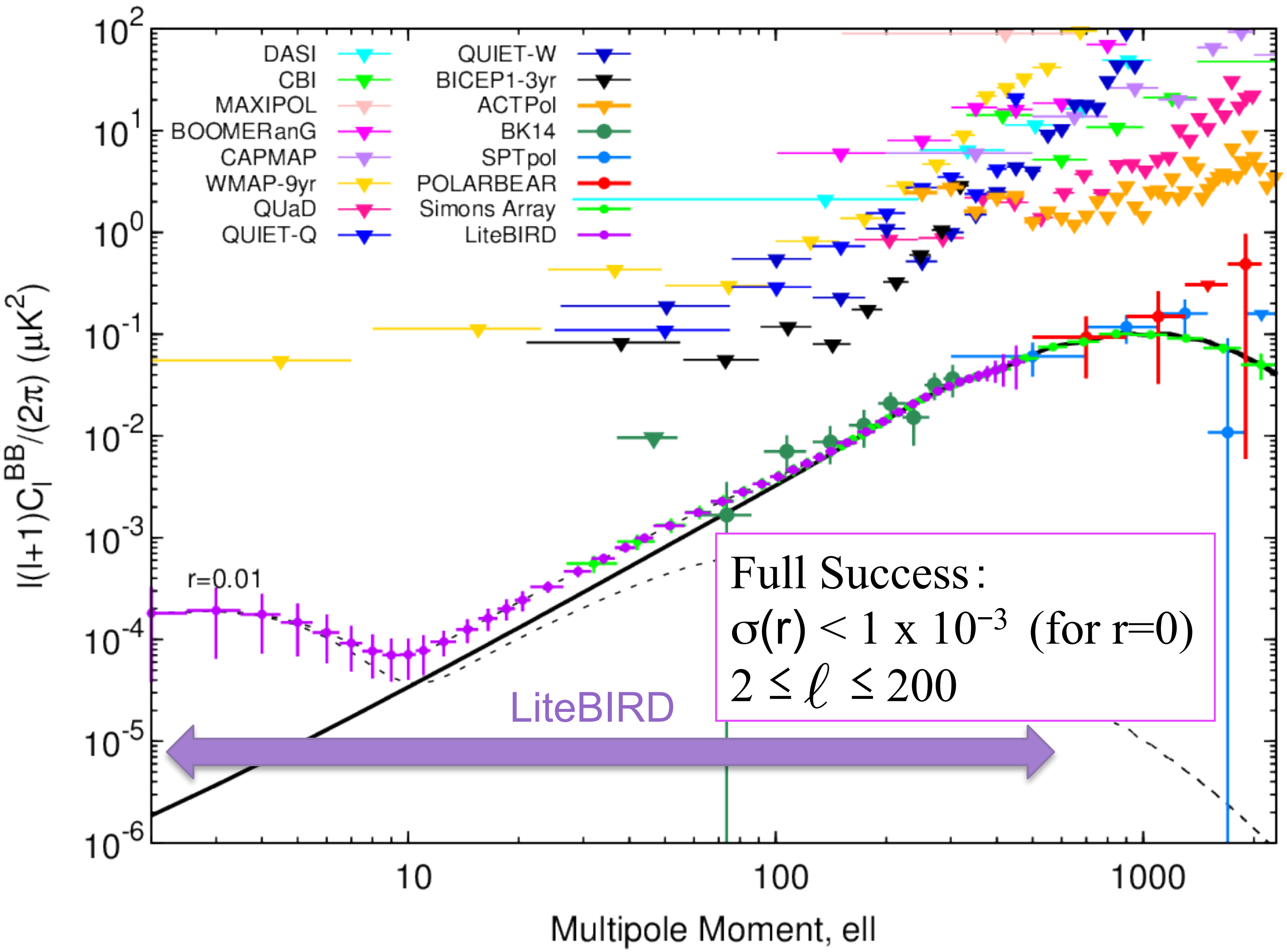
r < 0.06 at 95% confidence

BICEP2-Keck 2015

Current status of the B-mode measurements



LiteBIRD Expectation

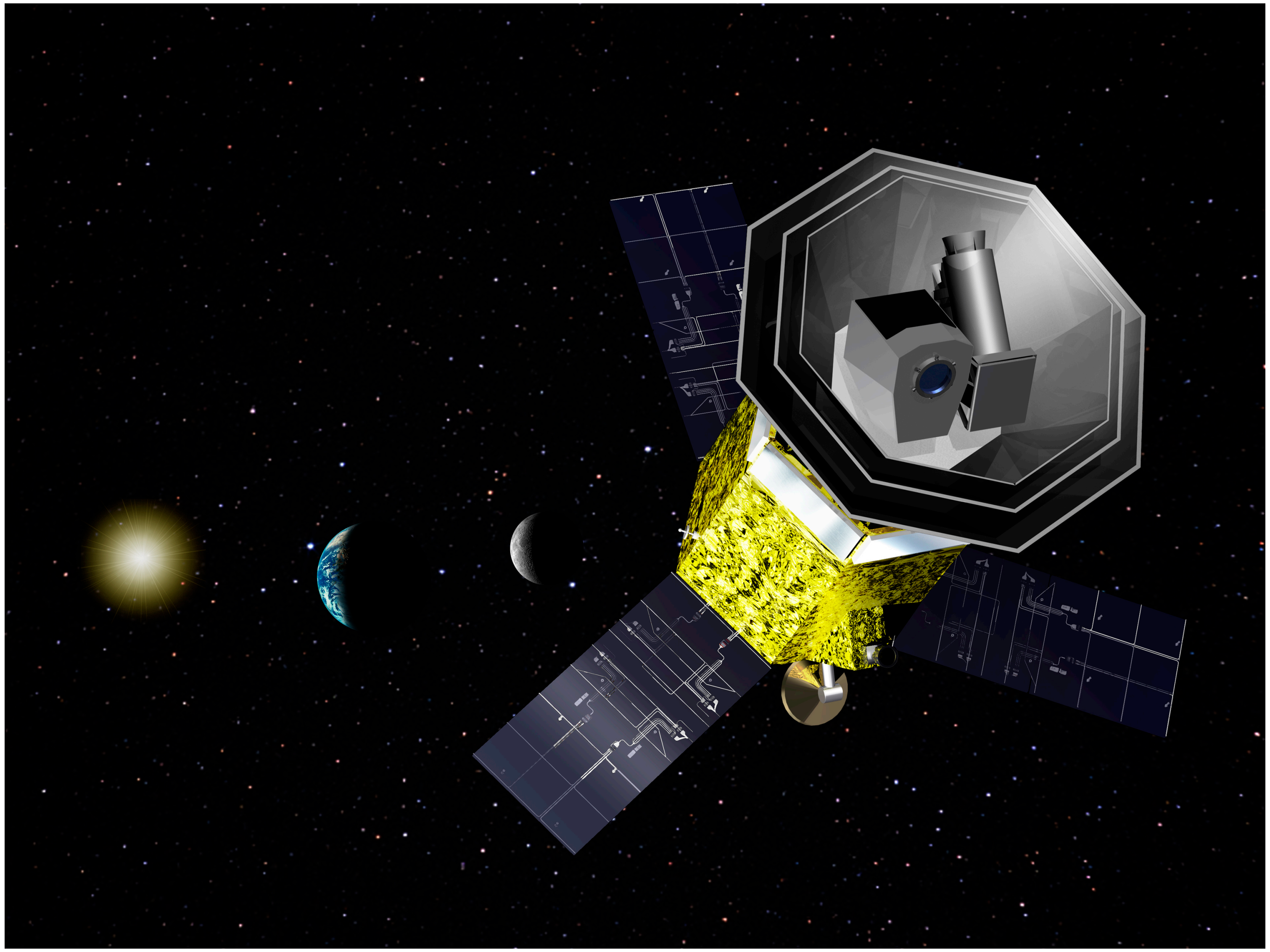


Full Success : $\sigma(r) < 1 \times 10^{-3}$ (for r=0)
$2 \leq \ell \leq 200$

LiteBIRD only

(without de-lensing)

LiteBIRD Mission



L-Class JAXA Mission
Selected by JAXA May 2019
CNES committed into Phase-A in 2020
Launch 2029

L2 orbit

All-sky Survey during 3 years

Large frequency coverage
15 bands 34 - 448 GHz

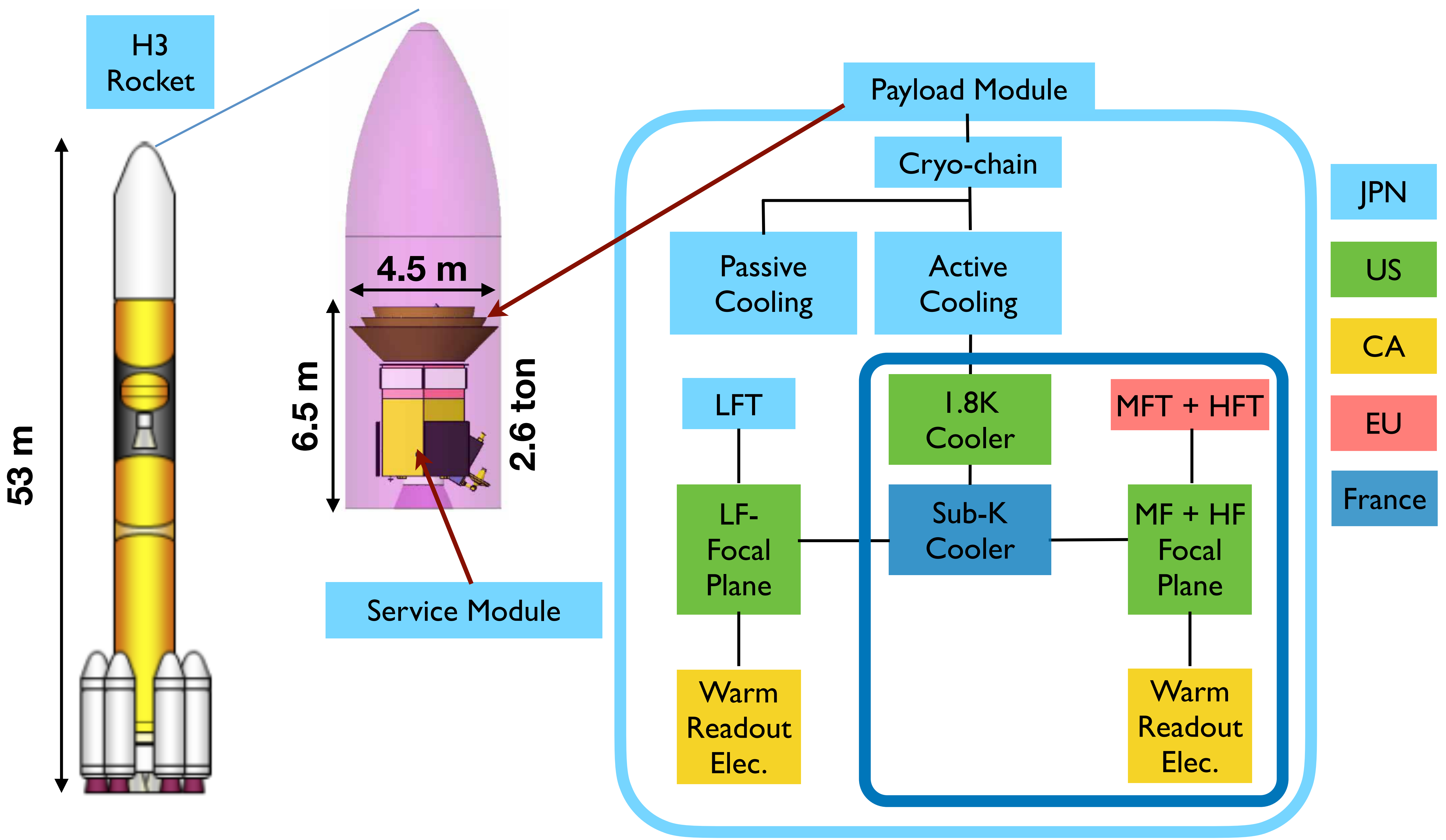
Resolution:

LFT	MHFT
69' - 20.7'	27.6' - 9.7'

Sensitivity: 2.8 uK.arcmin
after component separation
more than 100 times better than Planck/HFI in P

LiteBIRD Mission

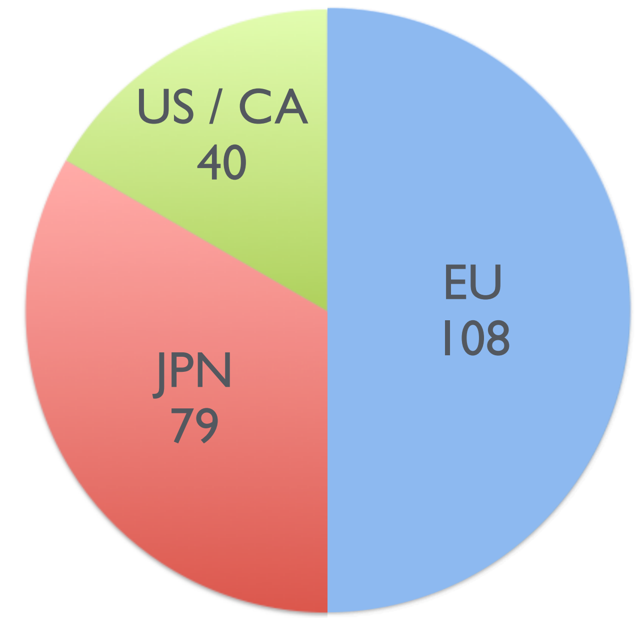
Payload



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



LiteBIRD Collaboration

LiteBIRD-Europe

~150 external 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)
Institut Néel (Grenoble)
IPAG (Grenoble)
IRAP (Toulouse)
LAL (Orsay)
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

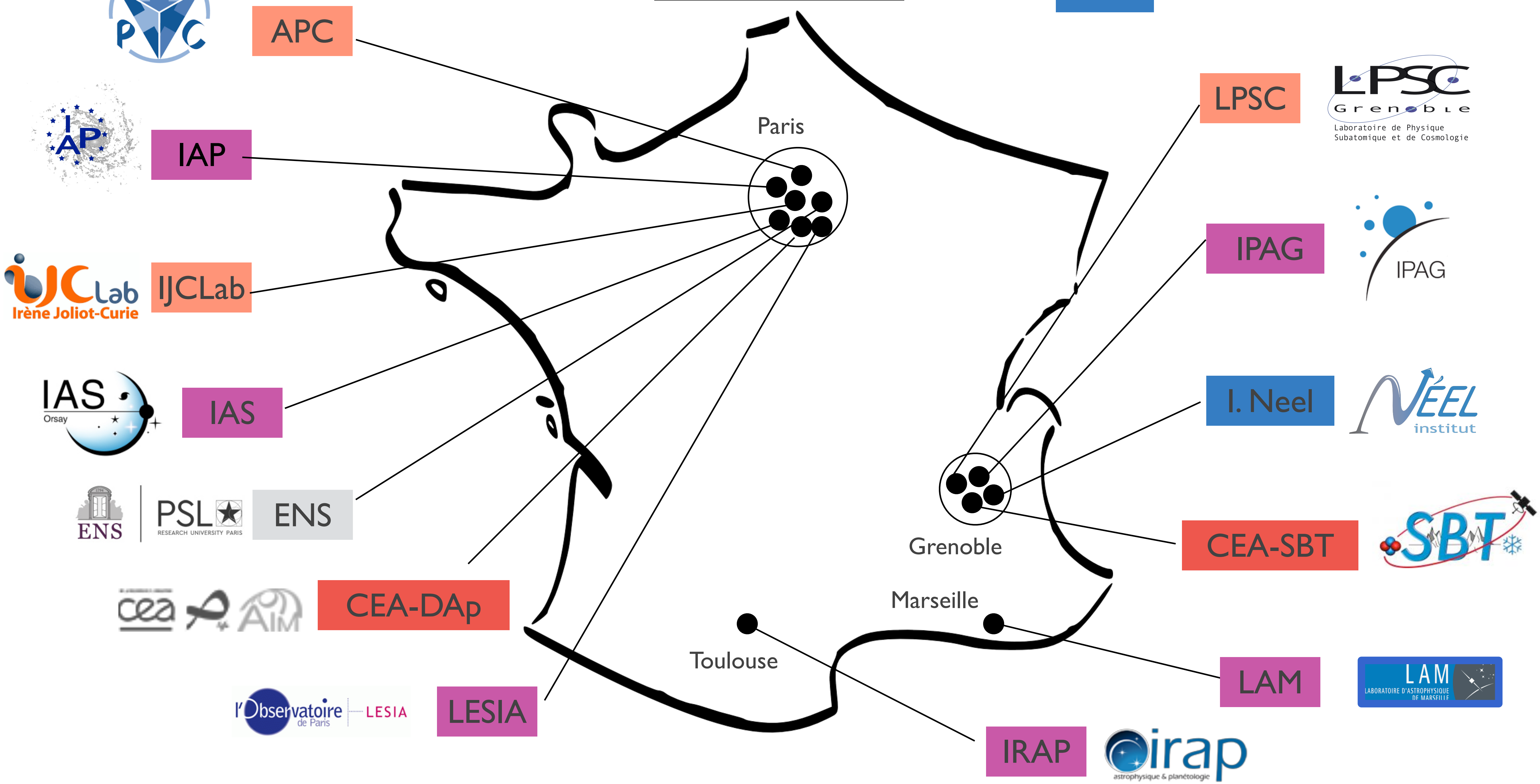
Maynooth

LiteBIRD Collaboration

LiteBIRD-FRANCE

50 chercheurs
17 ingénieurs
(42 External Members)

(light orange)	IN2P3
(magenta)	INSU
(blue)	INP
(red)	CEA
(light grey)	ENS



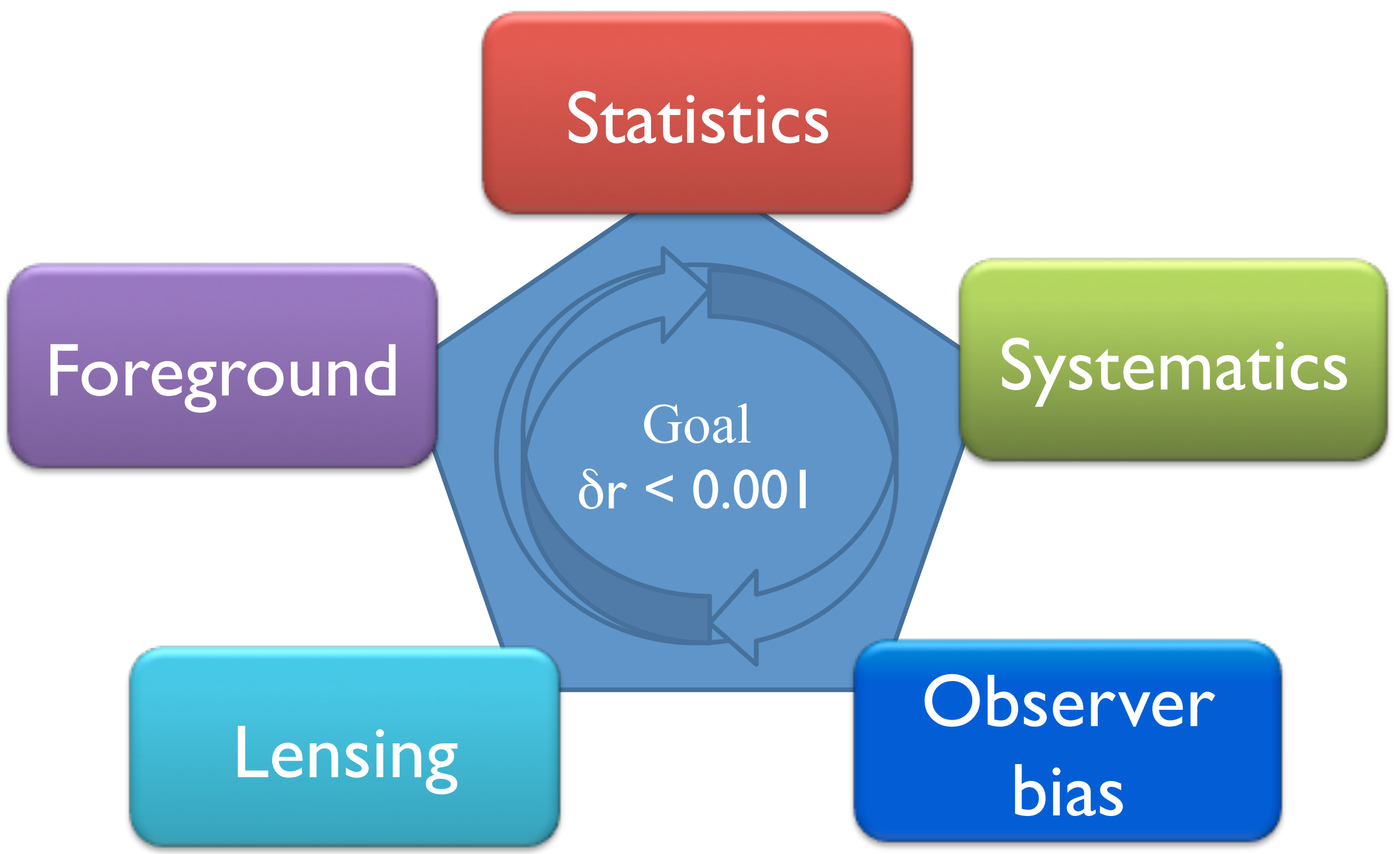
Mission Challenges

Mission Challenges

High Sensitivity Detectors

Large frequency coverage from Space

Mitigation and Control of Systematics

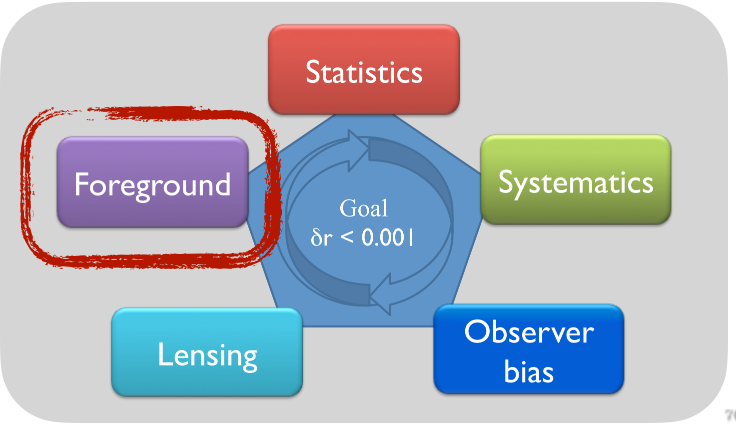


Continuously Rotating HWP

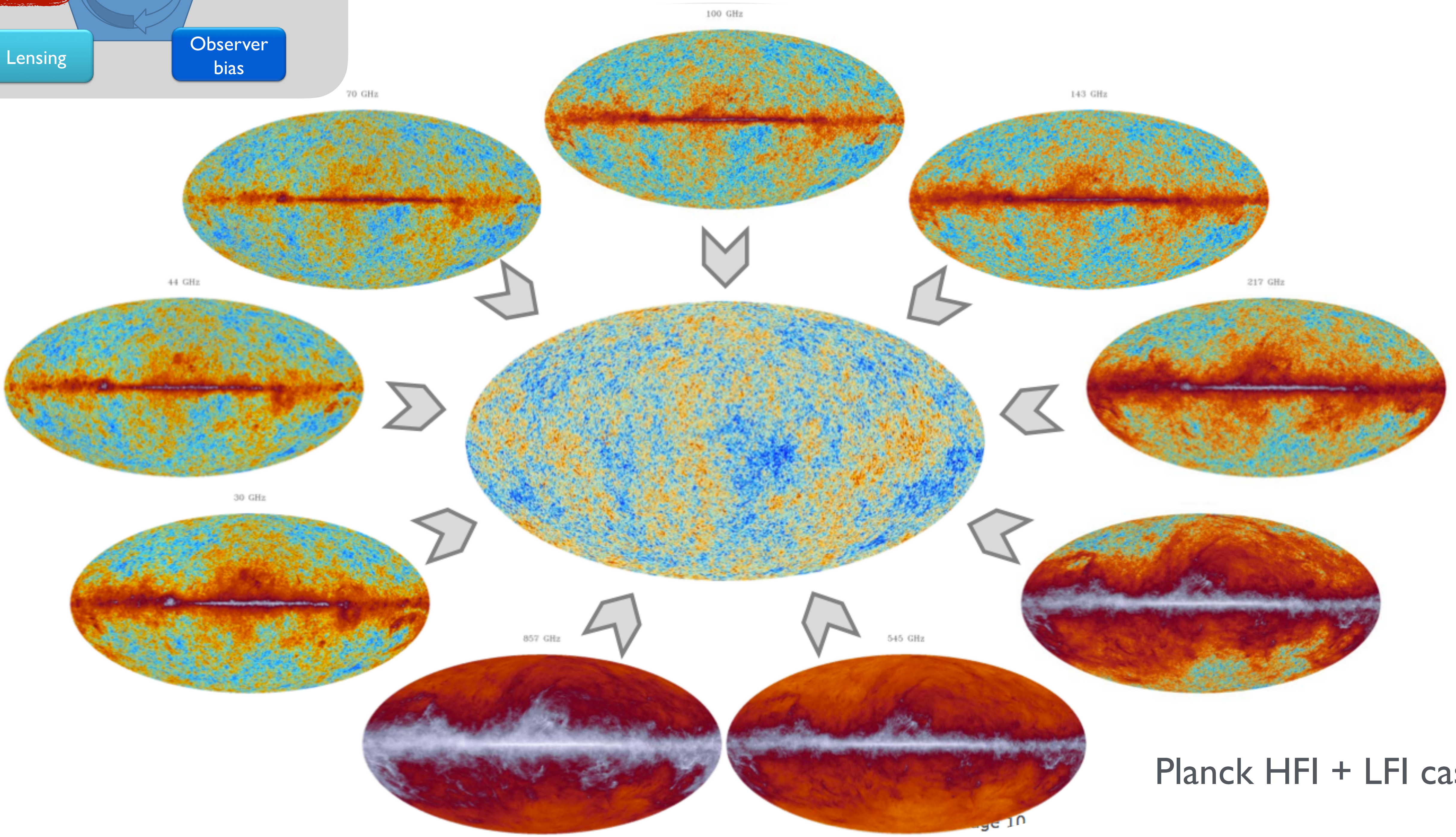
Focused on largest multipole scales

All-sky survey

Mission Challenges

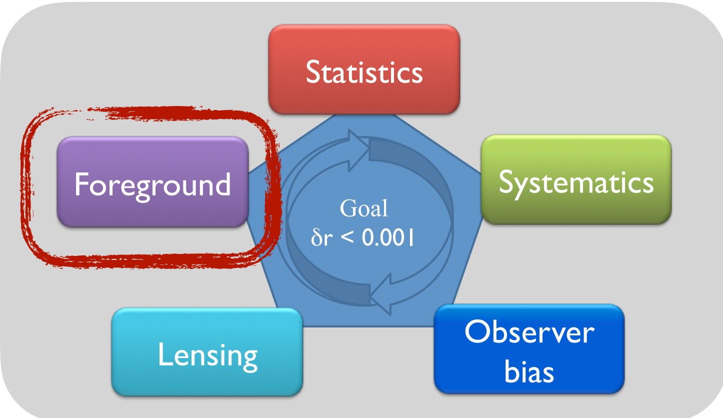


Foregrounds



Planck HFI + LFI case

Mission Challenges

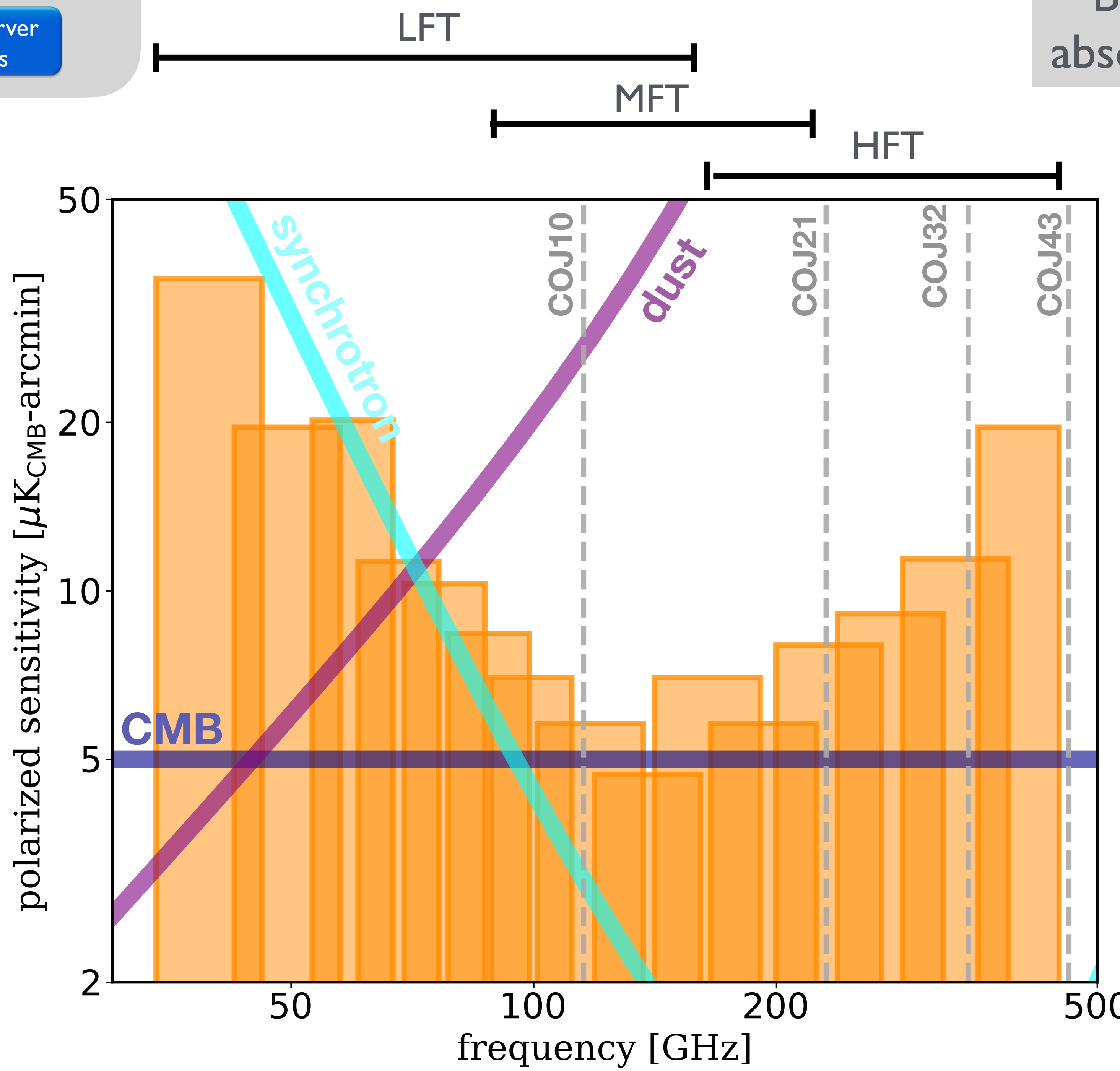


Foregrounds

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

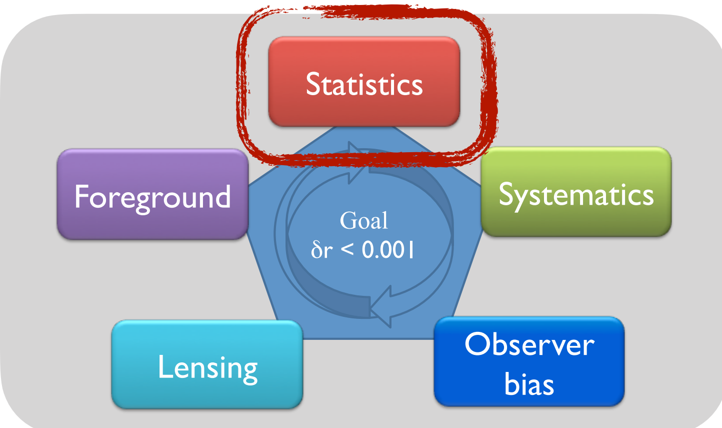
15 bands
from 34GHz
to 448GHz

+4600
detectors



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

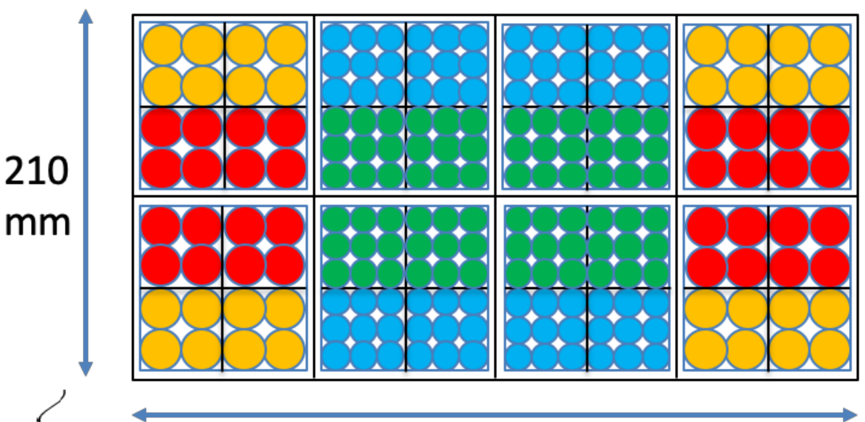
Mission Challenges



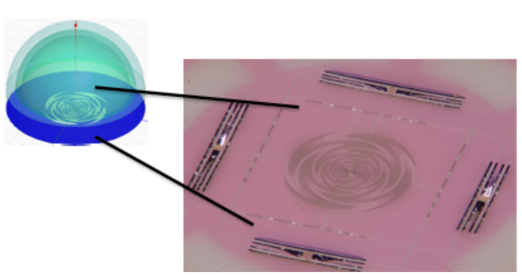
Statistics

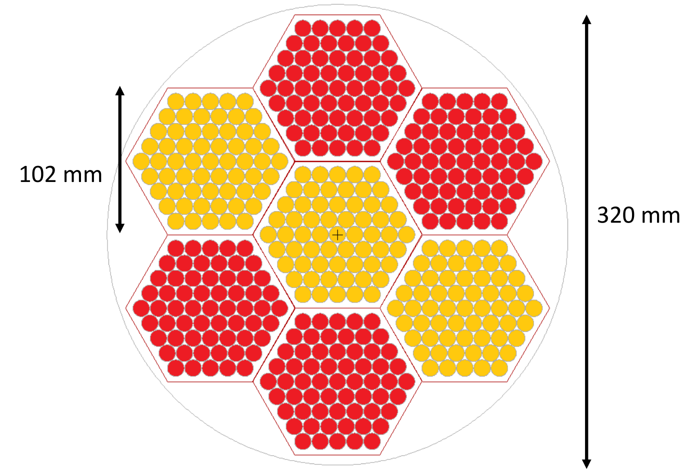
Number of detectors:4676
Overlap between instruments

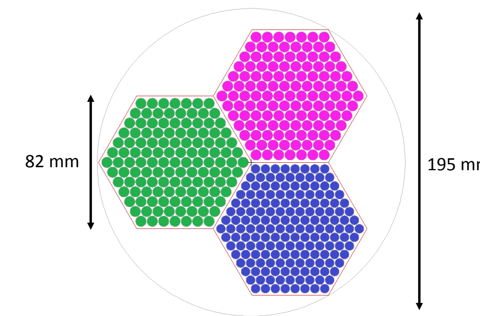
Rule of thumb:
1000 detectors in space = 100 000 detectors on ground

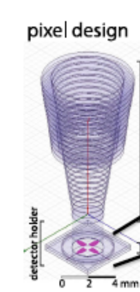


Lenslets

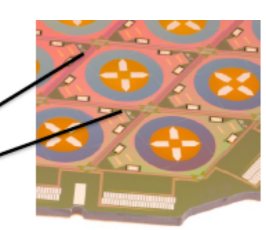








Platelets



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

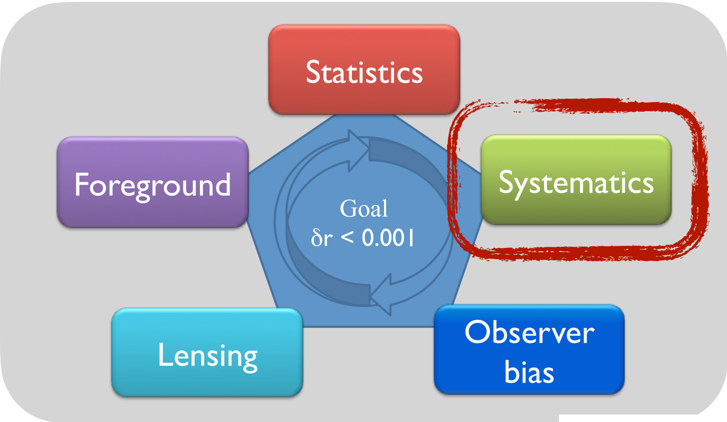
HFT (2.7:1)

195 | 235 | 280 | 337 | 502

1355 detectors
2 x 255 Dichroic TES
338 Monochromatic TES

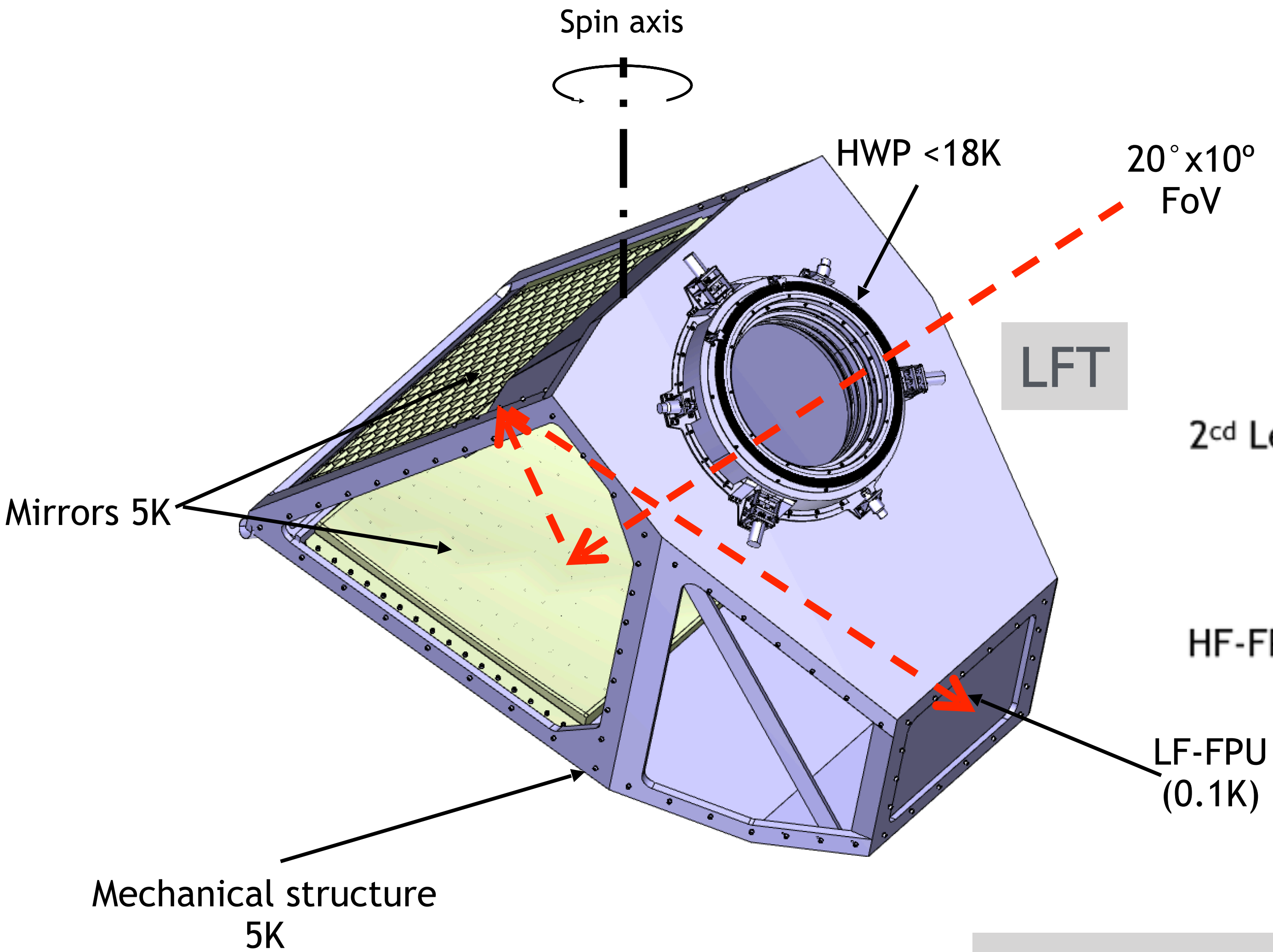
166 GHz — 558 GHz

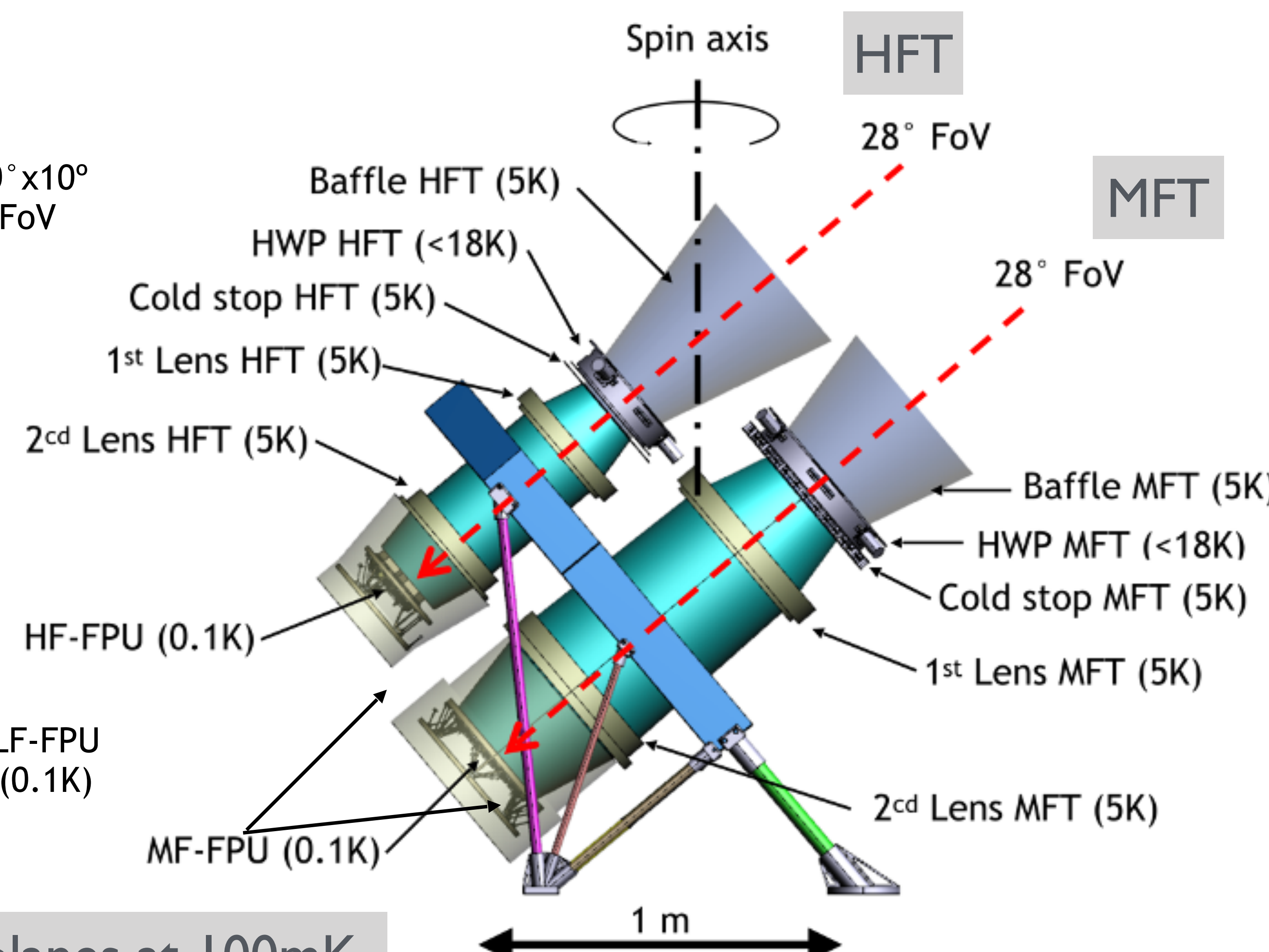
Mission Challenges



Systematics

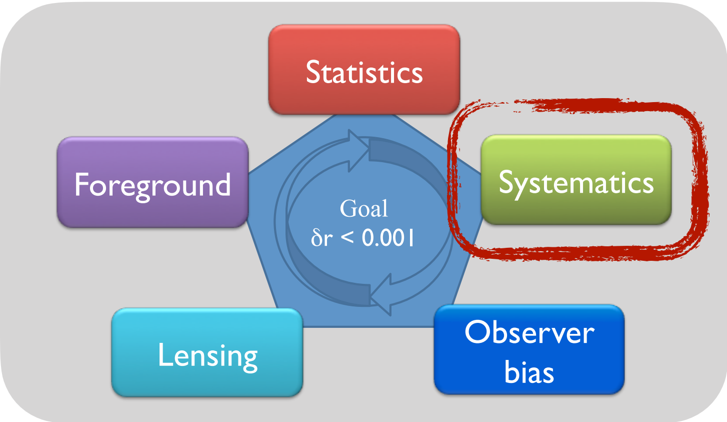
Full instruments and optics at 5K





Focal planes at 100mK

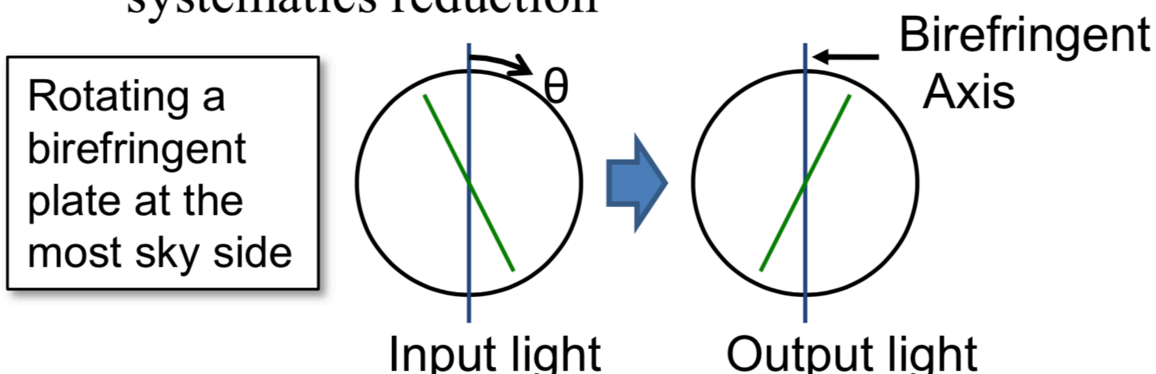
Mission Challenges



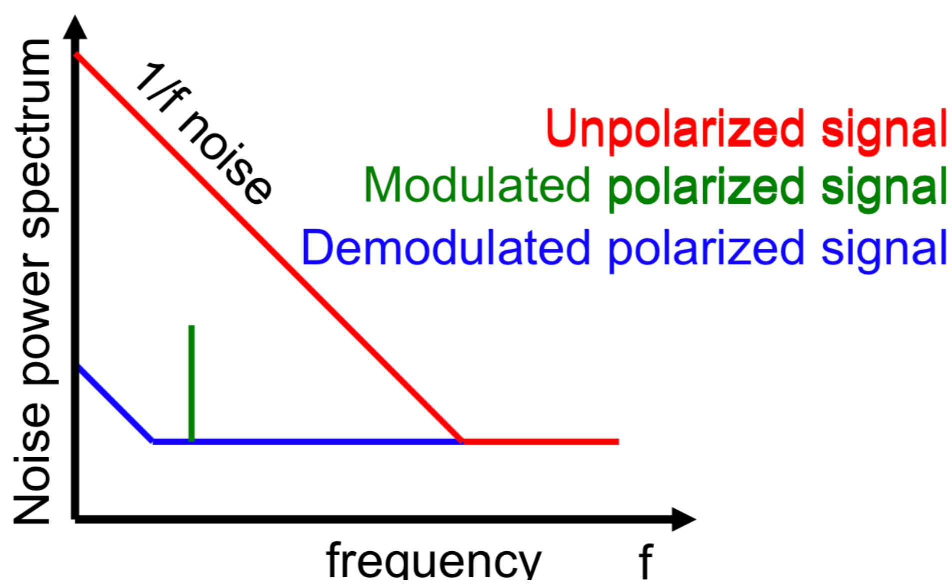
Systematics

Continuously Rotating Half-Wave Plates

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

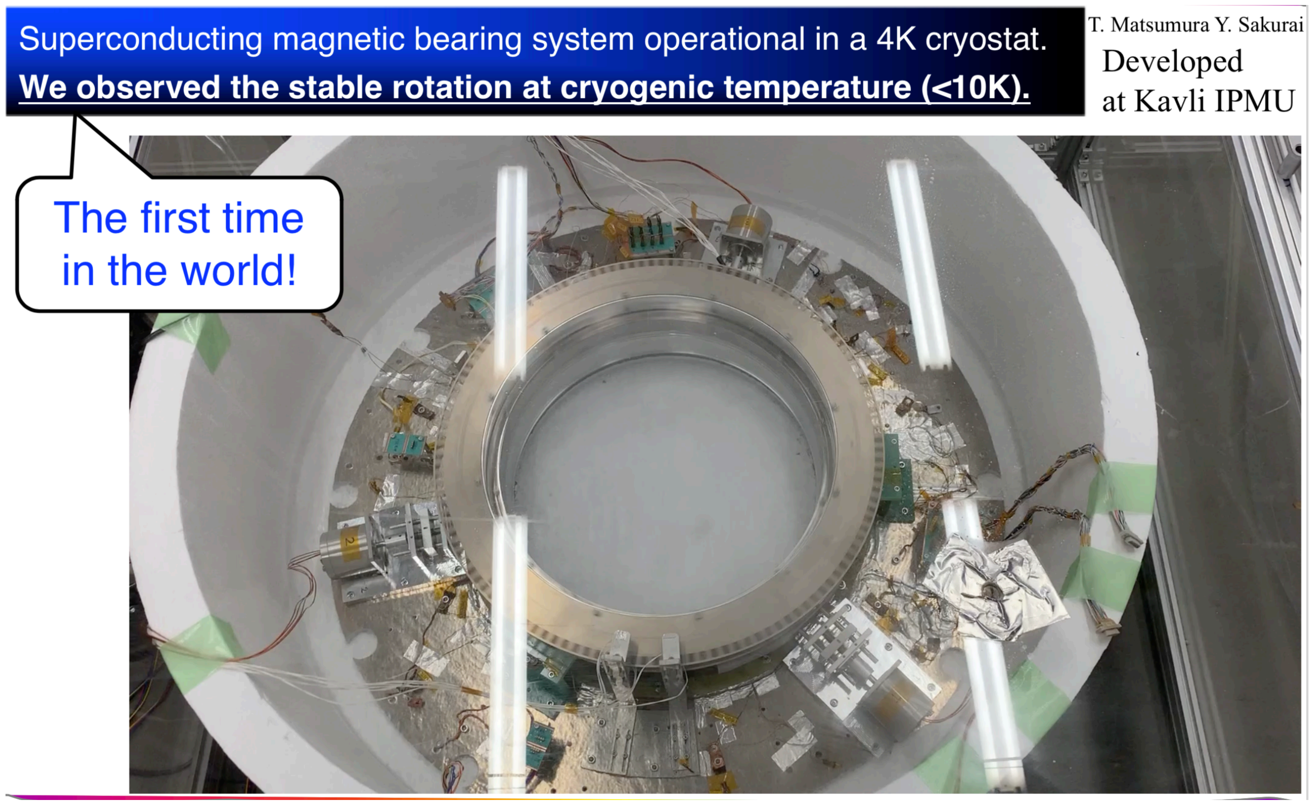


$I + P \cos 4\theta_{\mathrm{HWP}}$



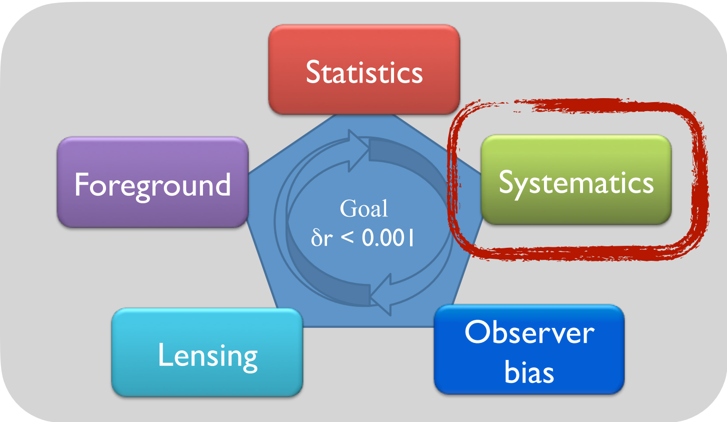
Magnetic sustentation

First prototype in the world developed at IPMU (Tokyo)



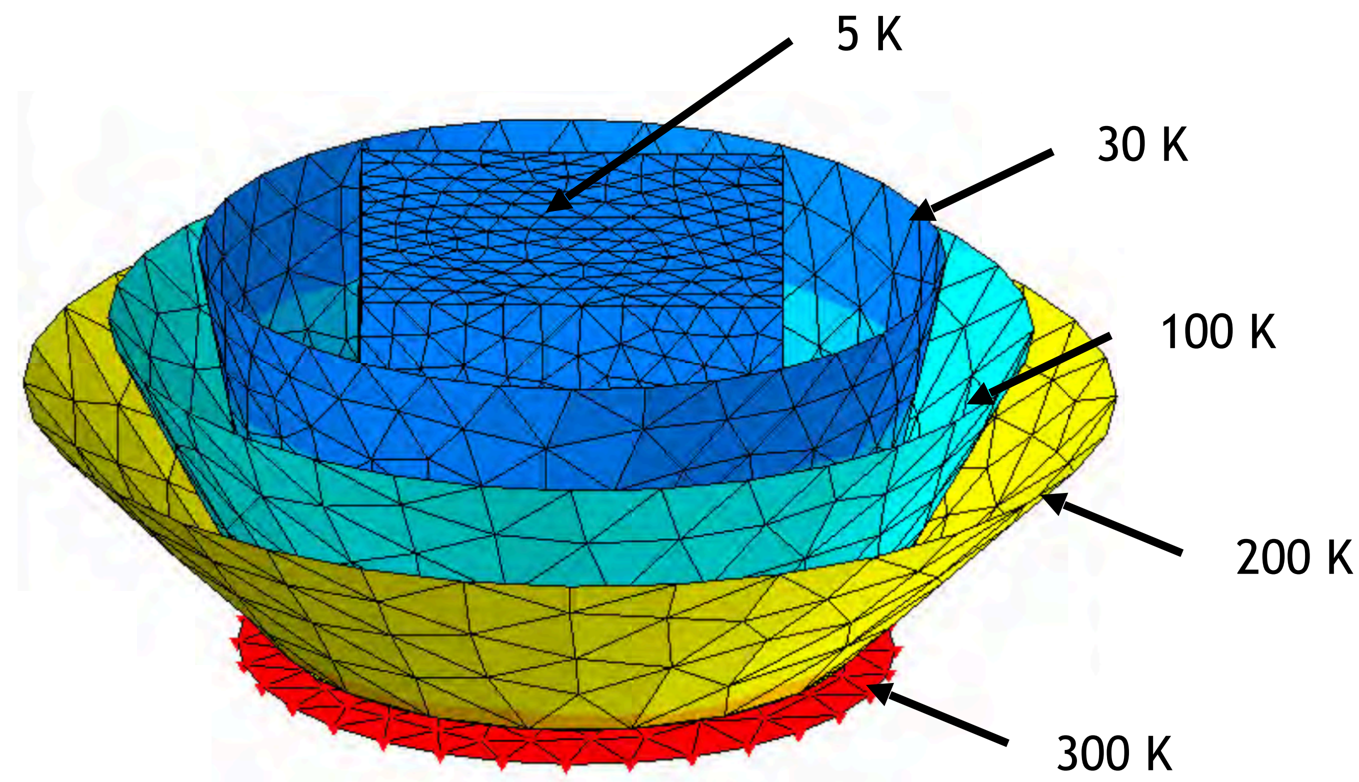
Parallel development in Italy

Mission Challenges

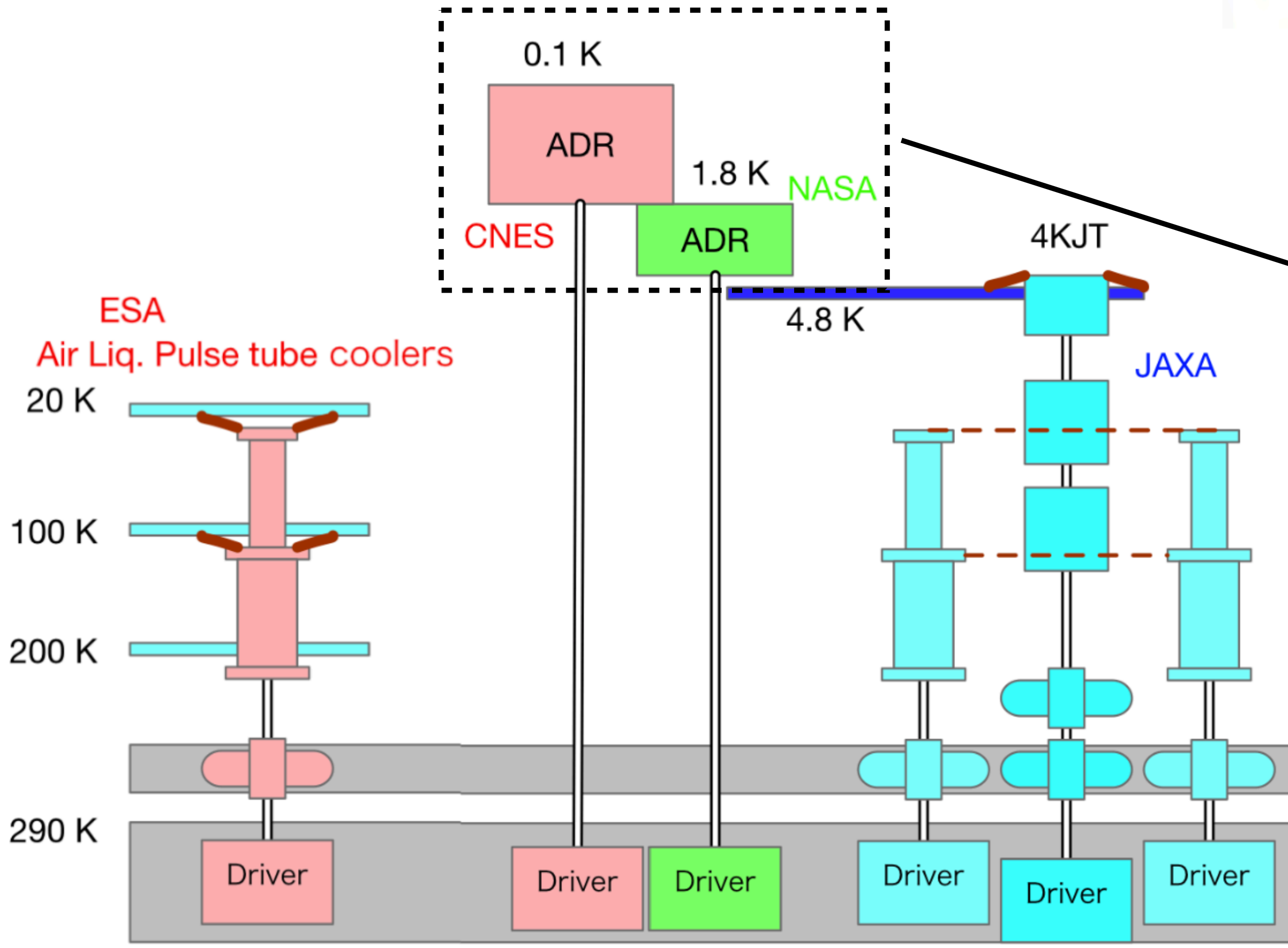


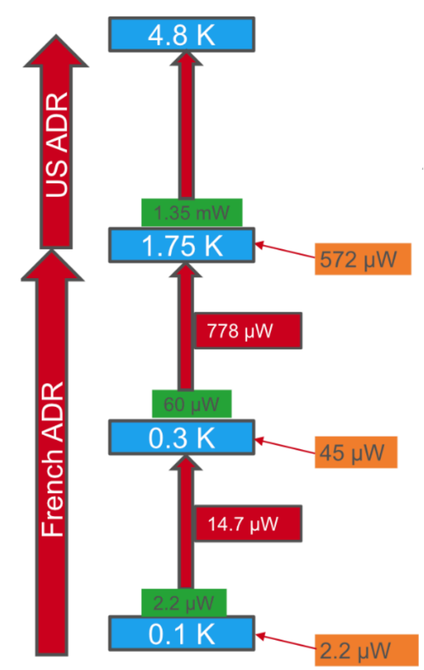
Systematics

Cryo-chain

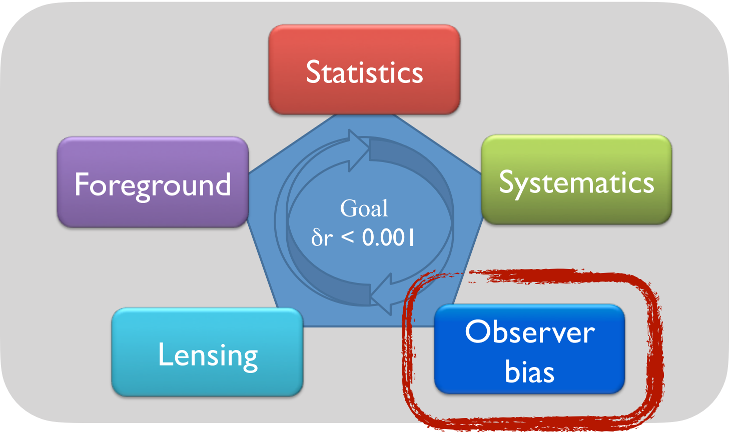


Continuous cooling at all stages, down to 0.1K, using multistage ADR



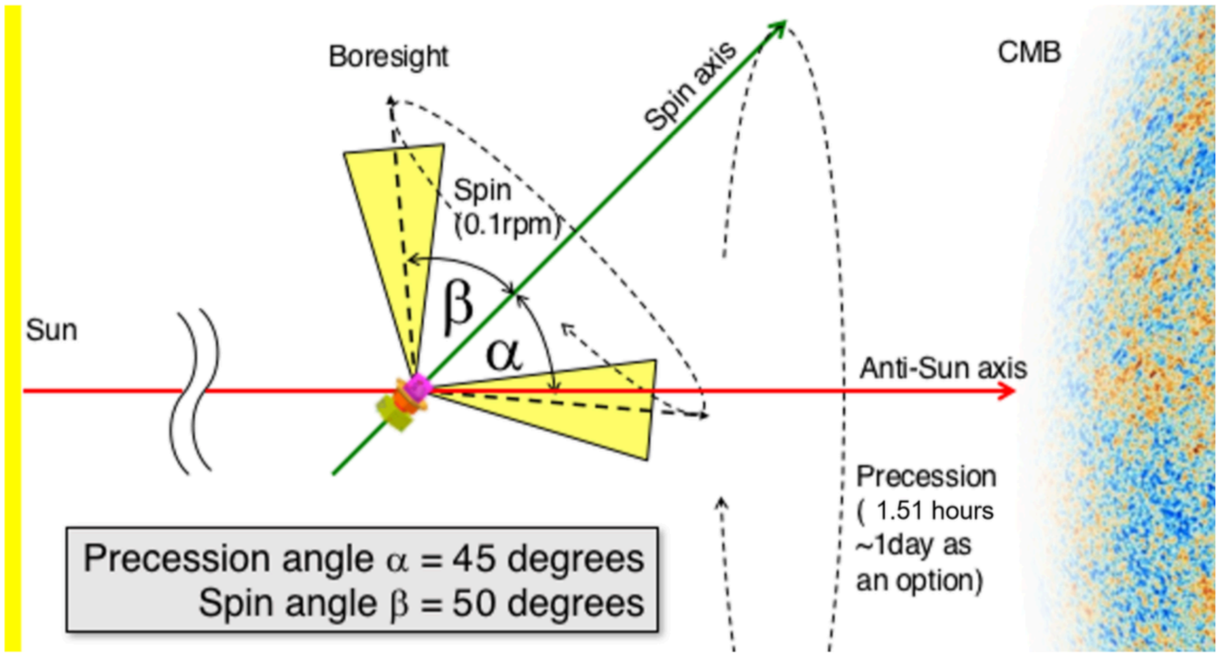


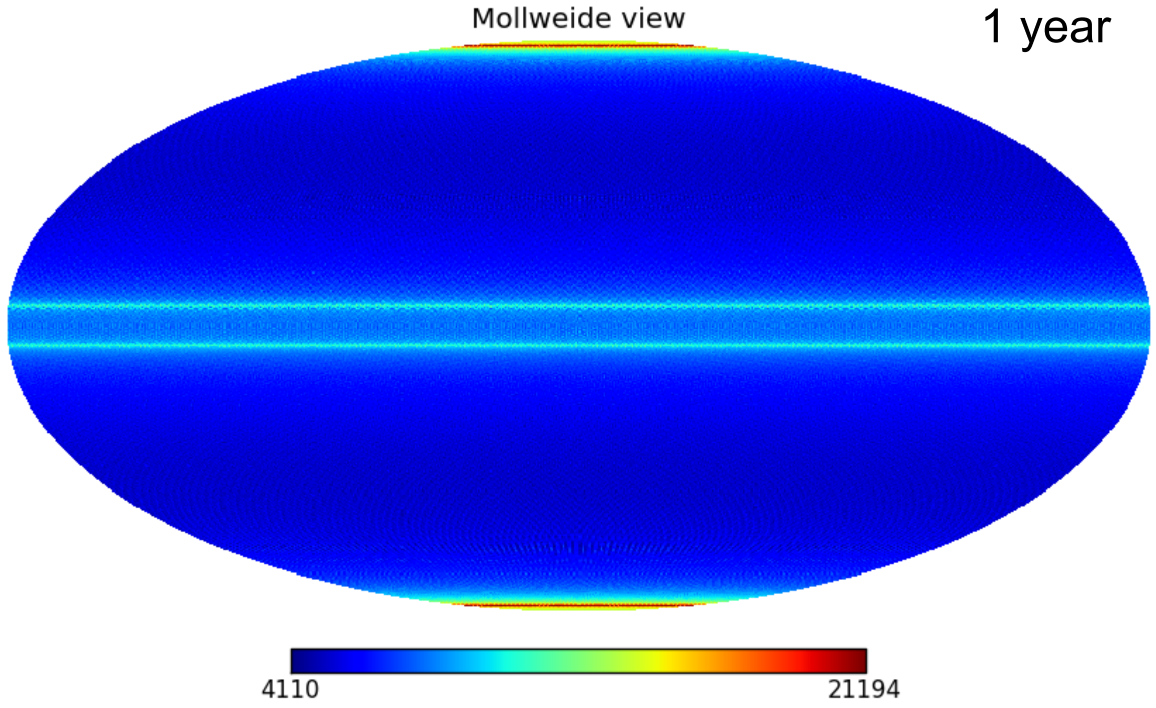
Mission Challenges



Whole Sky Survey

3 years of continuous all-sky survey

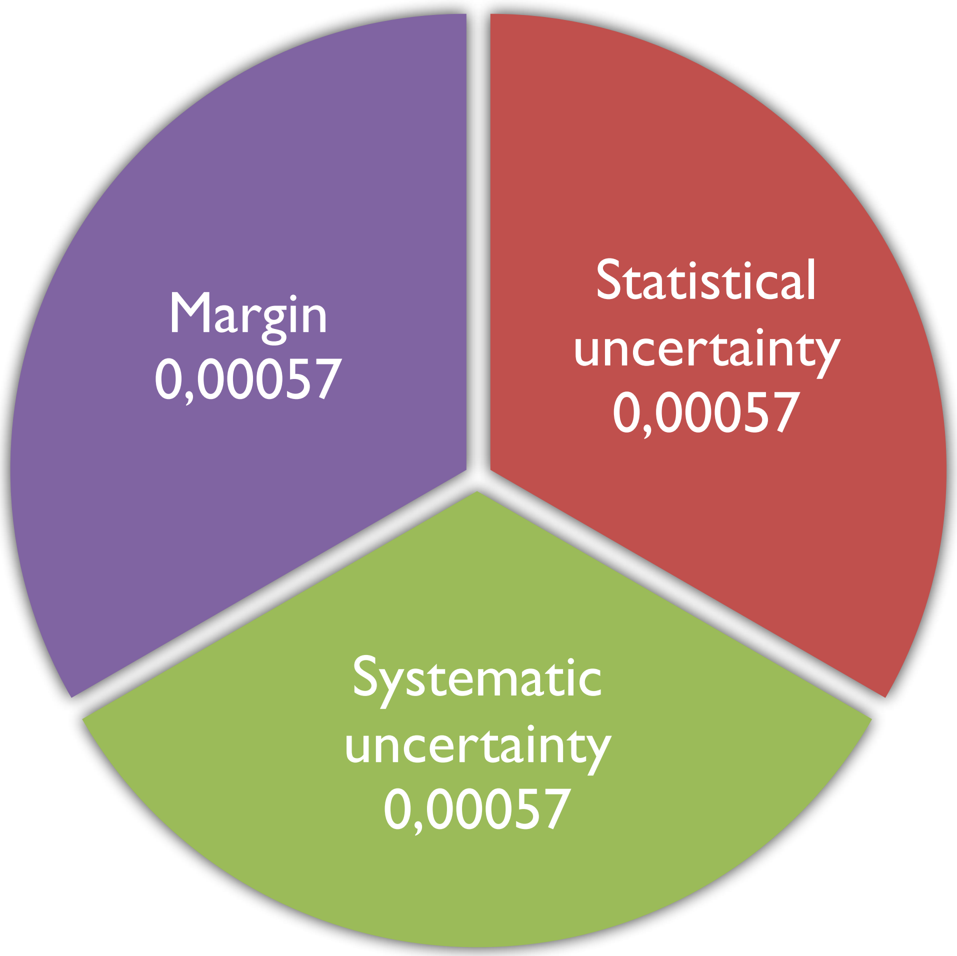




Scientific Outcomes

Full success

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

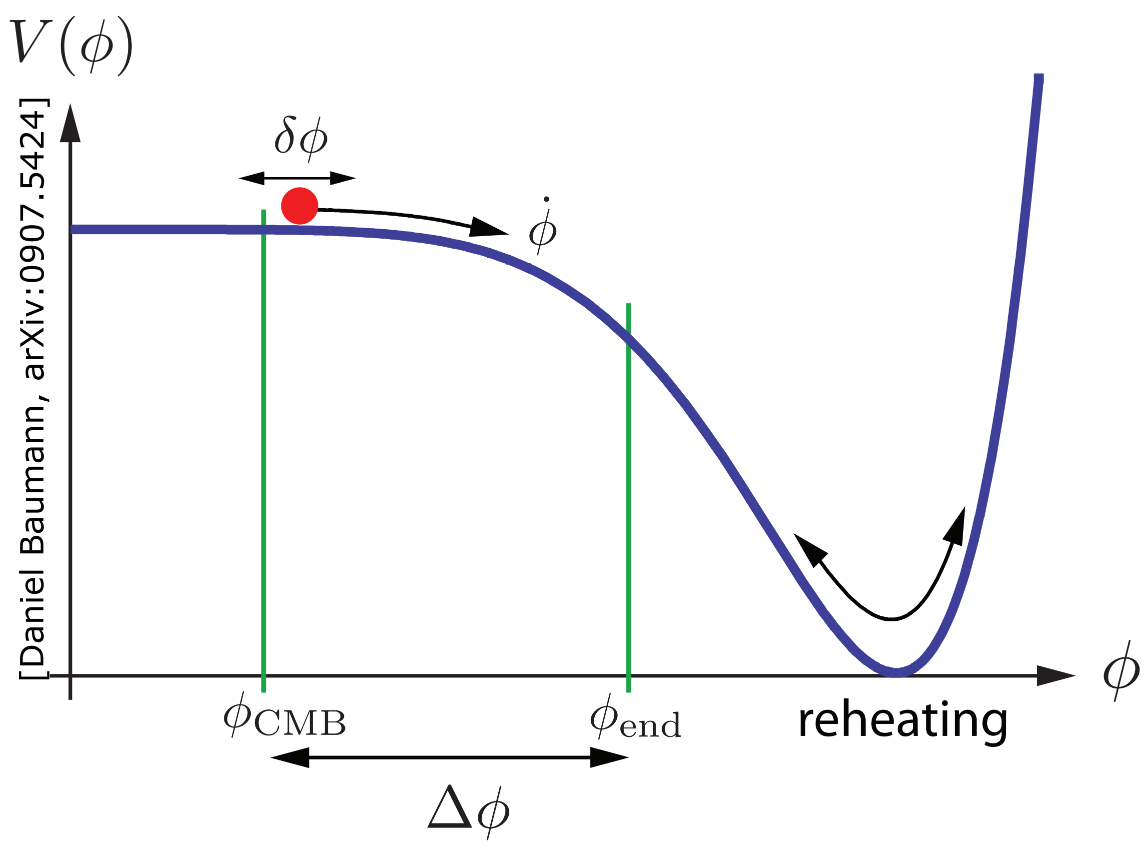
Scientific Outcomes

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**

$$V^{1/4}(\phi) \simeq 10^{16}\,\text{GeV}\left(\frac{r}{0.01}\right)^{1/4}$$

  - **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**

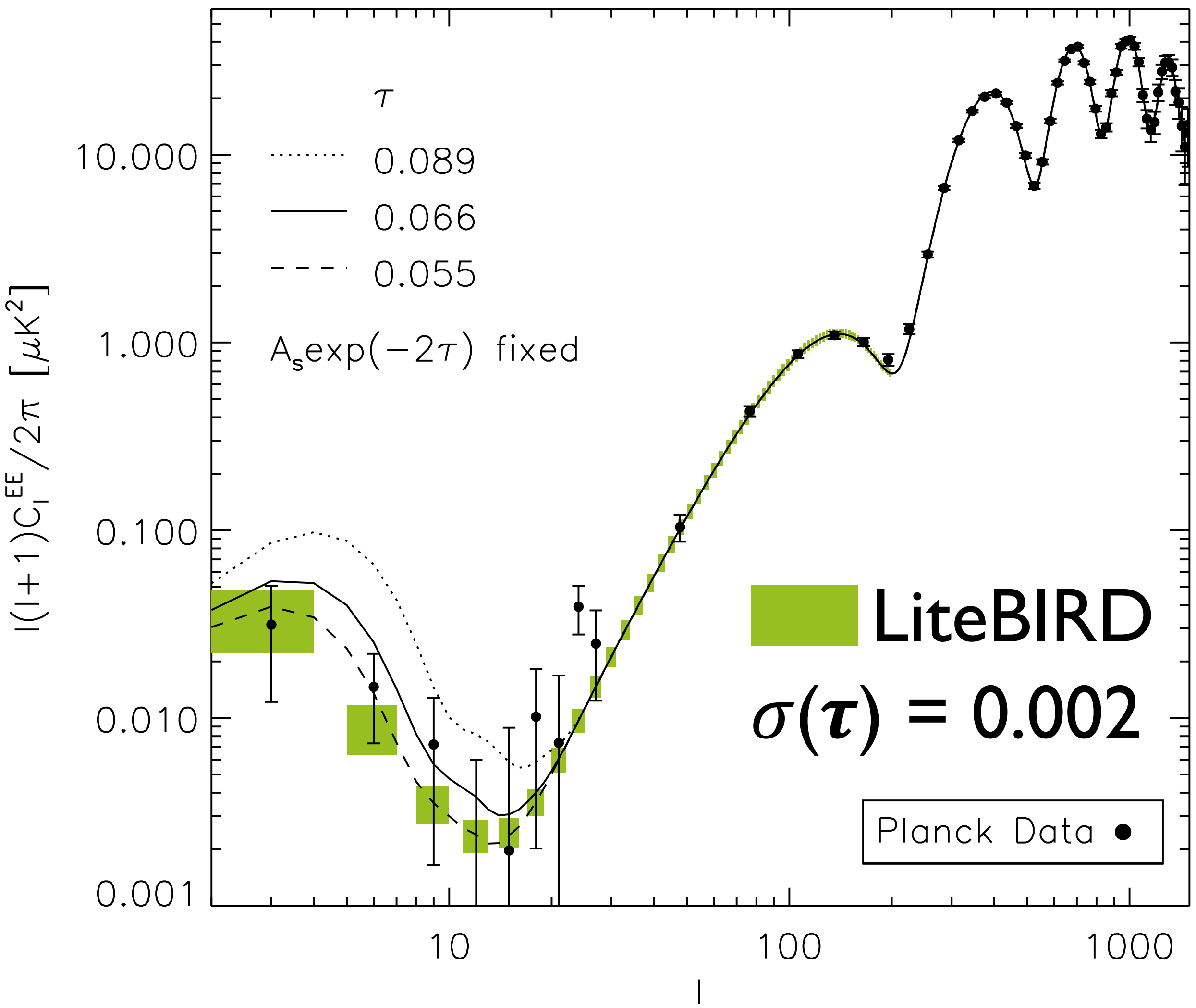
$$r = 8M_{\rm Pl}^2\left(\frac{V_\phi}{V}\right)^2$$

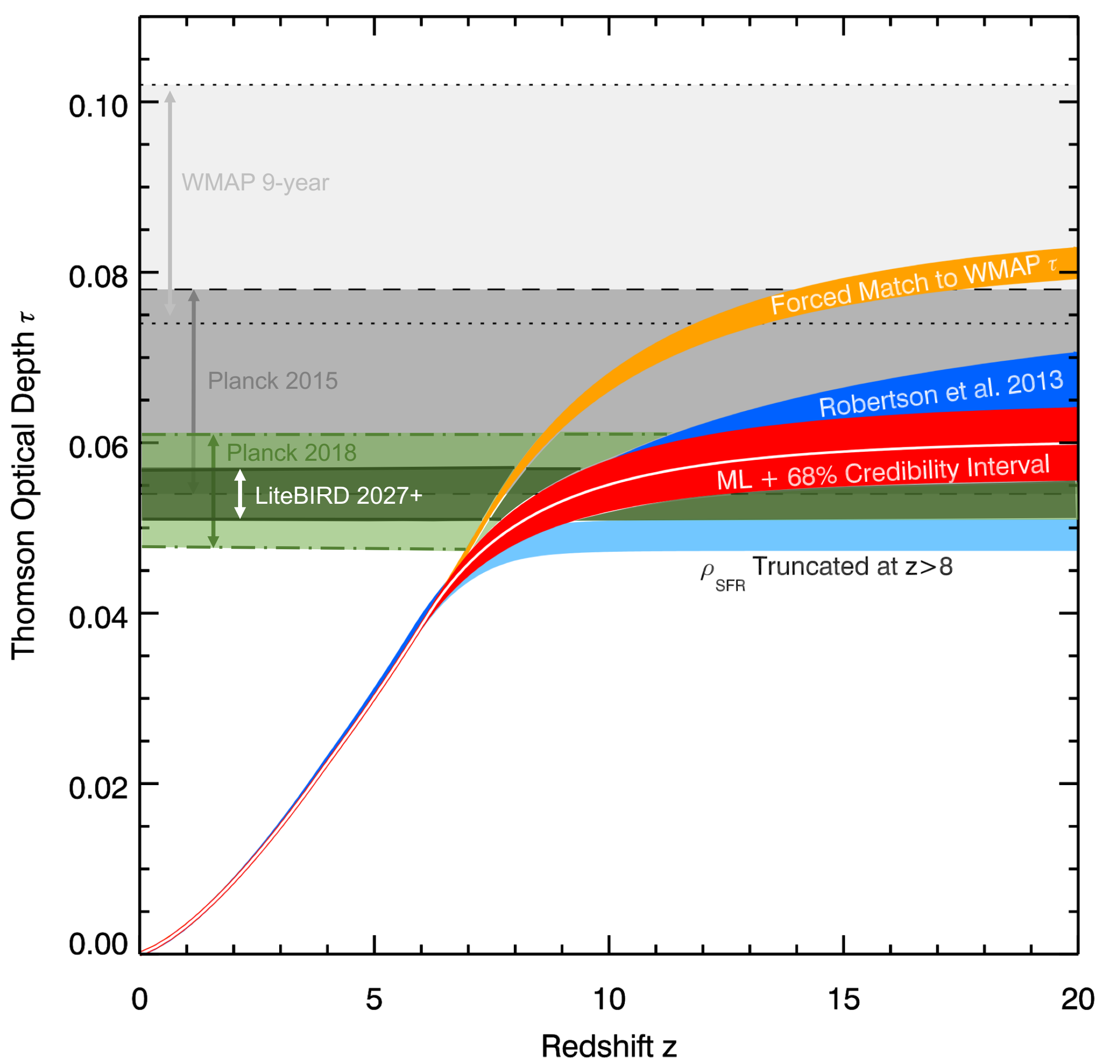
$$n_{\rm s} - 1 \equiv \frac{\mathrm{d}\ln\mathcal{P}_\zeta}{\mathrm{d}\ln k} \simeq -3M_{\rm Pl}^2\left(\frac{V_\phi}{V}\right)^2 + 2M_{\rm Pl}^2\frac{V_{\phi\phi}}{V}$$

Scientific Outcomes

Reionisation

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





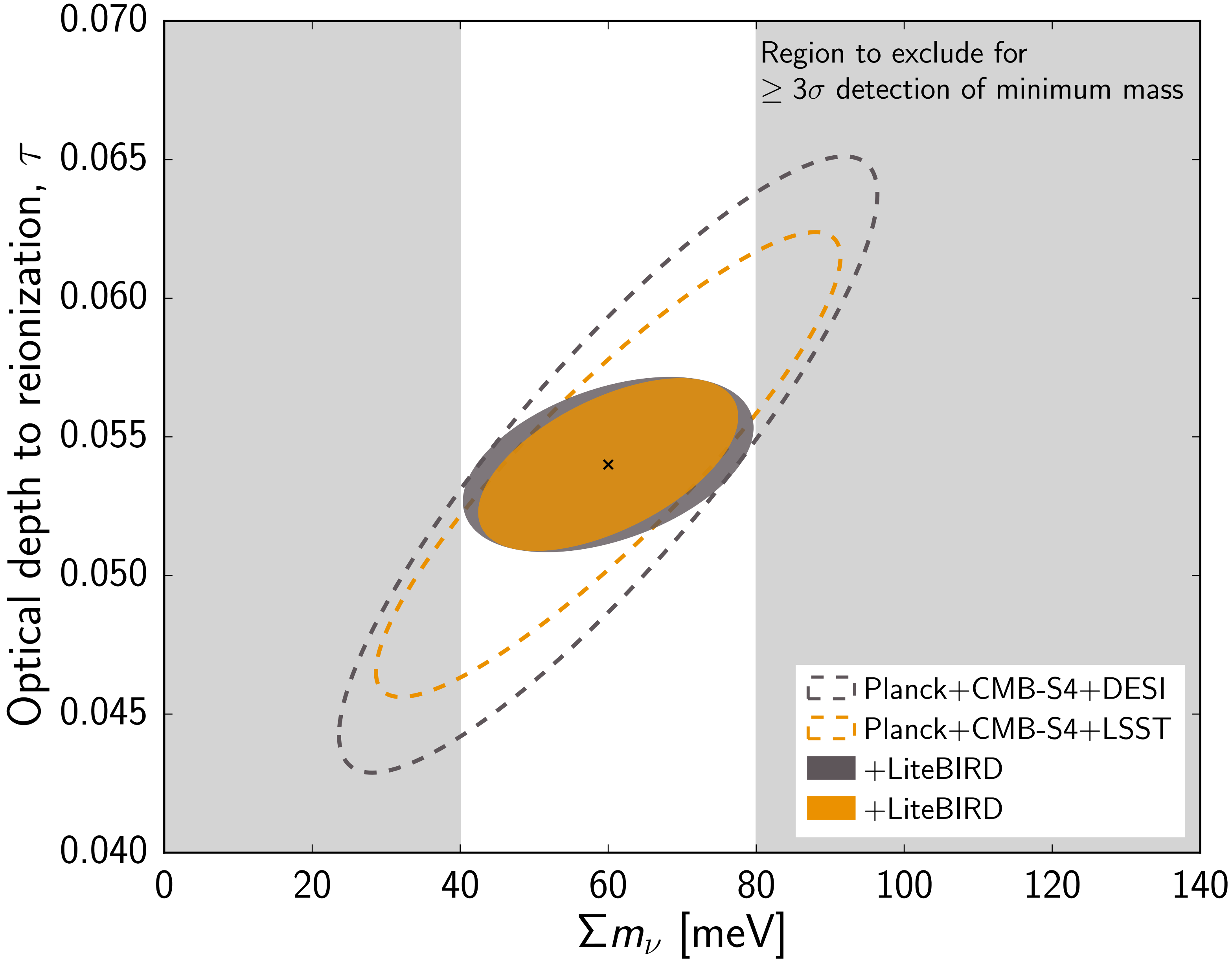
$\sigma(\tau)$ better than current Planck constraints by a factor 2

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)

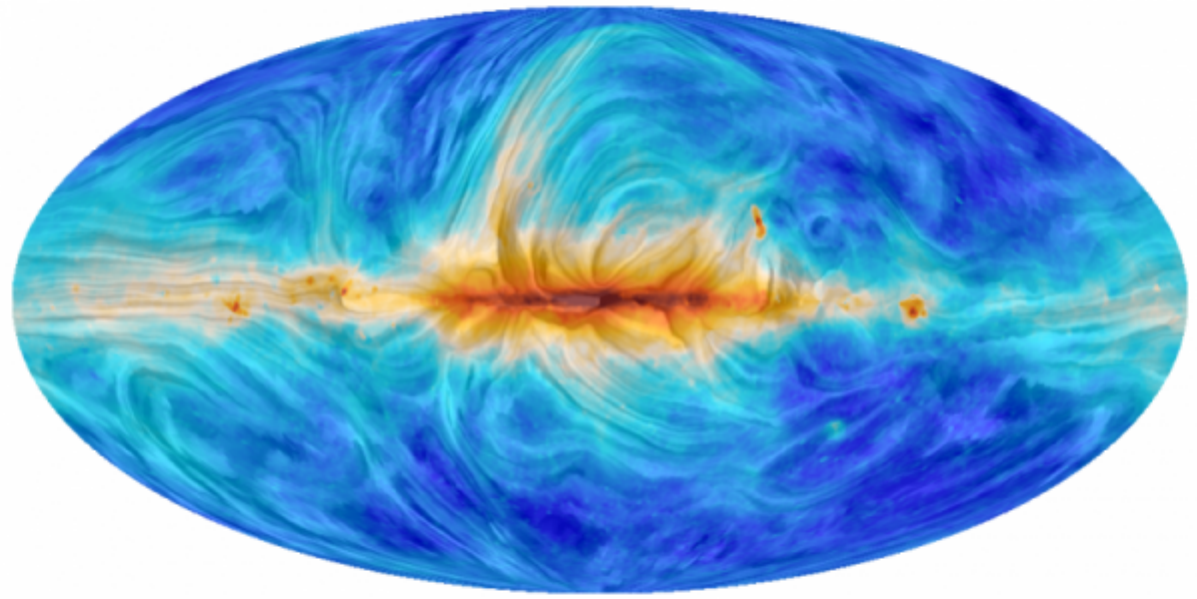


Scientific Outcomes

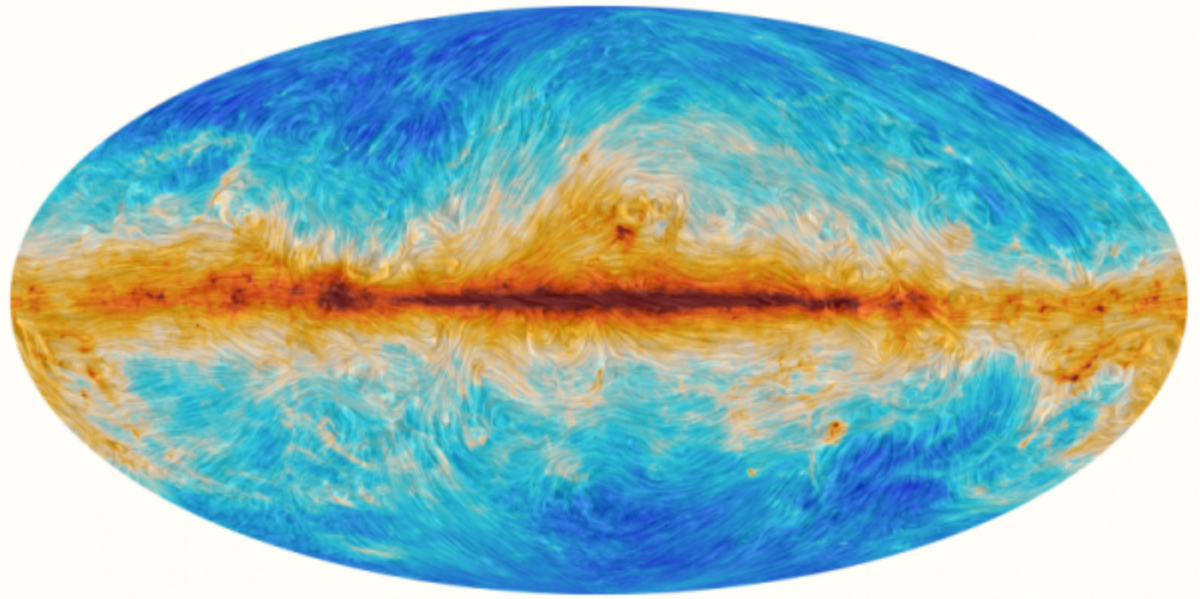
Galactic Science

- 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

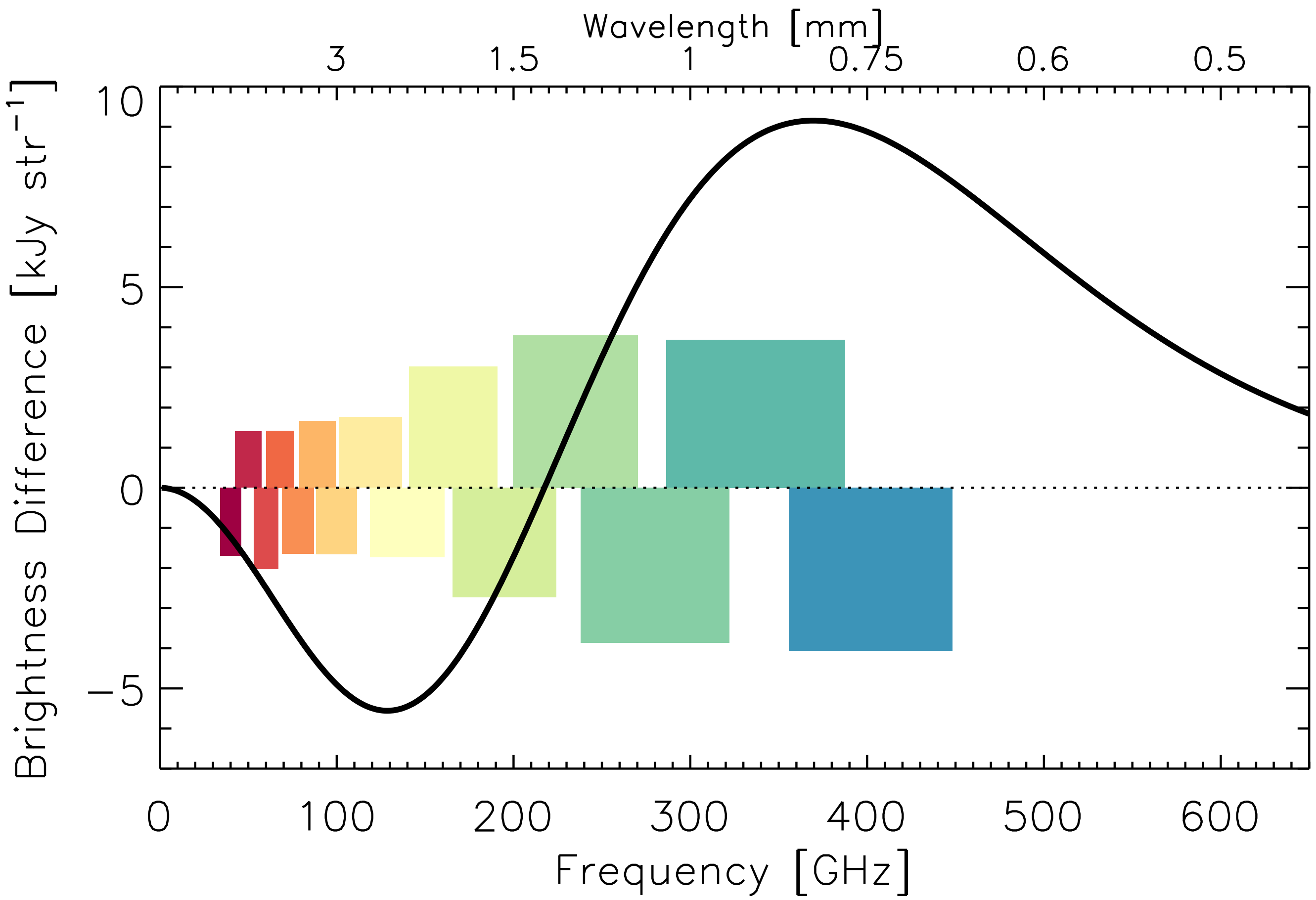


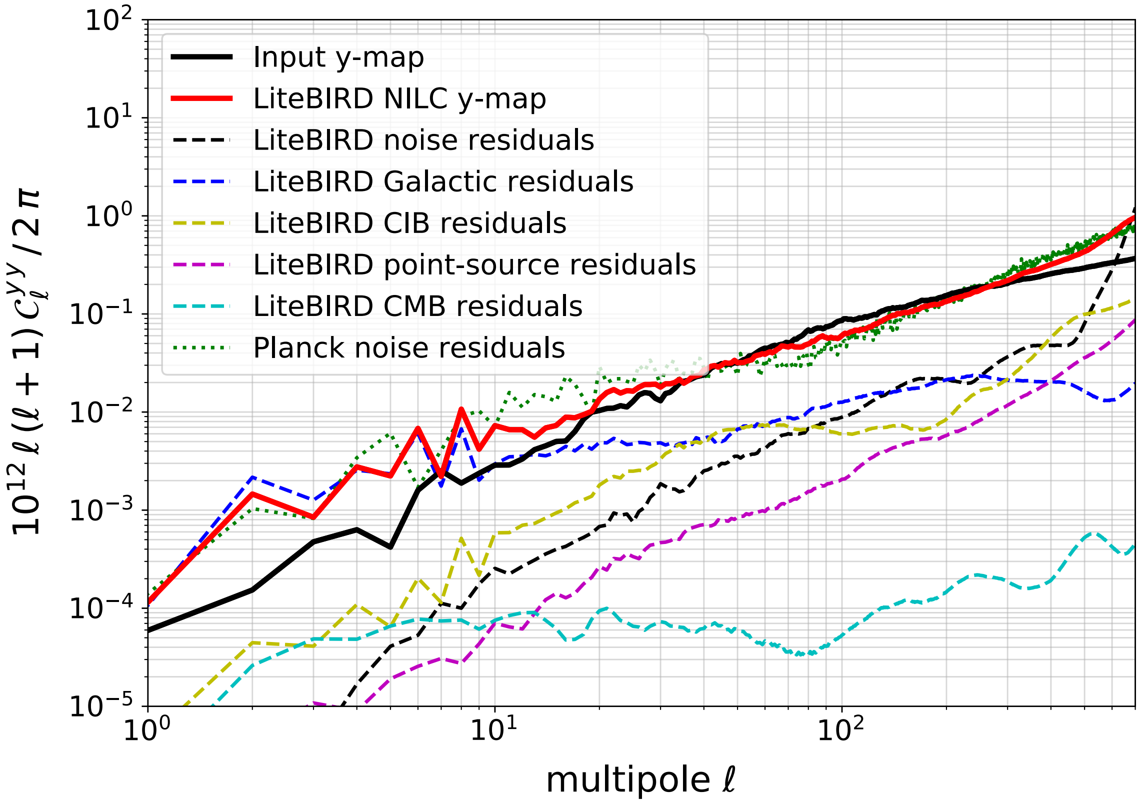
Dust

Scientific Outcomes

Mapping the hot gas in the Universe

- significant improvement on the SZ y-map in terms of foregrounds residuals thanks to the 15 bands





Scientific Outcomes

Spectral distortions of the CMB

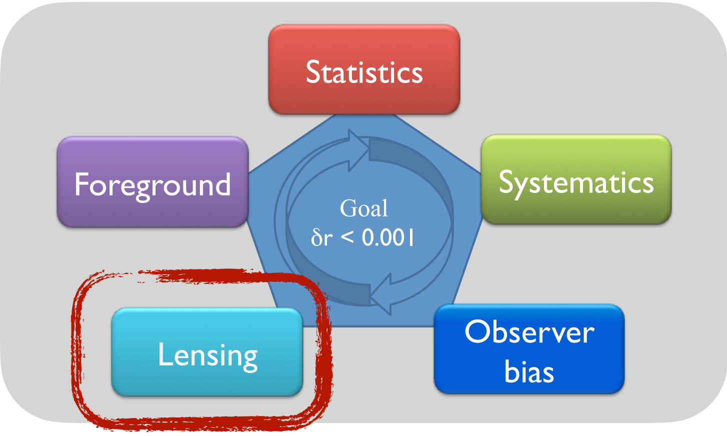
- Anisotropic CMB spectral distortions could be measured well
  - Forecasts better than PIXIE ! (15 bands are many)
  - Multi-field effects or non-Bunch-Davies initial conditions
    - spatially-varying chemical potential distributions [Pajer-Zaldarriaga-2012, Ganc-Komatsu-2012]
    - Effects on $C_\ell^{\mu\mu}$, $C_\ell^{\mu T}$

- Frequency Space Differential measurements for detecting any spectral distortion [Mukherjee-Silk-Wandelt 2018]
  - Use inter-frequency differences only

interesting theoretical ideas need experimental assessment:

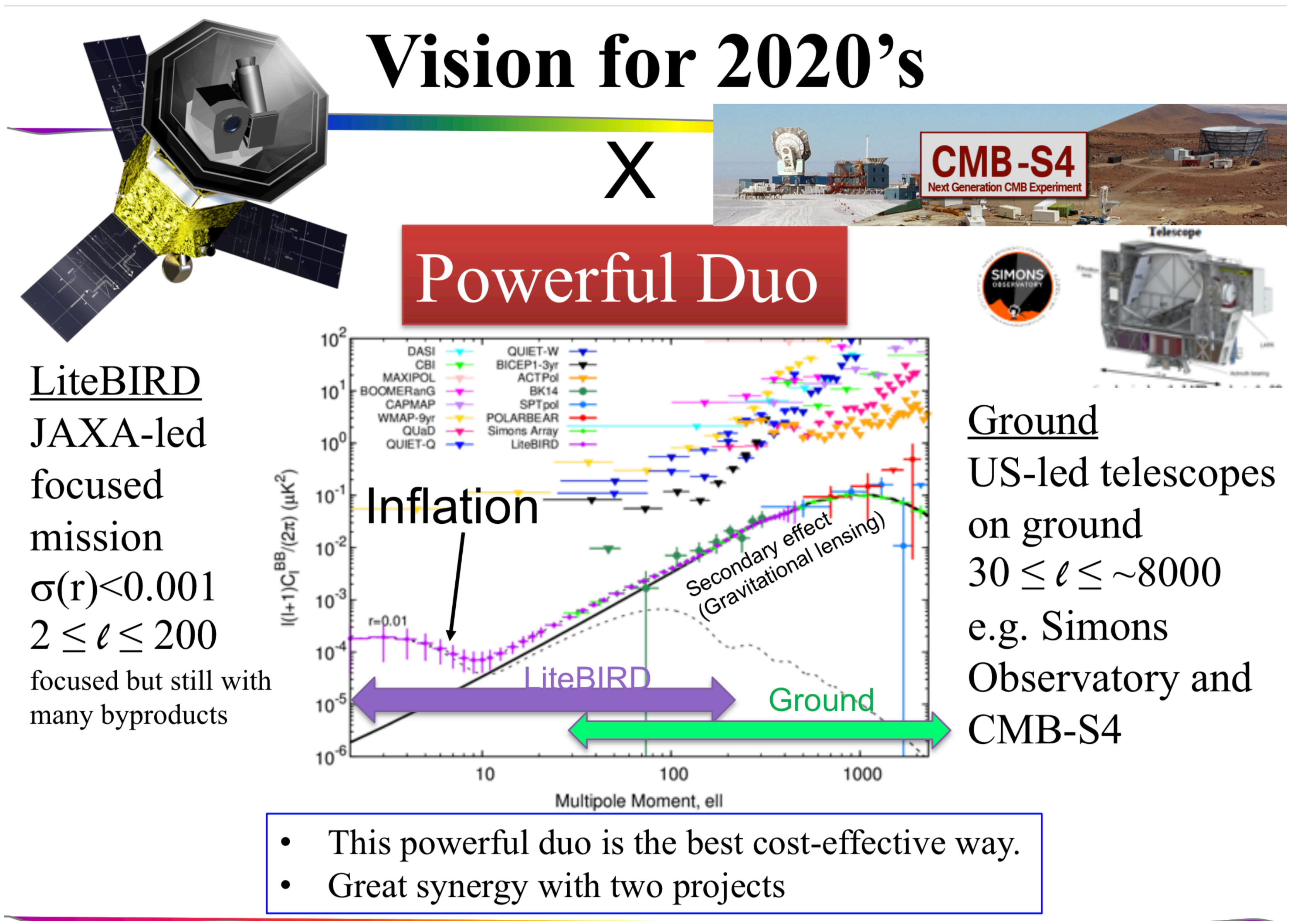
- include 1/f noise, systematic errors, etc…
- use advantages of multi-color detectors
- use "controlled imperfection" of HWP for gain calibration

Scientific Outcomes



Extra success

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

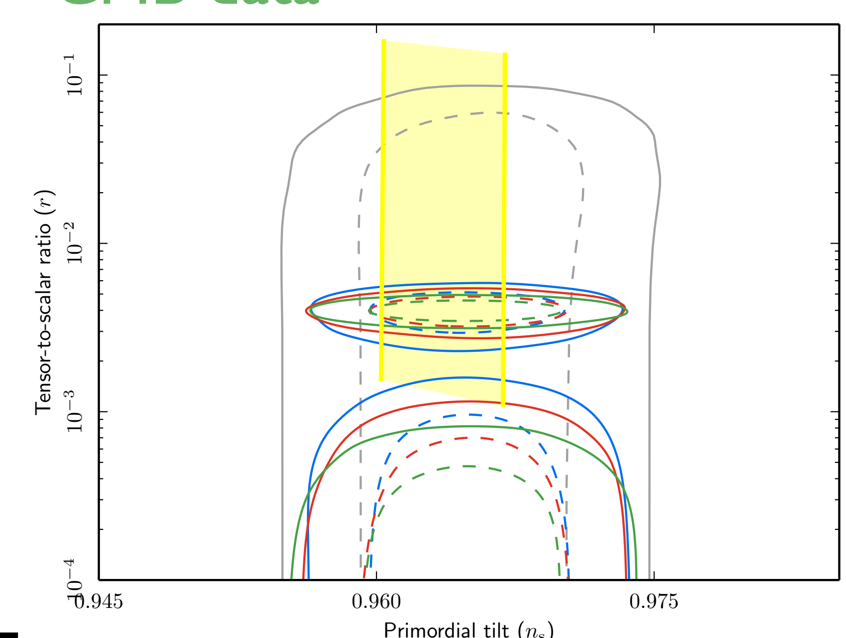


Aiming at detection with >5σ in case of Starobinsky model

Baseline

+ delensing w/Planck CIB & WISE

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



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 2028

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