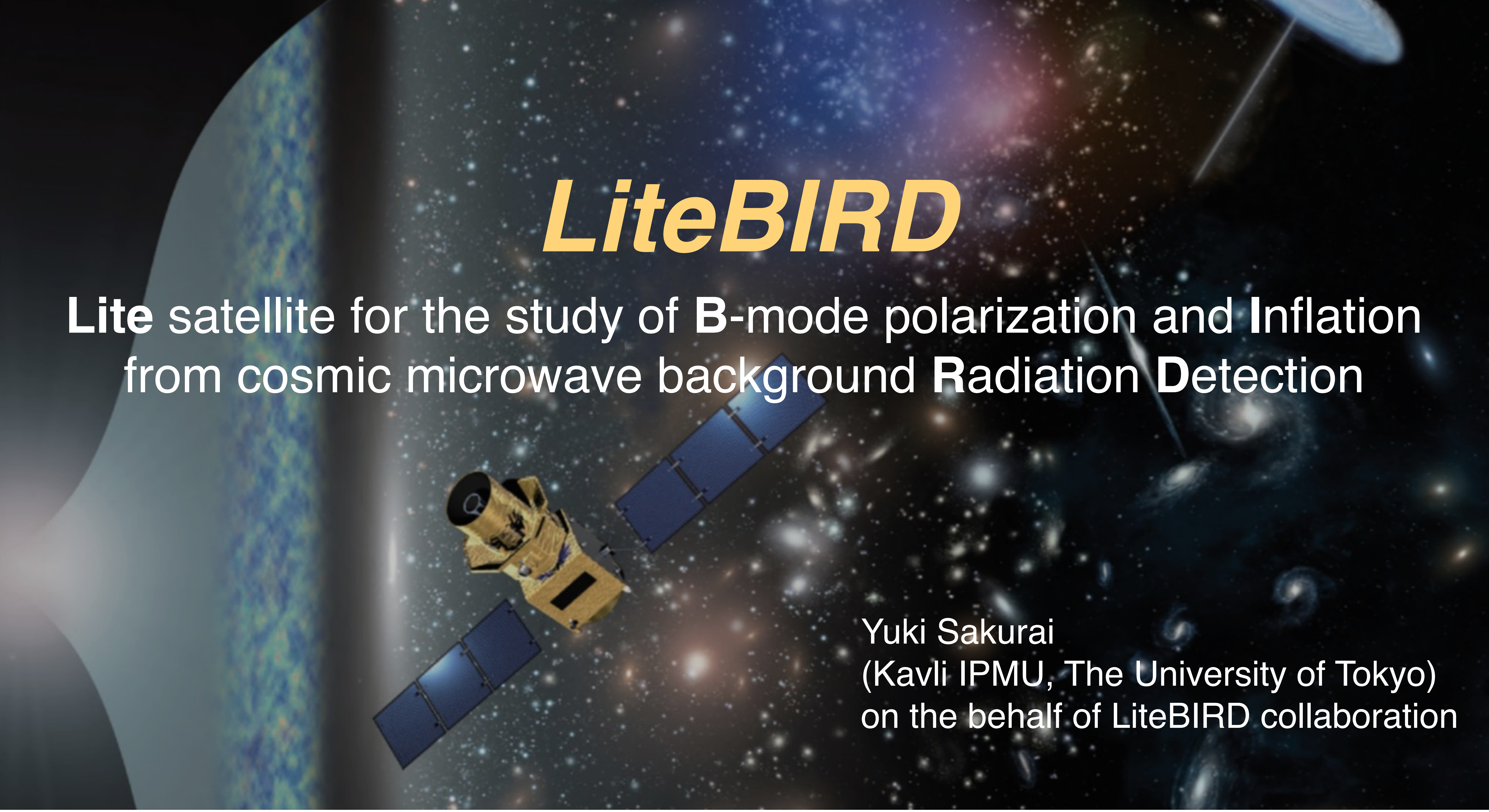


LiteBIRD

Lite satellite for the study of **B**-mode polarization and **I**nflation from cosmic microwave background **R**adiation **D**etection

Yuki Sakurai
(Kavli IPMU, The University of Tokyo)
on the behalf of LiteBIRD collaboration

東京大学
THE UNIVERSITY OF TOKYO

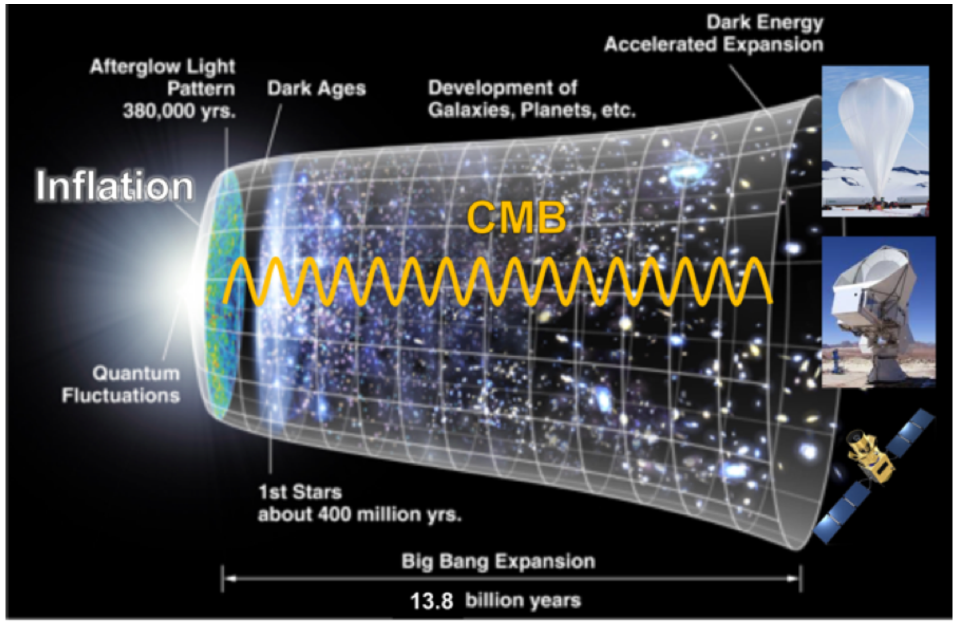
wpi World Premier International Research Center Initiative

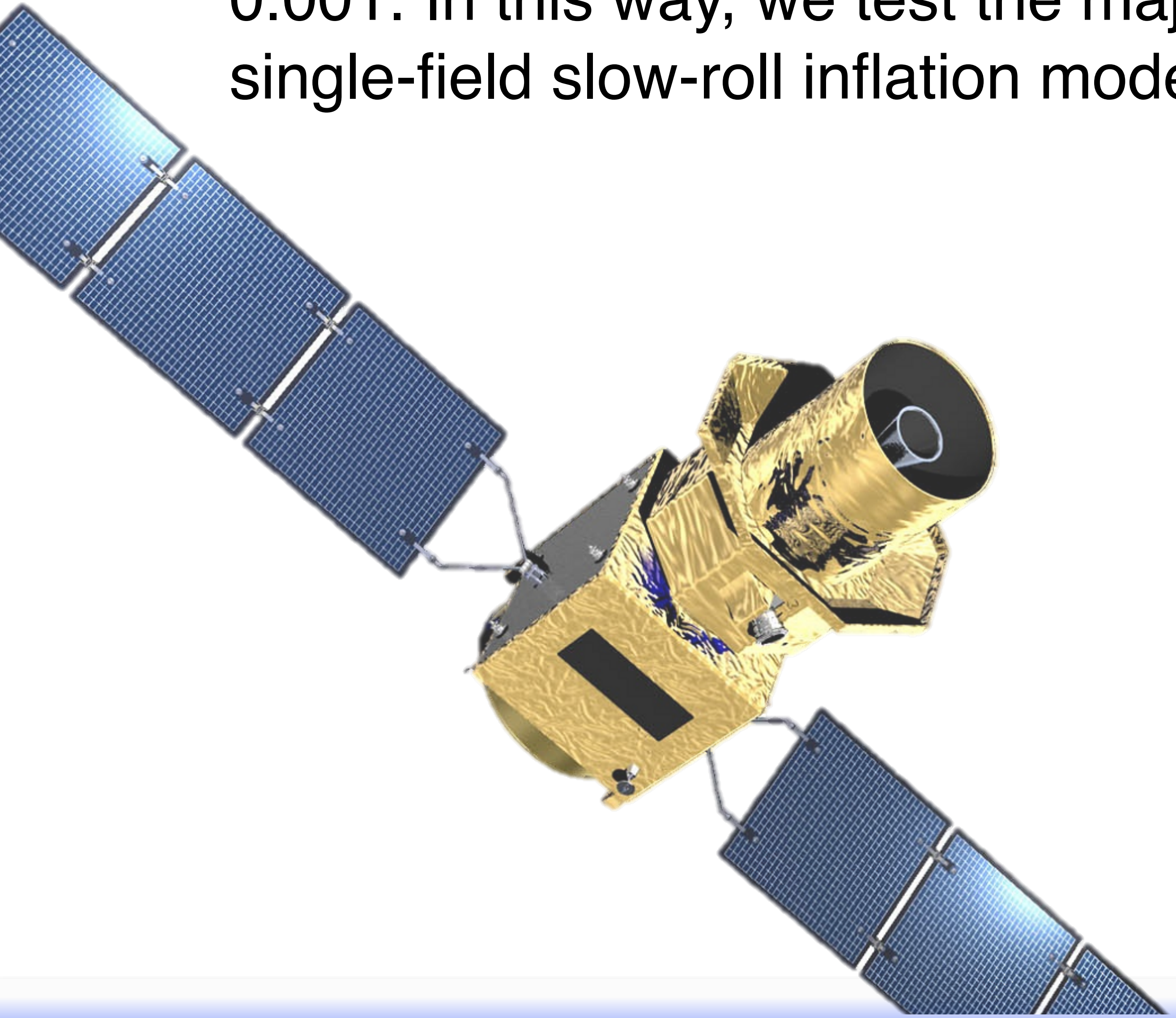
KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

研究拠点形成事業
Core-to-Core Program

LiteBIRD

LiteBIRD is a next generation CMB polarization satellite that is dedicated to probe the inflationary B-mode. The science goal of LiteBIRD is to measure the tensor-to-scalar ratio with the sensitivity of $\sigma(r) < 0.001$. In this way, we test the major large-single-field slow-roll inflation models.





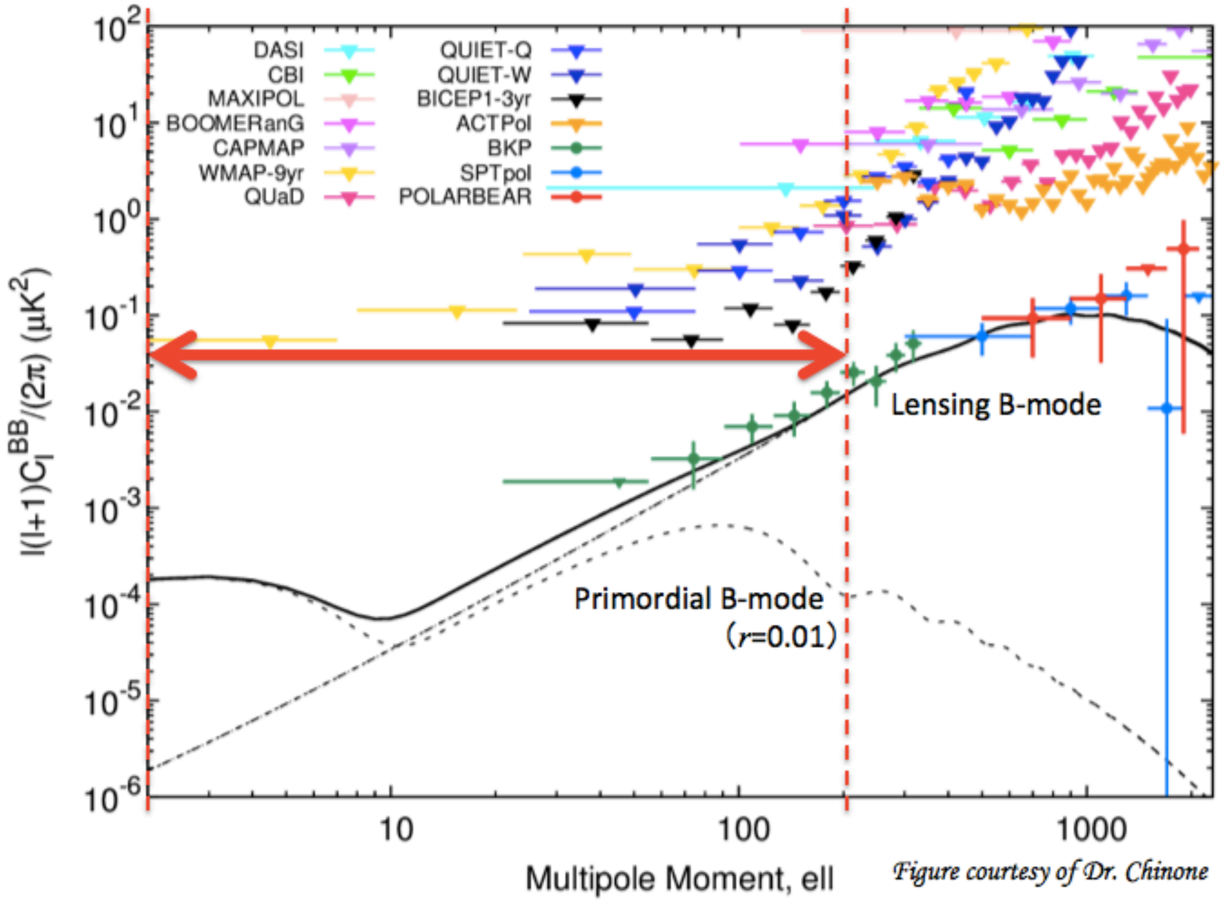


Figure courtesy of Dr. Chinone

LiteBIRD working group

152 members, international and interdisciplinary (as of July 2017)

JAXA
T. Dotani
H. Fuke
H. Imada
I. Kawano
H. Matsuhara
K. Mitsuda
T. Nishibori
K. Nishijo
A. Noda
A. Okamoto
S. Sakai
Y. Sato
K. Shinozaki
H. Sugita
Y. Takei
H. Tomida
T. Wada
R. Yamamoto
N. Yamasaki
T. Yoshida
K. Yotsumoto
Y. Sekimoto
T. Hasebe

Osaka U.
M. Nakajima
K. Takano

Osaka Pref. U.
M. Inoue
K. Kimura
H. Ogawa
N. Okada

Okayama U.
T. Funaki
N. Hidehira
H. Ishino
A. Kibayashi
Y. Kida
K. Komatsu
S. Uozumi
Y. Yamada

NIFS
S. Takada

Kavli IPMU
A. Ducout
T. Iida
D. Kaneko
N. Katayama
T. Matsumura
Y. Sakurai
H. Sugai
B. Thorne
S. Utsunomiya

KEK
M. Hazumi (PI)
M. Hasegawa
Y. Inoue
N. Kimura
K. Kohri
M. Maki
Y. Minami
T. Nagasaki
R. Nagata
H. Nishino
T. Okamura
N. Sato
J. Suzuki
T. Suzuki
S. Takakura
O. Tajima
T. Tomaru
M. Yoshida

SOKENDAI
Y. Akiba
Y. Inoue
H. Ishitsuka
Y. Segawa
S. Takatori
D. Tanabe
H. Watanabe

NAOJ
A. Dominjon
J. Inatani
K. Karatsu
S. Kashima
M. Nagai
T. Noguchi
M. Sekine

Kitazato U.
T. Kawasaki

Saitama U.
M. Naruse

NICT
Y. Uzawa

Konan U.
I. Ohta

Kansei Gakuin U.
S. Matsuura

AIST
K. Hattori

U. Tokyo
A. Kusaka
S. Sekiguchi
T. Shimizu
S. Shu
N. Tomita

Tohoku U.
M. Hattori
T. Morishima

Nagoya U.
K. Ichiki

Yokohama Natl. U.
T. Fujino
F. Irie
S. Nakamura
K. Natsume
R. Takaku
T. Yamashita

RIKEN
S. Mima
S. Oguri
C. Otani

TIT
S. Matsuoka

APC Paris
R. Stompor

Cardiff U.
G. Pisano

Paris ILP
J. Errard

CU Boulder
N. Halverson

McGill U.
M. Dobbs

MPA
E. Komatsu

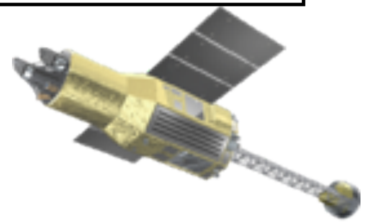
NIST
G. Hilton
J. Hubmayr

UC San Diego
K. Arnold
T. Elleot
B. Keating
G. Rebeiz

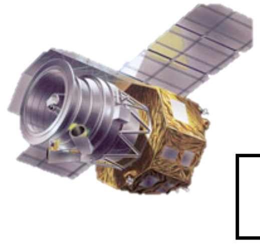
UC Berkeley / LBNL
D. Barron
J. Borrill
Y. Chinone
A. Cukierman
D. Curtis
T. de Haan
L. Hayes
J. Fisher
N. Goeckner-wald
C. Hill
O. Jeong
R. Keskitalo
T. Kisner
A. Kusaka
A. Lee(US PI)
E. Linder
D. Meilhan
P. Richards
E. Taylor
U. Seljak
B. Sherwin
A. Suzuki
P. Turin
B. Westbrook
M. Willer
N. Whitehorn

Stanford U.
S. Cho
K. Irwin
S. Kernasovskiy
C.-L. Kuo
D. Li
T. Namikawa
K. L. Thompson

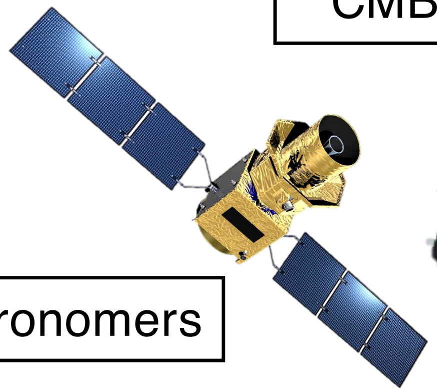
X-ray astrophysicists



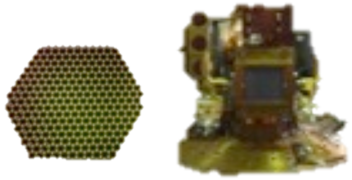
JAXA engineers



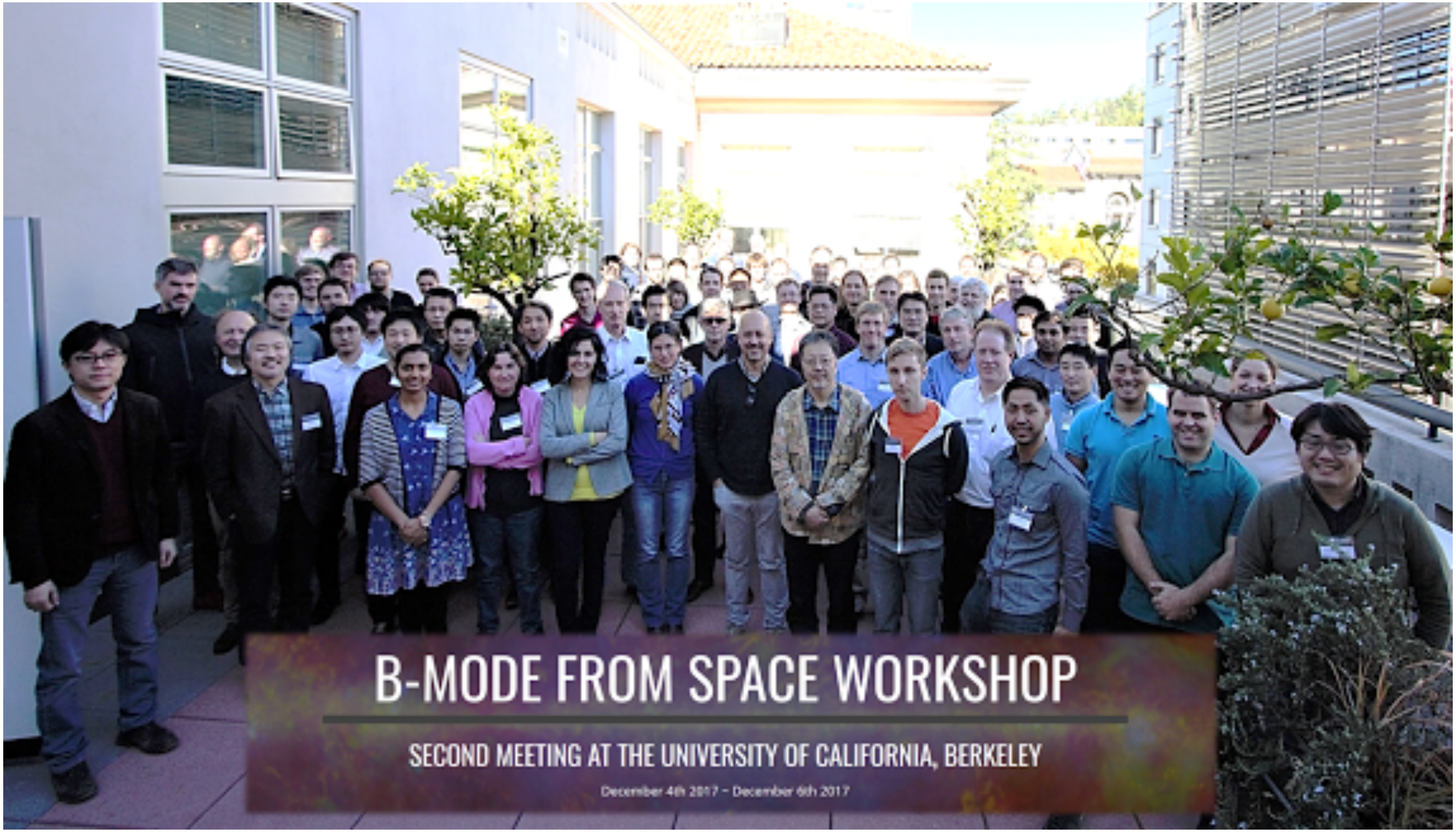
IR astronomers



CMB experimets



Super-conducting detector developers



B-MODE FROM SPACE WORKSHOP

SECOND MEETING AT THE UNIVERSITY OF CALIFORNIA, BERKELEY

December 4th 2017 – December 6th 2017

Full Success of LiteBIRD

$\sigma(r) < 1 \times 10^{-3}$ (for $r=0$)

All sky survey (for $2 \leq \ell \leq 200$)*

✓ $\sigma(r)$ is the total uncertainty on the r measurement that includes **statistics** ⊕ **systematics** ⊕ **foreground** ⊕ **lensing** ⊕ **observer bias** **

✓ The above should be achieved without delensing.

✓ Many inflationary models predict $r > 0.01$ ⇒ >10 sigma discovery

✓ Simple well-motivated inflationary models (single-large-field slow-roll models) have a lower bound on r,
$r > 0.002$, from Lyth relation.

$$r = \frac{1}{N^2}\left(\frac{\Delta\Phi}{m_{pl}}\right)^2 \approx 2 \cdot 10^{-3}\left(\frac{\Delta\Phi}{m_{pl}}\right)^2$$

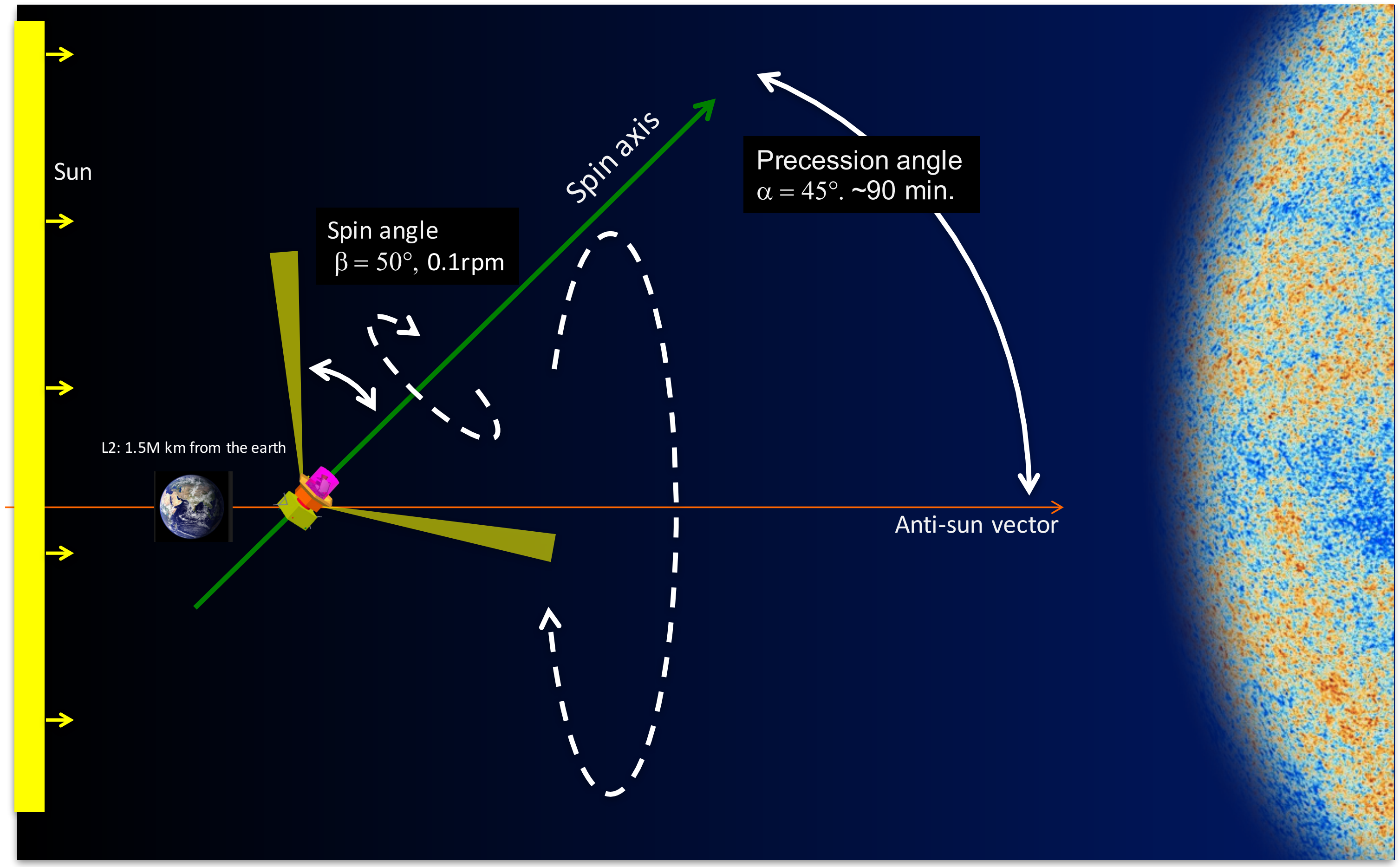
✓ No gravitational wave detection with LiteBIRD ⇒ exclude well motivated inflationary models (i.e. $r < 0.002$ @ 95% C.L.)

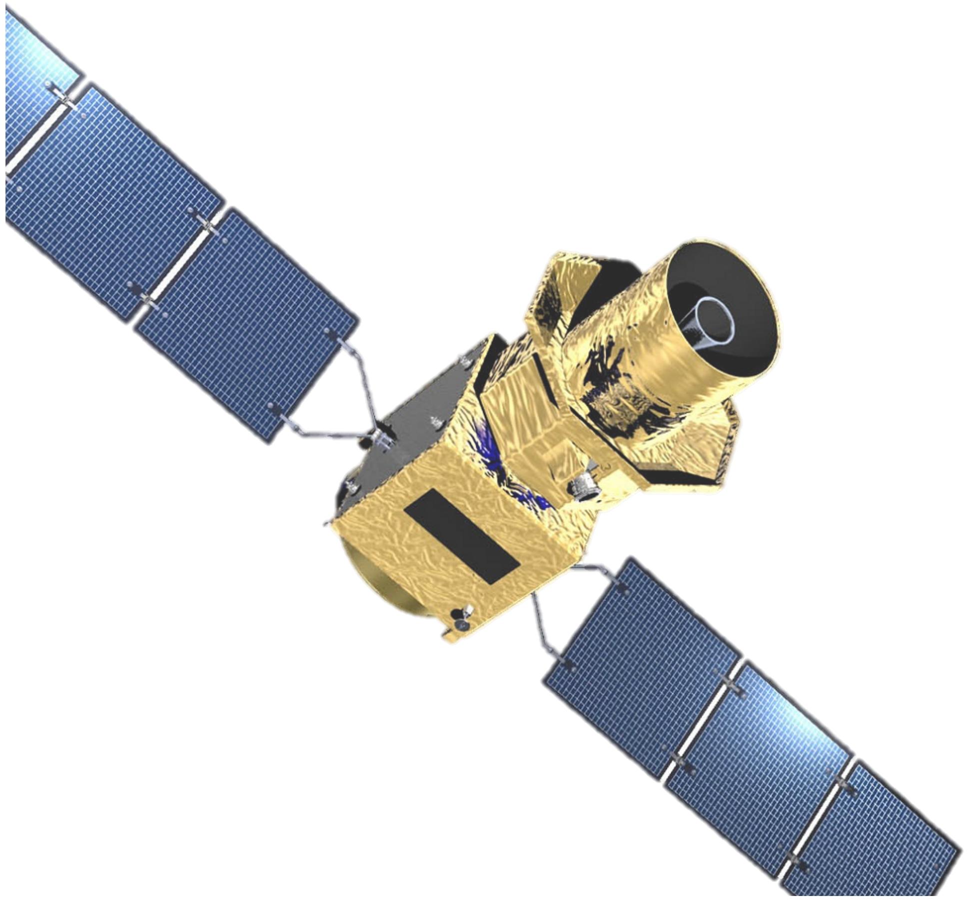
* More precise (i.e. long) definition ensures > 5σ r detection from each bump for r > 0.01.

** We also use an expression $\delta r = \sigma(r=0)$, which has no cosmic variance.

Observation Strategy

JAXA H3 Launch vehicle





Launch vehicle: JAXA H3

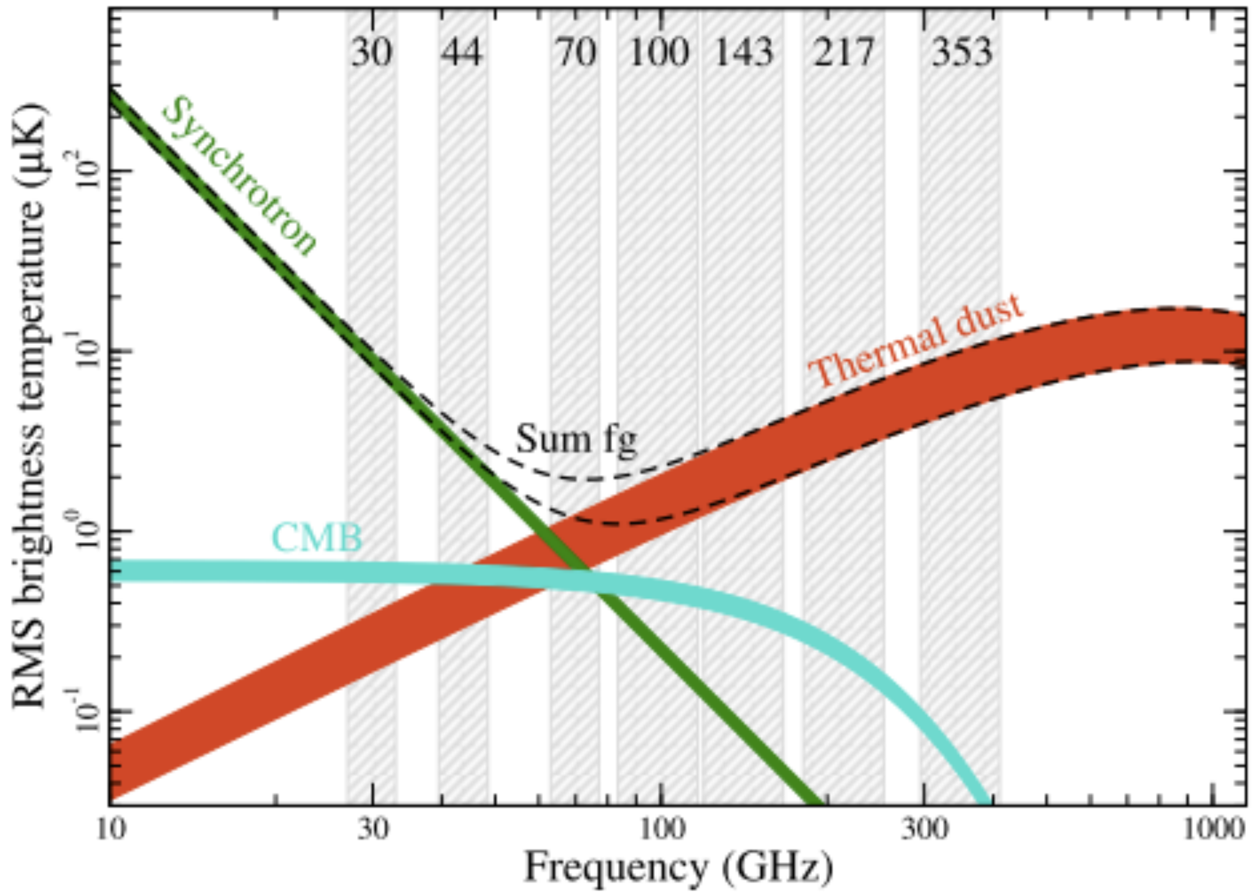
Observation location: Second Lagrangian point (L2)

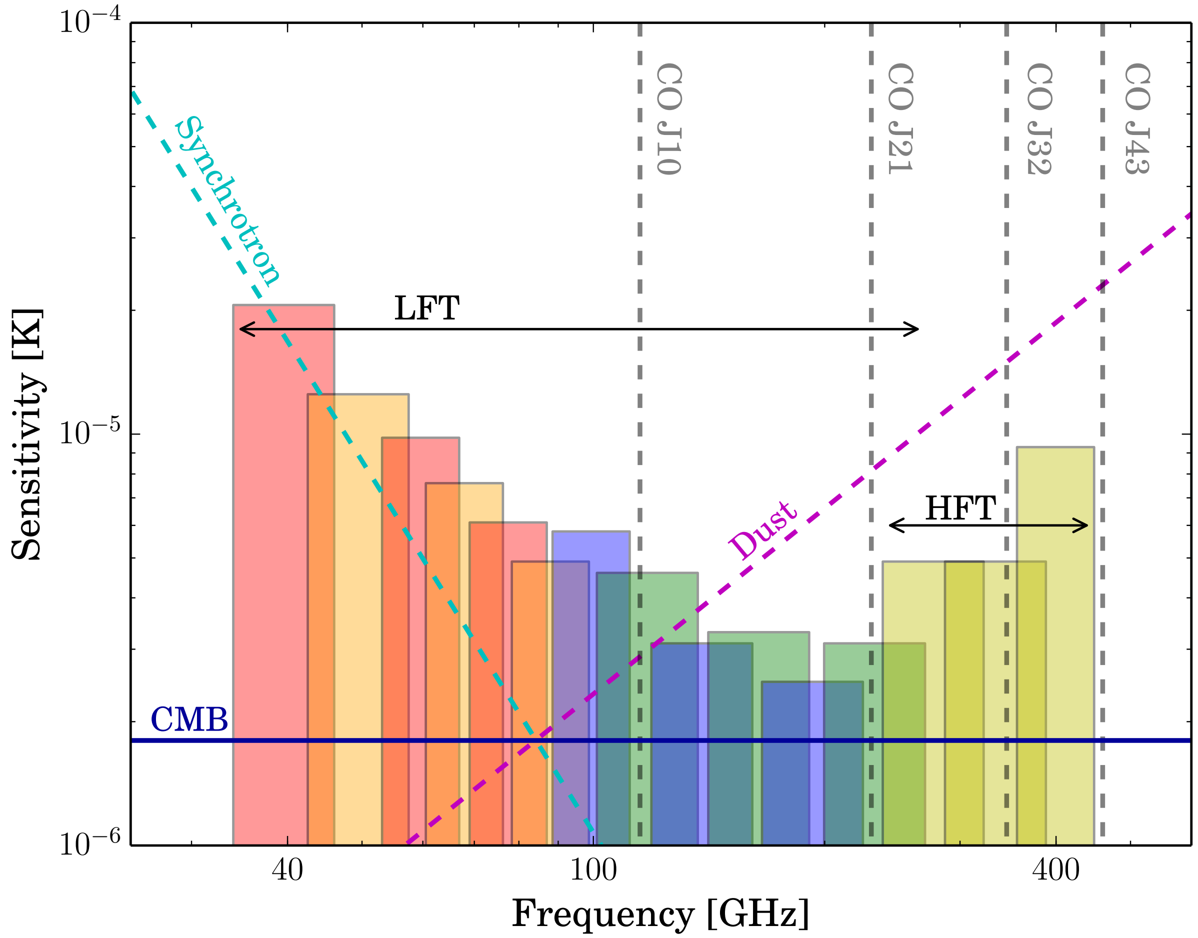
Scan strategy: Spin and precession, full sky

Observation duration: 3-years

Proposed launch date: Mid 2020's

Foreground Removal





Polarized foregrounds

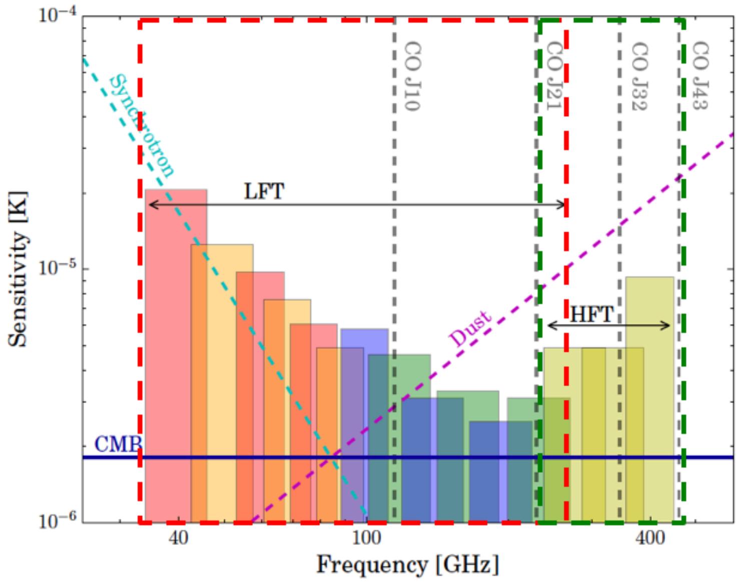
- Synchrotron radiation and thermal emission from inter-galactic dust
- Characterize and remove foregrounds

15 Frequency bands. Obs. band : 34〜448 GHz

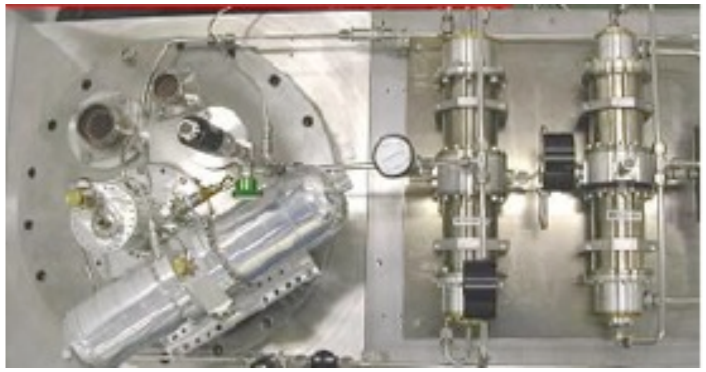
- Low Frequency Telescope (LFT) : 34〜270 GHz
- High Frequency Telescope (HFT) : 238〜448 GHz

Mission System Overview

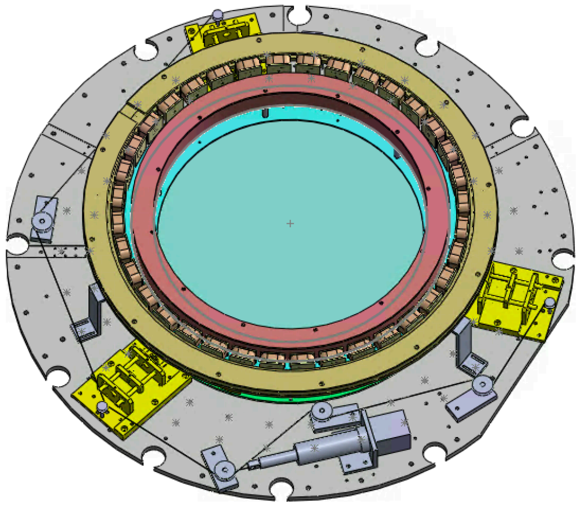
Frequency coverage

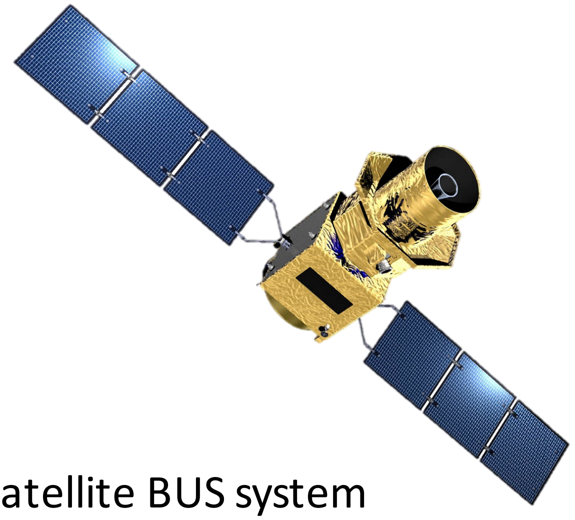


Cryogenics



Polarization modulator using HWP at aperture

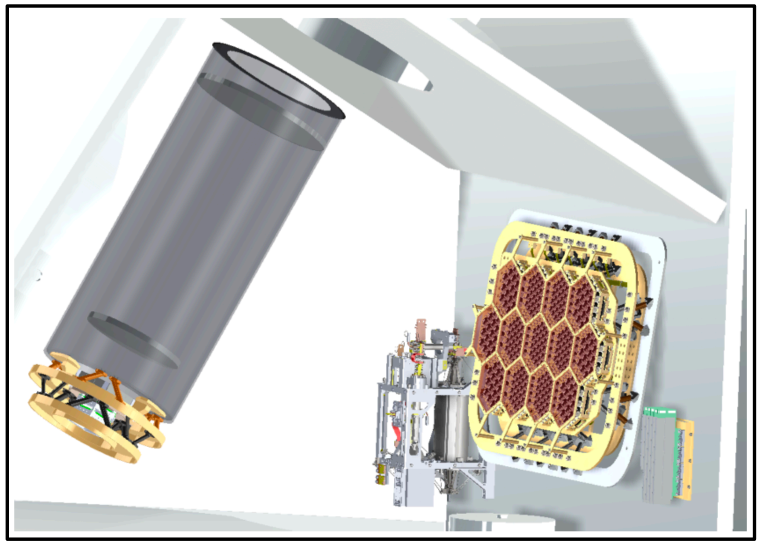


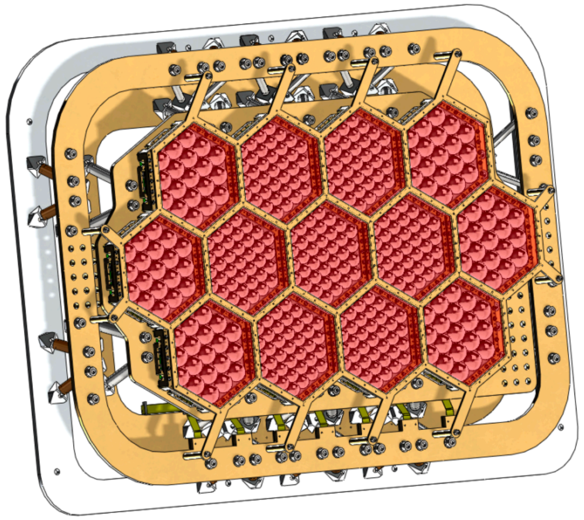


Satellite BUS system

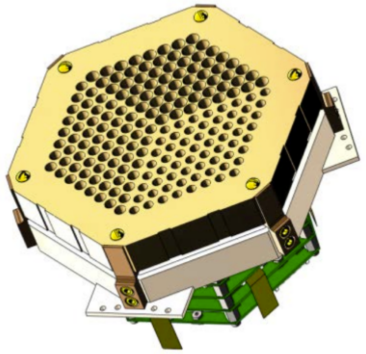
- Observing from L2 orbit
- The mission system consists of two telescopes.
- The entire telescope system is cooled down below 5K.

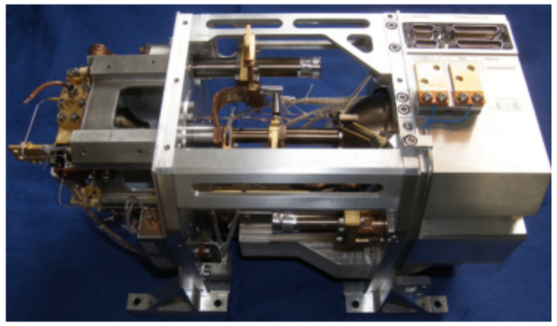
Two telescopes, LFT and HFT





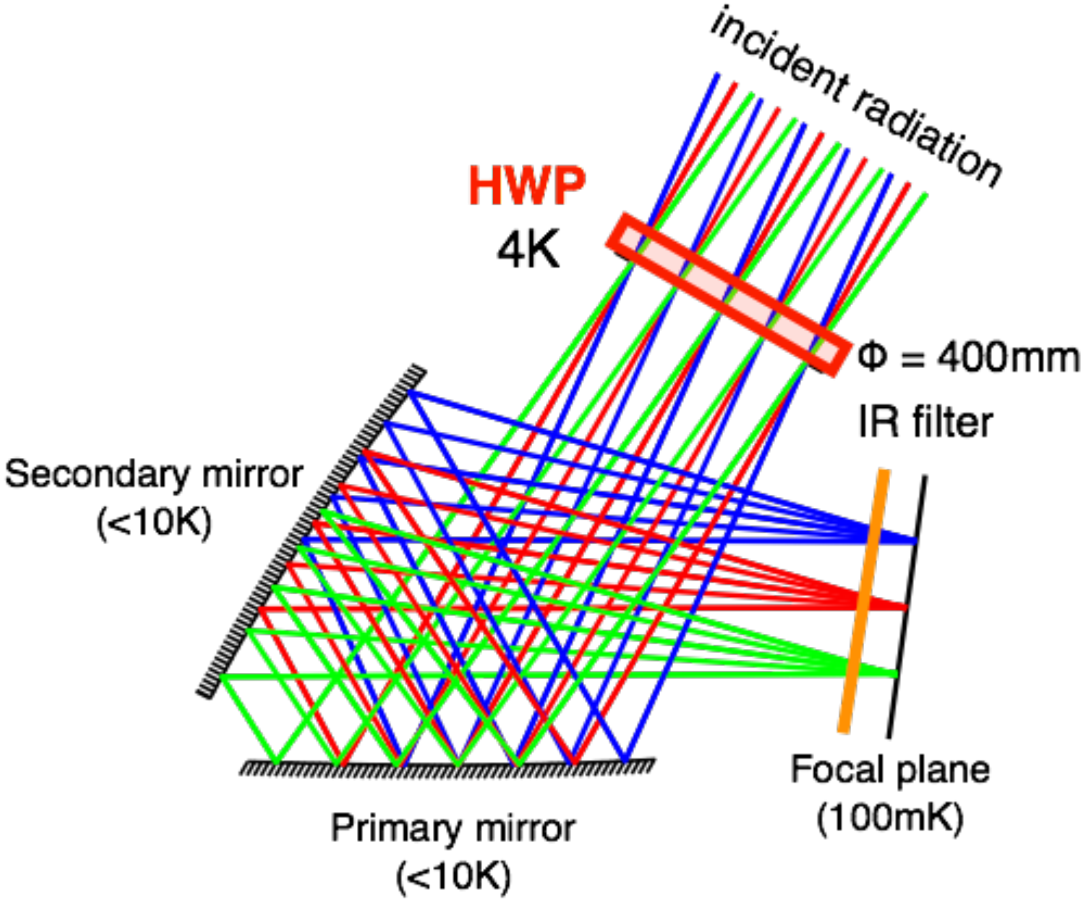
Focal plane for HFT

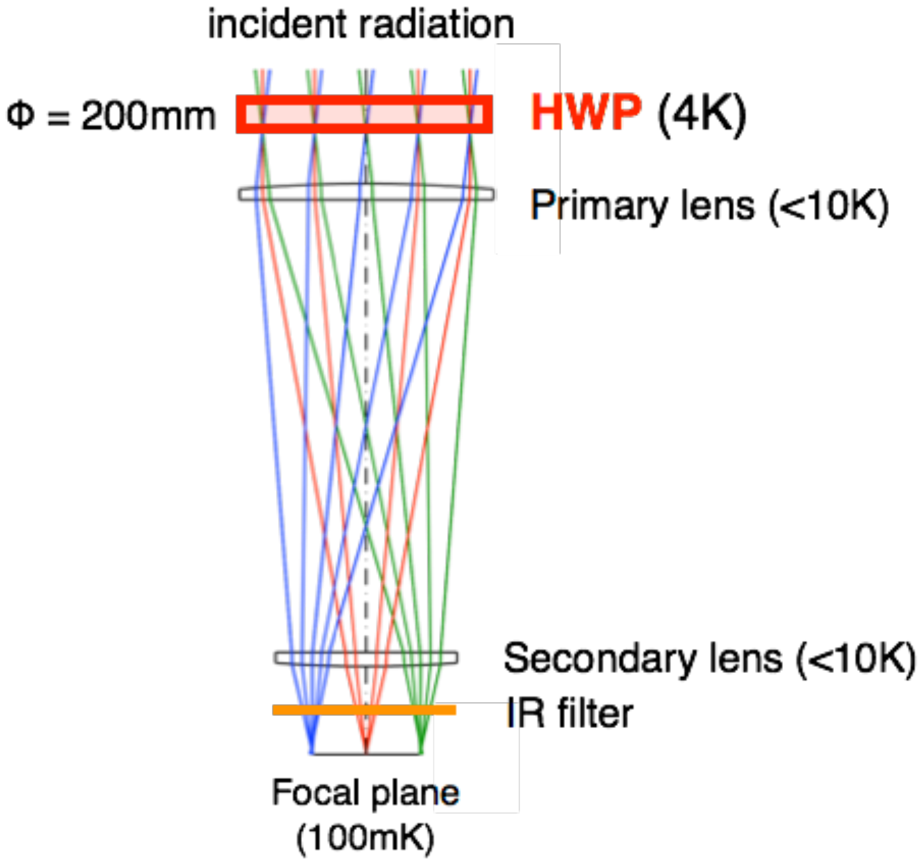




ADR to cool the TES detector to 100mK

Two Telescopes





Low frequency telescope (LFT)

- Cross-Dragone telescope
- Obs. Band: 34 ~ 270GHz
- Aperture size: 400mm
- Telecentric focal plane with the FOV is (10×20degs^2)

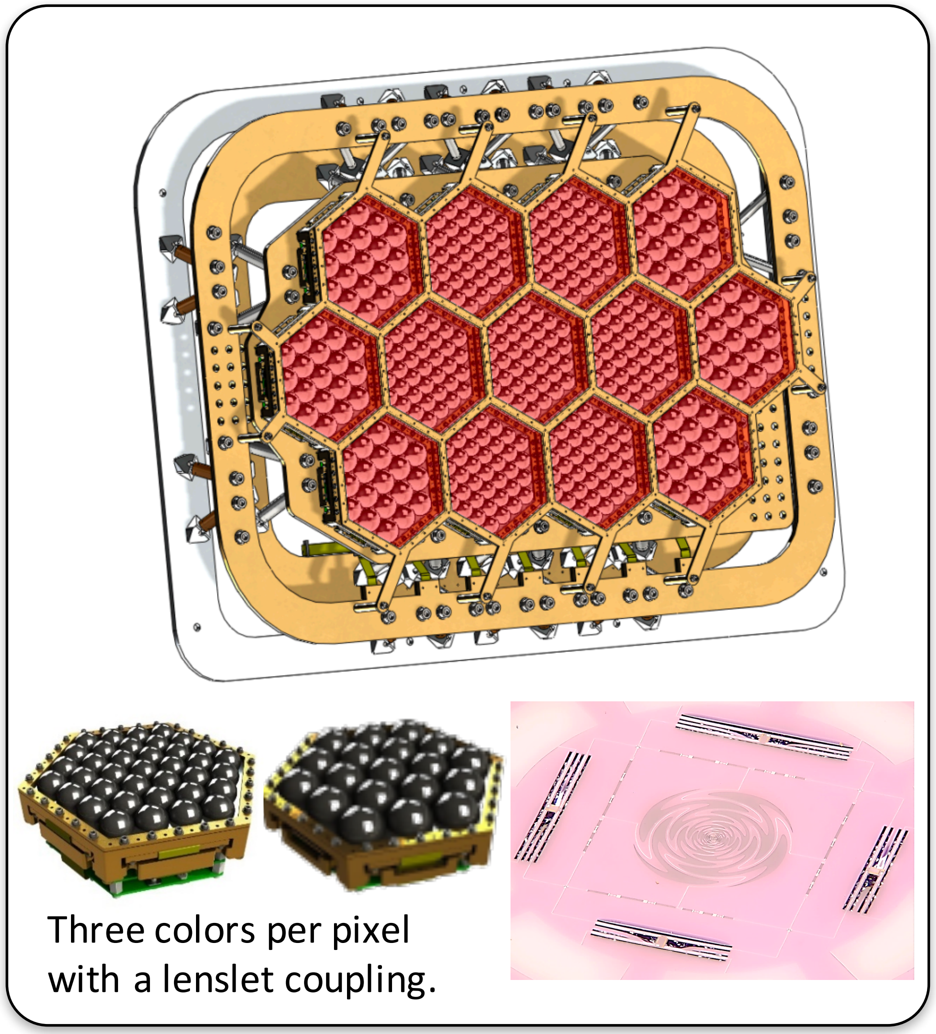
High frequency telescope (HFT)

- Refractive telescope
- Obs. Band: 238 ~ 448GHz
- Aperture size: 200mm
- Telecentric focal plane with the FOV is (5×5degs^2)

- Less than a degree of the beam size at all bands.
- Controlling the sidelobe by introducing the cryogenically cooled Lyot stop at 2K.
- Introduce the rotating polarization modulator at the aperture

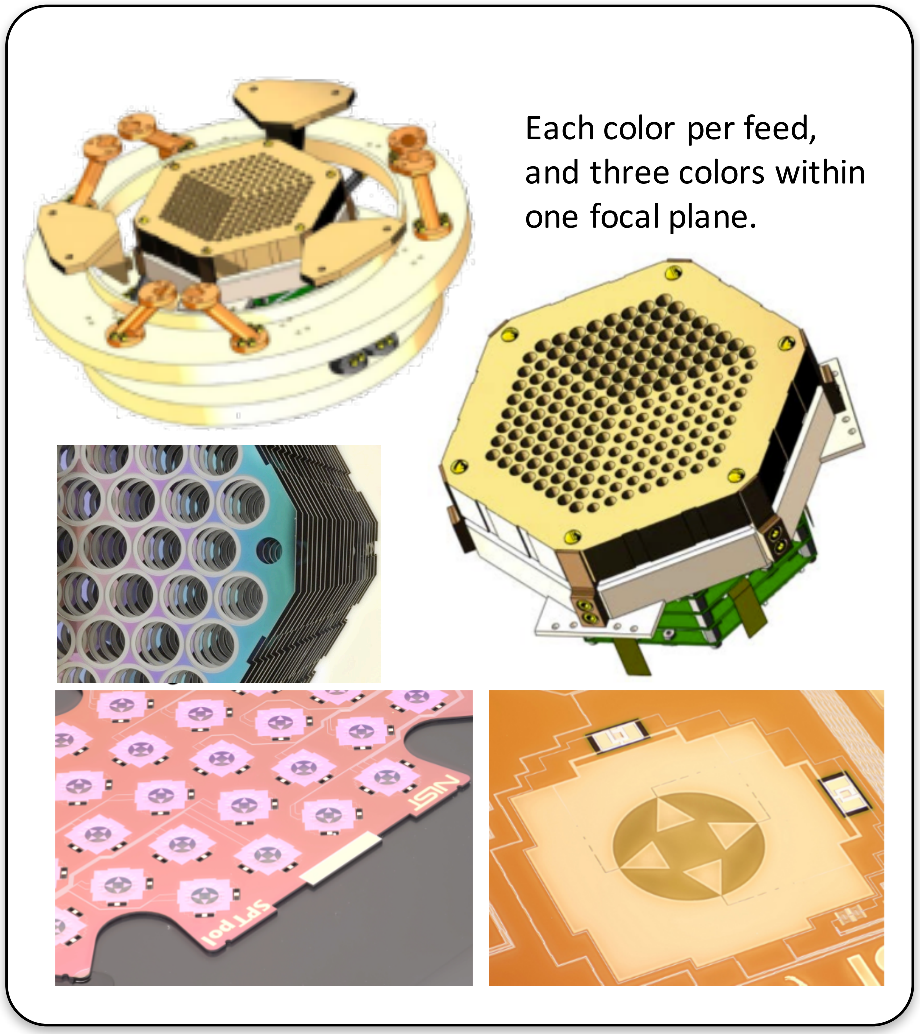
Focal Plane Unit using TES

Low frequency Focal Plane



Three colors per pixel
with a lenslet coupling.

High frequency Focal Plane

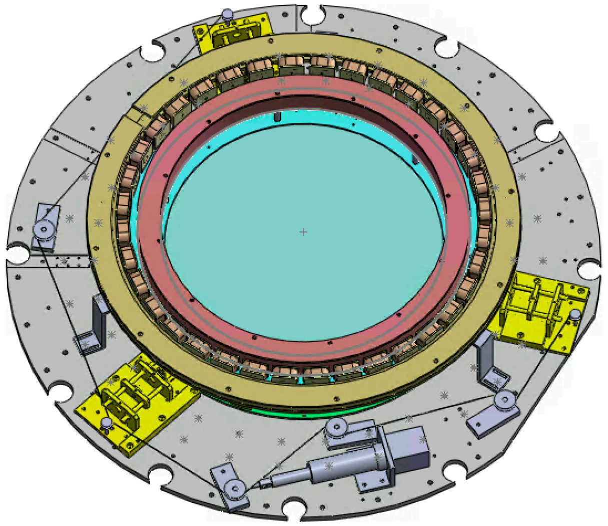


Each color per feed,
and three colors within
one focal plane.

- ✓ The current baseline design uses a single ADR to cool the both focal planes.
- ✓ The LF focal plane has 2238 TESs and the HF focal plane has 384 TESs. The total of 2622.
- ✓ The TES is read by SQUID together with the readout electronics is based on the digital frequency multiplexing system.
- ✓ The effect of the cosmic ray is evaluated by building a model. The irradiation test is in plan.

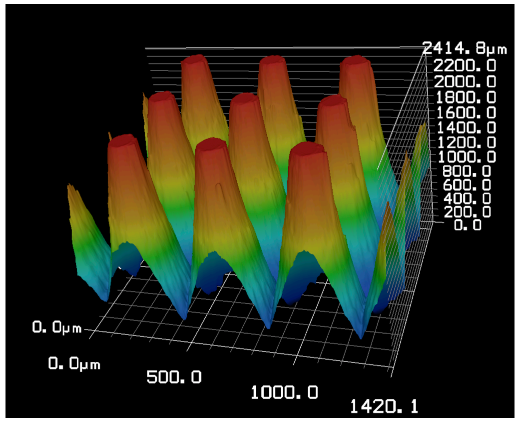
Polarization modulator

- Since the mission focuses on the primordial signal at low ell, we employ the continuously rotating achromatic half-wave plate (HWP).
- The HWP modulator suffices mitigating the 1/f noise and the differential systematics.



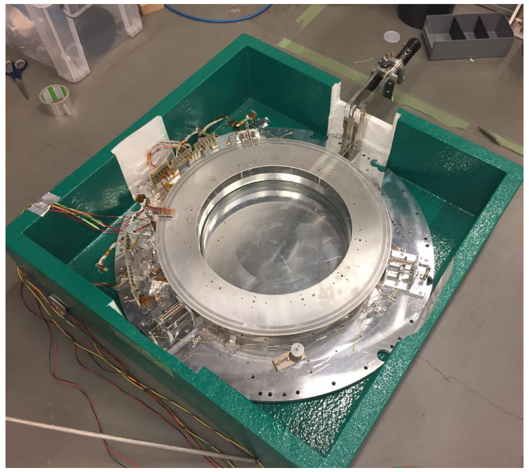
Broadband coverage

- The broadband coverage is done by the sub-wavelength anti-reflection structure.
- The broadband modulation efficiency is achieved by using 9-layer achromatic HWP.



Rotational mechanism

- The continuous rotation is achieved by employing the superconducting magnetic bearing. This system has a heritage from EBEX.
- The prototype system has built and test the kinetic and thermal feasibility.



Demonstration Model

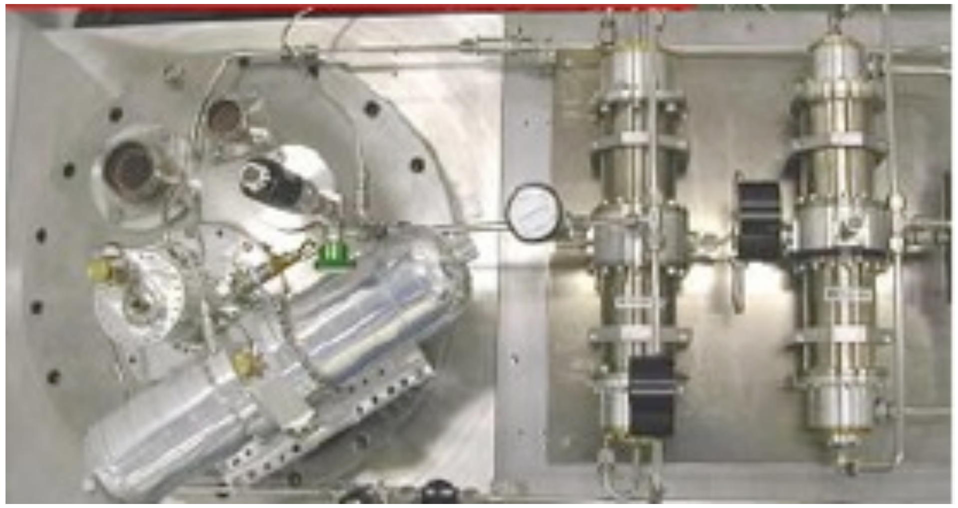
Cooling System

Cryogenics

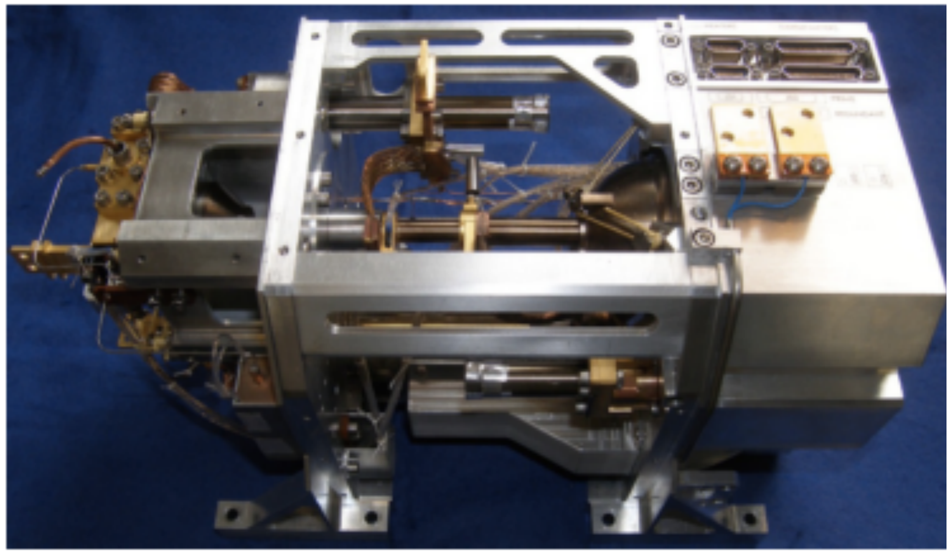
- ✓ Warm launch
- ✓ 3 years of observations
- ✓ 4 K for the mission instruments
- ✓ 100 mK for the focal plane

Mechanical cooler

- ✓ The 2-stage Stirling cooler + 4K-JT cooler from the heritage of the JAXA satellites: Akari (Astro-F), JEM-SMILES and Astro-H.
- ✓ The 1K-JT provides the 1.7 K interface to the sub-Kelvin stage.
- ✓ Sub-Kelvin cooler: ADR has a high-TRL and extensive development toward SPICA, and Athena.
- ✓ Closed dilution with the Planck heritage is also underdevelopment.



Stirling cooler and JT cooler@JAXA



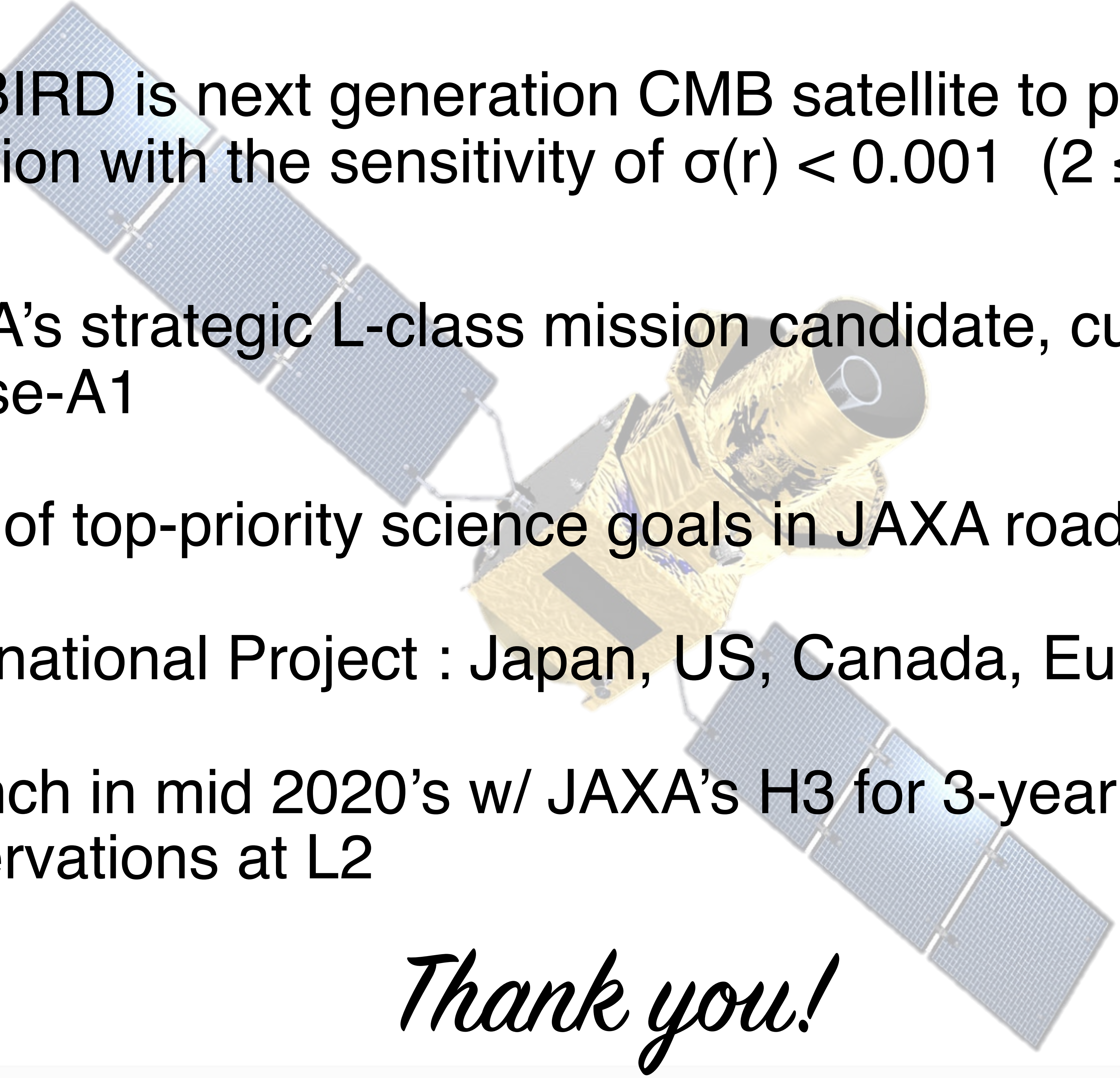
ADR sub-Kelvin cooler @ CEA

Mission status

- ✓ LiteBIRD is one of the serious candidate for the Strategic L-class slot in middle of 2020’s (the other is Solar-Power-Sail Trojan mission).
- ✓ Phase-A1 studies within ISAS/JAXA program started in September 2016 and will continue to August 2018 (2 years). Down selection for the L-class slot is then expected after Phase-A1.
- ✓ JAXA prefers focused missions for strategic large mission program. LiteBIRD is exactly a focused mission.
- ✓ MEXT roadmap 2017 (August 2017)
  - proposed by Japanese Radio Astronomy community
  - endorsed by Japanese HEP community
  - LiteBIRD is selected as one of 7 new large-scale projects
- ✓ JAXA roadmap
  - Probing inflation from B-mode listed as one of top scientific objectives

LiteBIRD is well endorsed !!

Summary



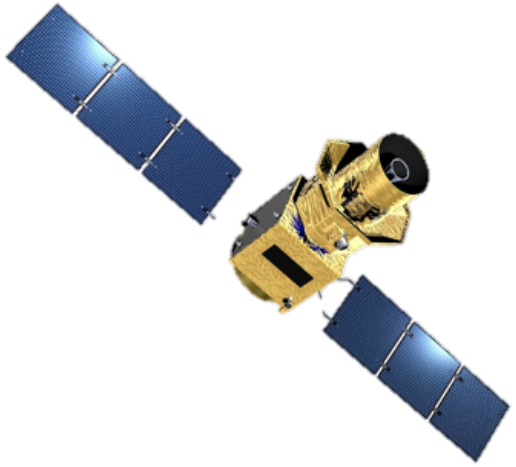
- ✓ LiteBIRD is next generation CMB satellite to probe the inflation with the sensitivity of $\sigma(r) < 0.001$ $(2 \leq \ell \leq 200)$.
- ✓ JAXA's strategic L-class mission candidate, currently in Phase-A1
- ✓ One of top-priority science goals in JAXA roadmap
- ✓ International Project : Japan, US, Canada, Europe
- ✓ Launch in mid 2020's w/ JAXA's H3 for 3-year observations at L2

Thank you!

BACKUP

Basic Japanese Vision for 2020's

Essentially the same vision I had in 2008, when Europe was focusing on Planck.



Powerful Duo

X

JAXA-led focused mission

$\sigma(r)<0.001$

$2 \le \ell \le 200$

focused but still with many byproducts

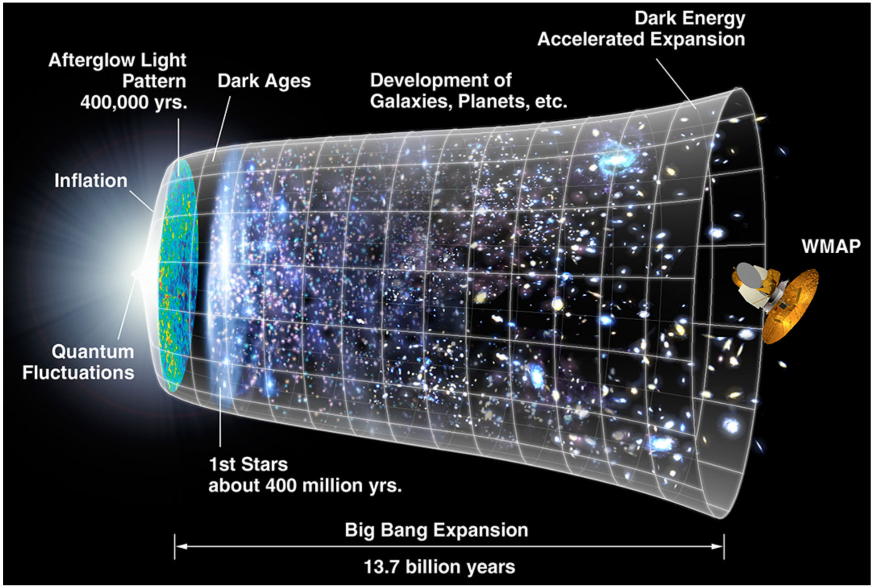
US-led telescopes on ground

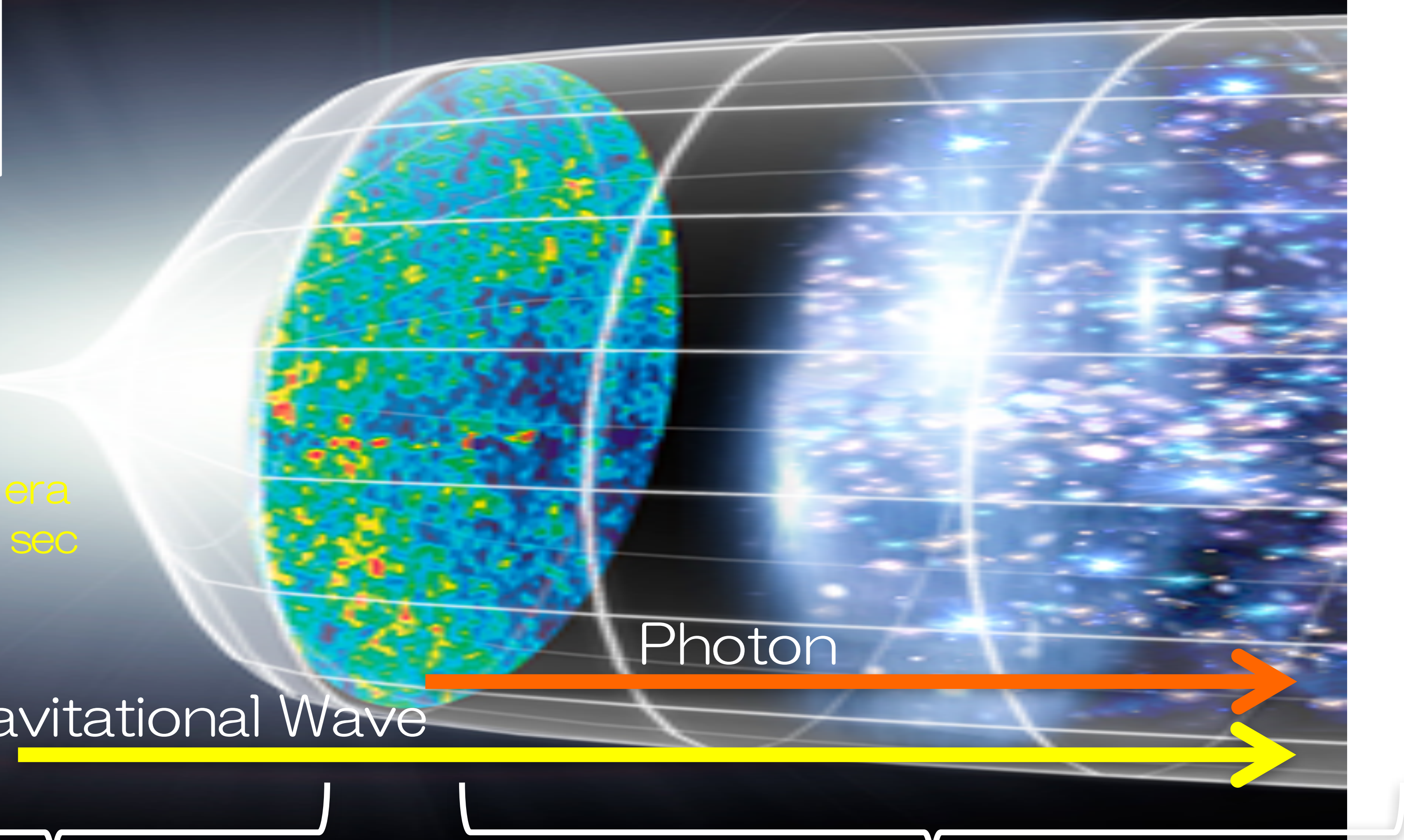
$30 \le \ell \le 3000\sim10000$

e.g. Simons Observatory and CMB-S4

- This powerful duo is the best cost-effective way.
- Great synergy with two projects
    - Foreground data from LiteBIRD, Delensing with CMB-S4 data

Probing inflation using CMB polarization





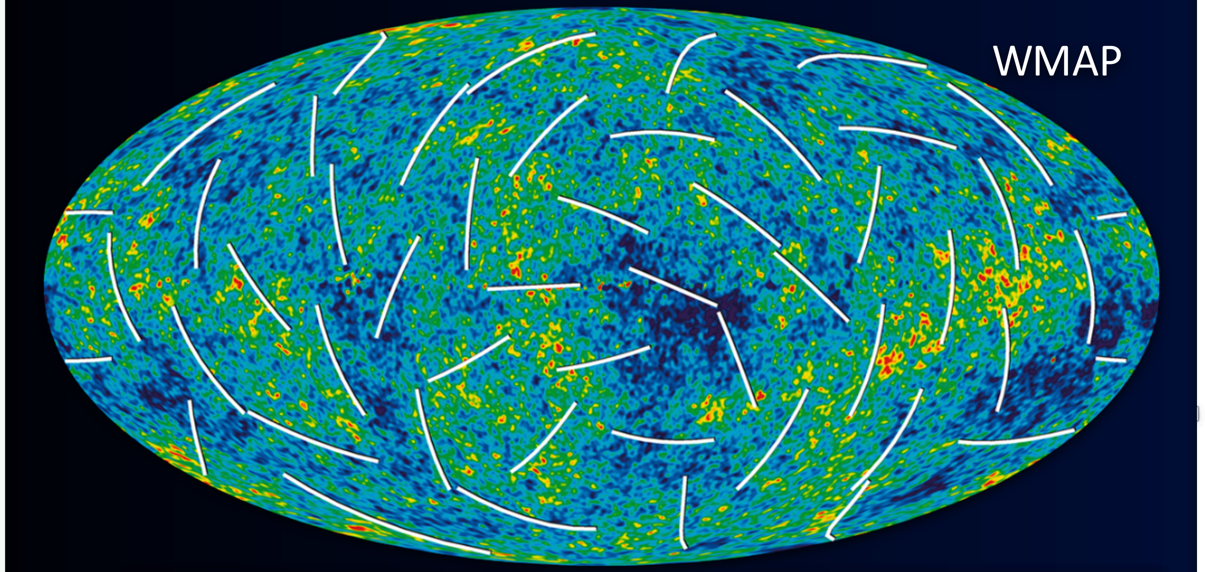
Probing inflation

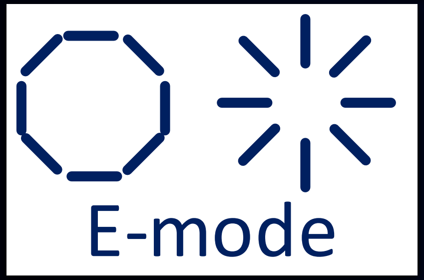
If inflation exists, the primordial gravitational wave has imprinted the particular CMB polarization pattern, called B-mode.

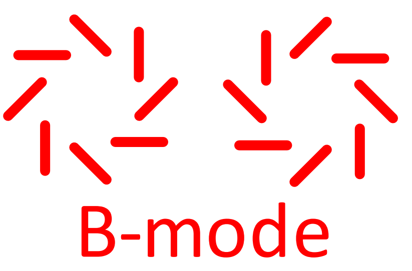
Probing the gravitational potential of the large scale structure

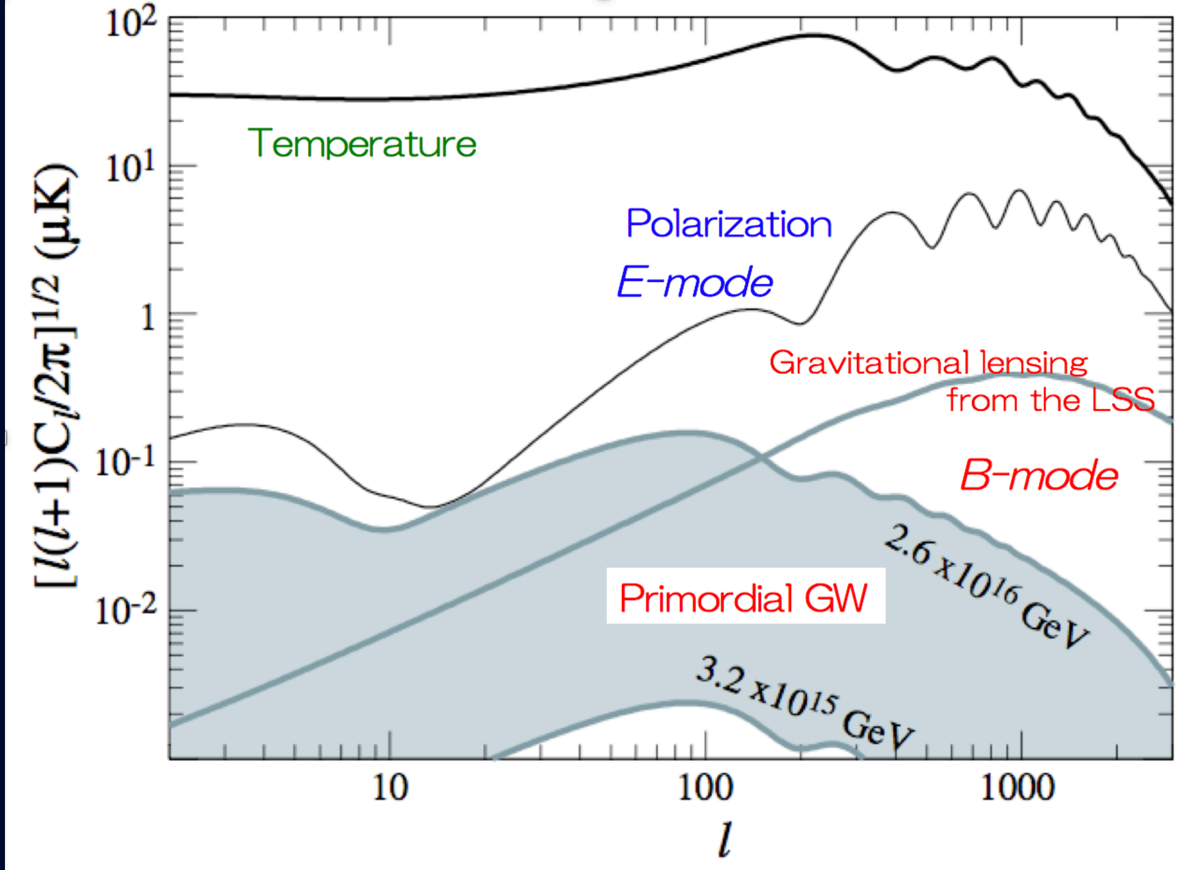
The CMB polarization (E-mode) is lensed and this effect produces B-mode pattern.

E-mode and B-mode









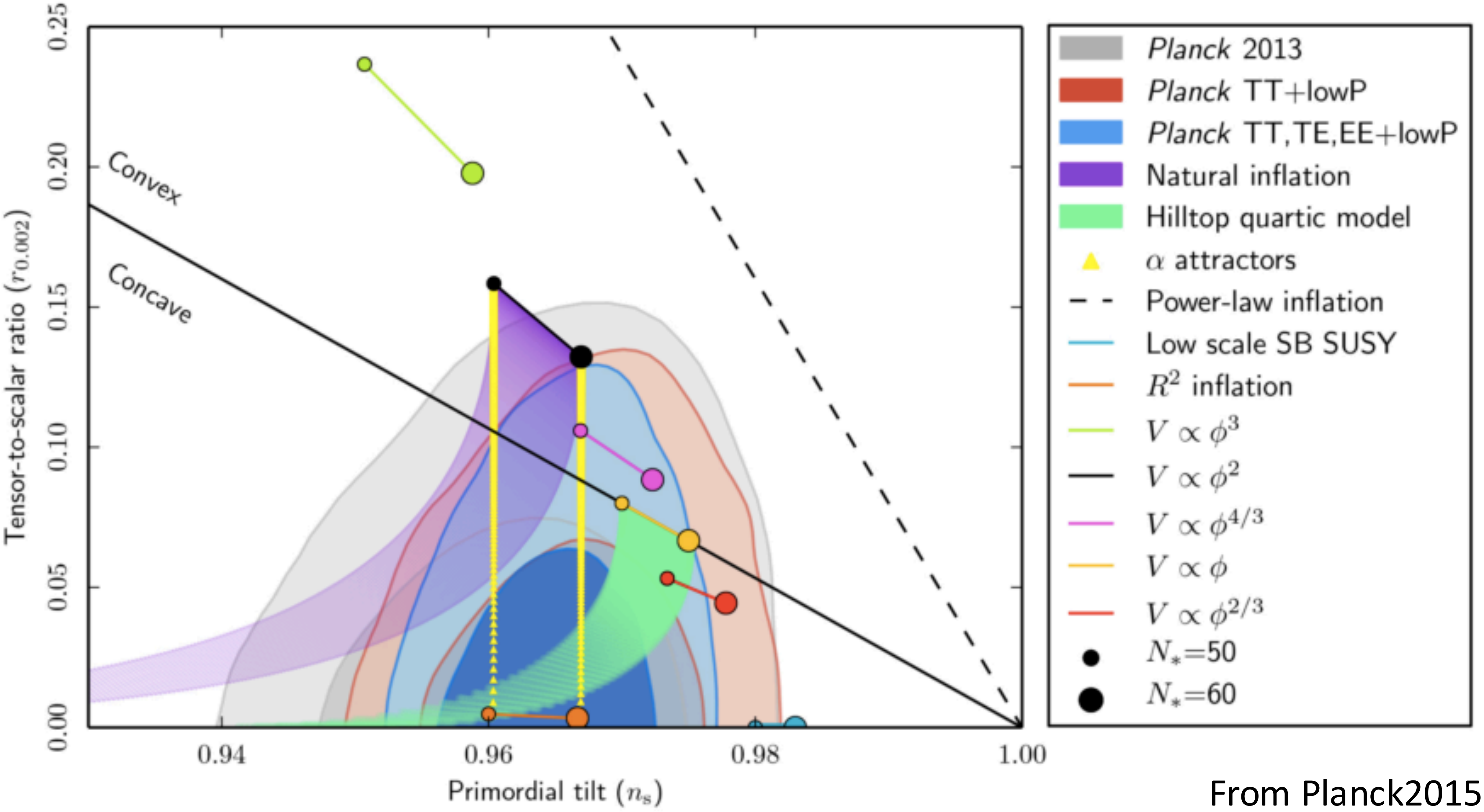
The CMB is expected to be linearly polarized regardless of the existence of inflation.

- The density perturbation creates the spatial polarization pattern called *E-mode*
- The primordial gravitational wave creates *E-mode* and ***B-mode***.

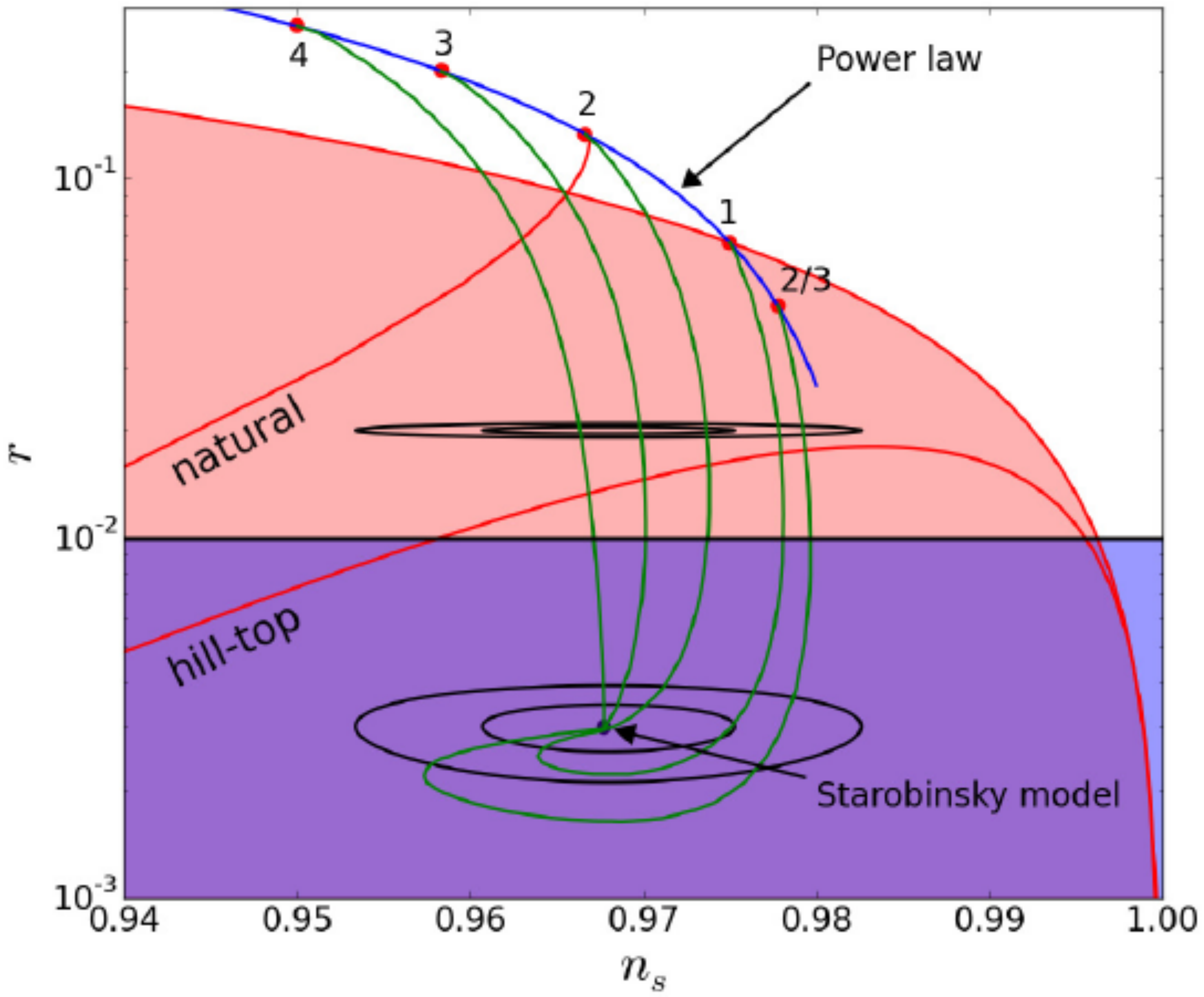
The primordial B-mode spectral power is proportional to the tensor-to-scalar ratio, *r*, and it relates to the energy scale of inflation as

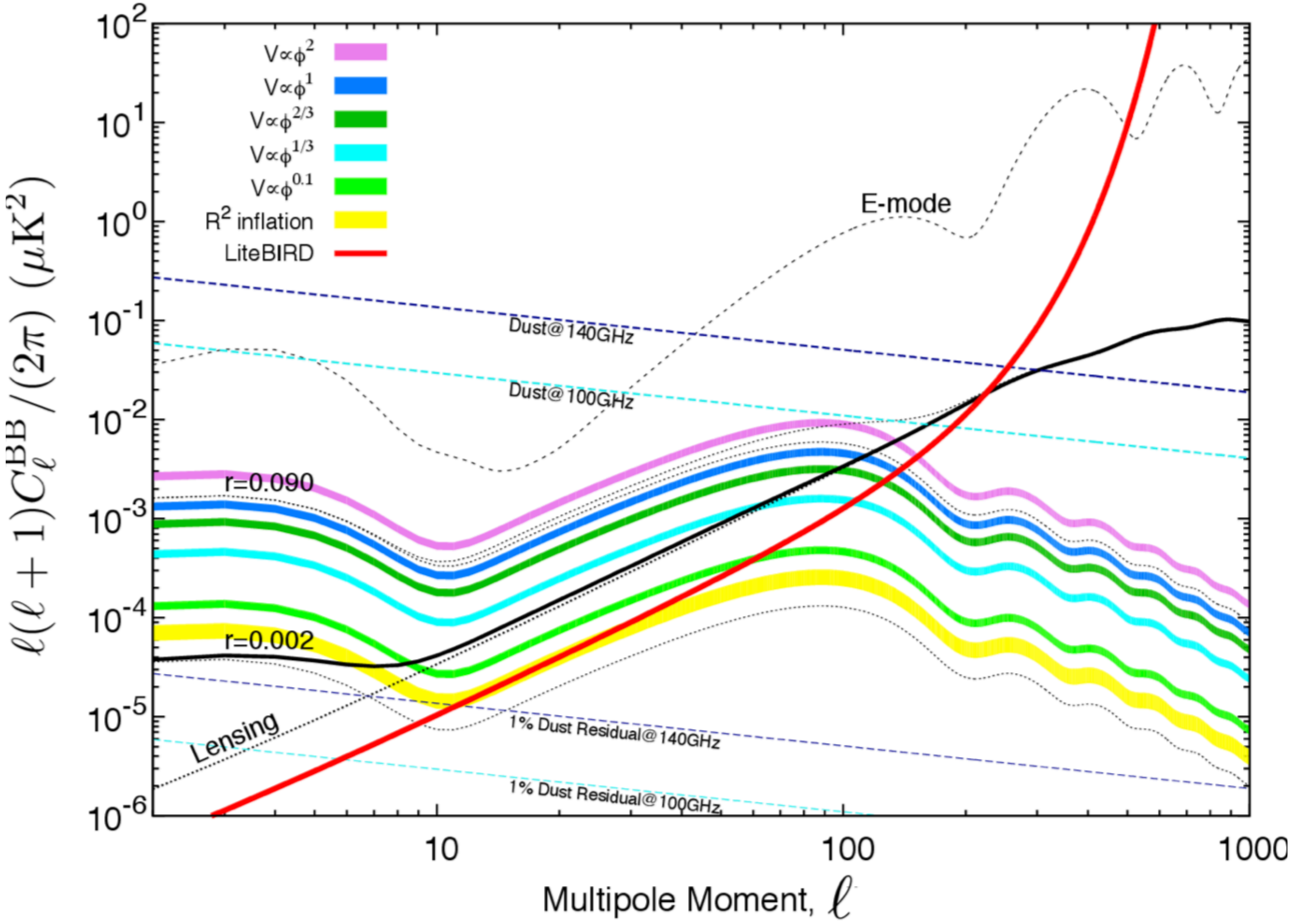
$$V^{\frac{1}{4}} = 1.06\times10^{16}\left(\frac{r}{0.01}\right)^{\frac{1}{4}}\ [\mathrm{GeV}]$$

We can probe the GUT scale physics experimentally by using the CMB polarization measurement.

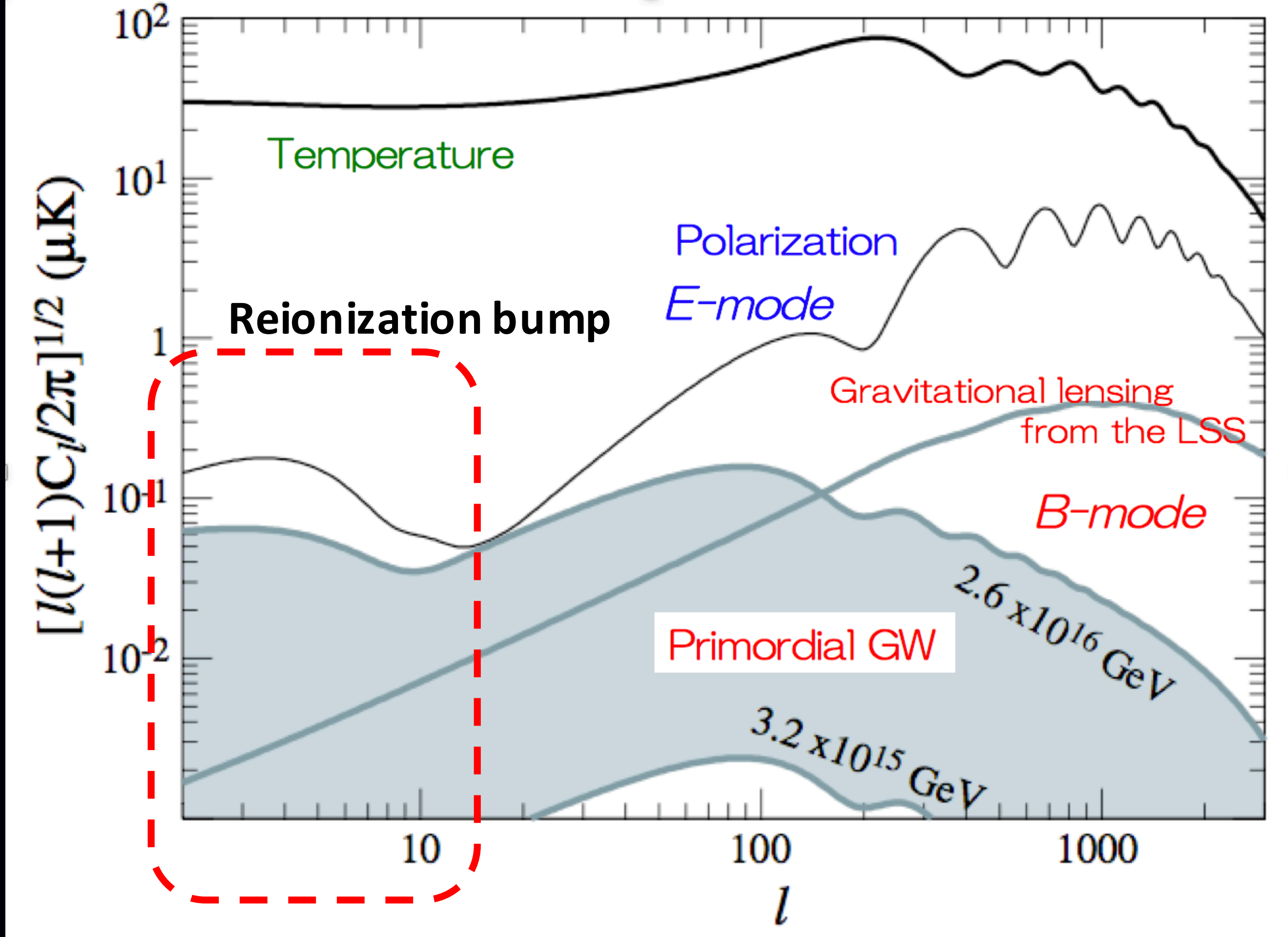


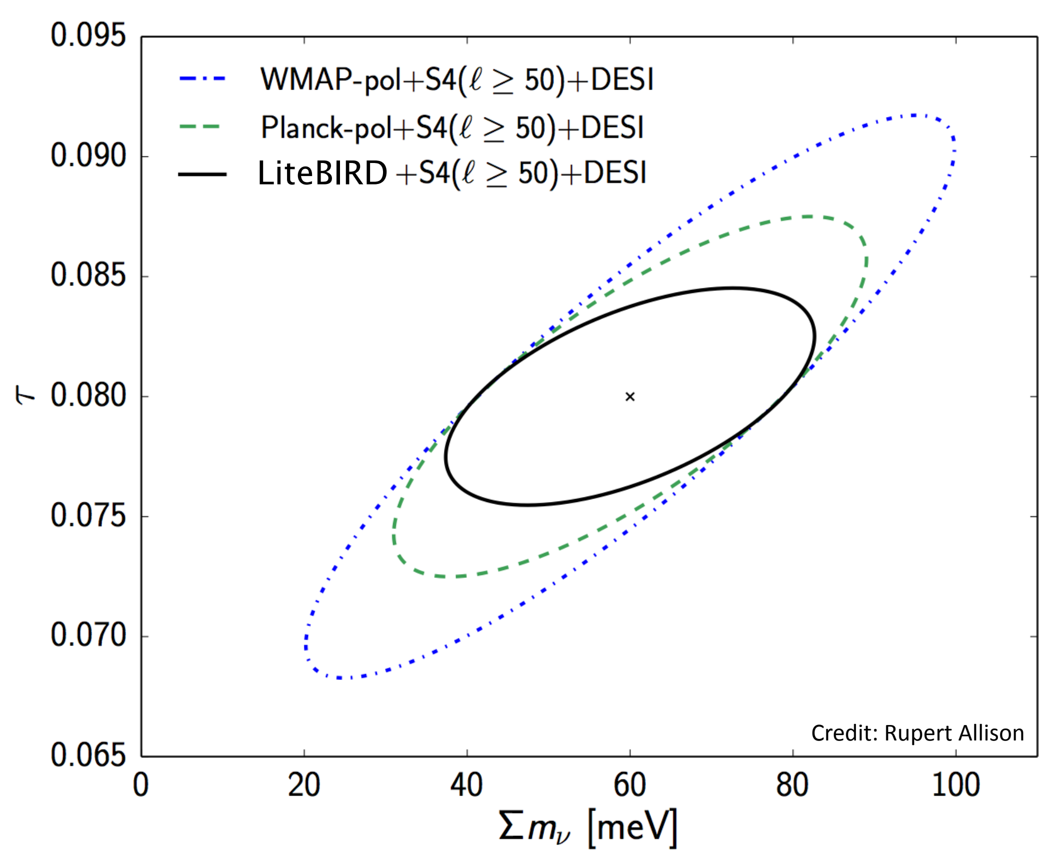
From Planck2015


Power law
4
3
2
1
2/3
natural
hill-top
Starobinsky model
10^{-1}
10^{-2}
10^{-3}
r
0.94
0.95
0.96
0.97
0.98
0.99
1.00
n_s

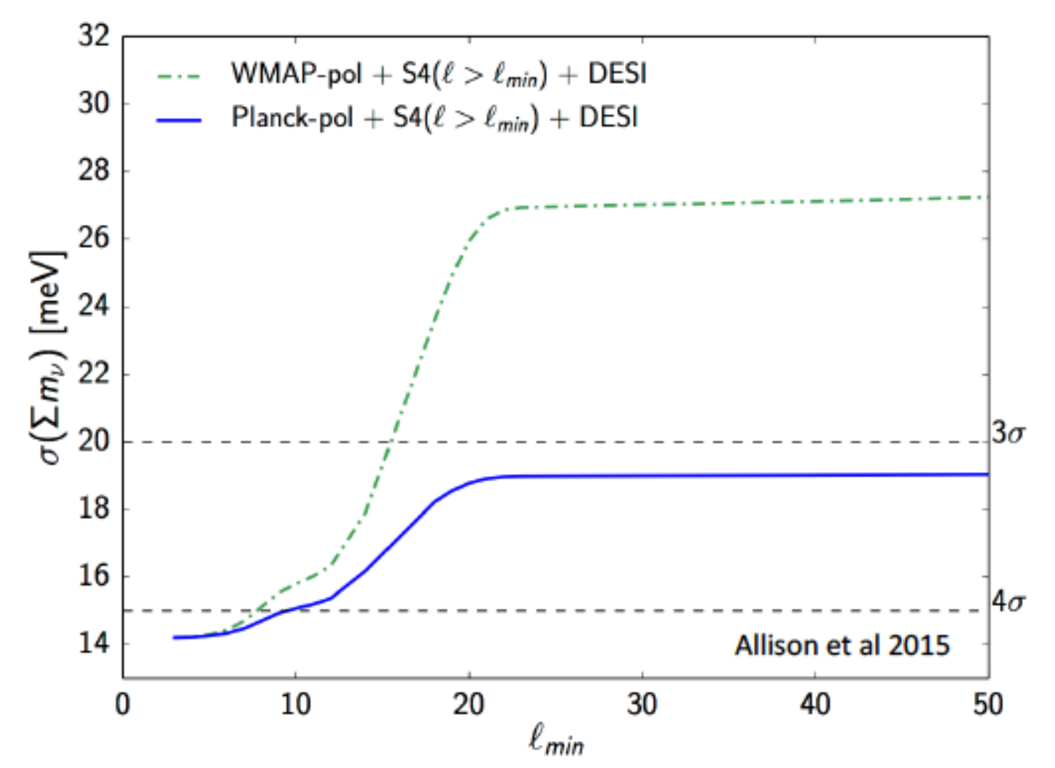

V∝φ^2
V∝φ^1
V∝φ^2/3
V∝φ^1/3
V∝φ^0.1
R^2 inflation
LiteBIRD
E-mode
Dust@140GHz
Dust@100GHz
r=0.090
r=0.002
Lensing
1% Dust Residual@140GHz
1% Dust Residual@100GHz
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10
100
1000
Multipole Moment, ℓ
ℓ(ℓ + 1)C_ℓ^BB/(2π) (μK^2)

Improve the neutrino mass with τ





Credit: Rupert Allison



Allison et al 2015

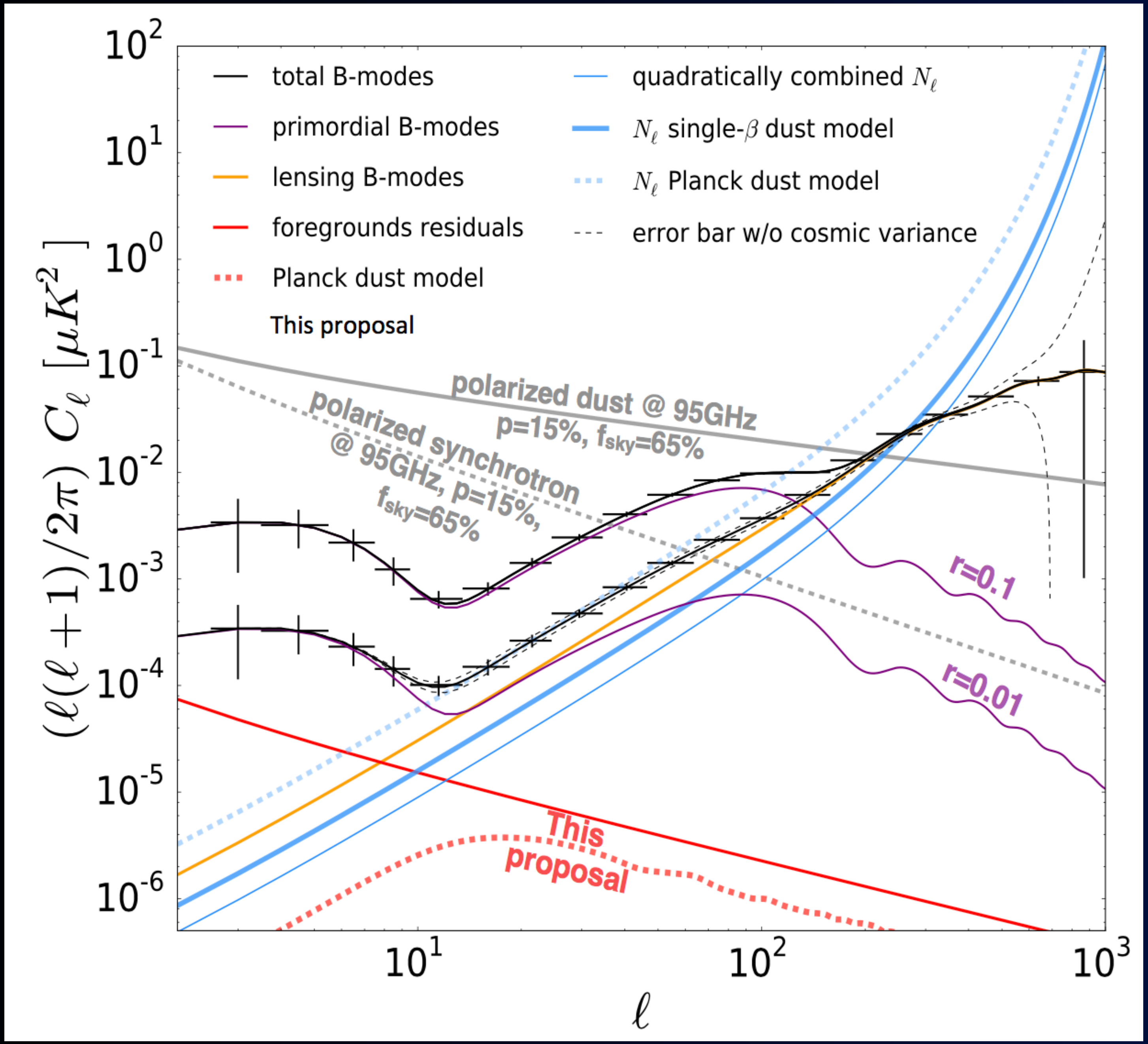
- The sum of the neutrino mass degenerates with τ.
- We can measure the signature of reionization of the universe, called reionization bump. The measurement of this bump allows to constrain the optical depth of the universe, τ. This signal appears at low ell range in the polarization power spectrum, E-mod and B-mode. The better E-mode measurements in the multipole $\ell < 20$ will improve τ measurement precision.

More outputs?

- The science beyond the inflation?
  - Reionization history
  - Weak gravitational lensing to low ℓ
  - Non-Gaussianity
  - Foreground science including the Galactic magnetic field (synchrotron, dust, anomaly…)
  - Non-standard pattern in the map domain

- The extra science output by combining the LiteBIRD data with the external data set (note: this is **LiteBIRD extra success** items)
  - Combining with the ground-based and balloon-borne CMB data to extend ℓ coverage: open up the delensing option to probe the inflation signal deeper
  - Combining with the multi-frequency for various cross-correlation, e.g. CIB.

Projected sensitivity including the component separation



Projected sensitivity by J. Errard

- $\sigma(r) = 0.45\times10^{-3}$ for $r = 0.01$ after removing the foreground. The cosmic variance and delensing w/ CIB is included.
- $\delta r < 0.4\times10^{-3}$ (95% C.L.) for undetectably small r.
  Note: $\sigma(r = 0) = \delta r = 2\times10^{-4}$
- Various algorithm development to remove the foreground is in progress.

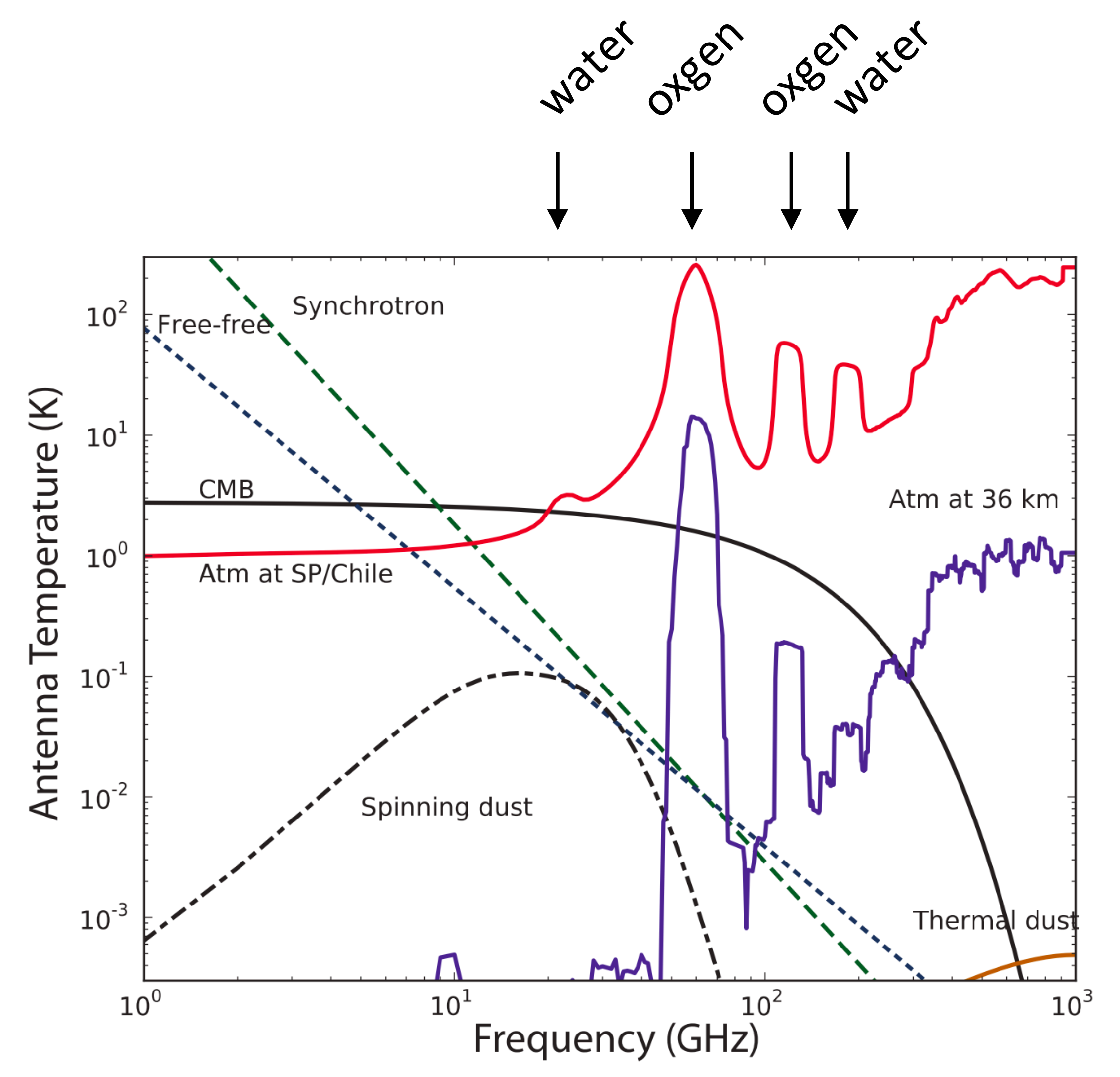
Instrumental systematics by R. Nagata

- $\sigma_{sys}(\text{total}) = 1.1\times10^{-4}$

Why Space?

Pros

- **No atmosphere**
    1. Instantaneous detector sensitivity increases by ×3〜10
    2. Free choice of the observing band. No atmospheric absorption nor emission.
    3. Remove the degeneracy between the signal fluctuation and the atmospheric fluctuation
- **Full sky access**: accessible to the large scale mode



Cons

- It takes long time to prepare.
- Technology has to be chosen 〜5-6 years before the launch.
- Expensive