# LiteBIRD

Hirokazu Ishino
(Okayama University)
on behalf of the LiteBIRD WG

# LiteBIRD

Lite (Light) Satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection

http://litebird.jp/

LiteBIRD is a next generation satellite that measures the Cosmic Microwave Background B-mode Polarization.

- By scanning all area of the sky, LiteBIRD will measure the tensor-to-scaler ratio *r* with an unprecedented precision of $\boldsymbol{\sigma_r \leq 0.001}$ to test the major large-single-field slow-roll inflation models.

# LiteBIRD working group

122 members, international and interdisciplinary.

**JAXA**
H. Fuke
I. Kawano
H. Matsuhara
T. Matsumura
K. Mitsuda
T. Nishibori
K. Nishijo
A. Noda
A. Okamoto
S. Sakai
Y. Sato
K. Shinozaki
H. Sugita
Y. Takei
M. Utsunomiya
T. Wada
N. Yamasaki
T. Yoshida
K. Yotsumoto

**Osaka U.**
S. Kuromiya
M. Nakajima
S. Takakura
K. Takano

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

**Okayama U.**
H. Ishino
A. Kibayashi
Y. Kibe
Y. Kida
A. Okamoto
Y. Yamada

**NIFS**
S. Takada

**Kavli IPMU**
K. Hattori
N. Katayama
H. Sugai

**KEK**
M. Hazumi (PI)
M. Hasegawa
N. Kimura
K. Kohri
H. Morii
T. Nagasaki
R. Nagata
H. Nishino
S. Oguri
T. Okamura
N. Sato
T. Suzuki
O. Tajima
T. Tomaru
M. Yoshida

**SOKENDAI**
Y. Akiba
Y. Inoue
H. Ishitsuka
Y. Segawa
H. Watanabe

**NAOJ**
A. Dominjon
J. Inatani
K. Karatsu
S. Kashima
T. Nitta
T. Noguchi
S. Sekiguchi
Y. Sekimoto
S. Shu

**Saitama U.**
M. Naruse

**NICT**
Y. Uzawa

**Konan U.**
I. Ohta

**U. Tokyo**
N. Tomita

**Kansei Gakuin U.**
S. Matsuura

**U. Tsukuba**
M. Nagai

**TIT**
S. Matsuoka
R. Chendra

**Tohoku U.**
M. Hattori
T. Morishima

**Nagoya U.**
K. Ichiki

**Yokohama Natl. U.**
T. Fujino
F. Irie
K. Mizukami
S. Nakamura
K. Natsume
T. Yamashita

**RIKEN**
S. Mima
C. Otani

**APC Paris**
R. Stompor

**CU Boulder**
N. Halverson

**McGill U.**
M. Dobbs

**MPA**
E. Komatsu

**NIST**
G. Hilton
J. Hubmayr

**Stanford U.**
K. Irwin
C.-L. Kuo
T. Namikawa

**U. Wales, Cardiff**
G. Pisano

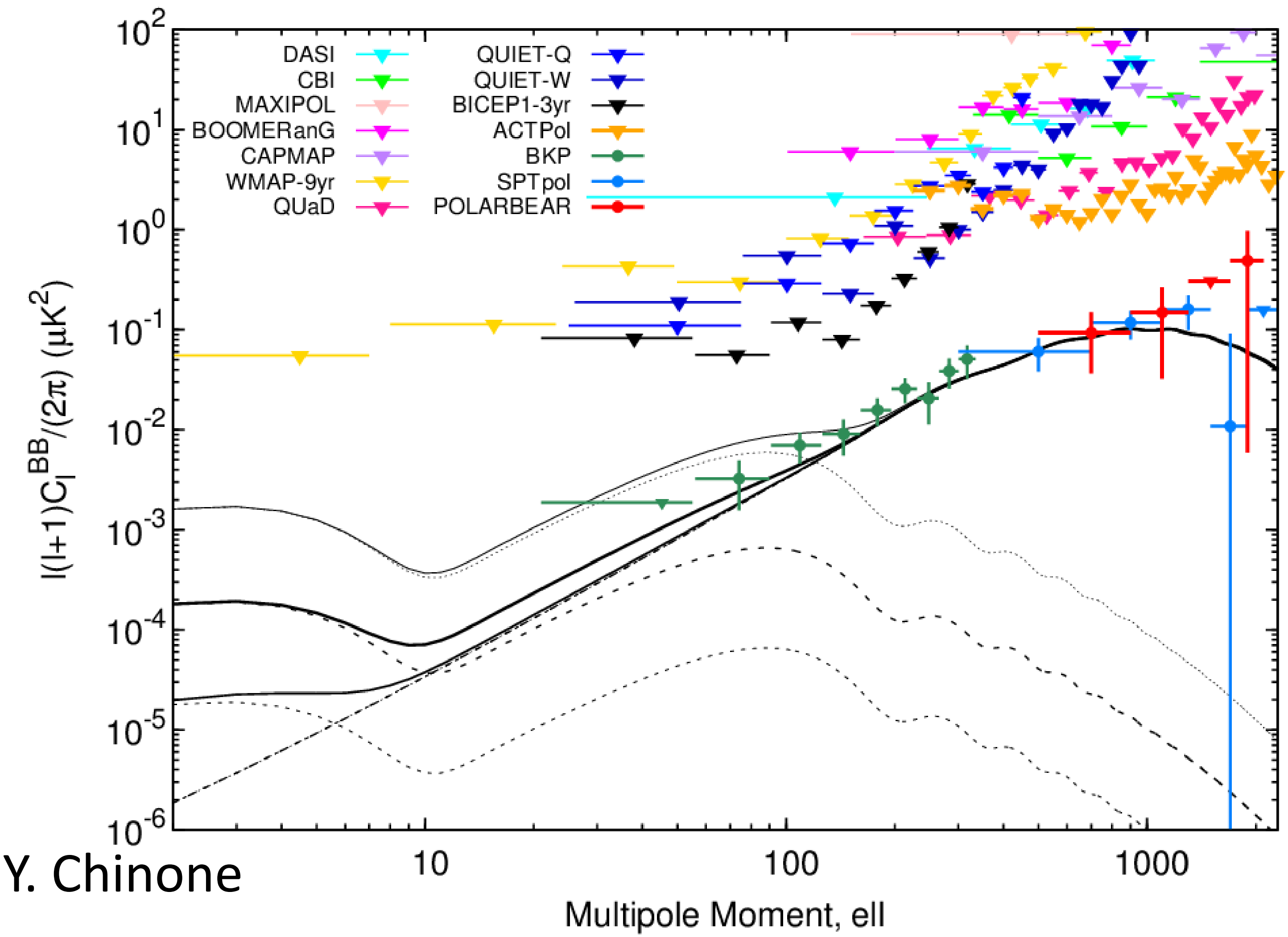
**U. Wisconsin**
K. Arnold

**UC Berkeley / LBNL**
J. Borrill
Y. Chinone
A. Cukierman
T. de Haan
J. Errard
N. Goeckner-wald
P. Harvey
C. Hill
Y. Hori
W. Holzapfel
O. Jeong
A. Kusaka
A. Lee(US PI)
E. Linder
P. Richards
U. Seljak
B. Sherwin
A. Suzuki
P. Turin
B. Westbrook
N. Whitehorn

**UC San Diego**
T. Elleflot
B. Keating
G. Rebeiz

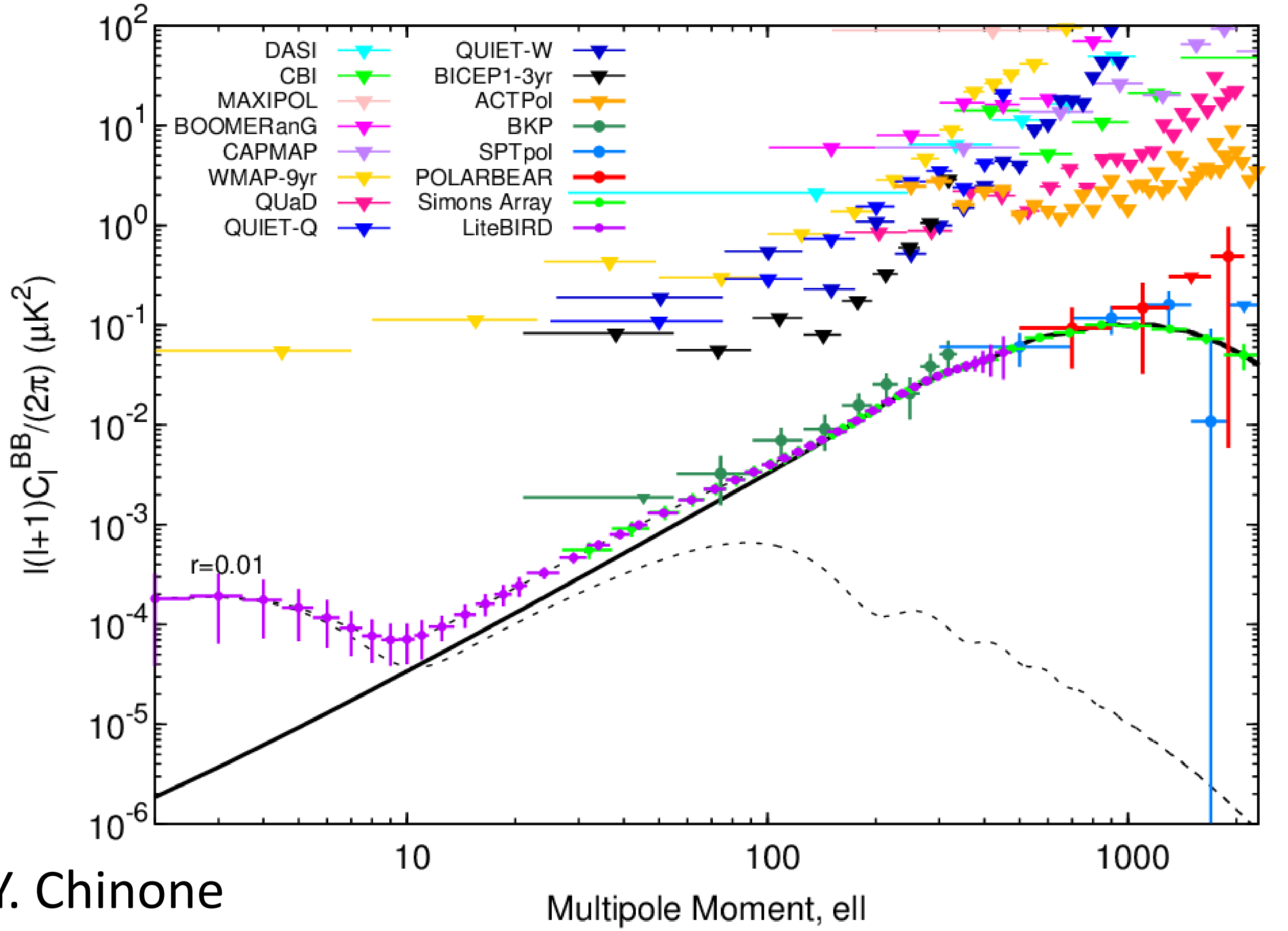
X-ray astrophysicists

# Results of the past B mode polarization measurements




Y. Chinone

# LiteBIRD aims to measure the large angular scale




Y. Chinone

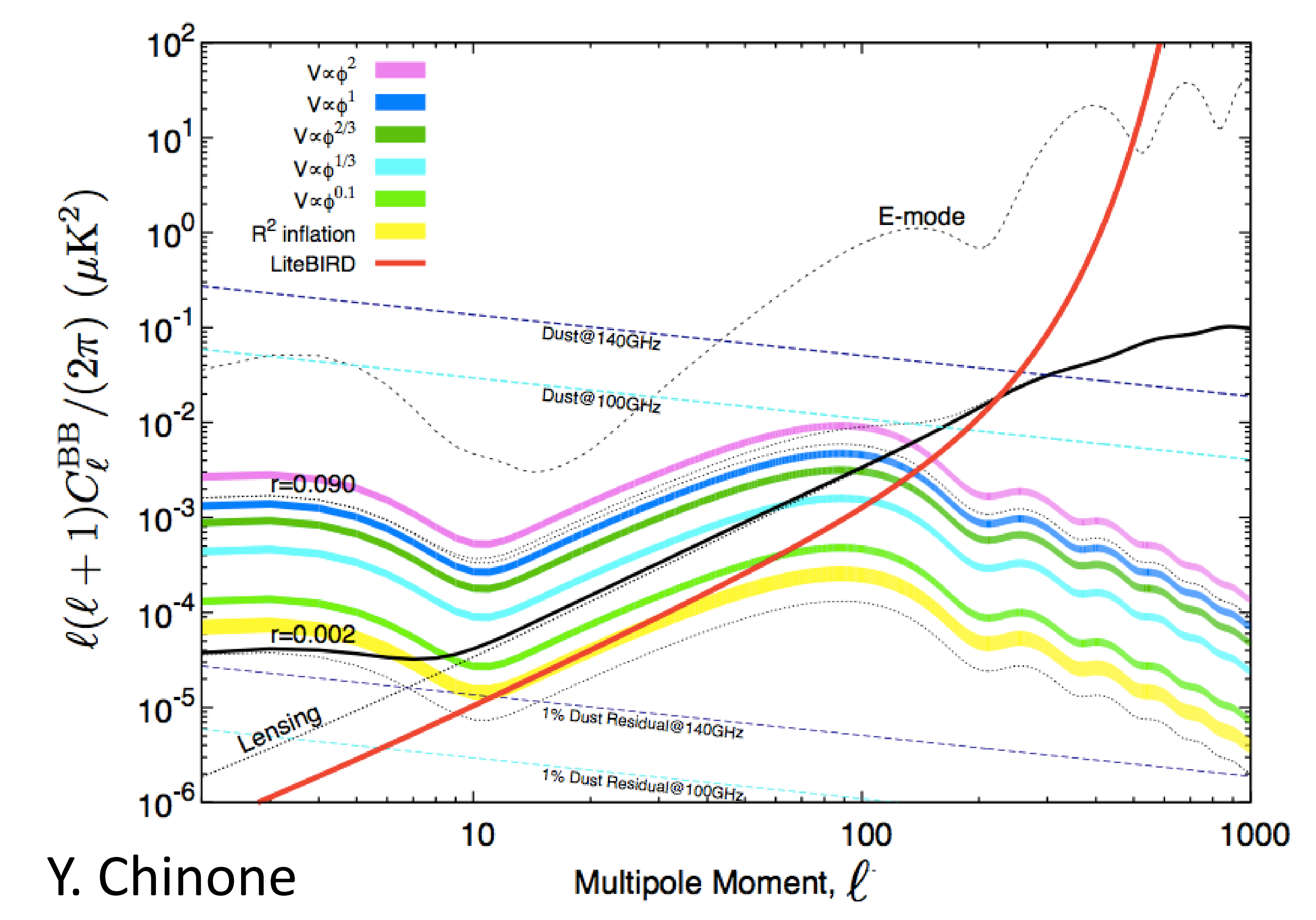
# Ingredients to achieve the mission

- Statistics
  - Sensitivity : 2.6μK arcmin (w/ margin, Baseline design)
    - Polarization sensitive superconducting detector array consisting of 2000 sensors with tri-chroic.
    - Three years observation at sun-earth L2
- Measurement system
  - Large FOV (20x10 degs)
  - Angular resolution of 40arcmin @140GHz
  - HWP to mitigate 1/*f* noise and systematics
- Foreground removal
  - Multi frequencies avoiding CO lines
    - 50 - 320 GHz with 6 bands (Baseline design)
  - Template method (N. Katayama and E. Komatsu) etc.
- Systematics
  - Studies with analytical methods, simulations, radiation tests etc.

# Why $\boldsymbol{\sigma_r \leq 0.001}$ ?

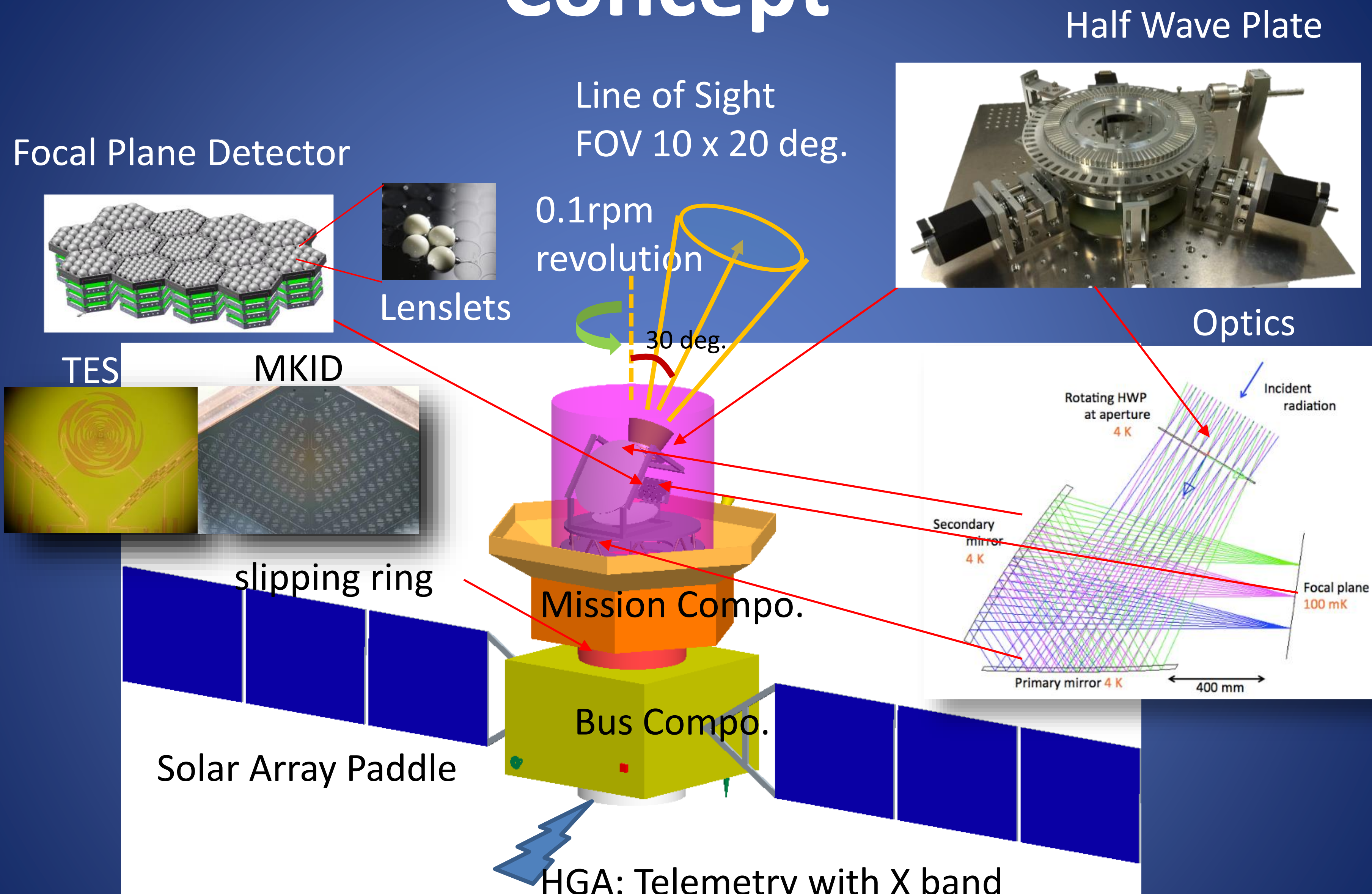
- Many models predict $r > 0.01$.
  - $10\sigma$ discovery
- Single field models with slow roll condition gives
$$\boxed{r \simeq 0.002\left(\frac{60}{N}\right)^2\left(\frac{\Delta\phi}{m_{pl}}\right)^2}$$
N: e-folding, $m_{pl}$: reduced Planck mass
- Giving a bound $r < 0.002$ (95% C.L.) may rule out large field models.

# Expected sensitivity

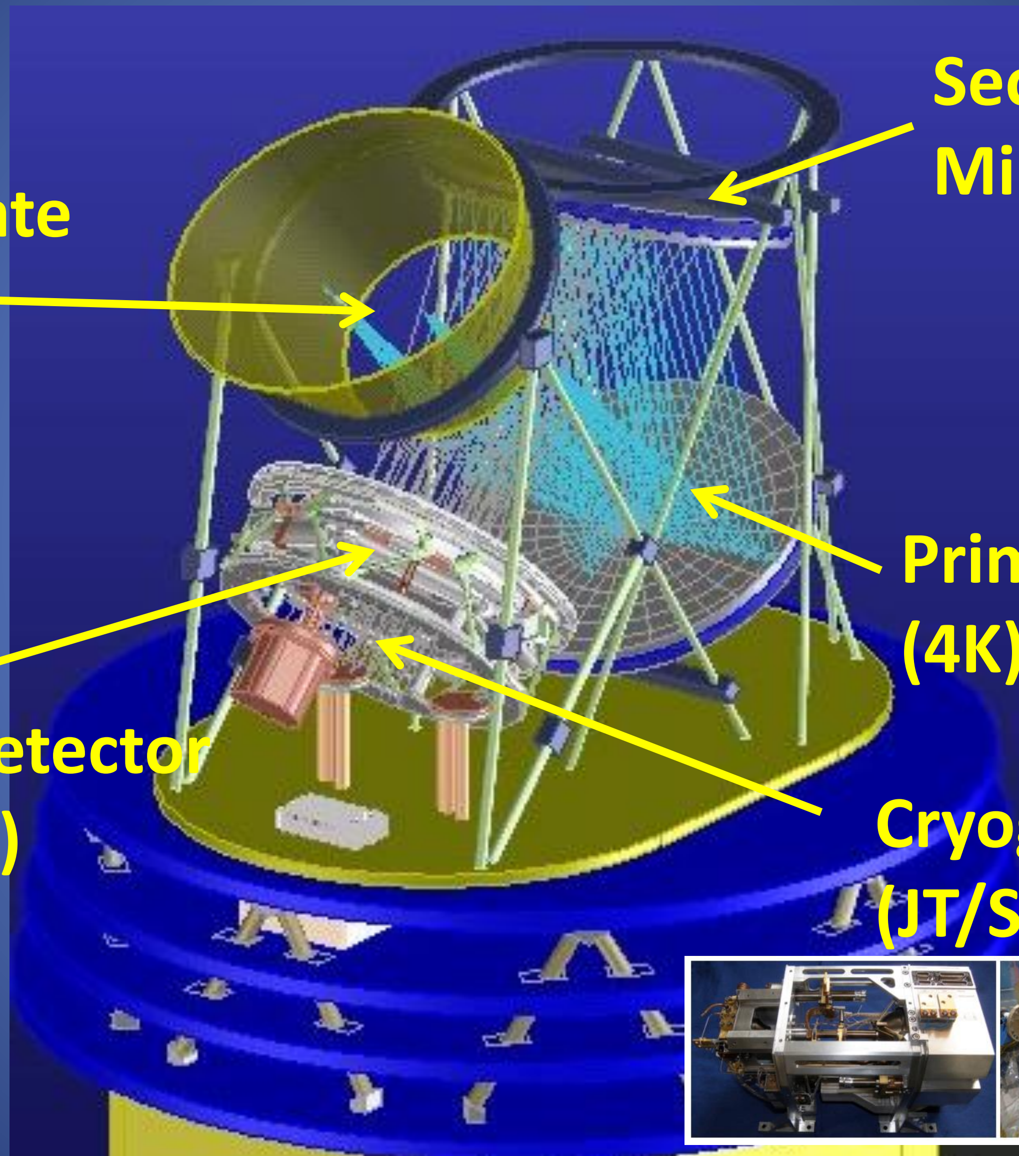



Measurements with $\mathrm{r} < 0.002$ (95% C.L.) for $2 \leq \ell \leq 200$ are important.

# Concept


Half Wave Plate
Line of Sight
FOV 10 x 20 deg.
Focal Plane Detector
0.1rpm
revolution
Lenslets
Optics
30 deg.
TES
MKID
Rotating HWP
at aperture
4 K
Incident
radiation
Secondary
mirror
4 K
Focal plane
100 mK
Primary mirror 4 K
400 mm
slipping ring
Mission Compo.
Bus Compo.
Solar Array Paddle
HGA: Telemetry with X band

# Mission components

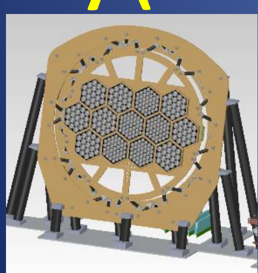


Half Wave Plate (4K)

Secondary Mirror (4K)

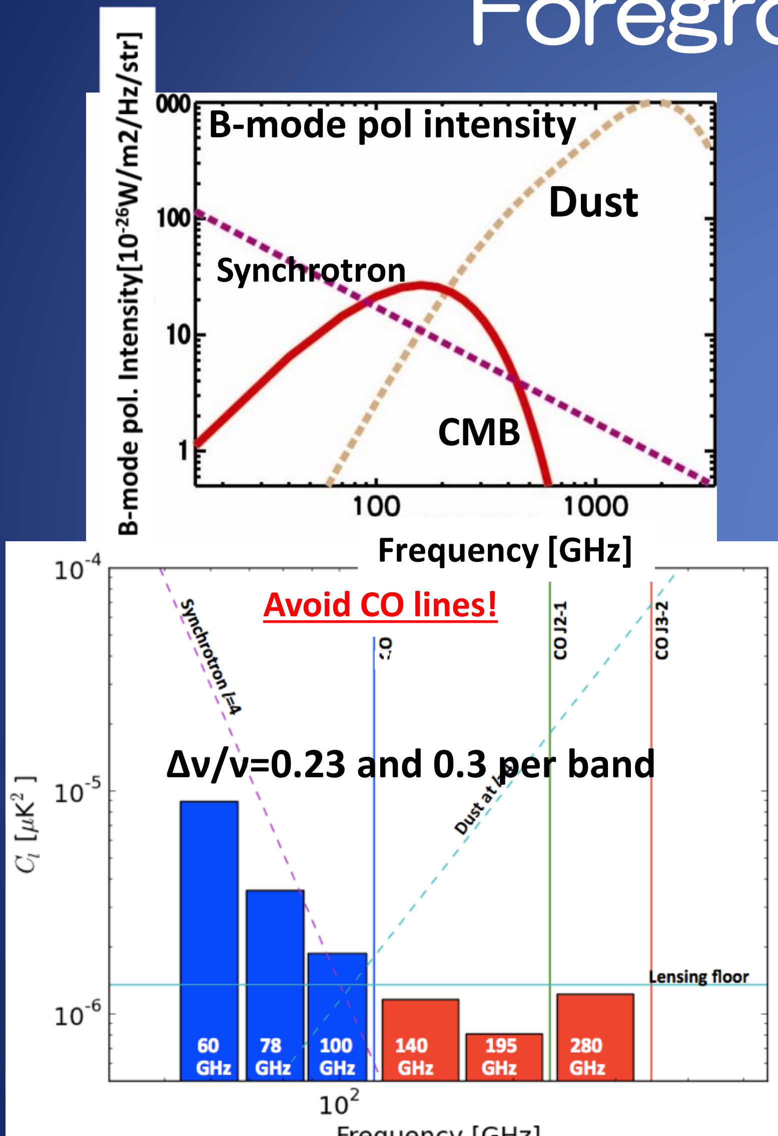
Primary Mirror (4K)

Focal Plane Detector Array (100mK)

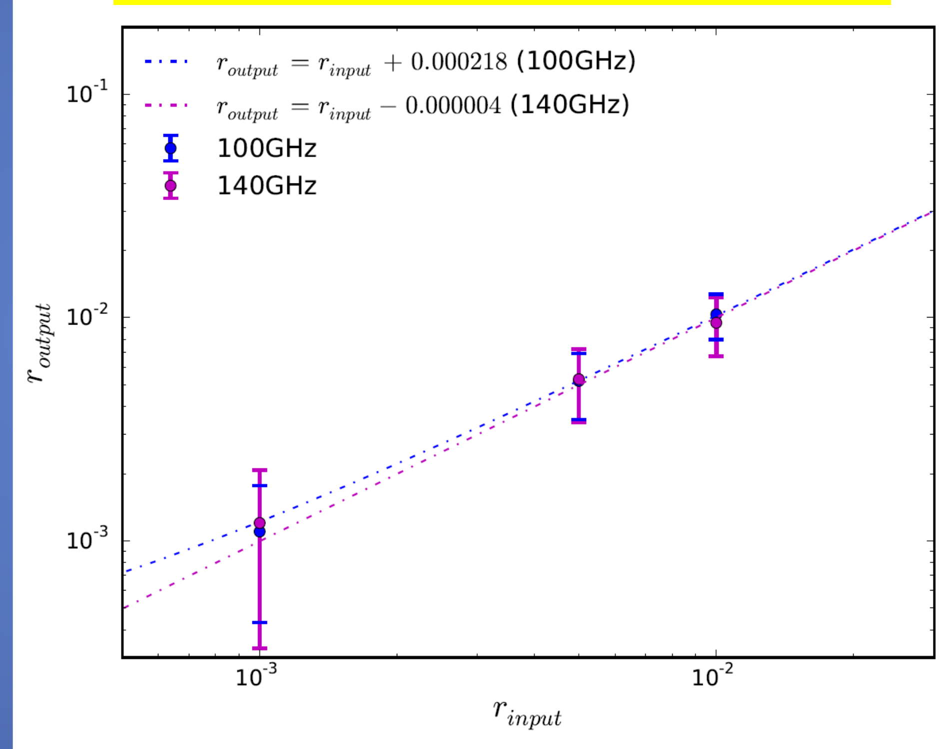


Cryogenic system (JT/ST + ADR)

# Multi-frequency Measurements and Foreground Removal




Based on N. Katayama and E. Komatsu, ApJ 737, 78 (2011)



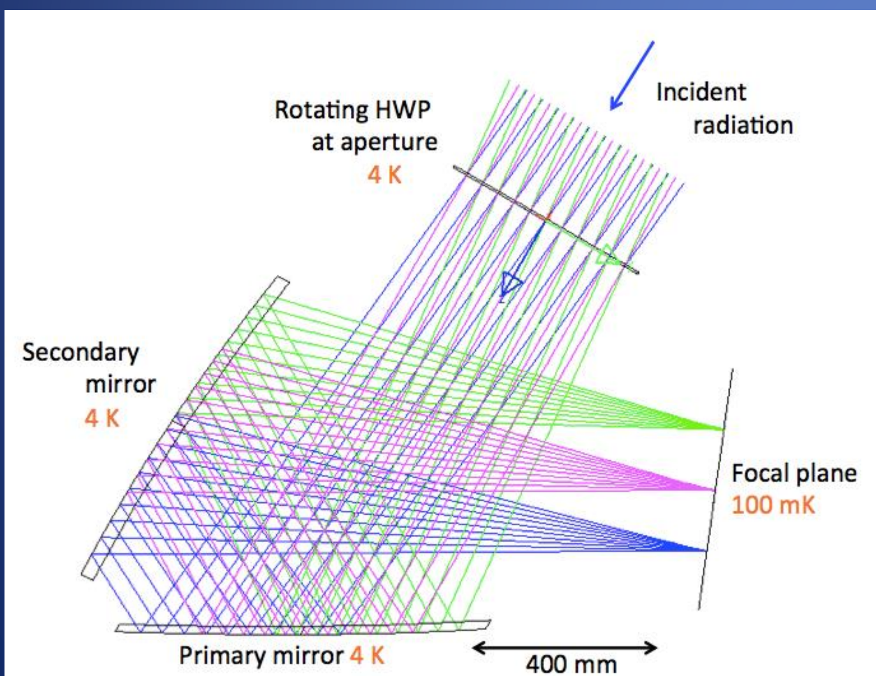

Measurement bias < 0.001 in a template method.

# Optics

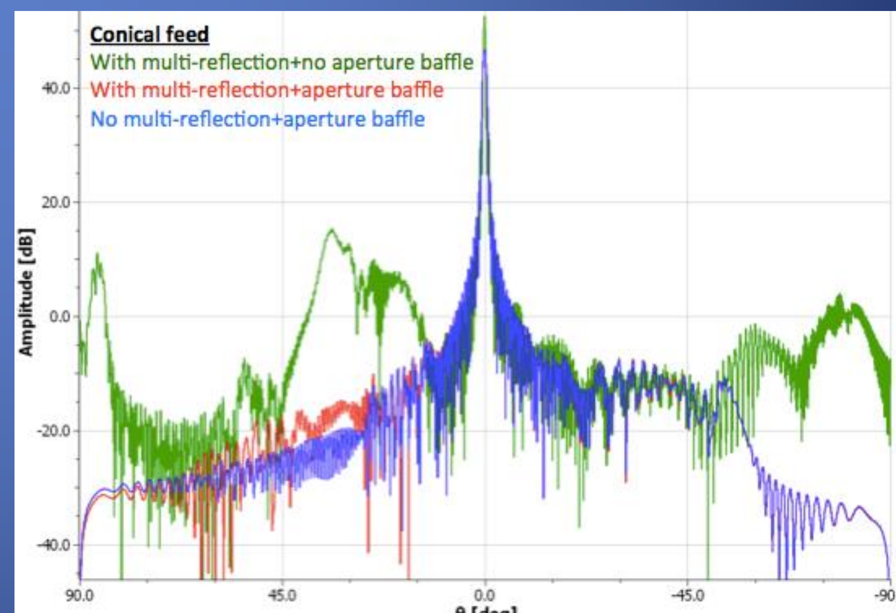
- Beam size：< 1 deg. for 6 bands
- FOV:　10 x 20 degs.
- Size：2m$\phi$　x　2mt

- Baffle and Mirrors @ 4K
- Half-wave plate to modulate polarization
- Tele-centric

Cross-Dragone Optical System




GRASP10 Simulation@60GHz, removing side-lobe w/ baffle

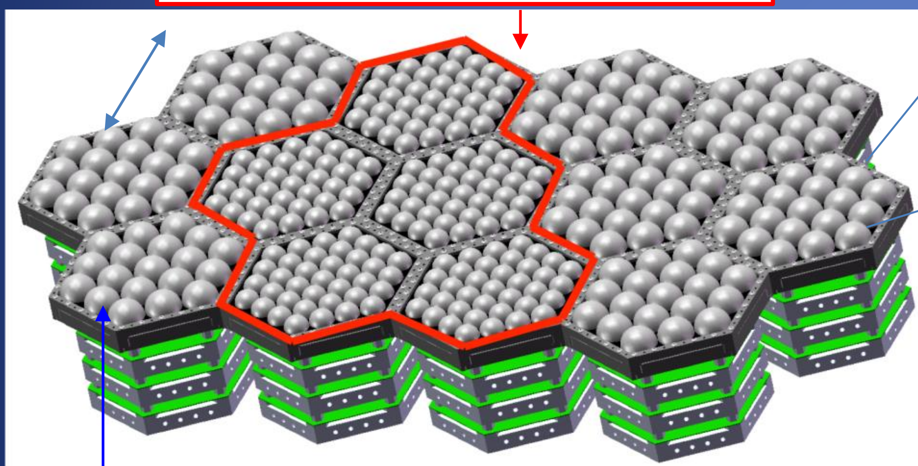



T. Matsumura, K. Kimura, N. Okada

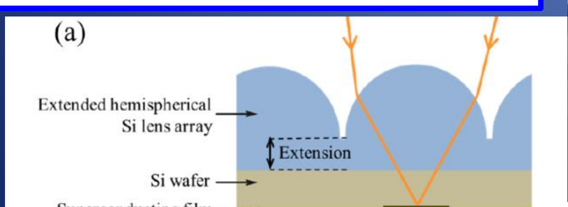
# Focal Plane Detector (JAXA Baseline Design)

- Sens.：Optical NEP=2 x $10^{-18}$ W/sq(Hz)
- 50-320GHz
- Tri-chroic per sensor
- 2.6μK・arcmin with 2022 channels (w/ margin)
- 100mK
- FP size：50cm x 30cm

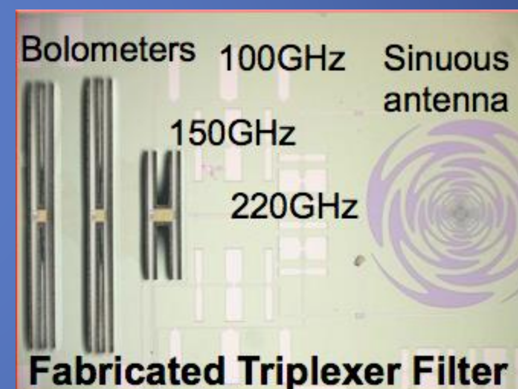
tri-chroic (140/195/280GHz)



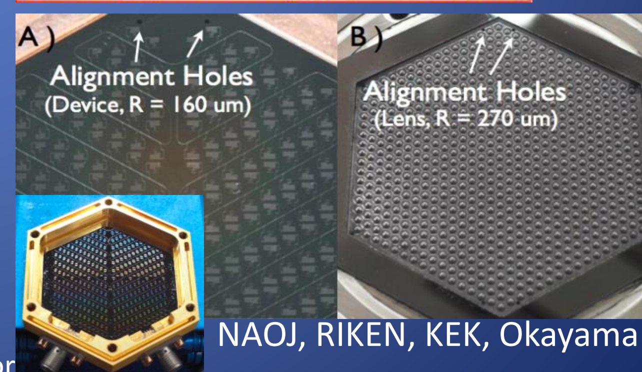
tri-chroic (60/78/100GHz)




## Detector：TES or MKID

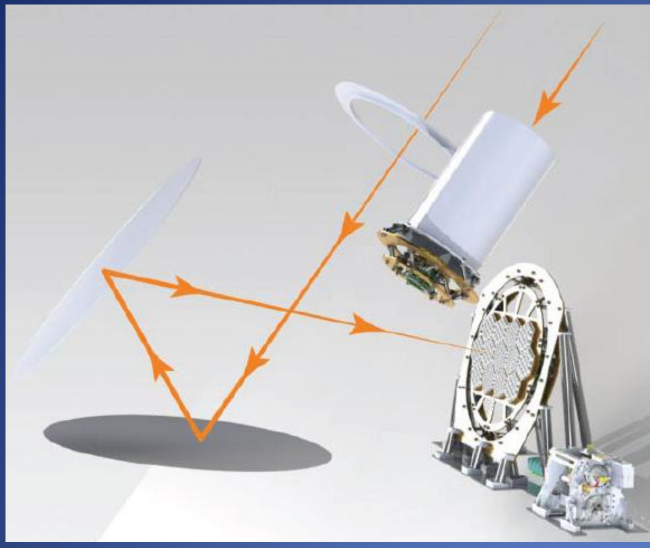



UC Berkeley

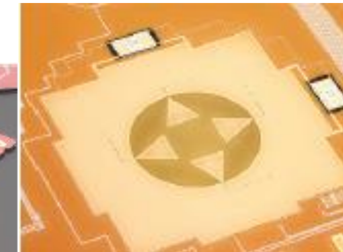


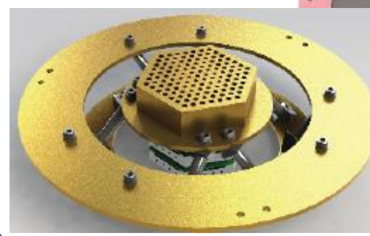

NAOJ, RIKEN, KEK, Okayama

# Focal Plane Detector with Extended Band

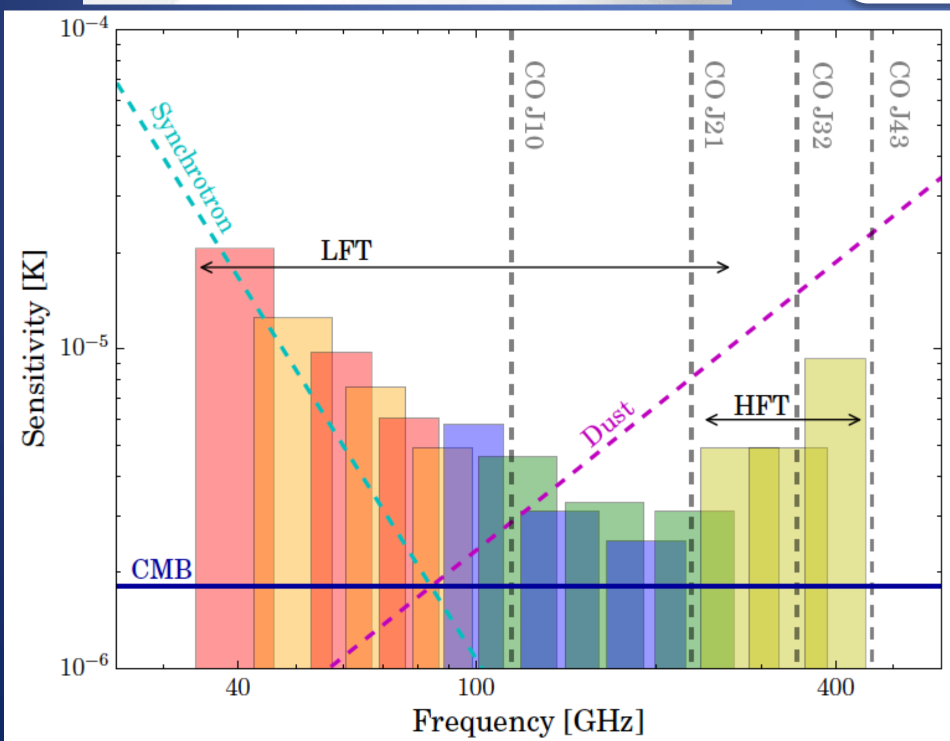


## High Frequency Telescope (HFT)

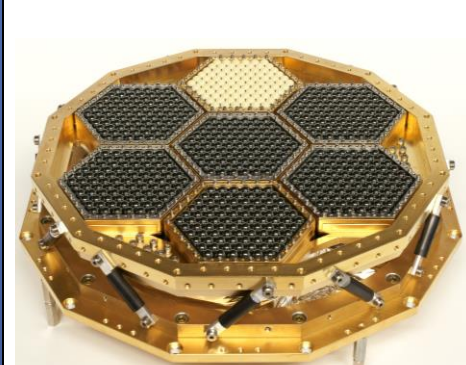


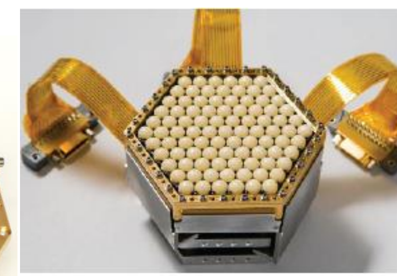


The TES array with corrugated feedhorn developed for ABS, ACTpol, SPTpol by UC Boulder, NIST, and Stanford.



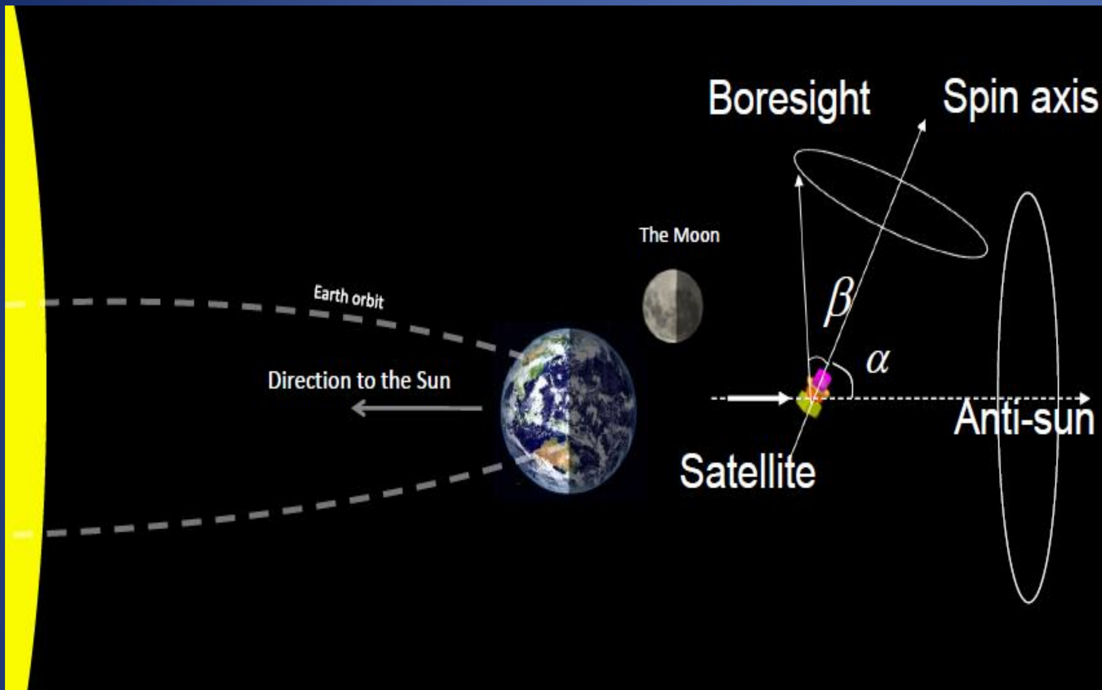

## Low Frequency Telescope (LFT)





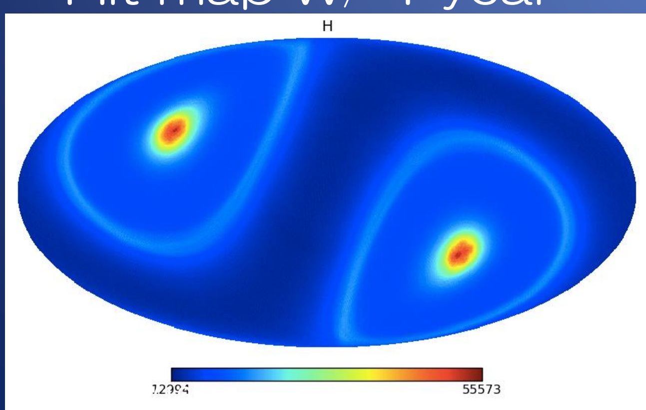
The TES array with a lenslet developed for POLARBEAR by UC Berkeley and UCSD.

# All sky survey @ sun-earth L2



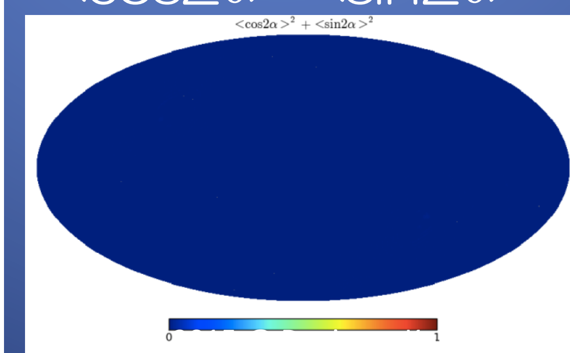

- avoid sun, decrease cross-link
    - $\alpha$=65 degs.
    - $\beta$=30 degs.
- Precession：90 min.
- Spin rate：10 min.
- Data rate：160 kbps
- Telemetry：X-band

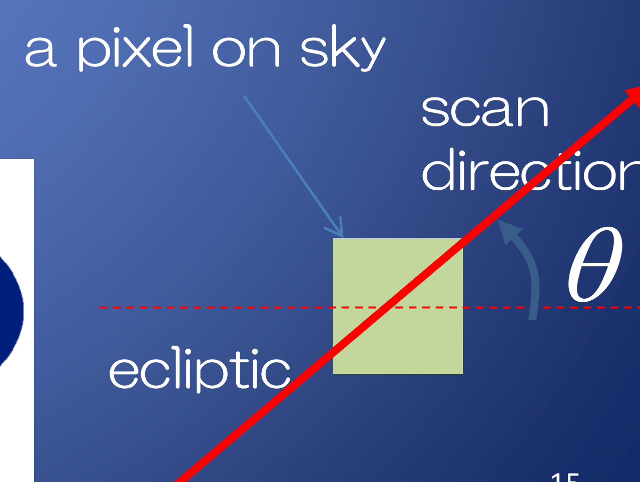
Hit map w/ 1 year




Cross-link

$=\langle\cos 2\theta\rangle^2+\langle\sin 2\theta\rangle^2$



# Systematics

W/O HWP

| Effects | Types | Requirement in bias case (L2) | Requirement in random case | Notes |
|---|---|---|---|---|
| Diff. beam width | False polarization | 0.8 % @ ell=2<br>0.2 % @ ell=200 | 2 % | Instantaneous |
| Diff. beam pointing | | 2 arcsec. | 20 arcsec. | |
| Diff. beam ellipticity | | 7 % @ ell=2<br>0.04 % @ ell=300 | 3 % | Focal plane average eases them by (up to) one order of magnitude. |
| Diff. gain calibration | | 0.002 % | 0.04 % | |
| | | | | |
| Abs. gain calibration | Pattern modulation | Parity preserved | 10 % | Calibration in every 10 min. |
| Beam size stability | | Parity preserved | O(10%) | |
| Angle calibration | | 1 arcmin. | 10 deg. | |
| Pointing knowledge | | 3 arcmin. | 5 arcmin. | |

Requirements $\delta r < 0.57 \times 10^{-3}$

R. Nagata

# Systematics

| Effects | Requirement w/o HWP | Requirement w/ HWP |
|---|---|---|
| Diff. beam width | 0.8 % @ ell=2<br>0.2 % @ ell=200 | 10 % |
| Diff. beam pointing | 2 arcsec. | 2 arcmin. |
| Diff. beam ellipticity | 7 % @ ell=2<br>0.04 % @ ell=300 | 10 % |
| Diff. gain calibration | 0.002 % | 3 % |

R. Nagata

HWP can relax the requirements for T->B leakage.

# Status

- JAXA/ISAS 2015 Down-selection for Strategic Large Missions 2021-2025
  - Three missions passed MDR down-selection
    - Solar-C, LiteBIRD, Solar Sail
  - one additional special mission in consideration
    - Phobos (or Deimos) sample return
  - These four missions continue studies for SRR
- NASA missions of opportunity
  - the proposal is down-selected and in Phase-A

# Summary

- LiteBIRD is a satellite for all-sky observation of the CMB B-mode polarization to measure the tensor-to-scaler ratio with a precision of $\boldsymbol{\sigma_r} \leq \mathbf{0.001}$ .
  - Allowing us to test the major large-single-field slow-roll inflation models.
- LiteBIRD has been down selected and in transition to phase-A1

# B mode from Space -- Part 1: The cience goals, status of spaceborne projects, foregrounds (Dec 10 -12), Part 2: Mission design, technologies and challenges for the spaceborne observations (Dec 14 -16) --

10-16 December 2015
Asia/Tokyo timezone



**Purpose of this Workshop:**
The goal of the workshop is to discuss the science goals, status of CMB polarization projects, foregrounds and mission design, technologies and challenges for the spaceborne observations of CMB polarization to detect primordial gravitational waves and thus to prove the inflation theory. The workshop will be the first meeting where the LiteBIRD mission is focused on.

**Dates:** Dec 10 (Thu) - 16 (Wed), 2015

Part 1: Dec. 10 -12th: the science goals, status of spaceborne projects, foregrounds

Part 2: Dec. 14 -16th: mission design, technologies and challenges for the spaceborne observations

**Venue:** Lecture Hall (1F), Kavli IPMU main building

**Program:** not yet vailable

**Organizers:** M. Hasegawa (KEK), M. Hazumi (Kavli IPMU/KEK), H. Ishino (Okayama), T. Matsumura (ISAS/JAXA), Y. Sekimoto (NAOJ), H. Sugai (Kavli IPMU), N. Katayama (Kavli IPMU)

**Contact Address: :** Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), the University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba 277-8583, Japan

# Backup Slides

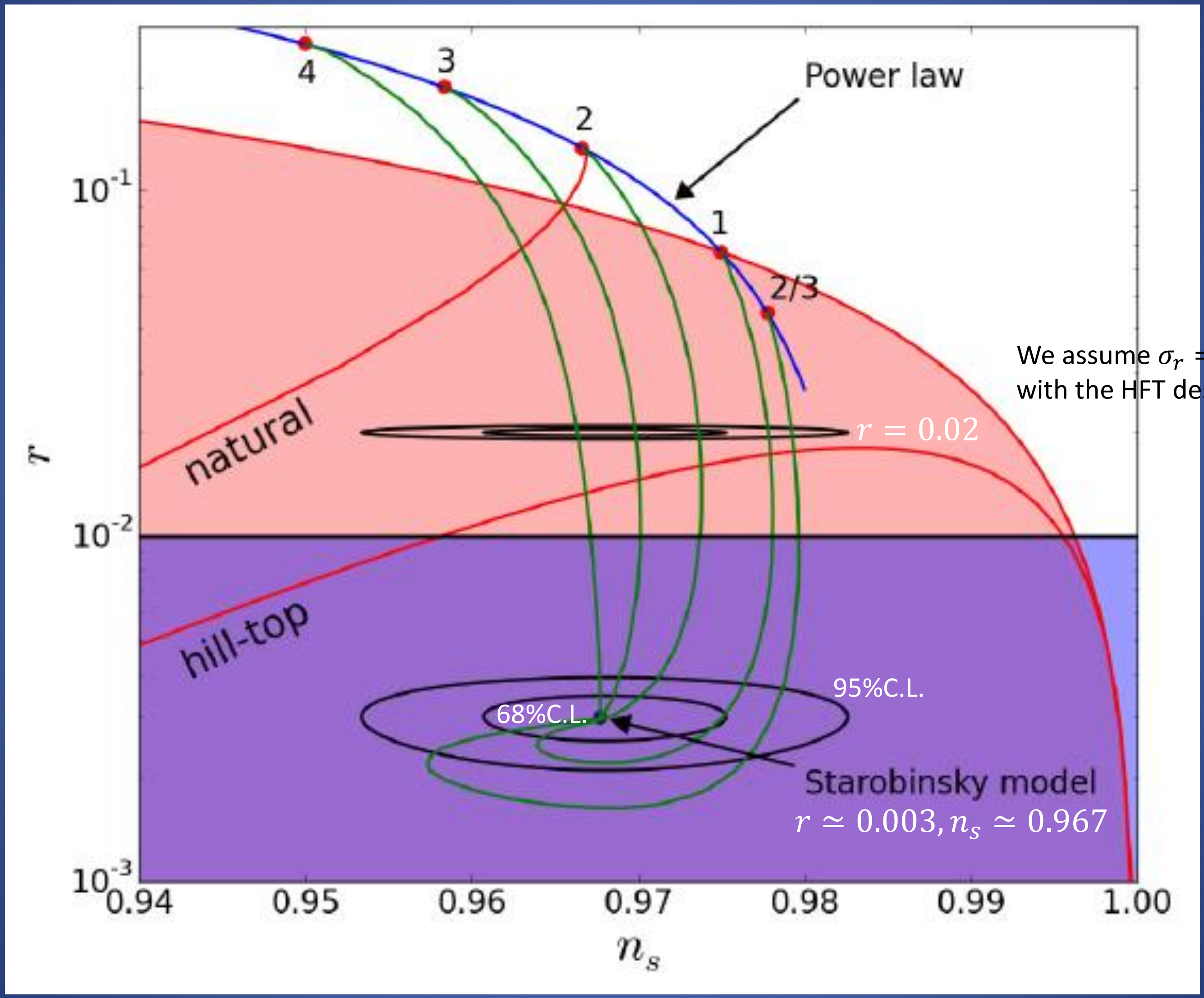
# Detector sensitivity

JAXA Baseline Design

| Band (GHz) | Beam (ar-cmin) | NET ($\mu K\sqrt{s}$) | Pixels per wafer | $N_{wf}$ | $N_{bolo}$ | $NET_{arr}$ ($\mu K\sqrt{s}$) | Sens. ($\mu K \cdot arcmin$) | Sens. with margin ($\mu K \cdot arcmin$) |
|---|---|---|---|---|---|---|---|---|
| 60 | 54.1 | 94 | 19 | 8 | 304 | 5.4 | 9.6 | 15.7 |
| 78 | 55.5 | 59 | 19 | 8 | 304 | 3.4 | 6.0 | 9.9 |
| 100 | 56.8 | 42 | 19 | 8 | 304 | 2.4 | 4.3 | 7.1 |
| 140 | 40.5 | 37 | 37 | 5 | 370 | 1.9 | 3.4 | 5.6 |
| 195 | 38.4 | 31 | 37 | 5 | 370 | 1.6 | 2.9 | 4.7 |
| 280 | 37.7 | 38 | 37 | 5 | 370 | 2.0 | 3.5 | 5.7 |
| total | | | | | 2022 | | 1.6 | 2.6 |

The margin takes into account ADR operation efficiency, cosmic ray glitch removal, detector yield and noise margin.

# Constraints on r vs $n_s$




We assume $\sigma_r = 4.5 \times 10^{-4}$ with the HFT design (15 bands)