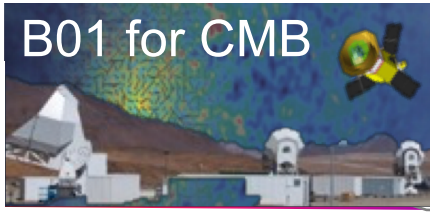



# B01：
# Large-area CMB surveys for studies of cosmic acceleration and large-scale structure

Masashi Hazumi (PI)

Co-Is（研究分担者）

Nobu Katayama
(Kavli IPMU)

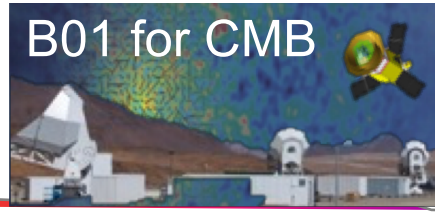
Kazuhisa Mitsuda
(ISAS/JAXA)

Yutaro Sekimoto
(NAOJ → ISAS)

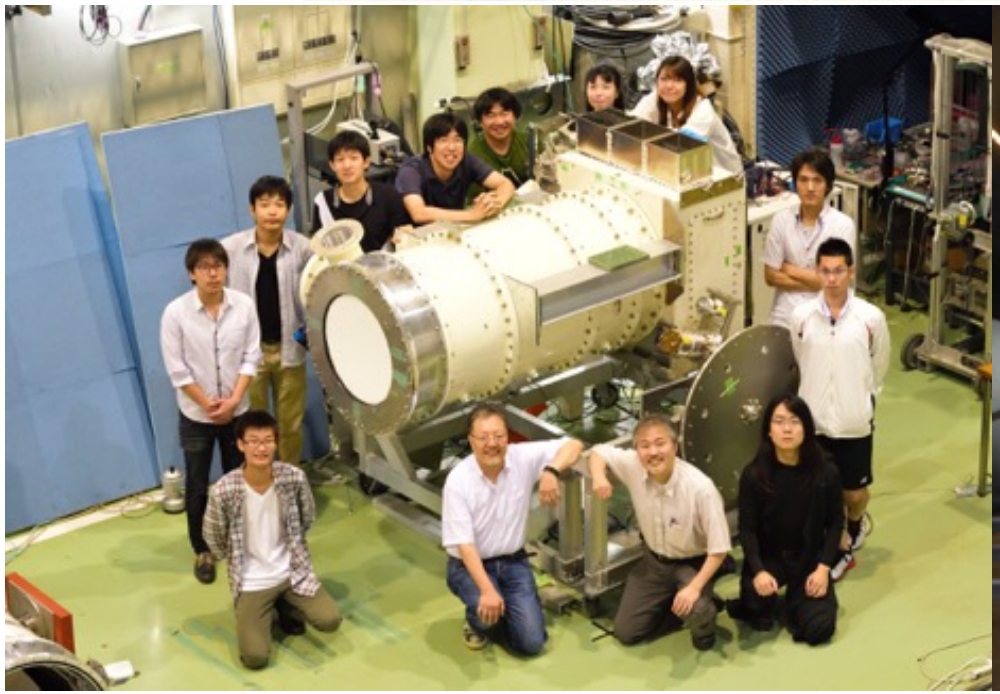
Hirokazu Ishino
(Okayama U.)

Masaya Hasegawa
(KEK)

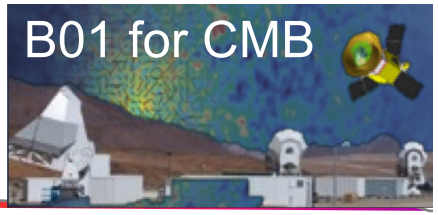
# Collaborators



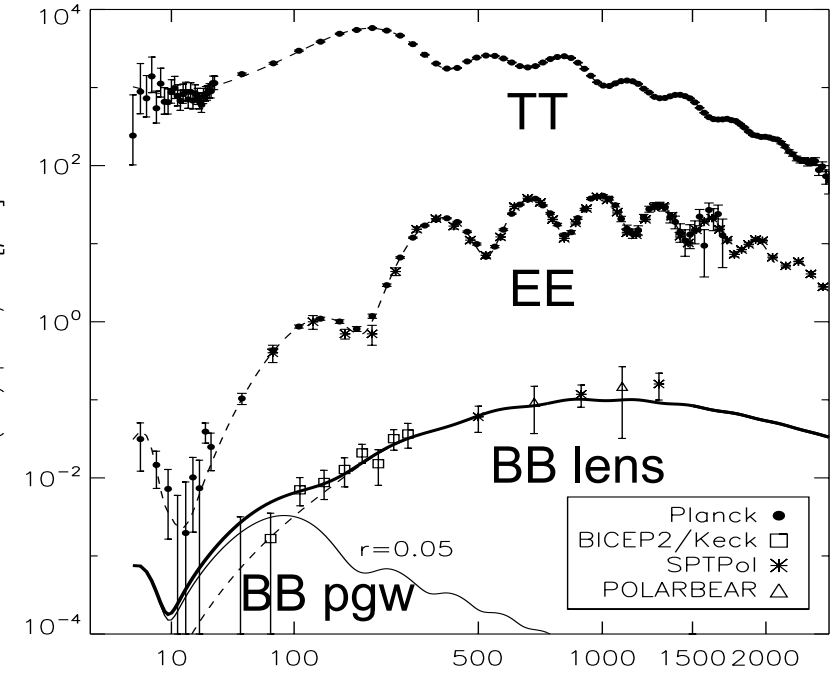




# Science

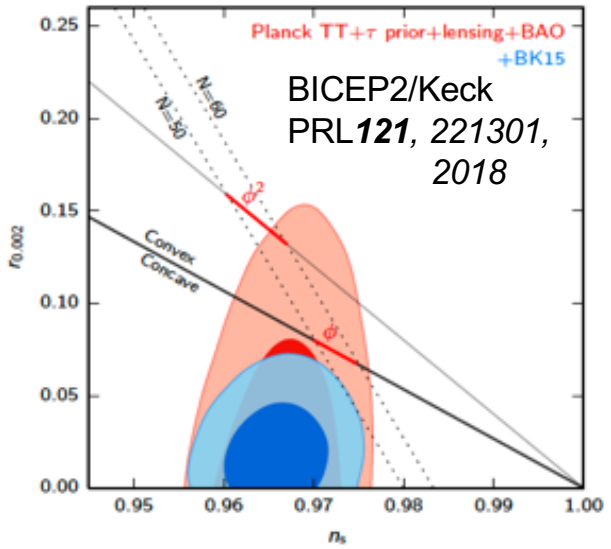



- CMB polarization measurements
- B-mode power spectra:
  - Low ell: primordial gravitational waves for testing cosmic inflation
  - High ell: sum of neutrino masses
- E-mode power spectra:
  - Improve $n_s$
  - Improve τ and neutrino properties

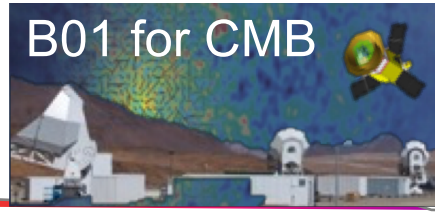



***Exciting & unique probe for***
- ***Primordial universe***
- ***Quantum gravity***
- ***Particle physics***

Current limit
$r < 0.06$
(95% C.L.)



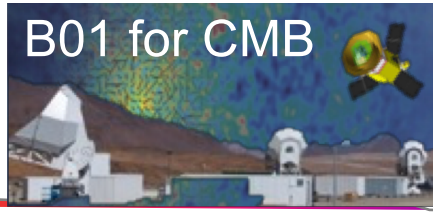
# B01 project overview



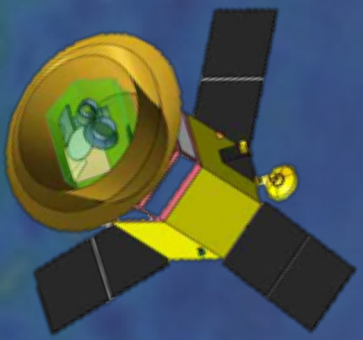

Space: LiteBIRD

Ground: Simons Array

# B01 project scope

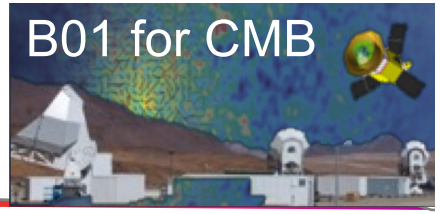



- LiteBIRD
  - Design, R&D of key components for launch in 2027
  - End-to-end Simulation on foreground separation and systematics mitigation
  - Establish the technology/system to achieve $\delta r < 0.001$



- Simons Array = "Advanced POLARBEAR"
  - Multi-chroic observations with three telescopes for 90/150/220/280 GHz
    - $\sigma(r) < 0.01$
    - $\sigma(\Sigma m_\nu) < 100$meV
    - n_s will also be improved from E-mode measurements.
  - Bonus as a general-purpose cosmology/astronomy telescope

# Simons Array





Yuji Chinone will talk on POLARBEAR analyses and Simons Array prospects.

# The first receiver for Simons Array at KEK

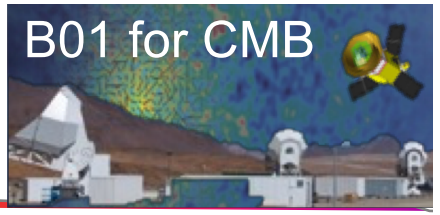

Sep. 2018：Photo at the completion of characterization, before shipping to Chile

Masaya Hasegawa (Project manager)
Daisuke Kaneko
Yuko Segawa
Sayuri Takatori
Takaho Hamada
Satoru Takakura
Fred Matsuda
Haruki Nishino
Yuto Minami
Haruaki Hirosei
Nobu Katayama
Masashi Hazumi
Daiki Tanabe

Development team members from KEK, Kavli IPMU, + associated students

>50% of us are in Chile now!

# Summary of tests at KEK




- Presentations at JPS Autumn 2018
  - Overview by Masaya Hasegawa and 4 other presentations

## 統合試験

+ 冷却　+ データ収集系

チャンネルマッピング
(サイトでクイックに各TESの周波数帯を特定する手法を開発)
(16aS37-6 瀬川)

アルミナ再結像レンズ(4K), IRフィルター(50K)

偏光角
シニアスアンテナ
TESボロメータ (AlMn)
統合試験全般
(16aS37-3 西野)
光学効率
ビーム特性

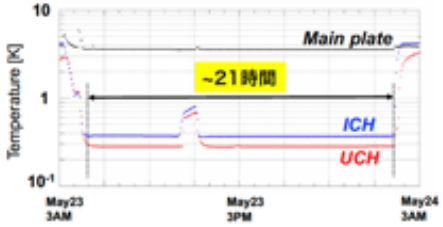
ノイズ, 時定数
飽和パワー
温度安定性
(16aS37-5 田邊)

システム全体の(温度)安定性

人工較正源
(16aS37-4 高取)

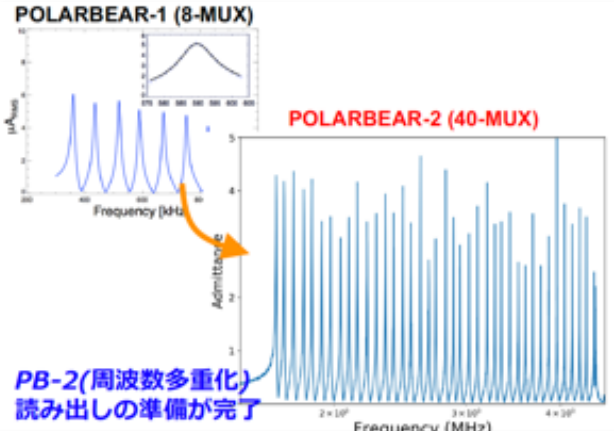
目的は、
- 実験の成立性の確認
- 光学・偏光特性の評価 (最終的な評価はサイトで)
- サイトで用いる較正装置の原理検証

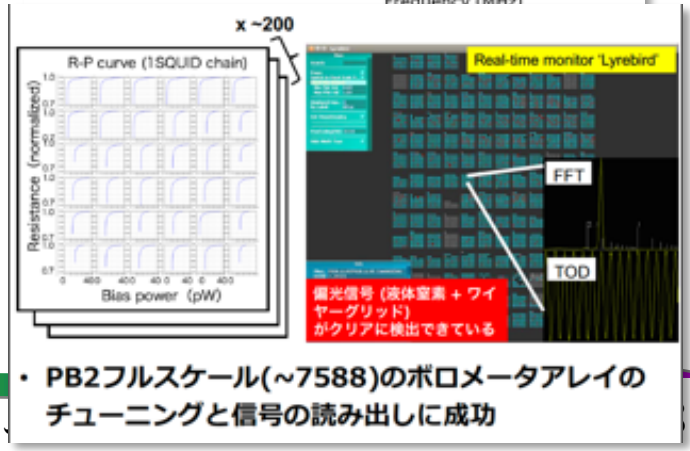
## 焦点面の冷却状況




| | 熱負荷 |
|---|---|
| Optical power | < ~2uW |
| 焦点面支持機構 | 20uW |
| 読み出しケーブル | 23uW |
| RFシールド | 9uW |
| 光学フィルター | 7uW |
| 減光フィルタ (実験室のみ) | ~8uW(@7K) |
| Total | ~69uW |

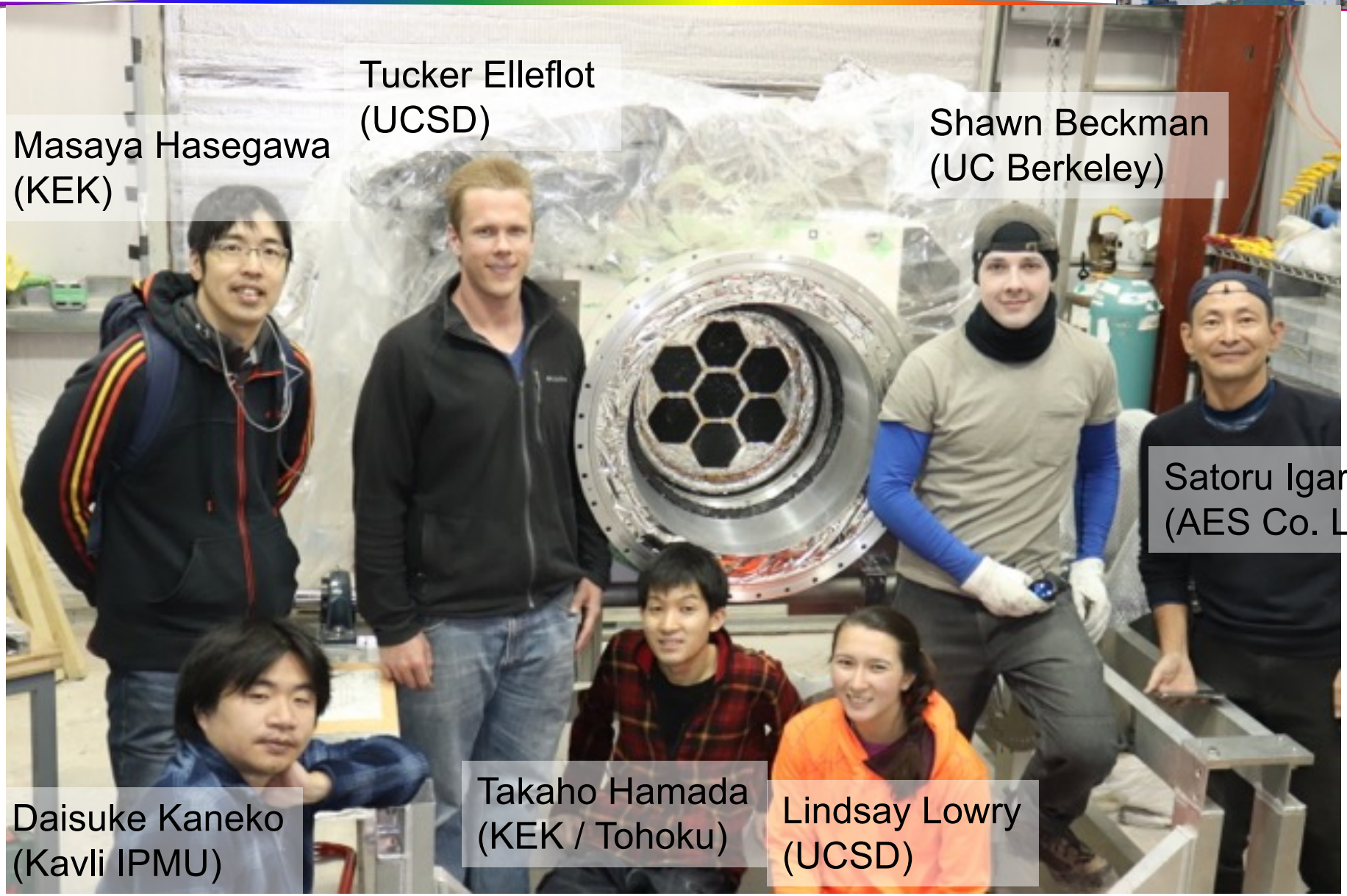
焦点面の冷却保持時間 > 20時間
→ 24時間観測サイクル実現の目処がついた



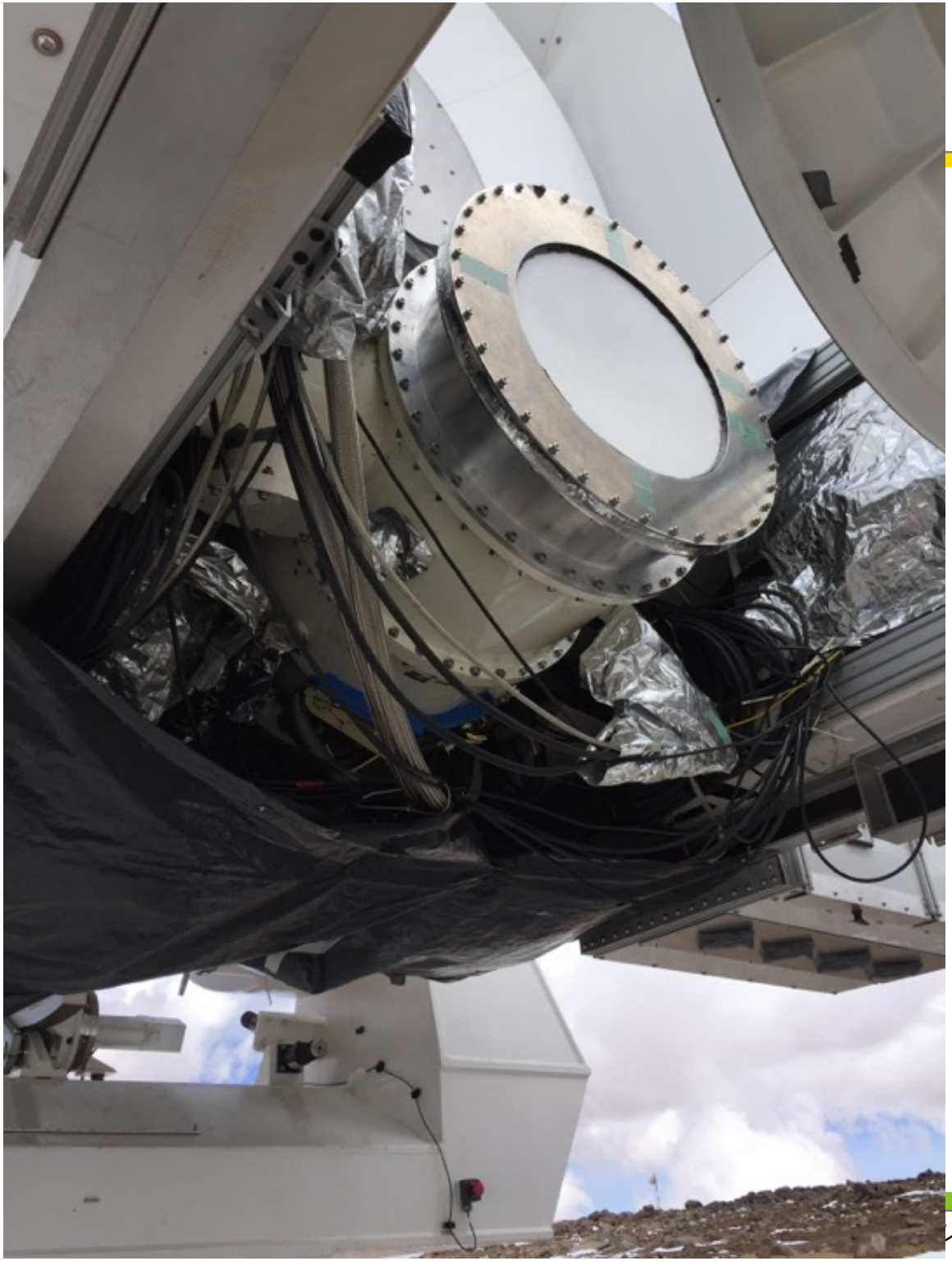




- PB2フルスケール(~7588)のボロメータアレイのチューニングと信号の読み出しに成功

# Assembly at the Chile site


F2101
FASSI

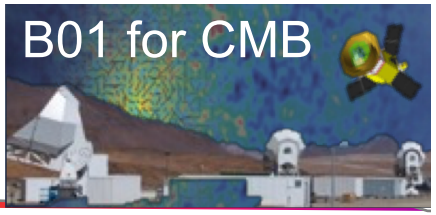


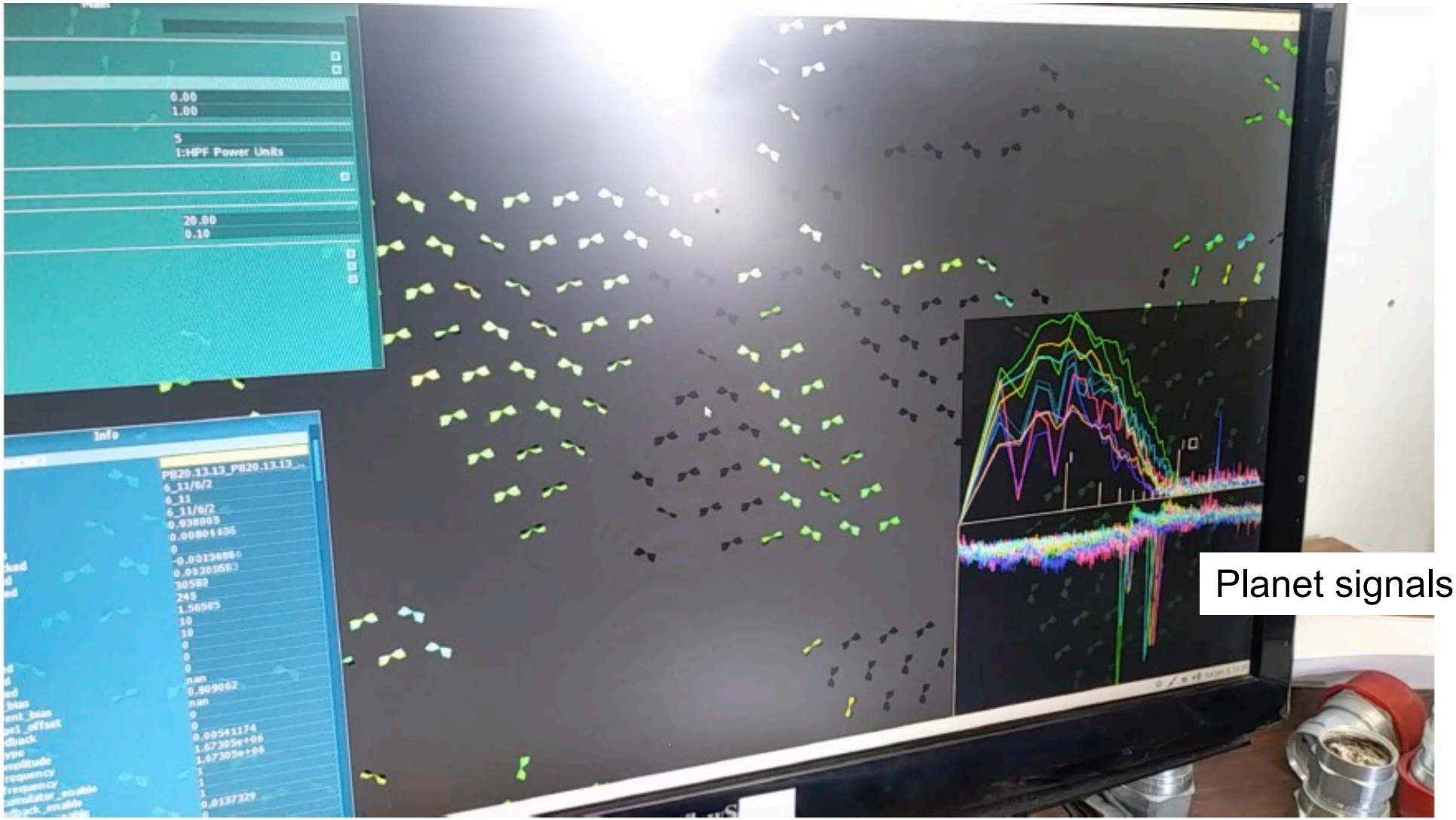


- We finally mounted our receiver system on the telescope! (Nov. - Dec 2018)*

*This photo was taken in Jan. 2019

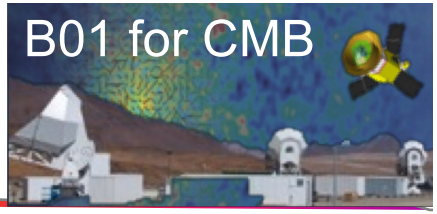
# First light!



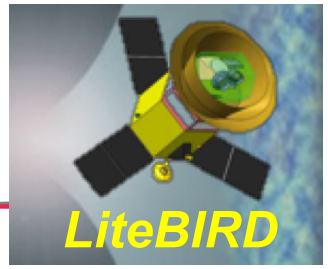

Jan. 5, 2019*

*Real first light was on Jan. 4 w/ the Moon.

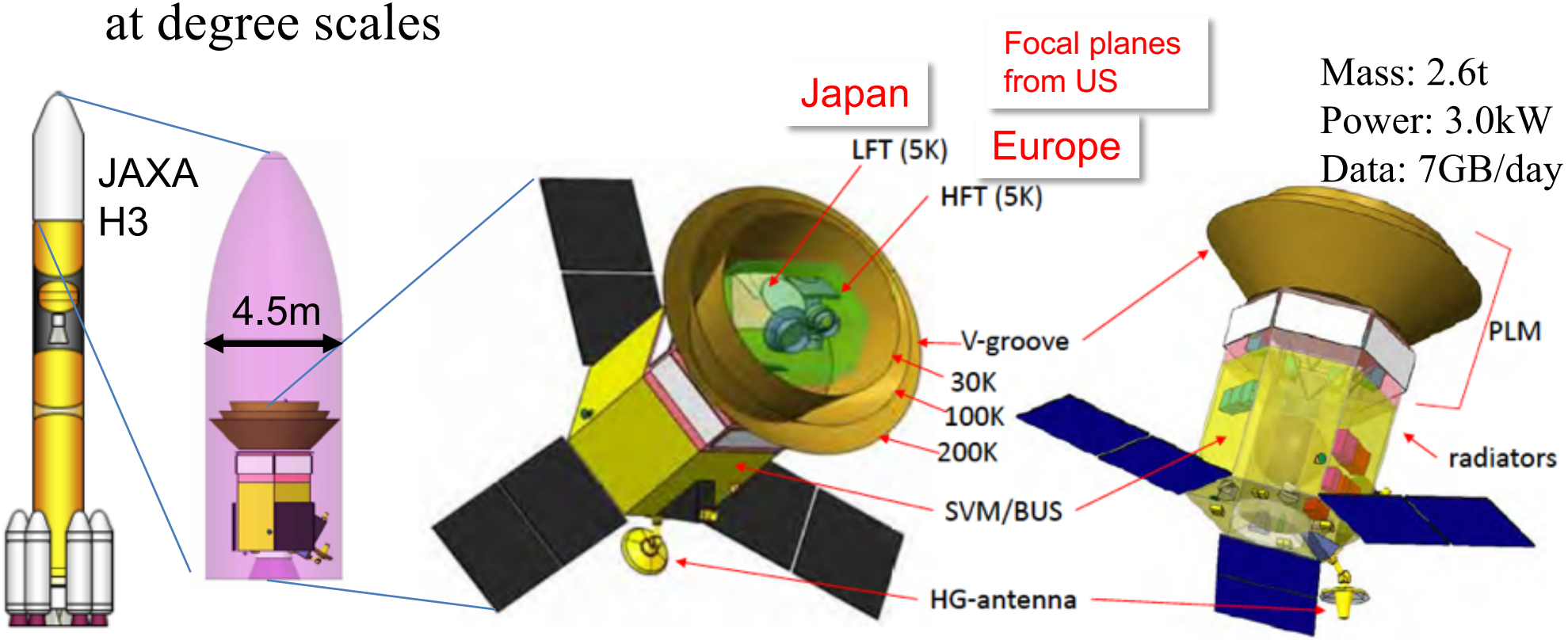


- Debugging, test observations and receiver characterization ongoing
- Updates will be shown at JPS and JAS meetings in March 2019 (this month).

# LiteBIRD Overview




- JAXA's L-class mission candidate
- Expected launch in 2027
- Observations for 3 years around Sun-Earth Lagrangian point L2
- Millimeter-wave all sky surveys (34–448 GHz, 15 bands) at degree scales

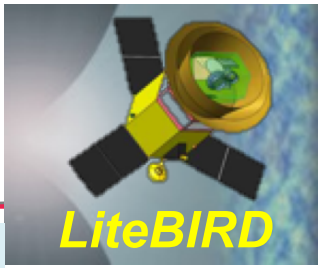


# Status and near-term schedule


- ISAS/JAXA Phase-A1 concept development completed (Sep. 2016 – Aug. 2018)
  - The most advanced status among all CMB space mission proposals in the world
  - Phase A committment from ASI, CNES, CSA, NASA (tech. development), ESA also conducted CDF studies on HFT w/ JAXA and European consortium
- Phase-A1 exit review (Nov.-Dec. 2018) ended successfully
  - About 950 pages of study reports
- Cost saving studies and cost review (Jan.-Mar. 2019)
- Final down selection (April-June 2019)
  - LiteBIRD or OKEANOS (solar-power sail)

We are here.

# LiteBIRD Joint Study Group



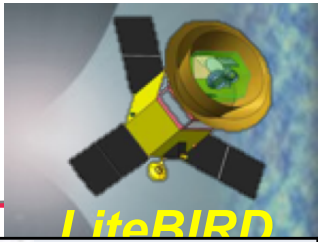

About 180 researchers from Japan, North America & Europe (a list as of Oct. 2018. The group is still growing!)

Experience: CMB exp., X-ray satellites, other large proj. (HEP, ALMA etc.)

Y. Sekimoto[14,37] , P. Ade[2], K. Arnold[49], J. Aumont[12], J. Austermann[29], C. Baccigalupi[11], A. Banday[12], R. Banerji[56], S. Basak[7,11], S. Beckman[49], M. Bersanelli[44], J. Borrill[20], F. Boulanger[4], M.L. Brown[53], M. Bucher[1], E. Calabrese[2], F.J. Casas[10], A. Challinor[50,60,64], Y. Chinone[16,47], F. Columbro[46], A. Cukierman[47,36], D. Curtis[47], P. de Bernardis[46], M. de Petris[46], M. Dobbs[23], T. Dotani[14,37], L. Duband[3], JM. Duval[3], A. Ducout[16], K. Ebisawa[14], T. Elleflot[49], H. Eriksen[56], J. Errard[1], R. Flauger[49], C. Franceschet[54], U. Fuskeland[56], K. Ganga[1], J.R. Gao[35], T. Ghigna[16,57], J. Grain[9], A. Gruppuso[6], N. Halverson[51], P. Hargrave[2], T. Hasebe[14], M. Hasegawa[5,37], M. Hattori[42], M. Hazumi[5,14,16,37], S. Henrot-Versille[19], C. Hill[21,47], Y. Hirota[38], E. Hivon[61], D.T. Hoang[1,63], J. Hubmayr[29], K. Ichiki[24], H. Imada[19], H. Ishino[30], G. Jaehnig[51], H. Kanai[59], S. Kashima[25], K. Kataoka[30], N. Katayama[16], T. Kawasaki[17], R. Keskitalo[20,48], A. Kibayashi[30], T. Kikuchi[14], K. Kimura[31], T. Kisner[20,48], Y. Kobayashi[39], N. Kogiso[31], K. Kohri[5], E. Komatsu[22], K. Komatsu[30], K. Konishi[39], N. Krachmalnicoff[11], C.L. Kuo[34,36], N. Kurinsky[34,36], A. Kushino[18], L. Lamagna[46], A.T. Lee[21,47], E. Linder[21,48], B. Maffei[9], M. Maki[5], A. Mangilli[12], E. Martinez-Gonzalez[10], S. Masi[46], T. Matsumura[16], A. Mennella[54], Y. Minami[5], K. Mistuda[14], D. Molinari[52,6], L. Montier[12], G. Morgante[6], B. Mot[12], Y. Murata[14], A. Murphy[28], M. Nagai[25], R. Nagata[5], S. Nakamura[59], T. Namikawa[27], P. Natoli[52], T. Nishibori[15], H. Nishino[5], C. O'Sullivan[28], H. Ochi[59], H. Ogawa[31], H. Ogawa[14], H. Ohsaki[38], I. Ohta[58], N. Okada[31], G. Patanchon[1], F. Piacentini[46], G. Pisano[2], G. Polenta[13], D. Poletti[11], G. Puglisi[36], C. Raum[47], S. Realini[54], M. Remazeilles[53], H. Sakurai[38], Y. Sakurai[16], G. Savini[43], B. Sherwin[50,65,21], K. Shinozaki[15], M. Shiraishi[26], G. Signorelli[8], G. Smecher[41], R. Stompor[1], H. Sugai[16], S. Sugiyama[32], A. Suzuki[21], J. Suzuki[5], R. Takaku[14,40], H. Takakura[14,39], S. Takakura[16], E. Taylor[48], Y. Terao[38], K.L. Thompson[34,36], B. Thorne[57], M. Tomasi[44], H. Tomida[14], N. Trappe[28], M. Tristram[19], M. Tsuji[26], M. Tsujimoto[14], S. Uozumi[30], S. Utsunomiya[16], N. Vittorio[45], N. Watanabe[17], I. Wehus[56], B. Westbrook[47], B. Winter[62], R. Yamamoto[14], N.Y. Yamasaki[14], M. Yanagisawa[30], T. Yoshida[14], J. Yumoto[38], M. Zannoni[55], A. Zonca[33],


LiteBIRD Global face-to-face meeting, @ Italian Space Agency, Jan. 2019

# Great contributions by B01 postdoctoral fellows!




Thermal design, Sensitivity calculations, Focal plane, configuration

Takashi Hasebe

Currently JAXA project researcher

LFT optics, Beam systematics

Hiroaki Imada

Currently Postdoc at LAL Orsay

Cosmic ray mitigation, Calibration method, Cryogenic tests

Yuto Minami

Currently Postdoc at IPNS, KEK

Requirements flowdown, Systematic errors

Ryo Nagata

Polarization modulator R&D

Yuki Sakurai

Currently Postdoc at Kavli IPMU

Scan strategy

Satoru Uozumi

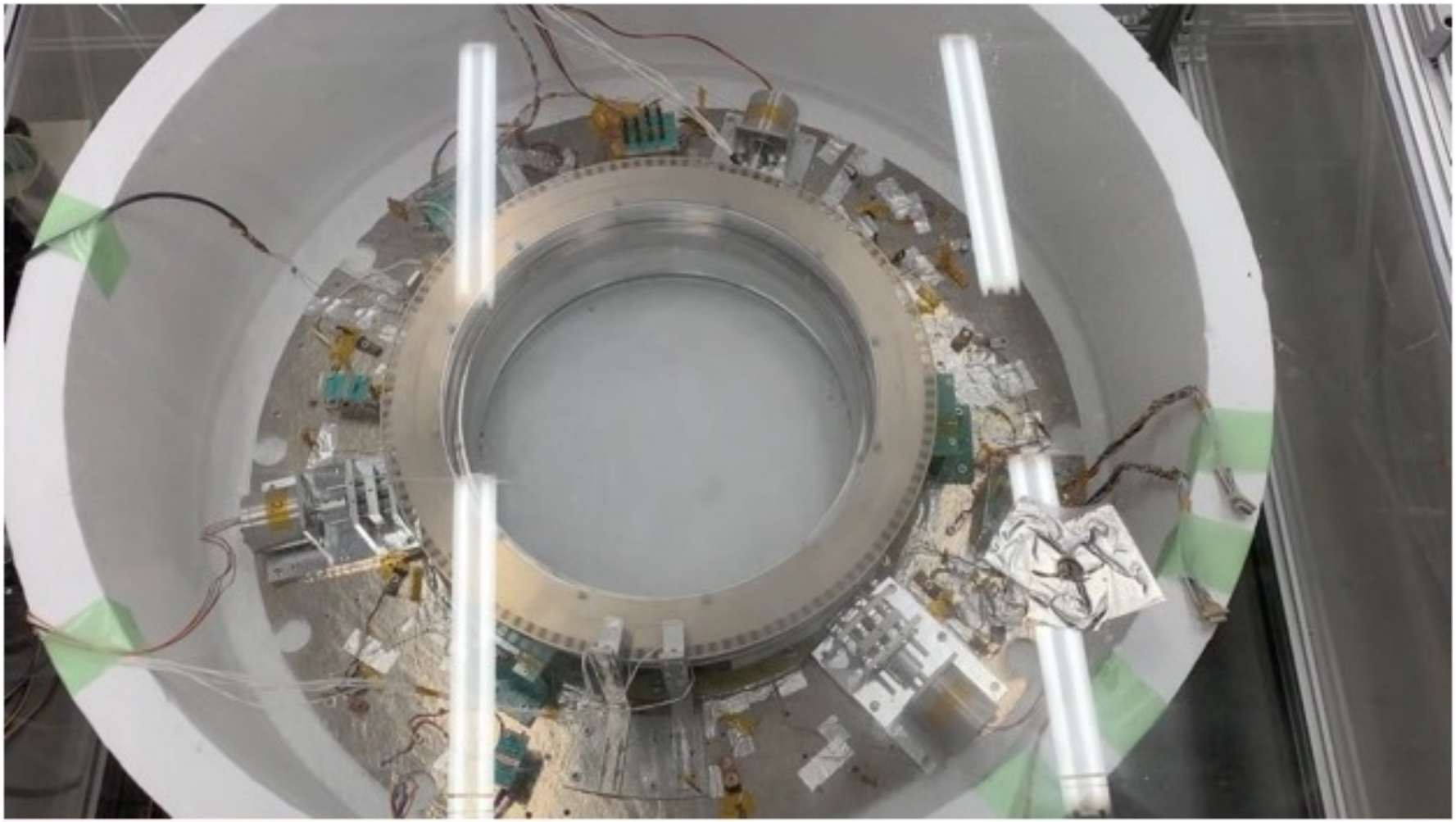
# Large (~450mmϕ) LFT polarization modulator

The first time in the world!

We developed superconducting magnetic bearing system and performed the rotation test in 4K cryostat. **We observed the stable rotation at cryogenic temperature (<10K).**

Tomo Matsumura

Developed at Kavli IPMU

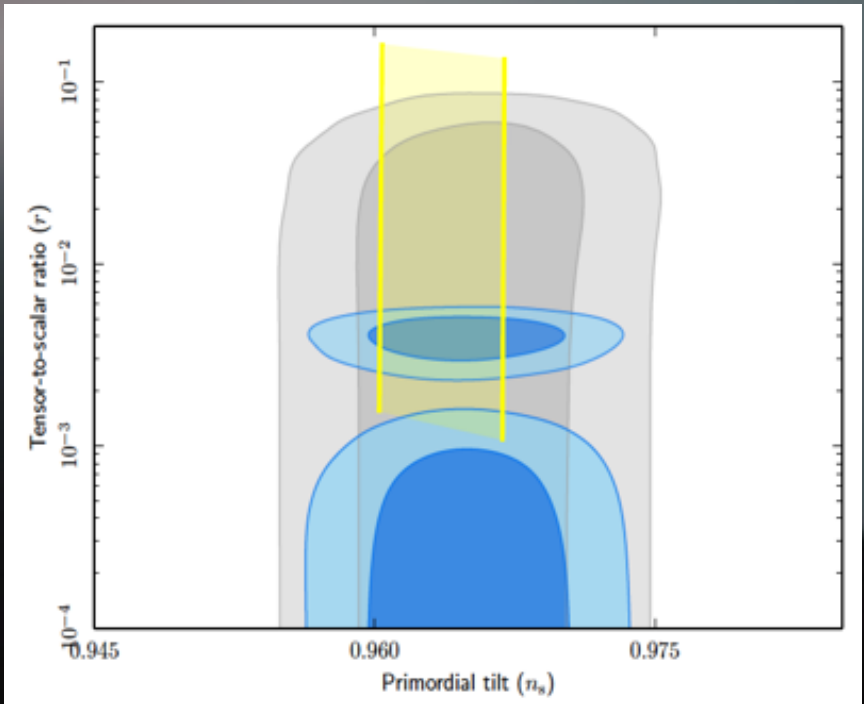


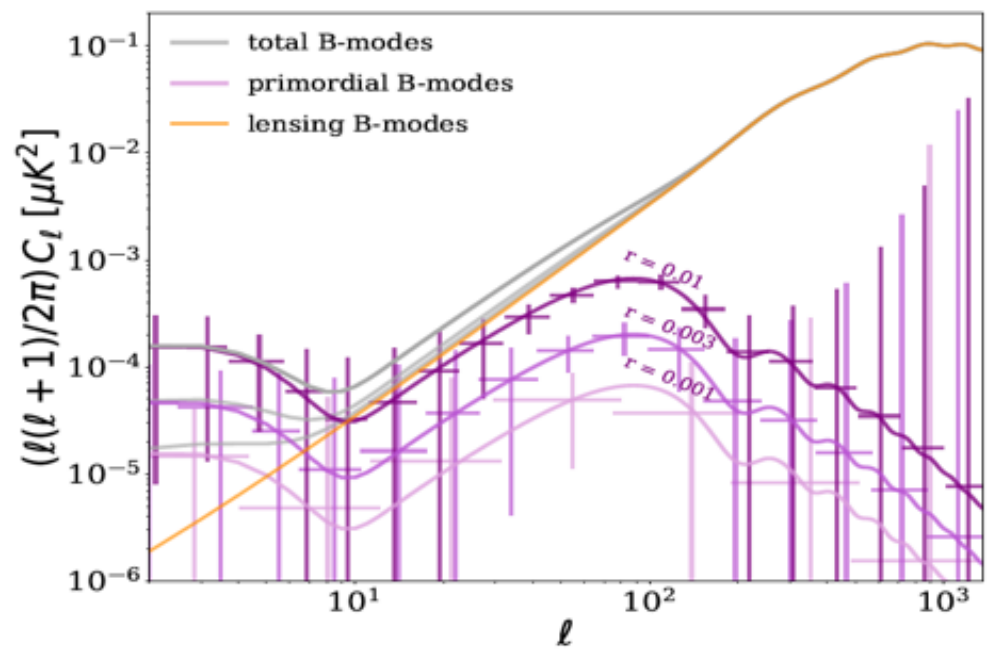
# LiteBIRD has a clear goal and can achieve it!


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

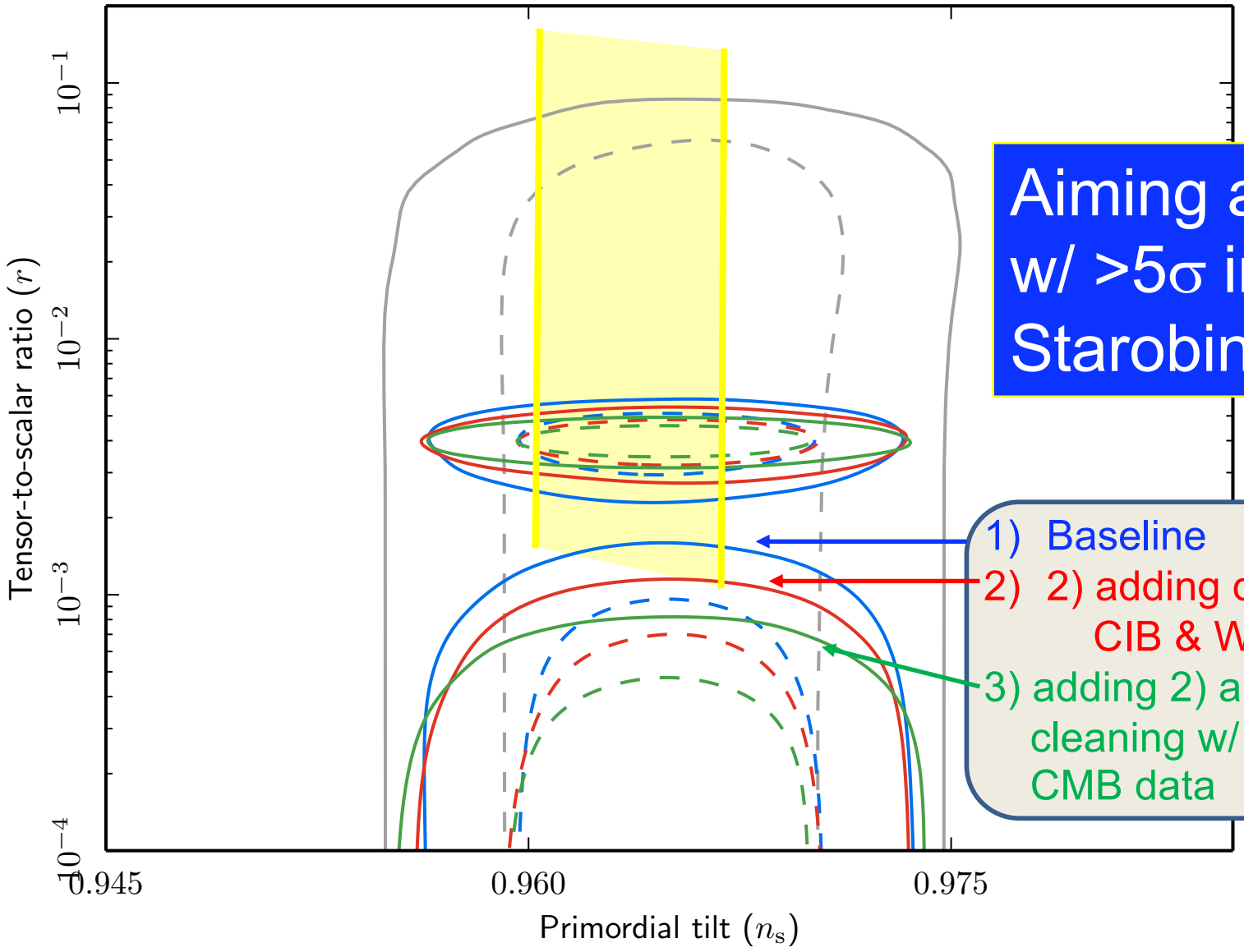
(Rationale)
- Simplest and well-motivated Starobinsky model will be tested.
- Clean sweep of simple models w/ $\Delta\phi > m_{\rm pl}$

- Detailed foreground cleaning studies yield $\sigma(r=0) = 0.5 \times 10^{-3}$
- Thorough systematic error studies yield total uncertainty $\delta r < 1.0 \times 10^{-3}$



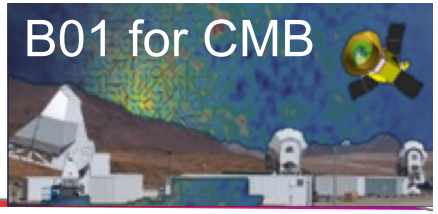
# Extra success w/ external data


Aiming at detection w/ >5σ in case of Starobinsky model

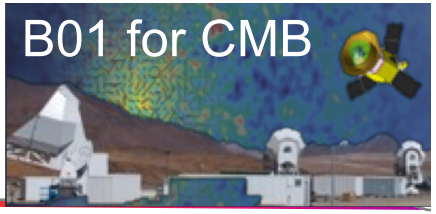
1) Baseline
2) 2) adding delensing w/ Planck CIB & WISE
3) adding 2) and extra foreground cleaning w/ high-resol. ground CMB data

# B01 publications & presentations




- >49 papers as of today
  - 4 cross-over papers
- Too many presentations to obtain the accurate number in time!

# B01-related Open Solicitation (公募研究)







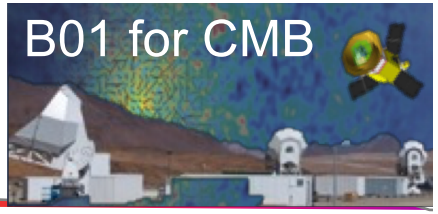
2018～2019

| 所属機関 | 氏名 | 課題 |
|---|---|---|
| 高エネ加速器研・素粒子研・研究員 | 南　雄人 | 宇宙初期の加速膨張を検証可能にする革新的な超伝導検出器の開発 |
| Kavli IPMU・学振特別研究員 | 高倉　理 | CMB偏光観測望遠鏡のための偏光補正装置の開発 |
| 理研・研究員 | 小栗　秀悟 | ガス冷却でつくる広帯域・高透過率なCMB光学系－反射防止のいらない断熱フィルター |
| UC Berkeley・研究員 | 茅根　裕司 | 最新のマイクロ波望遠鏡で探るインフレーション起源重力波と宇宙の暗黒成分 |

2016～2017

| 所属機関 | 氏名 | 課題 |
|---|---|---|
| 核融合科学研究所・助教 | 高田　卓 | ミリ波からサブミリ波領域における機能性高放射率材料の開発 |
| 核融合科学研究所・准教授 | 高山　定次 | 陶磁器焼成技術を応用したミリ波光学素子の開発 |
| 京大・准教授 | 田島　治 | 偽偏光を作らない光学系「超伝導ミラー」の開発研究 |

# Summary




- The first Simons Array receiver has been deployed in Chile and got the first light.
  - Will demonstrate the performance in JFY2019
- LiteBIRD concept development completed. We are confident that we achieve $\delta r < 0.001$.
- Lots of papers on R&D and simulation.
- Measurements papers from POLARBEAR-1
- Four cross-over papers
  - Will make more efforts to produce more.

**JFY2018 has been a very productive year!**