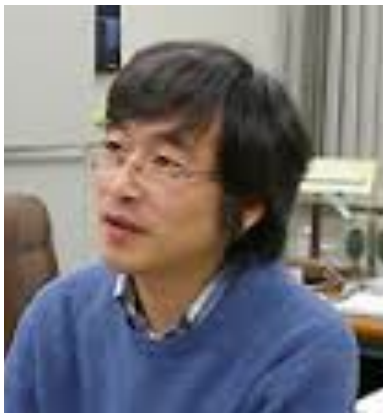
B01 Study Group：“Large-area CMB surveys for studies of cosmic acceleration and large-scale structure” JFY2015-2019

Masashi Hazumi
PI, KEK & Kavli IPMU)

Co-Is（研究分担者）

Nobu Katayama
(Kavli IPMU)



Kazuhisa Mitsuda
(ISAS/JAXA)

Yutaro Sekimoto
(NAOJ → ISAS)

Hirokazu Ishino
(Okayama U.)

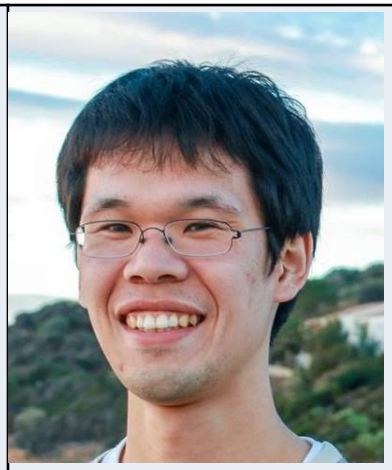
Masaya Hasegawa
(KEK)

Great contributions by B01 postdoctoral fellows!

Thermal design, Sensitivity calculations, Focal plane, configuration

Currently JAXA project researcher

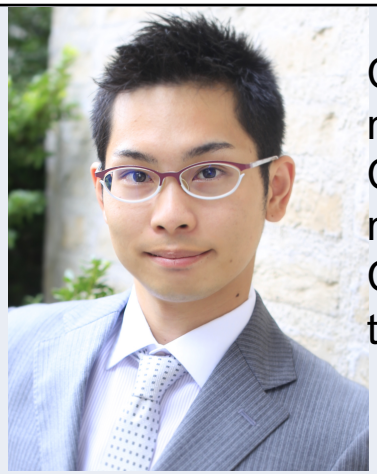
Takashi Hasebe



LFT optics, Beam systematics

Currently Postdoc at IJCLab

Hiroaki Imada



Cosmic ray mitigation, Calibration method, Cryogenic tests

Currently Postdoc at IPNS, KEK

Yuto Minami

Requirements flowdown, Systematic errors

Ryo Nagata (KEK)

Polarization modulator R&D

Currently Postdoc at Kavli IPMU

Yuki Sakurai

Scan strategy

Satoru Uozumi (Okayama)

B01-related Open-Solicitation Studies (公募研究)




2018～2019

→ See posters at this workshop

所属機関	氏名	課題
高エネ加速器研・素粒子研・研究員（KEK）	南　雄人 Yuto Minami	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: R&D on Superconducting Detector
Kavli IPMU・学振特別研究員	高倉　理 Satoru Takakura	CMB偏光観測望遠鏡のための偏光補正装置の開発: R&D on Polarization Calibrator
理研・研究員（RIKIN）	小栗　秀悟 Shugo Oguri	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: R&D on IR filter
東京大学・研究員（U Tokyo）	茅根　裕司 Yuji Chinone	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: CMB Data Analysis

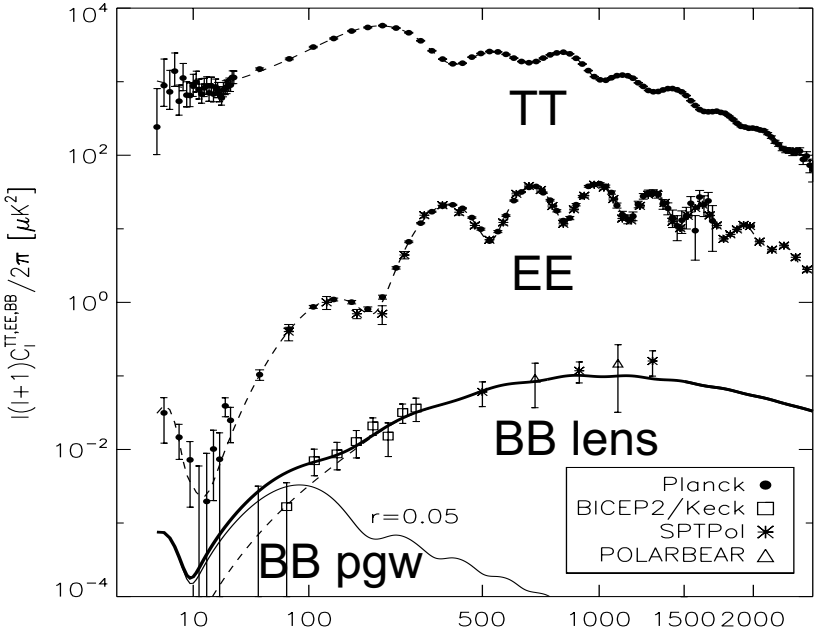
2016～2017

所属機関	氏名	課題
核融合科学研究所・助教（NIFS）	高田　卓 Suguru Takada	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 R&D on Absorber
核融合科学研究所・准教授（NIFS）	高山　定次 Teiji Takayama	陶磁器焼成技術を応用したミリ波光学素子の開発 R&D on mm-wave Optical Component
京大・准教授（Kyoto U.）	田島　治 Osamu Tajima	偽偏光を作らない光学系「超伝導ミラー」の開発研究 R&D on Superconducting Mirror

Science of Study Group B01

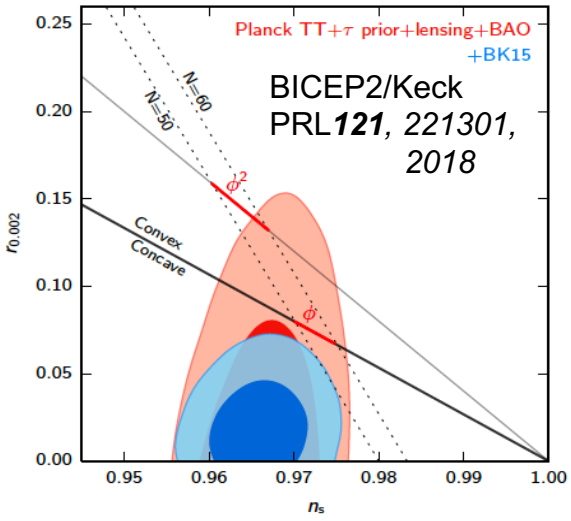
CMB polarization measurements

	B-mode	E-mode
Low ell	**Primordial gravitational waves for testing cosmic inflation**	**Improve τ and neutrino properties**
High ell	**Measure sum of neutrino masses**	**Improve n_s**



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

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



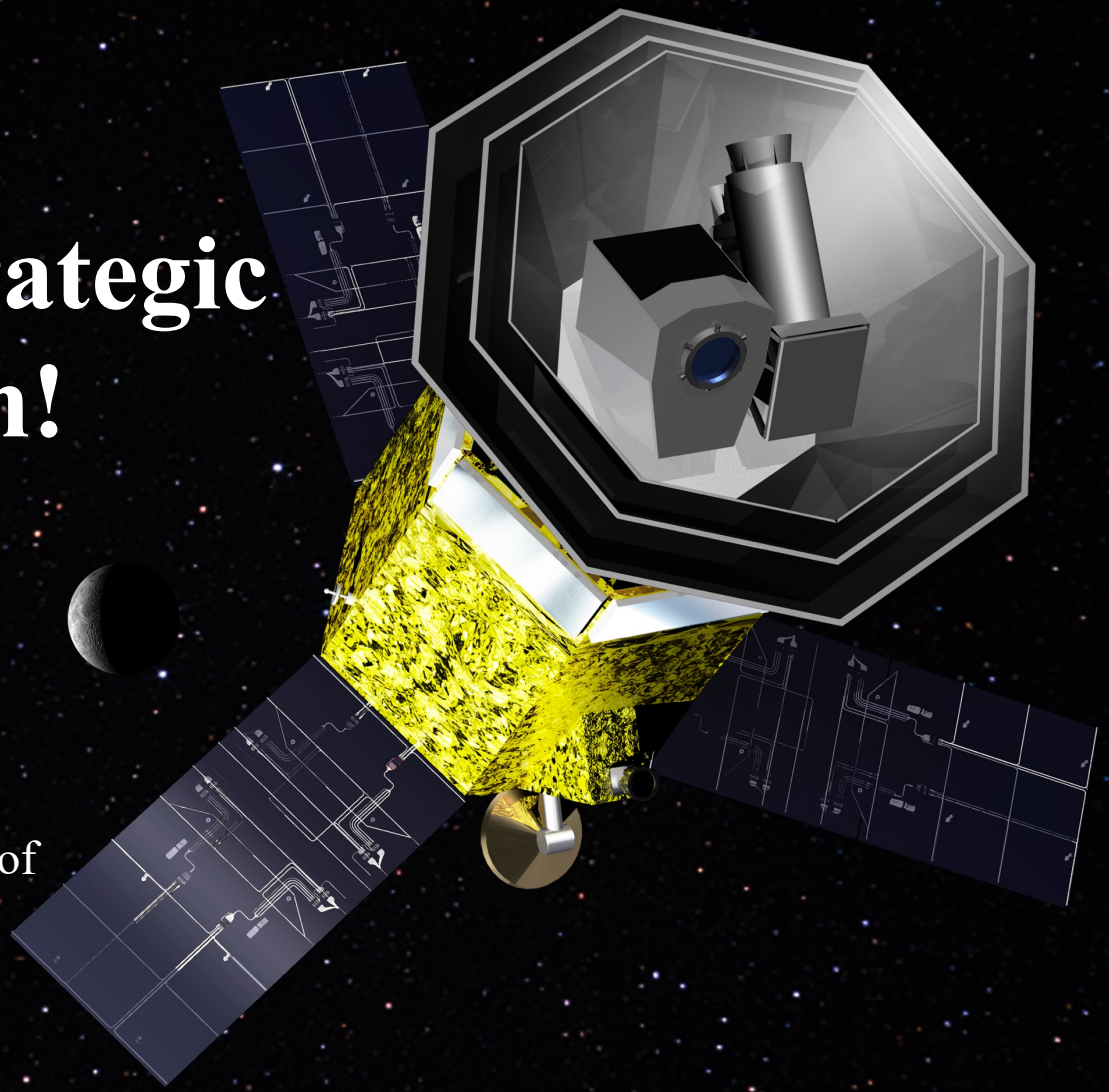
B01 Main Projects

Nature of B01 Study Group

- Instumentation
- Observation and Analysis

In May 2019, JAXA selected *LiteBIRD* for JAXA's strategic L-class mission!

Official announcement
http://www.isas.jaxa.jp/home/rikou/godo/2019/0602/gbi7uzhxfxmz/misison_selection_announcement_may2019.pdf



LiteBIRD:
Lite (light) satellite for the studies of
B-mode polarization and
Inflation from cosmic background
Radiation
Detection

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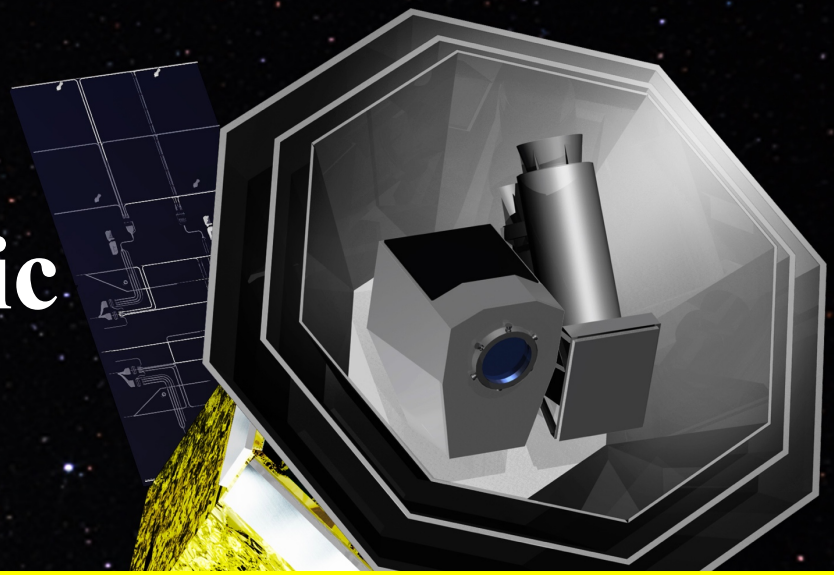


LiteBIRD:
Lite (light) satellite for the studies of
B-mode polarization and
Inflation from cosmic background
Radiation
Detection

This never happened without the "Cosmic Acceleration"
MEXT Grant-in-Aid for Scientific Research on Innovative Areas!

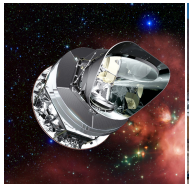
CMB torch passed from Planck to LiteBIRD

LiteBIRD kick-off symposium
July 1-2, 2019
ISAS/JAXA

LiteBIRD Joint Study Group

More than 250 researchers from Japan, North America & Europe

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

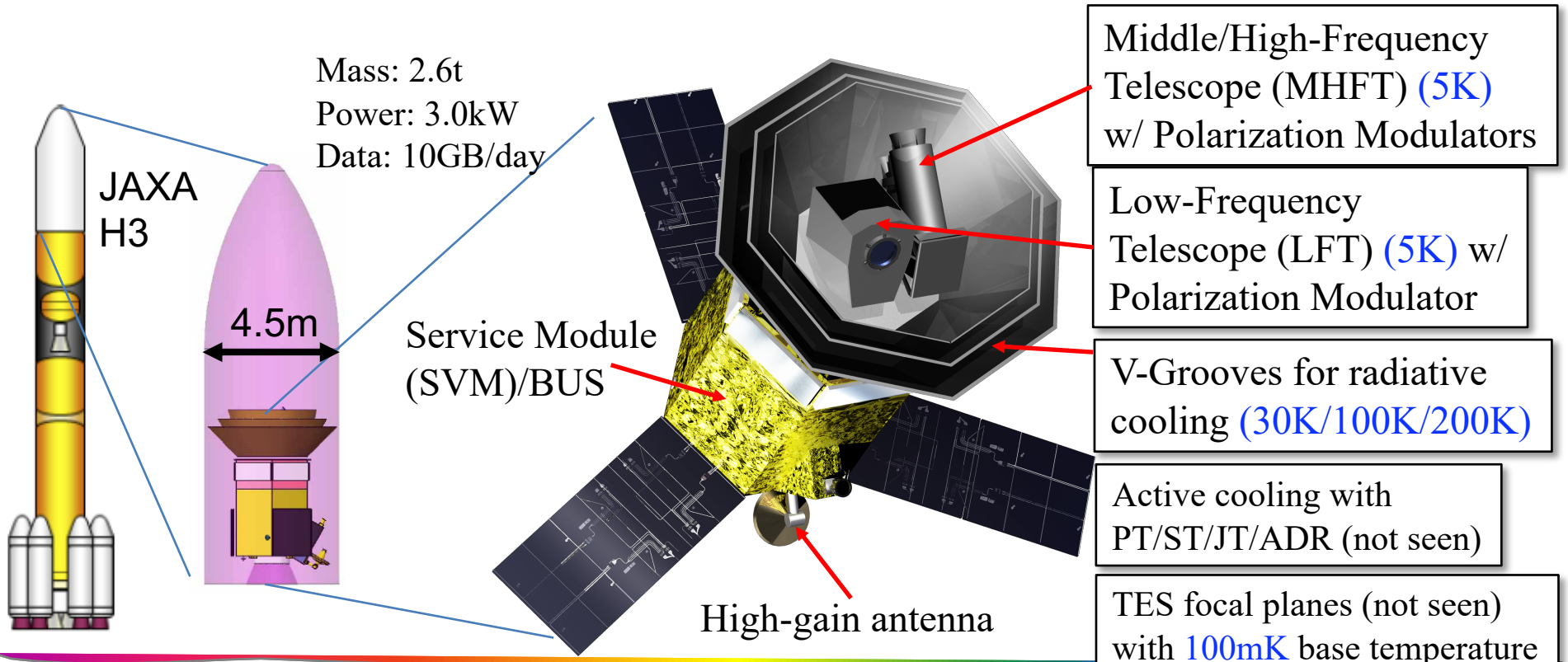




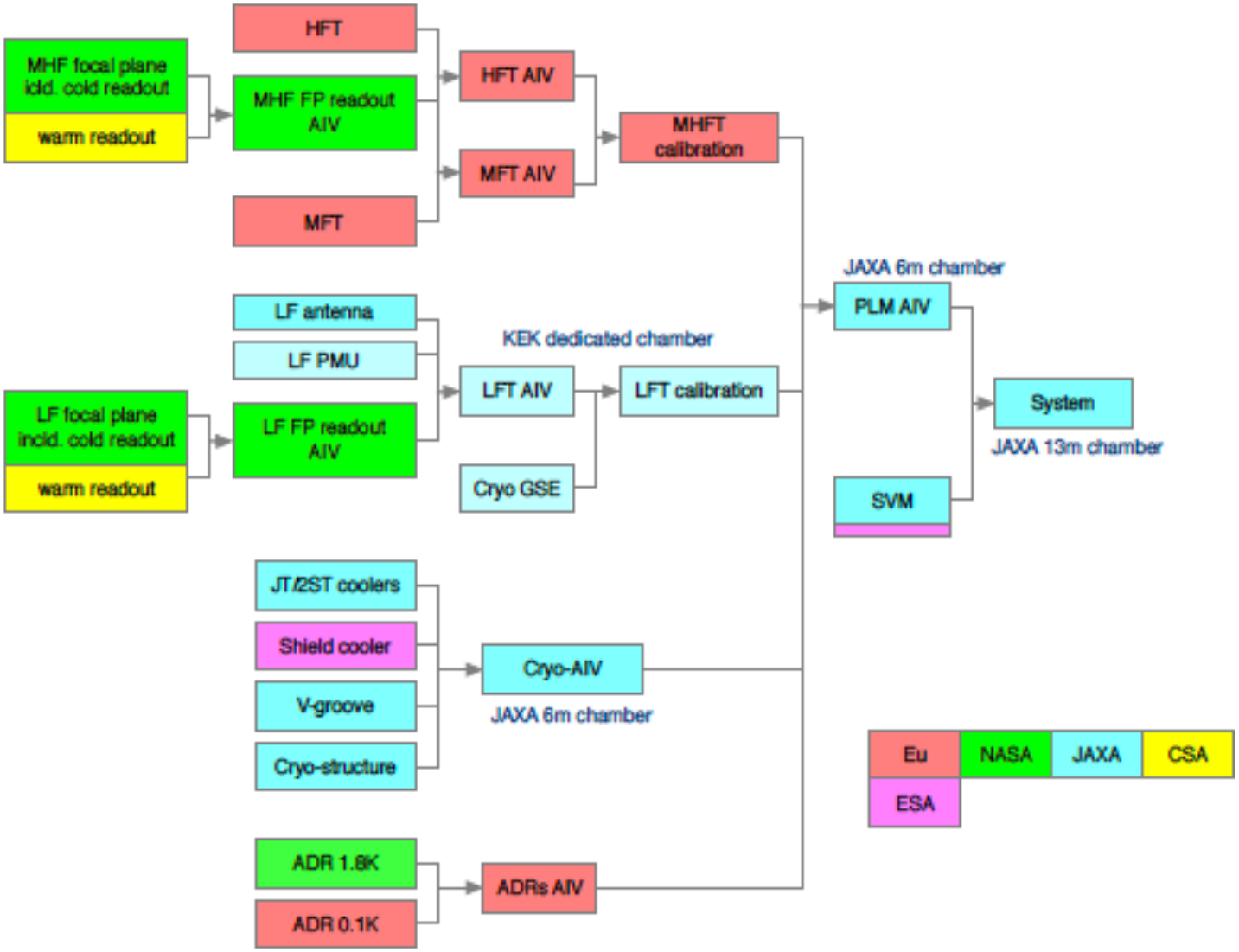
LiteBIRD global face-to-face meeting
Max Planck Institute for Extraterrestrial Physics,
Garching, Dec. 11-13, 2019

LiteBIRD Overview

- JAXA's L-class mission selected in May 2019
- Expected launch in Japanese fiscal year 2027 with JAXA's H3 rocket.
- Observations for 3 years (baseline) around Sun-Earth Lagrangian point L2
- Millimeter-wave all sky surveys (34–448 GHz, 15 bands) at 70–20 arcmin.
- Mission: δr (total uncertainty) < 0.001 (for r=0) with CMB B-mode observation



International Task Sharing



LiteBIRD has a clear goal and will achieve it!

Full Success:

- $\delta r < 1 \times 10^{-3}$ (for r=0)
- $>5\sigma$ observation for each bump (for $r \geq 0.01$)

Rationale

- Large discovery potential for $0.005 < r < 0.05$
- Simplest and well-motivated $R+R^2$ "Starobinsky" model will be tested.
- Clean sweep of single-field models with characteristic field variation scale of inflaton potential greater than m_{pl} (A. Linde, JCAP 1702 (2017) no.02, 006

w/ A01

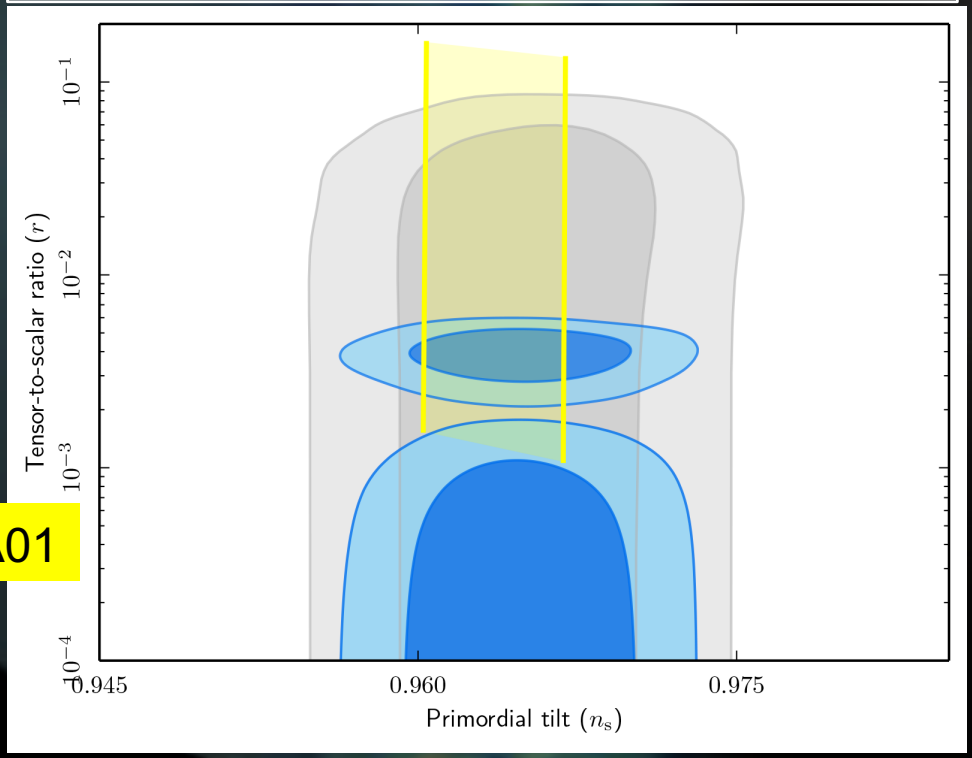
- Stringy "swampland" can be investigated

w/ C01

- Detailed foreground cleaning studies yield $\sigma(r=0) = 0.6 \times 10^{-3}$

w/ D01

- Thorough systematic error studies yield total uncertainty $\delta r < 1.0 \times 10^{-3}$ without delensing



Foreground Cleaning

w/ D01

Methodology

Synchrotron: $[Q_s, U_s](\hat{n}, \nu) = [Q_s, U_s](\hat{n}, \nu_*) \left(\frac{\nu}{\nu_*}\right)^{\beta_s(\hat{n}) + C_s(\hat{n}) \ln(\nu/\nu_*^C)}$

- AME is effectively absorbed by synchrotron curvature

Dust: $[Q_d, U_d](\hat{n}, \nu) = [Q_d, U_d](\hat{n}, \nu_*) \left(\frac{\nu}{\nu_*}\right)^{\beta_d(\hat{n})-2} \frac{B[\nu, T_d(\hat{n})]}{B[\nu_*, T_d(\hat{n})]}$

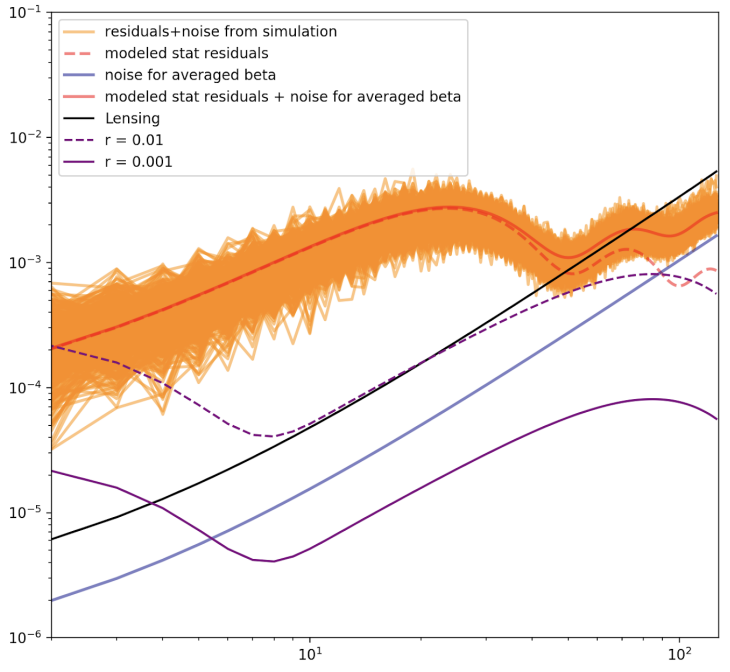
(8 parameters in each sky region) x (12 x $N_{\rm side}^2$)
= 6144 parameters w/ $N_{\rm side} = 8$
to take spatial variations into account

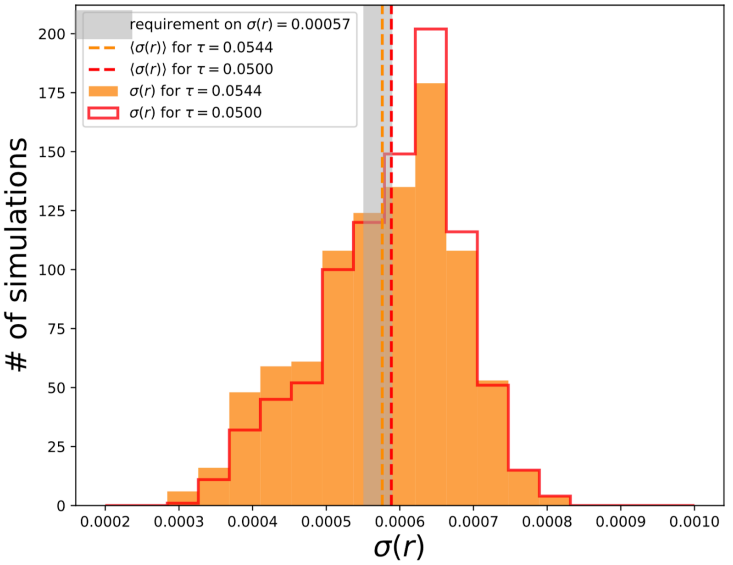
Results

"Multipatch technique" (extension of xForecast)*

- σ(r=0) = 0.0006
- Negligibly small bias

Consistent results from COMMANDER-2!





* Errard and Stompor, Phys.Rev. D99 (2019) no.4, 043529

Systematics and Calibration

w/ D01

Hirokazu Ishino
(Okayama U.)

Tomo Matsumura
(Kavli IPMU)

- One of the largest study groups at LiteBIRD
- Systematic approach for systematic uncertainties

List sources
14 categories
70 items

→ Assign each 1% of total budget
$\sigma(r)_{sys} < 5.7 \times 10^{-6}$

→ Define method (incl. calib. meth.)
estimate of $\sigma(r)_{sys}$

→ Allocate special budget for outstanding items

→ Sum on map base
total $\sigma(r)_{sys}$

iterartion

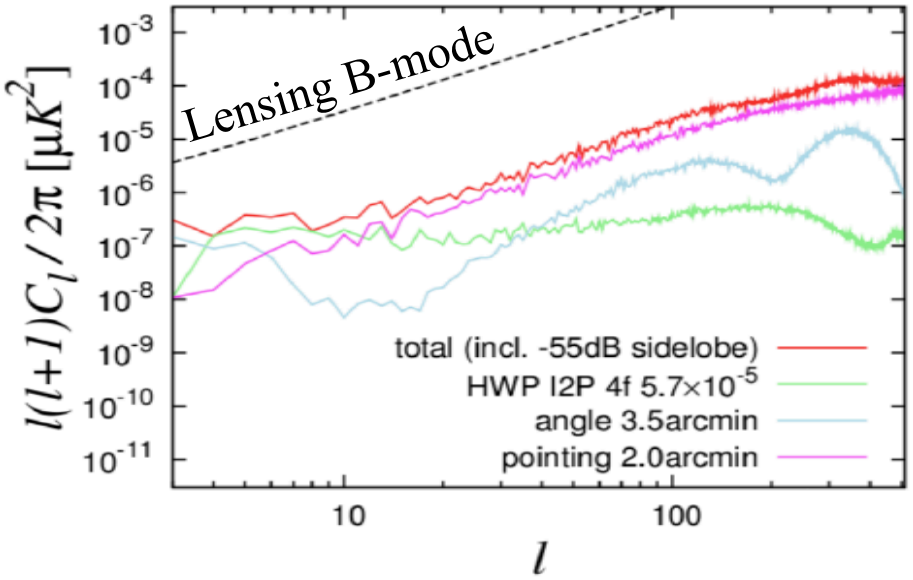
- Example: studies of systematic errors due to HWP imperfection

Realistic HWP for different frequencies and incident angles

→ Mueller matrix M from RCWA sim.
$1M_{IQ}$, $M_{IU} \sim 10^{-4}$ (worst case)

→ Obtain leakage Maps and BB power
$\sigma(r)_{sys}$

All known systematics will be adequately mitigated!



LiteBIRD Science Outcomes

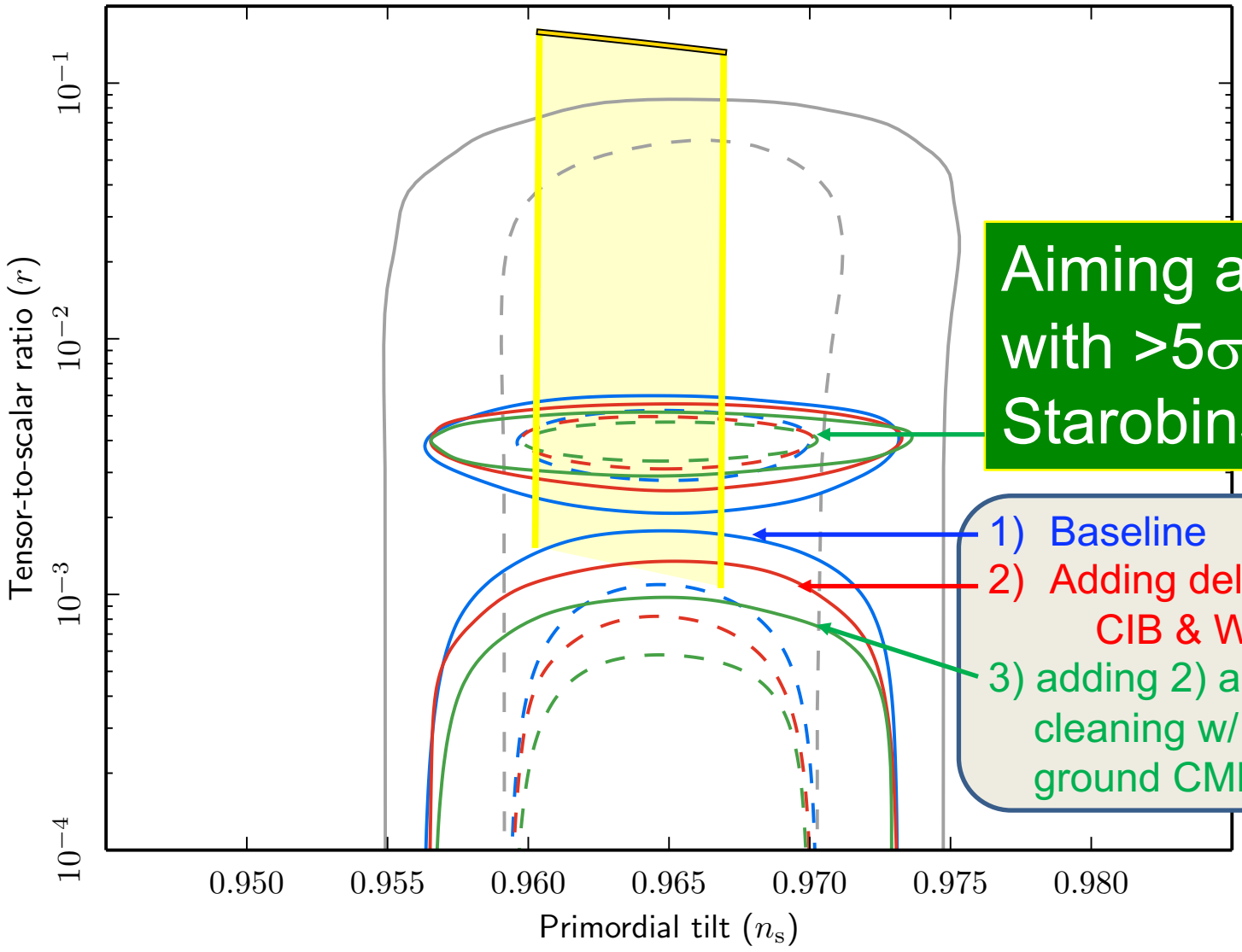
1. Full success

System requirements from full success only

2. Extra success; further improving sensitivity with external data
3. Characterization of B-mode and search for sources fields (e.g scale-invariance, non-Gaussianity, parity violation)
4. Power spectrum features in polarization
5. Large-scale E mode
   - its implications for reionization history and the neutrino mass
6. Cosmic birefringence
7. SZ effect (thermal and relativistic correction)
8. Elucidating anomalies
9. Galactic science

3. – 9. in principle guaranteed if full success is achieved.

2. Extra success; further improving sensitivity with external data

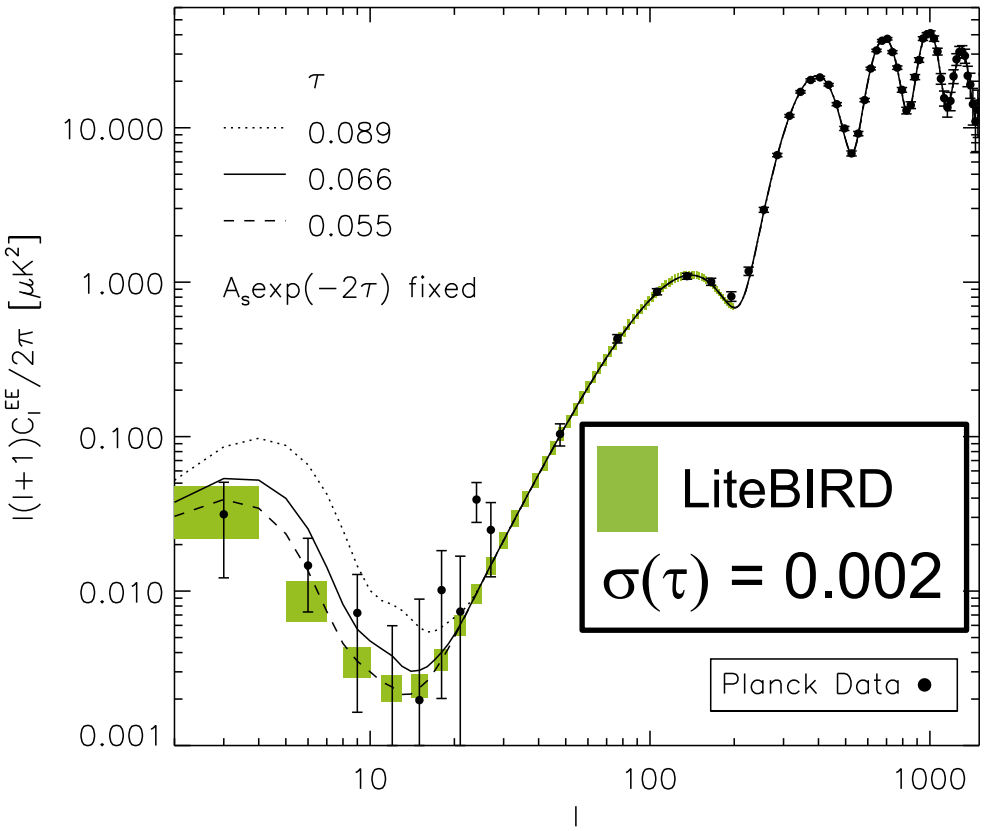


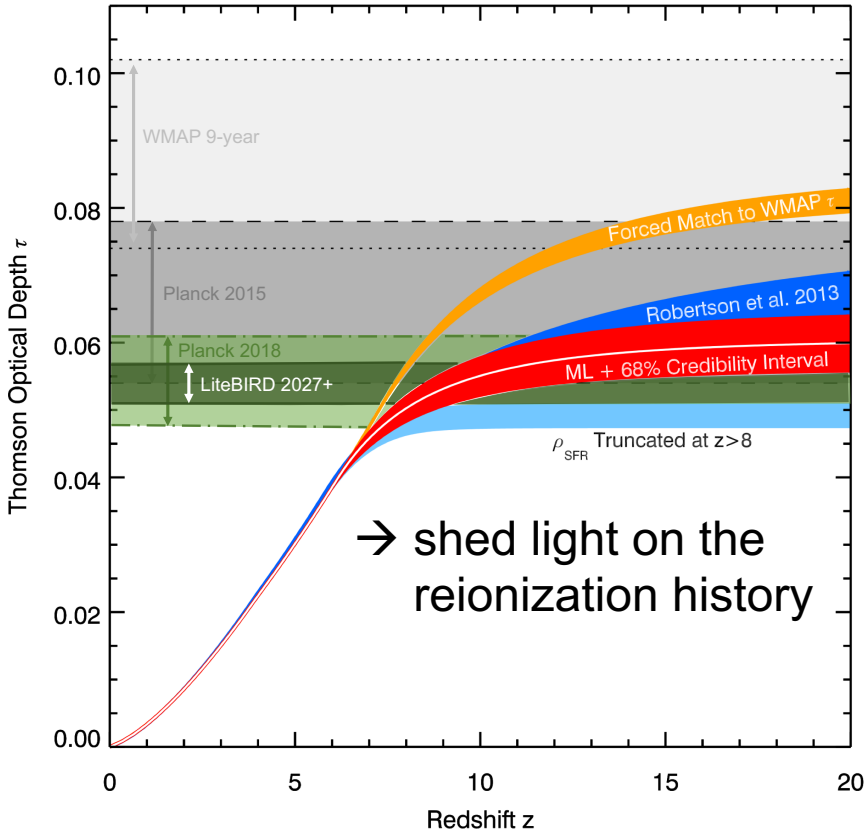
Aiming at detection with >5σ in case of Starobinsky model

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

5. Large-scale E-mode

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

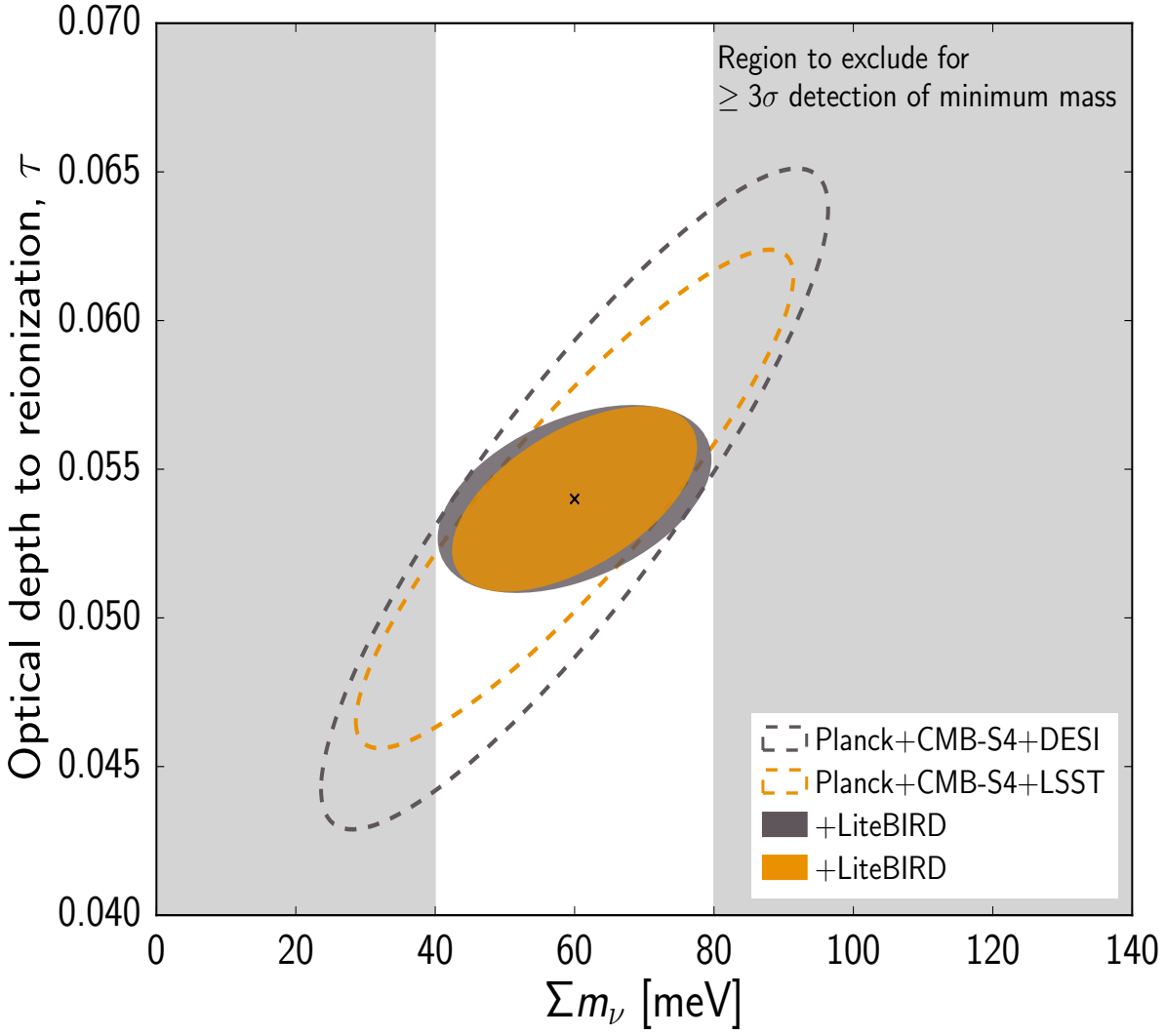




Σm_ν with improved τ

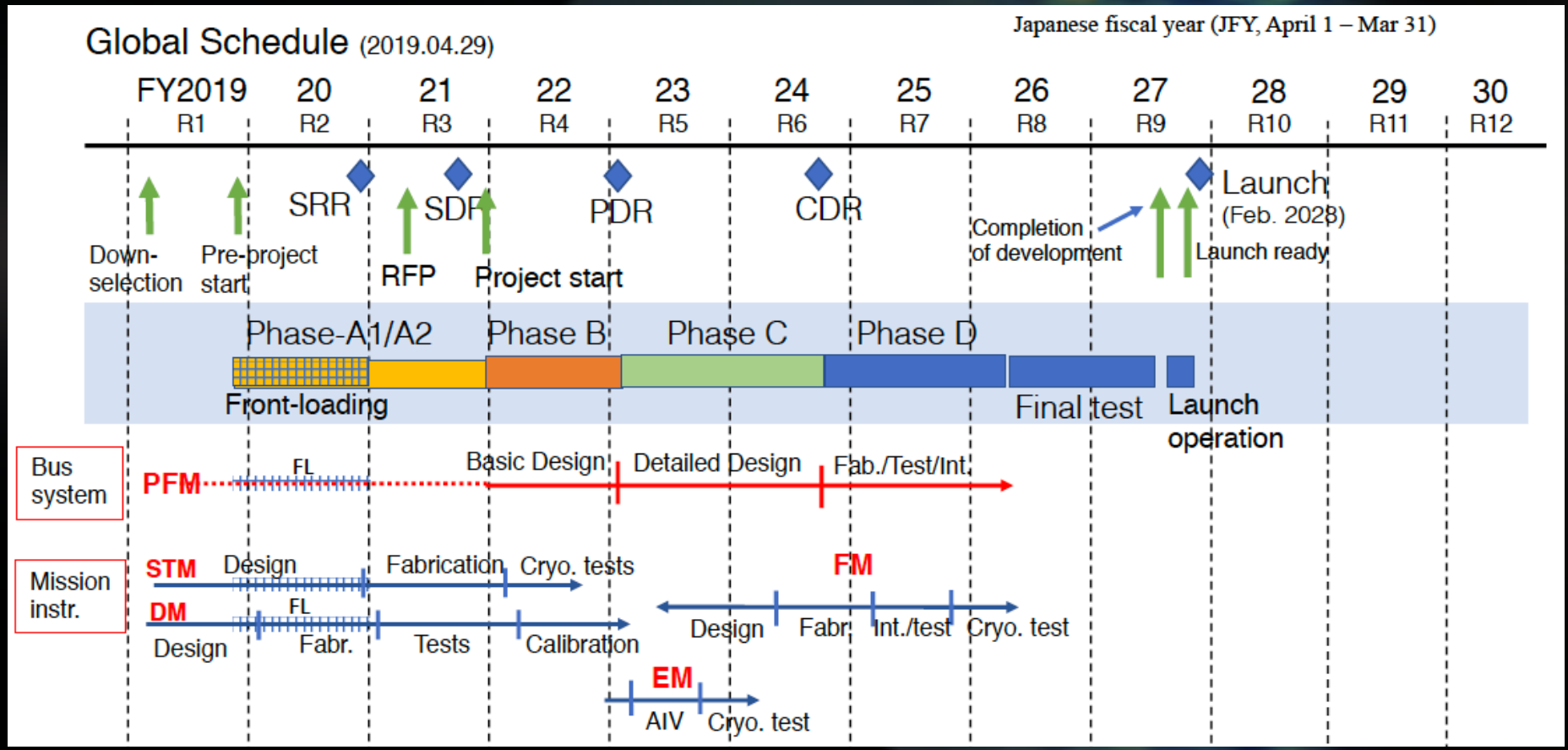
- $\sigma(\Sigma m_\nu) = 15$ meV
- $\geq 3\sigma$ detection of minimum mass for normal hierarchy
- $\geq 5\sigma$ detection of minimum mass for inverted hierarchy

Detailed investigations of systematic errors as the next step



Current Baseline Schedule

- Observations for 3 years in 2028-2031 at L2
- Project end in 2034 with final results



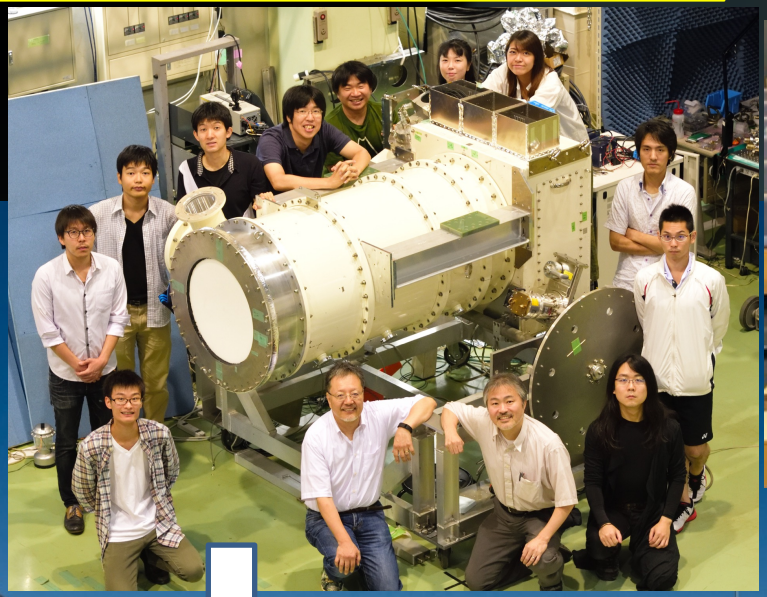
Simons Array in Atacama, Chile

Goal; [σ(r) ~0.006, with 4 bands]

First receiver system at KEK, Japan

+ focal plane
+ readout

Started observations in Jan 2019



Collaboration meeting at KEK (Mar 2017)

2nd and 3rd receivers will be deployed in 2020-2021

→ Talk by Masaya Hasegawa

- Important field test of detector & readout technology LiteBIRD plans to adopt.
- Marriage of Simons Array and ACT → Simons Observatory!

Papers from POLARBEAR observations

The following papers acknowledge B01 Grant-in-Aid.

1. "Measurement of the Cosmic Microwave Background Polarization Lensing Power Spectrum from Two Years of POLARBEAR Data," POLARBEAR Collaboration, arXiv:1911.10980.

2. "A Measurement of the Degree Scale CMB BB-mode Angular Power Spectrum with POLARBEAR," POLARBEAR Collaboration, arXiv:1910.02608.

3. "Internal delensing of cosmic microwave background polarization B-modes with the POLARBEAR experiment," POLARBEAR Collaboration, arXiv:1909.13832.

4. "Evidence for the Cross-correlation between Cosmic Microwave Background Polarization Lensing from POLARBEAR and Cosmic Shear from Subaru Hyper Suprime-Cam," POLARBEAR Collaboration, Astrophys.J. 882 (2019) 62 [arXiv:1904.02116].

5. "Cross-correlation of POLARBEAR CMB Polarization Lensing with High-zz Sub-mm Herschel-ATLAS galaxies," POLARBEAR Collaboration, Astrophys.J. 886 (2019) 38 [arXiv:1903.07046].

6. "Measurements of tropospheric ice clouds with a ground-based CMB polarization experiment, POLARBEAR," POLARBEAR Collaboration, Astrophys.J. 870 (2019) no.2, 102 [arXiv: 1809.06556]

7. "A Measurement of the Cosmic Microwave Background BB-Mode Polarization Power Spectrum at Sub-Degree Scales from 2 years of POLARBEAR Data," Astrophys.J. 848 (2017) no.2, 121 [arXiv:1705.02907].

Inter-group activities

The following papers acknowledge B01 Grant-in-Aid.

1. "Simultaneous determination of the cosmic birefringence and miscalibrated polarization angles from CMB experiments," Y. Minami, H. Ochi, K. Ichiki, N. Katayama, E. Komatsu, T. Matsumura, PTEP 2019 (2019) no.8, 083E02 [arXiv:1904.12440]. — w/ D01

2. "Evidence for the Cross-correlation between Cosmic Microwave Background Polarization Lensing from POLARBEAR and Cosmic Shear from Subaru Hyper Suprime-Cam," POLARBEAR Collaboration, Astrophys.J. 882 (2019) 62 [arXiv:1904.02116]. — w/ X00, B02, B03

3. "Reconstruction of primordial tensor power spectra from B-mode polarization of the cosmic microwave background," T. Hiramatsu, E. Komatsu, M. Hazumi, M. Sasaki, Phys.Rev. D97 (2018) no.12, 123511 [arXiv:1803.00176]. — w/ A01, D01

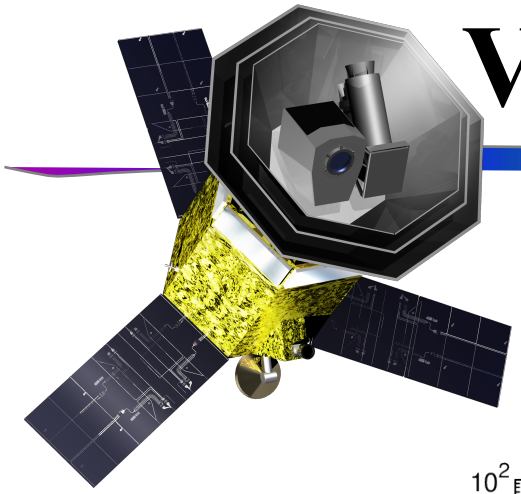
4. "Finding the chiral gravitational wave background of an axion-SU(2) inflationary model using CMB observations and laser interferometers," B. Thorne, T. Fujita, M. Hazumi, E. Komatsu, M. Shiraishi, Phys.Rev. D97 (2018) no.4, 043506 [arXiv:1707.03240] — w/ A01

5. "Testing statistics of the CMB B -mode polarization toward unambiguously establishing quantum fluctuation of the vacuum," M. Shiraishi, C. Hikage, R. Namba, T. Namikawa, M. Hazumi, Phys.Rev. D94 (2016) no.4, 043506 [arXiv:1606.06082]. — w/ A01

6. "Constraints on the neutrino parameters by future cosmological 21 cm line and precise CMB polarization observations," Y. Oyama, K. Kohri, M. Hazumi, JCAP 1602 (2016) 008 [arXiv:1510.03806] — w/ A01

In addition, papers from LiteBIRD collaboration are obvious examples of inter-group outcomes! (B01-A01-C01-D01)

Vision for next 15 years



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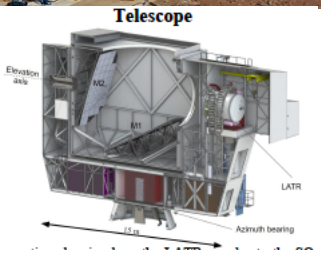
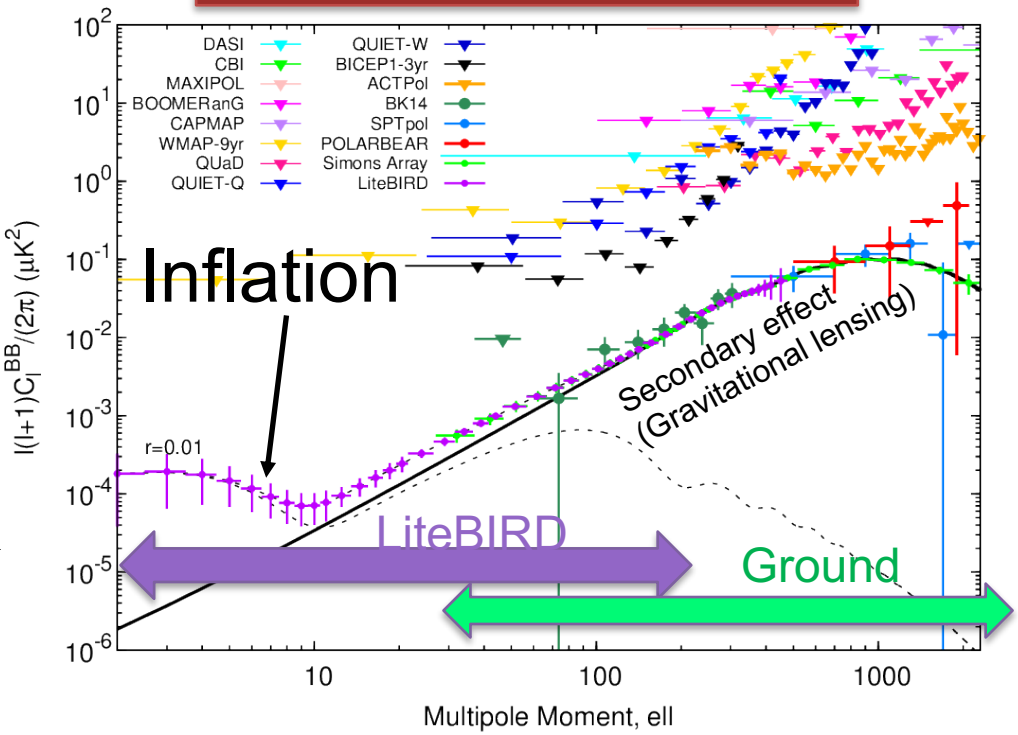
Powerful Duo



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



<u>Ground</u>
US-led telescopes on ground
$30 \leq \ell \leq$ ~8000
e.g. Simons Observatory and CMB-S4

- This powerful duo is the best cost-effective way with great synergy
- MoU between LiteBIRD and CMB-S4 for science and technology under discussion

Summary of B01 Achievements: JFY2015-2019

- B01 study group has paved the way for precision measurements of CMB polarization in 2020s.
  - LiteBIRD is selected!
    → never selected without this Grant-in-Aid program!
  - Instrumentation papers with original ideas
    → Talks in this session and posters
  - First Simons Array receiver was deployed and in test observations
    → Talk by Masaya Hasegawa in this session
- Publications with POLARBEAR observations
- Papers from inter-group activities thanks to this program