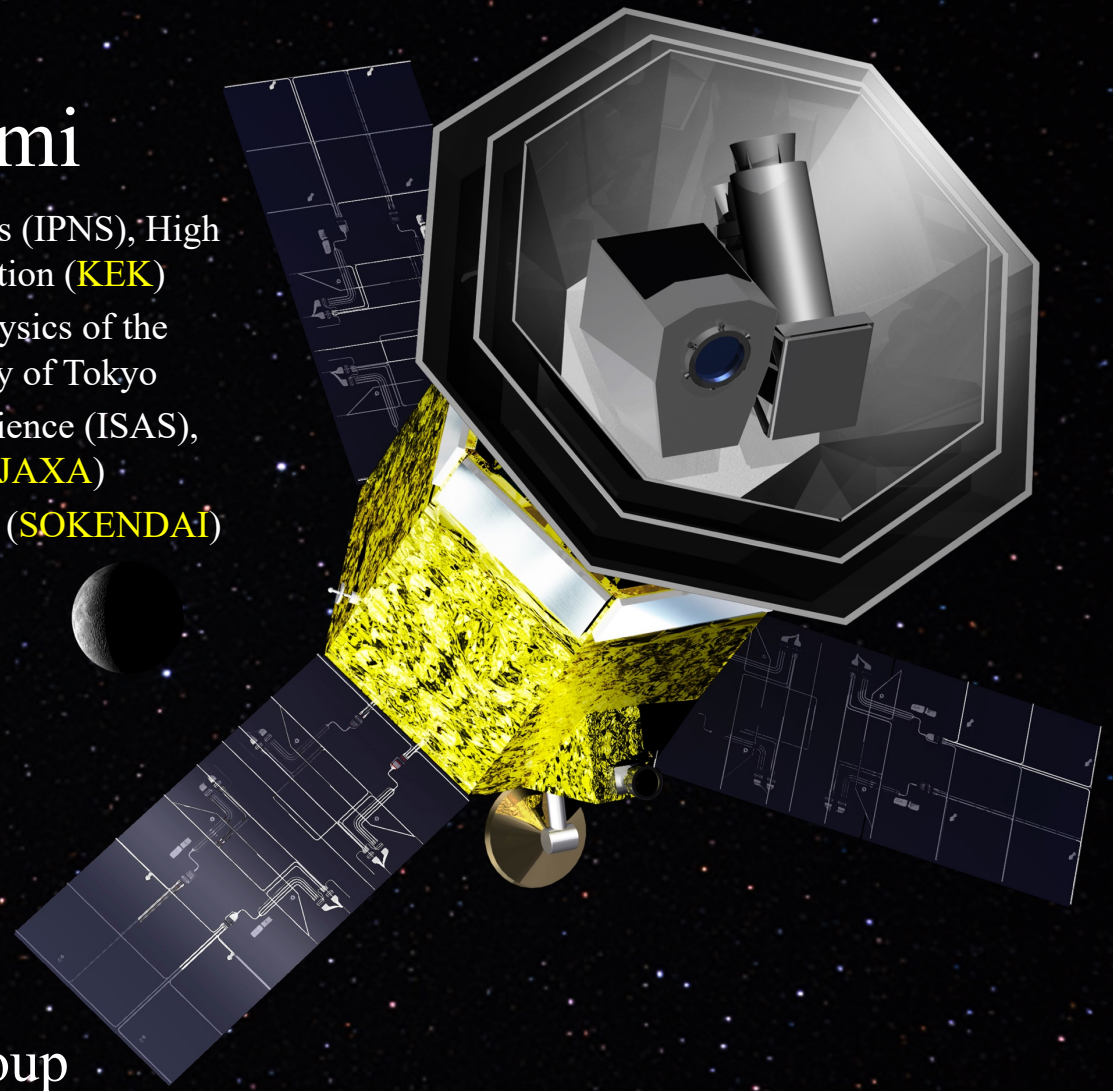
LiteBIRD

Masashi Hazumi

1. Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)
2. Kavli Institute for Mathematics and Physics of the Universe (Kavli IPMU), The University of Tokyo
3. Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA)
4. Graduate School for Advanced Studies (SOKENDAI)

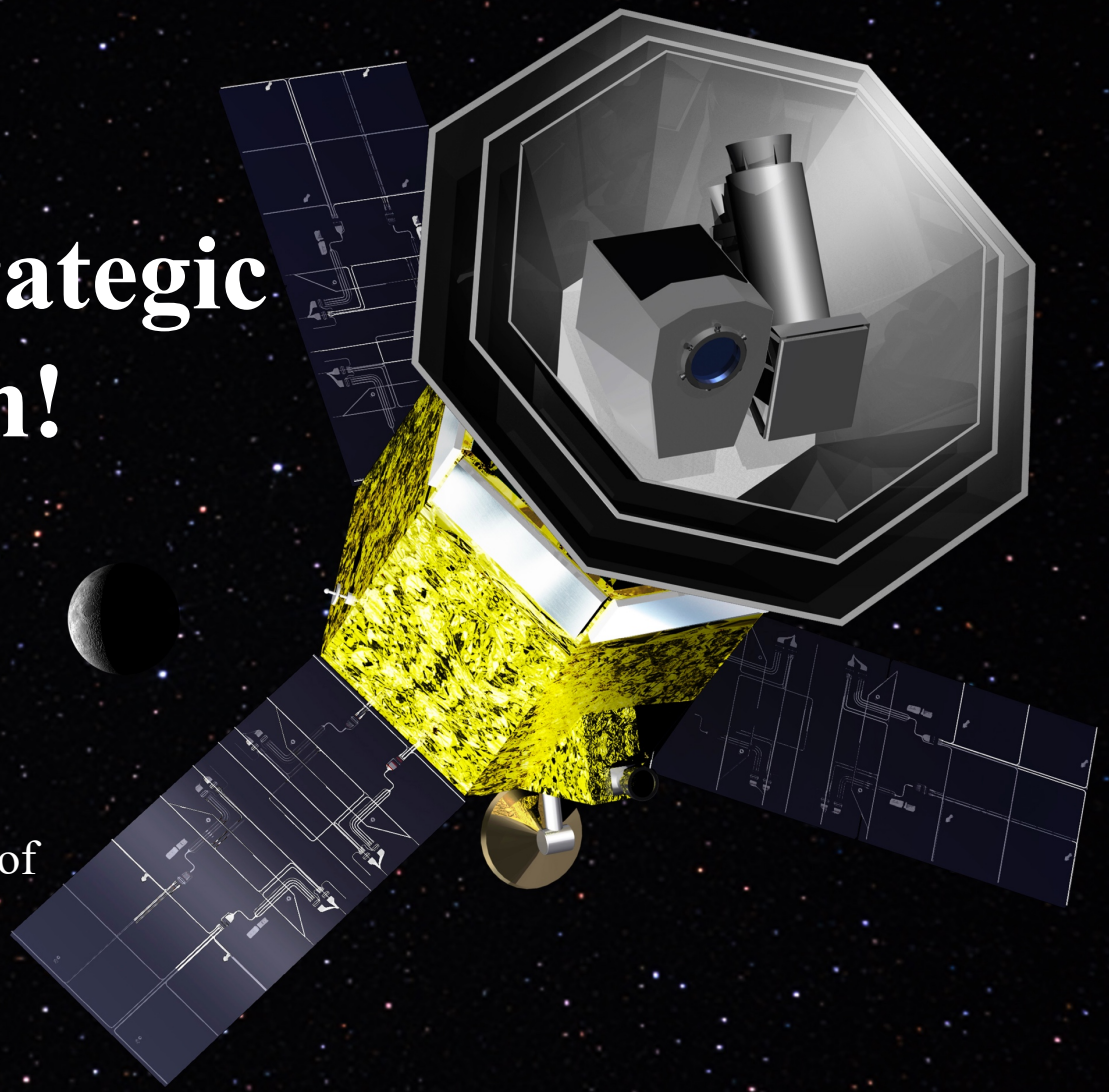


On behalf of the

LiteBIRD Joint Study Group

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

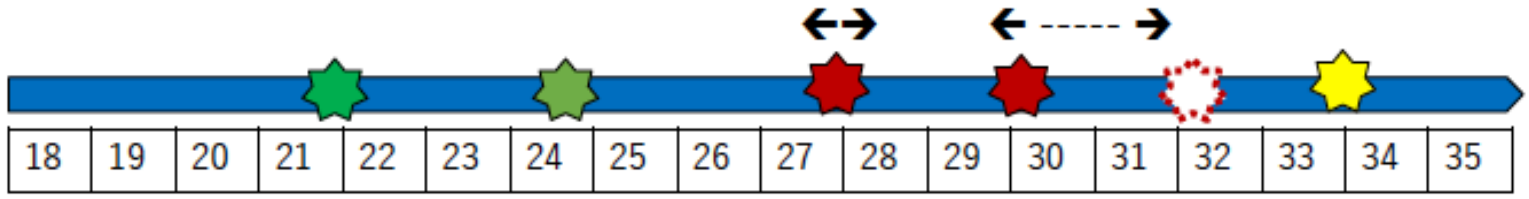


LiteBIRD:
Lite (light) satellite for the studies of
B-mode polarization and
Inflation from cosmic background
Radiation
Detection

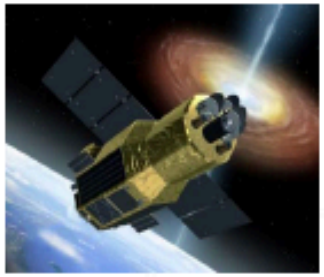
Strategic L-class missions at JAXA

(Slide made by T. Yamada of ISAS/JAXA)

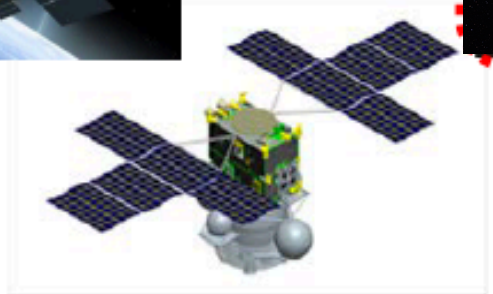
- Flagship science mission with HIIA/H3 vehicle
- 30B yen cost cap (300M USD for 1 USD = 100 yen)

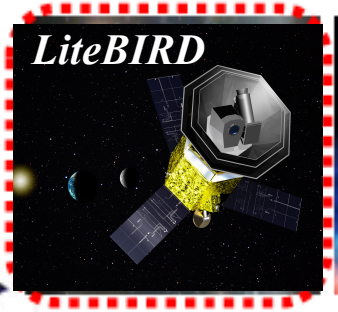


XRISM Project



MMX Pre-Project



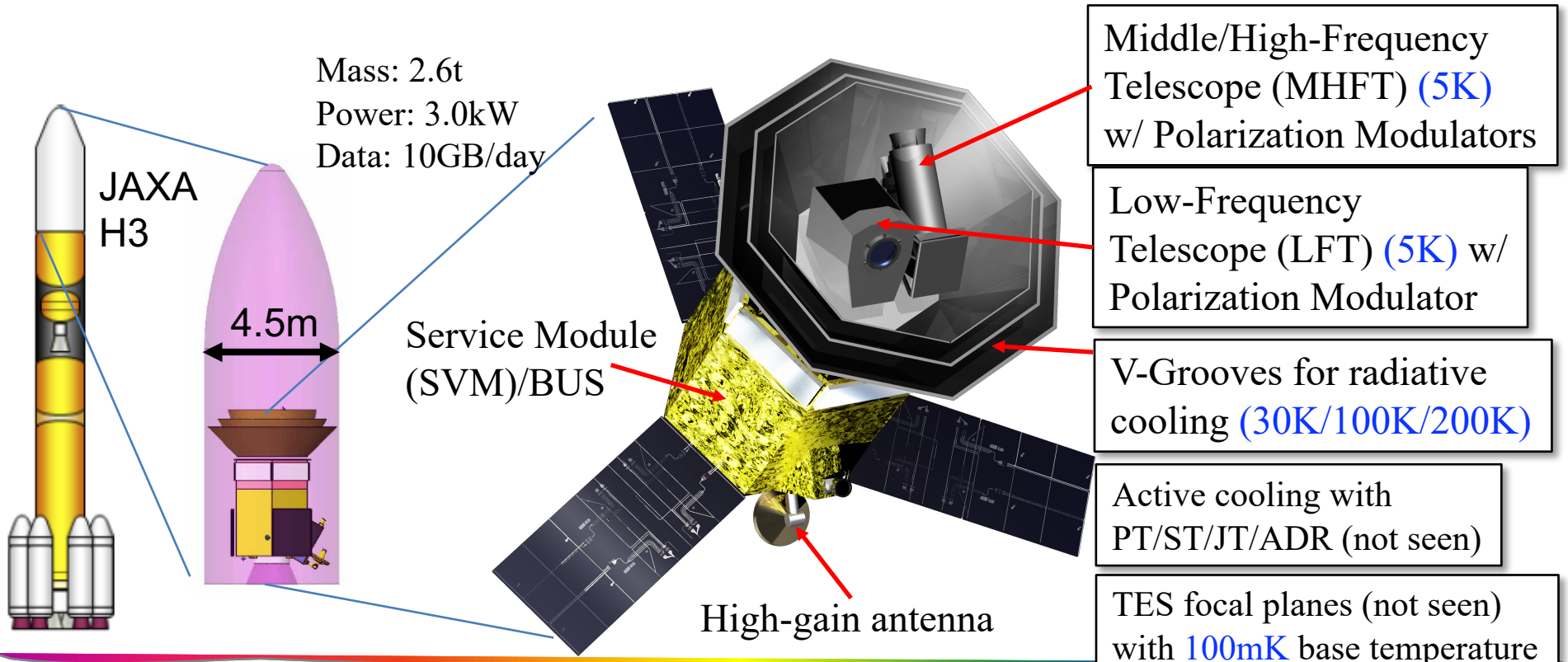


*SPICA needs to win ESA M5 selection.

	Mission/Mission Concept	JAXA Status (2019June)	Target launch
Strategic Large Class (L-Class)			
X-ray Recovery	XRISM [X-ray Astrophysics]	Project Phase B	FY2021
L-1	Martian Moon eXploror (MMX) [Phobos sample return]	Pre-Project Phase A2	2024
L-2	LiteBIRD [CMB B-mode]	Pre-Phase A2 completed	2027-28? TBA
L-3 candidate ESA Cosmic Vision-M5	SPICA [Infrared Astrophysics]	Pre-Phase A2 ESA Phase A (1/3 candidates) Final selection 2021	2030? TBA
	OKEANOS [Solar Power Sail Trojan]	Pre-Phase A2	

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



LiteBIRD has a clear goal and will achieve it!

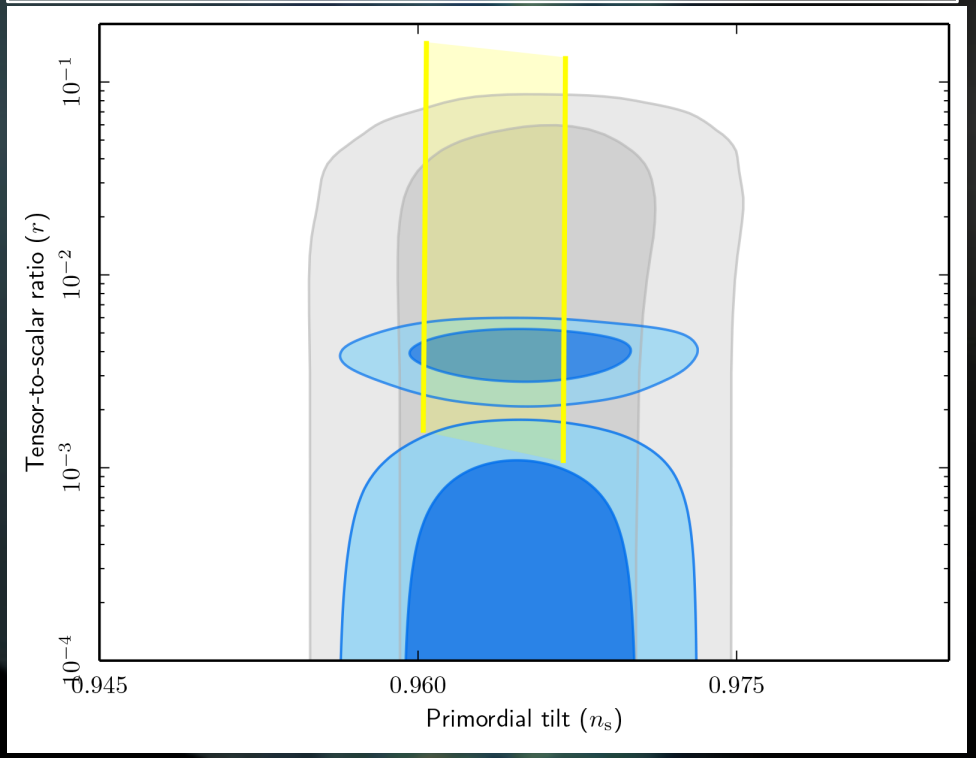
Full Success:

- $\delta r < 1 \times 10^{-3}$ (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

- Detailed foreground cleaning studies yield $\sigma(r=0) = 0.6 \times 10^{-3}$
- Thorough systematic error studies yield total uncertainty $\delta r < 1.0 \times 10^{-3}$ without delensing

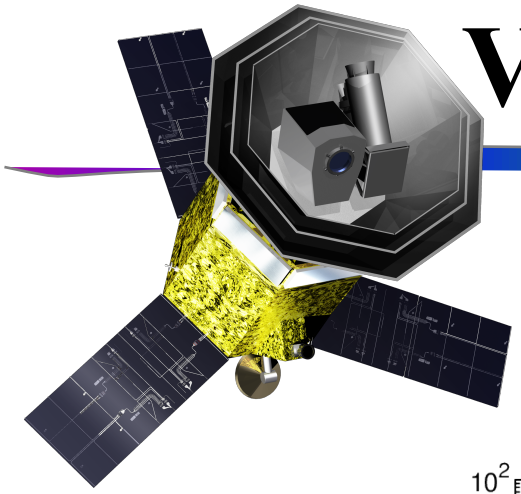


Why Measure from Space?

- Superb environment !
  - No statistical/systematic uncertainty due to atmosphere (cf. polarization due to icy clouds in POLARBEAR obs., S. Takakura et al. 2018)
  - No limitation on the choice of observing bands (except CO lines); important for foreground separation
  - No ground pickup

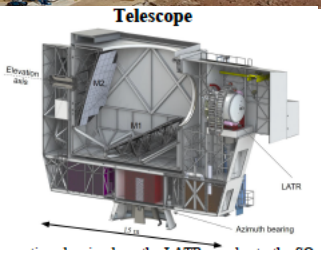
  Rule of thumb: 1,000 detectors in space ~ 100,000 detectors on ground
- Only way to access lowest multipoles w/ $\delta r \sim O(0.001)$
  - Both B-mode bumps need to be observed for the firm confirmation of Cosmic Inflation → We need measurements from space.
- Complementarity with ground-based CMB projects
  - Foreground information from space will help foreground cleaning for ground CMB data
  - High multipole information from ground will help "delense" space CMB data

Vision for next 15 years

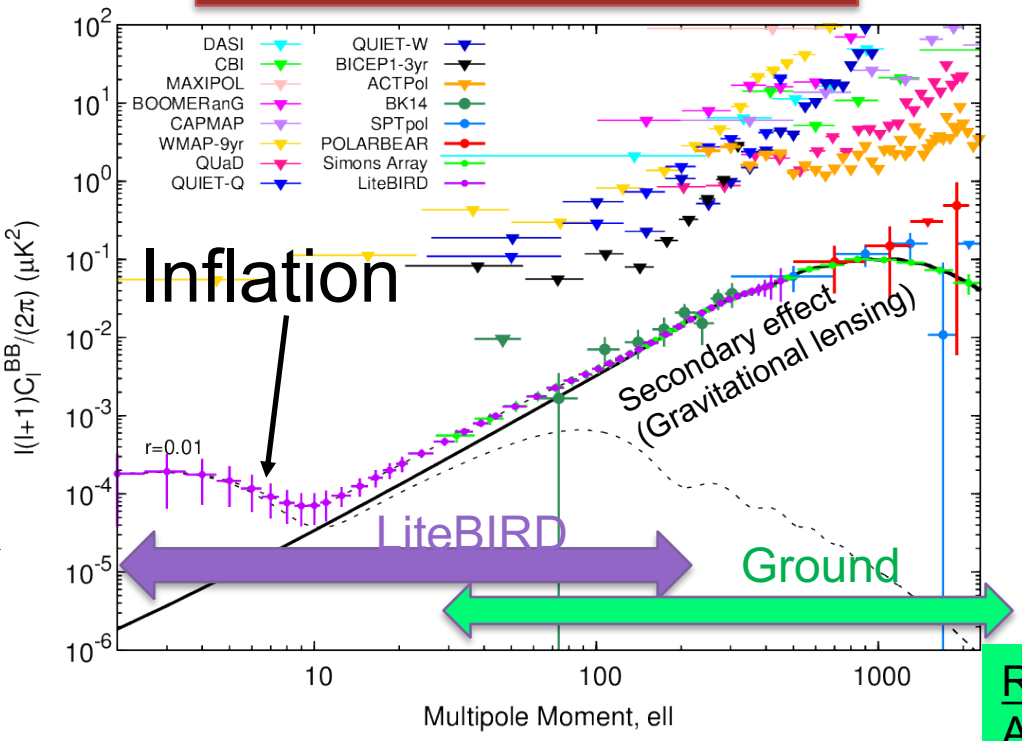


X

Powerful Duo



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

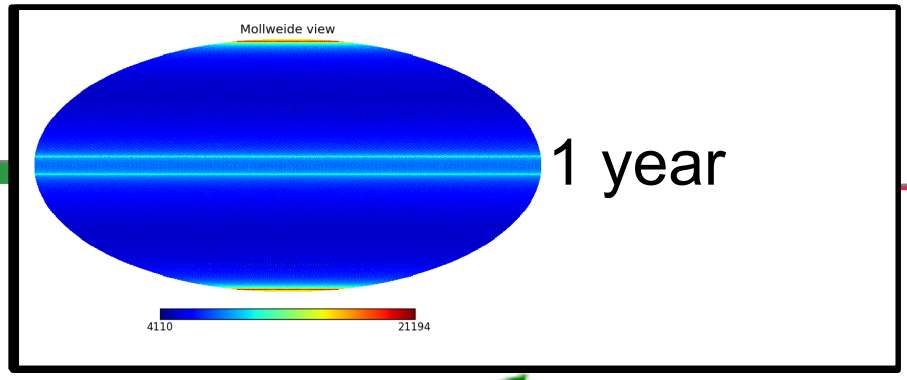


Ground
US-led telescopes on ground
$30 \leq \ell \leq$ ~8000
e.g. Simons Observatory and CMB-S4

Related talk
Adrian Lee (Wednesday)

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

Operation



Orbit:
Sun-Earth L2 Lissajous

Boresight
Spin axis
CMB
Spin
(0.1rpm)
β
α
Sun
Anti-Sun axis
Precession
(90min.,
~1day as
an option)

Precession angle α = 45 degrees
Spin angle β = 50 degrees

Foreground Cleaning

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

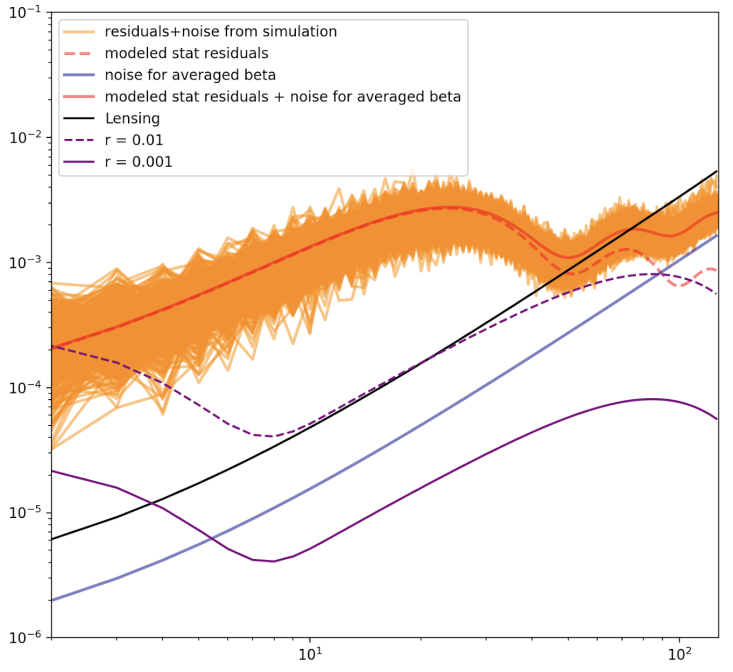
(8 parameters in each sky region) x (12 x $N_{\rm side}^2$)
= 6144 parameters w/ $N_{\rm side} = 8$
to take spatial variations into account

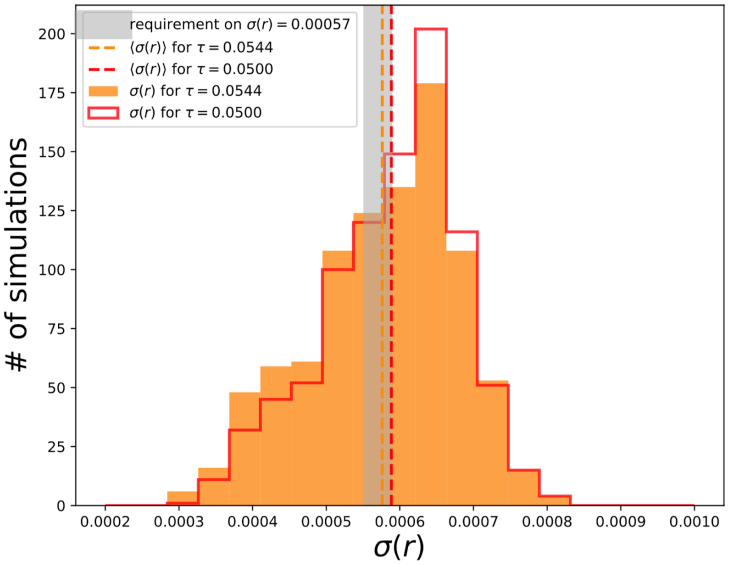
Results

"Multipatch technique" (extension of xForecast)*

- $\sigma(r=0) = 0.0006$
- Negligibly small bias

Consistent results from COMMANDER-2!





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

Systematics and Calibration

Related talks on Thursday
- Sophie Henrot-Versille
- Samantha Stever

- 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

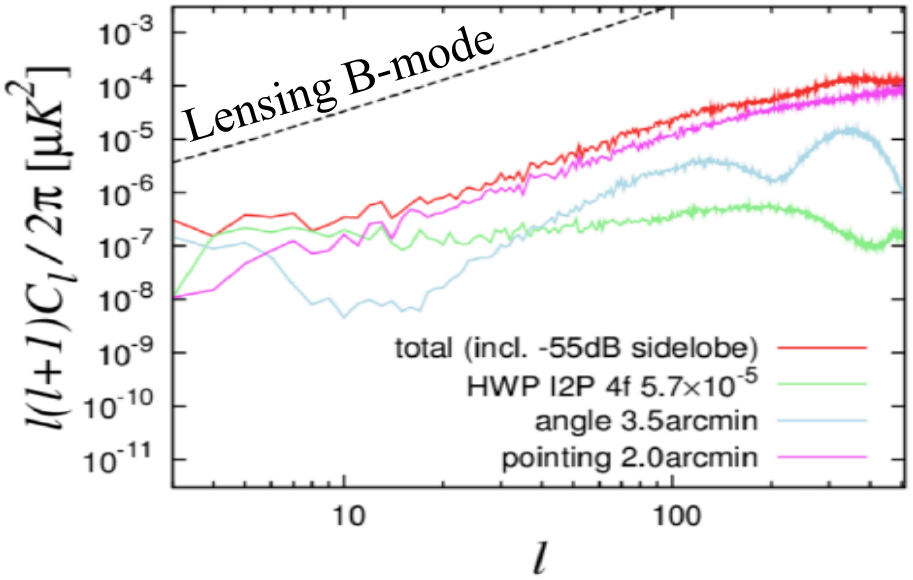
- Example: studies of systematic errors due to HWP imperfection

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

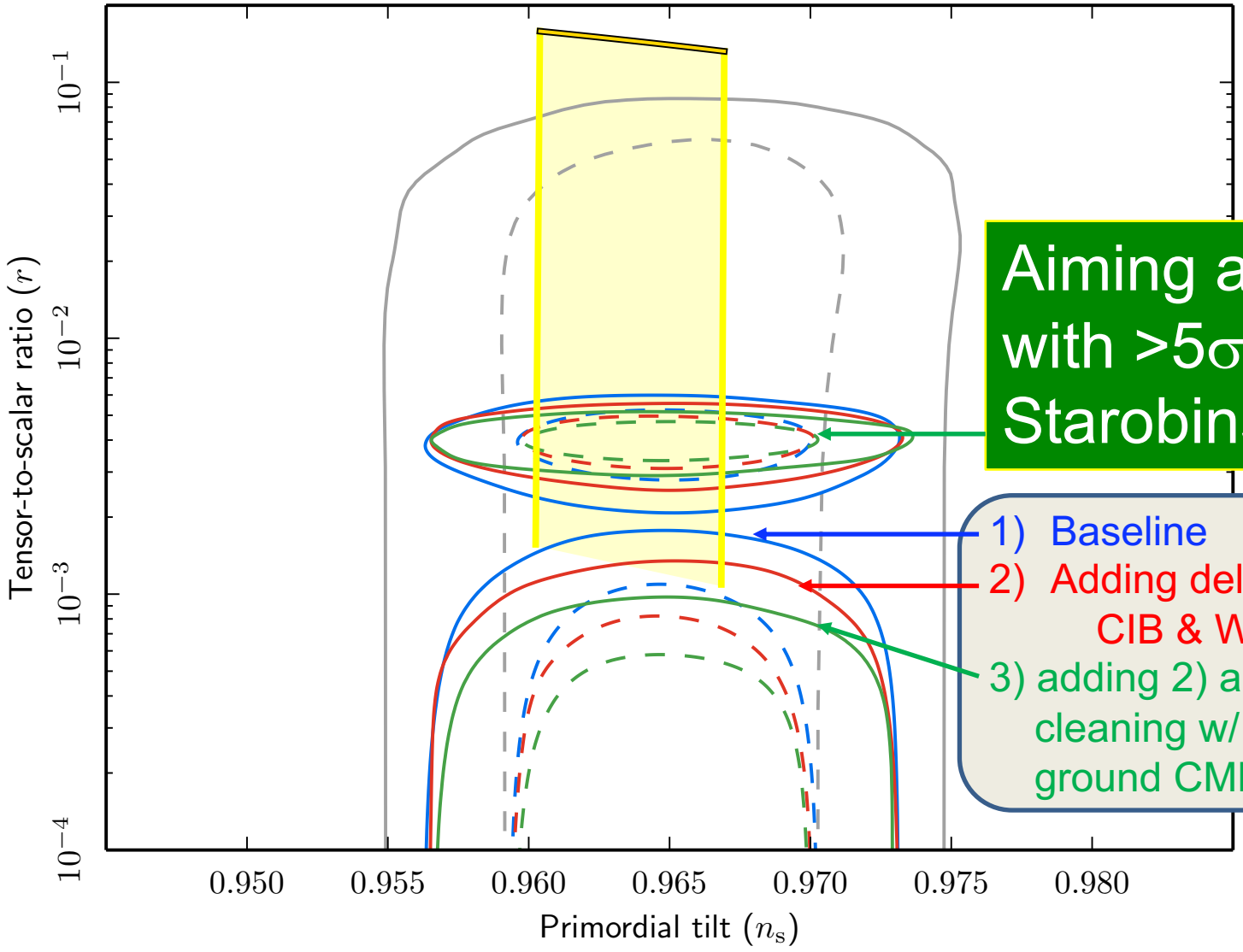
1. Full success

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

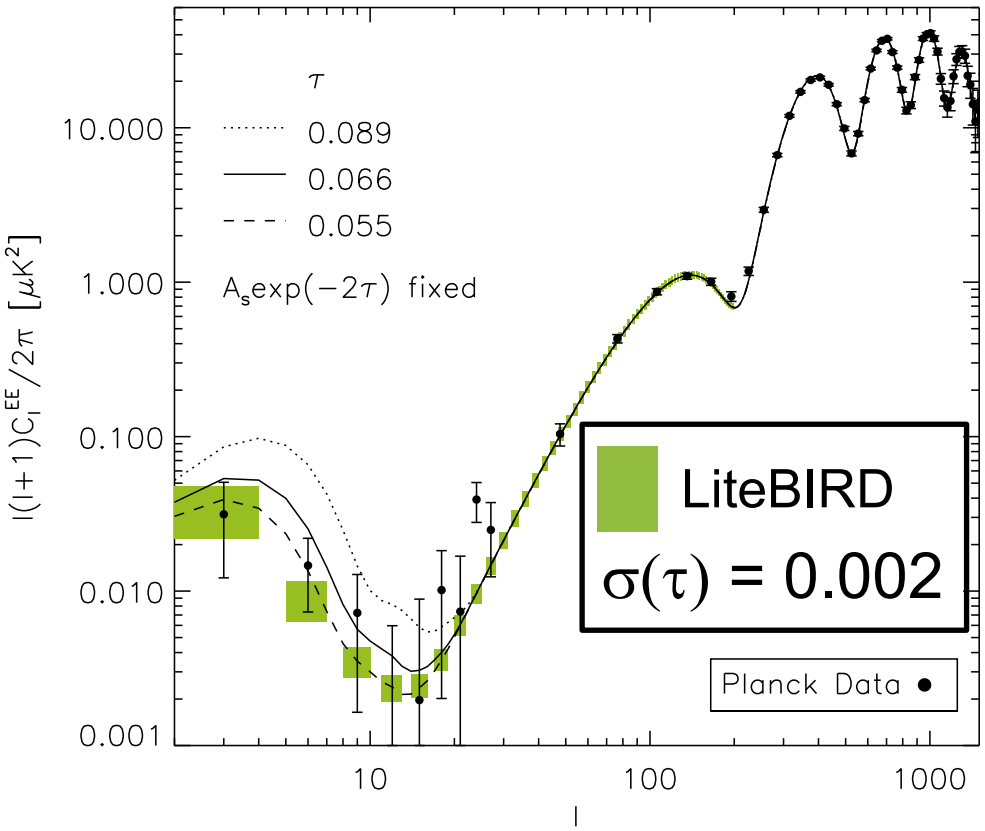


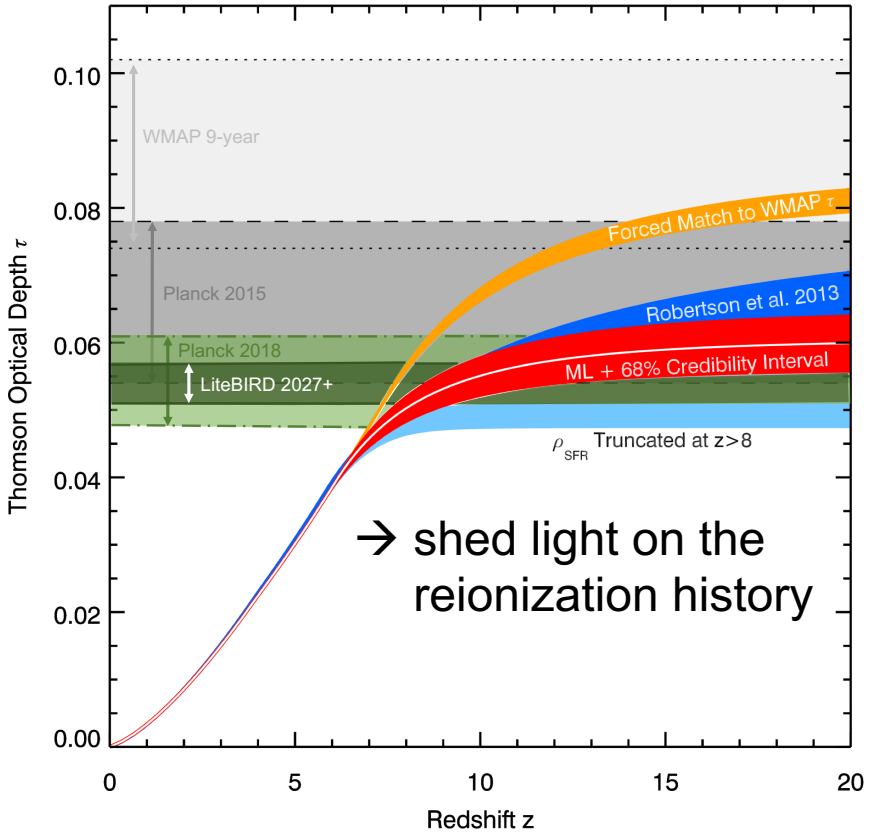
Aiming at detection with >5σ in case of Starobinsky model

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!

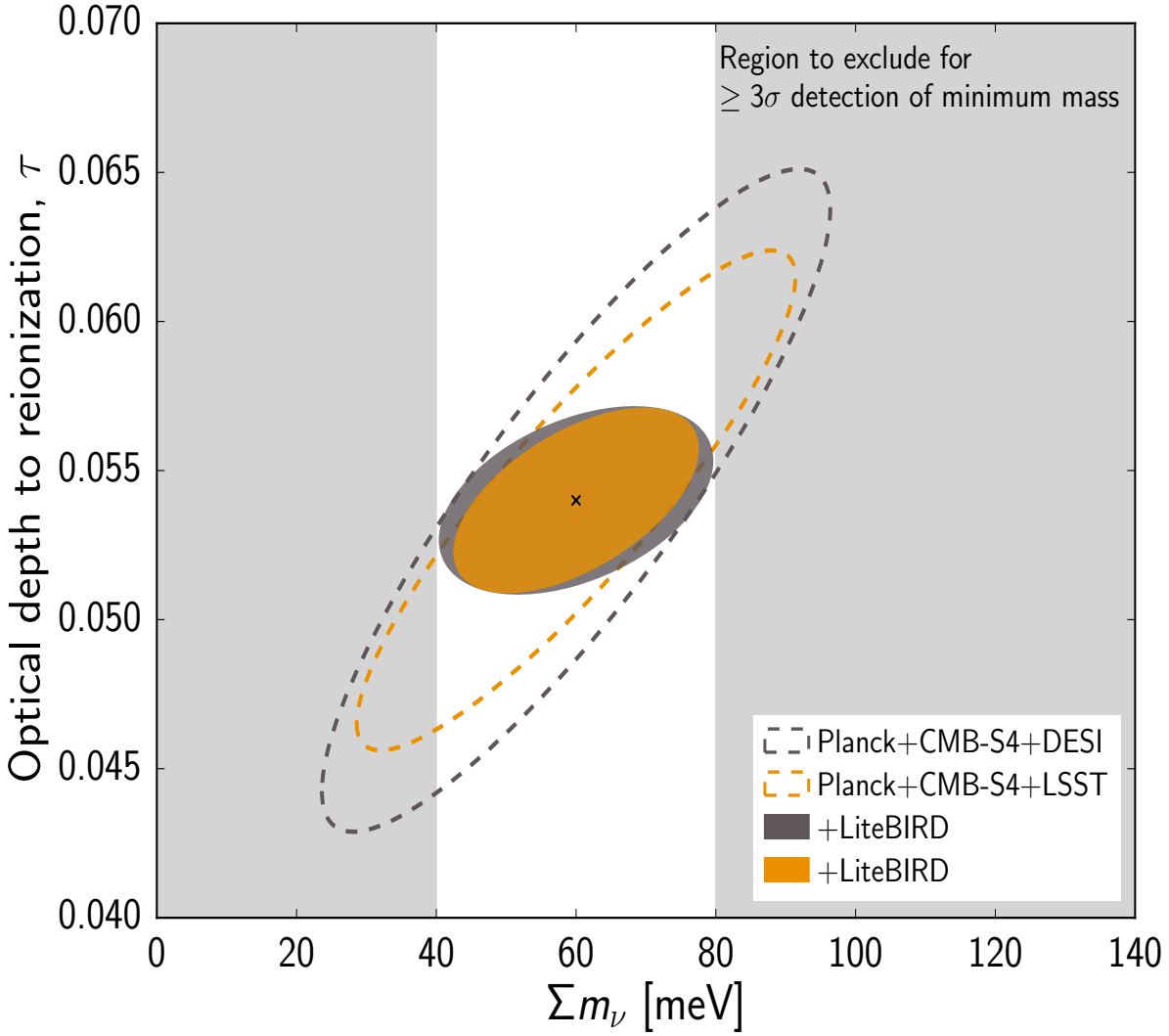




Σm_ν with improved τ

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

Caveat:
No systematic error included yet.



Related talks at this conference

1. Full success
   Clara Vergès (Monday)
   Nicoletta Krachmalnicoff (Tuesday)
   Suvodip Mukherjee (Wednesday)
   Blake Sherwin (Monday)
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
   Paolo Campeti (Monday)
5. Large-scale E mode
   - its implications for reionization history and the neutrino mass
6. Cosmic birefringence
   Yuto Minami (Monday)
7. SZ effect (thermal and relativistic correction)
8. Elucidating anomalies
9. Galactic science

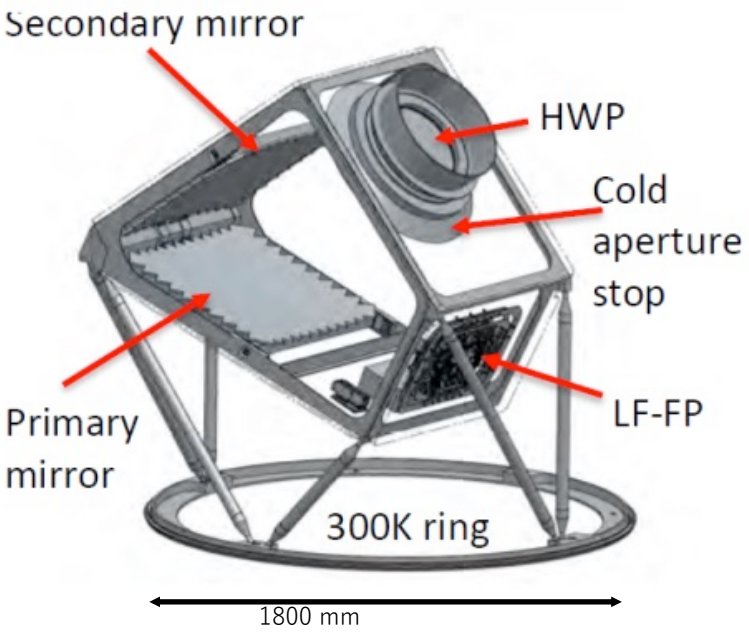
LiteBIRD Mission Instrument

Three features

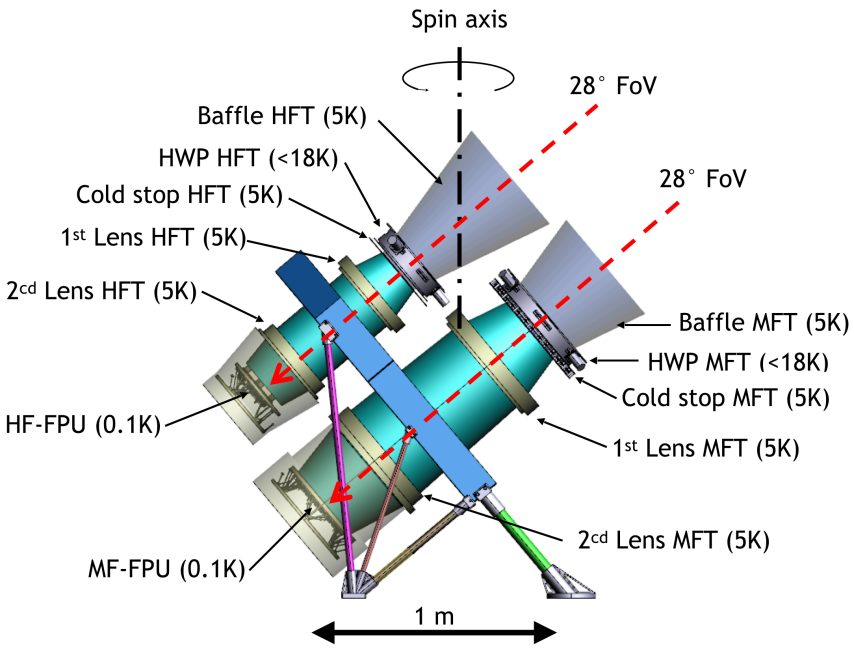
1. Two sets of telescopes w/ TES arrays
2. Polarization modulator w/ rotating half-wave plate (HWP) for 1/f noise & systematics reduction
3. Cryogenic system for 0.1K base temperature

1. Two sets of telescopes w/ TES arrays

LFT



MHFT

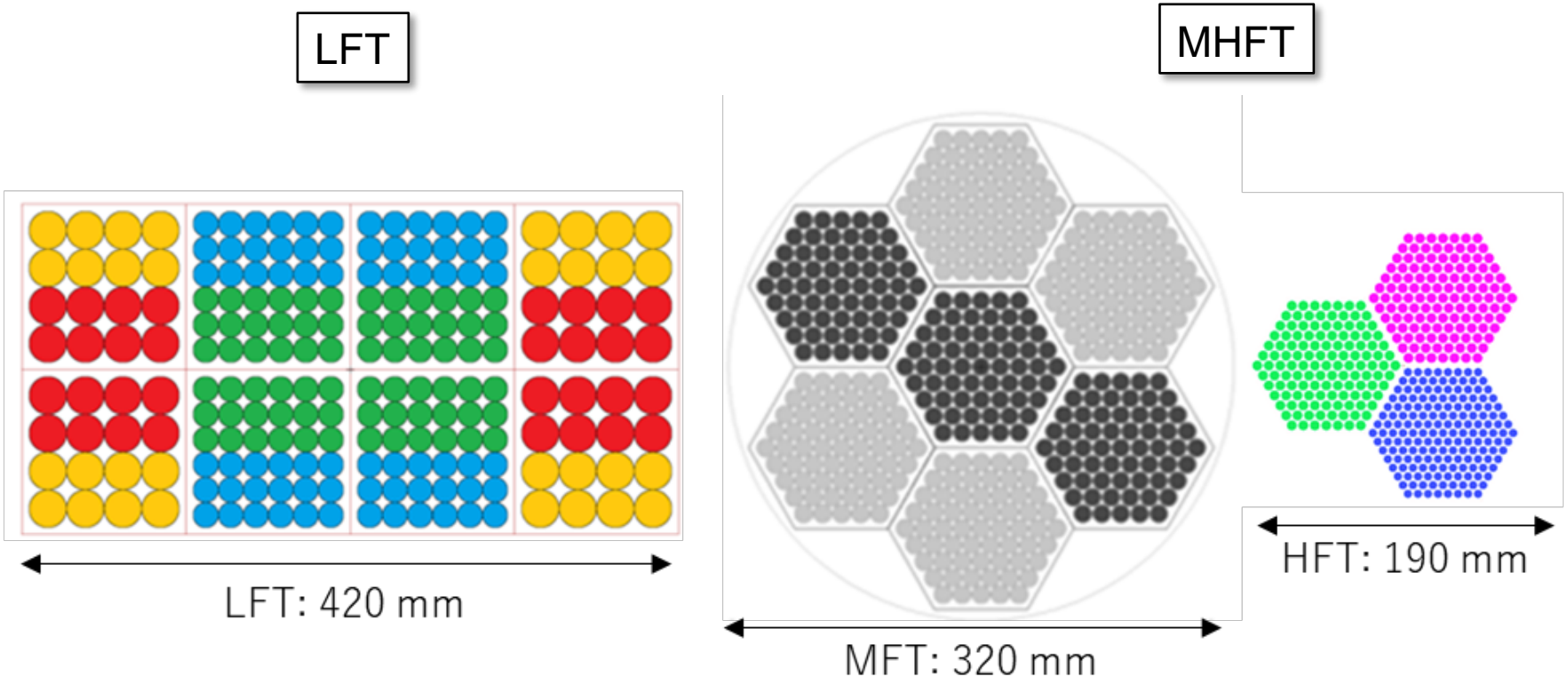


LiteBIRD Mission Instrument

Three features

1. Two sets of telescopes w/ TES arrays
2. Polarization modulator w/ rotating half-wave plate (HWP) for 1/f noise & systematics reduction
3. Cryogenic system for 0.1K base temperature

1. Two sets of telescopes w/ TES arrays

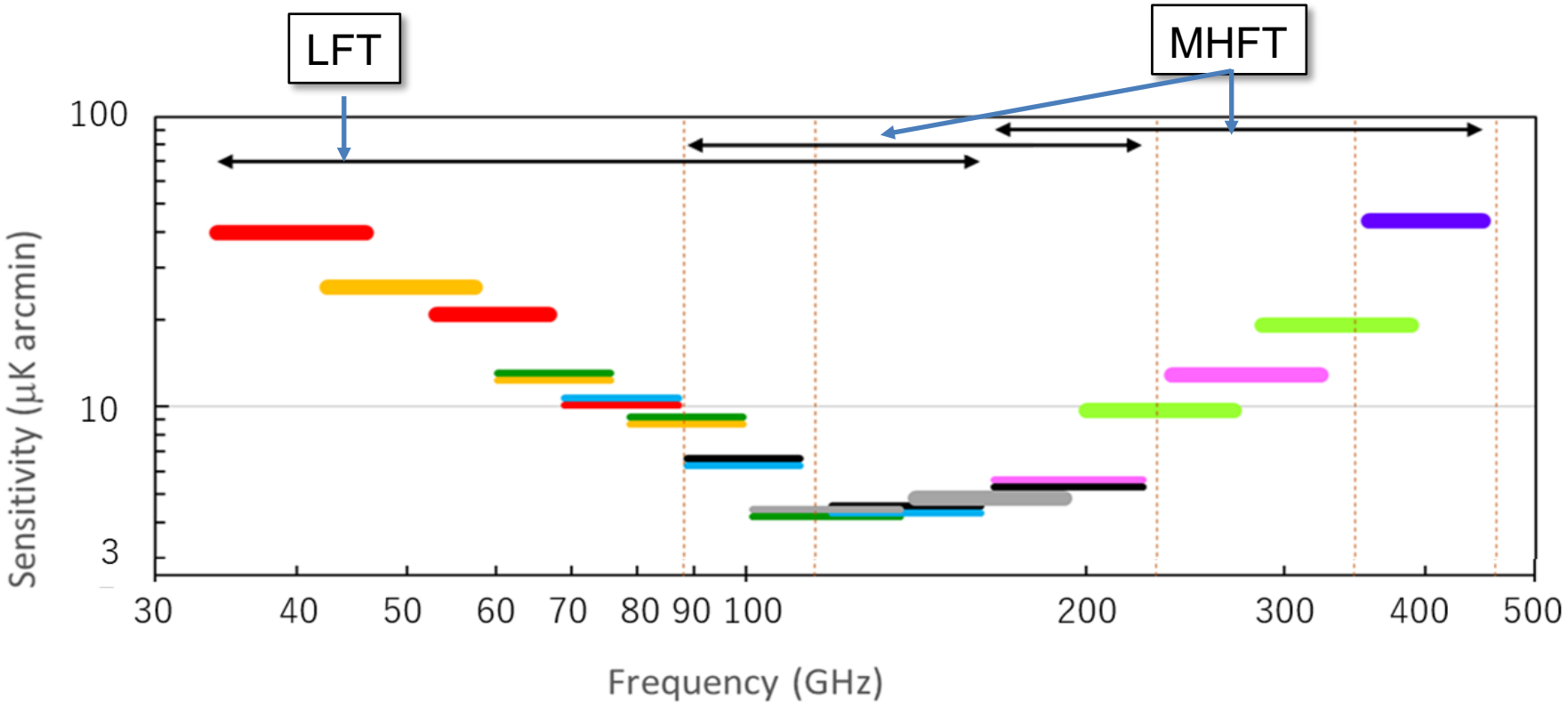


LiteBIRD Mission Instrument

Three features

1. Two sets of telescopes w/ TES arrays
2. Polarization modulator w/ rotating half-wave plate (HWP) for 1/f noise & systematics reduction
3. Cryogenic system for 0.1K base temperature

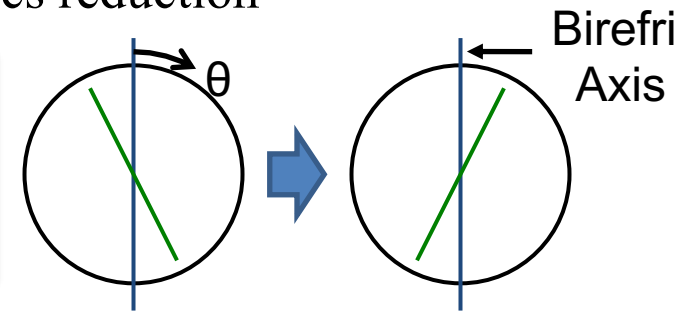
1. Two sets of telescopes w/ TES arrays



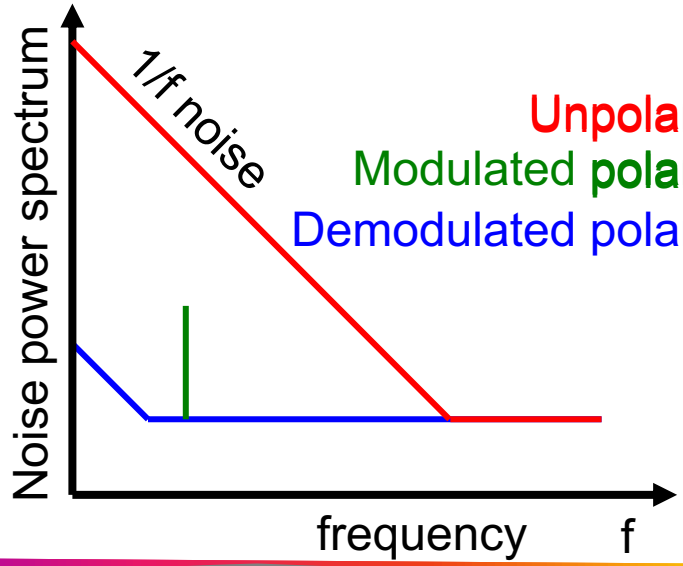
LiteBIRD Mission Instrument

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

Rotating a birefringent plate at the most sky side

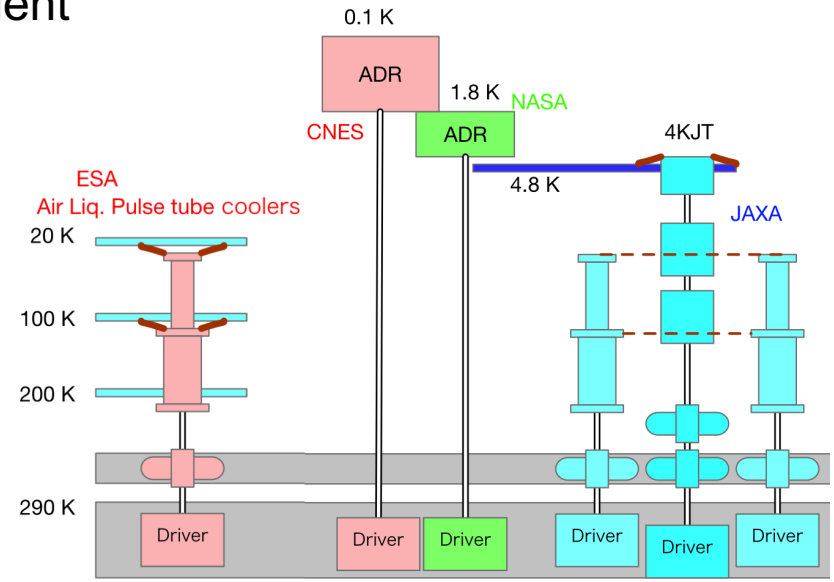


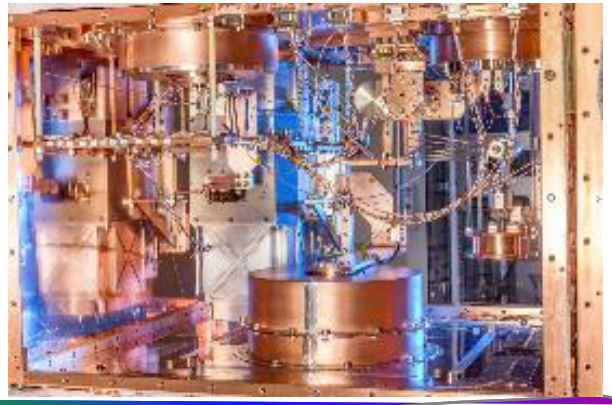
$$I + P\cos 4\theta_{\mathrm{HWP}}$$



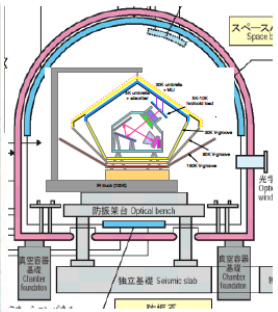
Unpolarized signal
Modulated polarized signal
Demodulated polarized signal

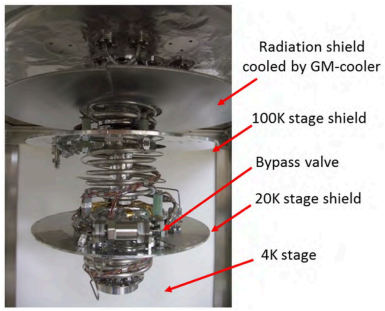
3. Cryogenic system for 0.1K base temperature

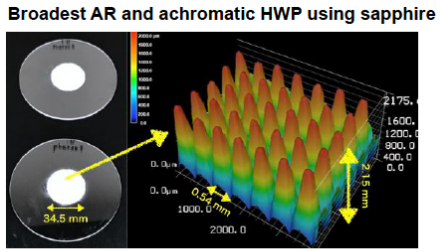


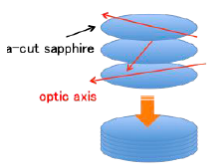


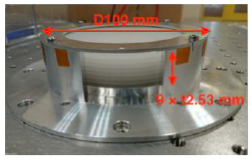
Technology development in Japan



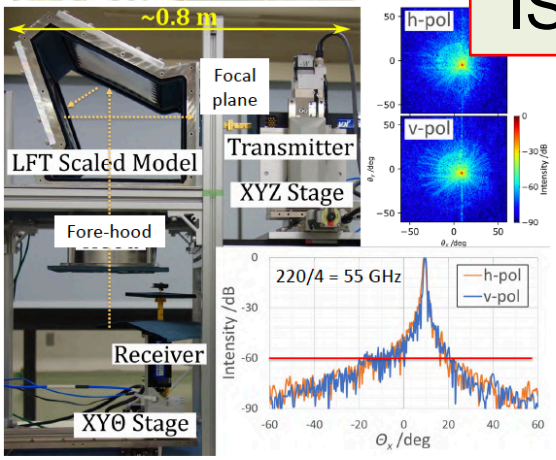






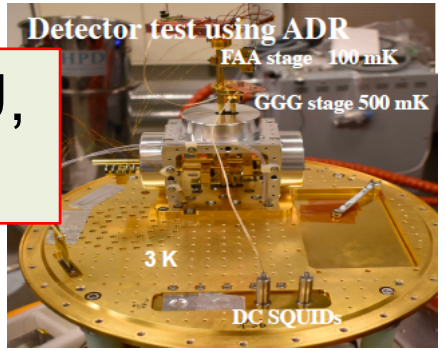


ISAS, JAXA

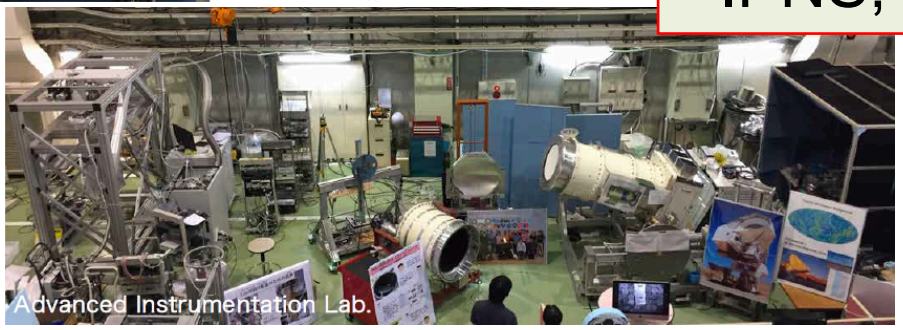


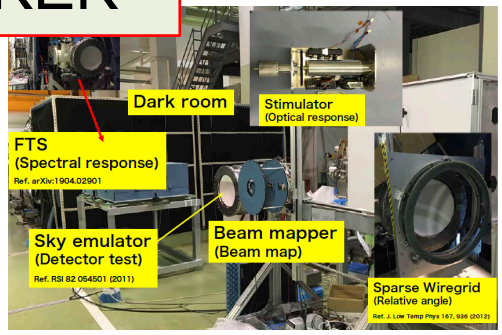
Collaboration
of 3 major
laboratories

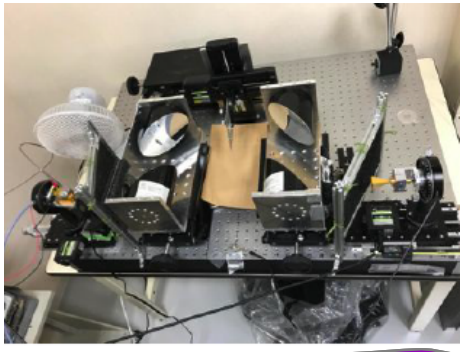
Kavli IPMU,
U. Tokyo



IPNS, KEK

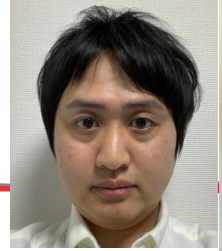






Large (~450mmϕ) LFT polarization modulator

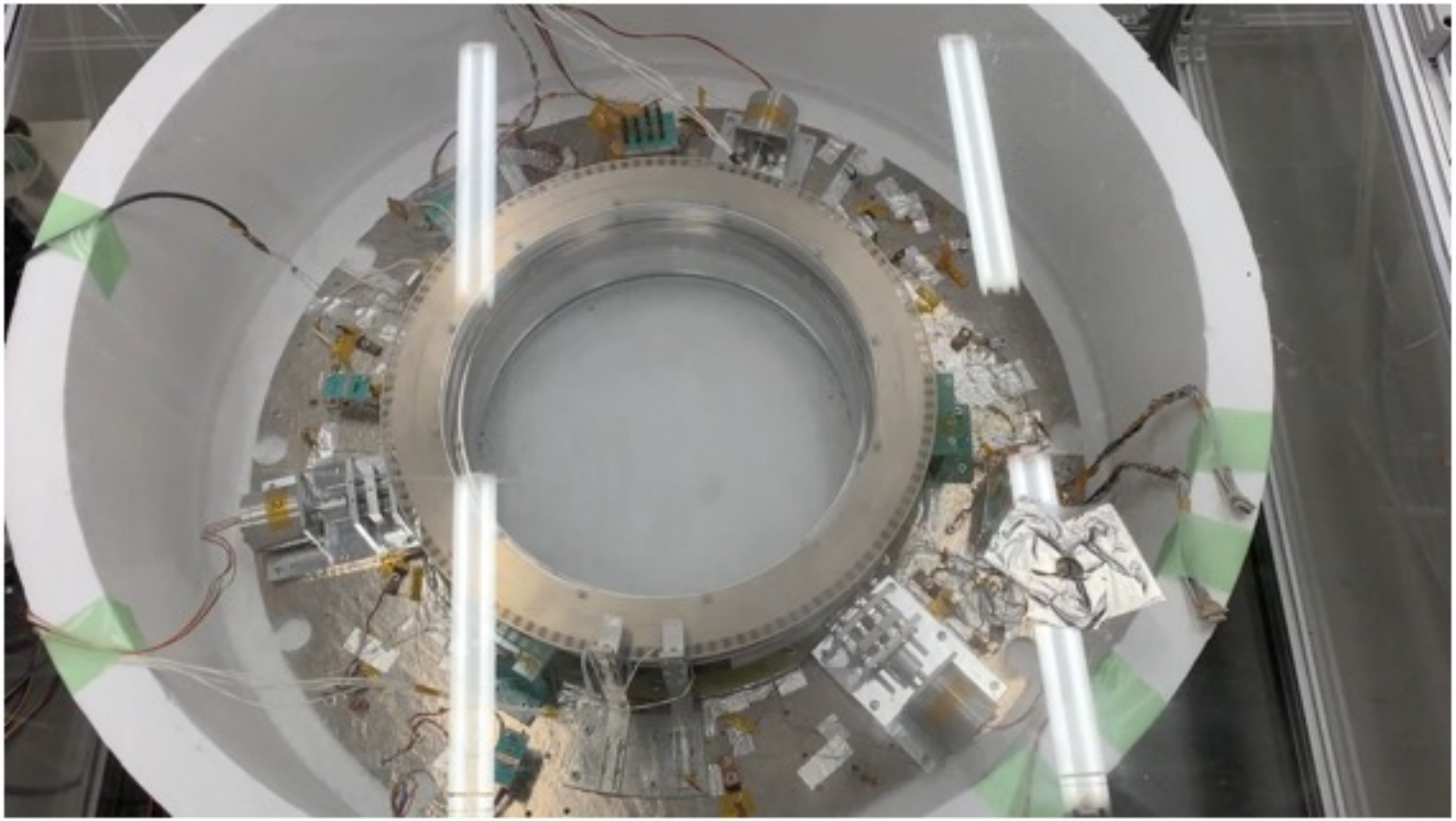
The first time in the world!



Yuki Sakurai

Tomo Matsumura

Rotation test of superconducting magnetic bearing system in the 4K cryostat.
The stable rotation at cryogenic temperature (<10K).



Developed at Kavli IPMU

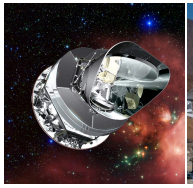
→ Talk by Yuki Sakurai (Thursday)

Also do not miss posters!

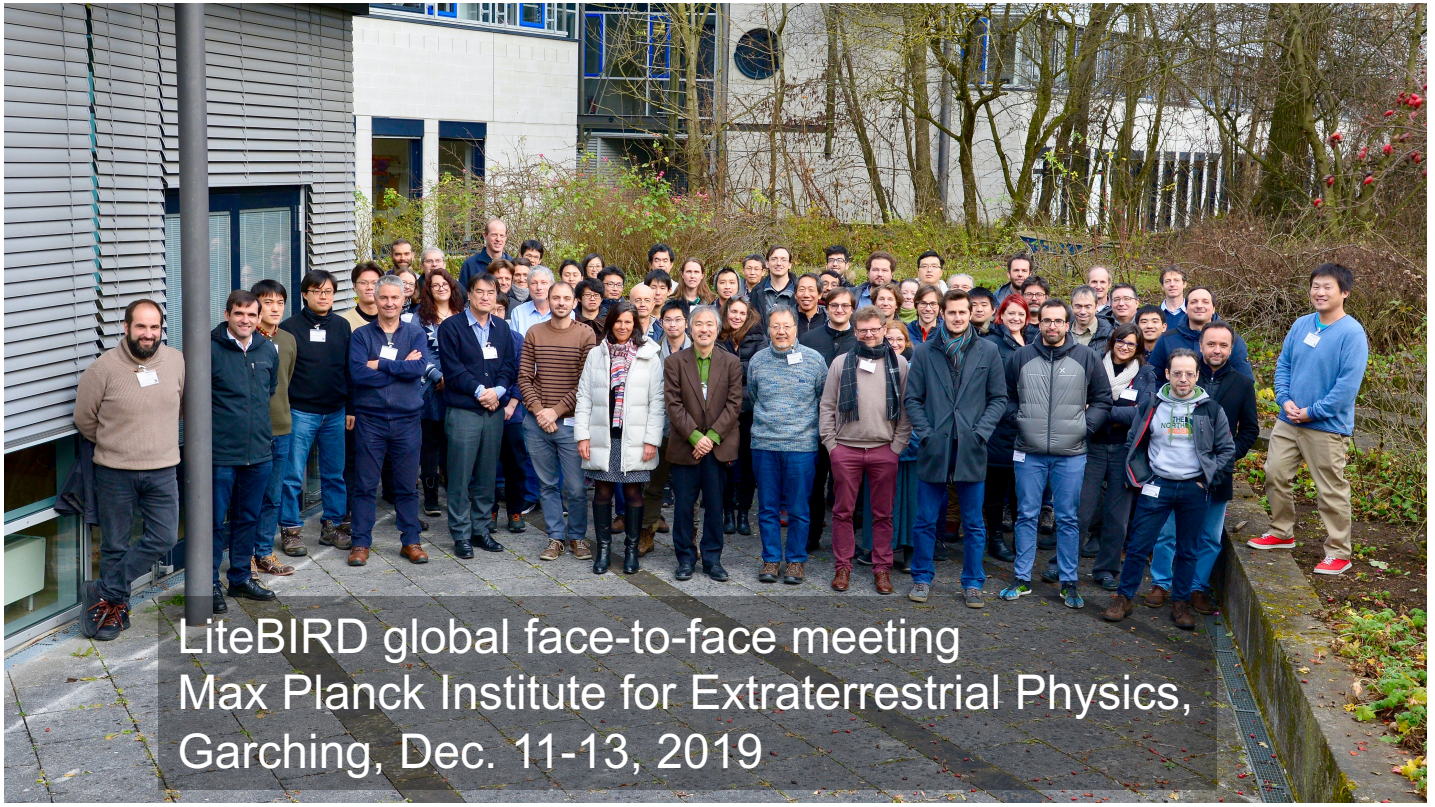
LiteBIRD Joint Study Group

More than 200 researchers from Japan, North America & Europe

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

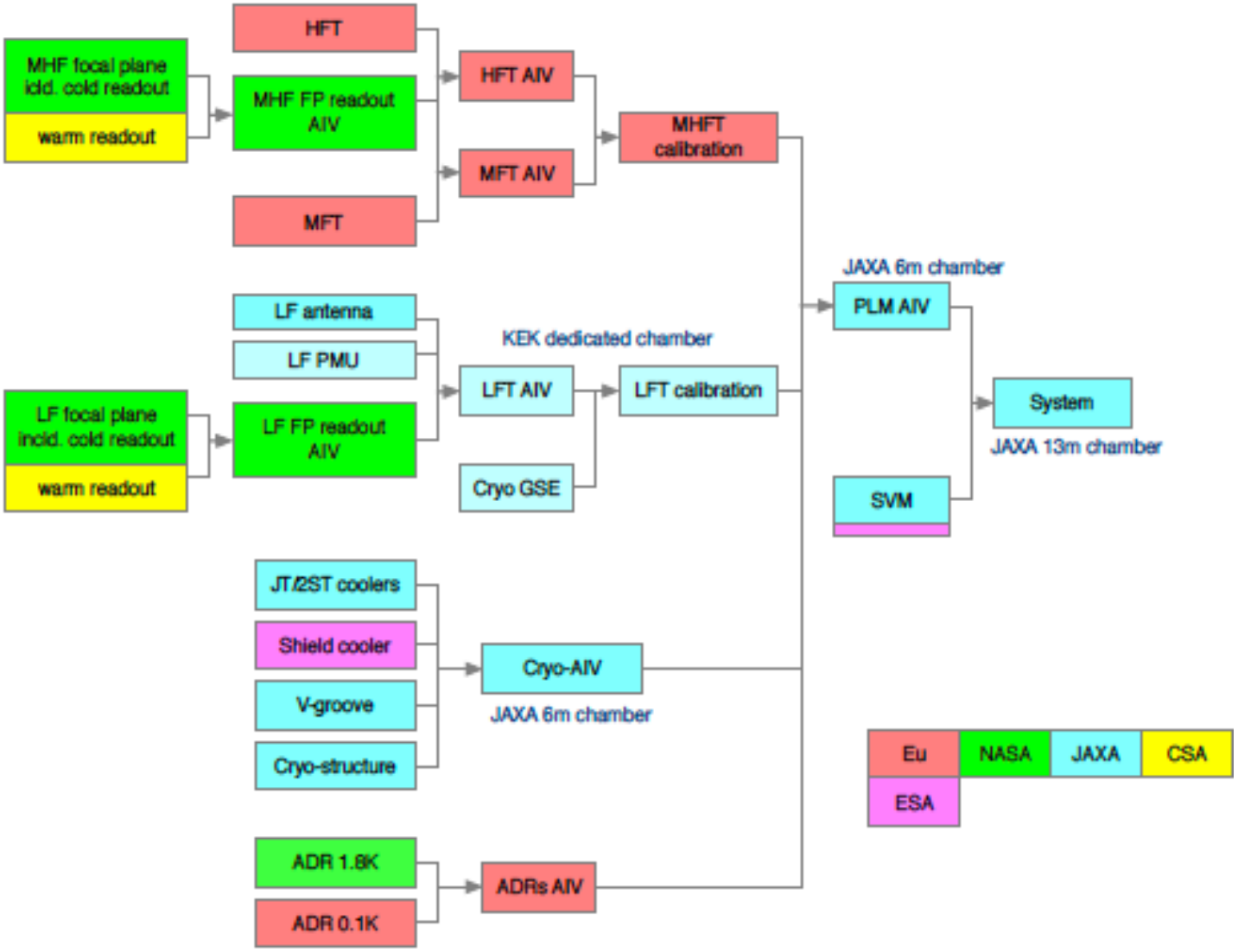






LiteBIRD global face-to-face meeting
Max Planck Institute for Extraterrestrial Physics,
Garching, Dec. 11-13, 2019

International Task Sharing

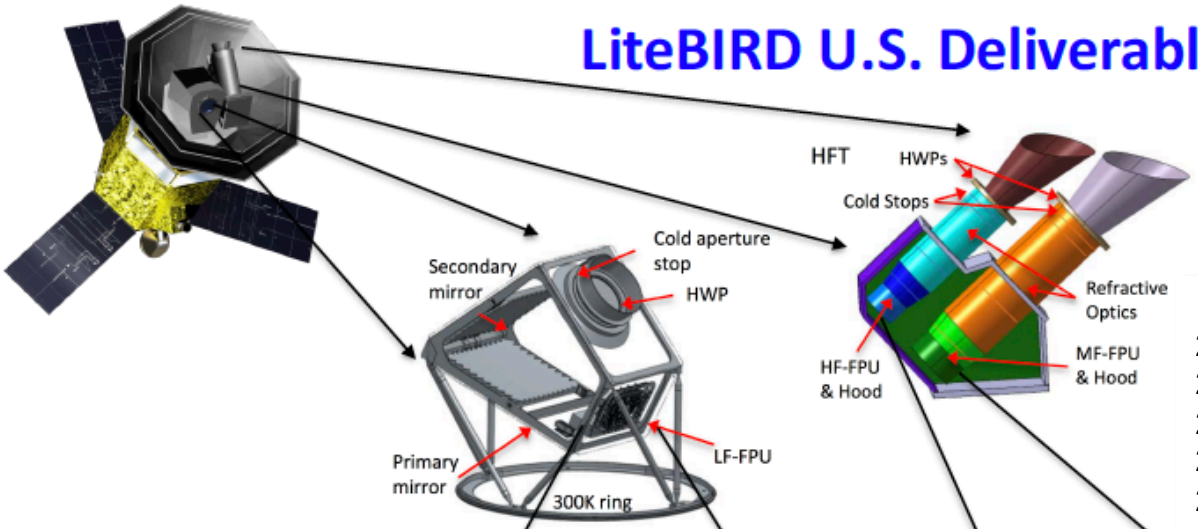


US LiteBIRD Program

UC Berkeley | Stanford University | CU Boulder | UC San Diego | NIST | Goddard

US PI:
Adrian Lee
(UC Berkeley)

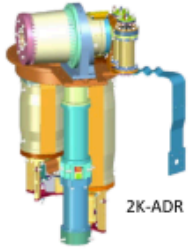
LiteBIRD U.S. Deliverables



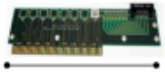
Milestones

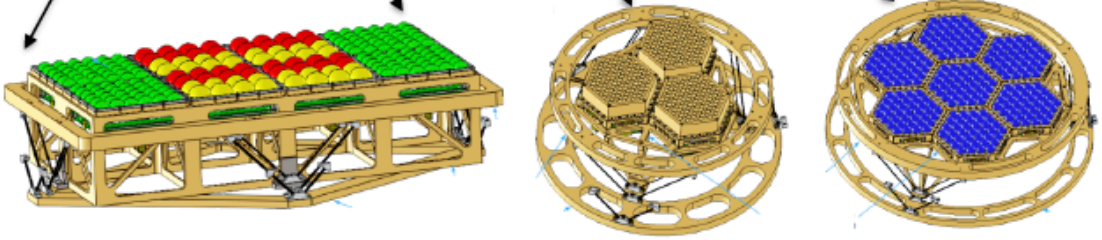
2018 Mar: Development funds from NASA
2019 Aug: NASA MO Pre-proposal
2020 May: Nominal start of NASA Phase A
2021 Feb: Conceptual Study Report
2021 Oct: Projected start of NASA Phase B

GSFC ADR 2K Cooler



SQUID Amplifiers





LF-FPU HF-FPU MF-FPU

HF = High Frequency, MF = Mid Frequency, LF = Low Frequency

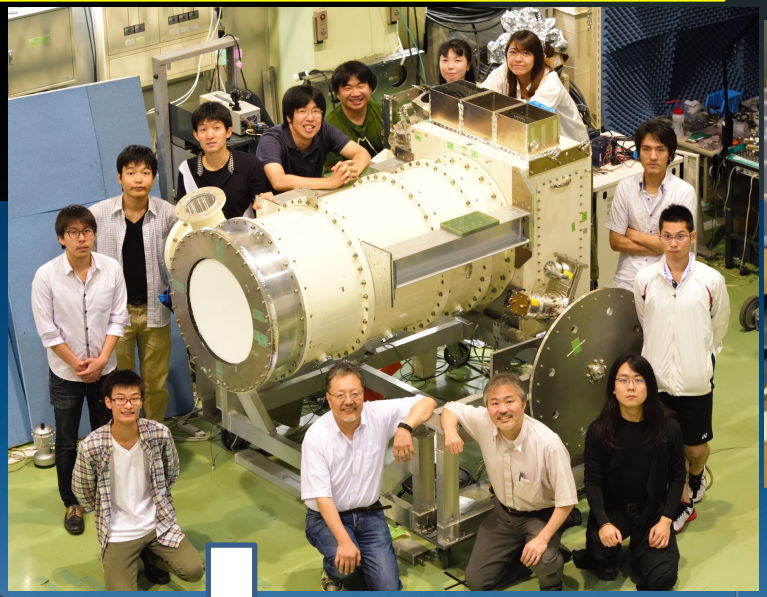
Simons Array in Atacama, Chile

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 Adrian Lee (Wednesday)

Important field test of detector & readout technology LiteBIRD plans to adopt.

Funded Canadian LiteBIRD Activities

Canadian PI; Matt. Dobbs (McGill U.)

2012
2013
2014
2015
2016
2017
2018
2019
2020

2012-2014: **Space Technology Development Program** (STDP)
Developed path-to-flight hardware and firmware

McGill University · COM DEV

2018: **Mission Contribution Study** (MCS) – 8 months
Explore Canadian contribution to mission instrumentation

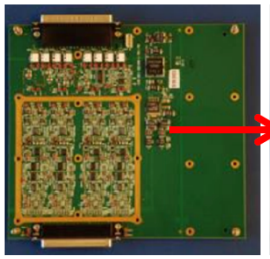
McGill University · Honeywell

2018-2019: **Science Maturation Study** (SMS) – 16 months
Formally link instrument performance to science objectives

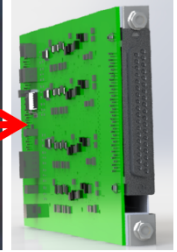
McGill University · University of Toronto · The University of British Columbia

2019-2020: STDP development funding
For path-to-flight signal processing unit development.

STDP SQUID Controller

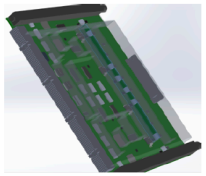


SQUID Controller Assembly

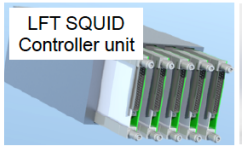


Mezzanine (2 channels)

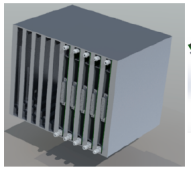
Digitizer Assembly (4 channels)



LFT SQUID Controller unit



LFT Signal Processing unit



McGill University

- **Matt Dobbs** (faculty)
- Jean-Francois Cliche (Engineer)
- Graeme Smecher (Engineer)
- Joshua Montgomery (student)

University of Toronto

- **Renée Hložek** (faculty)
- **Dick Bond** (faculty)
- Simran Nerval (student)
- Victor Chan (student)

University of British Columbia

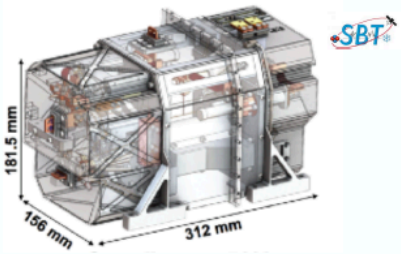
- **Douglas Scott** (faculty)

+ Honeywell Aerospace

LiteBIRD European Consortium

Spokesperson of European Consortium
Ludovic Montier (IRAP)

- CNES (France) committed to Phase A. New!
- ASI (Italy) committed to Phase A. New!
- Other national agencies and ESA under discussion.



ADR-sorption Hybrid cooler

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/OAS, Bologna
INAF/OATS, Trieste
Università di Milano-Bicocca
Università di Genova
IFNS-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-Institut für Astrophysik
Universitäts-Sternwarte, Ludwig-Maximilians-Universität München,
Dr. Karl Remeis-Sternwarte, Universität Erlangen-Nürnberg
RWTH Aachen Universität
Universität Bielefeld
Universität Göttingen

MHFT and ADR led by CNES

Spain

IFCA, IDR/UPM, DICOM/UC
ICCUB, IAC
Universidad de Oviedo
Universidad de Salamanca
Universidad de Granada
CEFCA

Holland

SRON
RuG

Norway

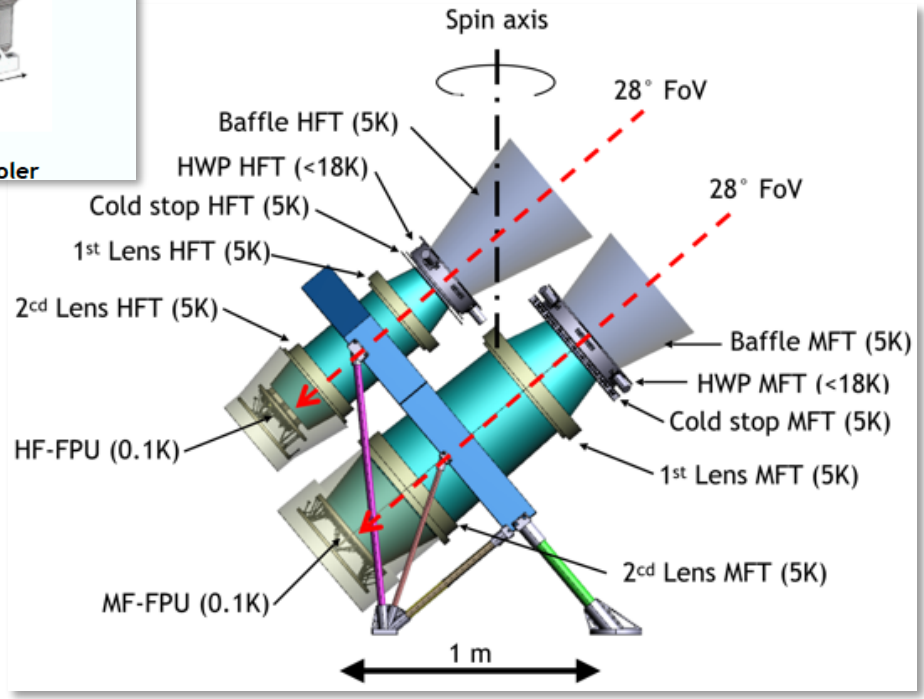
University of Oslo

Sweden

Stockholm University

Ireland

Maynooth



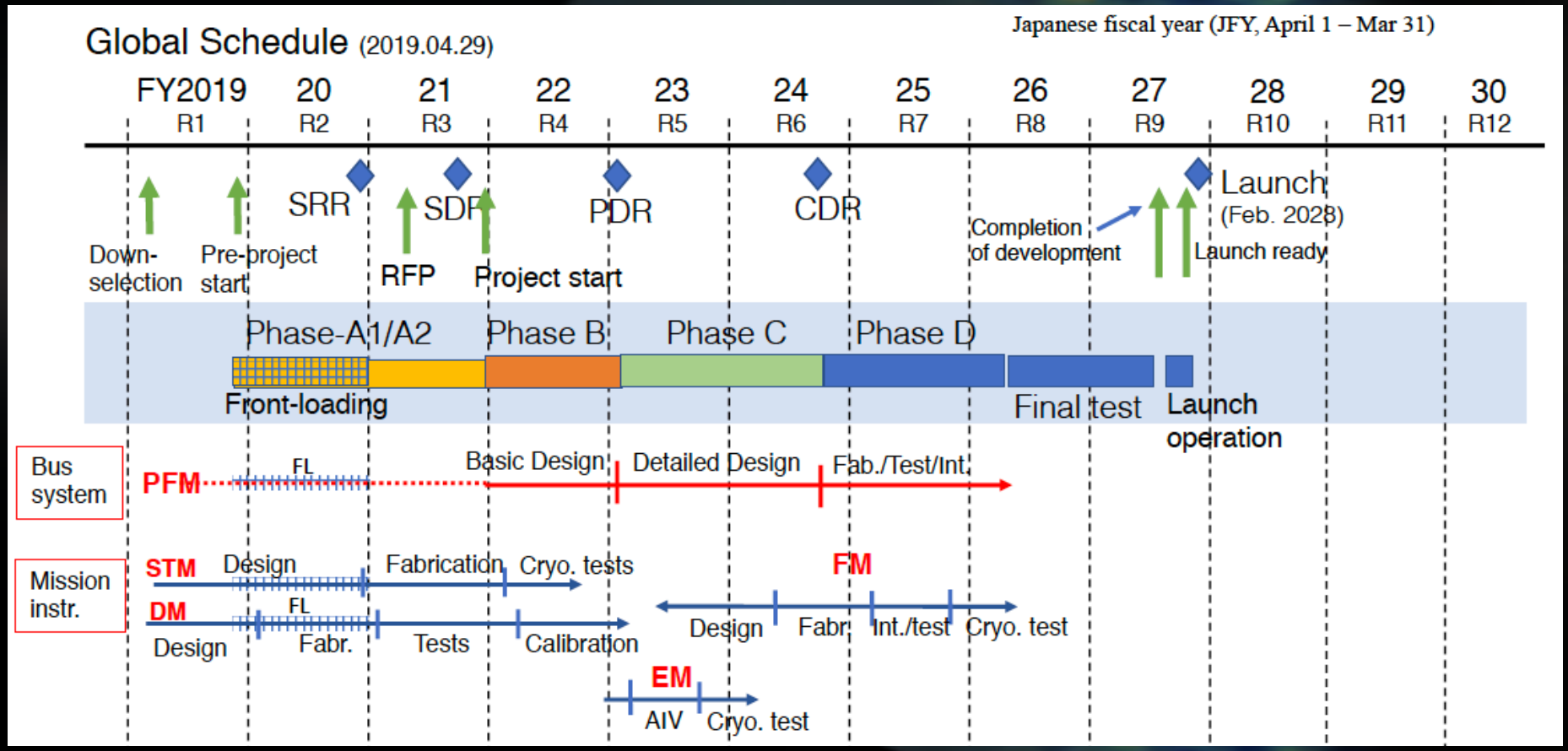
~50% of LiteBiRD Joint Study Group members belong to European consortium.

CMB torch passed from Planck to LiteBIRD

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

Current Baseline Schedule

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



LiteBIRD Summary

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

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

- Detailed foreground cleaning studies yield $\sigma(r=0) = 0.6 \times 10^{-3}$
- Thorough systematic error studies yield total uncertainty $\delta r < 1.0 \times 10^{-3}$
- $>5\sigma$ discovery for Starobinsky model when combined with external data

CMB B-mode from primordial gravitational waves generated during Inflation would provide

- Direct evidence for Inflation, and knowledge on how it happened
- First evidence for quantum fluctuation of space-time
- Knowledge on the Inflation energy scale and 'wake-up time" of our Universe
- Evoke sense of wonder beyond science