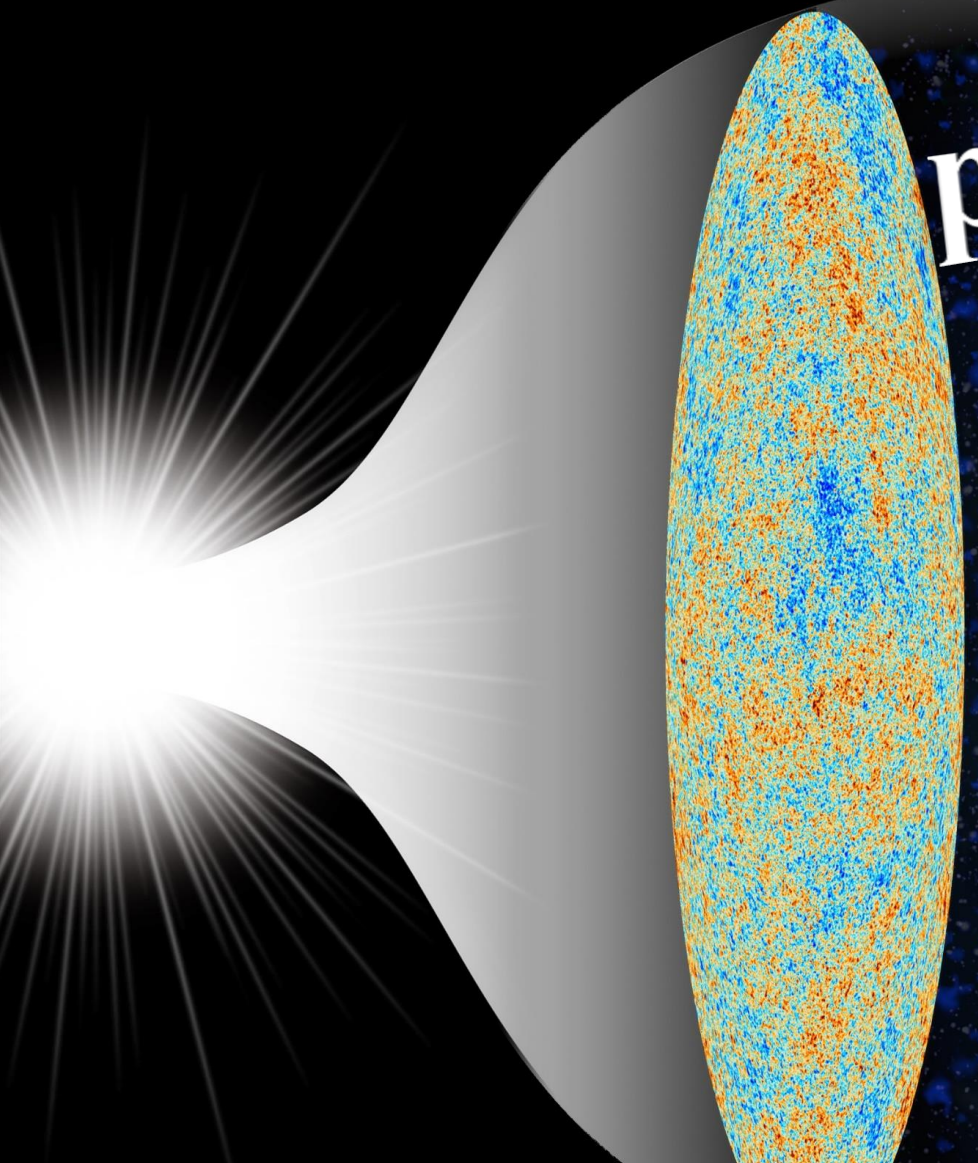
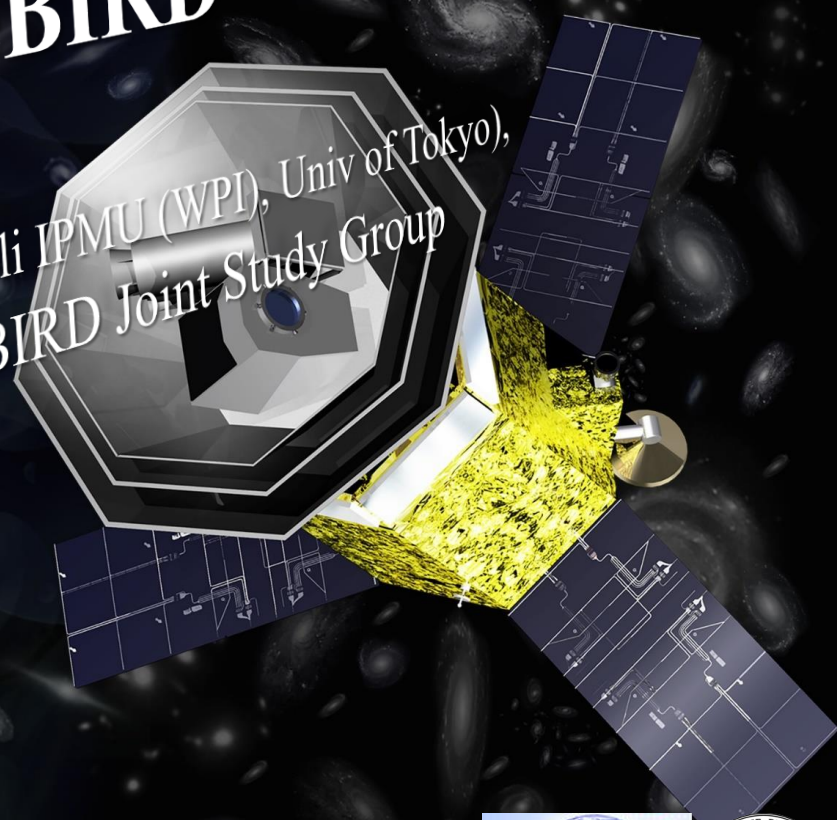
2019 Jul 24: 18th International Workshop on Low Temperature Detectors @ Milano, Italia

Updated design of CMB polarization experiment satellite LiteBIRD

Hajime SUGAI (Kavli IPMU (WPI), Univ of Tokyo),
On behalf of LiteBIRD Joint Study Group





KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

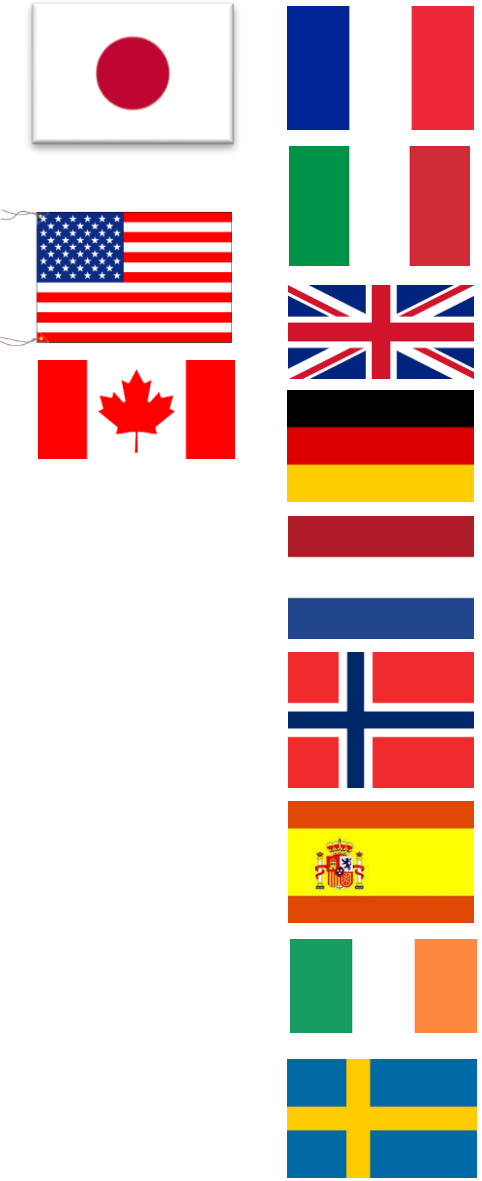
wpi World Premier International Research Center Initiative

Core-to-Core Program

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE · FOUNDED 1932 ·

LiteBIRD Joint Study Group

211 researchers from all over the world



H. Sugai[18], P. A. R. Ade[71], Y. Akiba[19,30], D. Alonso[71], K. Arnold[8], J. Aumont[44], J. Austermann[5], C. Baccigalupi[60,52,58], A. J. Banday[44], R. Banerji[66], R. B. Barreiro[68], S. Basak[49,60], J. Beall[5], S. Beckman[7], M. Bersanelli[63,55], J. Borrill[3,7], F. Boulanger[42], M. L. Brown[75], M. Bucher[38], A. Buzzelli[62], E. Calabrese[71], F. J. Casas[68], A. Challinor[74,72], V. Chan[37], Y. Chinone[7,18], J.-F. Cliche[34], F. Columbro[59,57], A. Cukierman[7], D. Curtis[7], P. Danto[40], P. de Bernardis[59,57], T. de Haan[3], M. De Petris[59,57], C. Dickinson[75], M. Dobbs[34], T. Dotani[15], L. Duband[39], A. Ducout[18], S. Duff[5], A. Duivenvoorden[70], J.-M. Duval[39], K. Ebisawa[15], T. Elleflot[8], H. Enokida[13], H. K. Eriksen[66], J. Errard[38], T. Essinger-Hileman[4], F. Finelli[53], R. Flauger[8], C. Franceschet[63,55], U. Fuskeland[66], K. Ganga[38], J.-R. Gao[65], R. Génova-Santos[67,69], T. Ghigna[76,18], A. Gomez[40], M. L. Gradziel[50], J. Grain[42], F. Grupp[48,47], A. Gruppuso[53], J. E. Gudmundsson[70], N. W. Halverson[9], P. Hargrave[71], T. Hasebe[15], M. Hasegawa[19,30], M. Hattori[31], M. Hazumi[19,15,18,30], S. Henrot-Versille[45], D. Herranz[68], C. Hill[7,3], G. Hilton[5], Y. Hirota[13], E. Hivon[41], R. Hlozek[37], D.-T. Hoang[1,77], J. Hubmayr[5], K. Ichiki[23], T. Iida[18], H. Imada[45], K. Ishimura[32], H. Ishino[26,19], G. C. Jaehnig[9], M. Jones[76], T. Kaga[15], S. Kashima[24], Y. Kataoka[26], N. Katayama[18], T. Kawasaki[20], R. Keskitalo[3], A. Kibayashi[26], T. Kikuchi[10], K. Kimura[27], T. Kisner[3], Y. Kobayashi[16], N. Kogiso[27], A. Kogut[4], K. Kohri[19], E. Komatsu[46], K. Komatsu[26], K. Konishi[14], N. Krachmalnicoff[60,52,58], C. L. Kuo[6,2], N. Kurinsky[6,2], A. Kushino[22], M. Kuwata-Gonokami[12], L. Lamagna[59,57], M. Lattanzi[54], A. T. Lee[7,3], E. Linder[3,7], B. Maffei[42], D. Maino[63,55], M. Maki[19], A. Mangilli[44], E. Martínez-González[68], S. Masi[59,57], R. Mathon[44], T. Matsumura[18], A. Mennella[63,55], M. Migliaccio[62,57], Y. Minami[19], K. Mistuda[15], D. Molinari[61], L. Montier[44], G. Morgante[53], B. Mot[44], Y. Murata[15], J. A. Murphy[50], M. Nagai[24], R. Nagata[19], S. Nakamura[33], T. Namikawa[74], P. Natoli[61,54], S. Nerval[37], T. Nishibori[17], H. Nishino[28], Y. Nomura[29], F. Noviello[71], C. O'Sullivan[50], H. Ochi[33], H. Ogawa[27], H. Ogawa[15], H. Ohsaki[13], I. Ohta[21], N. Okada[15], N. Okada[27], L. Pagano[61,54], A. Paiella[59,57], D. Paoletti[53], G. Patanchon[38], F. Piacentini[59,57], G. Pisano[71], G. Polenta[51], D. Poletti[60,52,58], T. Prouvé[39], G. Puglisi[6], D. Rambaud[44], C. Raum[7], S. Realini[63,55], M. Remazeilles[75], G. Roudil[44], J. A. Rubiño-Martín[67,69], M. Russell[8], H. Sakurai[12], Y. Sakurai[18], M. Sandri[53], G. Savini[73], D. Scott[36], Y. Sekimoto[15,19,30], B. D. Sherwin[74,72], K. Shinozaki[17], M. Shiraishi[25], P. Shirron[4], G. Signorelli[56], G. Smecher[35], P. Spizzi[40], S. L. Stever[18], R. Stompor[38], S. Sugiyama[29], A. Suzuki[3], J. Suzuki[19], E. Switzer[4], R. Takaku[12], H. Takakura[11], S. Takakura[18], Y. Takeda[15], A. Taylor[76], E. Taylor[7], Y. Terao[13], K. L. Thompson[6,2], B. Thorne[76], M. Tomasi[63,55], H. Tomida[15], N. Trappe[50], M. Tristram[45], M. Tsuji[25], M. Tsujimoto[15], C. Tucker[71], J. Ullom[5], S. Uozumi[26], S. Utsunomiya[18], J. Van Lanen[5], G. Vermeulen[43], P. Vielva[68], F. Villa[53], M. Vissers[5], N. Vittorio[62], F. Voisin[38], I. Walker[71], N. Watanabe[20], I. Wehus[66], J. Weller[48,47], B. Westbrook[7], B. Winter[73], E. Wollack[4], R. Yamamoto[10], N. Y. Yamasaki[15], M. Yanagisawa[26], T. Yoshida[15], J. Yumoto[12], M. Zannoni[64,55], A. Zonca[8]

Aim of LiteBIRD

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

To **test inflation** scenario.

Existence of hot big bang established since discovery of Cosmic Microwave Background (CMB) in 1964.

Problems remain on uniformity, flatness, monopole.
→ Inflation proposed since 1980s.

LiteBIRD tests whether or not inflation really existed before hot big bang.

Concepts of LiteBIRD

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

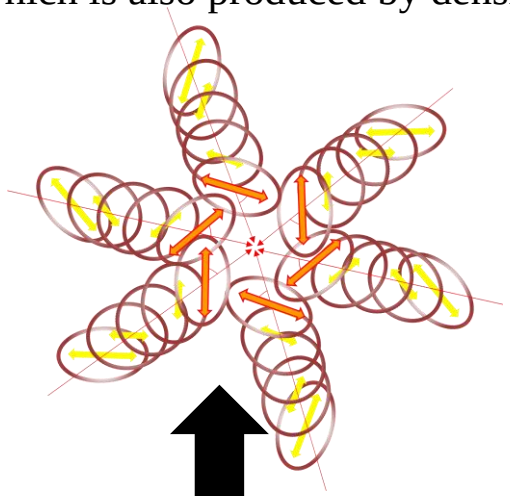
1. **Focused** on CMB B-mode polarization by primordial gravitational waves produced by inflation, targeting both of:
   - recombination era, with multipole moment $11 \leqq l \leqq 200$ ($17^\circ \geqq \theta \geqq 0.9^\circ$)
   - reionization era, with $2 \leqq l \leqq 10$ ($90^\circ \geqq \theta \geqq 18^\circ$),
   - optimizing the angular resolution as modest.

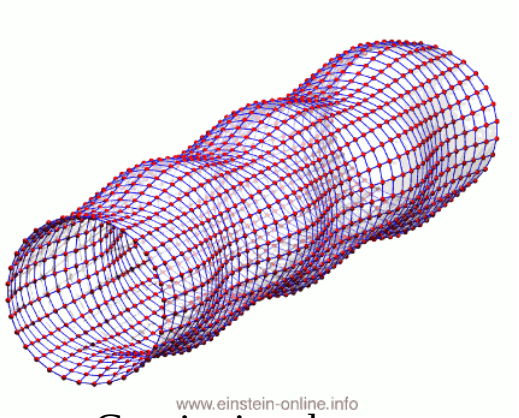
   Full success: $\delta r < 1 \times 10^{-3}$ (for r=0 (r=tensor-to-scalar ratio))

2. **Warm launch** without requirements of heavy vessels/tanks.

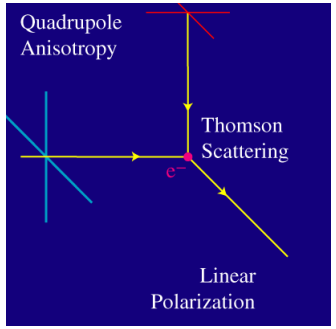
3. Use of **multichroic detectors** with ground-based heritage for the effective use of finite focal plane areas.

B mode spiral pattern produced as well as E mode, the latter of which is also produced by density fluctuation.





Gravitational wave
http://www.einstein-online.info/



Thomson Scattering
http://background.uchicago.edu/~whu/intermediate/Polarization/polar1.html

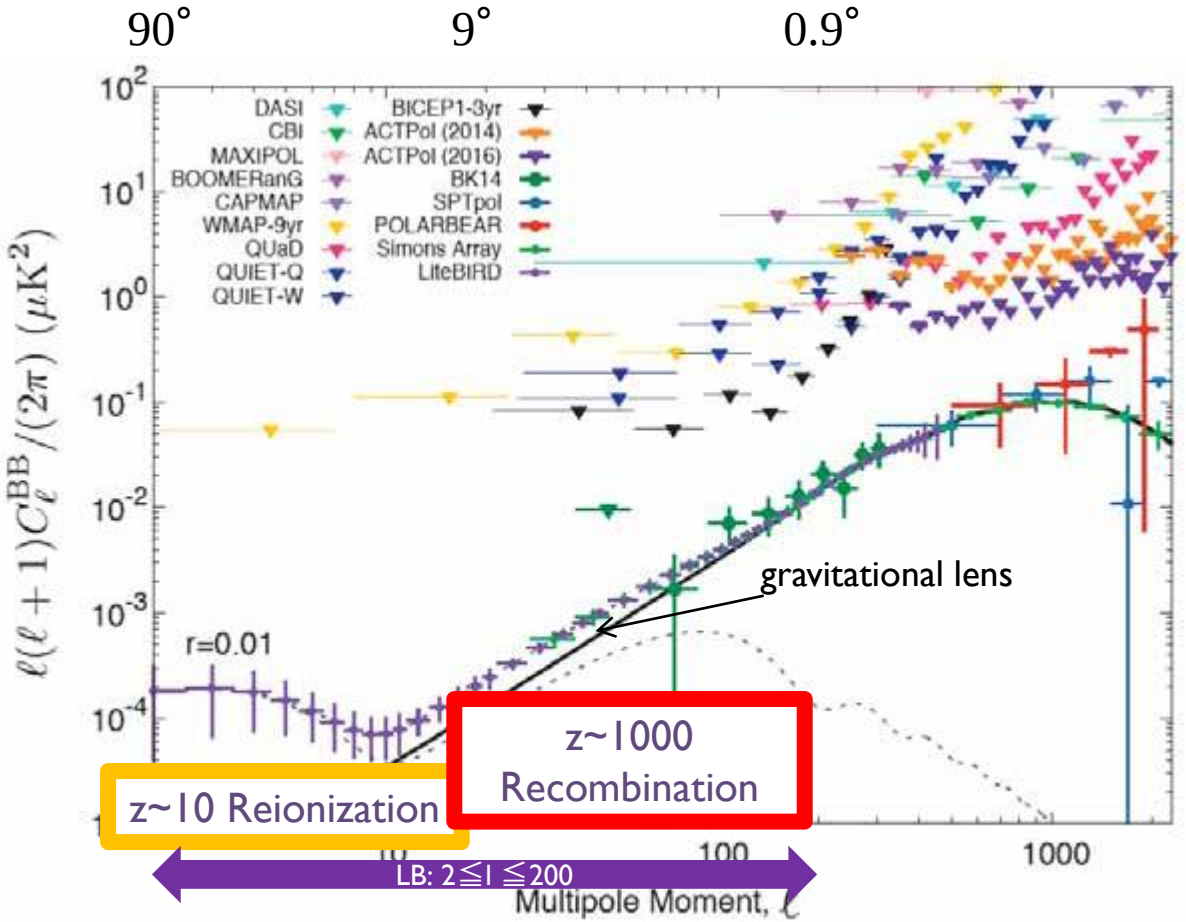
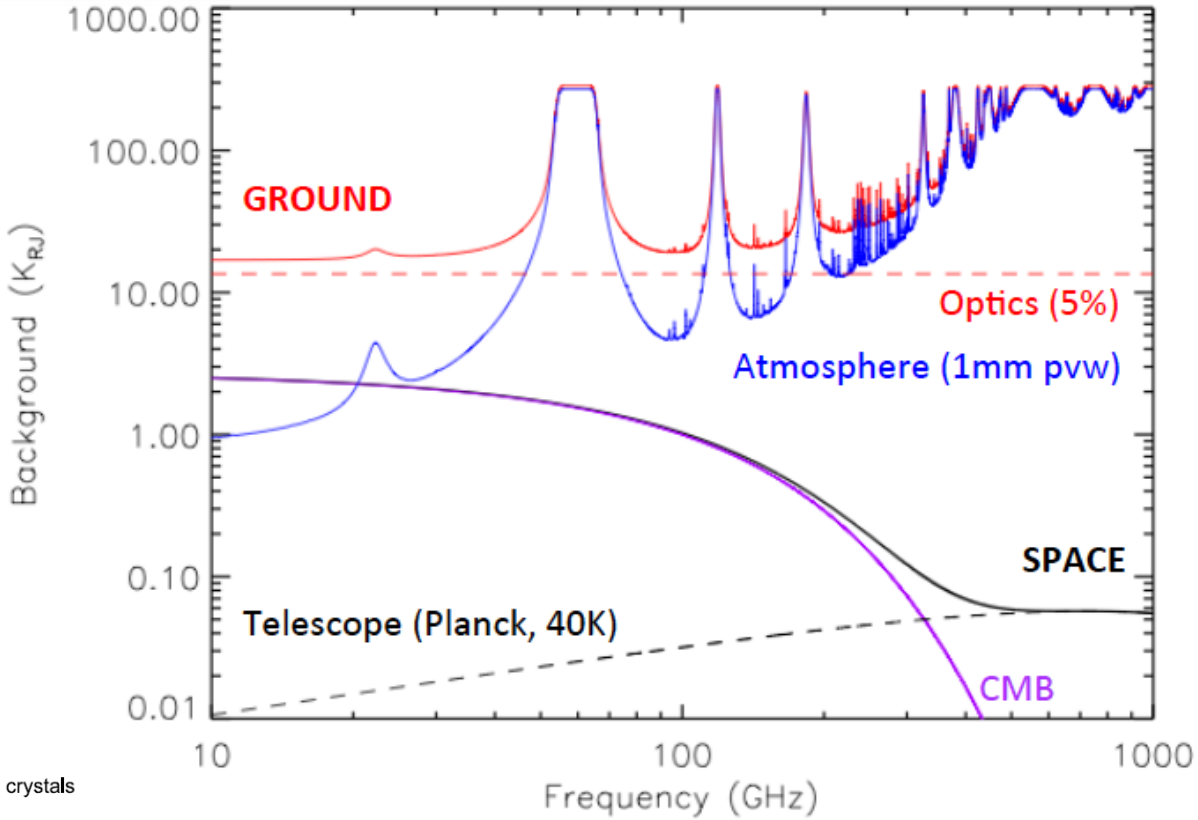


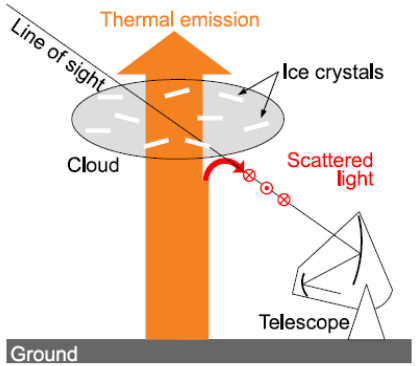
Figure 1: C_l^{BB} is B-mode power for each multipole moment (l = 180/(θ[°])), where B-mode is the strength of spiral-like spatial pattern of polarization distribution. Circles are measured values except for LiteBIRD and Simons Array, where they are predicted values for the case of tensor-to-scalar ratio (relative strength of gravitational wave) r equal to 0.01 as an example. Triangles are obtained upper limits. The lower dashed curve is the expected power spectrum by inflation, while the solid curve is due to gravitational lensing. Figure courtesy of Y. Chinone (UC Berkeley)

Advantages of Measurements from Space

- Free from atmospheric effects
  - High sensitivity
  - Stability; Less systematic errors
  - No restrictions on observing-band selection

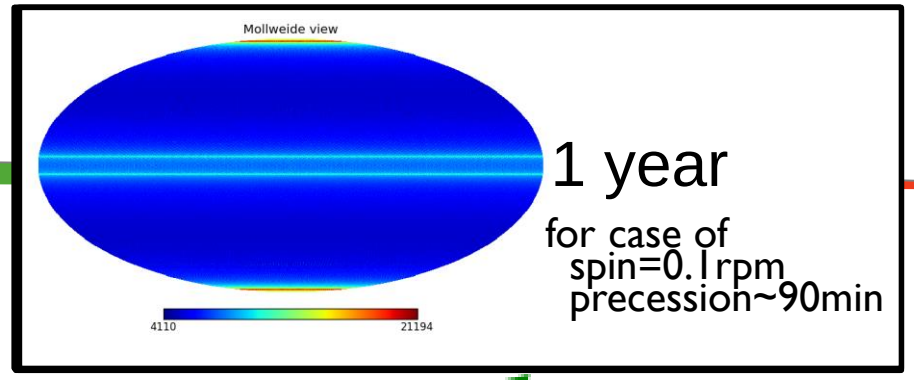


- No pickups from ground

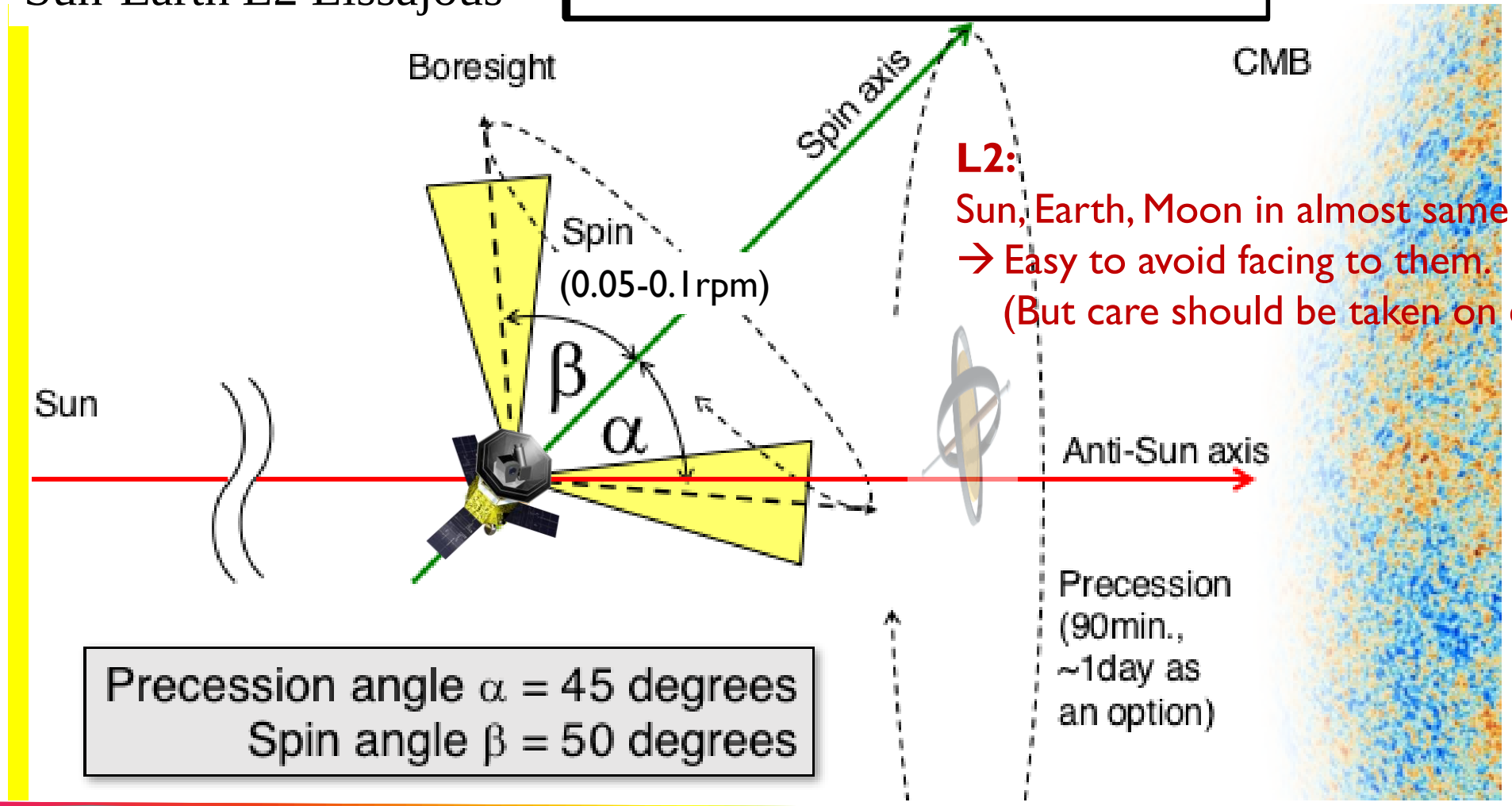


Tropospheric ice clouds (Takakura et al. 2018)

Scan strategy



Orbit:
Sun-Earth L2 Lissajous



L2:
Sun, Earth, Moon in almost same direction.
→ Easy to avoid facing to them.
(But care should be taken on cosmic rays.)

Current status of LiteBIRD

2019 May

ISAS/JAXA selected LiteBIRD as strategic large mission #2.

with design modification on cooling chain & focal planes:

Adiabatic Demagnetization Refrigerators (ADRs) in series, removing JAXA-provided 1K JT.

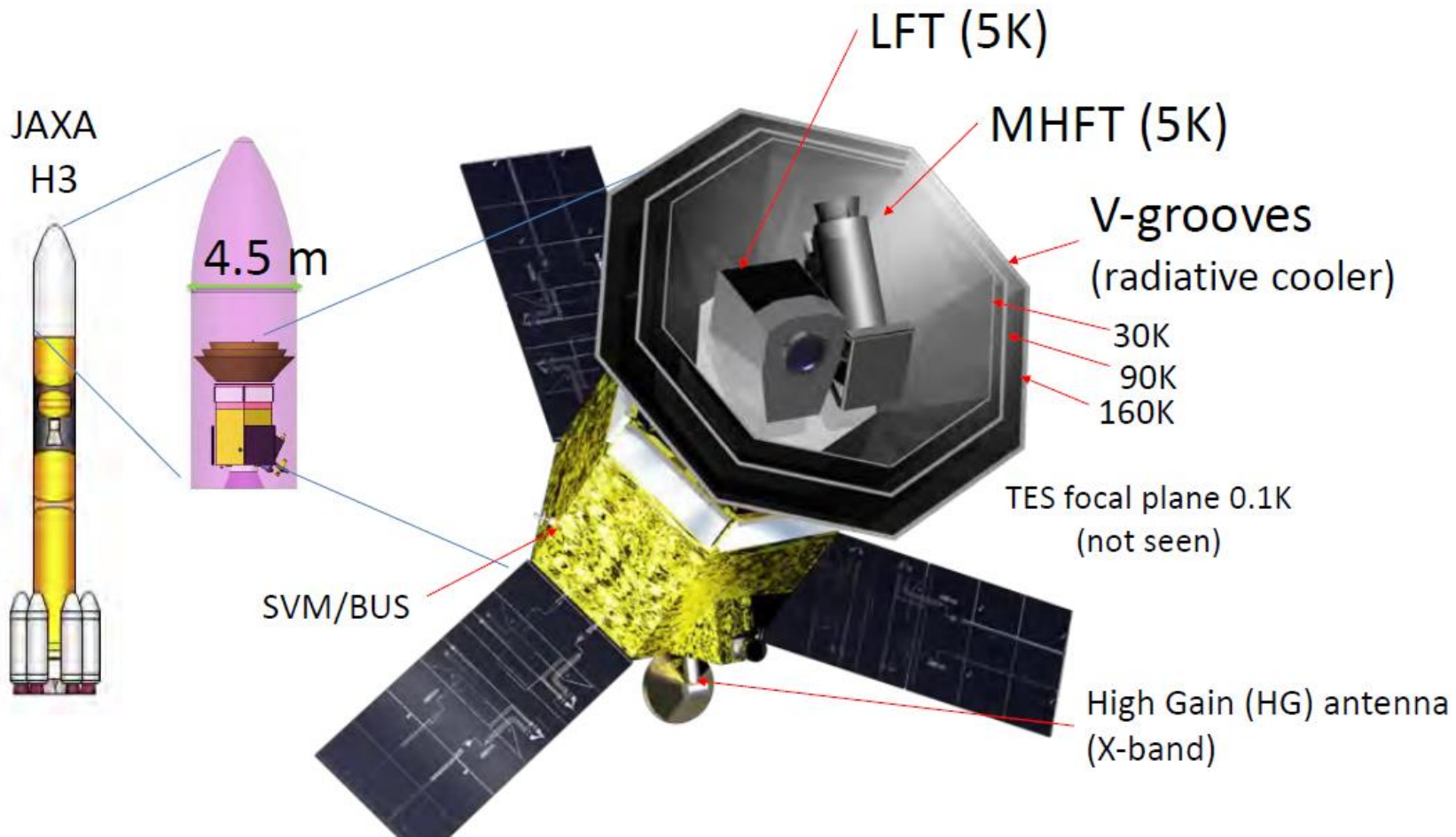
2019 July

LiteBIRD Kickoff Symposium @ ISAS/JAXA

LiteBIRD general view

15 frequency bands for foreground cleaning:

- Low Frequency Telescope (LFT): 34 to 161 GHz
- Medium/High Frequency Telescope (MHFT): 166 to 448 GHz



Mass: 2.6 ton
Electrical power: 3.0 kW

Launch planned in 2027 FY

Cooling chain

Current baseline:

i) Down to 4.8 K:

Sunshield and passive cooling with V grooves.

15K pulse tube coolers to strengthen this.

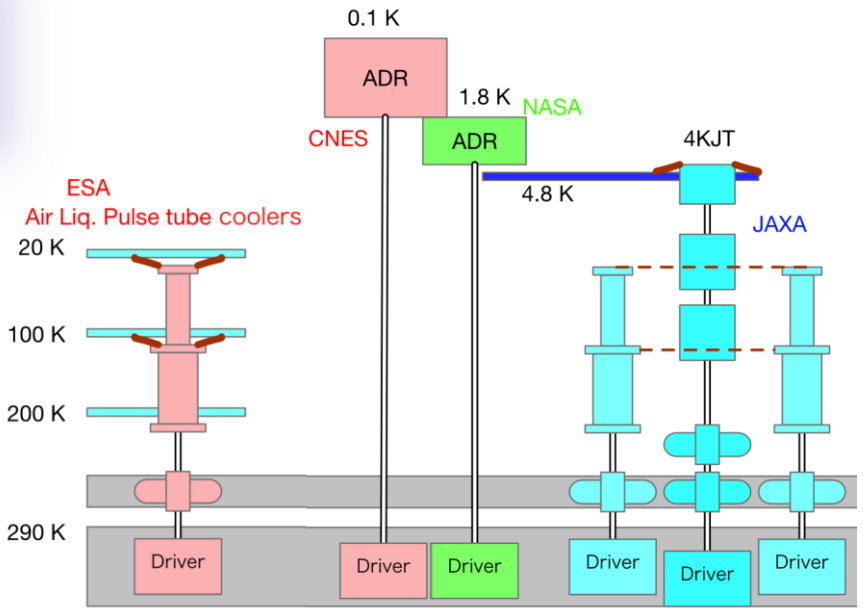
A 4K-JT with 2 double-ST precoolers.

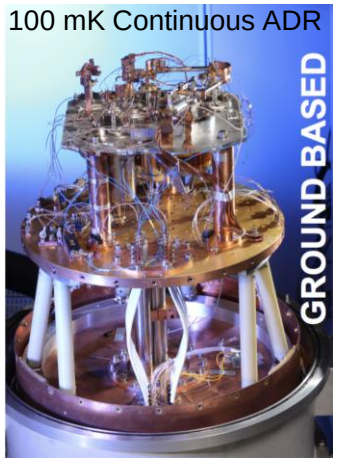
ii) From 4.8 K to 1.75 K:

A parallel three-stage Adiabatic Demagnetization Refrigerator (ADR) for providing continuous cooling at 1.75K.

iii) From 1.75 K to 100 mK:

A multi-staged ADR with continuous cooling at 300 mK and 100 mK.

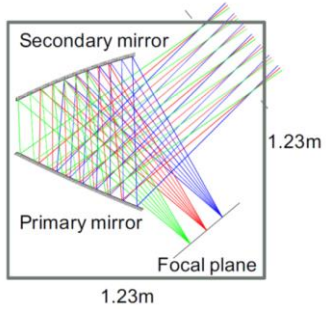




See J.-M. Duval, et al. in this workshop for details.

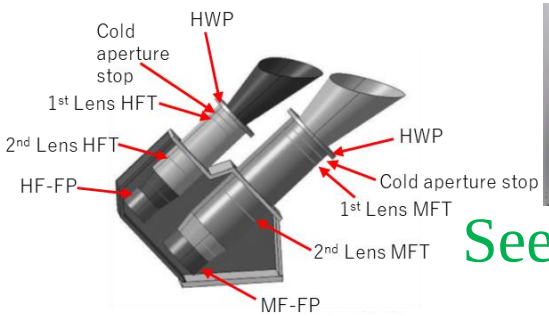
Telescopes, Focal planes & LiteBIRD Sensitivity

Low Frequency Telescope



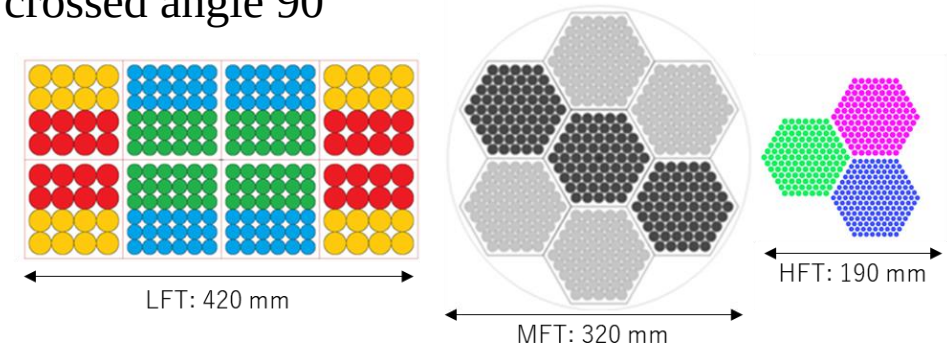
Crossed Dragone with crossed angle 90°

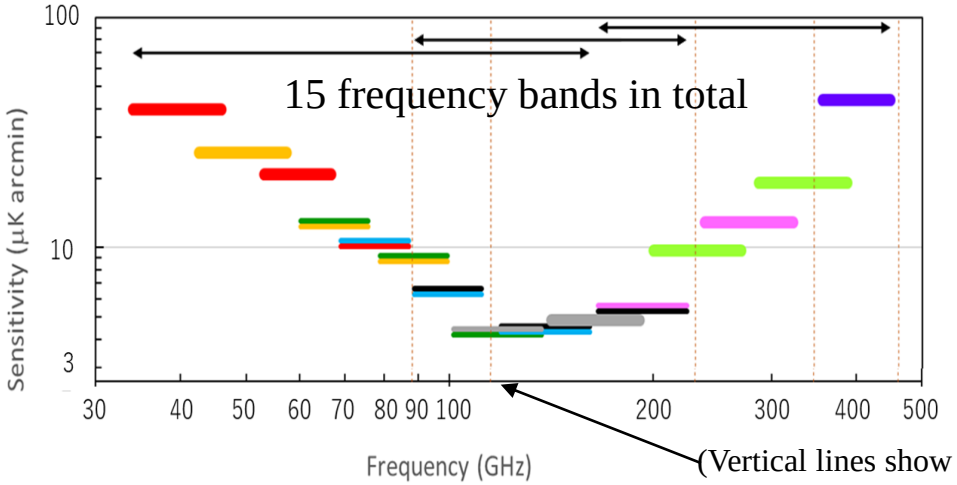
Medium/High Frequency Telescope



See B. Mot, et al. for MHFT

Multichroic pixels





(Vertical lines show CO/HCN line frequencies)

Total sensitivity 2μK・arcmin for $T_{mission}$ = 3yrs

Table 2. LiteBIRD telescope parameters

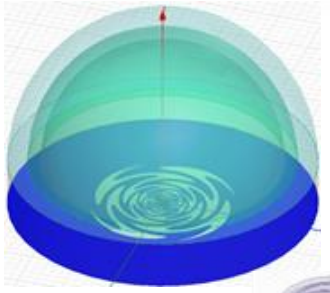
Telescope	Low Freq.	Medium Freq.	High Freq.
Frequency	34-161 GHz	89-224 GHz	166-448 GHz
Field of view	20° x 10°	28° diameter	28° diameter
Aperture diameter	400 mm	300 mm	200 mm
Angular resolution	70-24 arcmin	38-28 arcmin	29-18 arcmin
Rotational HWP	46~83 rpm	39~70 rpm	61~110 rpm
Number of detectors	1248	2074	1354

Transition-edge sensor (TES) developments

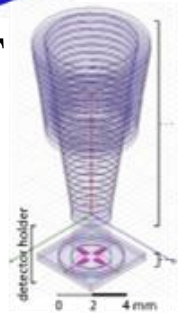
See B. Westbrook, et al.

TES bolometers form a multichroic pixel.

coupled with a silicon lenslet & a sinuous antenna for LFT&MFT.



coupled with silicon platelet-based corrugated horn & OMT for HFT.



See G. Jaehnig, et al.

TES parameter optimization for LiteBIRD:

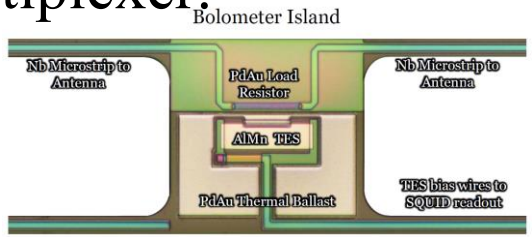
Low saturation power detector for satellite environment.

Noise equivalent power $\propto \sqrt{(P_{sat}\, T_b)}$, with T_c/T_b being optimized.

(P_{sat}: saturated power, T_c: transition temp., T_b: thermal bath temp.)

Sensor impedance coupling to frequency domain multiplexer.

Electro-thermal time constants controlled with additional heat capacity of PdAu.



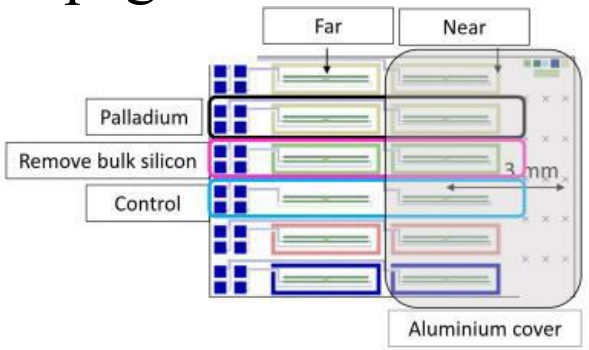
Transition-edge sensor (TES) developments

See Y. Minami, et al.

Cosmic-ray mitigation methods by reducing heat propagation:

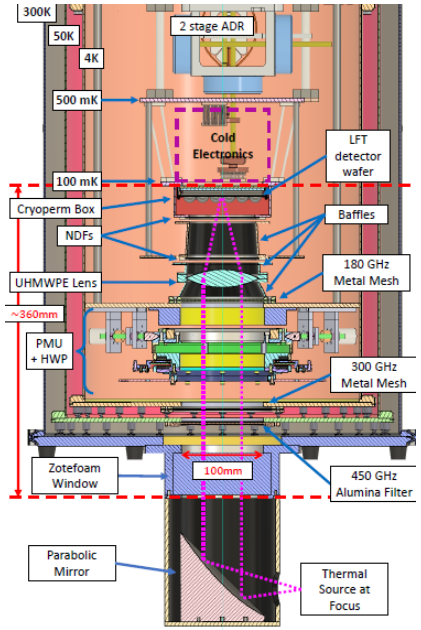
Palladium structures to absorb phonons.

Removing bulk silicon to block phonons.



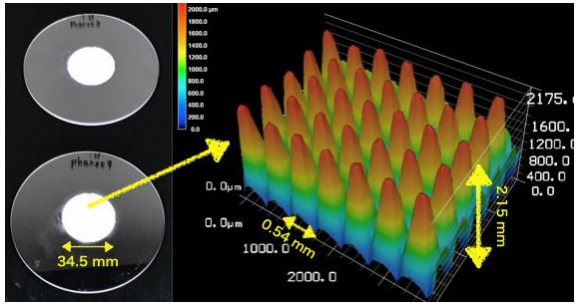
See T. Ghigna, et al.

Design of cryogenic testbed to study interaction between space-optimized detectors and other subsystems, especially polarization modulator unit consisting of magnetically rotating half wave plate.

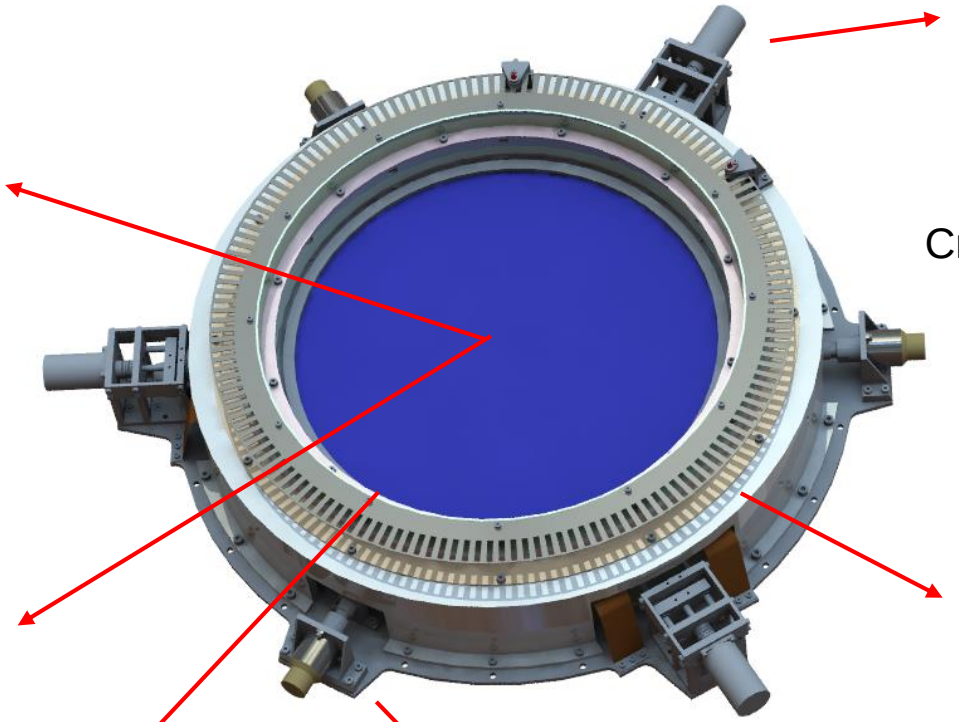


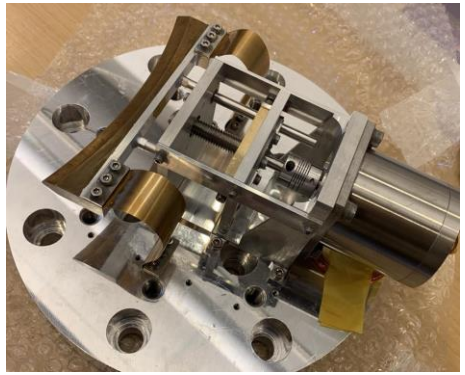
LFT Polarization modulator developments

(As for MHFT PM developments, see B. Mot, et al.)

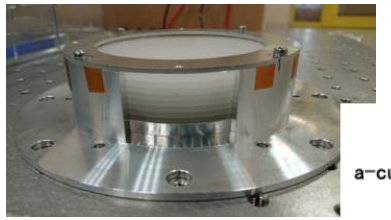


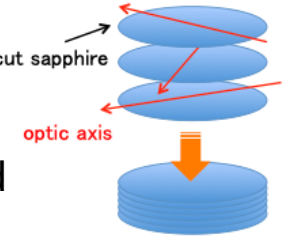
Anti-reflection structure



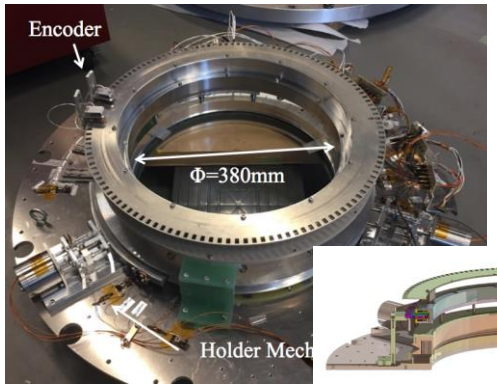


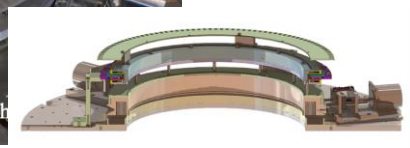
Cryogenic holder mechanism

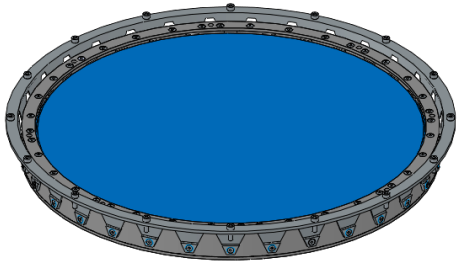


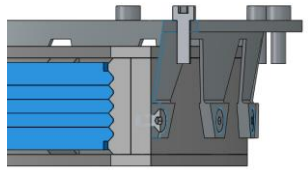


Sapphire stacked
Achromatic HWP

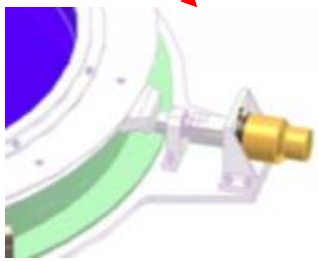


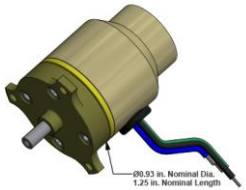




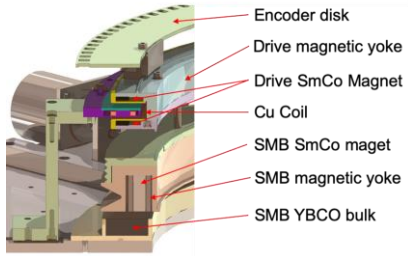


HWP holder





Launch lock mechanism



Rotation mechanism

[SPIE 10708-12] Y. Sakurai et al. "Design and development of a polarization modulator unit based on a continuous rotating half-wave plate for LiteBIRD"
[SPIE 10708-142] K. Komatsu et al. "Prototype design and evaluation of the nine-layer achromatic half-wave plate for the LiteBIRD low frequency telescope"

Summary – LiteBIRD –

- Aiming at detecting signature of inflation.

  Whole sky observations of mm wavelength radio linear polarization, without atmospheric effects.

  → Detect specific spatial pattern of CMB polarization angle distribution produced by primordial gravitational waves.

- Selected as strategic large mission #2.

- Plan to launch in 2027 FY; Three-year observations at L2.

LiteBIRD poster presentations

J.-M. Duval, et al. (108-157)
“LiteBIRD cryogenic chain: 100 mK cooling with mechanical coolers and ADRs”

B. Mot, et al. (183-311)
“The Medium and High Frequencies Telescopes of LiteBIRD”

B. Westbrook, et al. (226)
“Detector fabrication development for the LiteBIRD satellite mission”

G. Jaehnig, et al. (75-227)
“Development of Low-Frequency Space-Optimized TES Bolometer Arrays for LiteBIRD”

Y. Minami, et al. (74-272)
“Irradiation tests of superconducting detectors and comparison with simulations”

T. Ghigna, et al. (99-257)
“Design of a testbed for the study of system interference in space CMB polarimetry”

Table 1. Updated basic parameters and baseline design for LiteBIRD

Mission category	JAXA's strategic large mission
Launch vehicle	H3-22L or equivalent
Launch schedule	2027 FY
Ground station	JAXA's ground stations (USC, GREAT)
Observation period	3 years
Uncertainty of tensor-to-scalar ratio r	$\delta r < 1 \times 10^{-3}$
Multipole moment	$2 \leqq l \leqq 200$
Orbit	Sun–Earth Lagrange point 2; Lissajous orbit
Scan	"Precession" angle 45° ($10^{-2\sim-3}$ rpm); spin angle 50° (0.05~0.1 rpm)
Pointing knowledge	< 2.1 arcmin
Cooling system	Radiative cooling and mechanical refrigerators (Stirling and JT) without cryogen. Cool in space after launch. ADRs are used to cool the focal plane down to 100 mK
Focal-plane detector	Multi-chroic superconducting detector (TES) array with more than 4000 bolometers
Sensitivity	2 μK・arcmin
Observing frequencies	15 bands between 34 and 448 GHz
Modulation	Satellite spin and half-wave-plate modulation
Data transfer	9.6 GByte / day
Mass	2.6 ton
Electrical power	3.0 kW