Updated design of CMB polarization experiment satellite LiteBIRD

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On behalf of LiteBIRD Joint Study Group
LiteBIRD Joint Study Group

211 researchers from all over the world

Aim of LiteBIRD

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

1. **Focused** on CMB B-mode polarization by primordial gravitational waves produced by inflation, targeting both of:
   - recombination era, with multipole moment $11 \leq l \leq 200$ (17° $\geq \theta \geq 0.9°$),
   - reionization era, with $2 \leq l \leq 10$ (90° $\geq \theta \geq 18°$),
   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.

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

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

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Figure 1: $C_{l}^{BB}$ is B-mode power for each multipole moment ($l = 180/\theta^{2}$), 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) 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 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

Crossed Dragone with crossed angle 90°

Low Frequency Telescope

Medium/High Frequency Telescope

Multichroic pixels

Total sensitivity $2\mu \text{K} \cdot \text{arcmin}$ for $T_{\text{mission}} = 3\text{yrs}$

See B. Mot, et al. for MHFT

15 frequency bands in total

(VERTICAL LINES SHOW CO/HCN LINE FREQUENCIES)
Table 2. LiteBIRD telescope parameters

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Frequency</td>
<td>34-161 GHz</td>
<td>89-224 GHz</td>
<td>166-448 GHz</td>
</tr>
<tr>
<td>Field of view</td>
<td>20° x 10°</td>
<td>28° diameter</td>
<td>28° diameter</td>
</tr>
<tr>
<td>Aperture diameter</td>
<td>400 mm</td>
<td>300 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>70-24 arcmin</td>
<td>38-28 arcmin</td>
<td>29-18 arcmin</td>
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<tr>
<td>Rotational HWP</td>
<td>46~83 rpm</td>
<td>39~70 rpm</td>
<td>61~110 rpm</td>
</tr>
<tr>
<td>Number of detectors</td>
<td>1248</td>
<td>2074</td>
<td>1354</td>
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</table>
Transition-edge sensor (TES) developments

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.

TES parameter optimization for LiteBIRD:
Low saturation power detector for satellite environment.
Noise equivalent power $\propto \sqrt{(P_{\text{sat}} T_b)}$, with $T_c/T_b$ being optimized.
($P_{\text{sat}}$: 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.

See B. Westbrook, et al.
See G. Jaehnig, et al.
Cosmic-ray mitigation methods by reducing heat propagation:

- Palladium structures to absorb phonons.
- Removing bulk silicon to block phonons.

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.)

[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"
- 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/Specification</th>
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<tbody>
<tr>
<td>Mission category</td>
<td>JAXA’s strategic large mission</td>
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<tr>
<td>Launch vehicle</td>
<td>H3-22L or equivalent</td>
</tr>
<tr>
<td>Launch schedule</td>
<td>2027 FY</td>
</tr>
<tr>
<td>Ground station</td>
<td>JAXA’s ground stations (USC, GREAT)</td>
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<tr>
<td>Observation period</td>
<td>3 years</td>
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<tr>
<td>Uncertainty of tensor-to-scalar ratio $r$</td>
<td>$\delta r &lt; 1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Multipole moment</td>
<td>$2 \leq l \leq 200$</td>
</tr>
<tr>
<td>Orbit</td>
<td>Sun–Earth Lagrange point 2; Lissajous orbit</td>
</tr>
<tr>
<td>Scan</td>
<td>“Precession” angle 45° (10^{-2}<del>10^{-3} rpm); spin angle 50° (0.05</del>0.1 rpm)</td>
</tr>
<tr>
<td>Pointing knowledge</td>
<td>&lt; 2.1 arcmin</td>
</tr>
<tr>
<td>Cooling system</td>
<td>Radiative cooling and mechanical refrigerators (Stirling and JT) without cryogen.</td>
</tr>
<tr>
<td>Focal-plane detector</td>
<td>Cool in space after launch. ADRs are used to cool the focal plane down to 100 mK</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>2 $\mu$K · arcmin</td>
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<tr>
<td>Observing frequencies</td>
<td>15 bands between 34 and 448 GHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>Satellite spin and half-wave-plate modulation</td>
</tr>
<tr>
<td>Data transfer</td>
<td>9.6 GByte / day</td>
</tr>
<tr>
<td>Mass</td>
<td>2.6 ton</td>
</tr>
<tr>
<td>Electrical power</td>
<td>3.0 kW</td>
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