LiteBIRD

M. Tristram
on behalf of
the LiteBIRD Collaboration

CS IN2P3 (Oct. 2020)
are shown in the lower panels. The error bars show Gaussian uncertainties including cosmic variance. Note that the conservative band powers, although preferring slightly lower amplitudes (see Planck 2018 results. VIII) for 9 binned power spectrum likelihoods, should be borne in mind.

In the multipole range $2 < \ell < 30$, where the horizontal axis switches from logarithmic to linear, the base-likelihood with foreground and other nuisance parameters fixed to a best fit assuming CDM cosmology. In the multipole range $2 < \ell < 30$, we show the coadded frequency spectra (we describe in the next section, uses spectrum-based efficiency estimates from Planck Collaboration: Cosmological parameters 2018 -140). We have investigated the efficiency estimates of the CMB power spectra (we switch from logarithmic to linear).

The dashed line shows the prediction from the best fit to the conservative band powers, although preferring slightly lower amplitudes (see Planck 2018 results. VIII) for 9 binned power spectrum likelihoods, should be borne in mind.
TE polarization spectra highly consistent with TT spectra
EE spectra also consistent but still noisier
- **Consistency**
  The CMB anisotropies in temperature and polarisation (TT, TE, EE), CMB lensing $\Phi\Phi$, as well as BAO, BBN, and SNIa measurements are all consistent, among themselves and across experiments, within $\Lambda$CDM.

- **Robustness**
  These probes allow many different checks of the robustness for the $\Lambda$CDM model and some of its extensions, including flatness, sum of neutrinos masses and effective number, DM annihilation limits, dark energy equation of state $w(z)$, details of the recombination history ($A_{2s+1}, T_0$, and also fundamental constants variation, or any energy input...)

- **Precision**
  This network of consistency tests is passed with per cent level precision but for relative tensions (including $A_L$, $H_0$, $S_8$)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TT,TE,EE+lowE+lensing 68% limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_b h^2$</td>
<td>$0.02237 \pm 0.00015$</td>
</tr>
<tr>
<td>$\Omega_c h^2$</td>
<td>$0.1200 \pm 0.0012$</td>
</tr>
<tr>
<td>$100\theta_{MC}$</td>
<td>$1.04092 \pm 0.00031$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>$0.0544 \pm 0.0073$</td>
</tr>
<tr>
<td>$\ln(10^{10} A_s)$</td>
<td>$3.044 \pm 0.014$</td>
</tr>
<tr>
<td>$n_s$</td>
<td>$0.9649 \pm 0.0042$</td>
</tr>
</tbody>
</table>
• **Consistency**
  The **CMB anisotropies** in temperature and polarisation (TT, TE, EE), **CMB lensing** $\Phi\Phi$, as well as **BAO, BBN**, and **SNIa** measurements are all consistent, among themselves and across experiments, within $\Lambda$CDM.

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**what’s next ?**
Scientific outcomes

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Inflation energy (Full success / Extra success)
  - Constraints on the inflation potential
  - Beyond the B-mode power spectrum
Scientific outcomes

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- Cosmological parameters with E polarisation
  - Optical depth and reionization of the Universe
  - Elucidating low-\(\ell\) anomalies with polarization

- Neutrino sector
- Cosmic birefringence

- Anisotropic CMB spectral distortions
- Galactic science
- Mapping the hot gas in the Universe
Gravitational waves

Big leap between LISA and LiteBIRD

Quantum fluctuations in the very early Universe

- Binary supermassive black holes in galactic nuclei
- Phase transitions in the early universe
- Black holes, compact stars captured by supermassive holes in galactic nuclei
- Binary stars in the galaxy and beyond
- Merging binary neutron stars and stellar black holes in distant galaxies; fast pulsars with mountains

Wave Period

- **AGE OF THE UNIVERSE**
- **YEARS**
- **HOURS**
- **SECONDS**
- **MSEC**
- $10^{-16}$
- $10^{-14}$
- $10^{-12}$
- $10^{-10}$
- $10^{-8}$
- $10^{-6}$
- $10^{-4}$
- $10^{-2}$
- $10^1$
- $10^2$

Frequency (Hz)

- **INFLATION PROBE**
- **LISA**
- **BIG BANG OBS**
- **GEO, LIGO, VIRGO, TAM**
- Precision timing of millisecond pulsars
- Polarization map of cosmic microwave background

LiteBIRD

Gravitational waves with quantum origin

LISA

Gravitational waves with classical origin
Primordial gravitational waves

Opportunity to probe the Cosmic Inflation but also to shed light on GUT-scale physics

Observational test of quantum gravity

quantum fluctuations of spacetime

Inflation

primordial gravitational waves

imprints on the CMB (B-modes: "vortex" in polarization)
Inflation

**inflation** $\phi$

- dynamics of an homogeneous scalar field in a FRW geometry is given by

\[
\ddot{\phi} + 3H\dot{\phi} + V,\phi = 0 \quad \text{and} \quad H^2 = \frac{1}{3} \left( \frac{1}{2} \dot{\phi}^2 + V(\phi) \right)
\]

- inflation happen when potential dominates over kinetic energy (slow-roll)

$V(\phi)$

- where did $V(\Phi)$ comes from?
- why did the field start in slow-roll?
- why is the potential so flat?
- how do we convert the field energy into *particles*?
• According to single field, slow-roll inflationary scenario, quantum vacuum fluctuations excite cosmological scalar and tensor perturbations

\[ P_R(k) = A_s \left( \frac{k}{k_0} \right)^{n_s - 1} \]  

\[ P_T(k) = A_t \left( \frac{k}{k_0} \right)^{n_t} \]  

classify\( r = \frac{A_t}{A_s} \)

• with the definition of the tensor-to-scalar ratio “r”
Inflation

**matter**

- According to single field, slow-roll inflationary scenario, quantum vacuum fluctuations excite cosmological scalar and tensor perturbations

\[
\mathcal{P}_S(k) = A_s \left( \frac{k}{k_0} \right)^{n_s-1} \quad \text{scalar}
\]

\[
\mathcal{P}_T(k) = A_t \left( \frac{k}{k_0} \right)^{n_t} \quad \text{tensor}
\]

- with the definition of the tensor-to-scalar ratio \( r \)

\[
r = \frac{A_t}{A_s}
\]

which characterises the amplitude of GW and gives direct constraints on the shape of the potential

- energy scale of inflation

\[
V^{1/4}(\phi) \approx 10^{16} \text{GeV} \left( \frac{r}{0.01} \right)^{1/4}
\]

- inflaton field excursion

\[
\frac{\Delta \phi}{M_P} \approx \mathcal{N}_* \left( \frac{r_*}{8} \right)^{1/2} \approx \left( \frac{r}{0.001} \right)^{1/2}
\]

- derivative of the potential

\[
n_s - 1 \equiv \frac{d \ln \mathcal{P}_\zeta}{d \ln k} \approx -3M_{Pl}^2 \left( \frac{V_\phi}{V} \right)^2 + 2M_{Pl}^2 \frac{V_{\phi \phi}}{V}
\]
Primordial gravitational waves

Current status of the B-mode measurements

\[ r < 0.07 \text{ (95\% CL)} \]

[BICEP2 Collaboration 2018]

\[ r < 0.044 \text{ (95\% CL)} \]

[BICEP2+Planck [Tristram et al. 2020]]
Primordial gravitational waves

LiteBIRD Expectation

\[ \sigma_r < 0.001 \text{ (for } r=0) \]

LiteBIRD only
(no delensing)
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 $m_{pl}$

\[\text{Linde, JCAP 1702 (2017) no.02, 006}\]
Primordial gravitational waves

Full Success

- $\sigma(r) < 10^{-3}$ (for $r=0$, no delensing)
- $>5\sigma$ observation for each bump (for $r \geq 0.01$)

Statistical uncertainty

- foreground cleaning residuals
- lensing B-mode power
- 1/f noise

Systematic uncertainty

- Bias from 1/f noise
- Polarization efficiency & knowledge
- Disturbance to instrument
- Off-boresight pick up
- Calibration accuracy
A **cosmic variance limited** measurement of EE on large angular scales will be an important, and guaranteed, legacy for LiteBIRD.

\[ \sigma(\tau) = 0.002 \]

\( \sigma(\tau) \) better than current Planck constraints by a factor 2
Improvement in **reionization optical depth** measurement implies:

- $\sigma(\Sigma m_\nu) = 15$ meV
- determine neutrino hierarchy (normal v.s. inverted)
- measurement of minimum mass ($\geq 3\sigma$ detection NH, $\geq 5\sigma$ detection for IH)
Galactic science

With frequency range from 34 to 448 GHz and access to large scales, LiteBIRD will give constraints on:

- Characterisation of the foregrounds SED
- Large scale Galactic magnetic field
- Models of dust polarization grains

Synchrotron

Dust
LiteBIRD in a nutshell

L-Class JAXA Mission
Selected by JAXA (May 2019)
CNES Phase-A (end 2019)
Launch 2029

L2 orbit
All-sky Survey during 3 years
Large frequency coverage
15 bands 34 - 448 GHz
Resolution
LFT  70’ - 23.7’
MFT  37.8’ - 28.0’
MHFT 28.6’ - 17.9’
Sensitivity
2.8 uK.arcmin
after component separation (more than 100 times better than Planck in P)
The LiteBIRD mission

Payload

H3 Rocket

4.5 m

6.5 m

2.6 ton

Service Module

Payload Module

Cryo-chain

Passive Cooling

Active Cooling

LFT

LF-Focal Plane

Warm Readout Elec.

Sub-K Cooler

MHFT

MF + HF Focal Plane

Warm Readout Elec.

JPN

US

CA

EU

France

53 m

2.6 ton
Mission Challenges

- Statistics
  - Goal \( \delta r < 0.001 \)
- Observer bias
- Systematics
  - Mitigation and Control of Systematics
- High Sensitivity Detectors
- Lensing
  - Focused on largest multipole scales
- Foreground
  - Large frequency coverage from Space
- All-sky survey
  - Continuously Rotating HWP
Mission challenges

foregrounds

ESA and the Planck collaboration
The LiteBIRD mission

**frequency coverage**

15 bands from 34GHz to 448GHz

4676 detectors

9 bands LFT
5 bands MFT
5 bands HFT

with 4 overlapping bands
The LiteBIRD mission

Number of detectors: 4676
Overlap between telescopes

Lenslets

Platelets

focal plane

<table>
<thead>
<tr>
<th>MFT (2.5:1)</th>
<th>224 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>89 GHz</td>
<td></td>
</tr>
<tr>
<td>2075 detectors</td>
<td></td>
</tr>
<tr>
<td>366 Trichroic TES</td>
<td></td>
</tr>
<tr>
<td>488 Dichroic TES</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LFT (4.7:1)</th>
<th>161 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 GHz</td>
<td></td>
</tr>
<tr>
<td>1258 detectors</td>
<td></td>
</tr>
<tr>
<td>2 x (64 + 155) Trichroic TES</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HFT (2.7:1)</th>
<th>448 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>166 GHz</td>
<td></td>
</tr>
<tr>
<td>1355 detectors</td>
<td></td>
</tr>
<tr>
<td>2 x 254 Dichroic TES</td>
<td></td>
</tr>
<tr>
<td>338 Monochromatic TES</td>
<td></td>
</tr>
</tbody>
</table>
The LiteBIRD mission

Systematics

- telescopes and optics at 5K
- continuously Rotating Half-Wave Plates

focal planes at 100mK
CMB from space and ground

a powerful duo

Ground telescopes
30 ≤ ℓ ≤ 8000

LiteBIRD
2 ≤ ℓ ≤ 300
σ(r) < 0.001
CMB from space and ground

Extra Success

- improve $\sigma(r)$ with external observations
- delensing improvement to $\sigma(r)$ can be a factor $\geq 2$

Aiming at detection with $>5\sigma$ in case of Starobinsky model

Baseline
- delensing w/Planck CIB & WISE
- extra foreground cleaning w/ high-resolution ground CMB data
Synergy with other probes

- **Lensing**
  - LiteBIRD E-modes
  - CMB-S4 high-resolution
  - Improve our knowledge of the projected gravitational lensing produced by the large-scale structure

- **Integrated Sachs-Wolf effect**
  - Improvement on ISW signal (~20%)

- **Galaxy surveys**
  - Full-sky map of hot gas (thermal SZE)
  - 3D distribution of the matter (galaxy survey)
  - How gas traces the matter in the Universe
The LiteBIRD Collaboration

An international collaboration

More than 200 researchers from Japan, Europe & North America

The LiteBIRD Collaboration

An international collaboration

More than 200 researchers from Japan, Europe & North America


- Japan 34%
- Europe 49%
- US 14%
- Canada
About 100 members, including scientists experts on instrument and data analysis:

**France**
- APC (Paris)
- CEA-DAp (Saclay)
- CEA-SBT (Grenoble)
- ENS-LERMA (Paris)
- IAP (Paris)
- IAS (Orsay)
- IJClab (Orsay)
- Institut Néel (Grenoble)
- IPAG (Grenoble)
- IRAP (Toulouse)
- LAM (Marseille)
- LESIA (Meudon)
- LPSC (Grenoble)

**Italy**
- Università di Roma “Tor Vergata”
- Università di Milano
- Sapienza Università di Roma
- INAF/IASF, Bologna
- INAF/OATS, Trieste
- Università di Milano-Bicocca
- Università di Genova
- INFN-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 Society (MPA, MPE, MPIfR)
- Ludwig-Maximilians-Universität München
- Universität Bonn
- RWTH Aachen Universität

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

**Holland**
- SRON
- RuG

**Sweden**
- Stockholm University

**Norway**
- University of Oslo

**Ireland**
- Maynooth

**European Meetings**
- 06/19: Toulouse
- 04/19: Munich
- 11/18: Cardiff
- 10/18: Toulouse
- 04/18: Munich
- 02/18: Turin
- 10/17: Paris
- 07/17: Cardiff
Current French involvement

LiteBIRD-FRANCE

50 chercheurs
12 ingénieurs
Current French involvement

LiteBIRD-FRANCE

50 chercheurs
12 ingénieurs

Endorsement for LiteBIRD:
165 people
50 institutes
in Cosmology, Astrophysics, and Theoretical Physics
**CNES phase A2 (2019-2021)**

**US**
- Focal Plane
- Cold Readout Electronics

**Canada**
- Warm Readout Electronics

**UK**
- Optics

**Italy**
- HWP mechanism

**MHFT Mechanical Structure**
- 30K-5K cryo-structure

**Electronics & on-board software**
- Sub-K Cooler (LFT, MFT, HFT)

**Calibration**
MHFT (IN2P3)

CNES phase A2 (2019-2021)

**US**
- Focal Plane
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**Instrument Design & Management**

**MHFT Mechanical Structure**
- 30K-5K cryo-structure

**Electronics & on-board software**
- Sub-K Cooler (LFT, MFT, HFT)

**Calibration**
**Joint Study Groups**

- **systematics**
  - G. Patanchon (APC)
  - H. Ishino (IPMU)
  - J. Borrill (LBNL)

- **foregrounds**
  - N. Katayama (Japan)
  - R. Flauger (US)
  - C. Baccigalupi (Europe)

- **calibration**
  - T. Matsumura (Japan)
  - K. Arnold (US)
  - S. Henrot-Versille (IJClab)

- **Payload Module**
  - Y. Sekimoto (Japan)
  - K. Thompson (US)
  - B. Mot (IRAP)

**Performance Team**

- PI: Masashi Hazumi (JPN)
- PI-US: Adrian Lee (LBNL)
- PI-EU: Ludovic Montier (IRAP)

- Takashi Hasebe (Japan)
- Josquin Errard (APC)

**Data Management Group**

- Paolo Natoli (Italy)
- Matthieu Tristram (IJClab)

**Instrument Model Team**

**Simulation Team**

**Interim Governance Board**

- Interim Governance Board
- 40 members
  - (7 French including 4 IN2P3)

**LiteBIRD organisation (phase A)**

- PI: Masashi Hazumi (JPN)
- PI-US: Adrian Lee (LBNL)
- PI-EU: Ludovic Montier (IRAP)

**Science Ground Segment**

- under responsibility of the LiteBIRD international collaboration

**Collaboration bylaws**

- for phaseA under validation
  - (incl. governance, publication, configuration control, and data policies)
LiteBIRD @ IN2P3

- 3 labs (APC, IJClab, LPSC)
- 13 staff researchers
- 8 engineers

- CNES Task-sharing
  - responsible for the mechanical structure
  - responsible for the ground calibration

- LiteBIRD Management
  - Interim Governance Board (4 members)
  - Joint Study Groups (2 co-lead)
  - Data Management Group (1 co-lead)

- Large implication in science and forecasting studies
LiteBIRD is targeting one the **biggest discovery** of science in modern cosmology

- Primordial gravitational waves from inflation
  - B-mode power spectrum
  - Inflation energy (Full success / Extra success)
  - Constraints on the inflation potential
  - Beyond the B-mode power spectrum

- Cosmological parameters with E polarisation
  - Optical depth and reionization of the Universe
  - Elucidating low-$\ell$ anomalies with polarization

- Neutrino sector

- Cosmic birefringence

- Anisotropic CMB spectral distortions
- Galactic science
- Mapping the hot gas in the Universe
• The telescopes are designed in order to **overcome the challenges** related to the extreme sensitivity (reduction and control of systematics)

• The project is:
  - **selected** by the JAXA as the next Large Scale mission with a launch in early 2029
  - phase A undergoing at JAXA
  - **NASA** is under technology development. Participation needs to be consolidated
  - phase A is starting at CNES for the study of the Medium and High Frequency Telescopes
  - **ASI** commitment for a phase A
  - **ESA** is interested. Participation needs to be consolidated in the new context of M5 (SPICA is not selected).

| 2017 - 2019 | JAXA pre-Phase A |
| 2017 - 2019 | Class-L Mission Selection |
| May 2019 | JAXA Phase A1 |
| 09/2019 - 03/2022 | System Requirement Review |
| End 2021 | JAXA Phase A2 |
| 03/2022 - 03/2023 | Phase B (Preliminary design) |
| 03/2023 - 06/2024 | Phase C (EM development and tests) |
| 01/2024 - 09/2025 | Phase D (FM production and tests) |
| 09/2025 - 12/2028 | Launch |
| early 2029 | Mission Operation |
| 2029 - 2032 | 

current JAXA calendar
Conclusions

• LiteBIRD at IN2P3
  - Large involvement in the management
  - Responsibilities in the instrument hardware
  - Science Ground Segment: co-lead and need to increase!
  - Forecast and simulation: leader and need to increase!
  - Science Exploitation: expertise and interest in France (and at IN2P3 in particular)

• What we need from IN2P3
  - support: during phase A2 and for further phases (B, C, D)
  - manpower: PhD and Post-doc to increase IN2P3 participation to science and data analysis
  - help to keep the CMB community structured in France (keep expertise, increase scientific impact and relations between instrument/data-analysis/theory, relation with INSU & CEA)