PROCEEDINGS OF SCIENCE

The *LiteBIRD* Mission

Daniela Paoletti[a,b,*] **for the *LiteBIRD* Collaboration**

[a] *INAF/OAS Bologna, Osservatorio di Astrofisica e Scienza dello Spazio, Area della ricerca CNR-INAF, via Gobetti 101, I-40129*

[b] *INFN, Sezione di Bologna, Via Irnerio 46, I-40126, Bologna, Italy*

E-mail: daniela.paoletti@inaf.it

The *LiteBIRD* satellite (Lite satellite for the study of B-mode polarization and Inflation from cosmic background Radiation Detection) will perform a measurement of the cosmic microwave background polarization anisotropies on large and intermediate angular scales. Its sensitivity and wide frequency coverage in 15 bands will enable unprecedented accuracy in the measurement and foreground cleaning of the signal in B-mode polarization and a cosmic-variance-limited measurement of the E-mode polarization. Such data will have deep implications for cosmology and fundamental physics. The determination of the energy scale of inflation and constraints on its dynamics from B-mode polarization will shed light on one of the most important phases in the history of the Universe and the fundamental physics it implies. *LiteBIRD* measurements will also deepen our knowledge of reionization, allowing us to reduce the largest uncertainty in standard cosmology after-*Planck*, as well as to target some other major cosmological signatures, for example large-scale anomalies, parity-violating phenomena such as cosmic birefringence, and magnetism in the early Universe.

41st International Conference on High Energy physics – ICHEP2022
6–13 July, 2022
Bologna, Italy

PoS(ICHEP2022)085

1. *LiteBIRD* satellite

The Lite satellite for the study of B-mode polarization and Inflation from cosmic background Radiation Detection, *LiteBIRD*, represents the fourth generation of satellites dedicated to the observation and study of the cosmic microwave background (CMB) anisotropies. It will follow in the footsteps of its predecessors, starting with the first observation of CMB anisotropies with the COsmic Background Explorer (COBE) [1], then the Wilkinson Microwave Anisotropy Probe (WMAP) [2] and finally the *Planck* satellite [3]. The unprecedented sensitivity of *LiteBIRD*, its full-sky coverage and the foreground control given by its large frequency range will allow *LiteBIRD* to open the era of fundamental cosmology by crossing the final frontier of CMB anisotropy science, the measurement of CMB polarization. A review of the targets and the design of the *LiteBIRD* mission can be found in Ref. [4].

The *LiteBIRD* satellite is a JAXA L-class mission selected in May 2019, with a planet-wide collaboration spanning from Japan to North America to European countries. Its main goal is the high-precision measurement of CMB anisotropies in polarization on large and intermediate angular scales and in particular of the elusive primordial B-mode polarization signal. The expected launch is in late 2029 using JAXA's H3 rocket and *LiteBIRD* will perform an all-sky 3-year survey, in a Lissajous orbit around the Lagrangian point L2. The frequency range spans 40–402 GHz in 15 bands. The resolution of 10–18 arcmin is optimized for large and intermediate angular scales where most of the primordial B-mode polarization signal is expected. It will consist of three different telescopes onboard, a Low-Frequency crossed-Dragone Telescope (LFT) and two refractive telescopes mounted on a common structure, the Mid- and High-Frequency Telescopes, MHFT. The expected combined sensitivity is $2.2\,\mu K$arcmin and the presence of a half-wave plate modulator for each telescope will allow for reduction of the $1/f$ noise. The detectors will be multi-chroic transition-edge sensor (TES) bolometer arrays cooled to 100 mK.

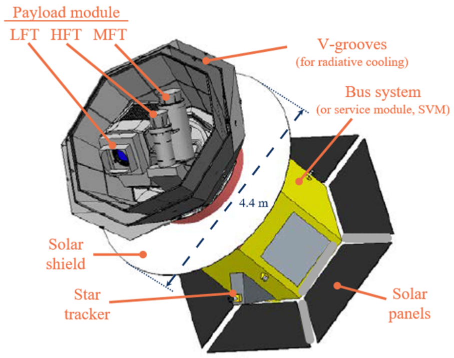

Figure 1: Scheme of the *LiteBIRD* payload

2. *LiteBIRD* and the CMB

The CMB is the relic radiation from the Big Bang, effectively emitted at the recombination epoch and almost isotropic except for small amplitude anisotropies of the order of $\Delta T/T \sim 10^{-5}$ in temperature, which represent the primordial inhomogeneities that seeded the large-scale structures we observe in the Universe today. The CMB is polarized thanks to Thompson scattering and the polarization can be analysed in terms of combinations of the Stokes parameters, with E and B modes representing the gradient and curl parts of the polarization pattern. E-mode polarization is generated by scalar cosmological perturbations, whereas B modes are the trace of inflationary gravitational waves or of exotic physics such as primordial magnetic fields or cosmic strings. The B-mode amplitude is not known a priori and if measured would provide crucial information on the

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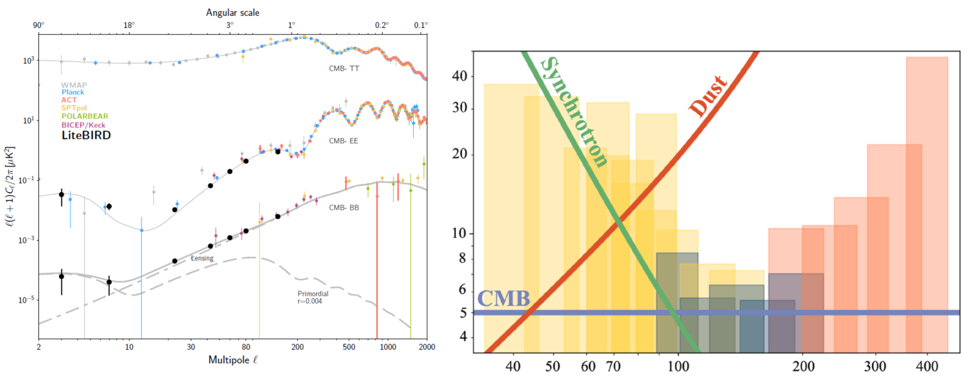

Figure 2: On the left, predictions of the error bars for *LiteBIRD* polarization measurements [4]. On the right, the frequency spectra of the expected astrophysical and cosmological signals in the microwave sky.

fundamental physics of the early Universe. The primary target of *LiteBIRD* is the measurement of a cosmic-variance limited E-mode polarization signal and the measurements of the B-mode polarization up to a limit in the tensor-to-scalar ratio of $r = 0.001$ in the worst case scenario [4]. The cosmic-variance-limited measurement of E-mode polarization on large and intermediate scales will have very strong implications for the study of the origin of large-scale anomalies, for the study of the dynamics of the epoch of reionization, for the determination of the initial conditions of cosmological perturbations and for beyond-standard-cosmological-model physics. The implications of a primordial B-mode measurement are enormous for fundamental physics, since it would provide knowledge of the inflationary mechanism and its energy scale. But in addition, as we will describe, B modes are also crucial for studying physics beyond the standard cosmological model, such as those containing parity violation or primordial magnetism.

3. The necessity of space

Although a space mission is limited both in size and weight, which in turn limits the number of detectors and telescope size, achieving the same sensitivity in space requires roughly two orders of magnitude fewer detectors than for a ground-based experiment. However, the main advantages of going into space are sky and frequency coverage. Only from space is it possible to measure the largest observable scales, where both the relevant E-mode and B-mode signals are boosted by the reionization bump. In addition, large-scale anomalies can be investigated only with full-sky coverage and therefore from space. At the same time a crucial point of the data analysis is the foreground subtraction, which is particularly relevant for the B-mode polarization whose signal is drowned by astrophysical contamination. The cleaning of the signal and extraction of CMB information relies on the different frequency dependencies of the contributing signals and requires a large frequency range. The atmosphere limits the high frequency range accessible from the ground, with frequencies higher than 200 GHz being dominated by thermal dust, the main contaminant for B-mode polarization, making space the only avenue possible to fully clean the B-mode signal.

4. Some examples of *LiteBIRD* science

In the following, we briefly mention some examples of the science that *LiteBIRD* will investigate.

Early Universe: Inflation is a crucial piece in the early Universe puzzle and is considered the baseline source of primordial B-mode polarization, which is not generated by standard scalar fluctuations but only by inflation or other exotic physics (CMB lensing also induces B modes, but this is a secondary anisotropy generated at late times on small scales). Therefore B modes can be considered the smoking gun of inflation, with their amplitude quantified in terms of the tensor-to-scalar ratio $r = \Delta_h^2(k)/\Delta_\zeta^2(2)$, which provides an insight into the energy scale of the inflation $V_* = (3\pi^2 A_s/2) r M_{Pl}^4$, and is one of the main observables for studying its dynamics. *LiteBIRD* will provide constraints at least at the level of $r < 0.001$, allowing it to significantly reduce the number of eligible inflationary models, as shown in Fig. 3. Predictions also show a significant detection of some standard models of inflation, such as the $R + R^2$ model [5], which predicts $r = 0.00461$, assuming $N_* = 51$.

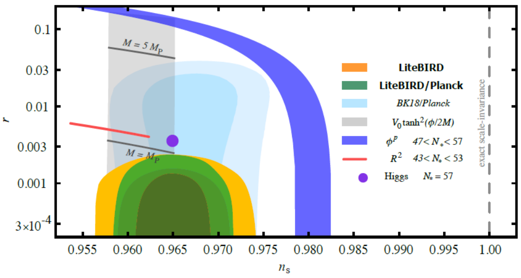

Figure 3: Contours in the 2D plane of n_s–r compared with inflationary slow-roll model predictions [4].

Beyond single field models-SU(2): *LiteBIRD* will allow us to study departures from the inflationary consistency of single slow-roll inflation and constrain a scale-dependent tensor power spectrum. An interesting case is the one with a combination of inflaton, axion and SU(2) gauge fields, where the axion and gauge fields are coupled with a Chern-Simons term and inflaton always dominates the energy density [6]. In this case the tensor power spectrum has a tilt-dependence related to the assumed model, as shown in the left panel of Fig. 4.

Cosmic Birefringence: Assuming the existence of a pseudoscalar field with a Chern-Simons term, this induces a rotation of the polarization plane of CMB photons through what is called cosmic birefringence. This will induce a B-mode polarization signal, but its most peculiar imprint on the CMB is the creation of non-zero odd cross-correlators, such as TB and EB, predicted to be null in the standard cosmological model. This effect can be measured by *LiteBIRD* with CMB-based estimators and analyses on the power spectra [7], but also new techniques are being developed in order to minimize the effect of the miscalibration angle [8]. Predictions indicate the possibility for *LiteBIRD* to detect a birefringence angle with a precision of $0.1°$.

Primordial Magnetism: Another relevant subject for B-mode polarization from *LiteBIRD* is the study of primordial magnetic fields (PMFs) generated in the early Universe that can source the cosmic magnetism observed in large-scale structures today. PMFs source independent cosmological perturbations and leave peculiar imprints in B-mode polarization, with some field configurations providing signals that can be confused with B modes from inflation (see right panel in Fig. 4 [9]). In addition PMFs modify the thermal and ionization history, leaving imprints also on the E-mode polarization. *LiteBIRD* will strongly constrain the amplitude of PMFs, breaking the nanogauss threshold.

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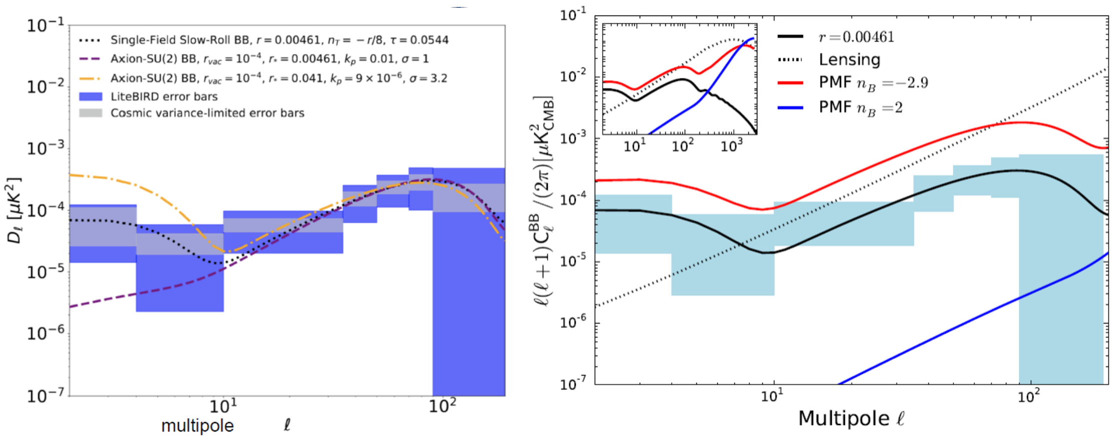

Figure 4: *B*-mode power spectrum from axion-SU(2) models on the left and PMFs on the right, both are compared with *LiteBIRD* sensitivity [4].

Reionization:The dynamics of reionization is still an open issue in cosmology, representing one of its greatest uncertainties through the integrated optical depth to reionization being the only parameter known worse than 1% after *Planck* [10]. In particular, reionization affects CMB anisotropies in temperature and polarization, with the peculiar imprints on large angular scales in the reionization bump in both *E*- and *B*-mode polarization. The measurement of cosmic-variance-limited *E*-mode polarization from *LiteBIRD* will allow us to break a good part of the degeneracies between the beyond-standard-cosmological-models and the history of reionization by constraining reionization from its large scale *E*-mode signal. This will improve the constraining power of the CMB on extensions to the standard cosmological model and provide crucial information on the dynamics of reionization itself [11].

Anomalies: The presence of anomalies on large angular scales was first identified by WMAP and then confirmed by *Planck*. Their significance lies around the 2–3 σ level, leaving open the possibility of them being statistical fluctuations [12]. In order to understand their origin and in particular if they are really sourced by primordial mechanisms related to the physics in the early Universe, *E*-mode polarization is crucial. Through the cosmic-variance-limited measurements of *E* modes, *LiteBIRD* will be able to shine new light on the different anomalies:

- low-ℓ lack of power (or lack of variance), *LiteBIRD* could indicate a non-standard inflation, e.g., violations in the slow-roll condition during inflation;
- alignments of low multipole moments, such as the quadrupole and octupole, not having random phases, but being correlated;
- hemispherical asymmetry or dipolar modulation, with current results being consistent with a modulation of power of around 7% on a particular range of scales, with the preferred direction $(l, b) = (209°;15°)$ with perhaps a hint of extensions to small scales;
- parity asymmetry, with the Universe being expected to be parity neutral. Some evidence for odd-parity preference for the largest multipoles exists;

- the 'Cold Spot', an anomalous temperature feature on angular scales of about 10 arcmin, with the structure centered at Galactic coordinates $(l; b) = (210°; -57°)$.

Overall the sensitivity and frequency range of *LiteBIRD* will allow us to measure CMB polarization and to clean the signal from astrophysical contamination with unprecedented accuracy. The high precision measurement of CMB polarization enabled by *LiteBIRD* will enable us to investigate several different regimes of physics beyond the standard cosmological model.

Acknowledgements

LiteBIRD (phase A) activities are supported by the following funding sources: ISAS/JAXA, MEXT, JSPS, KEK (Japan); CSA (Canada); CNES, CNRS, CEA (France); DFG (Germany); ASI, INFN, INAF (Italy); RCN (Norway); AEI (Spain); SNSA, SRC (Sweden); NASA, DOE (USA). DP acknowledges financial support by the agreement no. 2020-9-HH.0 ASI-UniRM2 "Partecipazione italiana alla fase A della missione LiteBIRD".

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