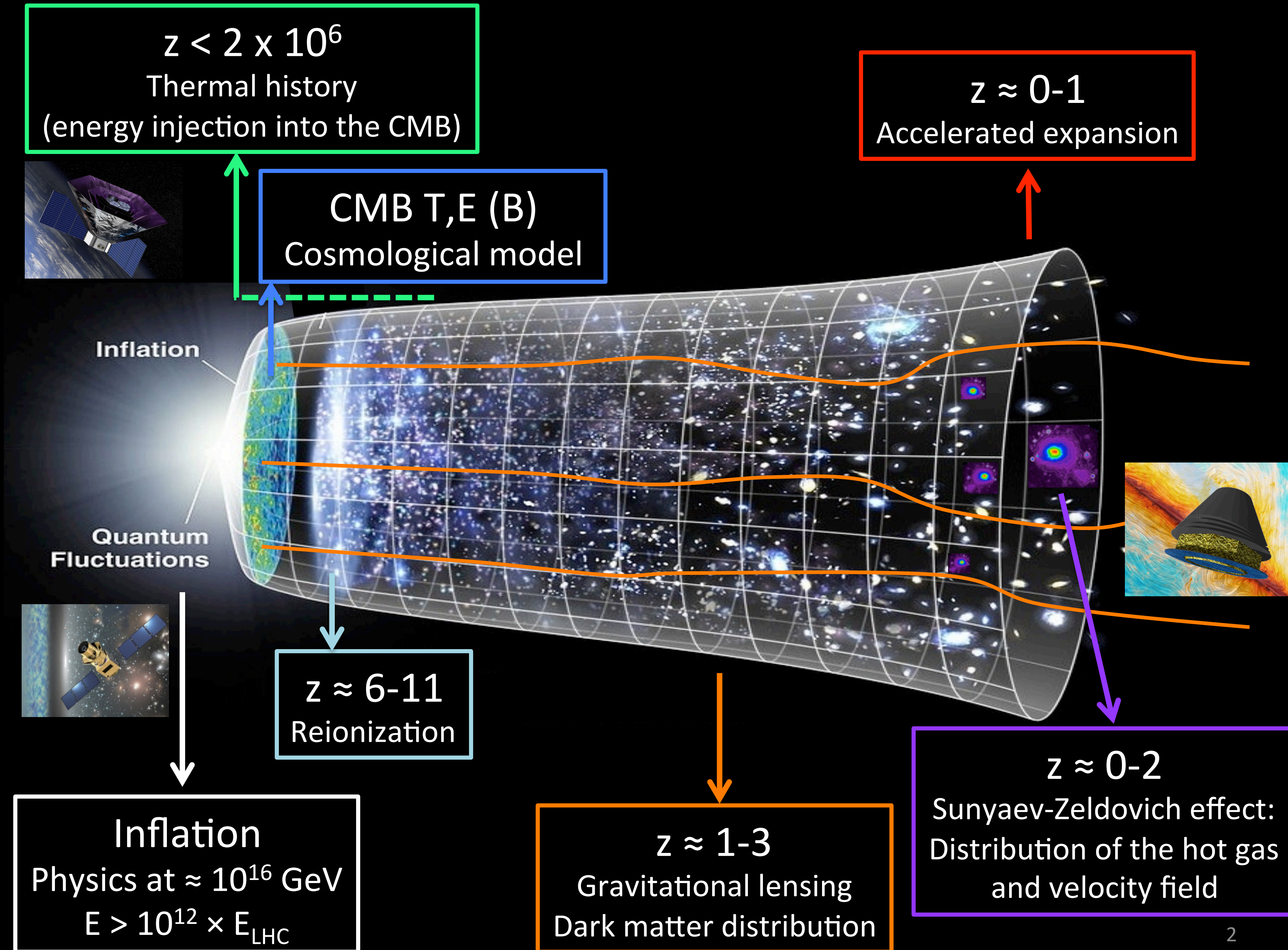
Mission spatiale de 4ème génération

Cas scientifique et défis expérimentaux

Jacques Delabrouille

Laboratoire APC, Paris
DAp, CEA-Saclay


z < 2 x 10^6
Thermal history
(energy injection into the CMB)
CMB T,E (B)
Cosmological model
z ≈ 0-1
Accelerated expansion
Inflation
Quantum Fluctuations
z ≈ 6-11
Reionization
Inflation
Physics at ≈ 10^{16} GeV
E > 10^{12} × E_{LHC}
z ≈ 1-3
Gravitational lensing
Dark matter distribution
z ≈ 0-2
Sunyaev-Zeldovich effect:
Distribution of the hot gas
and velocity field

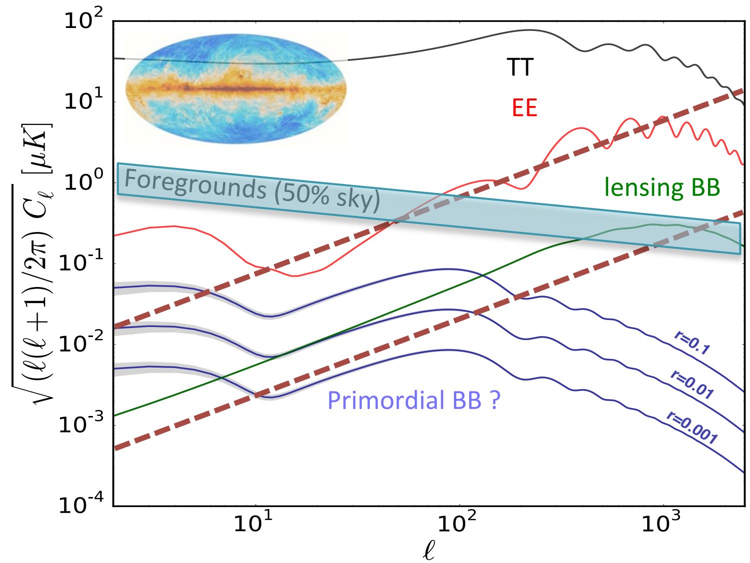
CMB polarization with CORE & "post-CORE" options

Primordial BB very important but uncertain:

- *foregrounds* are a potential killer at l < 10;
- *lensing* and foregrounds are issues at l≈80 ;
- *r could be << 0.001,* beyond detection capability.

CORE avoids these risks with:

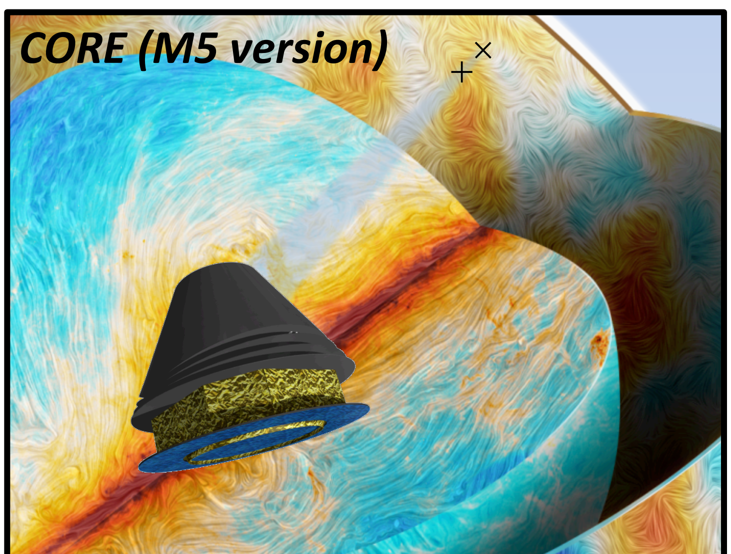
- primordial B-modes *down to fundamental limits,* after both de-lensing & foreground subtraction;
- *guaranteed* high-value **CMB polarization** science;
- *guaranteed* rich legacy.



Planck noise
50 μK.arcmin

1-2 μK.arcmin

space: 1000
ground: 100,000
detectors



Situation in 2017

CORE did not pass the ESA technical and programmatic screening for M5 in January 2017. The main issue was cost.

Drastic reductions of mirror and focal plane sizes do not solve the issue. An international partner seems necessary.

Activity for the coming 1-2 years (2018-2019)

- Investigate partnership with India for a joint mission to be launched post 2027 (e.g. in ≈ 2030). Encouraging preliminary contacts in 2017.

- Involvement of CORE consortium members to NASA CMB Probe study, in preparation for participation in a US-led mission post-2030.

Other CMB polarization projects

- **CMB-S4 (ground-based) in preparation in the US**
  - Objective: detect $r \geq 0.003$ or constrain $r < 0.001$ (95% CL)
  - 3 to 8% sky coverage for r, using fourteen 0.5m telescopes and one 6m telescope, 4x2 channels from 20 to 270 GHz; 240,000 detectors;
  - 40% sky coverage using two 6m telescopes (for N_{eff}); 140,000 detectors;
  - Budget 412 M$ + running costs; If funded, observations in 2027+ (Source: CDT document);
  - Leaves most of the CMB sky unobserved;
  - Largest scales impossibly (?) challenging; Observed sky probably anisotropically filtered;
  - Very limited high-frequency foreground monitoring.

- **LiteBIRD is in phase A in Japan**
  - Objective: $\sigma_r = 0.001$
  - One reflective and one refractive ≈30 cm cryogenic telescope with 5K rotating HWP;
  - Frequency coverage 40-400 GHz in 15 bands, most of CMB sensitivity between 140 and 200 GHz (where dust is the dominating foreground); Large scales only (FWHM 30'-60');
  - If selected by JAXA (decision ≈ end of 2018), launch foreseen in 2027+;
  - No de-lensing capability to detect the recombination bump for low r;
  - Limited high-frequency foreground monitoring (3 channels between 280 and 400 GHz, 20' beam). Detection of reionization bump is very challenging below the foreground emission.

- **Missing:**
  - **Full sky coverage with resolved CMB polarization (i.e. FWHM < 5');**
  - **Channels to monitor dust polarization, in particular on small scales;**
  - **Spectroscopy.**

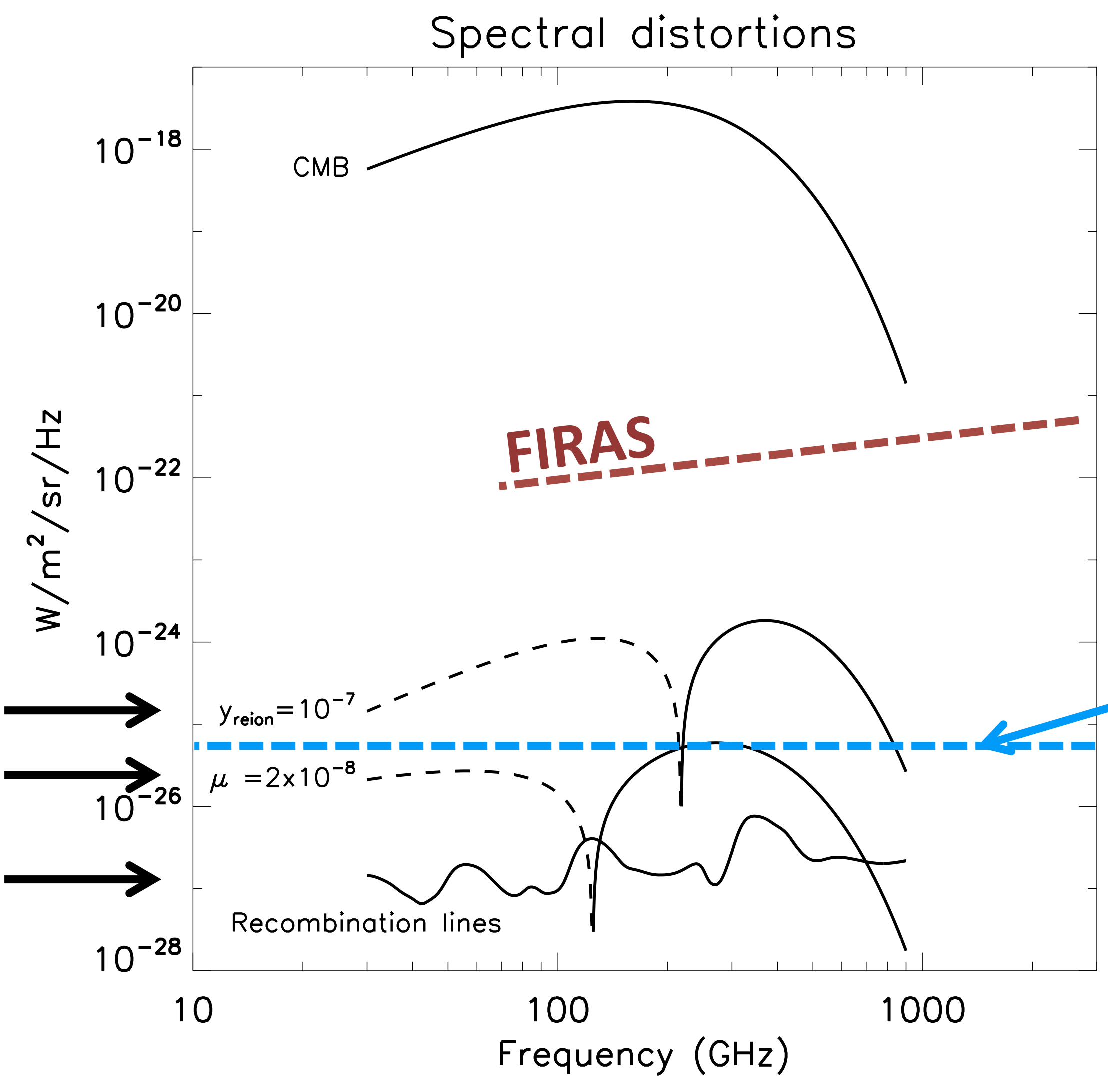
Requirements and challenges

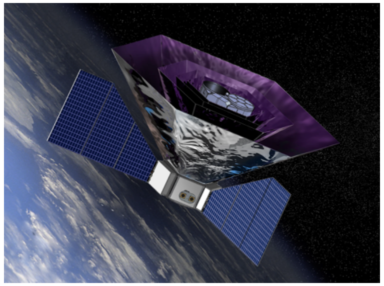
CORE satisfies this all

- Resolve the CMB over the full sky:
  - 1.5 meter class telescope in space to reach a few arcminute angular resolution.
- CMB Sensitivity of 1-2 μK.arcmin:
  - ≈2000 photon noise limited detectors (>200,000 from the ground) for 4 years of observation;
  - 40cm diameter focal plane cooled to 100mK in space (ground-based: many focal planes).
- Foregrounds and de-lensing:
  - a space mission is required (4 atmospheric windows only);
  - increased sky fraction requires increased foreground control;
  - observe the CIB for alternate de-lensing.
- Systematic effects and assessment of errors:
  - systematics minimization by design (best in space);
  - instrument calibration / characterization (best with one instrument in stable conditions);
  - redundancy (different frequency channels; independent sky patches; sub data sets).
- Absolute spectroscopy:
  - absolute calibration with a reference blackbody (technical challenge);
  - model and subtract foreground zero-level (CIB, dust, zodiacal light) to sub-percent accuracy !

PIXIE and CMB spectral distortions

CMB spectral distortions

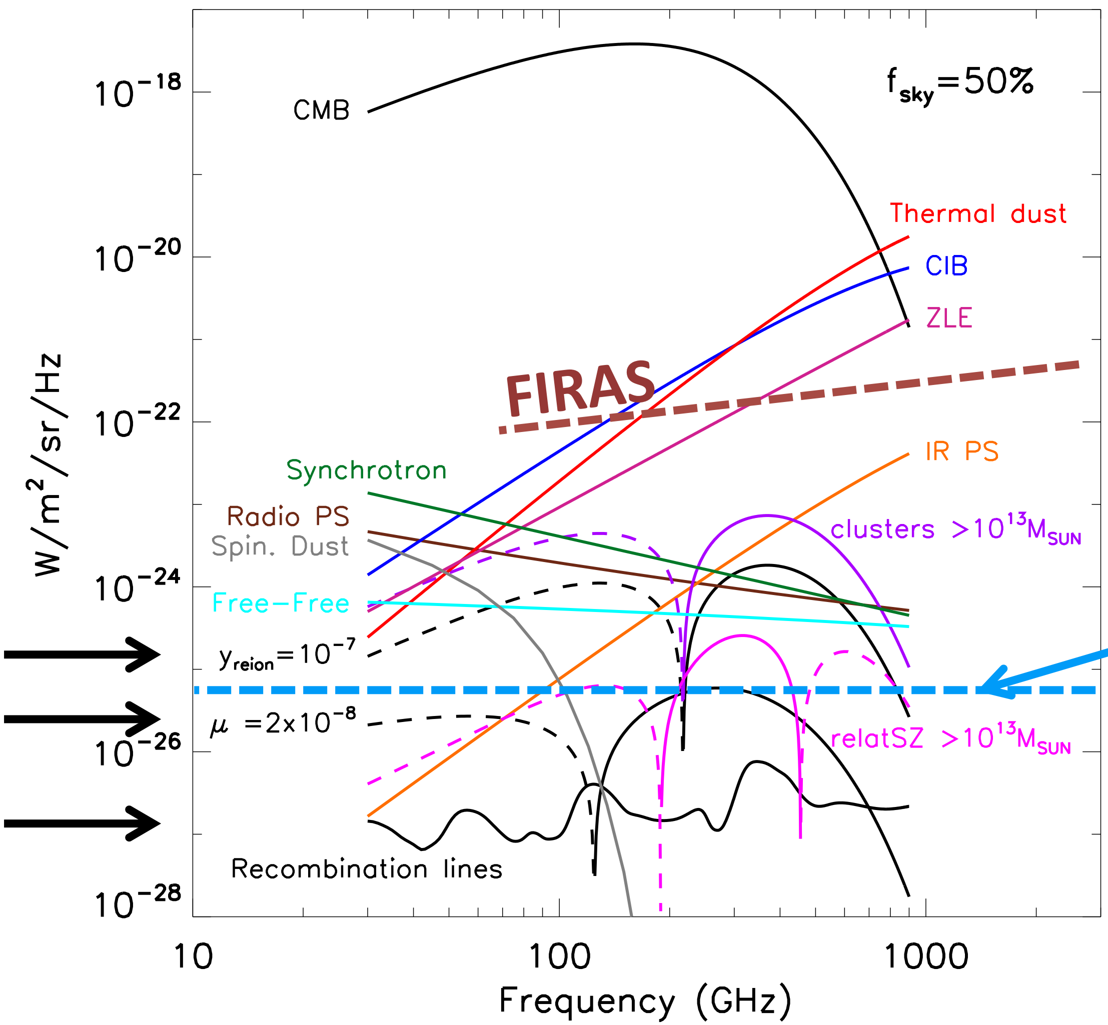


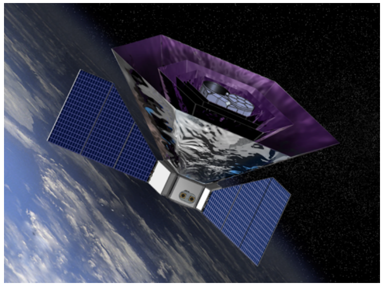


Noise
5 Jy/sr
(PIXIE)

PIXIE and CMB spectral distortions

CMB spectral distortions





Noise 5 Jy/sr (PIXIE)

Summary and plans

- The future of CMB observations still offers a very rich science case, which requires challenging observations.
- To address this science, CORE and PIXIE were strongly recommended in the French 2016 CMB roadmap (for good reasons).
- The non-selection of the CORE and PIXIE space missions leaves the CMB observational program with crucial gaps that are not covered by CMB-S4 or LiteBIRD as currently proposed:
  - full sky coverage on scales smaller than ≈1 degree is lacking;
  - full-sky de-lensing capability is lacking;
  - high frequency foregrounds monitoring is insufficient;
  - absolute spectroscopy reference is now 25 years old (FIRAS).
- At least another CMB space mission is needed to cover these gaps, possibly two!
- The future must be prepared, in an evolving context:
  - Discussions for a mission in partnership with India (ISRO) initiated; First contacts encouraging.
  - Ongoing study of a probe-class mission in the US;
  - In both cases, the option a dual-instrument (large imager + small spectrometer) is considered;
  - Optimization and feasibility work is ongoing;
  - Also time for the broader cosmology community to give input!

References

Space mission: "Exploring Cosmic Origins (ECO) papers" (special issue of JCAP)

DESIGN

- Mission: Delabrouille, de Bernardis, Bouchet et al. arXiv:1706.04516
- Instrument: de Bernardis, Ade, Baselmans et al. arXiv:1705.02170

SCIENCE

- Inflation: Finelli, Bucher, Achucarro et al. arXiv:1612.08270
- Lensing: Challinor, Allison, Carron, et al. arXiv:1707.02259
- Parameters: Di Valentino, Brinckmann, Gerbino et al. arXiv:1612.00021
- Clusters: Melin, Bonaldi, Remazeilles et al. arXiv:1703.10456
- Velocity: Burigana, Carvalho, Trombetti et al. arXiv:1704.05764
- Sources: De Zotti, Gonzalez-Nuevo, Lopez-Caniego et al. arXiv:1609.07263

PROCESSING

- Foregrounds: Remazeilles, Banday, Baccigalupi et al. arXiv:1704.04501
- Systematics: Natoli, Ashdown, Banerji et al. arXiv:1707.04224

Questions and answers

- Q: To fill the gaps mentioned in the talk, is it possible to upgrade LiteBIRD?
- *A: It has been attempted, but LiteBIRD is constrained by the science case initially accepted by JAXA, and by a general design that is largely frozen. A significant upgrade would require significant extra resources, and possibly a complete re-design, which also means delays. This is difficult to envisage in the present context of an on-going phase A.*

- Q: Is it necessary to observe a large fraction of sky?
- *A: Yes, for measuring the bump of reionisation B-modes, and for assessing the stationarity, gaussianity and scale-invariance of any detected B-modes. It also is essential for any science which is limited by cosmic variance (and more generally statistics), which is the case for the scientific exploitation of E-modes, for lensing science, and for de-lensing primordial B-modes contamination in particular. For an initial detection of primordial B-modes, a smaller patch of sky can be used (about 10% is appropriate).*