Designing future CMB experiments: how this will work

Short course: 101 level introductory course to provide a foundation for everyone coming to the workshop to understand the field.

Study visions and goals for workshop: leads present the targets to be achieved during the workshop, to be discussed and agreed to by participants.

Special topic presentations: define critical issues and open questions in 6 key areas that impact our ability to achieve future science goals. 2 areas will be discussed each day (Tue – Thu).

Breakout groups: these will be formed to address more specifically some of the specific issues raised in the preceding topical talks, and generate ideas to address them. Up to 3 groups will be formed each day.

Lightning talks: these short presentations are intended to augment our understanding of specific topics of importance as they arise during the meeting. They will be selected from a list that will be started on Day 1 and added to as we progress.

Remember to document discussions and ideas on the wiki – https://kisscaltech.pbworks.com/n/

Beyond the meeting: we aim to generate a white paper summarising the outcome of the meeting for the community, and continue to collaborate on solutions to key problems that have been formulated during the week.

What the workshop is not:
the intent of the workshop is not to design the ultimate CMB mission.

However, we will discuss relevant issues enabling us to answer the following questions:

- **Do we know how to pose the right questions to define such a project?**
- **Do we have sufficient information and tools to answer these questions?**
- **What do we need to do to answer yes to the above?**
- **How can these efforts towards future projects serve existing programs?**

What the workshop is:
an opportunity to bring together a diverse audience with different perspectives to gain insights into science questions, enabling technologies, and mission strategies, then to build collaborations required to allow an ultimate mission to be defined at a suitable later time.

Designing future CMB experiments: targets for the workshop

Science rationale

Identify specific issues where theoretical/observational/methodological progress is critically needed. [Focus of the topical presentations]

Proposed paths for advancement

Steps to be taken to address these issues - new theoretical treatments, observations, technology development programs. [Focus of the breakout groups]

Recommendations

Tools for the community, observation programs, proposals to support technology development. [Report from the meeting - a white paper, plus ongoing collaborations working towards scientific papers]

Designing future CMB experiments: why now?

Many programs to measure CMB polarisation are in progress or have been proposed. From the space perspective

CORE (Cosmic Origins Explorer): not selected after proposal to ESA's M5 call. This followed previous proposals COrE+, COrE and B-pol. The concept may be re-proposed to a later ESA call supported by ISRO (Indian Space Research Organisation).

LiteBIRD: proposed to JAXA in 2008 and currently in Phase-A study in Japan in collaboration with a team from the US. Comprising two telescopes the LFT and HFT, the latter of which a European consortium may take responsibility for.

PIXIE: a Fourier transform spectrometer to observe in 400 narrow frequency bands between 30 GHz and 6 THz, proposed to measure both CMB polarisation and spectral distortions of the background. Although PIXIE was not selected for NASA's Midex program, a follow-up project PRISTINE is under investigation.

PRISM: was proposed to ESA in 2013 as a possible large mission. It included a broad science case, comprising both CMB polarisation and spectral distortions.

PICO: an initial study is underway for a "Probe-class" mission.

Designing future CMB experiments: why now?

Many programs to measure CMB polarisation are in progress or have been proposed. From the ground

CLASS: degree scale experiment w/ dozens of horn antenna-coupled TES bolometers, operating at 100 mK in four bands 40, 90, 150, 220 GHz on 1m-class telescopes in the Atacama.

QUBIC uses bolometric interferometry, will observes the sky at two frequencies, 150 and 220 GHz, from the Atacama.

QUIJOTE: degree-scale polarimeters which uses horn-coupled HEMT amplifiers at 11, 13, 17, 19, 31, 41 GHz observing from the Canary Islands.

Polarbear2/Simons Array: array of three 3.5m diameter telescopes feeding broadband sinuous antenna-coupled TES bolometers at 90,150, 220, and 280 GHz from Atacama.

BICEP2, Keck (analysis nearing completion) BICEP 3 and Array: BICEP3 consists of a single telescope with the same 2560 detectors (observing at 95 GHz) as the five-telescope Keck array, but a 68 cm aperture. BICEP array will be a set of four such telescopes.

SPT3G: 16K sinuous antenna-coupled TES bolometers, operating at 95, 150, 220 GHz on the 10m diameter SPT at the South Pole.
Simons Obsservatory: >50,000 detectors, operating at 100mK on 6m and 0.5m telescopes in Chile

Advanced ACTpol: 8K horn antenna-coupled TES bolometers, operating at 100 mK in four bands 95, 150, 220 GHz on the 6m diameter ACT telescope in the Atacama.

Designing future CMB experiments: why now?

Many programs to measure CMB polarisation are in progress or have been proposed. From the balloon perspective

EBEX: **is a balloon-borne polarimeter designed to measure the intensity and polarization of the cosmic microwave background radiation. A second flight is being proposed.**

SPIDER: **six degree-resolution telescopes cooled to liquid Helium temperature (4 K) which observe at frequencies of 100 GHz, 150 GHz, and 280 GHz. Each telescope is coupled to a polarisation-sensitive transition-edge bolometer array cooled to 300 mK. Fflew in 2015 and will fly again in 2018.**

PIPER: **Observing the *whole* sky at four different frequencies — 200, 270, 350, and 600 GHz**

Designing future CMB experiments: why now?

These mission concepts differ in
•sensitivity
•frequency coverage
•number of detectors

where the differences are driven by
•mission-specific science targets
•differing assumptions about the level and complexity of foregrounds
•the range of frequencies required to clean the CMB from contamination
•the treatment of delensing

These are all issues to be addressed in this workshop – we hope that exploring innovative ideas and methodologies aiming at assessing properly the impact of the presence of foreground residuals, lensing-induced B-modes, and instrumental systematics in the CMB maps will help to understand what performances can be achieved given novel experimental designs.

Topic 1: What does it mean to talk about an ultimate CMB mission?

Leads: K.M. Gorski, J. Delabrouille, C. Lawrence

Possible discussion topics:

- **How do we define science drivers for an ultimate mission?**
- **How do we balance the trade-offs between primary science (e.g. Which value of the tensor-to-scalar ratio is reasonable to pursue) and secondary science (e.g. clusters)?**
- **How do these issues affect mission design criteria (the telescope, detectors, scanning strategy, observation frequencies, sensitivities, ….)?**

Topic 2: Systematics

Leads: B. Crill, A. Kogut, J. Bock, M. Tristram

Possible discussion topics:

- **Is there a need for a half-wave plate (HWP)?**
- **Minimising bandpass leakage**
- **Strategies to minimise/control instrumental polarisation**
- **Optimal calibration strategies for large numbers of detectors**
- **Calibration sources**
- **The interplay between systematic errors and foregrounds.**

Topic 3: Foregrounds

Leads: B. Barreiro, I. Wehus, R. Flauger, B. Hensley

Possible discussion topics:

- **Do we know enough about the statistical properties and frequency behaviour of the foregrounds?**
- **What is the relative importance of synchrotron emission compared to dust?**
- **Are dedicated observations are necessary to improve our understanding?**
- **What are the implications for mission design?**
- **Are current sky models (e.g. the PSM) adequate?**
- **Are existing component separation methods adequate?**
- **How do we treat residual foregrounds in further analysis?**

Topic 4: Lensing

Leads: A. Challinor, O. Doré

Possible discussion topics:

- **Optimising delensing strategies**
- **delensing via the CMB vs. alternative lensing templates (e.g., CIB, SKA continuum survey, galaxy surveys etc.)**
- **problems introduced by residual foregrounds and systematics**
- **handling imperfect delensing in further analysis.**

Topic 5: Polarised sources

Leads: B. Partridge, B. Barreiro, I. Wehus, S. Myers

Possible discussion topics:

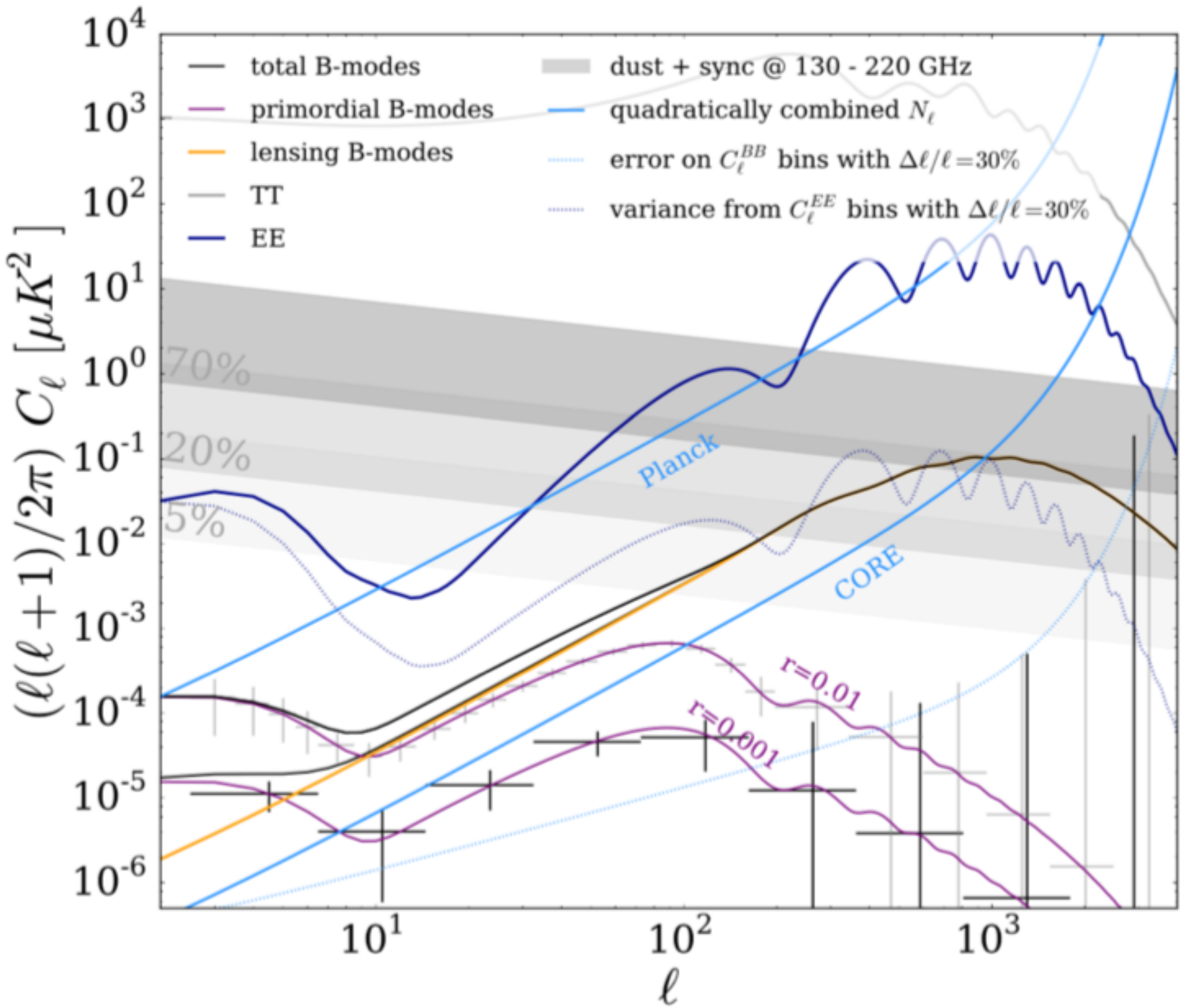
- are polarised sources a problem for future CMB missions?
- how well do we know the source populations contributing at microwave wavelengths (e.g. spectra, polarisation fractions and variability)
- are new observation programs needed to improve this knowledge (including observations concurrent with CMB measurements)?
- optimal blind methods for source detection in CMB observations (maps and/or timelines)
- non-blind source identification using deep catalogues of compact sources (detected with high resolution telescopes or interferometers)
- optimal methods for source subtraction (maps and/or timelines)
- how to handle source residuals in further analyses?

Topic 6: Methods

Leads: J. Jewell, G. Rocha, A. Mangilli, I. Wehus

Possible discussion topics:

- **how adequate are current statistical methodologies for the estimation of cosmological parameters (r and tau)?**
- **how well do these methods allow marginalisation over systematics and foreground residuals?**
- **discuss the need to develop novel methodologies that bypass Likelihood approximations e.g. Bayesian method (‘sampling-based’) for parameter estimation**
- **do we need new methods to tackle systematics and their interplay with foregrounds, CMB de-lensing, etc.**
- **what is the role of simulations, and are current simulation tools sufficient?**



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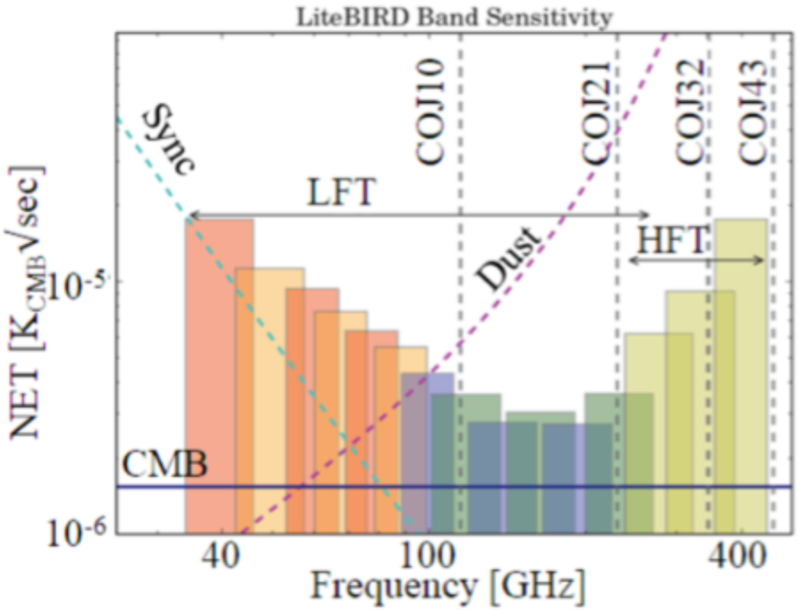
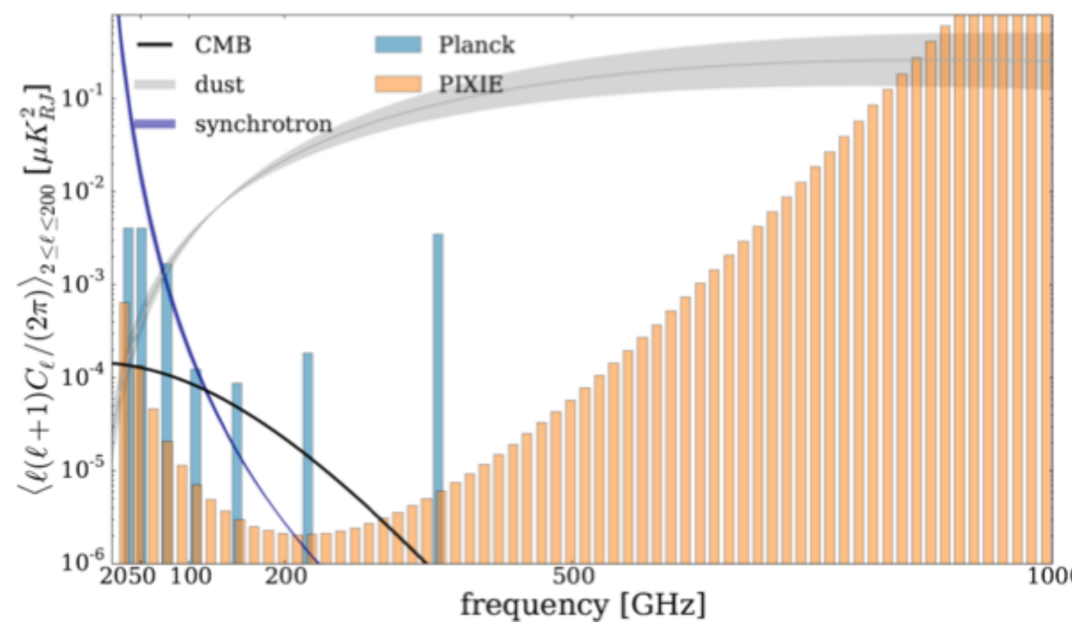
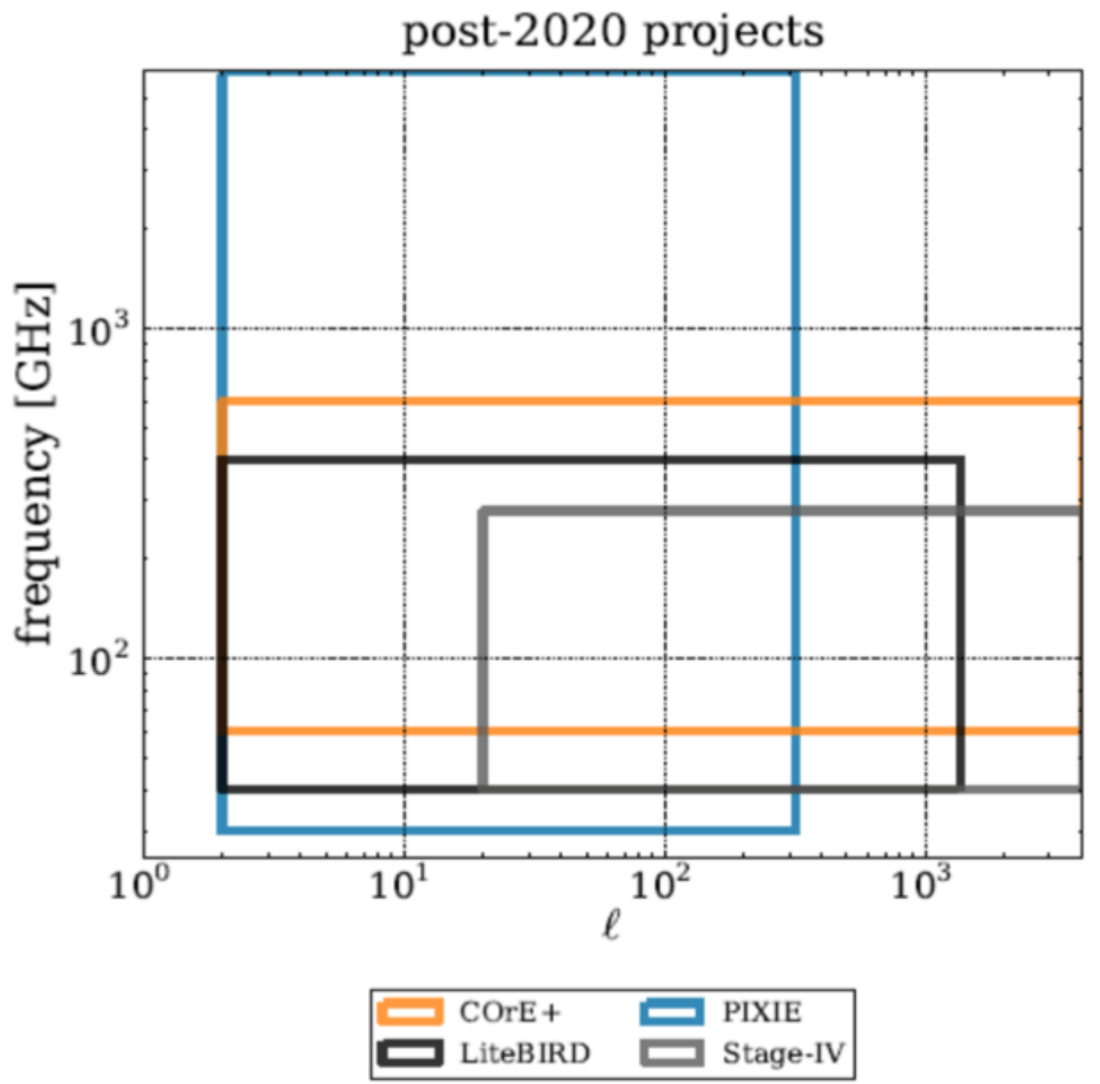


arXiv:1801.06987

Courtesy: J. Errard





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