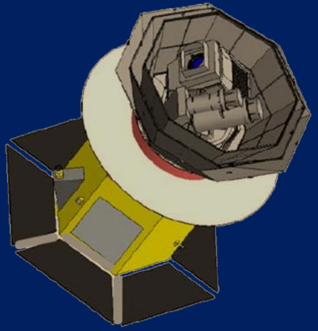
Panel 7: “Space and Ground complementarity”

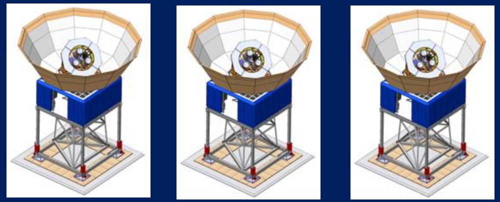
LiteBIRD

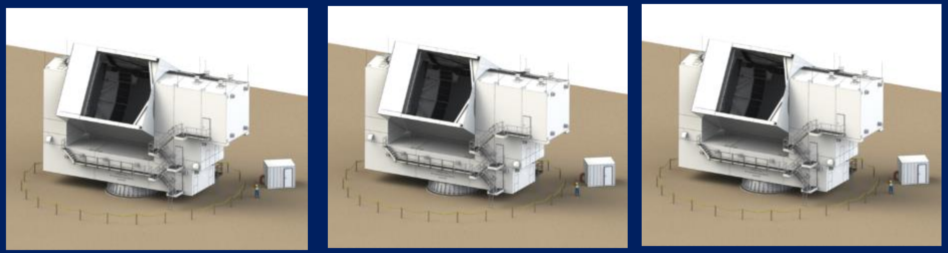


Lensing map & high-resolution polarization maps
to mitigate lensing B-mode noise

Multi-frequency large-scale polarization maps
to mitigate Galactic foregrounds B-mode

CMB-S4





Masashi Hazumi

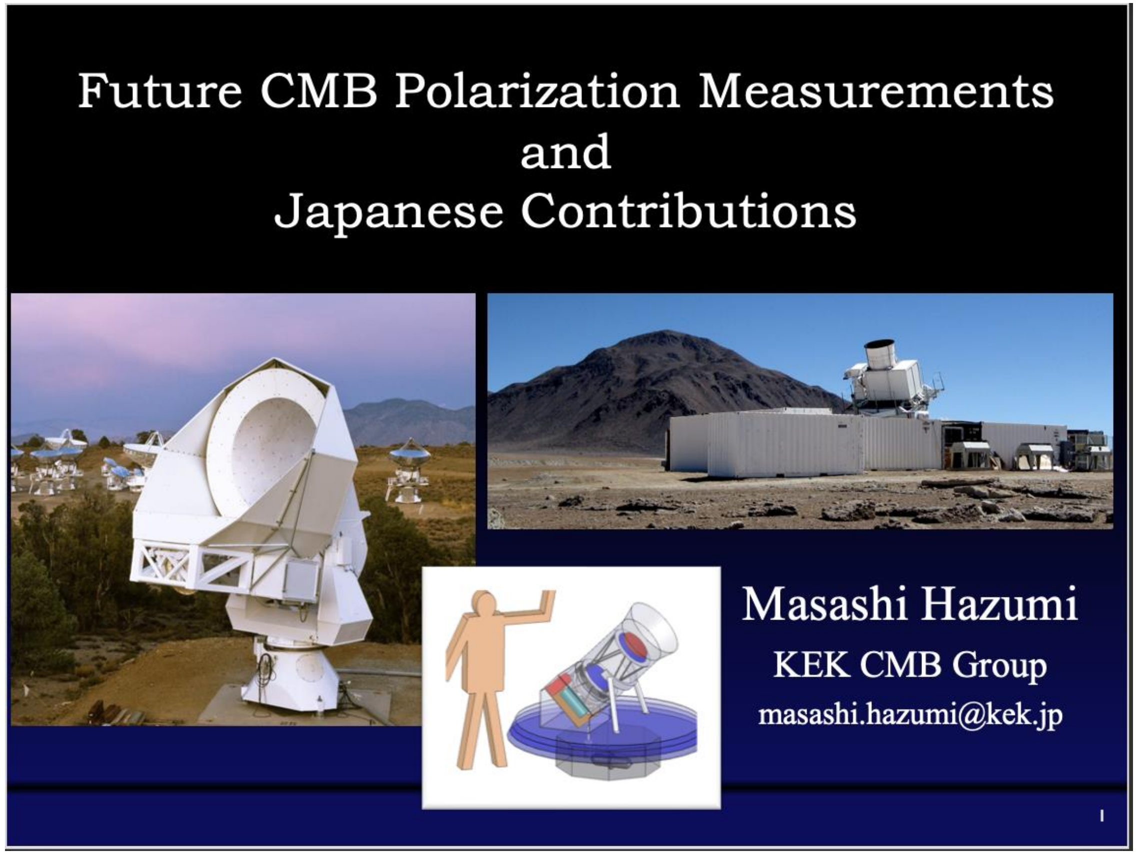
High Energy Accelerator Research Organization (KEK), Japan
and
Department of Physics and Center for High Energy and High Field Physics (CHiP),
National Central University (NCU), Taiwan

YKIS2010 symposium

Cosmology -- The Next Generation --

28 June (Mon) - 2 July (Fri), 2010

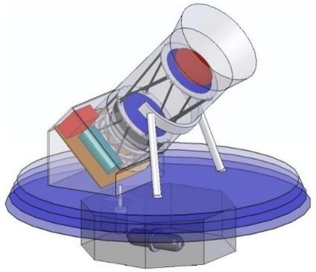
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto



Realizing the "powerful duo," i.e., a relatively small satellite and a massive ground array, remains the best strategy.

Powerful Duo

A fast-track cost-effective solution



Small satellite (LiteBIRD)

low l

high l

Ground-based superconducting CMB cameras, where you can use cutting-edge technologies

Q: Satellite needed if PGW discovered on ground ?

A: Yes ! for power-spectrum meas. (e.g. tensor spectral index)

→ further quantitative tests of inflation and quantum gravity

Driving scientific objective remains the same

Search for primordial gravitational waves

Huge discovery impacts

- Direct evidence for inflation
- Knowledge on the inflation energy scale
- First evidence for quantum fluctuation of space-time

Insight on quantum gravity, including String Theory

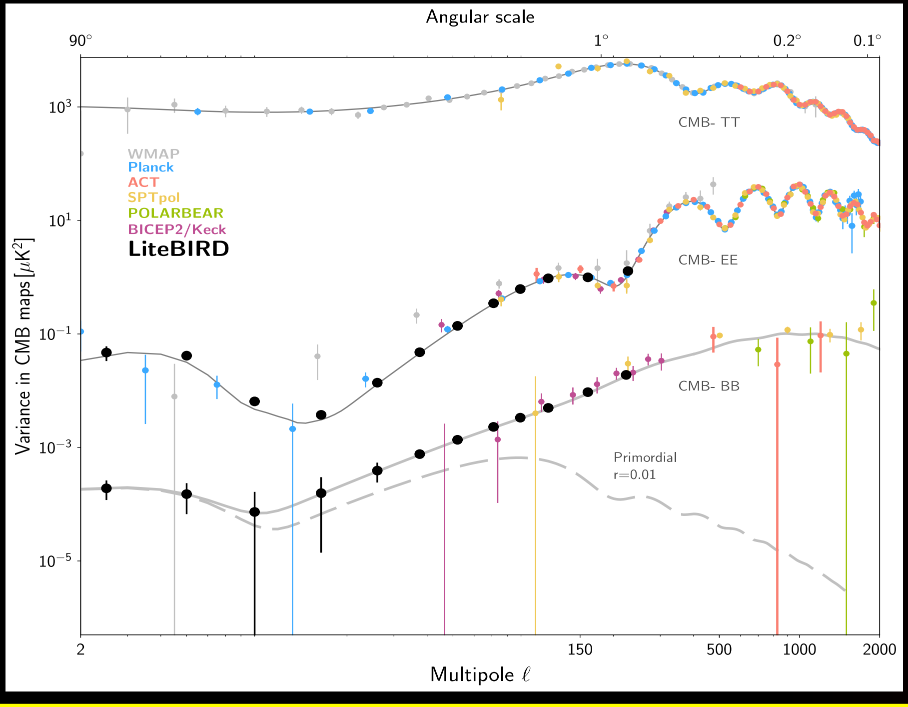
"Detecting primordial gravitational waves would be one of the most significant scientific discoveries of all time."

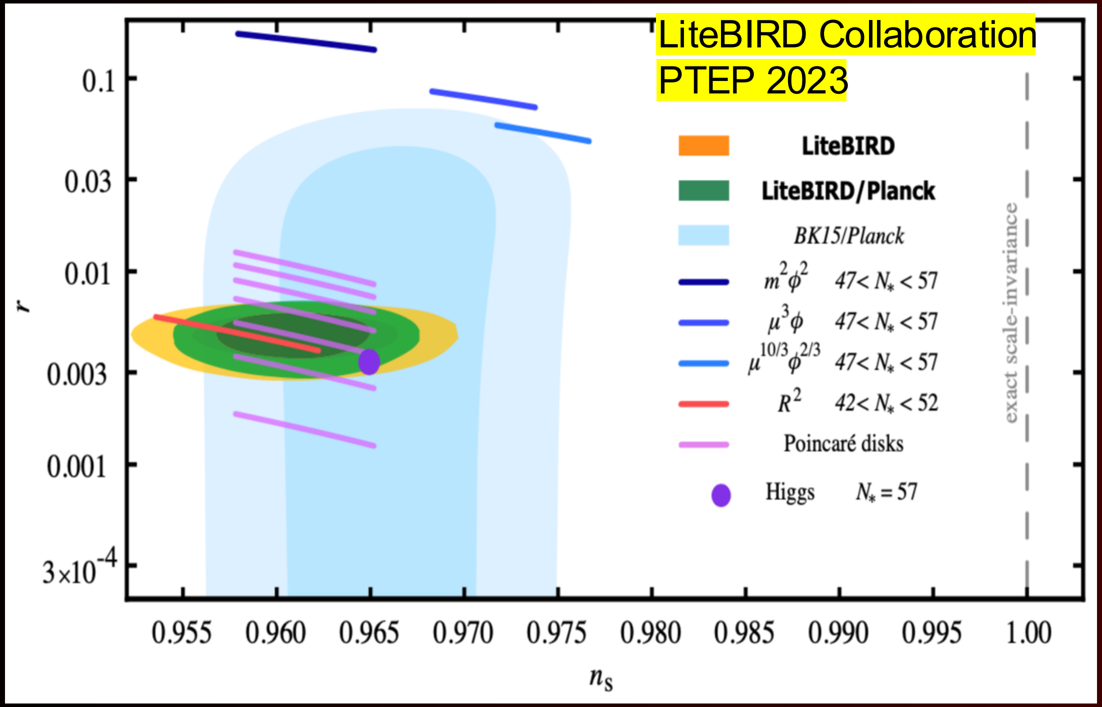
Final report of the task force on cosmic microwave background research "Weiss committee report" July 11, 2005, arXiv/0604101

The next important target is δr < 0.001, where δr includes the statistical and systematic errors, as well as the observer bias

Search for primordial gravitational waves

Current limit:
$r < 0.032$ (95% C.L.)
(M. Tristram et al. 2021, combining Bicep2/Keck 2018 and Planck PR4 data set)

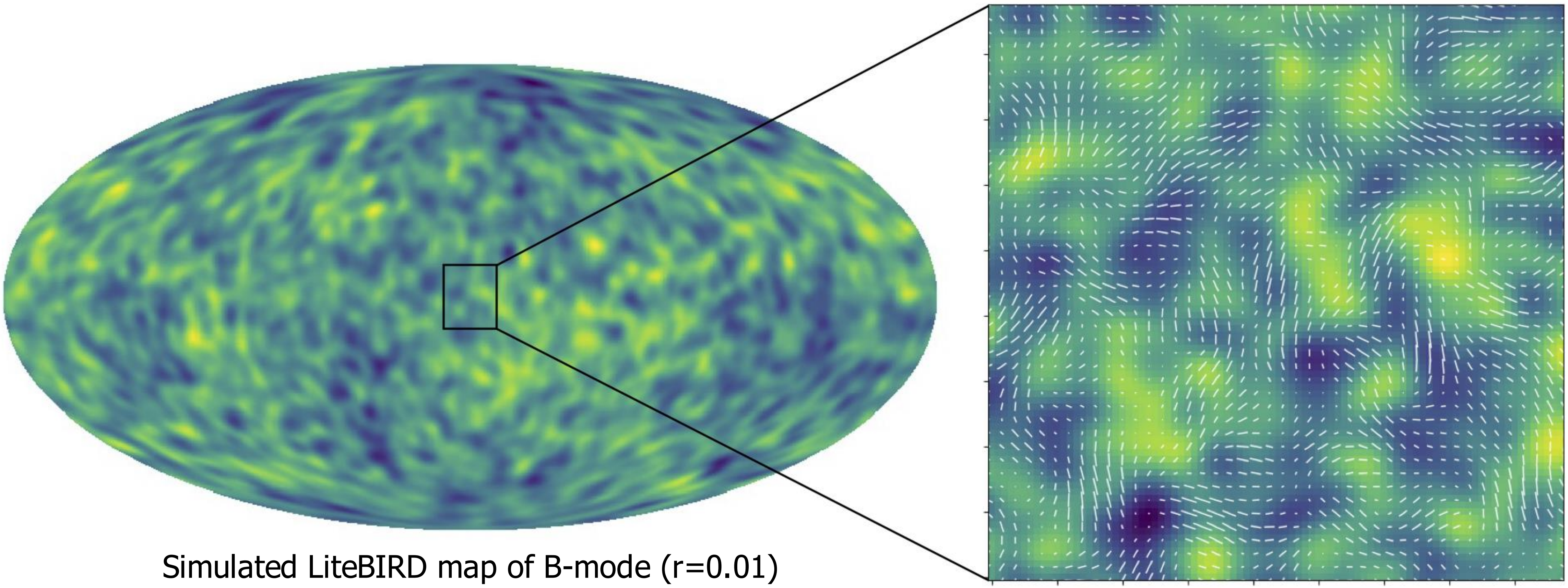




<u>Rationale for δr < 0.001</u>

- Large discovery potential for $0.003 < r < 0.03$
- Clean sweep of single-field models with characteristic field-variation-scale of inflaton potential greater than the Planck mass (A. Linde, JCAP 1702 (2017) no.02, 006)
  - Simplest and well-motivated $R+R^2$ “Starobinsky” model will be tested.

Simulated LiteBIRD B-mode map



Simulated LiteBIRD map of B-mode (r=0.01)

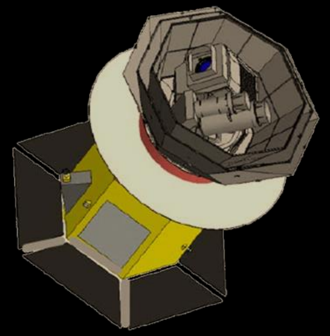
CMB-S4 & LiteBIRD complementarity

- New MoU signed in 2023
- Two lines of analysis for the CMB-S4 x LiteBIRD joint study:

✓ **CMB-S4**: Improving σ_r by foreground cleaning using LiteBIRD multi-frequency data

✓ **LiteBIRD**: Improving σ_r by delensing using CMB-S4 data (and other external tracers)

LiteBIRD



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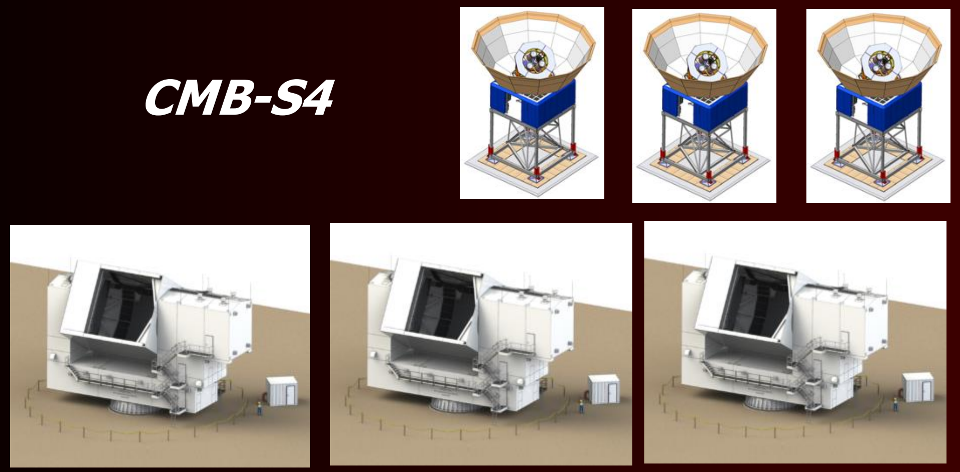
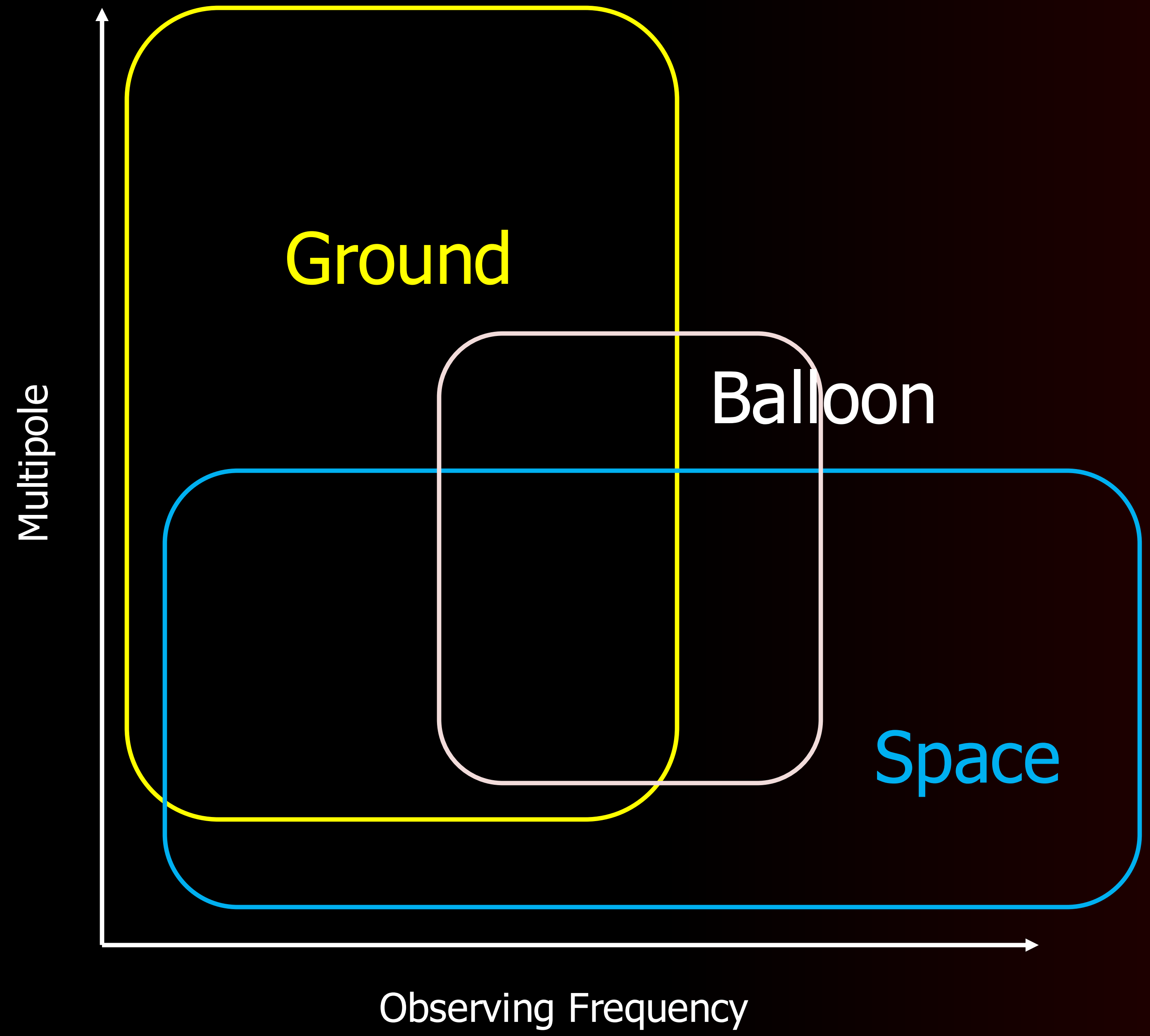


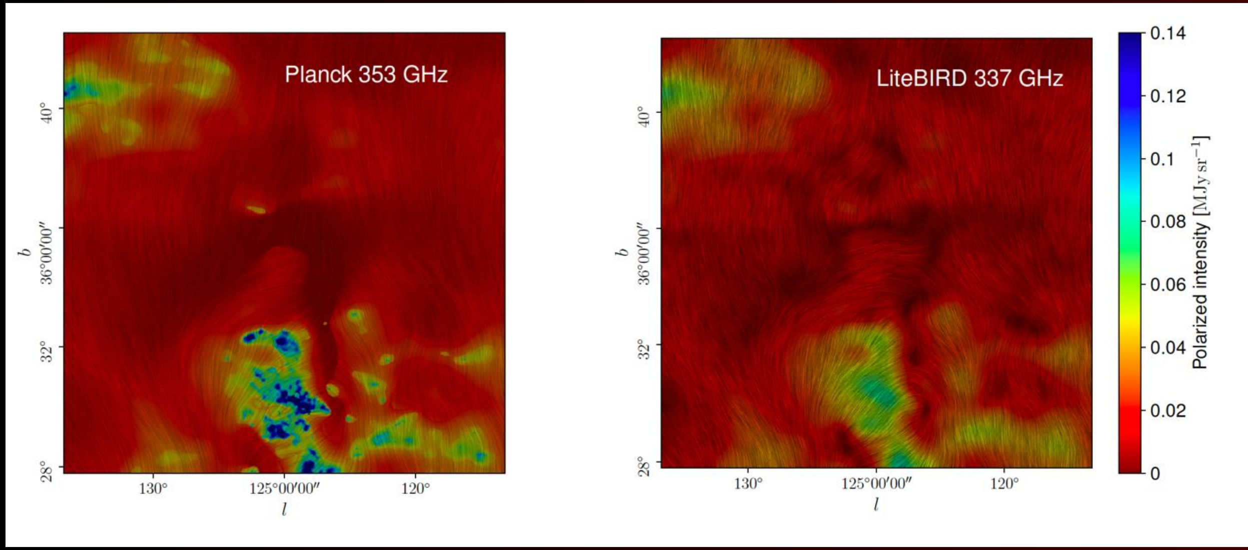
The current MoU focuses on the above two analyses. There are many synergies between CMB-S4 and LiteBIRD to be explored, including systematic uncertainties, calibration, and detector development.

See presentation by Francesco Piacentini on LiteBIRD instrument and reformation plan


Ground
Balloon
Space
Multipole
Observing Frequency

Foreground Cleaning

- See presentations and discussion at Panel 5 "Foregrounds".
- Our scope is foreground "cleaning", not a physical understanding of foregrounds.
  - Physical understanding of foregrounds, including the nature of galactic magnetic fields and interstellar dust, is perhaps even more challenging and has its own value. LiteBIRD can contribute to it. →

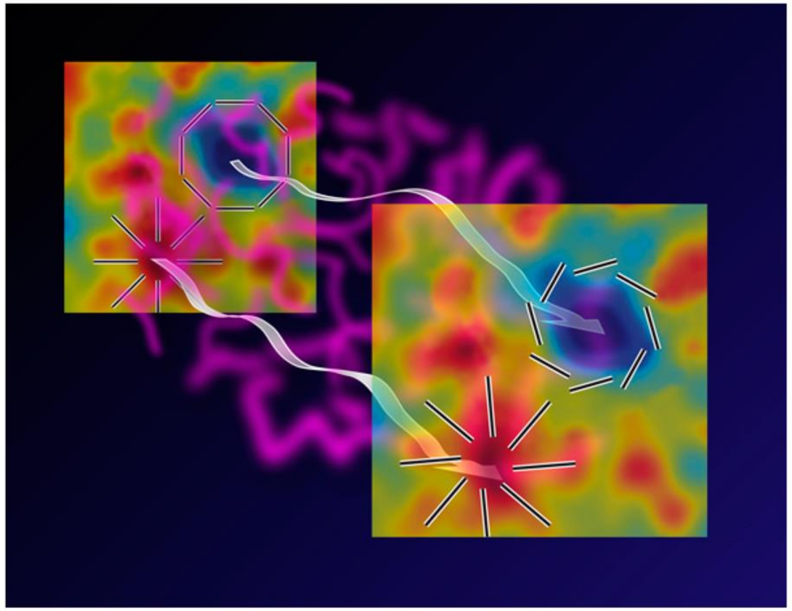


- Requirements flow for CMB-S4 and LiteBIRD are inevitably affected to some extent by the foreground uncertainties. ☹
- Ongoing projects, including Simons Observatory, will provide precious lessons learned on foreground cleaning ☺

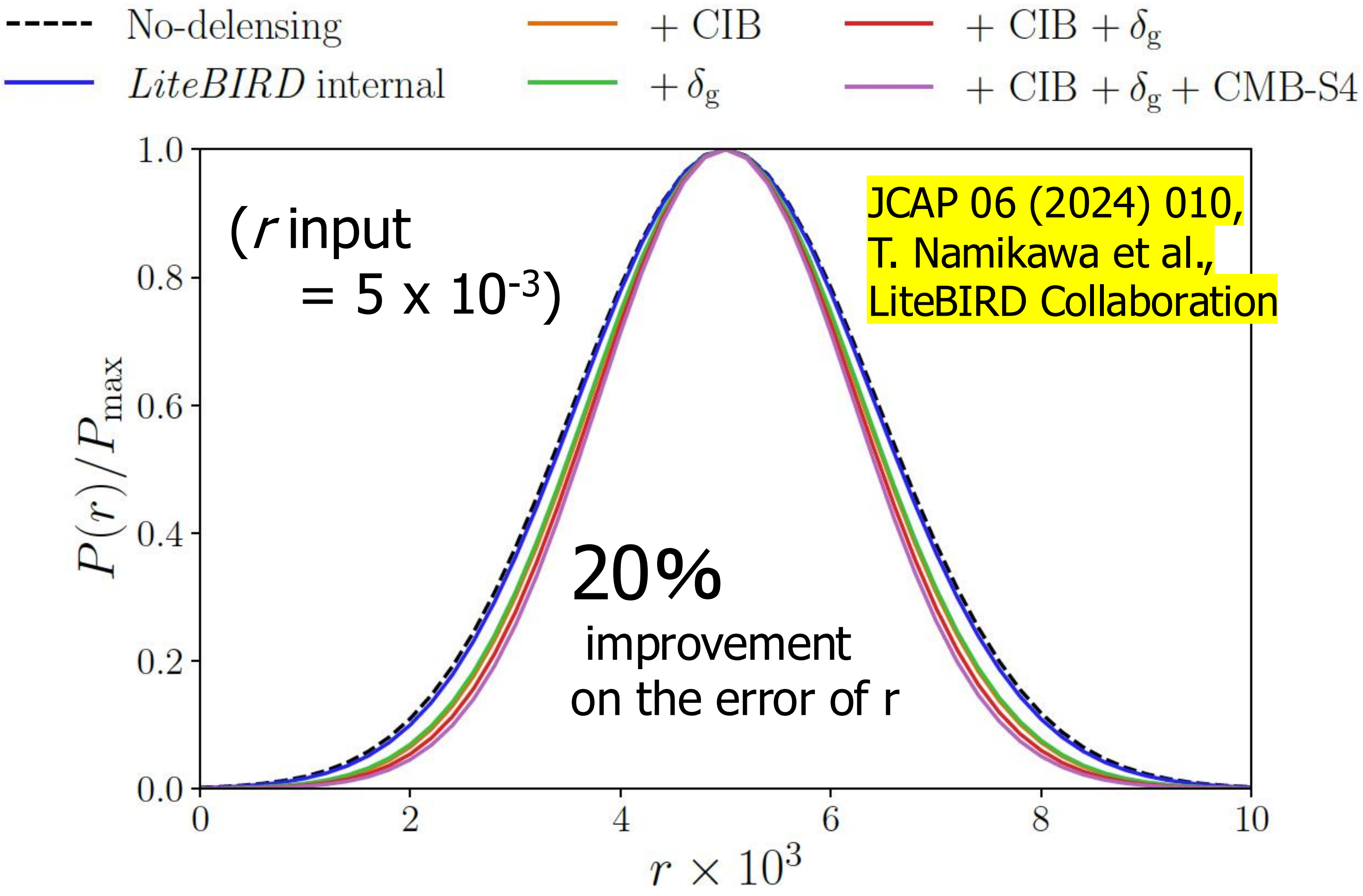
See presentation by Lyman Page

Improving δr with Multitracer Delensing

- LiteBIRD's full success does not rely on delensing to fully control its mission.
- External data can improve δr further.



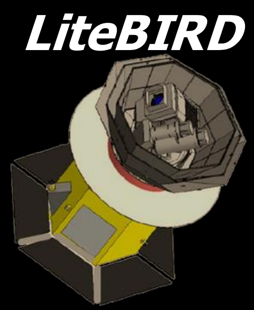
Credit APS/Alan Stonebraker,
https://physics.aps.org/articles/v6/107



Serendipity is essential at the same time

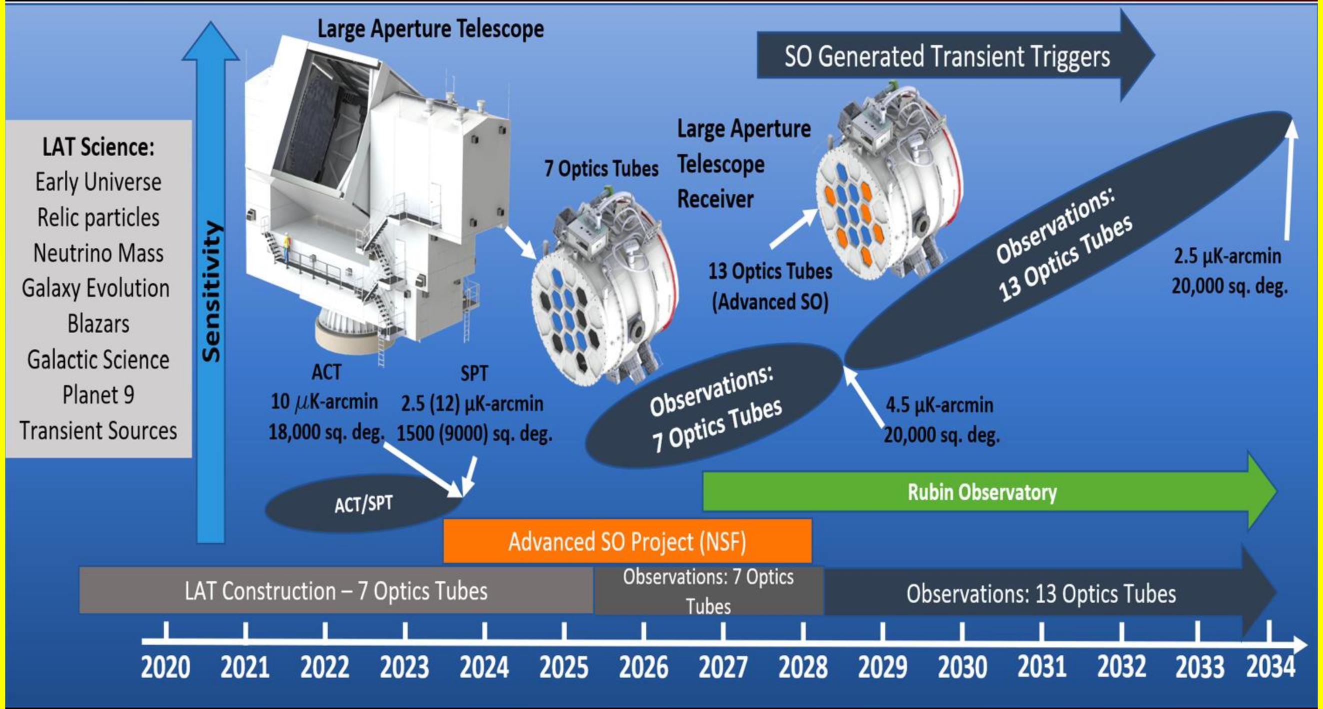
The importance of serendipity, i.e., the potential to discover something unexpected, shall never be underestimated. Space-Ground synergy is important in this regard.

- Rich scientific objectives beyond r
  - Optical depth, reionization of the Universe, and neutrino masses
  - Cosmic birefringence
  - Mapping the hot gas in the Universe
  - Anisotropic CMB spectral distortions
  - Primordial magnetic fields
  - Elucidating spatial anomalies with polarization
  - Galactic astrophysics



See presentation by Martina Gerbino

Rich scientific objectives from SO Large Aperture Telescope



arXiv:2503.00636

Comparing results from space and ground might lead to new anomalies.

Impact on Fundamental Physics

New particle(s) beyond SM

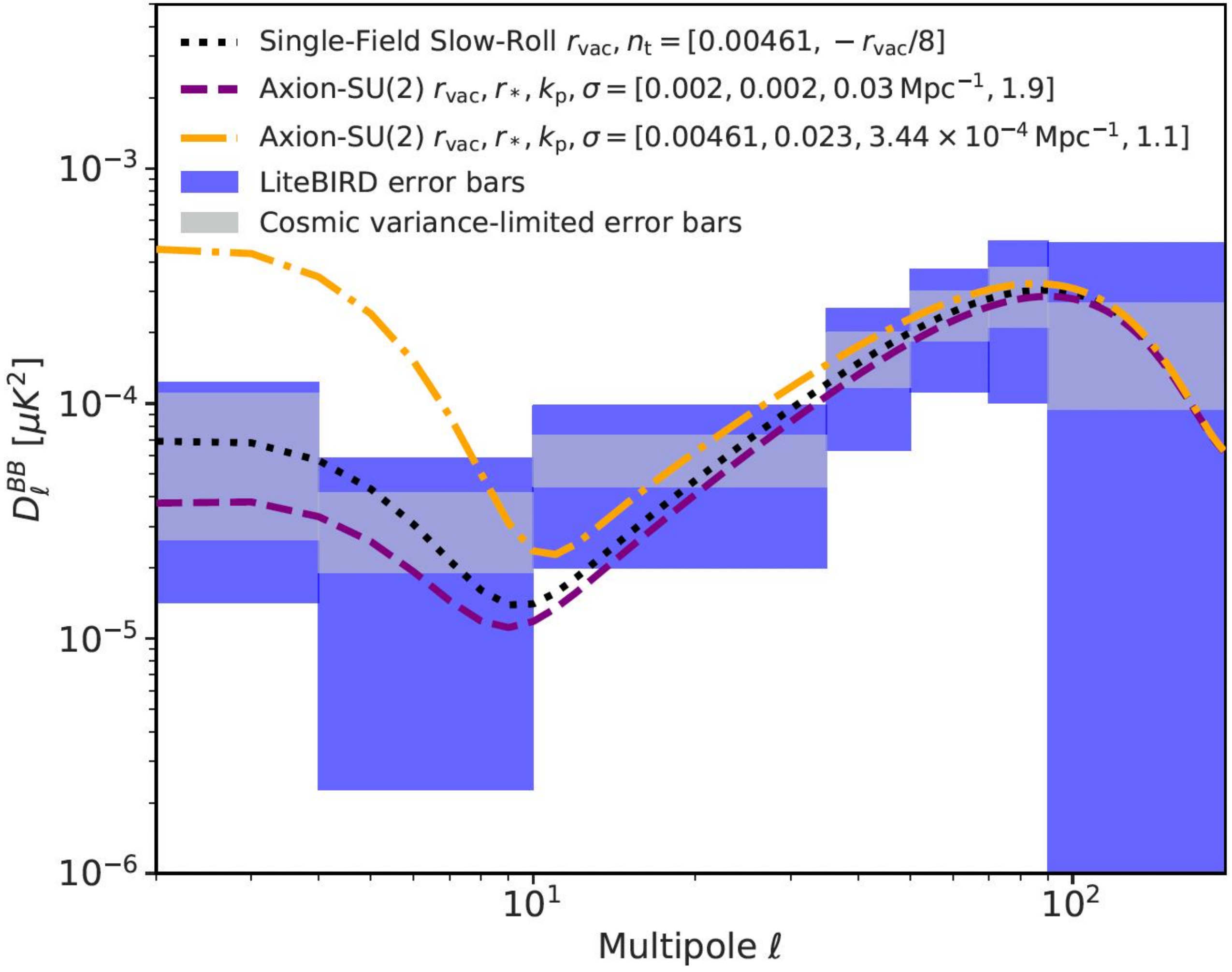
Ex)　Axion-SU(2) model

The example on the right figure shows that the spectrum can change due to the new gauge field. Large-angle correlations with multipoles smaller than 10 are where LiteBIRD's all-sky surveys are most powerful.

If you see such a non-standard spectrum, it is a great discovery.

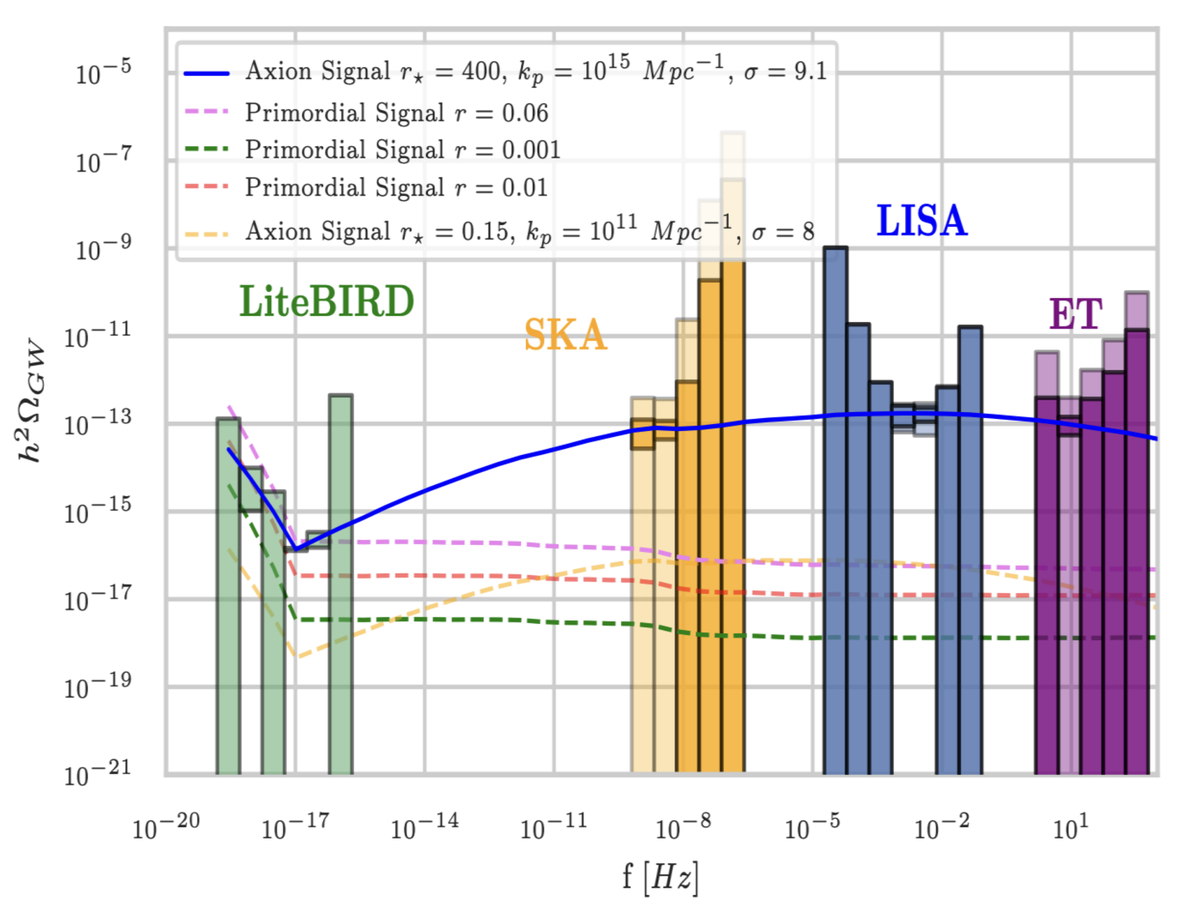
P. Campeti, et al. LiteBIRD Collaboration JCAP 06 (2024) 008

LiteBIRD Collaboration PTEP 2023



Coherent messages about the space-ground complementarity from the CMB community to neighboring communities are necessary for large projects like CMB-S4 and LiteBIRD

- To realize the powerful duo mentioned above, we must address budgetary and technical challenges.
- We need to integrate into the academic ecosystem of the astronomical and high-energy physics (HEP) communities. In this regard, the key is the support from neighboring communities, including the GW community. We must ensure they recognize the CMB B-mode search as necessary for exploring the gravitational-wave landscape.
- Cooperation between CMB-S4 and LiteBIRD to this end is very effective!



"Measuring the spectrum of primordial gravitational waves with CMB, PTA and laser interferometers" Paolo Campeti et al., JCAP01(2021)012