“Point d’information”

CMB-S4

The next-generation ground-based cosmic microwave background experiment

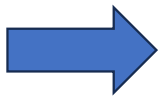
DPhP: E. Burtin, S. Loucatos, J.-B. Melin,

DAp: J.-L. Sauvageot, DEDIP: X. de la Broïse

with inputs from presentations by
J. Strait, J. Carlstrom, …

CSTD, DPhP, 2 Oct 2024

Content



- The CMB-S4 experiment and collaboration
- Irfu technical and scientific contributions

CMB-S4 science themes

Reminder

CMB-S4 tackles **four broad science themes**

1. **Primordial Gravitation waves and Inflation**
2. **The Dark Universe**
3. **Mapping Matter in the Cosmos**
4. **The Time-Variable Millimeter-Wave Sky**

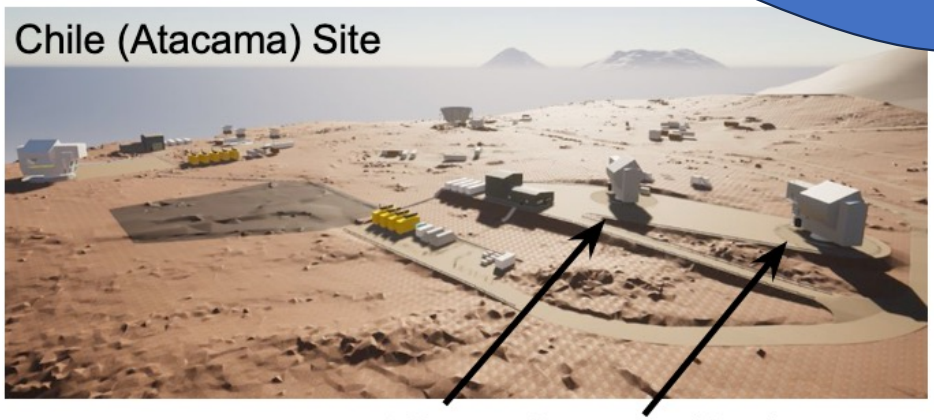
CMB-S4 baseline design

UNTIL May 2024

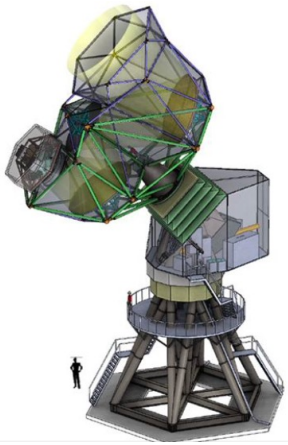
Reminder

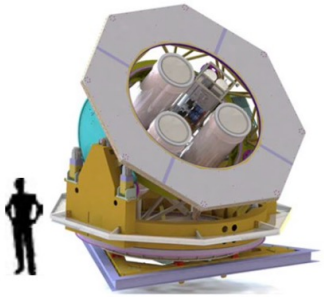
1 Large Aperture (5 m) Telescope

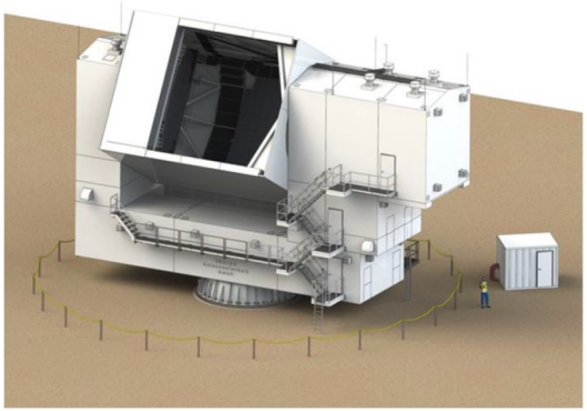
3 Small Aperture Telescopes (9 0.56-m aperture optics tubes)



2 Large Aperture (6 m) Telescopes







May 2024

- On May 7, NSF announced that they have decided "not to move the CMB-S4 project in its current form into the NSF Major Facility Design Stage at this time," since NSF "must prioritize the recapitalization of critical infrastructure at the South Pole."
- The South Pole will be closed to new experiments for at least 10 years.
- The CMB-S4 collaboration must develop a plan that does not include the South Pole.

August 2024

Creating two new task forces

- **All Chile Configuration** **working group** charged to "develop a more optimized configuration of CMB-S4 with all telescopes located in the high Atacama desert in Chile" that should have "the ability to achieve the inflation science goal of $\sigma(r) \leq 5 \times 10^{-4}$ within a reasonable survey duration, for a reasonable cost, with an acceptable level of scientific risk." reasonable survey duration: <10years, reasonable cost: <1B$

- **Current Experiments** **working group** charged to "Collect and evaluate information regarding the plans and capabilities of current CMB experiments that are able to address one or more of the CMB-S4 Science Goals" and to "Identify and quantify gaps between the combined sensitivity of the experiments considered and the Science Goals of CMB-S4." Exchange of information on systematics, efficiencies, HWP in progress with Simons Observatory, ACT, …

⇒ Reports expected in December 2024

September 2024

All Chile configuration

- Initial results using Parametric Likelihood forecasts and Medium Complexity foreground model suggests that **the raw sensitivity of 9 Max-Speed SATs is in the ball park but requires additional LAT delensing**.

3 SATs + 1 LAT @ South Pole
2 LATs @ Atacatama

9 SATs + 4 (5?) LATs @ Atacatama

- This study **does not address concerns about systematics or other risks**. [Sun avoidance, half-wave plate on SATs, atmosphere, etc.]

Content

- The CMB-S4 experiment and collaboration
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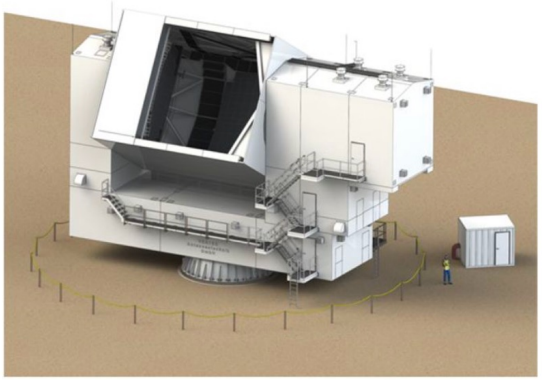
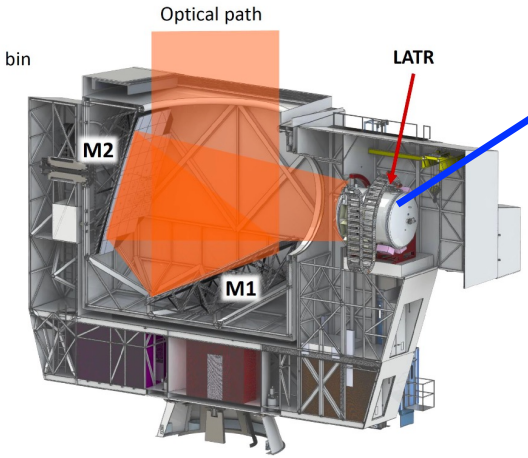
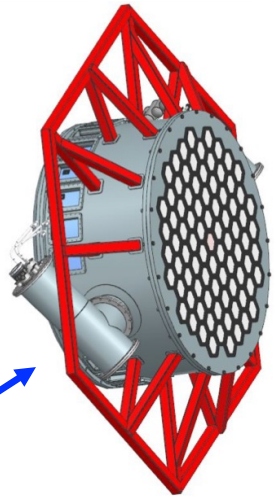
CMB-S4 optics tubes

Reminder



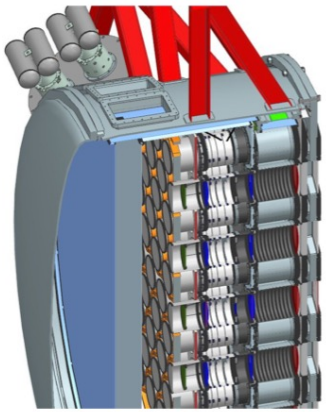
Large Aperture Telescope in Chile (LAT)

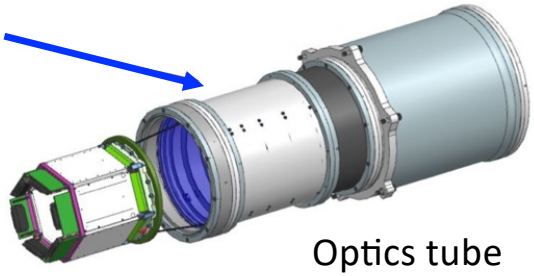




LAT receiver

LAT receiver



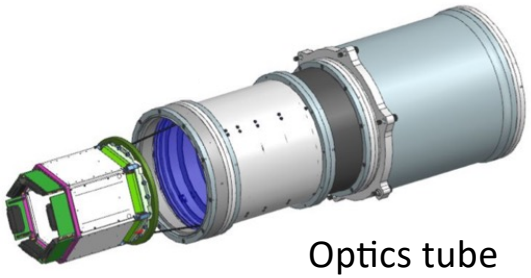


Optics tube

Detector module

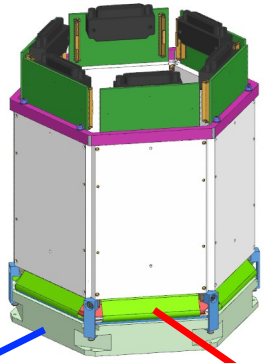
CMB-S4 detector modules

Reminder



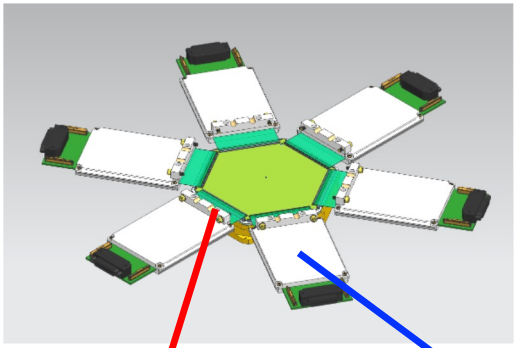
Optics tube

Detector module

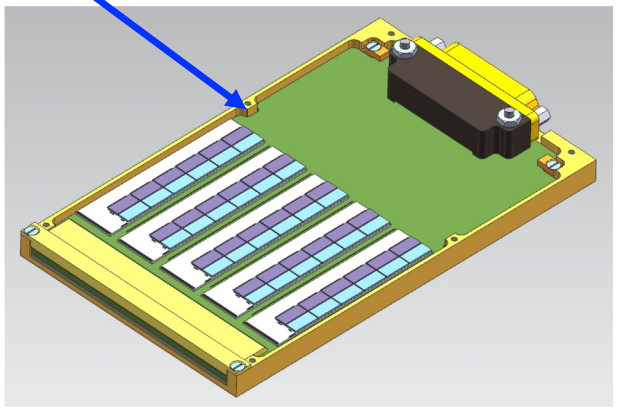


Detector module
(closed)

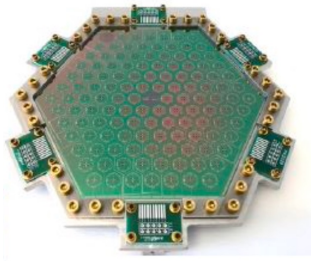
Detector module
(opened)



Readout board



Detectors



Flexible cryogenic cables

Irfu technical contribution to CMB-S4

Irfu: X. de la Broïse, J.-L. Sauvageot, E. Burtin, S. Loucatos, J.-B. Melin

APC: D. Prêle, M. Gonzalez, J.-P. Thermeau, M. Piat

➜ Develop the superconducting flexible cables linking detectors to their electronics
➜ If successful, envisage production of the cables

1 - flexible, in order to make the detector modules as compact as possible.

2 - superconducting. They must not dissipate energy when biasing or reading the detectors. Electrical resistance must be below 1mΩ to guarantee the voltage biasing required for the electro-thermal feedback.

3 - compact. They must be small enough to take as little space as possible. The wires will be 24μm wide, spaced by 46μm.

4 - thermally resistant, in order to introduce thermal boundary between shunt chips (which dissipate significant thermal power) and sensitive TES wafer

5 - reproducible and reliable. More than 95% of the wires in each cable must be functional.

➜ ANR project CMB-FLEX funded (500k€, 3 years)

Ongoing work with Hightec and Cicor/Microtech

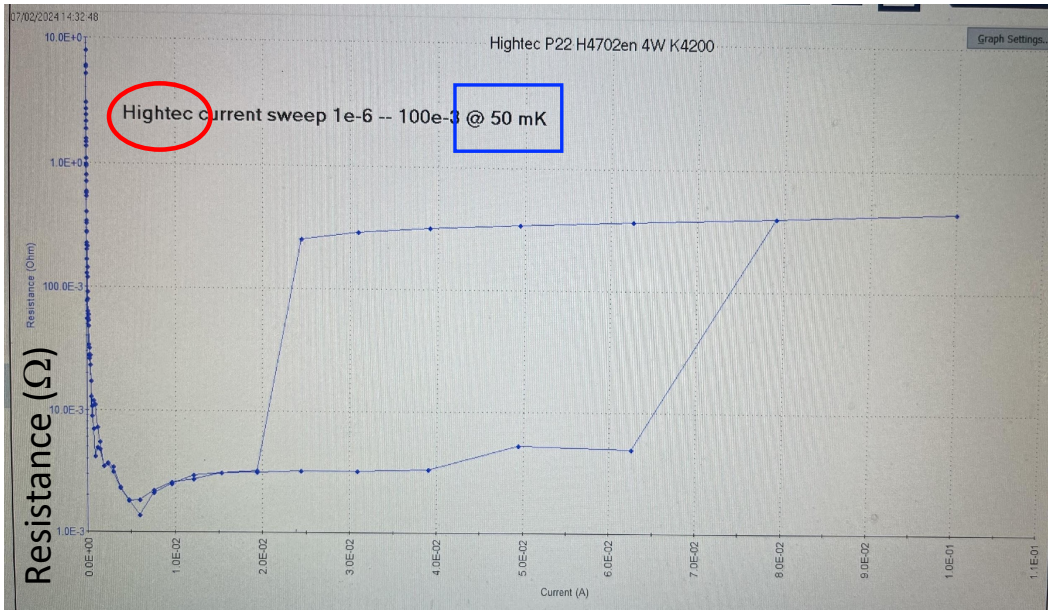
→ We plan to carry out the development of cables for CMB-S4 with two companies in parallel to mitigate risks: **Hightec** with whom we have collaboration experience, **and Cicor/Microtech** (Switzerland and Germany), which we have started to work with in 2023 and which is interested and equipped to carry out these developments with us.

Extremely tight specifications for the cables:
- residual resistance below 100μΩ at temperature 100mK
- critical current should be higher than 10mA

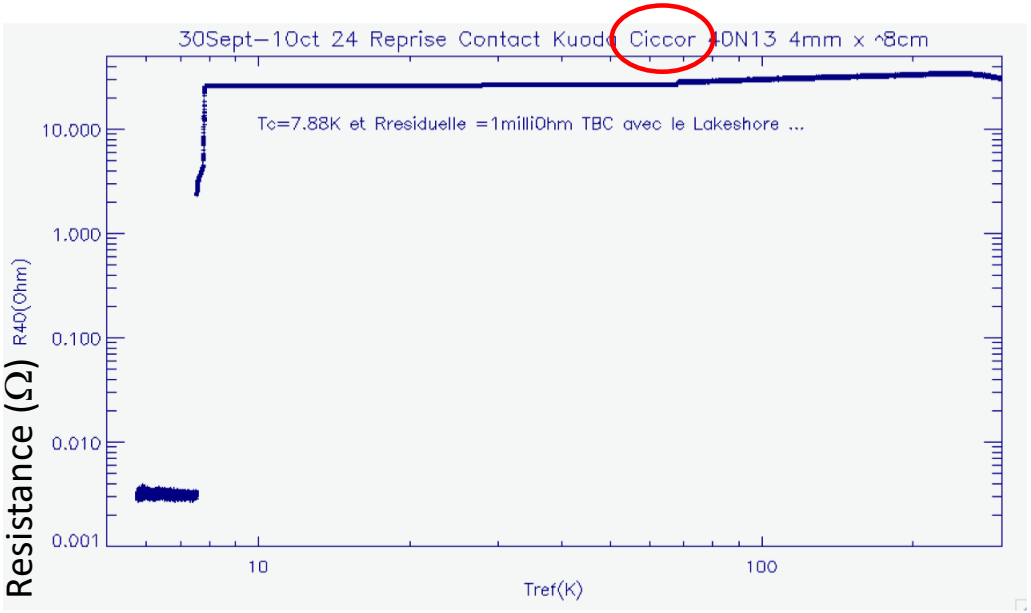
Hightec
- Produced cables close to specifications in May 2024 except for the critical current (<10mA)
- Inconsistent measurements between SLAC and IRFU for the critical current but they were performed at different temperature

Cicor/Microtech
- Produced multiple series of cables to test the NbTi alloy deposition methods
- Tests at IRFU at warm and cold temperature to test manufacturing, critical temperature and residual resistance

Progress on measurements



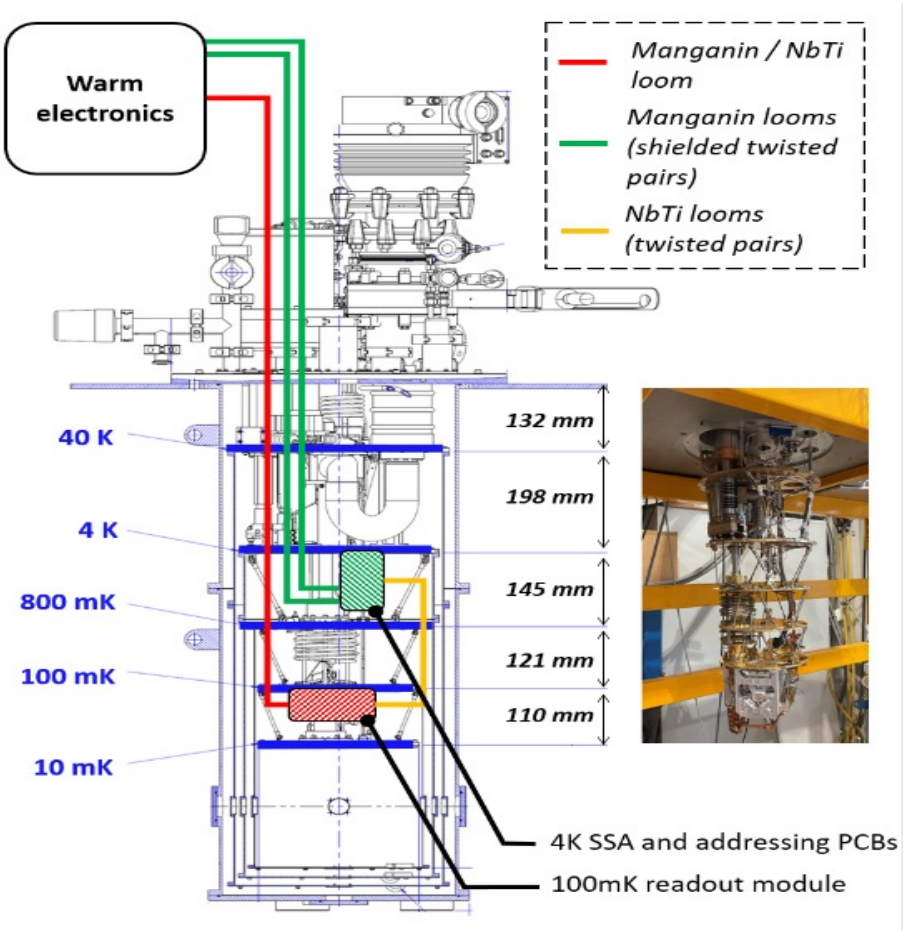
Current (A)



Temperature (K)

⇒ Critical current depends on temperature

Test bench being assembled at APC



CosmoLidar

➜ ANR proposal (lead E. Butin IRFU/DPhP) : use LIDAR observations in parallel to CMB observations to reduce impact of atmospheric noise

Partners : IRFU/DPhP, LSCE, Centre Pierre Binétruy Berkeley, APC, Institut de Planétologie et d'Astrophysique de Grenoble

- First test last summer at the Observatoire de Paris (near Denfert-Rochereau) was performed with LSCE and APC
- ANR proposal → two campaigns with increasing CMB detector and lidar sensitivity (IRAM 30m telescope Pico Veleta, and Simons Observatory Atacama)

Proposed Irfu scientific contribution to CMB-S4

DPhP: J.-B. Melin, E. Burtin, S. Loucatos

- **Galaxy cluster science and cosmology**
  Strong expertise on Planck, J.-B. Melin co-lead of the S4 cluster analysis WG
- **Fundamental physics and astrophysics from cross-correlation studies**
  Strong expertise on BOSS, eBOSS and DESI
- **Primary CMB cosmology and Inflation**
  We would like to develop this expertise at DPhP

→ Participation of the DPhP to Simons Observatory?

Summary and conclusions

- CMB-S4 is currently in a **re-design phase** (All Chile configuration).
- ANR project **CMB-FLEX funded**. It will enable us to pursue and amplify our ongoing efforts to develop the flexible superconducting cables for CMB-S4.
- **CosmoLidar project.** Goal: reduce impact of atmospheric noise in CMB observations using a LIDAR.
- **Some expertise in the group to envisage a visible contribution to the scientific analyses in CMB-S4.**

Back-up slides

French hardware participation

1. **Flexible superconducting circuits** (Al/Nb traces on Kapton etc.) NbTi traces. Intermediaries with Hightec and Cicor/Microtech + cryogenic characterizations. **CEA - Irfu**

2. **Warm Readout** From the whole WP to Custom **discrete components** (as ASIC) in the warm readout board implementation, including **differential front-end amplifiers**. **CNRS - APC**

All activities: Design, procurement … but also assemblies and characterizations must be scalable x100s compared to same activities as for QUBIC or even LiteBIRD

→ In the framework of APPEC, INFN declared interest in a CMB-S4 Europe coordination, if synergies are identified, mainly in electronics.

→ Irfu signed a Non-Disclosure Agreement (NDA) for technology with CMB-S4 in 2023

CMB-S4 science goals

The CMB-S4 **science goals** are

Goal 1. **Test models for inflation** by measuring or putting upper limits on r, the ratio of tensor fluctuations to scalar fluctuations

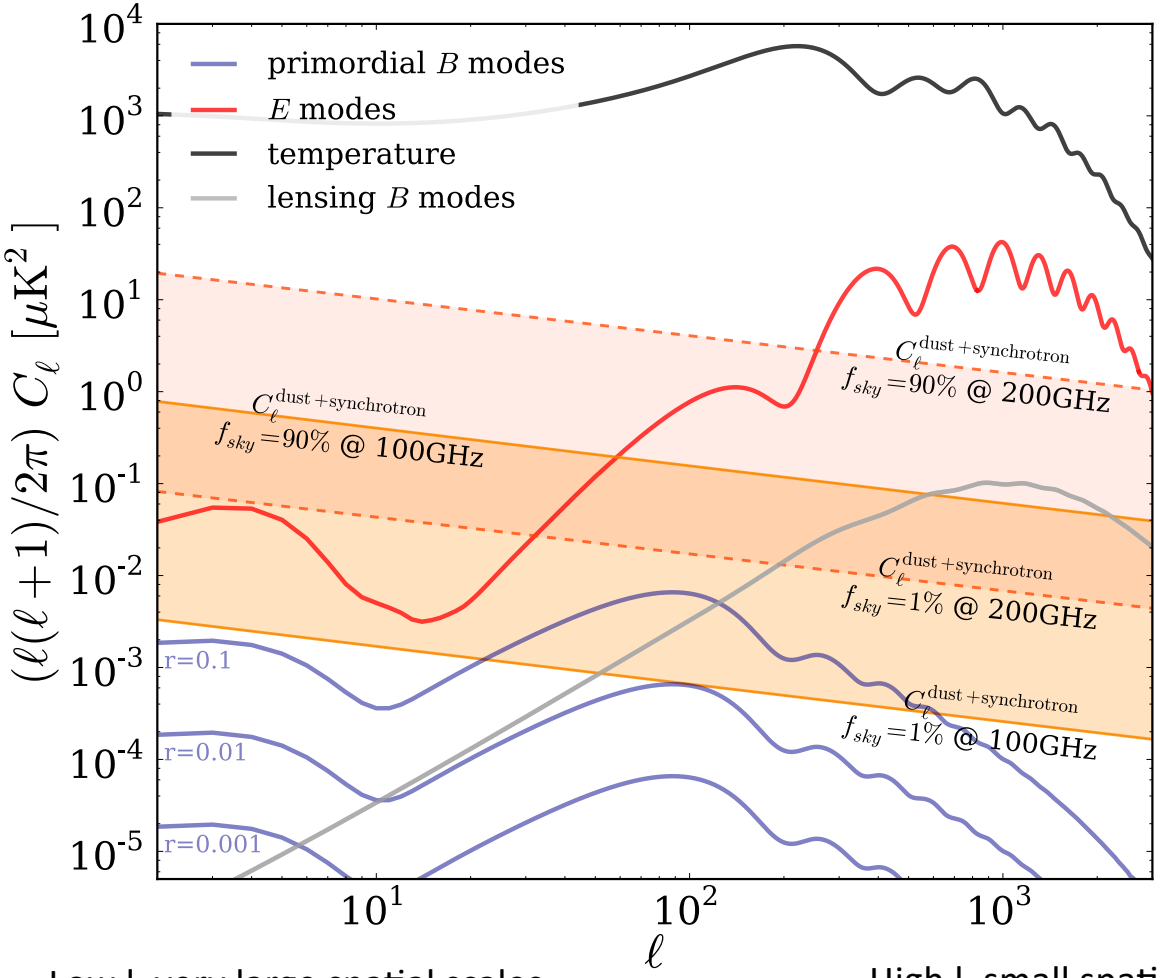
Goal 2. Determine the **role of light relics** particles in fundamental physics, and in the structure and evolution of the Universe

Goal 3. Measure the **emergence of galaxy clusters** as we know them today. Quantify the formation and evolution of the clusters and the intracluster medium during the crucial early period of galaxy formation.

Goal 4. **Explore the millimeter-wave transient sky**. Measure the rate of mm-transients. Use the rate of mm-wave Gamma-ray Bursts (GRBs) to constrain GRB mechanisms. Provide mm-wave variability and polarization measurements for stars and active galactic nuclei.

In the end, these driving goals set the **CMB-S4 baseline design** which will enable a much broader research program on fundamental physics, cosmology and astrophysics.

Inflation (Goal 1)

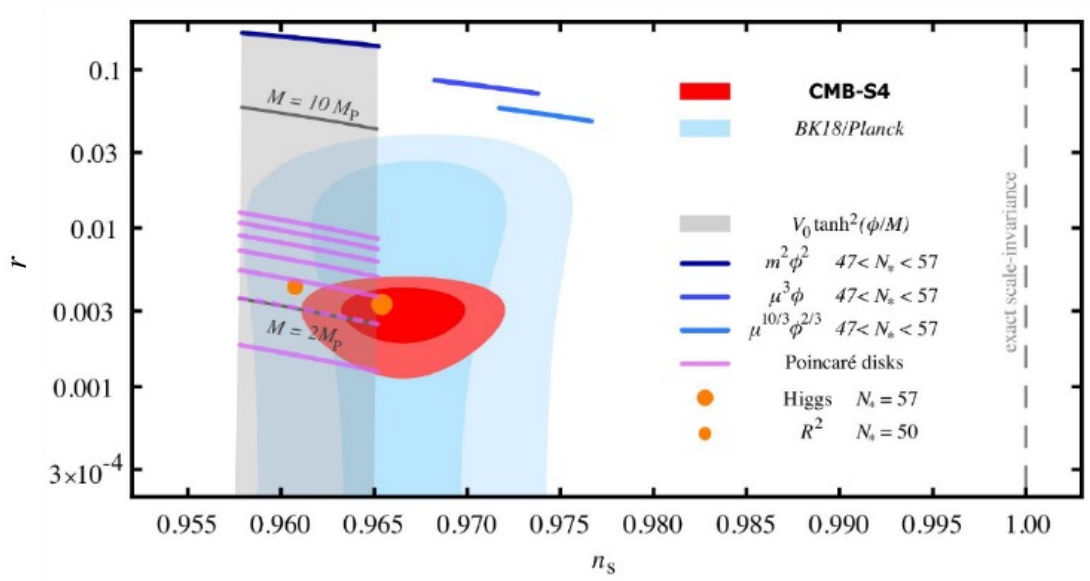


Errard et al. 2016

Low l, very large spatial scales

High l, small spatial scales

Inflation (Goal 1)

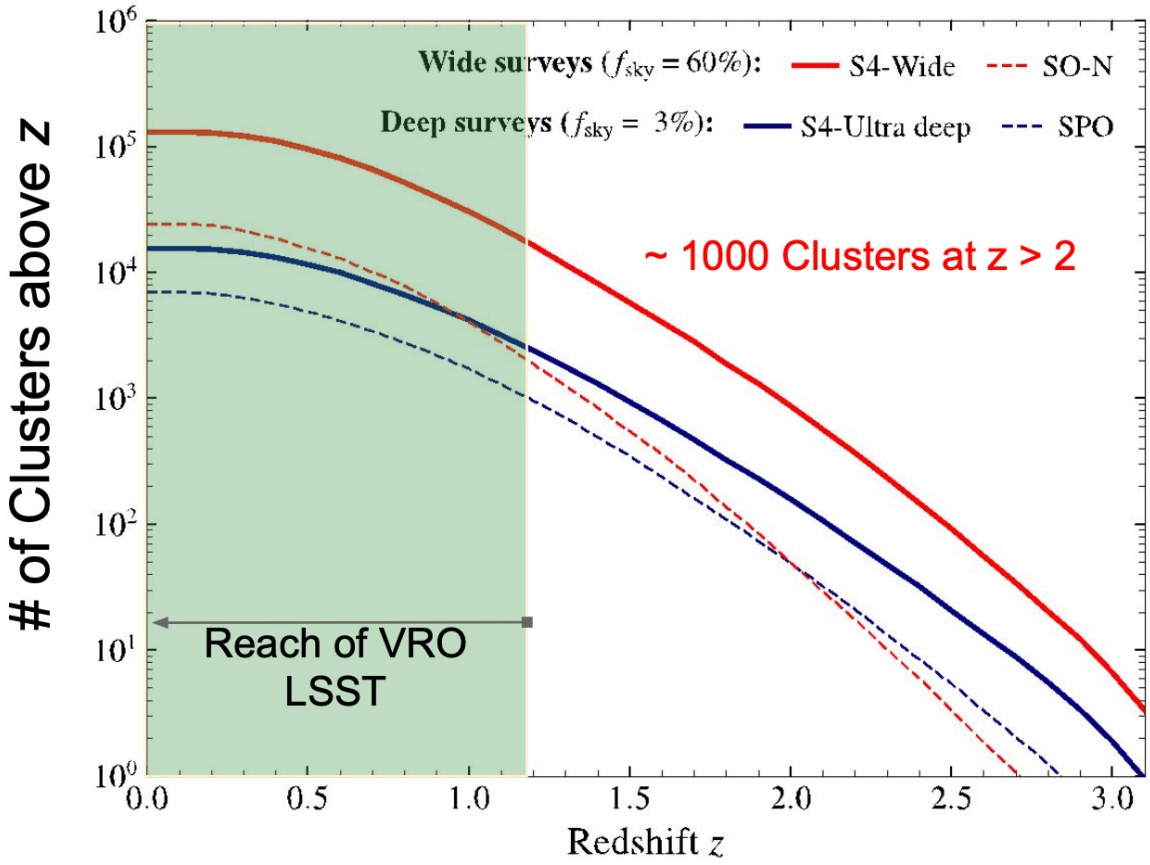


- CMB-S4 will **look for the unique signature of inflation via the detection of primordial CMB B-modes**

- **σ(r)< 0.0005 (about 2 orders of magnitude below current constraints)**
- **Upper limit on r of r≤0.001 at 95% C.L if r=0**, or by **measuring r at 5σ level if r>0.003**

- CMB-S4 will **detect or rule-out the leading inflationary models that naturally explain the measured value of n_s.**

Emergence of galaxy clusters (Goal 3)



- CMB-S4 will provide a **catalogue of massive clusters of galaxies to the highest redshifts**
- CMB-S4 will observe **hundreds of clusters of galaxies at z>2**, and **detect the first clusters formed in the universe at redshift z~3**
- CMB-S4 will **build up the link between clusters and protoclusters**