Constraining New Physics with the Cosmic Microwave Background

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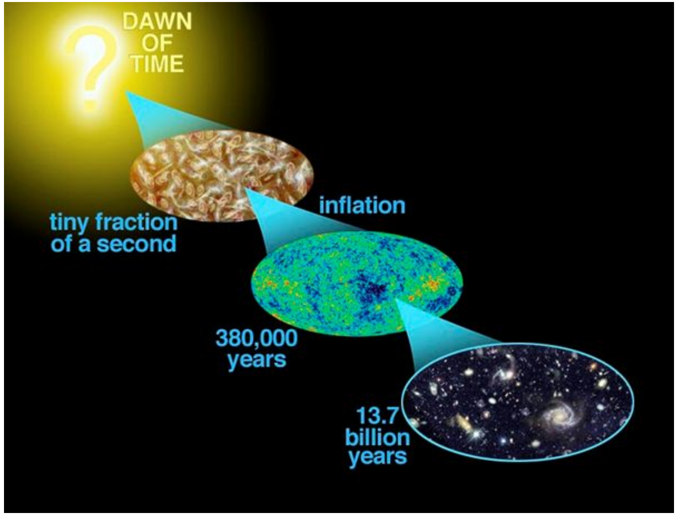
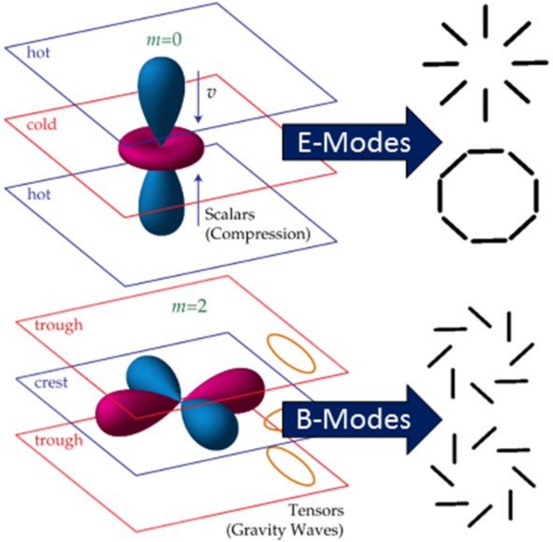
Photo Credit: Deborah Kellner

Cosmic Microwave Background



Inflation seeds initial scale-invariant **scalar** and **tensor** perturbations in the early universe → quadrupole moments

Density perturbations → Temperature Anisotropies

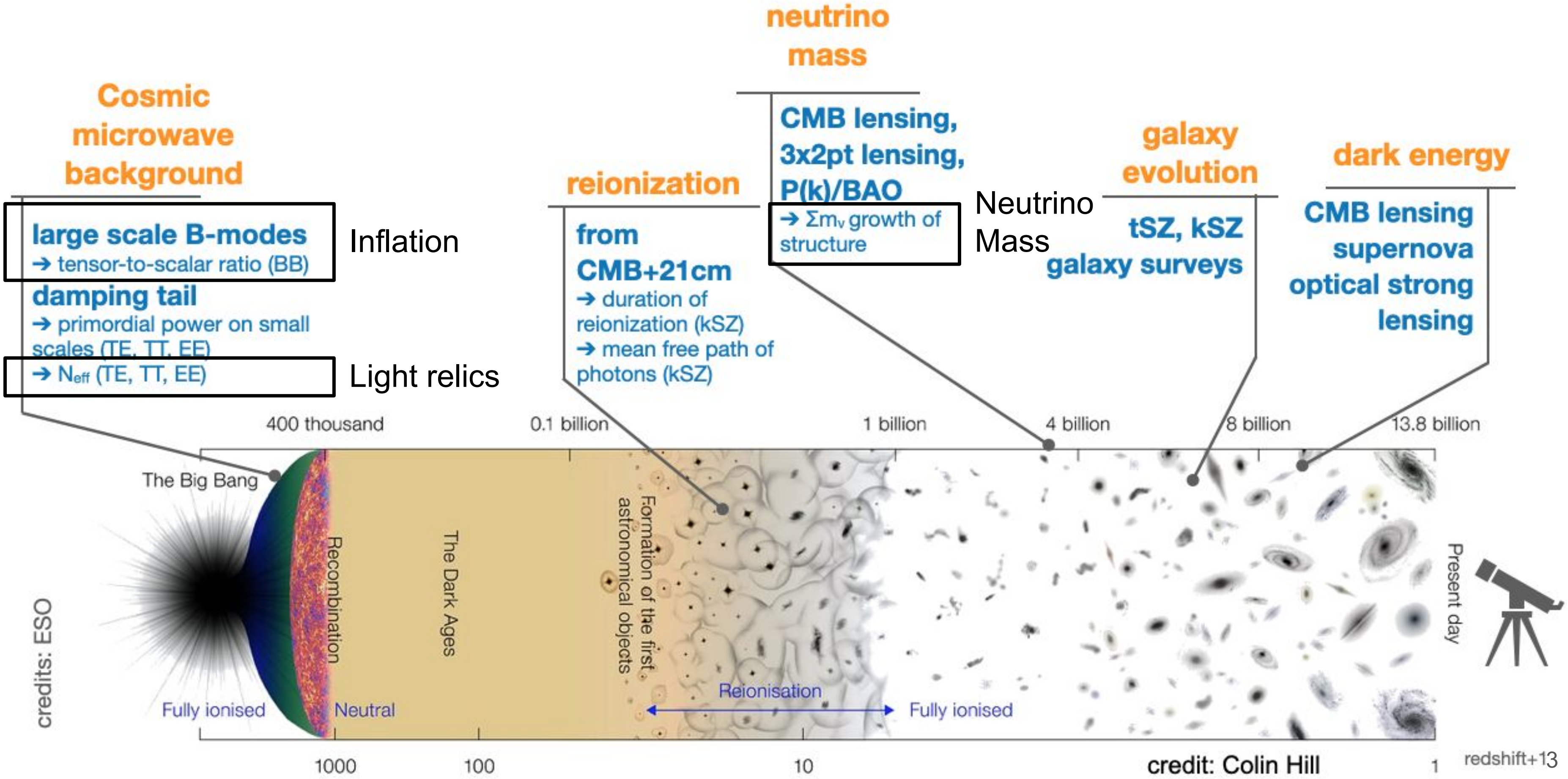


Quadrupole moments in the early universe + Compton scattering → Polarization in the CMB

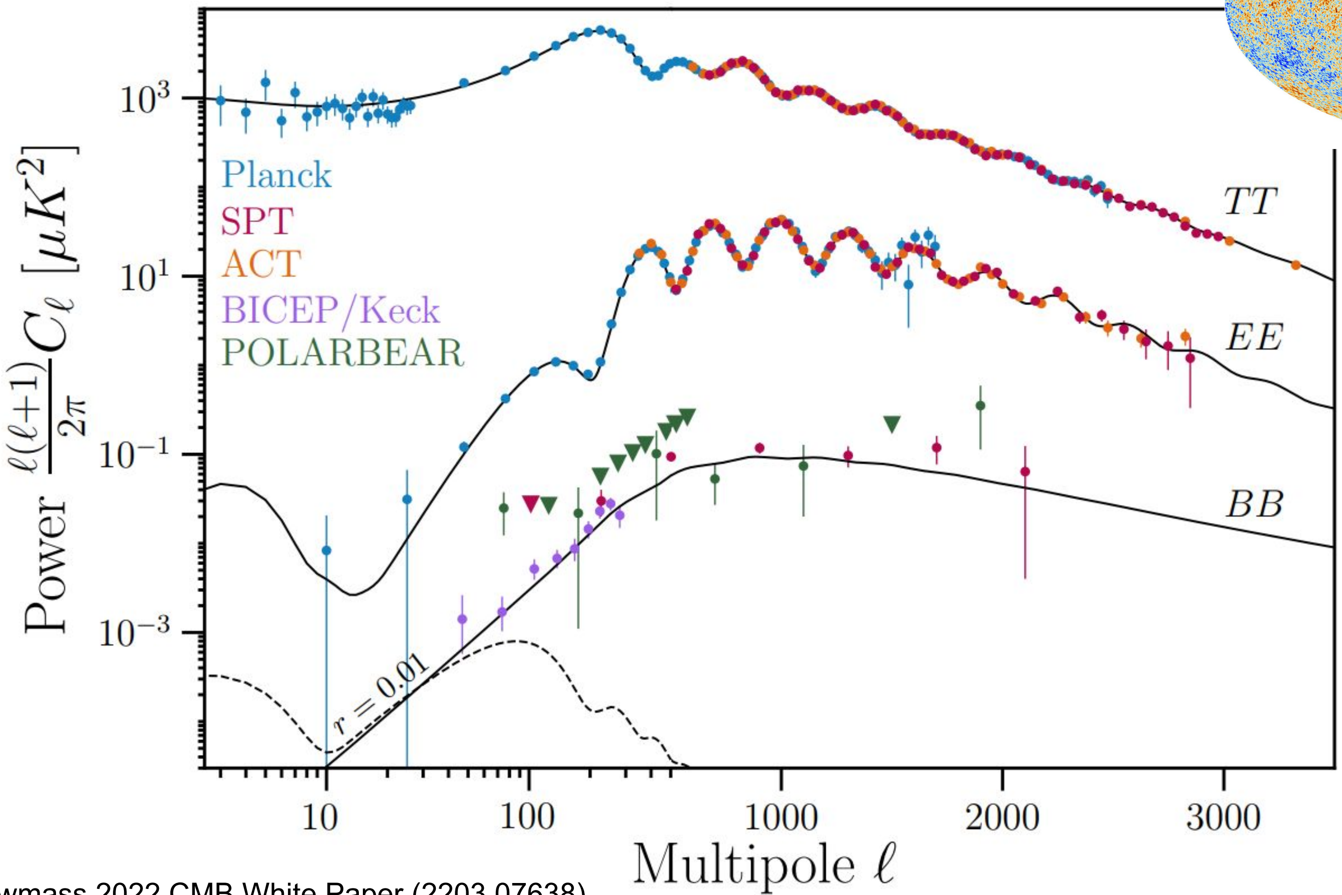
Density perturbations → E-modes
Gravitational Waves → E- and B- modes

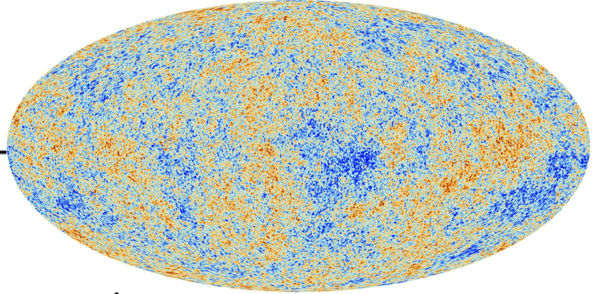
(Adapted from Hu, W. and White, M., 9706147)

Cosmology with the CMB



CMB Power Spectrum





Planck CMB Map

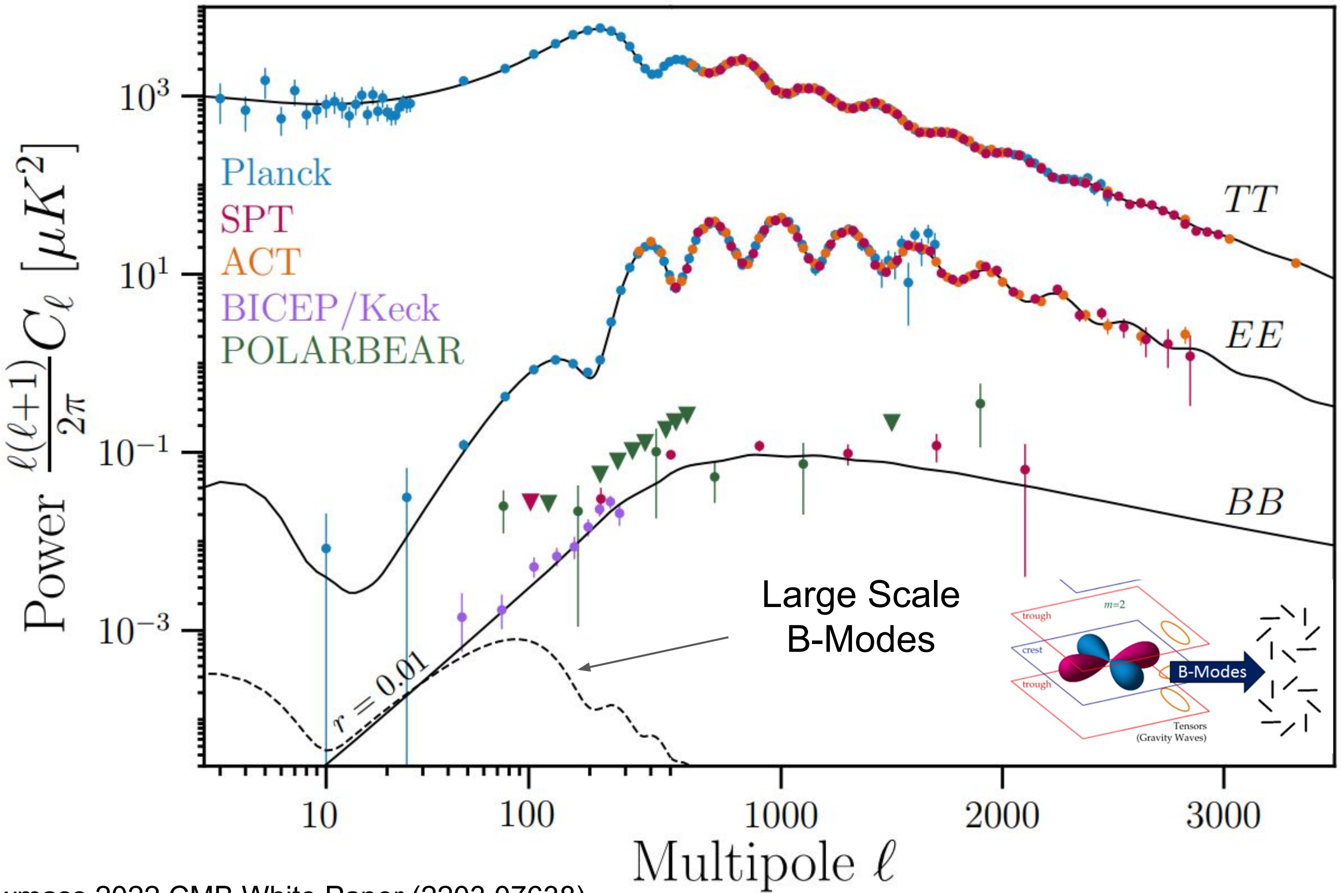
Expand in Spherical Harmonics

Power Spectrum:
power vs. angular scale

Many cosmological properties are encoded in different aspects of the power spectrum.

Snowmass 2022 CMB White Paper (2203.07638)

Inflationary Gravitational Waves



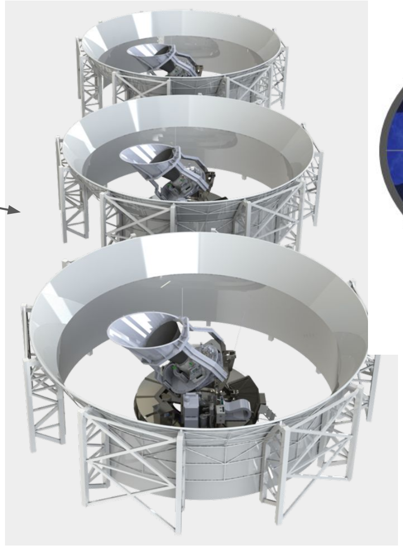
Snowmass 2022 CMB White Paper (2203.07638)

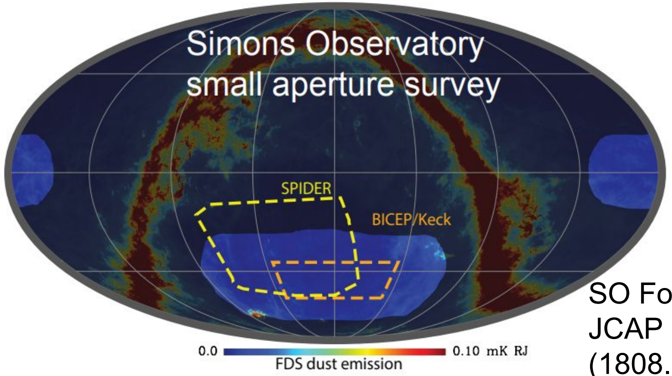
Large Scale B-Modes are the result of primordial gravitational waves from Inflation.

Amplitude (r)
→ Tensor-to-scalar ratio
→ Energy scale of Inflation

Large Angular Scales → Small Apertures Telescopes

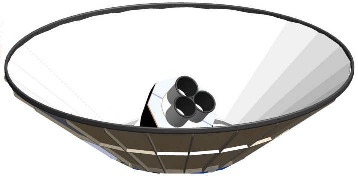
Simons Observatory
- 3 60 cm Aperture Telescopes
- 6 Frequency Bands





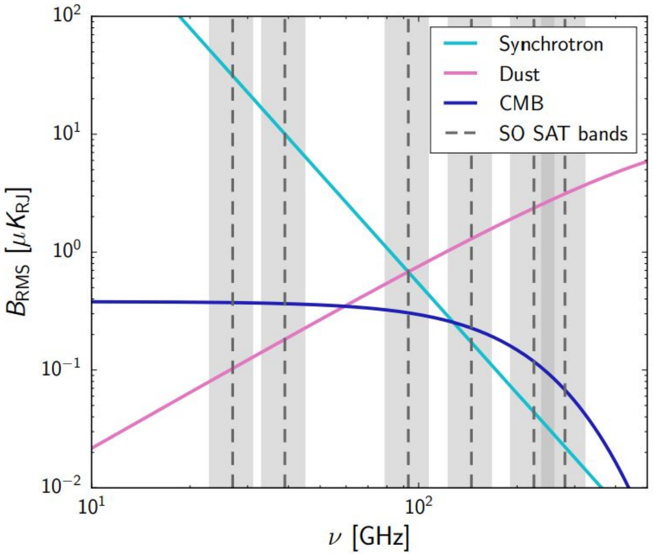
SO Forecasting
JCAP 02 (2019) 056
(1808.07445)

Reference CMB-S4 Design:
- 18 70 cm Aperture Telescopes
- 8 Frequency Bands



Deep Maps over small sections of sky but retaining the large scale information.

Different Frequency Bands → Remove Galactic Foregrounds



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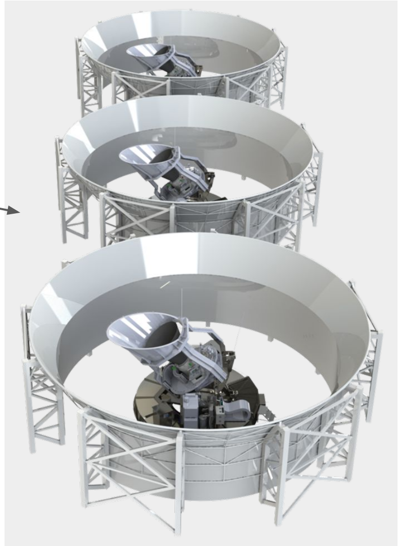

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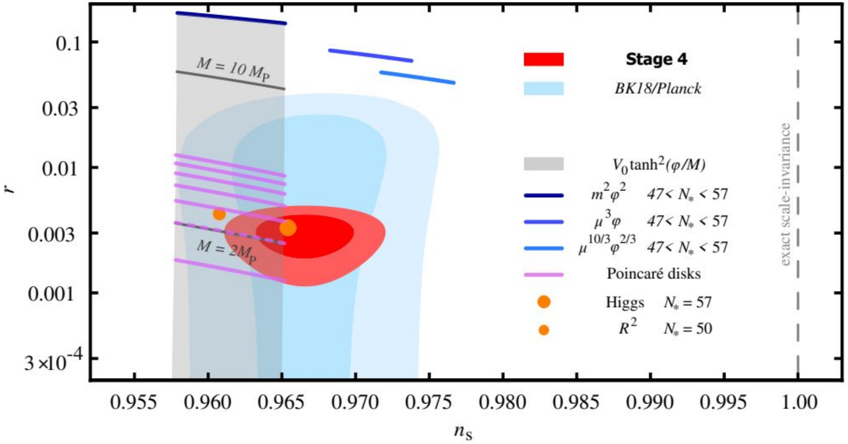


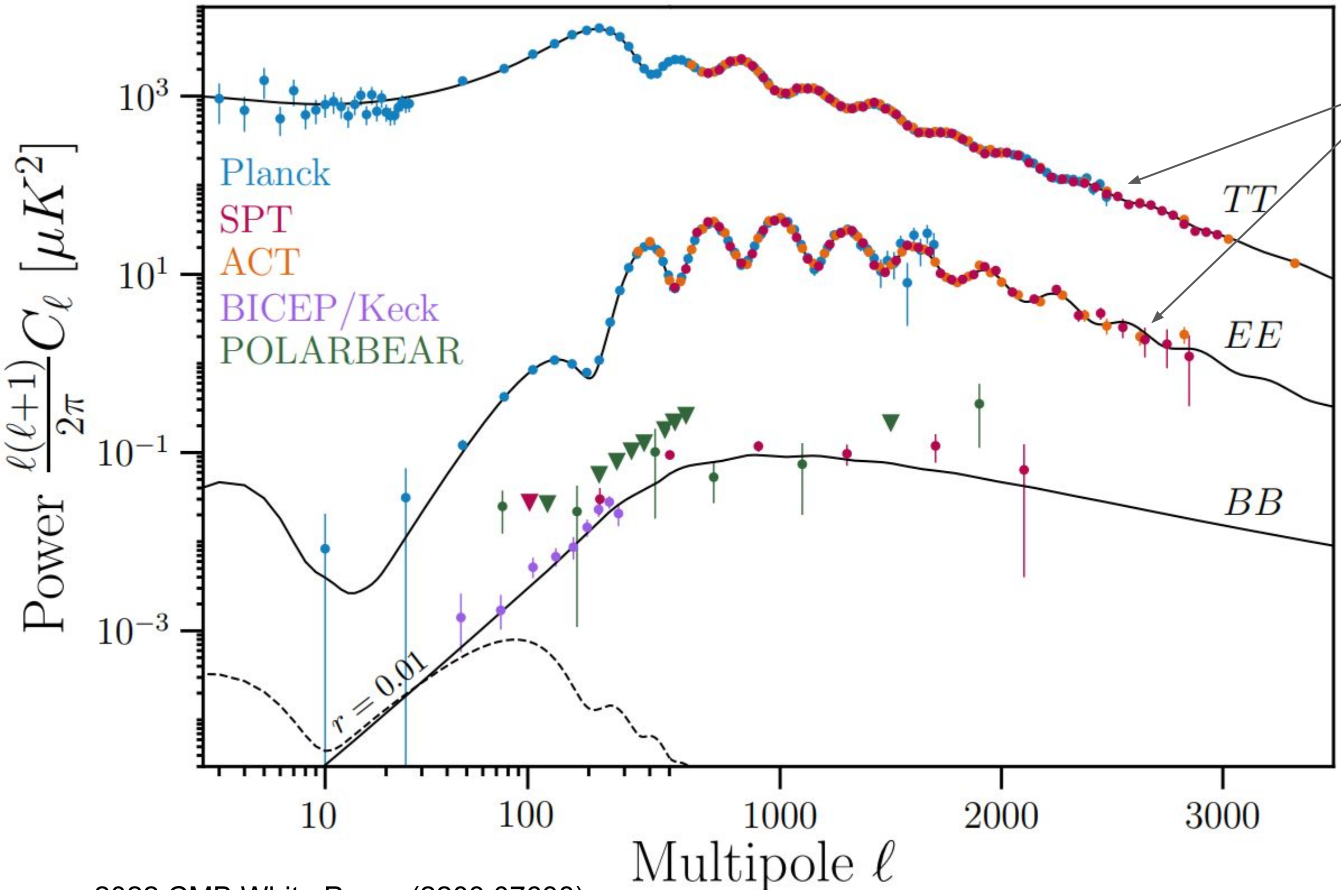
Snowmass 2022 CMB White Paper (2203.07638)

Deep Maps over small sections of sky but retaining the large scale information.

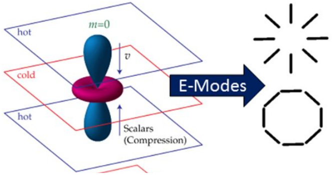
Different Frequency Bands → Remove Galactic Foregrounds

Constraints or measurements of the tensor-to-scalar ratio tells us about possible properties of the the inflaton field.

Effective Number Relativistic Species



Small Scale
TT, TE, EE



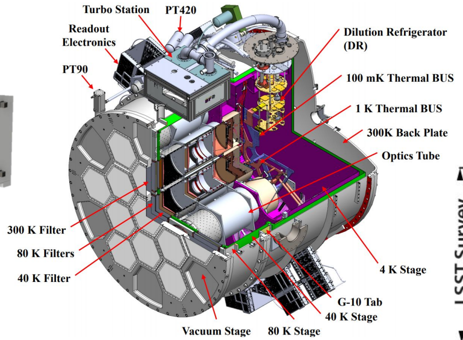
Small Scale TT, TE, EE are from acoustic oscillations in the primordial plasma.

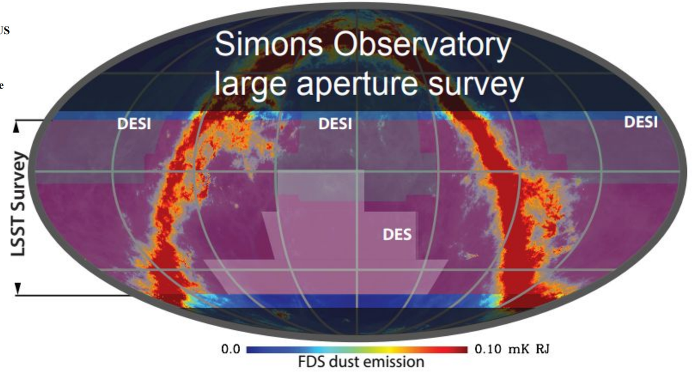
Relativistic species wash out power on small scales

Snowmass 2022 CMB White Paper (2203.07638)

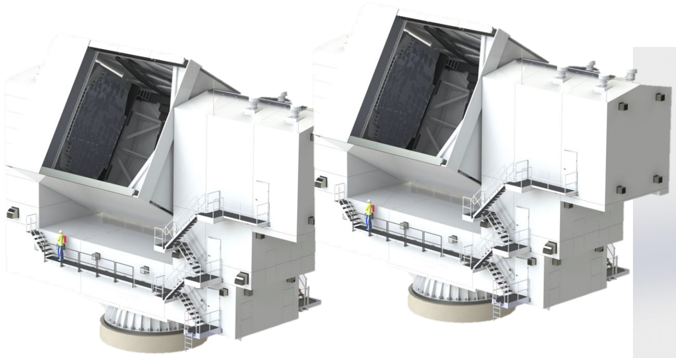
Small Angular Scales → Large Aperture Telescopes

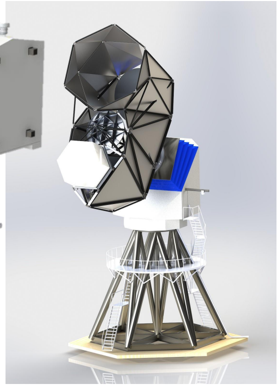
Simons Observatory
6 m Aperture Telescope
2.4 m Diameter Receiver
for 13 optics tubes

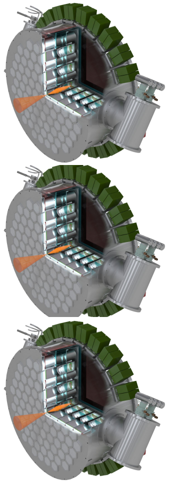




CMB-S4
2x 6m + 1x5m Aperture Telescopes
Each with 2.5 m Diameter Receiver
for 85 optics tubes





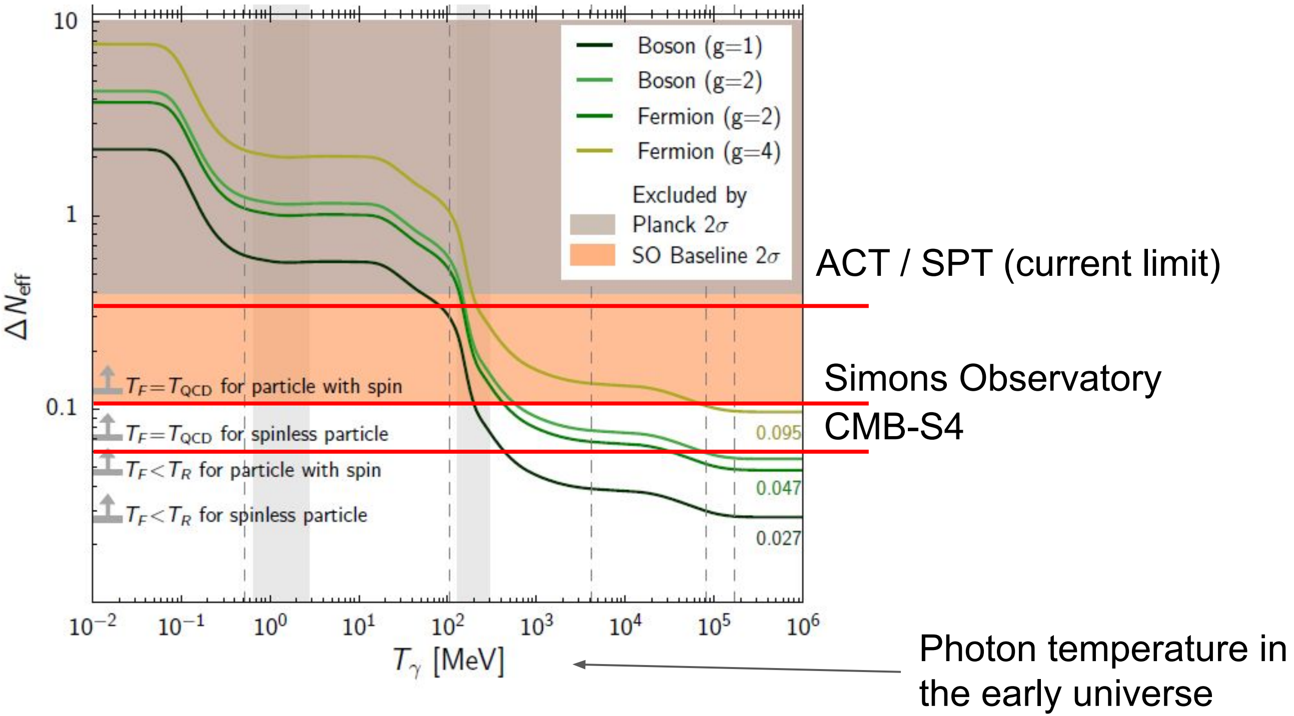


Observe large fractions of sky to measure as many small-scale modes as possible at arcminute resolution.

Similar frequency coverage / foreground cleaning as the SATs.

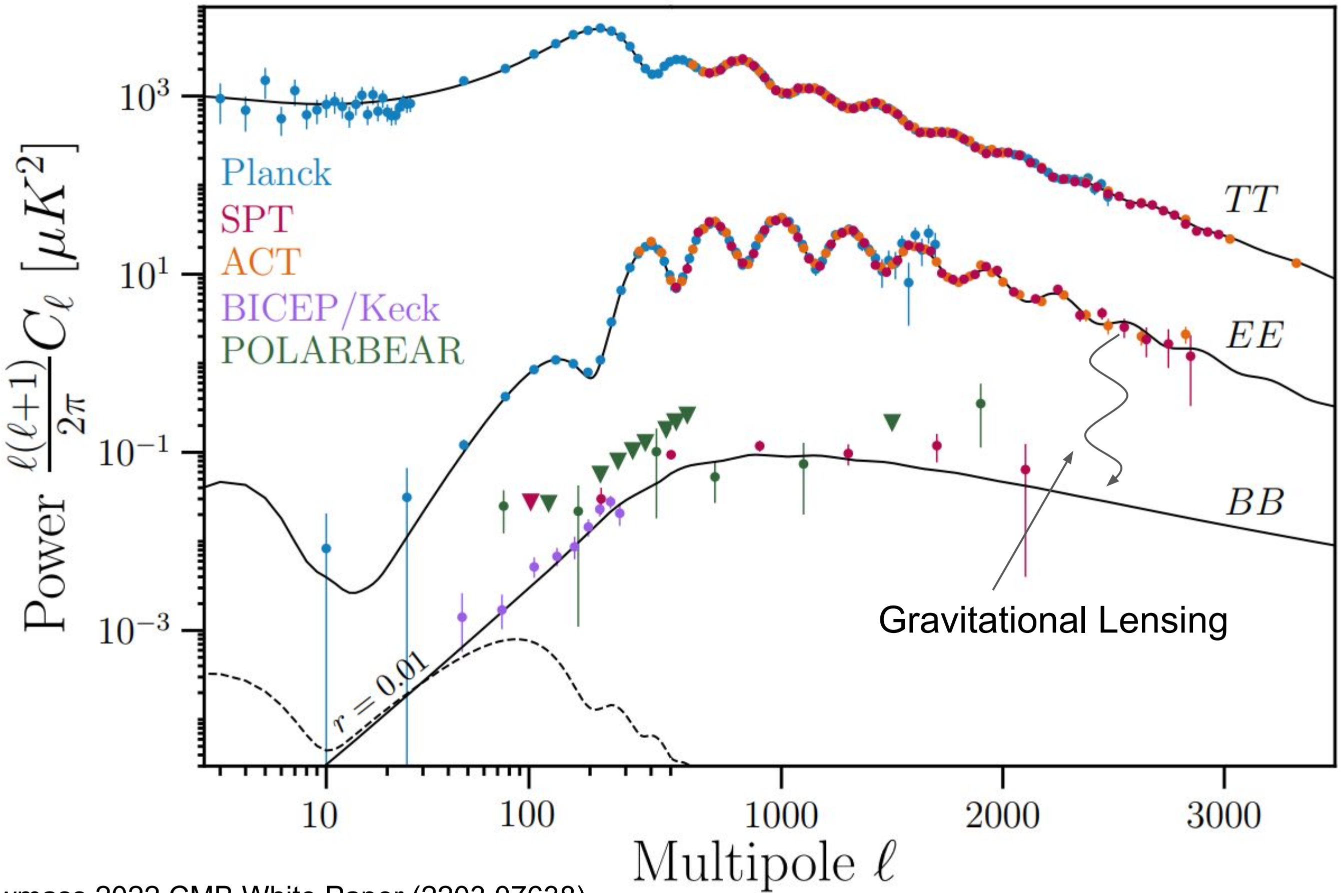
Small Angular Scales → Large Aperture Telescopes

Effective Number of Relativistic Species → Constraining particle physics beyond the standard model



SO Forecasting JCAP 02 (2019) 056 (1808.07445)

Sum of Neutrino Masses



Small Scale
TT, TE, EE, and BB

Small Scale BB is from gravitational lensing of E-Modes into B-Modes

Lensing tracks the growth of structure in the universe

Neutrinos inhibit the growth of structure in the universe, reduce the amount of lensing we can see.

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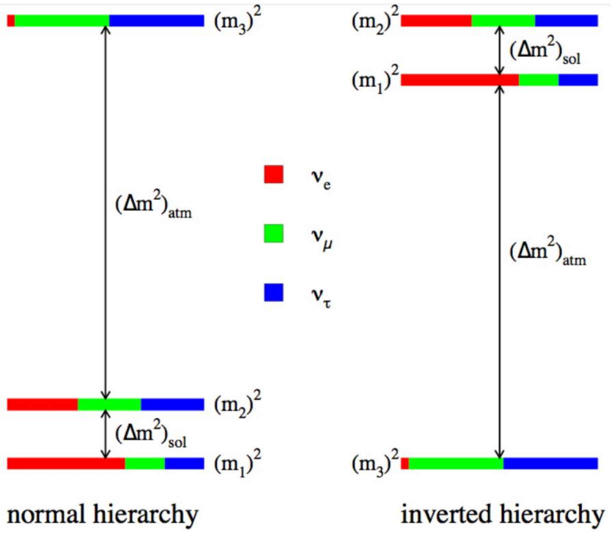
Sum of Neutrino Masses



Neutrino Oscillations give use a minimum possible neutrino mass.

Normal: $\sum m_\nu > 0.06$ eV
Inverted: $\sum m_\nu > 0.10$ eV

Cosmological Constraints / Forecasts:

Current, combining CMB with other datasets:

$\sum m_\nu < 0.09$ eV (95% confidence)

Valentino et al. Phys. Rev. D **104**, 083504, (2021)

Simons Observatory Forecast:

$\sigma(\sum m_\nu) \sim 0.04$ eV

CMB-S4 Forecast:

$\sigma(\sum m_\nu) \sim 0.03$ eV

Upcoming CMB experiments will be able to constrain the sum of the neutrino masses up to a few sigma.

Summary

Observations of the CMB enable measurements of high-energy physics

Large scale polarization observations will measure of constrain the tensor-to-scalar ratio, indicating the energy scale of the inflation field

Small scale temperature, polarization, and lenses measurements will constrain the effective number of relativistic particles in the early universe and the sum of the neutrino masses.

Thanks!