Prospects in CMB and Inflation

Kimmy Wu

2022-05-12 SLACmass

WPs: https://arxiv.org/abs/2203.08024 https://arxiv.org/abs/2203.05728
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Inflation: Theory and Observations

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Snowmass2021 Cosmic Frontier: Cosmic Microwave Background Measurements White Paper

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Snowmass 2021 CMB-S4 White Paper

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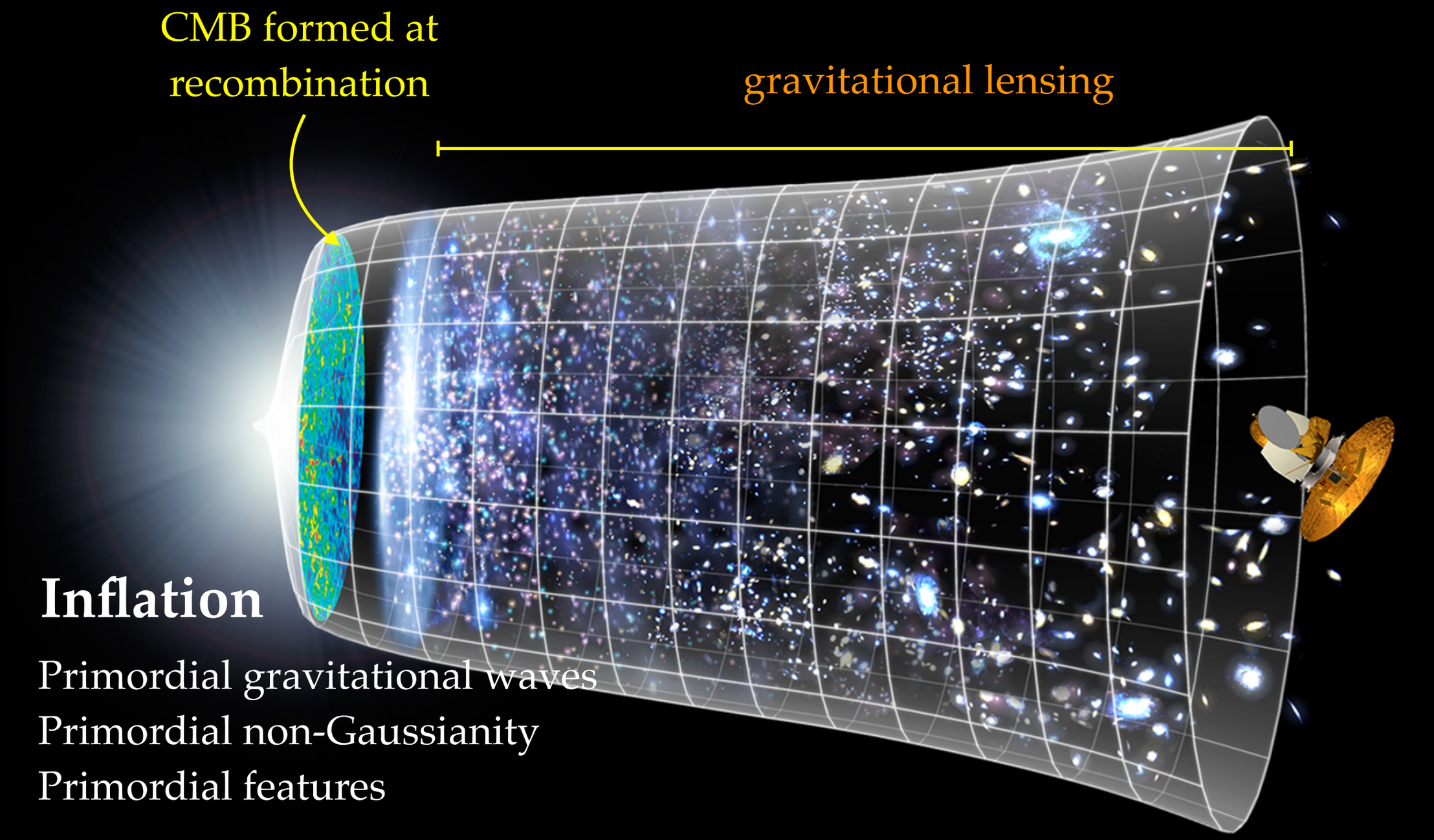
Snowmass2021 CMB-HD White Paper

The CMB-HD Collaboration[1], Simone Aiola[2], Yashar Akrami[3,4,5,6], Kaustuv Basu[7], Michael Boylan-Kolchin[8], Thejs Brinckmann[9,10], Sean Bryan[11], Caitlin M Casey[8], Jens Chluba[12], Sébastien Clesse[13], Francis-Yan Cyr-Racine[14], Luca Di Mascolo[15,16,17], Simon Dicker[18], Thomas Essinger-Hileman[19], Gerrit S. Farren[20,21], Michael A. Fedderke[22], Simone Ferraro[23, 24], George M. Fuller[25], Nicholas Galitzki[26], Vera Gluscevic[27], Daniel Grin[21], Dongwon Han[20], Matthew Hasselfield[2], Renée Hložek[28,29], Gil Holder[30], Selim C. Hotinli[22], Bhuvnesh Jain[18], Bradley Johnson[31], Matthew Johnson[32,33], Pamela Klaassen[34], Amanda MacInnis[35], Mathew Madhavacheril[33,27], Sayan Mandal[35], Philip Mauskopf[36,37], Daan Meerburg[38], Joel Meyers[39], Vivian Miranda[35], Tony Mroczkowski[40], Suvodip Mukherjee[33,41,42,43], Moritz Münchmeyer[44], Julian Munoz[45], Sigurd Naess[2], Daisuke Nagai[46], Toshiya Namikawa[47], Laura Newburgh[46], Hồ Nam Nguyễn[48], Michael Niemack[49], Benjamin D. Oppenheimer[50,45], Elena Pierpaoli[27], Srinivasan Raghunathan[51], Emmanuel Schaan[23,24], Neelima Sehgal[35], Blake Sherwin[20], Sara M. Simon[52], Anže Slosar[53], Kendrick Smith[33], David Spergel[2], Eric R. Switzer[19], Pranjal Trivedi[54], Yu-Dai Tsai[55], Alexander van Engelen[11], Benjamin D. Wandelt[2,56,57], Edward J. Wollack[19], and Kimmy Wu[58,59]

CMB: sensitive to physics of the early and late universe



Inflation

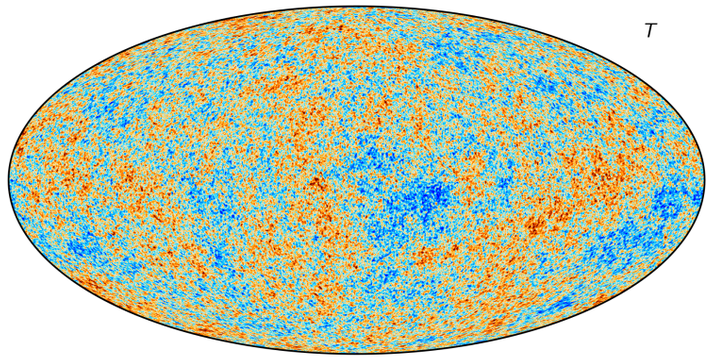
Primordial gravitational waves
Primordial non-Gaussianity
Primordial features

NASA/WMAP Science Team

TEMPERATURE

E-MODE POLARIZATION

B-MODE POLARIZATION



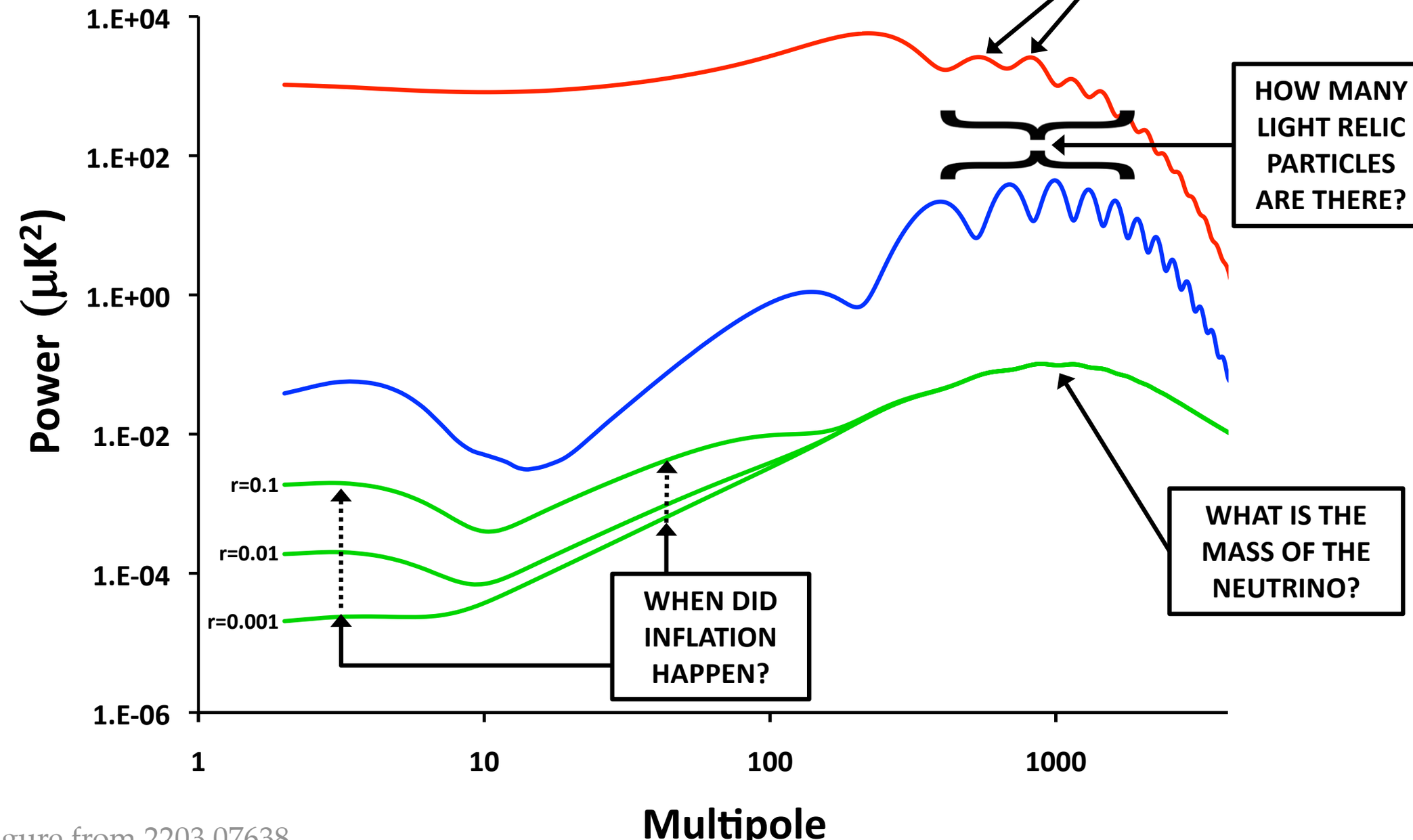


Figure from 2203.07638

CMB polarization is the Frontier

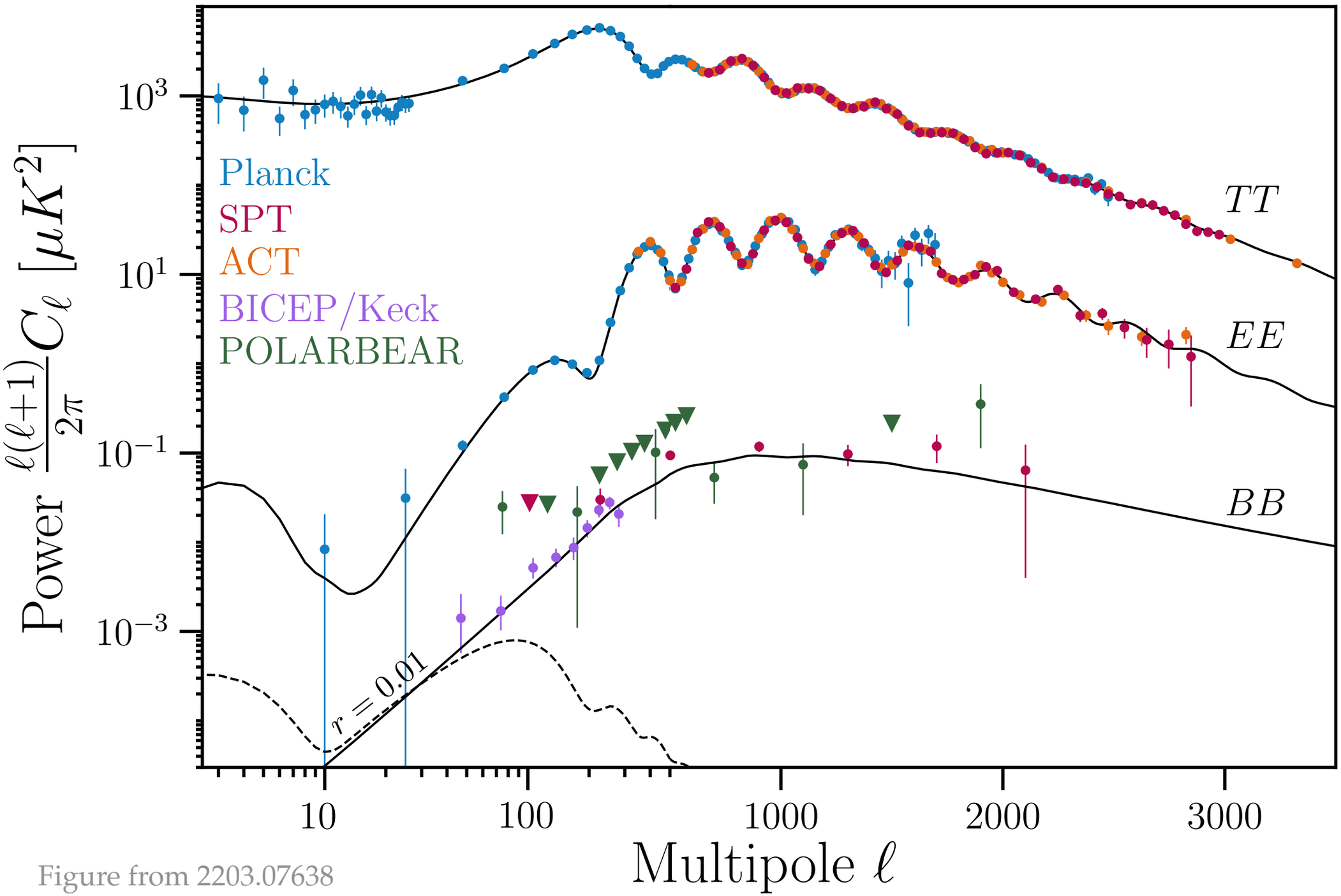
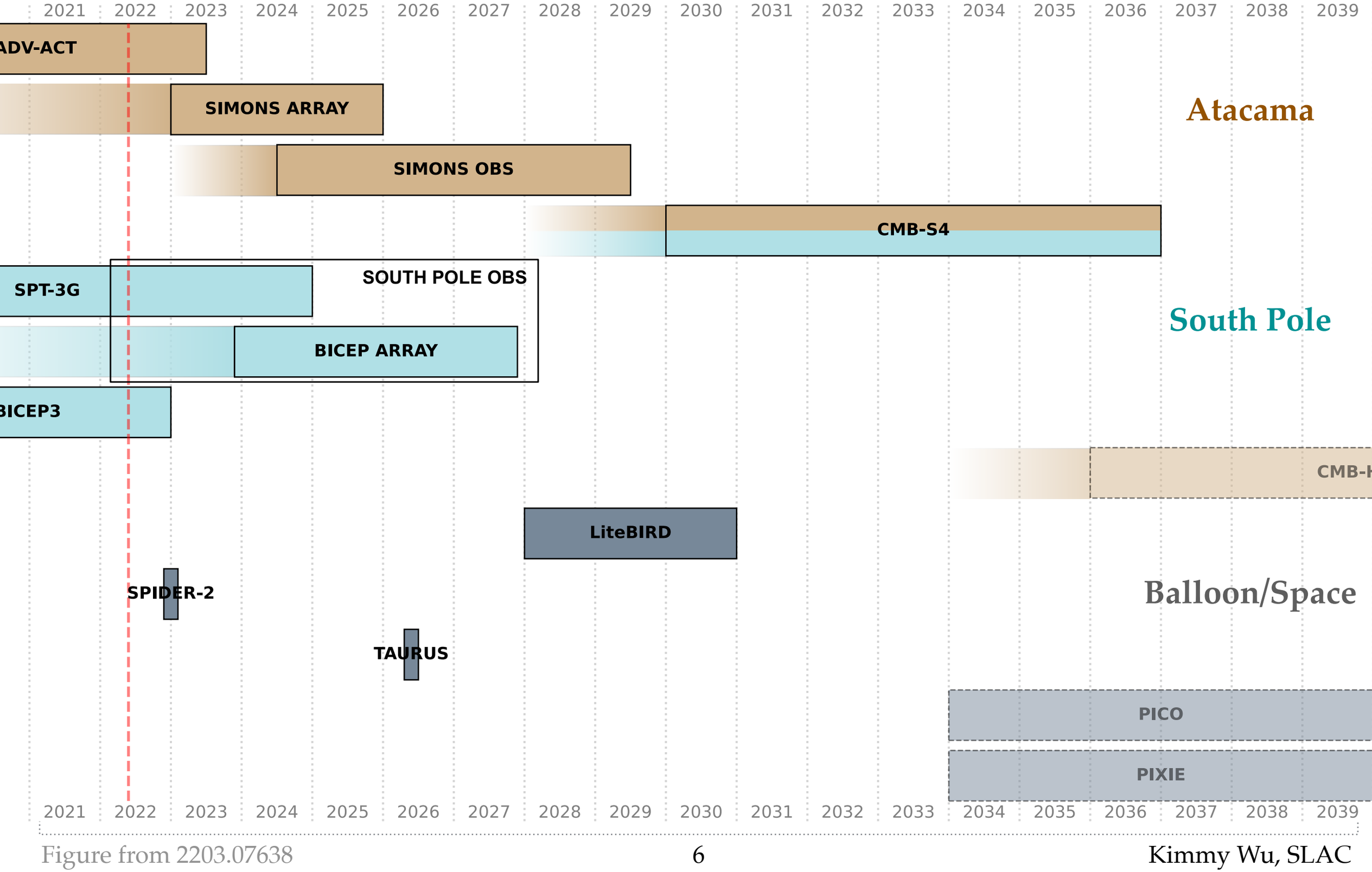


Figure from 2203.07638

Experiment landscape



What can we reach with CMB-S4?

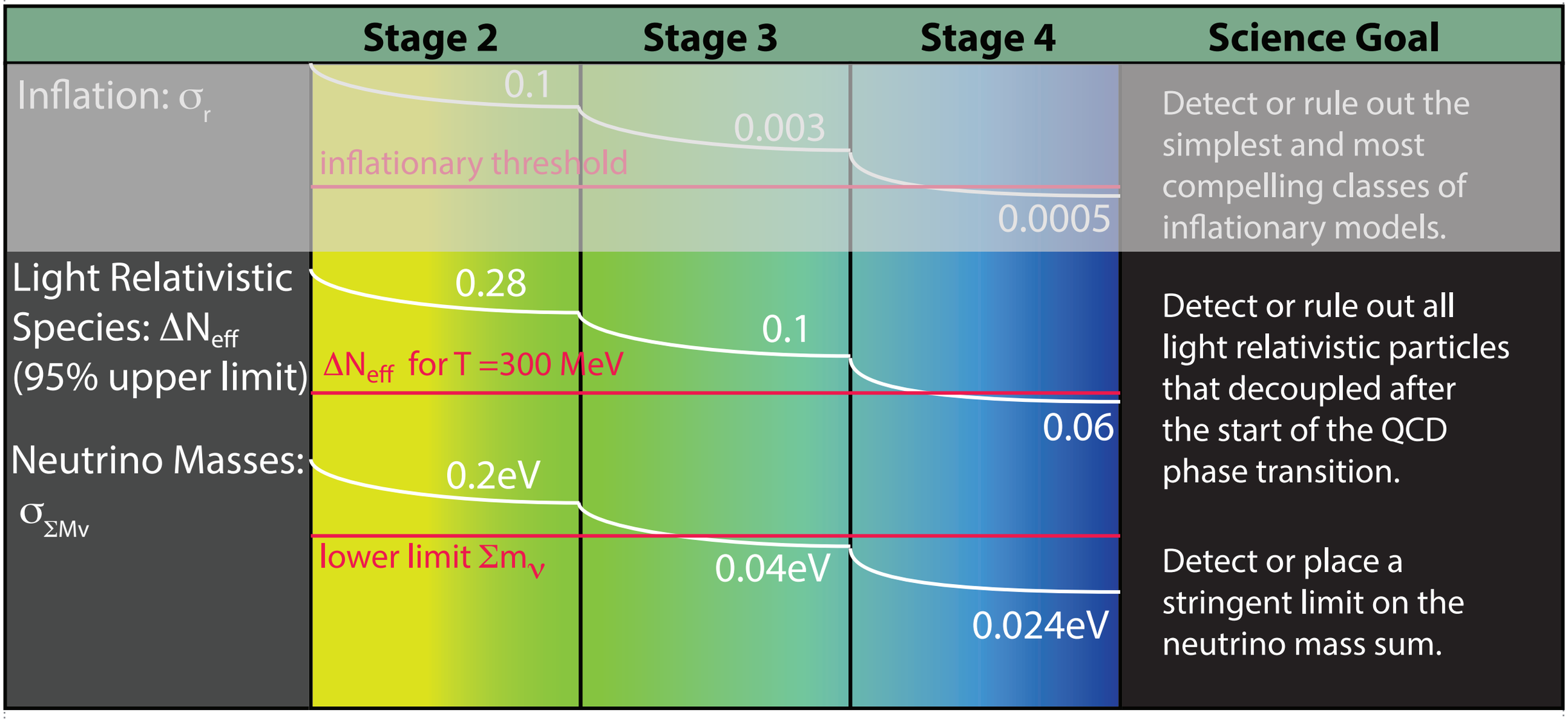


Figure from 2203.07638

PGW significance

- Inflation sources quantum fluctuations, esp. scalar & tensor metric fluctuations.
  → Tensor fluctuations are primordial gravitational waves.

- Observation of a non-zero tensor amplitude (tensor-to-scalar ratio r).
  → Glimpse of quantum gravity at work.

- In simple models:
  → Related to energy scale of inflation,
  → Constrains distance traversed by the inflaton.

From 2203.08128

PGW targets

- $r \gtrsim 0.01$:

  → Super-Planckian inflaton field excursion,

  → Evidence for approximate shift symmetry in quantum gravity.

- $r \gtrsim 0.001$:

  → Evidence for the simplest models of inflation which naturally predict observed n_s and have a characteristic scale $> M_p$.

  (cf. Starobinsky's R^2 inflation, Higgs inflation, α-attractors, …).

- Non-detection:

  → Vast restriction of inflationary model space,

  → Still insights into physics at very high scales.

From 2203.08128

CMB-S4 will detect or rule out targets

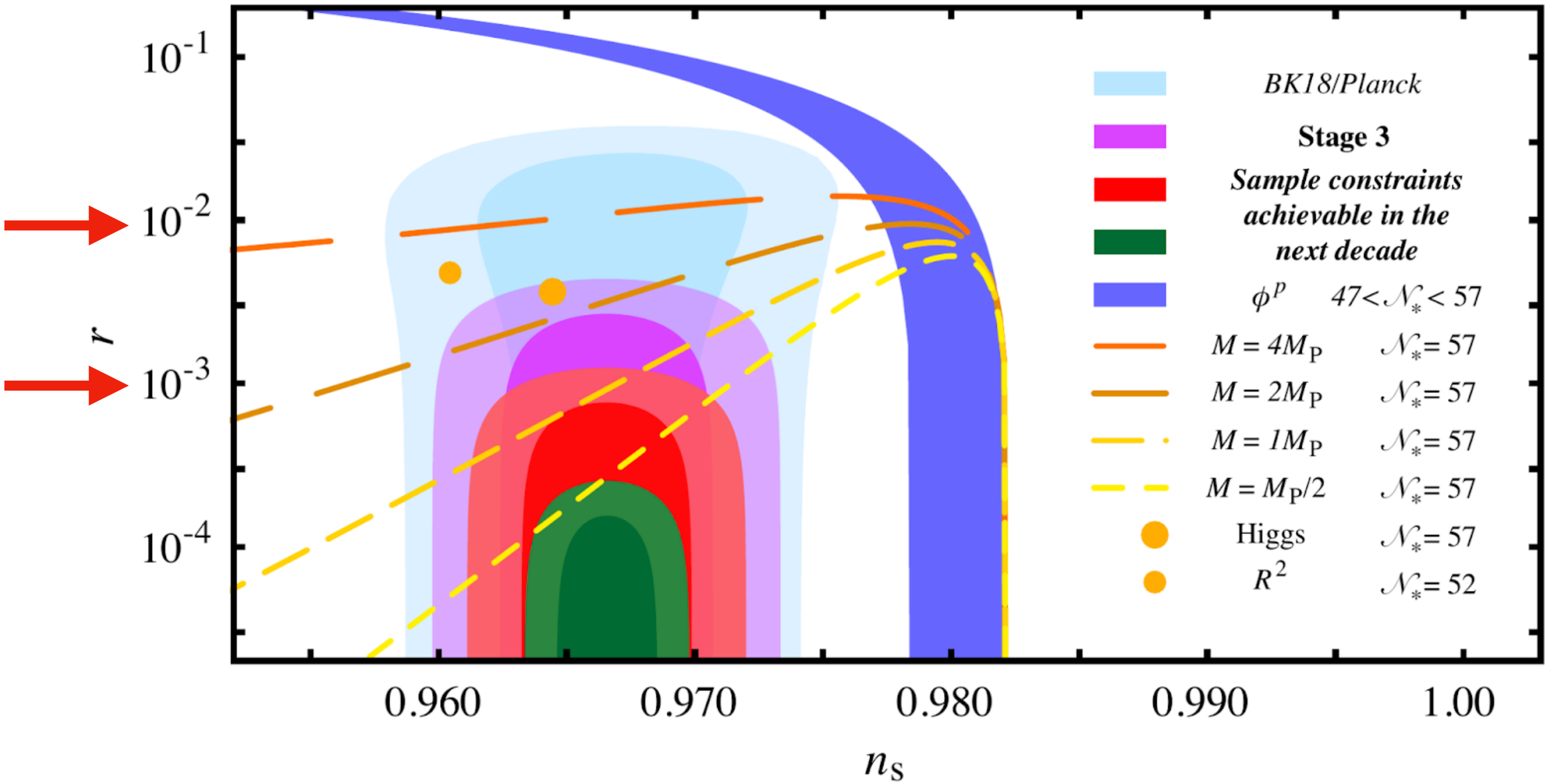
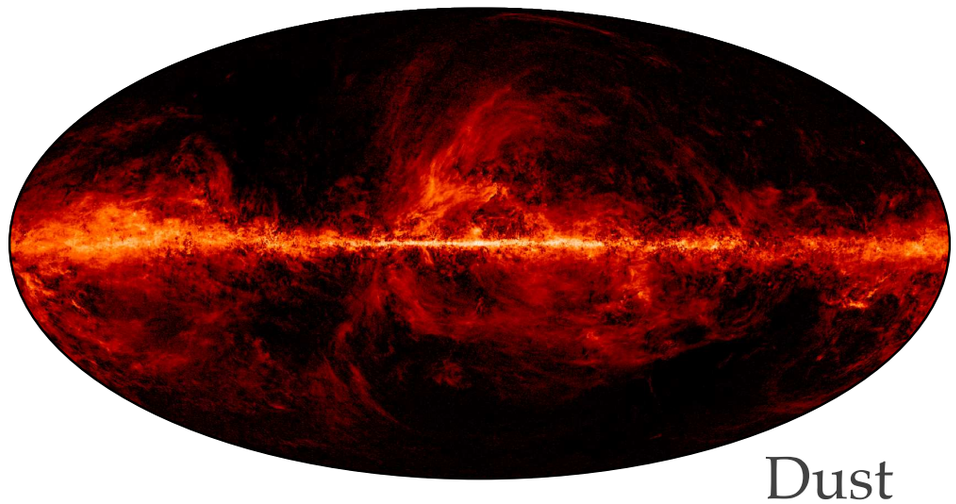


Figure from 2203.08128

Challenges to reaching PGW goal

- Galactic foregrounds
  - Polarized dust and synchrotron fields are non-Gaussian (Galactic magnetic field, filamentary structure of HI emission which dust field traces, etc.)
  - Need better simulations (MHD, modeling based on auxiliary data from non-mm bands) and analyses immune to / robust against foreground mismodeling.
- Delensing
  - For CMB-S4, need to remove > 90% of the lensing B mode power to reach *r* science goal.
  - Need small-scale Galactic foreground simulations to assess potential biases to the lensing B estimate if mismodeled.



Dust

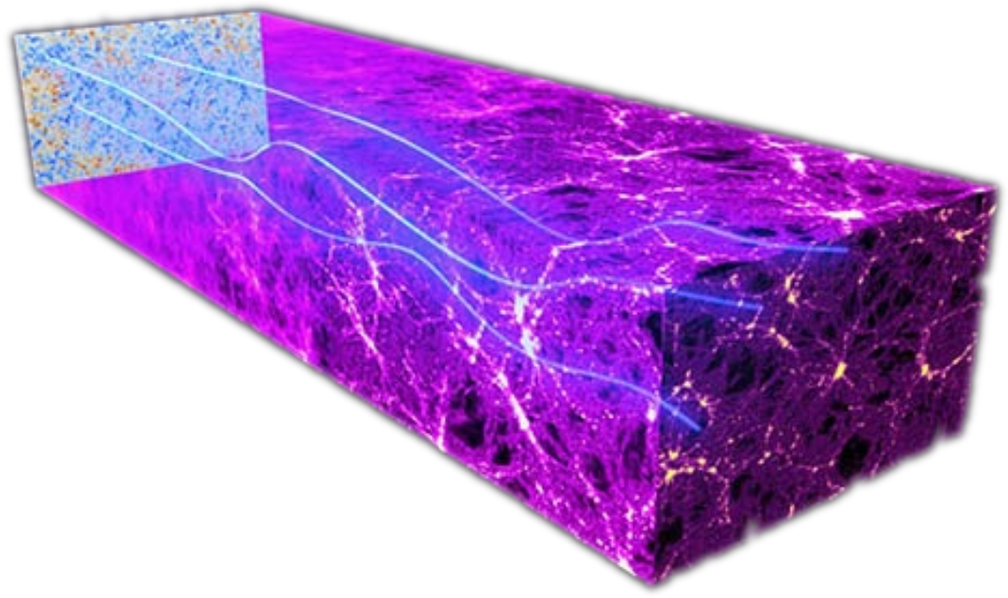
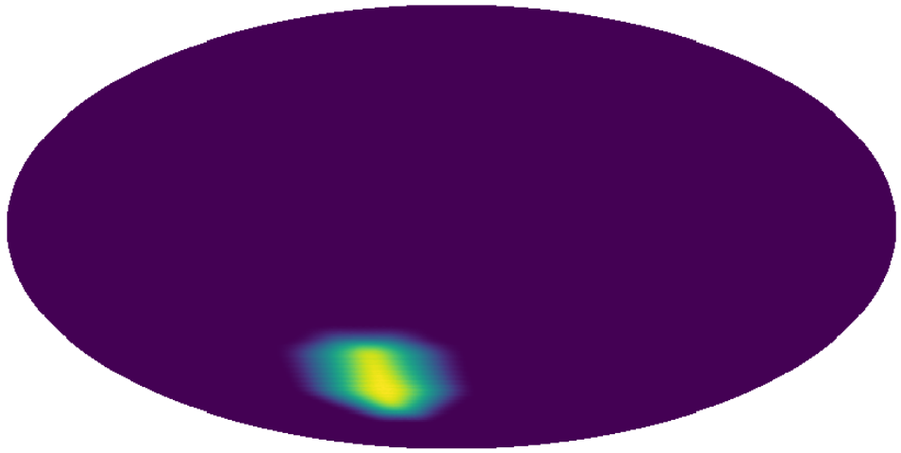


Image credit: ESA, Planck

From 2203.08128

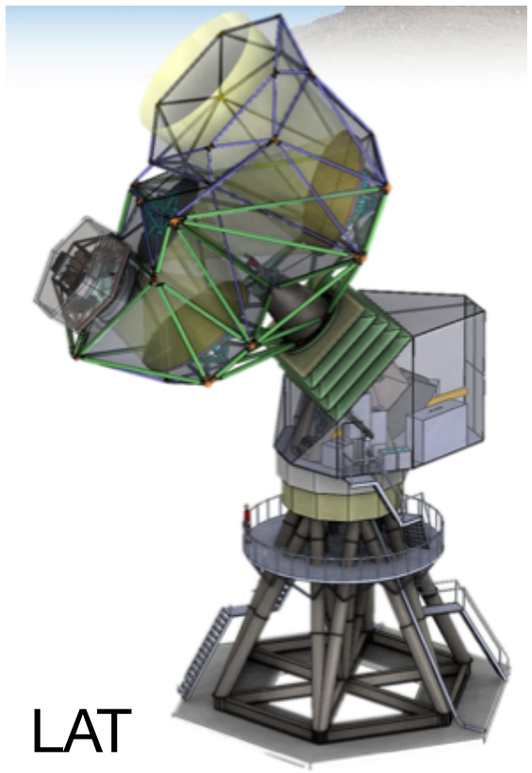
How is CMB-S4 designed so that PGW goals can be achieved

- Focus detectors on small patch of sky (~3%) —> ultra-deep observations across multiple bands.
  - Simpler foregrounds than large-patch observations
- Pairing small-aperture telescopes (SATs) with large-aperture telescope (LATs) observations.
  - SATs such as BICEP/Keck telescopes demonstrated recovery of degree-scale modes with control of instrumental systematics.
  - LATs are use for delensing: high S/N estimation of lensing B mode contribution requires more modes than is available to SATs.



95GHz SAT relative hits on the ultra-deep patch

SAT

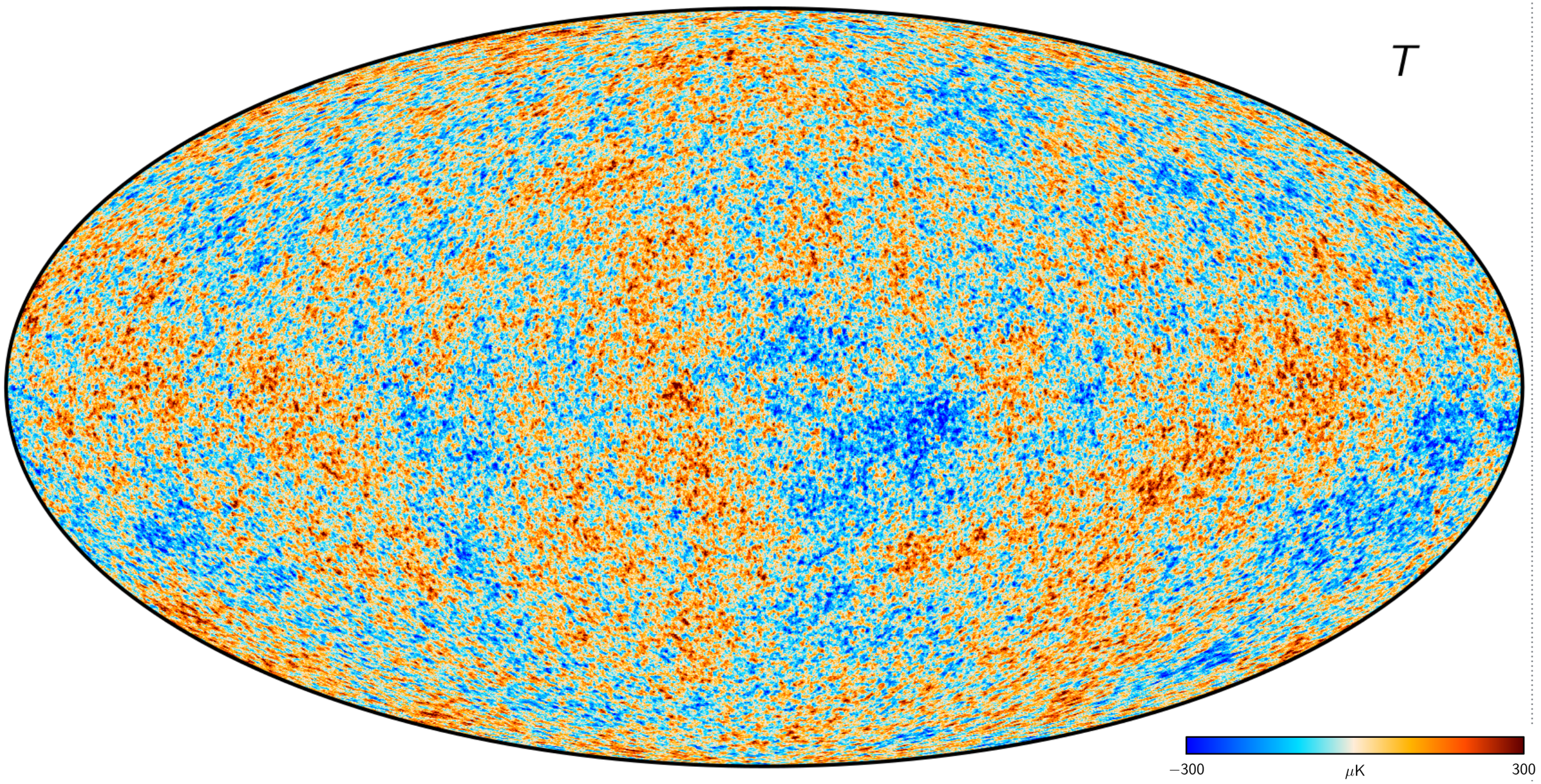


LAT

Summary

- CMB observations are foundational to model cosmology and essential to pushing frontier of understanding the early universe.
- Observations of PGWs have profound implications for HEP.
- CMB-S4 is designed to reach theoretically relevant thresholds of *r*.
- Lots of opportunities for further understanding the early universe through joint analyses with other surveys (optical, 21cm, line-intensity mapping) to constrain primordial non-Gaussianity and features.

Extras

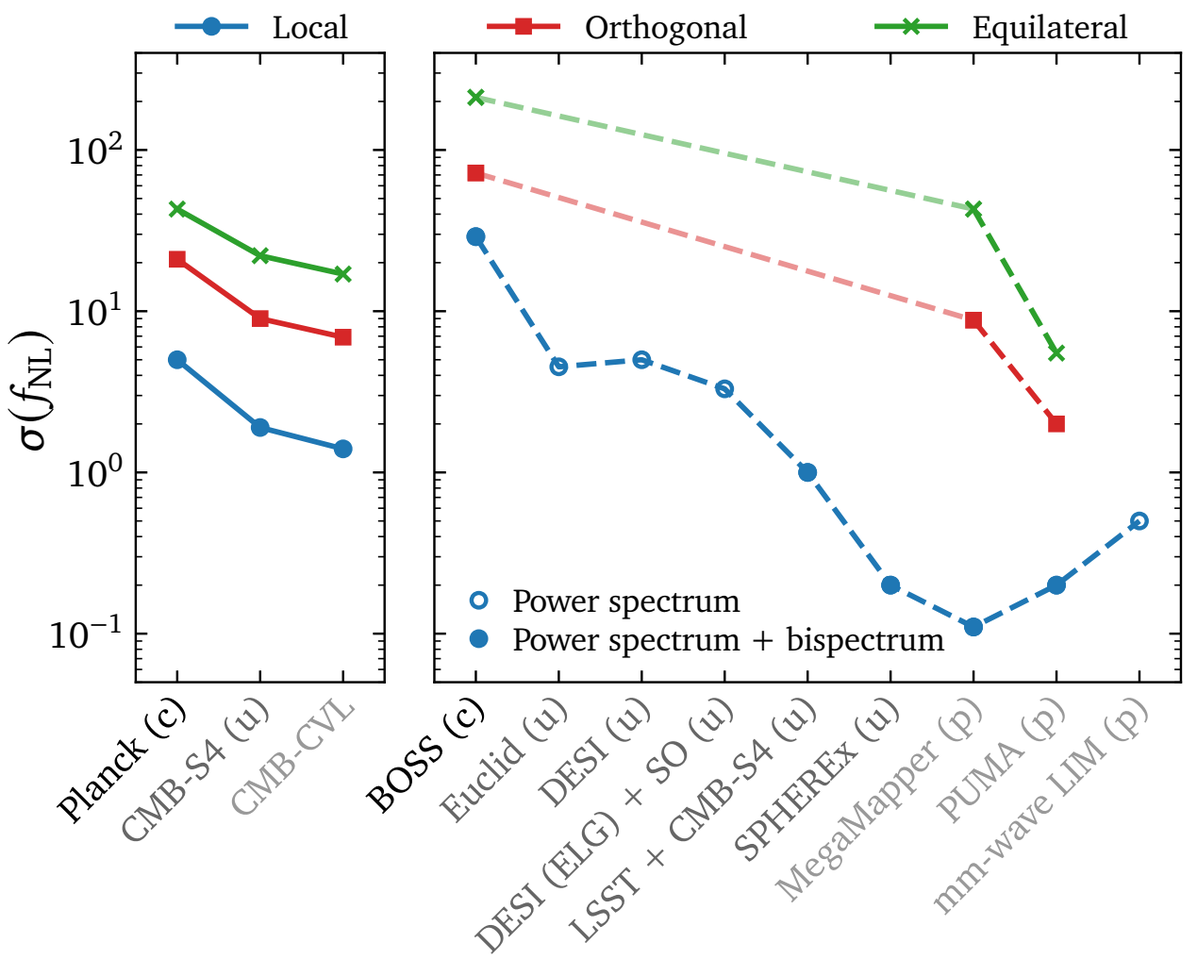


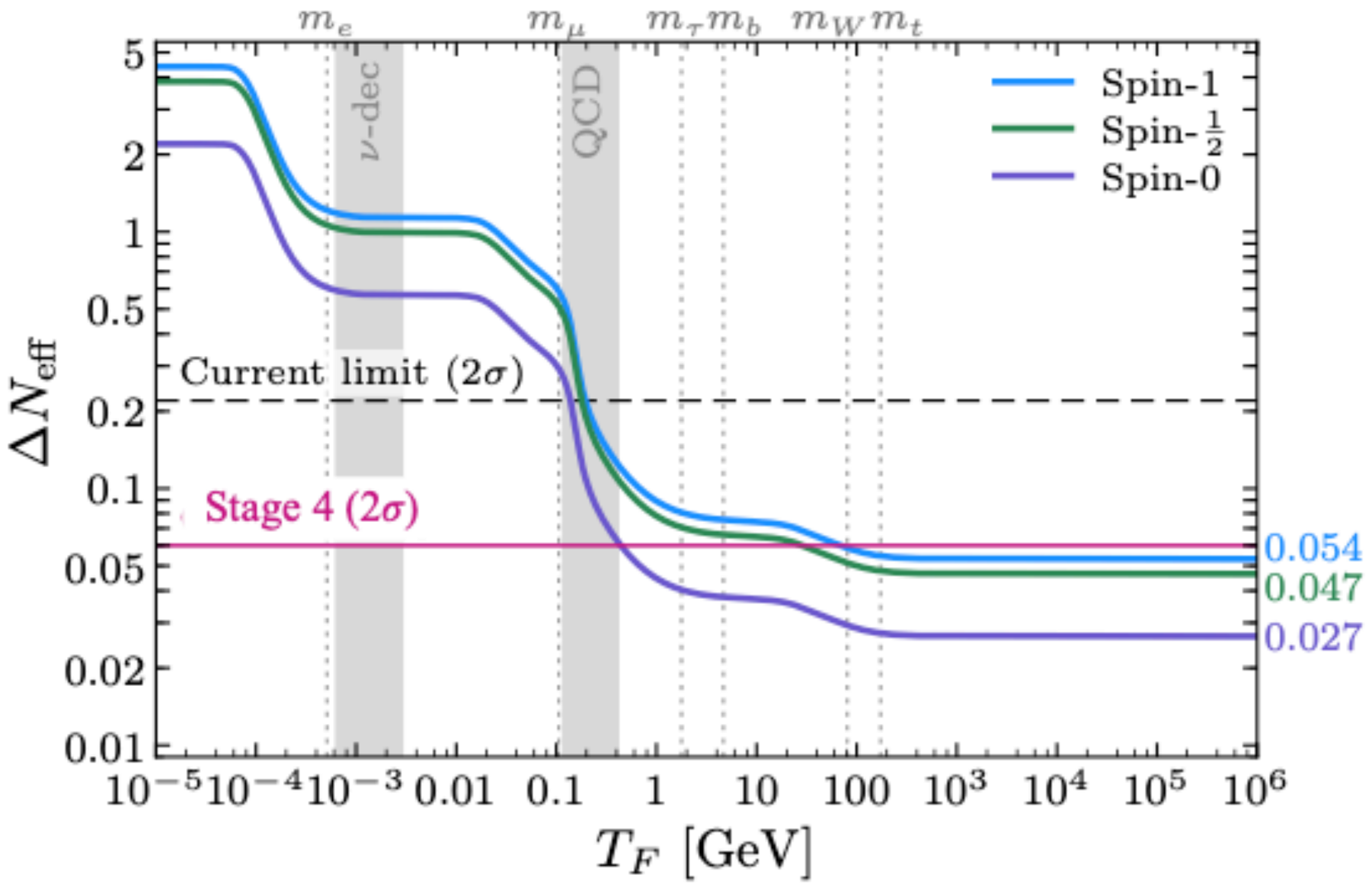
E modes

B modes

Other ways to probe inflation: Primordial non-Gaussianity, features in primordial spectrum

- Departures from the minimal power-low (near scale-invariant) primordial power spectrum are common when connecting inflationary models with particle physics —> features in primordial spectrum.
- Extra degrees of freedom that interacts with the inflaton d or curvature perturbation self-interaction are examples that generate PNGs.
- So far, observations provide no evidence for departures of Gaussianity of primordial fluctuations.
- For these two signatures, current CMB observations provide the most stringent constraints. With upcoming LSS surveys, CMB+LSS will provide the most powerful limits.




m_e
m_μ
$m_\tau m_b$
$m_W m_t$
ν-dec
QCD
Spin-1
Spin-$\frac{1}{2}$
Spin-0
Current limit (2σ)
Stage 4 (2σ)
0.054
0.047
0.027
$\Delta N_{\rm eff}$
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
10^{-5} 10^{-4} 10^{-3} 0.01 0.1 1 10 100 10^3 10^4 10^5 10^6
T_F [GeV]