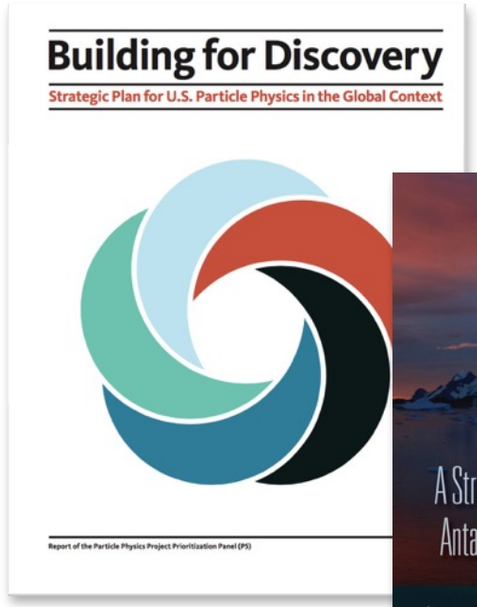
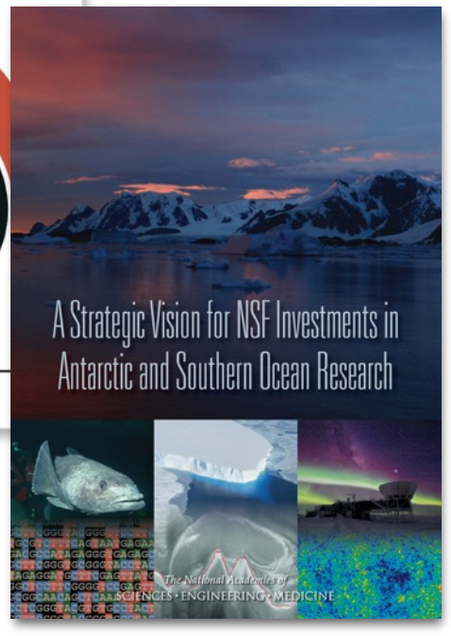
Welcome! (again)

CMB-S4
Next Generation CMB Experiment

Stage 4 CMB experiment: CMB-S4

- **A next generation ground-based program to pursue inflation, neutrino properties, dark radiation, dark energy and new discoveries.**
- **Greater than tenfold increase in sensitivity of the combined Stage 3 experiments (>100x current Stage 2) to cross critical science thresholds.**
- **O(500,000) detectors spanning 30 - 300 GHz using multiple telescopes and sites to map most of the sky, as well as deep targeted fields.**
- **Broad participation of the CMB community, including the existing CMB experiments (e.g., ACT, BICEP/Keck, CLASS, POLARBEAR/Simons Array & SPT), National Labs and the High Energy Physics community. International partnerships expected and desired.**





Recommended by P5 & NRC Antarctic reports

continuing series of community workshops to advance CMB-S4

U. Minnesota
Jan 16, 2015

LBNL, Berkeley
March 7-9, 2016

U. Michigan
Sep 21-22, 2015

U. Chicago
Sep 19-20, 2016

Working on conceptual design and iterate with science goals

Atacama CMB (stage 2 & 3)

Stage-2 ~ 1000 detectors
Stage-3 ~10,000 detectors

Photo: Rahul Datta & Alessandro Schillaci

South Pole CMB (stage 2 & 3)

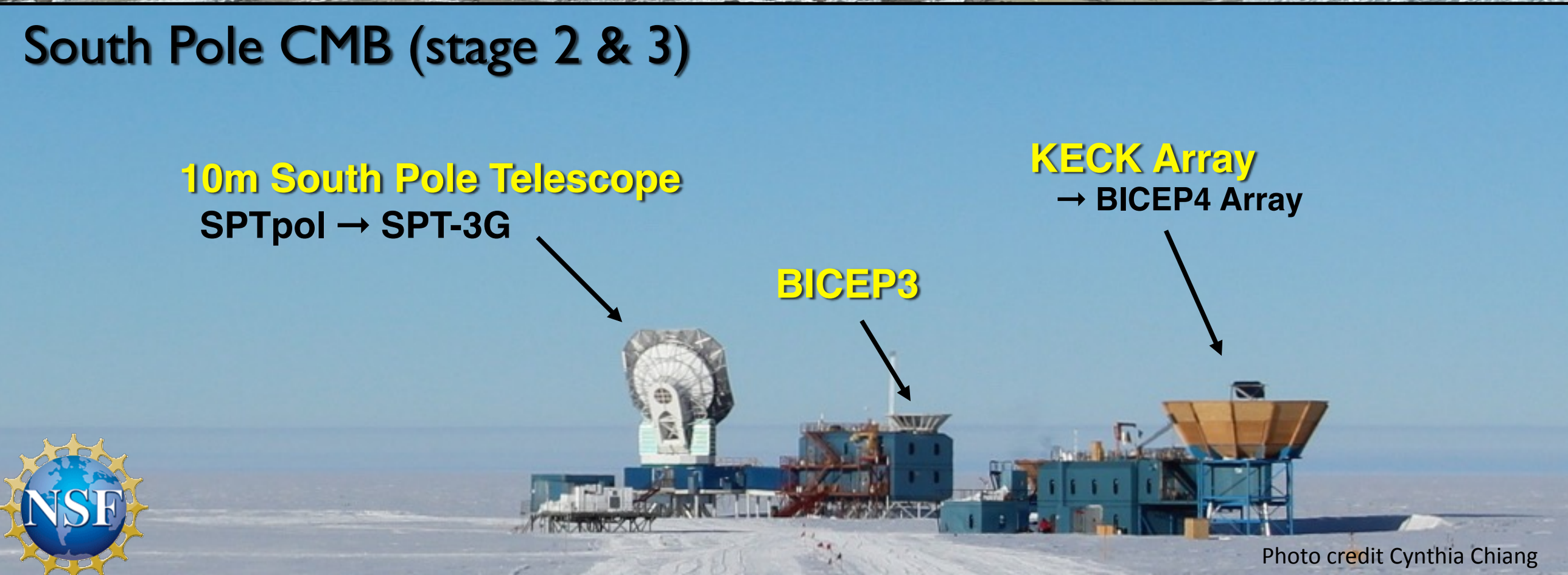


Photo credit Cynthia Chiang

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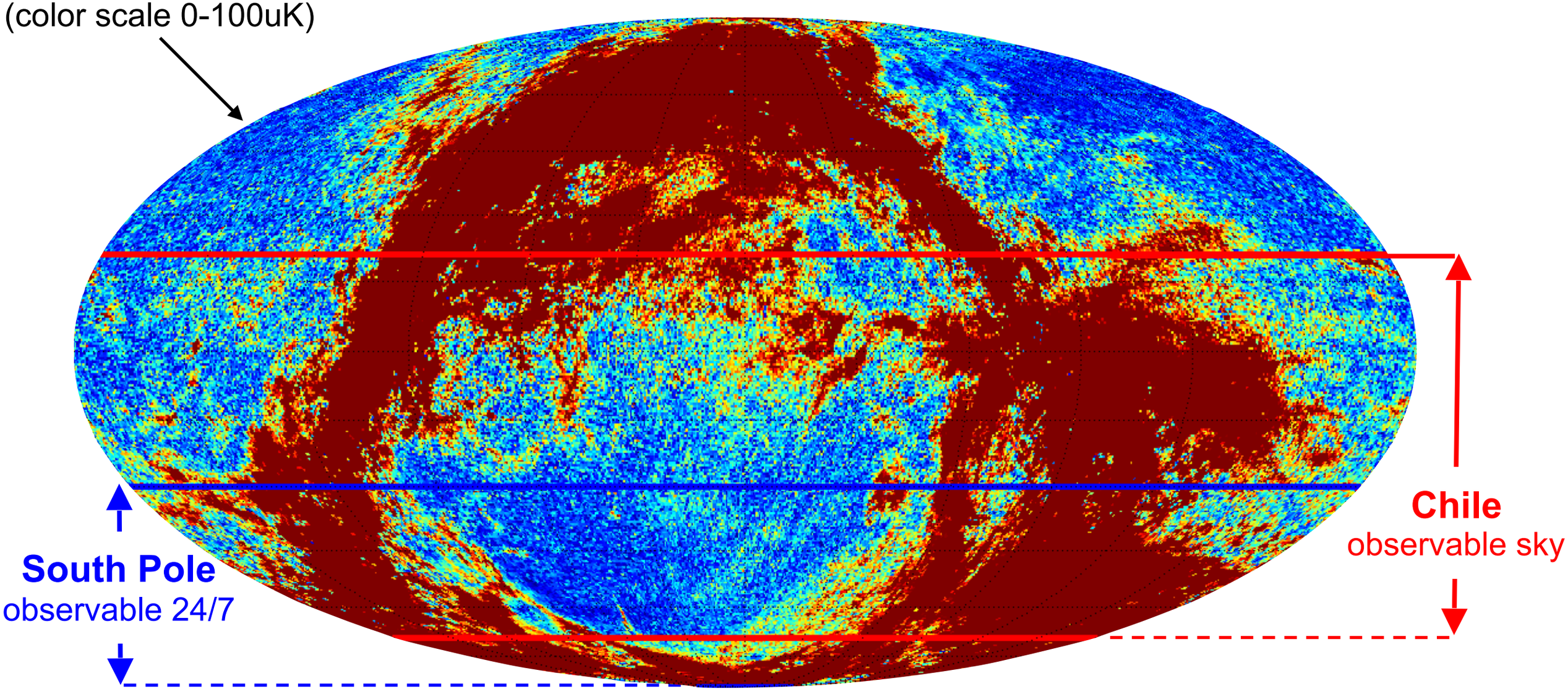
Telescopes at Chile and South Pole (established and proven CMB sites)

Planck 353GHz polarized intensity map in celestial coordinates (color scale 0-100uK)



possibly add new northern site, e.g., Tibet, Greenland

Figure from Clem Pryke

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Enhance Future Surveys science by overlapping coverage

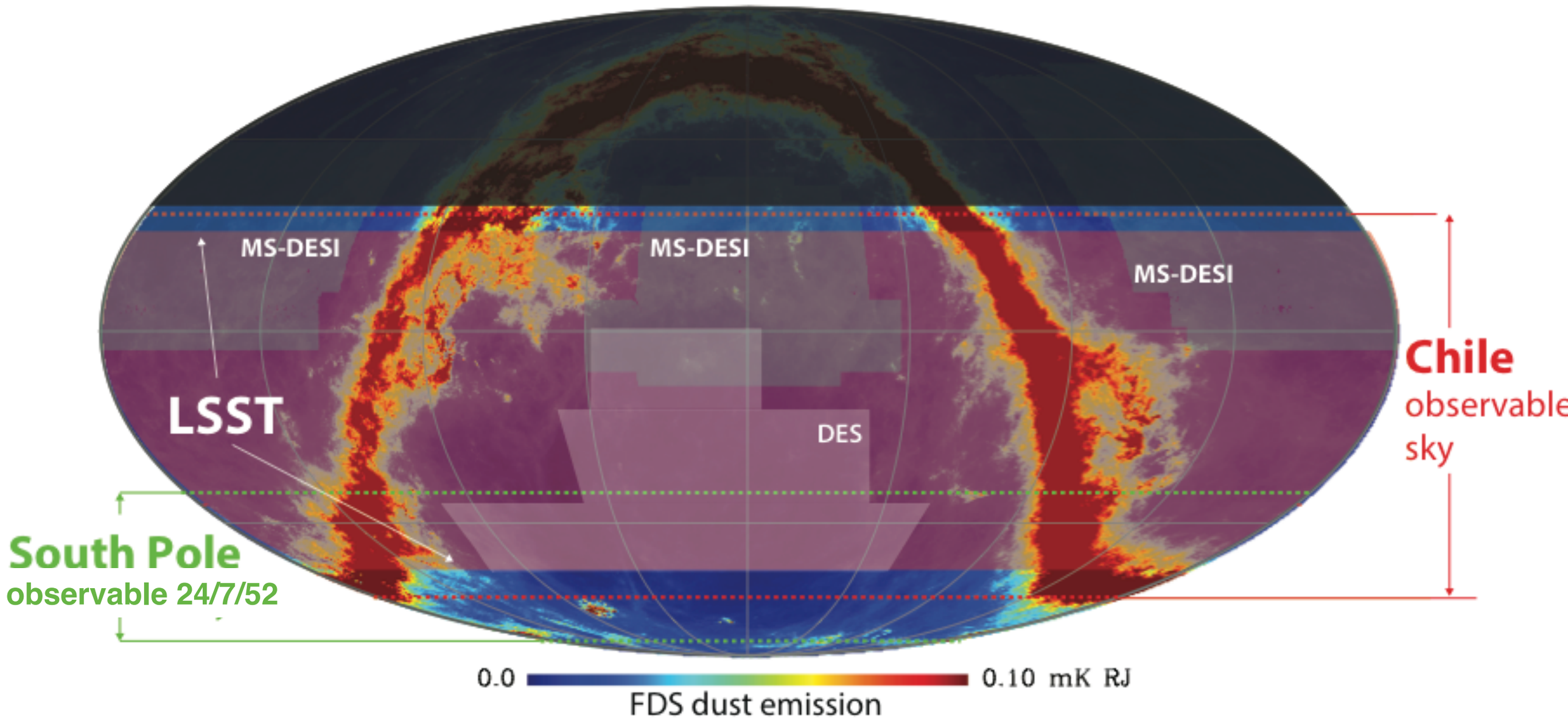


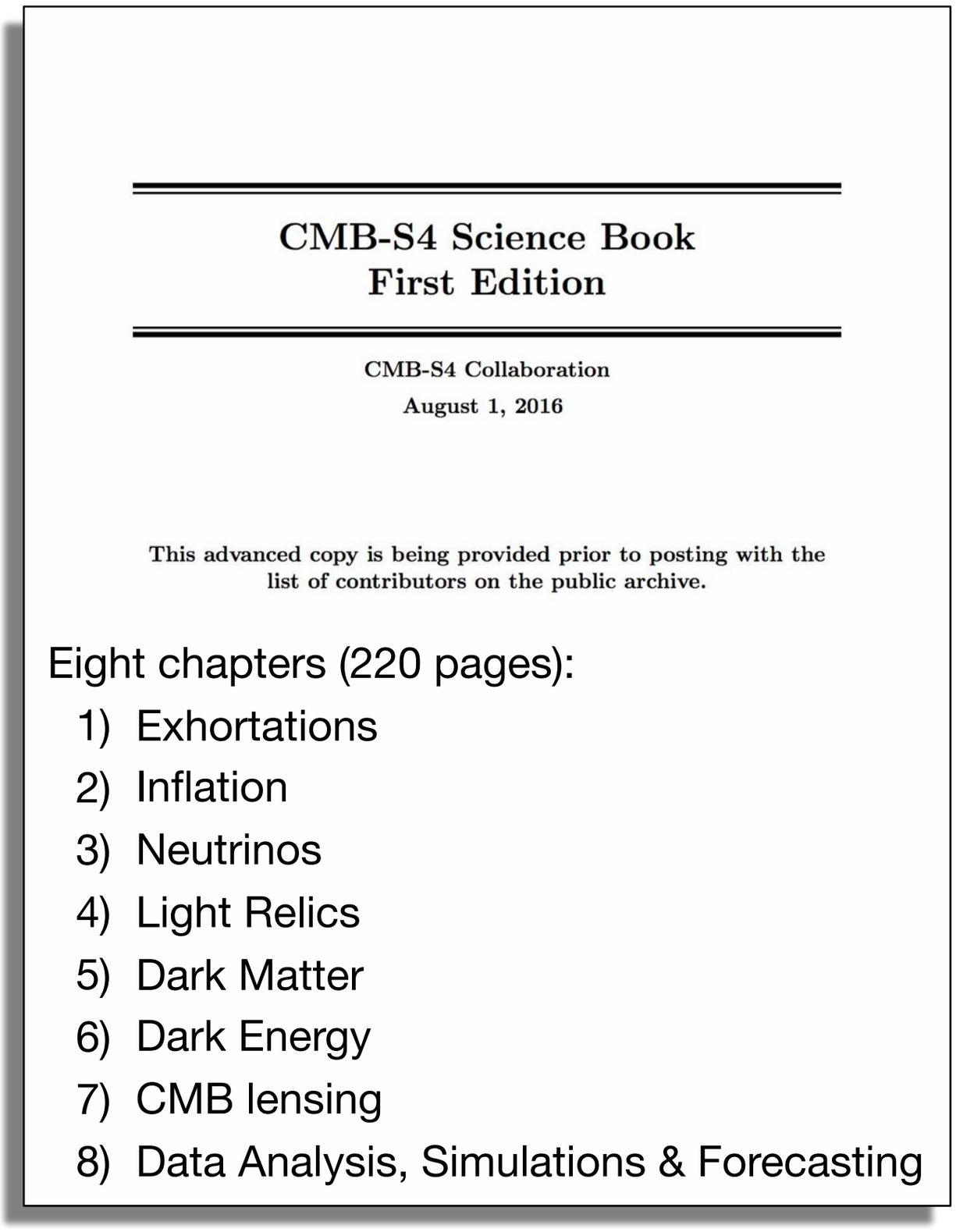
Figure from Jeff McMahon

CMB-S4 Science Book

download Science Book
and sign up as "contributor"
and/or "endorser" at
http://cmb-s4.org

Deadline for posting
on arXiv.

Monday September 26th



CMB-S4 Science Book
First Edition

CMB-S4 Collaboration

August 1, 2016

This advanced copy is being provided prior to posting with the list of contributors on the public archive.

Eight chapters (220 pages):

1) Exhortations
2) Inflation
3) Neutrinos
4) Light Relics
5) Dark Matter
6) Dark Energy
7) CMB lensing
8) Data Analysis, Simulations & Forecasting

CMB-S4 Instrument White Papers

4 white paper drafts (189 pages)
Available at http://cmb-s4.org

Detectors, multiplexing, readout – survey of current technologies and areas of focus for CMB-S4

September 16, 2016

CMB-S4: Detector Radio-Frequency Design

September 17, 2016

CMB-S4: Broadband Optics

September 15, 2016

CMB S-4: Telescope Design Considerations

September 15, 2016

T. Essinger-Hileman, N. Halverson, S. Hanany, A. Kusaka, M. D. Niemack, S. Padin, S. Parshley, C. Pryke, A. Suzuki, E. Switzer, K. Thompson, CMB-S4

CMB-S4 Science Book "aspirational goals"

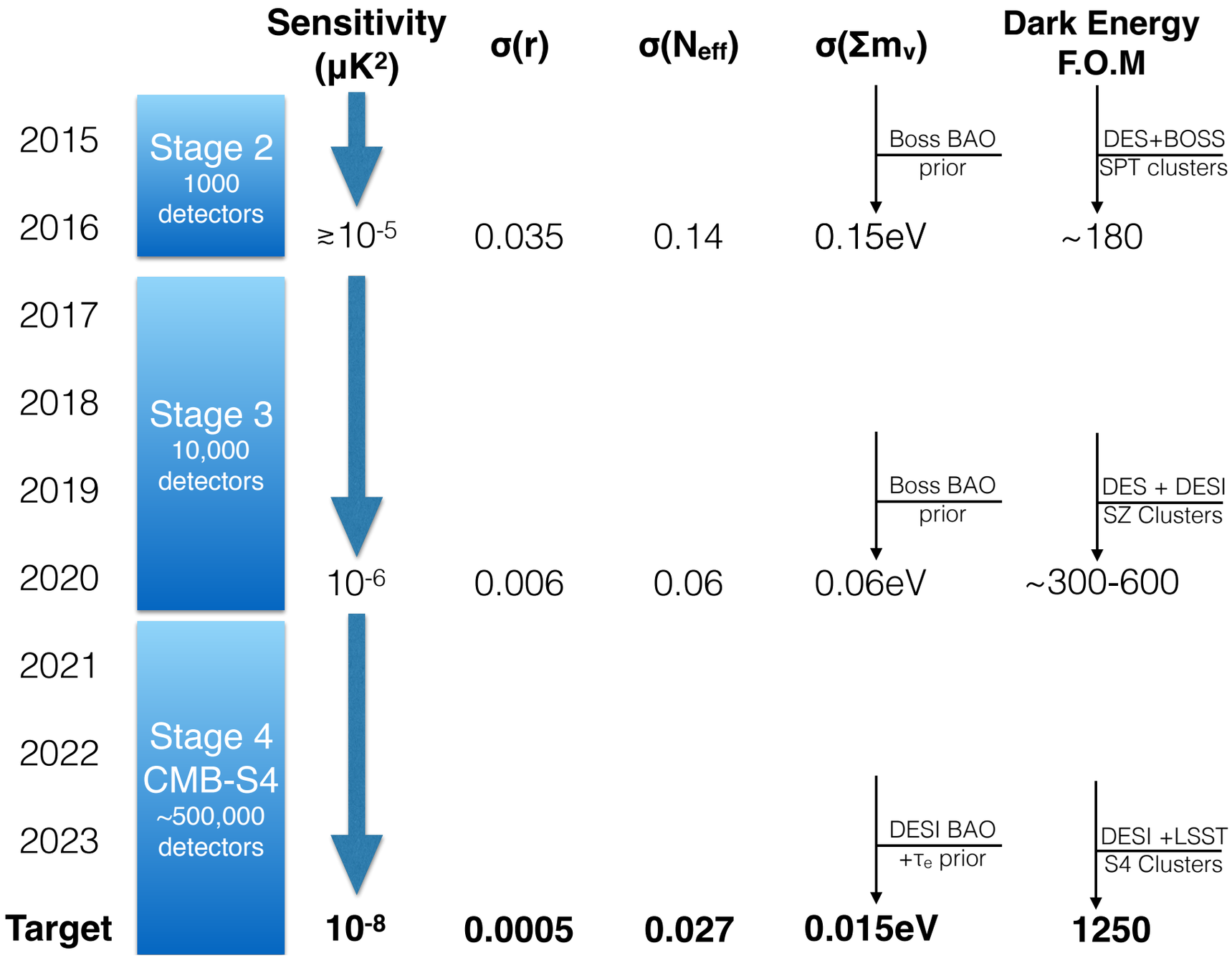


Figure 3. *Schematic timeline showing the expected increase in sensitivity (μK^2) and the corresponding improvement for a few of the key cosmological parameters for Stage-3, along with the threshold-crossing aspirational goals targeted for CMB-S4.*

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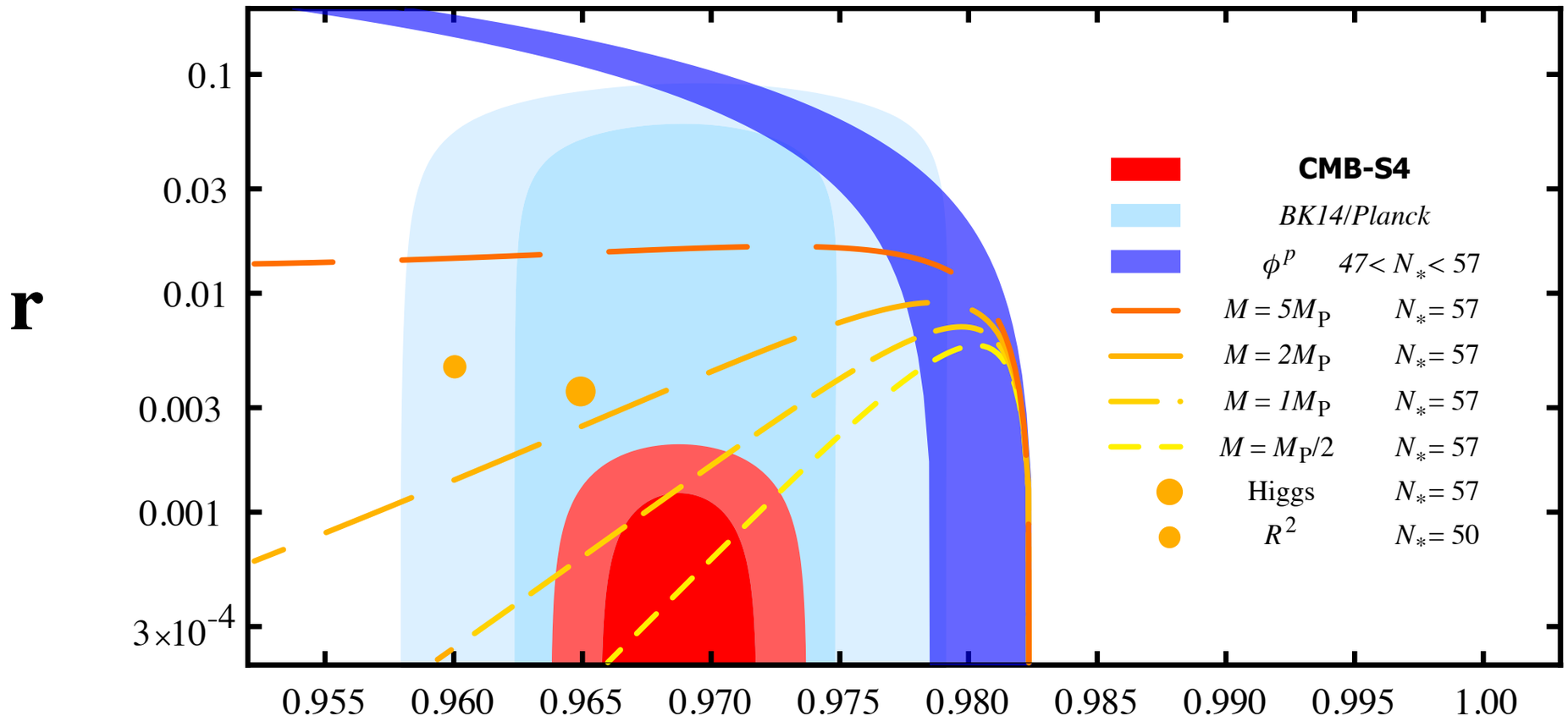

A detection of primordial B modes with CMB-S4 would provide evidence that the theory of quantum gravity must accommodate a Planckian field range for the inflaton.

Conversely a non-detection of B modes with CMB-S4 will mean that a large field range is not required.

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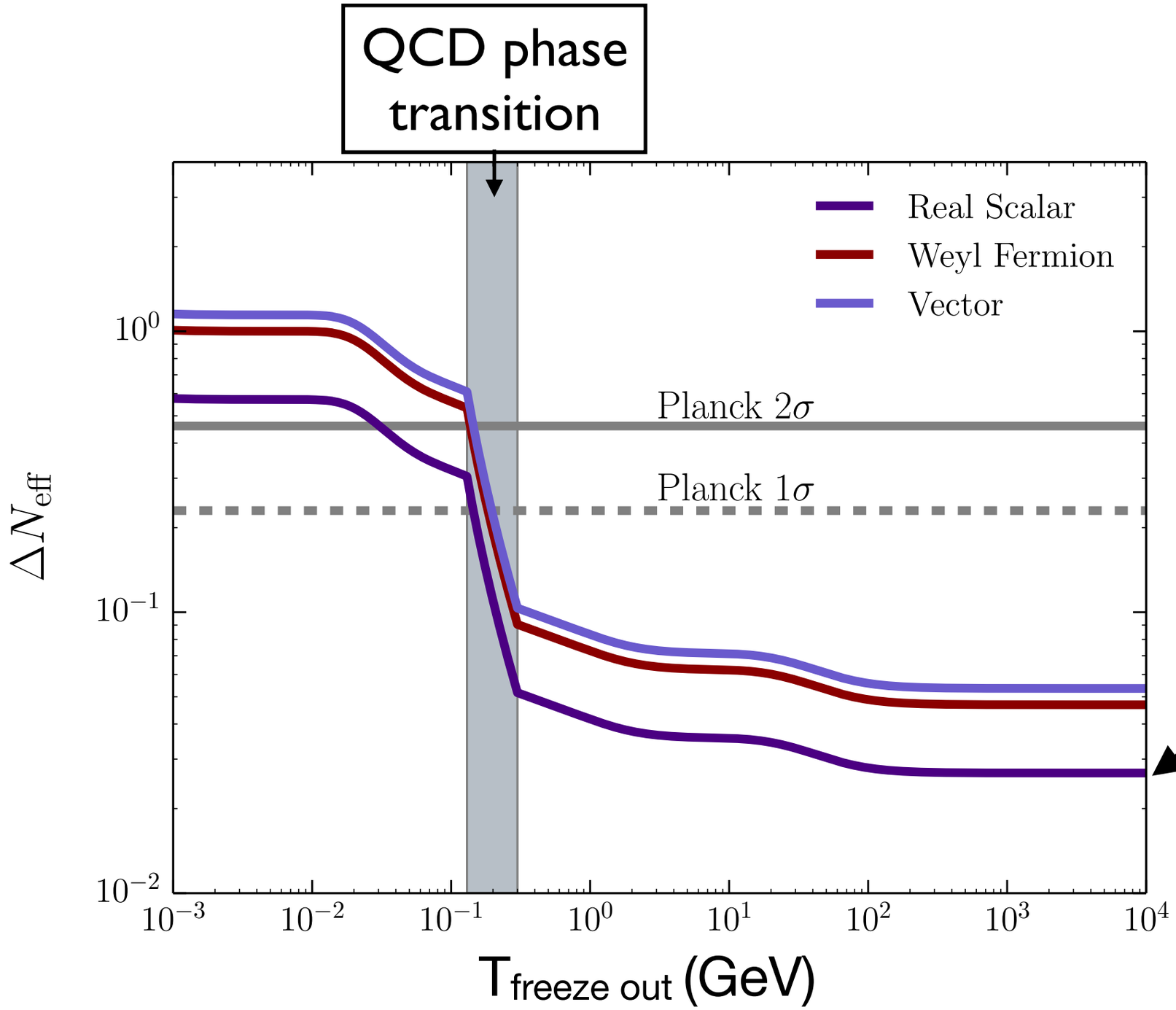
N_{eff} constraints and light thermal relics



N_{eff} measurements can constrain light thermal relics

Sets natural, and exceedingly challenging, target of $\Delta N_{eff} = 0.027$

Green, Meyers in CMB-S4 Science Book (http://CMB-S4.org)
also see Baumann, Green, Wallisch "A New Target for Cosmic Axion Searches" arXiv:1604.08614

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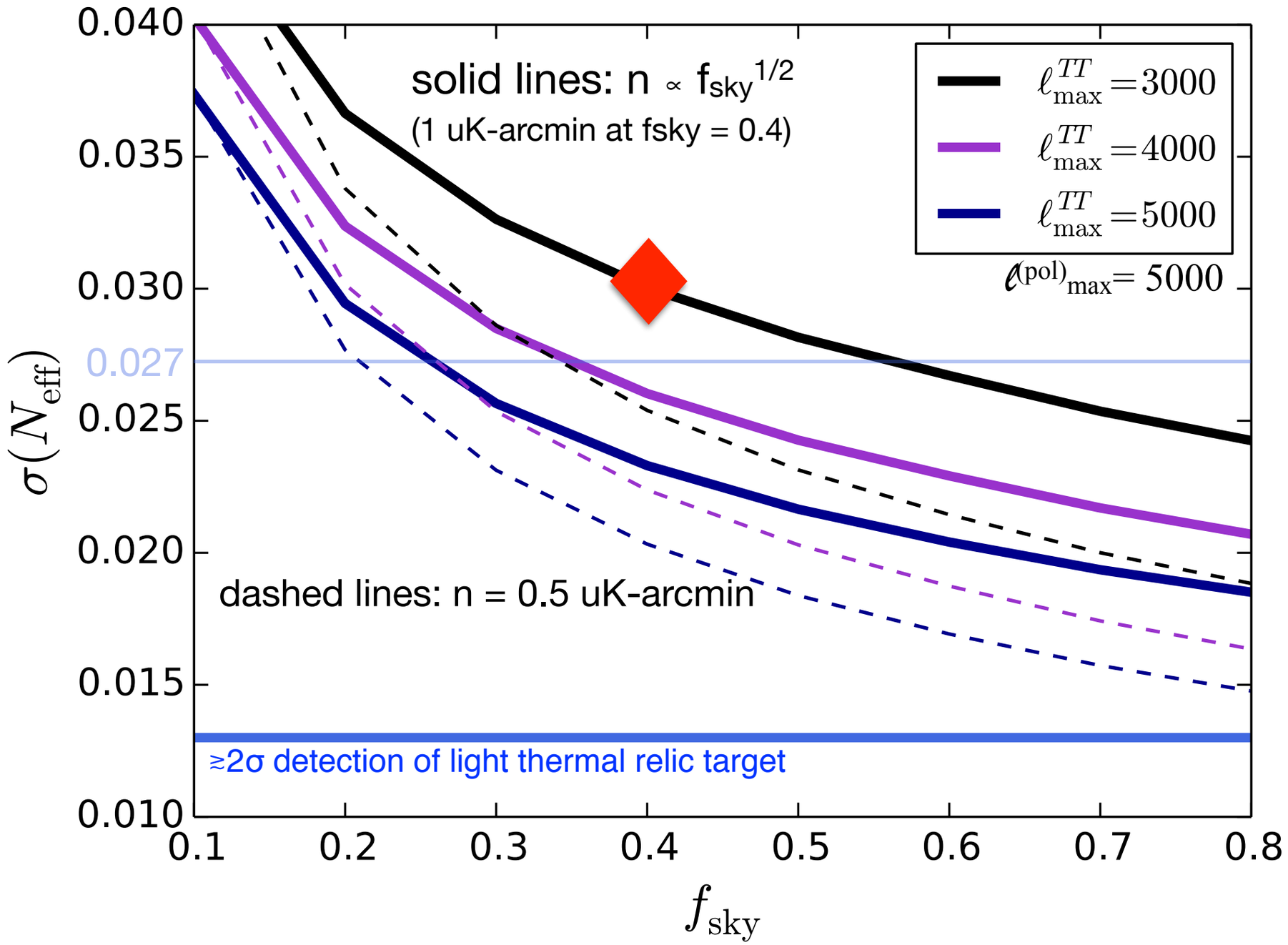
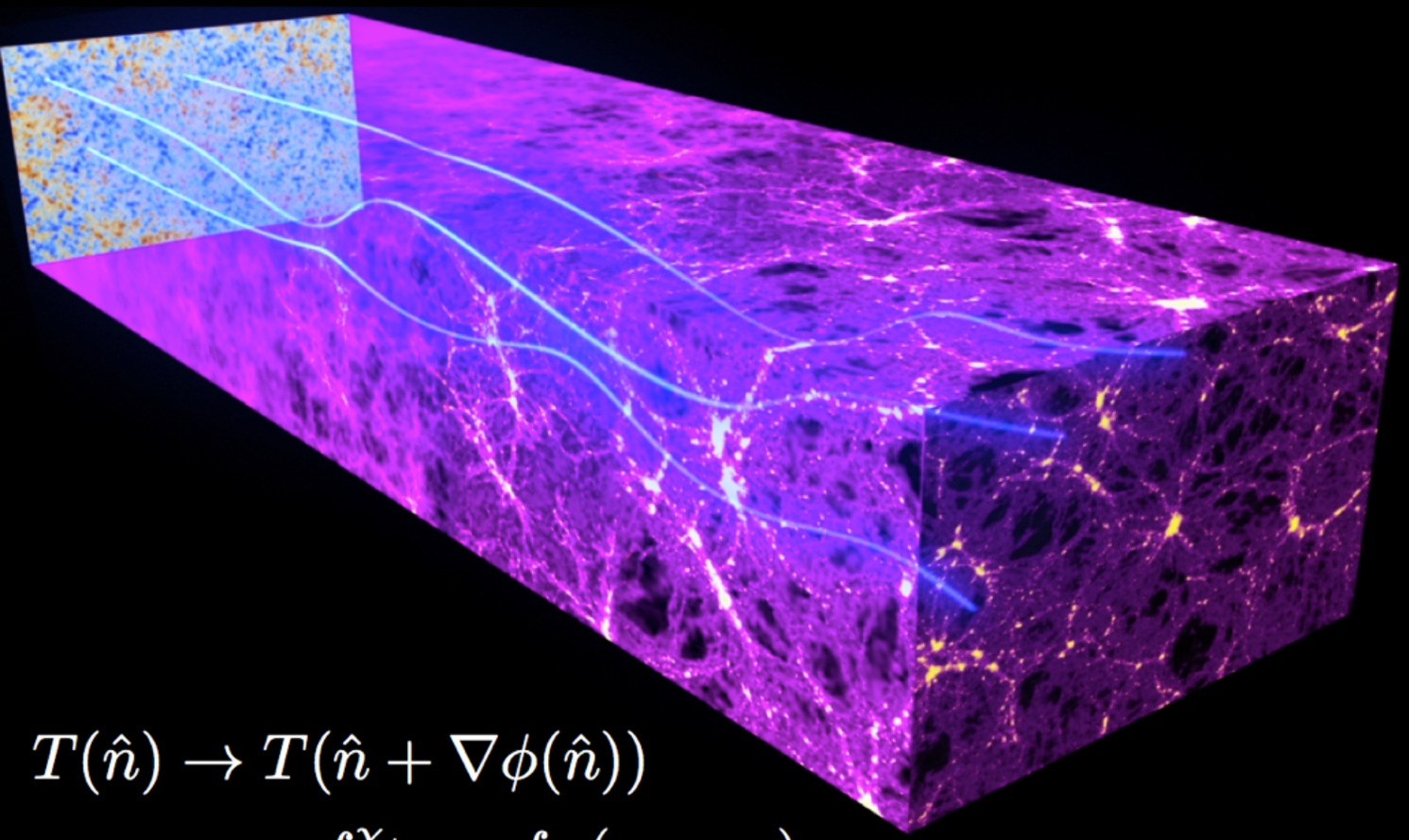
CMB-S4 projections for N_{eff}



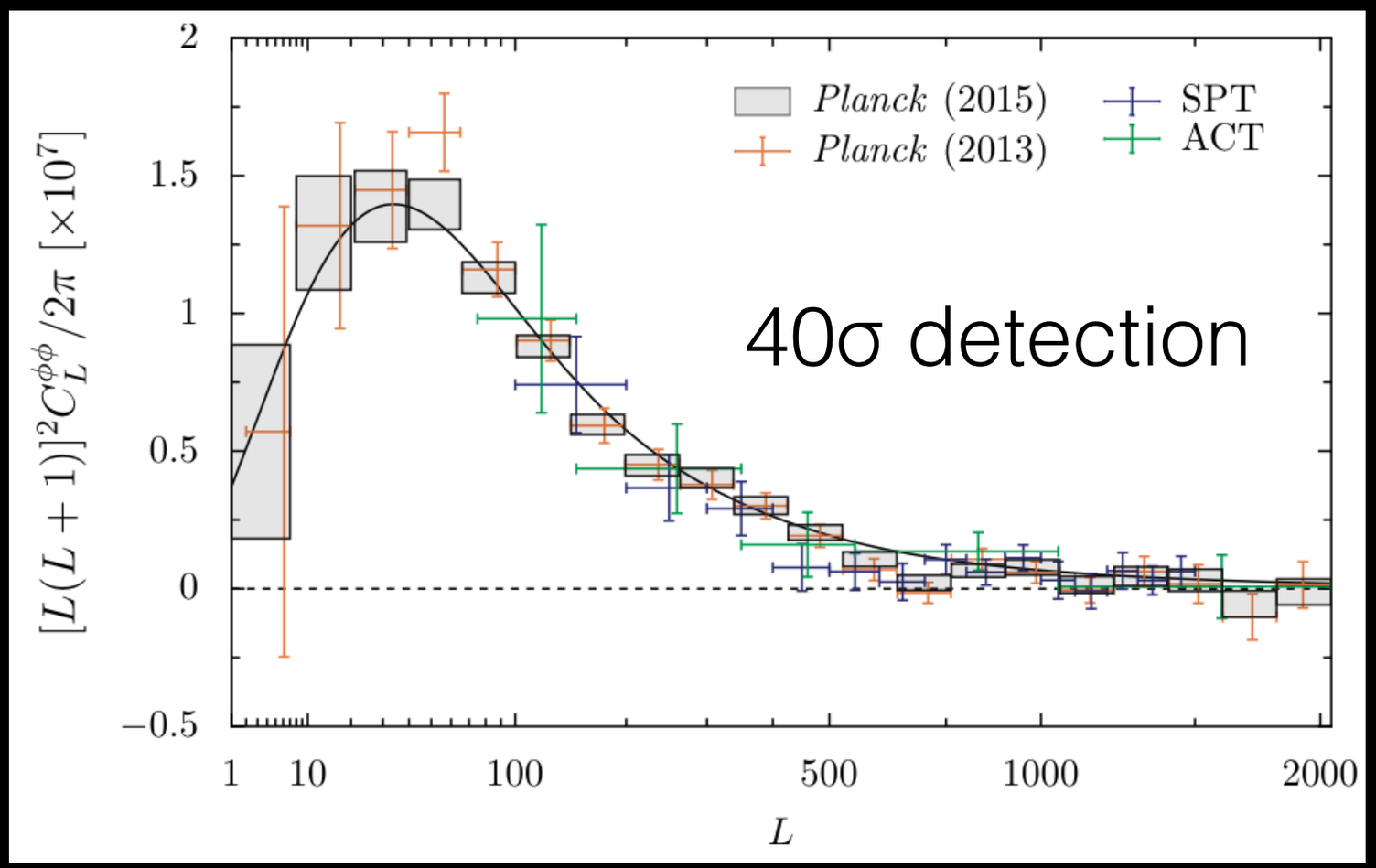
σ(N_{eff}) target very challenging



CMB lensing - great progress, but a long, long way to go

$$T(\hat{n}) \to T(\hat{n} + \nabla\phi(\hat{n}))$$

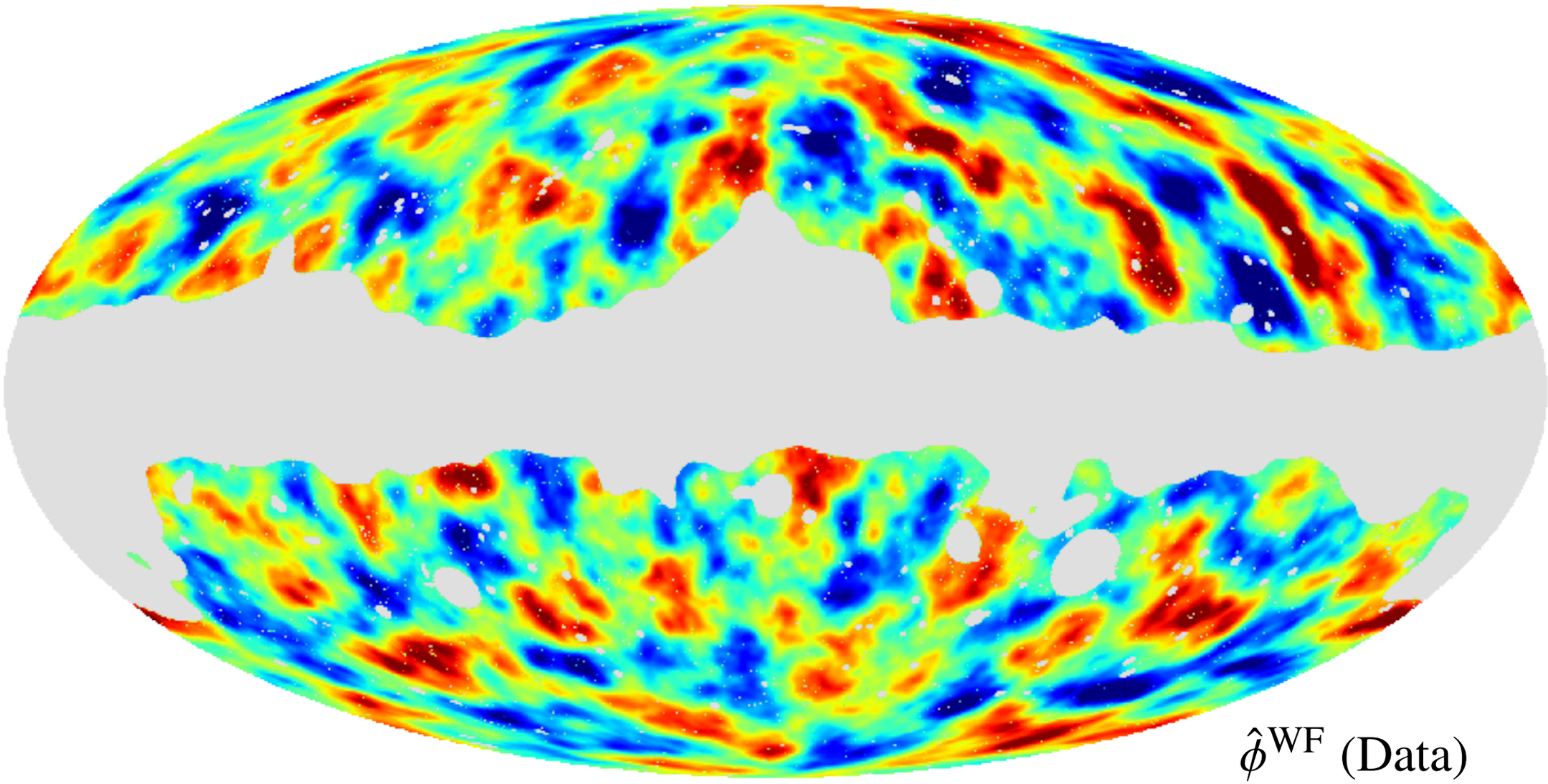
$$\phi(\hat{n}) = -2\int_0^{\chi_*} d\chi \frac{f_K(\chi_* - \chi)}{f_K(\chi_*) f_K(\chi)} \Psi(\chi\hat{n}; \eta_0 - \chi)$$



graphic from ESA Website

CMB lensing

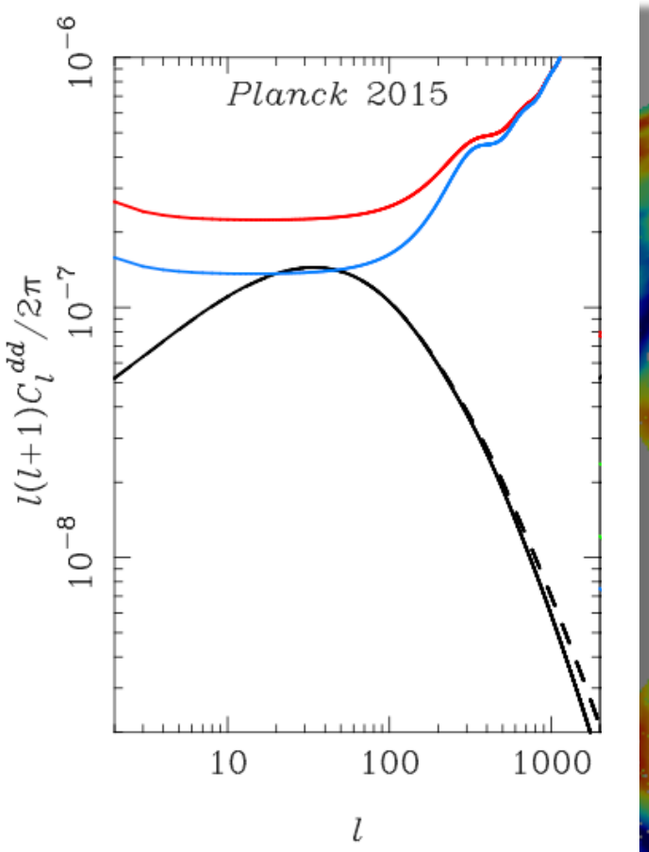
Planck lensing potential reconstruction (projected mass map).

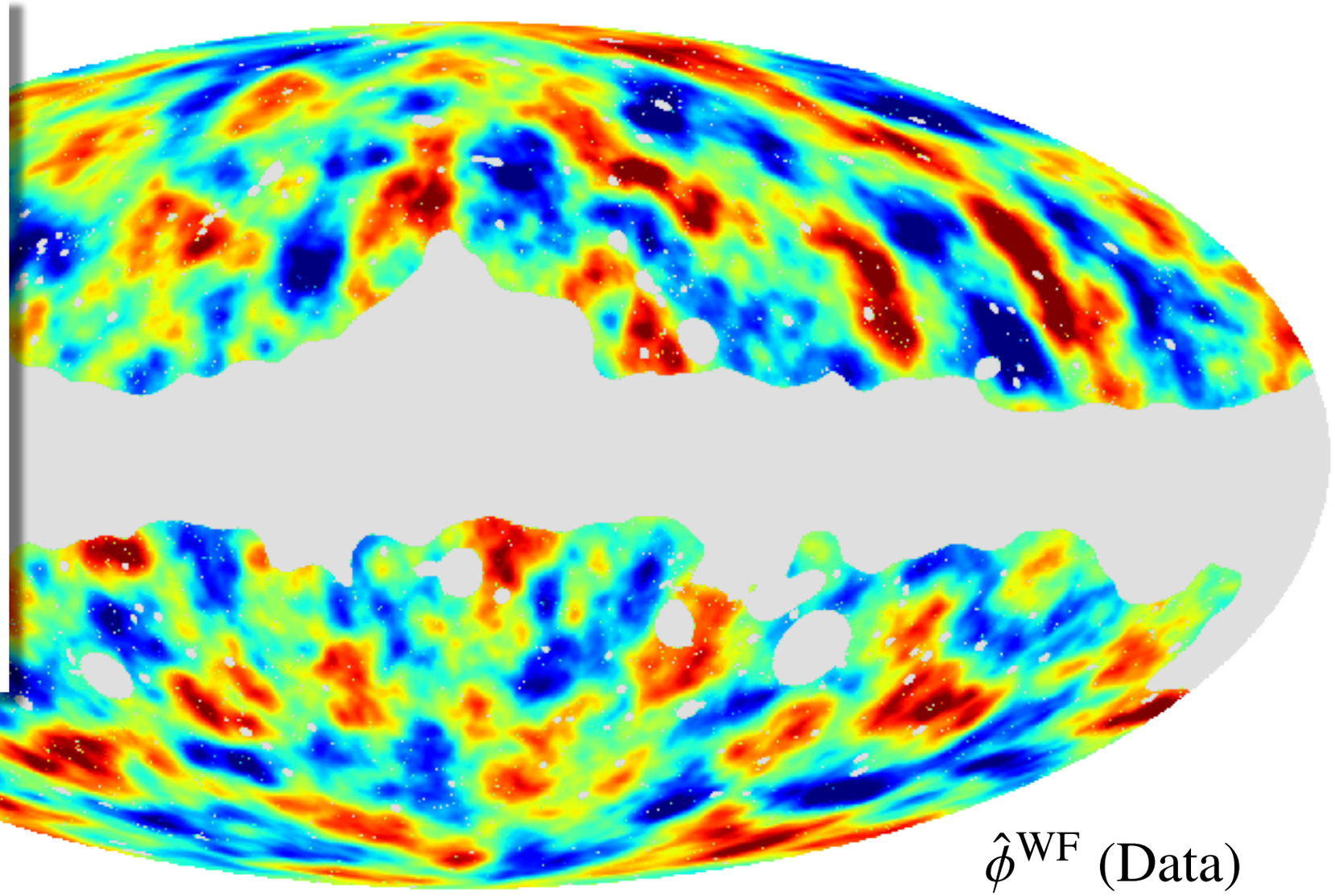


Planck XV (2015)

CMB lensing

Planck lensing potential reconstruction (projected mass map).





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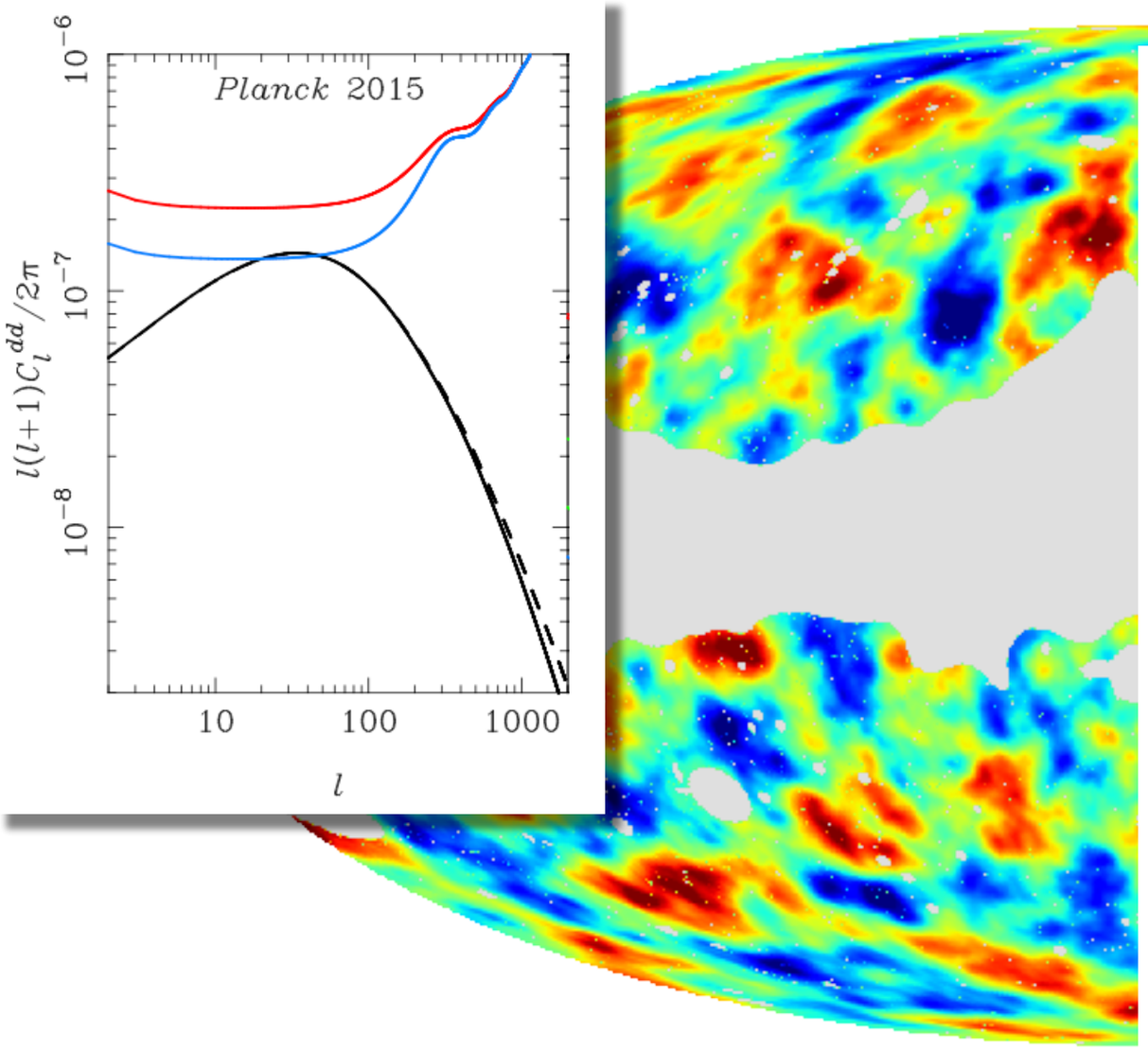

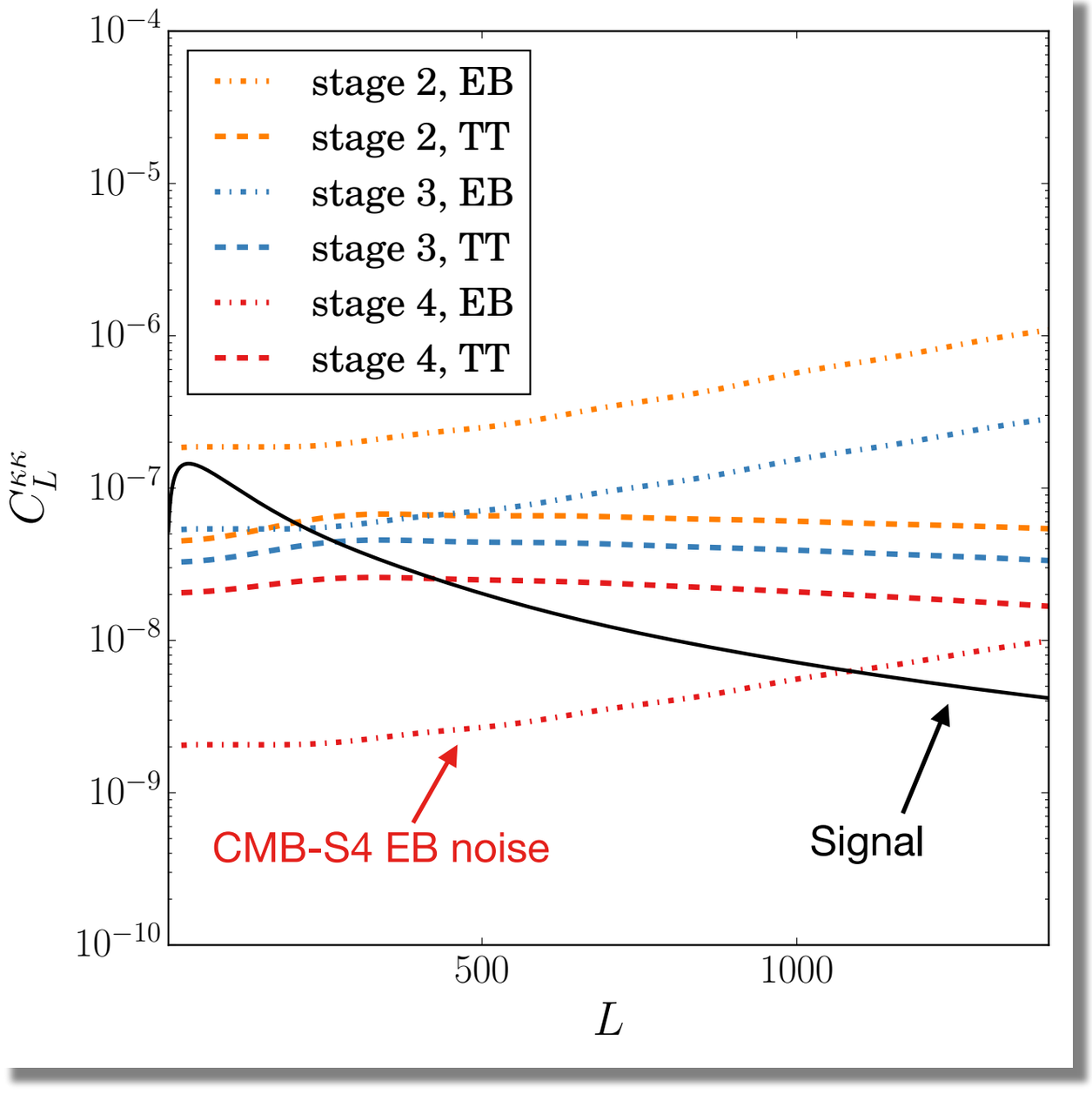

Planck XV (2015)

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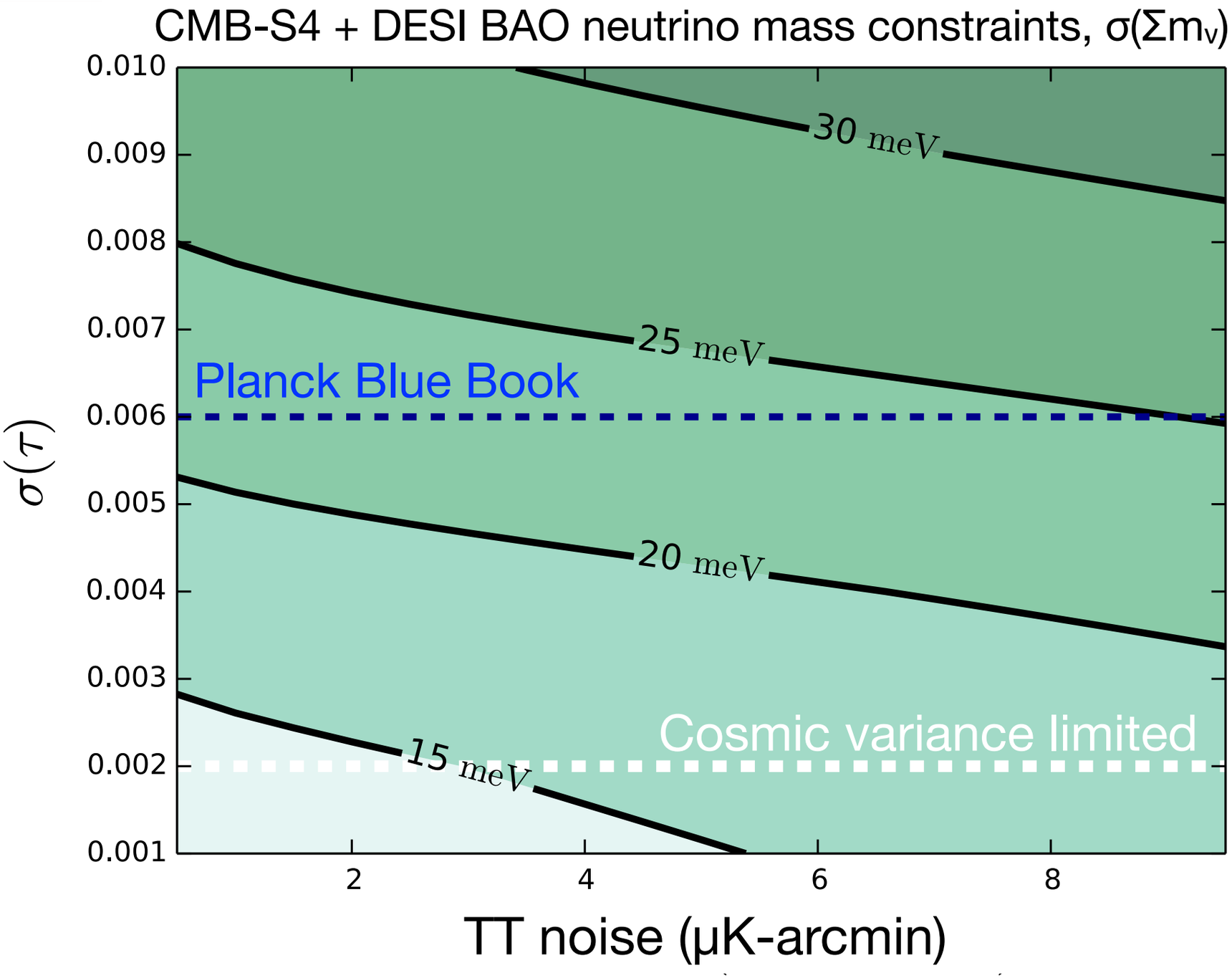

$\sigma(\Sigma m_\nu)$ limited primarily by uncertainty in τ_e

Overlap with 21 cm future survey

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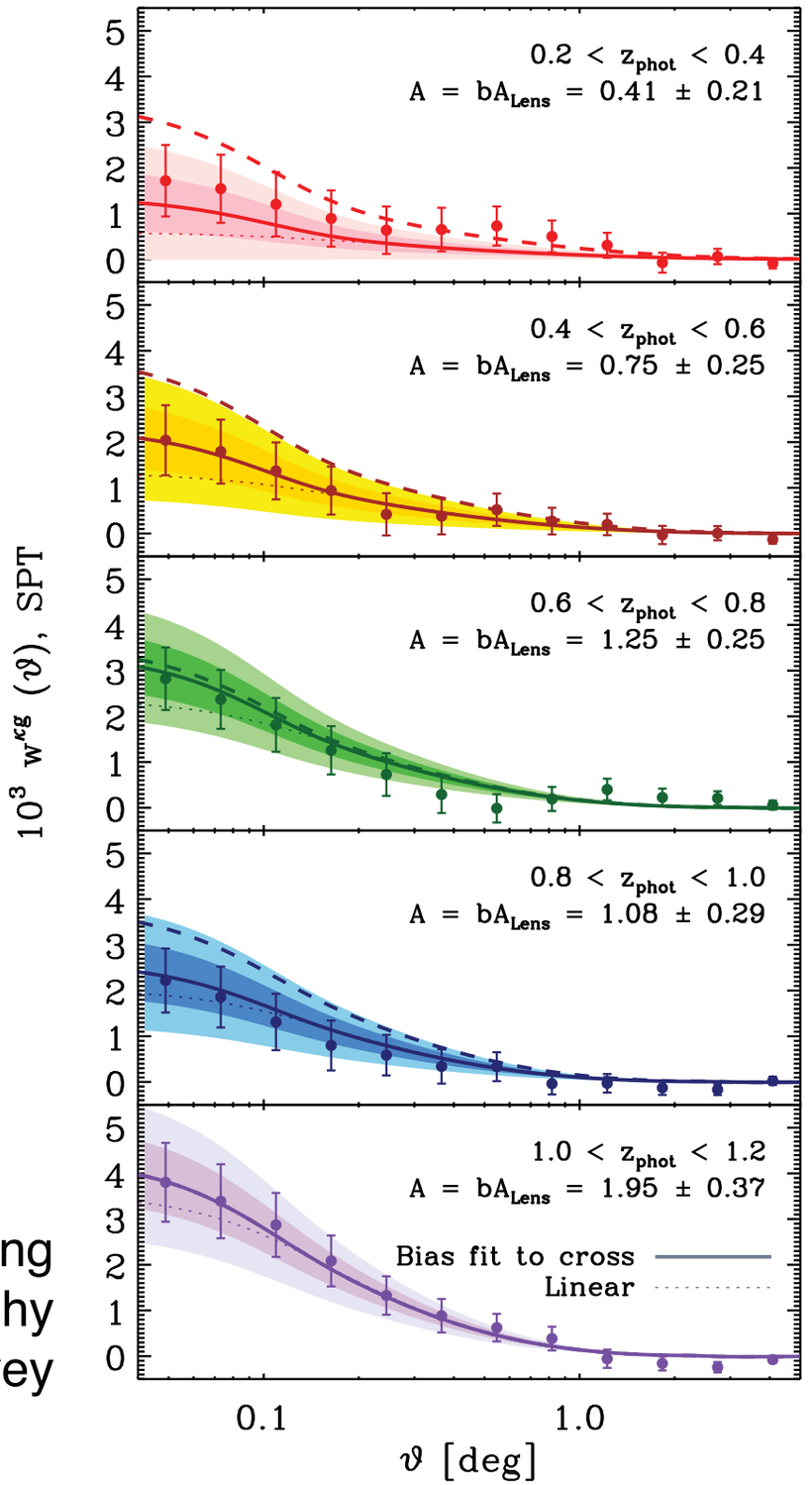
CMB lensing and optical surveys

“the most exiting topics on observational cosmology”

An obvious overlap area!

Giannantonio et al., 2016, beginning of CMB lensing tomography using 3% of DES survey

E.g., Galaxy and CMB-lensing cross-correlation



Giannantonio et al., 2016

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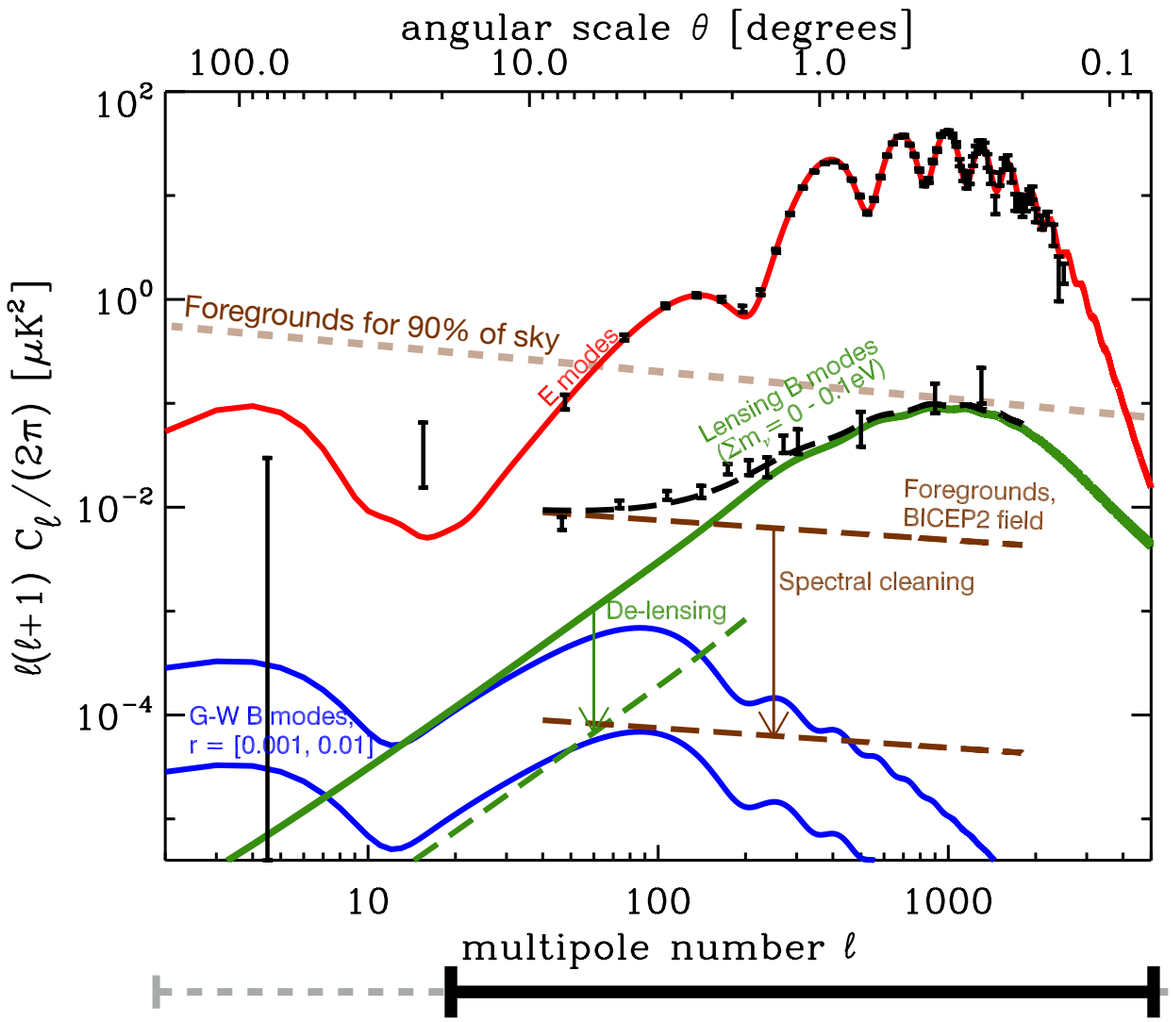
Angular range of CMB-S4

- Inflationary B modes search requires exquisite sensitivity at recombination bump (ℓ ~100) and high-ℓ for de-lensing.
- High-ℓ and large area for CMB lensing cosmic variance limited constraints on neutrino mass and N_{eff}
- Higher-ℓ for dark energy, gravity tests and to probe reionization, via SZ effects



ℓ range of CMB-S4

CMB-S4 "high-ℓ" science reach yet to be determined.

An obvious overlap area!

CMB-S4 SZ cluster projections and lensing mass calibration for dark energy via growth of structure

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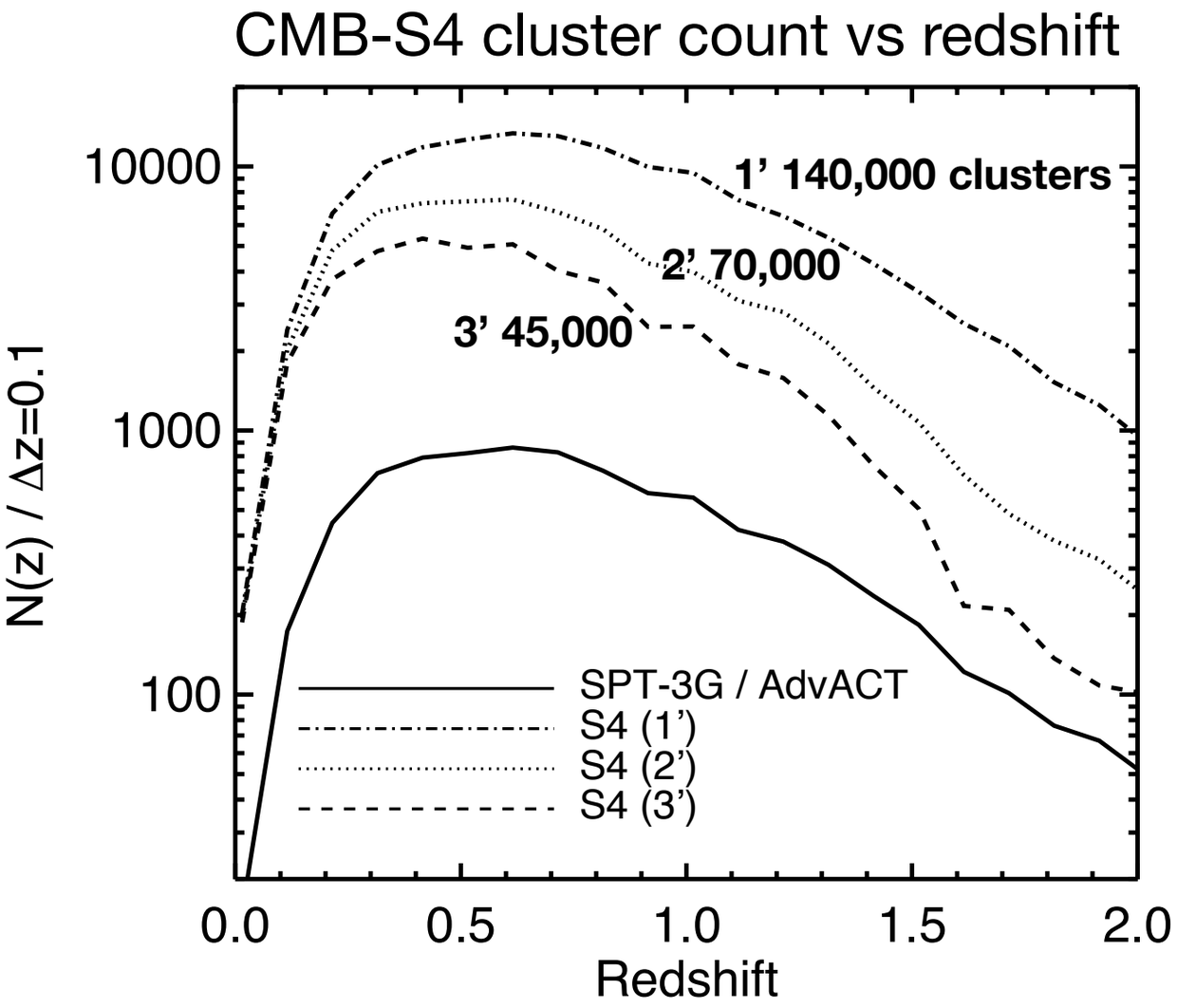

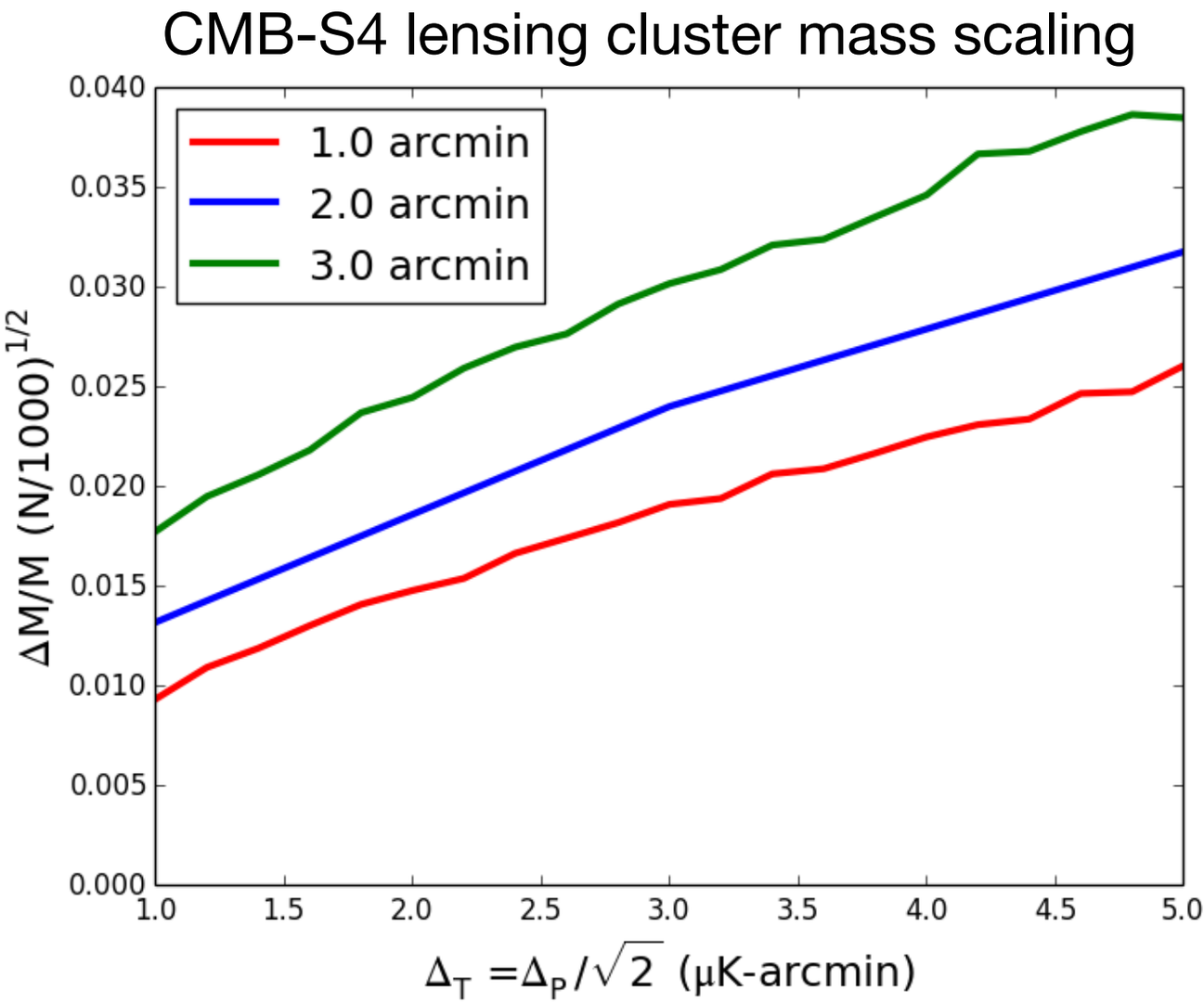

Cluster sample and mass calibration strong functions of beam size

Especially important at z > 1.

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summary

CMB-S4 will be a great leap forward for attaining unique CMB science goals.

CMB-S4 and Future Surveys should be highly complementary. Combined they should lead to improved and more robust science results, and potentially new science.