Probing Physics with CMB polarization

(Focusing on primordial gravity waves, new light particle species, and neutrino mass)

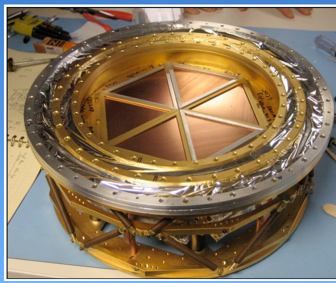
	r	N_{eff}	$Sum(m_\nu)$
LCDM value	0	3.046	> 59meV

John Ruhl
Case Western Reserve University
(For the CMB-S4 and SPT Collaborations)

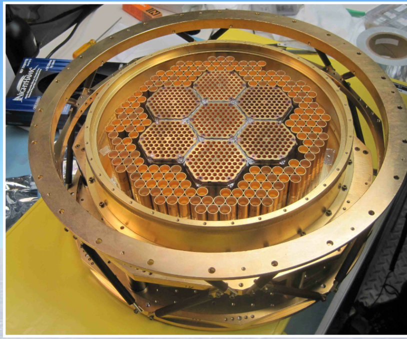
Argonne National Laboratory
KICP Kavli Institute for Cosmological Physics at the University of Chicago
Berkeley Lab
Case Western Reserve University
Cardiff University Prifysgol Caerdydd
NIST
The University of Chicago
LMU Ludwig-Maximilians-Universität München
Berkeley University of California
UC Davis University of California
McGill
Fermilab
M
Harvard-Smithsonian Center for Astrophysics
Colorado University of Colorado at Boulder
MIT
SLAC
Stanford University

The South Pole Telescope Collaboration

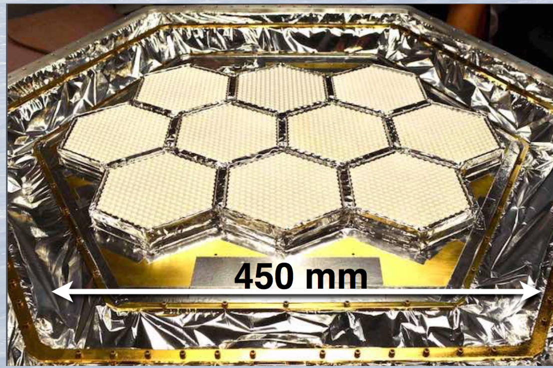
2007: SPT-SZ
960 detectors
95,150,220 GHz



2012: SPTpol
1600 detectors
95,150 GHz
+Polarization

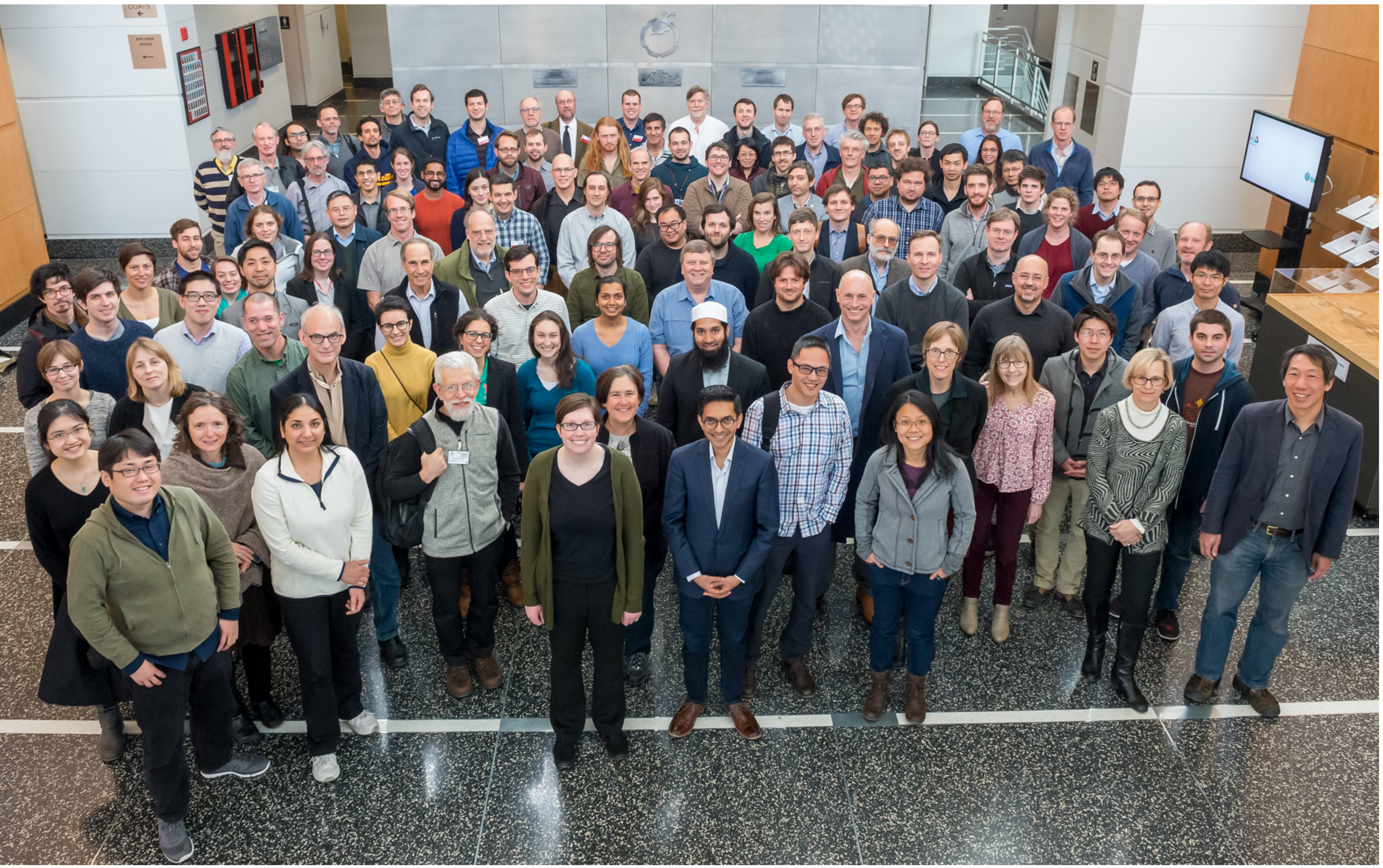


2017: SPT-3G
16,000 detectors
95,150, 220 GHz
+Polarization



funding:

NSF
U.S. Department of Energy
Gordon and Betty Moore Foundation
Kavli

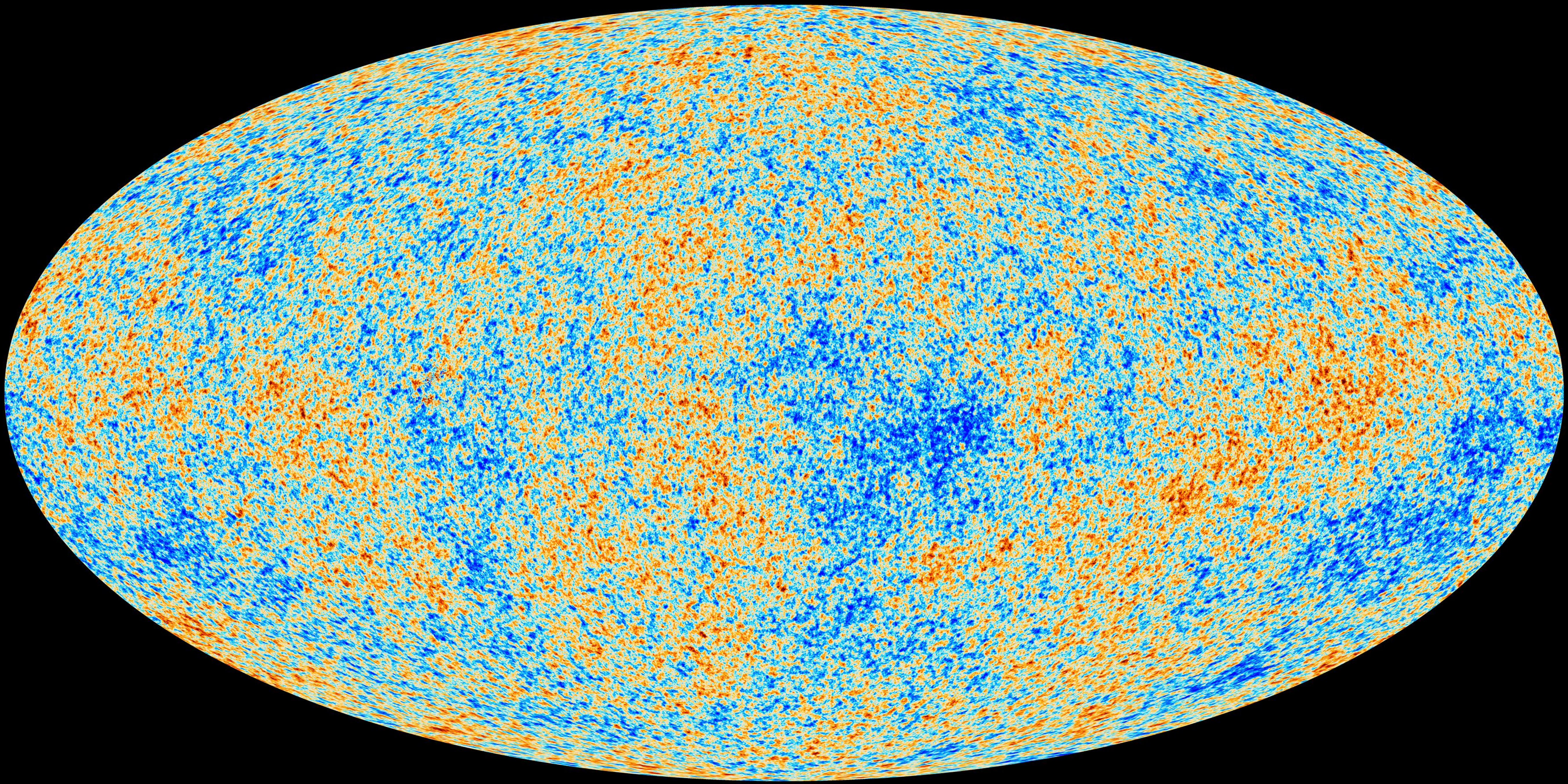


CMB-S4 collaboration at Spring 2018 meeting at ANL.
Spokespersons: Julian Borrill (LBL) and John Carlstrom (U. Chicago/ANL)

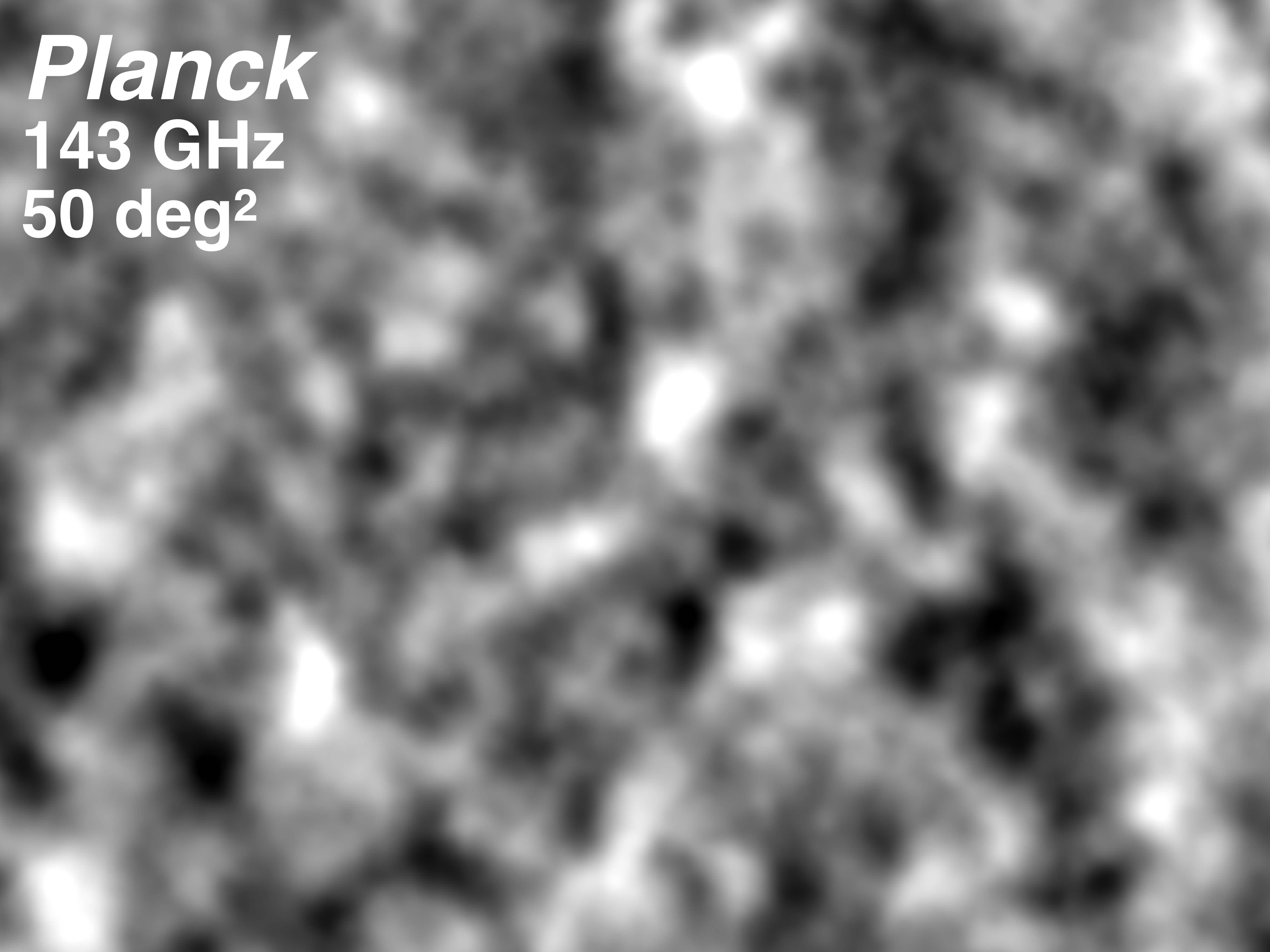
~150 CMB scientists, from all current US (and some non-US) CMB experiments.

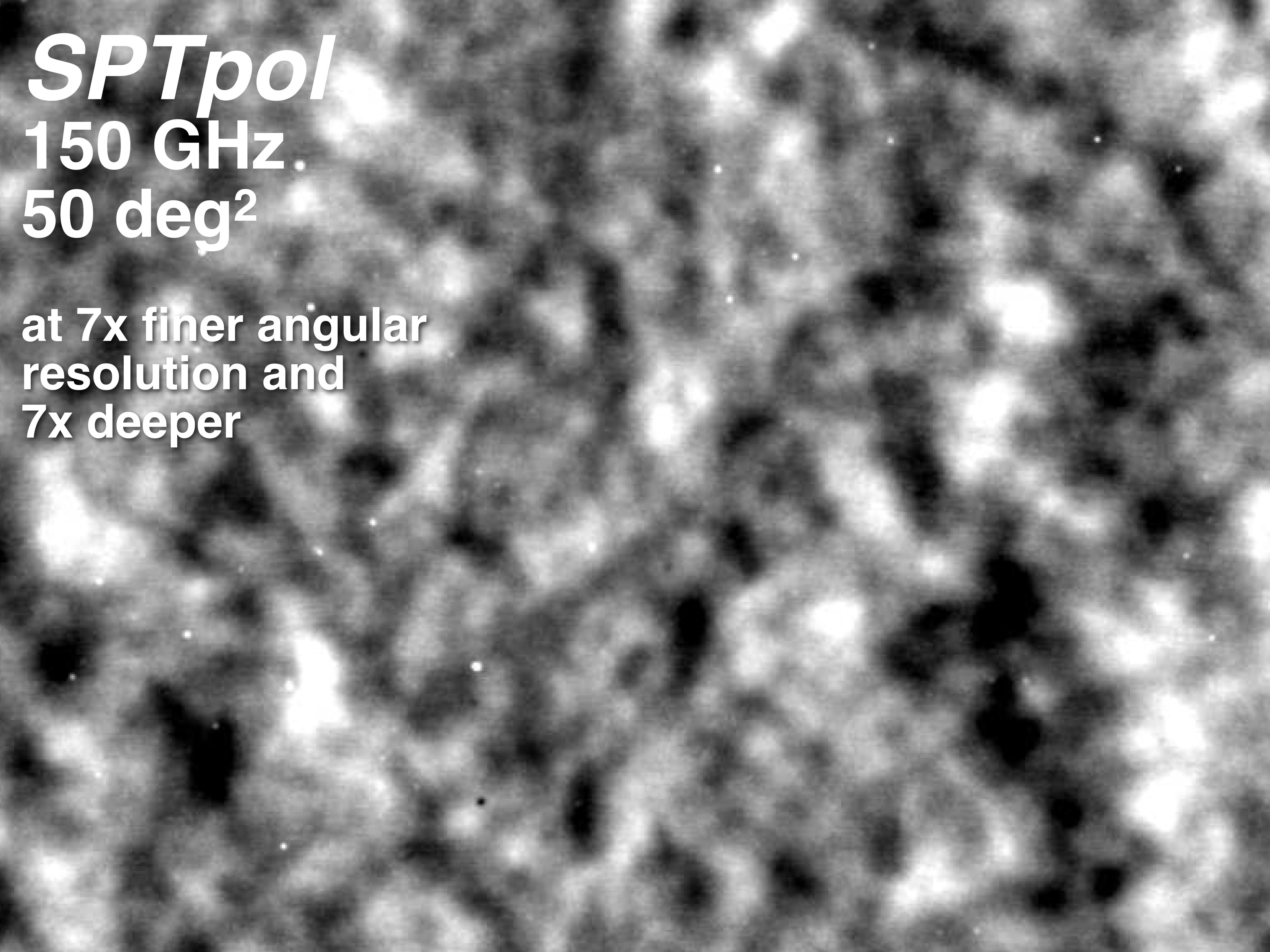
Meeting twice yearly for the past ~3 years; more info in a science book, a technology book, and a "Concept Definition Team" report all available at

http://cmb-s4.org

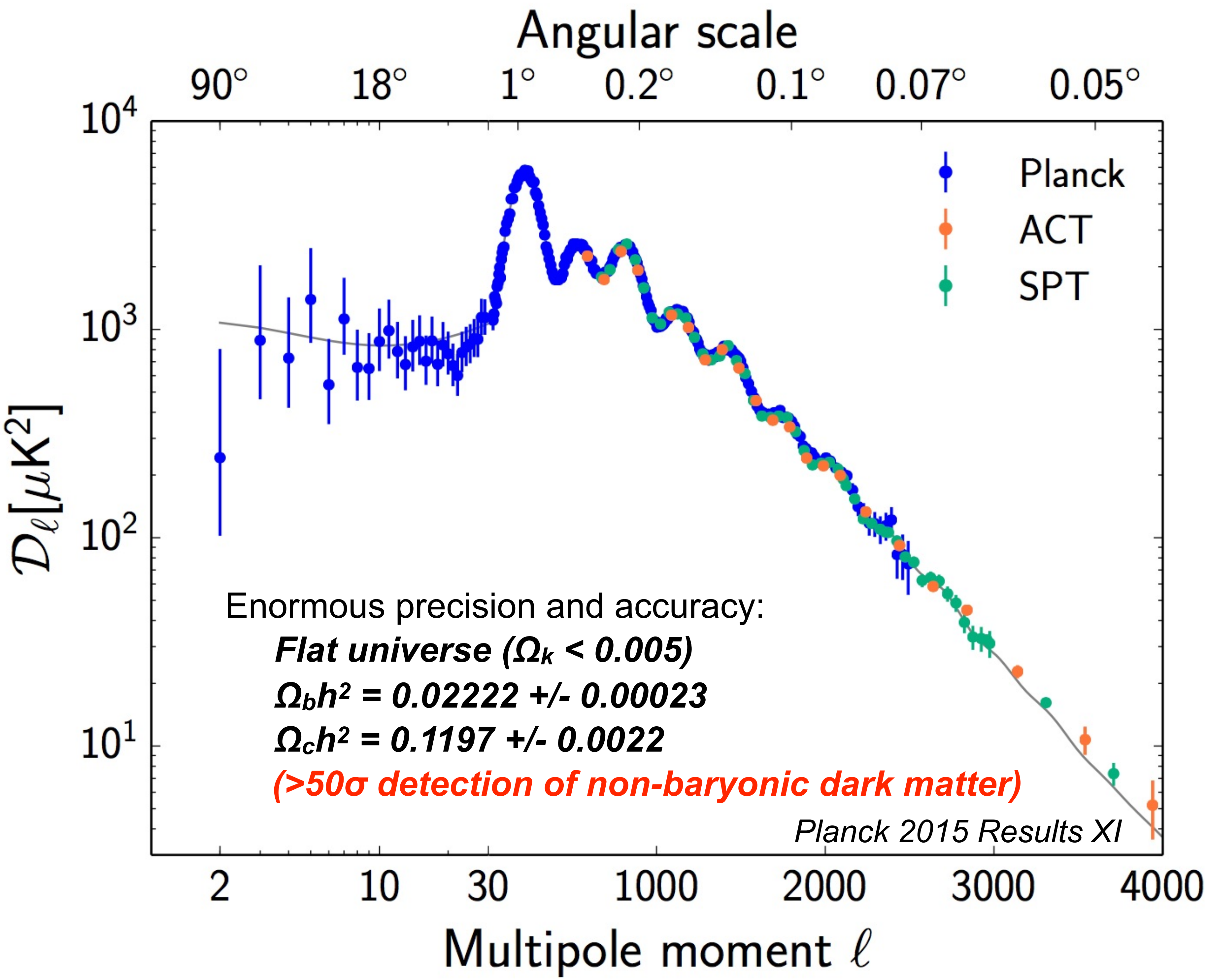


Planck Satellite - all sky CMB temperature anisotropy map


Planck
143 GHz
50 deg²


SPTpol
150 GHz
50 deg²
at 7x finer angular resolution and 7x deeper

Constraints on cosmological parameters



Enormous precision and accuracy:

Flat universe (Ω_k < 0.005)

$\Omega_b h^2$ = 0.02222 +/- 0.00023

$\Omega_c h^2$ = 0.1197 +/- 0.0022

(>50σ detection of non-baryonic dark matter)

Peaks => curvature, baryon and DM densities, and more.

TT-only parameters:

Damping tail =>
Sum(m_ν) < 0.7eV, *Planck_15*
N_{eff} ≈ 3.6 +- 0.5, *WMAP+SPT (2012)*

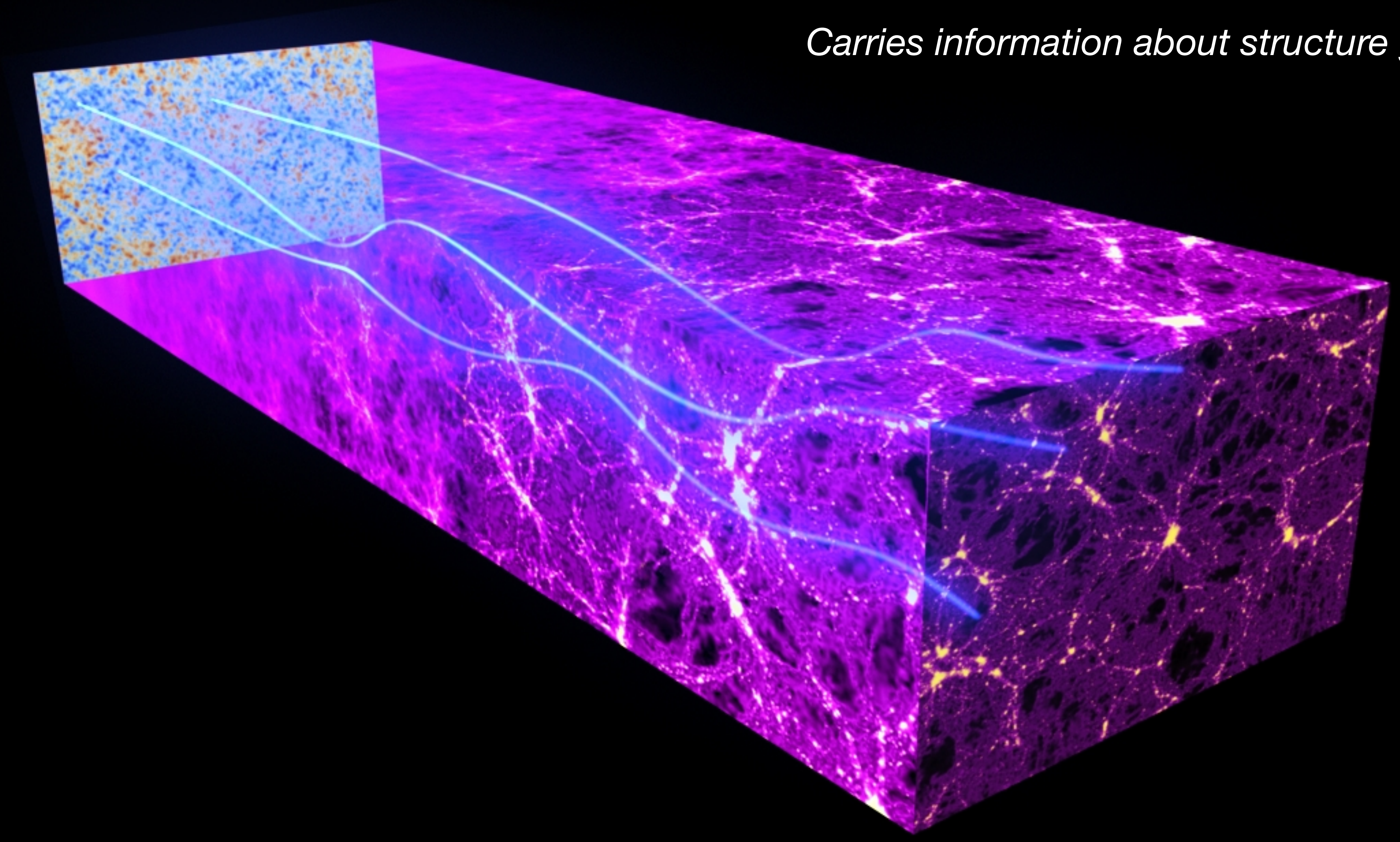
Low ell => r < 0.1 *Planck_15*

The future: polarization and lensing

“CMB lensing” : CMB photon paths diverted by large scale structure

Average ~2 arcminute deflections,
coherent over ~degree scales on the sky,
dominated by structure at z~2-3.

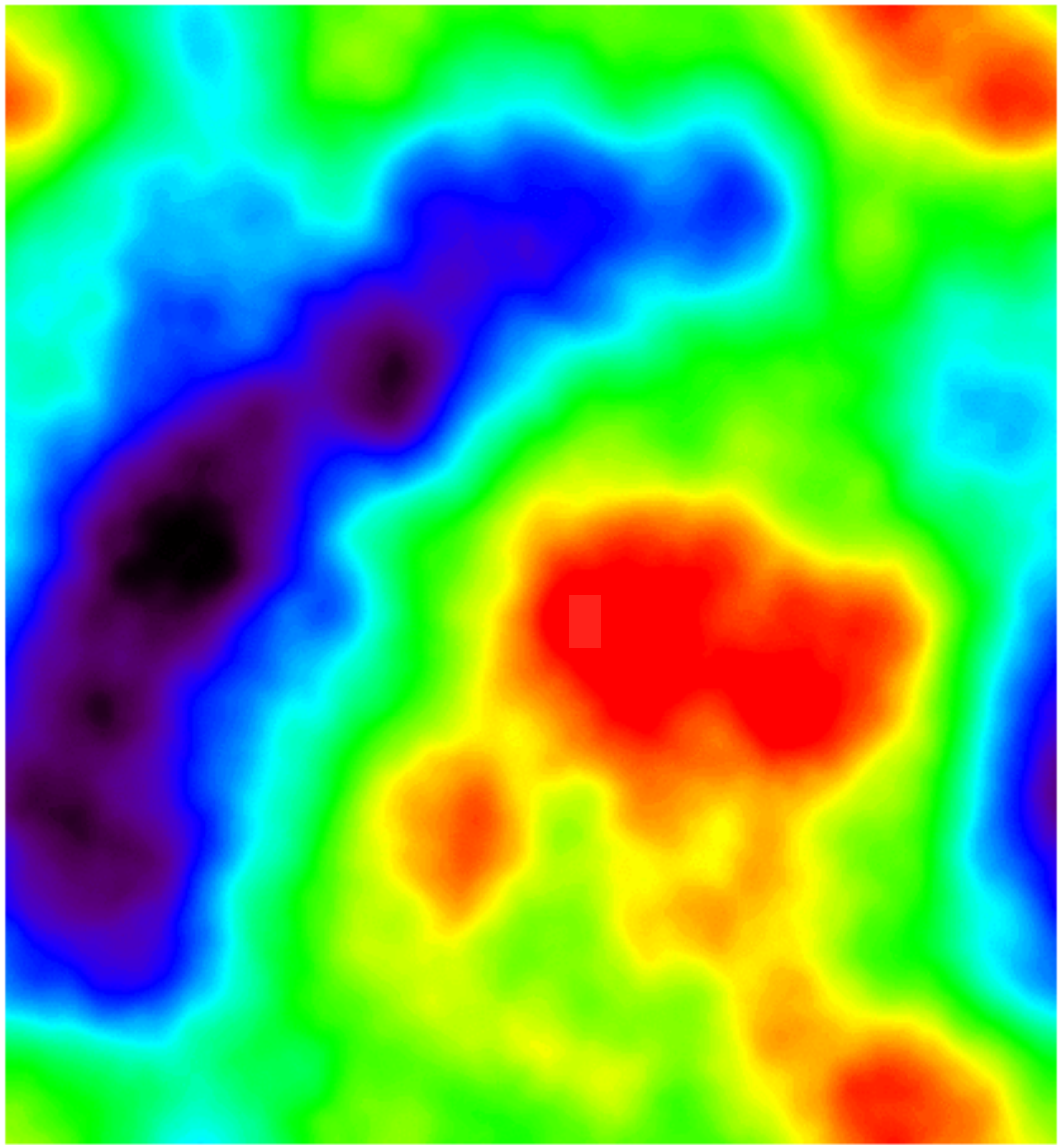
Carries information about structure growth.



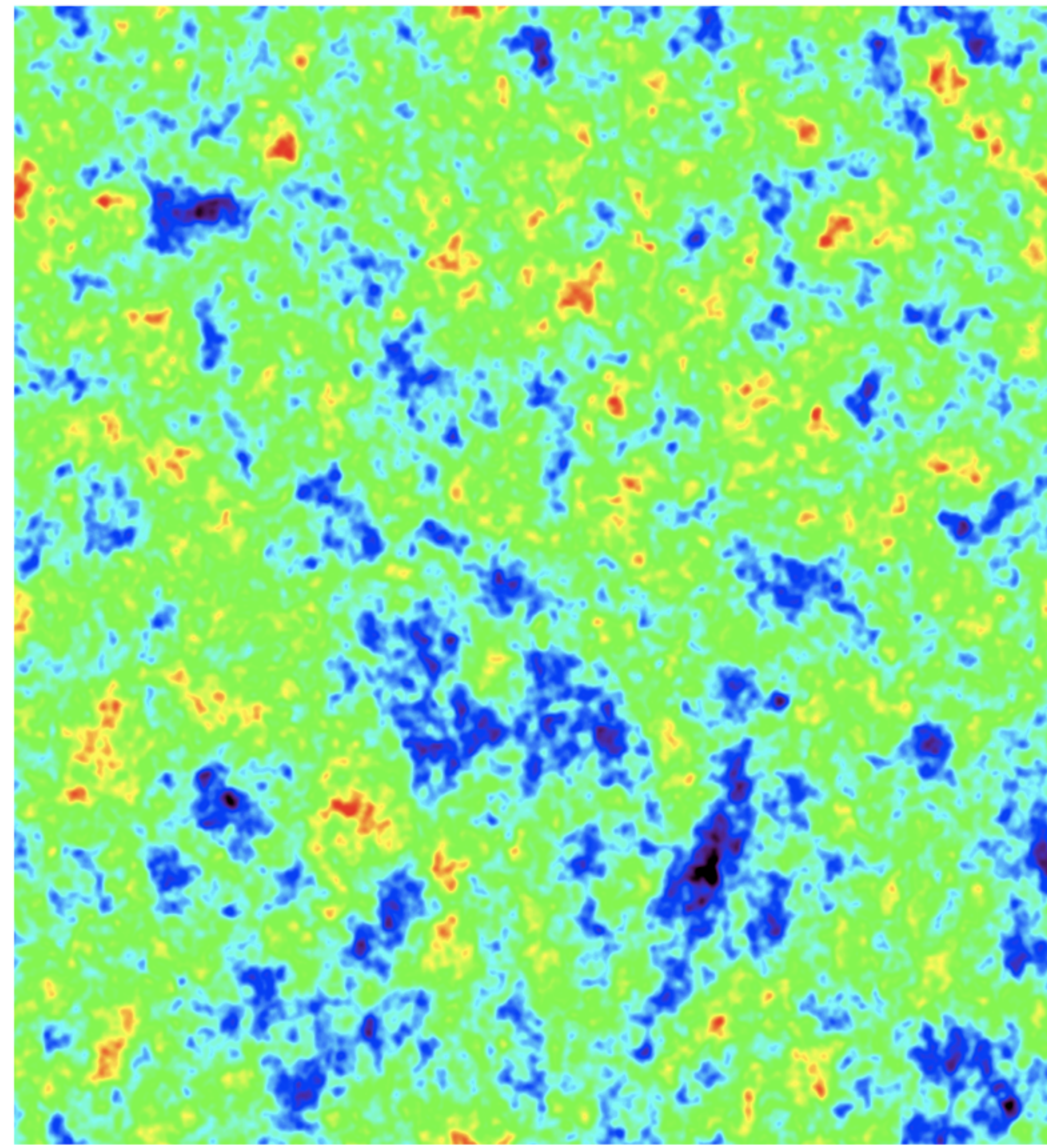
ESA

Lensing of the CMB

17°x17°



lensing potential

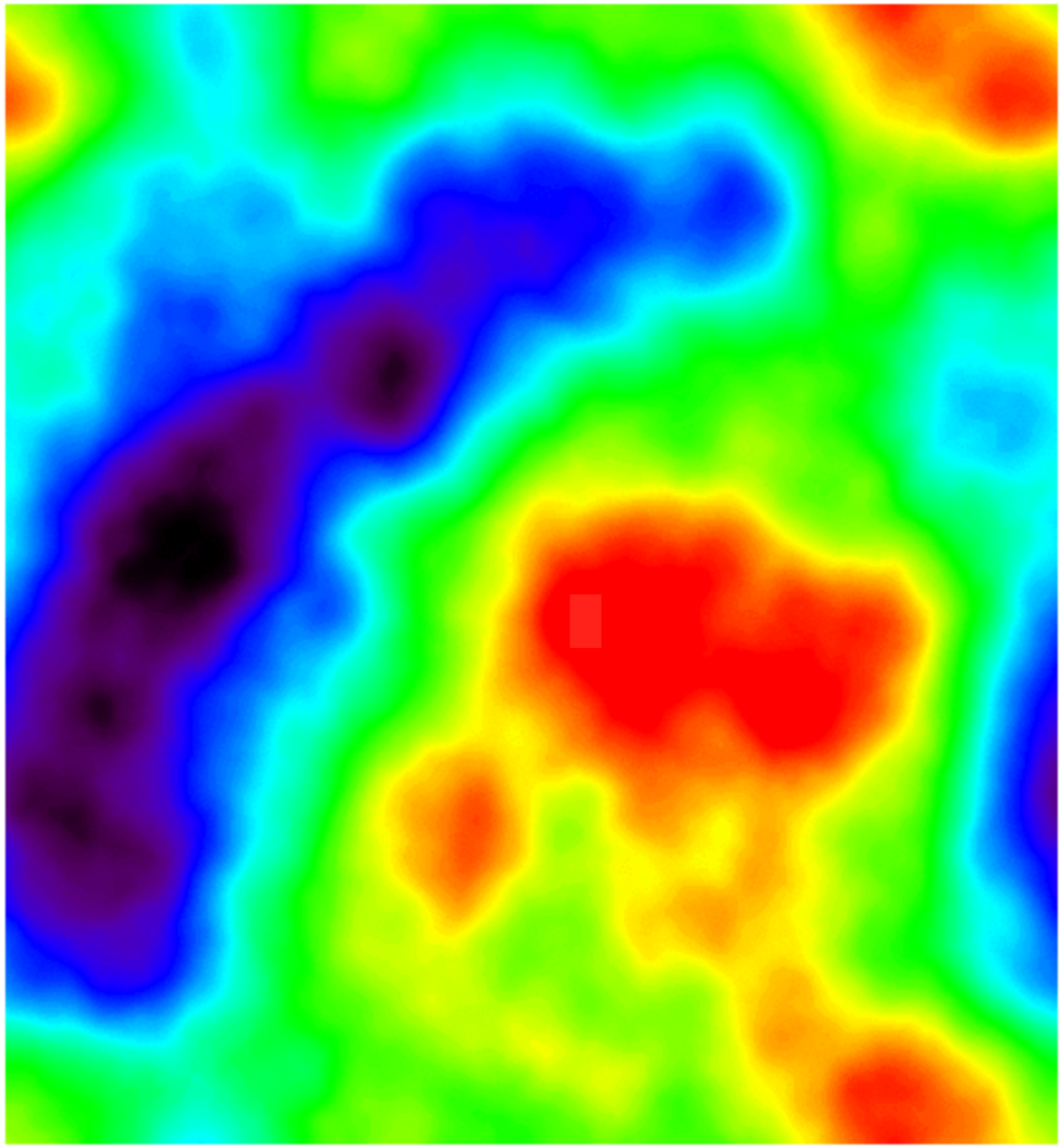


unlensed cmb

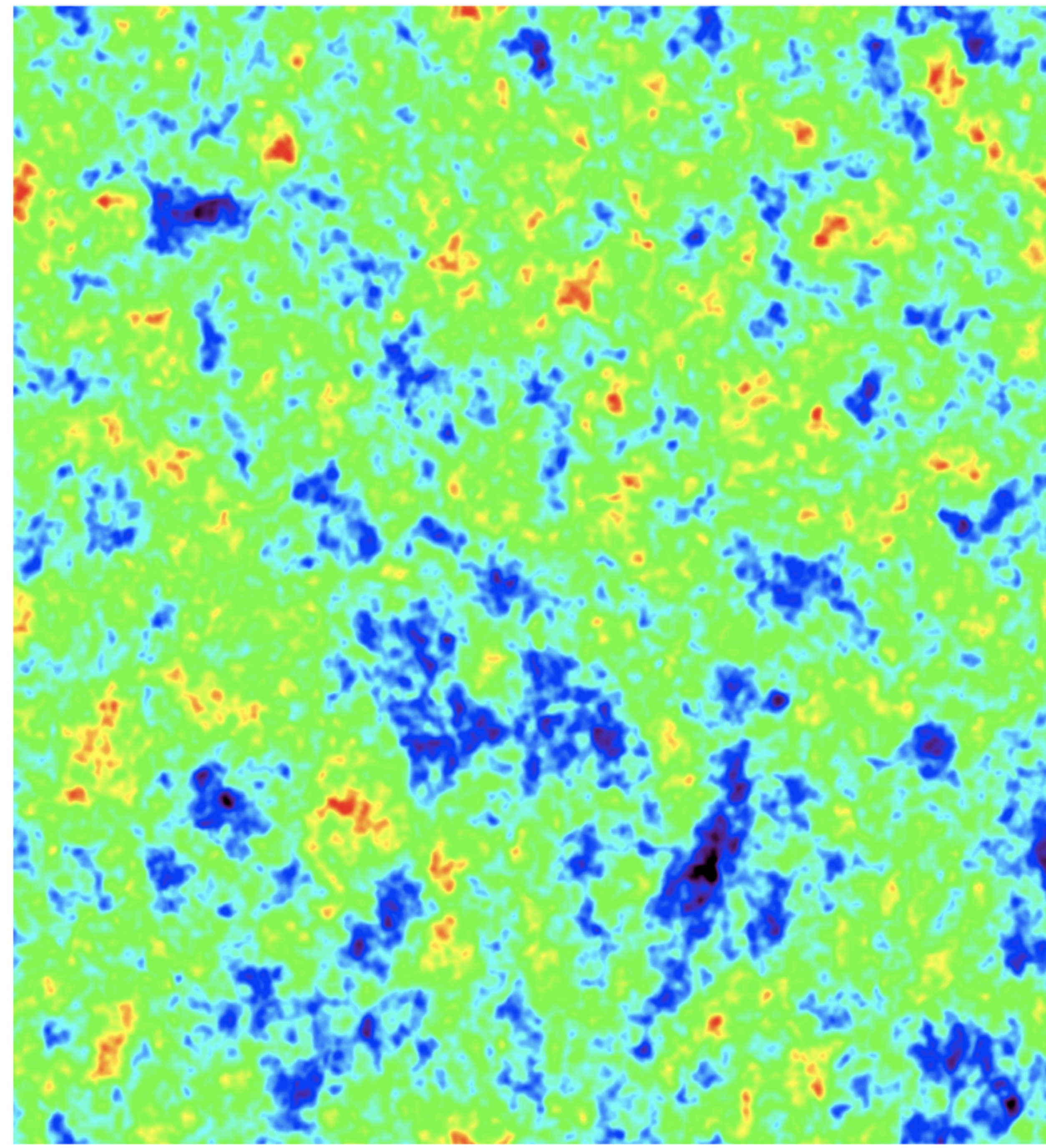
from Alex van Engelen

Lensing of the CMB

17°x17°



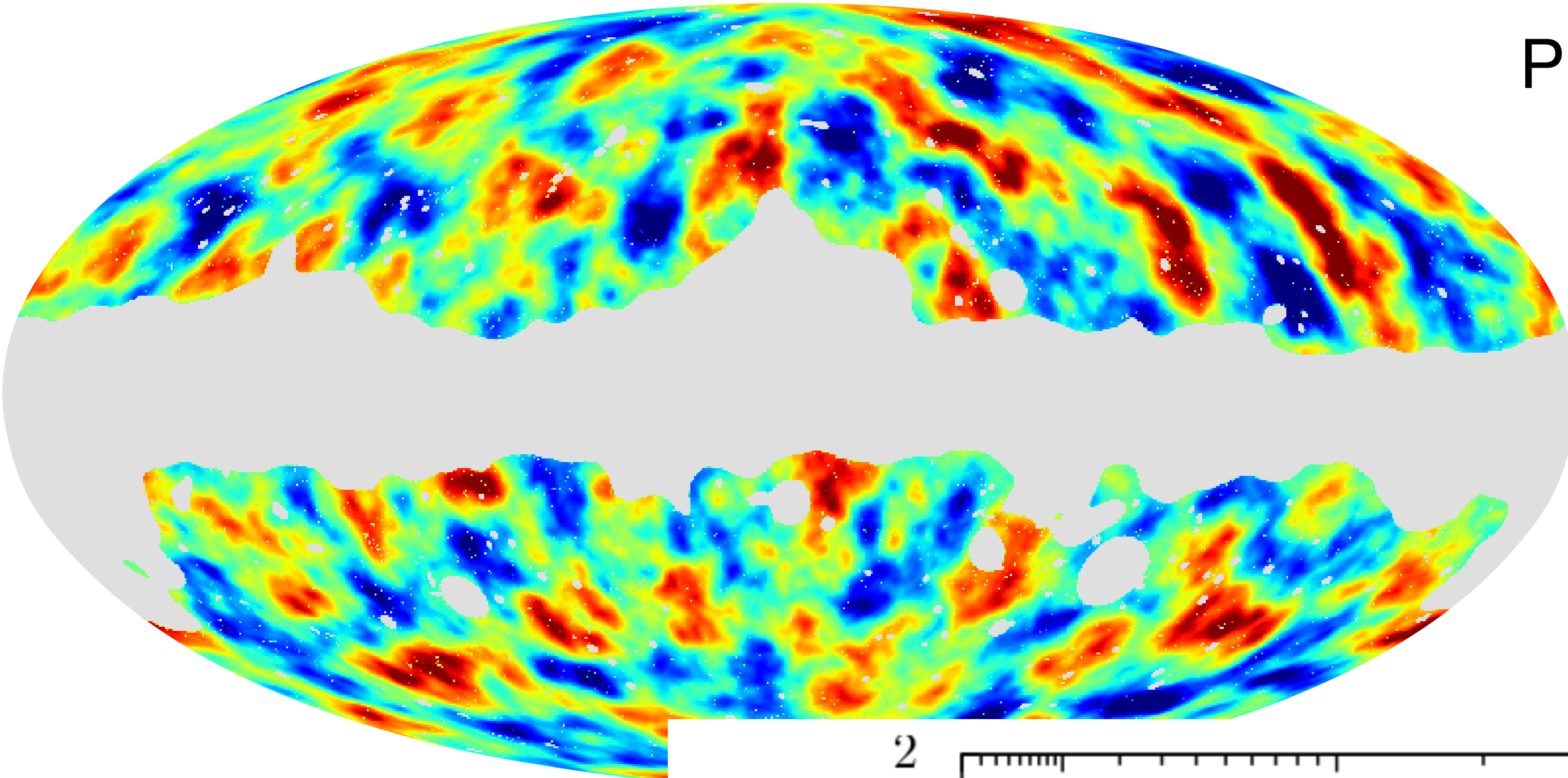
lensing potential

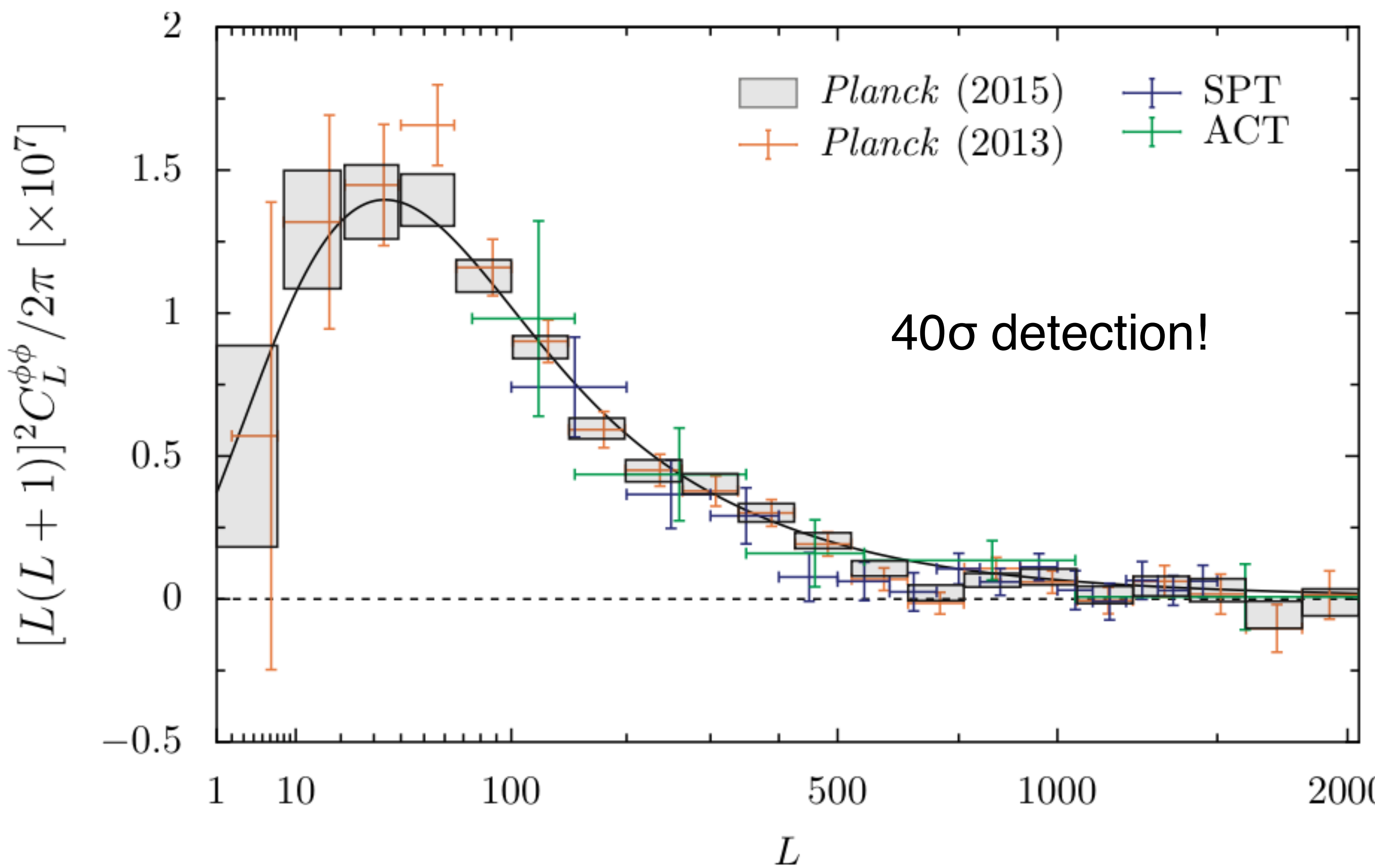


lensed cmb

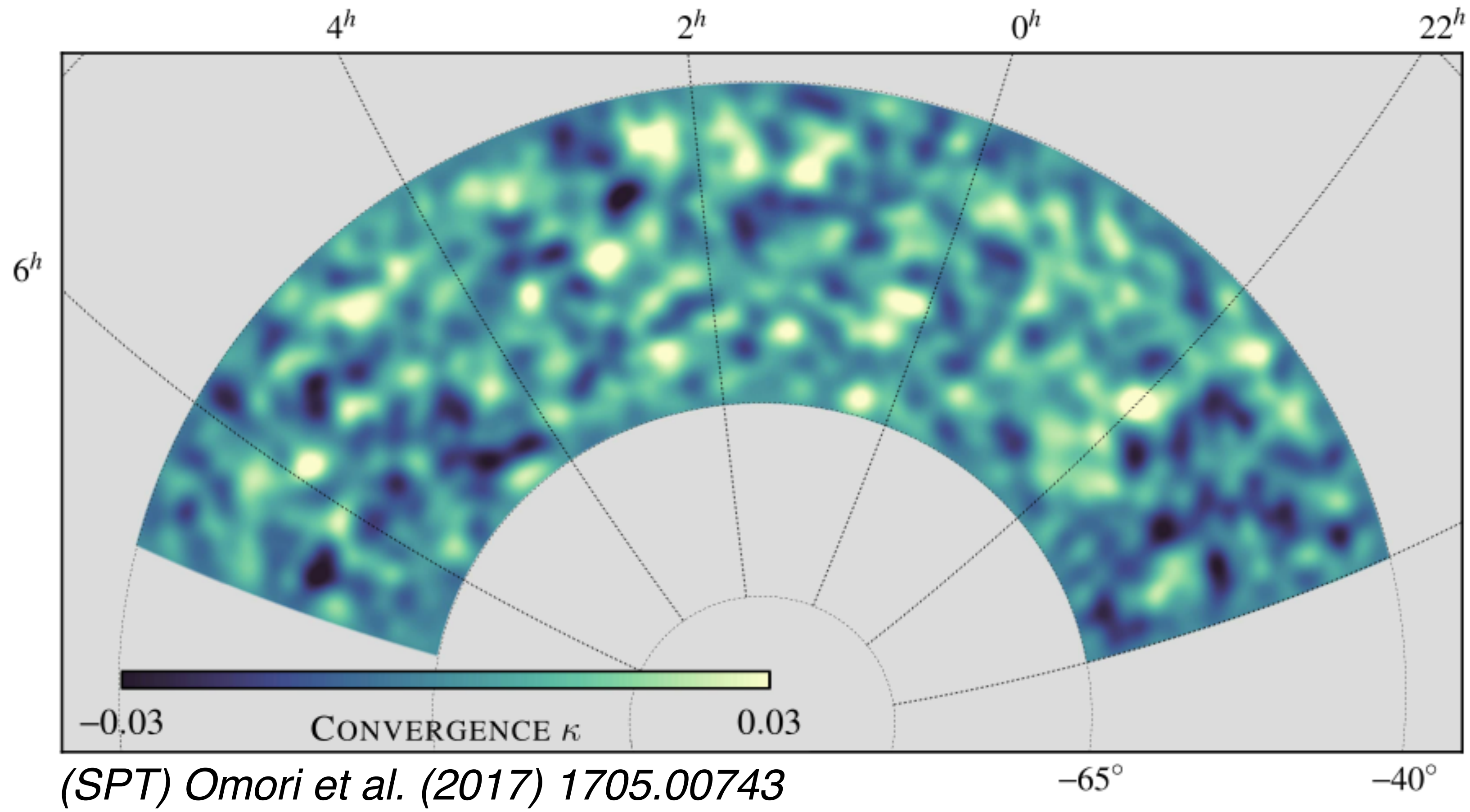
from Alex van Engelen

Planck XV arXiv:1502.01591





CMB lensing with SPT



(SPT) Omori et al. (2017) 1705.00743

SPT-SZ + Planck \ lensing map in SPT 2500 deg^2

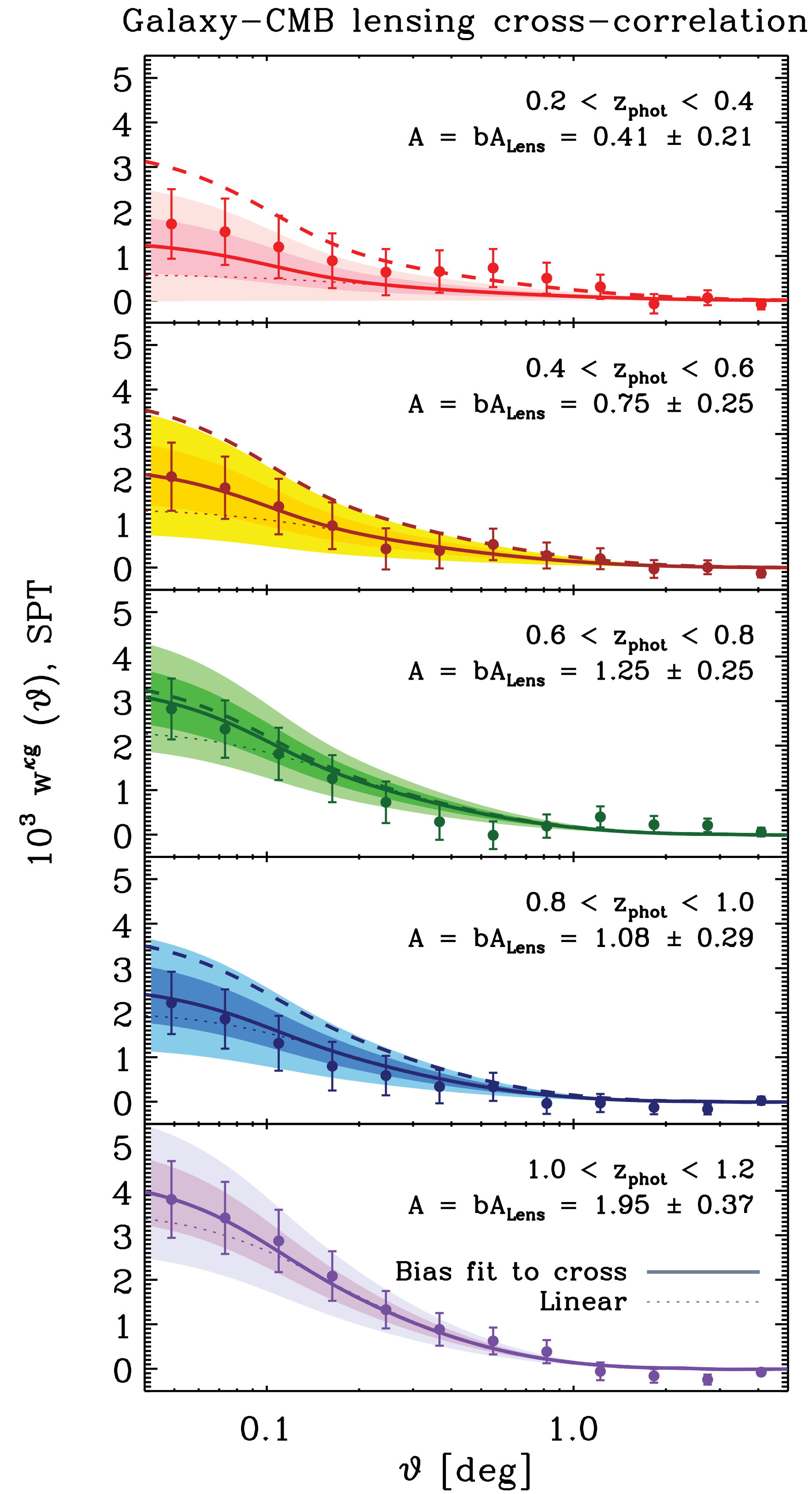
More sensitive lensing in SPTpol 100d and 500d regions (Story et al,2015; Mocanu et al. 2017)

SPT-3G will be deeper still

No great impact on parameters yet… but CMB-S4 -> 40% of the sky, very deep => strong limits joint with LSS/BAO (DESI), on neutrino mass from effects on structure growth.

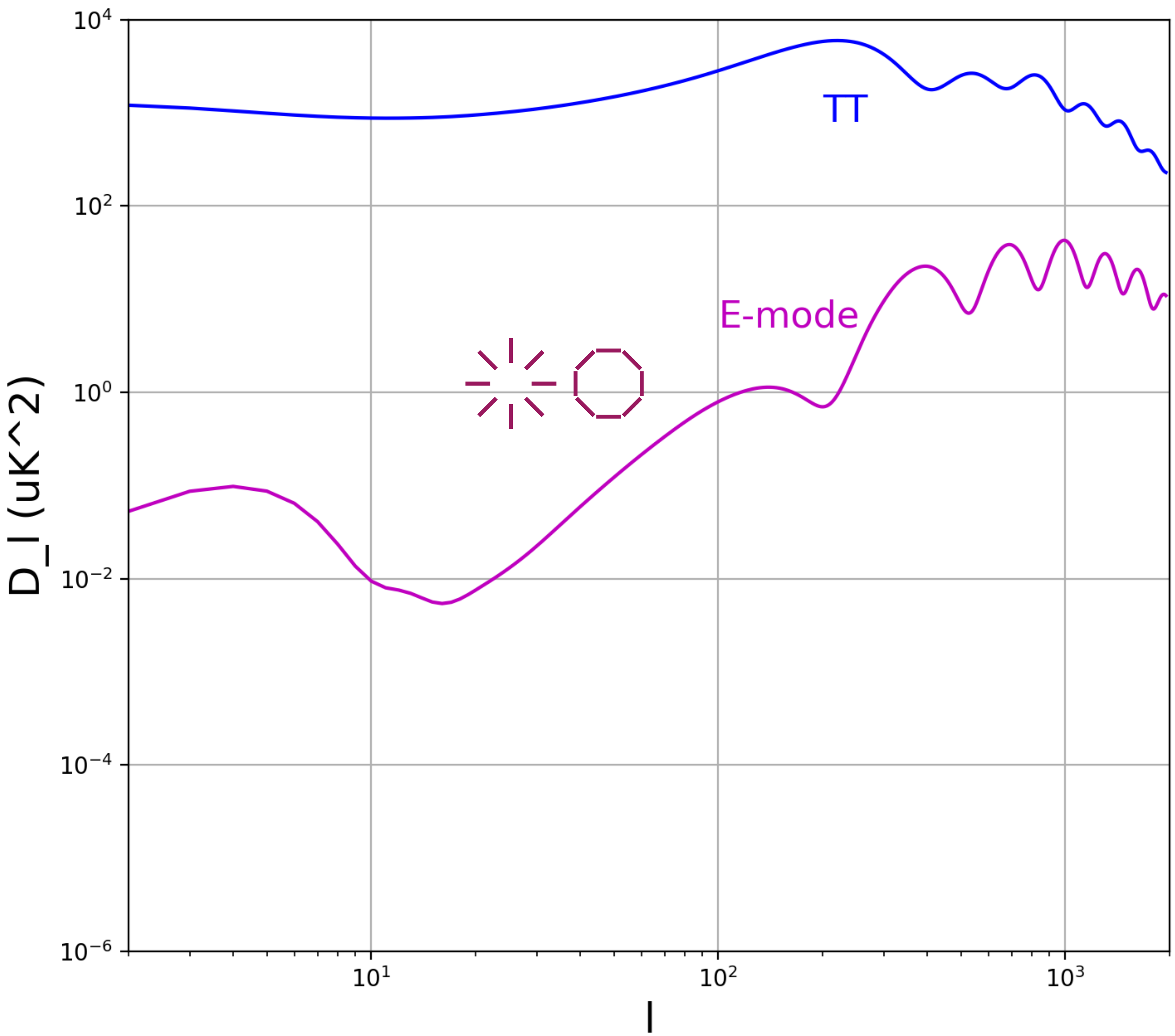
CMB lensing tomography with the DES Galaxies

(SPT-lensing cross-correlation with 3% of DES survey)



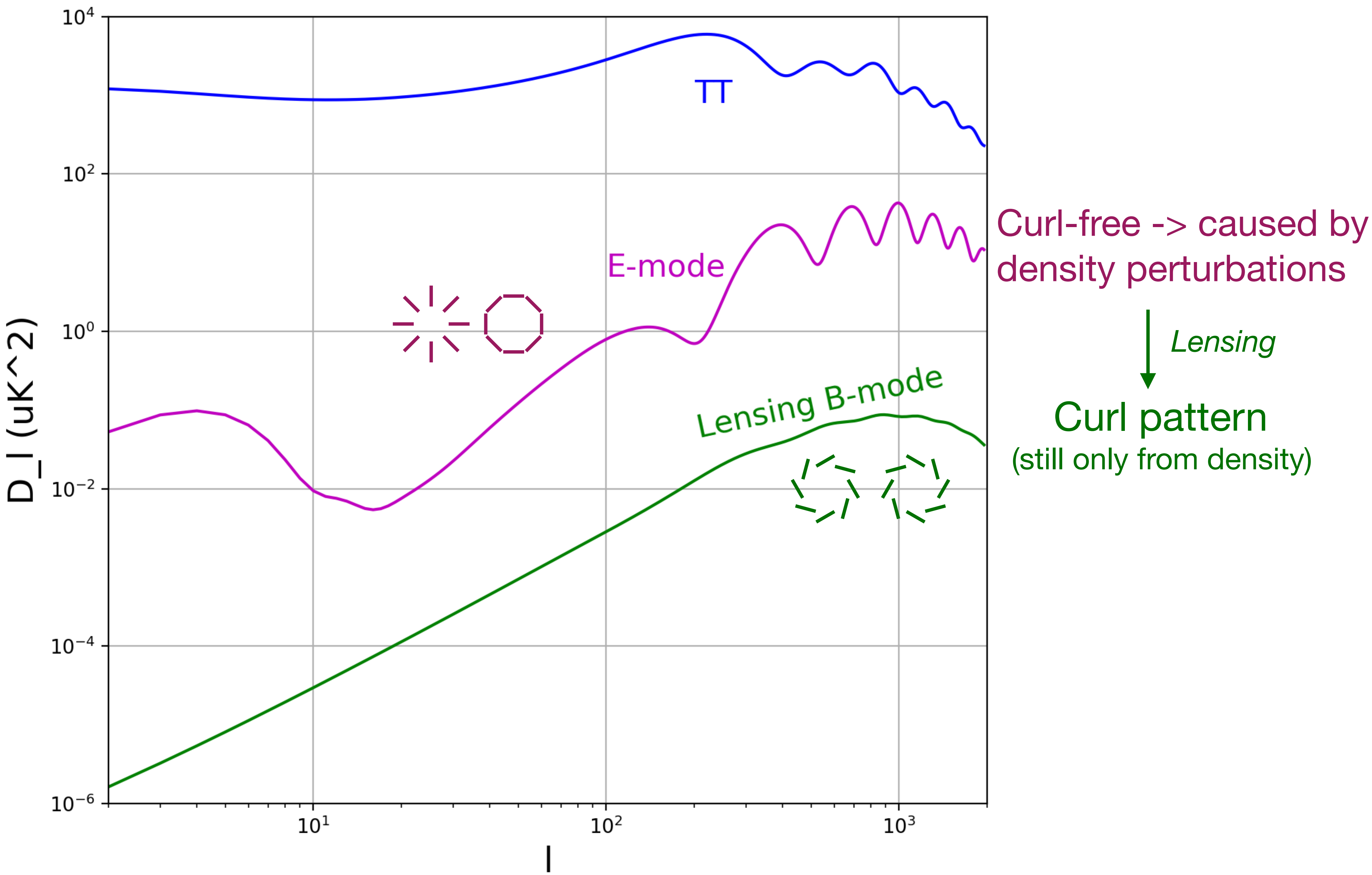
Giannantonio et al., MNRAS 456, 3213 (2016)

CMB Polarization Signals

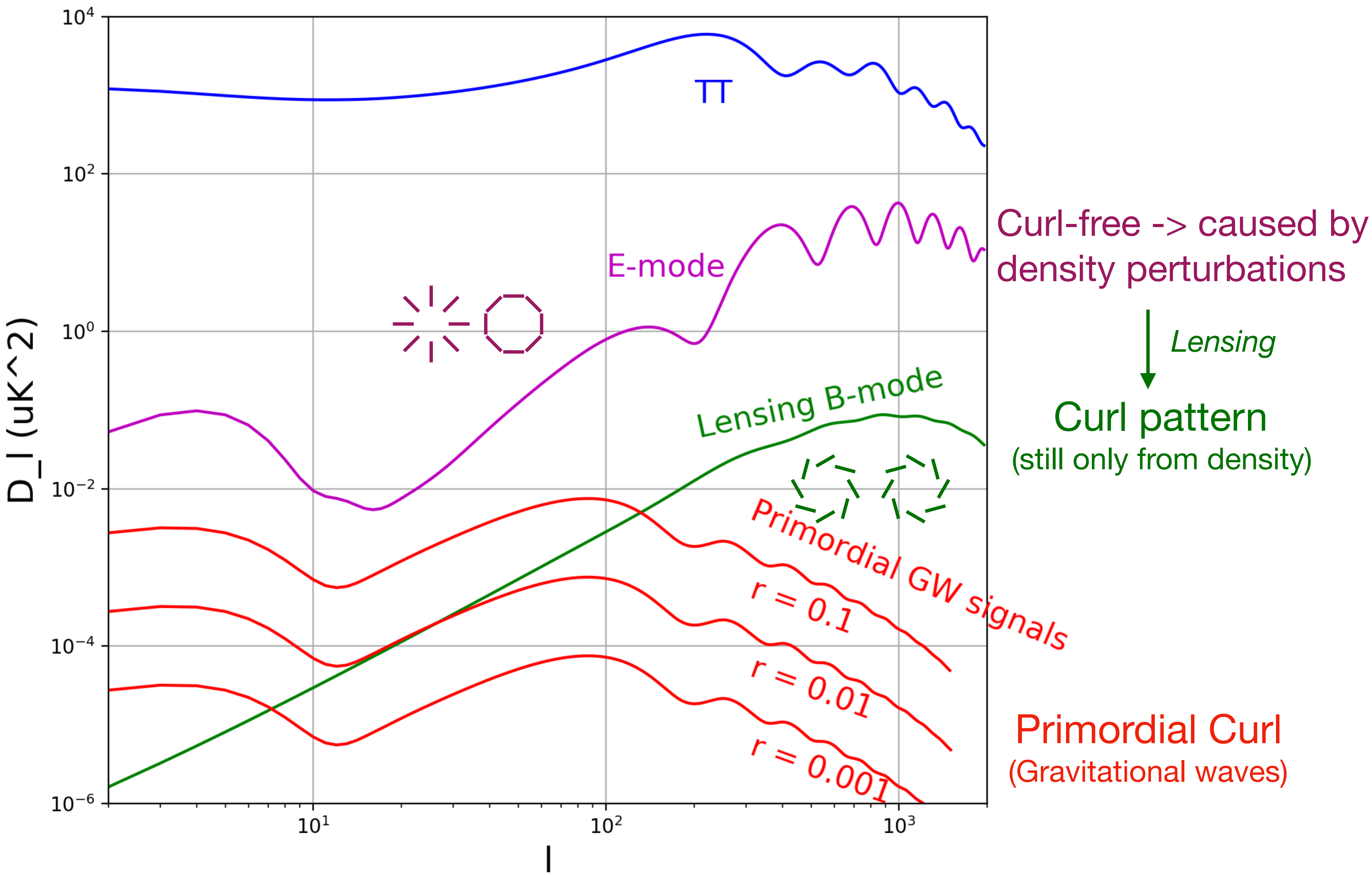


Curl-free -> caused by density perturbations

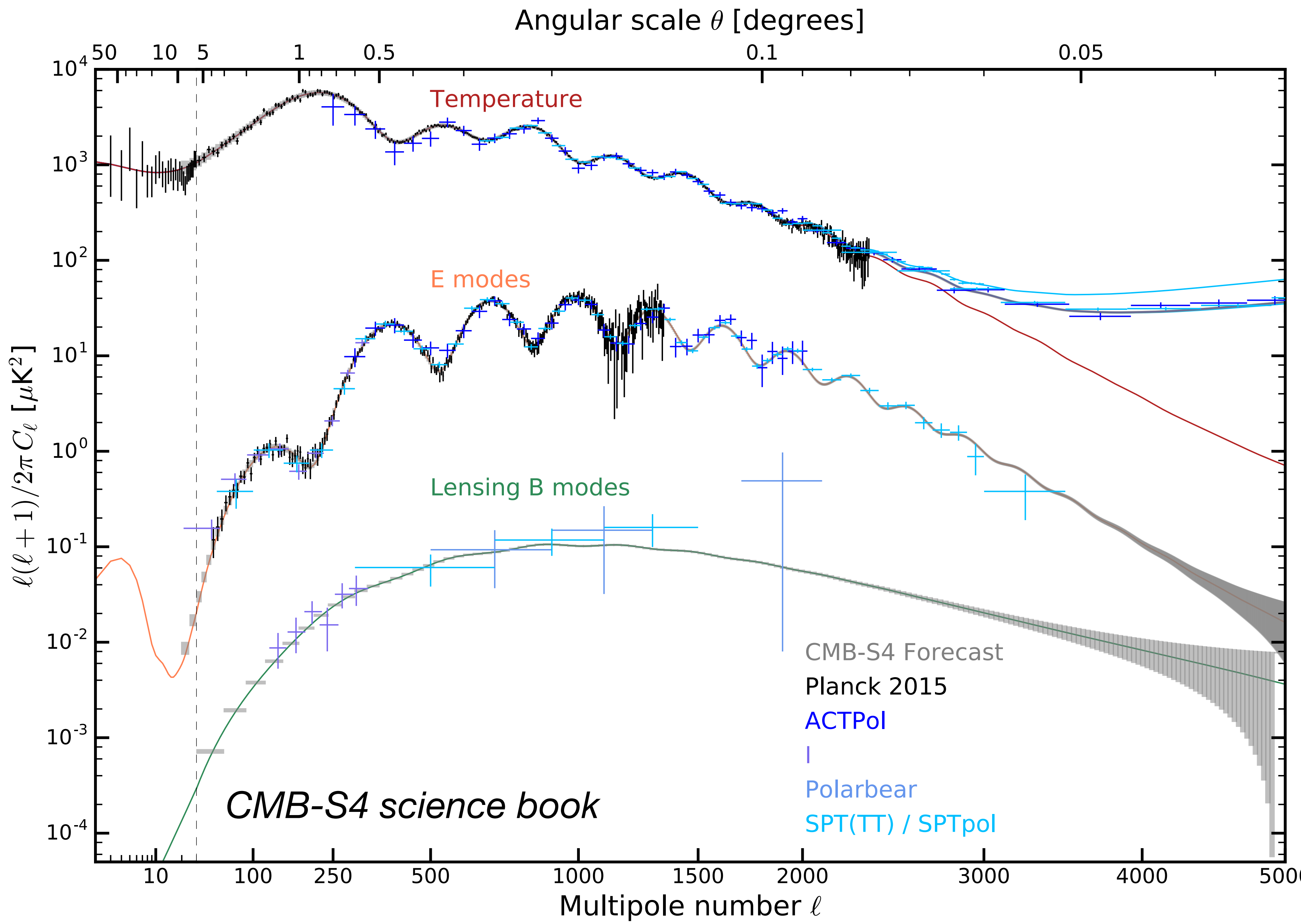
CMB Polarization Signals



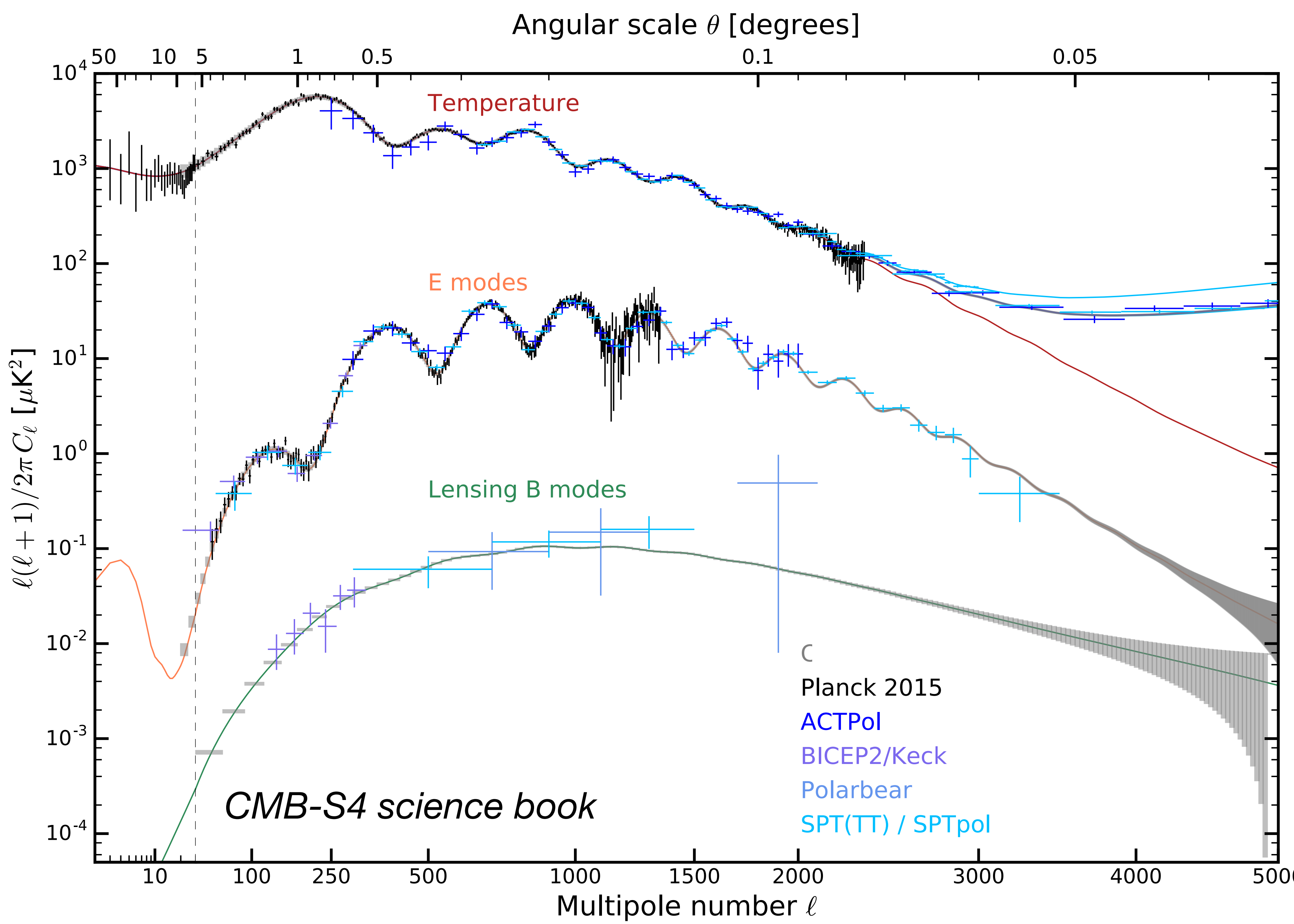
CMB Polarization Signals



Current state of CMB anisotropy measurements



Current state of CMB anisotropy measurements



CMB only:

Planck 2015 • Sum(m_ν) < 0.5eV,

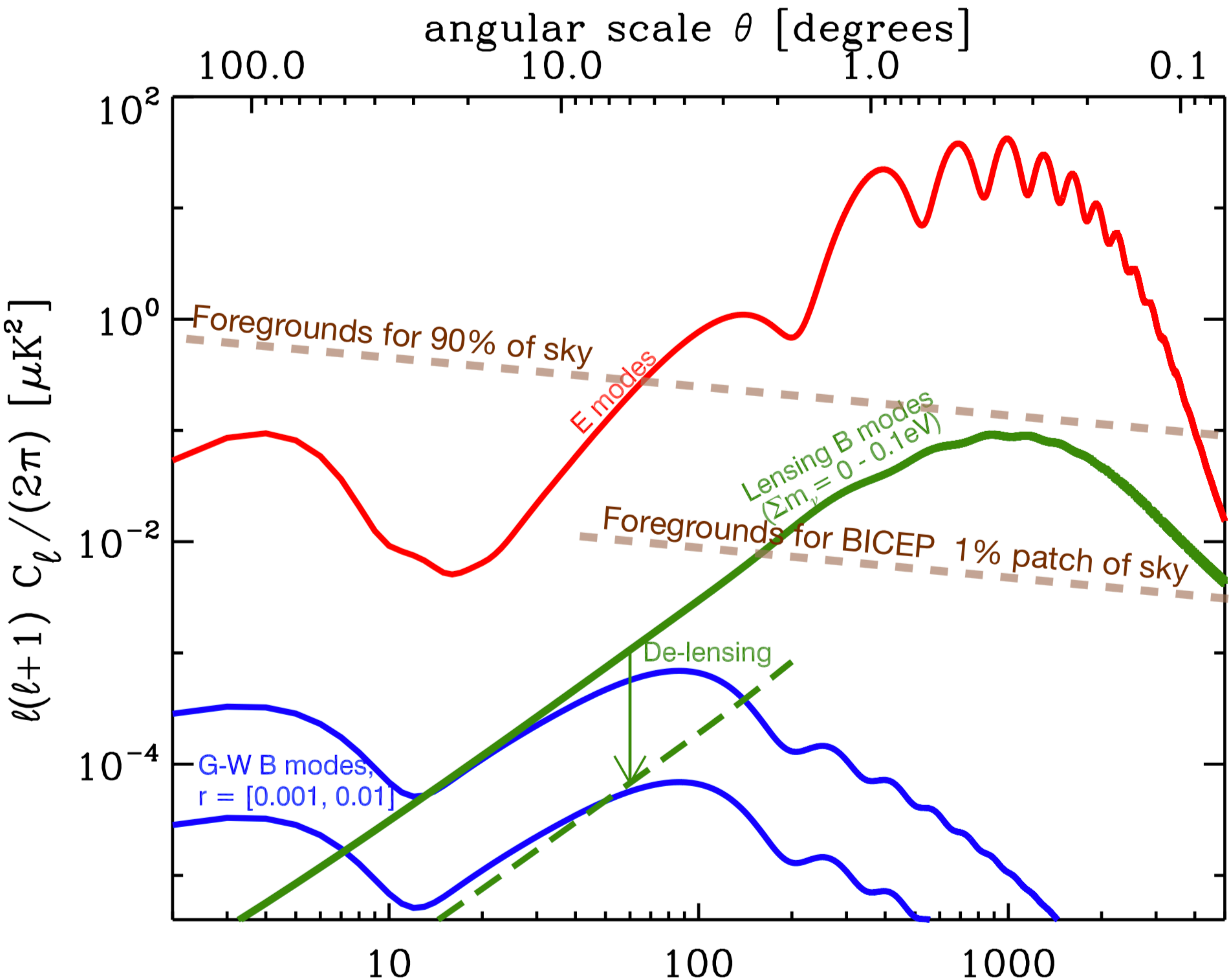
Planck 2015 • N_{eff}≈ 3.0+- 0.3

Planck 2015 + BKP • r < 0.09

Add BAO:

• Sum(m_ν) < 0.2eV *Planck 2015*

CMB-S4 Goal #1 - Search for primordial gravitational waves via their "B-mode" polarization signature



Challenges:

- Sensitivity,
- Galactic foregrounds,
- Lensing B-modes

CMB-S4 Survey:

- ~3-8% of sky
- 0.5m telescopes +
- 5m telescope for delensing
- ~1uK-arcmin depth

Figure from J. Carlstrom/T. Crawford.

Sensitivity =>

Increase detector count by a factor of ≈10 over current instruments.

Source: CDT Report (2017)		Band center in GHz									
		20	**30**	**40**	**85**	**95**	**145**	**155**	**220**	**270**	**N_det total**
5m telescopes (2-3)											
Beam fwhm	arcmin	11	7	5.2	-	2.2	1.4	-	1	0.8	
Number of detectors		420	890	1,600		75,000	75,000		25,700	25,700	**204,310**
0.5m telescopes (~14)											
Beam fwhm	arcmin	-	77	58	27	24	16	15	11	8.5	
Number of detectors			260	470	17,000	21,000	18,000	21,000	34,000	54,000	**165,730**

≈ 370,000 detectors

Foregrounds =>

Observing bands from 20GHz to 270GHz, to subtract out Galactic Dust and Synchrotron emission by a factor of ~10.

Source: CDT Report (2017)		Band center in GHz									
		20	30	40	85	95	145	155	220	270	N_det total
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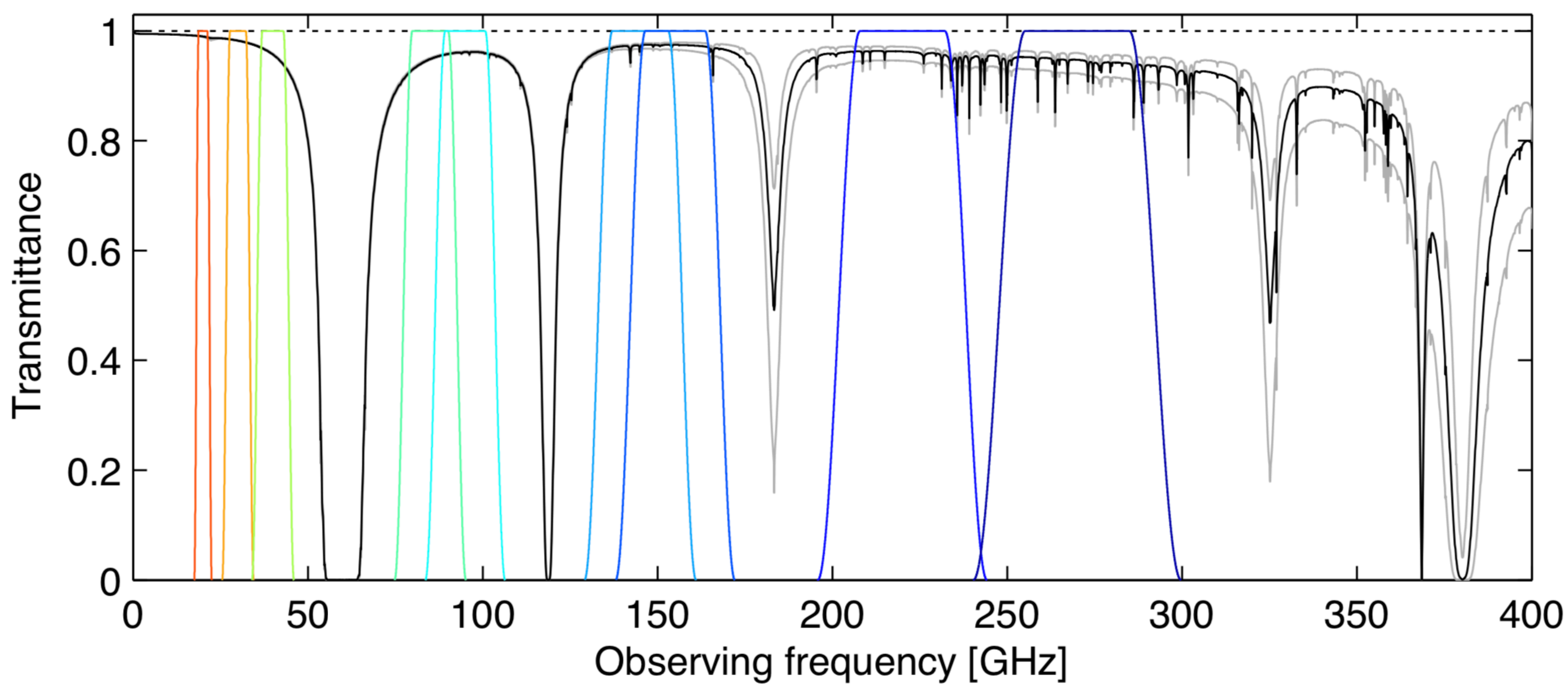
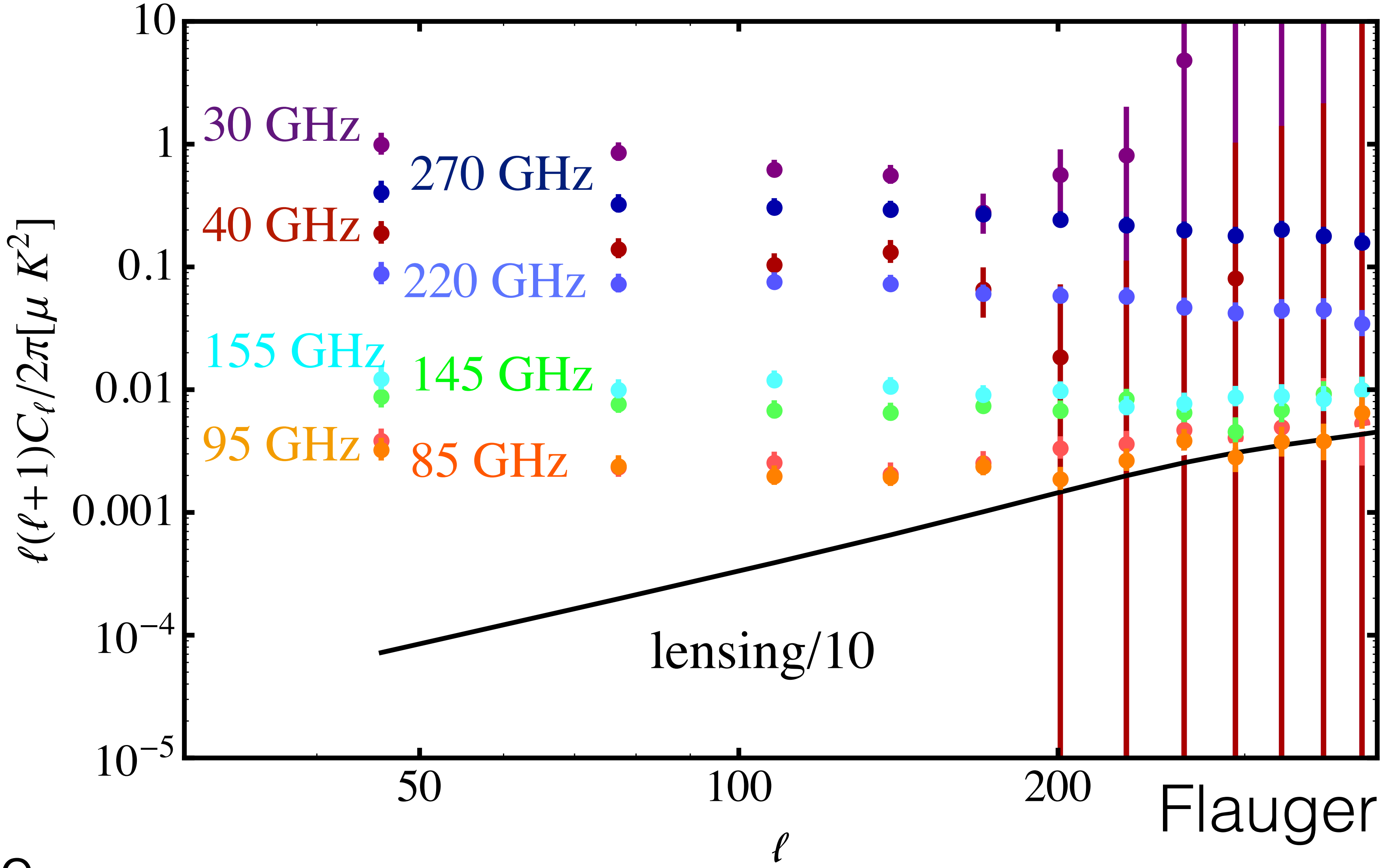


The B-mode foreground problem

The challenge is to use maps with auto-spectra below to tell the difference between...

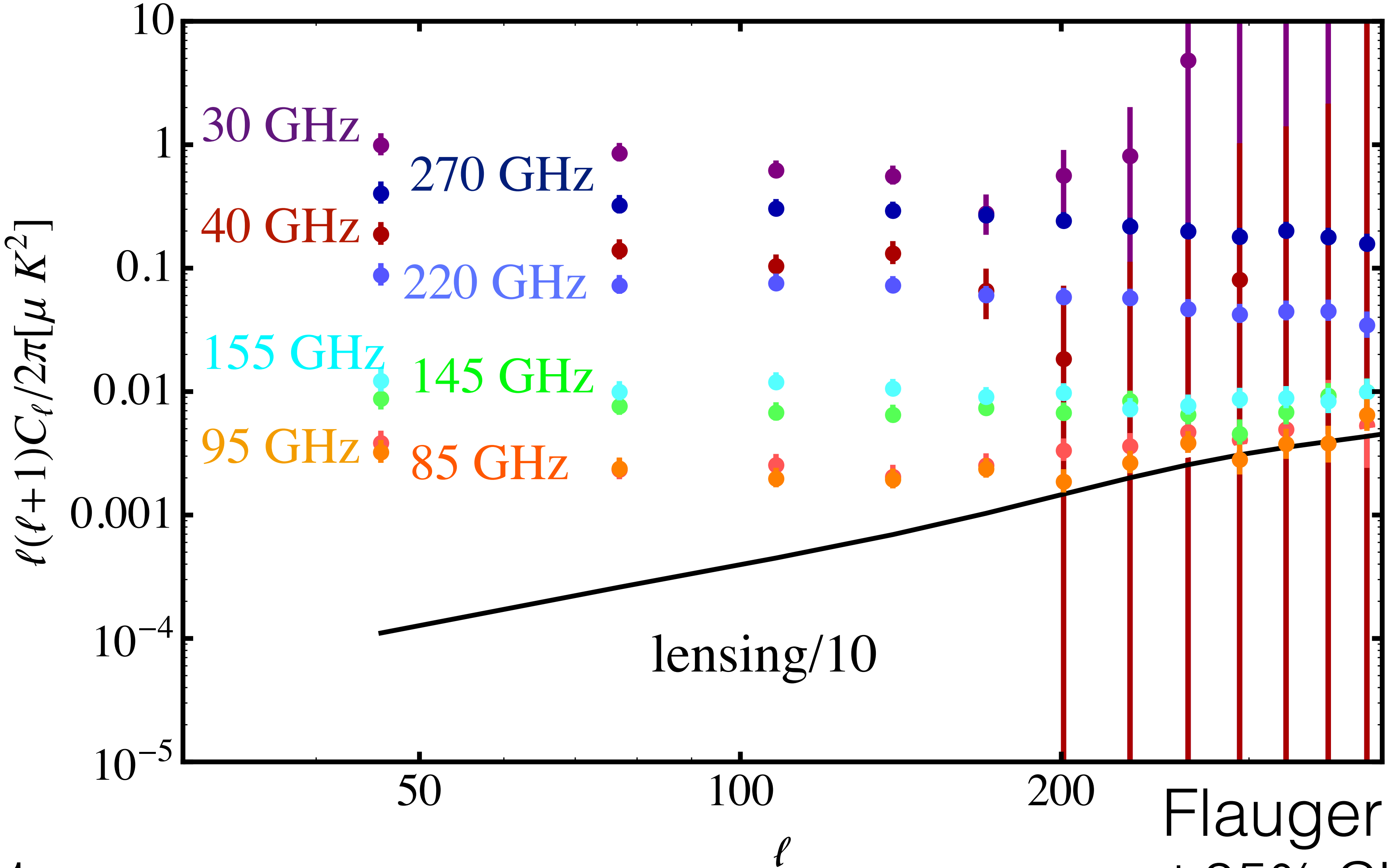


Flauger

r=0.000

The B-mode foreground problem

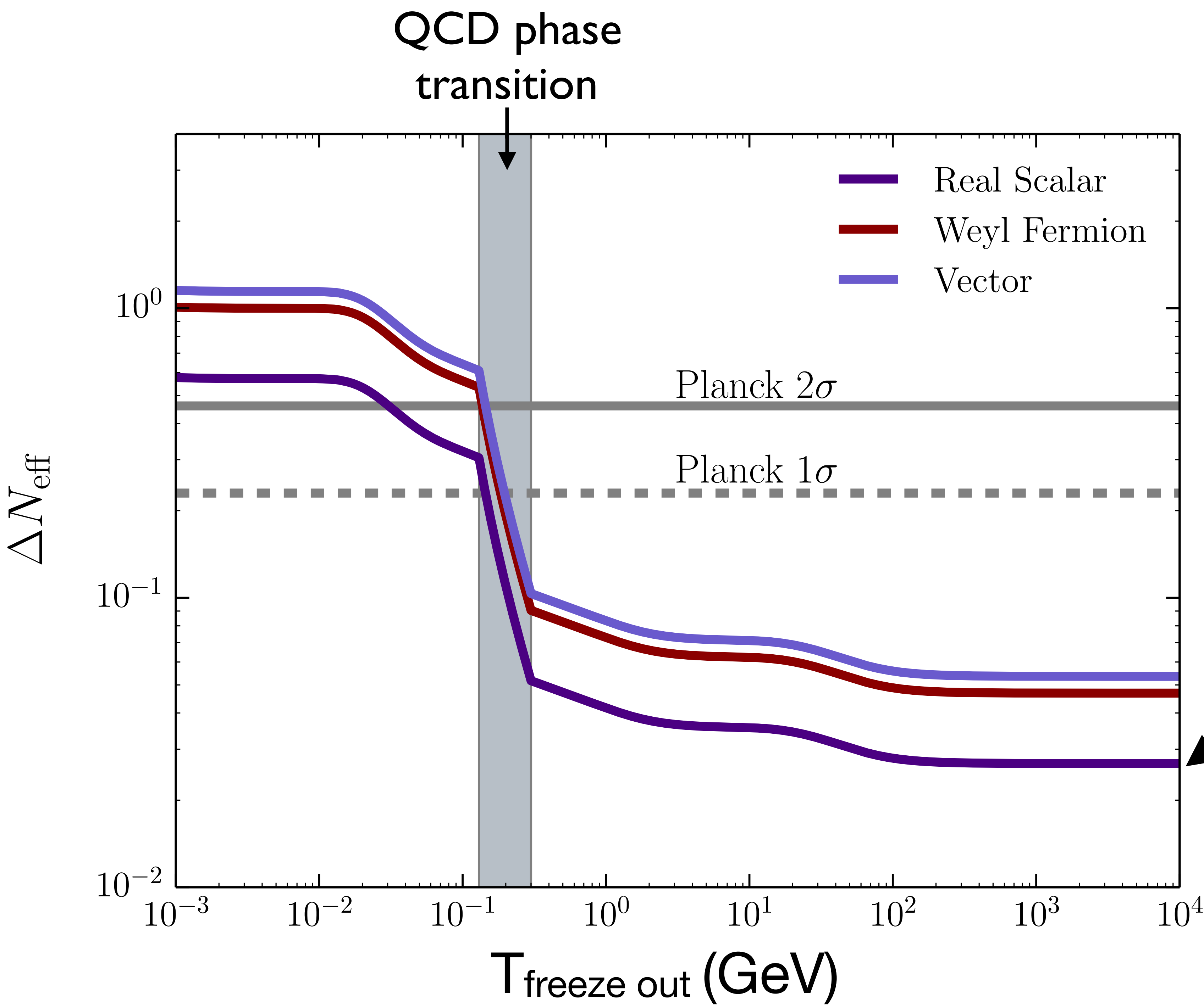
and...



Flauger
at 95% CL

r=0.001

N_{eff} and light thermal relics



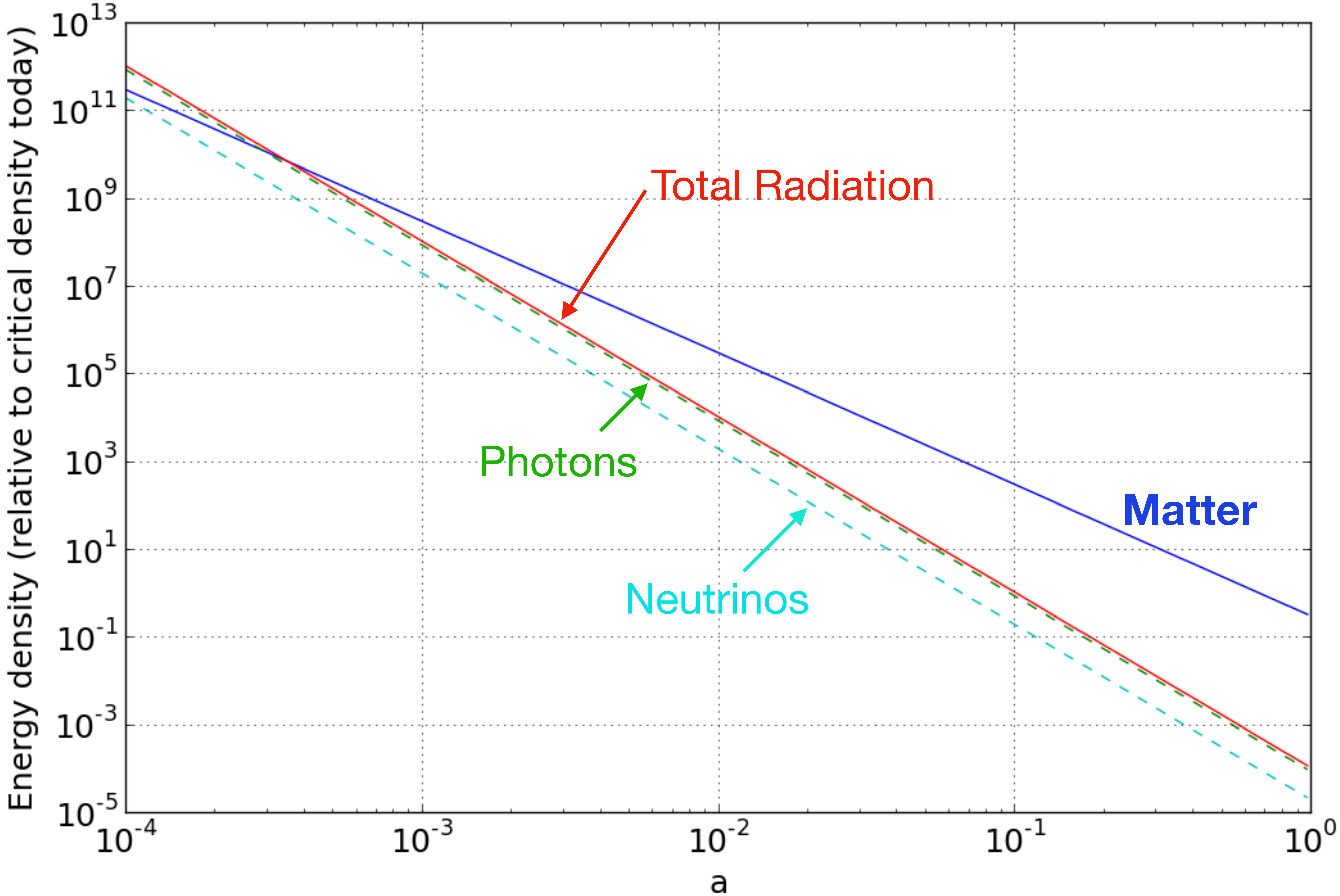
Standard Model:
$N_{eff} = 3.046$

Sets natural, and exceedingly challenging, target of $\Delta N_{eff} = 0.027$ for a relic scalar, 0.054 for a vector.

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

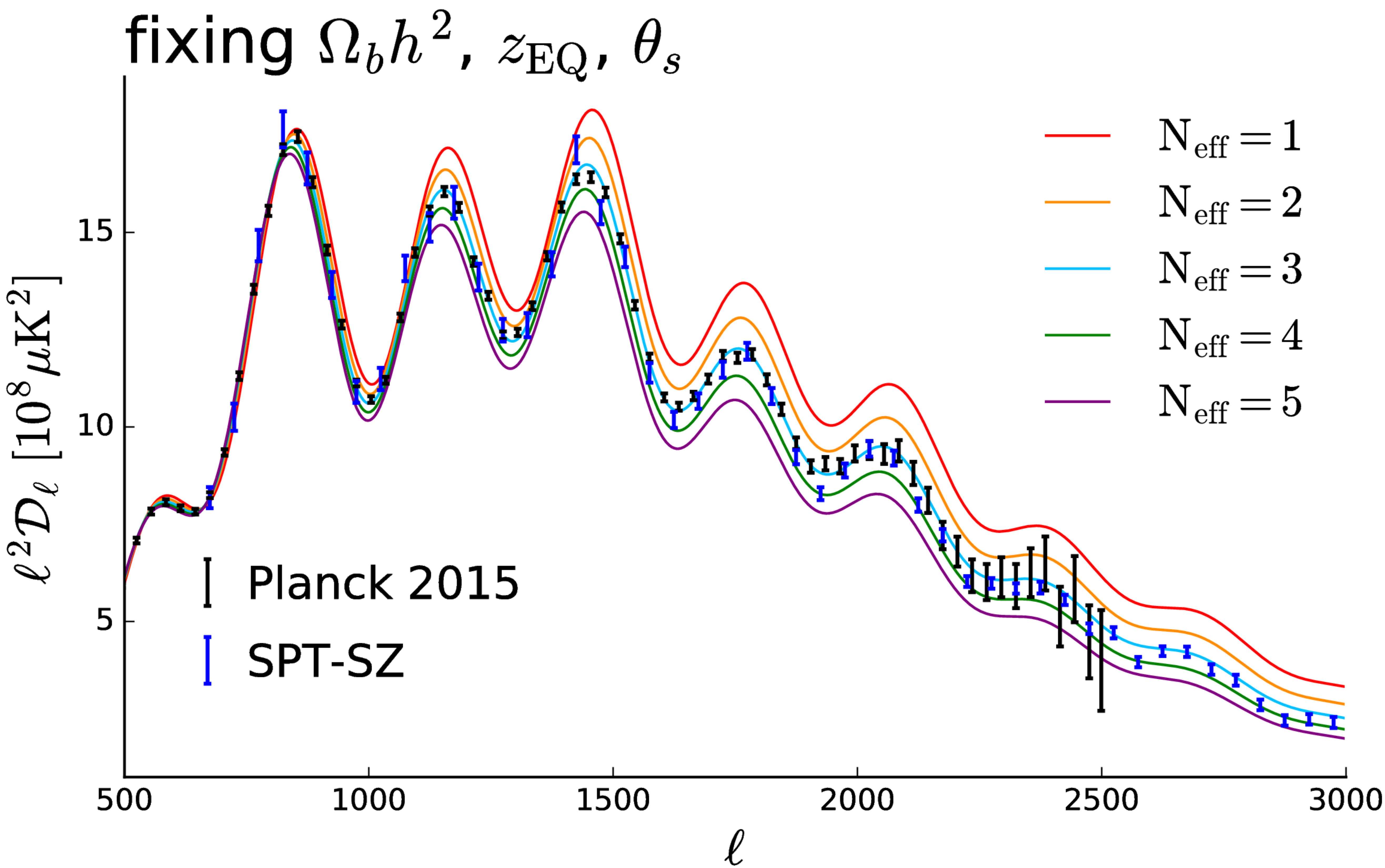
Goal #2 - Search for new "light" particle species

(via effect on early expansion rate)



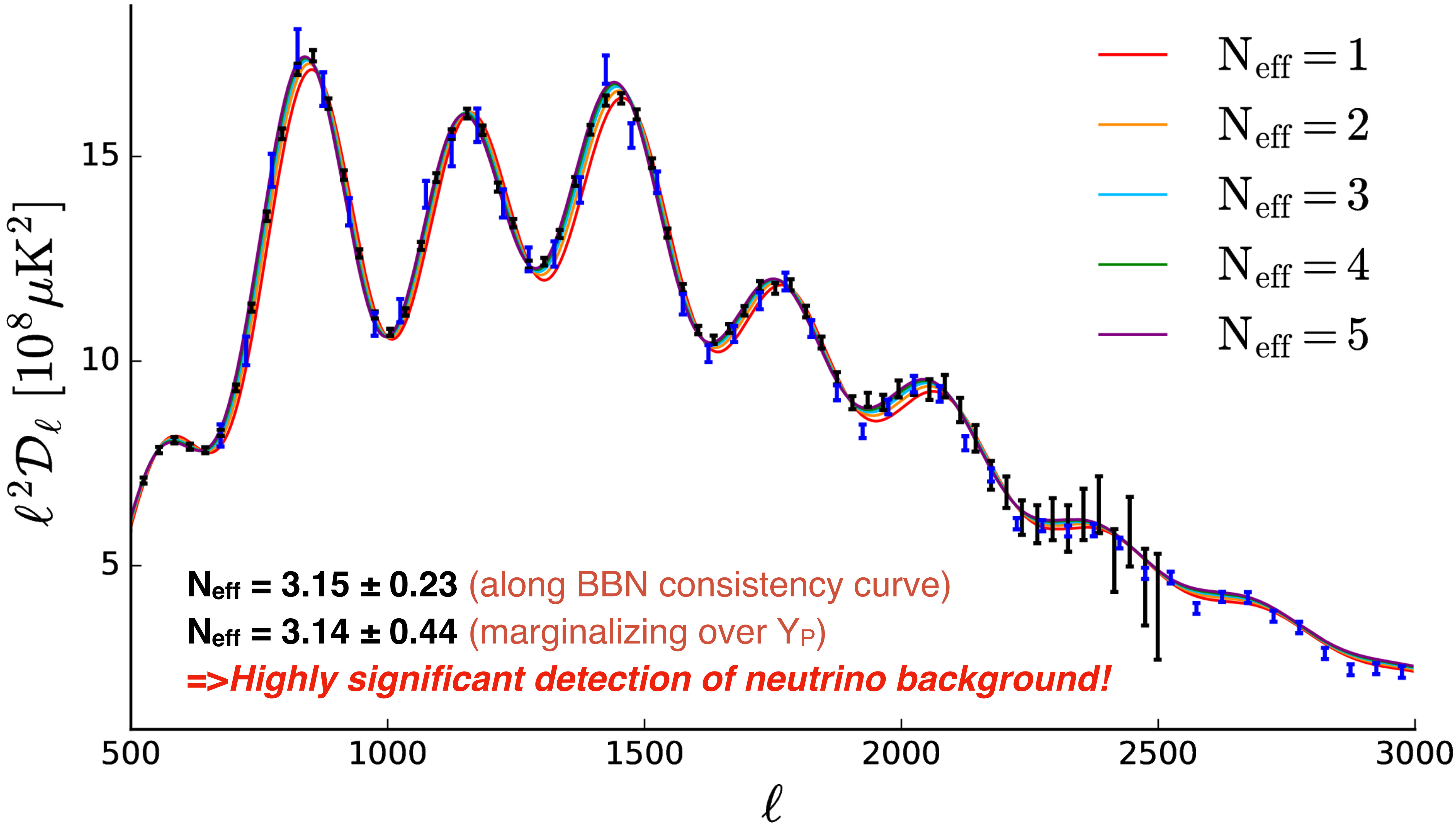
$$\rho_r = T_\gamma^4 (1+z)^4 \left[1 + \mathbf{N}_{\mathrm{eff}} \left(\frac{7}{8}\right)\left(\frac{4}{11}\right)^{4/3}\right]\left(\frac{\pi^2}{15}\right)$$

N_{eff} and CMB damping



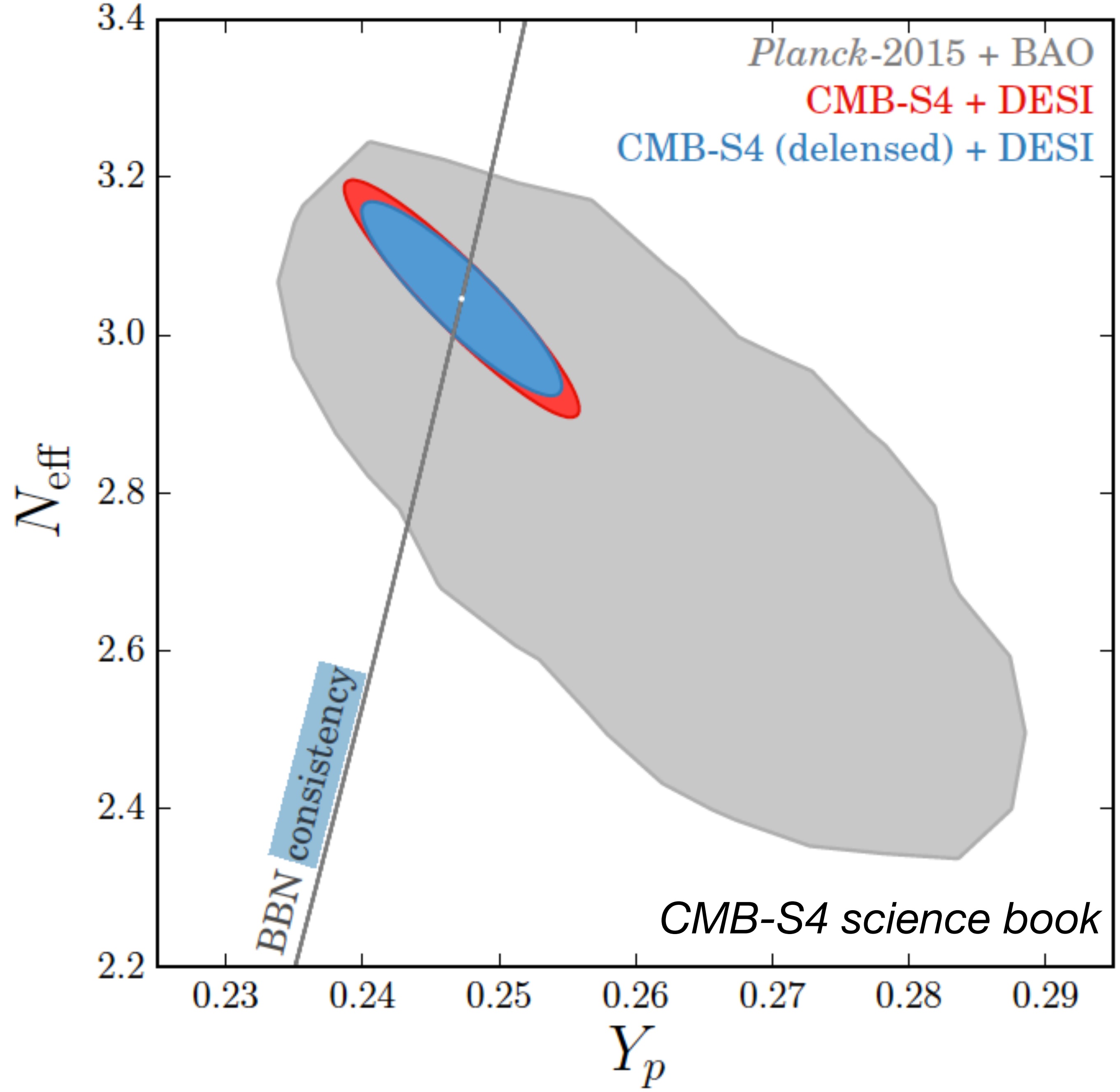
Helium fraction & N_{eff} degeneracy

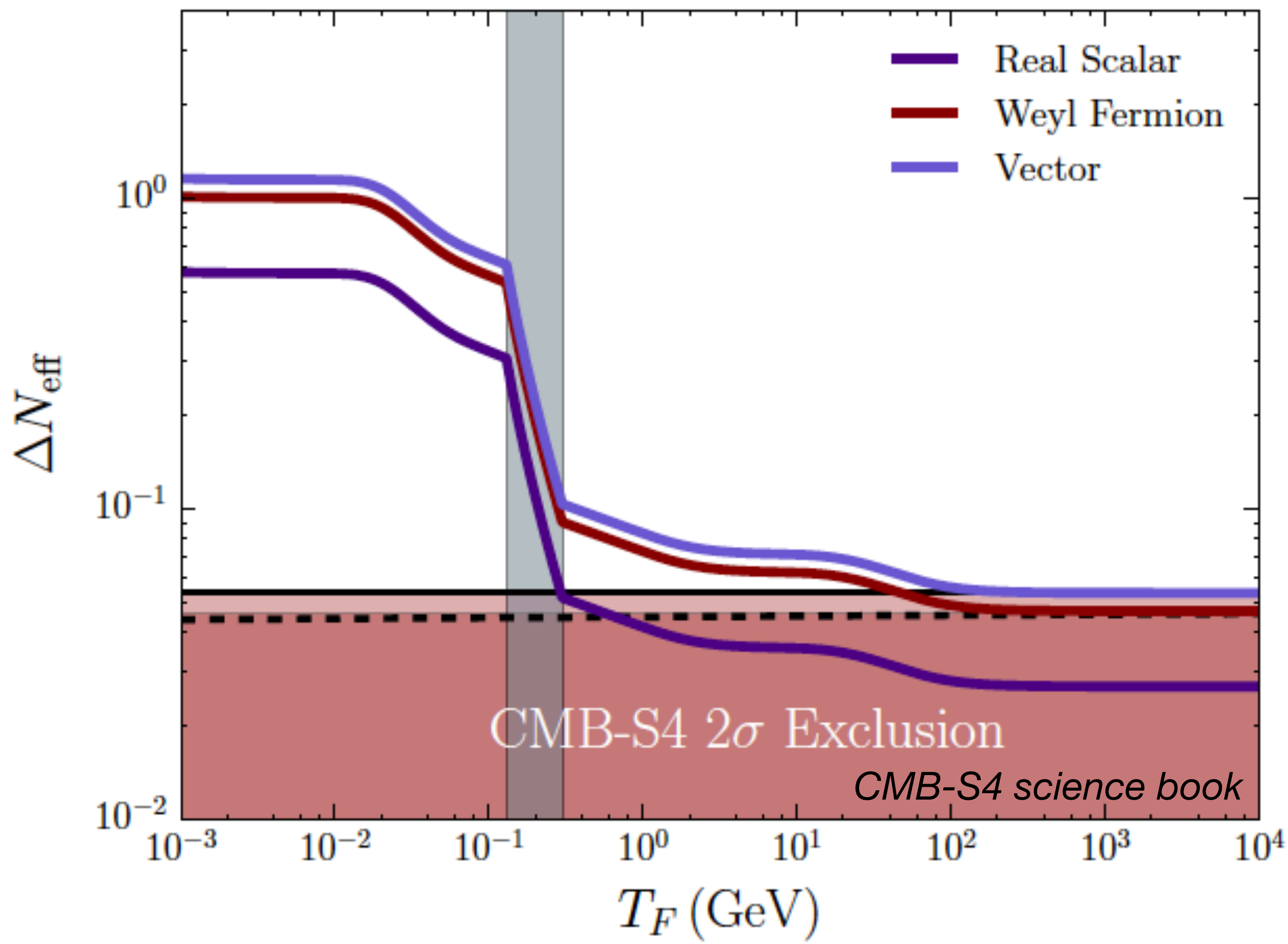
Also keep θ_d constant with N_{eff} by varying the helium fraction, Y_P



CMB-S4 promises much tighter bounds on Neff, whether marginalizing over Yp or not.

Survey: ~40% of sky with small beams (~5m telescopes), to ~1uK-arcmin depth





Real Scalar
Weyl Fermion
Vector
10^0
10^{-1}
10^{-2}
ΔN_{eff}
CMB-S4 2σ Exclusion
CMB-S4 science book
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
T_F (GeV)

Great prospects for probing physics...

From CMB-S4 Science Book Figure 3

	r	N_{eff}	$Sum(m_\nu)$
LCDM	0	3.046	> 59meV

2015

2016

2017

2018

2019

2020

		$\sigma(r)$	$\sigma(N_{eff})$	$\sigma(\Sigma m_\nu)$
Stage 2 ~1000 detectors	eg SPTpol	0.035	0.14	Boss BAO prior 0.15eV
Stage 3 ~10,000 detectors	eg SPT3g	0.006	0.06	Boss BAO prior 0.06eV
Target Stage 4 CMB-S4 ~500,000 detectors		**0.0005**	**0.027**	DESI BAO + T_e prior **0.015eV**

Thank you!