Universität Bielefeld

Status of Cosmology

Dominik J. Schwarz

- What do we know?
- Open questions
- How to make progress?
- Future facilities / German activities

KAT meeting, Mainz 2018

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- What do we know?
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- Future facilities / ~~German activities~~ Global activities

KAT meeting, Mainz 2018

Talk based on

➜ Denkschrift 2017
➜ Planck legacy release
➜ my point of view

denkschrift2017.de

Based on community papers:

Dark Energy, Dark Matter and Large-Scale Structure

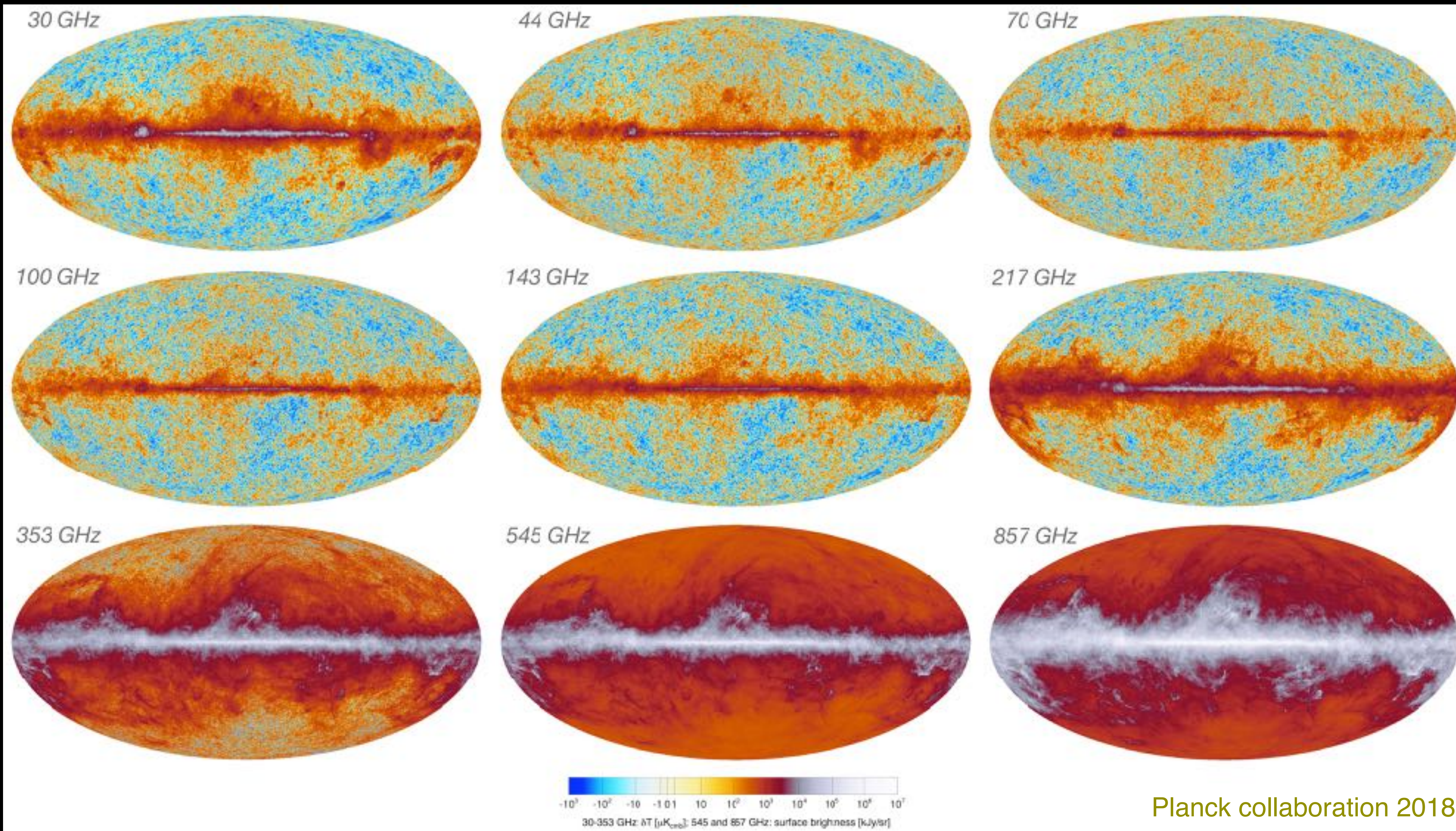
The Early Universe from Inflation to Reionization

What have we learned?

The Universe is
➜ statistically isotropic and homogeneous
➜ spatially flat
➜ dynamic and expands
➜ dominated by dark matter and dark energy

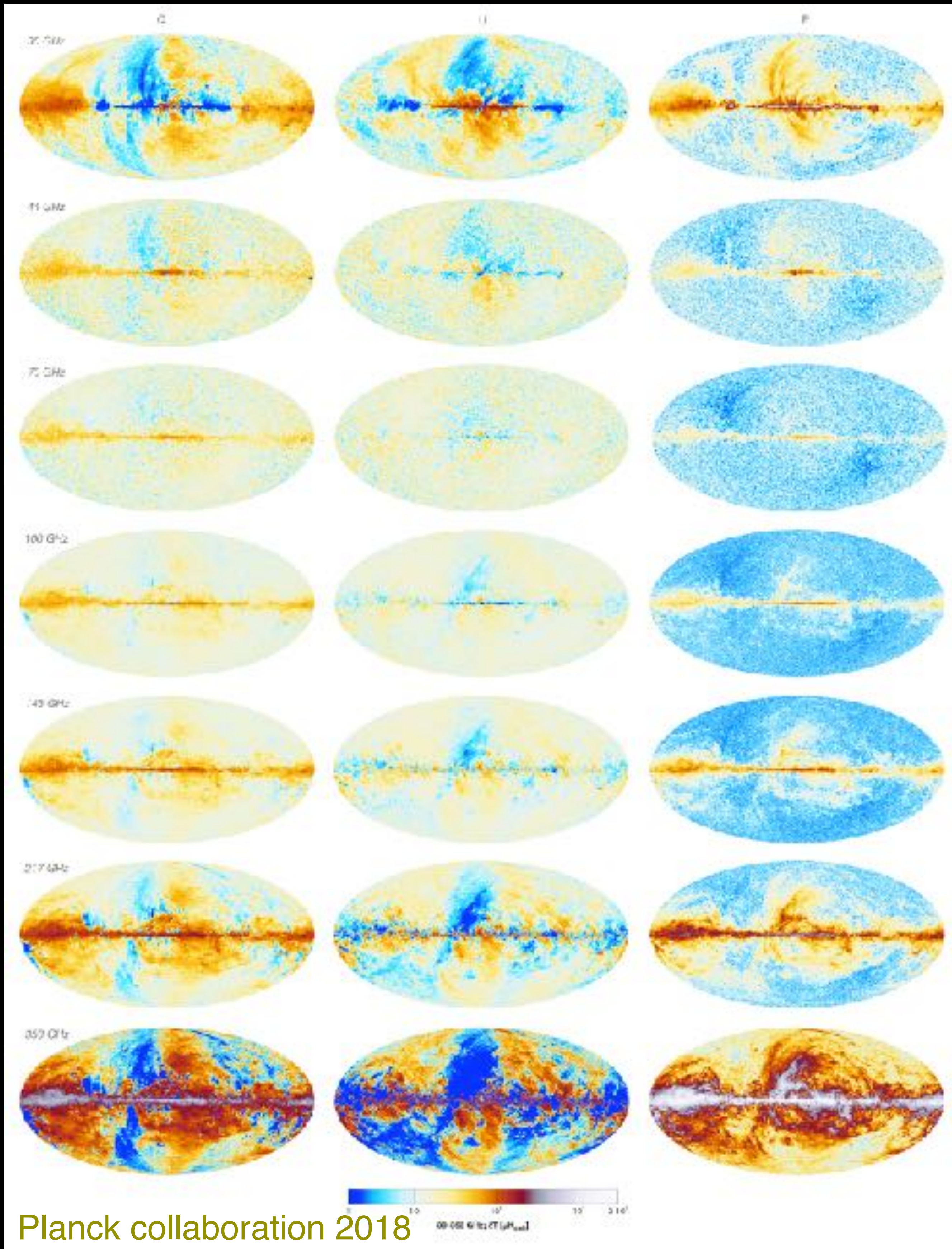
Cosmic structures
➜ grow via gravitational instability
➜ are seeded by quantum fluctuations

Planck legacy



full-sky maps in 9 frequency bands

Planck legacy



Planck collaboration 2018

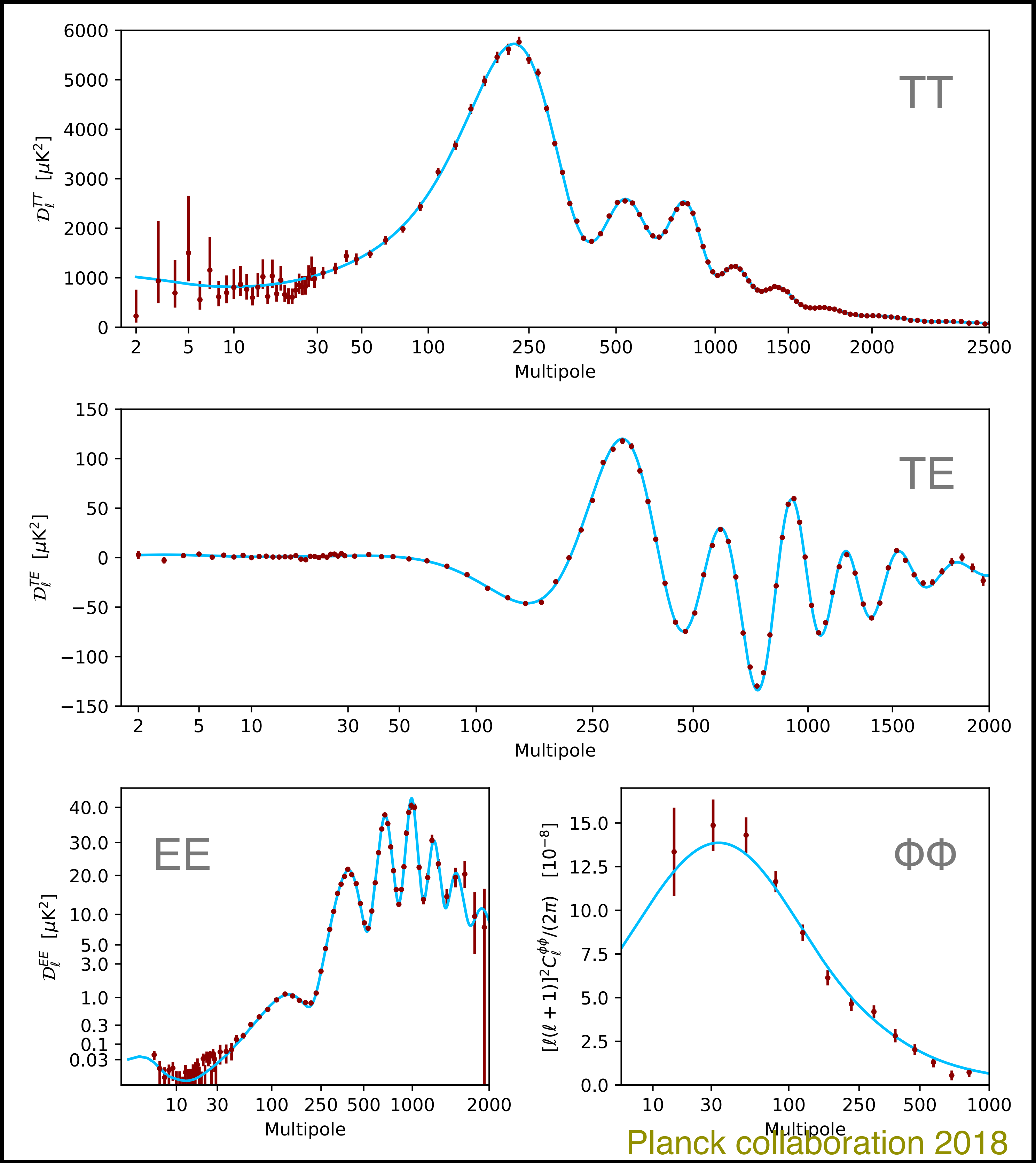
full-sky polarisation of
Stokes Q, U and polarised intensity
in 7 frequency bands

foreground dominated:
polarised synchrotron emission at low frequencies and polarised thermal dust emission at high frequencies

polarised signal is decomposed into E- and B-mode pattern (parity even and parity odd pattern)

density and pressure fluctuations: E-modes
vorticity fluctuations: B-modes
gravitational waves: E- & B-modes

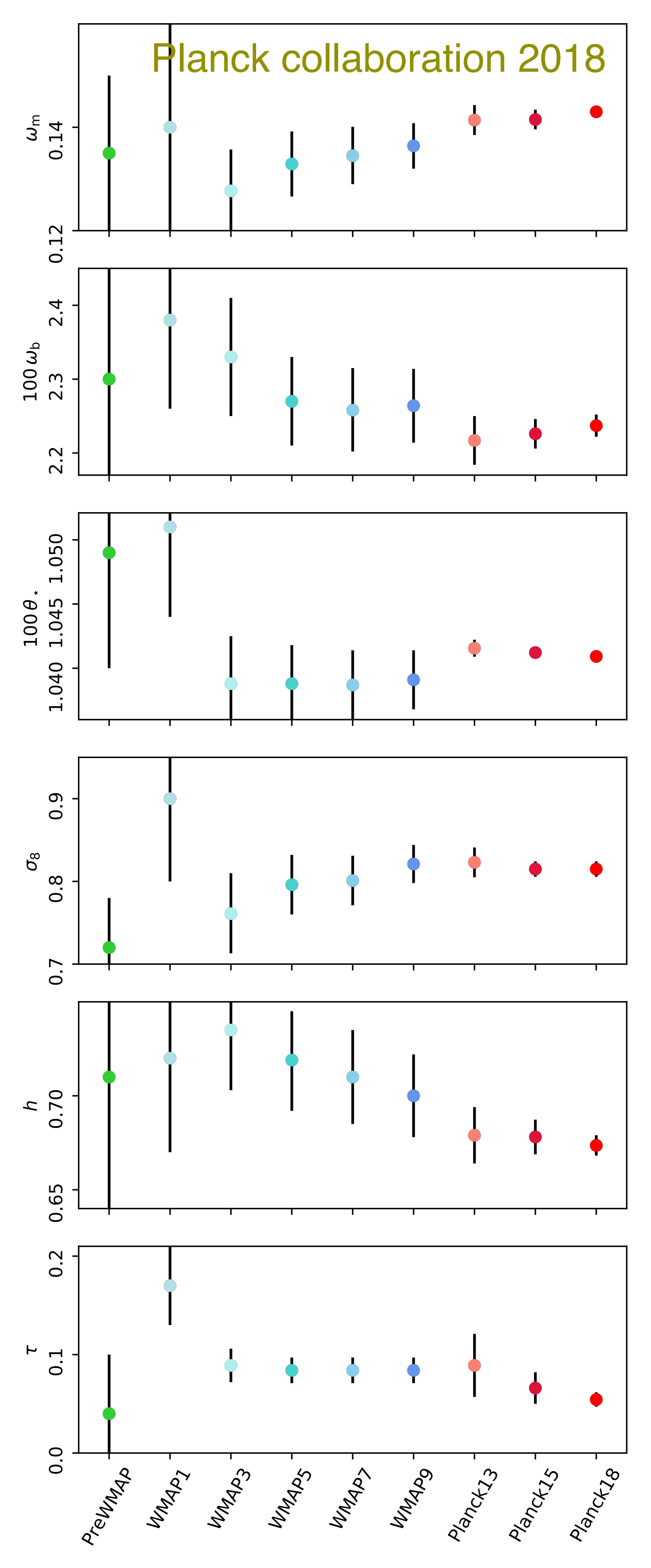
Planck legacy



angular band power spectra for the auto- and cross-correlations: TT, TE, EE and ΦΦ

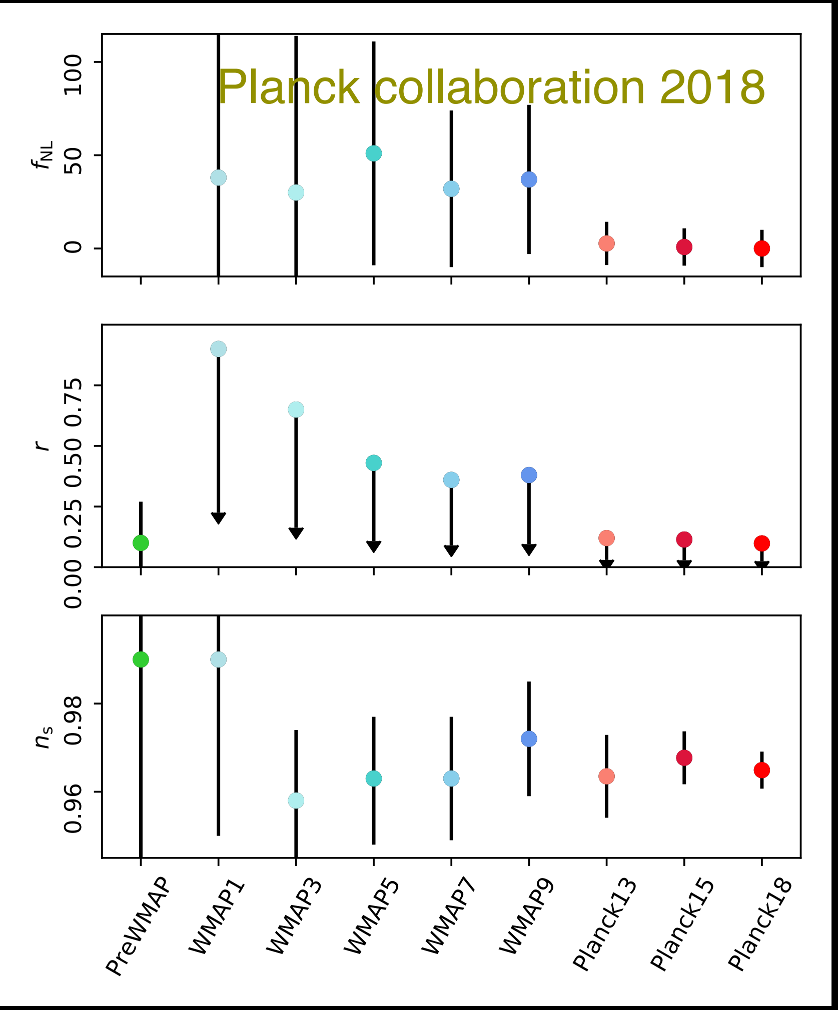
T … temperature
E … E-mode polarisation pattern
Φ … gravitational lensing potential

Cosmological parameters

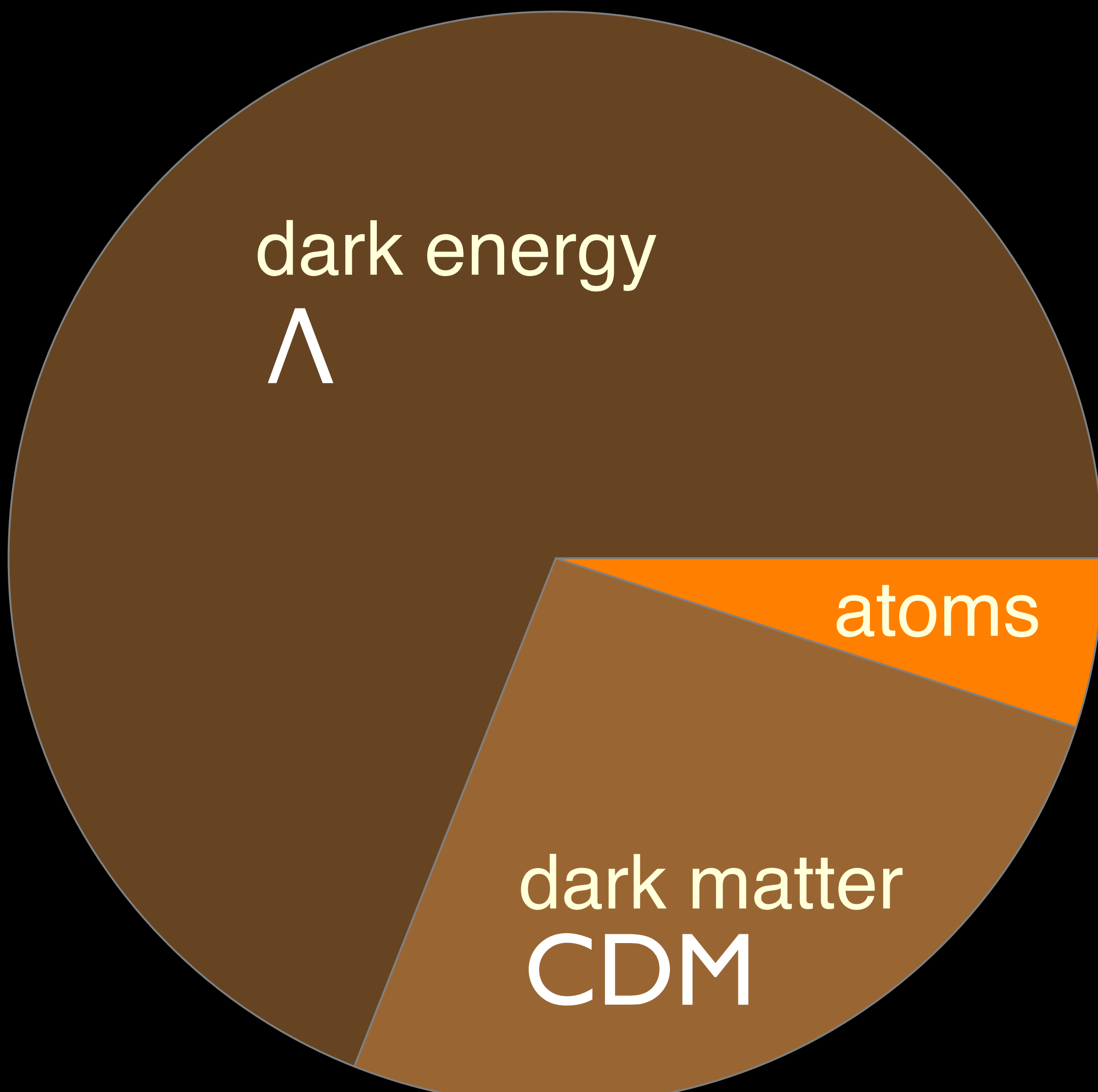


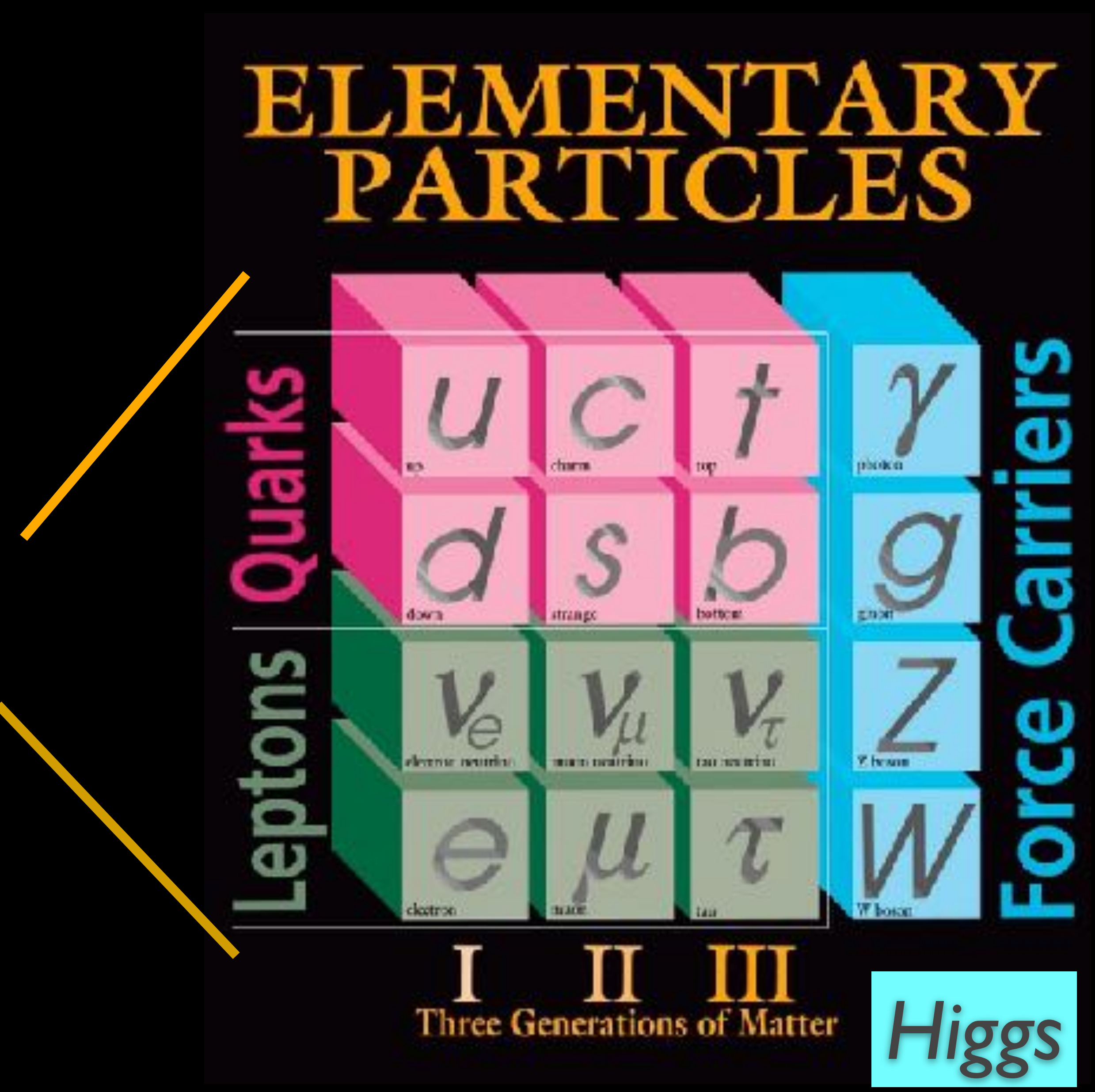
T_0 = 2.7255(6) K based on COBE/FIRAS, fixed
T_1 used to fix cosmic reference frame

ΛCDM model has 6 independent parameters:
A_s, n_s, ω_m, ω_b, and h are measured better than 1 per cent,
τ at 10 per cent precision



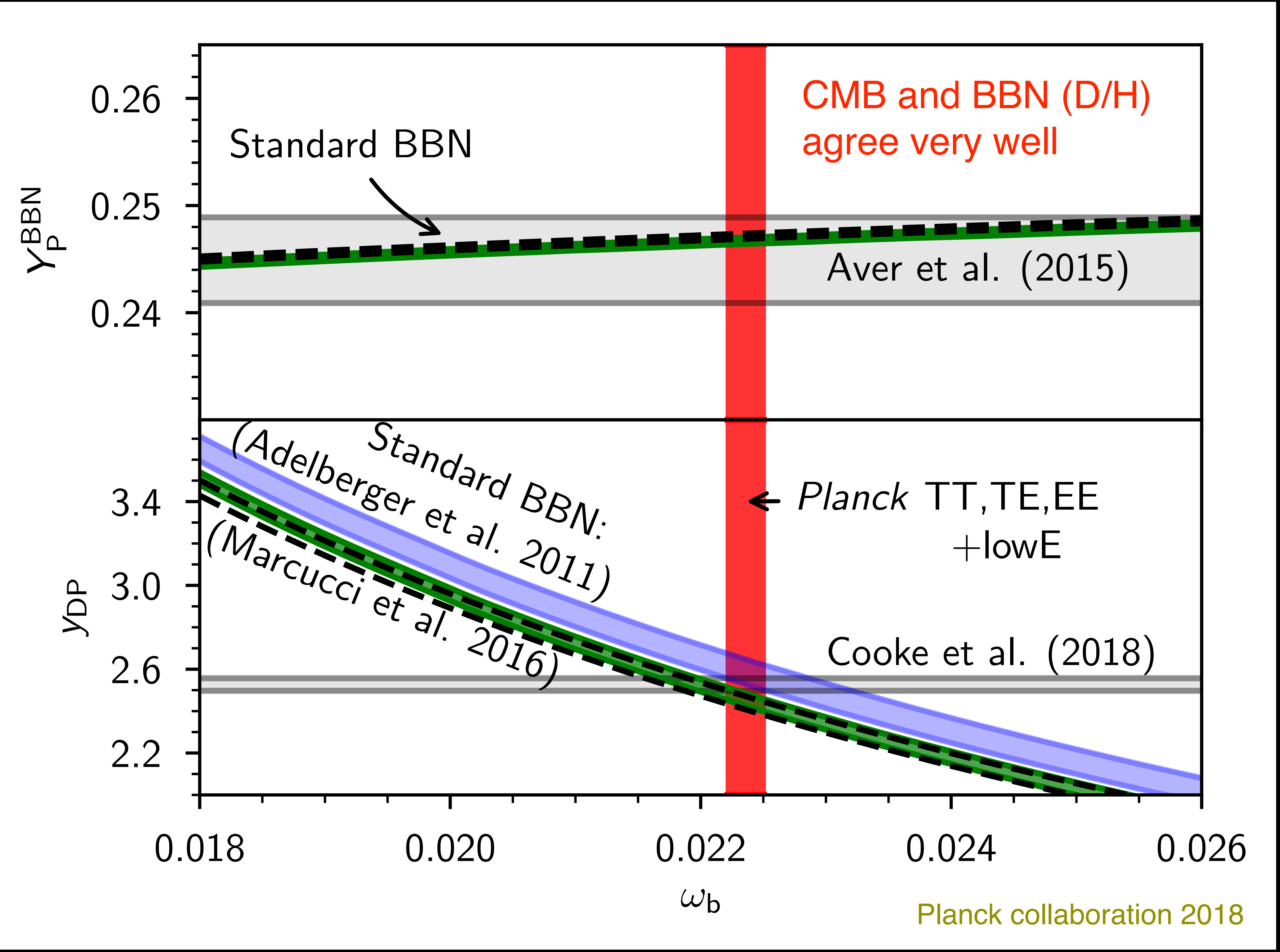
Composition of Universe





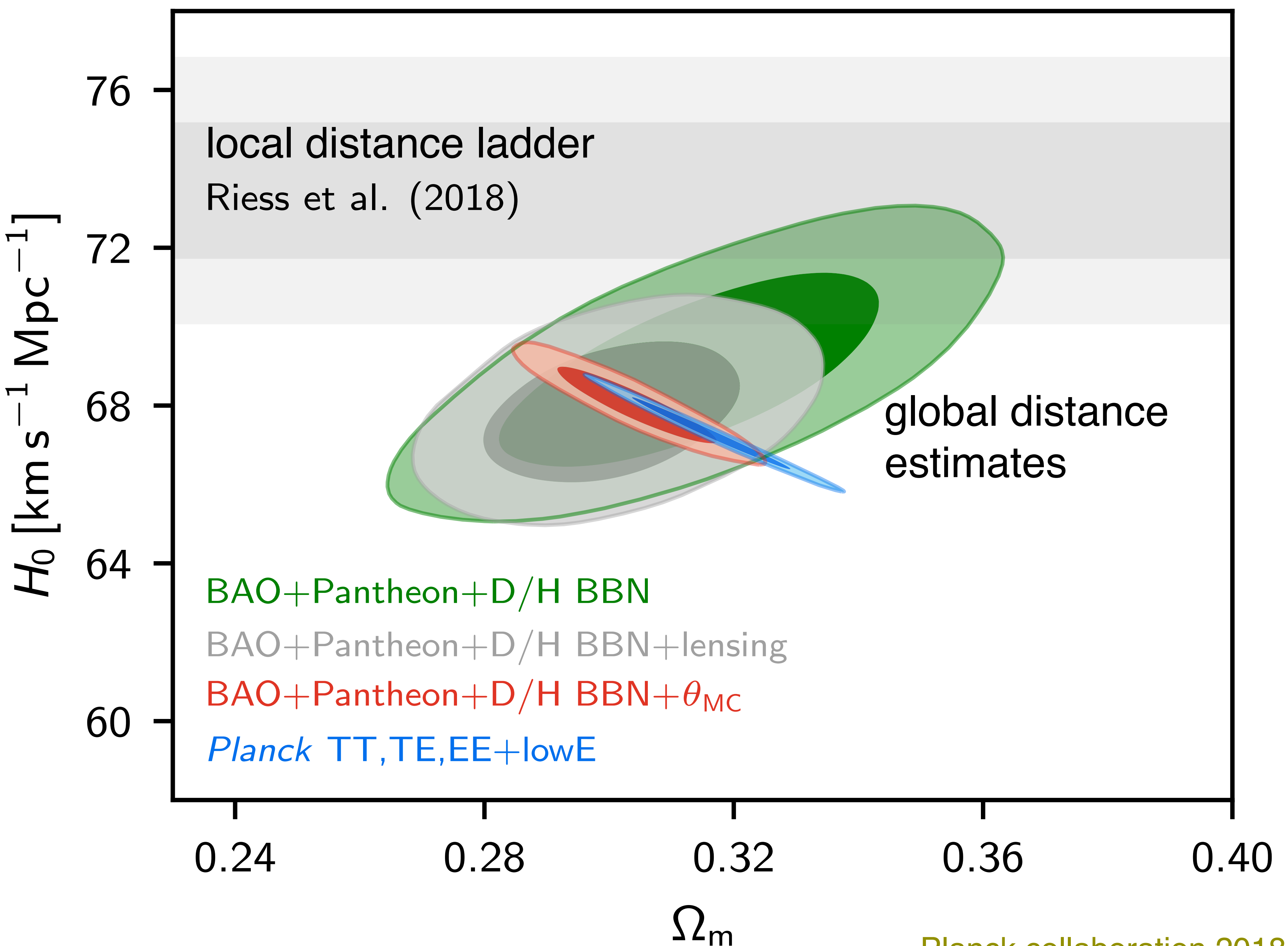
Consistency

Baryonic matter



Tension on H_0

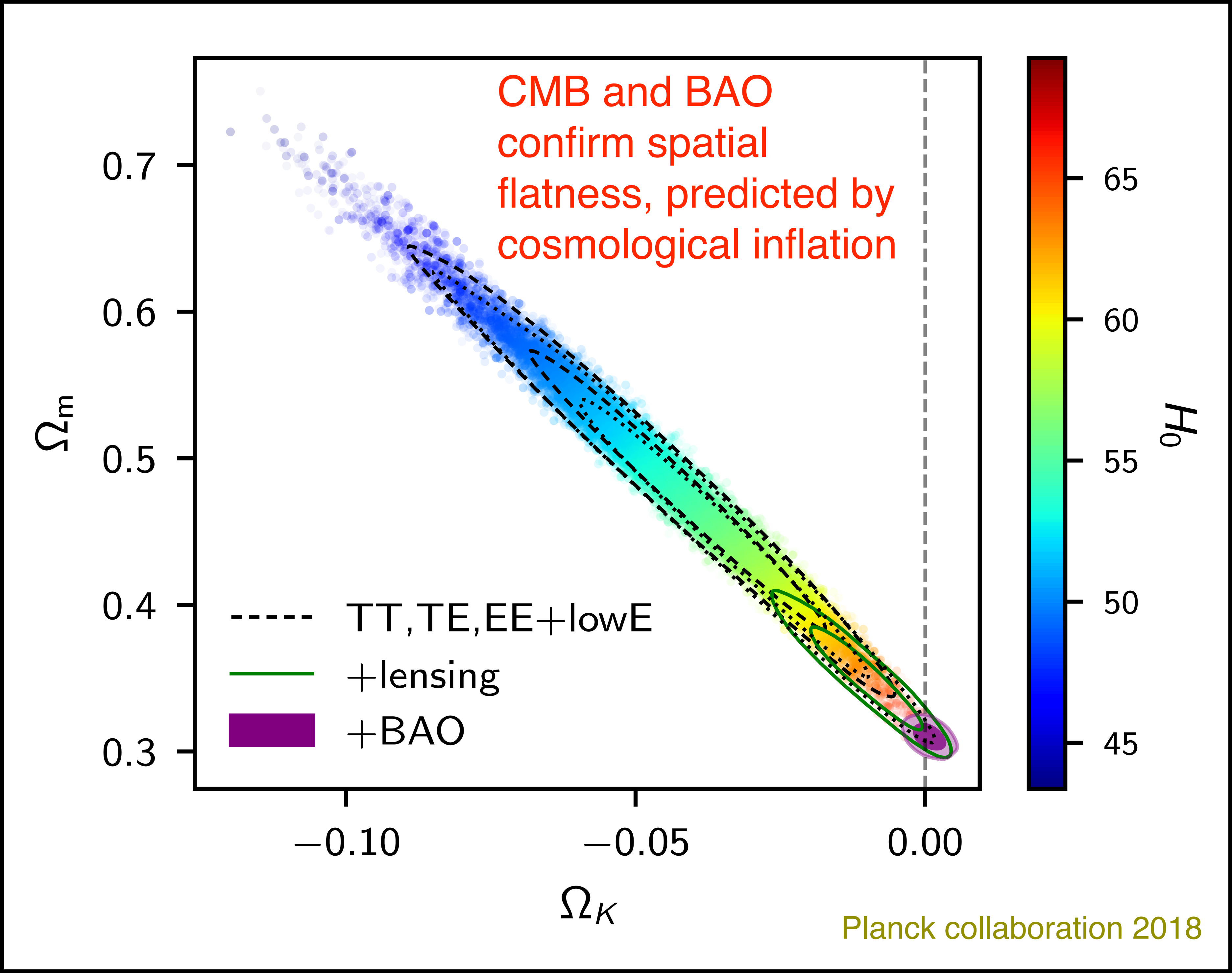
Tension on Hubble expansion rate H_0



Planck collaboration 2018

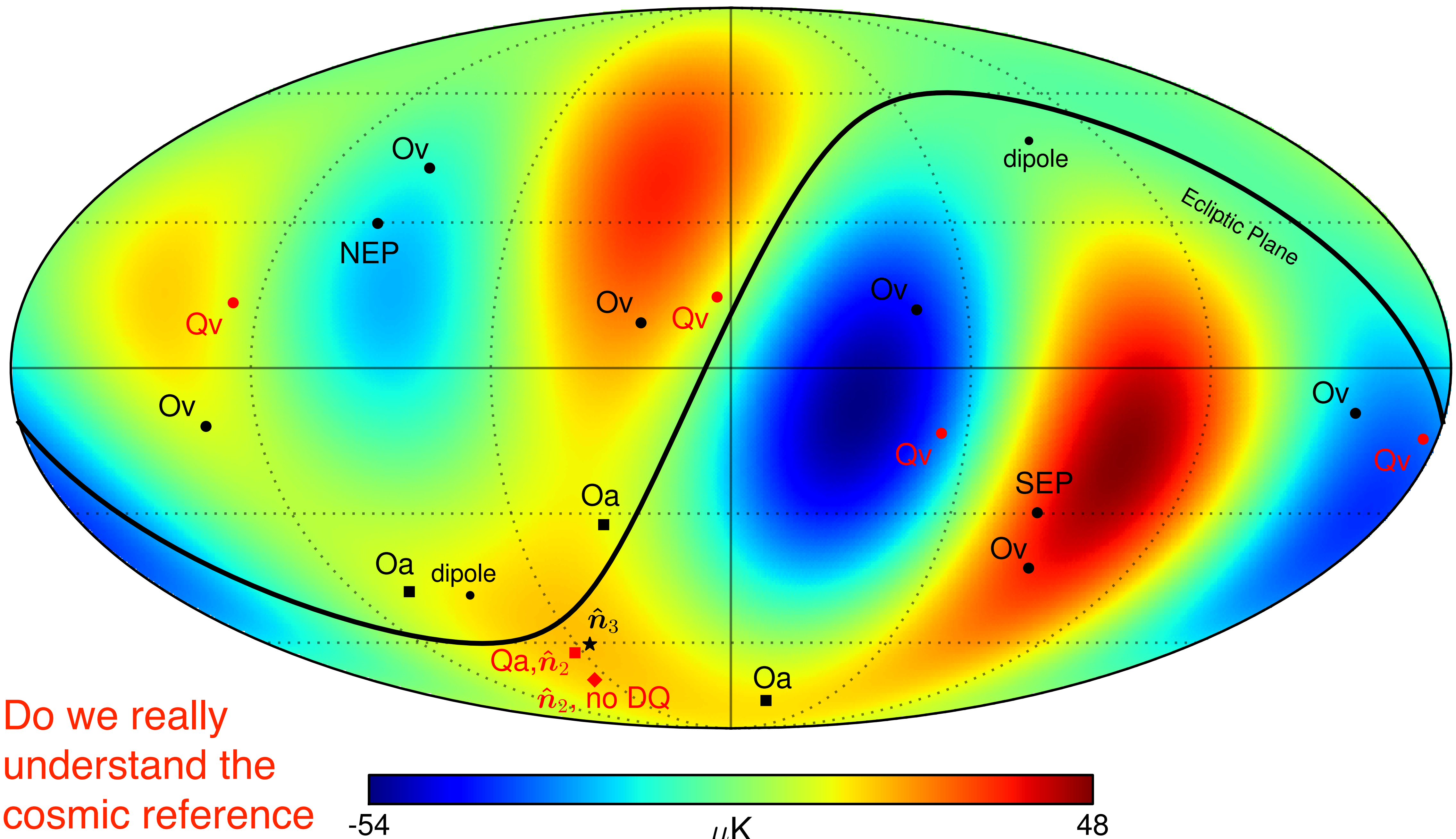
Model extension

Deviation from spatial flatness does not help



Tension at large angles

Alignment of dipole, quadrupole and octopole
and other anomalies at large angular scaled

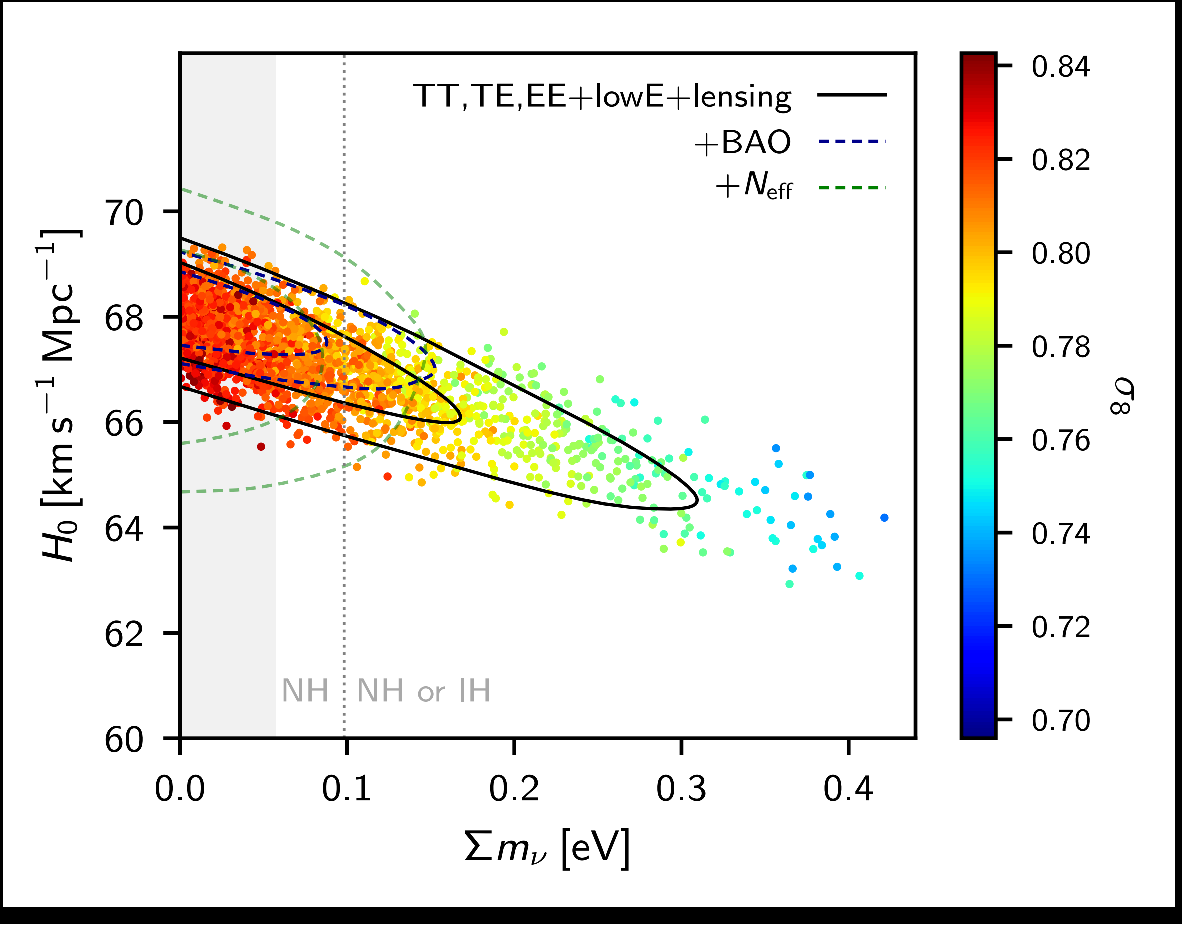


Do we really understand the cosmic reference frame?

Schwarz et al. 2004, Copi et al. 2013

Constraints

Neutrino masses



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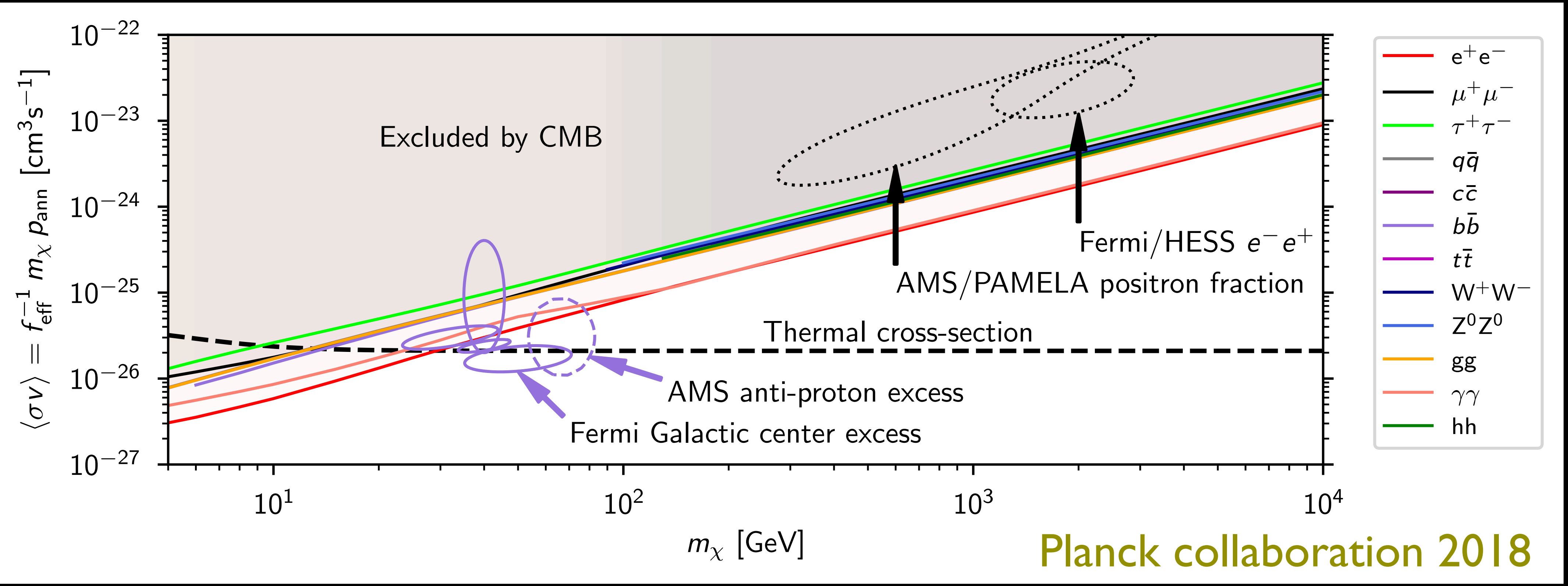
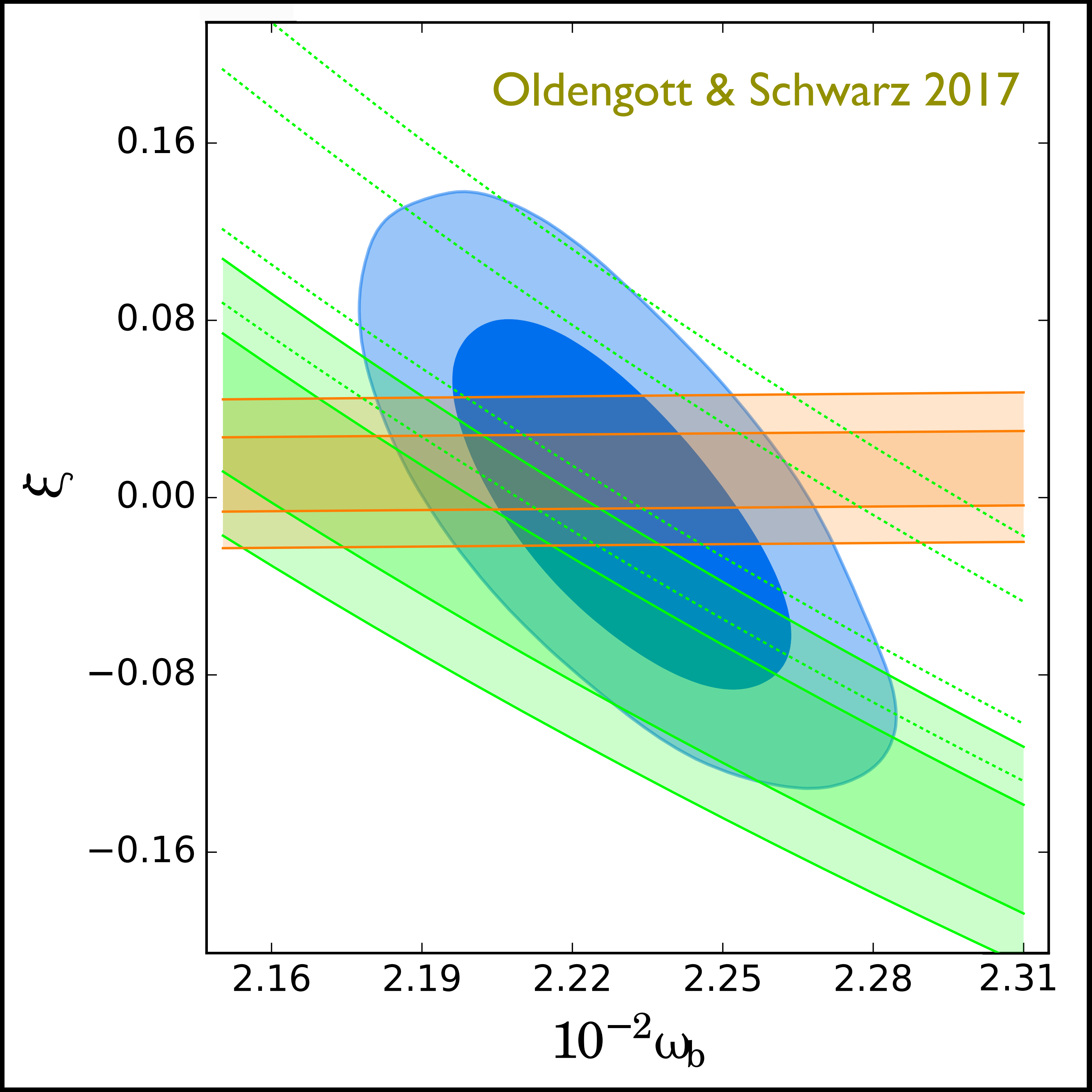
Annihilating DM



Planck collaboration 2018

Constraints

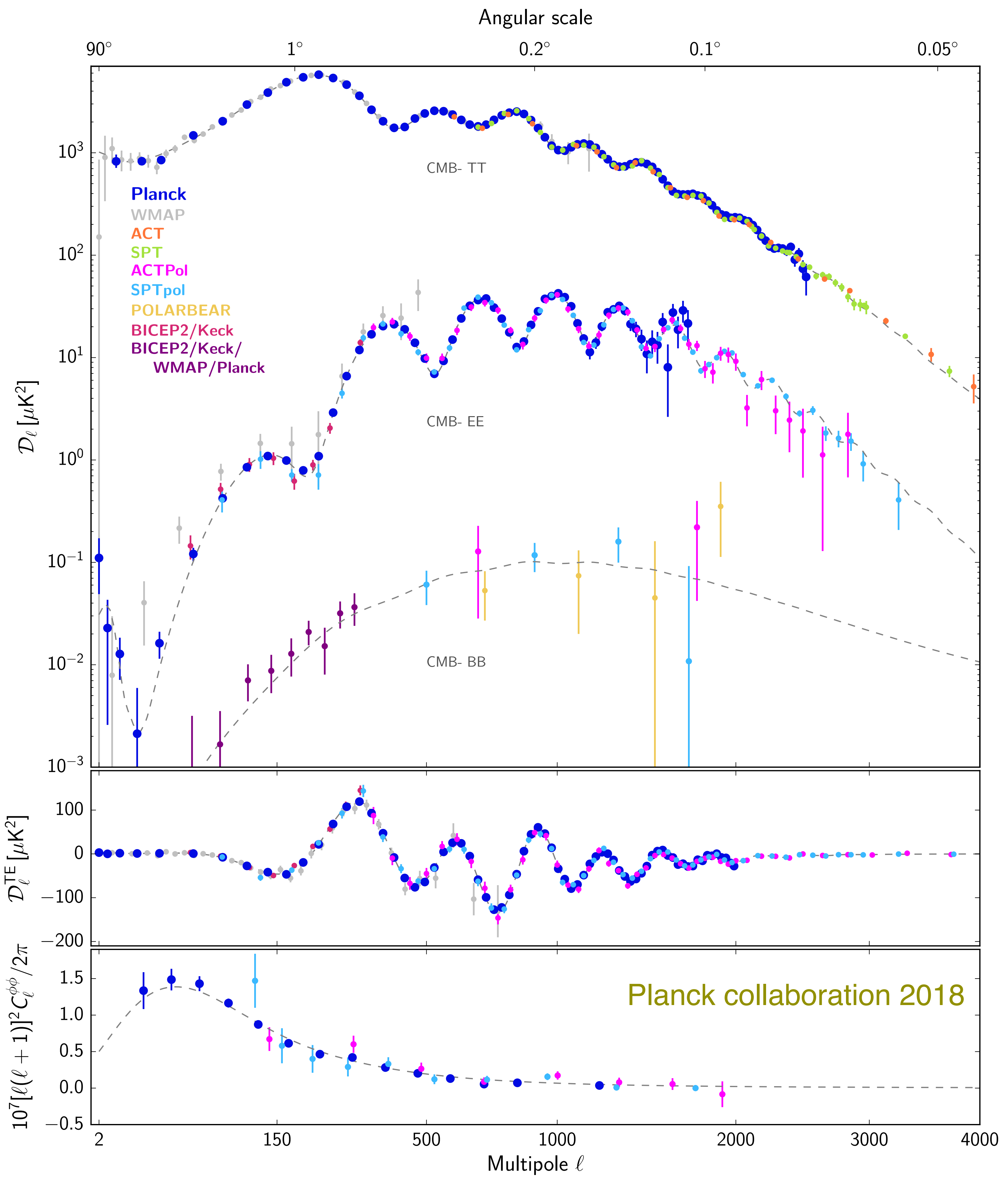
Lepton asymmetry could be much larger than baryon asymmetry = neutrino asymmetry today



limit on lepton asymmetry
blue: Planck 2015 + lensing + self-consistent BBN
orange: He-4
green: D

difference between filled green band and dashed green band is due to systematic uncertainties in nuclear physics data used in BBN codes

progress on probing the early Universe in the BBN epoch is currently limited by nuclear physics data, not by observations



Summary CMB

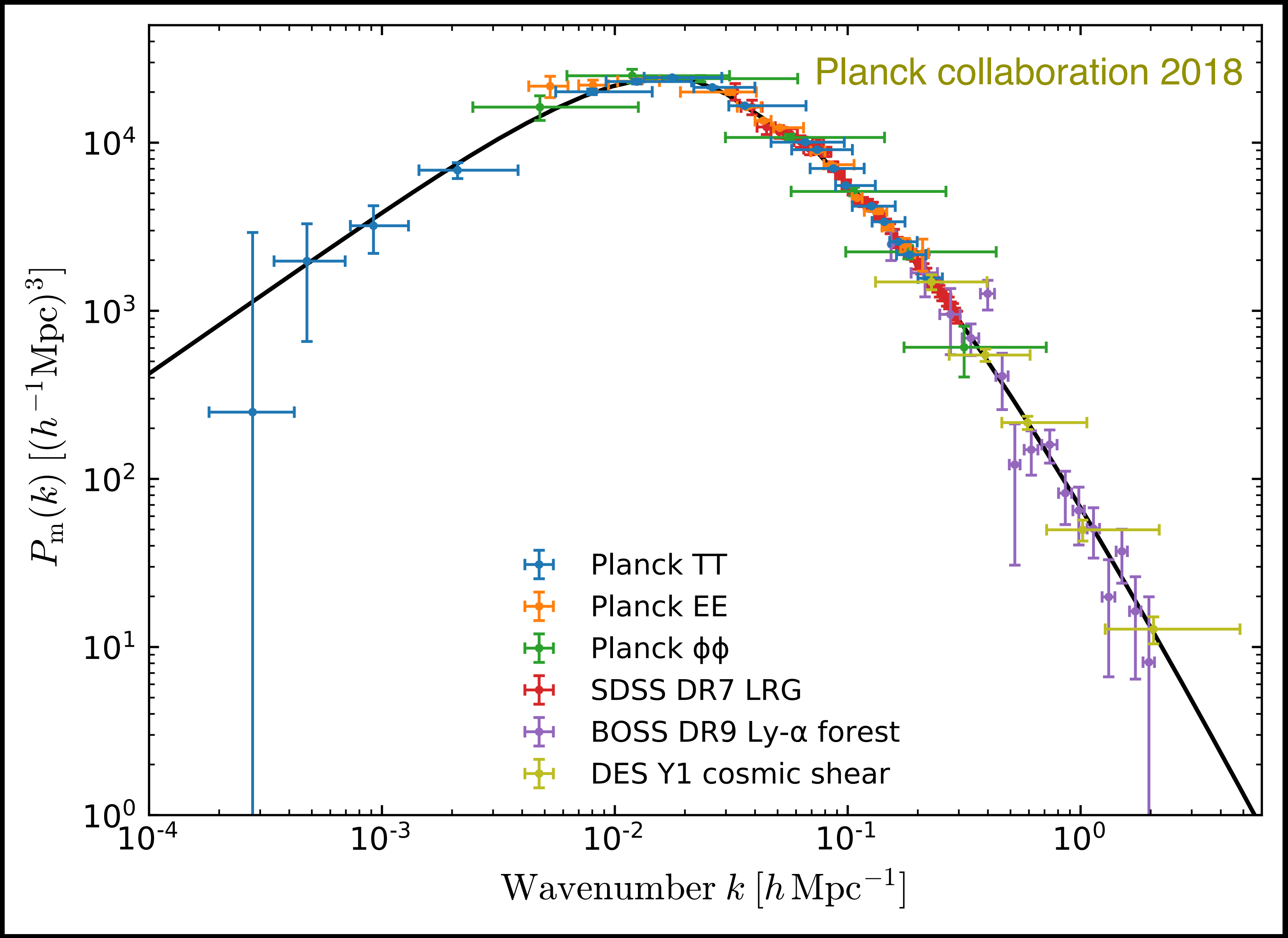
Challenges

➜ E- & B-modes at large angles: space mission

➜ intensity and polarisation on small angles: ground based

➜ foreground studies: radio, sub-mm & IR

Summary
Cosmic LS Structure



Challenges

➜ modelling of non-linear scales

➜ measure largest scales at low redshift ($z < 1$): wide surveys

➜ first galaxies and first supermassive black holes: deep surveys

(Some) Open questions

- ➜ Did Einstein have the final word on gravity?
- ➜ Did inflation happen?
- ➜ Origin of Matter
- ➜ When and how did galactic BHs form?
- ➜ Cosmic Reionisation
- ➜ Cosmic Magnetic Fields
- ➜ Nature of Dark Energy
- ➜ Nature of Dark Matter
- ➜ Role of Neutrinos
- ➜ What is Life and when and how did it appear?

How to make progress?

➜ Steady progress in theory & observation

➜ Polarised CMB

➜ 3d structure

➜ New probes:

HI intensity mapping & real time cosmology

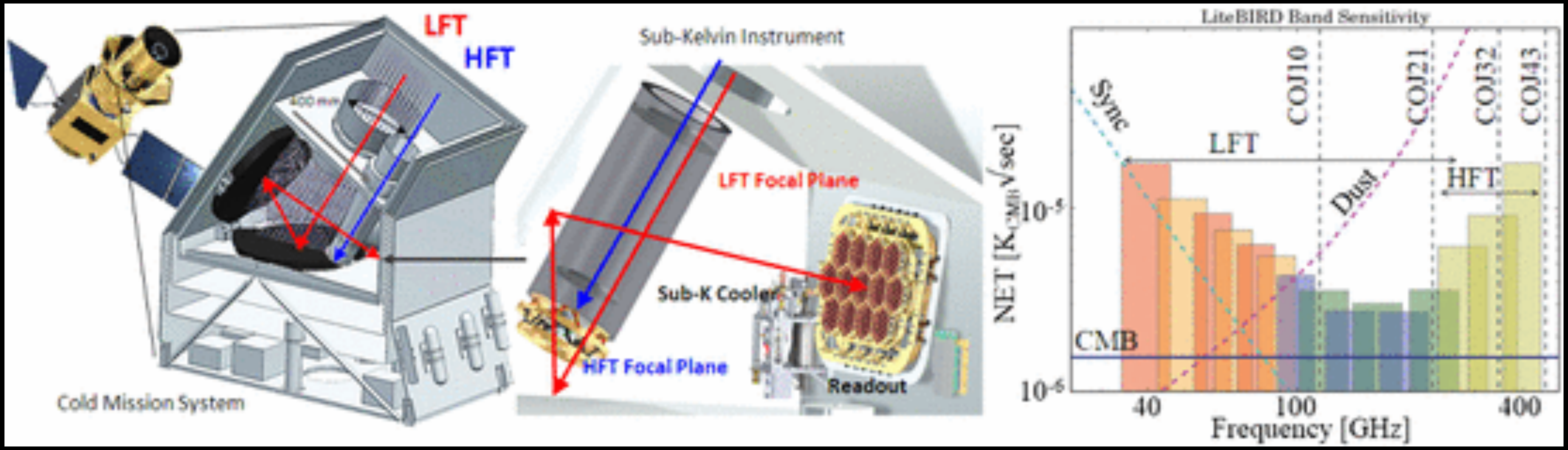
➜ Multi-frequency & multi-messenger cosmology

➜ Measure cosmological parameters &

Test the fundamental assumptions

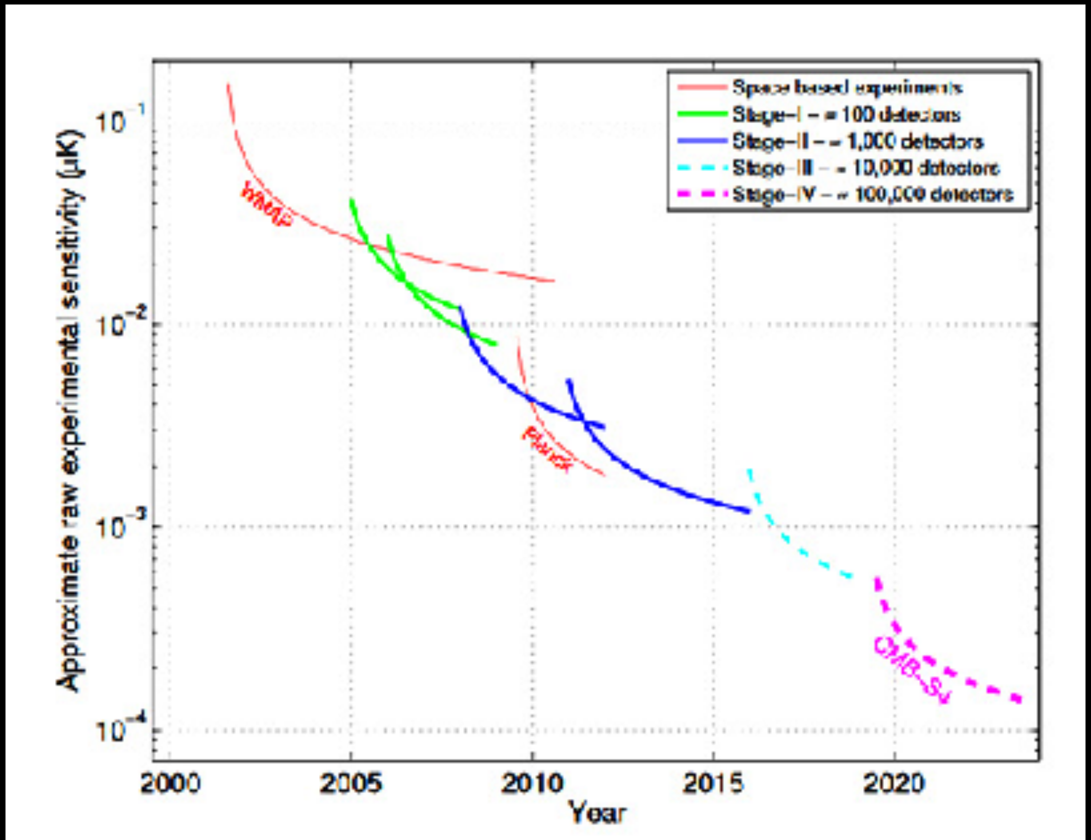
Plans for the CMB

LiteBIRD:

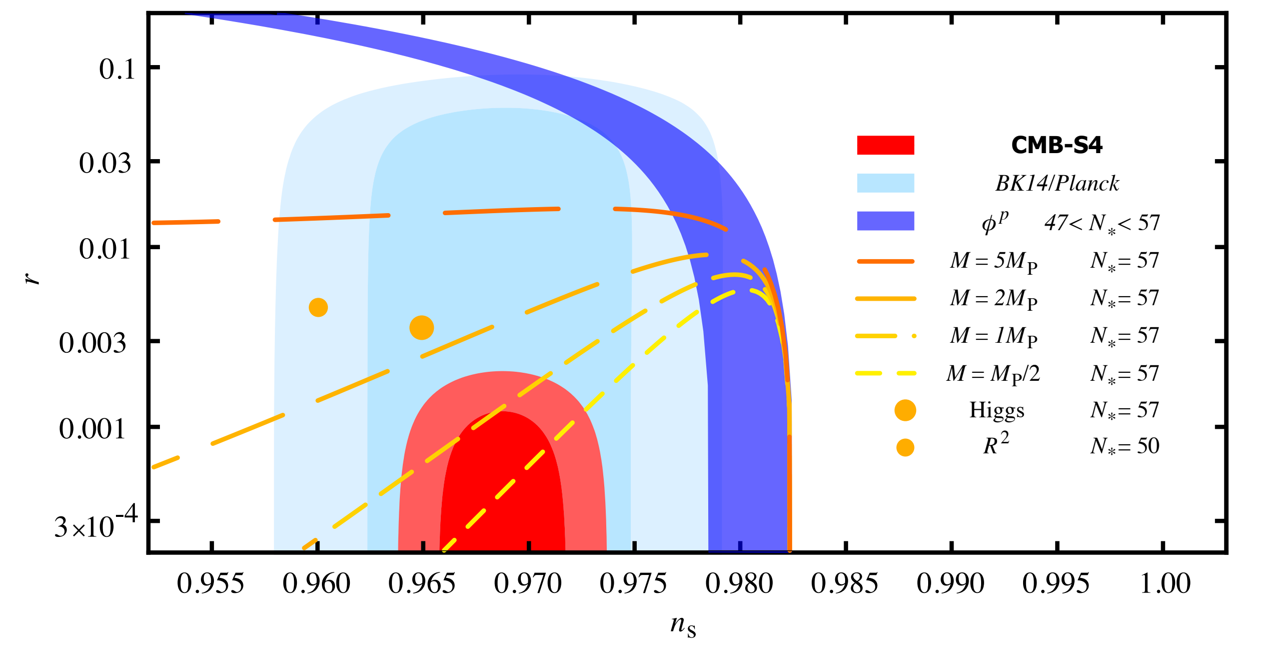


SPT
CCAT-p

CMB-S4

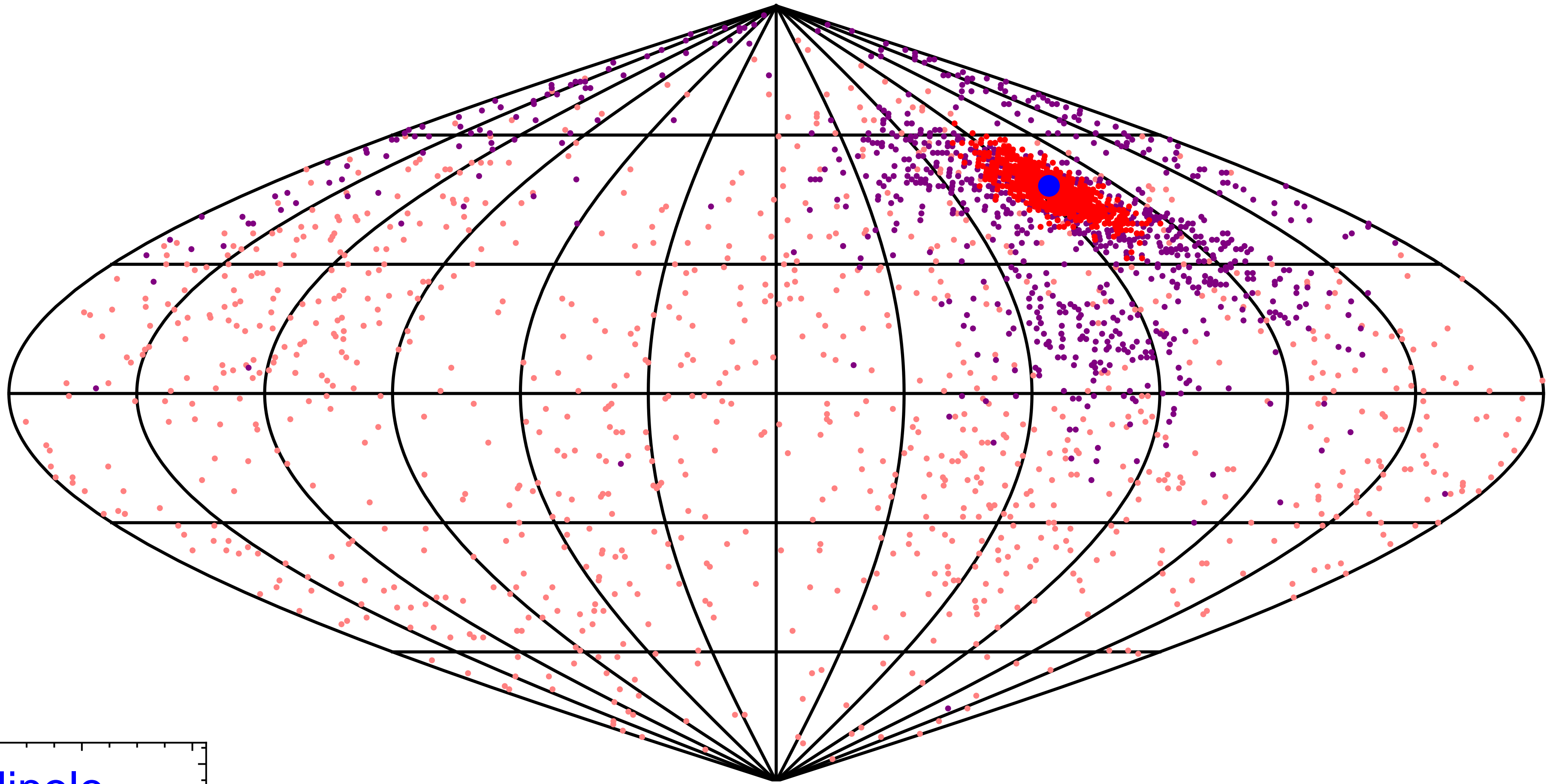


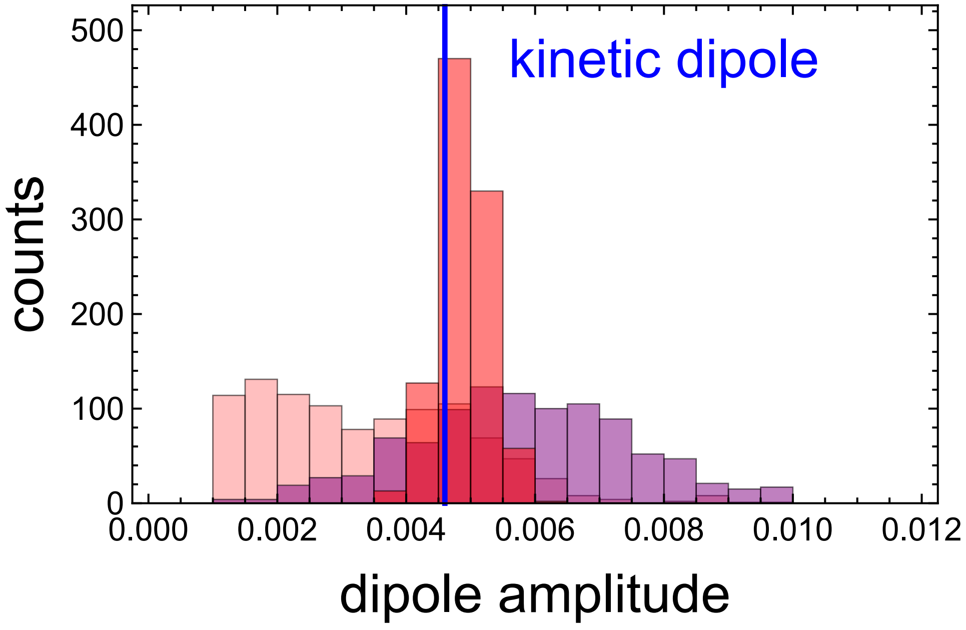
Measure or constrain scale of inflation



Test foundations: SKA

- CMB dipole
- structure dipole
- kinematic & structure dipole
- kinematic & structure dipole, w/o local structure

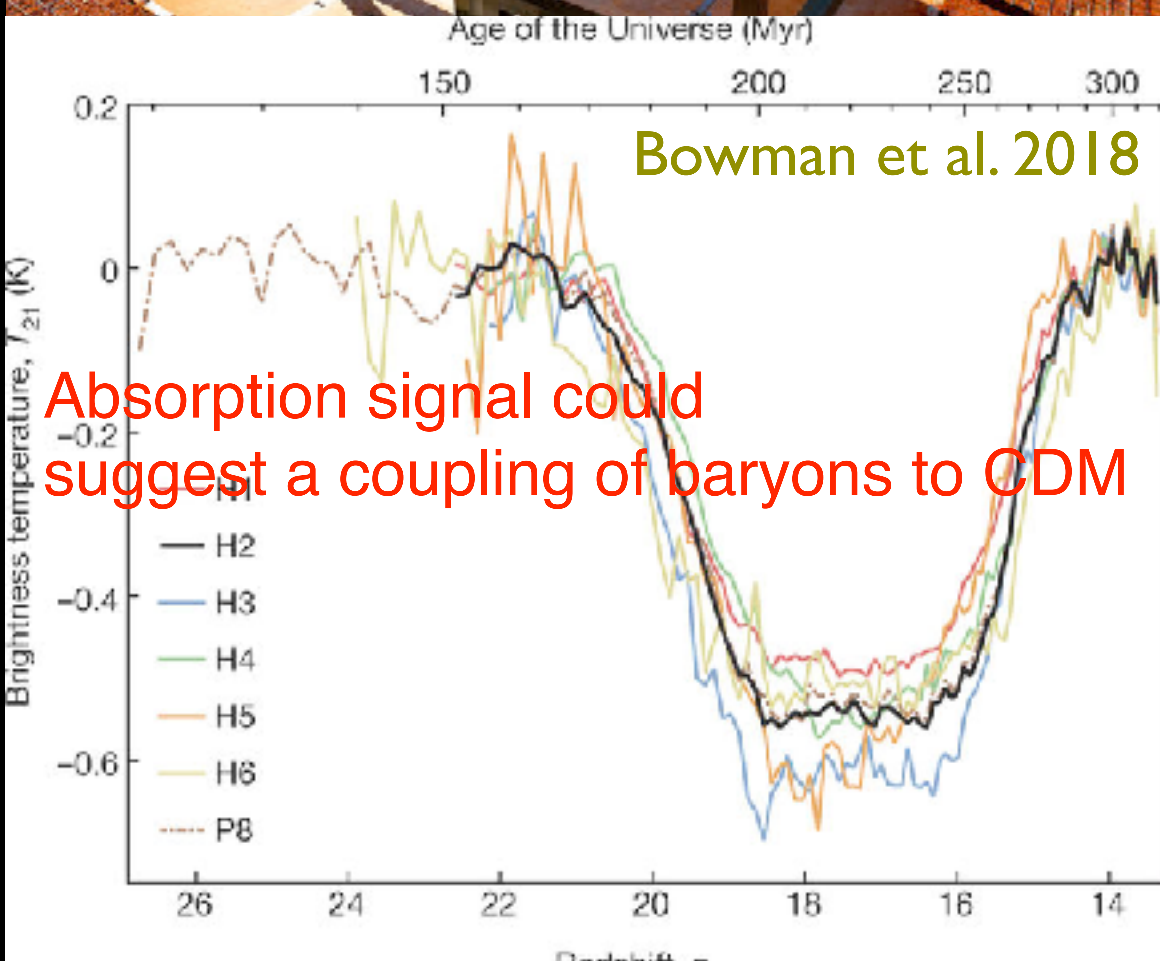




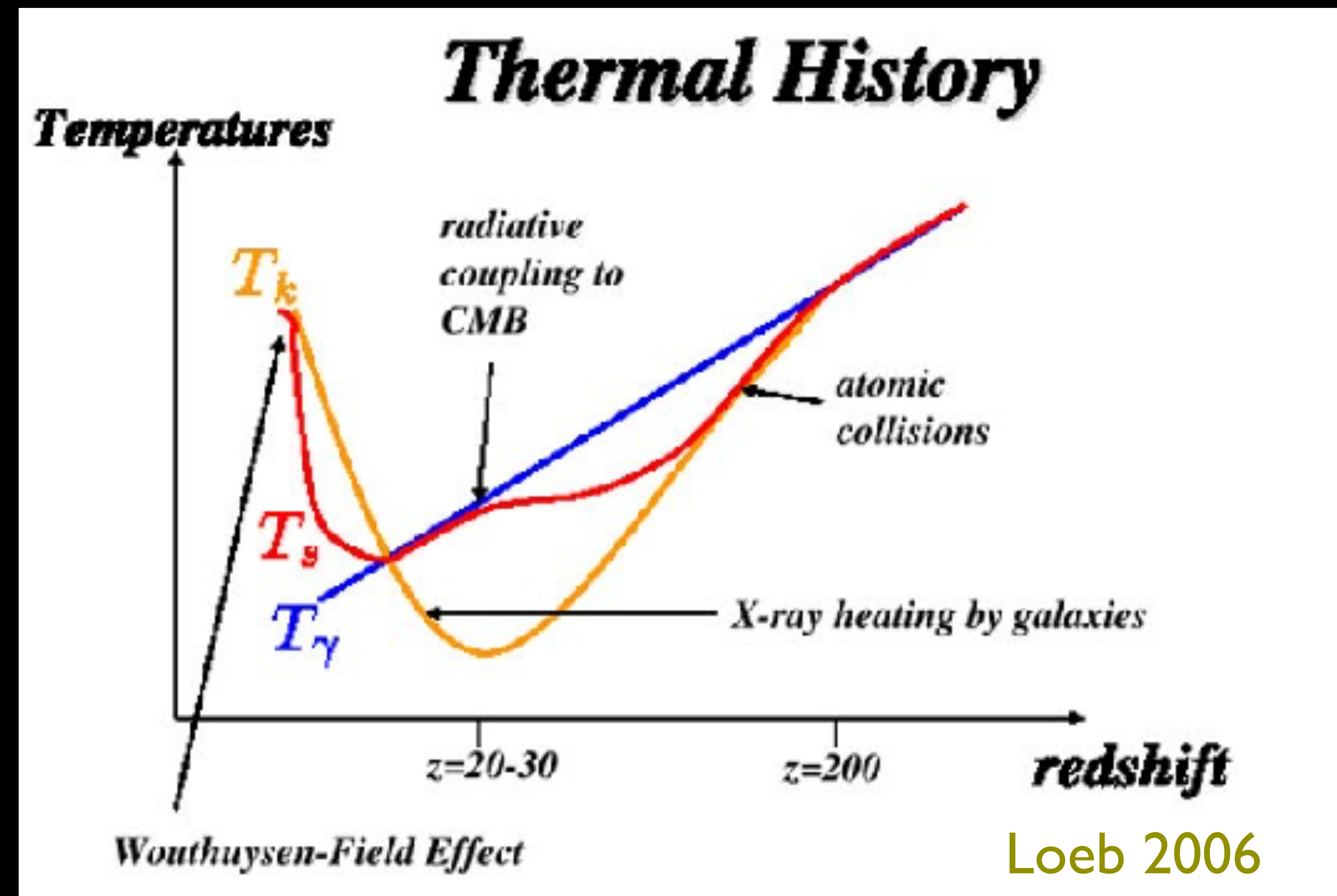
SKA-Mid band 1 wide survey with lower flux density threshold of 20 μJy
local structure: $z < 0.5$

SKA Red Book, in prep.

Unexpected EDGES



Absorption signal could suggest a coupling of baryons to CDM



MNRAS 000, 1–17 (2015) Preprint 19 September 2018 Compiled using MNRAS LaTeX style file v3.0

TODAY ON arXiv: Probe the COSMIC DAWN

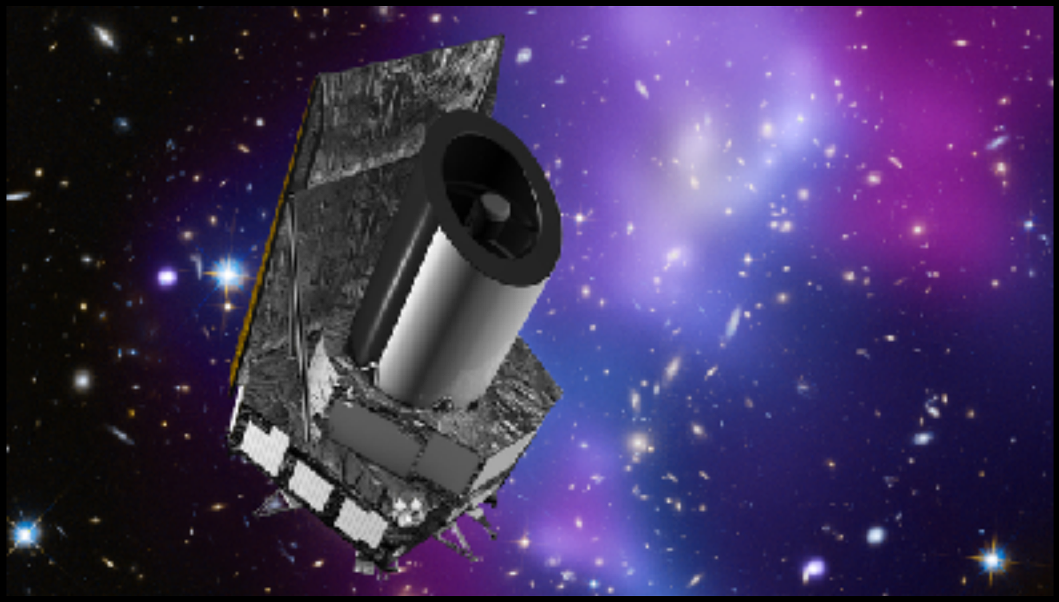
The first power spectrum limit on the 21-cm signal of neutral hydrogen during the Cosmic Dawn at $z = 20 - 25$ from LOFAR

B. K. Gehlot[1*], F. G. Mertens[1], L. V. E. Koopmans[1†], M. A. Brentjens[2], S. Zaroubi[1,3], B. Ciardi[4], A. Ghosh[5,6], M. Hatef[1,2], I. T. Iliev[7], V. Jelić[8], R. Kooistra[1], F. Krause[1,9], M. Mitra[1], M. Mevius[2], G. Mellema[10], A. R. Offringa[2], V. N. Pandey[1,2], M. B. Silva[1], J. Schaye[11], A. M. Sardarabadi[1], H. K. Vedantham[2], and S. Yatawatta[1,2]

Major Space Missions

Gaia

Euclid



eROSITA

James Webb Space Telescope

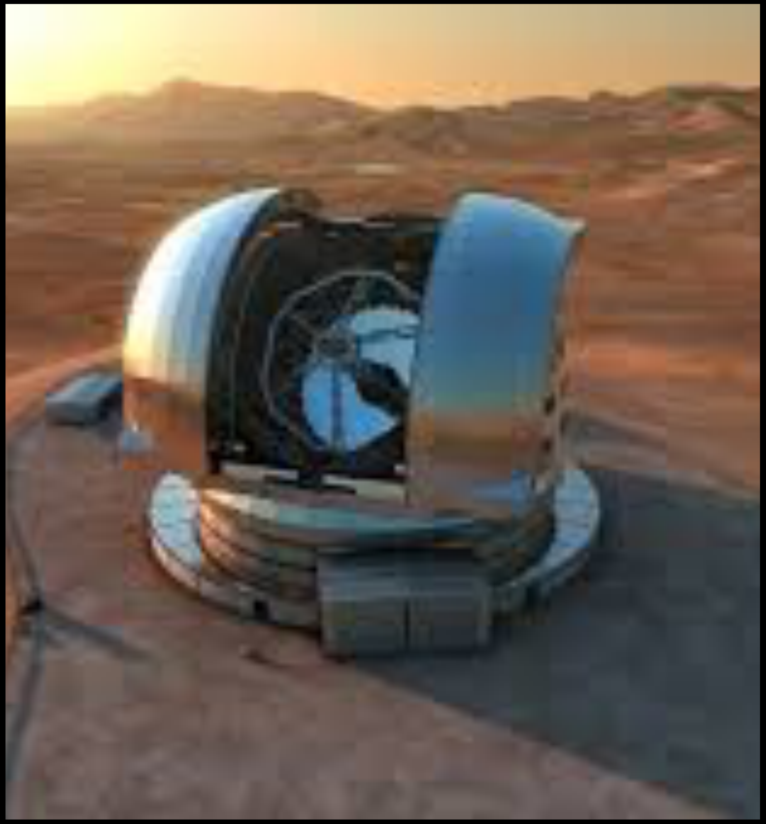
Major Ground Observatories

LOFAR/LOFAR2.0:

ALMA:

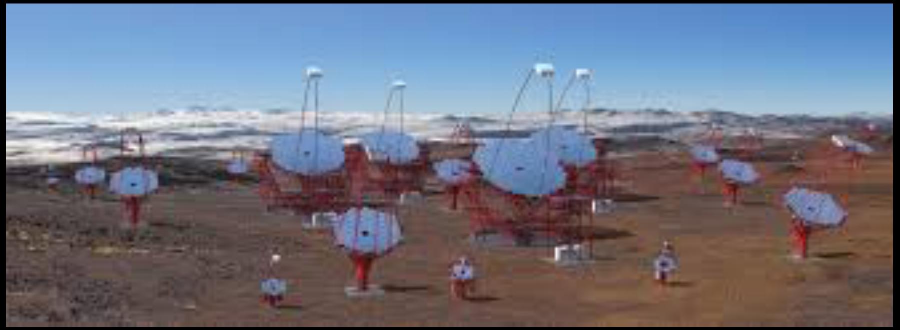
MeerKAT/SKA (Low & Mid):

ELT:



LSST:

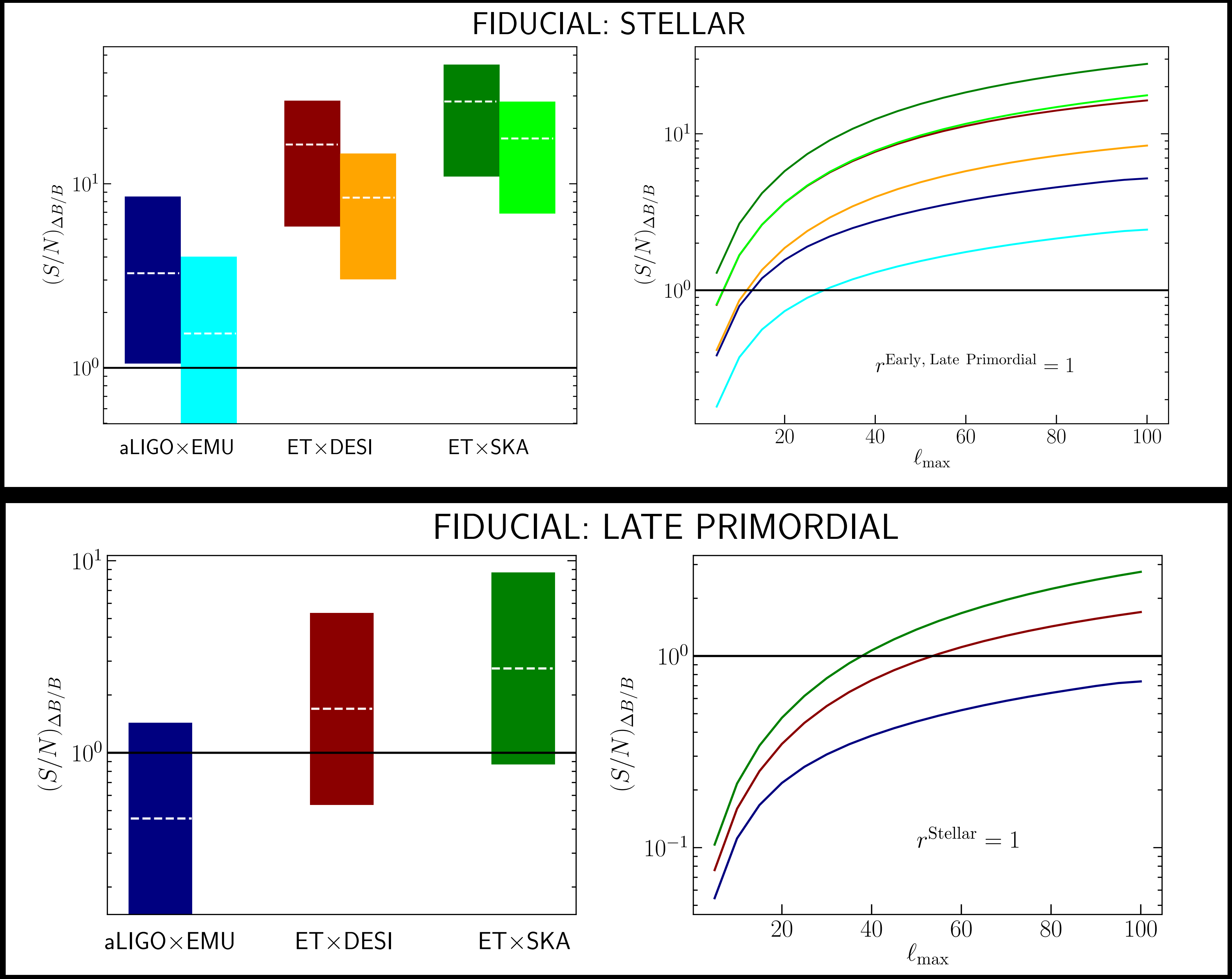
CTA:



Synergies: example

Large-scale structure surveys and gravitational wave observatories:
Origin of black holes — stellar or primordial ?

Scelfo et al. 2018



Conclusions

- Inflation & ΛCDM: excellent global fit
- Tensions at ~3σ:
  H_0 (local vs. global or early vs. late) and
  large scale anomalies

- Nature of Dark Matter & Dark Energy
- Origin of Matter
- Scale and Mechanism of Inflation

- History of Reionization
- History of Cosmic Magnetism
- Formation of galactic BHs

Expect the Unexpected