DESY Theory Workshop 2017, 27.09.2017

Planck results and connection with particle physics

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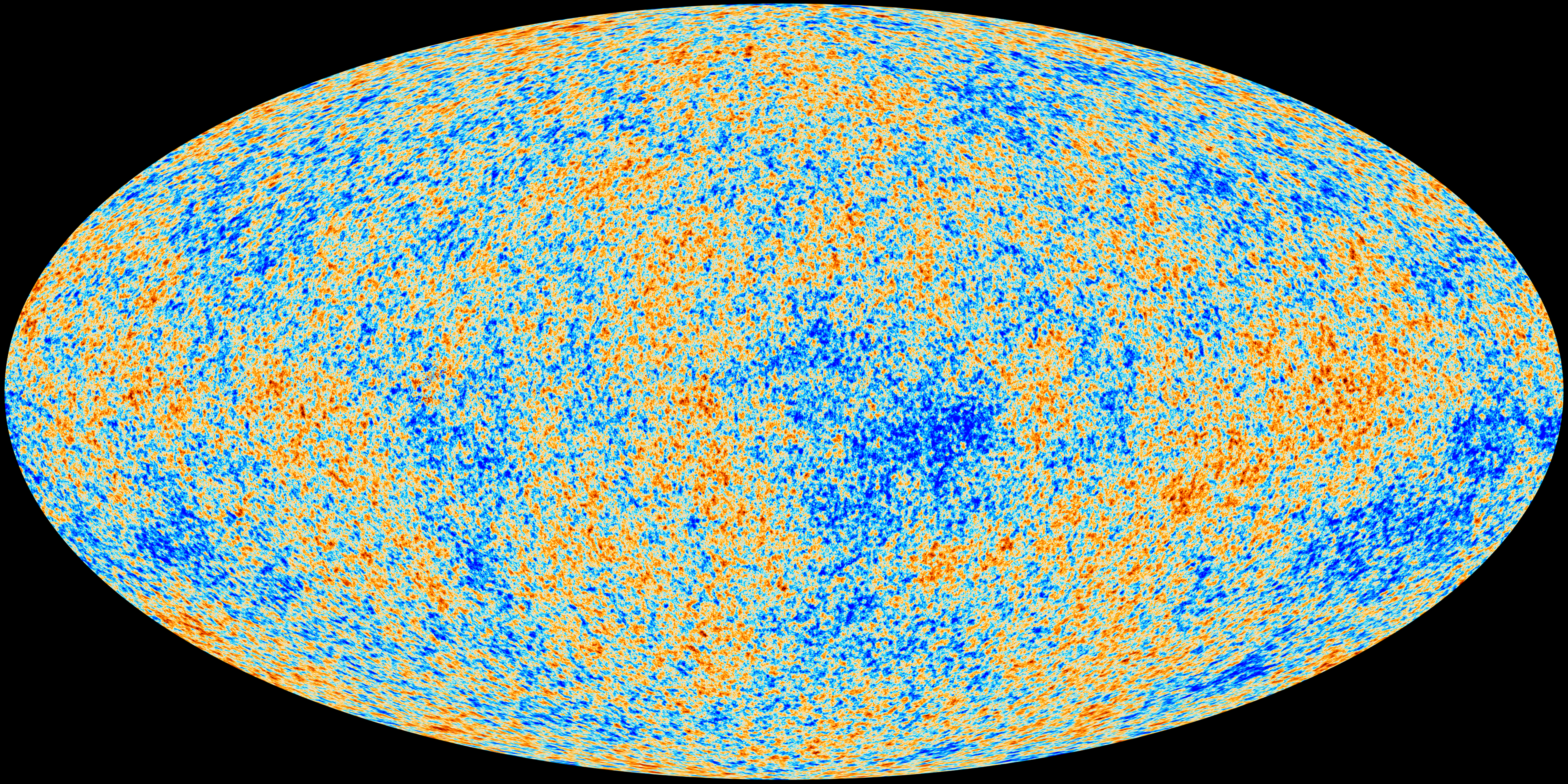
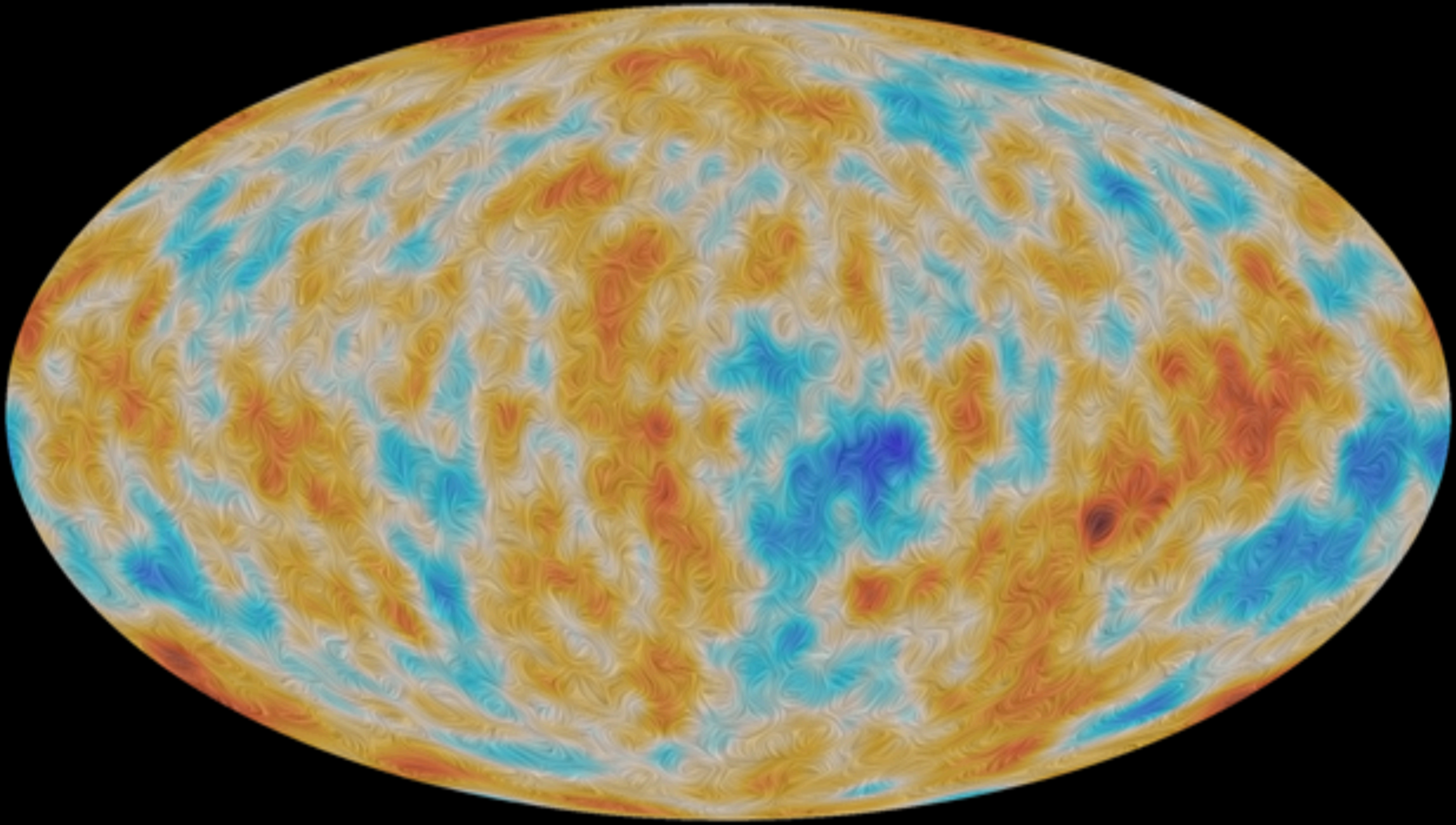
Three main observables



Three main observables



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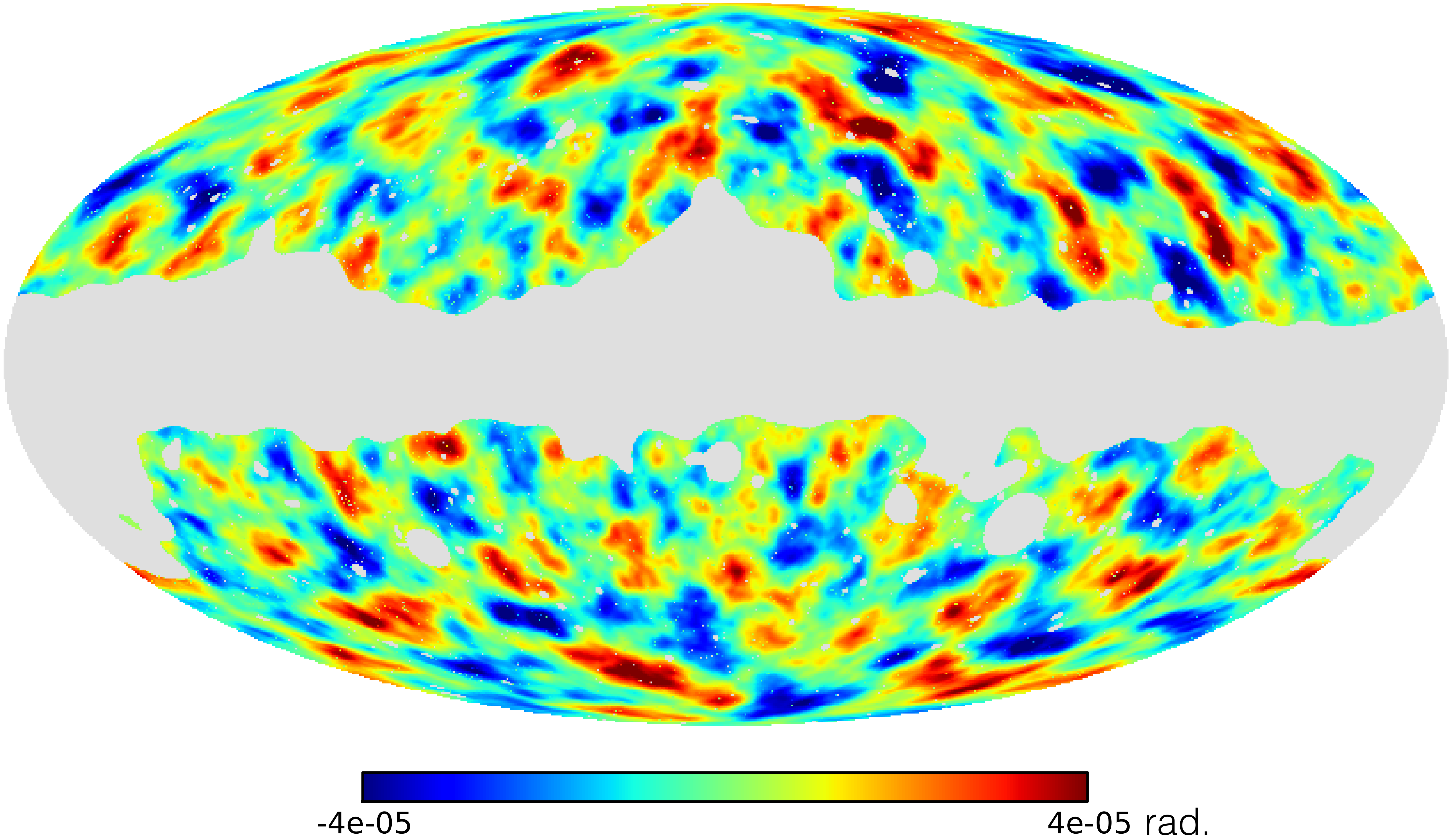
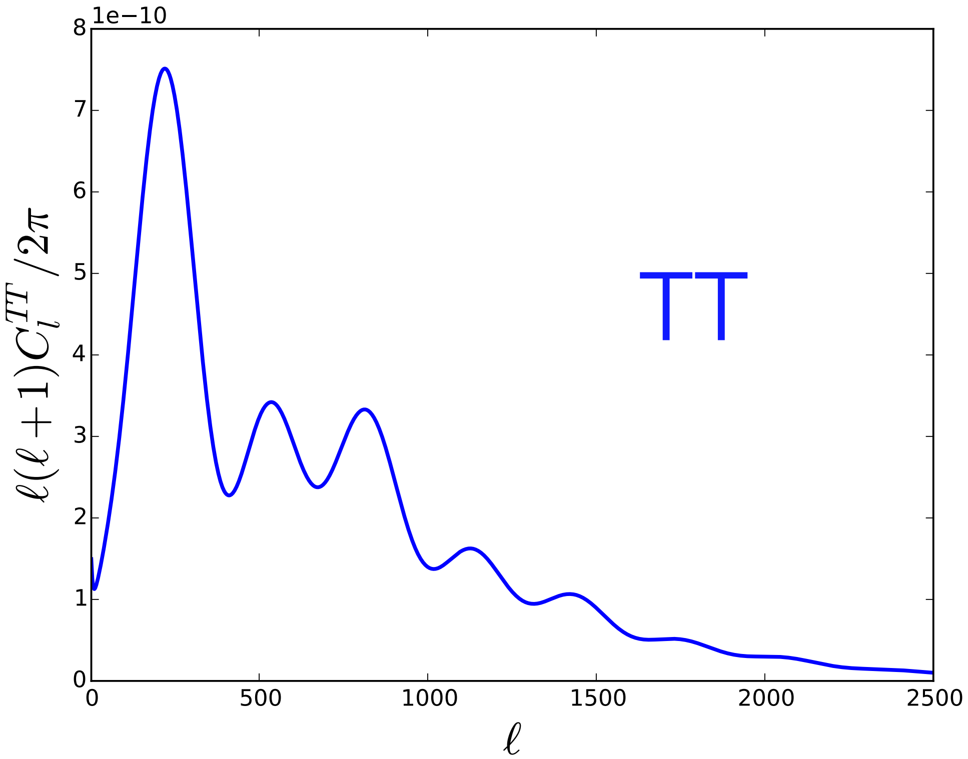
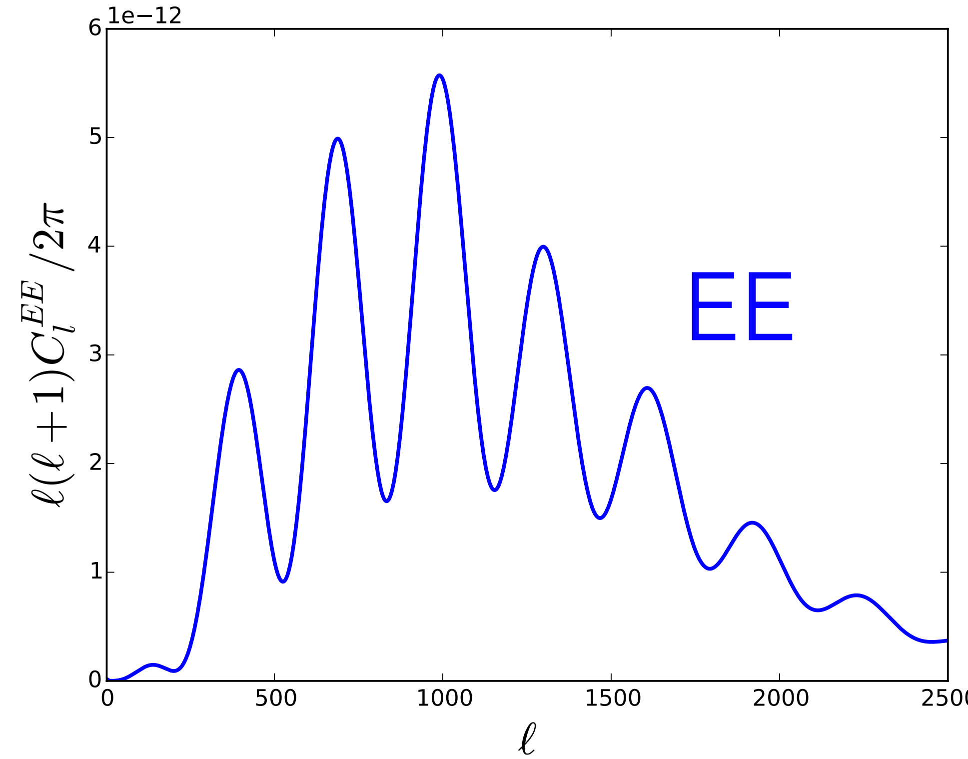
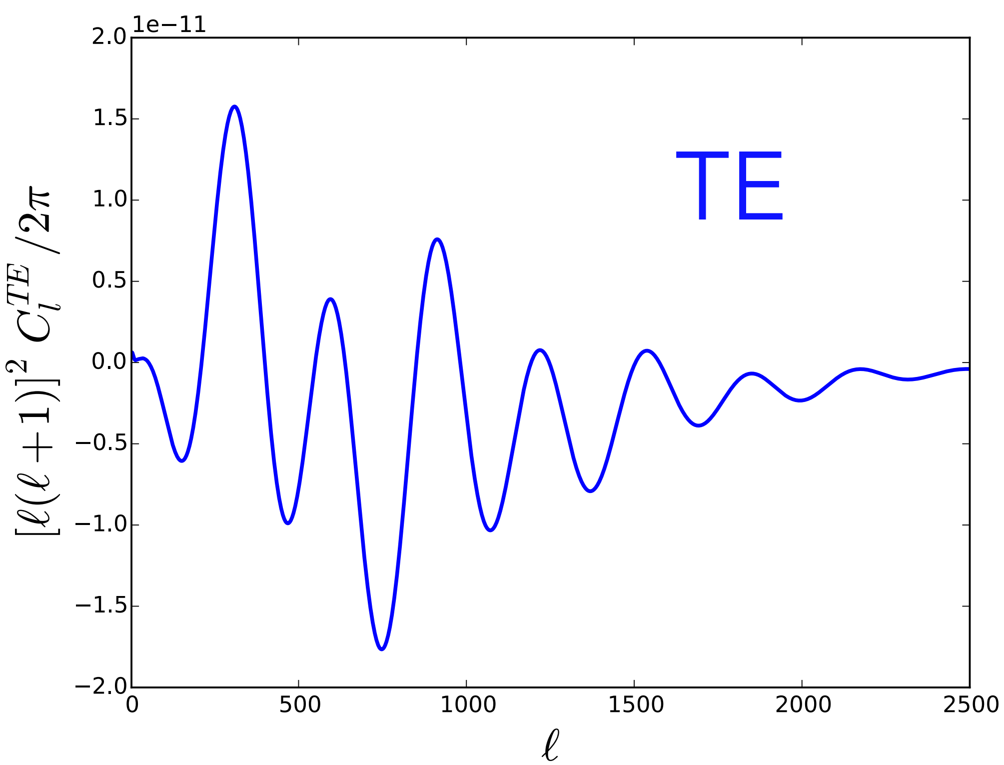
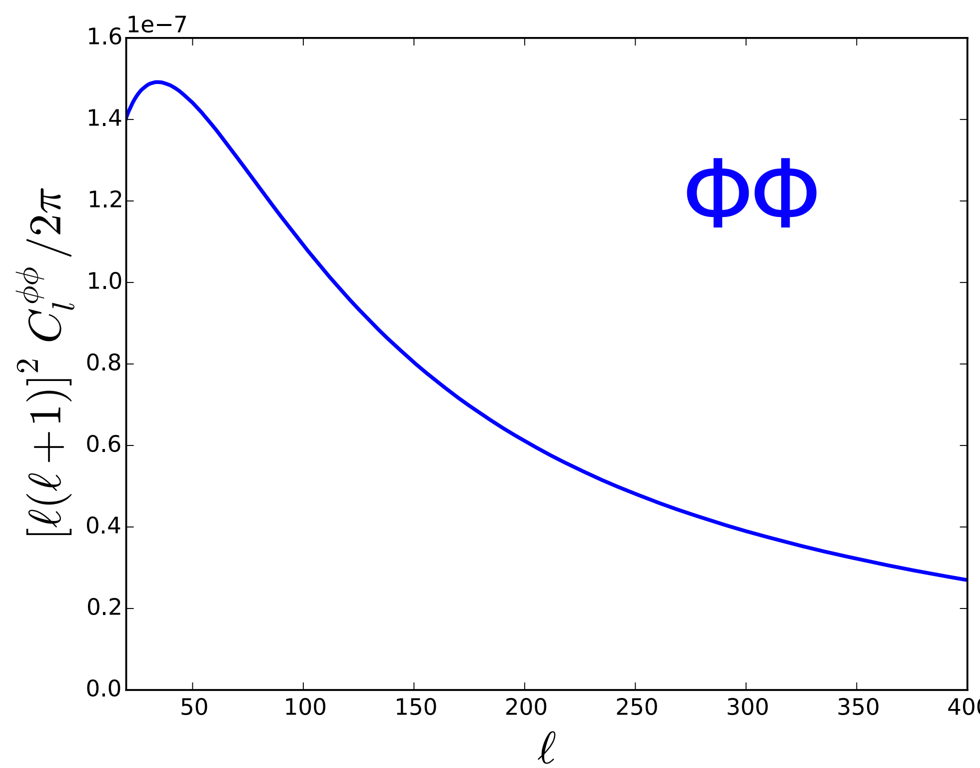


Four two-point correlation functions









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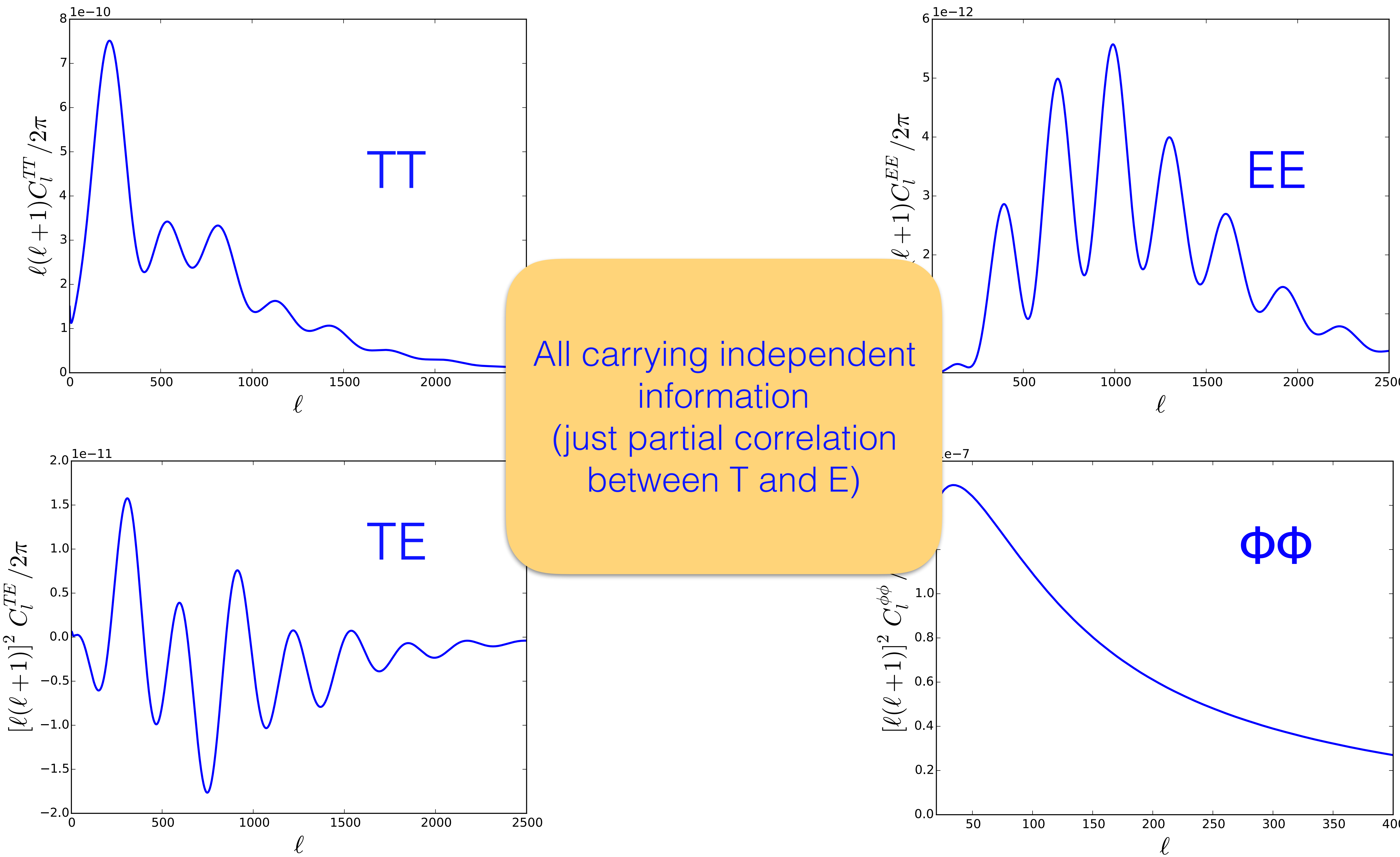
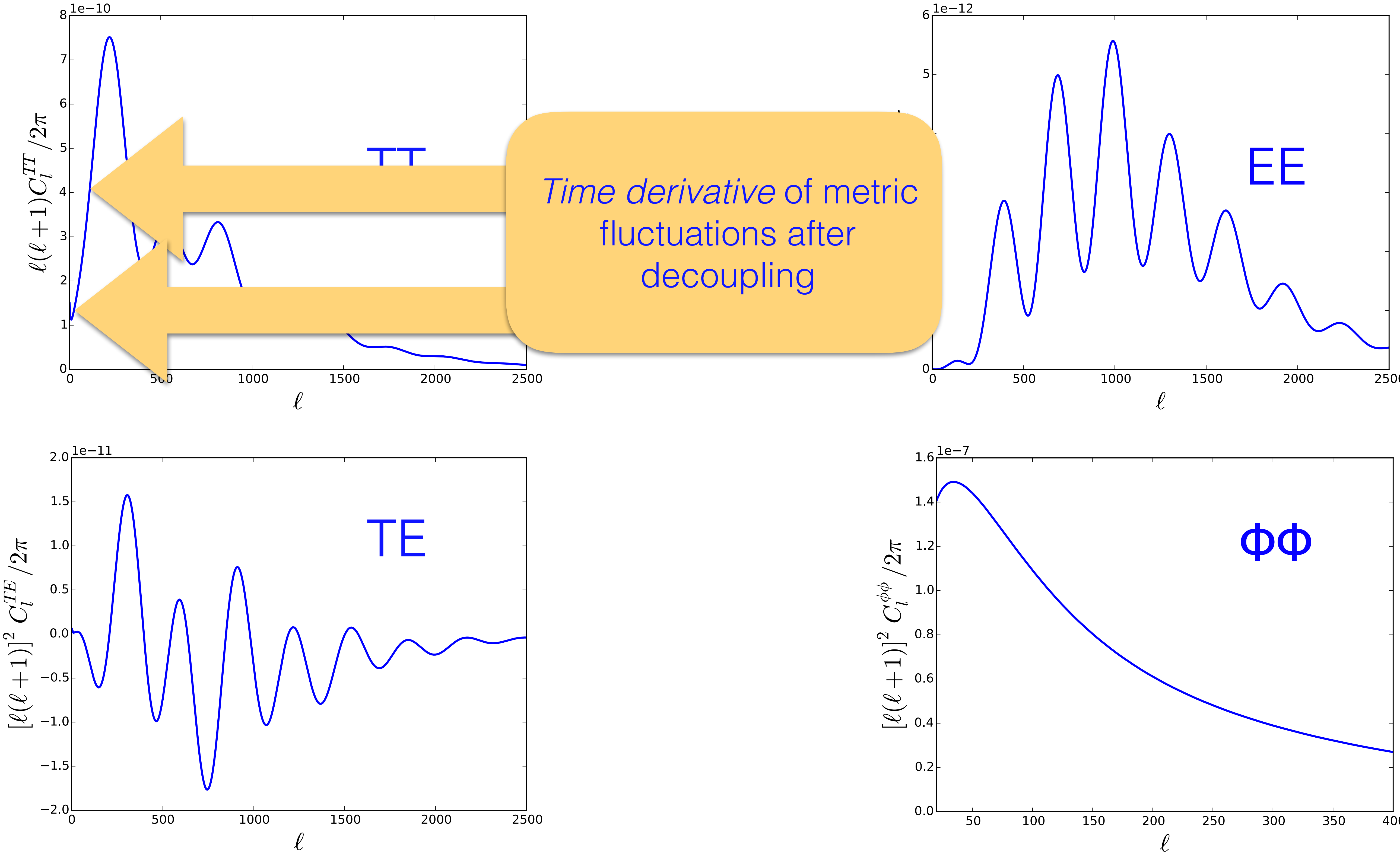


All carrying independent information
(just partial correlation between T and E)

Four two-point correlation functions



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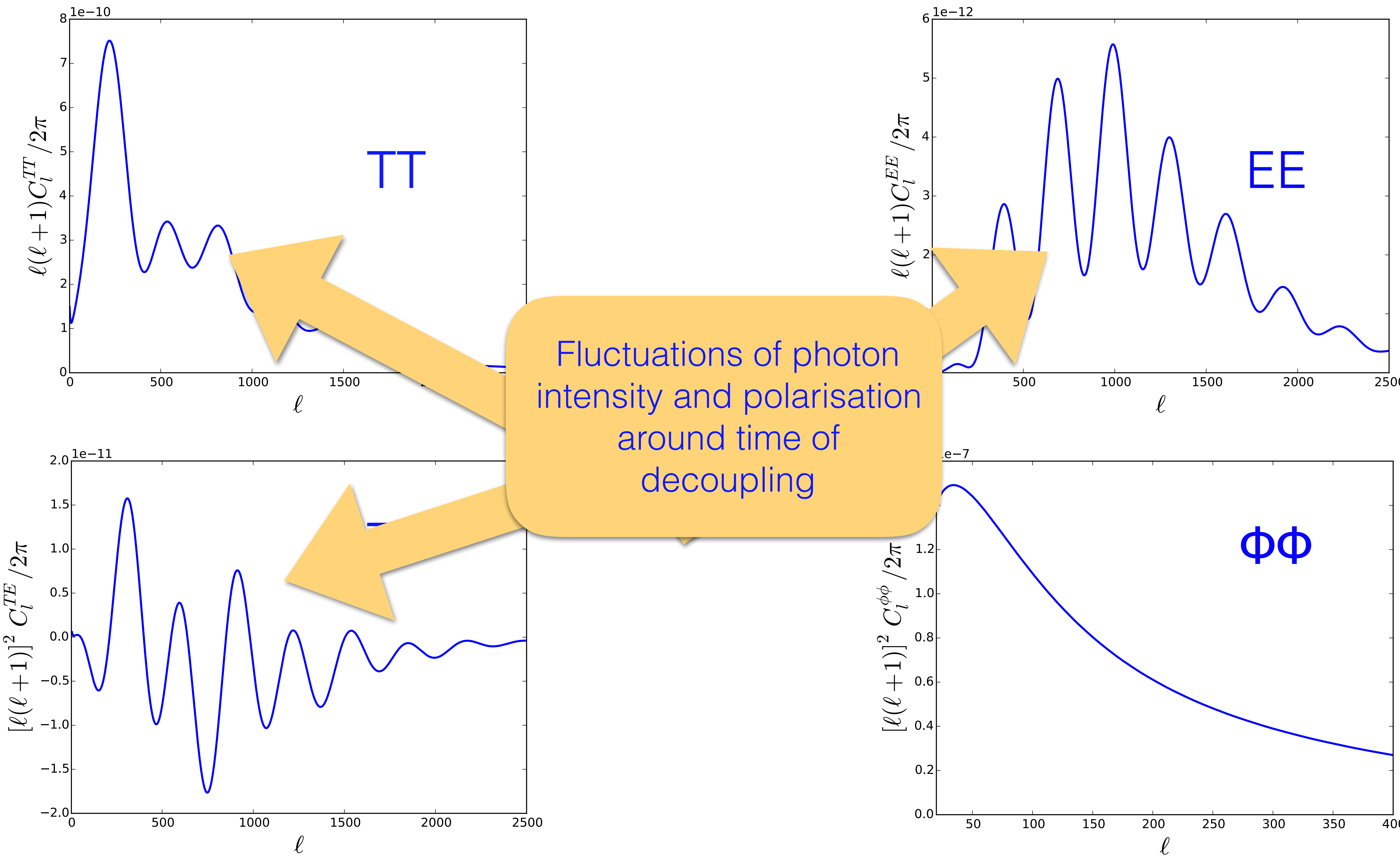

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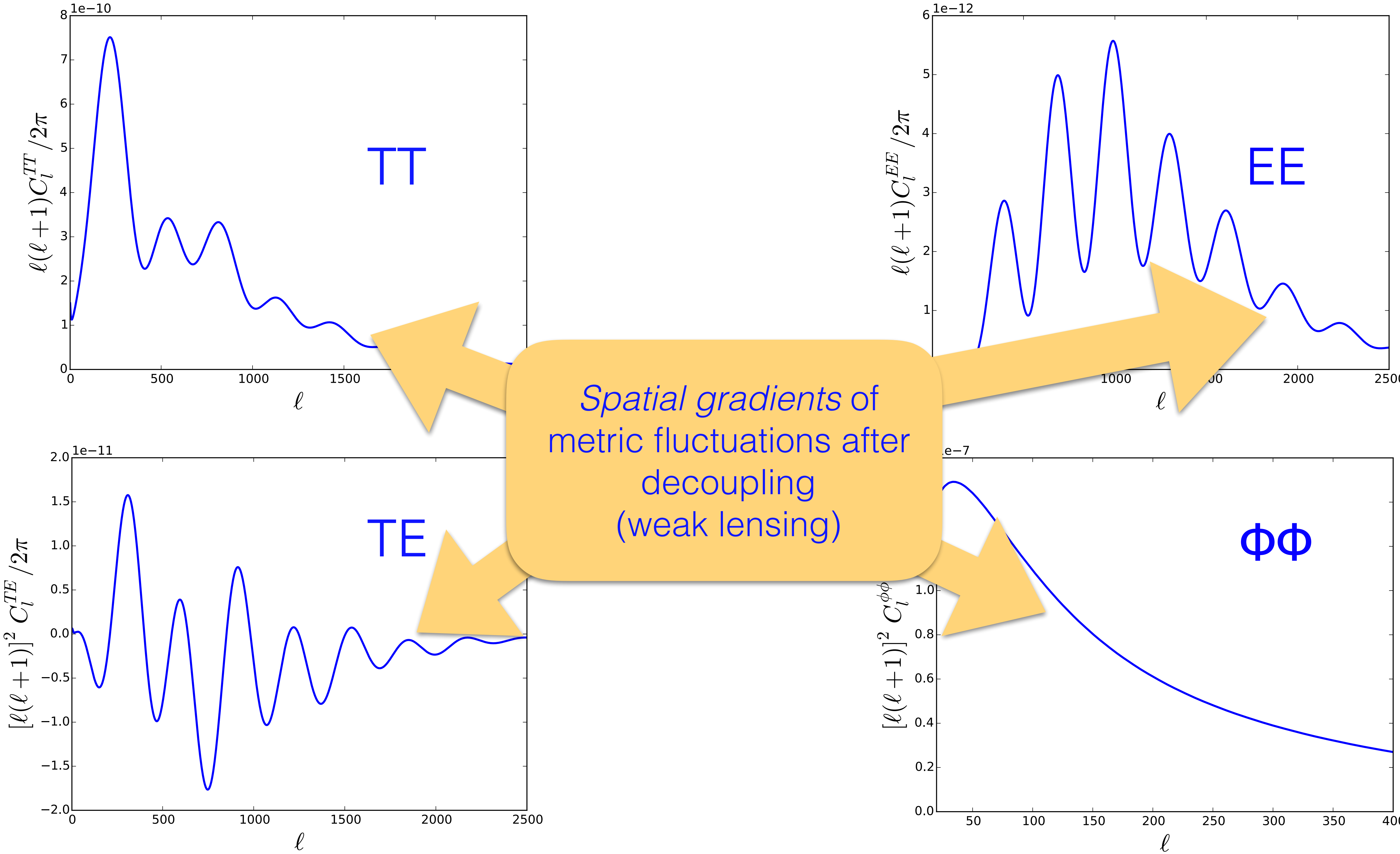

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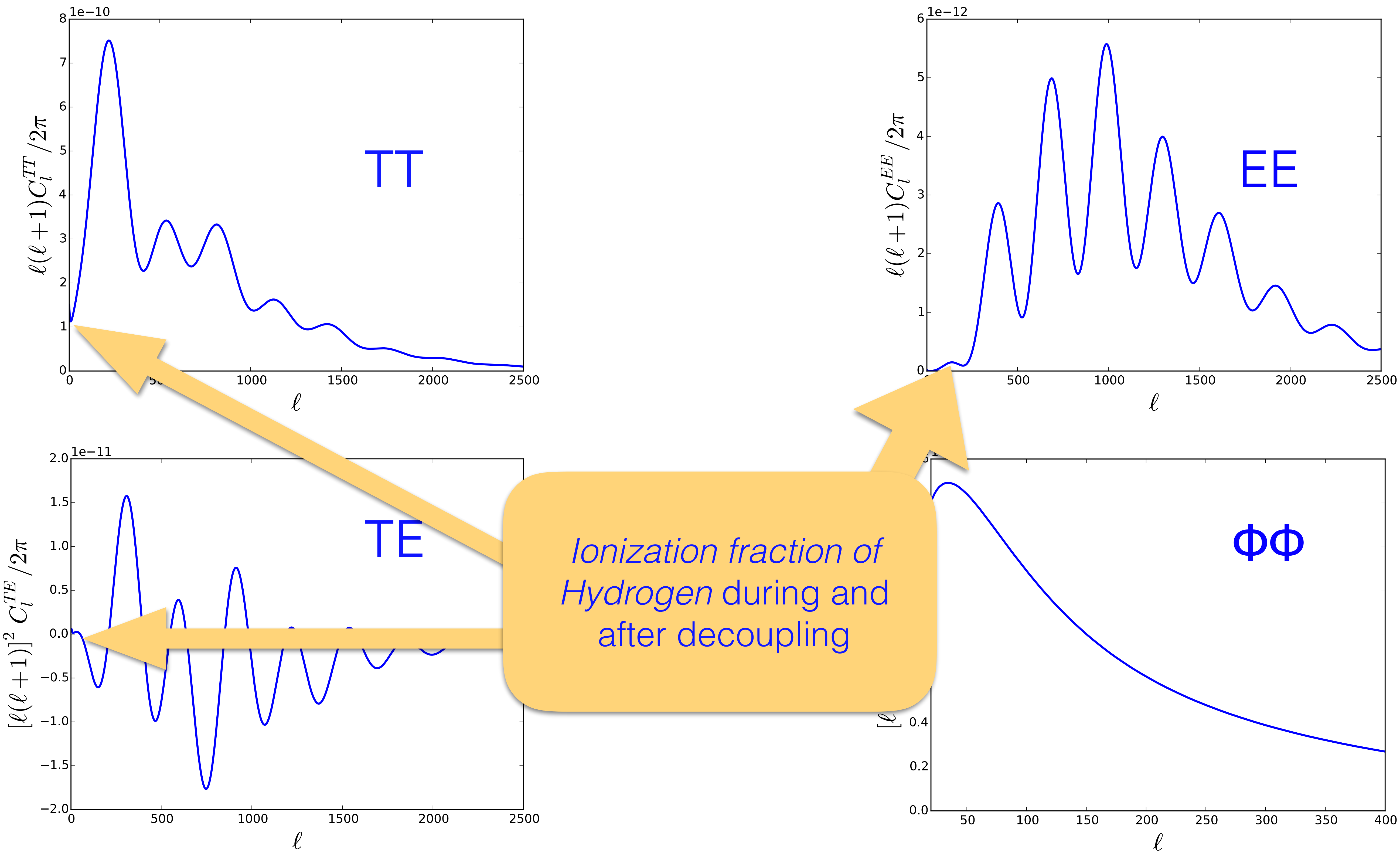

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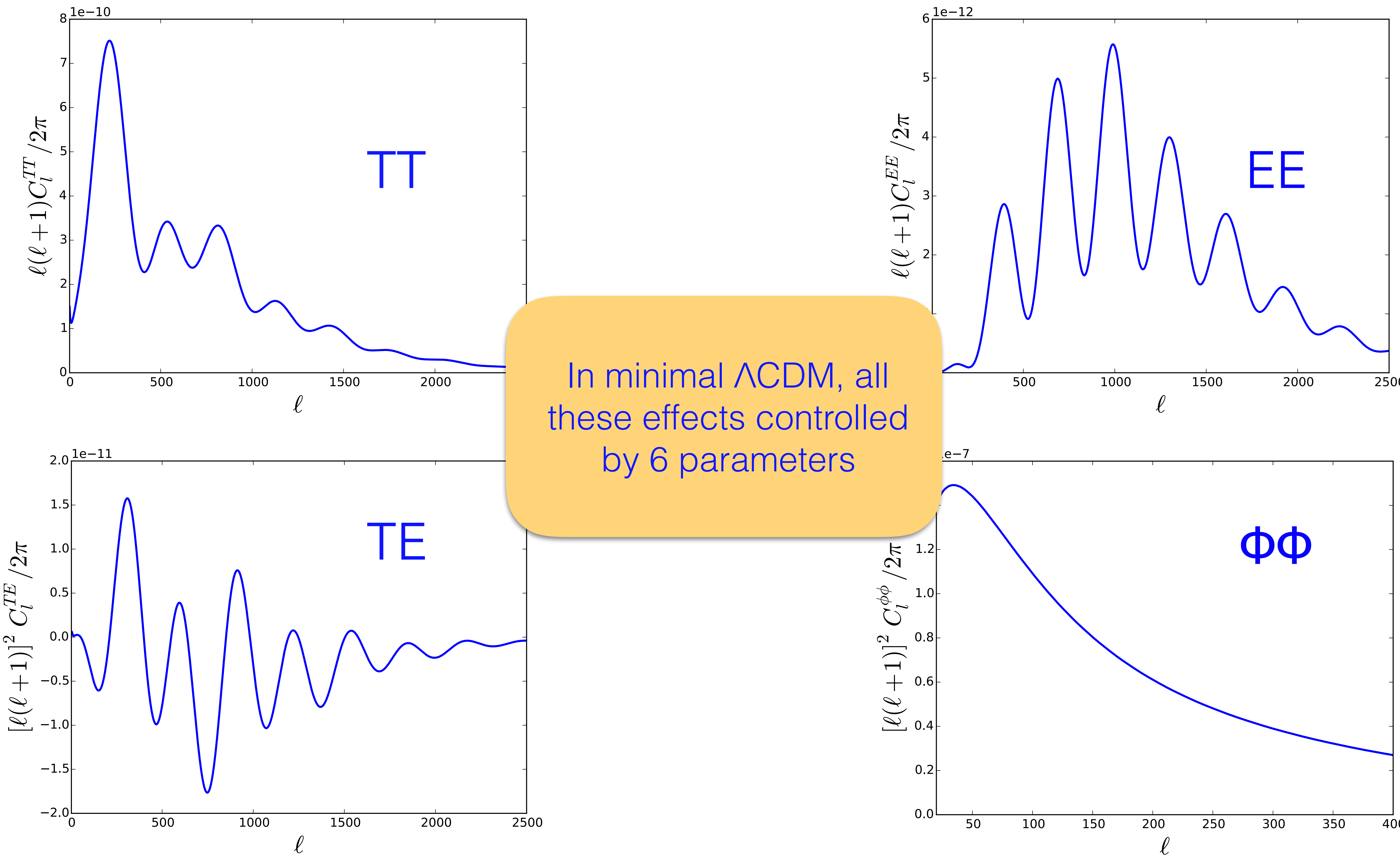
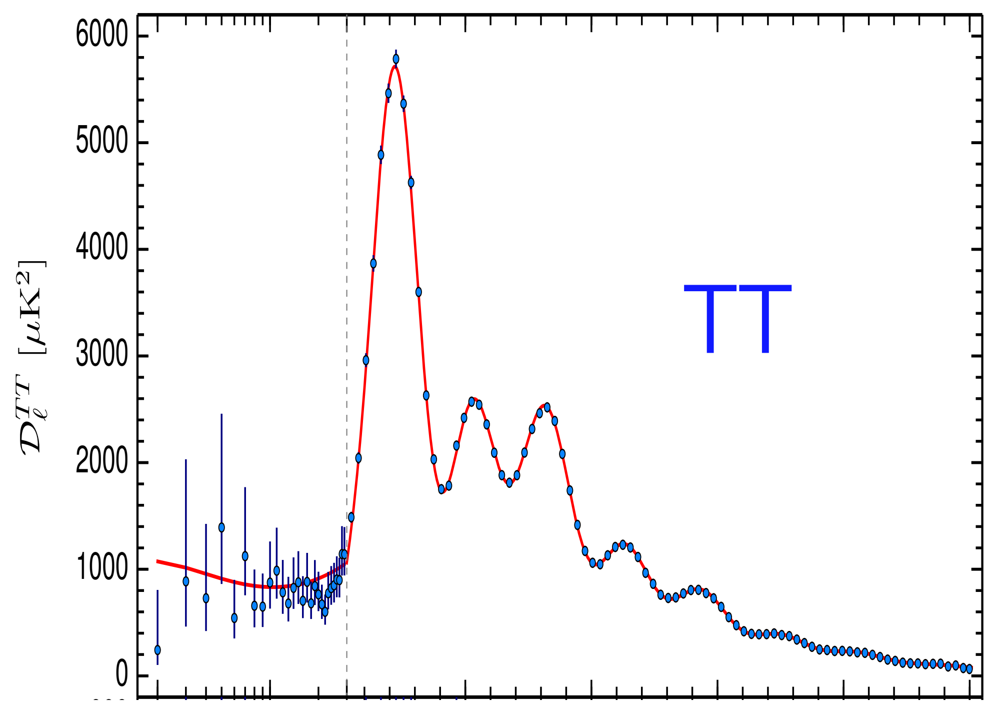
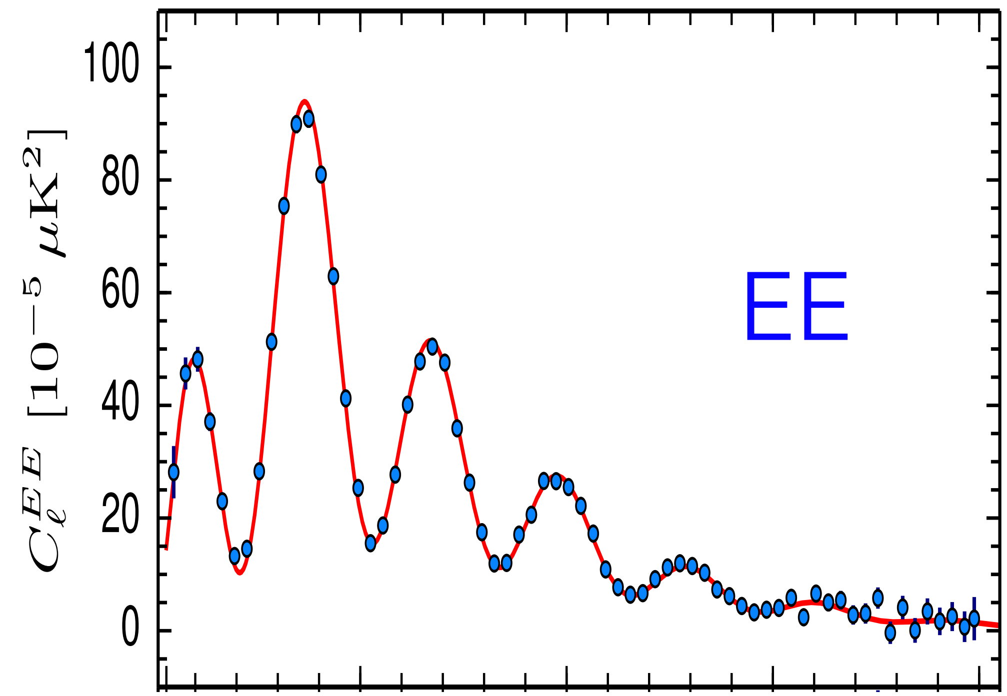
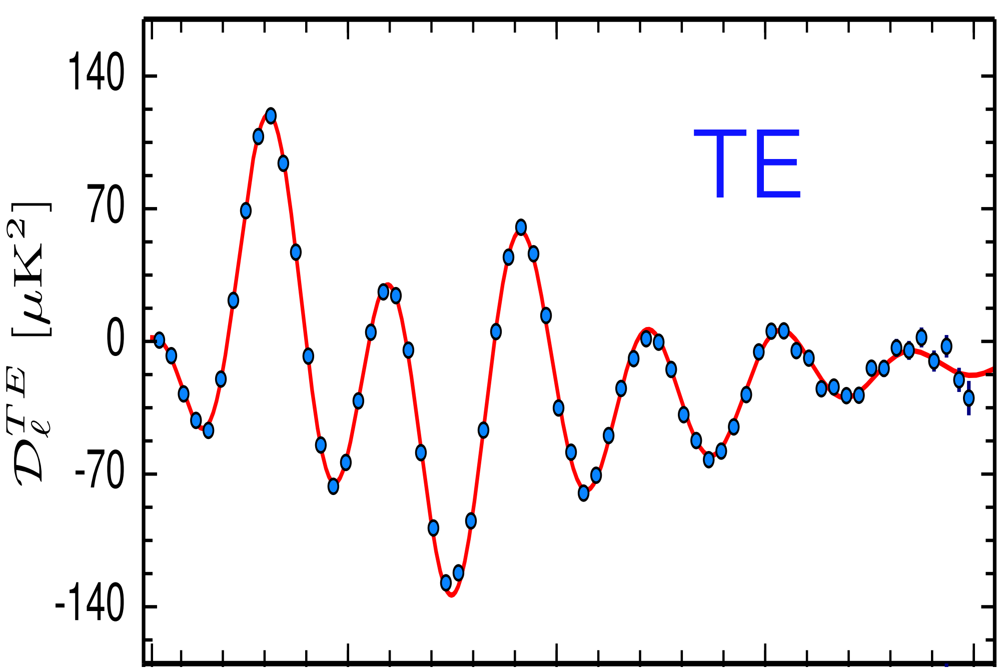


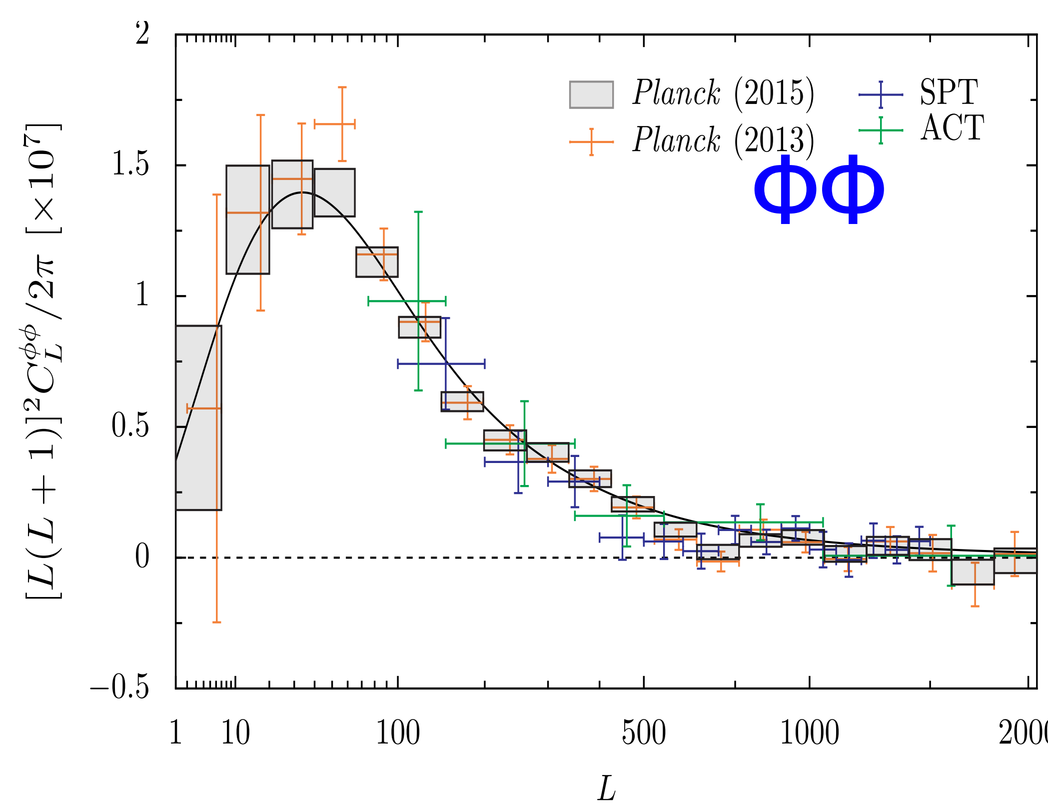
In minimal ΛCDM, all these effects controlled by 6 parameters

Main 2015 results from *Planck*









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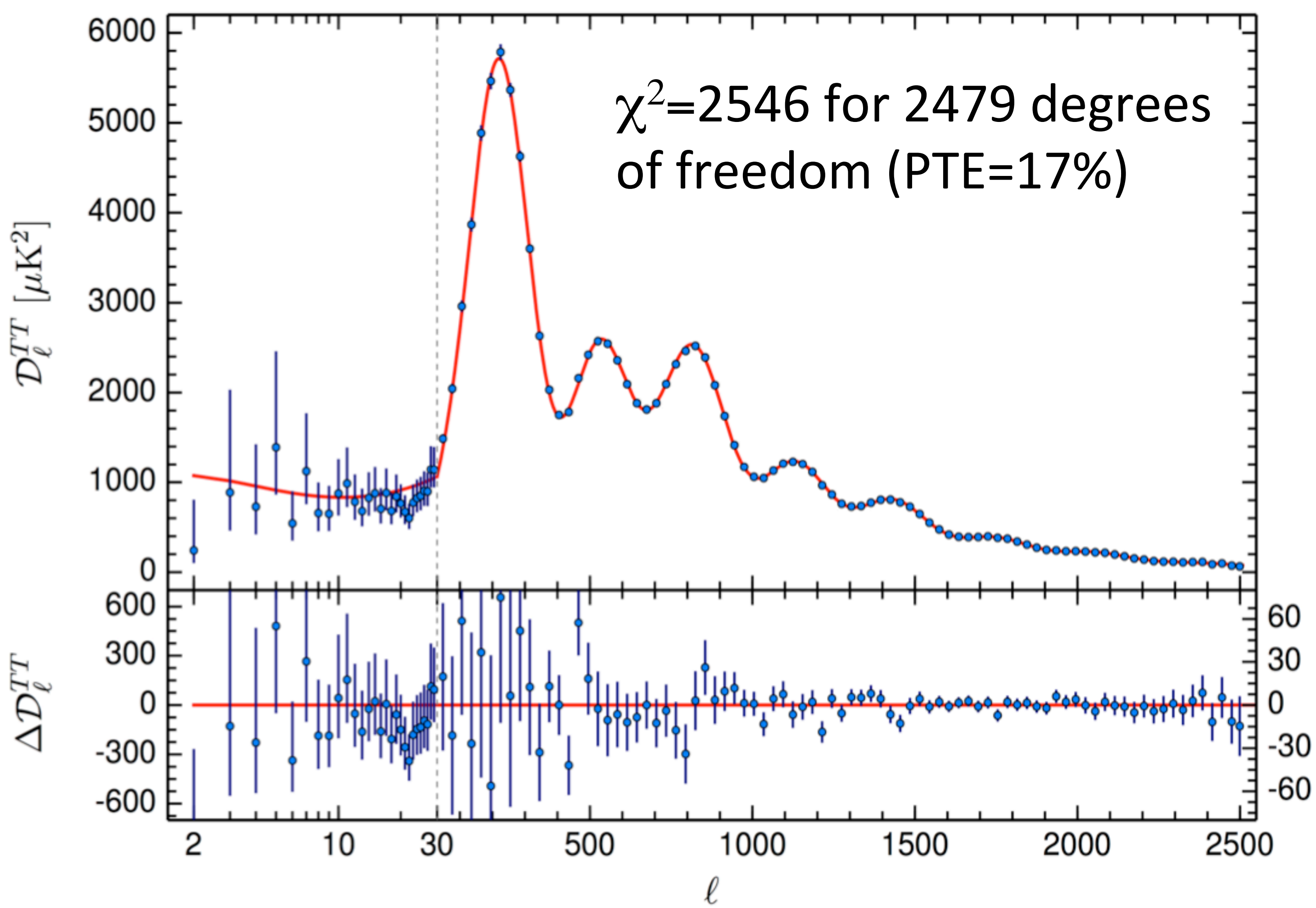


Curvature:
Compatible with flatness at the level of 10^{-3}

$$\Omega_K = 0.000 \pm 0.005 \; (95\%)$$
(PlanckTT+lowP+Lensing+BAO)

Sum of neutrino masses:
Bound already stronger than what achievable by Katrin (tritium beta decay)

$$\sum m_\nu < 0.23 \text{ eV}$$
(PlanckTT+lowP+Lensing+ext)

Number of relativistic species:
Compatible with standard predition N_{eff}=3.046 with 3 active neutrinos

$$N_{\rm eff} = 3.13 \pm 0.32$$
(PlanckTT+lowP)

Helium abundance
Good agreement with measurements of primordial abundances and BBN predictions

$$Y_P^{\rm BBN} = 0.253 \pm 0.021$$
(PlanckTT+lowP)

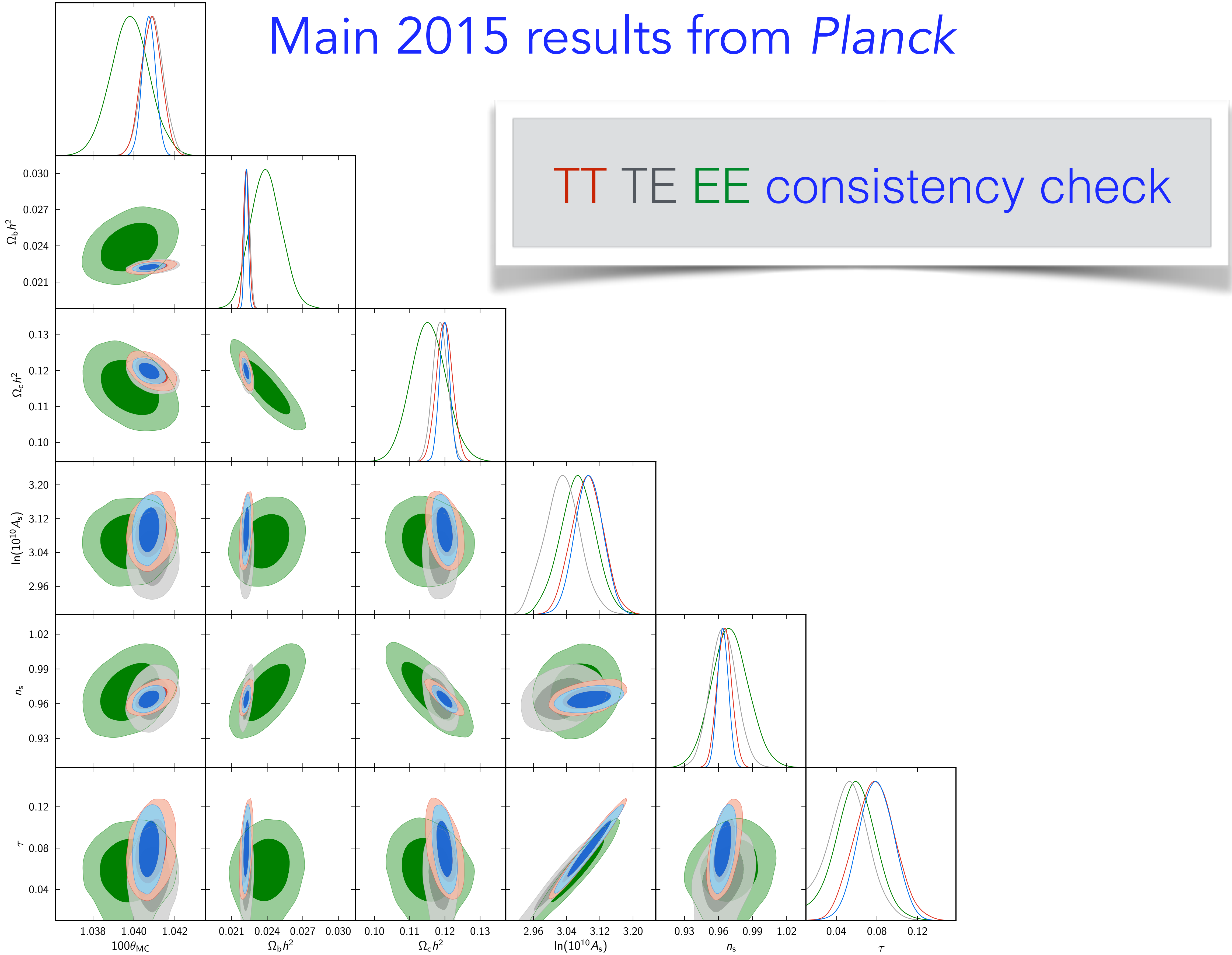
Running of the scalar spectral index
Compatible with no running

$$\frac{dn_s}{d\ln k} = -0.0084 \pm 0.0082$$
(PlanckTT+lowP)

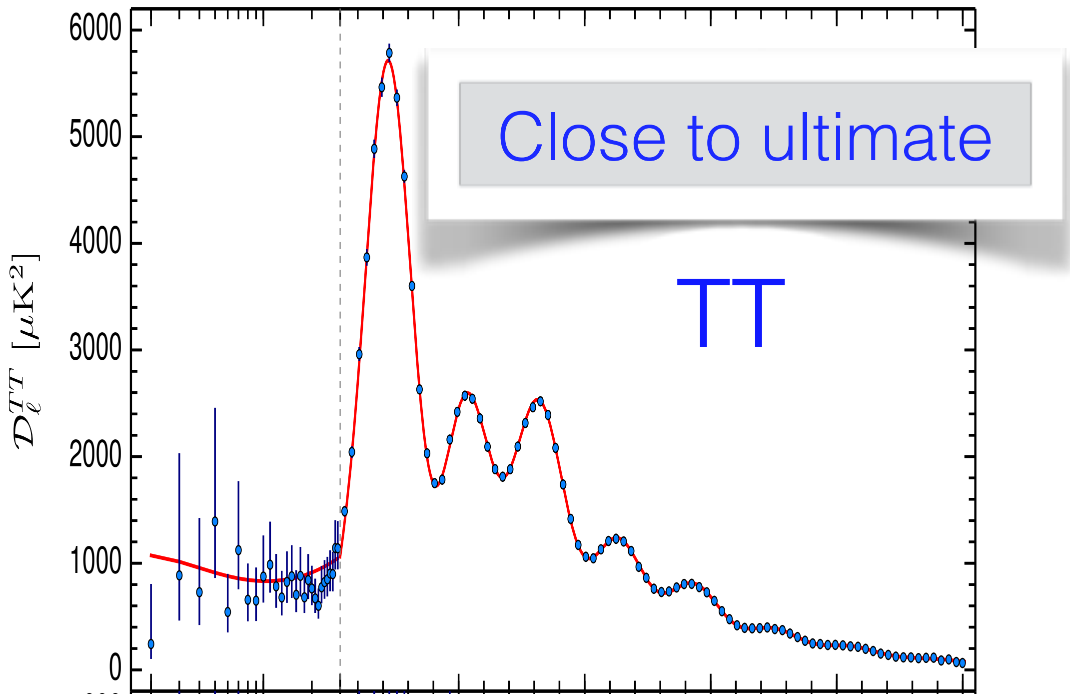
ΛCDM = excellent fit to the data, most parameters at the ~1% level

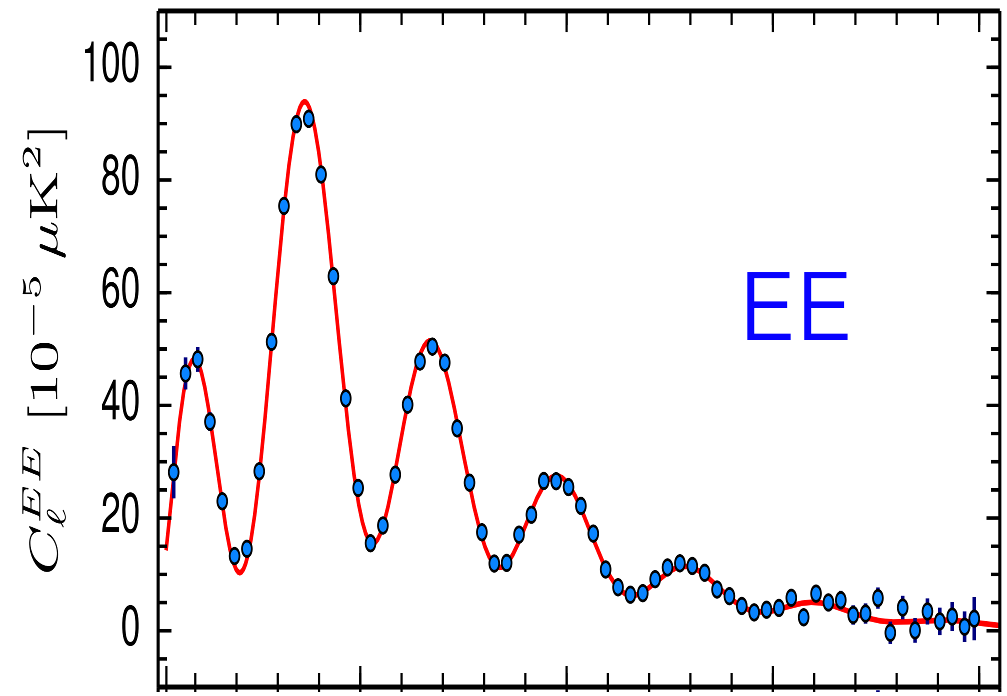
No evidence for extensions of minimal ΛCDM

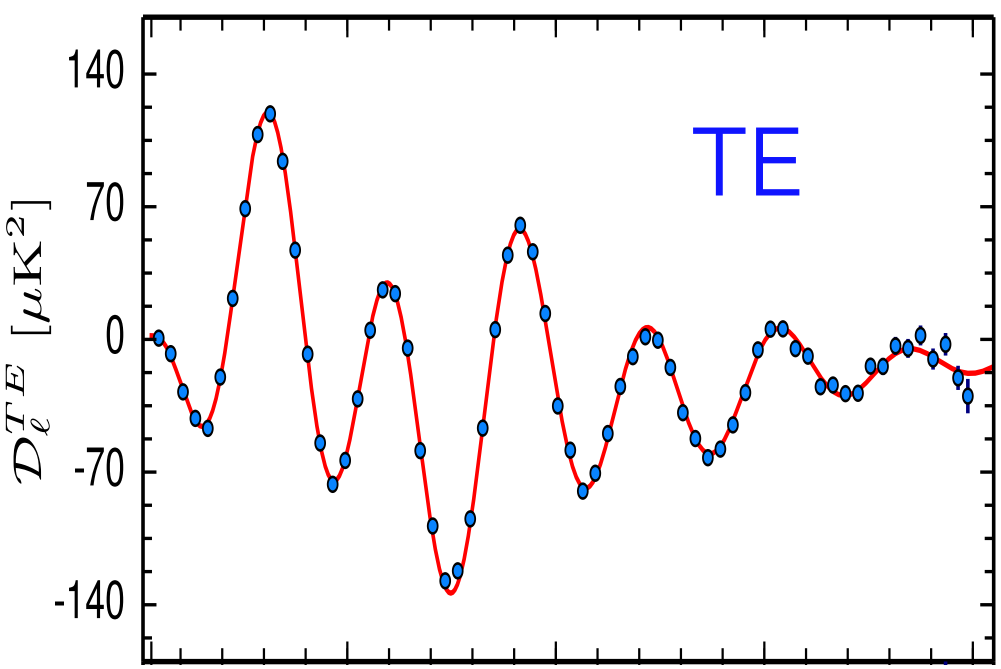
Main 2015 results from *Planck*

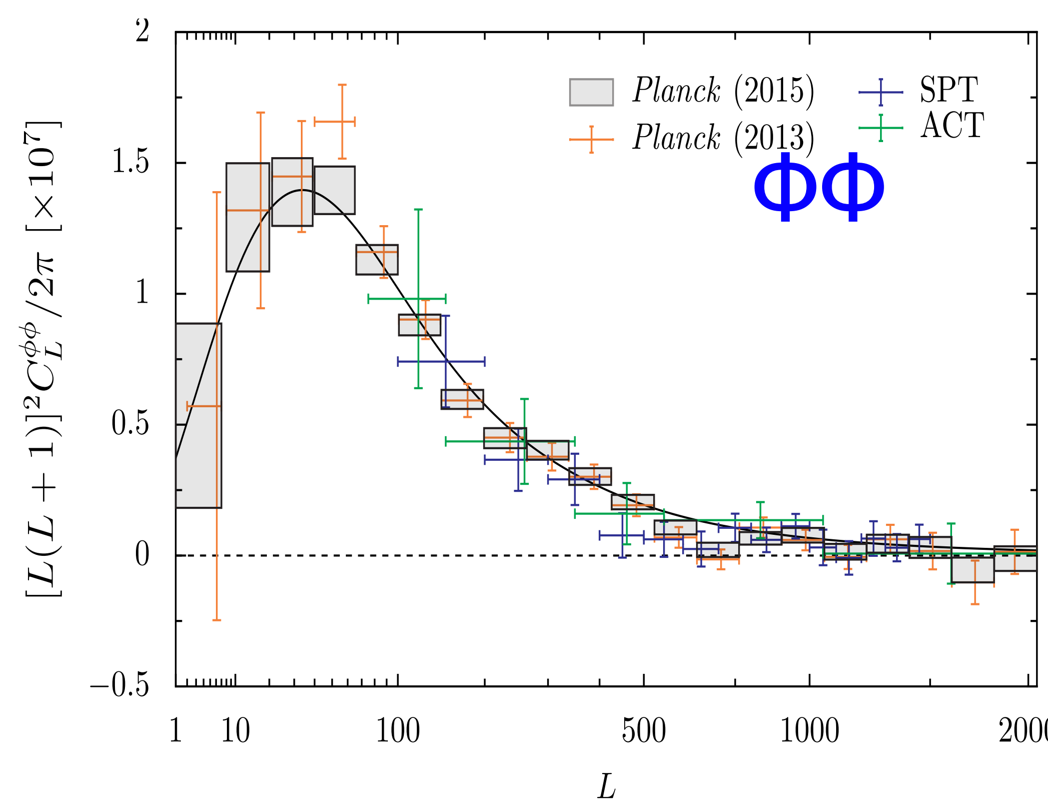


Status of the post-2015 *Planck* analysis









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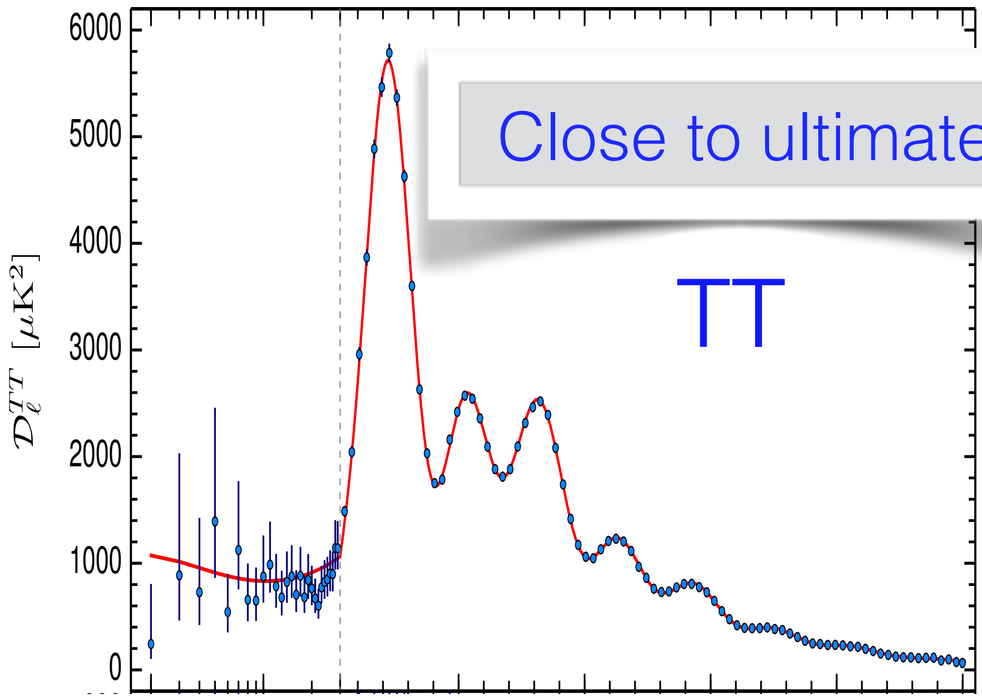
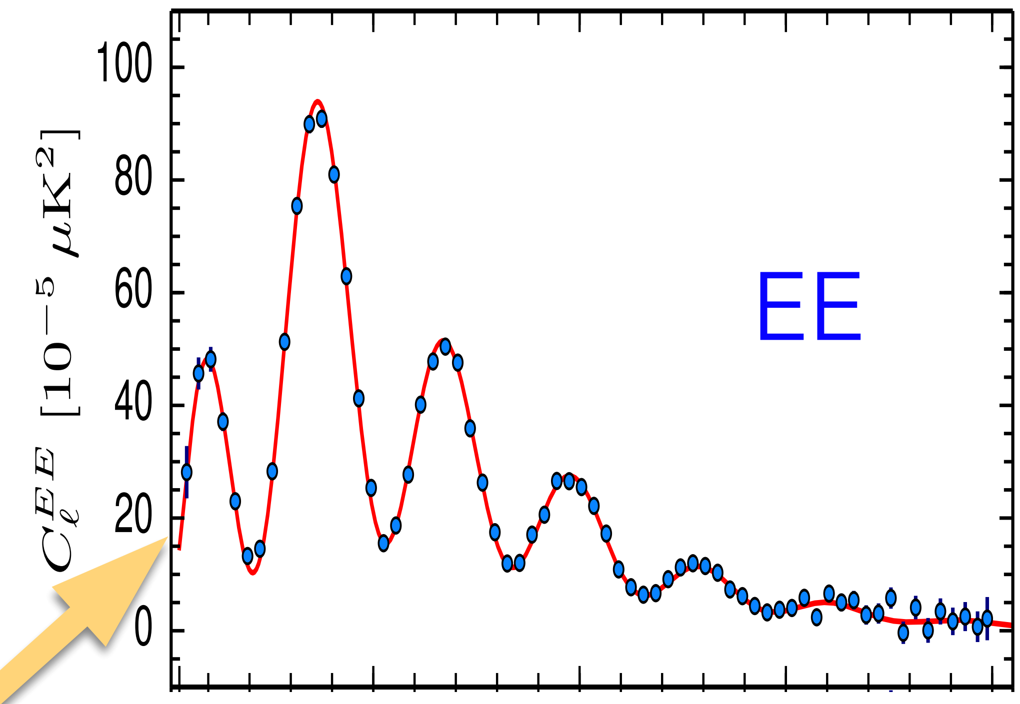
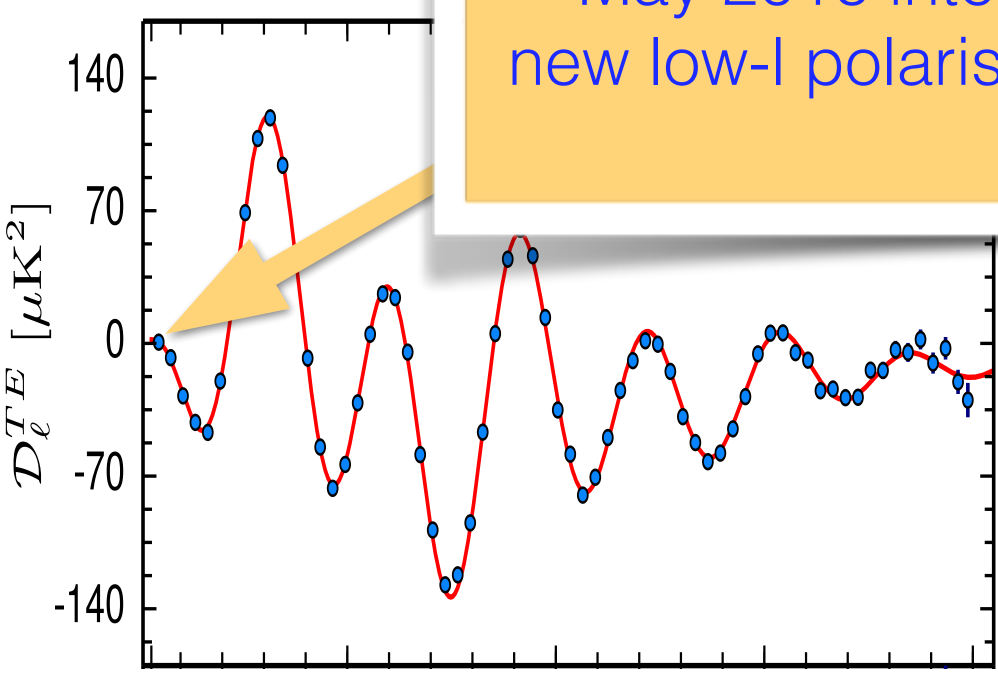
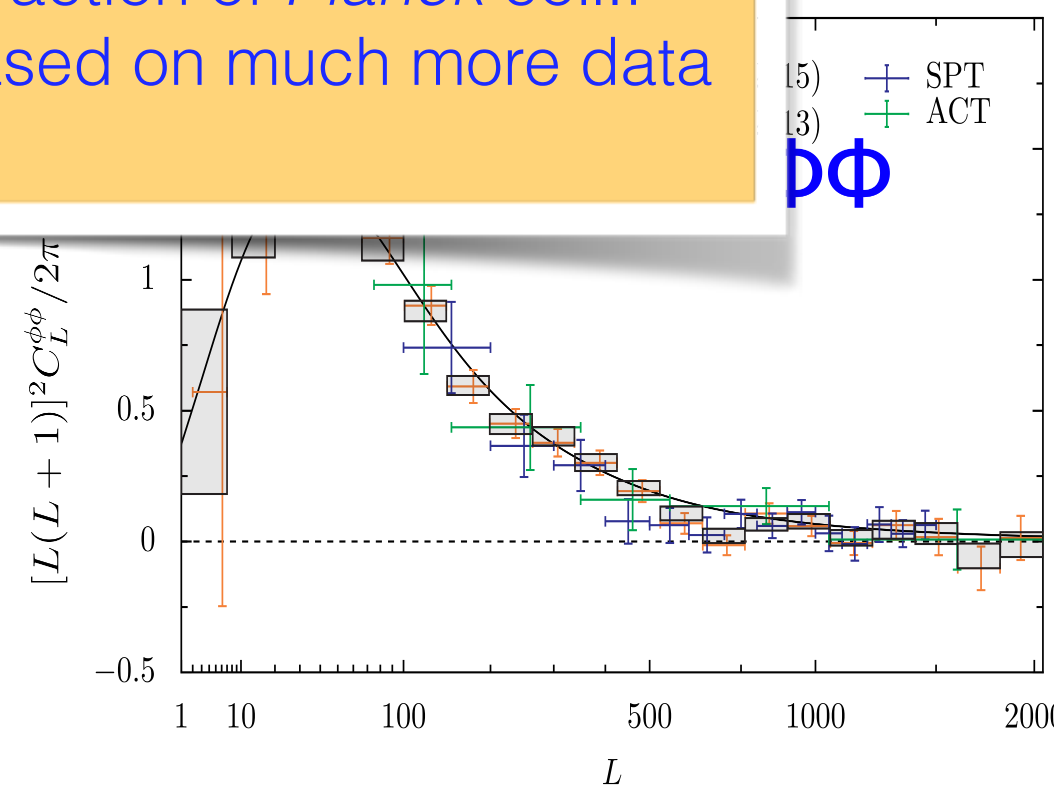


Close to ultimate



May 2016 intermediate results, fraction of *Planck* coll.:
new low-l polarisation likelihood based on much more data
(HFI)





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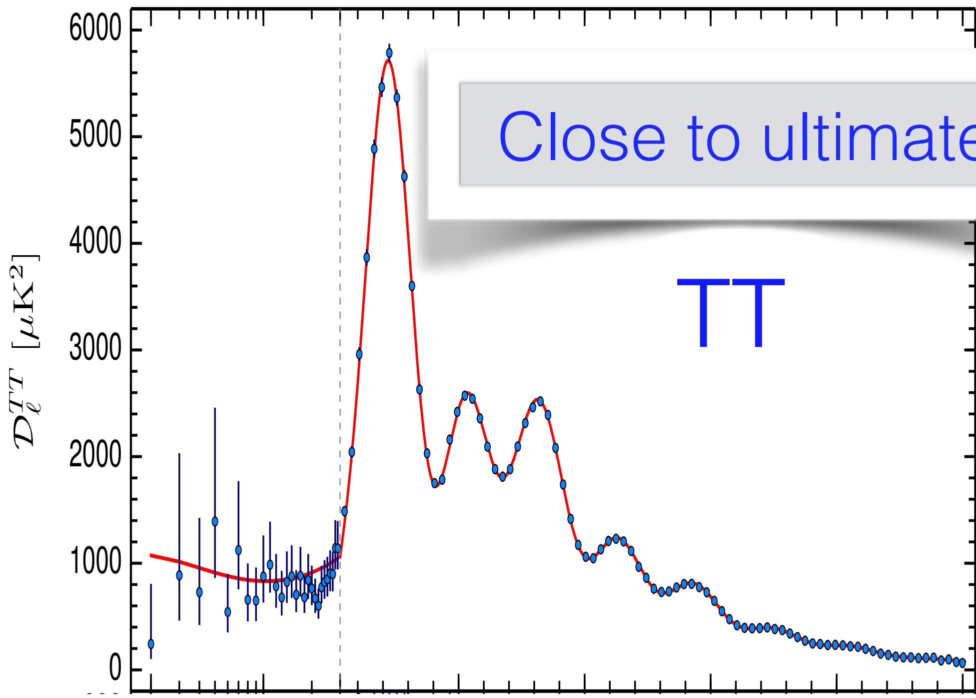
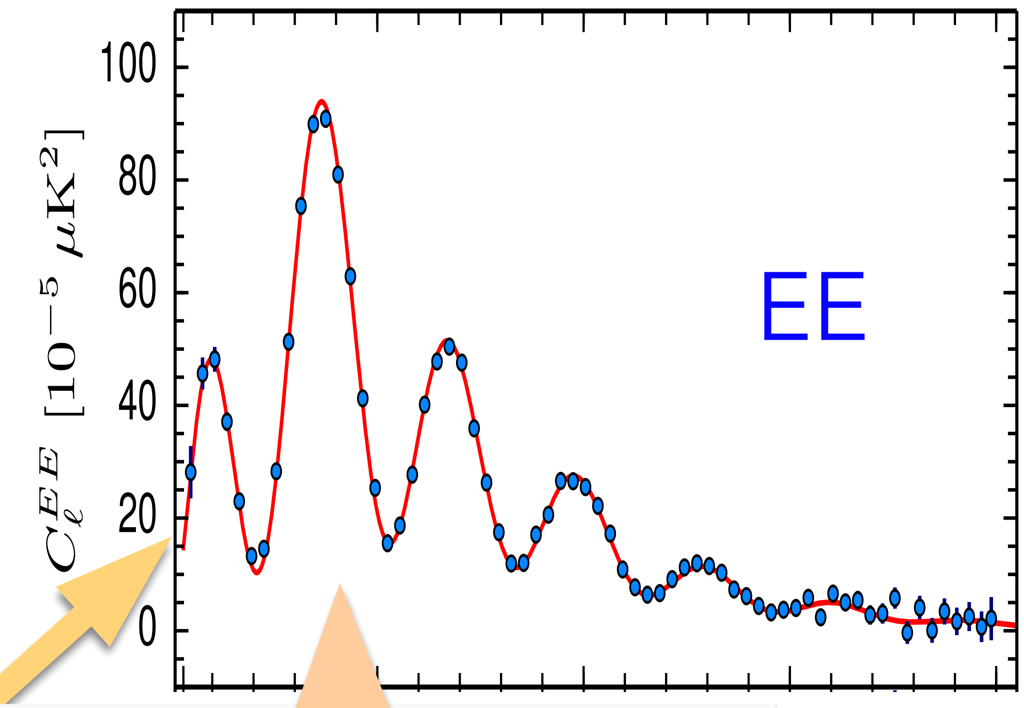
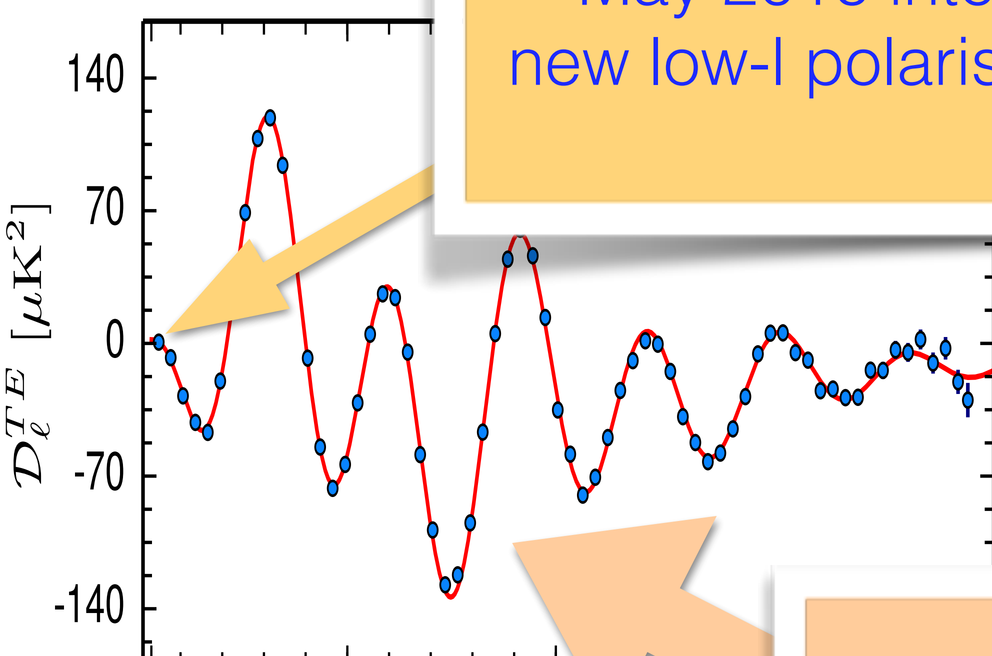
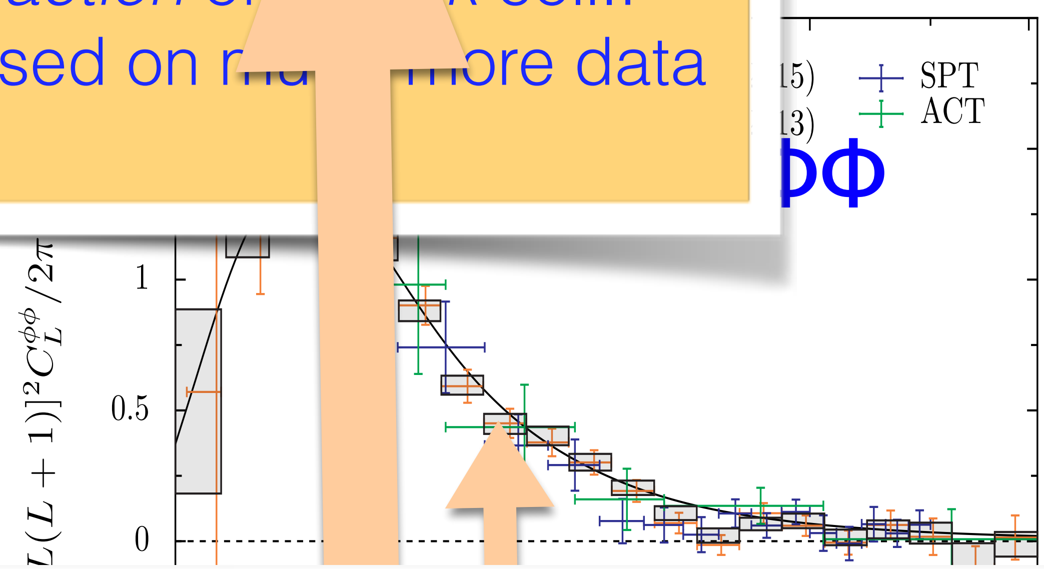




May 2016 intermediate results, *fraction* of ck coll.:
new low-l polarisation likelihood based on m more data
(HFI)





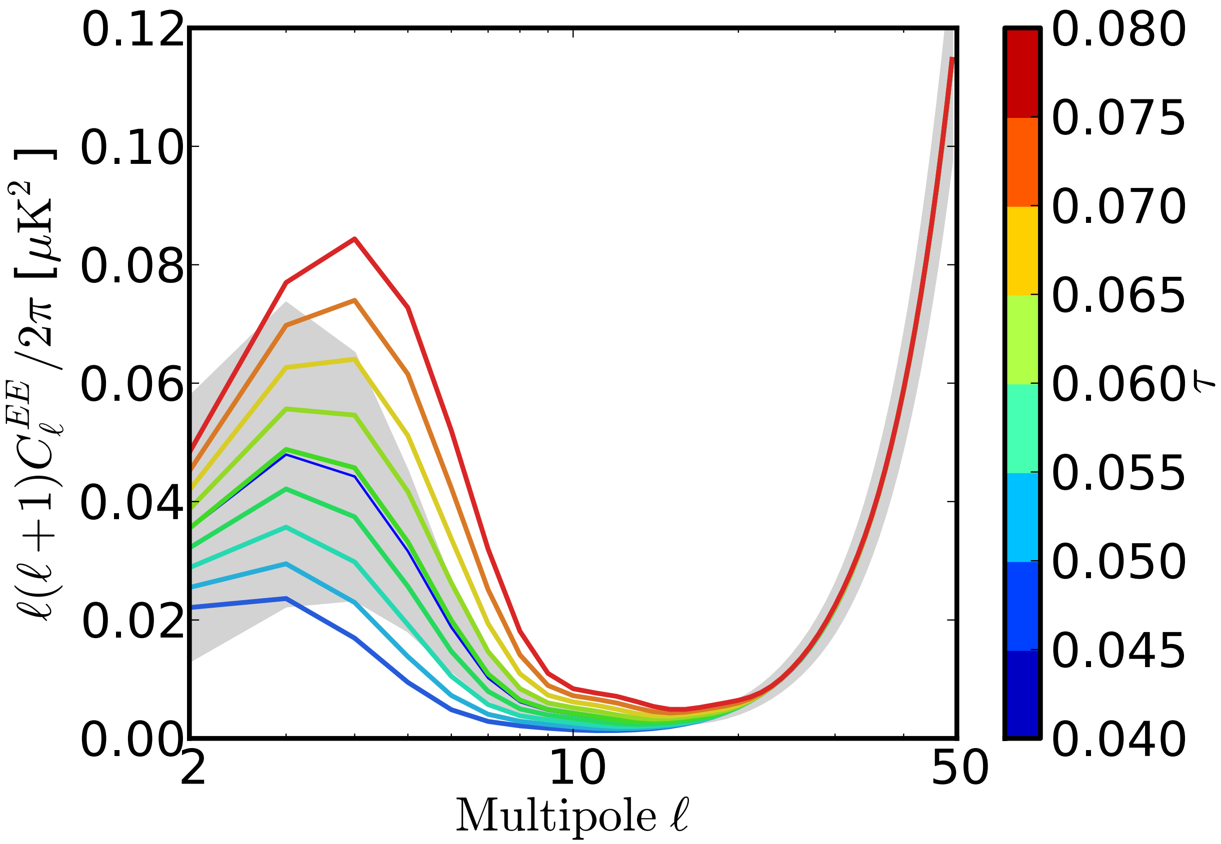
Winter 2017-2018 new data release:
new likelihoods, with all data and improved systematic removal especially for polarisation

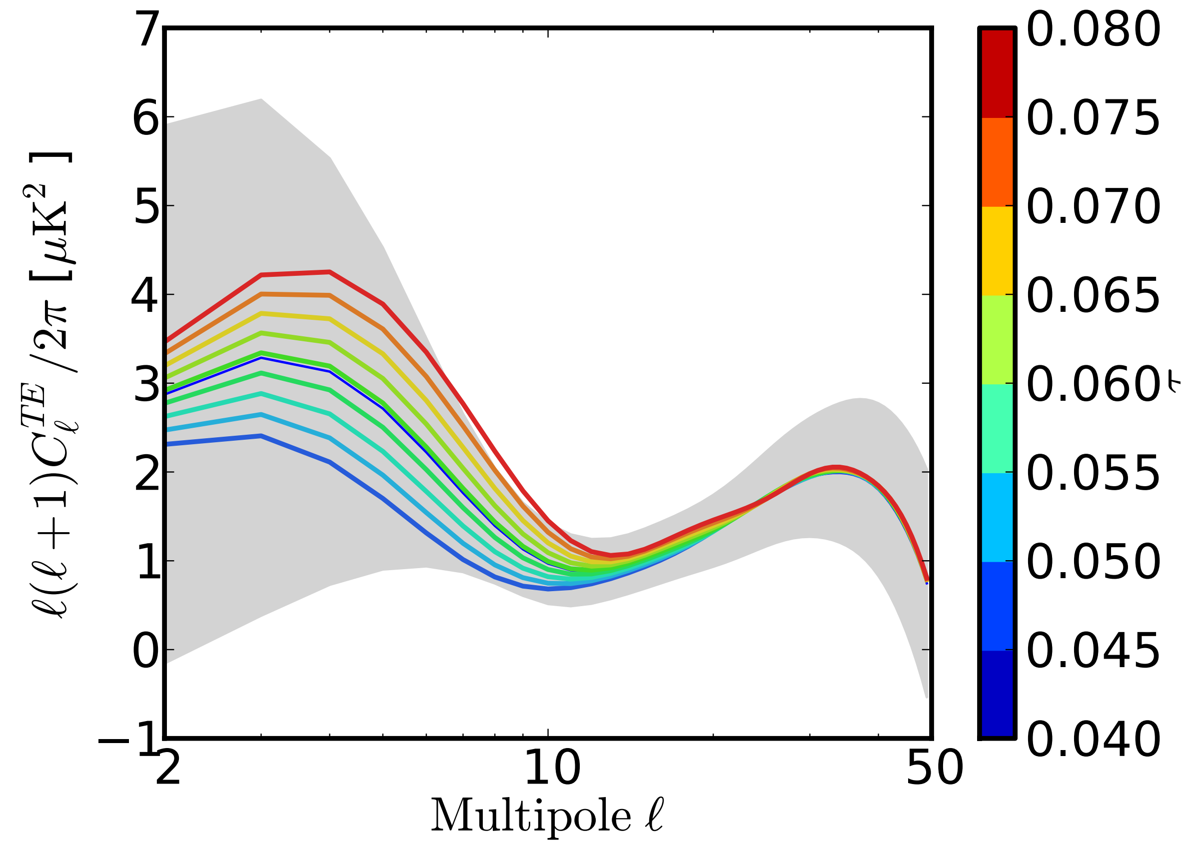
esa planck

May 2016 intermediate results

1605.03507
1605.02085

Grey bands: new C_l^{EE} and C_l^{TE} constraints (<30)



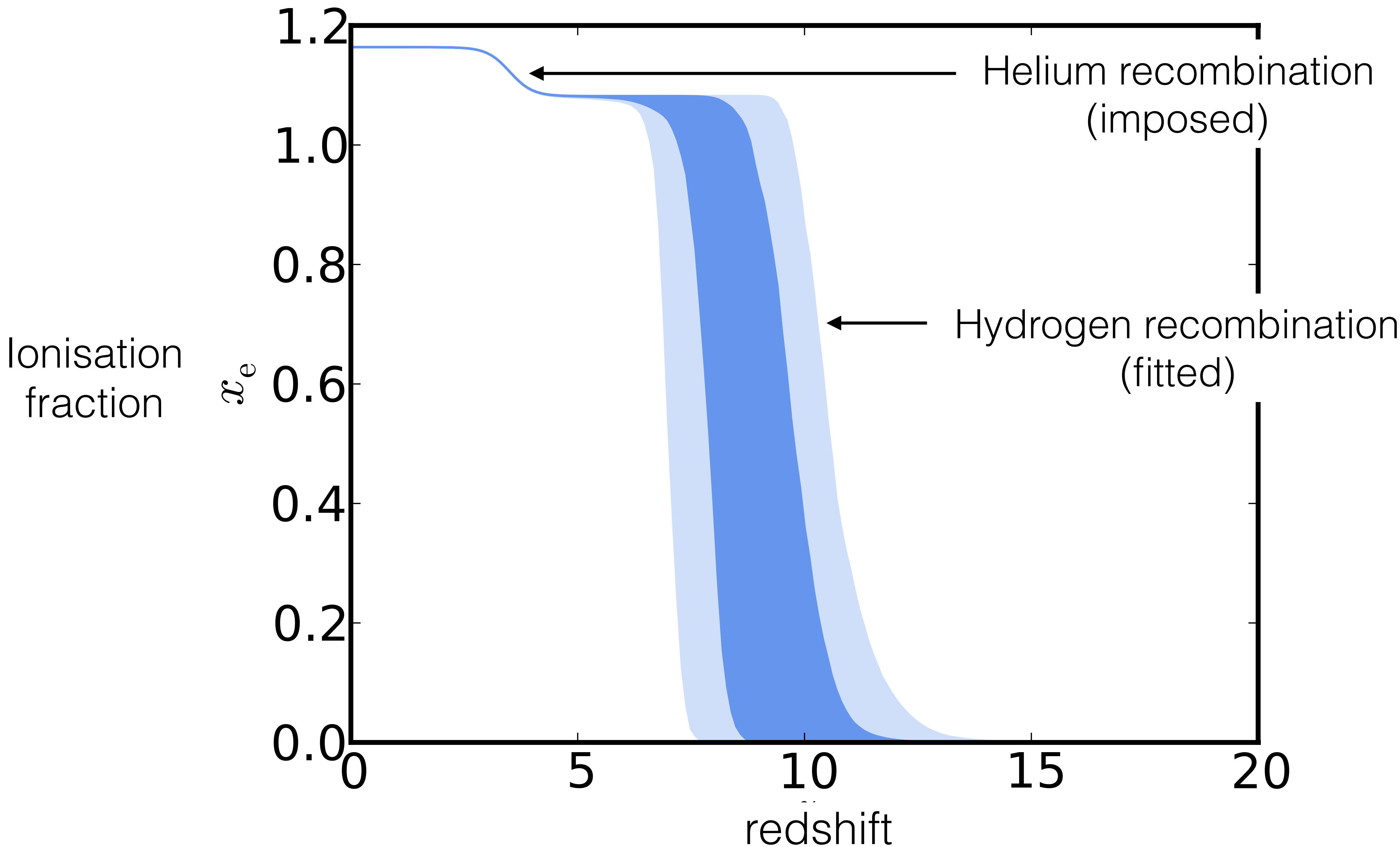


… mainly bringing new information on reionisation history

May 2016 intermediate results

1605.03507
1605.02085

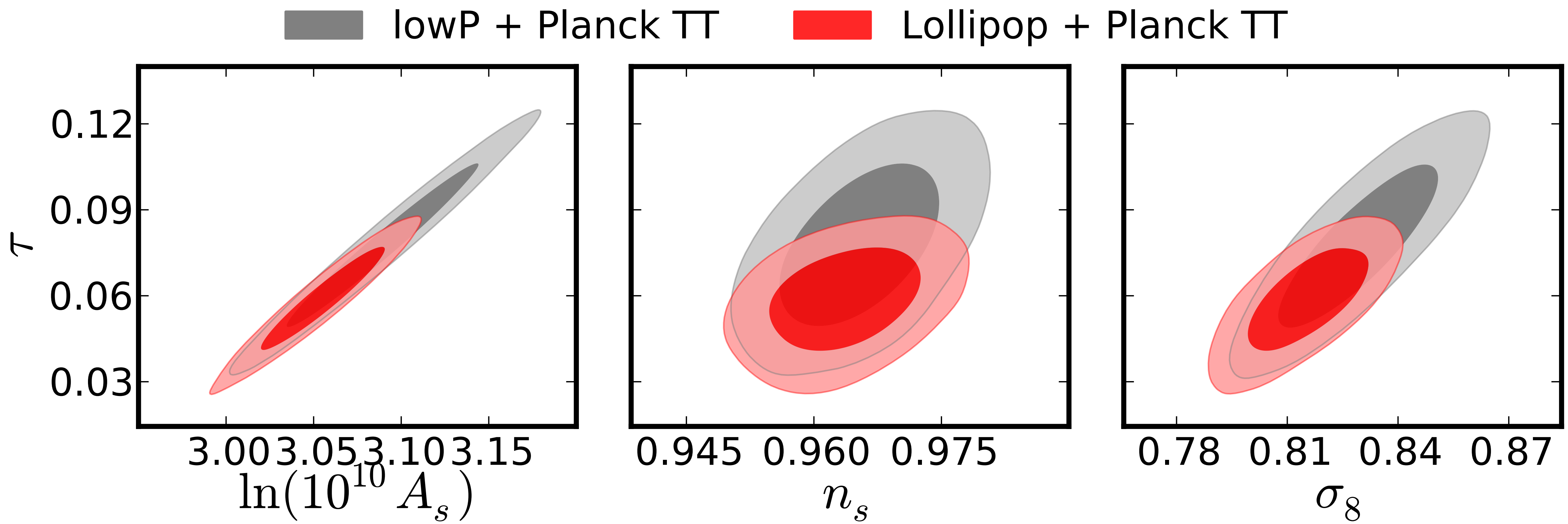
Reionisation history: more and more now compatible with quasar constraints



May 2016 intermediate results

1605.03507
1605.02085

New constraints propagate to ΛCDM parameters:



May 2016 intermediate results

1605.03507
1605.02085

New constraints propagate also to neutrino mass:

Smaller τ_{reio} >> smaller primordial amplitude A_s
>> prediction of less CMB lensing, but C_l^{TT} appear quite lensed
>> tighter neutrino mass bounds

More conservative:

Planck 2015 high-l TT,TE,EE + new 2016 low-l TT,TE,EE:
M_ν < 340 meV (95%CL)

More agressive:

Planck 2015 high-l TT,TE,EE + new 2016 low-l TT,TE,EE + lensing **ΦΦ** :
M_ν < 140 meV (95%CL)

Planck 2013 + Lyman-α from BOSS:
M_ν < 120 meV (95%CL)

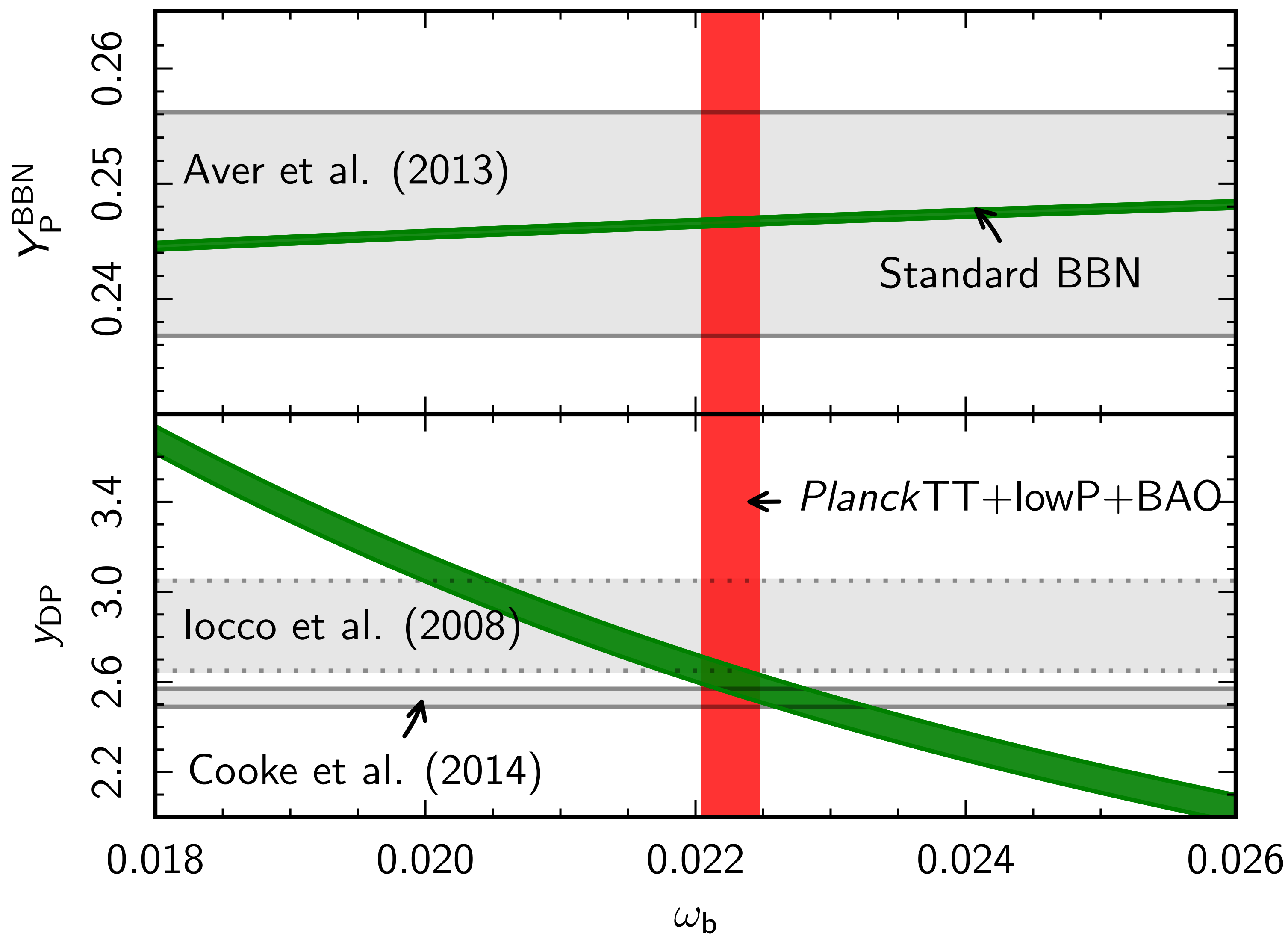
BBN Nucleosynthesis

CMB-BBN concordance from 2015:

Nuclear physics at T~1MeV

versus

Relativistic hydrodynamics + QED at T~1eV



Since then:

- new Helium prediction halved error (Aver et al. 2013), but still well consistent
- nuclear rate affecting Deuterium: new theoretical calculation (Marcucci et al 2016) lowers $y_{DP}(\omega_b)$, thus further improving consistency

BBN Nucleosynthesis

CMB-BBN concordance from 2015:

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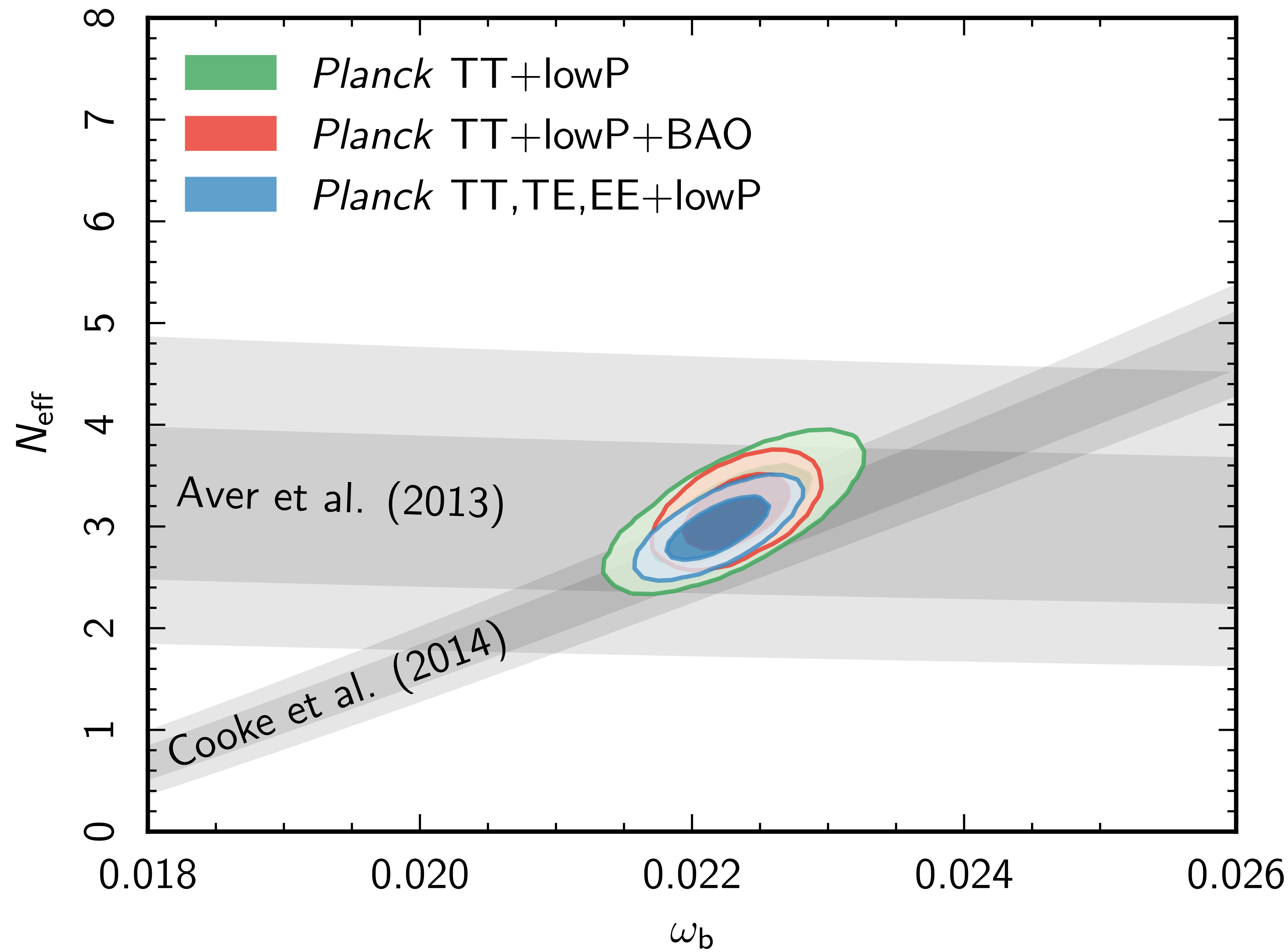

Relaxing N_{eff}=3.046

BBN Nucleosynthesis

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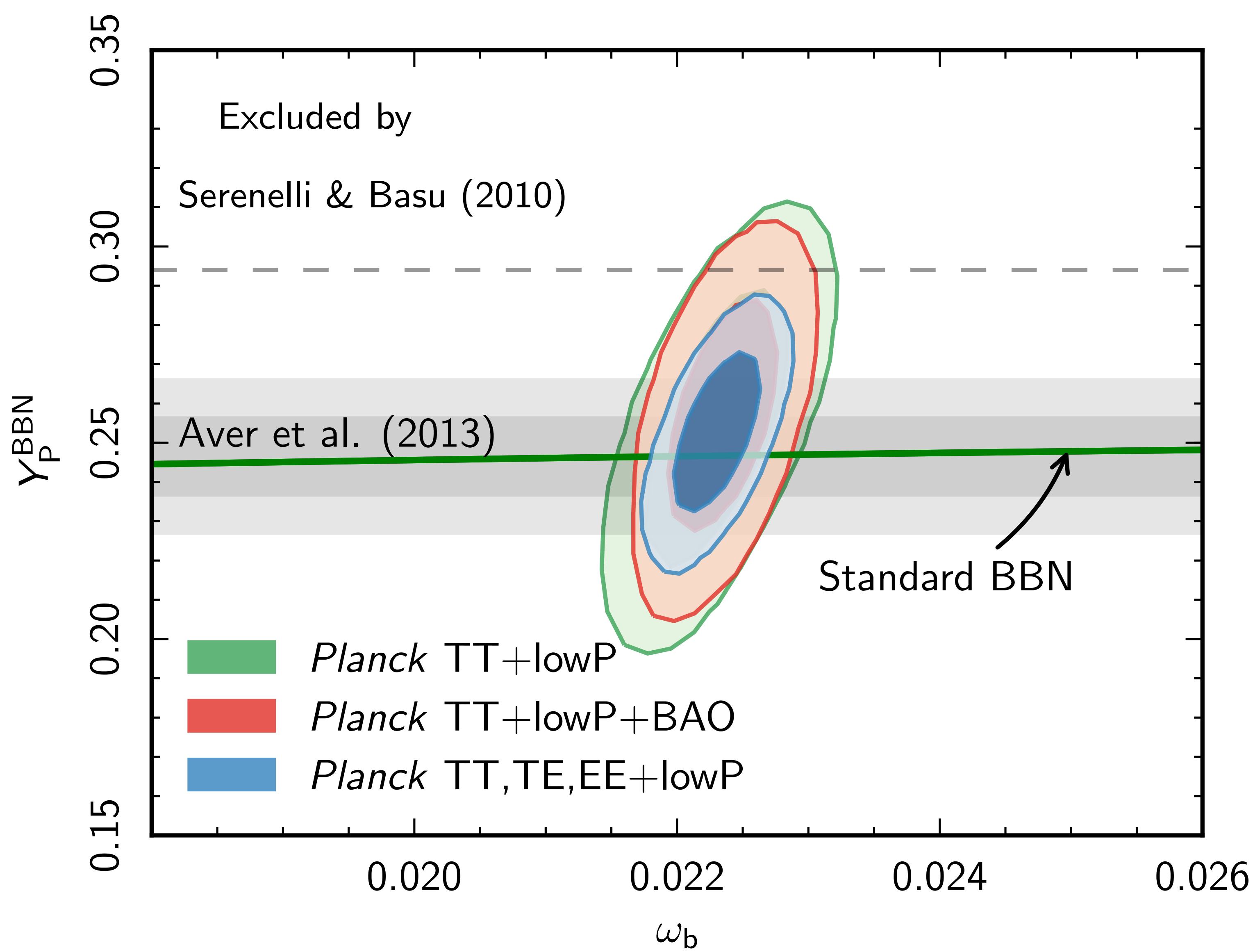
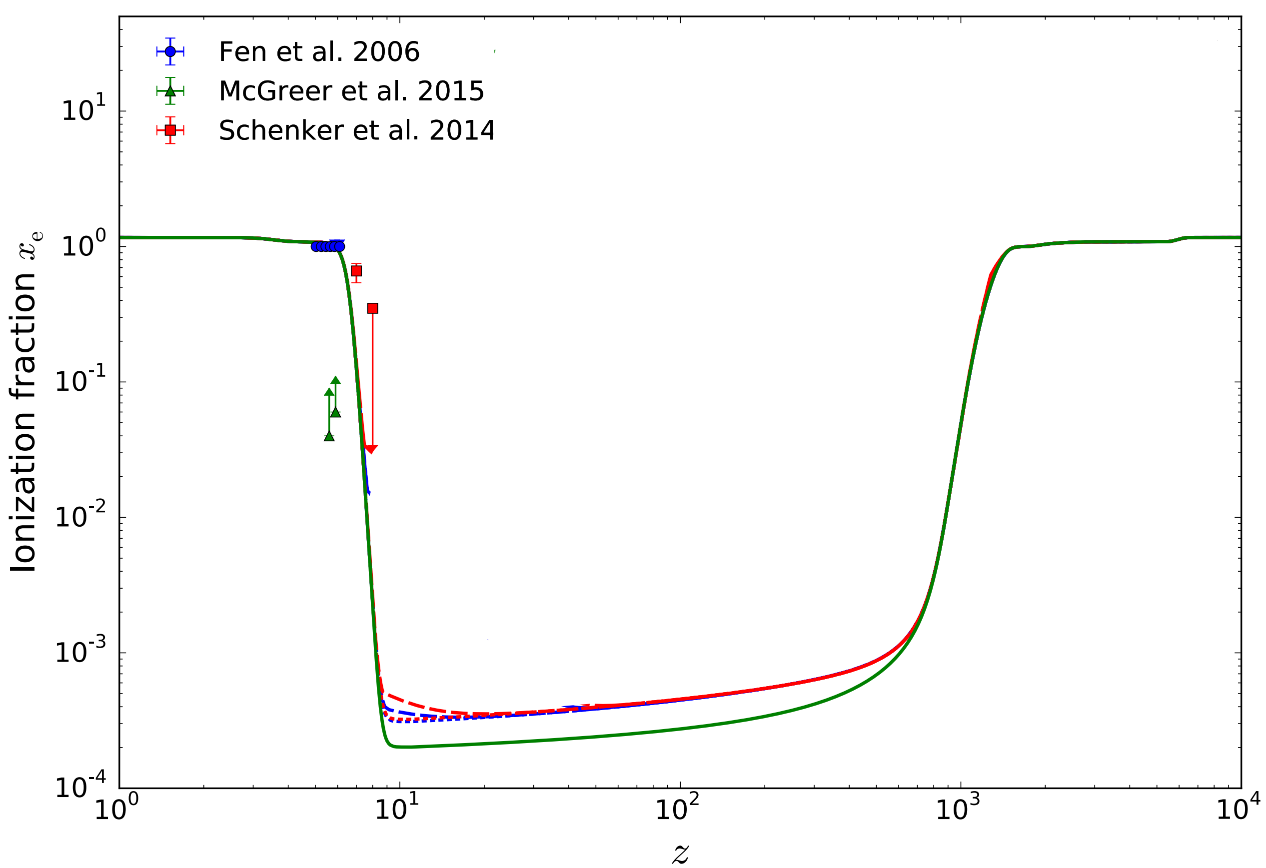


Predicting helium fraction directly from CMB

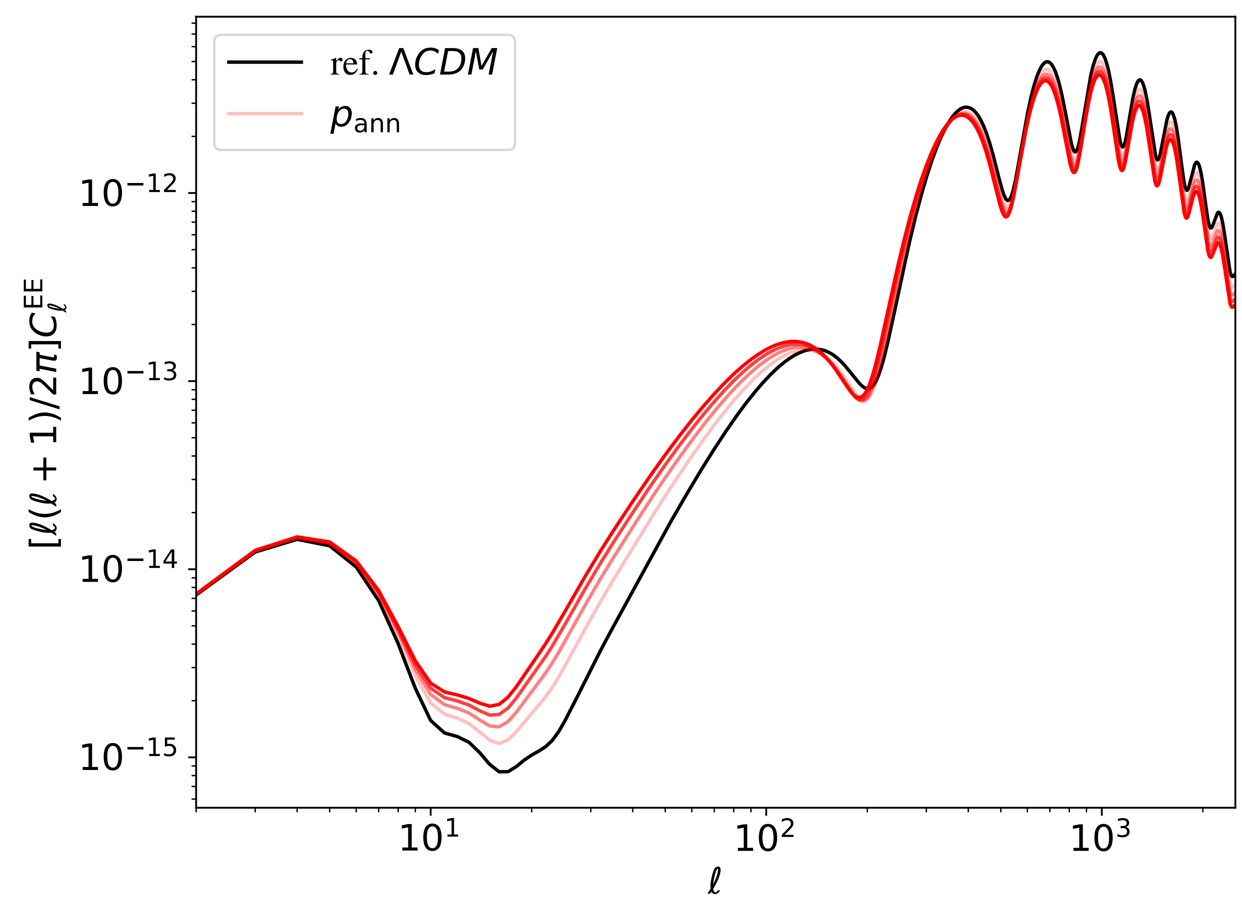
DM constraints

- WIMP annihilation cross-section: CMB effect controlled by <σv>/m (for each fixed branching ratios):

Energy injected in IGM through heating, ionisation, excitation:



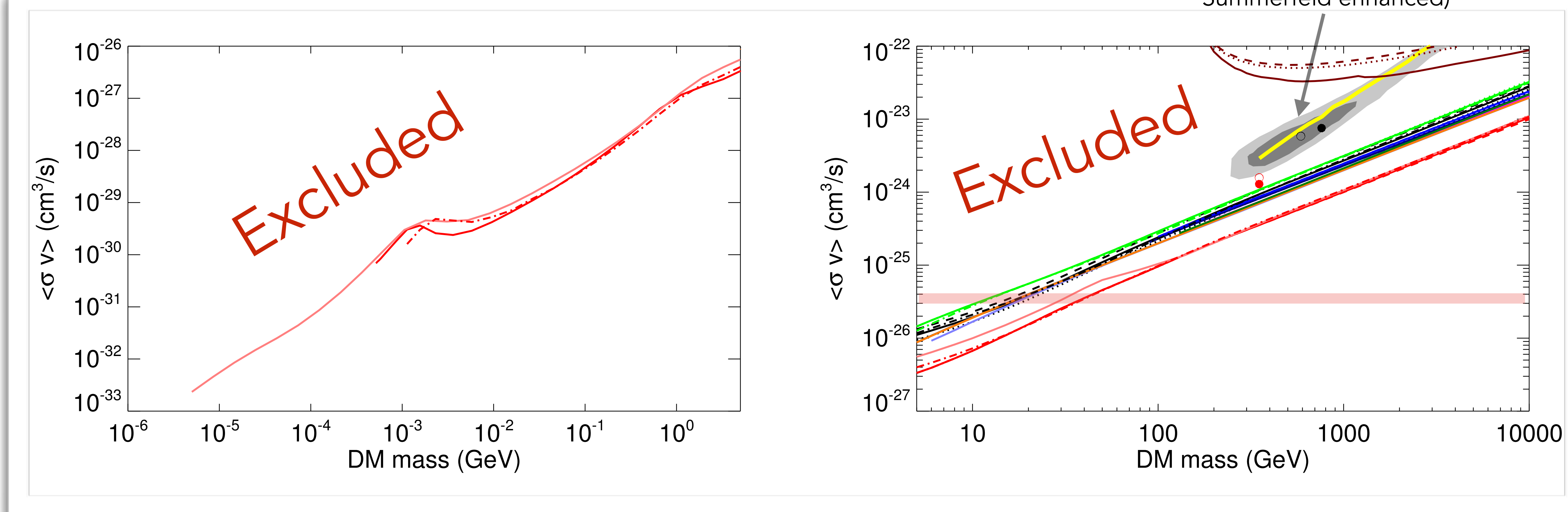
Most characteristic signature for polarisation:



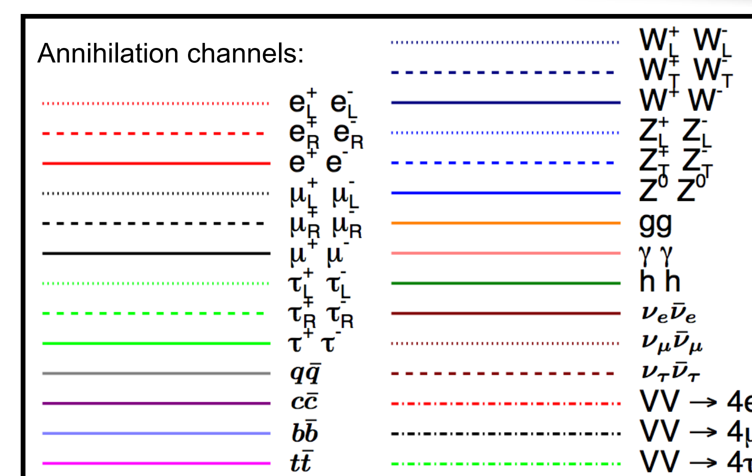
DM constraints

- constraints competitive with DM indirect detection:

Pamela, Fermi, AMS-02 positron anomaly (s-wave, Summerfeld enhanced)



- Thermal WIMP cross-section: m > 10 to 40 GeV (95%CL, Slatyer 2015)



- potential x3 improvement with ideal CMB experiment (cosmic variance limited, perfect foreground cleaning) but not by Planck

DM constraints

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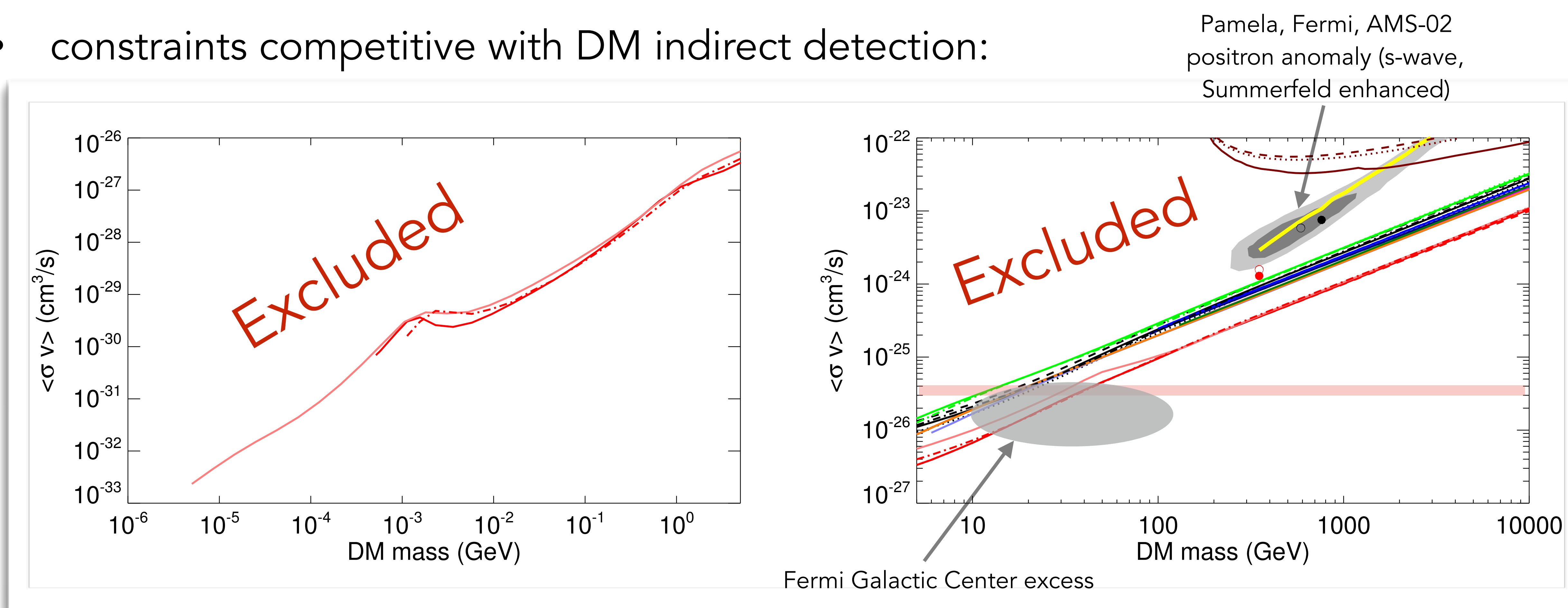

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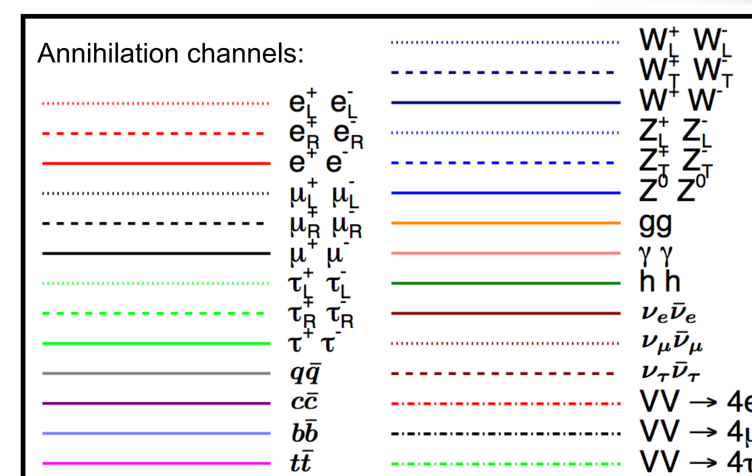

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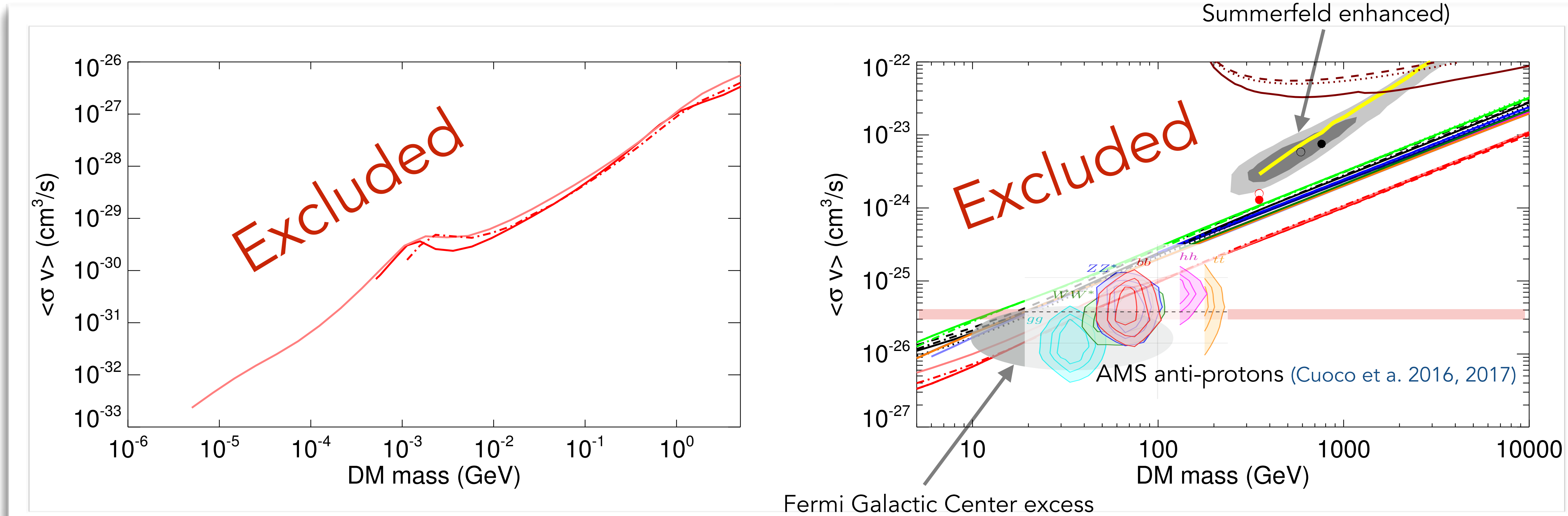

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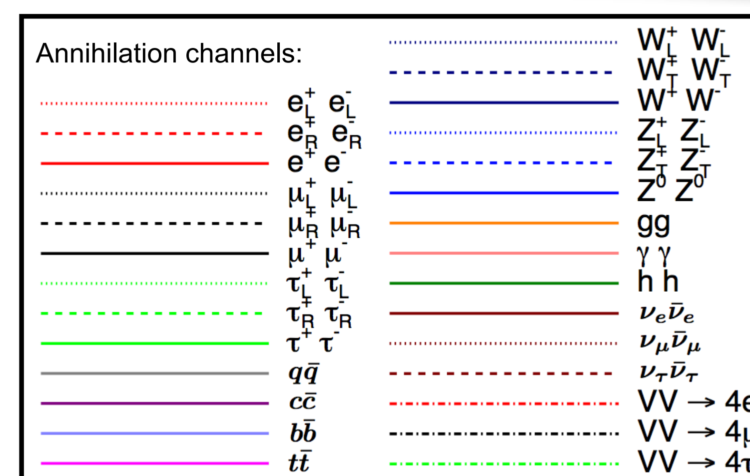


  - potential x3 improvement with ideal CMB experiment (cosmic variance limited, perfect foreground cleaning) but not by Planck

DM constraints

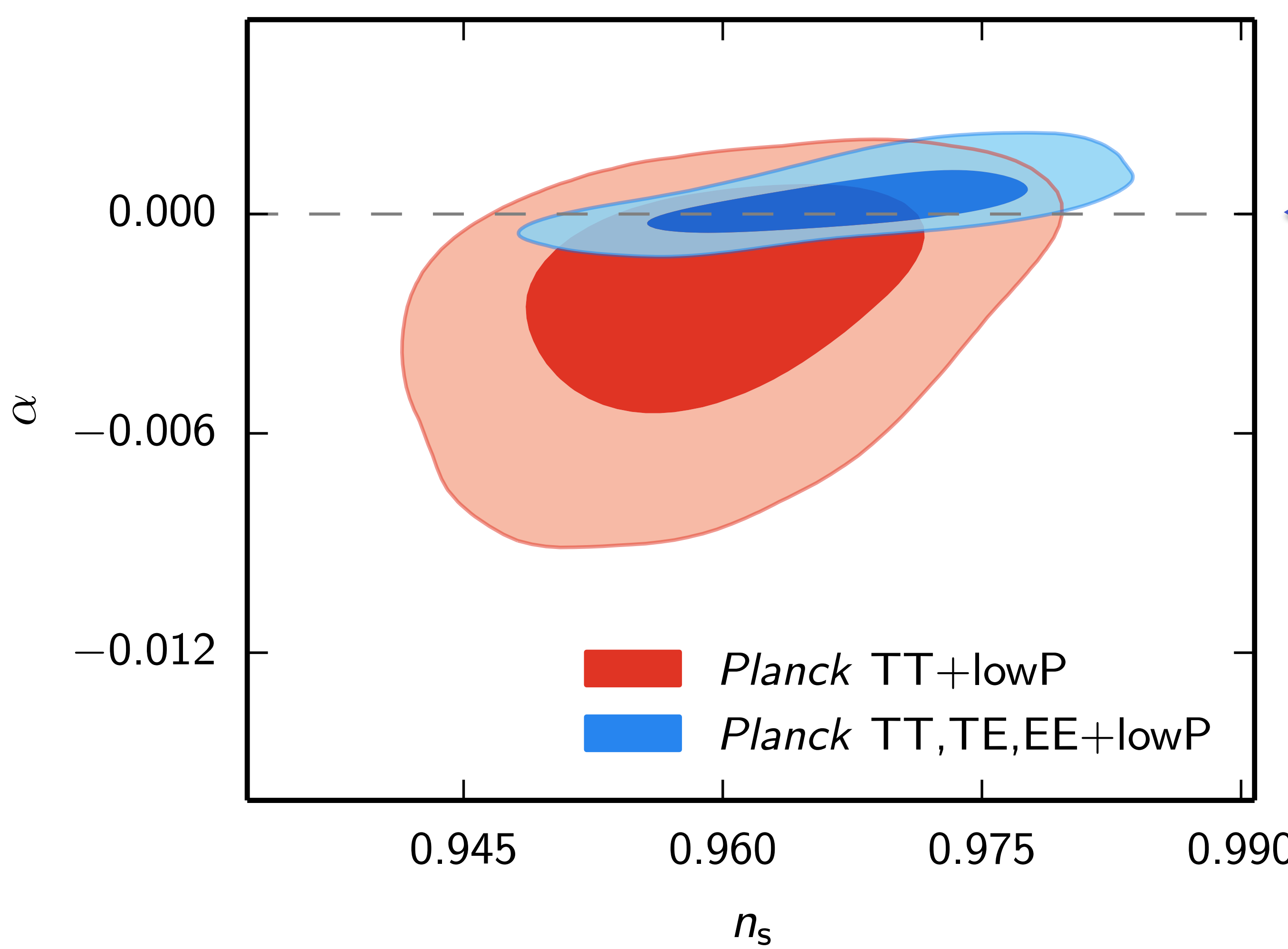
- Beyond Planck publications: wide range of constraints derived from Planck on DM decay, PBH evaporation, possible small but non negligible DM scattering rates, etc.

- some covered by talk of Pasquale Serpico (anisotropies) and Jens Chluba (spectral distorsions)

Inflation

No statistically significant evidence for deviations from canonical slow-roll single-field :

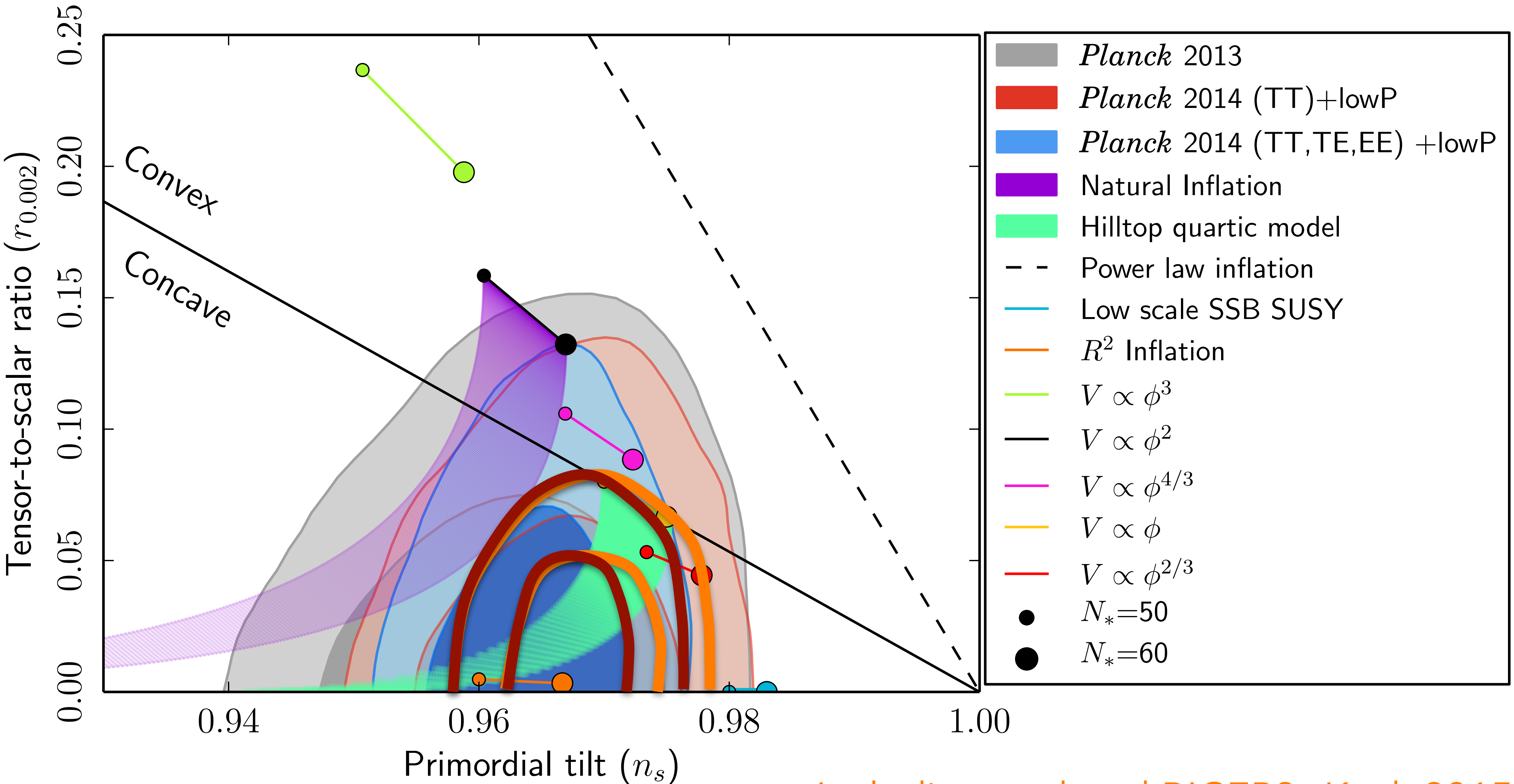
- no primordial non-gaussianity
- no running of spectral index
- no features in primordial spectrum
- no isocurvature modes (here, restricted case of correlated CDM iso. modes):



purely adiabatic

Isocurvature modes: example of big improvement triggered by polarisation!

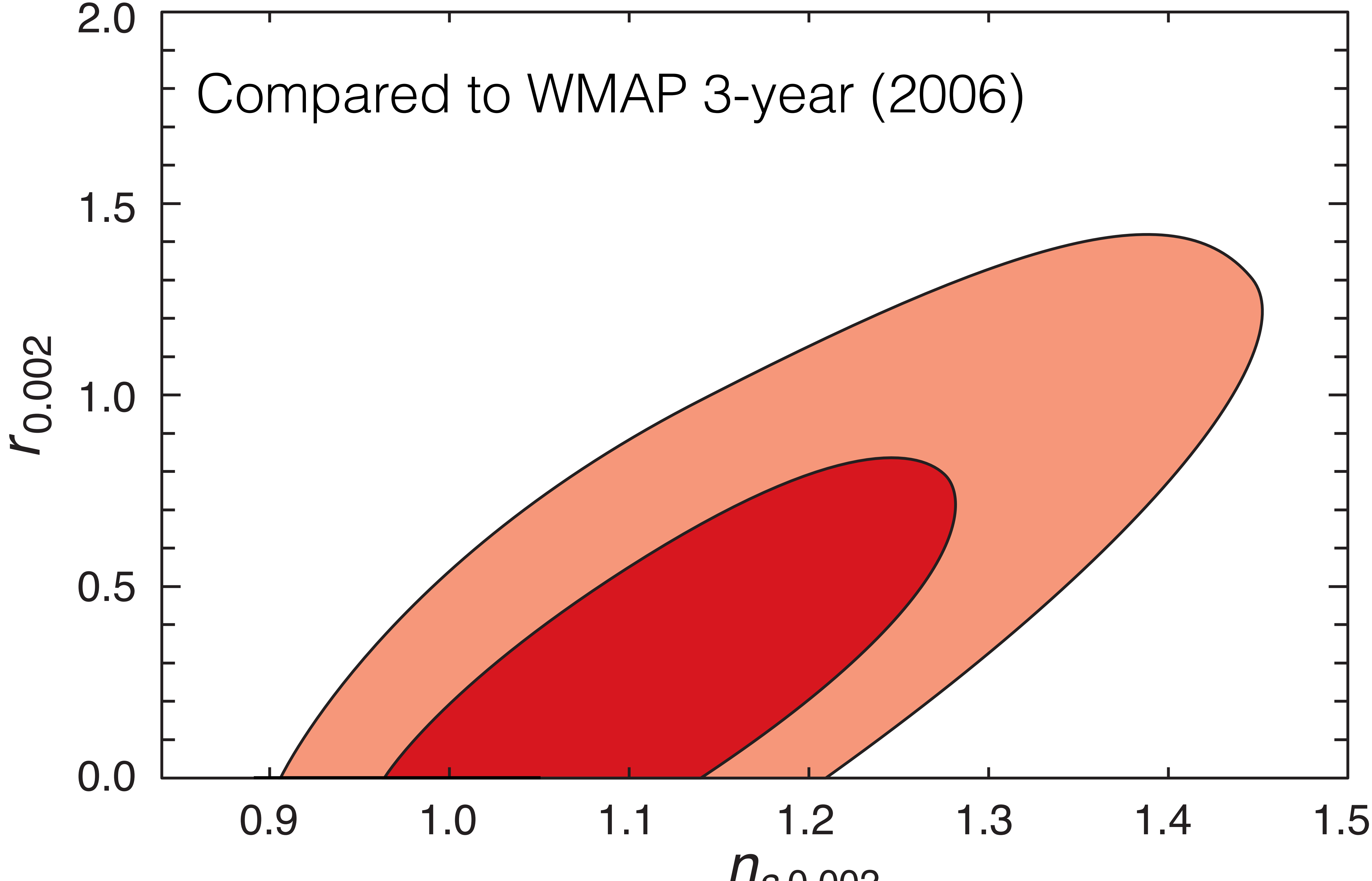
Inflation



Including updated BICEP2+Keck 2015

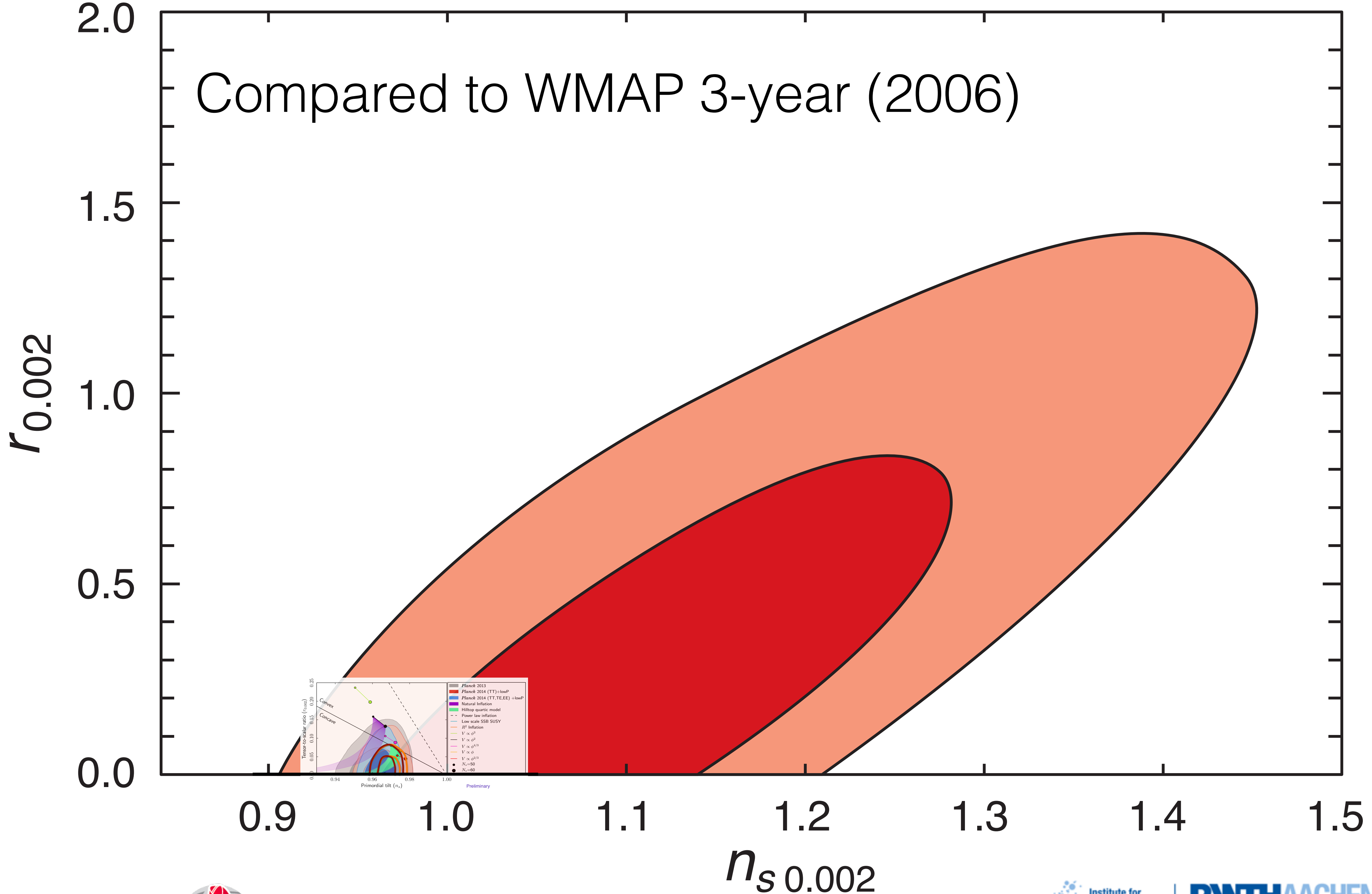
+ Planck low-l 2016 (rough estimate)

Inflation



Compared to WMAP 3-year (2006)
2.0
1.5
1.0
0.5
0.0
$r_{0.002}$
0.9
1.0
1.1
1.2
1.3
1.4
1.5
$n_{s\,0.002}$

Inflation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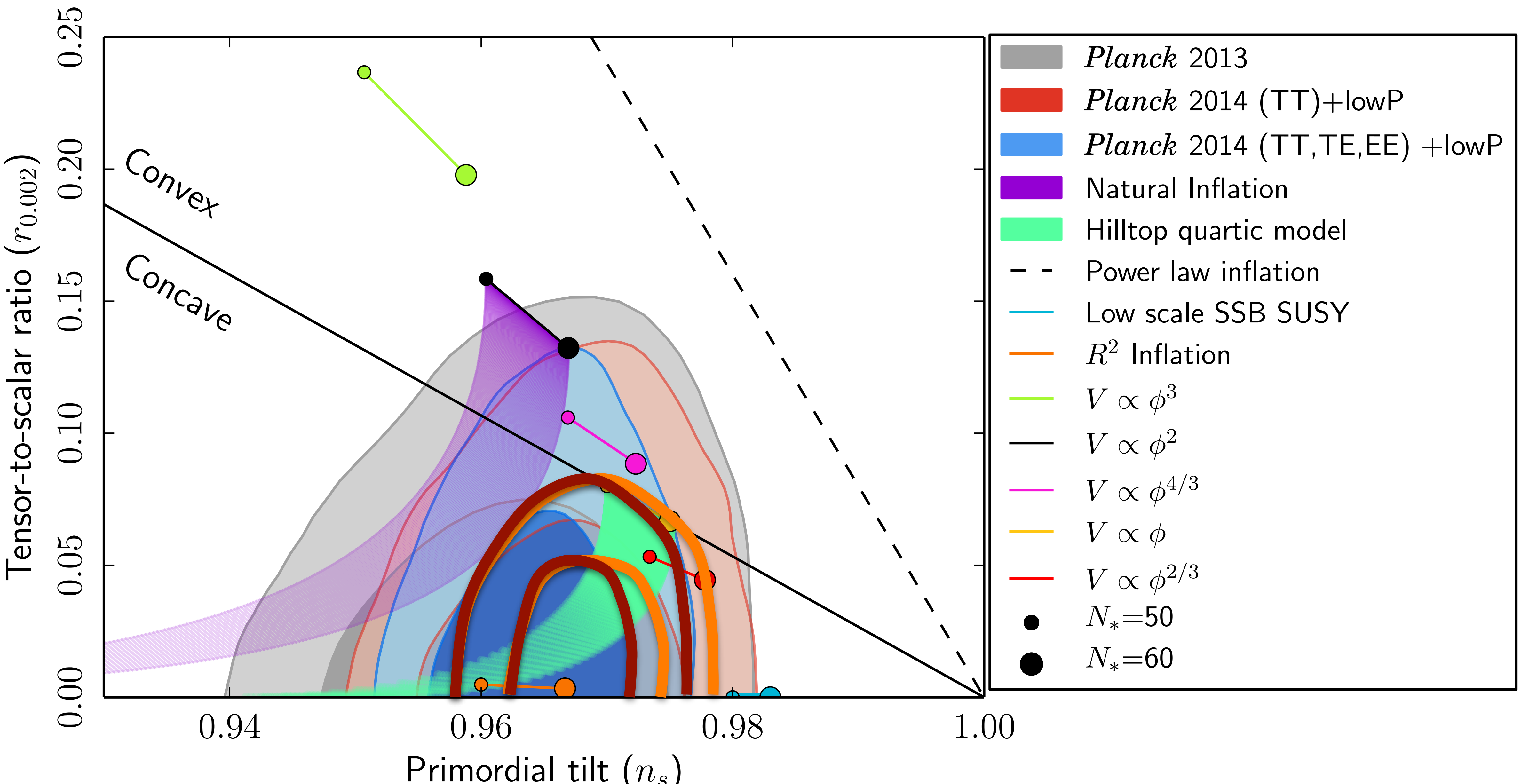
1.5
$n_{s\,0.002}$

Inflation

- Tension on convex models with canonical kinetic term
- OK for Starobinsky, Higgs, some hilltop/SSB, logarithmic radiative corrections



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Other datasets

WMAP in the common range (2<l<800)

Other datasets

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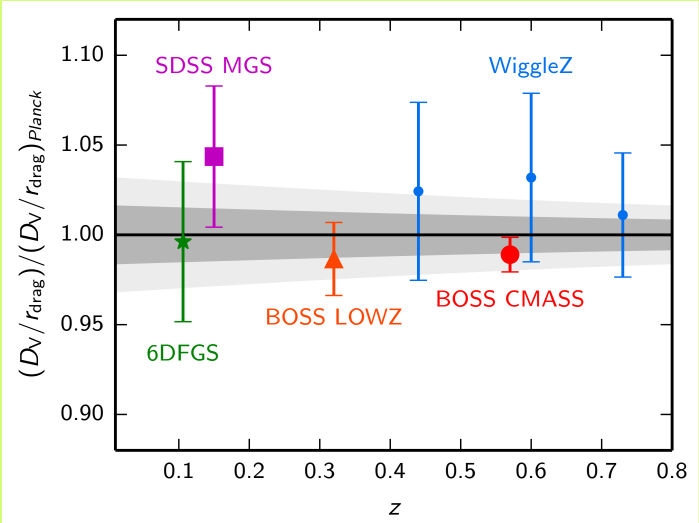
Other datasets

Baryon Acoustic Oscillations



Planck 2015

WMAP in the common range (2<l<800)

Other datasets

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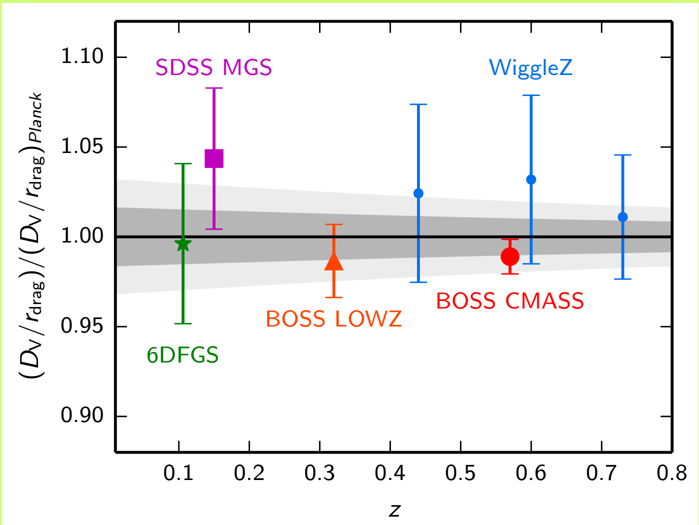
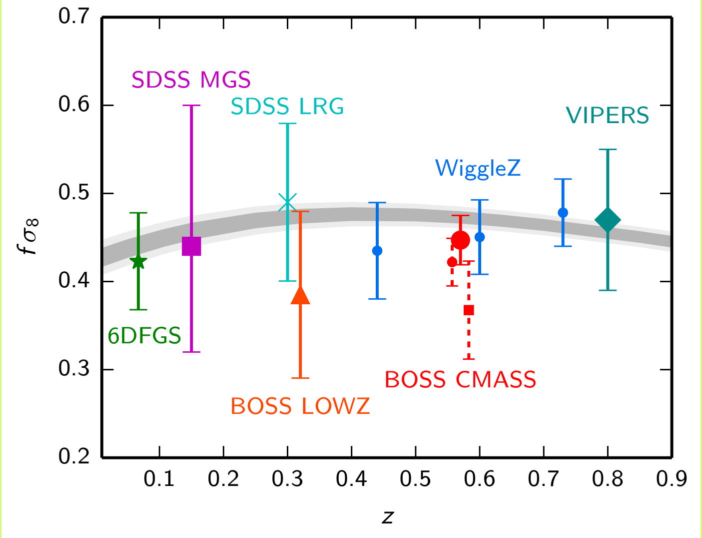


Planck 2015

Redshift Space Distorsions



Planck 2015

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WMAP in the common range (2<l<800)

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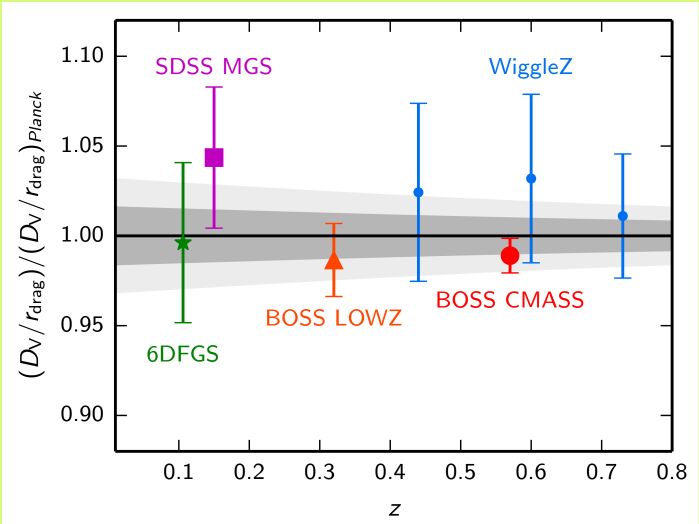

Planck 2015

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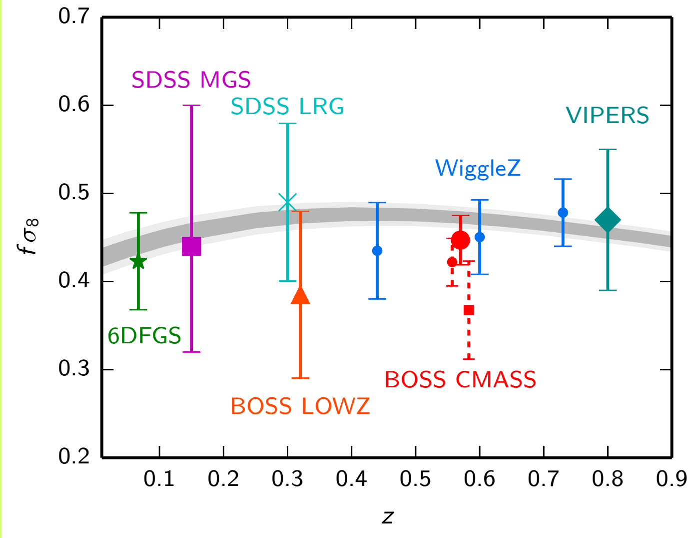
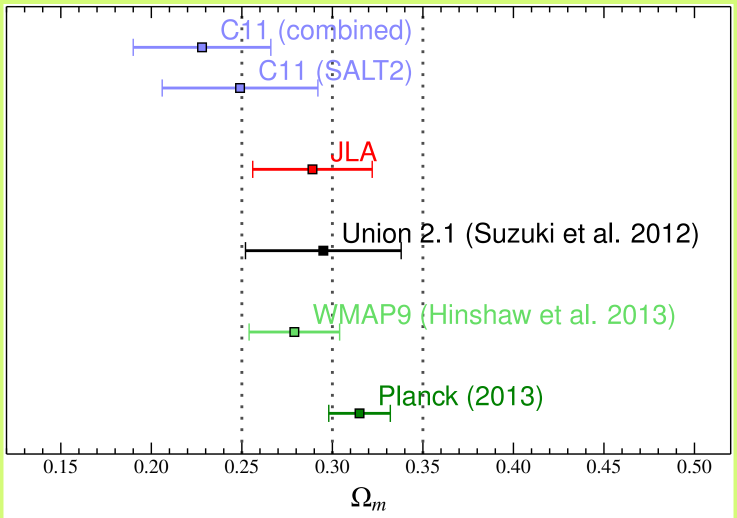


Planck 2015

Supernovae luminosity



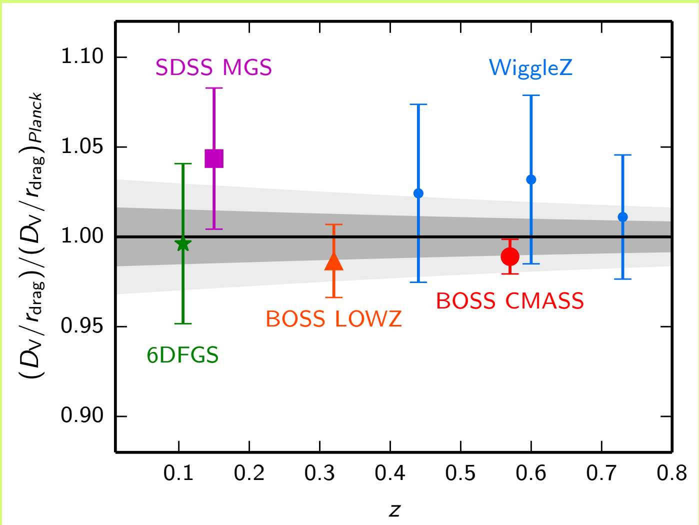
Betoule et al. 2014

WMAP in the common range (2<l<800)

Other datasets

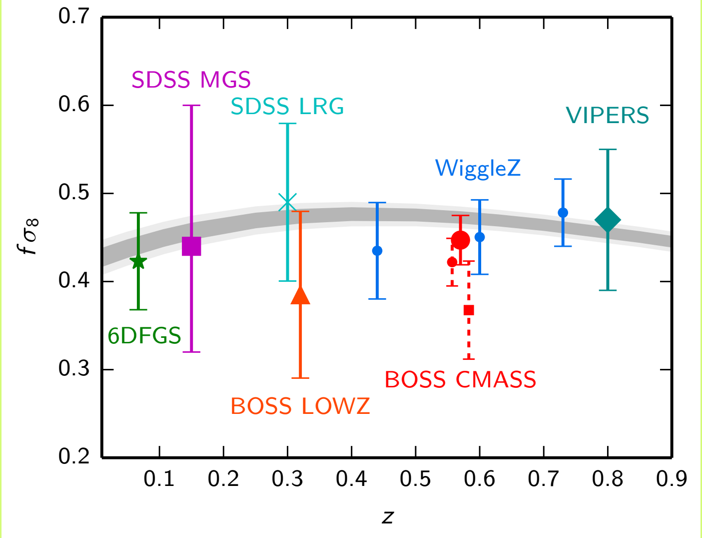
BBN and primordial abundances

Baryon Acoustic Oscillations



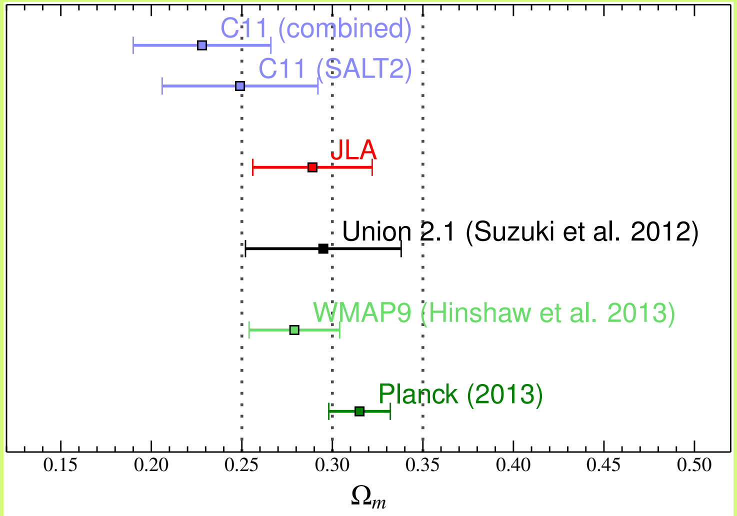
Planck 2015

Redshift Space Distorsions



Planck 2015

Supernovae luminosity



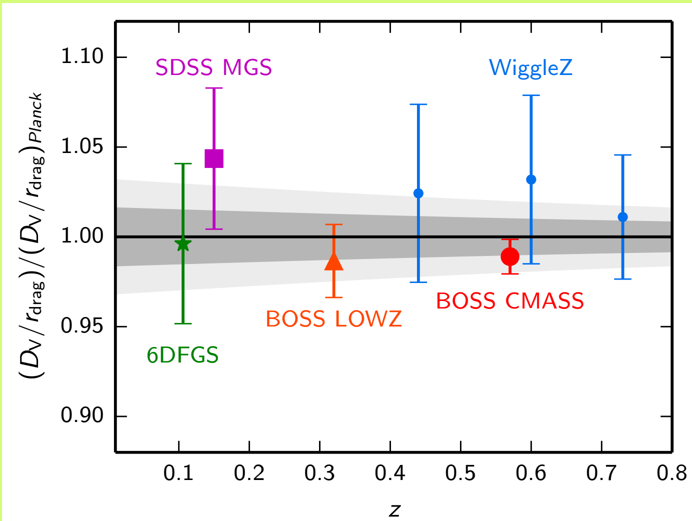
Betoule et al. 2014

Other datasets

WMAP in the common range (2<l<800)

BBN and primordial abundances

Baryon Acoustic Oscillations



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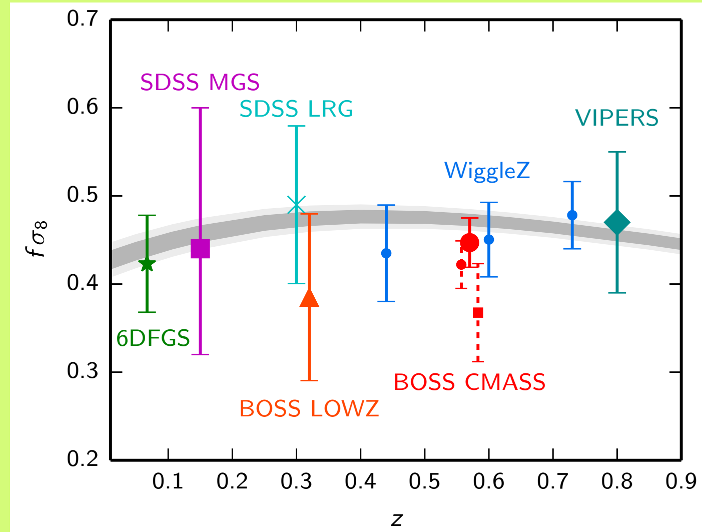

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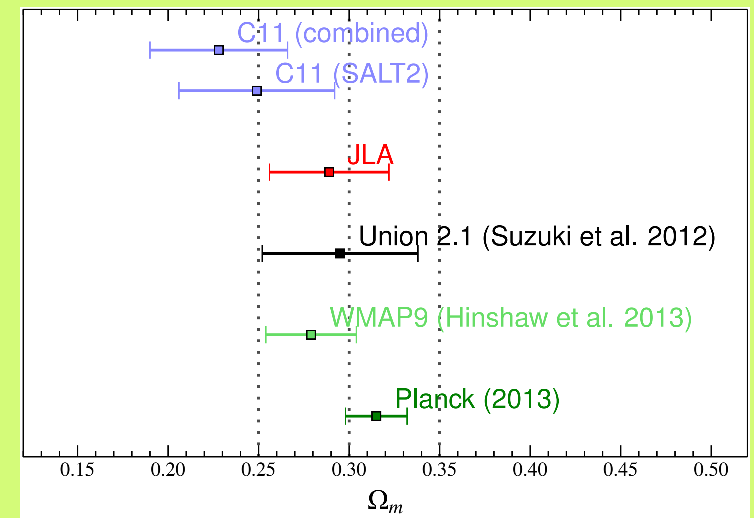

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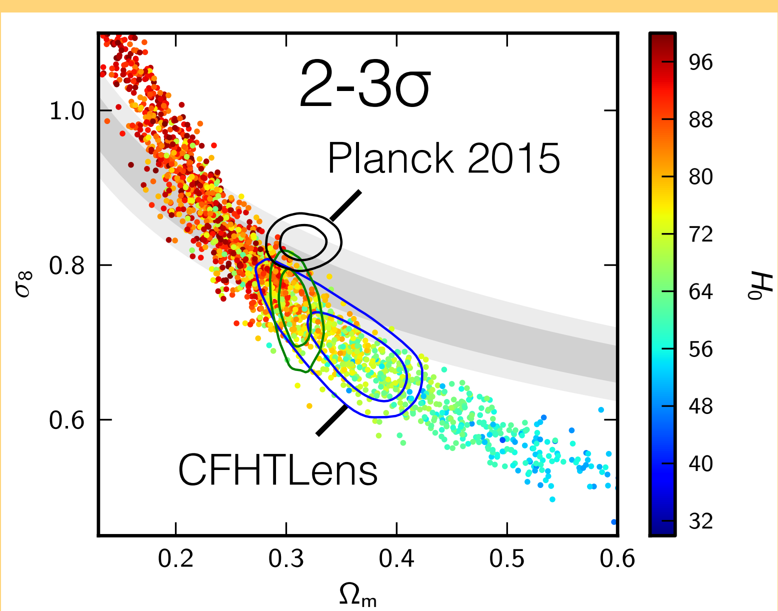

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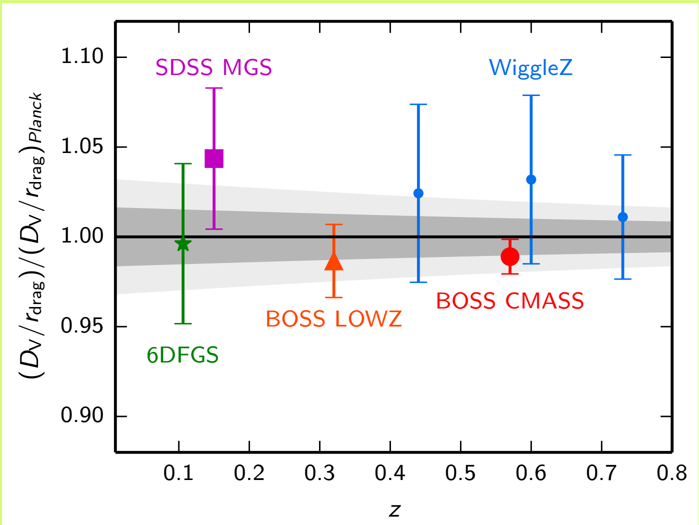

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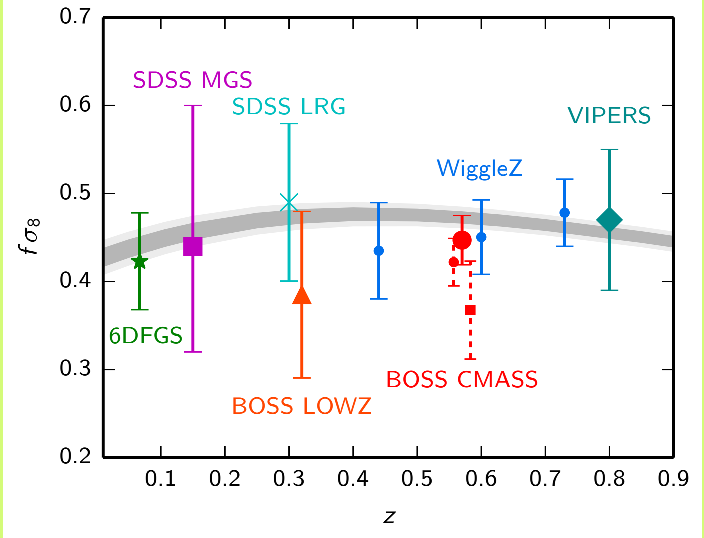

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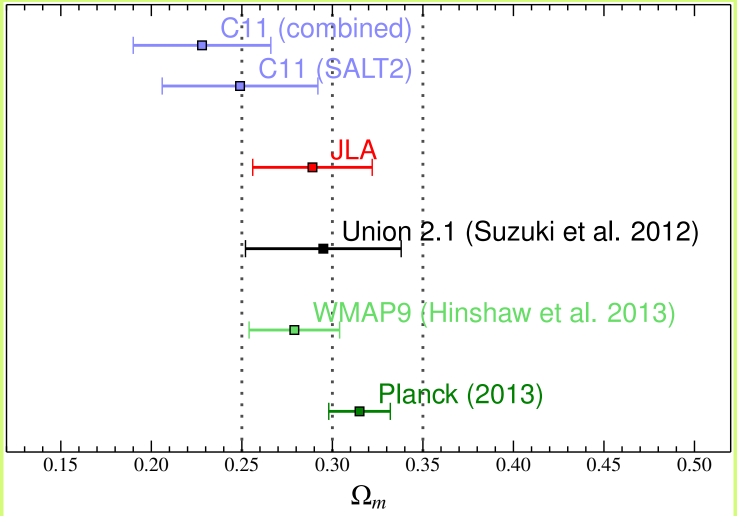

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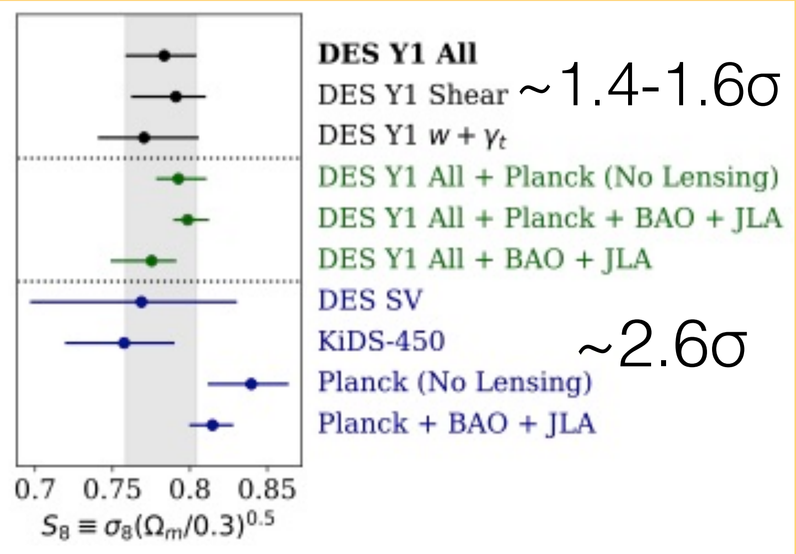

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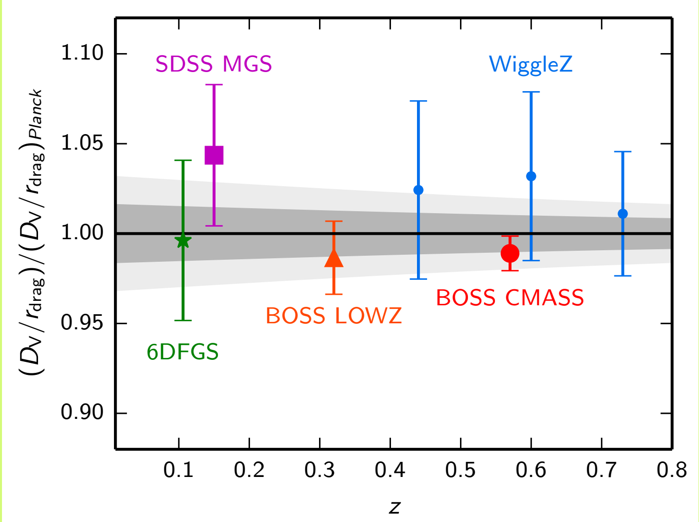

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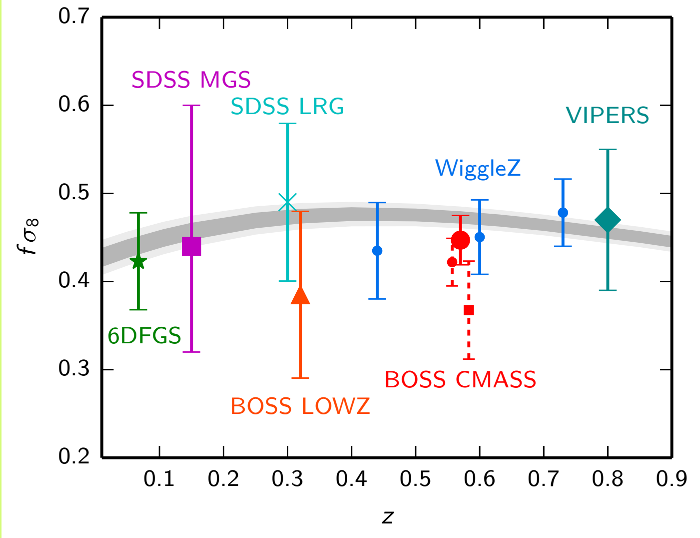

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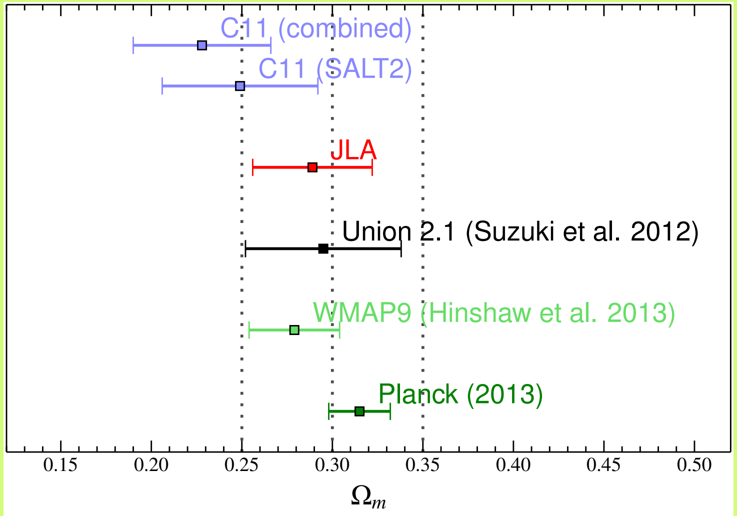

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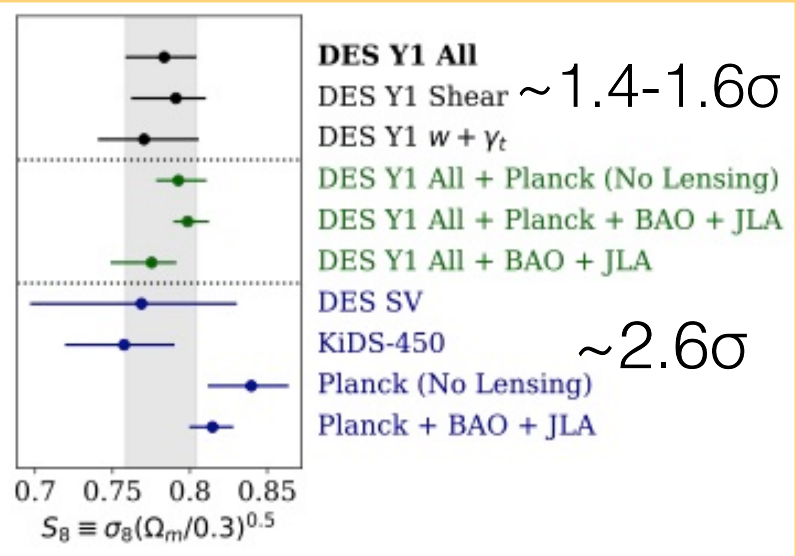
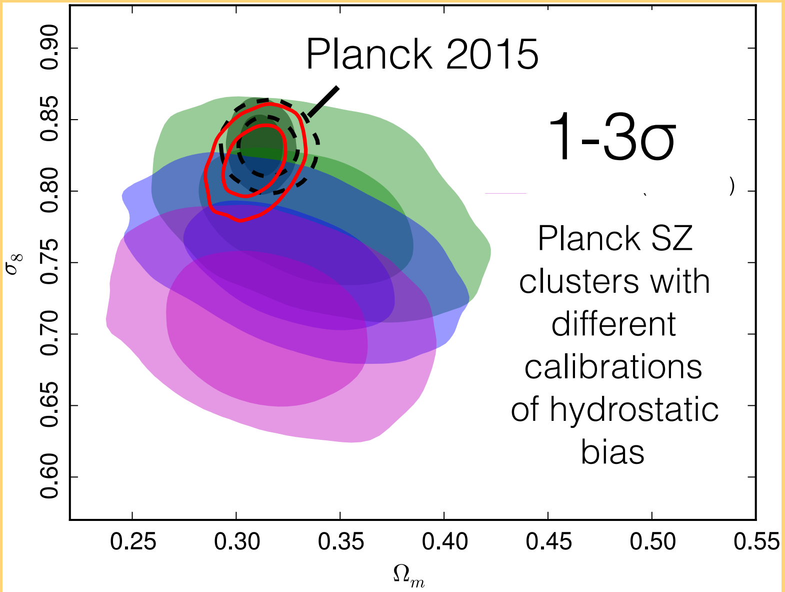


Cluster counts (σ_8, Ω_m)



esa planck

TTK Institute for Theoretical Particle Physics and Cosmology

RWTH AACHEN UNIVERSITY

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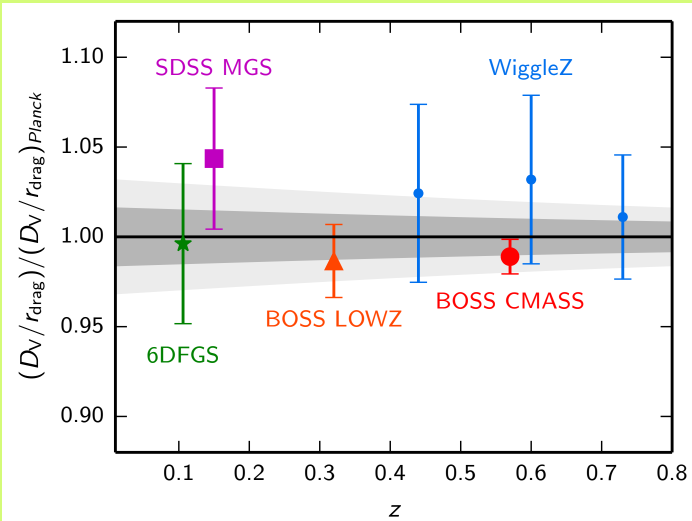

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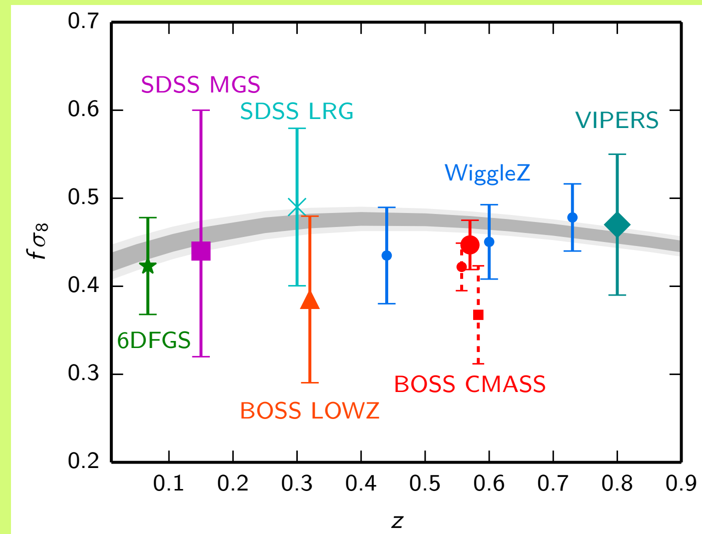

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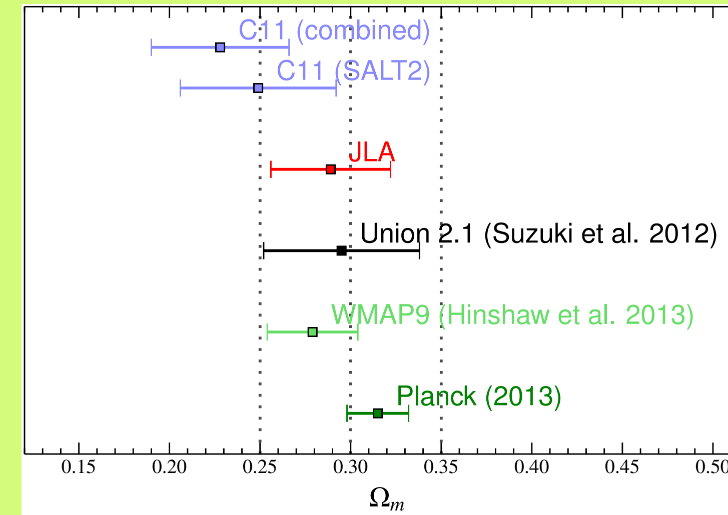

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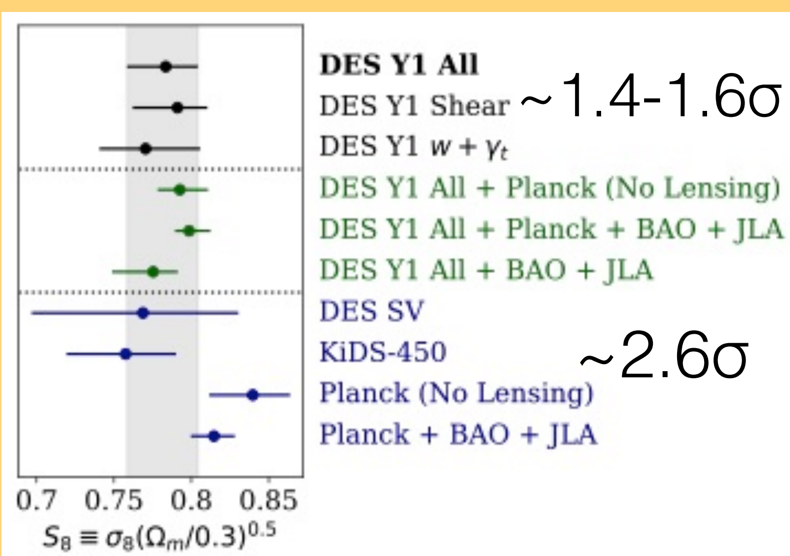
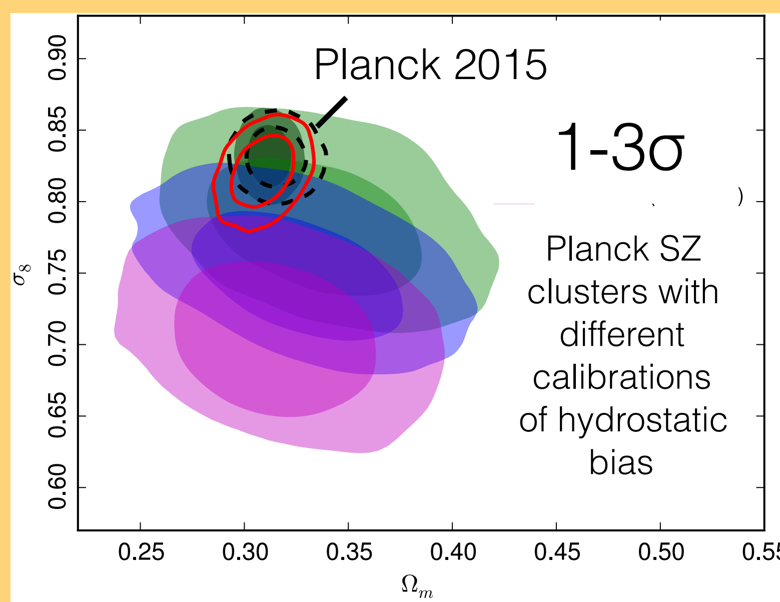


~1.4-1.6σ

~2.6σ

Cluster counts (σ_8, Ω_m)



1-3σ

Planck SZ clusters with different calibrations of hydrostatic bias

direct H_0 measurements

H_0=66.9±0.91 (PlanckTT+SIMlow_HFI, Planck 2016)

H_0=73.±1.8 (Riess+16)

3.2σ

H_0=72.8±2.4 (Riess+11)

H_0=70.6 ± 3.3 (Efstathiou+14)

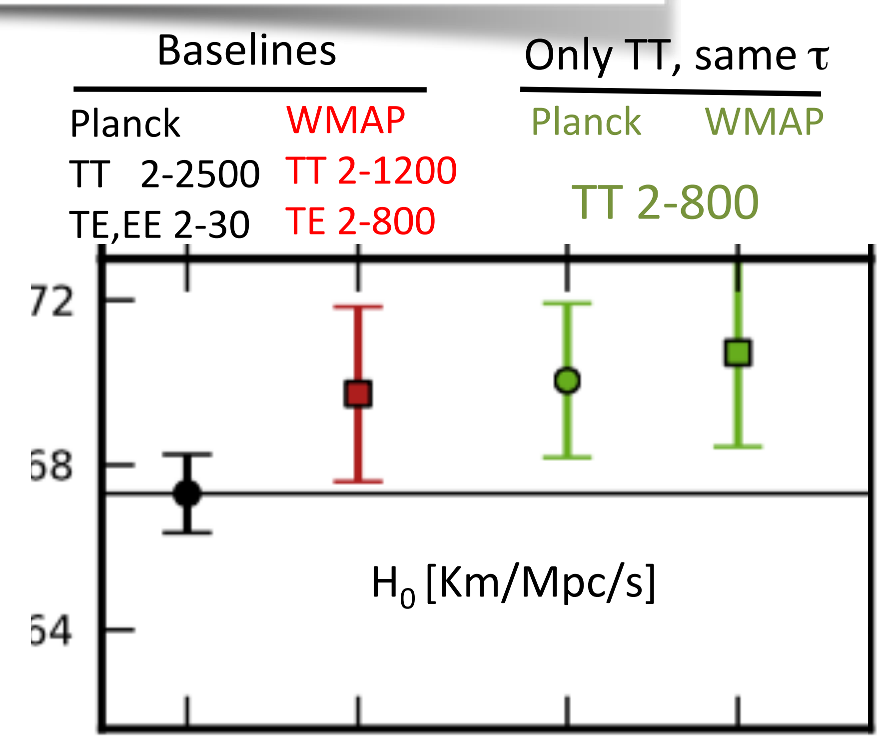
H_0=74.3 ± 2.6 (Freedman+12)

[Km/s/Mpc]

Other datasets

Discussion of parameter shifts between WMAP/SPT/Planck in 1608.02487 (Galli, Millea, Knox, Narmani, Scott, White & Planck col.)

- CMB-H_0 tension: Planck versus WMAP:



- Is parameter shift (from l<800 to l<2500) anomalous?
    - 5000 random realisations of LCDM models tested by Planck: 16% have shifts at least as big.
    - Related to 20<l<30? Related to smoothing of peaks (A_L>1)? Maybe but this is real data…

What if the tension was real?

H_0 and σ_8 are NOT measured directly by CMB experiments…

… only extrapolated down to low-z assuming ΛCDM or simple extensions!

So it could be real and calling for a (small) change of paradigm!

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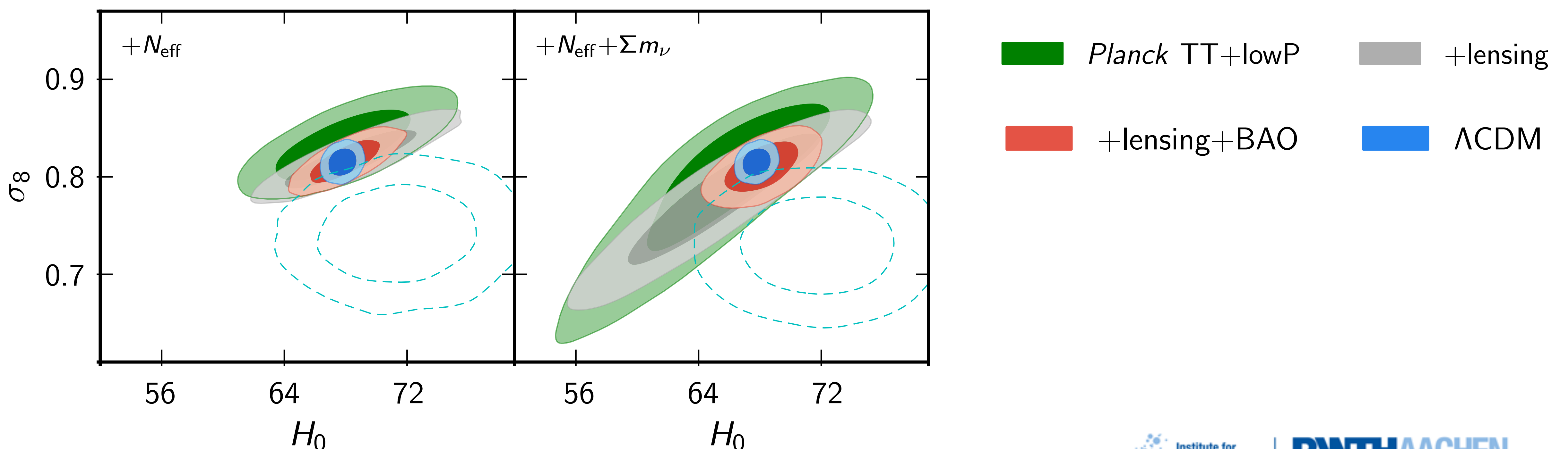

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But lots of other particle-physics-motivated possibilities, some of them proved to work (much better agreement with "anomalous" H_0 and/or σ_8) !

- Interacting DM-DR "motivated" by potential freedom and complexity of Dark Sector

  JL, Marques-Tavares, Schmaltz 2016; Buen-Abad, Schmaltz, JL, Brinckmann 1708.09406

  See also 1708.07030

- Interacting active-sterile neutrino "motivated" by short baseline anomaly in neutrino oscillation experiments

  Archidiacono et al. 2016

- Self-interacting active neutrinos

  Lancaster et al. 2017; Oldengott et al. 2017

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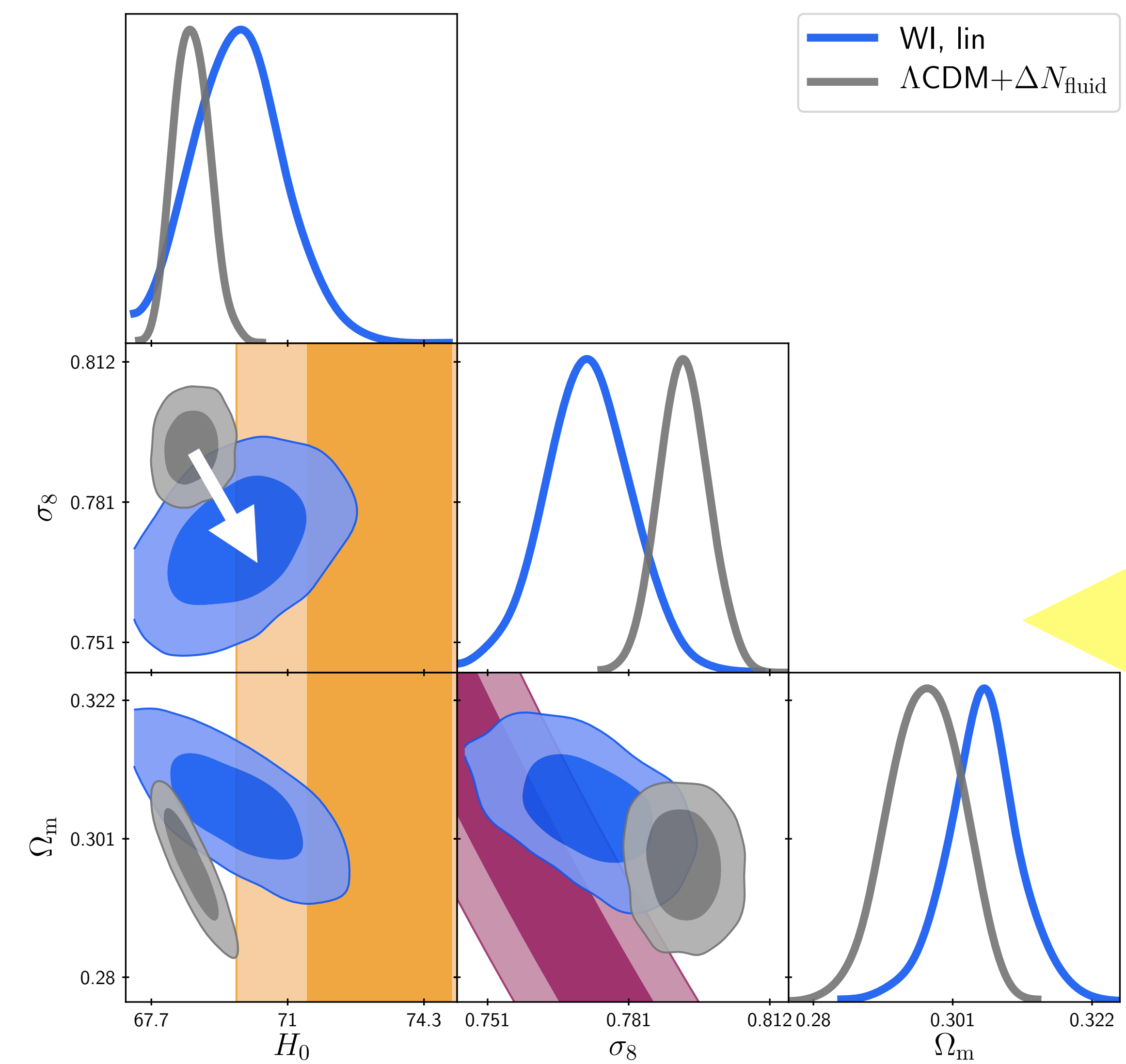

Up to 4.1σ evidence for DM-DR scattering rate

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Buen-Abad, Schmaltz, JL, Brinckmann 1708.09406

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