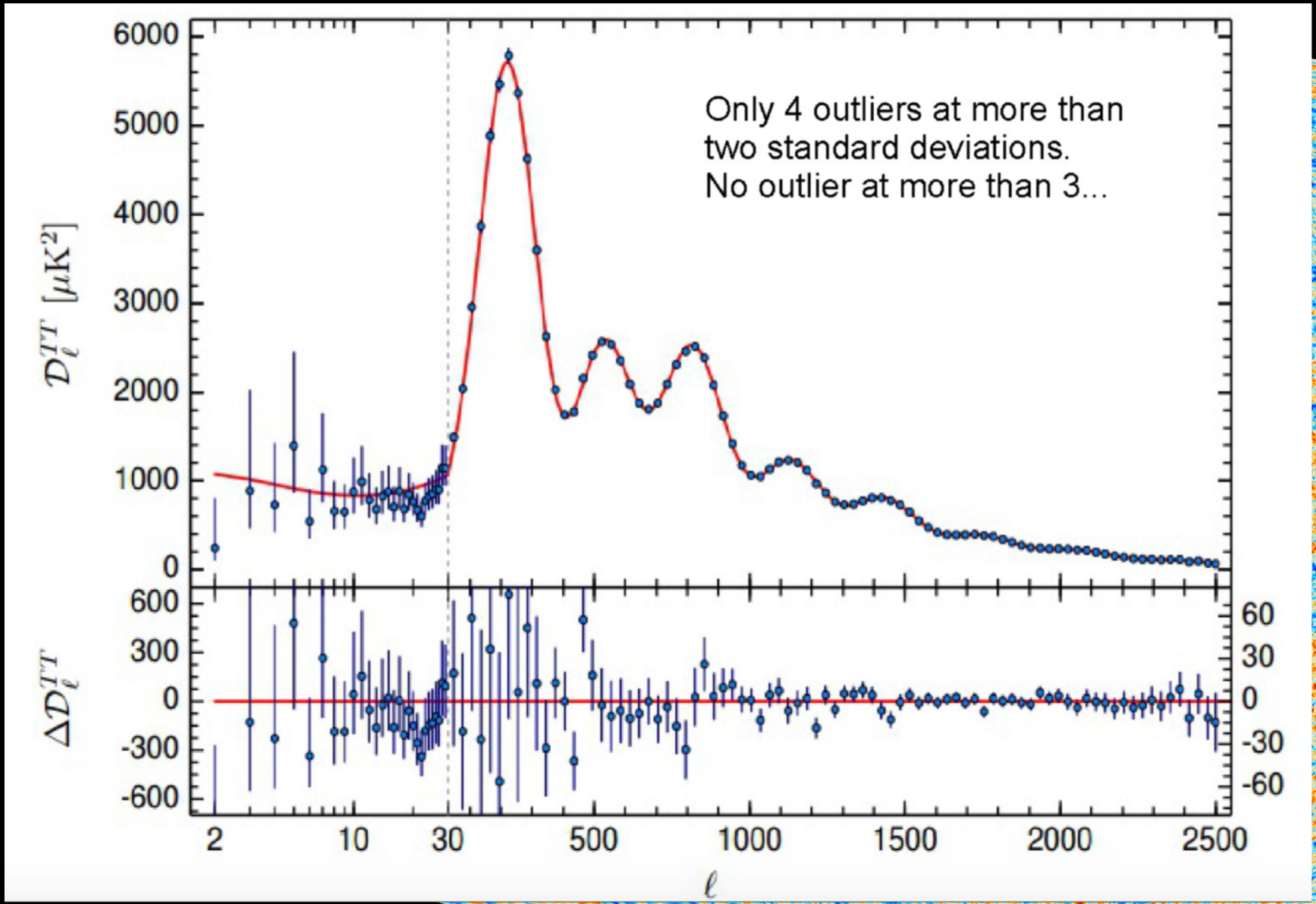
COSMIC MICROWAVE BACKGROUND POLARIZATION MEASUREMENTS AND COSMOLOGICAL DATA TENSIONS

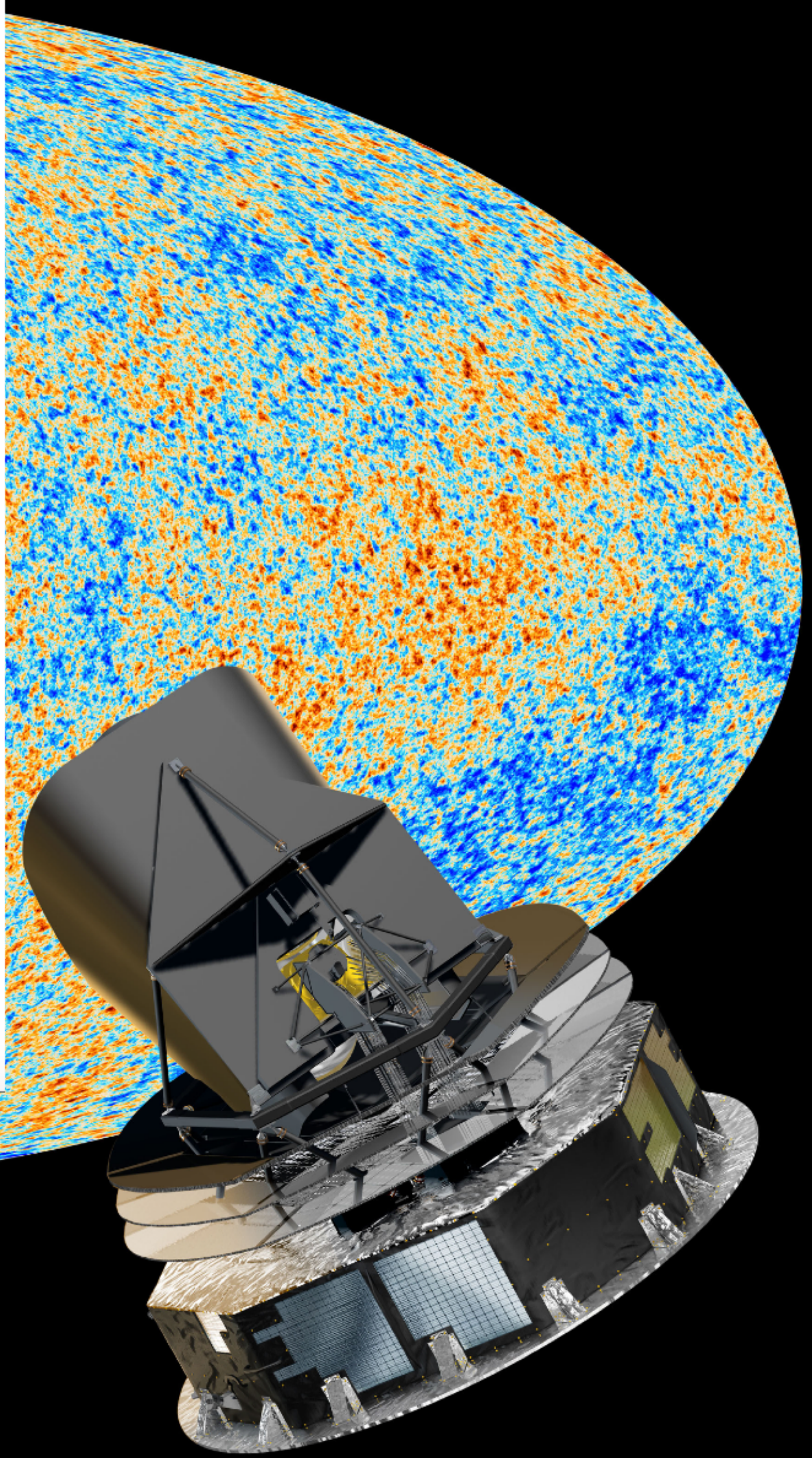
TENSIONS IN COSMOLOGY
6-12 SEPTEMBER 2023 (SEPTEMBER 11TH)
MON REPOS, CORFU

ALESSANDRO MELCHIORRI
UNIVERSITY OF ROME “SAPIENZA”

A PERFECT (LCDM) UNIVERSE ?



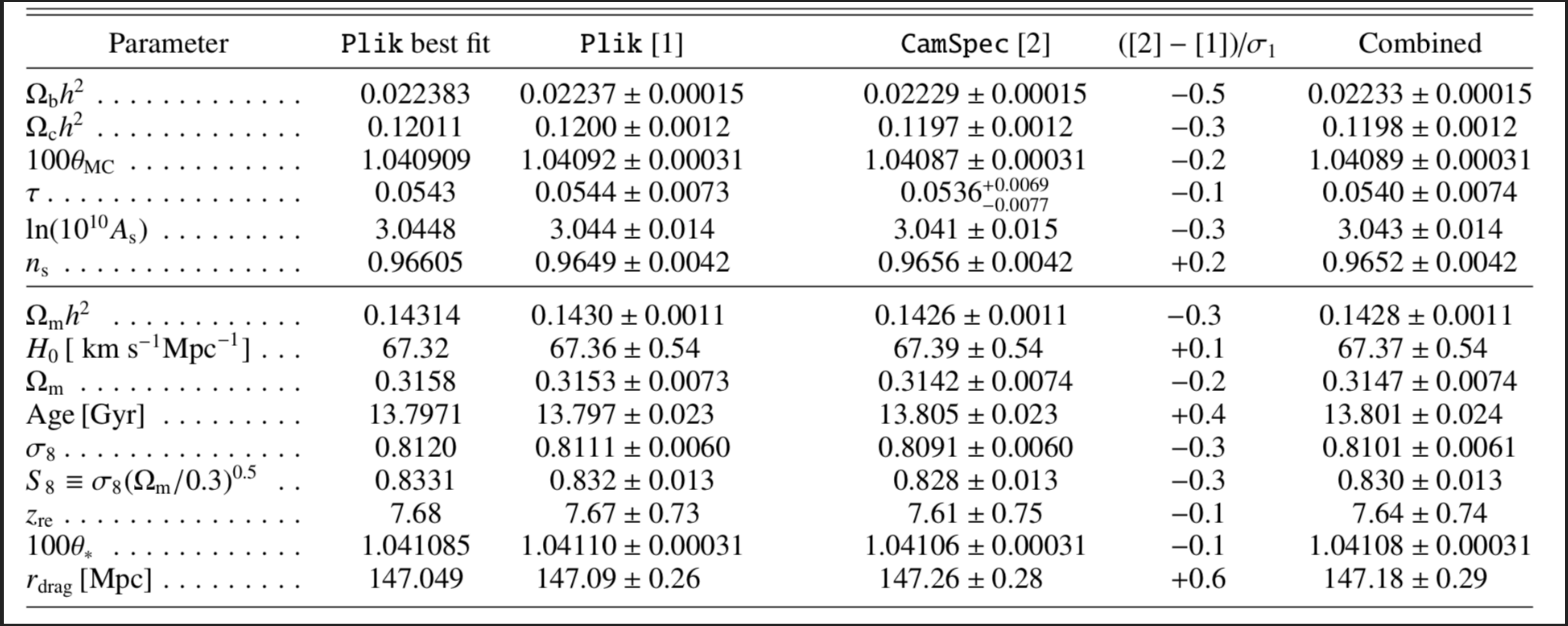
Only 4 outliers at more than two standard deviations. No outlier at more than 3...



The recent CMB measurements made by the Planck satellite are in perfect agreement with the expectations of the LCDM model.

Planck collaboration, arXiv:1502.01589

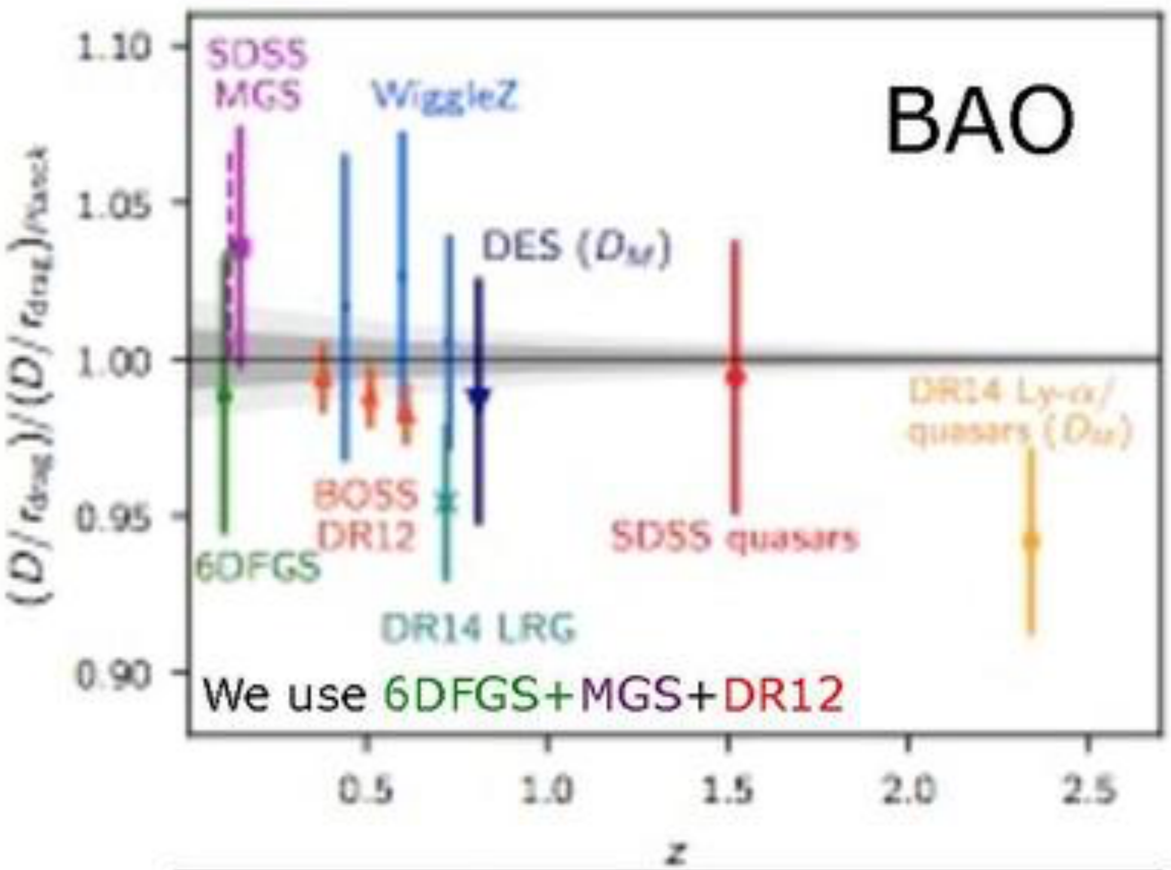
Cosmological Parameters from Planck 2018

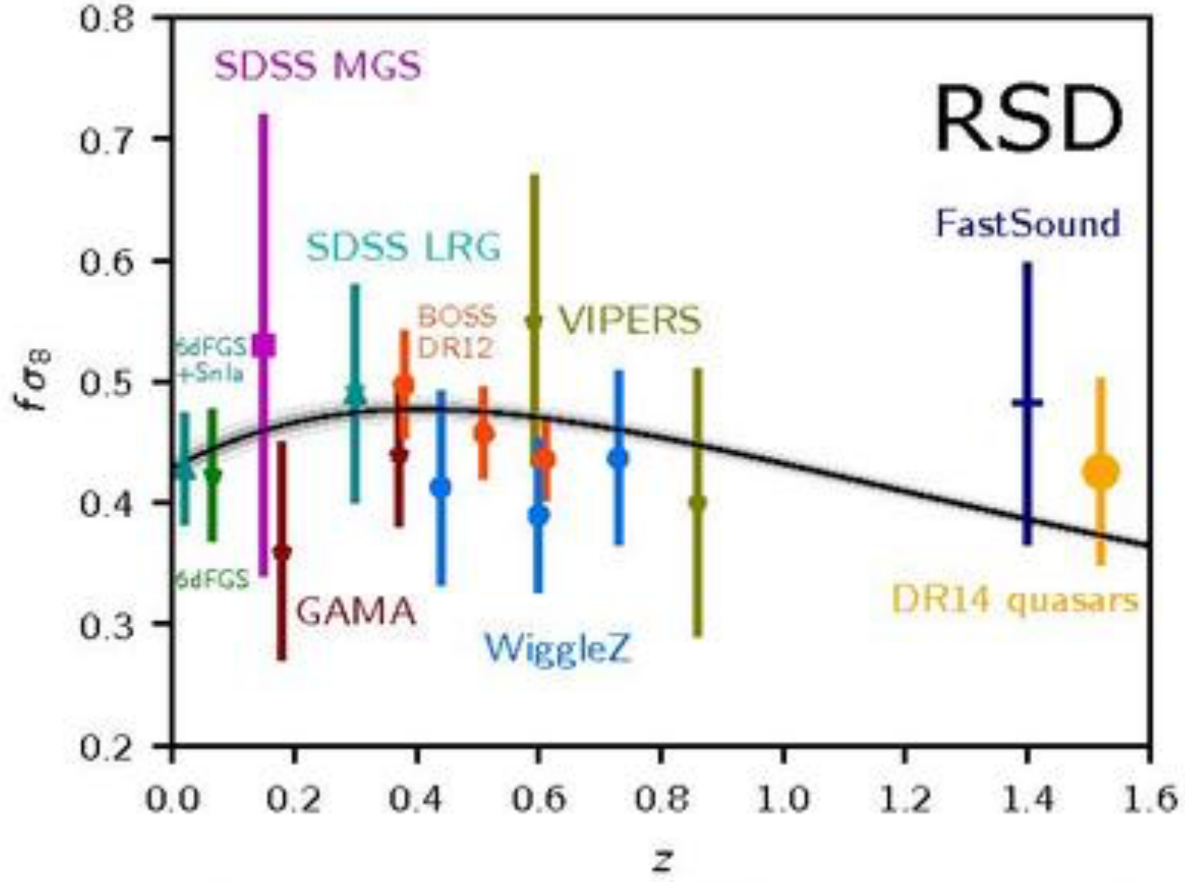


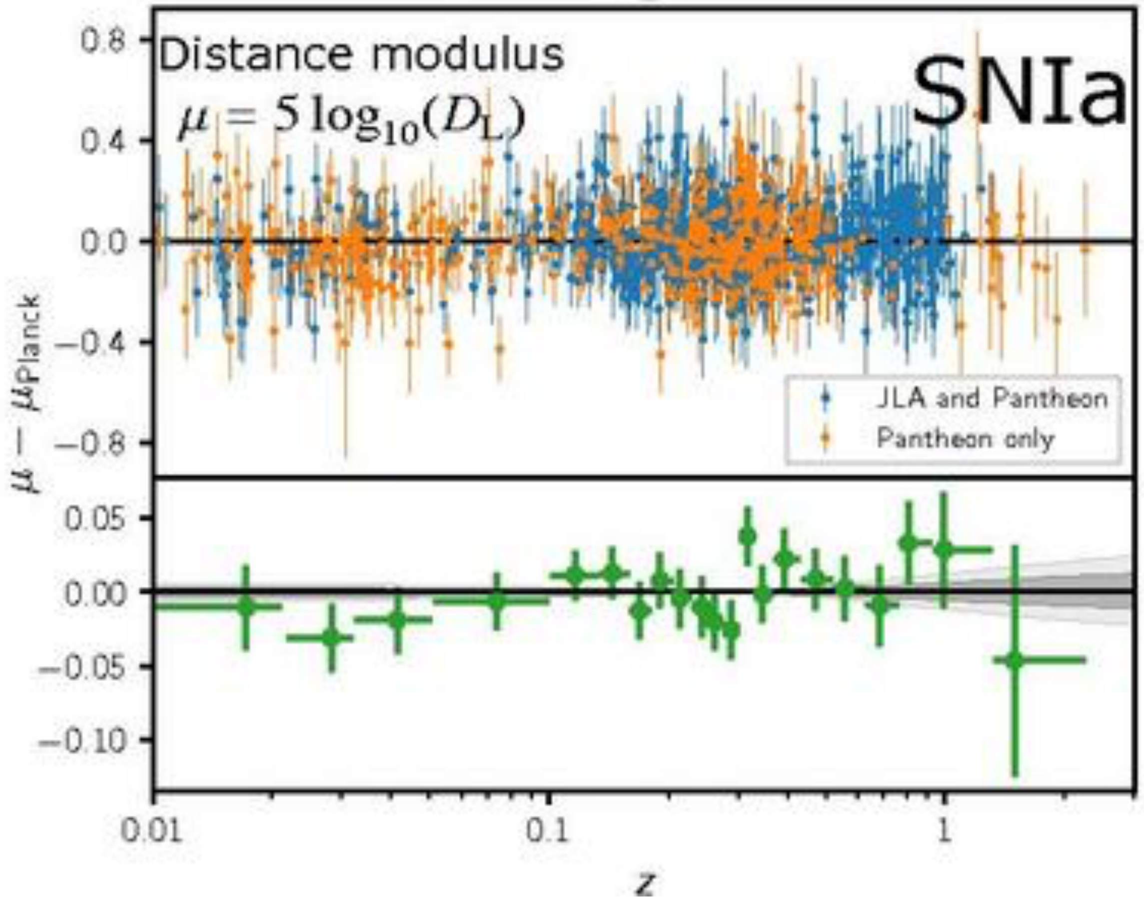
Parameter	Plik best fit	Plik [1]	CamSpec [2]	$([2]-[1])/\sigma_1$	Combined
$\Omega_b h^2$	0.022383	0.02237 ± 0.00015	0.02229 ± 0.00015	−0.5	0.02233 ± 0.00015
$\Omega_c h^2$	0.12011	0.1200 ± 0.0012	0.1197 ± 0.0012	−0.3	0.1198 ± 0.0012
$100\theta_{MC}$	1.040909	1.04092 ± 0.00031	1.04087 ± 0.00031	−0.2	1.04089 ± 0.00031
τ	0.0543	0.0544 ± 0.0073	$0.0536^{+0.0069}_{-0.0077}$	−0.1	0.0540 ± 0.0074
$\ln(10^{10} A_s)$	3.0448	3.044 ± 0.014	3.041 ± 0.015	−0.3	3.043 ± 0.014
n_s	0.96605	0.9649 ± 0.0042	0.9656 ± 0.0042	+0.2	0.9652 ± 0.0042
$\Omega_m h^2$	0.14314	0.1430 ± 0.0011	0.1426 ± 0.0011	−0.3	0.1428 ± 0.0011
H_0 [km s^{-1}Mpc^{-1}]	67.32	67.36 ± 0.54	67.39 ± 0.54	+0.1	67.37 ± 0.54
Ω_m	0.3158	0.3153 ± 0.0073	0.3142 ± 0.0074	−0.2	0.3147 ± 0.0074
Age [Gyr]	13.7971	13.797 ± 0.023	13.805 ± 0.023	+0.4	13.801 ± 0.024
σ_8	0.8120	0.8111 ± 0.0060	0.8091 ± 0.0060	−0.3	0.8101 ± 0.0061
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$	0.8331	0.832 ± 0.013	0.828 ± 0.013	−0.3	0.830 ± 0.013
z_{re}	7.68	7.67 ± 0.73	7.61 ± 0.75	−0.1	7.64 ± 0.74
$100\theta_*$	1.041085	1.04110 ± 0.00031	1.04106 ± 0.00031	−0.1	1.04108 ± 0.00031
r_{drag} [Mpc]	147.049	147.09 ± 0.26	147.26 ± 0.28	+0.6	147.18 ± 0.29

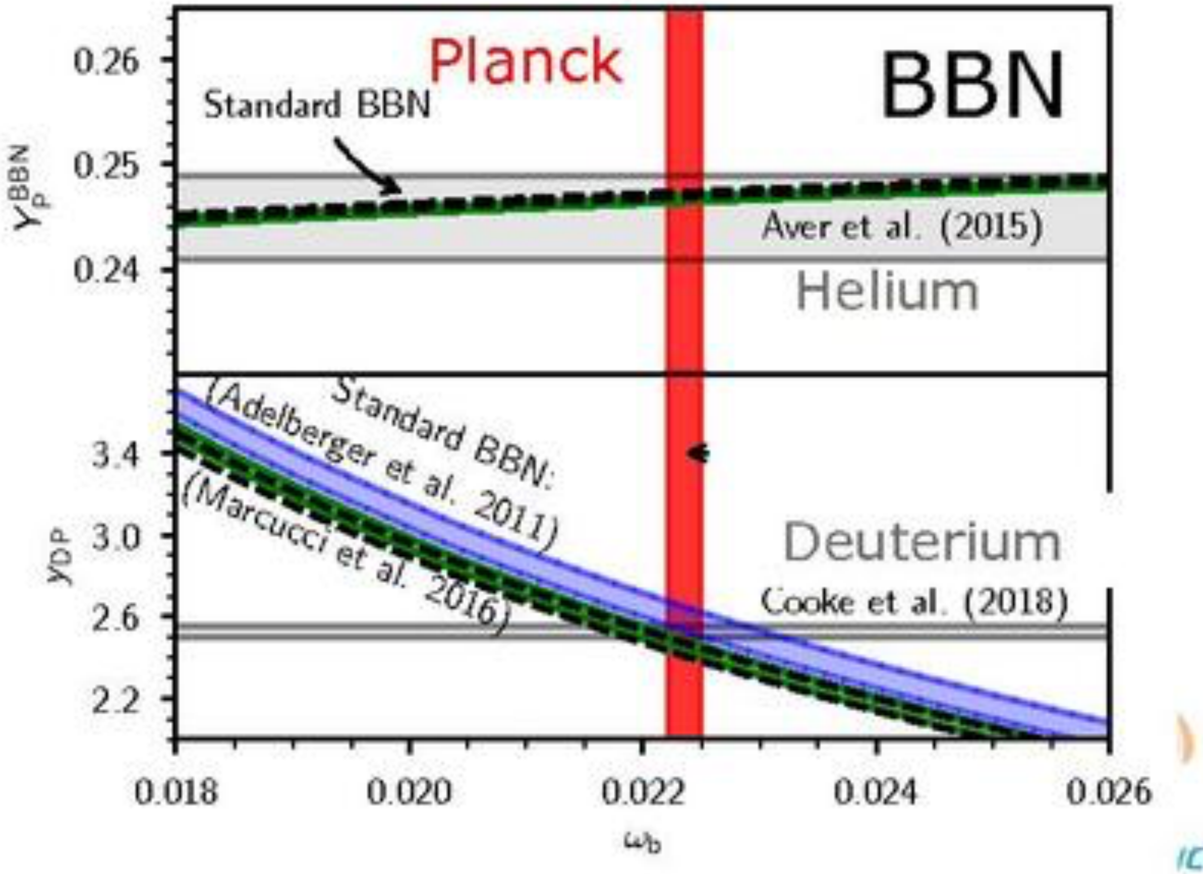
The 6 parameters of the LCDM model are measured with incredible precision. From these parameters we can also derive precise constraints on more parameters (like the age of the universe) that are not directly measured by the CMB.

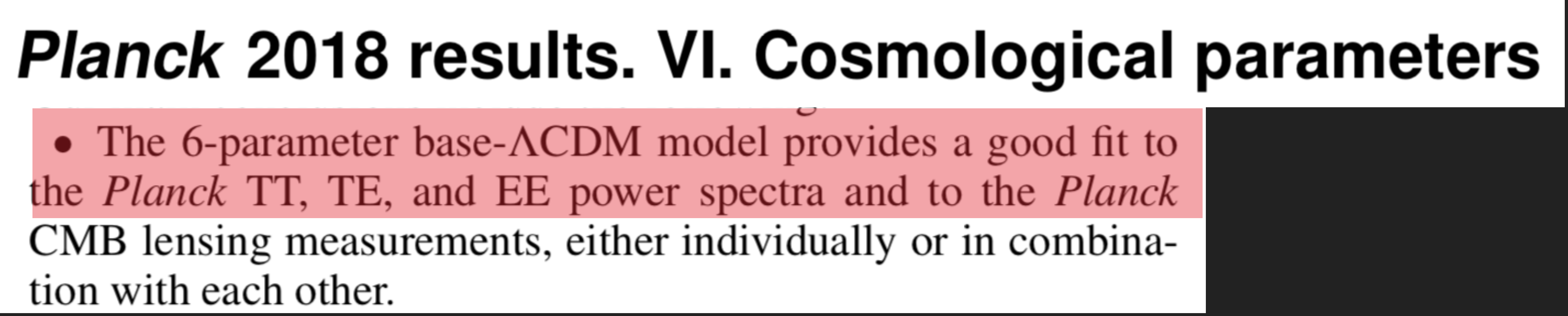
Good consistency with BAO, RSD, SnIa, BBN





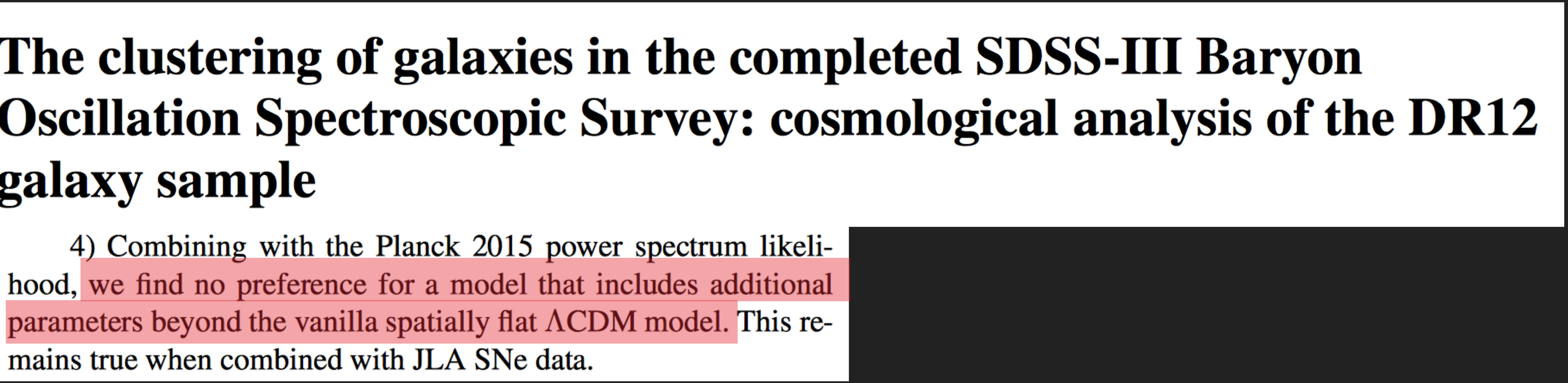






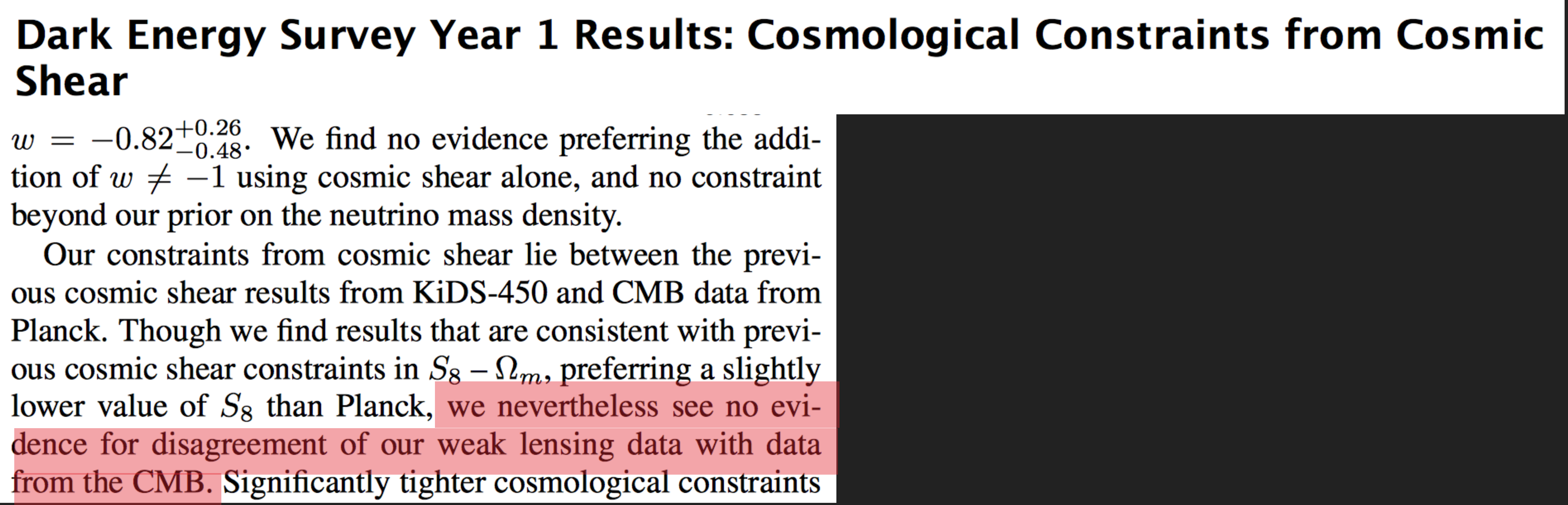
Planck 2018 results. VI. Cosmological parameters

- The 6-parameter base-ΛCDM model provides a good fit to the *Planck* TT, TE, and EE power spectra and to the *Planck* CMB lensing measurements, either individually or in combination with each other.



The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample

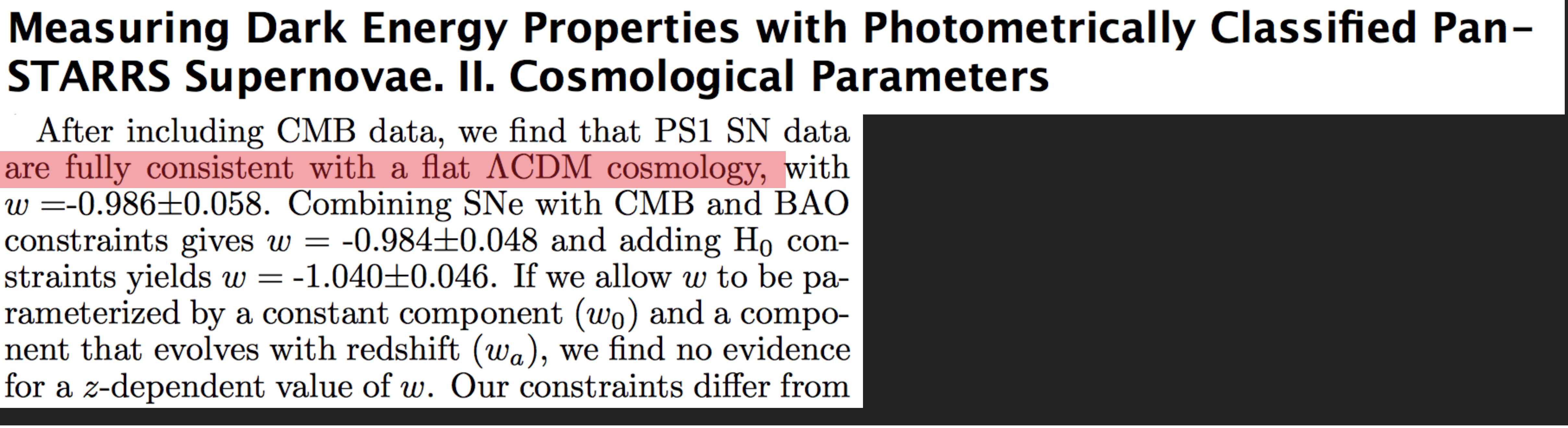
4) Combining with the Planck 2015 power spectrum likelihood, we find no preference for a model that includes additional parameters beyond the vanilla spatially flat ΛCDM model. This remains true when combined with JLA SNe data.



Dark Energy Survey Year 1 Results: Cosmological Constraints from Cosmic Shear

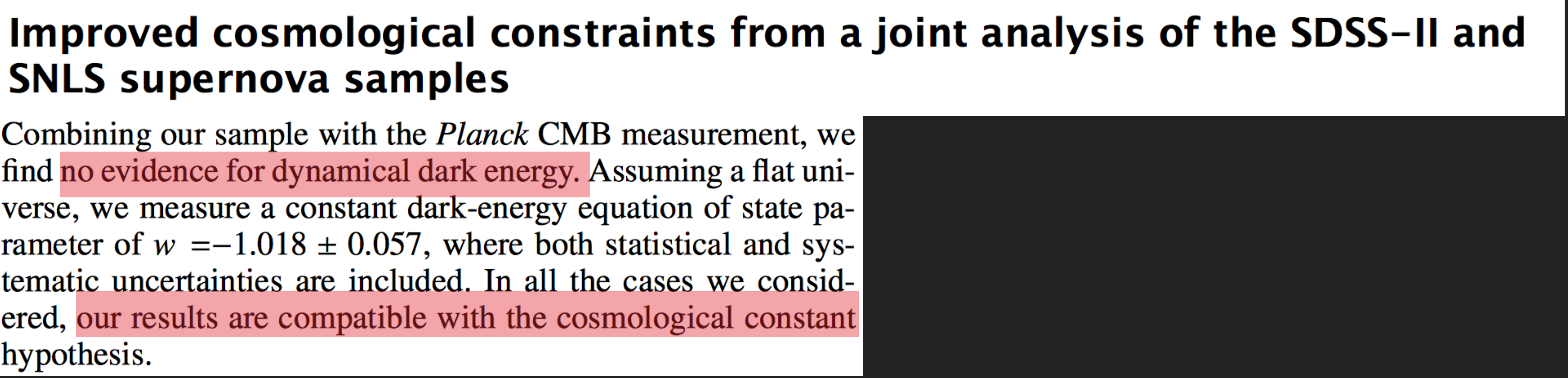
$w = -0.82^{+0.26}_{-0.48}$. We find no evidence preferring the addition of $w \neq -1$ using cosmic shear alone, and no constraint beyond our prior on the neutrino mass density.

Our constraints from cosmic shear lie between the previous cosmic shear results from KiDS-450 and CMB data from Planck. Though we find results that are consistent with previous cosmic shear constraints in $S_8 - \Omega_m$, preferring a slightly lower value of S_8 than Planck, we nevertheless see no evidence for disagreement of our weak lensing data with data from the CMB. Significantly tighter cosmological constraints



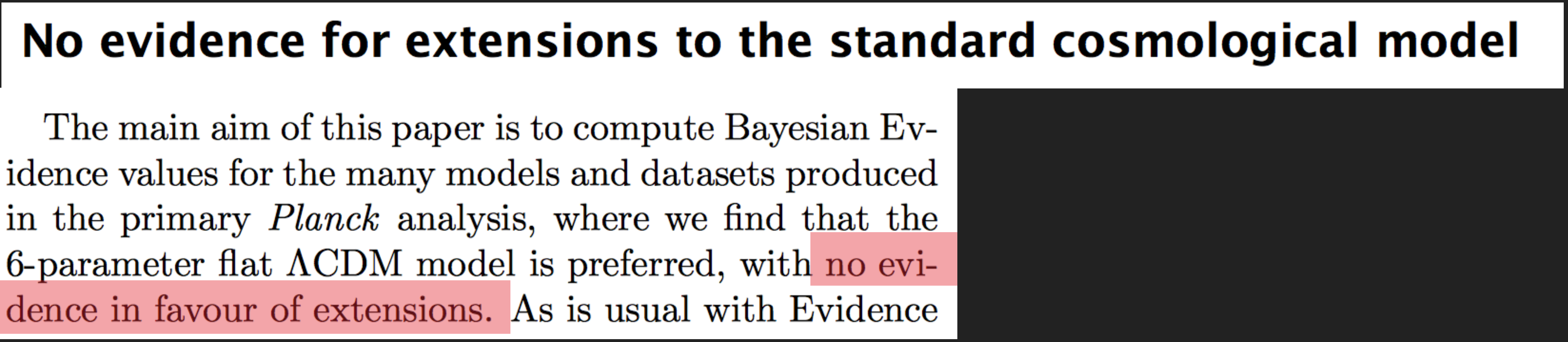
Measuring Dark Energy Properties with Photometrically Classified Pan-STARRS Supernovae. II. Cosmological Parameters

After including CMB data, we find that PS1 SN data are fully consistent with a flat ΛCDM cosmology, with w =-0.986±0.058. Combining SNe with CMB and BAO constraints gives w = -0.984±0.048 and adding H_0 constraints yields w = -1.040±0.046. If we allow w to be parameterized by a constant component (w_0) and a component that evolves with redshift (w_a), we find no evidence for a z-dependent value of w. Our constraints differ from



Improved cosmological constraints from a joint analysis of the SDSS-II and SNLS supernova samples

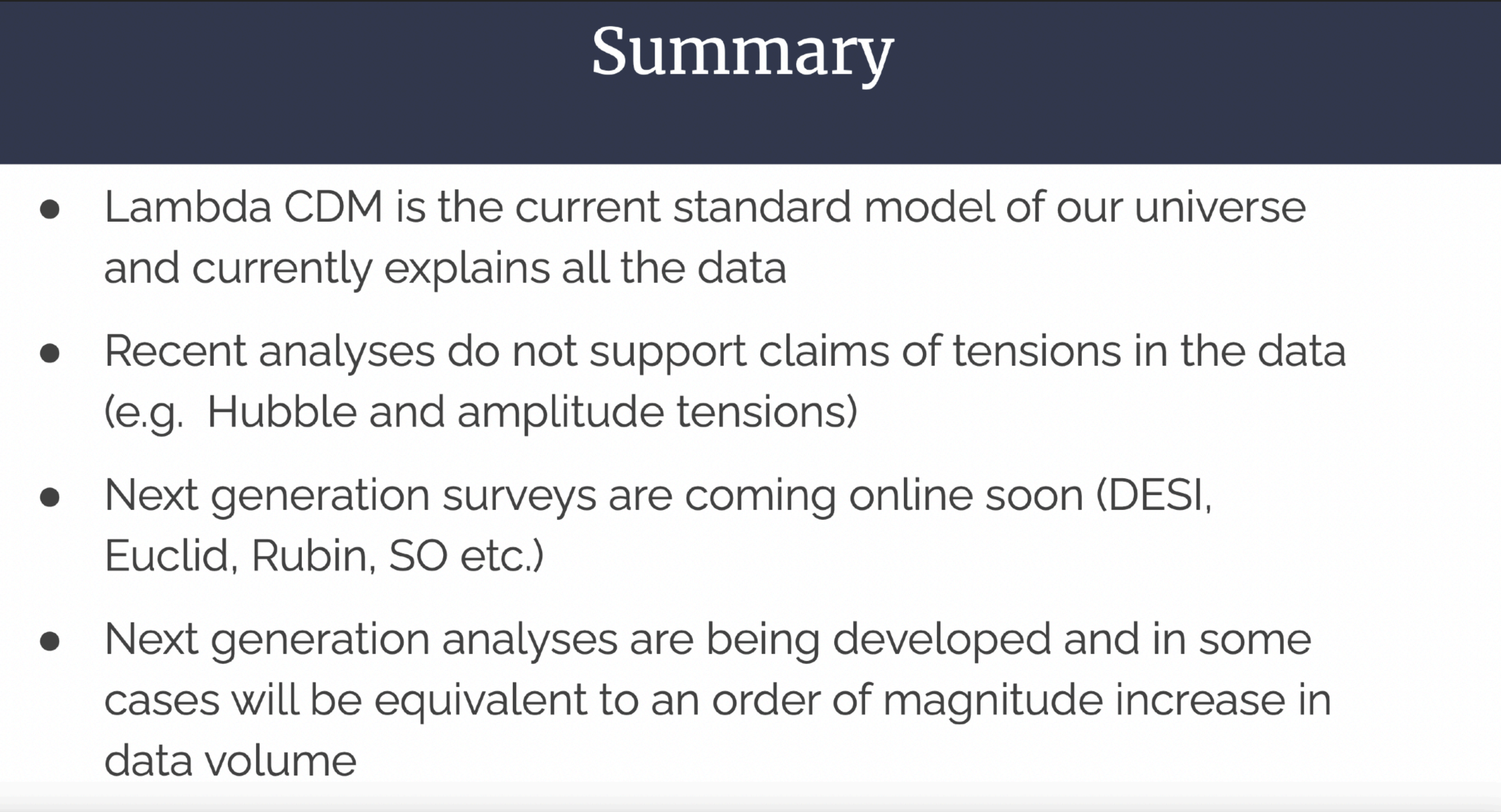
Combining our sample with the *Planck* CMB measurement, we find no evidence for dynamical dark energy. Assuming a flat universe, we measure a constant dark-energy equation of state parameter of w =−1.018 ± 0.057, where both statistical and systematic uncertainties are included. In all the cases we considered, our results are compatible with the cosmological constant hypothesis.



No evidence for extensions to the standard cosmological model

The main aim of this paper is to compute Bayesian Evidence values for the many models and datasets produced in the primary *Planck* analysis, where we find that the 6-parameter flat ΛCDM model is preferred, with no evidence in favour of extensions. As is usual with Evidence

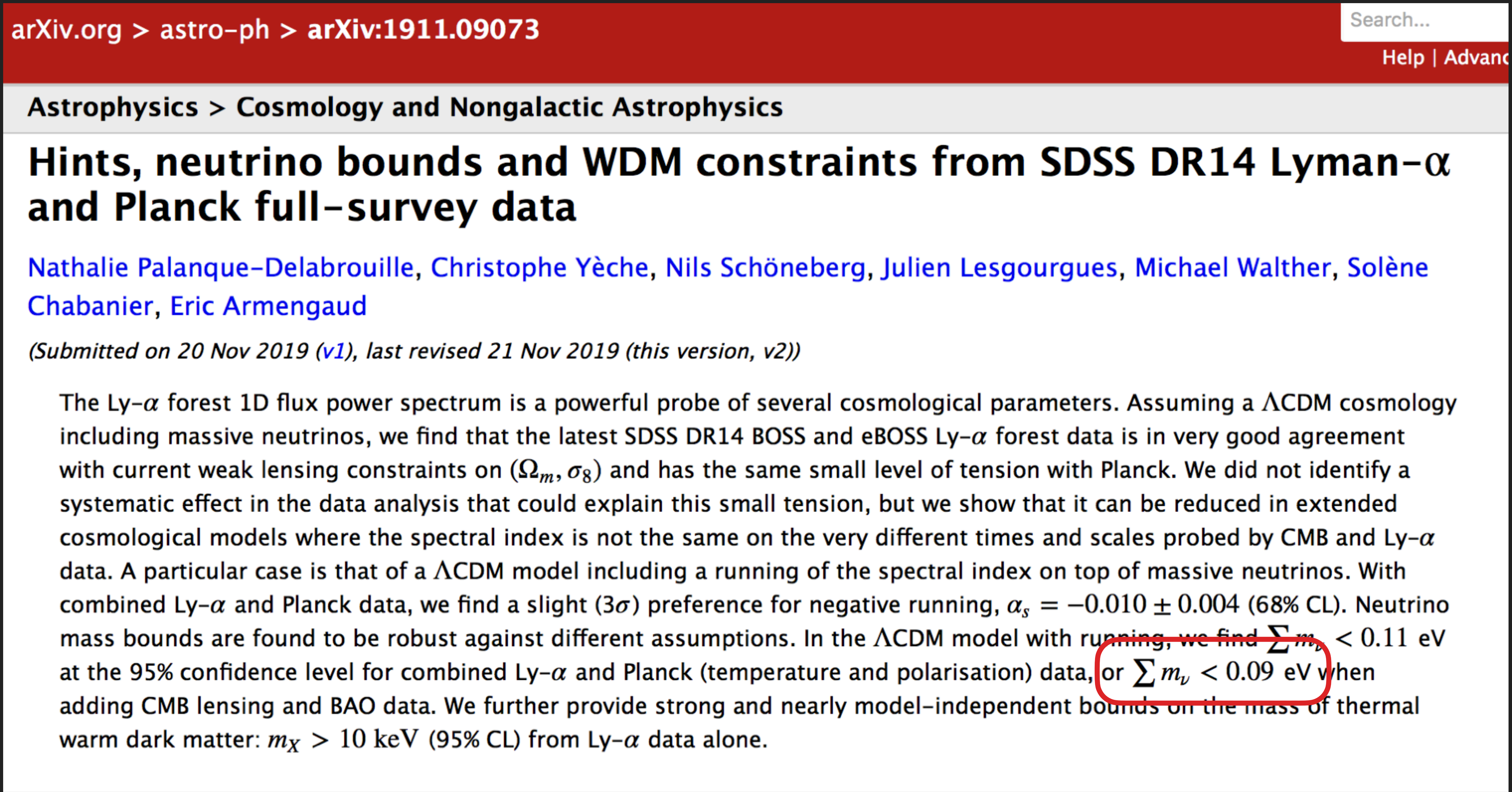
UROS SELJAK'S CONCLUDING REMARKS AT RECENT COSMOLOGY IN MIRAMARE 2023 CONFERENCE



Summary

- Lambda CDM is the current standard model of our universe and currently explains all the data
- Recent analyses do not support claims of tensions in the data (e.g. Hubble and amplitude tensions)
- Next generation surveys are coming online soon (DESI, Euclid, Rubin, SO etc.)
- Next generation analyses are being developed and in some cases will be equivalent to an order of magnitude increase in data volume

CONSEQUENCES I: WE CAN TEST FUNDAMENTAL PHYSICS WITH COSMOLOGY.



arXiv.org > astro-ph > **arXiv:1911.09073**

Astrophysics > Cosmology and Nongalactic Astrophysics

Hints, neutrino bounds and WDM constraints from SDSS DR14 Lyman-α and Planck full-survey data

Nathalie Palanque-Delabrouille, Christophe Yèche, Nils Schöneberg, Julien Lesgourgues, Michael Walther, Solène Chabanier, Eric Armengaud

(Submitted on 20 Nov 2019 (v1), last revised 21 Nov 2019 (this version, v2))

The Ly-α forest 1D flux power spectrum is a powerful probe of several cosmological parameters. Assuming a ΛCDM cosmology including massive neutrinos, we find that the latest SDSS DR14 BOSS and eBOSS Ly-α forest data is in very good agreement with current weak lensing constraints on (Ω_m, σ_8) and has the same small level of tension with Planck. We did not identify a systematic effect in the data analysis that could explain this small tension, but we show that it can be reduced in extended cosmological models where the spectral index is not the same on the very different times and scales probed by CMB and Ly-α data. A particular case is that of a ΛCDM model including a running of the spectral index on top of massive neutrinos. With combined Ly-α and Planck data, we find a slight (3σ) preference for negative running, $\alpha_s = -0.010 \pm 0.004$ (68% CL). Neutrino mass bounds are found to be robust against different assumptions. In the ΛCDM model with running, we find $\sum m_\nu < 0.11$ eV at the 95% confidence level for combined Ly-α and Planck (temperature and polarisation) data, or $\sum m_\nu < 0.09$ eV when adding CMB lensing and BAO data. We further provide strong and nearly model-independent bounds on the mass of thermal warm dark matter: $m_X > 10\ \mathrm{keV}$ (95% CL) from Ly-α data alone.

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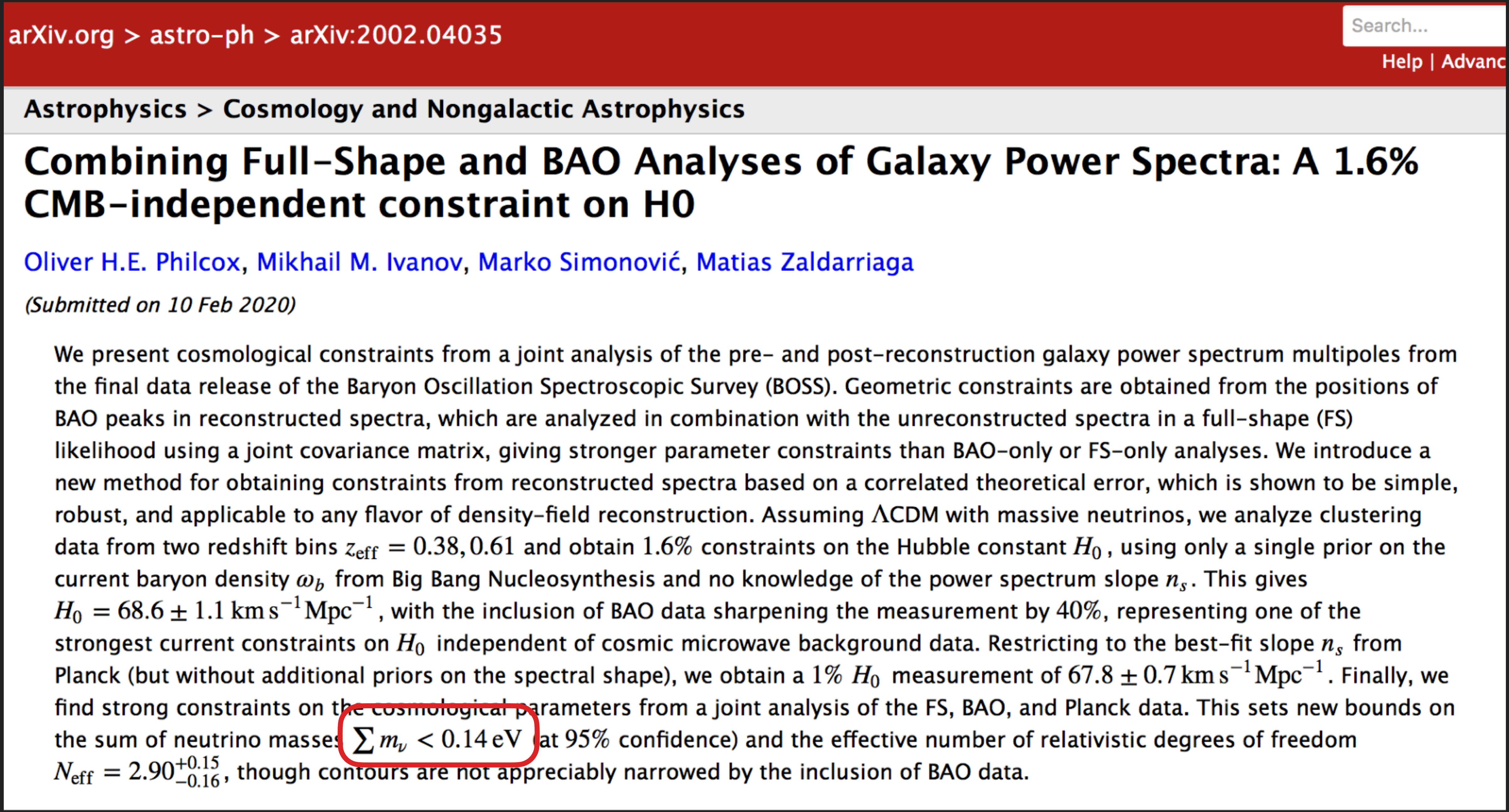


Astrophysics > Cosmology and Nongalactic Astrophysics

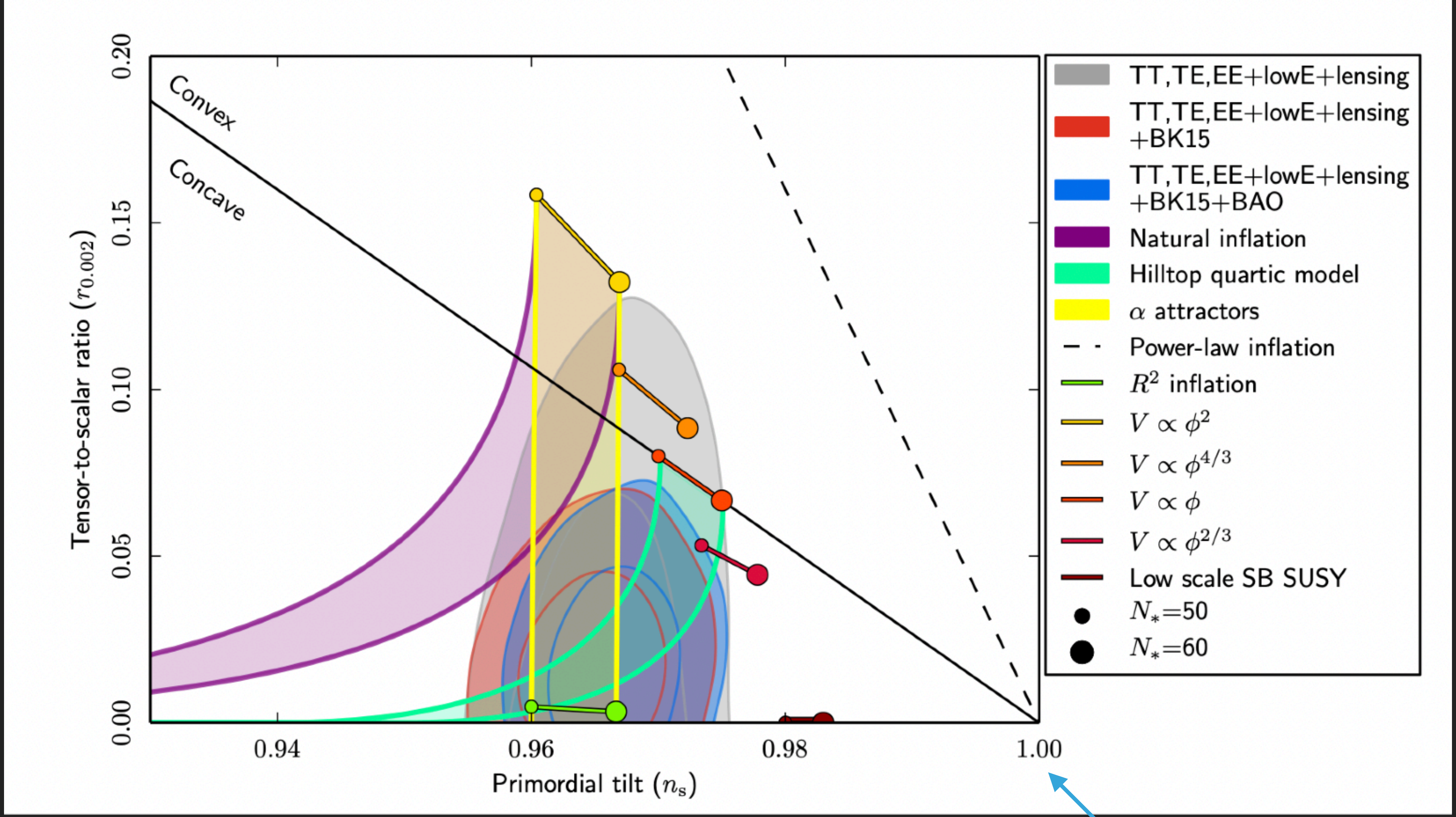
Combining Full-Shape and BAO Analyses of Galaxy Power Spectra: A 1.6% CMB-independent constraint on H0

Oliver H.E. Philcox, Mikhail M. Ivanov, Marko Simonović, Matias Zaldarriaga

(Submitted on 10 Feb 2020)

We present cosmological constraints from a joint analysis of the pre- and post-reconstruction galaxy power spectrum multipoles from the final data release of the Baryon Oscillation Spectroscopic Survey (BOSS). Geometric constraints are obtained from the positions of BAO peaks in reconstructed spectra, which are analyzed in combination with the unreconstructed spectra in a full-shape (FS) likelihood using a joint covariance matrix, giving stronger parameter constraints than BAO-only or FS-only analyses. We introduce a new method for obtaining constraints from reconstructed spectra based on a correlated theoretical error, which is shown to be simple, robust, and applicable to any flavor of density-field reconstruction. Assuming ΛCDM with massive neutrinos, we analyze clustering data from two redshift bins $z_{\rm eff} = 0.38, 0.61$ and obtain 1.6% constraints on the Hubble constant H_0, using only a single prior on the current baryon density ω_b from Big Bang Nucleosynthesis and no knowledge of the power spectrum slope n_s. This gives $H_0 = 68.6 \pm 1.1\,{\rm km\,s^{-1}Mpc^{-1}}$, with the inclusion of BAO data sharpening the measurement by 40%, representing one of the strongest current constraints on H_0 independent of cosmic microwave background data. Restricting to the best-fit slope n_s from Planck (but without additional priors on the spectral shape), we obtain a 1% H_0 measurement of $67.8 \pm 0.7\,{\rm km\,s^{-1}Mpc^{-1}}$. Finally, we find strong constraints on the cosmological parameters from a joint analysis of the FS, BAO, and Planck data. This sets new bounds on the sum of neutrino masses $\boxed{\sum m_\nu < 0.14\,{\rm eV}}$ (at 95% confidence) and the effective number of relativistic degrees of freedom $N_{\rm eff} = 2.90^{+0.15}_{-0.16}$, though contours are not appreciably narrowed by the inclusion of BAO data.

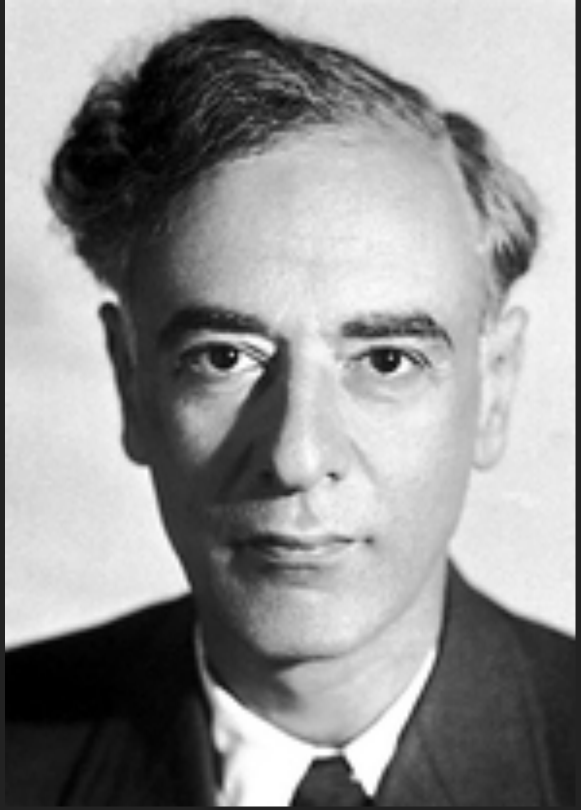
CONSEQUENCES I: WE CAN TEST FUNDAMENTAL PHYSICS WITH COSMOLOGY.



Harrison Zeldovich spectrum is highly excluded. Major evidence for inflation.

CONSEQUENCES II: WE (COSMOLOGISTS) MAY START IN LOOKING FOR ANOTHER JOB ...

BUT IT IS TRUE ?



“Cosmologists are often in error but seldom in doubt.”
Lev Landau

THE CURRENT COSMOLOGICAL SCENARIO IS BASED ON "UNKNOWN" PHYSICS

Dark Matter: needed to form structure.

Inflation: needed for primordial homogeneity

Dark Energy: needed for explaining the current state of accelerated expansion.


Cosmology
@2023
Dark Matter
Inflation
Dark Energy
CW

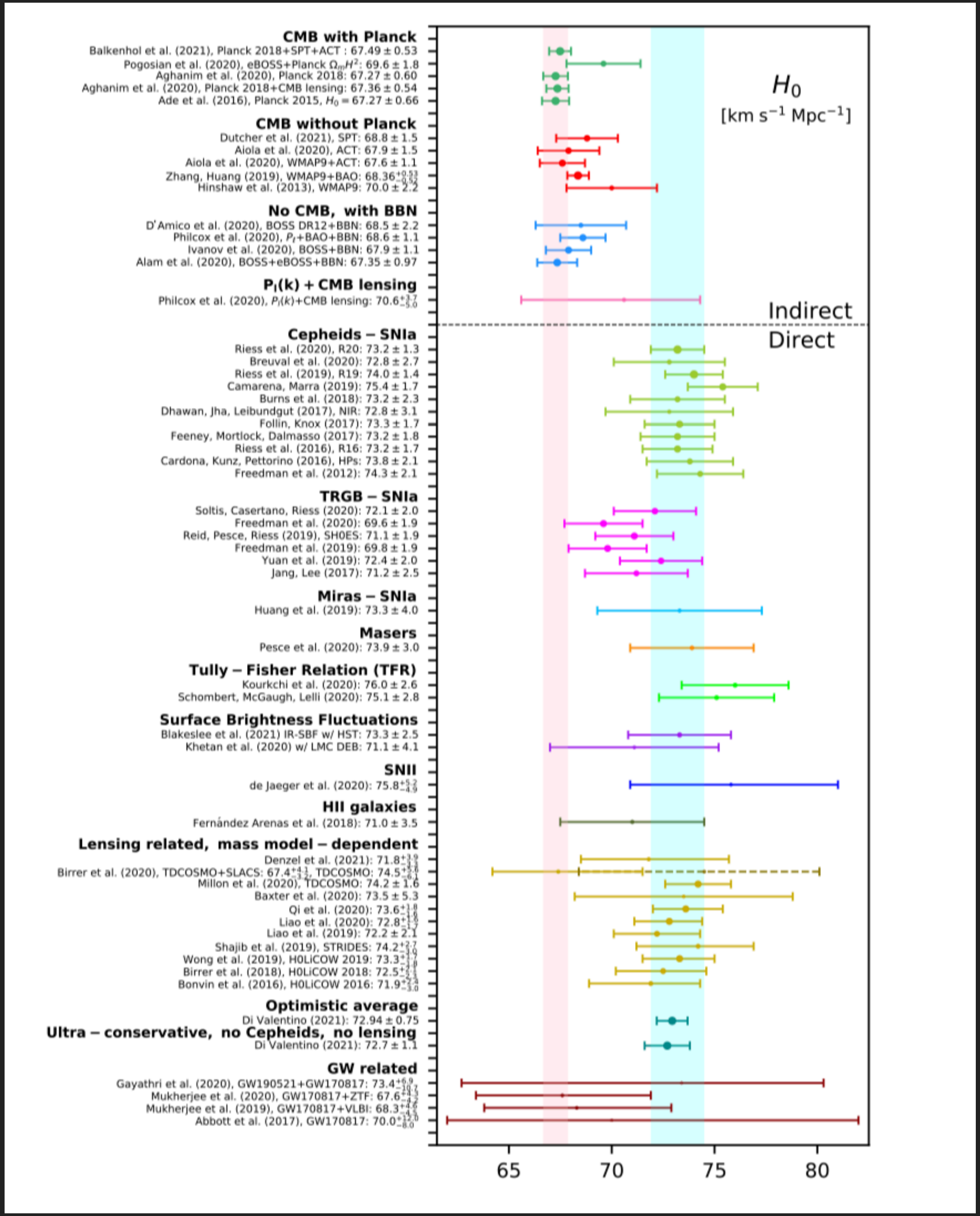
THE CURRENT “STANDARD” COSMOLOGICAL MODEL IS ALSO BASED ON SEVERAL (QUESTIONABLE) ASSUMPTIONS !

WE SHOULD LOOK FOR ANOMALIES NOT BECAUSE THEY COULD PROVIDE INDICATION FOR “NEW PHYSICS” BUT BECAUSE THEY CAN SHED LIGHT ON WHAT ACTUALLY ARE DARK ENERGY, DARK MATTER AND INFLATION !

LCDM IS NOT THE COSMOLOGICAL EQUIVALENT OF THE STANDARD MODEL OF PARTICLES PHYSICS (WHERE ALL PARTICLES , CROSS SECTION, ETC HAVE BEEN MEASURED IN LABORATORY) !

DO WE HAVE ANOMALIES ?

HUBBLE TENSION

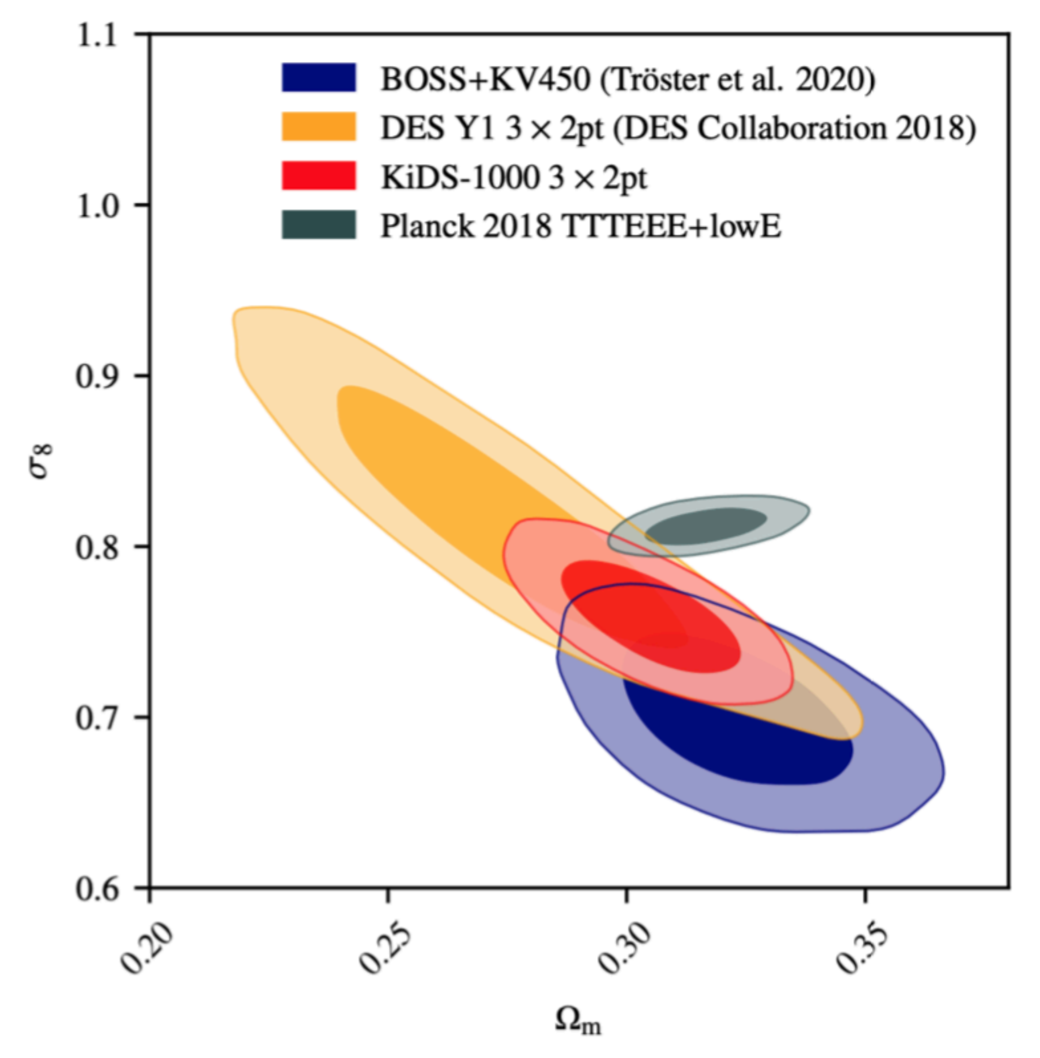


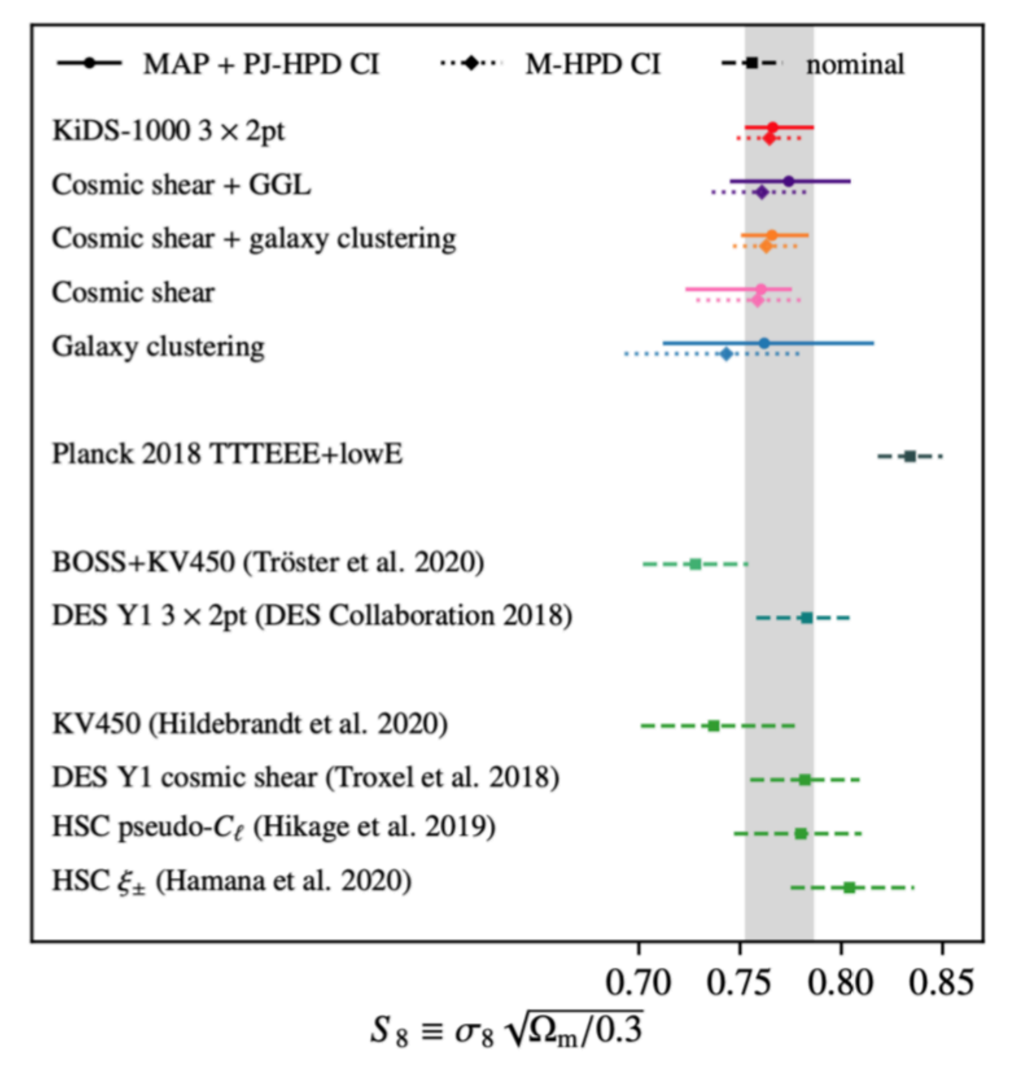
The value of the Hubble constant derived by Planck assuming LCDM is (at least) 4.4 sigmas away from the SHOES result.

Di Valentino, Mena, Pan, Visinelli et al, arXiv:2103.01183

COSMIC SHEAR TENSION

A clear tension (about 3 σ) is present between Planck and cosmic shear data from CFHTLenS, KiDS-450 and DES on the σ_8 vs Ω_m plane. This comparison assumes LCDM.

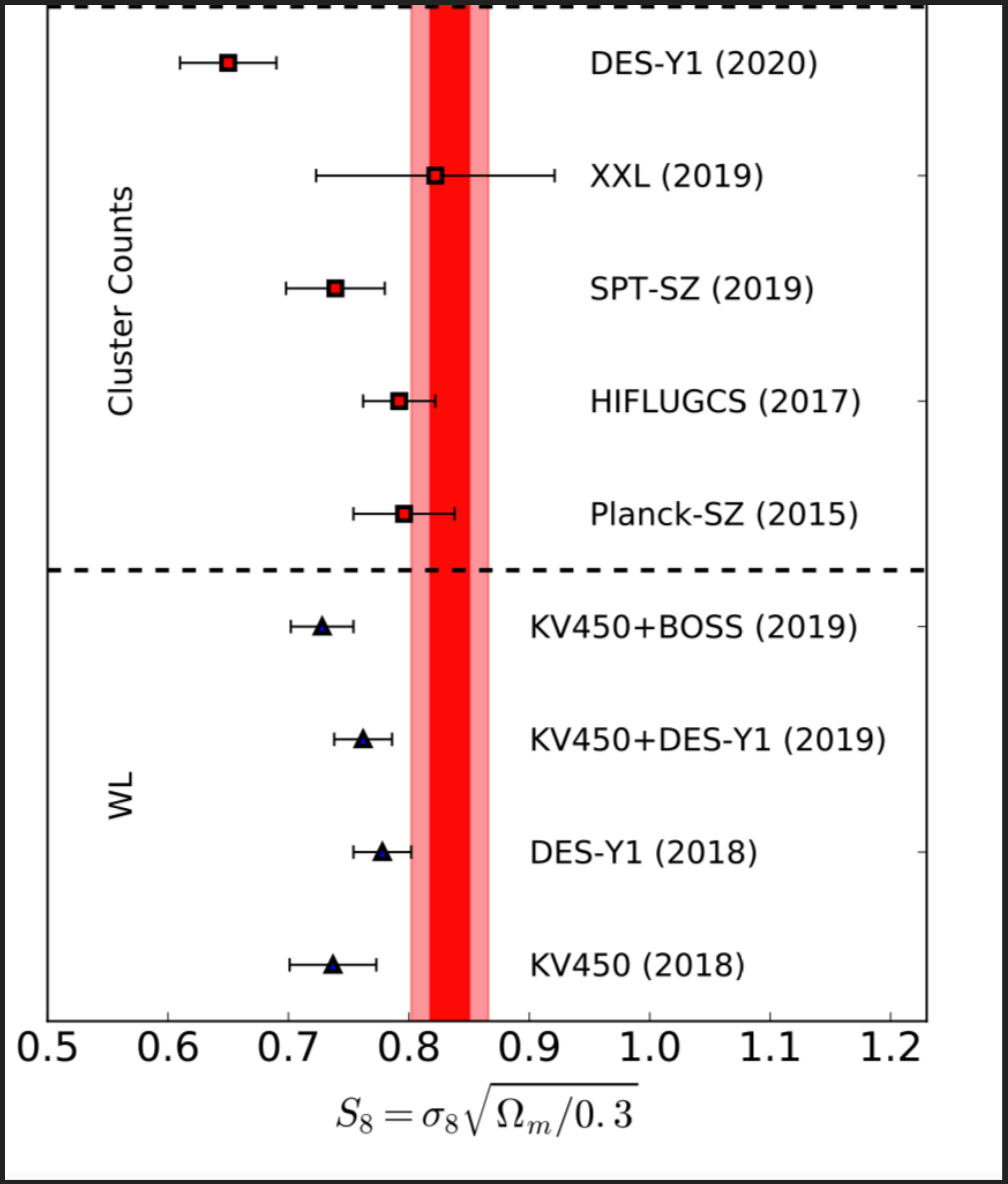




Heymans et al, arXiv:2007.15632

S8 TENSION

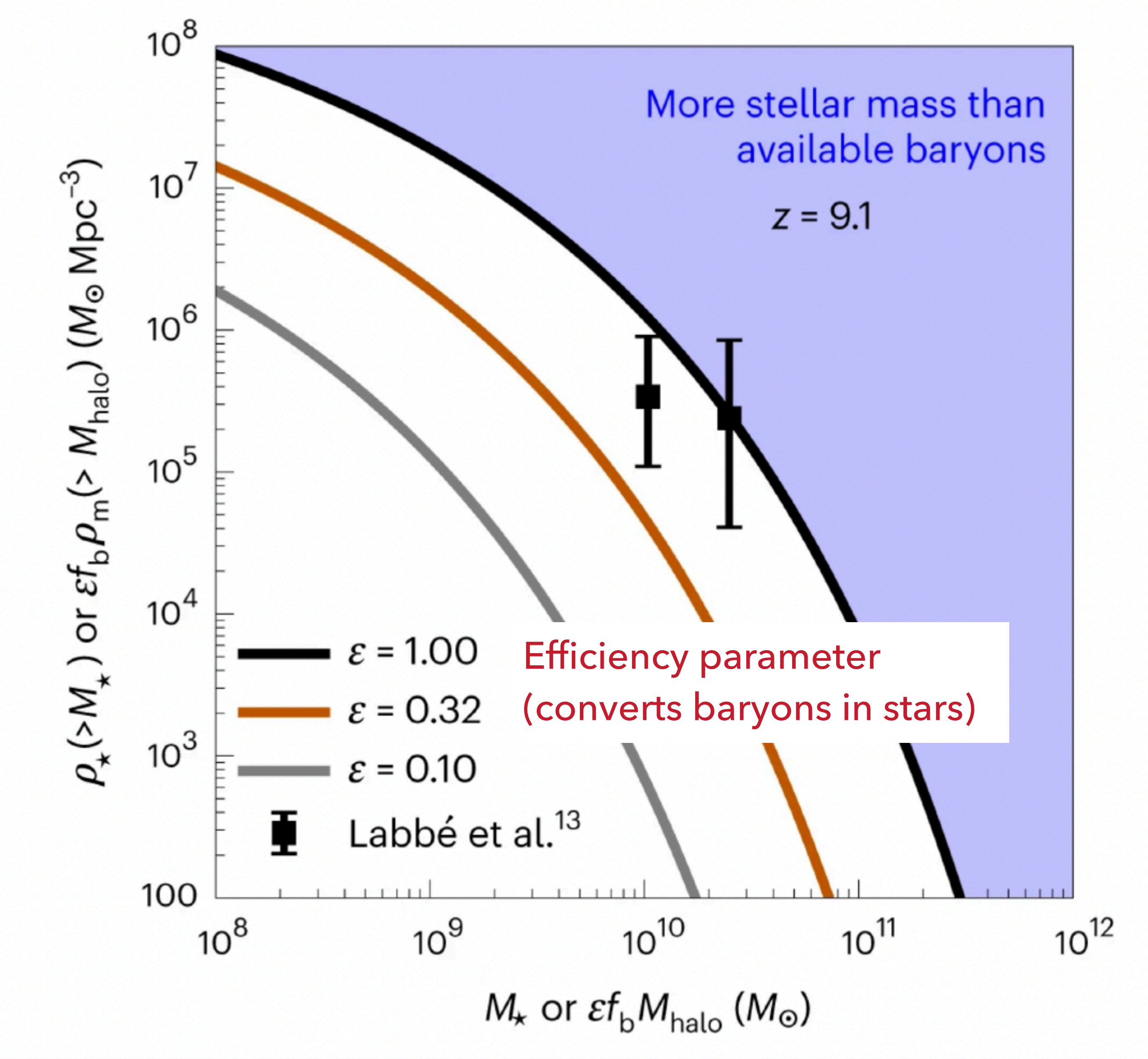
Cosmic Shear data agree well with Cluster Counts data and both suggest a smaller value for the S8 parameter than what derived from Planck primary CMB data.



Corasaniti, Sereno, Ettori, arXiv:2103.03283

“JWST” TENSION

THERE ARE TOO MANY HIGH-REDSHIFT MASSIVE GALAXIES IN JWST OBSERVATIONS?



Efficiency parameter (converts baryons in stars)

IVO LABBÉ, ET AL.

NATURE 616, 266–269 (2023)

MICHAEL BOYLAN-KOLCHIN

NATURE ASTRONOMY

731–735 (2023)

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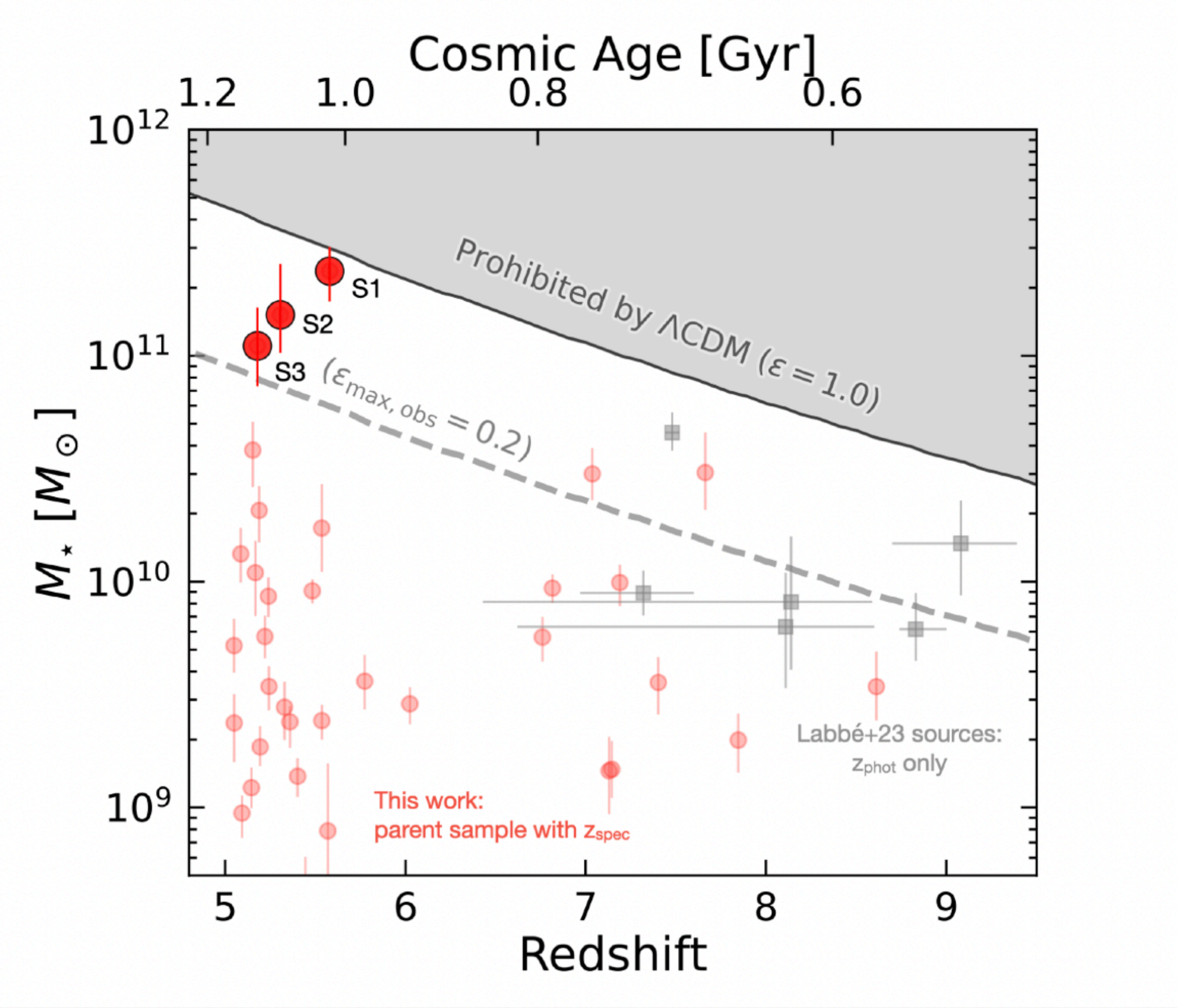
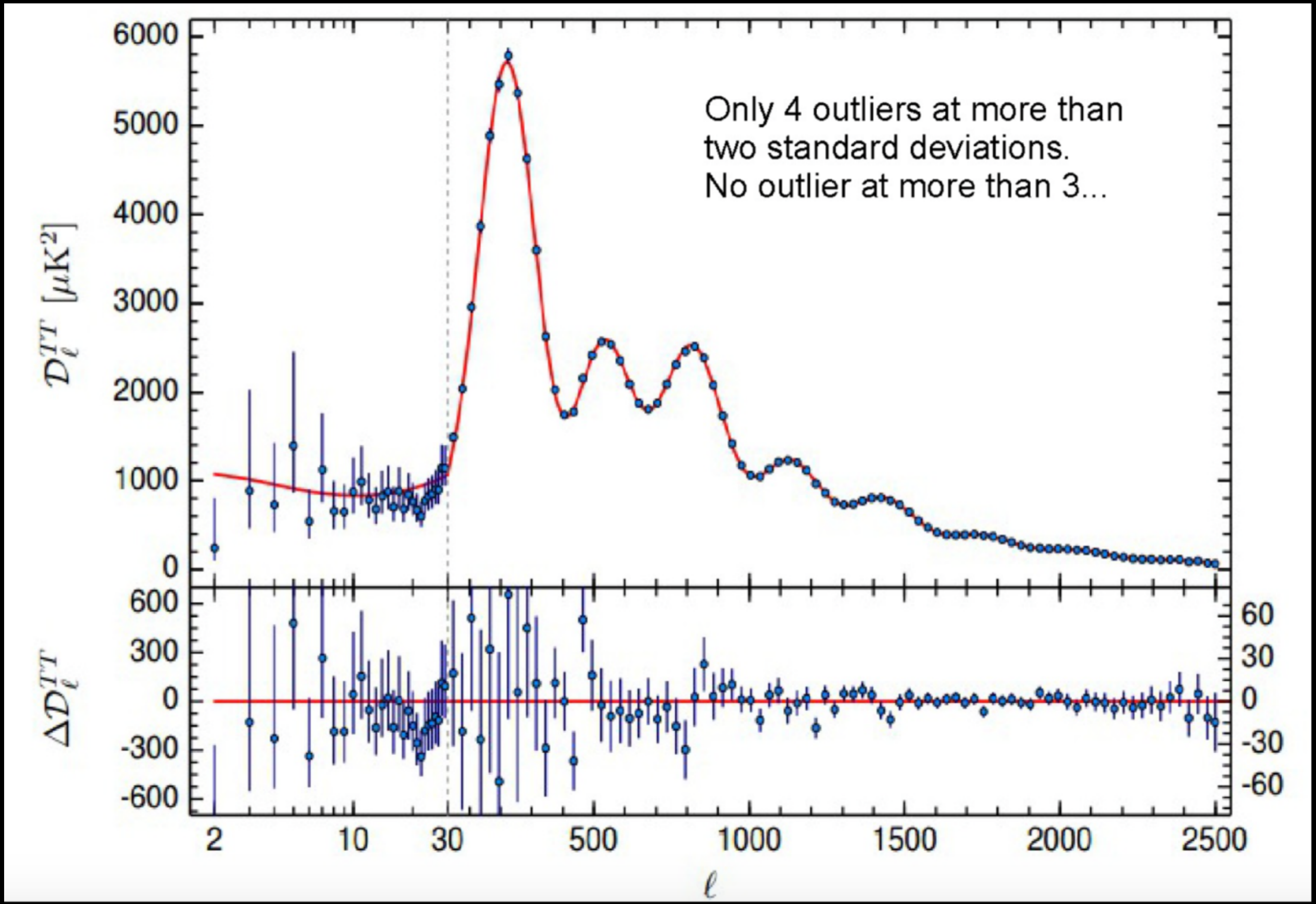


M. XIAO ET AL.
ARXIV:2309.02492

REPORT SIMILAR SYSTEMS AT SLIGHTLY LOWER REDSHIFT (Z~5-6),

THESE OBJECTS ARE CONFIRMED WITH SPECTRA.

A PERFECT (LCDM) UNIVERSE



Only 4 outliers at more than two standard deviations. No outlier at more than 3...

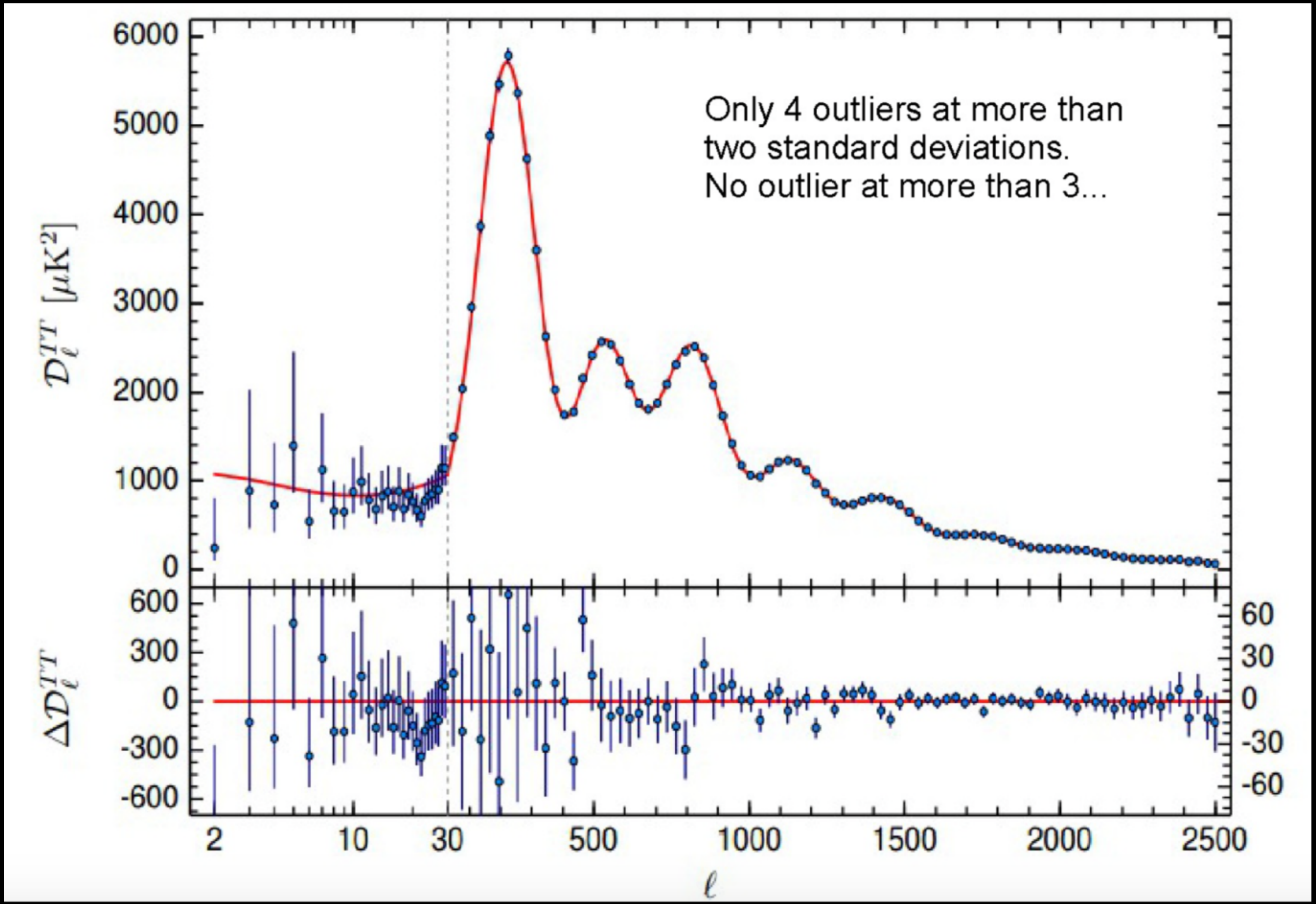
The recent CMB measurements made by the Planck satellite are in perfect agreement with the expectations of the LCDM model.

Planck collaboration, arXiv:1502.01589

Be careful, what may seem beautiful and harmonious can conceal a terrible truth!

Bronzino, Allegoria con Venere e Cupido (Aphrodites and Eros), 1545, London, National Gallery

A PERFECT (LCDM) UNIVERSE



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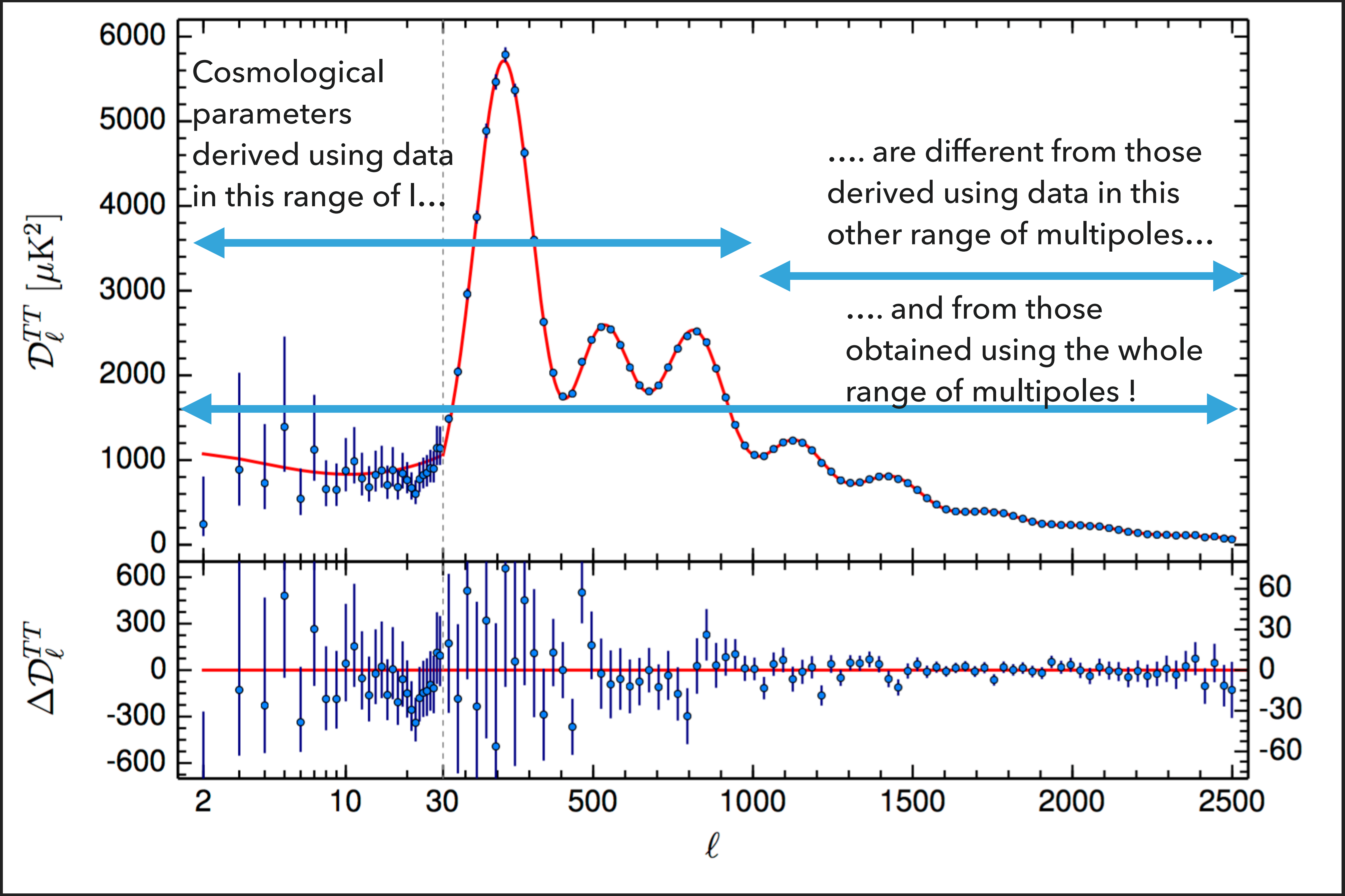
ANOMALIES IN TT SPECTRA ?



Cosmological parameters derived using data in this range of l…

…. are different from those derived using data in this other range of multipoles…

…. and from those obtained using the whole range of multipoles !

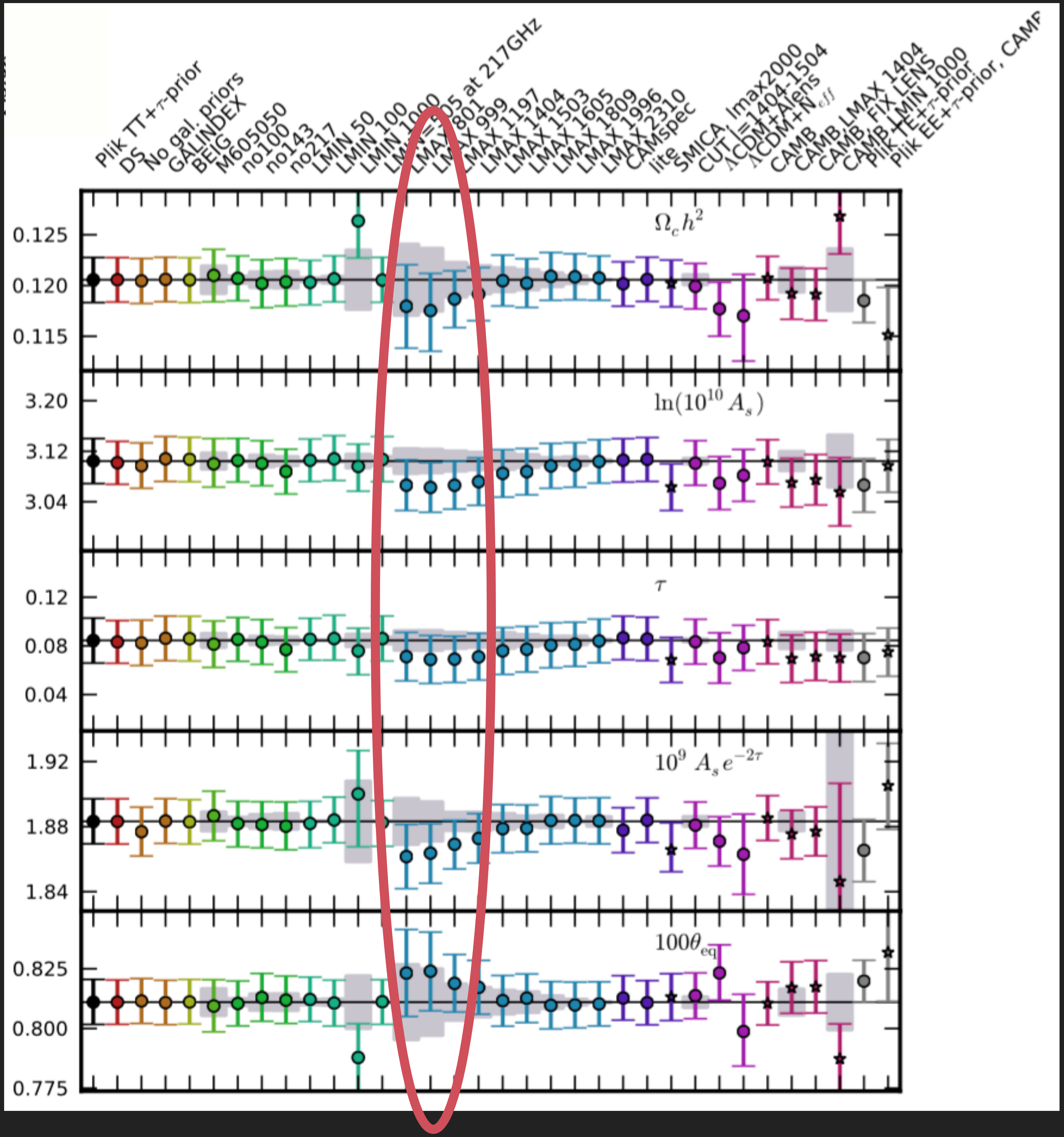
ANOMALIES IN TT SPECTRA ?

If we estimate LCDM parameters in the multipole range 2<l<1000 Planck temperature data gives slightly different values (1-2σ) than what we get when analyzing the whole range (2<l<2300).

(Planck 2015 paper IX, arXiv:1507.02704, figure 35, but see also discussion by Addison et al, arXiv:1511.00055)

From where it comes ?

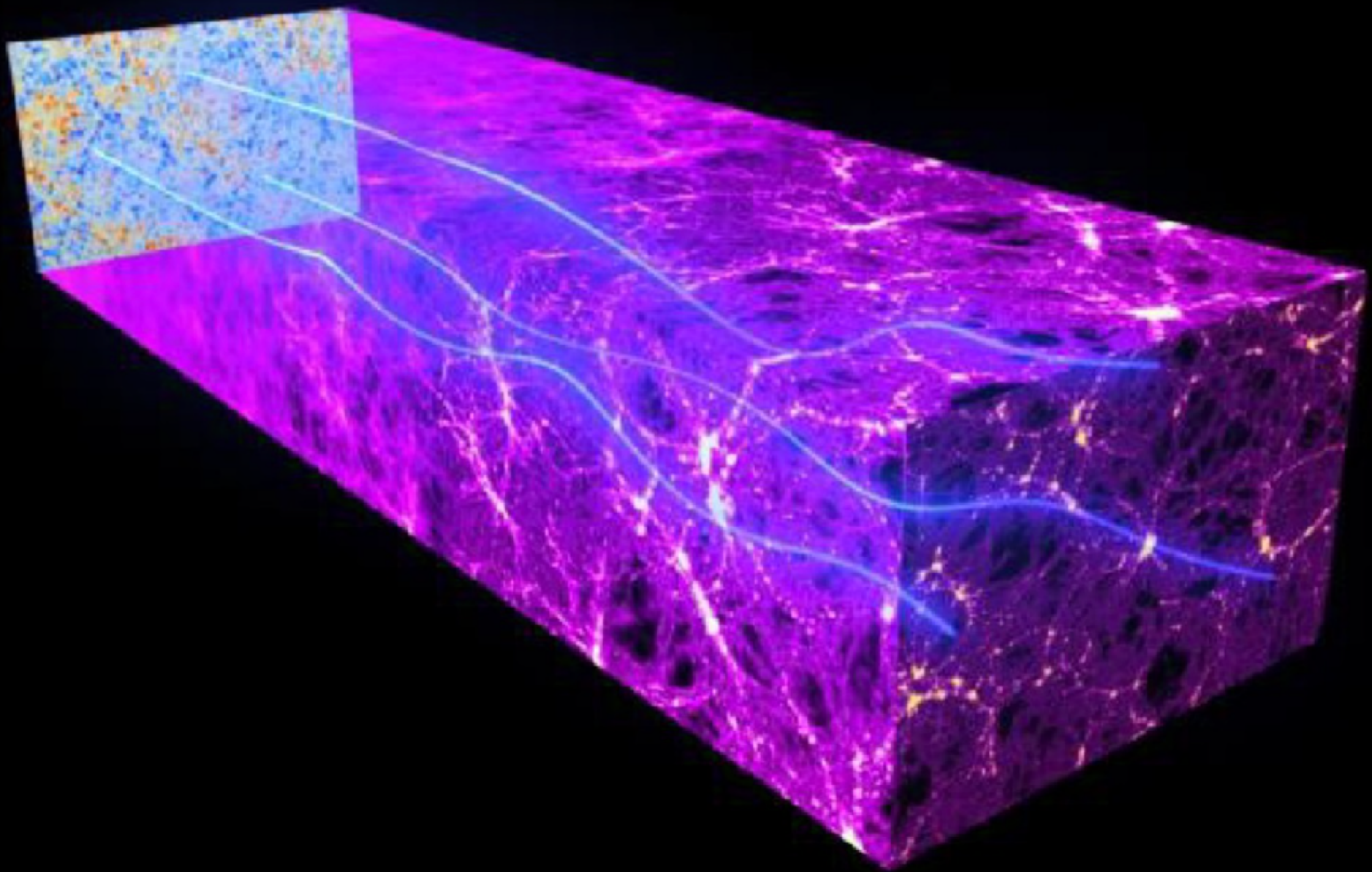
Unknown systematic or new physics ? can an extra parameter solve this ?



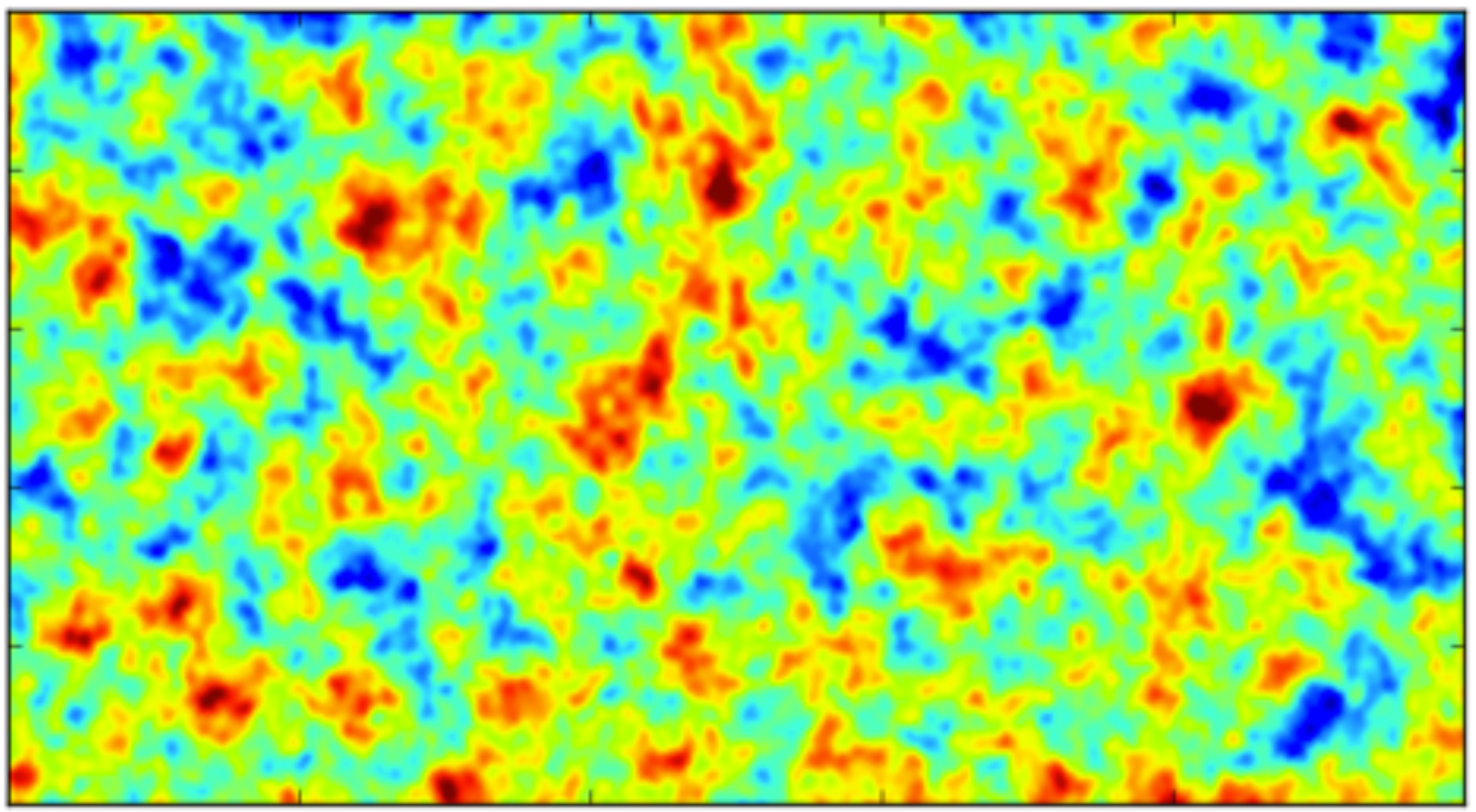
CMB LENSING

CMB photons emitted at z=1100 are deflected by the gravitational lensing effect of massive cosmic structures.

This affects the CMB anisotropy angular spectrum by smearing the high l peaks.

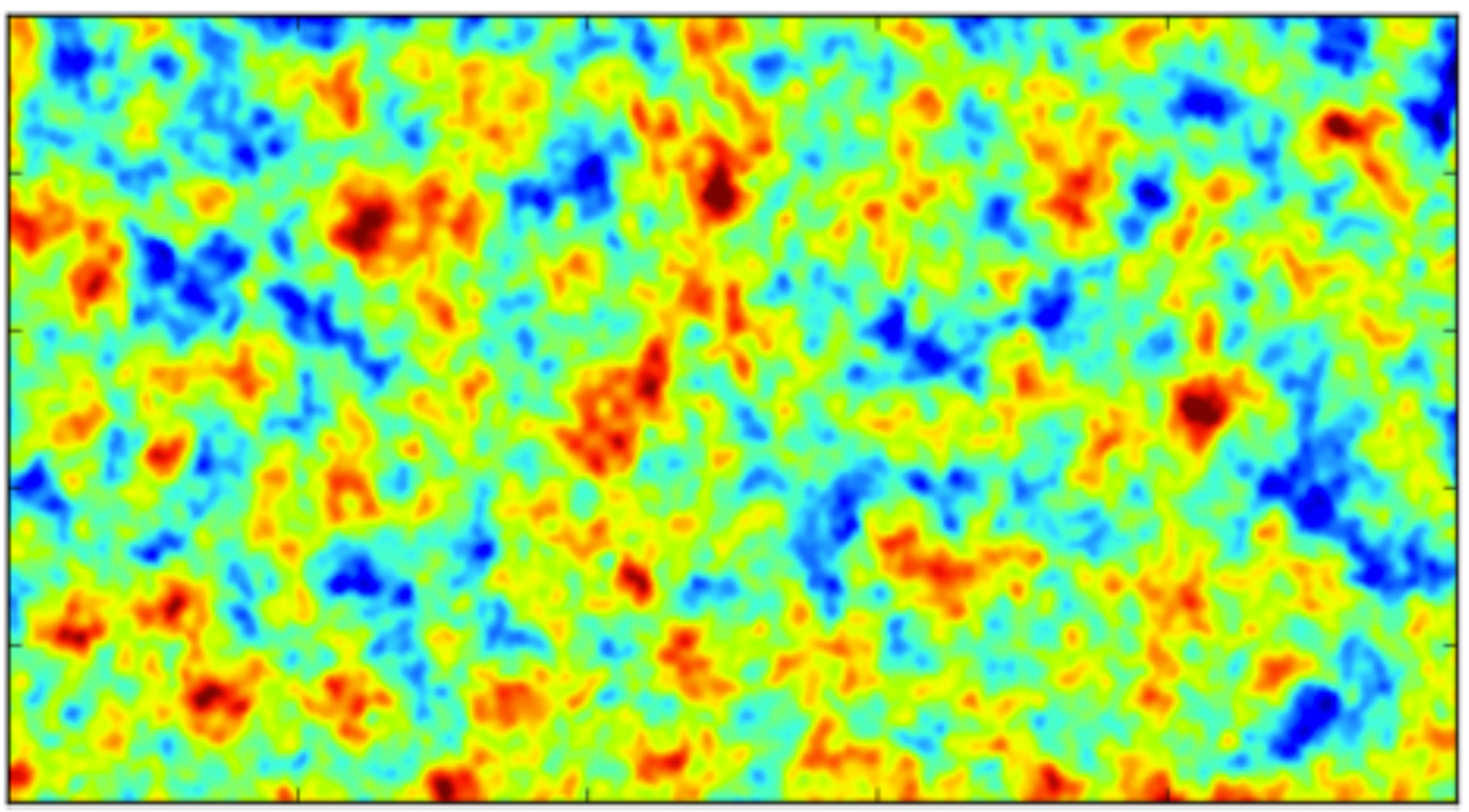


CMB LENSING



A simulated patch of CMB sky – **before dark matter lensing**

CMB LENSING



A simulated patch of CMB sky – **after dark matter lensing**

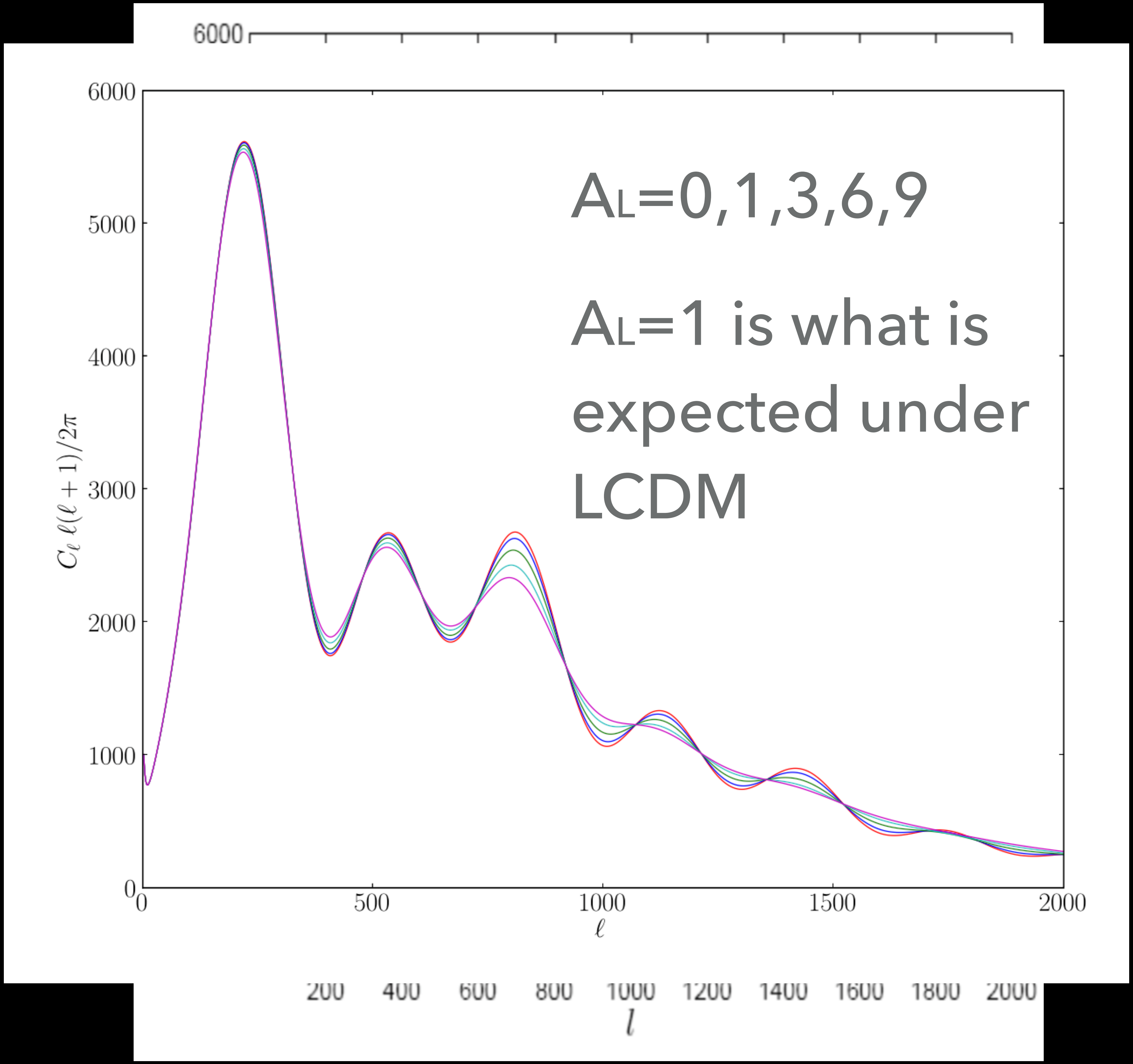
CMB LENSING

CMB photons emitted at z=1100 are deflected by the gravitational lensing effect of massive cosmic structures.

This affects the CMB anisotropy angular spectrum by smearing the high l peaks.

This effect is taken into account in CMB theory but we can anyway parametrize the lensing amplitude by an effective rescaling parameter A_L.

(Calabrese, Slosar, Melchiorri, Smoot, Zahn, 2008).



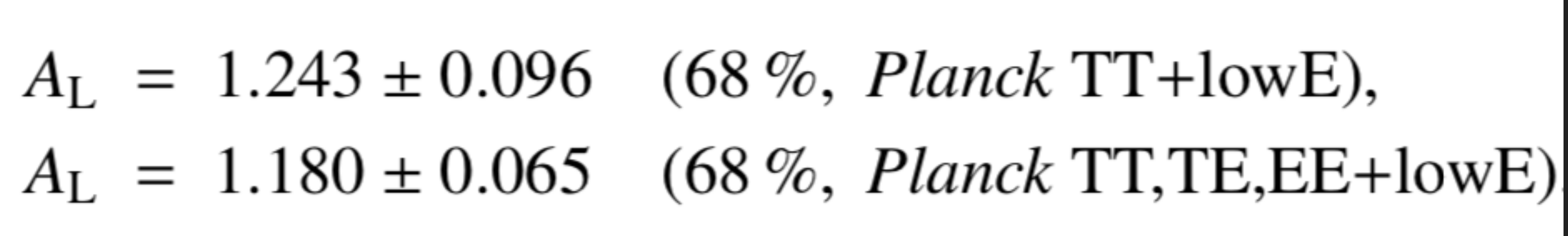
A_L=0,1,3,6,9

A_L=1 is what is expected under LCDM

THE A_L ANOMALY

Planck 2018 analysis prefers AL>1 at 2.8 standard deviations

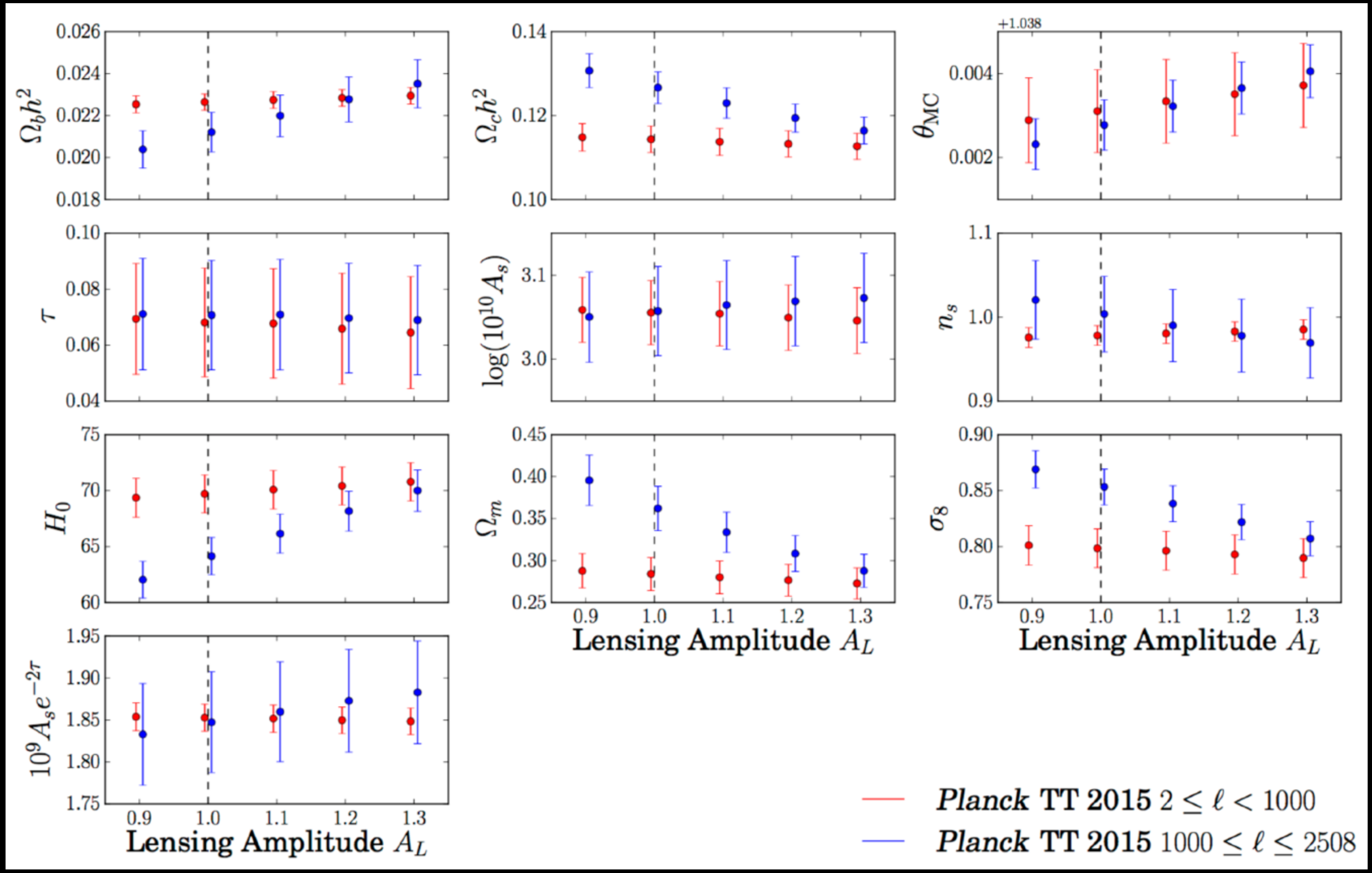
(Exactly 3 sigmas with 1 tail analysis).



$$
\begin{aligned}
A_{\mathrm{L}} &= 1.243 \pm 0.096 \quad (68\,\%,\ \textit{Planck}\ \mathrm{TT{+}lowE}),\\
A_{\mathrm{L}} &= 1.180 \pm 0.065 \quad (68\,\%,\ \textit{Planck}\ \mathrm{TT,TE,EE{+}lowE}).
\end{aligned}
$$

TENSION SMALL/LARGE SCALE CMB IS SOLVED BY A_L

When A_L~1.2 we have the same parameters constraints from 2<l<1000 and 1000<l<2508 !



Addison et al, arXiv:1511.00055

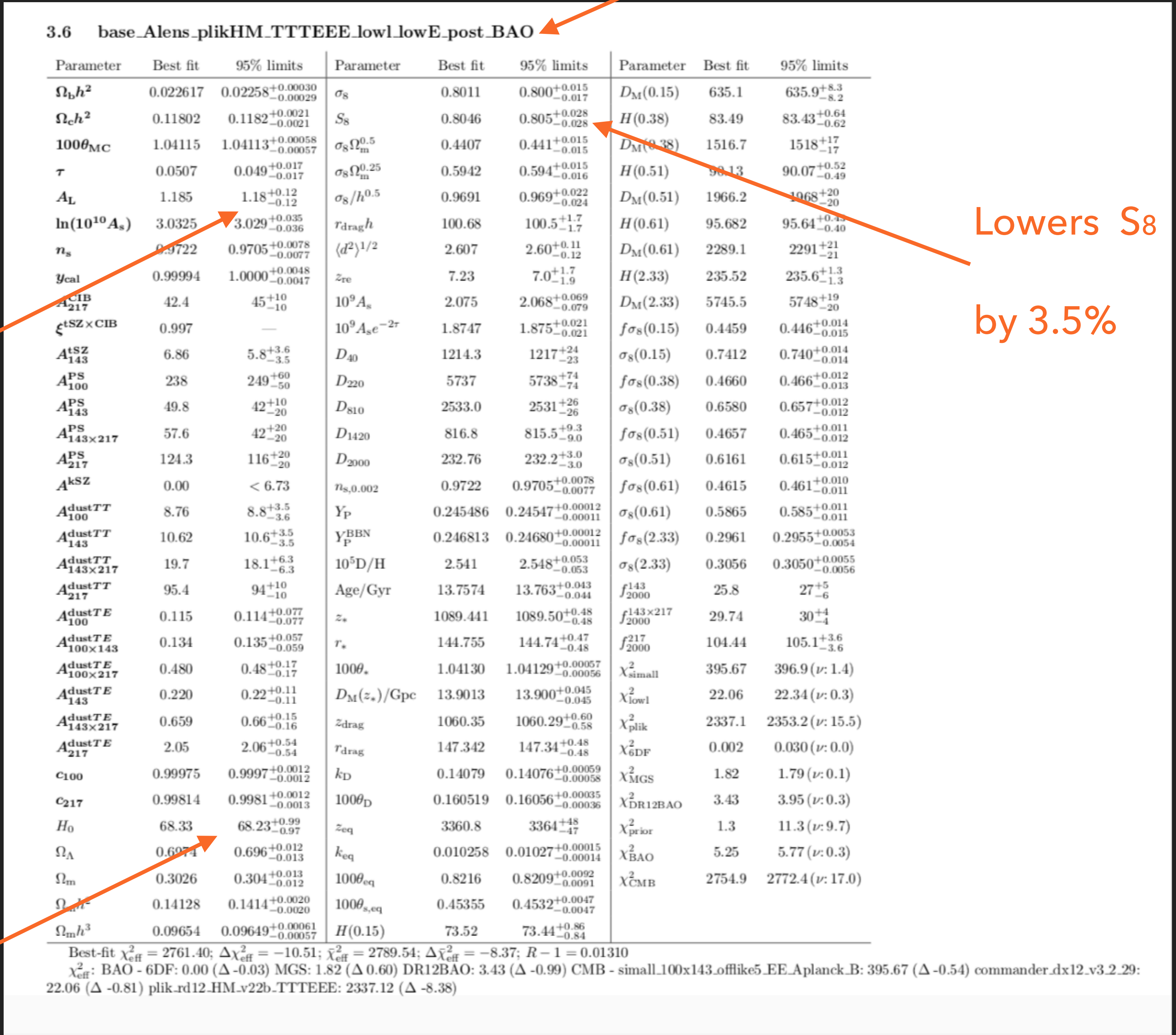
A_L IS THE KEY ?

Perfectly consistent with BAO

Suggested by

Planck+BAO

at about 3 σ



3.6 base_Alens_plikHM_TTTEEE_lowl_lowE_post_BAO

Parameter	Best fit	95% limits	Parameter	Best fit	95% limits	Parameter	Best fit	95% limits
$\Omega_b h^2$	0.022617	$0.02258^{+0.00030}_{-0.00029}$	σ_8	0.8011	$0.800^{+0.015}_{-0.017}$	$D_M(0.15)$	635.1	$635.9^{+8.3}_{-8.2}$
$\Omega_c h^2$	0.11802	$0.1182^{+0.0021}_{-0.0021}$	S_8	0.8046	$0.805^{+0.028}_{-0.028}$	$H(0.38)$	83.49	$83.43^{+0.64}_{-0.62}$
$100\theta_{MC}$	1.04115	$1.04113^{+0.00058}_{-0.00057}$	$\sigma_8\Omega_m^{0.5}$	0.4407	$0.441^{+0.015}_{-0.015}$	$D_M(0.38)$	1516.7	1518^{+17}_{-17}
τ	0.0507	$0.049^{+0.017}_{-0.017}$	$\sigma_8\Omega_m^{0.25}$	0.5942	$0.594^{+0.015}_{-0.016}$	$H(0.51)$	90.13	$90.07^{+0.52}_{-0.49}$
A_L	1.185	$1.18^{+0.12}_{-0.12}$	$\sigma_8/h^{0.5}$	0.9691	$0.969^{+0.022}_{-0.024}$	$D_M(0.51)$	1966.2	1968^{+20}_{-20}
$\ln(10^{10}A_s)$	3.0325	$3.029^{+0.035}_{-0.036}$	$r_{drag}h$	100.68	$100.5^{+1.7}_{-1.7}$	$H(0.61)$	95.682	$95.64^{+0.43}_{-0.40}$
n_s	0.9722	$0.9705^{+0.0078}_{-0.0077}$	$\langle d^2\rangle^{1/2}$	2.607	$2.60^{+0.11}_{-0.12}$	$D_M(0.61)$	2289.1	2291^{+21}_{-21}
y_{cal}	0.99994	$1.0000^{+0.0048}_{-0.0047}$	z_{re}	7.23	$7.0^{+1.7}_{-1.9}$	$H(2.33)$	235.52	$235.6^{+1.3}_{-1.3}$
A^{CIB}_{217}	42.4	45^{+10}_{-10}	10^9A_s	2.075	$2.068^{+0.069}_{-0.079}$	$D_M(2.33)$	5745.5	5748^{+19}_{-20}
$\xi^{tSZ\times CIB}$	0.997	—	$10^9A_se^{-2\tau}$	1.8747	$1.875^{+0.021}_{-0.021}$	$f\sigma_8(0.15)$	0.4459	$0.446^{+0.014}_{-0.015}$
A^{tSZ}_{143}	6.86	$5.8^{+3.6}_{-3.5}$	D_{40}	1214.3	1217^{+24}_{-23}	$\sigma_8(0.15)$	0.7412	$0.740^{+0.014}_{-0.014}$
A^{PS}_{100}	238	249^{+60}_{-50}	D_{220}	5737	5738^{+74}_{-74}	$f\sigma_8(0.38)$	0.4660	$0.466^{+0.012}_{-0.013}$
A^{PS}_{143}	49.8	42^{+10}_{-20}	D_{810}	2533.0	2531^{+26}_{-26}	$\sigma_8(0.38)$	0.6580	$0.657^{+0.012}_{-0.012}$
$A^{PS}_{143\times217}$	57.6	42^{+20}_{-20}	D_{1420}	816.8	$815.5^{+9.3}_{-9.0}$	$f\sigma_8(0.51)$	0.4657	$0.465^{+0.011}_{-0.012}$
A^{PS}_{217}	124.3	116^{+20}_{-20}	D_{2000}	232.76	$232.2^{+3.0}_{-3.0}$	$\sigma_8(0.51)$	0.6161	$0.615^{+0.011}_{-0.012}$
A^{kSZ}	0.00	< 6.73	$n_{s,0.002}$	0.9722	$0.9705^{+0.0078}_{-0.0077}$	$f\sigma_8(0.61)$	0.4615	$0.461^{+0.010}_{-0.011}$
A^{dustTT}_{100}	8.76	$8.8^{+3.5}_{-3.6}$	Y_P	0.245486	$0.24547^{+0.00012}_{-0.00011}$	$\sigma_8(0.61)$	0.5865	$0.585^{+0.011}_{-0.011}$
A^{dustTT}_{143}	10.62	$10.6^{+3.5}_{-3.5}$	Y_P^{BBN}	0.246813	$0.24680^{+0.00012}_{-0.00011}$	$f\sigma_8(2.33)$	0.2961	$0.2955^{+0.0053}_{-0.0054}$
$A^{dustTT}_{143\times217}$	19.7	$18.1^{+6.3}_{-6.3}$	10^5D/H	2.541	$2.548^{+0.053}_{-0.053}$	$\sigma_8(2.33)$	0.3056	$0.3050^{+0.0055}_{-0.0056}$
A^{dustTT}_{217}	95.4	94^{+10}_{-10}	Age/Gyr	13.7574	$13.763^{+0.043}_{-0.044}$	f^{143}_{2000}	25.8	27^{+5}_{-6}
A^{dustTE}_{100}	0.115	$0.114^{+0.077}_{-0.077}$	z_*	1089.441	$1089.50^{+0.48}_{-0.48}$	$f^{143\times217}_{2000}$	29.74	30^{+4}_{-4}
$A^{dustTE}_{100\times143}$	0.134	$0.135^{+0.057}_{-0.059}$	r_*	144.755	$144.74^{+0.47}_{-0.48}$	f^{217}_{2000}	104.44	$105.1^{+3.6}_{-3.6}$
$A^{dustTE}_{100\times217}$	0.480	$0.48^{+0.17}_{-0.17}$	$100\theta_*$	1.04130	$1.04129^{+0.00057}_{-0.00056}$	χ^2_{simall}	395.67	396.9 (ν: 1.4)
A^{dustTE}_{143}	0.220	$0.22^{+0.11}_{-0.11}$	$D_M(z_*)$/Gpc	13.9013	$13.900^{+0.045}_{-0.045}$	χ^2_{lowl}	22.06	22.34 (ν: 0.3)
$A^{dustTE}_{143\times217}$	0.659	$0.66^{+0.15}_{-0.16}$	z_{drag}	1060.35	$1060.29^{+0.60}_{-0.58}$	χ^2_{plik}	2337.1	2353.2 (ν: 15.5)
A^{dustTE}_{217}	2.05	$2.06^{+0.54}_{-0.54}$	r_{drag}	147.342	$147.34^{+0.48}_{-0.48}$	χ^2_{6DF}	0.002	0.030 (ν: 0.0)
c_{100}	0.99975	$0.9997^{+0.0012}_{-0.0012}$	k_D	0.14079	$0.14076^{+0.00059}_{-0.00058}$	χ^2_{MGS}	1.82	1.79 (ν: 0.1)
c_{217}	0.99814	$0.9981^{+0.0012}_{-0.0013}$	$100\theta_D$	0.160519	$0.16056^{+0.00035}_{-0.00036}$	$\chi^2_{DR12BAO}$	3.43	3.95 (ν: 0.3)
H_0	68.33	$68.23^{+0.99}_{-0.97}$	z_{eq}	3360.8	3364^{+48}_{-47}	χ^2_{prior}	1.3	11.3 (ν: 9.7)
Ω_Λ	0.6974	$0.696^{+0.012}_{-0.013}$	k_{eq}	0.010258	$0.01027^{+0.00015}_{-0.00014}$	χ^2_{BAO}	5.25	5.77 (ν: 0.3)
Ω_m	0.3026	$0.304^{+0.013}_{-0.012}$	$100\theta_{eq}$	0.8216	$0.8209^{+0.0092}_{-0.0091}$	χ^2_{CMB}	2754.9	2772.4 (ν: 17.0)
$\Omega_m h^2$	0.14128	$0.1414^{+0.0020}_{-0.0020}$	$100\theta_{s,eq}$	0.45355	$0.4532^{+0.0047}_{-0.0047}$			
$\Omega_m h^3$	0.09654	$0.09649^{+0.00061}_{-0.00057}$	$H(0.15)$	73.52	$73.44^{+0.86}_{-0.84}$			

Best-fit $\chi^2_{eff} = 2761.40$; $\Delta\chi^2_{eff} = -10.51$; $\bar{\chi}^2_{eff} = 2789.54$; $\Delta\bar{\chi}^2_{eff} = -8.37$; $R - 1 = 0.01310$

χ^2_{eff}: BAO - 6DF: 0.00 (Δ -0.03) MGS: 1.82 (Δ 0.60) DR12BAO: 3.43 (Δ -0.99) CMB - simall_100x143_offlike5_EE_Aplanck_B: 395.67 (Δ -0.54) commander_dx12_v3_2_29: 22.06 (Δ -0.81) plik_rd12_HM_v22b_TTTEEE: 2337.12 (Δ -8.38)

Lowers S_8

by 3.5%

Increases H_0

by 1.5%

WHAT IS THE NEUTRINO MASS ?

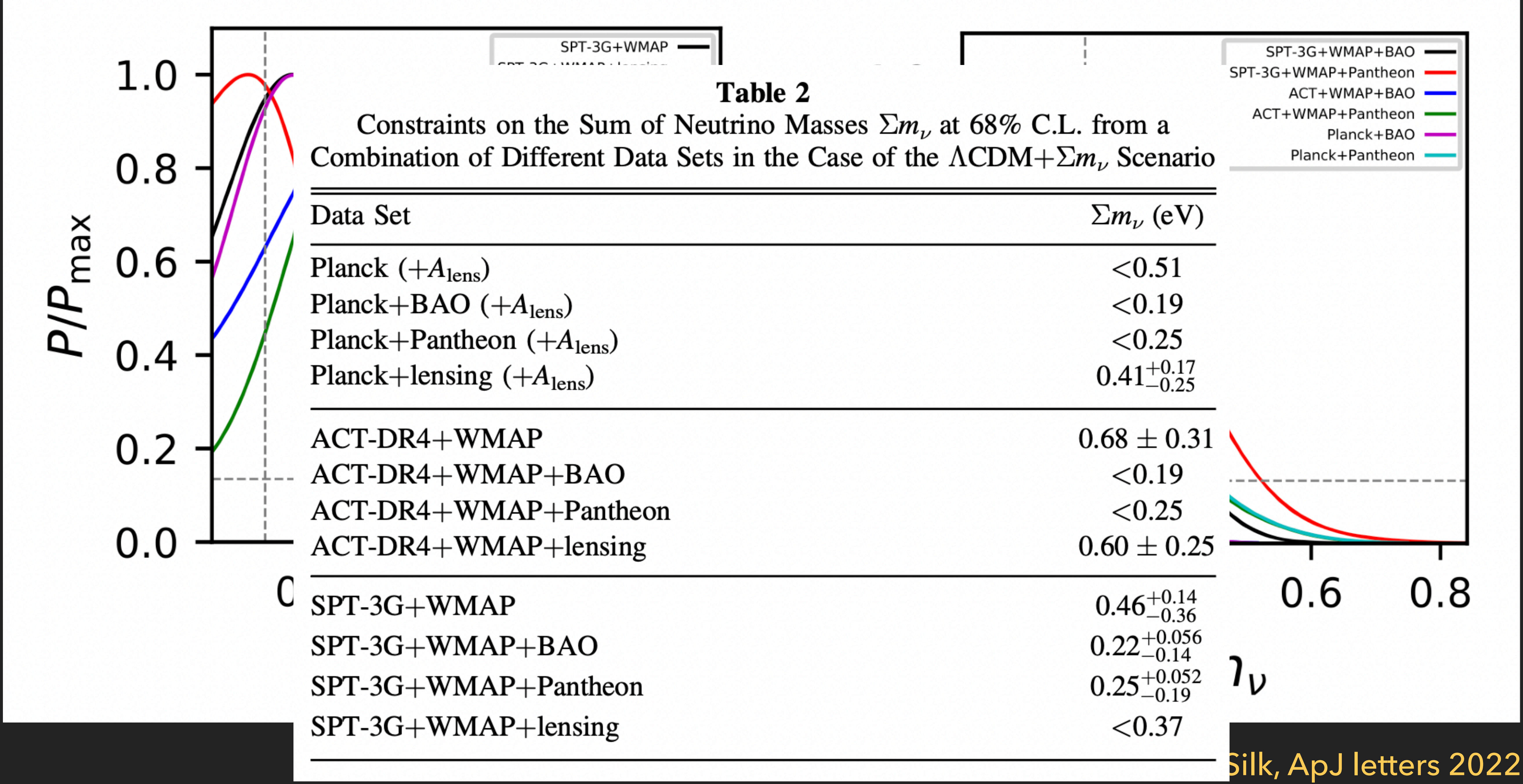


Table 2

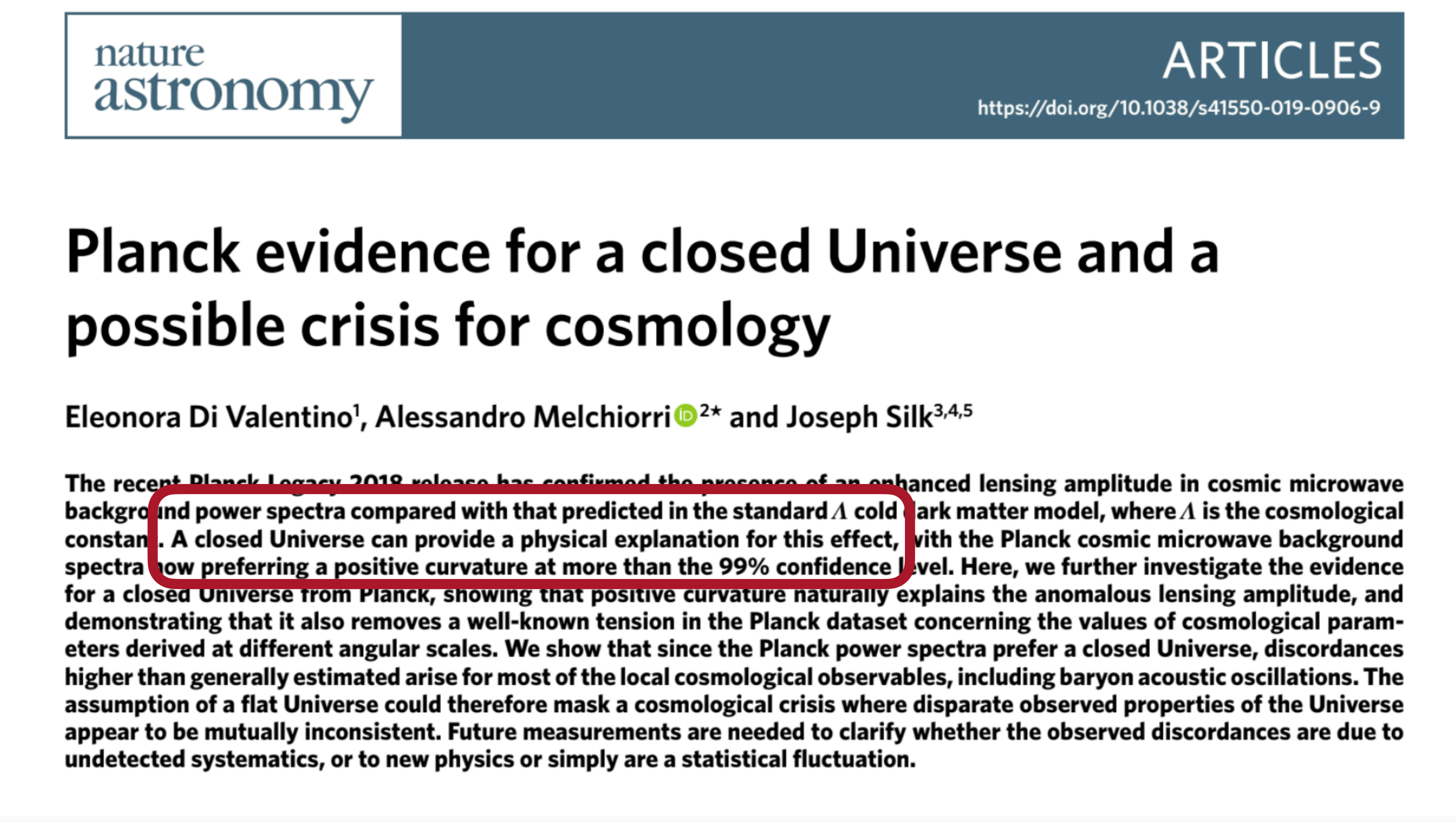
Constraints on the Sum of Neutrino Masses Σm_ν at 68% C.L. from a Combination of Different Data Sets in the Case of the ΛCDM+Σm_ν Scenario

Data Set	Σm_ν (eV)
Planck (+$A_{\rm lens}$)	<0.51
Planck+BAO (+$A_{\rm lens}$)	<0.19
Planck+Pantheon (+$A_{\rm lens}$)	<0.25
Planck+lensing (+$A_{\rm lens}$)	$0.41^{+0.17}_{-0.25}$
ACT-DR4+WMAP	0.68 ± 0.31
ACT-DR4+WMAP+BAO	<0.19
ACT-DR4+WMAP+Pantheon	<0.25
ACT-DR4+WMAP+lensing	0.60 ± 0.25
SPT-3G+WMAP	$0.46^{+0.14}_{-0.36}$
SPT-3G+WMAP+BAO	$0.22^{+0.056}_{-0.14}$
SPT-3G+WMAP+Pantheon	$0.25^{+0.052}_{-0.19}$
SPT-3G+WMAP+lensing	<0.37

Silk, ApJ letters 2022

No dataset excludes masses above 0.3 eV !

BUT . . .
WHAT IS AL ?



nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-019-0906-9

Planck evidence for a closed Universe and a possible crisis for cosmology

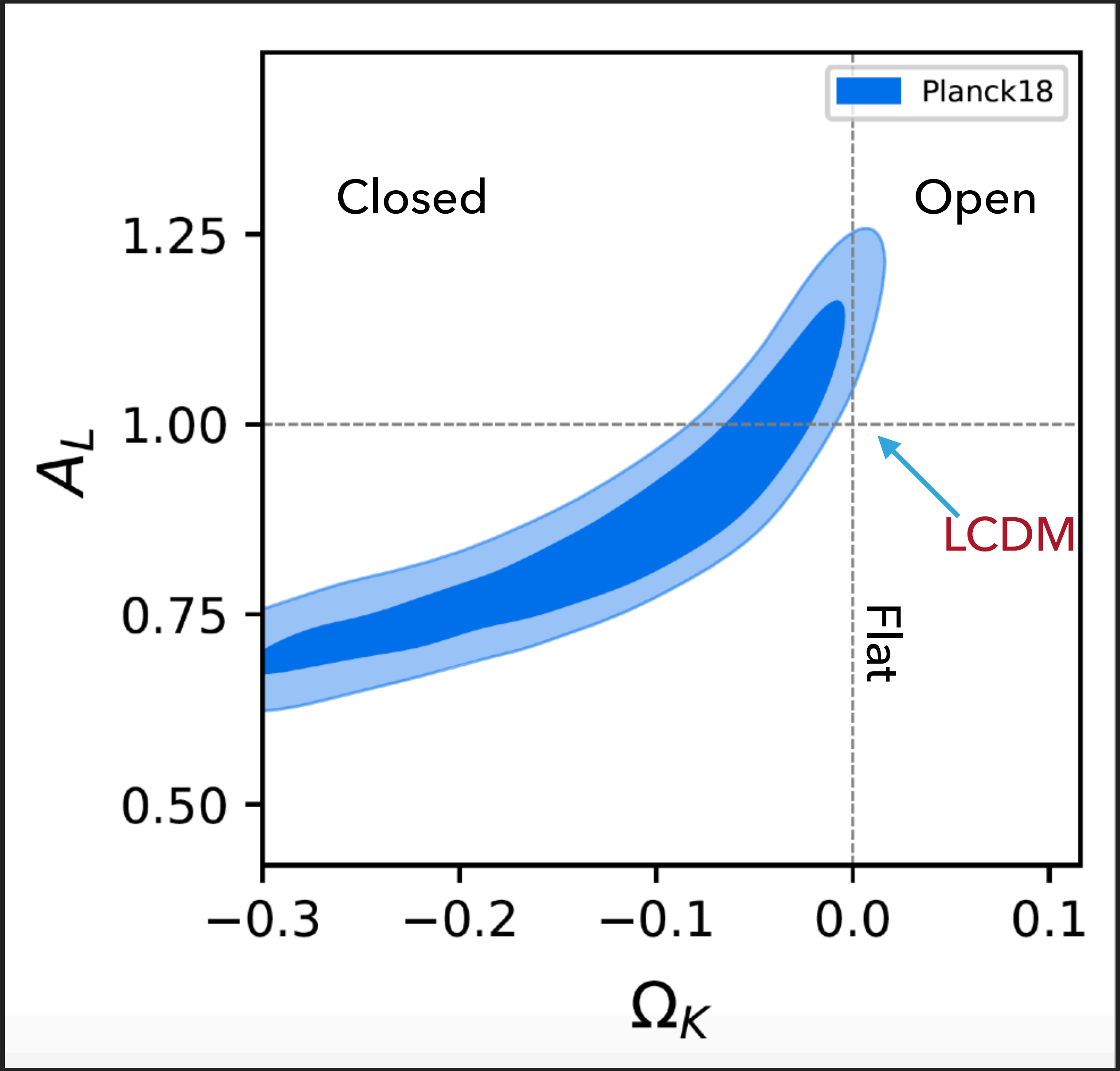
Eleonora Di Valentino[1], Alessandro Melchiorri[2*] and Joseph Silk[3,4,5]

The recent Planck Legacy 2018 release has confirmed the presence of an enhanced lensing amplitude in cosmic microwave background power spectra compared with that predicted in the standard Λ cold dark matter model, where Λ is the cosmological constant. A closed Universe can provide a physical explanation for this effect, with the Planck cosmic microwave background spectra now preferring a positive curvature at more than the 99% confidence level. Here, we further investigate the evidence for a closed Universe from Planck, showing that positive curvature naturally explains the anomalous lensing amplitude, and demonstrating that it also removes a well-known tension in the Planck dataset concerning the values of cosmological parameters derived at different angular scales. We show that since the Planck power spectra prefer a closed Universe, discordances higher than generally estimated arise for most of the local cosmological observables, including baryon acoustic oscillations. The assumption of a flat Universe could therefore mask a cosmological crisis where disparate observed properties of the Universe appear to be mutually inconsistent. Future measurements are needed to clarify whether the observed discordances are due to undetected systematics, or to new physics or simply are a statistical fluctuation.

THE Ω_K AND A_L ANOMALIES

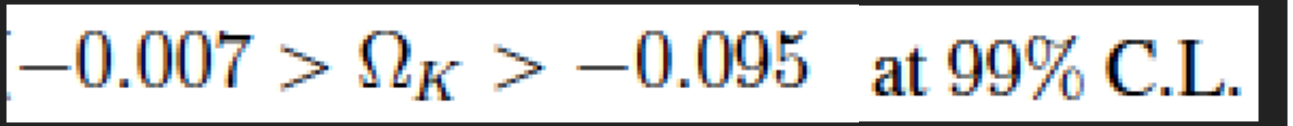
If we let curvature to vary we have more dark matter in a closed universe….

…and more dark matter increases the lensing signal at lower redshifts.

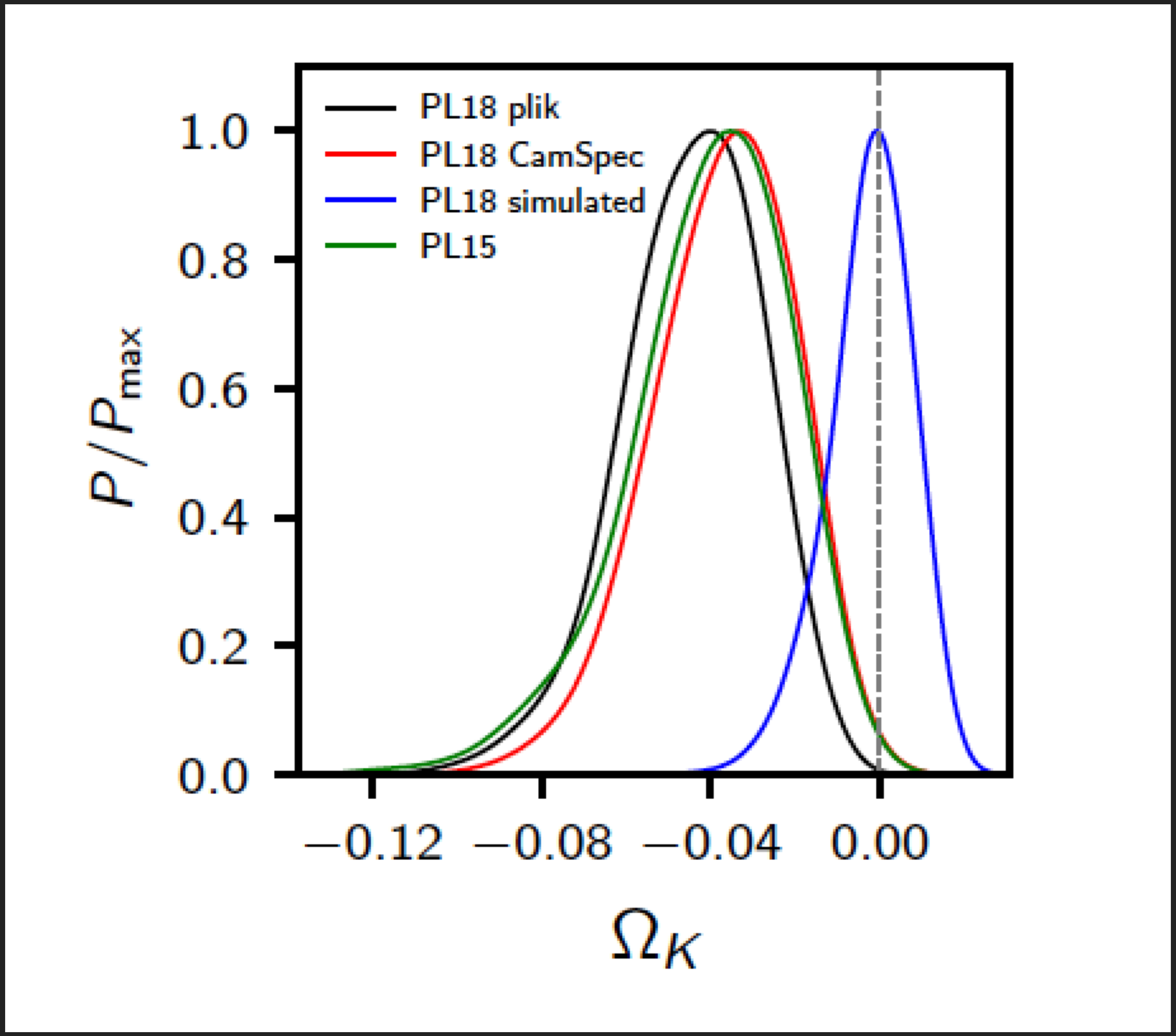


THE Ω_K ANOMALY

Planck alone data is providing a more than 3.4σ evidence for a positive curved universe:

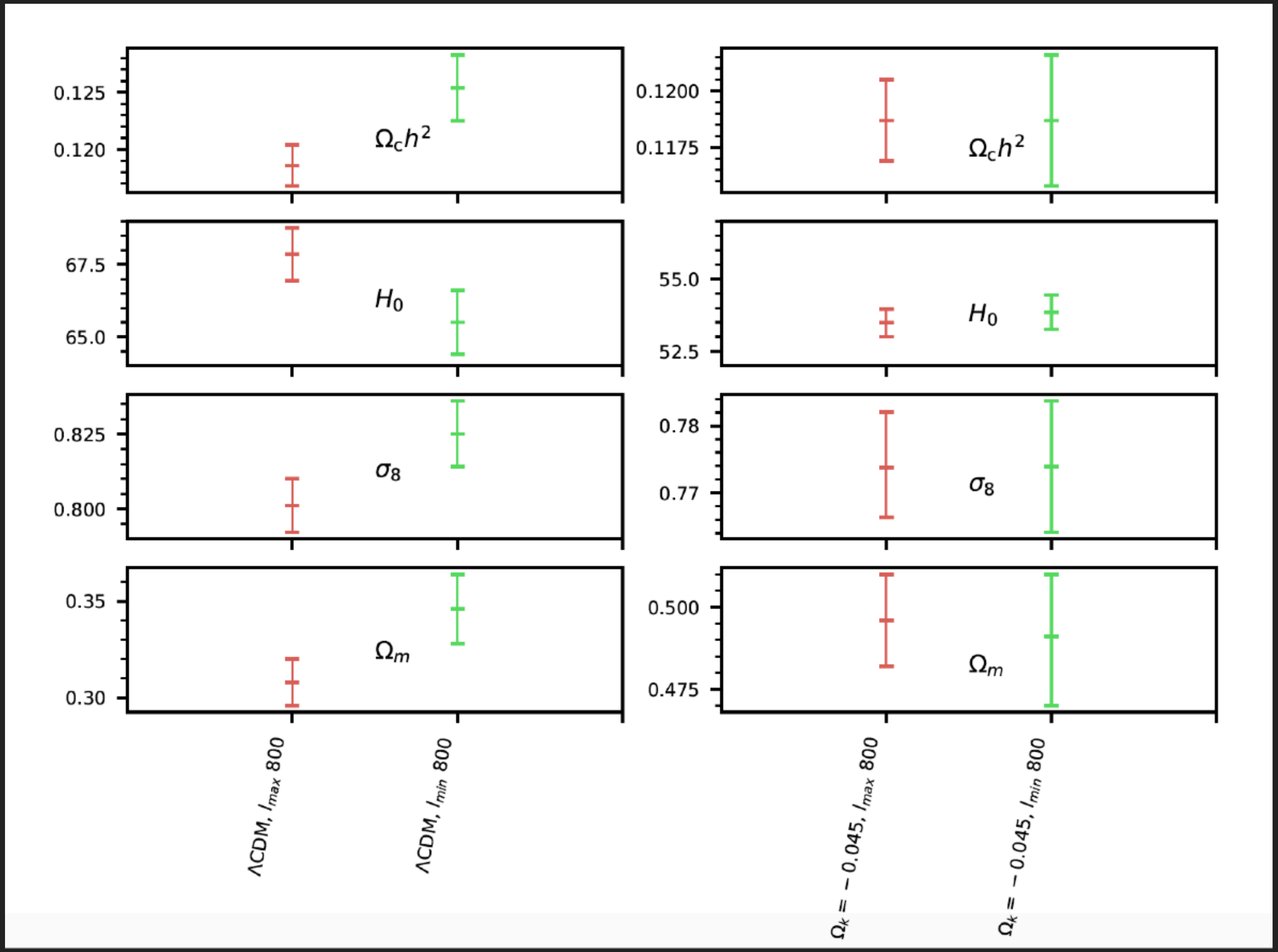


$$-0.007 > \Omega_K > -0.095 \quad \text{at } 99\% \text{ C.L.}$$



Di Valentino, Melchiorri, Silk Nature Astronomy 2020

THE Ω_k ANOMALY



Di Valentino, Melchiorri, Silk 2020

The parameter shift between large and small scales disappears when we consider closed models !

SOME COMMENTS…

New Scientist:

“If this is true, it would have profound implications on our understanding of the universe,” says David Spergel at Princeton University. “It’s a really important claim, but I’m not sure it’s one that’s backed by the data. In fact, I’d say the evidence is actually against it.”

Quanta Magazine:

Antony Lewis, a cosmologist at the University of Sussex and a member of the Planck team who worked on that analysis, said:“is that it is just a statistical fluke.” Lewis and other experts say they’ve already closely scrutinized the issue, along with related puzzles in the data.

Salon:

“The result is intriguing, but only of borderline statistical significance to be believed. There are several independent lines of evidence that suggest the Universe is flat, and that this claim is a statistical fluke or a misinterpretation of the data,” Avi Loeb, chair of Harvard's astronomy department, told Salon via email.

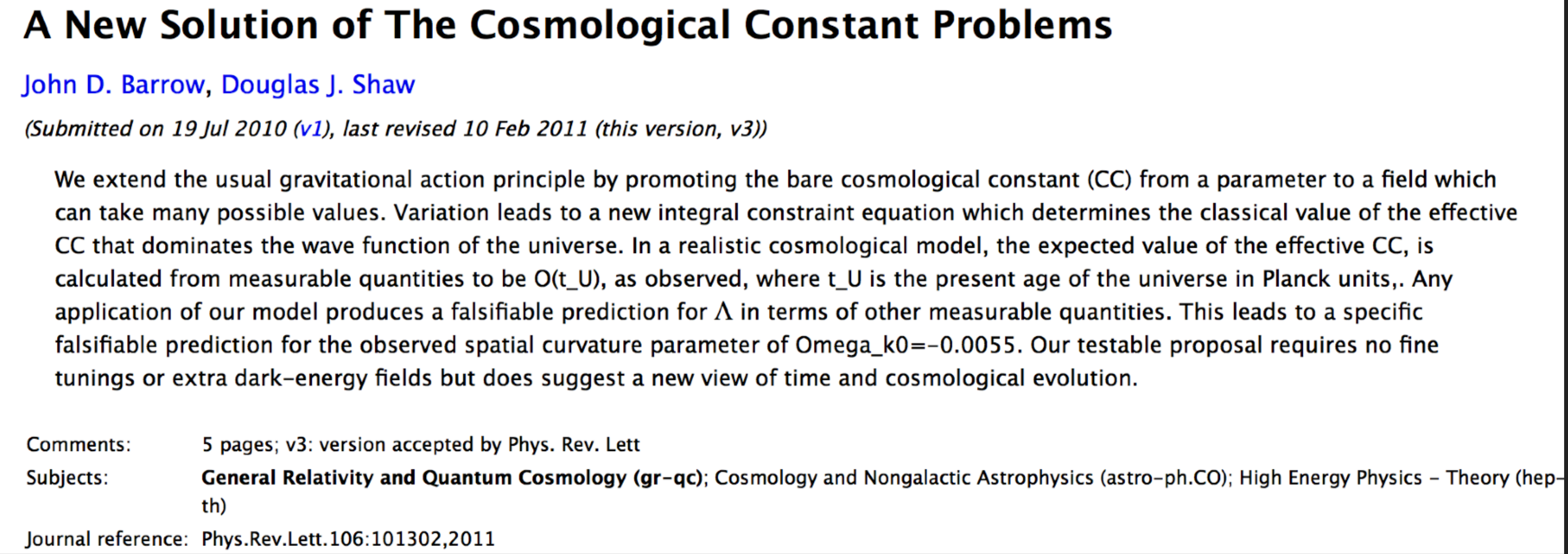
Scientific American:

Efstathiou asked not to be directly quoted, but pointed out in an email to Live Science that if the universe were curved, it would raise a number of problems—contradicting those other data sets from the early universe and making discrepancies in the universe’s observed rate of expansion much worse. Gratton said he agreed.

Neue Zurich Zeitung:

Martin Kunz von der Universität Genf, wie Melchiorri ein Mitglied der Planck-Arbeitsgruppe, teilt diese Ansicht nicht. An der Analyse von Melchiorri und seinen Mitarbeitern hat er nichts auszusetzen. Was ihn stört, ist die Interpretation der Planck-Daten. Dass es in diesen Daten kleinere Unstimmigkeiten gebe, sei seit längerem bekannt.

CLOSED MODELS



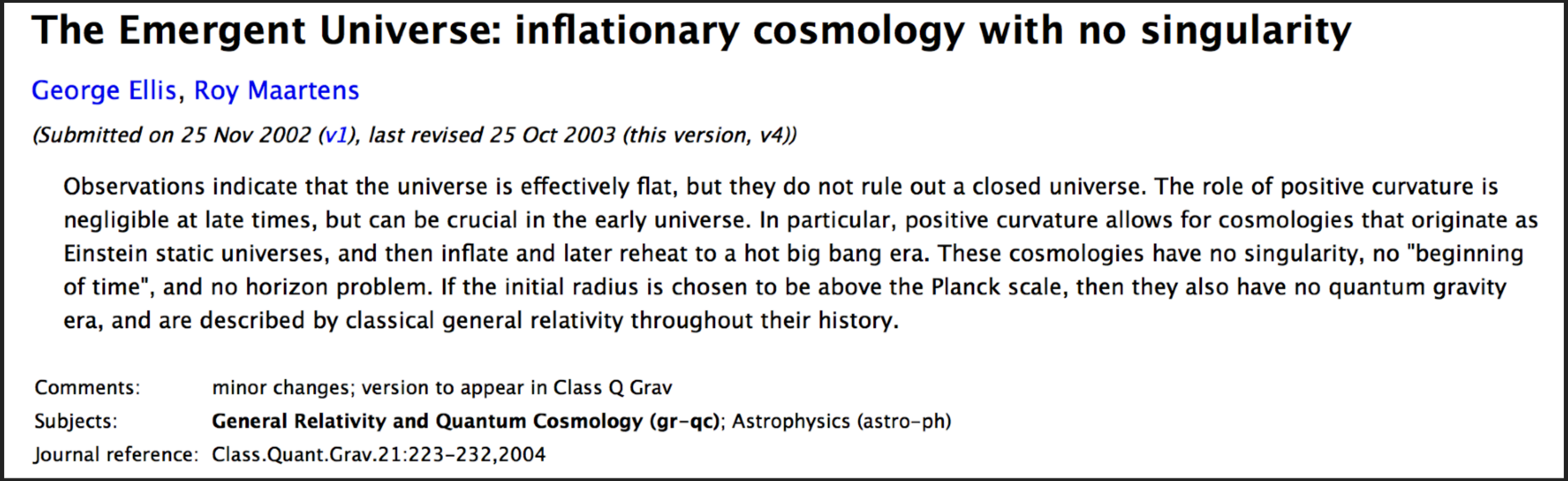
A New Solution of The Cosmological Constant Problems

John D. Barrow, Douglas J. Shaw

(Submitted on 19 Jul 2010 (v1), last revised 10 Feb 2011 (this version, v3))

We extend the usual gravitational action principle by promoting the bare cosmological constant (CC) from a parameter to a field which can take many possible values. Variation leads to a new integral constraint equation which determines the classical value of the effective CC that dominates the wave function of the universe. In a realistic cosmological model, the expected value of the effective CC, is calculated from measurable quantities to be O(t_U), as observed, where t_U is the present age of the universe in Planck units,. Any application of our model produces a falsifiable prediction for Λ in terms of other measurable quantities. This leads to a specific falsifiable prediction for the observed spatial curvature parameter of Omega_k0=-0.0055. Our testable proposal requires no fine tunings or extra dark-energy fields but does suggest a new view of time and cosmological evolution.

Comments:	5 pages; v3: version accepted by Phys. Rev. Lett
Subjects:	**General Relativity and Quantum Cosmology (gr-qc)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); High Energy Physics - Theory (hep-th)
Journal reference:	Phys.Rev.Lett.106:101302,2011



The Emergent Universe: inflationary cosmology with no singularity

George Ellis, Roy Maartens

(Submitted on 25 Nov 2002 (v1), last revised 25 Oct 2003 (this version, v4))

Observations indicate that the universe is effectively flat, but they do not rule out a closed universe. The role of positive curvature is negligible at late times, but can be crucial in the early universe. In particular, positive curvature allows for cosmologies that originate as Einstein static universes, and then inflate and later reheat to a hot big bang era. These cosmologies have no singularity, no "beginning of time", and no horizon problem. If the initial radius is chosen to be above the Planck scale, then they also have no quantum gravity era, and are described by classical general relativity throughout their history.

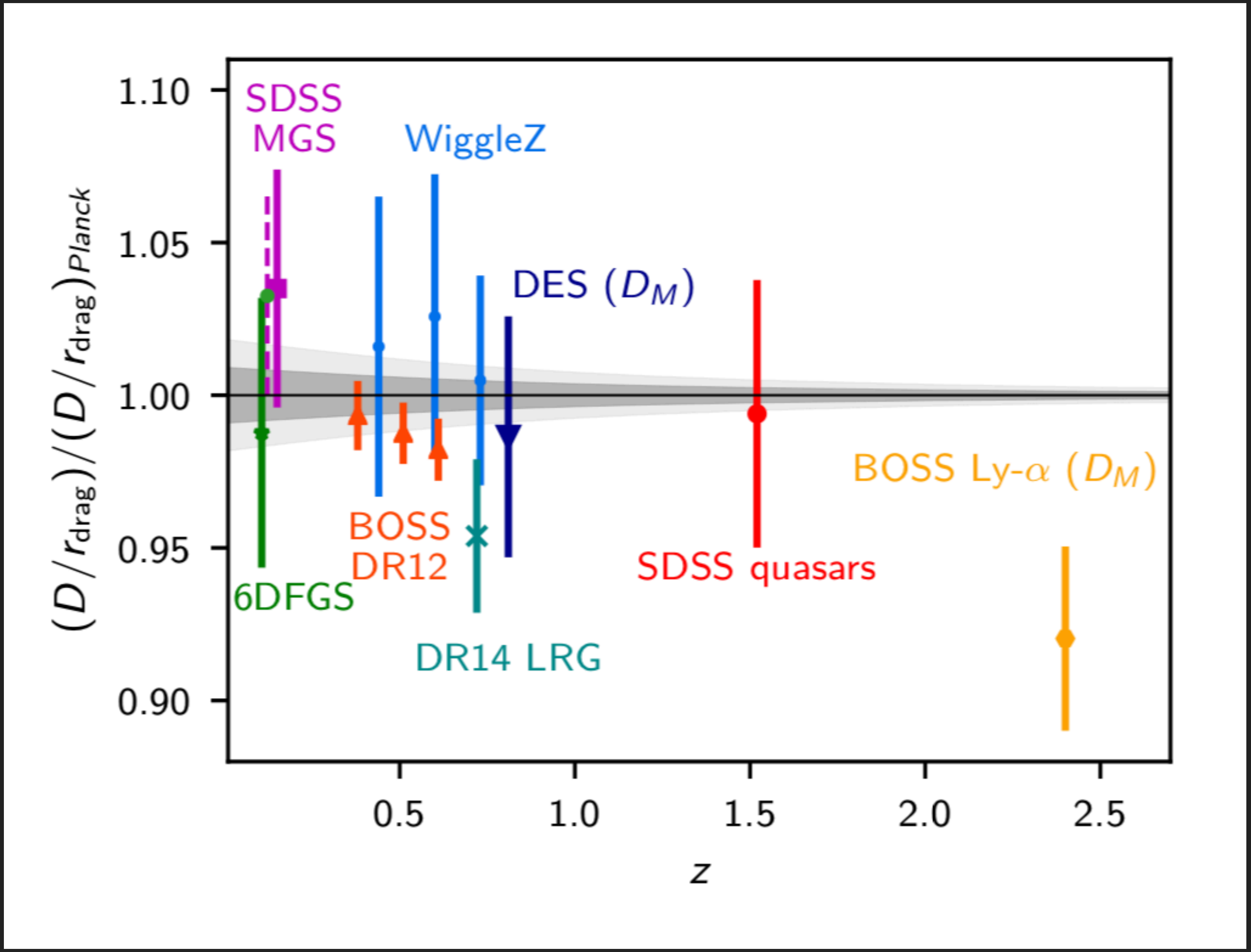
Comments:	minor changes; version to appear in Class Q Grav
Subjects:	**General Relativity and Quantum Cosmology (gr-qc)**; Astrophysics (astro-ph)
Journal reference:	Class.Quant.Grav.21:223-232,2004

TENSIONS IN A CURVED UNIVERSE

We have a strong constraint for a flat universe when we combine with BAO.

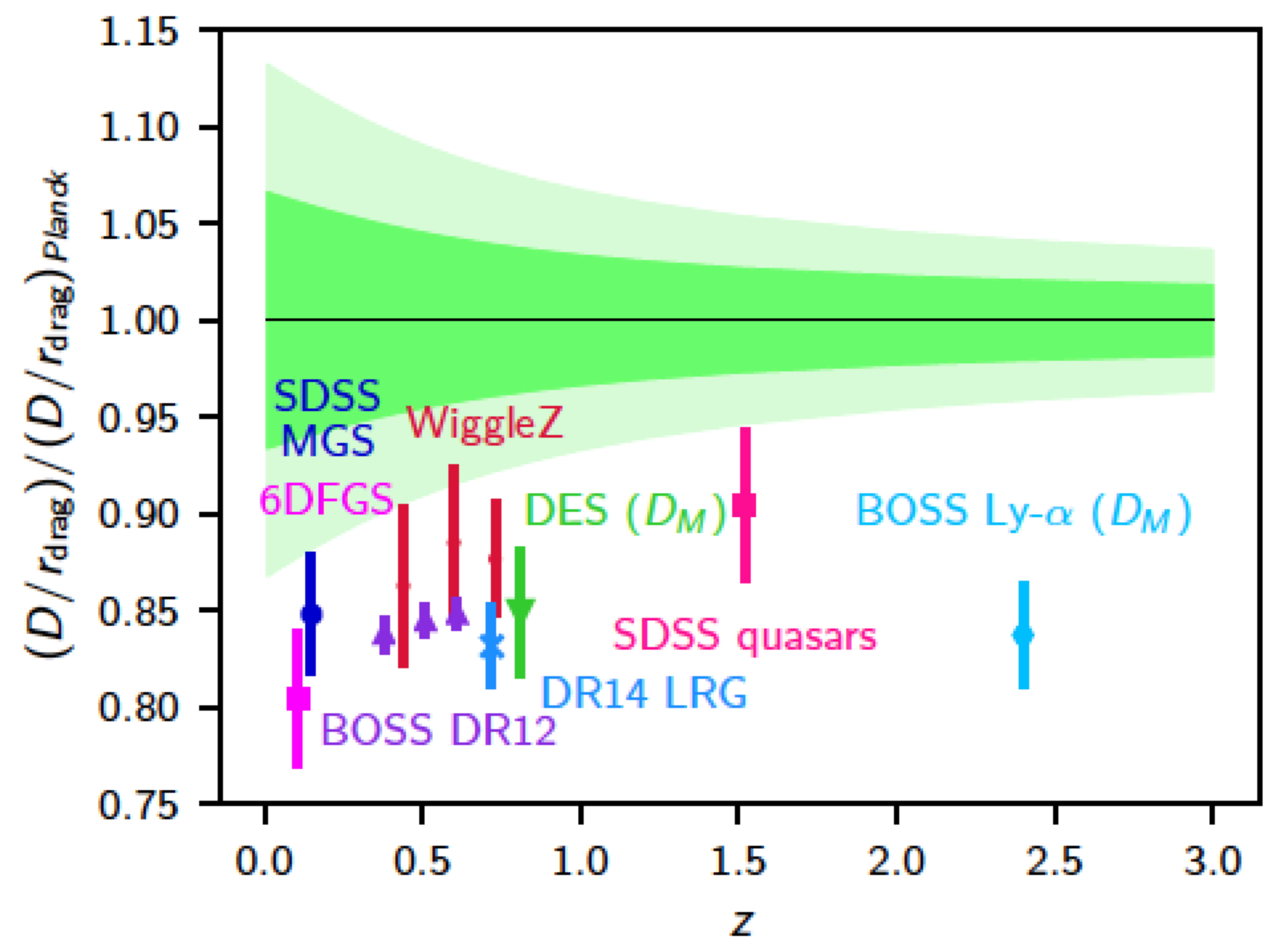
BAO are considered in good agreement with Planck but this result is obtained under the assumption of flatness.

What happens when we let curvature to vary ?



TENSIONS IN A CURVED UNIVERSE

When we let curvature to vary…Planck spectra are inconsistent with BAO DR12 measurements at the level of 3 standard deviations !



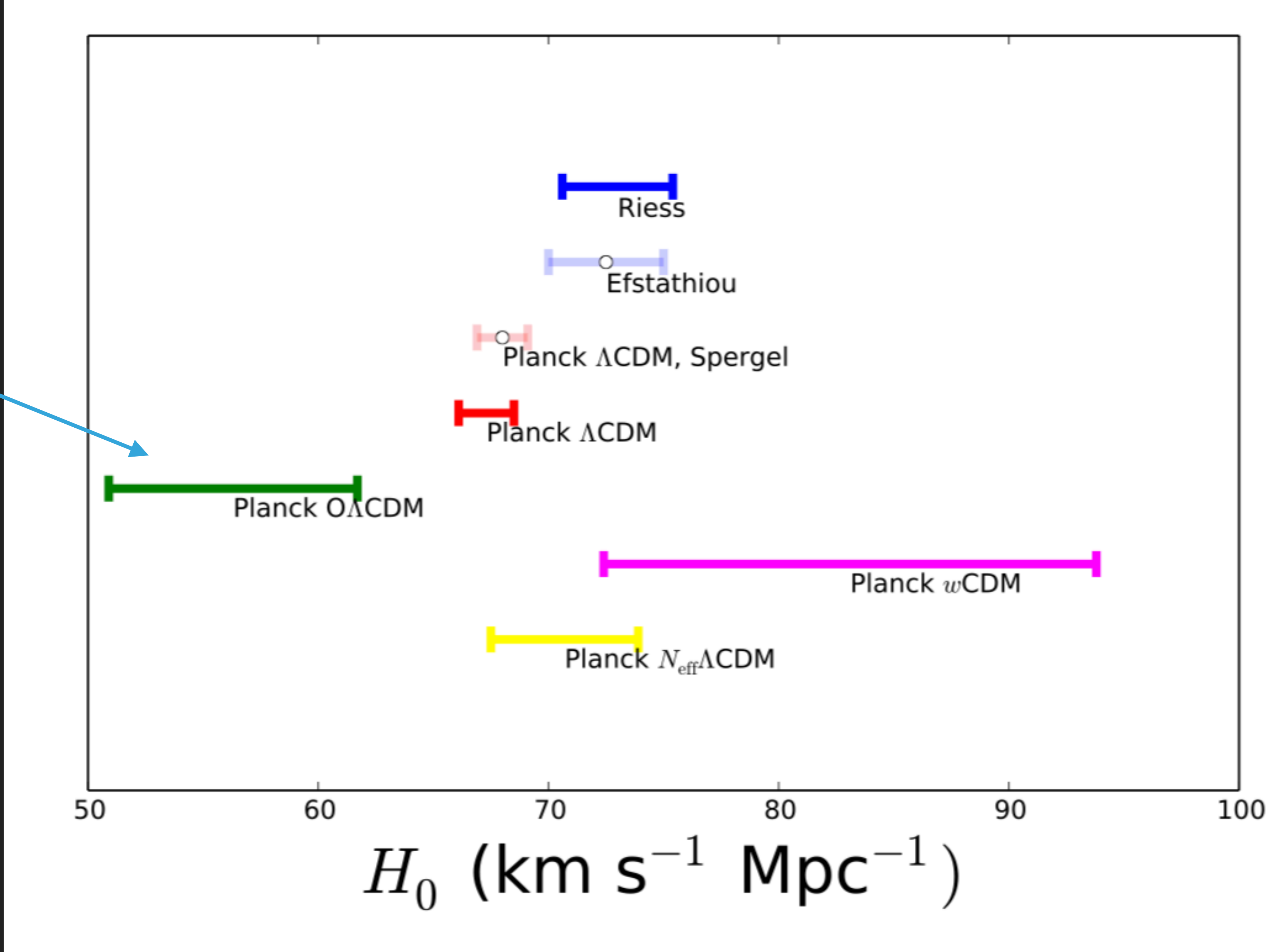
Di Valentino, Melchiorri, Silk 2020

H0 TENSION IN A CURVED UNIVERSE

Planck constraint is shifted

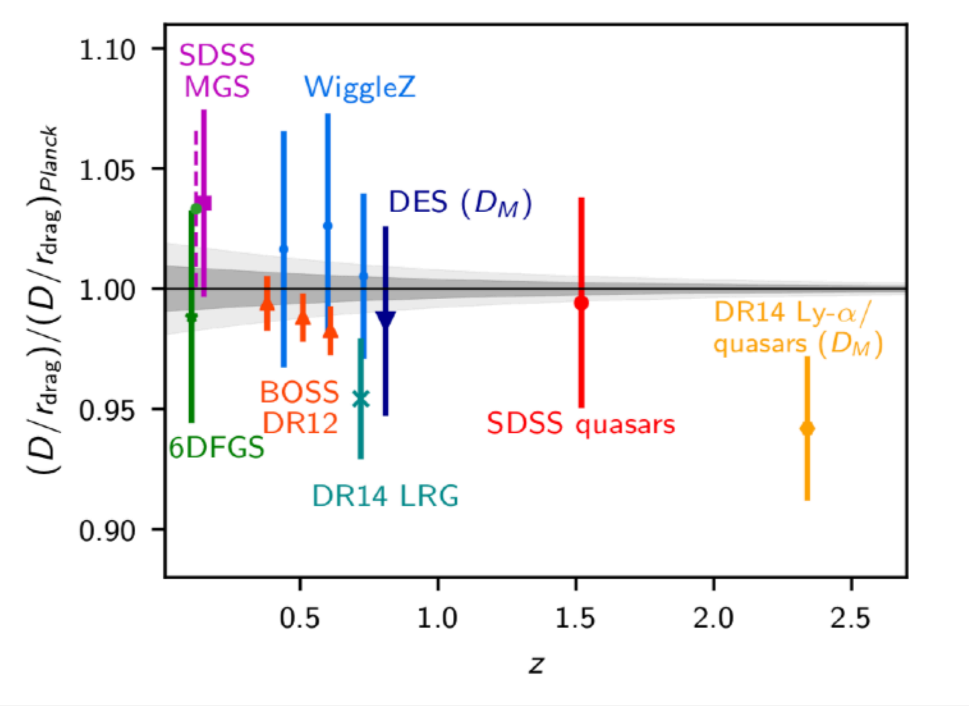
towards even smaller values

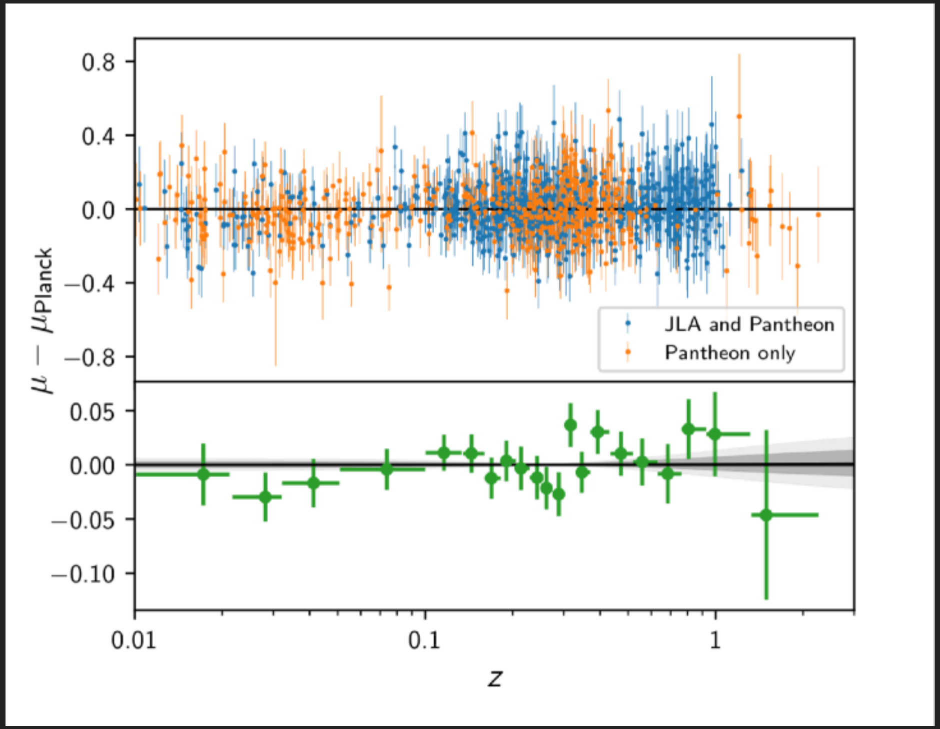
of H0 !

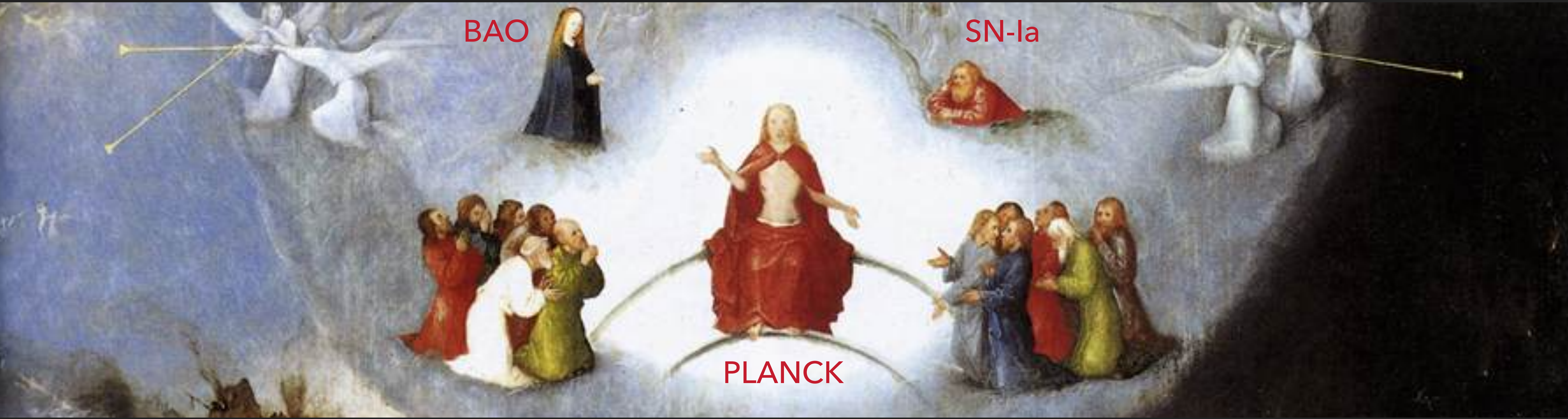


Cuesta et al, Mon.Not.Roy.Astron.Soc. 448 (2015)

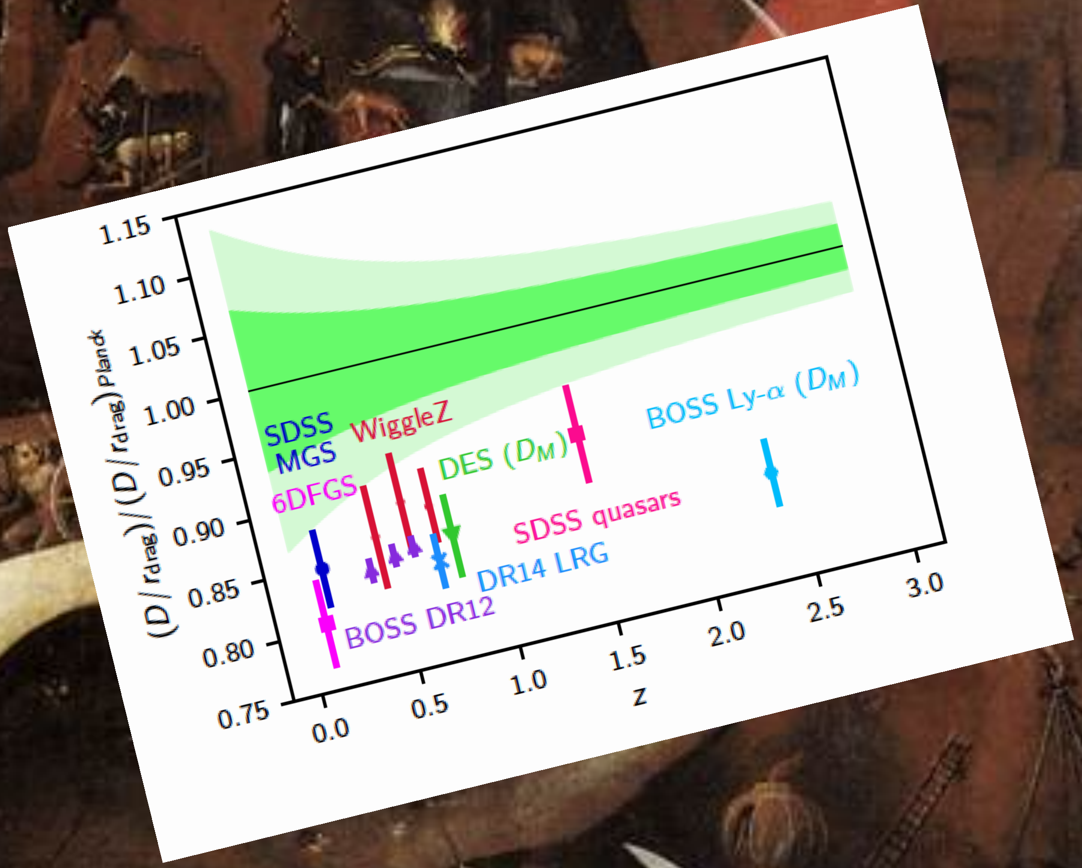
IF YOU ASSUME FLATNESS . . .







...IF YOU LET CURVATURE TO VARY...



RECAP:

THERE IS SOME MODEL DEPENDENCY IN THE CONSISTENCY WITH ΛCDM IN THE PLANCK DATASET. IF YOU INCREASE THE PARAMETER SPACE BY CONSIDERING THE LENSING PARAMETER, THE RESULT IS AN ANOMALY OF AROUND 3 STANDARD DEVIATIONS.

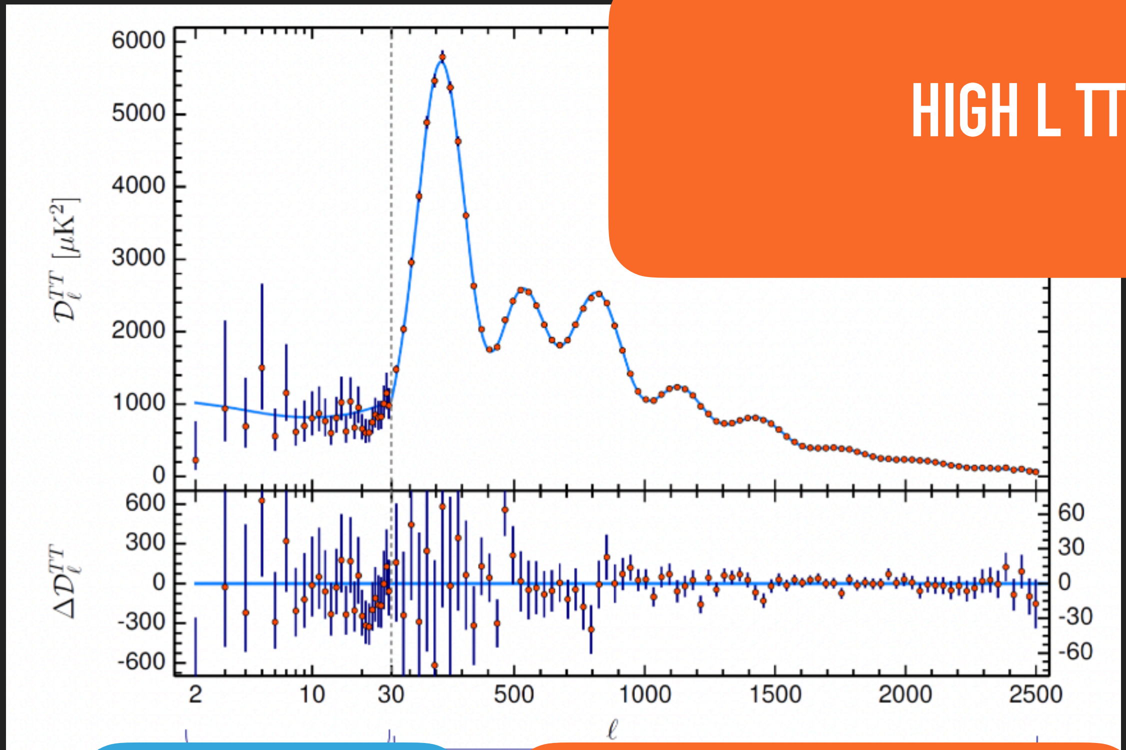
THIS ANOMALY CAUSES THE PLANCK DATA TO FAVOR A CLOSED UNIVERSE AT 3.4 STANDARD DEVIATIONS.

HERE, WE ARE NOT ADVOCATING FOR A CLOSED UNIVERSE, BUT HOW CAN WE TRUST CURRENT COSMOLOGICAL CONSTRAINTS ON NEUTRINO MASSES IF ΛCDM DOES NOT PROVIDE A PERFECT FIT?

ΛCDM CANNOT BE USED AS A LABORATORY TO TEST FUNDAMENTAL PHYSICS.

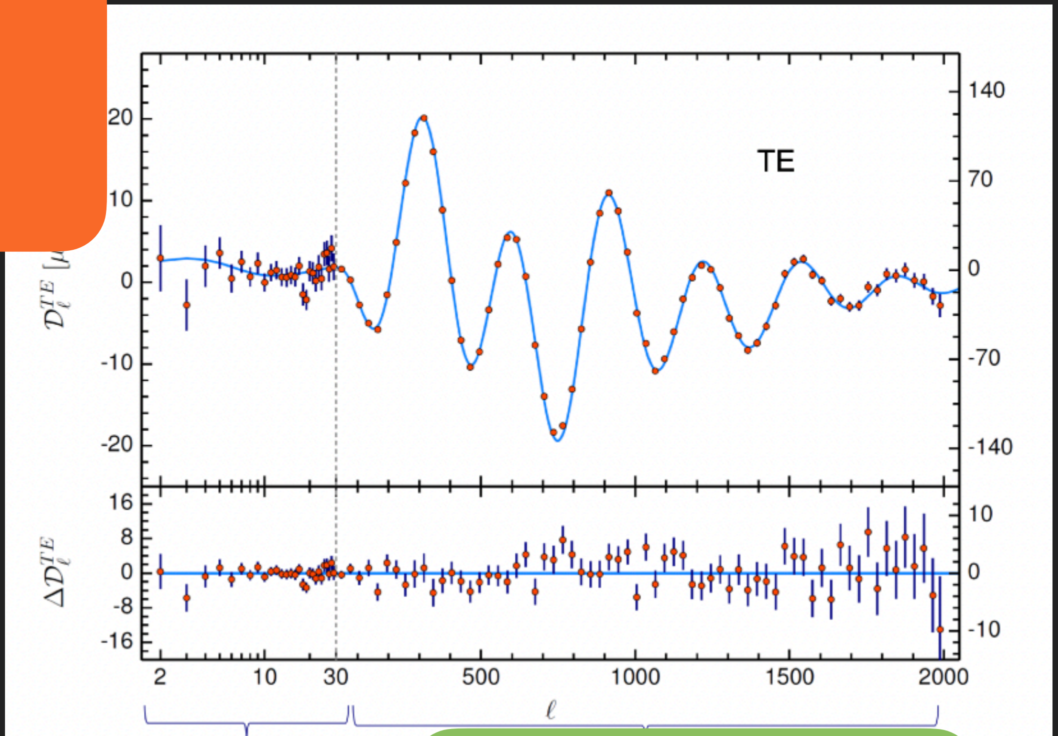
PLANCK 2018 SPECTRA

HIGH L TT



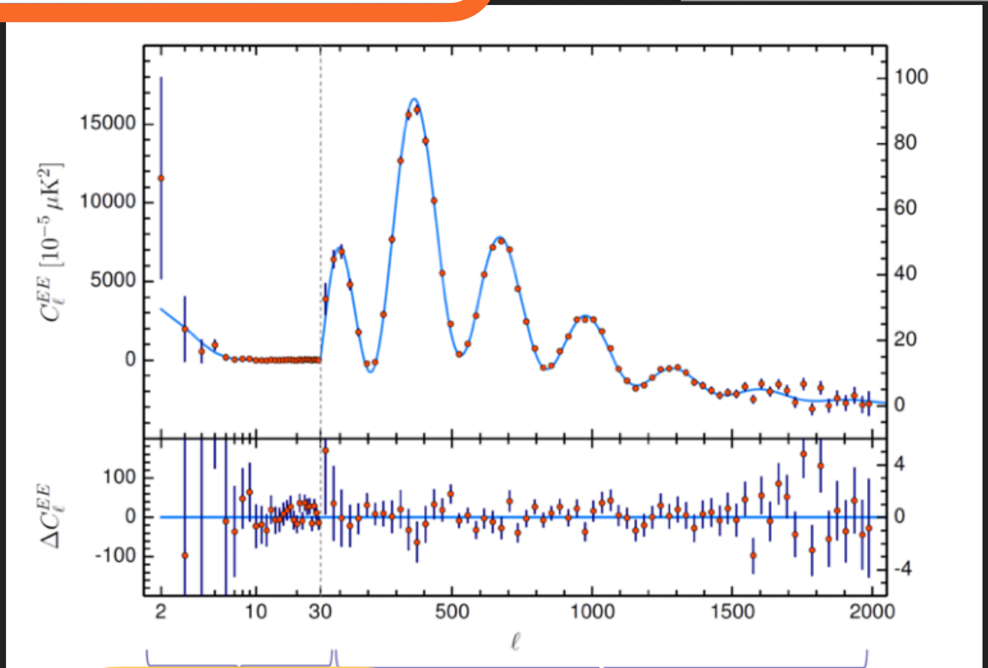
$2 \leq \ell \leq 29$:
“Commander”
Gibbs likelihood

$\ell \geq 30$: “plik” HM C_ℓ likelihood



$2 \leq \ell \leq 29$
NOT USED

$\ell \geq 30$: “plik” HM C_ℓ likelihood



$2 \leq \ell \leq 29$
lowE “SimAll” likelihood

$\ell \geq 30$: “plik” HM C_ℓ likelihood

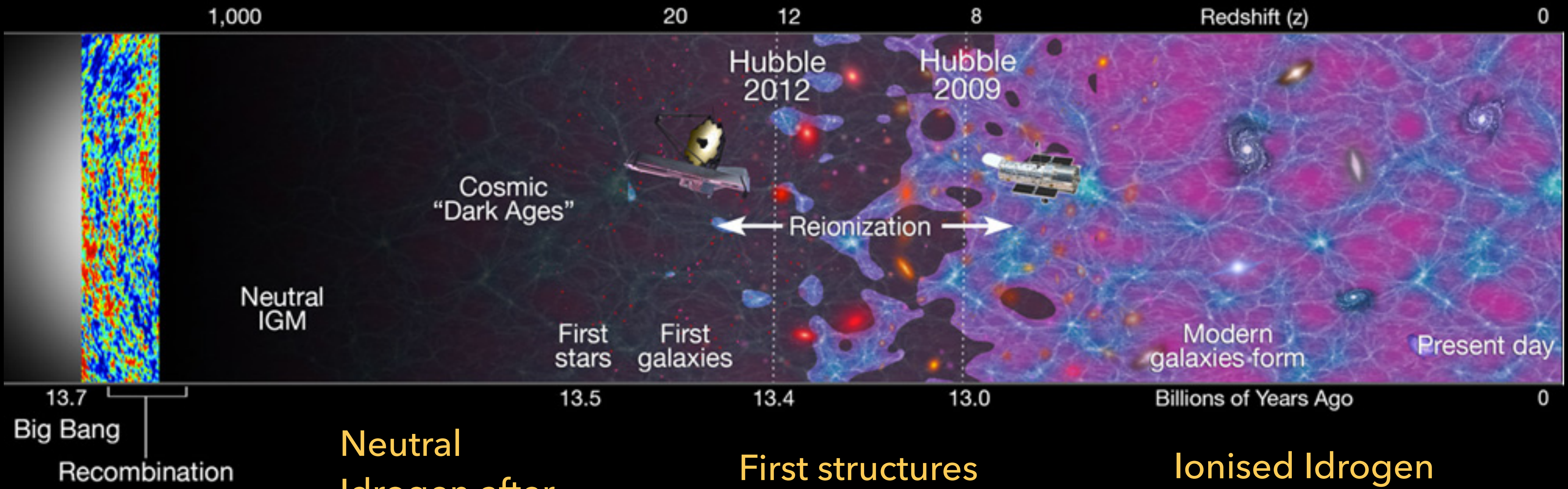
LOW L TT

LOW L EE

HIGH L TEEE

REMINDER: THE LOWE POLARISATION IS CRUCIAL IN DETERMINING THE OPTICAL DEPTH

Universe reionize around this epoch

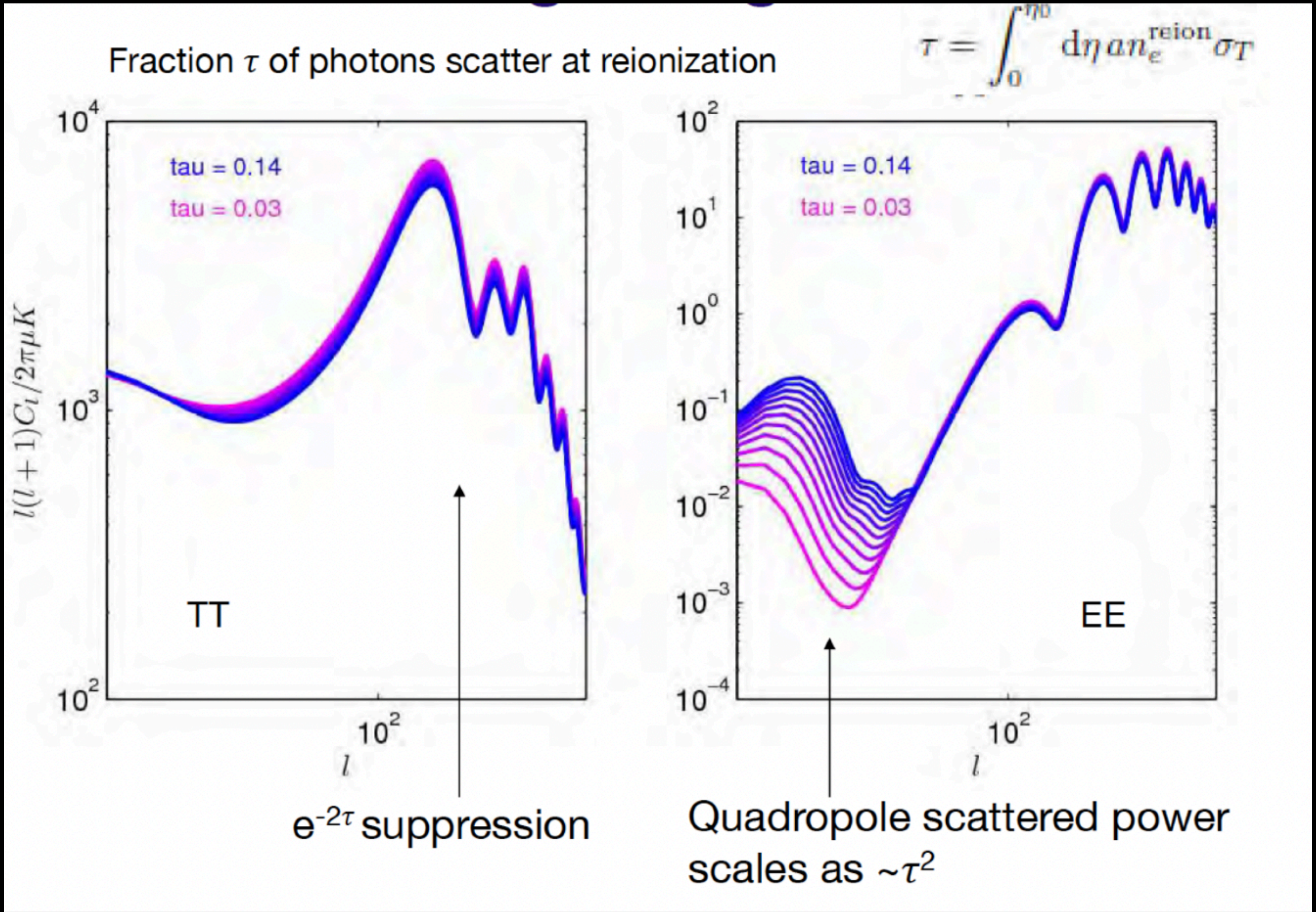


Neutral Idrogen after recombination

First structures formation

Ionised Idrogen after reionization

REMINDER: THE LOWE POLARISATION IS CRUCIAL IN DETERMINING THE OPTICAL DEPTH

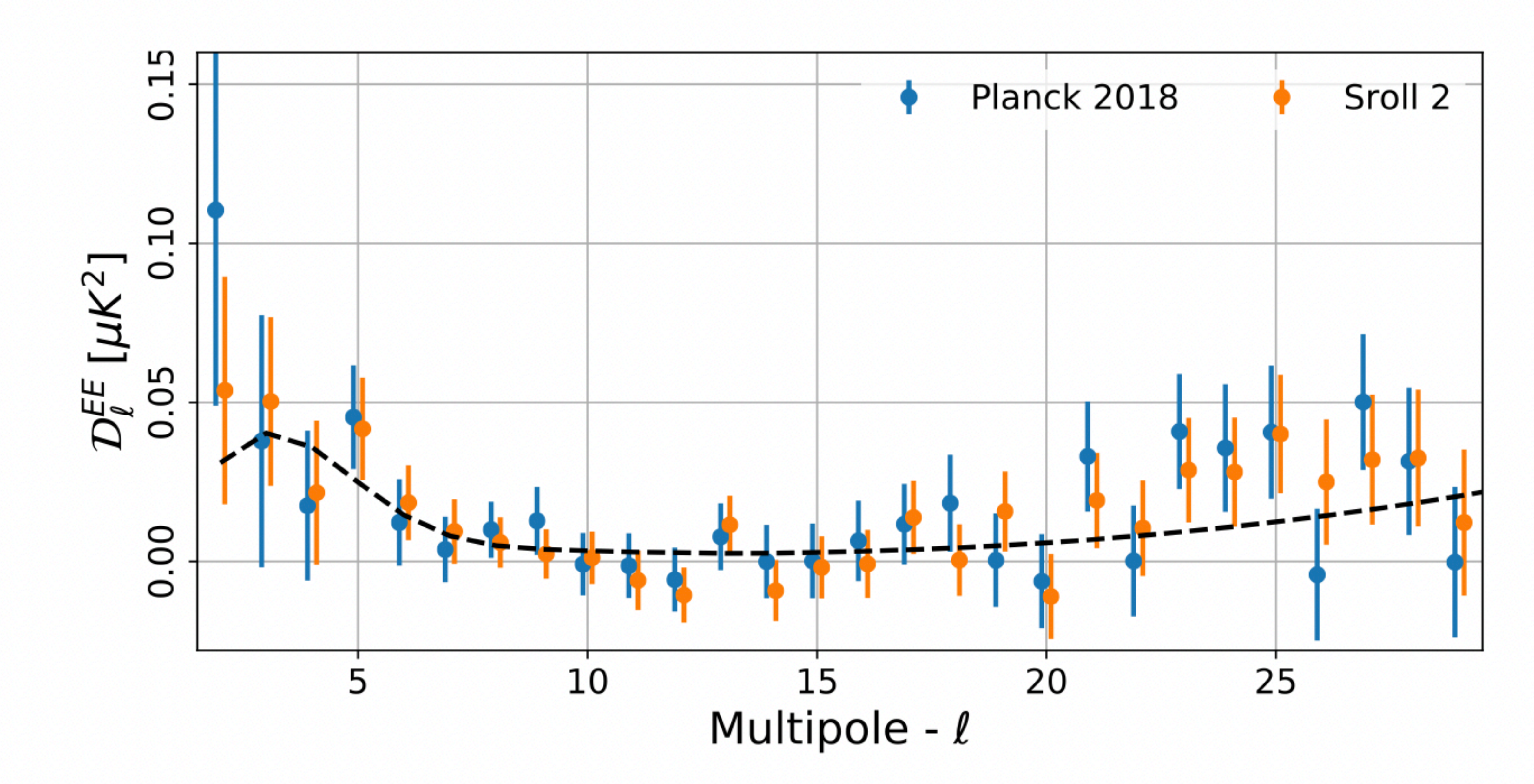

Fraction τ of photons scatter at reionization

$$\tau = \int_0^{\eta_0} d\eta\, a n_e^{\mathrm{reion}} \sigma_T$$

$e^{-2\tau}$ suppression

Quadropole scattered power scales as $\sim\tau^2$

LOW E POWER SPECTRA

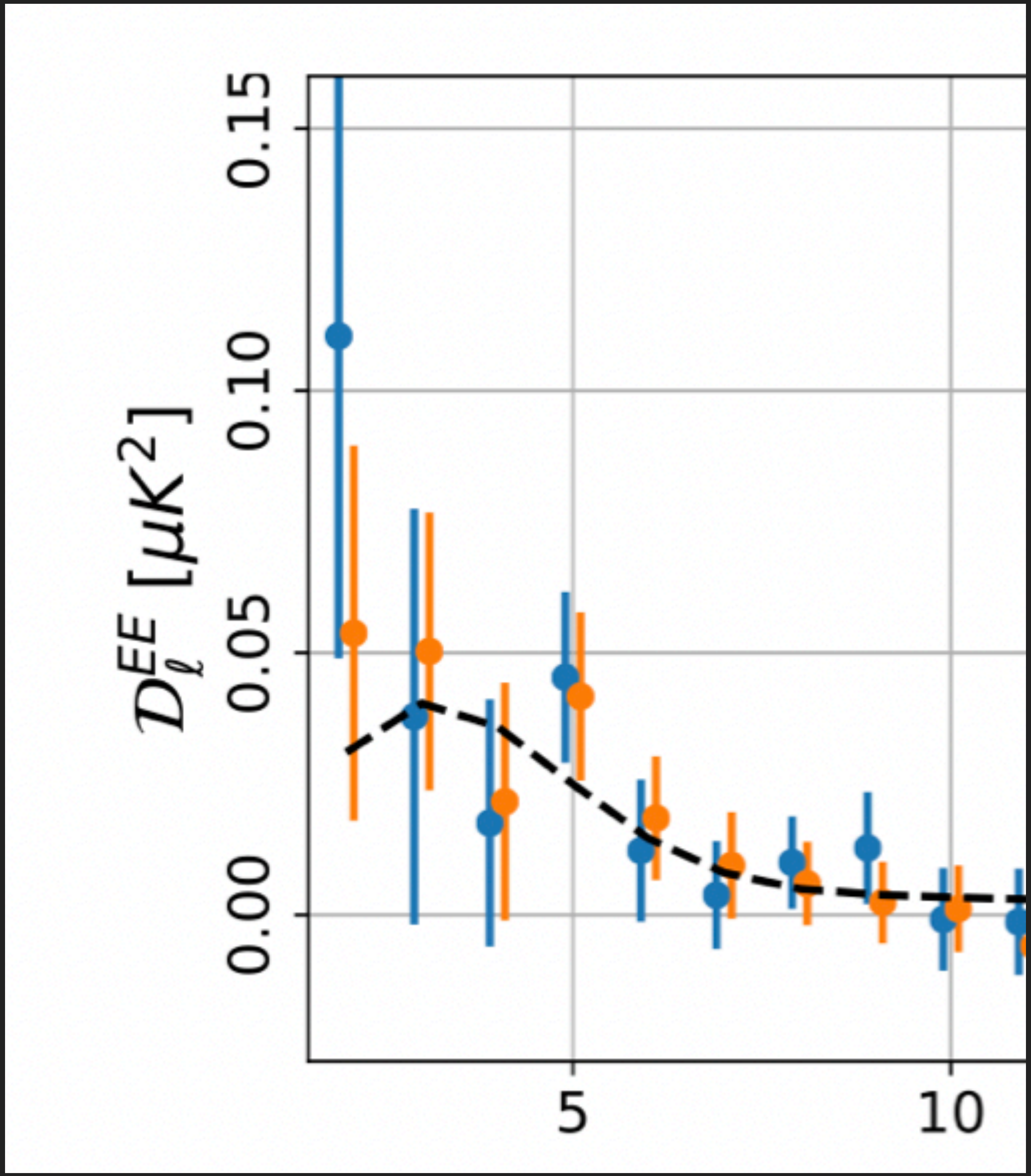


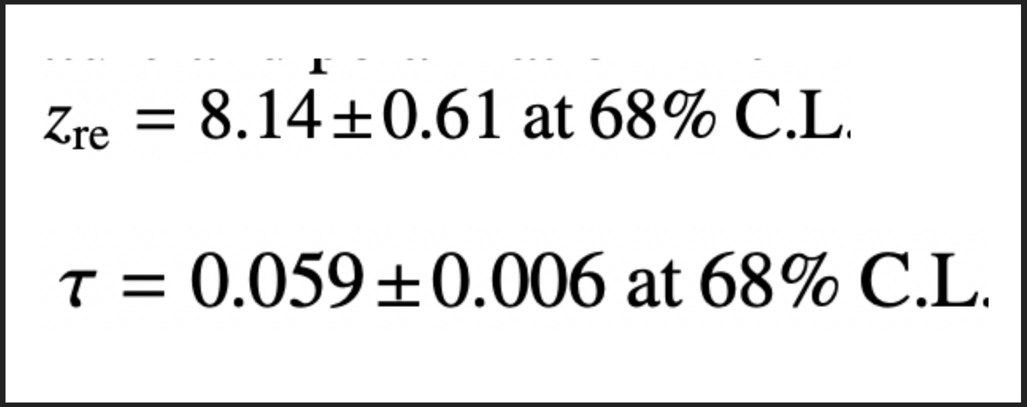
$z_{\rm re} = 8.14 \pm 0.61$ at 68% C.L.

$\tau = 0.059 \pm 0.006$ at 68% C.L.

Pagano et al, 2020

LOW E POWER SPECTRA

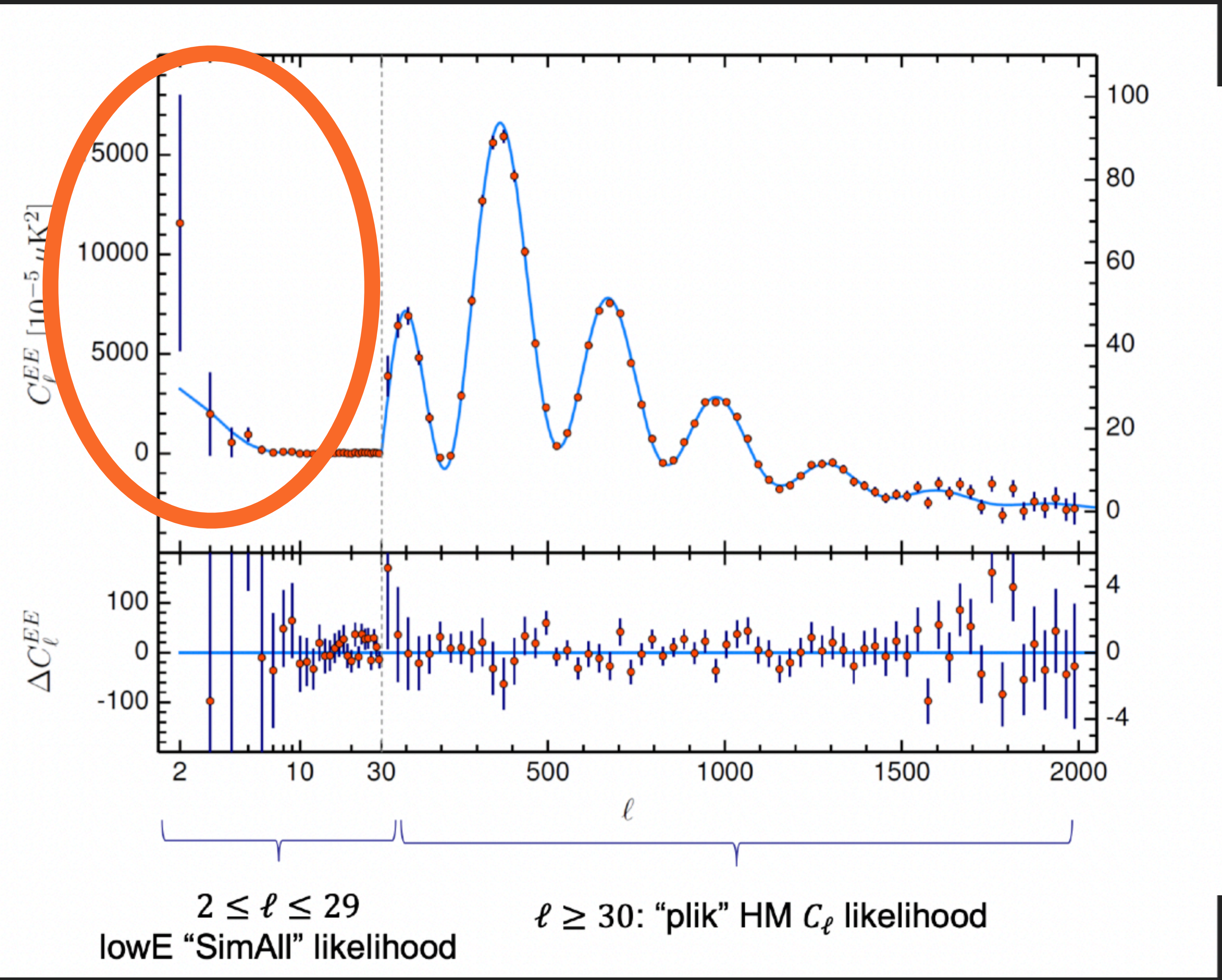


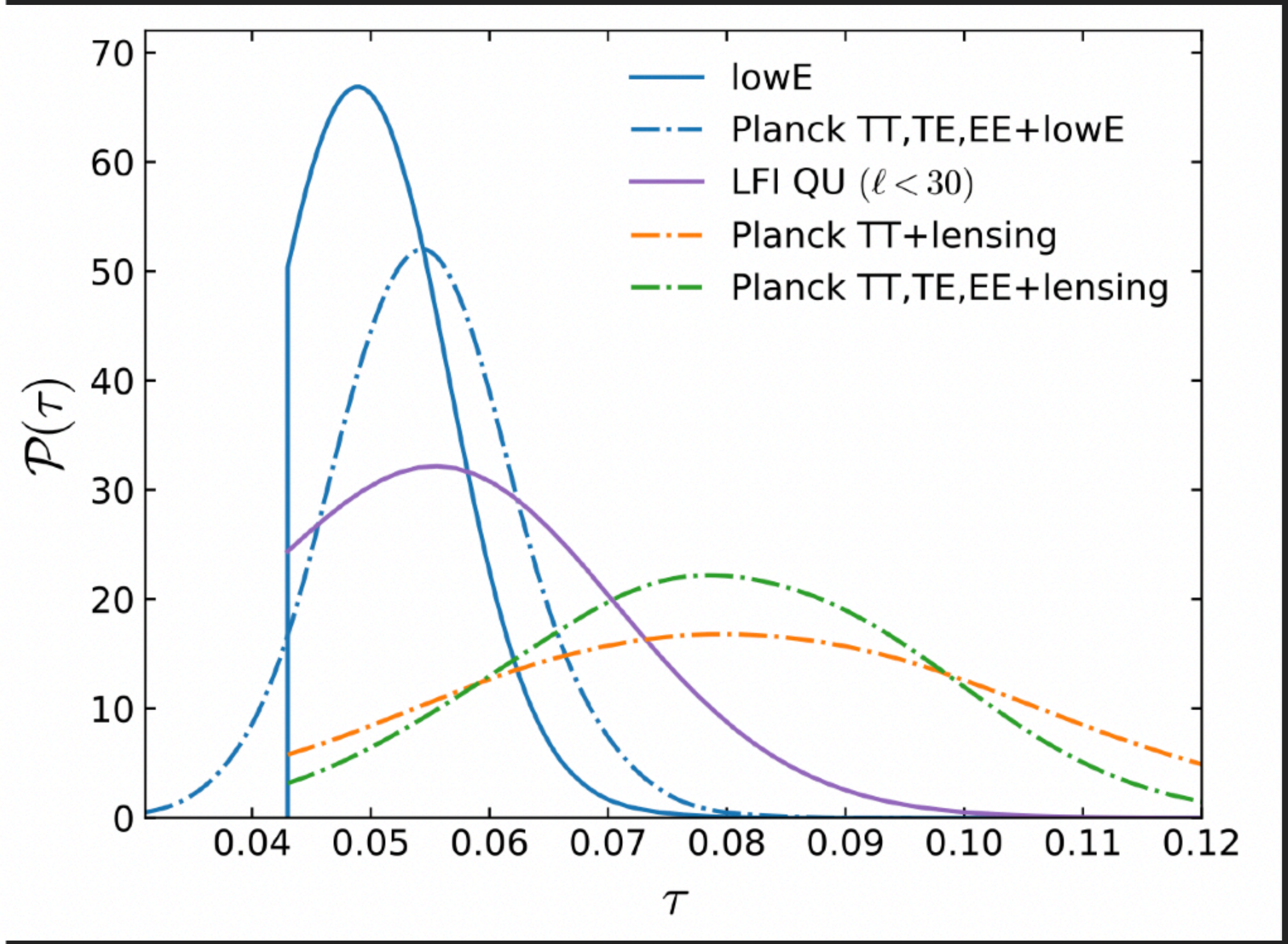


$z_{\mathrm{re}} = 8.14 \pm 0.61$ at 68% C.L.

$\tau = 0.059 \pm 0.006$ at 68% C.L.

HOW MUCH SHOULD WE TRUST LOWE FROM PLANCK ?

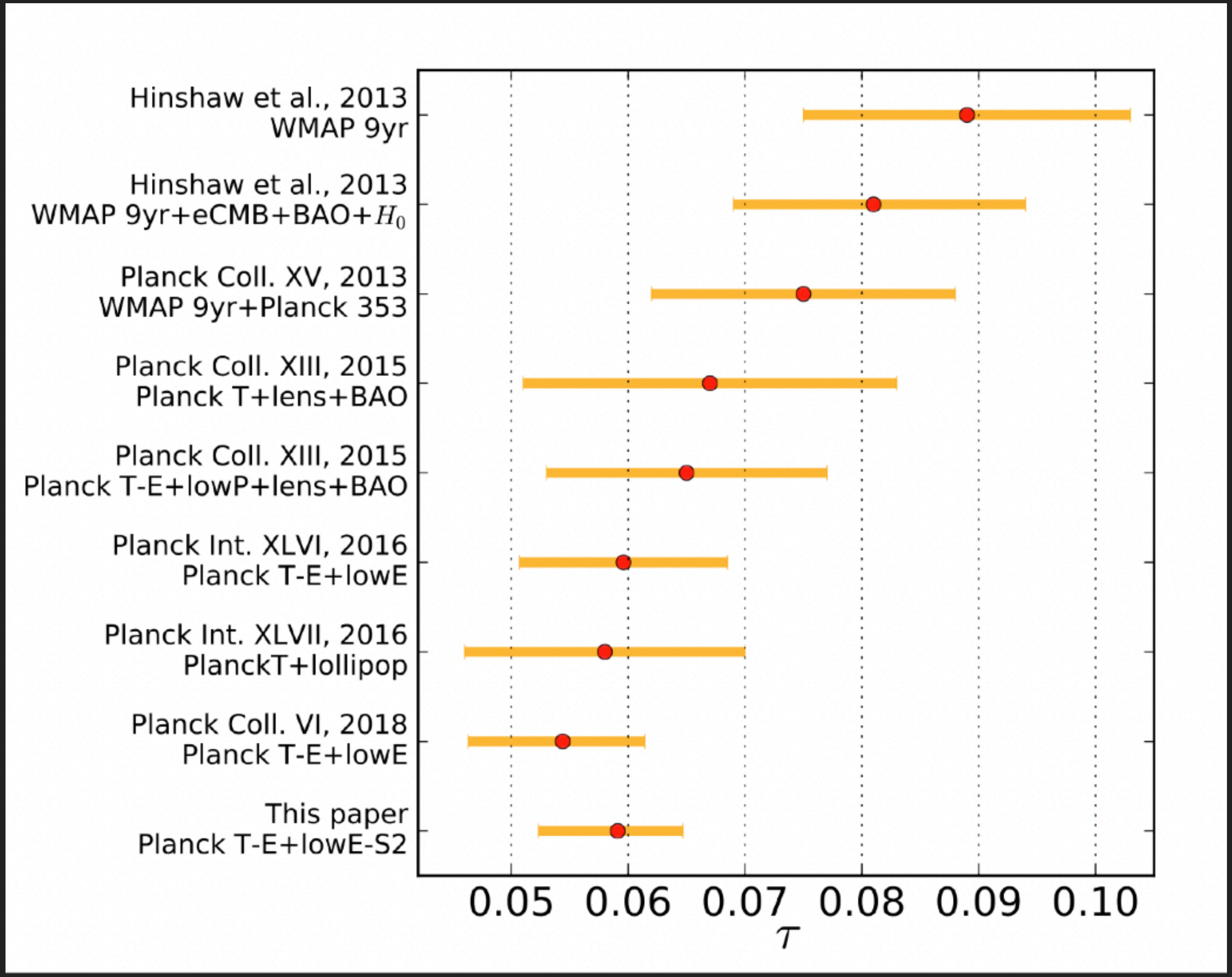




4 datapoints!!!! optical depth could be even lower without prior >0.04 !

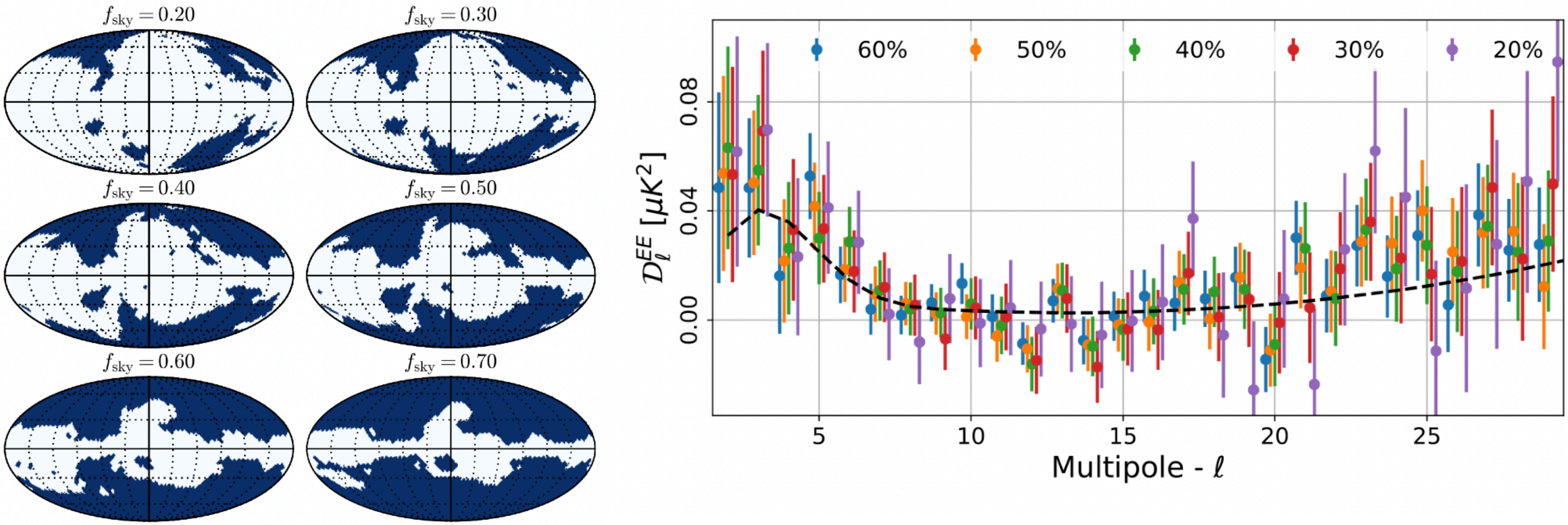
TROUBLES WITH LOWE?

POLARIZATION OF THE CMB AT LARGE ANGULAR SCALES IS PRIMARILY INFLUENCED BY GALACTIC FOREGROUNDS. HISTORICALLY, ITS VALUE HAS UNDERGONE SIGNIFICANT CHANGES.



TROUBLES WITH LOWE?

ONE COMMONLY PERFORMED TEST TO ASSESS FOREGROUND REMOVAL IS ANALYZING MAPS WITH DIFFERENT GALAXY FRACTION REMOVALS.



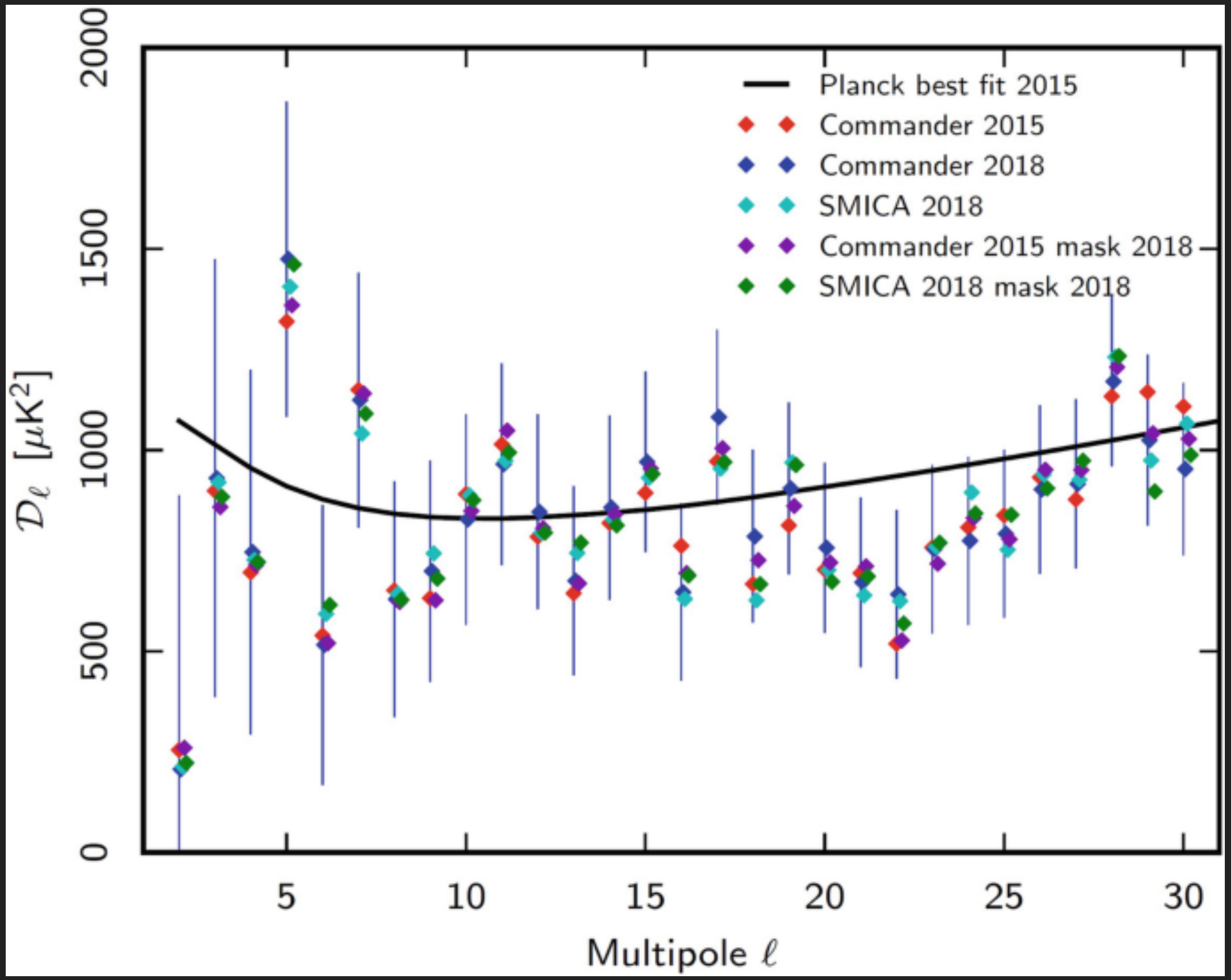
THE RESULT FOR THE OPTICAL DEPTH IS NOT SIGNIFICANTLY AFFECTED. DIFFERENT GALAXY FRACTIONS ONLY IMPACT POLARIZATION AT L>10.

BUT MY CONCERN IS, WHY????

LOW L TEMPERATURE POWER SPECTRA

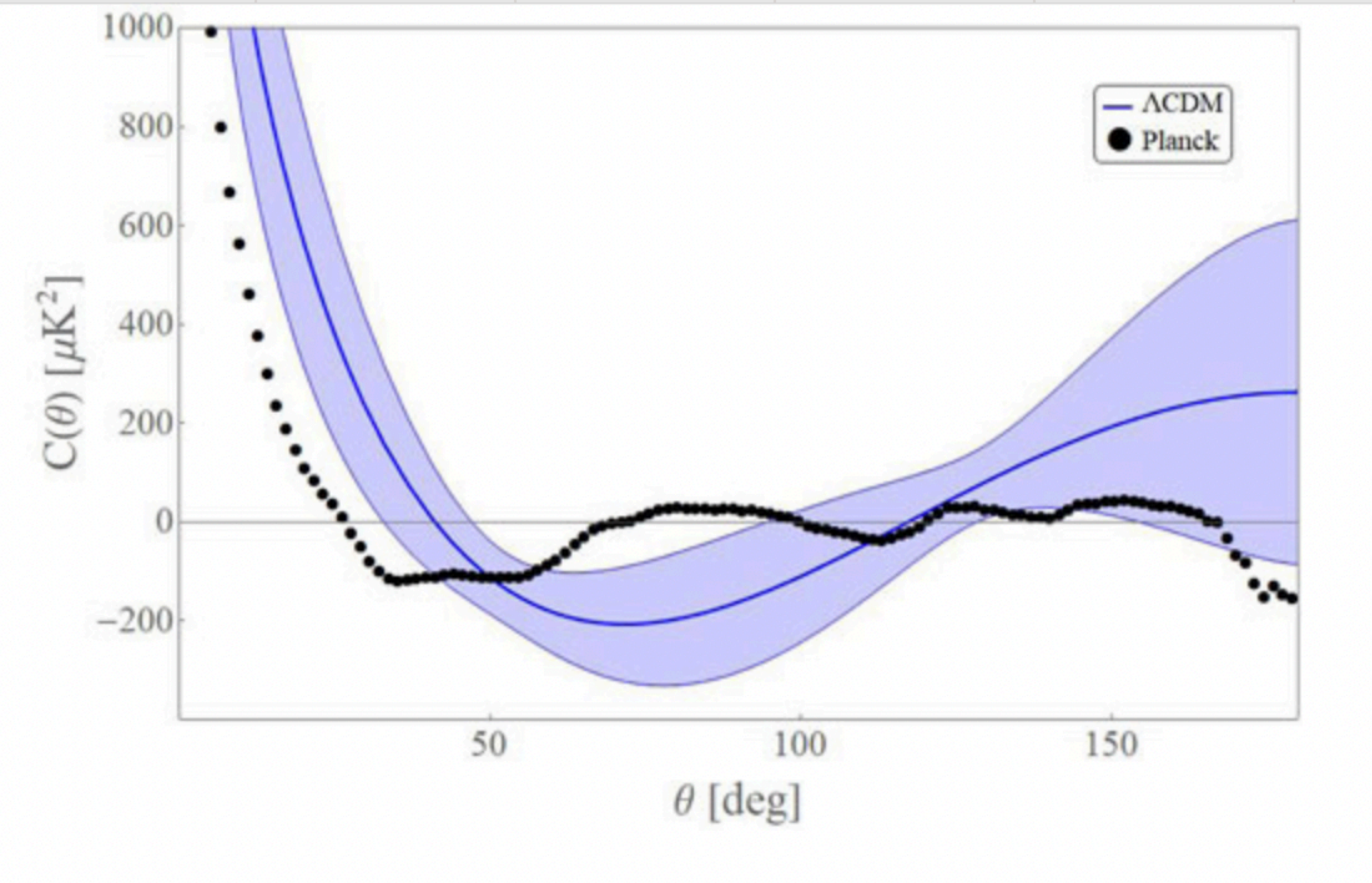
ANOTHER CONCERN IS THE TEMPERATURE SPECTRUM, WHICH EXHIBITS SEVERAL ANOMALIES (SUCH AS A LOW QUADRUPOLE AND A DIP AROUND L=22).

THE CROSS TE SPECTRUM AT THESE SCALES FAILS SEVERAL TESTS AND HAS BEEN EXCLUDED FROM THE PLANCK ANALYSIS.



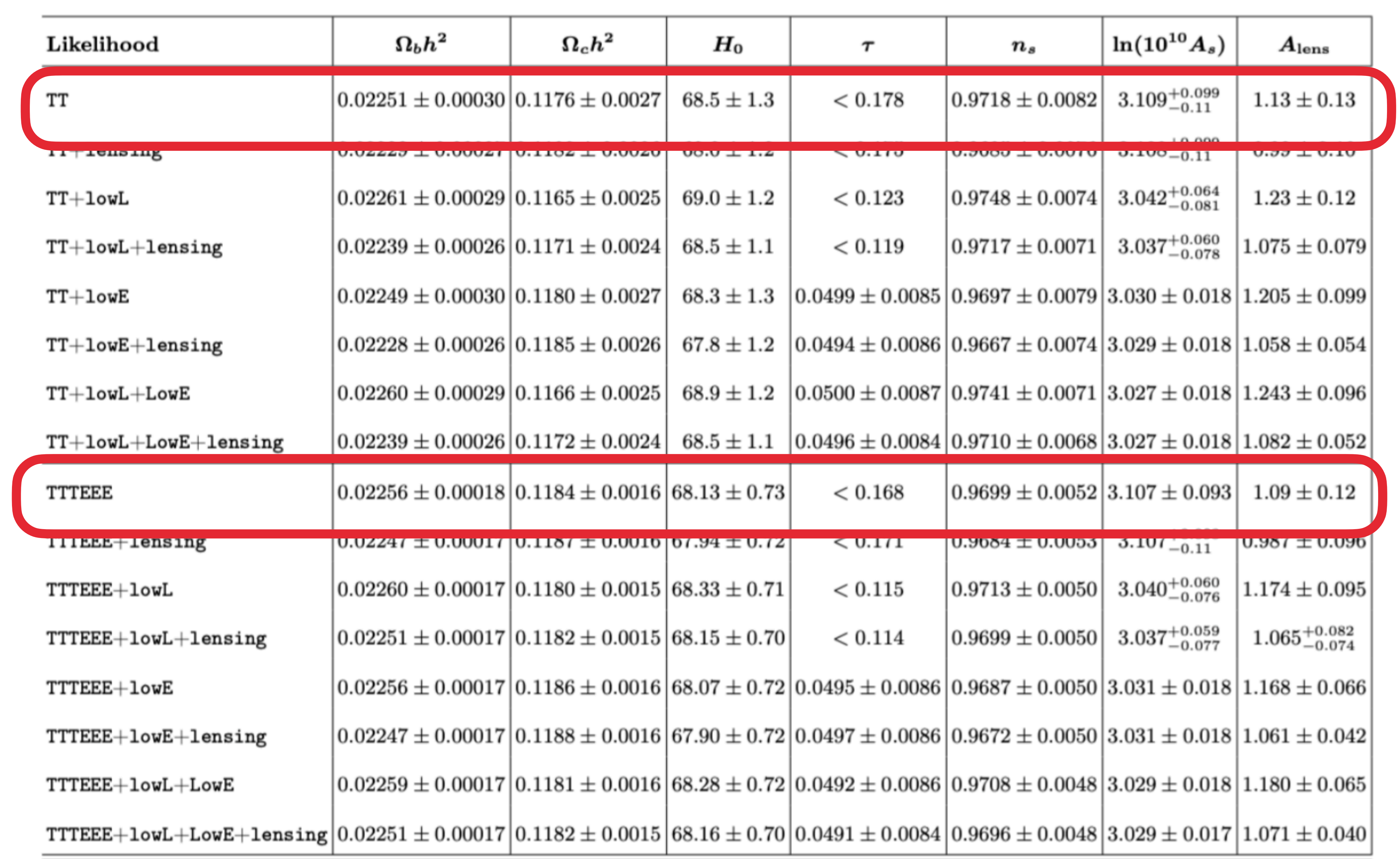
LOW L TEMPERATURE POWER SPECTRA

AND LET'S NOT FORGET THE LONG STANDING PROBLEM OF THE CORRELATION FUNCTION…



ARE YOU READY FOR A BIG SURPRISE?

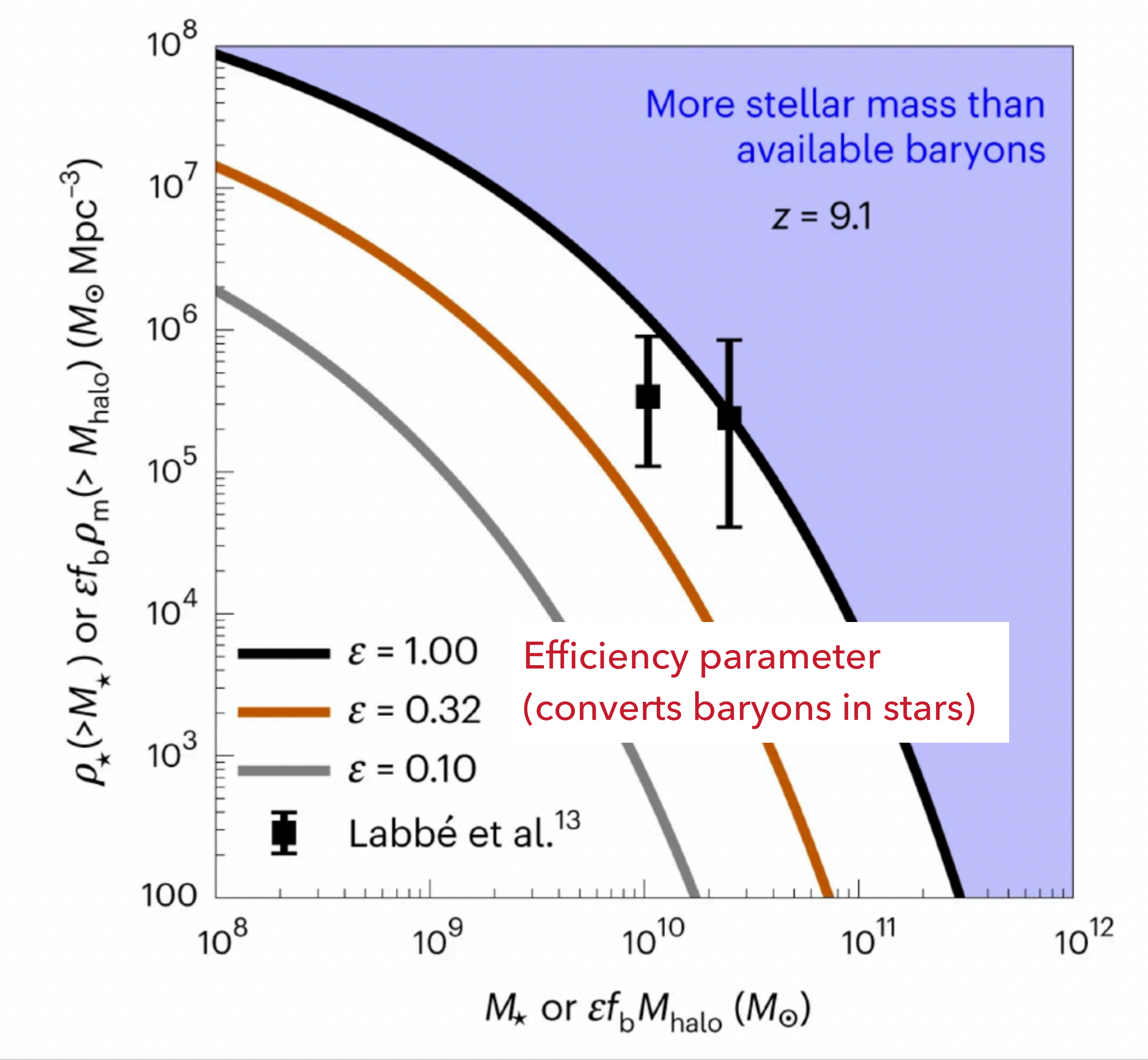
NO AL ANOMALY WITH NO LOW L TT AND EE DATA!



Likelihood	$\Omega_b h^2$	$\Omega_c h^2$	H_0	τ	n_s	$\ln(10^{10} A_s)$	$A_{\rm lens}$
TT	0.02251 ± 0.00030	0.1176 ± 0.0027	68.5 ± 1.3	< 0.178	0.9718 ± 0.0082	$3.109^{+0.099}_{-0.11}$	1.13 ± 0.13
TT+lensing	0.02229 ± 0.00027	0.1182 ± 0.0026	68.6 ± 1.2	< 0.175	0.9685 ± 0.0076	$3.108^{+0.099}_{-0.11}$	0.99 ± 0.10
TT+lowL	0.02261 ± 0.00029	0.1165 ± 0.0025	69.0 ± 1.2	< 0.123	0.9748 ± 0.0074	$3.042^{+0.064}_{-0.081}$	1.23 ± 0.12
TT+lowL+lensing	0.02239 ± 0.00026	0.1171 ± 0.0024	68.5 ± 1.1	< 0.119	0.9717 ± 0.0071	$3.037^{+0.060}_{-0.078}$	1.075 ± 0.079
TT+lowE	0.02249 ± 0.00030	0.1180 ± 0.0027	68.3 ± 1.3	0.0499 ± 0.0085	0.9697 ± 0.0079	3.030 ± 0.018	1.205 ± 0.099
TT+lowE+lensing	0.02228 ± 0.00026	0.1185 ± 0.0026	67.8 ± 1.2	0.0494 ± 0.0086	0.9667 ± 0.0074	3.029 ± 0.018	1.058 ± 0.054
TT+lowL+LowE	0.02260 ± 0.00029	0.1166 ± 0.0025	68.9 ± 1.2	0.0500 ± 0.0087	0.9741 ± 0.0071	3.027 ± 0.018	1.243 ± 0.096
TT+lowL+LowE+lensing	0.02239 ± 0.00026	0.1172 ± 0.0024	68.5 ± 1.1	0.0496 ± 0.0084	0.9710 ± 0.0068	3.027 ± 0.018	1.082 ± 0.052
TTTEEE	0.02256 ± 0.00018	0.1184 ± 0.0016	68.13 ± 0.73	< 0.168	0.9699 ± 0.0052	3.107 ± 0.093	1.09 ± 0.12
TTTEEE+lensing	0.02247 ± 0.00017	0.1187 ± 0.0016	67.94 ± 0.72	< 0.171	0.9684 ± 0.0053	$3.107_{-0.11}$ [illegible]	0.987 ± 0.096
TTTEEE+lowL	0.02260 ± 0.00017	0.1180 ± 0.0015	68.33 ± 0.71	< 0.115	0.9713 ± 0.0050	$3.040^{+0.060}_{-0.076}$	1.174 ± 0.095
TTTEEE+lowL+lensing	0.02251 ± 0.00017	0.1182 ± 0.0015	68.15 ± 0.70	< 0.114	0.9699 ± 0.0050	$3.037^{+0.059}_{-0.077}$	$1.065^{+0.082}_{-0.074}$
TTTEEE+lowE	0.02256 ± 0.00017	0.1186 ± 0.0016	68.07 ± 0.72	0.0495 ± 0.0086	0.9687 ± 0.0050	3.031 ± 0.018	1.168 ± 0.066
TTTEEE+lowE+lensing	0.02247 ± 0.00017	0.1188 ± 0.0016	67.90 ± 0.72	0.0497 ± 0.0086	0.9672 ± 0.0050	3.031 ± 0.018	1.061 ± 0.042
TTTEEE+lowL+LowE	0.02259 ± 0.00017	0.1181 ± 0.0016	68.28 ± 0.72	0.0492 ± 0.0086	0.9708 ± 0.0048	3.029 ± 0.018	1.180 ± 0.065
TTTEEE+lowL+LowE+lensing	0.02251 ± 0.00017	0.1182 ± 0.0015	68.16 ± 0.70	0.0491 ± 0.0084	0.9696 ± 0.0048	3.029 ± 0.017	1.071 ± 0.040

GIARÈ ET AL., IN PREP.

THERE ARE TOO MANY HIGH-REDSHIFT MASSIVE GALAXIES IN JWST OBSERVATIONS?



Efficiency parameter
(converts baryons in stars)

IVO LABBÉ, ET AL.

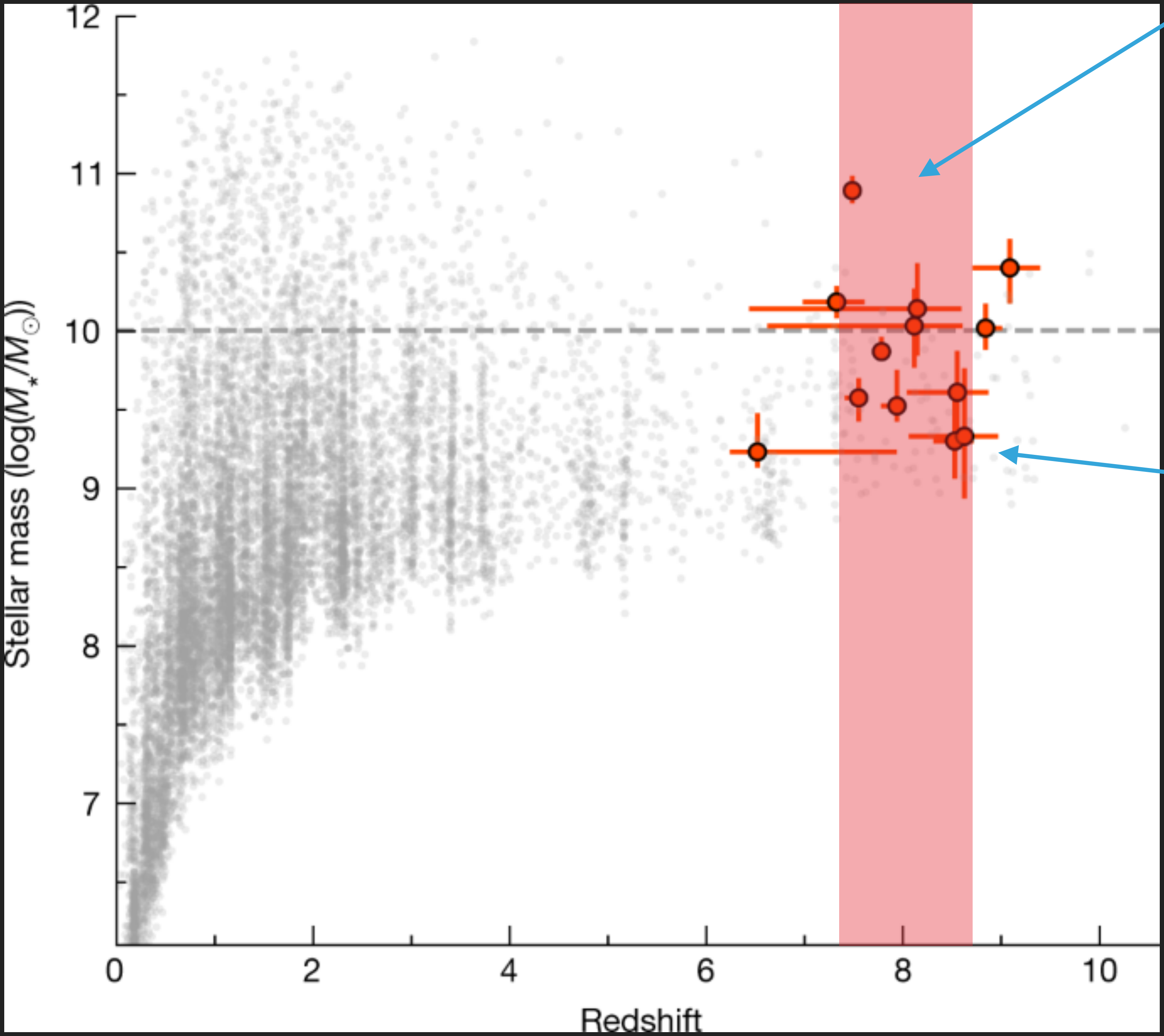
NATURE 616, 266–269 (2023)

MICHAEL BOYLAN-KOLCHIN

NATURE ASTRONOMY

731–735 (2023)

THERE ARE TOO MANY HIGH-REDSHIFT MASSIVE GALAXIES IN JWST OBSERVATIONS?



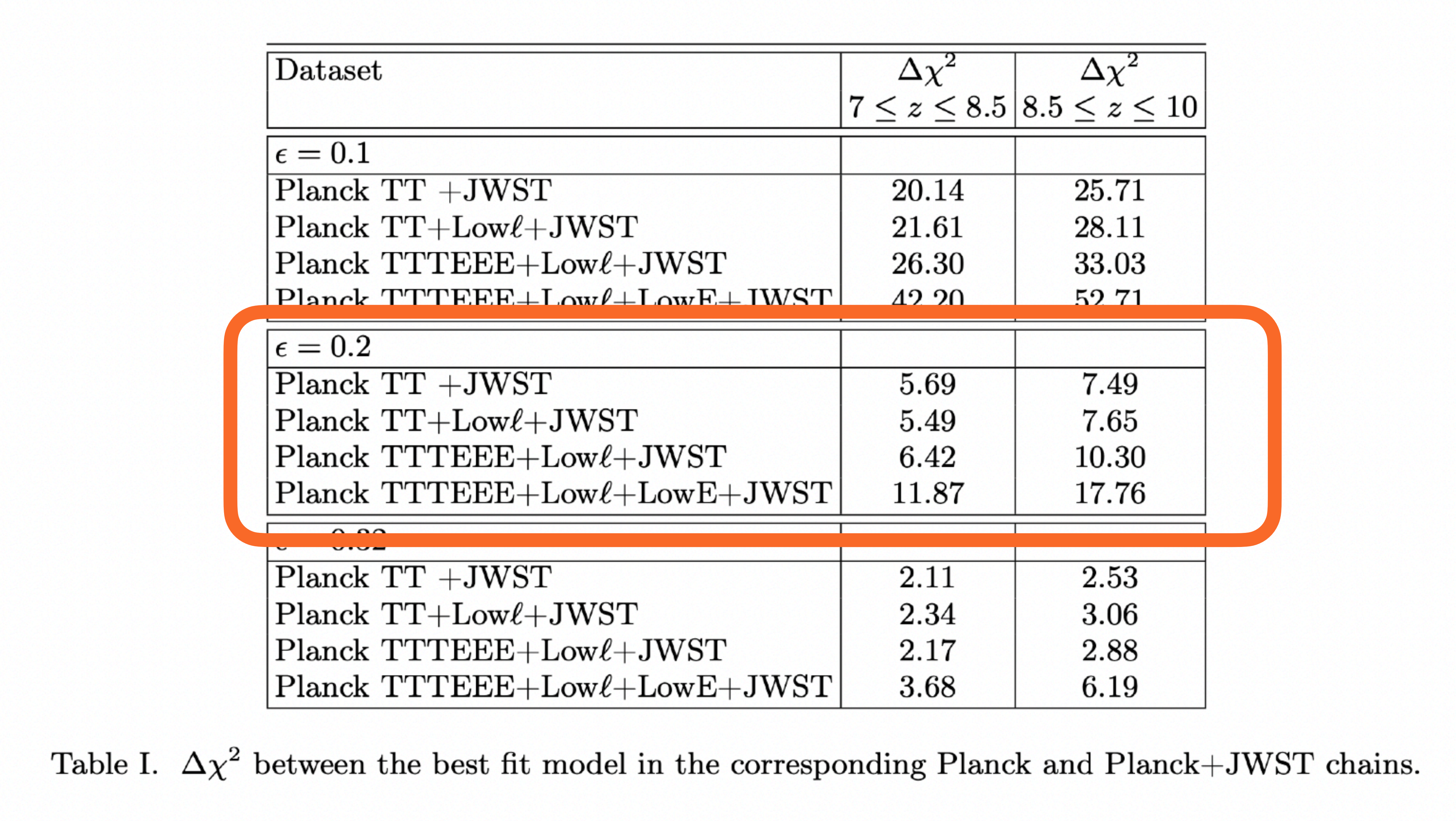
Reionization starts in this region according to Planck data

Red galaxies with M>10^10 solar masses detected by JWST

IVO LABBÉ, ET AL,

NATURE 616, 266–269 (2023)

IF YOU REMOVE PLANCK LOW E POLARISATION DATA YOU HAVE A BETTER CONSISTENCY WITH JWST

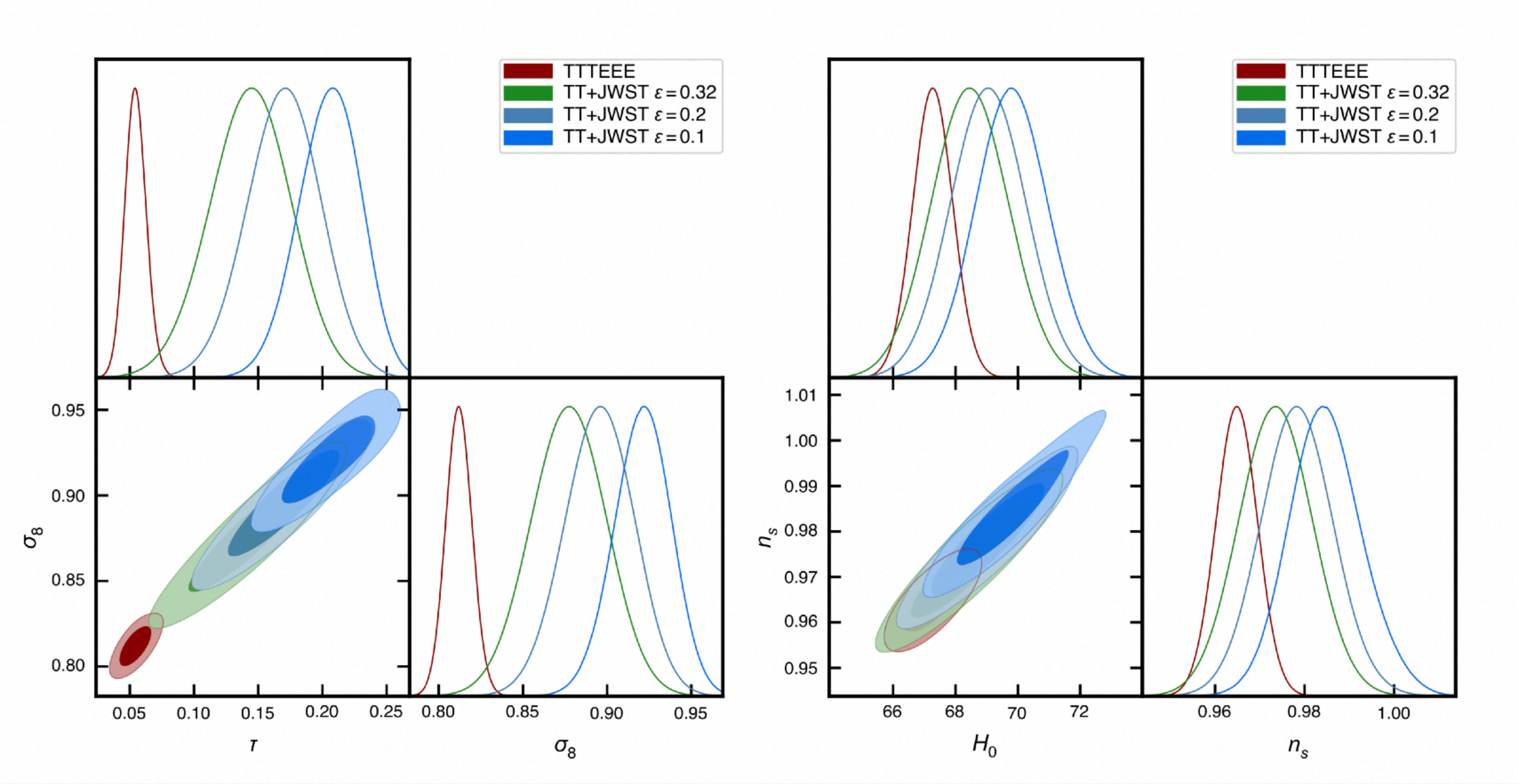


Dataset	$\Delta\chi^2$ $7 \leq z \leq 8.5$	$\Delta\chi^2$ $8.5 \leq z \leq 10$
$\epsilon = 0.1$		
Planck TT +JWST	20.14	25.71
Planck TT+Lowℓ+JWST	21.61	28.11
Planck TTTEEE+Lowℓ+JWST	26.30	33.03
Planck TTTEEE+Lowℓ+LowE+JWST	42.20	52.71
$\epsilon = 0.2$		
Planck TT +JWST	5.69	7.49
Planck TT+Lowℓ+JWST	5.49	7.65
Planck TTTEEE+Lowℓ+JWST	6.42	10.30
Planck TTTEEE+Lowℓ+LowE+JWST	11.87	17.76
$\epsilon = 0.32$		
Planck TT +JWST	2.11	2.53
Planck TT+Lowℓ+JWST	2.34	3.06
Planck TTTEEE+Lowℓ+JWST	2.17	2.88
Planck TTTEEE+Lowℓ+LowE+JWST	3.68	6.19

Table I. $\Delta\chi^2$ between the best fit model in the corresponding Planck and Planck+JWST chains.

FORCONI, RUCHIKA ET AL., ARXIV:2306.07781

WITHOUT POLARISATION: PLANCK+JWST GIVES HIGHER S8 AND HIGHER…HO!



FORCONI, RUCHIKA ET AL., ARXIV:2306.07781

CONCLUSIONS

- With the increase in the precision of cosmological data, tensions between datasets and the ΛCDM model are starting to emerge.
- These tensions can indicate the possible presence of additional physics and the need for modifications to the ΛCDM model.
- However, another important aspect of these tensions is that we can't use the ΛCDM model as a laboratory to place constraints on fundamental physics, such as the neutrino sector and inflation.
- Planck polarization data, especially at large scales, is in tension with the TT data. Planck low L data (both polarization and temperature) are anomalous and contribute to the Al anomaly.
- Without the low L data, Planck is compatible with High-z JWST galaxies. This shifts H0 to 69-70 km/s/Mpc but also changes Sigma8 to 0.9.”