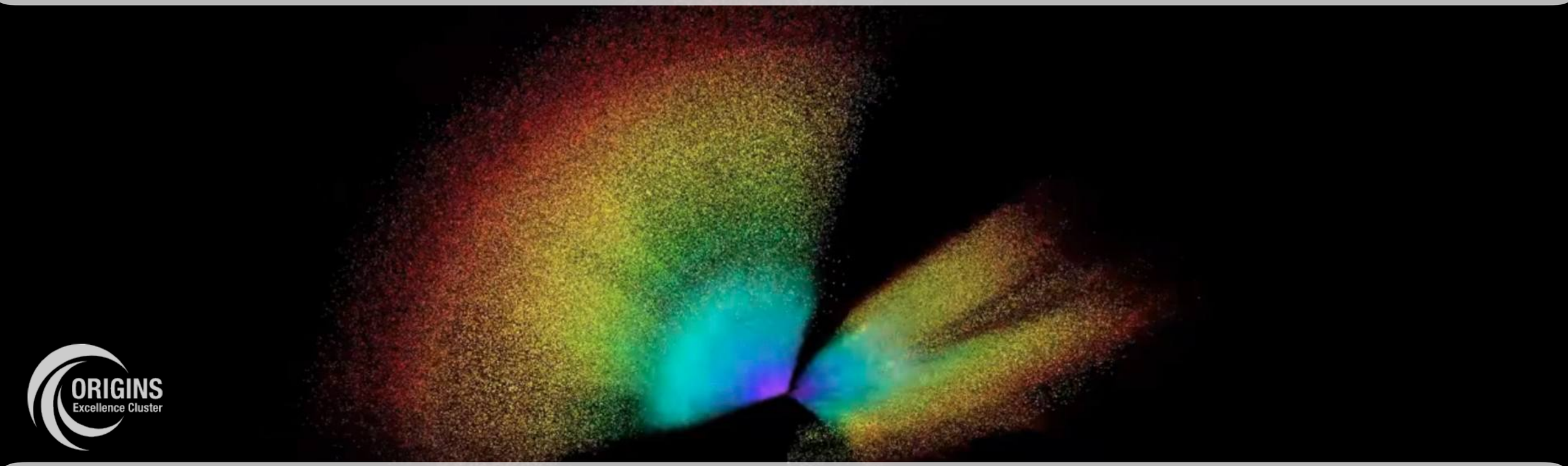
Cosmological implications of anisotropic clustering measurements in BOSS and eBOSS



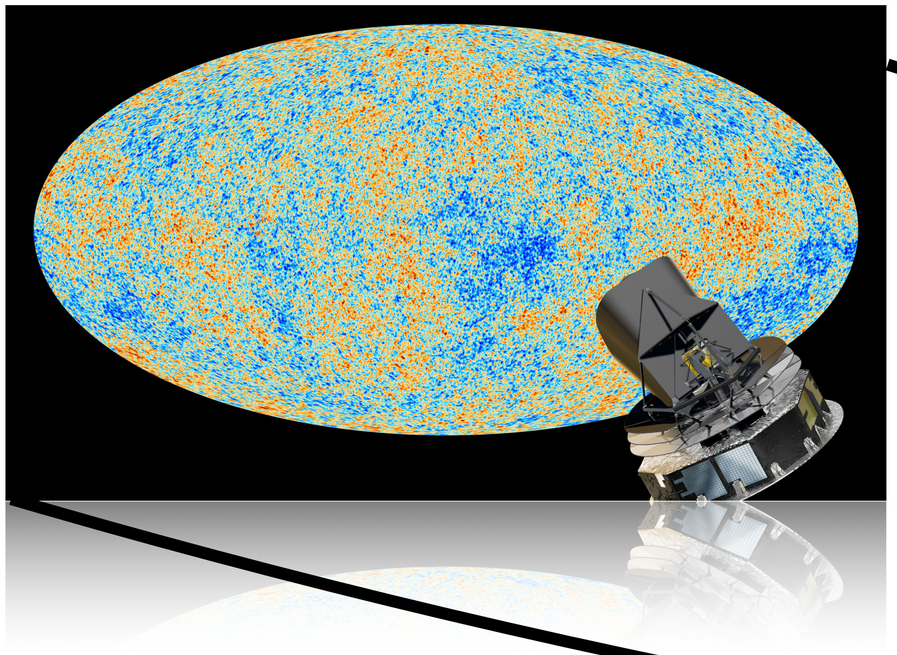
Agnė Semėnaitė

Ariel G. Sánchez, Andrea Pezzotta and eBOSS collaboration

arXiv: 2111.03156

Planck - the cosmological standard

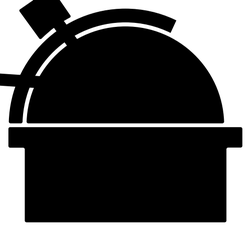
$z = 1100$



The cosmic microwave background signature gives the most precise measurements of cosmological parameters to date.

ΛCDM:

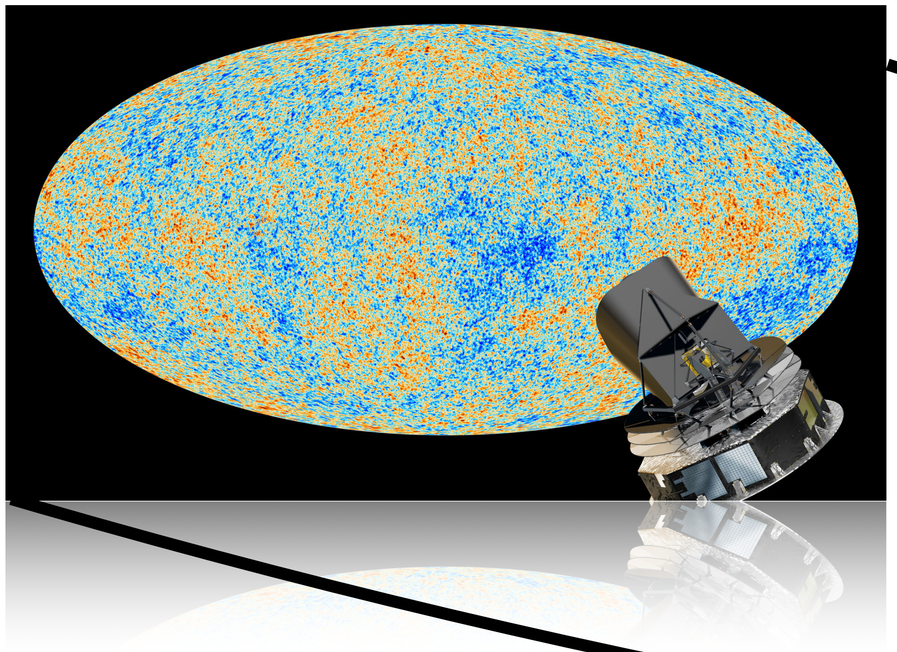
$\Omega_c h^2, \Omega_b h^2, H_0, n_s, A_s, \tau$



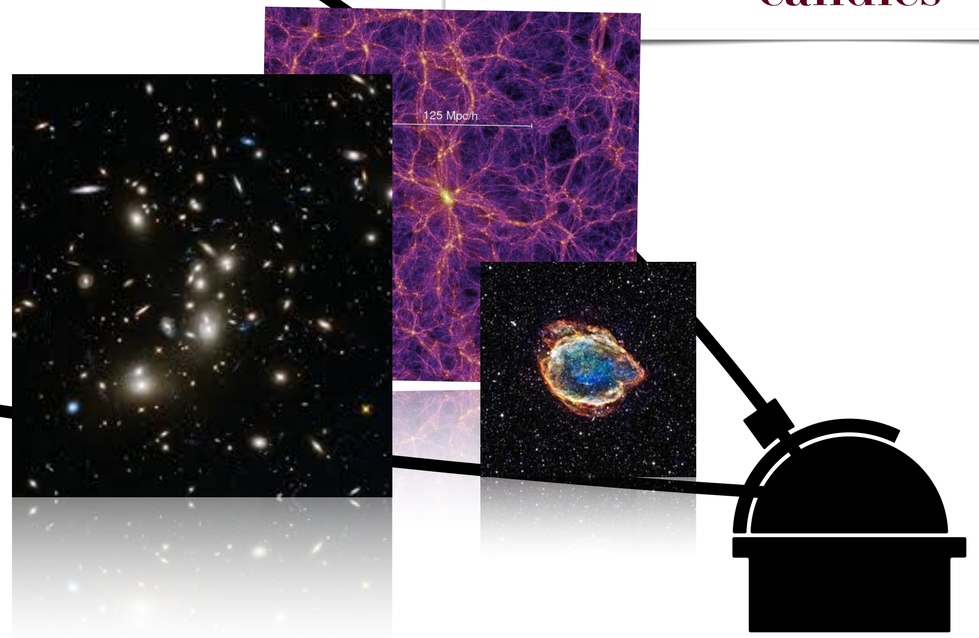
$z = 0$

Planck - the cosmological standard

$z = 1100$



We can compare Planck's predictions for the low redshift universe with our observations of the large scale structure or direct measurements using standard candles

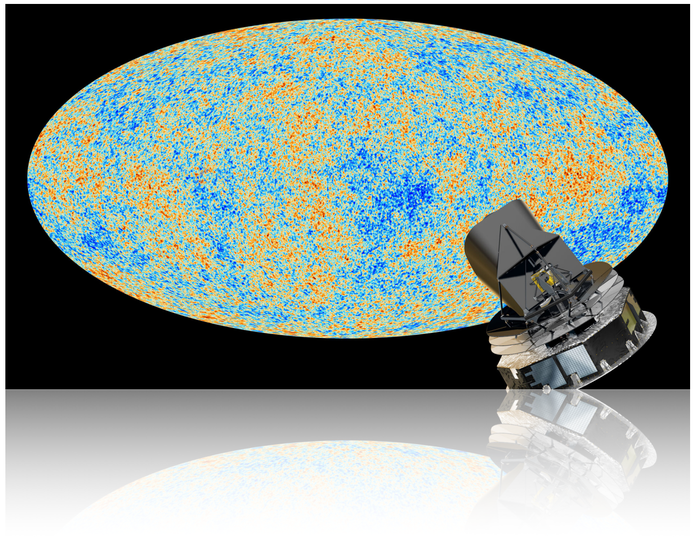


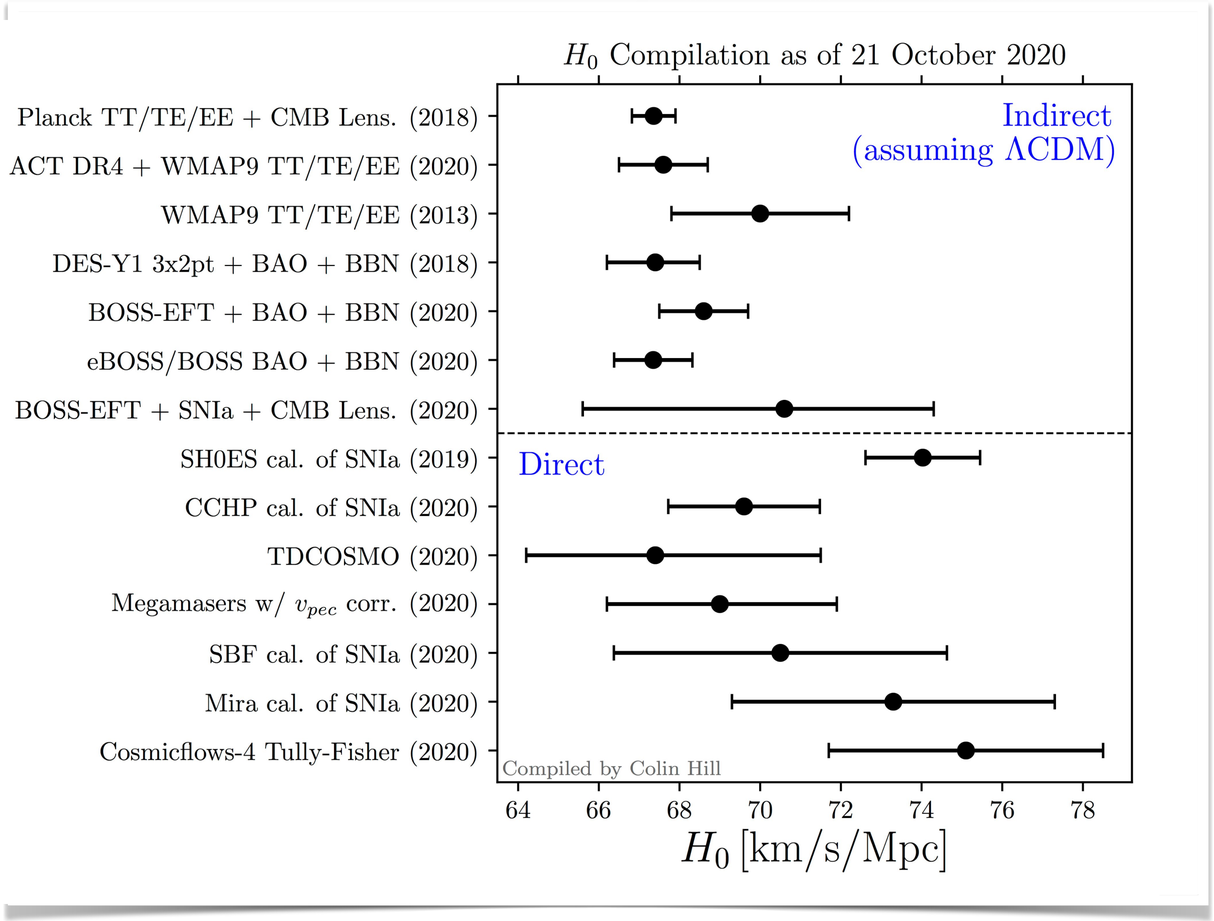
$z = 0$

ΛCDM:

$\Omega_c h^2, \Omega_b h^2, H_0, n_s, A_s, \tau$

Cracks in the model?



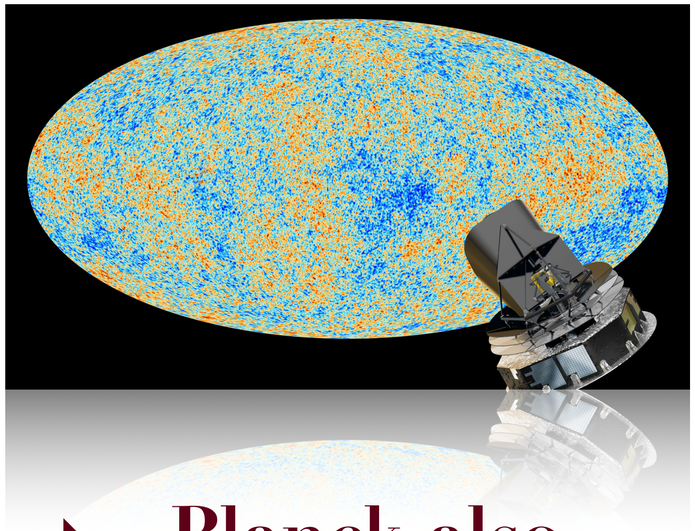


?

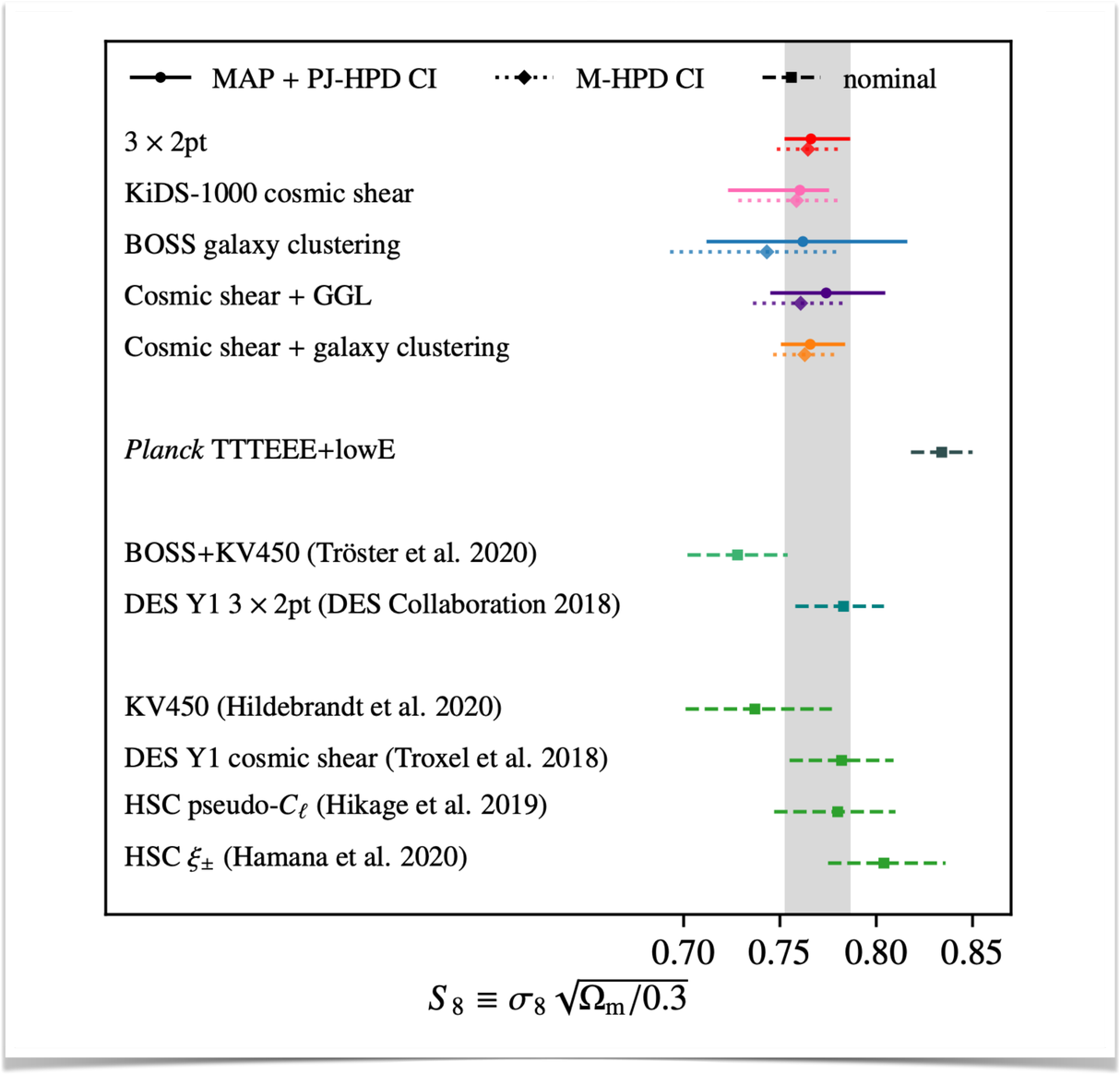
Image: Colin Hill

- **The rate of expansion of the Universe today, as measured directly seems to be greater than Planck's prediction…**

Cracks in the model?



- Planck also predicts a higher lensing amplitude than measured by weak lensing surveys.



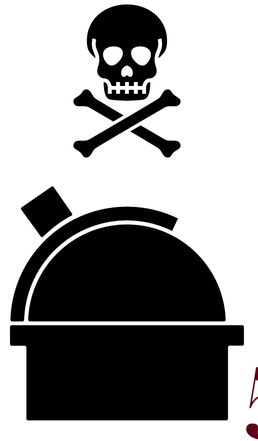
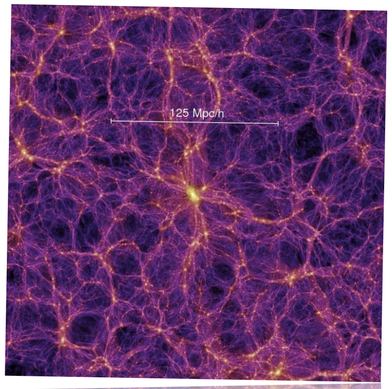
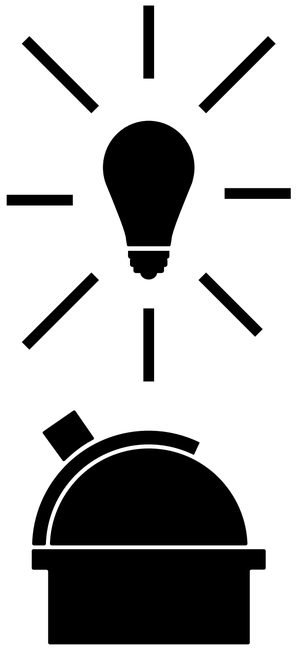


Image: Heymans, Tröster & the KiDS Collaboration

This work:

- We present full shape eBOSS quasar clustering analysis.
- Combine with full shape BOSS galaxy clustering wedges re-analysis with an updated model for power spectrum and bias modelling.
- Obtain combined large scale structure constraints for the low redshift Universe by complimenting the clustering measurements with weak lensing and clustering measurements (3x2pt) from Dark Energy Survey, Year 1 data release.

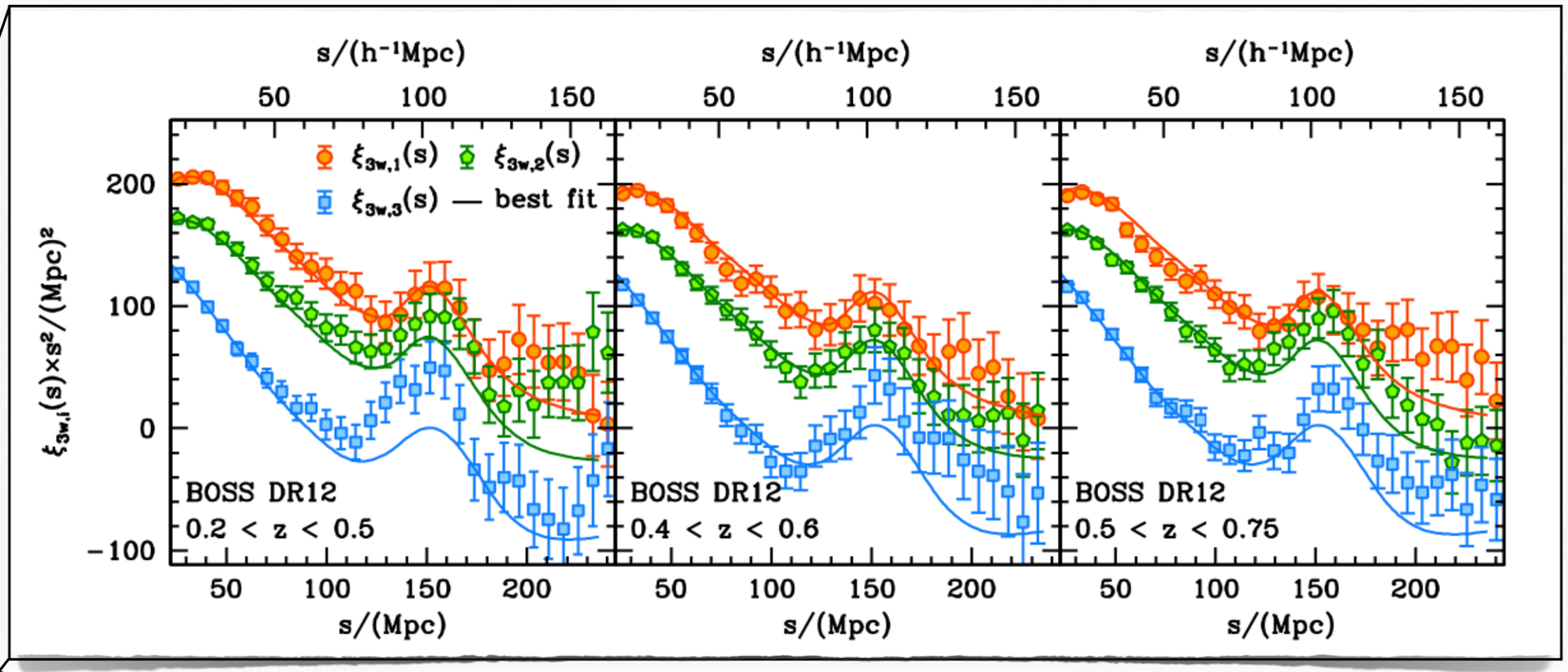


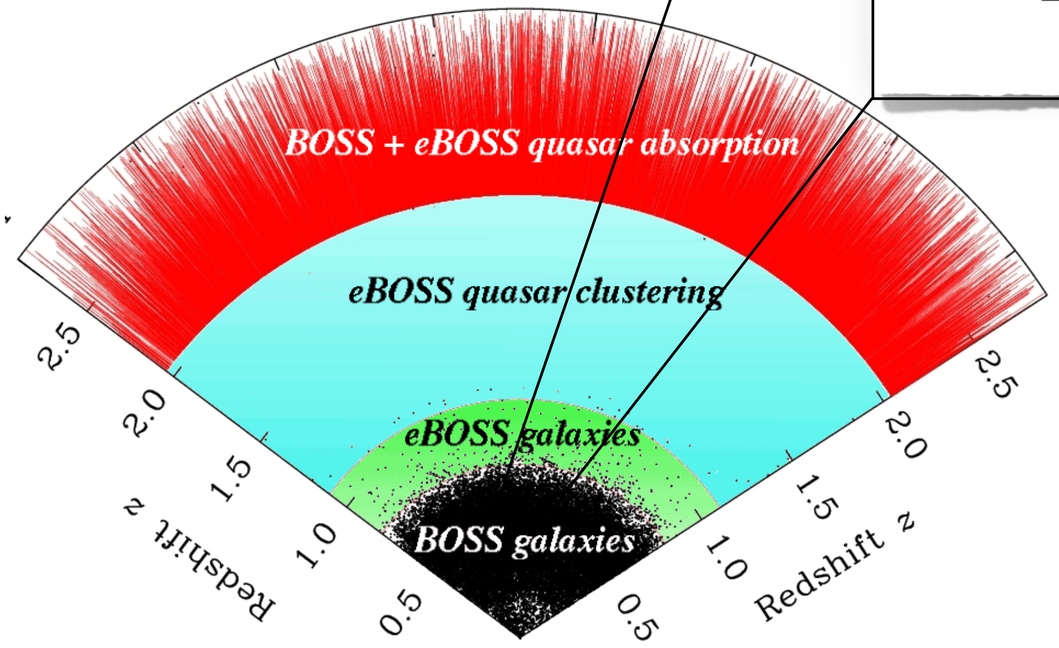


arXiv: 2111.03156

Clustering measurements

Sánchez et al., 2017





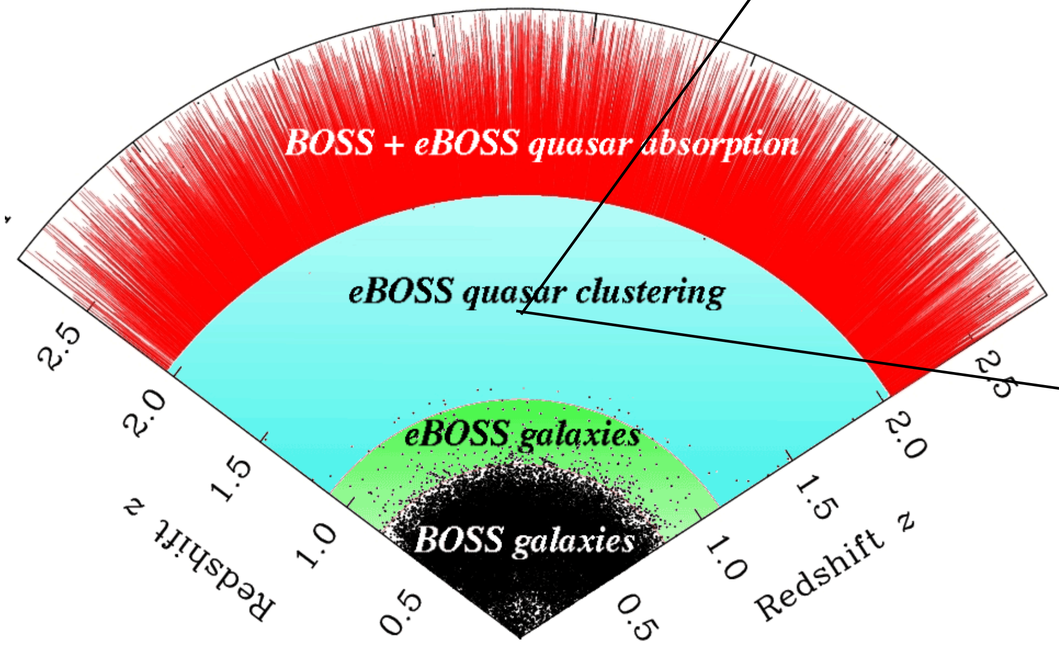
- **BOSS** *clustering wedges,* 2 redshift bins to avoid overlapping: low-z and high-z. $\xi^{\mu 2}_{\mu 1} = \frac{1}{\Delta\mu}\int_{\mu_1}^{\mu_2}\xi(\mu, s)d\mu$

Clustering measurements

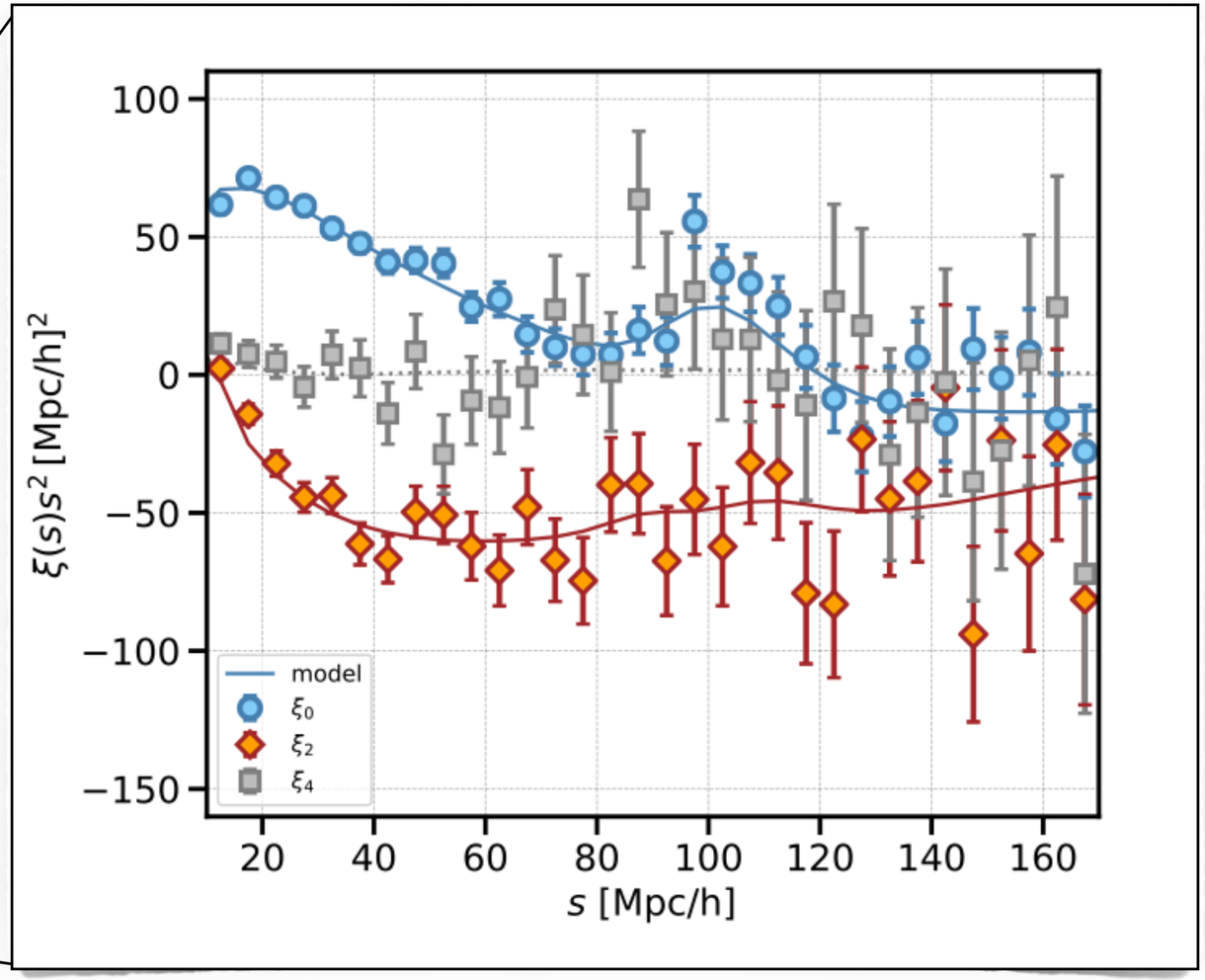
- **eBOSS** quasar clustering *multipoles* one redshift bin:

$$0.8 < z < 2.2$$

$$\xi_l(s) = \frac{2l+1}{2}\int_{-1}^{1} L_l(\mu)\xi(\mu, s)d\mu$$



Hou et al., 2020



Modelling

$P(k, \mu)$

Non-linear clustering:

Galaxy bias:

RSD:

Modelling

Non-linear clustering:

$$P(k,\mu) = W_{\infty}(ifk\mu)\, P_{\mathrm{novir}}(k,\mu)$$

Galaxy bias:

RSD:

- Taruya, Nishimichi, Saito (2010) + Scoccimarro (2004).

$$W_{\infty}(\lambda) = \frac{1}{\sqrt{1-\lambda^2 a_{\mathrm{vir}}^2}} \exp\left(\frac{\lambda^2\sigma_v^2}{1-\lambda^2 a_{\mathrm{vir}}^2}\right)$$

Modelling

$$P(k,\mu) = W_{\infty}(ifk\mu)\, P_{\mathrm{novir}}(k,\mu)$$

Non-linear clustering:

- **RESPRESSO** - matter power spectrum predictions based on response function approach (Nishimichi et al. 2017)

Galaxy bias:

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Non-linear clustering:

- **RESPRESSO** - matter power spectrum predictions based on response function approach (Nishimichi et al. 2017)

Galaxy bias:

- One loop bias + **co-evolution** relations (Eggemeier et al., 2019)

$$\delta = b_1\delta_m + \frac{b_2}{2!}\delta_m^2 + \gamma_2\mathcal{G}_2(\Phi_v) + \gamma_{21}\mathcal{G}_2(\varphi_1,\varphi_2) + \dots.$$

$$\gamma_{2,\rm ex} = 0.524 - 0.547 b_1 + 0.046 b_1^2$$

$$\gamma_{21} = -\frac{2}{21}(b_1 - 1) + \frac{6}{7}\gamma_2\,.$$

RSD:

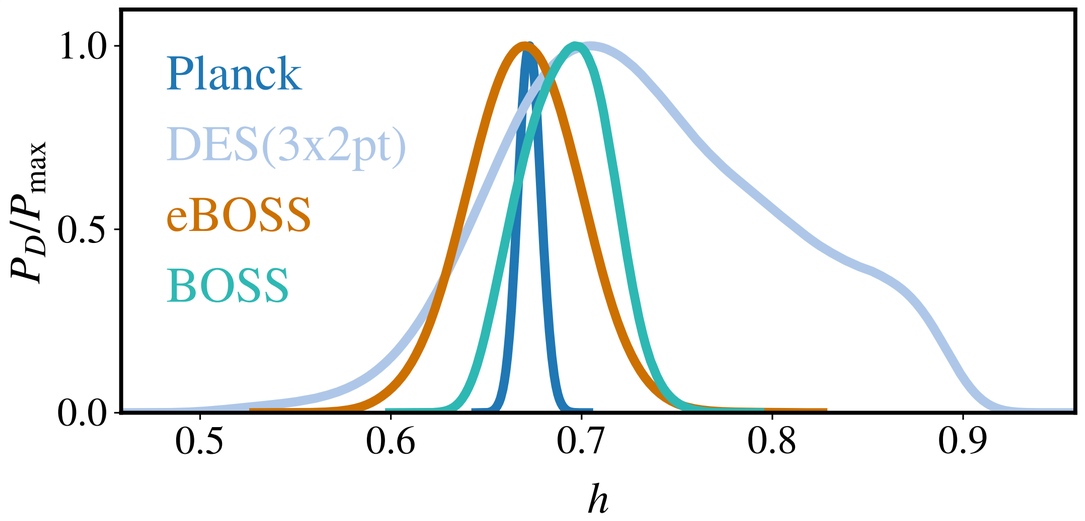
- Taruya, Nishimichi, Saito (2010) + Scoccimarro (2004).

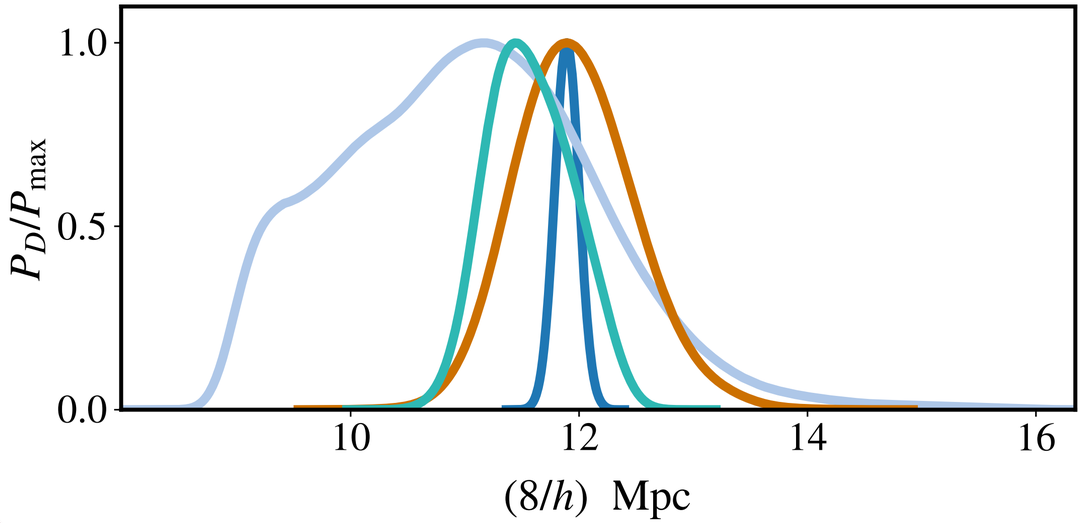
$$W_\infty(\lambda) = \frac{1}{\sqrt{1-\lambda^2 a_{\rm vir}^2}}\exp\left(\frac{\lambda^2\sigma_v^2}{1-\lambda^2 a_{\rm vir}^2}\right)$$

Parameter space

Sánchez (2020)

- Different probes recover different posteriors for Hubble parameter $h = H_0/100$.





Parameter space

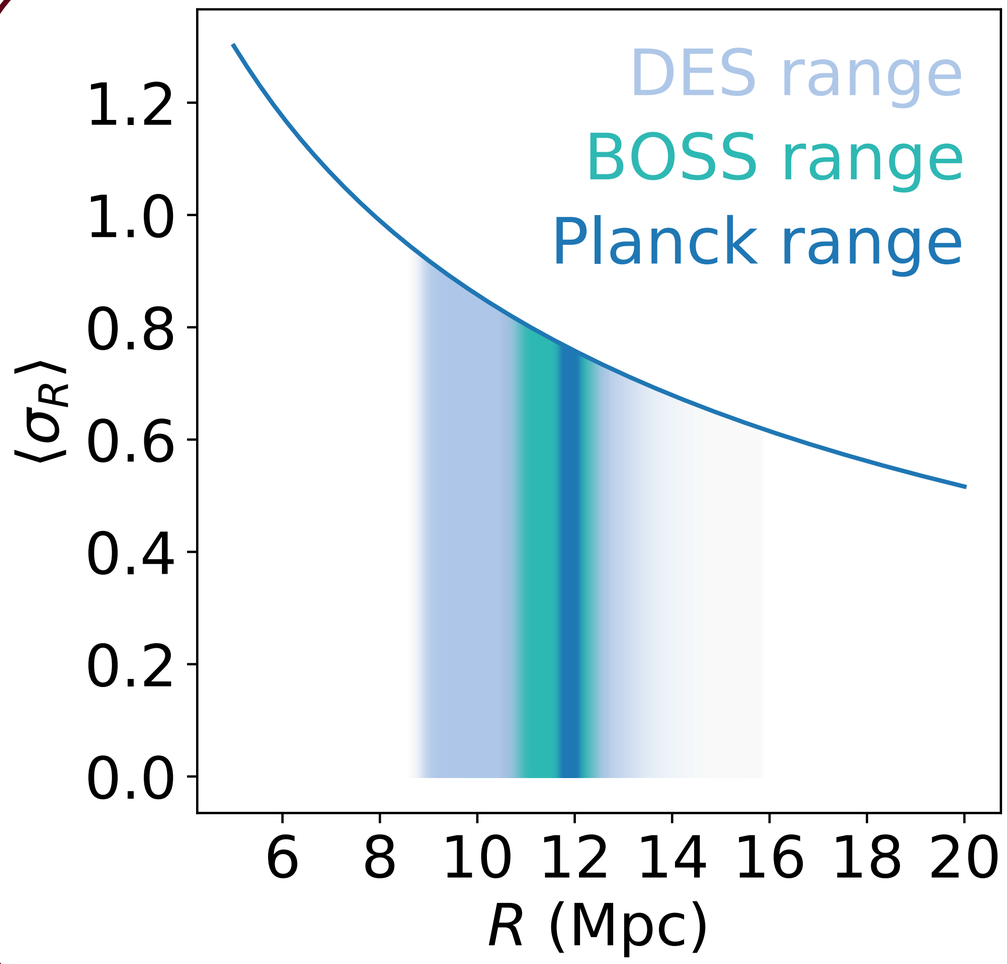
Sánchez (2020)

- When we define a parameter through h units, the measured value gives a weighted average of the quantity over h ($h = H_0/100$).

σ_8 measured in radius of 8 h^{-1}Mpc

$$\Omega_m = \omega_m/h^2$$

$$\Omega_{DE} = \omega_{DE}/h^2$$



Parameter space

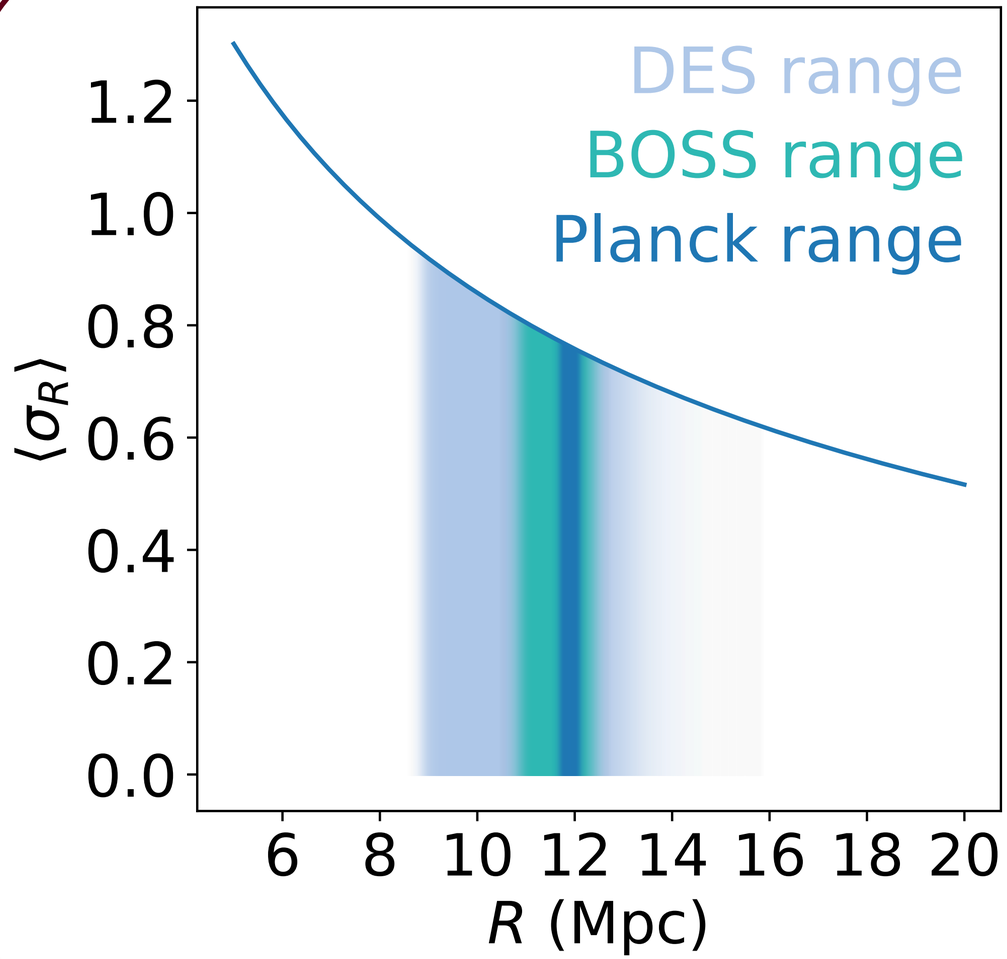
Sánchez (2020)

- When we define a parameter through h units, the measured value gives a weighted average of the quantity over h ($h = H_0/100$).

σ_{12} measured in radius of 12 Mpc

$\omega_{\rm m} = 8\pi G\rho_{\rm m}/(3H_{100}^2)$ $100\,{\rm km\,s^{-1}\,Mpc^{-1}}$

$\omega_{\rm DE} = 8\pi G\rho_{\rm DE}/(3H_{100}^2)$



Results: BOSS+eBOSS

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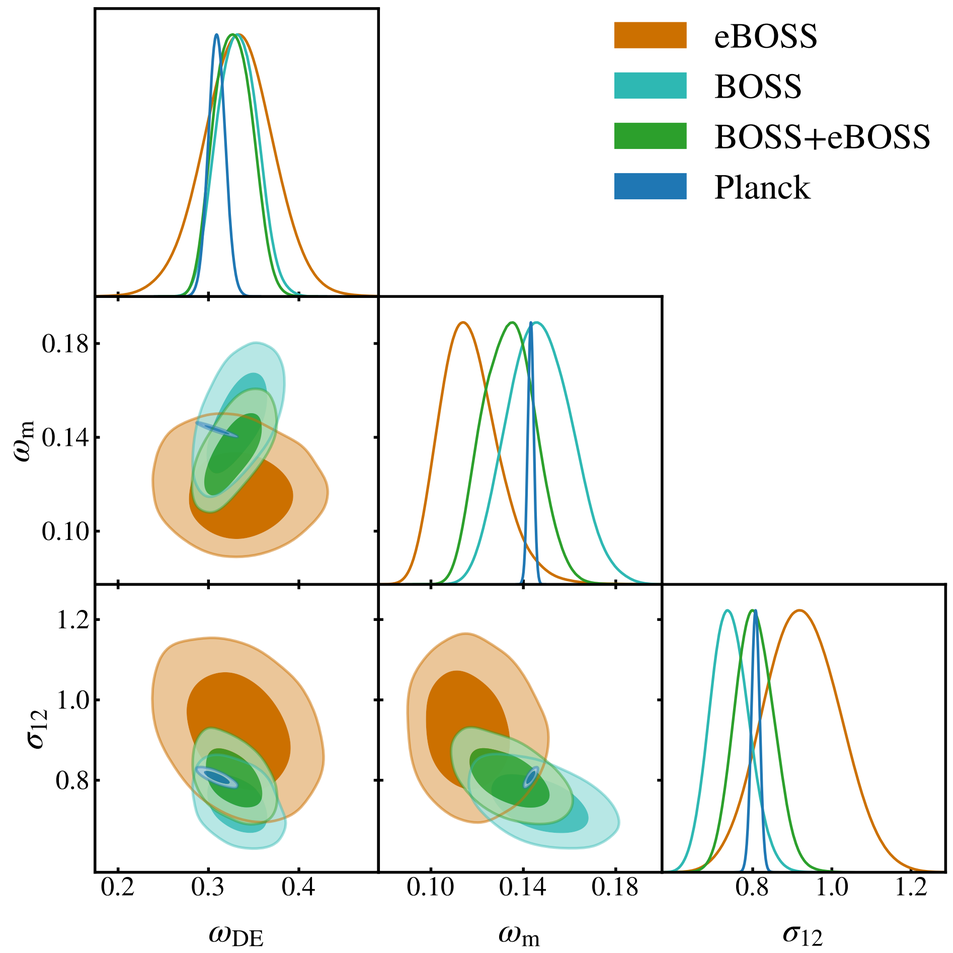

Joint constraints are in an excellent agreement with Planck:

- Suspiciousness: $0.64 \pm 0.07\sigma$

$$\sigma_{12} = 0.805 \pm 0.049$$
$$(\sigma_8 = 0.814 \pm 0.044)$$

arXiv: 2111.03156

Results: BOSS+eBOSS

Sánchez et al. (2021) distinguishes between *shape* and *evolution* parameters.

- We want to test the effect of a prior on **shape** parameters ω_b, ω_{cdm} and n_s.

- We explore the impact it has on **evolution** parameters σ_{12}, A_s, ω_{DE}.

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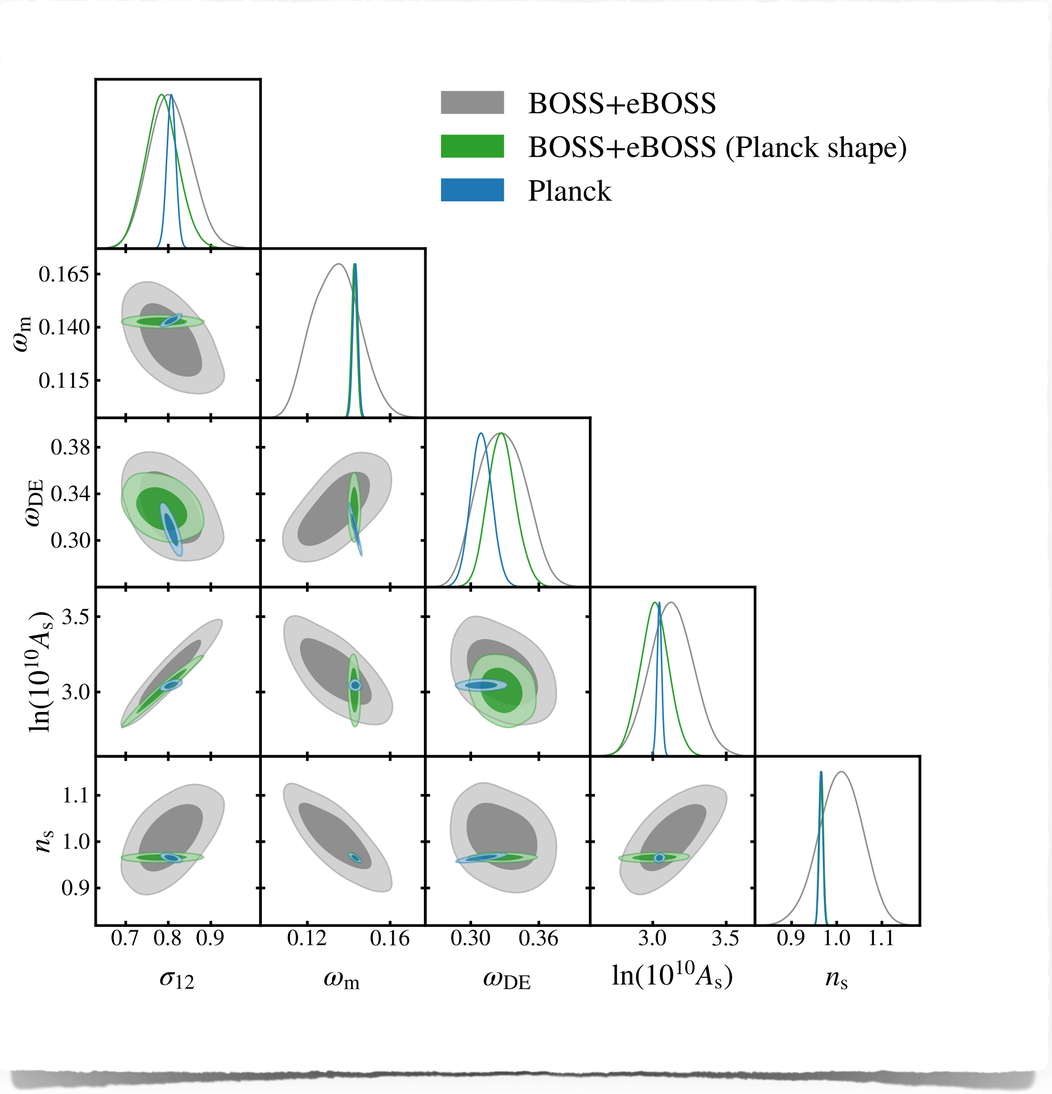
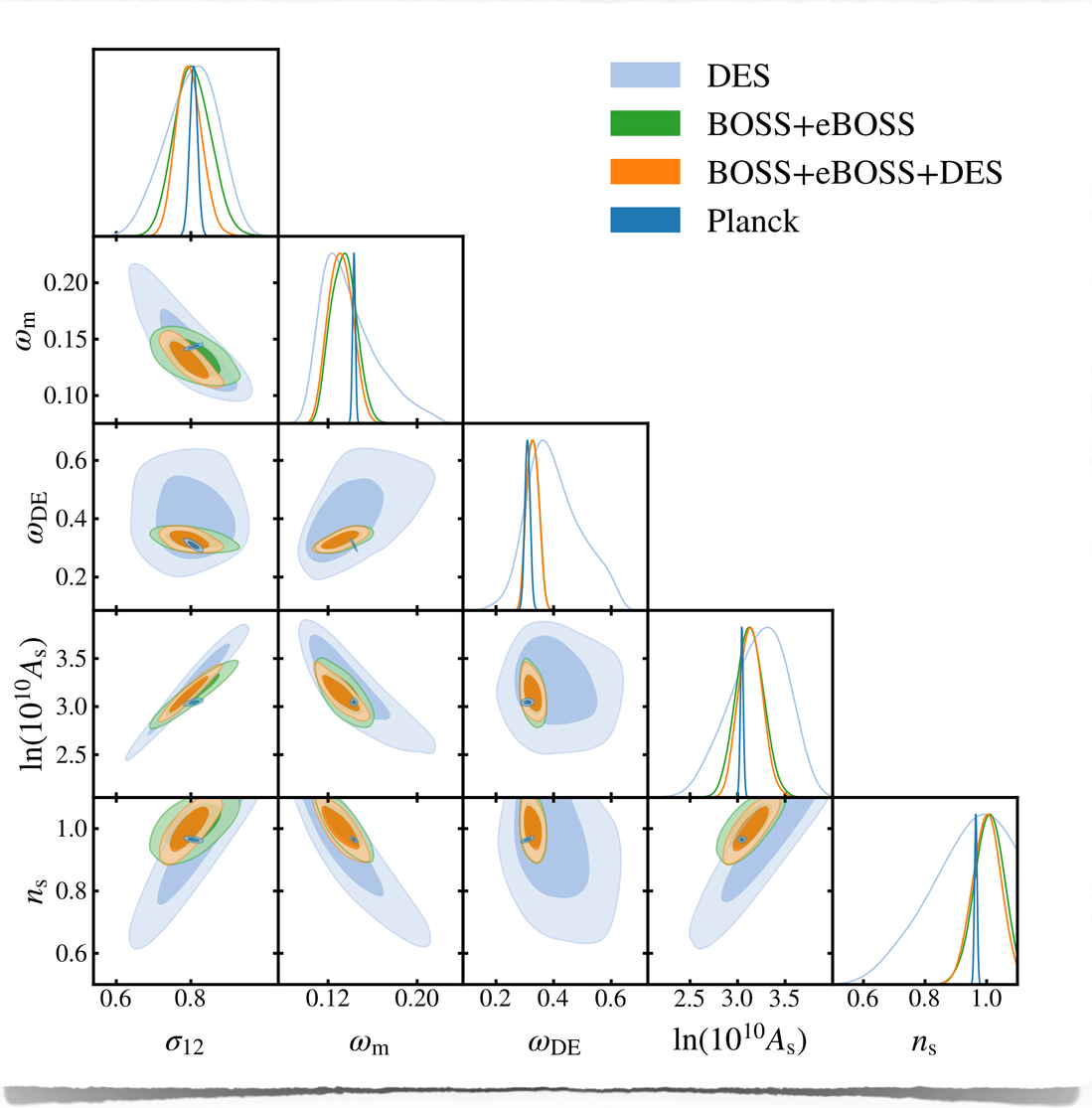


arXiv: 2111.03156

Results: BOSS+eBOSS+DES

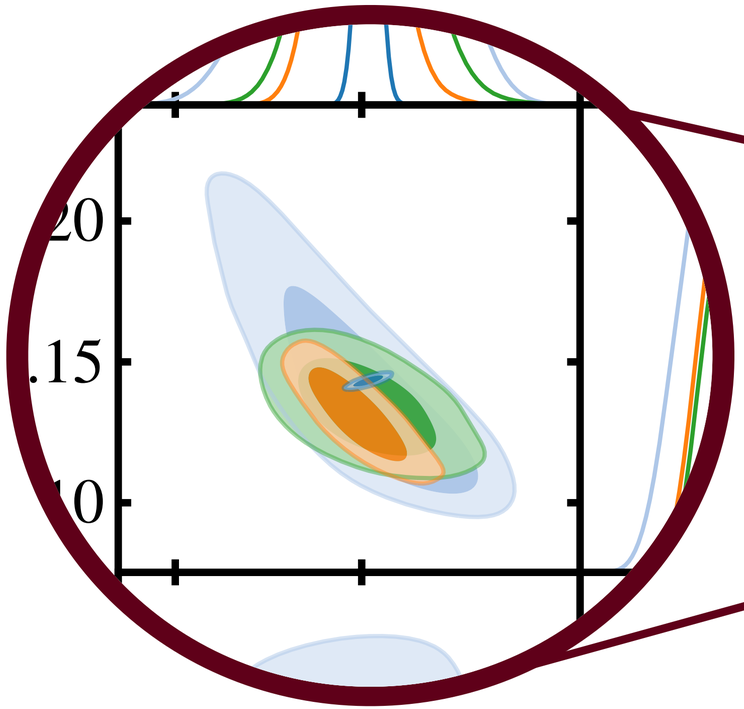
Adding DES slightly degrades the agreement with Planck:

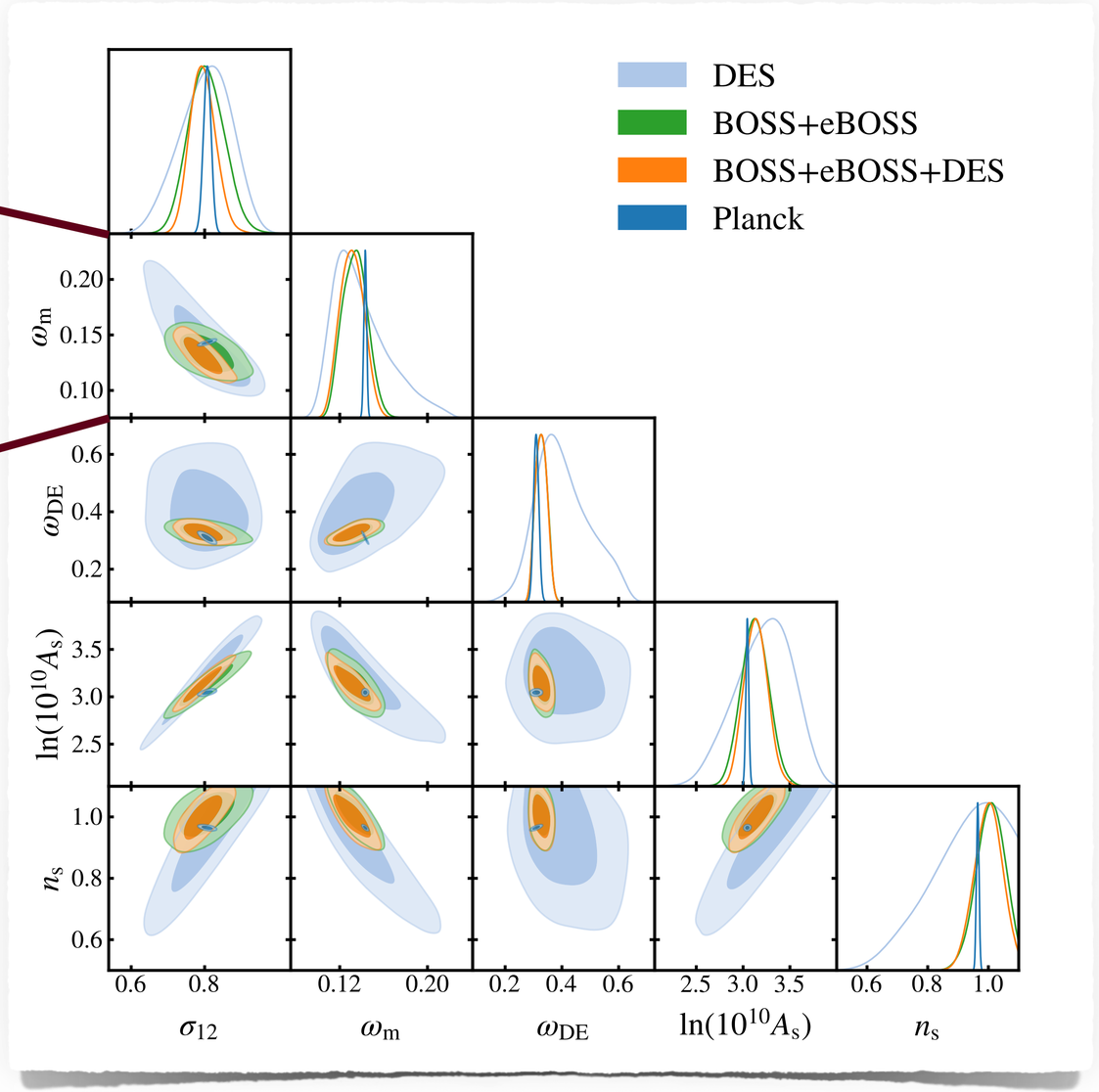
- Suspiciousness: $1.54 \pm 0.1\sigma$



arXiv: 2111.03156

Results: BOSS+eBOSS+DES





arXiv: 2111.03156

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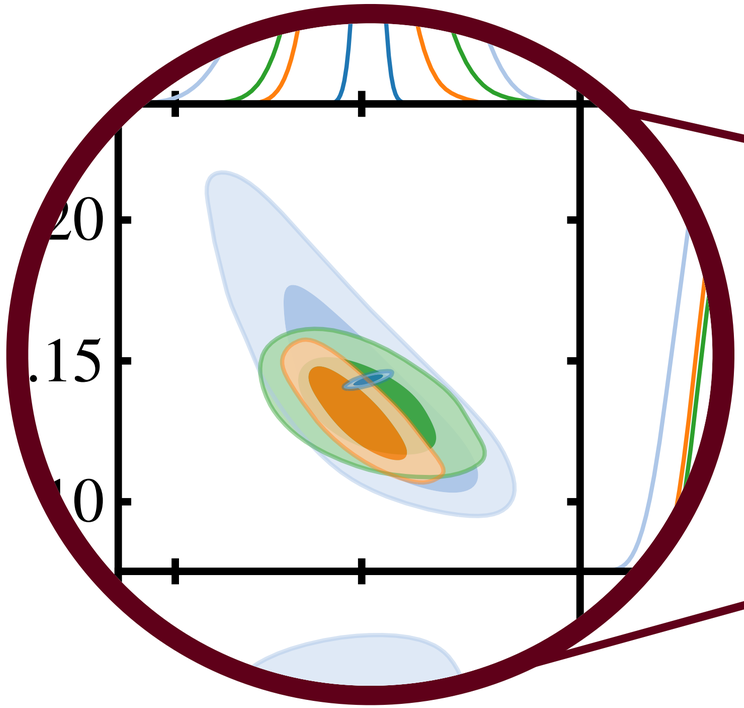
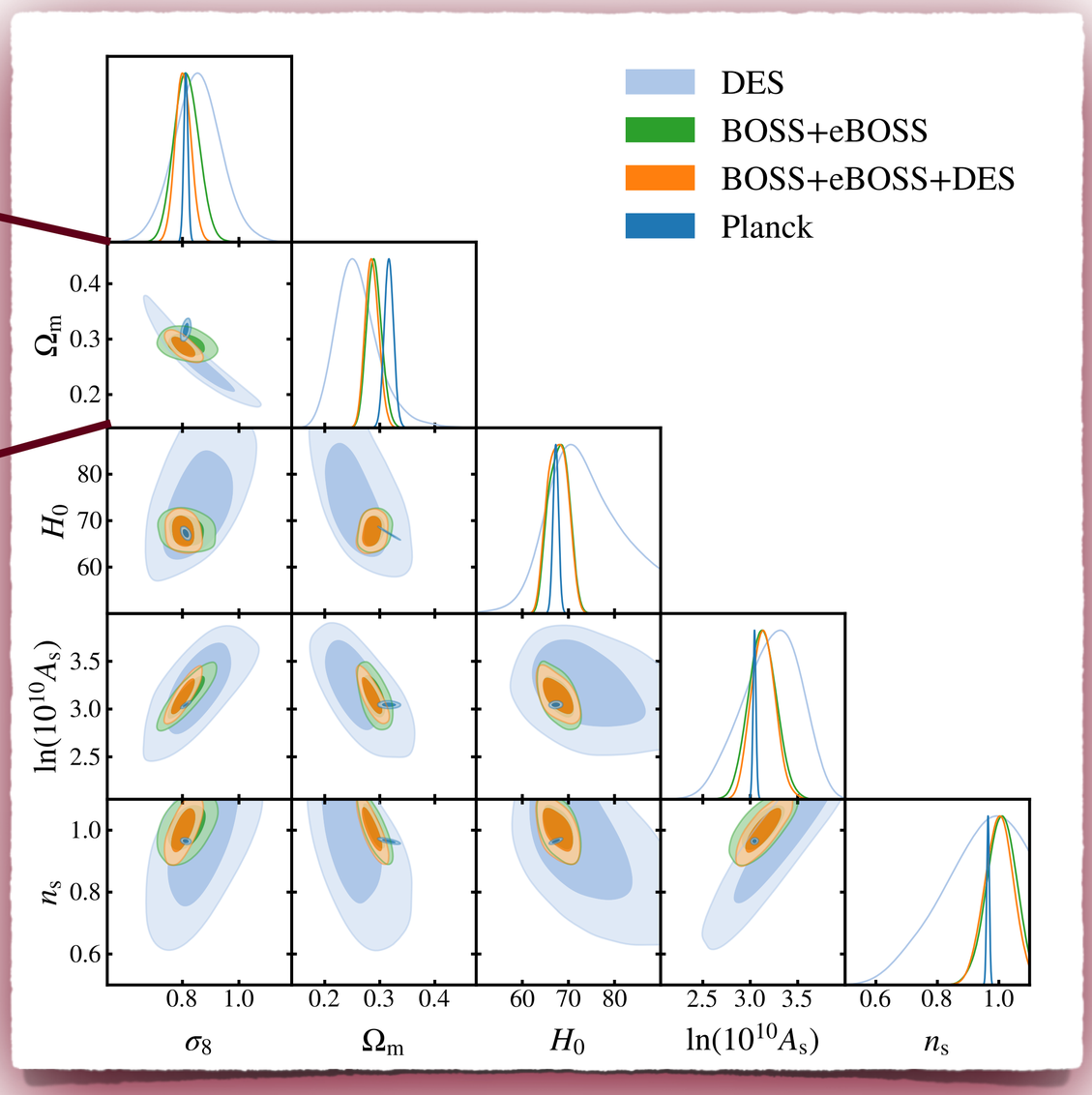


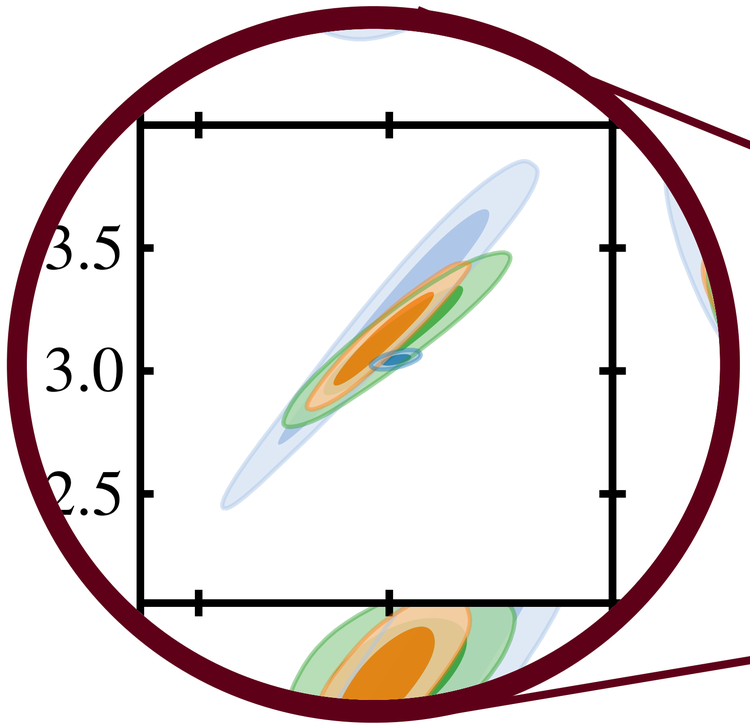


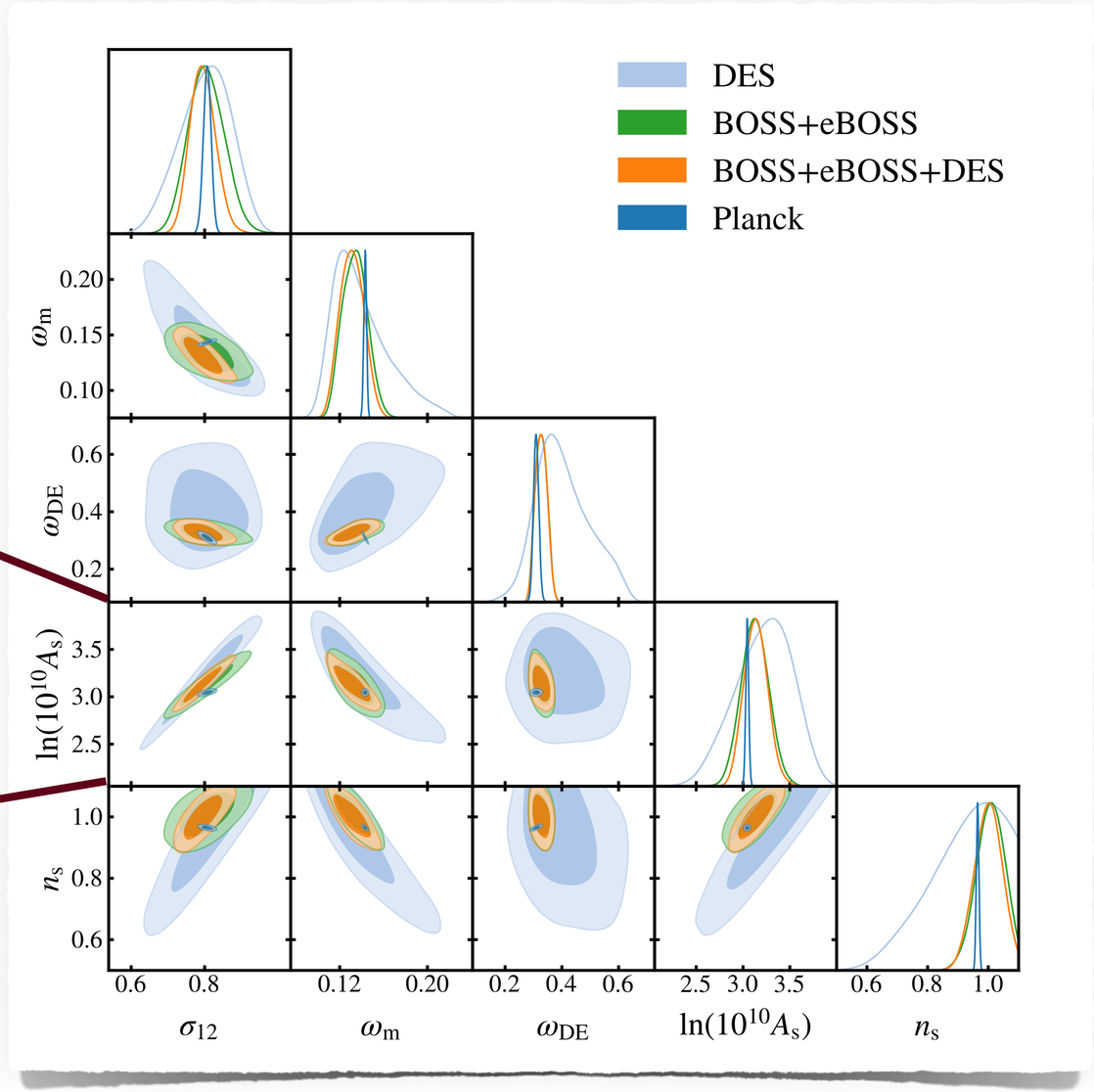
- The discrepancy in $\Omega_m - \sigma_8$ space for weak lensing appears when Mpc/h units are used.

arXiv: 2111.03156

Results: BOSS+eBOSS+DES

- Planck prefers slightly *more total structure growth* than the large scale structure probes.





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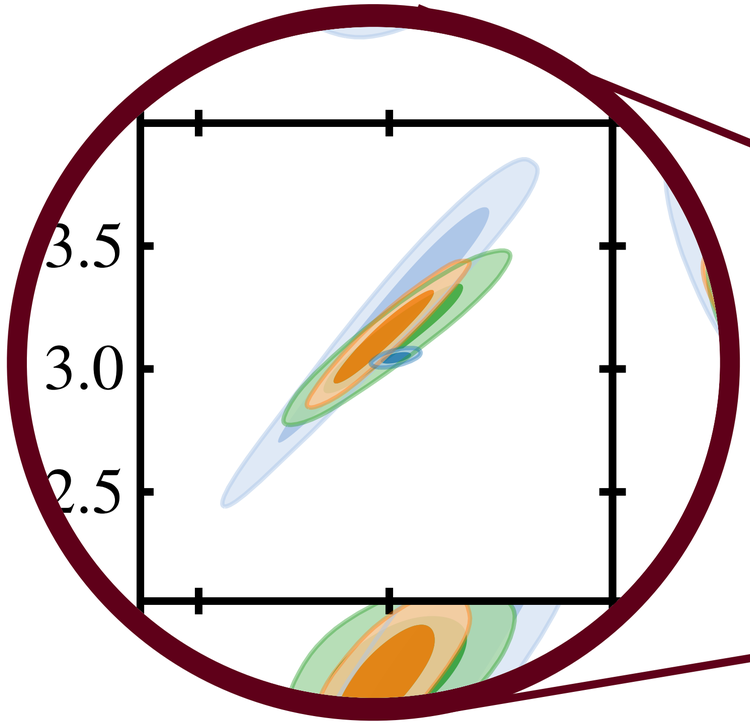
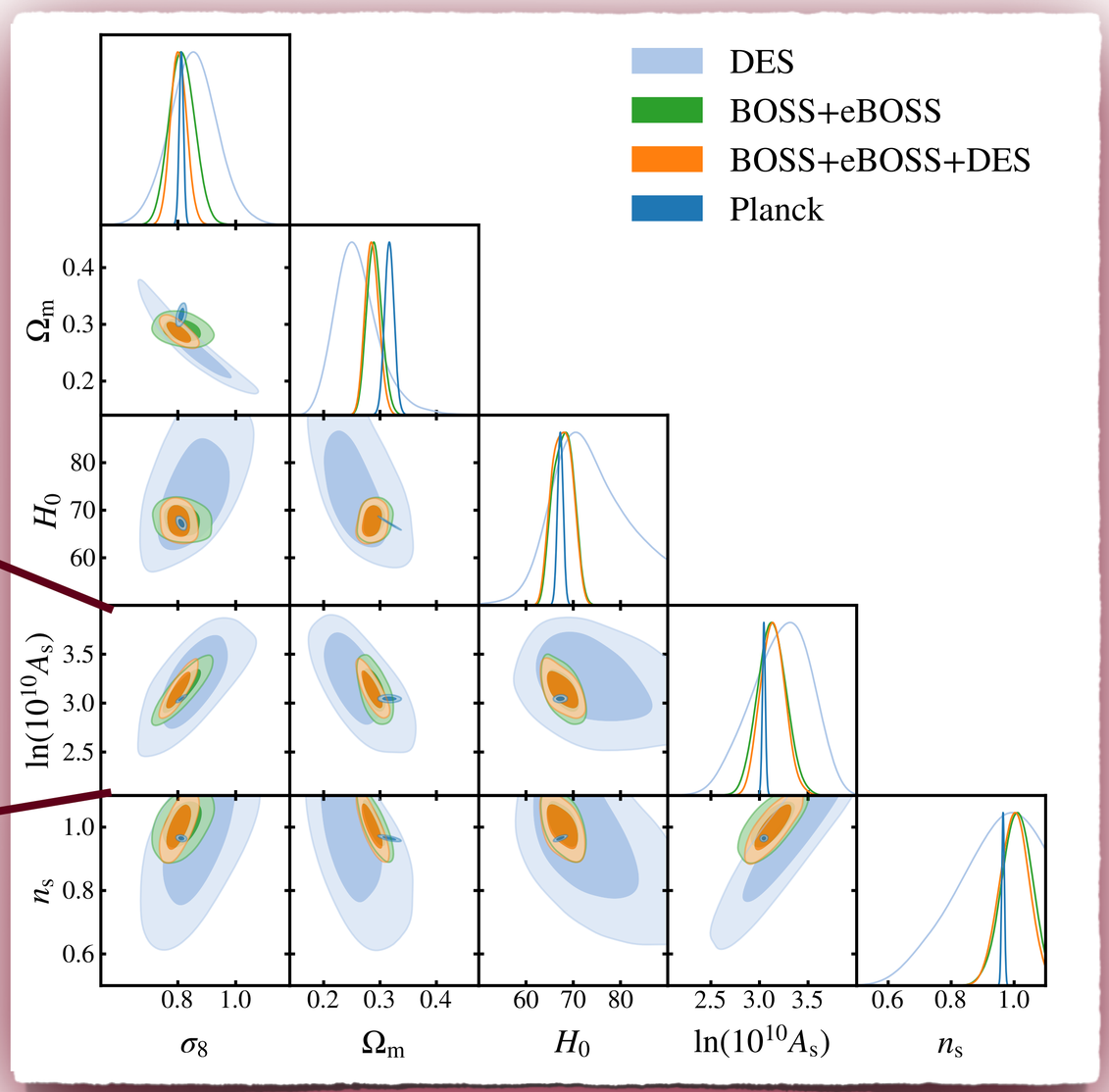
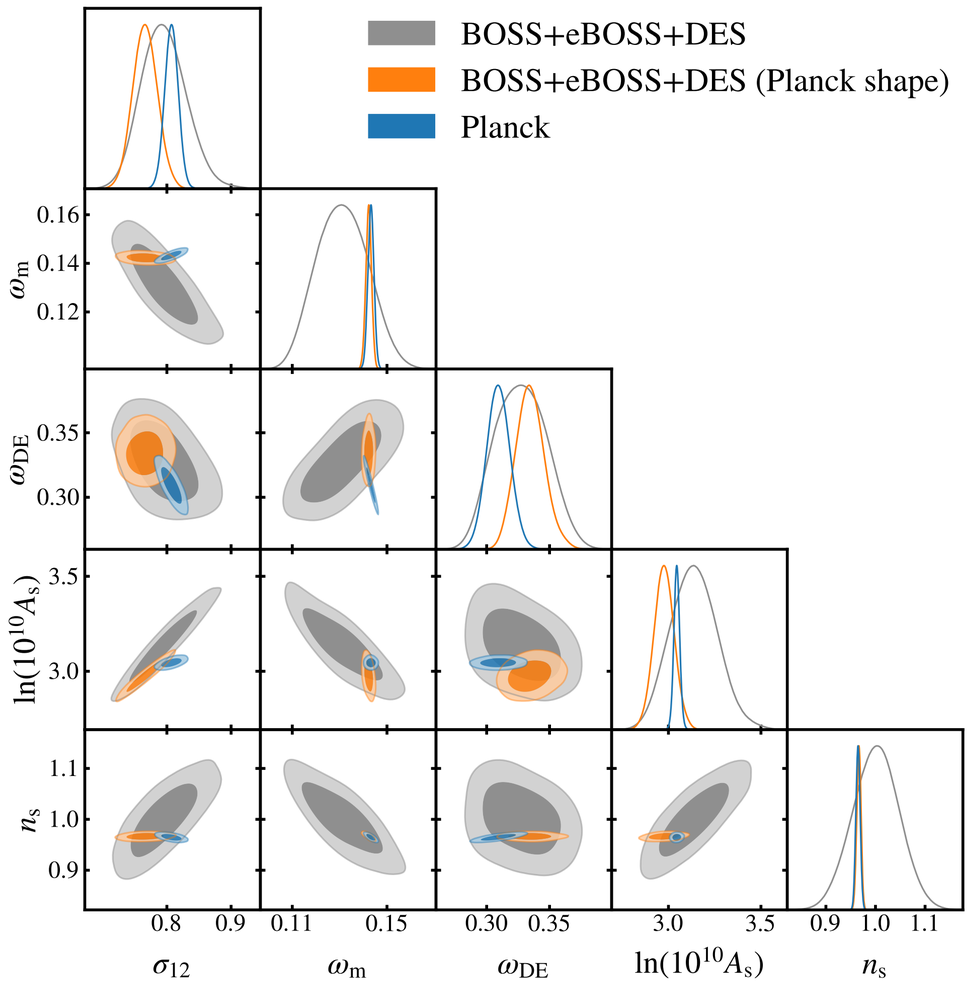




arXiv: 2111.03156

Results: BOSS+eBOSS+DES

- Fixing the shape parameters tightens the constraints on σ_{12} and A_s, which are subsequently given to be 1.89σ and 1.22σ below Planck values.
- ω_{DE} is recovered to be 1.73σ higher than Planck.



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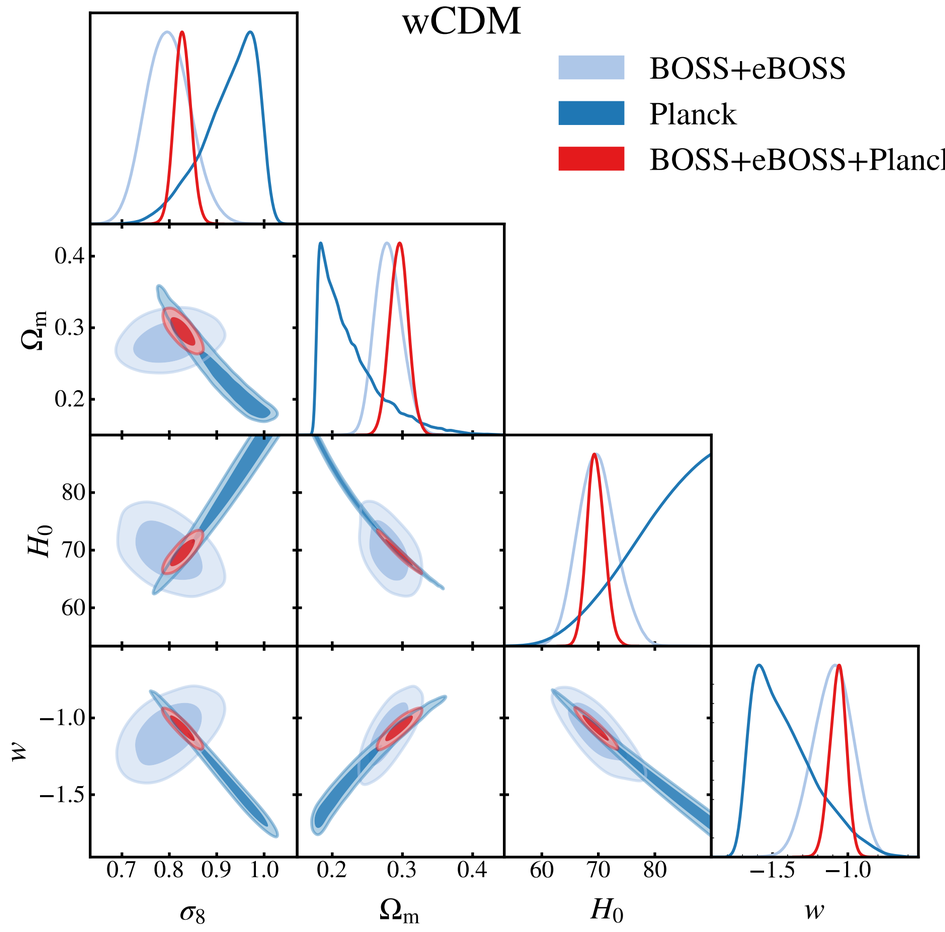
wCDM: constraining alternative dark energy models

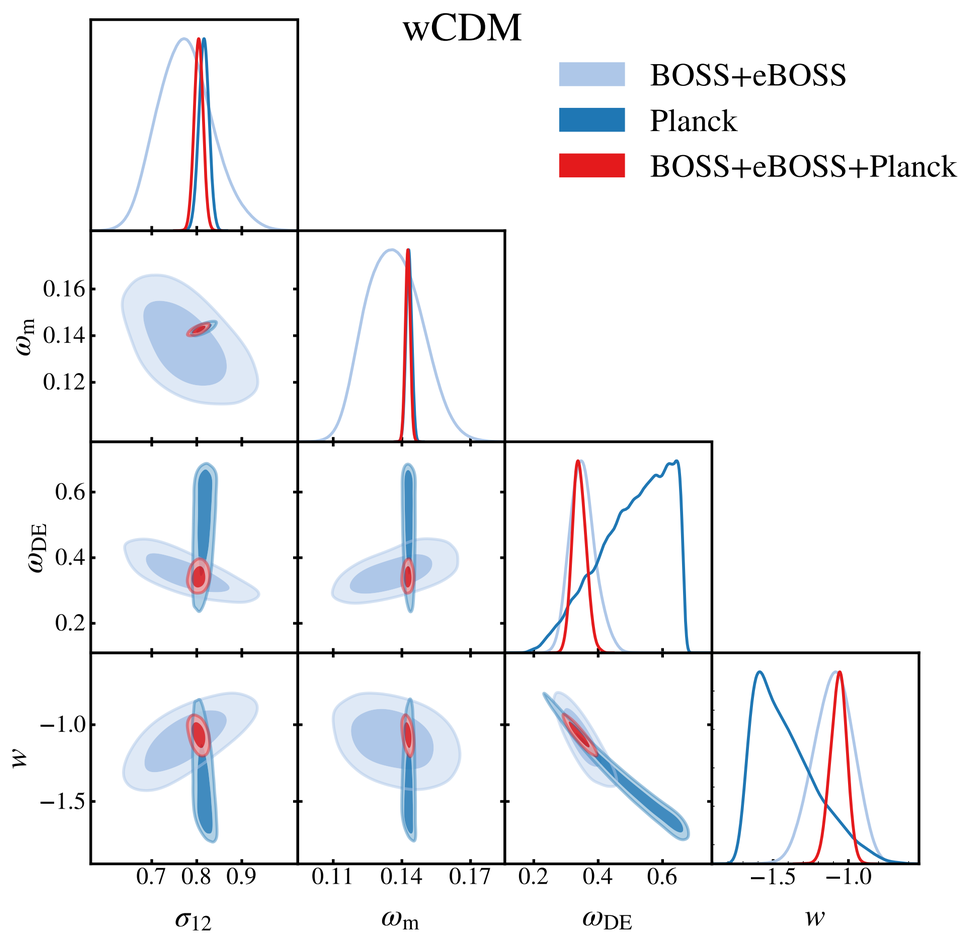
(Semenaite et al. , in prep)

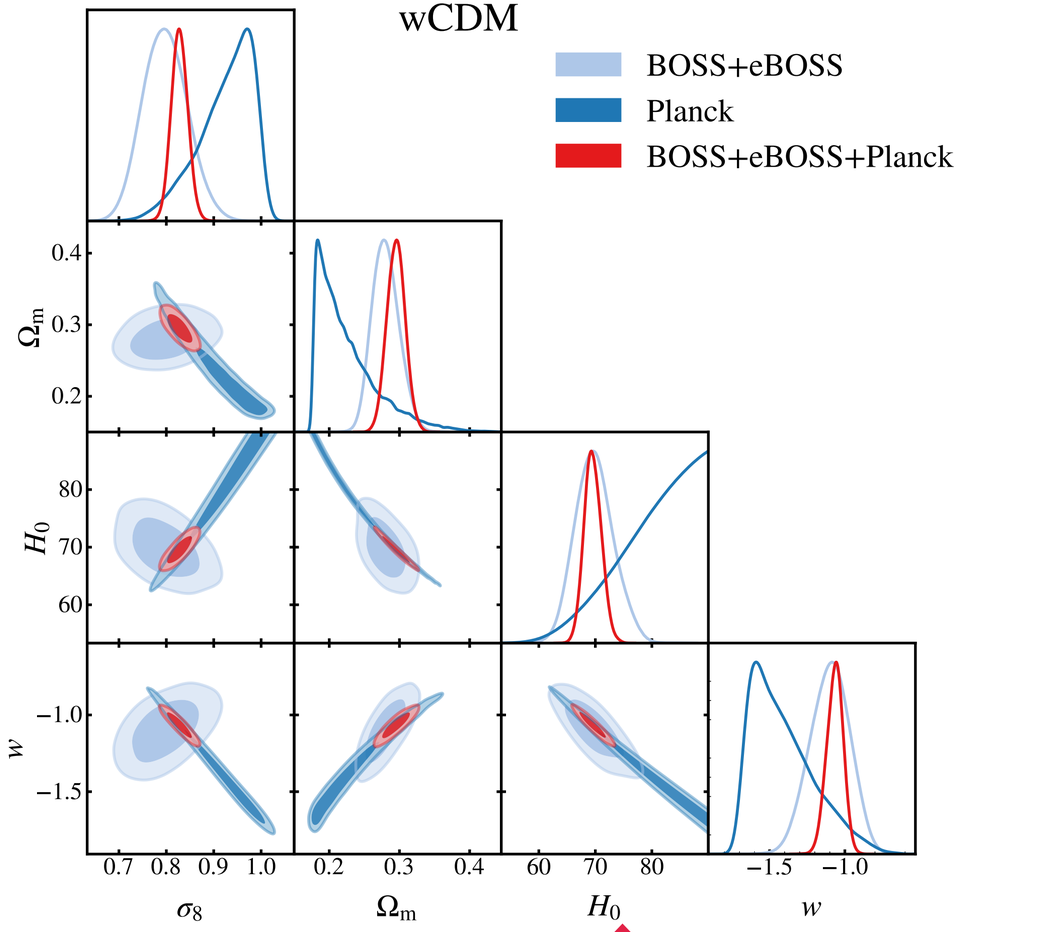
wCDM: constraining alternative dark energy models



(Semenaite et al. , in prep)

wCDM: constraining alternative dark energy models

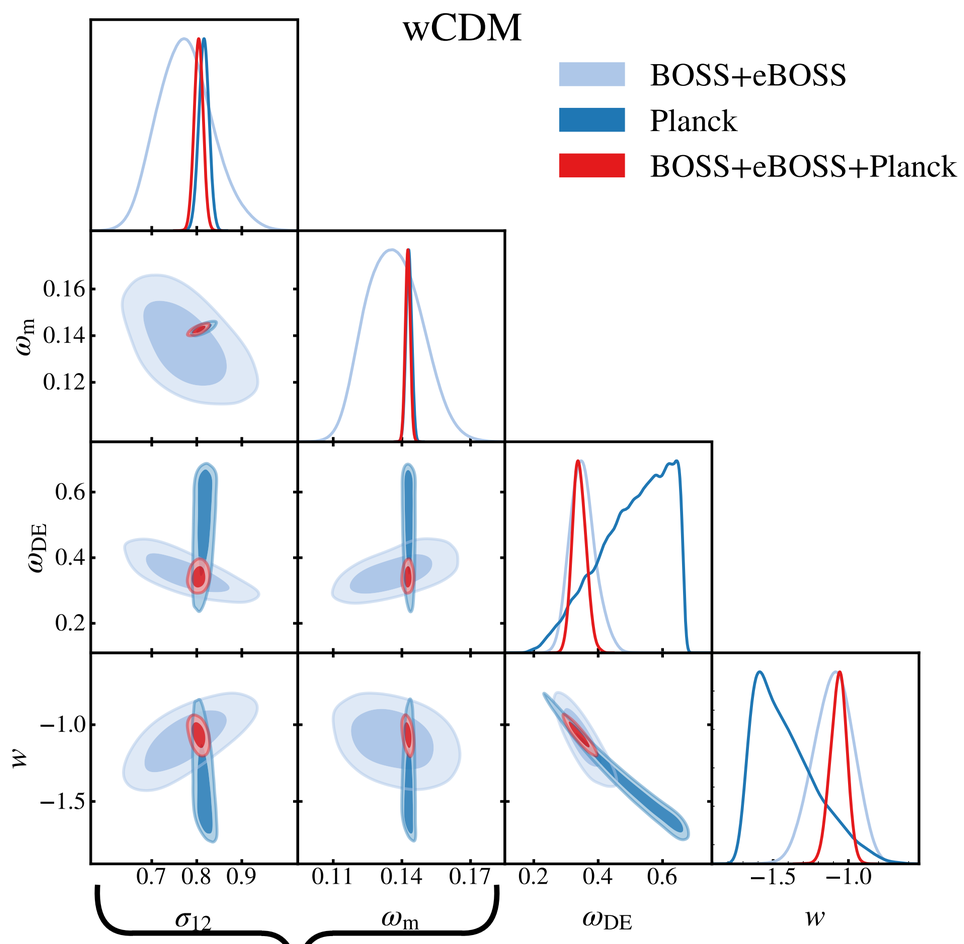


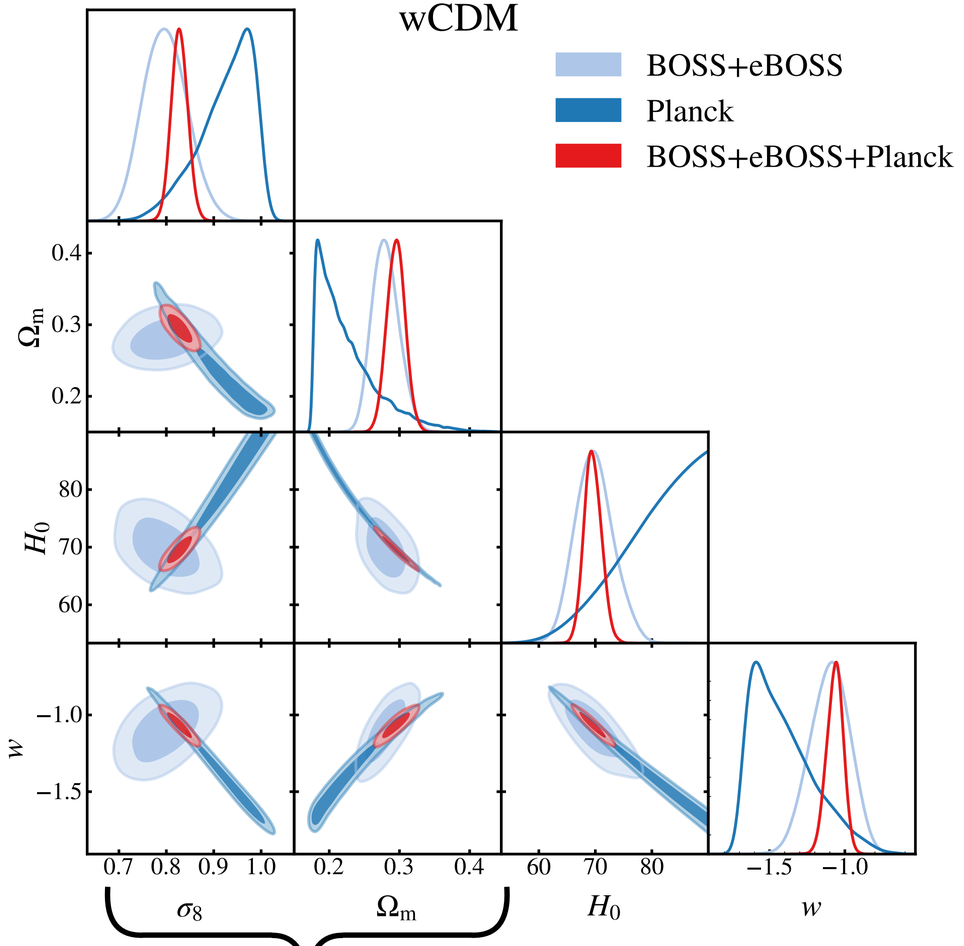


The degeneracies in H_0 are due to unconstrained ω_{DE}

(Semenaite et al. , in prep)

wCDM: constraining alternative dark energy models

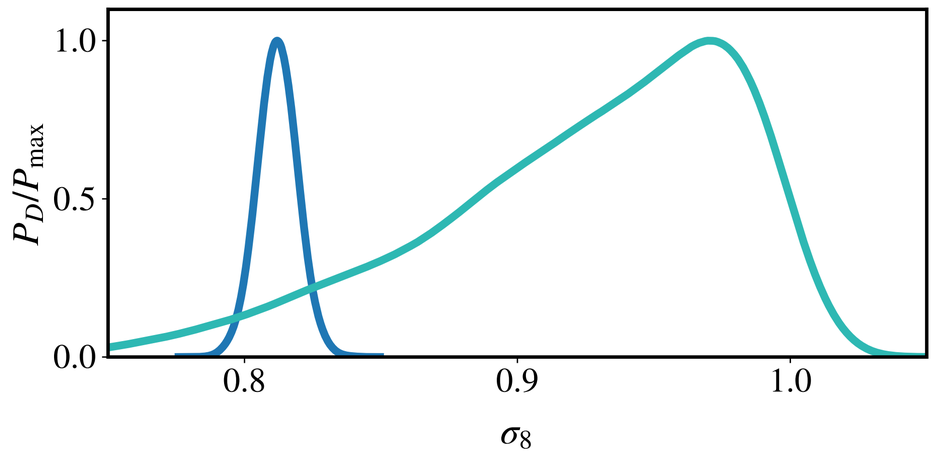


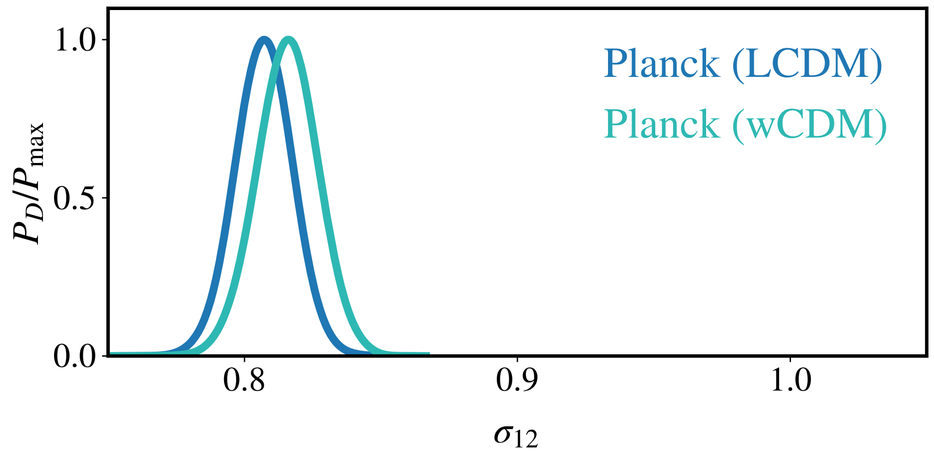


But Planck ***does constrain*** ω_m and σ_{12} even with evolving dark energy!

(Semenaite et al. , in prep)

wCDM: constraining alternative dark energy models





- First Planck constraint on power spectrum amplitude today in wCDM cosmology!

$$\sigma_{12} = 0.816 \pm 0.011 \quad \text{wCDM}$$

$$(\sigma_{12} = 0.807 \pm 0.011) \quad \Lambda\text{CDM}$$

(Semenaite et al. , in prep)

Summary:

- We analyse the full shape of anisotropic clustering measurement from eBOSS quasar and BOSS galaxy samples.

- We find consistency between the clustering measurements and Planck within ~0.6σ (~1.5σ when DES is added), as measured by the suspiciousness statistic.

- When imposing prior on the cosmological parameters that define the shape of the linear matter power spectrum we find a preference for a higher $\omega_{\rm DE}$ by the low-redshift data sets, as compared to Planck.

- We show that CMB does constrain clustering amplitude today, even within varying dark energy models and present the first wCDM Planck linear density field variance constraint $\sigma_{12} = 0.816 \pm 0.011$.