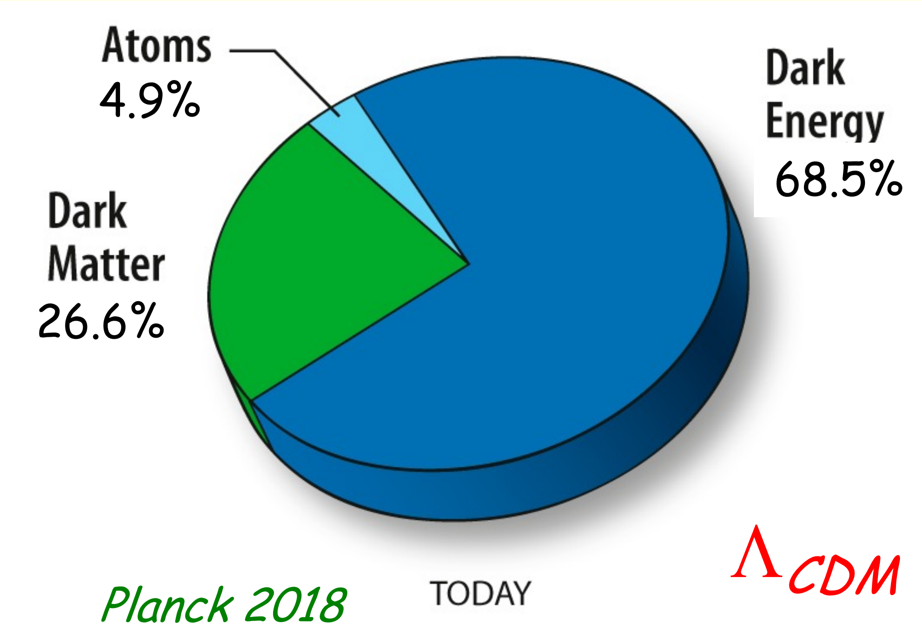
Overview of recent results in observational cosmology

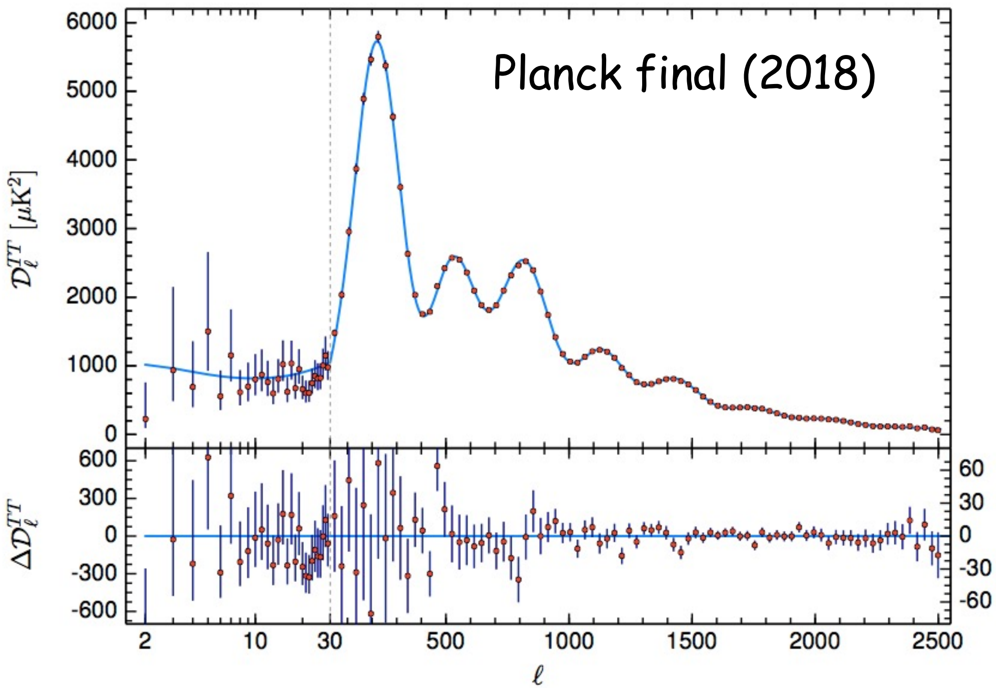


V.Ruhlmann-Kleider
CEA/Irfu/DPhP - Saclay

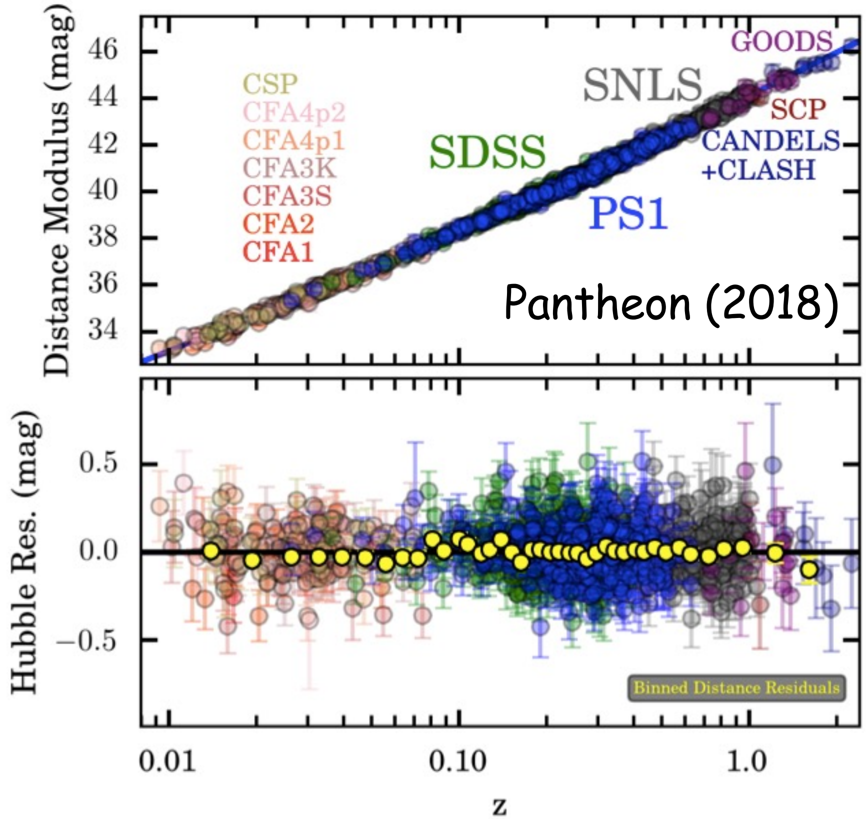
$$\Omega_M+\Omega_\Lambda+\Omega_k=1$$

1. Cosmological probes and constraints after Planck
2. Large scale structure: from SDSS to DESI

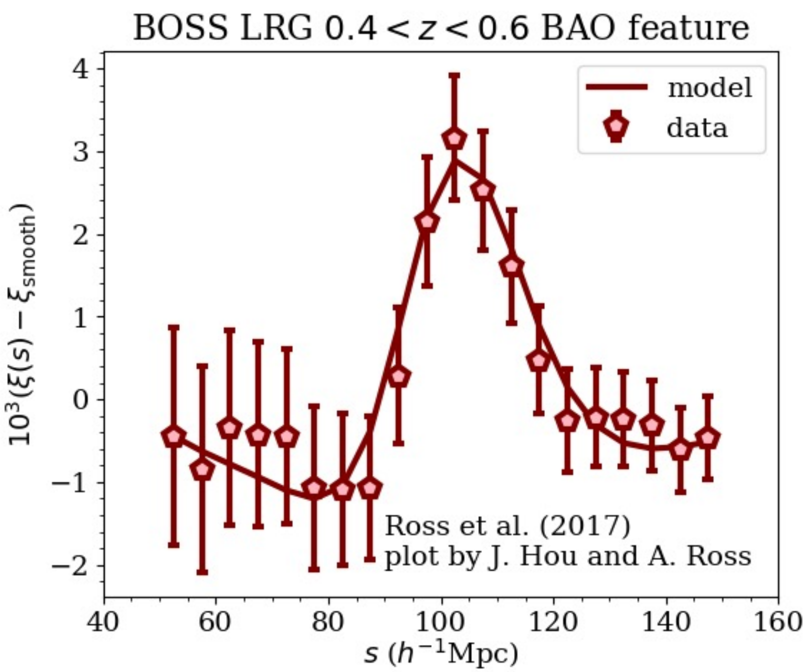
Cosmological probes



CMB: TT+EE+TE spectra (imprint of acoustic oscillations at the last scattering surface z=1089) + CMB lensing signal



SN Ia: luminosity distances (z≤2)

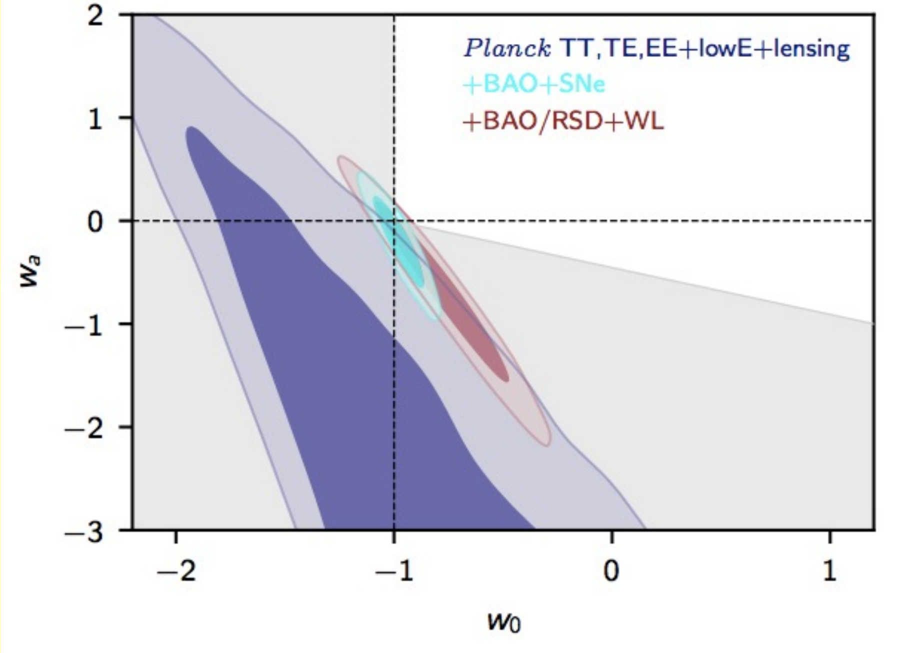


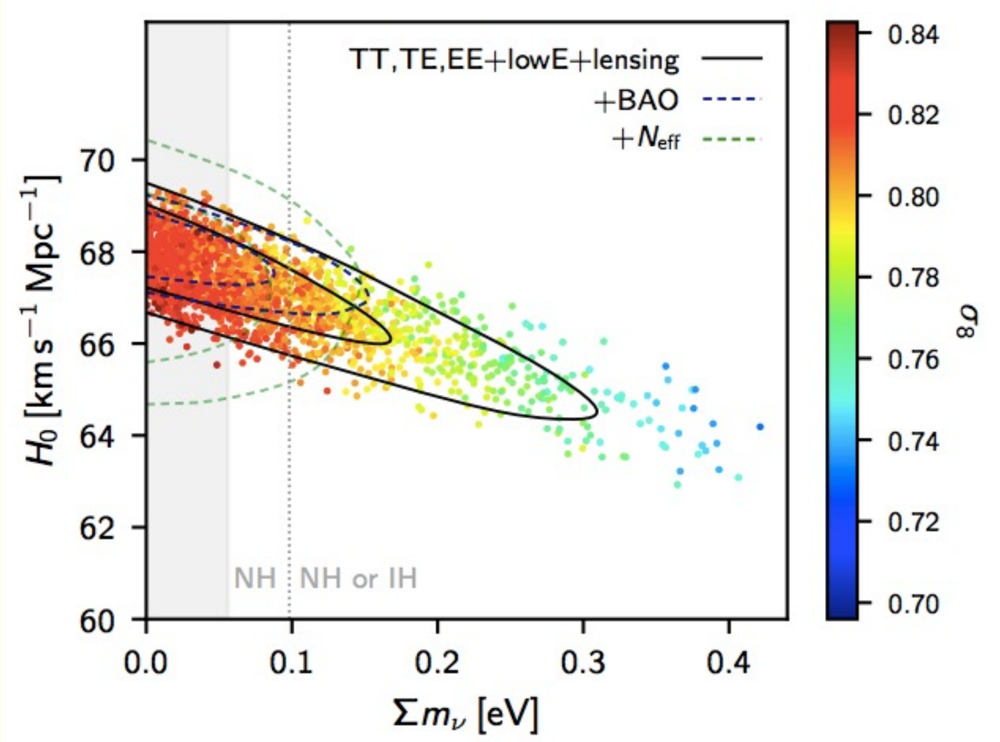
BAO: imprint of acoustic oscillations in the distribution of ordinary matter (galaxies, quasars, interg. H clouds, z<2.3)

Cosmological constraints from Planck final paper

flat $w_0 w_a$CDM

- w_a~0 & w_0~-1 (=Λ_{CDM}) preferred by data
- flat w_0CDM: w_0=-1.03±0.03



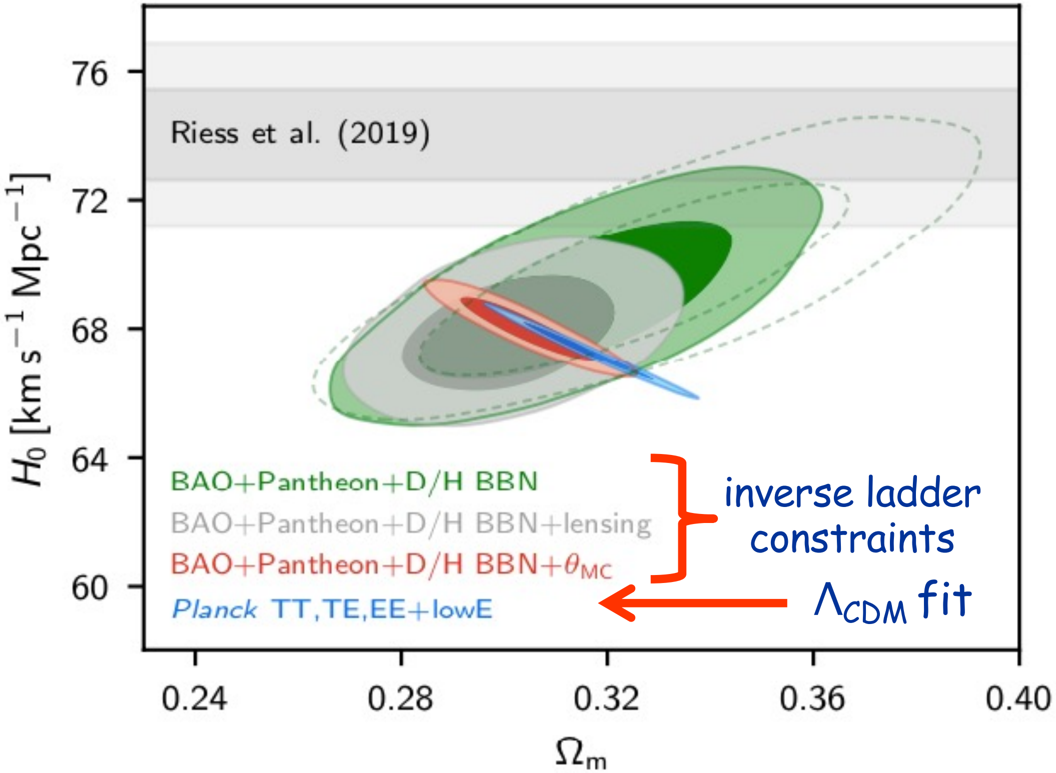


Λ_{CDM} + Σm_ν

$\Sigma m_\nu \leq 0.12 eV$ (95%CL)

(from Planck + BAO data)

Planck Collaboration, A&A 641 (2020) A6



Λ_{CDM} fit

H_0=67.36±0.54 km/s/Mpc

(all Planck data)

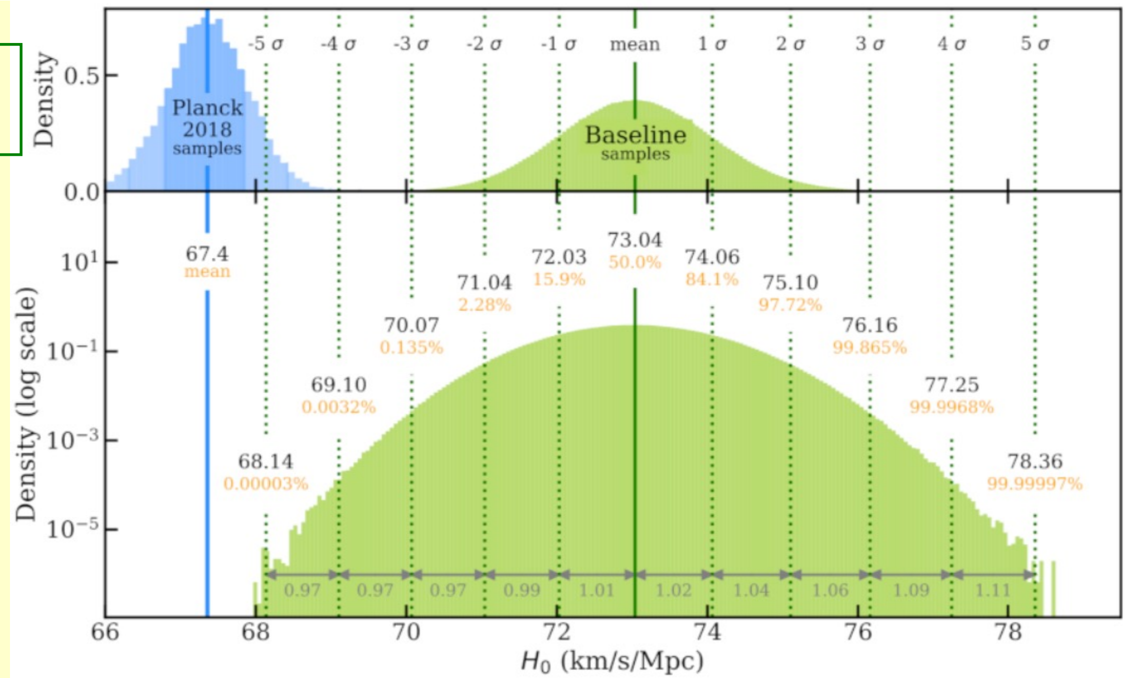
Planck Collaboration, A&A 641 (2020) A6

Direct measurement (SH0ES)

H_0=73.04±1.04 km/s/Mpc

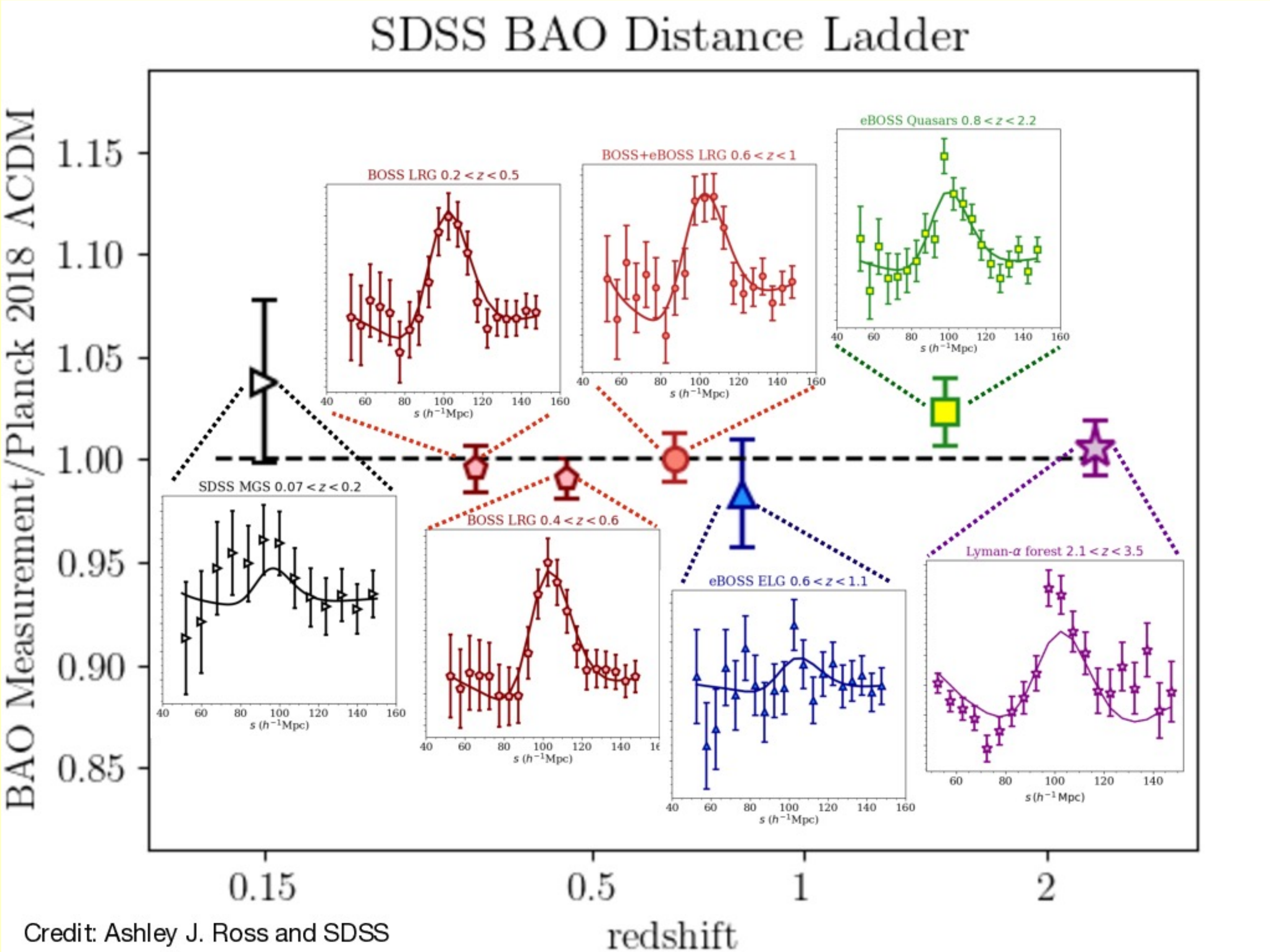
A.Riess et al, ApJ 944L (2022) 7R

5σ tension



LSS/clustering: final SDSS results on BAO (2020)

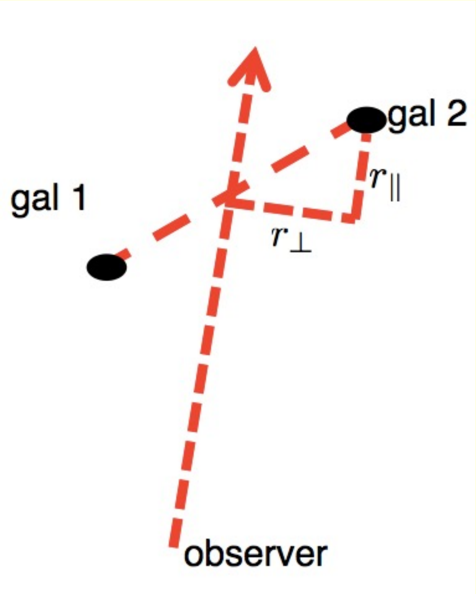
https://www.sdss.org/science/cosmology-results-from-eboss/

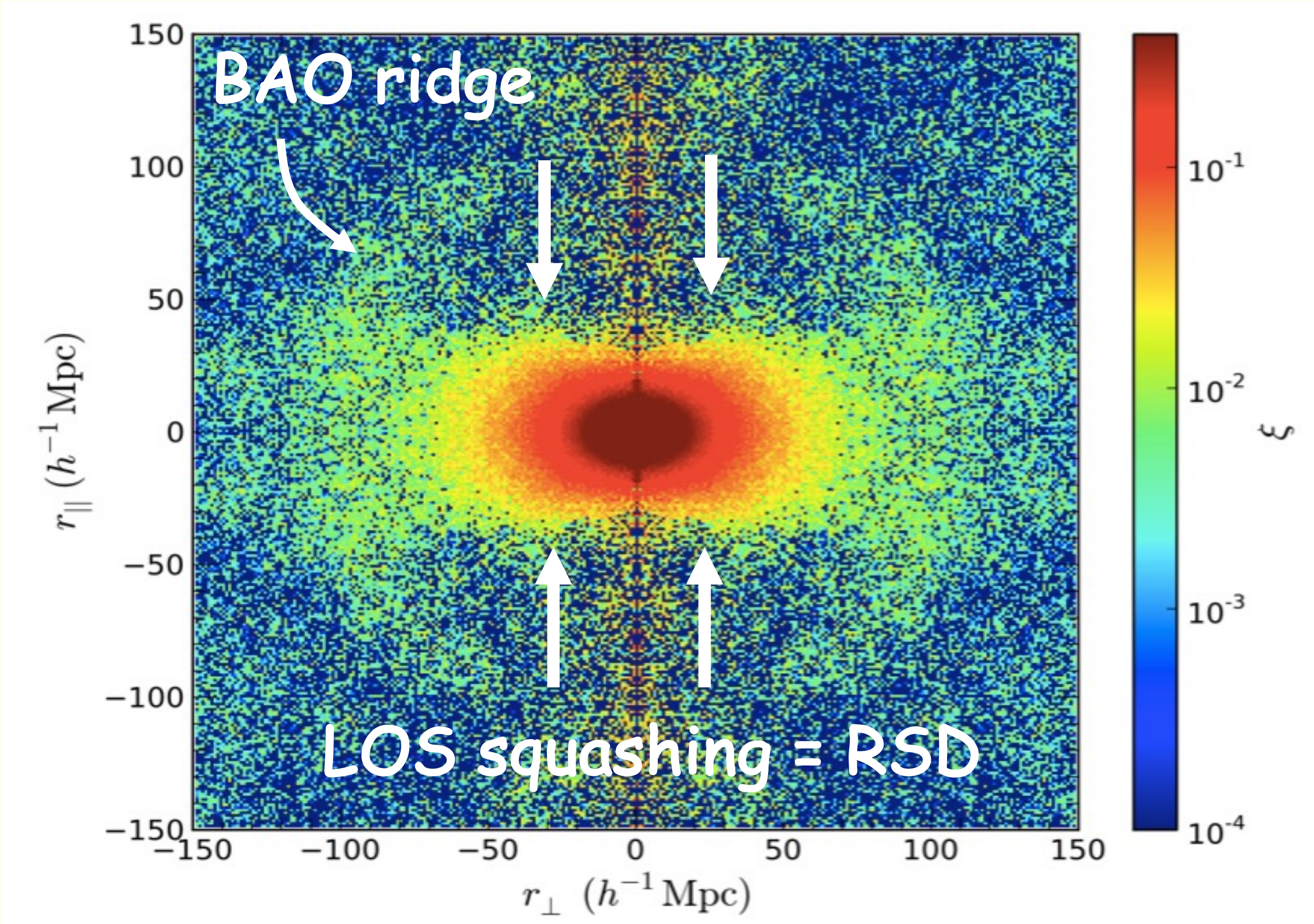


BAO scales measured for different matter tracers over 0.15<z<2.5, with different technics (2PCF, P(k)), ⊥ and ∥ to the line of sight. Precision : ≲5%, stat > syst

Very good overall agreement with Planck 2018 best-fit.

LSS/clustering: beyond BAO



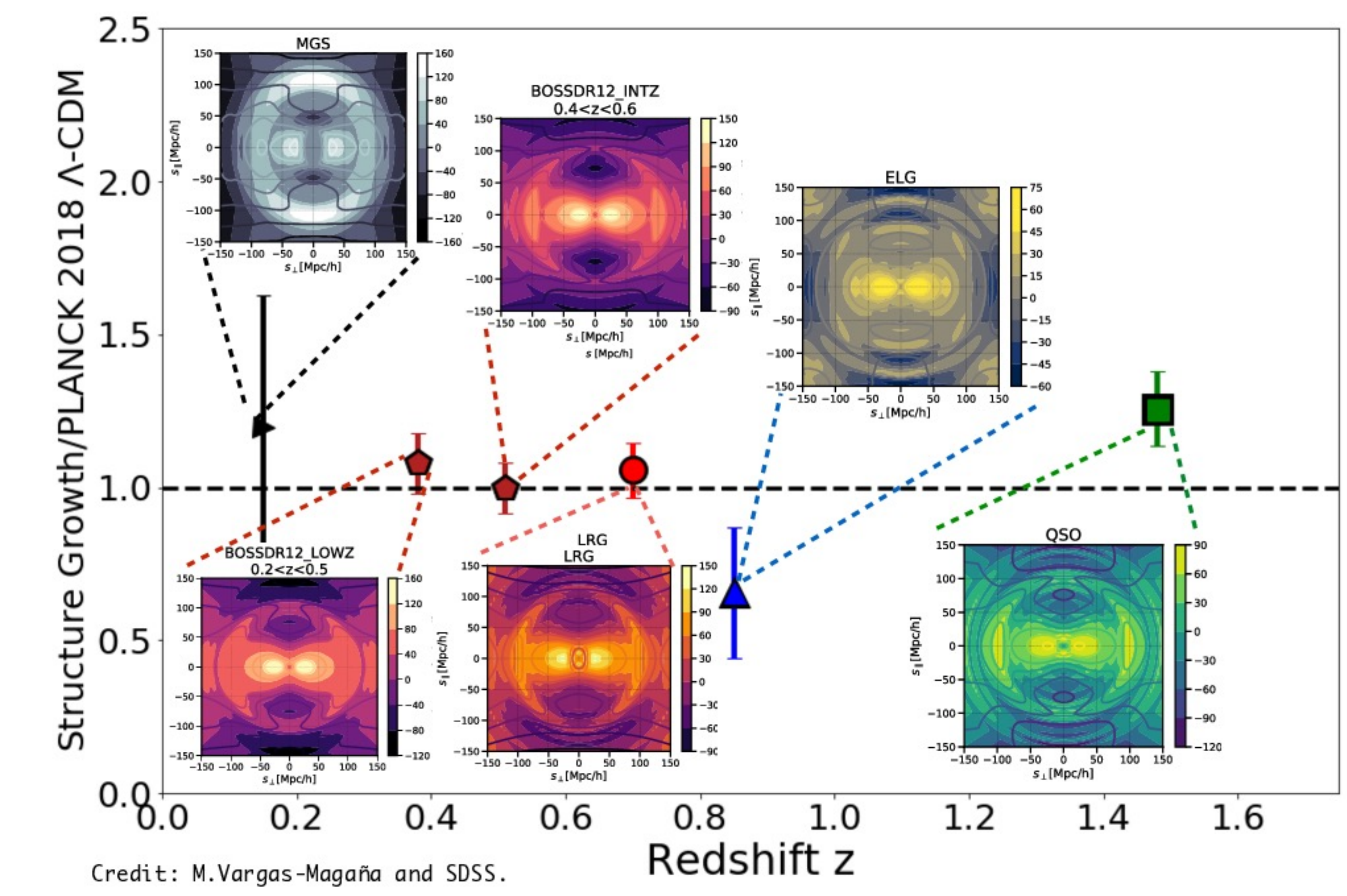


observed redshift:
Hubble expansion +
peculiar velocity due
to gravity

L.Samushia et al, 2014, MNRAS, 439, 3504.

Redshift Space Distortion : a way to measure structure growth & test gravity, full shape analysis of matter power spectrum required

LSS/clustering: final SDSS results on RSD (2020)



Structure growth measured for different matter tracers over 0.15<z<1.5, with different technics (2PCF, P(k)). Best precision: 6-10%

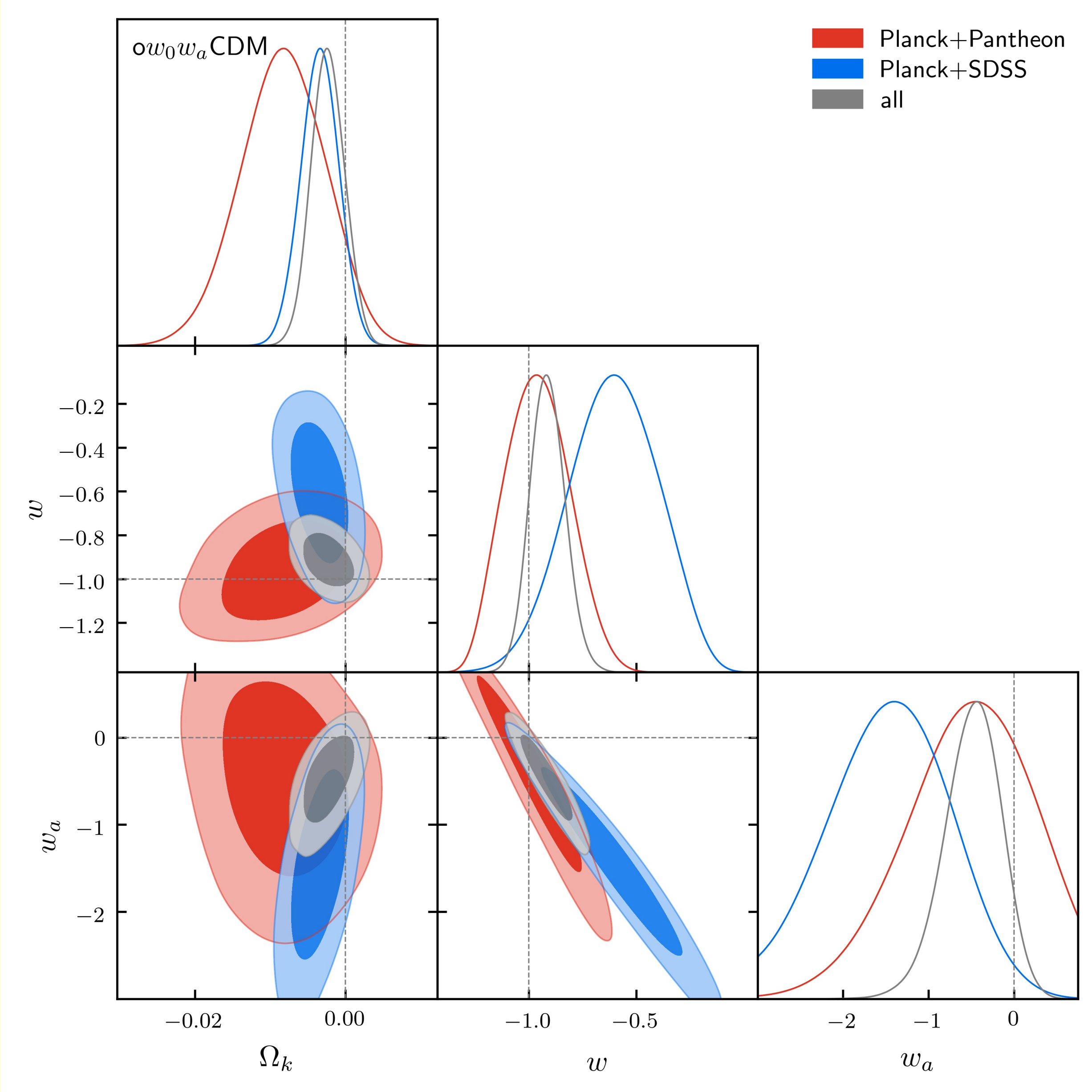
Good overall agreement with Planck 2018 best-fit but test is not stringent.

Cosmological constraints from SDSS final paper

open w_0w_aCDM

- Ω_k~0 (<1σ)
- w_0~-1 (1.1σ)
- w_a~0 (1.3σ)

ΛCDM preferred by data



- flat w_0CDM:

w_0=-1.020±0.027

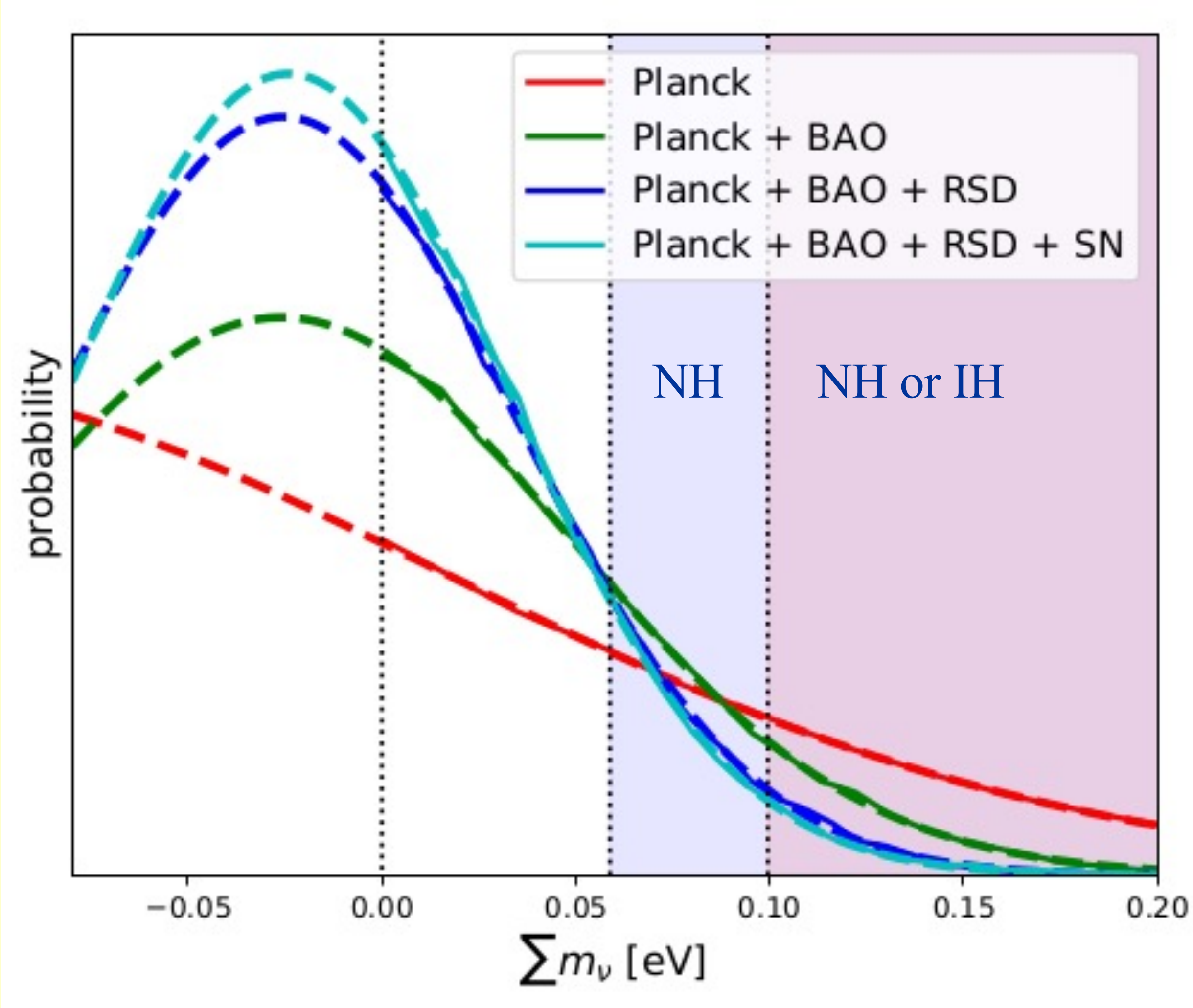
(Planck, SDSS BAO+RSD, SN, DES 3x2pt data)

Alam et al, PRD 103 (2021) 083533

$\Lambda_{CDM} + \Sigma m_\nu$

$\Sigma m_\nu \leq 0.099$ (95%CL)

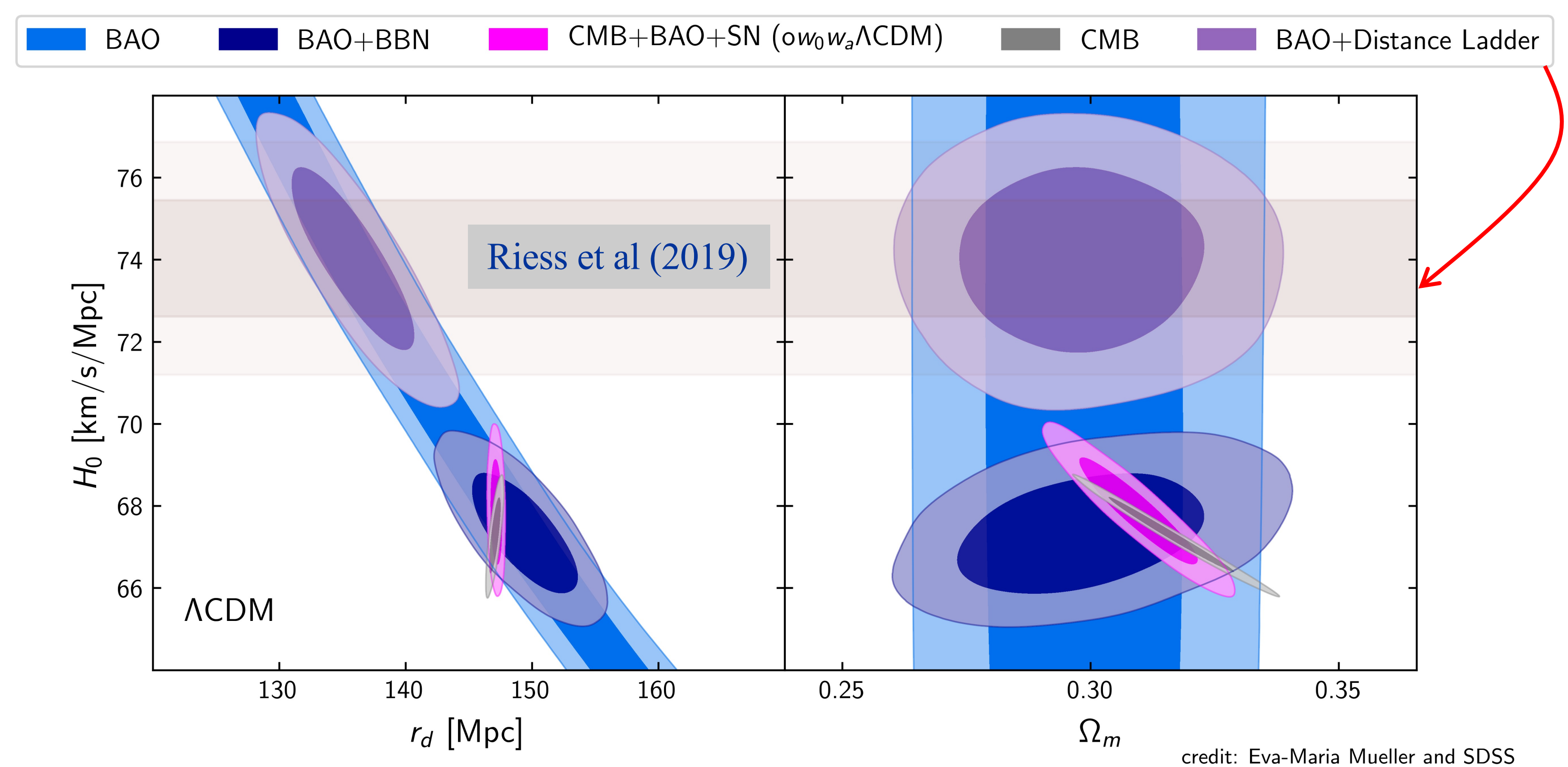
(Planck+BAO+RSD+SN data, $\Sigma m_\nu > 0$ prior)



Alam et al, PRD 103 (2021) 083533

Inverse ladder constraints from SDSS

Alam et al, PRD 103 (2021) 083533



H_0=67.87±0.86 km/s/Mpc (CMB + BAO + SN data, ow_0w_aCDM model)

H_0=67.35±0.97 km/s/Mpc (BAO + BBN data, Λ_{CDM} model)

⇒ tension cannot be restricted to systematic errors in Planck data or to the strict assumption of the Λ_{CDM} model

Non standard primordial physics ? Need new & well controlled measurements

LSS: the Dark Energy Spectroscopic Instrument

Abareshi et al, arXiv:2205.10939

- Mayall telescope @ Kitt Peak NO, Arizona
- 4 m, 8 deg^2 FoV
- FP: 5,000 robotically positioned fibers
- 10 triple-arm spectrographs

  (360-980nm, $\lambda/\delta\lambda$=2000/5500)

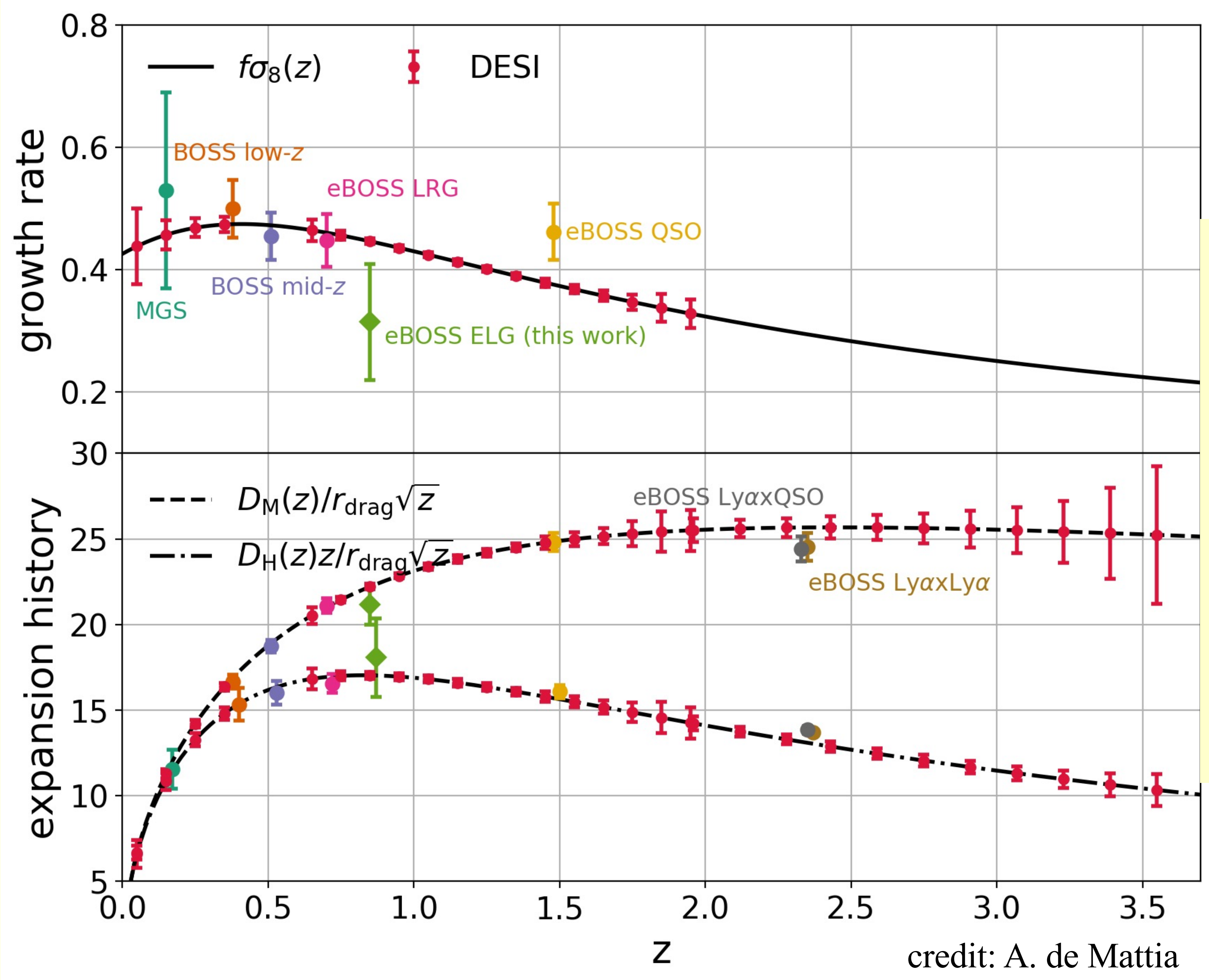
- Started: 14/05/2021 for 5yrs
- 14,000 deg^2, 40 million redshifts ~ 10 x SDSS BAO surveys

DESI: a wide spectroscopic survey dedicated to clustering measurements, BAO scale and growth rate

Prospects

RSD:
18 z bins,
δz=0.1

BAO:
29 z bins,
δz=0.1



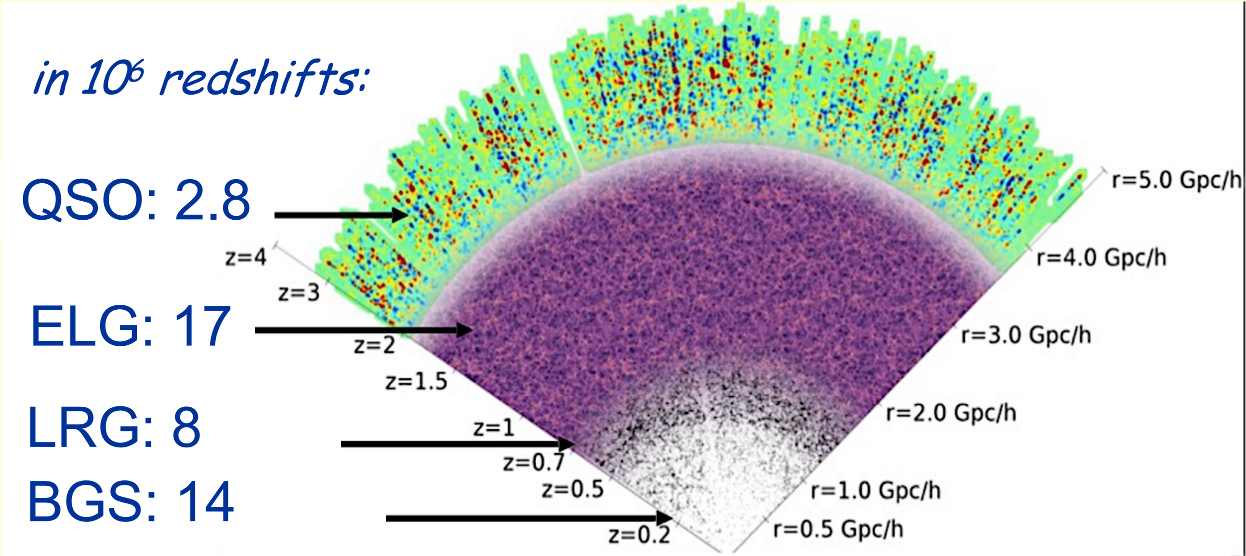
DESI coll., arXiv:1611.00036

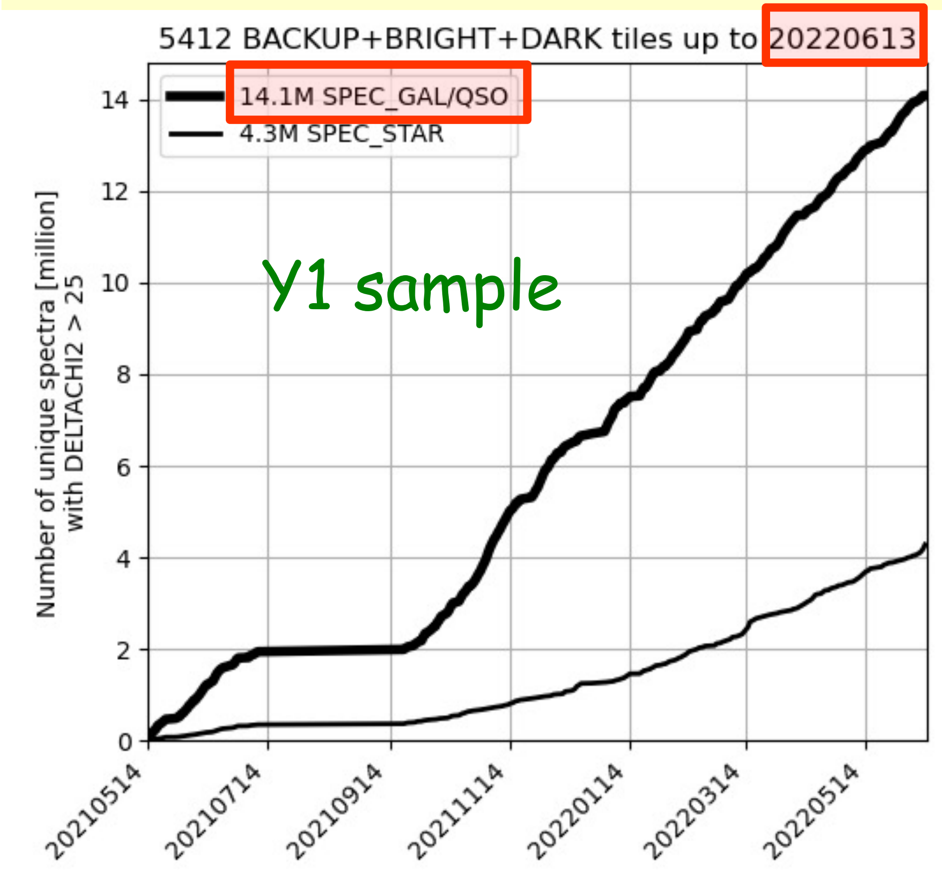
⇒ Forecast (BAO+RSD+Planck):

$\delta w_p = 0.01 \quad \delta w_a \approx 0.1$

DESI tracers

expected: 40. 10^6 redshifts in 5yrs





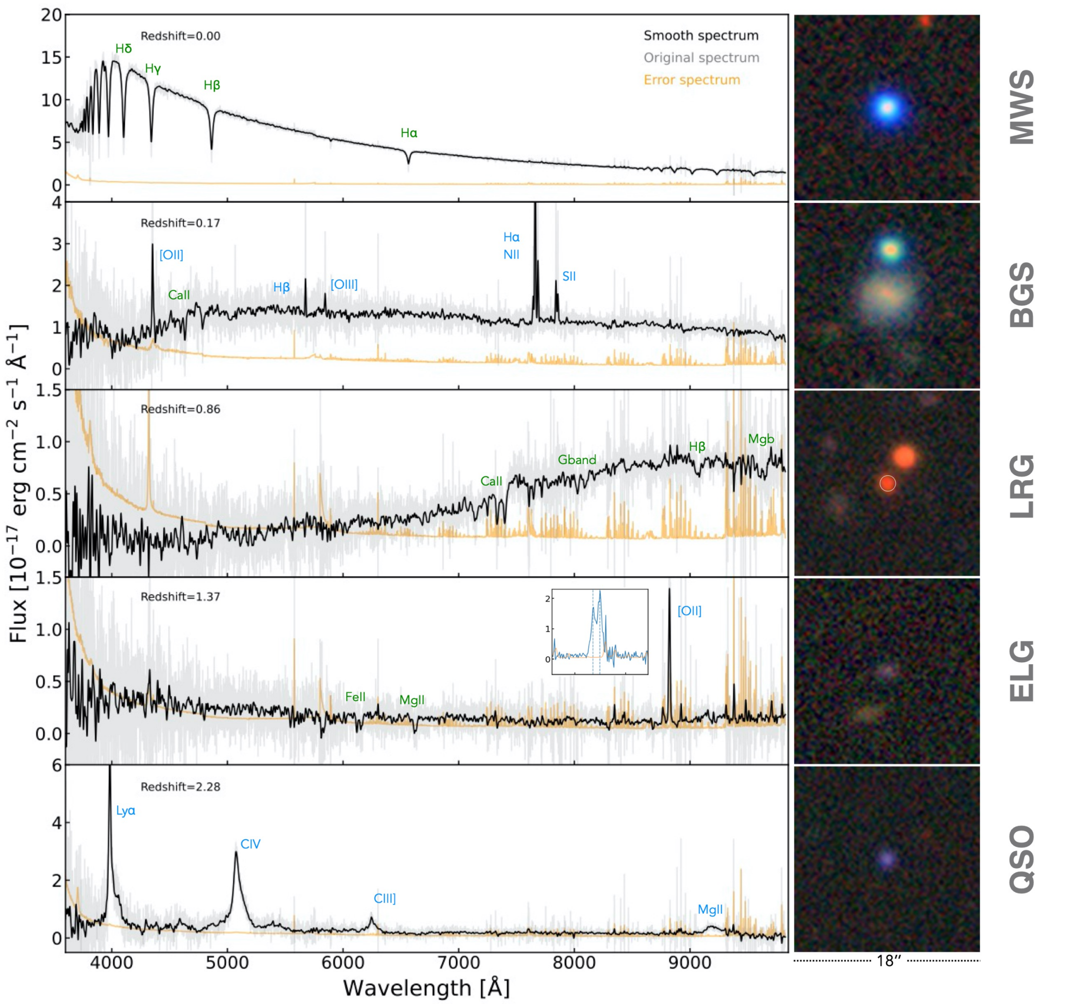
Survey status

Program completeness:

- dark time: 28.8%
- bright time: 41.2%

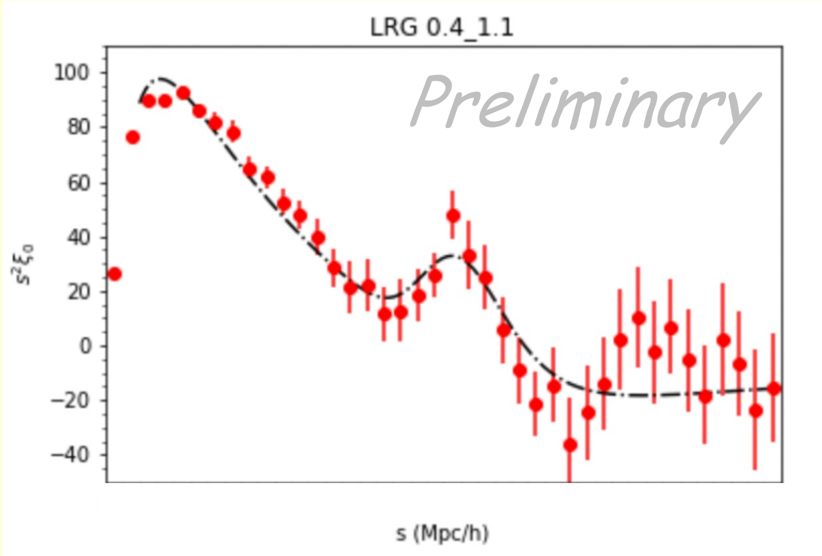
Present status: observations resumed on September, 10 after a ~3-month shutdown due to wildfires in June

Science output



https://www.desi.lbl.gov/category/blog

- Published: instrument, target selection validation
- To come in early 2023: galaxy-DM halo connection, BAO on early data (~1.8 10^6 redshifts)



To come by end 2023: Y1 clustering analyses and cosmological results

Stay tuned !

CONCLUSIONS

- Main cosmological measurements today: CMB, SNeIa, BAO. All data compatible with a flat Λ_{CDM} concordance model.

w=-1.026$\pm$0.033 Ω_{DE}= 0.6929$\pm$0.0075 H_0= 68.21$\pm$0.82 km/s/Mpc

SDSS paper (Planck, SDSS BAO, SN)

- Much progress in Large Scale Structure measurements: beyond BAO data available (RSD, WL) but impact is modest for now

w=-1.020$\pm$0.027 Ω_{DE}= 0.6992$\pm$0.0066 H_0= 68.64$\pm$0.73 km/s/Mpc

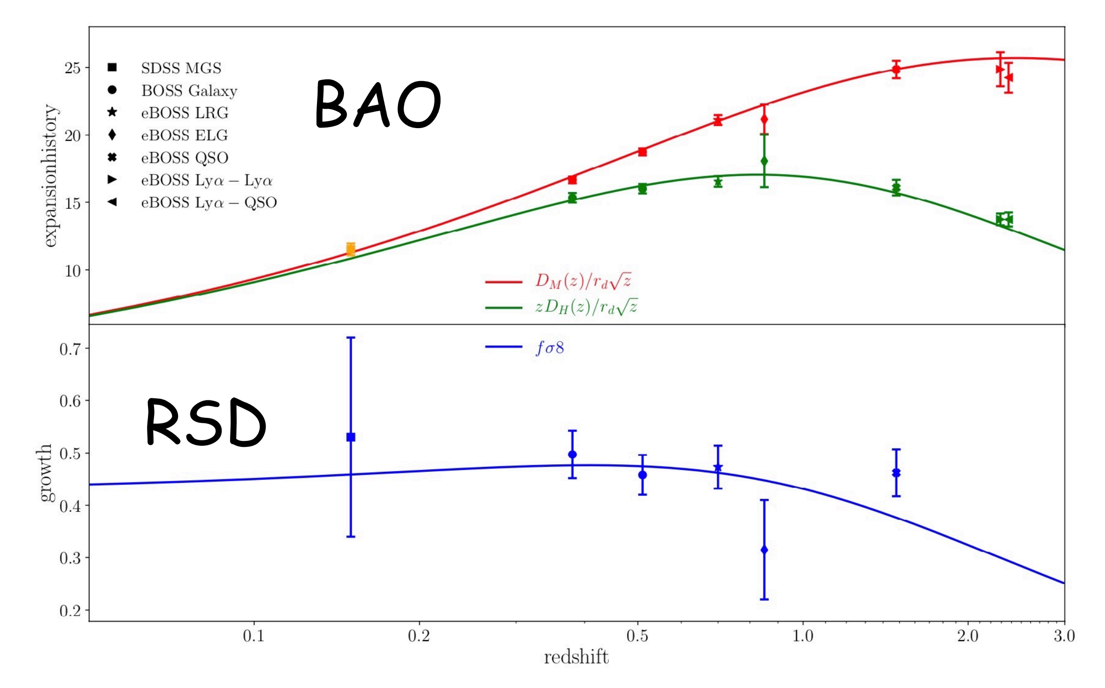
SDSS paper (Planck, SDSS BAO+RSD, SN, DES 3x2pt data)

- Future of LSS: DESI (2021-2026) then: Rubin-LSST, Euclid, Roman-WFIRST, all with similar constraining power on the DE equation of state, then DESI-II …

Back up slides

SDSS LSS summary

Alam et al, PRD 103 (2021) 083533



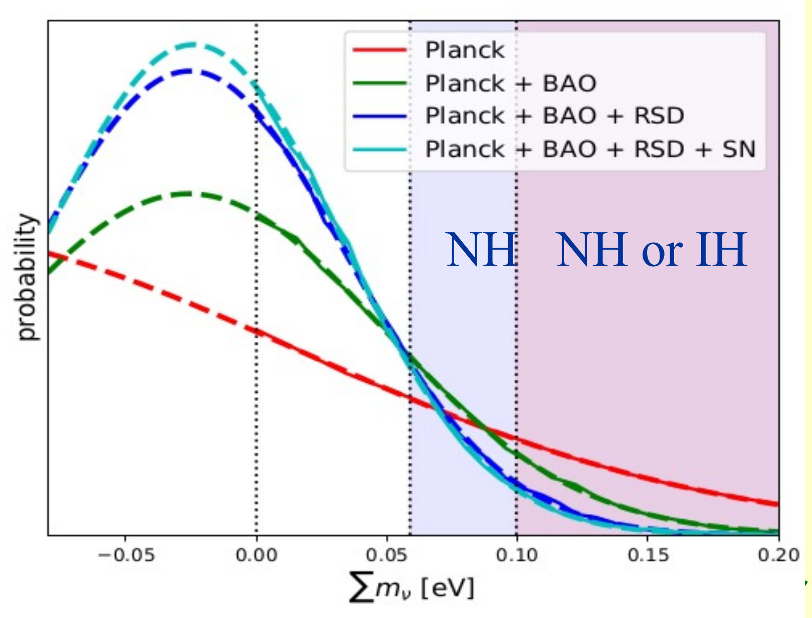
wCDM constraints

w=-1.026±0.033 (CMB+BAO+SN)
w=-1.09±0.11 (CMB+RSD)

Λ_{CDM} + Σm_ν constraints

$\Sigma m_\nu \leq 0.129$ (CMB+BAO)
$\Sigma m_\nu \leq 0.102$ (CMB+BAO+RSD)

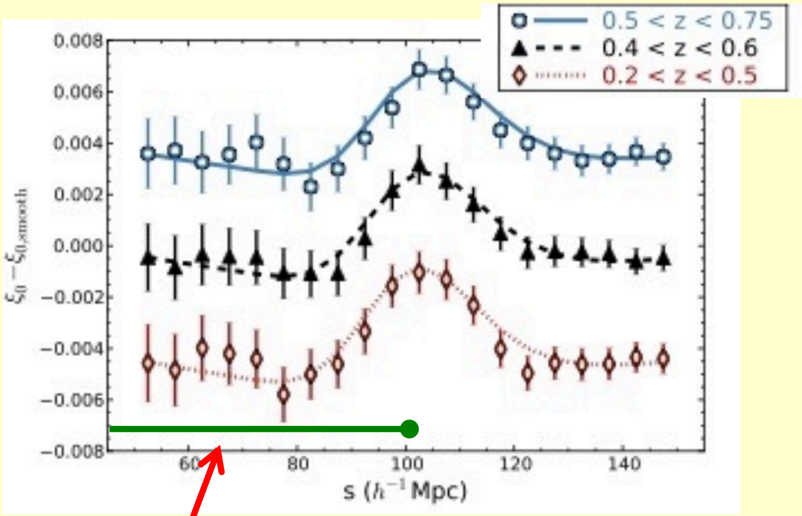
(95%CL)



From BAO ...

Method

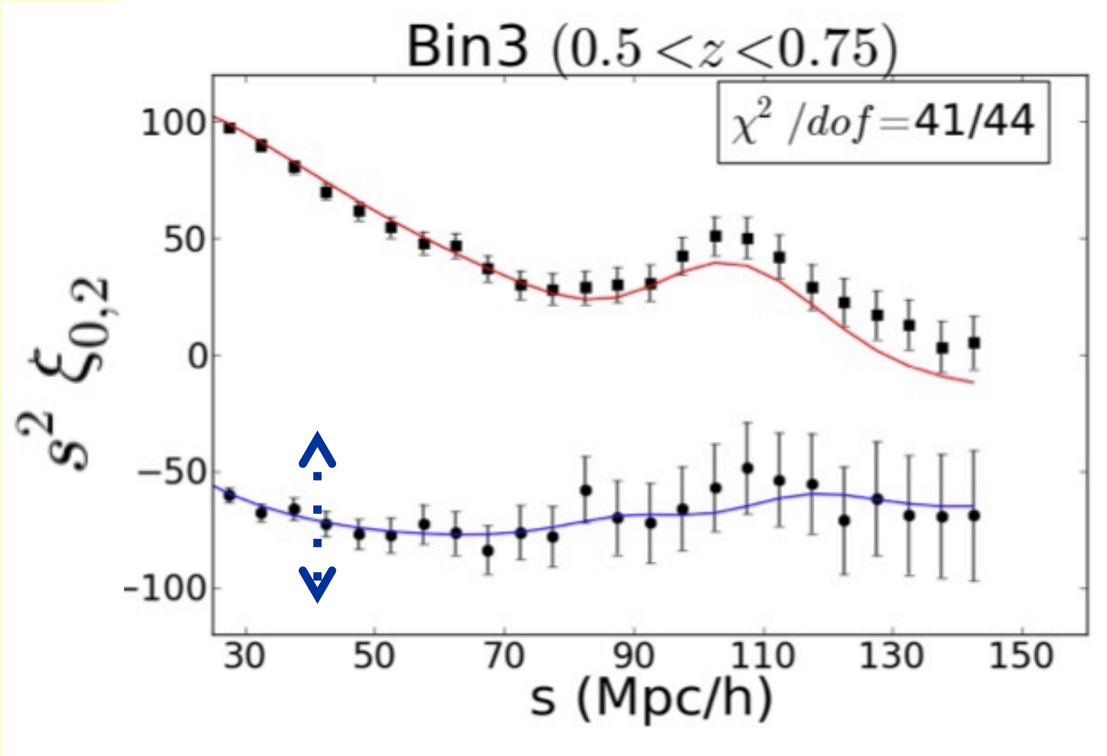
S. Alam et al., 2017, MNRAS,470, 2617A



BAO scale

... to full shape analysis

S. Satpathy et al., 2017, MNRAS, 469, 1369S



quadrupole amplitude = gravity strength

requires understanding of matter clustering on small scales (i.e. below BAO scale)

RSD modelling

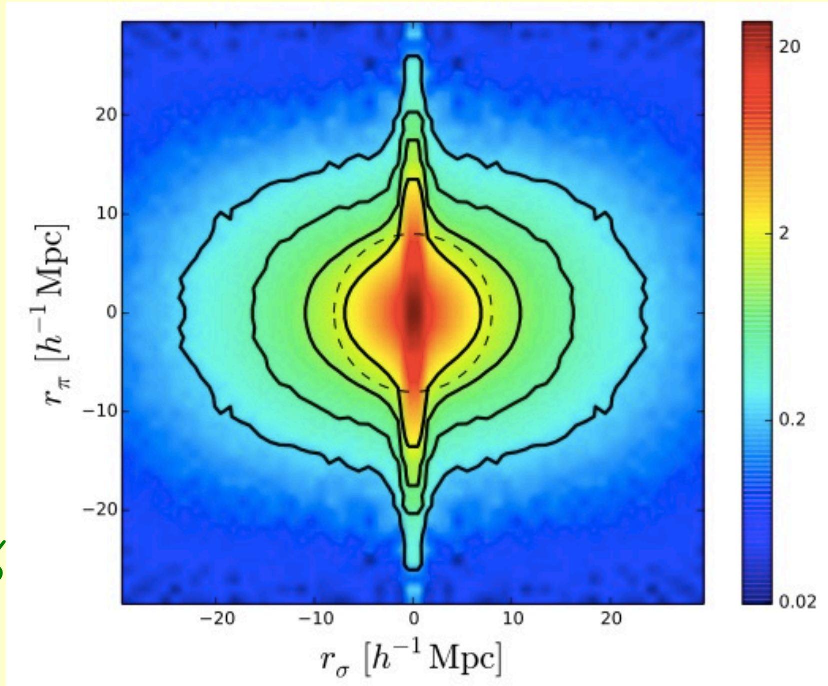
- Taruya, Nishimichi, Saito model (2010) used in BOSS/eBOSS:

$$P_g(k,\mu)=e^{-(fk\mu\sigma_v)^2}\Big[P_{g,\delta\delta}(k)+2f\mu^2P_{g,\delta\theta}(k)+f^2\mu^4P_{\theta\theta}(k)+b^3A(k,\mu,f)+b^4B(k,\mu,f)\Big]$$

Finger of God effect (incoherent velocities) $r_\sigma \ll 8h^{-1}$Mpc

Kaiser effect (large scale infall velocities) $r > 8h^{-1}$Mpc

TNS corrections



B. Reid et al., 2014, MNRAS,444..476R

- with:

$\mu \equiv \cos(\vec{k},\vec{u}_{los})$

$\sigma_v^2 \equiv \langle v_{los}^2 \rangle$

δ,θ *density, velocity*

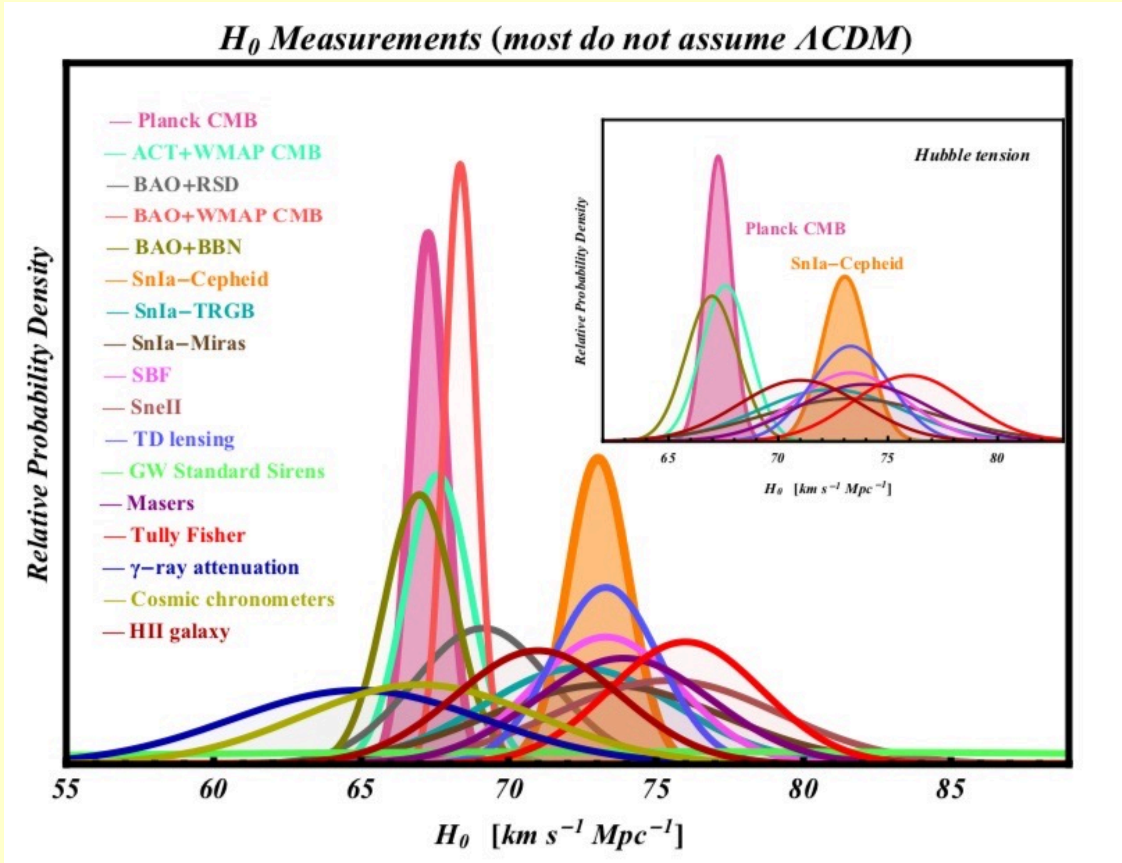
- and:

$P_{g,\delta\delta}, P_{g,\delta\theta} \xleftrightarrow{\text{bias model}} P_{\delta\delta}, P_{\delta\theta}$

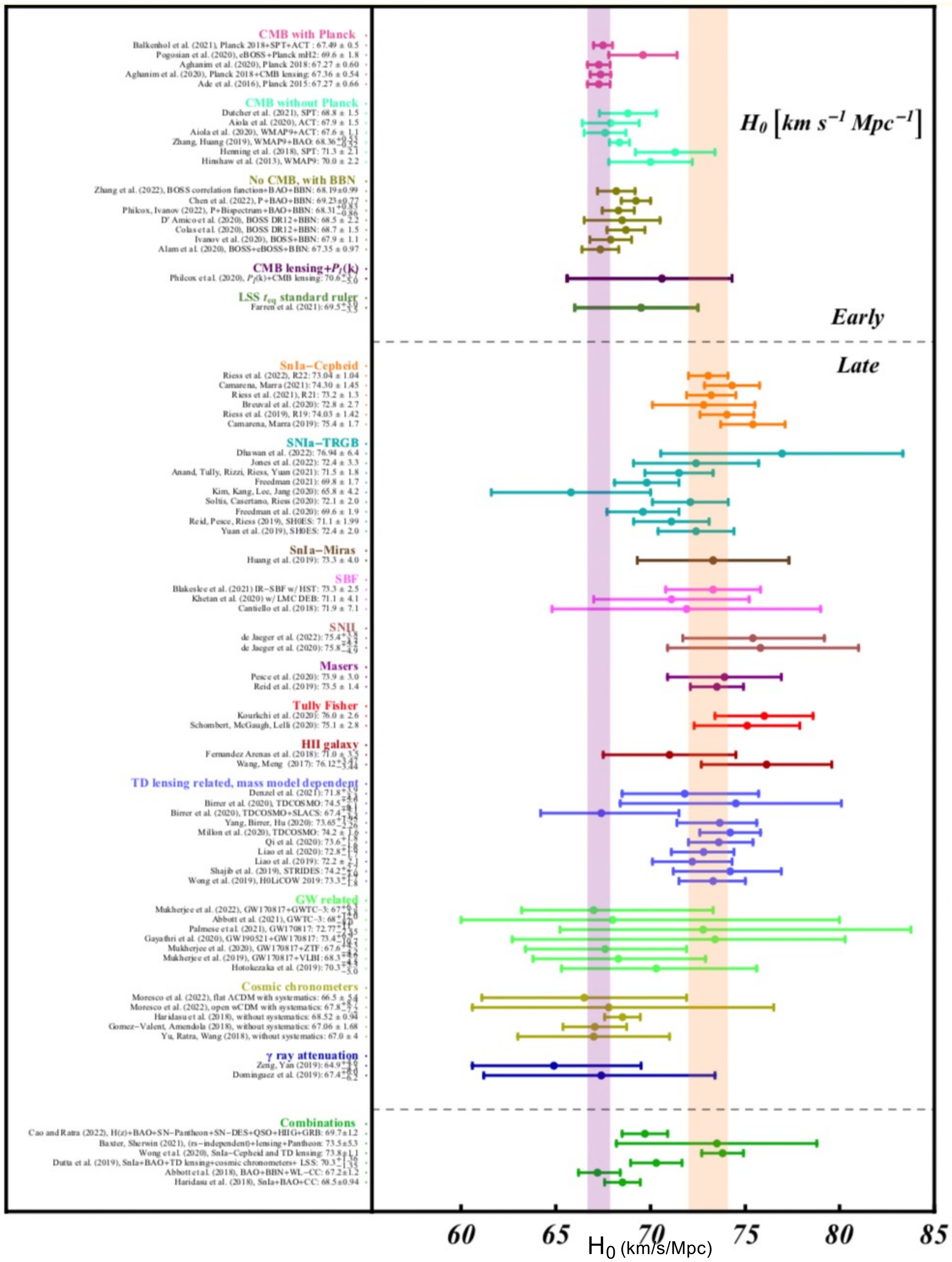
$P_{\delta\delta}, P_{\delta\theta}, P_{\theta\theta}, A, B$: 2-loop PT

H_0 Recap

- local H_0 measurement $\neq$ H_0 constraints using early Universe data (BBN, CMB)
- No systematic uncertainty obviously missed in either method
- Hint for non standard pre-decoupling physics ? (e.g. early dark energy)
- Need for independent measurements (TRGB calibration of SNeIa, time delay cosmography, masers in the Hubble flow, GW standard sirens) and well controlled ones

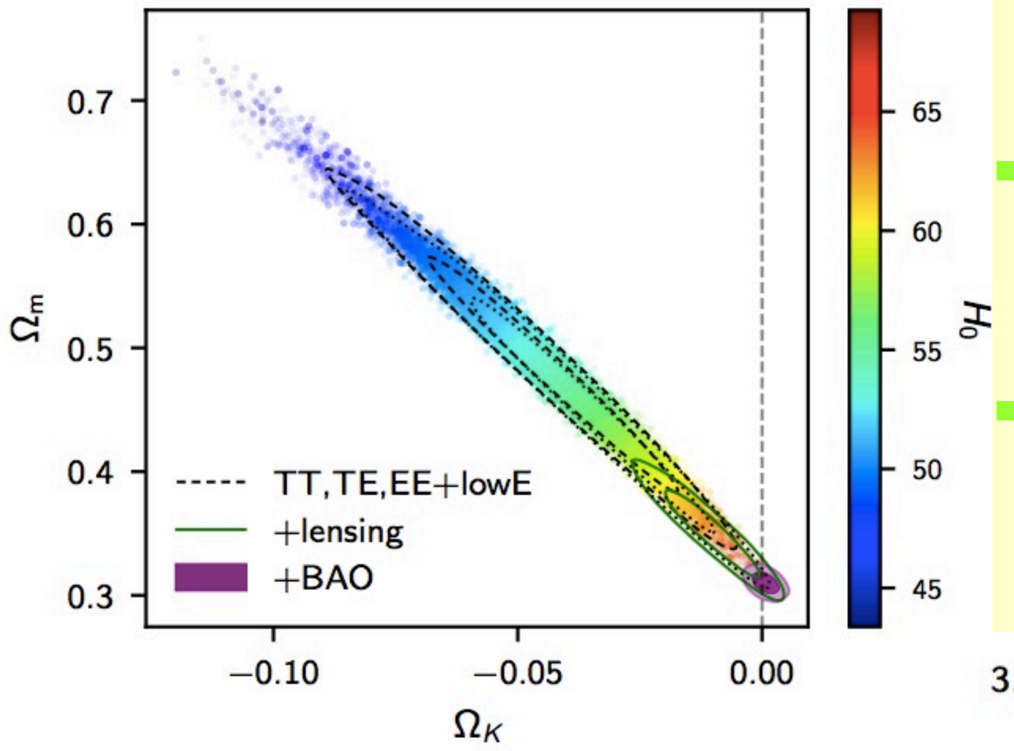


L.Perivolaropoulos & F.Skara, arXiv:2105.05208



H_0 measurements

- Compilation of *L.Perivolaropoulos & F.Skara, arXiv:2105.05208*



Λ_{CDM}

Planck Collaboration, A&A 641 (2020) A6

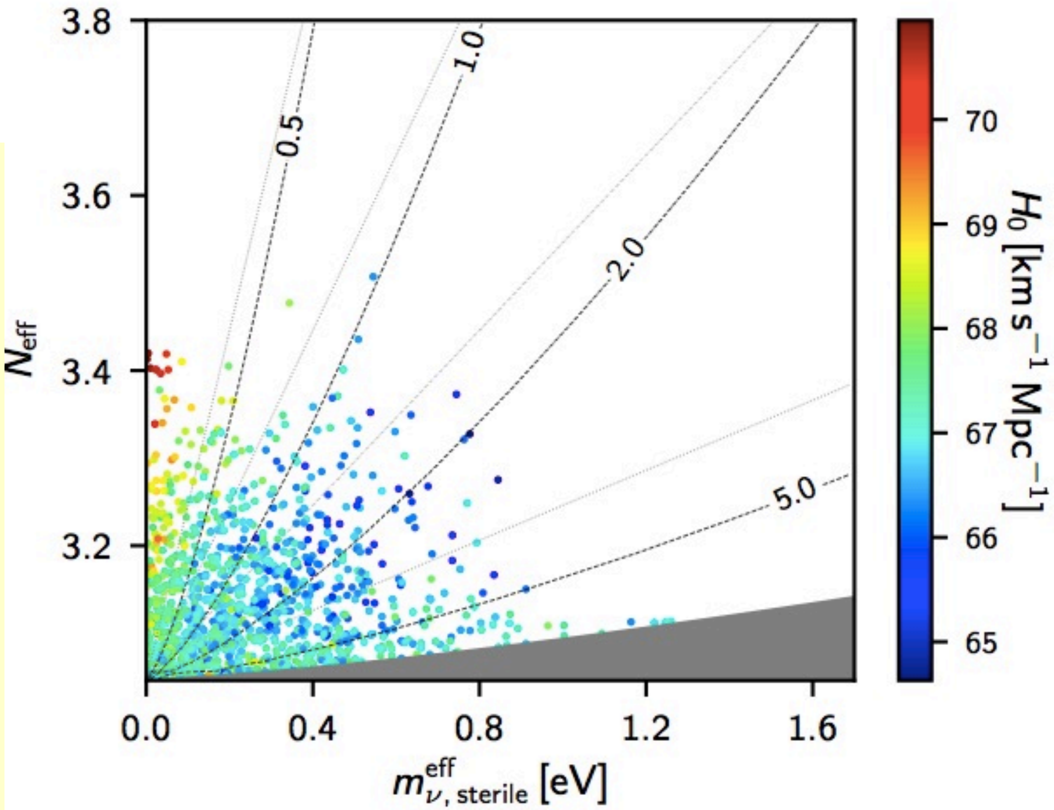
- our Universe is spatially flat to a 1σ accuracy of 0.2%
- matter accounts for 30% of energy budget, dark energy required

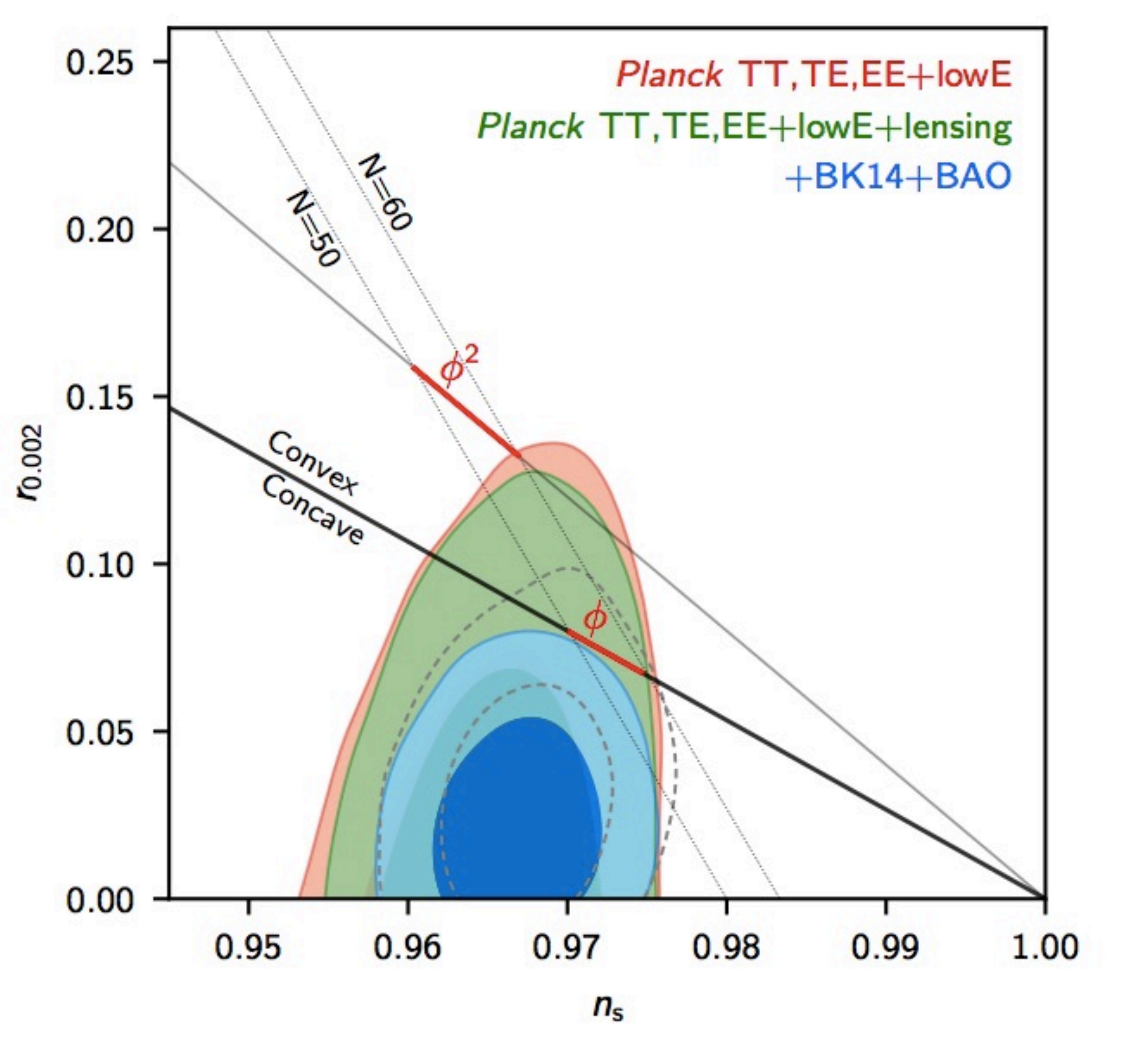
Λ_{CDM}+N_{eff}+$m_{\nu,sterile}$(<10eV)

$N_{eff} \leq 3.29 \quad m^{eff}_{\nu,sterile} \leq 0.23eV$

(95%CL)

- one thermalized sterile ν (short baseline anomaly) excluded at 6σ (any mass)





$\Lambda_{CDM}+r_{0.002}$

$r_{0.002} \leq 0.065$ (95%CL)

$n_s = 0.9670 \pm 0.0037$

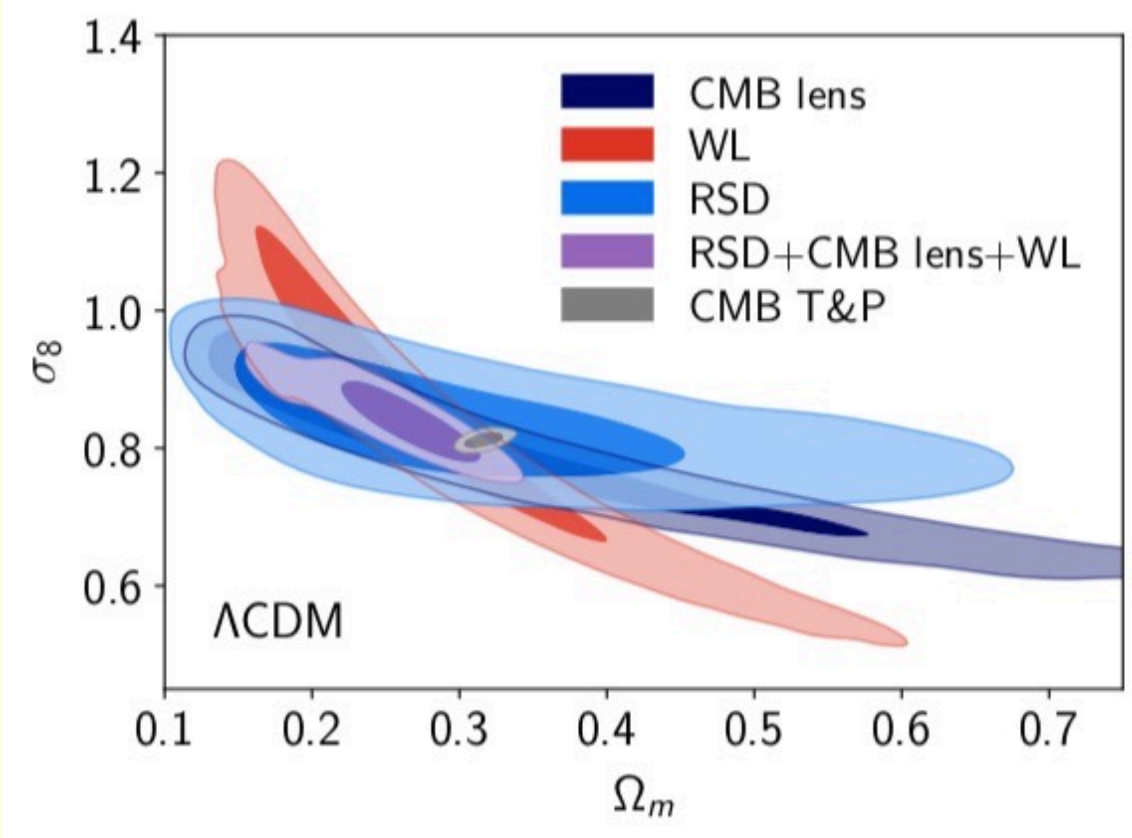
Planck Collaboration, arXiv:1807.06209

- All convex inflation potentials excluded at the 95% CL

Cosmological constraints from SDSS final paper

ΛCDM

- RSD data agree with CMB lensing and WL
  (from DES-Y1 3x2pt)
- the combined constraint agrees with CMB (wo lensing)
- This remains true for other models
  (e.g. open w_0w_aCDM)

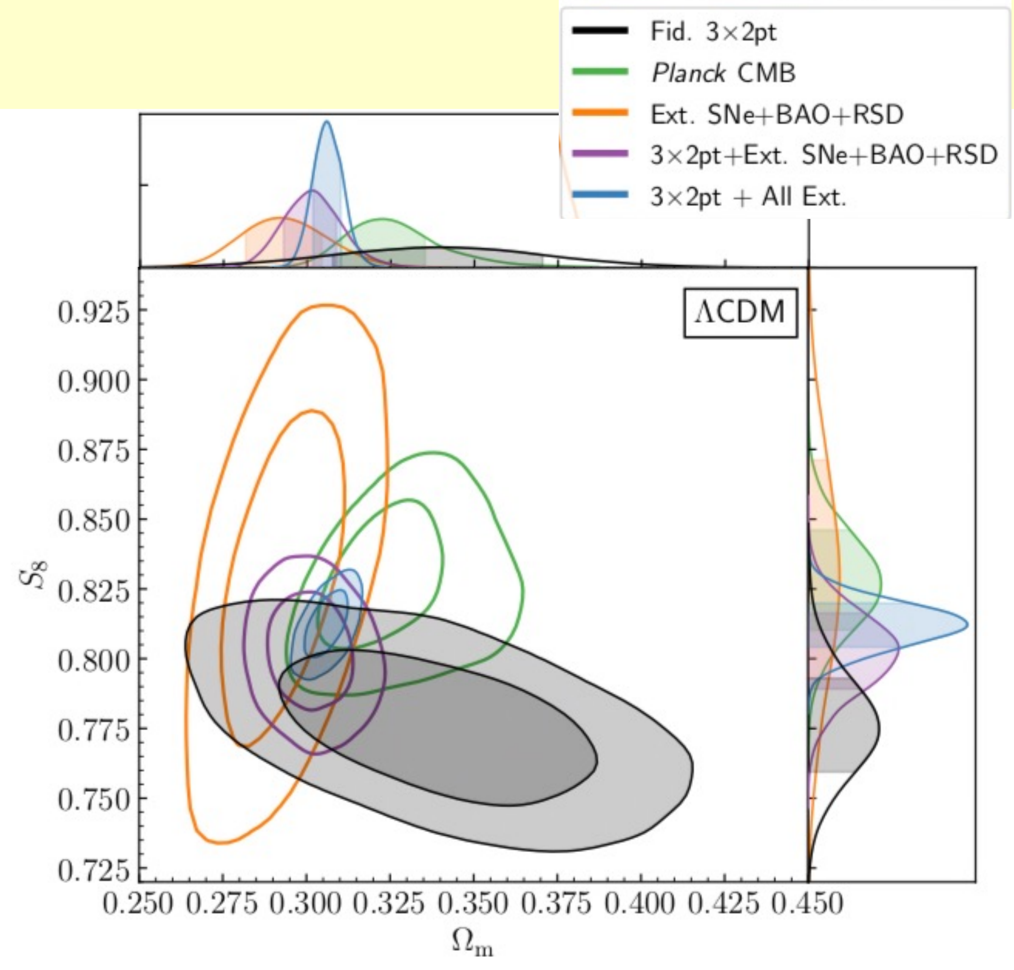


Alam et al, PRD 103 (2021) 083533

Cosmological constraints from DES Y3 clustering +WL paper

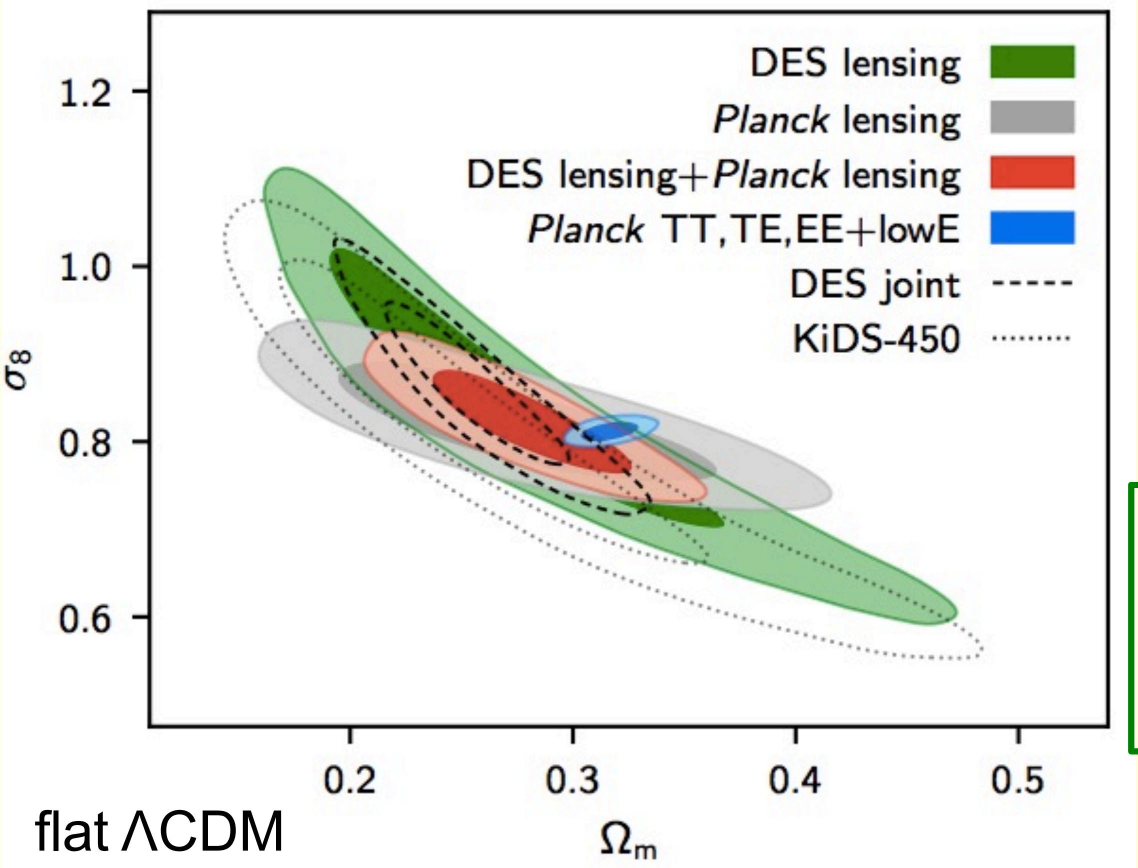
ΛCDM

- WL (3x2pt) data agree with CMB (wo lensing) and external data (SNe,BAO,RSD)
- Revised Y3 analyses (wrt blinded fiducial one) due to unexpected disagreement between clustering and lensing amplitudes
- Coherent comparison with other WL surveys (KiDS, HSC) yet to be done



$$S_8 \equiv \sigma_8 (\Omega_m / 0.3)^{0.5}$$

Abbott et al, PRD 105 (2022) 023520



DES-Y1 vs CMB

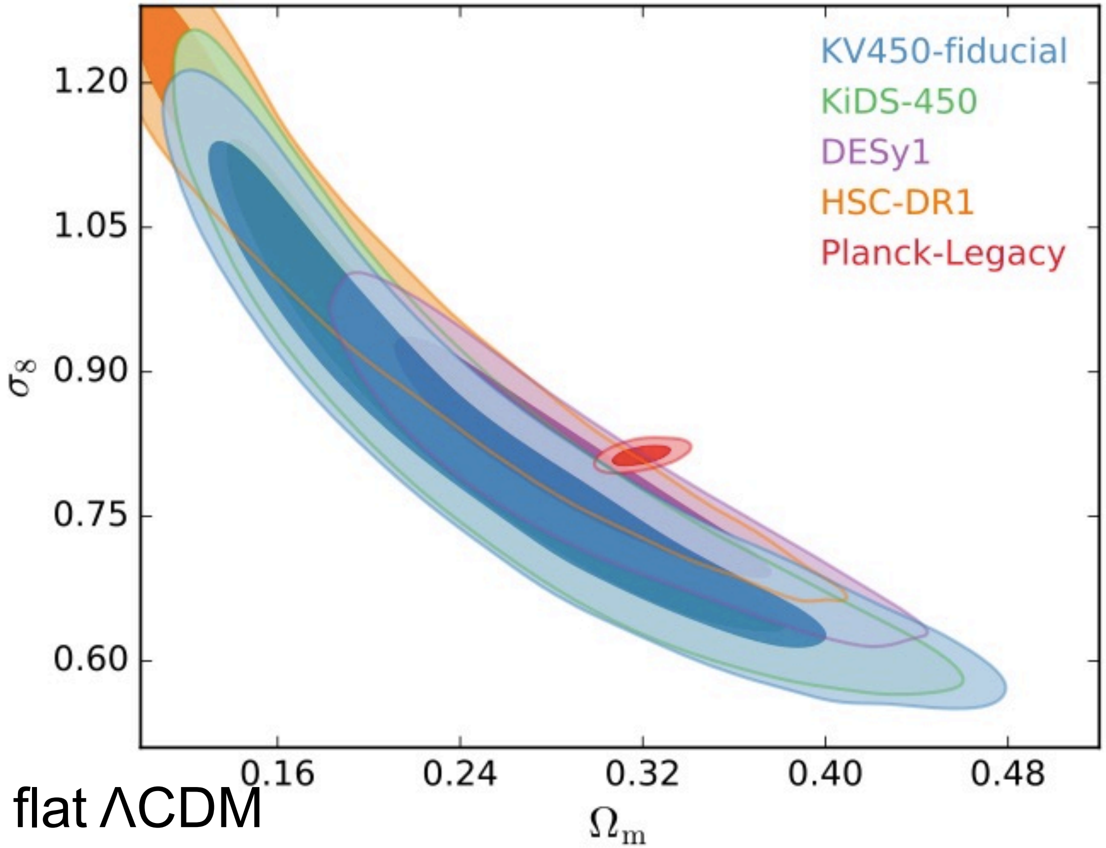
Planck Collaboration, arXiv:1807.06209

Note: DES-Y1 values slightly updated in final Planck paper

	Planck all	***DES all***
S_8	0.832±0.013	0.792±0.024
Ω_m	0.315±0.007	$0.257^{+0.023}_{-0.031}$

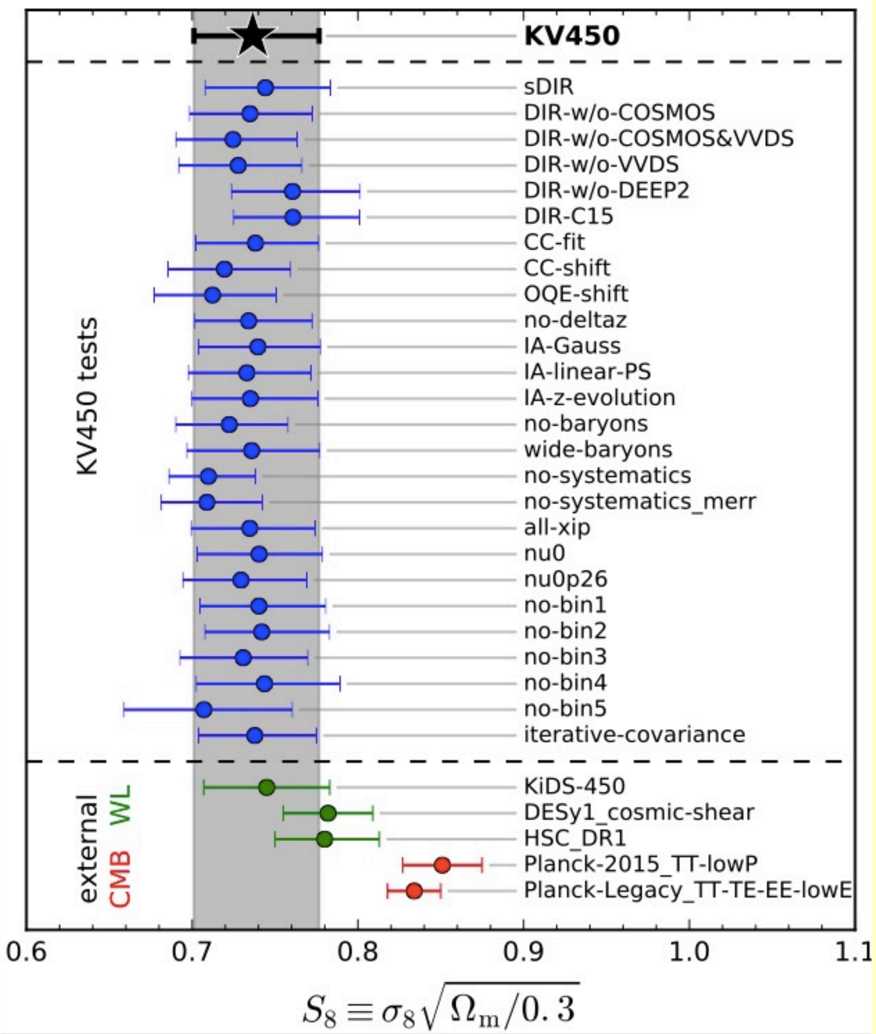
with $S_8 \equiv \sigma_8 (\Omega_m / 0.3)^{0.5}$

- Lensing from DES (& other WL surveys) agree with CMB lensing.
- Mild tension (2σ) between lensing and Planck T&E constraints: can Λ_{CDM} reconcile measurements of high redshift (linear) perturbations and low redshift (non linear) clustering ?
- Same trend with cluster data. More (precise) data needed for a conclusive evidence. See DES-Y3



KiDS-VIKING-450

H.Hildebrandt et al, arXiv:1812.06076



- 9 band imaging (optical+NIR)

⇒ robust source photo-z calibration

⇒ no hint of residual systematics

- 2.3σ discrepancy with Planck-2018
- S_8 increase with calibration based on COSMOS-15 photo-z ctlg: artificial (outliers) ? Could impact DES & HSC

WL Summary

- weak lensing probes total matter distribution (so no need for a bias model) ⇒constrains geometry & growth rate
- tiny signal means tight constraints on survey design & analysis to control systematics (PSF control, unbiased photometric redshifts, non-linear predictions, mitigation of residual systematic effects….)

  systematics in shear measurements & photo-z bias must be < 1%
- many observables & statistics (shear & convergence, 2-pt statistics and derived functions, tomography, shear peak counts, higher order stat. ….)
- combination with clustering and galaxy-galaxy lensing : very helpful to constrain part of WL systematics (self-calibration)
- status (end 2019):
  - uncertainty on S_8 : stat $\gtrapprox$ syst
  - mild (2σ) tension between WL and CMB data (without lensing)
  - WL does not add much yet to current dark energy constraints