A Precise Measurement of H_0 from DES, BAO, and BBN

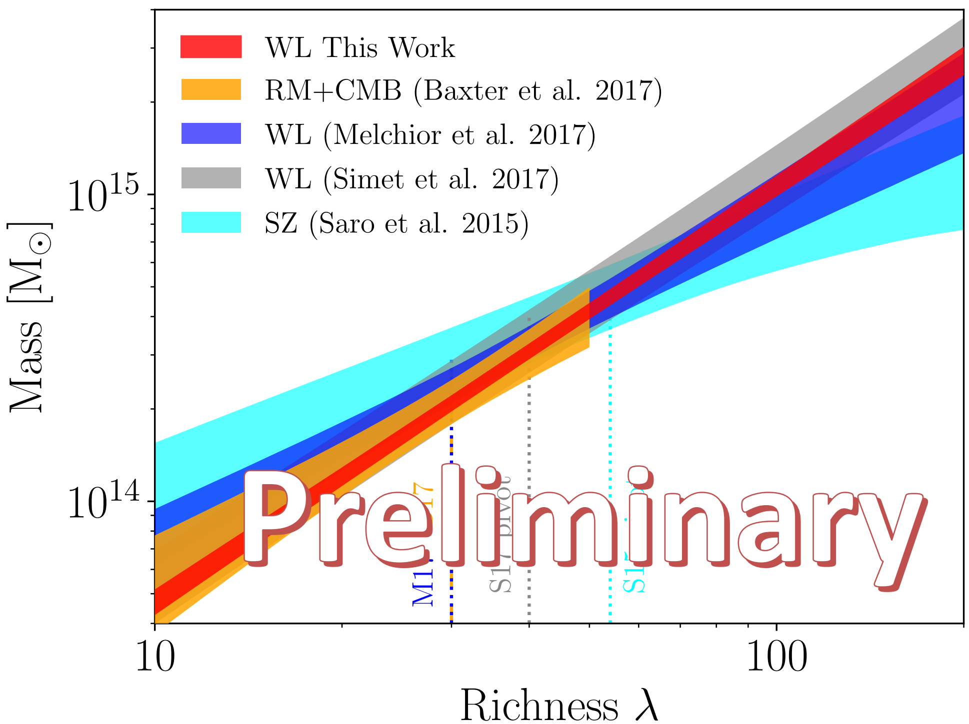
Eduardo Rozo, University of Arizona

On behalf of the Dark Energy Survey Collaboration

Statistical challenges for large scale structure in the era of LSST

What I Won't Be Talking About

Mass calibration of the DES redMaPPer cluster catalogue.



Tom McClintock

Tamas Varga

4% systematic uncertainty

McClintock et al, on arxiv in ~2 weeks.

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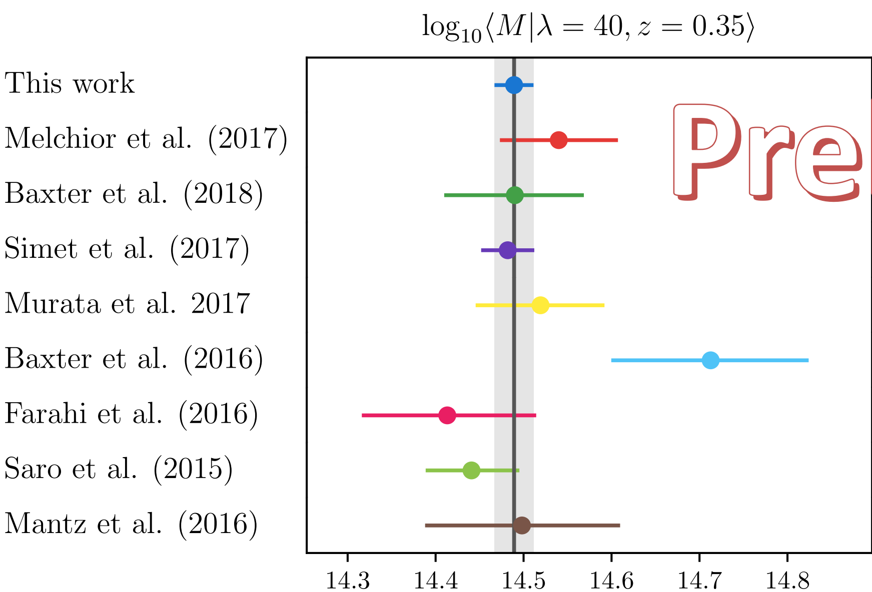
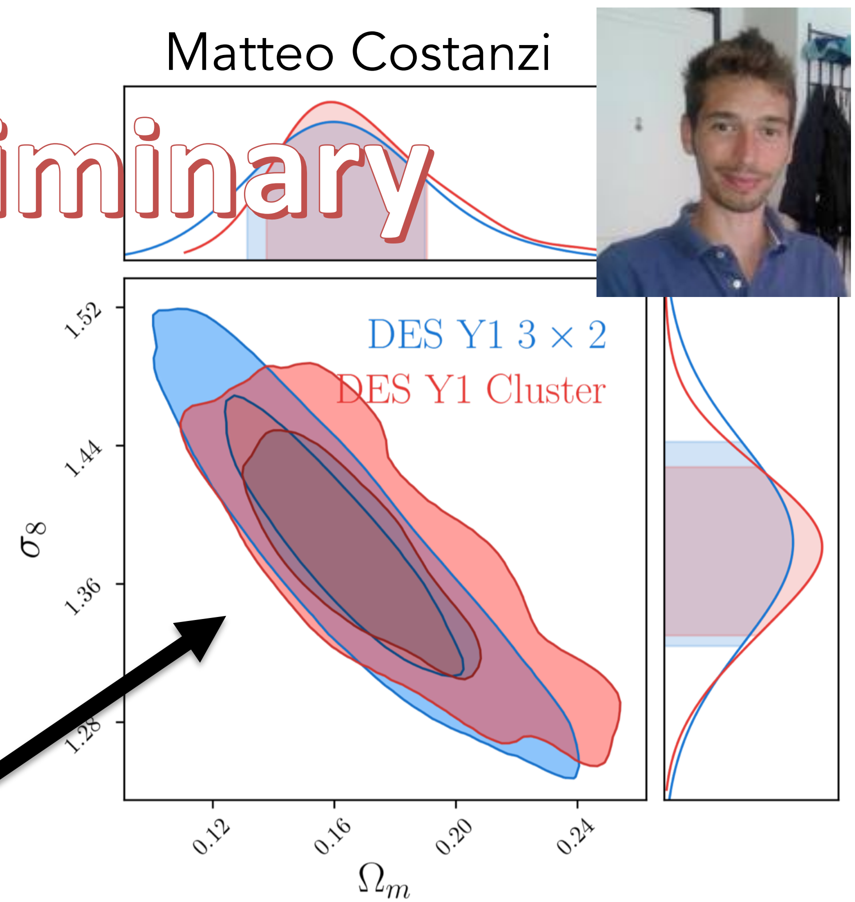


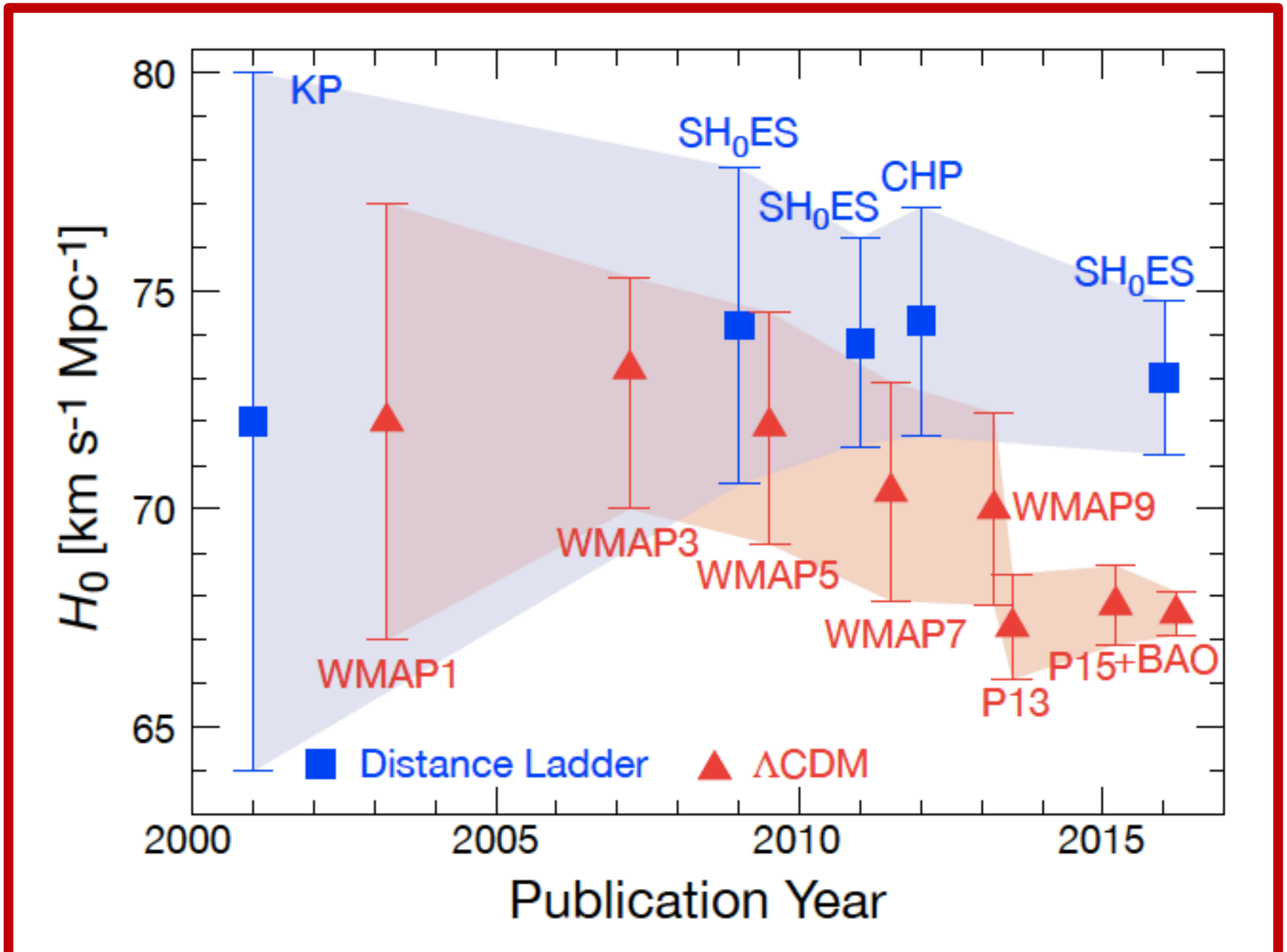
Matteo Costanzi



Blinded cosmology

A Precise Measurement of H_0 from DES, BAO, and BBN

The Hubble Constant Problem



Freedman 2017.

Why It Matters

Observing Dark Energy
ASP Conference Series, Vol. 339, 2005
Sidney C. Wolff and Tod R. Lauer

Dark Energy Probes in Light of the CMB

Wayne Hu

"The single most important complement to the CMB for measuring the dark energy equation of state at $z \sim 0.5$ is a determination of the Hubble constant to better than a few percent."

Basic idea:

- In flat LCDM, CMB already constrains all cosmological parameters.
- CMB accurately predicts both the expansion history and growth of large scale structure.
- Deviations in any of these observables can provide evidence of dark energy.
- H_0 is the cosmological parameter that varies the most as we vary dark energy while holding the CMB fixed.

H_0 constraints are especially powerful probes of dark energy!

An Under-appreciated Fact

In a flat LCDM model,

BAO+BBN + (any probe of Ω_m)

=

Hubble constant measurement

DES+BAO+BBN results in a very clean measurement of H!

Though see Aubourg et al. 2015.

A Precise Measurement of H_0 from DES+BAO+BBN

The BAO Story I Usually Hear

BAO = Baryon Acoustic Oscillations

- The CMB measures the sound horizon r_s of the photon-baryon fluid in the early Universe.
- This sound horizon is imprinted into the galaxy density today: BAO is a standard ruler calibrated by the CMB.
- With r_s calibrated, we can use BAO to measure $H(z)$ and D_A using BAO observables.

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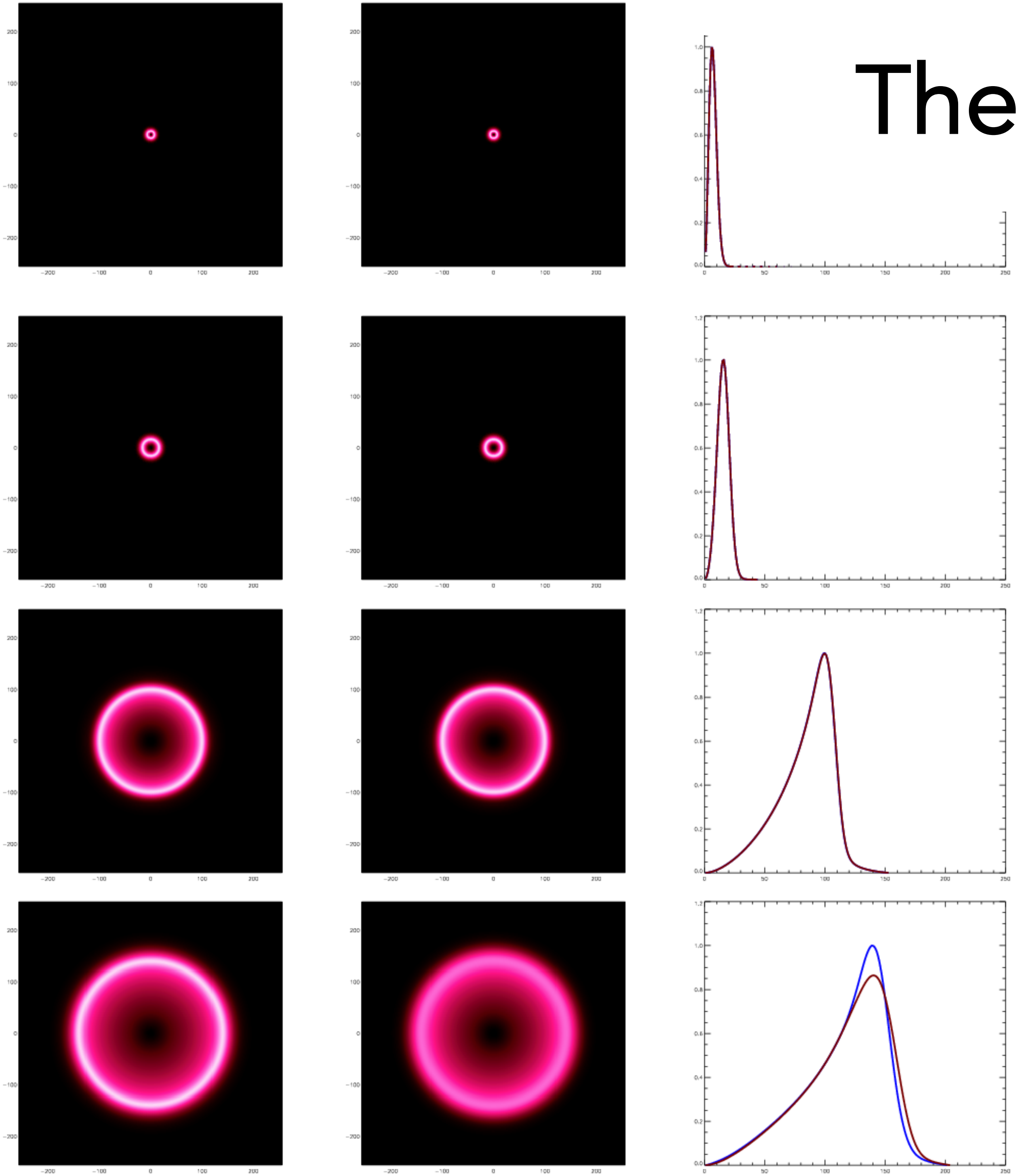
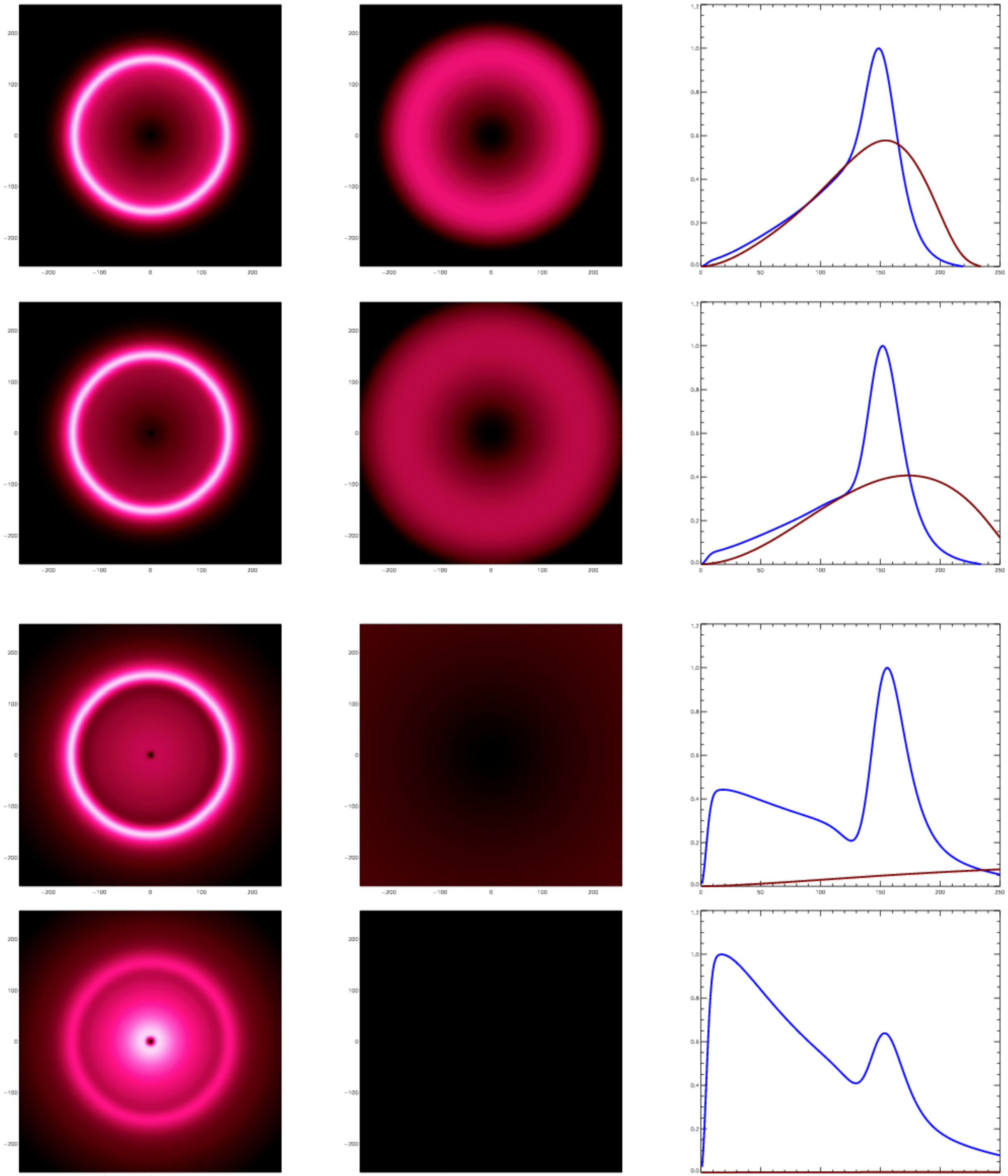
True but incomplete.

The BAO Story



Over/under-densities
launch density waves.

After decoupling, pressure goes to zero, and so the waves stall.



Gravitational accretion preserves the density peak from the stalled waves in the dark matter.

What Does BAO Measure?

The sound horizon scale is imprinted into the galaxy density distribution.

What is r_s?

$r_s = c_s t$

c_s = sound speed = $\sqrt{\delta P/\delta\rho}$
t = time to recombination

P depends T_{CMB}
ρ depends on T_{CMB} and $\Omega_b h^2$
t depends on T_{CMB}, $\Omega_m h^2$. :: assumes no early DE.

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Parameters: $\Omega_b h^2, \Omega_m h^2$

BAO Observables

We don't measure distances. We measure:

- angles: $\theta_s = r_s/D_A$
- redshift intervals: $\Delta z = H(z)r_s/c$.

H(z) depends on: H_0 (h), $\Omega_m h^2$.

D_A is an integral over H(z).

Parameters: $\Omega_b h^2, \Omega_m h^2, h$

Bottom Line

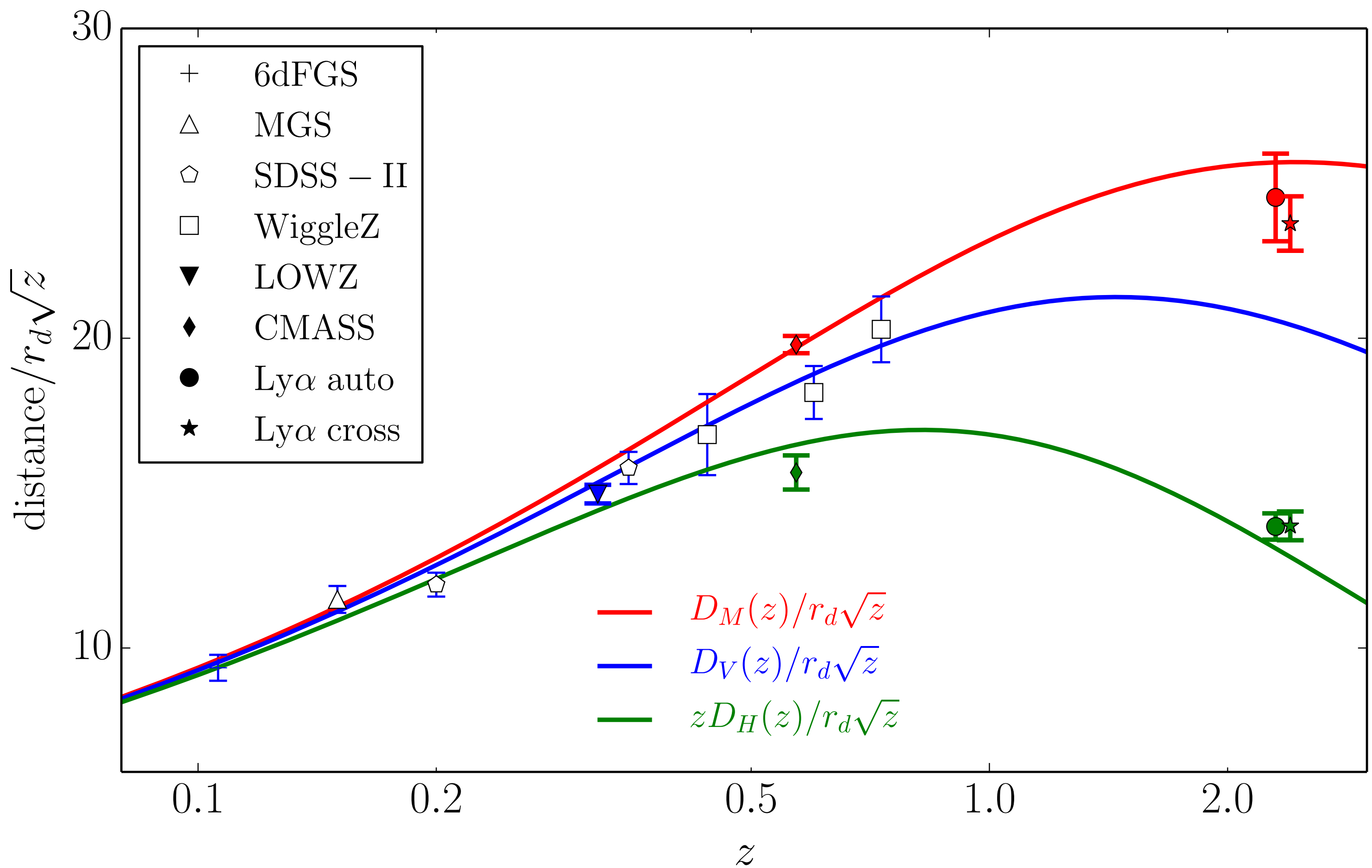
A single BAO measurements is degenerate in $\Omega_b h^2$, Ω_m, h.

$\Omega_b h^2$: BBN measures this number

Ω_m: DES measures this number

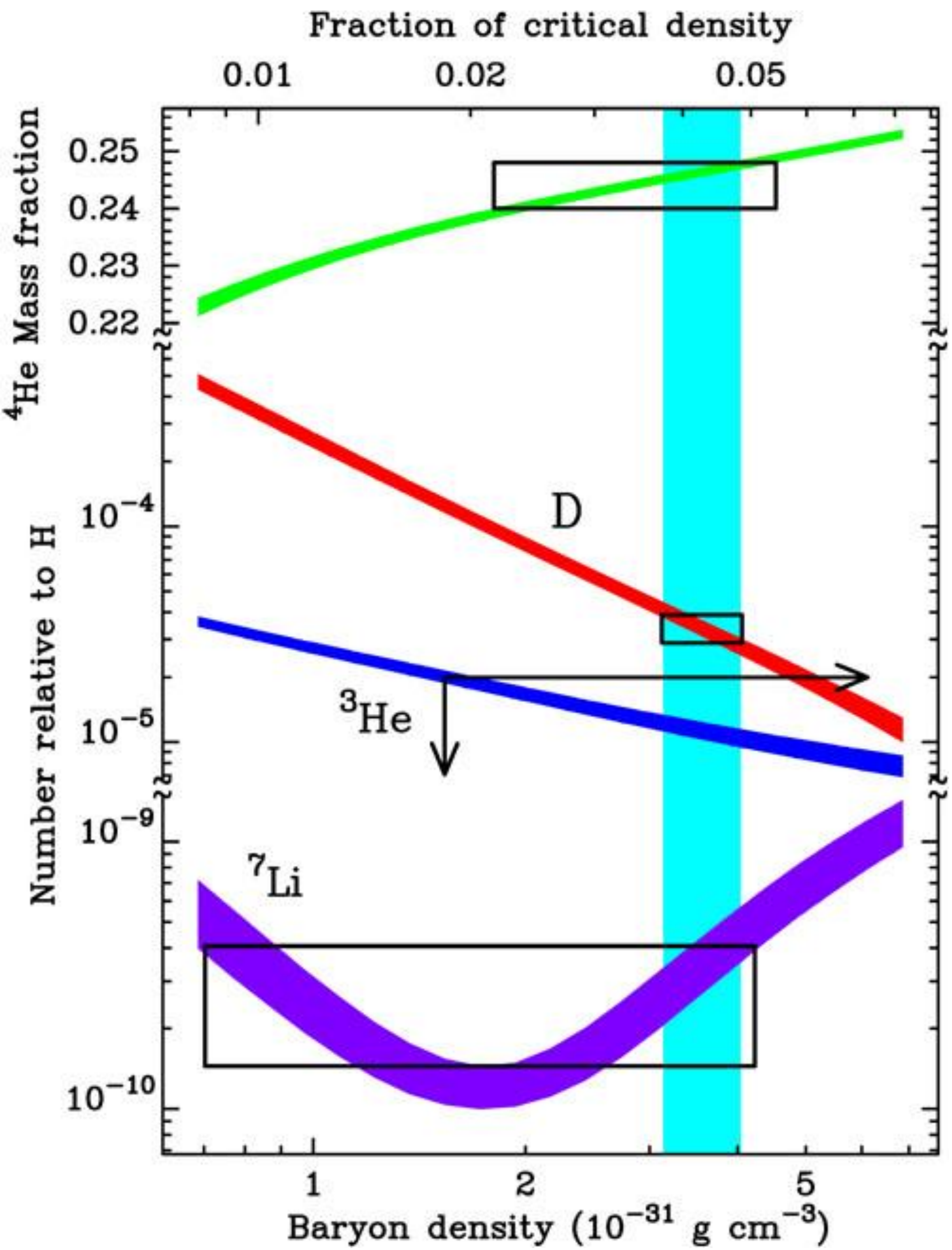
DES+BAO+BBN can measure *h*!

BAO Measurement



Aubourg et al. 2015

Big Bang Nucleosynthesis



- D burns to produce He.
- More baryons ⟶ faster burn.
- D decreases w/ $\Omega_b h^2$.

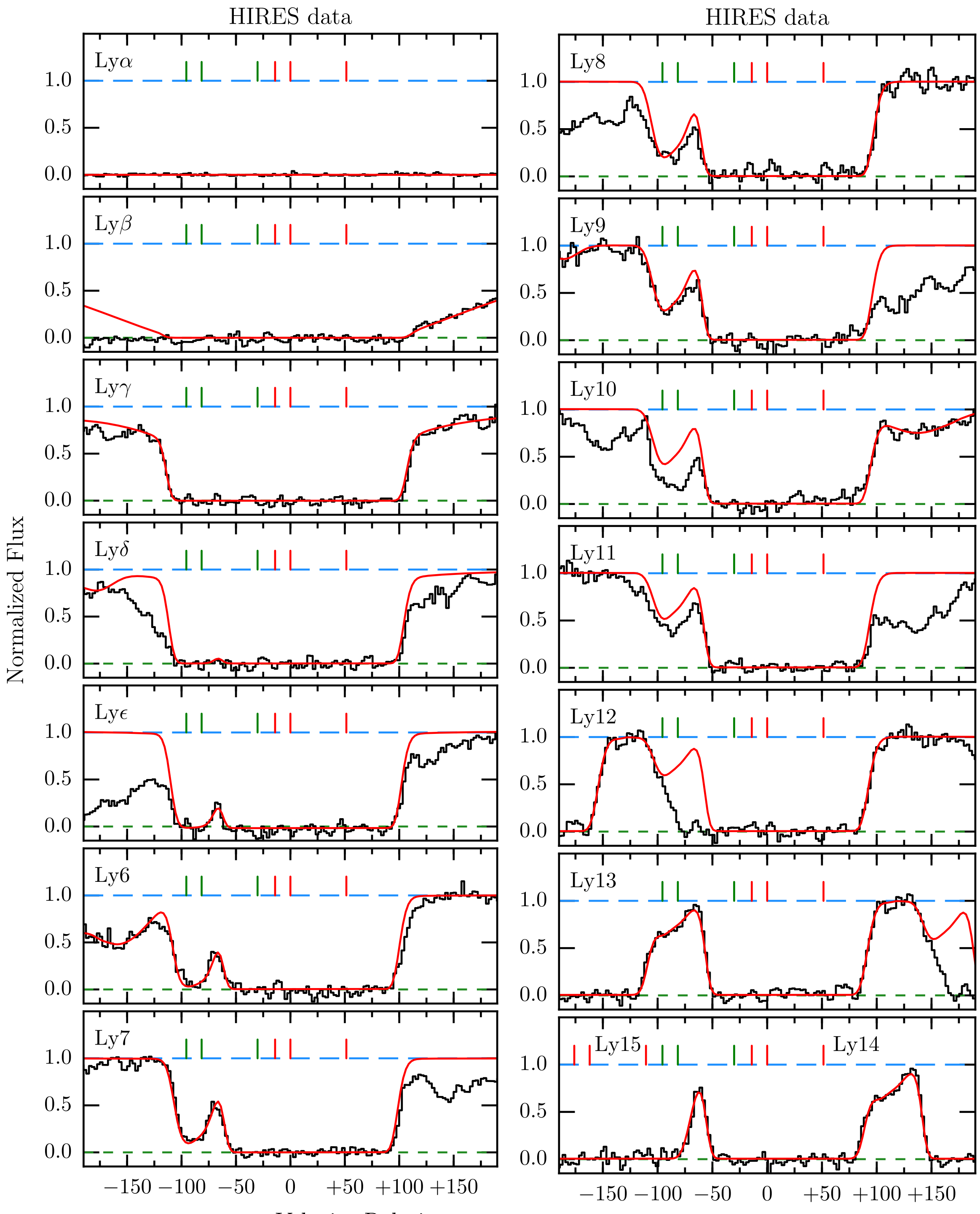
But how to measure?

Burles et al. 2001

Primordial D/H Measurement

- Use quasar absorption spectra
  - simultaneously model D and H absorption
- Look for low-metallicity lines of sight
  - Ensures pristine primordial abundances
- Look for damped Ly-α systems.
  - Lots and lots of D and H means high S/N
  - Can model several absorption lines simultaneously!

Cook et al. 2016



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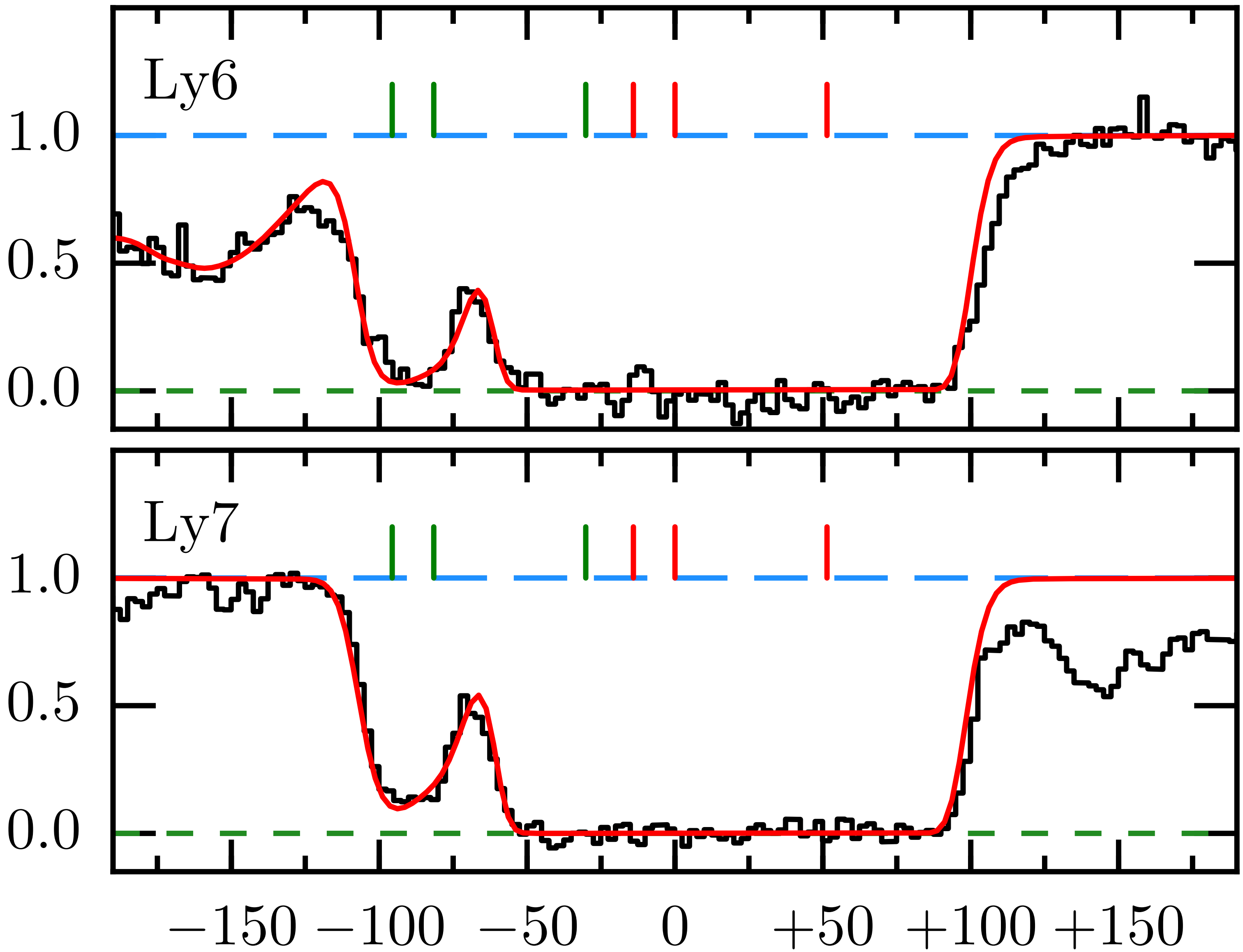


Cook et al. 2016

BBN Constraints

- $\Omega_b h^2$ = (2.208 ± 0.052) x 10^{-2}

- Dominant error:

  - uncertainty in the d(p,γ)^{3}He rate.

  - ongoing experimental efforts to better constrain this rate.

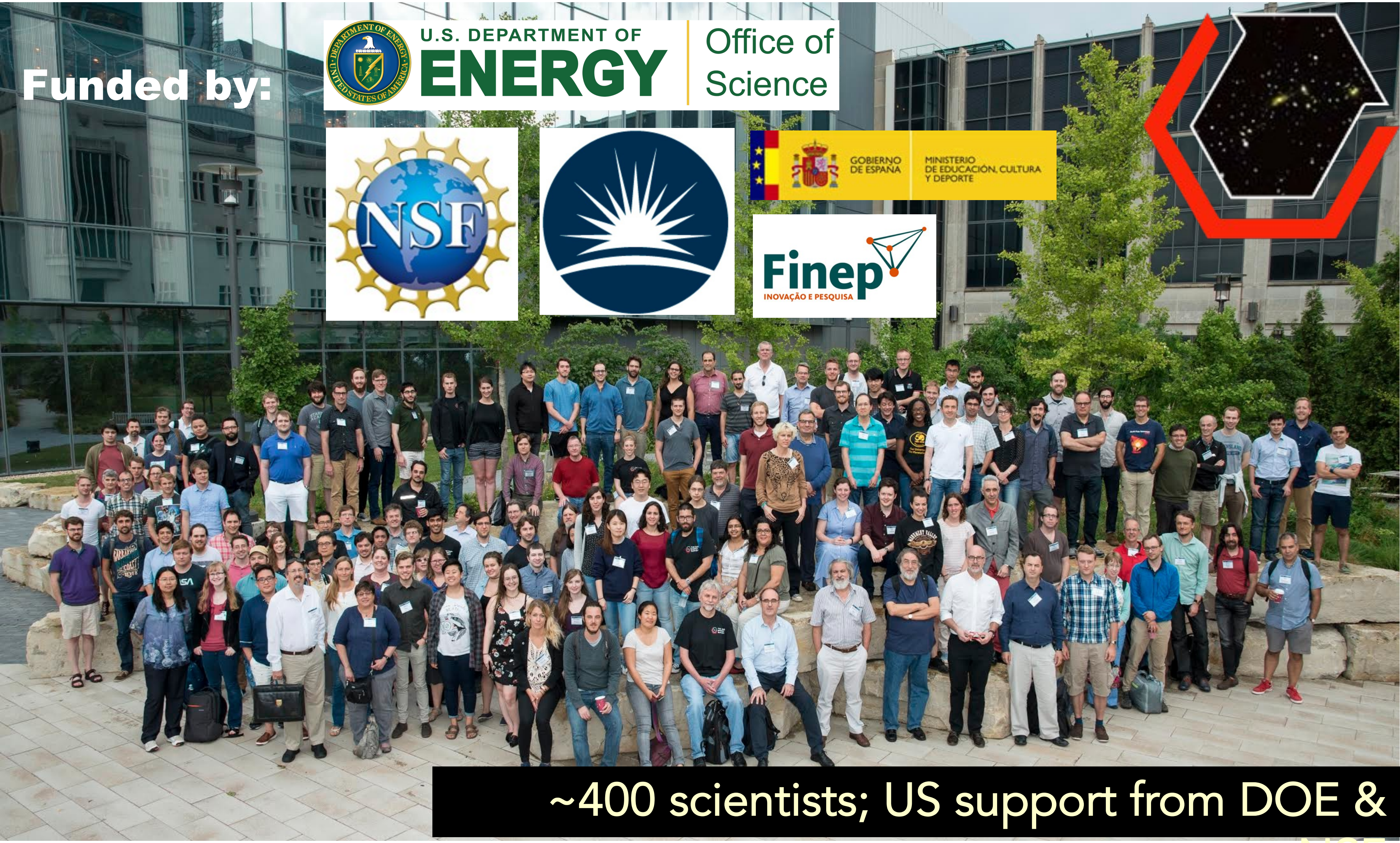
- BBN uncertainty is easily sub-dominant for our analysis.

Dark Energy Survey

Credit: Bjoern Soergel

Funded by:

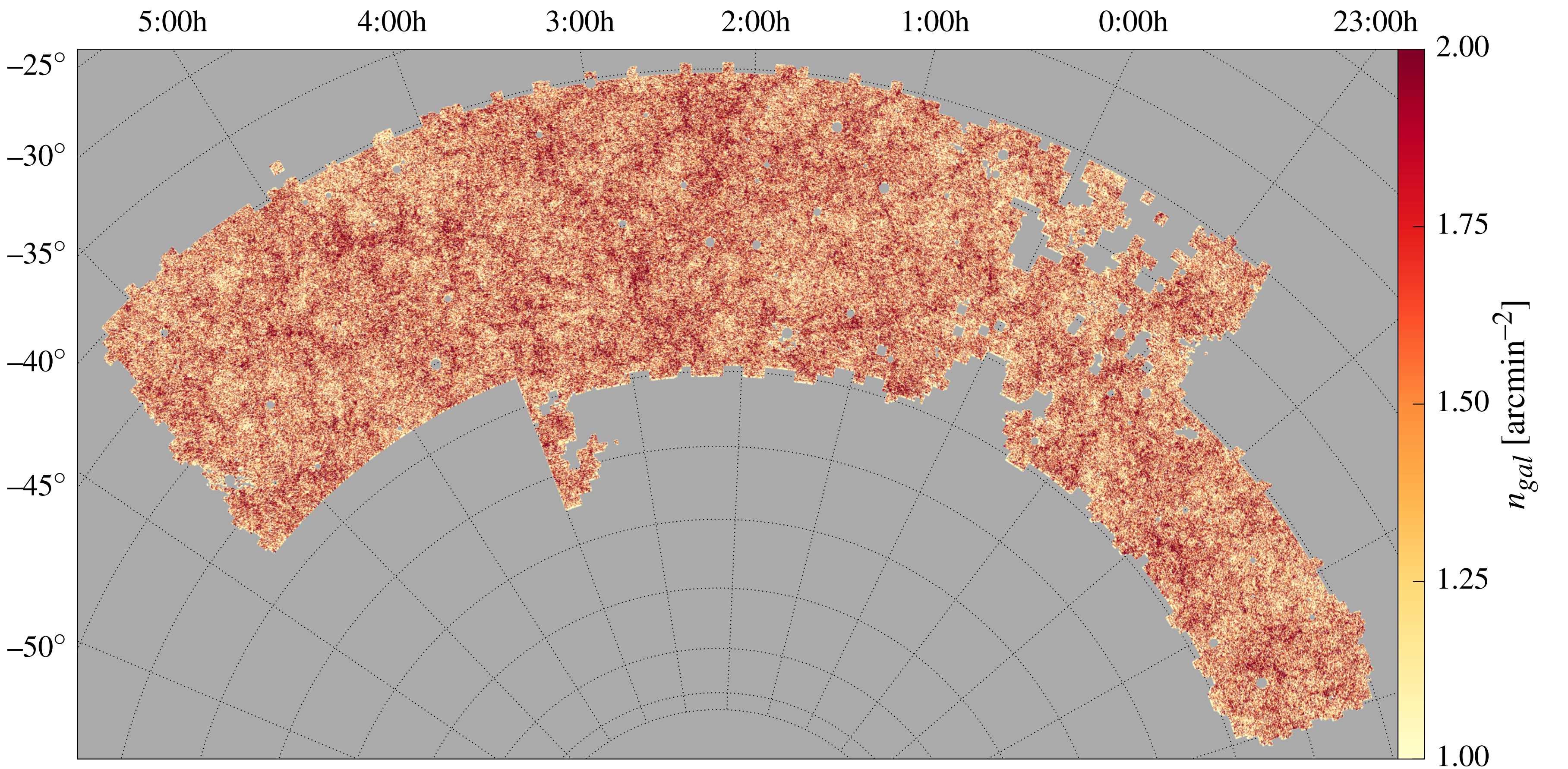
U.S. DEPARTMENT OF ENERGY | Office of Science



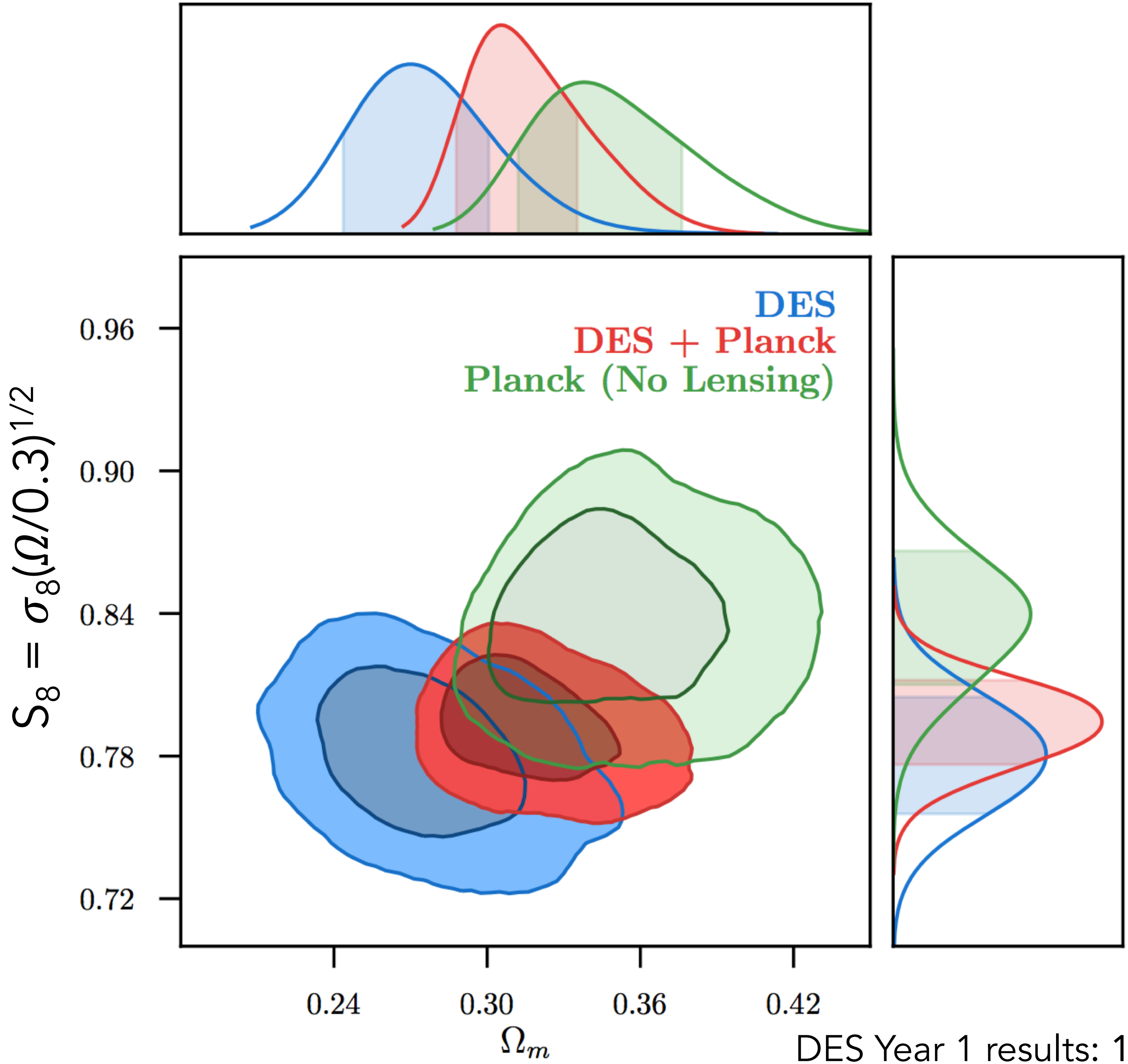
~400 scientists; US support from DOE & NSF

Collaborating institutions:

DES Y1 Results



Y1 3x2pt analysis: gg-clustering + gg-lensing + cosmic shear

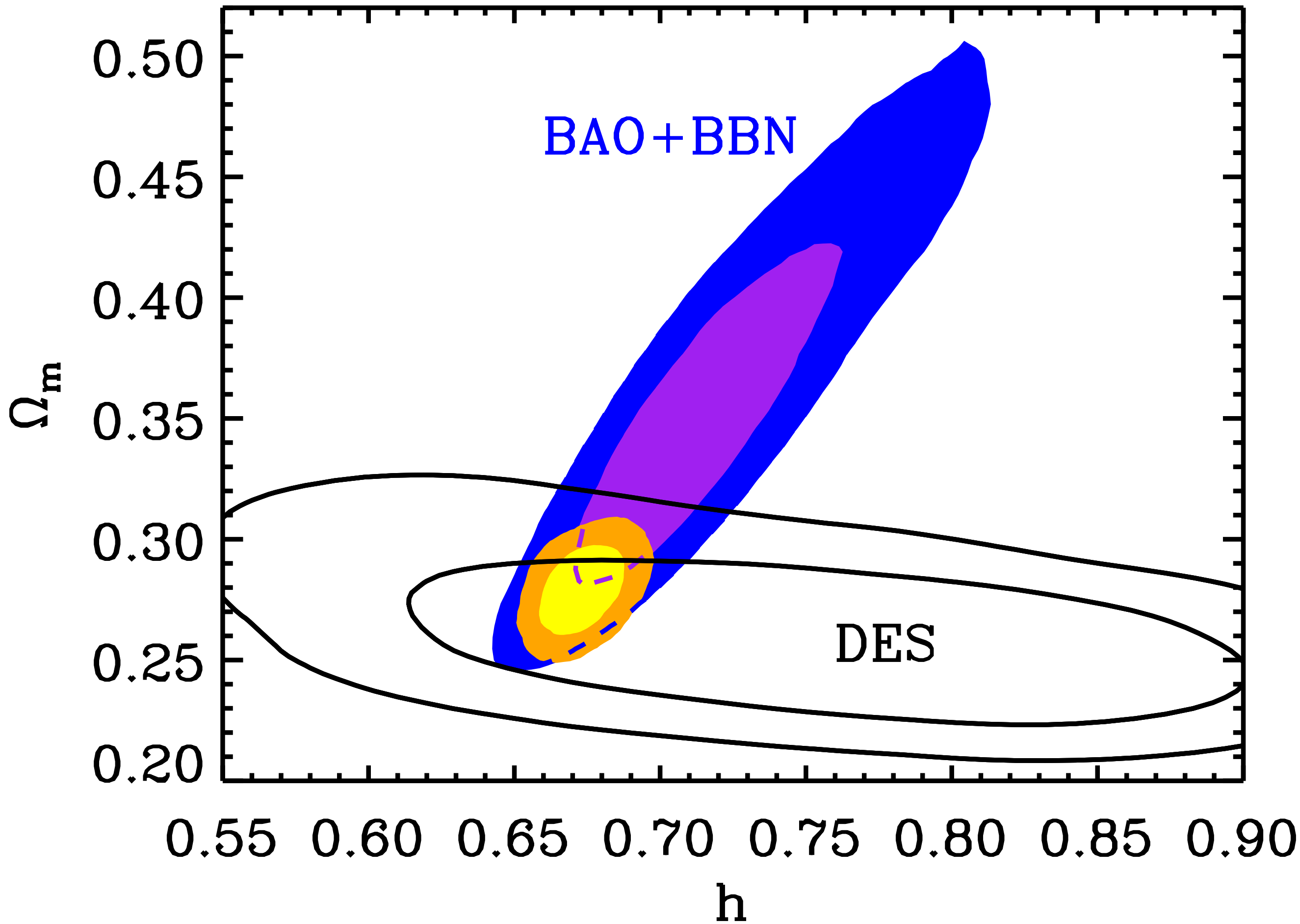


DES Year 1 results: 1708.01530

Analysis

- Flat ΛCDM
- Minimal neutrino mass: $\sum m_\nu = 0.06$ eV
- BBN from Cooke et al.
- BAO from BOSS, SDSS main, 2dF, 6dF
- DES Y1 combined probes

$$H_0 = 67.2^{+1.2}_{-1.0}\ \text{km/s/Mpc}$$



Dark Energy Survey Year 1 Results: 1711.00403

Comparison to External Data Sets

Four independent data sets that reach percent level precision:

- *Planck:* TT+low-*l* polarization
- SPTpol: High-*l* polarization
- SH0ES: Distance Ladder (cepheids + SN)
- H0LiCOW Strong lensing

- **Data sets are statistically independent of each other:**
  - **no covariance!**
  - **No shared observational systematics!**

Consistency

Planck: Ω_m, Ω_b, h, σ_8, n_s

SPTpol: Ω_m, Ω_b, h, σ_8, n_s

DES+BAO+BBN: Ω_m, Ω_b, h, σ_8

SH0ES: h

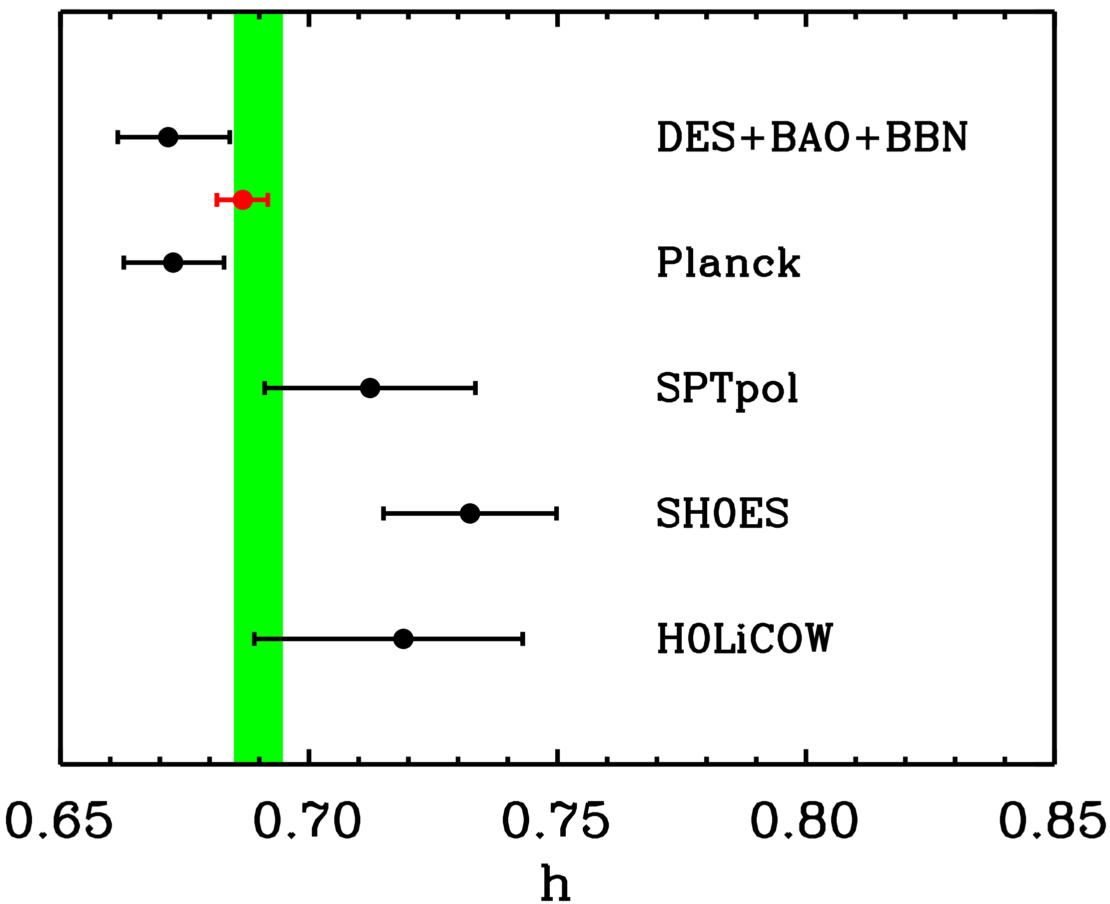
H0LiCOW: h

χ^2/DOF = 20.7/11

Significance: 2.1σ

All data is consistent with flat LCDM model.

DES+BAO+BBN: $H_0 = 67.2^{+1.2}_{-1.0}$ km/s/Mpc



Everything: $H_0 = 69.1^{+0.4}_{-0.6}$ km/s/Mpc

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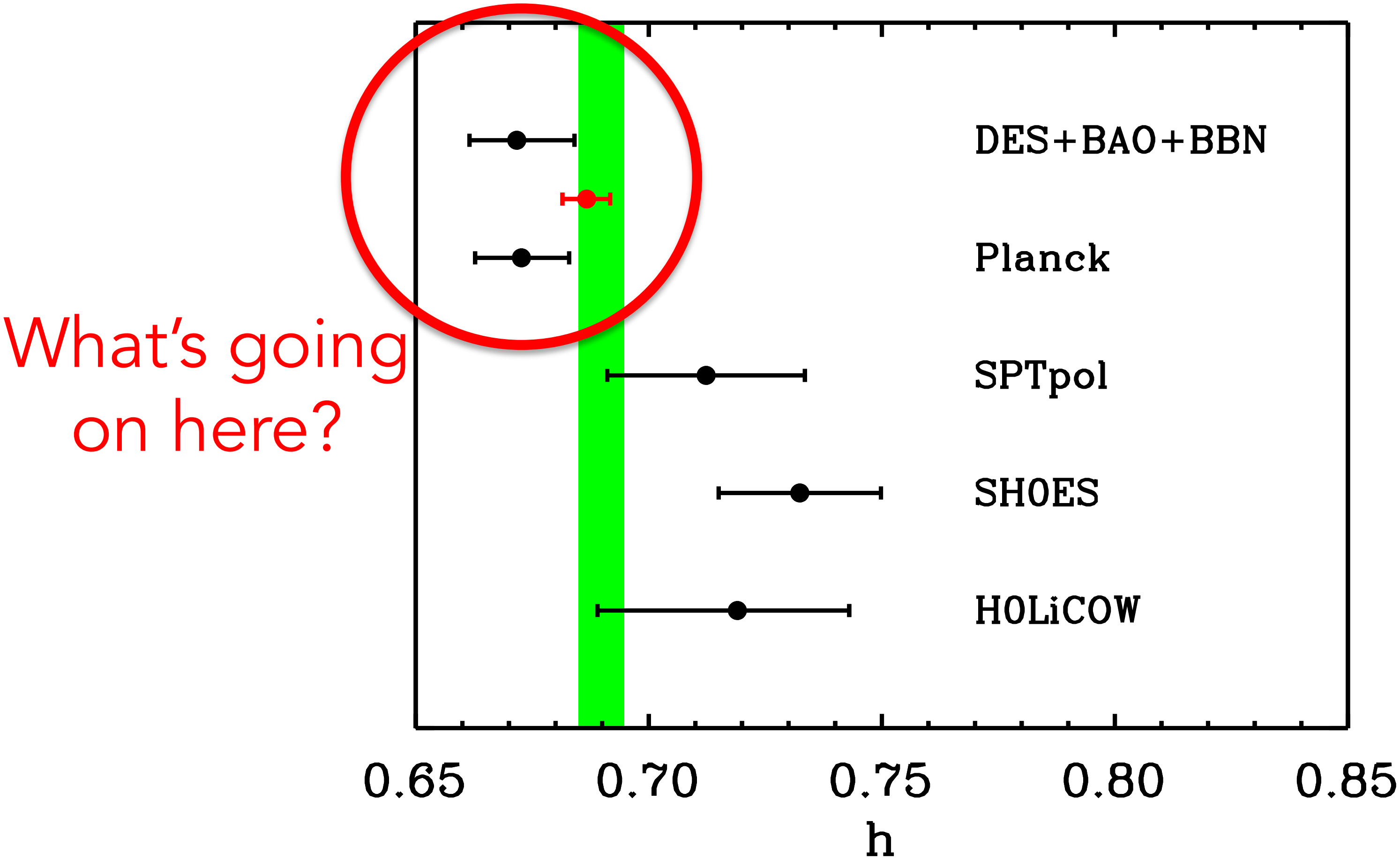

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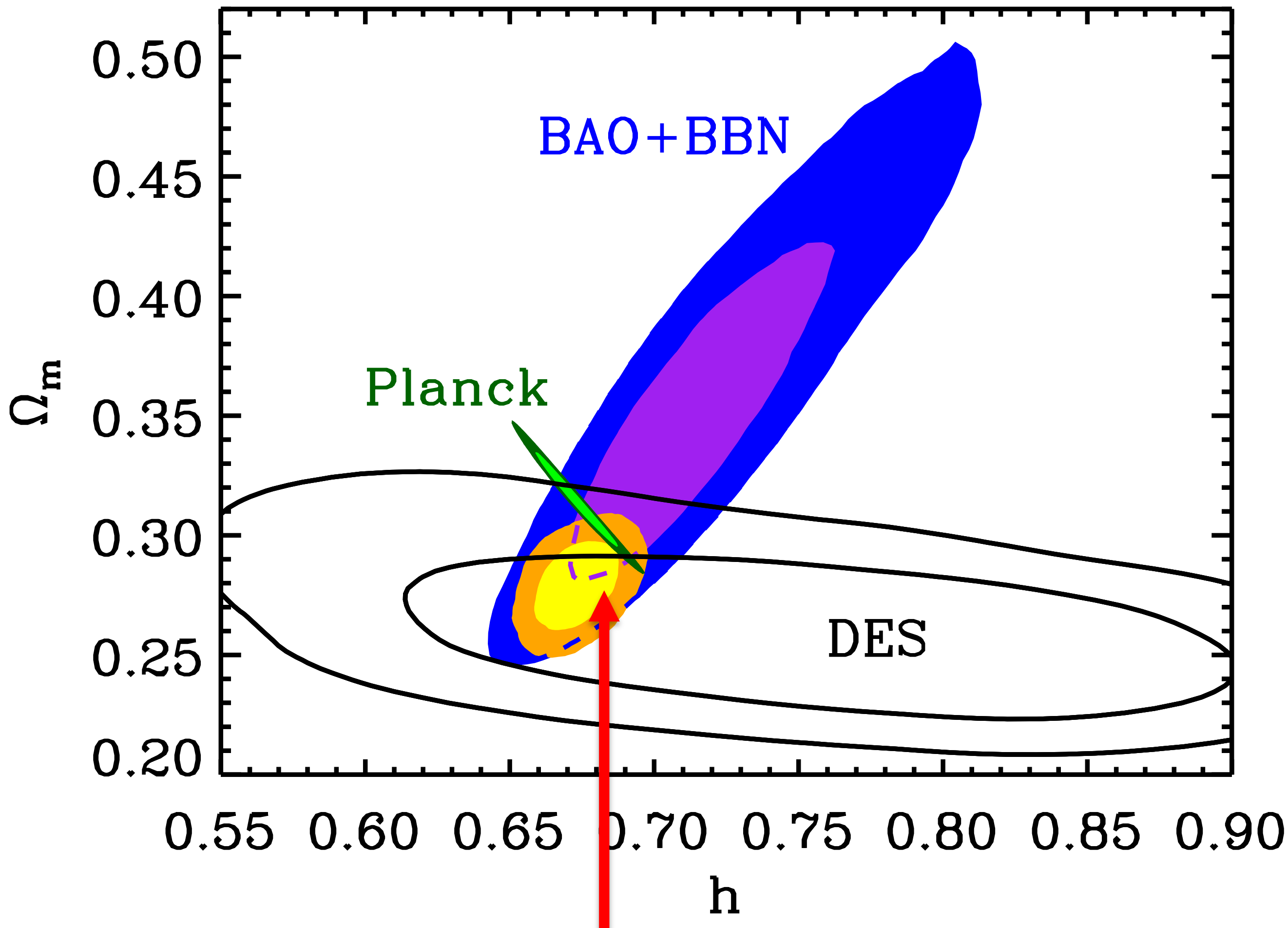
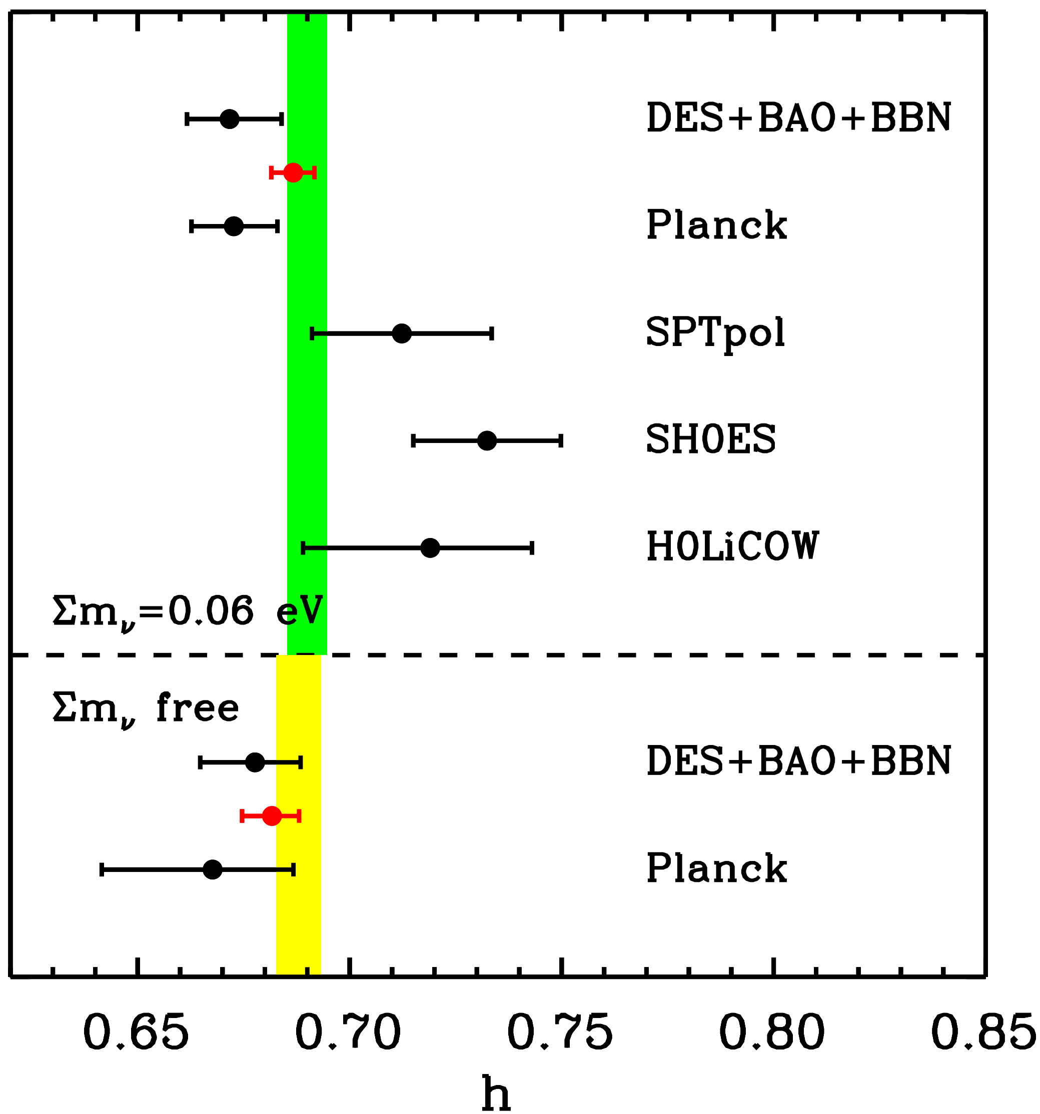


Intersection of *Planck* w/ DES+BAO+BBN is at high *h*

The Impact of Neutrino Masses



Summary

- DES+BAO+BBN measures H_0 with the same precision as *Planck*, yet is **completely decoupled from the CMB**.

- $H_0 = 67.2^{+1.2}_{-1.0}$ km/s/Mpc

- There are now 5 measurements of H_0 that are:
    - Statistically independent
    - Share no common observational systematics
    - The entire set has an acceptable χ^2

- No evidence for dynamical dark energy/MG