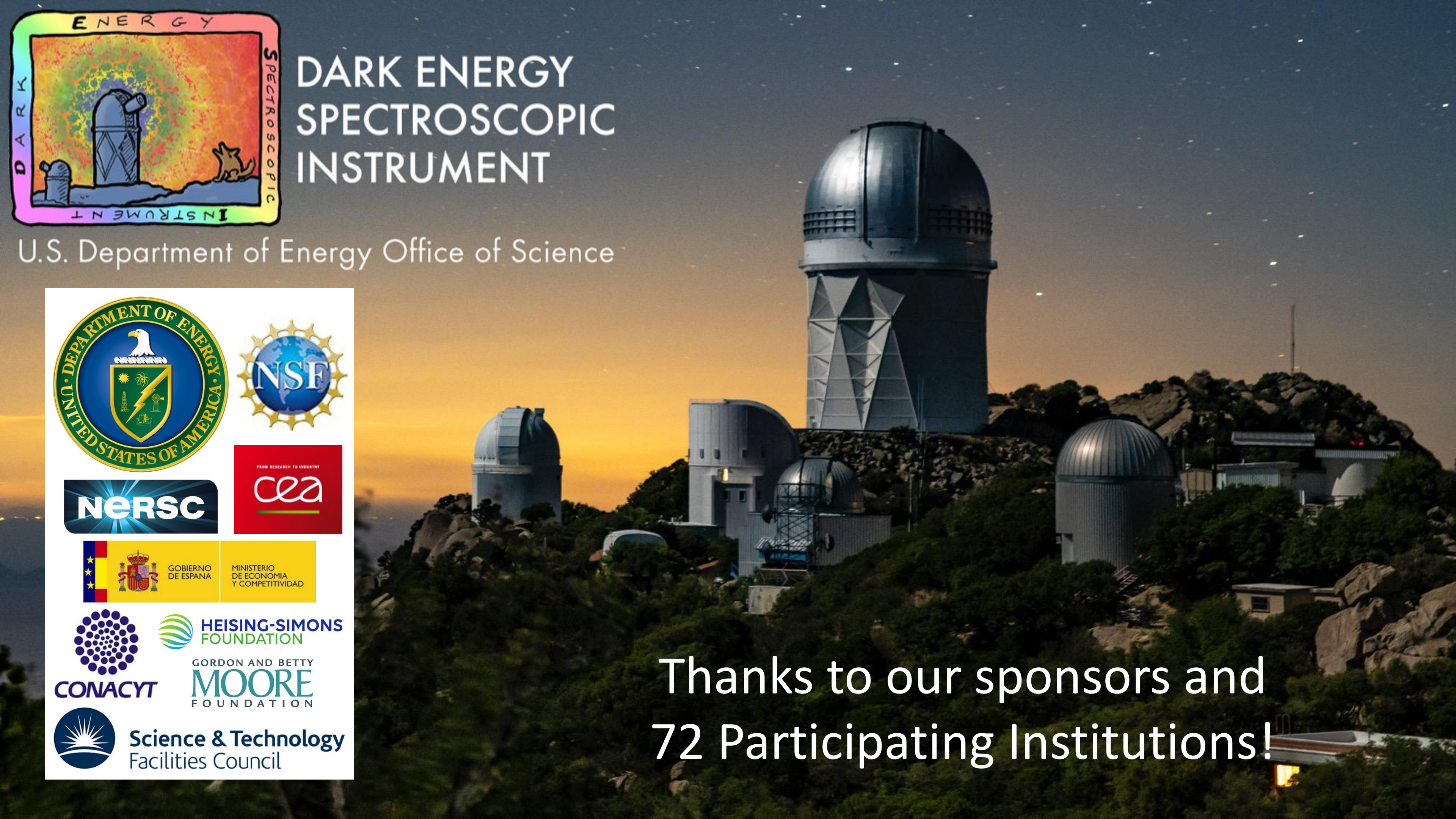
Measuring H_0 Without the Sound Horizon: A New Constraint From DESI

Erik Zaborowski
PhD Candidate
zaborowski.11@osu.edu

BCCP Seminar Oct 21, 2025

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

THE OHIO STATE UNIVERSITY

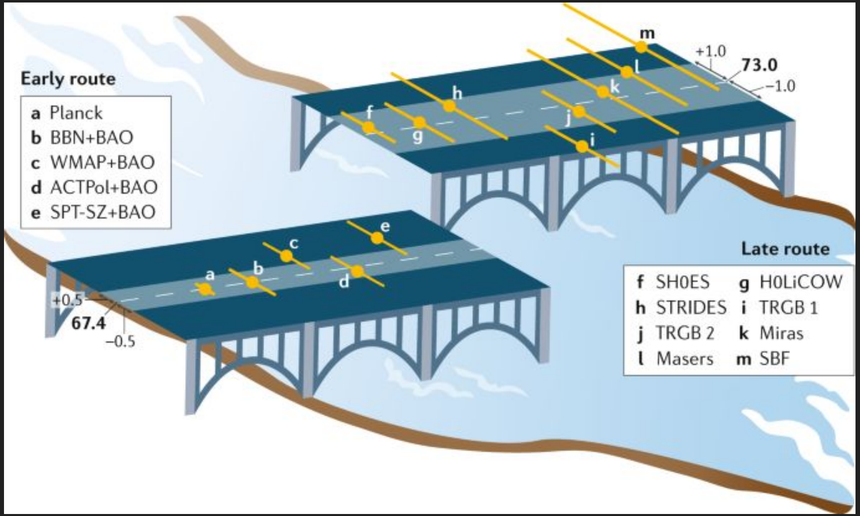

ENERGY SPECTROSCOPIC INSTRUMENT DARK
DARK ENERGY
SPECTROSCOPIC
INSTRUMENT
U.S. Department of Energy Office of Science
DEPARTMENT OF ENERGY UNITED STATES OF AMERICA
NSF
NERSC
FROM RESEARCH TO INDUSTRY
cea
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD
CONACYT
HEISING-SIMONS FOUNDATION
GORDON AND BETTY MOORE FOUNDATION
Science & Technology Facilities Council
Thanks to our sponsors and
72 Participating Institutions!

Motivation: Probing the Hubble tension

- Now **>6σ tension** between local (SH0ES) and early-time (*Planck*/ACT/SPT) H_0 measurements

- *Key observation:* Many early-time probes (CMB, BAO) infer H_0 primarily via the **sound horizon**

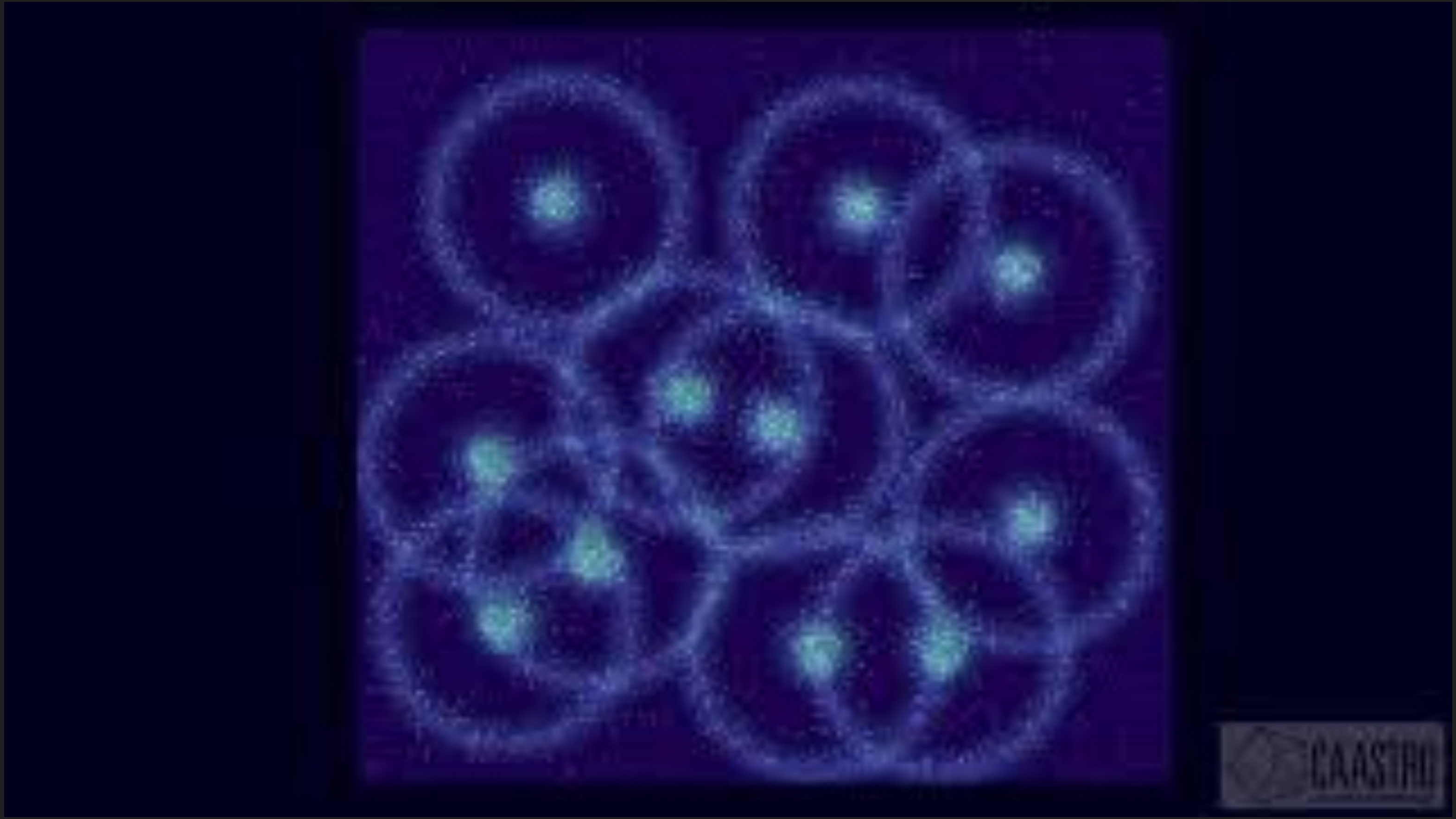
  → Proposed solutions **often target this scale**



Credit: Adam Riess

Question: *Can we measure H_0 independently of sound horizon and SNe Ia calibration?*

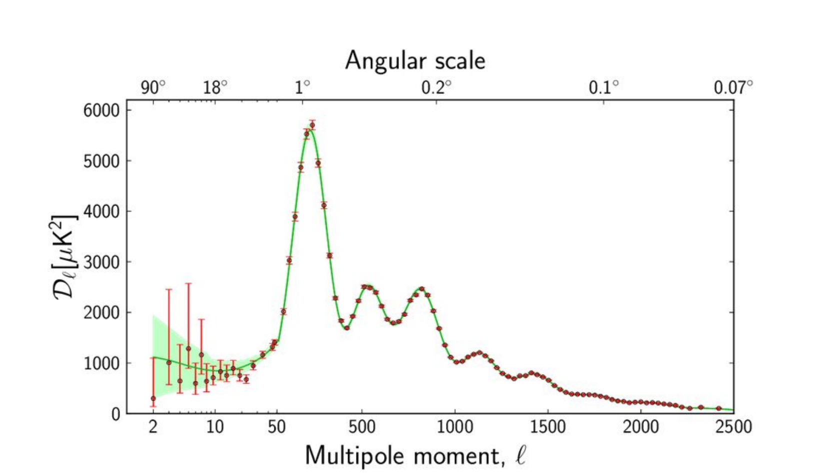
Detour: Sound horizon physics



The sound horizon in observations

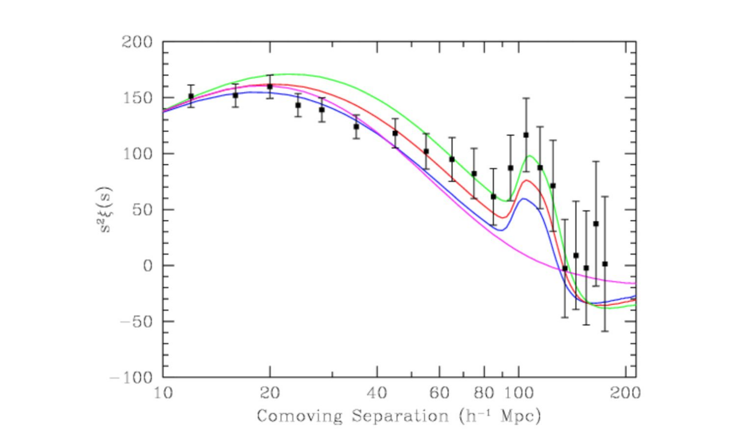
- Two closely related distances:

$r_s \equiv$ sound horizon at **photon decoupling** (sets **CMB peak spacing**)



Credit: Hans Winther

$r_d \equiv$ sound horizon at **baryon decoupling** (the **BAO ruler** used at low z)



Credit: Daniel Eisenstein

Shorter sound horizon → reduced Hubble tension

$$r_\mathrm{d} = \int_{z_\mathrm{d}}^{\infty} \frac{c_s(z)}{H(z)}\, dz$$

$$\simeq 147\ \mathrm{Mpc} \times \left(\frac{\omega_\mathrm{b}}{0.0223}\right)^{-0.13} \left(\frac{\omega_\mathrm{bc}}{0.143}\right)^{-0.23} \left(\frac{N_\mathrm{eff}}{3.04}\right)^{-0.1}$$

- Many sound horizon observables (e.g. CMB acoustic angle, BAO) are distance ratios: $D(z) / r_\mathrm{d} \sim f(\Omega_\mathrm{m}, z) / H_0 r_\mathrm{d}$

  → Can trade off **lower r_d** for **higher H_0**

- Proposed **new physics** to resolve the Hubble tension often takes this approach (e.g. early dark energy, ΔN_eff)

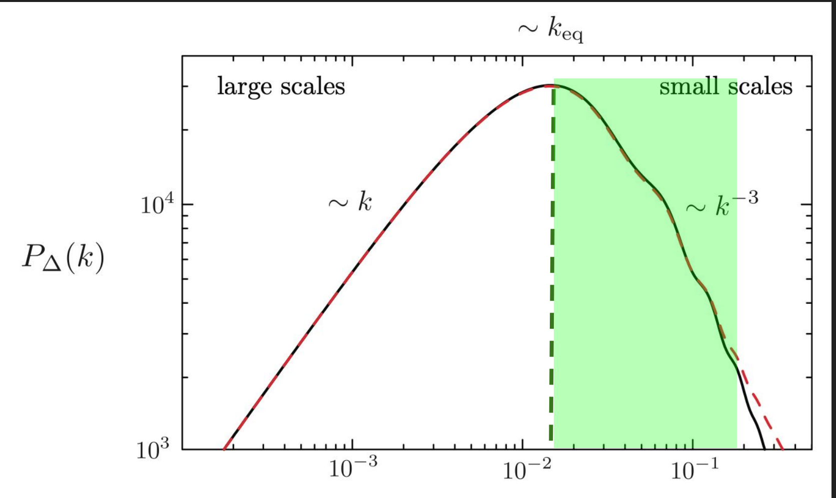
Goal: *Test these ideas with a sound horizon-independent technique*

Another ruler: The matter-radiation equality scale

- Wavenumber k_{eq} when $\Omega_m(z_{eq}) = \Omega_r(z_{eq})$
- Well-known as the **turnover scale** of the matter power spectrum

$$k_{\rm eq} = \left(2H_0^2 z_{\rm eq}\right)^{1/2} \simeq 7.46 \times 10^{-2}\,\omega_{\rm bc} \left(\frac{T_{\rm CMB}}{2.7{\rm K}}\right)^{-2} \ {\rm Mpc}^{-1}$$

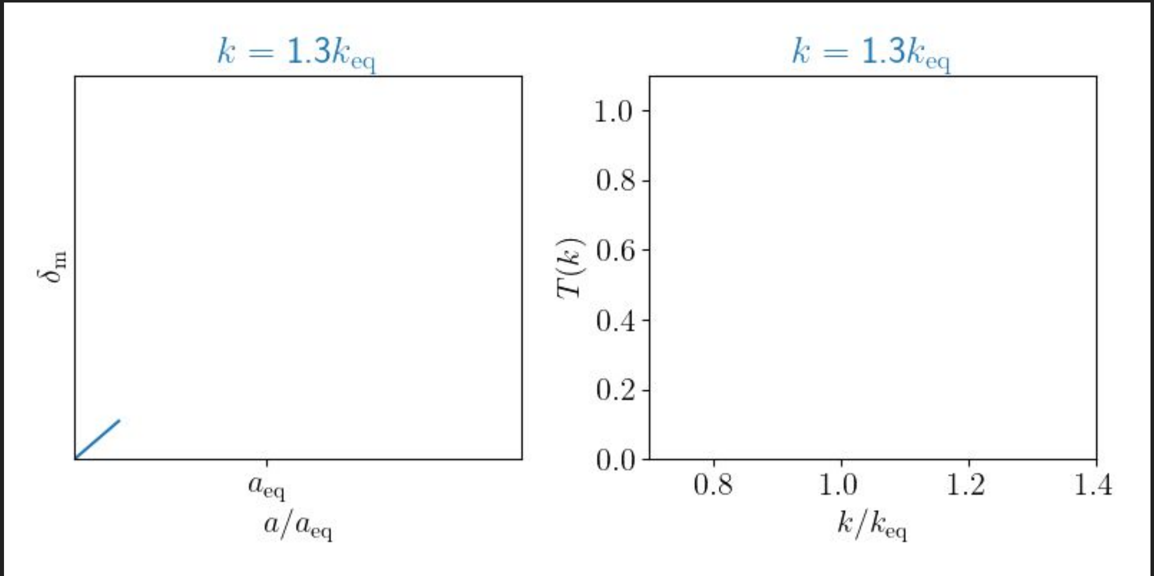
- Also **modulates the broadband shape** for $k > k_{eq}$



Credit: Baumann

Equality scale intuition

- **During radiation domination:** growth suppressed by pressure support (δ ~ ln a)
- **During matter domination:** perturbations grow unimpeded (δ ~ a)
- **Shape of power spectrum** contains k_{eq} information



Animation inspired by David Parkinson

Two standard rulers → two H_0 measurements

- Each standard ruler probes physics at **different times**
  - $\boldsymbol{r_s}$ **:** $z \sim 1{,}100$ / $t \sim 370{,}000$ yr
  - $\boldsymbol{k_{eq}}$ **:** $z \sim 3{,}400$ / $t \sim 51{,}000$ yr
- Each may be **impacted differently** by modified pre-recombination physics

We can ask:

1. Is H_0 from k_{eq} still in tension with **local measurements**? (independent H_0 tension probe)
2. Is H_0 from k_{eq} **consistent with** $\boldsymbol{r_s}$? (ΛCDM null-test)

A demonstration with early dark energy

Farren, Philcox, Sherwin (2022)

- Gerrit Farren et al. ran a **Euclid-like H_0 forecast** for EDE vs. ΛCDM, with / without r_s information
- ***Finding:* EDE increases inferred H_0** from r_s, relative to broadband / k_{eq}

Gerrit

Erik

ΛCDM

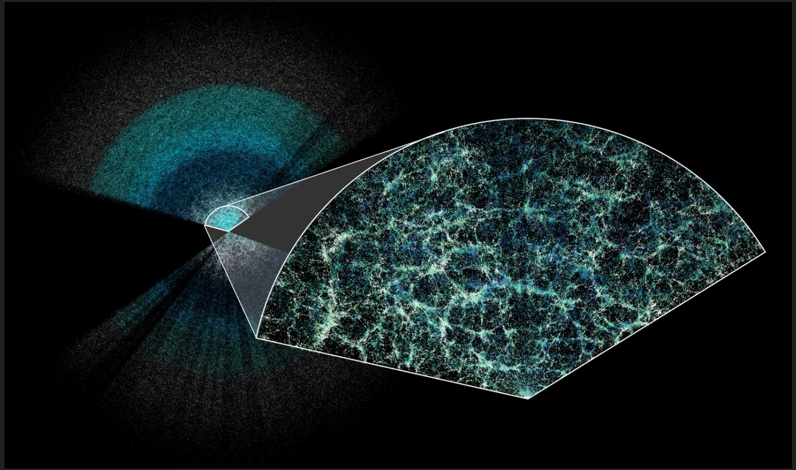
	H_0
FS	$68.1^{+1.2}_{-1.6}$
FS + r_s marg.	$68.0^{+1.5}_{-2.0}$
FS + BBN	68.17 ± 0.40
FS + BBN + r_s marg.	$\mathbf{68.15 \pm 0.72}$
BAO + BBN	68.28 ± 0.49
BAO + BBN + r_s marg	$68.8^{+1.4}_{-1.6}$

EDE

	EDE (*Planck*+SH0ES)	EDE (ACT)
FS	$67.58^{+0.95}_{-1.4}$	$67.08^{+0.95}_{-1.2}$
FS + r_s marg.	66.7 ± 1.8	$64.53^{+0.88}_{-0.74}$
FS + BBN	69.54 ± 0.45	73.43 ± 0.51
FS + BBN + r_s marg.	$\mathbf{67.39^{+0.89}_{-0.79}}$	$\mathbf{66.82 \pm 0.53}$
BAO + BBN	$\mathbf{69.97 \pm 0.50}$	$\mathbf{74.62 \pm 0.69}$

A new measurement: Zaborowski et al. (2025) (imminent)

- DESI DR1
  - Galaxy clustering *r_s-dependent*
  - Lyman-α forest (3-d AP effect)
- Minimal external assumptions
  - BBN ω_b prior (Schoeneberg 2024)
  - CMB acoustic scale θ_* (*Planck* 2018)
- Additional r_s-free datasets
  - DES Year 5 supernovae
  - *Planck*+ACT CMB lensing [× unWISE galaxies]
  - DES Year 3 6×2pt



Claire Lamman / DESI Collaboration

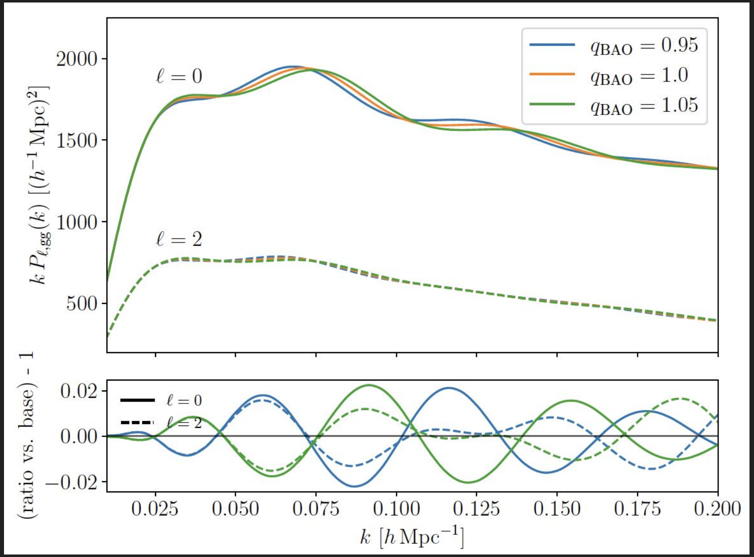
Removing the sound horizon dependence

- **Rescale** power spectrum wiggles:

$$P_{\rm lin}\left(k, q_{\rm BAO}\right) = P_{\rm lin}^{\rm smooth}\left(k\right) + P_{\rm lin}^{\rm wiggly}\left(q_{\rm BAO}^{-1} \cdot k\right)$$

- Changes the **effective sound horizon** scale by factor $1/q_{\rm BAO}$
- **Marginalize** over this scale during analysis

→ Residual H_0 information primarily from broadband / k_{eq}

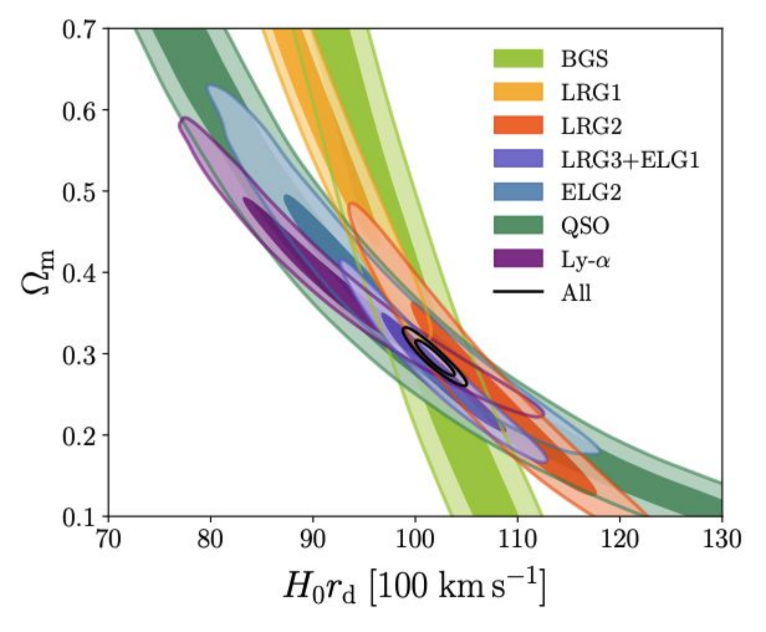


Zaborowski et al. (2025)

Developed by Farren, Philcox, Sherwin (2022)

Uncalibrated post-reconstruction BAO (and θ_*)

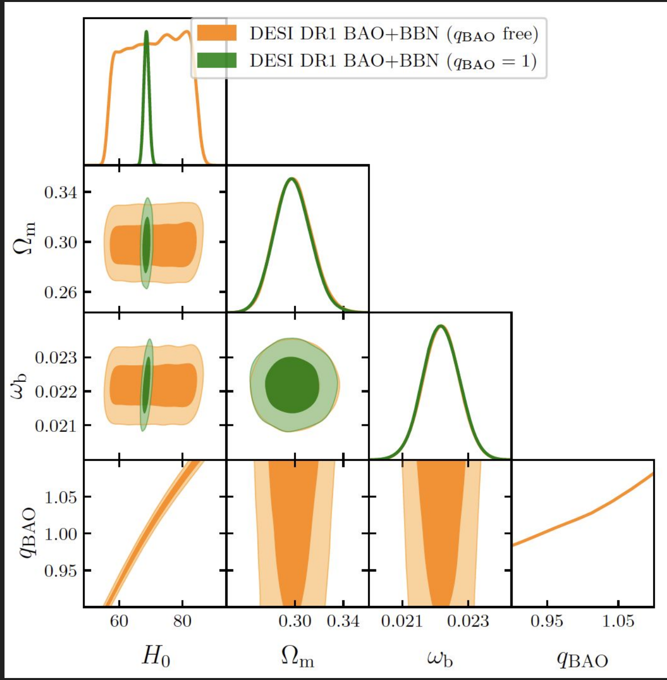
- Uncalibrated ≡ **agnostic of** (absolute) $\boldsymbol{r_\mathrm{d}}$
- Standard BAO analysis only constrains params Ω_m and $H_0 r_\mathrm{d}$ before BBN calibration



DESI DR1 BAO
(DESI Collaboration et al. 2024)

Uncalibrated post-reconstruction BAO (and θ_*)

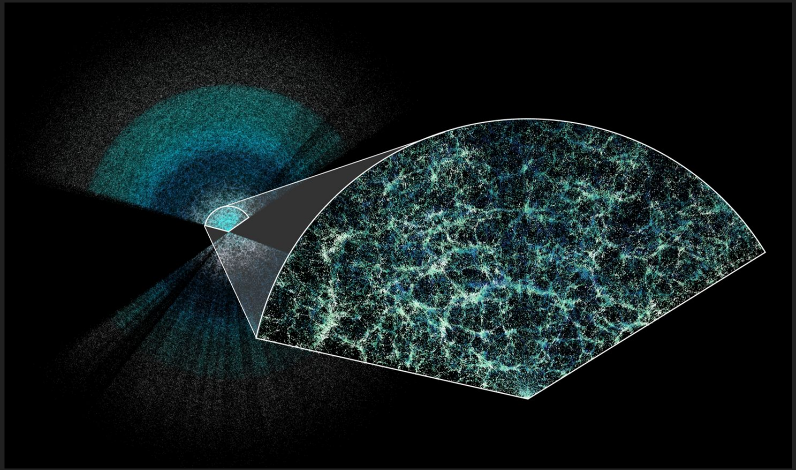
- Uncalibrated ≡ **agnostic of** (absolute) $\boldsymbol{r_d}$
- Standard BAO analysis only constrains params Ω_m and $H_0 r_d$ before BBN calibration
- We achieve this using a **consistent rescaling** ($r_d \to r_d / q_{BAO}$)
- Can include θ_* similarly ($r_s \to r_s / q_{BAO}$)



Zaborowski et al. (2025)

A new measurement: Zaborowski et al. (2025) (imminent)

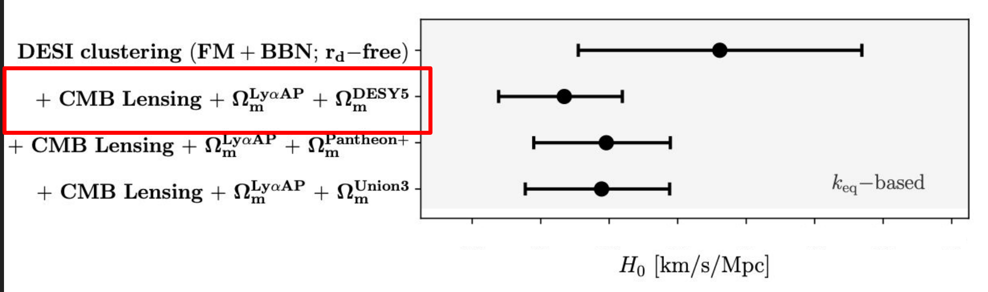
- DESI DR1
  - Galaxy clustering
  - Lyman-α forest (3-d AP effect)
- Minimal external assumptions
  - BBN ω_b prior (Schoeneberg 2024)
  - CMB acoustic scale θ_* (*Planck* 2018)
- Additional r_s-free datasets
  - DES Year 5 supernovae
  - *Planck*+ACT CMB lensing [× unWISE galaxies]
  - DES Year 3 6×2pt



Claire Lamman / DESI Collaboration

Uncalibrated type-Ia supernovae

- Trace the shape of the local expansion history **(sensitive to Ω_m)**
- Previous work: Results highly sensitive to supernovae **(high $\Omega_m \rightarrow$ low H_0)**
- This work: **Test robustness** by comparing DES Y5 SNe (which caused largest shift) vs. supernova-independent alternative datasets

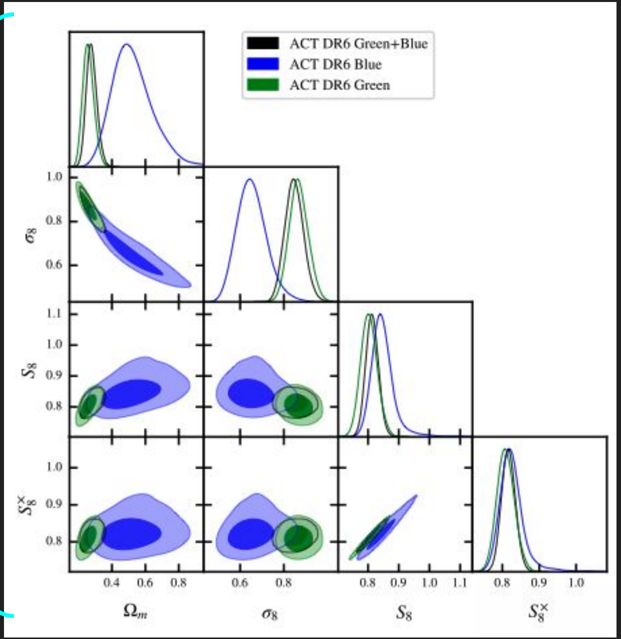


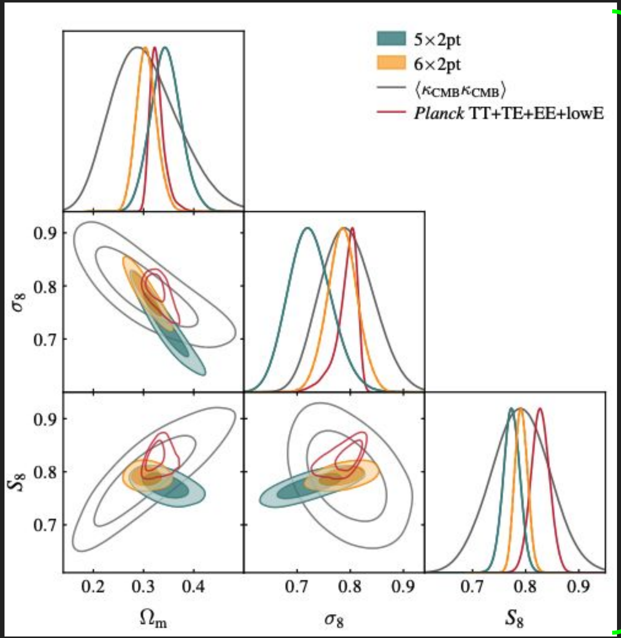
Zaborowski et al. (2024)

Supernova-independent datasets

Gerrit Farren et al. (2024)

ACT+*Planck* lensing × unWISE 2D clustering





DES, SPT et al. (2022) (DES Y3 6×2pt)

Includes standard 3×2pt (galaxy clustering and lensing), plus *Planck* and SPT lensing

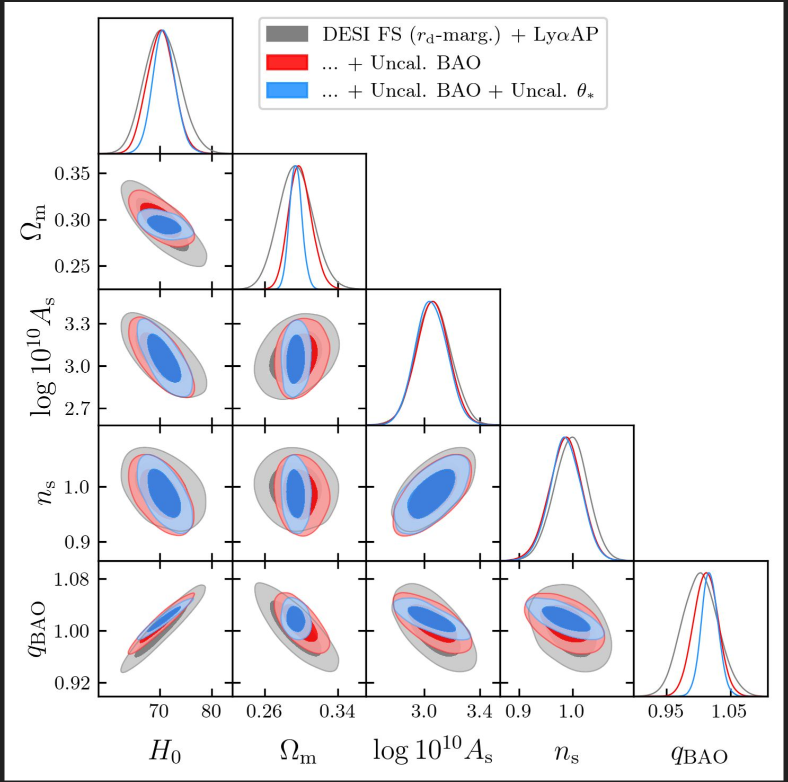
Results!

- **First:** DESI DR1 + minimal assumptions
  - Full-Shape + BBN
  - … + Uncalibrated BAO
  - … + Uncalibrated θ_*
- **Next:** Layer on additional datasets
  - DES Year 5 supernovae
  - Planck+ACT CMB lensing [× unWISE galaxies]
  - DES Year 3 6×2pt
- **Finally:** H_0 landscape and Hubble tension implications

Results: DESI DR1 + minimal assumptions

Zaborowski et al. (2025)

	H_0 [km s^{-1} Mpc^{-1}]	$q_{\rm BAO}$
DESI FS + LyαAP + BBN	$70.5^{+3.3}_{-3.4}$	$1.003^{+0.027}_{-0.028}$
… + Uncal. BAO	70.2 ± 2.6	1.011 ± 0.019
… + Uncal. BAO & θ_*	$70.8^{+2.0}_{-2.2}$	$1.018^{+0.012}_{-0.013}$

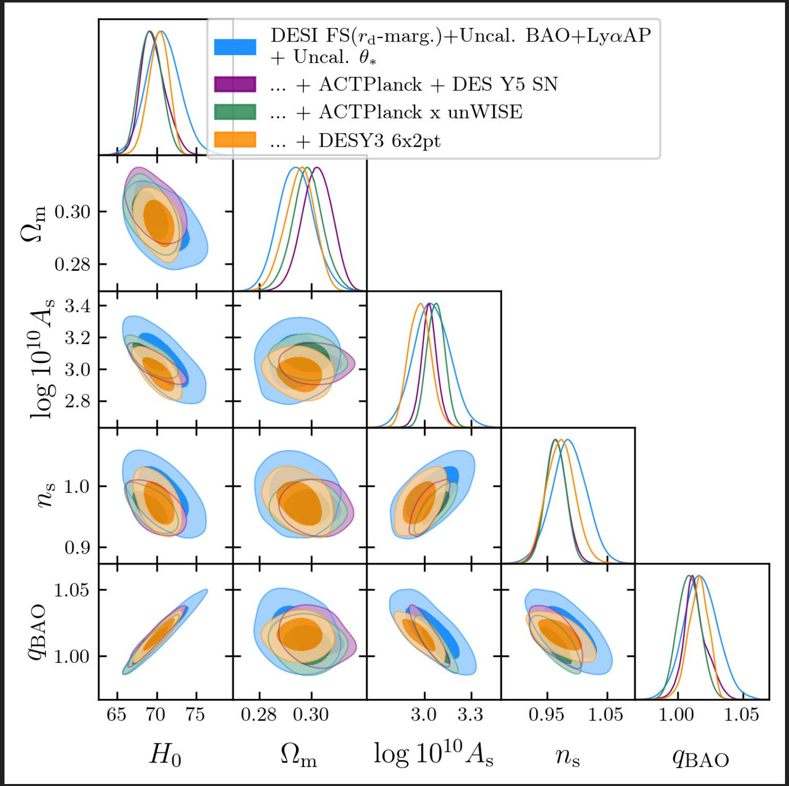


- **~3% H_0 constraint** - already rivals 2024 result including SNe

Results: Additional datasets

Zaborowski et al. (2025)

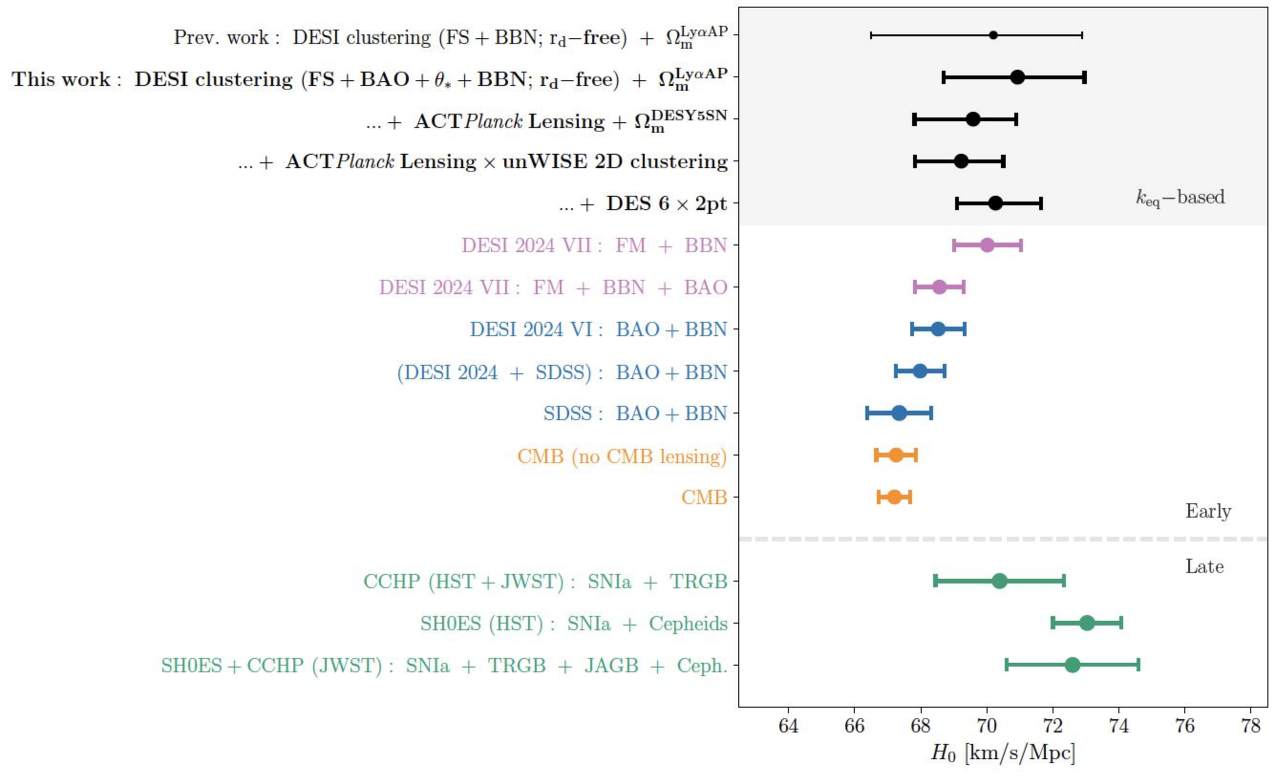
	H_0 [km s^{-1} Mpc^{-1}]	$q_{\rm BAO}$
DESI (FS+BAO+LyαAP) + BBN + θ_*	$70.8^{+2.0}_{-2.2}$	$1.018^{+0.012}_{-0.013}$
… + ACT+*Planck* Lensing + DES Y5 SN	$69.6^{+1.3}_{-1.8}$	$1.014^{+0.007}_{-0.010}$
… + ACT+*Planck* Lensing × unWISE	$69.2^{+1.3}_{-1.4}$	1.009 ± 0.009
… + DES Y3 6×2pt	$70.3^{+1.4}_{-1.2}$	1.016 ± 0.008



- Highly consistent and robust results when including BAO+θ_*
- **Avg H_0 constraint is sub-2%**

Updated H_0 landscape

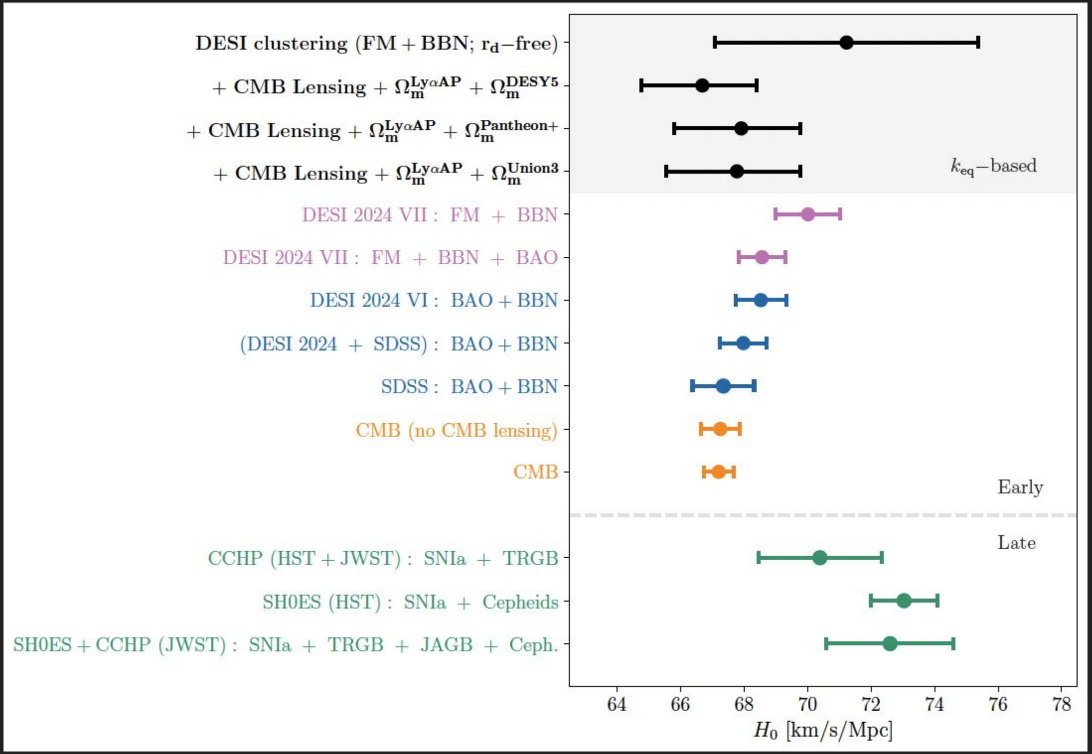
- **Higher H_0** than in previous work
- Trend emerging?
  - **More sound horizon → lower H_0**
  - **More broadband → higher H_0**
- Slight preference for $q_{\rm BAO} > 1$ → **reduced r_s**



Zaborowski et al. (2025)

Previous H_0 landscape

- Previously, concluded high consistency between r_s- and k_{eq}-based H_0
- Results driven by high supernova Ω_m



Zaborowski et al. (2024)

(Refresher) Early dark energy

Farren, Philcox, Sherwin (2022)

- **EDE increases inferred H_0** from r_s , relative to k_{eq}
- However, **opposite direction** from what we see in this work (although we do see mild preference for **reduced sound horizon** ($q_{BAO} > 1$))
- Any meaning that H_0 from k_{eq} sits between r_s and SN measurements? **Future work!**

ΛCDM

	H_0
FS	$68.1^{+1.2}_{-1.6}$
FS + r_s marg.	$68.0^{+1.5}_{-2.0}$
FS + BBN	68.17 ± 0.40
FS + BBN + r_s marg.	$\mathbf{68.15 \pm 0.72}$
BAO + BBN	68.28 ± 0.49
BAO + BBN + r_s marg	$68.8^{+1.4}_{-1.6}$

EDE

	EDE (*Planck*+SH0ES)	EDE (ACT)
FS	$67.58^{+0.95}_{-1.4}$	$67.08^{+0.95}_{-1.2}$
FS + r_s marg.	66.7 ± 1.8	$64.53^{+0.88}_{-0.74}$
FS + BBN	69.54 ± 0.45	73.43 ± 0.51
FS + BBN + r_s marg.	$\mathbf{67.39^{+0.89}_{-0.79}}$	$\mathbf{66.82 \pm 0.53}$
BAO + BBN	$\mathbf{69.97 \pm 0.50}$	$\mathbf{74.62 \pm 0.69}$

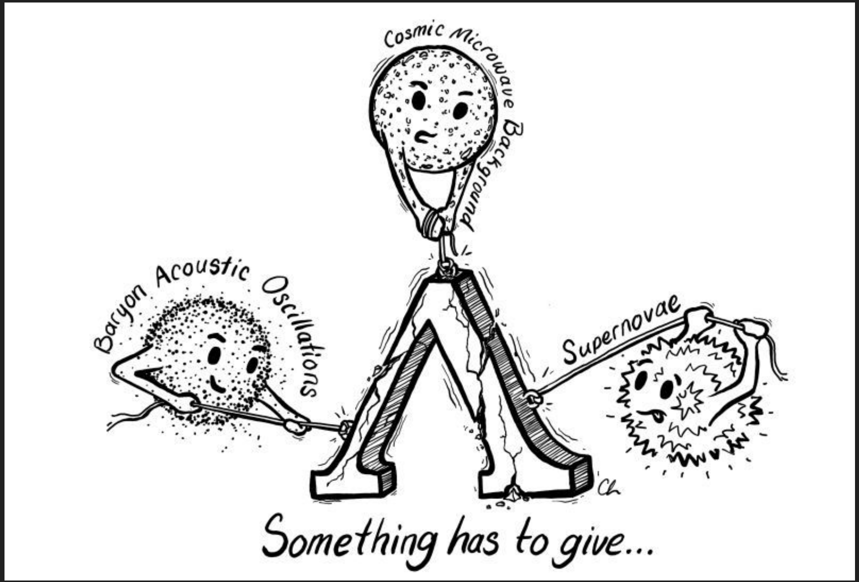
Gerrit

Erik

Outlook

- Lots of room to improve precision
  - Statistics limited measurement - expect $1/\sqrt{2}$ improvement just from DESI DR2/DR3
  - Cross-correlations, HOD-informed priors to beat down nuisance uncertainties
- In parallel, investigate specific models of modified physics to understand results
  - Early-Universe (e.g. early dark energy)
  - Late-Universe (e.g. $w_0 w_a$)
- Future k_{eq}-based constraints will precisely probe physical origin of Hubble tension

Conclusions

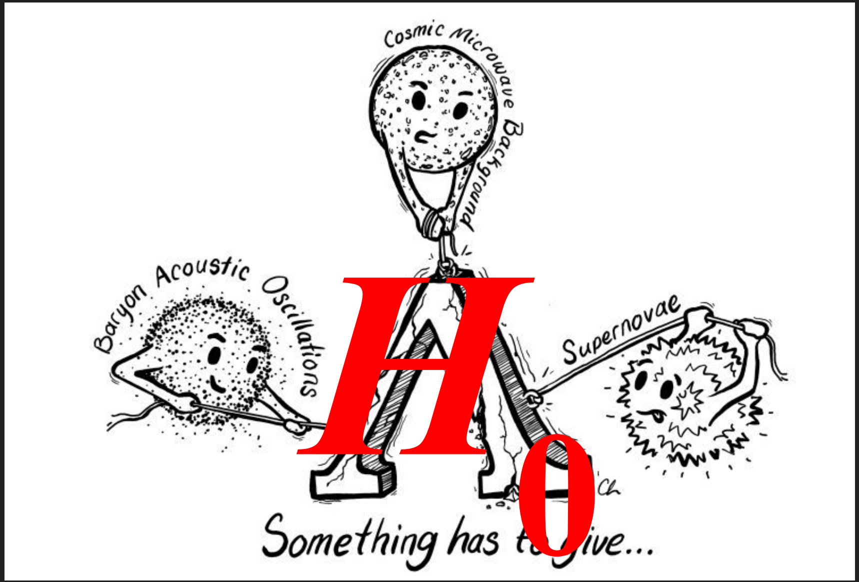


Credit: Claire Lamman

- **Sub-2% H_0**, independent of both sound horizon and supernovae
- H_0 intermediate between local and sound horizon-based measurements - future data will determine if trend or fluke
- Ongoing work to understand these results in the context of modified physics

Thank you!

Conclusions



Credit: Claire Lamman (and EZ)

- **Sub-2% H_0**, independent of both sound horizon and supernovae
- H_0 intermediate between local and sound horizon-based measurements - future data will determine if trend or fluke
- Ongoing work to understand these results in the context of modified physics

Thank you!