BAO with DESI

the Dark Energy Spectroscopic Instrument

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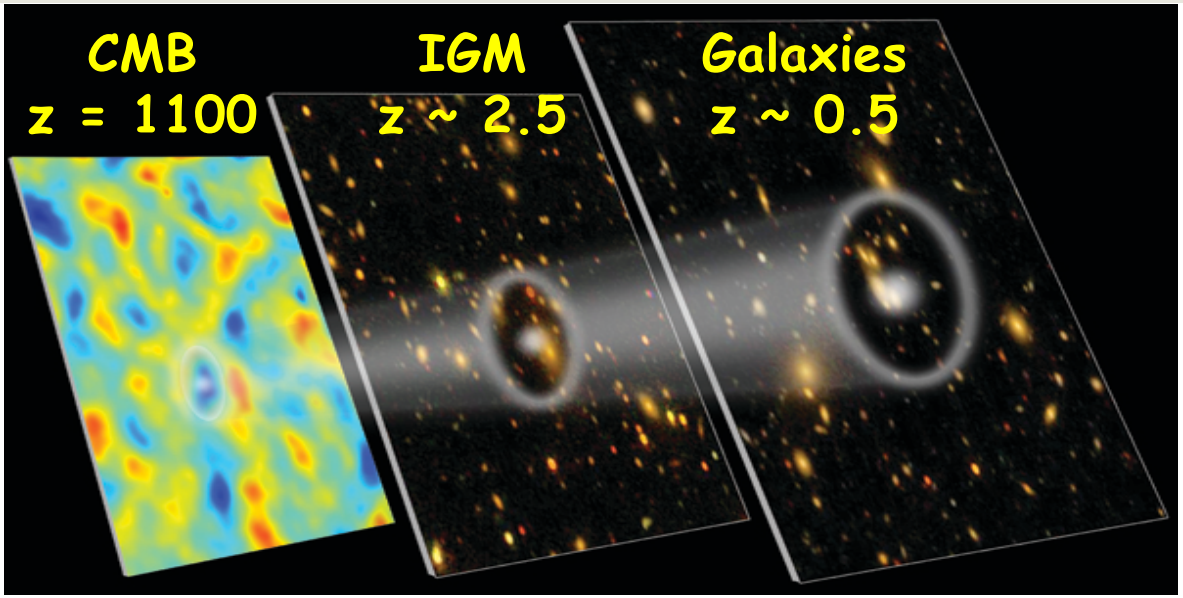
(CEA-Saclay)

H0 conference, June 2020

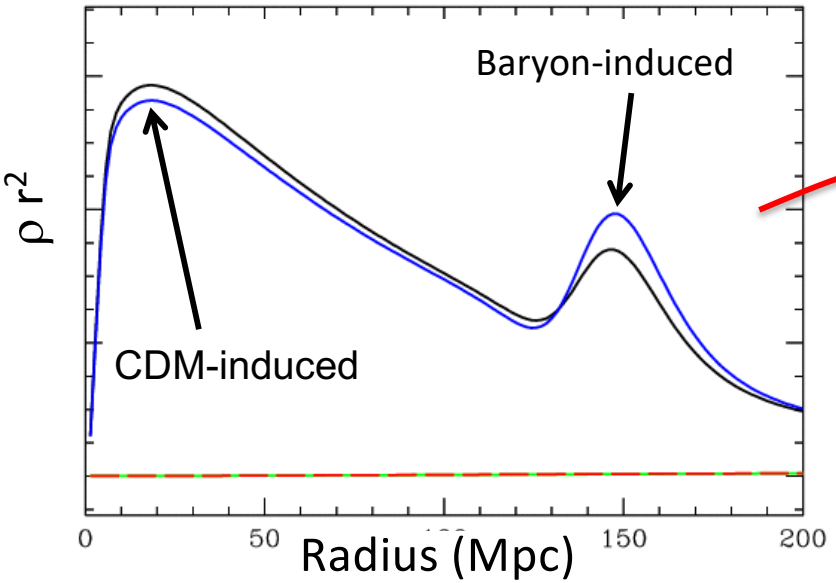
Baryon Acoustic Oscillations (BAO)

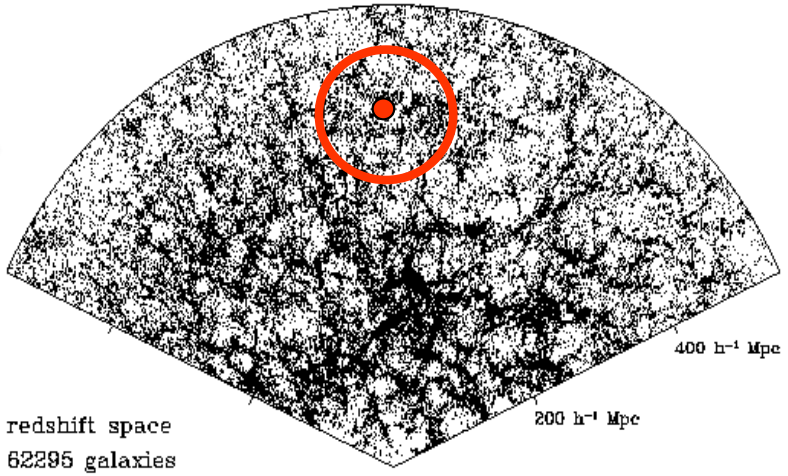


Propagation of baryon-photon overdensity wave in plasma

Wave frozen at recombination, at comoving r_s ~ 150 Mpc

Standard ruler in LSS
A preferred 3D scale





Baryon Acoustic Oscillations (BAO)

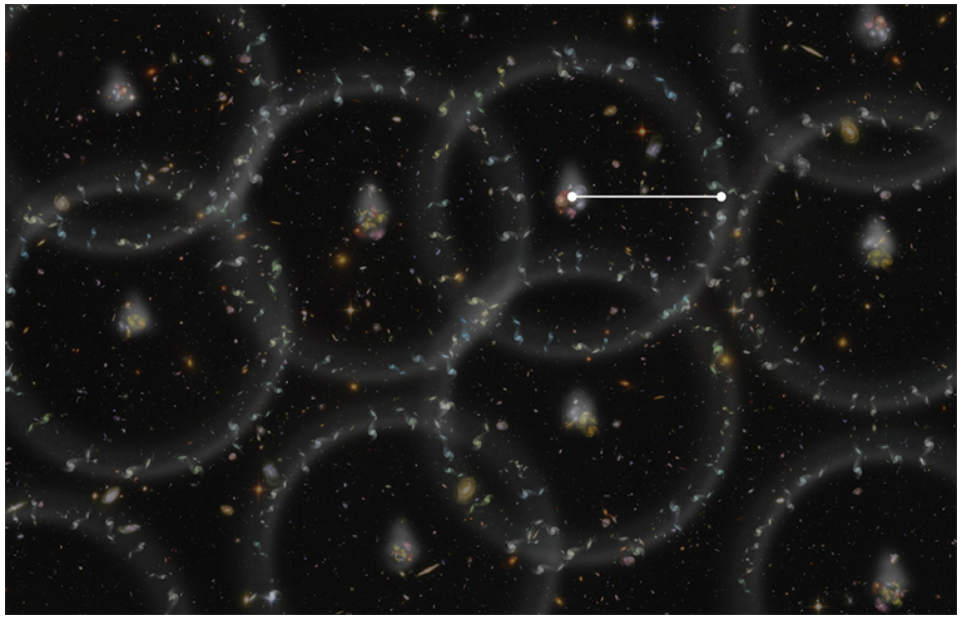
Two approaches

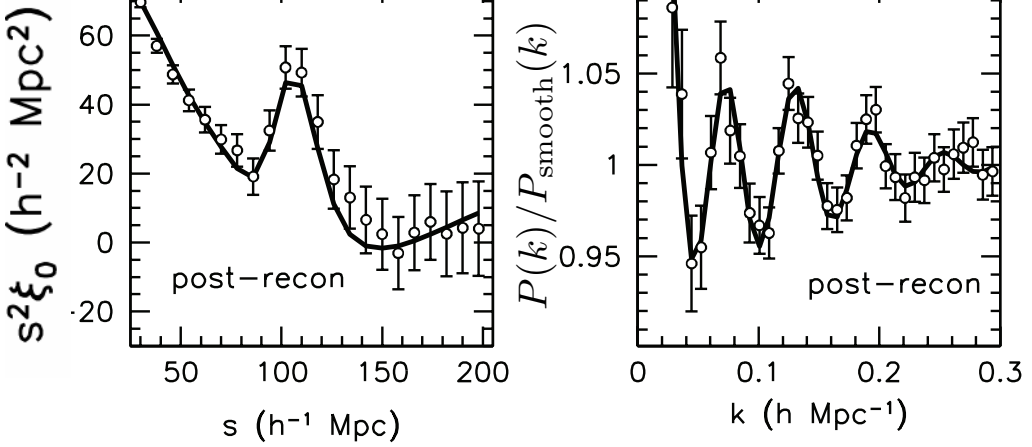
Measurement of BAO:

statistically, using 2-point statistics

Bump in real-space correlation function

Wiggles in Fourier-space power spectrum



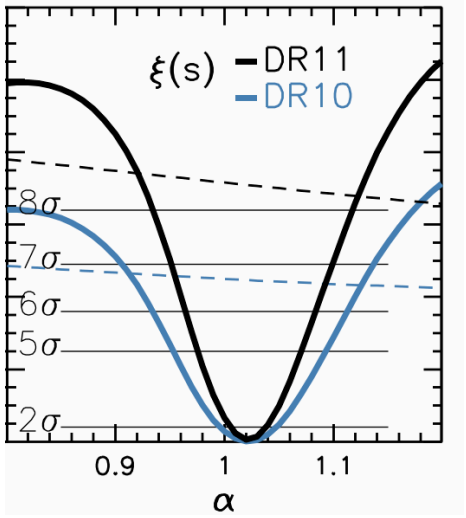


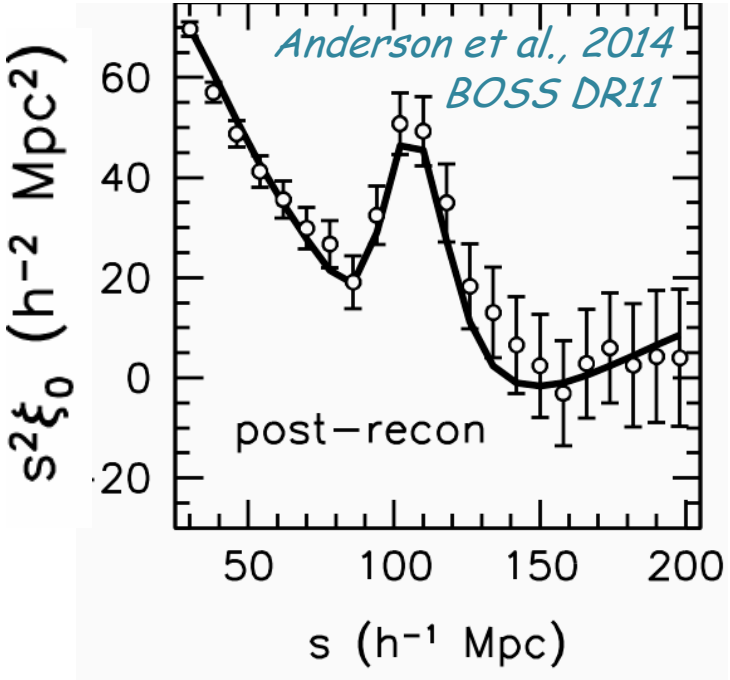
Anderson et al., 2014

Baryon Acoustic Oscillations (BAO) - BOSS

Isotropic measurement

- >8σ detection of BAO feature (BOSS only)





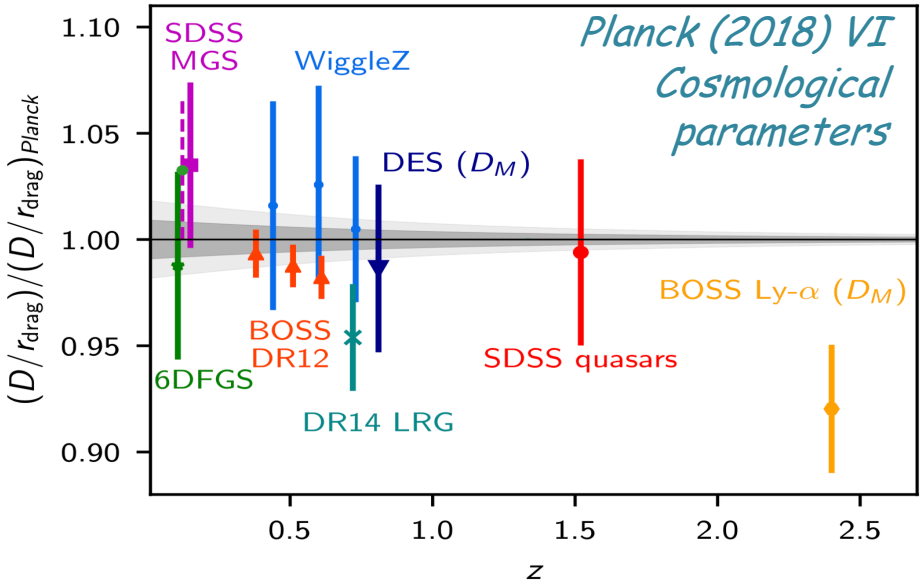
- **Fiducial model**
  - Compare observed feature to model
  - Quantify departures with factor $\alpha = \frac{[D_V/r_d]}{[D_V/r_d]_{\rm fid}}$
- **BAO scale at 1% precision**
  - Lowz (z~0.3) $\alpha = 1.018 \pm 0.021$
  - CMASS (z~0.6) $\alpha = 1.014 \pm 0.010$

Baryon Acoustic Oscillations (BAO) - BOSS

Isotropic measurement

Excellent agreement with Planck

$D_V = [\ (1+z)^2\ D_A{}^2\ .\ cz\ H(z)\ ]^{1/3}$



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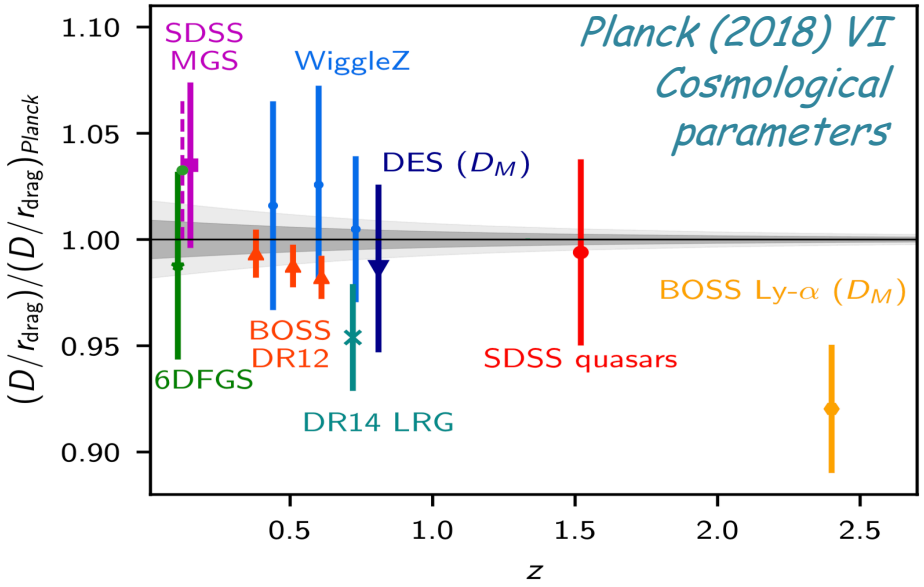
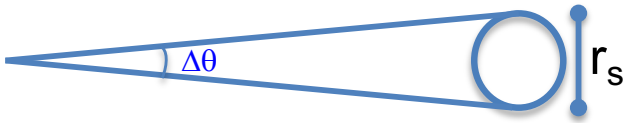


Anisotropic measurement

- **Transverse direction**

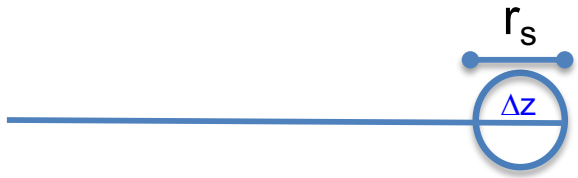


$\Delta\theta = r_s / [(1+z)\ D_A(z)]$

$\Rightarrow$ Angular distance $D_A(z)$

as SNIa: $D_L(z) = (1+z)^2\ D_A(z)$

- **Radial direction** (along line of sight)

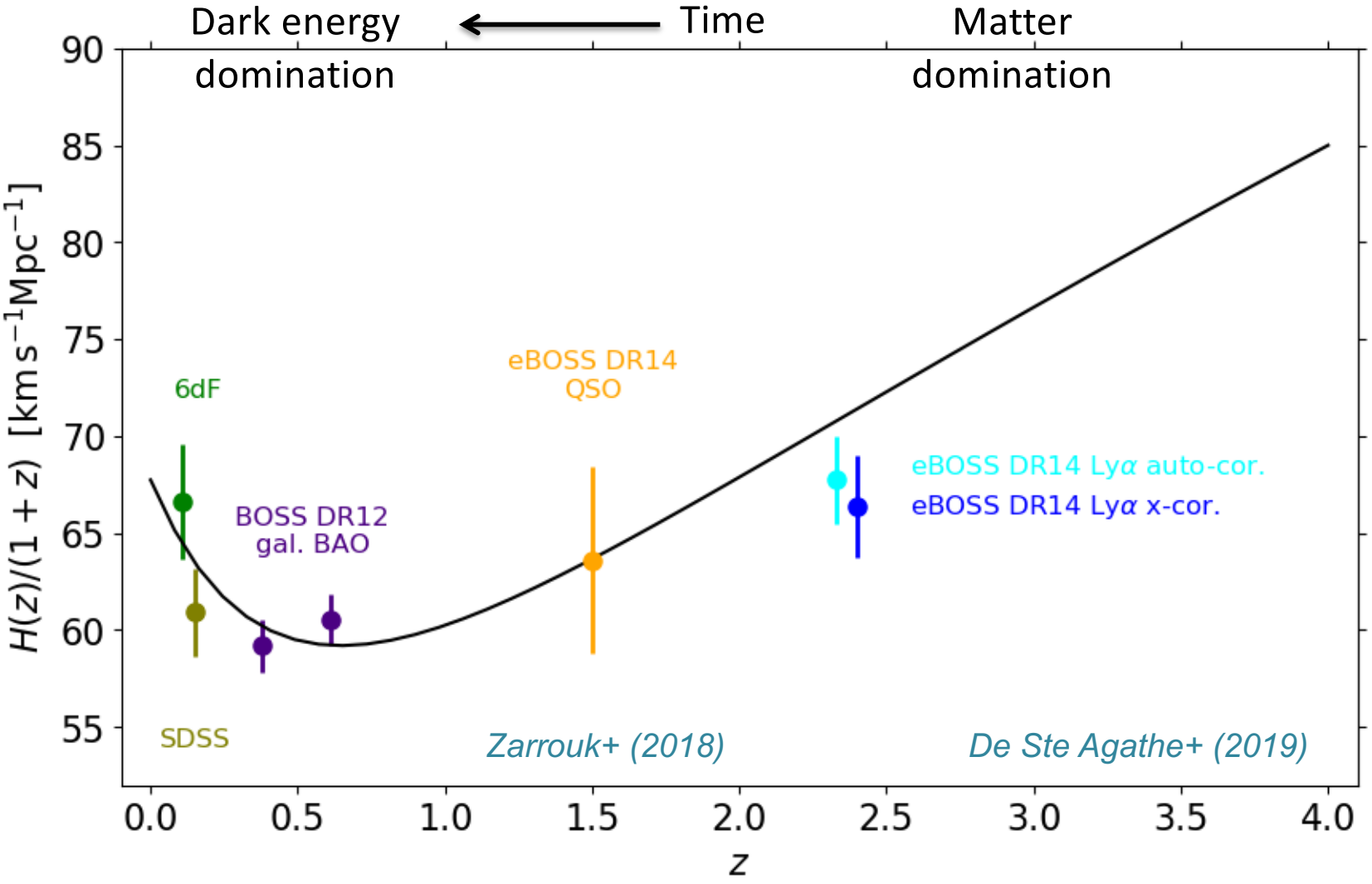


$\Delta z = r_s\ H(z) / c$

$\Rightarrow$ Hubble parameter $H(z)$

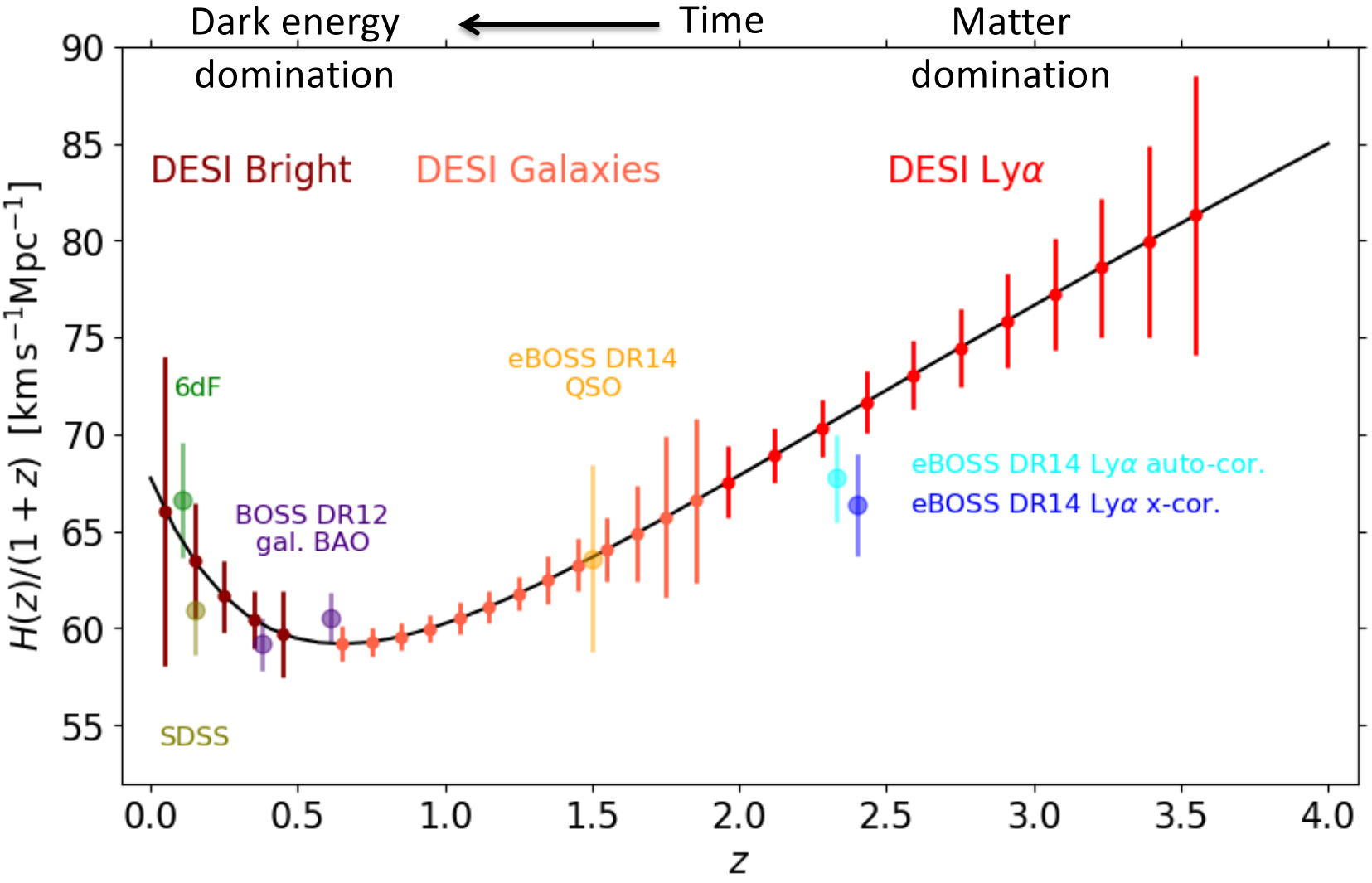
Baryon Acoustic Oscillations (BAO) - BOSS

Expansion history



Baryon Acoustic Oscillations (BAO) - BOSS

Expansion history




DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science
NERSC
GOBIERNO DE ESPANA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD
HEISING-SIMONS FOUNDATION
CONACYT
GORDON AND BETTY MOORE FOUNDATION
Science & Technology Facilities Council
Thanks to our sponsors and 69 Participating Institutions!

DESI science requirements

- Stage-IV DE experiment
  - factor of merit x3 w.r.t. Stage III

  with *factor of merit* defined
  in DETF (2005)

Eq. of state parameter
$w = p/\rho = w_0 + (1\text{-}a)\, w_a$

- Relying upon robust techniques
  - Baryon Acoustic Oscillations (BAO)
  - Redshift Space Distortions (RSD)

DESI science goals - ingredients

$$\frac{\sigma_P}{P} \propto \frac{1}{\sqrt{V}} \times \frac{nP+1}{nP}$$

- Optimize volume density n
  - "nP ~ 1" (beyond which more valuable to increase volume)

clustering power dominates over galaxy shot noise

- Maximize Volume V = A x Δz
  - 14,000 sq.deg. footprint
  - 0 < z < 3.7 (for clustering)

$\Longrightarrow$ DESI targets

- Five populations that should give the easiest redshifts over a broad redshift range
- Allow redshift overlap for cross-correlations

DESI targets

Five target classes

35 million redshifts

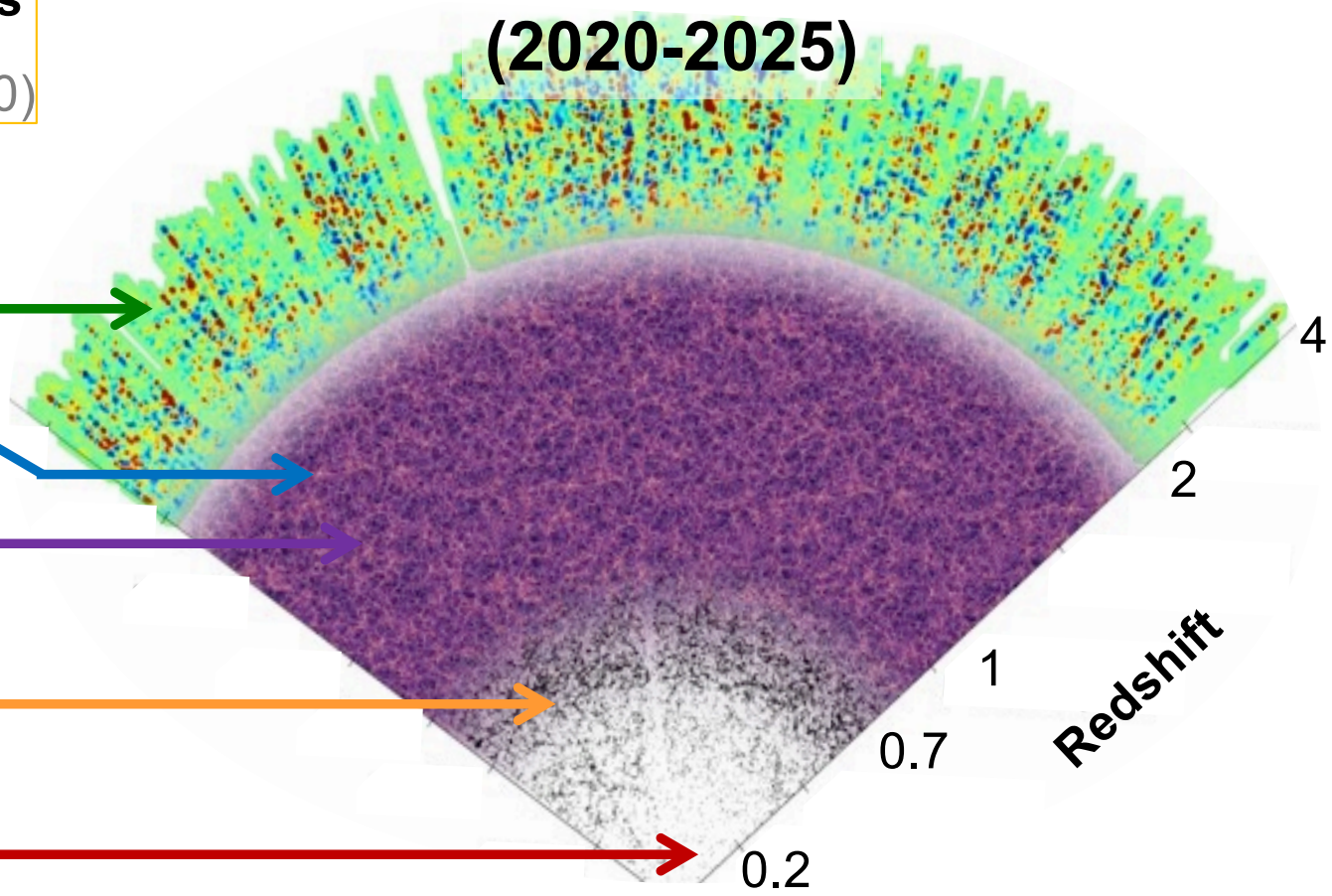
(SDSS x20)

2.4 million QSOs
Lya z > 2.1
Tracers 1.0 < z < 2.1

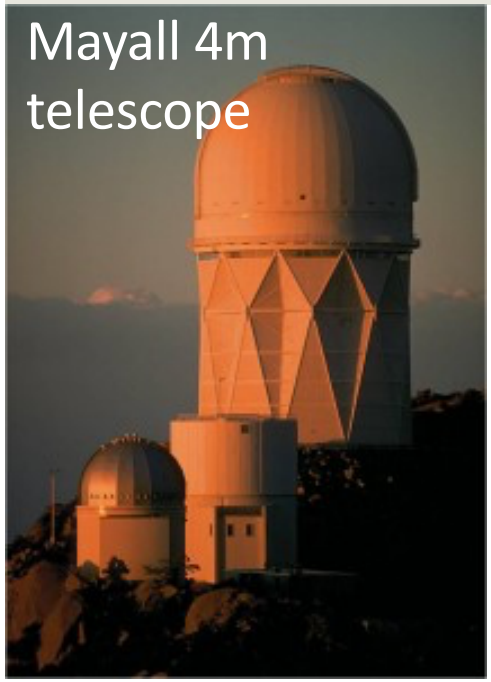
17 million ELGs
0.6 < z < 1.6

6 million LRGs
0.4 < z < 1.0

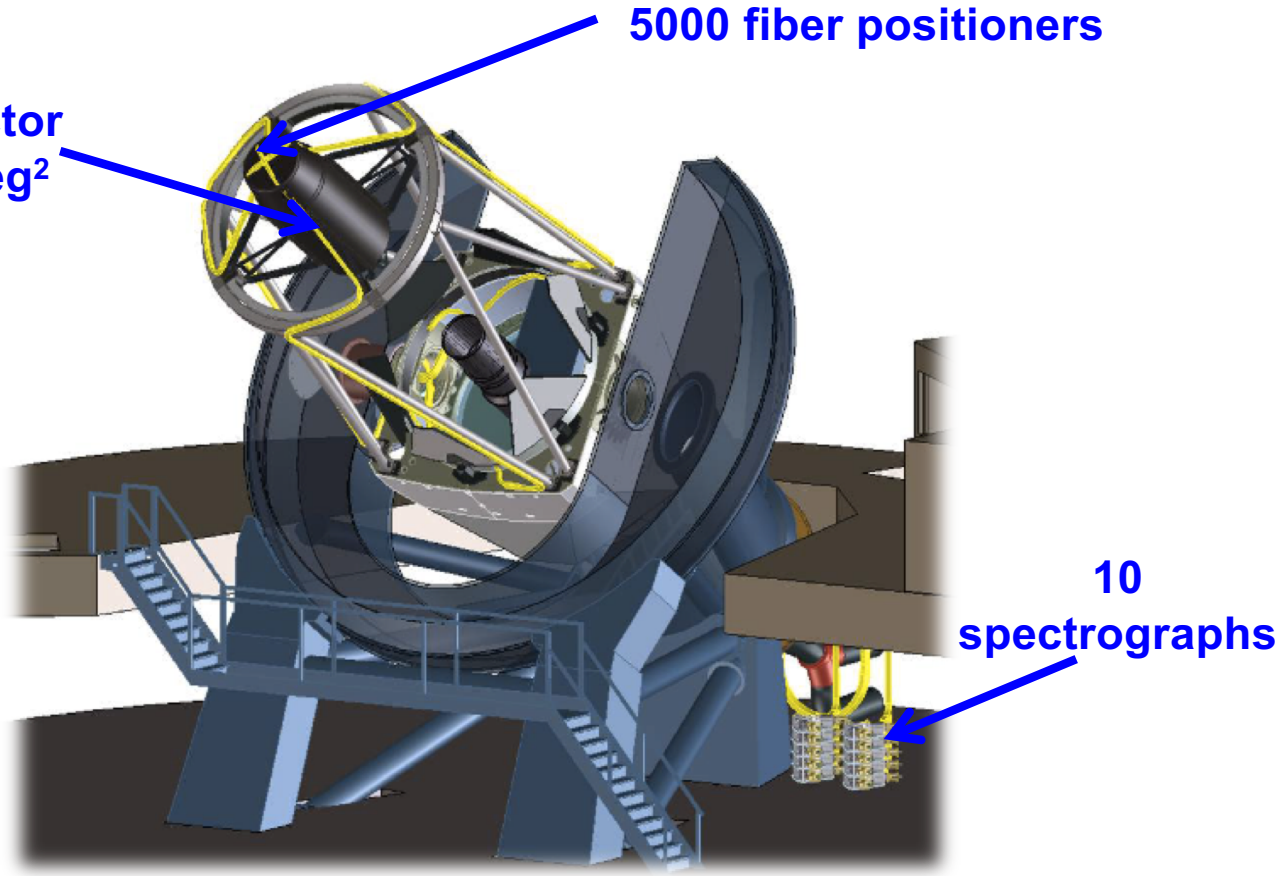
10 million
Brightest galaxies
0.0 < z < 0.4



DESI concept

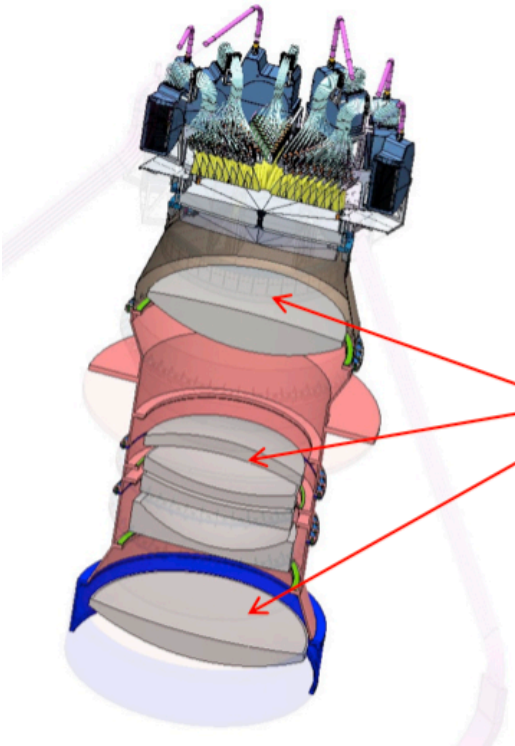


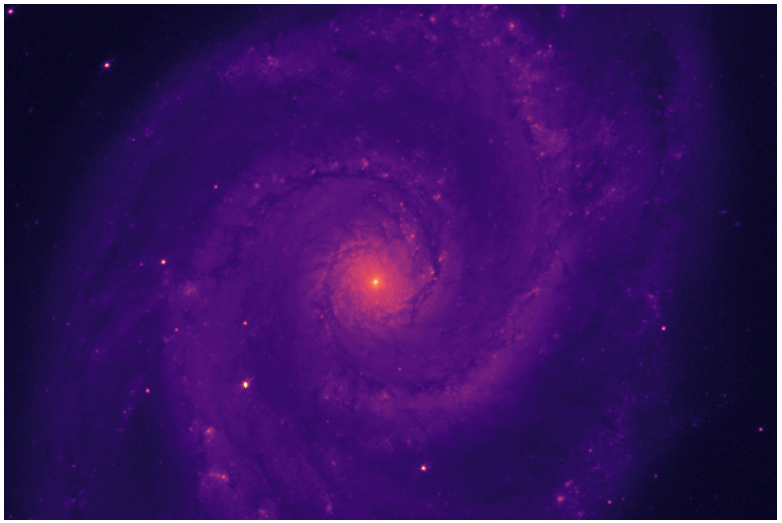
- 4m telescope at Kitt-peak (Arizona)
- Scale-up of BOSS with massively parallel fiber-fed spectrograph



DESI main hardware components

- Wide-field corrector
  FOV ~ 8 deg^2

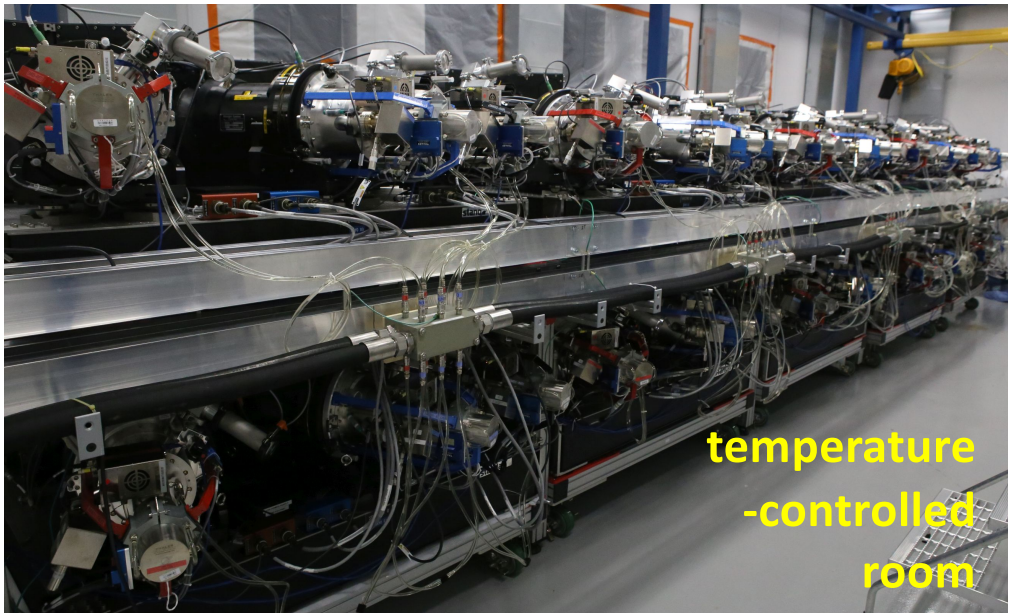




→ Sub-arcsecond images
over entire field of view !
(First light, April 2019)

DESI main hardware components

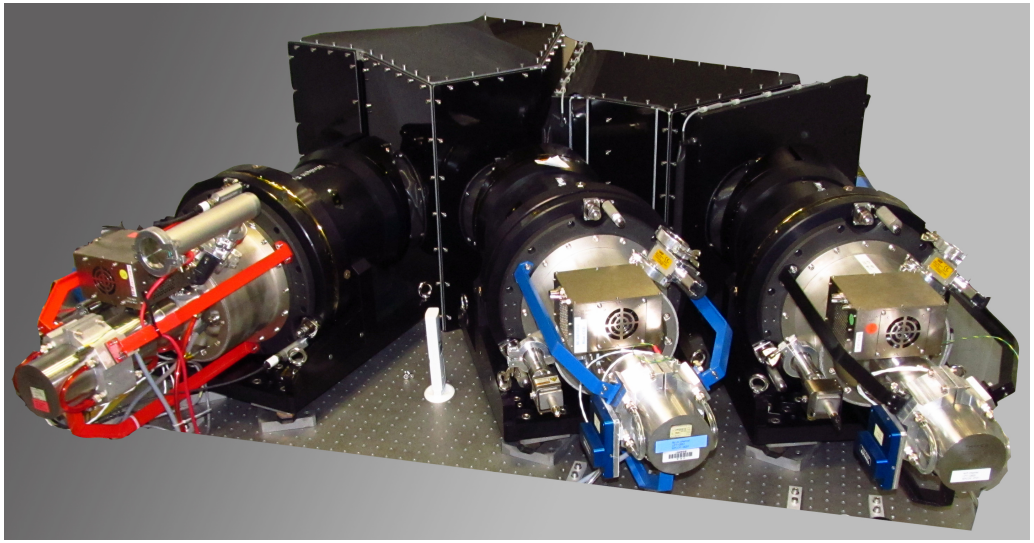
- Ten 3-channel spectrographs



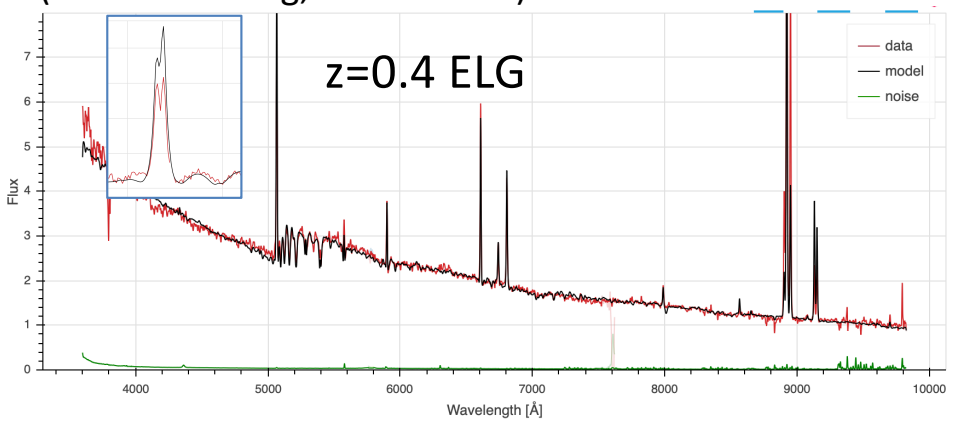
to cover from λ = 360 nm to 980 nm

Lyα λ121.6 nm
down to z = 2.0

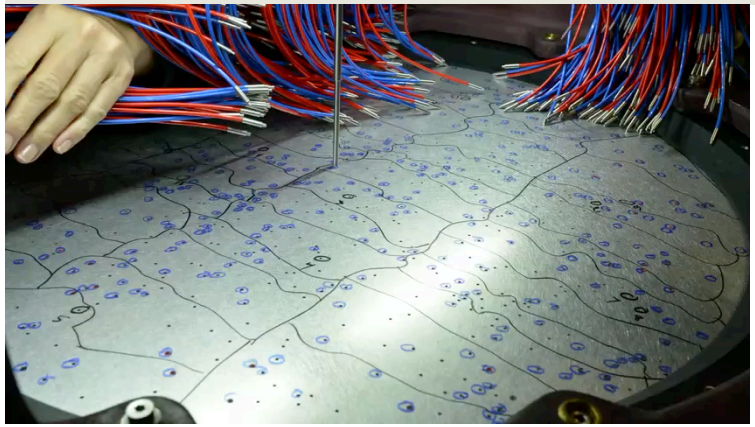
[OII] λ373 nm
up to z = 1.6



(Commissioning, March 2020)

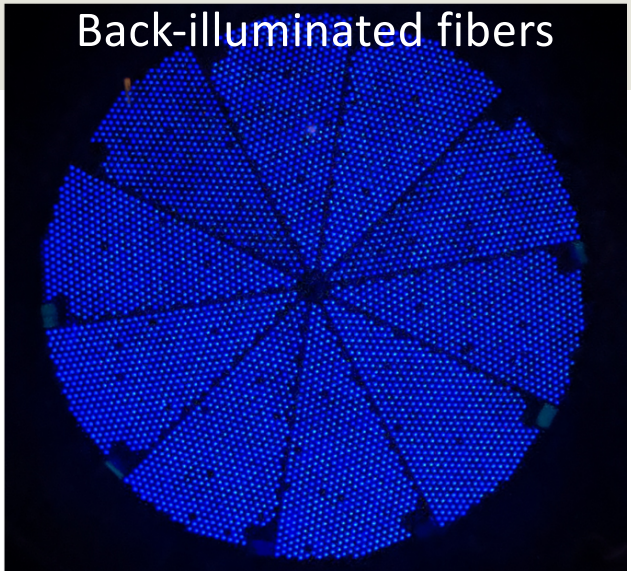


DESI main hardware components

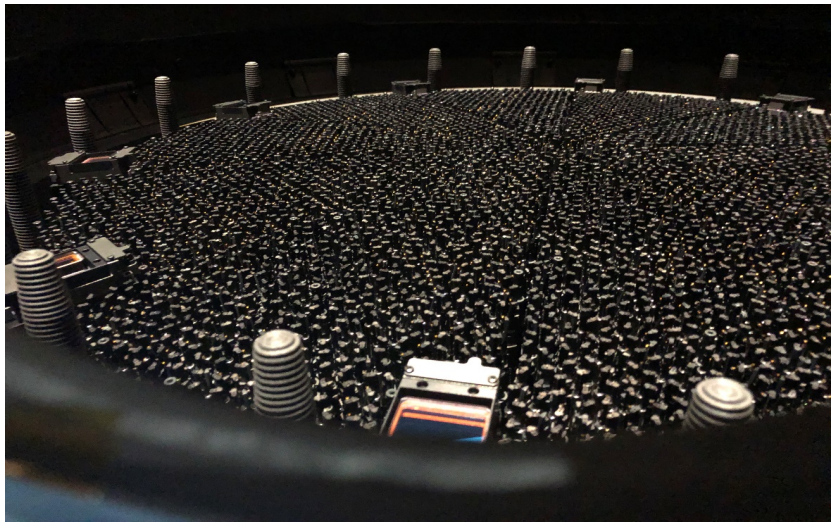


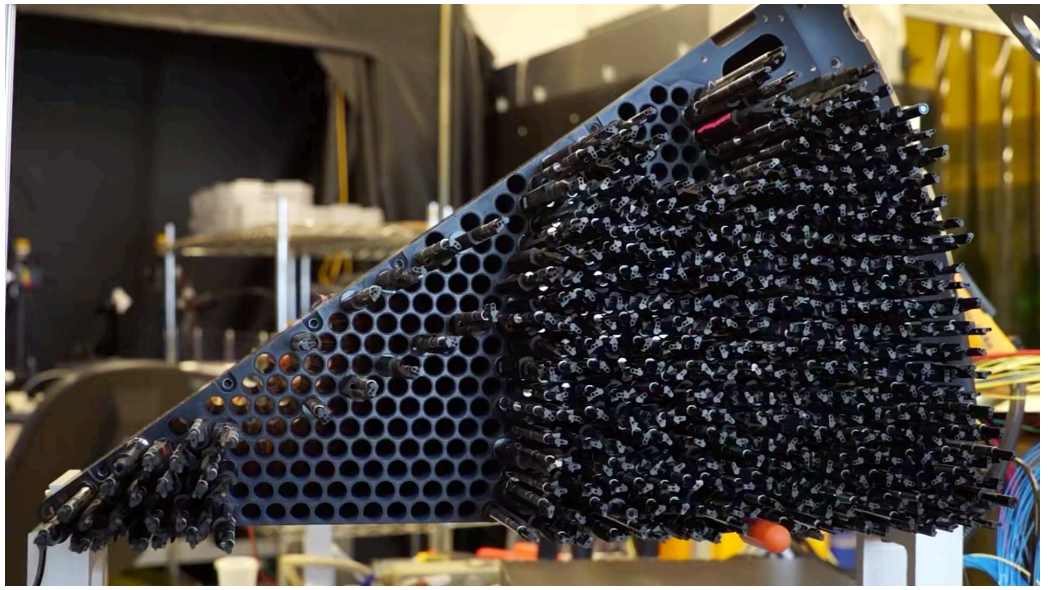
SDSS: 1-hr plugging

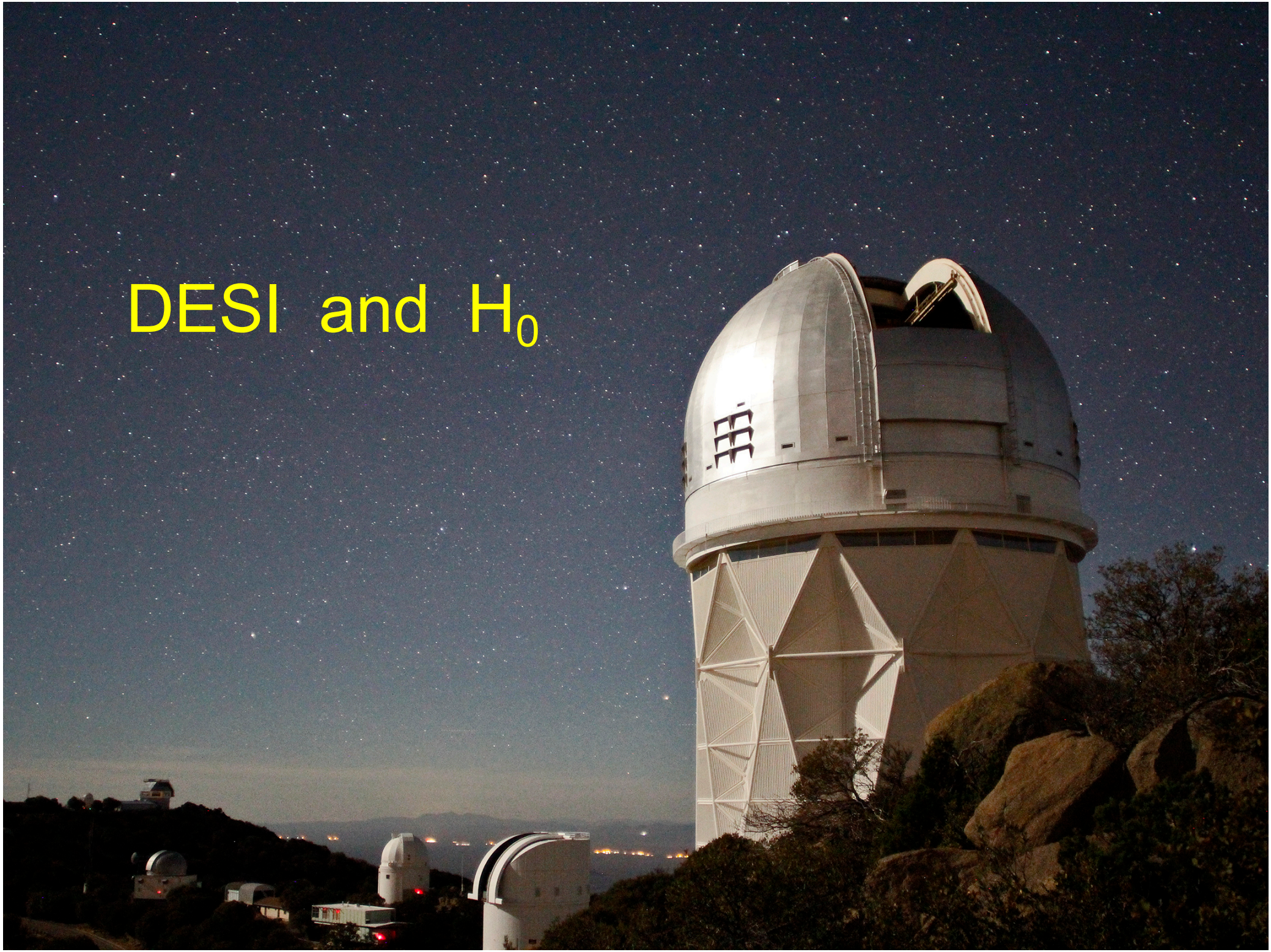
- 5000 robotic fiber positioners



DESI: 1-mn positioning

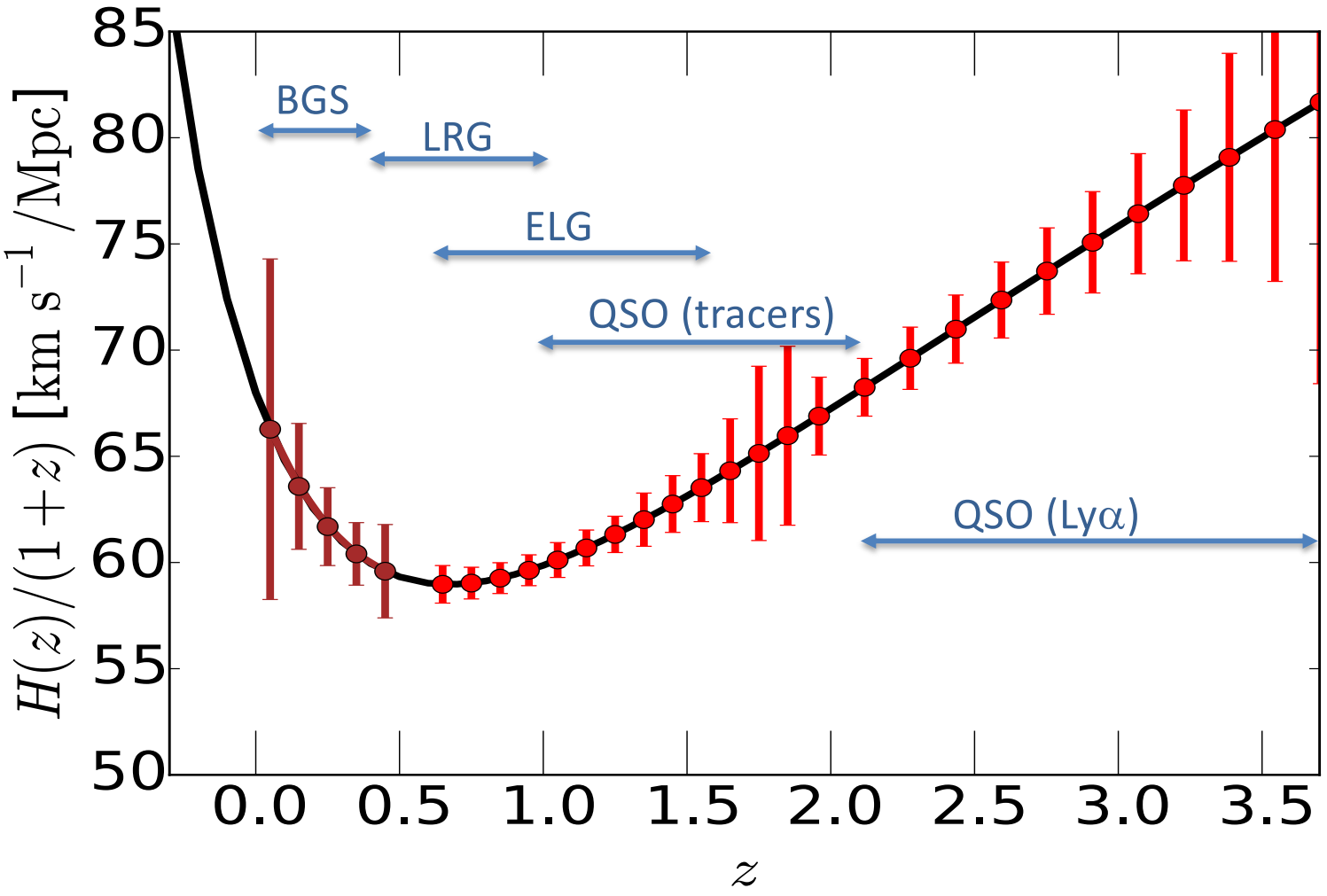





DESI and H_0

Baryon Acoustic Oscillations (BAO) - DESI

Expansion history



DESI goals

BAO:

$\sigma(R) < 0.28\%$ at $z<1.1$

$\sigma(R) < 0.39\%$ at $z>1.1$

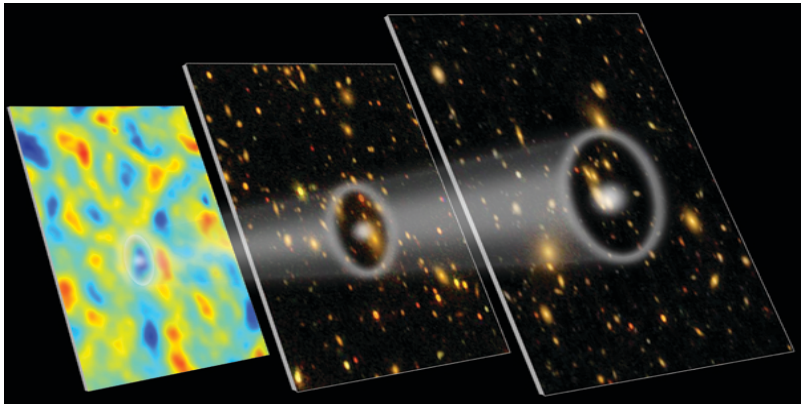
Expansion:

$\sigma(H) < 1\%$ at $1.9<z<3.7$

BAO and H_0

BAO measures $\Delta\theta$ and Δz

$$\Rightarrow \quad \frac{r_d}{D_A(z)} \quad \text{and} \quad \frac{r_d}{c/H(z)}$$



Requires r_d → $H(z)$ → H_0

$= f(\Omega_b, \Omega_c)$ $\quad$ $= f(\Omega_m(z), H_0)$

From CMB
(Planck 2018)
$100\Omega_b h^2 = 2.229 \pm 0.015$

From ^{2}D + BBN
(Cooke et al. 2018)
$100\Omega_b h^2 = 2.166 \pm 0.019$

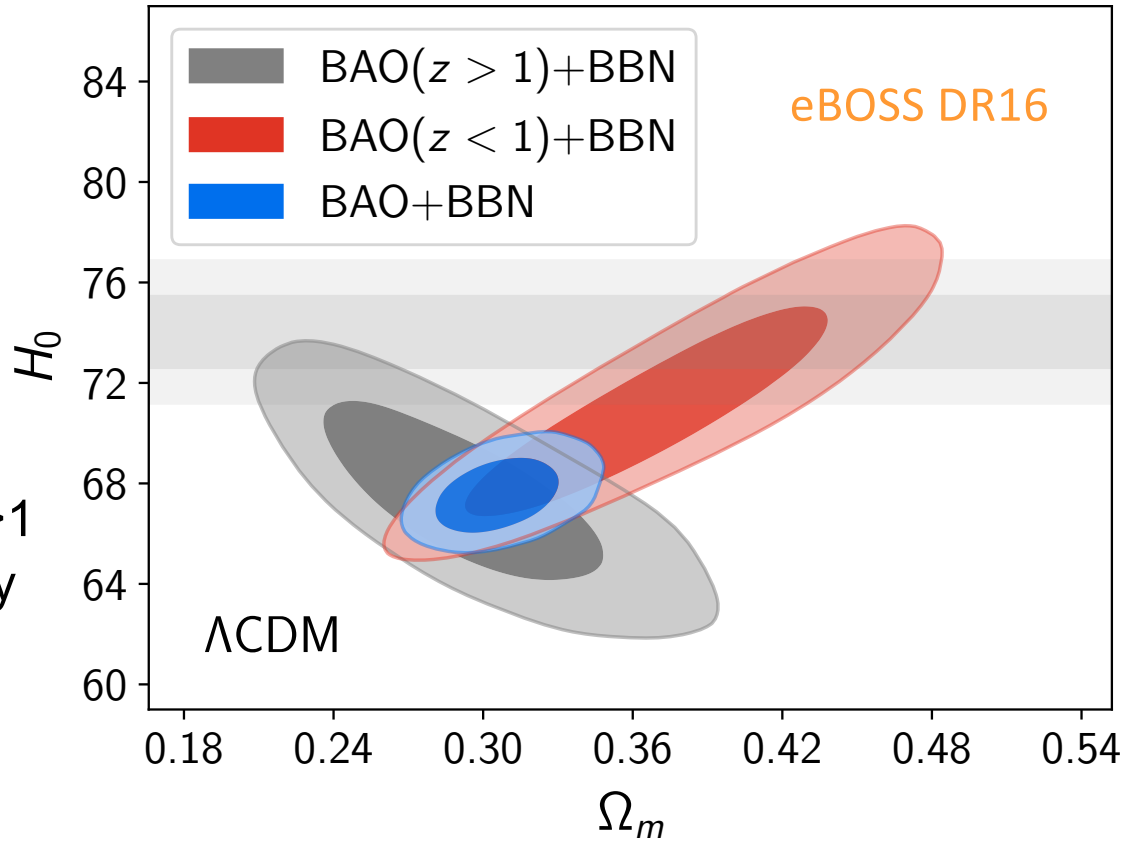
Parameter degeneracy
constrained by z-dependence
of BAO measurement
(z<1 vs. z>1)
Result insensitive to Ω_k, w(z)

BAO and H_0

Coming up soon !

eBOSS DR16 BAO +BBN
z=0.15 (galaxy) to z=2.35 (Lyα)
$\delta H_0 = 1.0$

- excellent compatibility z<1 vs. z>1
- internal lift the H_0-Ω_m degeneracy



BAO and H_0

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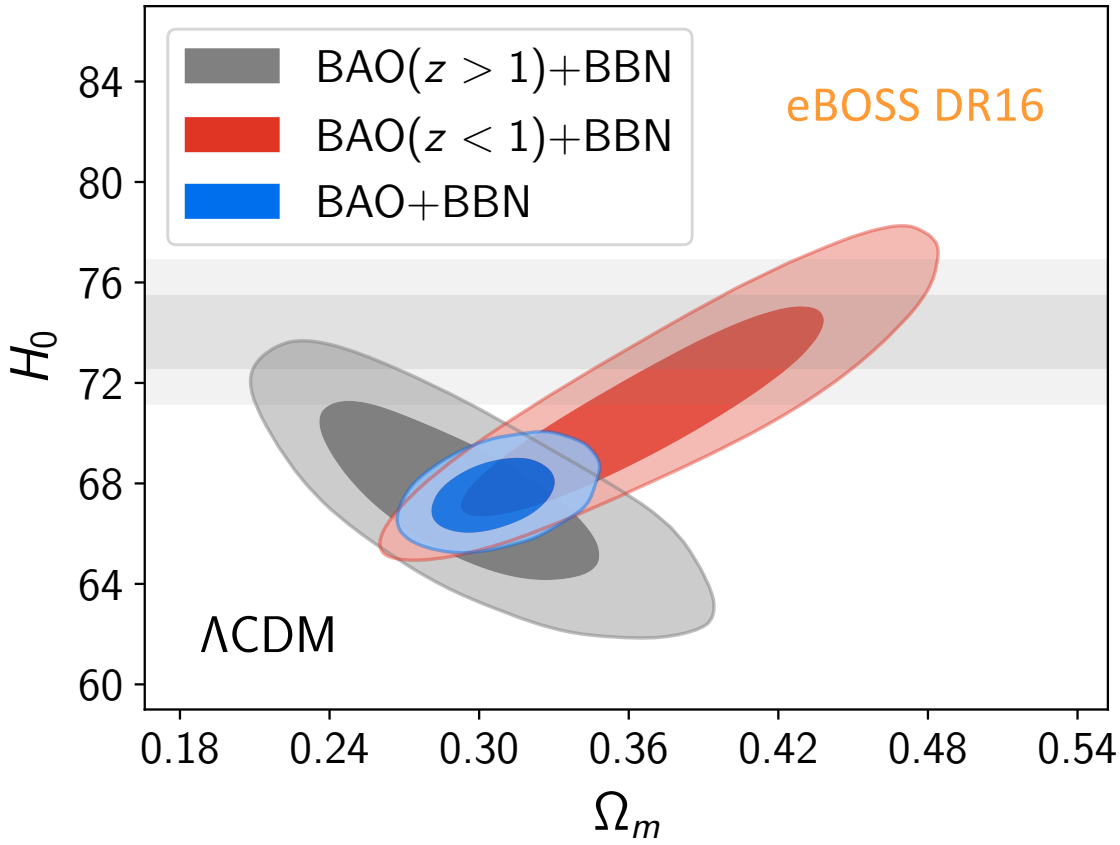


DESI forecast

$\delta H_0 = 0.19$ (Planck + ΛCDM + fixed m_ν)
$\delta H_0 = 0.27$ (Planck + ΛCDM + free m_ν)

BAO and H_0

Coming up soon !

eBOSS DR16 BAO

z=0.15 (gal.) to 2.35 (Lya)

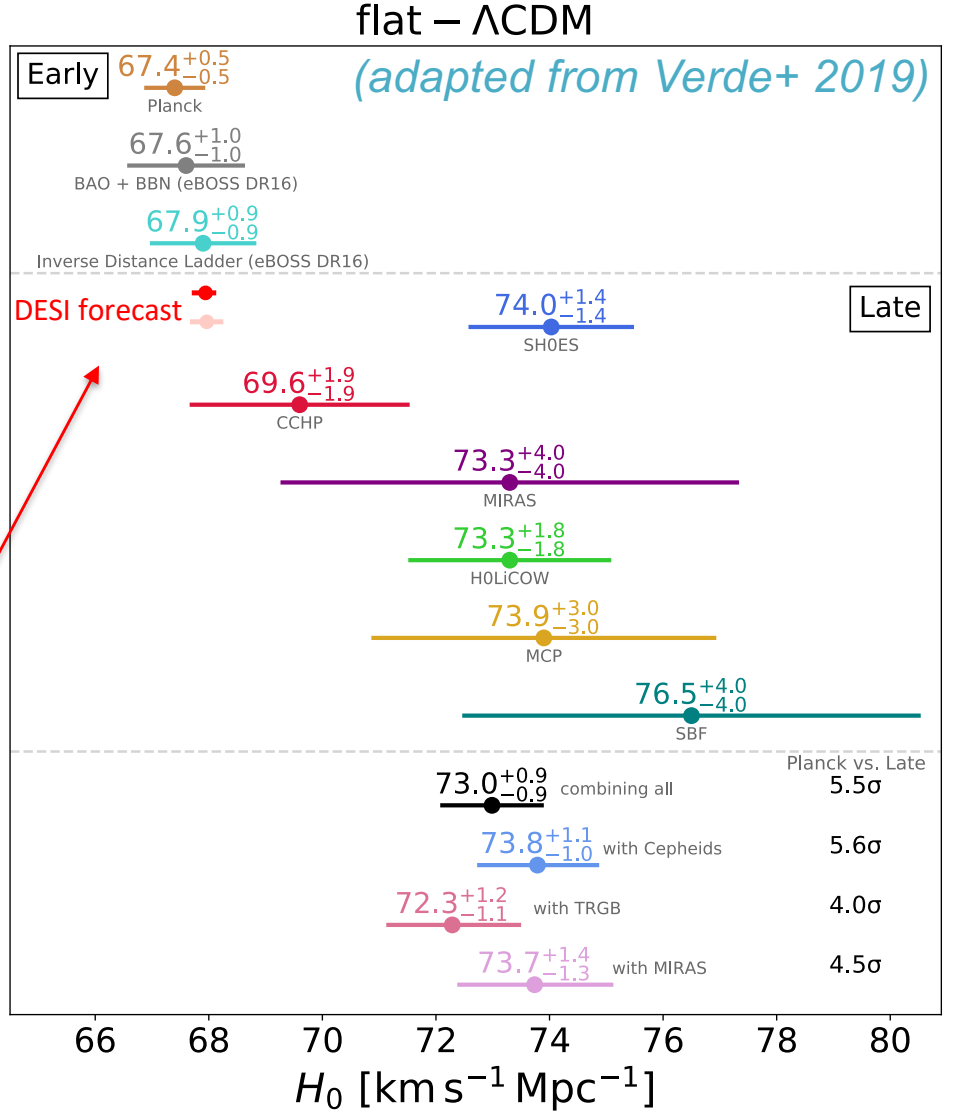
H_0 = 67.6 ± 1.0 (+BBN, ΛCDM)

H_0 = 67.9 ± 0.9 (+CMB+SN, ow_0w_aCDM)

DESI forecast

δH_0 = 0.19 (Planck + ΛCDM + fixed m_ν)

δH_0 = 0.27 (Planck + ΛCDM + free m_ν)



BAO and H0 in the DESI era

Conclusions

- BAO can provide a constraint on H_0
  - through the inverse distance ladder approach
  - Mostly insensitive to the model of cosmic evolution
  - Independent of CMB when r_d is determined from BBN + ^{2}D

- BAO + rd – current status (eBOSS DR16)
  - H0 = 67.6 ± 1.0 (BAO+BBN, LCDM)
  - H0 = 67.9 ± 0.9 (BAO+CMB+SN, ow_0w_aCDM)

- BAO measurements from DESI expected to yield
  - δH_0 = 0.19 (Planck + ΛCDM + fixed m_ν)
  - δH_0 = 0.27 (Planck + ΛCDM + free m_ν)