



The cosmological implications from the extended Baryon Oscillation Spectroscopic Survey

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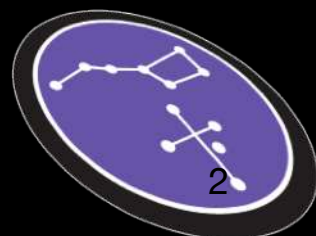
julian.bautista@port.ac.uk





20 years of SDSS redshift surveys

<https://www.youtube.com/watch?v=KJJXbcf8kxA> (by EPFL.ch)



(e)BOSS

(extended) Baryon Oscillation Spectroscopic Survey

Dawson et al. 2016

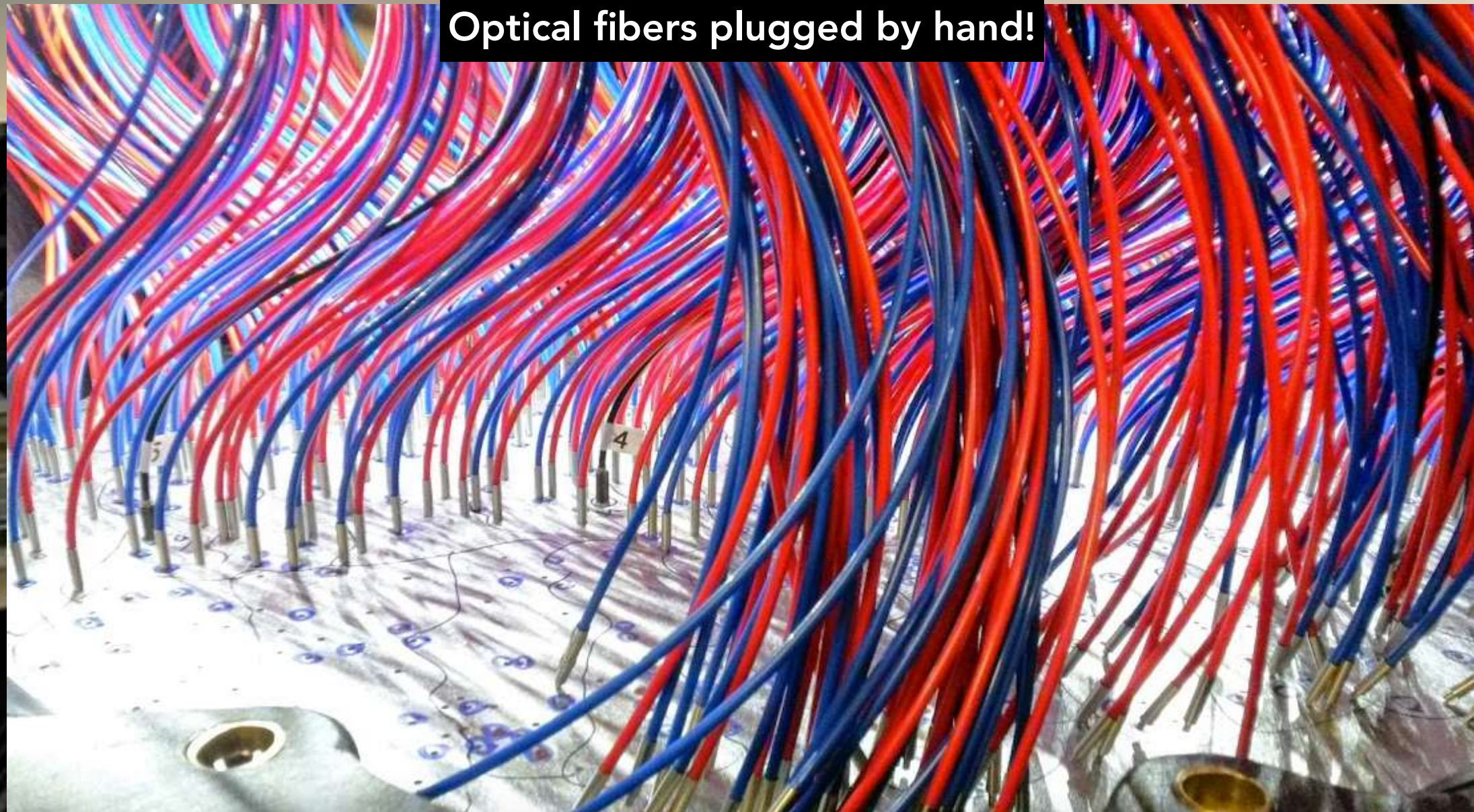


Sloan Digital Sky Survey Telescope
Apache Point Observatory, New Mexico, USA

(e)BOSS

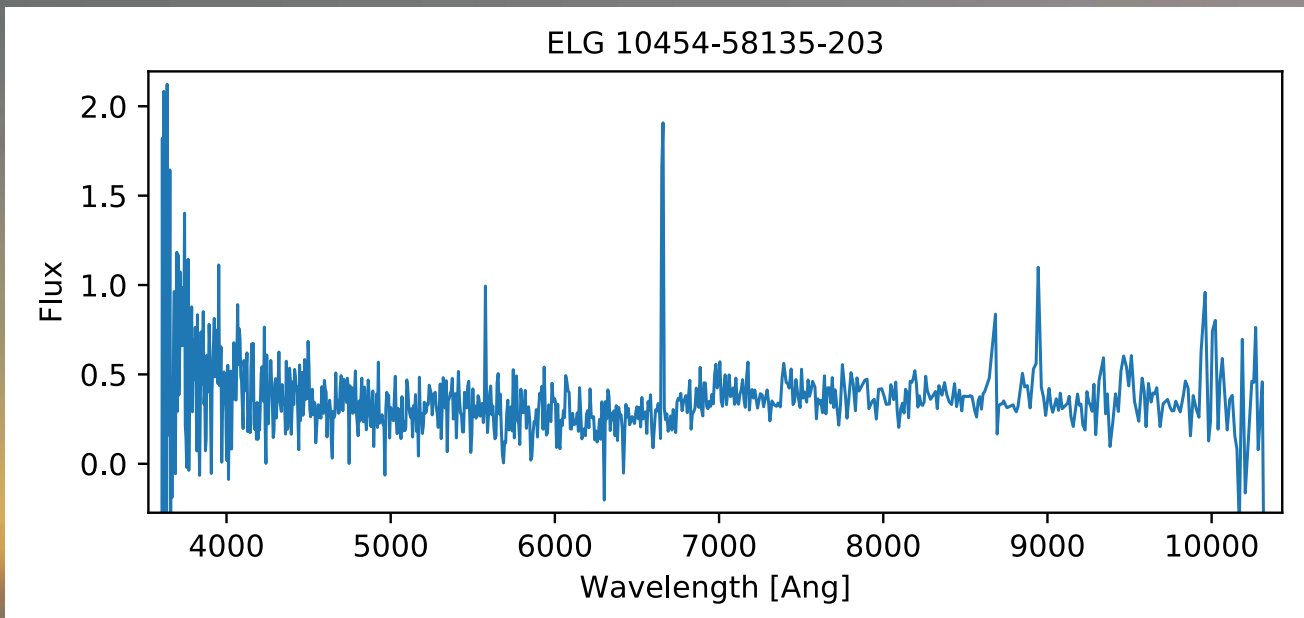
(extended) Baryon Oscillation Spectroscopic Survey

Dawson et al. 2016

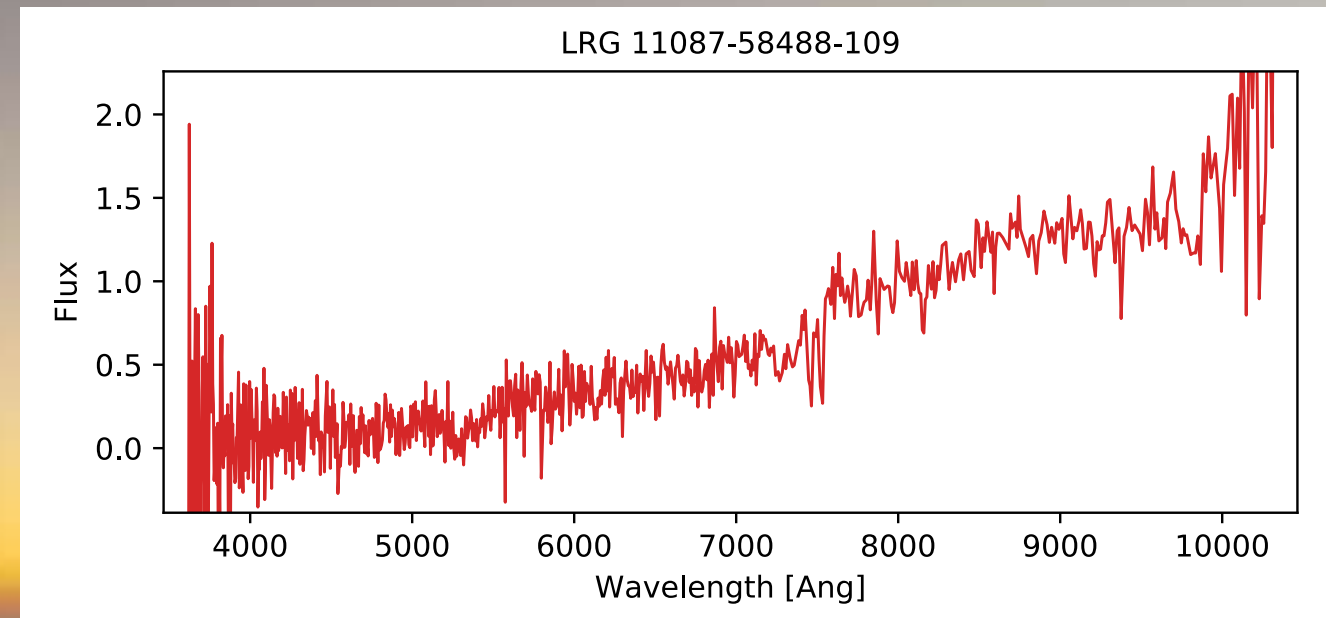


eBOSS Spectra

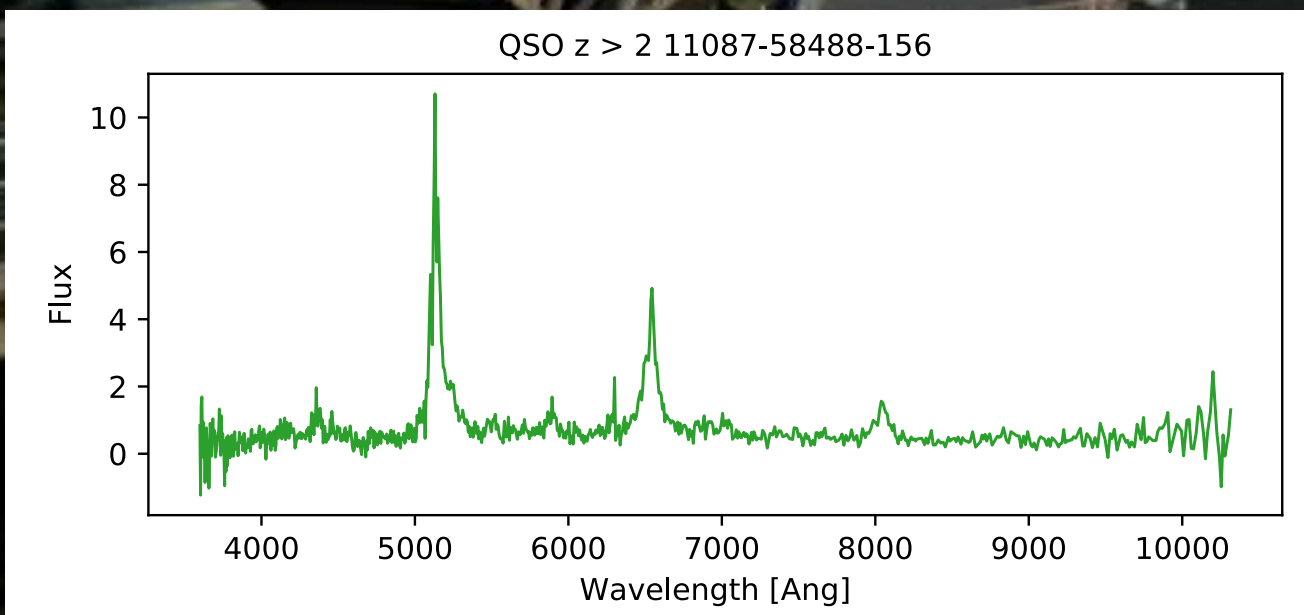
Emission Line Galaxies



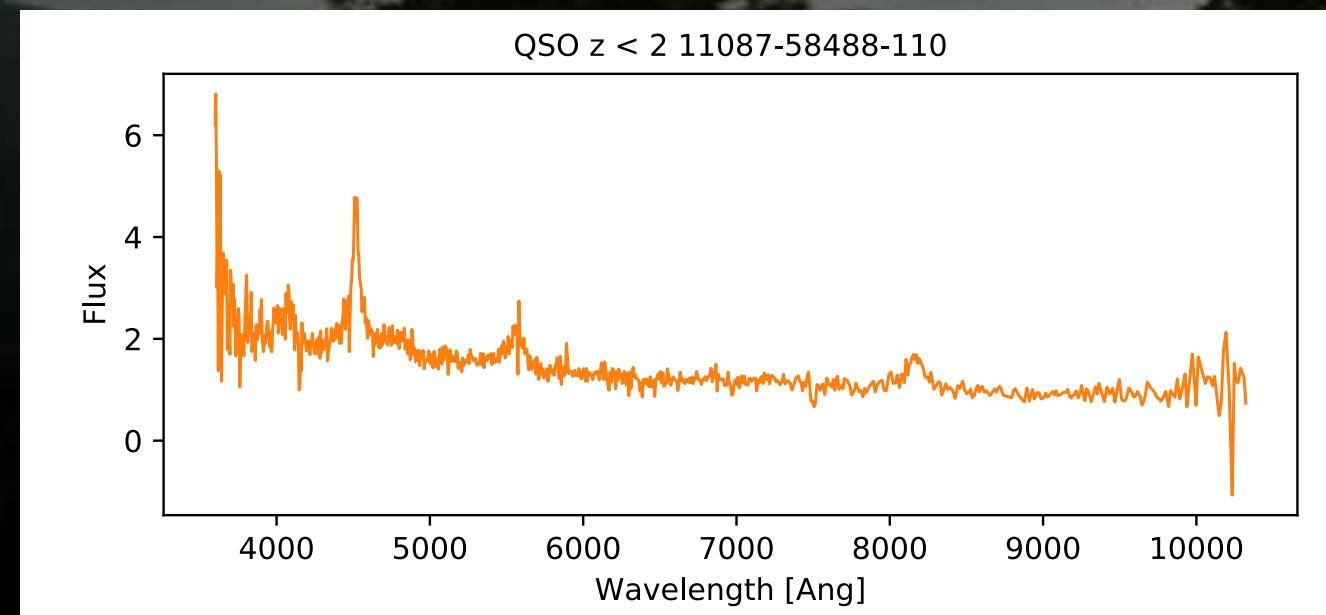
Luminous Red Galaxies



Quasars ($z > 2$) for Lyman-alpha forest

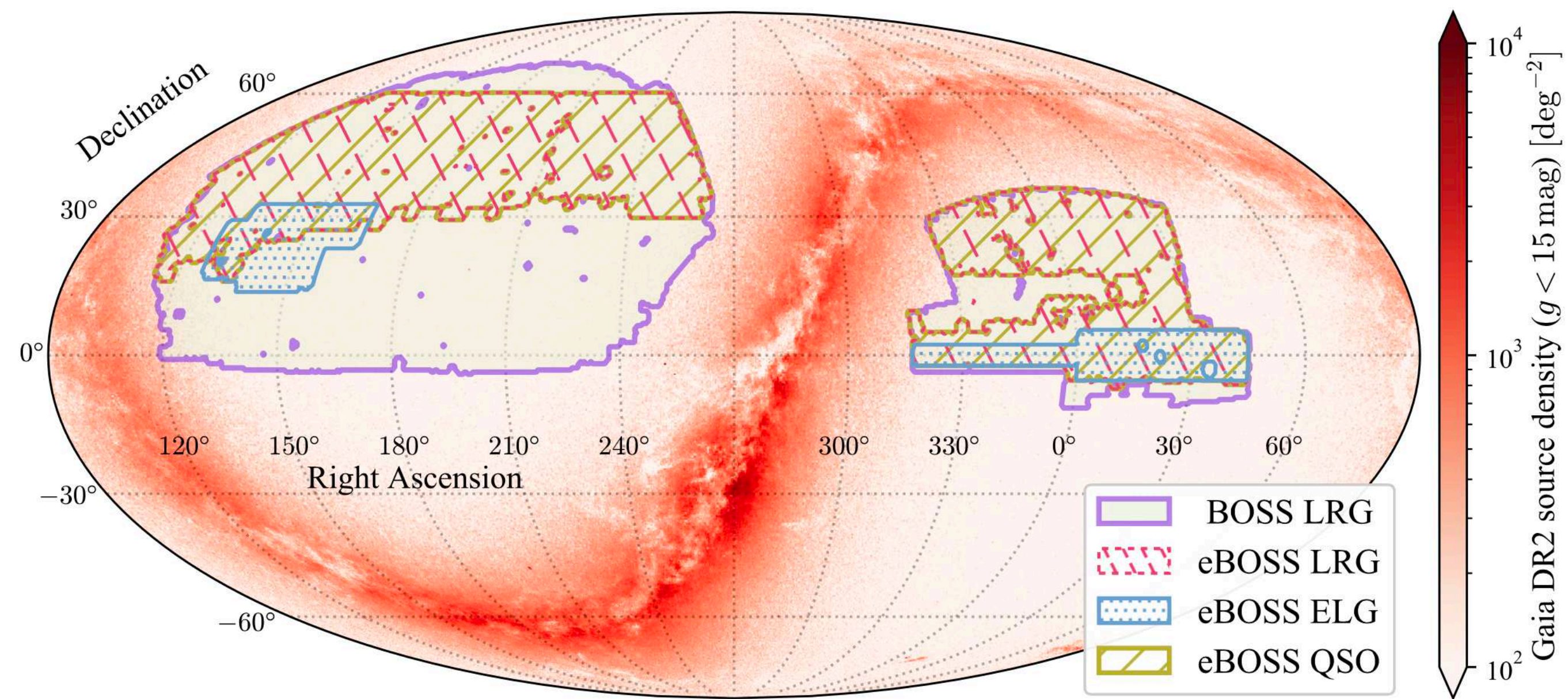


Quasars ($0.8 < z < 2.2$)



Redshifts obtained with *redrock* (galaxies) and *QuasarNET* + visual inspection (QSOs)

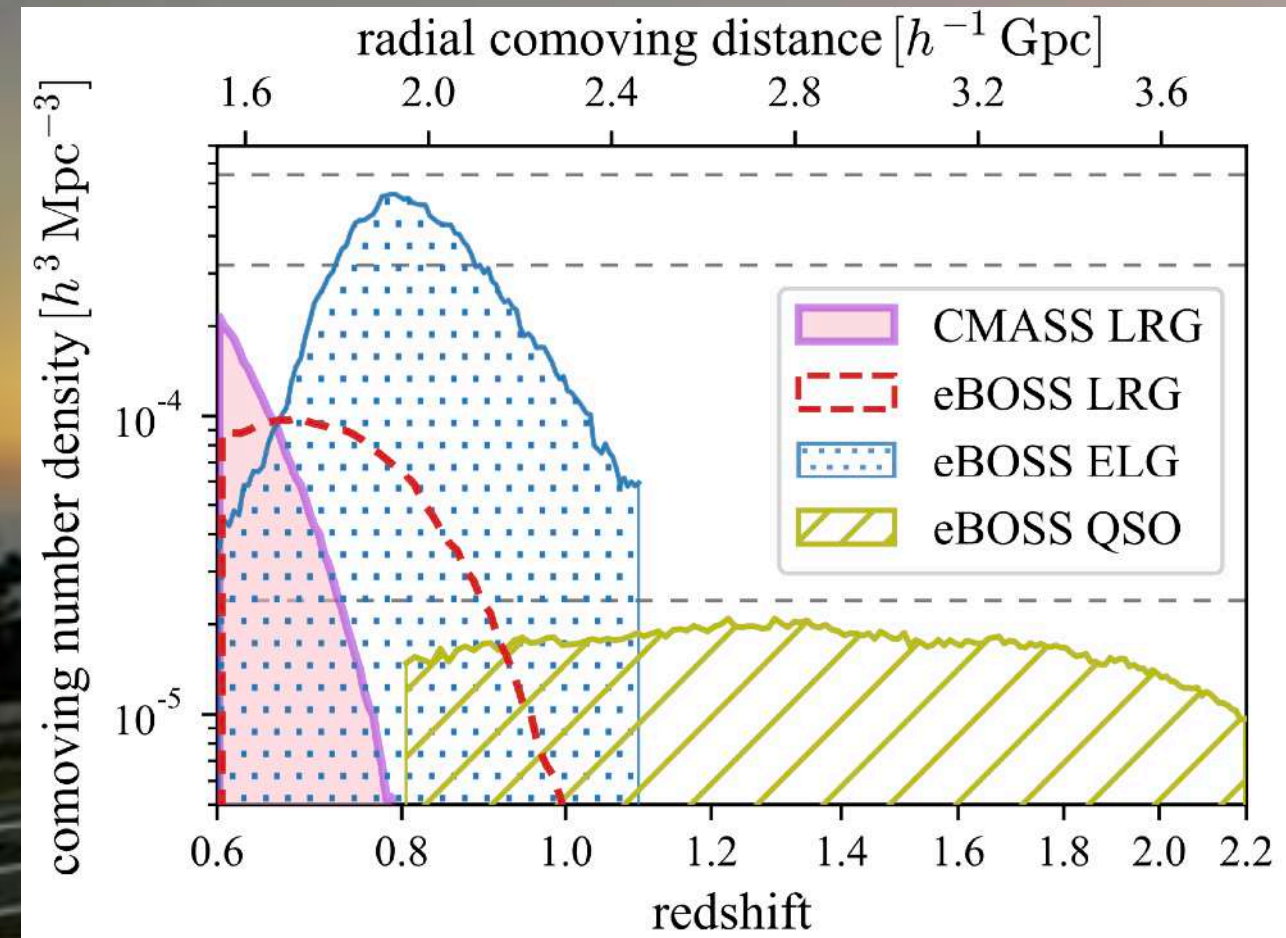
eBOSS Footprint



(Figure from C. Zhao et al. 2020)

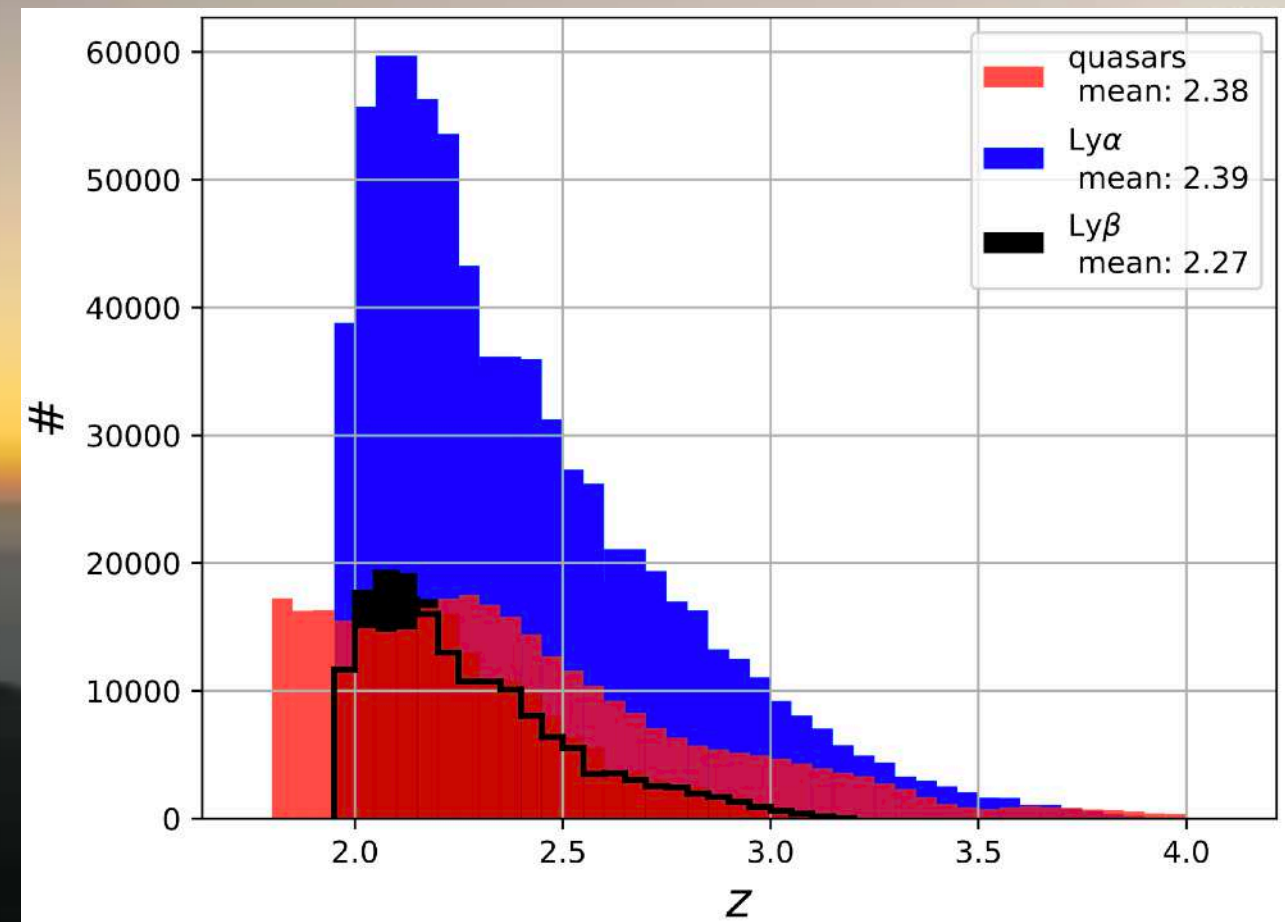
Number density of tracers

Discrete tracers



(Figure from C. Zhao et al. 2020)

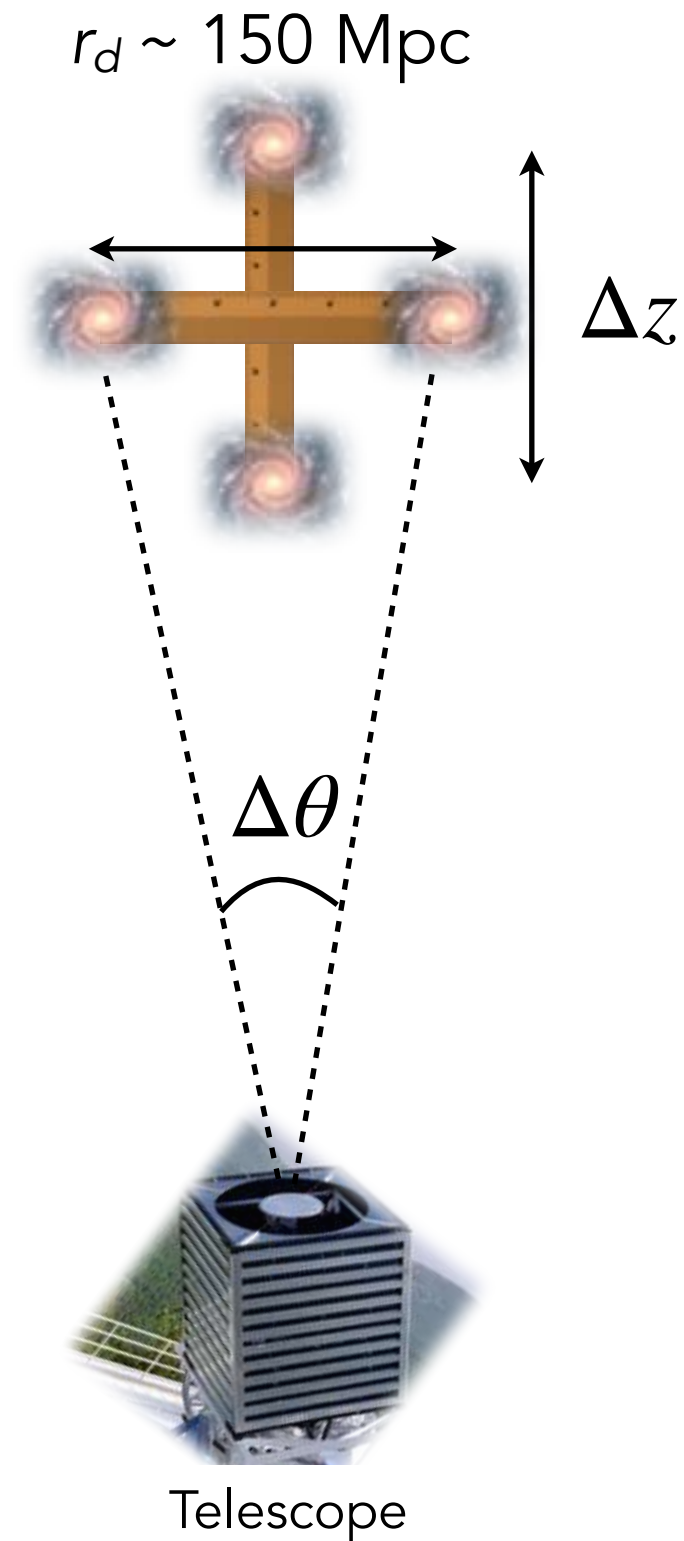
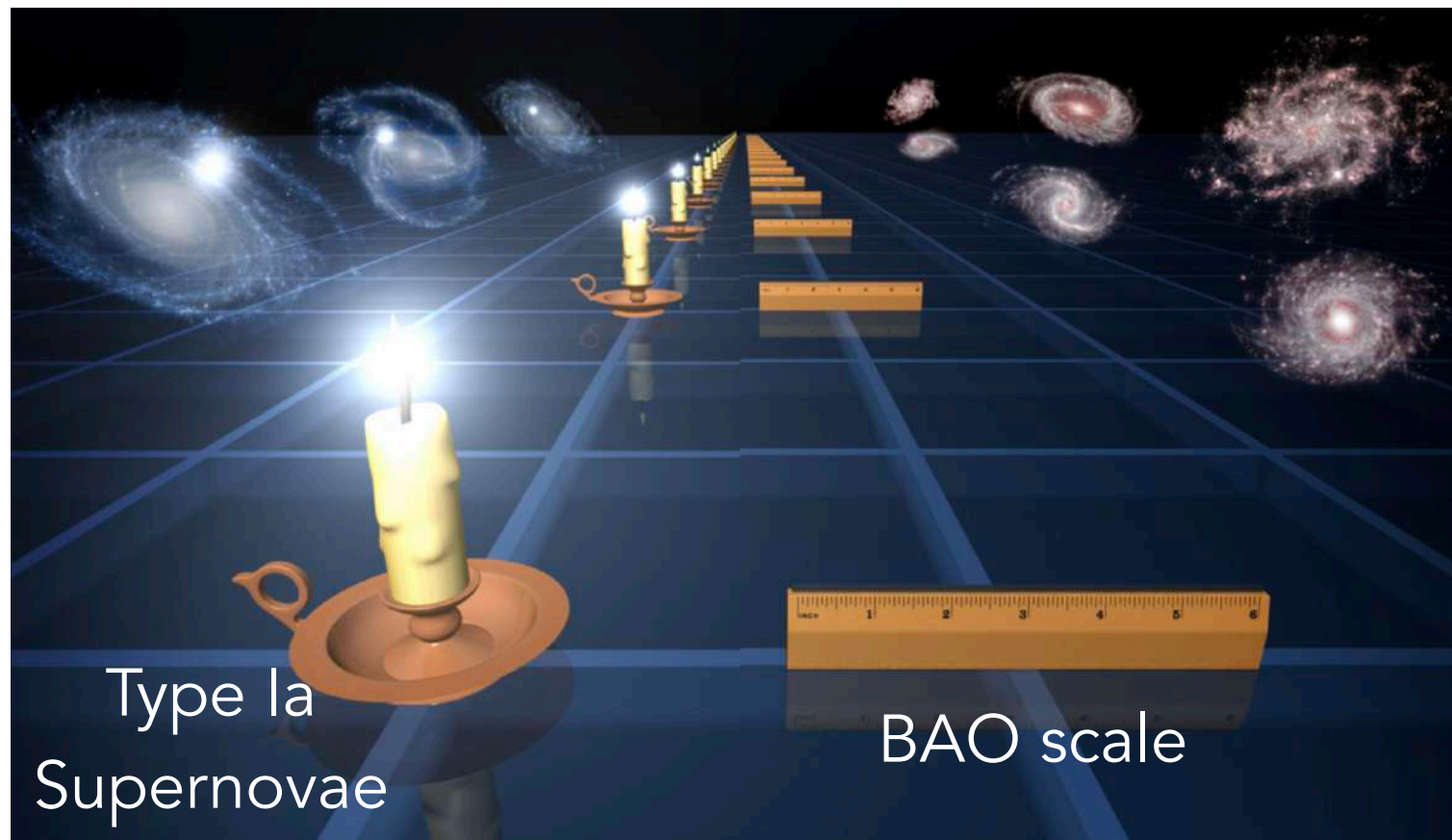
Lyman-alpha/beta forest



(Figure from du Mas des Bourboux et al. 2020)

Baryon Acoustic Oscillations (BAO)

Geometrical probes of the expansion



$$\Delta\theta = \frac{r_d}{D_M(z)}$$

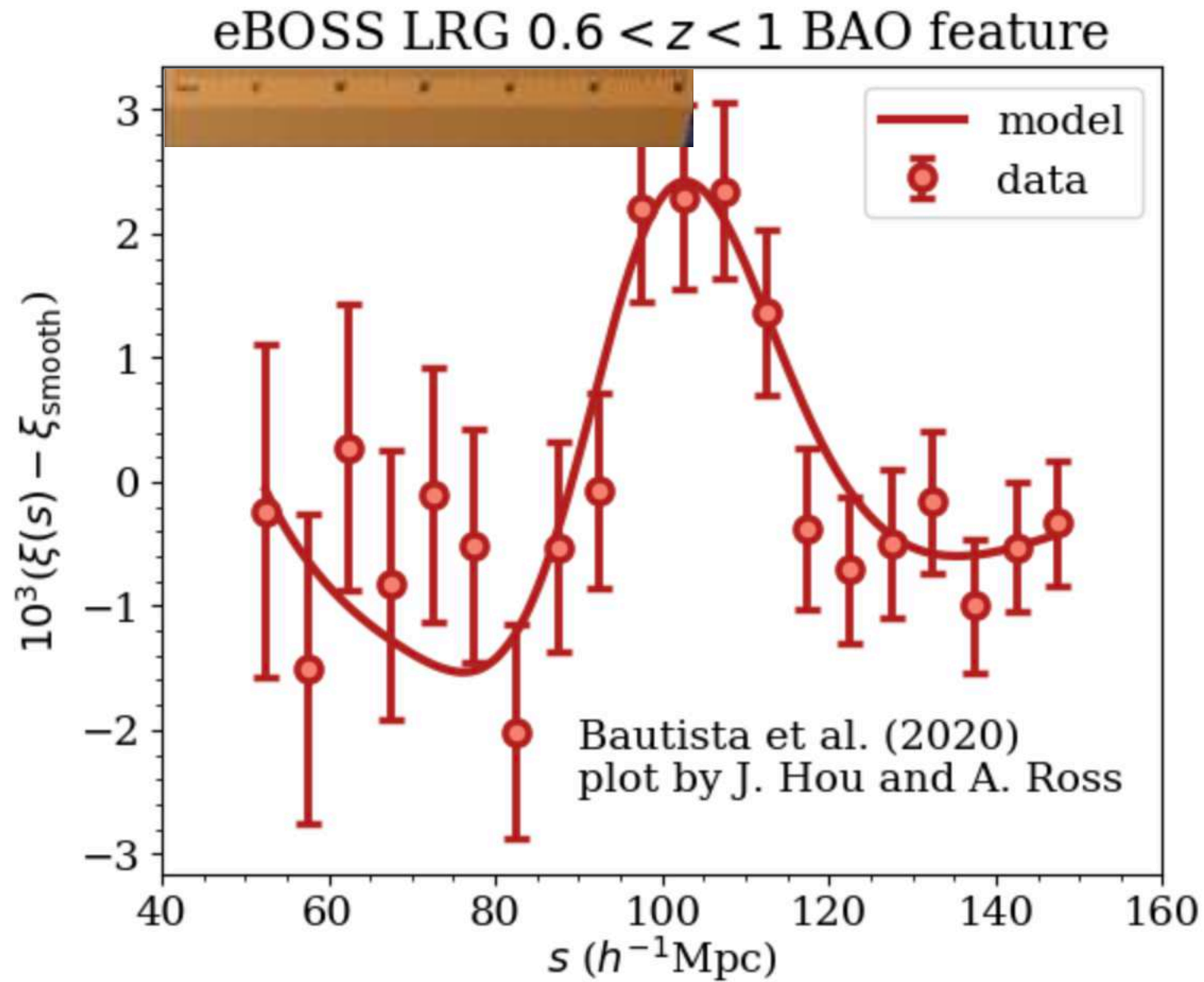
Distances

$$\Delta z = \frac{r_d H(z)}{c}$$

Expansion rate of the Universe



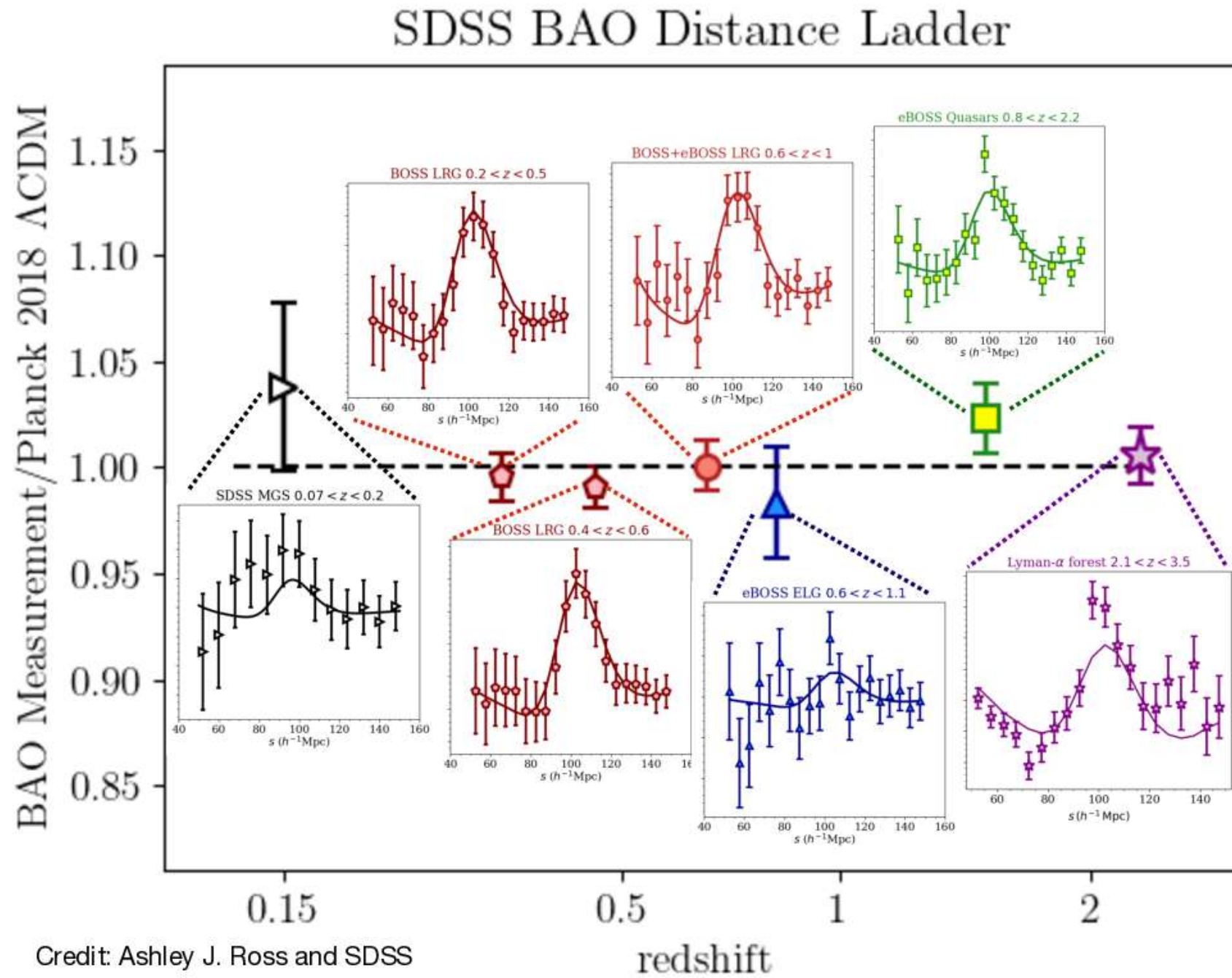
Baryon Acoustic Oscillations (BAO)



For more, see talk by Mariana Vargas-Magaña



Baryon Acoustic Oscillations (BAO)



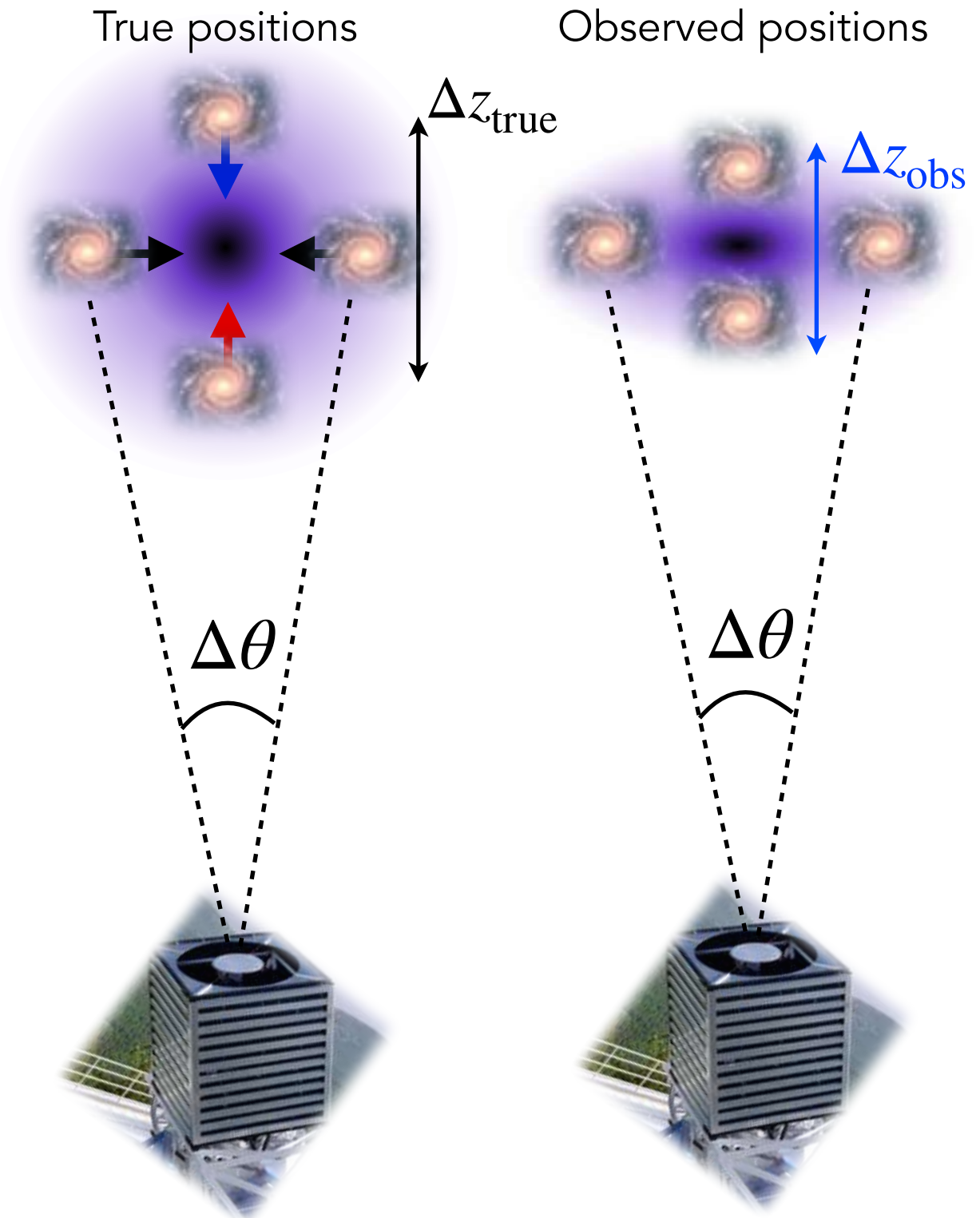
Peculiar velocities modify redshifts and squeeze structures in the radial direction

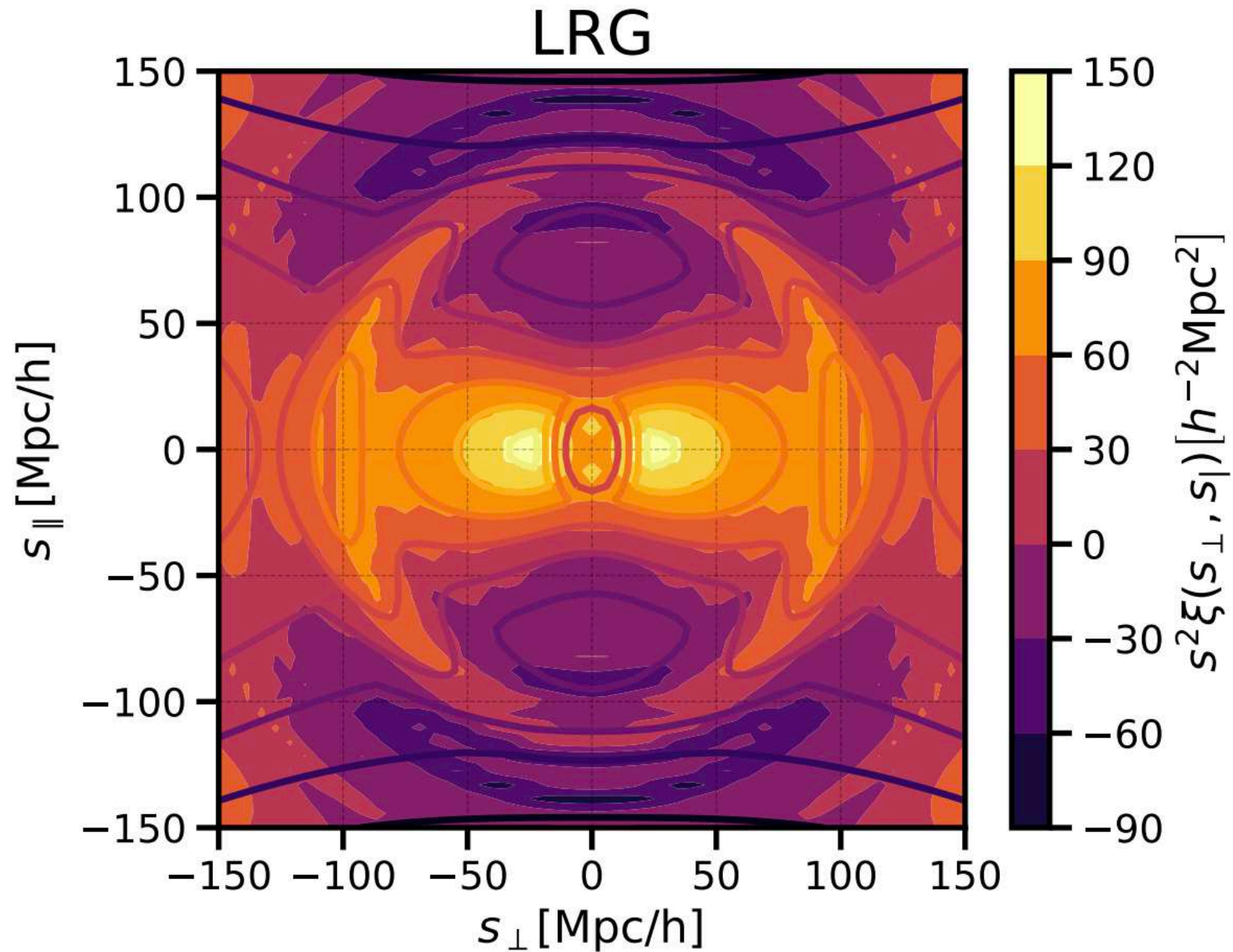
Growth rate of structures in general relativity (GR) :

$$f(z) \sim [\Omega_m(z)]^{\gamma=0.55}$$

We can measure $f(z)$ from the RSD

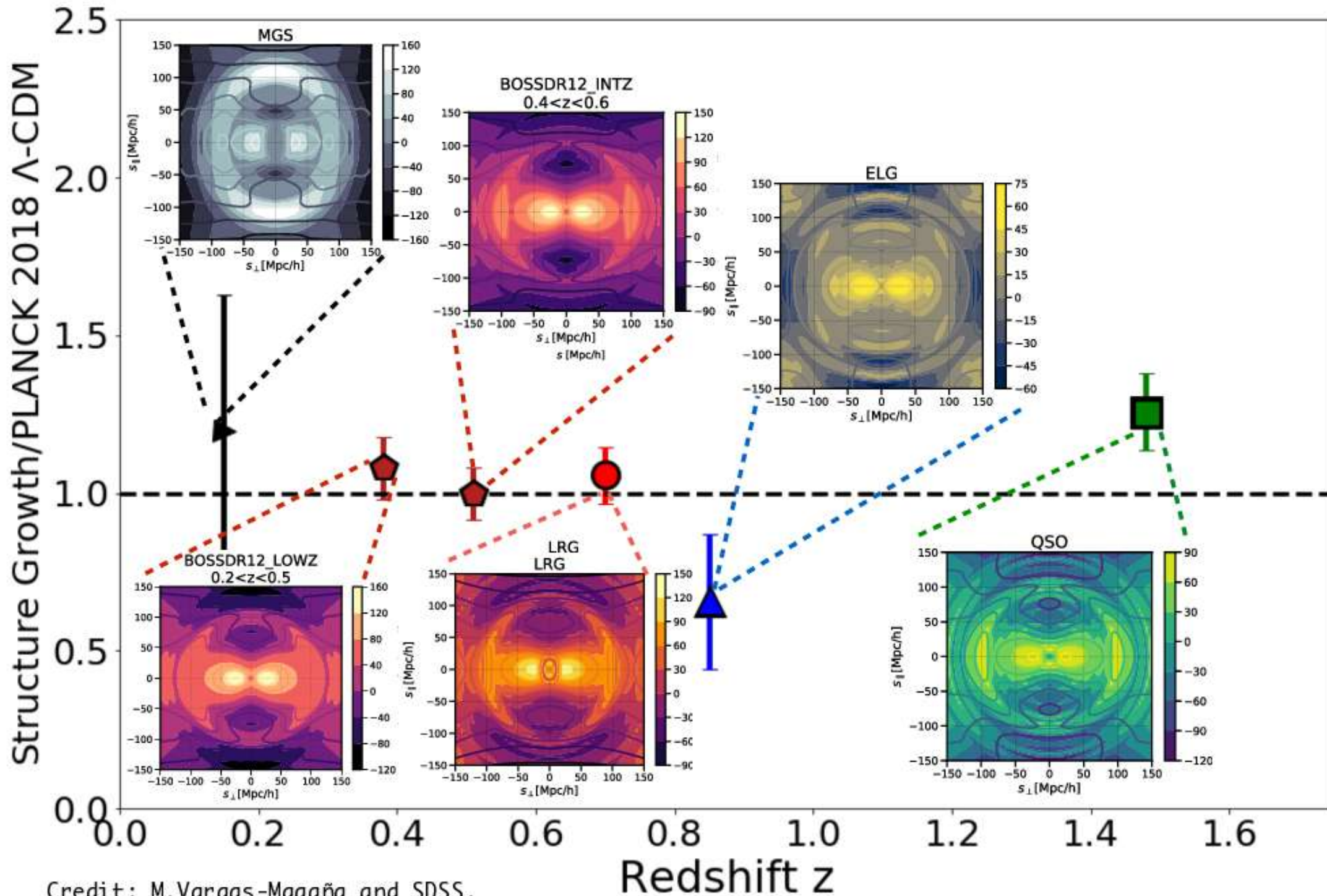
RSD allow us to test the validity of GR





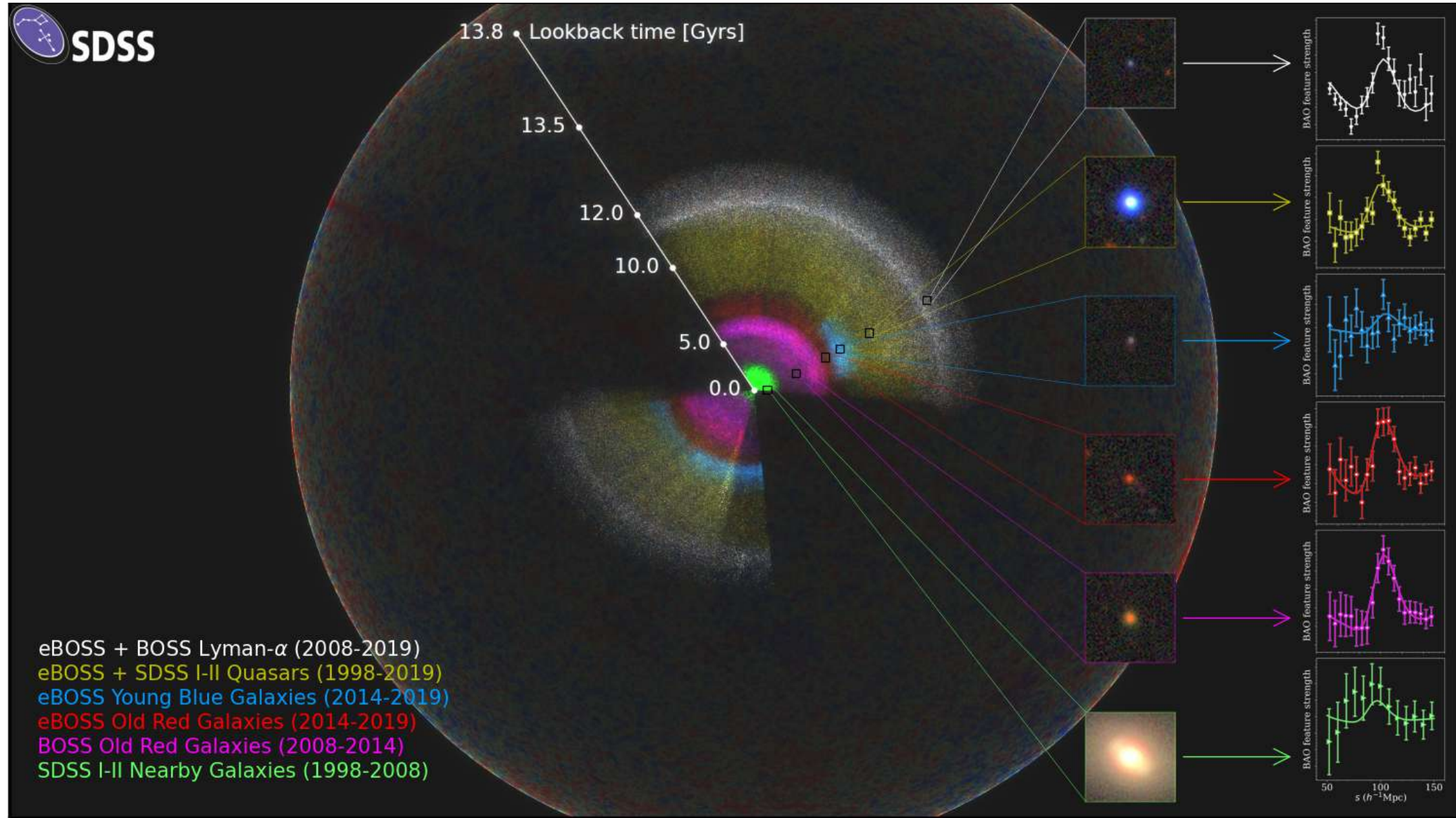
Bautista et al. (2020)
(plot by Jiamin Hou, MPE)

For more, see talk by Hector Gil-Marín



Largest 3D map of the Universe

Fly-through: <https://www.youtube.com/watch?v=KJJXbcf8kxA>



Anand Raichoor (EPFL), Ashley Ross (Ohio State University) and the SDSS Collaboration.

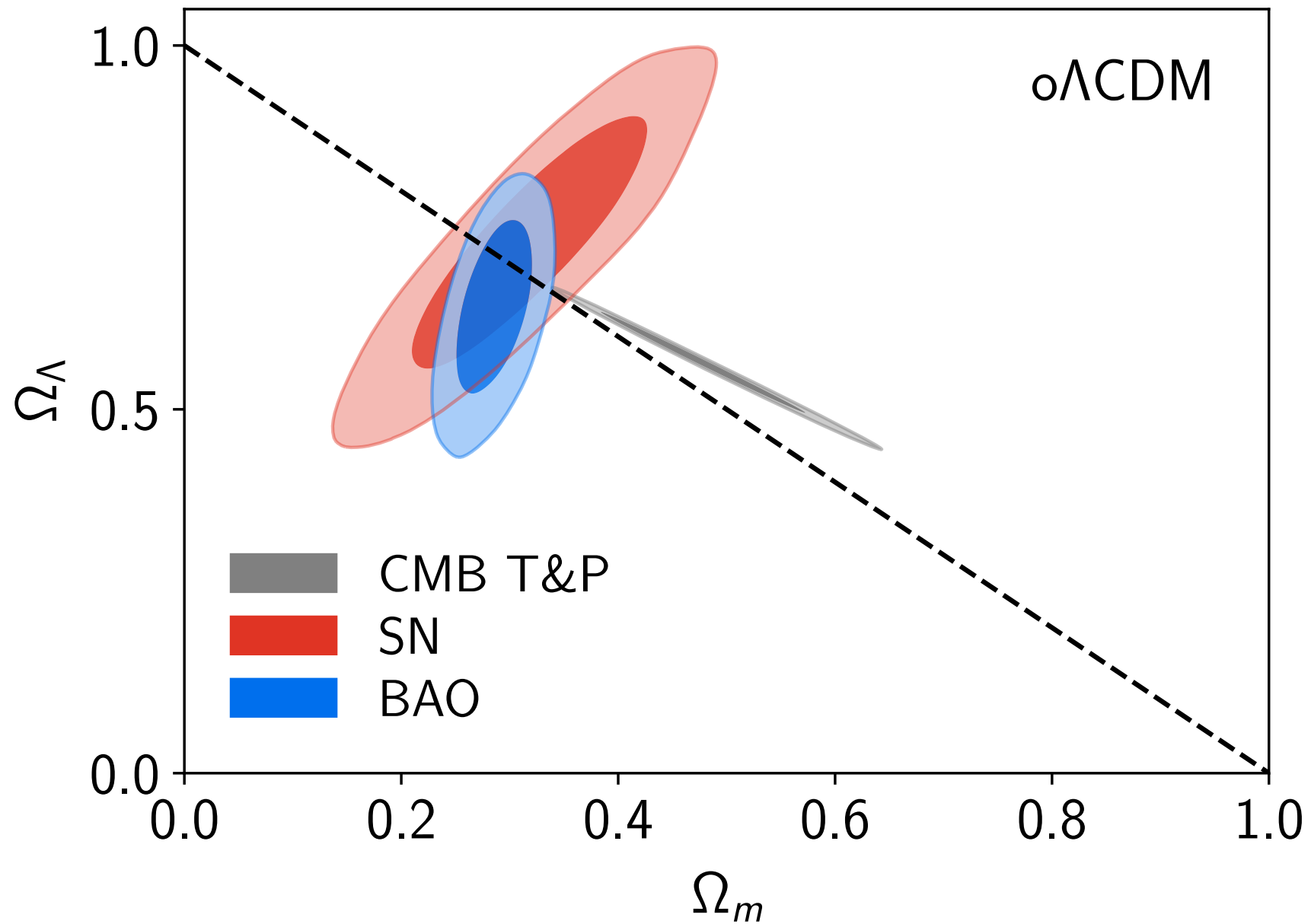
Extra science: Cosmology with voids by Seshadri Nadathur
Multi-tracer analysis by Gongbo Zhao



20 years of cosmology with SDSS

The acceleration of our Universe, curvature, massive neutrinos

(eBOSS Collaboration, 2020)



Detection of Dark Energy by BAO



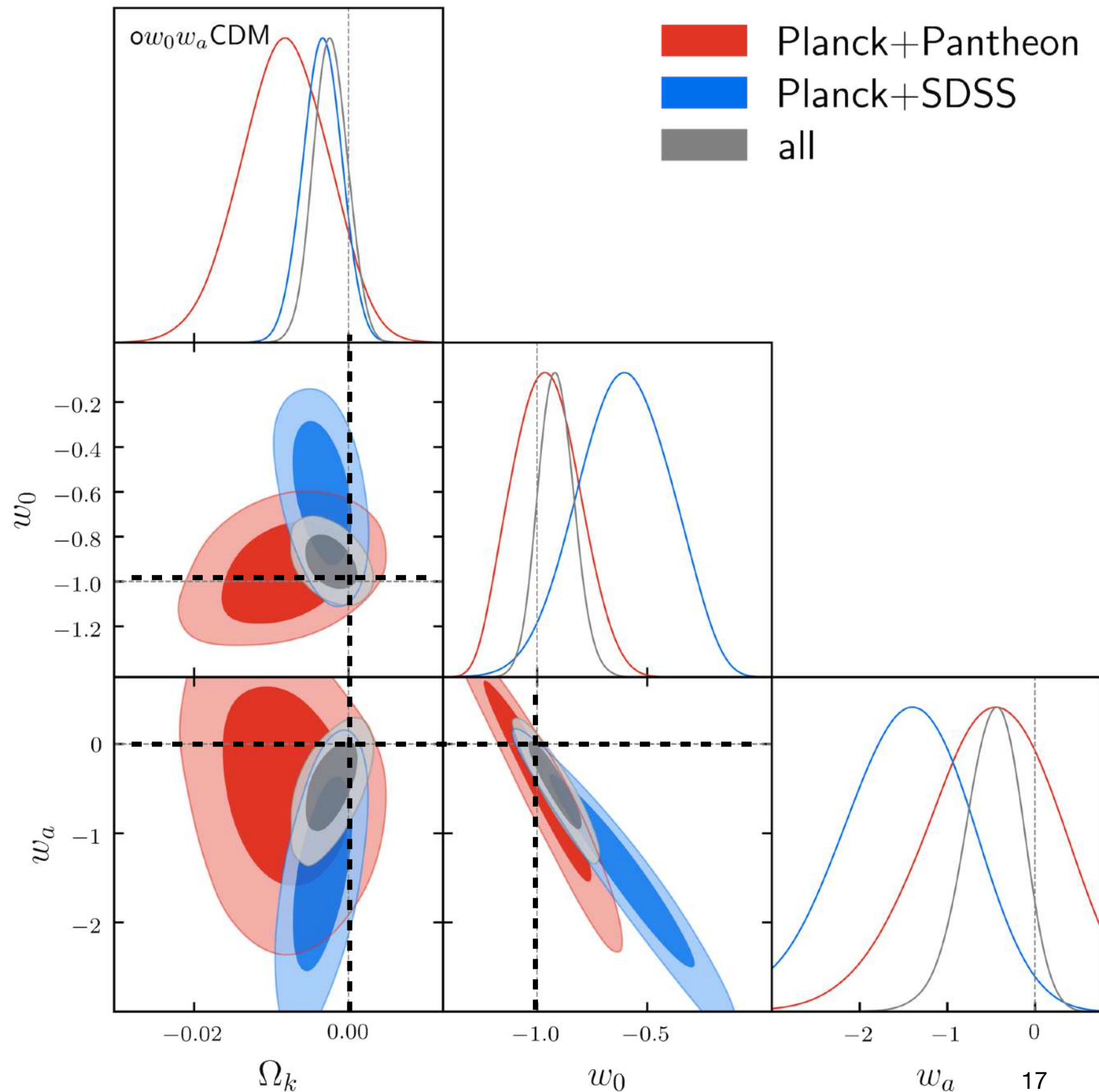
What is the nature of Dark Energy?



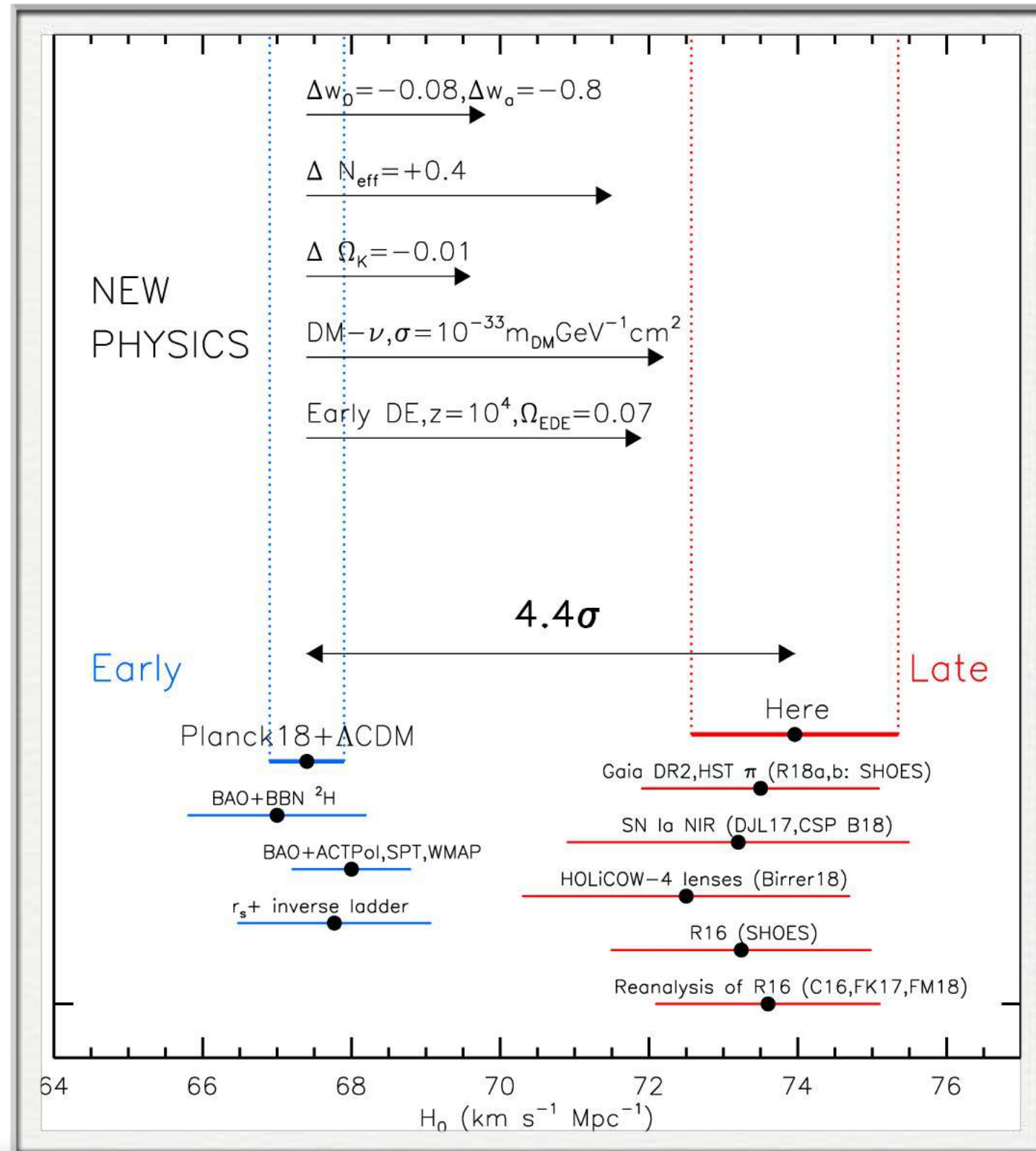
- Good agreement with LCDM
- Dark Energy model consistent with cosmological constant

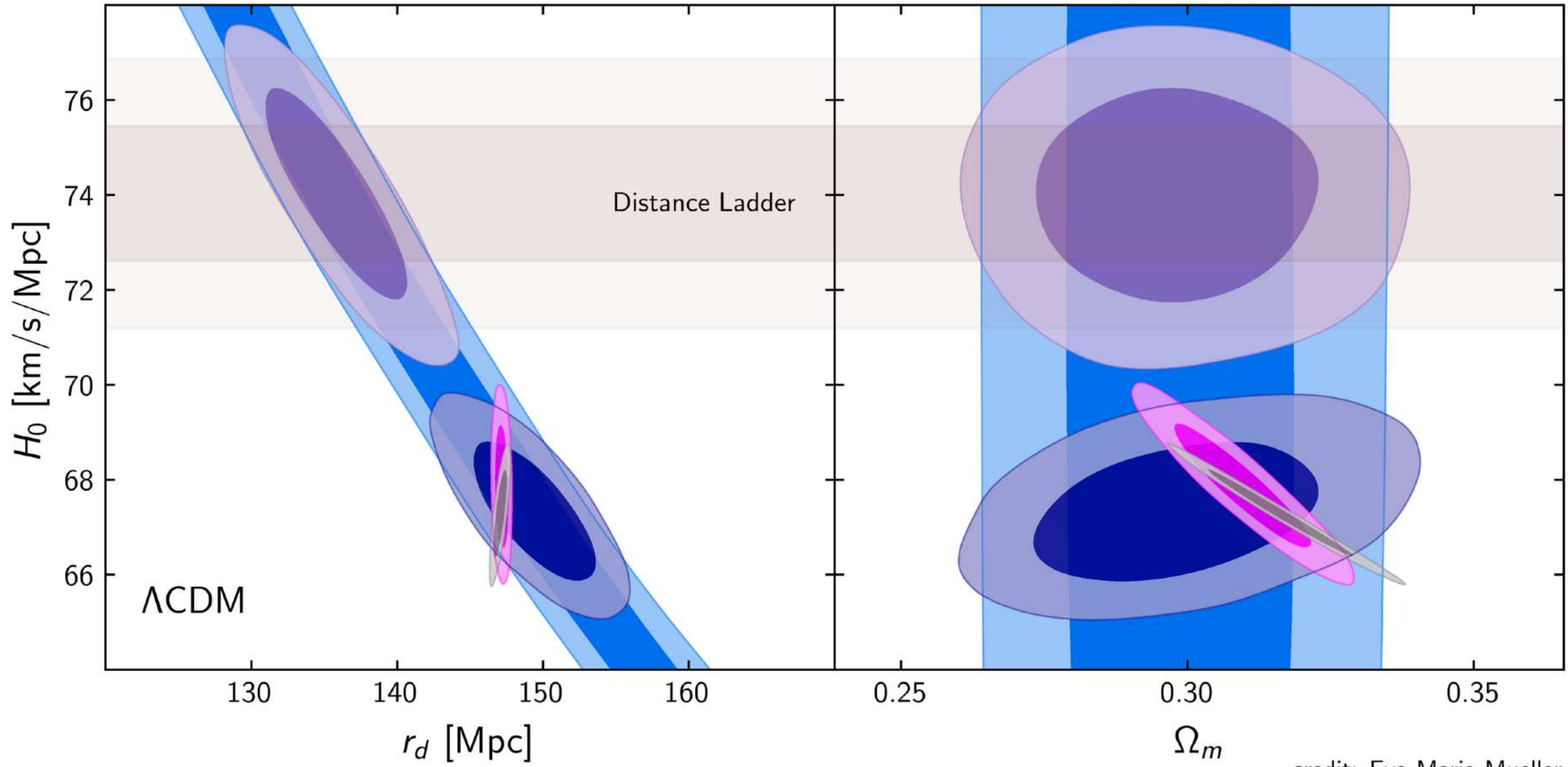
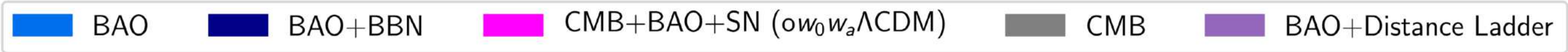
- Complementarity between BAO/RSD, CMB and SN

$$w(a) = w_0 + w_a(1 - a)$$



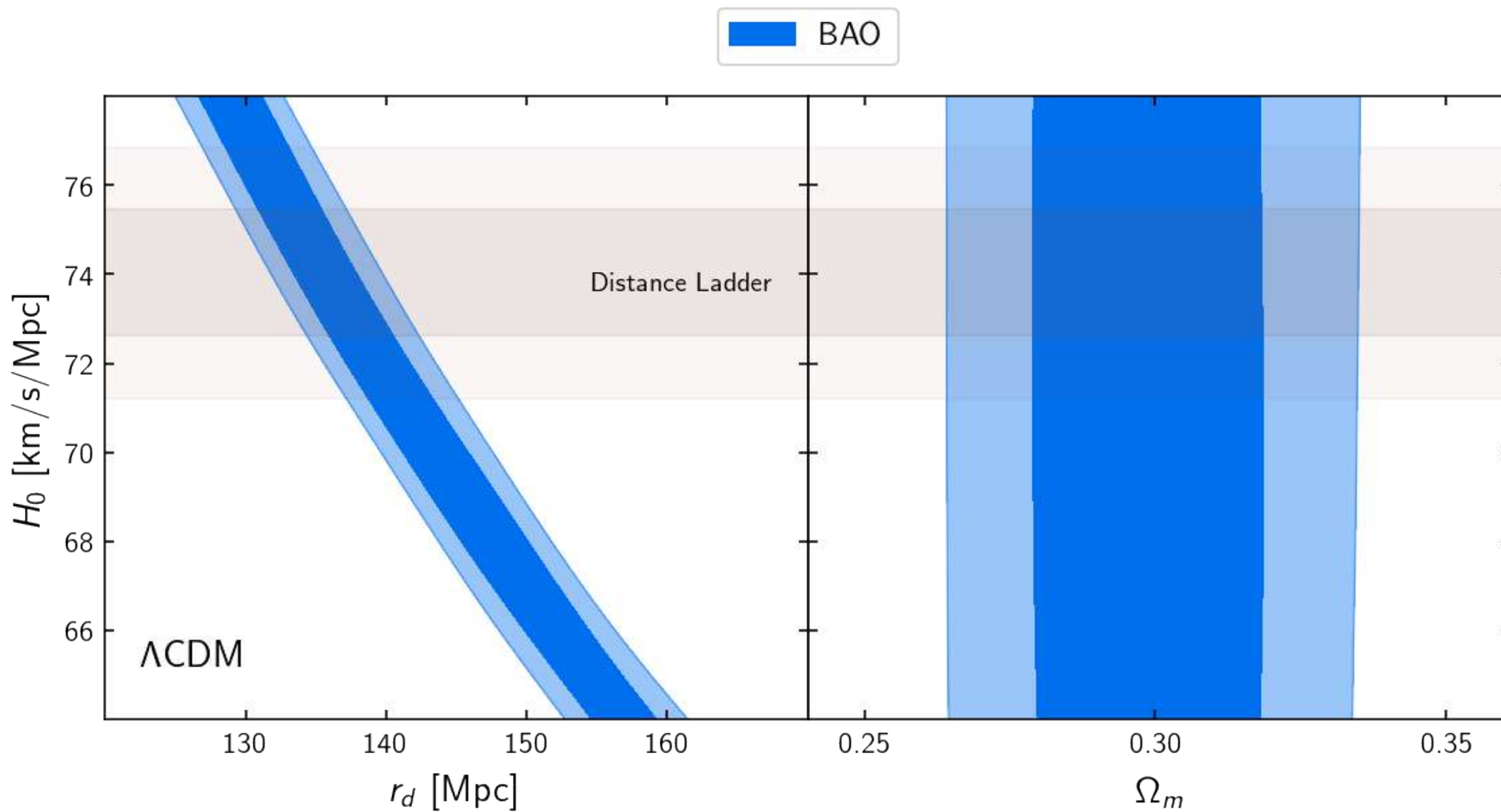
(eBOSS Collaboration, 2020)





credit: Eva-Maria Mueller and SDSS

What can we learn from BAO?



credit: Eva-Maria Mueller and SDSS

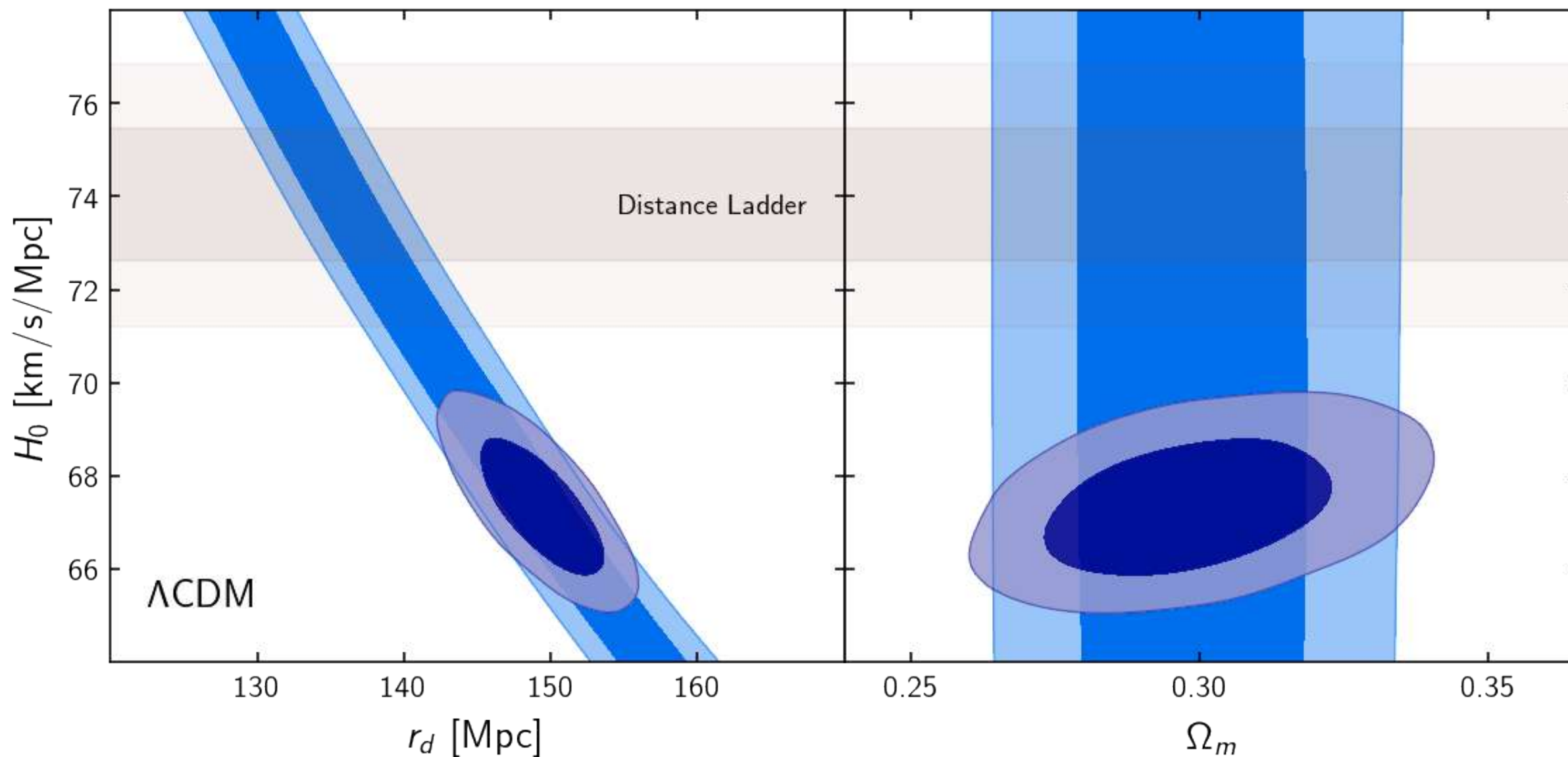
$$D_H(z)/r_d$$

$$D_M(z)/r_d$$

$$D_H(z) = \frac{c}{H(z)}$$

$$D_M(z) = \frac{c}{H_0} S_k \left(\frac{D_C(z)}{c/H_0} \right)$$

BAO BAO+BBN



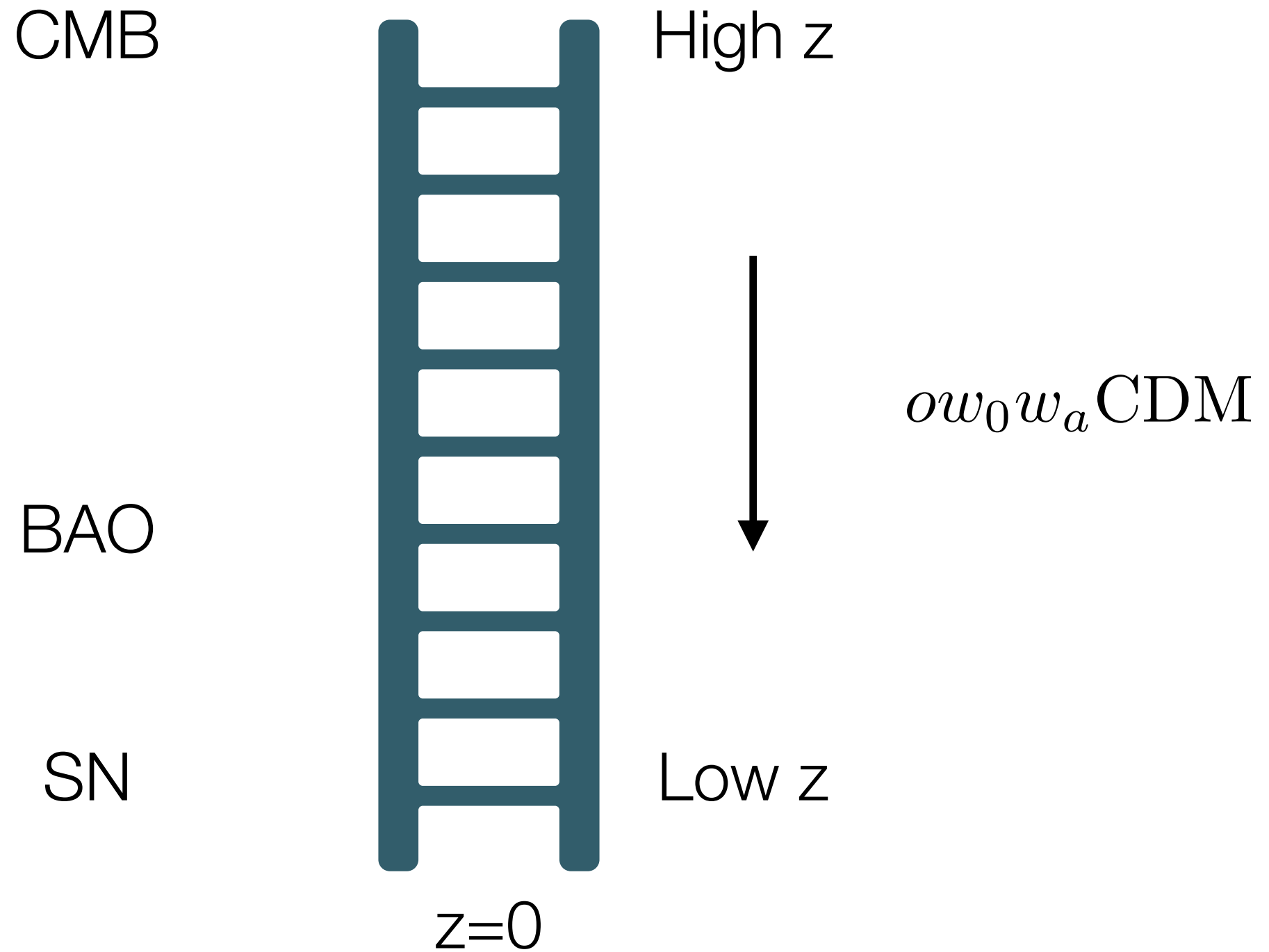
credit: Eva-Maria Mueller and SDSS

$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz$$

distance traveled by sound waves between the end of inflation and decoupling of baryons from photons after recombination
 → need information on baryon density $\Omega_b h^2$



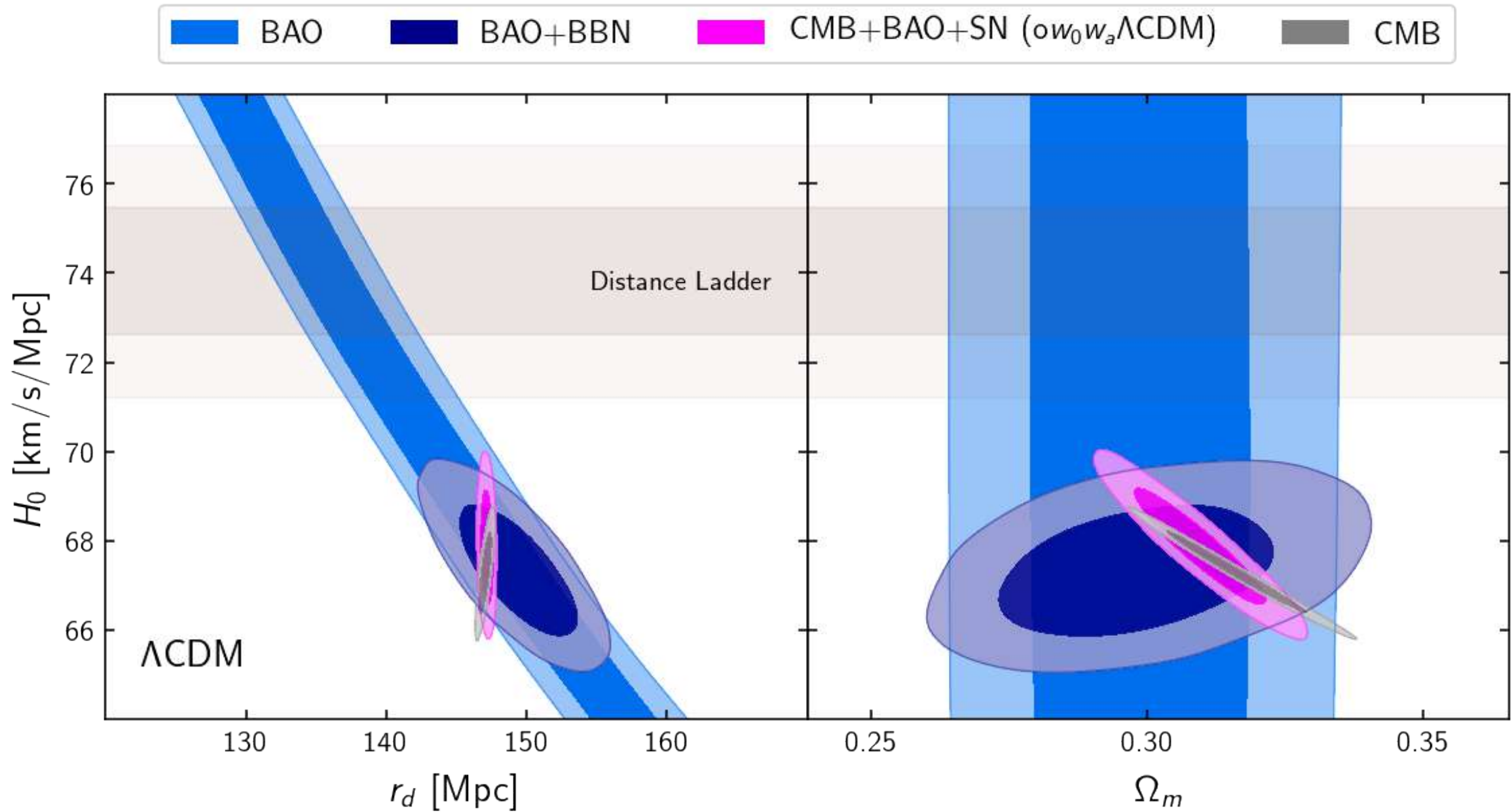
Hubble Parameter Tension



Inverse Distance Ladder



Hubble Parameter Tension

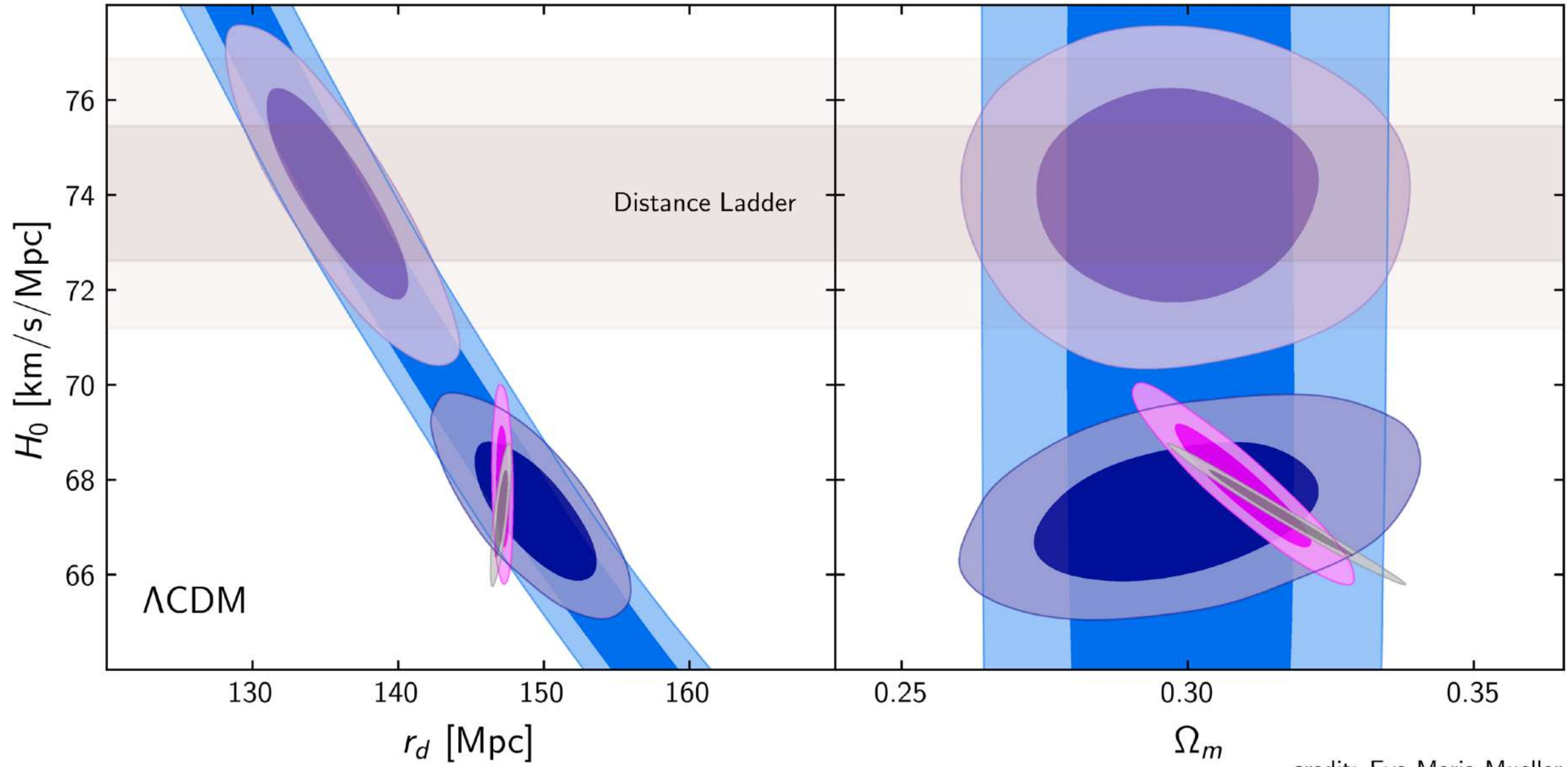
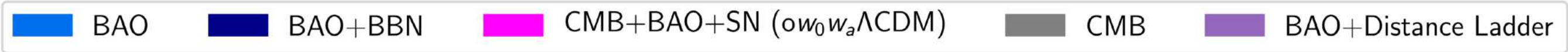


credit: Eva-Maria Mueller and SDSS

Dark Energy cannot explain the difference!



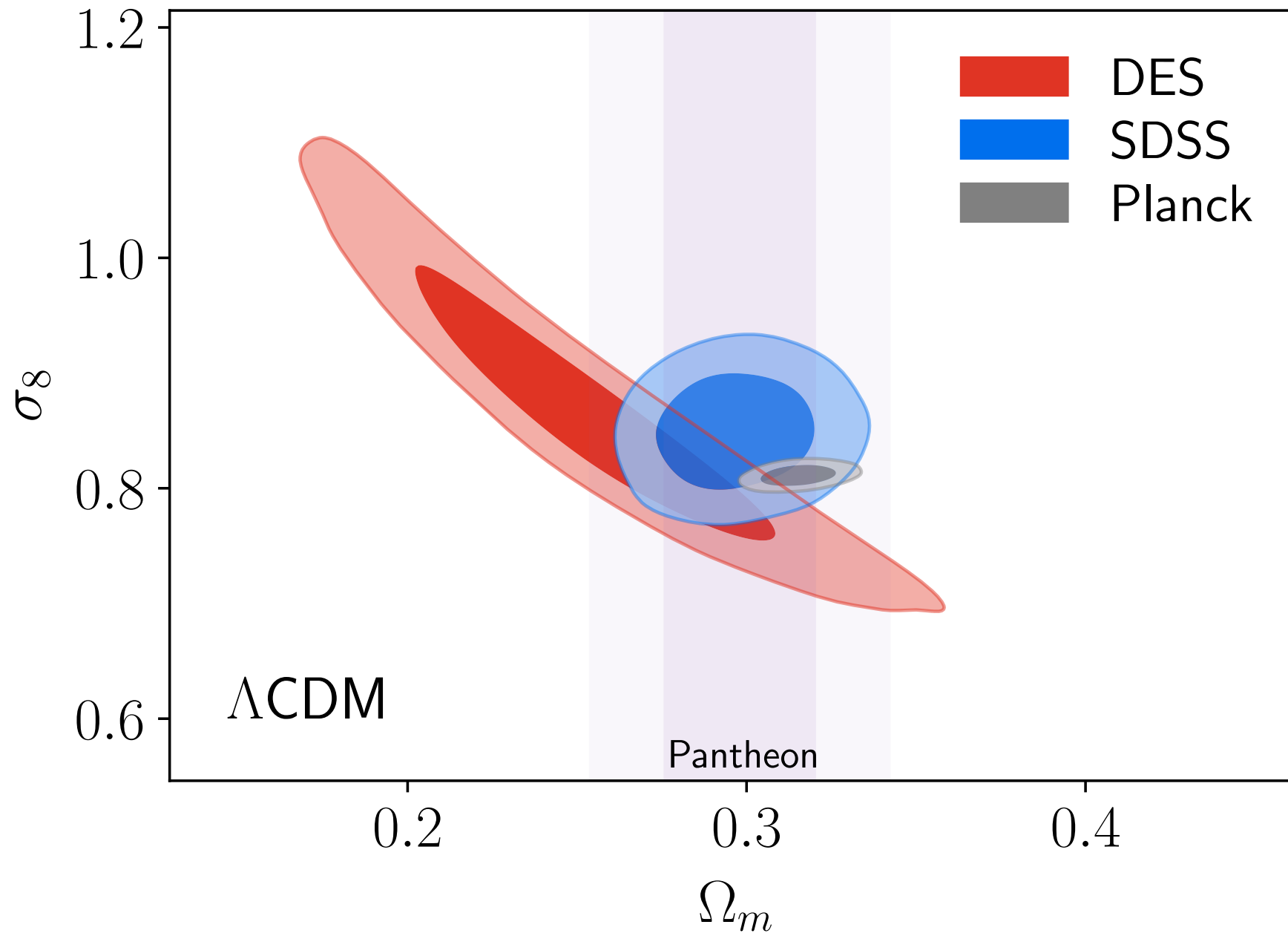
Hubble Parameter Tension

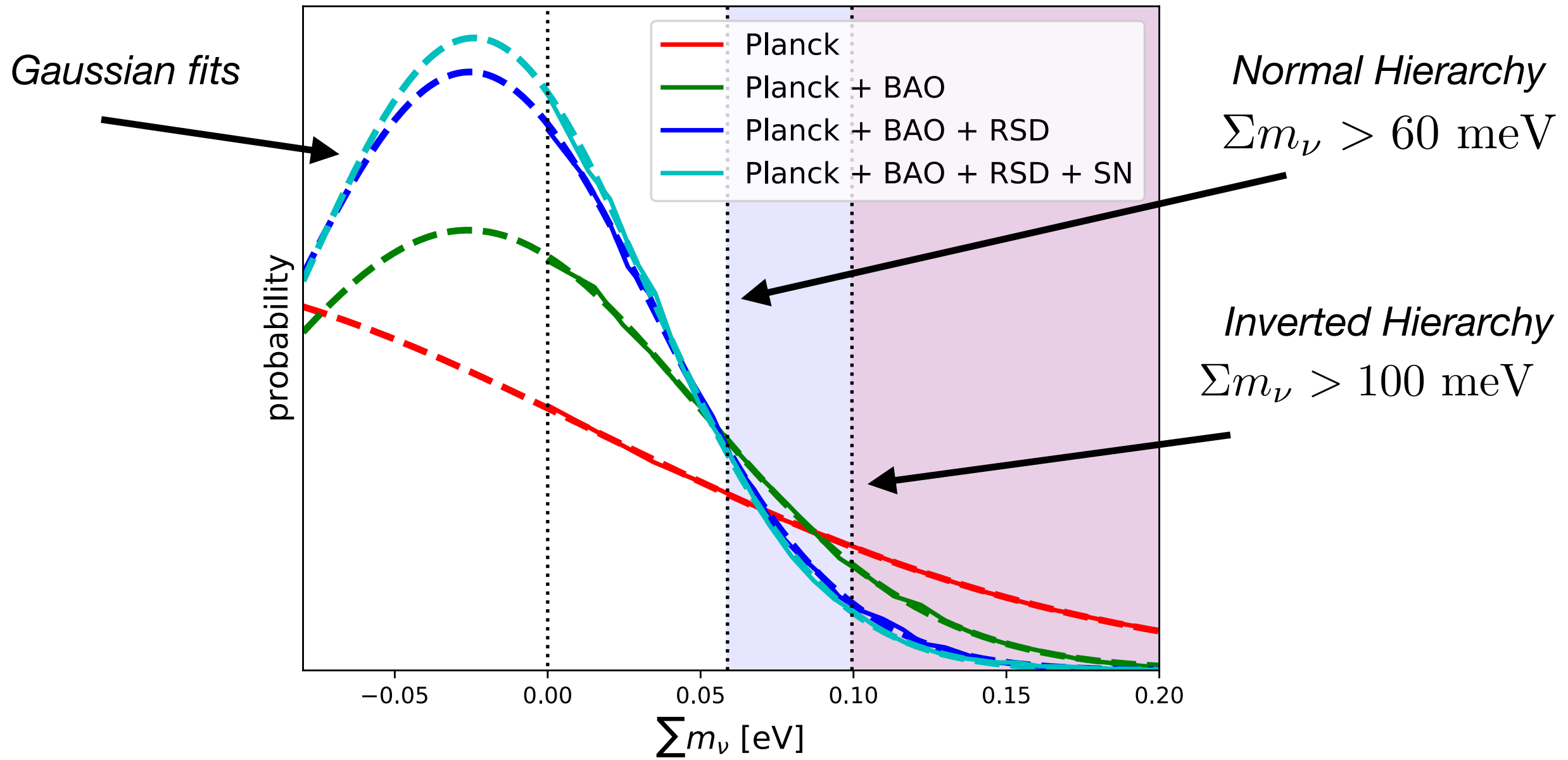


credit: Eva-Maria Mueller and SDSS



$\sigma_8 - \Omega_m$ Discrepancy





$\Sigma m_\nu < 0.099$ eV (95)%

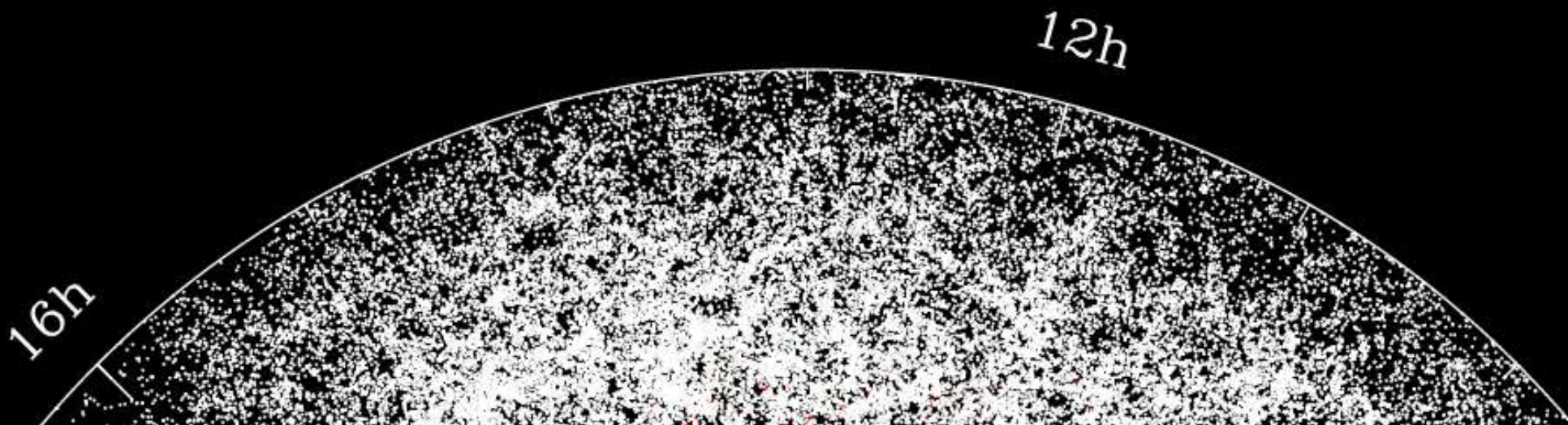


Legacy of BOSS/eBOSS



- Conclusion of Stage-III Dark Energy surveys with spectroscopy
- Over 4M spectra obtained (more spectra than rest of the world combined)
- Sample with the largest redshift range than any other probe
- Percent-level precision on BAO distance scale at each redshift
- Growth measurements to $z < 1.5$

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Useful links:

The official SDSS press release

<https://www.sdss.org/press-releases/no-need-to-mind-the-gap/>

The eBOSS program

<https://www.youtube.com/watch?v=TKiYOnsE8Y4>

Fly-through the largest 3D map of the Universe

<https://www.youtube.com/watch?v=KJJXbcf8kxA>

List of publications

<https://www.sdss.org/science/final-bao-and-rsd-measurements/>