The Dark Energy Spectroscopic Instrument (DESI): Overview and early data

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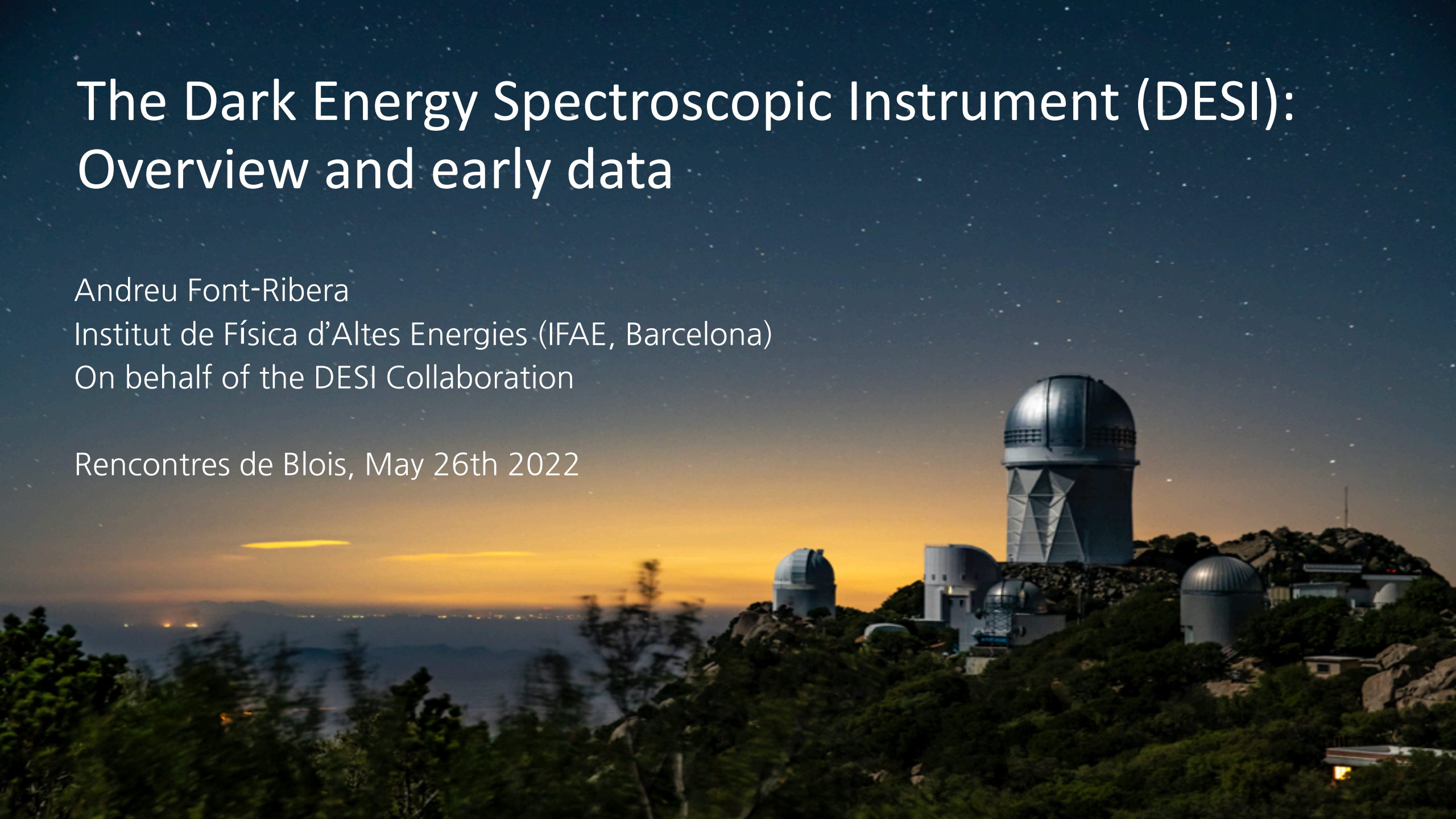
On behalf of the DESI Collaboration

Rencontres de Blois, May 26th 2022



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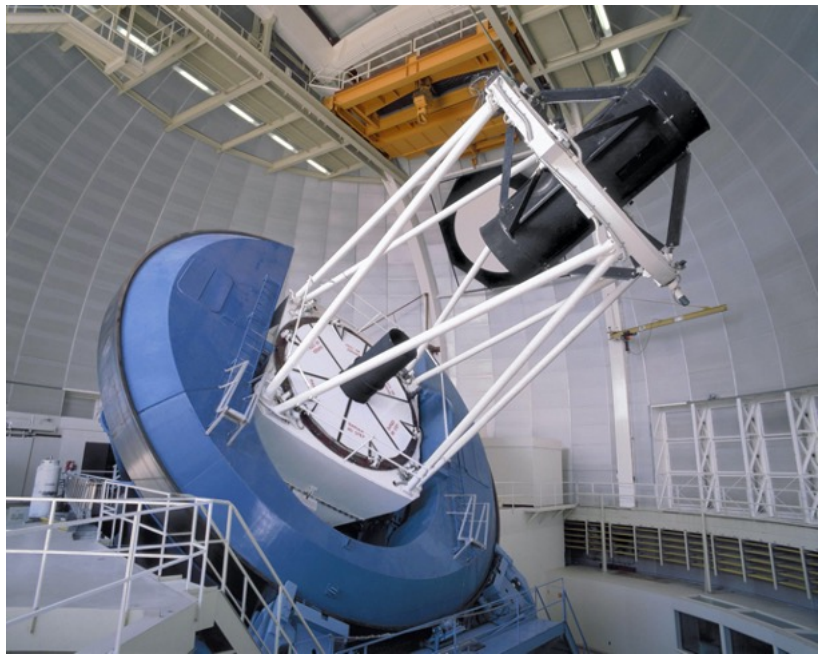
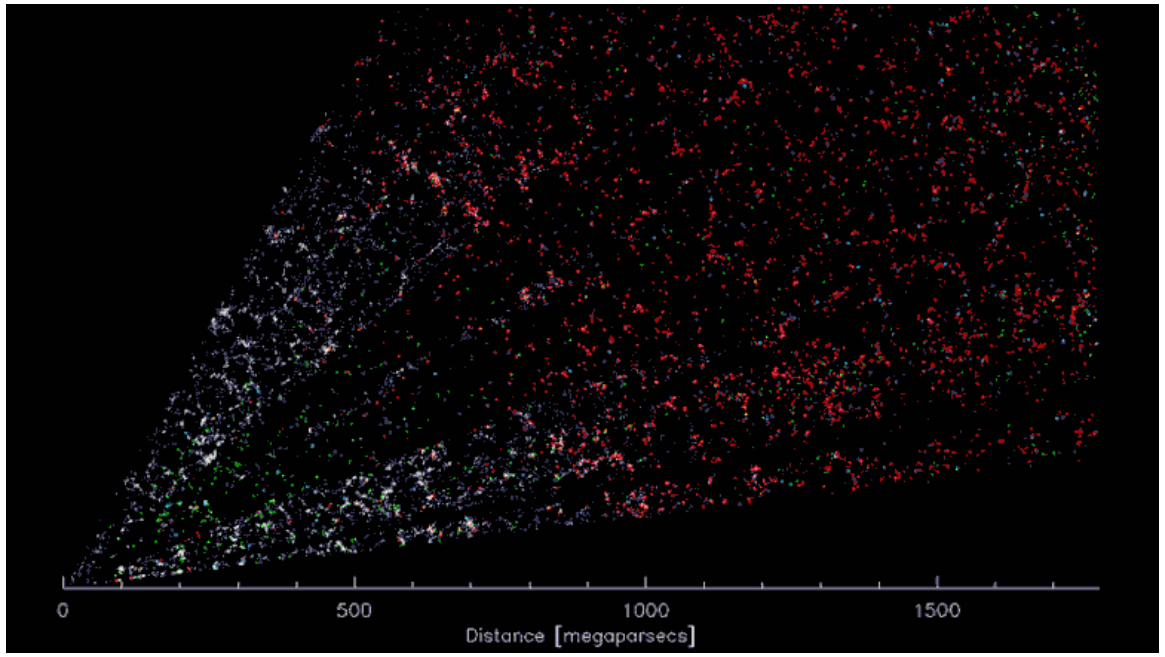
1st anniversary of DESI

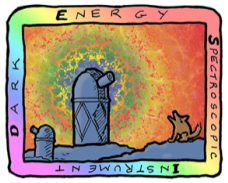
DESI started its 5-year survey on May 15th 2021, the first Stage-IV Dark Energy experiment on sky



Multi-object spectrograph (5k fibers) at the 4-m Mayall telescope (KPNO, Arizona)



Already the largest redshift survey ever!



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Overview

- Science goals: dark energy, modified gravity and massive neutrinos
- Main probes: Baryon Acoustic Oscillations (BAO) and Redshift Space Distortions (RSD)
- Instrument and survey overview
- Early data and expected data releases

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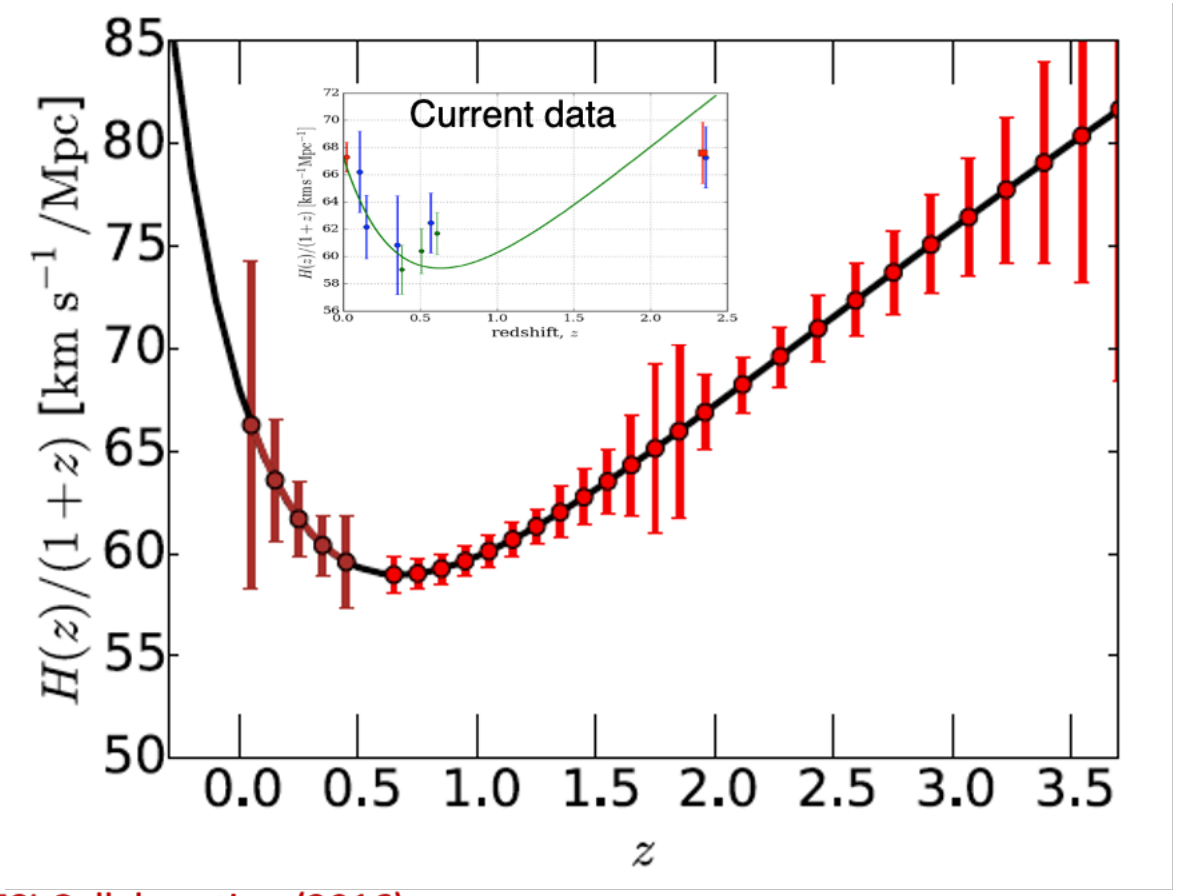
Science Goals: Dark Energy

- The accelerated expansion of the Universe is now confirmed by independent cosmological probes
- Its cause is one of the biggest questions in physics, and a main science case for ongoing and future experiments
- DESI will measure the expansion history and constrain the equation of state of dark energy

$$w = p/\rho$$



arXiv:1611.00036 - DESI Collaboration (2016)

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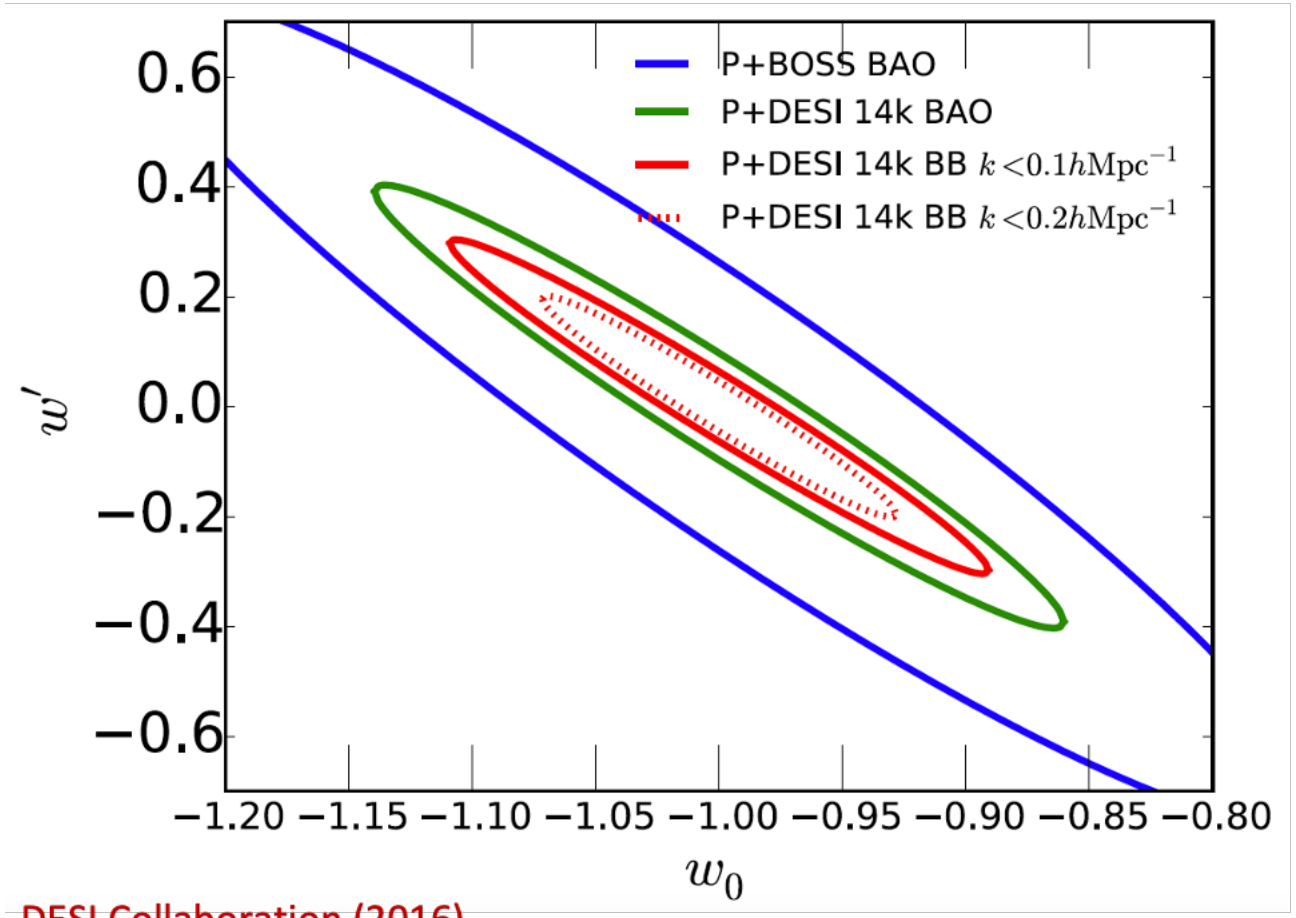

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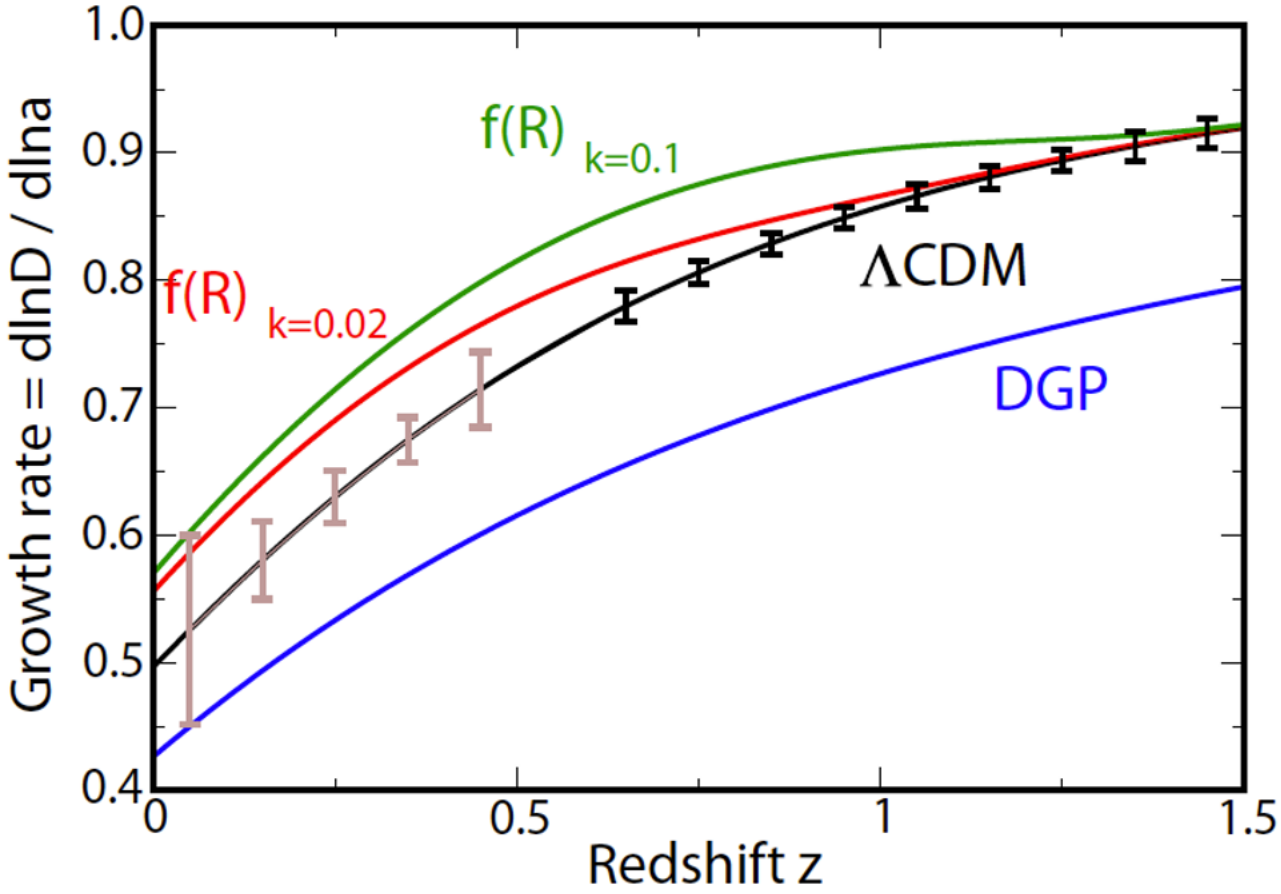
Science Goals: Modified Gravity

- Modified gravity (MG) models can mimic the expansion of dark energy (DE) models
- One can distinguish between MG and DE by also measuring the growth of structure
- DESI will study the anisotropy in the distribution of galaxies to provide accurate measurements of the growth rate



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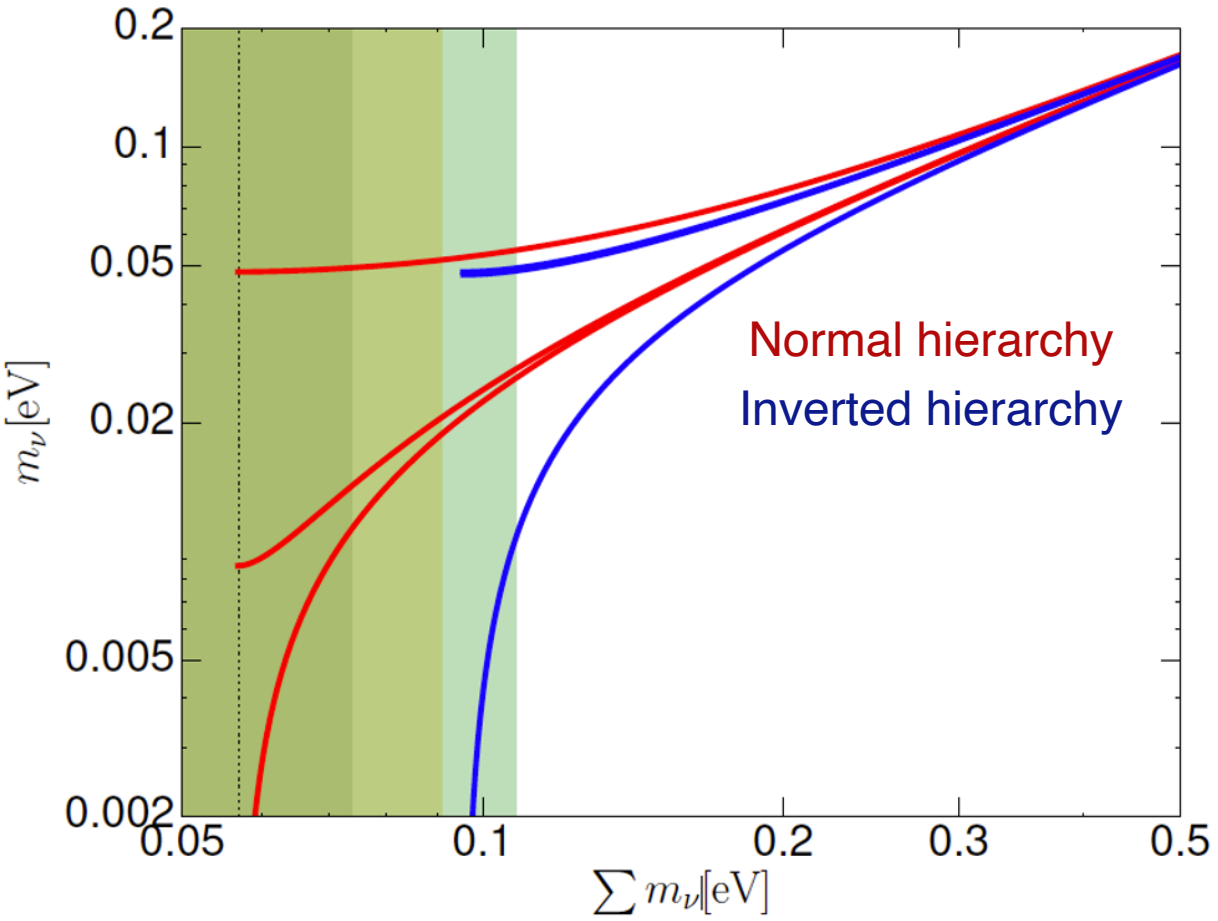
Science Goals: Massive Neutrinos

- Massive neutrinos leave an imprint in the distribution of matter, affecting both its expansion and growth
- In combination with Planck, DESI will be able to accurately measure the sum of the neutrino masses within 0.02 eV
- Depending on the true masses, we might be able to distinguish between the different neutrino hierarchies



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Baryon Acoustic Oscillations (BAO)

We can relate redshift to distance if we have a cosmological model

Comoving distance $$D_C(z) = \frac{c}{H_0}\int_0^z dz' \frac{H_0}{H(z')}$$

Hubble constant (current expansion rate)

Hubble parameter (expansion rate)

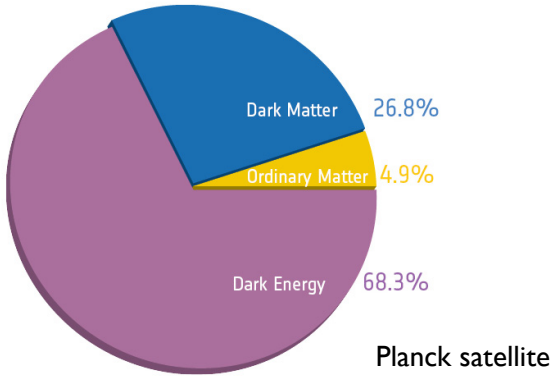
$$\frac{H^2(z)}{H_0^2} = \Omega_r (1+z)^4 + \Omega_m (1+z)^3 + \Omega_\Lambda + \Omega_k (1+z)^2$$

Radiation

Dark Energy

Matter (baryonic or dark)

Curvature



Planck satellite

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Baryon Acoustic Oscillations (BAO)

To study the expansion we want to measure the distance to different redshift

Standard candle (SNe Ia)

known luminosity

+

measure flux

↓

distance

Standard ruler (BAO)

known size

+

measure angle

↓

distance

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Baryon Acoustic Oscillations (BAO)

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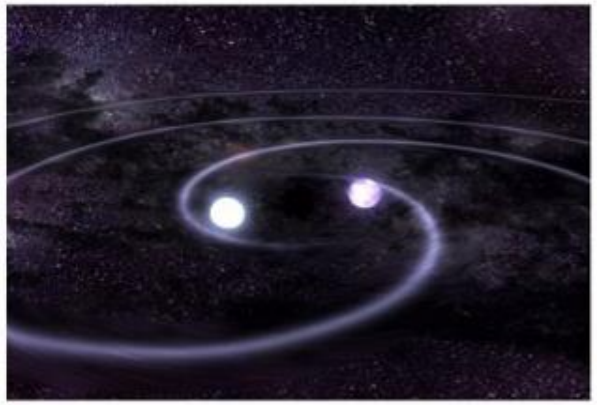
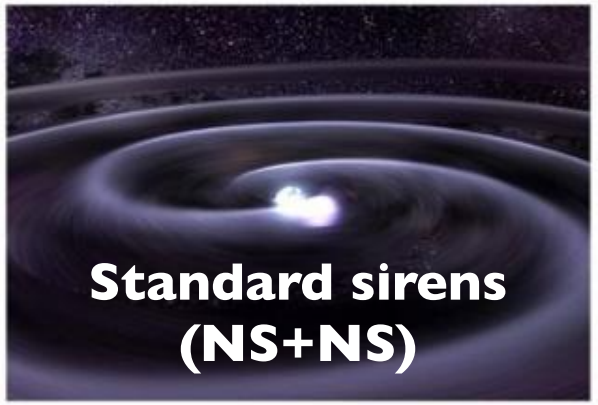
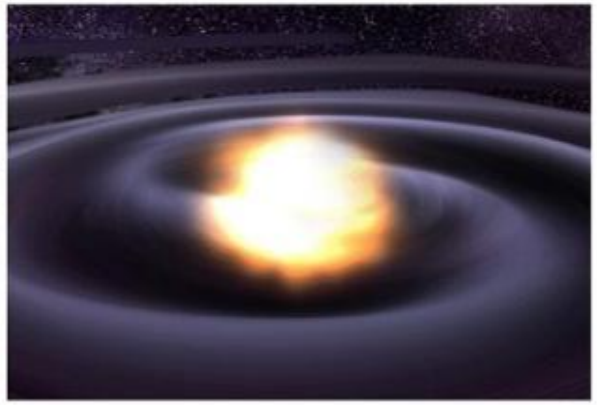






:

Standar (SNe Ia)

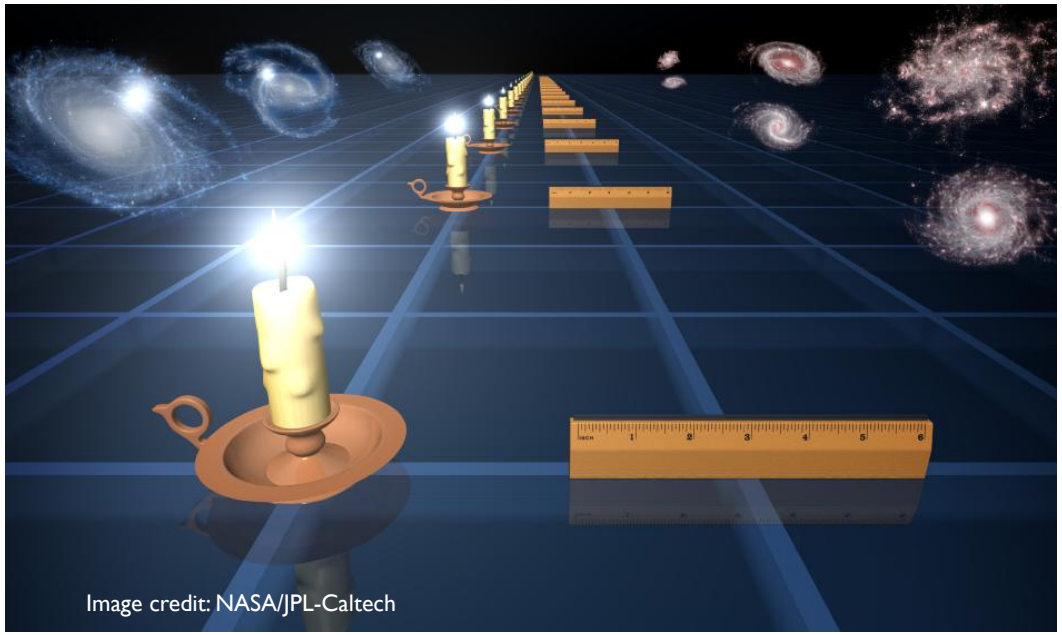
known luminosity

+

measure flux

↓

distance



rd ruler (BAO)

known size

+

measure angle

↓

distance

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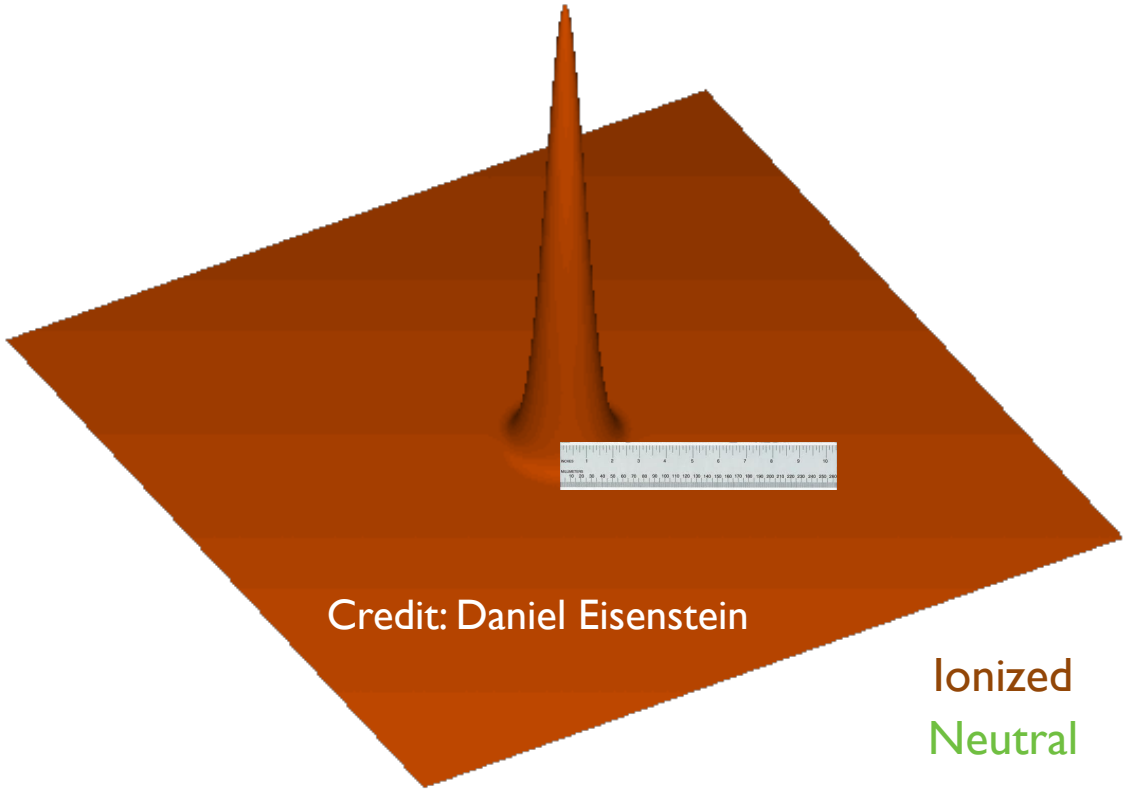
Baryon Acoustic Oscillations (BAO)

Before recombination (z >1100), photons and ionized matter were tightly coupled

Primordial density fluctuations generated sound waves in the plasma

These waves froze out at recombination, leaving an imprint at a characteristic scale



Sound horizon at recombination (from Planck): $r_d = 147.6 \pm 0.3$ Mpc

$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz \qquad c_s(z) = 3^{-1/2} c \left[1 + \tfrac{3}{4}\rho_b(z)/\rho_\gamma(z)\right]^{-1/2}$$

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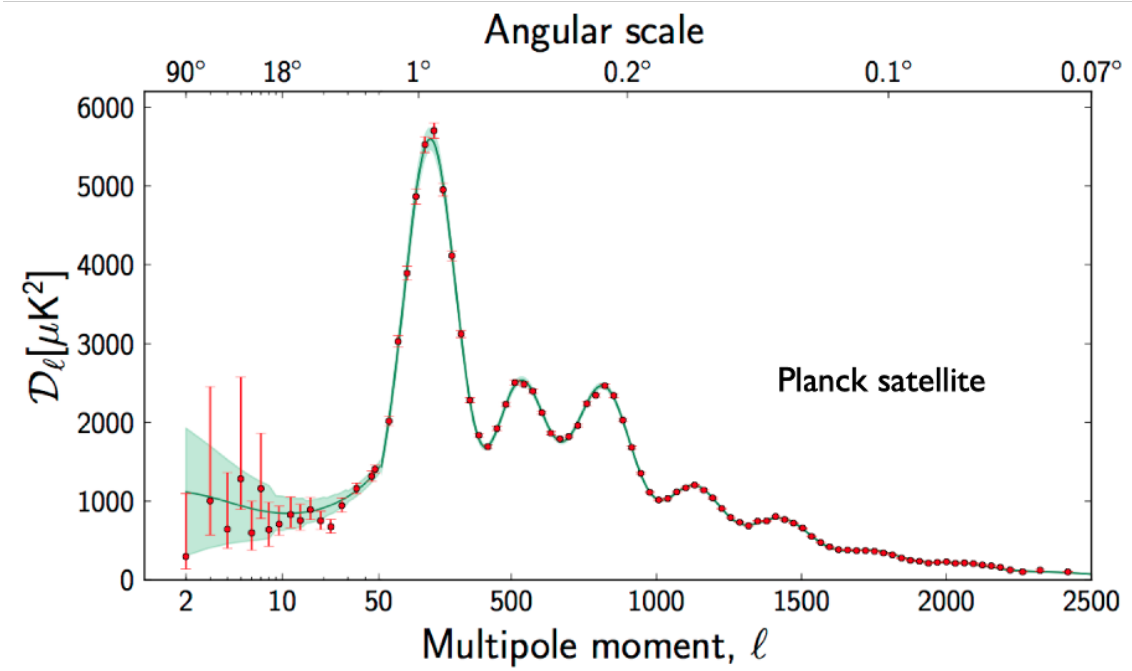
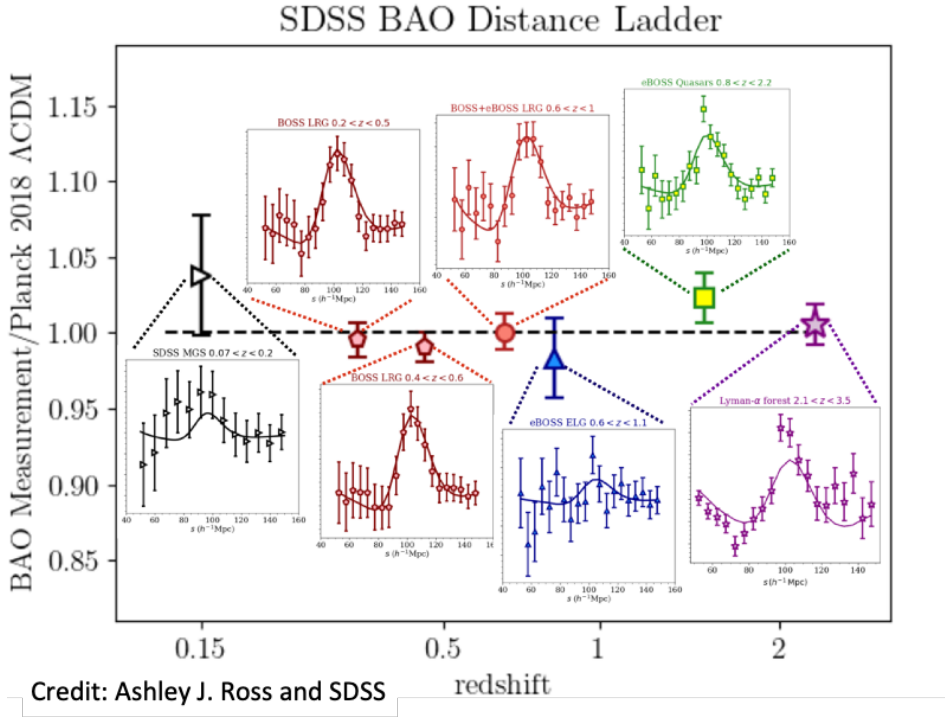
Baryon Acoustic Oscillations (BAO)



Acoustic waves in the photon-baryon plasma in the early Universe left an imprint in the CMB, at a well-known scale known as the *sound horizon*



Credit: Ashley J. Ross and SDSS

BAO have also been detected in the distribution of matter at low redshift, and can be used as a standard ruler to measure distances to galaxies

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Redshift Space Distortions (RSD)

Sound horizon at recombination (from Planck): $r_d = 147.6 \pm 0.3$ Mpc

$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz \qquad c_s(z) = 3^{-1/2} c \left[1 + \tfrac{3}{4}\rho_b(z)/\rho_\gamma(z)\right]^{-1/2}$$

We measure BAO peak in the transverse direction in BOSS: $\Delta\theta_{BAO} = \frac{r_d}{1+z} \boxed{\frac{1}{D_A(z)}}$

We can study the expansion!

We measure BAO peak along the line of sight in BOSS: $\Delta v_{BAO} = \frac{r_d}{1+z} \boxed{H(z)}$

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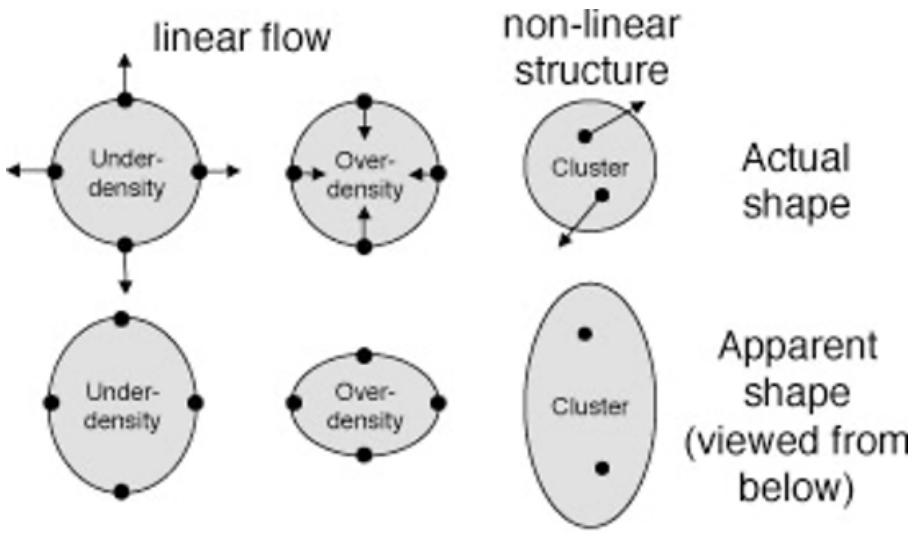
Redshift Space Distortions (RSD)

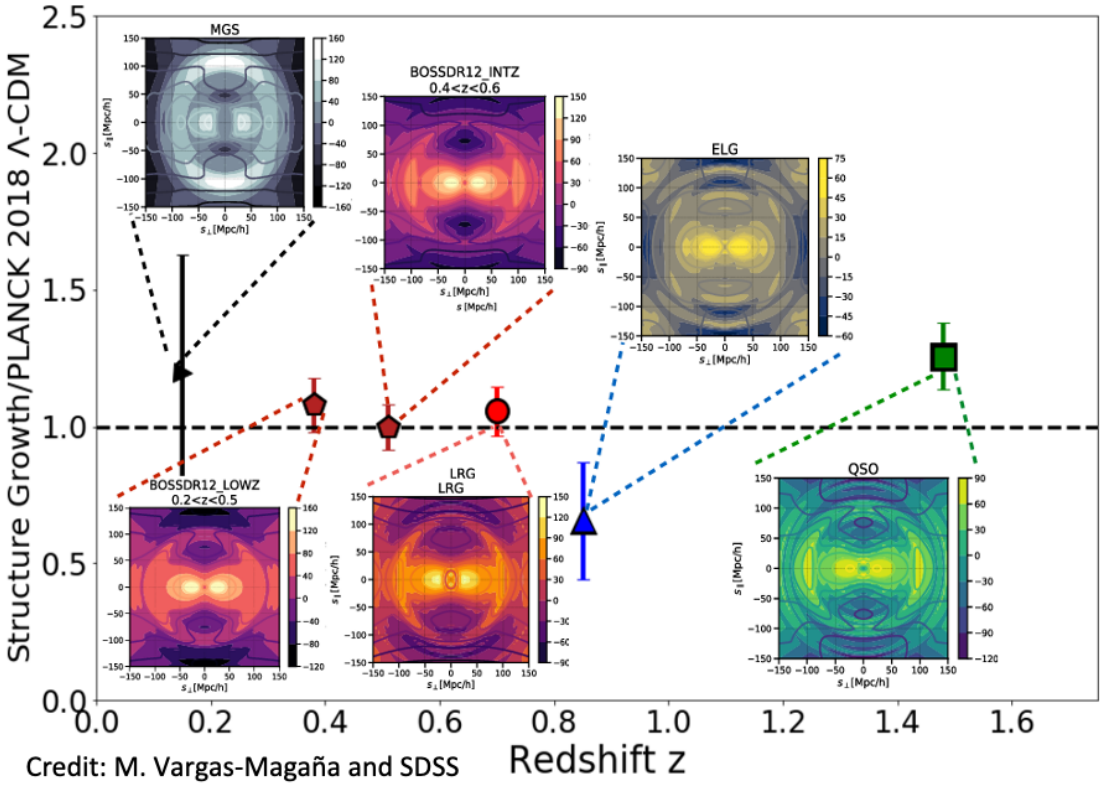
Our galaxy maps are distorted, since our radial coordinate is inferred from its redshift (velocity)

On large (linear scales), the anisotropy in the galaxy correlations depends on the amplitude matter fluctuations and the theory of gravity

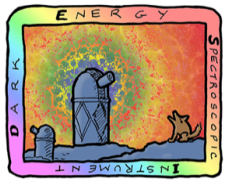


Credit: Will Percival

RSDs can therefore be used to measure the growth of structure as a function of time



Credit: M. Vargas-Magaña and SDSS



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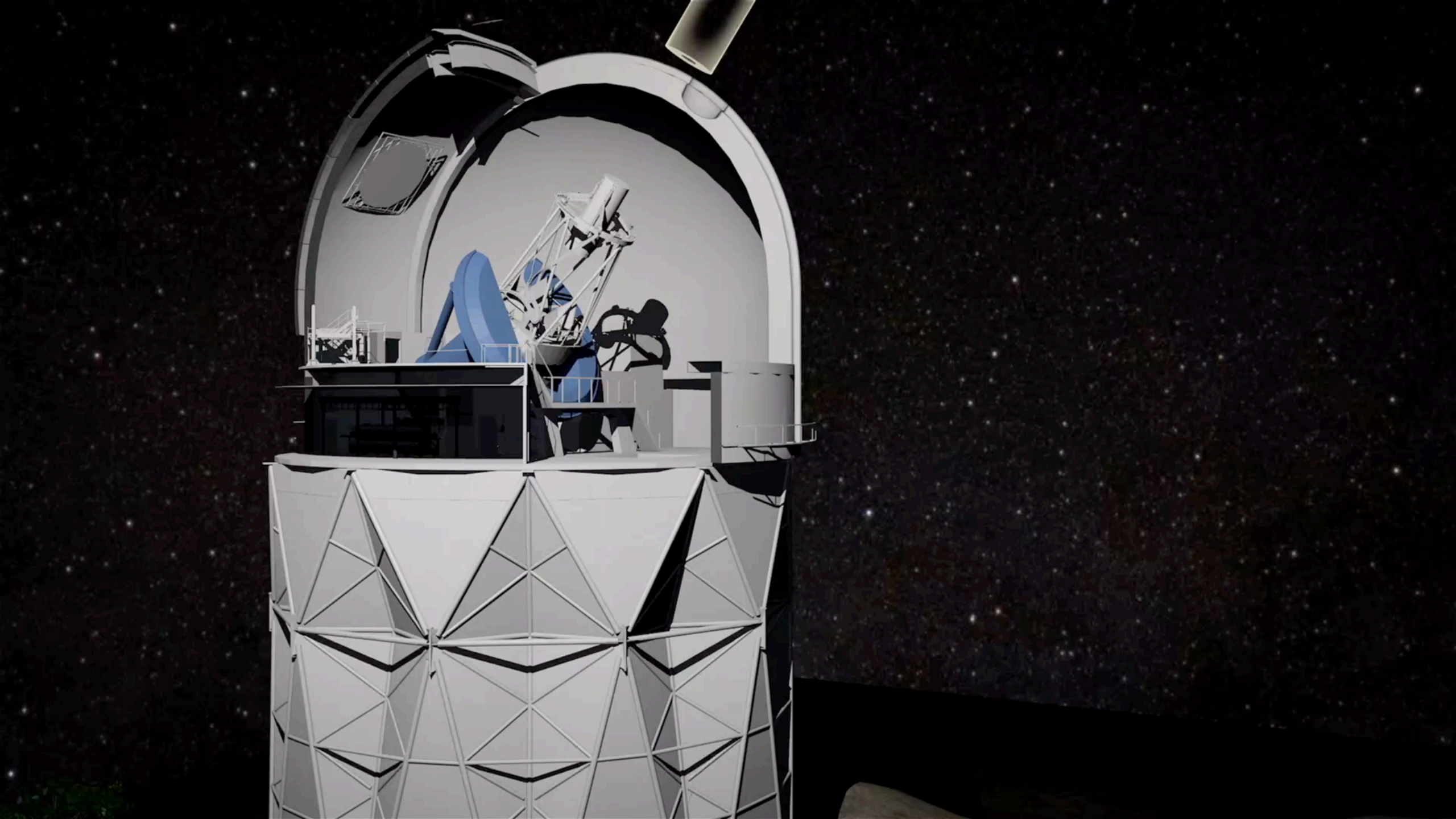

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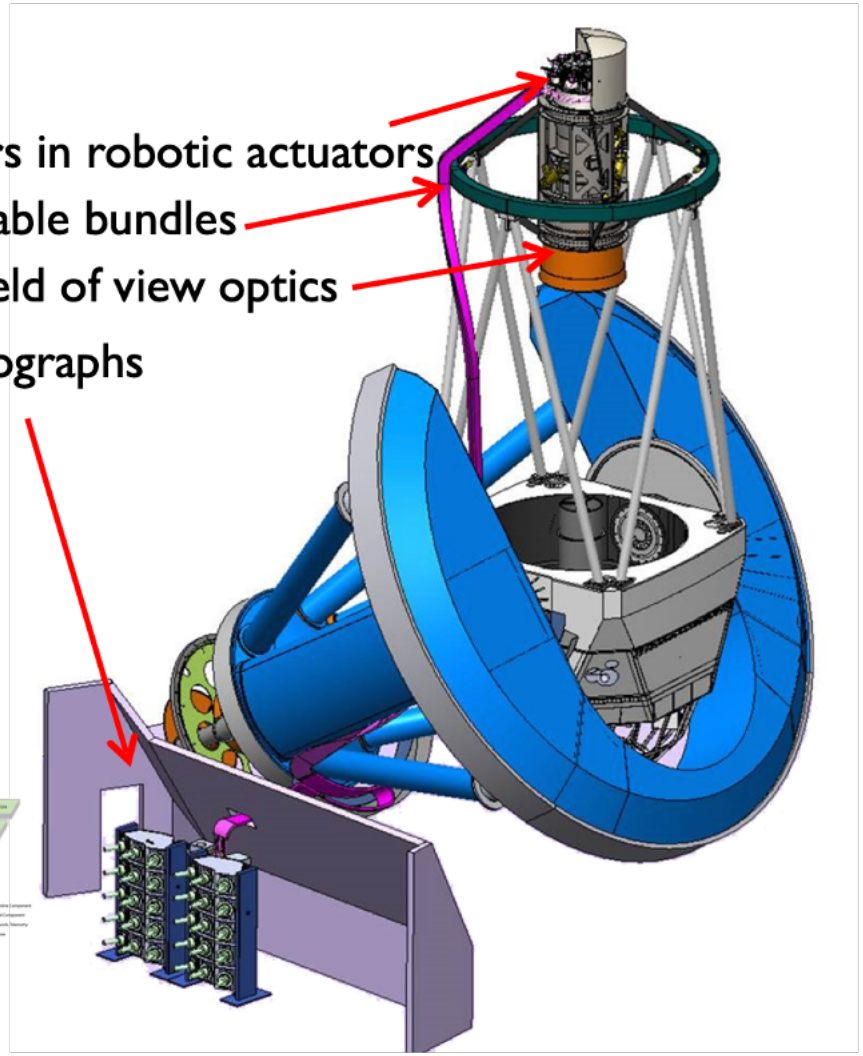
Instrument Overview

- 5000 fibers in robotic actuators
- 10 fiber cable bundles
- 3.2 deg. field of view optics
- 10 spectrographs



Readout & Control

Mayall 4m Telescope
Kitt Peak (Tucson, AZ)

Increase BOSS/eBOSS datasets by an order of magnitude

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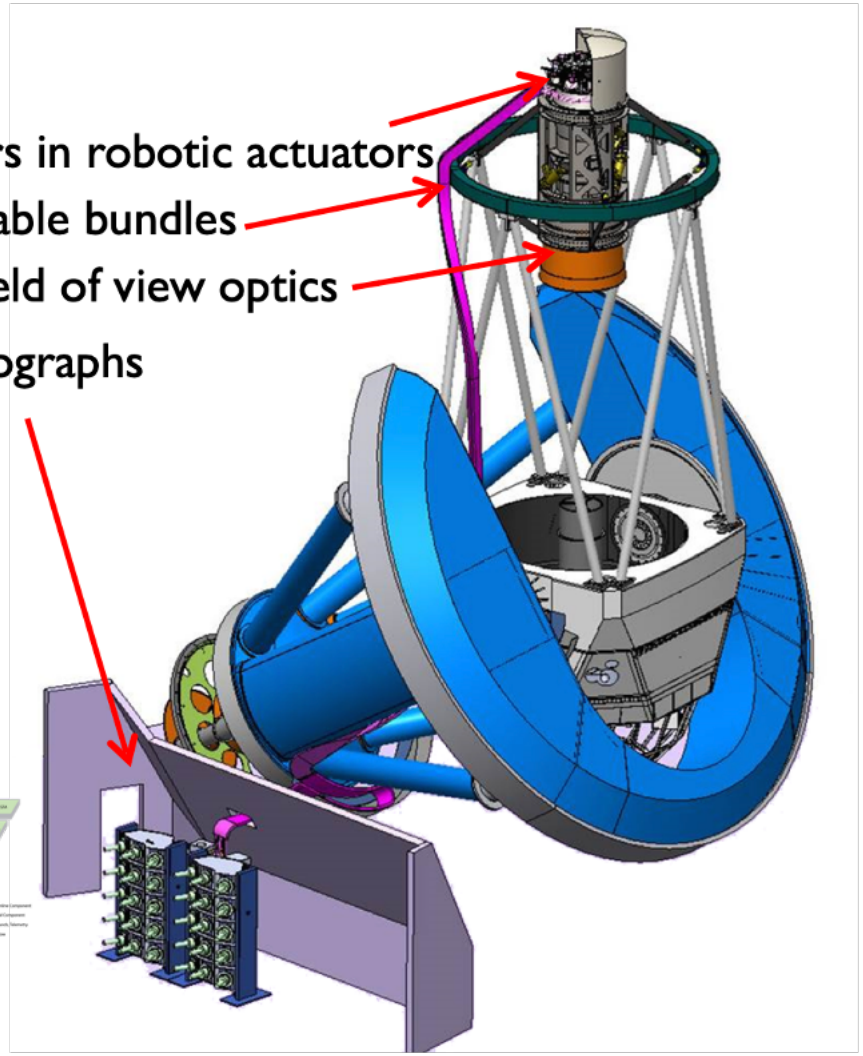

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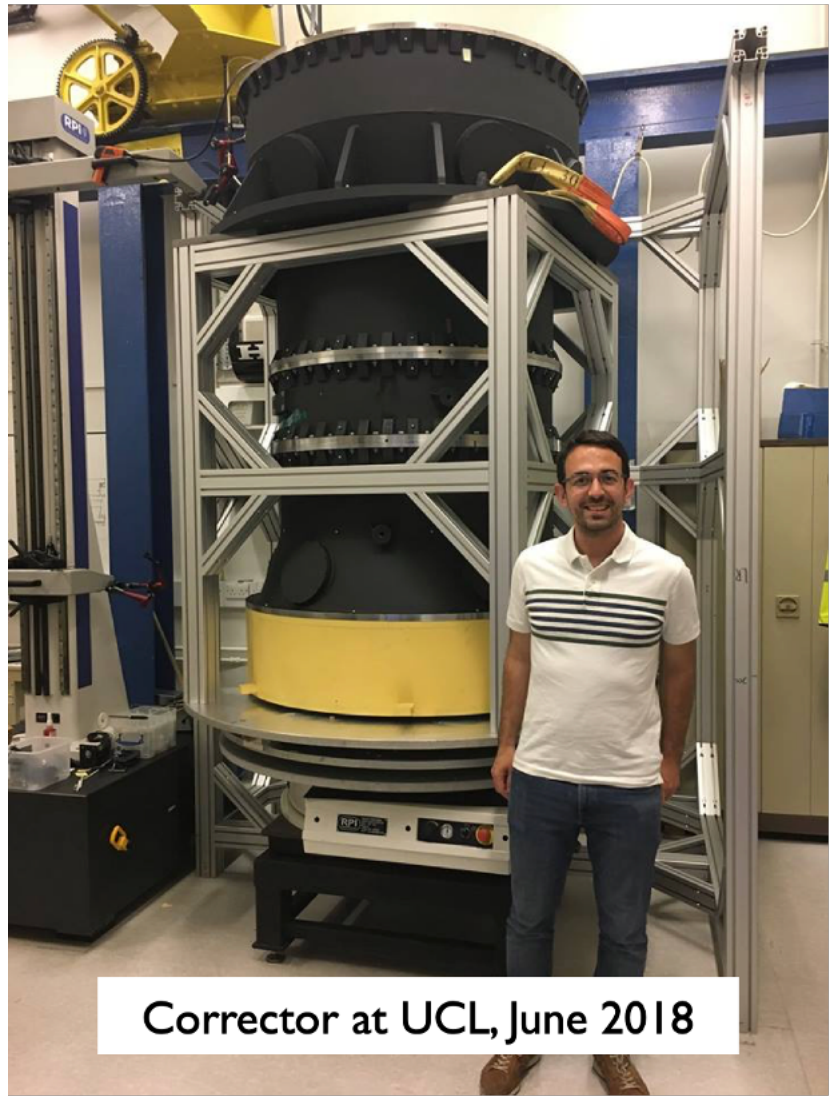

Corrector at UCL, June 2018

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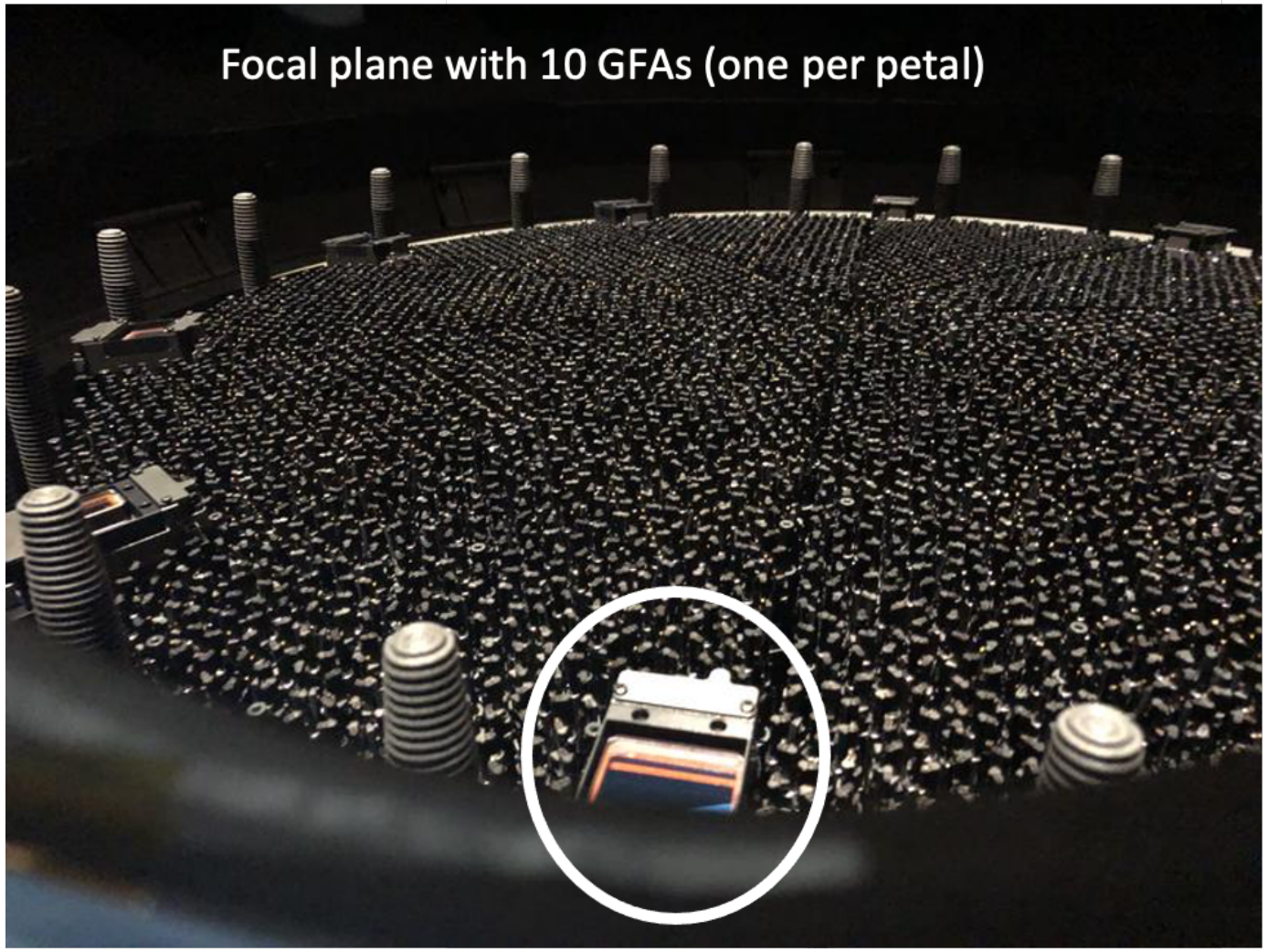

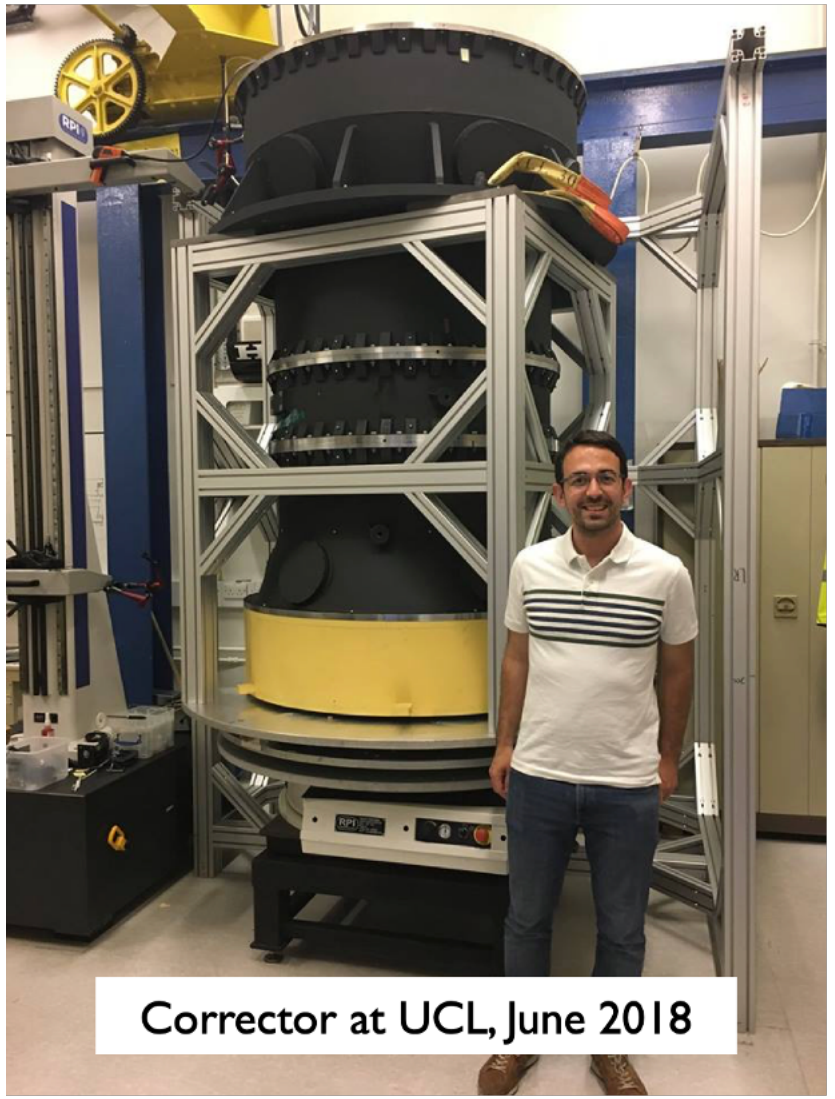

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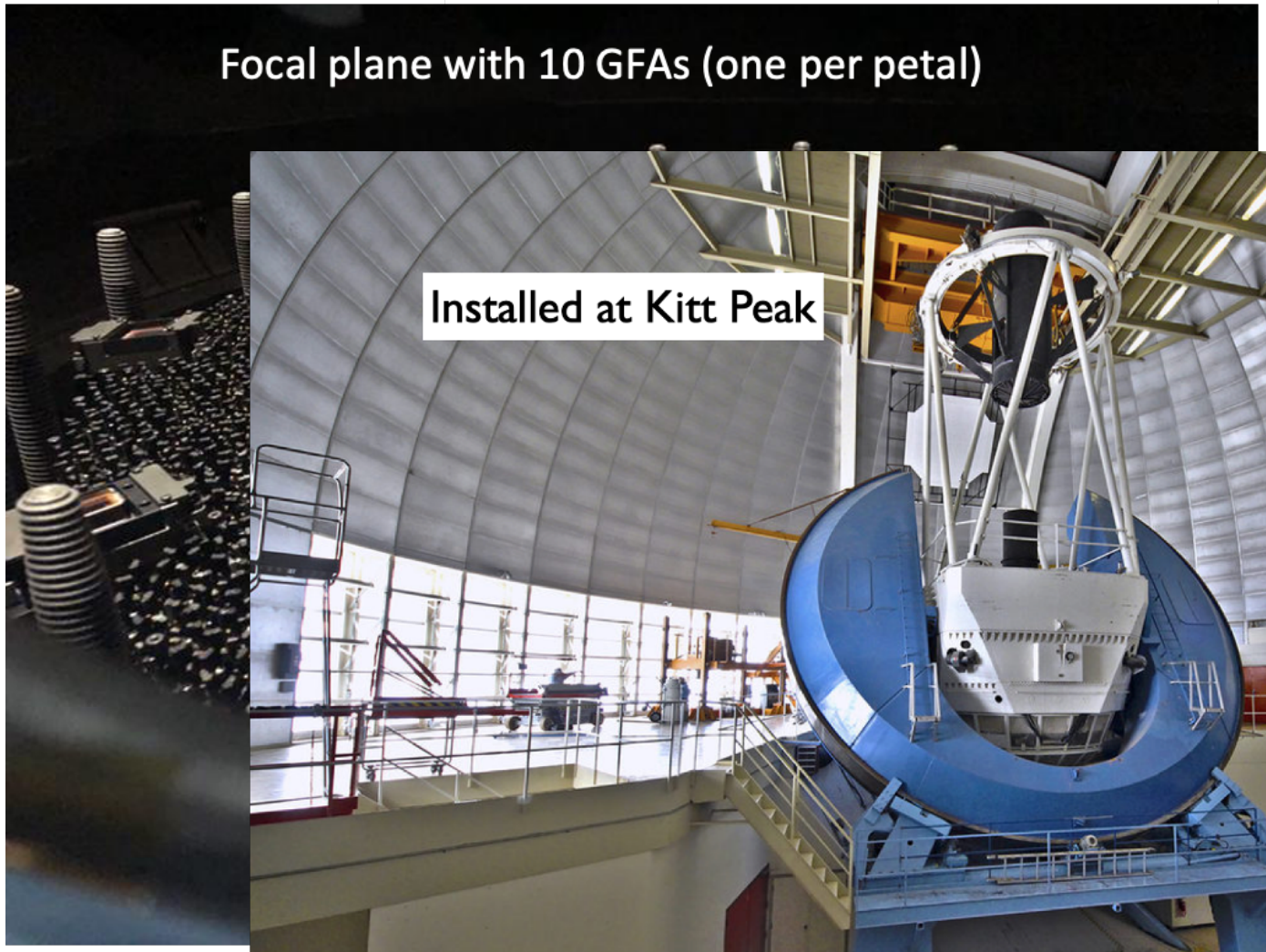

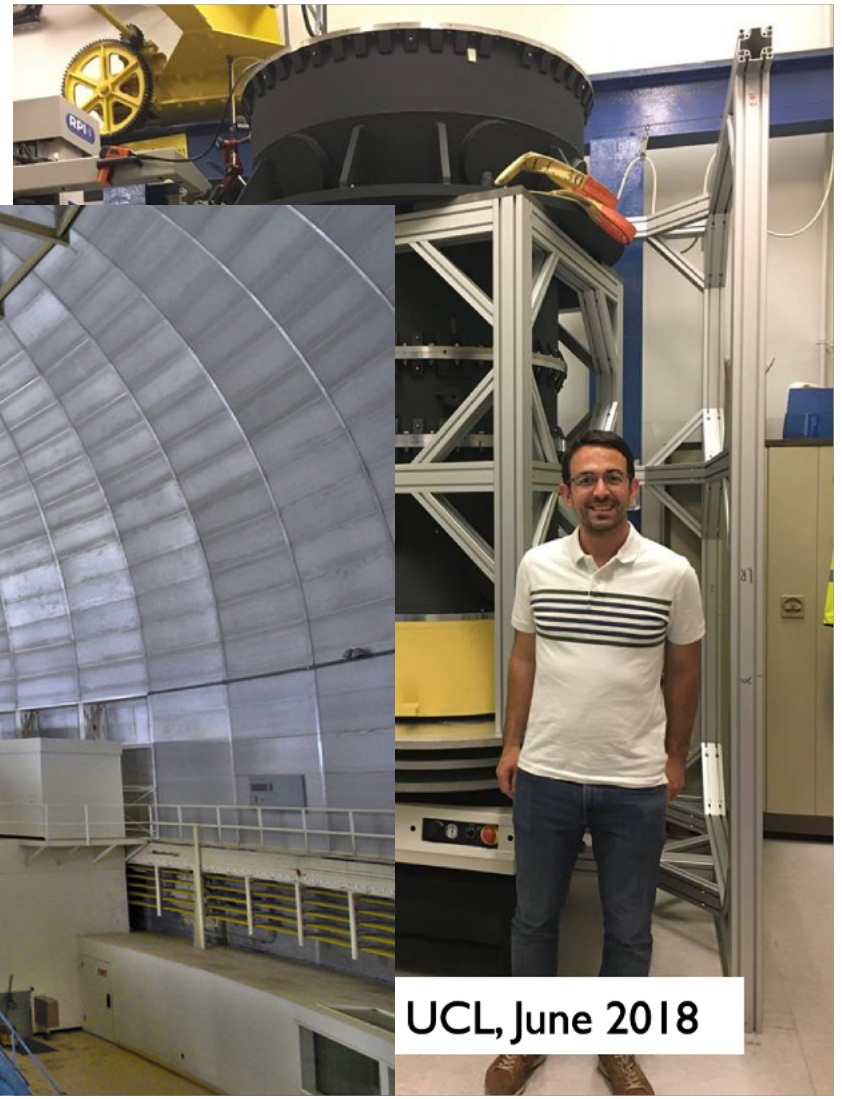

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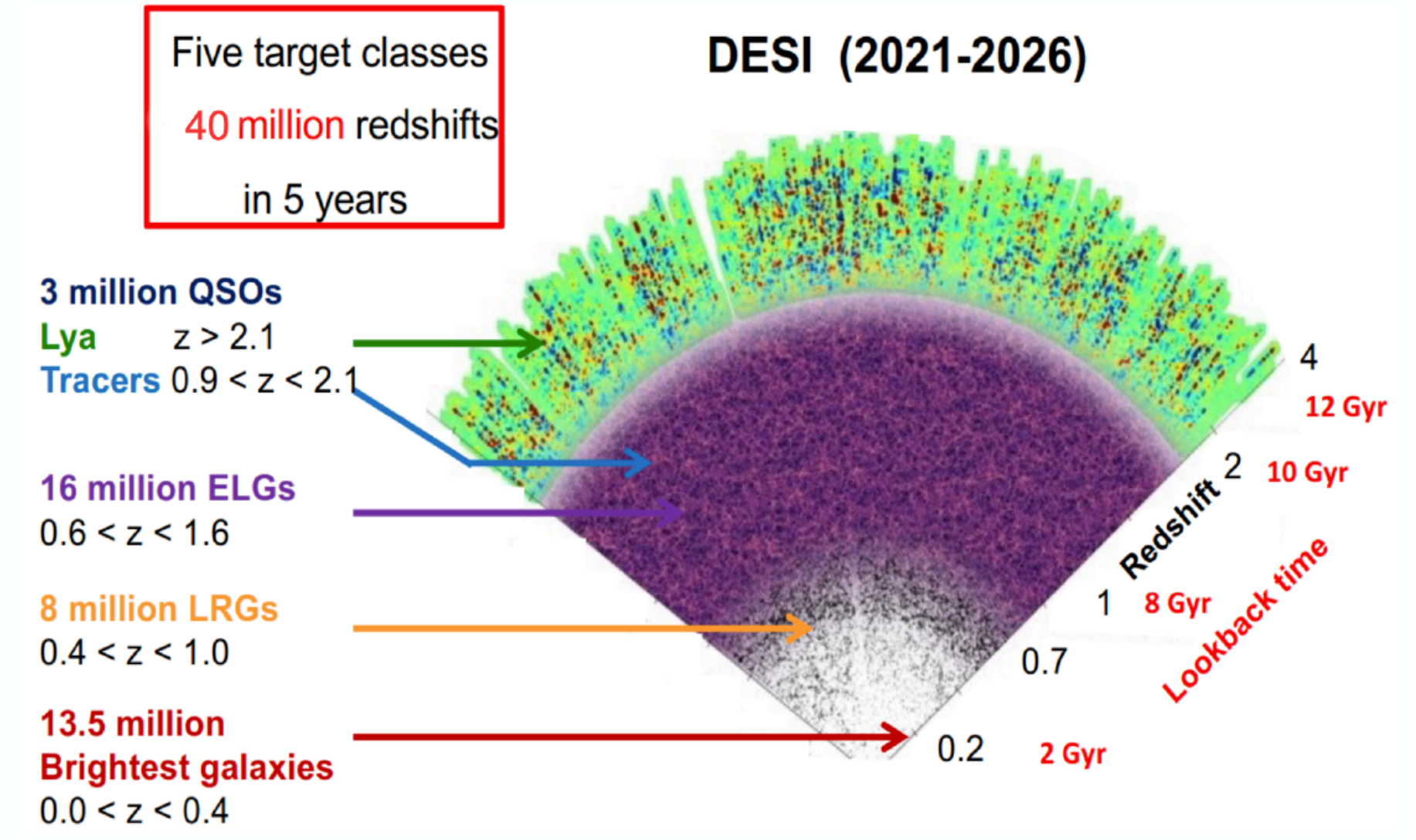
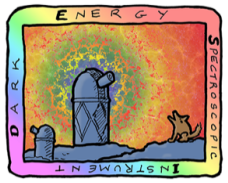
Survey Overview





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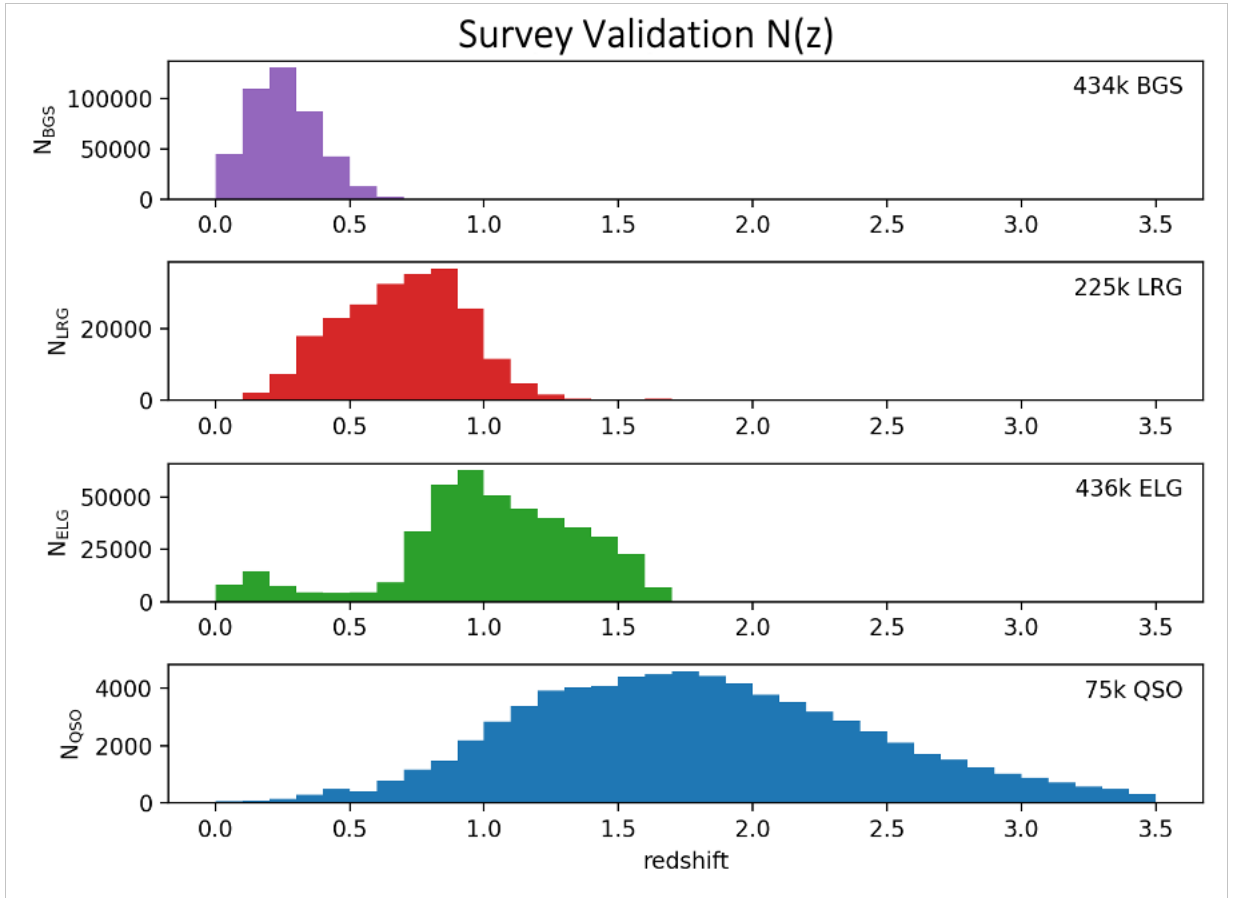
Early Data Release (EDR)

- Over 1 million redshifts obtained during Survey Validation (SV, Dec 2020– May 2021)
- Includes 4 different tracers to cover a wide redshift range, but also lots of stars!
- These will be published in the Early Data Release (EDR)



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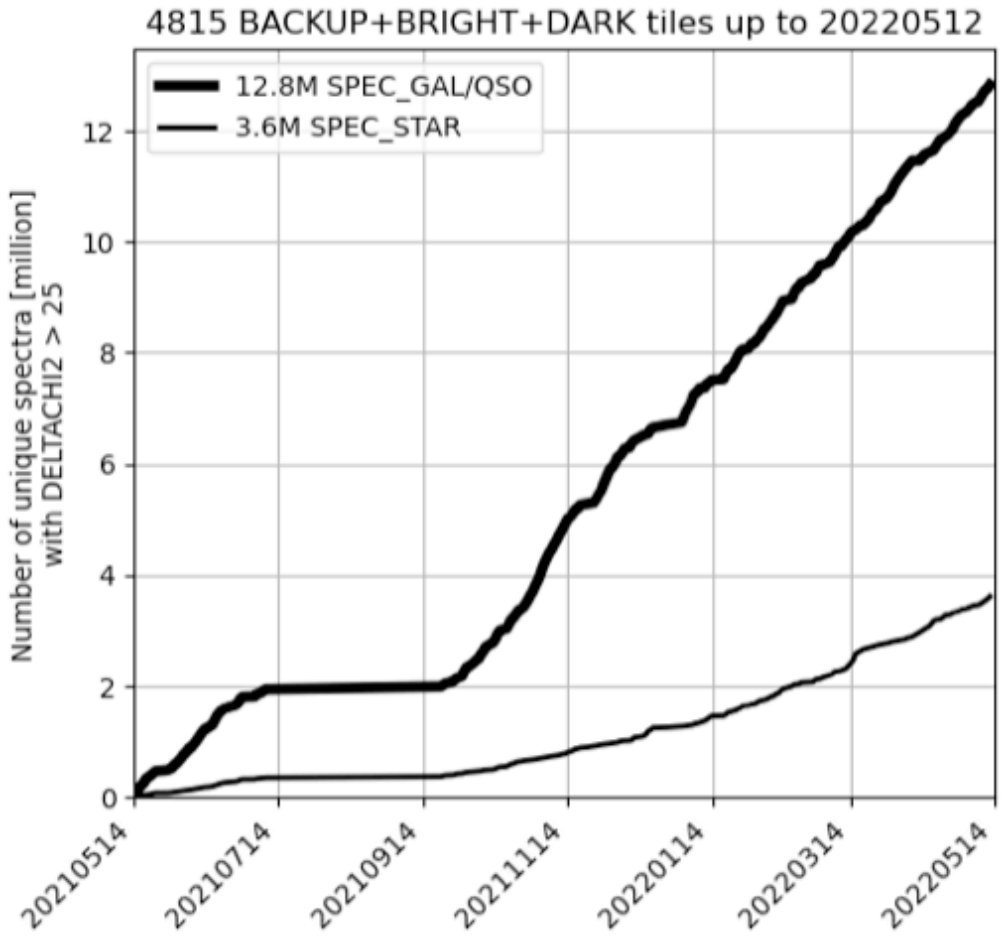
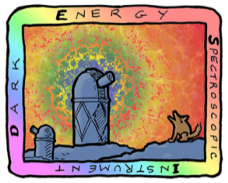
Main Survey

- After two months of main survey observations (May-July 2021), we paused for some instrument upgrades
- Restarted observations in September 2021, and we already have more than 12M extragalactic redshifts
- The first data release (DR1) will include data until September 2022





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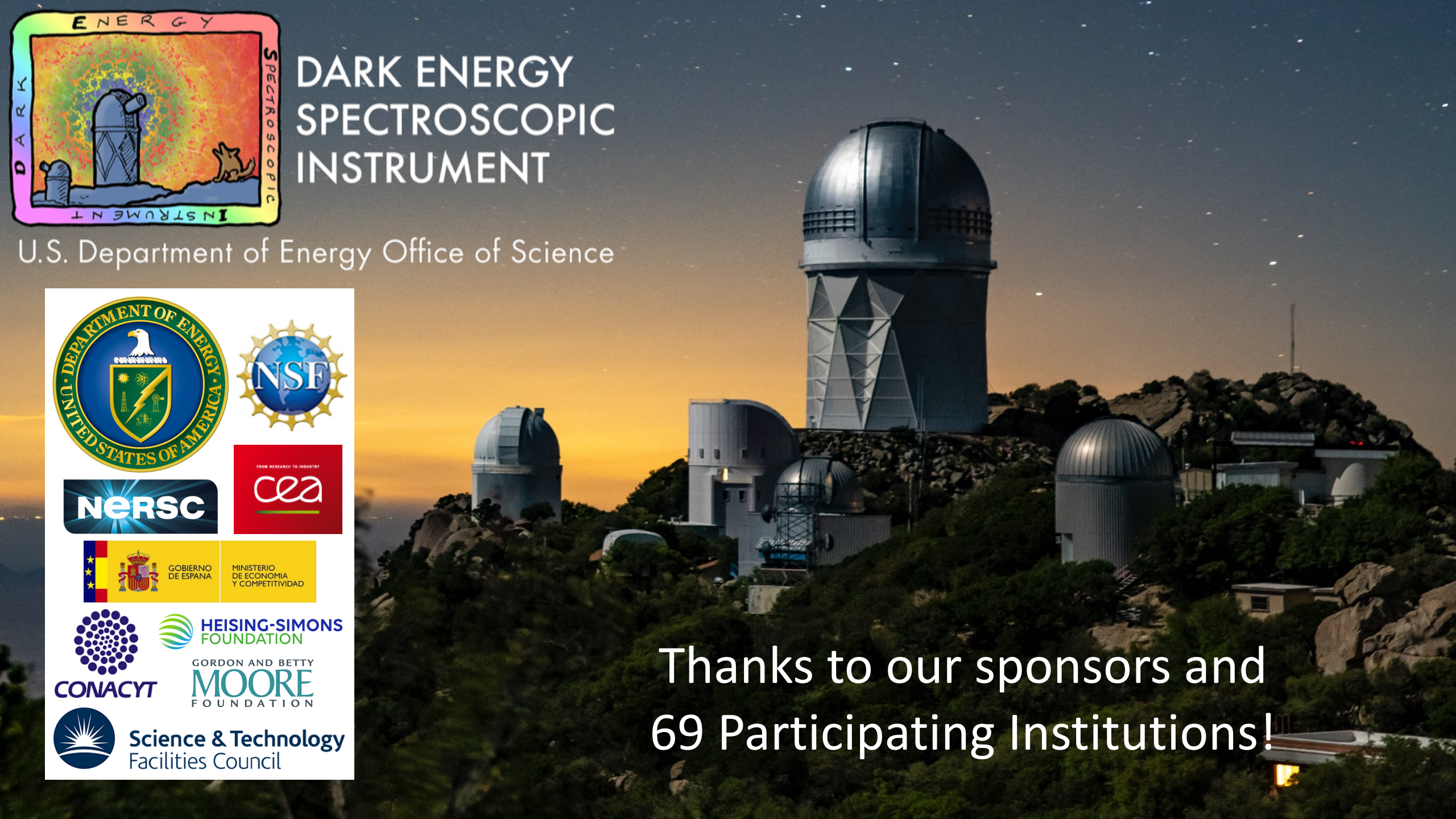
Summary

- The Dark Energy Spectroscopic Instrument is observing at full speed!
- Early Data Release will contain >1M spectra from Survey Validation
- First cosmological results to appear with DR1 (date TBD)
- New state of the art for dark energy, modified gravity and neutrinos masses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