DESI

The Dark Energy Spectroscopic Instrument

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Outline

- Introduction
- Science
- Instrument
- Current Status

Mystery of Dark Energy

- **What is the source of the accelerated expansion of the universe**
  - **Cosmological constant (w= -1)?**
  - **New long-range repulsive force?**
  - **Modification of gravity?**
  - **Other ideas?**

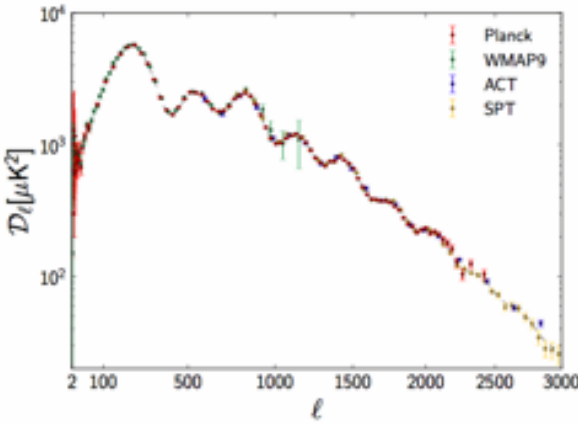
- **Experimentally we study two major aspects of our universe**
  - **The expansion history of the universe, to see if the energy density of dark energy is constant or varying in time**
  - **The growth of structures (such as clusters of galaxies) to see if this is consistent with what general relativity and the measured expansion rate would predict.**

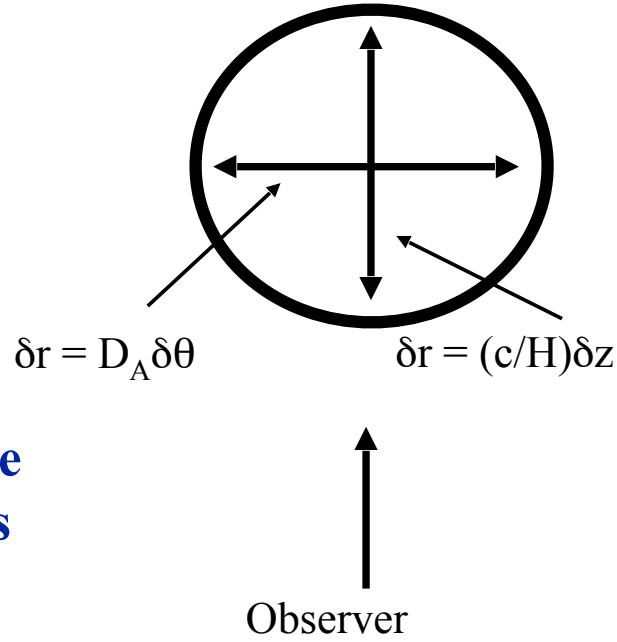
Background

- DESI is a Stage IV project that evolved from two successful project models
  - SDSS/BOSS (DOE Stage II and III)
  - DES/DECam (DOE Stage III)
- SDSS I and II proved the power of a large area survey for constraining Dark Energy and the ability to use photometric (approximate) as well as spectroscopic (precise) redshifts. Developed the Baryon Acoustic Oscillations (BAO) probe for dark energy and made the 1st measurement using galaxies.
- BOSS (SDSS III) continued with the survey approach and further developed the BAO probe using spectroscopic redshifts to constrain Dark Energy
- DES built a new camera for the Blanco telescope to perform a large area imaging survey using photometric redshifts: allows DE measurements using 4 probes: Weak lensing, SN, clustering and BAO
- DESI will build a new top end for the Mayall telescope on Kitt Peak (the twin of the Blanco) and measure spectroscopic redshifts of millions of galaxies and quasars. Primary science is BAO

Baryon Acoustic Oscillations (BAO)

- Sound waves in the early Universe produce a peak in the clustering of matter that shows up in the distribution of galaxies we see today.
- This peak was imprinted on the universe when the photons and baryons decoupled (~360,000 million years after the Big bang, redshift of about 1000); the peak serves as a standard ruler.
- The scale depends on the sound speed and the propagation time - these depend on the matter to radiation ratio and the baryon to photon ratio.
- The CMB anisotropies measure these and fix the scale of the standard ruler
- Spectroscopic redshift surveys can measure this scale both along and across the line of site over the history of the universe by measuring the distances between galaxies and galaxy clusters
- Yields measurement of the Hubble parameter H(z) and the angular diameter distance $D_A(z)$





DESI Science

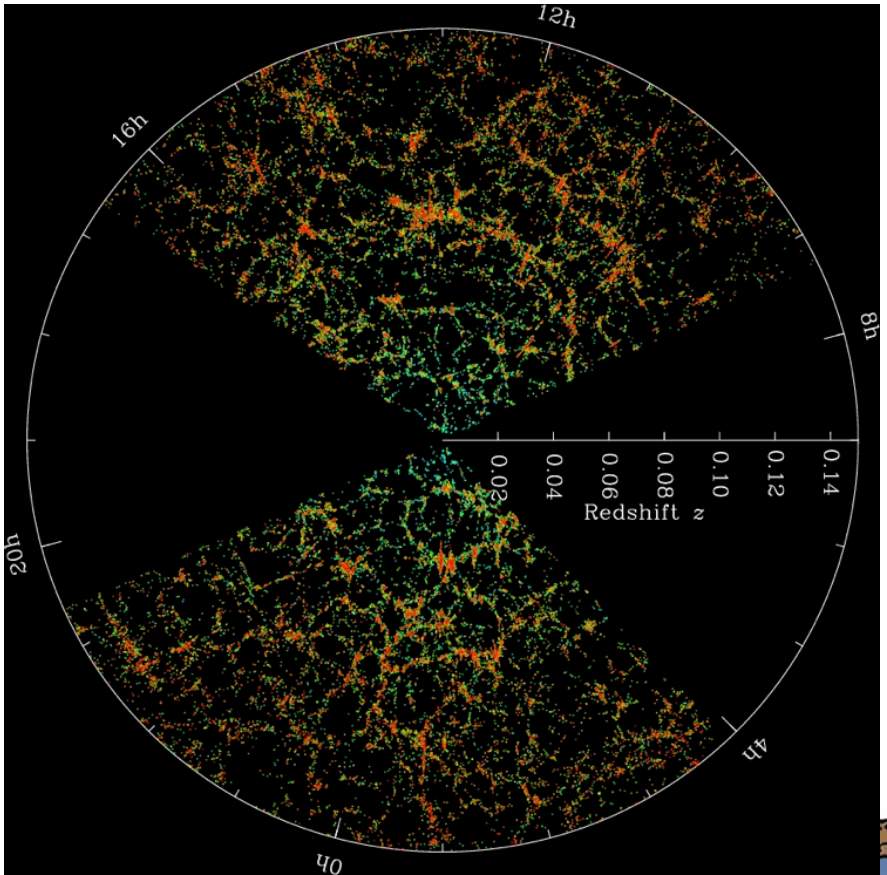
- **The primary science goal for DESI is to use the BAO technique to measure the cosmic distance scale over nearly the entire northern sky and over nearly the entire age of the universe (out to redshift of 3.5, 12 billion years ago)**
  - **Since BAO is fundamentally a measurement of the separations between galaxies, not the absolute properties of the galaxies themselves, it has low systematic uncertainties.**
- **Can test for modifications to gravity by measuring the growth rate of structures using a new technique called red-shift space distortions in galaxy clustering.**
- **Can measure the mass of the neutrino through the effect on clustering**
- **Can investigate inflation by measuring non-Gaussianity and spectral shape of inflationary perturbations**

DESI in a nutshell

- To perform the survey DESI requires a new wide field optical corrector, a 5000 fiber positioner and a spectroscopic system on a wide field 4m telescope
- The survey is planned to take ~ 4 years to measure precise redshifts of ~ 25 million galaxies and ~2 million Quasars
- The DESI (the Dark Energy Spectroscopic Instrument) project was formed in 2012 from the merger of the BigBoss and the DESpec wide field multi-object spectrograph concepts.
- The DESI collaboration is led by LBNL and has 21 US Universities, 5 DOE labs, 19 foreign institutions, totaling ~180 collaborators
- The collaboration is in its formative stages, new collaborators are welcome! Let us know if you are interested.
- DESI received CD-0 approval in Sept. 2012
- P5 gave DESI a favorable review and DOE has told the project to proceed with a CD-1 review scheduled in Sept. 2014.

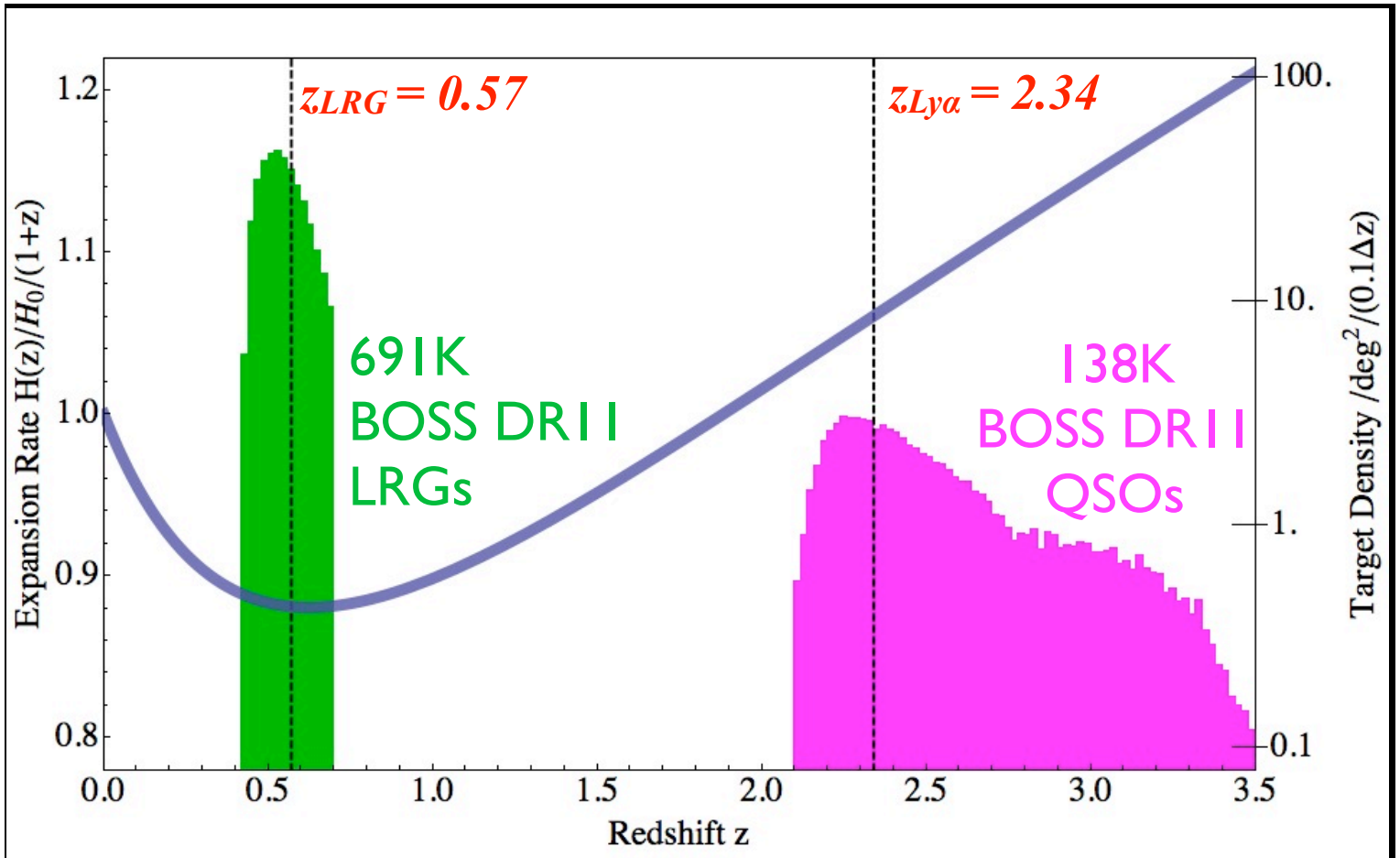
SDSS/BOSS

- SDSS has two instruments: a 3 deg. FOV imager and a 1000 fiber spectroscopy system on a telescope with a 2.4m mirror at Apache Pt. AZ
- SDSS-I and SDSS-II: ~1 million spectroscopic redshifts, 1st BAO measurement with galaxies
- BOSS is SDSS-III – Dedicated study of BAO: with 90% of the survey completed they have a 1% measurement of the distance scale



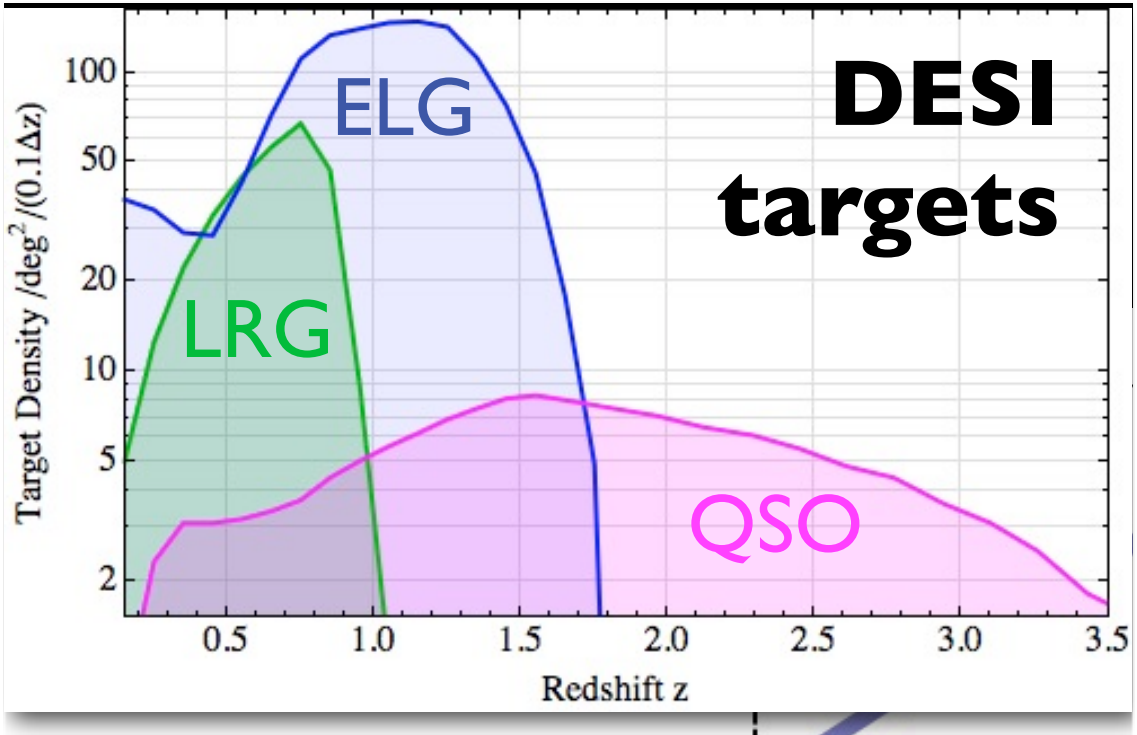
SDSSIII/BOSS

- Measured > 8000 sq. deg., 1.2M galaxies and 240k Quasars
- Demonstrated that quasars (much brighter than SN) can be used to probe BAO at high redshifts using the Lyman Alpha Forest (z =3.5 is about 12 billion years ago, most of the age of the universe)



The DESI Survey

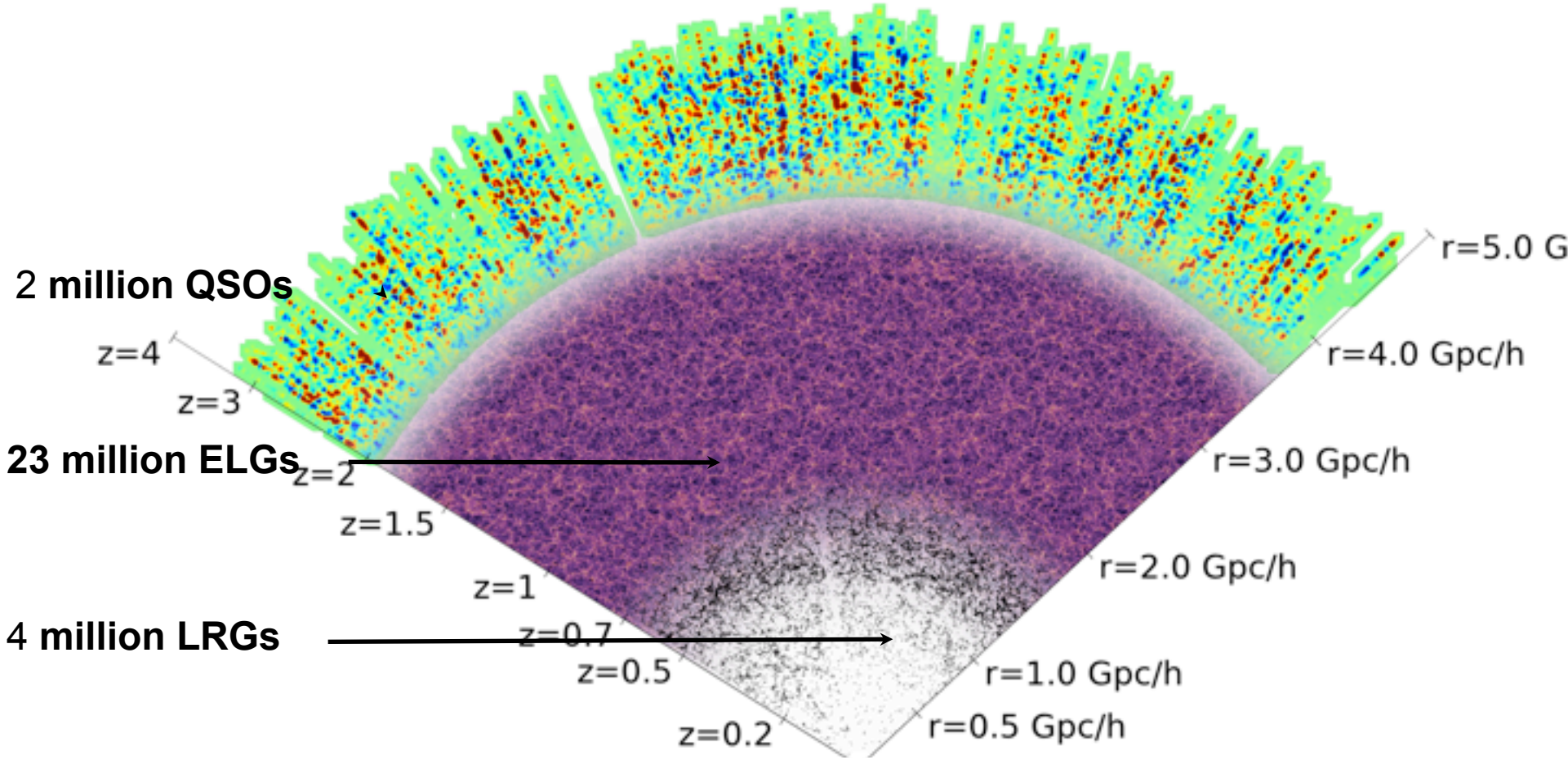
- A spectroscopic survey over 14,000 deg^2
  - 4m telescope, 5000 robotically positioned fibers, spectrograph range 360 - 980 nm, 3.2 deg. field of view optical corrector
- 4 million Luminous Red Galaxies (LRGs)
- 23 million Emission Line Galaxies (ELGs)
- 1.4 million quasars (QSO)
- 0.6 million quasars at z>2.2 for Lyman-alpha-forest



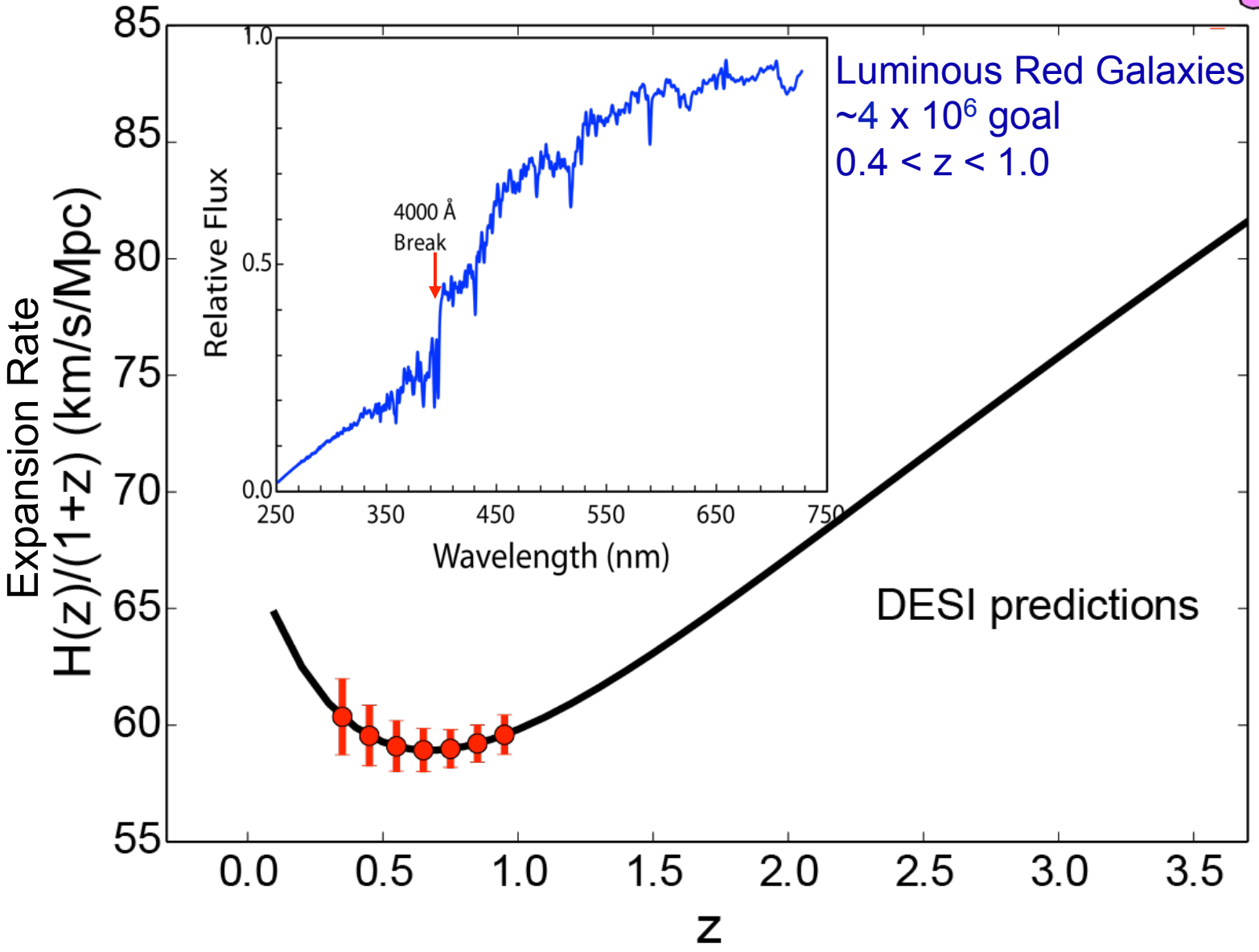
The DESI Survey in context

The largest spectroscopic survey for dark energy

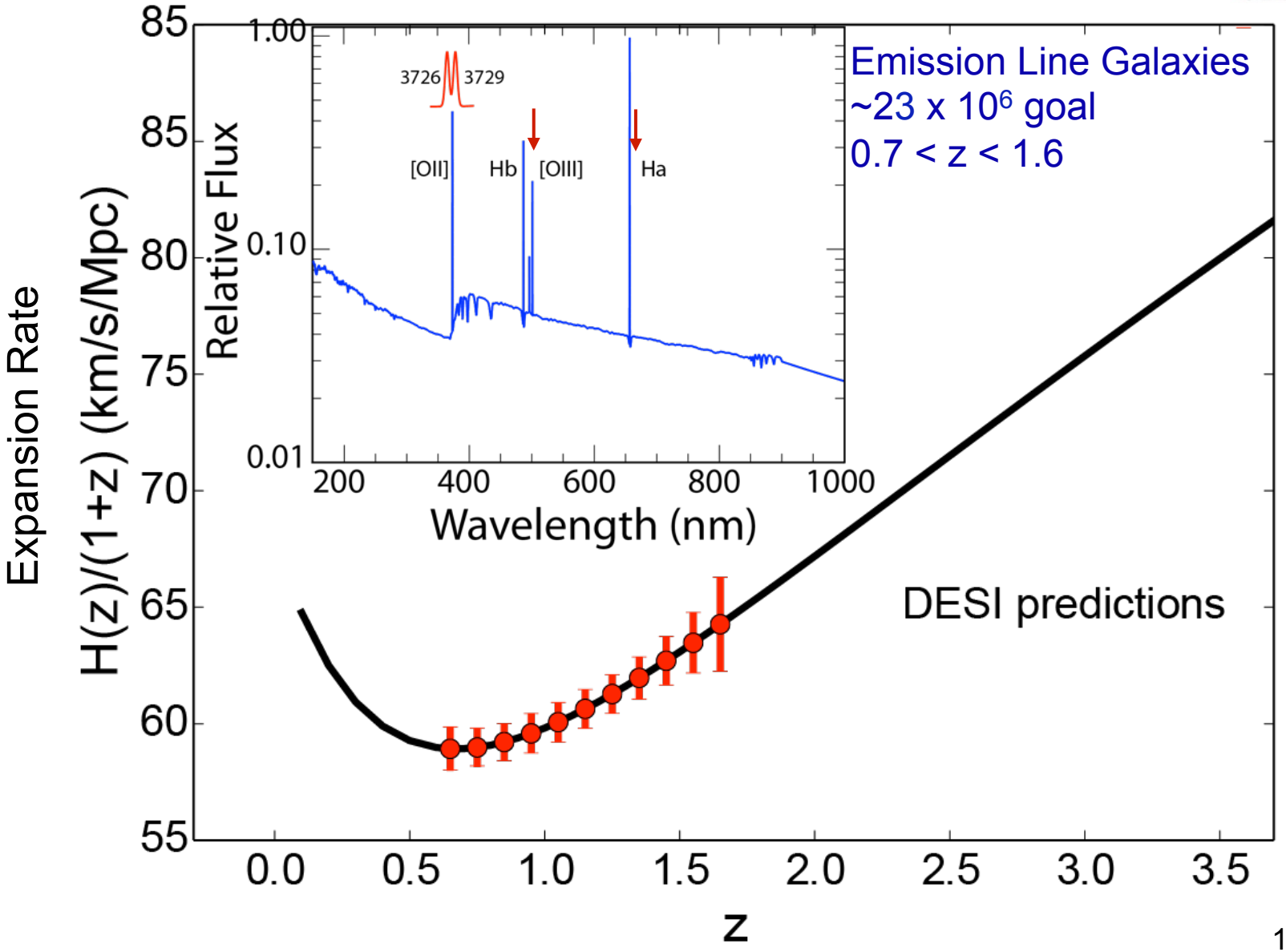
SDSS ~$2h^{-3}Gpc^3$ ⇨ BOSS ~$6h^{-3}Gpc^3$ ⇨ DESI $50h^{-3}Gpc^3$



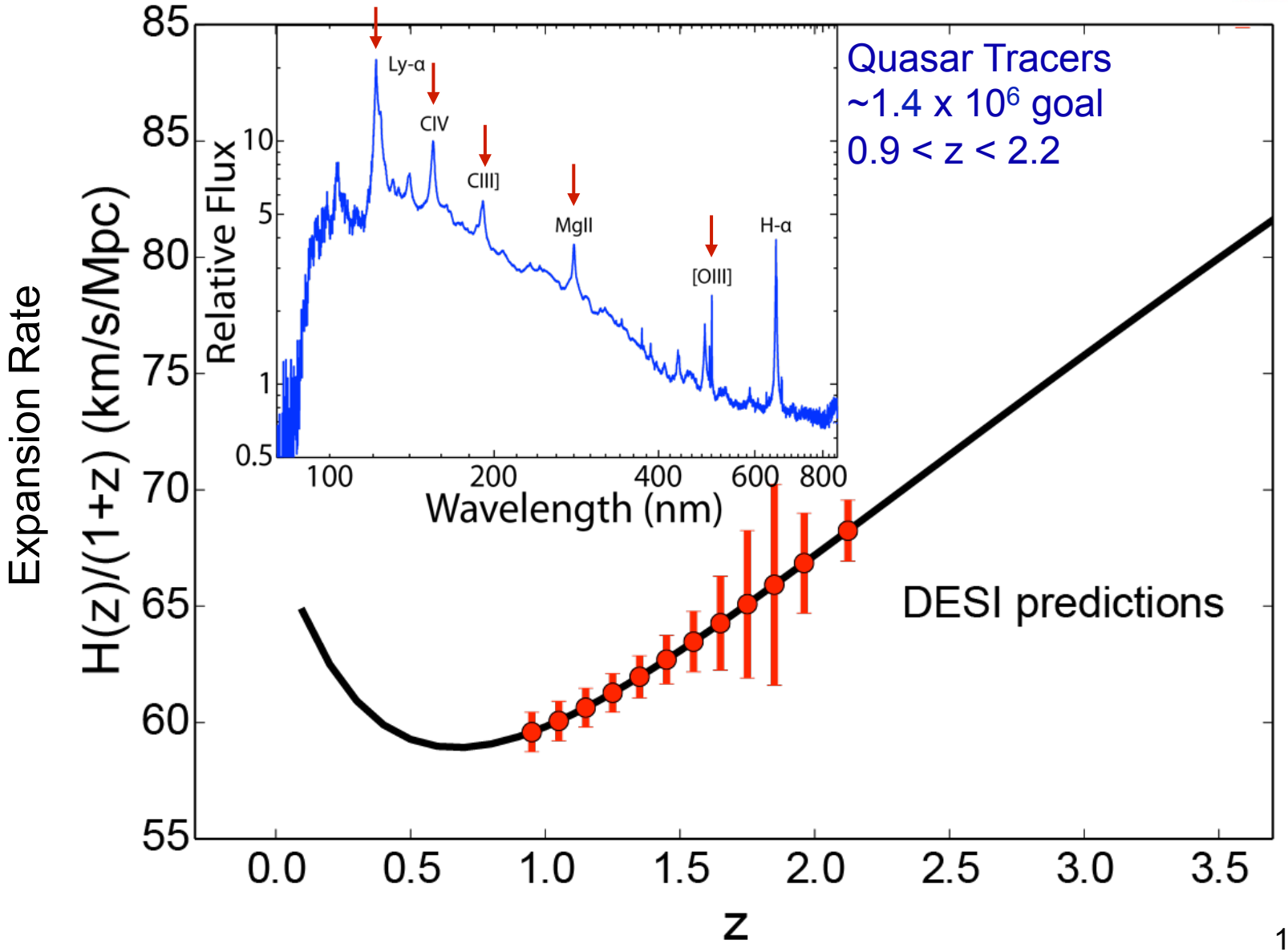
LRG Targets


Luminous Red Galaxies
~4 x 10^6 goal
0.4 < z < 1.0
DESI predictions
Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
Relative Flux
4000 Å
Break
Wavelength (nm)

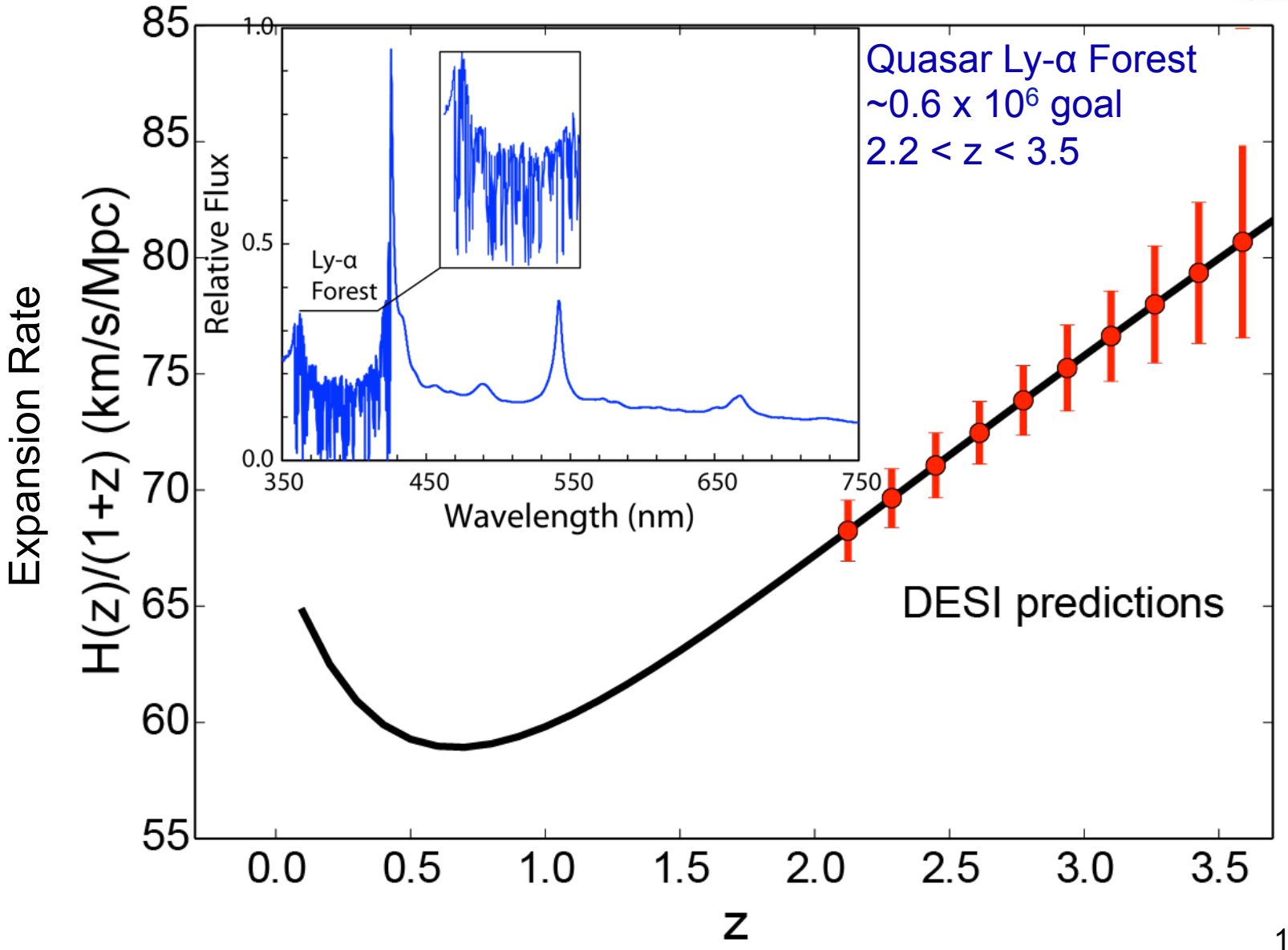
ELG Targets


Emission Line Galaxies
~23 x 10^6 goal
0.7 < z < 1.6
DESI predictions
Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
Relative Flux
Wavelength (nm)
3726
3729
[OII]
Hb
[OIII]
Ha
85
80
75
70
65
60
55
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1.00
0.10
0.01
200
400
600
800
1000

QSO Targets


Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
Relative Flux
Wavelength (nm)
Ly-α
CIV
CIII]
MgII
[OIII]
H-α
Quasar Tracers
~1.4 x 10^6 goal
0.9 < z < 2.2
DESI predictions

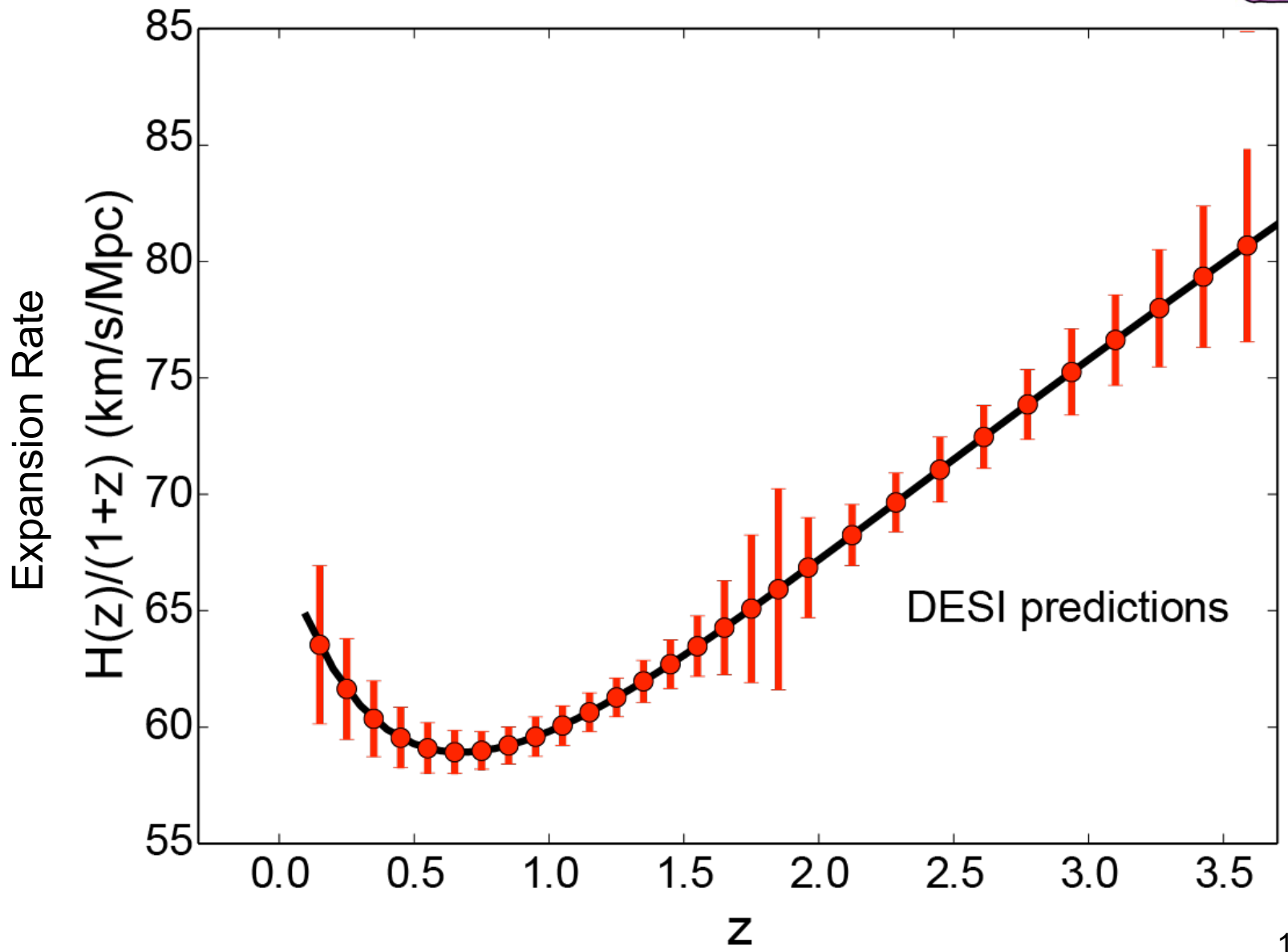
Ly-α Forest QSO Targets



Lyman Alpha Forest

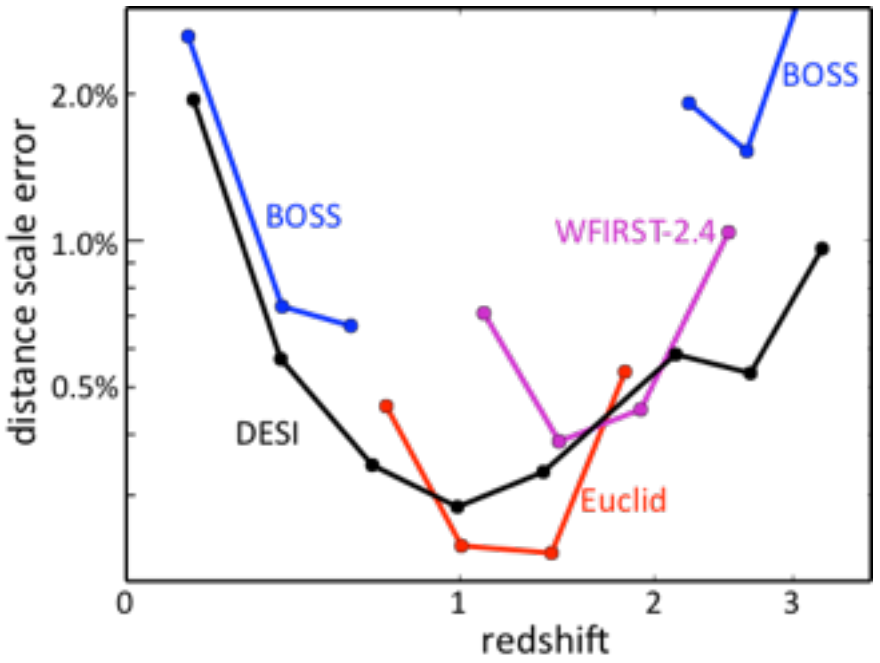
- Quasars are very bright - the Lyman Alpha forest technique can be used to measure the mass between us and the quasar to very high redshifts
- Not a property of the quasar itself, this uses the light from the quasar to probe the mass between us and it.
- Clouds of gas between us and the quasars absorb the ultraviolet light at the wavelength of the Lyman alpha line of neutral hydrogen (1220 Angstroms, the transition from the ground state, n=1, to the first excited state n=2)
- The clouds are numerous, and at different wavelengths
- The wavelength of the absorption line corresponds to the redshift of the cloud. This produces a "forest" of absorption lines between ~ 3500 and 4500 Angstroms for clouds at redshifts between 2.2 and 3.5

DESI on the Hubble Diagram



BAO in DESI

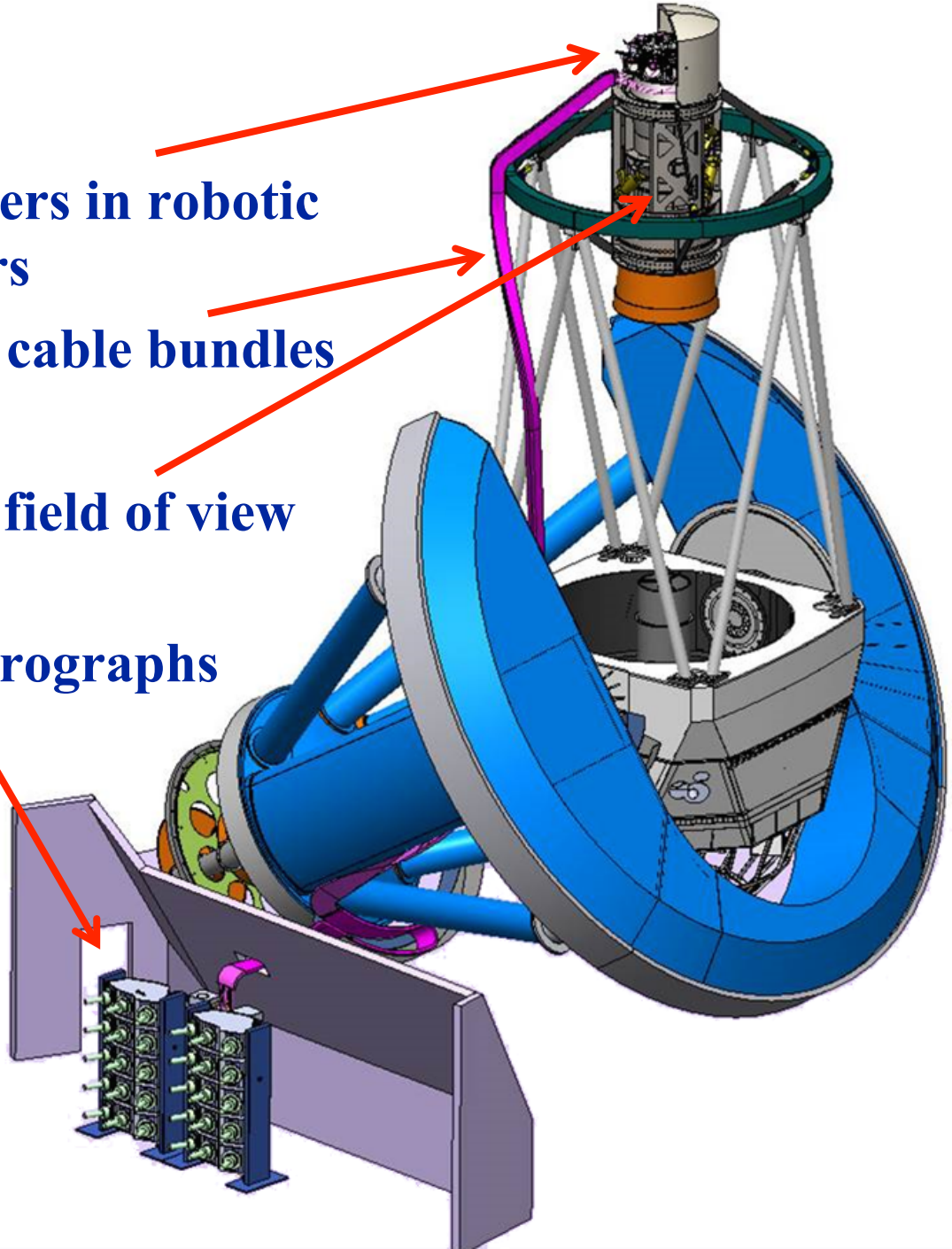
- DESI will produce a world-leading survey of the cosmic distance scale
- Will measure H(z) to better than 0.3% statistical errors
- Systematic uncertainties on H(z) and $D_A(z)$ of less than 0.2%



- DESI will far exceed other ground-based projects on its timescale and will be competitive with satellite missions

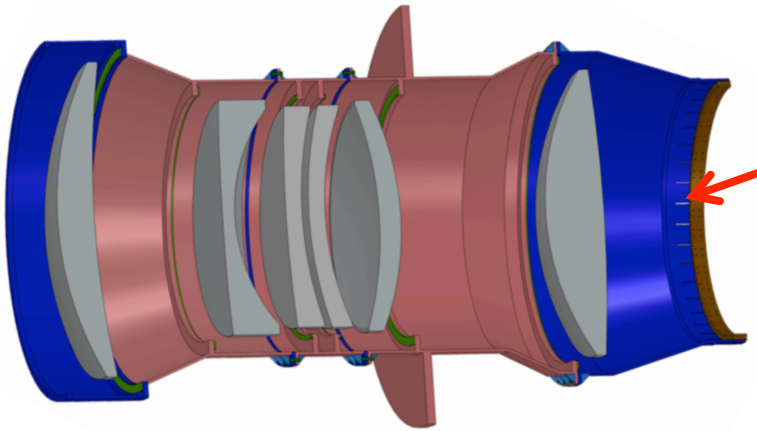
DESI

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

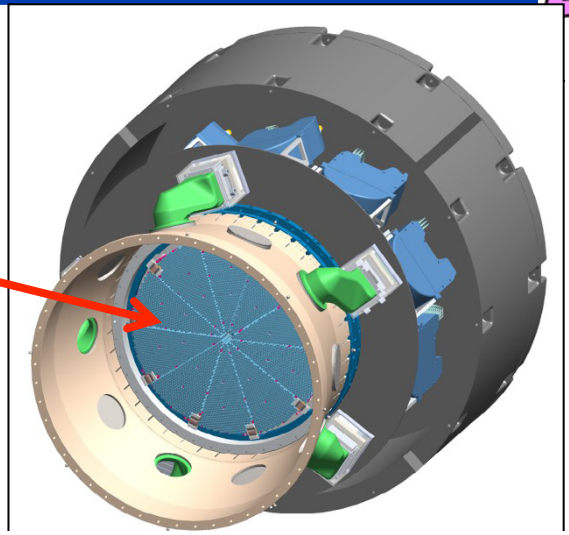


Mayall 4m Telescope
Kitt Peak
Tucson, AZ

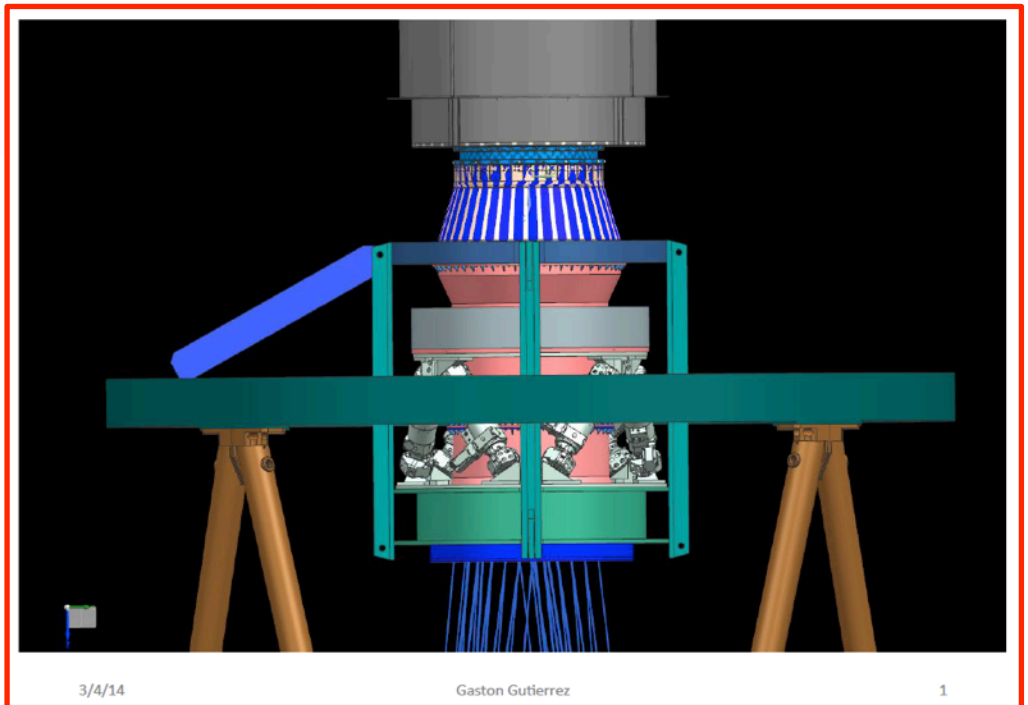
DESI Barrel Cage and Rings



Focal Plane: 5000 fiber tips, robotically positioned



Fermilab is responsible for corrector barrel, the new cage and rings, as well as the CCD packaging and testing (similar to DECam)



Part of the DESI team at the telescope

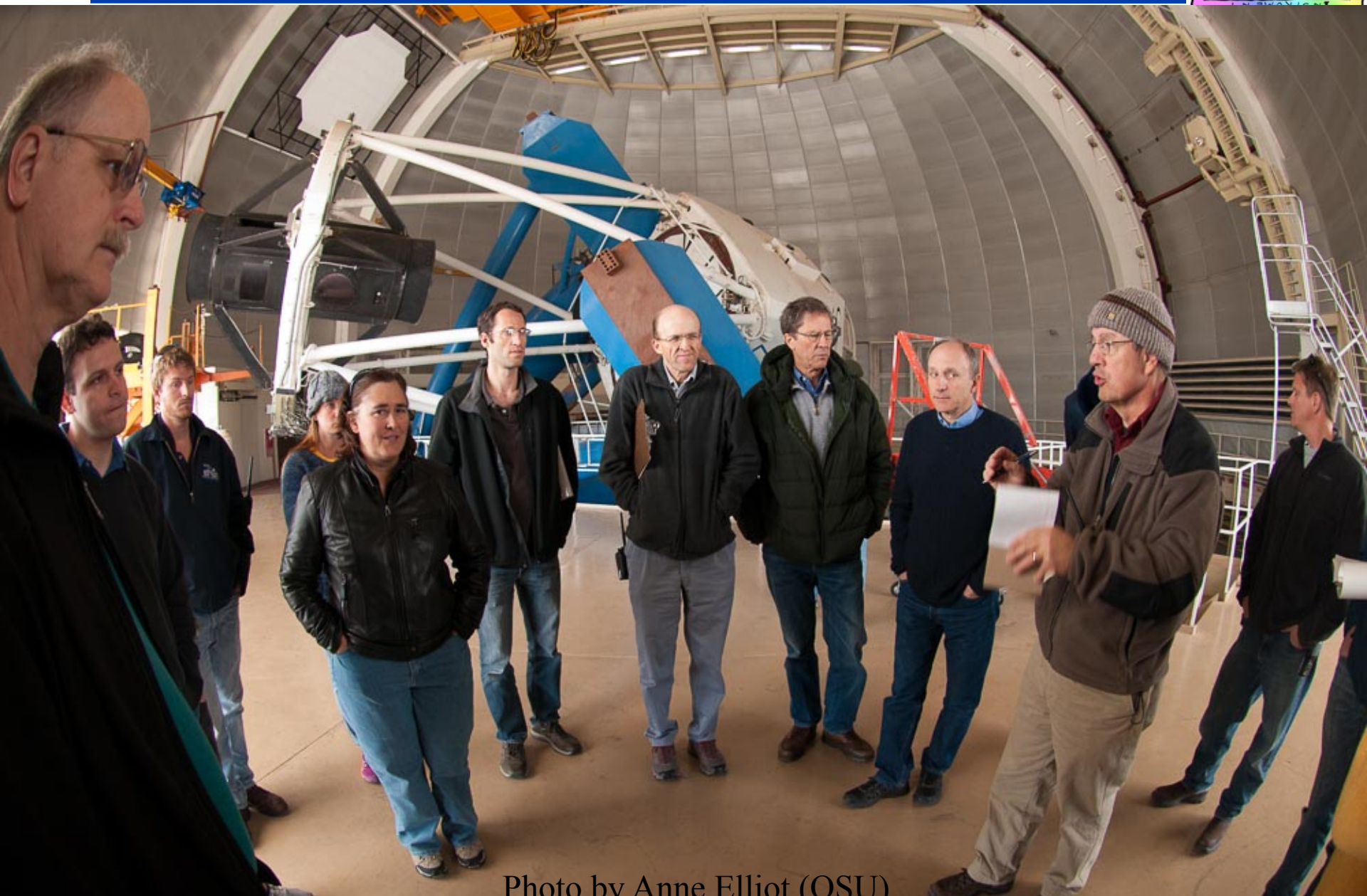


Photo by Anne Elliot (OSU)

DESI Funding

LBL/DESI won a grant from the Moore foundation to jump start early procurements:

- **Fabrication of the first spectrograph**
- **Fabrication of the lens blanks**

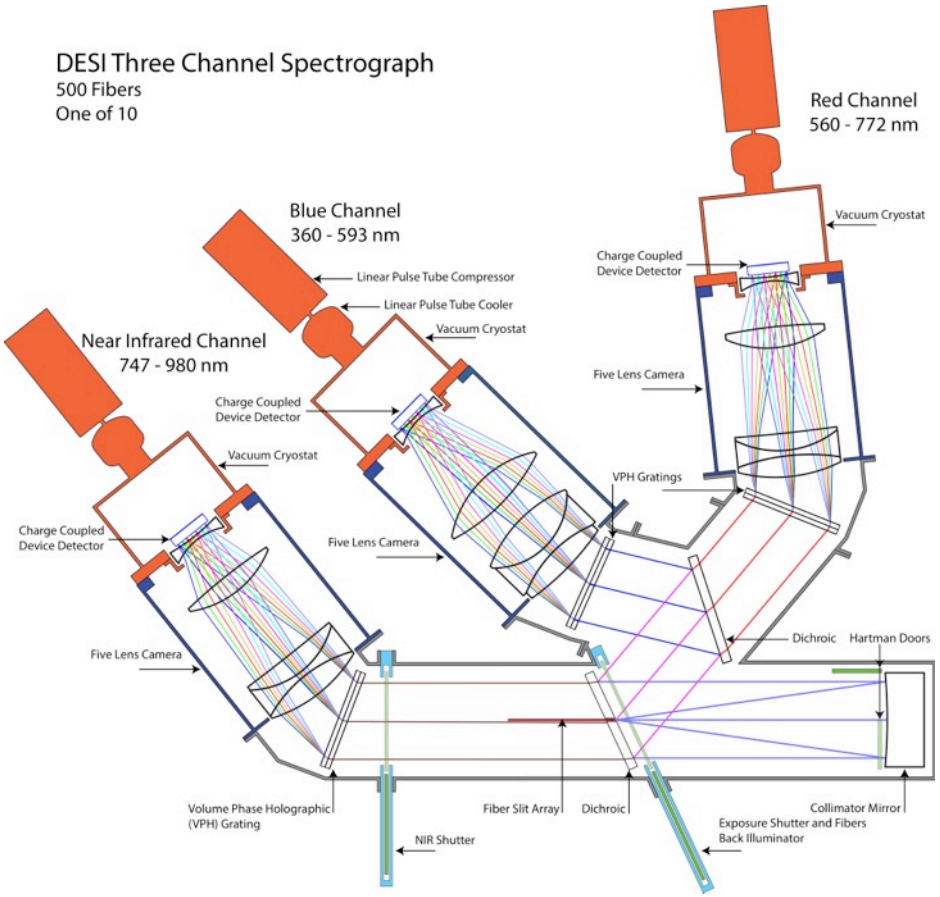
The 1st spectrograph fabrication has started and will be complete by end of 2015!

Contracts for the lens blanks are getting placed this summer.

DOE is funding R&D in preparation for a CD-1 review in Sept. 2014.

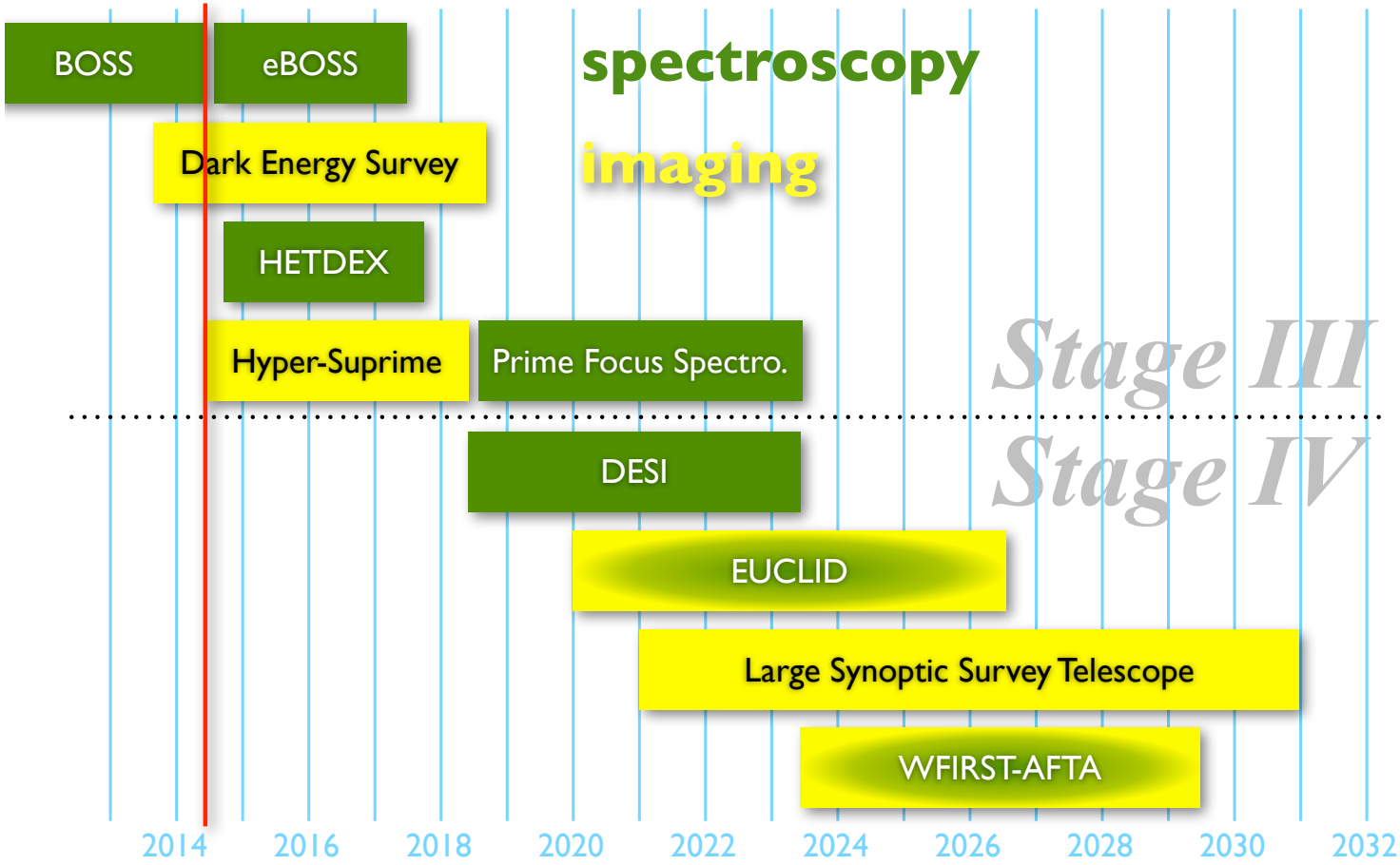
Foreign collaborators also receiving R&D support and pursuing funding

DESI Spectrograph



DESI in Context

The dark energy facilities roadmap

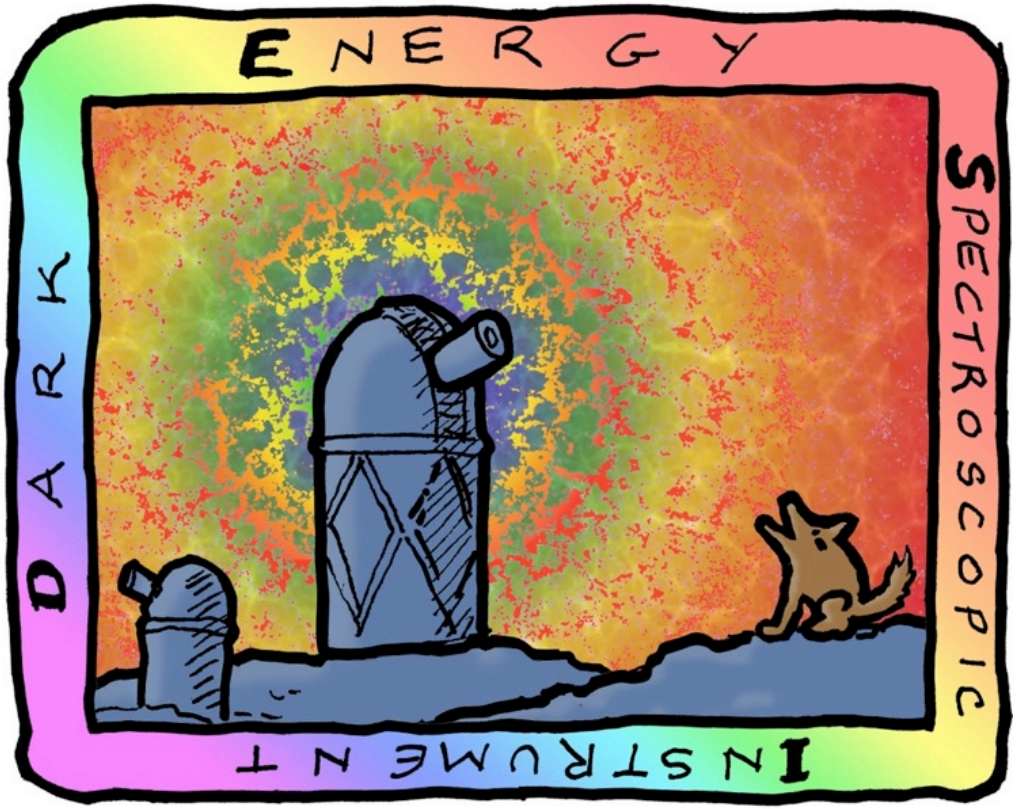


DESI Collaboration Meeting May 2014

Conclusion

- **DESI builds on the long and successful experience of multiple collaborations in defining, building and executing wide area surveys to study the mystery of Dark Energy**
  - **—SDSS, BOSS, DES**
- **DESI will take a large step forward in BAO measurements in both statistical precision and redshift coverage**
  - **—Will essentially complete BAO measurements in the northern sky out to redshift of 1.5.**
  - **—Will continue measurements out to redshift of 3.5 using galaxies, quasars and the Lyman alpha forest**
  - **—Will also provide additional cosmological constraints on the neutrino mass and redshift space distortions**
  - **—P5 gave DESI a favorable review and DOE has told the project to proceed with a CD-1 review scheduled in Sept. 2014**

Extra slides


ENERGY
SPECTROSCOPIC
INSTRUMENT
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