DESI

The Dark Energy Spectroscopic Instrument

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Outline

- Introduction
- Baryon Acoustic Oscillations
- Sloan Digital Sky Survey: BOSS and eBOSS.
- DESI
- 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?**

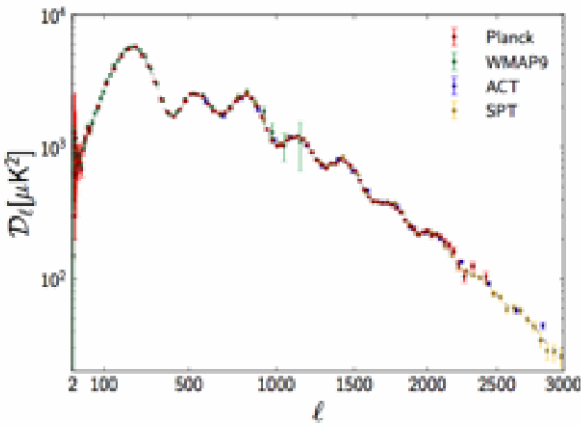
- **Experimentally we study two major aspects of our universe**
  - **The expansion history of the universe to see if the energy density of dark energy is constant or varying in time**
  - **The growth of structures (such as clusters of galaxies) to see if this consistent with what general relativity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

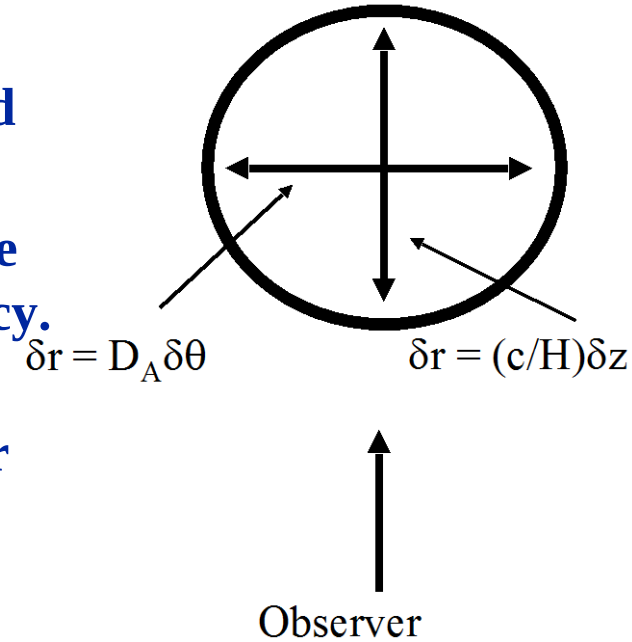
Background

- **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 which 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)

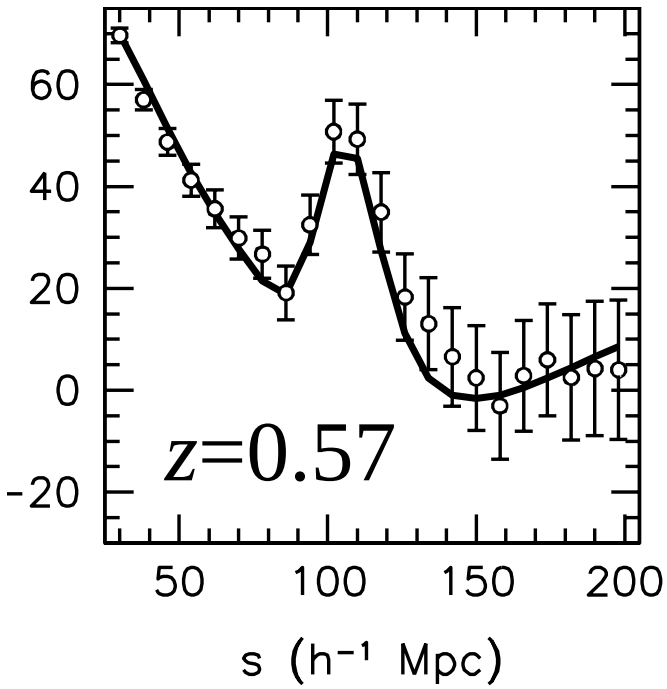
- **Sound waves in the early Universe produce a sharp characteristic scale in the anisotropies of the cosmic microwave background and in the clustering of matter in the late-time Universe.**
- **The scale was imprinted on the universe when the photons and baryons decoupled (~400,000 years after the Big bang, redshift *z* ~ 1000).**
- **The scale can be extremely well calibrated, as it depends only on simple physics: the sound speed and the propagation time.**
- **The CMB anisotropies imply these and calibrate the scale of the standard ruler to sub-% accuracy.**
- **Spectroscopic redshift surveys can measure this scale both along and across the line of sight over the history of the universe by measuring the distances between galaxies.**
- **Yields measurement of the Hubble parameter H(z) and the angular diameter distance $D_A(z)$.**

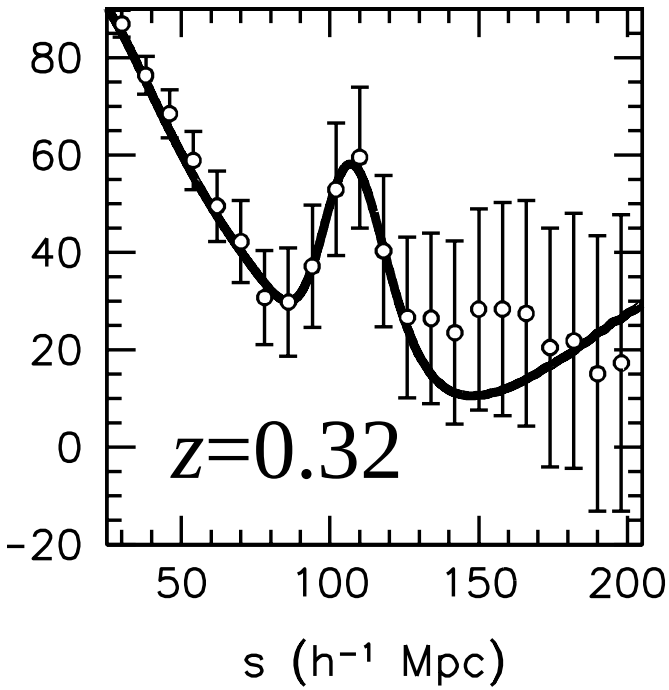




BAO in 2014

- **SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS) has observed 2 million targets over 10,000 square degrees.**
- **Key Project now complete, 3 months ahead of schedule.**
- **World-leading BAO measurements from galaxy samples, yielding 2.1% distance to z=0.32 and 1.0% to z=0.57!**

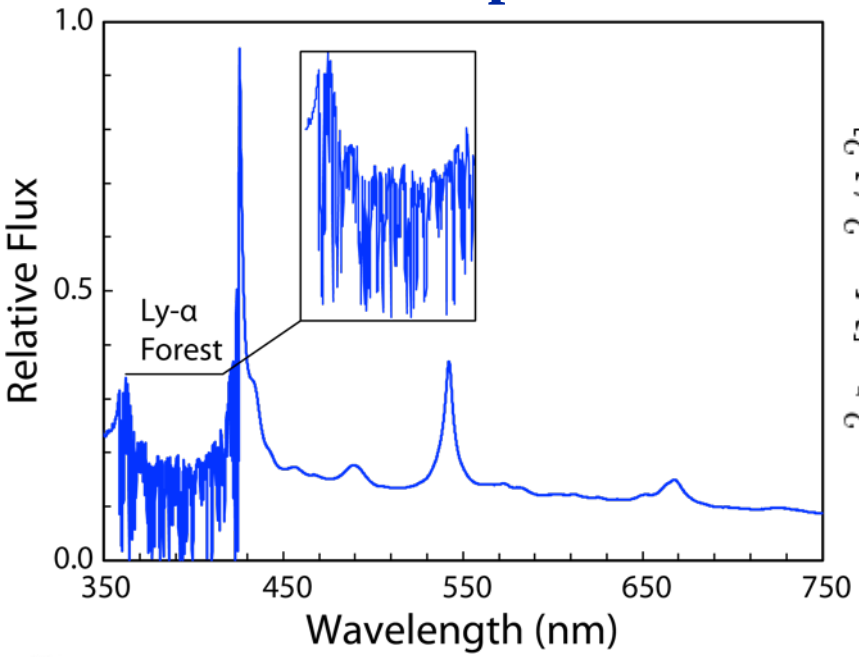


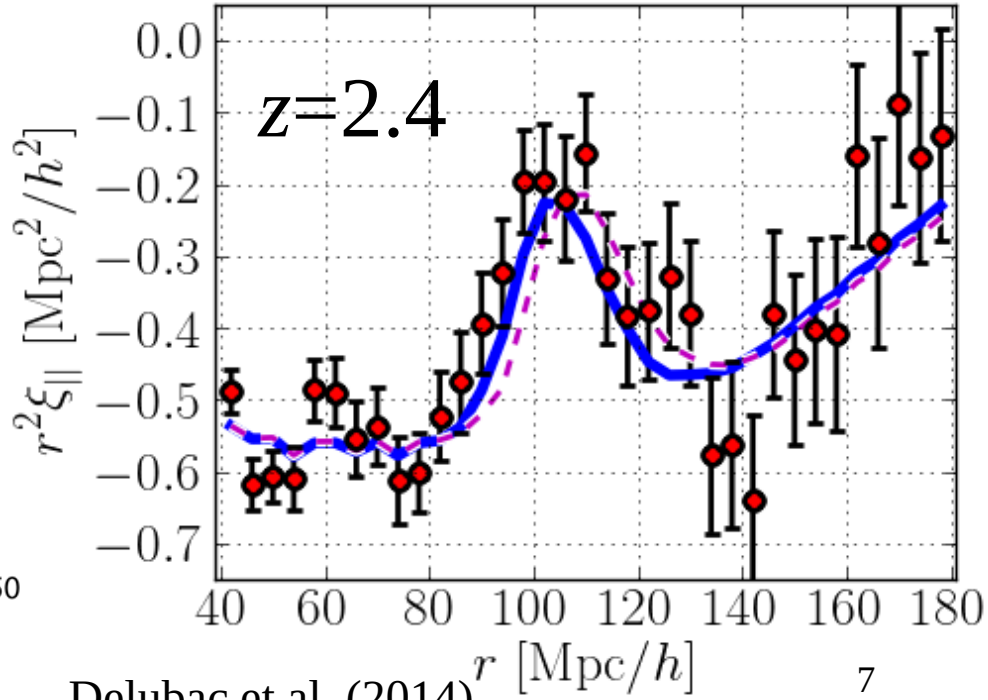


Anderson et al. (2014); Tojeiro et al. (2014)

BAO in the Lyman α Forest

- **SDSS-III BOSS has pioneered the detection of BAO in the Intergalactic Medium.**
- **Uses Lyman α Forest from 160,000 quasars to produce a sparse 3-d map of intergalactic neutral hydrogen.**
- **BAO detection now at 5σ, producing a 3% measurement of the Hubble parameter at z=2.4!**

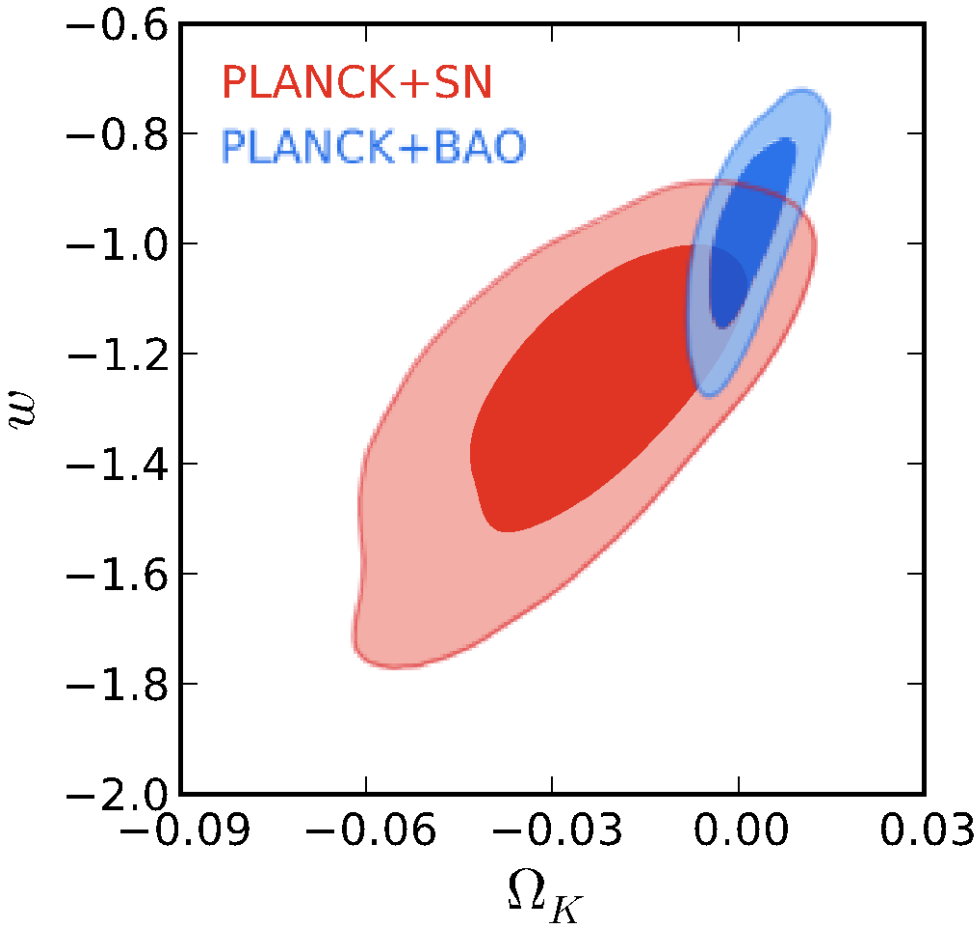




Delubac et al. (2014)

Cosmological Constraints

- **For non-flat wCDM, Planck+BAO finds:**
  $\Omega_K = 0.002 \pm 0.005$,
  $w = -0.98 \pm 0.11$,
  $\Omega_m = 0.314 \pm 0.020$,
  $H_0 = 67.3 \pm 2.2$ km/s/Mpc



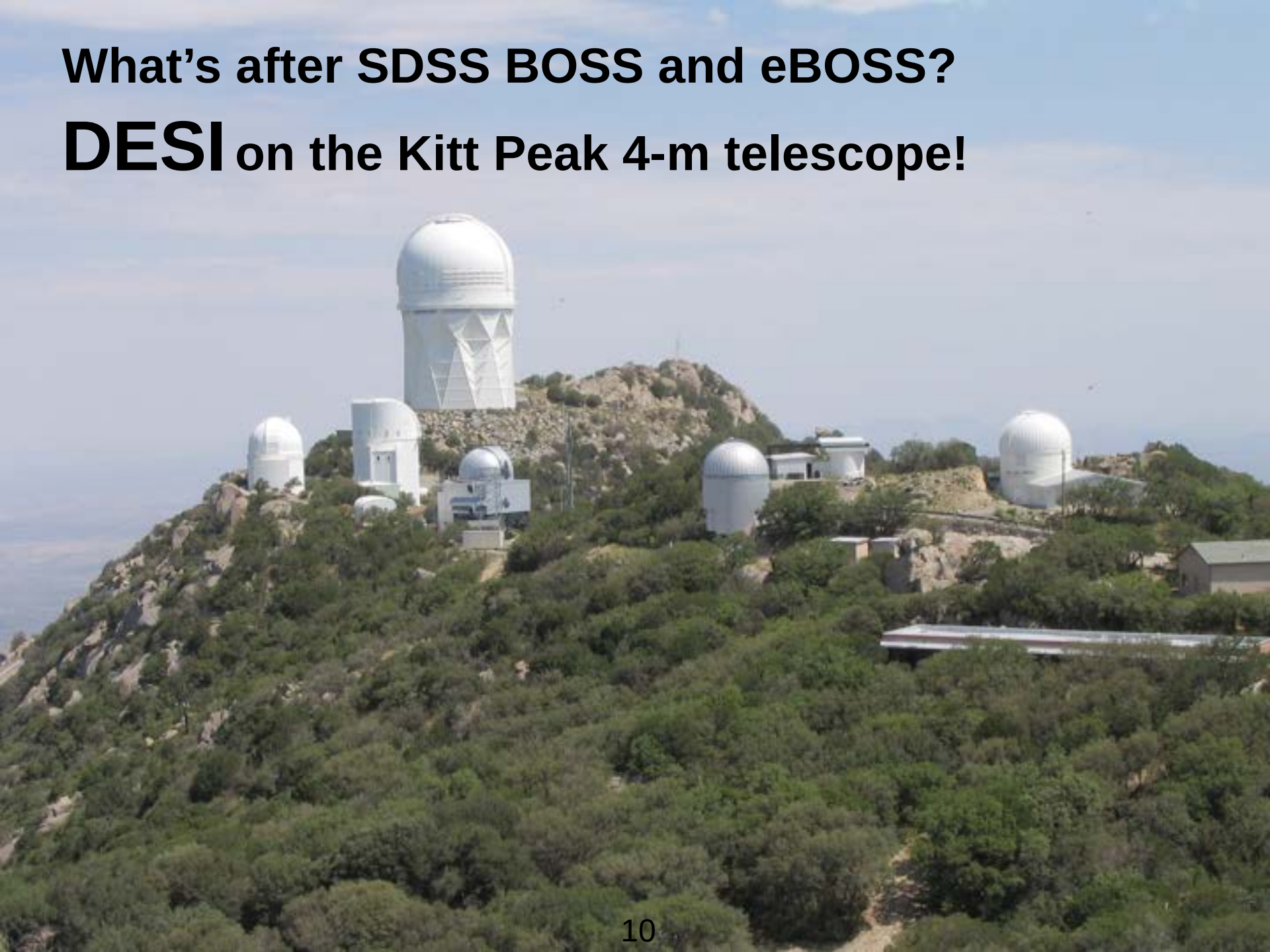
- **BAO is now a core cosmological measurement; same physics spanning z=0.1 to z=1000!**

SDSS-IV eBOSS

- **SDSS-IV will begin next month!**
- **eBOSS:1.5M objects over 7500 deg^2:**
  - **—375K Luminous red galaxies 0.6<z<0.8.**
  - **—270K Emission line galaxies 0.6<z<1 (1500 deg^2).**
  - **—900K Quasars at 1<z<3.5, both as tracers of LSS themselves and for the Lyman α forest.**
- **First step for BAO into 1<z<2 window.**
  - **—2% BAO distance with ELGs and QSOs; 1% with LRGs.**
- **Many other opportunities in cosmology, quasar, and galaxy science.**
- **Stepping stone to DESI.**

What's after SDSS BOSS and eBOSS?

DESI on the Kitt Peak 4-m telescope!



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)
- 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 suppression of small-scale clustering.
- Can investigate inflation by measuring non-Gaussianity and spectral shape of inflationary perturbations.

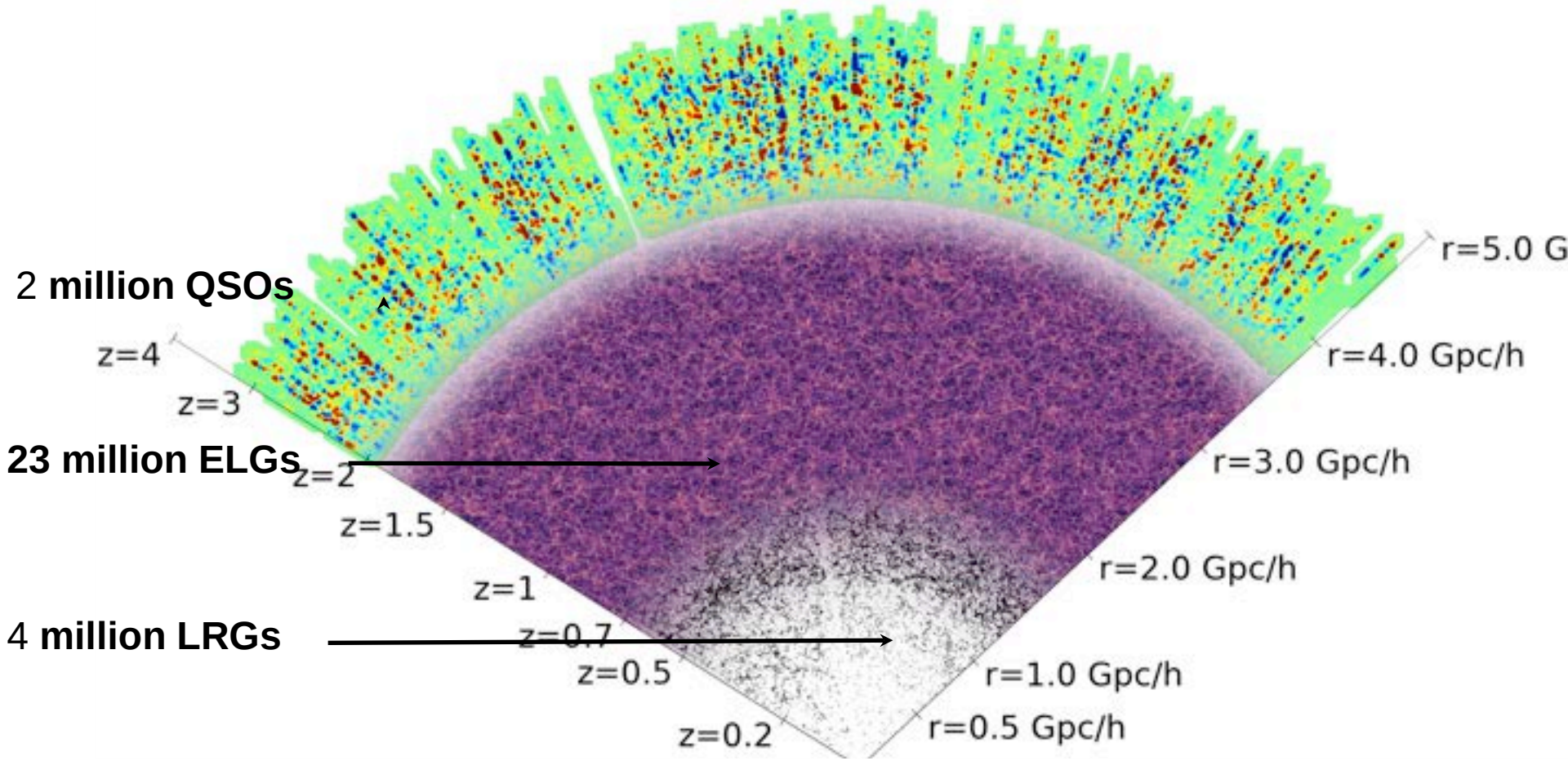
DESI in a nutshell

- 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 CD-1 review scheduled in Sept. 2014.

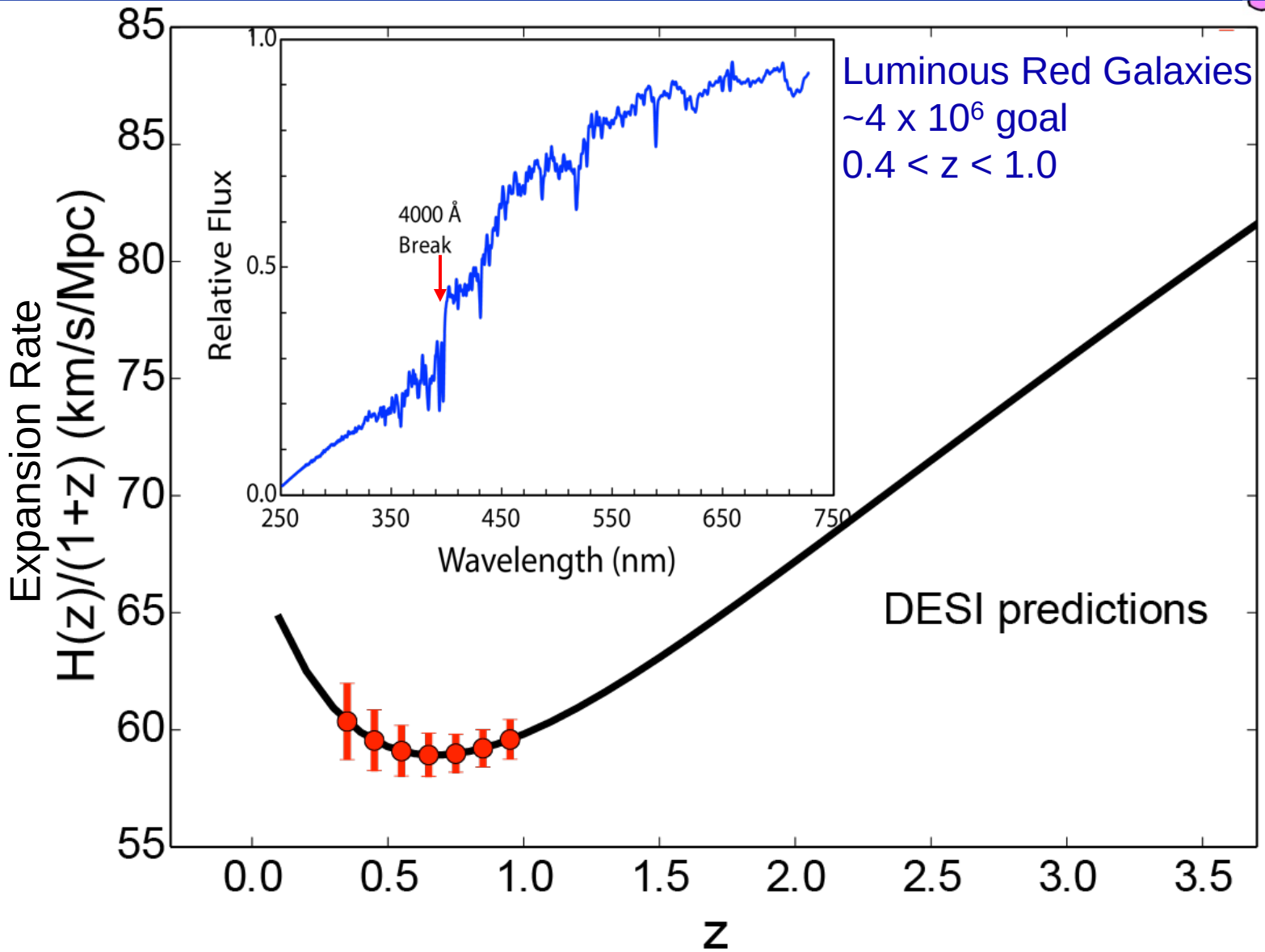
The DESI Survey in context

The largest spectroscopic survey for dark energy

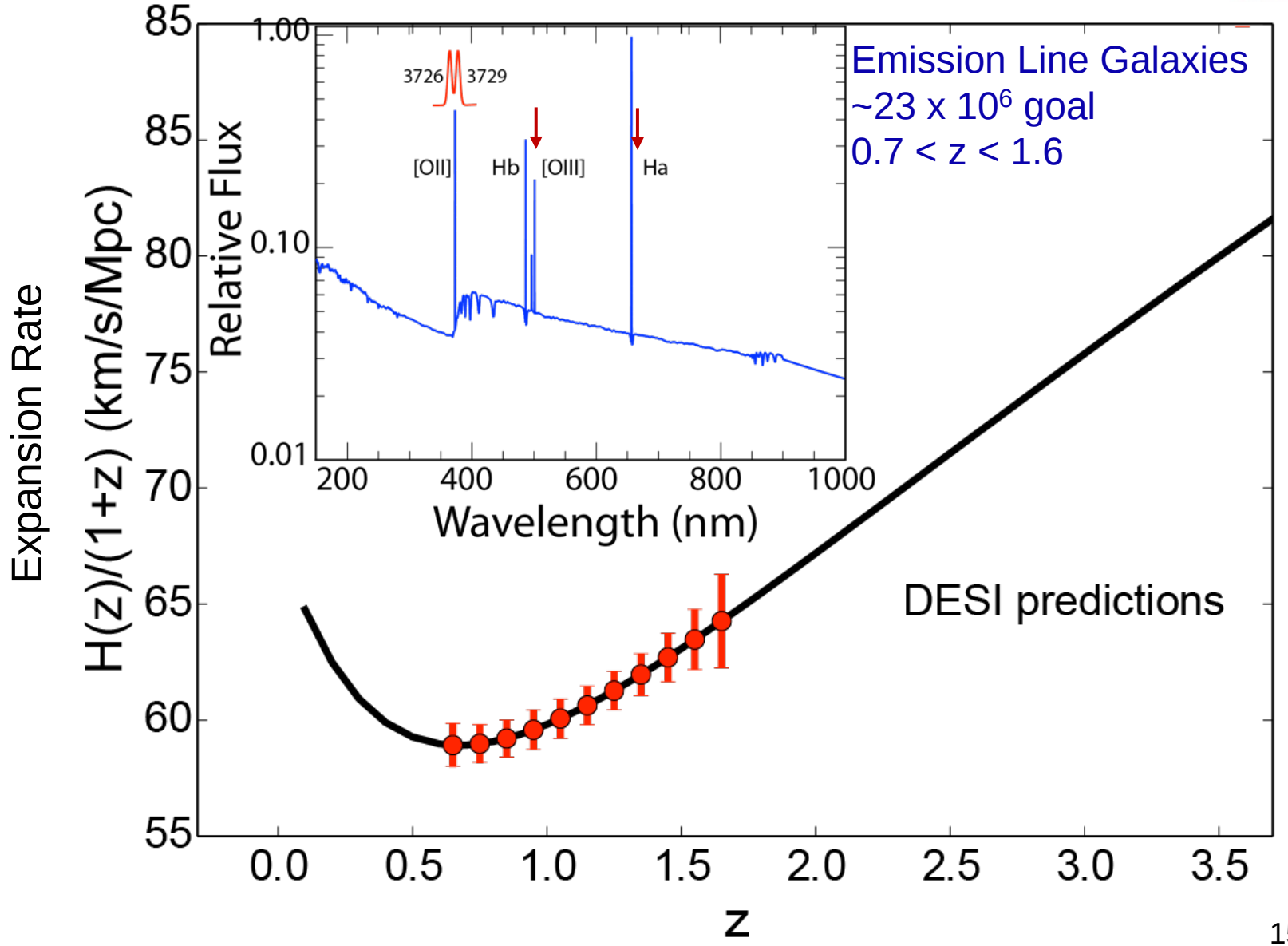
SDSS ~2h^{-3}Gpc^3 ➡ BOSS ~6h^{-3}Gpc^3 ➡ DESI 50h^{-3}Gpc^3



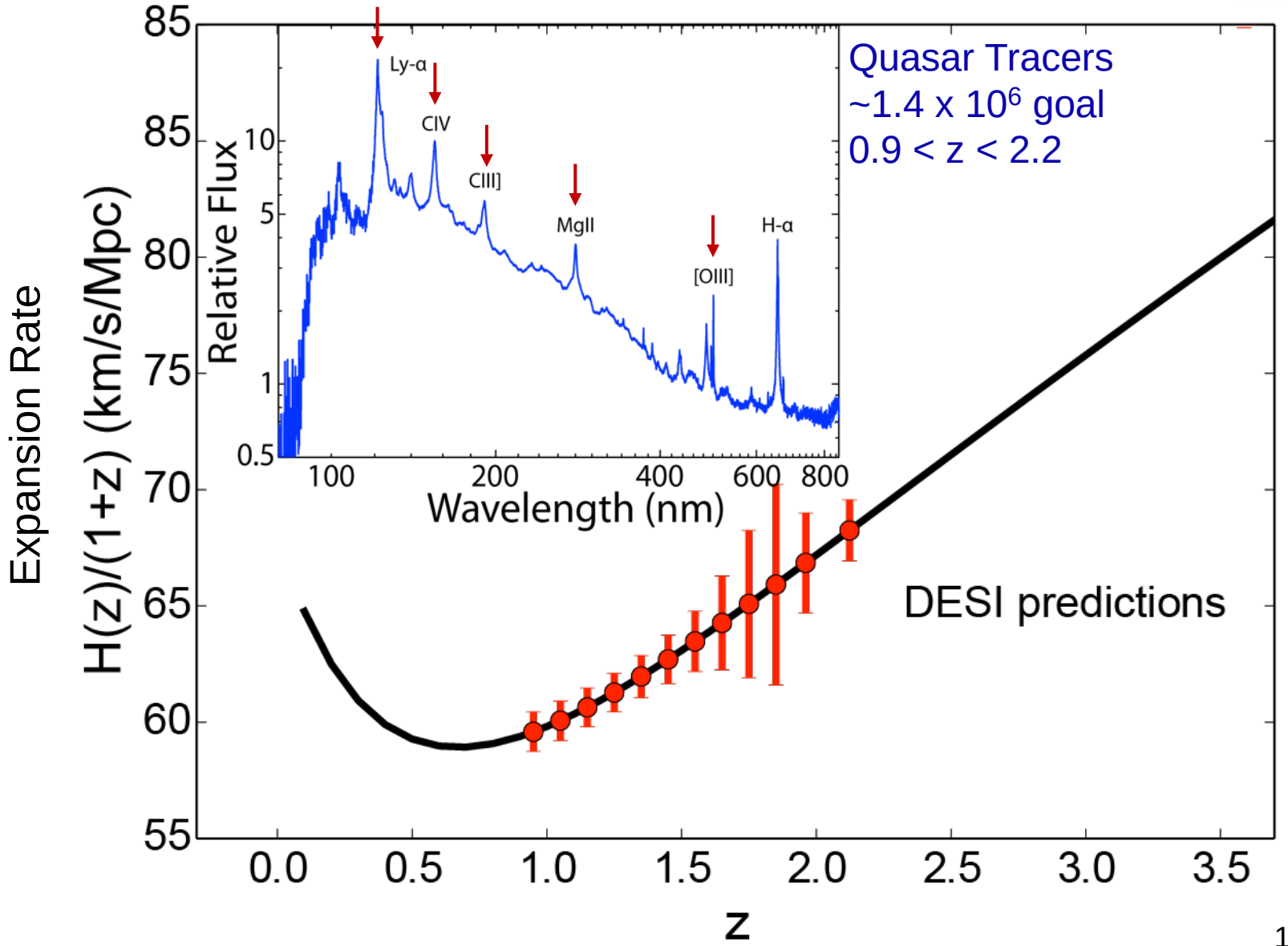
LRG Targets


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
Wavelength (nm)
4000 Å
Break

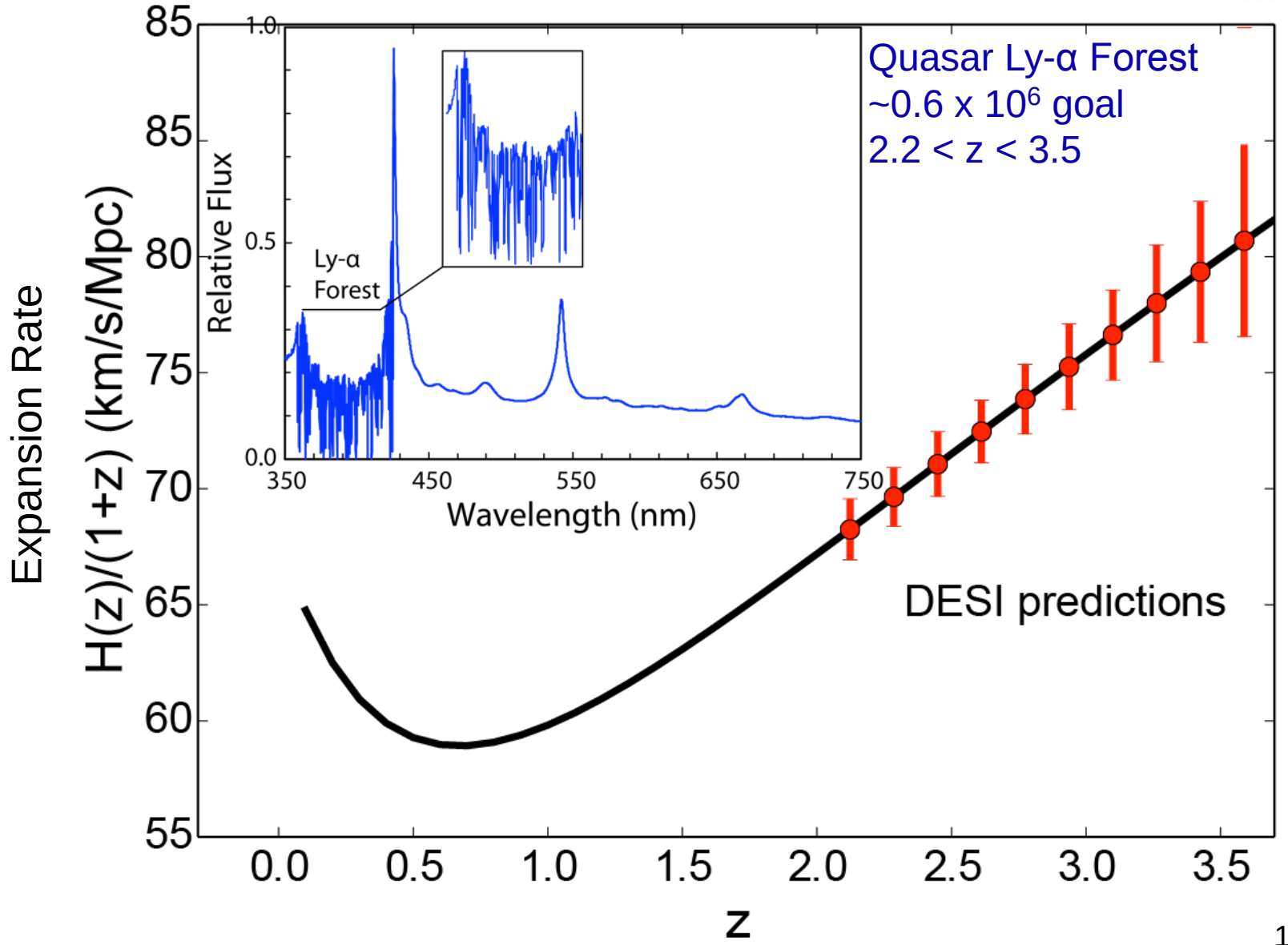
ELG Targets


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

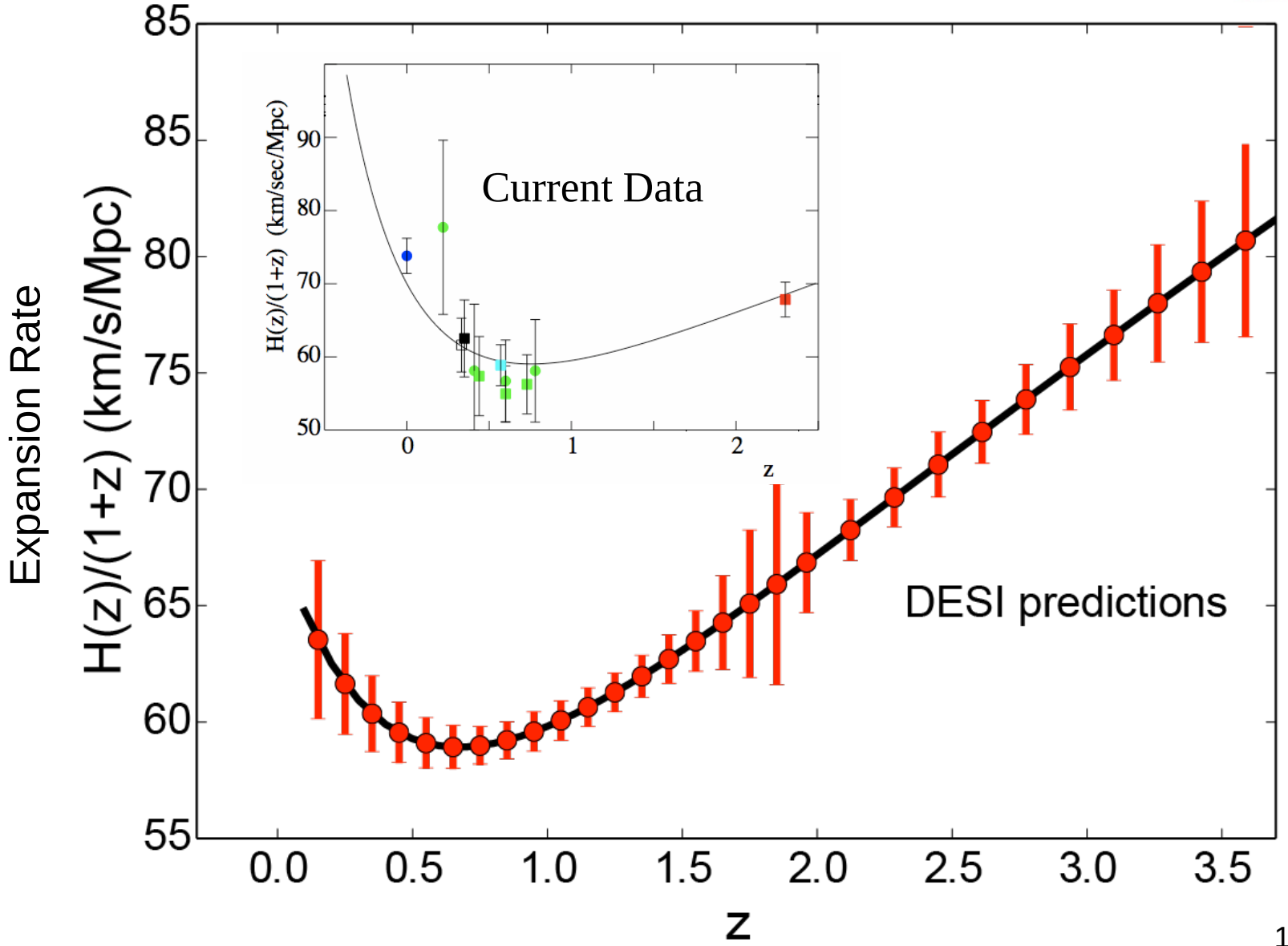
QSO Targets


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

Ly-α Forest QSO Targets

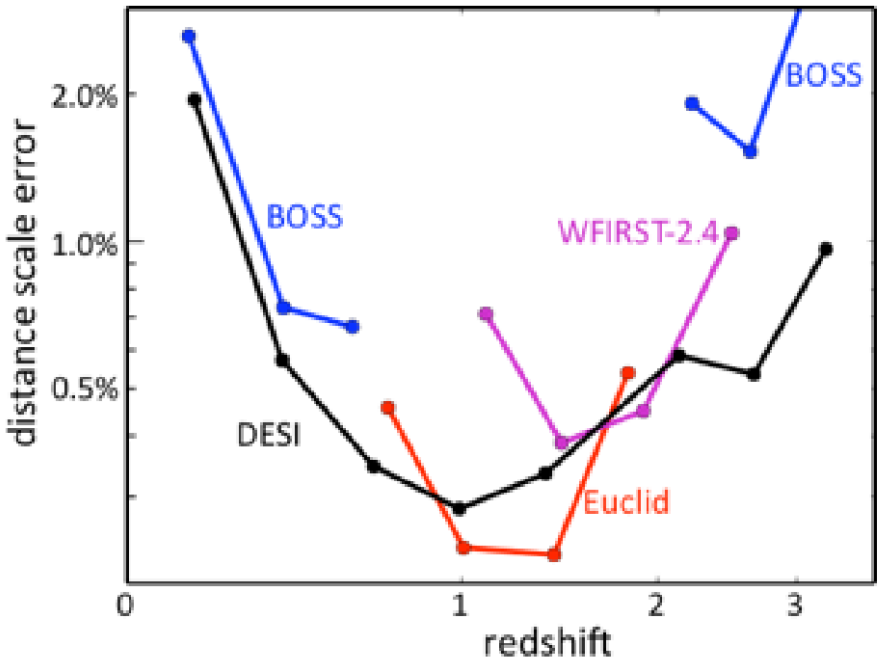


DESI on the Hubble Diagram



BAO in DESI

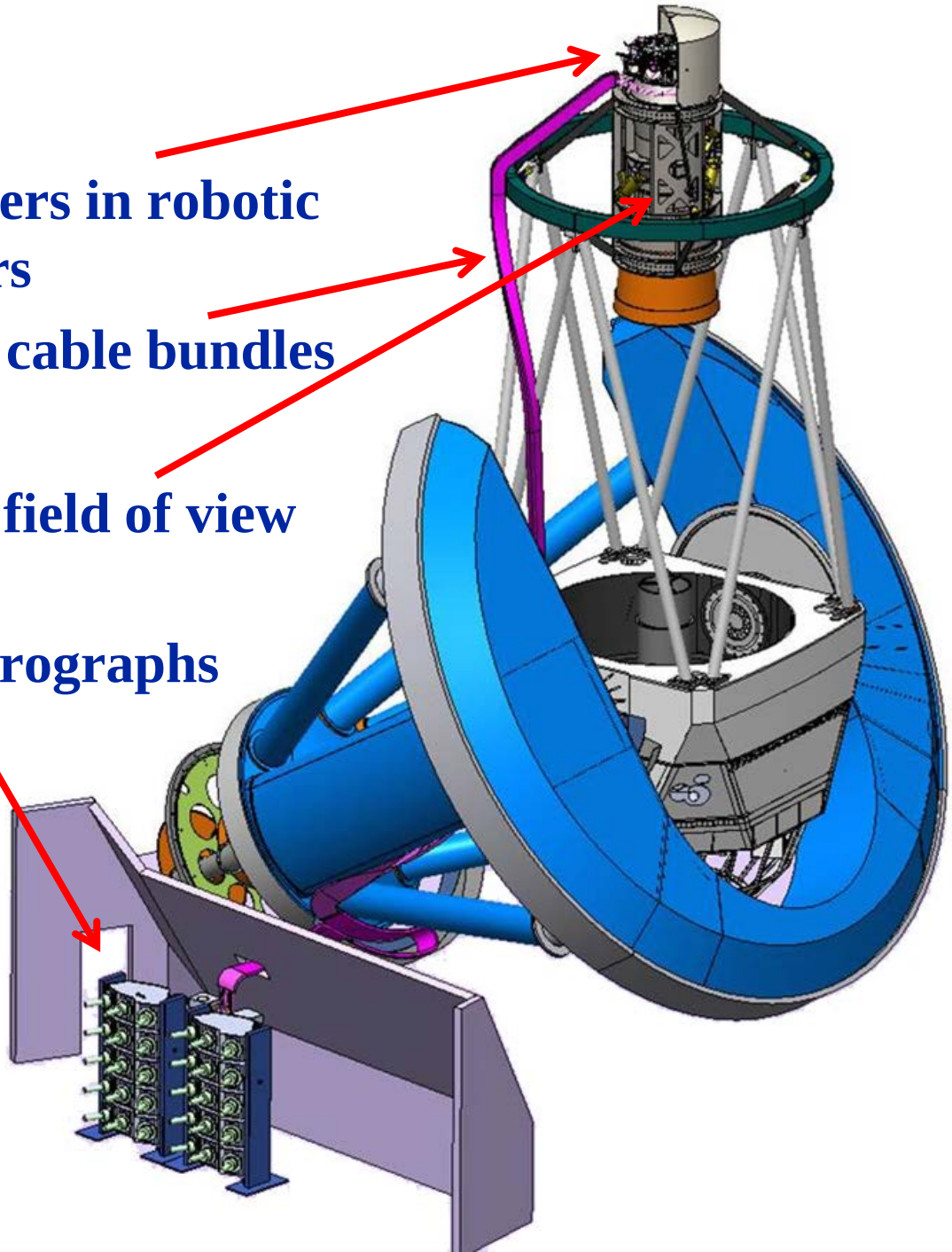
- **DESI will produce a world-leading survey of the the cosmic distance scale**
- **Will measure distance scale to better than 0.3% statistical errors.**
- **Systematic uncertainties on H(z) and $D_A(z)$ of less than 0.2%**



- **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 Funding

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

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

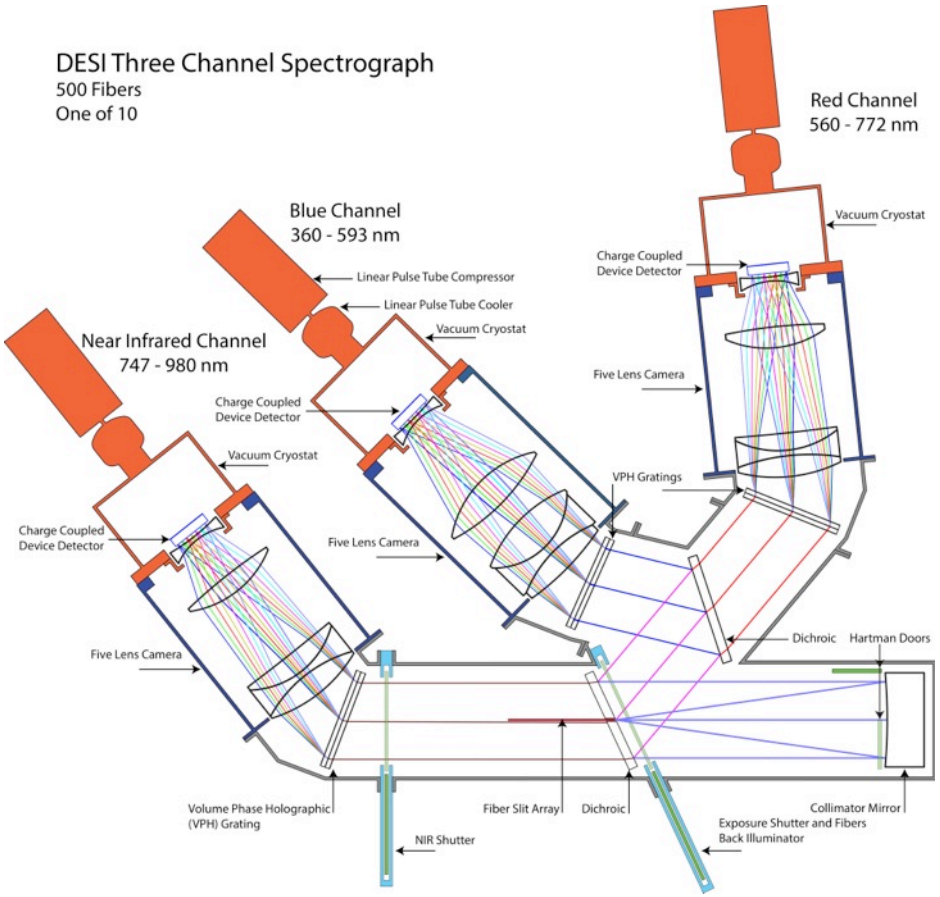
Contracts for the lens blanks are getting placed this summer.

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.

Technically-limited schedule starts survey operations in late 2018.

DESI Spectrograph



DESI Collaboration Meeting May 2014

Getting Involved

- **There is plenty of work remaining in hardware, software, operations, and science analysis!**
- **We would like to see the collaboration grow in size and diversity of experience.**
- **Project work is partially, but certainly not fully, allocated.**
- **Science collaboration opportunities are rich and very much open.**

- **Please contact Daniel Eisenstein or Risa Wechsler (co-Spokespersons), Michael Levi (Director), David Schlegel or Brenna Flaugher (co-Project Scientists), or other DESI team members if you are interested!**

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 to project to proceed with a CD-1 review scheduled in Sept. 2014

DARK ENERGY SPECTROSCOPIC INSTRUMENT

Extra slides