



Francisco Prada
Instituto de Astrofísica de Andalucía (CSIC)



ESAC, April 25th, 2018

The Mystery of Dark Energy



Accelerated expansion of the Universe



The Nobel Prize in Physics 2011
Saul Perlmutter, Brian P. Schmidt, Adam G. Riess



Saul Perlmutter



Brian P. Schmidt



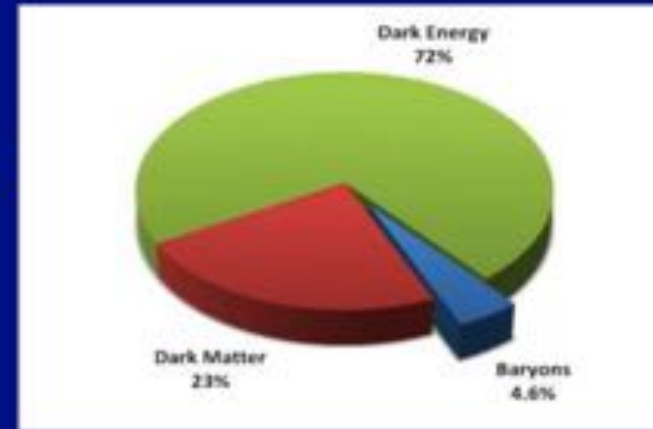
Adam G. Riess

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae".

Top Scientific Objectives



Physics of the Universe Understanding Scientific Principles



The two highest level questions in the field are the following:

- Is cosmic acceleration caused by a breakdown of Einstein General Relativity on cosmological scales, or is it caused by a new energy component with negative pressure ("dark energy") within General Relativity?
- If the acceleration is caused by "dark energy," is its energy density constant in space and time and thus consistent with quantum vacuum energy or does its energy density evolve in time and/or vary in space?

Large Survey Projects



VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY

LOFAR

Quijote Project

MOST

Javalambre
Physics of the Accelerating Universe
Astrophysical Survey

Planck

eRosita

COre/PRISM

Euclid

ESA
European Space Agency

The ESA logo and the European Union flag.

SDSS-III

HETDEX
Hobby-Eberly Telescope Dark Energy Experiment
Illuminating the Darkness

DARK ENERGY SURVEY

ESO

LSST
Large Synoptic Survey Telescope

The national flag of Argentina.

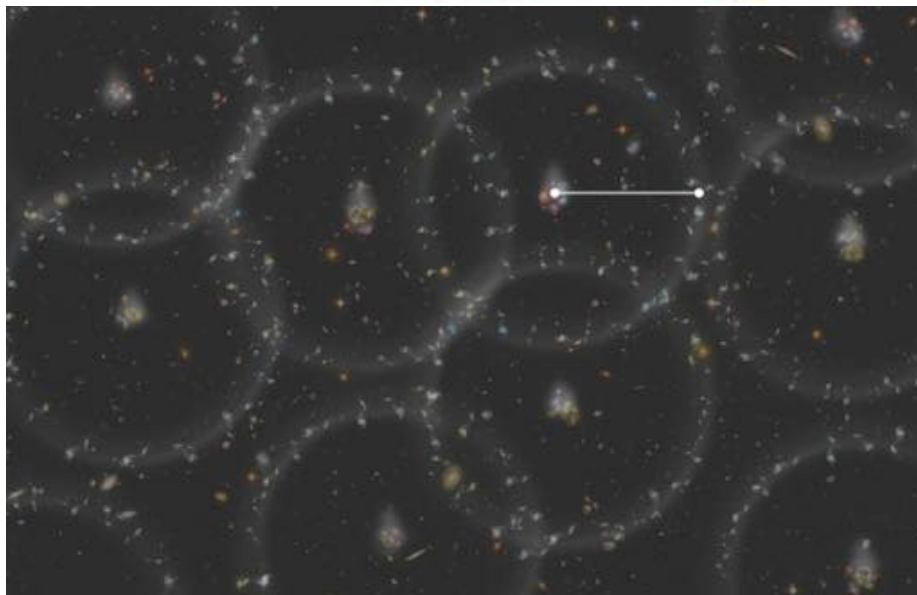
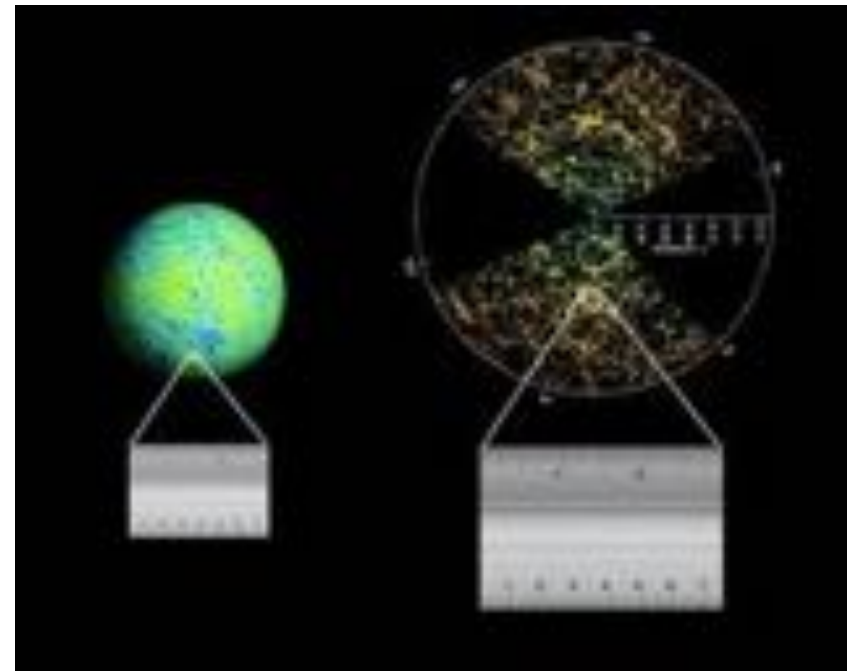
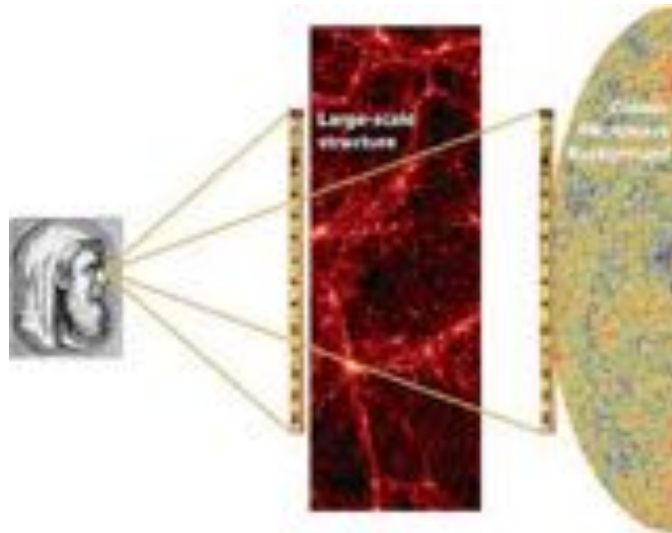
SKA
SKA AFRICA
SQUARE KILOMETRE ARRAY

The national flag of South Africa.

How to measure Dark Energy?

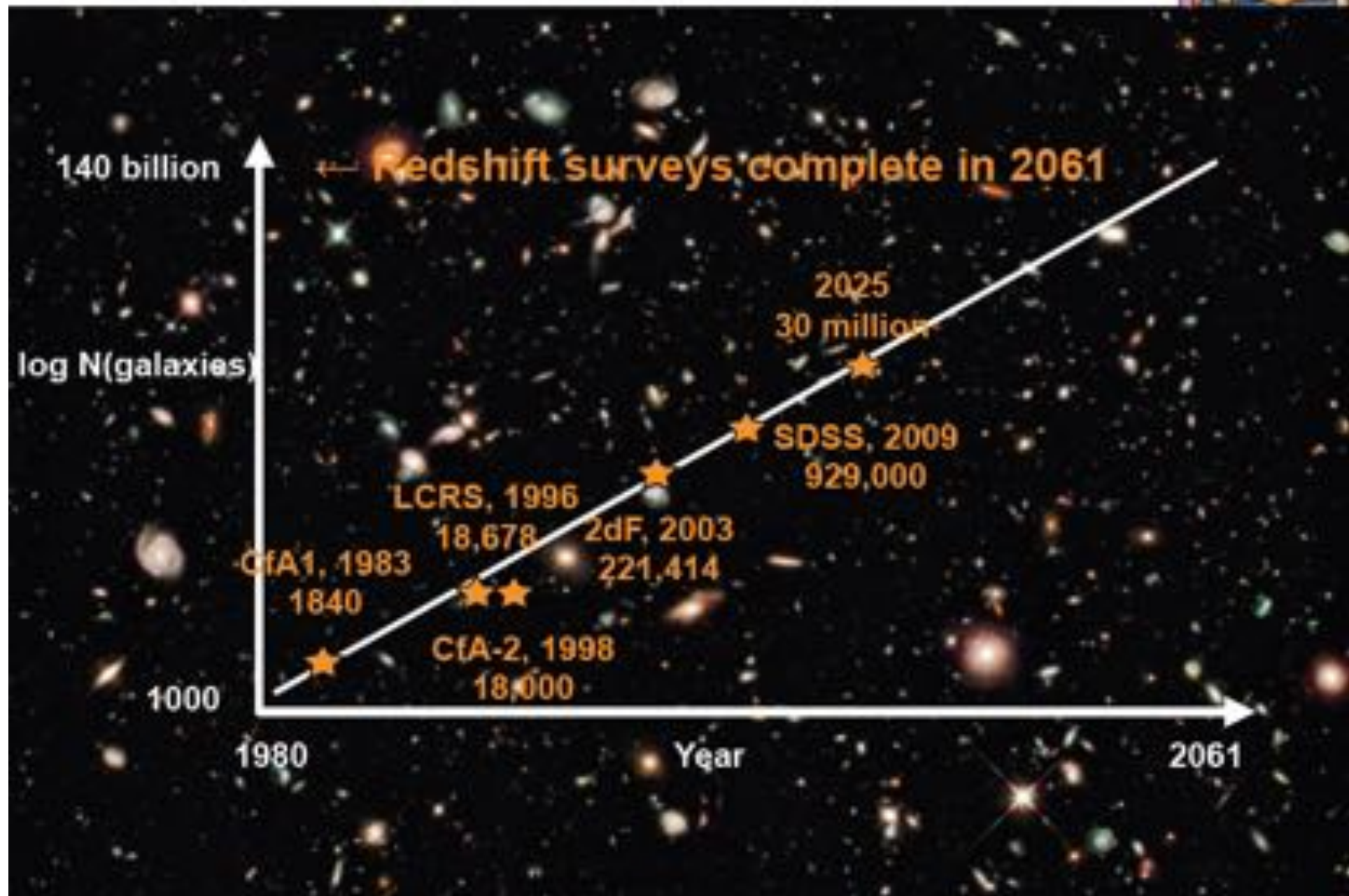


Baryonic Acoustic Oscillations as standard ruler



LSS catalogs provides a picture of the distribution of matter such that one can search for a BAO signal by seeing if there is a larger number of galaxies separated at the sound horizon.

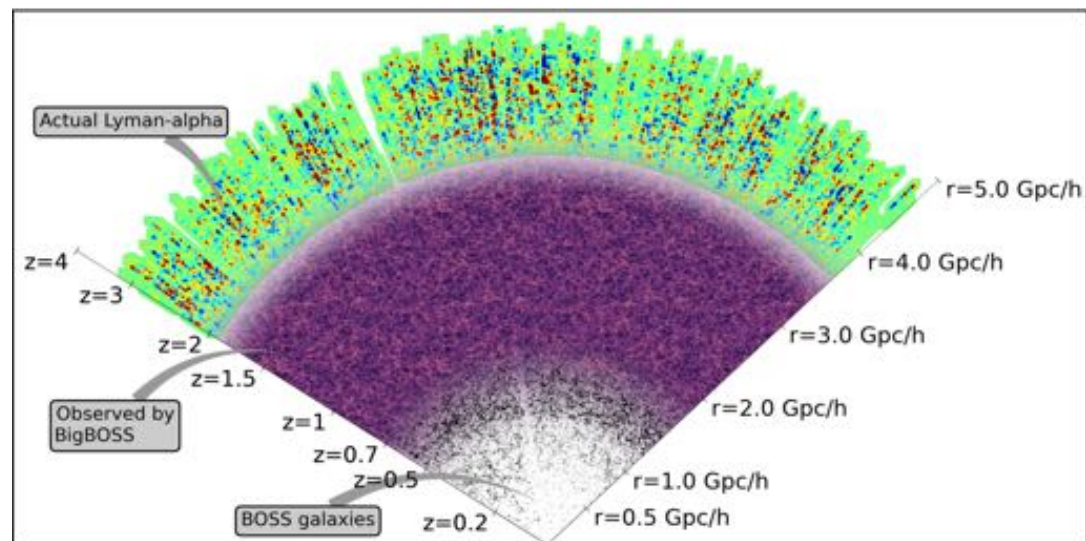
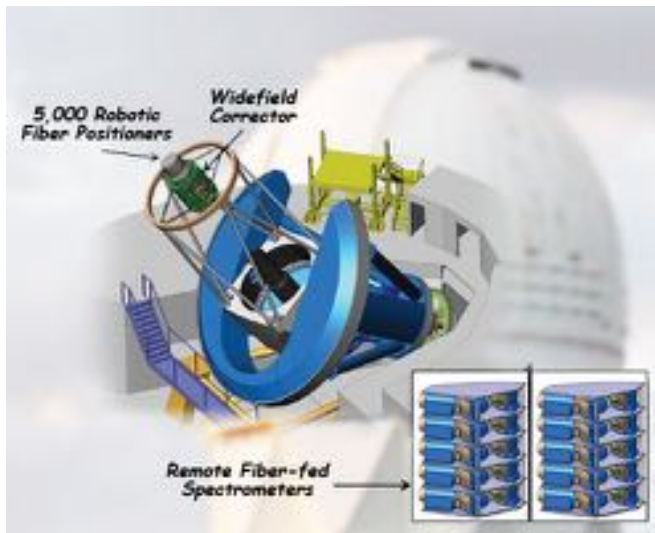
DESI gets us back on the curve



DESI: The Ground-Based Dark Energy Experiment



- New instrument to study dark energy
- DESI will cover 18,000 deg² on the sky
- It will take spectra of 25 millions of galaxies and 5 millions of QSOs
- Unprecedented volume & statistics to test for indications of new physics!
- “Mid-scale” in time: 2019-2023 operations
- Site selection: Mayall 4-m @ Kitt Peak
- DOE + institution partners pays for the new instrument, the installation, and operations
- DESI project will build:
 - A telescope corrector creating an 8 deg² FOV
 - 5000 fiber positioners
 - Ten 3-arm spectrographs of medium resolution based upon the LBNL fully-depleted CCDs (as used in BOSS and DECam)



DESI Collaboration



1st DESI Collaboration Meeting, July 15 - 18, 2013



US Members: Brookhaven National Laboratory, Carnegie Mellon University, Fermi National Accelerator Laboratory, Johns Hopkins University, **Lawrence Berkeley National Laboratory**, National Optical Astronomy Observatory, New York University, The Ohio State University, SLAC National Accelerator Laboratory, University of California, Berkeley, University of Kansas, University of Michigan, University of Pittsburgh, University of Utah, Yale University, Harvard, & more!

International Institutions: Ewha Womans University, Korea; French Participation Group; Goettigen Univ., Mexico Participation group, Granada-Madrid-Tenerife Participation Group; Shanghai Astronomical Observatory, UK Participation Group; USTC China; EPFL Switzerland, & more!

DESI: Status, Progress and Plans



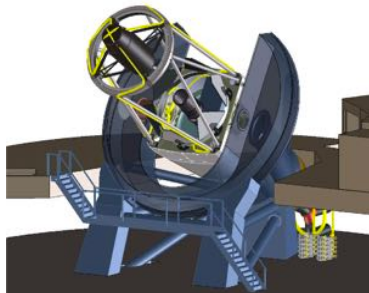
- Announcement of Opportunity for Large Science Programs Providing New Observing Capabilities for the Mayall 4m Telescope on Kitt Peak
Letter of intent (LoI), March 2010 → **500 nights awarded**
- **BigBOSS CD-0 granted (Successful Review in Dec'11 by the US Department of Energy)**

- Science Case
- Preliminary design
- R&D



- **DESI CD-0 review on Septemer'14 (Conceptual Design Review)**
- CD-1 is coming soon by start 2015
 - Complete R&D and design
 - Complete cost and schedule baseline
- Construction started in 2016
- First Light 2019

KPNO Mayall 4m



DESI has key international partners (2010-2015):

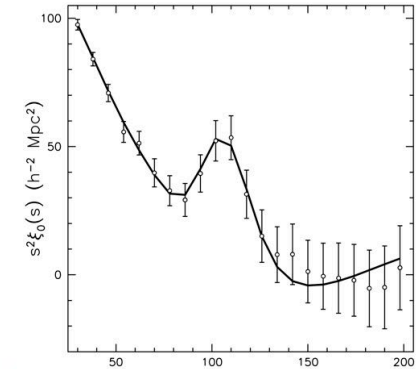
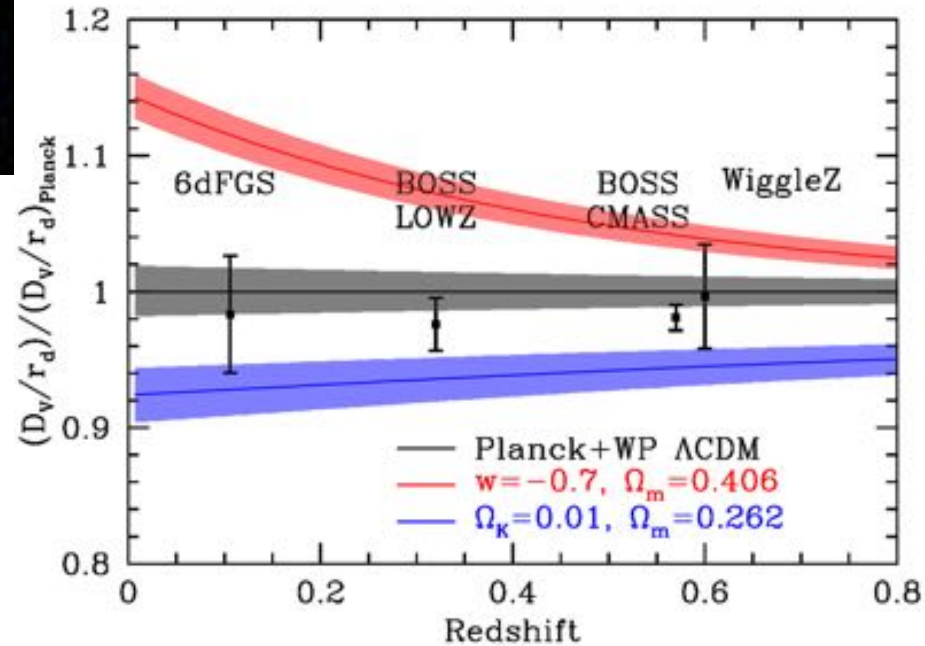
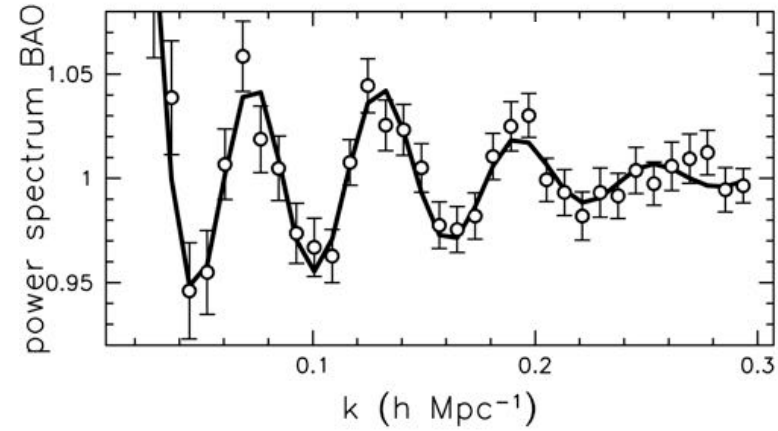
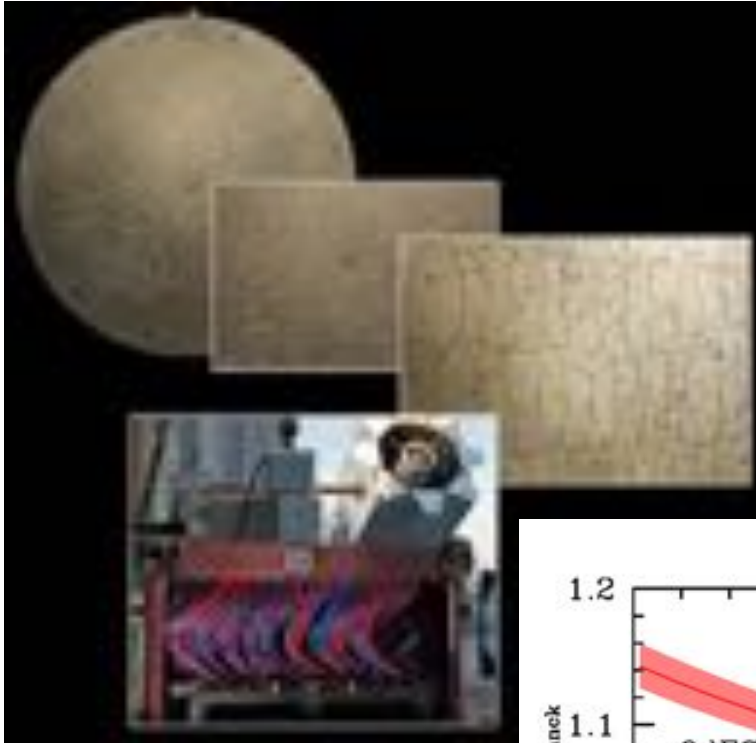
Spain/Switzerland [robots]

Spain [focal plate]

UK [optics, fibers]



SDSS-III/BOSS DR11 results!

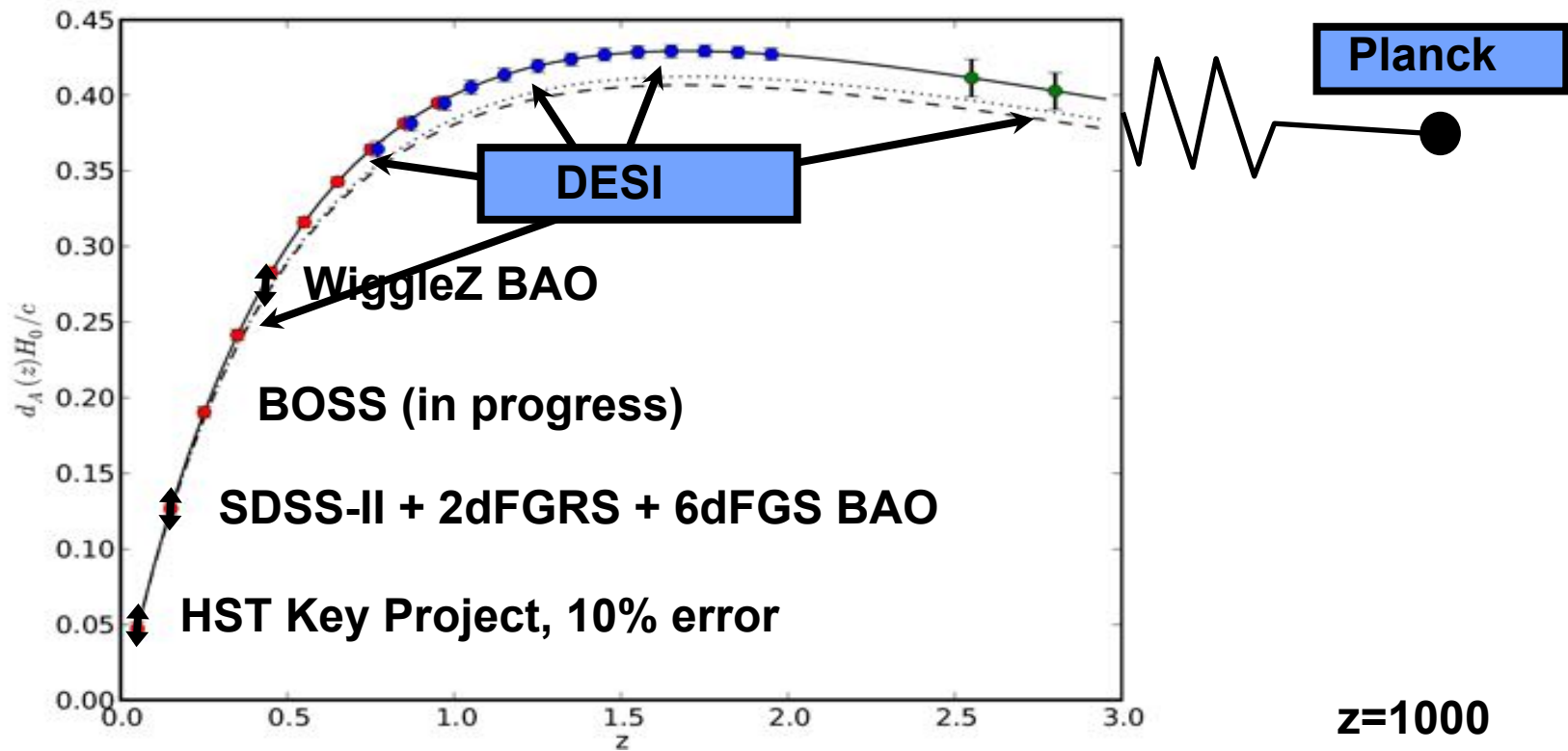


DESI Design Goals



DESI measures distances

- Measure distance scale to $<0.3\%$ between $0.0 < z < 1.1$
- Measure distance scale to $<0.3\%$ between $1.1 < z < 1.9$
- Measure the Hubble parameter to $< 1\%$ in the bin $1.9 < z < 3.7$

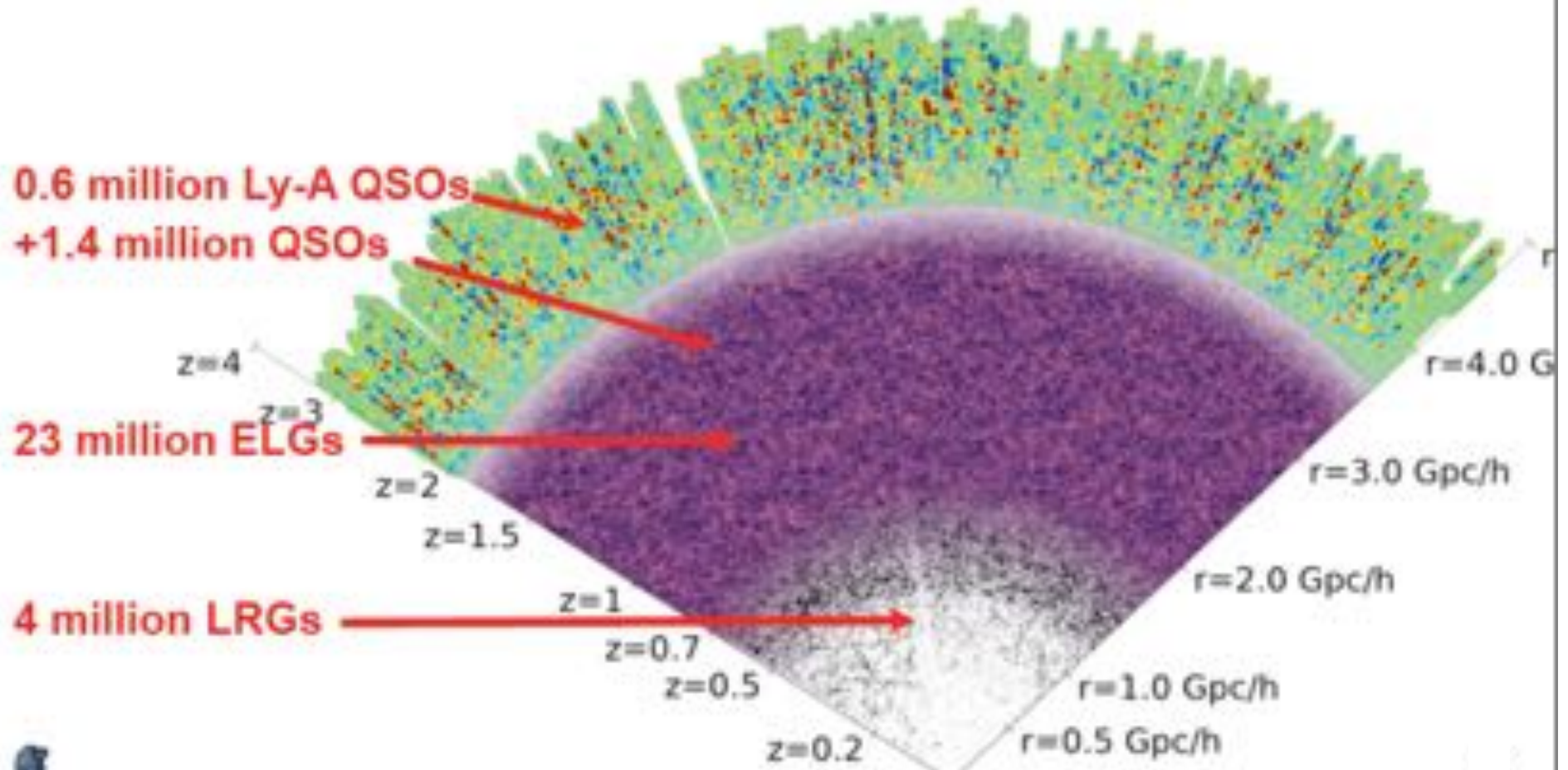


What is DESI?



Four target classes spanning redshifts $z=0 \rightarrow 3.5$

Includes all the massive black holes in the Universe (LRGs + QSOs)

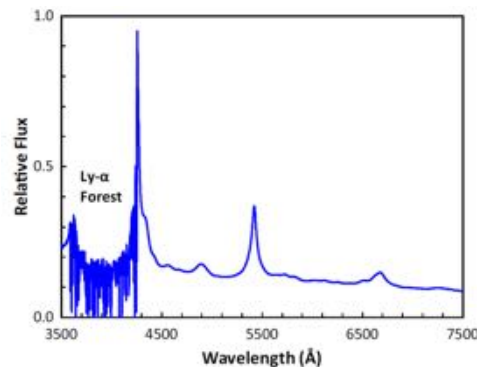


Summary of Science Requirements

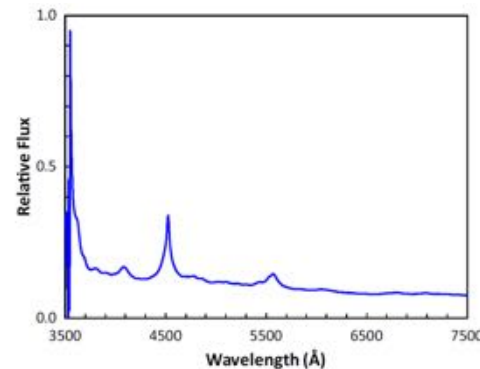


- Target spectral features in their redshift bands
 - Bandpass from 360 – 980 nm
- Single exposure ELG measurement at $S/N > 7$ for 8×10^{-17} erg/sec/cm²
 - Drives throughput and exposure time (nominal 1200 s using the Mayall 4m)
- Target redshift precision, e.g., ELG [OII] doublet resolution
 - Drives spectral resolution (1500 – 4000 in ten 3-channel spectrographs)
- Galaxy numbers and allotted survey time
 - Drivers number of spectra per exposure (5000 spectra)
 - Field of view (8 deg²)

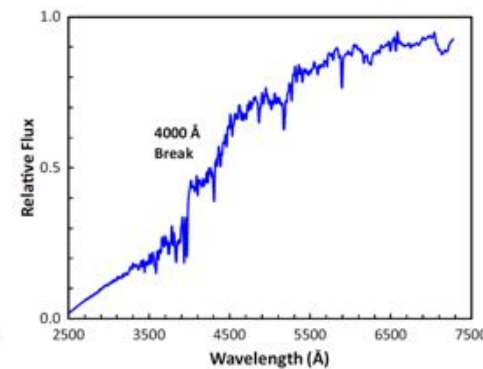
Lyman- α forest QSO



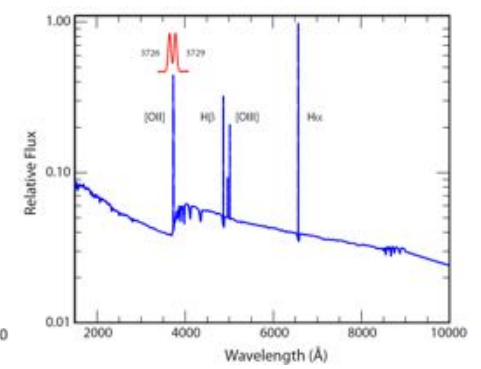
Tracer QSO



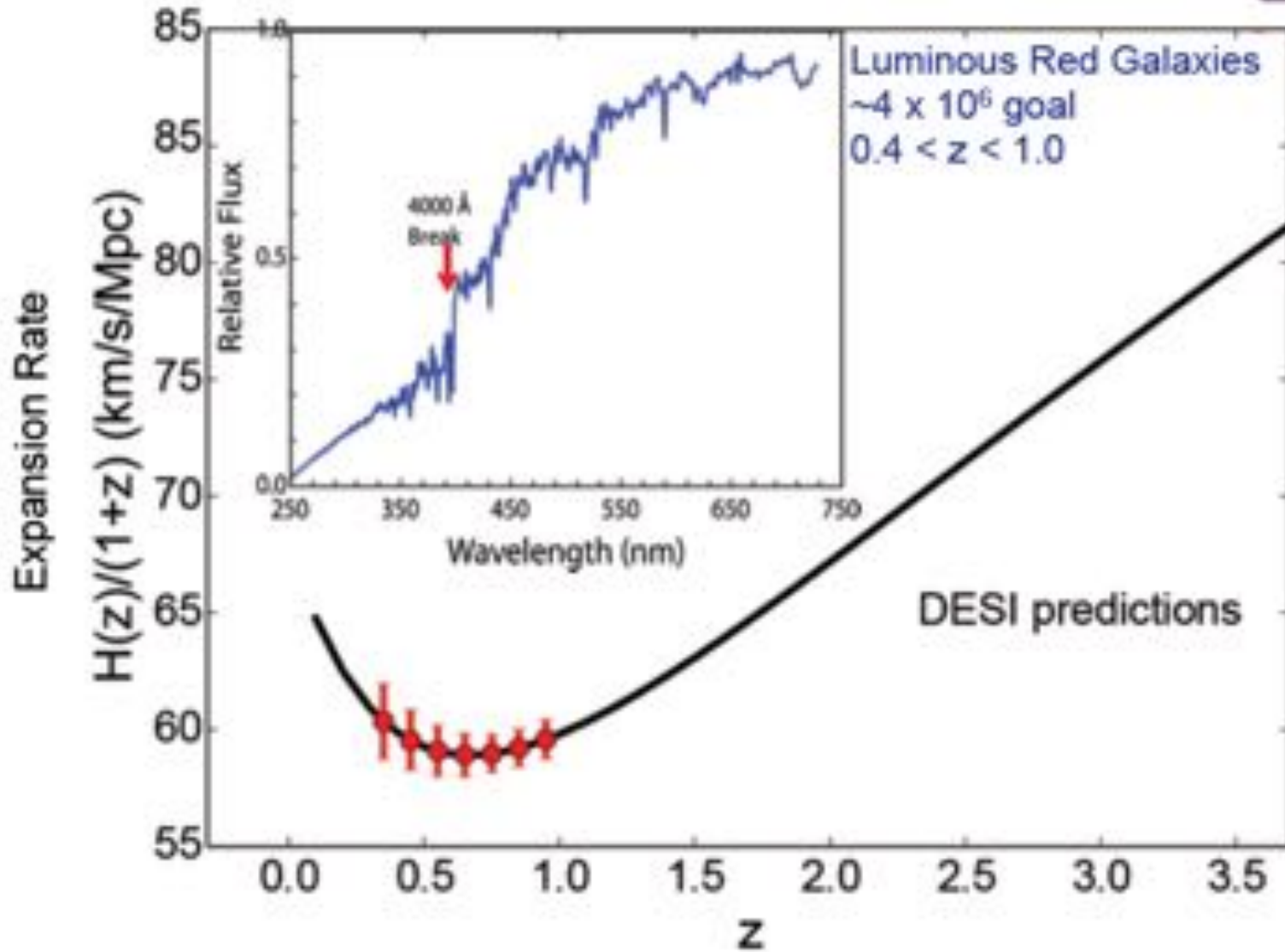
LRG



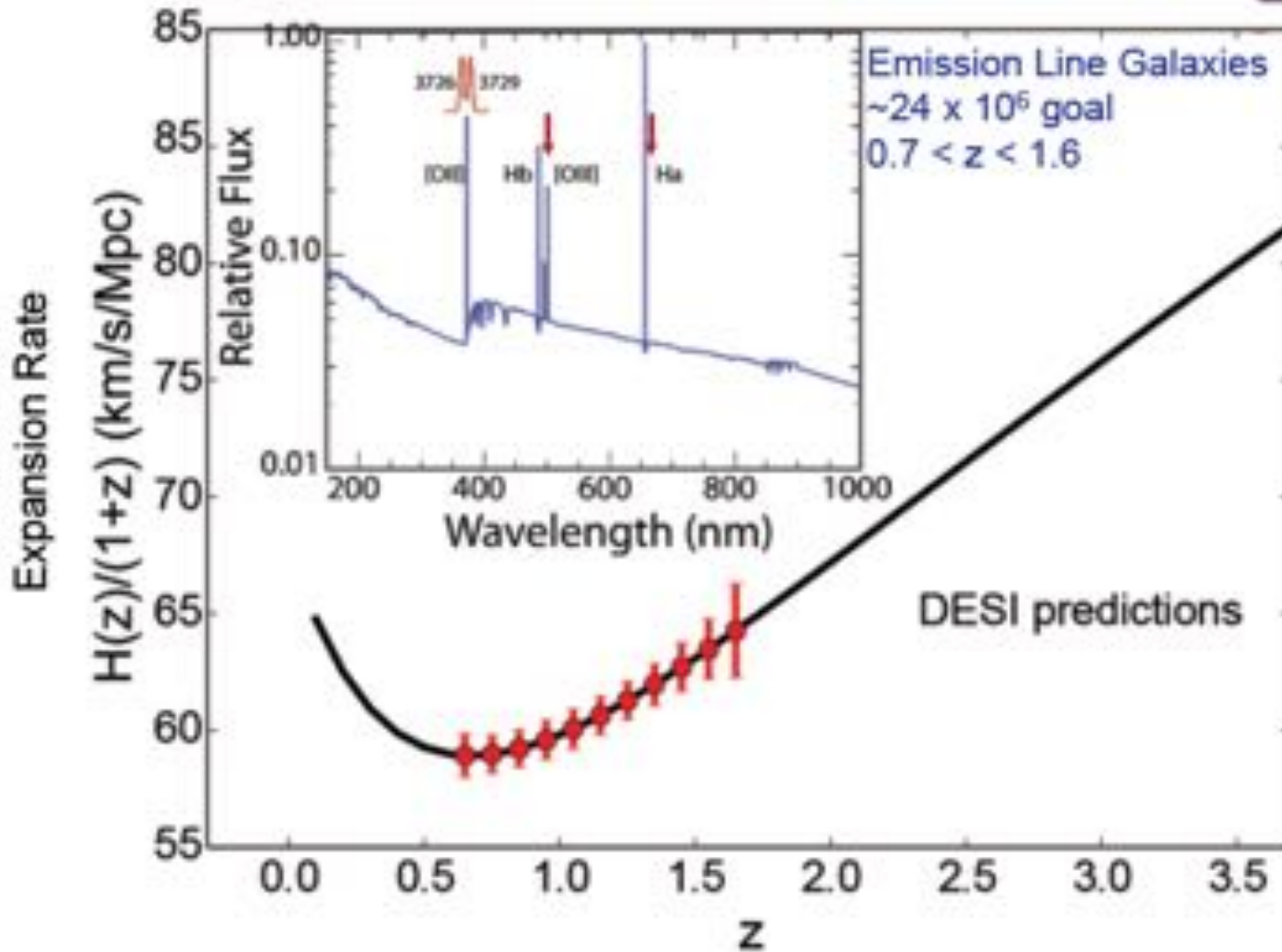
ELG



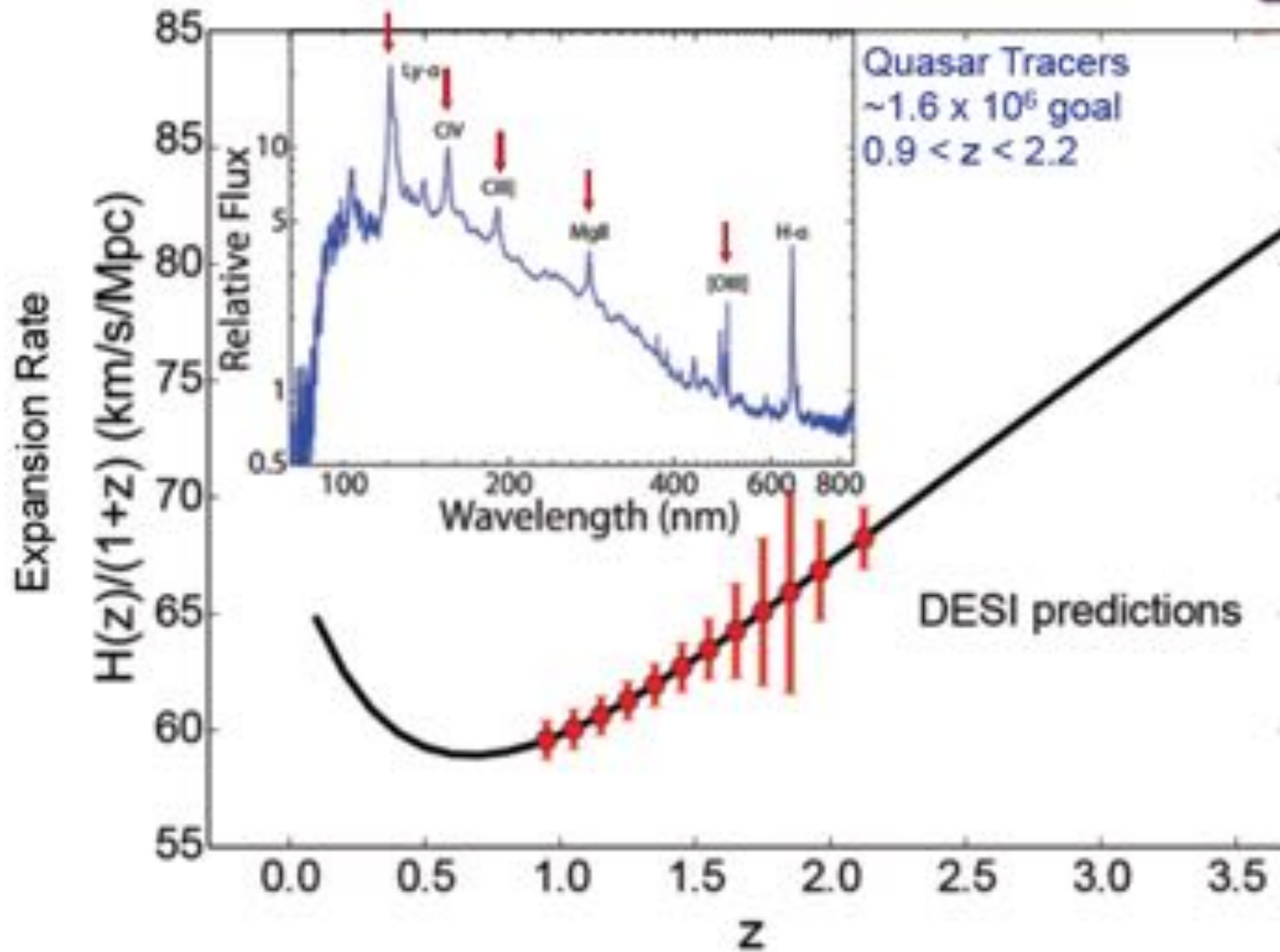
LRGs



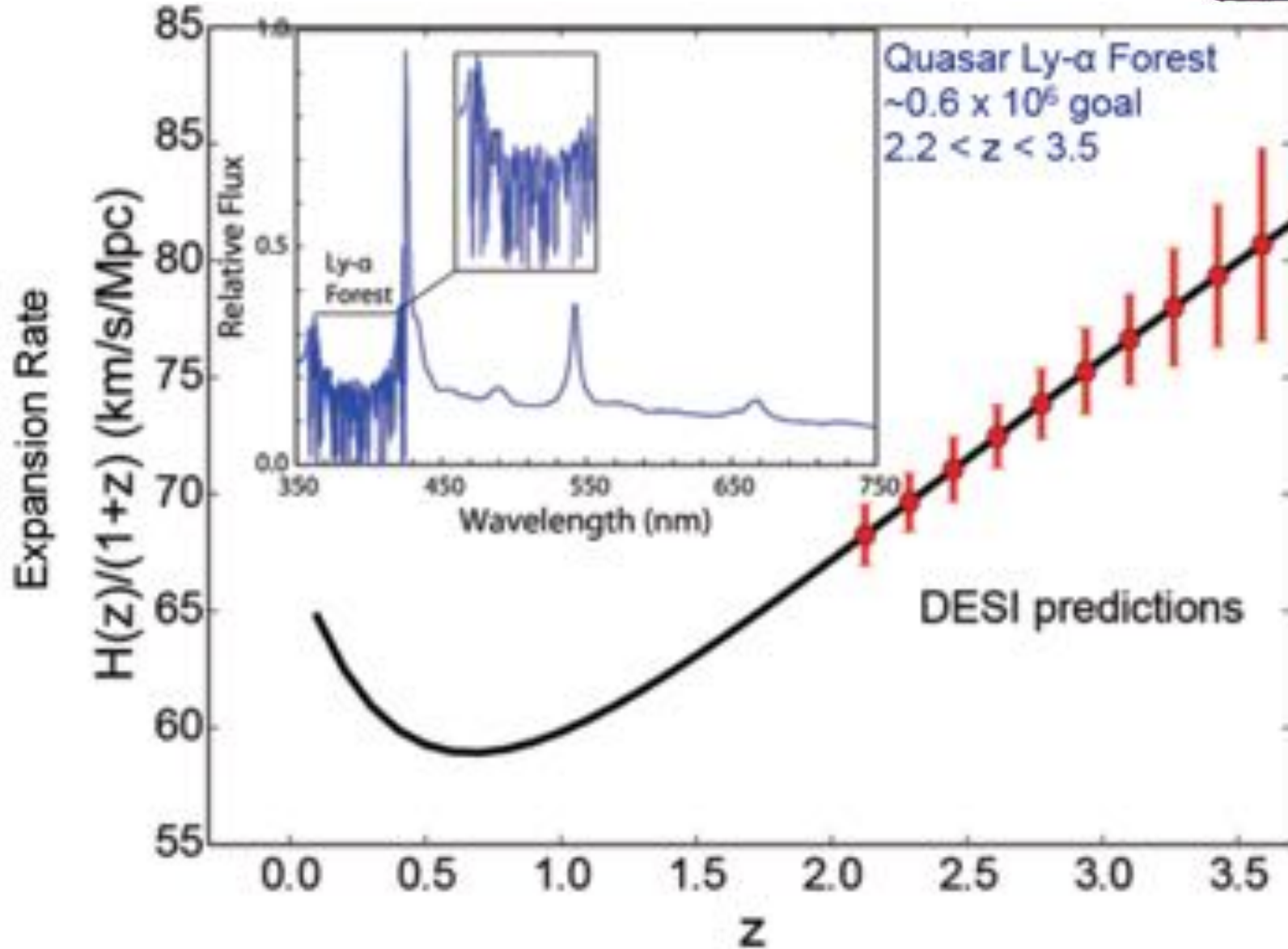
ELGs



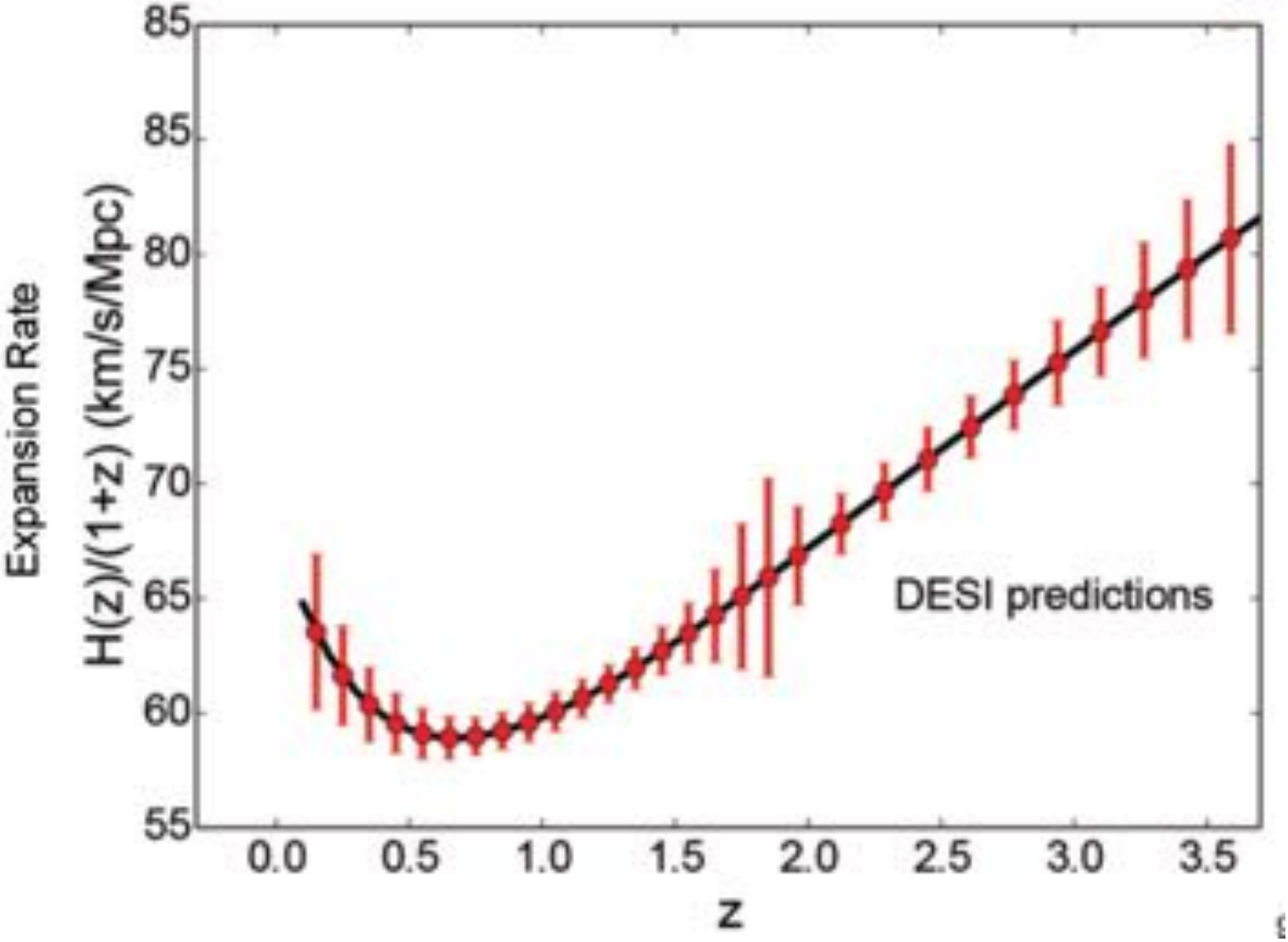
QSOs



QSO Ly-alpha forest



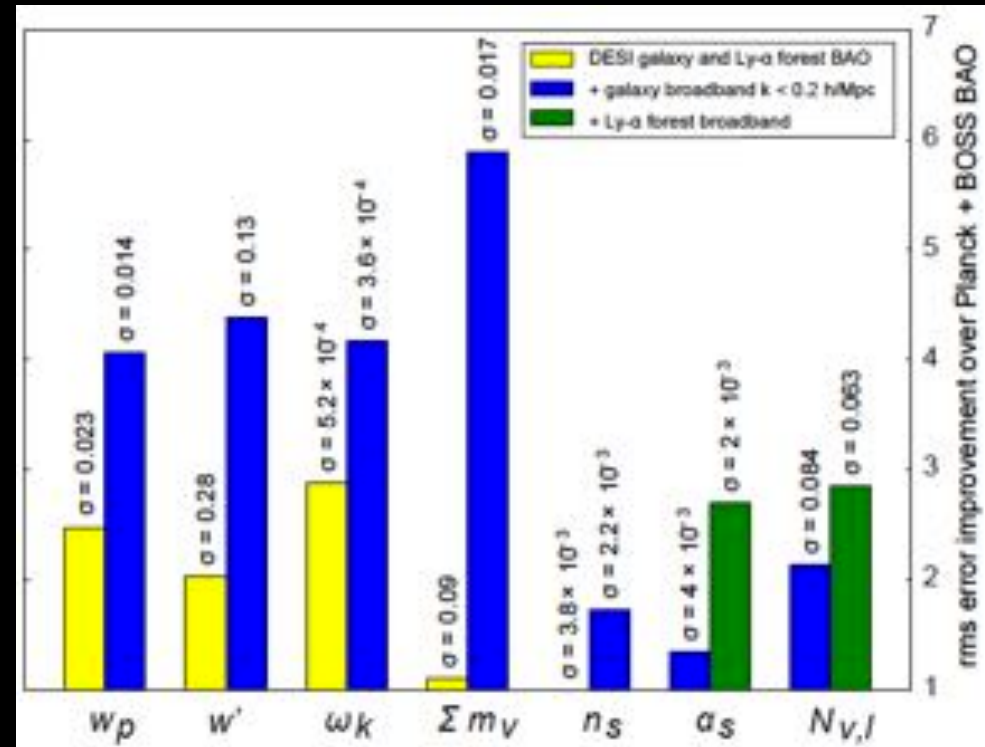
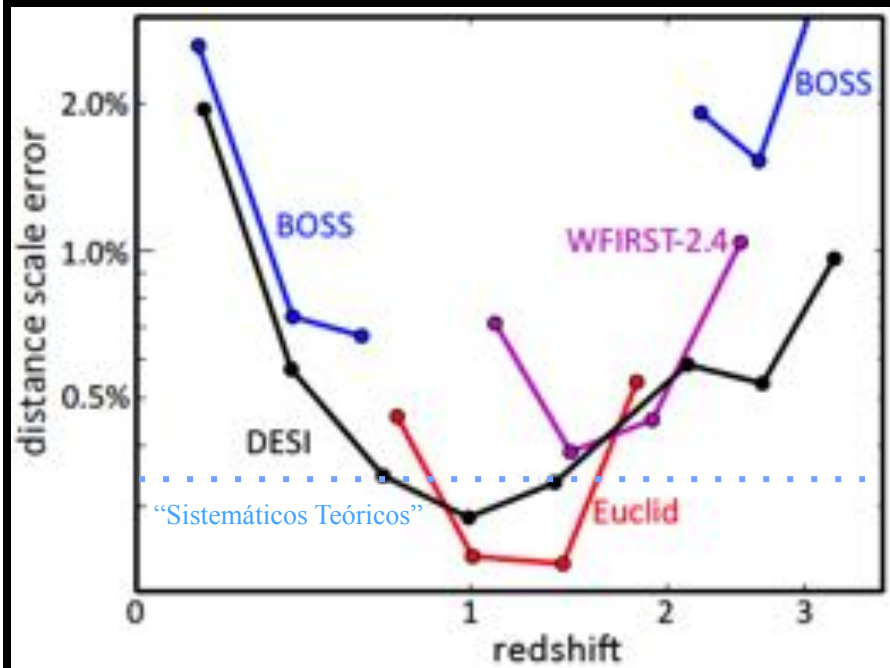
DESI on the Hubble Diagram



Forecast on distance scale error



Proyecto	Status
SDSS-III/ BOSS	2009-2014
SDSS-IV/ eBOSS	2014-2020
Euclid	2021-2027
DESI	2019-2022



Imaging for DESI

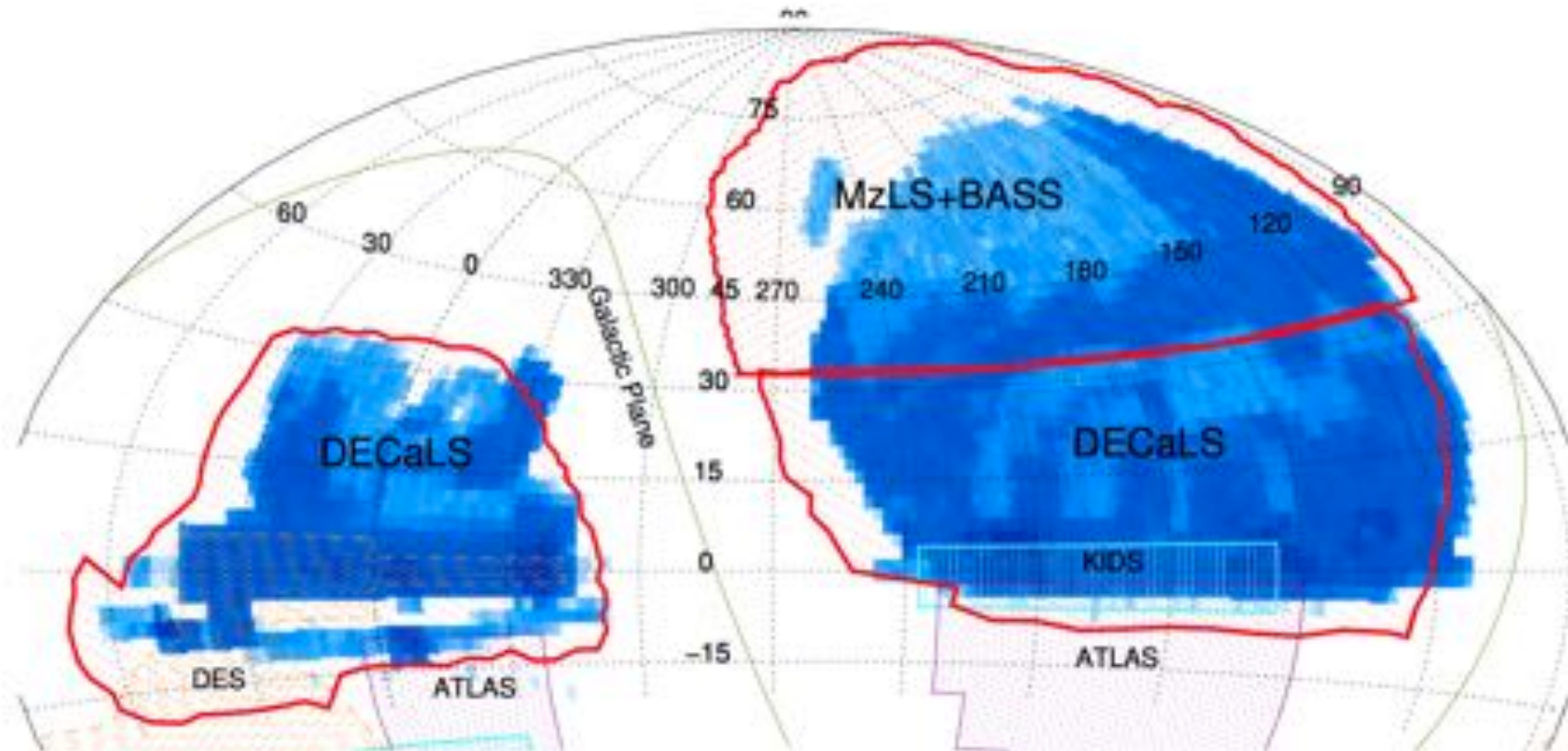
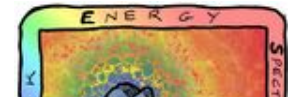


Figure 1. The footprints of the optical imaging surveys contributing to DESI imaging, demarcated by the thick red outlines, are shown here in an equal-area Aitoff projection in equatorial coordinates. The region

Dey et al. 2018





OVERVIEW OF THE DESI LEGACY IMAGING SURVEYS

9

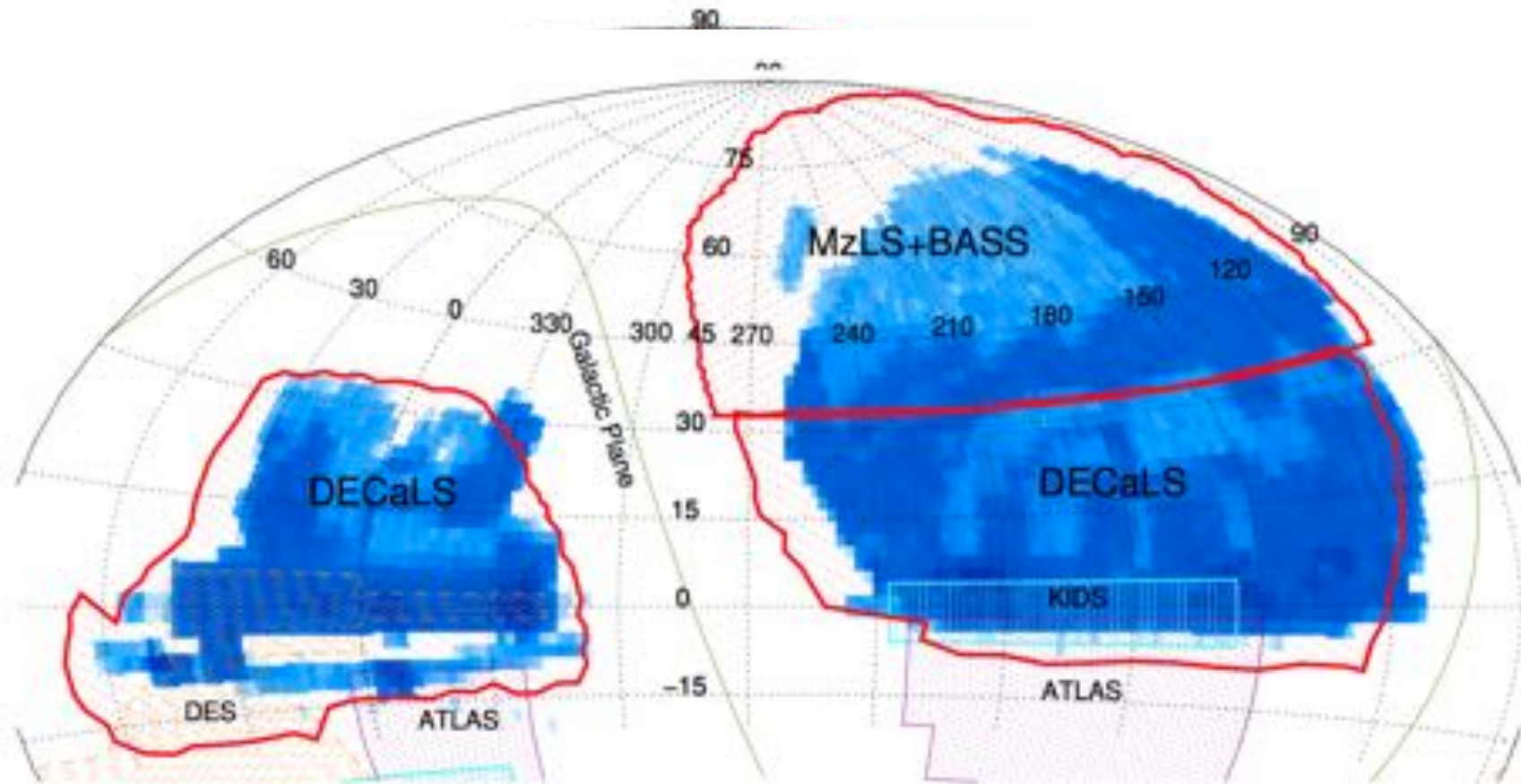



Figure 1. The footprints of the optical imaging surveys contributing to DESI imaging, demarcated by thick red outlines, are shown here in an equal-area Aitoff projection in equatorial coordinates. The region <http://legacysurvey.org/status/>,




Community Science



NOAO Efforts on Community Science

- "BigBOSS" Community Workshop
 - Held in Tucson on 13,14 Sep 2011
 - Attended by ~70 participants
 - 4 break-out sessions:
 - Galactic (*Marla Geha, Yale*)
 - Extragalactic (*Eric Bell, U. Michigan*)
 - Transients (*Mansi Kasliwal, Carnegie Obs.*)
 - Diffuse Media (*Jason Prochaska, UCSC*)
 - <http://www.noao.edu/meetings/bigboss/>



- "BigBOSS" Community Science Committee
 - Connie Rockosi & Joan Najita (co-Chairs); Carles Badenes, Jennifer Johnson, Casey Papovich, Caty Pilachowski, Greg Rudnick
 - Report is public now:
 - <http://ast.noao.edu/sites/default/files/bigboss-csc-report.pdf>

DESI, Berkeley, July 2013

16

DESI bright time opportunities



100% of Mayall available in 2018+

DOE funding only for dark time operations of Key Project

Bright time opportunities: If science collab. can fund

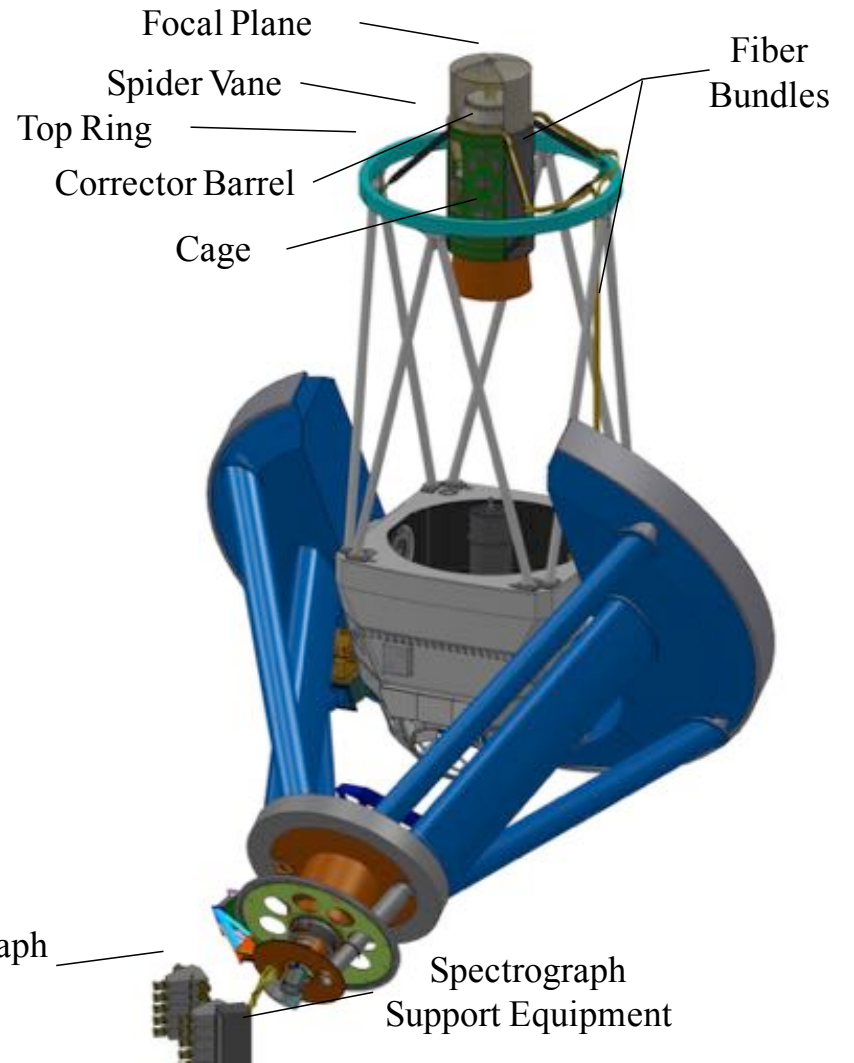
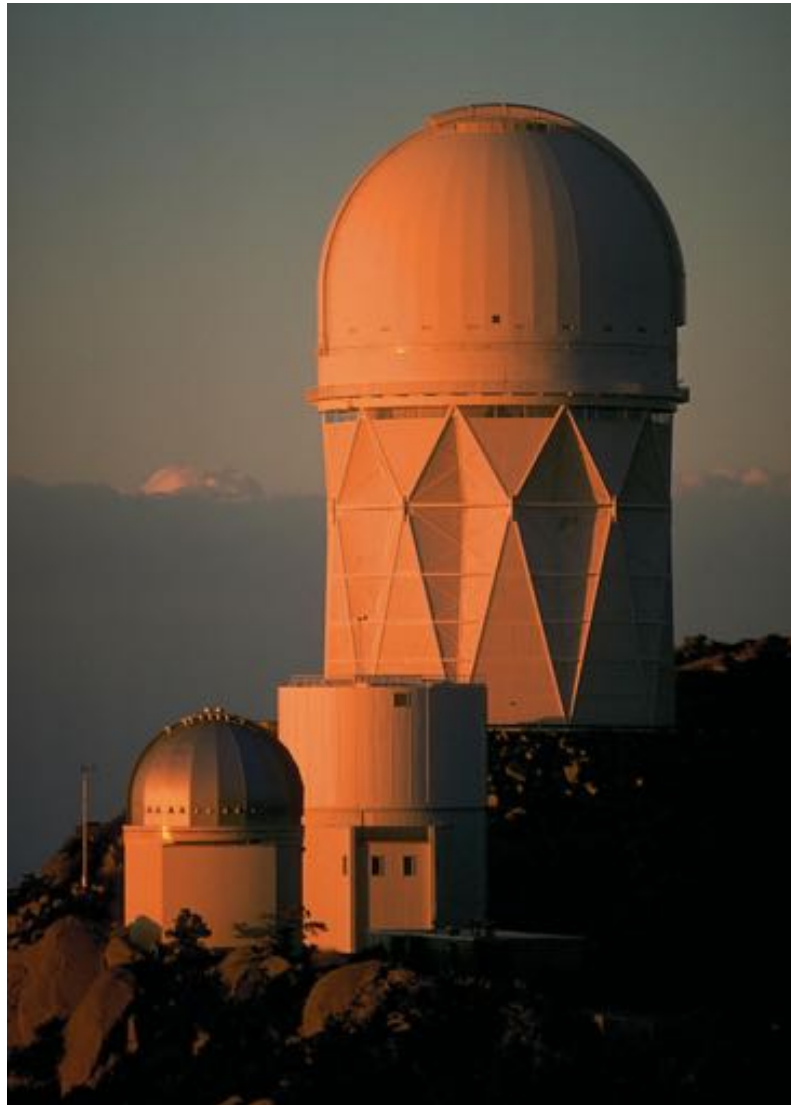
Rich Kron charged on behalf of collab.

Addressing Decadal Survey Science through Community Access to Highly Multiplexed Spectroscopy with BigBOSS on the KPNO Mayall Telescope

Caty Pilachowski (Indiana U), Carles Badenes (U of Pittsburgh), Stephen Bailey (LBNL), Aaron Barth (UC Irvine), Rachel Beaton (U of Virginia), Eric Bell (U of Michigan), Rebecca Bernstein (UC Santa Cruz), Fuyan Bian (U of Arizona), Michael Blanton (NYU), Robert Blum (NOAO), Adam Bolton (U Utah), Howard Bond (STScI), Mark Brodwin (U of Missouri), James Bullock (UC Irvine), Jeff Carlin (RPI), Ranga-Ram Chary (Caltech/IPAC), David Cinabro (Wayne State), Michael Cooper (UC Irvine), Jorge L. C. Cota (ININ, Mexico), Marc Davis (UC Berkeley), Kyle Dawson (U of Utah), Arjun Dey (NOAO), Megan Donahue (MSU), Jeremy Drake (CfA), Erica Ellingson (U Colorado), Lorenzo Faccioli (Kavli/Peking), Xiaohui Fan (U of Arizona), Harry Ferguson (STScI), Eric Gawiser (Rutgers), Maria Geha (Yale U), Mauro Giavalisco (U Mass), et al. (59 additional authors not shown)

(Submitted on 1 Nov 2012)

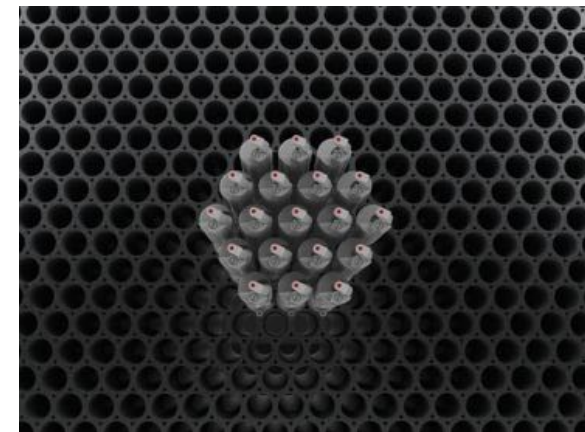
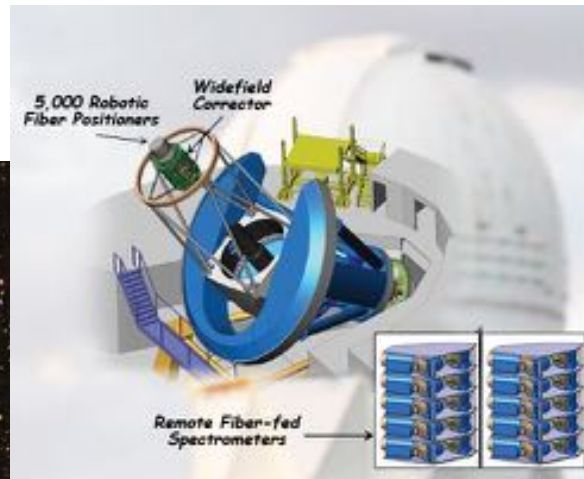
DESI Instrument



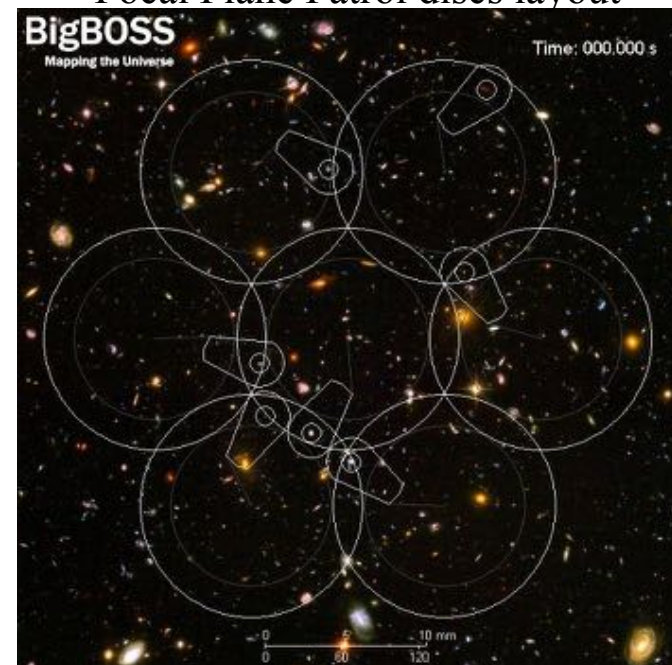
Mayall Telescope



DESI in Action!



Focal Plane Patrol discs layout



DESI in Action!

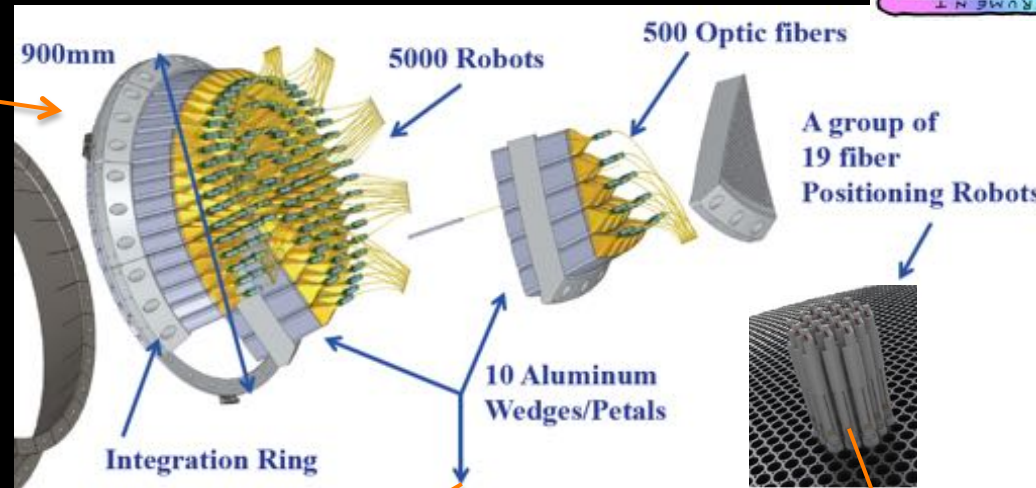
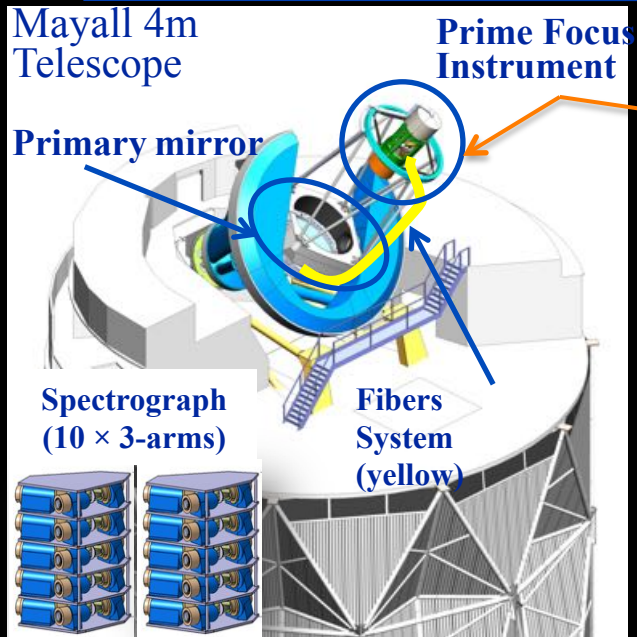


SIDE Team IAA-CSIC
IAA/AVS BigBOSS Fiber Positioner
A simulated performance of the anticollision software

<http://side.iaa.es>



Spain participation in the DESI Instrument (2010-2015)

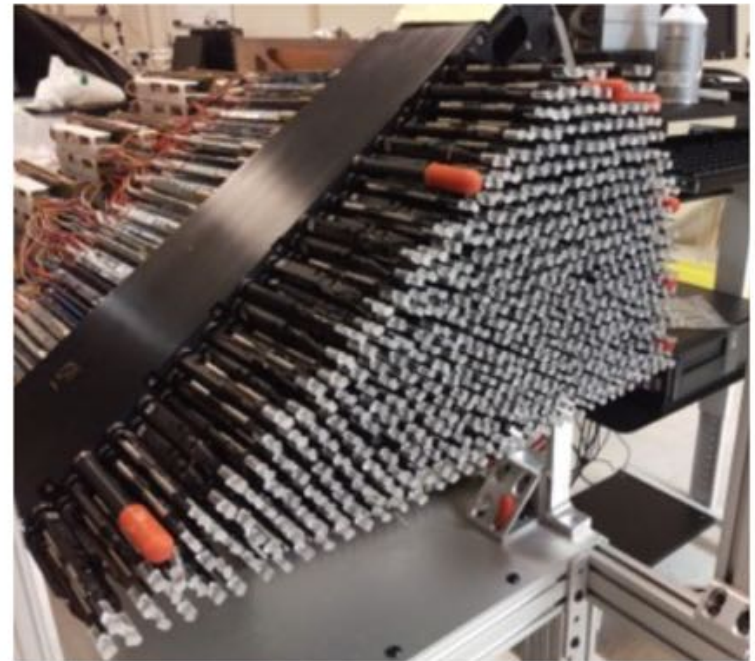
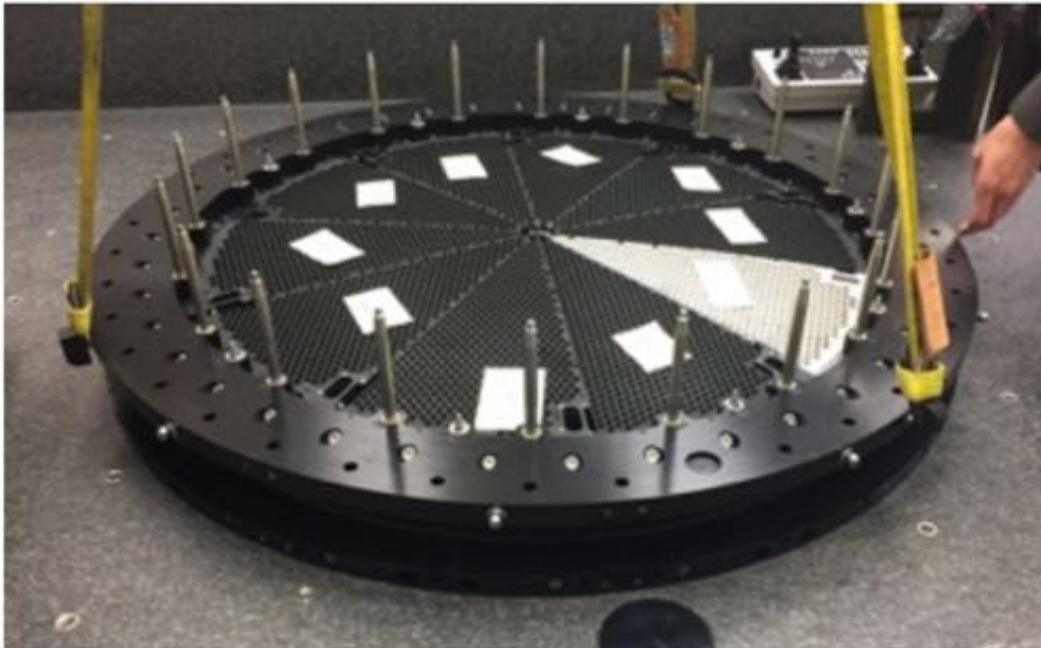
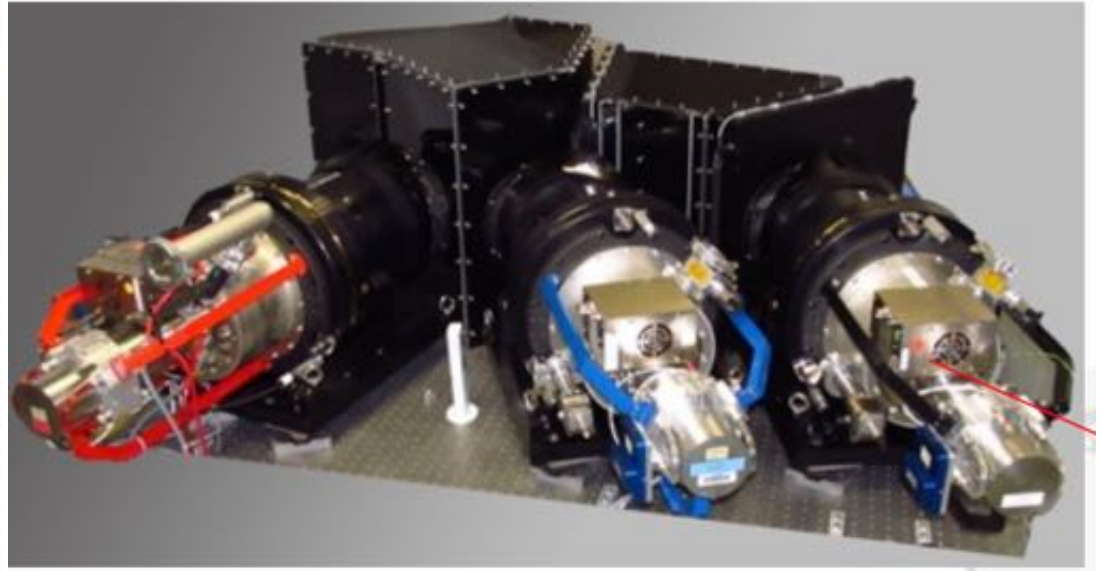
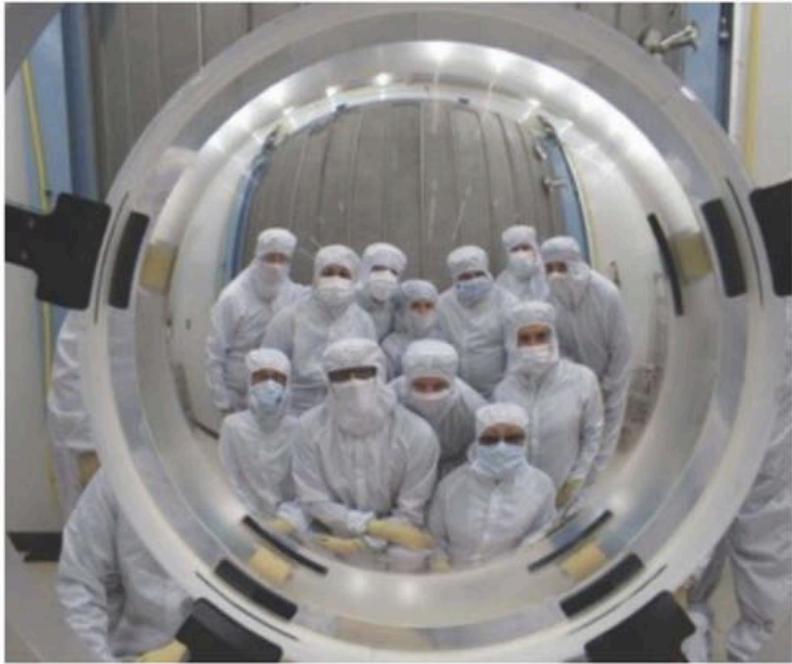


New ES-CH positioner for DESI



Focal Plate Demonstrator as being built!







Thank you!