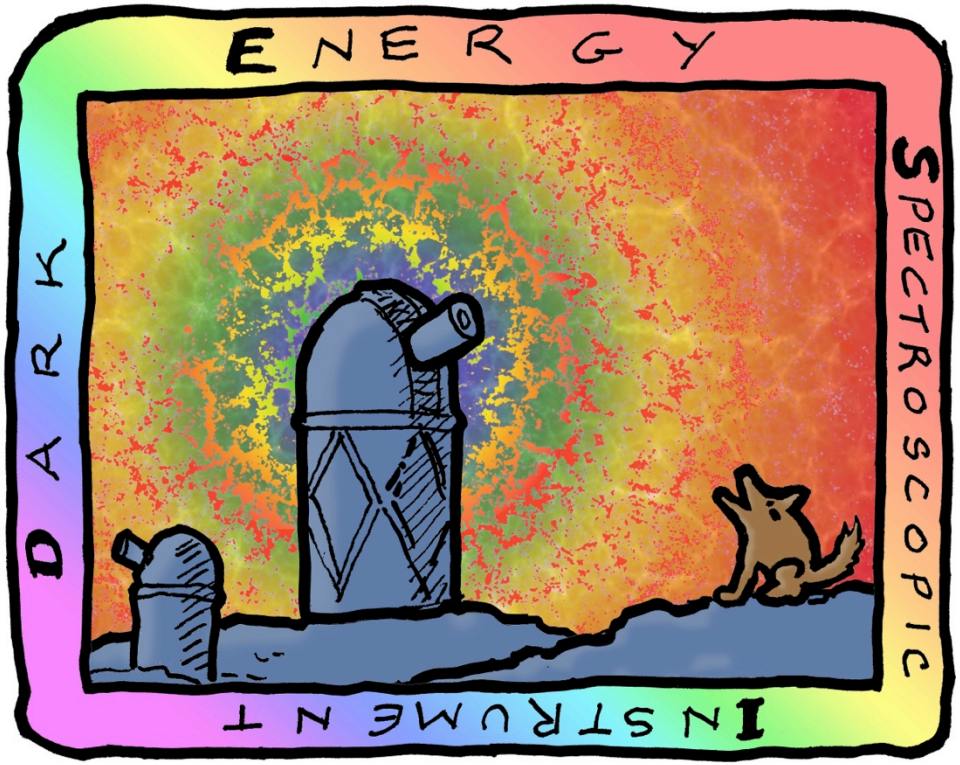


Jorge Cervantes-Cota, ININ

on behalf of the DESI Collaboration

PPC 2014

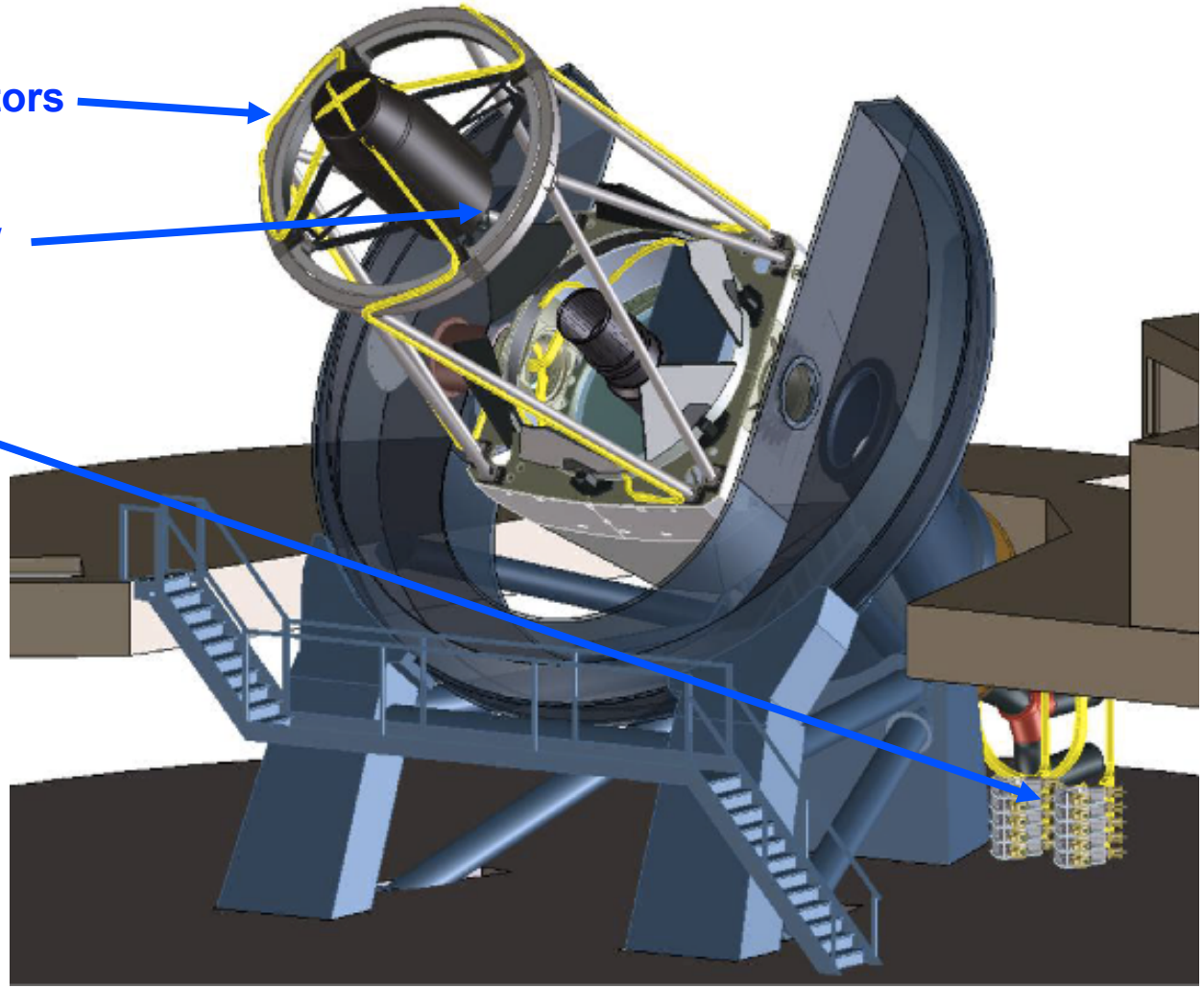
DESI Overview

- **DESI is the Dark Energy Spectroscopic Instrument**

- **Pioneering Stage-IV Experiment**
  - **recommended by Community DE report (Rocky-III, 2012).**
  - **Recommended recently in the P5 report.**
  - **should fill the gap between DES and LSST.**
  - **on sky before Euclid.**

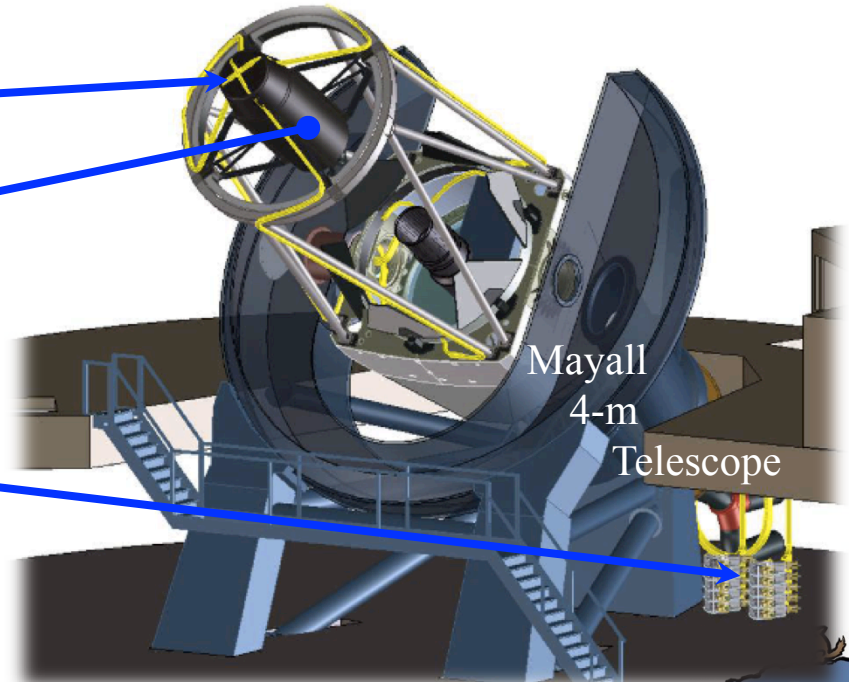
- **DESI meets this goal**
  - **scientifically ambitious enough to satisfy Stage IV criteria**
  - **At least *x10* more galaxies than BOSS**
  - **technically advanced enough to be ready on 2018 time frame**
  - **will be a statistically limited**
  - **rich scientific program: incl. DE, inflation, neutrino mass hierarchy**

DESI Instrument

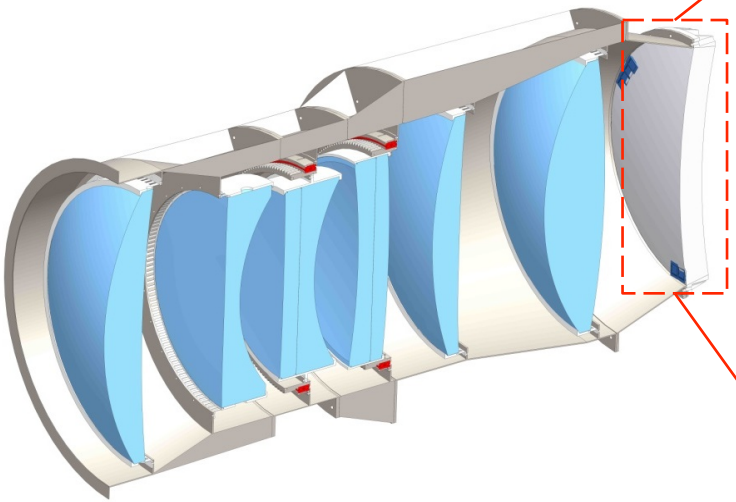


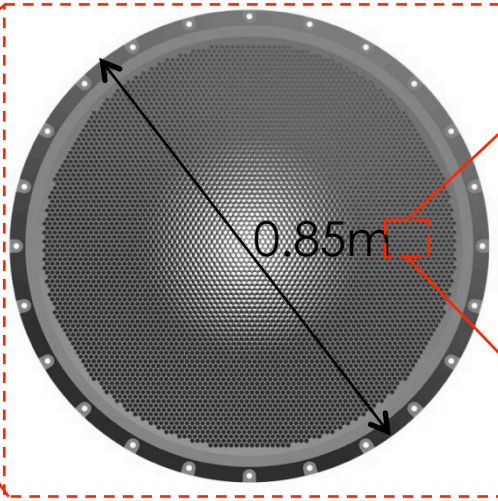
DESI Reference Concept

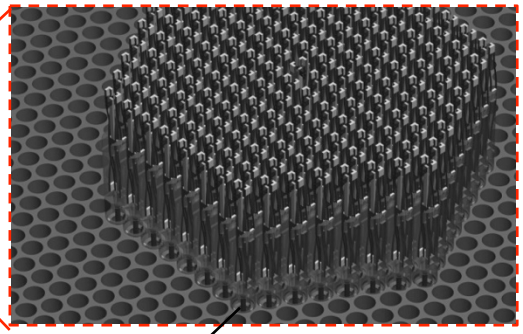
- Scale up BOSS to a massively parallel fiber-fed spectrometer
- Stage-IV BAO and Power Spectrum, build upon BOSS
- Broad range of target classes: LRG's, ELG's, QSO's
- Broad redshift range: $0.5 < z < 1.6$, $2.2 < z < 3.5$
- Sky area: 14,000 – 18,000 square degrees
- Number of redshifts: 20 – 35 million
- Medium resolution spectroscopy, R ~ 3000 – 5000
- Spectroscopy from blue to NIR
- Automated fiber system, N_{fiber} ~ 4000 – 5000



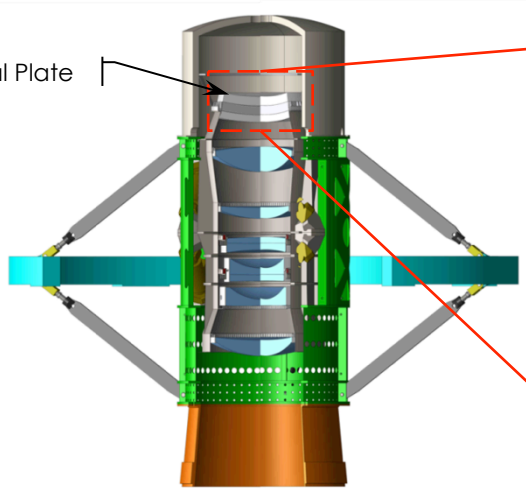
DESI Instrumentation

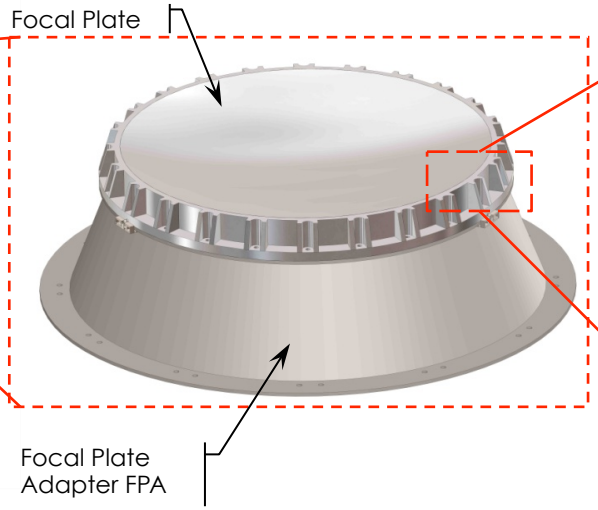


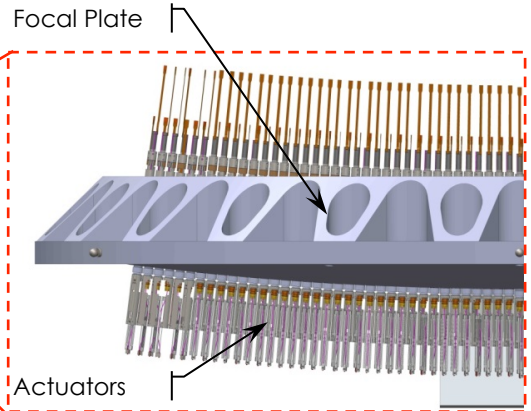




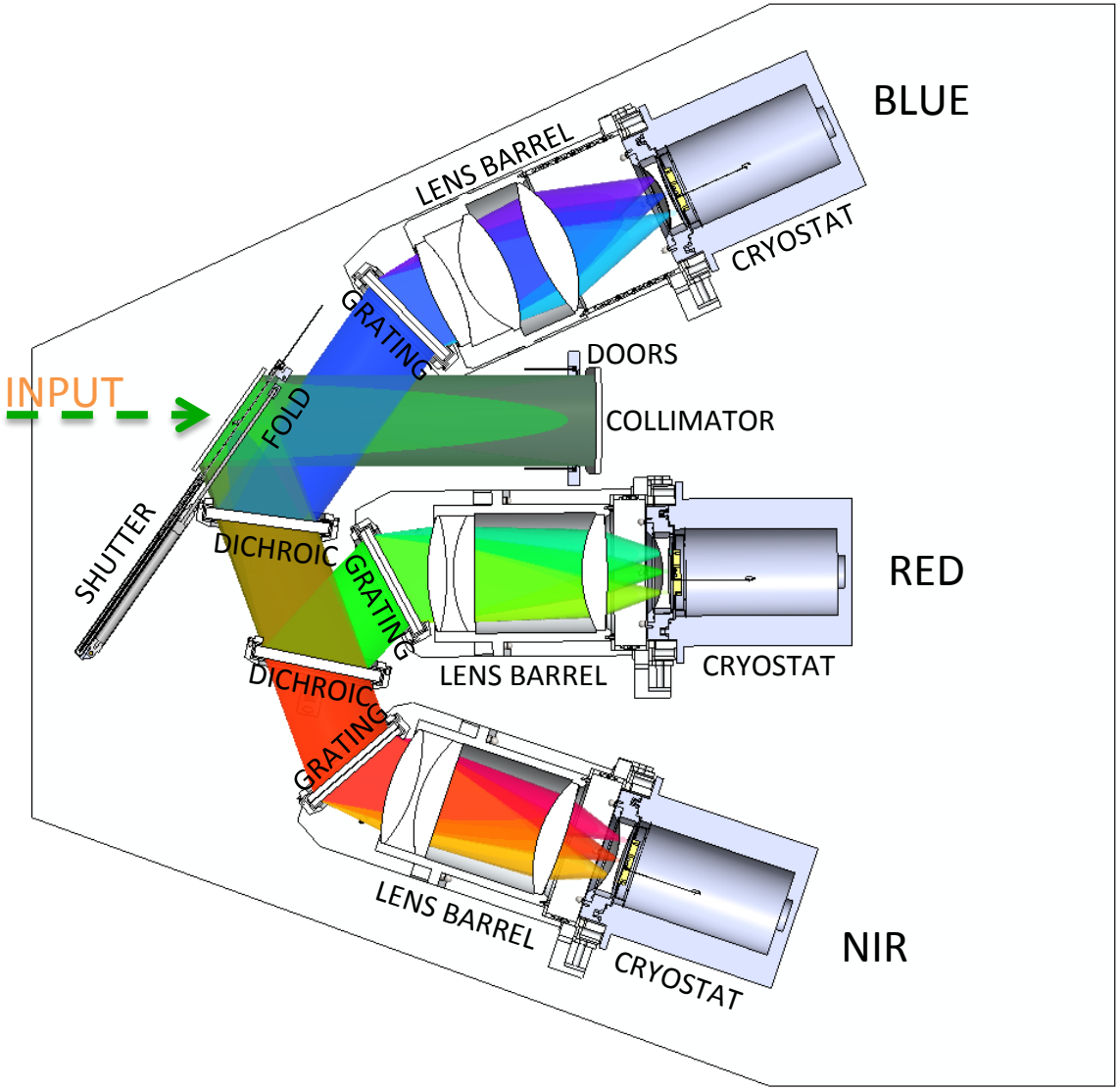
fiber positioners in an array of
precision holes in the focal plate



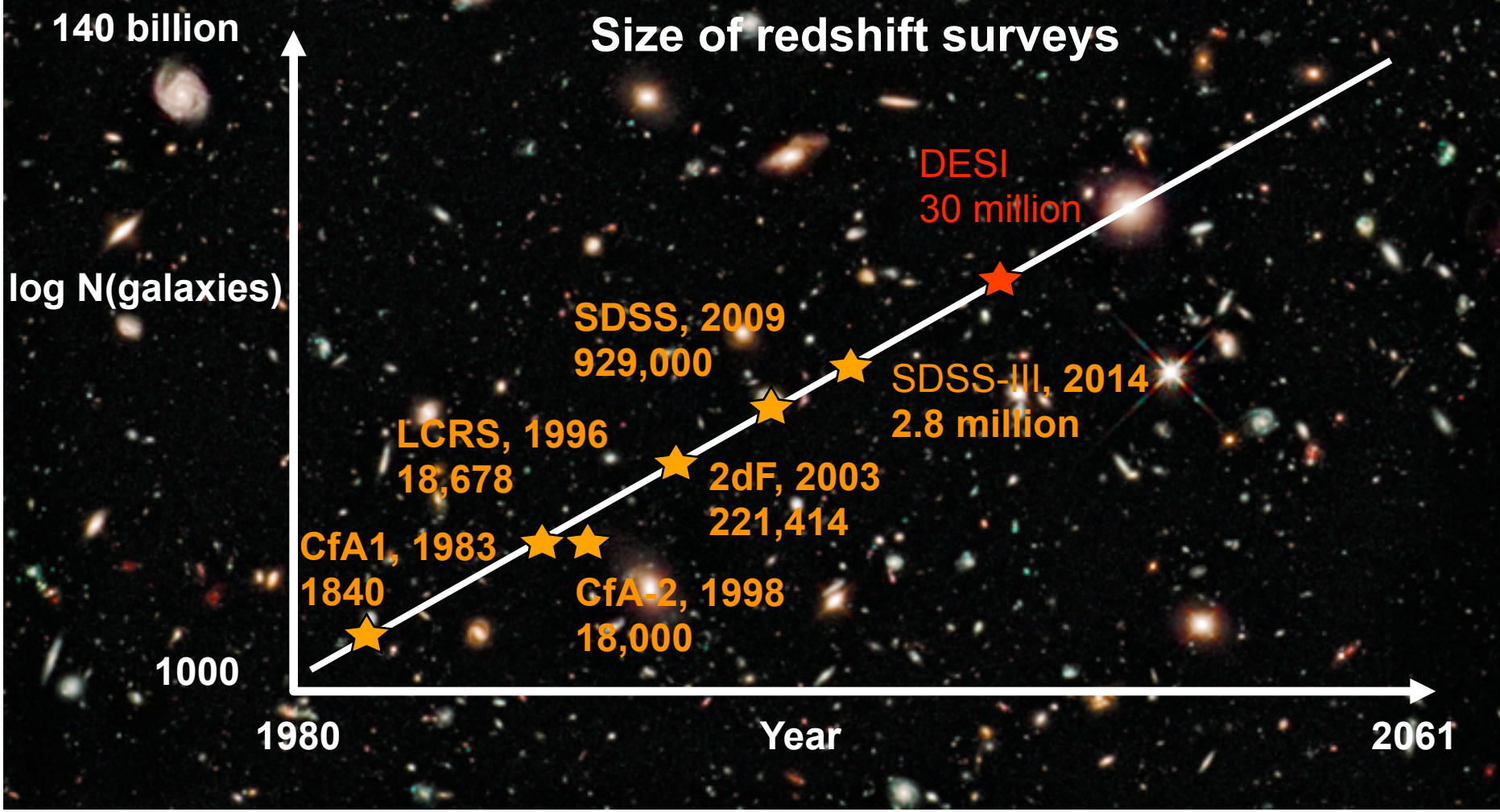




Spectrograph



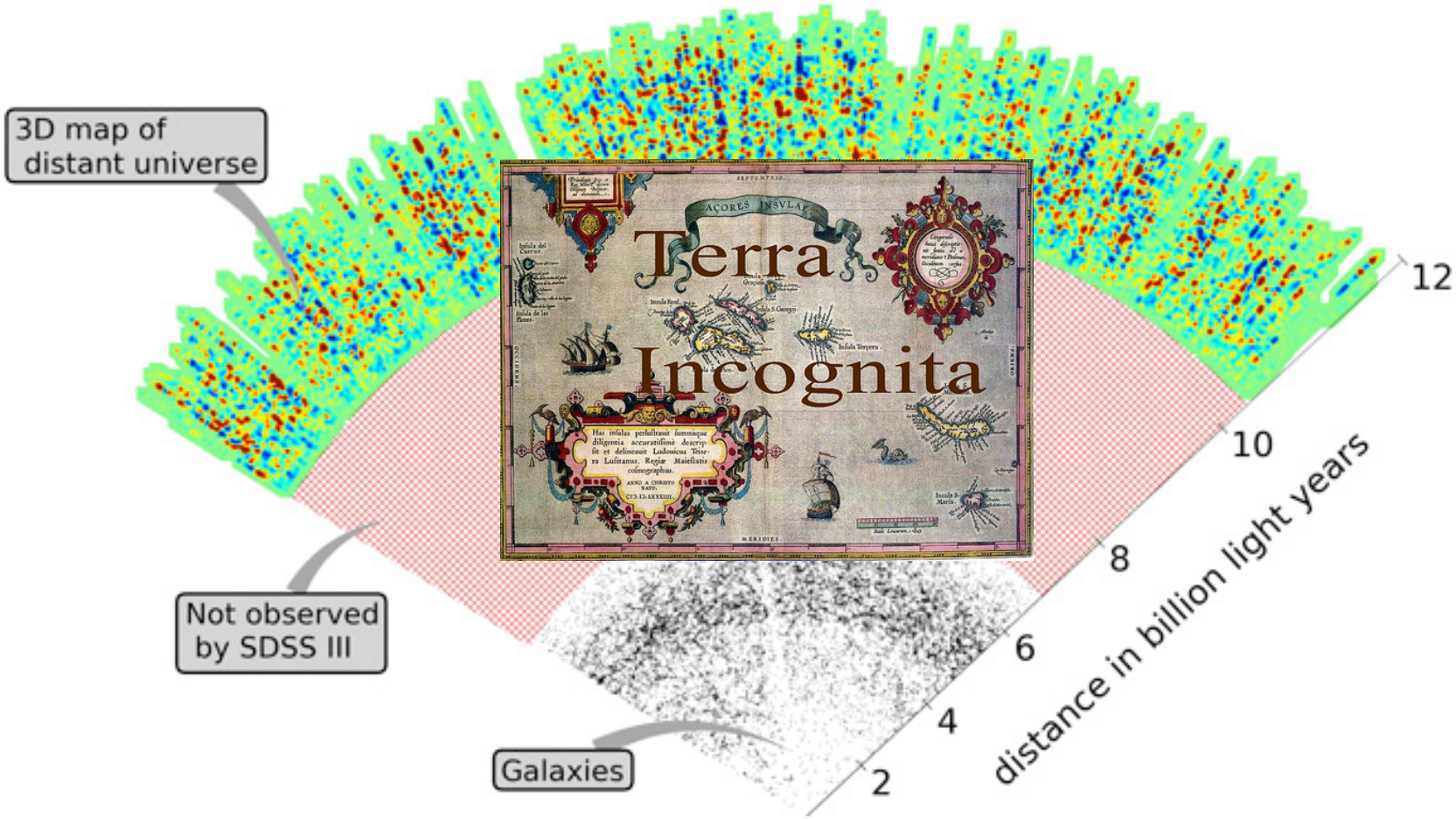
DESI ahead of the curve if completed by 2024



HST Ultra-Deep Field
10,000 galaxies / (11 arcmin^2)

Where are we with SDSS-III/BOSS ?

SDSS-III/BOSS completed on April 1, 2014
1.5 million redshifts spanning ~6 $h^{-3}Gpc^3$



What is the DESI survey?

1. An imaging (targeting) survey over 14,000 deg^2

g-band to 24.0 mag

r-band to 23.6 mag

z-band to 23.0 mag

2. A spectroscopic survey

4 million Luminous Red Galaxies (LRG)

23 million Emission Line Galaxies (ELG)

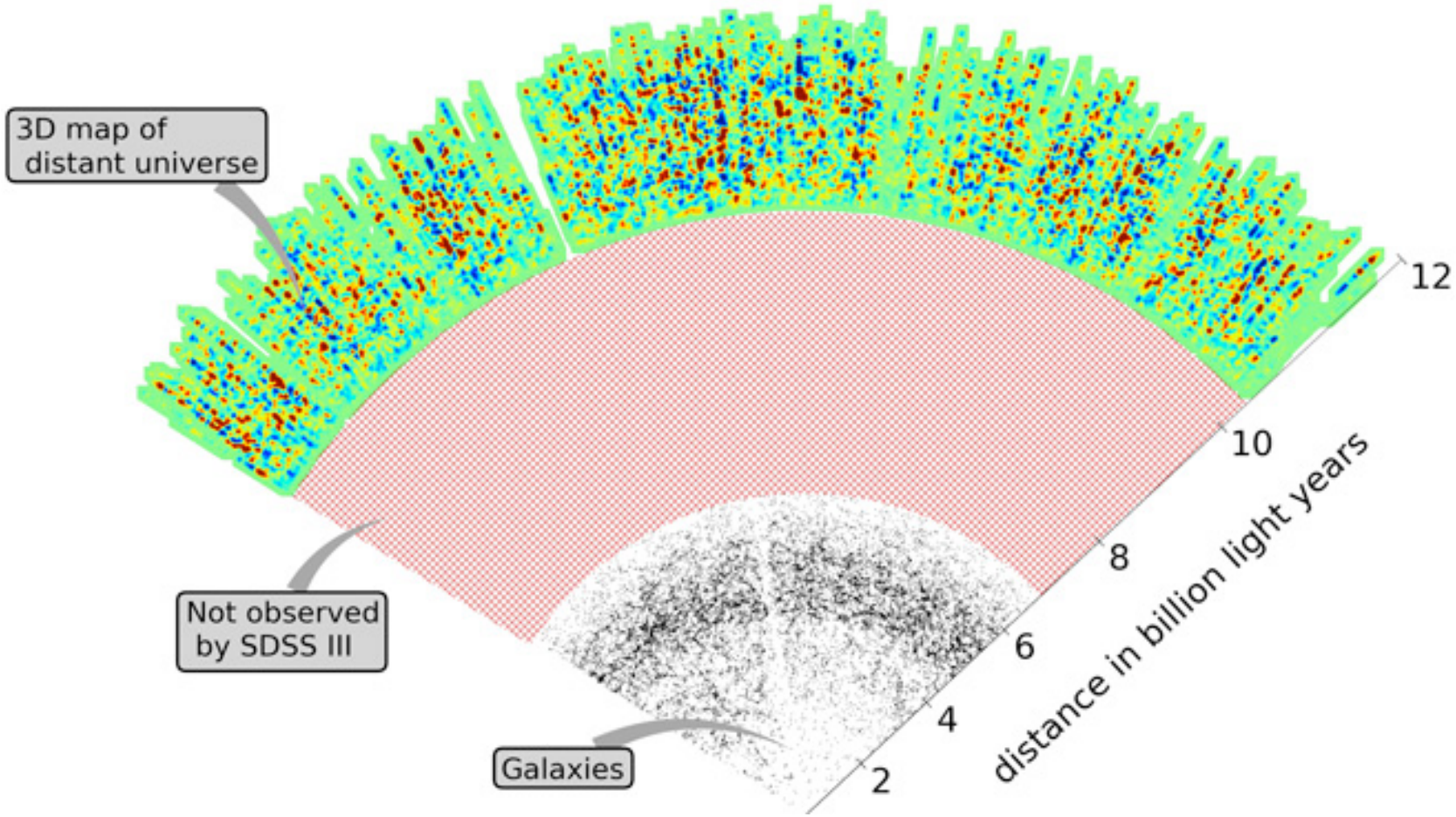
1.4 million quasars

0.6 million quasars at z>2.2 for Lyman-alpha-forest

What is the DESI survey?

The largest spectroscopic survey for dark energy

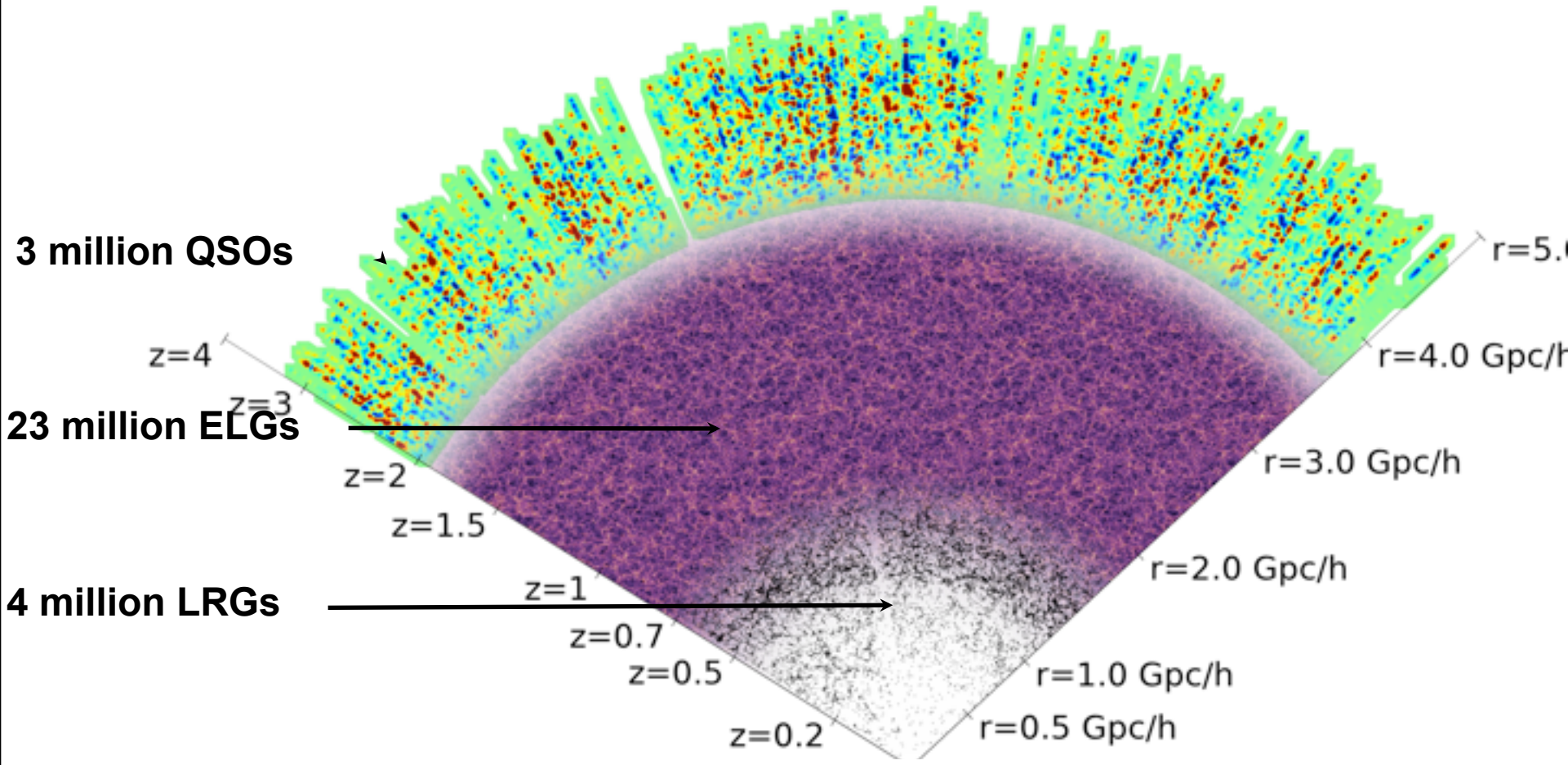
SDSS ~$2h^{-3}Gpc^3$ ⇨ BOSS ~$6h^{-3}Gpc^3$



What is the DESI survey?

The largest spectroscopic survey for dark energy

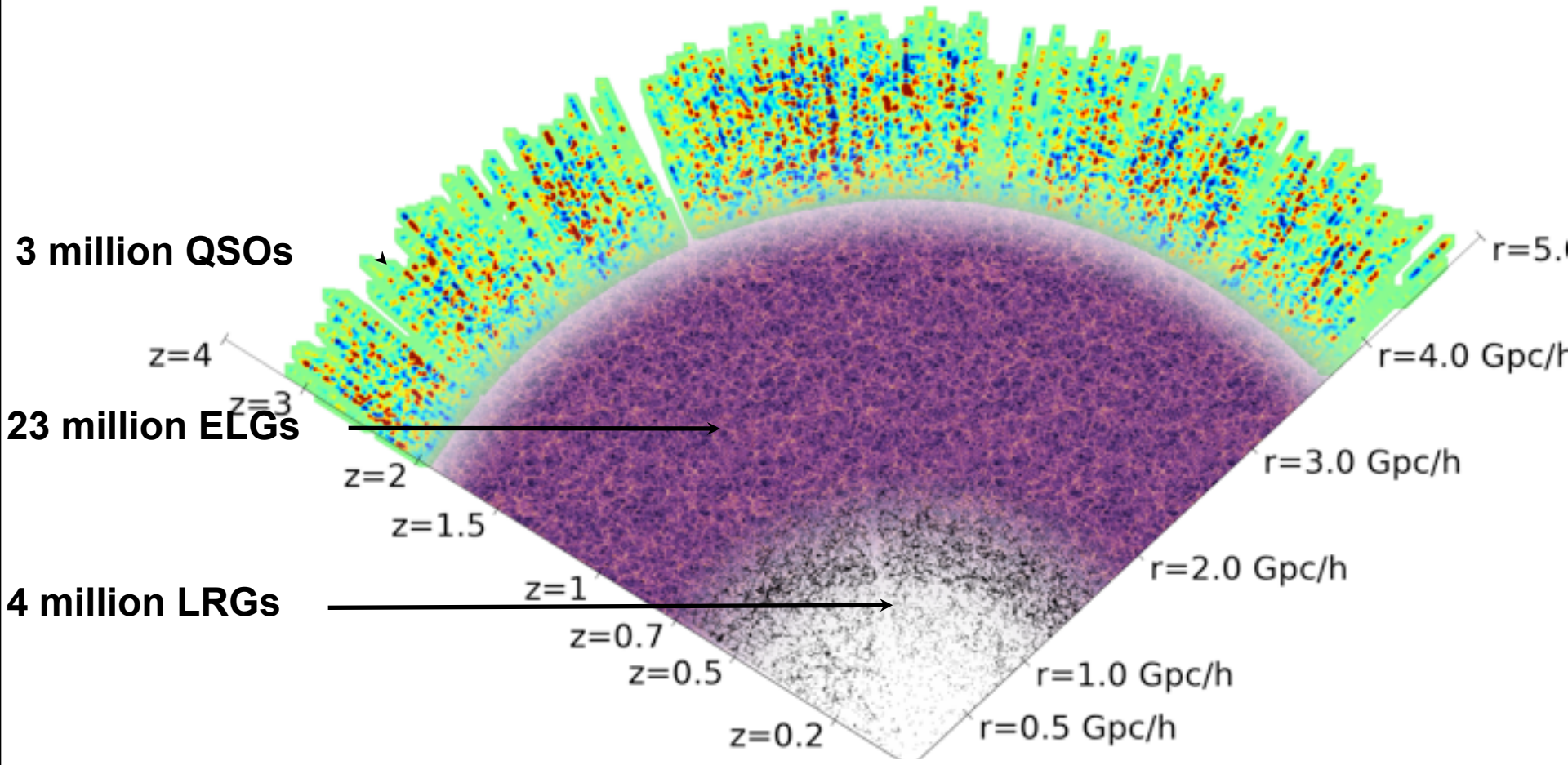
SDSS ~$2h^{-3}Gpc^3$ ➡ BOSS ~$6h^{-3}Gpc^3$ ➡ DESI $50h^{-3}Gpc^3$



What is the DESI survey?

Four target classes spanning redshifts z=0 → 3.5

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



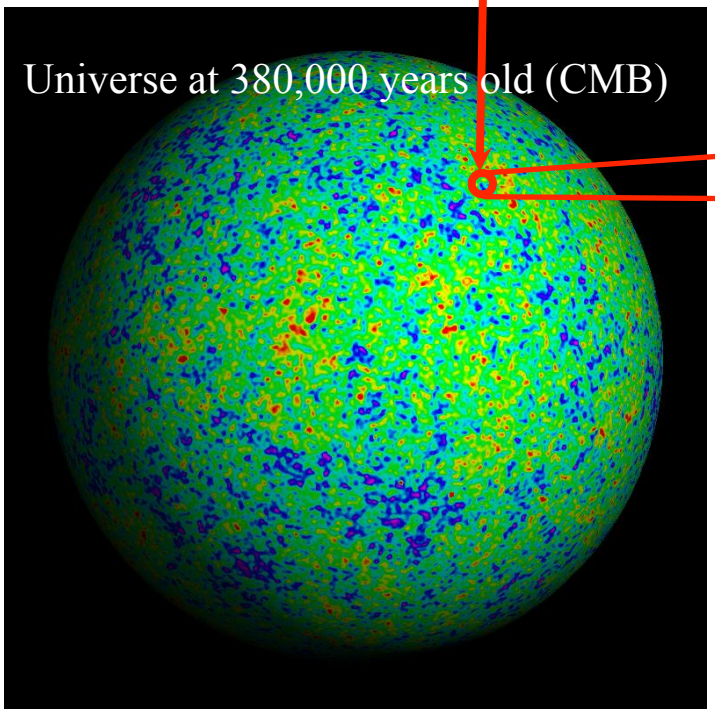
DESI Key Project goals

- **Dark Enegy through the distance-redshift relation**
  - 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
- **Gravitational growth**
  - Constrain the growth factor at ~ a few percent level up to z=1.5
- **Beyond Dark Energy**
  - Constrain spectral index of primordial perturbations and its running to < 0.4%
  - Measure the neutrino masses to < 0.017 eV

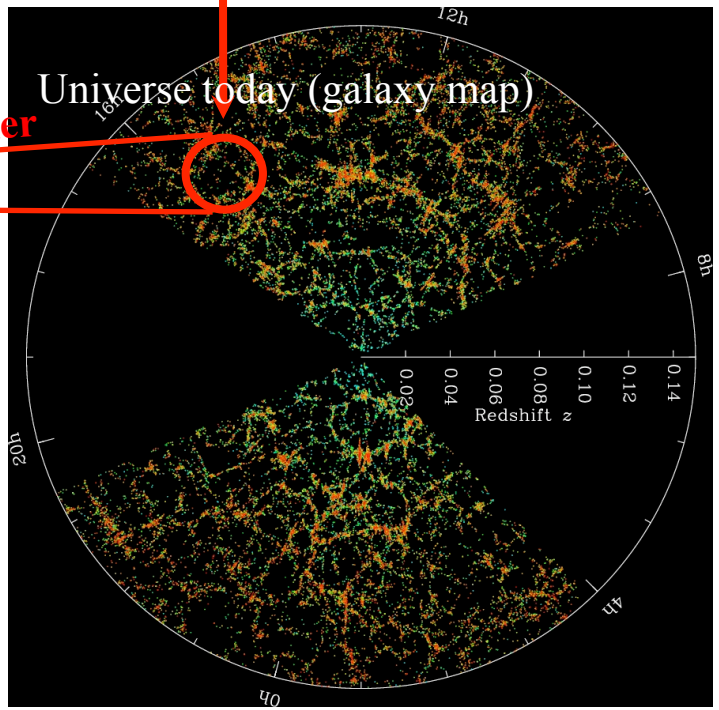
Baryon Acoustic Oscillation (BAO)

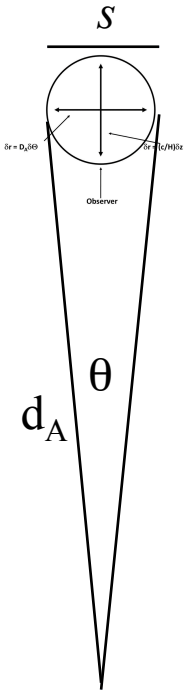
These fluctuations of 1 part in 10^5 gravitationally grow into...

...these ~unity fluctuations today



standard ruler

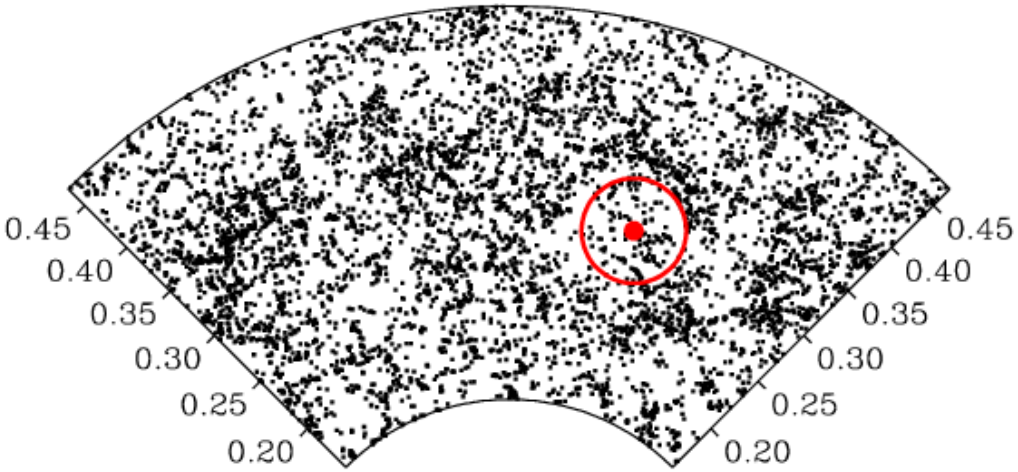




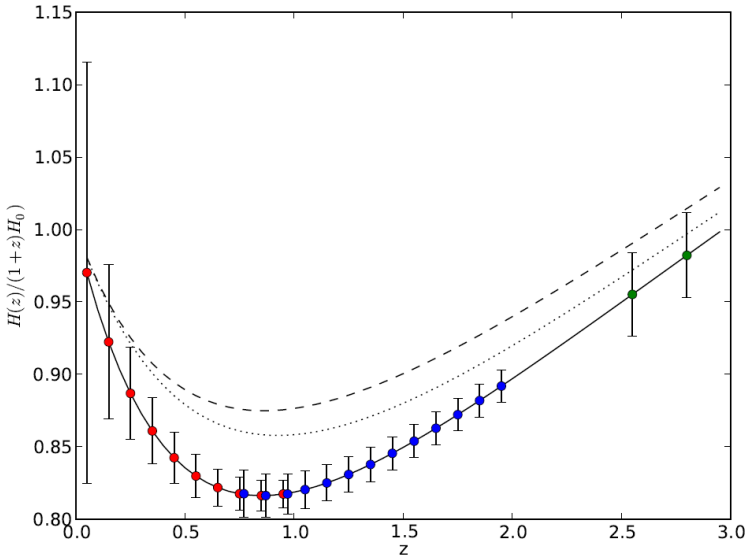
$$s = (1+z)d_A(z)\theta$$

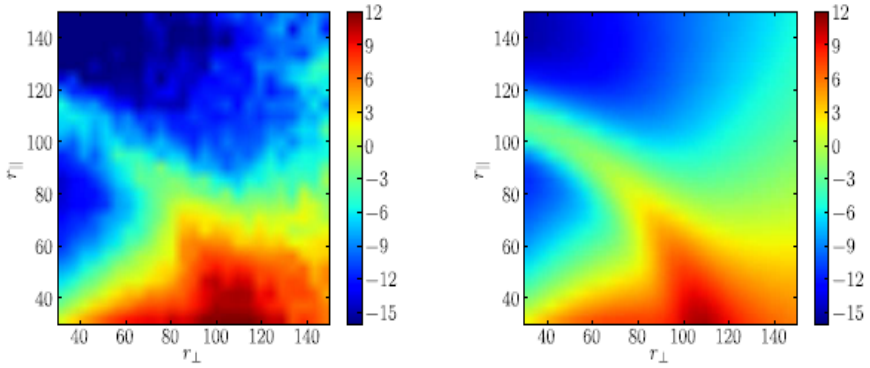
$$\frac{\Delta z}{H(z)} \approx s$$

BAO: Geometric probe of dark energy



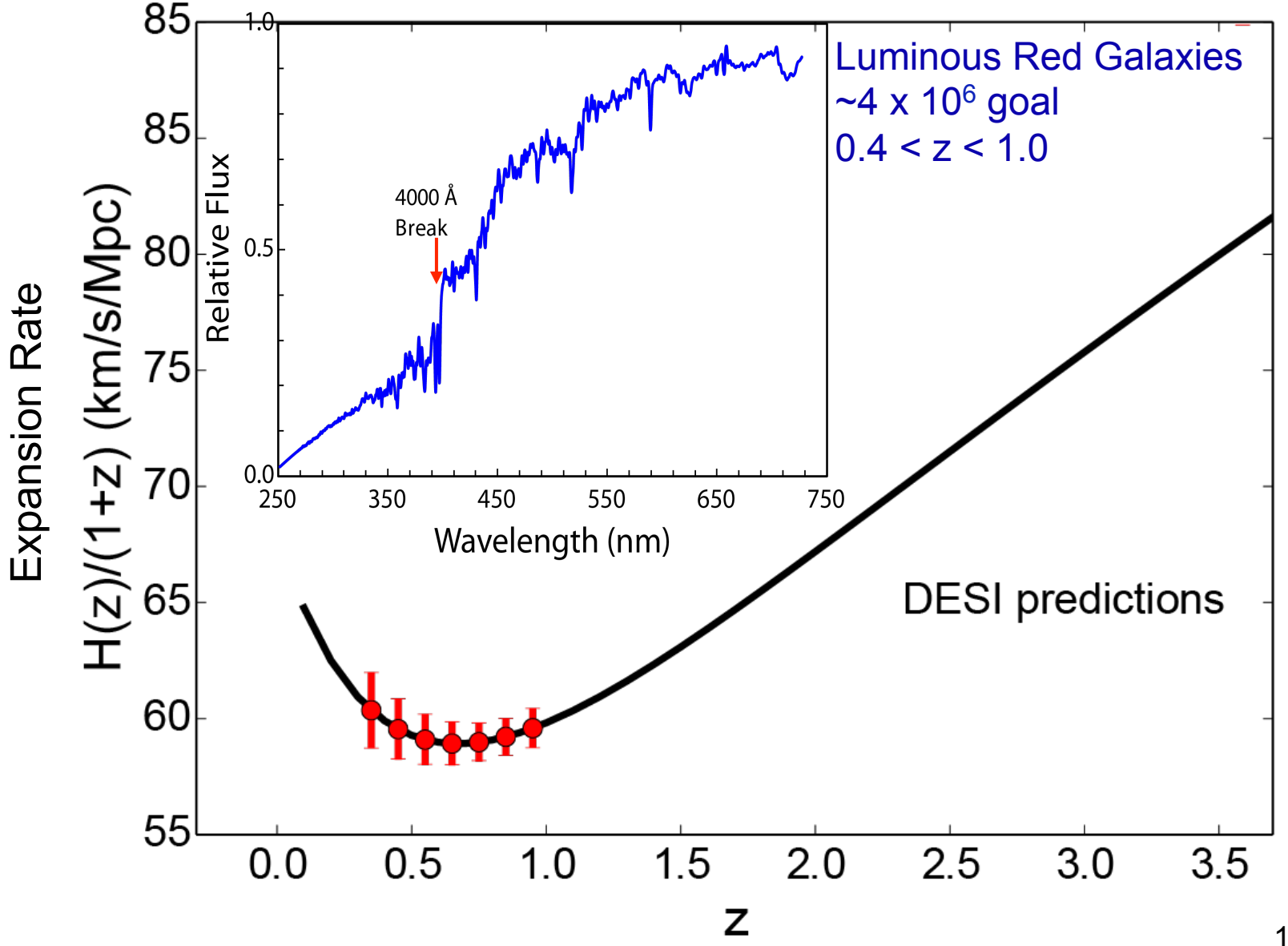
BAO scale in SDSS galaxies.



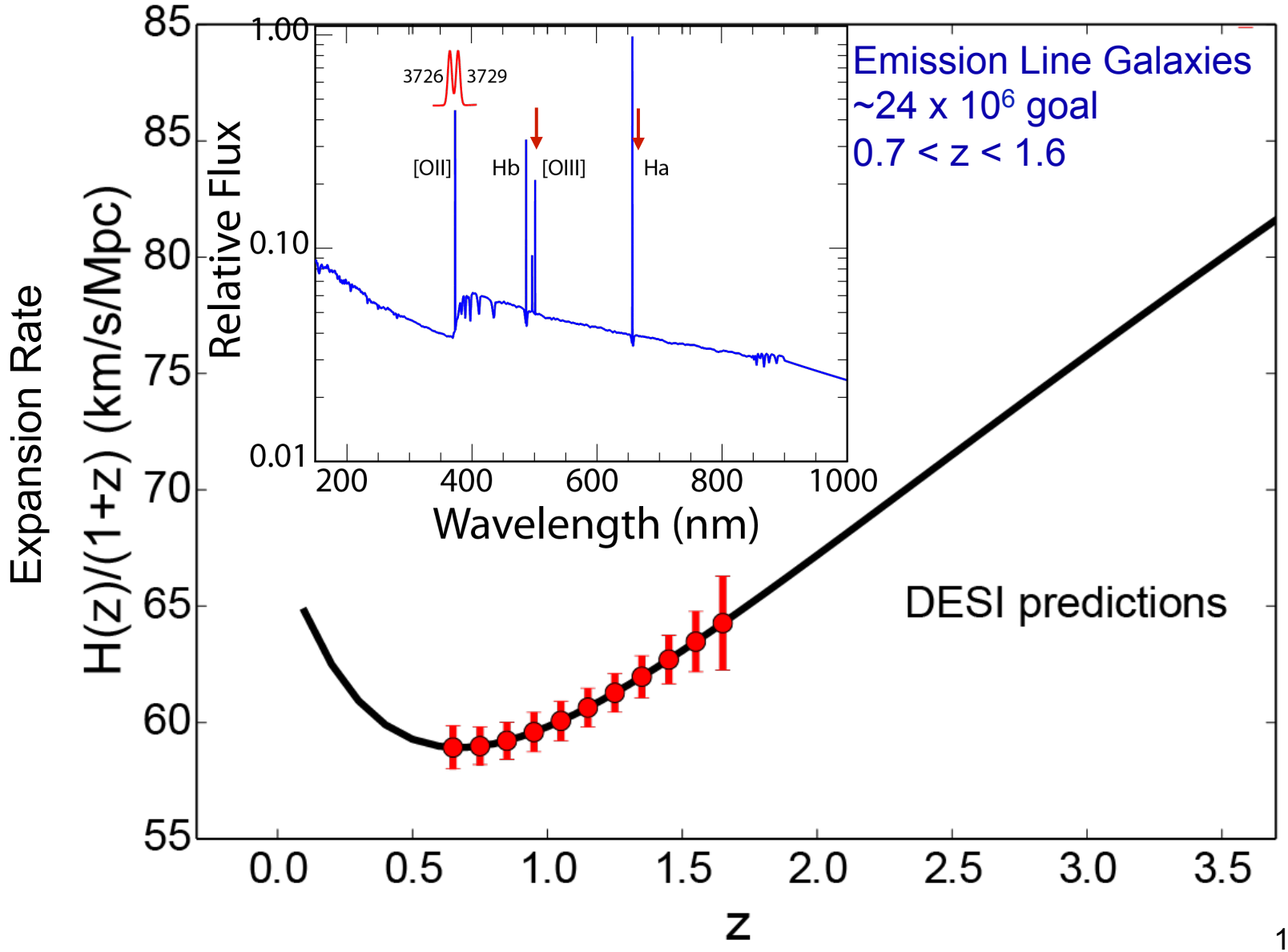


BAO in Lyman-Alpha (Slosar et al)

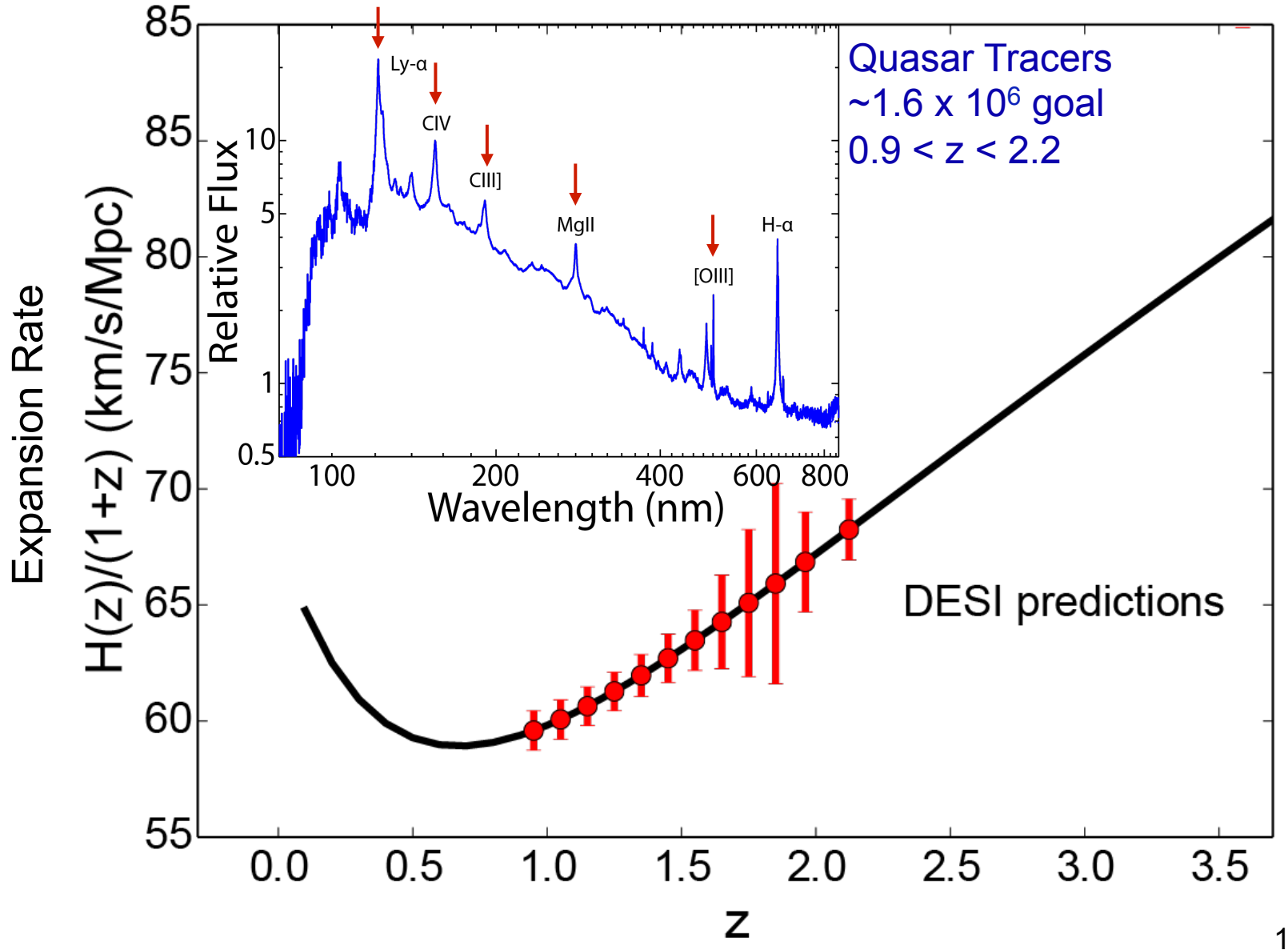
LRG Targets


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
85
80
75
70
65
60
55
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1.0
0.5
0.0
250
350
450
550
650
750

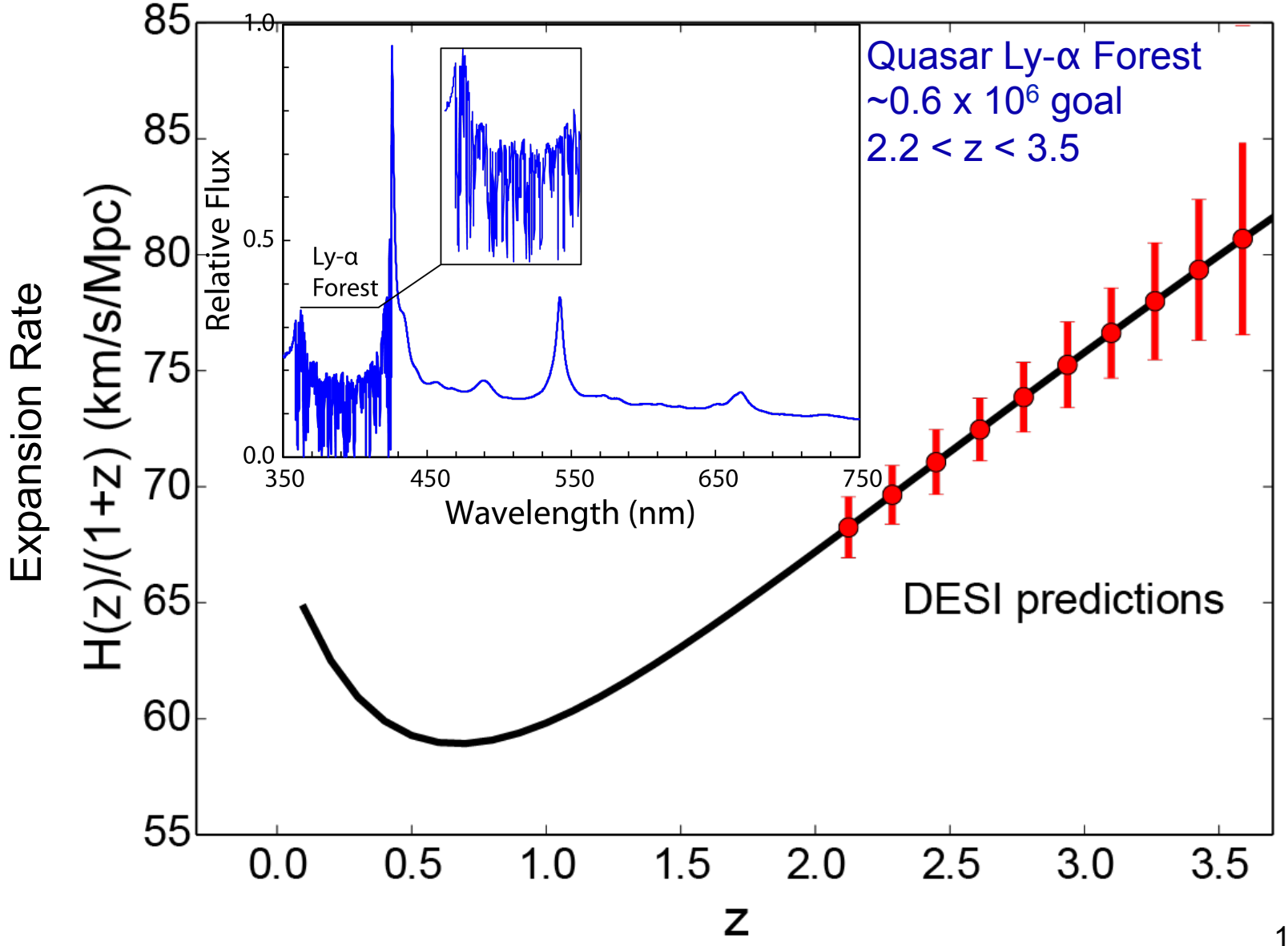
ELG Targets


Emission Line Galaxies
~24 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
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

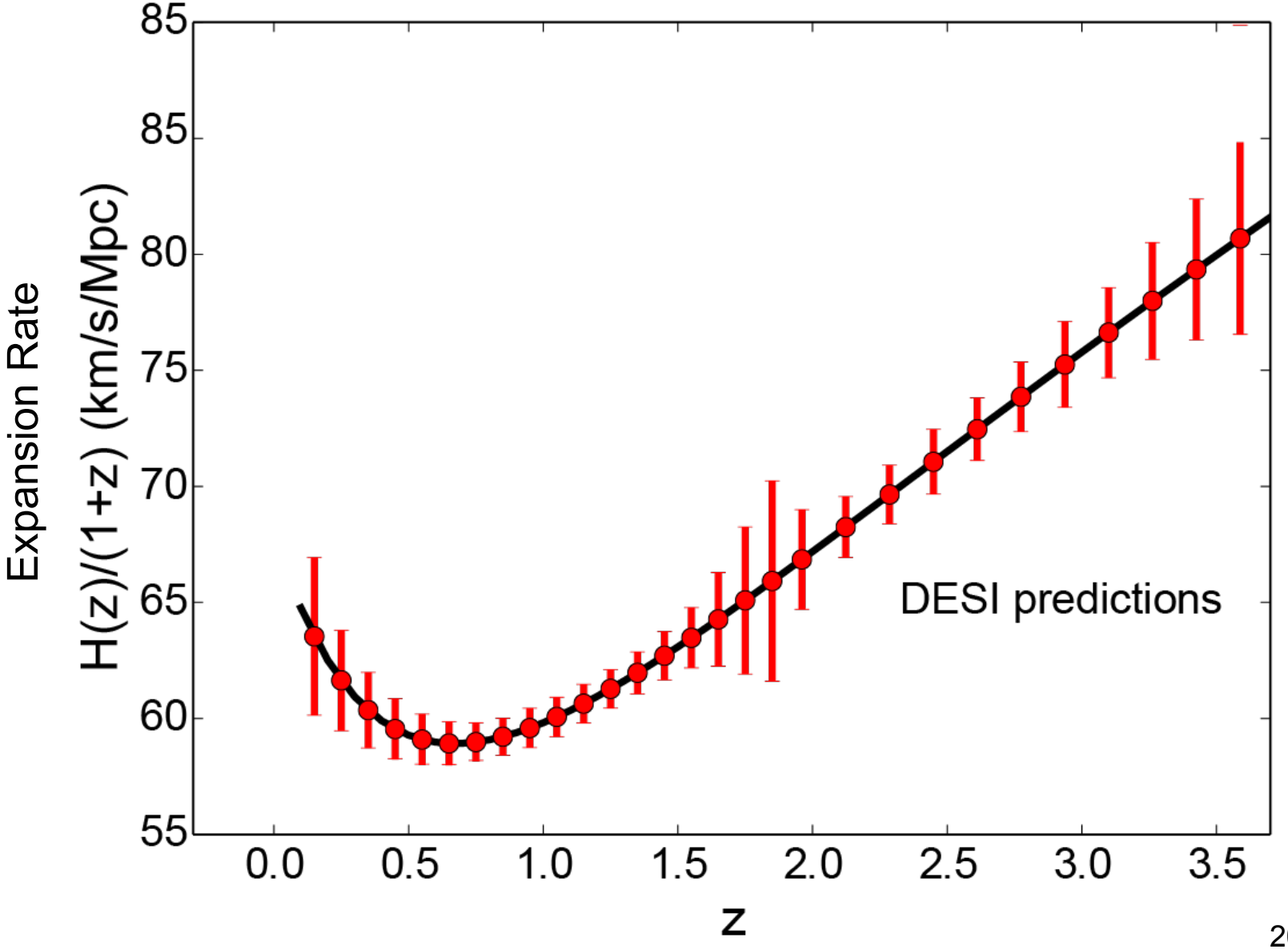
QSO Targets


Quasar Tracers
~1.6 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

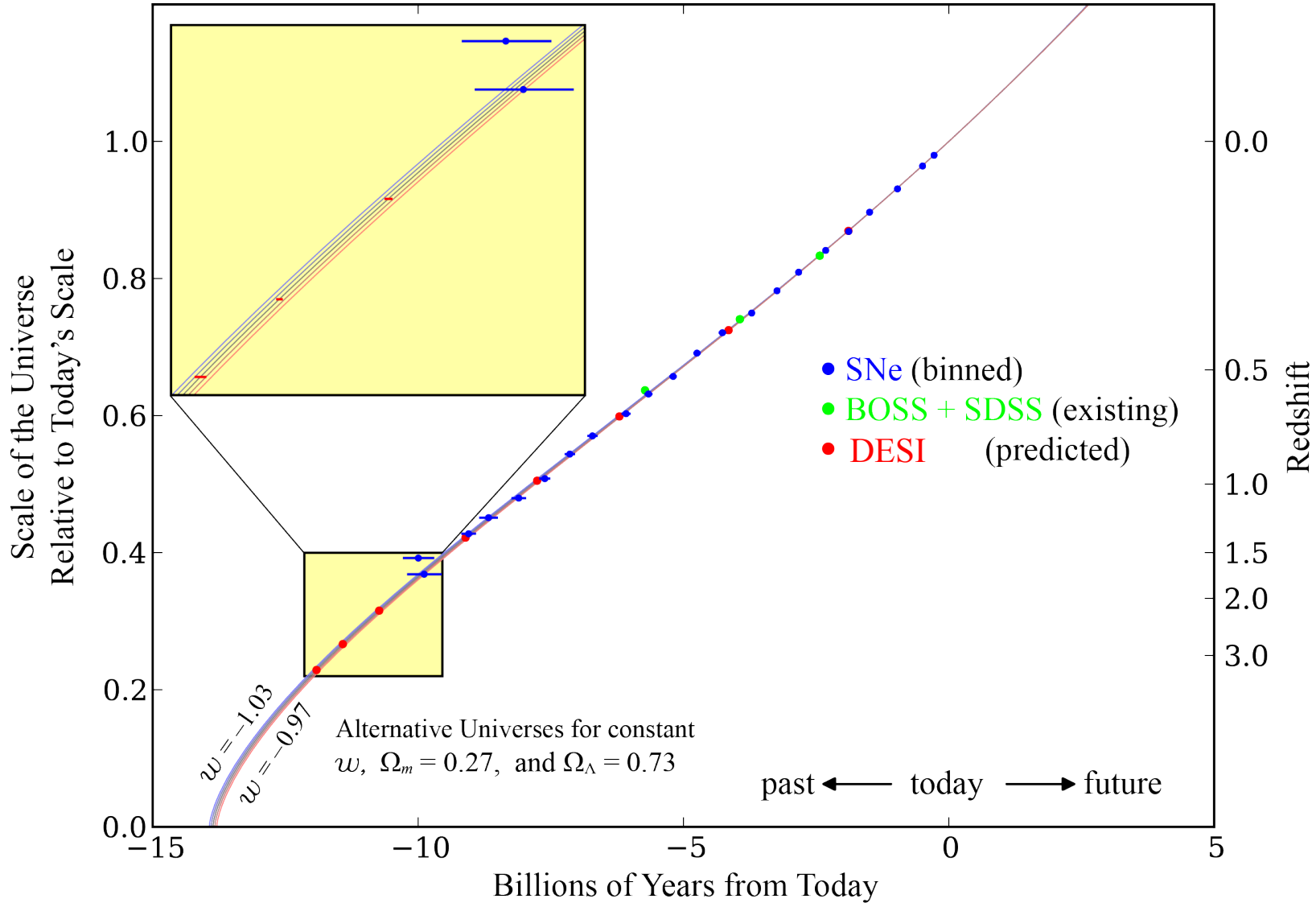
Ly-α Forest QSO Targets



DESI on the Hubble Diagram



DESI Will Discriminate Between Dark Energy Models



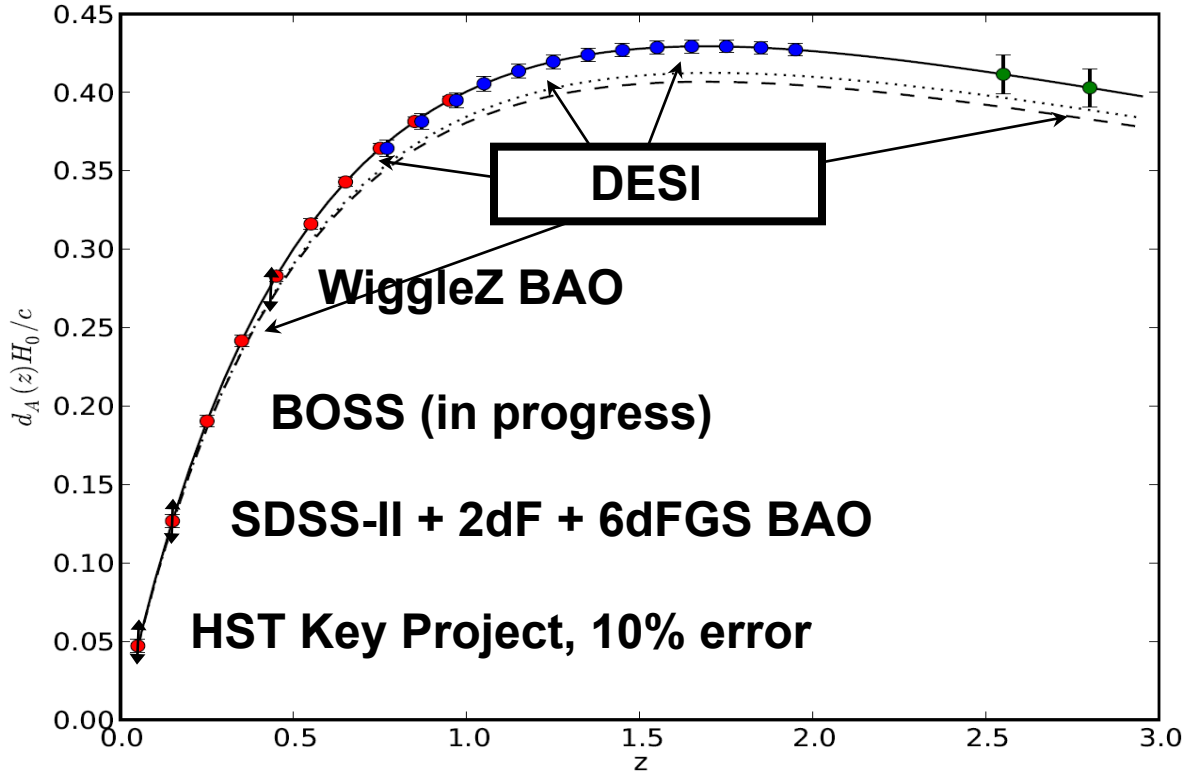
DESI science reach: BAO

Dark energy from Stage IV BAO

—*Geometric probe with 0.3-1% precision from z=0.5 -> 3*

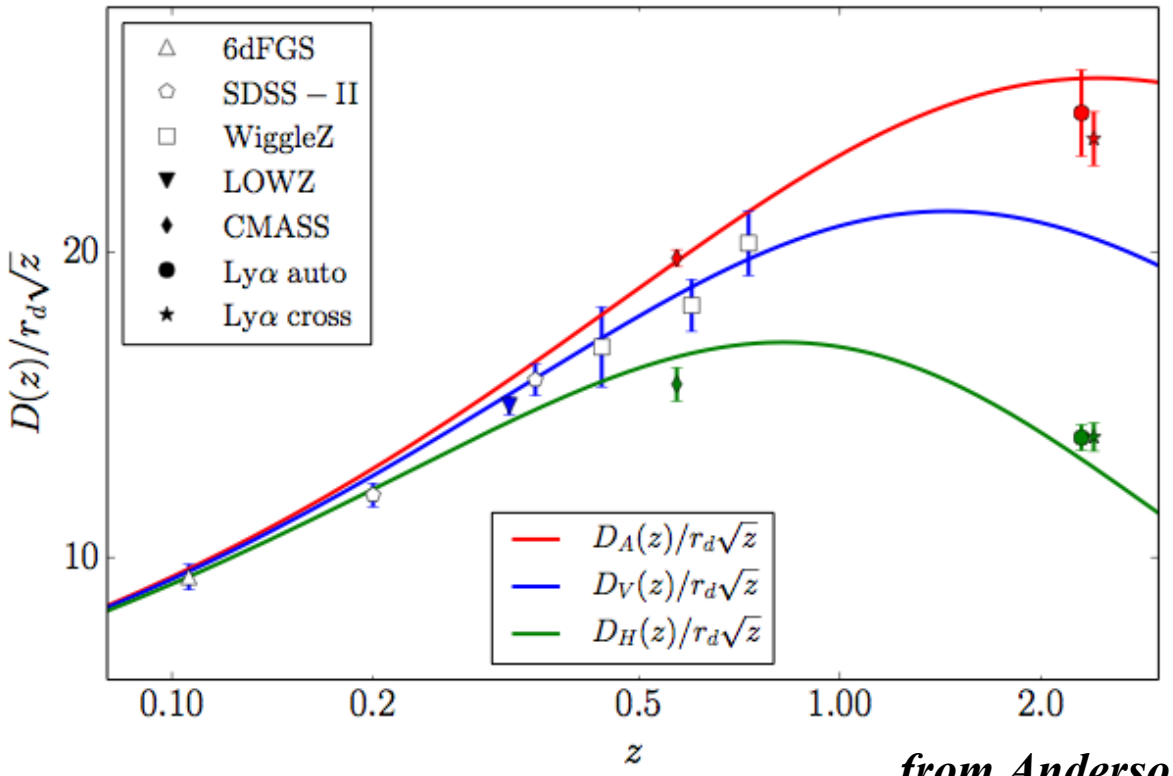
—*35 measurements with 1% precision*

DESI BAO "Hubble diagram"



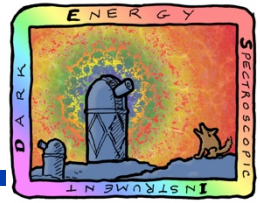
Where are we with SDSS-III/BOSS ?

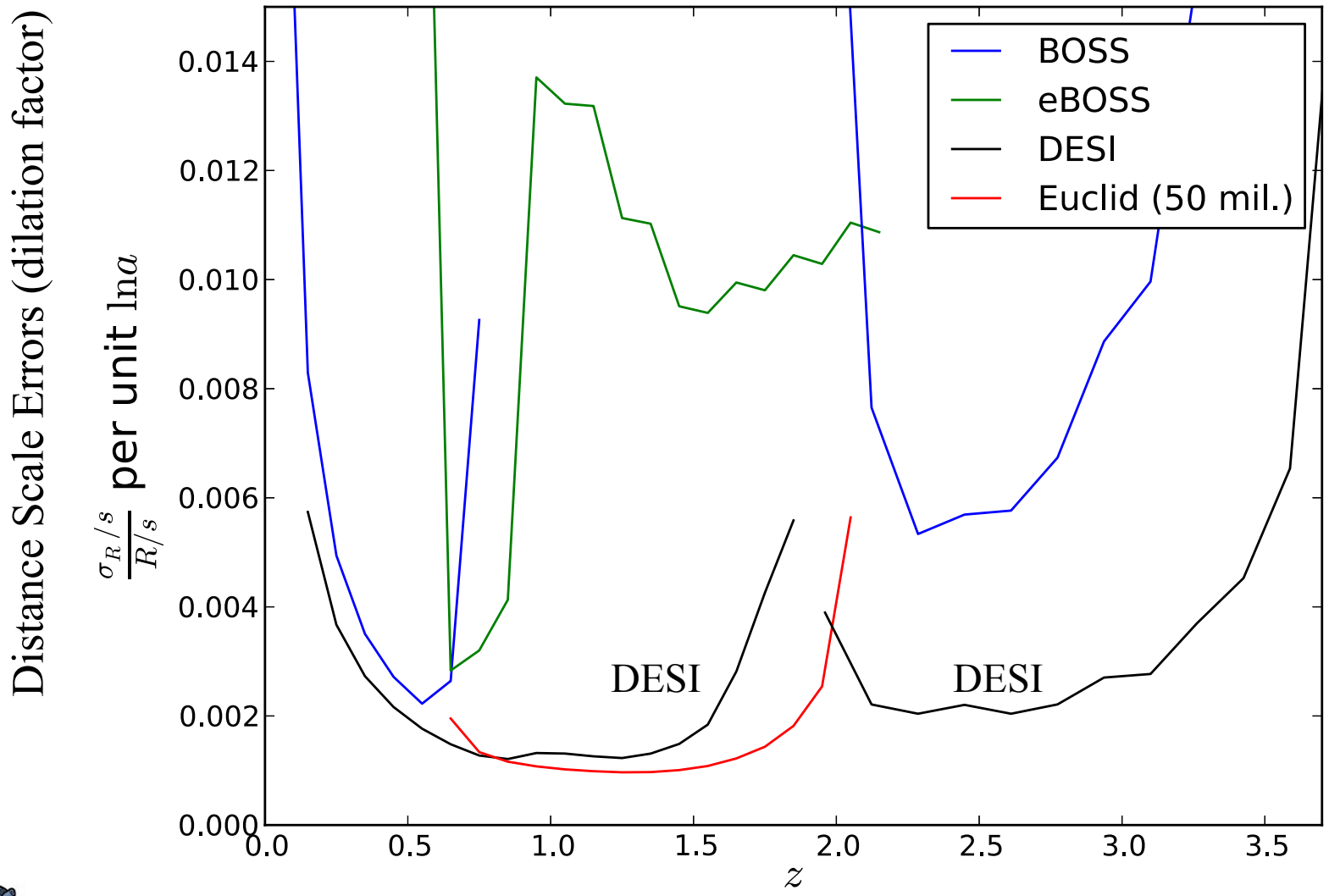
Some tension with ΛCDM



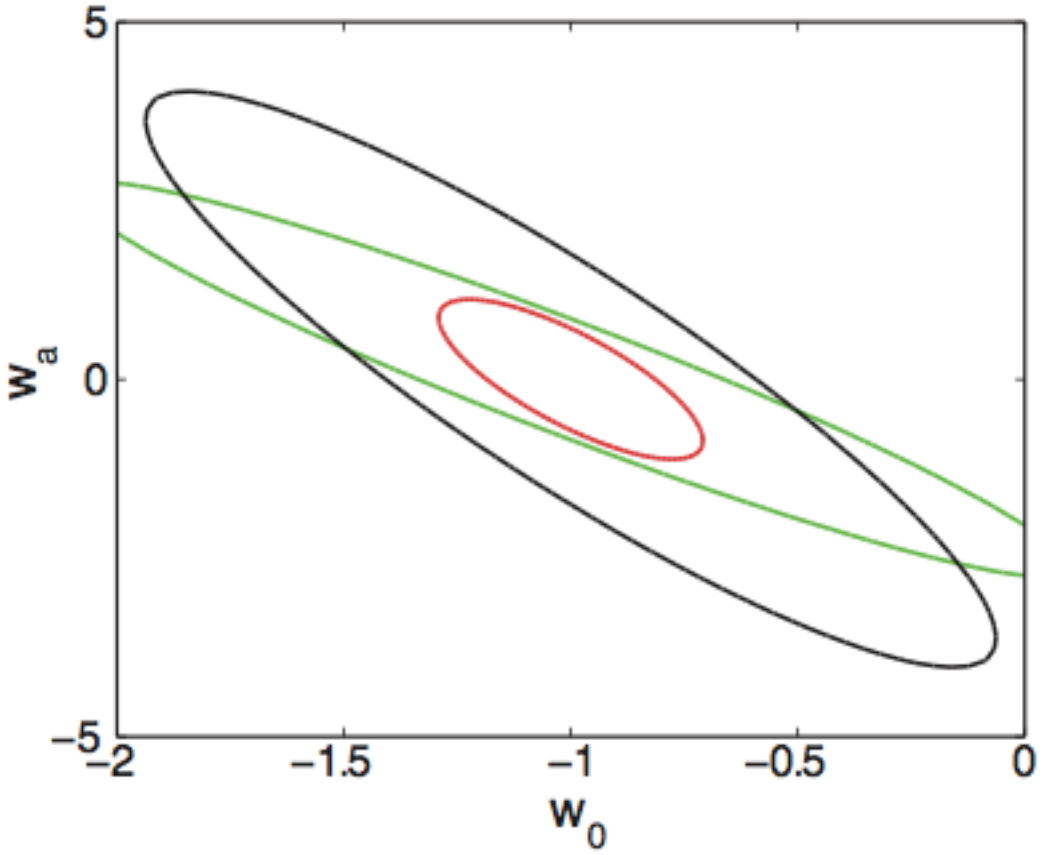
from Anderson et al. 2014 & Delubac et al 2014, & Font-Ribera et al 2014

DESI Compared to Current/Future Surveys





Dark Energy eq. of state



Green DES-like weak lensing survey;
Black for DESI; red is the joint combination

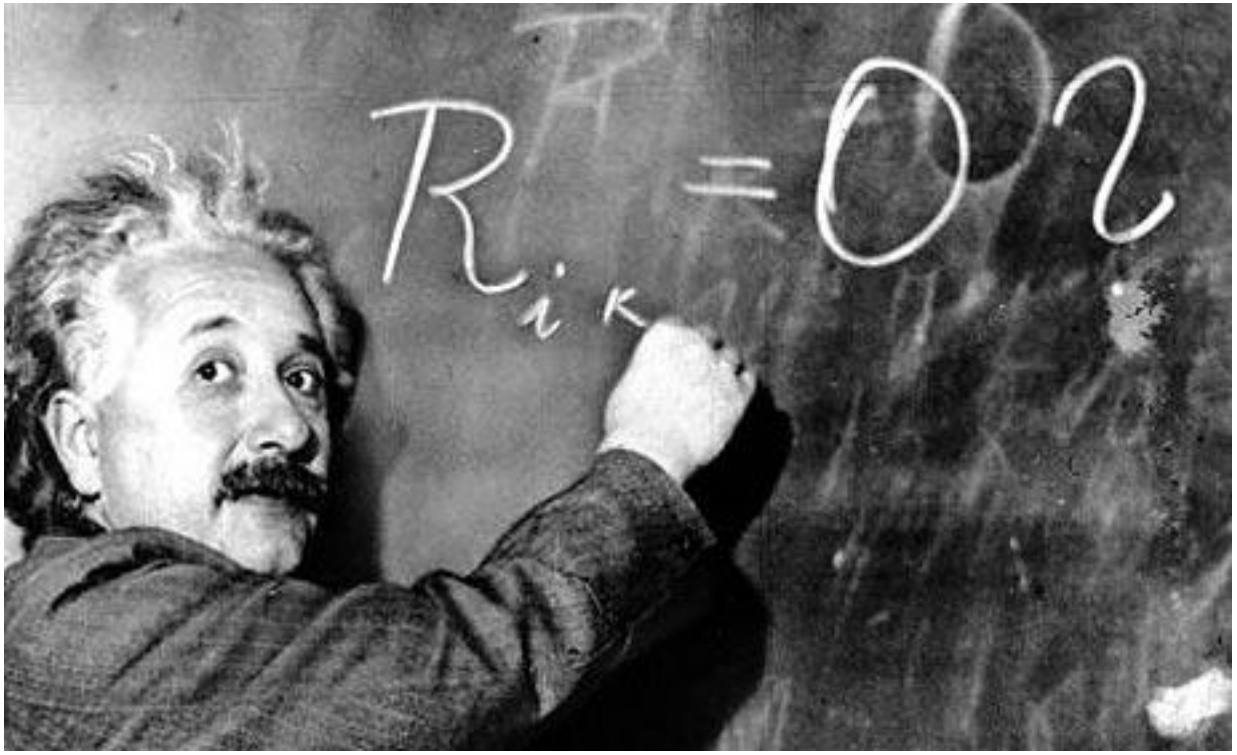
Dark Energy nature

Determine if dark energy is…

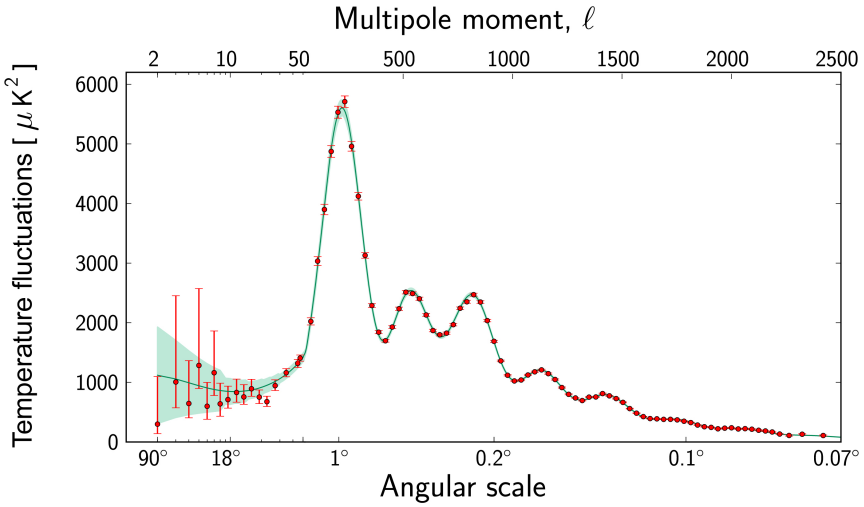
(1) Einstein's cosmological constant, Λ

(2) new field, or

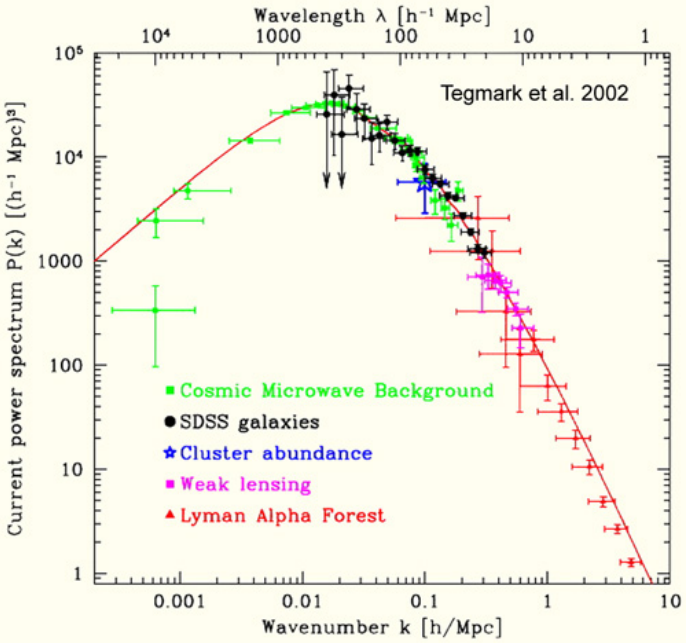
(3) failure of General Relativity



Power spectra



Planck 2013



Deluback et al 2014

Matter Power spectrum:

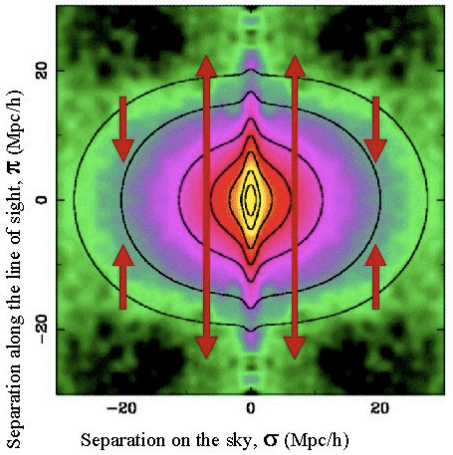
$$P(k,\mu_k) = b^2(1+\beta\mu_k^2)^2 \times \left[P_{\rm peak}(k)\exp(-k^2\Sigma^2(\mu_k)/2) + P_{\rm smooth}(k)\right]$$

$\beta \equiv f/b$ f: Growth rate b: bias

Redshift Space Distortion

The linear growth rate:

$$f \equiv \frac{H_0 a_0}{Ha}\frac{d\ln D}{d\tau} = \frac{d\ln D}{d\ln a}$$



The 2dF Galaxy Redshift Survey Team (2001)

CDM in GR gives: $f(\Omega_M) \approx \Omega_M^{0.6}$

ΛCDM in GR gives: $f(\Omega_M, \Omega_\Lambda) \approx \Omega_M^{0.6} + \frac{\Omega_\Lambda}{70}\left(1 + \frac{\Omega_M}{2}\right)$

$$\beta \equiv f/b$$

$$\frac{P^s(k)}{P(k)} = 1 + \frac{2}{3}\beta + \frac{1}{5}\beta^2$$

Modified Gravity?

$$\Psi = (1 - \zeta)\Phi,$$

TABLE II. Results from fits to the RSD data. The first line of results is for the LRG_{60} data set, and the second line is for LRG_{200}. For each set, we present the best-fit values of the gravitational slip at redshift 0 and 1 (ζ_0 and ζ_1). The uncertainties are at the 1 standard deviation level. The fiducial value of both parameters in general relativity is 0. We also indicate the correlation coefficient ρ of the distribution of the fit to these two parameters, the minimum χ^2 of the fit and corresponding probability to exceed (PTE).

ζ_0	ζ_1	ρ	χ^2	1-PTE
-2.94 ± 1.94	0.32 ± 0.13	-0.72	1.34	0.99
-2.07 ± 1.88	0.28 ± 0.10	-0.70	3.31	0.86

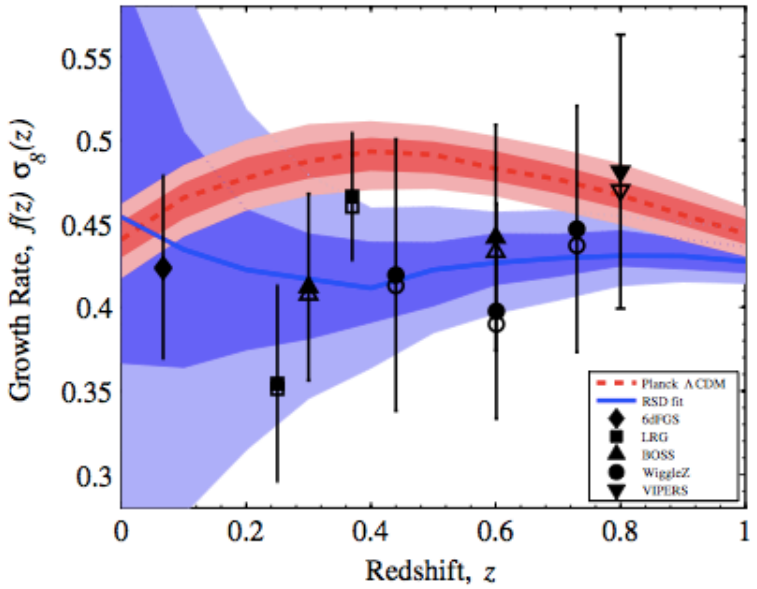
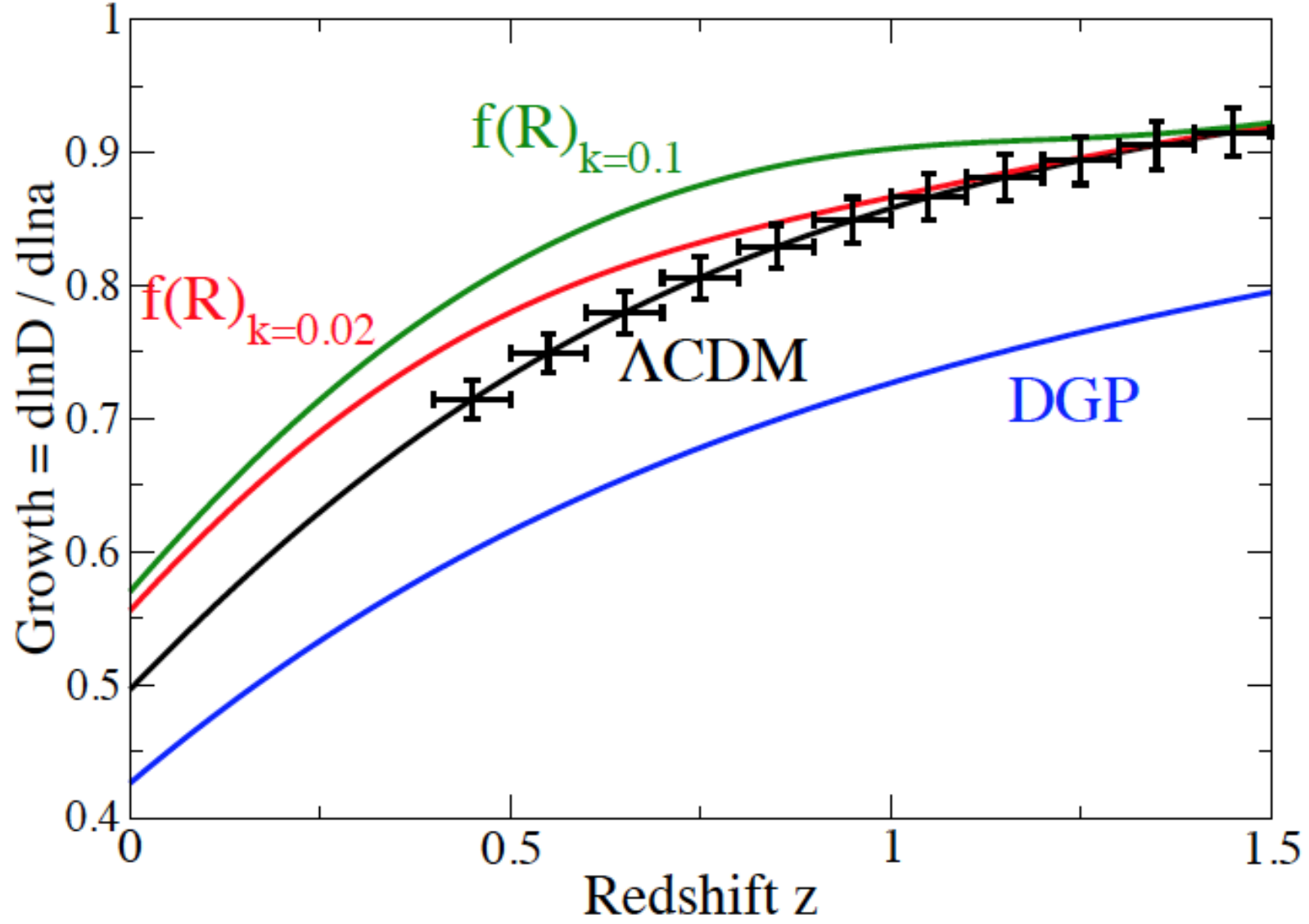


FIG. 1 (color online). Comparing models to recent measurements of $f(z)\sigma_8(z)$. We are plotting results for the LRG_{200} data set. The open markers are the original published values from the RSD measurements, and the filled markers are after accounting for the Alcock-Paczynski effect in going from WMAP to Planck cosmology. The measurement error bars are at the 1 standard deviation uncertainty level. The dashed red line illustrates the expected growth rate from ΛCDM with Planck parameters, with the 1 and 2 standard deviation uncertainty illustrated with the shaded bands. The solid blue line and corresponding blue shaded regions illustrates the best fit to the RSD data with the gravitational slip model. We note that almost all the measurements include our best fit model at the 1 standard deviation uncertainty level, which is reflected in the low χ^2 in Table II. The 1 standard deviation range of the model (the darker blue band) is narrower than the typical 1 standard deviation uncertainty on any of the measurements because the fit has been calculated from the several independent measurements.

DESI - RSD Constraints on the growth of density fluctuations



From D. Huterer & D. Kirkby et al, 2013

Spectral index with SDSS-III/BOSS

Measures of the inflationary epoch

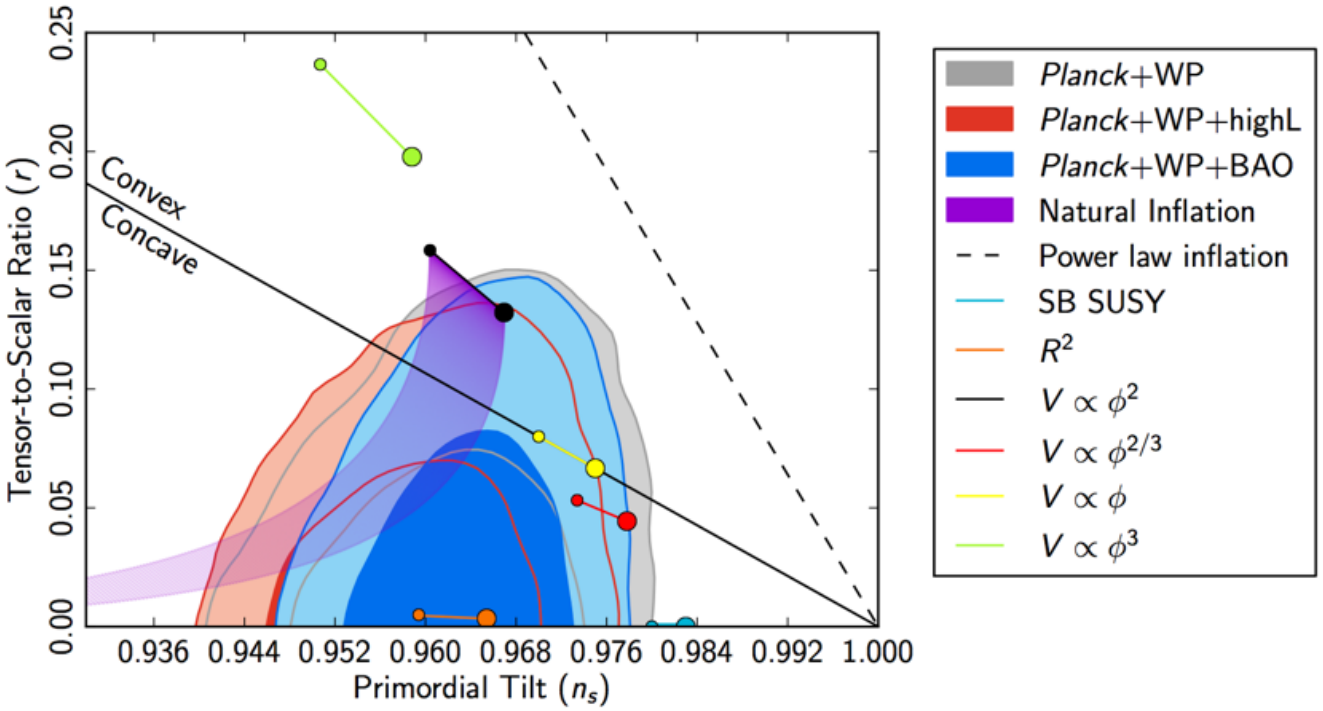


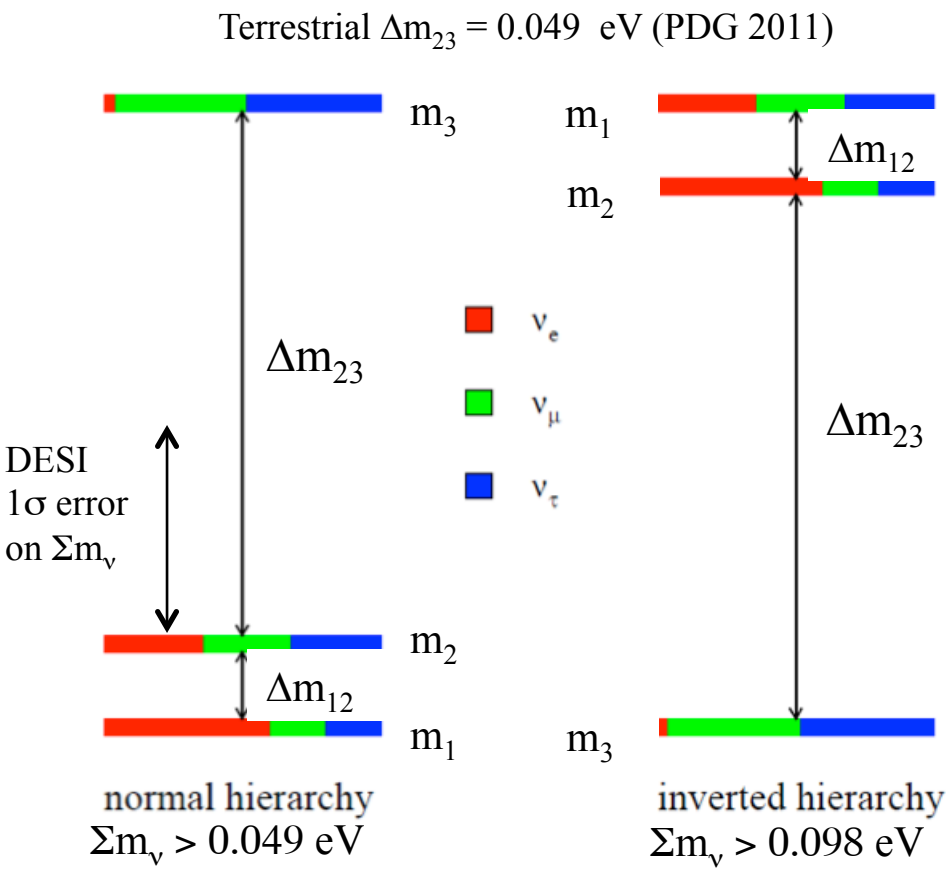
Fig. 26. Marginalized 68 % and 95 % confidence levels for n_s and r from Planck+WP and BAO data, compared to the theoretical predictions of selected inflationary models.

from Planck overview paper (2014)

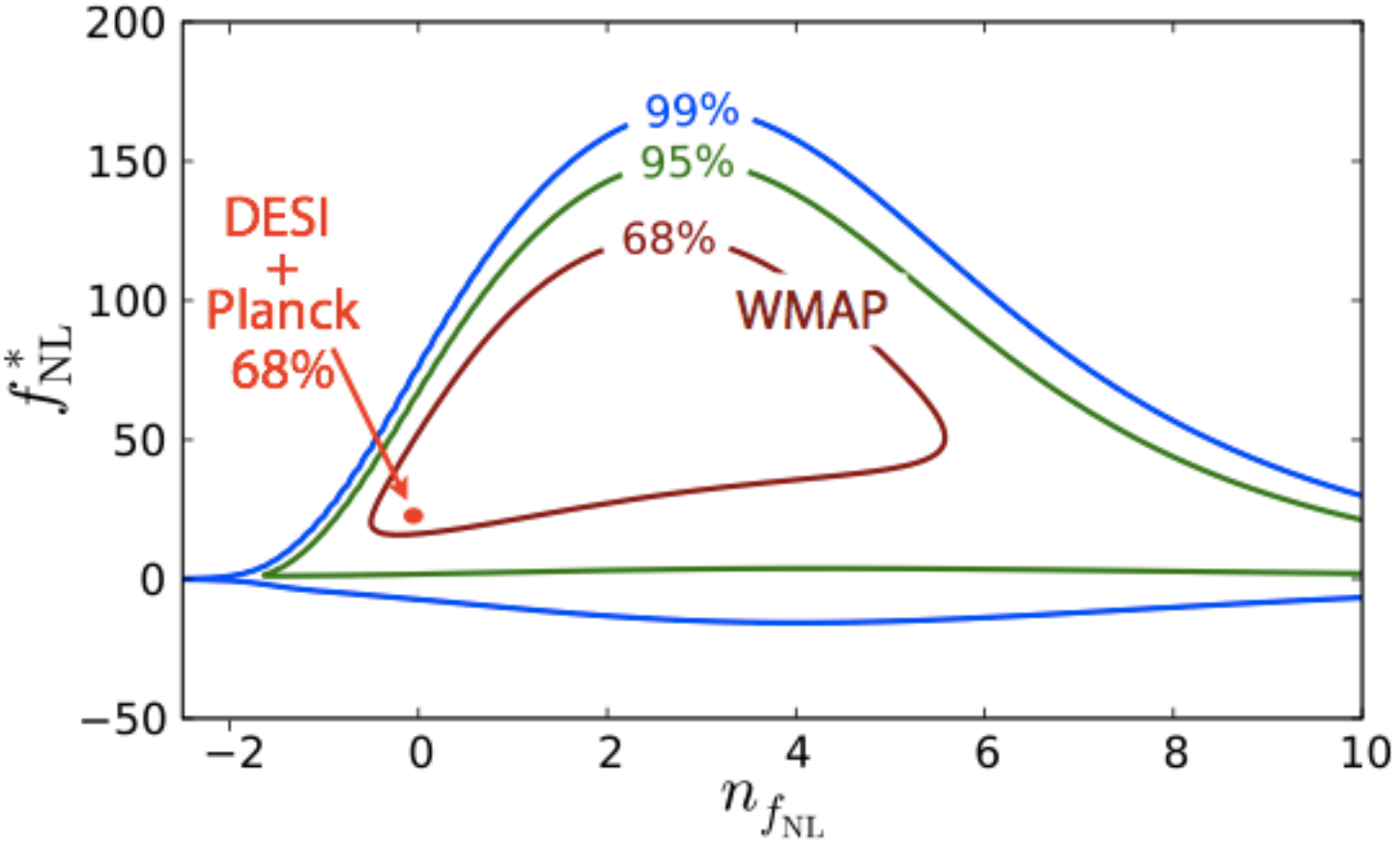
DESI Science Reach: neutrino mass hierarchy

Terrestrial experiments measure Δm^2 of neutrino masses

→ *DESI sensitivity is 0.017 eV, measured from power spectrum of galaxy map*



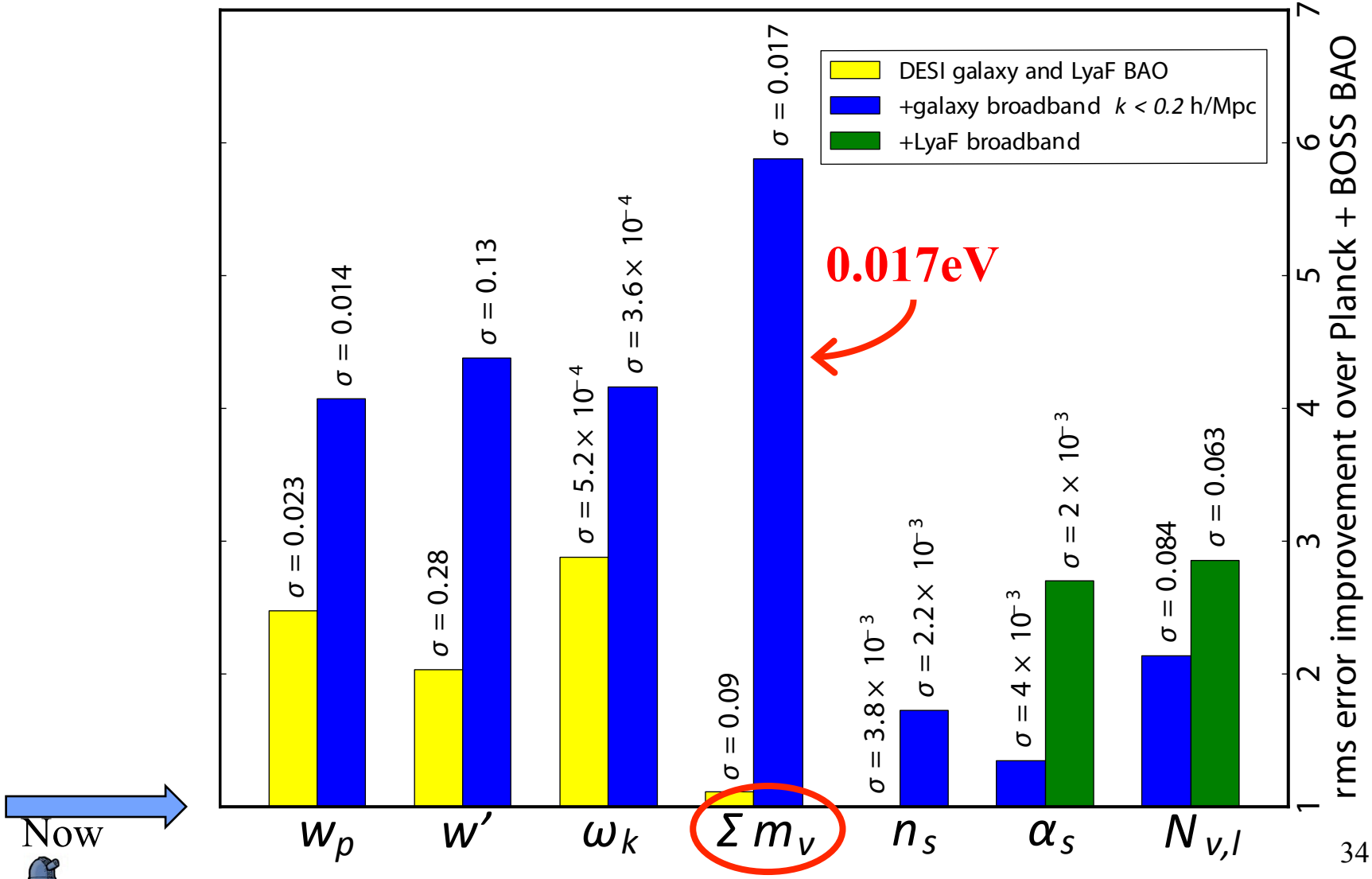
Primordial Non-Gaussianities



$$f_{\rm NL}(k) = f^*_{\rm NL}(k/k_*)^{n_{f_{\rm NL}}}$$

Broad Scientific Goals

Improvement over Planck + BOSS (normalized to 1.0):



Now

Ref: P. McDonald (LBL)

DESI Status

- **BigBOSS -> DESI (see white paper arXiv:1106.1706)**
- **The DOE Office of Science calls for a Mid-scale Dark Energy Spectroscopic Instrument (MS-DESI) experiment in September 2012.**
- **The new instrument to be operated in the 2018 - 2022 time period and perform Stage IV dark energy measurements.**
- **DOE requested Mayall site from NSF as the preferred site**
- **Established reference concept**
- **Conceptual design review scheduled for Sept, 2014**

34 Current Institutions (and growing)

- AAO
- Argonne
- Brazil
- Brookhaven
- Carnegie Mellon Univ.
- Durham
- EPFL
- ETH Zurich
- FNAL
- Harvard
- IAA Spain
- Kansas
- KASI
- LAM/CPPM
- Mexico
- NOAO
- New York Univ.
- Portsmouth
- Saclay
- SJTU
- SLAC
- Spain
- Texas A&M
- The Ohio State Univ.
- Univ. College London
- UC Berkeley
- UC Irvine
- UC Santa Cruz
- U. Edinburgh
- U. Michigan
- U. Pittsburgh
- U. Utah
- USTC
- Yale

DESI Meeting
July 15, 2013

Conclusion

- **DESI will have a rich science program**
  - **scientifically ambitious enough to satisfy Stage IV criteria**
  - **rich scientific program: incl. DE, inflation, neutrino mass hierarchy**
  - **Expect to be in operation in 2018**
- **Mayall selected as preferred site**
- **Gordon and Betty Moore Foundation Award**
- **Conceptual design review by DOE, Sept 2014.**