BigBOSS

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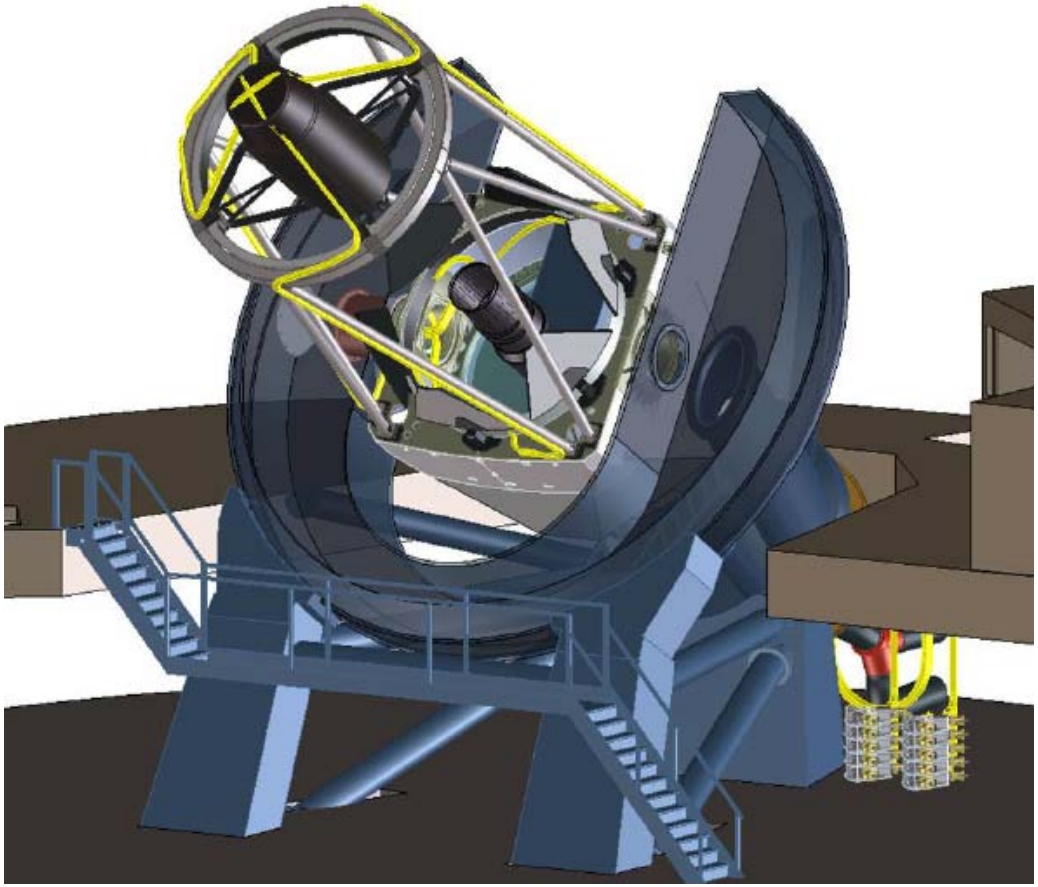
BigBOSS Overview

Talk Outline:

- **BigBOSS Objectives**
- **Collaboration**
- **Instrument**
- **Targets**
- **Science Reach**
- **Status**
- **Conclusions**



Dark Energy Task Force (DETF)

Four promising techniques in this 2006 report

I. Baryon Acoustic Oscillation (BAO)

Geometry

II. Clusters (CL)

Gravitational growth (non-linear regime)

III. Supernovae (SN)

Geometry

IV. Weak Lensing (WL)

Geometry + gravitational growth (linear regime)

Add 5th technique demonstrated in 2008,2011

V. Redshift-Space Distortions (RSD)

Gravitational growth (linear + non-linear regime)

(Guzzo et al 2008, Blake et al 2011)

BigBOSS Scientific Objectives

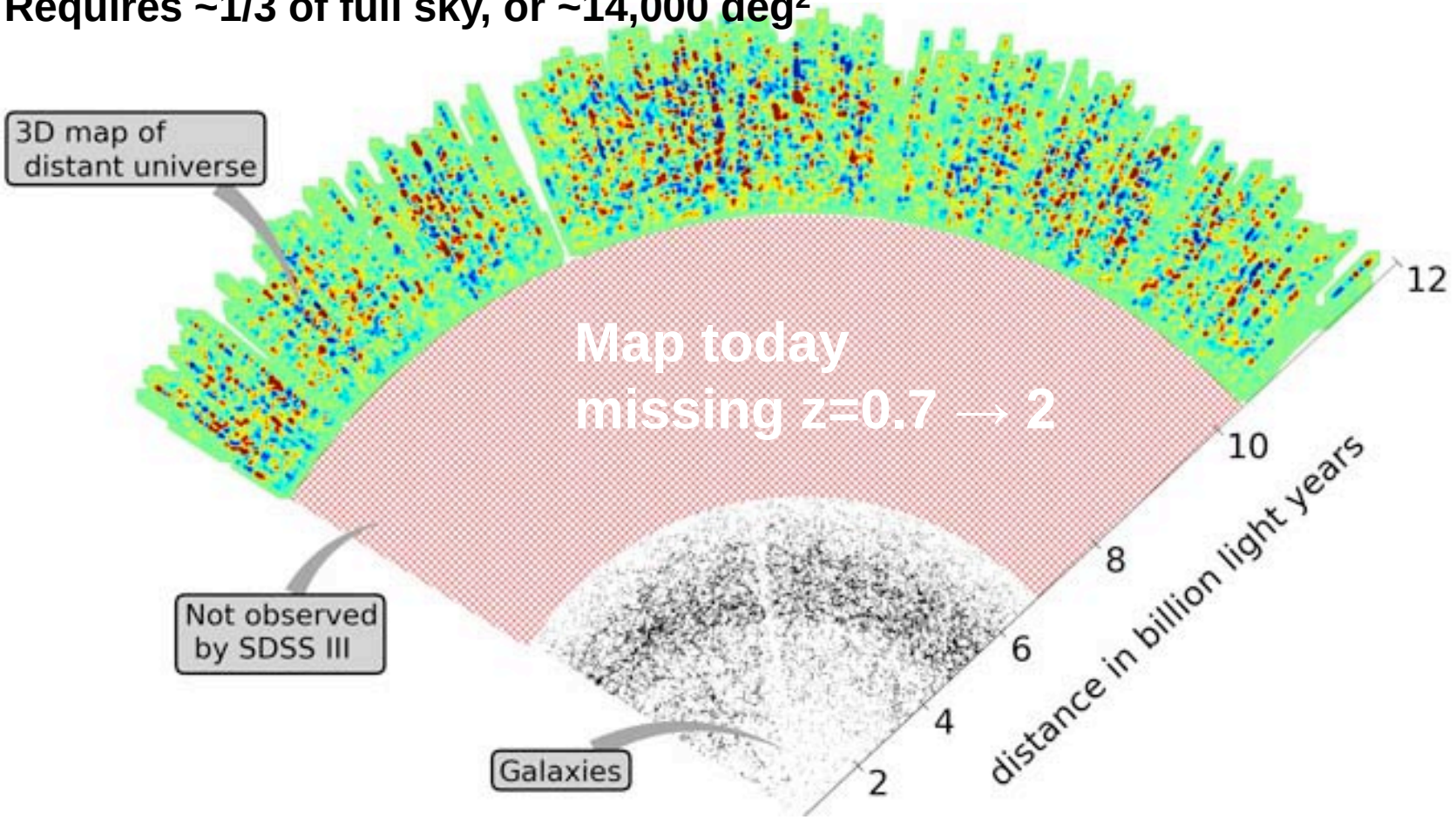
- For BAO, DETF defined progressive survey capabilities:
  - Stage I: knowledge ca. 2006 -- BAO detection by SDSS-I
  - Stage II: running experiments -- SDSS-I + SDSS-II, WiggleZ
  - Stage III: near-term experiments -- 3X better than Stage II: BOSS, HETDEX
  - Stage IV: 10X better than Stage II -- BigBOSS

- BigBOSS is a Stage IV DE Survey
  - Precise measurements of expansion using BAO
  - Precise measurements of growth using RSD
- Probes inflation
  - Primordial power spectrum
  - Non-gaussianities
- Precise probe of contents of Universe
  - Neutrino masses
- Things we haven't even thought of!

BigBOSS: Stage-IV BAO

BigBOSS designed as Stage IV BAO

Requires spectroscopic redshifts
Requires >20 million objects spanning z=0→2
Requires ~1/3 of full sky, or ~14,000 deg²



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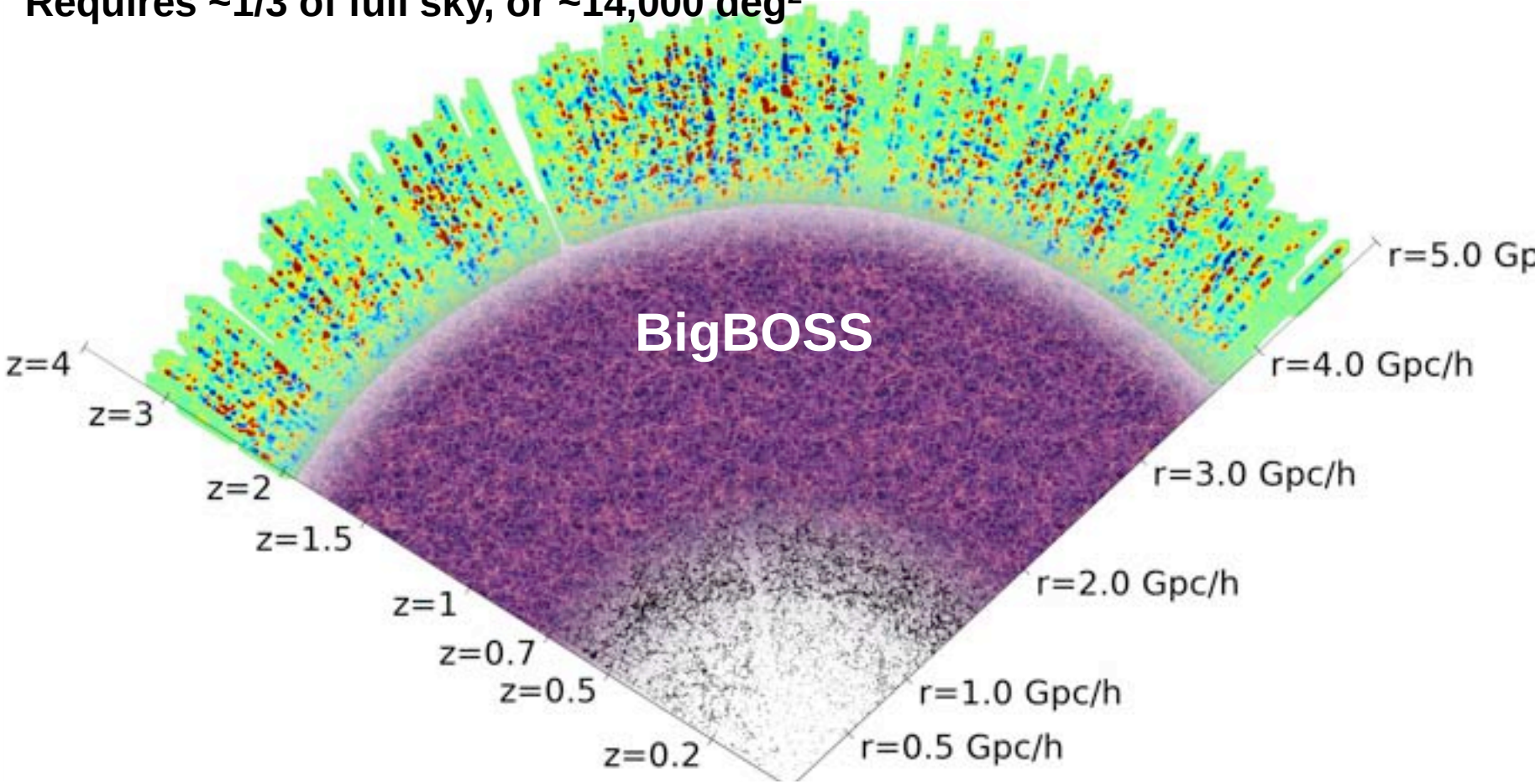


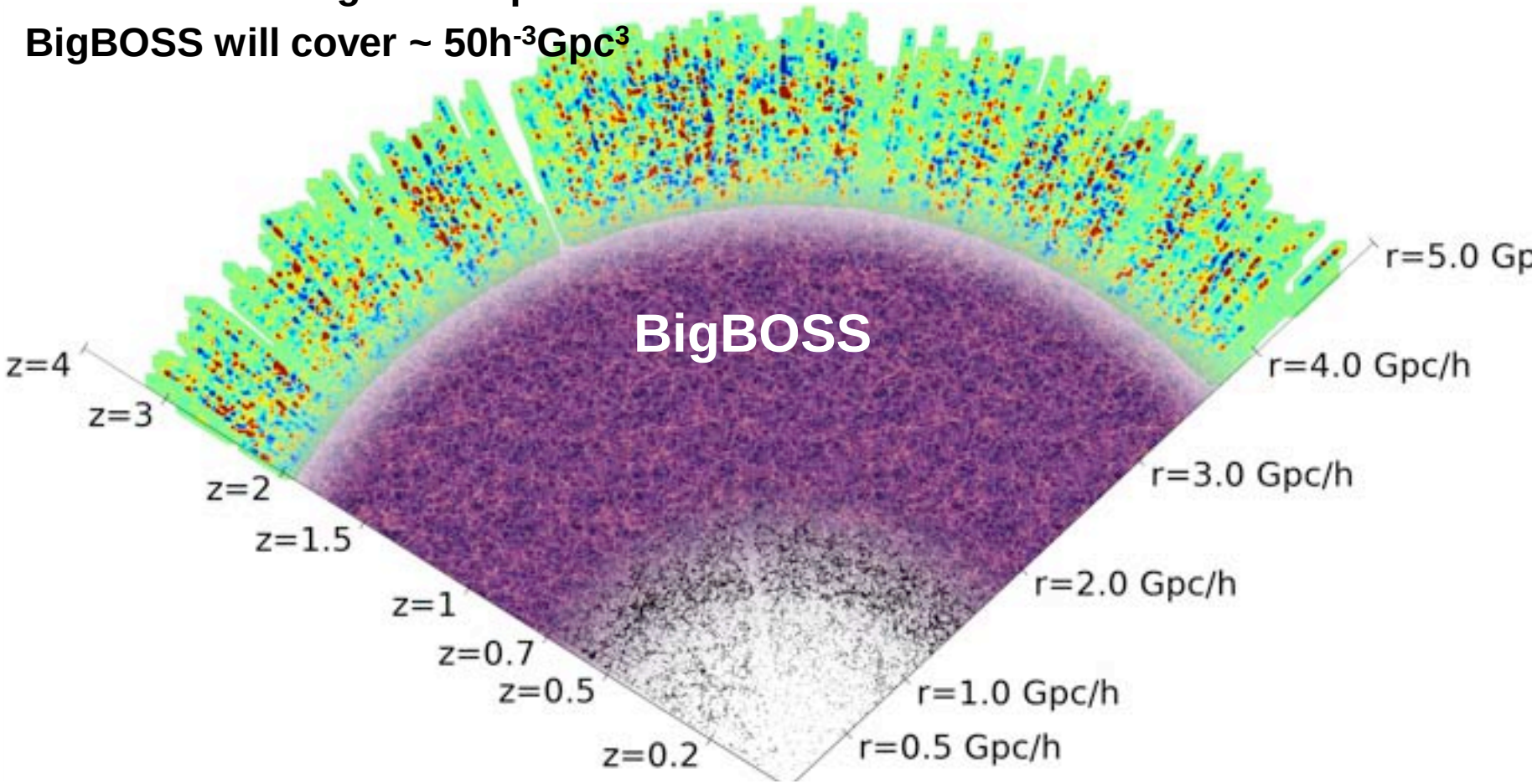
BigBOSS is BIG!

BigBOSS designed as Stage IV BAO

SDSS covered ~ $2h^{-3}Gpc^3$

BOSS is covering ~ $6h^{-3}Gpc^3$

BigBOSS will cover ~ $50h^{-3}Gpc^3$

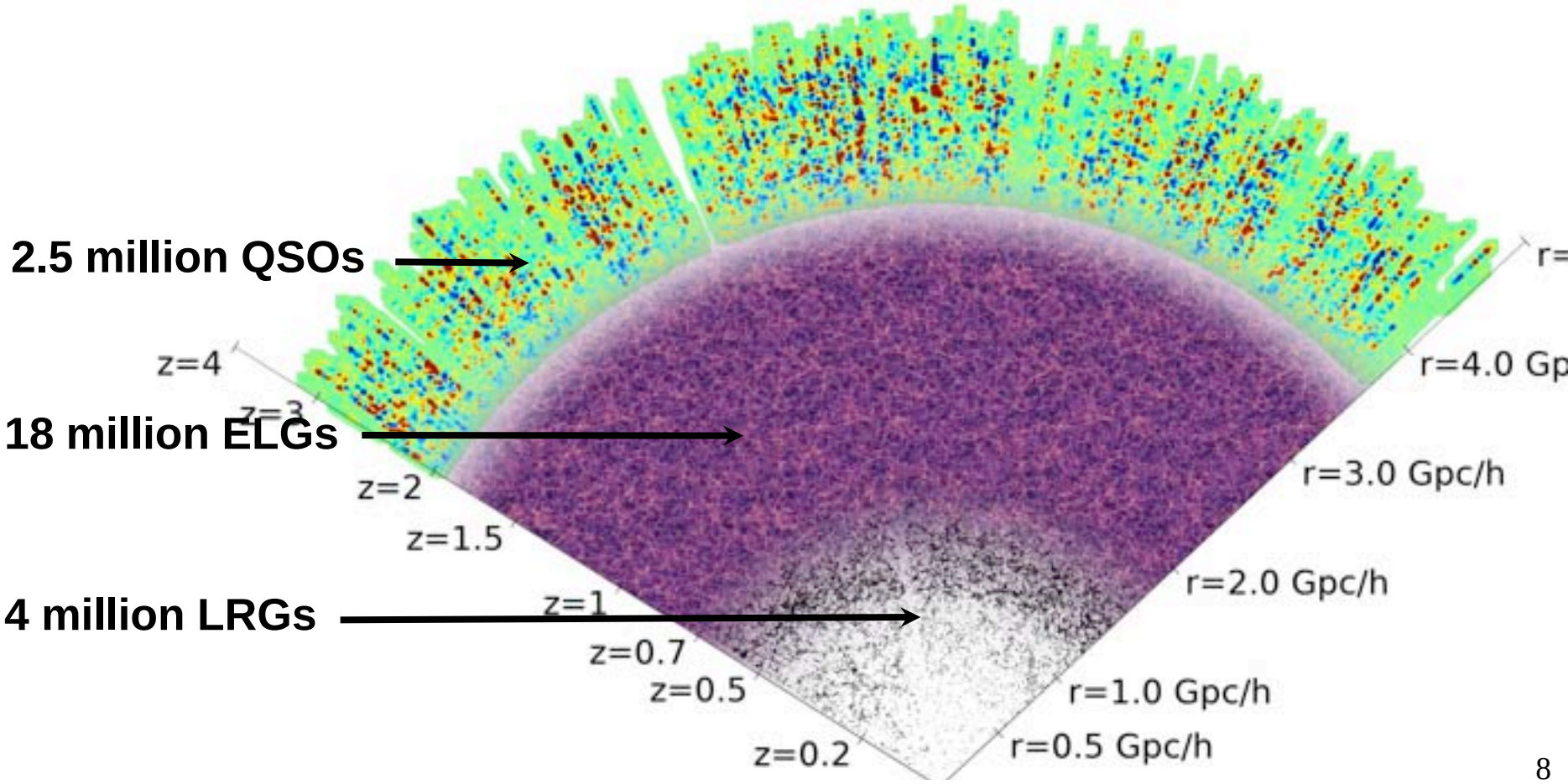


BigBOSS Science Reach

BigBOSS will enlarge redshift-space maps to 24 million objects

10X larger than SDSS + SDSS-II + BOSS

Necessary for Stage IV dark energy from BAO, RSD



BigBOSS Collaboration

… and growing!

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.

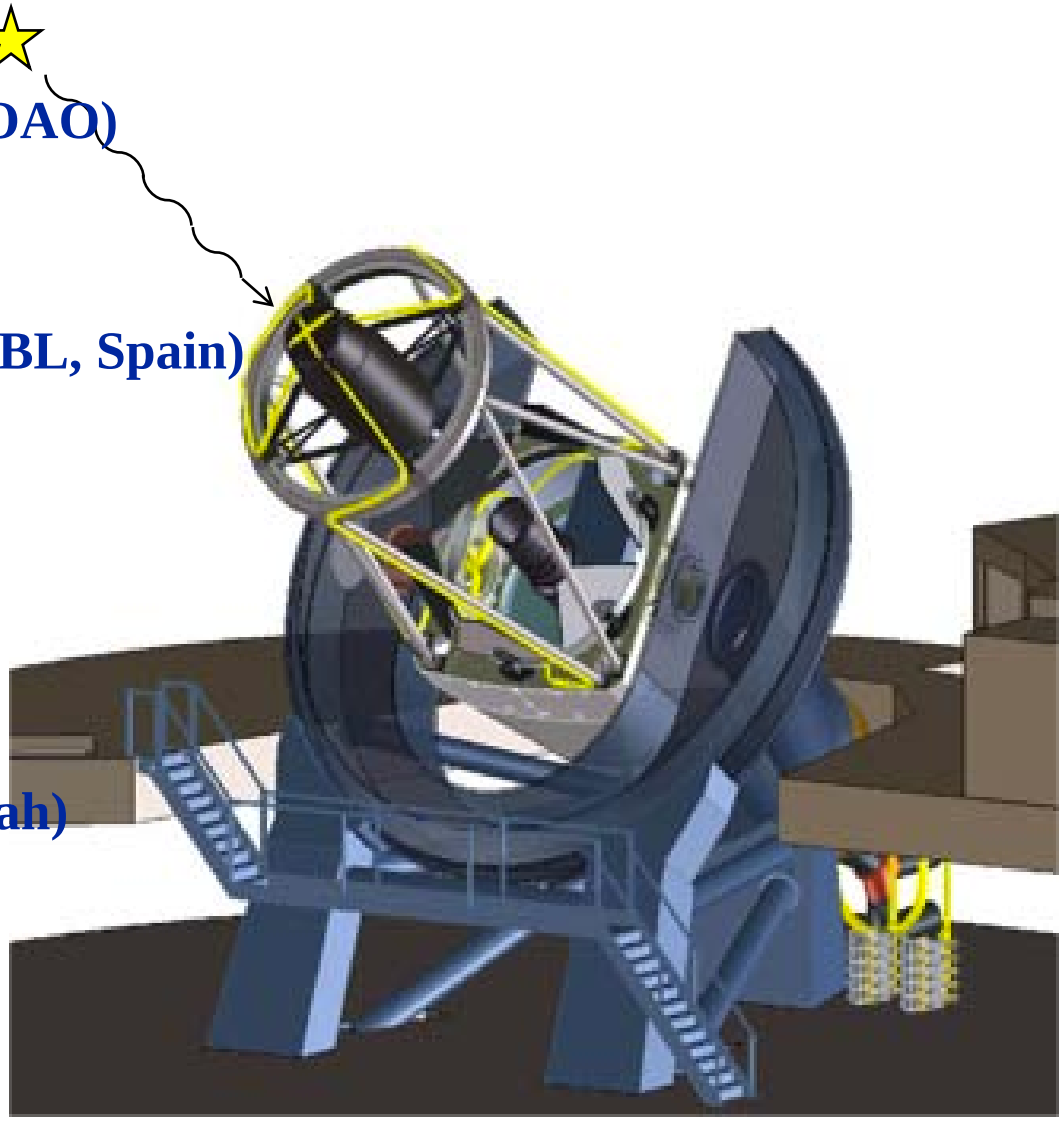
International Institutions:

Ewha Womans University, Korea; French Participation Group (APC, IAP- Paris; CPP, CPT, LAP Marseille; CEA, IRFU – Saclay); Spanish Participation Group (IAA, Granada; IAC, Tenerife; ICC, Barcelona; IFT, Madrid; U. Valencia); Shanghai Astronomical Observatory, UK Participation Group (Durham, Edinburgh, UC London, Portsmouth); University of Science and Technology of China.

Instrument Overview

A photon's path through the BigBOSS instrument:

- **4m primary class telescope (NOAO)**
- **3º corrector optics (LBL, UK)**
- **Focal plane (Spain)**
- **5000 fiber Actuators (China, LBL, Spain)**
- **Fiber System (LBL, UK)**
- **Spectrographs (Marseille)**
- **Dewars/Cryogenics (Saclay)**
- **Detectors (LBL)**
- **DAQ (Ohio)**
- **Computing (NERSC, NYU, Utah)**
- **Guiding (SLAC)**
- **Alignment (Yale)**
- **Calibration (U. Michigan)**



BigBOSS Requirements

BigBOSS instrument + survey strategy flows down from requirements

BIGBOSS SCIENTIFIC OBJECTIVE: PERFORM A STAGE IV BAO SPECTROSCOPIC SURVEY

LEVEL 1
SCIENTIFIC REQUIREMENTS

- Measure the distance scale error σ_R/R to < 1% for $0.5 < z < 3.0$
  (in 6 bins with $\Delta\ln(1+z) = 0.2$)
- Measure H(z) to 1.5% up to z=2.5
  (in 4 bins at <z> = 0.7, 1.1, 1.5, 2.5)
- Constrain growth, $\sigma_8(z)$ f(z), with <2% relative error
  ($\Delta z = 0.1$ bins, $k_{max} = 0.2$, for $0.5 < z < 1.5$)
- Measure galaxy power spectrum to < 1% up to z=1.5
  ($\Delta k = 0.02$ Mpc/h bins, $k_{max} = 0.3$)

ADDITIONAL SCIENTIFIC GOALS

- Inflation: constrain spectral index and its running to < 1%
- Measure the sum of neutrino masses Σm_ν with $\sigma < 0.020$ eV

LEVEL 2
DATA SET REQUIREMENTS

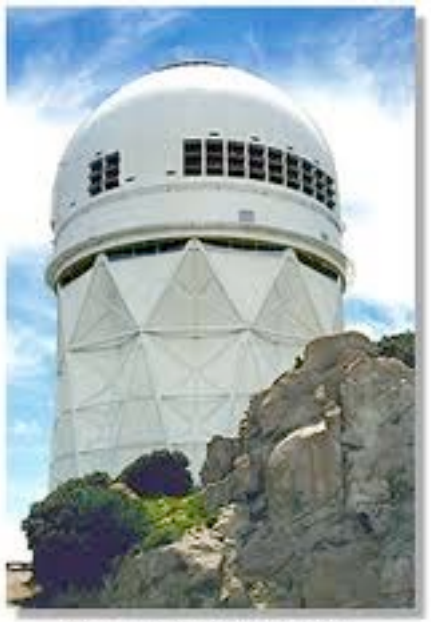
- Survey Area: 14,000 sq deg
- Redshift range:
  - LRGs $0.5 < z < 1.0$
  - ELGs $0.5 < z < 1.6$
  - Tracer QSOs $0.5 < z < 3.5$
  - Ly-α QSOs $2.2 < z < 3.5$
- Galaxy $dN/dV > 1\text{x}10^{-4}$ $(h/\text{Mpc})^3$
- Number of redshifts: 20M
- Redshift accuracy:
  - $\sigma_z < 0.001(1+z)$ rms
  - < 5% catastrophic failures
  - resolve OII doublet for $0.76 < z < 1.6$

LEVEL 3
INSTRUMENT REQUIREMENTS

- Operational Constraints
  - < 500 nights
  - Instrument compatible with Mayall telescope
  - Preserve use of f/8 secondary
  - Typical seeing, weather for site used in forecasts
- Field of View: 3 deg diameter
- Number of Fibers: 5000
- Operational overheads: total < 60 s/exposure
- Spectral Range and Resolution
  - 360 nm < λ <660 nm: R > 1500
  - 620 nm < λ <840 nm: R > 3000
  - 800 nm < λ <980 nm: R > 4000
- Optical Throughput vs λ
- Fiber Positioning Error < 0.35 asec (rms, includes actuators, guiding, tracking, target astrometry)

Mayall Telescope

- 3.8m Diameter
- Located at Kitt Peak, AZ
- Operated by NOAO and offered for large scale survey projects
- Compatible with wide-field corrector optics to achieve 3-degree field of view
- Other candidate 4m telescopes
  - Blanco at CTIO (Chile); optical twin, identical to Mayall, potential for southern survey next decade
  - CFHT (Mauna Kea)
  - UKIRT???? (Mauna Kea)
  - Calar Alto
  - no other 4m class telescopes that are available at reasonable sites are compatible with 3 deg field of view



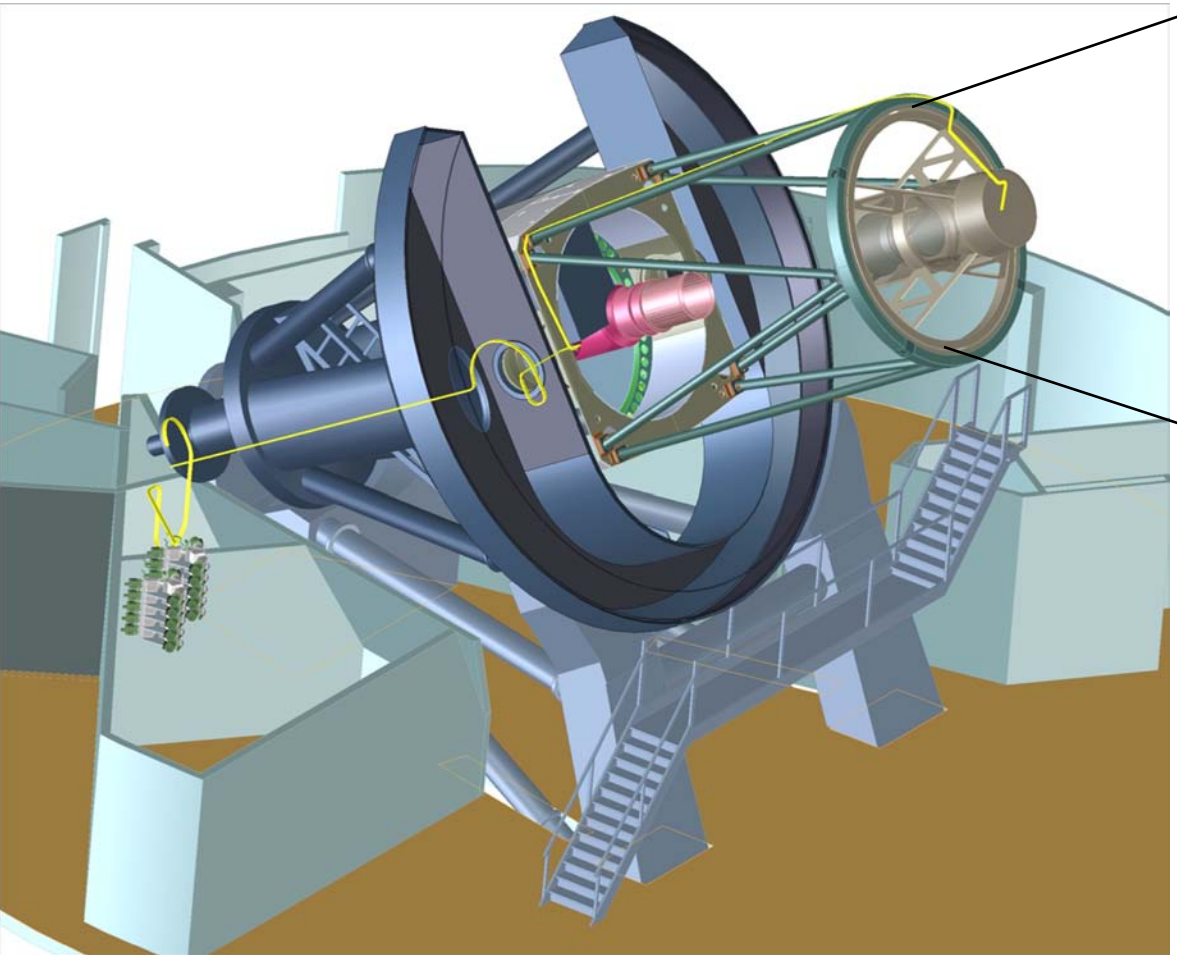
Mayall 4-Meter Telescope

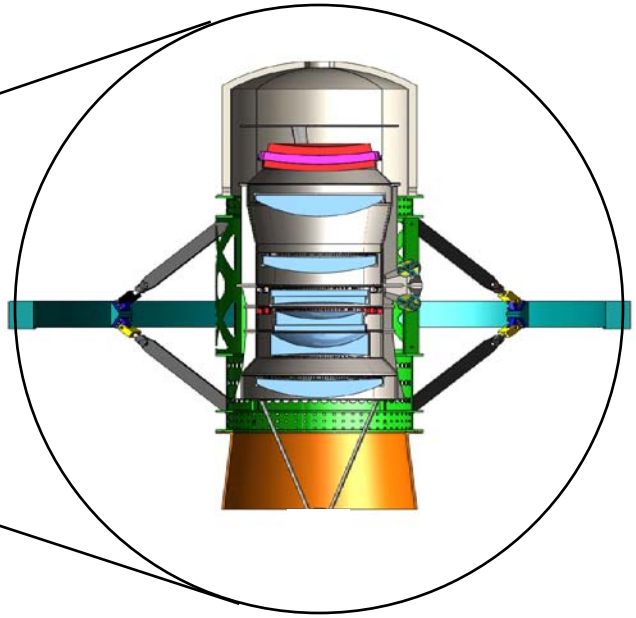
Investigated Siting Options

Name	Site	Notes and Exclusions	M1 f/#	M1 Diam. (m)	f/#	f (m)	Suitable for BigBOSS 3-degree corrector?
Vista	Chile	ESO	f/1.0	4.1	1	4.1	no
Starfire	New Mexico	Military	f/1.5	3.5	1.5	5.2	no
SOAR	Chile		f/1.7	4.2	1.7	7.1	no
WIYN	Arizona		f/1.8	3.5	1.8	6.3	no
ARC	New Mexico		f/1.8	3.5	1.8	6.3	no
Discovery Channel	Arizona		f/1.9	4.2	1.9	8.0	marginal, with 1.5m C1
Galileo TNG	Spain		f/2.2	3.6	2.2	7.9	marginal
NTT ESO	Chile	ESO	f/2.2	3.5	2.2	7.7	yes
William Herschel	Spain		f/2.5	4.2	2.5	10.5	marginal
UKIRT	**Mauna Kea**	**NIR**	**f/2.5**	**3.8**	**2.5**	**9.5**	**under study**
Victor Blanco	**Chile**	**Twin to Mayall**	**f/2.8**	**4**	**2.8**	**11.2**	**yes**
Mayall	**Arizona**	**Twin to Blanco**	**f/2.8**	**3.8**	**2.8**	**10.6**	**yes**
AEOS	Maui, Hawaii	Military	f/3.0	3.7	3	11.1	yes
ESO 3.6m	Chile	ESO Committed	f/3.0	3.6	3	10.8	yes
AAT	Australia	2 arcsec seeing	f/3.2	3.9	3.2	12.6	yes
Hale	Palomar		f/3.3	5.1	3.3	16.8	no, massive corrector
MPI-CAHA	Calar Alto, Spain		f/3.5	3.5	3.5	12.3	yes
CFHT	**Mauna Kea**	**Proposed 10m**	**f/3.8**	**3.6**	**3.8**	**13.7**	**yes**

New 3^0 FOV Corrector

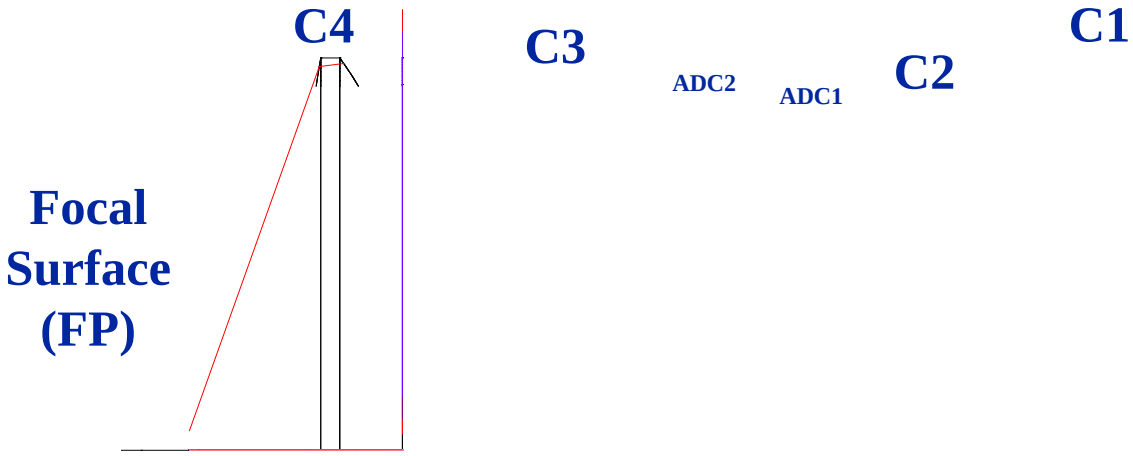
- New optical concept with ADC
  - Corrector ingests light at F/2.8, outputs at F/4.5



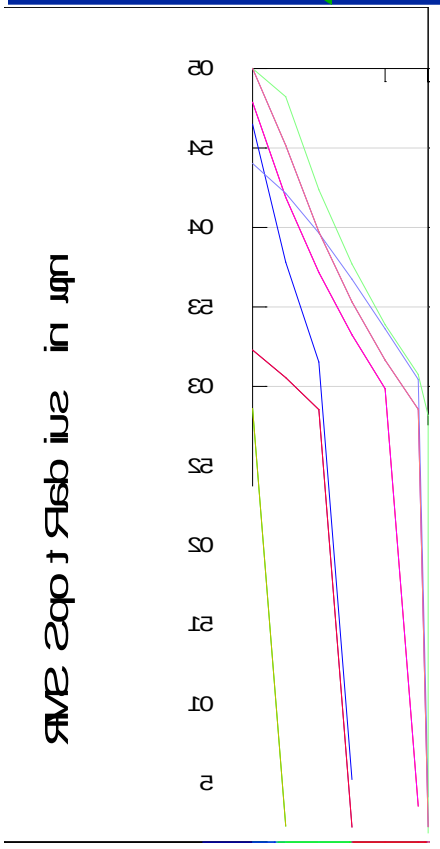


Corrector Design

- Six lens groups
- Four fused silica lens elements
  - Two elements have aspheres on one surface each
- Two ADC prisms (LLF1/N-BK7)
- Convex focal surface, Ø890mm outer diameter



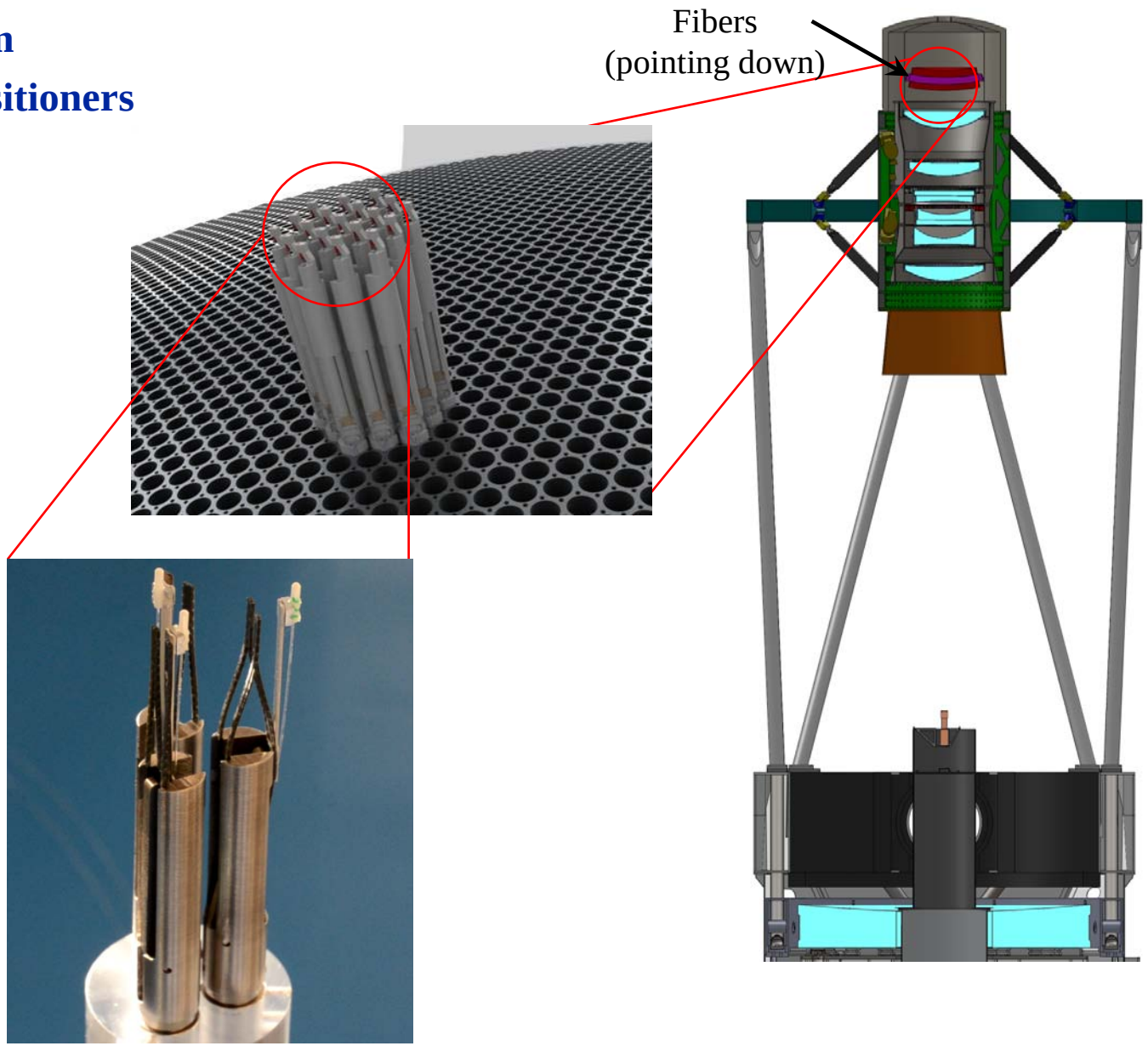
Corrector Optical Performance (Geometric Blur)



<20μm rms over 550-980nm

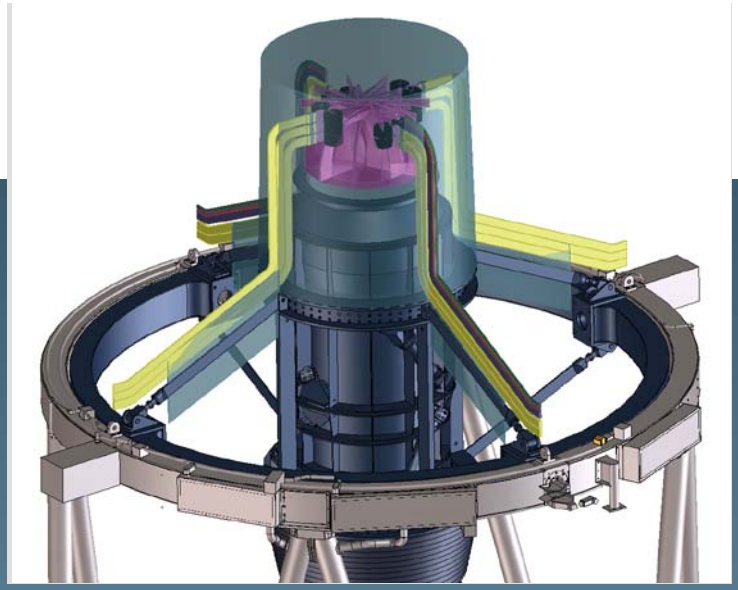
Focal Plane System

- **Focal Plane System**
  - **5000 fiber positioners**



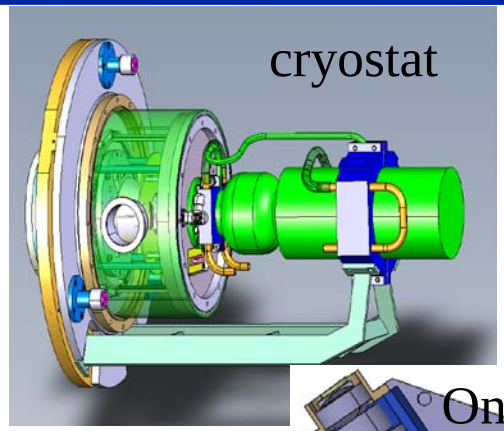
Fiber System

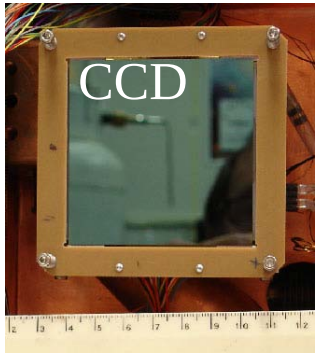
- 120 micron core fibers
- 40m fiber run from positioners to spectrograph room



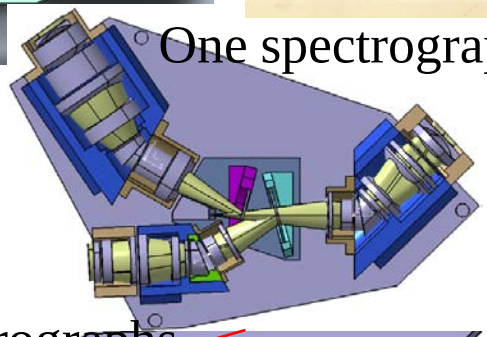
Spectrograph

- 10 spectrographs, 500 fibers each
- 3-arms 360nm – 980nm
- Linear pulse-tube cooler
- BOSS heritage LBNL CCDs
- Similar in design to SDSS (Smee, etal)
- R ~ 4000

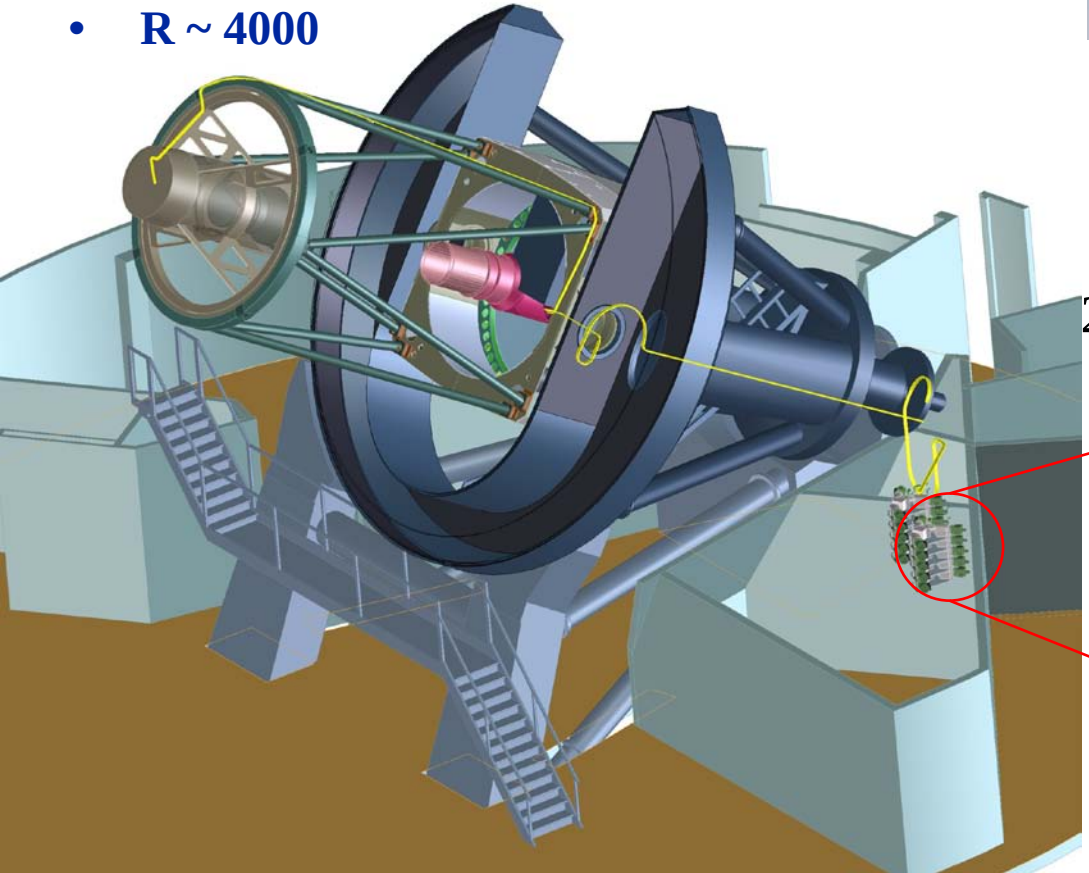


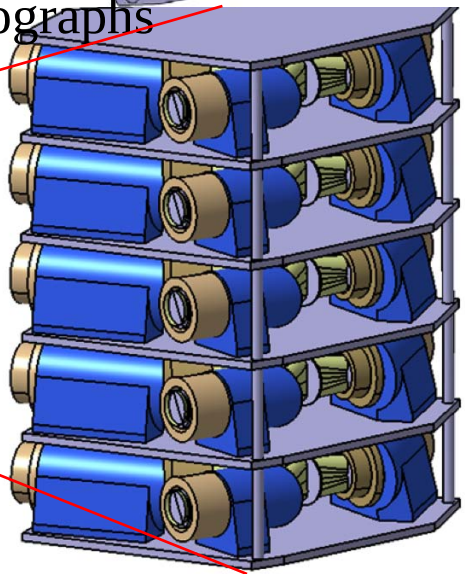


One spectrograph



2xFive spectrographs



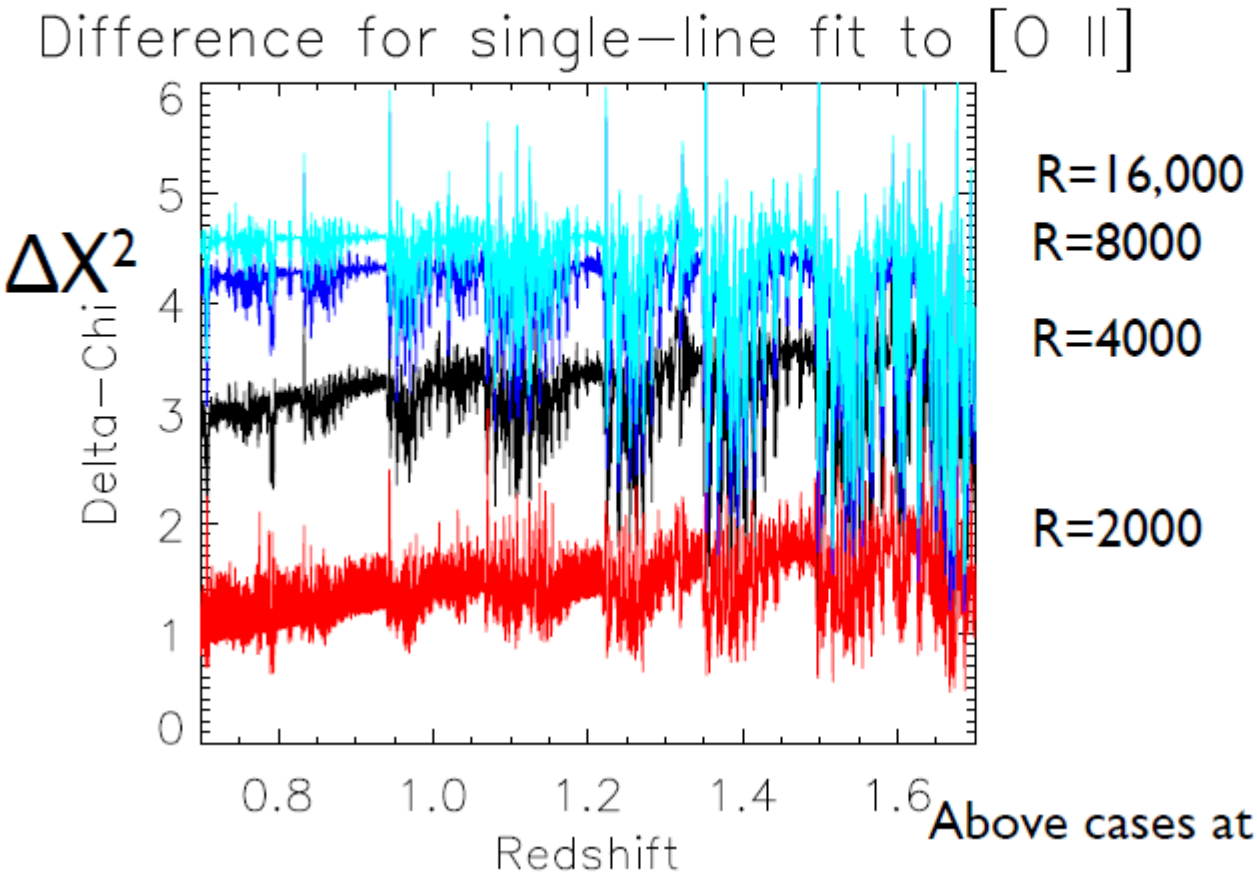


High-Resolution Requirement

Single-line vs. [O II] discrimination

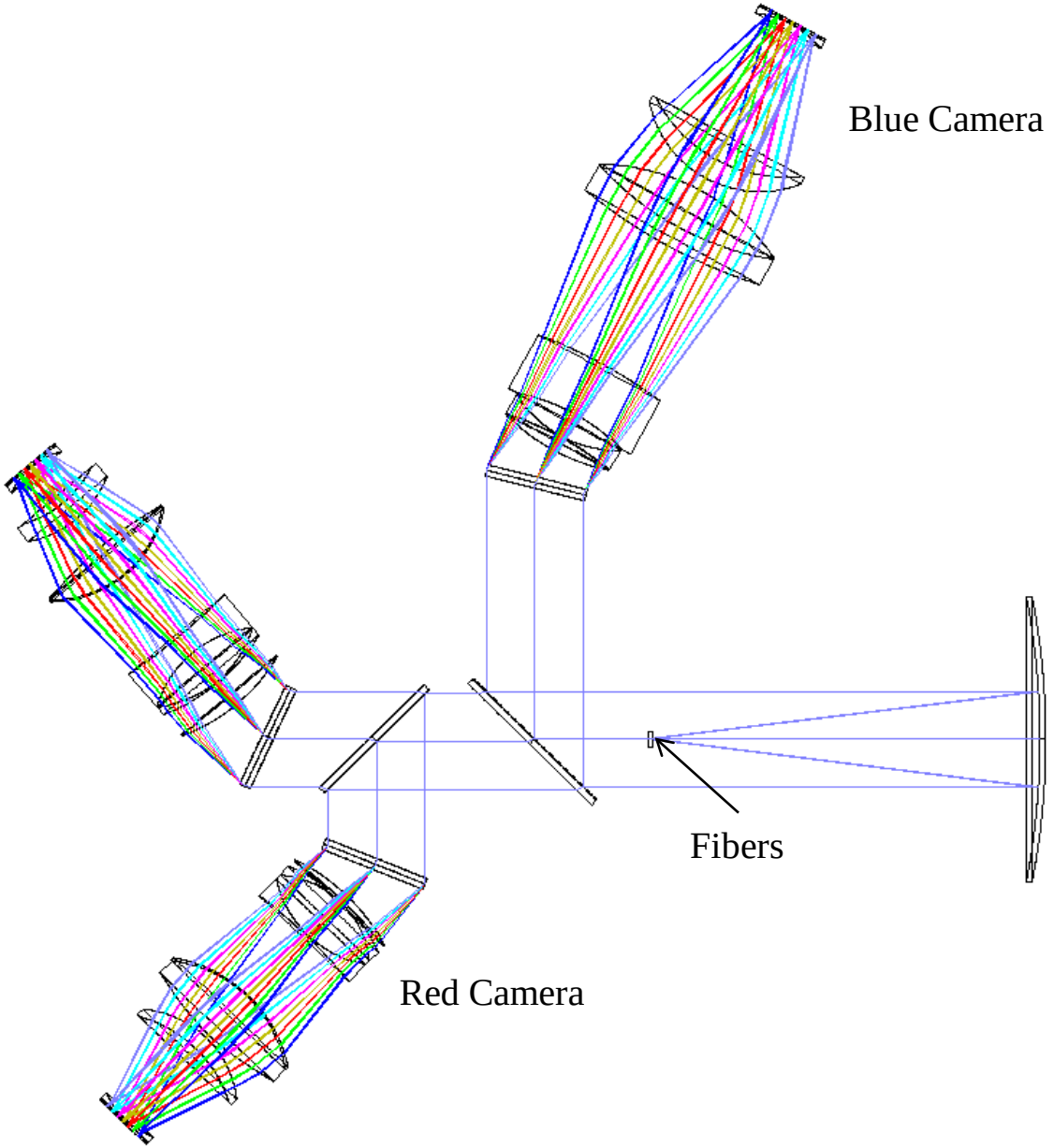
Catastrophic redshift errors avoided at R>4000

At R=2000, [O II] doublet at 7-sigma is degenerate with a single-line

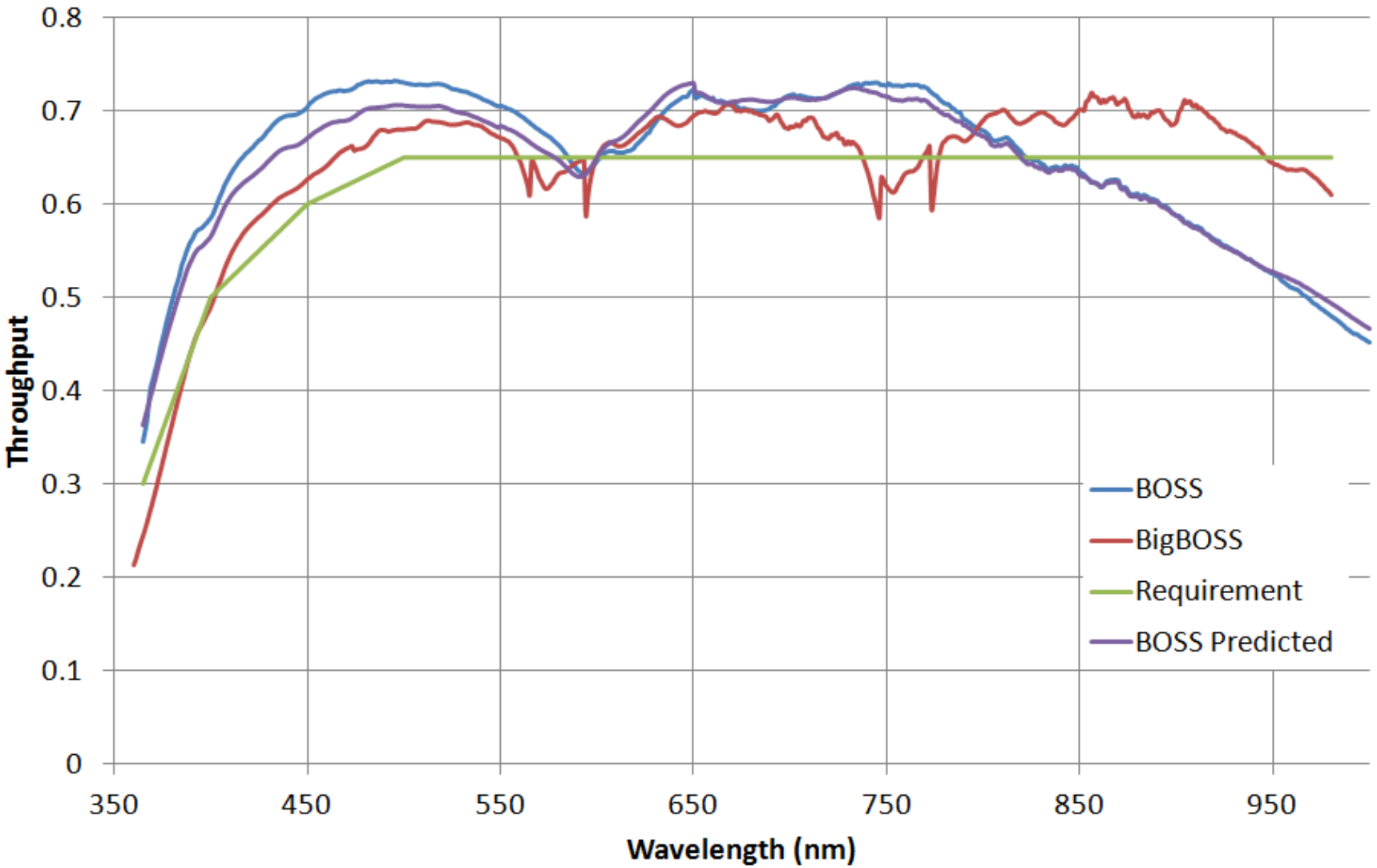


Above cases at vdisp = 70 km/s

BigBOSS Spectrograph Concept

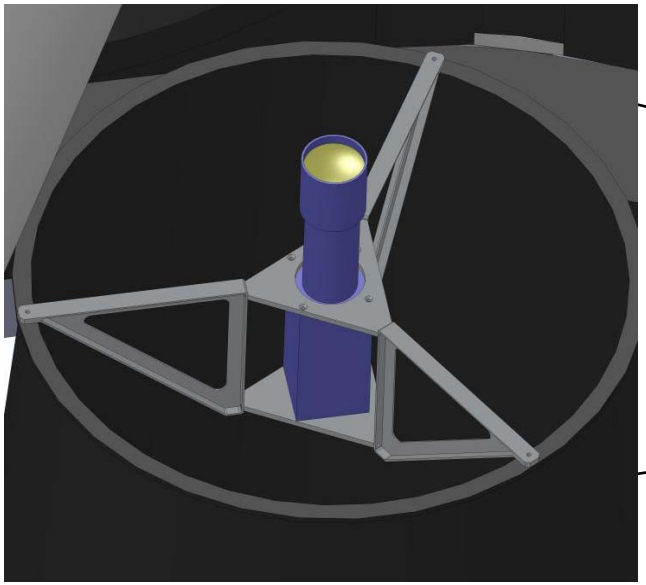


Throughput Comparison

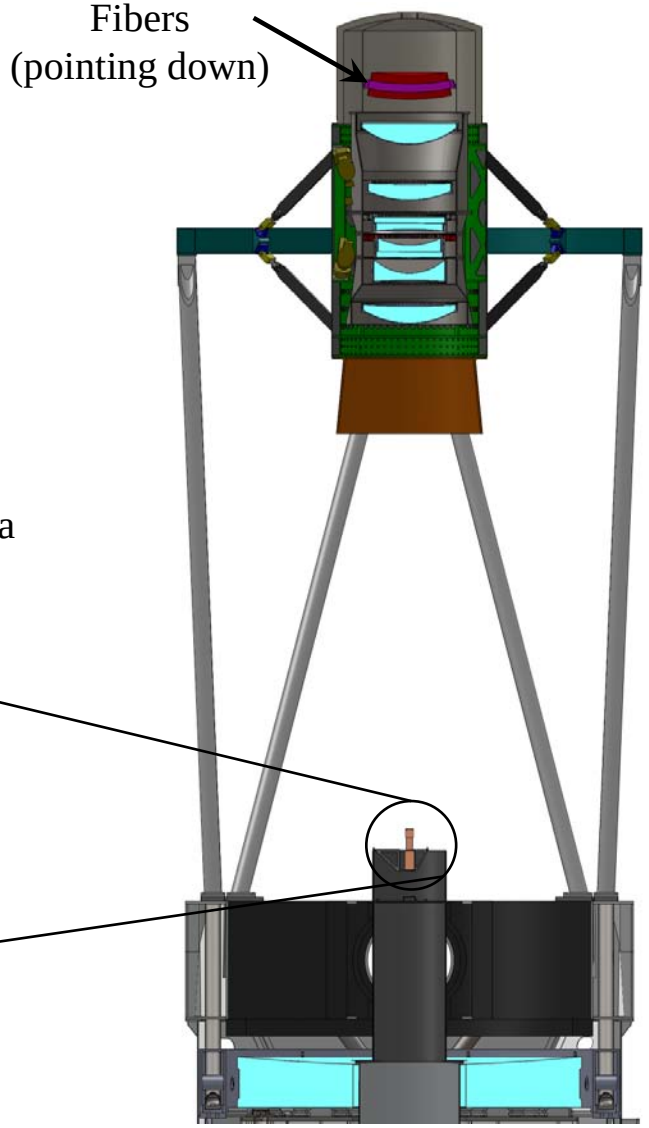


Fiber View Camera

- **Determines location of fibers**
- **Only possible because corrector is “slow” - F4.5**
- **Heritage: FMOS**



Fiber View Camera
(looking up)



BigBOSS tracers of dark energy

Four target categories:

1. Luminous Red Galaxies (LRGs)	**$z = 0.5 \rightarrow 1$**	**2 exposures**
2. Emission Line Galaxies (ELGs)	**$z = 0.5 \rightarrow 1.6$**	**1 exposure**
3. Tracer QSOs	**$z = 0.5 \rightarrow 3.5$**	**1 exposure**
4. Lyman-alpha QSOs	**$z > 2.2$**	**5 exposures**

Targeting sources:

- SDSS imaging (complete over 11,000 deg^2)

- WISE satellite (complete over full-sky)

-PTF-1 and PTF-2 (running over 14,000 deg^2)

-PanSTARRS

Opportunity to augment with proposal-based sources:
i.e., from CTIO DECam, CFHT Megacam, KPNO Mosaic, Subaru HSC

1. Luminous Red Galaxies (LRGs)

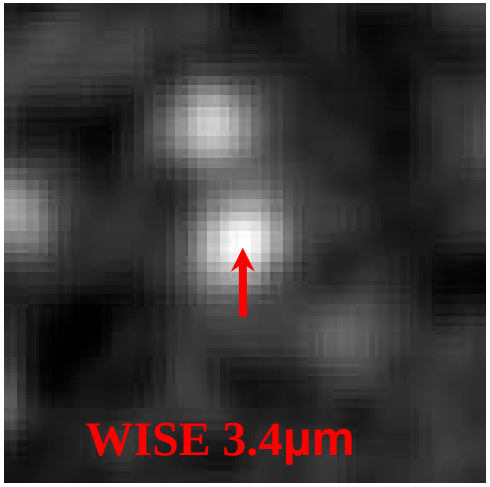
LRG tracers at 0.5 < z < 1.0

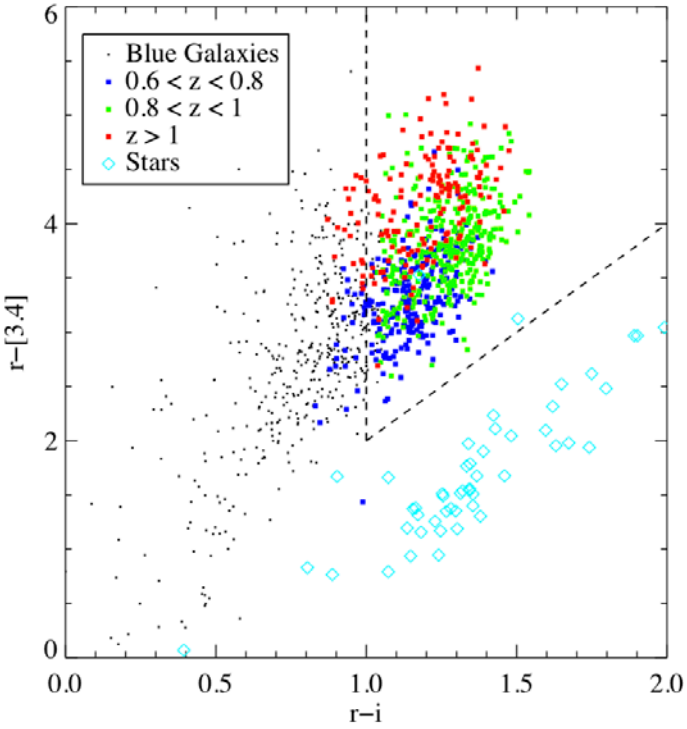
The most massive galaxies in the Universe
Excellent tracers of dark matter halos
Well-studied in N-body simulations

BigBOSS targets:

4 million LRGs to z=1

Selected at 3.4 micron from WISE satellite
+ SDSS/PTF-1 imaging
WISE data complete!





2. Emission Line Galaxies (ELGs)

ELGs tracers at 0.5 < z < 1.6

Epoch of star formation peaks in these galaxies at z~1

Easy to select from optical colors

Test data:

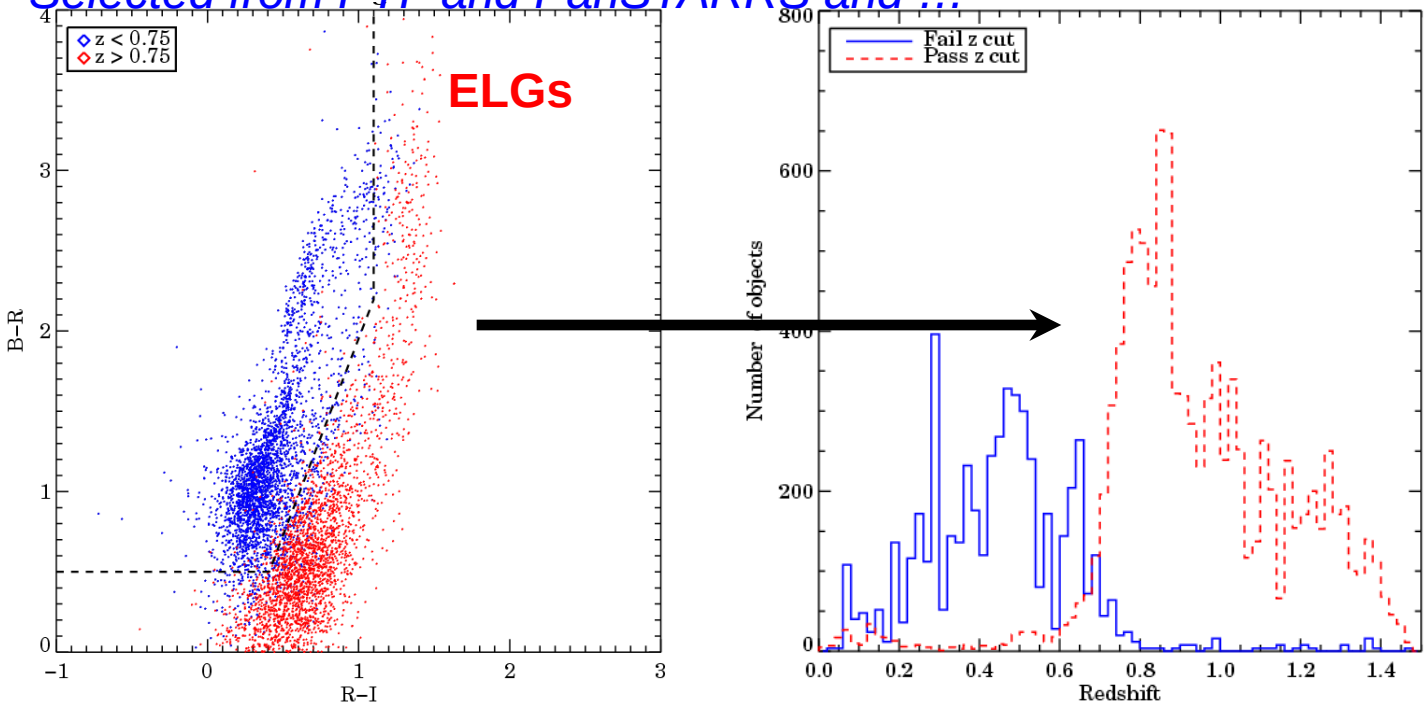
40,000 ELGs from DEEP2, VVDS over 4 deg2 total

Well-studied population to greater depth than BigBOSS

BigBOSS targets:

18 million ELGs in BigBOSS survey

Selected from PTF and PanSTARRS and …

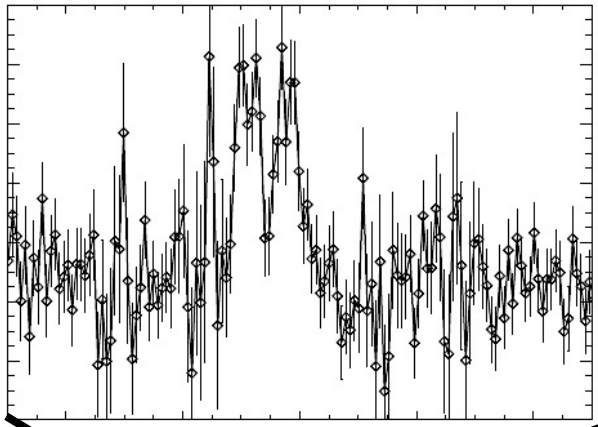


2. Emission Line Galaxies (ELGs)

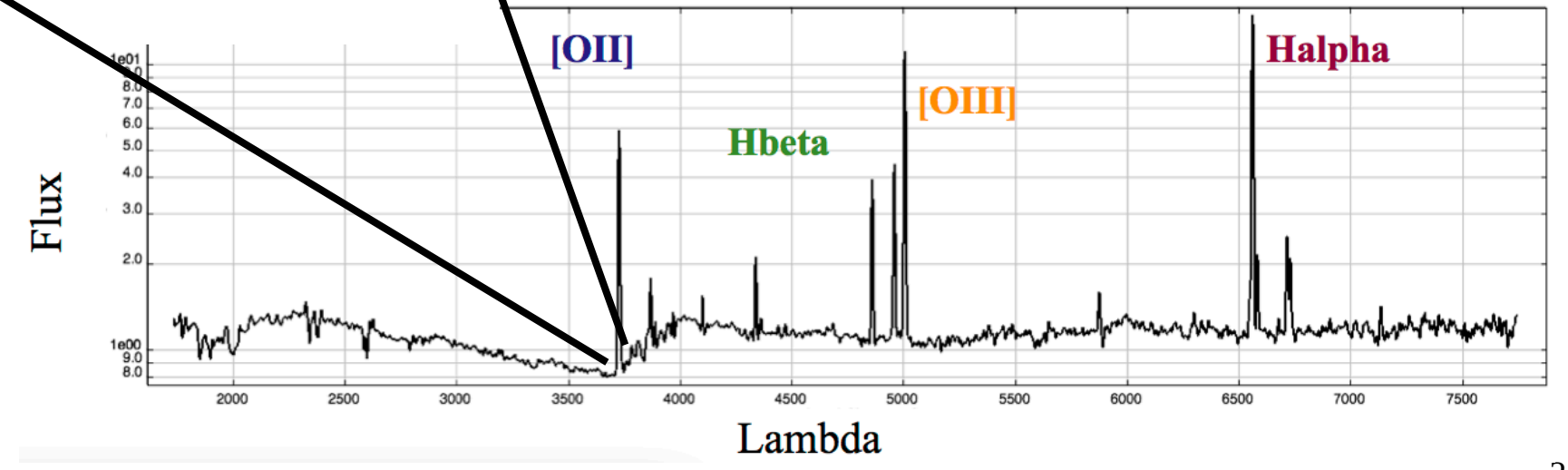
ELGs unique signature of [O II] doublet, detectable from z=0 to z=1.7

Well-studied as the ~5% brightest galaxies in the DEEP2 survey

ELGs drive BigBOSS wavelength coverage, throughput, & resolution



[O II] doublet at 3726.032 + 3728.815 Ang
BigBOSS detects to z=1.6 at 9700 Ang



3. QSOs as tracers

QSO tracers at 0.5 < z < 3.5

The brightest objects at z > 2

+ QSO Lyman-alpha forest at 2.2 < z < 3.5

Test data:

SDSS imaging to g=22, spectra for 200,000

PTF-1 imaging to g=23.5, spectra in test fields from BOSS, MMT

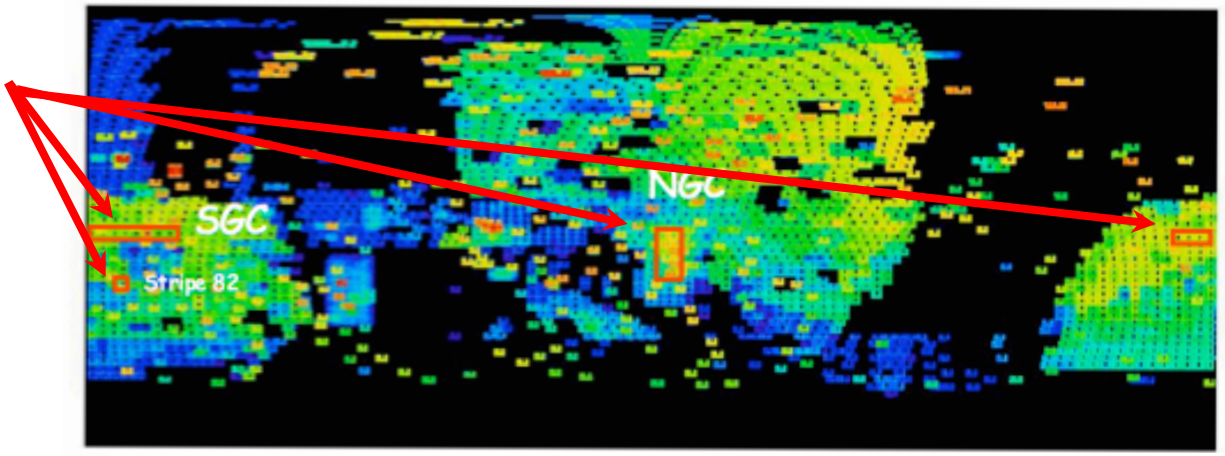
BigBOSS targets:

2.5 million QSOs from PTF-1 and PTF-2

Every QSO to r < 23.5

Simplify target selection -- select QSOs at all redshifts from variability

PTF test fields



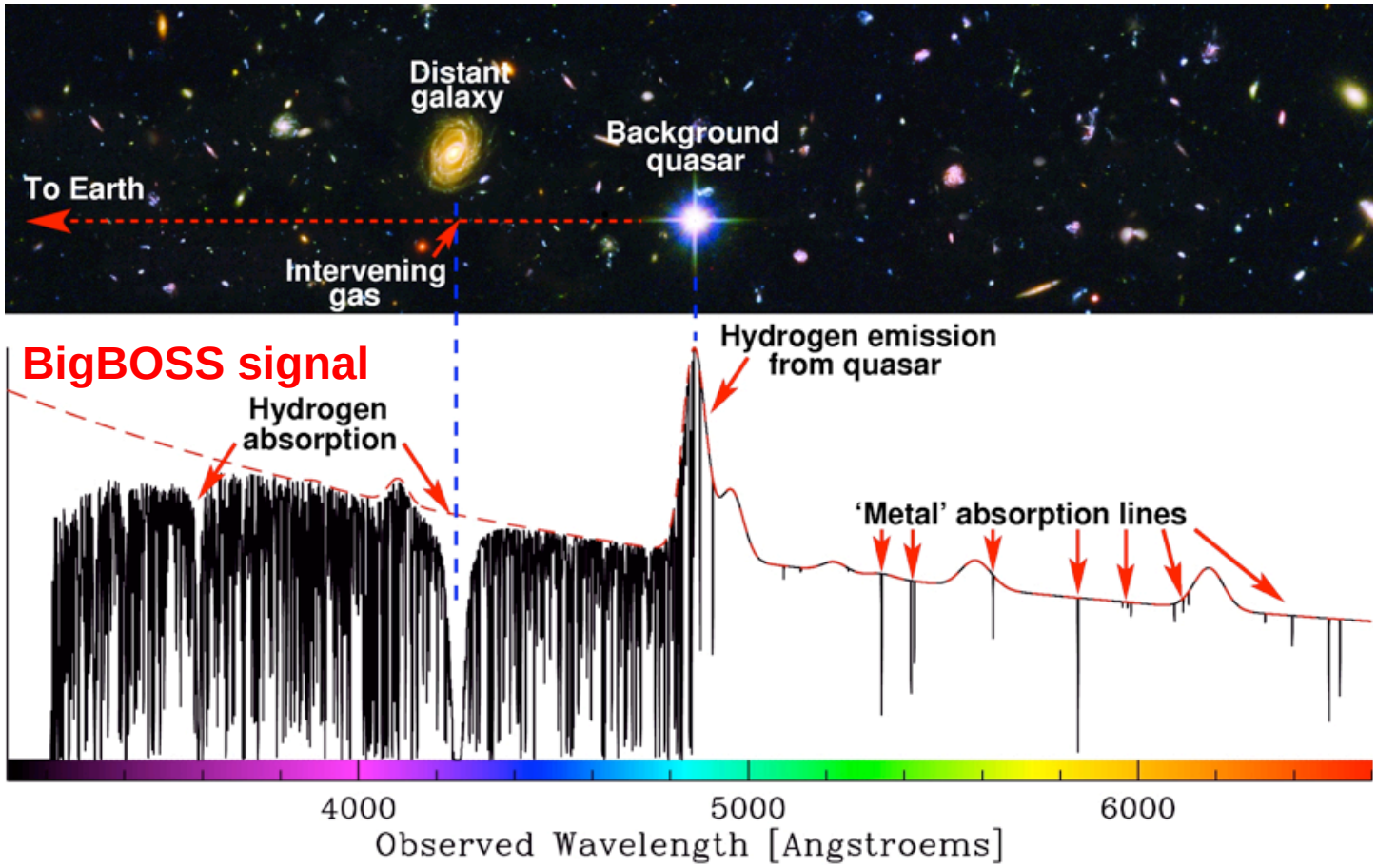
4. Lyman-alpha forest from QSOs

QSOs at z < 2.2 will be observed once → "tracer QSOs"

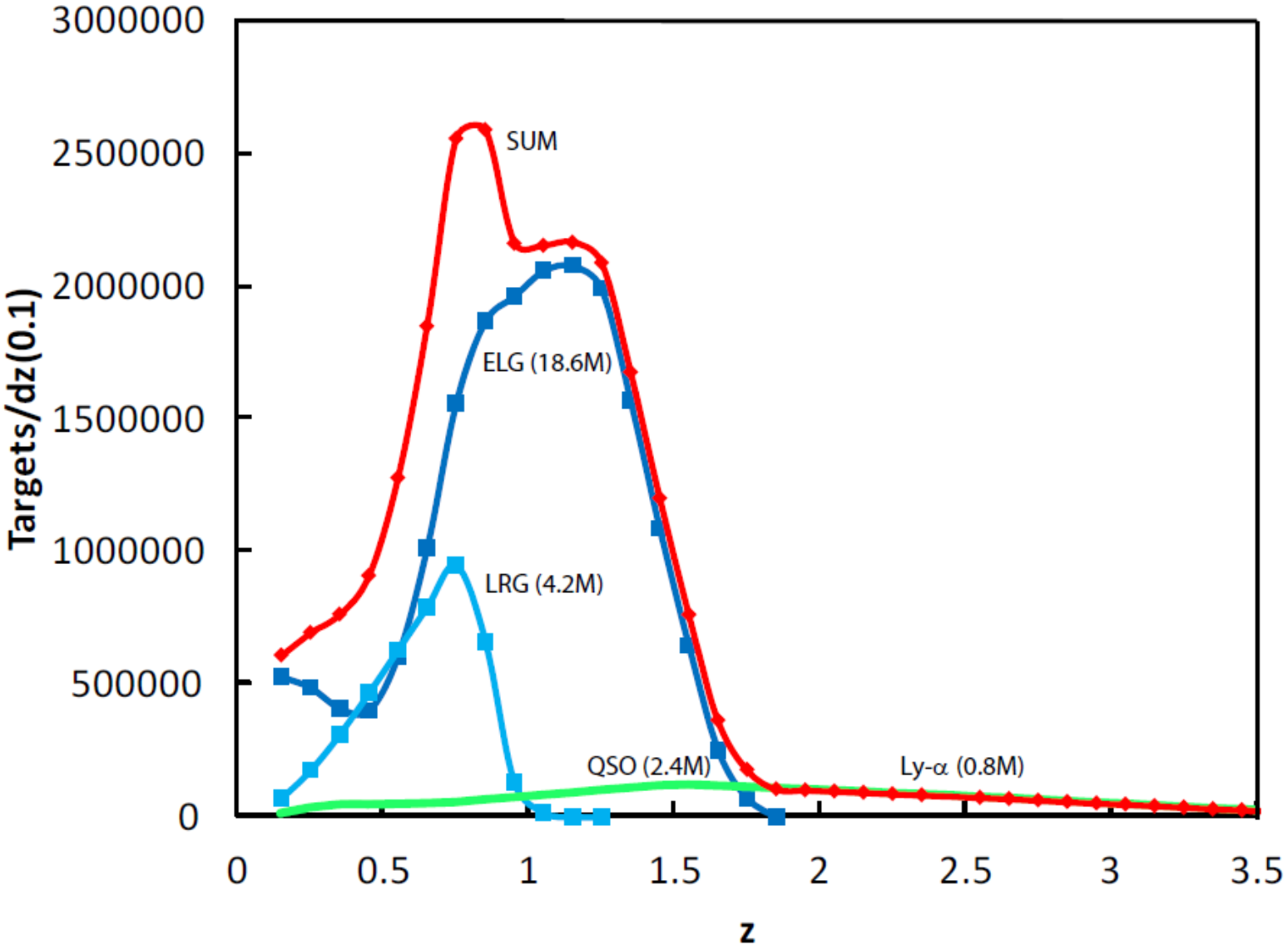
QSOs at z > 2.2 will be observed 5X for high S/N for "Lyman-alpha forest"

Map of hydrogen gas along line-of-sight skewers

BOSS validating their use as 3-D maps for BAO



BigBOSS tracers



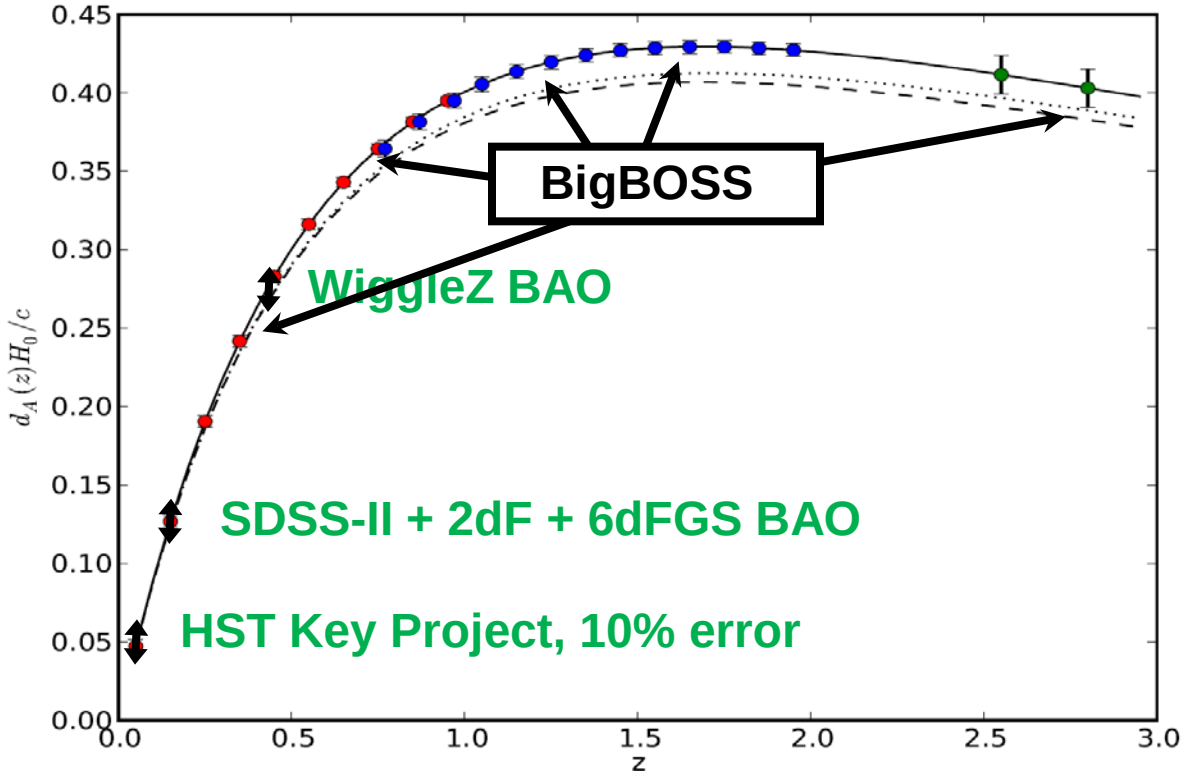
BigBOSS science reach: BAO

Dark energy from Stage IV BAO

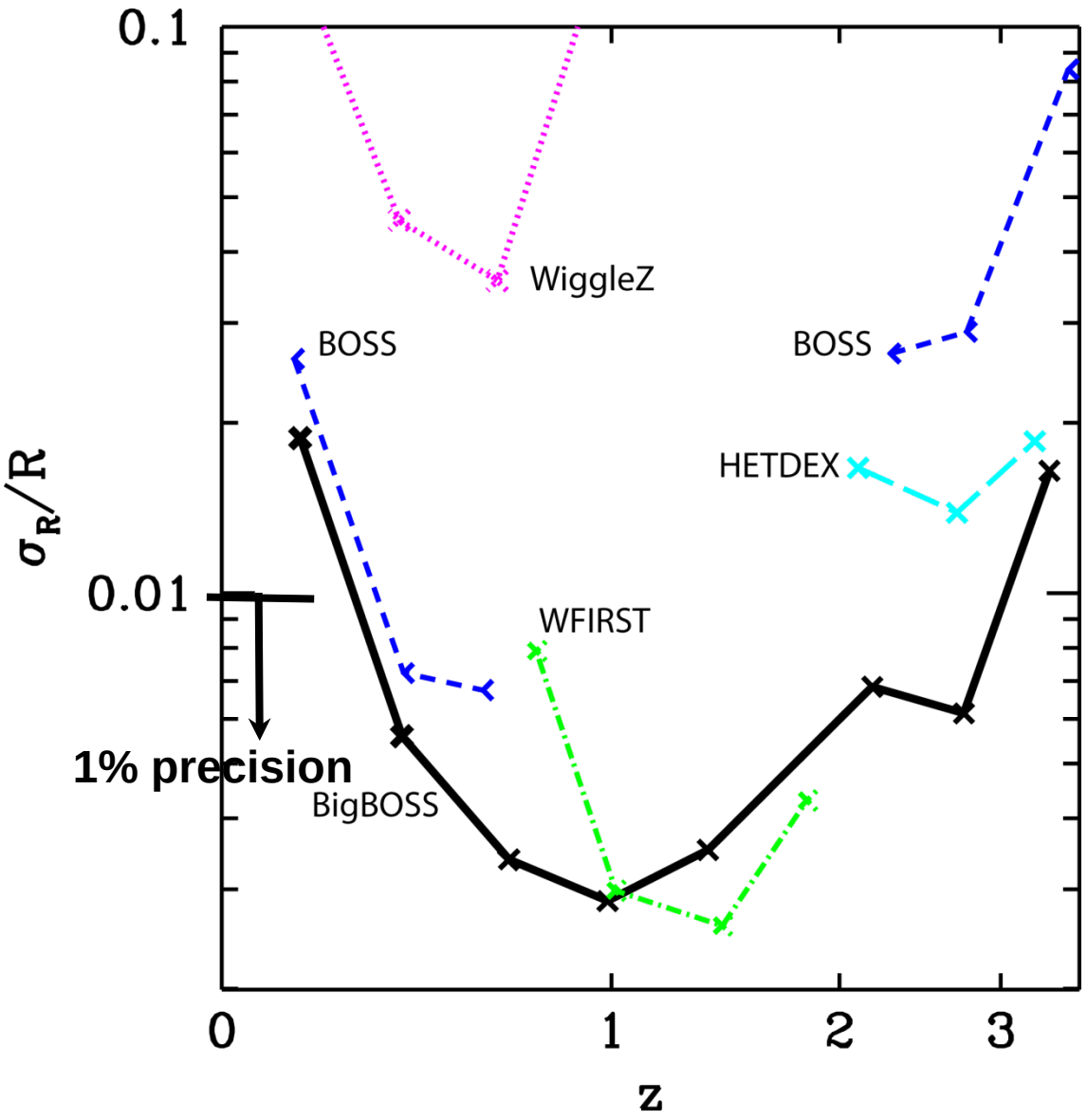
—*Geometric probe with 0.3-1% precision from z=0.5 -> 3*

BigBOSS BAO "Hubble diagram"

d_A



BigBOSS Science Reach: Distance constraints



- Distance scale factor
- BigBOSS has < 1% distance errors over the widest redshift range
- Probe the expansion history over the widest redshift range

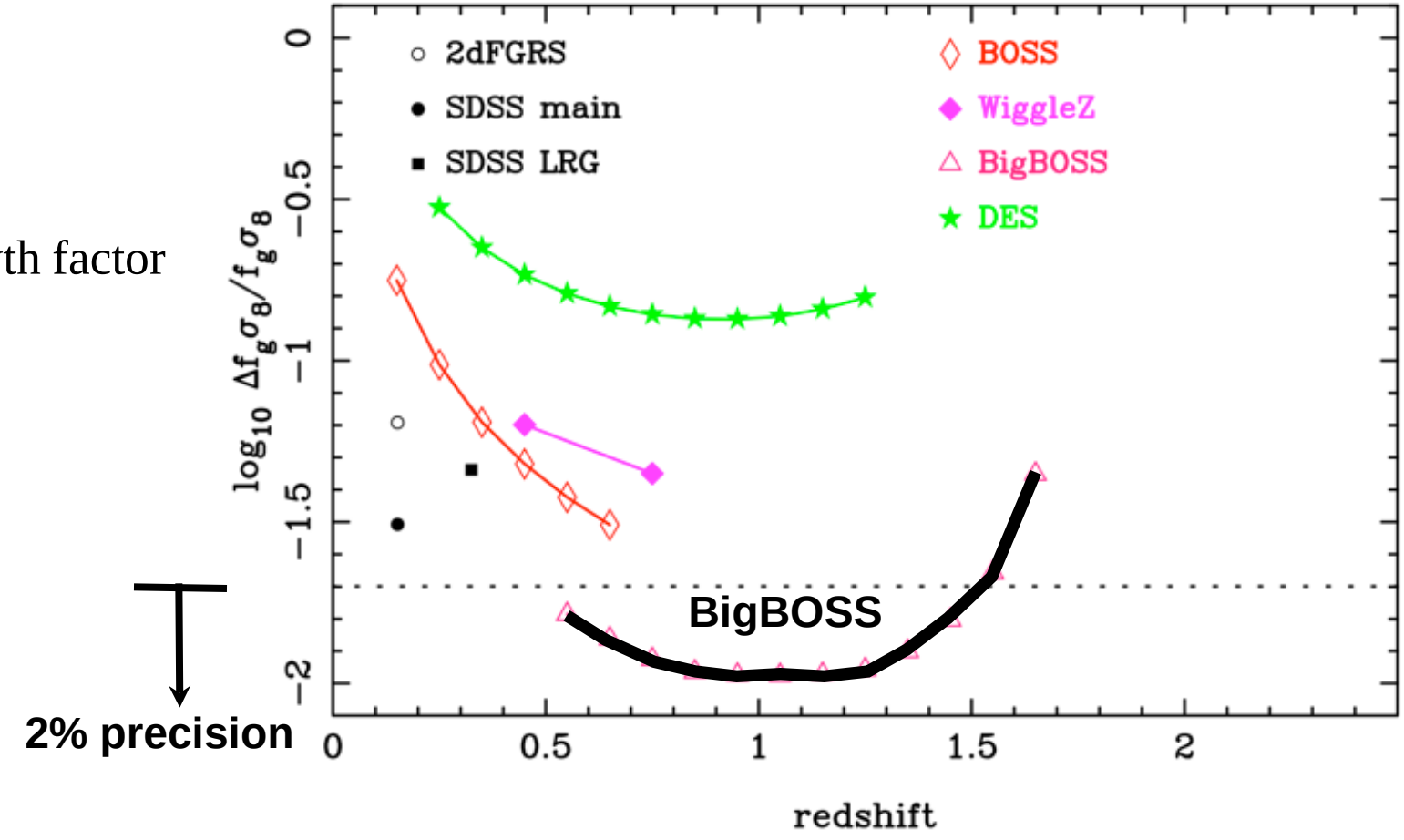
BigBOSS RSD predictions

Dark energy from Stage IV RSD

—*Gravitational growth with 2% precision from z=0.5 -> 1.5*

BigBOSS RSD precision

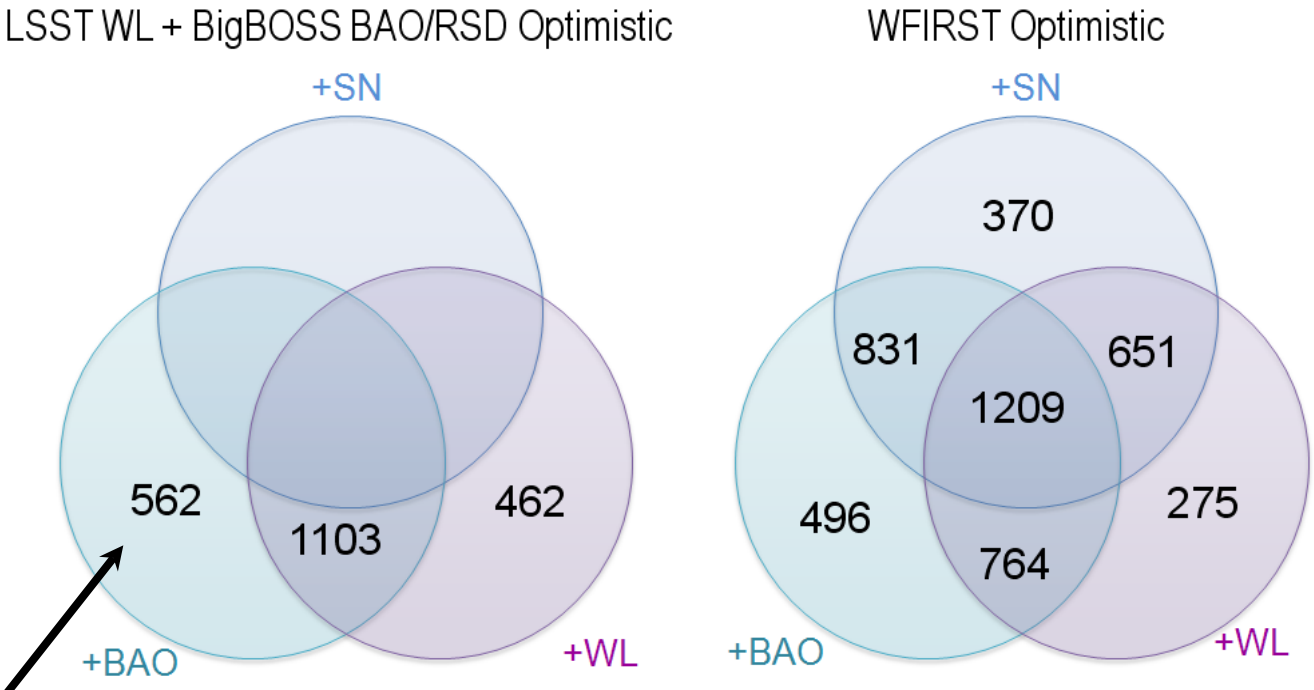
Growth factor



BigBOSS Stage IV science reach

BigBOSS Figure-of-Merit achieves Stage IV

Independently verified by WFIRST Science Definition Team calculations of DETF figures of merit



BigBOSS

Fig. reproduced from WFIRST Science Definition Team report
http://wfirst.gsfc.nasa.gov/science/WFIRST_Interim_Report.pdf

Broad-band power for DE

Broad-band power spectrum offers strong potential for dark energy measurements beyond those from BAO only

(fits include all P(k) information, including RSD)

	FoM
BigBOSS BAO	125
+BAO III	132
+SN III	163
BigBOSS P(k), k_{max}= 0.15 hMpc^{-1}	430
+BAO III	437
+SN III	466
BigBOSS P(k), k_{max}= 0.30 hMpc^{-1}	661
+BAO III	667
+SN III	691

Neutrino mass measurements

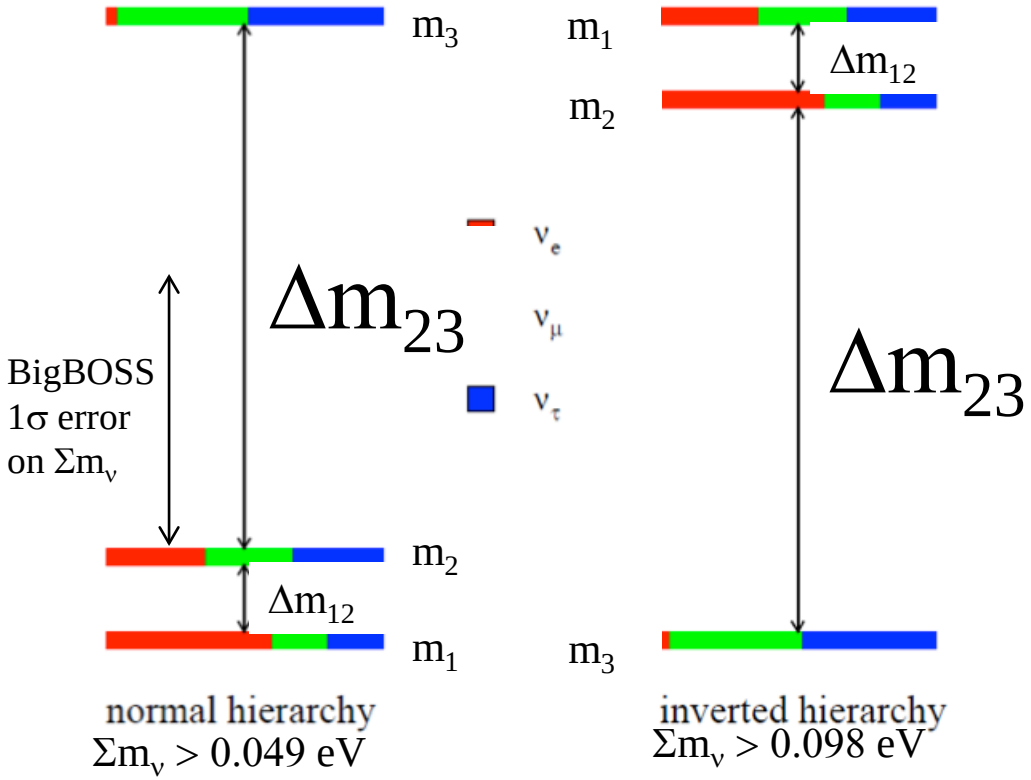
Cosmological and inflation parameters and sum of neutrino masses <0.024 eV.

Terrestrial experiments measure Δm^2 of neutrino masses

Sensitivity is 0.024 eV

Measured from power spectrum of galaxy map

Terrestrial Δm_{23} = 0.049 eV (PDG 2011, mostly Kamland)

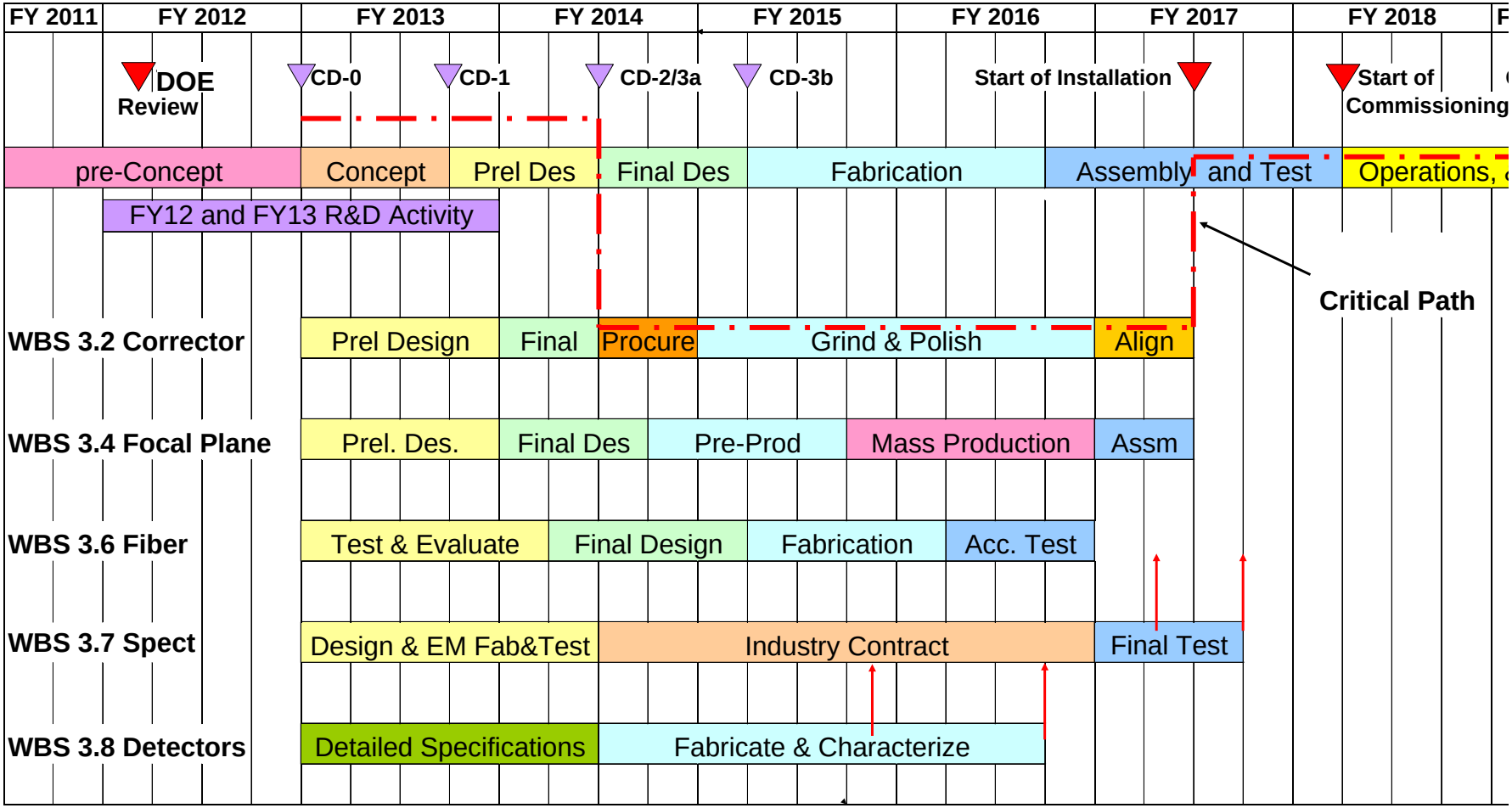


BigBOSS History

- **BigBOSS proposed in 2009**
  - **Reviewed in 2009 by HEPAP/PASAG**
    - "legitimate possibility of achieving a significant fraction of the BAO science goals for JDEM'
    - **"Substantial immediate support for BigBOSS R&D is recommended"**
    - "(NSF/NOAO) are essential partners in the BigBOSS project and planning."
  - **Reviewed by Astro2010 (decadal survey)**
    - **Study of dark energy one of the three science themes**
  - **October 2010 response to NOAO Large Science Programs**
    - **"Schmidt committee" non-advocate review by NOAO, milestones**
    - **Proposal accepted by NOAO for 500 nights on Mayall Telescope**
  - **Proposal to DOE in 2011 followed by successful review.**

- **BigBOSS is in a funded R&D phase.**
  - **We have requested from DOE a 2014 "construction start" (that's when the preliminary design review happens, final design starts along with early procurements.**
  - **On sky by end of 2017.**

Simplified Schedule



Conclusion

Dark Energy science following DETF recommendations

BOSS will complete BAO+RSD stage III in 2014

—1.5 million galaxies + 160,000 QSOs

—~1% measure of expansion at z=0.3, 0.5, 2% measure at z=2.5

BigBOSS designed as BAO+RSD stage IV

—22 million galaxies + 2.5 million QSOs

—BAO: Geometry, 1% precision from z=0.5 →1.6 and z=2→3

—RSD: Gravitational growth, 2% precision @ 5 redshifts

—Neutrino masses at 0.024 eV

—Inflation probe using more modes than Planck

BigBOSS is a stage IV experiment to commence this decade