Little

BOSS:
Ground-Based Stage III
BAO Experiment

Dark Energy Task Force (DETF) report (June 2006)

The "Big 4" techniques:

I. Baryon Acoustic Oscillations (BAO)

Sound scale in distribution of galaxies: $d_A(z)$ and $H(z)$.

II. Clusters (CL)

Spatial distribution of galaxy clusters: $d_A(z)$, $H(z)$

Growth of structure

III. Supernovae (SN)

Flux and redshift of Type Ia SNe: $d_L(z)$.

IV. Weak Lensing (WL)

Distortion of background images due to grav. lensing: $d_A(z)$

Growth of structure

DETF defines progressive capabilities:

Stage I: knowledge ca. 1996
Stage II: running experiments
BAO Stage III: near-term experiments
BAO Stage IV: JDEM satellite, Square Kilometer Array, LSST

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The "Big 4" techniques:

I. BAO

$d_A(z)$ and $H(z)$.

II. Clusters (CL)

$d_A(z)$, $H(z)$

Growth

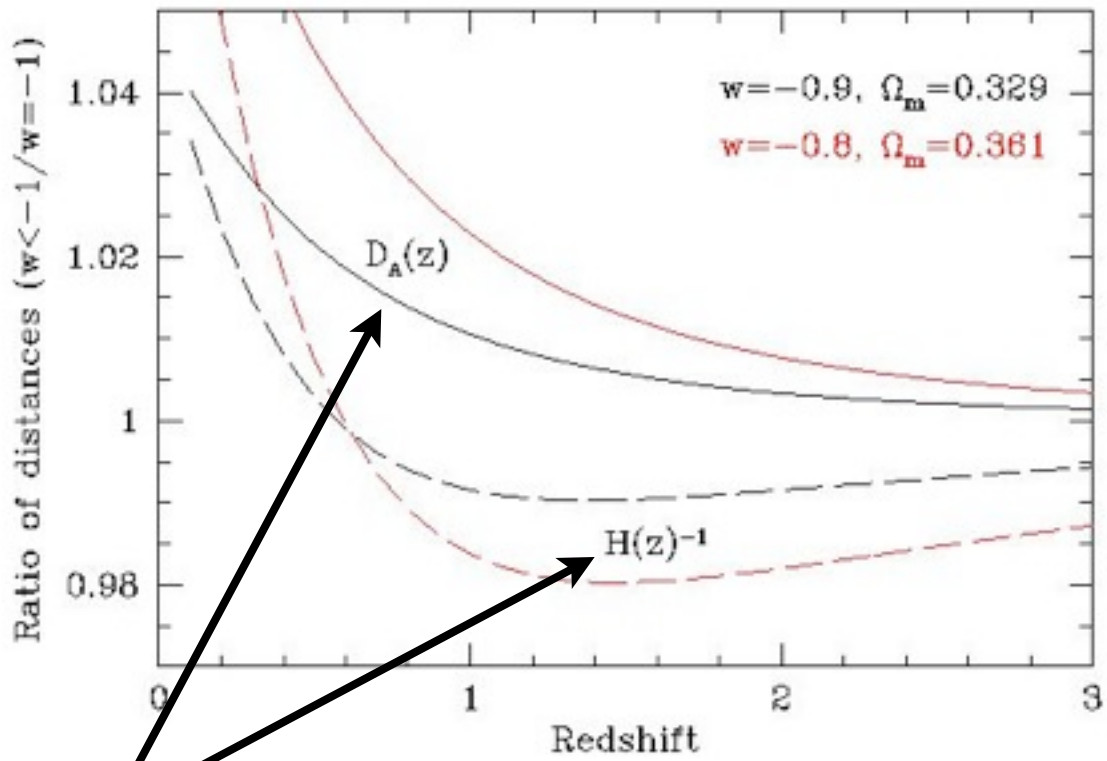
III. Supernovae (SN)

$d_L(z)$.

IV. Weak Lensing (WL)

$d_A(z)$

Growth

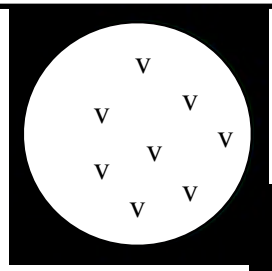


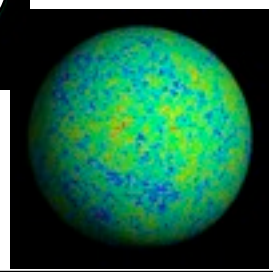
These are the direct **observables**

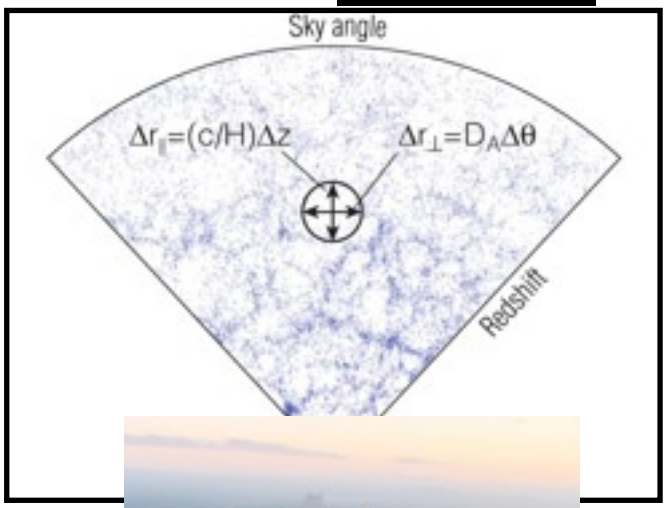
Each measurement is low S/N: ~1 for SN, ~0.01 for WL, ...

Ultimately limited by systematic errors of each technique

BAO and dark energy







BAO: What tracer objects to use?

$z=10^{11}$ Neutrino background
(not for BAO ruler, but horizon at ν decoupling)

$z=1087$ CMB: Planck will measure d_A to 0.1%

$z=20$ H gas in 21-cm emission

$z=5$ Ly-A emitter galaxies
QSO absorption lines

$z=2$ Galaxies,
galaxy clusters,
SNe

$z=0$

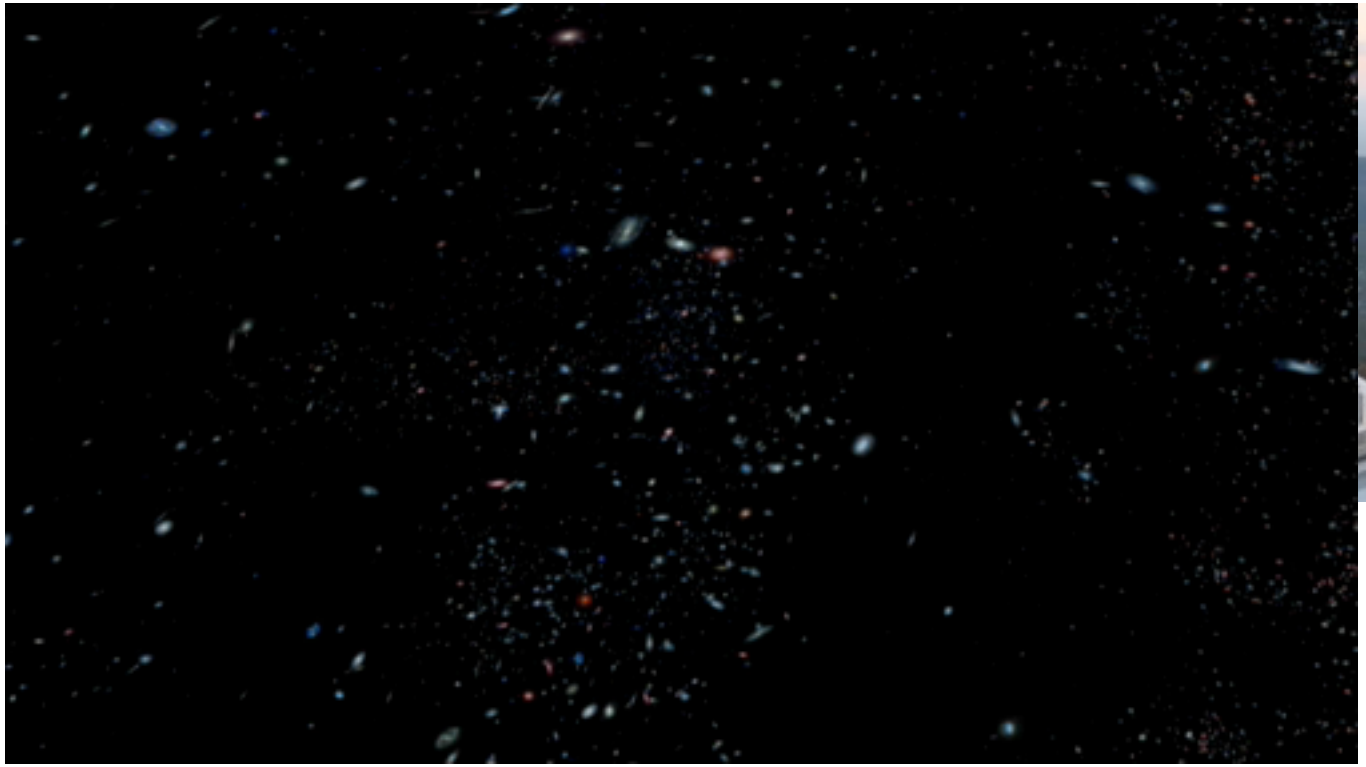
All existing BAO measurements

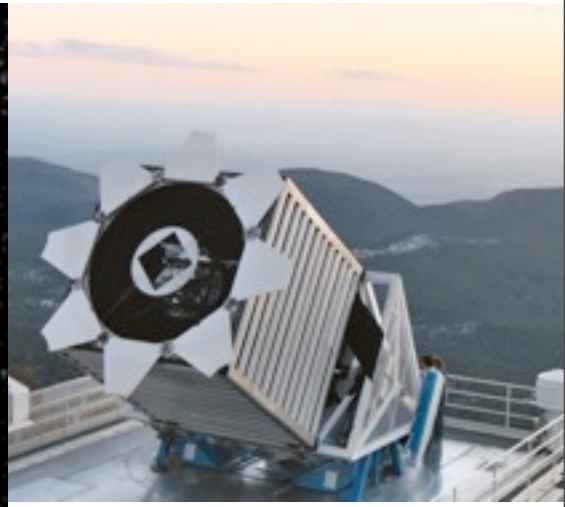
Definitely the hard way,
but it's been suggested!
(Angulo et al 2006)
(Zhan et al 2008)

BAO from 3-D maps: SDSS

Finally technologically possible

Sloan Digital Sky Survey (SDSS) telescope
⇒ **Optical design** for large focal plane: 7 deg^2
⇒ **Fiber-fed** spectrographs: 640 redshifts simultaneously



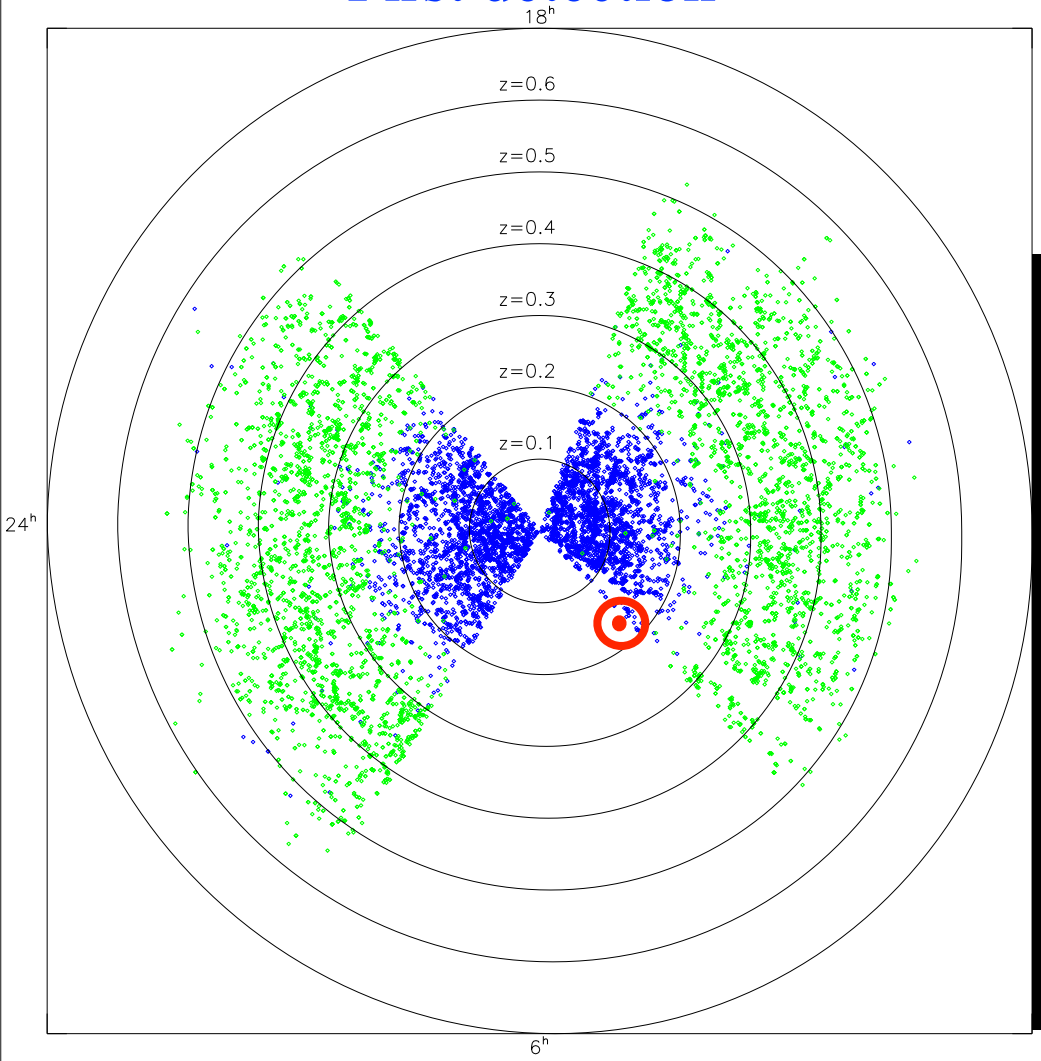


SDSS telescope,
Apache Point, New Mexico

Courtesy: Dinoj Surendran & Mark Subbarao, U Chicago & Adler Planetarium for SDSS

BAO from 3-D maps: SDSS

First detection

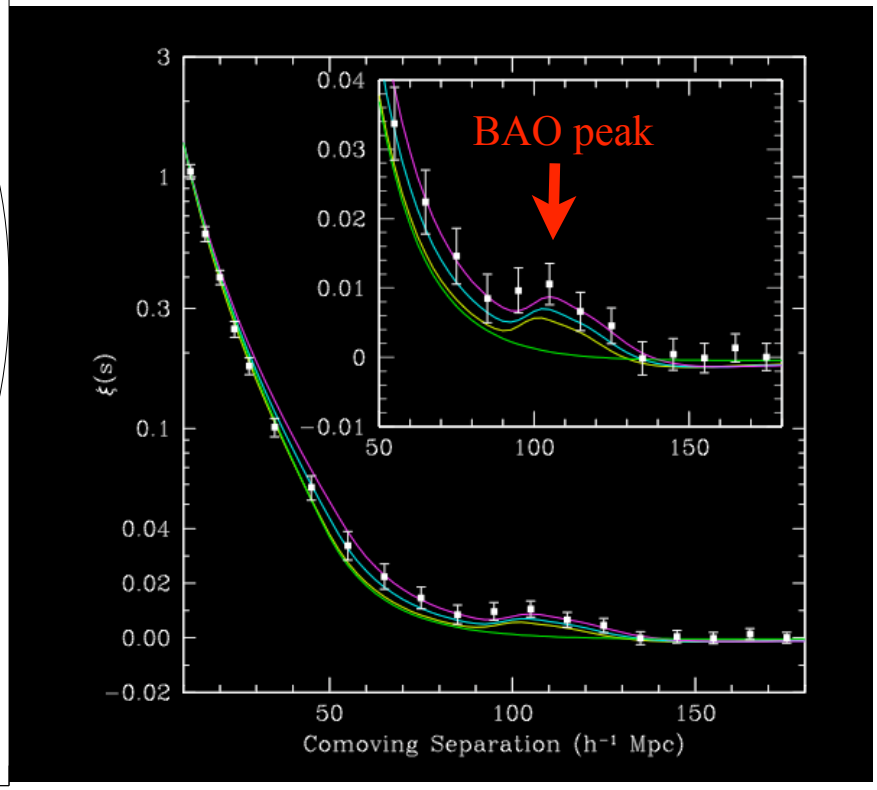


SDSS luminous red galaxies (LRGs)

Sparse sampled at 10^{-4} galaxies/Mpc^3

47,000 galaxies over 4000 deg^2 by 2004

80,000 galaxies over 8000 deg^2 by July 2008



Eisenstein et al 2005

Next-Generation BAO Experiment: BOSS == Baryon Oscillation Spectroscopic Survey

A variety of facilities considered for next-gen BAO experiment:
Lick 3-m, Keck 10-m, MMT 6.5-m, ...

SDSS telescope secured for next-gen BAO experiment:
July 2006: Competitive proposal to use (upgraded) SDSS telescope for next-gen BAO
Nov 2006: BOSS proposal selected for all dark+grey time for 2009-2014
Feb 2007: DOE R&D proposal for upgrading SDSS spectroscopic system
Sep 2007: Commitment from Alfred P. Sloan Foundation
June 2008: Commitment from NSF
Jan 2009: Commitment from DOE

Partners:

- Univ. of Arizona
- Brazilian Participation Group
- Cambridge Univ.
- Case Western Univ.
- Univ. of Florida
- French Participation Group
- Univ. of Heidelberg
- Johns Hopkins Univ.
- IMPU Institute (Japan)
- Korean Institute for Advanced Study
- Lawrence Berkeley Lab
- Los Alamos National Lab
- MPA Garching
- Michigan State Univ/JINA
- New Mexico State Univ.
- New York Univ.
- Ohio State Univ.
- Penn State Univ.
- Univ. of Pittsburgh
- Univ. of Portsmouth
- Astronomical Institute Potsdam
- Princeton Univ.
- UC Santa Cruz
- Univ. of Utah
- Univ. of Virginia
- Univ. of Washington

BOSS == Baryon Oscillation Spectroscopic Survey at SDSS telescope

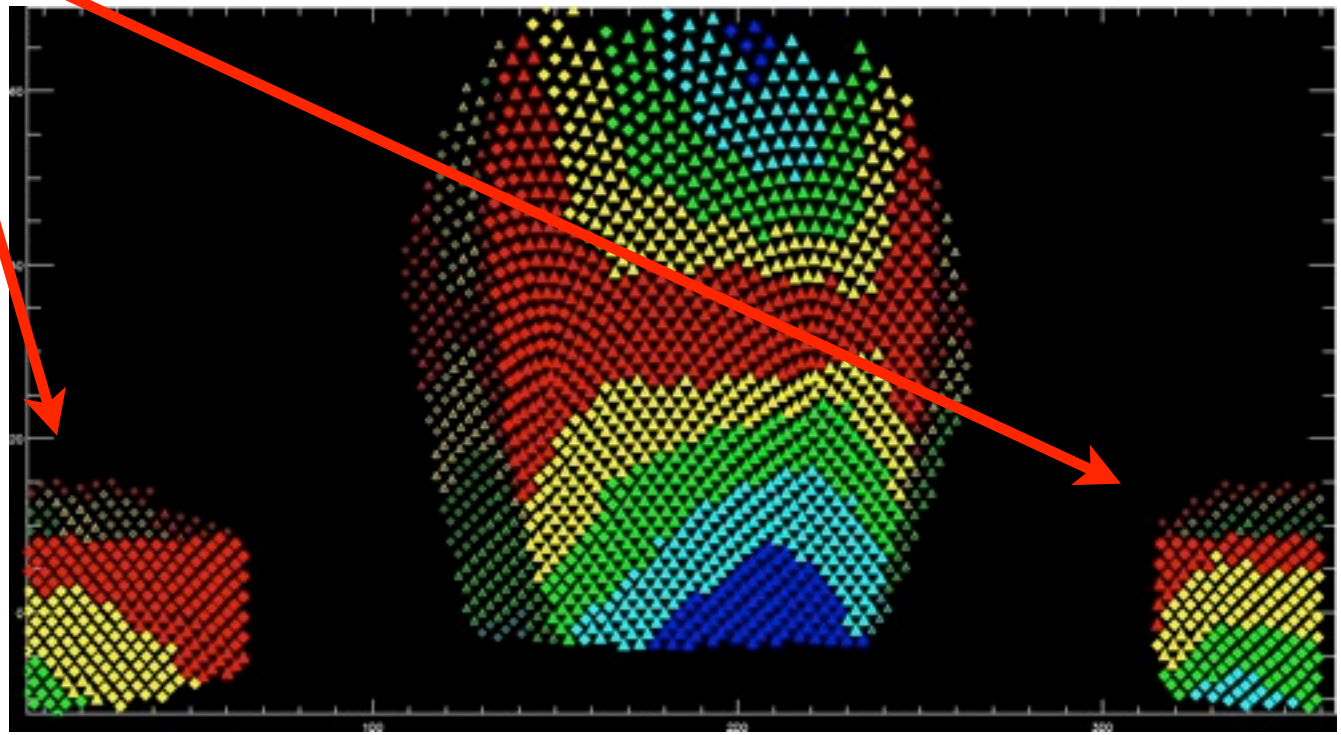
All targets selected from SDSS

Requires 10,000 deg^2 footprint

→ SDSS imaging of additional 2000 deg^2 in Fall 2008 + 2009

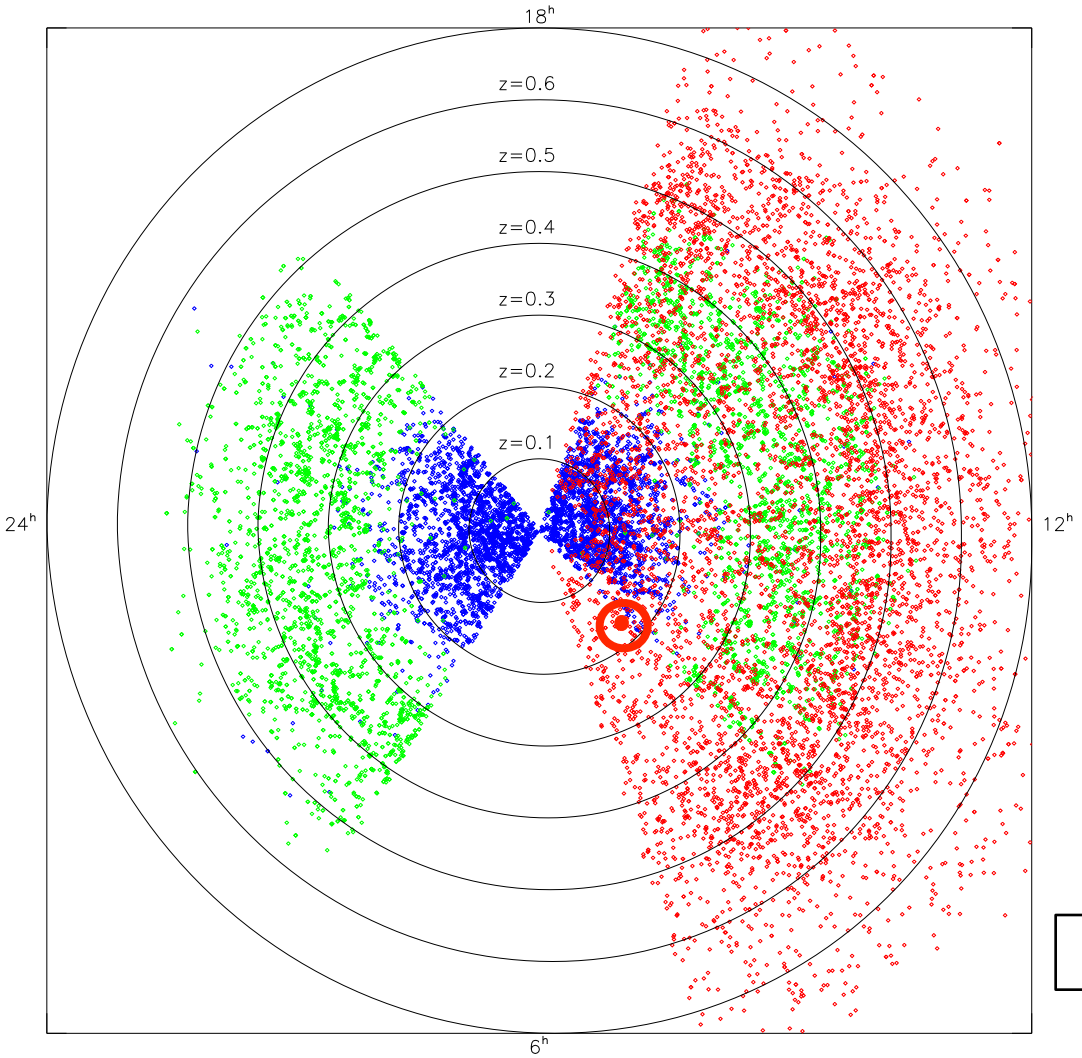
BOSS footprint
Additional 2800 deg^2

SDSS & SDSS-II
footprint
7600 deg^2



BOSS == Baryon Oscillation Spectroscopic Survey at SDSS telescope

Two simultaneous spectroscopic surveys from 2009-2014
- ➙ **BAO from 1.3 million galaxies at z=0.3, 0.6**
- ➙ BAO from 160,000 QSOs at 2.2<z<3



SDSS main galaxy survey
~1 million galaxies
Too little volume for BAO

SDSS luminous red galaxies (LRGs)
Sparse sampled at 10^{-4} galaxies/Mpc^3
47,000 galaxies by 2004
80,000 galaxies by 2008
8000 deg^2 (finish in 2008)

BOSS red galaxies
10,000 deg^2
5x sample density (shot noise)
2x volume

Turn this photo-z sample ➙ spectro-z

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$$P_{\rm raw}(\mathbf{k}) = \left[P_F(\mathbf{k}) + n^{-1} P_F^{\rm 1D}(k_\parallel)\right] W^2\left(k_\parallel R\right) + P_N^{\rm eff}$$

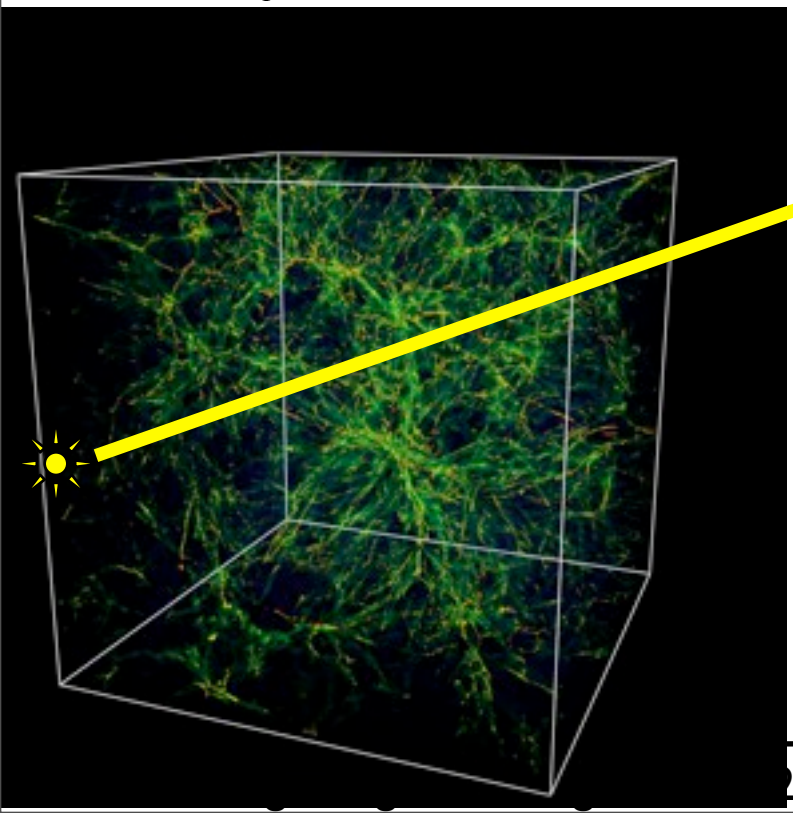
Ideal 3D power (perfectly sampled)

Sampling noise
n=surface density of lines of sight
(analogous to galaxy shot noise)

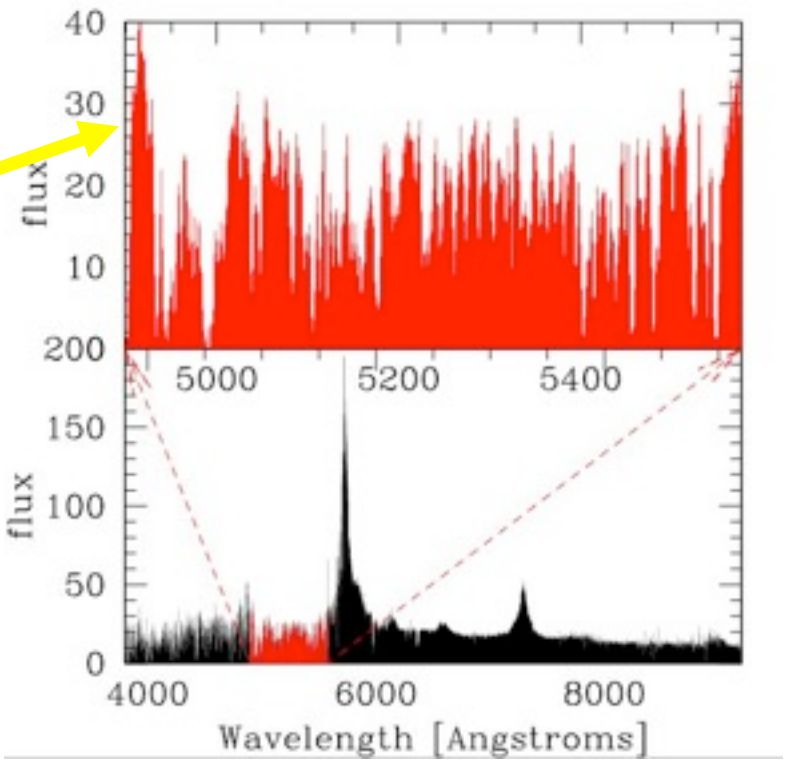
Resolution

Detector noise

Simulation of the IGM (R. Cen)
Neutral H in 25 h^{-1}Mpc box



Lyα forest in SDSS QSO spectrum at z=3.7



http://sdss3.org

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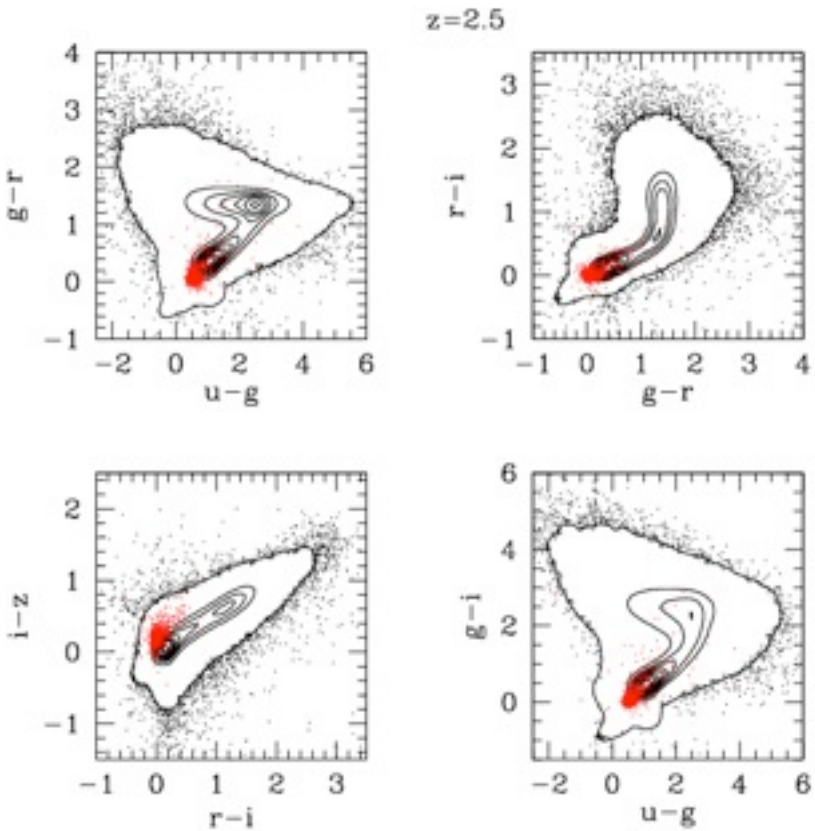
Two simultaneous spectroscopic surveys from 2009-2014
- ~~BAO from 1.3 million galaxies at z=0.3, 0.6~~
- **BAO from 160,000 QSOs at 2.2<z<3**

Selecting these QSOs is a challenge:

Current "State-of the Art" has ~11,000 2<z<3 QSOs ⇒ ~15x increase

Quasar number counts fall FAST beyond z~2 peak (Richards et al. 2006; Jiang et al. 2006, Hopkins 2007)

Snag is the 2.5<z<3 objects defy the UVX selection method.



BOSS == Baryon Oscillation Spectroscopic Survey at SDSS telescope

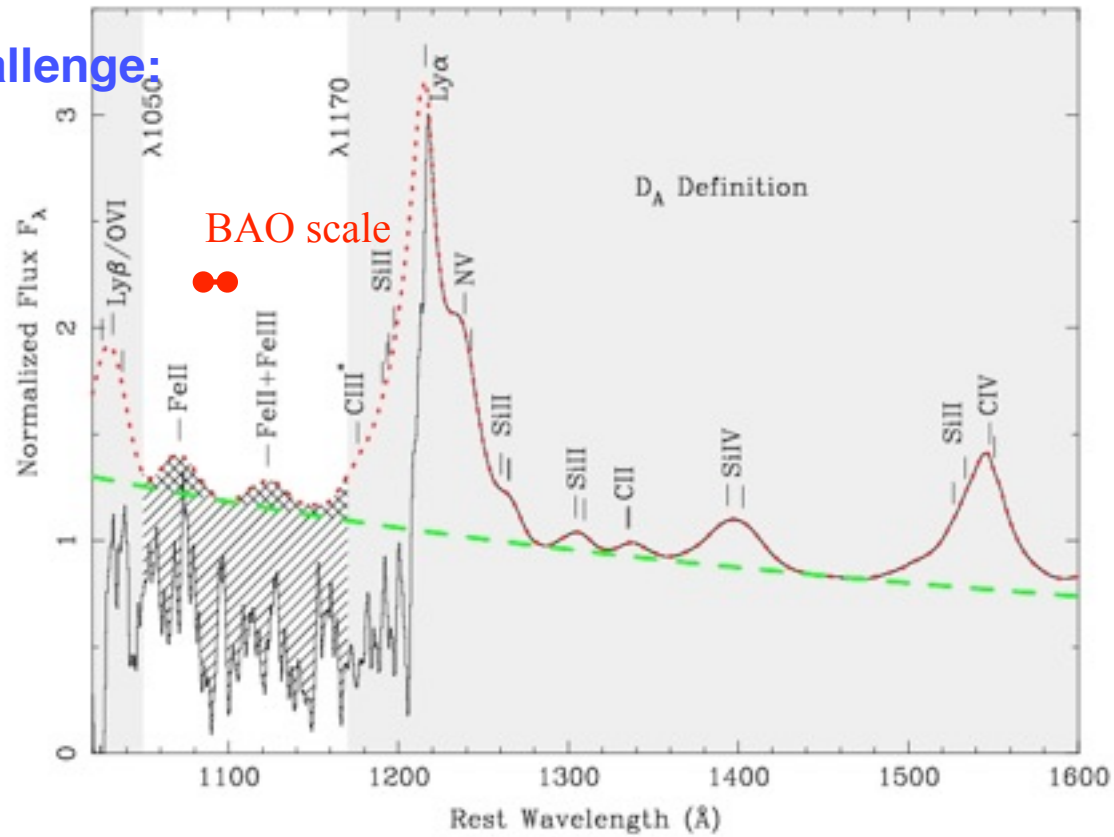
Two simultaneous spectroscopic surveys from 2009-2014
→ BAO from 1.3 million galaxies at z=0.3, 0.6
→ **BAO from 160,000 QSOs at 2.2<z<3**

Analyzing these QSOs is a challenge:

- **Photoionization equilibrium with a near-uniform ionizing background gives the neutral density (the gas is almost completely ionized).**

$$n_{HI} \propto \left(\frac{\rho}{\rho_0}\right)^{2-0.7(\gamma-1)}$$

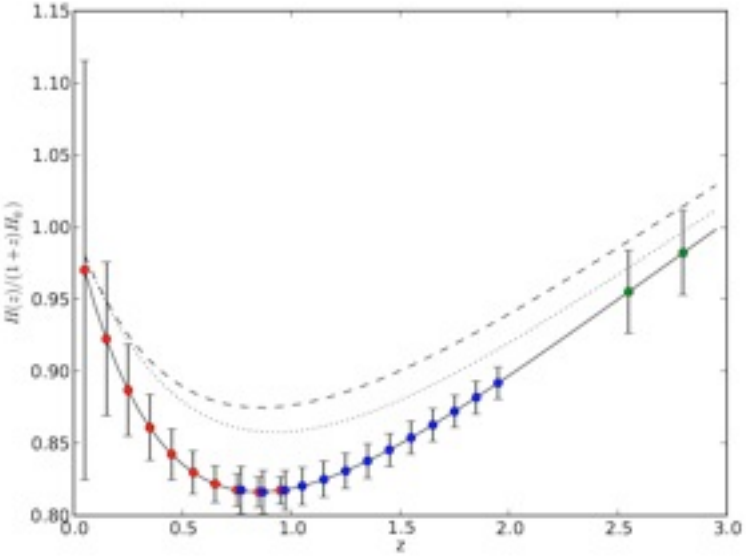
- **Peculiar velocities change the position of the absorption.**
- **Thermal broadening smoothes the observed features.**

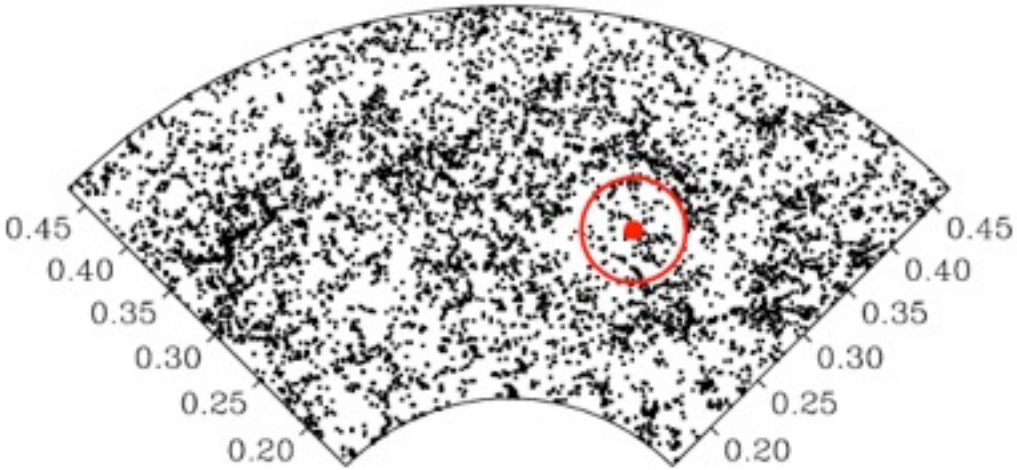


Continuum-fitting to the LyA forest: Courtesy of Nao Suzuki

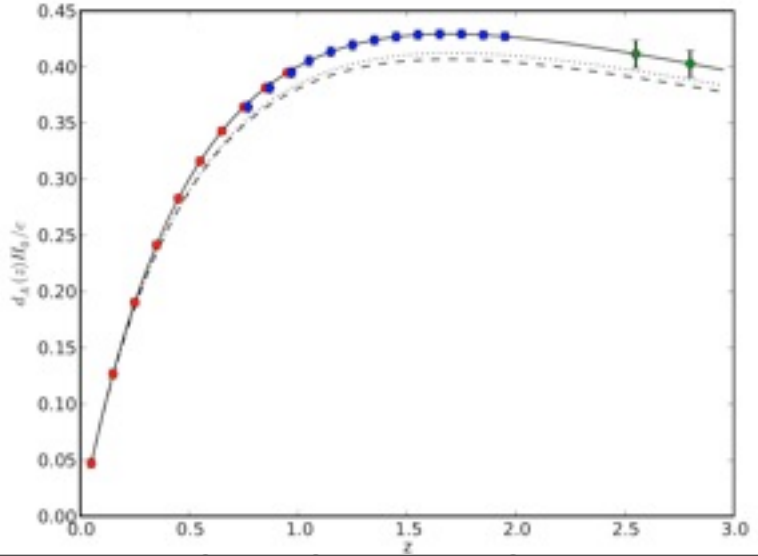
BAO in BOSS:
Geometric probe of dark energy

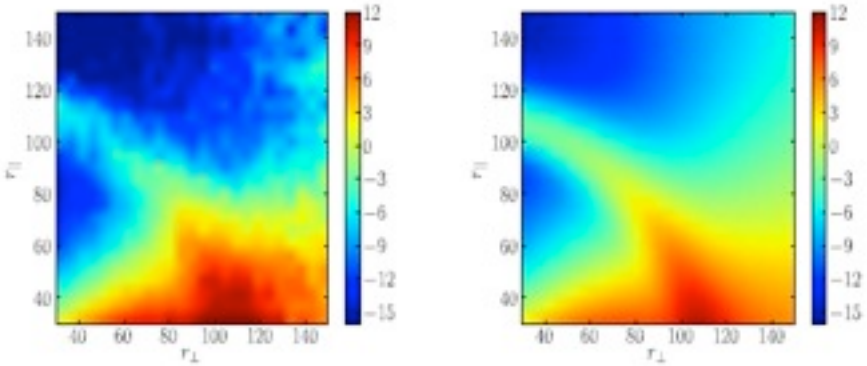
This is what the data will look like!





BAO scale in SDSS galaxies.

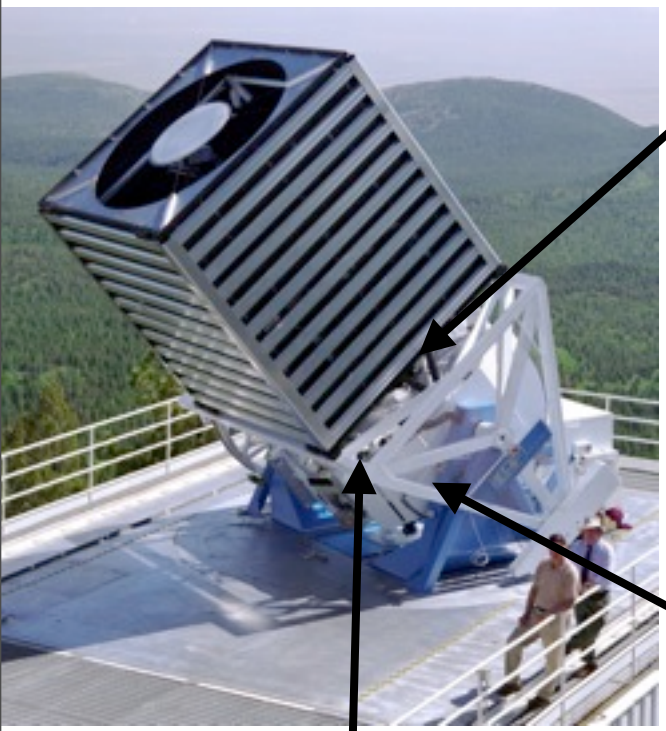




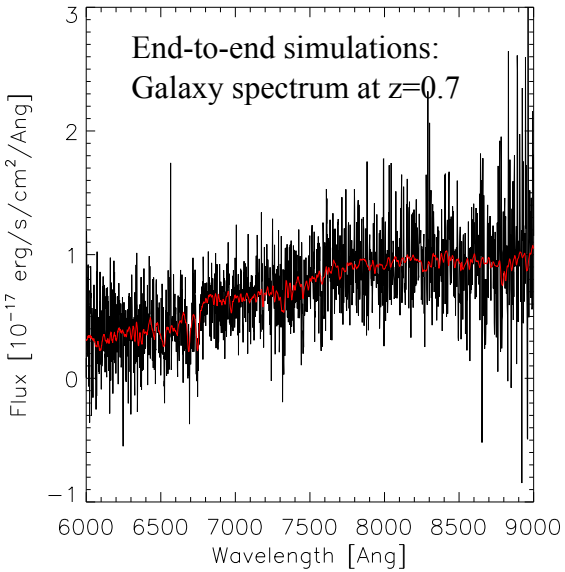
BAO in Lyman-Alpha (Slosar et al in prep.)

BOSS status

Largest field-of-view of
any large telescope -- DONE!

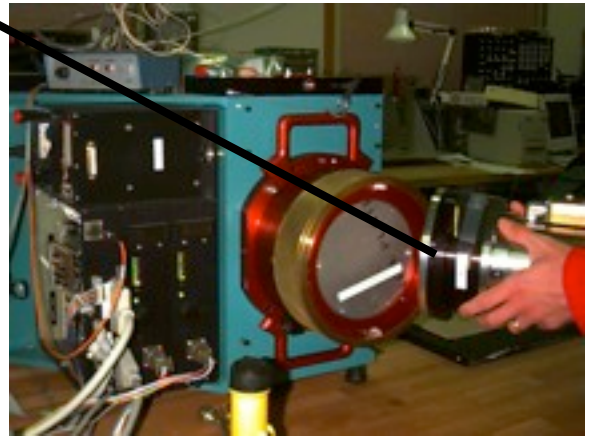


1000 small-core fibers to replace existing
(more objects, less sky contamination)



Software development underway

Swap gratings for VPH

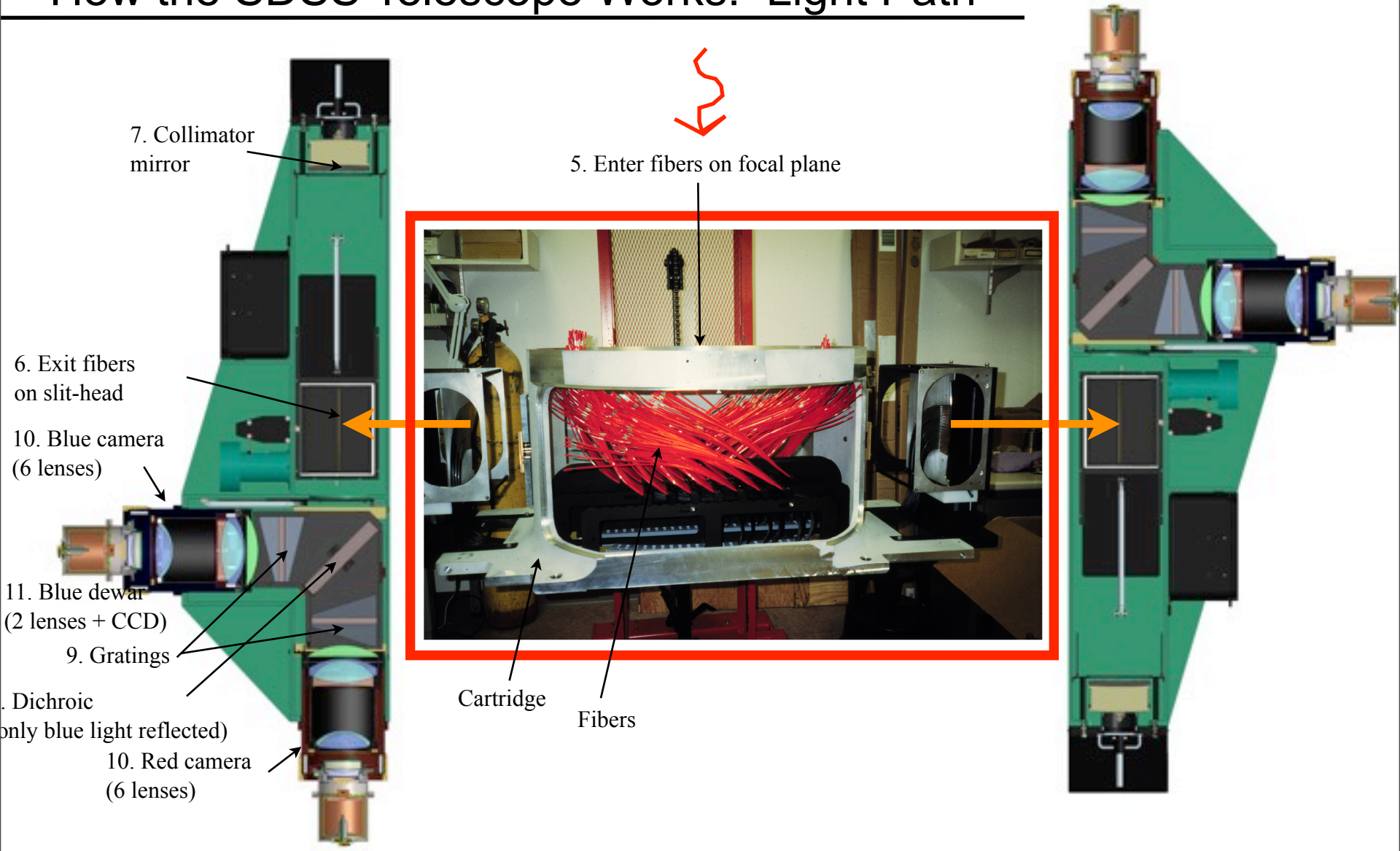


Replace red CCDs w/red-sensitive **LBL/SNAP CCDs**, making it possible to go to higher-z

Replace blue CCDs w/UV-sensitive e2v CCDs, making it possible for Lyα at z=2.3→3

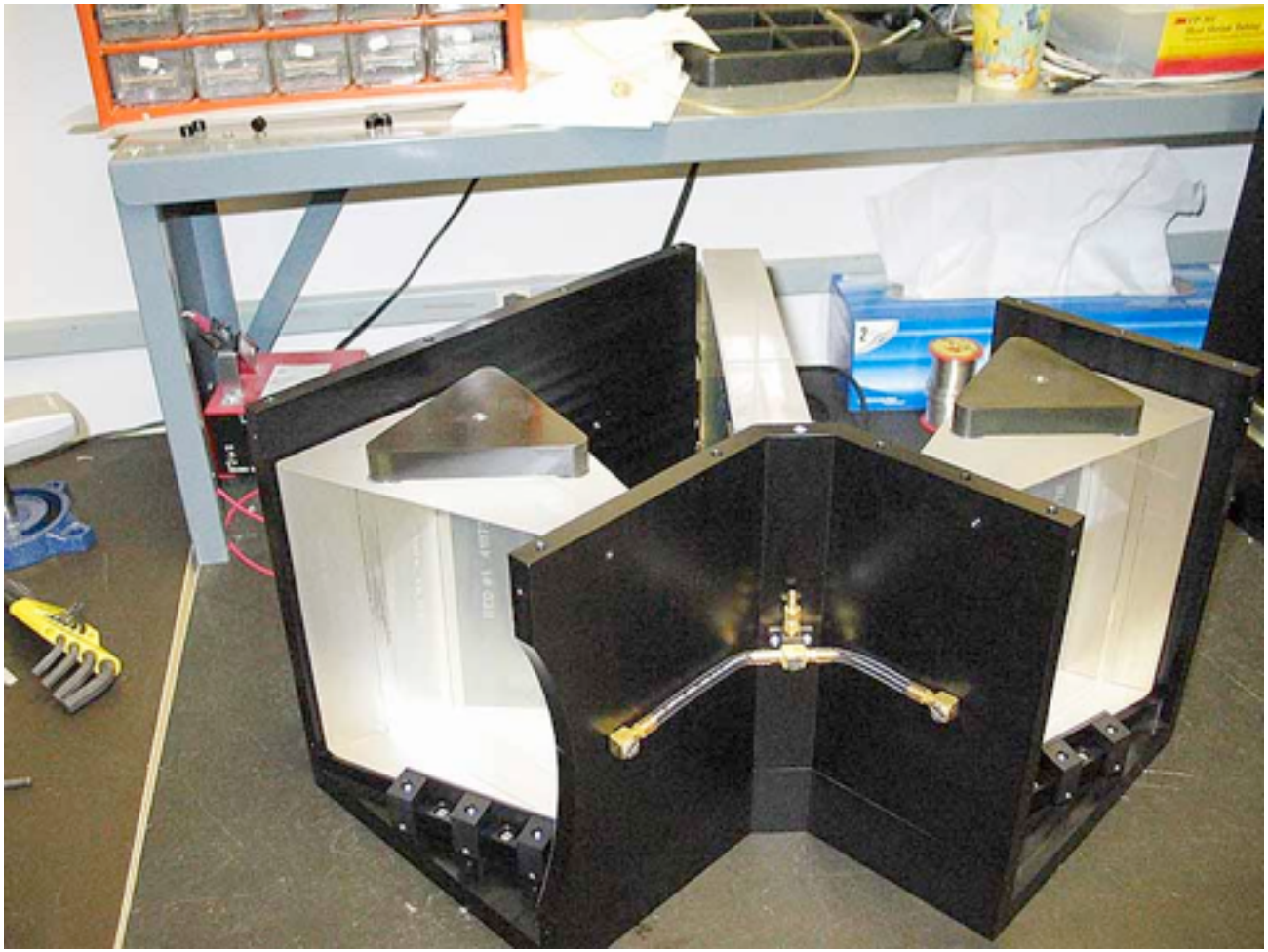
BOSS status

How the SDSS Telescope Works: Light Path



BOSS status

VPH grisms (Johns Hopkins)



BOSS status

Dewars (Princeton)

BOSS status

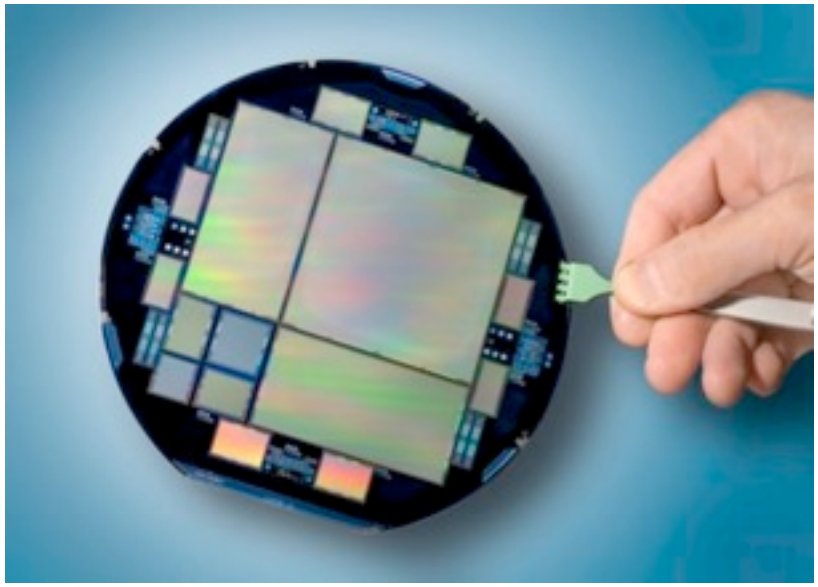
Electronics (Santa Cruz, Princeton, Ohio State)

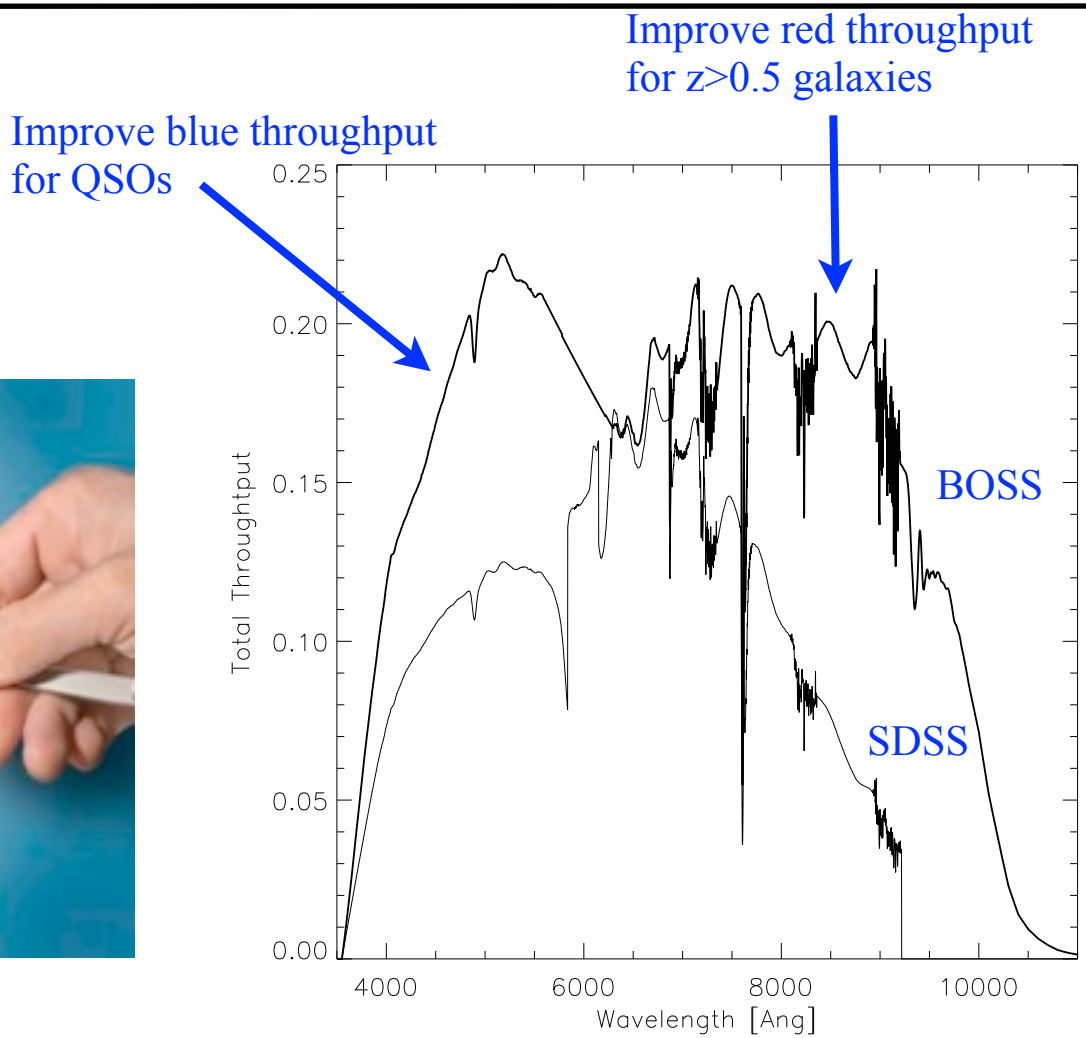
BOSS status

CCDs (Berkeley Lab)

Improve throughput:

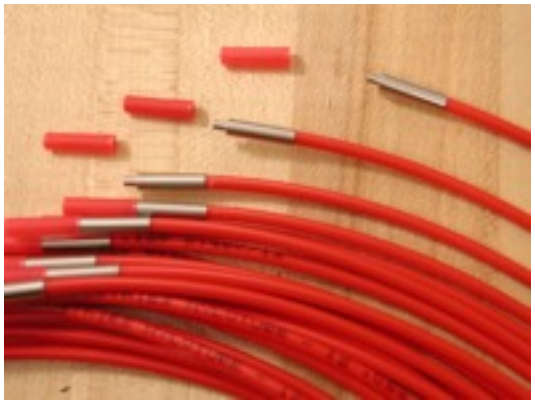
SITe → e2v, LBNL CCDs
Ruled → VPH gratings
Aluminum → silver collimators





BOSS status

Fiber system (U. Washington)

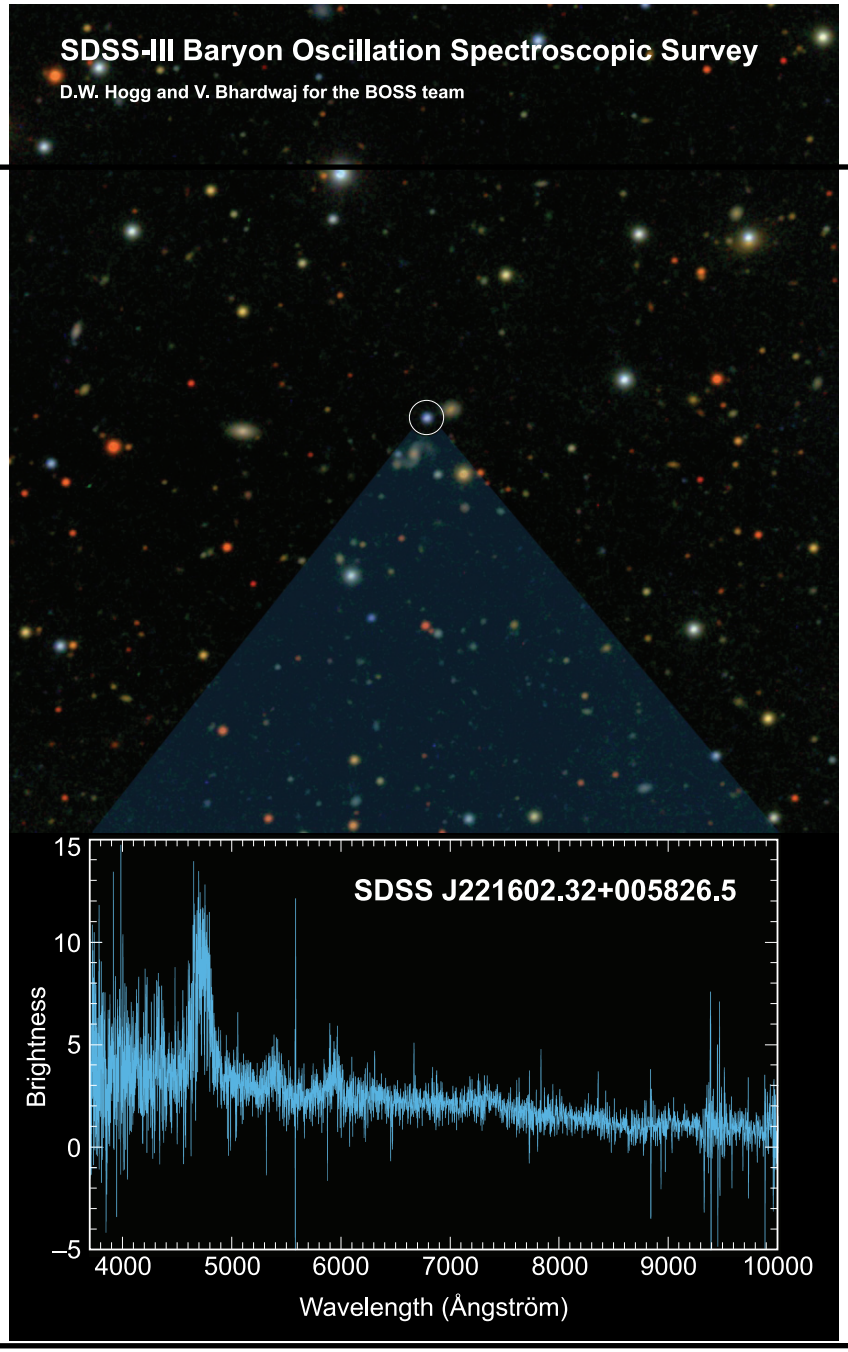


fibers

cartridges

BOSS status - plug plates

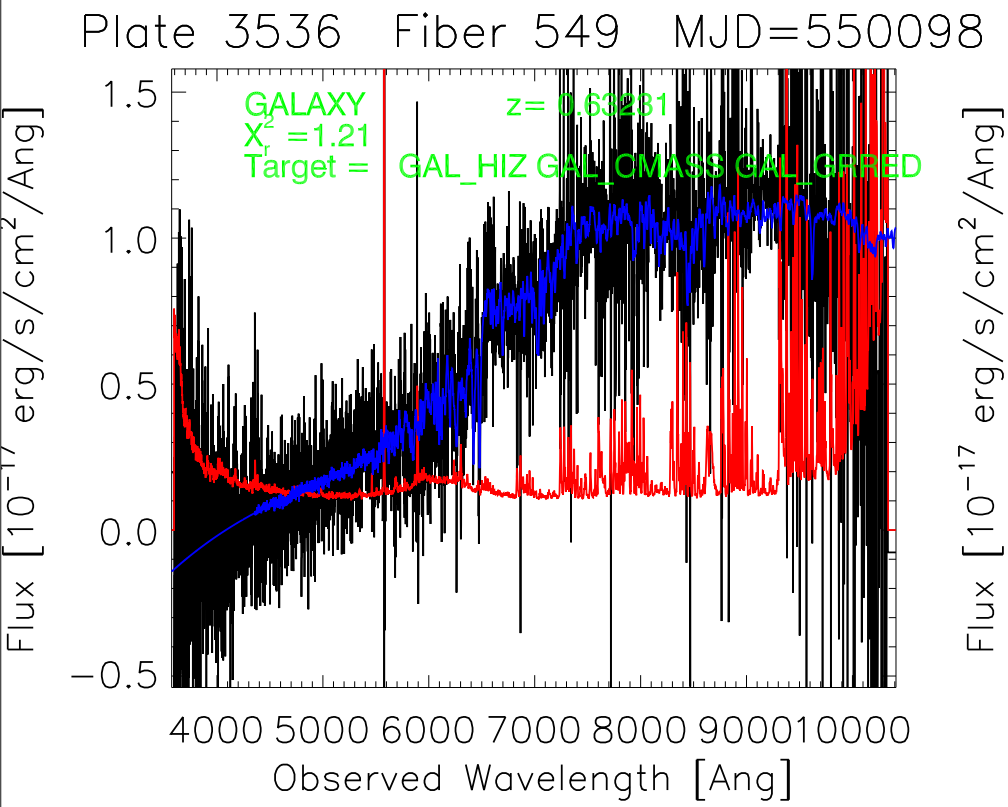
BOSS First Light 14-15 Sep 2009



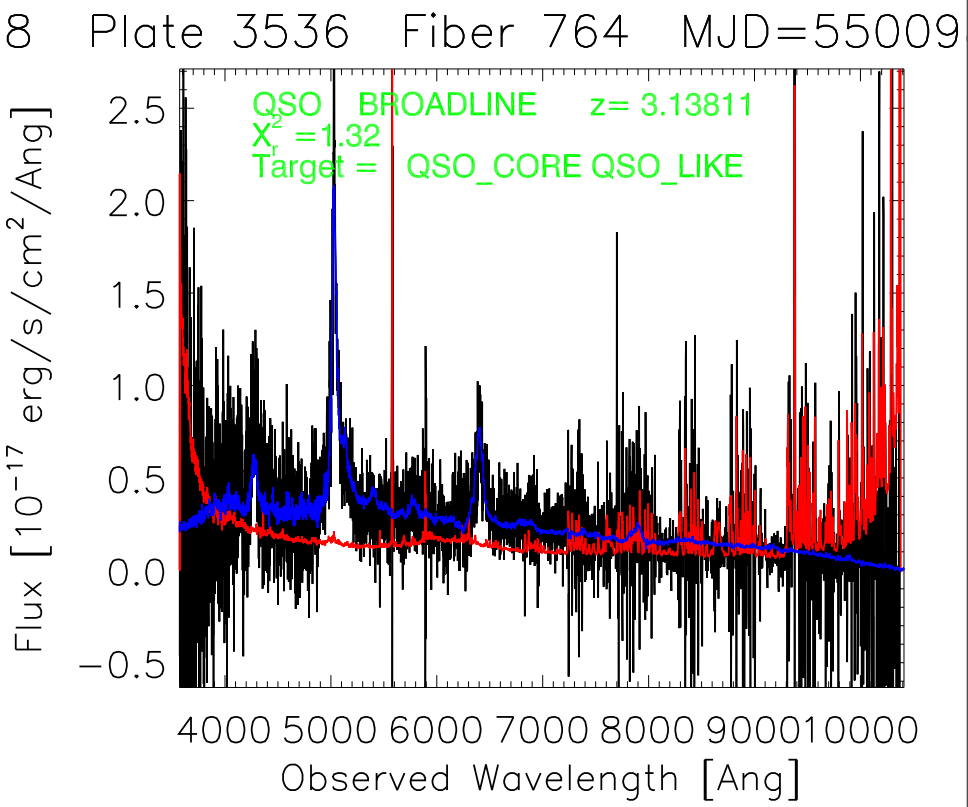
BOSS First Light
14-15 Sep 2009

We're the "noisy data" survey

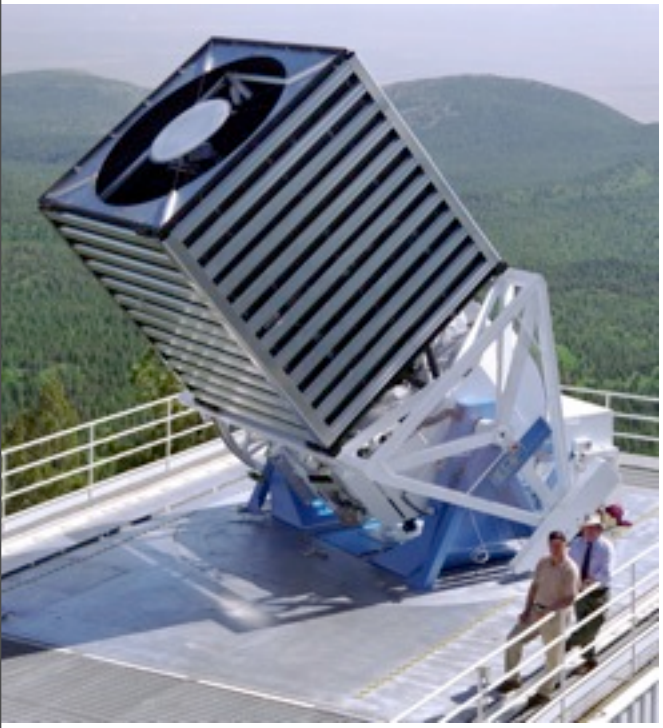
Galaxy z=0.6



QSO z=3.1



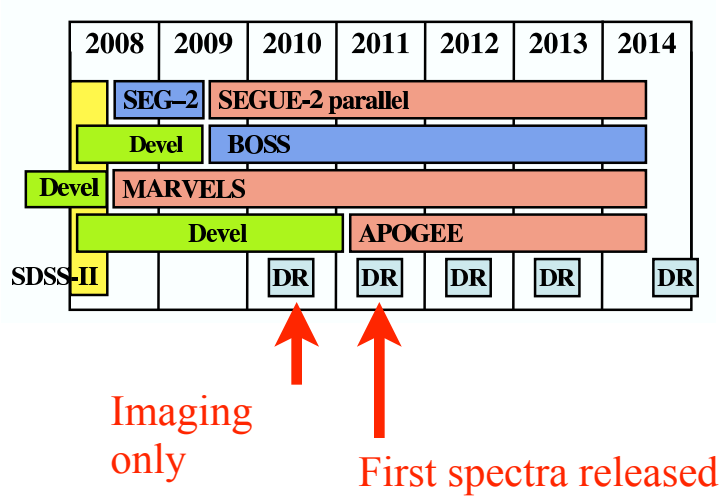
BOSS status



Observing Plan:

Fall 2008 + Fall 2009: Complete imaging survey
Summer 2009: Commissioning
Sep 2009: Begin survey
July 2014: End survey

Public data releases:



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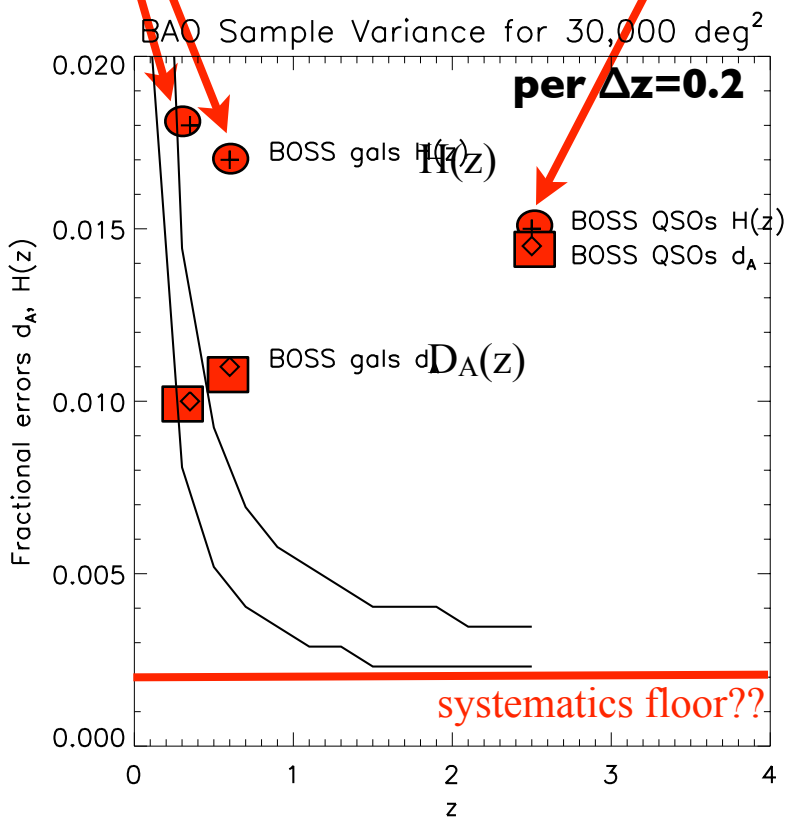
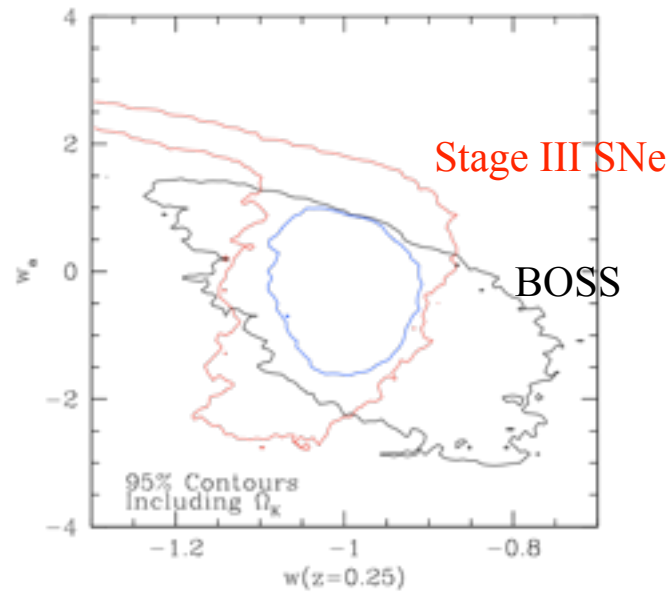


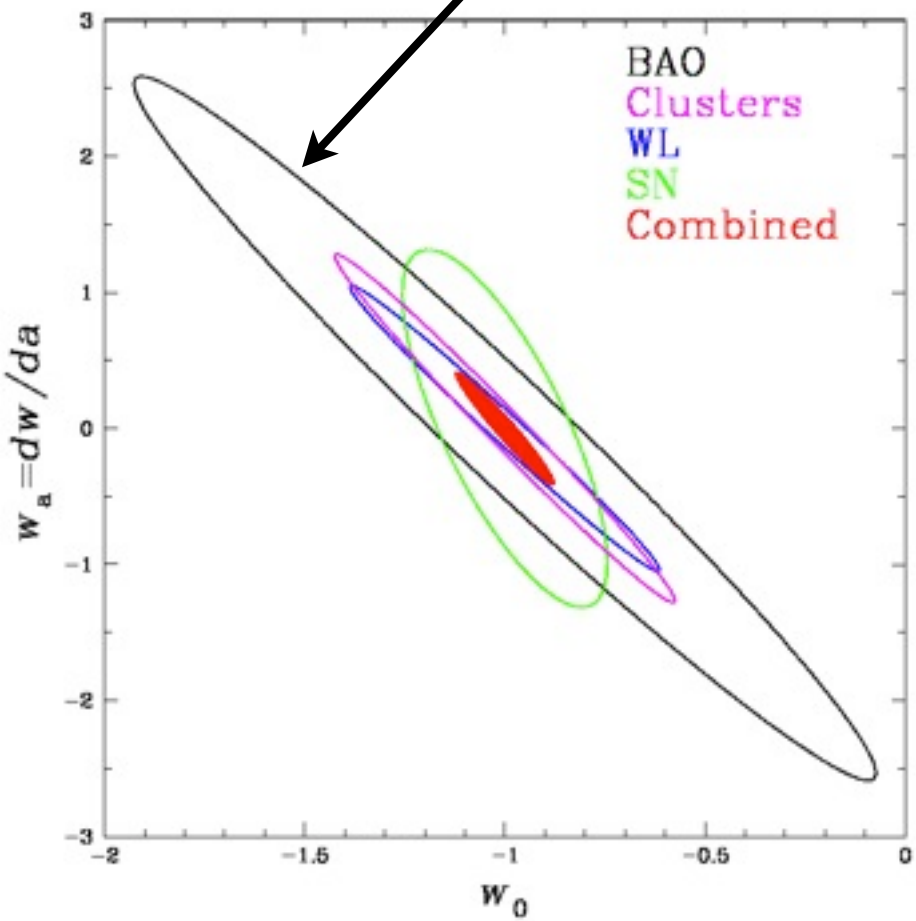


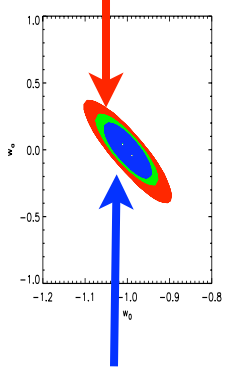
- ➤ BOSS will be near cosmic-variance limit for z<0.7
- ➤ Could improve by √2 by repeating in Southern sky
- ➤ An equivalent photo-z BAO survey would require 50,000 deg^2

BOSS: Baryon Oscillation Spectroscopic Survey Complements Imaging-Only Surveys

BAO from Dark Energy Survey (imaging only)

BAO from BOSS (spectroscopic)





DES + BOSS combined

DETF figure of merit = inverse area of ellipse

$w(z) = w_0 + w_a(1-a)$