BOSS
The Baryon Oscillation Spectroscopic Survey

Nikhil Padmanabhan\(^1\)
for the BOSS Collaboration

\(^1\)Lawrence Berkeley Labs

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Outline

1. BOSS : A next generation BAO experiment

2. BOSS in detail
   - LRGs
   - QSOs
   - Dark Energy Constraints
   - Other Science

3. Simulating BOSS

4. Summary
BOSS: A next generation BAO experiment

- How to do a precision $z < 1$ BAO expt.?
- After SDSS, then what?

- SDSS imaging detects red galaxies to $z \sim 0.8$ (2SLAQ, AGES)
- The SDSS spectrograph still is one of the best wide field MOS.

Percival et al, 2006
BOSS in overview

- $\Omega = 10,000 \text{ deg}^2$
- Fill in SDSS stripes in the south; $8500\text{deg}^2$ in North, $2500\text{deg}^2$ in South
- LRGs: $z \sim 0.1 - 0.7$
- QSOs (Lyman-$\alpha$ forest): $z \sim 2.3 - 3.3$
- 1% $d_A$, 2% $H$ at $z \sim 0.35, 0.6$
- 1.5% $d_A$, $H$ at $z \sim 2.5$
- Leverage existing hardware/software where possible
### BOSS: A brief history

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2006</td>
<td>Competitive proposal to use (upgraded) SDSS telescope for next-generation BAO experiment</td>
</tr>
<tr>
<td>Nov 2006</td>
<td>BOSS proposal selected (from 7) for all dark+grey time for 5 of 6 years</td>
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<td>Nov 2006</td>
<td>First BOSS collaboration meeting (NYU)</td>
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<tr>
<td>Feb 2007</td>
<td>DOE R&amp;D proposal for upgrading SDSS spectroscopic system</td>
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<tr>
<td>Oct 2007</td>
<td>Approval from Sloan foundation</td>
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<tr>
<td>2007 -</td>
<td>Funding proposals in to NSF and DOE</td>
</tr>
<tr>
<td>2009-2014</td>
<td>BOSS spectroscopic survey at APO</td>
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[http://cosmology.lbl.gov/BOSS](http://cosmology.lbl.gov/BOSS)
BOSS : A next generation BAO experiment

**BOSS : As part of SDSS-3**

- **SEGUE-2**: Kinematic and chemical structure from 350,000 stars in the outer Galaxy.
- **APOGEE**: High resolution IR spectroscopy of stars in the Galactic bulge, bar and disk.
- **MARVELS**: Radial velocity planet search around 11,000 stars
- **BOSS**: BAO with 1.5 million LRGs ($z < 0.7$) and 160,000 QSOs ($2.3 < z < 3.3$)
LRGs

- Targeting based on SDSS *gri* photometry
  - $i < 20$
  - Experience from SDSS, 2SLAQ, AGES

- $\sim 150$/deg$^2$, $\bar{n} \sim 3 \times 10^{-4} (h/$Mpc$)^3$

- Sample similar to photometric samples analyzed in NP et al (2007), Blake et al (2007).

- Bias passively evolving; $b(z)D(z) \sim 1.7$ ($\sigma_8 = 0.8$)

- Small-scale clustering well understood in terms of HODs.
LRGs as tracers of LSS

A slice $500\ h^{-1}\ Mpc$ across and $10\ h^{-1}\ Mpc$ thick.

SDSS, $z \sim 0.5$
LRGs as tracers of LSS

A slice $500\, h^{-1} \text{Mpc}$ across and $10\, h^{-1} \text{Mpc}$ thick.

BOSS, $z \sim 0.5$
Modeling LRGs

Photometric selection similar to BOSS LRGs

NP, White, Norberg, Porciani, in prep
LRG forecasts

- Fisher matrix analysis
- Marginalize over shape information, only use acoustic signature. Note that this is conservative!
- $V_{\text{eff}} \sim 5(G_{\text{pc}}/h)^3$
- Measure $d_A$ and $H$ to 1 and 1.5% at $z \sim 0.35, 0.6$
QSOs

- 8000 deg$^2$
- $g = 22$
- 20/deg$^2$
- Selected based on SDSS colors/variability if available

McDonald and Eisenstein, 2006

![Histogram](Redshift vs. Quasar Density)
BAO with QSOs : A cartoon

Reconstructing the 3D density field from skewers

*Not to scale!*

DM
BAO with QSOs: A cartoon

Reconstructing the 3D density field from skewers

*Not to scale!*

SDSS
**BAO with QSOs: A cartoon**

Reconstructing the 3D density field from skewers

*Not to scale!*

![Image of 3D density field reconstruction from skewers](image)
QSO forecasts

- $8000 \text{ deg}^2$
- $g = 22$
- $1.5\%$ in $d_A, H$
- Comparable to other high-z surveys, but with 2.5m telescope

McDonald and Eisenstein, 2006
Hardware upgrades

- Replace $640 \times 3$ arcsec fibers with $1000 \times 2$ arcsec fibers.
- Replace existing red/blue CCDs with (larger & better) LBL/Fairchild/E2V CCDs.
- Replace existing gratings to VPH grisms.
- Increase wavelength range to 3700 - 9800 Å.
Dark Energy Constraints

DETF FoM = 122 (BOSS BAO), 257 (+P(k)), 479 (+WL+SN+CL)
BOSS in Context

Compared with other spectroscopic BAO surveys

<table>
<thead>
<tr>
<th>Project</th>
<th>Redshift</th>
<th>Area (deg$^2$)</th>
<th>$\bar{n}(\times 10^{-4})(\text{Mpc}/h)^3$</th>
<th>FoM</th>
</tr>
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<tbody>
<tr>
<td>Stage II</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>53</td>
</tr>
<tr>
<td>WiggleZ</td>
<td>0.4-1.0</td>
<td>1000</td>
<td>3.0</td>
<td>67</td>
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<tr>
<td>HETDEX</td>
<td>2.0-4.0</td>
<td>350</td>
<td>3.6</td>
<td>70</td>
</tr>
<tr>
<td>WFMOS</td>
<td>0.5-1.3</td>
<td>2000</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>2.3-3.3</td>
<td>300</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>BOSS LRG</td>
<td>0.1-0.8</td>
<td>10000</td>
<td>3.0</td>
<td>86</td>
</tr>
<tr>
<td>+ QSO</td>
<td>2.0-3.0</td>
<td>8000</td>
<td>-</td>
<td>122</td>
</tr>
<tr>
<td>+ Stage III</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>331</td>
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</tbody>
</table>
More Cosmology

- Precision measurements of $H_0$ (1%), $\Omega_K$ (0.2%)
- Constrains $D(2)/D(1000)$ and $D(0.5)/D(1000)$ to 0.6% and 1% within $\Lambda$CDM
- Improved large scale structure constraints (250,000 modes with $k < 0.2$)
- Improved measurements from the Lyman-$\alpha$ forest
- Improved measurements of neutrino masses
- A S/N=200 measurement of $\xi_{gm}$ from galaxy-galaxy lensing, direct probe of $D(z)$
- Constrain $f_{nl} < \sim 10$
- .....
Galaxy Formation/ Evolution

- Evolution of massive galaxies
- Improved QSO clustering measurements at $z > 2$
- Piggy-back program will double $N_{QSO}$ with $z > 3.6$
- Synergy with next generation imaging surveys (eg. Pan-STARRS) [cross-correlation studies, galaxy-galaxy lensing]
- Serendipitous stellar studies (from QSO targeting)
- Spectroscopic detection of galactic scale strong lensing systems
- Projects we haven’t thought of......
Simulating BOSS

- $40 \times 8 \text{ (Gpc/h)}^3$ simulations
- $80 \times \text{BOSS}$
- Low resolution simulations
- Galaxies populated according to density to match clustering of LRGs
Anisotropic Clustering

- Isotropic clustering constrains
  \[ D_V \equiv d_A^{2/3} / H^{1/3} \]

- Warp box holding \( D_V \) constant; consider 5,10% warps

- Amplitude change, not shift
What’s next for BOSS?

- **July, 2008:** SDSS-II ends, SDSS-III begins
- Complete 2000 deg$^2$ on imaging in the South in Fall 2008.
- Upgrade spectrographs Summer 08/09.
- LRG/QSO spectroscopy Fall 2009 - 2014

At which point, we should know....

- $w_p = -???.?? \pm 0.03$, $w_a =???.?? \pm 0.28$
- $h = 0.?? \pm 0.008$, $\Omega_K = 0.?? \pm 0.002$
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  - \( w_p = -??..?? \pm 0.03, w_a = ??..?? \pm 0.28 \)
  - \( h = 0.?? \pm 0.008, \Omega_K = 0.?? \pm 0.002 \)
BOSS in a nutshell

- On the SDSS 2.5m telescope
- Using LRGs between $z=0$ to 0.7, 1% distance constraints
- Using the Lyman-$\alpha$ forest, $z=2.3$ to 3.3, 1.5% distance constraints
- Within a factor of 2 of a low-$z$ cosmic-variance BAO measurement
- DETF FoM = 122, 331 (with Stage III)
- Lots of auxiliary science