Brief Overview

• SDSS Basics:
  - 5 band photometric survey ($u', g', r', i', z'$), running from near IR to near UV
  - Follow-up spectroscopy (640 fibers fed to 2 spectrographs)
  - Data Release 4: 6670 deg$^2$ & 180 million objects in photometric survey; 4783 deg$^2$ & 673,000 galaxies in spectroscopic survey

• 3 Projects:
  - Baryon Oscillations with Luminous Red Galaxies (Eisenstein et al., astro-ph/0501171)
  - Cosmic Magnification with Photometric Galaxies & Quasars (RS et al, astro-ph/0504510)
  - Cluster Mass Profiles from Weak Lensing (Sheldon & Johnston et al., astro-ph/05?????)
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• 3 Projects:
  ⋆ Baryon Oscillations with Luminous Red Galaxies (Eisenstein et al. astro-ph/0501171) \(100 \, h^{-1}\text{Mpc}\)
  ⋆ Cosmic Magnification with Photometric Galaxies & Quasars (RS et al. astro-ph/0504510) \(0.06 - 10 \, h^{-1}\text{Mpc}\)
  ⋆ Cluster Mass Profiles from Weak Lensing (Sheldon & Johnston et al. astro-ph/05?????) \(0.01 - 1 \, h^{-1}\text{Mpc}\)
Baryon Oscillations
Baryon Oscillations

- **Magic Time:** After matter-radiation equality, but before recombination $(1000 < z < 10,000)$

- Dark matter: dominates expansion, falling into gravitational potentials set up during inflation

- Photons: Oscillating in dark matter potentials

- Baryons: Still coupled to photons
Baryon Oscillations

- Coupled baryons act as a drag on photon fluid (extra mass on a spring)
- Compression phase stronger, rarefaction weaker
- After recombination, oscillations imprinted on matter power spectrum
- Strength depends on $\Omega_b/\Omega_M$
- Physical ruler at multiple redshifts
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Wayne Hu
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White (astro-ph/0507307)
Finding the Oscillations

- Large physical scale requires wide, deep spectroscopic survey

- Choose Luminous Red Galaxy sample

- Volume-limited to $z \sim 0.4$

- Redshift-space correlation function; peaks collapse to single feature

Eisenstein et al. (astro-ph/0501171)
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Improved Cosmological Constraints

- Including baryon peak improves constraints on $w$ & $\Omega_m h^2$ by factor of 2
- No extra information on spectral index $n$
- Removing flat prior: $\Omega_K = -0.010 \pm 0.009$ vs $-0.045 \pm 0.032$ without LRGs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WMAP + SDSS Main</th>
<th>+ LRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w$</td>
<td>$-0.92 \pm 0.30$</td>
<td>$-0.80 \pm 0.18$</td>
</tr>
<tr>
<td>$\Omega_M h^2$</td>
<td>$0.145 \pm 0.014$</td>
<td>$0.135 \pm 0.008$</td>
</tr>
<tr>
<td>$\Omega_m$</td>
<td>$0.329 \pm 0.074$</td>
<td>$0.326 \pm 0.037$</td>
</tr>
<tr>
<td>$h$</td>
<td>$0.679 \pm 0.100$</td>
<td>$0.648 \pm 0.045$</td>
</tr>
<tr>
<td>$n$</td>
<td>$0.984 \pm 0.033$</td>
<td>$0.98 \pm 0.035$</td>
</tr>
</tbody>
</table>
Cosmic Magnification
Two Effects of Gravitational Lensing

- Weak lensing of background sources introduces **shear** and **magnification**
Two Effects of Gravitational Lensing

- Shear distorts source image shapes (curl-free vector field)
- Galaxy-galaxy lensing & cosmic shear
Two Effects of Gravitational Lensing

- Magnification ($\mu$) increases the angular size of source images.
- Increases flux (amplification) but decreases density on the sky (dilution).
Quantifying Cosmic Magnification I

Start with flux-limited background sample (e.g. QSOs):

\[ n_0(f) \, df = a_0 \, f^{-s(f)} \, df \]  \hspace{1cm} (1)

Lens images through foreground structure (e.g. local galaxies) with magnification \( \mu \)

\[ n(f) \, df = \frac{1}{\mu} \, n_0 \left( \frac{f}{\mu} \right) \, \frac{df}{\mu} \]

\[ = \mu^{s(f)-2} \, n_0(f) \, df \]  \hspace{1cm} (2)

Converting this to magnitude space, we get

\[ N(m) \, dm = \mu^{2.5 \, s(m)-1} \, N_0(m) \, dm \]

\[ = \mu^{\alpha(m)-1} \, N_0(m) \, dm \]  \hspace{1cm} (3)
Quantifying Cosmic Magnification II

• If we are in the weak lensing regime ($\mu \approx 1$),

$$w_{GQ}(\theta) = 12\pi^2 \Omega_M (\alpha(m) - 1) \int d\chi \, dk \, k \, K(k, \theta, \chi) \, P_{gm}(k, \chi)$$

$$= (\alpha(m) - 1) \times w_0(\theta),$$

where $K$ depends on the foreground and background redshift distributions and $P_{gm}(k)$ is the galaxy-dark matter power spectrum.

• For $\alpha(m) > 1$, increasing amplification outweighs the dilution effect, yielding a positive cross-correlation. For $\alpha(m) < 1$, dilution wins and the cross-correlation is negative.

• Lensing signal amplitude is much smaller than intrinsic clustering, so redshift segregation is vital.
Controversy

- First lensing motivated measurements in late 1980s and early 1990s
  - Lick, IRAS & APM galaxies, Abell & Zwicky clusters
  - optical UVX and radio selected QSOs

- More recently, Guimaraes, Myers & Shanks (2003) used 2dF QSOs + APM & SDSS galaxy groups

- Consistently detect signal $\sim 10 \times$ the expected lensing effect
The Four Horsemen

- Photometric Calibration
  - Small amplification effect requires excellent photometry
  - Photographic plates not up to the challenge

- Uniform Selection Function
  - Photographic plates have variable depth of field
  - Spectroscopic surveys require detailed selection function

- Redshift Overlap
  - Physical clustering dominates lensing signal
  - Require either spectroscopy or photometric redshifts for each object

- Object Density
  - Poisson errors dominate
  - When object density is low, only systematic signal is detected
The Data

- SDSS DR3 photometric data
  - 5000 square degrees (1/8 total sky)
  - North Galactic Cap & 3 South Galactic Stripes
- Remove areas with poor seeing (> 1″.4) and high Galactic extinction. Also block out regions around bright ($r' < 16$) galaxies and saturated stars ⇒ 3800 square degrees
- 13 million galaxies with $17 < r' < 21$
  - Mean redshift $z \sim 0.3$
  - Maximum redshift $z \sim 0.75$
- 195,000 photometrically selected QSOs with $17 < g' < 21$. Use photometric redshifts to select $1 < z < 2.2$
Photometric QSO Selection

- Traditional QSO selection involves cuts in 2-D projections

- Kernel Density Estimation (KDE) uses full 4-D color space
  - 2 training sets: QSOs & stars
  - compute distance in color space to assign new objects

- SDSS spectroscopic selection
  85% efficient for $i' < 19$

- KDE selection $> 95\%$ efficient for $g' < 21 \Rightarrow 10\times$ density

Richards et al. (2004)
QSO Photometric Redshifts

- QSO Spectrum: Power-law + broad emission lines
- Photometric redshifts driven by redshifting of emission lines through SDSS filters
- Calculate probability of photo-z as a function of $z \Rightarrow$ upper and lower redshift bounds and probability within bounds
- For $1 < z < 2.2$, mean probability $\sim 0.85$

Weinstein et al. (2004)
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Measurement in $g'$

- Select 5 magnitude bins in $g'$: 
  $17 < g' < 19$, $19 < g' < 19.5$, 
  $19.5 < g' < 20$, $20 < g' < 20.5$, 
  $20.5 < g' < 21$

- Calculate $\langle \alpha - 1 \rangle$ in each bin:

$$\langle \alpha - 1 \rangle = \frac{\int N(m)(\alpha(m) - 1)}{\int N(m)} \quad (5)$$

- Expect to see positive correlation for $g' < 19.5$ and negative correlation for $g' > 20$
Measurement in $g'$

- Select 5 magnitude bins in $g'$:
  
  17 < $g'$ < 19, 19 < $g'$ < 19.5, 
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  20.5 < $g'$ < 21

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\[
\langle \alpha - 1 \rangle = \frac{\int N(m)(\alpha(m) - 1)}{\int N(m)} \quad (6)
\]

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Optimal Signal

- Magnitude bin measurements verify amplitude of expected signal and variation with $\langle \alpha - 1 \rangle$

- $\langle \alpha - 1 \rangle$ for full QSO sample very close to zero

- To extract full lensing significance, use second moment:
  - Re-calculate estimator weighting each QSO by $\alpha(m) - 1$
  - Expected signal:
    \[
    w_{GQ, O}(\theta) = \langle (\alpha - 1)^2 \rangle \times w_0(\theta) \tag{7}
    \]

- Instead of canceling, positive and negative correlations add coherently
Optimal $g'$

- 105,000 QSOs
- $8\sigma$ detection of lensing against null
- Excellent match to expected signal
- For $z \sim 0.3$, detecting lensing on scales from $60 \, h^{-1} \, \text{kpc}$ to $10 \, h^{-1} \, \text{Mpc}$
A Word of Warning

Cluster Lensing

The following is still preliminary work. These plots should be taken as such.
Cluster Lensing
Cluster Lensing

- Measure tangential shear relative to cluster center
- Average shear is proportional to enclosed projected mass gradient ($\Delta \Sigma$)
Cluster Finding

- **MaxBCG** Method: Brightest Cluster Galaxies tend to have same color and passive evolution

- Find galaxies with BCG colors and look for nearby galaxies with same color and fainter magnitude

- Photometric redshifts: $\Delta z \sim 0.01$

- Current data set: 600,000 “clusters”; 10,000 w/ $N_{gal} \geq 10$
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Jim Annis
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Expectations from Simulations

Navarro, Frenk, & White (1997)
Expectations from Simulations

Navarro, Frenk, & White (1997)
Results

Sheldon & Johnston
Mass Profile

\[ M_{\text{vir}} = 32.7 \pm 3 \times 10^{2} \, h^{-1} M_{\odot} \]
\[ R_{\text{vir}} = 0.61 \pm 0.02 \, h^{-1} \text{Mpc} \]
Halo Occupation Distribution

Sheldon & Johnston
Halo Occupation Distribution

Kravtsov (2004)

Sheldon & Johnston
Summary

SDSS

- Uniform 5 color photometry over 8000 deg$^2$, 200 million objects
- >750,000 galaxy spectra covering >5000 deg$^2$
- SDSS II will add a few hundred deg$^2$ & fill in spectroscopy

Baryon Oscillations

- Large volume from LRGs ⇒ high S/N detection of baryon oscillation at 100 $h^{-1}$ Mpc
- Establishes standard ruler for future deep spectroscopic surveys
Summary

Cosmic Magnification

- Uniform photometric QSO data set yields an $8\sigma$ detection of magnification & matches predicted amplitude and angular shape
- Magnification with galaxies or QSOs will complement future cosmic shear surveys

Cluster Lensing

- Mean cluster mass profile matches NFW halo profile as predicted from simulations
- Halo Occupation Distribution from lensing matches semi-analytic predictions