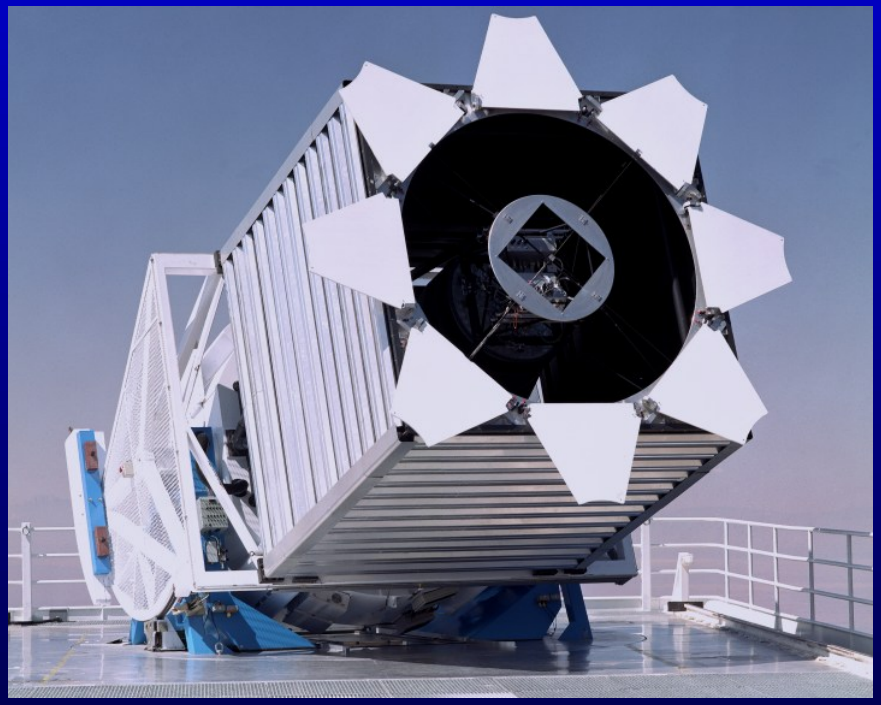

SDSS Large Scale Structure Review

Ryan Scranton

3 August 2005

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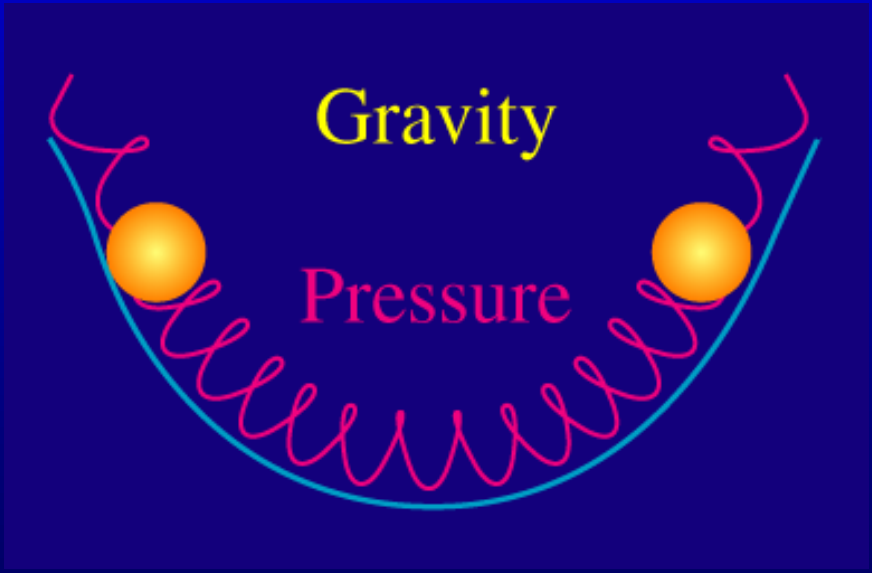
- 3 Projects:
  - ⋆ Baryon Oscillations with Luminous Red Galaxies (Eisenstein et al. `astro-ph/0501171`) **100 h^{-1}Mpc**
  - ⋆ Cosmic Magnification with Photometric Galaxies & Quasars (RS et al. `astro-ph/0504510`) **0.06 - 10 h^{-1}Mpc**
  - ⋆ Cluster Mass Profiles from Weak Lensing (Sheldon & Johnston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

Baryon Oscillations

Baryon Oscillations

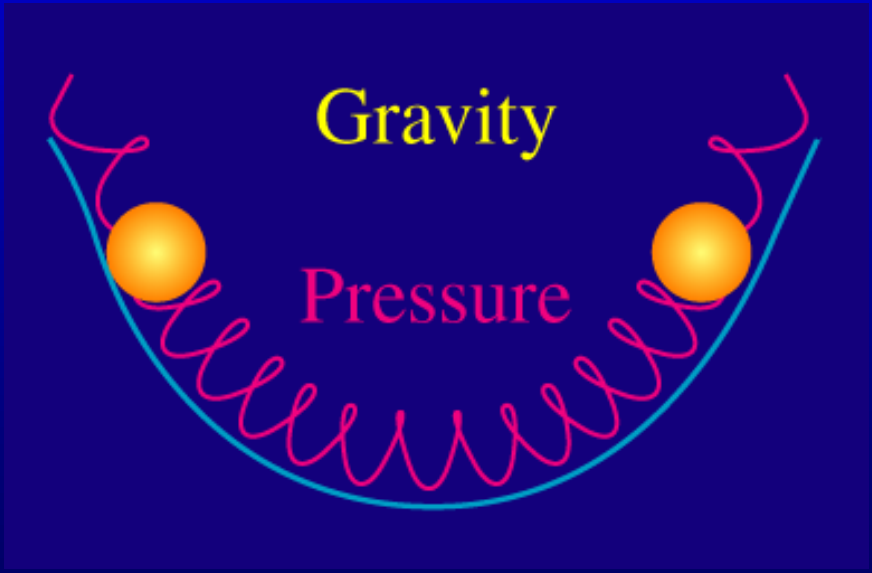
- **Magic Time:** After matter-radiation equality, but before recombination ($1000 < z < 10,000$)
- Dark matter: dominates expansion, falling into gravitational potentials set up during inflation
- Photons: Oscillating in dark matter potentials
- Baryons: Still coupled to photons



Wayne Hu

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 Ω_b/Ω_M
- Physical ruler at multiple redshifts



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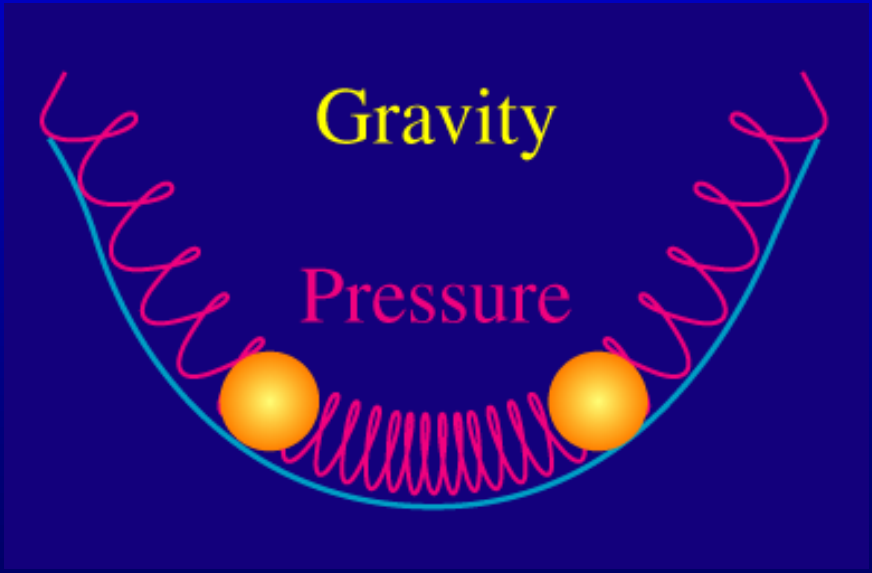

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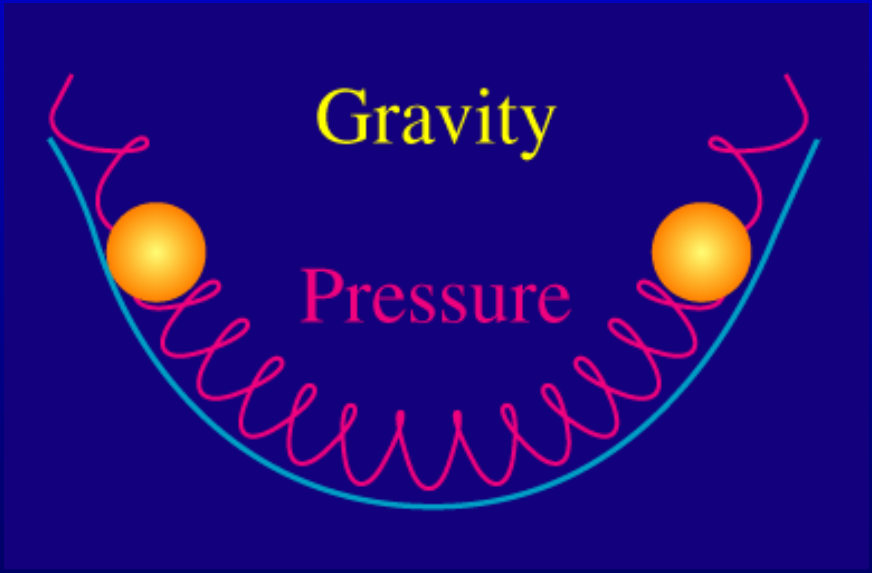

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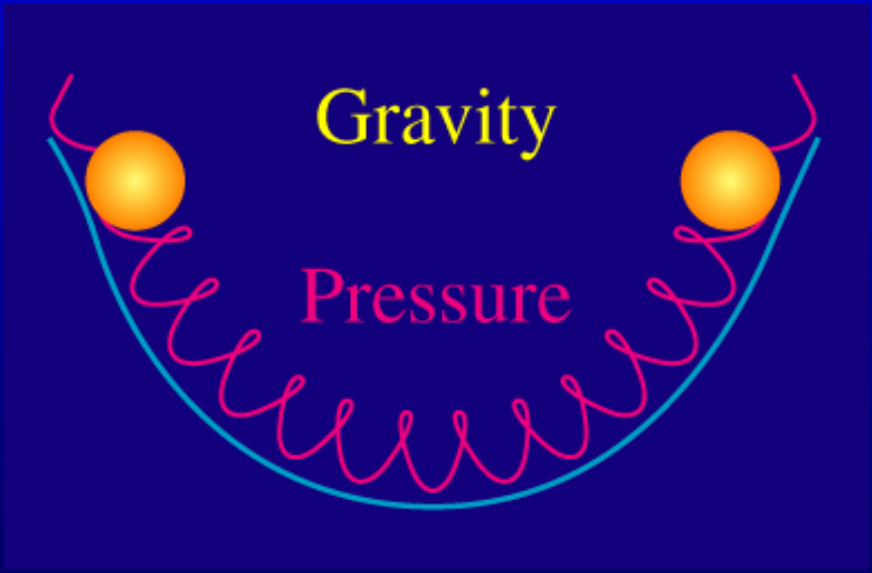

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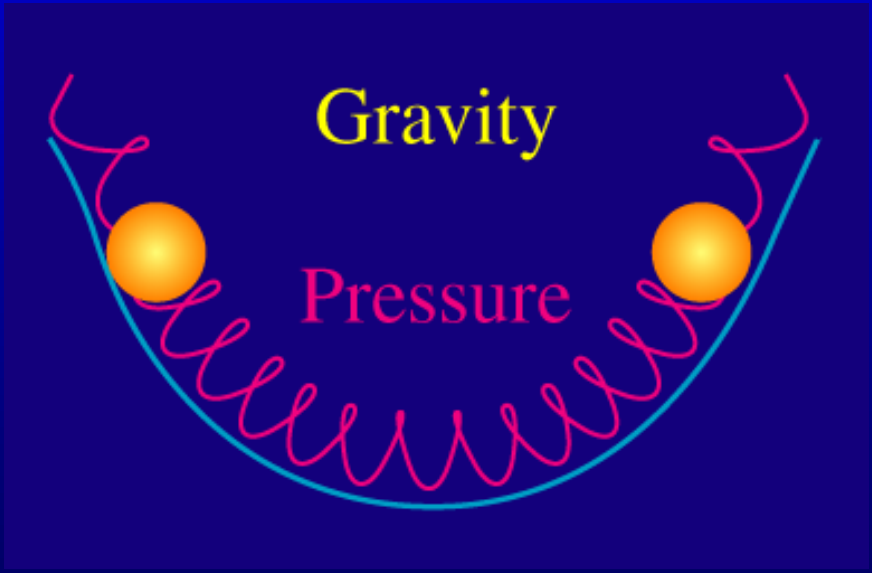

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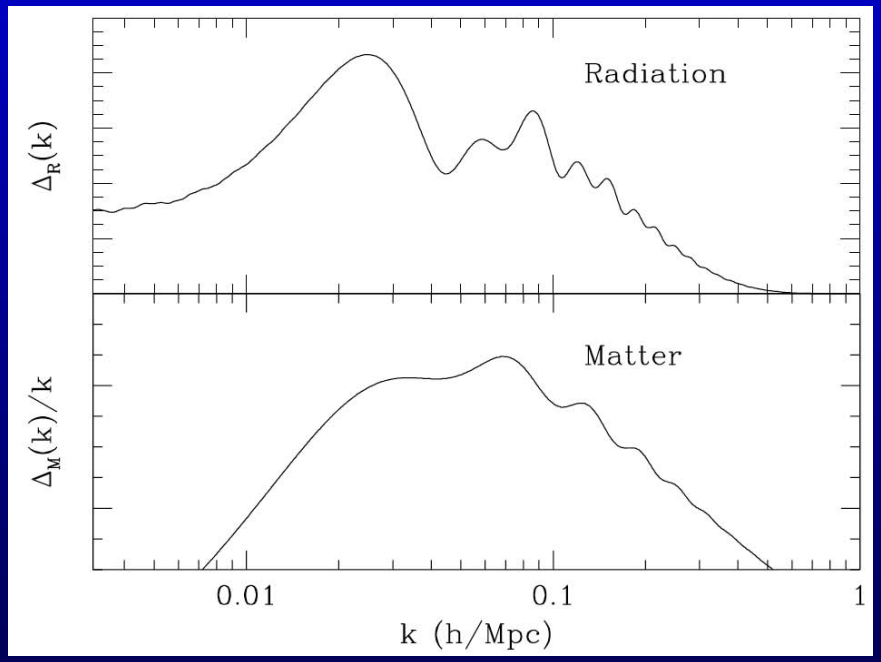
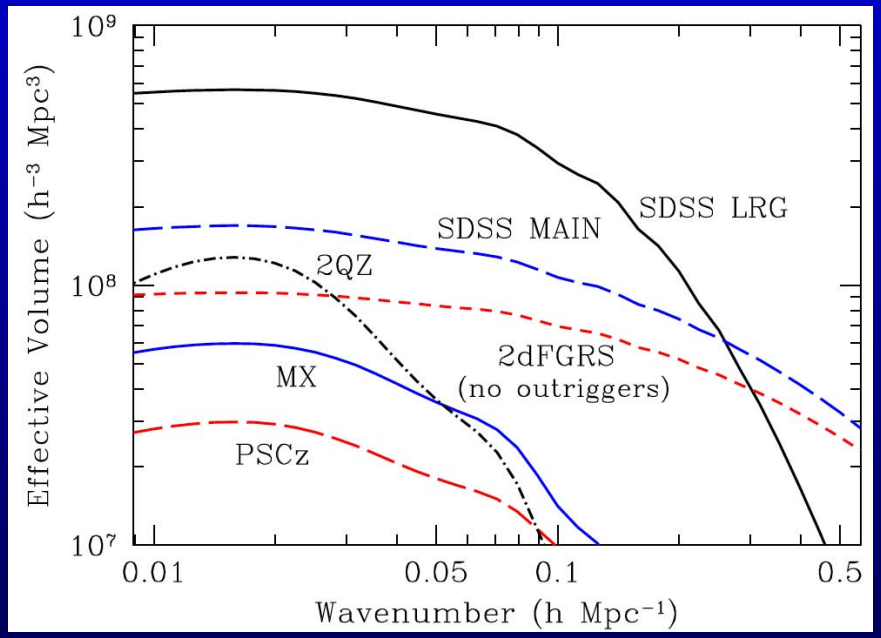


White (`astro-ph/0507307`)

Finding the Oscillations

- Large physical scale requires wide, deep spectroscopic survey
- Choose **L**uminous **R**ed **G**alaxy 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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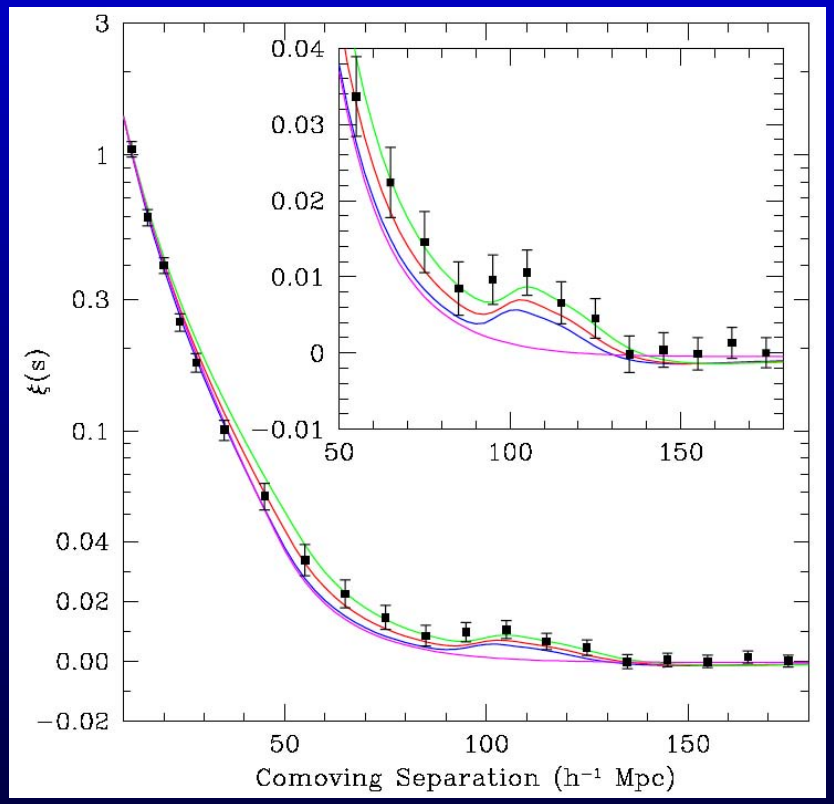

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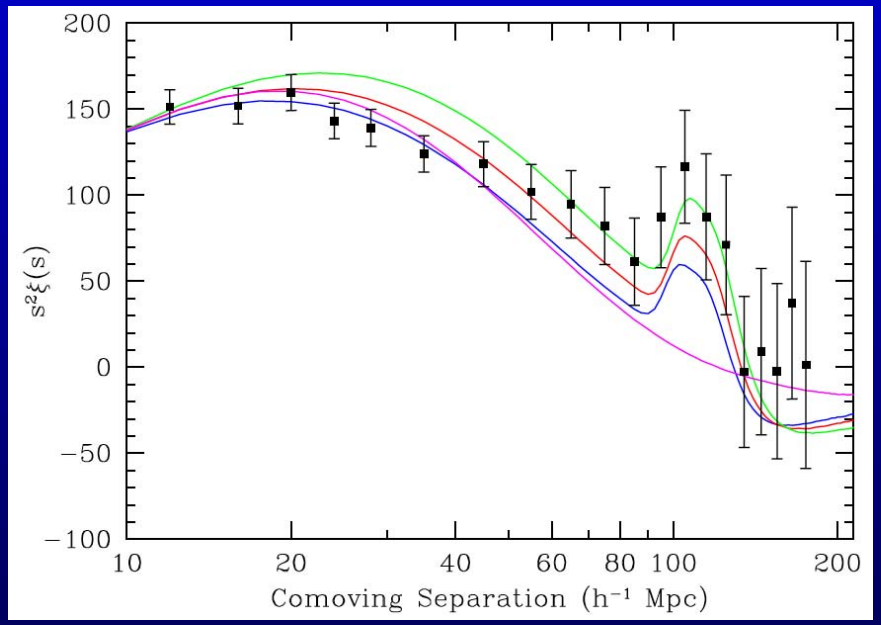


Eisenstein et al. (astro-ph/0501171)

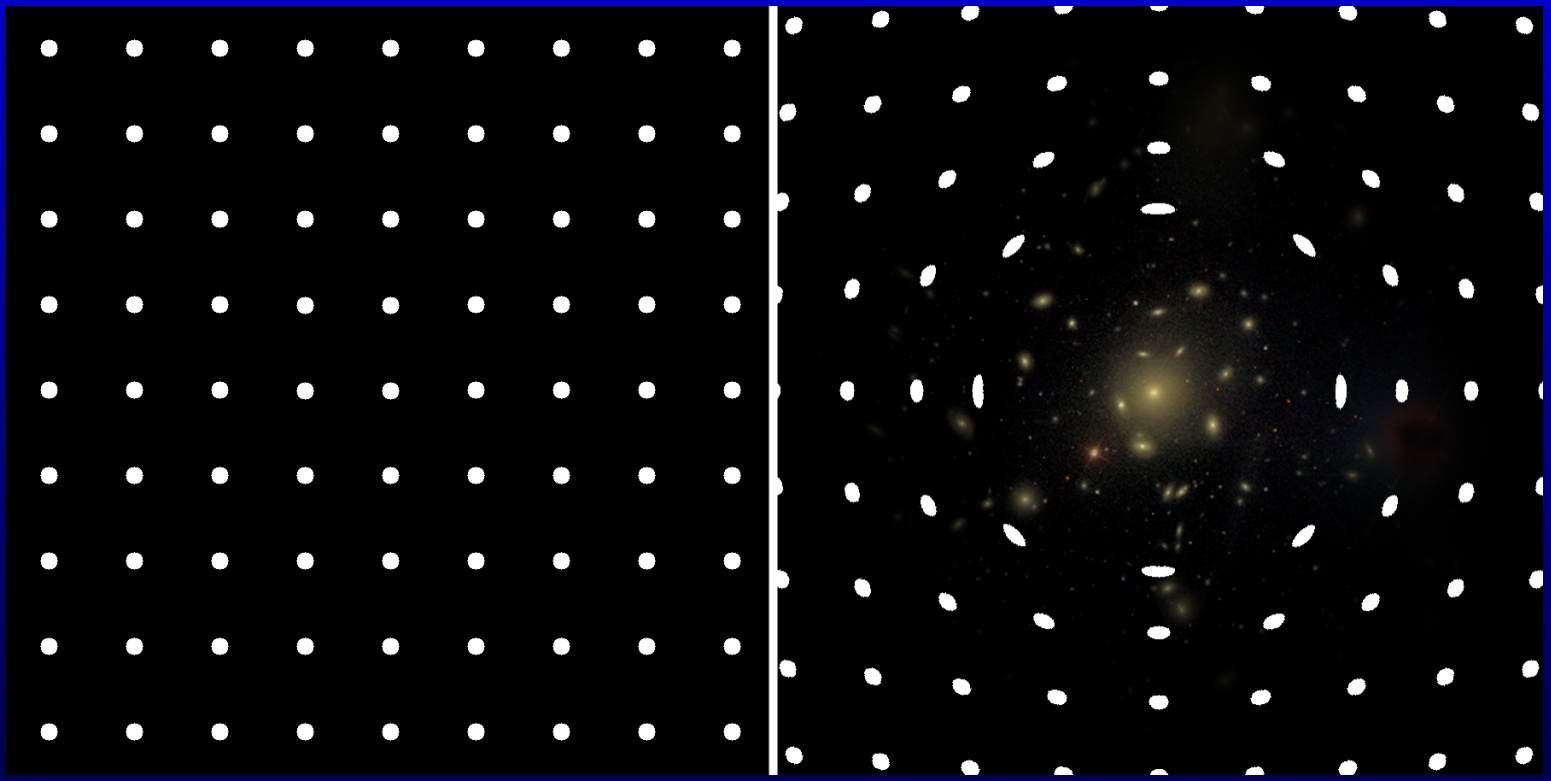
Improved Cosmological Constraints

- 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 ± 0.032 without LRGs

Parameter	WMAP + SDSS Main	+ LRG
w	-0.92 ± 0.30	-0.80 ± 0.18
$\Omega_M h^2$	0.145 ± 0.014	0.135 ± 0.008
Ω_m	0.329 ± 0.074	0.326 ± 0.037
h	0.679 ± 0.100	0.648 ± 0.045
n	0.984 ± 0.033	0.98 ± 0.035

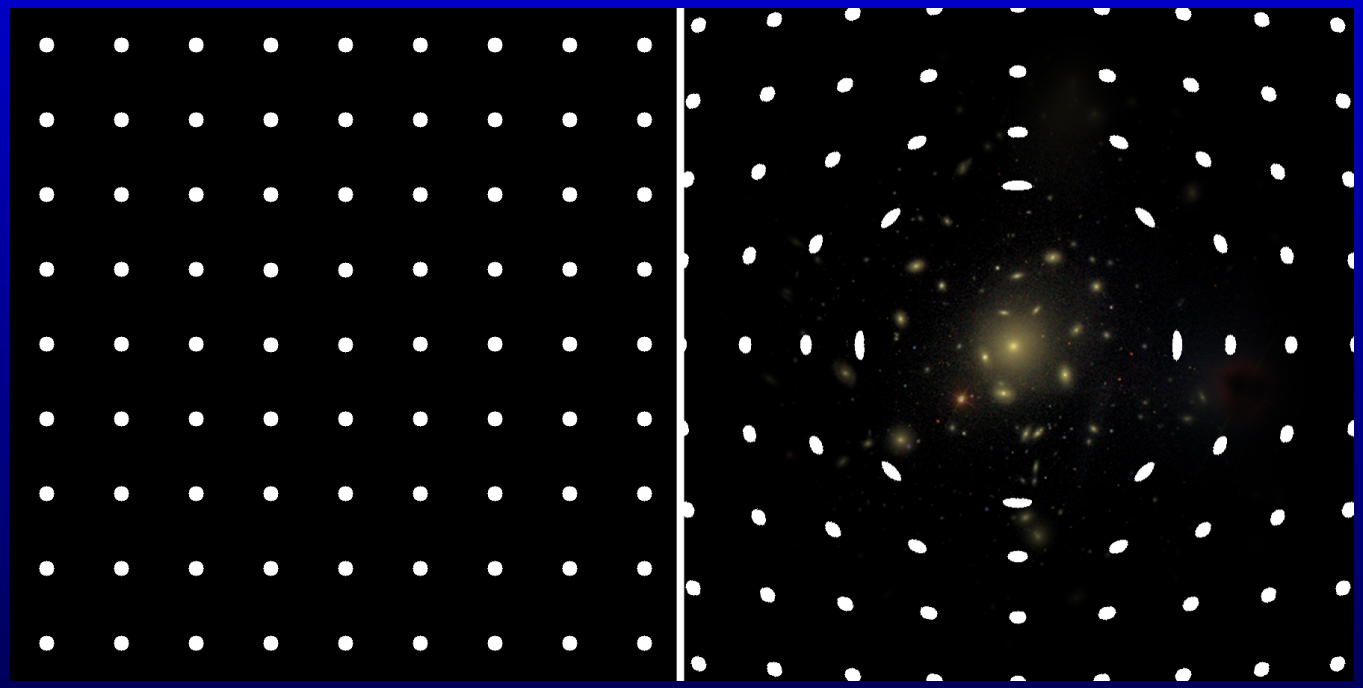
Cosmic Magnification

Two Effects of Gravitational Lensing



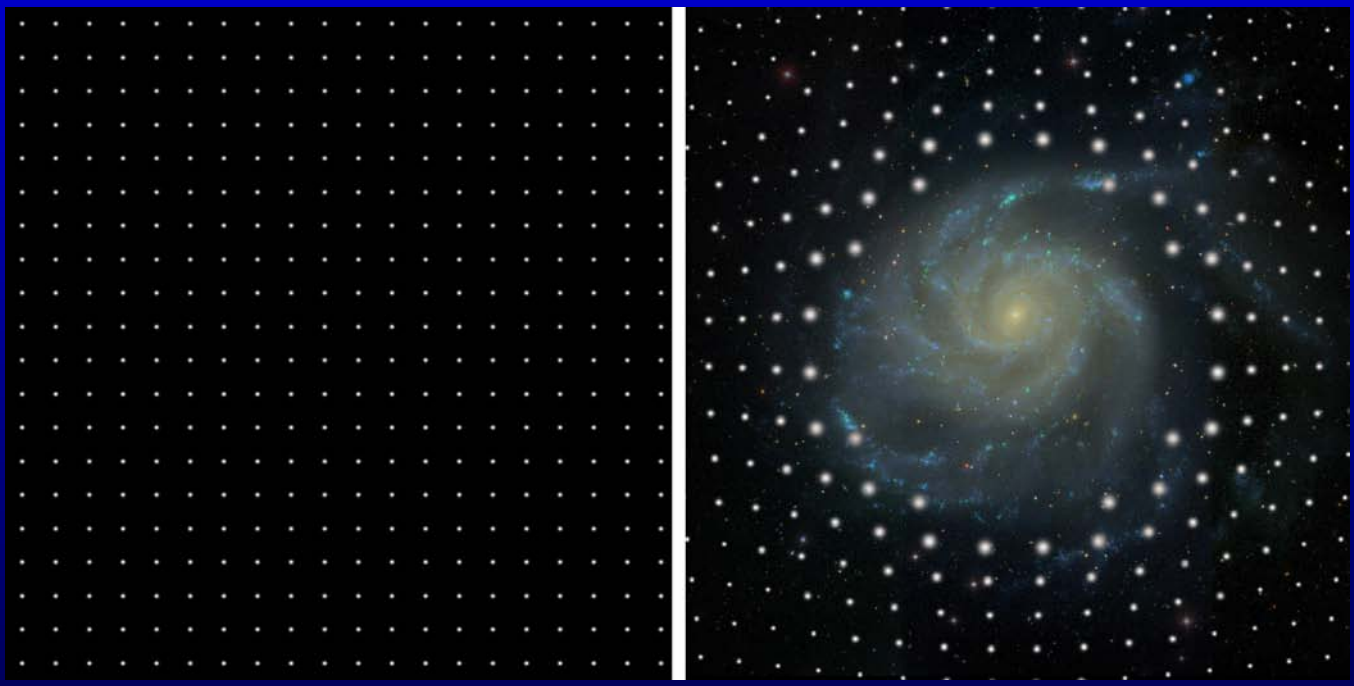
- Weak lensing of background sources introduces **shear** and **magnification**

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 (μ) 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):

$$\mathrm{n}_0(f)\,\mathrm{d}f = a_0\, f^{-s(f)}\,\mathrm{d}f \tag{1}$$

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

$$\begin{aligned} \mathrm{n}(f)\,\mathrm{d}f &= \frac{1}{\mu}\,\mathrm{n}_0\left(\frac{f}{\mu}\right)\frac{\mathrm{d}f}{\mu} \\ &= \mu^{s(f)-2}\,n_0(f)\,\mathrm{d}f \end{aligned} \tag{2}$$

Converting this to magnitude space, we get

$$\begin{aligned} \mathrm{N}(m)\,\mathrm{d}m &= \mu^{2.5\,s(m)-1}\,\mathrm{N}_0(m)\,\mathrm{d}m \\ &= \mu^{\alpha(m)-1}\,\mathrm{N}_0(m)\,\mathrm{d}m \end{aligned} \tag{3}$$

Quantifying Cosmic Magnification II

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

$$\begin{aligned} w_{\rm GQ}(\theta) &= 12\pi^2\Omega_M(\alpha(m)-1)\int {\rm d}\chi\, {\rm d}k\, k\, \mathcal{K}(k,\theta,\chi)\, P_{gm}(k,\chi) \\ &= (\alpha(m)-1)\, \times w_0(\theta), \end{aligned} \tag{4}$$

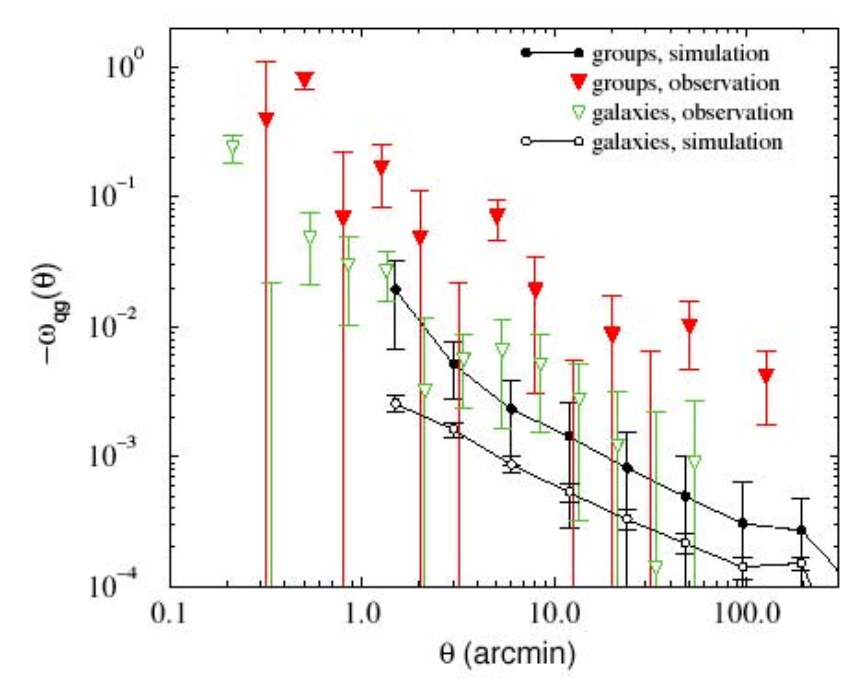
  where $\mathcal{K}$ depends on the foreground and background redshift distributions and $P_{gm}(k)$ is the galaxy-dark matter power spectrum.

- 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

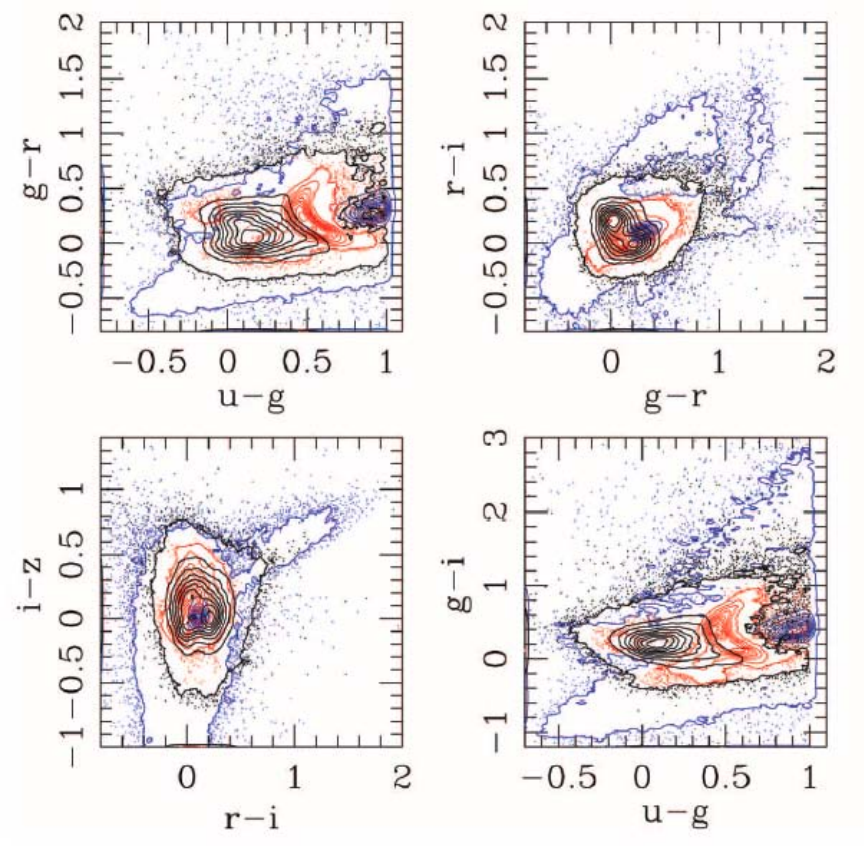
- Photometric Calibration
  - Small amplification effect requires excellent photometry
  - Photographic plates not up to the challenge
- Uniform Selection Function
  - Photographic plates have variable depth of field
  - Spectroscopic surveys require detailed selection function
- Redshift Overlap
  - 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 $\Rightarrow$ 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

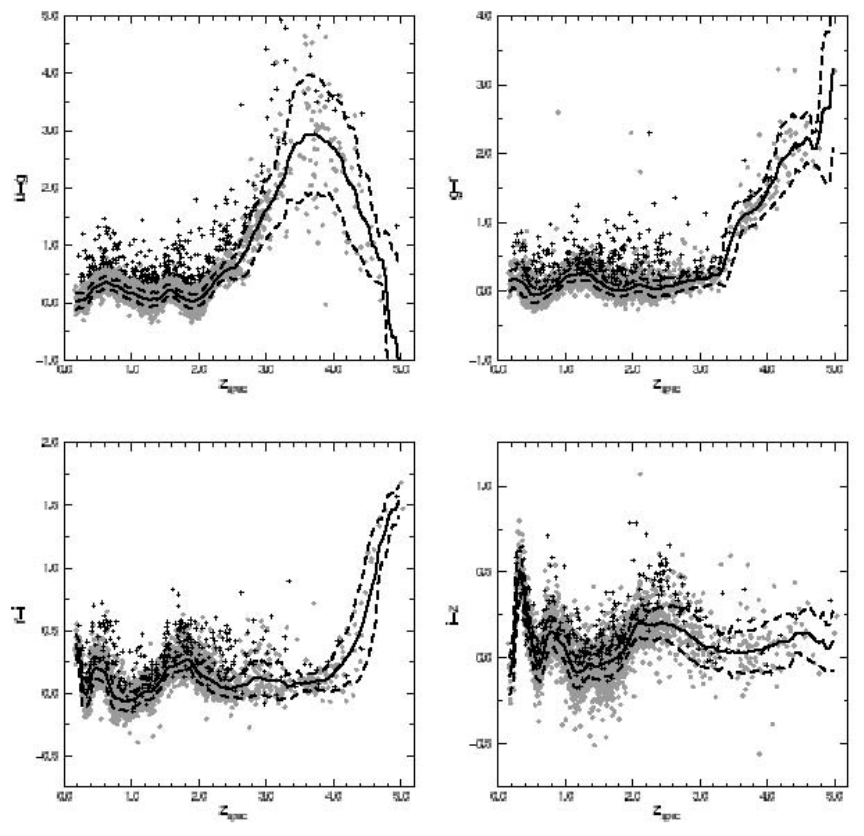
- Traditional QSO selection involves cuts in 2-D projections
- Kernel Density Estimation (KDE) uses full 4-D color space
  - ⋆ 2 training sets: QSOs & stars
  - ⋆ compute distance in color space to assign new objects
- SDSS spectroscopic selection 85% efficient for $i' < 19$
- KDE selection $> 95\%$ 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 ~ 0.85



Weinstein et al. (2004)

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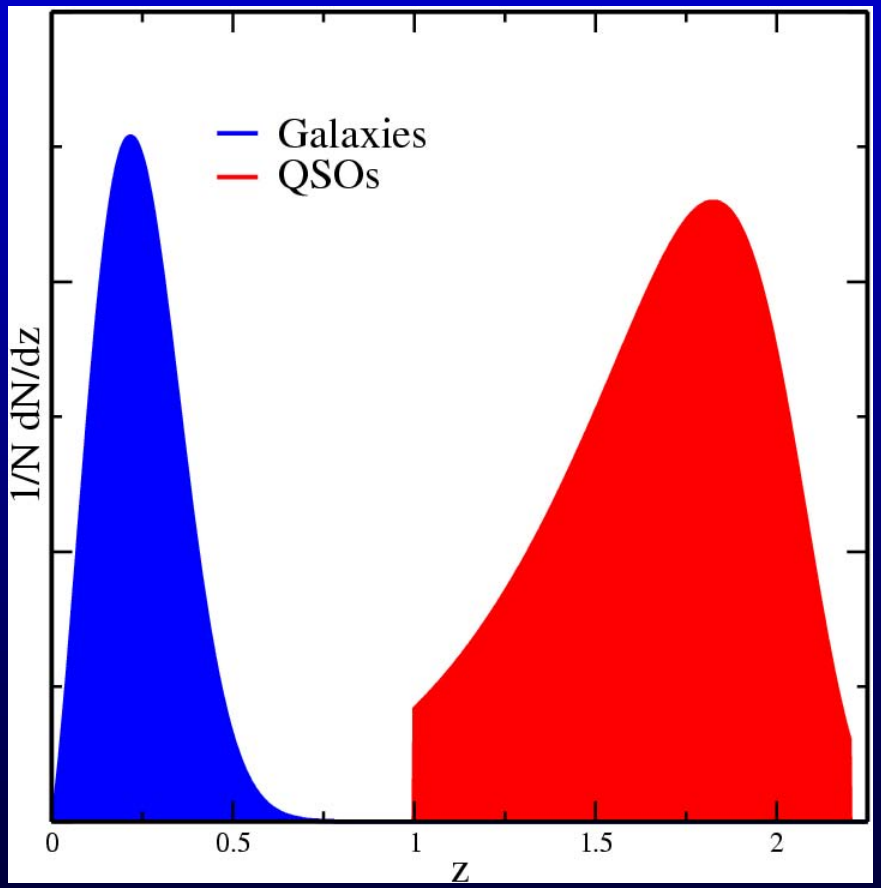


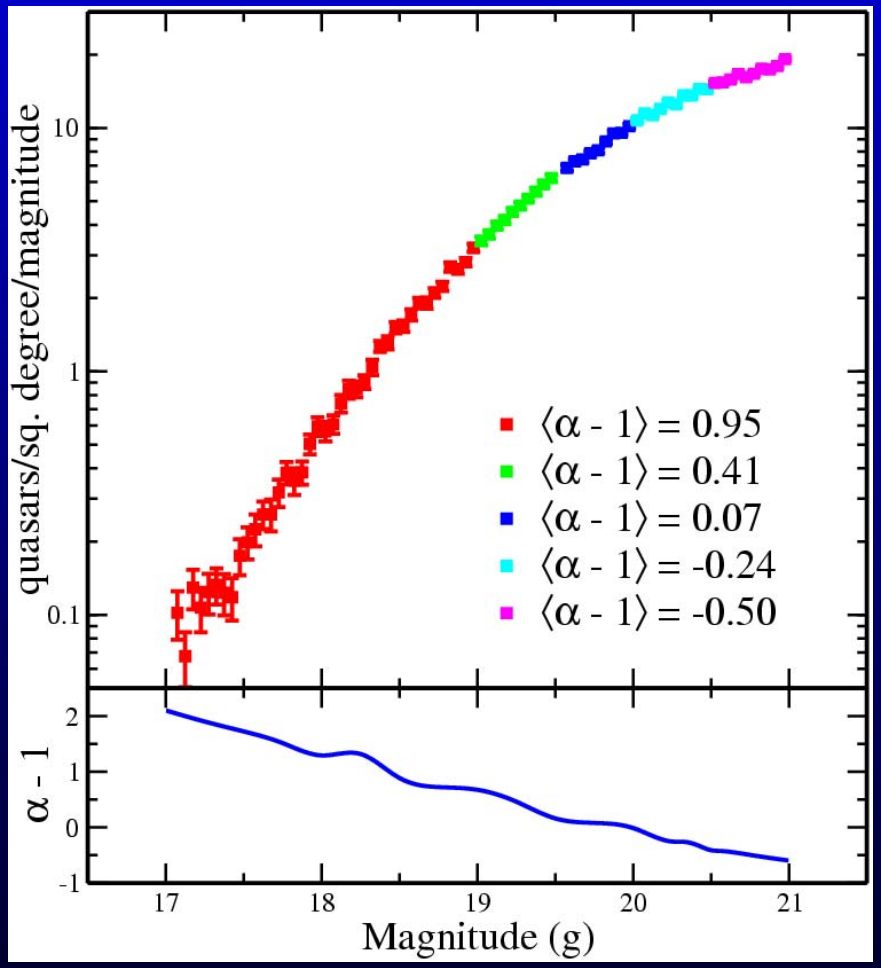
Measurement in g'

- 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:

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

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



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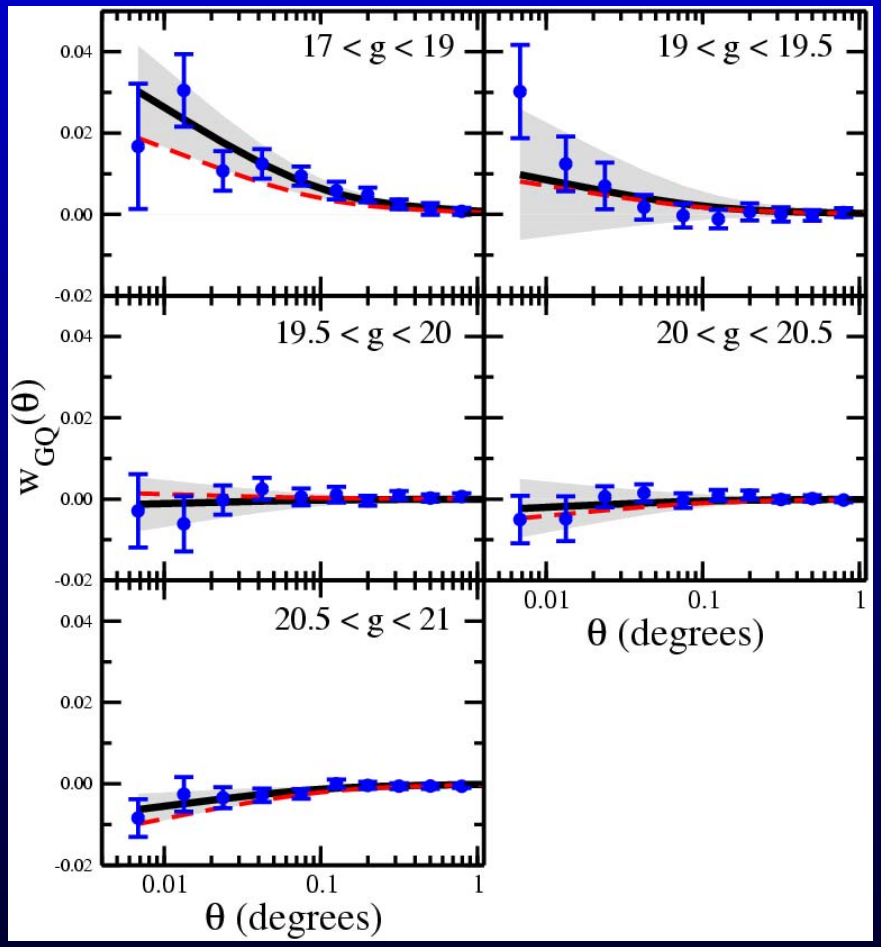


Optimal Signal

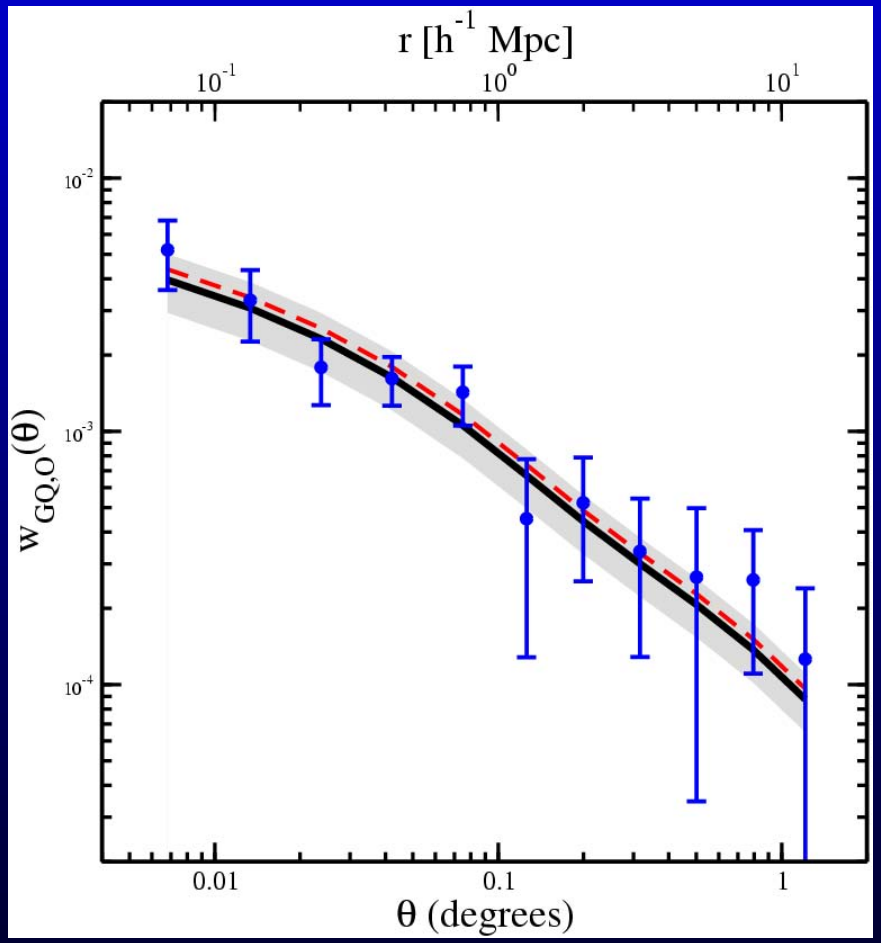
- Magnitude bin measurements verify amplitude of expected signal and variation with $\langle \alpha - 1 \rangle$
- $\langle \alpha - 1 \rangle$ for full QSO sample very close to zero
- To extract full lensing significance, use second moment:
  - ⋆ Re-calculate estimator weighting each QSO by $\alpha(m) - 1$
  - ⋆ Expected signal:

$$w_{\mathrm{GQ,O}}(\theta) = \langle (\alpha - 1)^2 \rangle \times w_0(\theta) \tag{7}$$

- Instead of canceling, positive and negative correlations add coherently

Optimal g'

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

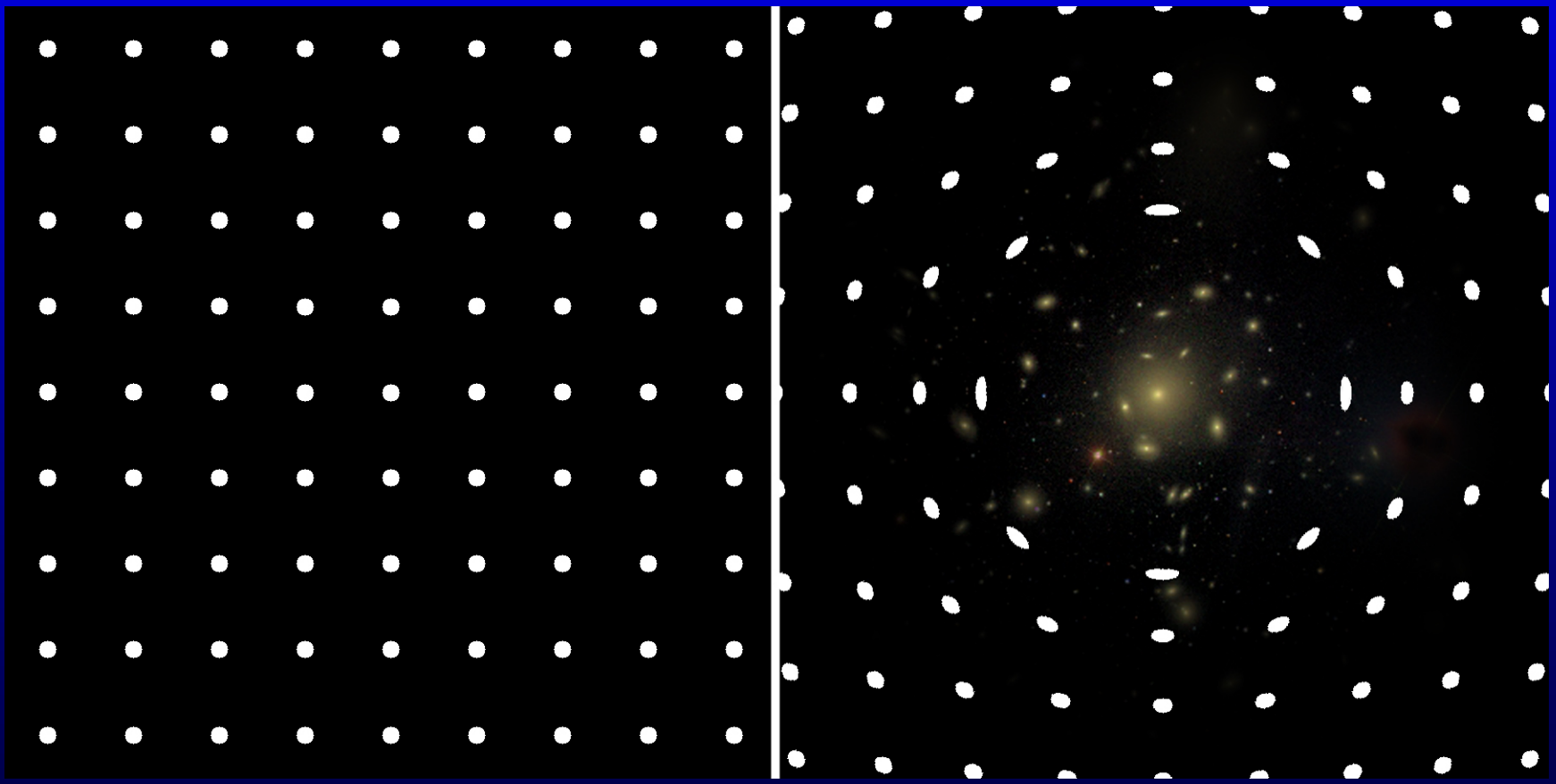


A Word of Warning

Cluster Lensing

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

Cluster Lensing



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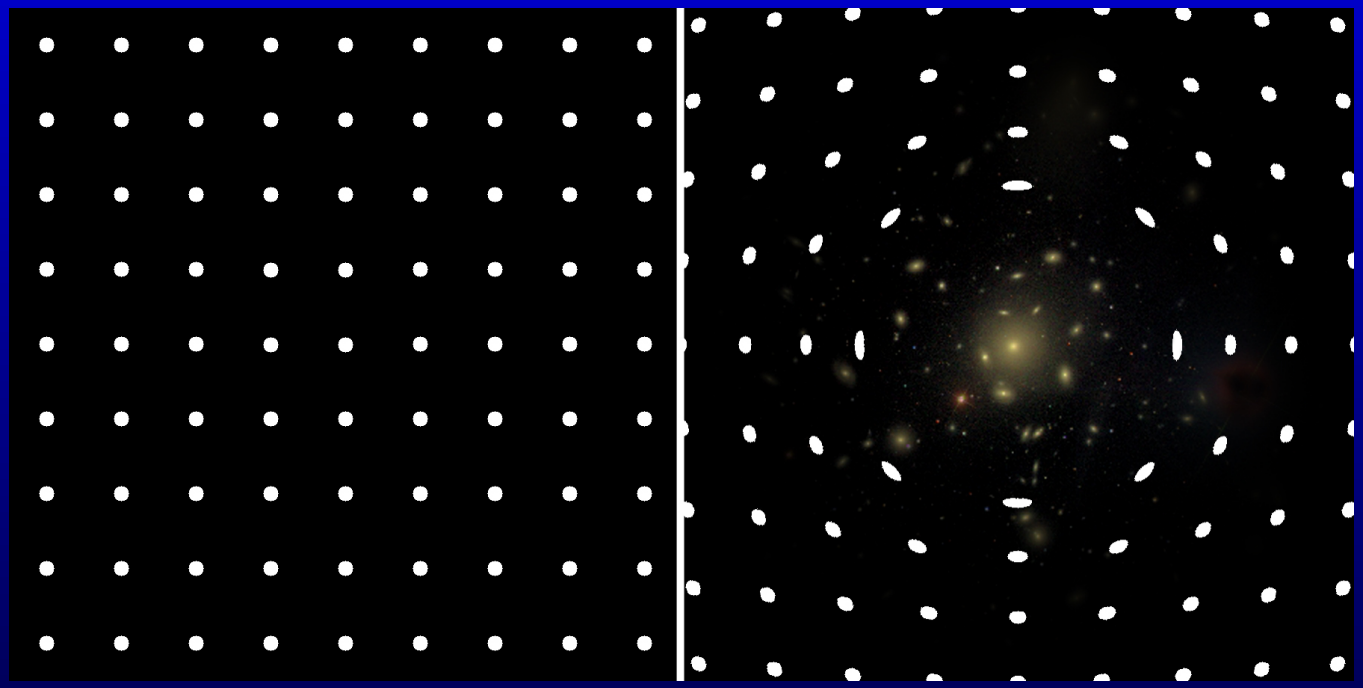
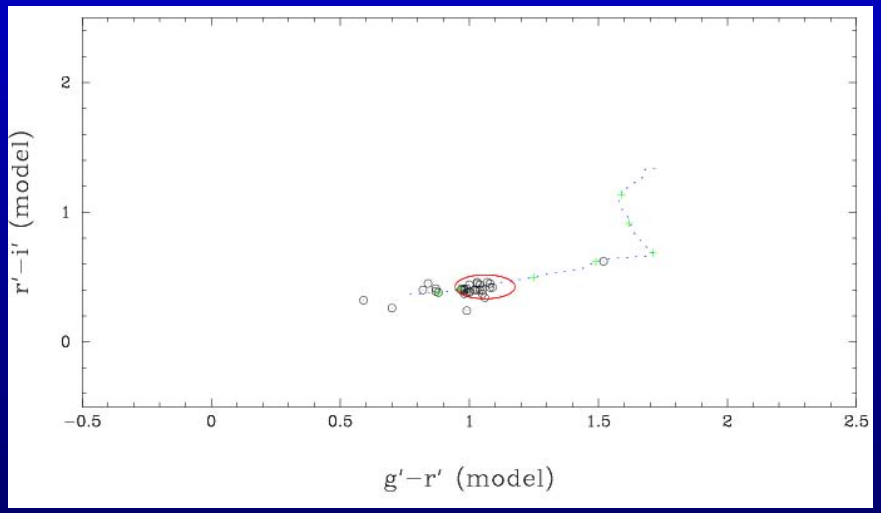


- Measure tangential shear relative to cluster center
- Average shear is proportional to enclosed projected mass gradient ($\Delta\Sigma$)

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/ $N_{gal} \geq 10$



Jim Annis

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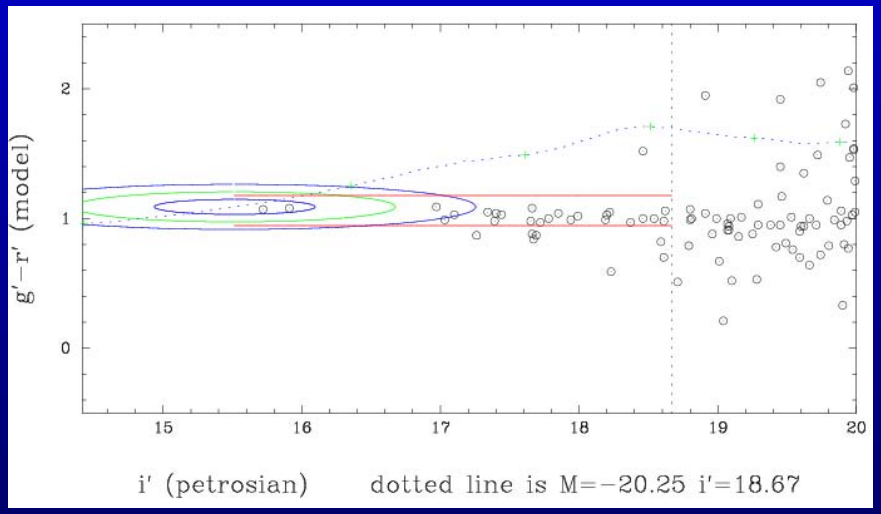

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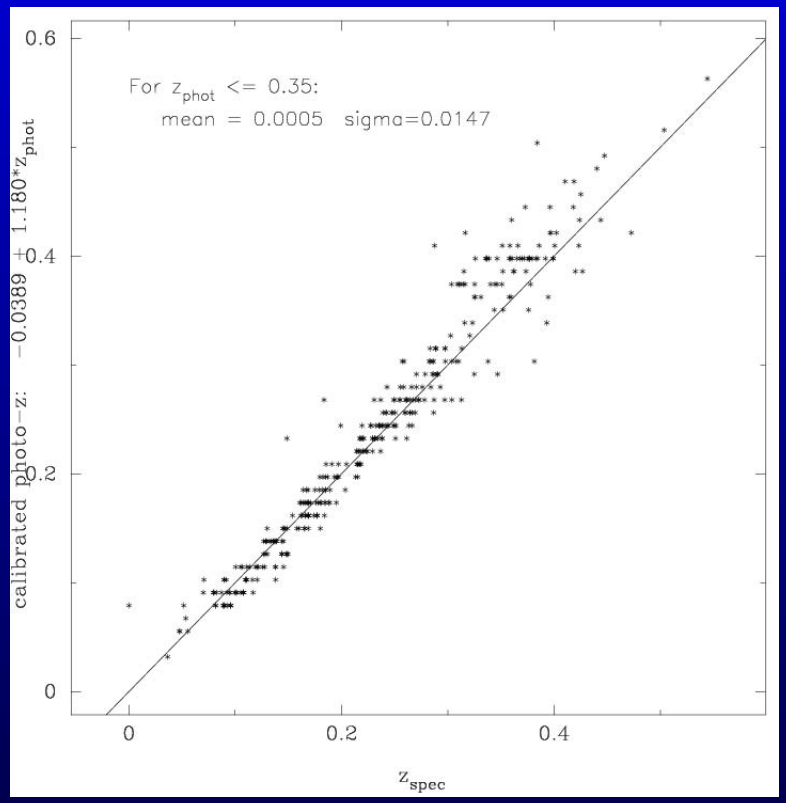
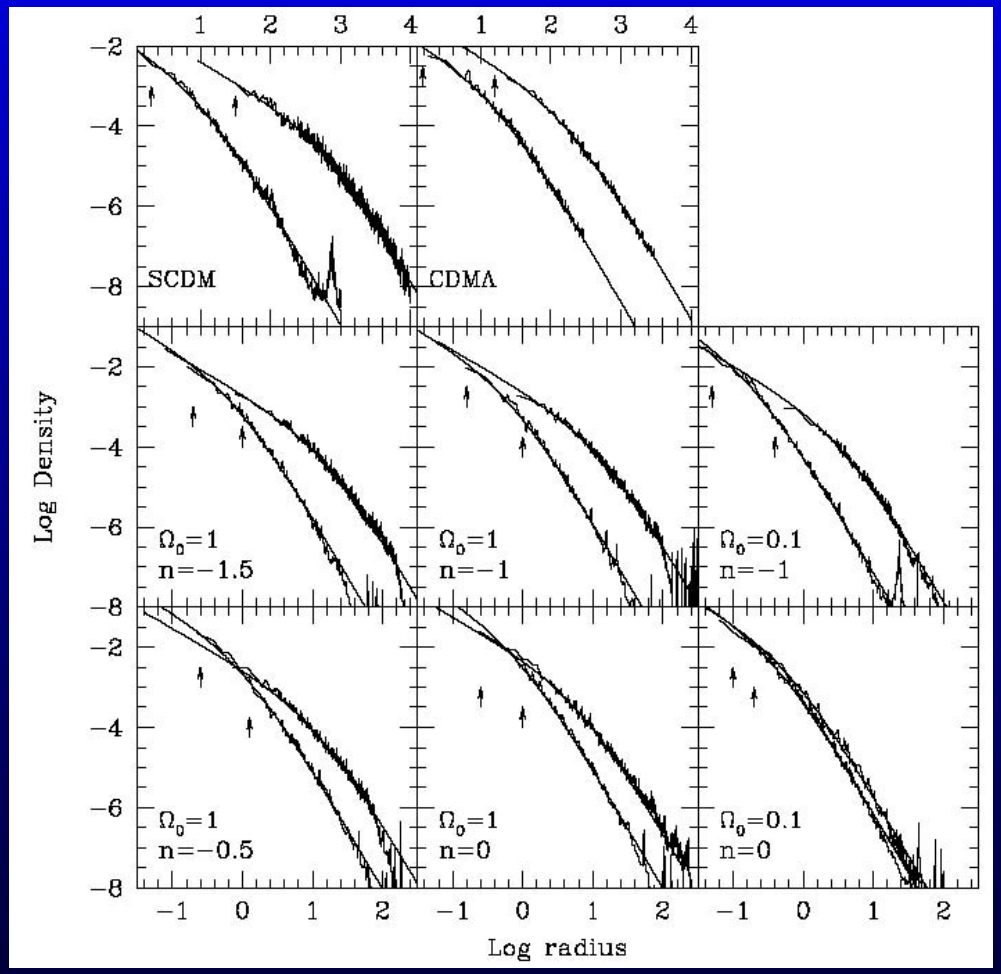


Jim Annis

Expectations from Simulations



Navarro, Frenk, & White (1997)

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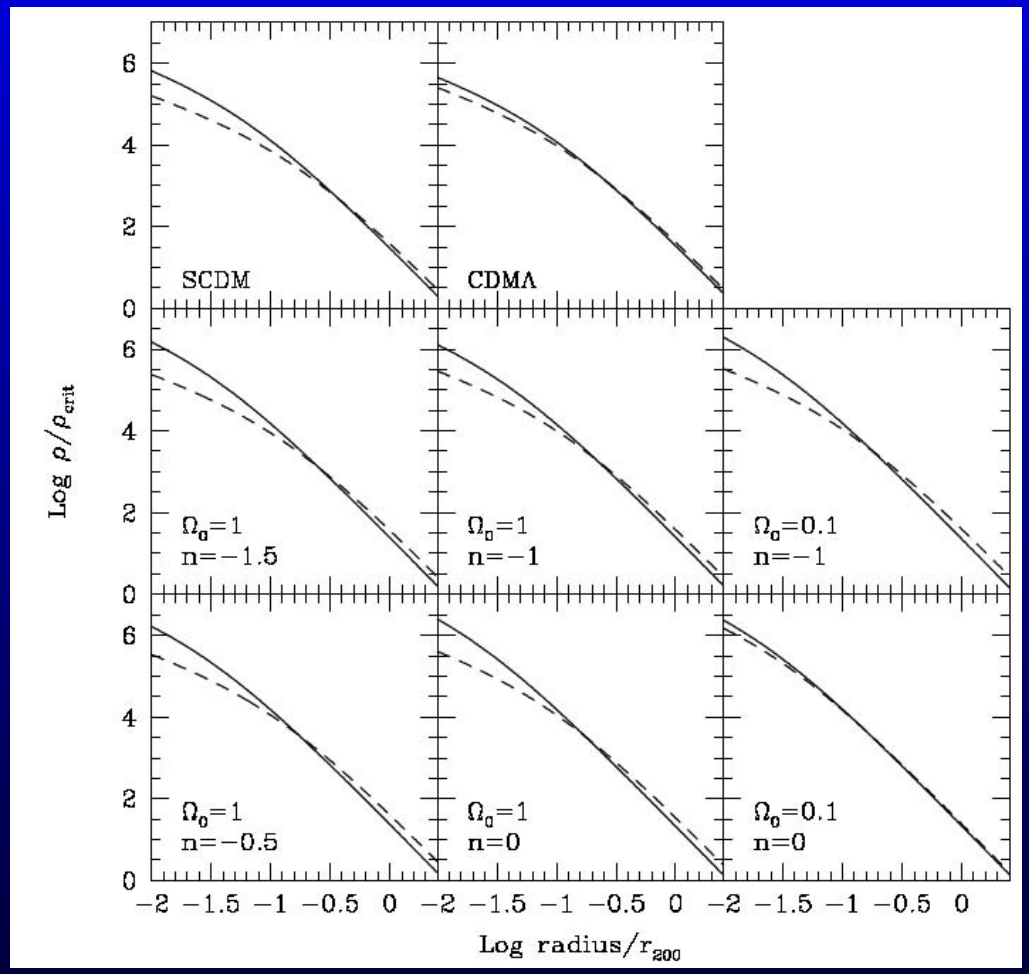
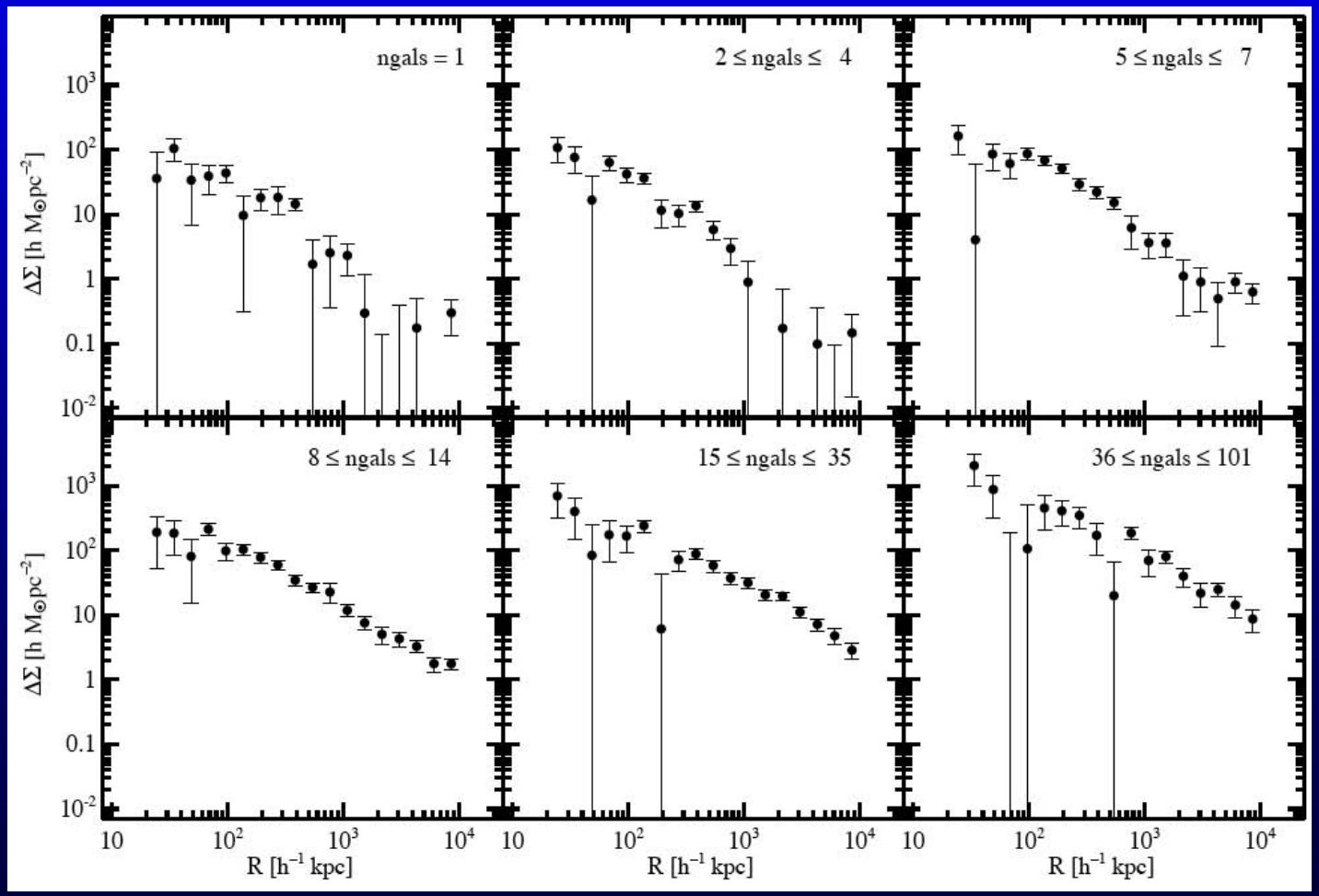


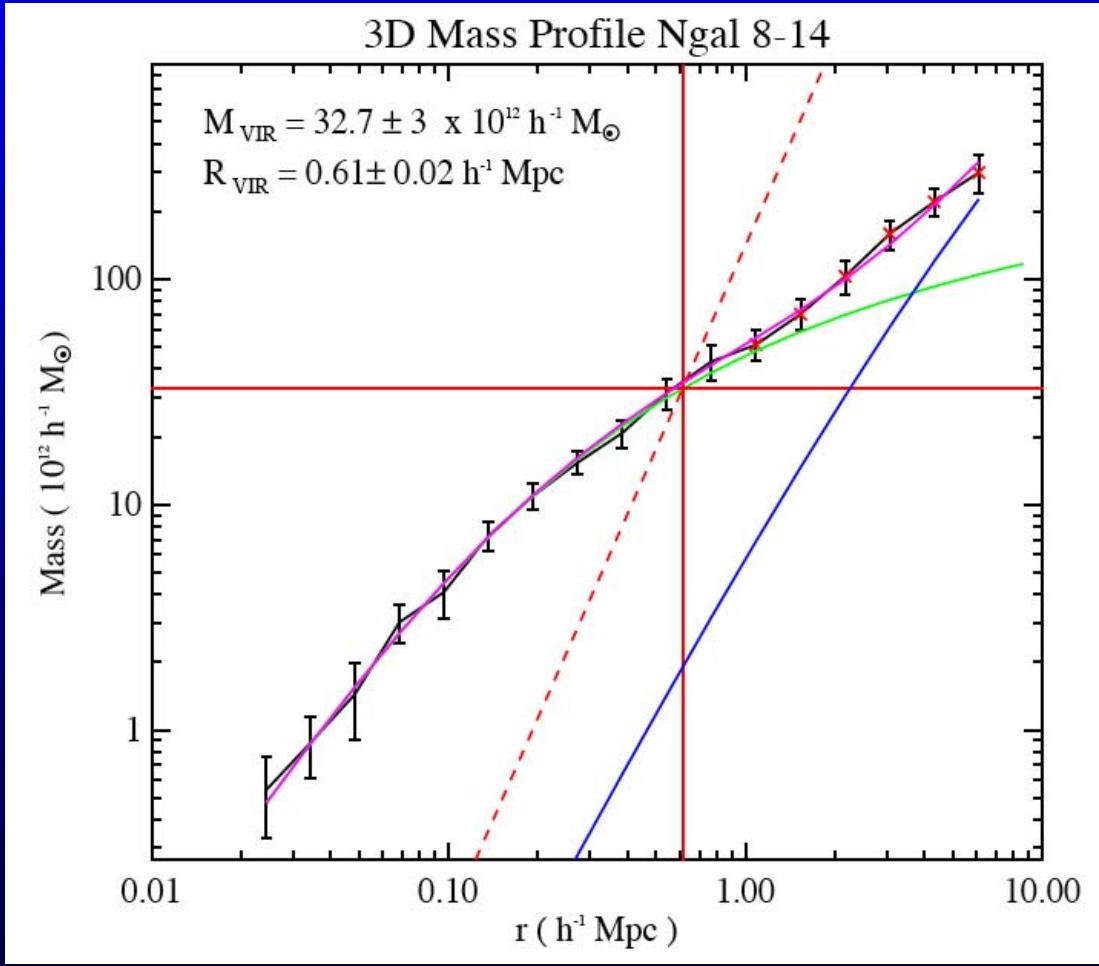
Navarro, Frenk, & White (1997)

Results



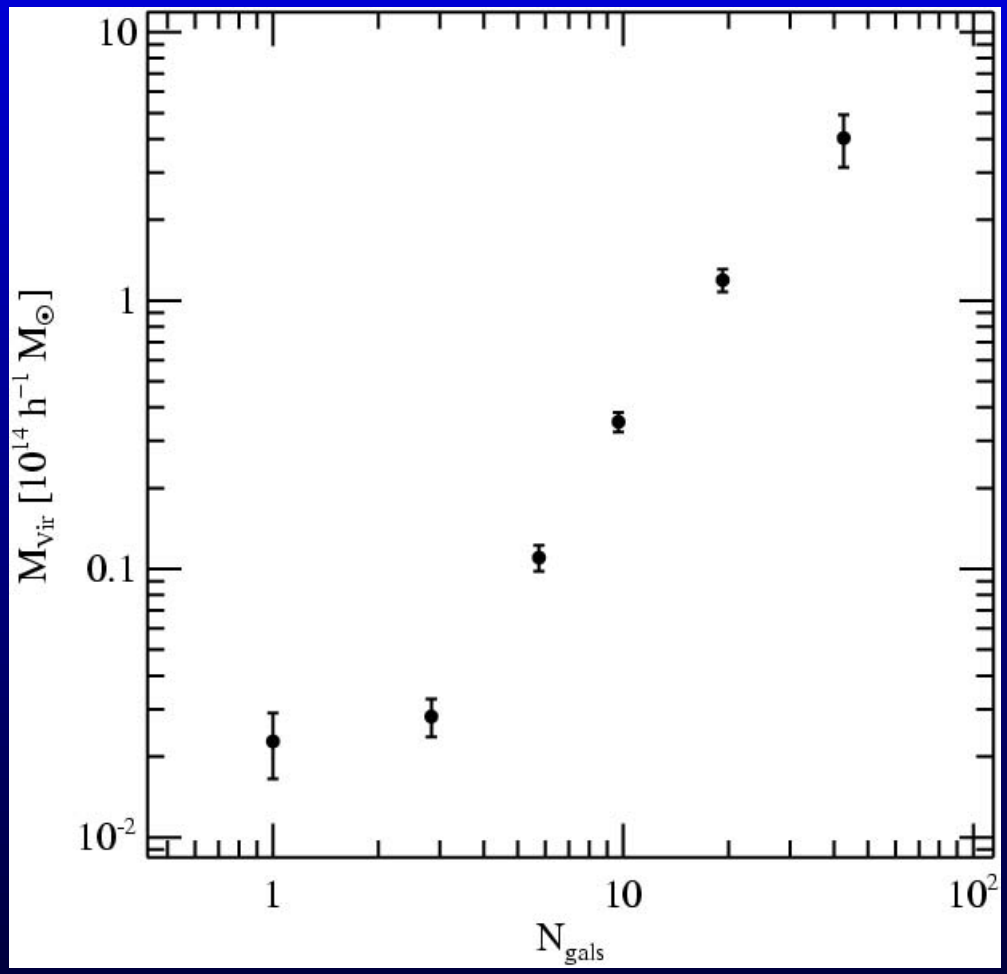
Sheldon & Johnston

Mass Profile



Sheldon & Johnston

Halo Occupation Distribution



Sheldon & Johnston

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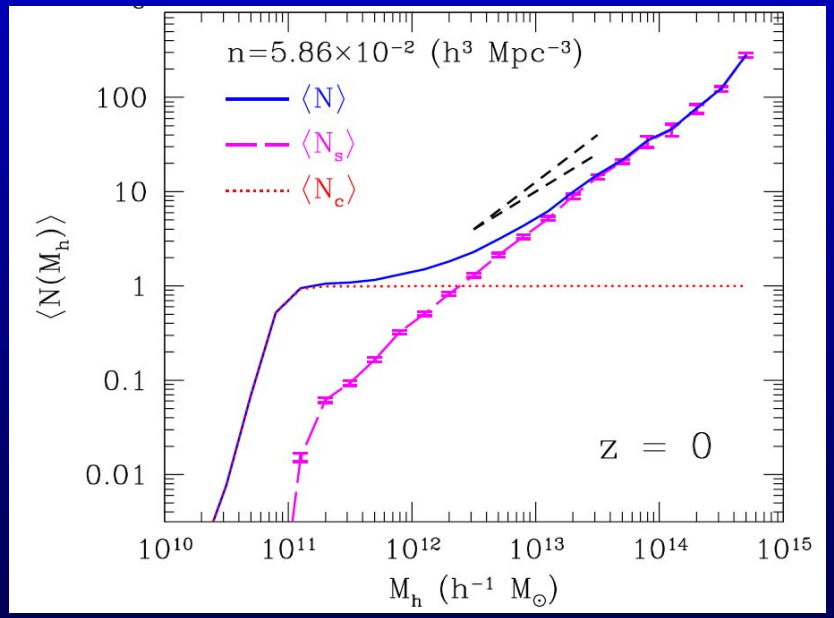
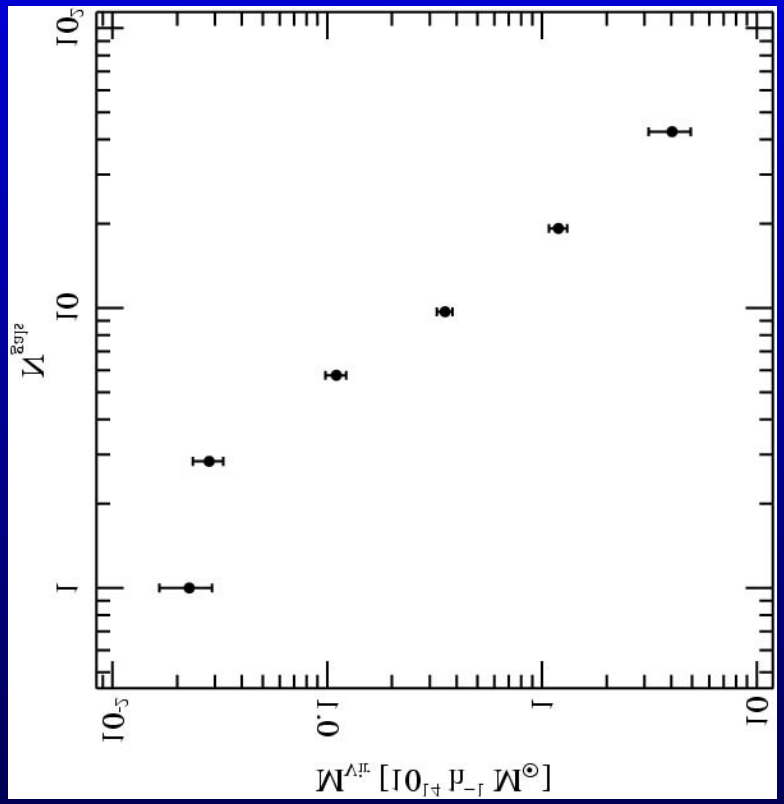


Kravtsov (2004)



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 $\Rightarrow$ 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 8σ 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