SLOAN DIGITAL SKY SURVEY (E885)

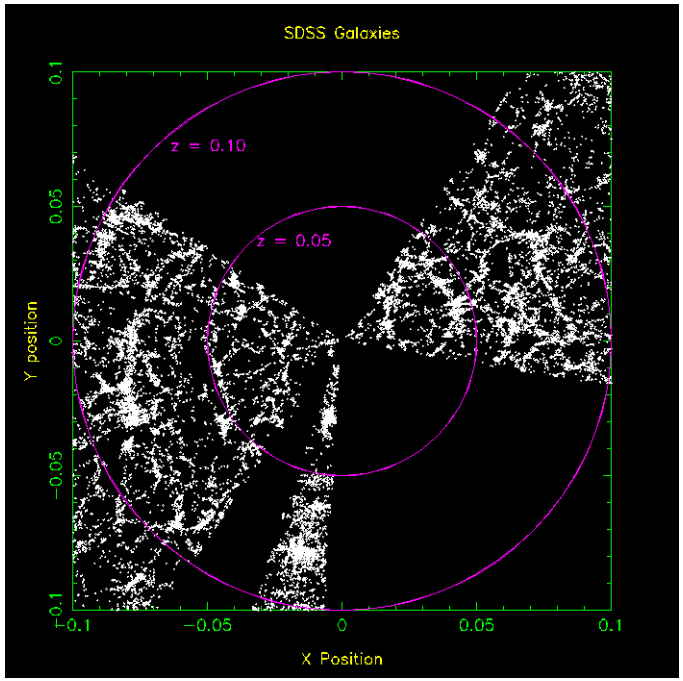
Stephen Kent (Fermilab)

I. Description/Status of survey

- Operations
- Data Products

II. Science projects with SDSS

- Galaxy properties
- Large Scale Structure
- CMB-SDSS Correlation
- Quasars



SLAC Topical Conference
Cosmic Connections
Aug 8, 2003

Partner Institutions

Fermi National Accelerator Laboratory
Princeton University
University of Chicago
Institute for Advanced Study
Japanese Promotion Group
US Naval Observatory
University of Washington
Johns Hopkins University
Max Planck Institute for Astronomy, Heidelberg
Max Planck Institute, Garching
New Mexico State University
Los Alamos National Laboratory
University of Pittsburgh

Funding Agencies

- Alfred P. Sloan Foundation
- Participating Institutions
- NASA
- NSF
- DOE
- Japanese Monbukagakusho
- Max Planck Society

Sloan Digital Sky Survey

Goals:

1. Image ¼ of sky in 5 bands
2. Obtain redshifts of 1 million galaxies and quasars

Science:

Measure large scale structure of

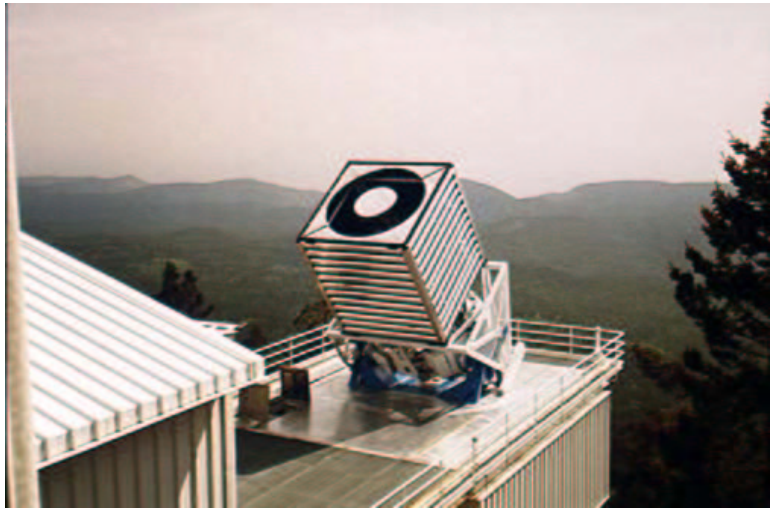
a) galaxies in 0.2% of the visible universe

b) quasars in 100% of the visible universe

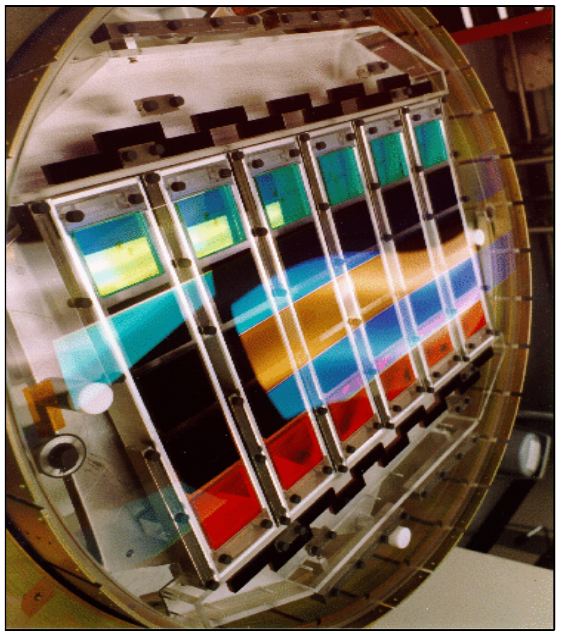
Astrophysics/Particle Physics Connection:

Large scale structure today arose in universe from processes occuring above $T=10^{27}$ K ($E=10^{14}$ Gev).

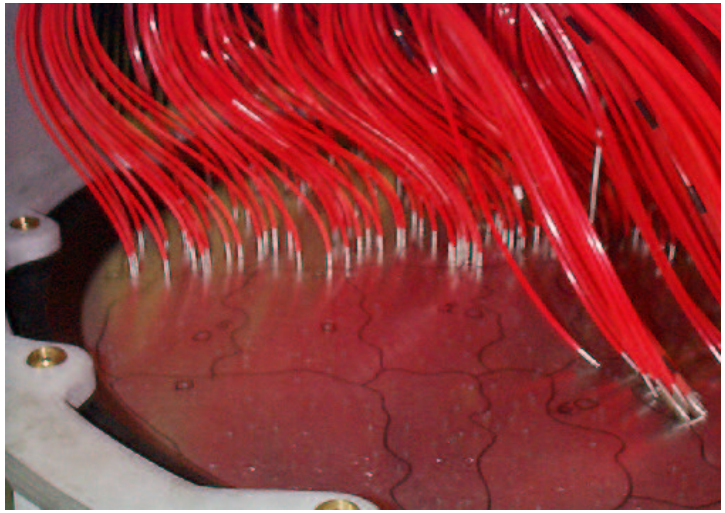
Detectors/Equipment



2.5 m Telescope



Mosaic Imaging Camera



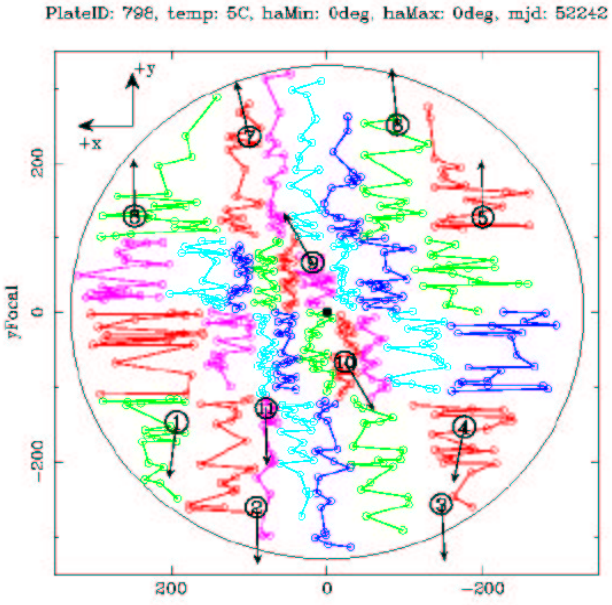
640 Fiber Spectrograph

“Photometric” telescope

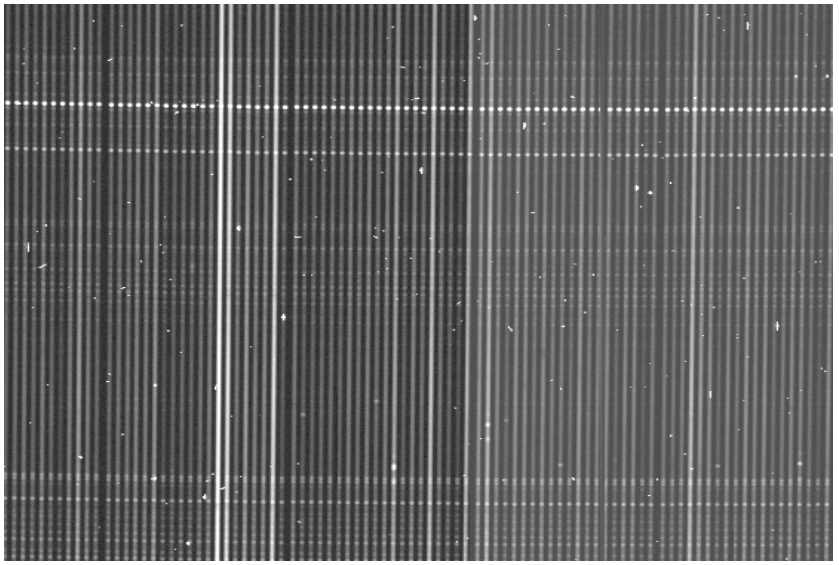
Survey Operations

1. Image Sky

2. Identify Galaxies, Quasars



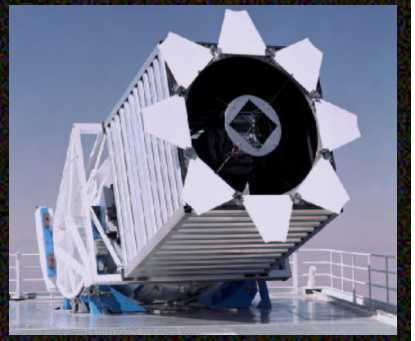
3. Design Plugplates



4. Obtain Spectra

Sloan Digital Sky Survey

Current Status (Aug. 2003)



	Baseline	Percent Complete
IMAGING	8452 sq. deg.	**78% as of Aug 6, 2003**
SPECTROSCOPY	1688 tiles	**48% as of Aug 6, 2003**
MT (calibrations)	1563 patches	**93% as of Aug 6, 2003**

Operations began: Apr 1, 2000

Operations end: Jun 30, 2005

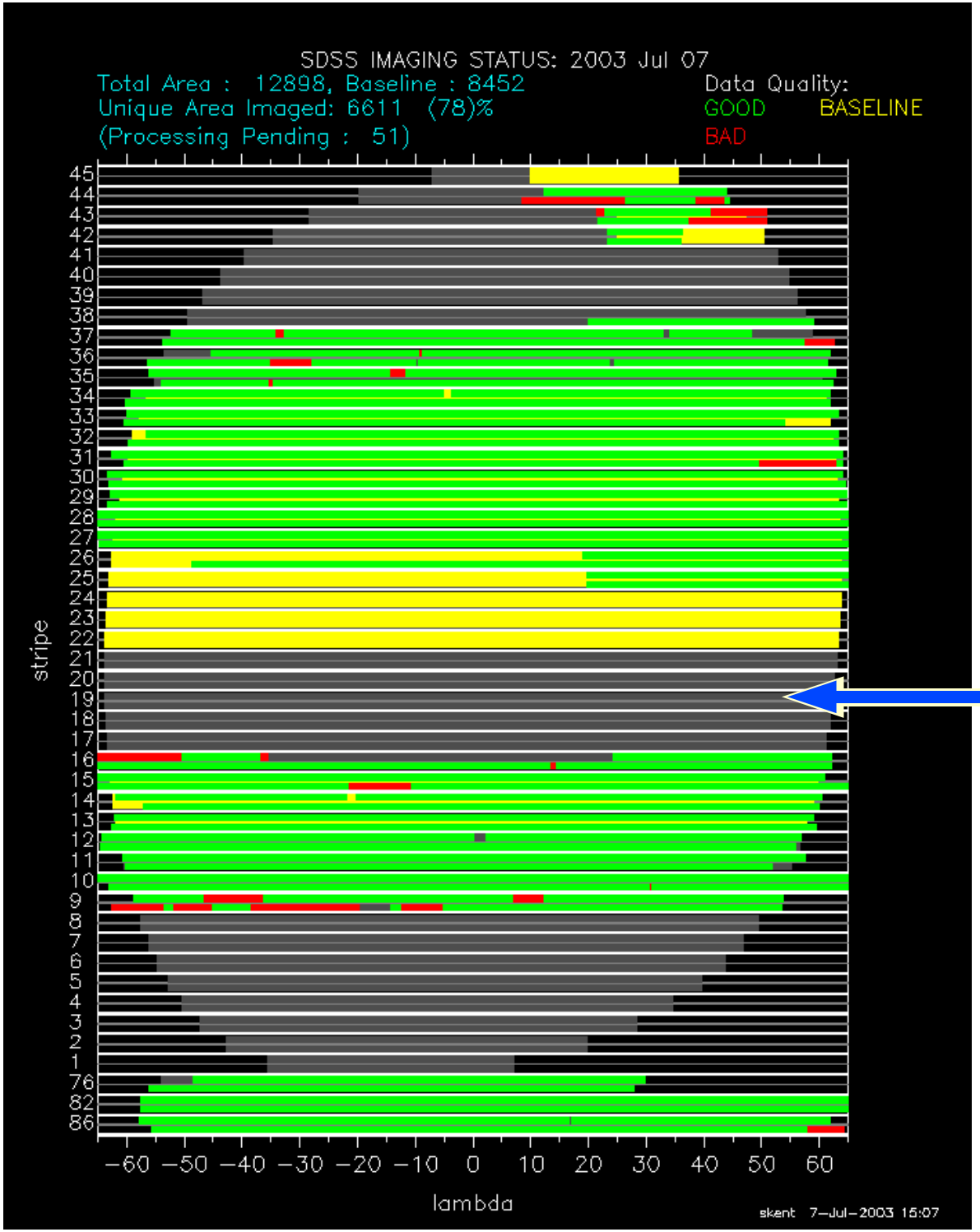
Proposed 2 year extension

Imaging Sky Coverage

Good Data

Bad Data

To Do (5 yr baseline)



Close the gap: proposed 2 year extension

Strength of SDSS

IMAGING

	DPOSS (plates)	SDSS
Depth	r = 20.5	r = 22.5
Accuracy	20%	2%
Bands	J, F, N	u, g, r, i, z
Area	30,000 sq deg	5000 sq deg

SPECTROSCOPY

	2dF	SDSS
Galaxies	220,000	400,000
QSOs	30,000	~40,000
Matching photometry?	Plates	CCD

Catalog Information

- Imaging
  - Magnitudes (5 bands) ==> 4 colors
  - Morphology (crude)
  - Size
  - Shape
  - Position
- Spectroscopy
  - Redshift => Luminosity, distance
  - Velocity Dispersion
  - Line strengths (abs., emission)

Research Results

- **Publications**
  - 277 total
  - (185 in refereed journals)
  - 35 additional based on SDSS data
- **40 Ph. D. Theses (most in progress)**

- **Topics**
  - Hi Z Quasars
  - Gravitational Lensing
  - QSO & Galaxy Corr. Function
  - Galaxy Clusters
  - Galaxy Struct./Evol.
  - Milky Way Halo
  - Brown Dwarfs
  - White Dwarfs
  - Asteroids

Data Release 1 to public

Now Available (www.sdss.org)

All data through June 30, 2001

SDSS Data Release 1

Sloan Digital Sky Survey

Where to Start
News and Updates
Tutorials
Data Products
Data Access
Sky Coverage
Instruments
Data Flow
Algorithms
Glossary
Help and Feedback
Search

The Sloan Digital Sky Survey (see www.sdss.org for general information) will map one-quarter of the entire sky and perform a redshift survey of galaxies, quasars and stars. The DR1 is the first major data release and provides images, imaging catalogs, spectra, and redshifts for download.

This release contains the "beta" processing of the DR1 data set. About DR1 explains what we mean by "beta".

Please refer to the credits page for our sources of funding, participating institutions, how to acknowledge the use of SDSS data in your publications. Please also note how to refer to SDSS sources in your publications using the proper IAU nomenclature for SDSS sources.

Imaging

Footprint area	2099 sq. deg.
Imaging catalog	53 million unique objects
Data volume	images 2.338 TB catalogs 0.462 TB
Magnitude limits (95% detection repeatability for point sources)	*u* 22.0, *g* 22.2, *r* 22.2, *i* 21.3, *z* 20.5
PSF width	1.4" median in *r*
Photometric calibration	*r* 2%, *u*–*g* 3%, *g*–*r* 2%, *r*–*i* 2%, *i*–*z* 3%
Astrometry	< 0.1" rms absolute per coordinate

Spectroscopy

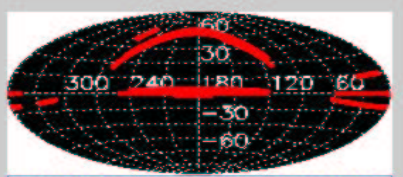
Spectroscopic area	1360 sq. deg. (Note: we earlier erroneously reported 1556 sq. deg. as spectroscopic area.)
Resolution	1800
Signal-to-noise	>4 per pixel at *g*=20.2
Redshift accuracy	30 km/sec rms (from repeat observations)
Target magnitude limits for main samples	Galaxies: Petrosian *r*'<17.77 Quasars: PSF *i*'<19.1
Spectroscopic catalog	186,250 objects, classified into 134,000 Galaxies 17,700 Quasars (redshift <2.3) 980 Quasars (redshift >2.3) 17,600 Stars 4500 M stars and later 9700 Sky spectra 1770 Unknown class
Data volume	calibrated spectra ("2d") 0.014 TB spectra, redshifts, line measurements ("1d") 0.039 TB

This is version v1_20030714_1801 .

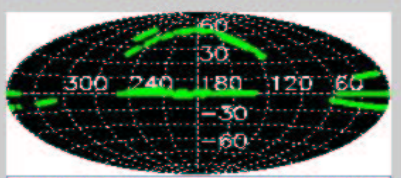
If you are using Netscape 4.x and see oversized fonts, please look at the workaround on the Credits page.

Send your questions to sdss-helpdesk@fnal.gov

News: All temporarily unavailable data have been restored. More...



SDSS DR1 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



SDSS DR1 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)

What is Cosmology?

- **Good old days**
  - H_0, q_0
- **Modern Times**
  - H_0
  - $\Omega_{Total} = \Omega_\Lambda + \Omega_{Matter} + \Omega_\nu$
  - $\Omega_{Baryon} + \Omega_{CDM}$
  - σ_8, n, w, b

SDSS will measure

SDSS will try to measure

Cosmology du Jour (ΛCDM)

$H_0 = 72$

$\Omega_{Total} = 1$

$\Omega_\Lambda = 0.7$

$\Omega_{CDM} = 0.25$

$\Omega_{Baryon} = 0.05$

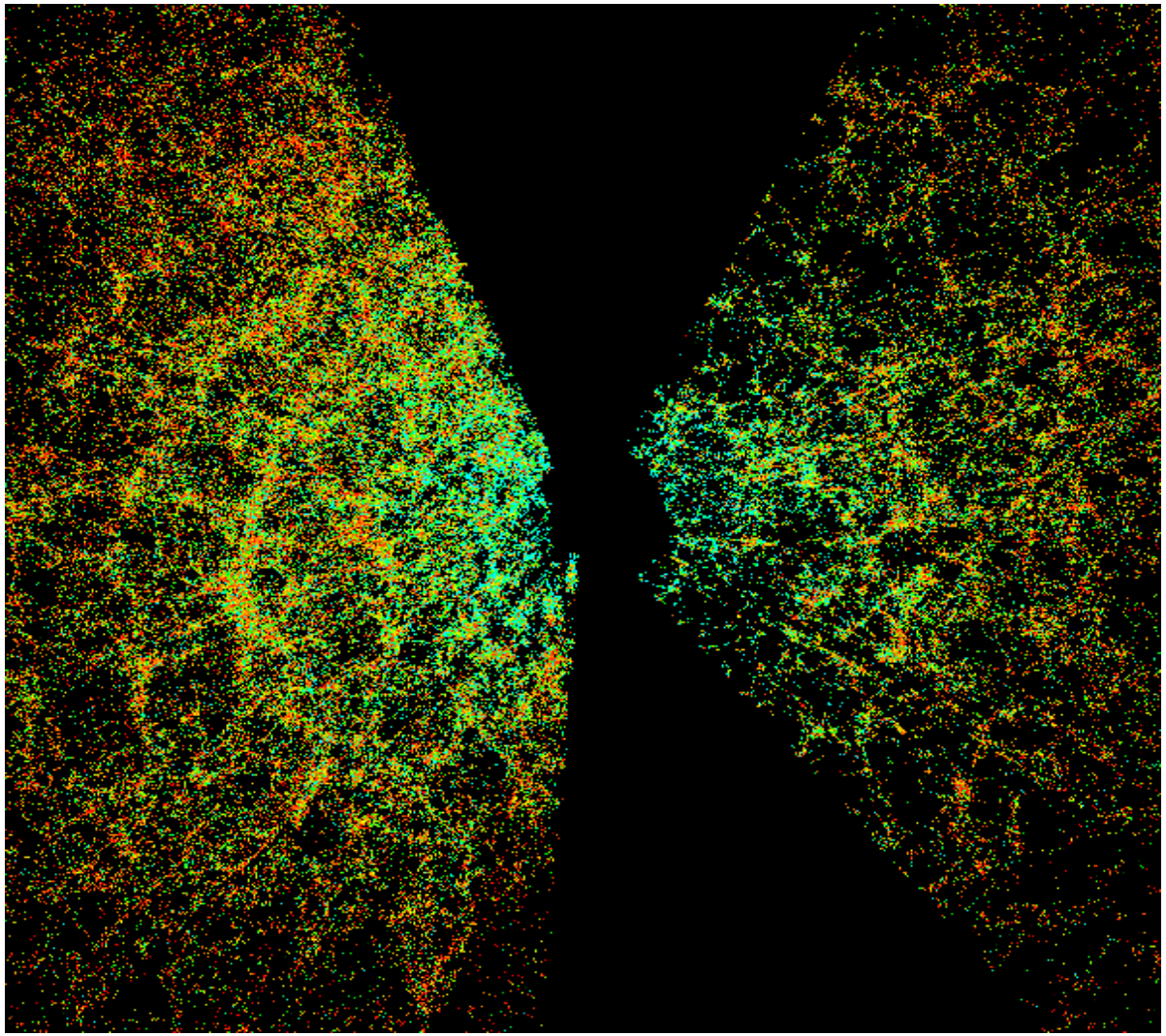
$\sigma_8 = 0.9$

$n = 1$

$w = -1$

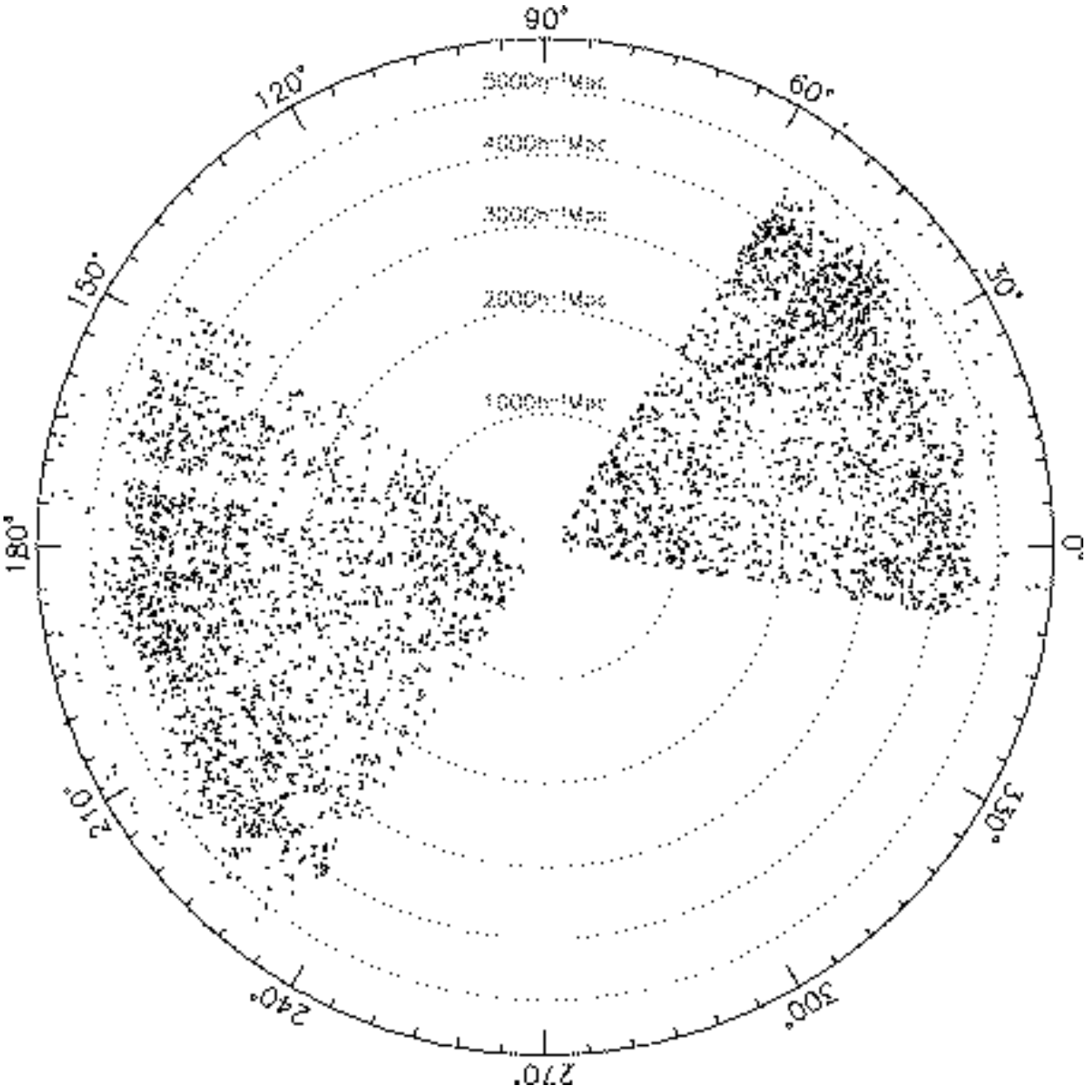
$b = 1$

Obligatory Pie Diagram



The clustering of galaxies that we see today arose from quantum fluctuations laid down at the end of the inflationary epoch in the early universe.

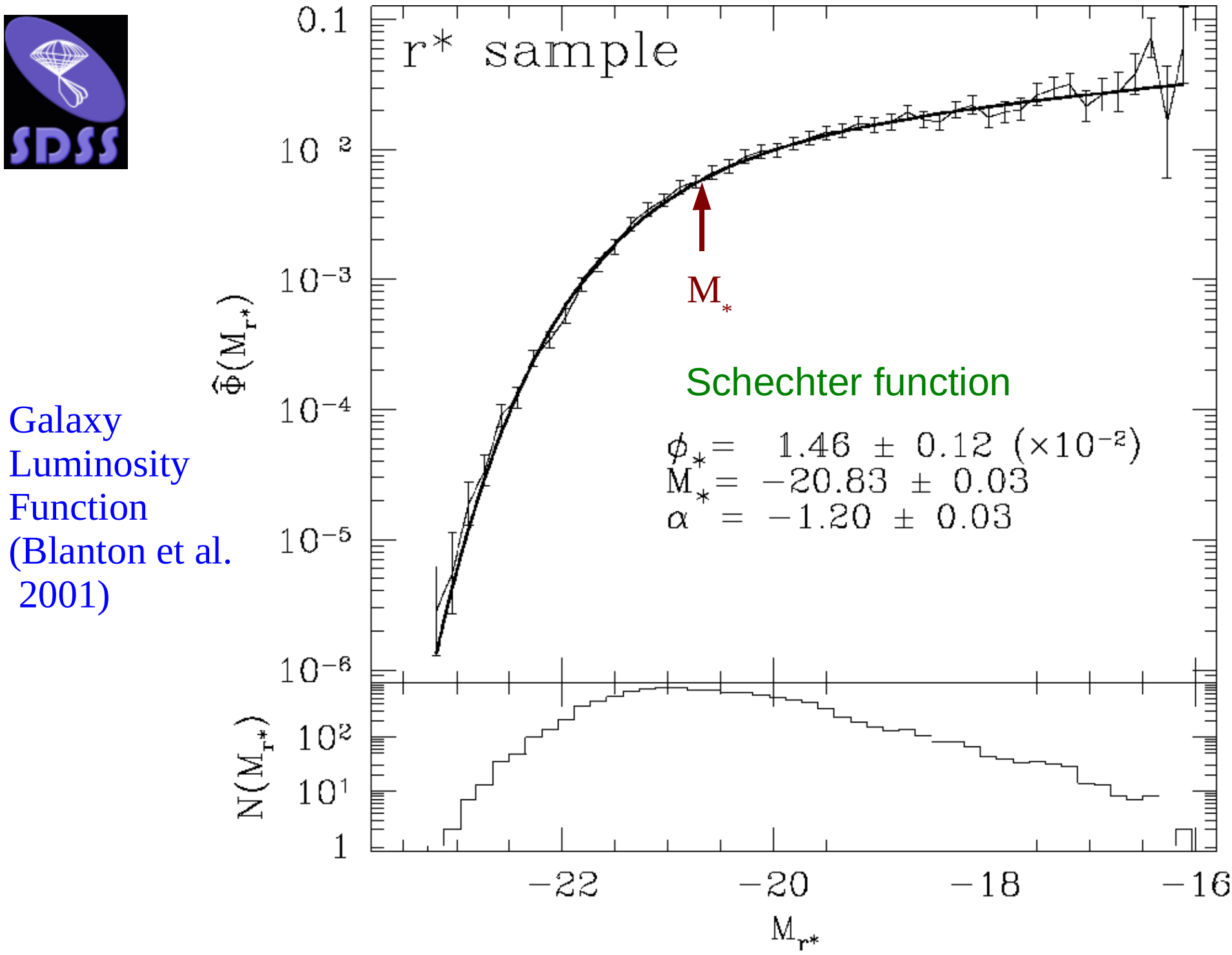
Distribution of Galaxies around Sun to z=0.15



Distribution of Quasars to z = 2

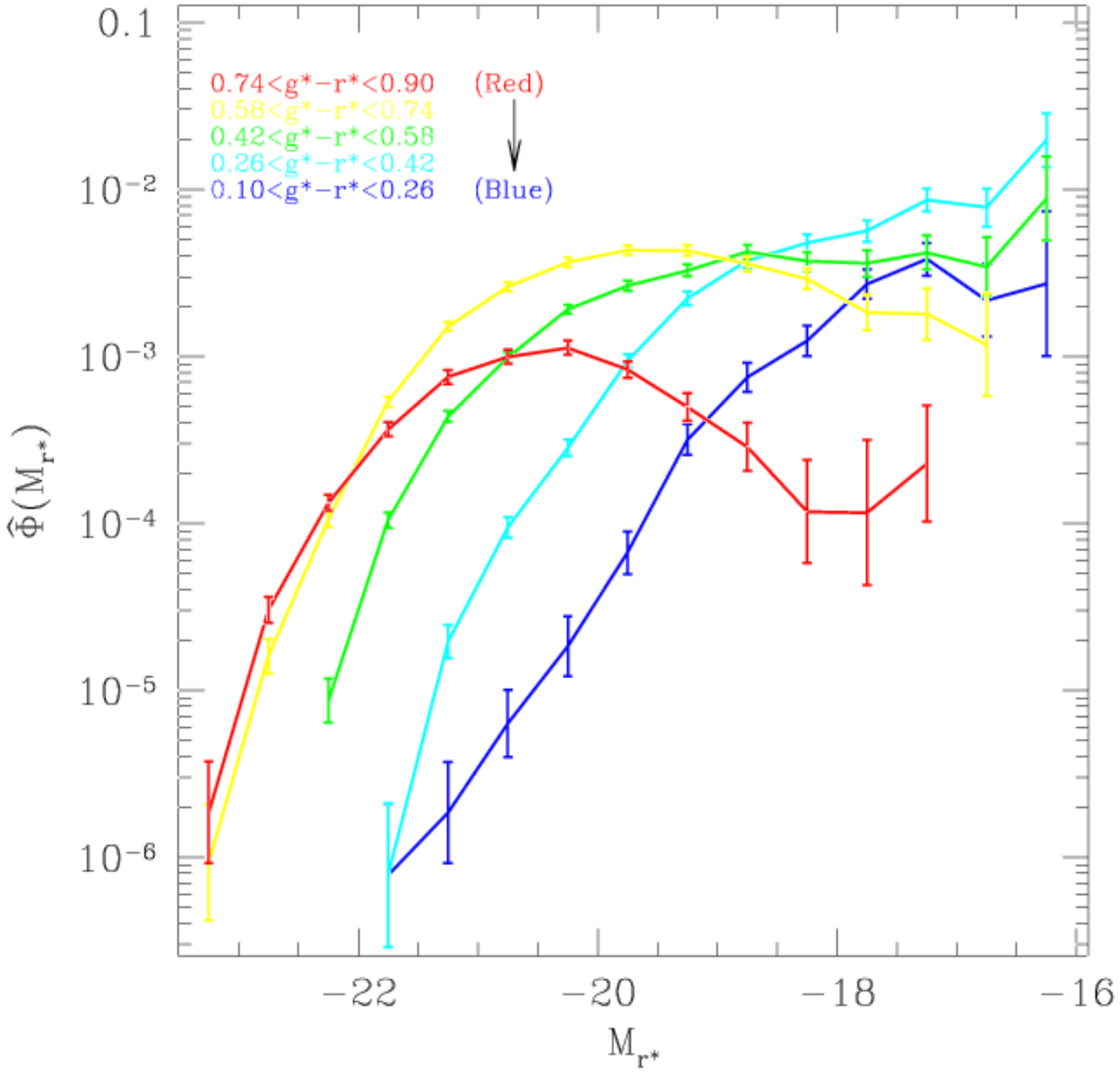
Galaxy Properties - Why SDSS?

- Want to understand biasing between galaxies (luminosity) and mass.
- Number of galaxies is a multivariate function of
  - Luminosity
  - Morphology/color
  - Environment (density)
  - Redshift
  - Surface brightness
  - ...
- Requires large sample of galaxies with accurate data!



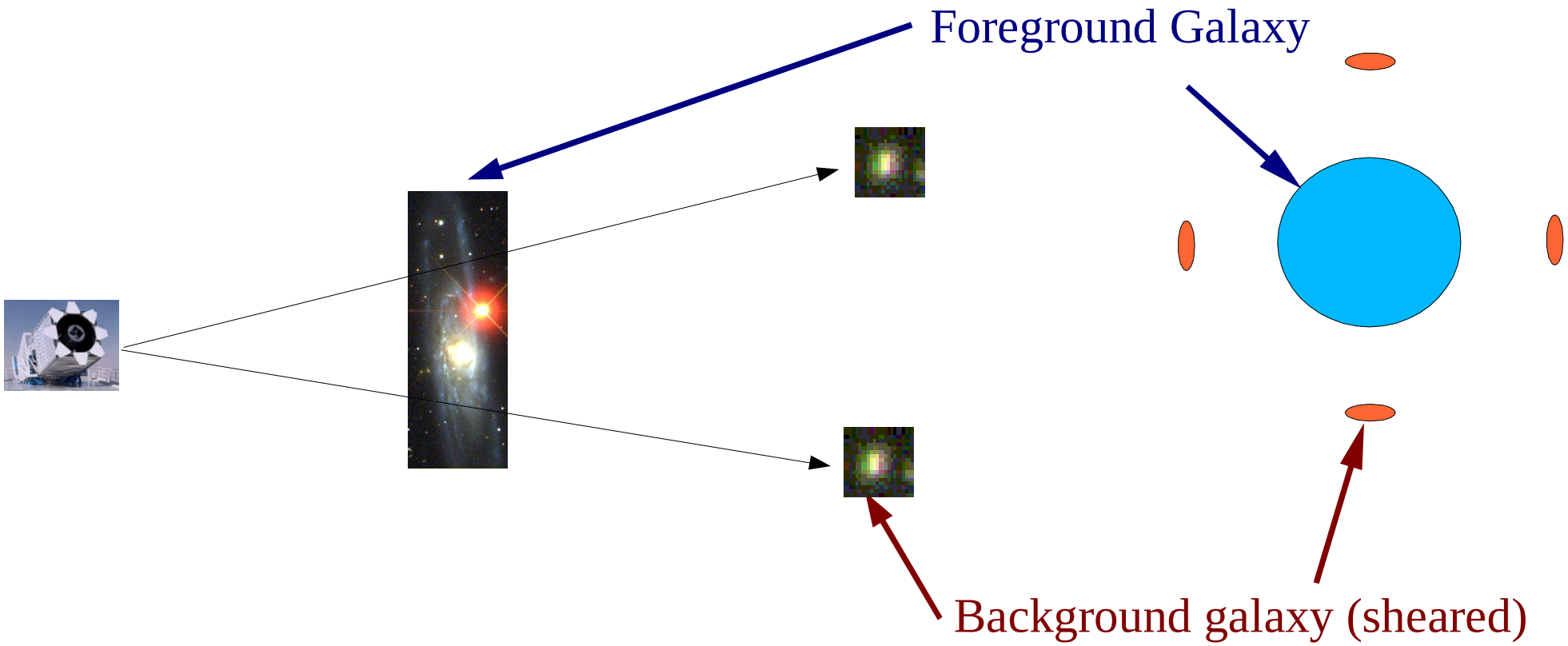
Galaxy Luminosity Function (Blanton et al. 2001)

Same figure but sorted by galaxy color.



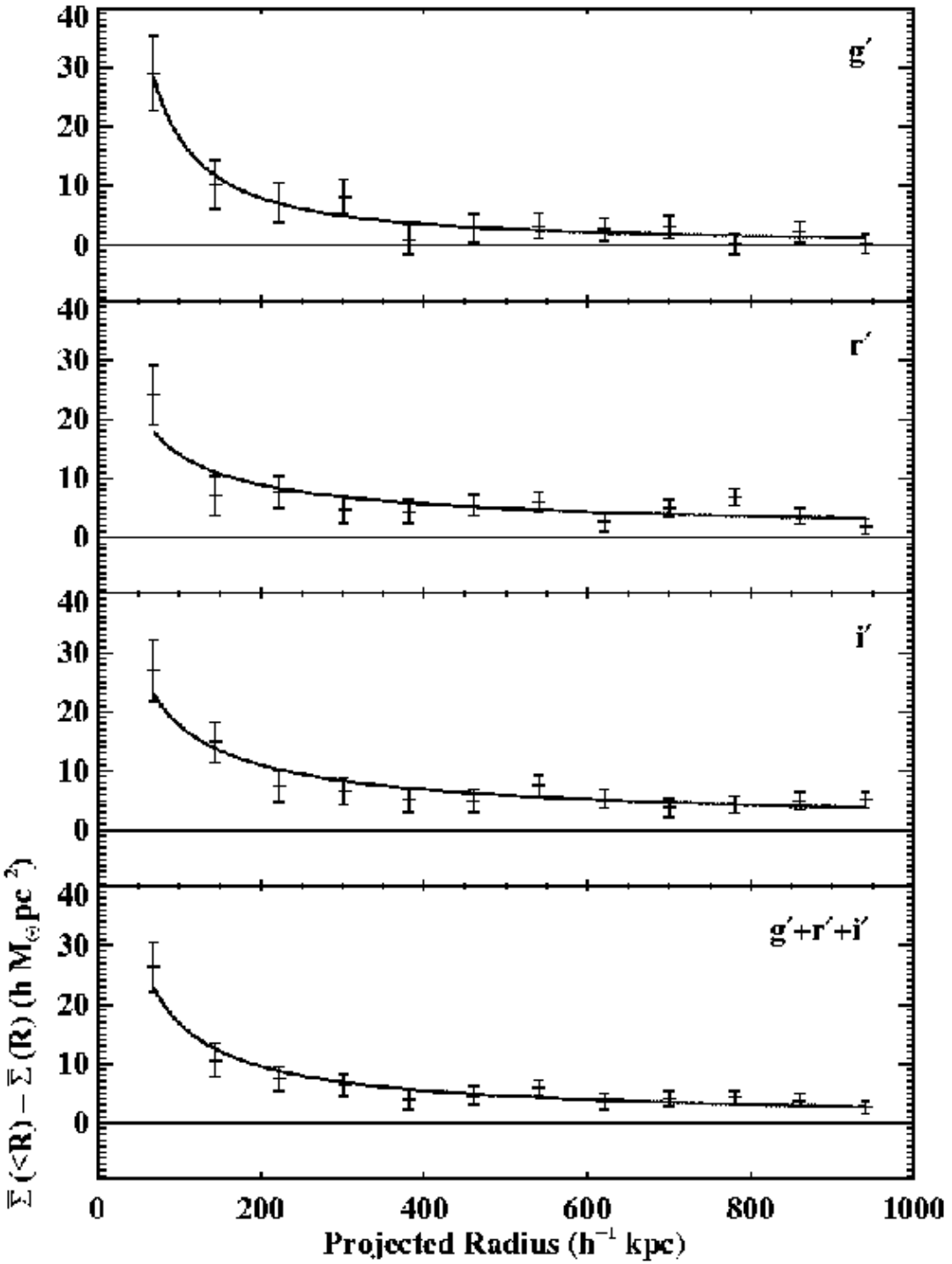
Weak Lensing - Compare light with mass

McKay, Sheldon, et al (2001, 2002)



Shear ($\varepsilon = 1-b/a$) measures projected mass density

Shear and mass Density vs. Radius for ensemble of 31,000 foreground galaxies



Weak Lensing Calibration of M/L vs. Morph. Type and Color

TABLE 3
MASS AND M/L FITS FOR DIFFERENT GALAXY TYPES

Galaxy Type	$\langle M(R\leq 260\ kpc)\rangle$ [a] $10^{12}\ h^{-1}\ M_\odot$	$\langle M/L_{u'}\rangle$ [b] $h\ M_\odot/L_\odot$	$\langle M/L_{g'}\rangle$ $h\ M_\odot/L_\odot$	$\langle M/L_{r'}\rangle$ $h\ M_\odot/L_\odot$	$\langle M/L_{i'}\rangle$ $h\ M_\odot/L_\odot$	$\langle M/L_{z'}\rangle$ $h\ M_\odot/L_\odot$
All	2.6 ± 0.3	329 ± 40	290 ± 35	170 ± 21	124 ± 15	100 ± 12
Spirals	1.5 ± 0.4	167 ± 48	192 ± 55	143 ± 41	112 ± 32	97 ± 28
Ellipticals	4.1 ± 0.5	647 ± 77	425 ± 51	221 ± 26	158 ± 19	123 ± 14

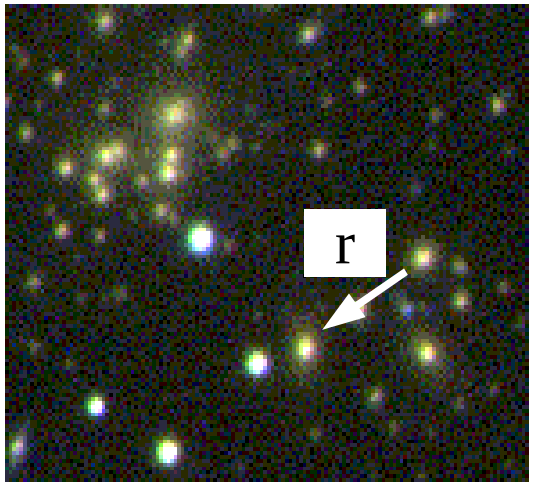
[a]Based on fits to singular isothermal spheres

[b]$M = M(R\leq 260\ kpc)$

McKay + Blanton ==> Ω(matter) > 0.16

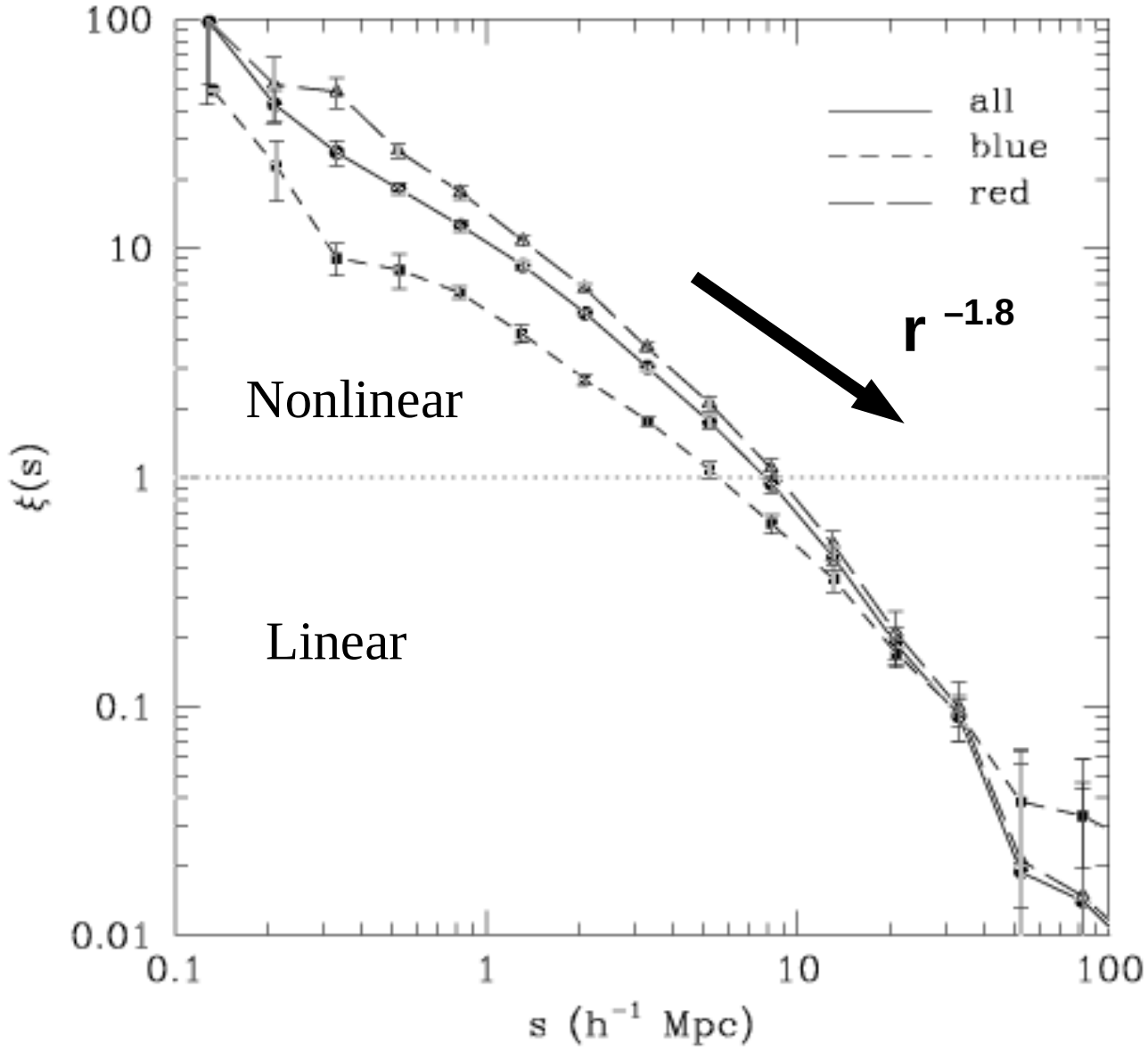
2-Point Correlation Function

- One measure of galaxy clustering
- $\varepsilon(r) = \langle \Delta\rho(r')\Delta\rho(r'+r) \rangle$
- Approximation: $\varepsilon = (r/r_0)^{-\gamma}$
  - $r_0 \approx 8$ Mpc (correlation length)
  - $\gamma \approx 1.8$
- Power spectrum: $P(k)$ = Fourier Transform of $\varepsilon(r)$



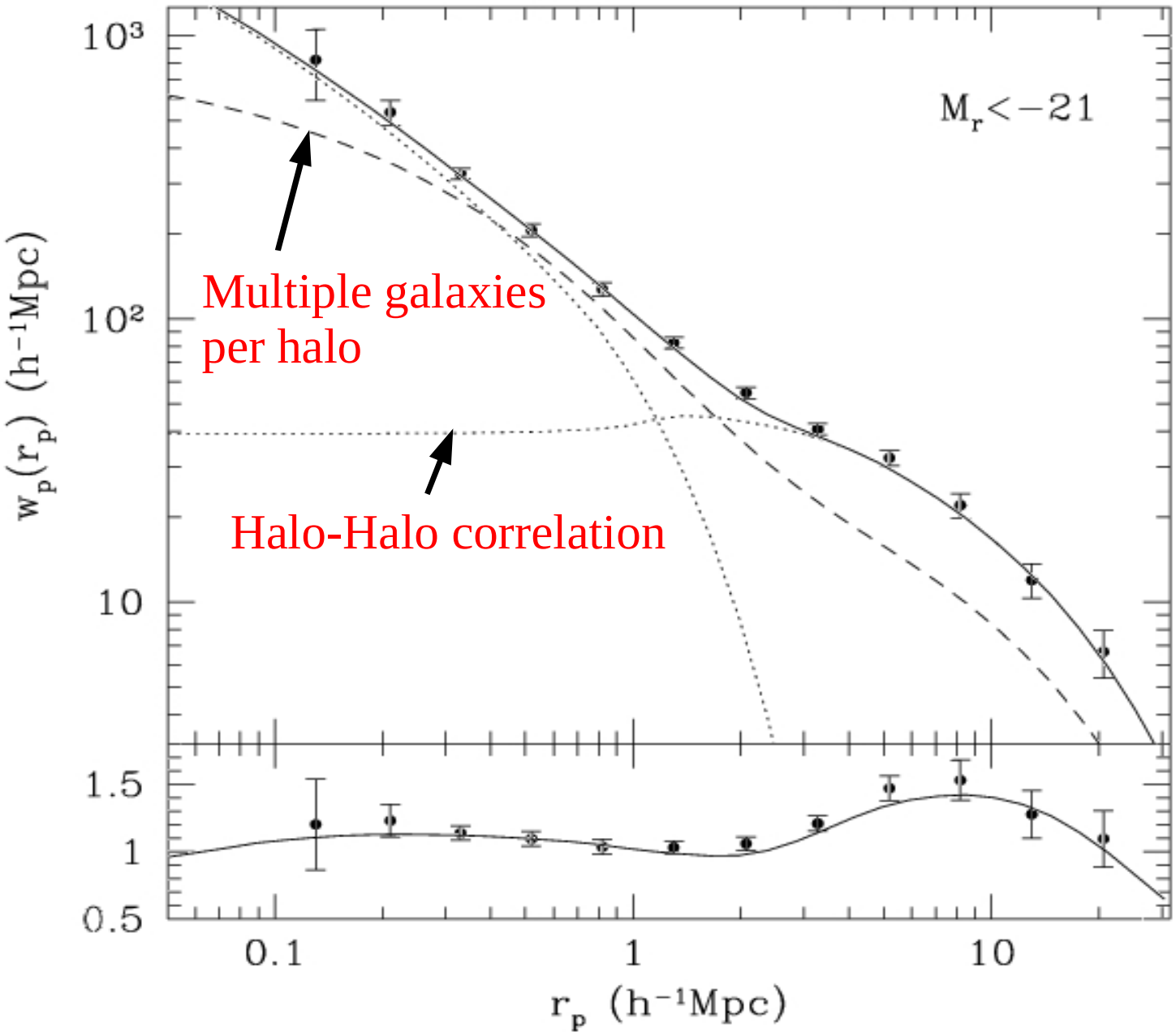
Galaxy 2-point correlation function vs. galaxy color

Zehavi et al 2002



Departures from Power Law: Halo Occupation Distribution Model

Galaxy-Galaxy angular 2-point correlation Function (Zehavi et al. 2003)



The Cluster Finding Renaissance

SDSS Cluster Finders:

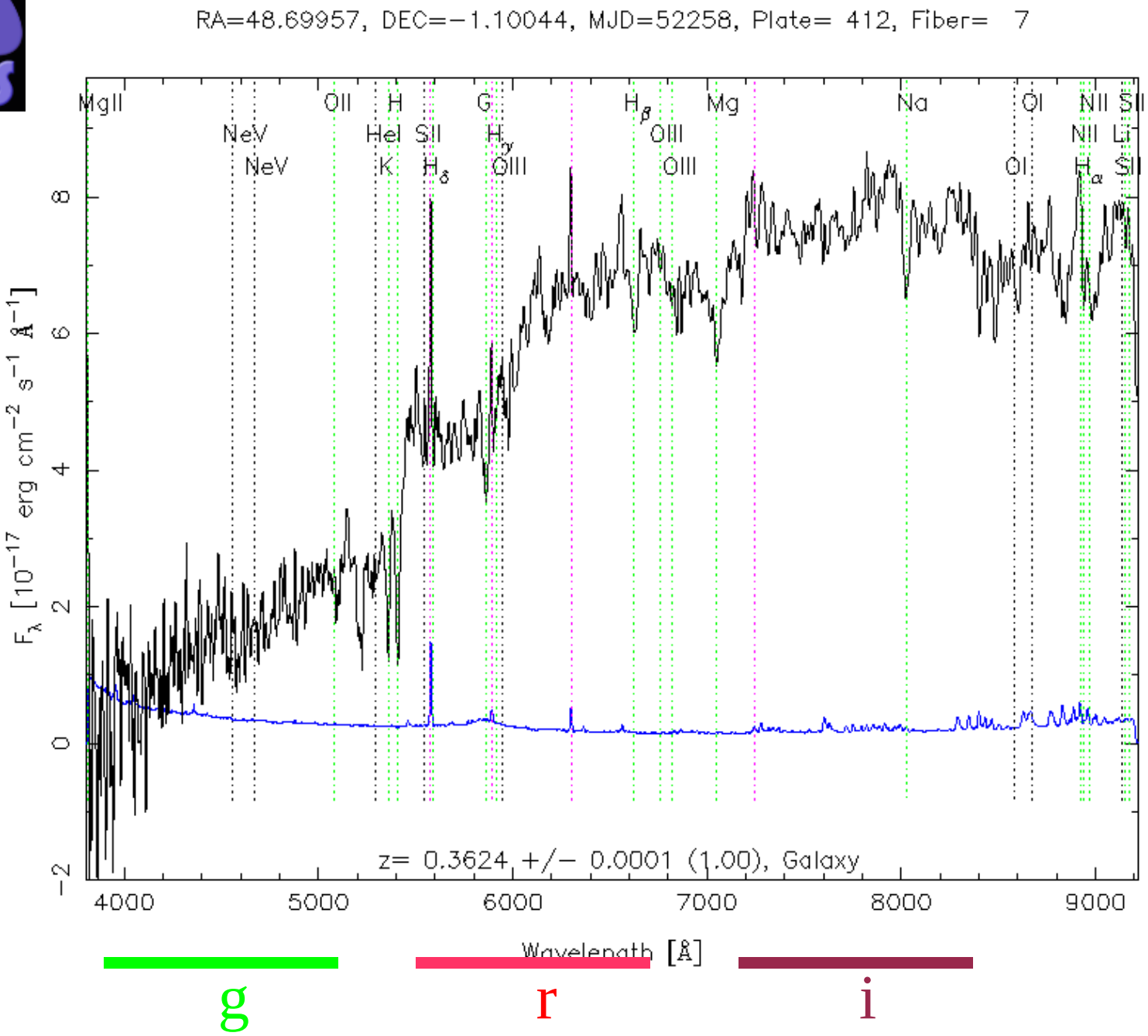
Photo-z is revolutionizing cluster finding

- maxBcg (Annis et al) — Photometry
  - Search for BCG and E/SO ridge
- Hybrid Matched Filter (Kim et al) — Photometry
  - Matched filter on luminosity function and radial profile
- Cut and Enhance (Goto et al) — Photometry
  - Color cuts, gaussian cloud, image processing
- Voronoi Tessalation (Kim et al) — Photometry
  - Color cuts, then tessalation
- C4 (Miller et al) — Photometry
  - Near neighbors in color-color space
- SRC: SDSS-RASS Catalog (Annis et al) — Xray cross ID
  - E/S0 overdensities at RASS faint source position
- FOG: The finger of god catalog (Annis et al) — Spectroscopy
  - Velocity space search for fingers of gods.

Galaxy Clusters

Abell 1689 Galaxy Cluster

Elliptical Galaxy Spectrum



Rest-frame g-r, r-i are same for all E, S0 galaxies

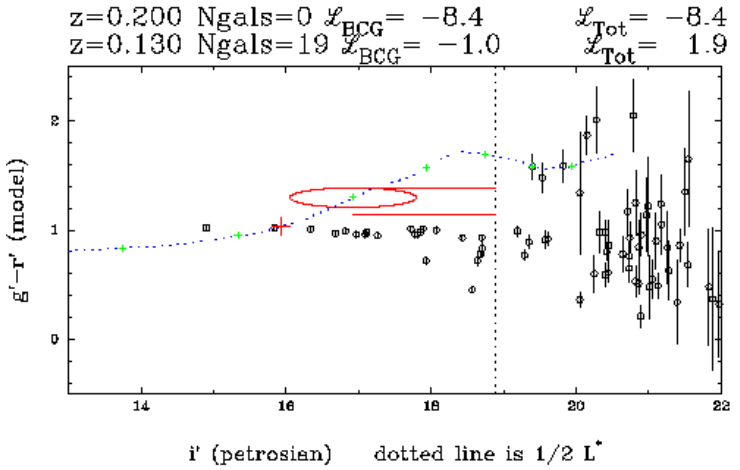
g-r, r-i colors measure redshift

The maxBcg Algorithm

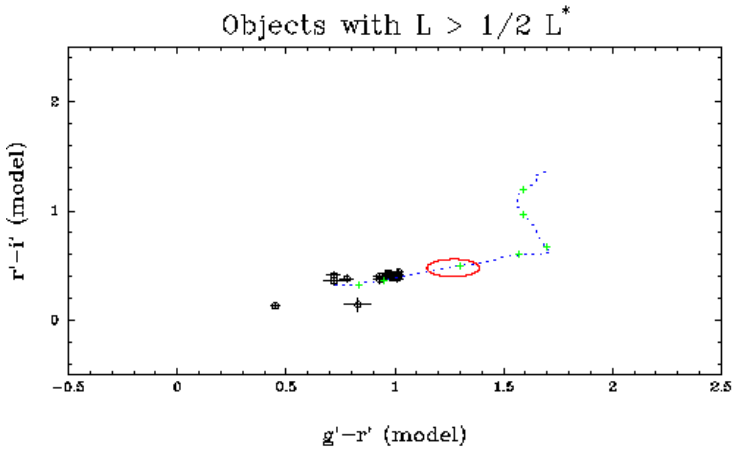
(Annis et al, 2002, Bahcall 2003)

- Animation of process for a single galaxy

- Perform step for all galaxies
- Build a 3-d map
- Locate maxima



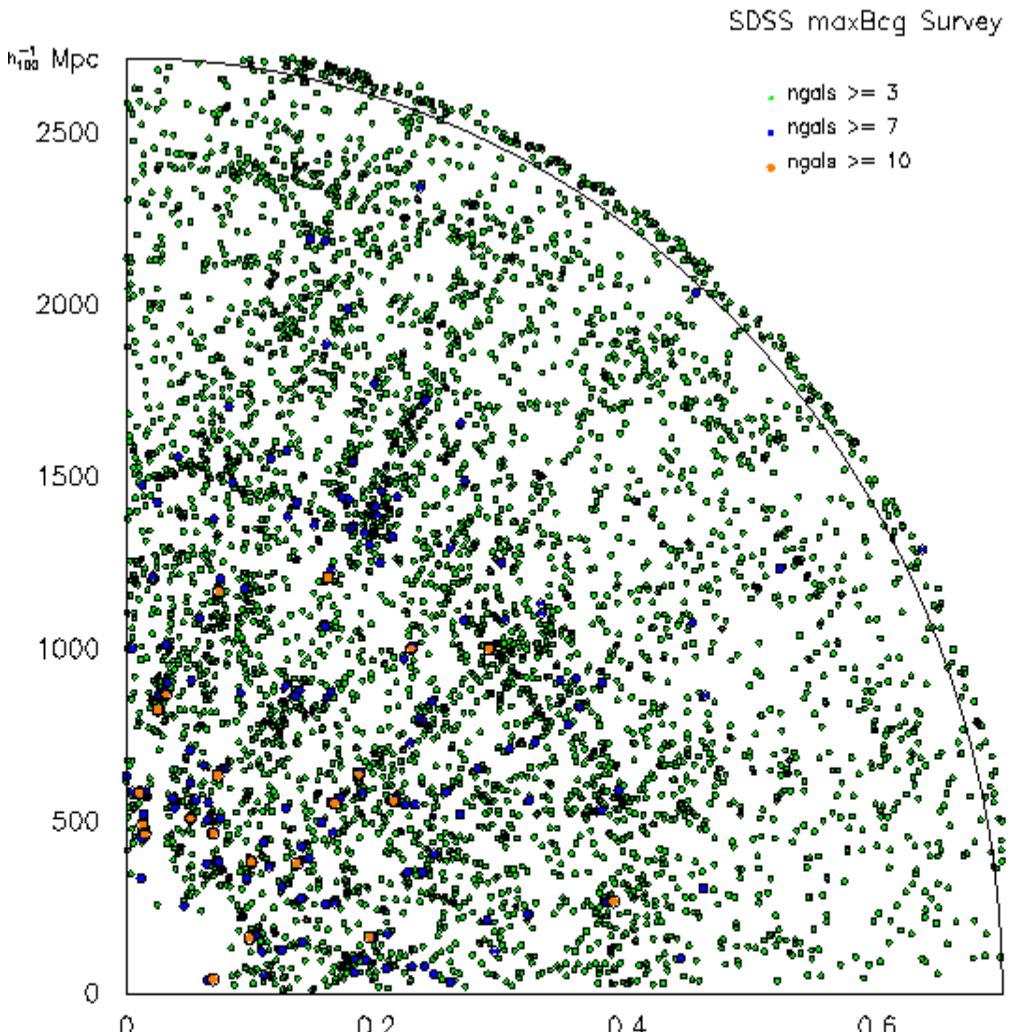
- Strengths
  - Works to high z
  - Very good photo-z
- Weaknesses
  - Strong assumptions built in



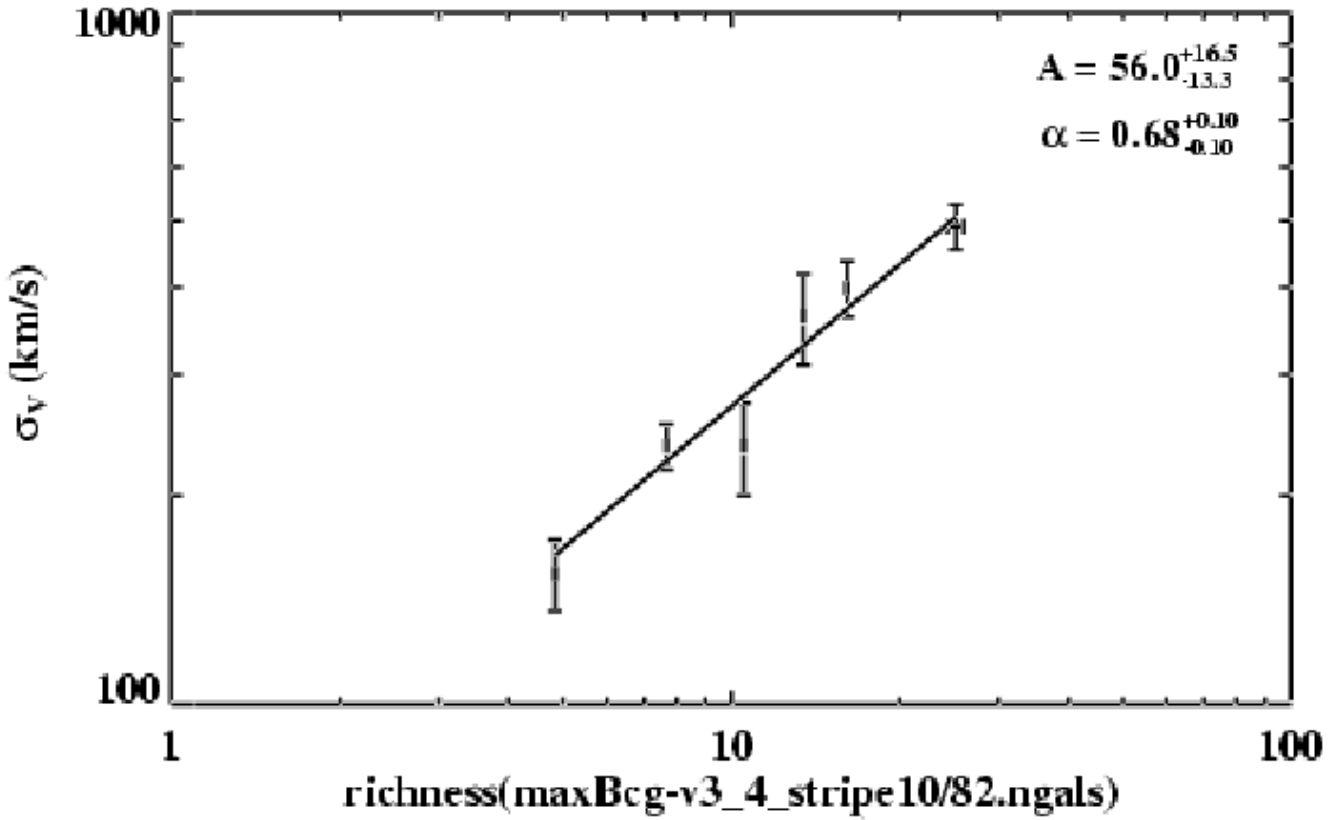
The maxBcg Cluster Catalog

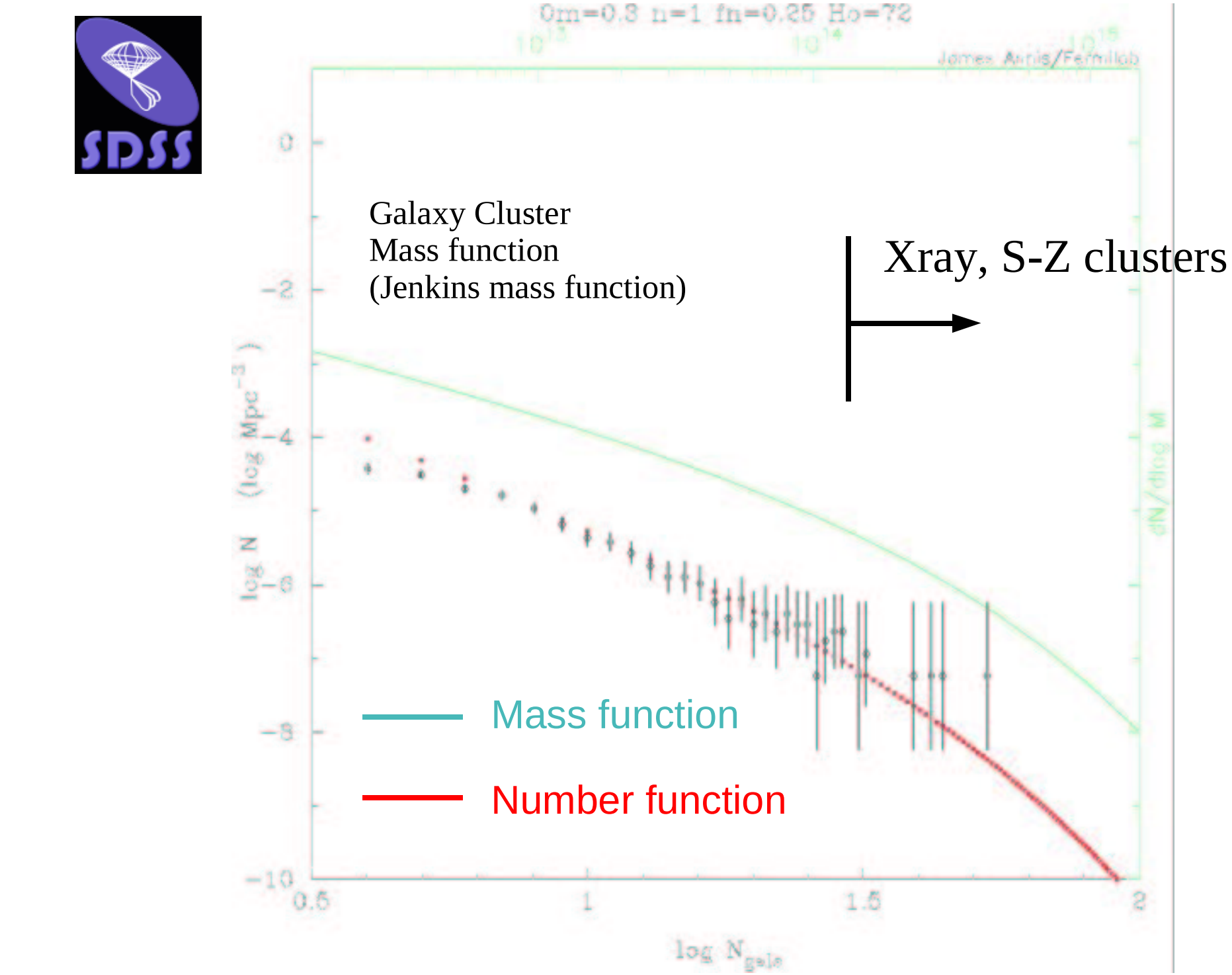
- The 200 sq-degrees currently analyzed gives a catalog of 4000 clusters
-
- Photometric redshift for each cluster good to 0.015
-
- Mass estimates from total galaxy light

- Plot shows all clusters from a wedge 90^{o} wide and 3^{o} high, out to redshifts of 0.7



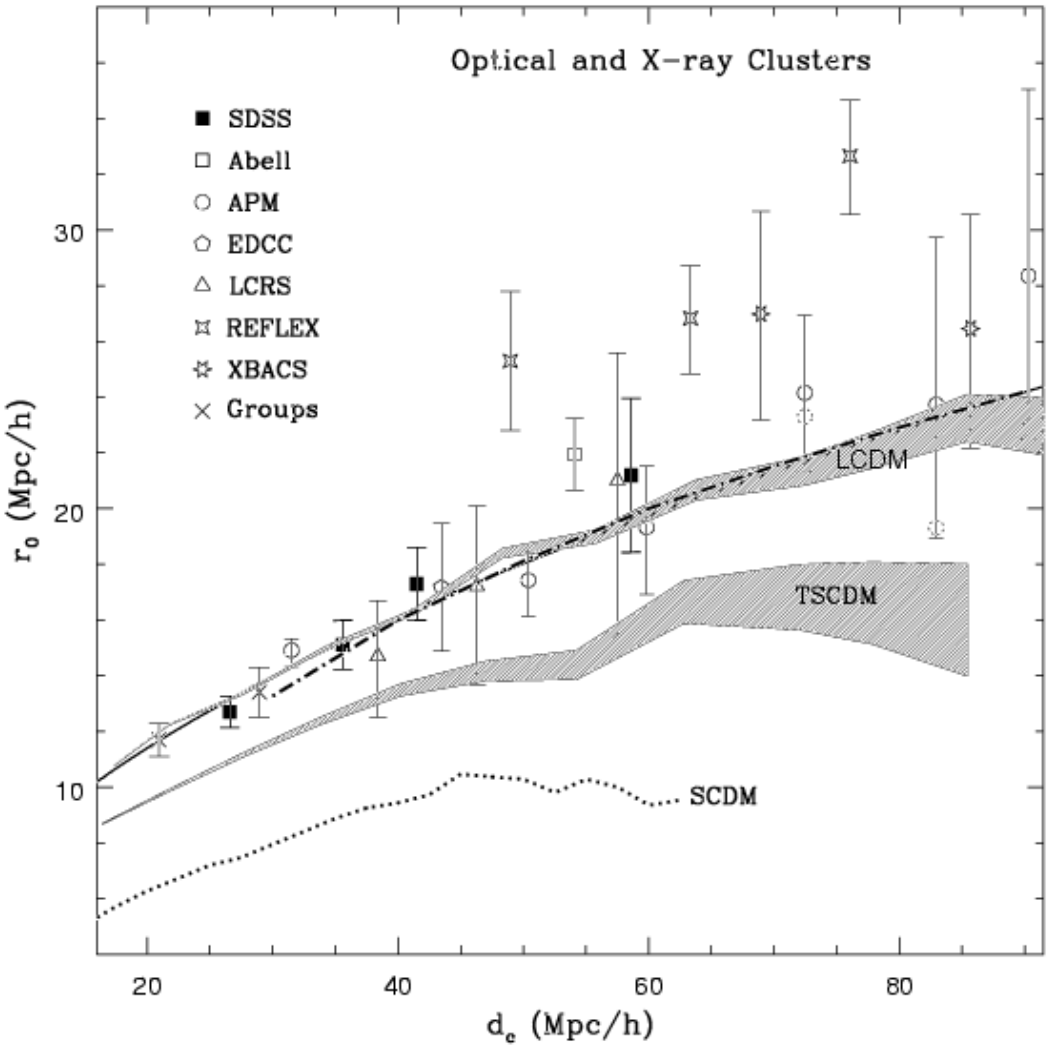
maxBcg Calibration from weak lensing (Sheldon et al. 2002)




Galaxy Cluster
Mass function
(Jenkins mass function)
Xray, S-Z clusters
Mass function
Number function
Om=0.3 n=1 fn=0.25 Ho=72
James Annis/Fermilab
log N (log Mpc^-3)
log N_gals
dN/dlog M
0
-2
-4
-6
-8
-10
0.5
1
1.5
2

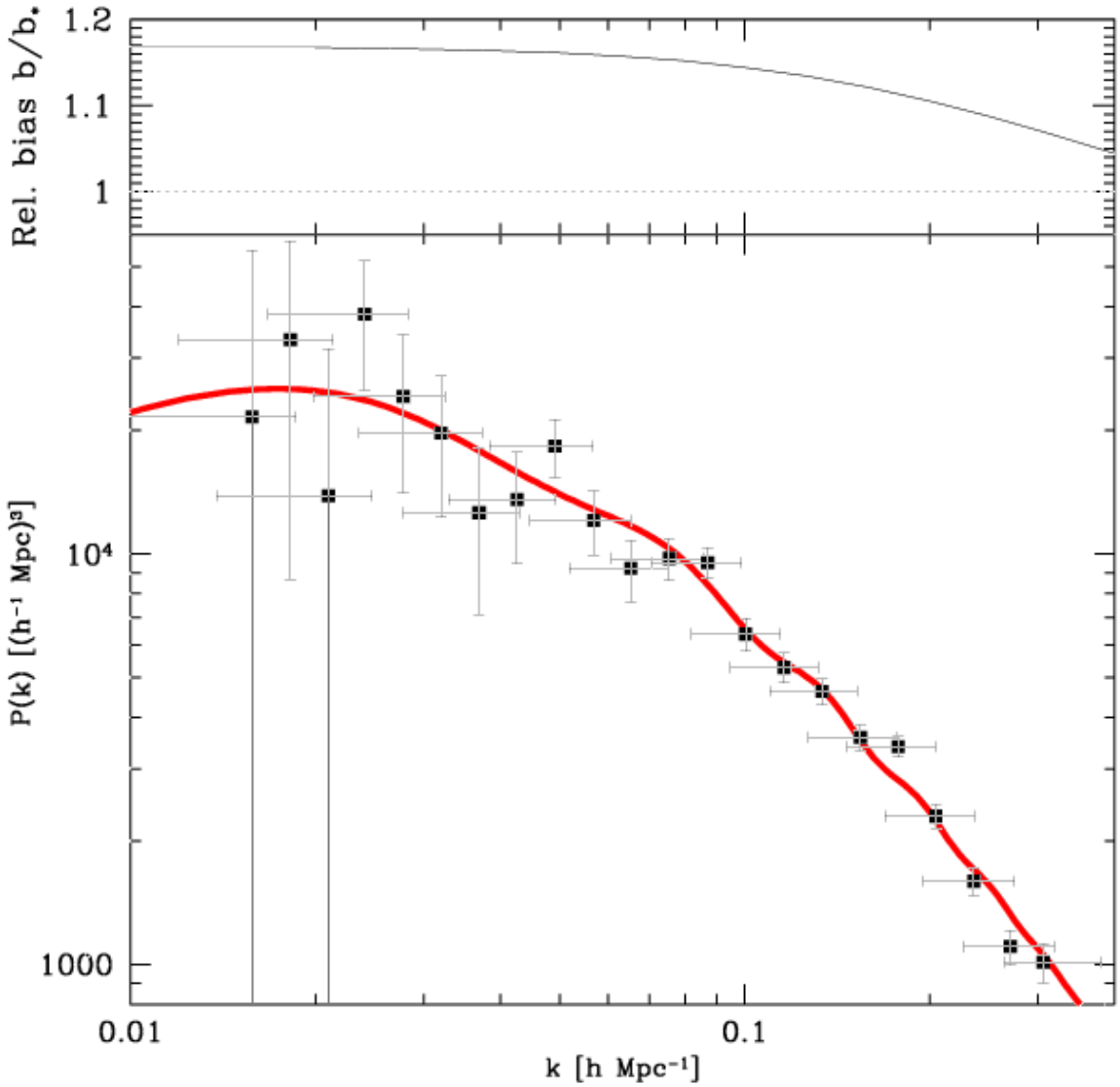
Cluster-Cluster correlation length vs cluster richness

(Bahcall et al 2003)



Three-dimensional Power Spectrum

(Tegmark et al 2003)

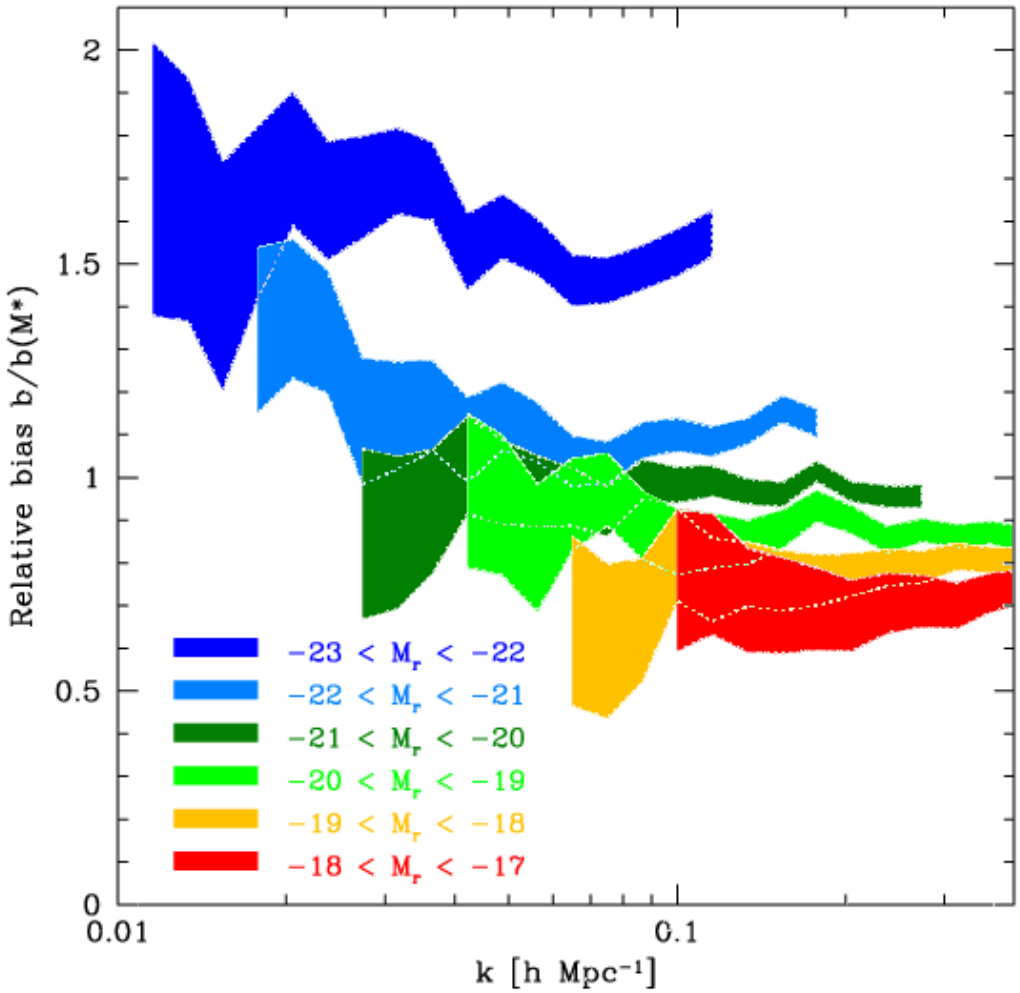


ΛCDM adjusted to L* galaxy

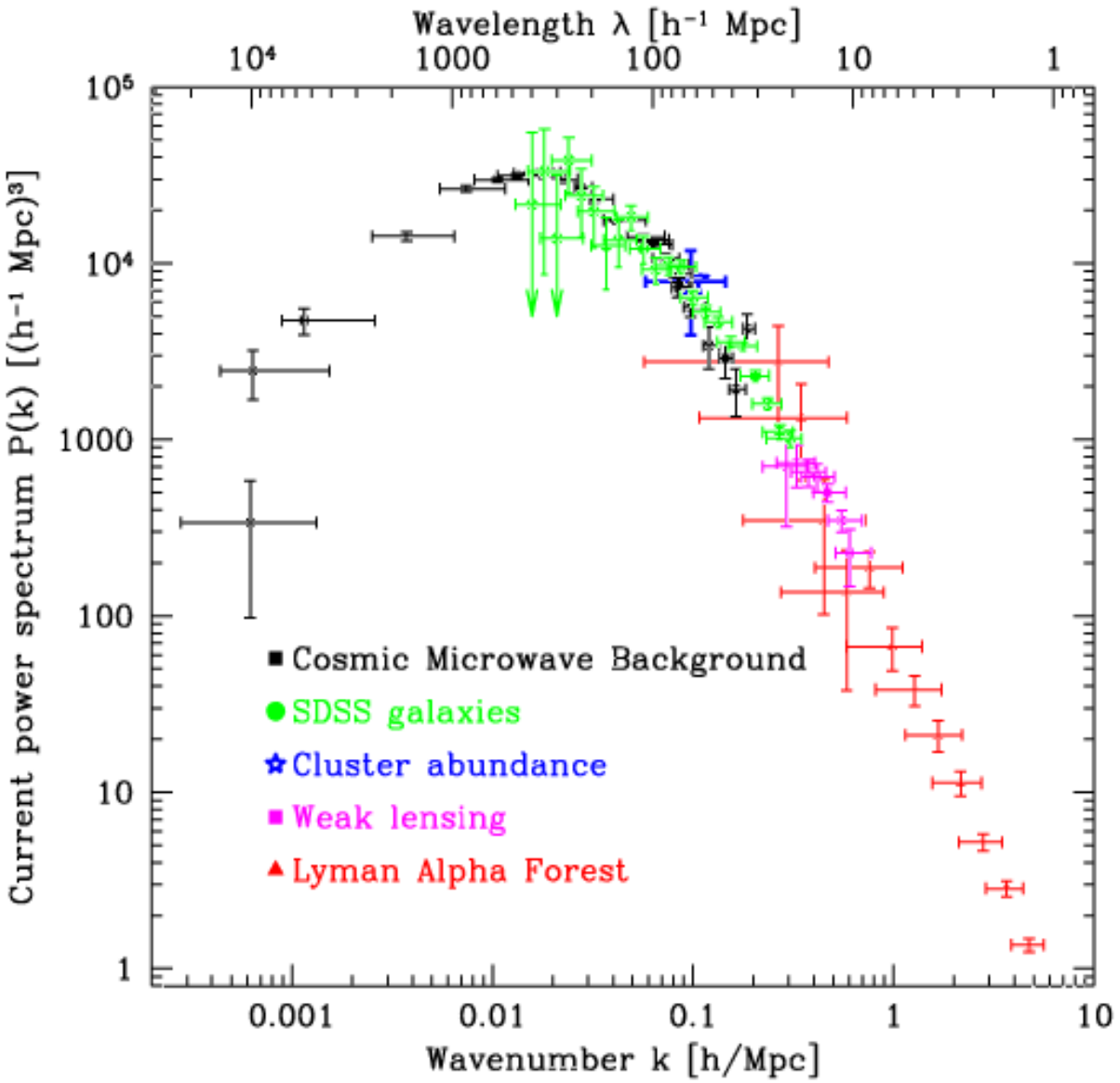
$\Omega_M h = 0.213 \pm .023$

$\sigma_8 = 0.96 \pm .02$

Bias vs. Galaxy Luminosity

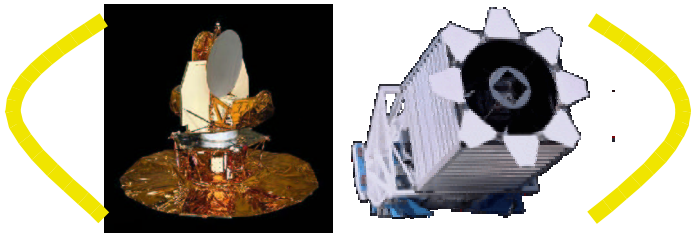


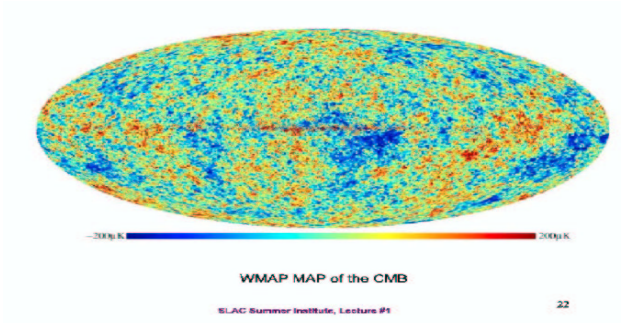
SDSS vs Rest of World



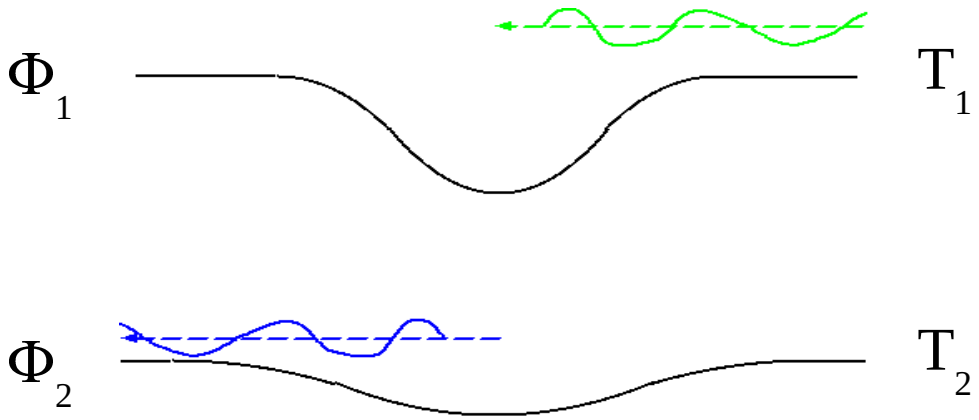
Correlating WMAP with SDSS

(Scranton et al. 2003)



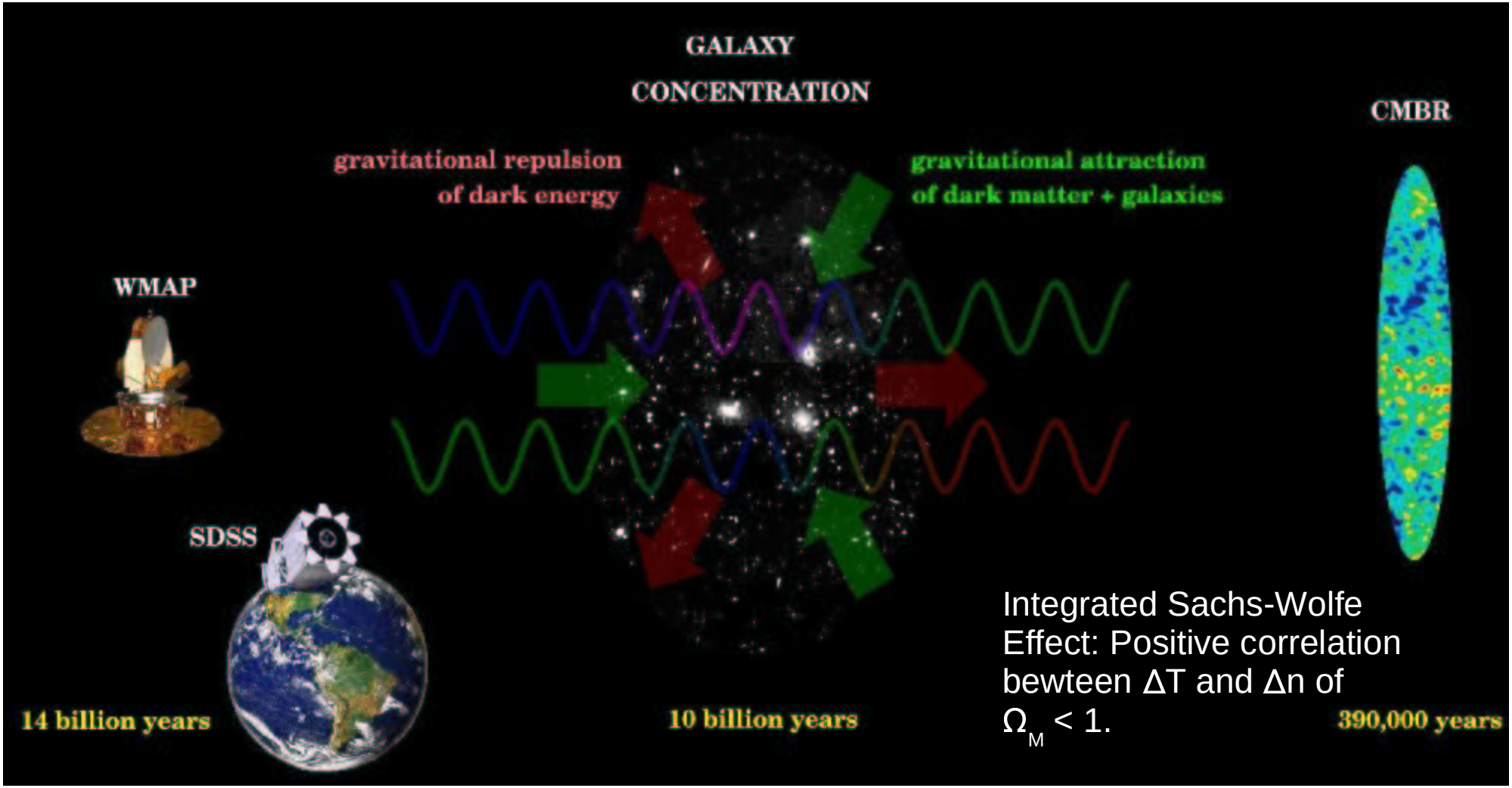


Integrated Sachs-Wolfe Effect



$$\Delta\nu \approx G\Delta M_1/r_1 - G\Delta M_2/r_2$$

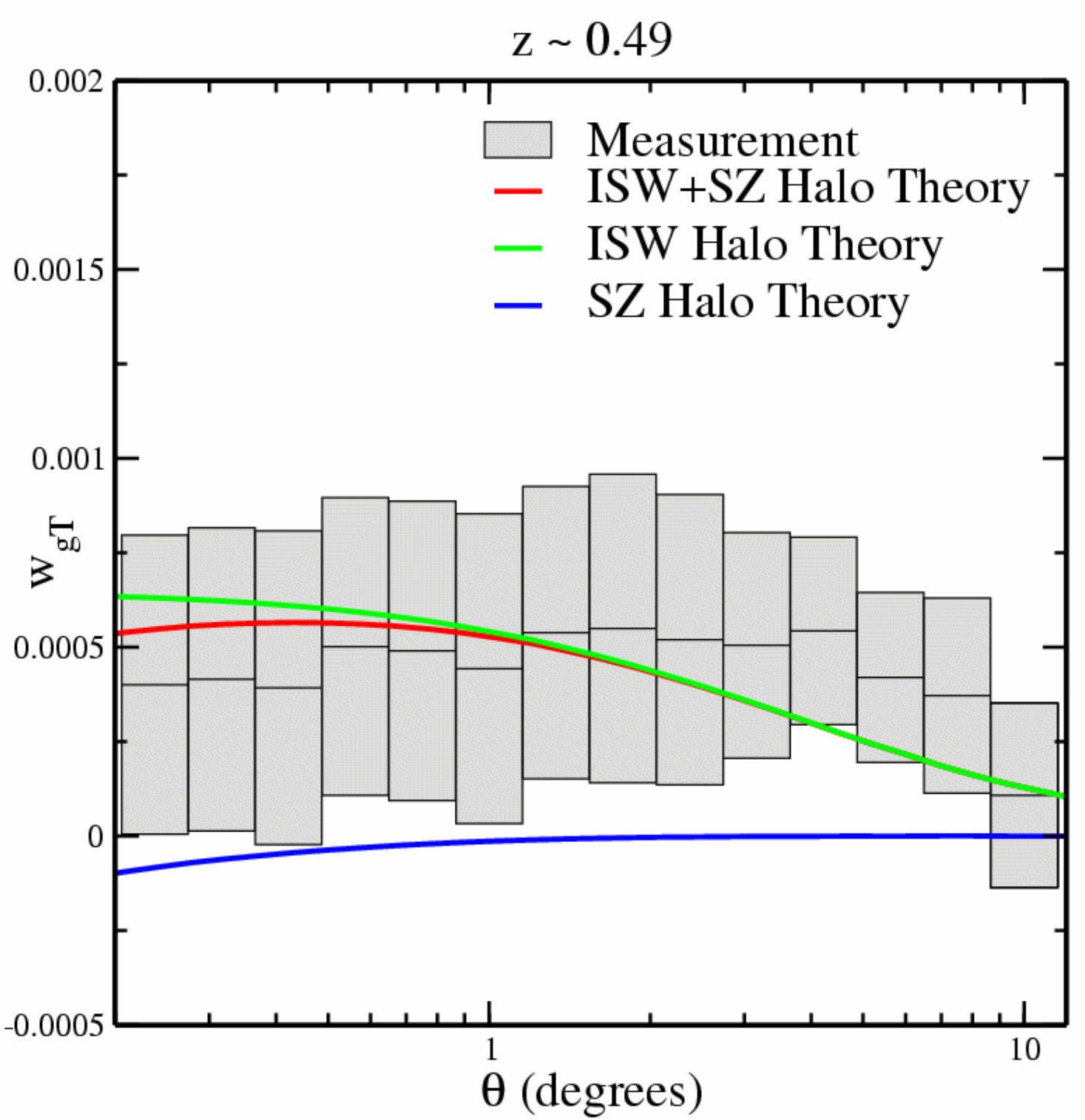
What Are We Measuring?

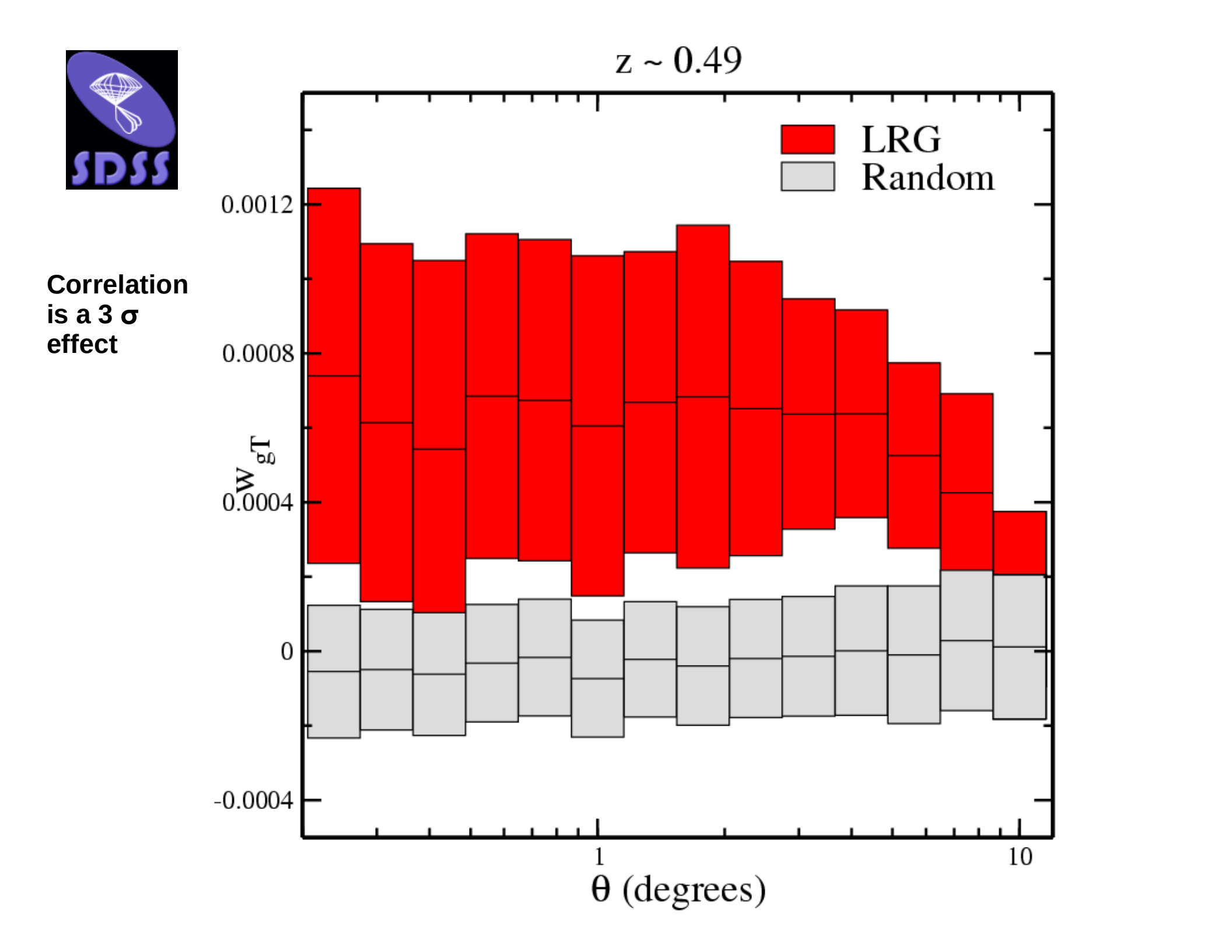


Integrated Sachs-Wolfe Effect: Positive correlation bewteen ΔT and Δn of $\Omega_M < 1$.

Red Galaxy count/CMB correlation

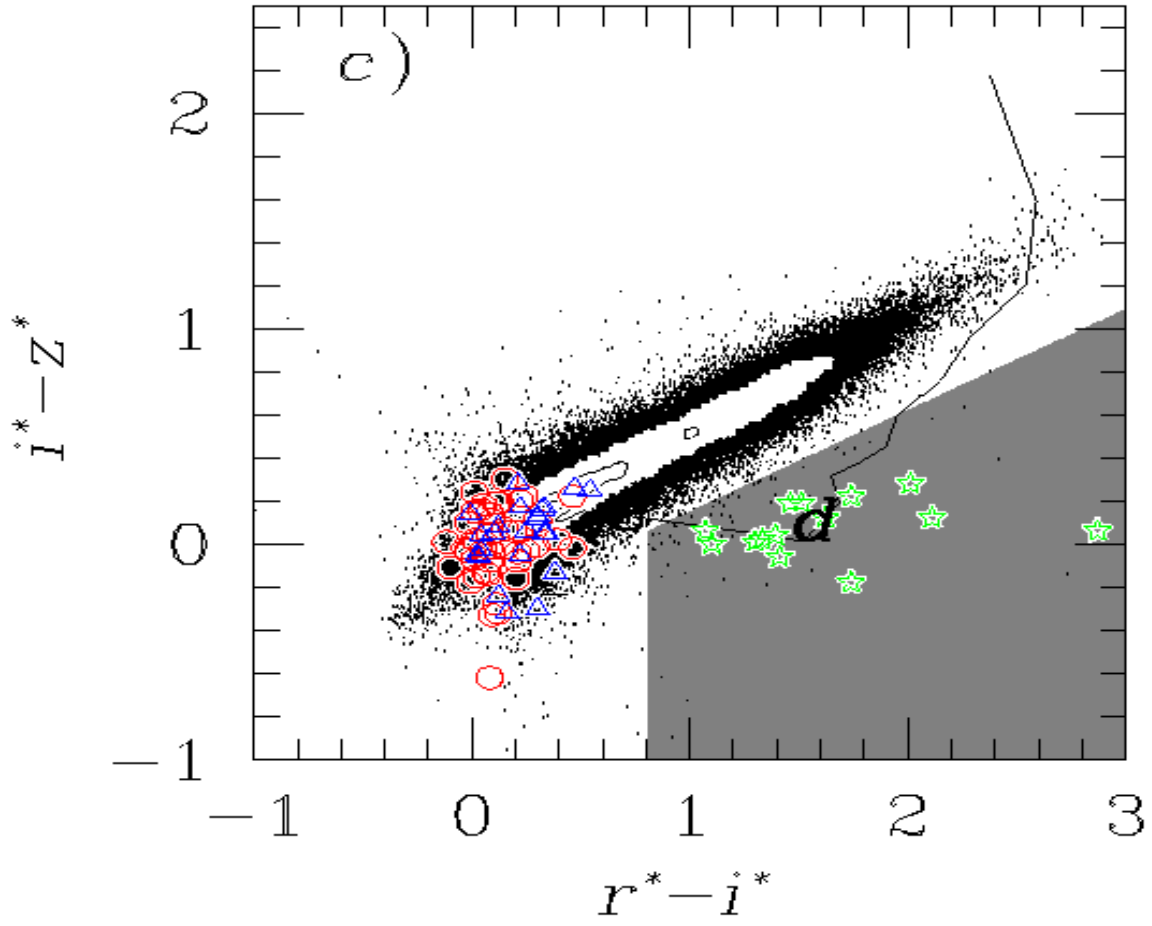
= $<\Delta T_{CMB} \Delta n_{Gal}>$





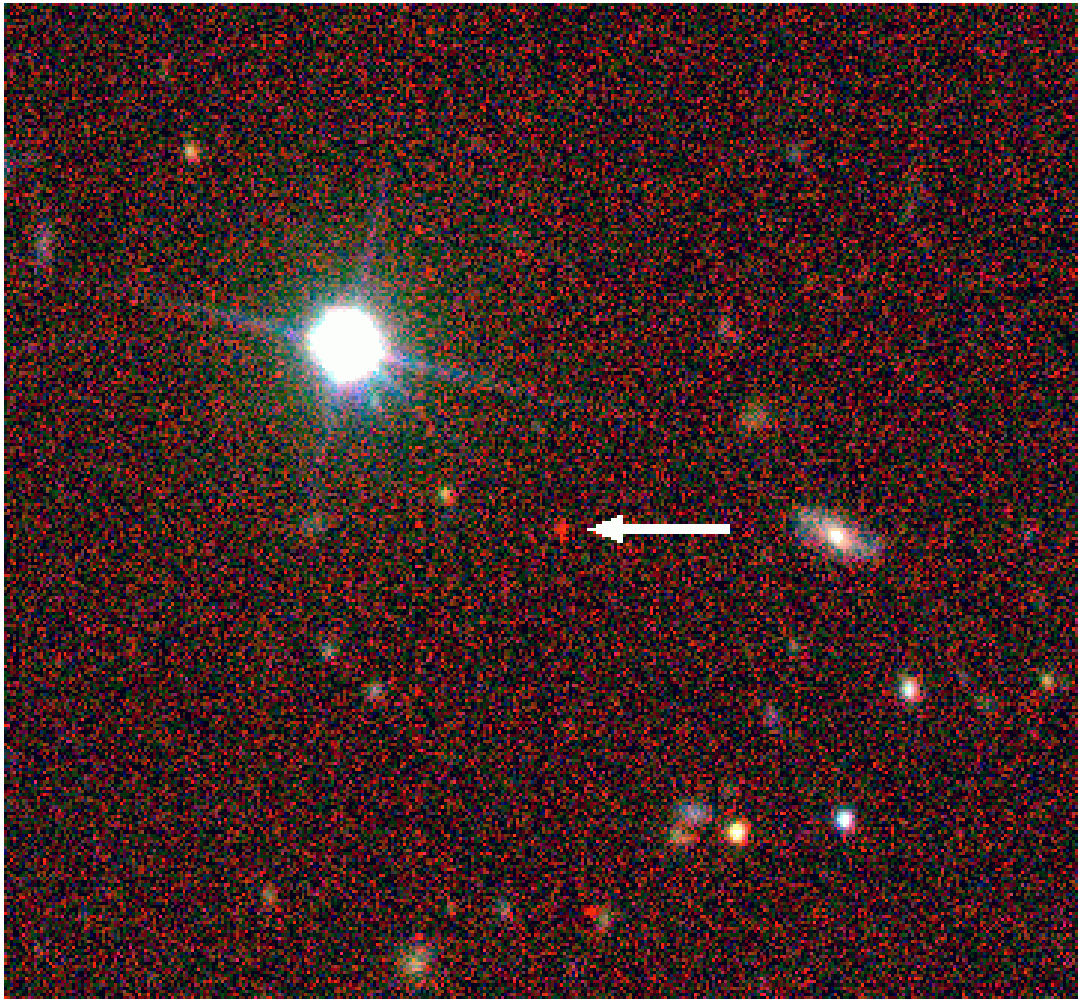
Correlation is a 3 σ effect

How to find High Redshift QSOs

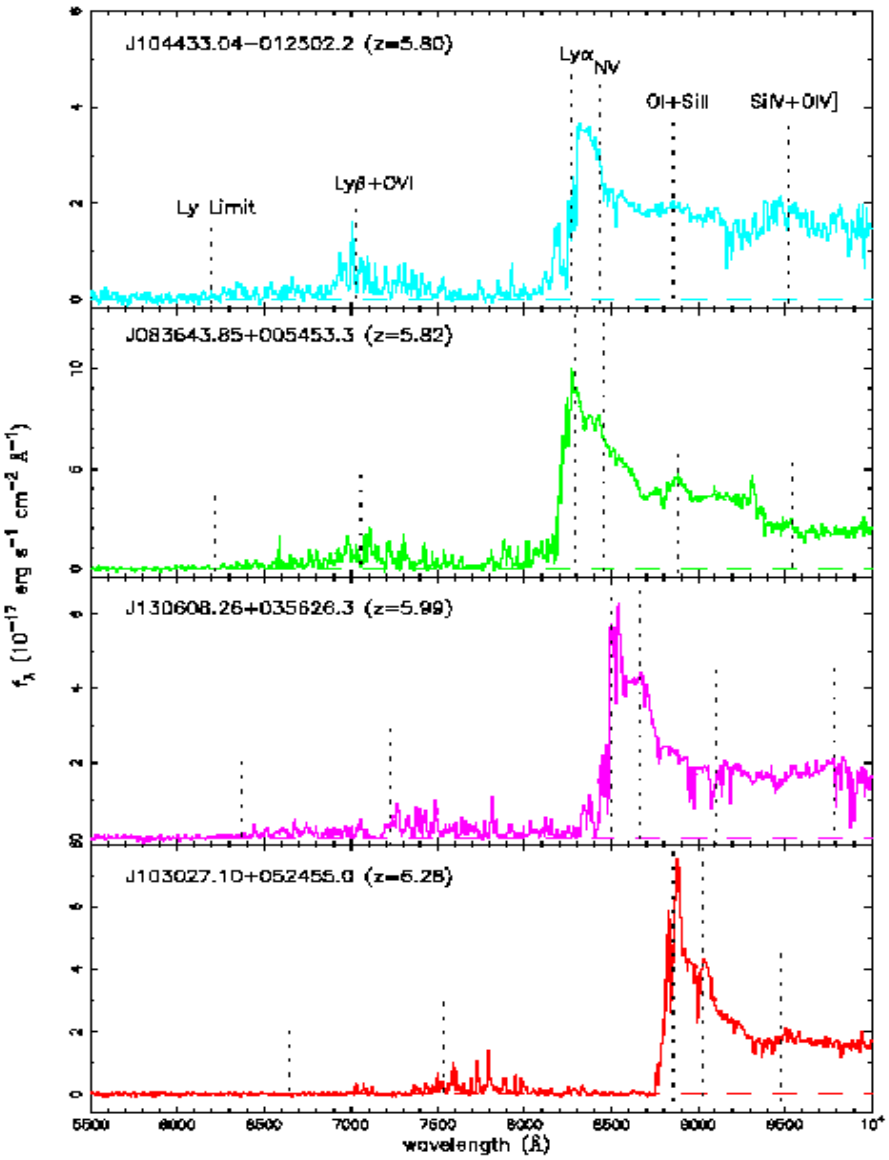


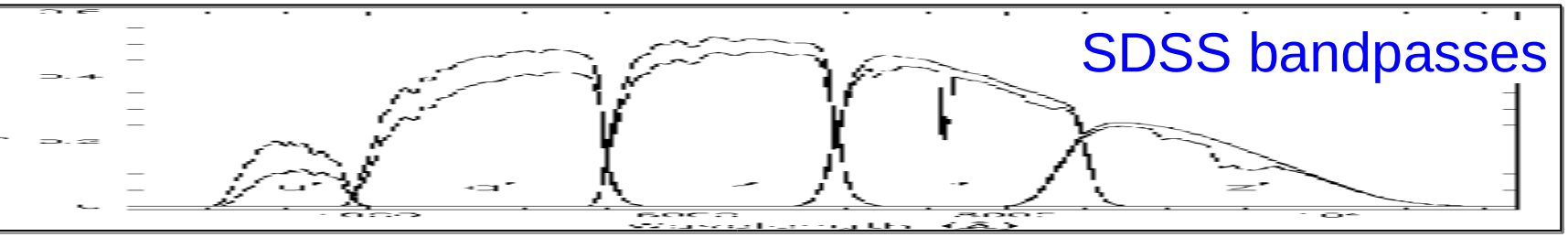
o 3.6 < z < 4.0
o 4.0 < z < 4.5
o 4.5 < z

z=6.28 Quasar (r', i', z')

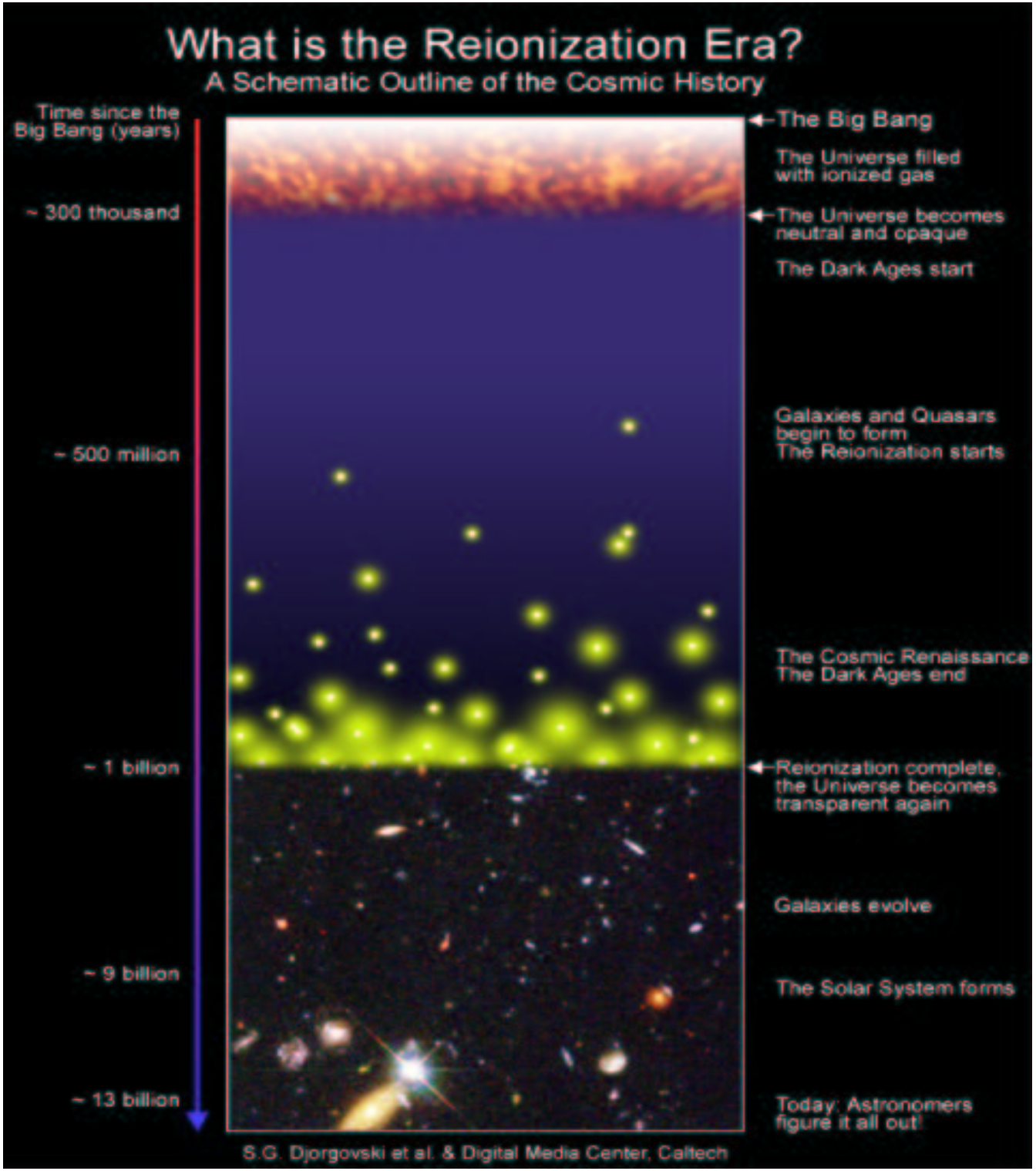


Lyman Alpha Forest vs. Redshift



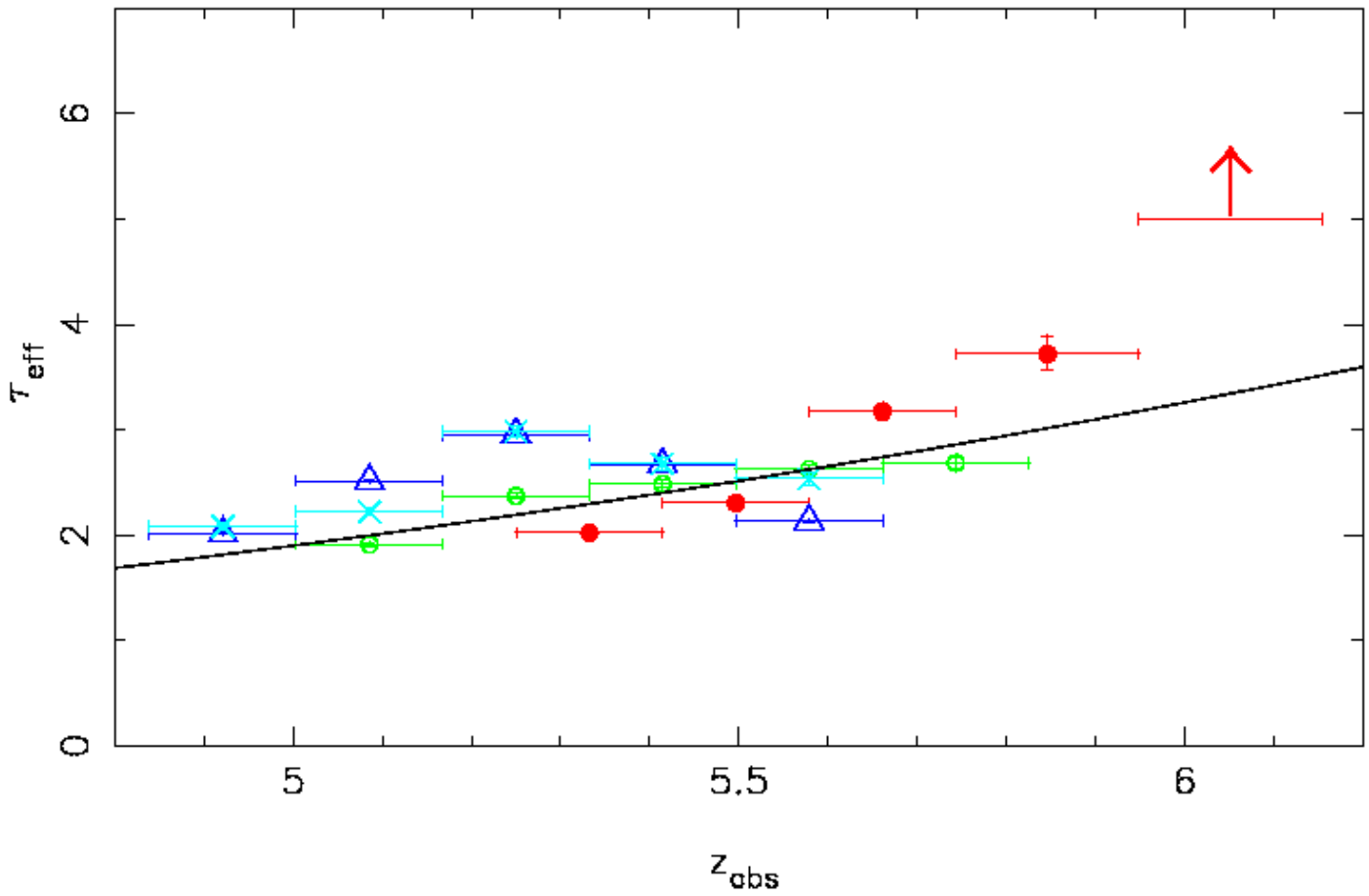


SDSS bandpasses



End of the Dark Ages

Optical Depth vs. Redshift



Conclusions

- SDSS is performing successfully
- We are testing "cosmology du jour" with ever increasing precision
- 400,000 redshifts + 30 Terabytes of processed data: *Quantity has a quality all its own*
- Producing leading edge science in a wide range of disciplines