Weak Lensing Magnification and Large Scale Structure

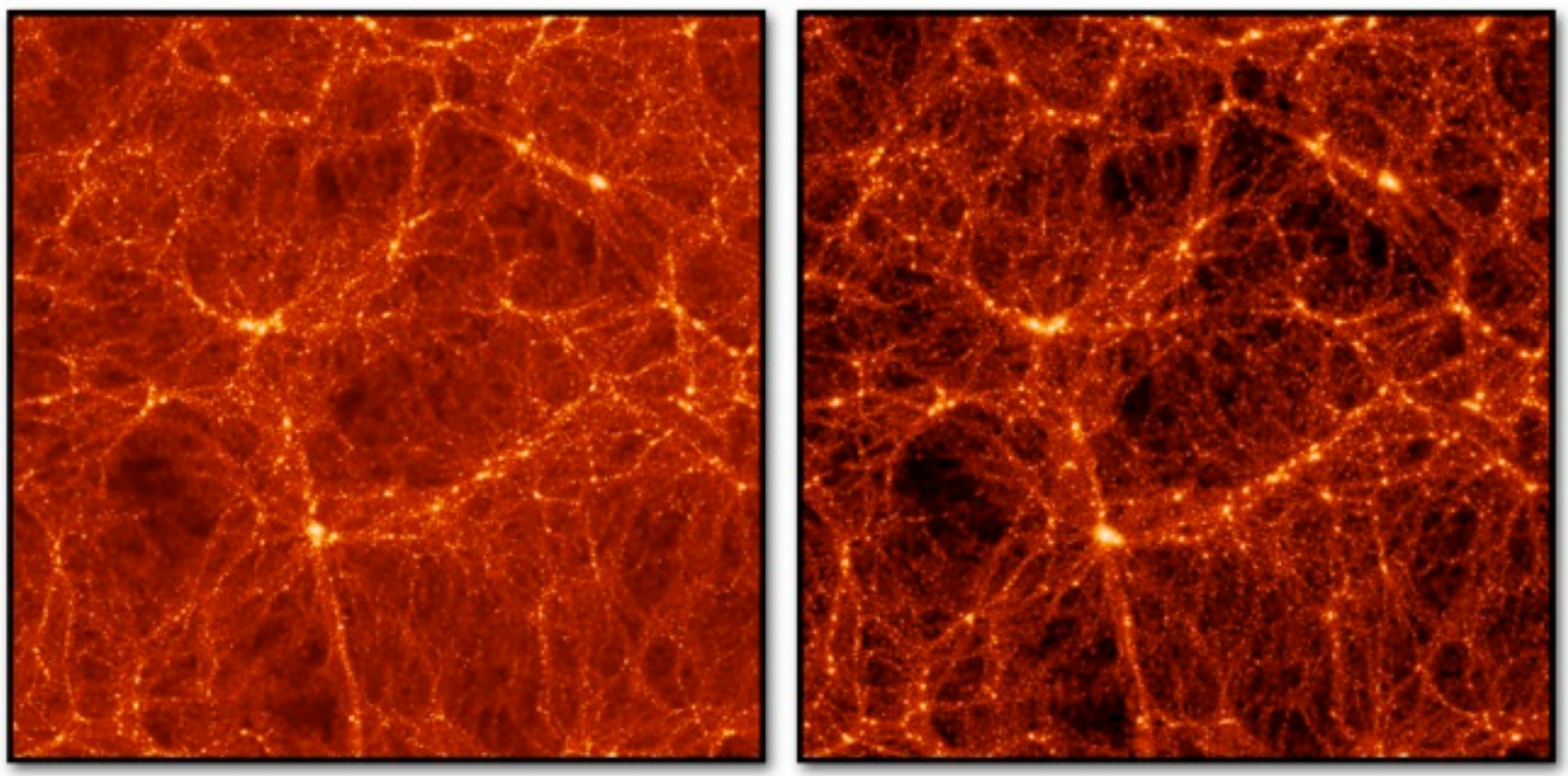
Anne Bauer
IEEC-CSIC, Barcelona, Spain

Outline

- Large scale structure and cosmology: what are we trying to measure and why?
- What is gravitational lensing? Magnification?
- Recent results using the Sloan Digital Sky Survey
- Upcoming surveys: DES, PAU

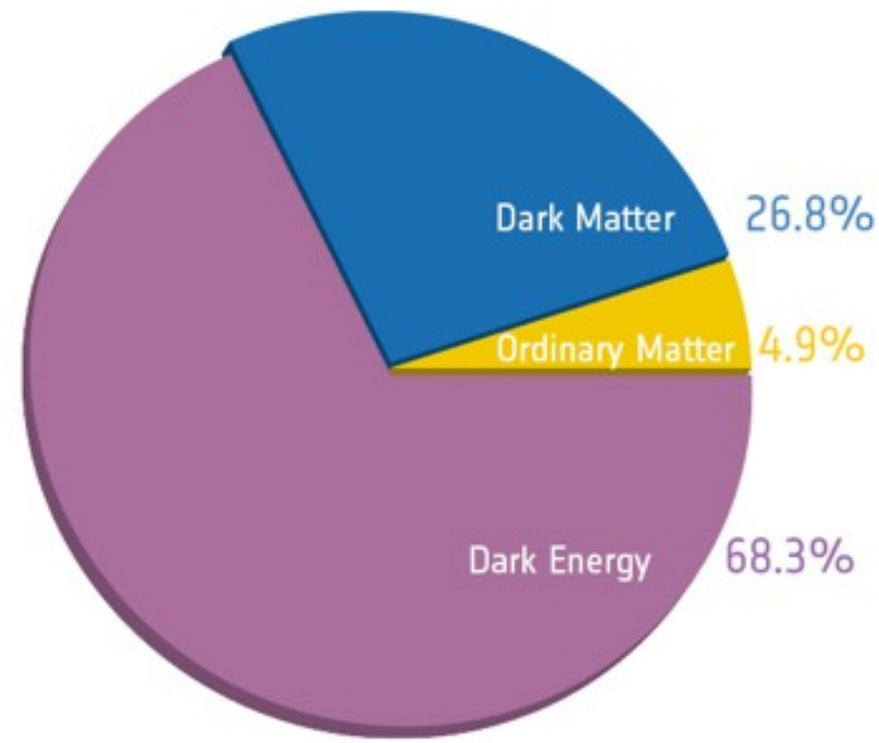
The distribution of matter & Cosmology

- Dark matter and dark energy, vs. time, determine clustering of matter in the universe.

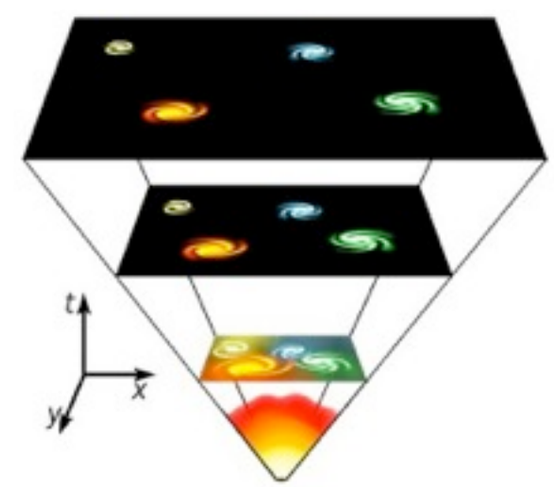


Dark matter shapes visible matter in a way that reflects the nature of dark energy. How galaxies are distributed in a Universe with no dark energy (left) would differ measurably from one in which dark energy is significant (right).

http://newscenter.lbl.gov/news-releases/2010/01/19/weak-lensing-gains-strength/



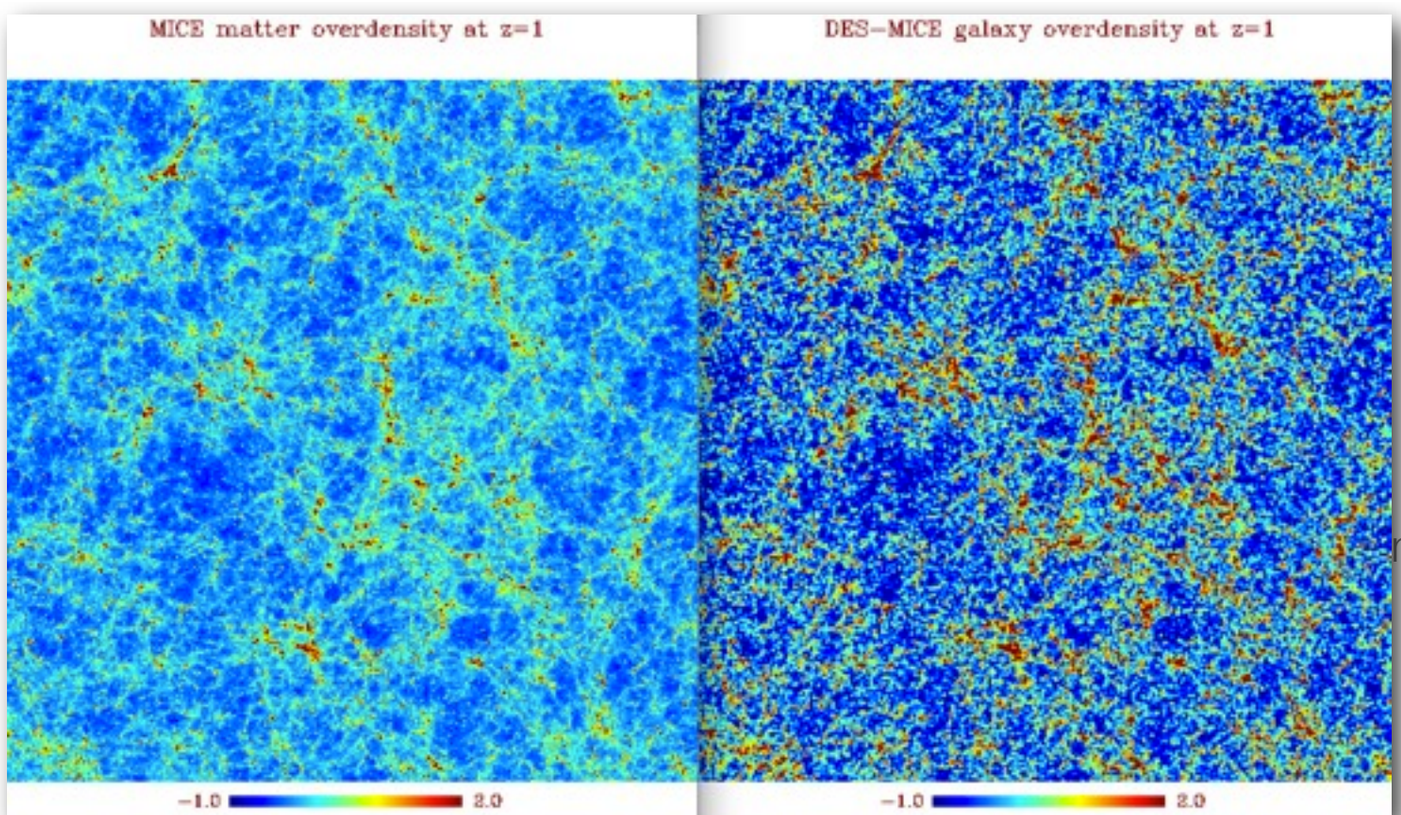
http://planck.cf.ac.uk

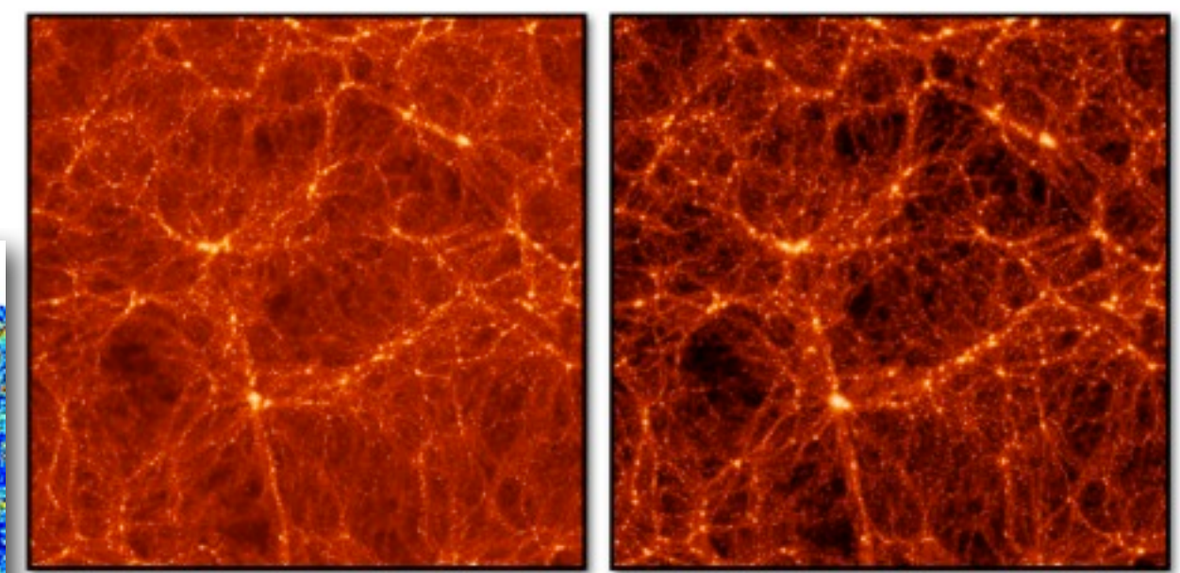


http://www.marialachica.com/index.php/page/23/

The distribution of matter & Cosmology

- Dark matter and dark energy, vs. time, determine clustering of matter in the universe.
- Galaxies trace dark matter, so we can measure galaxy positions to determine total matter distributions

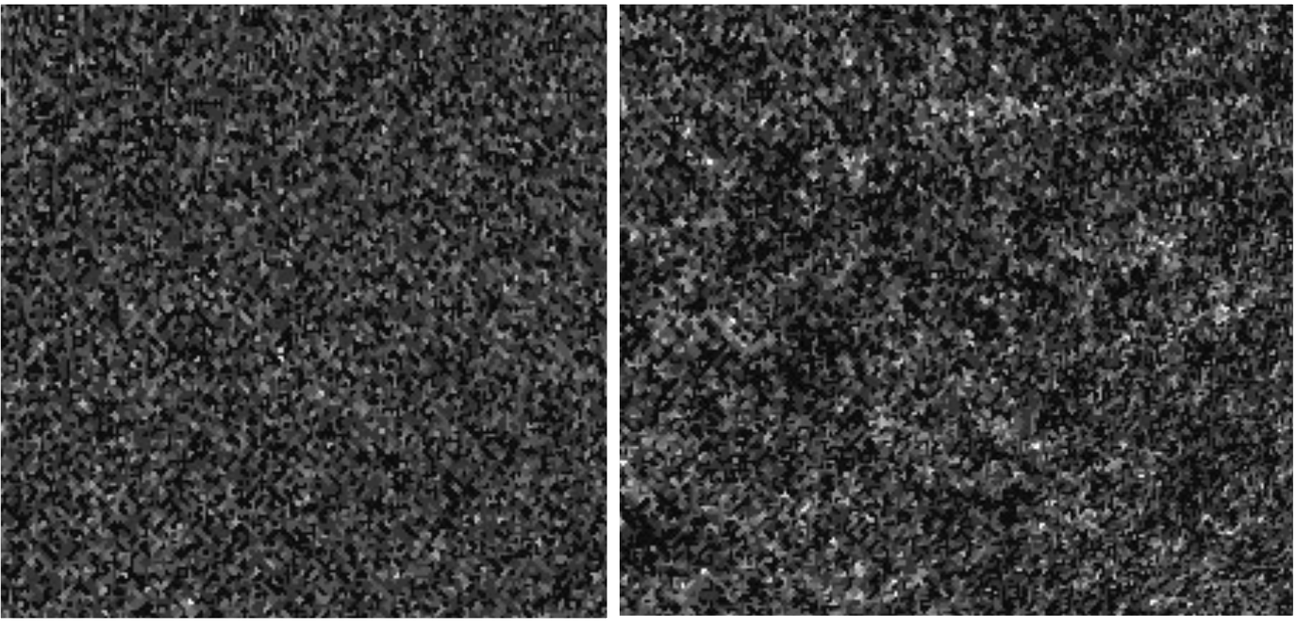




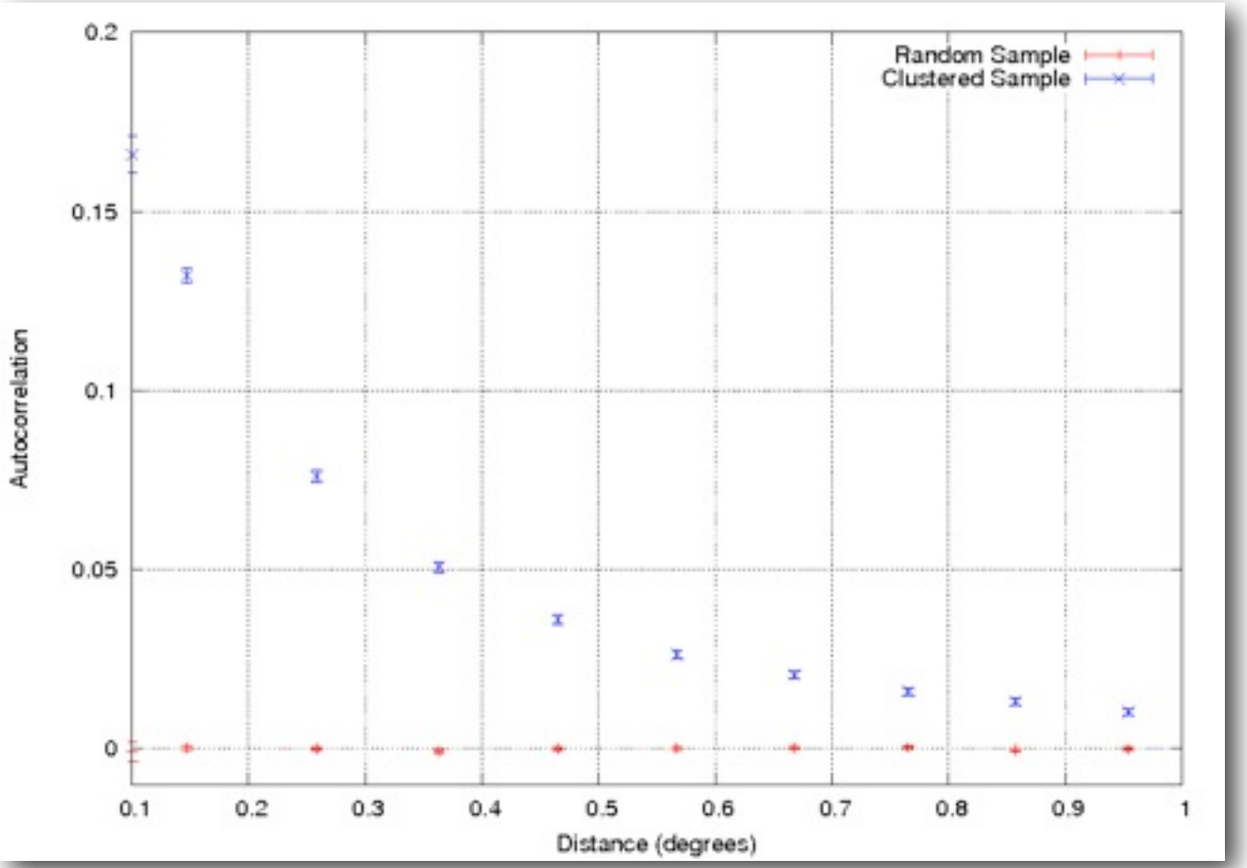
Dark matter shapes visible matter in a way that reflects the nature of dark energy. How galaxies are distributed in a Universe with no dark energy (left) would differ measurably from one in which dark energy is significant (right).

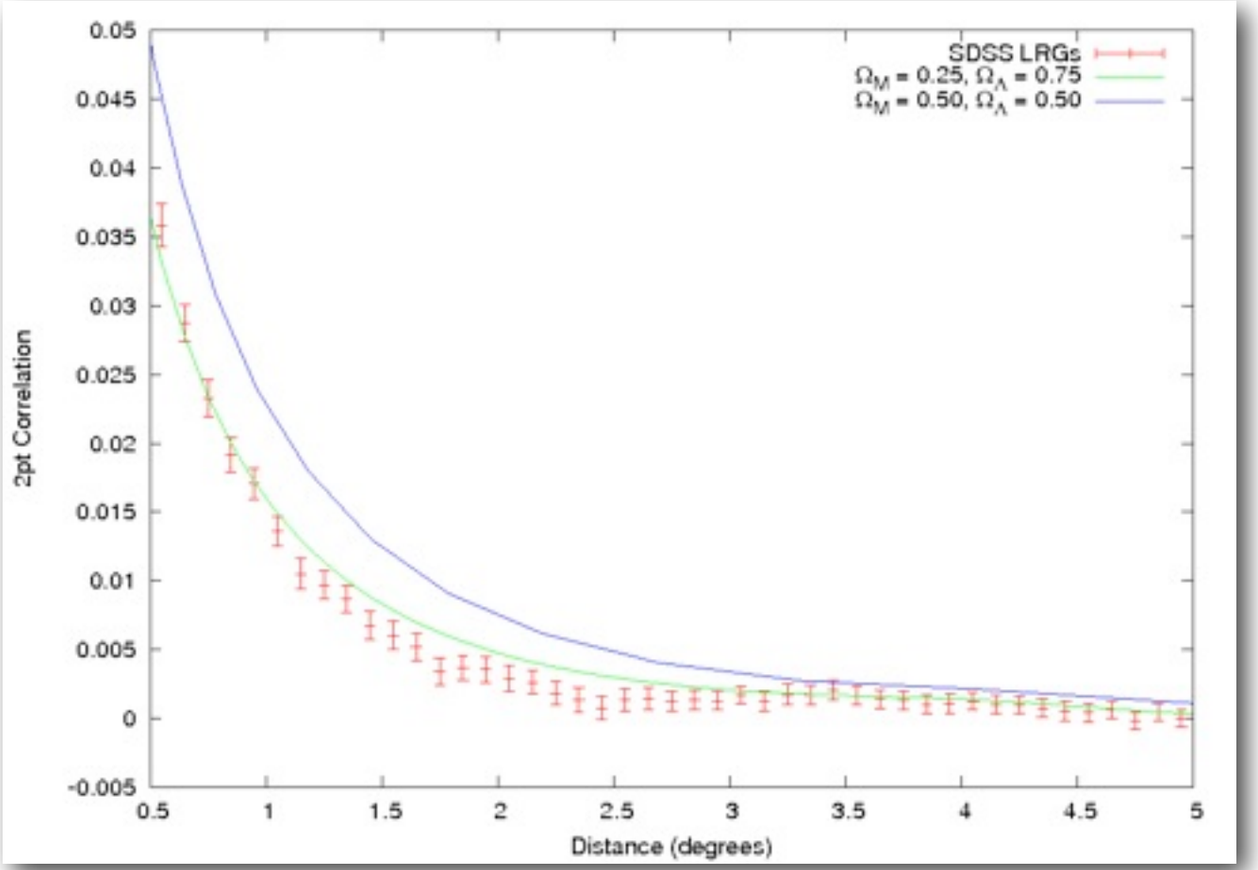
newscenter.lbl.gov/news-releases/2010/01/19/weak-lensing

The distribution of matter & Cosmology: Galaxy position correlations



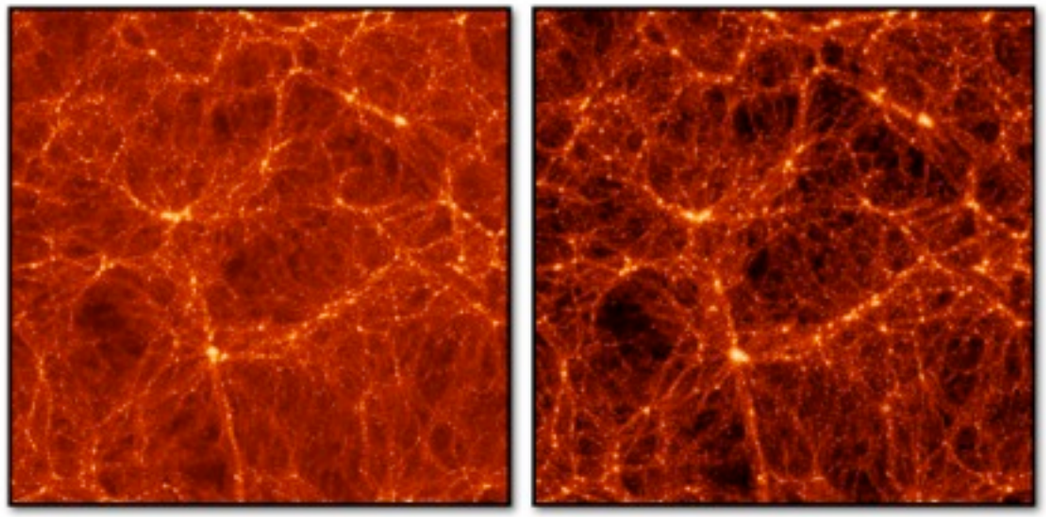
- 2-point correlation function
  - w(r) ≡ < δ(x)δ(x+r) >
    where δ is overdensity (N-<N>) / <N>





The distribution of matter & Cosmology: Cluster counts

- Different quantities/properties of DM & DE predict different clustering of matter (large scale structure)
- Implication: The number of massive overdensities per area depends on cosmology
- Count number density of massive haloes (e.g. $>10^{14} M_\odot$ galaxy clusters)
  → Cosmological constraints!



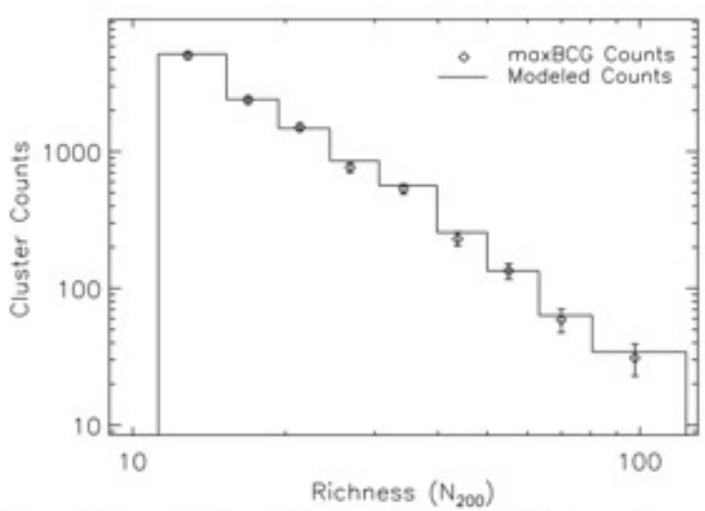


Figure 1. Observed (diamonds) and modeled (solid line) cluster counts as a function of richness in our best-fit model described in Section 4. The model counts are computed using the best-fit model detailed in Section 4, and are a good fit to the data.

Rozo et al., ApJ 708:645 (2010)

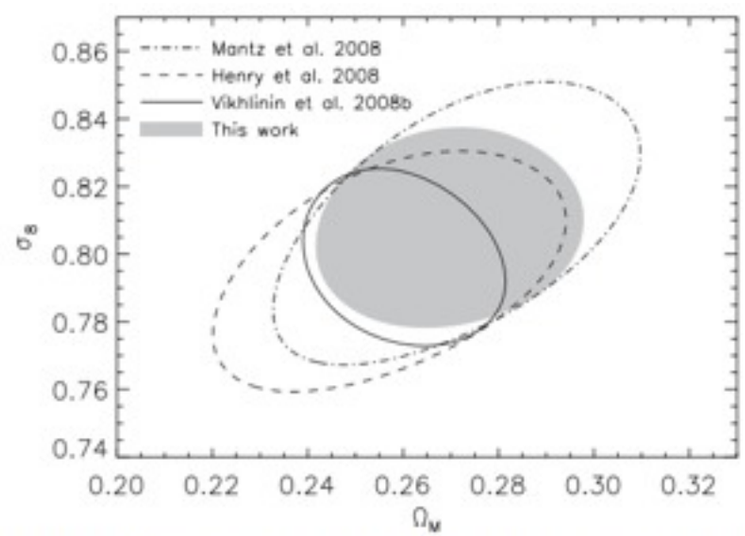
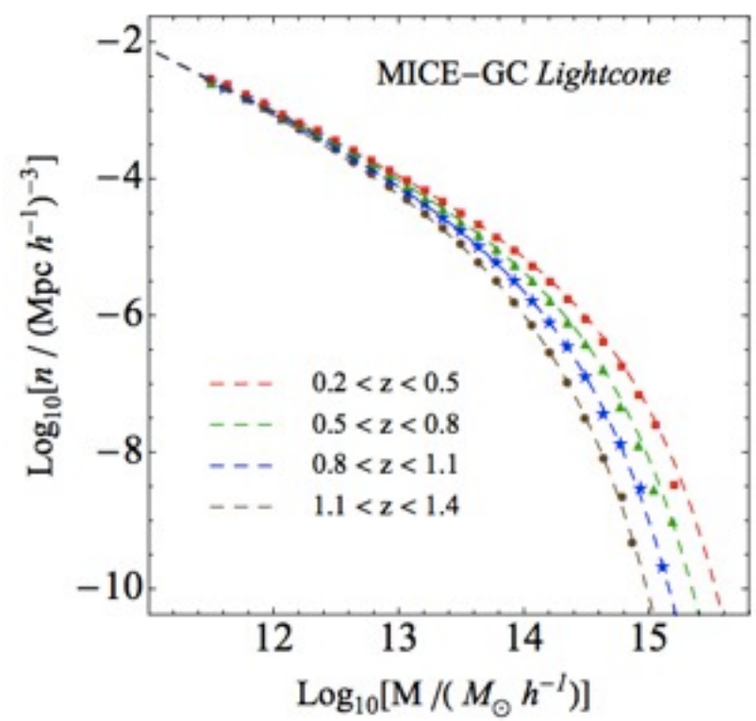
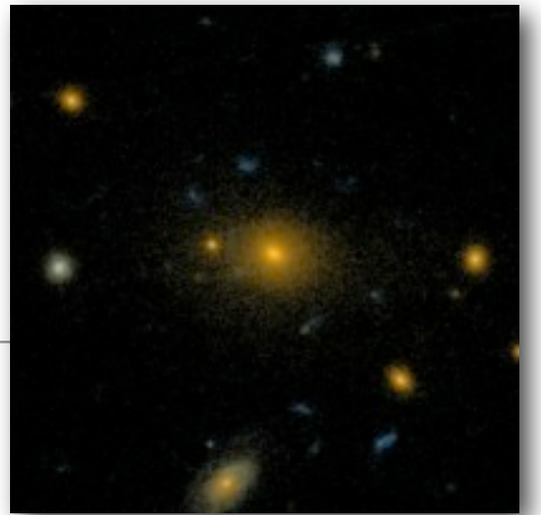


Figure 13. Comparison of optical and X-ray cluster abundance constraints on σ_8–Ω_m. Contours show 68% confidence regions for a joint WMAP5 and cluster abundance analysis assuming a flat ΛCDM cosmology. In addition to our results (filled ellipse), we consider the latest cluster abundance constraints from the low-redshift cluster luminosity function (dashed; Mantz et al. 2008), temperature function (dash-dotted; Henry et al. 2009), and mass function as estimated with Y_X (solid; Vikhlinin et al. 2009b). All four studies are in excellent agreement with each other despite the tight cosmological constraints and the

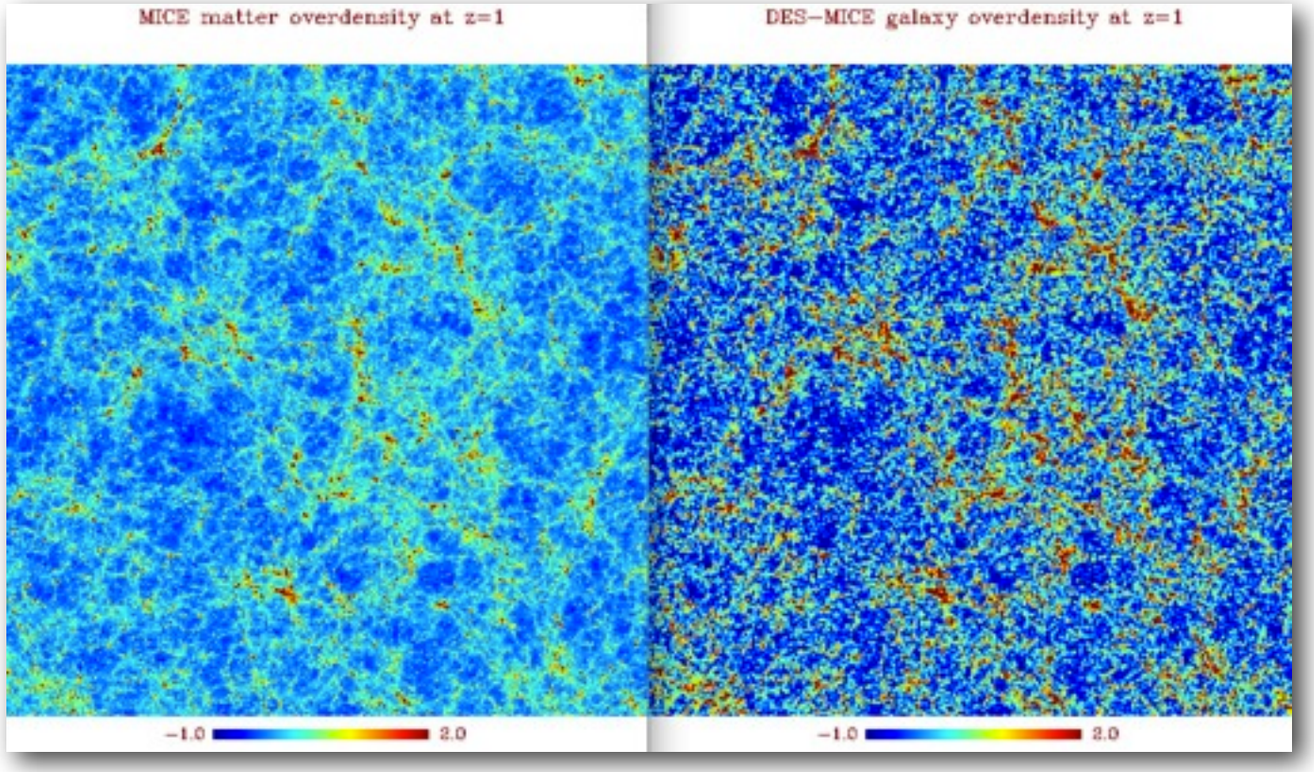


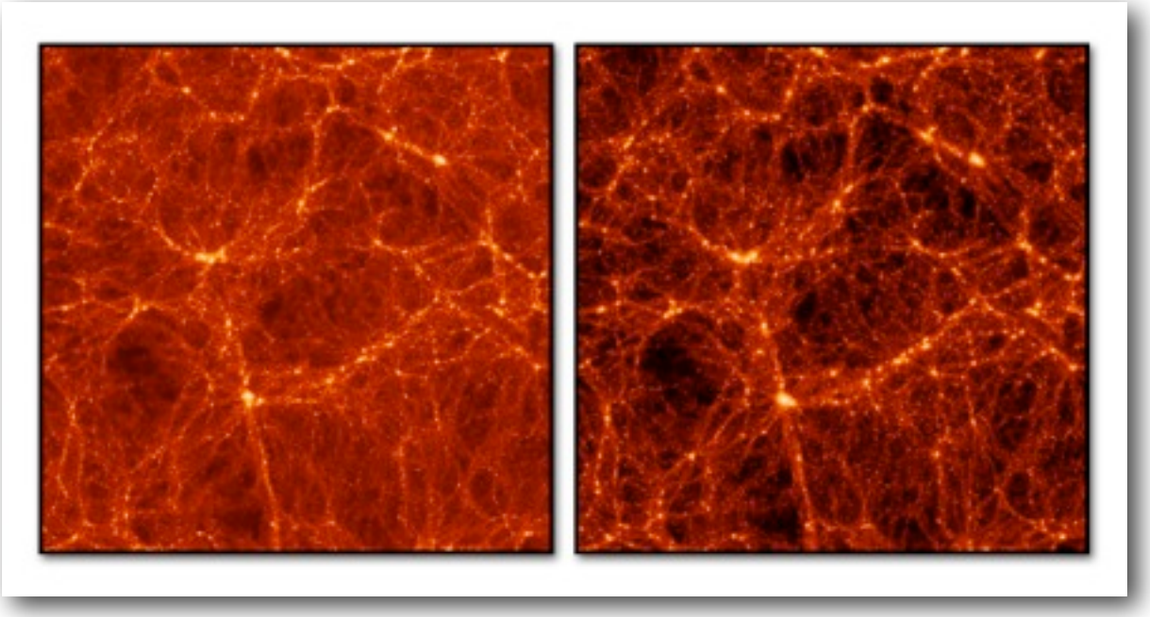
Crocce et al. arxiv.org/1312.2013

Bias: how to relate observables to mass?



- We detect galaxies, galaxy clusters, etc.
- Cosmology determines statistics of total mass, dominated by dark matter.
  - We need to know the total mass of galaxies & galaxy clusters
- Gravitational lensing measures total mass (useful for cosmology & studying bias)





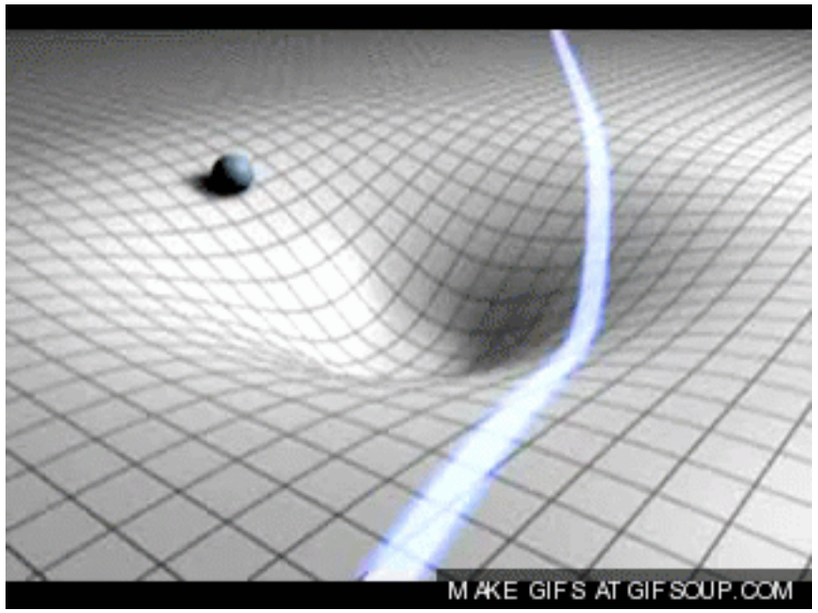
Gravitational Lensing: to measure *total mass*

- General relativity (gravity):
  - Spacetime is curved by the presence of mass
  - Objects travel along paths given by the shape of spacetime
  - Light takes the shortest path between two points in spacetime
- Changes in gravitational potential cause light to change path

$$\frac{d}{d\chi}\alpha_i = -2\Psi_{,i}$$

Ψ is the Newtonian potential

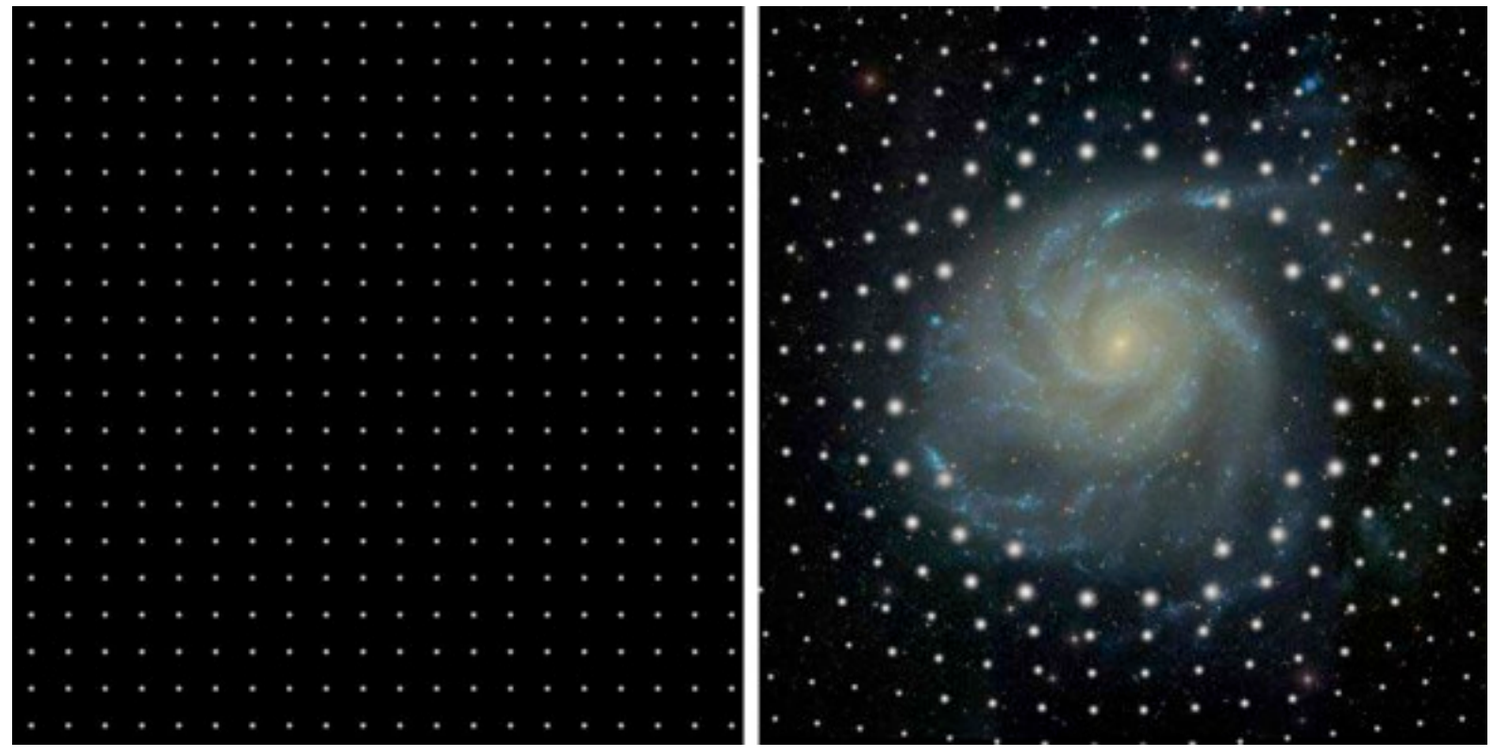
- A source behind a massive lens is distorted (shear), magnified, and its apparent position is changed



http://gifsoup.com/view/763130/space-time-o.gif

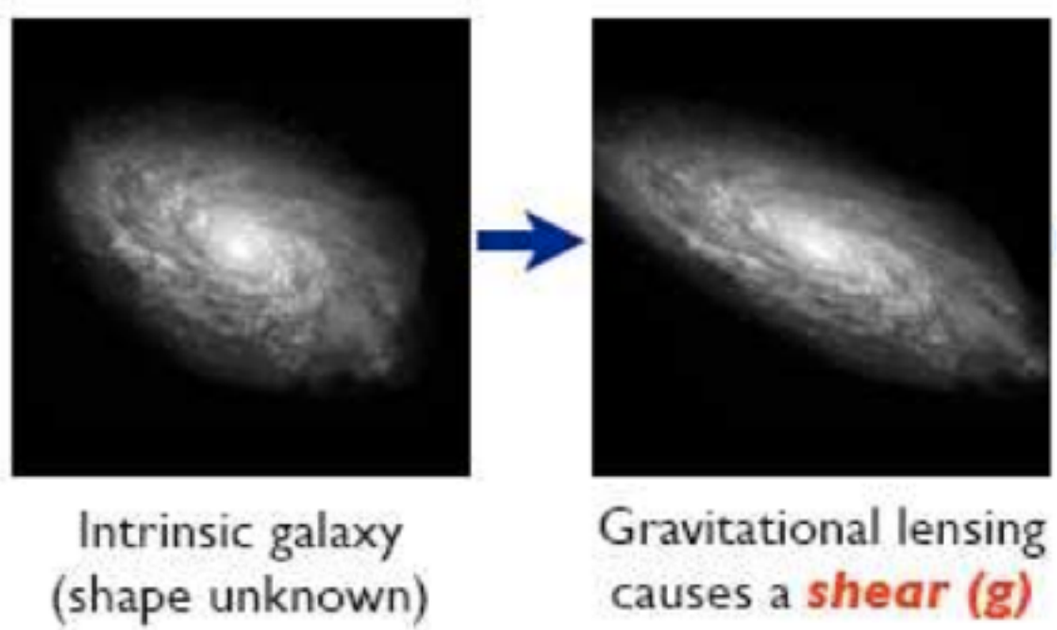
Lensing effects: magnification and shear

- Magnification

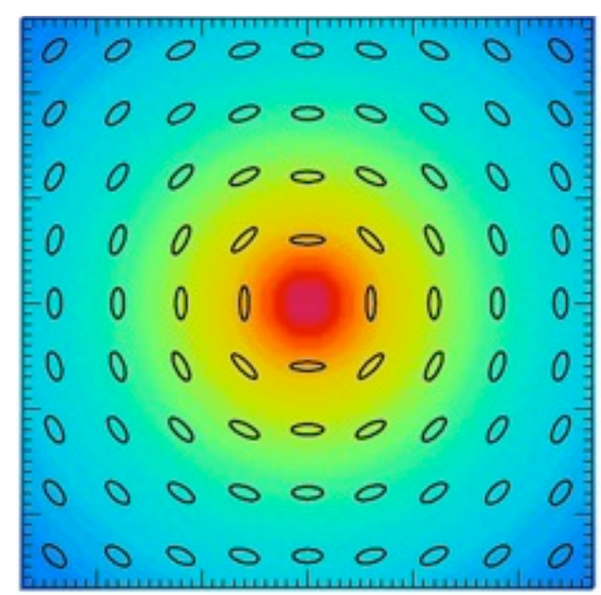


www.sdss.org

- Shear



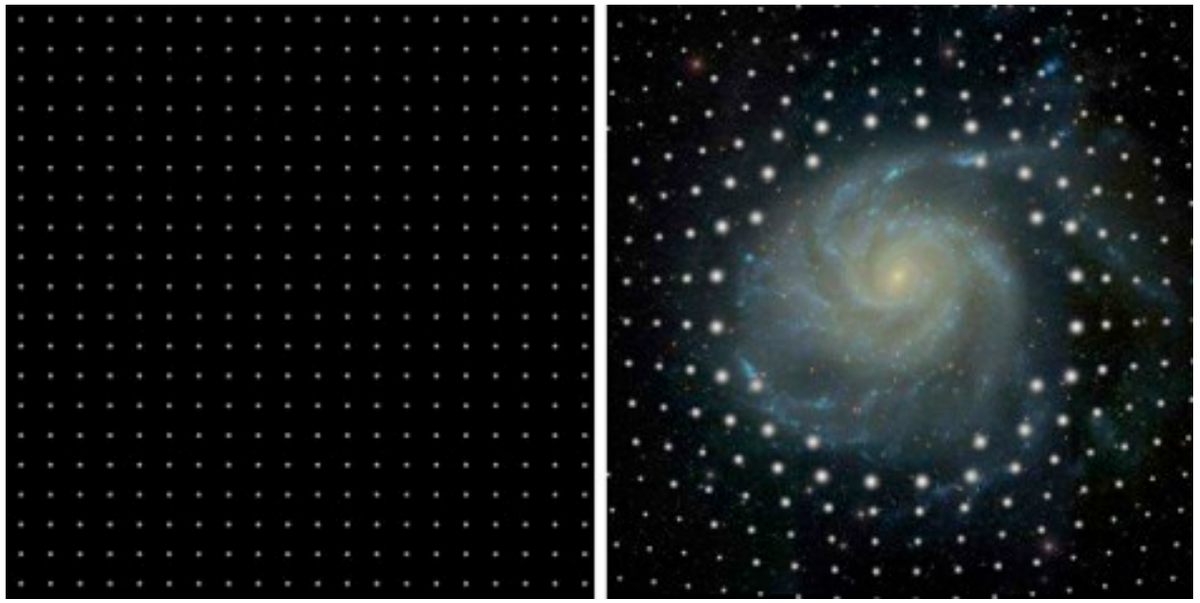
www.great08challenge.info



cmarchesin.blogspot.com

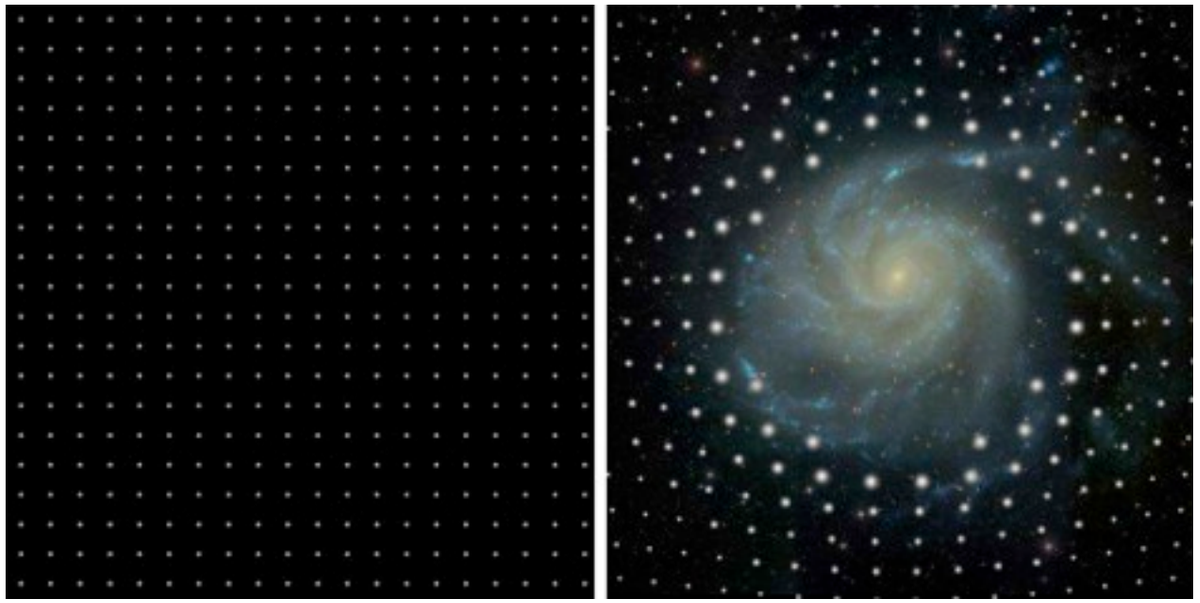
Flux-limited surveys: 2 effects on overdensities

- Typically, sky surveys detect objects down to a flux limit.
- Magnification increases flux → more detections behind a lens!
- Magnification distorts area → fewer detections behind a lens!
- Total signal depends on the background source properties: how many faint ones there are that will become brighter than the flux limit.



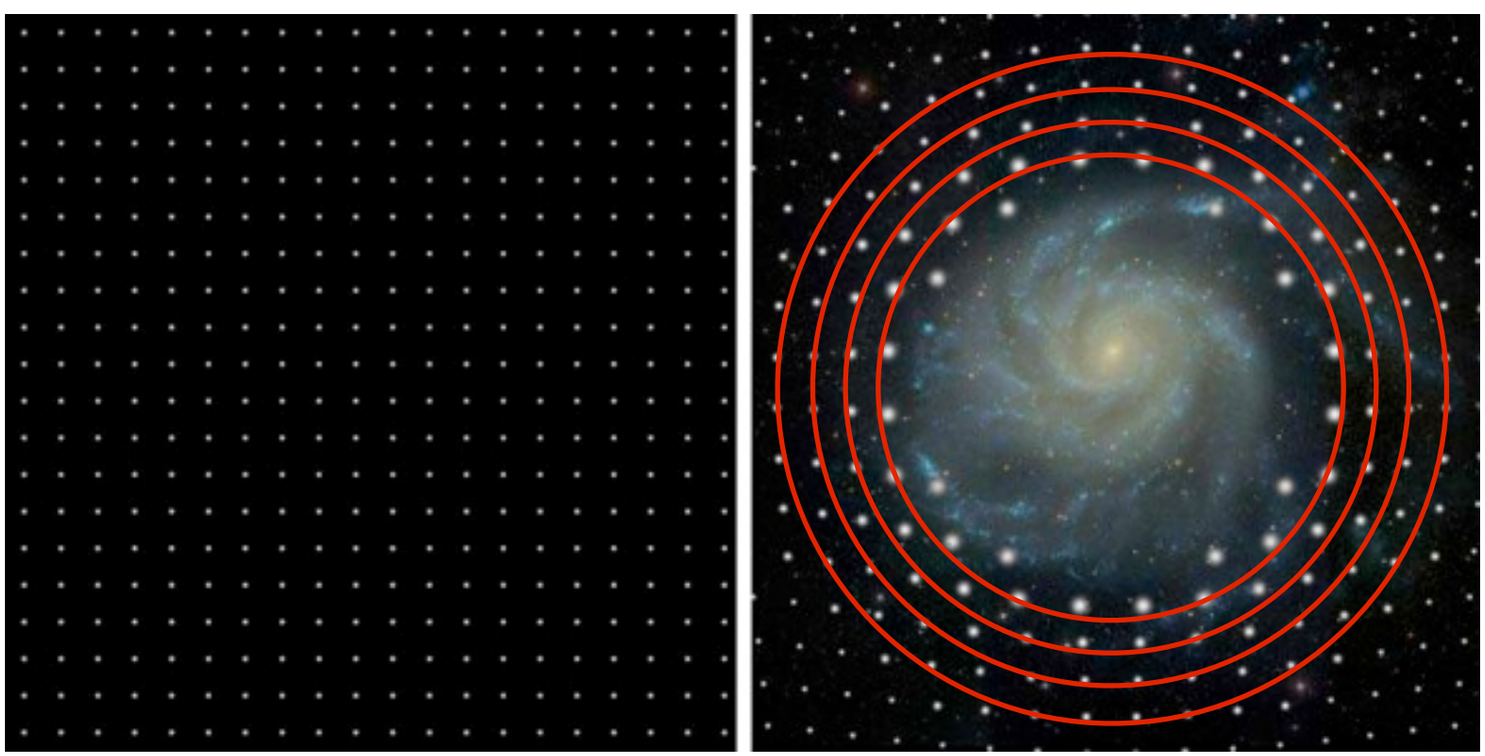
Flux-limited surveys: 2 effects on average fluxes

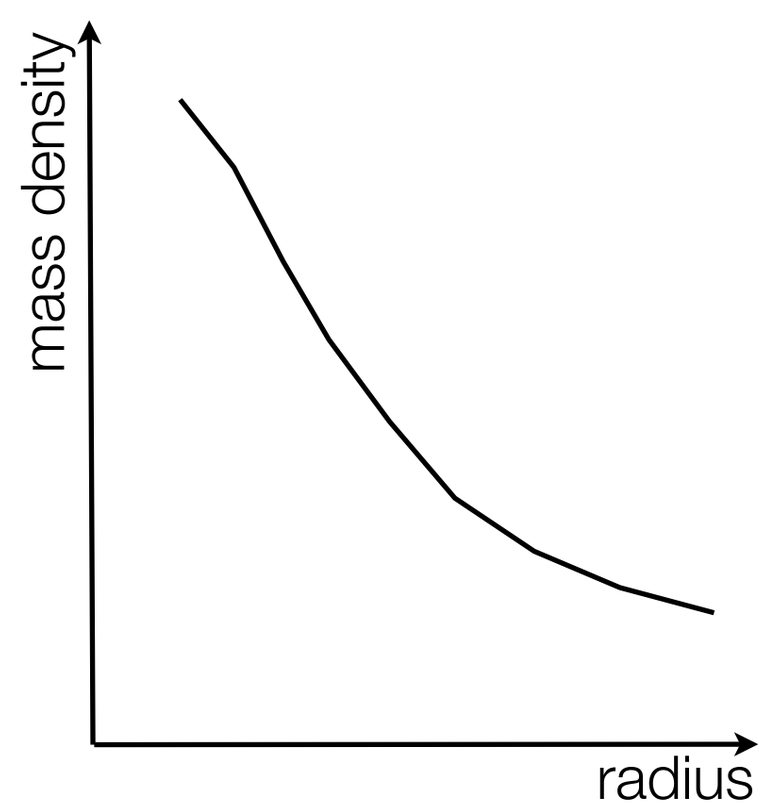
- Magnification increases fluxes of individual objects
- Average flux of the sample will depend on any extra detections introduced by lensing
- Total signal depends on the background source properties: how many faint ones there are that will become brighter than the flux limit.



How to measure magnification

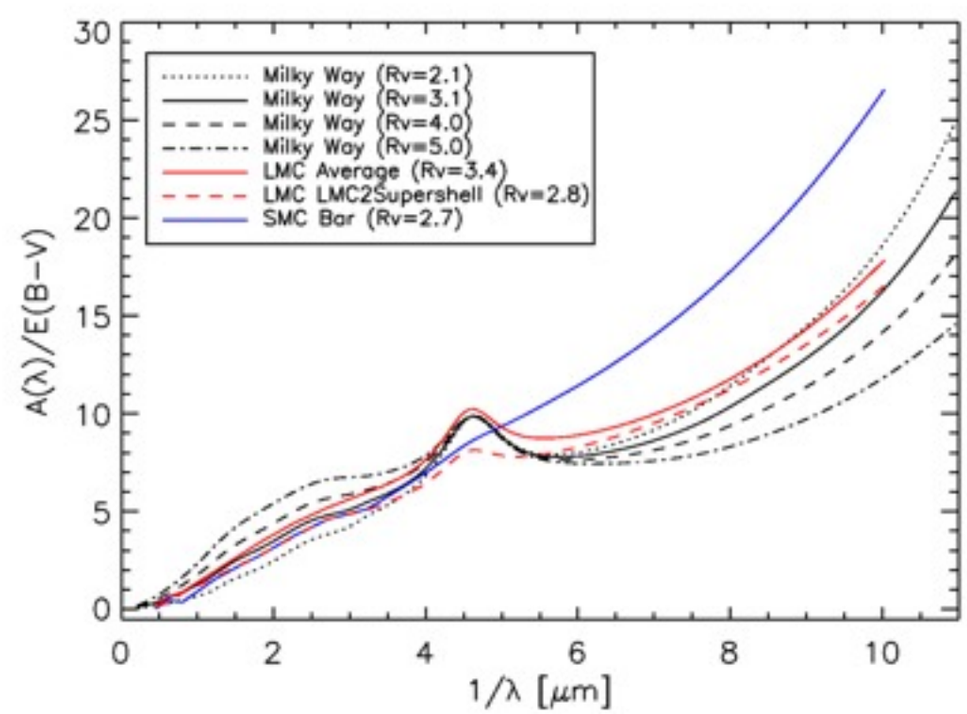
- Measure background object detection rate & average flux vs. distance from the lens
- e.g. measure μ in annuli around the lens to find a spherical mass profile
- Results are proportional to the projected (2D) mass of the lens





Complication: dust extinction!

- Dust in the lens will absorb light from the source
  - Degenerate with magnification! (Opposite effect)
    - Can be of comparable magnitude
- Chromatic! Dust absorption causes reddening. Lensing is achromatic.
  - With colors, we can measure reddening and distinguish dust from magnification
  - Studying dust properties is also interesting for galaxy formation science



http://etc.stsci.edu/etcstatic/users_guide/_images/ext_curves_etc.png

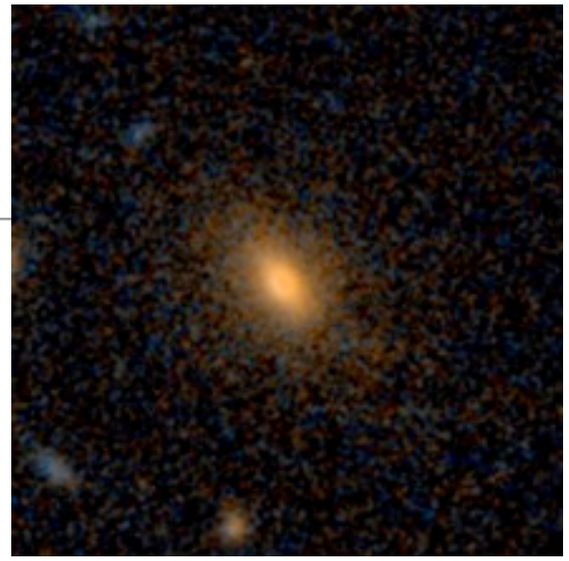
Magnification of Photometric LRGs by Foreground LRGs and Clusters in SDSS

Anne H. Bauer[1*], Enrique Gaztañaga[1], Pol Martí[2], Ramon Miquel[2,3]
[1] *Institut de Ciències de l'Espai, CSIC/IEEC, E-08193 Bellaterra, Spain*
[2] *Institut de Física d'Altes Energies, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain*
[3] *Institució Catalana de Recerca i Estudis Avançats, E-08010 Barcelona, Spain*

arxiv:1312.2458

- Using large, public catalogs of lenses and sources to measure lens mass profiles and dust content
- Observables:
  - Fluctuation (increase) in counts
  - Fluctuation (increase) in flux
  - Flux decrease & reddening due to dust extinction
- Proof of principle and development of technique in advance of better data
  - First measurement of magnification with LRG sources (bright, easy to measure)

Data



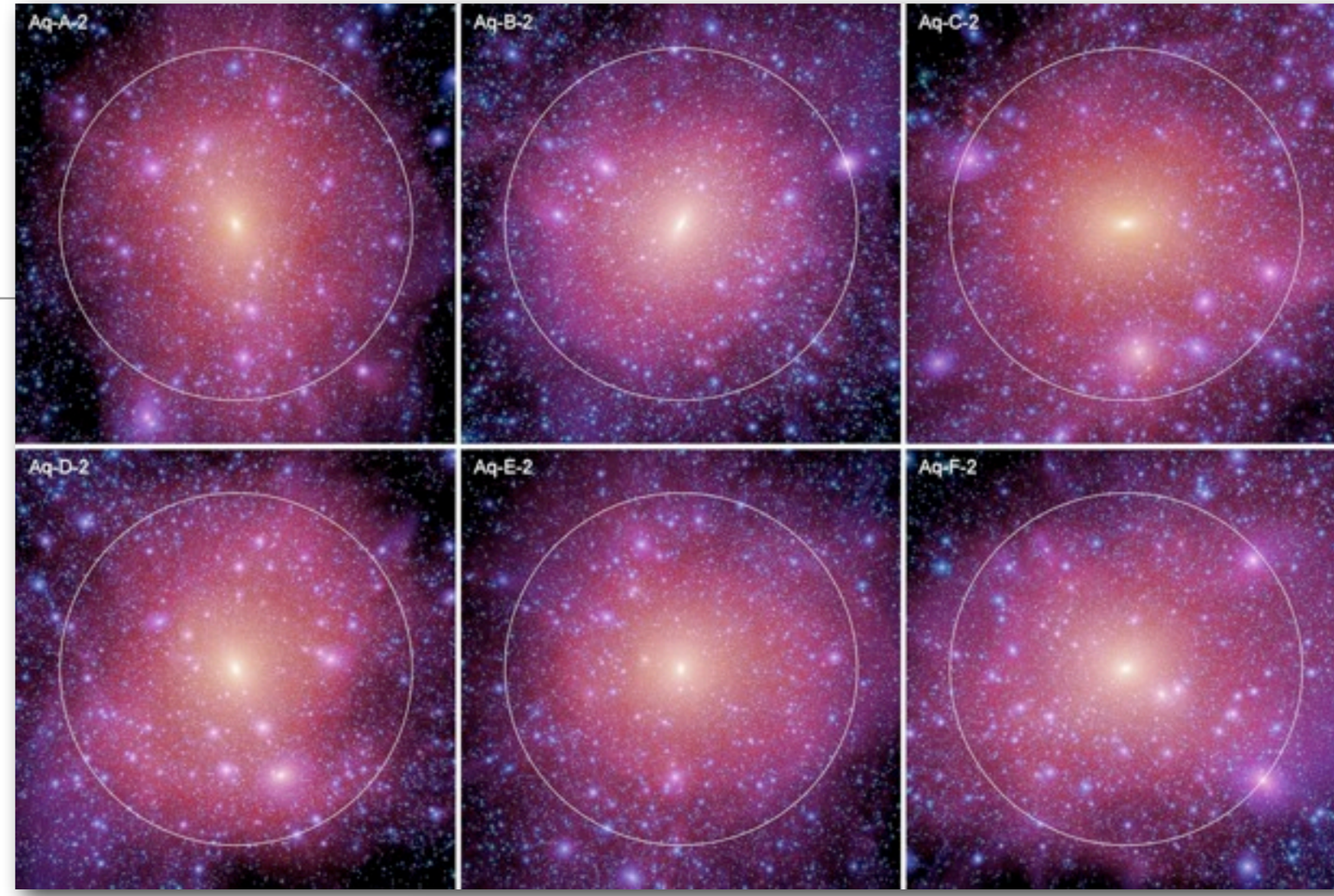
- Sources (photometric)
  - MegaZ LRG catalog, $0.5<z_{phot}<0.6$, 572,900 sources
- Lenses (spectroscopic)
  - LRGs: Cabré & Gaztañaga (2009)
    - $0.1<z_{spec}<0.4$
    - richness bin 0
  - Clusters: Wen, Han, & Liu (2012)
    - $0.1<z_{spec}<0.4$
    - richness bins 1-5

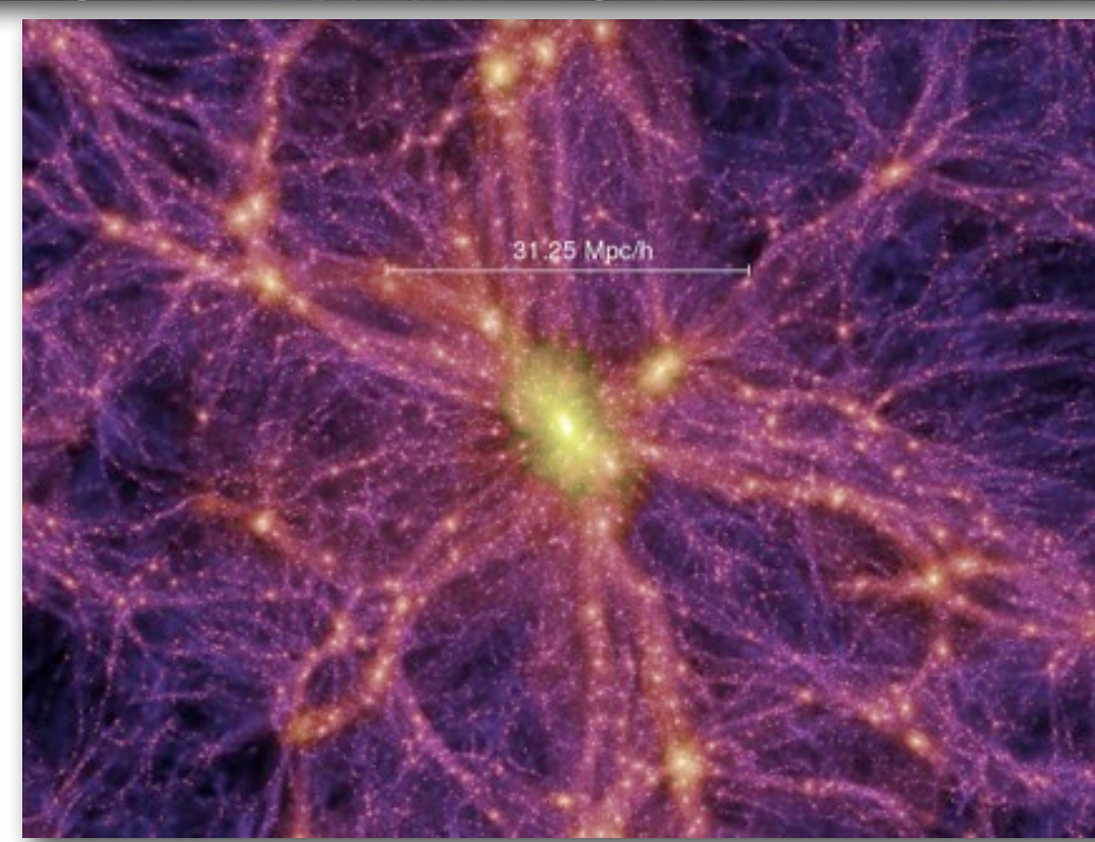
Richness Bin	Richness N	# lenses
0	<12	66613
1	12-17	12270
2	18-25	9765
3	26-40	4649
4	41-70	1638
5	71-220	295

Lens model

1. Dark matter halo
2. Brightest cluster galaxy (BCG)
3. Second halo term
4. Dust to mass ratio Γ

These make up Σ: the 2D projected lens matter profile





Millennium Aquarius Simulation

Lens model

1. Dark matter halo

$$c(M_{200}, z) = \frac{4.6}{1+z}\left(\frac{M_{200}}{1.56 \times 10^{14} h^{-1} M_\odot}\right)^{-0.13}$$

   * NFW profile $$\rho(r) = \frac{\delta_c \rho_{\rm crit}}{(r/r_s)[1+(r/r_s)]^2}$$

2. BCG

   * Cuspy halo profile $$\rho(r) = \frac{\delta_c \rho_{\rm crit}}{(r/r_s)^\gamma [1+(r/r_s)^2]^{(n-\gamma)/2}} \quad \text{with } (\gamma, n) = (2, 4)$$

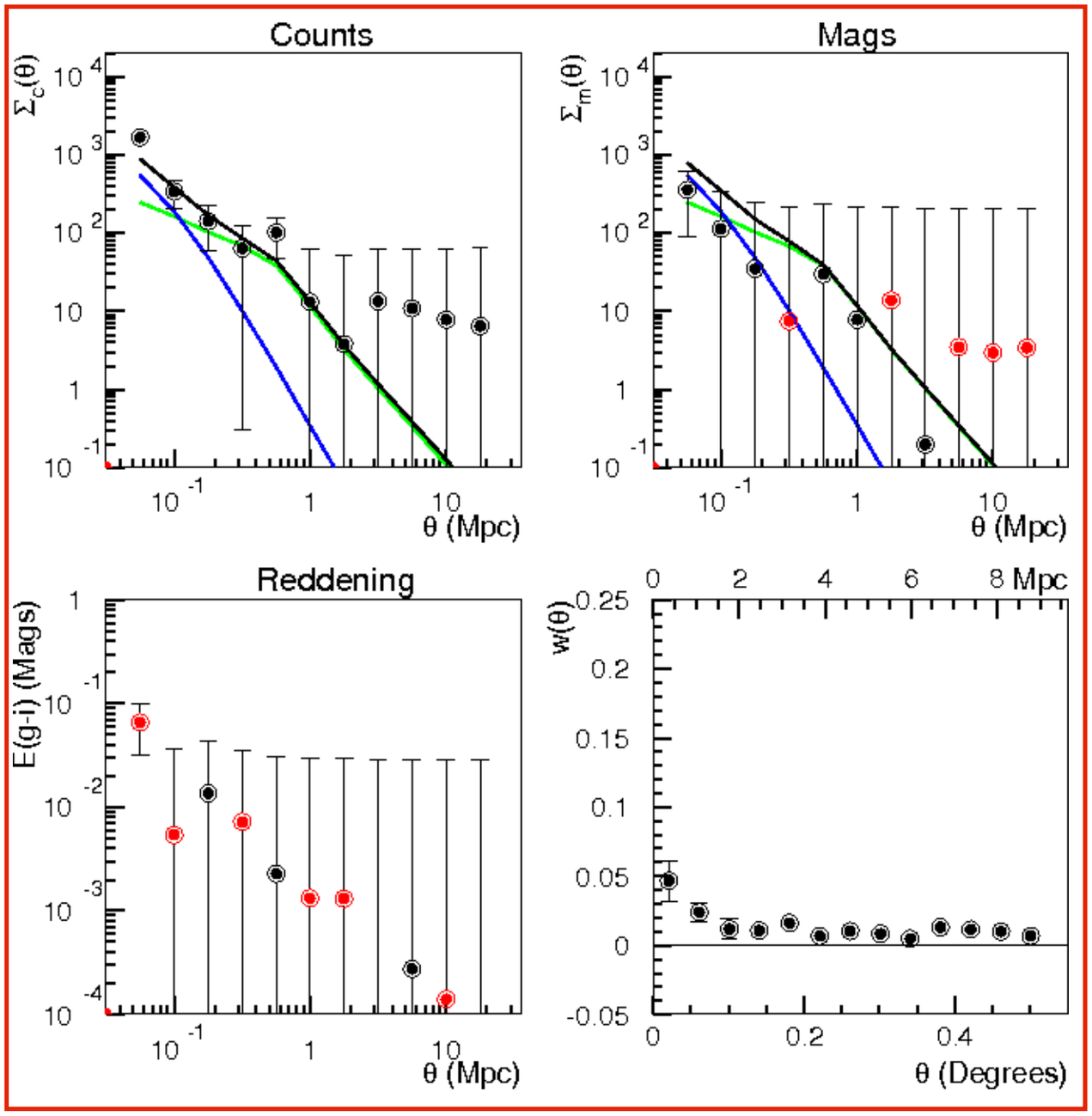
3. Second halo term

   * Correlation between the linear dark matter power spectrum and the NFW profile; constrains the bias of the lens: b_o

4. Dust to mass ratio Γ

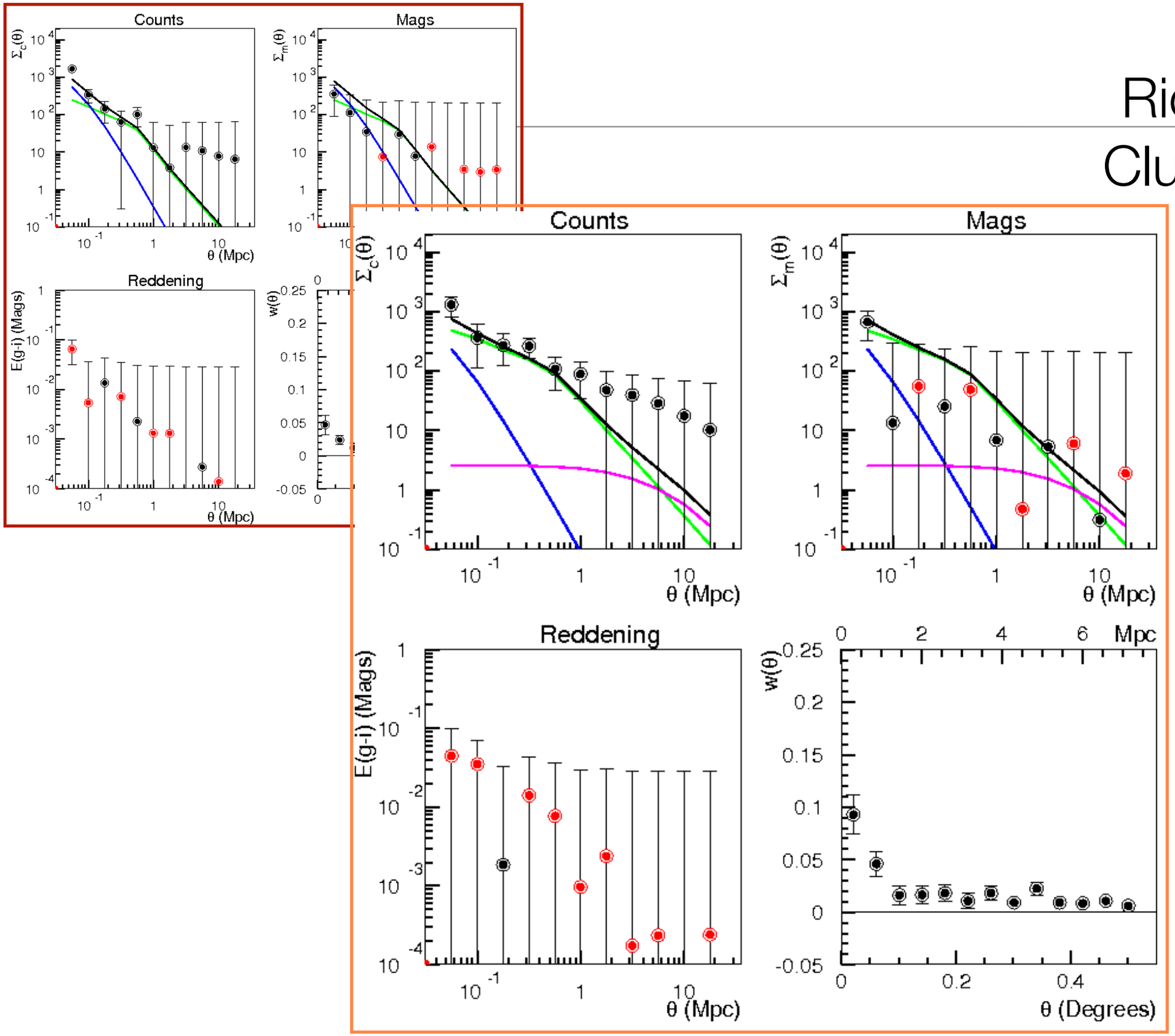
   * Relates reddening measurements to the total mass density profile

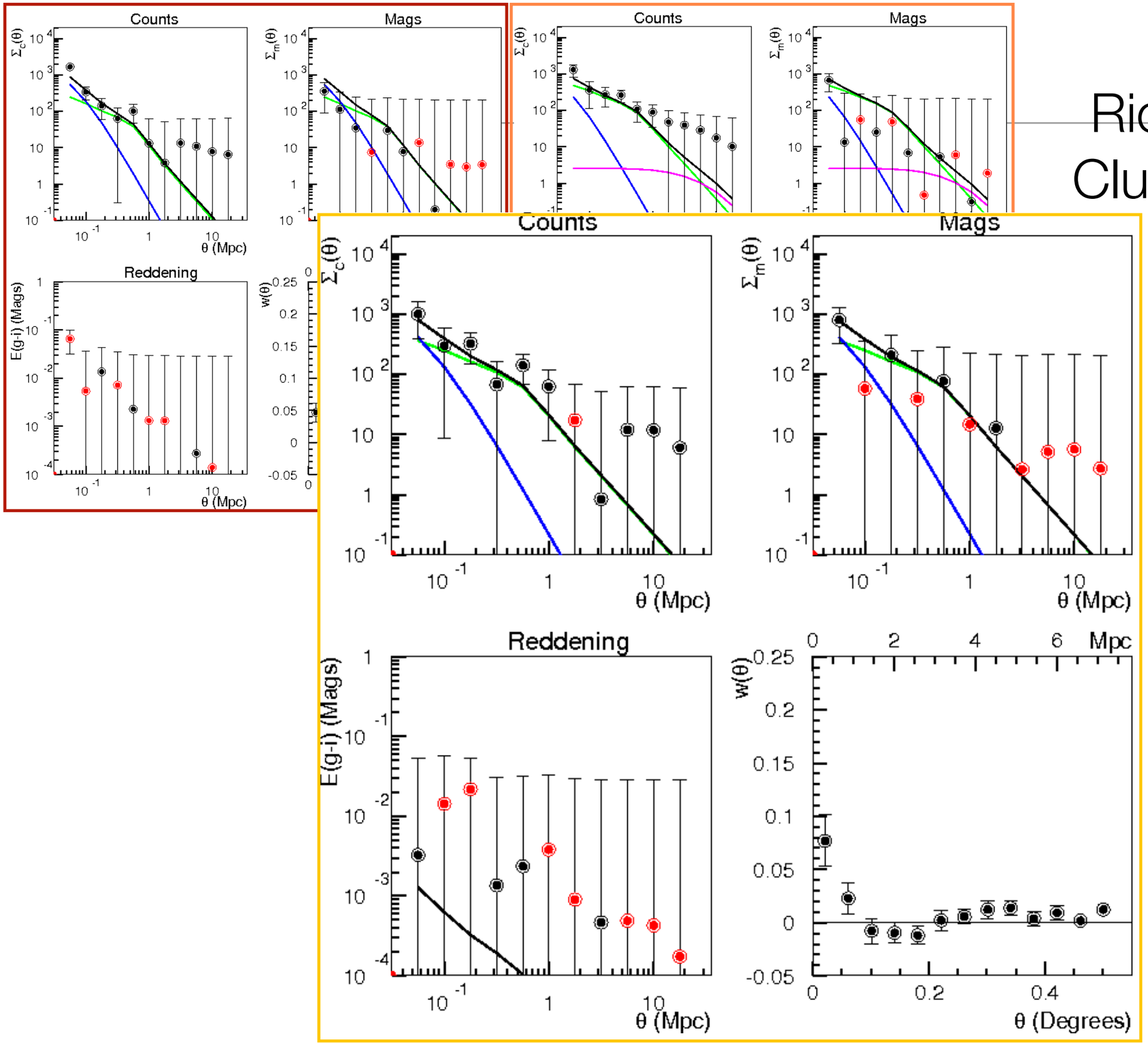
Results: counts, magnitudes, reddening, xcorr



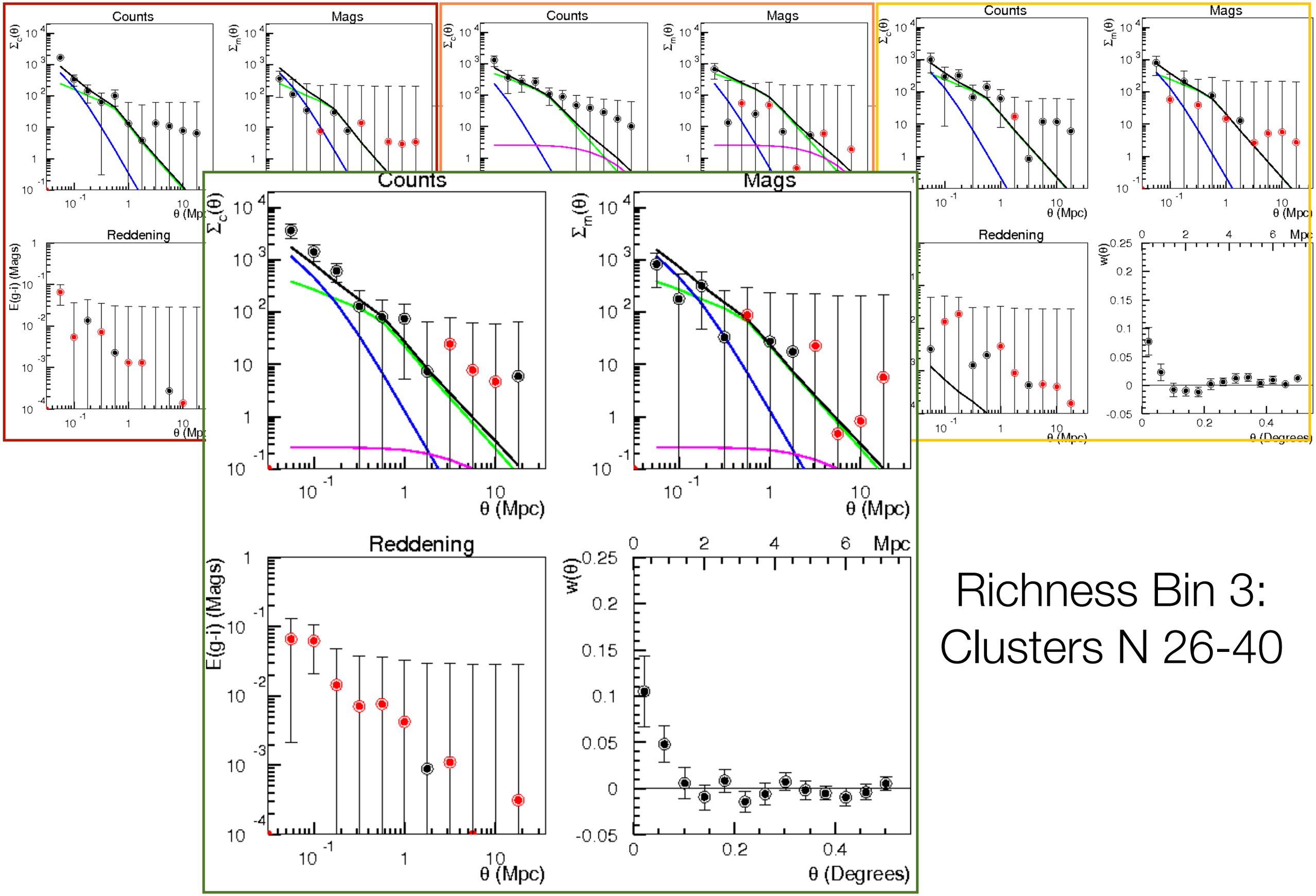
Richness Bin 0:
LRG lenses

Richness Bin 1: Clusters N 12-17

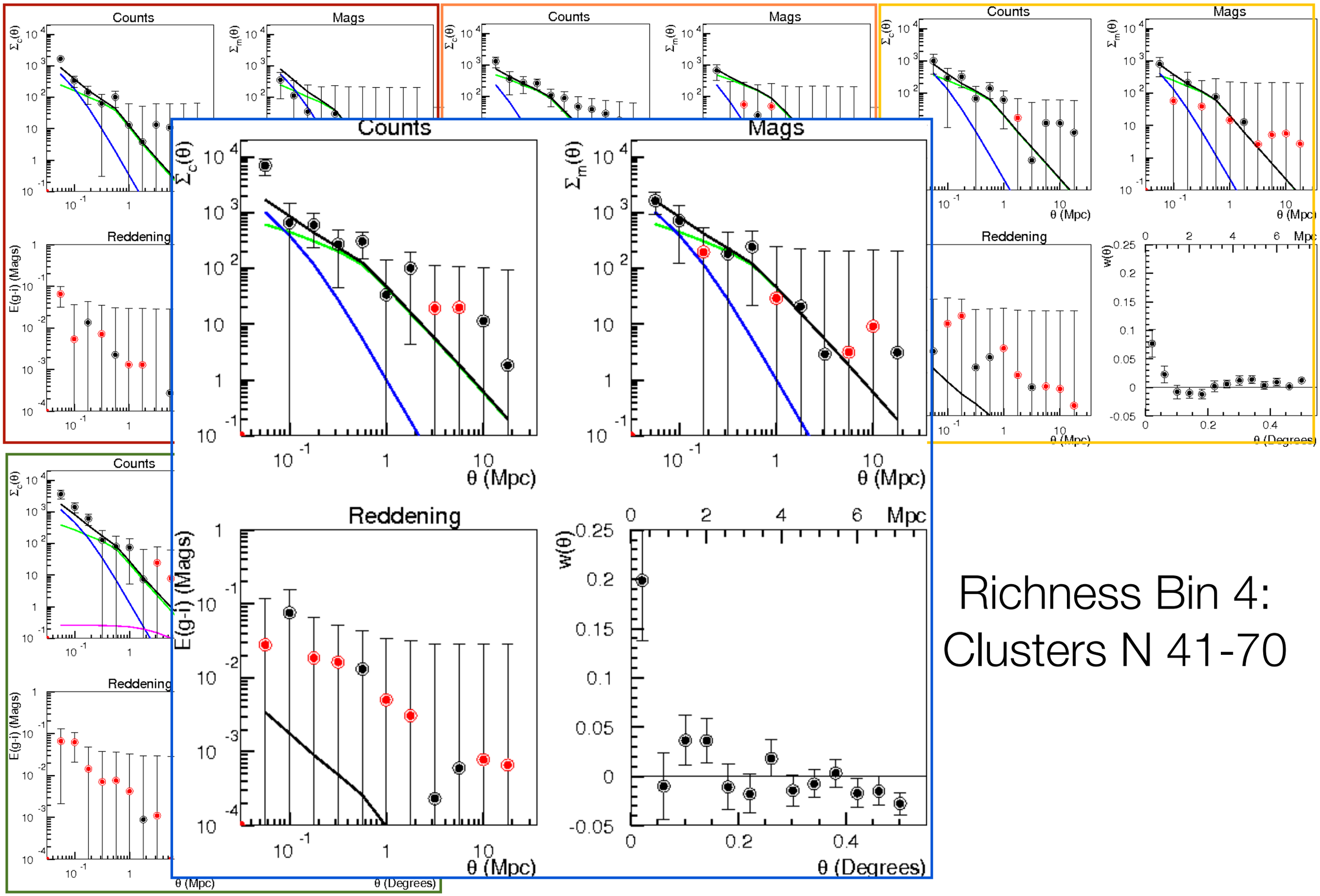




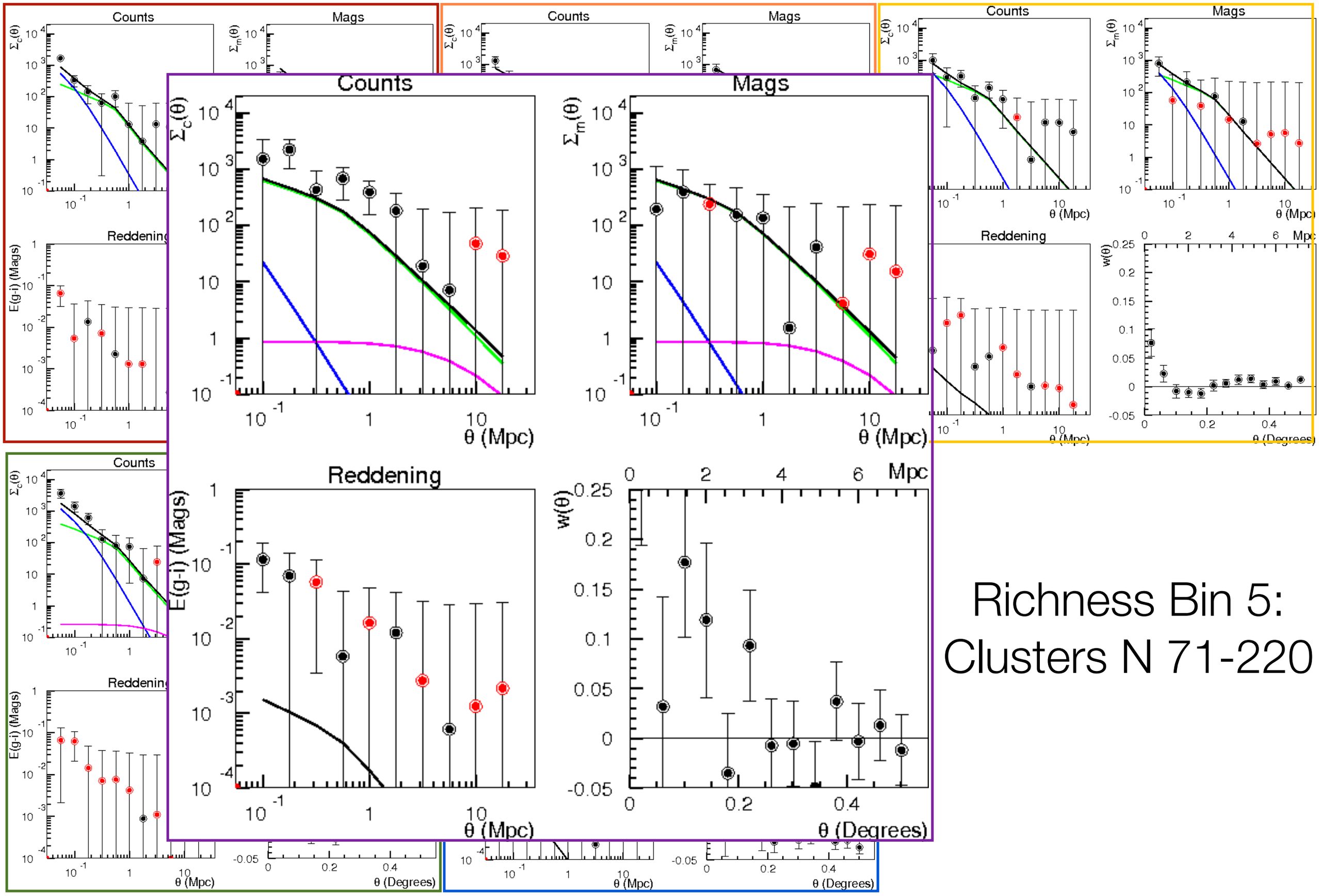
Richness Bin 2: Clusters N 18-25



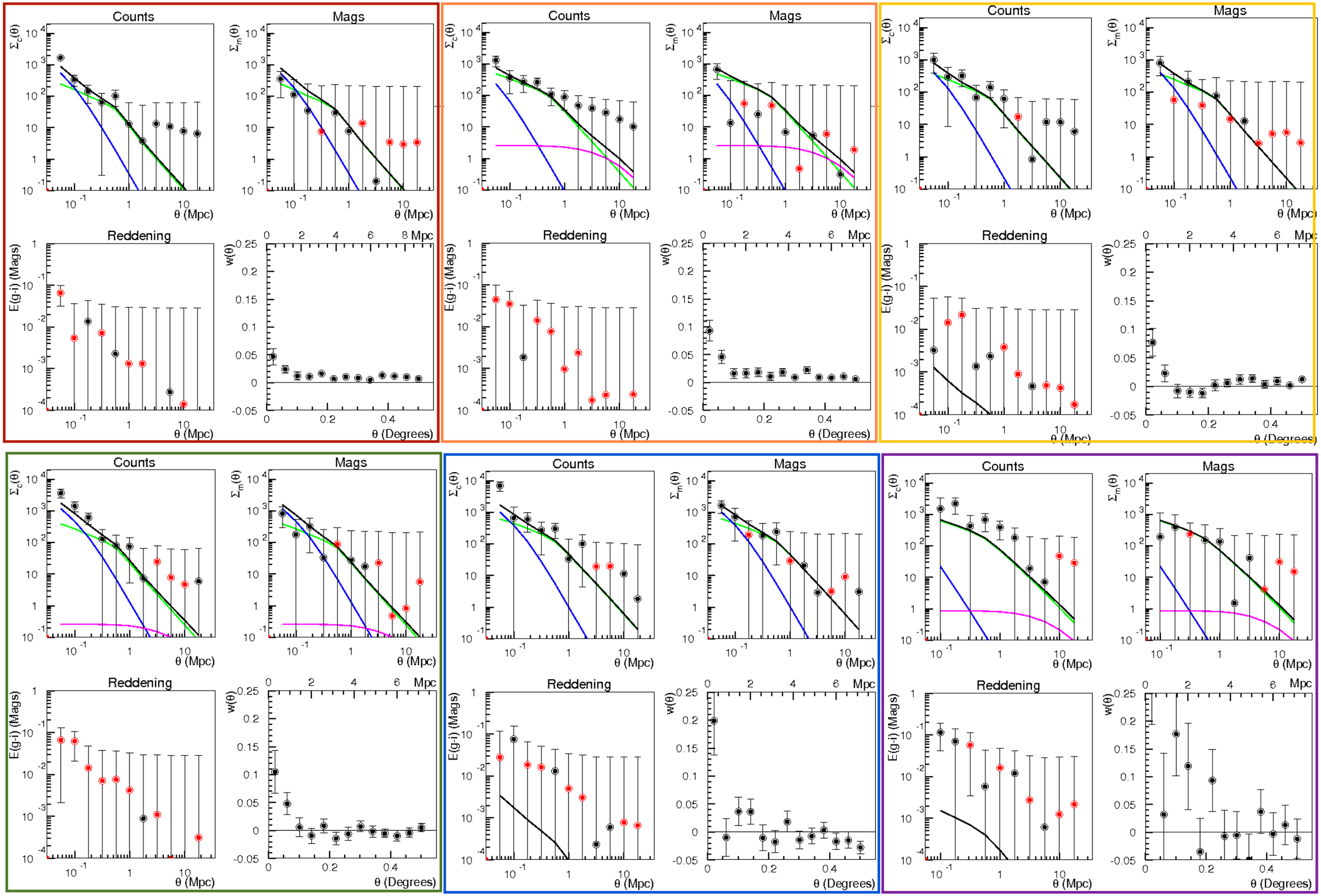
Richness Bin 3:
Clusters N 26-40



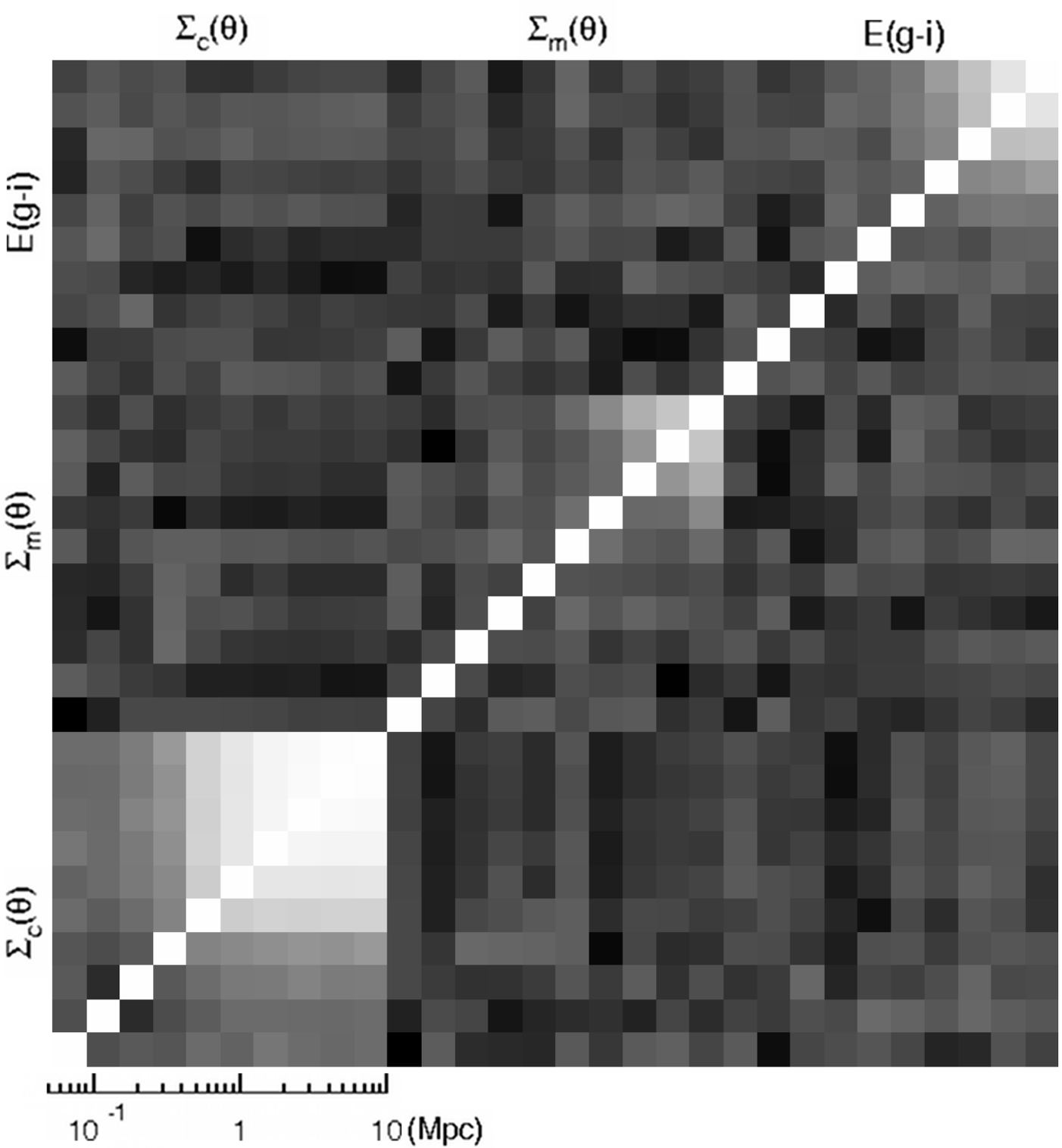
Richness Bin 4:
Clusters N 41-70



Richness Bin 5:
Clusters N 71-220

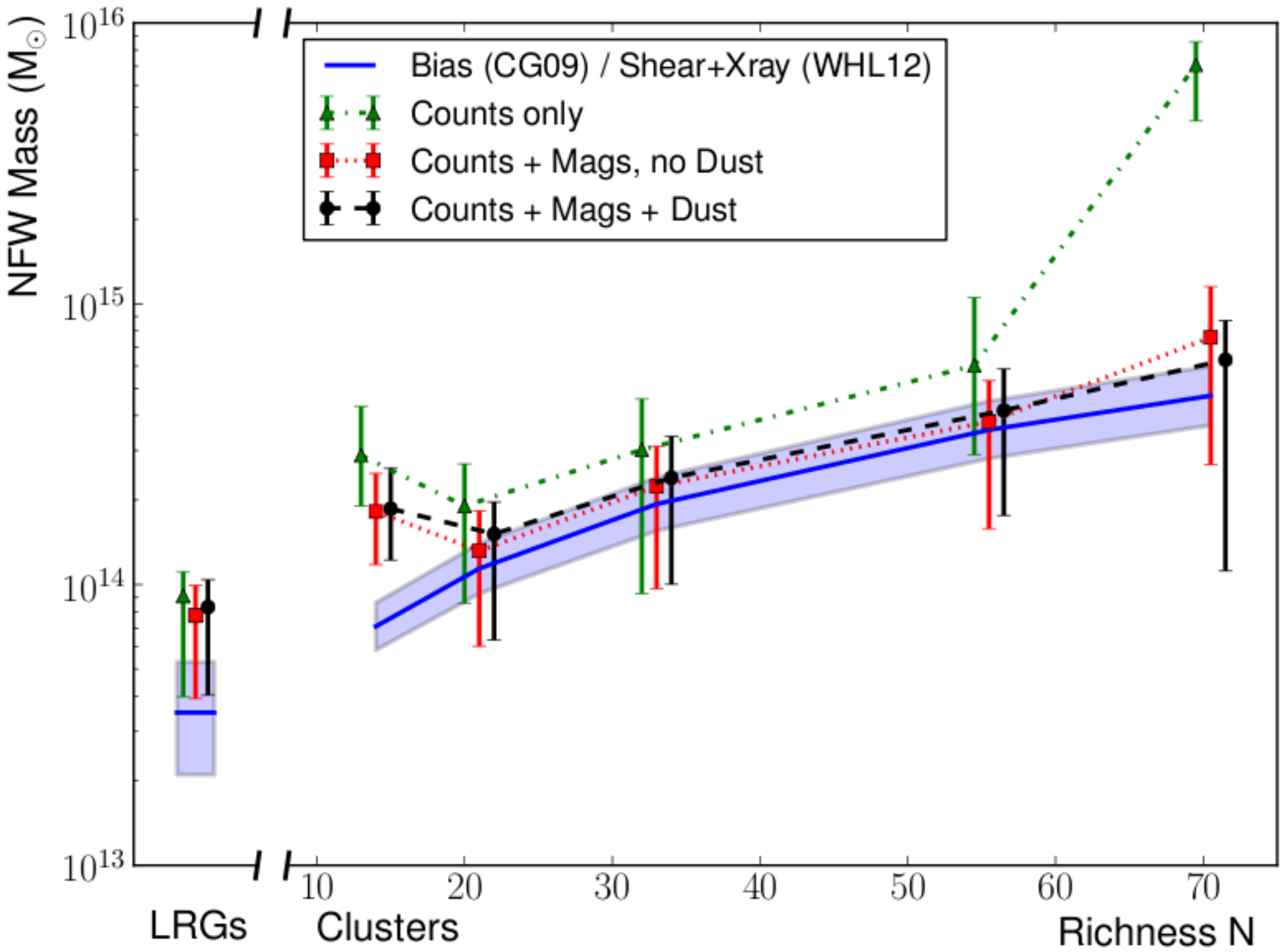

Counts
Mags
Reddening
$\Sigma_c(\theta)$
$\Sigma_m(\theta)$
E(g-i) (Mags)
w(θ)
θ (Mpc)
θ (Degrees)
Mpc

Correlation matrix for clusters with N 18-25



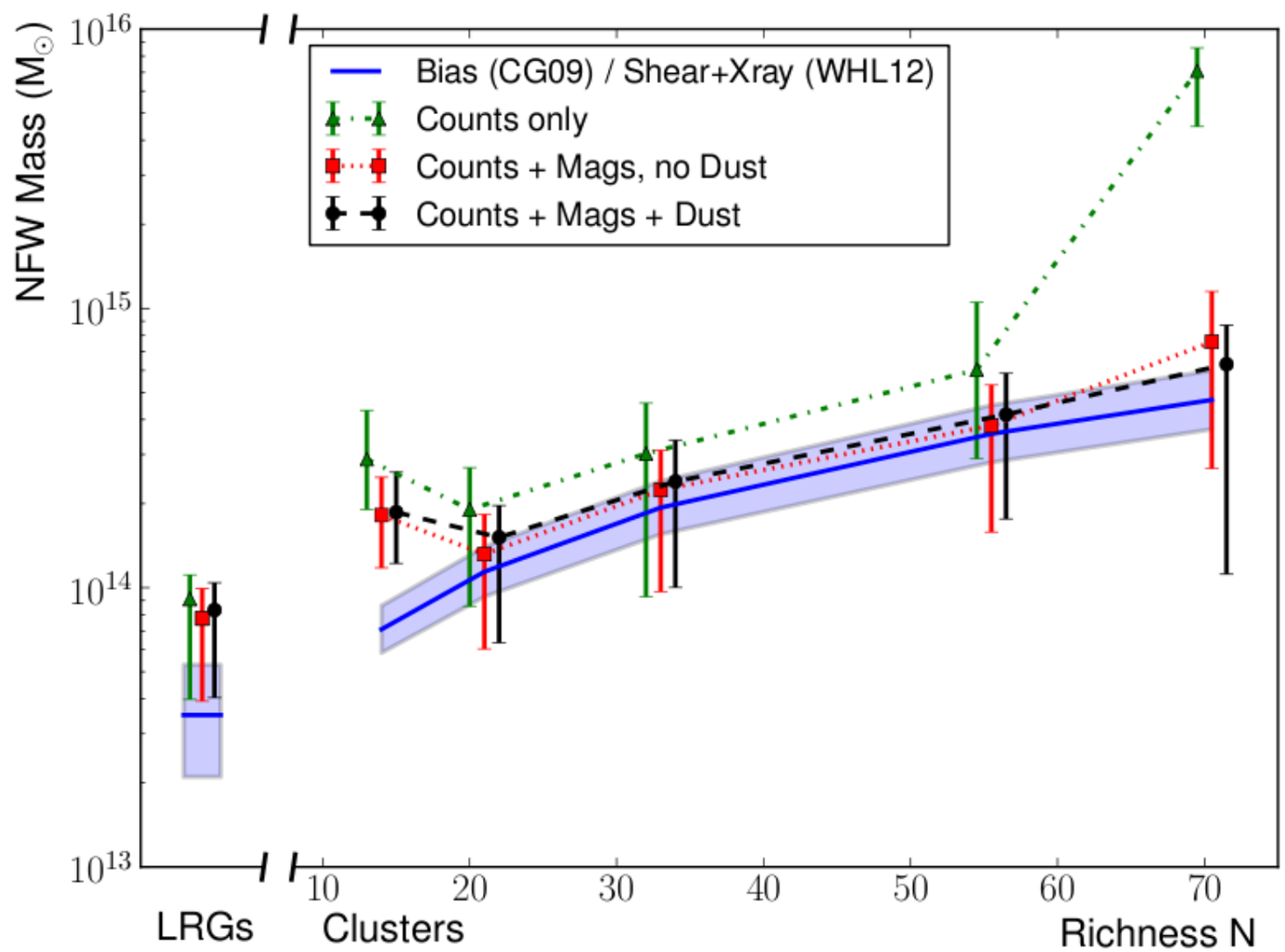
- No significant cross-covariance between probes
- Counts covariance between angular bins >> mags angular covariance

Mass-Richness Relation



Mass-Richness Relation

- In agreement with previous measurements
- Even though the magnitudes and reddening data are upper limits, they do influence the fits

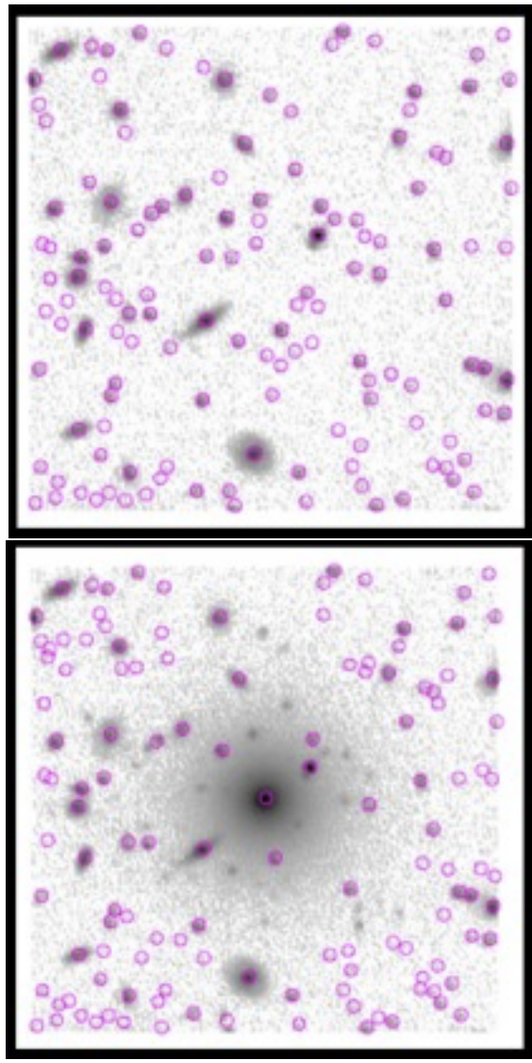


Dust to mass ratio Γ

- 3σ upper limits: [2.43, 3.18, 4.92, 2.53, 4.92, 9.68] e–5 .
- The upper limits are given by the ~2% systematic errors on the photometry
  - ≲1% errors very difficult, especially in crowded fields!
- Previous studies of SEDs (Bourne et al. 2012) and spectroscopy+shear (Mandelbaum 2006) imply LRGs have Γ ~ 5e-6
- Menard (2010) uses magnification and reddening of QSOs behind SDSS galaxies (not just LRGs) to find the galaxies' Γ ~ 1.e-5
- Clusters are less dusty than galaxies? (Chelouche et al. 2007; Muller et al. 2008) We can't say.

SDSS Results Summary

- We measure lens masses consistent with X-ray, shear, and clustering measurements
- Including low signal-to-noise magnitude lensing and dust reddening data affects the best-fit masses
  - Improves their agreement with previous measurements
- We simultaneously fit the counts, magnitudes, and reddening measurements to constrain the mass profile and dust-to-mass ratio of the lenses.
- Systematic errors are beginning to limit the measurements
  - Background subtraction in the cluster fields is likely biasing the detection rate and photometry, to different extents
  - Very different Σ_c and Σ_m signal at small angular scales; Σ_c alone gives unreasonably high BCG mass



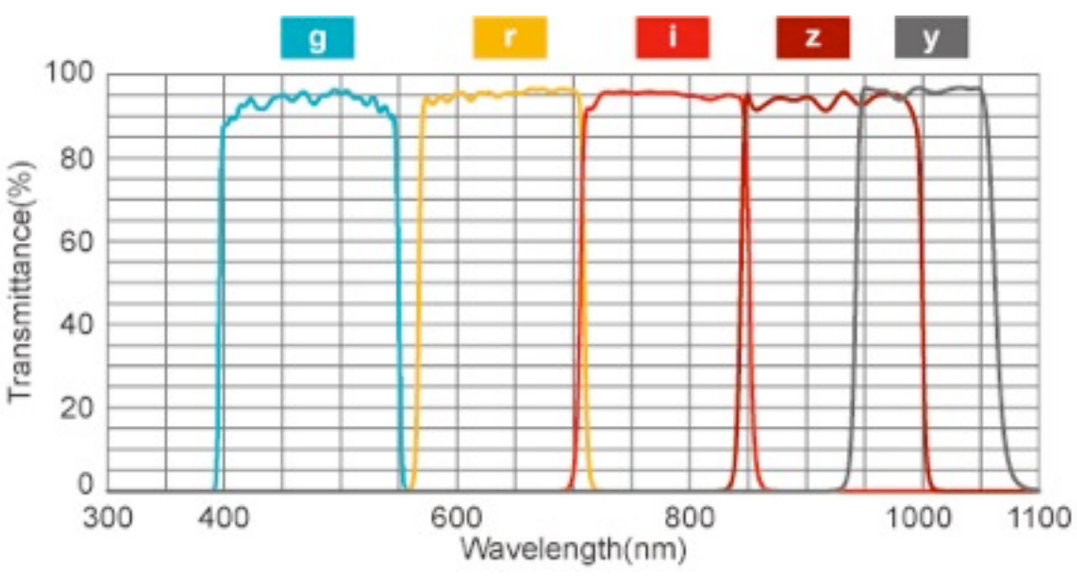
Yuanyuan Zhang

Current work and prospects

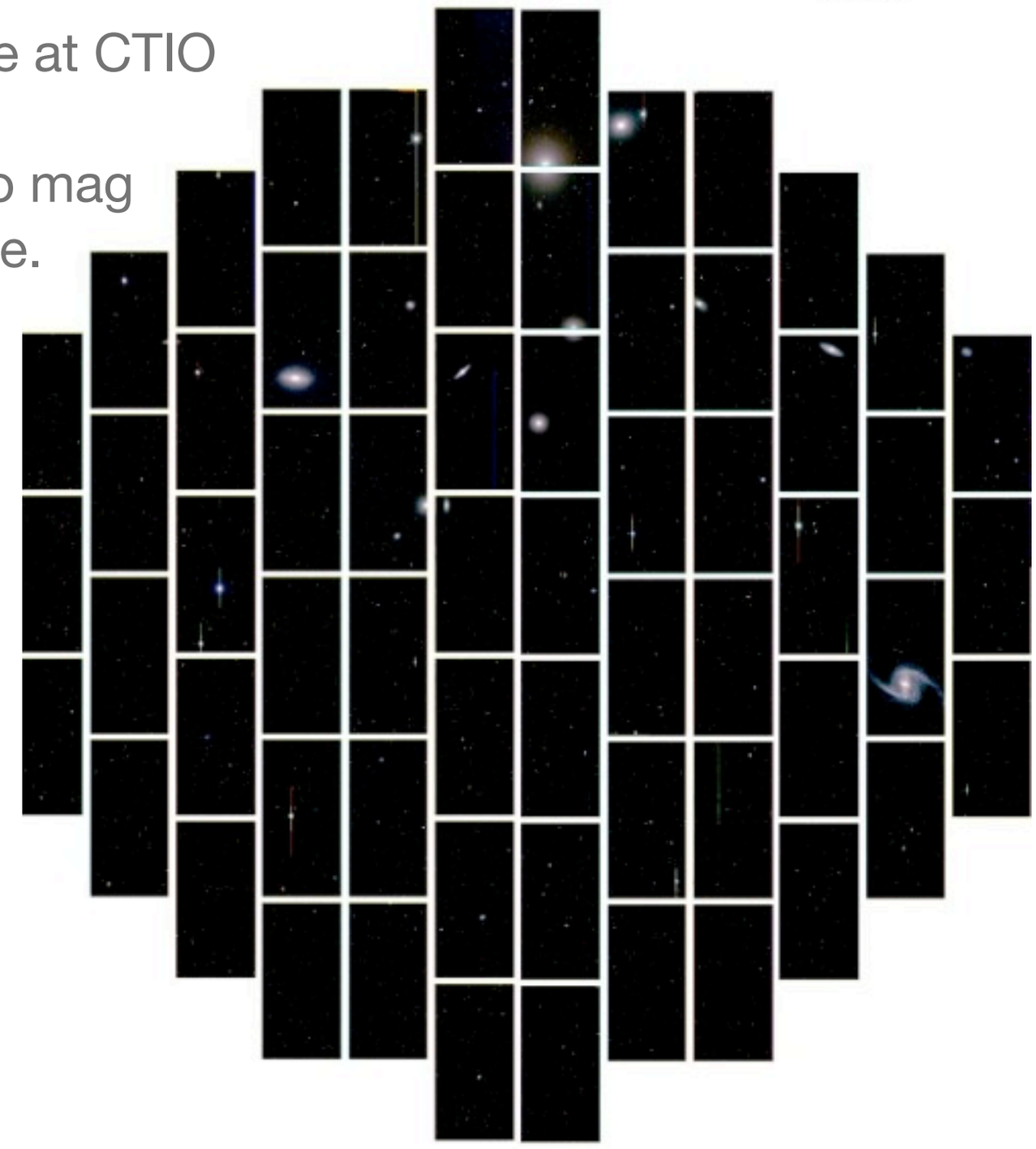
Dark Energy Survey

DARK ENERGY SURVEY

- Taking data at the Blanco 4-m telescope at CTIO
- Will cover 5000 square degrees down to mag ~24-24.5. Currently ~hundreds available.
  - >50 times deeper than MegaZ!!
- 3 square degree field of view
- 5 broadband optical-NIR filters: grizy



http://www.asahi-spectra.com

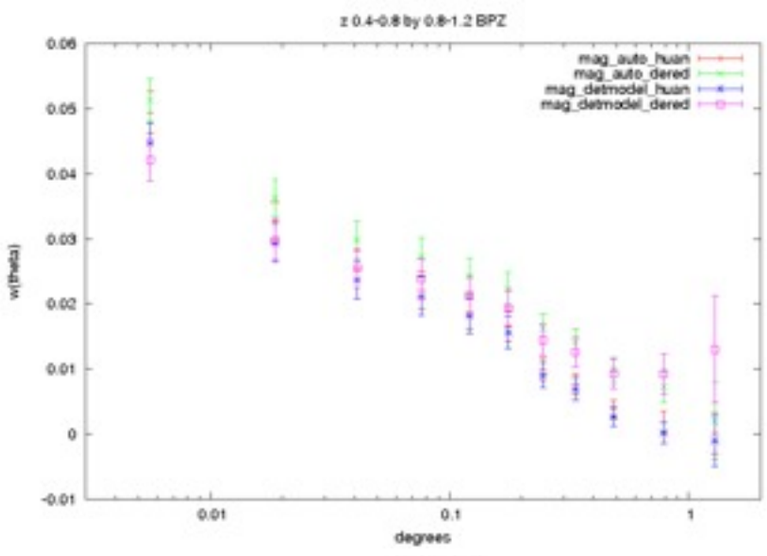


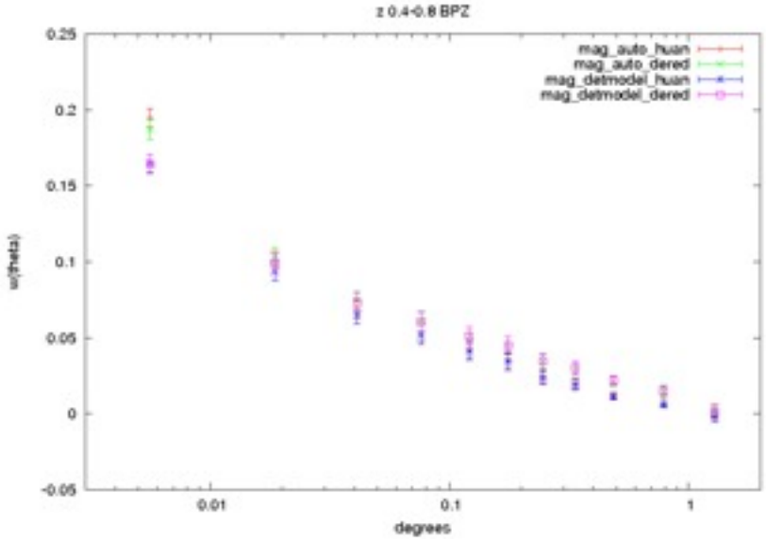
http://www.ctio.noao.edu/noao/ctio-news

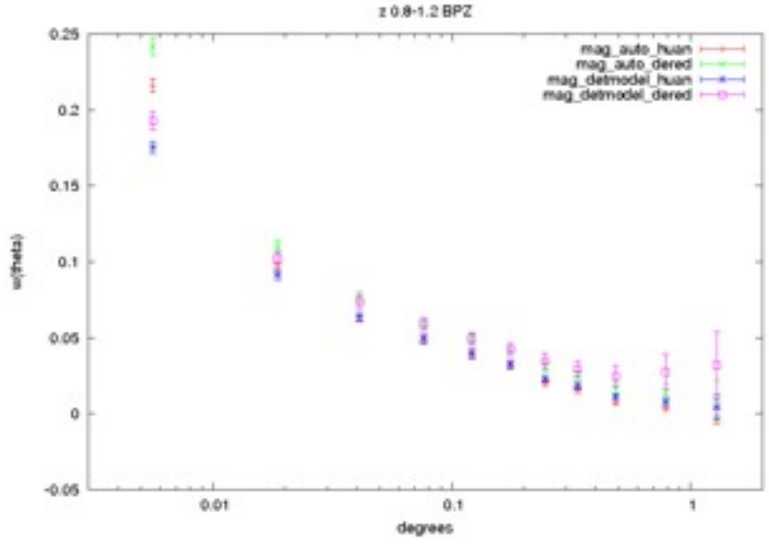
DES current work

DARK ENERGY SURVEY

- Examining correlations to check for systematic problems
  - Magnification science comes after we “understand” the data!
- E.g., how do the correlation functions depend on:
  - magnitude measurement method
  - photometric calibration method
  - image seeing, airmass
  - etc...!?



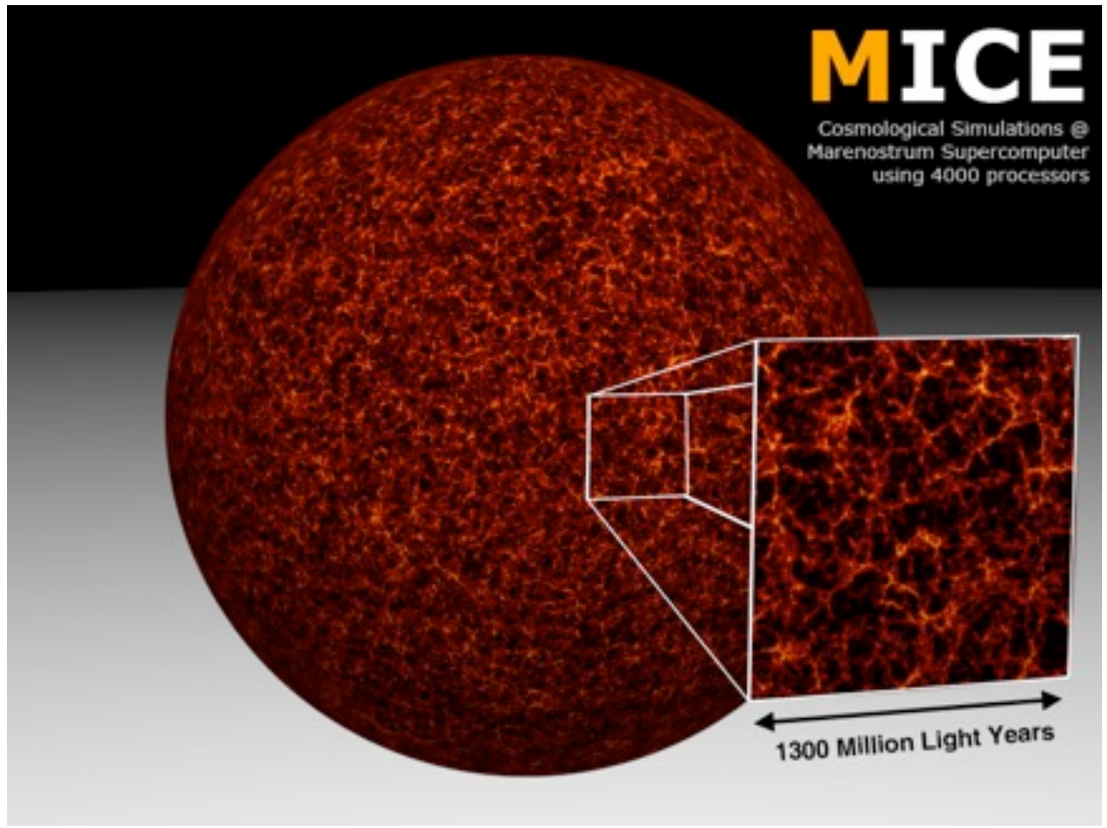


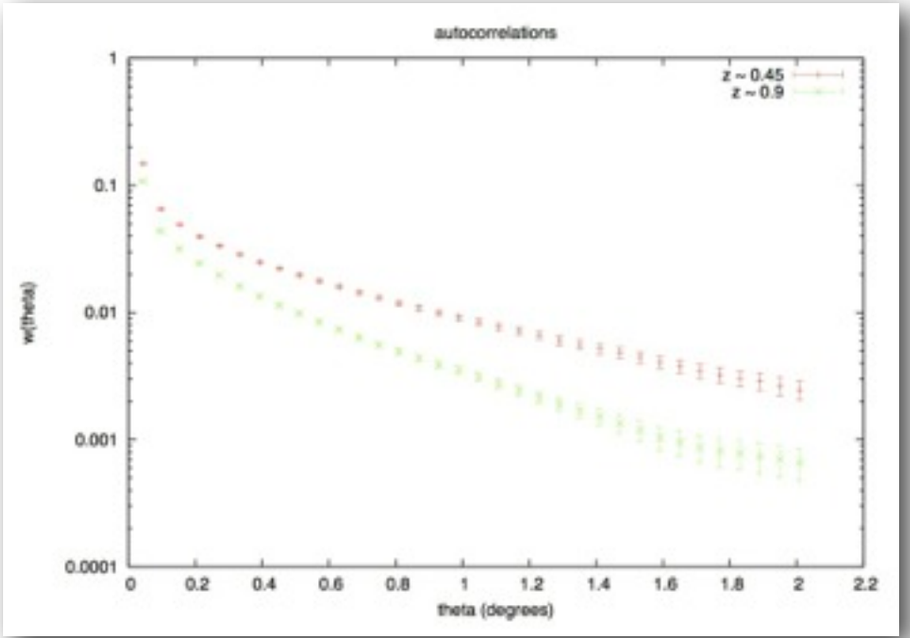


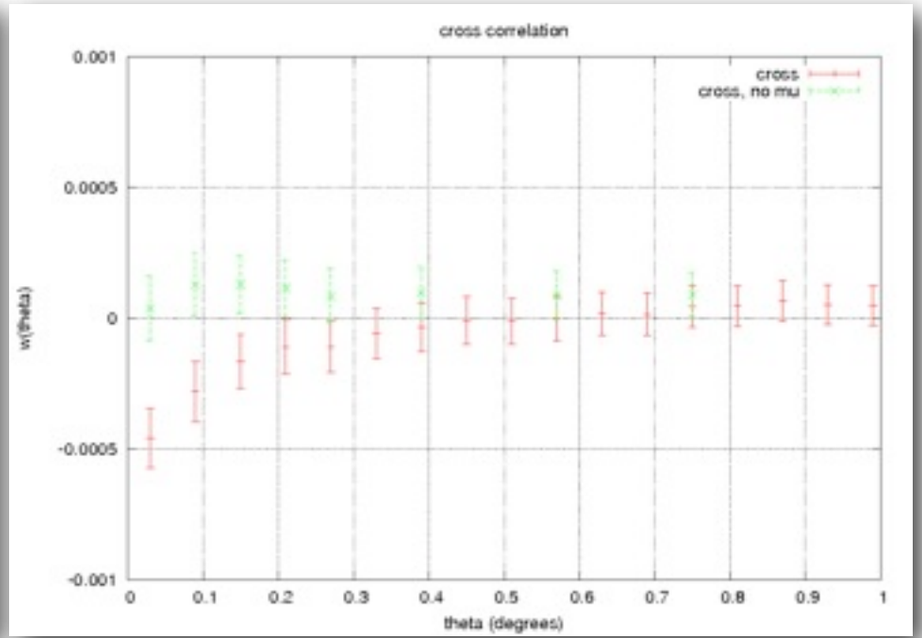
Magnification in DES: simulations

MICE
Marenostrum Institut de Ciències de l'Espai Simulations

- MICE N-body simulations (Fosalba, Crocce, Gaztañaga, Castander arxiv:1312.1707)
- Lensing shear, magnification maps (Fosalba, Gaztañaga, Castander, Crocce arxiv:1312.2947)
- Mock galaxy catalog generated using a halo model (Crocce, Castander, Gaztañaga, Fosalba, Carretero arxiv:1312.2013)
- Public catalog available at http://cosmohub.pic.es/

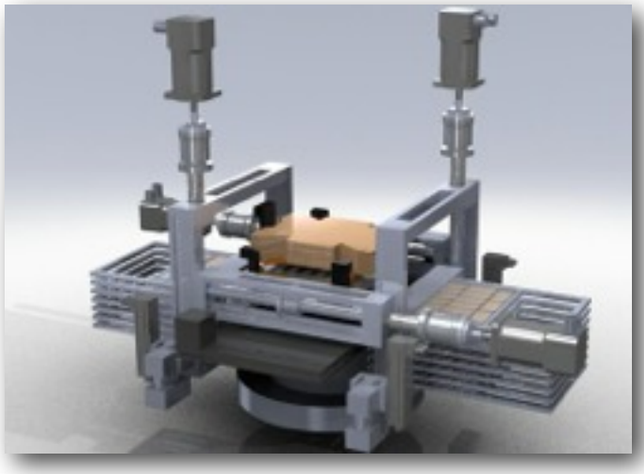


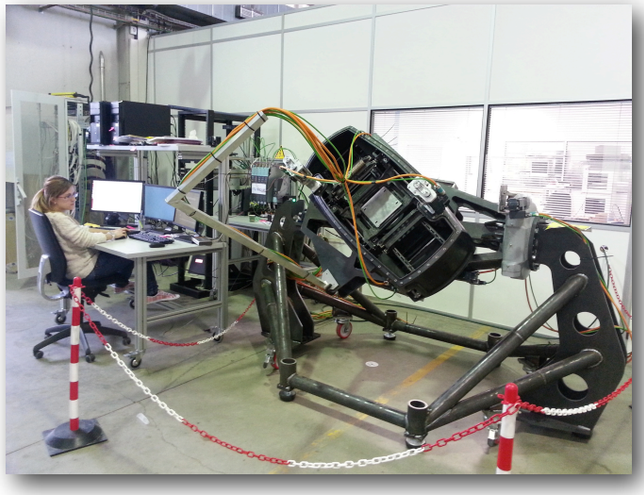




Physics of the **A**ccelerating **U**niverse

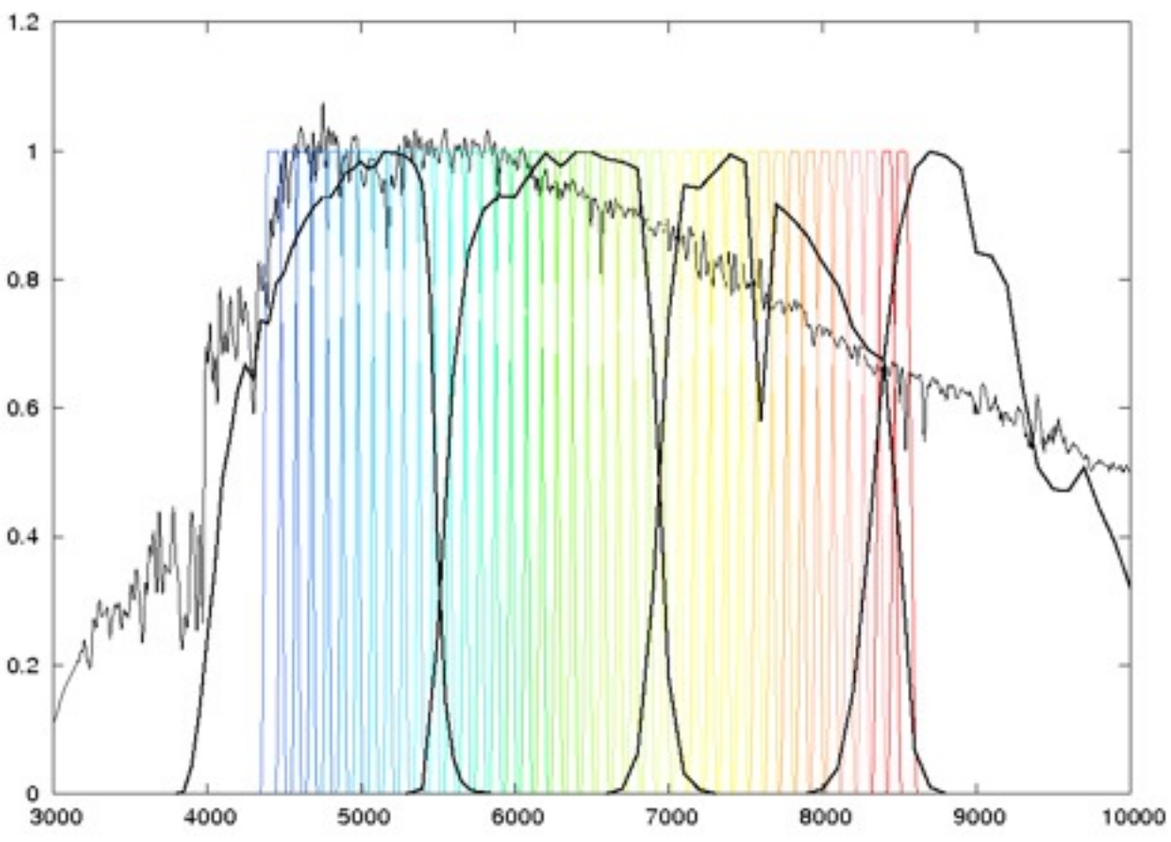
- Will measure 3D position of many galaxies extremely well
  - Enabling exquisite cross-correlations to measure lensing
- Commissioning scheduled for May 2014
- Camera under construction in Madrid & Barcelona
- Will be mounted on the William Herschel 4m telescope
- 6 broad band + 40 narrow band filters
  ugriZy + 100Å-wide filters from 4500-8500Å
  - Allow for precise distance measurements to galaxies
- ~ 1PB of data!! Much data reduction!



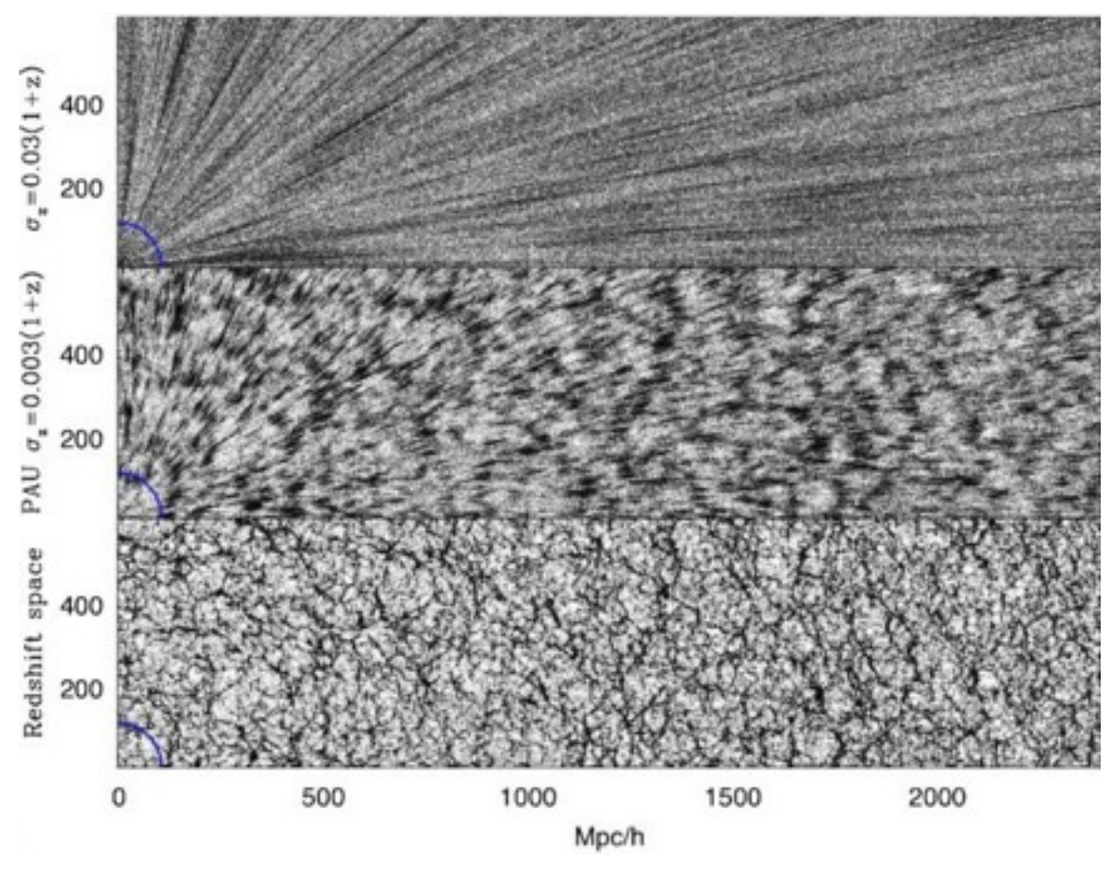


PAU's 46 filters: Great photo-z: radial precision!

- Redshift errors 10x better than typical surveys (0.0035(1+z))
- Can make many redshift bins for cross-correlations (~100!!)
- Lensing magnification and redshift space distortions are main science probes. Measure not just the most massive objects, but typical large scale structure (cosmology-dependent)



Angstroms



Summary

- Cosmology predicts the statistical distribution of matter
- Gravitational lensing probes the total matter of the lenses
  - Important for linking to large scale structure theory
  - Important for understanding galaxy formation (bias)
- Lensing magnification is a young, growing field
  - Current public survey data are sufficient to measure μ
  - Technique has different systematic errors from, e.g., shear
  - Upcoming surveys will bring significant improvements!