Studying Galaxies, Clusters, and Cosmology with Weak Lensing Magnification

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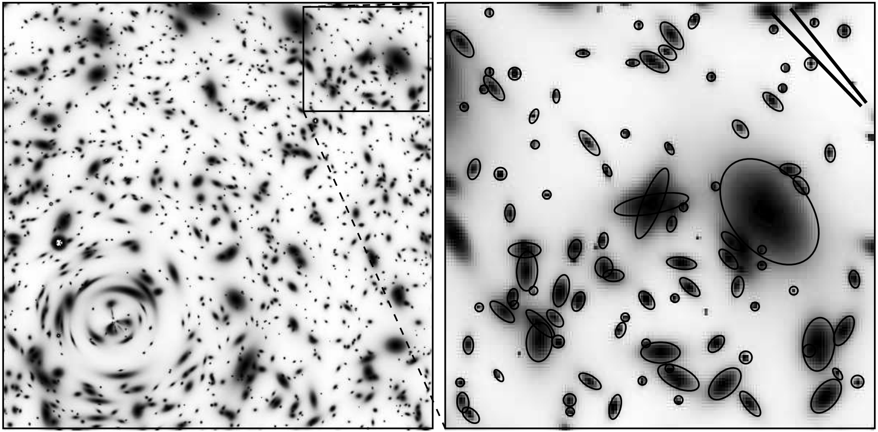
Outline

Weak Gravitational Lensing



from Mellier (1999)

Weak Gravitational Lensing

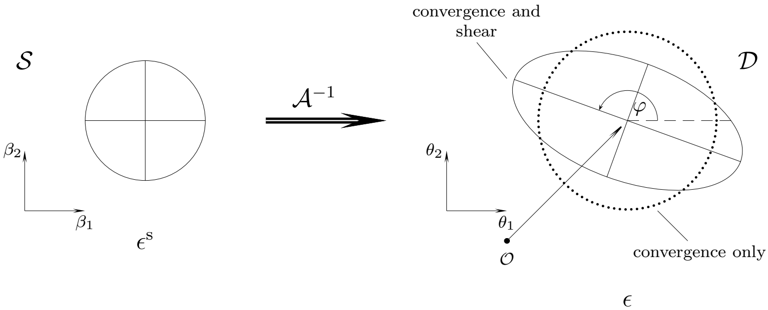
Characteristics

- Sensitive to both, dark and visible matter
- Weak distortions and magnifications
- Statistical method

Can be used to study...

- Galaxy clusters (individually or stacked)
- Galaxies (stacked)
- Large scale structure (cosmic shear)

Lensing of a circular source



from P. Schneider, Saas Fee lecture on “Weak Gravitational Lensing”

Shear based methods

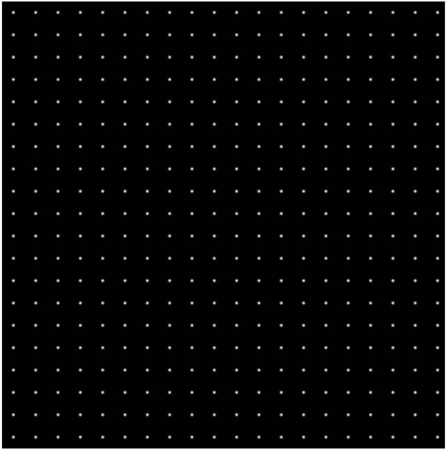
Advantages

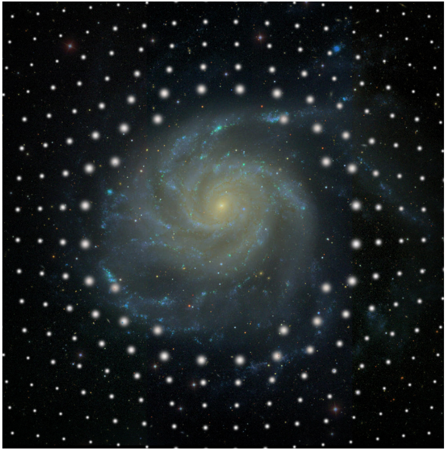
- Expectation value of intrinsic ellipticities is known: $\left\langle \epsilon^{(s)} \right\rangle = 0$
- $\langle \epsilon \rangle = \left\langle \epsilon^{(s)} \right\rangle + \gamma = \gamma$
- Higher S/N per galaxy than magnification based methods
- Absolute photometric calibration unimportant (but photo-z's...)

Disadvantages

- PSF (atmosphere + instrument)
- Pixelisation
- Noise
  $\Rightarrow$ **Measuring accurate shapes is extremely difficult**
- Astrophysical problem: Intrinsic alignments

Magnification





from SDSS press release, April 26, 2005

Magnification based methods

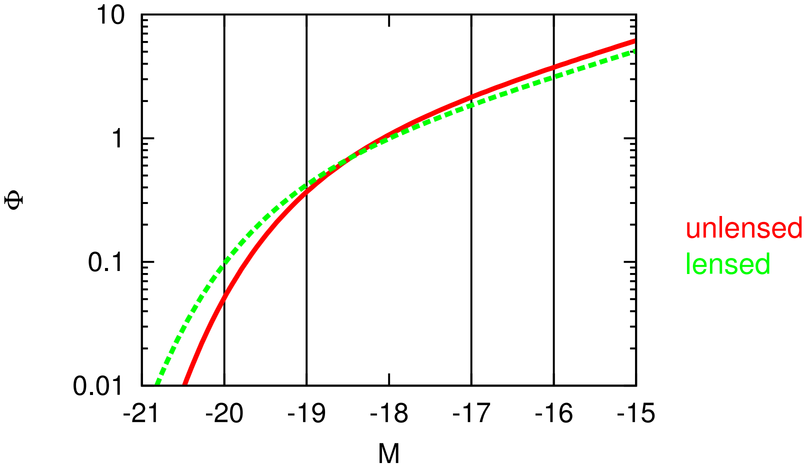
Advantages

- Magnitudes easier to measure than shapes
- More galaxies with magnitudes available
- Higher redshift sources usable
- $\Rightarrow$ **Break-even redshift for each data set beyond which magnification becomes more powerful than shear**

Disadvantages

- Intrinsic distribution of magnitudes not a priori known
  $\Rightarrow$ **Need to measure the LF first**
- Strong requirements on photometric homogeneity
- Precise correction for galactic dust needed

Magnification Observables



Effects of Magnification

Number density effect

$$N(>f) = \mu^{-1} N_0(>\mu^{-1} f)$$

$$\text{with } N_0(>f) = A f^{-\alpha}$$

$$\Rightarrow$$

$$N(>f) = \mu^{\alpha-1} N_0(>f)$$

$$w_{\rm sl}(\theta) = \langle\alpha_2 - 1\rangle\ b_1\ w_{\mu\delta}(\theta) + f_{\rm c} b_1 b_2 w_{\delta\delta}(\theta) + \langle\alpha_1 - 1\rangle\ \langle\alpha_2 - 1\rangle\ w_{\mu\mu}(\theta)$$

- Measure slope α
- Estimate the galaxy bias of the lenses
- No redshift overlap! Ensure $f_{\rm c} = 0$
- $w_{\mu\mu}$ accessible through nulling

Effects of Magnification

Magnitude shift

For a single galaxy: $\delta m = -2.5 \log \mu$

But there is also dust:

$$\delta m(\lambda) = -2.5 \log \mu + \frac{2.5}{\ln 10} \tau(\lambda)$$

Depending on the shape of the LF:

$$\delta m_{\rm obs}(\lambda) = \langle m \rangle - \langle m_0 \rangle = \mathrm{C} \times \delta m(\lambda)$$

- Choose a magnitude interval with an LF feature
- Measure C from LF
- Measure mag-shift in different bands

Effects of magnification

Observables

- $< \delta_{g1}\delta_{g2} >$: **Angular cross-correlation function between high-*z* sources and low-*z* lenses (bias-dependent)**; Scranton et al. (2005), Hildebrandt et al. (2009)
- $< \delta_{g1}\delta m_2 >$: Magnitude shift of sources as a function of distance from the lenses (bias-dependent); Ménard et al. (2010)
- $< \delta m_1 \delta m_2 >$: Cross-correlation of the magnitude shifts of sources in different redshift slices (bias-*independent* but GI probably very large)

Note that the terms “high-*z*” and “low-*z*” get different meanings in magnification measurements compared to shear measurements.

Signal for galaxy lenses

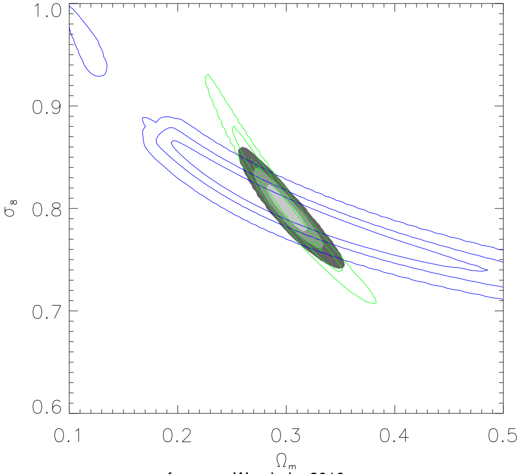
Angular cross-correlation

$$w_{\rm sl}(\theta) = \langle \alpha - 1 \rangle \; b \; w_{\mu\delta}(\theta)$$

$$w_{\mu\delta}(\theta) = \frac{3 H_0^2 \, \Omega_{\rm m}}{c^2} \int_0^{\chi_{\rm H}} {\rm d}\chi' \; f_K(\chi) \; W_{\rm s}(\chi') \; G_{\rm l}(\chi') \; a^{-1}(\chi') \quad \times$$
$$\int_0^{\infty} \frac{k \, {\rm d}k}{2\pi} \; P_\delta(k, \chi') \; J_0[f_K(\chi') \; k \; \theta] \; ,$$

$w_{\mu\delta}(\theta) \propto \Omega_{\rm m} \sigma_8^2$ on small scales

Cosmological constraints from galaxy cross-corr.



from van Waerbeke 2010a

1500 sq. deg.
Cosmic shear
Cosmic magnification

Dominant noise in magnification from clustering of sources.

Signal for cluster lenses

Example: SIS

$\mu(\theta) = \frac{\theta}{\theta - \theta_E}$,

with $\theta_E = 4\pi \left(\frac{\sigma_v}{c}\right)^2 \frac{D_{ds}}{D_s}$

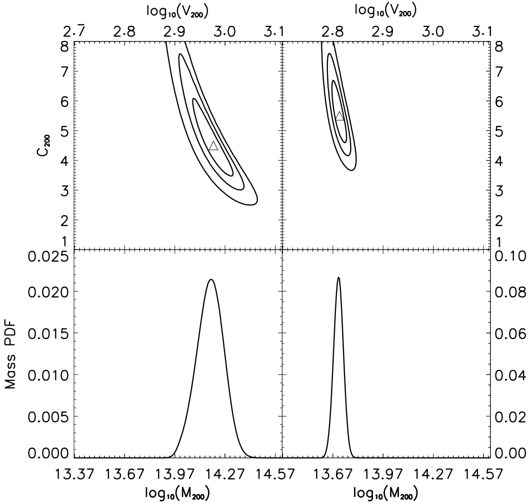
$w(\theta) = \mu(\theta)^{\alpha-1} - 1 \approx \langle \alpha - 1 \rangle \, \delta\mu(\theta) = \langle \alpha - 1 \rangle \frac{\theta_E}{\theta - \theta_E}$

with $\delta\mu(\theta) = \mu(\theta) - 1$

The mass, M_{200}, is related to the line-of-sight velocity dispersion, σ_v, through:

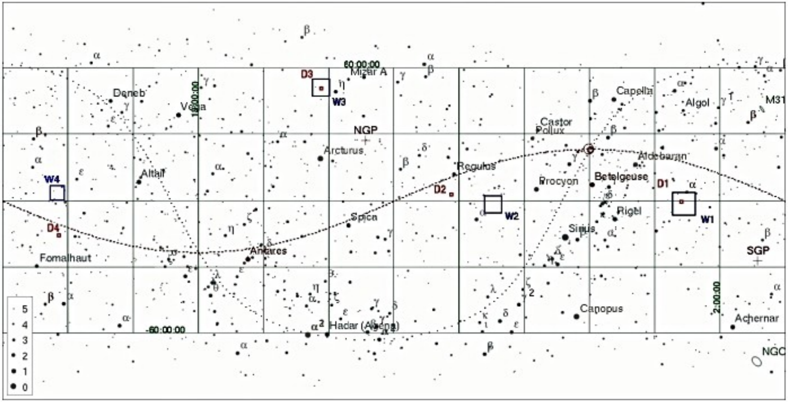
$$M_{200} = \frac{3^{\frac{3}{2}} \sigma_v^3}{\sqrt{\frac{4}{3}\pi 200 \rho_{crit} G^3}}$$

Expected signal for $z \sim 1$ cluster lenses in CFHTLenS



from van Waerbeke 2010b

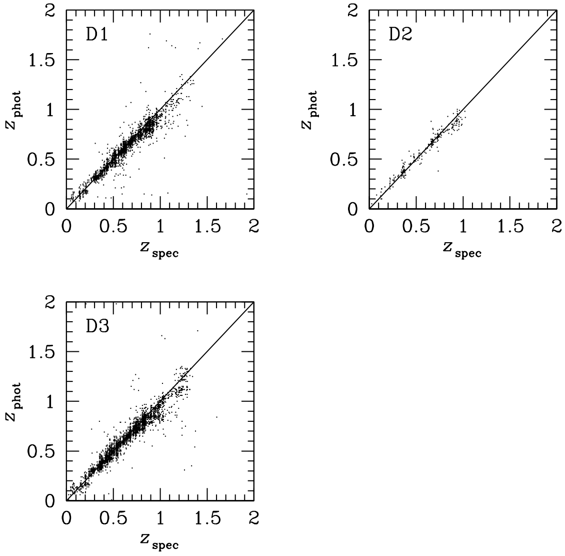
The CFHTLS



CFHTLS-Deep: 4 sq. deg. in *ugriz* to $i_{\rm lim.} \sim 27.5$ (5-σ AB)

CFHTLS-Wide: 170 sq. deg. in *ugriz* to $i_{\rm lim.} \sim 25.5$ (5-σ AB)

Photo-z accuracy (with *BPZ*) in the Deep



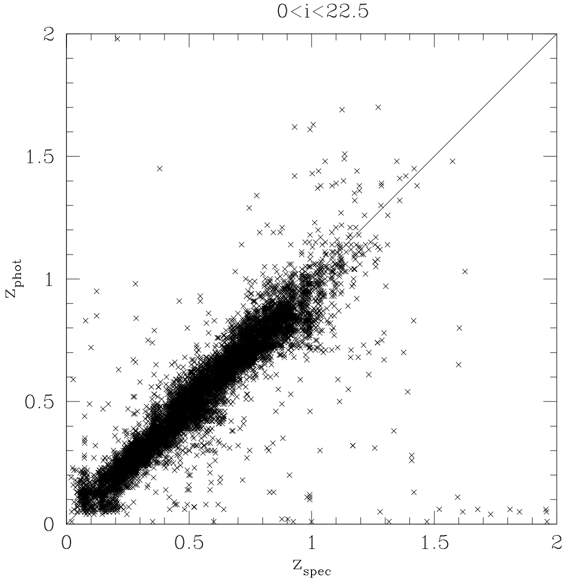
from Hildebrandt et al. (2009a)

for $i < 24$:

$\sigma_{\Delta z/(1+z)} = 0.035$

2.0% outliers

Photo-*z* accuracy (with *BPZ*) in the Wide

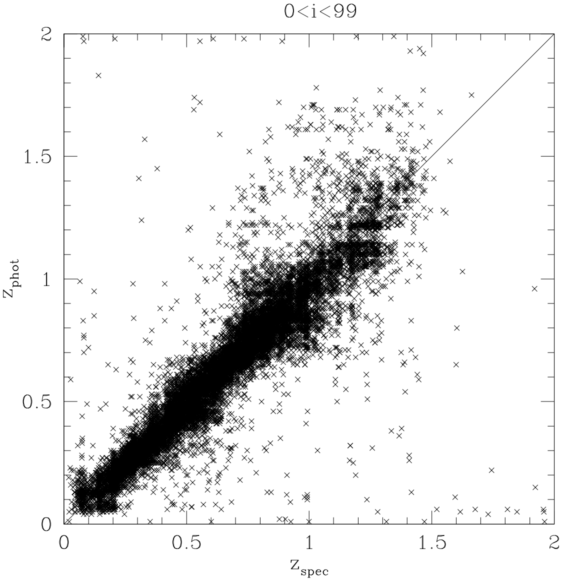


for $i < 22.5$:

$\sigma_{\Delta z/(1+z)} = 0.039$

1.9% outliers

Photo-z accuracy (with *BPZ*) in the Wide



for $i < 24$:

$\sigma_{\Delta z/(1+z)} = 0.042$

2.7% outliers

Photo-*z* accuracy (with *BPZ*) in the Wide

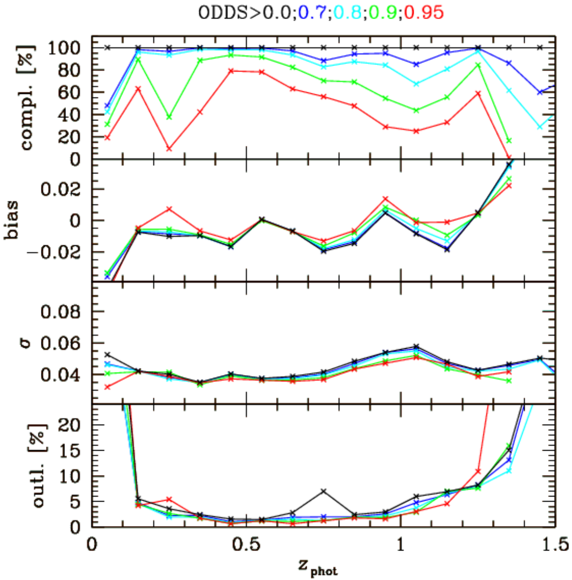


Photo-*z* accuracy (with *BPZ*) in the Wide

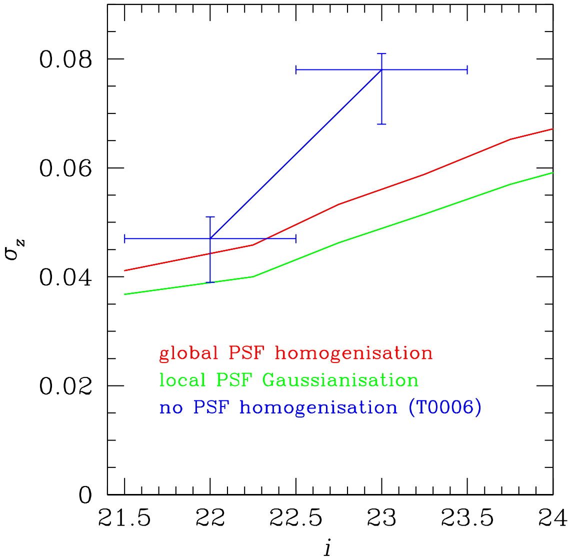
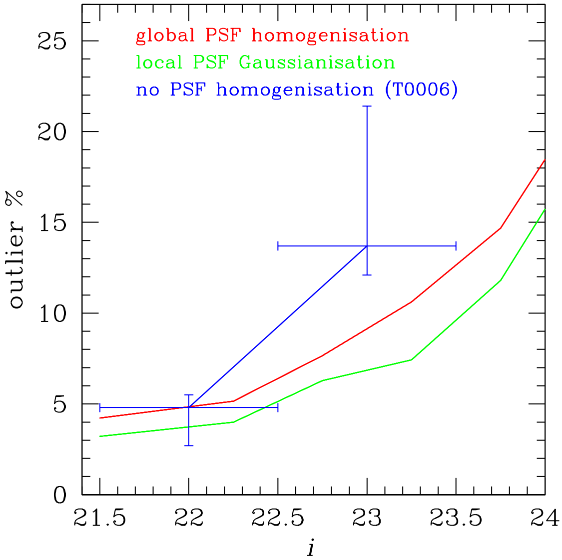
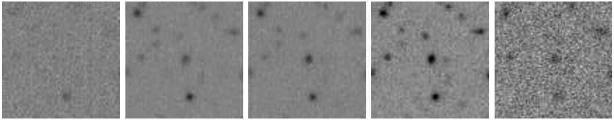


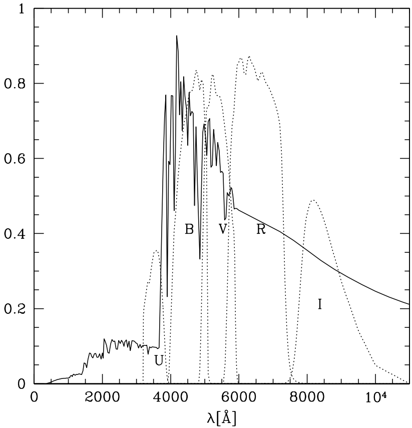
Photo-z accuracy (with *BPZ*) in the Wide



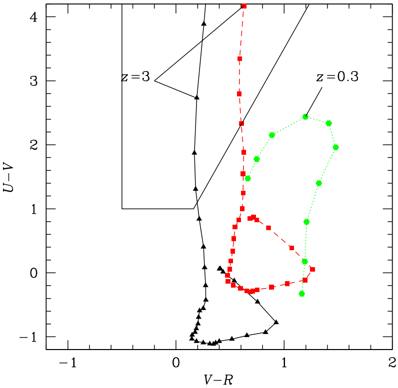
LBG selection

U=*27.2* B=25.4 V=24.7 R=24.3 I=23.9

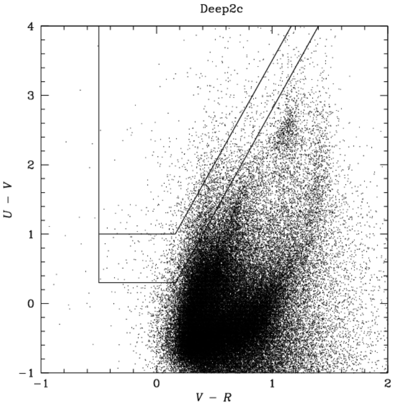




LBG selection

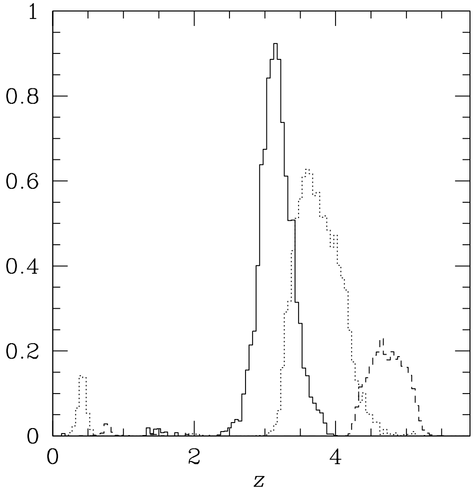


from Hildebrandt et al. 2005



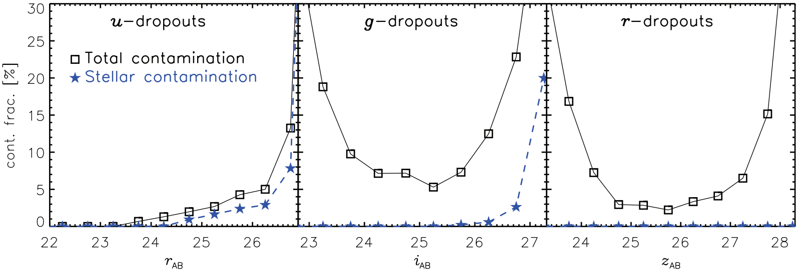
from Hildebrandt et al. 2007

LBG redshift distributions in CFHTLenS

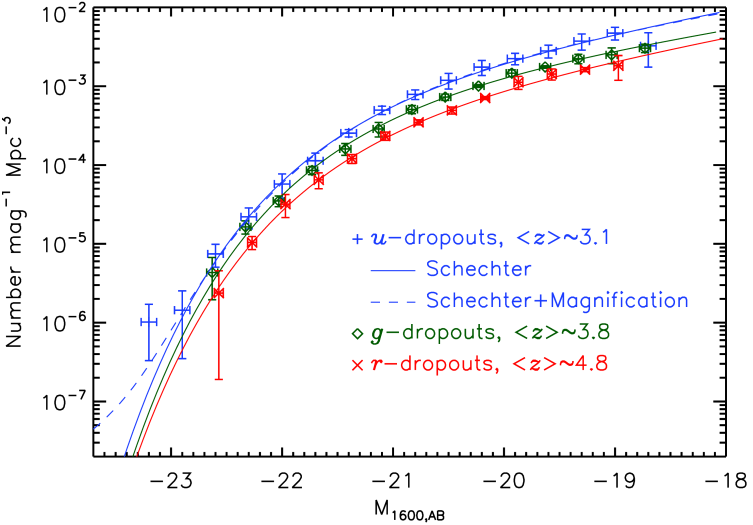


from Hildebrandt et al. (2009b)

LBG contamination

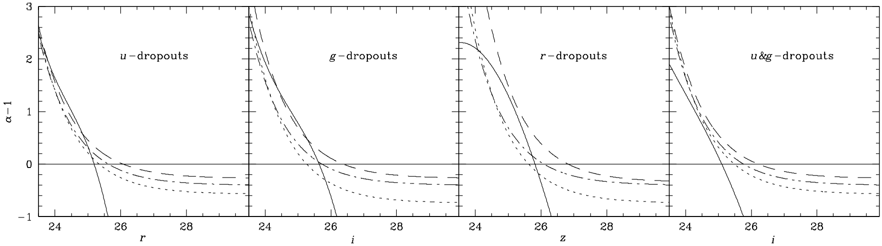


LBG LFs from the CFHTLS Deep



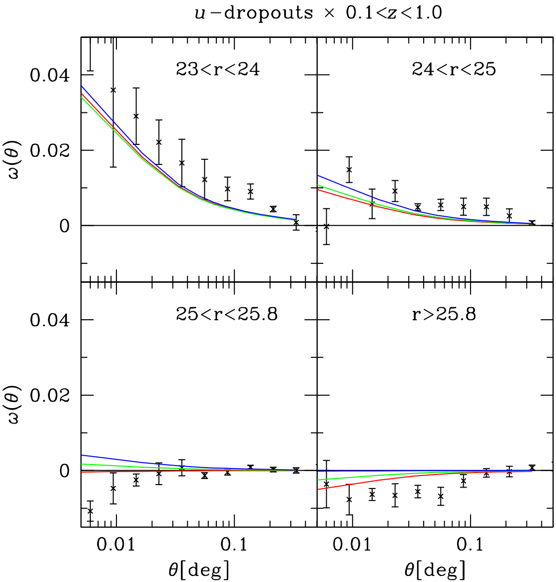
from van der Burg et al. (2010)

LF slopes



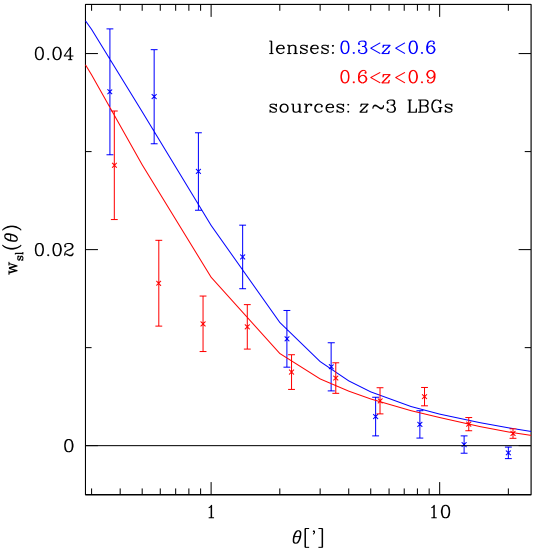
from Hildebrandt et al. (2009b)

Scaling with mag of the background sample (Deep)

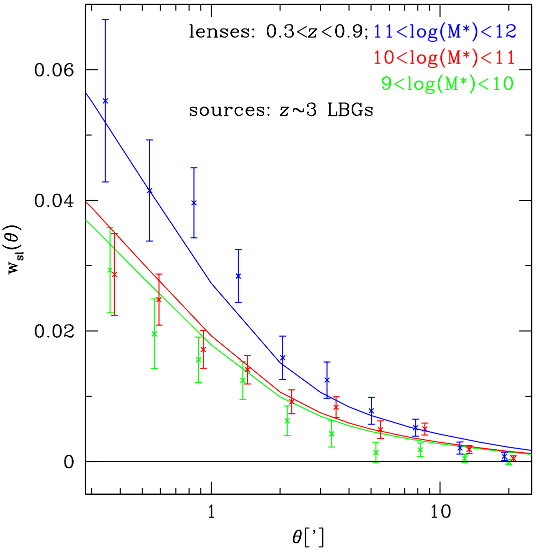


from Hildebrandt et al. (2009b)

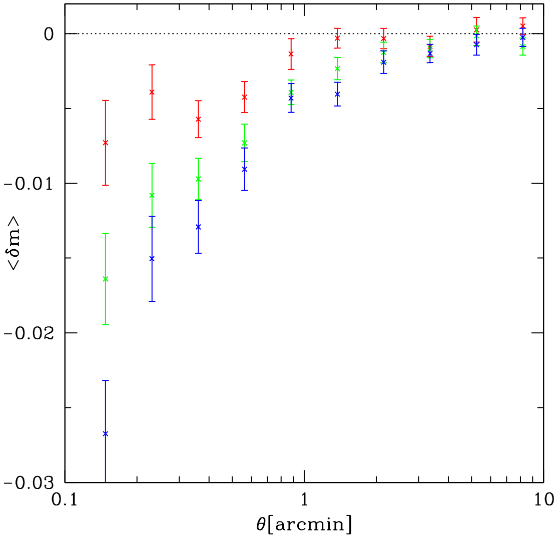
Scaling with redshift of the foreground sample



Scaling with mass of the foreground sample



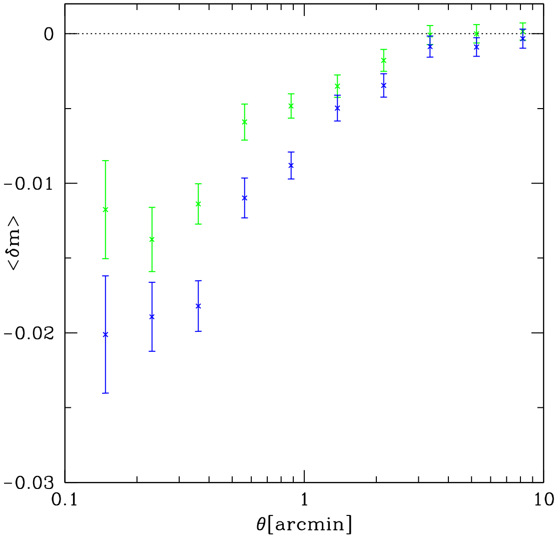
Mag shift $< \delta_{g1} \delta m_2 >$, *u*-dropouts, CFHTLenS-WIDE



lenses: $0.4 < z < 0.8$

g-band
r-band
i-band

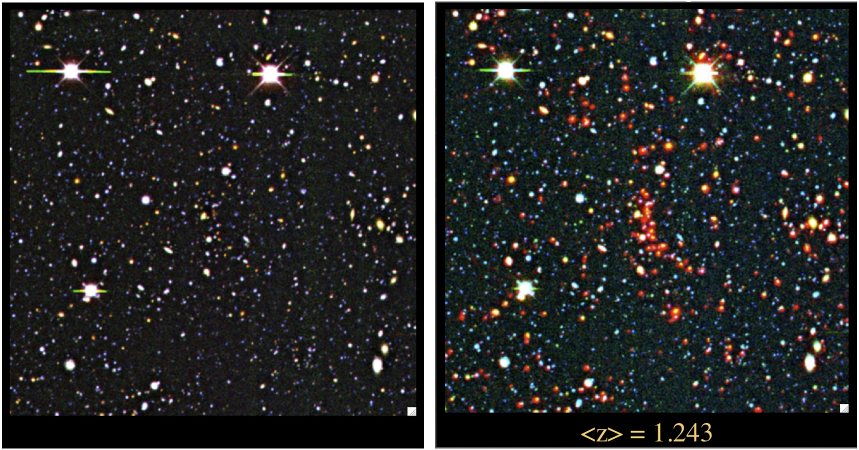
Mag shift $< \delta_{g1} \delta m_2 >$, *g*-dropouts, CFHTLenS-WIDE



lenses: $0.4 < z < 0.8$

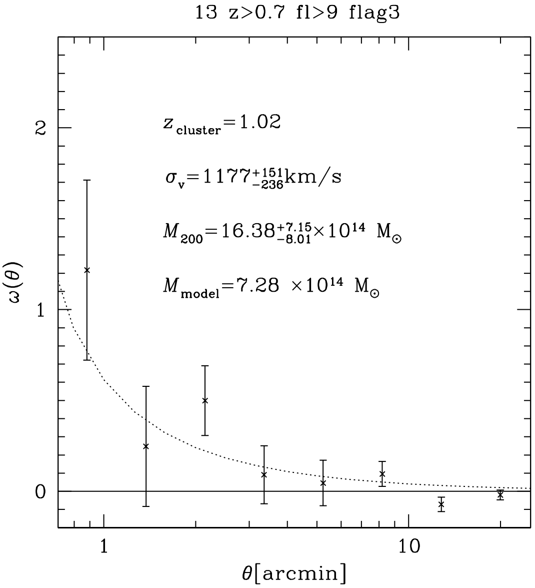
r-band
i-band

Masses of SpARCS high-z clusters

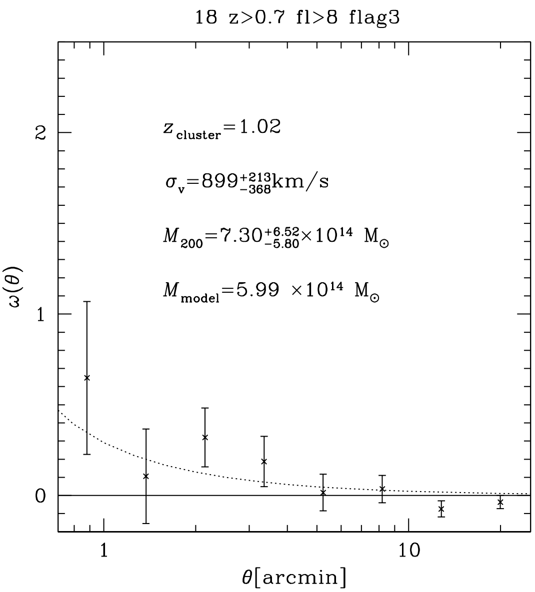


from the presentation by Mark Brodwin at the conference, “CL J2010+0628: from Massive Galaxy Formation to Dark Energy” at IPMU in Japan, in 2010.

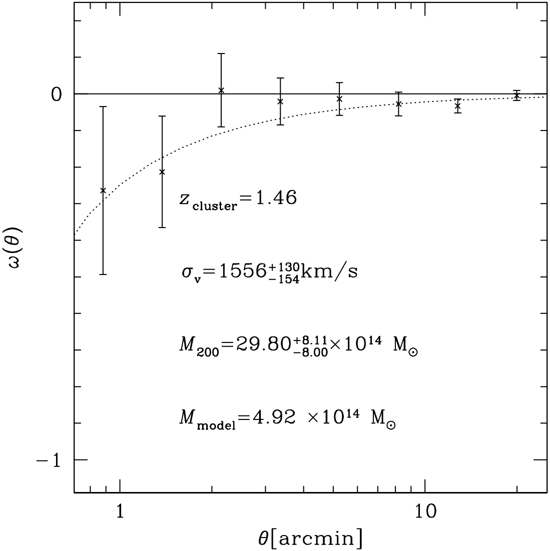
Masses of SpARCS high-z clusters **(PRELIMINARY)**



Masses of SpARCS high-z clusters **(PRELIMINARY)**



Masses of SpARCS high-z clusters **(PRELIMINARY)**



Summary

Number Density Effect

- Scaling with $< \alpha - 1 >$
- Scaling with redshift
- Scaling with mass/galaxy-bias

Mag Shift Effect

- Mag-shift scaling with colour

High-z Cluster Magnification

- First detection of $z \sim 1$ clusters

Outlook

Number Density Effect, to be done

- Determine bias from data (auto-correlation)
- Apply correction for dust
- Use photo-z selected sources
- Constrain cosmological parameters (also nulling)

Magnitude Shift Effect, to be done

- Measure dark-matter halo profile
- Measure dust halo profile

High-z Cluster Magnification, to be done

- Estimate robust α's for the Wide
- Expand the area for high-z cluster science