Weak gravitational lensing

a mass calibrator

and/or

a cluster finder?

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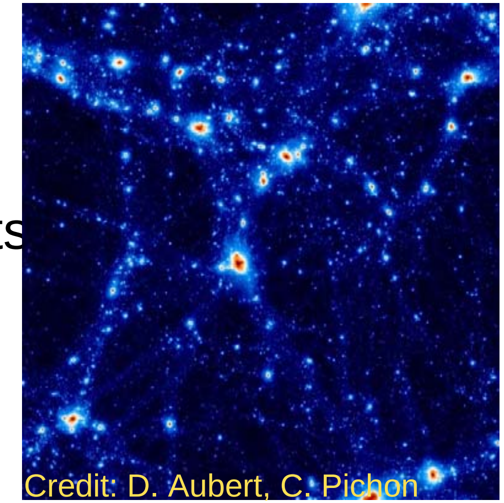
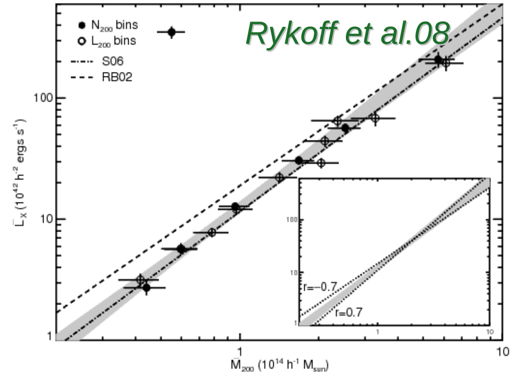
Galaxy clusters for cosmology



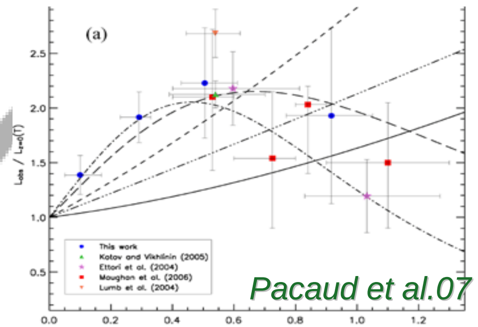
- Clusters of galaxies as nodes of the Cosmic Web
  - Counts and clustering powerful cosmological tests (Ω_m, σ_8) .
  - Complementary probe of Dark Energy EoS.

- **How many? How distant? How massive?**

- Most survey techniques (optical, X-rays, SZ) rely on loosely constrained scaling relations between the physics of baryons and halo mass



- Redshift evolution of Scaling Relations is crucial but less controlled!!



- **Weak gravitational lensing (WL)** is directly sensitive to the projected mass of halos.
  - Allow to **weigh independently-found clusters**
  - Can achieve a **mass selected** sample of clusters at 0.05<z<0.8 *(access to under luminous 'dark clusters')*

Weak gravitational lensing : Basics

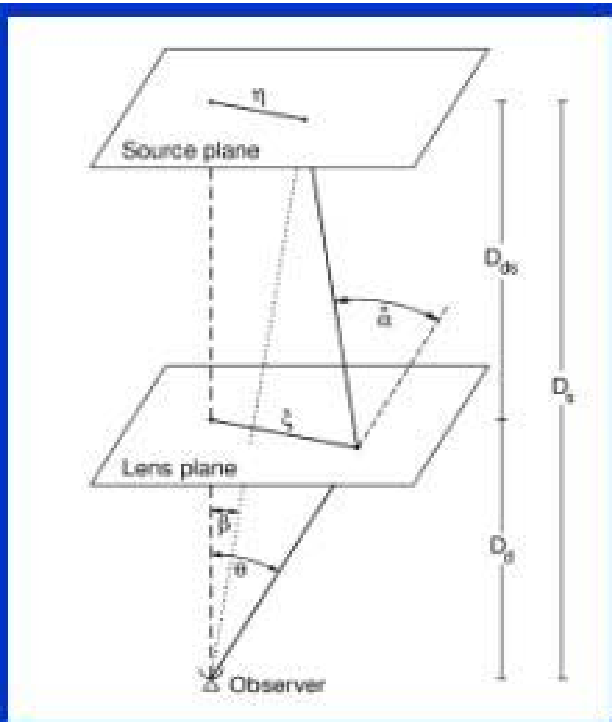
$$\boldsymbol{\alpha} = -\frac{2}{c^2}\int_S^O \boldsymbol{\nabla}_\perp \Phi \, \mathrm{d}l \, .$$

- Lens equation

$$\vec{\eta} = \frac{D_{os}}{D_{ol}}\vec{\xi} - D_{ls}\vec{\alpha}\left(\vec{\xi}\right) \Longleftrightarrow \vec{\beta} = \vec{\theta} - \vec{\alpha}\left(\vec{\theta}\right)$$

- Effective potential

$$\psi\left(\vec{\alpha}\right) = \frac{1}{\pi}\int \kappa\left(\vec{\alpha}\right) \ \ln\left|\vec{\theta} - \vec{\theta'}\right| \ \mathrm{d}^2\theta'$$



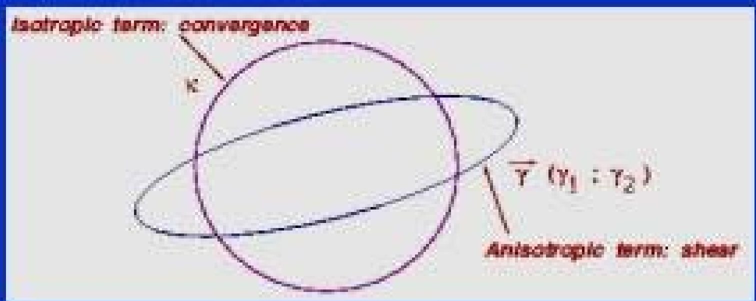
Gravitational lensing

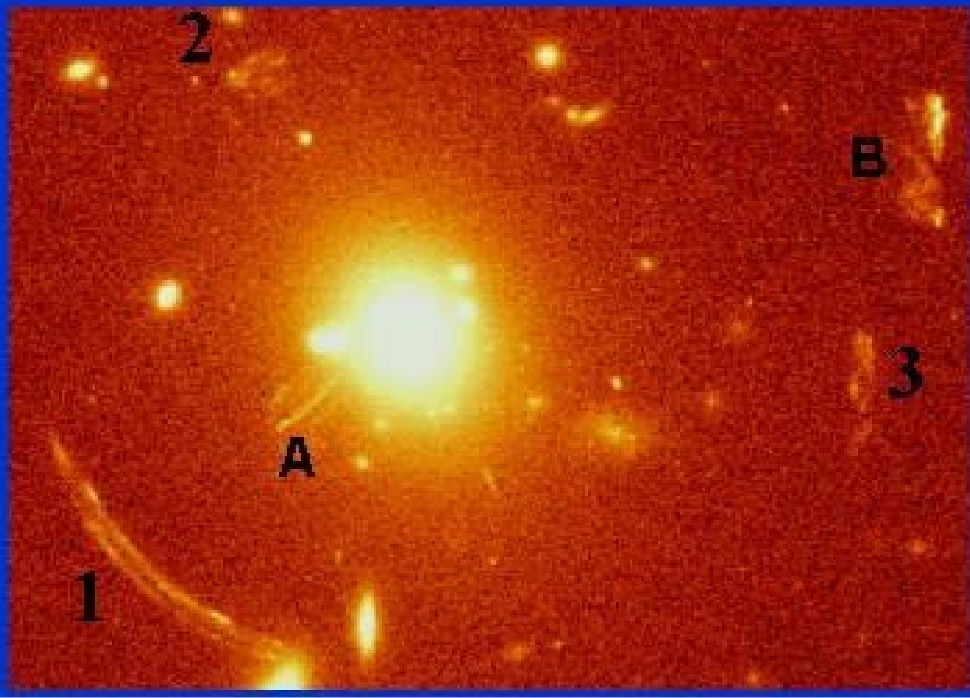
- Lens Mapping & Magnification Tensor M

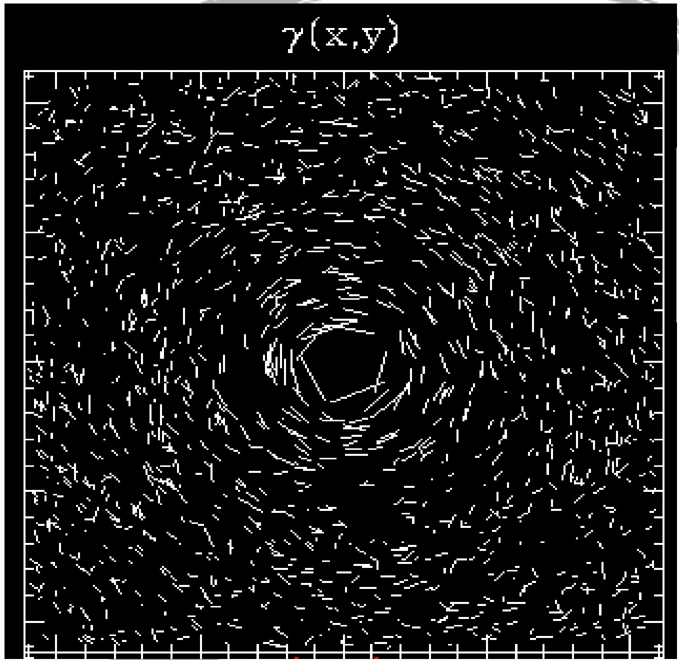
$$A = \frac{\partial\vec{\beta}}{\partial\vec{\theta}} = \left(\delta_{ij} - \frac{\partial^2\psi\left(\vec{\theta}\right)}{\partial\theta_i\partial\theta_j}\right) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix} = M^{-1}$$

- Convergence, Shear

$$\begin{cases} \kappa = \frac{1}{2}\left(\psi_{11} + \psi_{22}\right) \\ \gamma_1\left(\vec{\theta}\right) = \frac{1}{2}\left(\psi_{11} - \psi_{22}\right) = \gamma\left(\vec{\theta}\right)\cos\left[2\Phi\left(\vec{\theta}\right)\right] \\ \gamma_2\left(\vec{\theta}\right) = \psi_{12} = \gamma\left(\vec{\theta}\right)\sin\left[2\Phi\left(\vec{\theta}\right)\right] \end{cases}$$

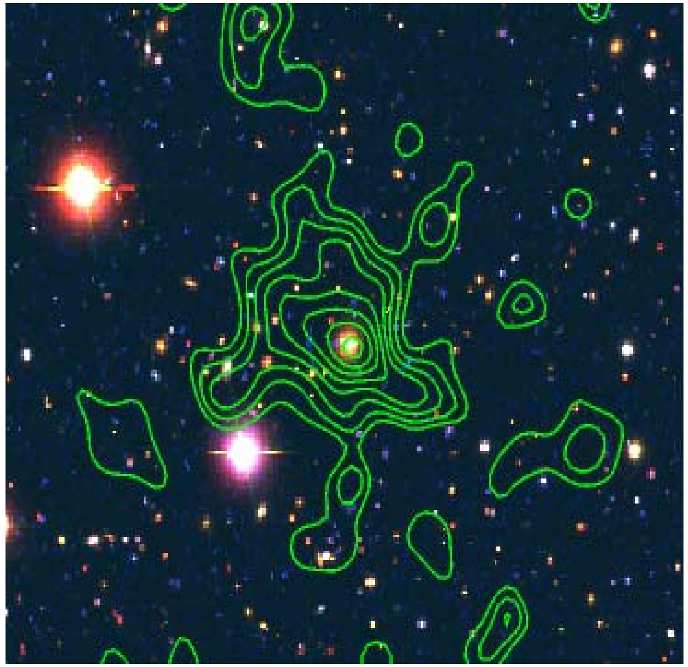




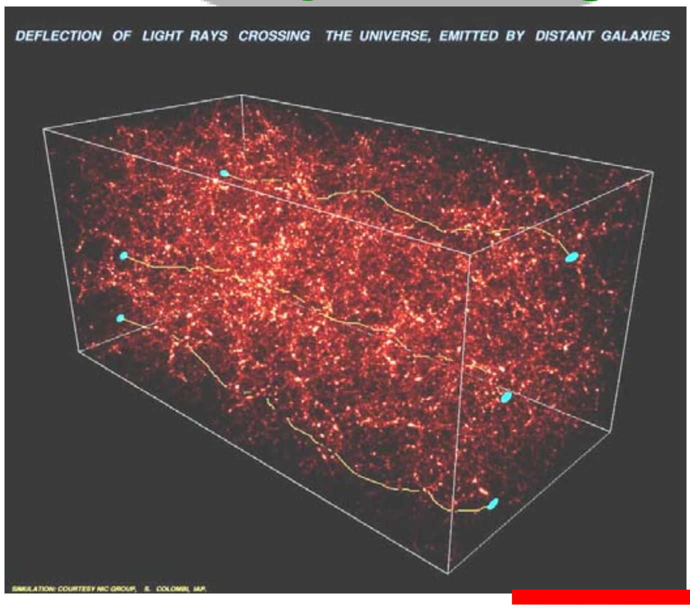


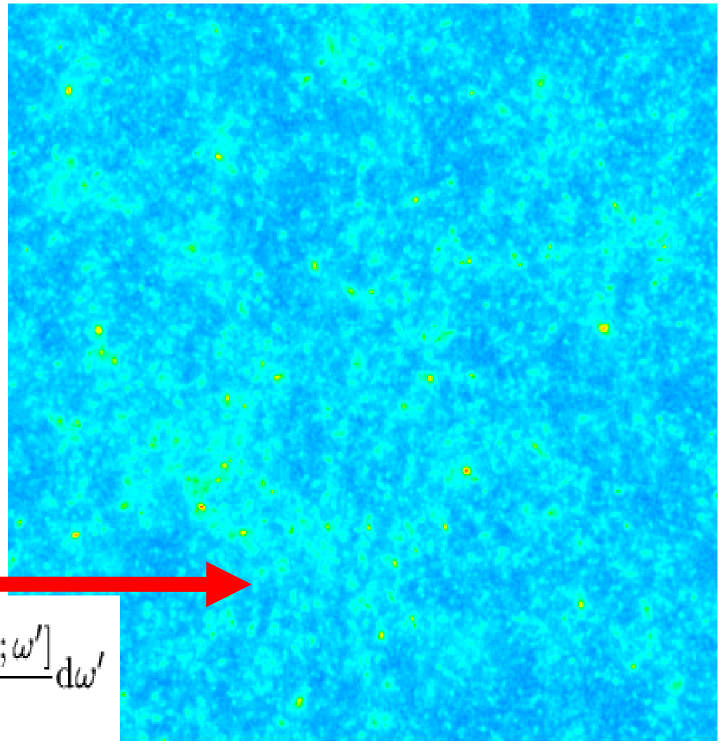
Mass reconstruction

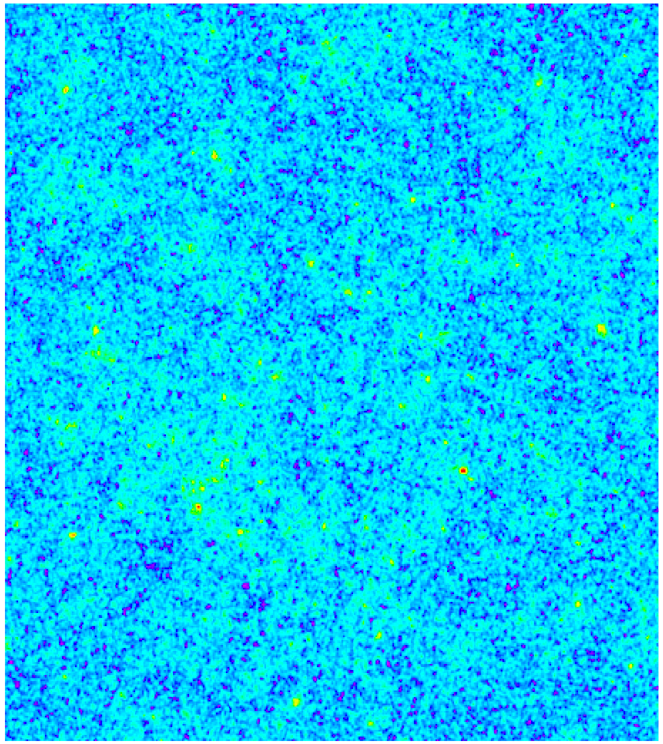
$$\kappa(\vec{\theta}) = \frac{1}{\pi}\int_{\mathbb{R}^2} \mathrm{d}^2\vec{\vartheta}\,\mathcal{D}^*(\vec{\theta}-\vec{\vartheta})\gamma(\vec{\vartheta})$$



Ray-tracing through N-body simulations





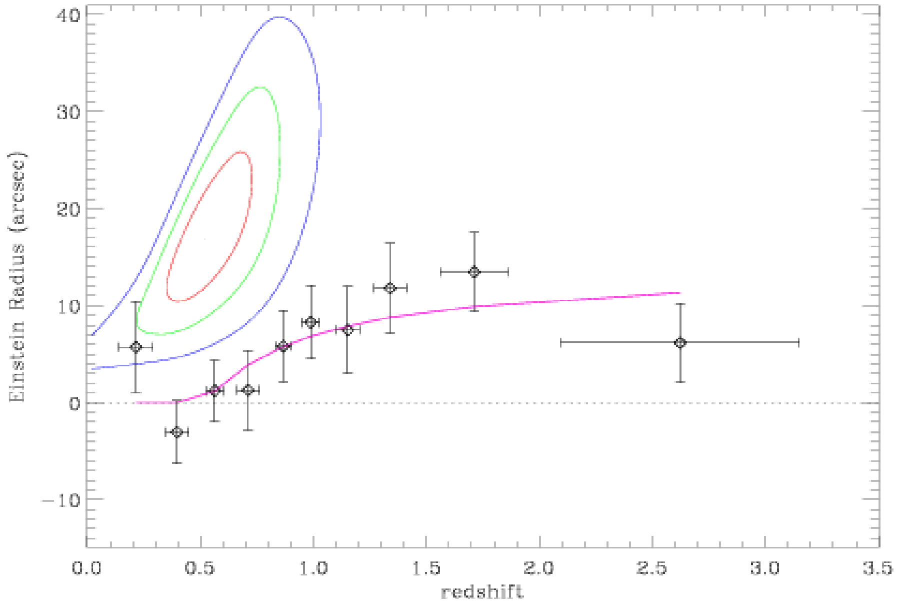


$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega}\frac{f_K(\omega-\omega')\,f_K(\omega')}{f_K(\omega)}\frac{\delta\left[f_K(\omega')\boldsymbol{\theta};\omega'\right]}{a(\omega')}\mathrm{d}\omega'$$

Weak lensing for measuring cluster masses

Tomography

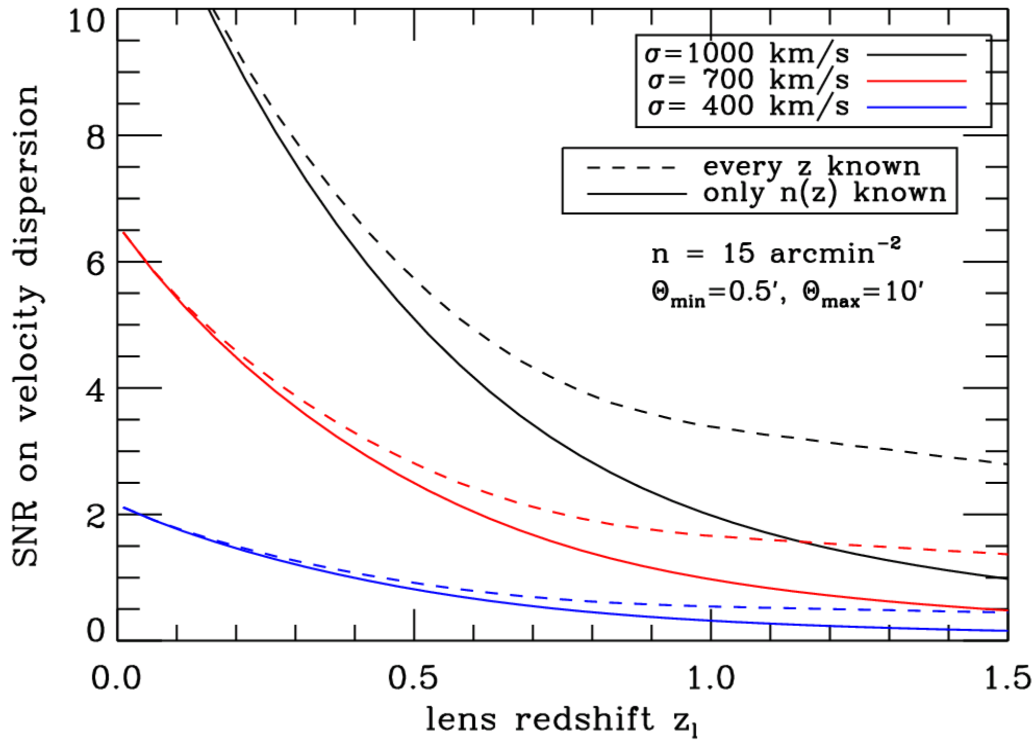
- Photo-z for proper weighting of background sources (D_{ls}/D_s efficiency): gives velocity dispersion (or mass) AND lens redshift!



Gavazzi & Soucail 07: split sources into 10 z_s-quantiles and measure Einstein radius for each: ♦ = 760±110km/s z_l=0.52±0.12

Typical SNR achieved on a velocity dispersion measurement At z=0.4, σ= 700 km/s : ~30%
=1000 km/s : ~14%

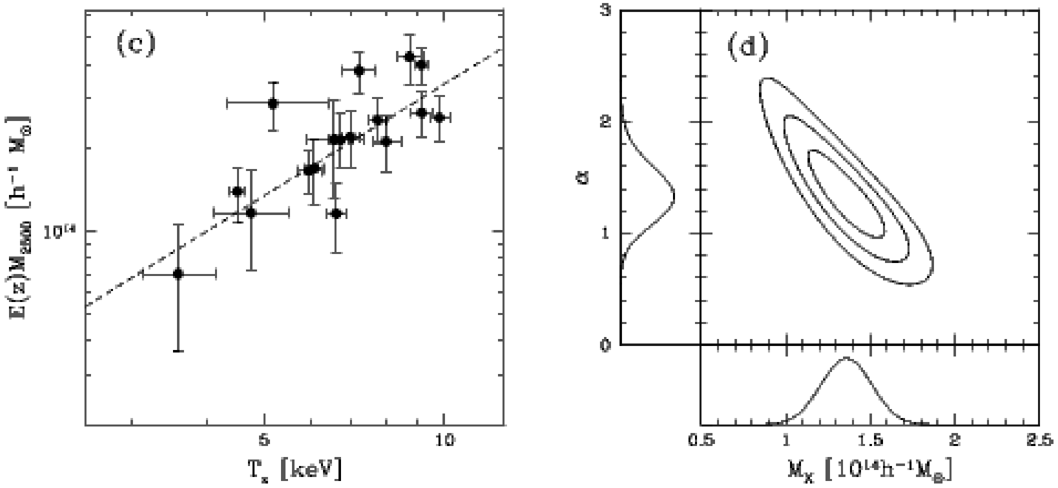
Tomography useful at z>0.7



Calibration of M-T relation

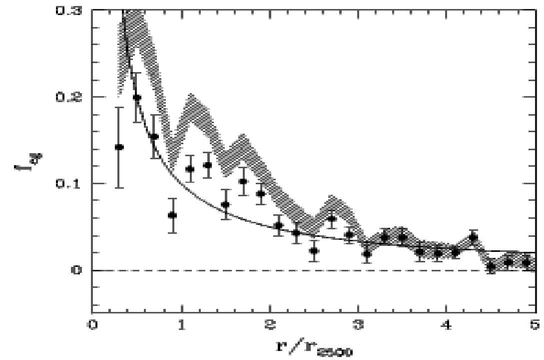
Hoekstra 2007: 20 Massive clusters

$E(z)\ M_{2500} = 1.4 \pm 0.2 \times 10^{14}\ (T/4keV)^{1.34+0.3-0.25}$



- Consistent with self-similar
- 14% error on global normalisation
- Per individual cluster: ~ 25% (including LSS, depth R<25)

- Careful account of signal dilution by cluster members (lower by ~4% M(<500kpc/h))

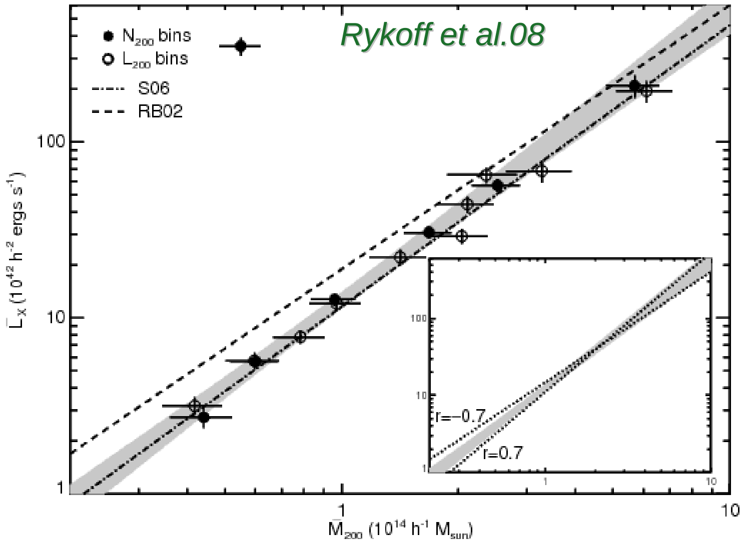


Calibration of M-L_X relation

Rykoff et al 2008: 17000 maxBCG clusters (SDSS). Cross-correlation WL (Sheldon et al. 07, see below) and X-rays from RASS.

$L_X/10^{42} = 12.6 \pm 1.35^{stat} \pm 1.6^{syst}\ (M_{200}/10^{14})^{1.65 \pm 0.13}$

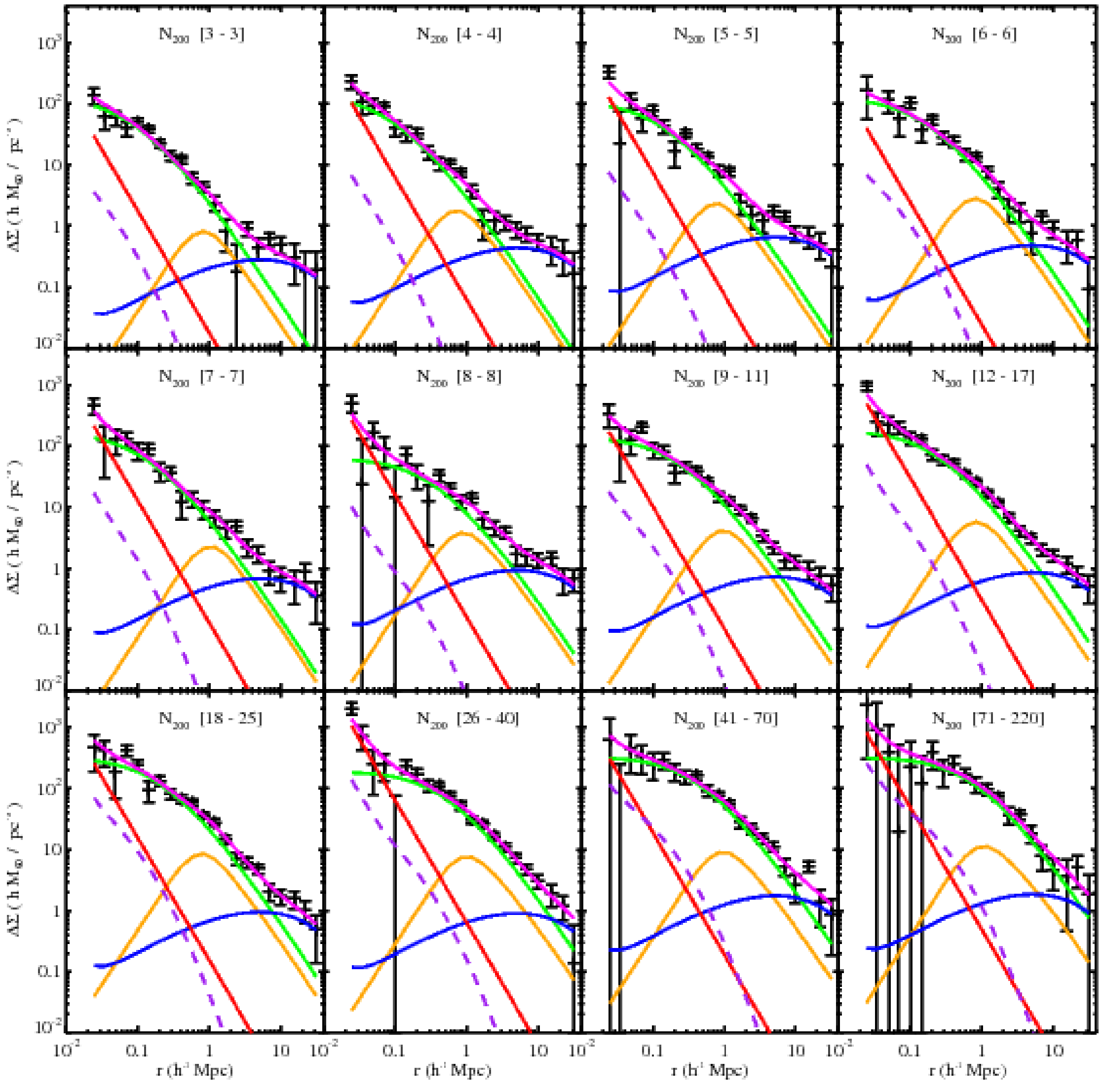
- Nor SDSS and RASS optimal from WL and LX but great coverage
- 10% stat error BUT already dominated but systematics (13%)



Calibration of M-N_{200} (optical richness)

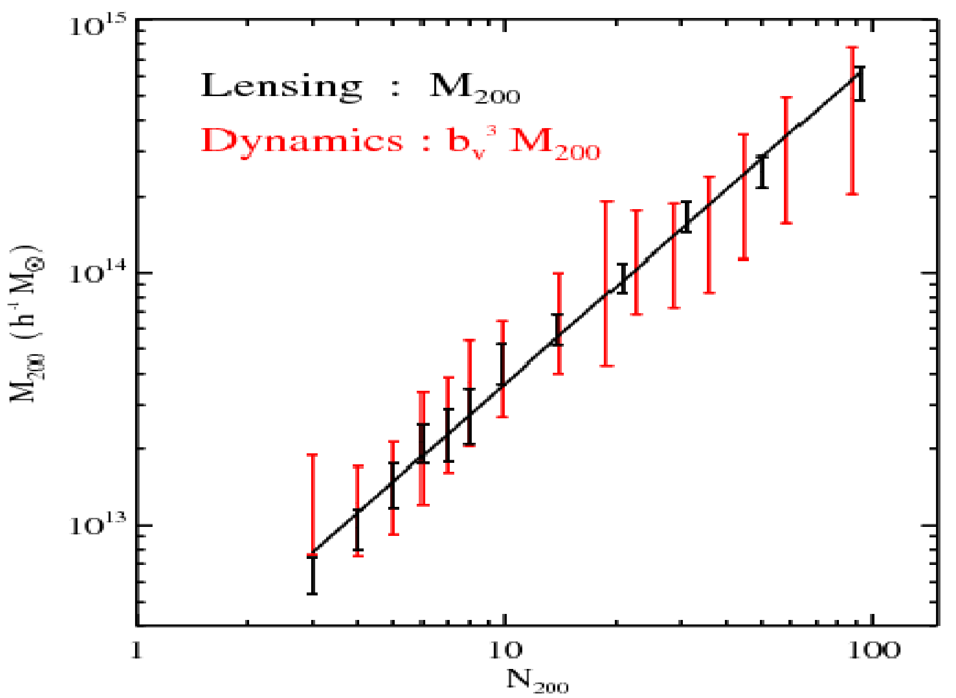
Johnston et al 07 stacked 13823 optically-selected MaxBCG clusters to get mean shear signal in several richness bins:

$$M_{200} = 8.8\pm0.4^{stat}\pm1.1^{syst} \times 10^{13}\, (N/N_{200})^{1.28\pm0.4}$$



- Consistent with dynamics of cluster members
- 5% statistical error on global normalisation
- Systematics dominate at 12% level

(clusters photoz, miscentering)

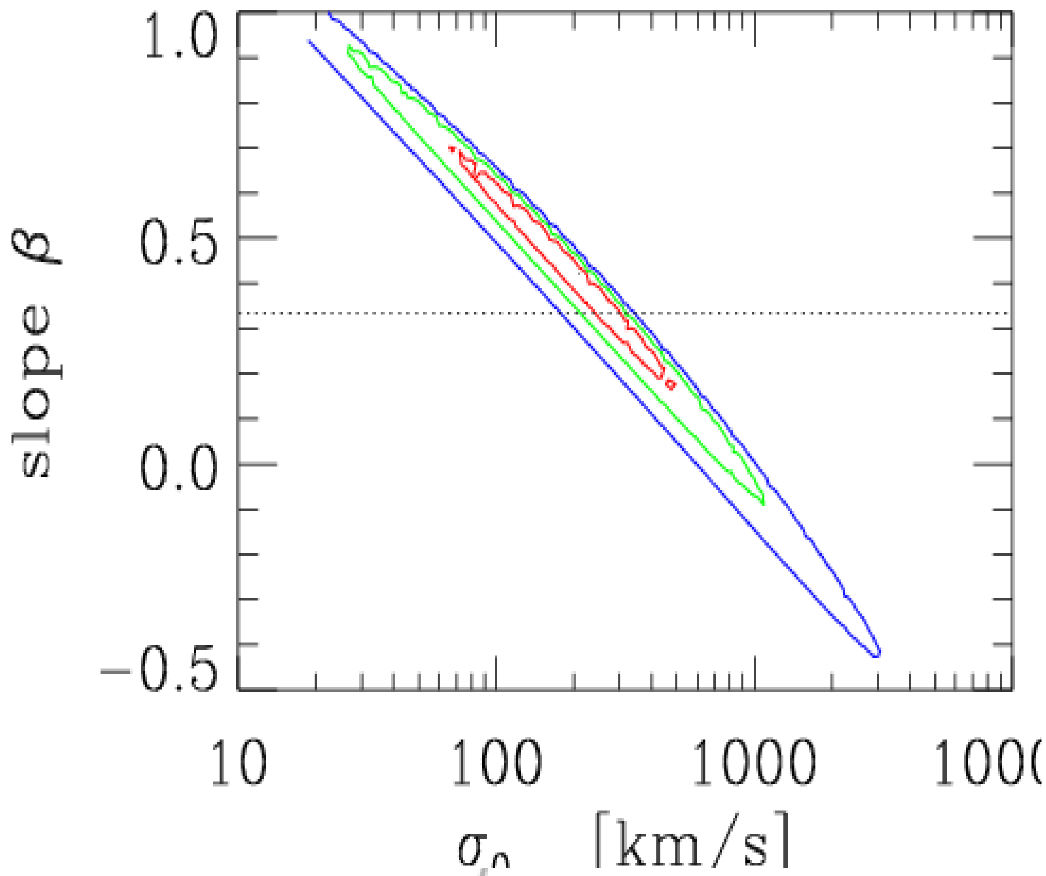


Scaling between mass and galaxy content in the CFHTLS deep

Col. C. Benoist (OCA, Nice)
Extension of Gavazzi & Soucail 07

•123 « first class » optically-selected clusters of Olsen et al 07, (matched filter technique) in 4deg^2 deep fields.

•Maximum Likelihood analysis of isothermal profile around optical centres to constrain scaling ♦ ♦ ☹♌



•Assuming constant M/L β=1/3 and no redshift evolution:

10% measurement of normalisation

♦

Systematics

- Shape measurements (ie shear calibration):

ShearTEstingProgram STEP1 (Heymans et al.06) : typical 7% accuracy

STEP2 (Massey et al.07): 2% or better

New methods (*e.g.* Lensfit, Miller et al.07, Kitching et al.08) : ~0.3-0.5%

… We expect a 10^{-3} calibration for ground-based images in the coming years.

- Photometric redshifts:

  - Hoekstra 07 : “M(<500kpc/h) is ~4% biased low if cluster member galaxies are not removed from background shear catalogue”
  - Automatic with tomographic approach (Gavazzi&Soucail07)
  - Better knowledge of redshift distribution of sources $N_{bg}(z)$

=> Need for multiband Optical+NIR photometry + addional spectra

For a 200 deg² survey:

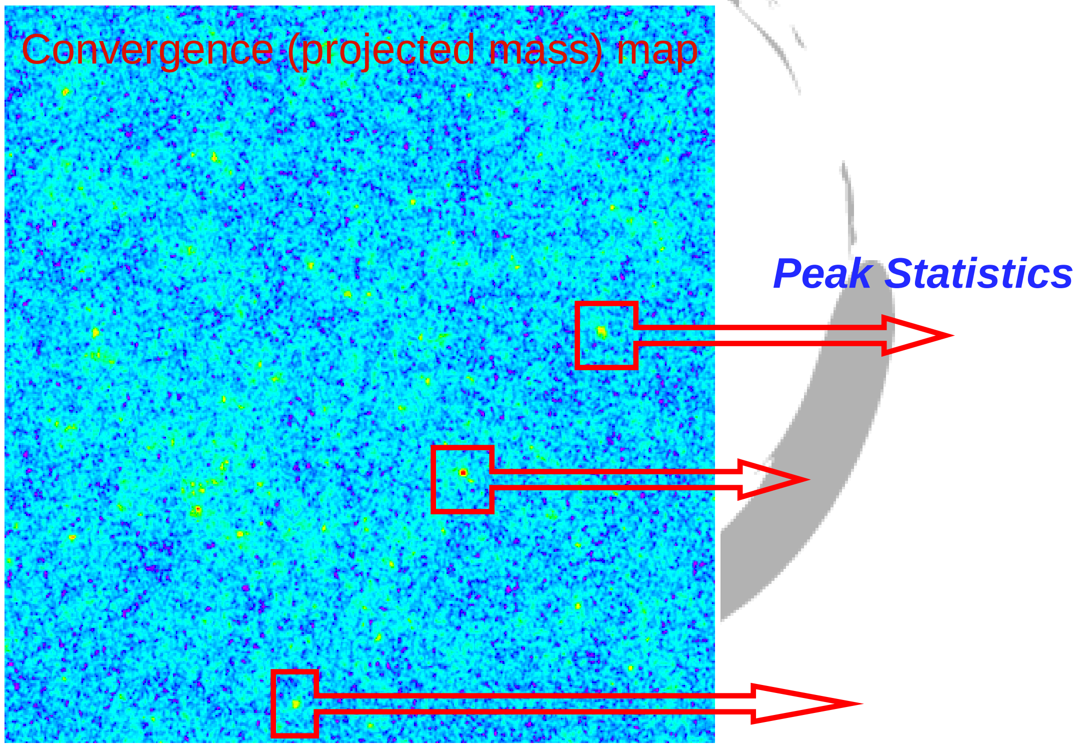
- Optical detections in CFHTLS-wide will yield 1-2% calibration of mass-richness
- Extrapolation of Hoestra07 results also gives 1-2% statistical errors

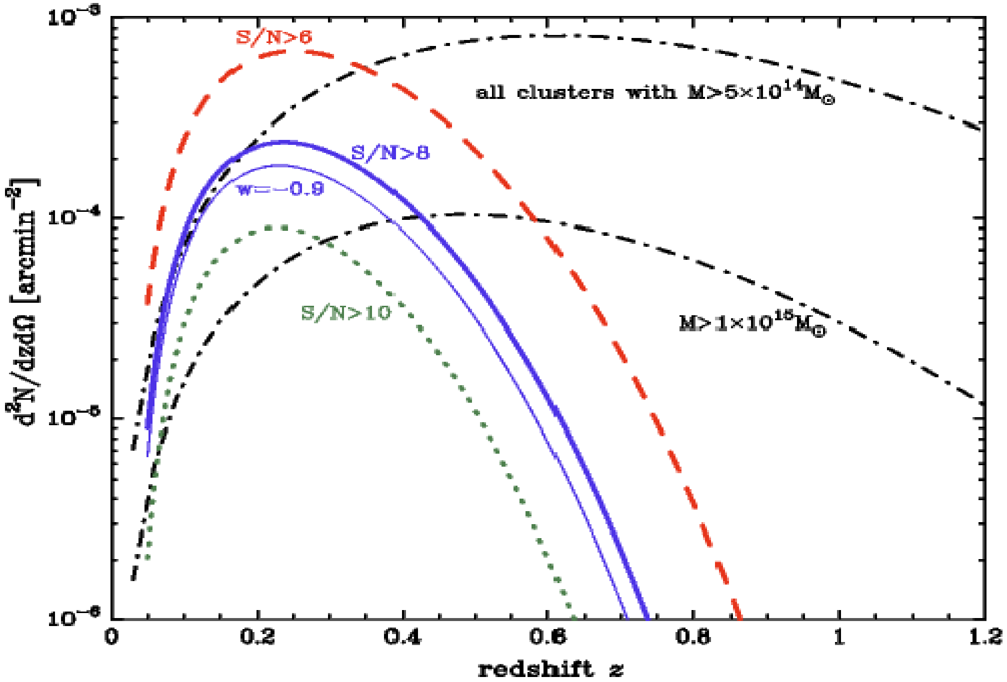
=> Shear calibration will be OK

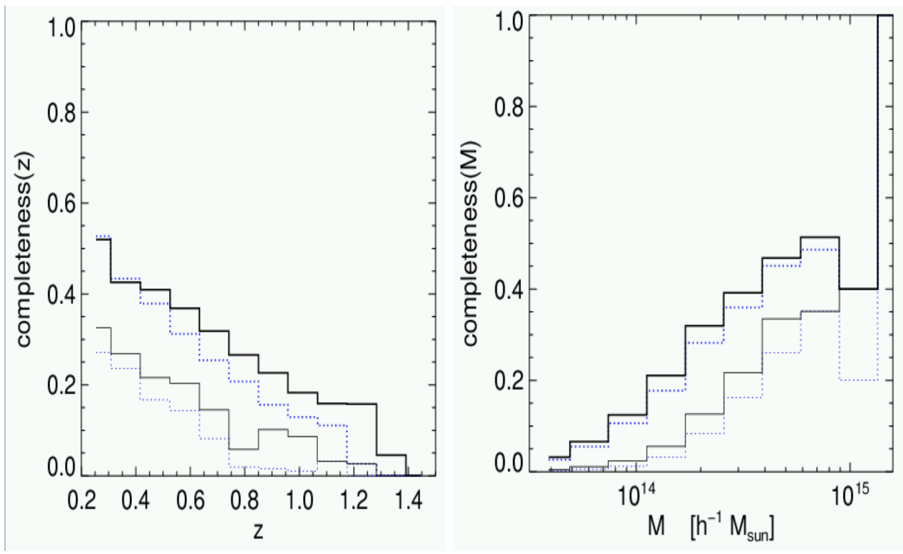
=> more efforts on photometric redshifts $N_{bg}(z)$, *but less critic*

Weak lensing for direct cluster detections

Weak lensing cluster detection







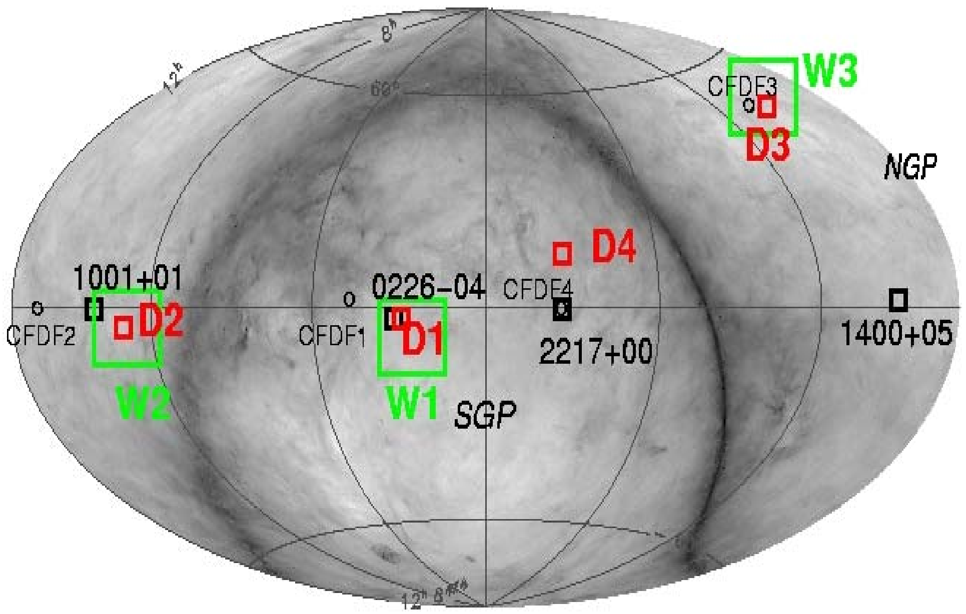
Hennawi&Spergel05

Sensitive to most massive $M>10^{13.5}M_o$ clusters in the range $0.05 < z < 0.7$

- Low completeness (<30% for efficiency > 75%)
- Projections of groups may mimic clusters
- Easily calibrated with "cheap" simulations

Example: CFHTLS deep

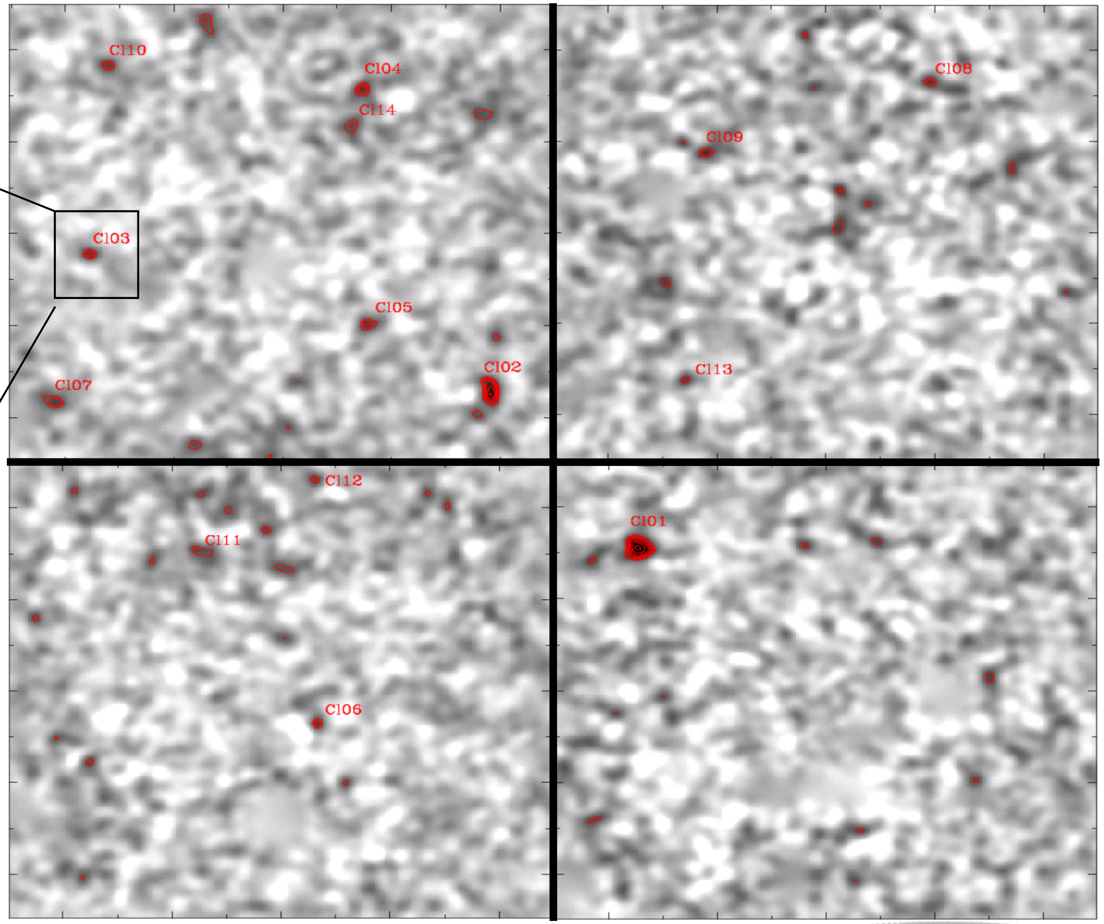
Gavazzi & Soucail 07



- 4x1deg² patches with Megacam@CFHT, down to i_{AB}~26, seeing<0.9''
- u*g'r'i'z' photometry allows accurate photo-z (Ilbert et al.06)
- n_{bg} ~ 25-33 arcmin^{-2}
- PSF smearing corrected with KSB method
- shear ♑, convergence & inversion
- Gaussian filtering (1arcmin scale), shape very efficient Hennawi&Spergel05

Kappa maps

Gavazzi & Soucail 07

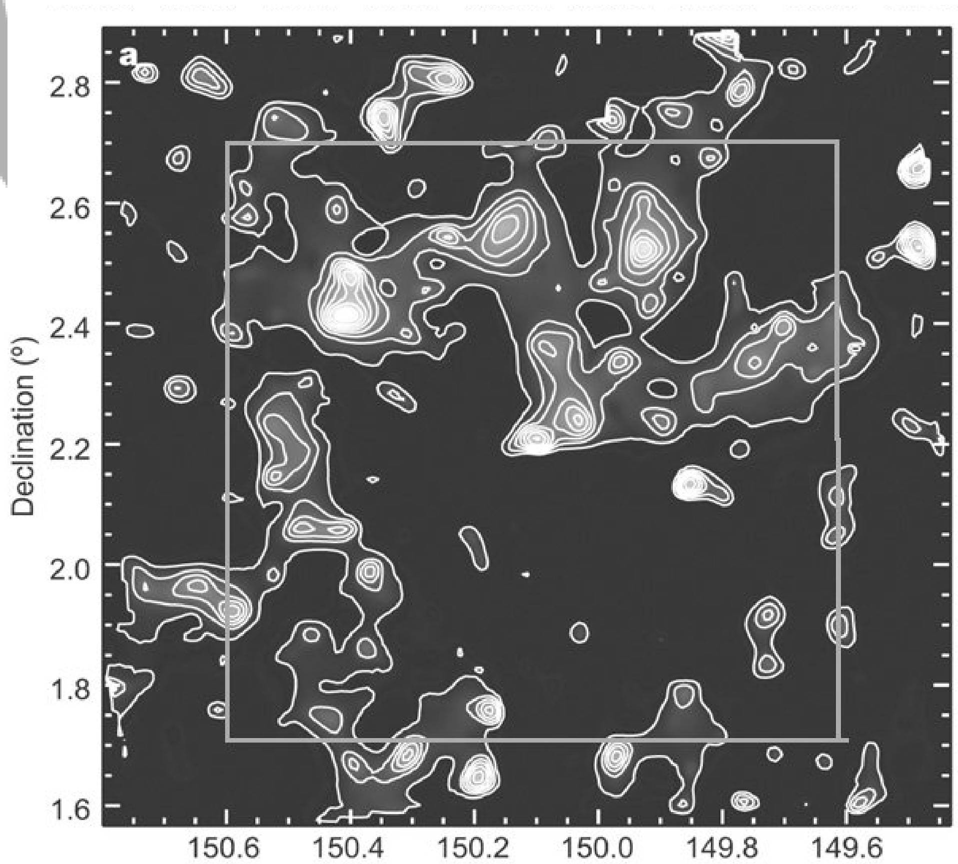


- 14 peaks as cluster candidates with snr >3.5
- 9 with obvious optical counterpart (bright E/S0 galaxies). 6 dubious (or dark clumps?)
- 5 out of 7 detection in D1 are confirmed by XMM-LSS
- All X-ray detected groups/clusters within $0.1<z<0.7$ are recovered
- Velocity dispersion as low as 460 km/s (*ie* Tx~ 1keV).

Comparison to Cosmos results

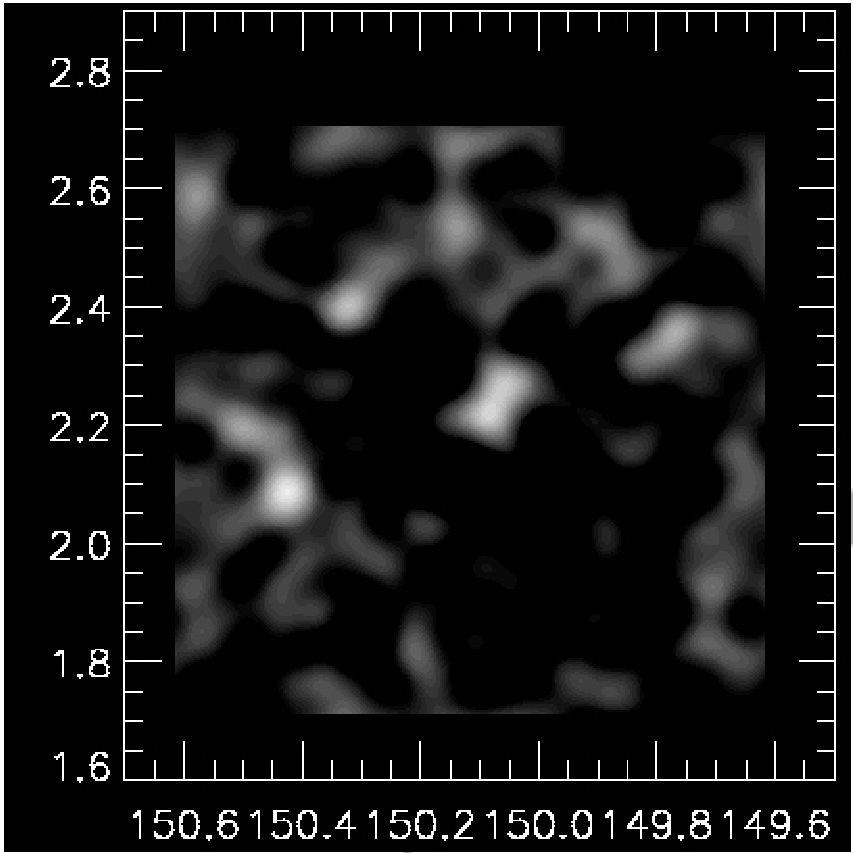
HST/COSMOS

Massey et al. 07



CFHTLS D2

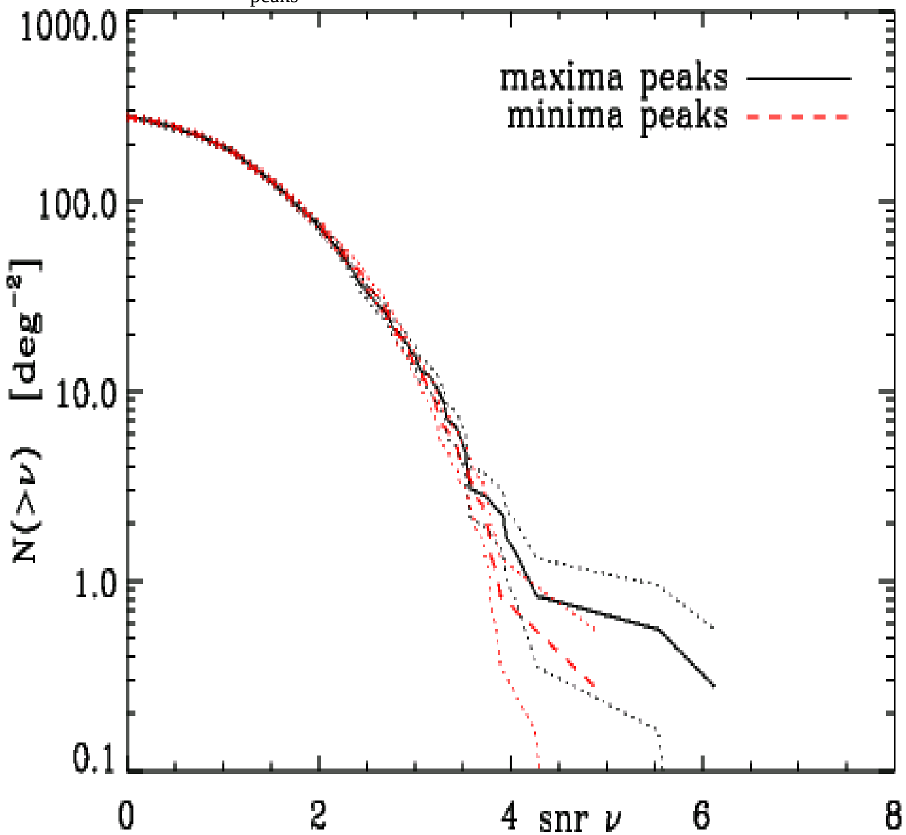
Gavazzi & Soucail 07

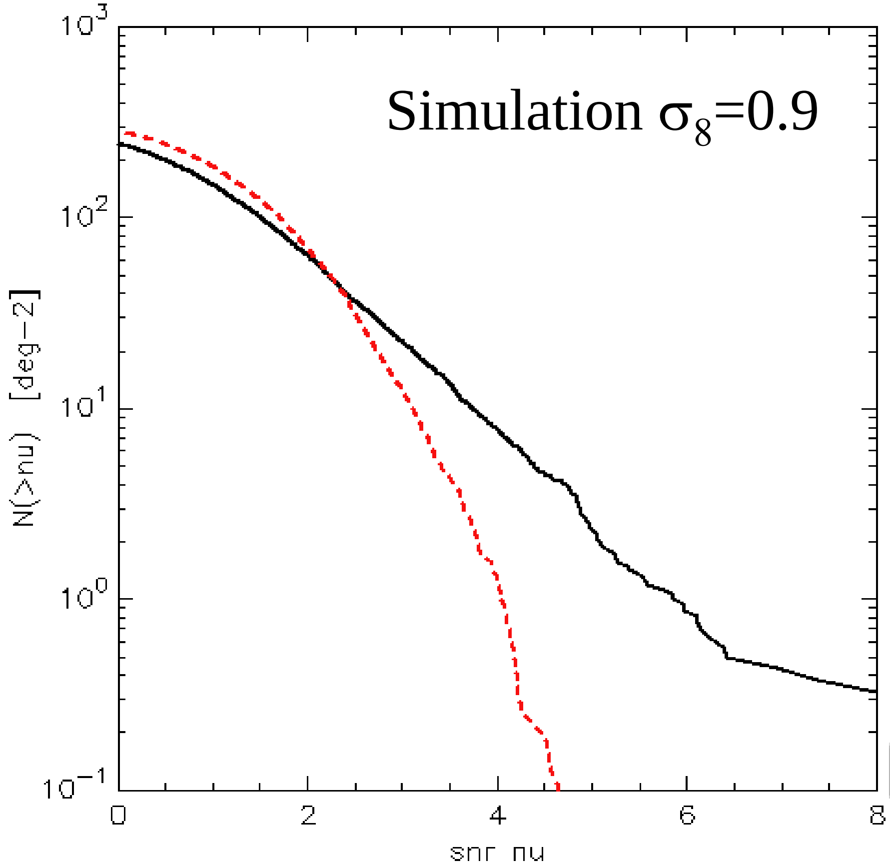


Look alike on scales > 2-3 arcmin (when greater shot noise is beaten down)

Peak statistics in CFHTLS deep

1. $N_{peaks}(>\nu)$ marginally asymmetric (non-gaussian)





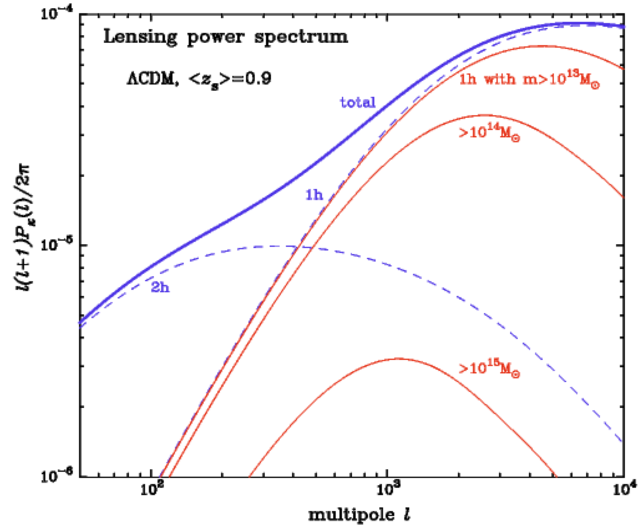
For a typical CFHTLS-wide survey ($i_{AB}<24$, $n_{bg}\sim12$ arcmin^{-2}, fov 200deg^2)

Snr ν	4	5	6	7	8
N(>ν)	240	70	25	12	<1
N(>ν) (convolved w/ noise)	650	213	87	26	<10

Weak lensing on top of a cluster survey

Given an optical survey underlying an X-rays survey, what does it already tells us on cosmology **by its own**?

Takada&Bridle07



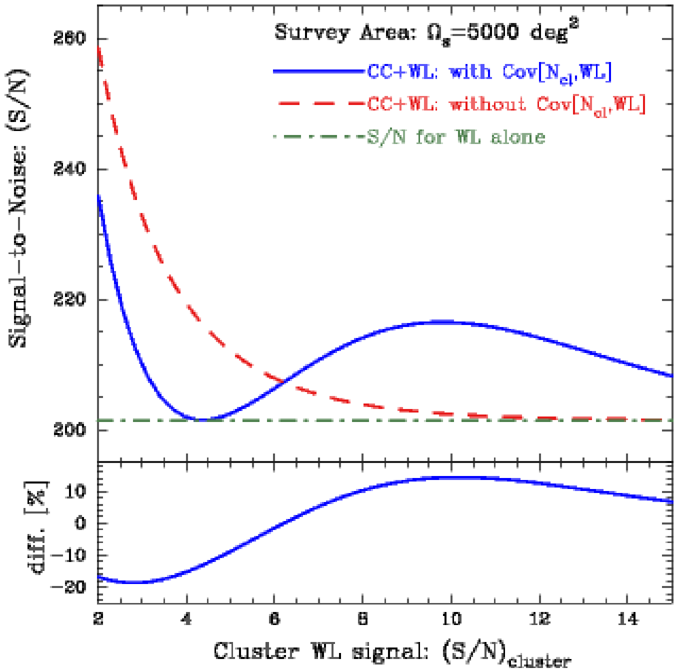
Already provides cosmic shear

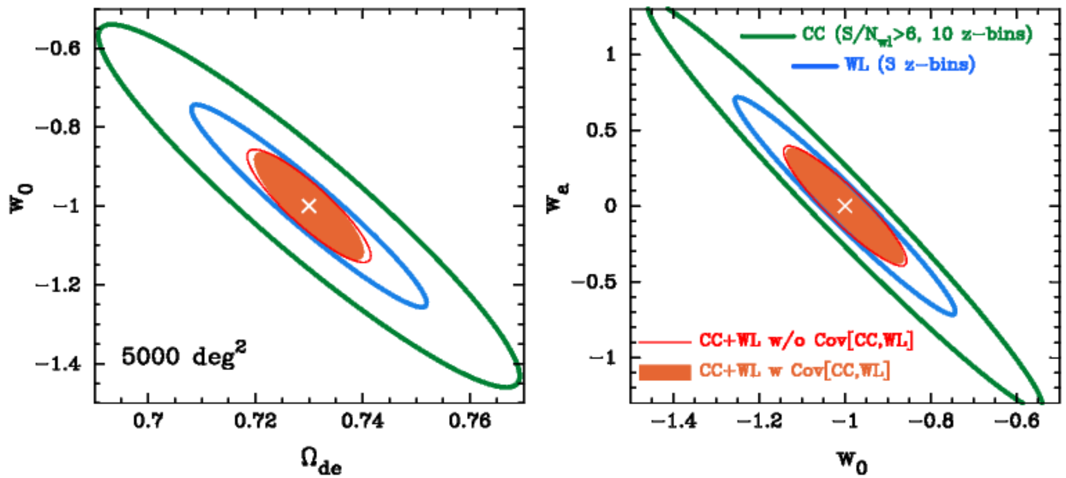
- Shear 2-point correlation function
- Statistics of convergence peaks
- Somewhat redundant?

$$\left(\frac{S}{N}\right)^2_{c+g} \equiv \sum_{i,j} D_i \left[(\boldsymbol{C}^{g+c})^{-1}\right]_{ij} D_j .$$

$$\boldsymbol{C}^{g+c} \equiv \begin{pmatrix} \boldsymbol{C}^{g} & \boldsymbol{C}^{gc} \\ \boldsymbol{C}^{gc} & \boldsymbol{C}^{c} \end{pmatrix}$$

$$\boldsymbol{D} = \left\{P_{(11)\kappa}(l_1), \ldots, P_{(n_s n_s)\kappa}(l_{\max}), N_{(1)}, \ldots, N_{(b)}\right\}$$

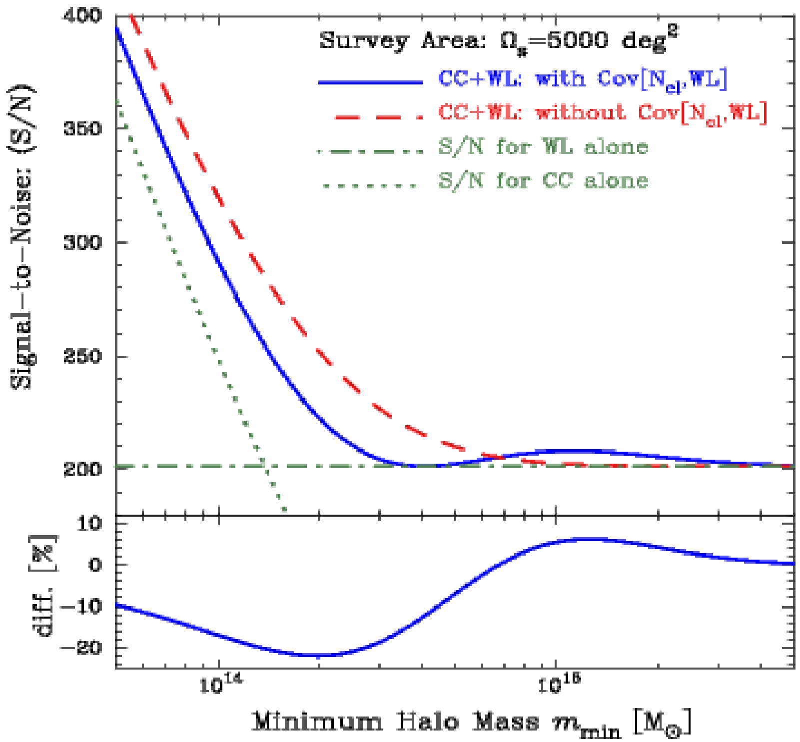




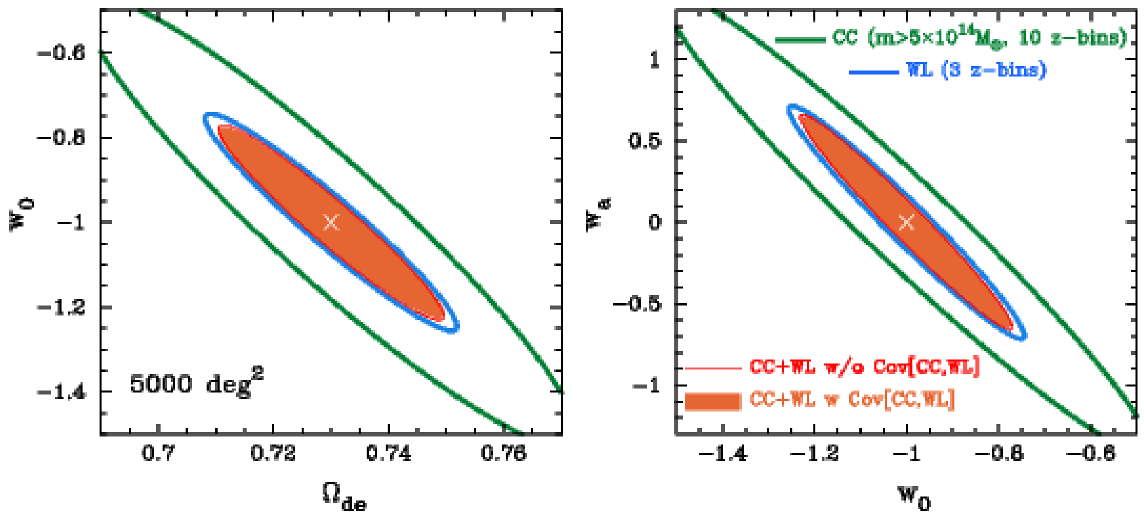
Some gain on Dark Energy EoS parameters

With cluster counts from X-rays ?

Takada&Bridle07



Simple mass selection M>5x10^{14} from z=0.05-1 !!!



Small gain on Dark Energy…

One needs to go much lower in mass (~10$^{13.5}$) for a significant gain over cosmic shear alone!

Also needs more realistic selection function

Conclusion

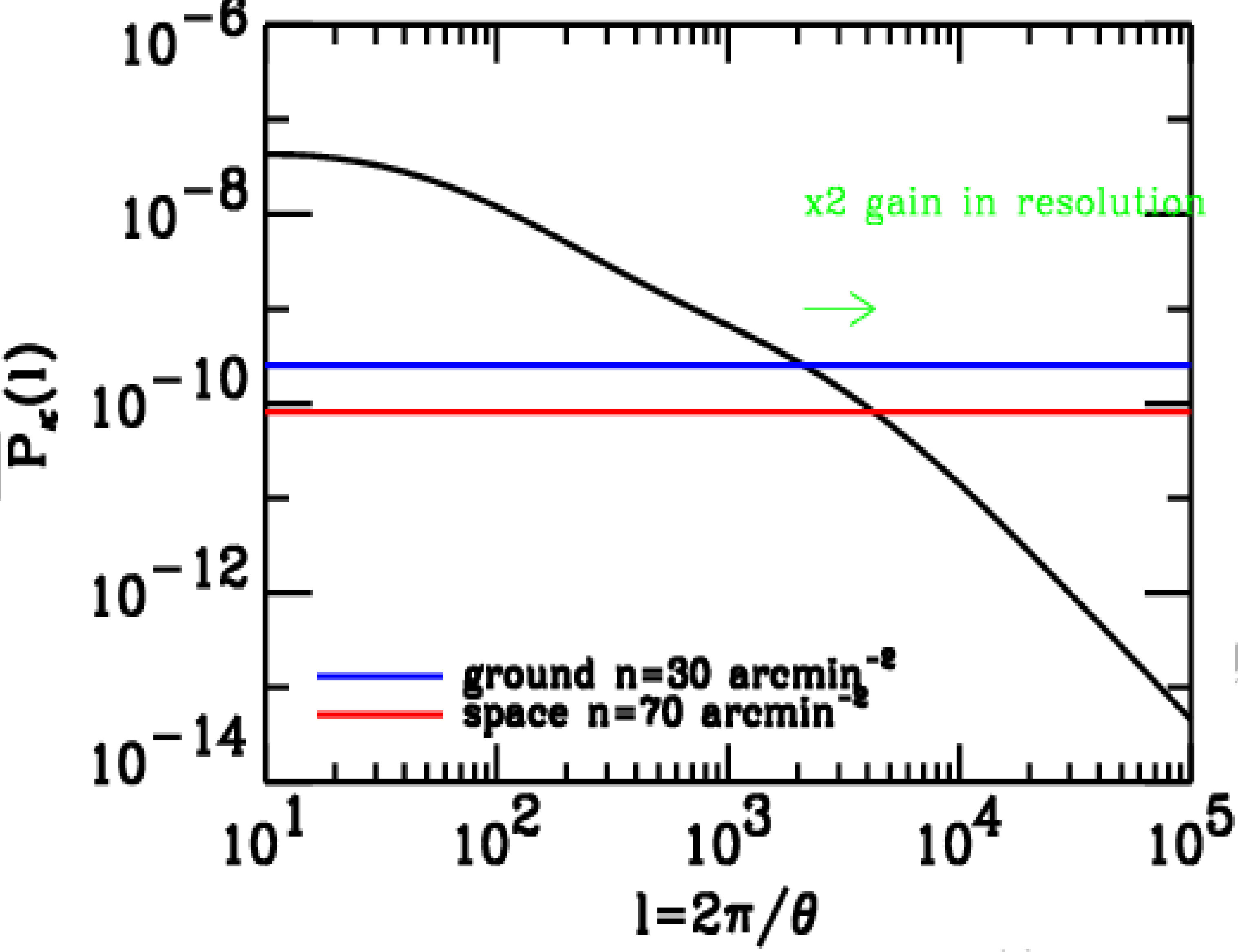
- Weak lensing is an efficient mass probe
  - 10%-40% statistical error per halo
  - Now 2-10% systematic error provided multiband photometry.
  - Will soon drop below the 1% calibration error. Required for upcoming A>150deg^2 deep surveys!

=> Need for optical follow-up of X-rays survey for WL masses.

- BUT, this optical WL survey, by its own, will catch most of the information relevant for cosmological parameters (2-point statistics + convergence peaks).
- Combined WL+X-rays+… still crucial for understanding systematics.

In this respect, we should go for a deep survey strategy

(deep 50 better than shallow 200).



x2 gain in resolution
ground n=30 arcmin^-2
space n=70 arcmin^-2
$P_\epsilon(l)$
$l=2\pi/\theta$