Weak lensing as a mass calibrator and/or a cluster finder

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1. Using Weak Lensing alone as a cluster finder.

Here we consider a standard ΛCDM model and use Takada & Bridle (2007) calculations to estimate the evolution of the cluster mass function as well as the sensitivity of a Weak Lensing (WL) cluster survey done by identifying high peaks in projected mass reconstructions. Predictions reflect a typical ground-based imaging survey of depth $R < 25$ comparable or slightly lower than the current depth of CFHTLS-deep ($i_{AB} = 26$) and slightly higher than CFHTLS-wide $i_{AB} = 24.$.

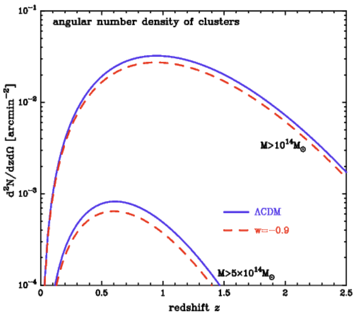

Figure 1. The average angular number density of halos with masses above a given threshold, per unit square arcminute and per unit redshift interval. The upper and lower pair of curves are for halos with $M/M_\odot \geqslant 10^{14}$ and 5×10^{14}, respectively. Increasing the dark energy equation state from $w = -1$ to $w = -0.9$ decreases the number density, as shown by the dashed curves.

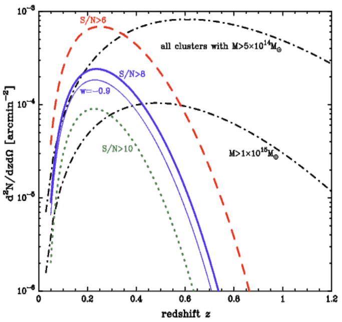

Figure 2. As in the previous plot, but shown here is the number density for the lensing-based cluster sample, where clusters having a lensing signal greater than a given detection threshold are selected in the sample as described around equation (5). The dashed, solid and dotted curves show the results for the detection thresholds $(S/N)_{\rm cluster} \geqslant 6, 8$ and 10, respectively. For comparison, the two dot-dashed curves show the number density for the mass-selected cluster sample with masses $M/M_\odot \geqslant 5, 10 \times 10^{14}$. Increasing w_0 from $w_0 = -1.0$ to $w_0 = -0.9$ leads to a decrease in the number density as shown by the thin-solid curve, compared to the bold-solid curve. The lensing selected number densities peak at a redshift $z \sim 0.25$, reflecting redshift dependence of the lensing efficiency function for source galaxies at $z_s \sim 1$.

Fig. 1.— From (Takada & Bridle 2007). *Left:* Predicted number of clusters for a ΛCDM cosmology. *Right:* number of peaks detected above a given SNR threshold. Those predictions are designed for relatively deep optical observations that translate in good lensing capabilities. For comparison, such a depth is more typical of a CFHTLS-deep survey. Quoted SNR values should be divided by a factor of ~ 1.4, in order to rescale predictions to the CFHTLS-wide depth. Note that only small changes in the redshift sensitivity would occur. In addition a small benefit would be obtained at $0.5 < z < 1$ by taking advantage of photometric redshifts to downweigh low redshift sources (Hennawi & Spergel 2005; Gavazzi & Soucail 2007).

2. Combining cluster counts and cosmic shear

When asking what would be the design of an X-rays survey given that an optical imaging survey suitable for WL already exists on the same region of the sky, it is worth keeping in mind

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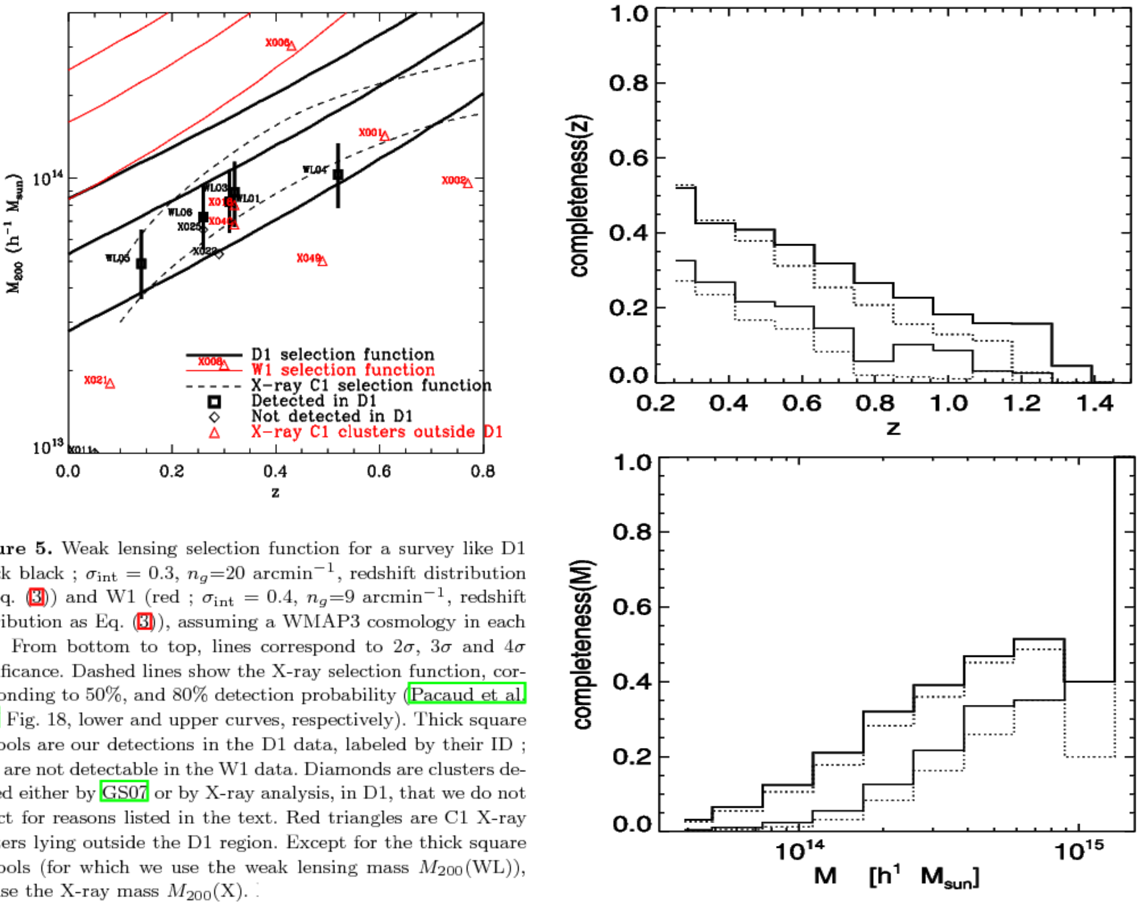

Figure 5. Weak lensing selection function for a survey like D1 (thick black ; $\sigma_{\rm int}$ = 0.3, n_g=20 arcmin^{-1}, redshift distribution as Eq. (3)) and W1 (red ; $\sigma_{\rm int}$ = 0.4, n_g=9 arcmin^{-1}, redshift distribution as Eq. (3)), assuming a WMAP3 cosmology in each case. From bottom to top, lines correspond to 2σ, 3σ and 4σ significance. Dashed lines show the X-ray selection function, corresponding to 50%, and 80% detection probability (Pacaud et al. 2007 Fig. 18, lower and upper curves, respectively). Thick square symbols are our detections in the D1 data, labeled by their ID ; they are not detectable in the W1 data. Diamonds are clusters detected either by GS07 or by X-ray analysis, in D1, that we do not detect for reasons listed in the text. Red triangles are C1 X-ray clusters lying outside the D1 region. Except for the thick square symbols (for which we use the weak lensing mass M_{200}(WL)), we use the X-ray mass M_{200}(X).

Fig. 2.— *Left:* From (Bergé et al. 2007). Comparison between XMM-LSS (X-rays) and weak lensing sensitivities in a deep (*e.g.* CFHTLS-deep, black) and wide (*e.g.* CFHTLS-wide, red) scenario. Overlaid are XMM-LSS sensitivities which are comparable to deep weak lensing cluster detections in the redshift range $0.1 \lesssim z \lesssim 0.5$. For a survey similar to CFHTLS-wide. Very similar results were also found in (Gavazzi & Soucail 2007). *Right:* Prediction of WL cluster detection completeness from N-body simulations by (Hennawi & Spergel 2005) as a function of redshift (top) and mass (bottom) for two SNR detection thresholds and depending on the availability (solid) or not (dotted) of photometric redshift for sources allowing tomography.

that cosmic shear measurement would also be available. Here again we use Takada & Bridle (2007) calculations on the combination of a cosmis shear power spectrum measurement and a cluster count experiment. The authors thoroughly take into account the covariance between those measurements if performed on the same region of the sky. They are based on a 5000 deg^2 survey but qualitatively similar conclusions could be drawn with a factor of $\sim$ 5 larger uncertainties. Fig.3 shows the gain in total SNR = $\vec{d}^T C^{-1} \vec{d}$, with $\vec{d} = [\vec{d}_{\rm wl}, \vec{d}_{\rm clust,count}]$ the data vector, made of one WL cosmic shear part, typically the convergence power spectrum split in 3 photometric source redshift bins for tomography $P_\kappa(\ell, z_j)$ at several wavenumbers ℓ and a cluster count part at $\sim$ 10 various redshifts and subject to a given selection function $\varphi(M, z)$. C is the covariance matrix of $\vec{d}$. An ideal case of a mass-selected cluster sample $\varphi(M, z) = \Theta(M - m{\rm min})$, independent of z, is shown on the left panel. We see that a cluster-count experiment improves the amount of information only if it is able to detect clusters down to low masses ($m_{\rm min} \sim 10^{14}{\rm M}_\odot$). Otherwise cosmic shear does almost all the job. On the other hand, a cluster finding method able to detect a few $\times 10^{13}{\rm M}_\odot$ clusters, combined with a cosmic shear power spectrum measurement, would double the information content in the survey.

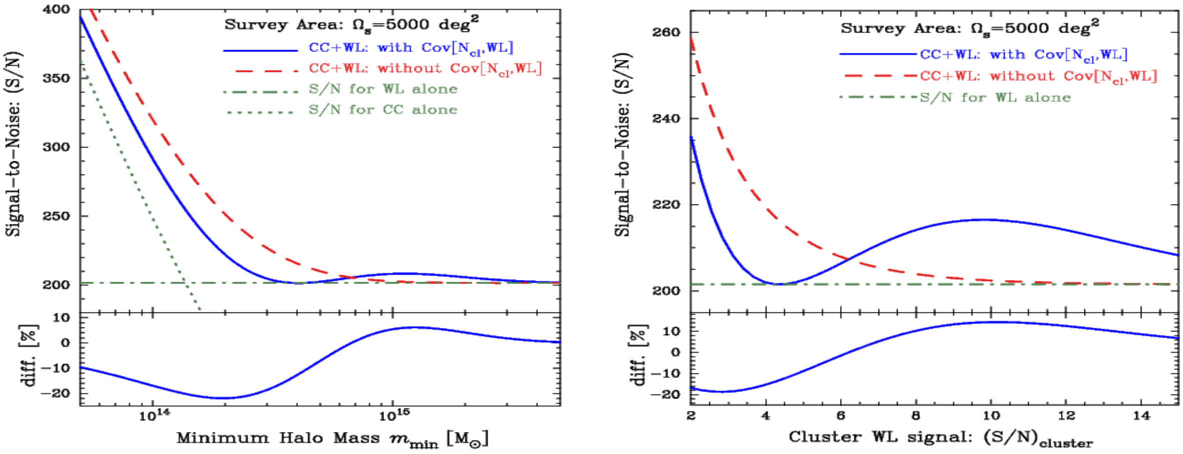

Fig. 3.— Improvement of overall SNR when combining WL cosmic shear and a cluster count experiment from (Takada & Bridle 2007). *Left:* The cluster count experiment achieves a mass-limited sample down to a limiting mass $m_{\rm min}$. For small values of $m_{\rm min}$ there is a clear benefit of combining WL and cluster counts. *Right:* For a more practical scenario of a cluster selection function typical of a WL cluster detection analysis, instead of a limiting mass, the gain in SNR is shown as a function of the threshold in convergence peak amplitude of the survey. Here the benefit is relatively low. In both cases, the dashed and solid lines distinguish the cases when covariance between cluster counts and lensing signal is neglected or properly taken into account.

For a selection function $\varphi(M, z)$ typical of lensing-based cluster counts (again identified as peaks in mass maps) results are shown on the right panel of Fig.3. Here the benefit of combining cosmis shear and convergence peaks statistics is modest (of order 10-20% even when going to low threshold amplitude peaks). On the other hand, a very interesting property of WL peak counts is that statistics are not sensitive to systematic multiplicative errors on the calibration of shape measurements whereas power spectrum measurements are. Therefore, a combination of both methods is still worthwhile.

No strong dependency is to be expected on the geometry of such an imaging WL-motivated survey. On large scales, cosmic variance would be slightly less of a problem when considering a long stripe as compared to a square survey. Cluster counts improving the sensitivity on small non-linear scales, a combined cosmic shear – cluster count analysis would take the most of an elongated shape survey.

3. Prospects of using WL to calibrate masses

X-rays cluster detections cannot be considered as a pure mass selection. In the optimistic case of a flux selection, this can be quite easily cast into a redshift dependent luminosity-selected sample. Then, given the important scatter in the X-rays L-T relation, that interesting property is partially lost. In addition, another important ingredient for reconstructing the halo mass function from halo temperature counts, is the M-T relation. Although it is thought to be much less scattered than M-L, its calibration is poorly known (especially at high redshift) and little is known about the intrinsic dispersion.

In the local universe ($z < 0.15$), masses are probably more efficiently inferred from X-rays itself and/or velocity dispersions of galaxies. On the other hand, in the range $0.15 \lesssim z \lesssim 0.7$, weak lensing mass estimates are available on individual clusters. Typically, at redshift $z = 0.3$, for observations achieving a depth intermediate between CFHTLS-deep and CFHTLS-wide and taking into account the limiting source of uncertainties that come from intervening large scale structure along the line of sight, Hoekstra (2003) estimated that a 30%, (resp. 20%, 15%) error can be achieved on a single cluster of mass $M_{200} = 5$ (resp. 10, 20) $\times 10^{14} \mathrm{M}_\odot$.

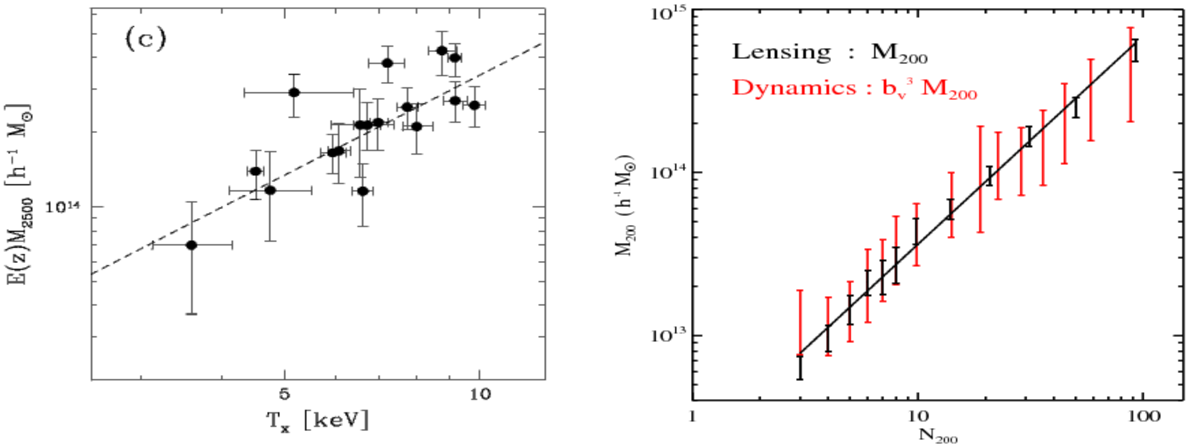

Fig. 4.— *Left:* From (Hoekstra 2007) WL mass measurement vs X-rays temperature for 20 massive clusters at $z \sim 0.1 - 0.4$, leading to mass-temperature relation: $M/M_{2500} = (1.4 \pm 0.2) \left(\frac{T}{5\,\mathrm{keV}}\right)^{1.34 \pm 0.29} 10^{14}$ at $z = 0$ consistent with self-similarity. *Right:* From (Johnston et al. 2007) comparison of WL and kinematical mass estimates in the MaxBCG cluster sample as a function of *binned* cluster richness (at $z \sim 0.15$).

Among the latest attempts of calibrating M-T with WL, one can mention Hoekstra (2007) who used 20 massive clusters and achieved a $\sim 15\%$ estimate of the M-T normalisation. It is important to keep in mind that the accuracy of present-day WL measurement is limited by a few percent systematic error on the shear calibration which, added to another few percent error on mass calibration due to uncertainties in the redshift distribution of source, translates into a $5 - 10\%$ systematic error on M-T. This is still below statistical errors but would soon be the main limitation. However a WL analysis of 13823 *stacked* optically-selected clusters at $z \sim 0.1$ in the SDSS survey, allowed Johnston et al. (2007) to measure the scaling relation between mass M_{200} and cluster richness N_{200}. They found $M_{200}/\mathrm{M}_\odot = (8.8 \pm 0.4_{stat} \pm 1.1_{sys}) \times 10^{13} \left(\frac{N_{200}}{20}\right)^{1.28 \pm 0.04}$. we see that, here, systematic errors dominate at the 12% level. On the other hand the right panel of Fig. 4 shows the comparion between $M_{200} - N_{200}$ relations as inferred from either WL or kinematics of cluster galaxies. If galaxies are not biased dynamical tracers, the agreement between mass estimates differ by less than $\sim 10\%$.

With a 200 deg^2 X-rays survey, one could detect about 1000 clusters of galaxies in the range $0.15 \lesssim z \lesssim 0.6$. Assuming that WL data of depth comparable to that of Hoekstra (2007) study are available, and that errors on temperature are much smaller for a single cluster, one could achieve a 2% accuracity on the normalisation of $M - T$. Therefore, progress has to be made before all systematics could be put below that limit.

4. Conclusions

A combination of a 200 deg^2 X-rays survey with an already present weak lensing experiment could be conceived in two ways. i) coupling a cosmic shear measurement with cluster counts would be valuable (significanty better than cosmic-shear alone) provided one can probe halos done to low masses ($\sim 10^{14}\mathrm{M}_\odot$) and relatively high redshifts. This is not the case for a WL-based cluster detection experiment. Could this be achieved with X-rays? Here additional errors on temperature or selection function estimates were neglected. ii) Assuming they are under control we are left with the problem of calibrating the M-T relation with WL. Of order 10% systematic uncertainties on mass are still to be expected with WL due to systematics in shape measurements and lack of knowledge of the redshift distribution of the faintest sources. Combining SZ, WL and X-rays mass estimates would give some hints/control on such biases. In this respect, it may be preferable to devote some of the survey time to achieve very deep control observations (about 50 deg^2), large enough for encompassing $\sim$ 200 clusters for wich rich photometric redshifts, deep and good seeing imaging would yield precise WL masses, as well as X-rays temperatures would be *just* below the level of systematics.

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