A Cluster Survey in Weak Lensing

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August 31, 1999

We propose a weak lensing survey over blank fields to construct a mass–selected galaxy cluster catalog, with the primary objective of constraining the mass function of collapsed structures and the density parameter of the universe, \( \Omega \).

Galaxy clusters may be employed in a variety of ways to gain understanding of the cosmological model describing our universe and of the physics responsible for structure formation. In standard models, galaxies and large-scale structure are formed from the collapse of initially small density perturbations that grow under the influence of gravity. Gaussian models assume that on any given scale these perturbations follow a normal distribution with a variance related to the power spectrum, which is then the unique characterization of the perturbations. Due to this Gaussian nature, an assumption consistent with present data, the local cluster abundance is an extremely sensitive indicator of the power spectrum, its amplitude and shape (e.g., Bartlett 1997). The local power spectrum thusly determined, the evolution of the cluster abundance in redshift can then be used to constrain the density parameter of the universe, \( \Omega_0 \), as pointed out by Oukbir & Blanchard (1997). This is possible because it is \( \Omega_0 \) that governs the growth of density perturbations, and hence of the power spectrum; and the constraint is quite powerful, once again due to the Gaussian nature of the perturbations.

These considerations represent some of the driving science behind many galaxy cluster surveys, in the optical, X-ray and radio. To actually use such cluster catalogs, which are constructed according to the selection criteria applicable to each type of observation, one must translate the observables, e.g., an X-ray flux, into the key theoretical quantities, cluster virial mass and redshift. Depending on the exact nature of the observations, this opens the door to a variety of modeling uncertainties. Here we immediately see the attractiveness of cluster surveys based on weak lensing: they directly probe the
mass distribution and select clusters according to their mass (the remaining caveat being that it is actually the projected mass that is ‘observed’). It is for this reason that galaxy cluster surveys based on weak lensing are very promising for cosmology. This is our motivation for proposing such a survey with the MEGACAM instrument.

A weak lensing survey for clusters, which is to say cluster selection based solely on a lensing signature, requires wide-field imaging with excellent seeing and image quality, the very goals of the MEGACAM project. One of the rather interesting issues that must be tackled in order to understand the output of such a survey is the question of cluster detection – it is not a standard flux that one measures, but rather a two-dimensional shear field, and so there are several ways to approach the problem. For the following simple estimation of the performance of a MEGACAM survey, we make the assumption that all clusters may be described by an isothermal mass density profile. Then, all lensing measurements depend on a single quantity, the Einstein radius, which is a function of cluster mass, redshift and the redshift of the lensed, background galaxies: \( \Theta_E(M, z, z_s) \). The optimal detection method yet to be found, we will quote our results in terms of this radius.

Numerical simulations attest to the fact that the cluster abundance as a function of mass and redshift is adequately modeled by the Press–Schechter mass function (Press & Schechter 1977). Using the functional form of \( \Theta_E(M, z, z_s) \), and for an assumed \( z_s \), we may translate a given, observational limit on \( \Theta_E \) into a detectable mass as a function of redshift, and then use this to integrate the mass function to obtain the cluster counts at this limiting Einstein radius. Figure 1 shows the resulting limiting detection mass as a function of redshift, while Figures 2 and 3 present the cluster counts and redshift distributions, respectively. The calculations have been performed using power-law power spectra, a fairly reasonable approximation over the mass range under consideration, and are all normalized to the present day abundance of X-ray clusters, as indicated by the local temperature function (Oukbir et al. 1997).

We have estimated the minimum detectable Einstein radius for a MEGACAM survey as follows: from previous experience, one has been able to detect clusters in weak shear down to velocity dispersion of \( \sim 500 \) km/s, which, for clusters at low redshift and for large values of \( z_s \), corresponds to \( \Theta_E \sim 5 - 10 \) arcsecs. We take this value for the presentation of what a MEGACAM survey may be able to achieve. There is a slight uncertainty due to the unknown redshift distribution of the background, lensed galaxies. A reasonable limiting magnitude for a weak lensing survey would be \( B \sim 25 - 26 \). It now appears that the average redshift of such galaxies is close to unity, and it is very unlikely that any weak lensing survey performed with MEGACAM will reach galaxies beyond \( z_s \sim 2 \); thus, in our figures we plot pairs of curves for
Figure 1: Detectable mass as a function of redshift for two different values of limiting Einstein radius in a critical model, as indicated. The lower curve in each pair is for the background, source galaxies at redshift $z_s = 2$, while the upper curve corresponds to $z_s = 1$. A crude estimate indicates that a MEGACAM survey could reach $\theta_E \sim 5 - 10$ arcsecs limiting detection (see text).
Figure 2: The integrated cluster counts $N(\geq \theta_E)$ for two cosmological models. The models have been normalized to the present day abundance of X-ray clusters (see text for details). The upper curve in each pair is for background, lensed galaxies at $z_s = 2$, while the lower curve in each case corresponds $z_s = 1$. 
these two cases.

What we learn from the Figures is that a MEGACAM survey should find anywhere from several to several tens of clusters per square degree, depending on the exact model. These objects include low-mass clusters, with masses approaching $\sim 10^{14}$ solar masses, and this limit is almost independent of redshift if the background sources are indeed at redshifts $z_s > 1$. Most interestingly is that the expected difference in redshift distributions between critical and open models clearly appears: once the redshift distribution of the background galaxies is constrained, the cluster distribution may be used in turn to constrain the density parameter, $\Omega$, as mentioned above. The great advantage in this case of a weak shear survey is that there will remain no possible uncertainties due to cluster gas evolution, which must be accounted for in other types of observations, such as in the X-ray. The critical point is, to once again emphasize, that with a weak shear survey one selects clusters on (projected) mass, a quantity much more directly related to the mass function than other observables.

Some of the important questions not yet treated in this response to the call for ideas concern possible projection effects and the optimization of the survey. As already mentioned, the weak shear is actually sensitive to mass projected along the entire line-of-sight, leading possibly to a sort of confusion, the implications of which should be examined more closely. How best to perform the survey is in practice a question of depth versus solid angle. To properly answer this question requires a better understanding of the influence on the limiting detectable $\Theta_E$ of different background galaxy selection techniques, e.g., fainter magnitude limits or color cuts to impose photometric redshift constraints. Further studies would help to specify the best bands and magnitude limits. Roughly speaking, given the numbers from the integrated counts in Figure 2, it seems likely that a survey area of between 10 to 100 square degrees will be required, to obtain at least several tens of objects. Notice that the issue is not decoupled from the underlying model and that an open model could produce many more than this (in this context, we remark that inclusion of a cosmological constant should lead to counts more similar to the open model than to the critical one, because the mass function evolution is more similar to the open case). In this light, it is also worth mentioning that such a weak lensing cluster survey could easily be included in other blank-field surveys, in which case a more general optimization strategy would apply.

It is clear that MEGACAM is well suited for such project. The Toulouse group has well developed expertise in both lensing observations and cluster modeling. Modeling will be developed even further, addressing the questions posed above, with the potential arrival of G. Kruse as a postdoctoral fel-
Figure 3: Redshift distribution of clusters detected with $\Theta_E = 5$ arcsecs for the same two cosmological models as in Figure 2. The upper curve in each pair is for source galaxies at $z_s = 2$, while the lower curve corresponds to $z_s = 1$. Note the clear difference in the distributions for the two cosmologies, the low density model having many more objects at high redshift.
low, who’s thesis work with P. Schneider focussed on simulations of cluster detection via weak lensing (Schneider et al. 1998; Kruse & Schneider 1998).

References


