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# Weak Lensing halo detection by Euclid

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**Abstract.** It has been widely shown that weak lensing surveys can be used for detecting dark matter concentrations. Here we use the aperture mass method to predict the detectability and number density of cluster-sized halos from a weak lensing survey as expected from the future space-based Euclid mission. The method bases on the image distortion of background galaxies caused by the gravitational potential of intervening dark matter distribution. Preliminary results on the expected number density of halos with a given signal-to-noise ratio are presented for different cosmologies, showing how halo number counts can be a useful probe to discriminate among different cosmological models.

**Key words.** Gravitational lensing: weak – Methods: analytical – Galaxies: clusters: individual – Cosmology: dark matter – Cosmology: dark energy

## 1. Introduction

Galaxy clusters are the most massive bound and virialized objects in the Universe. Their comoving number density as function of mass and redshift is a powerful comological probe of the growth of structures.
The gravitational fields of these objects deflect light-rays traveling near them, according with the general relativity theory. This effect, called gravitational lensing, causes a coherent distortion of the shape of the background galaxies, which appears stretched tangentially around the cluster. By measuring this distortion (*shear*), it is possible to reconstruct the projected mass distribution of the intervening dark matter, without any assumption about its composition or dynamical behavior (Kaiser & Squires 1993), since weak lensing is only sensitive to the amount of mass along the line of sight.
For this own property, weak lensing technique can be used to perform a blind search of unknown mass concentrations on wide-field surveys, by searching signifcant signal peaks in the shear maps. However, this requires high-quality data, with well controlled, stable point-spread function, joined with reliable photometric redshift information for removal of intrinsic shape alignments of galaxies and to disentagle background and foreground sources.
Actually, several weak lensing optimized surveys with ground- (KIDS, PanSTARRS, DES, LSST) and space-based (Euclid, JDEM/WFIRST) telescopes are proposed and planned.
Euclid (PI: Refregier, Cimatti) is an all sky space mission, currently passed the ESA

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Cosmic Visions Definition Phase. If finally approved, it is expected to flight in 2018 (see Laureijs et al. 2010; Laureijs 2009 for details). Its primary goal is to constrain the cosmological parameters with high accuracy using mainly two independent cosmological probes: weak gravitational lensing and Baryonic Acoustic Oscillations. For this purpose, Euclid will measure the shape and spectra of galaxies over the entire extragalactic sky (20000 $deg^2$), out to redshift 2, thus covering the period over which dark energy accelerated the universe expansion. The baseline mission is based on a 1.2m telescope equipped with a wide-field (0.5 $deg^2$) imager in the Visible and a NIR instrument for imaging and spectroscopy. The visible channel is used to measure the shapes of galaxies for weak lensing. For all galaxies, photometric redshifts are obtained from the broad-band visible and NIR measurements and complementary ground-based observations. This will allow Euclid to detect hundreds of thousands of galaxy groups and clusters over a wide range of masses ($10^8 \div 10^{15} M_\odot$) and redshifts (Refregier et al. 2010).

## 2. Method

We use the aperture mass $M_{ap}$-statistics, introduced by Schneider (1996), to predict the detectability and the number density of cluster-sized halos from a Euclid-like weak lensing survey. $M_{ap}$ is defined as the spatially filtered projected mass distribution, $\kappa$ (or convergence), inside a circular aperture of angular radius $\theta$:

$$M_{ap} = \int d^2\theta \int_{z_l}^{\infty} dz_s \kappa(\theta, z_l, z_s) U(\theta) p(z_s) \quad (1)$$

where U is a compensated filter, $z_l$ and $z_s$ are the lens and source redshifts, respectively, and $p(z_s)$ is the normalized redshift distribution of the source galaxies.

The variance of $M_{ap}$ can be computed analytically as:

$$\sigma_c^2(\theta_0) = \frac{\pi\sigma_\epsilon^2}{n} \int_0^{\theta_0} d\theta\theta Q^2(\theta) \quad (2)$$

where $\sigma_\epsilon$ is the ellipticity dispersion of sources, $n$ is the average number density of galaxies inside the aperture and $Q(\theta)$ is the filter function. The signal-to-noise ratio ($snr$) associated to each halo detection is then $snr = M_{ap}/\sigma_c$.

We assume as halo model the universal density profile found by Navarro et al. (1996) and the relation between the concentration and virial mass proposed by Bullock et al. (2001). Moreover, we use as filter function $Q(\theta)$ the one proposed by Schirmer et al. (2004), that maximises the $snr$ for NFW mass profiles since it mimics their radial shear profile. The parameters values used for this function were empirically found in (Hetterscheidt et al. 2005).

The galaxy redshift distribution is parametrized as in Bergé, Amara & Réfrégier (2010):

$$p(z) = \frac{\beta}{\Gamma[(1+\alpha)/\beta]} \left(\frac{z}{z_0}\right)^{\alpha} exp\left[-\left(\frac{z}{z_0}\right)^{\beta}\right] \quad (3)$$

($\alpha = 2, \beta = 1.5, z_0 \sim z_m/1.412$). We assume a median redshift $z_m \sim 1$, a galaxy number density $n \sim 40$ gal/$arcmin^2$ and an ellipticity dispersion $\sigma_\epsilon \sim 0.35$ as expected for the future Euclid survey (Bergé, Amara & Réfrégier 2010; Refregier et al. 2010).

WMAP7 values are used for cosmological parameters (Komatsu et al. 2010).

## 3. Results

Results are obtained for two different cosmologies: a standard $\Lambda CDM$ model and dynamical dark energy model, initially introduced to ease the fine tuning and the coincidence problems and motivated in the contest of the particle physics, where dark energy arises from an evolving scalar field $\phi$, with a SUGRA self-interacting potential (Brax et al. 2000):

$$V(\phi) = \frac{\Lambda^{4+\alpha}}{\phi^\alpha} e^{4\pi G\phi^2}$$

admitting tracker solutions for any $\alpha > 0$ and yelding a varying state parameter $w(z) = P_\phi/\rho_\phi$ ($P_\phi$ and $\rho_\phi$ being the pressure and the energy density of the DE scalar field). For any choice of the energy scale $\Lambda$ and the parameter $\alpha$ the above potential yield a fixed $\Omega_{DE}$. Here we prefer to fix $\Omega_{DE}$ and $\Lambda = 1GeV$; the related $\alpha$

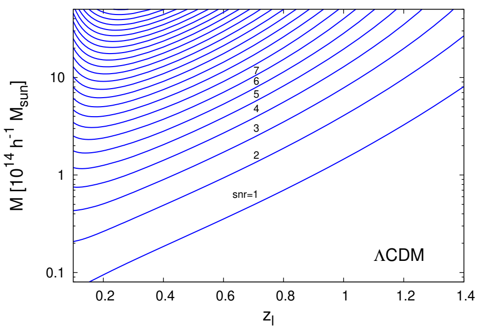


**Fig. 1.** The detectability of cluster-sized halos by $M_{ap}$-statistics is plotted as function of mass (in $10^{14}h^{-1}M_{\odot}$) and redshift of the cluster. The contour lines are the *snr*.

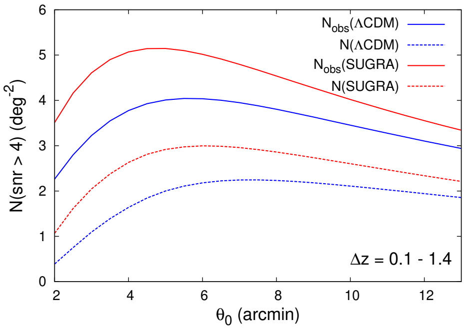


**Fig. 2.** The intrinsic and observable halo number density $N(> snr_t)$ are shown as function of the aperture filter radius in the redshift range $z = 0.1 \div 1.4$ for two different cosmologies: a $\Lambda CDM$ and a SUGRA model.

value is then suitably fixed.

In Figure 1 we show the weak lensing detectability of cluster-sized halos expected from Euclid for a ΛCDM cosmology (only slightly differences occur in the SUGRA case): the expected *snr* of cluster detection by means of $M_{ap}$-statistics is plotted as function of mass (in $10^{14}h^{-1}M_{\odot}$) and redshift of the cluster. By using a Schirmer filter function, masses of $1 \times 10^{14}h^{-1}M_{\odot}$ should be detectable at *snr* greater than 4 for redshifts lower than 0.4.

A fixed filter radius $\theta_0 = 6$ *arcmin* is used to compute the aperture mass: it seems to be a good choice for maximising the number of detectable halos for the whole redshift bin $z \in [0.1 \div 1.4]$ and the two cosmologies considered, as shown in Figure 2.

Then we calculate the number density of halos $N(> snr_t)$ above a given *snr*-threshold:

$$N(> snr_t) = \int dV_p(1 + z_l)^3 \int_{M_t}^{\infty} dMN_{halo}(M, z_l) \quad (4)$$

in order to consider only significant peaks in the aperture mass map. We chose 4 as $snr_t$, since for lower values of *snr* there is a strong contamination of spurious peaks due to intrinsically aligned Large Scale Structures (as shown in Maturi et al. 2010). The $snr_t$ value corresponds to a mass threshold value $M_t$, since the aperture mass is a monotonically increasing function of halo mass for constant values of $z_l$ and filter radius.

The comoving number density of halos $N_{halo}$ is calculated using the Press & Schechter (1974) formalism.

Taking into account only the noise due to the intrinsic ellipticity distribution of background sources, we then obtain the observable halo number density $N_{obs}(> snr_t)$ by convolving the intrinsic number density $N(> snr_t)$ by $p(\Delta M_{ap})$, where $p$ is the distribution of the difference between the real value and the measured value of $M_{ap}$. Following Kruse & Schneider (1999) we assume $p$ to be Gaussian:

$$p(\Delta M_{ap}) = \frac{1}{\sqrt{2\pi}\sigma_c} exp\left[-\frac{\Delta M_{ap}^2}{2\sigma_c^2}\right] \quad (5)$$

This noise source causes an increasing of the halo number counts we could detect (as shown in Fig.2) giving us their upper limits (discussion about this approximation can be found in Hetterscheidt et al. 2005 and Kruse & Schneider 1999).

In Figure 2, the intrinsic and observable halo number density $N(> snr_t)$ are shown as function of the aperture filter radius in the redshift range $z = 0.1 \div 1.4$.

In Figure 3 we compare the observable halo number density $N_{obs}$ in different redshift bins ($\Delta z = 0.1$) for both cosmologies. The expected number of halos is computed for $snr_t = 4$ and $snr_t = 6$. In both cases, a lower $N_{obs}$ is expected for the ΛCDM model in almost the whole redshift range considered; the difference between the two models is higher at low red-

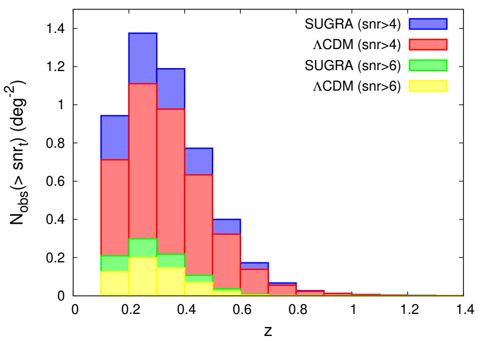


**Fig. 3.** The observable halo number density $N_{obs}$ in different redshift bins ($\Delta z = 0.1$) for two cosmologies: a $\Lambda CDM$ and a SUGRA model.

shift ($z \leq 1$) where the different volume factor play an important role.

In the computation of the number counts the statistical error is driven by Poisson noise. For such a wide survey as Euclid (20000 $deg^2$) this error is tiny thanks to the high statistics of clusters available, allowing to disentagle even small differences in the halo mass function of different cosmological models.

In this analysis we did not take into account the noise due to the Large Scale Structure, which could affect $N_{obs}$. By considering only peaks with $snr > 4$ should however reduce the contamination of spurious detections due to such a noise as explained in Maturi et al. 2010. This point is currently under investigation.

## 4. Conclusions

We have shown preliminary results on the expected weak lensing halo number counts from a Euclid-like survey. The aperture mass $M_{ap}$-statistics was used to predict the detectability of cluster-sized halos with a signal-to-noise ratio greater than 4 for two different cosmologies: a standard $\Lambda CDM$ model and a dynamical dark energy model (SUGRA). These results show how halos number counts can be a useful probe to discriminate among different cosmological models.

The present analysis is going to be improved (Mainini et al. 2010) by considering the effect of the Large Scale Structures on the signal-to-noise ratio computation. Further, we plan to extend the analysis to a wider class of cosmologies, e.g. modified gravity models.

This work is in preparation of the Euclid mission aimed to map the geometry and the evolution of dark matter universe with unprecedented precision.

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