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Weak lensing study of low mass groups: implications for Ω_m

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Abstract.
We report on the first measurement of the average mass and mass-to-light ratio of galaxy groups by analysing the weak lensing signal induced by these systems. The Canadian Network for Observational Cosmology Field Galaxy Redshift Survey (CNOC2) allows the identification of a large number of groups at intermediate redshifts. For our analysis we use a sample of 50 groups which are selected on the basis of a careful dynamical analysis of group candidates. We detect a signal at the 99% confidence limit. The best fit singular isothermal sphere model yields an Einstein radius $r_E = 0\farcs72 \pm 0\farcs29$. This corresponds to a velocity dispersion of $\langle\sigma^2\rangle^{1/2} = 274^{+48}_{-59}$ km/s, which is in good agreement with the dynamical estimate. Under the assumption that the light traces the mass, we find an average mass-to-light ratio of $191 \pm 83\ h$ in the restframe B band. Unlike dynamical estimates, this result is insensitive to problems associated with determining group membership. We use the observed mass-to-light ratio to estimate the matter density of the universe, for which we find $\Omega_m = 0.19 \pm 0.10$ ($\Omega_\Lambda = 0$), in good agreement with other recent estimates. For a closed universe ($\Omega_m + \Omega_\Lambda = 1$), we obtain $\Omega_m = 0.13 \pm 0.07$.

1. Introduction

Galaxy groups, like the Local Group, are the most common structures in the universe. Despite being numerous, groups are hard to identify because the contrast with the smooth background of galaxies is low, and their galaxy properties are that of the field. To date most systems have been found using large redshift surveys or X-ray observations.

Measuring the mass locked up in these systems is important, but difficult (cf. Gott & Turner 1977). Nolthenius & White (1987) showed that the masses inferred from redshift surveys depend on the survey parameters, the group selection procedure, and the way galaxies cluster. Consequently, an independent measure of the group mass is needed. Here we study the groups by their weak lensing effect on the shapes of the images of the faint background galaxies.

The weak lensing signal is maximal if the lenses are at intermediate redshifts, but even then, given the low masses of these systems, the expected signals are too low to yield significant detections for individual groups. Thus we have to

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study the ensemble averaged signal of a large number of groups at intermediate redshifts.

The groups identified in the Canadian Network for Observational Cosmology Field Galaxy Redshift Survey (CNOC2) (e.g. Lin et al. 1999; Yee et al. 2000; Carlberg et al. 2000) are ideal targets for our study. To study the population of field galaxies at intermediate redshifts ($z = 0.15 - 0.55$) CNOC2 targeted four widely separated patches on the sky, for which multi-colour data were obtained, as well as spectroscopic redshifts for $\sim$ 5000 galaxies brighter than $R_C = 21.5$. The survey allows the identification of a large number of groups at intermediate redshifts (Carlberg et al. 2000).

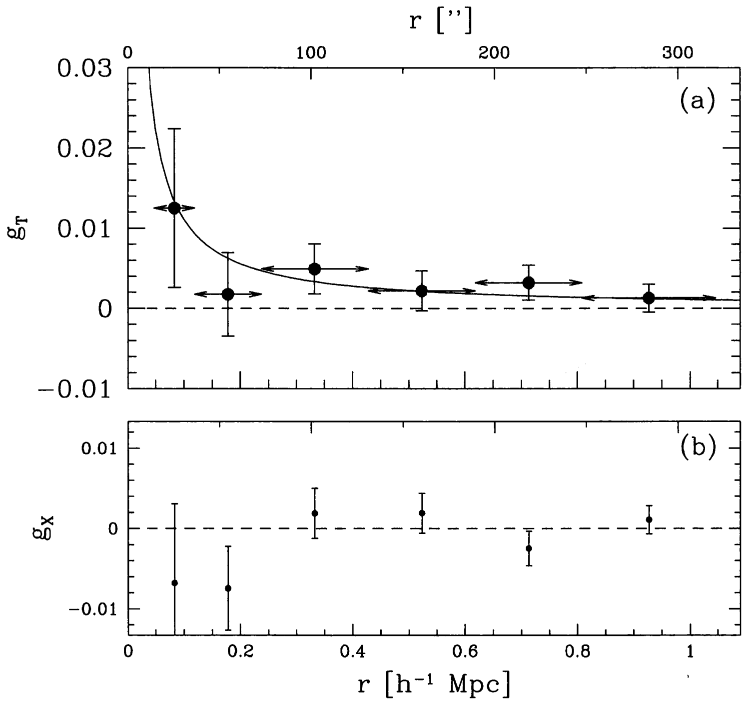

Figure 1. (a) The ensemble averaged tangential distortion as a function of radius around the 50 galaxy groups from Carlberg et al. (2000). The amplitude of the signal corresponds to that of the 'average' group at the median group redshift $z = 0.33$. The profile of the best fit singular isothermal sphere model (to the solid points), which has a velocity dispersion of 274^{+48}_{-59} km/s, is indicated by the solid line. (b) The signal when the phase of the distortion is increased by $\pi/2$: no signal should be present if the signal in (a) is due to lensing.

2. Data analysis

We obtained deep R-band images of the central 31 by 23 arcminutes of two patches from the CNOC2 survey using the 4.2m William Herschel Telescope.

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The analysis presented here are described in Hoekstra et al. (2000b) and a detailed discussion about the object analysis, including the corrections for the PSF can be found in Hoekstra et al. (2000c). We end up with catalogues of ~ 30000 galaxies with $22 < R < 26$ in each field. These galaxies are used to measure the weak lensing signal, enabling us to study the average properties of an ensemble of 50 groups from the CNOC2 survey (Carlberg et al. 2000).

3. Results

Most of the groups are relatively poor, and many of these systems have been selected on the basis of only a few members. The first question that comes to mind is whether the selected structures are genuine. The detection of a weak lensing signal provides an important test to check the validity of the group selection.

Ideally one would like to scale the signals of the various groups with an estimate of their mass, but the uncertainty in the observed velocity dispersions are too large. Therefore we assume that all groups have the same mass and mass profile, and scale the signals of the various groups to that corresponding to the 'average' group at $z = 0.33$.

Figure 1a shows the ensemble averaged tangential distortion as a function of radius around the 50 groups taken from the CNOC2 survey. The amplitude of the signal, which is significant at the 99% confidence level, corresponds to that of the 'average' group at a redshift of $z = 0.33$. Various tests, like increasing the phase of the distortion by $\pi/2$, placing the groups at random positions, or randomizing the ellipticities of the sources yield no signal. Furthermore the results are robust against imperfect corrections for the PSF anisotropy. We therefore conclude the detected signal is due to weak lensing by galaxy groups.

Fitting a singular isothermal sphere model ($\kappa = r_E/2r$) to the observed distortion yields $r_E = 0\farcs72 \pm 0\farcs29$. To relate this measurement to an estimate of the average mass of the groups we use the photometric redshift distribution inferred from both Hubble Deep Fields (cf. Hoekstra et al. 2000a), converted to the R band. As the groups are on average at relatively low redshifts, the dependence of the mass estimate on the redshift distribution is rather weak.

Thus we find that the observed distortion corresponds to $\langle\sigma^2\rangle^{1/2} = 274^{+48}_{-59}$ km/s (68% confidence). This result is in good agreement with the dynamical estimate of $\langle\sigma^2\rangle^{1/2} = 230$ km/s, based on the group velocity dispersions.

3.1. Mass-to-light ratio and Ω_m

Under the assumption that the light traces the mass, we derive the expected tangential distortion as a function of radius. To measure the mass-to-light ratio, we scale the resulting tangential distortion to match the observed signal. We find that the results are consistent with a constant mass-to-light ratio with radius for which we find a value of $191 \pm 83\ h$ in the restframe B band. After correction for luminosity evolution to $z = 0$ (assuming $L_B \propto (1 + z)$) we obtain a value of $254 \pm 110\ h$.

Carlberg et al. (1997) measured the mass-to-light ratio of a sample of 15 rich clusters, and the corresponding average cluster mass-to-light ratio is $438 \pm 76\ h$. Thus the average group mass-to-light ratio in the B band is lower than the value typically found for rich clusters, but consistent with the bluer colours of the groups.

To obtain an estimate of Ω_m, we combine our estimate of the mass-to-light ratio with the luminosity density derived by Lin et al. (1999), which is also based on the CNOC2 survey. Convolving the redshift distribution of the groups with their redshift dependent luminosity density yields $j = (3.2 \pm 0.6) \times 10^8 h \mathrm{L}_{B\odot} \mathrm{Mpc}^{-3}$ (assuming $\Omega_m = 0.2$ and $\Omega_\Lambda = 0$).

We obtain $\Omega_m = 0.19 \pm 0.10$ for an $\Omega_\Lambda = 0$ cosmology. Our estimate for Ω_m decreases to a value of $\Omega_m = 0.13 \pm 0.07$ for $\Omega_\Lambda = 0.87$. The value for Ω_m is derived in a self consistent way, and therefore is independent of the cosmology assumed throughout the paper. We note that we also made a small correction ($\sim 15\%$) to account for the slightly redder colours of the groups compared to the field.

Our results on Ω_m agree well with the results from other methods such as the combination of high redshift supernovae and CMB measurements (e.g., De Bernardis et al. 2000). Some caveats should be noted as well. Our measurement of the mass-to-light ratio is stable against changes in group membership, but the result is only correct if the light traces the mass.

The results presented here are based one quarter of the sample of groups found by Carlberg et al. (2000). Observations of the remaining groups would approximately double the accuracy of the measurements, which is important to test main assumption made in our analysis: does the light trace the mass?

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