Galaxy-galaxy lensing in clusters: new results

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Abstract. A synopsis of the recent results from our study of galaxy-galaxy lensing in clusters is presented. We have applied our analysis techniques to the sample of HST cluster-lenses that span a redshift range from $z = 0.18 - 0.58$. We find that there is evidence that the total mass of a typical early-type cluster L* galaxy increases with redshift. For the lowest redshift bin, a sensible comparison can be made with field galaxies and it is found that cluster galaxies are less massive and less extended than equivalent luminosity field galaxies. This agrees broadly with the theoretical picture of tidal stripping of dark matter halos in high density cluster environments. We also find the following trends – at a fixed luminosity both the mass-to-light ratio and the fiducial truncation radius increase with redshift from $z = 0.18 - 0.58$.

1. Introduction

Recent work on galaxy-galaxy lensing in the cores of rich clusters suggests that the average mass-to-light ratio and spatial extents of the dark matter halos associated with morphologically-classified early-type cluster members is significantly different from those of comparable luminosity field galaxies (Natarajan et al. 1998 [N98]). For field galaxies galaxy-galaxy lensing has been used to place more uncertain constraints on halo masses and sizes, with the claim that halos of field galaxies extend beyond 100 kpc (Brainerd, Blandford & Smail 1996; Ebbels et al. 2000; Hudson et al. 1998).

The detailed mass distribution within clusters – the fraction of the total cluster mass that is associated with individual galaxies – has important consequences for the frequency of galaxy interactions. The global tidal field of the cluster potential well is strong enough to truncate the dark matter halo of a galaxy whose orbit penetrates the cluster core. Compact dark halos indicate a high probability for galaxy–galaxy collisions over a Hubble time within a rich cluster. However, since the internal velocity dispersions of cluster galaxies ($\sim 120–200$ km s$^{-1}$) are significantly lower than their orbital velocities, these interactions are in general unlikely to lead to mergers, suggesting that the en-
counters of the kind simulated in the galaxy harassment picture by Moore et al. (1996) are frequent and lead to morphological transformation. In high resolution N-body simulations of galaxy halos within a rich cluster Ghiogna et al. (1998) report that halos that traverse within the inner 200 kpc of the cluster centre suffer significant tidal truncation.

From the analysis of local weak distortions in the cluster AC114 at a redshift of 0.31, N98 found that the total mass of a fiducial $L^*$ cluster spheroidal galaxy was contained within $\sim 15$ kpc radius halo ($\sim 8\text{--}10 R_e$) with a mass-to-light ratio $M/L_V \sim 23^{+15}_{-6}$ (90% c.l., $h = 0.5$) in solar units within this radius. This limit on the truncation radius points to cluster galaxies having of a significantly more compact and less massive halo than an equivalently luminous field galaxy.

However, we point out that several complex biases need to be taken into account to extend the analysis to such a non-uniform sample – these HST cluster-lenses span a large range in mass, richness, and X-ray luminosity, fortunately, they form a subset of the well-studied MORPHS clusters (Couch et al. 1998; Smail et al. 1997). No significant evolution in luminosity was found in the spheroidal populations of these clusters (Barger et al. 1998), therefore, any likely biases arising purely from differences in star formation activity due to different morphological mixes at various redshifts are expected to be small.

2. Analysis techniques

We model the cluster potential as a composite of a large-scale smooth component and the sum of smaller-scale perturbers which are associated with bright, early-type galaxies in the cluster. Details of the procedure can be found elsewhere (Natarajan & Kneib 1997; N98). Using both the observed strong lensing features and the shear field as constraints, the relative fraction of mass that can be attributed to the smooth component and the perturbers are computed using a maximum-likelihood method. The likelihood prescription provides bounds on both the fiducial central velocity dispersion (in km/s) and the outer extent (in kpc) for an ensemble of galaxies using a parameterised description of the scaling of the velocity dispersion and truncation radius with luminosity (the constraints are not sensitive to the details of this parametric form).

3. Results and Conclusions

Here we present the results of the application of our technique to the WFPC2 images of five HST cluster-lenses (Couch et al. 1998; Smail et al. 1997). The clusters span a wide redshift range: A 2218 at $z = 0.18$; AC 114 at $z = 0.31$; Cl0412–65 at $z = 0.51$; Cl0016+16 at $z = 0.55$ and Cl0054–27 at $z = 0.58$. We find that the mass-to-light ratio in the $V$-band of a typical $L^*$ increases as a function of redshift, with a mean value that ranges from roughly 10–24. The average value of the fiducial truncation radius varies from about 15 kpc at $z = 0.18$ to 60 kpc at $z = 0.58$. For the galaxy models that we have used in our analysis, the typical total mass of an $L^*$ varies with redshift from $\sim 2.8 \times 10^{11} M_\odot$ to $\sim 7.7 \times 10^{11} M_\odot$. The mass-to-light ratios quoted here take passive evolution of elliptical galaxies into account as given by the stellar population synthesis.
models of Bruzual & Charlot. The mass obtained for a typical bright cluster galaxy by Tyson et al. (1998) from the strong lensing analysis of the cluster Cl0024+16, at $z = 0.41$, is consistent with our results. Note that the preliminary numbers quoted here are average values, the estimates and discussion of error bars is presented in Natarajan, Kneib & Smail (2000).

These observed trends are in good agreement with theoretical expectations from cluster formation and evolution models (Ghigna et al. 1998). Qualitatively, in the context of this paradigm, fewer cluster members in a dynamically younger cluster of galaxies are likely to have suffered passages through the inner regions and are hence expected to be less tidally stripped. Detailed analysis and interpretation of these results are presented in a forthcoming paper.

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