Constraining the Mass Distribution of Cluster Galaxies by Weak Lensing

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Abstract. Analysing the weak lensing distortions of the images of faint background galaxies provides a means to constrain the mass distribution of cluster galaxies and potentially to test the extent of their dark matter halos as a function of the density of the environment. Here I describe simulations of observational data and present a maximum likelihood method to infer the average properties of an ensemble of cluster galaxies.

1 Introduction

Measurements of the rotation curves of spiral galaxies indicate that they are embedded in massive dark matter halos. The deflection of light rays through the gravitational action of mass concentrations, usually called gravitational lensing, provides a way to obtain information about the mass distribution of galaxies at radial distances from their centre where there are no more luminous test particles to probe the gravitational potential. The light deflection causes small distortions of the images of faint background galaxies. Recent statistical analyses (Brainerd et al. 1996, Griffiths et al. 1996) of these weak distortion effects suggest that the dark galaxy halos are indeed rather extended, as some popular theories of structure formation predict them to be. During the formation of galaxy clusters the extended halos of galaxies may be stripped off due to tidal forces of the cluster potential or during encounters with other galaxies. Ultimately the individual galaxy halos should merge and form a global cluster halo. In this contribution I discuss how this merging picture could be tested observationally by exploiting the weak lensing effects.

The distortions of the images of background galaxies produced by massive galaxy clusters are strong enough to allow a parameter-free reconstruction of the clusters’ surface mass density, and several algorithms have been developed for this purpose (e.g. Kaiser and Squires 1993, Seitz and Schneider 1995, 1996). The smoothing length which has to be implemented in these techniques, however, is larger than galaxy scales, i.e., the amount of information available does not suffice to reconstruct cluster galaxies individually. Therefore, one has to superpose the effects of a large number of galaxies statistically in order to infer the average properties of an ensemble of galaxies.

Section 2 presents simulations of a galaxy cluster which are sufficiently realistic for the purposes of this work, and demonstrates how individual galaxies modify the distortion pattern of a smooth cluster mass distribution. Section 3...
discusses a maximum likelihood method for constraining the mass distribution of cluster galaxies, and Sect. 4 presents results of the simulations. Finally, in Sect. 5 some suggestions for refining the simulations are mentioned, and observational prospects are discussed. A closely related work was recently published by Nataraajan and Kneib (1997); in contrast to their maximum likelihood method, the mass profile of the cluster is not assumed to be known but is reconstructed from image distortions as mentioned above.

2 Simulations

2.1 Cluster and Cluster Galaxies

A galaxy cluster with a total mass of about $10^{15}h^{-1}M_\odot$ located at a redshift of $z_d = 0.16$ was selected from numerical N-body simulations (Bartelmann et al. 1995). Within this paper a quadratic field of view with side length $10'$ is considered, which roughly corresponds to a physical size of $1h^{-1}$ Mpc at the cluster redshift. In order to populate the dark matter distribution of this cluster with galaxies the following requirements were specified:

1. The total mass-to-light ratio of the cluster was chosen to be $300h M_\odot/L_\odot$.
2. Galaxy luminosities $L$ were drawn from a Schechter function with canonical parameters (and a cutoff at $0.1L_\star$).
3. Galaxy positions were randomly drawn from those of the N-body particles.

This procedure resulted in a rich cluster of 359 galaxies, 40 of which are brighter than $L_\star$. For the mass distribution of the cluster galaxies, a simple truncated isothermal sphere (Brainerd et al. 1996) was used. The surface mass density $\Sigma$ as a function of the projected radius $\xi$ is given by

$$\Sigma(\xi) = \frac{\sigma^2}{2G\xi} \left( 1 - \frac{\xi}{\sqrt{s^2 + \xi^2}} \right),$$

where the two parameters, velocity dispersion $\sigma$ and cutoff radius $s$, were chosen as functions of the luminosity according to the following scaling relations:

$$\sigma = \sigma_\star \left( \frac{L}{L_\star} \right)^{1/\eta} \quad \text{and} \quad s = s_\star \left( \frac{L}{L_\star} \right)^{\nu}.$$  

For the first of these relations, which is motivated by the observed Tully-Fisher and Faber-Jackson relations, a value of $\eta = 4$ was used for the scaling index and the velocity dispersion $\sigma_\star$ of an $L_\star$-galaxy was fixed at 200 km/s. For simplicity, no distinction between spiral and elliptical galaxies was made. The scaling relation for the cutoff radius is more conjectural, and choosing $\nu = 0.5$ yields a mass-to-light ratio for the galaxies which is independent of luminosity. To test the method, two models were used for the cutoff radius. Choosing $s_\star = 3.4h^{-1}$ kpc gives a total $L_\star$-galaxy mass of $M_\star = 10^{11}h^{-1}M_\odot$, whereas an extended halo of $s_\star = 34h^{-1}$ kpc results in $M_\star = 10^{12}h^{-1}M_\odot$. These galaxy mass models were added to the global cluster mass distribution, which was scaled such that the total mass of the system remains constant (see Fig. 1 left).