GRAVITATIONAL MAGNIFICATION AND CLUSTER MASSES

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1. Introduction

The shear distortion of galaxies behind a large cluster provides us with only a relative measure of the mass of the cluster (Tyson et al. 1990, Kaiser & Squires 1993) due the invariance of shear to a sheet of matter. Thus we can at best only place lower limits on cluster masses, with the constraint that the surface density, $\kappa(\theta) = \Sigma(\theta)/\Sigma_c$, is non-negative. However, an absolute measurement of the mass can be obtained via the magnification of background galaxies (Broadhurst, Taylor & Peacock 1995, hereafter BTP). Here we describe the magnification effect, its observational consequences and mass reconstruction in the linear and nonlinear regimes. We also describe a number of applications in progress.

2. Lens Magnification

In general, gravitational lensing induces a change in the size and shape of an image galaxy. This distortion in the image is characterized by the image magnification, $A(z)$, for a galaxy at redshift z, such that the ratio of source to image areas is

$$A = |(1-\kappa)^2 - \gamma^2|^{-1} \simeq 1 + 2\kappa, \tag{1}$$

where γ is the shear and the approximation holds in the weak lensing regime. Surface brightness is a conserved quantity , so the change in image area produces a shift in apparent magnitude, $\Delta m = 2.5 \log_{10} A(z)$. As a result the effective flux limit decreases. BTP have shown that the lensed redshift distribution is related to the unlensed distribution by

$$N'(z) = A(z)^{\beta(z)-1} N(z) \tag{2}$$

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where $\beta(z) \equiv -d\ln N(z)/d\ln L_m$, and L_m is the limiting survey luminosity. Hence, one can hope to measure the magnification by comparing a lensed background source distribution with that of an unlensed field. In the linear regime, this will provide us with an absolute estimate of the surface mass density. In the nonlinear regime, shear information must also be included to solve equation (1) for κ. However, there is now a four-fold degeneracy of solutions. We can overcome this by assuming continuity of the surface density field and integrating our solutions from the linear regime inwards.

BTP have shown that with redshift information the uncertainty in surface density is only shot–noise limited when estimated from distortions in the background magnitude distribution, but has an additional uncertainty due to intrinsic clustering when estimated from redshift distributions. These uncertainties are similar ($\simeq 20\%$) when the mass resolution is about $\theta_R \simeq 10' n^{-1/2}$, where n is the mean number density of background galaxies per square arcminute. In the absence of redshifts it is still possible to measure a magnification by looking at galaxy counts behind the lensing cluster (BTP). However while this increases the number of available sources we are again subject to an increased uncertainty due to intrinsic density perturbations as well as contamination by foreground galaxies.

We are currently undertaking three interelated applications. Broadhurst et al. (1995) have examined the number counts behind A1689 (z=0.18) and shown that a measurable magnification can be seen from the suppression of red band galaxies (Broadhurst 1995). We are also awaiting Hubble Space Telescope imaging of A1689 to measure both the magnification and shear fields. When this is available we expect to place strong constraints on the absolute mass and cluster profile in both the linear and nonlinear regimes. Finally, we have obtained narrow band imaging of A1689 and A2218. Using a succession of narrow band filters we can estimate galaxy redshifts and so reduce the effects of foreground contamination as well as providing valuable redshift information for estimating the magnification.

3. Conclusions

We have shown that lens magnification is a measurable effect and can be used to estimate the absolute cluster mass in both linear and nonlinear regimes. We are currently applying these methods to A1689.

References

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