The Density Profiles of the Galaxy Clusters Abell 1351 & Abell 1995

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Introduction

Galaxy clusters are the largest well-defined structures in the universe, and represent rare high-density peaks in the matter density distribution. They are therefore essential in providing us a more profound understanding of the nature of dark matter. Neither the nature nor the dynamical state of the gravitating matter affect the mass estimates obtained through gravitational lensing, as lensing measurements do not make assumptions about the dynamical state of the gravitating matter. Applying gravitational lensing to clusters of galaxies hence provides a powerful way to identify large density peaks in the Universe, independent of their baryonic content.

Using weak lensing measurements we probe the mass distribution of the galaxy clusters Abell 1351 and Abell 1995. These clusters resemble a very different mass structure and dynamical state, and are the two extremes from a larger sample of 38 clusters of similar mass and redshift (Dahle et al. 2002, ApJS, 139, 313). Using the κ mass reconstruction algorithm of Kaiser & Squires (1993, ApJ, 404, 441) (KS93) we quantitatively reconstruct the projected surface mass distribution of the clusters. By comparing the measurements to the singular isothermal sphere (SIS) profile and the Navarro, Frenk, & White (1997, ApJ, 490, 493) (NFW) model we also obtain mass estimates of the clusters and discuss their concentration parameters.

The galaxy clusters

Abell 1351 and Abell 1995 are both at redshift $z = 0.32$. They were observed with the 3.6m Canada-France-Hawaii Telescope (CFHT), using the CFH12K wide-field imager covering an area of 42' × 28' on the sky.

X-ray studies show Abell 1351 to be a galaxy cluster exhibiting significant dynamical activity and undergoing a major merger event (Allen et al. 2003, MNRAS, 342, 287), which indicates a cluster still in its formation phase. Abell 1995 is in contrast classified as a relaxed cluster (Pedersen & Dahle 2006, ApJ, in press), assumed to be in a state of dynamical equilibrium.

Modelling the lensing data

Comparing observed distortions in the background galaxies to those predicted by theoretical density profiles enables us to estimate the mass of a galaxy cluster. We estimate the radial mass distributions of Abell 1351 and Abell 1995 assuming that the clusters are spherically symmetric, following either an SIS or an NFW profile. The χ^2-test is used to determine the best fit parameters for each model.

The results are presented in Table 1 and it is seen that both models yield similar mass estimates, where those of the SIS profile represent the mass within r_{200} found in the NFW fitting.

The NFW profile

An NFW galaxy cluster is characterised by the scale radius, $r_s = r_{200}/c$, where c is the concentration parameter of the cluster. The mass density of the profile scales as $\rho(r) \propto r^{-1}$ for $r < r_s$ and $\rho(r) \propto r^{-3}$ for $r > r_s$. Hence, the smaller the concentration parameter, the slower the mass density of a cluster will decrease with radius.

Abell 1995

For Abell 1995 we find $c = 1.7^{+1.3}/_{-1.2}$, suggesting a scale radius close to r_{200} (see also Fig. 3). If the mass density of a cluster is decreasing slowly ($\rho \propto r^{-1}$), the shear values will decrease slowly too, indicating that the mass is close to evenly distributed going from small to large radii. As seen in Fig. 3 this phenomenon is present in Abell 1995, the best fit curve being nearly flat.

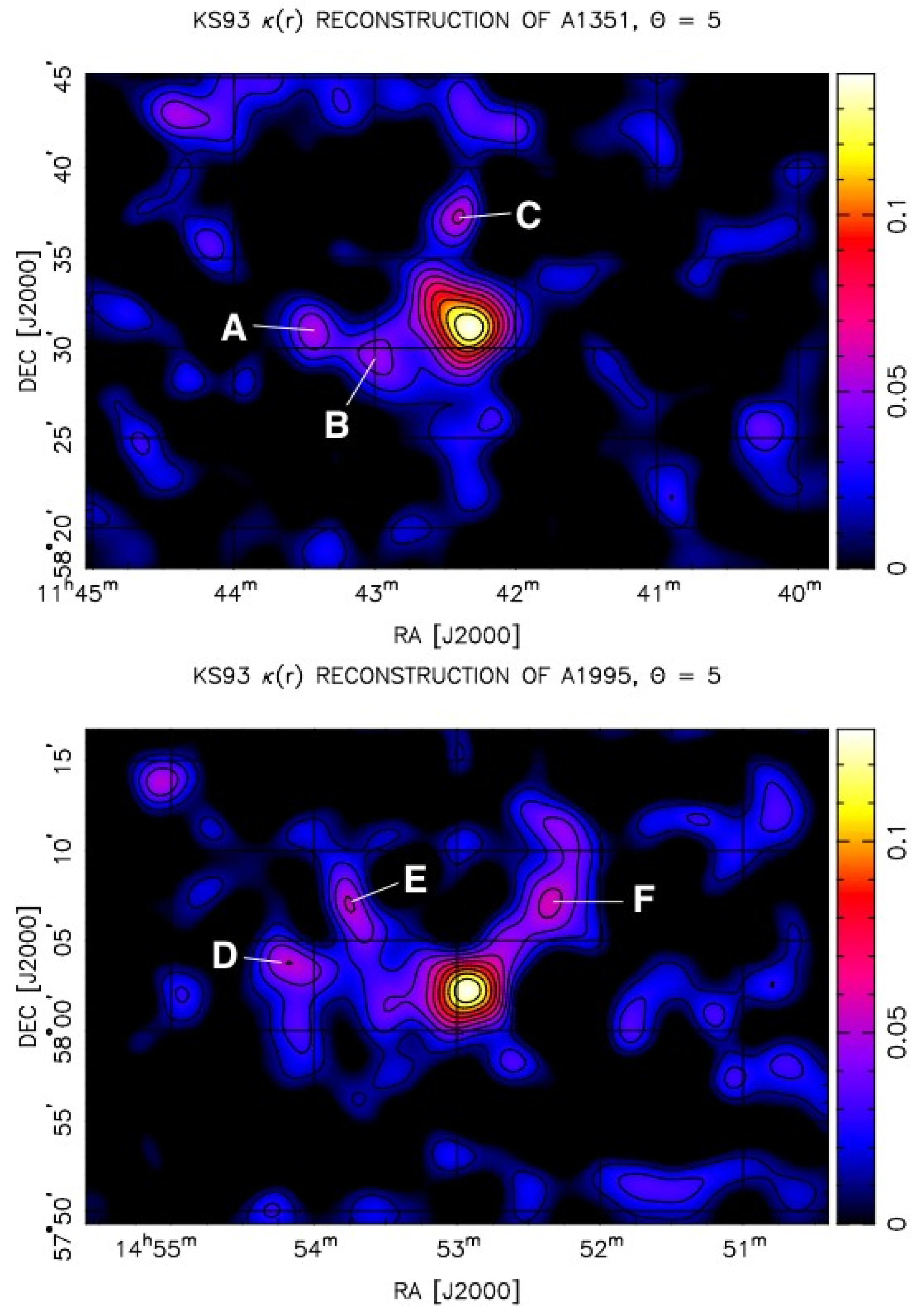

Figure 1: The projected surface mass density in the fields of Abell 1351 (top) and Abell 1995 (bottom).

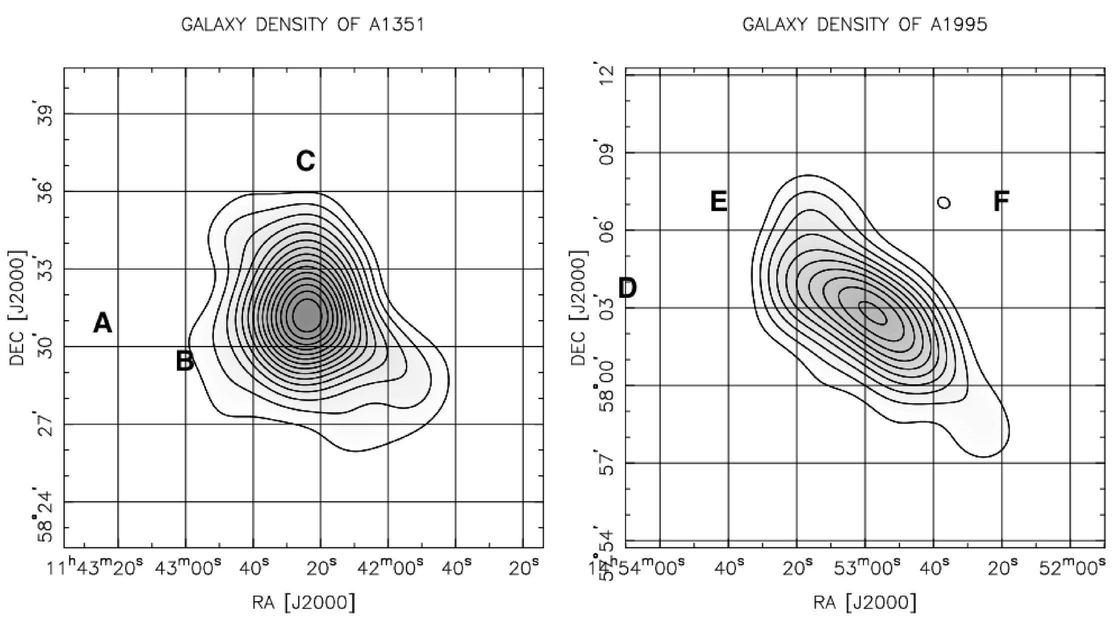

Fig. 2: The galaxy density distribution of Abell 1351 (left) and Abell 1995 (right). The surrounding mass peaks are indicated by corresponding letters.

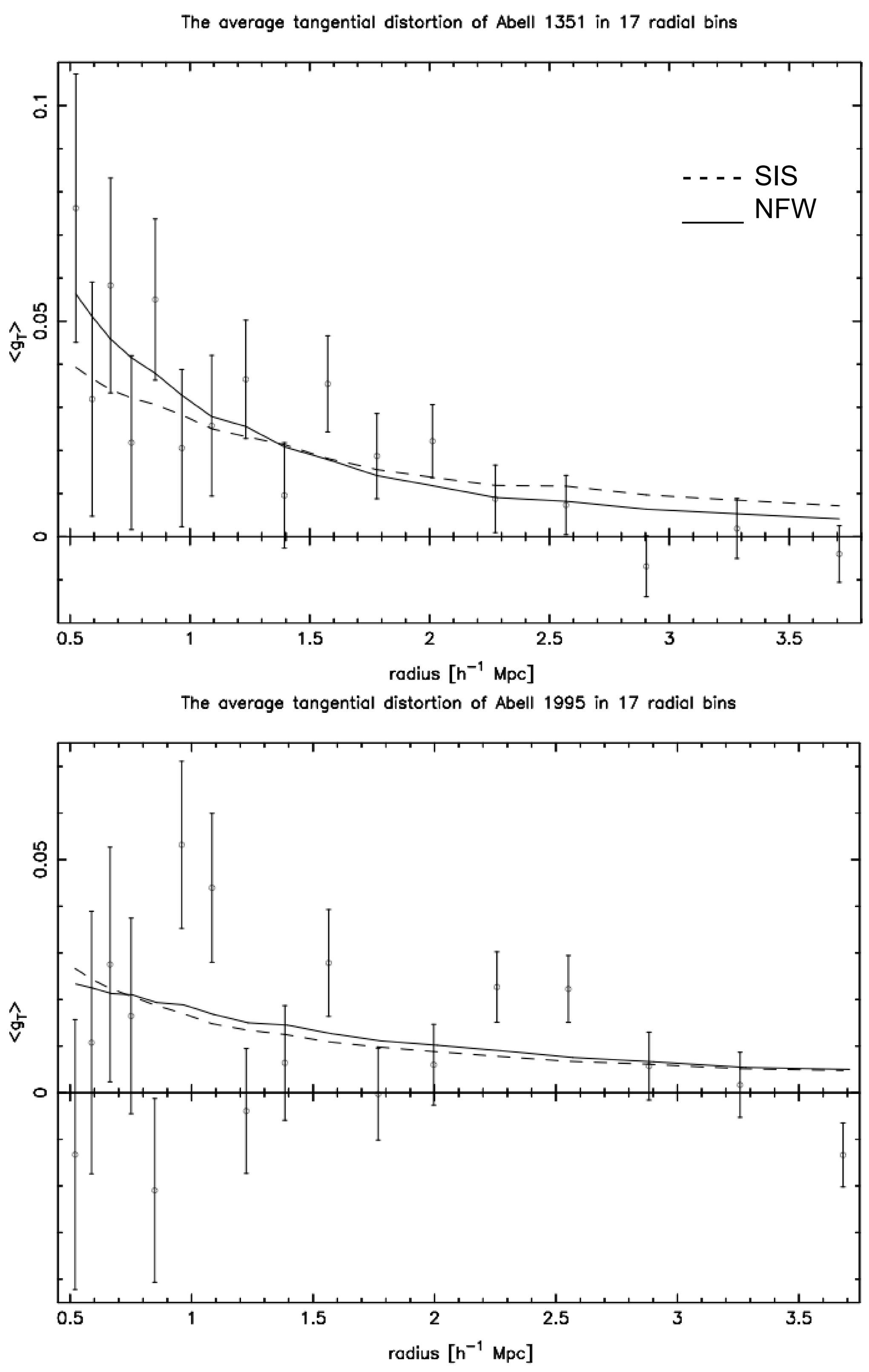

Figure 3: The reduced tangential shear as a function of radius for Abell 1351 (top) and Abell 1995 (bottom).

Abell 1351

The concentration parameter of Abell 1351 was initially determined to $c = 11.2^{+x}/_{-4.9}$. This large value implies a small scale radius, suggesting most of the mass is concentrated near the cluster centre. This is also seen in Fig. 3, where the NFW curve drops steeply for small radii, indicating that the shear values decrease rapidly.

The shear values are measured from a radial cut-off, r_{min}=150", to avoid the cluster galaxy contamination present at small radii. As seen in Table 2, the best fit c of Abell 1351 depends strongly on r_{min}. Because c is estimated from r_s, it is crucial that $r_{min} < r_s$ in order to obtain an accurate estimate of c. If our measurements do not include r_s, c is basically unconstrained. We believe this is the case for Abell 1351, yielding no upper limit for its concentration parameter when r_{min}=150".

Reducing r_{min} will provide clearer results. However, the cluster galaxy contamination amongst the background galaxies will increase at small radii, leading to potential biases which increase with decreasing r_{min}. Letting 100"≤ r_{min}≤150", we see from Table 2 that whilst c decreases with smaller r_{min}, r_{200} and M_{200} remain stable. Once r_{min} approaches 130" c becomes constrained, and we therefore believe the concentration parameter for Abell 1351 lies within $3.2 \leq c \leq 14.7$.

The κ mass reconstruction

Using the KS93 κ reconstruction algorithm, the shear measurements from background galaxies are converted into the projected dimensionless surface mass density (Fig. 1). The central mass peaks of both clusters are significant on the 8σ level. In addition we identify 3 surrounding mass peaks close to each cluster's centre, appearing on the 3 - 3.5σ level.

The true existence of these smaller peaks is hard to determine from the κ reconstruction alone. We therefore compare the mass distribution to the cluster galaxy light density seen in Fig. 2. The light peaks are significant on the 15.5σ and 10σ levels for Abell 1351 and Abell 1995, respectively. We observe small positional offsets to the north-east for both clusters with respect to their mass peaks, 17" for Abell 1351 and 39" for Abell 1995. Such offsets are common in weak lensing studies (Schirmer et al. 2007, A&A, 462, 875).

For Abell 1351 the light distribution resembles well the central mass, stretching towards the east and hence increasing the probability of finding a mass concentration located in peak B. For Abell 1995 the mass distribution appears circular, though we find a rather elliptical light distribution extending towards peak E. Hence, the object and thus mass density in this area is increased, making it plausible that peak E is indeed physical and not a noise peak. The nature of the peaks left remains currently unclear.

Table 1: Results from modelling the lensing data.

	Abell 1351	Abell 1995
SIS		
θ_E	$16''.8 \pm 2''.5$	$10''.8 \pm 2''.7$
σ_v [km s^{-1}]	1060 ± 80	840 ± 105
M_{SIS} [$10^{14} h^{-1} M_\odot$]	6.38 ± 0.10	3.48 ± 0.33
NFW		
c	$11.2^{+x}_{-4.9}$	$1.7^{+1.3}_{-1.2}$
r_{200} [h^{-1}Mpc]	1.22 ± 0.02	1.06 ± 0.10
M_{200} [$10^{14} h^{-1} M_\odot$]	5.84 ± 0.29	3.83 ± 1.14

Table 2: Results from varying r_{min} for Abell 1351.

r_{min}	c	r_{200} [h^{-1}Mpc]	M_{200} [$10^{14} h^{-1} M_\odot$]	No. of galaxies
100″	$4.9^{+3.6}_{-2.2}$	1.23 ± 0.05	5.98 ± 0.73	15 630
110″	$6.0^{+4.7}_{-2.8}$	1.20 ± 0.05	5.55 ± 0.62	15 582
120″	$6.8^{+7.6}_{-3.3}$	1.20 ± 0.05	5.55 ± 0.62	15 529
130″	$6.2^{+8.5}_{-2.8}$	1.23 ± 0.04	5.98 ± 0.58	15 482
140″	$10.0^{+x}_{-5.5}$	1.21 ± 0.04	5.69 ± 0.49	15 428
150″	$11.2^{+x}_{-4.9}$	1.22 ± 0.02	5.84 ± 0.29	15 358

Tracing Cosmic Evolution with Galaxy Clusters: Six years later, Sesto, Italy
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