MASS–TO–LIGHT RATIOS OF 2DF GALAXIES
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ABSTRACT
We compute $M_{260}^{\text{dyn}}$, the dynamical mass interior to a radius of $260h^{-1}$ kpc, for a set of 809 isolated host galaxies in the 100k data release of the 2dF Galaxy Redshift Survey. The hosts are surrounded by 1556 satellite galaxies, as defined by a set of specific selection criteria. Our mass estimator and host/satellite selection criteria are taken from those used by the Sloan Digital Sky Survey (SDSS) collaboration for an analysis of $M_{260}^{\text{dyn}}$ for SDSS galaxies and, overall, our results compare well with theirs. In particular, for $L \geq 2L^*$ we find $(M_{260}^{\text{dyn}}/L)_{b,j} = (193 \pm 14) h M_{\odot}/L_{\odot}$, with a weak tendency for hosts with $L < 2L^*$ to have a somewhat higher $M/L$. Additionally, we investigate $M/L$ for bright ($b_j \leq 18$) galaxies with elliptical, S0, and spiral morphologies. There are 159 hosts in the elliptical/S0 sample and, similar to the full sample, we find $(M_{260}^{\text{dyn}}/L)_{b,j} = (271 \pm 26) h M_{\odot}/L_{\odot}$ for galaxies with $L \geq 2L^*$, and a weak tendency for intrinsically fainter galaxies to have a somewhat higher $M/L$. In stark contrast to this, we find the line of sight velocity dispersion for the 243 spiral hosts to be independent of the host luminosity, with a value of $\sigma_v = 189 \pm 19$ km s$^{-1}$. Thus, for spiral hosts we find that $(M_{260}^{\text{dyn}}/L)_{b,j} \propto L^{-1.0 \pm 0.2}$, where $(M_{260}^{\text{dyn}}/L)_{b,j}$ for a $2L^*$ spiral is of order 200 $h M_{\odot}/L_{\odot}$.

Subject headings: galaxies: fundamental parameters — galaxies: halos — galaxies: luminosity function, mass function — galaxies: structure — dark matter

1. INTRODUCTION
It is generally accepted that large, bright galaxies reside within massive dark matter halos; however, the radial extent of the halos is not well-constrained and, hence, neither is the total mass nor the mass–to–light ratio of these objects. Galaxy–galaxy lensing, in which the halos of foreground galaxies weakly distort the shapes of background galaxies, has recently proven to be a powerful method by which the masses and mass–to–light ratios of galaxies may be constrained. Galaxy–galaxy lensing has been detected by a number of different groups (see, e.g., the review by Brainerd & Blandford 2003 and references therein) and, in particular, the Sloan Digital Sky Survey (SDSS) collaboration has obtained measurements of the galaxy–galaxy lensing shear with extremely high statistical significance (e.g., Fischer et al. 2000; McKay et al. 2001).

Using weak lensing measurements of the projected mass correlation function, McKay et al. (2001), hereafter SDSS01, found that $M_{260}^{\text{dyn}}$, the mass of lens galaxies interior to a radius of $260h^{-1}$ kpc, scaled roughly linearly with the luminosities of the lens galaxies in all bandpasses except $u'$. Since the galaxy–galaxy lensing shear is small ($\lesssim 0.5\%$ in the case of the SDSS galaxies) and is not without its own sources of error (including the separation of lenses from sources), McKay et al. (2002) performed an independent estimate of the masses of dark matter halos surrounding SDSS galaxies using the dynamics of satellite galaxies. Their sample consisted of 618 host galaxies and 1225 satellites, which was considerably smaller and shallower than the sample in the weak lensing analysis due to the necessity of redshifts for all of the galaxies. Nevertheless, McKay et al. (2002), hereafter SDSS02, found that their dynamical analysis led to trends in the dependence of $M_{260}^{\text{dyn}}$ on the host galaxy luminosity that were reasonably consistent with the trends obtained from their previous weak lensing analysis. However, the mass–to–light ratios found from the dynamical analysis were systematically lower than those from the lensing analysis $(M_{260}^{\text{dyn}}/L) \sim 0.8 M_{260}^{\text{dyn}}/L$.

Here we perform a dynamical analysis of the masses of isolated host galaxies in the 100k public data release of the 2dF Galaxy Redshift Survey, hereafter 2dFGRS. The 2dFGRS is a spectroscopic survey in which the objects are selected in the $b_j$ band from the APM galaxy survey (Madgwick et al. 1990a,b), and extensions to the original survey. Ultimately, the survey will provide spectra for $\sim 250,000$ galaxies brighter than $b_j = 19.45$ and will cover an area of order 2000 square degrees (see, e.g., Colless et al. 2001).

Our host galaxies span a redshift range which is similar to that of the SDSS02 galaxies, and our sample is of a similar size. We select host/satellite combinations and determine dynamical masses for the host galaxies based upon the methods outlined in SDSS02 in order to compare most easily to their results. In particular, we investigate the apparent lack of dependence of $M_{260}^{\text{dyn}}/L$ on the host luminosity found by SDSS02, and the somewhat low value of the dynamical mass–to–light ratio in comparison to the lensing mass–to–light ratio.

Throughout, we adopt a flat, $\Lambda$–dominated universe with parameters $\Omega_0 = 0.3$, $\Lambda_0 = 0.7$, and $H_0 = 100h$ km s$^{-1}$ Mpc$^{-1}$. Consistent with this, we take the absolute magnitude of an $L^*$ galaxy in the $b_j$ band to be $M_{b,j} = -5 \log_{10} h = -19.66 \pm 0.07$ (Norberg et al., 2002).

2. HOST AND SATELLITE SELECTION
In order to compare to the results of SDSS02, we select host and satellite galaxies from the 2dF survey according to the SDSS02 criteria:
• Host galaxies must be “isolated”. They must be at least twice as luminous as any other galaxy that falls within a projected radius of $2h^{-1}$ Mpc, as well as within a velocity difference of $|dv| \leq 1000 \text{ km s}^{-1}$.

• Potential satellite galaxies must be at least 4 times fainter than their host, must fall within a projected radius of $500h^{-1} \text{ kpc}$ of their host, and the satellite-host velocity difference must be $|dv| \leq 1000 \text{ km s}^{-1}$.

These basic selection criteria result in 864 hosts and 2340 satellites. As noted by SDSS02, however, many of the hosts have a large number of satellites around them (in one case, a potential host in our sample has 605 satellites). These are, therefore, most likely to be associated with cluster systems, rather than being truly isolated. To eliminate these objects, we impose a further restriction that the luminosity of the host be greater than the sum total of the luminosities of the satellites. This, too, was done by SDSS02, and reduces our 2dF sample to 859 hosts and 1693 satellites.

Finally, we impose two additional cuts on the host galaxies. First, eyeball morphologies are available for the 2dF galaxies with $b_J \leq 18$, and 29 of the above hosts are classified as galaxy–galaxy mergers. We delete these hosts from the sample on the basis that they are unlikely to be fully relaxed systems. Second, we delete all hosts with $L > 6L^*$ because the velocity dispersions of their satellites are poorly fit by the technique we adopt (see below), and the number of interloper galaxies (as opposed to genuine satellites) appears to be both large ($\gtrsim 45\%$) and have a large dispersion ($\sim 20\%$). These additional cuts leave us with a final sample of 809 host galaxies and 1556 satellites. Of these, 75 are classified as ellipticals, 84 are classified as S0, and 243 are classified as spirals. The sample of spirals is uniformly distributed in inclination angle, and there is no correlation between host luminosity and median inclination angle. The ellipticals have a total of 171 satellites, the S0’s have a total of 303 satellites, and the spirals have a total of 478 satellites. The median redshift of the 809 host galaxies in the full sample is $z_{\text{med}} = 0.073$, while for the spiral hosts $z_{\text{med}} = 0.055$, and for the elliptical and S0 hosts $z_{\text{med}} = 0.062$.

The probability distribution of the luminosities of the host galaxies, the probability distribution of the number of satellites around individual hosts, and the probability distribution of the difference in apparent $b_J$ magnitude between the hosts and their satellites are shown in panels a, b, and c of Figs. 1, 2, and 3. Fig. 1 shows results for the entire sample of 809 hosts, while Fig. 2 shows the results for the 159 hosts classified as elliptical or S0, and Fig. 3 shows the results for the 243 hosts classified as spirals.

3. HALO VELOCITY DISPERSIONS

In order to compare with SDSS02, we adopt an analysis technique that is identical to theirs. The radial velocity dispersions of the host galaxy halos, $\sigma_v$, are computed by fitting a combination of a Gaussian and a constant offset to histograms of the velocity differences between the hosts and satellites. The width of the best–fitting Gaussian is a measure of $\sigma_v$, while the offset accounts for the fact that there will, necessarily, be some fraction of interloper galaxies that are selected as satellites when, in fact, they are not dynamically associated with the host galaxy. Like SDSS02, we find that this technique provides very good fits to the velocity difference histograms, yielding values of $\chi^2$ per degree of freedom, $\chi^2/\nu$, that are $\lesssim 1$ for hosts with $L \leq 6L^*$. In the case of hosts with $L > 6L^*$, $\chi^2/\nu \gtrsim 2.5$ and, hence, we do not consider these objects further.

Because it is likely that more interlopers will have velocities that are greater than their hosts (e.g., Zartisky &
White 1994), we determined $\sigma_v$ for the host galaxies by fitting Gaussians plus constant offsets to 3 different velocity difference histograms: (i) velocity differences taken to be the absolute value, $|dv|$, of the measured difference, (ii) negative velocity differences, and (iii) positive velocity differences. We define the velocity difference to be $dv \equiv v_{\text{host}} - v_{\text{sat}}$, so that negative values of $dv$ correspond to satellites which are more distant in velocity space. In all cases, the best-fitting velocity dispersions are in very good agreement amongst the 3 histograms. In addition, we find a clear difference in the number of interlopers. In the case of the full sample of 809 hosts, the interloper fraction is $(33 \pm 3\%)$ while for hosts with elliptical and S0 morphologies the interloper fraction is much lower, $(14 \pm 4\%)$. Lastly, for all of our samples of host galaxies, we find that $\sigma_v$ is independent of the radius at which it is determined.

Results for $\sigma_v$ as a function of median host luminosity are shown in panel d of Figs. 1, 2, and 3. In the case of the full host sample and the elliptical/S0 host sample, the relationship between velocity dispersion and median host luminosity is fit best by linear relations, and these are shown by the solid lines in panel d of Figs. 1 and 2. For the full host sample we find $\sigma_v = (31 \pm 8)L/L^* + (141 \pm 18)$ km s$^{-1}$, and for the elliptical/S0 sample we find $\sigma_v = (43 \pm 7)L/L^* + (149 \pm 22)$ km s$^{-1}$. This is somewhat different from the results of SDSS02 who found $\sigma_v \propto \sqrt{L}$. We note, however, that our data are consistent with such a relationship, and the best-fitting function of the form $\sigma_v \propto \sqrt{L}$ is shown by the dashed lines in these figures. Strikingly different from these results, however, is the relationship of velocity dispersion and median host luminosity for the spiral hosts. From panel d of Fig. 3, it is clear that $\sigma_v$ for the spiral hosts is independent of host luminosity, and we find $\sigma_v = 189 \pm 9$ km s$^{-1}$ for these objects.

4. Host Masses and Mass-to-Light Ratios

To determine the masses of the dark matter halos which surround our host galaxies, we adopt the following mass estimator:

$$M(r) = -G\frac{r}{\partial \ln \rho \partial \ln r} \left[ \frac{\partial \ln \rho \partial \ln \langle v^2 \rangle}{\partial \ln r} + 2\beta \right]$$

(e.g., Binney & Tremaine, 1987). Here $r$ is a 3-dimensional radius, $\langle v^2 \rangle$ is the mean square radial velocity of the satellites, $\rho(r)$ is the number density of satellites, and $\beta$ is a measure of the anisotropy in the velocity dispersion of the satellites:

$$\beta \equiv 1 - \frac{\langle v^2 \rangle}{\langle v^2 \rangle_{\text{rad}}}$$

Although other methods of obtaining dynamical masses using satellite galaxies have been adopted in the literature (see, e.g., Bahcall & Tremaine 1982; Zaritsky et al. 1997), this is the method adopted by SDSS02 and, therefore, we adopt it as well. SDSS02 have used the GIF simulation, which incorporates semi-analytic galaxy formation within a large cosmological N-body simulation (e.g., Kauffmann et al. 1999), to evaluate this mass estimator. In particular, SDSS02 find that the velocity anisotropy of the satellite galaxies in the GIF simulation is small (i.e., $\beta$ is consistent with zero at the 2-σ level), and that the mean square line of sight velocity dispersion, $\sigma_v^2$, is consistent with the mean square radial velocity dispersion, $\langle v^2 \rangle_{\text{rad}}$, at the 1-σ level. Combining this with the fact that the line of sight velocity dispersion is observed to be independent of radius, the mass estimator used by SDSS02 reduces to:

$$M(r) = -\frac{r\sigma_v^2}{G} \frac{\partial \ln \rho}{\partial \ln r}$$

We compute $\rho(r)$ for the satellites in our sample and find $\rho(r) \propto r^{-2.11 \pm 0.06}$ for the satellites surrounding the hosts in the full sample, $\rho(r) \propto r^{-2.11 \pm 0.09}$ for the satellites surrounding elliptical and S0 hosts, and $\rho(r) \propto r^{-2.2 \pm 0.1}$ for the satellites surrounding spiral hosts. These are all consistent with the results of SDSS02 who find $\rho(r) \propto r^{-2.1}$ for their sample.

Having obtained the number density of satellites as a function of radius, we now use the values of $\sigma_v$ from Figs. 1, 2, and 3 to determine the mass-to-light ratios of the host galaxies. For consistency with SDSS02, we adopt a fiducial projected radius of $260h^{-1}$ kpc. Shown in Fig. 4 are the results for $(M^{\text{dyn}}_{260}/L)_{b_J}$ in units of $hM_\odot/L_\odot$ as a function of median host luminosity. The top panel shows results for the full sample of host galaxies, the middle panel shows results for the elliptical and S0 hosts, and the bottom panel shows results for the spiral hosts.

From Fig. 4, then, we find that $(M^{\text{dyn}}_{260}/L)_{b_J}$ for the 809 hosts in our full sample is fairly constant for hosts with $L \gtrsim 2L^*$ and has a value of $(193 \pm 14)hM_\odot/L_\odot$. For hosts with $L < 2L^*$ there is a weak suggestion of a somewhat higher mass-to-light ratio. Similarly, $(M^{\text{dyn}}_{260}/L)_{b_J}$ for the elliptical and S0 hosts is fairly constant for hosts...
with $L \gtrsim 2L^*$ and has a value of $(271 \pm 26)h M_\odot/L_\odot$. Again, there is a slight suggestion that elliptical and S0 hosts with $L < 2L^*$ have a somewhat higher mass-to-light ratio. In contrast, over the range of host luminosities explored here, $(M_{260}/L)_{h, j}$ for the spiral hosts shows a clear monotonic decrease with luminosity, and is consistent with a power-law of the form $(M_{260}/L)_{h, j} \propto L^{-1.0\pm0.2}$.

5. DISCUSSION

The 2dF and SDSS02 host/satellite samples are of comparable depths and have similar sizes, so it is not unreasonable to make comparisons between them. The comparison is, however, somewhat limited by the fact that the 2dF galaxies are selected in $b_j$, while the SDSS02 galaxies are selected in $r'$, with host luminosities obtained in $u'$, $g'$, $r'$, $i'$, and $z'$. (The transformation from the SDSS photometry is given by $b_j = g' + 0.155 + 0.152(g' - r')$; Norberg et al. 2002). Also, SDSS02 did not perform separate dynamical analyses for the hosts of early- and late-type galaxies, so a direct comparison is not possible in this case.

In all 5 SDSS photometric bands, SDSS02 find $M_{260} \propto L$, so that in a given band, a single mass-to-light ratio characterizes the hosts. That mass-to-light ratio is a sharply decreasing function of the central wavelength of the bandpass (e.g., a factor of order 3 higher in $u'$ than in $z'$). In $g'$, SDSS02 find $M_{260}^{zen}/L = (171 \pm 40)h M_\odot/L_\odot$ and in $r'$ $M_{260}^{zen}/L = (145 \pm 34)h M_\odot/L_\odot$. These compare well with the mass-to-light ratio that we obtain, $(193 \pm 14)h M_\odot/L_\odot$, for the host galaxies our full sample that have luminosities of $L \gtrsim 2L^*$.

Since we cannot compare our $M_{260}^{dyn}/L$ for host galaxies of different morphologies to the results of SDSS02, we instead compare them to the weak lensing results of SDSS01. SDSS01 did not classify their galaxies according to visual morphology but, instead, used spectral features to place subsets of their lens galaxies into broad “early-” and “late-type” categories. The early-types represent about 40% of the total number of lens galaxies, and the late-types represent another 40% of the total number of lens galaxies. Table 3 of SDSS01 shows that in the bluer bands, $M_{145}^{zen}/L$ is somewhat morphology-dependent, with the mass-to-light ratio of the ellipticals exceeding that of the entire lens sample by a factor of 1.5 $\pm 0.2$ in $g'$ and by a factor of 1.3 $\pm 0.2$ in $r'$. Again, this compares well with our results for the elliptical/S0 hosts in the 2dF sample, where we find that $M_{260}^{dyn}/L$ for the elliptical/S0 hosts exceeds that of the full sample by a factor of 1.4 $\pm 0.2$ for hosts with $L \gtrsim 2L^*$ (e.g., Fig. 4).

Our result that $M_{260}^{dyn}/L \propto L^{-1}$ for the spiral hosts is in clear conflict with the results of SDSS01, who found that $M_{145}^{zen}/L$ was independent of luminosity in all but the very bluest band ($u'$). However, our result stems from the fact that the line of sight velocity dispersion is independent of luminosity for the spiral hosts. While this is consistent with the lensing results of SDSS01, it is consistent with the dynamical results of Zaritsky et al. (1997) who found that the velocity difference, $dv$, between 69 isolated spiral galaxies ($-22.4 < M_B < -18.8$) and 115 satellites was independent of the inclination-corrected H-I linewidth of the host and was, therefore, independent of the luminosity of the host (through, e.g., the Tully–Fisher relation).

Whether the conflict between the lensing and dynamical results for the halos of spiral galaxies is due to differences in sample selection or due to systematic effects in one or both of the mass estimators remains to be determined. However, the ultimate completion of both the SDSS and the 2dfGRS will aid tremendously in the resolution of this issue, and we look forward to the wealth of data that both surveys will provide in the near future.

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REFERENCES