SHAPE ALIGNMENTS OF SATELLITE GALAXIES

G. M. Bernstein1 and P. Norberg2

Received 2002 April 10; accepted 2002 April 22

ABSTRACT

We test a sample of satellites of isolated primary galaxies, extracted from the 2dF Galaxy Redshift Survey, for any tendency to be aligned along (or against) the primary-to-satellite radius vector. If tidal effects induce such an alignment, it would contaminate recent measurements of galaxy halo masses that use the coherent alignment induced on background galaxies by gravitational lensing. The mean tangential ellipticity of 1819 satellites within 500 kpc projected radius is \( \langle e_\perp \rangle = +0.004 \pm 0.008 \), so no tidal alignment is detected. This implies at 95% confidence that satellite alignment is less than a 20% contamination of the alignment signal recently attributed to galaxy-galaxy lensing by Smith et al. and McKay et al.

Key words: galaxies: dwarf — galaxies: halos — gravitational lensing

On-line material: color figure

1. INTRODUCTION

A number of the satellite galaxies of the Milky Way are distorted, in some cases dramatically (see, e.g., Dohm-Palmer et al. 2001), by tidal interactions with the Galaxy. The obvious manifestations of tidal distortion are streams of material that are liberated by tidal forces to lead or trail the satellite in its orbit. One might also expect the tide to stretch the satellites’ gravitational potential wells along the radial direction and, hence, induce a tendency for the bound parts of satellite galaxies to be extended toward their primaries. Since our vantage point precludes a measurement of the satellites’ extent along the Galactic radius vector, it is not possible to test this hypothesis for the Milky Way satellites. Given a large sample of satellites around other galaxies, however, we can test whether the (projected) satellite major axes have a tendency to be circumferential or radial rather than randomly oriented.

While a detection of satellite shape alignments would serve as a crude gauge of the effect of tidal forces on satellite morphologies, it would be a significant nuisance for measurements of galaxy masses using weak gravitational lensing. In such studies, the halo mass distribution of the primary (foreground) galaxy is inferred by measuring the slight tendency toward circumferential alignment that the gravitational lensing distortion of the primary galaxy induces upon the images of distant background galaxies. This “galaxy-galaxy lensing” signal was first proposed and sought by Tyson et al. (1984) and was tentatively detected by Brainerd, Blandford, & Smail (1996). More recently, it has been detected at high significance by Fischer et al. (2000), Smith et al. (2001, hereafter Sm01), and McKay et al. (2001, hereafter McK01). The latter two studies use foreground galaxies with redshifts measured by the Las Campanas (Sheetman et al. 1996) and Sloan (York et al. 2000) redshift surveys, respectively, and are able to determine the halo masses as a function of luminosity and morphological type. Such information is extremely valuable—but subject to error if the measured mean circumferential ellipticities are due to intrinsic alignments of the primaries’ satellites rather than the lensing effect. In galaxy-galaxy lensing measurements to date, there has been no attempt to cull the satellites from the sample of lensed background galaxies.

In this work, we test for shape alignment among a sample of satellites of isolated galaxies found in the 2dF Galaxy Redshift Survey (2dFGRS; Colless et al. 2001), in an effort to see whether such alignments are a significant difficulty for galaxy-galaxy lensing studies. The following sections describe the satellite sample, the determination of their mean elongations, and the implications for weak-lensing studies and for tidal effects. Throughout the paper, we adopt a flat \( \Omega_0 = 0.3, \Lambda_0 = 0.7 \) cosmology to convert redshift into comoving distance, and we assume the value of the Hubble constant to be \( H_0 = 70 \) km s\(^{-1}\) Mpc\(^{-1}\).

2. SATELLITE SAMPLE

The sample of satellite galaxies around isolated primaries was obtained from the 2dFGRS data set as of 2001 December. The details of how we identify the satellites and primaries within the survey and the tests on the robustness on the method used are given in Norberg et al. (2002). However, in order to be complete, we briefly repeat the steps of this satellite selection scheme below, which follows that developed by Zaritsky et al. (1993). The criteria for isolation of the primary galaxy are more relaxed in this work than for studies of satellite galaxy dynamics. Using the full 2dFGRS redshift catalog, containing over 200,000 galaxies, we first select regions of sufficiently high redshift completeness. We then loop over all galaxies that are at least 2.2 mag brighter than the magnitude limit of the 2dFGRS and localize the galaxies that are isolated. A bright galaxy is isolated and considered as a primary if all its neighboring galaxies with \( \Delta V = |V^{\text{prim}} - V^{\text{gal}}| \leq 1000 \) km s\(^{-1}\) and within a projected distance \( \leq 500 \) kpc are such that \( b^{\text{gal}}_J > b^{\text{prim}}_J + 2.2 \).

Finally, all galaxies around a primary that are within a projected distance \( \leq 500 \) kpc and with relative velocity \( \Delta V = |V^{\text{prim}} - V^{\text{gal}}| \leq 500 \) km s\(^{-1}\) are considered as detected satellites around bright isolated galaxies. Only galaxies with a good redshift measurement will be taken up in our catalog of primaries and satellite galaxies. We also make sure, by using the full photometric 2dFGRS catalog, that
no bright galaxy without a redshift measurement lies within the projected radius of an isolated primary. In other words, we eliminate any source of contamination due to spectroscopic determination failure.

We note here that the minimum required magnitude difference between primaries and satellites is about the same as the typical foreground-background magnitude difference in the Sm01 and McK01 lensing studies. This selection makes this satellite sample particularly appropriate for determination of the lensing contamination. However, we have to point out that for most primaries we have only detected one or two satellite galaxies, this mainly being due to the limiting depth of the 2dFGRS, of typically $b_J = 19.45$. As a matter of fact, only 12 primaries in our catalog of 1227 primaries have six or more galaxy satellites around them, and we have also detected 5886 primaries without any spectroscopically confirmed satellite galaxy.

3. ELLIPTICITY DETERMINATIONS

3.1. Shape Measurements

Shapes for all satellites were taken from Automatic Plate Measuring facility (APM) scans of photographic survey plates (Maddox et al. 1990). We rotate the APM-determined shapes into a coordinate system with the y-axis along the radius vector from primary to secondary. There result two ellipticity components, which are defined by

$$ e_+ = \frac{I_{xx} - I_{yy}}{I_{xx} + I_{yy}}, \quad e_- = \frac{2I_{xy}}{I_{xx} + I_{yy}}, $$

where $I_{ij}$ are the quadratic central moments of the galaxy intensity integrated within a bounding isophote. Figure 1 illustrates the meaning of $e_+$ and $e_-$. We expect a tidal effect to be manifested as nonzero $(e_+)$. The mean $e_-$ must be zero if the universe has inversion symmetry; hence, we can use $e_-$ as a test for systematic errors.

The unweighted isophotal moments produced by the APM software are noisier and more difficult to correct for PSF distortions than more recently devised ellipticity estimators. The satellites are however all at least 1 mag above the $b_J = 20.5$ limit of the APM catalog and should hence have fairly high signal-to-noise ratio and be well resolved in the APM images. In fact, we make no correction at all for PSF effects. Crudely, the measured ellipticity $e$ will be related to the true image ellipticity $e'$ and the PSF ellipticity $e^*$ by

$$ e = (1 - R)e' + Re^*, $$

where $R$ is the ratio of the intensity-weighted moment $\langle r^2 \rangle$ of the PSF to that of the measured image. In our application, the second term has no effect, since $e^* = 0$ if the PSF orientation has no correlation with the primary-satellite vector. We can estimate the effect of the circularization factor $(1 - R)$ in the first term by noting that the measured satellite shapes have $\langle e_+^2 \rangle = \langle e_-^2 \rangle = (0.31 \pm 0.01)^2$. This measured value will be a factor $(1 - R)^2$ smaller than the intrinsic $\langle e_+^2 \rangle$ of the population. Bernstein & Jarvis (2002, hereafter BJ02) find the rms intrinsic ellipticity of high surface brightness galaxies in the nearby universe to be 0.30. If the intrinsic shapes of satellites are similar to those of high surface brightness galaxies in an apparent magnitude–limited sample, then the circularization factor $1 - R$ is unity to within 10% or so. BJ02 find an rms ellipticity of 0.48 for the lowest surface brightness subset of nearby galaxies. If the satellites have this intrinsic dispersion, then $(1 - R) \approx 0.6$. But the higher shape dispersion of low surface brightness galaxies is due to a preponderance of disk galaxies, which should be largely absent from the satellite sample. This prejudice is reinforced by the observation that the distribution function for $|e|$-values for the satellites is very similar to BJ02’s distribution function for high surface brightness galaxies (their Fig. 4). It therefore seems more likely that there is negligible PSF circularization in the APM ellipticities, so we will not make any correction for the $1 - R$ term.

As a further check on the possibility of PSF circularization, we split the satellite galaxies into a bright half ($b_J < 18.8$) and a faint half ($b_J > 18.8$). The brighter half is presumably nearer and better resolved than the fainter half, so a substantial circularization effect would be manifested as a lower rms ellipticity for the fainter half. The rms ellipticities $\langle e_+^2 \rangle^{1/2}$ of the brighter and fainter subsamples are $0.355 \pm 0.008$ and $0.298 \pm 0.007$, respectively. The circularization of the fainter half is hence a $\approx 15\%$ effect; the fainter galaxies could also just be intrinsically rounder.

3.2. Mean Ellipticities

An unweighted average of the 1819 satellite ellipticities yields

$$ \langle e_+ \rangle = +0.004 \pm 0.008, \quad \langle e_- \rangle = +0.005 \pm 0.008. $$

In the weak-lensing measurements, one ideally weights low-c galaxies more heavily, as they offer better sensitivity to lensing shear. Such a weighted average is not justified in considering the effect of tidal forces on intrinsic satellite shapes. It is, however, relevant for assessing the contamination of weak-lensing data by satellite alignments, since the lensing data are weighted. Following BJ02, we apply a weight $w(e) = (e^2 + 0.01)^{-1/2}$ to each satellite. In this scheme, we obtain

$$ \langle e_+ \rangle = +0.002 \pm 0.007, \quad \langle e_- \rangle = +0.007 \pm 0.007. $$
There is clearly no significant detection of net satellite alignment, in either component, and the $e_x$-values show that our uncertainties are sensible.

As illustrated in Figure 2, no alignment is detected even when we restrict the sample to the smaller projected radii where tidal effects should be stronger. We have also tested for alignment in the half of the galaxies that have primaries brighter than $M_{B_J} = -21.5$. The unweighted mean $\langle e_x \rangle = +0.025 \pm 0.012$, a $2 \sigma$ signal, but the weighted mean is only $1.4 \sigma$ nonzero and there is no detection of real significance. Further restricting the sample to small projected radii does not increase the measured mean.

4. IMPLICATIONS

4.1. Tidal Distortions of Satellites

Equation (3) indicates that, for satellites within 500 kpc projected radius, the mean radial or circumferential elongation is less than 2% in projection at 95% confidence. We wish to place some bound on the three-dimensional satellite shapes from the limit on the projected shape. We now define a parameter $\epsilon$ that characterizes the mean departure of satellite shapes from spherical symmetry. We place a Cartesian coordinate system on each satellite such that the $y$-axis is along the primary-satellite radius vector and the $z$-axis is perpendicular to both the line of sight and the $y$-axis. The luminosity distribution of each satellite has second central moments $I_{xx}$, $I_{yy}$, and $I_{zz}$ in this system. Because the ensemble of primary-satellite systems must be isotropic with respect to the line of sight, the mean transverse moments must satisfy $\langle I_{xx} \rangle = \langle I_{zz} \rangle$. We can then quantify the mean tidal distortion by defining $\sigma^2$ and $\epsilon$ such that

$$\langle I_{xx} \rangle = \langle I_{zz} \rangle = \sigma^2(1 - \epsilon/2),$$

$$\langle I_{yy} \rangle = \sigma^2(1 + \epsilon).$$

A positive value of $\epsilon$ would indicate the presence of a radial elongation from tidal effects. It is also possible that a nonzero $\epsilon$ could arise if satellites tend to be found along and align with the dark matter filaments that are believed to underly the large-scale distribution of galaxies. We are not aware of any theoretical estimates of the size (or sign!) expected of such an effect.

If there is no absorption in the galaxy, then the mean projected second moments can be simply related to the intrinsic elongation $\epsilon$ via

$$\langle e_x \rangle = \epsilon/2.$$

We may thus bound the mean radial asymmetry of satellites to be $\langle \epsilon \rangle < 4\%$ at 95% confidence.

4.2. Weak-Lensing Measurements

Equation (4) implies that the population of satellites will produce a false lensing distortion of $|\delta| < 0.016$ at 95% confidence. Fischer et al. (2000) measured the angular correlation between foreground and “background” samples and inferred that the pollution of the “background” sample by neighbors of the foreground galaxy—that is, satellites—is about 15% within impact parameters of 60 $h^{-1}$ kpc. The contamination in Sm01 is significantly lower, 10% at most. Hence the deleterious effect of satellite alignment will be significantly diluted at these radii and will be even weaker at larger radii. For the Sm01 data, we may conclude that the false distortion signal produced by aligned satellites satisfies

$$|\delta_{\text{false}}| < 0.0016$$

at 95% confidence within 60 $h^{-1}$ kpc impact parameter. Since Sm01 detect a mean distortion of $\delta \approx 0.008$ at this impact parameter around an $L_*$ galaxy at $z = 0.1$, the error due to satellite alignments is at most a 20% effect. We cannot yet conclude that the effect is totally negligible, but this is likely the case, especially at larger impact parameters, where the satellite fraction is smaller and the tidal effect drops more rapidly than the lensing shear.

Larger and deeper satellite samples containing more primaries with many satellite galaxies each may reveal a significant alignment, and future galaxy-galaxy lensing measurements will be aiming for higher precision. If the satellite alignments do ultimately pose a barrier to high precision, then their deleterious effect could be eliminated by using photometric redshift estimates to exclude the bulk of the satellite population from the sample of lensed background galaxies. Satellite alignments do not, however, seem to be a problem for current galaxy-galaxy lensing data.

We are grateful to the 2dFGRS team for allowing us to use their data prior to publication, and to Carlos Frenk for useful discussions. The 2dFGRS is being carried out using the Two Degree Field facility on the 3.9 m Anglo-Australian Telescope (AAT). We thank all those involved in the smooth running and continued success of the 2dF and the AAT. This work was supported in part by grant AST 96-24592 from the National Science Foundation and in part by a PPARC rolling grant at Durham. P. N. is supported by the Swiss National Science Foundation and an Overseas Research Students award.
REFERENCES

Bernstein, G. M., & Jarvis, M. 2002, AJ, 123, 583 (BJ02)
Brainerd, T. G., Blandford, R. D., & Smail, I. 1996, ApJ, 466, 623
Colless, M., et al. 2001, MNRAS, 328, 1039
Dohm-Palmer, R. C., et al. 2001, ApJ, 555, L37
Fischer, P., et al. 2000, AJ, 120, 1198
Maddox, S. J., Sutherland, W. J., Efstathiou, G., & Loveday, J. 1990, MNRAS, 243, 692
McKay, T. A., et al. 2001, ApJ, submitted (astro-ph/0108013) (McK01)
Norberg, P., et al. 2002, in preparation
Sheetman, S. A., Landy, S. D., Oemler, A., Tucker, D. L., Lin, H., Kirshner, R. P., & Schechter, P. L. 1996, ApJ, 470, 172
Smith, D. R., Bernstein, G. M., Fischer, P., & Jarvis, M. 2001, ApJ, 551, 643 (Sm01)
Tyson, J. A., Valdes, F., Jarvis, J. F., & Mills, A. P., Jr. 1984, ApJ, 281, L59
York, D. G., et al. 2000, AJ, 120, 1579
Zaritsky, D., Smith, R., Frenk, C., & White, S. D. M. 1993, ApJ, 405, 464