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GALAXY CLUSTERING AS A FUNCTION OF SURFACE BRIGHTNESS

MARC DAVIS[1,2] AND S. DJORGOVSKI[1]
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ABSTRACT

Using diameters and magnitudes of galaxies listed in the Nilson catalog, we examine the angular correlation properties of high– and low–surface brightness galaxies. The low–surface brightness galaxies are less tightly clumped than the higher surface brightness galaxies; they also fill in some conspicuous holes in the distribution of the high–surface brightness galaxies. The angular correlations are weaker and shallower for the low–surface brightness galaxies; when account is taken for the differing redshift distribution of the subsets, we find the spatial clustering length scale to be a factor of two smaller than for the high–surface brightness galaxies. This finding demonstrates that galaxy formation must have been dependent on the large-scale clustering environment and suggests that the luminous galaxy distribution may not be a fair tracer of the mass distribution on any scale. Although the effect is apparent from the sky-projected angular correlations, the relative amplitudes of the spatial clustering must be regarded as preliminary because they are derived from an incomplete and possibly biased redshift sample.

Subject headings: cosmology — galaxies: clustering — galaxies: formation

I. INTRODUCTION

Over the past decade the two-point correlation function of galaxies $\xi(r)$ has proved to be the most quantitative measure of galaxy clustering (see Fall 1979 and Peebles 1980 for reviews). It is a robust statistic, with an amplitude and power-law slope that is quite reproducible from sample to sample. To understand the evolution of clustering in the universe, we must know how the galaxy correlations are related to the underlying mass distribution. If the galaxy clustering fairly traces the mass distribution on scales in excess of ~ 500 kpc, we live in an open universe ($\Omega_0 \approx 0.2$) (Davis and Peebles 1983). Numerical simulations confirm that the random peculiar velocity field of galaxies is not consistent with $\Omega_0 = 1$ if galaxies fairly trace the mass distribution (Aarseth, Gott, and Turner 1979; Efstathiou and Eastwood 1981; Davis *et al.* 1985).

Most studies of galaxy correlations use magnitude-limited galaxy samples. For a Schechter luminosity function (Schechter 1976) the galaxies thus selected are predominantly L_* galaxies. Because the luminosity function for spirals and ellipticals is very nearly identical, there is no bias in morphological selection. It is known that the correlation function of elliptical galaxies is steeper and of higher amplitude than that for spirals (Davis and Geller 1976; Dressler 1980). However, the spiral pairs outnumber the elliptical pairs by a factor of ~ 20, so that the overall bright galaxy correlations are dominated by the spirals. These correlations are dominated by galaxies of reasonably high surface brightness (SB).

The mass directly associated with the luminous parts of galaxies is quite small, amounting to a contribution of $\Omega_g < 0.01$. Presuming that galaxies are fair tracers of the much larger underlying mass distribution, we should expect $\xi(r)$ to be unchanged whether measured with giant or dwarf galaxies, if the present morphological appearance and luminosity of a galaxy are random variables established prior to the formation of large-scale structure. One tracer should be as good as another if galaxies are fair tracers of the mass distribution. We already know that this ignores environmental effects, which is the usual explanation for the enhanced clustering of ellipticals. In this *Letter* we shall demonstrate that $\xi(r)$ is sensitive to the intrinsic properties of the galaxy sample even after controlling for the different clustering properties of spirals and ellipticals. Because SB is independent of distance for low redshift, it is a convenient parameter for subdividing a large galaxy sample. We find a systematic trend of clustering amplitude with SB of the galaxies; low–SB galaxies are significantly less clustered than high–SB galaxies. The effect is not simply the result of stripping of low–SB galaxies in denser regions, although that effect may also be present. We find low SB to be less concentrated in the high density regions and also to fill in some of the low density voids in the distribution of the high–SB galaxies.

II. THE DATA SET

The data set for our analysis in the *Uppsala General Catalog of Galaxies* (UGC) (Nilson 1973). This catalog lists the diameters, ellipticities, morphological types, and Zwicky magnitudes (or Nilson's estimates) for each galaxy. The catalog lists all galaxies with $\delta \geq -2\overset{\circ}{.}5$ and with diameter greater than 1′. It is a diameter-limited, rather than a magnitude-limited, catalog and reaches to rather low SB (26 mag arcsec^{-2}). We do not know how complete the sample is at low SB, but as long as the completeness is uncorrelated with position on the sky, our analysis is unaffected. The magnitude estimates for the low–SB objects are presumably rather coarse; again, our analysis is not affected provided the errors are random.

With the available information it is straightforward to derive rudimentary SB information, viz., the mean Zwicky SB within the Nilson isophote. We limit our analysis to galaxies with $|b_{II}| \geq 20°$. The galactic absorption lowers the mean SB in a nontrivial way: both the apparent magnitude and isophotal diameter change in a mutually (partly) compensating way, but with the overall effect of lowering the mean SB. The clustering amplitude decreases for all samples by 10%–20% when the galactic limit is changed from 20° to 30° which is a small effect; we use the 20° limit because it includes the Perseus cluster. We

[1] Astronomy Department, University of California, Berkeley.
[2] Physics Department, University of California, Berkeley.

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exclude the southern galactic cap galaxies with $6^h > \text{R.A.} > 3^h$, where obscuration is known to be substantial.

We divide the catalog into morphological types: ellipticals ($T \leq -4$), lenticulars ($-3 \leq T \leq 0$), and spirals/irregulars ($T \geq 1$). For each morphological type we derive the median [SB(50%)] and quartile [SB(25%) and SB(75%)] points of SB distribution. The medians for the three morphological groups are 23.39, 23.24, and 23.48, in units of Zwicky magnitudes arcsec^{-2}. Within each morphological group, we form the subsamples with SB > SB(50%), SB < SB(50%), SB > SB(75%), and SB < SB(25%), and then merge the corresponding SB–selected subsamples of different morphologies together. By this scheme we at least partially compensate the known tendency for ellipticals to cluster more strongly than spirals. The upper quartile SB galaxies have a median SB 7.5 times that of the lower quartile galaxies. The SB distributions are quite similar for all morphological types, which may seem surprising but results because the diameter is chosen at approximately the 26th mag arcsec^{-2} isophote. If more central measures of SB were available, the morphological types would certainly be quite separated and the amplitude of the effect reported here would presumably increase.

In order to estimate the redshift distributions for the subsamples, we matched the UGC with the general redshift catalog compiled by J. Huchra. This redshift list contains the CfA sample (Huchra *et al.* 1983) plus most other known redshifts of nearby galaxies. The redshift completeness as a function of SB, as expected, increases for higher SB galaxies, although the completeness increases also for the lowest SB, which are all nearby, relatively well-studied dwarf galaxies. The heliocentric redshift distribution is plotted in Figure 1 for the upper and lower quartile SB subsets of the catalog; plots are shown for the entire UGC sample and for its small southern subsample ($b < -20$, $19^h < \text{R.A.} < 3^h$) separately.

We also constructed histograms of the redshift distribution in which each galaxy is inversely weighted by the completeness at its SB. (The completeness fraction varies by more than a factor of 3.) These histograms are indistinguishable from Figure 1, suggesting that SB is not an important selection criterion at a given redshift. Since a good fraction of the low–SB redshifts were obtained by Fisher and Tully (1981) using a 21 cm system insensitive to galaxies with $z > 0.01$, we must conclude that the more distant objects are not in the UGC, presumably because their size drops below the catalog limit.

Thus, we believe the available redshift distributions for our SB–selected samples are reasonably fair representations of the complete data base. Median redshifts for the selected subsets are listed in Table 1. The number of most significance for our analysis is the ratio of the median distances of the high–SB to low–SB samples; it is unlikely that a complete redshift sample will reduce this ratio below unity. The lower SB is comprised

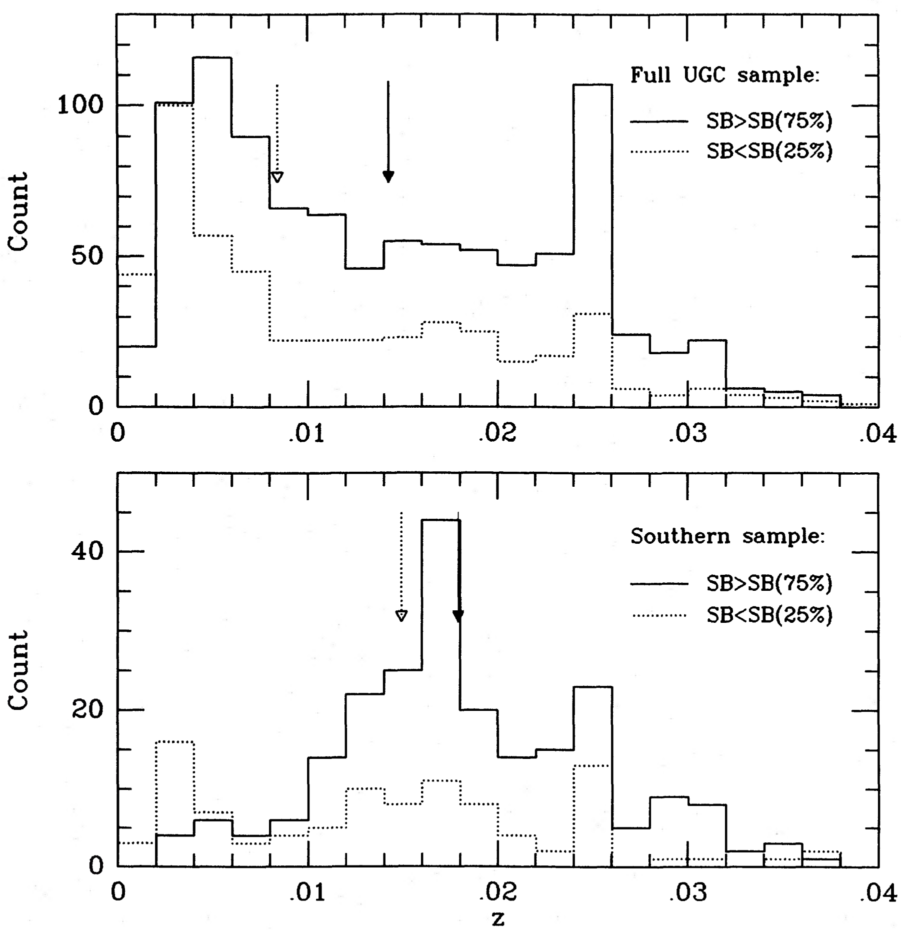

FIG. 1.—(*top*) Radial velocity distribution for those galaxies in the upper and lower quartiles of surface brightness with measured redshift. Median redshifts are indicated by the arrows. (*bottom*) The same for galaxies drawn only from the southern galactic sample.

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TABLE 1

CLUSTERING PARAMETERS FOR SURFACE BRIGHTNESS–SELECTED SAMPLES WITH $|b_{II}| \geq 20°$

Sample	Number	SB_{med}	z_{med}	β	B	A	r_0[a]
Full SB > SB(50%)	5161	22.8	0.0153	0.60	0.67	10.6	4.4
Full SB < SB(50%)	5175	24.1	0.0137	0.57	0.62	5.8	3.2
Full SB < SB(75%)	2595	22.4	0.0143	0.64	1.02	15.3	5.3
Full SB < SB(25%)	2593	24.6	0.0084	0.44	0.78	3.7	2.5
South SB > SB(75%)	724	22.6	0.0179	0.83	1.01	30.3	6.5
South SB < SB(25%)	724	24.8	0.0149	0.38	0.76	3.7	2.6

[a] h^{-1} Mpc.

largely of dwarf galaxies seen to somewhat smaller redshifts than the higher SB sample. The luminosity distribution for these subsets confirm this behavior, although the lower SB distribution is bimodal, with approximately half the galaxies with measured redshift overlapping that of the upper quartile sample. Median redshifts for the high–SB and low–SB galaxies are quite different in the full UGC sample, but not as different in southern galactic cap sample. The foreground Virgo supercluster dominates the full UGC sample for the low–SB galaxies, but the southern galactic sky is dominated by the anti-Virgo void in the foreground and the more distant Perseus supercluster, which leads to the completely different redshift distribution.

III. THE ANALYSIS OF CLUSTERING

Figure 2 shows the distributions on the sky for the upper quartile [SB > SB(75%)] and lower quartile [SB < SB(25%)] samples. Some clustering differences are apparent on sight: there is more of the small-scale clustering in the high–SB sample, and there are voids (e.g., the Perseus-Pisces void at R.A. $\approx 1^h$), which are absent from the low–SB sample. The high–SB galaxies appear to be better delineators of large-scale coherence in the structure.

In order to quantify the clustering differences, we compute the two-point angular correlation function $w(\theta)$, using the method described by Sharp (1979) and Hewett (1982), with results shown in Figure 3. The high–SB galaxies cluster more strongly, and this trend is proportional to the SB contrast between the samples. The differences are more prominent on small angular scales ($\theta < 1°$). We parameterize the autocorrelation functions by fitting them to a power-law form:

$$w(\theta) = B\theta^{-\beta}$$

for $\theta < 10°$. The fit parameters are listed in Table 1. The power-law fit is clearly a crude approximation to the data, but a more precise fit would not be informative. We can now use our limited redshift information to estimate roughly the spatial clustering differences for our samples. For power-law clustering, we can write the spatial autocorrelation function as:

$$\xi(r) = Ar^{-(1+\beta)} .$$

The redshift space distribution can be used to relate A to B. We presume the redshift space distribution matches that of a homogeneous universe, except for $cz < 3000$ km s^{-1}, where the Virgo supercluster has effectively increased the density by a factor of 2 (average of northern and southern hemispheres; see, e.g., Davis and Huchra 1982). Given the space distribution, power-law correlations can be trivially inverted (Peebles 1980, § 52). This procedure is better than a simple scaling argument because the shapes of the redshift distributions change for the different SB samples. The results are listed in Table 1. The correlation length scale r_0, [$\xi(r) = (r/r_0)^{-\gamma}$] is also listed for each subsample. The main point to note is that the spatial clustering length scale for the low SB samples is a factor of 2 less than for the high SB samples, and that the amplitude of the high SB samples matches that of magnitude-limited samples, viz., $r_0 \approx 5h^{-1}$ Mpc. The sign of the effect is discernible simply from the angular distribution; the amplitude will remain somewhat uncertain until more redshift data are available. The effect in spatial clustering cannot be smaller than the effect in projected (angular) clustering, since the low–SB galaxies are certainly not more distant (in the average) than the high–SB galaxies. These results are quite consistent with those of Sharp, Jones, and Jones (1978) who compared the clustering properties of DDO dwarfs to Zwicky galaxies. Additionally, within the errors, our results are not inconsistent with the measured clustering of companion dwarf galaxies about spirals (Lake and Tremaine 1980).

IV. IMPLICATIONS

We seem to have found a component of the universe less clustered than galaxies typically included in correlation studies. Does this imply that the properties of a galaxy are preordained at birth to be correlated with its present clustering environment, or is the observed effect entirely due to environmental processes operating after the formation of groups and clusters? Perhaps tidal disruption has preferentially eliminated low–SB galaxies in a cluster environment. If such an effect were responsible for the diminution of the low–SB galaxies in clusters, we would expect observable tidal truncation in the outer isophotes of practically all galaxies in clusters relative to less clustered galaxies. Such an effect may have been observed in the central regions of rich clusters like Coma (Strom and Strom 1978) but is generally not observed in the poorer groups and clusters typical for this catalog and the universe. The possibility of increased mergers in the higher density regions is also an unlikely explanation for the observations, since mergers will lead to decreased surface density unless the merger process is nonhomologous or dissipational.

If the SB–clustering correlation is to be entirely in terms of pregalactic conditions, the clear implication is that there was substantial crosstalk between large-scale and small-scale structure formation, as would be expected either in a "top-down" scenario (e.g., a universe dominated by massive neutrinos) or in a hierarchical scenario with sufficient power on large scales (e.g., a universe dominated by cold dark matter). In other words, the SB correlations are quite inconsistent with the expectations of a purely hierarchical model of isothermal initial conditions.

What can we infer about the underlying matter clustering

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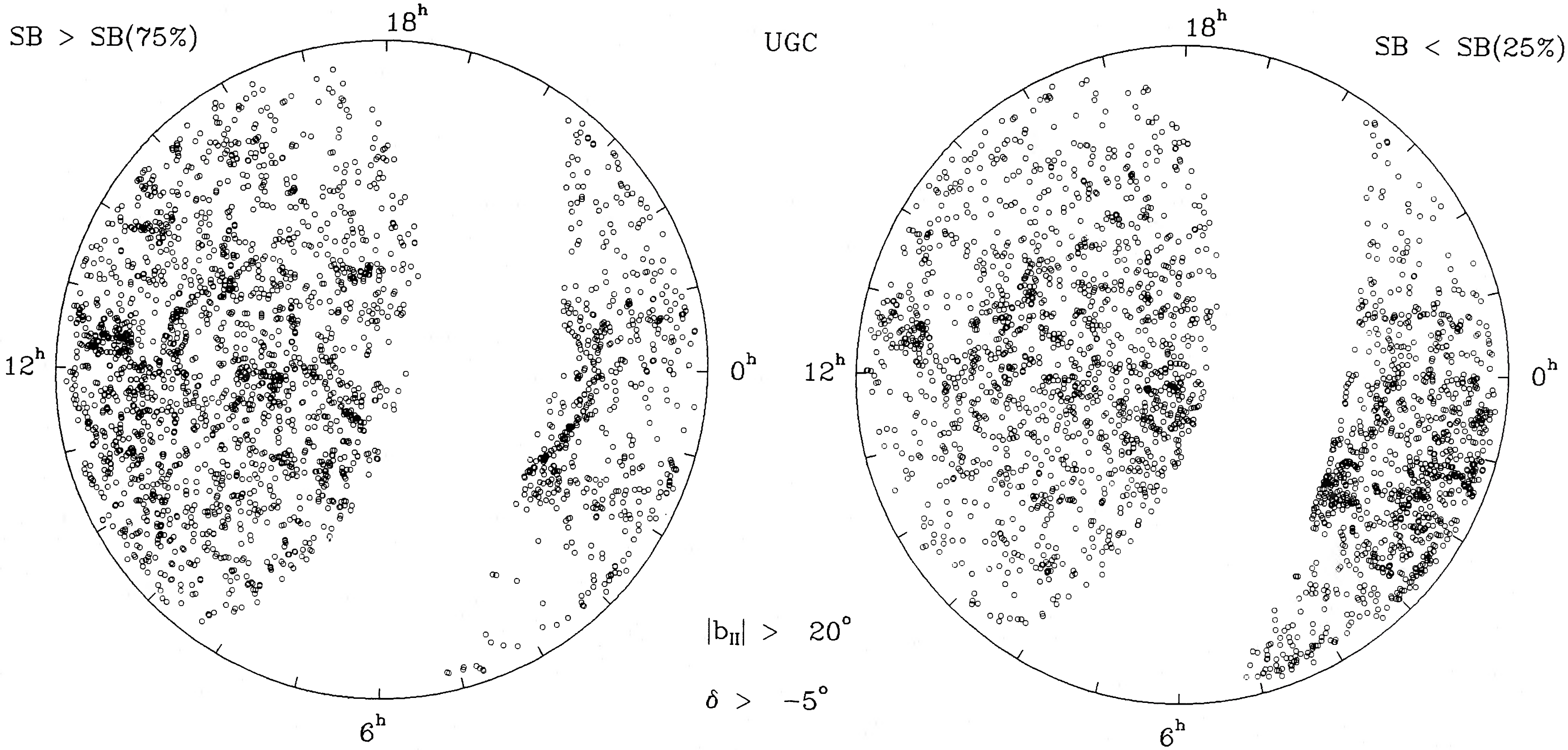

FIG. 2.—(*left*) Projected distribution on the sky for the upper quartile (high) surface brightness sample. (*right*) The same, but for the lower quartile (low) surface brightness sample. The excised band corresponds to $|b_{II}| < 20°$.

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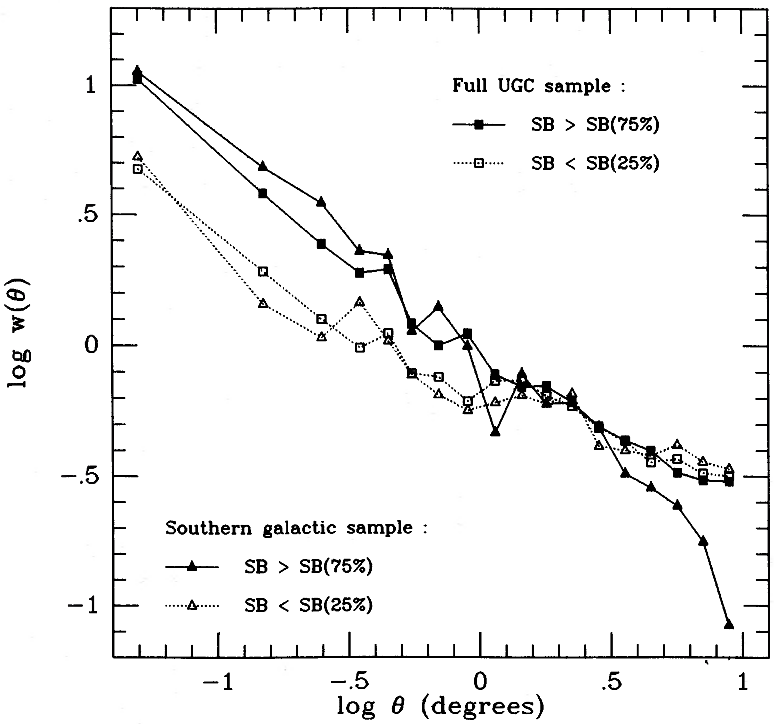

FIG. 3.—Angular two-point autocorrelation functions for the galaxies with surface brightness in the upper and lower quartiles of the surface brightness distribution in the full and southern samples.

from our results? If we knew that the mass-to-light ratio were the same for all galaxies, we would still conclude the bright galaxies trace the mass, because they overwhelmingly dominate the luminosity density of the universe. There are, however, alarming reports that the masses of galaxies as inferred from binary galaxy studies are practically independent of luminosity. Such a result applies both to L_* galaxies (White *et al.* 1983) and to a meager sample of DDO dwarfs in binary pairs (Lake and Schommer 1984). These results together suggest the possibility that the high–SB galaxies may not be a fair mass tracer on any scale and are more clustered than the universe as a whole. Such a possibility has been suggested by Kaiser (1984) and its implications have been discussed by Kaiser (1985), Bardeen (1985), and Bardeen *et al.* (1985). If high–SB galaxies formed only where the initial density contrast exceeded a fixed threshold at some past epoch, then their present correlation properties will indeed be biased in the desired sense.

This mechanism works particularly well if there is considerable power on large scales, as in a universe dominated by cold dark matter (Peebles 1982; Bond and Efstathiou 1984; Blumenthal and Primack 1983). Numerical simulations of large-scale clustering are not consistent with all the observational constraints for any value of Ω_0 if galaxies trace the mass density; if, however, they are biased by the above recipe, the match to observation is much improved (Davis *et al.* 1985). If indeed this is the correct explanation of the SB–clustering effect, then measurement of cluster masses underestimates Ω_0 by a nonnegligible factor.

Further observational progress on this subject will require much more complete redshift sampling of the low–SB galaxies. Improved magnitude and diameter estimates would also be welcome. It is not inconceivable that systematic errors in Zwicky magnitudes and/or Nilson diameters correlated with position are responsible for a part of this curious effect. Future progress in the theory of galaxy formation will hopefully tell us someday how and if high–SB galaxies could become biased mass tracers.

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MARC DAVIS: Department of Astronomy, 601 Campbell Hall, University of California, Berkeley, CA 94720

S. DJORGOVSKI: Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

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