The Clustering of Faint Galaxies on Small Angular Scales

Tereasa G. Brainerd and Casey J. Law

Boston University, Dept. of Astronomy, Boston, MA 02215

James Brauher

IPAC, California Institute of Technology, Pasadena, CA 91125

S. G. Djorgovski and Ken Banas

California Institute of Technology, 105-24, Pasadena, CA 91125

Abstract. We present a preliminary measurement of the angular clustering of faint \( R \leq 25 \) field galaxies in which we concentrate on the behavior of \( \omega(\theta) \) on small angular scales \( \theta < \sim 10'' \). The galaxies are strongly clustered and \( \omega(\theta) \) is well-characterized by a power law of the form \( A_\omega \theta^{-\delta} \). The best-fitting value of the power law index, \( \delta \), is, however, steeper than the fiducial value of \( \delta = 0.8 \), indicating that there are more pairs of galaxies separated by \( \theta < \sim 10'' \) in our sample than would be otherwise expected. Using the best-fitting form of \( \omega(\theta) \), we estimate that \( \sim 10\% \) of the galaxies are in physically close pairs (separations \( \lesssim 21 h^{-1} \) kpc). This is a factor of order 2 larger than local galaxy samples but comparable to galaxy samples with \( \langle z \rangle \sim 0.4 \). The mean redshift of our galaxies is of order 0.95, and, therefore, our result suggests that there was little or no evolution in the merger rate of galaxies between \( z \sim 1 \) and \( z \sim 0.4 \).

1. Introduction

The angular clustering of faint \( R \)-selected field galaxies has been studied extensively (e.g., Efstathiou et al. 1991; Roche et al. 1993, 1996; Brainerd, Smail & Mould 1995; Hudon & Lilly 1996; Lidman & Peterson 1996; Villumsen, Freudling & da Costa 1996; Woods & Fahlman 1997), and a prime motivation of these studies has been to investigate the nature of the faint field population. In particular, it is possible to infer the effective correlation length of the sample and the rate at which clustering evolves from a combination of the amplitude of the angular autocorrelation function, \( \omega(\theta) \), and the redshift distribution of the faint galaxies, \( N(z) \). These observations can then be used to link properties of the faint field population with samples of local galaxies. While the exact interpretation remains controversial, it is generally accepted that overall \( \omega(\theta) \) is fitted well by a power law of the form \( \theta^{-0.8} \) (although see Infante & Pritchet (1995) for evidence of a flattening in the power-law coefficient at faint limits).

Here we investigate the clustering of faint galaxies and focus on the behavior of \( \omega(\theta) \) at small angular separations. We obtain a clear measurement of \( \omega(\theta) \) on
scales of $\theta < 10''$ whereas previous investigations have been largely limited to scales of $\theta \gtrsim 20''$. Additionally, we use the clustering properties of the galaxies to estimate the number of pairs of galaxies that are physically close to each other in space (separations of $\lesssim 21 h^{-1}$ kpc).

2. Observations

The data consist of deep $R$-band imaging of 11 independent fields that were obtained in good conditions with the Low Resolution Imaging Spectrograph on the 10-m Keck-I telescope. Each of the $6' \times 8'$ fields is centered on a high redshift quasar with high galactic latitude; however, the presence of the quasar in the field is irrelevant to the present investigation (i.e., the presence of a small group of galaxies at the redshift of the quasar will not influence the results below). The galaxy catalogs are complete to $R = 25.0$ and the apparent magnitudes of the galaxies have been corrected for extinction. In order to reduce the stellar contamination in the object catalogs, only objects with $R \geq 21$ are considered in the analysis below. There is, of course, some residual stellar contamination of the galaxy catalogs at faint limits and we estimate that to be: $\sim 16\% (21.0 \leq R \leq 24.0)$, $\sim 13\% (21.0 \leq R \leq 24.5)$, $\sim 11\% (21.0 \leq R \leq 25.0)$. The integral constraints vary little from field to field due to the use of the same detector in all cases as well as the lack of very large, bright galaxies in the fields.

3. Analysis and Results

To compute the angular clustering of the faint galaxies we use the Landy & Szalay (1993) estimator:

$$\omega(\theta) = \frac{DD - 2DR + RR}{RR}$$  \hspace{1cm} (1)

where $DD$, $DR$, and $RR$ are the number of unique data-data, data-random, and random-random pairs within a given angular separation bin. Regions of the frame where faint galaxy detection was either lower than average or impossible (e.g., due to the presence of bright stars and galaxies) were masked out when computing $DR$ and $RR$. Raw correlation functions (uncorrected for stellar contamination or the integral constraint) were determined for each of the fields, from which a mean correlation function was computed.

The results for the mean raw correlation function are shown in Figure 1, where the error bars show the standard deviation in the mean. From top to bottom, the panels show the results for objects with $21.0 \leq R \leq 24.0$, $21.0 \leq R \leq 24.5$, and $21.0 \leq R \leq 25.0$, respectively. Also shown are the formal best-fitting power laws of the form $\theta^{-\delta}$ (solid lines) and the best-fitting power laws of the form $\theta^{-0.8}$ (dashed lines). The power laws in the figure have been suppressed by the appropriate integral constraints and no correction for residual stellar contamination has been applied.

The number of pairs of galaxies that we observe to be separated by $\theta \sim 3''$ is larger than the number predicted by the fiducial $\theta^{-0.8}$ power law (i.e., the power law that is typically obtained from measurements that have been performed on

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scales of $\theta \gtrsim 10''$). This is consistent with the results of Carlberg et al. (1994) and Infante et al. (1996) who both found $\omega(\theta)$ to have a higher amplitude on small angular scales ($\theta \lesssim 6''$) than a simple inward extrapolation of $\omega(\theta)$ as measured at large angular scales. As yet, however, it is unclear whether the steepening of $\omega(\theta)$ is due to the existence of a population of “companion” galaxies (which are not seen at the present epoch) or luminosity enhancement (e.g., due to interactions) of intrinsically faint galaxies that are in pairs.

In the absence of significant luminosity enhancement, we can estimate the number of pairs of galaxies that are physically close to each other simply by using the following probability:

$$P = \int_\beta^\theta 2\pi \rho \alpha \exp(-\pi \rho \alpha^2) \, d\alpha$$

(e.g., Burkey et al. 1994), where $\rho$ is the number density of galaxies brighter than the faintest member in a pair of galaxies that is a candidate for close physical separation, $\theta$ is the observed angular separation between the galaxies, and $\beta$ is the smallest separation observed between all detected galaxies ($\beta \sim 1''$ in our data). Using Eqn. (2) we compute the number of pairs of galaxies for which $P \leq 0.05$ and $P \leq 0.10$ in our data. Additionally, we use Monte Carlo simulations (in which the magnitudes of the galaxies are shuffled at random) to calculate the number of pairs of galaxies that would have $P \leq 0.05$ and $P \leq 0.10$ simply by chance. The latter step allows the removal of random superpositions from the estimate of the “true” number of close pairs in the sample.

Figure 1. Mean correlation functions computed using the 11 independent estimates of $\omega(\theta)$ that were obtained in each magnitude bin.
Below $\theta \sim 3''$ there are fewer pairs of galaxies with $P \leq 0.05$ and $P \leq 0.10$ in the actual data than are expected in a random distribution (i.e., based on the Monte Carlo simulations), indicating that we are undercounting the very closest pairs due to blending of the images. Using our measured $\omega(\theta)$, however, we can correct the faint pair counts on scales $1'' \leq \theta \leq 2''$ and estimate the fraction of galaxies in our sample that are in truly close physical pairs.

Based on a simple extrapolation of the CFRS redshift distribution, we expect that the mean redshift of our galaxies is $\sim 0.95$ and, hence, if $\Omega_0 = 1$, physical pairs of galaxies that are separated by $\theta \leq 5''$ will be within $21h^{-1}$ kpc of each other. The best-fitting power law form of $\omega(\theta)$ (corrected for stellar contamination and the integral constraint) then yields an estimate of the pair fraction at this physical separation of $\sim 10\%$ for $P \leq 0.10$, which agrees with the results obtained by Carlberg et al. (1994) for the fraction of galaxy pairs with separations $\leq 19h^{-1}$ kpc at $\langle z \rangle \sim 0.4$. This suggests, therefore, that little evolution in the merger rate of galaxies occurred between $z \sim 1$ and $z \sim 0.4$.

4. Future Work

A significant amount of work remains to be done on this project, including a clustering analysis of 7 additional independent fields and a more rigorous study of the number of pairs of faint galaxies located at close physical separation.

Acknowledgments. Financial support under NSF contract AST-9616968 (TGB) and a Boston University Presidential Graduate Fellowship (CJL) are gratefully acknowledged. The observations were obtained at the W. M. Keck Observatory, which is operated jointly by the California Institute of Technology and the University of California. Data analysis was performed exclusively on the Origin2000 at Boston University’s Scientific Computing & Visualisation facility.

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