Clustering in the Caltech Faint Galaxy Redshift Survey

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ABSTRACT

The Caltech Faint Galaxy Redshift Survey has collected ∼2000 spectra taken with multi-slit masks using the Low Resolution Imaging Spectrograph at the Keck Observatory (Oke *et al.* 1995) in two widely separated fields on the sky, each ∼1 x 1 deg^2. Most of these objects are faint field galaxies; about 10% are Galactic stars and about 1% are broad-lined AGNs.

I summarize the small scale clustering of this sample as well as the evidence in support of large scale structure.

Subject headings:

1.   Introduction

The defining features of the Caltech Faint Galaxy Redshift Survey that distinguish it from existing and ongoing or planned surveys are that it is possible to reach to fainter magnitudes ($K \sim 20$ mag, $R \sim 24$ mag) and that completeness is emphasized rather than sparse sampling over a large field. Objects are observed irrespective of morphology so as not to exclude AGNs or other unusual extragalactic sources.

The CFGRS is working on two fields. The first field at J005325+1234. The central survey field measures 2×7.3 arcmin^2 with a statistical sample containing 195 infrared-selected objects complete to $K = 20$ mag. After several seasons of observing, a redshift completeness of 84% was achieved. There are 139 galaxies with redshifts as well as 24 spectroscopically confirmed Galactic stars and 32 objects for which spectroscopic redshifts cannot be assigned (most of these are EROs) in the $K \leq 20$ sample. There are 13 additional objects with redshifts (including two more stars) that are just outside the field boundary or are within the field but too faint. Thus in this field there are 150 galaxies with redshifts which lie in the range [0.173, 1.44].

In addition, six-color broad band photometry from 0.36 to 2.2μ is available for all these objects. For the set of galaxies with redshifts, rest frame spectral energy distributions can be derived (assuming a cosmological model) which reach far into the UV for the higher redshift objects.

A suite of papers containing all the material for the field at J005325+1234 and an analysis thereof has been published (Cohen *et al.* 1999a, Cohen *et al.* 1999b, Pahre *et al.* 1999).

Our second field is the HDF-North (Williams *et al.* 1996). Here, as described by Cohen *et al.* (2000), after several years of effort, the spectroscopy is 92% complete to $R = 24$ in the HDF itself, and 92% complete to $R = 23$ in the Flanking Fields covering a circle with diameter 8 arcmin centered on the HDF. Cohen *et al.* (2000) contains a large collection of previously unpublished redshifts as well as a compilation of all published data for the region of the HDF; see Cohen *et al.* (2000) for details. The total sample of objects with redshifts in the region of the HDF now exceeds 660.

Accompanying the spectroscopic paper is a four-color photometric catalog of the region of the HDF with high quality astrometric positions, Hogg *et al.* (2000). The R band of this catalog was used to define the spectroscopic sample completeness and the spectroscopic sample has been matched onto this R-band catalog.

To facilitate work on clustering at a scale larger than that permitted by the small solid angle subtended by the two main fields, each of the two main fields is surrounded by outrigger fields separated by up to 30 arcmin from the main field. Redshifts exist for about 500 galaxies in the outrigger fields around J005325+1234 and about 300 galaxies in the outrigger fields 30 arcmin N, S, E and W of the HDF.

We now focus exclusively on the issue of galaxy clustering in these samples.

2. Evidence for the Presence of Groups to $z \sim 1.2$

There is clear evidence for the presence of bound groups of galaxies out to $z \sim 1.2$. The best place to see this is in the HDF sample. We use a Gaussian kernel smoothing to define groups. A σ of 300 km s^{-1} is used for the signal and a much larger smoothing width is used to define the mean distribution in z of the sample. The ratio of the two functions is the overdensity Figure 1 shows the overdensity of the HDF sample as a function of z for $z < 1.25$. The membership and velocity dispersions of the groups are calculated as well; see Cohen *et al.* (2000) for details. Every field that we have looked at, both the main fields and the outrigger fields, shows similar small scale structure.
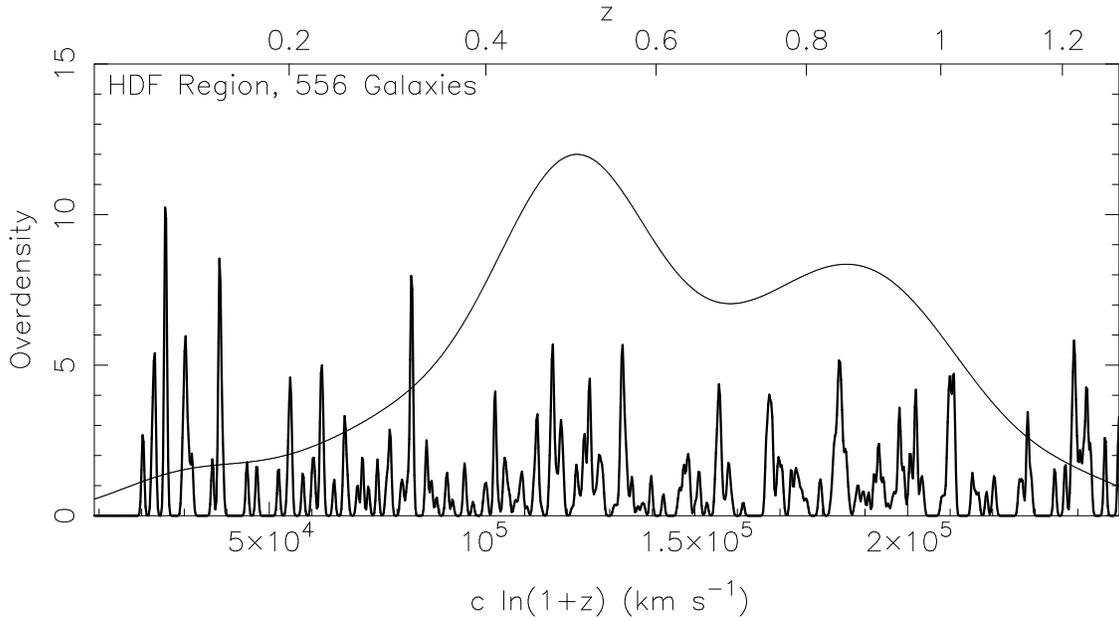
The overdensity is shown as a function of z for the HDF sample. The thin line is the heavily smoothed distribution of galaxies.

3.   A Formal Analysis of Small Scale Clustering

David Hogg has carried out an analysis of the two point correlation function from the CFGRS database as it existed roughly 6 months ago. His results are summarized in Figure 2, which shows the correlation length deduced from our work for the 1 x 1 deg^2 area of the field at J005325+1234 and for the 8 arcmin diameter field of the region of the HDF. The results are shown for three bins in z, and compared to those of several recent surveys.

This figure supports and extends earlier work which suggested that the correlation length decreases with z. There are several important caveats. There appear to be substantial field-to-field variations, particularly in the lower z bins, with the HDF showing abnormally low correlation lengths. Perhaps this has occurred because the HDF was selected to be devoid of bright galaxies. Also galaxies whose spectra are dominated by absorption lines are more strongly clustered than are galaxies with emission lines.
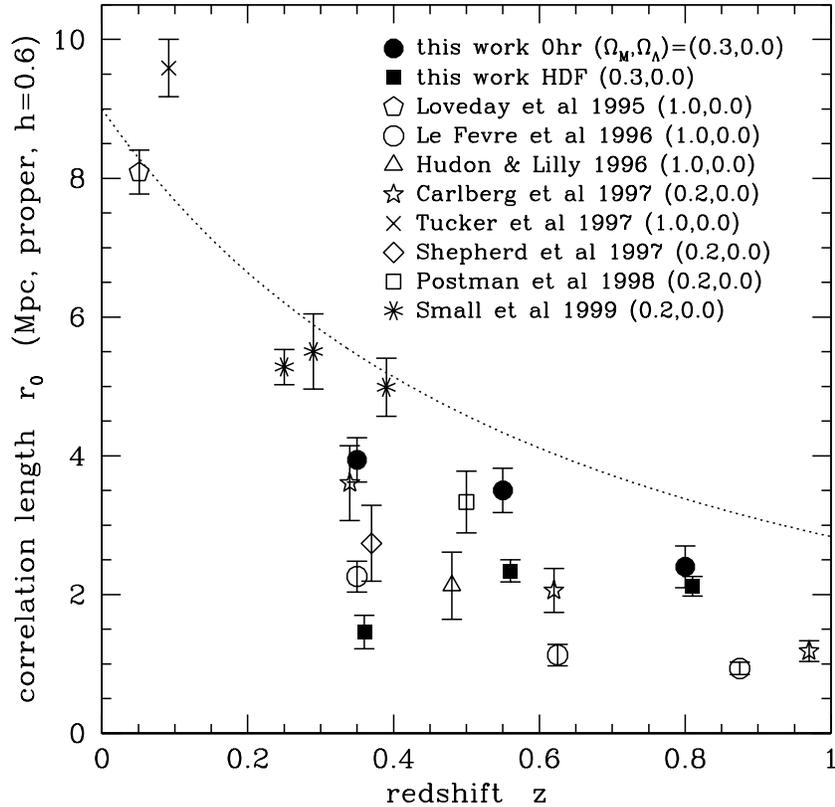
Figure 2. The correlation length is shown as a function of z for the HDF sample and for the 1x1 deg^2 sample in the field J005325+1234. Published measurements for r_0 are all converted to $H_0 = 60$ km s^{-1} Mpc^{-1}.

4. Evidence for the Presence of Large Scale Structure

There are two ways to approach this issue using our data. Given the very large sample in the HDF we can assume each group/small cluster represents the intersection of a "wall" similar to those seen locally (e.g. de Lapparent, Geller & Huchra 1986) with the line of sight to the HDF. One then examines the distance in comoving coordinates between adjacent redshift peaks in the statistically complete sample of groups to obtain Figure 3. This figure (from Cohen *et al.* 2000) shows that a characteristic separation of about 70 Mpc in our cosmology ($H_0 = 60$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$, $\Lambda = 0$) seems reasonable.
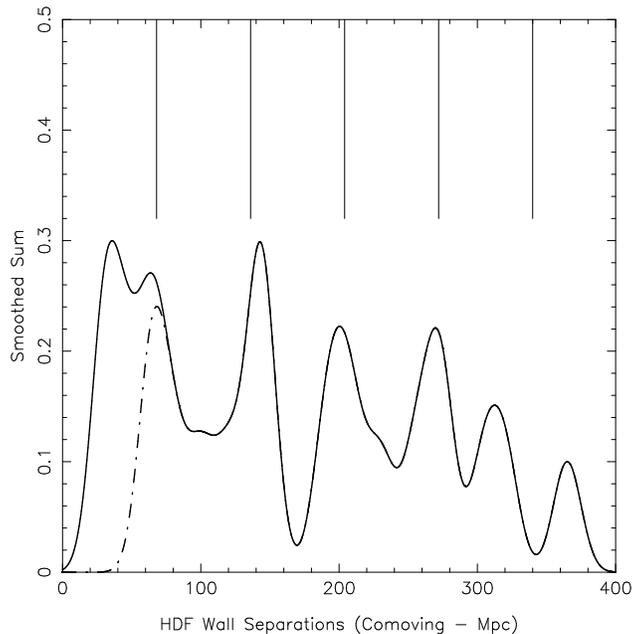
Figure 3. The difference in comoving distance along the line of sight between adjacent redshift peaks is shown for the HDF sample smoothed by a Gaussian with $\sigma = 10$ Mpc. If differences less than 50 Mpc are omitted, the dashed line is obtained. The vertical lines have a spacing of 68 Mpc. ($H_0 = 60$ km s^{-1} Mpc^{-1}.)

The second approach is look for correlations between the main field and the outrigger fields across the full 1 x 1 deg^2 area on the sky. While such attempts are still preliminary, the results are tantalizing. First one needs to establish what tolerance is allowed in $\Delta(z)$ across this field. This is discussed in Cohen *et al.* (2000); it is about 0.012 for $z \sim 1$. Figure 4 shows a comparison of the HDF with the sum of the outrigger fields around the HDF. It provides tantalizing evidence for partial coherence across a scale of 1 degree. A lot more work, and of course a bigger sample of objects with redshifts, is going to be required to produce a definitive result.

David Hogg and Roger Blandford are working on a formal analysis of this data. The non-continuous sample fields and the selection effects for the sample within each of the fields make this quite difficult.
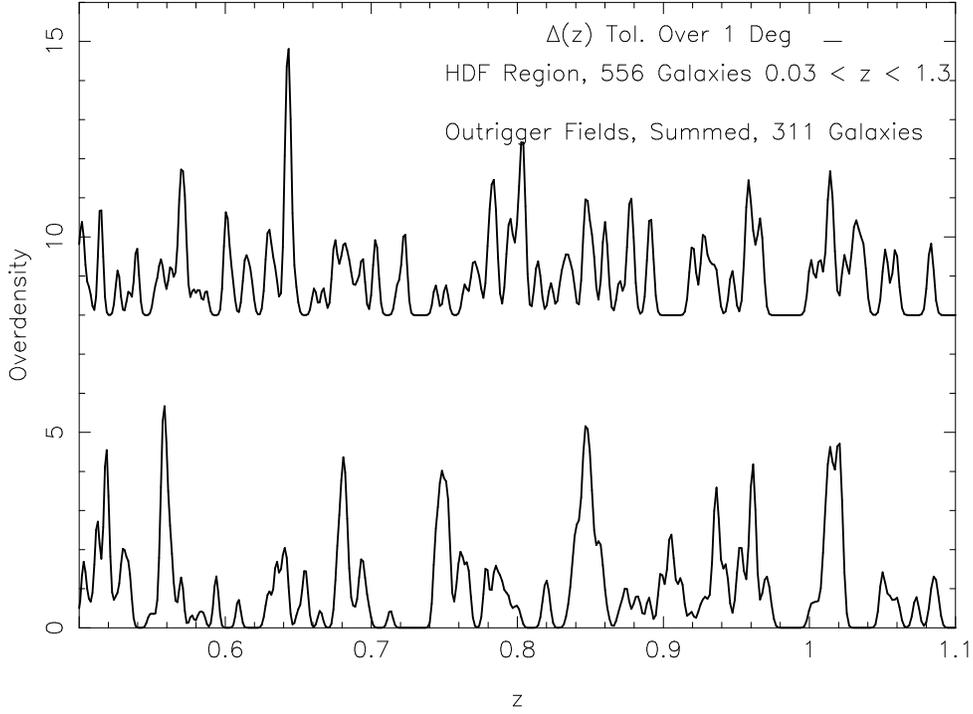
Figure 4. The overdensity group finding function is shown for the HDF for $0.5 < z < 1.1$. The overdensity function for four outrigger fields there taken together is shown shifted upward. The short horizontal line denotes the expected tolerance in matching peaks across fields 1 deg apart.

5. Summary

Our survey demonstrates very strongly that galaxies are clustered on a small scale at all redshifts up to at least $z \sim 1.2$, and that these structures are very similar in many respects such as size, velocity dispersion, and total luminosity to groups and small clusters of galaxies as seen locally.

In terms of large scale structure, our survey suggests a characteristic scale near 70 Mpc with ($H_0 = 60$ km s^{-1} Mpc^{-1}). The physical processes that could lead to such a scale being imprinted on the fluctuation spectrum are discussed in Szalay (1999). The characteristic scale we have found is significantly smaller that the deduced locally from the LCRS (Shectman *et al.* 1996) of 128 Mpc by Doroshkevich *et al.* (1996) and of 215 Mpc by Broadhurst *et al.* (1990). We do not find the strict periodicity claimed by Broadhurst *et al.*.

We offer up one final comment. Because of the ubiquitous presence of groups of galaxies, and the relatively small z separation between such, it is going to be quite difficult to use photometric redshift techniques to work on galaxy clustering problems. Photo-zs can be accurate to perhaps

10%, adequate for galaxy luminosity functions, but that is not sufficient here. This problem is going to have to be resolved the old fashioned way, with real spectroscopic redshifts, big surveys, and large samples. Its going to take a while, even with the current generation of 8 - 10 m telescopes.

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