A Progress Report on the Caltech Faint Galaxy Redshift Survey

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ABSTRACT

I review recent progress on determining the SEDs and luminosity functions for galaxies in the large magnitude limited sample in the region of the HDF-North of the Caltech Faint Galaxy Redshift Survey.

1. Spectral Energy Distributions and Galaxy Luminosity Functions

The Caltech Faint Galaxy Redshift Survey, of which I am the PI, has assembled a redshift survey, described in Cohen et al. (2000), of objects in the region of the HDF-N observed with the LRIS (Oke et al. 1995) at the Keck Observatory over the past four years. It includes redshifts for about 95% of the sample of objects in the photometric catalog of Hogg et al. (1999) with $R < 24$ within the HDF itself, and for about 93% of the sample of objects with $R < 23.5$ within a circle of diameter 8 arcmin centered on the HDF, currently 729 objects with measured $z$ in total. The analysis of this data set has commenced, and several papers from our group have already been published. Carlberg et al. (2000) discuss the kinematic pairs and their implications for the merger rate, Hogg, Cohen & Blandford (2000) analyzes clustering of galaxies, and van den Bergh et al. (2000) deals with the evolution of galaxy morphology, all to $z \sim 1$. We thus focus here on not yet published current and future work.

The logical next step is a derivation of the luminosity function for this very complete faint sample of field galaxies. We have utilized the photometric catalogs appropriate for our HDF sample and used them to derive the rest frame SEDs of the galaxies. In order to do this, one must adopt a model for the SED of a galaxy. We adopt the model of a double power law, whose index changes at 4000 Å, for $F_{\nu}$. While by no means a perfect representation of galaxy SEDs in their full complexity, this simple model permits an illuminating comparison of rest frame properties of galaxies.

A histogram of the two power law indices as a function of galaxy spectral type is shown for our sample in the region of the HDF in figures 1a,b. The galaxy spectral types are defined from our spectra and refer to the relative dominance of emission or absorption lines in our galaxy spectra. See Cohen et al. (1999a) for details.

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1Based in large part on observations obtained at the W.M. Keck Observatory, which is operated jointly by the California Institute of Technology and the University of California

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As expected, galaxies with signs of recent star formation (i.e. those which show emission lines) have bluer continuum slopes in the rest frame UV and the optical/near-infrared.

We see no change with redshift in the relationship between SED characteristics and galaxy spectral type based on the strength of narrow emission and absorption features, except that actively star forming galaxies become bluer in the mean in the rest-frame UV at higher redshift. This regularity in the behavior of galaxy SEDs across our broad wavelength coverage and up to \( z \sim 1 \) is one reason why photometric redshifts work reasonably well at least out to \( z \sim 1 \) with high precision photometric data sets.

At least some galaxy evolutionary synthesis models predict a more rapid change in SED parameters with redshift than is observed in our sample. However, its not clear that the comparison is fair in that the galaxy evolutionary models follow the evolution of a particular galaxy with time, while we look at samples which we believe to have similar spectra in various redshift bins.

The redder galaxies tend to be more luminous. Although galaxies with strong absorption lines and no emission features are \( \sim 15\% \) of the total sample in the region of the HDF with \( 0.25 < z < 0.8 \), they are \( \sim 50\% \) of the 25 most luminous galaxies in the sample at rest-frame \( R \).

In many respects, these luminosity–density–spectrum correlations extend results for rich clusters of galaxies to lower density environments.

Furthermore there is no evidence in our sample of a population of very red galaxies with strong emission lines (i.e. dusty starbursts). Such objects would be detected if they fell within the magnitude limit of the sample and their redshifts were such that the emission lines lie within the optical window. A detailed description of the SED analysis is given in Cohen (2000).

Figure 2 shows the inferred rest frame luminosity at \( K \) of our sample in the region of the HDF.

Using standard maximum likelihood techniques and the formalism described above, we have derived the parameters of the best fitting luminosity function. The faint end slope of the luminosity function (\( \alpha \)) for galaxies in the region of the HDF for \( z \leq 0.8 \) shows the same dependence of \( \alpha \) on galaxy type as is seen locally. Galaxies with strong emission lines have a LF with a steeper \( \alpha \). The reddest galaxies have a much flatter low luminosity slope. The derived range of \( \alpha \) is consistent with local and other surveys, e.g. Lin et al. (1996) for the LCRS, and Lin et al. (1999) for CNOC2.

The derived rest frame \( L^*(R) \) is shown in figure 3 as a function of galaxy spectral type and redshift. Its behavior is consistent with other surveys at lower \( z \) and with the better determined (i.e. lower \( z \)) region for the CFRS (Lilly et al. 1995). Except in the rest frame UV, it is also consistent with the predictions obtained for passive galaxy evolution. We have used this formalism to calculate the evolution of the LF over the full range of rest wavelengths and redshifts included in our sample, but there is no room to discuss the results here. We have done the most detailed
comparisons with the evolutionary models of Poggianti (1997). These seem to work well in the rest frame optical/near-IR, but not so well in the rest frame UV, where problems might be anticipated.

Passive evolution at constant stellar mass appears to be a good approximation to the actual behavior of at least the most luminous galaxies in this large sample of galaxies in the region of the HDF out to $z \sim 1.5$. This applies to wavelengths redder than rest frame $U$.

The total comoving number density for $L^*$ galaxies is difficult to obtain for $z > 1$ from an optically selected sample as there are many correction factors which become larger with increasing redshift. Pushing all of these, which include, for example, the number of EROs missing from our sample, as hard as possible, I deduce a comoving number density for galaxies with $L > L^*/2$ for $z > 1$ which is 80% of the value we see for $z \sim 0.6$. Thus our cosmological density statistics and LFs as a function of $z$ do not support the suggestion of large scale merging of luminous galaxies near $z \sim 1$. Substantial numbers of minor perturbative mergers are not ruled out.

2. Signs of Galaxy Evolution

The $z \sim 1$ “E” galaxies are more luminous than their low $z$ counterparts. We see, as have many other groups, a strong evolution with $z$ of the prevalence and strength of emission lines, implying that the mean SFR increases strongly between $z = 0$ and $z = 1$, by about a factor of perhaps 10. The most luminous galaxies show this trend very strongly.

We see modest evolution of $L^*$ with $z$ consistent with passive evolution. We do not see strong changes in the cosmological comoving volume density of luminous galaxies. There is no evidence for a large increase with $z$ of the rate of major mergers.

To reconcile the above with the view that galaxies form or assemble near $z \sim 1$ is hard. Most galaxies, and particularly the most luminous galaxies, appear to have formed considerably earlier than $z \sim 1$ both in the field as well as in populous galaxy clusters.

3. Starbursts and Other Future Work

Using the spectroscopic definition of Cohen et al. (1999a), there are 7 starbursts in the HDF sample. At least 3 of the 7 starbursts are definite merger candidates in that there is a second galaxy in the sample within a projected distance of $30 \, h^{-1}$ kpc with exactly the same redshift to within the measurement uncertainty.

Future papers will present the equivalent widths of various absorption and emission features in all the spectra, an analysis of galaxy abundances and star formation rates based on this material, and details for the starbursts.
4. Acknowledgment

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Fig. 1.— A histogram of the spectral index $\alpha_{UV}$ is shown for galaxies of spectral classes $A$, $I$, and $E$ in the range $0.5 < z < 1.05$. 
Fig. 2.— A histogram of the the spectral index $\alpha_{IR}$ is shown for galaxies of spectral classes $A$, $I$ and $E$ in the range $0.5 < z < 1.05$. 
$L(K)$ is shown as a function of the cosmological comoving volume for galaxies in the region of the HDF with secure redshifts. The lines at the top of the distribution represent the track of a galaxy of a $L^*$ (at $K$) galaxy with $L = 10^{11} L_\odot$ at $z = 0$. The evolutionary corrections at $K$ calculated by Poggianti (1997) for E, Sa and Sc galaxies are applied in calculating these tracks for $z > 0$. 
Fig. 4.— The rest frame luminosity at $R$ is shown as a function of redshift for data from the LCRS, CNOC2, CFRS and the present sample. The thick solid lines represent the track of a passively evolving elliptical or Sc galaxy calculated by Poggianti (1997) set to the local value of $L^*(R)$ at $z = 0$. 