The Extremely Red Objects Found Thus Far in the Caltech Faint Galaxy Redshift Survey[1]

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Abstract. We discuss the very red objects found in the first field of the Caltech Faint Galaxy Redshift Survey, for which the observations and analysis are now complete. In this field, which is 15 arcmin^2 and at J005325+1234 there are 195 objects with $K_s < 20$ mag, of which 84% have redshifts. The sample includes 24 spectroscopically confirmed Galactic stars, 136 galaxies, three AGNs, and 32 objects without redshifts.

About 10% of the sample has $(R-K) \geq 5$ mag. Four of these objects have redshifts, with $0.78 \leq z \leq 1.23$. Three of these are based on absorption features in the mid-UV, while the lowest redshift object shows the standard features near 4000Å. Many of the objects still without redshifts have been observed spectroscopically, and no emission lines were seen in their spectra. We believe they are galaxies with $z \sim 1 - 1.5$ that are red due to their age and stellar content and not to some large amount of internal reddening from dust.

Among the many other results from this survey of interest here is a determination of the median extinction in the mid-UV for objects with strong emission line spectra at $z \sim 1 - 1.3$. The result is extinction by a factor of ~2 at 2400Å.

1. Introduction

We have completed the analysis of the data for the first field of this survey, which is 2 x 7.3 arcmin^2 field at J005325+1234. The sample is selected ignoring morphology at K and consists of the 195 objects with $K < 20$ mag in this field. These were observed with the Low Resolution Imaging Spectrograph (Oke *et al.*

[1]Based 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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1995) at the Keck Observatory. Six color photometry ($UBVRIK$) is available for the entire field as well from Pahre *et al.* (1998).

Redshifts were successfully obtained for 163 of the 195 objects in the sample to achieve a completeness of 84%. These redshifts lie in the range [0.173, 1.44] and have a median of 0.58 (excluding 24 spectroscopically confirmed Galactic stars). The sample includes two broad lined AGNs and one QSO. The objects are assigned to spectral classes based on the relative preponderance of emission lines versus absorption lines in their spectra. The four spectral classes used for extragalactic objects are "$\mathcal{E}$" for emission line dominated spectra (33 galaxies), "$\mathcal{A}$" for absorption line dominated spectra (51 galaxies), "$\mathcal{C}$" for composite spectra (52 galaxies), and "$\mathcal{Q}$" for AGNs. A few starbursts were found, classified as "$\mathcal{B}$", but for the present discussion they are grouped together with the emission line galaxies.

2. Rest Frame Spectral Energy Distributions

The galaxy rest frame SEDs derived from out $UBVRIK$ photometry are very closely correlated to the galaxy spectral types. Both are also correlated with galaxy luminosity; blue galaxies show the signature of recent star formation in their spectra and are less luminous for $z < 0.8$ than red galaxies which show no evidence for recent star formation in their spectra. Representative SEDs are shown in Figure 1. The SEDs for selected galaxies (D0K183, 172, 108, 188 and 158) with $z > 0.9$ shown in Figure 1a are remarkably flat (blue). Figure 1b shows the SEDs for all the absorption line galaxies in the $z = 0.58$ peak; they have quite steep (red) spectra.

2.1. The Extremely Red Objects in Our Sample

There are 24 Galactic stars in this sample, mostly M dwarfs or M subdwarfs. The reddest galactic star identified spectroscopically in this field has $(R - K) = 4.6$ mag. There are 19 objects in this sample with $(R - K) \geq 5$ mag, which we call the very red objects, and which we believe to be galaxies rather than Galactic stars. Four of these have redshifts, most of which are somewhat uncertain. Figure 2 shows the rest frame SEDs for the four very red galaxies with redshifts.

The second panel of Figure 2 shows the SEDs for three of the very red objects which do not have redshifts, calculated assuming $z = 1$. Redder than B, these look similar to those SEDs shown in the first panel of this figure, but the objects are somewhat fainter. Most of the U and B magnitudes for these objects are upper limits, as indicated by the vertical bars going downward from the relevant points.

A more complete discussion of the redshift peaks (i.e. groups and poor clusters of galaxies), luminosity function, the cosmological volume density, the constraints on mergers, the ultraviolet extinction and other issues can be found in two papers, one of which has been submitted to ApJ (Cohen *et al.*1998a) while the other (Cohen *et al.* 1998b) will be published in ApJS.

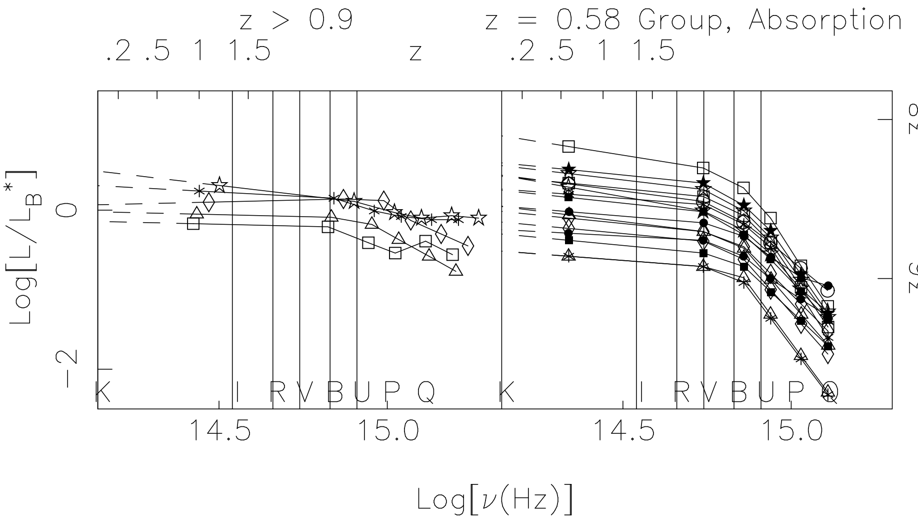

Figure 1. The rest frame spectral energy distributions (SEDs) for selected galaxies. The abscissa is the rest frequency and the rest wavelengths corresponding to our 6 color photometry augmented by the two supplementary ultraviolet bands P and Q ($\log(\nu)$=15.0 and 15.1) are indicated. The ordinate is the logarithm of the spectral power in units of both L_B^* and W. Each galaxy SED shows the rest wavelengths corresponding to the observations and dashed lines are used to indicate extrapolations. The upper horizontal scale can be used in conjunction with the K point to measure the redshift of the galaxy.

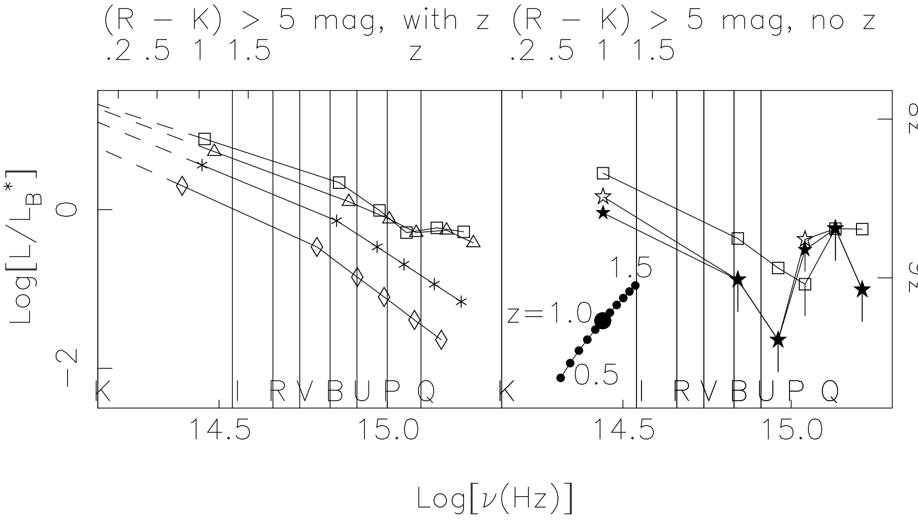

Figure 2. The rest frame SEDs for the four extremely red galaxies for which redshifts have been determined from our survey. The second panel shows the rest frame SEDs for three of the extremely red galaxies without redshifts, calculated assuming $z = 1$. The line in the lower left indicates how the SEDs will shift for $0.5 < z < 1.5$.

3. Final Comments

We have determined the fraction of very red objects among our sample. For counts to $K < 20$ mag, $\sim$10% of the sample of 195 objects is very red, i.e. has $(R - K) \geq 5$ mag. If one excludes the known Galactic stars from the sample, this fraction does not change substantially.

We have examined the spectra of many of these extremely red objects and have succeeded in determining the redshifts of four of them, although the redshifts are not as certain as one might desire. We suggest that these are galaxies with $z \sim 1 - 1.5$ in which reddening by dust is not playing a major role. In particular they are not heavily reddened starbursts. (If they were, we should have seen some moderately reddened emission line galaxies, and there were no such beasts among our sample). Instead we believe their extremely red colors are a direct consequence of their age, stellar composition , k-corrections, etc. and that these extremely red objects are the analogs at this redshift range of local elliptical galaxies. We thus support Persson *et al.* (1993) and Graham & Dey (1996), who among others, have speculated that such objects are passively-evolved elliptical galaxies with $z > 1$.

More work is going to be required to get some first class redshifts for these, or similar, hopefully brighter, objects, to establish their nature in a more definitive way.

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