The First 1−2 Gyrs of Galaxy Formation: Dropout Galaxies from $z \sim 3 - 6$

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Abstract. The unique high–resolution wide–field imaging capabilities of HST with ACS have allowed the characterization of galaxies at redshift 6, less than 1 Gyr from recombination. The dropout technique, applied to deep ACS i, z images in the RCDS 1252–2927, GOODS and UDF–Parallel fields has yielded large samples, allowing determination of their properties (e.g., size, color) and meaningful comparisons against lower redshift dropout samples. The use of cloning techniques has enabled us to control for many of the strong selection biases that affect the study of high redshift populations. A clear trend of size with redshift has been identified, and its impact on the luminosity density and star formation rate can be estimated. There is a significant, though modest, decrease in the star formation rate from redshifts $z \sim 2.5$ out through $z \sim 6$. The latest data also allow for the first robust determination of the luminosity function at $z \sim 6$.

1 Introduction

The advent of the HST Advanced Camera, the ACS (Ford et al 2003) has greatly increased our ability to "watch galaxies form". The sensitivity, resolution and excellent filter set have provided us with images from which large samples of high redshift galaxies can be derived. Of particular interest are those galaxies with red enough i-z colors to qualify as i-dropouts – galaxies at redshifts $z \sim 6$. Such objects have been the focus of a number of papers over the last year (e.g., Bouwens et al 2003b, Stanway et al 2003, Yan et al 2003, Dickinson et al 2004). Spectroscopic confirmation is beginning to appear (e.g., Bunker et al 2003, Dickinson et al 2004) but is challenging as Weymann et al (1998) demonstrated with their $z = 5.6$ object, which took over 6 hours on Keck.

The current frontier for high redshift objects is at $z \sim 6$ (the ACS UDF and NICMOS UDF–IR images together will likely extend the dropout sources to redshifts 7 and beyond, but the samples will be small). Rapid changes in the properties of high redshift galaxies must occur beyond $z \sim 6$ and so careful characterization of objects even those separated by small intervals of time, is a well-justified goal – especially given that only 650 million years separates $z \sim 15$ from $z \sim 6$. In this context there is great value in having large samples of $z \sim 3-5$ objects which are more amenable to thorough, quantitative study.

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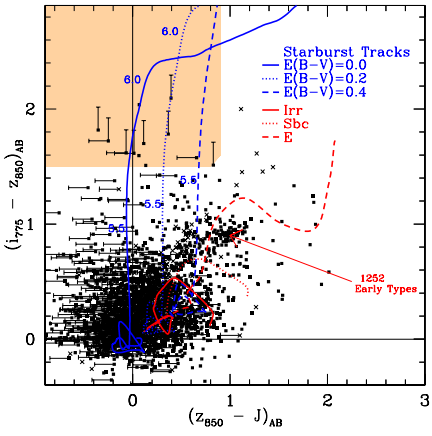

Fig. 1. Selection of i-dropouts in the i-z z-J two–color plane. This example is for the HST ACS from the RCDS 1252–2927 field (Rosati et al 1998). The selection limits (particularly the $(i-z) > 1.5$ cut – see Bouwens et al 2003b) returns $z \sim 6$ galaxies with little contamination (an estimated 11% contamination rate).

2 Fields and Object Selection

While data from several fields have been used to identify high redshift dropouts, three fields have stood out for their value for dropout studies over the last year – namely the RCDS 1252–2927 field, the GOODS fields, and the UDF–parallels (UDF–Ps). All have excellent HST ACS i_{775} and z_{850} data, while the GOODS and the UDF-Ps fields also have deep B_{435} and V_{606} data. The excellent IR data (Lidman et al 2004) in RCDS 1252–2927 also makes a substantial contribution to the selection of i–dropouts, helping to establish the degree of contamination in the samples.

The selection of i–dropouts is shown in Fig 1 for the RCDS 1252–2927 field (from Bouwens et al 2003b). The ACS data reaches typically to $z_{850,AB} \sim 27.3$ mag (6σ), while the ground-based IR data goes impressively deep, down to $J_{AB} = 25.7$ and $Ks_{AB} = 25.0$ mag (5σ). The fraction of $z \sim 6$ objects in the IR coverage in RCDS 1252–2927 is impressively small (0.3%), only 12 out of ∼3000 galaxies. Even so the estimated contamination is only about 11%. A number of these candidates have been observed with Keck and the VLT and confirmed to be at $z \sim 6$. A total of 23 $z \sim 6$ galaxies are found in four ACS pointings of the RCDS 1252–2927 field, giving a surface density of 0.5 ± 0.2 i–dropouts per square arcmin to $z_{AB} = 26.5$ mag. The objects are very small, though all are resolved, with typical half-light radii of $0.15''$ or ~ 0.9 kpc. The $z \sim 6$ objects reach down to $\sim 0.3 L_{*,z=3}$ (Steidel et al 1999).

Two of the brighter i–dropouts from the RCDS 1252–2927 field are shown in Fig 2, along with their location in the two–color plane, and SED fits that are used to establish the redshifts. The ACS i and z data from the HDF–N also allowed for a search for i–dropouts. A reassuring result was that the Weymann et al (1998) object in the HDF–N, spectroscopically verified to be at $z = 5.60$, was very close to meeting our i–dropout criterion (its $i-z = 1.2$ color was just a little too blue). While not a true i–dropout, it suggested that our selection was