UV LUMINOSITY FUNCTION AT Z\textasciitilde4, 3, AND 2

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Abstract We use very deep ($R_{lim}=27$) $U_{n}GR_{I}$ imaging to study the evolution of the faint end of the UV-selected galaxy luminosity function from $z\sim4$ to $z\sim2$. We find that the number of sub-$L^*$ galaxies increases from $z\sim4$ to $z\sim3$ while the number of bright ones appears to remain constant. We find no evidence for continued evolution to lower redshift, $z\sim2$. If real, this differential evolution of the luminosity function suggests that differentially comparing key diagnostics of dust, stellar populations, etc. as a function of $z$ and $L$ may let us isolate the key mechanisms that drive galaxy evolution at high redshift and we describe several such studies currently underway.

1. The Keck Deep Fields

The shape of the galaxy luminosity function bears the imprint of galaxy formation and evolutionary processes and suggests that galaxies below $L^*$ differ substantially from those above it in more than just luminosity. Our understanding of galaxy formation may profit from studying the evolution of not just the bright but also the faint component of the galaxy population at high redshift.

To study the evolution of the galaxy luminosity function at high redshift, we have carried out a very deep imaging survey that uses the very same $U_{n}GR_{I}$ filter set and color-color selection technique as used in the work of Steidel et al. (1999, 2003, 2004), but that reaches to $R\approx27$ --- 1.5 magnitudes deeper and significantly below $L^*$ at $z=2$--$4$ (Sawicki & Thompson, 2005). These Keck Deep Fields (KDF) were obtained with the LRIS imaging spectrograph on Keck I and represent 71 hours of integration split into five fields that are
Figure 1. Color-color diagrams showing the selection regions for selecting high-$z$ samples in the KDF. The left-hand panel illustrates selection of $z \sim 3, 2.2, \text{and } 1.7$ samples; only a third of the objects in our catalog are plotted. The right hand panel shows the selection of $z \sim 4$ galaxies. The filters we used and our color selection are both identical to those used by the Steidel team to select galaxies at $z \sim 1.7-4$. However, our data reach to $R=27$, or 1.5 magnitudes deeper and thus significantly below $L^*$ at these redshifts. Contact authors for higher resolution Figure.

grouped into 3 spatially-independent patches to allow us to monitor the effects of cosmic variance. We use the $U_n GRI$ filter set and spectroscopically-confirmed and -optimized color-color selection techniques developed by Steidel et al. (1999, 2003, 2004). Consequently, we can confidently select sub-$L^*$ star-forming galaxies at $z \sim 4, 3, 2.2, \text{and } 1.7$ without the need for what at the magnitudes we probe would be extremely expensive spectroscopic characterization of the sample. To $R=27$, the KDF contains 427, 1481, 2417, and 2043, $U_n GRI$-selected star-forming galaxies at $z \sim 4, z \sim 3, z \sim 2.2, \text{and } z \sim 1.7$, respectively, selected using the Steidel et al. (1999, 2003, 2004) color-color selection criteria (Fig. 1). A detailed description of the Keck Deep Field observations, data reductions, and the high-$z$ galaxy selection can be found in Sawicki & Thompson (2005).

2. Luminosity function at high redshift

Figure 2 shows the luminosity function of UV-selected star-forming galaxies at $z \sim 4, 3, \text{and } 2.2$. At $z \sim 4$ and 3, we augment our KDF data with the identically-selected and similarly-computed Steidel et al. (1999) LF measurements at bright magnitudes, $R<25.5$. As in Steidel et al. (1999), our LF calculation uses the effective volume technique, calculating $V_{eff}$ using recovery tests of artificial high-$z$ galaxies implanted into the imaging data. We do not present the results for $z \sim 1.7$ here because that analysis is still ongoing as the
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Figure 2. The luminosity function of high-$z$ rest-frame UV-selected galaxies at $z \sim 4$, $z \sim 3$, and $z \sim 2.2$. No dust correction has been applied; error bars include both $\sqrt{N}$ counting statistics and field-to-field scatter. There is a clear deficit of faint LBGs at $z \sim 4$ compared to $z \sim 3$ and $z \sim 2.2$.

A narrow selection window in the $U_n-G$ color makes it necessary to carry out a more sophisticated treatment of completeness and effective volume at $z \sim 1.7$ than in the higher redshift bins. Our data reach down to very faint luminosities which correspond to star formation rates (not adjusted for dust) of only 1–2 $M_\odot$/yr (Fig. 2).

As Fig. 2 shows, we find a factor of $\sim 3$ evolution in the number counts (or, alternatively, 2 mag in luminosity) of faint Lyman Break Galaxies from $z \sim 4$ to $z \sim 3$ while at the same time, there is no evidence for evolution from $z \sim 4$ to $z \sim 3$ at the bright end (Steidel et al. 1999; and Fig. 2). Thus, it seems that the luminosity function of high-$z$ galaxies evolves in a differential way, suggesting that different mechanisms drive the evolution of the faint and of the luminous galaxies. It is unlikely that the observed evolution is due to a selection bias because (1) if it were, we would expect the deficit to be present at bright and faint magnitudes, and (2) to make up the deficit would require an unreasonably enormous expansion of the $z \sim 4$ color selection box (Fig. 2). We therefore conclude that the evolution from $z \sim 4$ to $z \sim 3$ is likely a reflection of a true differential, luminosity-dependent evolutionary effect. At the same time, we see no evidence for evolution at the faint end from $z \sim 3$ to $z \sim 2.2$ (the bright end remains unconstrained at present) suggesting that the mechanism responsible for the evolution at earlier epochs saturates at lower redshifts.
3. What is behind the evolution of the LF?

At present, it is not clear what is responsible for the observed differential evolution of the LF. One straightforward possibility is that the number of faint (but not bright) LBGs simply increases over the 500 Myr from $z \sim 4$ to $z \sim 3$ (but not beyond). Another possibility is that dust properties — its amount or covering fraction — may be decreasing in faint LBGs thus making them brighter. Alternatively, if star formation in individual faint LBGs is time-variable, then they may brighten and fade (and thus move in and out of a given magnitude bin in the LF) with duty cycle properties that change with redshift. However, whichever mechanism is responsible, it appears to saturate by $z \sim 2.2$.

The fact that the LF evolution appears to be differential suggests that different evolutionary mechanisms are at play as a function of UV luminosity. Studies that differentially compare key galaxy properties as a function of luminosity and redshift should help us isolate the mechanisms that are responsible for this evolution. For example: (1) The KDF is designed to measure galaxy clustering as a function of both luminosity and redshift and doing so will let us relate the potentially time-varying UV luminosity to the more stable dark matter halo mass. (2) We will also use a high-quality $\sim$1000-hour 80-object composite spectrum of a faint $z \sim 3$ LBG (Gemini GMOS observations are underway) to compare key diagnostics of dust, superwinds, and stellar populations in a faint and a luminous (e.g., Shapley et al. 2003) composite LBG. (3) Broadband rest-frame UV-optical colors constrain the stellar population age and the amount of dust in LBGs (e.g., Sawicki et al. 1998; Papovich et al. 2001) and we can use this approach to look for systematic differences in age and dust content. Significantly, all such studies will be making differential comparisons, thereby reducing our exposure to systematic biases in models or low-$z$ analogs.

A key point is that we have identified luminosity and redshift as important variables in galaxy evolution at high $z$. While LBG follow-up studies to date have primarily focused on luminous galaxies at $z \sim 3$, extending such studies as a function of $z$ and $L$ should yield valuable insights into how galaxies form and evolve: studying how key diagnostic properties of high-$z$ galaxies vary with $L$ and $z$ will help us constrain what mechanisms drive galaxy evolution in the early universe.

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