Star Forming Galaxies in the 'Redshift Desert'

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Abstract. We describe results of optical and near-IR observations of a large spectroscopic sample of star-forming galaxies photometrically-selected to lie in the redshift range $1.4 \lesssim z \lesssim 2.5$, often called the "redshift desert" because of historical difficulty in obtaining spectroscopic redshifts in this range. We show that the former "redshift desert" is now very much open to observation.

1 Background

The "redshift desert" results from an accident of nature in which the windows of low atmospheric opacity and low terrestrial background are barren of familiar, strong spectroscopic features that make redshift identification easy using ground-based spectroscopy. At $z \sim 1.4$ the last of the strong nebular lines, [OII] $\lambda3727$, passes well into the range where most optical spectrographs perform less well because of decreasing CCD quantum efficiency and rapidly increasing sky brightness. The result has been that there is a dearth of direct spectroscopic information on galaxies at $z \gtrsim 1.4$ until $z \gtrsim 2.5$, at which point (for star forming galaxies, at least) techniques like Lyman break selection coupled with normal optical spectroscopy have been quite successful. The difficulties with spectroscopy in the desert translate directly into larger uncertainties in photometric redshifts, since both methods depend on strong spectral features at observationally accessible wavelengths. Of course, nature has conspired to make this redshift range between $z \sim 1.5 - 2.5$ perhaps one of the most crucial in understanding the development of massive galaxies and of their central black holes, as we have heard from a number of talks at this meeting. There is thus a very strong impetus to gain access to galaxies in this range of redshifts, in spite of the difficulties that may be encountered.

Following the familiar rest-optical nebular lines into the near-IR is certainly possible in principle, but to date there has been little effort to do this in a wholesale manner because there have not been many instruments capable of multiplexed spectroscopy in the near-IR; this of course will change significantly over the next $\sim 3 - 5$ years as cryogenic multi-object near-IR spectrographs come on line. We have adopted an alternative strategy: to push faint object spectroscopy into the blue/UV portion of the observed spectrum, where the same spectral features used for the identification of galaxies at $z \sim 3$ [1] remain

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accessible down to $z \sim 1.4$, thereby closing the gap in redshift space that has been called the "desert".

Studying galaxies at $z \sim 2$ is quite rewarding for both scientific and practical reasons: This redshift range $1.5 \lesssim z \lesssim 2.5$ evidently contains the peak of the QSO epoch, and may well contain the formation era for most of the stars in today's massive galaxies, judging by the redshift distribution of bright sub-mm sources [2]. But it is much more than a crucial epoch for galaxies and AGN– at these redshifts, it is possible to simultaneously study the diffuse intergalactic medium (IGM) *and* star forming galaxies in the same volumes, allowing for a direct examination of the magnitude of the effects of supernova feedback on the properties of galaxies and the IGM. Because both background QSOs and spectroscopically accessible galaxies have much higher surface densities than at higher redshifts where such experiments have already been done [3], $z \sim 2$ may be the optimal redshift for joint IGM/galaxy studies. In terms of attaining physical understanding of the galaxies one finds, $z \sim 2$ offers significant advantages as well: first, the surface density of galaxies bright enough for detailed spectroscopic studies using 8m-class telescopes at both optical and near-IR wavelengths is high; secondly, as we describe below, one has access to diagnostic spectroscopy in both the rest-frame far-UV *and* the rest-frame optical, allowing independent means of measuring physical properties such as chemical abundances, stellar initial mass function, and mass.

2 Survey of the "Redshift Desert"

We began our survey of $z \sim 2$ galaxies in the fall of 2000 just after the commissioning of the LRIS-B instrument (see [4]) on the Keck I telescope. Our approach to identifying which galaxies to target in order to efficiently survey galaxies at $z \sim 2$ was largely empirical, in the sense that we chose the region in color-space that would be occupied by galaxies having the same rest-frame SEDs as $z \sim 3$ LBGs in the sample of objects that have been observed from $0.3-2.2\mu$m (see [5] for a full description and motivation of the color selection). Generally speaking, this means that the galaxies we are selecting for spectroscopy have the same range of UV color as the better-studied LBGs at $z \sim 3$. Because we began our survey with the primary aim of studying the connection between the galaxies and the IGM, we have focused most of our efforts on the redshift range $2 \lesssim z \lesssim 2.5$ (we refer to this particular color selection as "BX" objects) where the Lyman α forest is easily studied from the ground, and in fields having more than 1 suitable $z \sim 2.5$ background QSO for studying the IGM component. However, we have recently obtained additional spectroscopy in both the GOODS-N and Groth/Westphal fields, where in addition to the $z \sim 2-2.5$ "BX" objects we have targeted objects expected to lie in the range $1.5 \lesssim z \lesssim 2$ (and which we refer to as "BM" objects). A more in-depth overview of the survey and its initial results is given in [4].

Figure 1 shows the results to date for the spectroscopy of the two new photometrically selected samples, with $\langle z \rangle = 2.20 \pm 0.32$ and $\langle z \rangle = 1.70 \pm 0.34$ for the