The success of the Hubble Deep Field (HDF) data in identifying galaxies at redshifts up to \( \sim 3 \) has been quite spectacular. It is possible to extend this to even higher redshifts using infrared techniques, several of which are briefly described in this paper.

1 Introduction

Other papers in this volume describe some of the results which have come from the HDF data. I describe here several types of observations in the infrared which can take us beyond the redshifts probed by the HDF. Although I have split this paper into two main sections, one covering emission-line techniques and the other covering continuum-based techniques, it should be noted that all of these survey methods make use of some strong spectral feature in order to select galaxies out of a background of field galaxies at lower redshift.

2 Emission-Line Surveys

Stretching the intended meaning of infrared to include CCD-based narrowband surveys at wavelengths beyond 7000 Å includes searches for Ly\( \alpha \)-bright galaxies up to a redshift approaching 7. Field surveys for such objects have, to date, been unsuccessful at identifying any significant population of galaxies, though observations targeting existing structures, such as quasar absorption-line systems of known redshift, have identified a number of interesting objects. Because the Ly\( \alpha \) line is resonant, and can suffer multiple scattering off atomic hydrogen as it passes through the ISM, the chances of absorption by dust grains is proportionally higher. This dust quenching of the Ly\( \alpha \) line is generally thought to explain the lack of success in these field surveys.

Recent, detailed models by Thommes & Meisenheimer, including both dust formation and a scatter in the time when massive star formation begins, give considerably more pessimistic predictions on the volume density of forming galaxies than the canonical results of Baron & White. Even so, it should still be possible to identify high-redshift galaxies by targeting their Ly\( \alpha \) emis-
sion redshifted into the CCD infrared. The Calar Alto Deep Imaging Survey
(CADIS) is attempting to cover sufficient volume and depth to reach these new
limits, and several \( z > 5 \) candidate objects have been identified to date.

If sufficient dust is generated early on in a starburst to completely destroy
the Ly\(\alpha\) photons, then it would still be possible to detect the starbursts through
other emission lines, most notably the restframe optical lines of [O II] 3727\(\AA\),
H\(\beta\) 4861\(\AA\), [O III] 5007\(\AA\), and H\(\alpha\) 6563\(\AA\). At high redshift, these lines are
shifted into the near infrared \(JHK\) bands, where they can be imaged through
narrowband filters.

This technique has only been practical since the development of reason-
ably large infrared arrays.\(^5\)\(^6\) There are several groups currently engaged in
surveys using this technique,\(^1\)\(^7\)\(^8\) with a number of objects having already been
identified. These surveys primarily target the H\(\alpha\) line at \(z \simeq 2.4\), where it is
redshifted into the \(K\) band, but the method is sensitive to any emission lines,
and can be used to image [O II] 3727\(\AA\) at redshifts as high as five.

3 Continuum Surveys

Complementary to the emission-line surveys are those based on continuum
features. Steidel et al.\(^9\) have used the Lyman limit feature at a restframe wave-
length of 912\(\AA\) with remarkable success to identify a population of galaxies
at \(z \simeq 3.25\), many without strong emission lines despite relatively high star
formation rates.

If we try to push this technique into the near infrared, we run into prob-
lems with the continuum depression across the Ly\(\alpha\) line, which increases dramati-
cally at redshifts greater than four.\(^10\) Extrapolating to \(z \simeq 7\), which places the
Ly\(\alpha\) line between the \(I\) and \(J\) bands, one would expect that virtually all of the
flux blueward of the Ly\(\alpha\) line would be absorbed. These \(I\)-band drop-out ob-
jects would appear around \(J \simeq 23.4\) (Johnson), assuming little extinction from
dust, for star formation rates of \(\simeq 50 M_\odot \text{yr}^{-1}\). Such limits are technologically
feasible with the current generation of infrared arrays on 4m-class telescopes.

Rather than searching directly for forming galaxies at high redshift, an-
other method of probing the earliest epoch of galaxy formation is to look for
old, evolved objects at lower redshift. Evolved, or passively evolving, stellar
populations, such as found locally in elliptical galaxies, can develop a strong
break in their spectra around 4000\(\AA\) a few hundred million years after their
last burst of star formation, giving another spectral feature on which to base
a survey. Sufficiently evolved objects at \(z > 1\) can imply formation redshifts
of \(z > 3\).

As this 4000\(\AA\)-break feature is redshifted through the optical bands, the
optical-to-infrared colors of these objects becomes increasingly red. At $z \simeq 1.5$, this break lies between the $I$ and $J$ bands. Deep, multicolor imaging in the near infrared can thus distinguish these “extremely red objects” from foreground galaxies. This is potentially a new population of objects; while relatively easy to detect at near infrared wavelengths, no significant numbers of these objects would have been included in even the deepest, optically-selected redshift surveys. Several such galaxies have recently been identified from serendipitous observations, though the true extent of any field population is largely unknown. A large-scale field survey would thus be valuable, to determine the space density of such objects and produce a sample for further study.

4 Conclusions

The development of large infrared arrays has opened up several possibilities for pushing beyond the redshifts probed by the HDF data. Current ground-based efforts perhaps presage what we might expect from the NICMOS camera on the Hubble Space Telescope.

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