SURVEYS FOR Z > 1 FIELD GALAXIES

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ABSTRACT

In the course of the comprehensive CFRS redshift survey to I_{AB} = 22.5 (see Lilly et al, these proceedings) with the CFHT MOS/SIS spectrograph, we have observed ~25 field galaxies with z > 1. However, it is clear that almost an equal number, predominantly red galaxies, have likely been missed largely because of limitations in the observed wavelength range. The properties of the observed galaxies and the reasons for the presumed incompleteness are briefly discussed in this contribution, and strategies for improving our methods of observing high redshift galaxies are explored. In particular, it is demonstrated that sky subtraction to the required limiting magnitude is possible even with very low spectral resolution, and that new IR arrays and new optical designs for multi-object spectrographs will allow us to easily reach field galaxies at z > 1.

1. Introduction

Spectra of ~1050 objects to a limiting isophotal I_{AB} = 22.5 were obtained during the course of the Canada-France Redshift Survey (CFRS). As discussed by Lilly et al, spectra were taken of all objects to this limiting magnitude, so no observational bias is present against compact galaxies or AGNs, for example. However, the spectroscopic wavelength range was limited to 4200 – 8600Å in order that three tiers of spectra could be observed simultaneously. All spectra were reduced independently by three members of the team and reliability grades or “notes” were assigned, for which quite accurate assessments of reliability were derived from repeat observations of the objects. In addition, comparison of the spectra of galaxies at lower redshift which had strong [OII] and/or Hα lines with those of objects at higher z which only displayed a single strong emission line in their spectra (due to the fact that most features had been redshifted out of the observed range) allowed us to develop a technique to assign unambiguous redshifts for these objects (Lilly et al).

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This technique fails for single-line galaxies at the very highest redshifts because of the limited useful spectral range observable, but the lack of other features and slope of the continua make it highly likely that the assigned redshifts for these galaxies is also correct. The CFRS survey is in the final stages of analysis, and a few details may change, but the overall conclusions discussed here will not.

2. Observing $z > 1$ Galaxies

2.1. Sky Subtraction

As the redshift of galaxies increases to $z \sim 1$, the standard features used to determine redshifts in low resolution spectra are redshifted into a region of markedly increased emission from the night sky (one reason why the CFRS spectra were limited to $z<8600\text{Å}$). Although a few features remain visible (e.g., $3727\text{[OII] and Ca H and K}$), the increased noise at longer wavelengths and the difficulty of distinguishing “breaks” from features due to poorly-subtracted night sky emission means that deriving reliable redshifts for “non-emission line” galaxies at such high redshifts is virtually impossible for such spectra, in agreement with the conclusions regarding incompleteness in the previous section.

![Fig. 1. A CFHT MOS/SIS spectrum of a galaxy at $z \sim 0.4$, with the night sky superimposed (dashed line). Note that although the sky emission increases strongly towards redder wavelengths, the effectiveness of the sky subtraction is poorer at both blue and red wavelengths, and hence it is largely a function of the quantum efficiency of the CCD detector.](image)

The conventional wisdom is that this virtual impossibility of deriving redshifts for $z > 1$ objects is due to the rapidly increasing brightness of the night sky at longer wavelengths, combined, of course, with the decreasing brightness of the objects at increasing $z$. Looking at figure 1, the origin of this belief is easily understood, since the sky-to-object contribution increases dramatically as a function of wavelength.
However, a closer look at the sky-subtracted spectrum of the object shows that the increase in the noise is not significantly worse in the region near 8600 Å where the sky has become very bright (this spectrum is not one of the standard CFRS spectra, but extends to the long wavelength limit of the CCD). In fact, if the principal emission lines from the object are removed, and the residual spectrum displayed in counts instead of flux, it is obvious that sky subtraction is not the major limiting factor at all, but rather the CCD response. It should perhaps be emphasized that the original spectrum only had a resolution of ∼40 Å, or R ∼ 200 at 8000 Å, but the sampling is higher than the nominal 2.5 pixels which has become the default standard in astronomy; there were 5 pixels per spectral resolution element and the spatial sampling was 0.′′31 per pixel. The conclusion, which to some extent is based on our whole CFRS dataset, is that sky subtraction is not the chief limiting factor (as long as other instrumental factors have been taken care of, particularly flexure, orthogonality of the slits to the dispersion direction, CCD alignment and accuracy of the slitlet manufacture). As mentioned above, the declining response of the quantum efficiency of the CCD is a major factor.

2.2. New Technical Developments

Although there has been some success in improving the red quantum efficiency of CCDs (e.g., Schemp) their physical properties precludes any response beyond 1.08 μ. Fortunately there are spectacular advances in the development of 1024x1024 near-IR arrays; the “Aladdin” InSb array should have a quantum efficiency > 85% from 0.7μ to > 2.4μ, and the “Hawaii” HgCdTe array is purported to have a quantum efficiency > 50% over the same range. New, very transparent glasses (e.g. Schott ULTRAN) have also allowed optical designs to be extended from the traditional “visible” light region into the near-IR as well. A recent design for an imaging spectrograph for CFHT yields superb optical images at all wavelengths from 0.4μ to 2.2μ with transmission, including reflection losses, of ∼80% over the entire range. The combination of these new optical designs and new near-IR arrays will allow spectra of high redshift galaxies to be obtained with multi-object (uncooled) spectrographs in the accessible ground-based windows from 0.7 - 2.0μ. For redshift surveys where the redshifts are a priori unknown, wide wavelength regions are essential so at least two prominent spectral features can be observed. Even if the wavelength range is limited to < 1.4μ, redshifts can easily be determined up to z ∼ 2 (see section 4).

3. CFRS z > 1 galaxies

There are approximately 23 galaxies with z > 1 in the CFRS catalog, yet the observed luminosity function for 0.5 < z < 0.75 (where we have very good data and statistics) indicates that at least twice that number should have been observed. Examination of the restframe colour–absolute magnitude diagrams at increasing redshift (figure 2) demonstrates that the galaxies with colours redder than Sbc are missing at z > 1. Of course, this could be simply be an effect of galaxy evolution, but
the facts that many of our failures (i.e., objects for which no redshift was derived) are located in the area of the (B-I) – (I-K) two colour diagram where red high z objects are expected to lie, and that it is difficult to identify non-emission line objects at \( z > 1 \) with our limited spectral range, lead us to the conclusion that there are probably \( \sim 50 \) galaxies in our sample which have \( z > 1 \).

Fig. 2. Derived B absolute magnitudes versus restframe colours for galaxies in different redshift slices. Galaxies redder than local Sbc galaxies (to the right of the dotted vertical line in each panel) were not found at the very highest redshifts, most likely for instrumental reasons.

Given that the new IR array detectors combined with new optical designs will allow spectra to be obtained in the required wavelength interval, are the high redshift galaxies observable in sufficient numbers with current telescopes? Since in our large CFRS survey of \( \sim 750 \) galaxies only \( \sim 50 \) have \( z > 1 \), it might appear at first sight rather daunting. The CFRS sample was selected in a completely unbiased way, so if the subsequent biases are acceptable, size and colour criteria or radio or X-ray emission could be used to enhance the probability of selecting \( z > 1 \) galaxies. Unbiased samples could also be selected at redder wavelengths. For example, assuming relatively mild evolution (evolution reaching 1.3 mag for \( z > 1.3 \)) the redshift distribution for I and J selected samples are compared in figure 3 to our observed CFRS \( I < 22 \) data. Selection of \( J < 22 \) (or \( H < 21 \)) galaxies gives a relatively large fraction (\( > 25 \%) \) of \( z > 1 \) galaxies compared to the CFRS sample, or even a fainter I selected sample.

Are galaxies at these faint red magnitudes realistically observable? Our CFRS data, somewhat inadvertently, demonstrate that it is feasible. The CFRS galaxies were selected on the basis of isophotal magnitudes, and crowding and confusion at the faint limit led us to observe some galaxies fainter than our survey limit. The mean \( I_{AB} \) in a 3" aperture of the 25 \( z > 1 \) galaxies (see examples in figure 4) is 22.6, and the faintest is 24.4. Hence it is possible even with our present
instrumentation and, with the advent of higher quantum efficiency (thinned) CCDs at CFHT, observations of such galaxies is certainly feasible.

Fig. 3. The numbers of galaxies at each redshift predicted to be found in I and J selected samples compared to a model fit to the distribution of the CFRS galaxies (relatively mild luminosity evolution was assumed - see text).

Fig. 4. Two examples of spectra of the $z > 1$ CFRS galaxies. Note that one is considerably fainter than our nominal survey limit.

The highest redshift in the CFRS sample is $\sim 1.4$, owing to the 8600Å red limit of the spectra. In order to go to $z \sim 2$, near-infrared detectors will have to be used, but fortunately the atmospheric windows will still allow enough spectral features through to confidently measure a redshift (figure 5). Based on our CFRS data, $\sim 300$ galaxies with $1 < z < 2$ are expected in a 5' field at $J < 22$. We estimate that their redshifts could be measured in $\sim 4$ hours with a multi-object spectrograph on an 8m telescope.
Fig. 5. A diagram showing the location of atmospheric absorption (upper panel) and how the wavelengths of spectral features which are important in determining redshifts from low resolution data vary with redshift.

5. Conclusions

Our CFRS data shows that the spectra of field galaxies at $z > 1$ are very similar to those in the local Universe. They also demonstrate that surveys of field galaxies up to at least $z \sim 2$ are feasible with new large near-IR detectors coupled with efficient multi-object spectrographs. Such a project will be relatively easy on 8–10m telescopes.

6. Acknowledgements

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7. References

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