WFCAM, UKIDSS, and $z = 7$ quasars

Steve Warren  
Astrophysics, ICSTM, Prince Consort Rd, London SW7 2BW, UK

Paul Hewett  
Institute of Astronomy, Madingley Rd, Cambridge, CB3 OHA, UK

Abstract. We estimate the number of $z \simeq 7$ quasars that will be discovered in the Large Area Survey (LAS) element of the UKIRT Infrared Deep Sky Survey (UKIDSS). The LAS will cover 4000 sq degs of the northern sky to $K = 18.4$, which is 3 mag. deeper than 2MASS. The Sloan Digital Sky Survey has extended the quasar redshift limit to $z = 6.3$. We demonstrate that to reach higher redshifts $z \sim 7$, when Ly$\alpha$ has passed through the $z$ band, combinations of standard broad-band filters such as $zJH$ and $zJK$ are ineffective. Instead the wavelength range between $z$ and $J$ must be exploited. We introduce the $Y$ passband $0.97 - 1.07 \mu$m for this purpose. High-redshift quasars up to redshift $z = 7.2$ can be selected from a $iYJ$ or $zYJ$ two-colour diagram, as bluer than L and T dwarfs.

1. Motivation

Over the past two years the Sloan Digital Sky Survey (SDSS) has had considerable success in searches for quasars of very high redshift $z > 5$ (e.g. Schneider, these proceedings). Currently the highest redshift recorded is $z = 6.3$ (Fan et al., 2001a). Perhaps the most important motivation for searching for sources at even higher redshifts is the possibility of detecting and studying the epoch of reionisation. Analysis of the optical depth blueward of the Ly$\alpha$ emission line in the spectrum of the $z = 6.3$ quasar indicates that we may be on the threshold of this event (Becker et al., 2001). The detection of quasars of higher redshift could probe the neutral IGM during or even before the epoch of reionisation. Although the optical depth in Ly$\alpha$ is too high to provide a useful measure of the neutral fraction in the IGM (e.g. Madau, these proceedings), other species, observable with NGST, might provide a measure. Also other probes of the IGM have been suggested (e.g. Loeb and Rybicki, 2000).

2. Higher redshifts than SDSS

The multicolour technique for finding high-redshift quasars exploits the break in the spectrum across Ly$\alpha$, caused by Ly$\alpha$ absorption. The highest redshift quasars in the SDSS are detected in an $izJ$ two-colour diagram. A quasar at $z \sim 6$ is very red in $i - z$, but blue in $z - J$ relative to other sources with the
Figure 1. Two-colour \( zJK \) diagram showing colours of stars O to M (filled circles), and L and T brown dwarfs, open and filled squares respectively. All magnitudes are on the Vega system. The chains show model quasar colours \( 5 < z < 8, \Delta z = 0.1 \), with three different continuum slopes. This two-colour diagram is ineffective for selecting quasars in the redshift range \( 6 < z < 7 \), and other combinations of \( zJHK \) are no better. Quasars \( z > 7 \) could be selected by identifying objects \( z - J > 3.2 \), i.e. in the box shown. But to reach \( J = 19 \) requires a depth \( z = 22.2 \), whereas the SDSS only reaches \( z = 19.9 \).
Figure 2. Two-colour $iYJ$ diagram showing colours of stars O to M (filled circles), and L and T brown dwarfs, open and filled squares respectively. All magnitudes are on the Vega system. The chains show model quasar colours $5 < z < 8$, $\Delta z = 0.1$, with three different continuum slopes. Any objects $i - Y > 3$, in the selection box shown, are candidate quasars in the redshift range $5.8 < z < 7.2$. Because the SDSS reaches $i = 22.0$ this works to a limit $Y = 22.0 - 3.0 = 19.0$. In fact the UKIDSS LAS will reach $Y = 20.5$ so deeper optical data will allow the discovery of fainter high-redshift quasars.
same $i - z$ colours i.e. L and T dwarfs. The passbands and depths of the SDSS mean that the survey is unlikely to find any quasars beyond $z = 6.5$ because at these redshifts the quasars become too faint to be detected in the $z$ band, due to $\text{Ly}\alpha$ absorption (Fan et al. 2001a).

To reach higher redshifts it is natural to consider shifting the filter set to longer wavelengths, and using the combination $zJH$ or $zJK$. This does not work however, because the energy peak of cool stars lies in the near-infrared, so that quasars are no longer bluer than cool stars. This is illustrated in Fig. 1 which shows predicted colours of quasars in the redshift range $5 < z < 8$. The quasars lie close to, or within the stellar locus, and do not emerge until $z - J > 3.2$. This requires prohibitively deep observations in the $z$ band.

3. The UKIDSS Large Area Survey

The UKIRT Infrared Deep Sky Survey (UKIDSS, www.ukidss.org) is the next generation near-infrared sky survey, the successor to 2MASS. The instrument is WFCAM, which is equipped with $4 \times 2048$ arrays, giving 0.21 sq. degs coverage per exposure. UKIDSS will commence in 2003 and comprises five elements. One of these, the Large Area Survey (LAS), is a wide-field survey over 4000 sq. degs to $K = 18.4$. This depth is three magnitudes deeper than 2MASS. The UKIDSS LAS will be the true near-infrared counterpart to the SDSS.

The problem in finding $z = 7$ quasars is that they have similar colours to brown dwarfs at near-infrared wavelengths. However by introducing a passband between $z$ and $J$ we can separate out the quasars. UKIDSS will use a filter called $Y$ covering the wavelength range $0.97 - 1.07 \mu$m (some observers call this wavelength range $z(ir)$, but since there is no overlap with the SDSS $z$ band we prefer a distinct name). Fig. 2 compares the colours of high-redshift quasars $5 < z < 8$, with the colours of stars and brown dwarfs. The quasars are well separated from the L and T dwarfs in the redshift range $5.8 < z < 7.2$.

UKIDSS will use the SDSS data for the short-wavelength band. Either the $i$ or the $z$ band is equally effective, because the shorter lever arm of the $z - Y$ colour (better for detecting the spectral break) compensates for the greater depth of the $i$ band. The SDSS $i$ limit is 22.0 which means that using a selection limit $i - Y > 3$, as shown in Fig. 2, UKIDSS can detect all quasars in the redshift range $5.8 < z < 7.2$, and brighter than $Y = 19.0$. Using the luminosity function of Fan et al. (2001b) we expect to detect about 10 quasars over this redshift range over 4000 sq. degs. These are the very brightest high-redshift quasars, and the most useful for follow-up spectroscopy. However larger numbers could be detected using deeper optical imaging, such as the proposed CFH Legacy Survey (www.cfht.hawaii.edu/Science/CFHLS/).

References

Becker, R. H., Fan, X., White, R. L., et al., 2001, AJ, 122, 2850
Fan, X., Narayan, V. K., Lupton, R. H., et al., 2001a, AJ, 122, 2833
Fan, X., Strauss, M. A., Schneider, D. P., et al., 2001b AJ, 121, 54
Loeb, A., Rybicki, G. B. 1999, ApJ, 524, 527