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# Spectroscopy of Quasar Candidates from SDSS Commissioning Data

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**Abstract.** The Sloan Digital Sky Survey has obtained images in five broad-band colors for several hundred square degrees. We present color-color diagrams for stellar objects, and demonstrate that quasars are easily distinguished from stars by their distinctive colors. Follow-up spectroscopy in less than ten nights of telescope time has yielded 22 new quasars, 9 of them at $z > 3.65$, and one with $z = 4.75$, the second highest-redshift quasar yet known. Roughly 80% of the high-redshift quasar candidates selected by color indeed turn out to be high-redshift quasars.

The Sloan Digital Sky Survey (SDSS; [1,2]) will use a dedicated 2.5m telescope at Apache Point Observatory in Southeast New Mexico to obtain CCD images to $\sim 23^m$ in five bands ($u', g', r', i', z'$; [3]) over 10,000 square degrees of high Galactic latitude sky. The imaging camera ( [4]) contains 30 $2048 \times 2048$ and 24 $2048 \times 400$ CCDs in its focal plane, and takes data at a rate of 20 square degrees an hour in drift-scan mode in all five colors; the data rate is roughly 1 Gbyte per square degree. Specialized software has been written to carry out astrometric and photometric calibration of the data, and to find and measure the properties of all objects detected in the images. The brightest $10^6$ galaxies and $1.5 \times 10^5$ quasar candidates will be followed up spectroscopically on the same telescope, using a pair of double spectrographs fed by a total of 640 fibers.

The SDSS obtained first light in imaging mode in May 1998, and is now undergoing intensive commissioning. We report here on the distribution of stellar objects in color-color space, the selection of quasar candidates, and follow-up spectroscopy with the Apache Point 3.5m telescope.

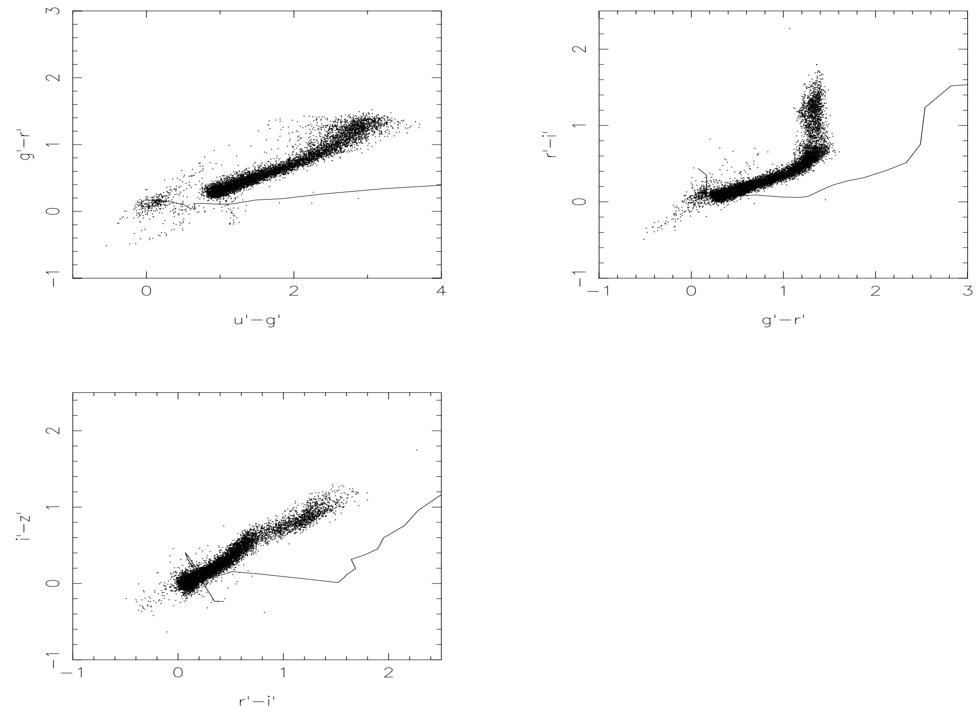


**FIGURE 1.** Simulated distribution of stellar objects in projections of SDSS color space over 10 square degrees towards the North Galactic Pole, which includes quasars, normal stars, white dwarfs and compact emission line galaxies to $r' = 20$. The solid line is the mean locus of quasars as a function of color.

The SDSS will use the colors and morphology of objects to identify quasar candidates from the photometric data: objects with stellar appearance and colors that lie well outside the stellar locus in color space will be flagged for spectroscopic investigation.

The distinction between quasars and stars in color-color space is illustrated in Figure 1, which shows model distributions of stars and quasars in a series of three SDSS color-color diagrams, from the simulations of ref. [5]. These simulations put in realistic SED's for stars, quasars, and compact emission-line galaxies, and attempt to model the stellar populations and spatial distributions of stars for the North Galactic Pole. The mean locus of quasars as a function of redshift is shown as the solid line; for $z < 2.5$, quasars are very blue in $u' - g'$, and can be distinguished quite easily from stars (and hot white dwarfs as well, which tend to be bluer in $g' - r'$; see the discussion in ref. [5]). At higher redshifts, the Lyman forest, and eventually, Lyman-limit systems, move through the SDSS filters, causing the colors to become redder. Note that at most redshifts, the quasar locus is well-separated from the stellar locus; the pernicious exception is quasars at $z \approx 2.8$, which have very similar broad-band colors to an F star. The reddest bands will permit identification of quasars with redshifts higher than six.

Figure 2 shows the color-color diagram of stellar objects with $r^* < 20$ from 20 square degrees of SDSS imaging commissioning data taken in September 1998[1].

1) The asterisk * indicates that the final SDSS photometric system has not yet been defined; this is preliminary photometry, accurate to perhaps 0.05 mag.

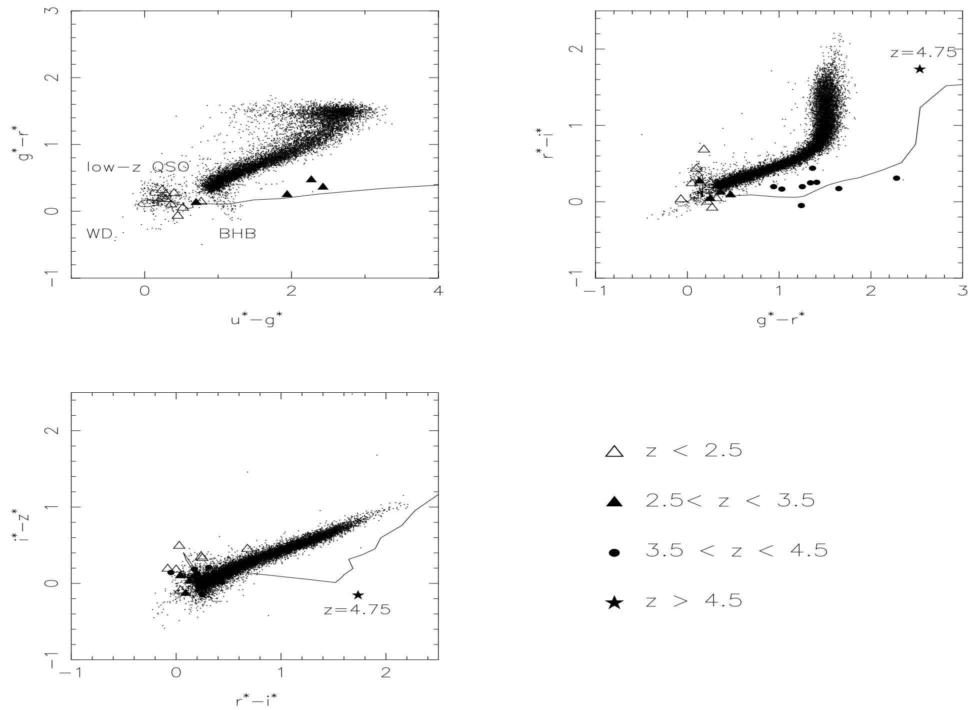


**FIGURE 2.** Observed color-color diagrams of 20 square degrees from the SDSS test data ($r^* < 20$). The positions of 22 newly discovered quasars (selected from 130 square degrees) are indicated. Already known quasars are not indicated in this figure.

Notice the qualitative similarity to the simulations in Figure 1, and the narrowness of the distribution: this is a tribute both to the quality of the data, and the pipeline used to reduce it. As the SDSS spectrographs have not been commissioned as of this writing, we are using the Double Imaging Spectrograph on the Apache Point 3.5m telescope to carry out spectroscopy of promising high-redshift quasar candidates. Superposed on Figure 2 are the places in color-color space where the 22 new quasars we have identified thus far lie, based on roughly 130 square degrees of imaging data.

These quasars do not by any means constitute a complete sample. In the last two nights of spectroscopic data, we have concentrated on those objects which appeared from their broad-band colors to be high-redshift candidates. Out of 11 candidates, 9 are indeed quasars at $z > 3.65$ (the two high-redshift quasars previously known in the survey area also stood out cleanly in the color-color diagrams, and would have been selected as well). All are brighter than $i^* = 20$. This success rate far surpasses the typical 10% found in the literature for high-redshift quasar surveys [6–8], although again, we do not have a complete sample to make this quantitative.

Figure 3 shows our spectra of the three highest-redshift quasars we have found thus far, plus one which shows strong associated absorption. The one at $z = 4.75$ is the second-highest redshift quasar known (the current redshift holder is $z = 4.90$; see ref. [9]). These spectra are of quite low resolution, roughly 7Å pixel$^{-1}$, while the SDSS spectrographs will deliver 1-1.5Å pixel$^{-1}$ over a similar wavelength coverage.

These objects were selected from roughly 1% of the sky that the SDSS will image. We therefore expect that there are enormously more high-redshift quasars to be discovered as part of the SDSS.

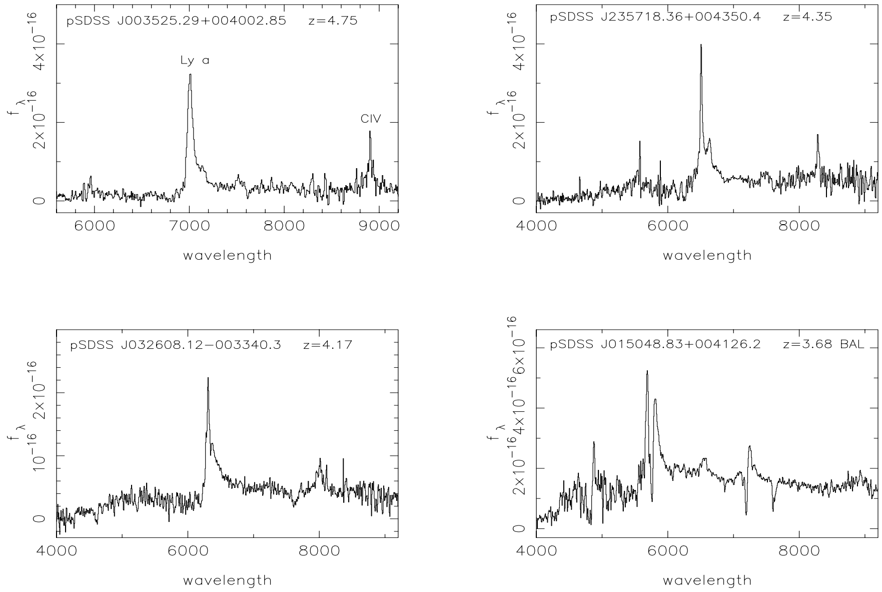


**FIGURE 3.** Spectra of 3 new SDSS quasars with $z > 4$, plus one with a broad absorption-line spectrum, obtained with the 3.5m ARC telescope and Double Imaging Spectrograph.


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