The Astronomical Journal, 131:1203–1209, 2006 March

A SURVEY OF $z > 5.7$ QUASARS IN THE SLOAN DIGITAL SKY SURVEY. IV. DISCOVERY OF SEVEN ADDITIONAL QUASARS[1,2]

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Received 2005 September 24; accepted 2005 November 28

ABSTRACT

We present the discovery of seven quasars at $z > 5.7$, selected from $\sim$2000 deg^2 of multicolor imaging data of the Sloan Digital Sky Survey. The new quasars have redshifts z from 5.79 to 6.13. Five are selected as part of a complete flux-limited sample in the SDSS northern Galactic cap; two have larger photometric errors and are not part of the complete sample. One of the new quasars, SDSS J1335+3533 ($z = 5.93$), exhibits no emission lines; the 3 σ limit on the rest-frame equivalent width of the Lyα+N v line is 5 Å. It is the highest redshift lineless quasar known and could be a gravitational lensed galaxy, a BL Lac object, or a new type of quasar. Two new $z > 6$ quasars, SDSS 1250+3130 ($z = 6.13$) and SDSS J1137+3549 ($z = 6.01$), show deep Gunn-Peterson absorption gaps in Lyα. These gaps are narrower than the complete Gunn-Peterson absorption troughs observed among quasars at $z > 6.2$ and do not have complete Lyβ absorption.

Key words: quasars: absorption lines — quasars: emission lines — quasars: general

Online material: color figure

1. INTRODUCTION

This paper is the fourth in a series presenting i-dropout $z \gtrsim 5.7$ quasars selected from the multicolor imaging data of the Sloan Digital Sky Survey (SDSS; York et al. 2000; Stoughton et al. 2002). In Fan et al. (2000) and the first three papers of this series (Fan et al. 2001b, hereafter Paper I; Fan et al. 2003, hereafter Paper II; Fan et al. 2004, hereafter Paper III), we presented the discovery of 12 luminous quasars at $z = 5.74$–6.42, selected from $\sim$4600 deg^2 of SDSS imaging in the northern Galactic cap. In this paper we describe the discovery of seven new quasars at $z = 5.79$–6.13, selected from $\sim$2000 deg^2 of new SDSS imaging data. The scientific objectives, photometric data reduction, candidate selection, and additional photometric and spectroscopic observation procedures are described in detail in Paper I and are not repeated here. We present the photometric observations of the i-dropout candidates in the new area in § 2. The spectroscopic observations and the photometric and spectroscopic properties of the newly discovered quasars are described in § 3. SDSS J133550.81+353315.8[17] ($z = 5.93$; SDSS J1335+3533 for brevity) is a quasar without detectable emission lines; we discuss the properties of this unusual object in § 4.

Following the previous papers in this series, we use two cosmologies to present our results: (1) $H_0 = 50$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0$, and $\Omega_M = 1$ (Ω-model); and (2) $H_0 = 71$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.73$, and $\Omega_M = 0.27$ (Λ-model; Spergel et al. 2003).

2. CANDIDATE SELECTION AND IDENTIFICATION

The SDSS is using a dedicated 2.5 m telescope (Gunn et al. 2006) and a large-format CCD camera (Gunn et al. 1998) at the

[1] Based on observations obtained with the Sloan Digital Sky Survey; the Apache Point Observatory's 3.5 m telescope, which is owned and operated by the Astrophysical Research Consortium; the MMT Observatory, a joint facility of the University of Arizona and the Smithsonian Institution; the University of Arizona's 2.3 m Bok Telescope; the Kitt Peak National Observatory's 4 m Mayall Telescope; the 6.5 m Walter Baade Telescope at the Las Campanas Observatory, a collaboration between the Observatories of the Carnegie Institution of Washington, the University of Arizona, Harvard University, the University of Michigan, and the Massachusetts Institute of Technology; and the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration, and made possible by the generous financial support of the W. M. Keck Foundation.

[2] This paper is dedicated to the memory of John N. Bahcall.

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[17] The IAU naming convention for SDSS sources is SDSS JHHMMSS.SS±DDMMSS.S, and the positions are expressed in J2000.0 coordinates. The astrometry is accurate to better than 0.″1 in each coordinate.

Apache Point Observatory in New Mexico to obtain images in five broad bands (*u*, *g*, *r*, *i*, and *z*, centered at 3551, 4686, 6166, 7480, and 8932 Å, respectively; Fukugita et al. 1996; Stoughton et al. 2002) of high Galactic latitude sky in the northern Galactic cap. About 7400 deg^2 of sky have been imaged at the time of this writing (2005 August). The imaging data are processed with a series of pipelines (Lupton et al. 2001; Pier et al. 2003), resulting in astrometric calibration errors of $<0''.1$ rms per coordinate and photometric calibration to better than 0.03 mag (Hogg et al. 2001; Smith et al. 2002; Ivezić et al. 2004; Tucker et al. 2005). These data have been made publicly available in a series of data releases (Early Data Release: Stoughton et al. 2002; Data Releases 1–3: Abazajian et al. 2003, 2004, 2005; Data Release 4: Adelman-McCarthy et al. 2006).

Quasars at redshifts larger than 5.7 have $i - z > 2.2$ in the SDSS filter system and become *i*-dropout objects with weak or no detection in all but the reddest (*z*) band. In Papers I, II, and III we presented results from a survey of *i*-dropout quasar candidates selected from ~ 4600 deg^2 of high Galactic latitude sky in the SDSS main survey area, observed in the springs of 2000–2003. In the springs of 2004 and 2005 we continued the search in 92 new SDSS imaging runs. These imaging data were taken between 2003 May (run 3926) and 2005 April (run 5237) and cover $\sim$2400 deg^2 of the sky. We applied the same color selection criteria as in Paper II (see Figs. 1 and 2 in Paper II) to the new SDSS imaging data to select $z > 5.7$ quasar candidates. A total of $\sim$230 *i*-dropout candidates that satisfy the color selection criteria [with *z*-band photometric error $\sigma(z) < 0.10$] were selected in the main survey area. These candidates were selected as part of a flux-limited complete sample (Paper III). We have also selected a number of fainter candidates with larger *z*-band photometric error $\sigma(z) = 0.10$–0.12, although they are not part of the complete sample.

The photometric and spectroscopic observations were carried out over a number of nights between 2004 January and 2005 June. A total of 198 candidates (85% of those selected) from the complete sample were observed; thus, the effective area of this sample is $\sim$2000 deg^2. In addition, data on about 30 fainter candidates with $\sigma(z) = 0.10$–0.12 were also acquired.

We first obtained independent *z* photometry to eliminate false detections due to cosmic rays and to improve the $i - z$ color measurement, using the Seaver Prototype Imaging Camera (SPICAM) on the ARC 3.5 m telescope at the Apache Point Observatory. Unfortunately, poor weather limited the number of objects we were able to observe in the *z* band.

Additional *J*-band photometry allows separation of $z \sim 6$ quasars from L/T dwarfs, which have similar $i - z$ colors but much redder $z - J$ colors (e.g., Paper I). *J*-band observations were carried out using a number of IR imagers: (1) the 256×256 NICMOS imager on Steward Observatory's 2.3 m Bok Telescope at Kitt Peak; (2) GRIM II (the near-infrared grism spectrometer and imager) on the ARC 3.5 m, which we used through 2004 December; (3) NIC-FPS (the Near-Infrared Camera/Fabry-Perot Spectrometer), also on the ARC 3.5 m, which replaced GRIM II in 2004 December; and (4) PANIC (Persson's Auxiliary Nasmyth Infrared Camera; Martini et al. 2004) on the 6.5 m Baade Telescope at Las Campanas Observatory.

Spectroscopic observations were carried out over a number of observing runs between 2004 January and 2005 June using (1) the Red Channel Spectrograph on the MMT 6.5 m telescope on Mt. Hopkins; (2) the Multi-Aperture Red Spectrometer (MARS) on the 4 m telescope on Kitt Peak; and (3) the Echellette Imaging Spectrograph (ESI; Epps & Miller 1998) on the Keck II telescope on Mauna Kea, Hawaii.

3. DISCOVERY OF SEVEN NEW QUASARS AT $z > 5.7$

Among the 198 *i*-dropout candidates with $\sigma(z) < 0.10$ that we have observed, 52 are false *z*-band-only detections that are most likely cosmic rays, 129 are M or L dwarfs (mostly classified photometrically based on their red $z - J$ colors), and 12 are likely T dwarfs (Chiu et al. 2006). Several objects still lack proper infrared spectroscopy, so the T dwarf classification is still preliminary. We have not yet obtained *J*-band photometry for the remaining candidates. Therefore, the quasars reported in this paper do not form a complete sample. Among the faint [$\sigma(z) > 0.10$] candidates that are not identified as quasars, roughly half are likely cosmic rays and half are late-type stars, although the larger photometric error does not allow accurate typing.

Five of the *i*-dropout candidates with $\sigma(z) < 0.10$ and two faint candidates with $0.10 < \sigma(z) < 0.12$ are identified as quasars at $z = 5.79$–6.13. The finding charts of the seven new quasars are presented in Figure 1. Their spectra are flux-calibrated to match the observed *z*-band photometry and are shown in Figure 2. Table 1 presents the photometric properties of the new quasars, and Table 2 presents the measurements of their continuum properties. Following Papers I, II, and III, the quantity AB_{1280} is defined as the AB magnitude of the continuum at rest frame 1280 Å, after correcting for interstellar extinction using the map of Schlegel et al. (1998). We extrapolate the continuum to rest frame 1450 Å, assuming a continuum shape $f_\nu \propto \nu^{-0.5}$, to calculate AB_{1450}. None of the seven quasars is detected in the Faint Images of the Radio Sky at Twenty cm (FIRST) radio survey (Becker et al. 1995) or NRAO VLA Sky Survey (NVSS; Condon et al. 1998). The FIRST survey has a typical 5 σ flux limit of $\sim$1 mJy at 20 cm. Assuming a power-law continuum of $f_\nu \propto \nu^{-0.5}$ in both radio and UV wavelengths, we find that quasars in this paper have a radio-loudness parameter $R = F_{5\,\mathrm{GHz}}/F_{4400}$ smaller than 10, the usual division between radio-loud and radio-quiet objects (e.g., White et al. 2000). We have checked the publicly available archival X-ray coverage of these seven quasars, focusing on observations made by sensitive X-ray imaging detectors. SDSS J0927+2001 and SDSS J1250+3130 lie within pointed X-ray observations made by the *Einstein* IPC (1.7 ks) and *ROSAT* PSPC (0.7 ks), respectively, but no X-ray detections were obtained. The relatively short exposures and significant off-axis angles of these two quasars do not allow physically tight constraints to be placed on their X-ray–to–optical flux ratios (see Strateva et al. 2005). The other five quasars only have imaging X-ray coverage in the *ROSAT* All-Sky Survey, and no detections were obtained, indicating 3 σ upper limits of X-ray flux of ~ 3.1–5.7×10^{-13} ergs cm^{-2} s^{-1} in the 0.1–2.4 keV band. Results from a recent *Chandra* observation of SDSS J0840+5624 will be reported in Shemmer et al. (2005). The discovery of these seven new quasars brings the total number of $z > 5.7$ quasars from the SDSS to 19.

3.1. *Notes on Individual Objects*

SDSS J081827.40+172251.8 ($z = 6.00 \pm 0.02$): This quasar was discovered using the Keck II telescope on 2005 April 12. Figure 2 shows a spectrum with 20 minute exposure time using the Keck ESI, smoothed to a resolution of 1800. SDSS J0818+1722 has very weak emission lines: the rest-frame equivalent width of Lyα+N v is $\sim$10 Å, compared to an average of $\sim$75 Å for high-redshift quasars (Schneider et al. 1991; Fan et al. 2001a; Paper III). The current spectrum has a moderate signal-to-noise ratio (S/N); Lyα+N v is the only detected line. The redshift is determined from the fit to the Lyα+N v complex. The uncertainty in this redshift comes from two sources. The first is absorption

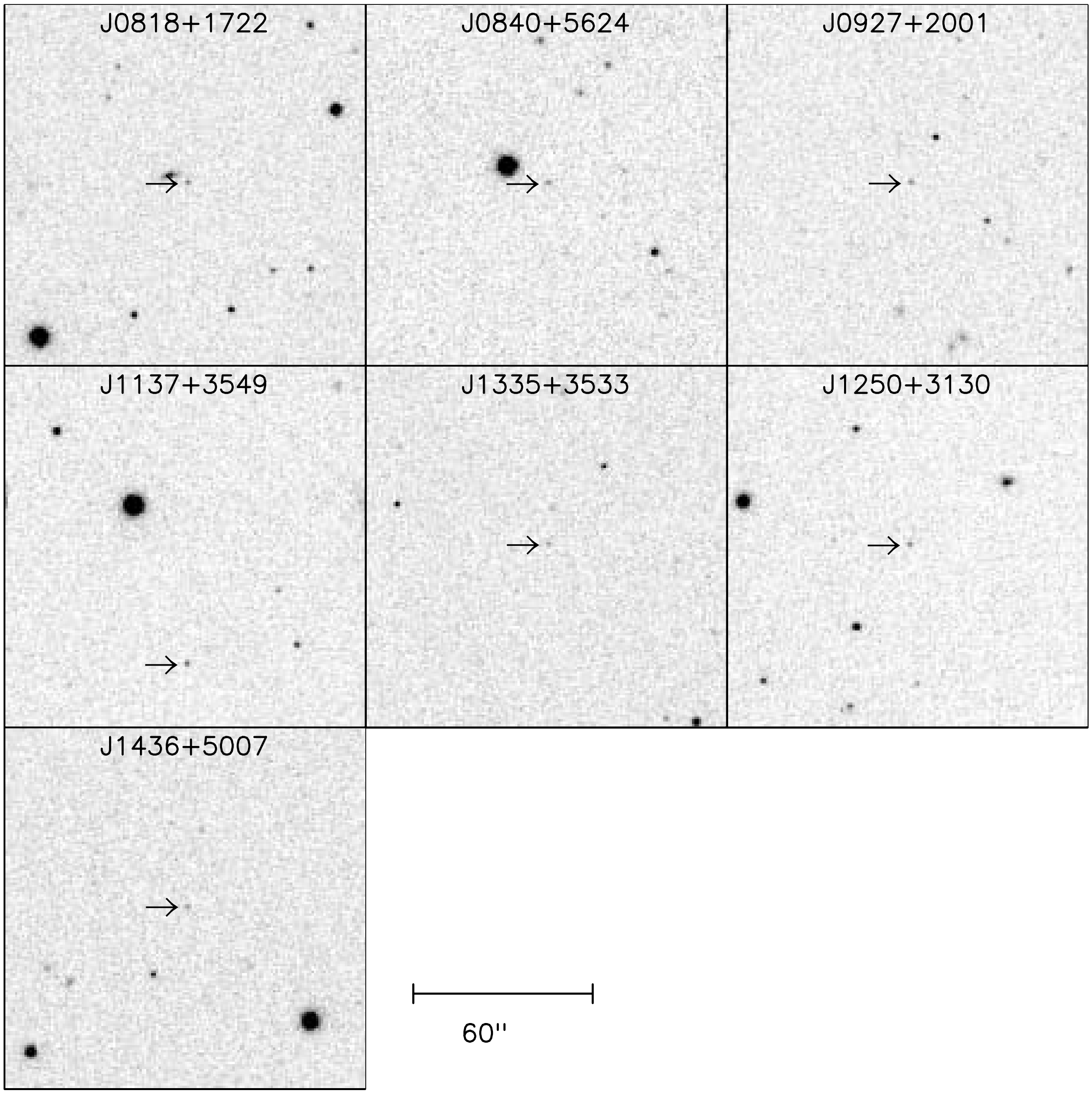

FIG. 1.—SDSS z-band images of the seven new $z > 5.7$ quasars. Each side of the finding chart is 120″. North is up, and east is left.

in the blue end of the line due to absorption from the Lyα forest. The second is the offset in the redshift determined from Lyα and from high-ionization lines such as C IV on the one hand, and from low-ionization lines such as Mg II on the other. Richards et al. (2002a) use a large sample of SDSS quasars to show that C IV is blueshifted from Mg II by 824 ± 511 km s^{-1}, corresponding to an uncertainty of $\sim$0.02 at $z \sim 6$. Following Papers I, II, and III we adopt an error bar of 0.02 in the quasar redshift to reflect these uncertainties.

There is also a strong absorption line at $\sim$8870 Å that is resolved into a doublet in the full resolution spectrum. We tentatively identify this feature as the C IV $\lambda\lambda$1548, 1551 doublet at a redshift of 4.726.

SDSS J084035.09+562419.9 (**$z = 5.85 \pm 0.02$**): This object was discovered on 2004 January 13 using the MMT. Figure 2 shows a spectrum with 60 minute exposure time using the MMT Red Channel Spectrograph. The S/N of the spectrum is relatively low. The redshift is estimated by the best-fit Lyα+N V emission.

SDSS J092721.82+200123.7 (**$z = 5.79 \pm 0.02$**): This quasar was discovered on 2005 May 6 using the Kitt Peak 4 m telescope. Figure 2 shows a spectrum with 220 minute exposure time with MARS on the Kitt Peak 4 m telescope. The redshift is estimated by the best-fit Lyα+N V emission.

SDSS J113717.73+354956.9 (**$z = 6.01 \pm 0.02$**): This quasar was discovered on 2004 April 27 using the MMT. Figure 2 shows a 40 minute Keck ESI spectrum taken on 2005 January 6. The spectrum shows clear detections of Lyα+N V, O I, and Si IV emission. We adopt the average of the best-fit values of these lines as the quasar redshift. A strong and marginally resolved absorption feature is detected at 9180 Å; we are not able to unambiguously identify this feature.

The absorption spectrum shows a dark absorption gap in Lyα transition immediately blueward of the emission line, where no flux is detected. Following Becker et al. (2001), Fan et al. (2002), and White et al. (2003), we define the transmitted flux ratio as

$$\mathcal{T}(z_{\rm abs}) \equiv \left\langle f_\nu^{\rm obs}/f_\nu^{\rm con} \right\rangle, \qquad (1)$$

where $f_\nu^{\rm con}$ is the continuum level extrapolated from the red side of the Lyα emission line. We find an average transmitted flux $\mathcal{T} = -0.005 \pm 0.004$ for $z_{\rm abs}$ between 5.83 and 5.90. The

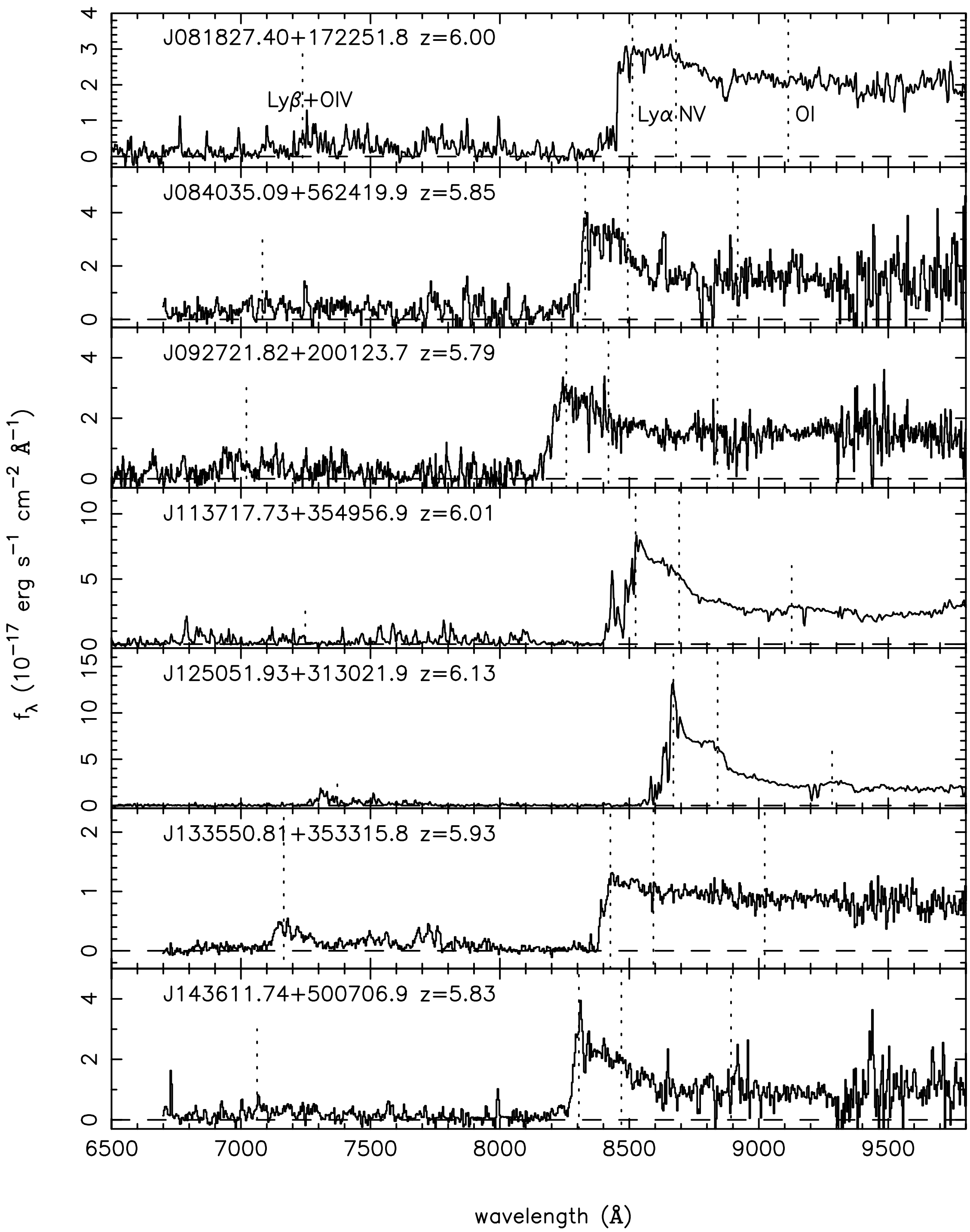

Fig. 2.—Spectra of the seven new quasars at $z > 5.7$. The spectral resolutions are between 500 and 4000, depending on the spectrograph used. Vertical lines indicate wavelengths at which major emission lines are expected.

effective Lyα optical depth in this dark gap is $\tau_{\rm eff} > 5.5$, comparable to the limits measured in the complete Gunn & Peterson (1965) troughs detected in quasars at $z > 6.1$ (Becker et al. 2001; Fan et al. 2002; White et al. 2003; Paper III. See also Songaila 2004). The redshift extent of this dark gap is considerably narrower than those seen in quasars at $z > 6.1$. Furthermore, flux is clearly detected in the Lyβ transition over the same redshift range, with an average transmitted flux of $\mathcal{T}_\beta = 0.013 \pm 0.003$, indicating that the intergalactic medium (IGM) is still highly ionized in this region, although the mean optical depth has increased substantially from lower redshift. In a subsequent paper (Fan et al. 2005), we present a full analysis of the Gunn-Peterson absorption in the spectra of this and the other 18 $z > 5.7$ SDSS quasars.

SDSS J125051.93+313021.9 ($z = 6.13 \pm 0.02$): This quasar was discovered on 2004 April 24 using the MMT. We did not carry out J-band photometry; the red $i - z$ color and lack of detection ($J > 16.5$) in the Two Micron All Sky Survey (2MASS; Skrutskie et al. 1997) suggested that it was likely to be a high-redshift quasar. Figure 2 shows a 60 minute Keck ESI spectrum taken on 2005 January 6. The spectrum shows clear detections of Lyα+N v, Lyβ+O vi, O i, and Si iv emission lines.

TABLE 1
Photometric Properties of Seven New $z > 5.7$ Quasars

Quasar (SDSS)	Redshift	i	z	J	SDSS Run
J081827.40+172251.8	6.00 ± 0.02	22.19 ± 0.22	19.60 ± 0.08	18.54 ± 0.05	5045
J084035.09+562419.9	5.85 ± 0.02	22.43 ± 0.34	19.76 ± 0.10	19.00 ± 0.10	4204
J092721.82+200123.7	5.79 ± 0.02	22.12 ± 0.17	19.88 ± 0.08	19.01 ± 0.10	5138
J113717.73+354956.9	6.01 ± 0.02	22.57 ± 0.30	19.54 ± 0.07	18.41 ± 0.05	4392
J125051.93+313021.9	6.13 ± 0.02	22.14 ± 0.18	19.53 ± 0.08	>16.5	4623
J133550.81+353315.8	5.93 ± 0.04	22.67 ± 0.99	20.10 ± 0.11	18.97 ± 0.05	4470
J143611.74+500706.9	5.83 ± 0.02	22.76 ± 0.28	20.00 ± 0.12	19.04 ± 0.10	3180

Notes.—The SDSS photometry (i, z) is reported in terms of "asinh magnitudes" on the AB system. The asinh magnitude system is defined by Lupton et al. (1999); it becomes a linear scale in flux when the absolute value of the S/N is less than about 5. In this system, zero flux corresponds to 24.4 and 22.8 in i and z, respectively. The J magnitude is on a Vega-based system.

We adopt the average of the best-fit values of these lines as the quasar redshift. It is the highest redshift object presented in this paper, and the fifth most distant quasar yet discovered.

On the blue wing of the O I emission line, a Mg II doublet at $z_{\rm abs} = 2.29$ is clearly detected, with a total rest-frame equivalent width of 4.5 Å.

In the absorption spectrum of this quasar, we detect a deep Gunn-Peterson absorption gap at $5.69 < z_{\rm abs} < 5.95$ in the Lyα transition. The average transmitted flux, $\mathcal{T} = 0.005 \pm 0.003$, indicates a lower limit of the Gunn-Peterson optical depth: $\tau_{\rm eff} > 5.3$. Similar to the case of J1137+3549, residual flux is clearly detected over the same redshift range in the Lyβ transition, with a transmitted flux of $\mathcal{T}_\beta = 0.008 \pm 0.002$.

SDSS J133550.81+353315.8 ($z = 5.93 \pm 0.04$): This quasar was discovered on 2005 June 13 using the MMT. Figure 2 shows a 120 minute MMT Red Channel Spectrograph spectrum. This object has a z-band photometric error $\sigma(z) = 0.11$; therefore, it is not part of the complete flux-limited sample of $z \sim 6$ quasars. SDSS J1335+3533 is the most unusual object presented in this paper; it does not have a detectable Lyα+N V emission line. We discuss its properties and possible interpretations in § 4.

SDSS J143611.74+500706.9 ($z = 5.83 \pm 0.02$): This object was discovered on 2004 April 28 using the Kitt Peak 4 m telescope. Figure 2 shows a spectrum with 60 minute exposure time using the MMT Red Channel Spectrograph. This object has a z-band photometric error $\sigma(z) = 0.12$, and therefore will not be part of the complete flux-limited sample of $z \sim 6$ quasars. The redshift is estimated by the best-fit Lyα+N V line.

4. SDSS J1335+3533, A LINELESS QUASAR AT $z = 5.93$

Figure 3 shows the MMT spectrum of SDSS J1335+3533. This object is clearly at high redshift: it exhibits a sharp Lyα break at $\lambda < 8410$ Å and a sharp Lyβ break at $\lambda < 7130$ Å, indicating a redshift $z > 5.92$. However, no strong Lyα emission line is detected. Although there is a hint of excess flux at the edge of the Lyα break, the spectrum is consistent with a pure power-law continuum. Fitting a power-law plus emission-line model to the spectral region redward of the Lyα break, we find the 3 σ limit on the rest-frame equivalent width of the Lyα+N V line to be 5 Å.

Most high-redshift quasars are characterized by the presence of strong Lyα and N V emission lines, and the rest-frame equivalent width of Lyα+N V is 70 ± 15 Å for $z \sim 4$ quasars (e.g., Schneider et al. 1991; Vanden Berk et al. 2001; Fan et al. 2001a, 2004). Figure 3 also displays the composite spectrum of 16 non–broad absorption line (non-BAL) quasars at $z > 5.7$ (excluding SDSS J1335+3533), constructed following the procedure described in Paper III. The lack of Lyα is striking. The current observations do not have sufficient S/N to place strong constraints on the presence of O I and Si IV lines; another strong emission line, C IV, is now beyond 1 μm and will require new infrared spectroscopy. We base our estimate of the redshift of SDSS J1335+3533 on the size of the proximity effect zone in the Lyα forest close to the Lyα emission line. Details of calculating the size of the proximity zone around luminous quasars at $z \sim 6$ are described in a subsequent paper (Fan et al. 2005). Briefly, in regions of the IGM close to the quasar, transmitted flux is enhanced due to increased ionizing flux from the quasar itself. The transmitted flux declines to that in the average IGM at large distances; at $z > 5.7$, $\mathcal{T} < 0.05$.

Fluxes in the 16 other $z > 5.7$ non-BAL quasars from the SDSS drop to 20% of the continuum level at a redshift $\Delta z = 0.11 \pm 0.04$ blueward of the Lyα emission line. This value is a function of luminosity and redshift. SDSS J1335+3533 is close to the median redshift and luminosity of our sample. Including these effects does not change our redshift estimate. For this quasar the transmitted flux falls to 20% of the extrapolation of the long-wavelength flux at $z_{\rm abs} = 5.82$, implying that the true redshift of the quasar is $z = 5.93 \pm 0.04$. We obtain a similar redshift using the onset of the Lyβ forest in the spectrum. Note

TABLE 2
Continuum Properties of New $z > 6$ Quasars

Quasar (SDSS)	Redshift	AB_{1280}	AB_{1450}	M_{1450} (Λ-Model)	M_{1450} (Ω-Model)	$E(B-V)$ (Galactic)
J081827.40+172251.8	6.00	19.41	19.34	−27.37	−27.14	0.04
J084035.09+562419.9	5.85	20.10	20.04	−26.64	−26.40	0.04
J092721.82+200123.7	5.79	19.94	19.87	−26.78	−26.55	0.03
J113717.73+354956.9	6.01	19.70	19.63	−27.08	−26.85	0.02
J125051.93+313021.9	6.13	19.71	19.64	−27.11	−26.87	0.02
J133550.81+353315.8	5.93	19.96	19.89	−26.81	−26.58	0.01
J143611.74+500706.9	5.83	20.23	20.16	−26.51	−26.28	0.02

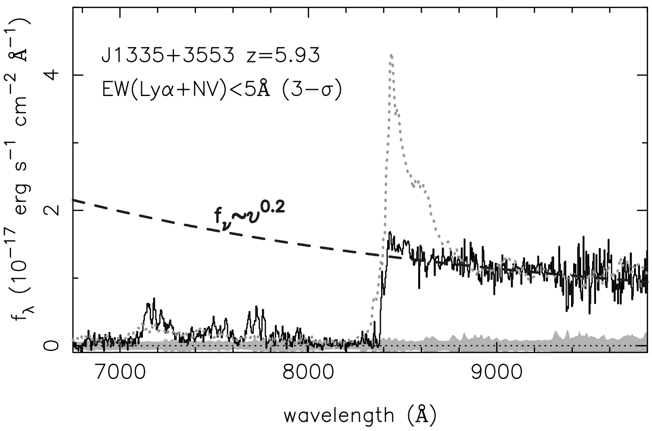

Fig. 3.—Spectrum of the lineless quasar SDSS J1335+3533 ($z = 5.93$). The shaded area around zero flux shows the 1 σ error array. The dashed line is the best-fit power law. The absolute value of the power-law index is uncertain by $\sim$0.3 due to possible error in the spectrophotometric calibration. The dotted line shows the composite spectrum of 16 quasars at $z > 5.7$ (arbitrary normalization). The Lyα+N v emission line has an average rest-frame equivalent width of $\sim$70 Å at $z > 4$, while for SDSS J1335+3533, it has a 3 σ upper limit of 5 Å. [*See the electronic edition of the Journal for a color version of this figure.*]

that this redshift determination depends somewhat on the assumed size of the H ii region around SDSS J1335+3533.

Lineless quasars are very rare at high redshift. This is unlikely to be a selection effect. The SDSS color selection of high-redshift quasars is mostly based on the presence of a strong Lyman break. It does not strongly select against quasars with small Lyα emission-line equivalent widths (Fan et al. 1999; Richards et al. 2002b). The first lineless quasar found at high redshift was SDSS J1532−0030 ($z = 4.62$; Fan et al. 1999); its spectrum is very similar to that of SDSS J1335+3533. Since then, the SDSS has discovered about a dozen quasars at $3 < z < 5$ with rest-frame Lyα equivalent width smaller than 5 Å (e.g., Anderson et al. 2001; Collinge et al. 2005). They appear to form a distinct class of high-redshift *lineless* quasars. SDSS J1335+3533 represents the most distant member of this class of objects.

The nature of these lineless quasars remains a mystery. They could be ultraluminous or lensed galaxies, high-redshift BL Lac objects, or a new class of quasar with very weak or absent broad emission lines. The absolute AB magnitude of SDSS J1335+3533 at 1450 Å (rest frame) is $M_{1450} = -26.81$ (Λ-model). Thus, although the S/N of our optical spectrum is probably not sufficient to rule out the presence of stellar absorption lines, this object is much too luminous to be an ordinary galaxy unless it is strongly lensed. There is no indication that SDSS J1335+3533 is extended beyond the point-spread function of the 1.″3 FWHM SDSS image; this is not yet a strong constraint on the lensing hypothesis.

BL Lac objects, by definition, show no or very weak emission lines. They are also characterized by strong radio and X-ray emission, optical variability, and strong and variable optical polarization due to synchrotron radiation from the relativistic jet (e.g., Urry & Padovani 1995). The highest redshift BL Lac object in the literature is at $z < 2$ (Laurent-Muehleisen et al. 1999). SDSS J1335+3533 is not detected in the FIRST radio survey; the 4 σ upper limit is 0.8 mJy beam^{-1} at this position, including CLEAN bias (White et al. 1997). This implies a radio-to-optical spectral index in the observed frame of $\alpha_{\rm ro} < 0.26$ (4 σ). Classical radio-selected BL Lac objects have $\alpha_{\rm ro} > 0.3$ (Stocke et al. 1990), while X-ray-selected BL Lac objects can have $\alpha_{\rm ro}$ as small as $\sim$0.1 (Laurent-Muehleisen et al. 1999). Collinge et al. (2005) present a sample of 386 BL Lac candidates identified from the SDSS by their lack of emission lines. Most of them are at low redshift ($z < 1$), and only $\sim$3% of these optically selected candidates have $\alpha_{\rm ro} < 0.2$. SDSS J1335+3533 is also not detected on the *ROSAT* full-sky pixel images (Voges et al. 1999), implying a 3 σ upper limit of X-ray flux of $\sim 3.7 \times 10^{-13}$ ergs cm^{-2} s^{-1} in the 0.1–2.4 keV band, and an optical-to–X-ray index in the observed frame $\alpha_{\rm ox} > 1.1$ at 3 σ. This limit does not yet place strong constraints on the BL Lac object hypothesis, as it is in the middle of the $\alpha_{\rm ox}$ distribution for X-ray-selected BL Lac objects (Stocke et al. 1990; Sambruna et al. 1996).

The current observations cannot yet place strong constraints on the nature of SDSS J1335+3533: whether it is a lensed galaxy, a very high redshift BL Lac object, or a new type of quasar with no or a very weak emission-line region. Further observations, including high-resolution imaging to test the lensing hypothesis, optical monitoring for variability, deep radio and X-ray observations (e.g., Schneider et al. 2003), and optical polarimetric measurements to test the BL Lac object hypothesis, are needed. *Spitzer Space Telescope* observations of such objects in the mid-infrared will probe the presence of hot dust in the vicinity of the object, differentiating the hypotheses that the source is active galactic nucleus–powered, star formation powered, or beamed (A. M. Diamond-Stanic et al. 2006, in preparation). Stalin & Srianand (2005) suggest that such objects could be explained by microlensing of the continuum source that only boosts the continuum; if this is the case, long-term monitoring will show a decreasing continuum and a detectable Lyα emission line after the lensing event passes.

5. FUTURE OBSERVATIONS

Combining the seven new quasars presented in this paper with those reported in Papers I, II, and III, we have a sample of 19 quasars at $z > 5.7$. Among them, 14 are selected using a uniform set of color selection criteria from an effective area of $\sim$6600 deg^2, forming a flux-limited sample. Because the spectroscopic observations of *i*-dropout candidates have not been completed, we do not derive statistical properties of the sample in this paper.

In the spring of 2005, the SDSS essentially completed its imaging survey in the northern Galactic cap, with a total area of $\sim$7550 deg^2. In the spring of 2006, we will continue to search for *i*-dropout quasar candidates in the remaining new area, as well as observing additional candidates in the previously studied area that meet the selection criteria because of improved photometric calibrations. Combining current data with these planned observations, we will be able to define a sample of $z > 5.7$ quasars covering the entire SDSS northern Galactic cap area, and use it to refine the measurements of the evolution of the luminosity function and emission-line properties of the highest redshift quasars.

Funding for the creation and distribution of the SDSS Archive has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the US Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is available at http://www.sdss.org. The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns

Hopkins University, the Korean Scientist Group, Los Alamos National Laboratory, the Max Planck Institute for Astronomy, the Max Planck Institute for Astrophysics, New Mexico State University, the University of Pittsburgh, the University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington. We thank the staffs at Apache Point Observatory, MMT, the Bok Telescope, Kitt Peak, Keck, and Magellan for their expert help. We acknowledge support from NSF grant AST 03-07384, a Sloan Research Fellowship and a Packard Fellowship for Science and Engineering (X. F.), and NSF grants AST 00-71091 and AST 03-07409 (M. A. S.).

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