The Third Data Release of the Sloan Digital Sky Survey

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ABSTRACT

This paper describes the Third Data Release of the Sloan Digital Sky Survey (SDSS). This release, containing data taken up through June 2003, includes imaging data in five bands over 5282 $\deg^2$, photometric and astrometric catalogs of the 141 million objects detected in these imaging data, and spectra of 528,640 objects selected over 4188 $\deg^2$. The pipelines analyzing both images and spectroscopy are unchanged from those used in our Second Data Release.

Subject headings: Atlases—Catalogs—Surveys

1. Introduction

The Sloan Digital Sky Survey (SDSS; York et al. 2000) is carrying out an imaging and spectroscopic CCD survey of the sky at high Galactic latitudes, using a dedicated wide-field 2.5m telescope at Apache Point Observatory in South-East New Mexico. The telescope saw first light in May 1998, and following an extensive period of commissioning, formal survey operations began in April 2000. The resulting data have been distributed to the public via web interfaces accessible from the SDSS public web site[65], and have been described in a series of papers:

- The Early Data Release, including data taken during commissioning, Stoughton et al. (2002; hereafter EDR paper), consisting of 462 $\deg^2$ of imaging data and spectra of 54,000 objects.
- The First Data Release, Abazajian et al. (2003; hereafter DR1 paper), consisting of imaging data over 2099 square degrees and spectra of 186,240 objects.
- The Second Data Release, Abazajian et al. (2004; hereafter DR2 paper), consisting of imaging data over 3324 square degrees and spectra of 367,360 objects.

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The SDSS imaging data are taken on photometric moonless nights (with photometricity determined by an auxiliary telescope; Hogg et al. 2001) of good seeing with a wide-field imaging camera operating in drift-scan mode (Gunn et al. 1998). Six parallel *scanlines* on the sky, each $13'$ wide, are observed by each of the columns of CCDs. Each of the five rows of the CCDs in the camera is fronted by a different filter, thus each scanline is observed in five filters, denoted (in order of observation) $r\,i\,u\,z\,g$ (Fukugita et al. 1996; Gunn et al. 1998; EDR paper). The imaging data are processed by automated software pipelines that measure the properties of all detected objects (Lupton et al. 2001), and perform astrometric (Pier et al. 2003) and photometric calibration, the latter to a set of standard stars observed with the Photometric Telescope (Smith et al. 2003). The resulting object catalogs are used to select targets for spectroscopy, including the "Main" sample of galaxies, magnitude-limited to $r_{Petrosian} = 17.77$ (Strauss et al. 2002), a sample of luminous red ellipticals to $r_{Petrosian} = 19.5$ (Eisenstein et al. 2001; DR2 paper), quasar candidates selected by their colors to $i = 19.1$ (for $z < 3$ candidates) and $i = 20.2$ (for higher-redshift candidates) (Richards et al. 2002), as well as a host of additional targets, including optical counterparts to ROSAT X-ray sources (Anderson et al. 2003), unusual stars, and calibration observations (EDR paper). All magnitude limits here are corrected for Galactic extinction following Schlegel, Finkbeiner, & Davis (1998). The list of spectroscopic targets is distributed among a series of spectroscopic *tiles* of 3° diameter (Blanton et al. 2003) to maximize observing efficiency. Each tile then forms the design for a spectroscopic plate: holes are drilled in aluminum plates corresponding to the position of each object for which spectra will be measured. At the telescope, optical fibers feeding a pair of double spectrographs are plugged into each plate; the spectroscopic observations, carried out under conditions not pristine enough for imaging, are typically 45 minutes per plate. The spectra are wavelength- and flux-calibrated, and run through an automatic pipeline to classify them and determine redshifts (EDR paper).

The previous data release papers describe the quality of the data; the basic attributes of the data are given in Table 1.

2. The Third Data Release

The SDSS Third Data Release (DR3) consists of all survey-quality data taken through June 2003 as part of the main SDSS survey. The footprints of the imaging and spectroscopic data are shown in Figure 1. The spectroscopic footprint is smaller: because spectroscopic targets are chosen from the imaging data, the spectroscopy always lags the imaging. As with previous data releases, DR3 does *not* include repeat imaging scans (mostly on the Celestial Equator in the Southern Galactic Cap; see Figure 1), repeat observations of spectroscopic plates that have been observed more than once, or imaging or spectroscopic data taken significantly outside the ellipse of the main survey footprint (as described in York et al. 2000). However, six spectroscopic plates, and thirty-four square degrees of imaging data in the Northern Galactic Cap in DR3 lie just outside this ellipse. As in previous data releases, DR3 does include imaging data that overlap between adjacent runs.

The SDSS has taken a considerable amount of imaging data at low Galactic latitudes outside the survey footprint; the subset of these data taken before Summer 2003 have been made publically available in a release separate from DR3, and is described by Finkbeiner et al. (2004).

As the survey has progressed, we have steadily improved the software used to process the imaging and spectroscopic data. These changes are described in the DR1 and DR2 papers, and at the public SDSS web site. Each subsequent release has incorporated all the data included in the previous release, necessitating a reprocessing of those data. For DR3, however, we have made *no* changes in the processing software, and therefore the DR2 subset of the DR3 data are *identical* to the data already made public in 2004 March. There is one exception to this statement, namely that we have updated some incorrect spectral classifications in DR3. We have also added several new auxiliary tables to the SDSS Catalog Archive Server (CAS) which will be useful for those using SDSS data. The Archive Introduction page in the Help menu on the CAS website[66] describes the CAS data model. It has a new link at the top for release-specific notes.

2.1. Updated redshifts

We have visually inspected the spectra of all objects which remained unclassified (spectral class UNKNOWN), and have updated the classification and redshift where appropriate. Many of these objects are of low signal-to-noise ratio, or are unusual objects of various types, especially unusual quasars (see Hall et al. 2002). There are 477 objects whose classifications were updated in this effort, including 377 objects included in DR2.

2.2. New auxiliary tables

We have added a separate database table that includes stellar B, V, R, and I Kron-Cousins photometry with accuracy of 0.02 mag or better from Stetson (2000), as downloaded from the Canadian Astronomy Data Centre photometric standards website[67]. These data, when cross-matched with SDSS, allow SDSS photometry of stars to be compared with an external catalog. After fitting for the conversion between the *ugriz* SDSS photometric system to the Kron-Cousins photometry used by Stetson, we find the residuals shown in Figure 2; the rms scatter is of order 2.5% in each band. There is some evidence that this scatter is dominated by errors in the photometric calibration of the SDSS. Further details will be given in Holtzman et al. (in preparation). We have also included data from the Third Reference Catalog of Galaxies (de Vaucouleurs et al. 1991), again to

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[66]http://skyserver.sdss.org

[67]`http://cadcwww.dao.nrc.ca/standards/`

allow cross-reference to SDSS data. Please see the CAS Archive Introduction page on the SkyServer website's Help page for more information about the Stetson and RC3 databases.

2.3. Imaging quality measures on a field-by-field basis

As part of quality assurance of the SDSS data, each of the $\sim 200,000$ $10' \times 13'$ fields within DR3 is assigned a quality flag, `FieldQAll`, which is now made available in a separate table, entitled *RunQA* in both the Catalog Archive Server and Data Archive Server. This flag is based on five attributes:

- The seeing in the r band.
- The mean offset between the $7''$ aperture magnitude, and the Point Spread Function (PSF) magnitude for bright stars on the frame. The accuracy of the results of the photometric pipeline are critically dependent on a correct model for the PSF, and the aperture minus PSF magnitude is an excellent diagnostic for problems in the PSF determination. This magnitude difference typically is large under conditions in which the seeing is varying rapidly (see the discussion in Ivezić et al. 2004).
- Systematic offsets of the stellar locus in color space, and/or increased width of the stellar locus. As described in Fan (1999), Finlator et al. (2000), Helmi et al. (2003), and many other papers, stars in the SDSS photometric system follow a narrow locus in color-color diagrams. One can define a series of four *principal colors* from fits to the stellar locus, which are linear transformations of the SDSS magnitudes which empirically are essentially constant over the sky (after correcting for foreground reddening following Schlegel et al. 1998). That is, systematic deviations of these principal colors as small as 1% could indicate problems in the data. These principal colors are defined as:
  - The s color, $s = -0.249u + 0.794g - 0.555r + 0.234$, which is perpendicular to the stellar locus in the $u - g, g - r$ diagram.
  - The w color, $w = -0.227g + 0.792r - 0.567i + 0.050$, which is perpendicular to the blue branch of the stellar locus in the $r - i, g - r$ diagram.
  - The x color, $x = 0.707g - 0.707r - 0.983$, which is perpendicular to the red branch of the stellar locus in the $r - i, g - r$ diagram.
  - The y color, $y = -0.270r + 0.800i - 0.534z + 0.059$, which is perpendicular to the stellar locus in the $r - i, i - z$ diagram.

  These principal colors are measured directly from the stars in running bins four fields wide. Deviations from the global mean principal colors are indications of photometric errors, especially those due to photometric calibration. Scatter around the principal colors within a single bin (i.e., a broad stellar locus) is another indication of poor data. For the present, we use the so-called s color in our overall quality assessment of each field (although statistics on all four colors are available in the *RunQA* table). In future work, we plan to incorporate information about all four colors in the field quality.

- Finally, the processing of the data itself can indicate problems. As described in §4.6 of the EDR paper (§4.6), a field can be given a so-called operational database quality of `BAD`, `MISSING`, or `HOLE`, often because the data corresponding to the field is particularly poor, or the photometric pipeline timed out on processing it (e.g., because of the presence of a naked-eye star in the field).

Based on these quantities, we assign `FieldQAll` for each field, as follows:

- By default, the field in question is assigned `FieldQAll=ACCEPTABLE` (listed in the *RunQA* table numerically as **1**).
- If the absolute value of the median PSF-aperture difference is greater than 0.05 magnitudes in any of the five bands, or if the absolute value of the s color median is larger than 0.05 magnitudes, or if the s color distribution width is 2.5 times larger than its median value for the whole run, or if the r-band seeing is worse than 3 arcseconds, or if the operational database quality is `BAD`, `MISSING`, or `HOLE`, the field in question is downgraded to BAD (listed as **0**).
- If the absolute median PSF-aperture difference is smaller than 0.03 magnitudes in all five bands, and if the absolute value of the s color median is smaller than 0.03 mag, and if the s color distribution width is smaller than twice its median value for the whole run, the field in question is upgraded to GOOD (listed as **2**).
- If the median PSF-aperture difference is smaller than 0.02 magnitudes in all five bands, and if the absolute value of the s color median is smaller than 0.02 mag, and if the s color distribution width is smaller than 1.5 times its median value for the whole run, and the r-band seeing is better than 2 arcseconds, the field in question is upgraded to EXCELLENT (listed as **3**).

In the DR3, 58% of fields are EXCELLENT, 26% are GOOD, 13% are ACCEPTABLE, and only 3% are BAD.

Examples of how to use the RunQA table can be found by selecting this table in the CAS Schema Browser on the SkyServer website.

3. Looking to the Future

Our next data release after DR3 will consist of data taken through July 2004; it will occur in July 2005. SDSS survey operations will end at about that time, and a final data release (DR5) is planned for early 2006. As Figure 1 implies, there will still be a substantial gap between the Northern and Southern pieces of the sky covered in the North Galactic Cap (i.e., $110^\circ < \alpha < 270^\circ$), and we are actively seeking funds to extend operations beyond summer 2005 to fill the gap.

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 U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/.

The SDSS is managed by the Astrophysical Research Consortium (ARC) 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 (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, Princeton University, the United States Naval Observatory, and the University of Washington.

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This preprint was prepared with the AAS LaTeX macros v5.0.

Table 1. Characteristics of the SDSS Third Data Release (DR3)

Imaging	
Footprint area	5282 deg^2
Imaging catalog	141 million unique objects
Magnitude limits:[a]	
u	22.0
g	22.2
r	22.2
i	21.3
z	20.5
Median PSF width	$1.4''$ in r
RMS photometric calibration errors:	
r	2%
$u-g$	3%
$g-r$	2%
$r-i$	2%
$i-z$	3%
Astrometry	$< 0.1''$ rms absolute per coordinate
Spectroscopy	
Footprint area	4188 deg^2
Wavelength coverage	3800–9200Å
Resolution $\lambda/\Delta\lambda$	1800–2100
Signal-to-noise ratio	> 4 per ~ 1Å pixel at $g = 20.2$
Wavelength calibration	< 5 km sec^{-1}
Redshift accuracy	30 km sec^{-1} rms for Main galaxies
	$\sim 99\%$ of classifications and redshifts are reliable
Number of spectra	528,640
Galaxies	374,767
Quasars	51,027
Stars	71,174
Sky	26,819
Unclassifiable	4,853

[a]95% completeness for point sources in typical seeing; 50% completeness numbers are typically 0.4 mag fainter (DR1 paper).

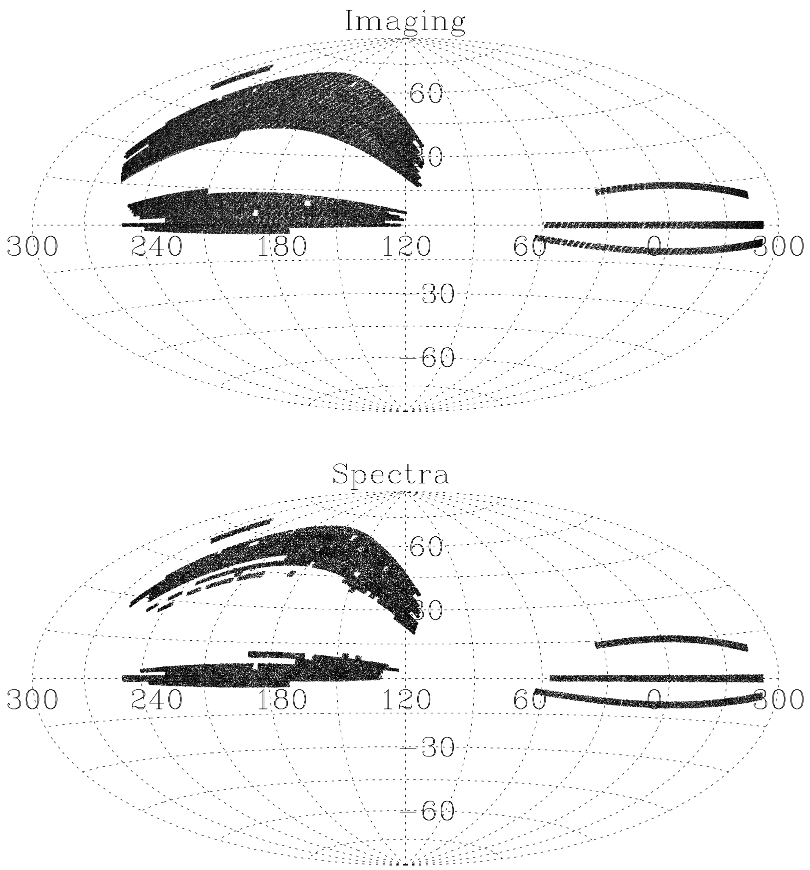

Fig. 1.— The footprint of the SDSS imaging (top) and spectroscopic (bottom) data included in DR3. The former covers 5282 deg^2, while the latter is 4188 deg^2. The figure is an Aitoff projection in equatorial coordinates. Note that it wraps at $\alpha = 300° = 20^{\rm h}$. The data in the Southern Galactic Cap ($60° > \alpha > 300°$) consist of three stripes. In the Northern Galactic Cap, the SDSS is working North from the Celestial Equator, and South from a region centered on $\delta \approx +45°$.

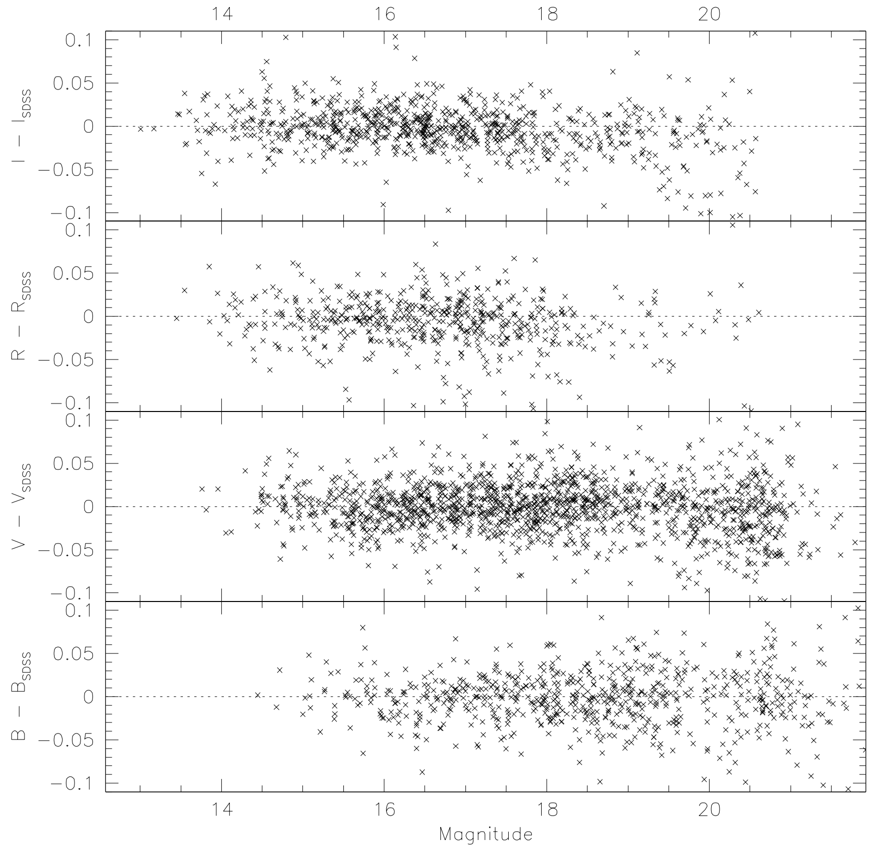

Fig. 2.— A comparison of SDSS and Stetson (2000) photometry of stars. After finding the best-fit conversion from SDSS *ugriz* photometry to the Kron-Cousins system used by Stetson, the residuals are found to be independent of magnitude (perhaps indicating that they are dominated by photometric calibration, and/or the uncertainties in the transformation between the two photometric systems), and have an rms of $\sim 2.5\%$.