L Dwarfs Found in Sloan Digital Sky Survey Commissioning Data II.
Hobby-Eberly Telescope Observations

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ABSTRACT

Low dispersion optical spectra have been obtained with the Hobby-Eberly Telescope of 22 very red objects found in early imaging data from the Sloan Digital Sky Survey. The objects are assigned spectral types on the 2MASS system (Kirkpatrick et al. 1999) and are found to range from late M to late L. The red- and near-infrared colors from SDSS and 2MASS correlate closely with each other, and most of the colors are closely related to spectral type in this range; the exception is the \((i^* - z^*)\) color, which appears to be independent of spectral type between about M7 and L4. The spectra suggest that this independence is due to the disappearance of the TiO and VO absorption in the \(i\) band for later spectral types; to the presence of strong Na I and K I absorption in the \(i\) band; and to the gradual disappearance of the 8400 Å absorption of TiO and FeH in the \(z\) band.

Subject headings: stars:low-mass, brown dwarfs - surveys

1. Introduction

In the last five years, deep, wide area sky surveys carried out at red and near-infrared wavelengths have discovered (among many other things) a large number of stellar objects much cooler than the coolest previously-known late M dwarfs (see Reid & Hawley 2000). This subject has long been of major astronomical interest because of its relevance to star formation, planet formation, stellar evolution and the total mass density of the Galaxy. These surveys, the Deep Near-Infrared Survey (DENIS - Delfosse et al. 1997) and Two-Micron All Sky Survey (2MASS - Skrutskie 1999) in \(JHK_s\), and, more recently, the Sloan Digital Sky Survey (SDSS - York et al. 2000) at optical wavelengths, have led to the discovery of large numbers of field brown dwarfs and the definition of two new spectral classes, types \(L\) (Becklin & Zuckerman 1988; Ruiz et al. 1997; Martín et al. 1999, Kirkpatrick et al. 1999, 2000), and \(T\) (Kirkpatrick et al. 1999; Burgasser 2001). Broadly speaking, the \(M \rightarrow L\) transition is marked by the disappearance of the strong TiO and VO bands from the red spectrum and the \(L \rightarrow T\) transition by the appearance of methane absorption at 1.6\(\mu m\) and 2.2\(\mu m\) (Oppenheimer et al. 1995; Martín et al. 1999; Kirkpatrick et al. 1999; Leggett et al. 2000; Burgasser 2001; Reid 2001; Kirkpatrick 2001; Geballe et al. 2001).

The definition and delineation of these two spectral classes, their analysis via spectral modeling and the extension of the stellar mass function to substellar masses have been the focus of much recent observational and theoretical work. Even with these new sky surveys, the identification of candidate objects is difficult because they are so faint, and their confirmation by spectroscopic observations requires a significant amount of observing time on large telescopes.
The SDSS has proven to be very effective at finding candidate objects throughout the late M, L and T classes. Although the SDSS is a visible-wavelength survey and these very cool objects emit but a tiny fraction of their luminosity at visible wavelengths, the reddest SDSS bands, $i$ and $z$ (see Fukugita et al. 1996; Gunn et al. 1998) have enabled the identification (not without some difficulty, see below) of numerous faint red objects, both brown dwarfs and high-redshift quasars. Spectra of candidate objects selected by color are observed either by the SDSS spectrographs or with other telescopes, at both optical and near-infrared wavelengths. Early results on L and T dwarfs based on SDSS data are given by Fan et al. (1999), Strauss et al. (1999), and Leggett et al. (2000).

This paper discusses results from one of the spectroscopic efforts, optical-wavelength observations of 22 SDSS red stellar candidate objects, made with the Hobby-Eberly Telescope (HET - Ramsey et al. 1998). These objects have spectral types from M7 to L7, a range of interest because the disappearance of the TiO and VO bands in this spectral region is very likely to be due to the condensation of these molecules into solids, producing dusty atmospheres (Tsuji et al. 1996).

The objects in this paper are all of the late-type stars/brown dwarfs observed with the HET during its commissioning/early operation phases, and do not comprise a complete sample. The next section describes the selection of target objects from the SDSS imaging, and the HET spectroscopy is described in Section 3. The spectral typing is described in Section 4, and the relationships among spectral type, effective temperature, and colors are described in Section 5. The conclusions are given in Section 6. Additional discussions of some of the objects in this paper are given by Geballe et al. (2001), Leggett et al. (2001b), and Hawley et al. (2001, in preparation).

2. Sloan Digital Sky Survey Imaging and Candidate Selection

The Sloan Digital Sky Survey uses a CCD camera (Gunn et al. 1998) on a dedicated 2.5-m telescope (Siegmund et al. 2001, unpublished) at Apache Point Observatory, New Mexico, to obtain images in five broad optical bands over 10,000 deg$^2$ of the high Galactic latitude sky centered approximately on the North Galactic Pole. The five filters (designated $u, g, r, i$, and $z$) cover the entire wavelength range of the atmospheric transparency/CCD response (Fukugita et al. 1996; Gunn et al. 1998). Photometric calibration is provided by simultaneous observations with a 20-inch telescope at the same site (Hogg et al. 2001). The survey data processing software measures the properties of each detected object in the imaging data in all five bands, and determines and applies both astrometric and photometric calibrations (Pier et al. 2001, unpublished; Lupton et al. 2001). At the time of this writing (Summer 2001) substantially more than 1000 sq. deg. of sky have been imaged with the SDSS, although some of the data do not meet the strict survey requirements for image quality. The limiting magnitudes for these data are about 22.7, 21.8, and 20.3 ($5\sigma$, point source) in $r, i$ and $z$ respectively (very few of the red objects discussed herein are detected in the $u$ or $g$ bands).
The automated image processing pipelines (Lupton et al. 2001) used to process the imaging data find objects and merge the observations of an object in each of the five bands; a formal flux density at the object position in bands in which the object is not detected is also measured. The software provides a set of flags for each detected and measured object which describe the processing of that object and indicate the presence of any problems in the data or in the data reduction. These flags were used to select objects with reliable data. Many faint late-type dwarfs (and high-redshift quasars) will be z-band-only detections, but at these faint levels single band detections are highly contaminated by artifacts, mostly cosmic rays and ghosts of bright objects. The objects for this study were selected according to the following criteria: (a) \((i^* - z^*) > +1.6\) (see Fan et al. 2000)\(^{14}\); (b) at least a 2σ detection in the \(i\) band and/or a detection in the 2MASS catalogue (although the released 2MASS catalogue does not at present provide complete overlap with the SDSS); and (c) uncontaminated by substandard data (bad CCD columns and cosmic rays) or by complex blending with the image of a nearby object.

Candidates were selected from six SDSS imaging runs: four equatorial scans (94, 125 in September 1998 and 752, 756 in March 1999; see Fan et al. 2000 for details) covering slightly over 500 deg\(^2\), and two scans taken in October 1999 (SDSS imaging runs 1035 and 1043) that covered a combined area of 67 deg\(^2\). A total of 71 objects was selected for the HET L dwarf spectroscopy program; in 1999 and 2000 we obtained spectra of 22 of the candidates. Since the HET operates in a queue mode, the objects were selected for observation based solely on their celestial position, so the 22 objects should provide a representative subsample.

The 22 objects for which spectroscopic observations are reported herein are listed in Table 1. We give the object name, the spectral type as determined in this paper, the \(r^*, i^*,\) and \(z^*\) point spread function magnitudes with their 1σ errors and, where available, the 2MASS \(JHK_s\) magnitudes and their errors. Note that the SDSS and 2MASS magnitudes are in different systems; the SDSS magnitudes are measured in the \(AB\) system (cf. Fukugita et al. 1996) whereas the 2MASS magnitudes are in the Vega system. In addition, the definition of SDSS magnitudes is modified to measure magnitudes which are calculated from flux densities measured at low signal-to-noise ratios, or which are formally zero or negative (Lupton, Gunn and Szalay 1999). The calibration of the magnitudes is accurate to 0.03 in the \(r\) and \(i\) filters and 0.05 in the \(z\) band (Stoughton et al. 2002). The photometry has not been corrected for foreground reddening (assumed to be negligible in the three bands for these nearby objects). The object name format is SDSSp Jhhmmss.ss±ddmss.s, where the coordinate equinox is J2000, and the “p” refers to the preliminary nature of the astrometry. The estimated astrometric accuracies in each coordinate are 0.10″ rms. Object names will frequently be abbreviated as SDSShhmm+dmm in this paper. Figure 1 displays finding charts for the 22 objects made from the SDSS \(i\) images. Note that these objects are likely to be nearby and to have large proper motions. The last column of Table 1

\(^{14}\)Throughout this paper, measured SDSS magnitudes will be denoted by \(r^*, i^*,\) and \(z^*\) because of the preliminary nature of the photometric calibration, while the bands themselves are denoted by \(r, i,\) and \(z\)
contains the SDSS imaging run number that is the basis for each set of coordinates; the UT dates of the run numbers are given in a footnote to the table.

Figure 2 shows the \((z^*, i^* - z^*)\) color-magnitude diagram for the objects, which are differentiated into three broad classes: (a) earlier than M9.5; (b) L0-L3; and (c) L4 and later (see Section 4). Note that every observed candidate is indeed a late-type star/L dwarf; there appears to be no contamination of our original sample by other classes of sources. The comparison sample consists of 50,000 high-latitude point sources randomly selected from a sample which contains objects which are well-detected and classified by the image processing software as stars (point sources) in the three most sensitive SDSS bands: \(g\), \(r\) and \(i\). The “blue” \((i^* - z^* \sim 0)\) stars are halo and disk main sequence turn-off stars, the red \((i^* - z^* \sim 1)\) stars are the disk M dwarfs. The late M and early L dwarfs have \(i^* - z^* = 1.6\) to 2; the later L dwarfs have colors that are about one magnitude redder.

Figure 3 shows the \(i^* - z^*\) vs. \(r^* - i^*\) diagram for 18 of the objects; the four sources not detected at the 3\(\sigma\) level in the \(r\) band are not plotted. The comparison sample is 15,000 stellar objects matched with 2MASS (from Finlator et al. 2000) which are relatively bright stars (because of the different depths of the SDSS and 2MASS), and biased towards the redder stars. The late M and L dwarfs are much redder in \(i^* - z^*\) but tend to be bluer in \(r^* - i^*\) than the values expected from the extrapolation of the colors of warmer stars (cf. Fan et al. 2000).

### 3. Spectroscopy of L Dwarf Candidates

Spectra of 22 SDSS L dwarf candidates were obtained with the HET’s Marcario Low Resolution Spectrograph (LRS; Hill et al. 1998a,b; Cobos Duenas et al. 1998; Schneider et al. 2000) between May 1999 and December 2000. The LRS is mounted in the Prime Focus Instrument Package, which rides on the HET tracker. The dispersive element was a 300 line mm\(^{-1}\) grism blazed at 5500 Å. An OG515 blocking filter was installed to permit calibration of the spectra beyond 8000 Å. The detector is a thinned, antireflection-coated 3072 \(\times\) 1024 Ford Aerospace CCD, and was binned 2 \(\times\) 2 during readout; this produced an image scale of 0.50” pixel\(^{-1}\) and a dispersion of \(\approx 4.5\) Å pixel\(^{-1}\). The spectra cover the range from 5100–10,200 Å at a resolution of approximately 20 Å.

The wavelength calibration was provided by Ne, Cd, and Ar comparison lamps; a 5\(^{th}\) order polynomial fit to the lines produced an rms error of less than 1 Å. The relative flux calibration and atmospheric absorption band corrections were performed by observations of spectrophotometric standards, usually taken from the primary spectrophotometric standard list of Oke & Gunn (1983). The objects were observed under a wide range of conditions; the FWHM of the spectra ranged from slightly under 2” to over 3”. The exposure times varied from 347 s to 4380 s, with a median of 1400 s. Absolute spectrophotometric calibration was performed by scaling each spectrum so that the \(i^*\) magnitudes synthesized from the spectra matched the SDSS photometric measurements;
this scaling used the SDSS response curves presented by Fan et al. (2001). The spectra, rebinned to a linear wavelength scale at 8 Å pixel$^{-1}$, are displayed in Figure 4. Spectra of four of the objects (SDSS0301+0020, SDSS0330+0000, SDSS0423–0414, and SDSS2555–0034) are of markedly lower quality than the other 18 observations: the low S/N spectra are binned at 16 Å pixel$^{-1}$ in the figure. The spectra are ordered by type, as discussed in the next section. Only one of the 22 objects, SDSS0224–0721 (M8.5), shows evidence for H$\alpha$ emission; this result is not surprising given the low resolution (20 Å) and limited signal-to-noise ratio of the spectra below 7000 Å.

4. Spectral Classification

As part of the SDSS low-mass stars and brown dwarfs identification effort, we have developed both spectral diagnostic and template fitting routines for M and L dwarfs; this work is described in detail in our upcoming paper presenting observations of several dozen late M and L dwarfs found by the SDSS (Hawley et al. 2001, in preparation). The spectral diagnostics are taken from the Kirkpatrick et al. (1999) prescription, augmented by several additional spectral features which proved more robust for lower spectral resolution, and often lower signal-to-noise ratio, spectra. The spectral types were assigned through a combination of the spectral diagnostic and template fitting results; the spectral types were independently checked by two of us (SLH, KRC) by visually comparing each HET spectrum with the Keck standards from Kirkpatrick et al. (1999). We estimate the uncertainty in the spectral types for the 18 stars with reasonable signal-to-noise ratio spectra to be about ±1 spectral type, while the spectral types of the four stars with poor signal-to-noise spectra are only suggestive and should be regarded as quite uncertain; these spectral types are denoted by a colon in Table 1. The objects presented in this paper have spectral classes ranging from M7 to L7.

The HET observation of one of the objects, SDSS1430+0013, was presented by Schneider et al. (2000); in that paper a preliminary classification of L0 was assigned, while this paper classifies the object as M8. Observations of a second object, SDSS0413–0114, were presented by Fan et al. (2000); the visual classification of that spectrum was L0, compared to L0.5 in Table 1 of this paper. SDSS0205+1251 is a 2MASS L dwarf, assigned spectral type L5 by Kirkpatrick et al. (2000); we classify it as L4 based on the HET data. In addition, four of the objects discussed in the present paper are described by Geballe et al. (2001): SDSS0107+0041 (L7 in the present paper) is classified as L5.5 by Geballe et al. (2001); SDSS0236+0048 (L6) as L6.5; SDSS0423–0414 (L5: as T0; and SDSS2255–0034 (L0:) as M8.5. The only discrepancy of note is for SDSS0423–0414, but the spectrum presented in this paper (see Figure 4) is of low signal-to-noise ratio, and hence the classification in Table 1 is only suggestive as discussed above. In general our results are in concurrence with the results of Reid et al. (2001), Testi et al. (2001) and Geballe et al. (2001) which show that the M→L spectral sequence can be consistently defined by both optical and infrared spectroscopy.
5. Discussion

The objects observed in this study were selected to have very red \((i^* - z^* > +1.6)\) colors. In the top panel of Figure 5, we plot the SDSS \(i^* - z^*\) color versus spectral type, including the data both from the present paper and from Fan et al. (2000). The \(i^* - z^*\) color is roughly constant at +1.8 (albeit with large scatter) until spectral type L2-L3, then steadily increases to nearly +3 for late L dwarfs. While the \(i^* - z^*\) color is not a good indication of spectral class for objects of M8 through L3, colors based on \(z^*\) and one of the infrared bands can be used for spectral classification for all types from late M to late L. The bottom panel in Figure 5 shows the relationship between spectral type and \(z^* - J\) (top); a plot of \(z^* - K_s\) vs. spectral type has a similar appearance.

What might produce the apparent lack of correlation between \(i^* - z^*\) color and spectral type in early L dwarfs? One possibility is that this result is merely an artifact of our selection technique. Since the sample selection required that \(i^* - z^* > +1.6\), any objects bluer than that limit cannot appear in Figure 5. We consider this explanation unlikely, however, given the distribution of the observations; the \(i^* - z^*\) measurements of the early L dwarfs cluster around a value of +1.9, with very few points bluer than +1.7. In any case, \(i^* - z^*\) cannot be an effective spectral type indicator in this range, for if our selection has missed a “blue” population, then the \(i^* - z^*\) variation is quite substantial. Figure 5 shows that the \(i^* - z^*\) color is, at least as far as the present data are concerned, only a very crude predictor of spectral type; it allows identification of cool substellar objects but not the measurement of spectral type.

Figure 6 displays the spectra of SDSS0411−0556 (M8.5) and SDSS0107+0041 (L7) compared with the filter responses of the SDSS \(r\), \(i\), and \(z\) filters. For late L and T dwarfs, the flux shortwards of about 8000 Å is almost completely suppressed by the extremely broad wings of the NaD \(\lambda 5889/5896\) and K I \(\lambda 7665/7699\) resonance lines (Tsuji et al. 1996; Kirkpatrick et al. 1999; Liebert et al. 2000; Burrows et al. 2000), as can be seen for spectra of type L4 and greater in Figure 4. The \(i^* - z^*\) color of these late-type dwarfs is strongly influenced by two features: the removal of flux from the \(i\) band for objects of about L2 and later by Na I and K I absorption; and strong absorption due to the TiO band at 8432 Å and FeH at 8692 Å. As Figure 4 and Kirkpatrick et al. (1999) show, these absorption bands peak at spectral types of about L0 and L3 respectively, and disappear at spectral types of about L2 and L5 respectively. An understanding of how these absorption features interplay with the SDSS filters as a function of temperature is complicated by the fact that because the bands occur close to the peak sensitivity of the SDSS \(z\) filter, the differences in the detailed \(z\) response of the individual columns of the SDSS camera and changes in the atmospheric water vapor column density during the observations will introduce scatter in the observations (and may account for some fraction of the variations seen in Figure 5). This complex issue will be further investigated in future work with a much larger sample of SDSS brown dwarfs (Hawley et al. 2001 in preparation).

Figure 7 shows optical-near infrared color-color diagrams for the objects with published 2MASS magnitudes from Fan et al. (2000) and the present paper. Both the \(H - K_s\) and \(J - K_s\)
colors versus \(i^*-z^*\) show, with the exception of one object in \(J - K_s\), a good correlation between the infrared and optical colors and a steady progression towards redder colors at both optical and infrared wavelengths. The outlying object, SDSS/2MASS0205+1251, is much redder in \(J - K_s\) relative to \(i^*-z^*\) than expected (Figure 7a). Since the \(H - K_s\) color of this object is close to the expected value (Figure 7b), this implies a significant reduction in \(J\) flux. We are not aware of a published near-infrared spectrum of this object; we speculate that its 1.15\(\mu\)m \(\text{H}_2\text{O}\) feature may be deeper than for objects of neighboring spectral type. The spectra of dwarfs of late M to early L spectral type are difficult to fit without including the effects of photospheric dust extinction, which makes the strong water bands shallower than expected from dust-free model atmospheres, whereas fits to late L and T dwarfs show that dust does not affect the model colors very much (Allard 1998; Jones & Tsuji 1997; Leggett et al. 2001a; Marley & Ackerman 2001). Thus the region around L4-L5 may be where dust is causing some scatter in the infrared colors.

6. Conclusions

We have obtained low-dispersion red spectra with the Hobby-Eberly telescope of 22 very red point source objects selected from early SDSS imaging data. Spectral types on the Kirkpatrick et al. (1999, 2000) system can be assigned with reasonable confidence to 18 of the objects, with the spectra for the other four having poor signal-to-noise ratio. We find:

- The 22 objects include nine late type M dwarfs (M7.5 - M9.5) and 13 L dwarfs, ranging from spectral types L0 to L7. The spectral types are in good agreement with those assigned in other work.
- The spectra show strong suppression of the optical-wavelength flux due to absorption in the wings of the Na I and K I lines (cf. Kirkpatrick et al. 1999, 2000; Burrows, Marley & Sharp 2000; and Liebert et al. 2000) for spectral types later than about L3.
- The SDSS \((i^*-z^*)\) colors from this paper and from Fan et al. (2000) show no trend with spectral types between M8 and L3. It is possible, but unlikely, that this is a result of our selection procedure. The increasing red color for spectral types L4 and later can be attributed to the suppression of the \(i\) flux by Na I and K I absorption and the disappearance of the strong TiO and FeH absorption from the \(z\) flux.
- The near-infrared colors \((J - K_s\) and \(H - K_s\)) from 2MASS are closely correlated with the \(i^*-z^*\) colors.
- The present paper contains only a small number of objects of type L4 and later. One object, SDSS/2MASS0205+1251 (L4) seems to have a weaker than expected \(J\)-band flux. Since the depth of the water bands is anticorrelated with the amount of dust present in the photosphere, the anomalous \(J\)-band measurement may arise from the absence of atmospheric dust in this object.
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15The SDSS Web site is http://www.sdss.org/.
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Figure Captions

Fig. 1.— Finding charts for the 22 objects discussed in this paper; each individual chart is 100′′ on a side. All frames are $i$ images taken with the SDSS camera. The small arrow in the lower left of each chart indicates the direction of north; all charts have “sky” parity, so east is located 90° counterclockwise from north.

Fig. 2.— Color-magnitude plot ($z^*$ vs. $i^* - z^*$) for the candidate L dwarfs, compared with data for 50,000 anonymous high-latitude stars (extracted from the SDSS data to be well detected and with point-source morphology in the SDSS $g$, $r$ and $i$ filters. Open stars: M dwarfs. Open circles: L0-L3. Filled circles: L4 and later.

Fig. 3.— SDSS Color-color plot for the 18 objects detected in all three of the $r$, $i$ and $z$ bands, compared with SDSS data for 15,000 stars from Finlator et al. (2000). The symbols are the same as in Figure 2.

Fig. 4.— HET LRS spectra of the 22 dwarfs ordered by spectral type. The spectral resolution is approximately 20 Å and the data have been rebinned to 8 Å pixel$^{-1}$. The four spectra with low signal-to-noise ratio (SDSS0301+0020, SDSS0330+0000, SDSS0423−0414, and SDSS2555−0034) are binned at 16 Å pixel$^{-1}$.

Fig. 5.— Top panel: SDSS ($i^* - z^*$) color vs. spectral type; the circles represent data from Table 1 and the crosses are objects from Fan et al. (2000). The open circles are the four objects with uncertain spectral type. The points corresponding to objects assigned the same spectral type have been slightly offset horizontally for clarity. Bottom panel: $z^* - J$ vs. spectral types; the symbols are the same as in the top panel. Note that $z^*$ is an AB based system, while $J$ measurements are normalized to Vega.

Fig. 6.— SDSS $r$, $i$, and $z$ relative system responses (including 1.3 airmasses) compared with HET spectra of SDSS0411−0556 (M8.5) and SDSS0107+0041 (L7). The strong absorption between about 8500 Å and 8800 Å seen in SDSS0411−0556 is due to the 8432 Å and 8692 Å TiO and FeH bands, which disappear at about L3-L4 (see Figure 4).

Fig. 7.— (Upper Panel) $(J - K_s)$ vs. $(i^* - z^*)$ and (lower panel) $(H - K_s)$ vs. $(i^* - z^*)$ for objects from the present paper and Fan et al. (2000) with detections in the released 2MASS data. Crosses: type M. Open symbols: L0-L3. Filled symbols: L4 and later.

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<td>14.45 ± 0.05</td>
<td>13.66 ± 0.05</td>
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<tr>
<td>J022438.69−072158.5 M8.5</td>
<td>21.63 ± 0.13</td>
<td>19.16 ± 0.04</td>
<td>17.37 ± 0.02</td>
<td>15.12 ± 0.04</td>
<td>14.39 ± 0.06</td>
<td>13.90 ± 0.05</td>
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<tr>
<td>J023147.98−004544.2 M7.5</td>
<td>22.84 ± 0.25</td>
<td>19.90 ± 0.03</td>
<td>18.25 ± 0.02</td>
<td>16.20 ± 0.03</td>
<td>15.64 ± 0.11</td>
<td>15.44 ± 0.18</td>
<td>125</td>
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<tr>
<td>J023617.94+004854.8 L6</td>
<td>24.83 ± 0.61</td>
<td>21.50 ± 0.13</td>
<td>19.92 ± 0.05</td>
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<tr>
<td>J030136.53+002057.9 L1</td>
<td>23.79 ± 0.41</td>
<td>20.94 ± 0.08</td>
<td>19.10 ± 0.08</td>
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<tr>
<td>J030321.24−000938.2 L0</td>
<td>22.82 ± 0.23</td>
<td>20.22 ± 0.04</td>
<td>18.26 ± 0.03</td>
<td>16.13 ± 0.08</td>
<td>15.52 ± 0.12</td>
<td>14.87 ± 0.11</td>
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<tr>
<td>J032817.38+003257.2 L2.5</td>
<td>22.89 ± 0.26</td>
<td>20.61 ± 0.06</td>
<td>18.88 ± 0.04</td>
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<tr>
<td>J033017.77+000047.8 L0</td>
<td>23.07 ± 0.27</td>
<td>20.53 ± 0.06</td>
<td>18.91 ± 0.05</td>
<td>16.52 ± 0.10</td>
<td>15.88 ± 0.14</td>
<td>15.52 ± 0.18</td>
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<tr>
<td>J041117.92−055649.1 M8.5</td>
<td>21.91 ± 0.11</td>
<td>19.16 ± 0.02</td>
<td>17.28 ± 0.02</td>
<td>14.92 ± 0.04</td>
<td>14.27 ± 0.04</td>
<td>13.78 ± 0.05</td>
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<td>J041320.38−011424.9 L0.5</td>
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<td>19.64 ± 0.03</td>
<td>17.84 ± 0.03</td>
<td>15.33 ± 0.05</td>
<td>14.66 ± 0.05</td>
<td>14.14 ± 0.06</td>
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<tr>
<td>J042348.57−041403.5 L5</td>
<td>22.64 ± 0.20</td>
<td>20.21 ± 0.04</td>
<td>17.33 ± 0.03</td>
<td>14.45 ± 0.03</td>
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<td>12.40 ± 0.04</td>
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<td>19.45 ± 0.03</td>
<td>17.57 ± 0.02</td>
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<td>14.52 ± 0.06</td>
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<td>22.58 ± 0.20</td>
<td>20.54 ± 0.05</td>
<td>18.55 ± 0.04</td>
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<td>15.17 ± 0.08</td>
<td>14.53 ± 0.10</td>
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<td>J164010.59+003721.8 L0</td>
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<td>20.64 ± 0.05</td>
<td>18.76 ± 0.03</td>
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<td>J223040.16−003118.0 M9.5</td>
<td>23.36 ± 0.40</td>
<td>20.63 ± 0.06</td>
<td>18.74 ± 0.05</td>
<td>16.28 ± 0.08</td>
<td>15.90 ± 0.14</td>
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<tr>
<td>J225529.09−003433.4 L0</td>
<td>22.29 ± 0.17</td>
<td>19.87 ± 0.03</td>
<td>17.94 ± 0.03</td>
<td>—</td>
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Notes: Positions are in J2000.0 coordinates. The SDSS photometry is reported in terms of asinh magnitudes; see Lupton, Gunn, & Szalay (1999) for details. In this system, zero flux corresponds to 24.8, 24.4, and 22.8 in r*, i*, and z*, respectively. Note that SDSS magnitudes are AB-based and the infrared magnitude system is based on Vega. Spectral types followed by a colon have estimated errors of two subclasses.