Ultra-cool Dwarfs from Large Area Surveys

Z.H. Zhang¹,², H. R. A. Jones², D. J. Pinfield², R. S. Pokorny¹ and Z. Han¹
¹National Astronomical Observatories/Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011, China
²Centre for Astrophysics Research, Science and Technology Research Institute, University of Hertfordshire, College Lane, Hatfield AL10 9AB, U.K.

ABSTRACT
We selected brown dwarf candidates from the seventh Data Release of the Sloan Digital Sky Survey (SDSS DR7) with new photometric selection criteria based on a parameterization of well-known L and T dwarfs. Then we confirmed their status with SDSS spectra. The candidates without SDSS spectra are cross matched in the Two Micron All Sky Survey (2MASS) and the Fourth Data Release of the UKIRT Infrared Deep Sky Survey (UKIDSS DR4). With the help of colors based on SDSS, 2MASS and UKIDSS, we are able to estimate spectral types of our candidates. We obtain reliable proper motions using positional and epoch information downloaded direct from the survey databases.

Key words: star: low-mass, brown dwarfs — surveys

1 INTRODUCTION
Brown dwarfs occupy the mass range between the lowest mass stars and the highest mass planets. The central temperature of a brown dwarf is not high enough to achieve stable hydrogen burning like a star, but all brown dwarfs will undergo short periods of primordial deuterium burning very early in their evolution. Since the first discovery of an L dwarf (GD165 B; Becklin & Zuckerman 1988) and a T dwarf (Gl229 B; Nakajima et al. 1995), the projects searching for brown dwarfs have involved a number of large scale surveys, for example, the Deep Near-Infrared Survey (DENIS; Epchtein et al. 1997), the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) and the Sloan Digital Sky Survey (SDSS; York et al. 2000; Adelman-MaCarthy et al. 2009). Over five hundred L dwarfs and one hundred T dwarfs have been found in large scale sky surveys in the last decade (see, DwarfsArchives.org for a full list). Nearly 200 L and T dwarfs have been found in SDSS (e.g. Fan et al. 2000; Geballe et al. 2002; Hawley et al. 2002; Schneider et al. 2002; Knapp et al. 2003; Chiu et al. 2006; Zhang et al. 2009), and more than 300 in 2MASS (e.g. Burgasser et al. 1999, 2002, 2004; Kirkpatrick et al. 1999, 2000; Gizis et al. 2000; Cruz et al. 2003, 2007; Kendall et al. 2003, 2007; Looper et al. 2007; Reid et al. 2008). More recently, the UKIRT Infrared Deep Sky Survey (UKIDSS; Lawrence et al. 2007) is beginning to be very effective in searching for T dwarfs (Kendall et al. 2007; Lodieu et al. 2007; Warren et al. 2007; Burningham et al. 2008; Pinfield et al. 2008) and has a strong potential to achieve the discovery of Y dwarfs.

2 LARGE AREA SURVEYS
The photometric data used in this work are from the SDSS DR7, the Two Micron All Sky Survey and the Fourth Data Release of UKIDSS Large Area Survey (LAS). The SDSS DR7 photometric data catalog covers 11500 deg² in the main survey area (Legacy: 8147 deg², SEGUE: 3500 deg²) in five bands (u, g, r, i, z), with information on roughly 357 million distinct photometric objects (Legacy: 230 million, SEGUE: 127 million). Bright objects selected from the SDSS can be found in the Two Micron All Sky Survey which have photometric data of objects in J, H, and K bands. Most of known ultra-cool dwarfs found from SDSS have photometric data in 2MASS for they are bright enough for 2MASS. But most our faint ultra-cool dwarf candidates selected from SDSS could not be found in 2MASS. The UKIDSS LAS will image an area of 4000 deg² at high Galactic latitudes in the Y, J, H and K filters to Y = 20.5, J = 20.0, H = 18.8, K = 18.4 which are about three magnitudes deeper than 2MASS in J, H and K band. The LAS target 4000 deg² is a subsection of the Sloan survey. The fourth Data Release of UKIDSS LAS covers 1200 deg².

3 COLORS OF ULTRA-COOL DWARFS
Brown dwarfs are infrared objects and very faint in optical bands. The SDSS i – z color is particularly useful for L dwarf selection (as first pioneered by Fan et al. 2000), and expanded on by others (e.g. via the i-band drop-out method; e.g. Chiu et al. 2006). For the cooler T dwarf, almost all of the radiation is emitted beyond 10000 Å, and as such these objects are optically much fainter than L dwarfs. SDSS is
We have made a study of L and T dwarf color-color parameter-space using previously identified L and T dwarfs with photometric data available from either SDSS or 2MASS (from DwarfsArchives.org, as of September 25, 2007). A total of 431 L and 84 T dwarfs have 2MASS photometric data

($J$, $H$, $K$), and 193 L and 46 T dwarfs have SDSS photometric data ($u$, $g$, $r$, $i$, $z$). The study shows L dwarfs with a color of $i-z > 1.7$ and T dwarfs with a color of $i-z > 3$. (Zhang et al. in prepare). Figure 1 shows 2MASS $J$-$H$ and $H$-$K$ color of L and T dwarfs, solid lines shows the boundary of L dwarfs in $JHK$ color space. We can see that the $J$-$H$ and $H$-$K$ colors are red for L dwarfs and blue for late T dwarfs.

Around 1800 SDSS color selected late M and early L dwarfs are matched in 2MASS catalogue (Zhang et al. in prepare). Figure 2 shows the position of our SDSS color selected L and T dwarf candidates in 2MASS $JHK$ color space, solid lines shows the boundary of L dwarfs the same as in Figure 1.

We can estimate the spectral types of our ultra-cool dwarf candidates with the SDSS and 2MASS data based on the relationships between spectral types and SDSS-2MASS cross colors (e.g. Hawley et al. 2002). With a large number of M, L and T dwarfs now available, we made a study of the relationships between spectral types of M, L and T dwarfs and their colors from SDSS and 2MASS. Figure 3 shows the polynomial fitting for color-spectral type relationships. SDSS-2MASS cross colors $i-J$, $i-H$ and $i-K$ are the best colors for spectral typing.

Almost all the SDSS selected candidates can be de-
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This work is based in part on data obtained as part of the UKIRT Infrared Deep Sky Survey. This publication makes use of data products from the Two Micron All Sky Survey. This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France. Research has benefitted from the M, L, and T dwarf compendium housed at DwarfArchives.org and maintained by Chris Gelino, Davy Kirkpatrick, and Adam Burgasser. This work was part supported by the Natural Science Foundation of China under Grant Nos 10521001, 10433030 and the CAS Research Fellowship for International Young Researchers.

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4 DISCUSSION

SDSS-UKIDSS color-spectral type relationships yield much better estimates for spectral of ultra-cool dwarfs relative to SDSS-2MASS colors. With the increase in coverage of UKIDSS and the number of ultra-cool dwarfs discovered, we can get enough ultra-cool dwarfs with UKIDSS data to build new color-spectral type relationships.

The UKIDSS LAS target area is a subsection of SDSS. SDSS and UKIDSS have high resolution images (0.4″pixel⁻¹ for SDSS; 0.4″pixel⁻¹ for Y, H, K and 0.2″pixel⁻¹ for UKIDSS J) relative to 2MASS (1″pixel⁻¹) and have a epoch difference of ~3-8 years. So proper motions of ultra-cool dwarfs based on SDSS and UKIDSS offer great potential to confirm faint L dwarfs as UKIDSS coverage increases.

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Figure 4. Y − J vs. J − H diagram for known M, L and T dwarfs and new ultracool dwarf candidates (open diamonds) which matched in UKIDSS. Symbols are as in Figure 1. For comparison, the plot shows 1024 sources (dots) taken from UKIDSS LAS in 1 deg² with Y < 18.5.

As a M and L dwarf candidates population, our SDSS selected candidates are matched very well in 2MASS JHK color space and UKIDSS YJH color space.