Abstract. Recent discoveries from red optical proper motion and wide-field near-infrared surveys have uncovered a new population of ultracool subdwarfs, metal-poor stars and brown dwarfs extending into the late-type M, L and possibly T spectral classes. These objects are among the first low-mass stars and brown dwarfs formed in the Galaxy, and are valuable tracers of metallicity effects in low-temperature atmospheres. Like solar metallicity late-type dwarfs, ultracool subdwarfs emit the majority of their emergent flux at infrared wavelengths. Here I discuss how Spitzer observations will contribute to the study of these objects, enabling measurement of the temperature scale, tests for dust formation and the identification of surface gravity and metallicity diagnostics in the coldest brown dwarfs.

1. Ultracool Subdwarfs

Subdwarfs are metal-deficient stars, classically defined as lying below the stellar main sequence in optical color-magnitude diagrams (Kuiper 1939). These objects are not subluminous but rather hotter (i.e., bluer optical colors) than equivalent mass main sequence dwarfs, a consequence of their reduced metal opacity (e.g., Chamberlin & Aller 1951). Cool subdwarfs (spectral types sdK and sdM) are typically found to have halo kinematics, and are presumably relics of the early Galaxy. They are therefore important tracers of Galactic chemical history and are representatives of the first generations of star formation.

The high space velocities of halo subdwarfs allow them to stand out in proper motion surveys (Reid 1984). Early surveys using photographic plates (e.g., LHS catalog, Luyten 1979a; APM Proper Motion Survey, Scholz et al. 2000) identified several cool subdwarfs with spectral types as late as sdM7/esdM7 (Gizis 1997) and effective temperatures (T_{eff}) down to 3000 K (Leggett et al. 2000). More recent surveys, such as the SUPERBLINK catalog (Lépine et al. 2003b,c) and the SuperCosmos Sky Survey (Hambly et al. 2001b, SSS), have pushed our compendium of cool subdwarfs to even cooler temperatures. With spectral types extending beyond the end of the M dwarf regime (Scholz et al. 2004), these objects are ultracool subdwarfs.

2. L and T Subdwarfs

The first L subdwarf, 2MASS 0532+82 (Burgasser et al. 2003a), was serendipitously identified in the 2MASS catalog as a faint source invisible in optical survey
plates (e.g., POSS-II). Its optical and $J$-band spectrum is similar to that of an L7 dwarf (Figure 1), but its near-infrared colors are uniquely blue due to enhanced collision-induced H$_2$ absorption (e.g., Saumon et al. 1994). Optical and near-infrared bands of CaH, CrH and FeH are enhanced in this source, while the 2.3 µm CO bands are absent. These are the same molecular abundance patterns seen in M subdwarfs, due to the preferential formation of single metal hydrides over double metal oxides in cool metal-poor atmospheres (Mould 1976). The high proper motion of 2MASS 0532+82 ($\mu = 2'6$ yr$^{-1}$, implying $V_{\text{tan}} \approx 250$ km/s) confirms it as a very cool ($T_{\text{eff}} \leq 2000$ K) halo subdwarf. Four other L subdwarfs and L subdwarf candidates have been identified in the SUPERBLINK (Lépine et al. 2003a), 2MASS (Burgasser 2004b), SSSPM (Scholz et al. 2005) and SDSS (Sivarani et al. 2005) surveys.

![Figure 1](image)

**Figure 1.** Top: The 0.6-2.5 µm spectrum of the L subdwarf 2MASS 0532+82 (black) as compared to the L7 DENIS 0205-11 (grey). While red optical and $J$-band features are similar, the near-infrared spectrum of 2MASS 0532+82 is distinctly blue due to enhanced H$_2$ absorption. Bottom: Red optical spectra of 2MASS 0532+82 and DENIS 0205-11. Note the enhanced metal hydride bands in 2MASS 0532+82, consistent with subsolar metallicity; and the unexpected strength of TiO bands, perhaps indicative of suppressed condensate dust formation (from Burgasser et al. 2003b).

2MASS 0532+8246 is so cool that it is very likely a brown dwarf. Because halo stars are old in general, the vast majority of halo brown dwarfs should also be old and have cooled to T dwarf temperatures ($T_{\text{eff}} \leq 1500$ K). Indeed, a T subdwarf population may be dominant in the halo (Burgasser 2004a). Currently, only one source is a viable T subdwarf candidate, 2MASS 0937+29 (Burgasser et al. 2002). This $T_{\text{eff}} \approx 900$ K brown dwarf has blue near-infrared colors ($J - K_s = -0.6$) consistent with enhanced H$_2$ absorption, and an unusually strong 0.99 µm FeH band (Burgasser et al. 2003b). Compar-
ison of empirical data to spectral models also supports a subsolar metallicity (Burrows et al. 2002). However, it remains unclear as to whether surface gravity effects are responsible for these features (Burgasser et al. 2002; Knapp et al. 2004), and 2MASS 0937+29 does not exhibit halo-like kinematics (Vrba et al. 2004). Spitzer observations of this and other peculiar T dwarfs may help resolve this issue.

3. The Potential of Spitzer Observations

The abundance of molecular gaseous and condensate species in the atmospheres of late-type M, L and T dwarfs implies that their infrared spectra are highly sensitive to temperature, gravity and metallicity variations. Comprehensive investigations of these effects are currently underway (e.g., Gorlova et al. 2003). Spitzer observations of ultracool subdwarfs will be useful in identifying specific metallicity diagnostics in the 4-20 \( \mu \)m regime, where several major gaseous (e.g., H\(_2\)O, CH\(_4\) and NH\(_3\)) and condensate (e.g., silicates) species are found.

**Temperature Scales:** At wavelengths greater than \( \sim 11 \mu m \), the SEDs of ultracool dwarfs approach the Rayleigh-Jeans approximation for a thermal black-body (M. Marley, 2005, priv. comm.). Hence, measurement of the absolute flux at these wavelengths yields a direct determination of temperature (\( F_\lambda \propto T/\lambda^4 \)). While the temperature scale of solar-metallicity late-type dwarfs has been studied in detail (e.g., Golimowski et al. 2004), ultracool subdwarf temperatures are largely unknown. Combining infrared fluxes with forthcoming parallax determinations (F. Vrba, 2005, priv. comm.) will enable these measurements.

**Condensate Dust Formation:** Condensate dust is prevalent in the photospheres of late-type M and L dwarfs (Allard et al. 2001), and is believed to be responsible for the red near-infrared colors (\( J-K \sim 1.5-2.5 \)), depletion of TiO and VO gases (Lodders 2002), and photometric variability (e.g., Gelino et al. 2002) observed in these objects. Yet major condensates such as perovskite (CaTiO\(_3\)) and enstatite (MgSiO\(_3\)) are multiple metal species, and their formation may be inhibited in metal-poor atmospheres. There is indirect evidence of this with the retention of TiO gas bands in the L subdwarf 2MASS 0532+82 (Figure 1). The absence of dust can be readily traced thought its influence in the 5-9 \( \mu \)m region. Here, dust in M and L dwarf atmospheres produces a smooth, relatively featureless spectrum; without dust, major absorption bands of H\(_2\)O and CH\(_4\) are prominent (Figure 2). IRS observations of ultracool subdwarfs can test this prediction and explore the consequences for atmospheric chemistry.

**Gravity versus Metallicity Diagnostics:** Gravity and metallicity effects in the optical and near-infrared spectra of T dwarfs produce similar enhancements in pressure-sensitive K I and H\(_2\) features (Burgasser et al. 2002, 2003b; Knapp et al. 2004). Disentangling these effects is nontrivial. In the longer wavelength bands sampled by the IRS spectrograph, gravity effects are minimal, but reduced metallicities flatten the IR spectra due to increased H\(_2\) opacity and weak metal features (Figure 2). Empirical confirmation and characterization of these differences will enable the segregation of old disk and halo brown dwarfs for future studies of the substellar population in the vicinity of the Sun.
Figure 2.  

Left: Comparison of 2000 K theoretical spectra in the 6-9 \( \mu m \) region with (top) and without (bottom) dust. The presence of strong molecular features can test whether dust formation is inhibited in metal-poor atmospheres.  

Middle and Right: Theoretical model spectra for 1200 K brown dwarfs in the IRS SL2 (top) and SL1 (bottom) spectral windows, normalized at 6.3 and 8 \( \mu m \), respectively. The middle panels show variations due to surface gravity for (top to bottom) \( \log g = 4.5 \) to 5.5 (cgs) and \( Z = Z_{\odot} \). The right panels show variations due to metallicity for \( \log Z/Z_{\odot} = -2 \) to 0 and \( \log g = 5.5 \) (models courtesy A. Burrows and P. Hauschildt).

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