Searching for the M+T binary needle in the brown dwarf haystack

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Abstract. Multiplicity is a key statistic for understanding the formation of very low mass (VLM) stars and brown dwarfs. Currently, the separation distribution of VLM binaries remains poorly constrained at small separations (≤ 1 AU), leading to uncertainty in the overall binary fraction. We approach this problem by searching for spectral binaries whose identification is independent of separation. The combined spectra of these systems exhibit traces of methane imposed on an earlier-type spectra. When the primary of such a system is a late-type M or early-type L dwarf, however, the relative faintness of the T dwarf secondary (up to 5 magnitudes at K-band) renders these features extremely subtle. We present a set of spectral indices newly designed to identify these systems, and a spectral fitting method to confirm and characterize them. We apply this method to a library of over 750 spectra from the SpX Prism Spectral Libraries. We present new spectral binary candidates, compare them to recent discoveries, and describe ongoing followup to search for resolved companions and/or radial velocity variability.

Key words. Stars: brown dwarfs, Stars: low-mass, Stars: binaries: general, Techniques: spectroscopic.

1. Introduction

The primary mechanisms of brown dwarf formation remain an open question. As opposed to main sequence stars, brown dwarfs require high density regions inside giant molecular clouds to begin their collapse. The main problem is how to stop the accretion before the object grows to a star. Several mechanisms have been proposed. One theory postulates that brown dwarfs are the result of the turbulent fragmentation of protostellar clouds, where colliding turbulent flows create 2D localized high density regions in which the accretion can be terminated by lack of material in the third direction (Padoan & Nordlund 2002). Another theory suggests that brown dwarfs may form by the fragmentation of prestellar disks (Stamatellos & Whitworth 2009). If multiple cores form in the same region, the lowest mass member could be ejected by dynamical interaction, preventing the object from gaining mass, and forming a single, isolated brown dwarf (Reipurth & Clarke 2001). Finally, the photoerosion of prestellar cores by a nearby OB star through radiation pressure or stellar...
winds is a case that requires the presence of a
massive star (Whitworth & Zinnecker 2004).
While all of these theories can successfully
form brown dwarfs, it is not clear which one
prevails. One way to examine this is by study-
ing multiplicity. Turbulent fragmentation fa-
vors the formation of systems of several brown
dwarfs; disk fragmentation tends to form sin-
gle wide brown dwarf companions to main se-
quence stars; ejection of prestellar cores and
photoerosion prefers the formation of isolated
brown dwarfs. About $\sim 100$ VLM stars have
been discovered to date, which correspond to
a binary fraction of $\sim 15\%$ (Burgasser et al.
2006). While the low fraction would seem
to favor the ejection or photoerosion theo-
ries, most known systems were identified using
high-resolution imaging, and thus are limited
by the angular resolution of the instruments.
We can avoid this bias by studying spectral bi-
aries.
Spectral binaries are systems of two spec-
trally unresolved objects (due to their small
angular separation) whose blended-light spec-
tra shows features from both. In this study, we
are looking for T brown dwarf features in late
M and early L dwarf spectra. Since M dwarfs
are the most common objects in the galaxy,
and the brightest low-mass bodies, observing
them allows us to survey a large volume of the
sky. In particular, since the spectra of M and T
dwarfs are distinctive, we focus on a methane
absorption band at 1.6 $\mu$m, which is typical of
T dwarfs, but never found in M dwarfs since
their atmospheres are not cool enough to har-
bor CH$_4$.

### 2. SpeX Spectral Sample

We started with a sample of 989 low-resolution
(R $\sim 100$), near-IR spectra of M, L and T dwarfs
from the SpeX Prism Spectral Libraries. The
data span wavelengths of 0.8-2.3 $\mu$m, and were
obtained over the last 13 years from the SpeX
spectrograph, located at the Infrared Telescope
Facility in Mauna Kea, Hawaii (Rayner et al.
2003). This sample excludes known binaries,
but includes subdwarfs, unusually blue/red
dwarfs, and young brown dwarfs. The entire
sample was used for the template fitting, but
only 769 M7-L7 dwarfs were used to search
for spectral binaries.

### 3. Identifying new binaries

First, we visually selected binary candidates by
searching for indications of methane absorp-
tion. We specifically looked for a “dip” around
1.6 $\mu$m, where the left wall is due to flux from
the companion and the right side comes from
the primary. As can be seen in Figure 1, there
is a clear concavity in the H band, indicating
the presence of CH$_4$ in an early-L spectrum.

![Fig. 1.](image)

This figure shows in black the spectrum of 2MASS J0931+2802, a strong binary candidate
with component spectral types of L2 and T2. Early-
L and a early-T spectra (red and blue, respectively)
are added to create a binary template (green), which
proved to be a significantly better fit than any single
L dwarf template.

Since visual examination can be biased, we
also looked for binaries in a more quantita-
tive way using spectral indices. We used in-
dices previously defined by Burgasser et al.
(2002) and Burgasser et al. (2010), cus-
tomized to find L+T binaries, as well as three
new indices, designed for detecting M+T bi-
aries. The new indices were determined by
examining the spectra of previously confirmed
M+T binaries. After subtracting single tem-
plate spectra, we chose the regions showing
the greatest contrast and designed three spec-
tral indices accordingly. Comparing all 11 in-
dices and spectral types, we identified the 11
pairs that best distinguished known binaries, an example of which is shown in Figure 2. After defining regions that segregated our benchmark binaries, we identified 9 strong and 23 weak binary candidates.

Fig. 2. One of the 11 parameter spaces showing a combination of spectral indices. The red stars indicate the benchmarks, the blue circles are unusually blue objects, while the large and small green triangles correspond to strong and weak candidates.

In order to verify and characterize the binary candidates, we fit both single and binary templates. The latter were assembled by constraining the spectral type of the primary to M7-L7 and the secondary to L8-T8, resulting in a total of 65662 binary templates. The candidate spectra were compared to each single and binary template, and the best fits were ranked by their \(\chi^2\). Finally, an F-test statistic was used to compare the best single and binary fits to test the null hypothesis (that the source is single), and as a weighting factor to determine the average spectral type of each single and binary components.

4. Results

From the original sample of \(\sim 1000\) low-resolution NIR spectra, we identified 16 visual candidates, and 9 strong and 23 weak candidates from spectral indices. Of these, 7 appear to be promising binary candidates based on spectral template fits. We are now conducting high resolution imaging and spectroscopic monitoring observations to confirm their binary status and measure orbit properties, as shown in Figure 3.

Fig. 3. Forward-modeling fit of a high-resolution Keck/NIRSPEC spectrum of the binary candidate 2MASS J0931+2802. The center black line is the data; the red line is the best model fit; the green line includes telluric absorption. The bottom spectrum displays the residuals (black) and the uncertainties (gray). We extract RV, V\text{sin}i and atmospheric parameters from this fit.

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