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Hunting for brown dwarf binaries with X-Shooter

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Abstract

The refinement of the brown dwarf binary fraction may contribute to the understanding of the substellar formation mechanisms. Peculiar brown dwarf spectra or discrepancy between optical and near-infrared spectral type classification of brown dwarfs may indicate unresolved brown dwarf binary systems. We obtained medium-resolution spectra of 22 brown dwarfs of potential binary candidates using X-Shooter at the VLT. We aimed to select brown dwarf binary candidates. We also tested whether BT-Settl 2014 atmospheric models reproduce the physics in the atmospheres of these objects. To find different spectral type spectral binaries, we used spectral indices and we compared the selected candidates to single spectra and composition of two single spectra from libraries, to try to reproduce our X-Shooter spectra. We also created artificial binaries within the same spectral class, and we tried to find them using the same method as for brown dwarf binaries with different spectral types. We compared our spectra to the BT-Settl models 2014. We selected six possible candidates to be combination of L plus T brown dwarfs. All candidates, except one, are better reproduced by a combination of two single brown dwarf spectra than by a single spectrum. The one-sided F-test discarded this object as a binary candidate. We found that we are not able to find the artificial binaries with components of the same spectral type using the same method used for L plus T brown dwarfs. Best matches to models gave a range of effective temperatures between 950 K and 1900 K, a range of gravities between 4.0 and 5.5. Some best matches corresponded to supersolar metallicity.

1 Introduction

Stars are believed to be born in nurseries of several objects. After childhood they leave their birth place and settle on the main sequence. A majority of stars remain in binary or hierarchical systems. Multiplicity provides constraints on fundamental parameters, such as dynamical masses, essential to test atmospheric models. It is well known that the binary fraction decreases when decreasing mass. This fraction decreases from 80%-60% for O, A, B and G, K stars to 40% for the M dwarfs [9, 17] and 20% for brown dwarfs[9, 21, 17]

The peak of the separation distribution of brown dwarfs is ~ 3 au, which is very close to the limit of the high resolution imaging surveys [9].

Atmospheric models allow us to disentangle the effect of varying effective temperature, gravity, and metallicity on the spectral features. Below a effective temperature of ~ 2600 K, models predict that clouds of iron and silicate grains begin to form, changing the opacity.

Self-consistent atmospheric models, such as the BT-Settl models [4] and the Drift-PHOENIX models, [19], use cloud models where the dust properties do not require the definition of any other additional free parameters other than gravity, effective temperature and metallicity. Synthetic spectra for a specific set of atmospheric parameters can be compared to empirical spectra. These models are just starting to be tested on spectra of young late-type objects ([8], [25], [24], [7], [22]). They were used on spectra of L3-T7 dwarfs in [7] to reveal the behavior of these models over this spectral range (500-2500 nm) and test if they are able to reproduce spectra of unresolved brown dwarf binaries.

2 The sample

2.1 Sample selection

We selected a sample of 22 brown dwarfs found in the literature with optical spectral types between L3 and T7 which have discrepant optical and near-infrared classification, or, peculiar spectra. Optical subtypes are typically earlier than the near infrared subypes. These objects are candidates for unresolved binaries. Furthermore, to calibrate our results and confirm the reliability of our method, we added some known brown dwarfs systems, LHS 102B [18], formed by a L4.5 plus a L4.5, and SDSS J042348.56-041403.4 [12], formed by a L6±1 and a T2±1.

3 Empirical analysis

3.1 Finding L plus T brown dwarf binaries

Spectra of L plus T brown dwarf binary systems have been widely studied in the past years [9], [10], [6]. The combined spectra of these type of binary systems are expected to show peculiar characteristics, as they are a mix of two quite different spectra, with different atomic and molecular absorptions [15].

Burgasser et al. 2010 [10] described differences of L plus T binary systems in comparison with single template brown dwarf spectra: in general, spectra of L plus T binary systems show bluer spectral energy distribution in the near-infrared, and in particular, some spectral features vary, like the CH_4 and H_2O features at 1.1 μm which are deeper for binaries and the CH_4 feature at 1.6 μm is stronger in comparison to the 2.2 μm CH_4 band. Using such differences, [11], [10] and [6], defined spectral indices which help to detect L plus T brown dwarf binaries.

By calculating these indices we select those objects in our sample that are candidates L plus T binary systems. These indices selected two strong binary candidates and four weak candidates.

The next step in the empirical analysis consists on comparing our spectra with libraries of well characterized brown dwarf template spectra. First, we degrade the resolution of our X-Shooter spectra to the resolution of each template. Then we re-interpolate the library of brown dwarf template spectra and X-Shooter spectra to the same grid.

As template brown dwarf spectra we use McLean et al. (2003) [23] and Cushing et al. (2005) [15] spectra and SpeX Prism Spectral Library spectra[1]. In total we consider 462 spectra from SpeX Spectral Library, plus 14 from [15] library and 47 spectra from [23] library.

In our analysis we search for the best matches to single template spectra from libraries and to combinations of two template spectra from those libraries. Before comparing our X-Shooter spectra to combination of two template spectra coming from the libraries, we calibrate their fluxes to the same distance using the absolute magnitude-color relation published by Dupuy & Liu (2012) [16]. To identify the best matches to our spectra, we use a χ^2 approach as explained in Cushing et al. (2008) [14], as well as visual inspection. We test if the fit to a binary template is significantly better than the fit to a single template using a a one-sided F-test statistic. The F-statistic rejected one of our candidates, namely: SIMP0136.

We show the best matches to 2M1341 with a single and a composite spectra in Figure 1.

3.2 Finding L plus L or T plus T brown dwarf binaries

Spectroscopic identification of brown dwarf L plus L and T plus T binaries pairs has not been as developed as that for L plus T binaries. Differences within L or T brown dwarfs of different sub-types reside mainly in smooth changes of the spectral energy distribution. Therefore the search for binaries with similar spectral types is challenging.

Before comparing to the set of libraries following the same method as in Section 3.1, we first test the efficiency of this method to search for L plus L and T plus T binaries using synthetic binaries. To this aim we have chosen several L and T single and not peculiar brown dwarfs spectra from the SpeX library. Then, we calibrated their fluxes to the same distance, using the absolute magnitude-color relation published by [16]. We combined different pairs of L brown dwarfs spectra with L brown dwarf and different pairs of T brown dwarfs spectra with T brown dwarfs, creating L plus L and T plus T synthetic spectra of binaries.

[1] http://pono.ucsd.edu/~adam/browndwarfs/spexprism/

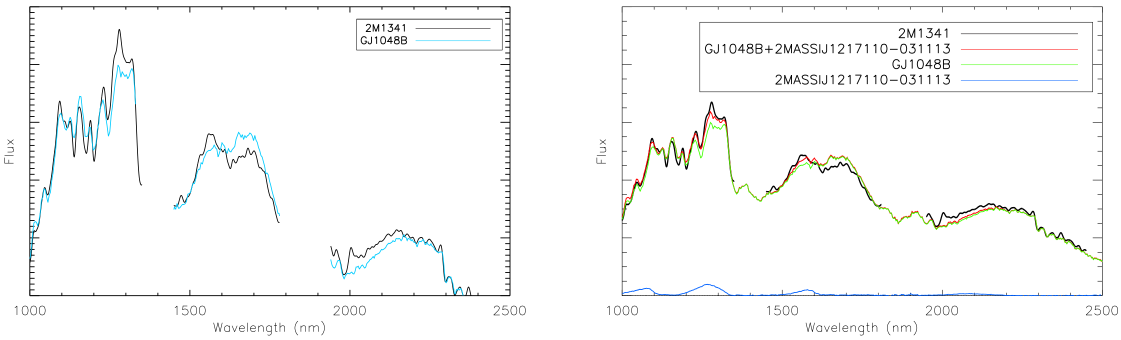

Figure 1: Best matches for object 2M1341 (L2, peculiar) to single and composite spectra from SpeX. Our spectra is shown in black. In the upper plot, we show the best match to a single spectra in blue. In the lower plot, we show in red the best match to a composite spectra. in green SpeX primary and in blue the SpeX secondary. The flux is F(λ).

We compared these artificial binary pairs to single SpeX templates and composites of two SpeX template spectra. Our objective is to test whether synthetic L plus L and T plus T binaries can be identified by comparing to spectral library spectra.

From this analysis, we conclude that L plus L and T plus T brown dwarfs binaries are not straightforward to detect just by comparing with single or composite spectral libraries. Therefore, additional data will be necessary to find these binaries, i.e. parallaxes, high resolution imaging or high resolution spectra.

4 Comparison to synthetic spectra

In this section, we compare the optical and near-infrared spectra of our objects, to predictions from BT-Settl atmospheric models [2, 1, 3], excepting brown dwarf binary candidates and objects with low signal to noise. We derive atmospheric parameters of the objects and to reveal non-reproducibilities of the models. The models are described in [3, 4, 5].

We selected subgrids of synthetic spectra with 400 K$\leq T_{eff} \leq$ 3000 K, $3.5 \leq \log g \leq 5.5$ and metallicities of +0.0 and +0.3, which are the metallicities for which the latest version of the BT-Settl models are available. The solar metallicity is based on metallicities calculated by [13]. The spacing of the model grid is 50 K and 0.5 dex in $\log g$. Effective temperature, gravity, metallicity and alpha element enhancement are described in the model name strings as `lte-LOGG+[M/H]a+[ALPHA/H]`.

The BT-Settl 2014 synthetic spectra were smoothed to the resolution of X-Shooter. The models were then reinterpolated on the X-Shooter wavelength grid. The spectra were normalized using the same method than in Section 3 and explained in [14]. The parameters $T_{\rm eff}$, $\log g$, and [M/H] have minimum uncertainties of 50 K, and 0.5 dex respectively. These errors correspond to the sampling of the atmospheric parameters of the model grids. In Figure 2 we show the best fit of the synthetic spectra to two of our targets.

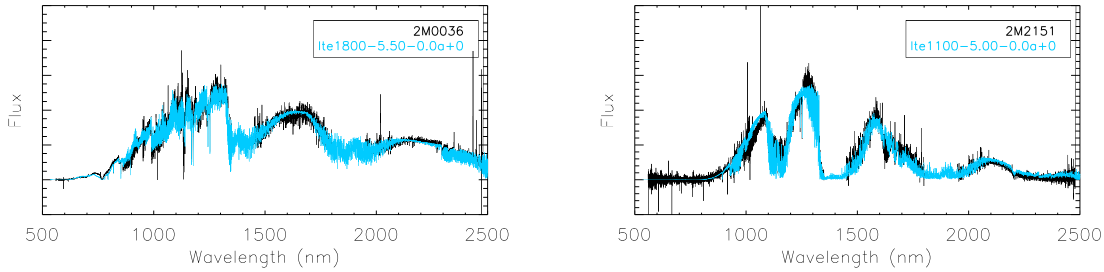

Figure 2: Best matches to BT-Settl models 2014. Effective temperature, gravity, metallicity and alpha element enhancement are described in the model name strings as `lte-LOGG+[M/H]a+[ALPHA/H]`. The flux is F(λ).

The CH_4 and the FeH molecules opacities are still incomplete in the new BT-Settl 2014 models. Methane line opacities are based on the semi-empirical list of Homeier et al. 2003 [20], which is highly incomplete in the H band and only supplemented with a small set of room-temperature transitions for the Y and J bands. This explains that the H-band is not well reproduced for any of the L or T brown dwarf spectra, and also the J band in the case of T brown dwarfs. For three of the L brown dwarfs, the best match is found for $\log g = 5.5$, with solar metallicity, four of the L brown dwarfs have best matches with $\log g = 5.0$, but [M/H] = +0.3.

5 Conclusions

We observed and analyzed 22 optical and near infrared medium resolution VLT/X-Shooter spectra of brown dwarfs. Two objects from our sample are known binaries, that allow us to test our analysis.

Using [11, 10] and [6] method, we selected six objects as potential L plus T binary candidates. We compared these six objects with spectral libraries of field brown dwarfs ([23], [15] and Spex) and composite spectra of these libraries.

We also examined the possibility to find L plus L or T plus T brown dwarfs binaries using a comparison to spectral libraries. As they are not remarkable differences in the spectral characteristics within subtypes of the same spectral type, apart from the SED, we are not able to find L plus L or T plus T brown dwarfs binary systems using this method. Additional data, such as parallax measurements, high-resolution imaging or high resolution spectra are necessary in order to find these systems.

We find that 27±11% of the L and T objects in our sample may be unresolved binary candidates with one L and one T possible members, which corresponds to a mass ratio of $q \geq 0.2$ for an age of a few Gyr (expected for most investigated objects). This percentage agrees with previous results. Our work does not explore smaller mass ratios.

BT-Settl models 2014 are able to reproduce the majority of the SEDs of our objects in the optical and in the near infrared. Nonetheless, these models usually fail to reproduce the shape of the H-band, due to incomplete opacities for the FeH molecule in BT-Settl 2014 models.

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