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A M/T dwarf binary from the Canada-France Brown Dwarf Survey: probing the L/T transition

C. Reylé[1], P. Delorme[2], E. Artigau[3], X. Delfosse[2], L. Albert[3], T. Forveille[2], A. S. Rajpurohit[1], F. Allard[4], D. Homeier[4], and A. C. Robin[1]

[1] Institut UTINAM, CNRS UMR 6213, Observatoire des Sciences de l'Univers THETA Franche-Comté-Bourgogne, Université de Franche Comté, Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France, e-mail: `celine@obs-besancon.fr`

[2] UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France

[3] Département de Physique and Observatoire du Mont Mégantic, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, QC H3C 3J7, Canada

[4] Centre de Recherche Astrophysique de Lyon, CNRS UMR 5574, Université de Lyon, École Normale Supérieure de Lyon, 46 allée d'Italie, 69364 Lyon Cedex 07, France

Abstract. Stellar-substellar binaries are interesting benchmarks. They are useful to constrain the complex substellar atmosphere physics, by using parameters brought by the much better characterized primary star. We report the discovery of CFBDS J111807-064016, a T2 brown dwarf bounded to the low-mass M4.5-M5 star 2MASS J111806.99-064007.8. The brown-dwarf was identified from the Canada France Brown Dwarf Survey, a wide field survey for cool brown dwarfs conducted on the CFHT telescope. The primary was subsequently identified as a co-moving object. We have obtained near-infrared spectroscopy and compare these data with recent atmosphere models to determine the physical parameters of both components, and estimated the masses using evolutionary models. This system is a particularly valuable benchmark since the brown dwarf is an early T: the cloud-clearing that occurs at the L/T transition is very sensitive to gravity and metallicity, but also to dust properties. The T-dwarf, with its metallicity estimate from the primary, provides an anchor for the colors of L/T transition brown dwarfs. This makes it a prime targets to test brown dwarf atmosphere and evolution models.

Key words. Stars: Low mass, brown dwarfs – binaries: general

1. Introduction

Our understanding of the physics of atmosphere in the brown dwarf and exoplanetary temperature range is made difficult by the observational degeneracy between the influence of age, metallicity and effective temperature. Brown dwarfs-main sequence star binaries offer a unique opportunity to break this degeneracy. Moreover, the discovery of such systems, and their frequency, put constraints on theories for brown dwarf formation. Such precious benchmarks systems are rare, however.

Send offprint requests to: C. Reylé

To date 20 T dwarf-main sequence star resolved systems are confirmed, including just 8 with a M-dwarf primary whose lower luminosity both eases the study of the faint companion and alleviates worries that irradiation influences the brown dwarf atmosphere. Among these systems, only 5 (Gl337D, HD 46588B, HN PegB, ϵ Indi Ba, and CFBDS J111807-064016, hereafter CFBDS 1118) have a early-T secondary, at the L-T transition, where cloud-clearing processes dramatically change the shape of emerging spectra. While cool atmosphere models perform relatively well in dusty atmospheres (late-M to mid-L) and in dust-free atmospheres (mid-T and later), they do not properly describe yet the more complex physics at the L/T transition (e.g. Helling et al. 2008). The detection of variability in a few of these objects (e.g. Artigau 2009; Radigan et al. 2012) moreover suggests that cloud coverage is spatially inhomogeneous and further complicates the modeling and interpretation.

2. Physical properties of the system

2.1. Astrometry and photometry

Near Infrared J, H, and K_s images were obtained with SOFI at the ESO NTT on March 2009. We obtained Discretionary Director Time with WIRCAM at CFHT for a third epoch on March 2012 (see Table 1).

Spectroscopic follow-up of both components have been performed with the XSHOOTER spectrograph on the ESO VLT-UT2. We computed the spectroscopic indices of the key molecular absorption bands TiO and CaH for the M-dwarf, H_2O and CH_4 for the T-dwarf and classified the components as a M4.5 to M5 dwarf and a T2 dwarf. Distances are estimated using M_J vs spectral type relations (Reylé et al. 2006; Dupuy & Liu 2012). The objects are located at the same distance range to the Earth, 70 to 120 pc.

Their respective proper motions agree within 1σ. Simulation of the galactic population with the Besançon Galaxy model (Robin et al. 2003) in the direction of CFBDS 1118 shows that there is only $\sim 3 \times 10^{-5}$ probability that a main sequence star with a proper motion within 3σ of the T-dwarf would lie by chance in the direction of CFBDS 1118. We therefore considers CFBDS 1118 and 2MASS J111806.99-064007.8 as a physical binary system. The components are separated by 7.7″, translating to a projected separation from 393 to 901 AU.

Table 1. Astrometry, proper motions, and photometry of the components.

	M-dwarf	T-dwarf
α	$11^h18^m06.99^s$	$11^h18^m07.13^s$
δ	-06°40′07.84″	-06°40′15.82″
z'		22.56 ± 0.08
J	13.84 ± 0.03	19.01 ± 0.02
H	13.25 ± 0.02	18.48 ± 0.03
K_s	12.95 ± 0.03	18.30 ± 0.03
μ_α	−201 ± 11 mas yr^{-1}	−190 ± 14 mas yr^{-1}
μ_δ	−49 ± 20 mas yr^{-1}	−60 ± 21 mas yr^{-1}

2.2. Kinematics, age, and metallicity

The proper motion translates into a rather high tangential velocity (77 ± 30 km s^{-1}), suggesting an old age. Assuming the kinematics of the system, simulations with the Besançon galactic model point to an age > 3 Gyr (81% probability) or 5 Gyr (58% probability). This is independently corroborated by the lack of Hα activity in the optical spectrum of the primary. Such a low activity for a mid M-dwarf indicates an age $\gtrsim$ 6 Gyr (West et al. 2008).

A metallicity estimate can be inferred from the primary spectrum using the strength of Na I, Ca I, and H_2O features in the K-band. Using the relations defined by Rojas-Ayala et al. (2010), we found [Fe/H] = −0.1 ± 0.1 dex, the average metallicity in the solar neighborhood.

2.3. Effective temperature, gravity, and mass

We have compared the most recent version of the BT-Settl stellar atmosphere models (see Rajpurohit et al. 2012; Allard et al. 2013) to the observed spectra of both components. The M-

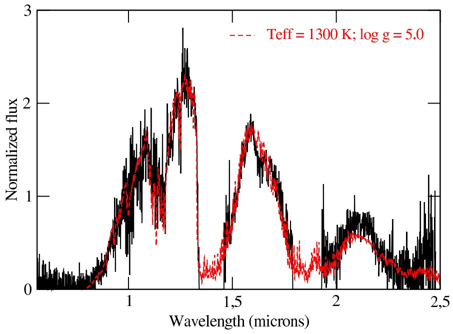

Fig. 1. Comparison of CFBDS 1118 spectrum (solid line) with BT-Settl models (dashed line).

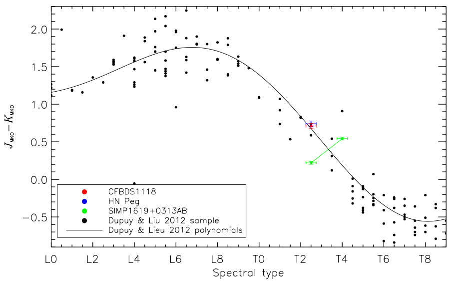

Fig. 2. $J - K_s$ color vs spectral type for L and Ts.

dwarf spectrum is best fitted by the synthetic spectrum with $T_{\rm eff}$ = 3000 K and $\log g$ = 5.0. Using the evolution models from Baraffe et al. (1998), this translates to a mass of 0.1 to 0.15 $M_\odot$. For the T-dwarf, the best fit is obtained with $T_{\rm eff}$ = 1300 K and $\log g$ = 5.0 (see Fig. 1). Assuming an old age, the gravity from evolution models is found to be higher by 0.5 dex. This discrepancy could be due to a strong metallicity effect, high gravity effects not well represented in the atmosphere models, or a wrong age estimate. However we are quite confident that the system is old due to the lack of activity in the M-dwarf, in agreement with the kinematics of the system. Thus the mass is 0.06 and 0.07 $M_\odot$ for CFBDS 1118, assuming an age of 5 Gyr and 10 Gyr, respectively.

3. Discussion

The properties of the T-dwarf are not expected to evolve much, as old brown dwarfs cool down more slowly. This object is among the most massive brown dwarfs, just below the hydrogen burning limit. This makes it a prime targets to test brown dwarf models.

This system is even more valuable as the brown dwarf is an early T. The cloud-clearing that occurs at the L/T transition is very sensitive to gravity and metallicity. This produces large scatter in the colors, as shown in Fig. 2. HN PegB, a T2.5 but very young dwarf (0.3 Gyr; Luhman et al. 2007) shows very similar photometric properties. Contrarily, the early T components of SIMP 1619+0313AB system show very different properties whereas they are coevals objects (Artigau et al. 2011). It shows that the L/T transition atmospheres are probably triggered by the dust content.

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