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PROBING EXTREME ATMOSPHERE PHYSICS: T DWARFS AND BEYOND

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Abstract. We present the latest results from the Canada-France Brown Dwarf Survey (hereafter CF-BDS), which identified about 70 T dwarfs and more than 300 L dwarfs. It particularly discovered CFBDS J005910.90011401.3 (Delorme et al. 2008a, hereafter CFBDS0059), the coolest brown dwarf known (Albert et al, in prep.). This lead to the discovery of a probable ammonia absorption band in the near infrared spectra of CFBDS0059 and ULAS J003402.77005206.7 (Warren et al. 2007, hereafter ULAS0034). These objects, along with the recently identified ULAS1335 (Burningham et al. 2008) are the coolest known brown dwarfs and their spectra probe a hitherto unobserved effective temperature range.

The spectra of both CFBDS0059 and ULAS J0034 show absorption by a wide band on the blue side of the H band flux peak, which we attribute to ammonia. If, as we expect, that feature deepens further for still lower effective temperatures, its appearance would become a natural breakpoint for the transition between the T spectral class and the new Y spectral type.

1 Introduction

Current atmosphere models are rather uncertain in the unexplored temperature range between the the 500-700 K coolest known brown dwarfs and the ∼100 K giant planets of the Solar System. Two major physical transitions are expected to occur between ∼ 700 K and ∼ 400 K and strongly alter the emergent near-infrared spectra (Burrows et al. 2003): NH_3 becomes an abundant atmospheric constituent and its near-infrared bands become major spectral features, and water clouds form and deplete H_2O from the gas phase. The corresponding near-infrared spectral changes are likely to be sufficiently drastic that the creation of a new spectral type will be warranted (Kirkpatrick et al. 2000).

However no ammonia absorption have been identfied in brown dwarfs spectra until recently, the discovery of ultracool brown dwarfs being challenging due to their very faint absolute magnitudes (J∼19). Two major wide field surveys, UKIDSS, Lawrence et al. (2007) and CFBDS Delorme et al. (2008b) have succeded into discovering a handful of these elusive objects. CFBDS singles-out brown dwarfs in the far-red, taking advantage of their very red $i' - z'$ colors while UKIDSS relies on near infrared identification. Their recent discoveries allowed to have a first look at cool atmospheres, below 600-700K.

We examine here the new spectral features, most notably a broad ammonia absorption band, which appears below 600K. Note that the absolute temperature estimates derived from models are still very uncertain, with mid-infrared estimations being in average 100K cooler than near infrared ones. this as been highlighted for differents objects by Leggett et al. (2009); Burningham et al. (2009) and Albert et al, in preparation. This latter paper also shows mid-infrared evidence that CFBDS0059 is the coolest brown dwarf known, with a temperature estimated at 525K.

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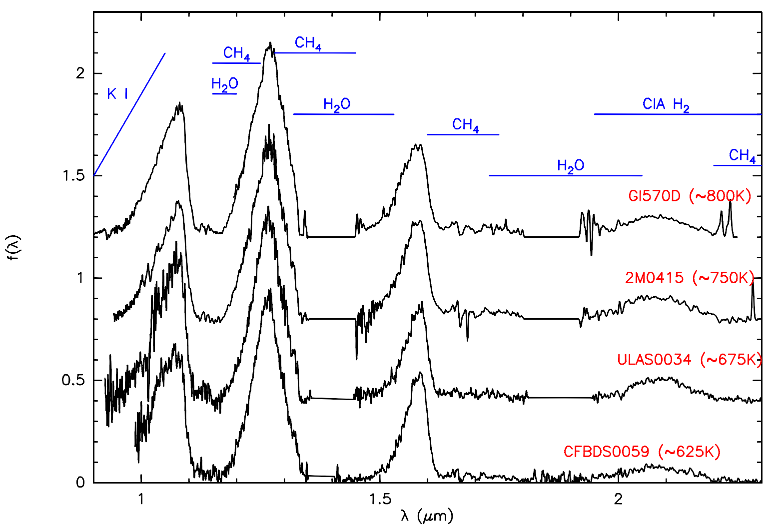

Fig. 1. 0.9 μm - 2.3 μm spectra of CFBDS0059 and the three other coolest brown dwarfs.The main T-dwarf spectral features are labeled. From Delorme et al. (2008a).

2 A new absorption feature in the H photometric band

Fig 1 presents spectrum of CFBDS0059, together with those of ULAS0034, >T8 (Warren et al. 2007), 2M0415, T8 (Burgasser et al. 2003) and Gl570, T7.5 (Burgasser et al. 2000), which successively were the coolest known brown dwarfs. Direct comparison of the four spectra can be used to shed light on incipient new features and atmospheric chemistry. Features which are seen in both CFBDS0059 and ULAS0034 are likely to be real even when their significance is modest in each object, and those which are absent or weaker in the two hotter brown dwarfs, can reasonably be assigned to low temperature molecules. Together with a significantly decreased K-band flux for CFBDS0059, one can notice in Fig 1 a narrowing of the H-band peak, particularly on its blue slope, that increases when temperature decreases.

To visually emphasize this broad feature, we bin the spectra to R=$\sim$100 and overlay the four H-band spectra (Fig. 2, left panel). The new wide-absorption feature is conspicuous in CFBDS0059 and well detected in ULAS0034, and with hindsight is weakly visible in the 2M0415 spectrum. It is however clearly stronger at $T_{\rm eff} < 700$K. Absorption sets in at $\sim 1.585\mu m$ and becomes deeper for $\lambda < 1.565\mu m$. These wavelengths overlap with strong H_2O and NH_3 bands. Either molecule could, a priori, be responsible for this new feature.

Is this new absorption due to ammonia?

Leggett et al. (2007) compare synthetic spectra computed with and without NH_3 opacity, and find that ammonia absorption in cold brown dwarfs strongly depletes the blue wing of the H band. Similarly, Saumon et al. (2000) plots synthetic H-band spectra with and without NH_3 opacity, and find differences for $\lambda < 1.565\mu$m.

Fig 2 right panel plots two BT-Settl models (Allard et al., in prep) for [$T_{\rm eff} = 600$K; $\log g = 4.75$], with and without near-infrared NH_3 opacity. As discussed in Delorme et al. (2008a) the models do not reproduce the observed H-peak shape very well, and a quantitative comparison is thus difficult. The comparison of the two models nonetheless confirms the Saumon et al. (2000) conclusion that ammonia produces strong absorption below $\sim 1.57\mu$m and weaker residual out to 1.595μm. These model predictions qualitatively match the behaviour seen in Fig 2, left panel.

To emphasize the changes in brown dwarfs spectra when their effective temperature decreases from $\sim$800 to $\sim$600 K, we plot in Fig 3,left panel, the ratio of the spectra of CFBDS0059 and Gl570. Right panel shows the equivalent plot for ULAS0034, which is very similar. The signal to noise ratio of the resulting K-band spectrum is too low for detailed analysis, and we therefore focus on the Y, J and H flux peaks. To avoid confusion from

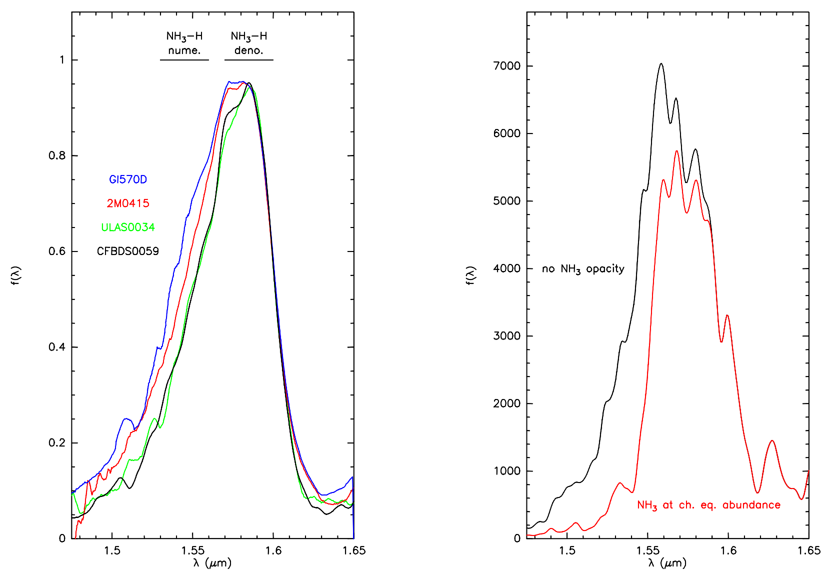

Fig. 2. Left: H-band spectrum of the four cool brown dwarfs binned to R∼100. **Right**: BT-Settl synthetic spectra for [$T_{\rm eff}$ = 600K; $\log g = 4.75$] with and without near-infrared NH_3 opacity; the NH_3 abundance is at its chemical equilibrium value. From Delorme et al. (2008a).

changes in the temperature-sensitive methane bands, we mostly ignore the parts of the spectrum affected by CH_4 absorption bands. The H-band spectrum ratio prominently shows the new absorption band, which sits outside the CH_4 bands and closely matches the 300 K NH_3 transmission spectrum of Irwin et al. (1999). Both spectra are strongly absorbed between 1.49 and 1.52 μm and rebound from 1.52 to 1.57μm. Water absorption, by contrast, is a poor match to the features of spectrum ratio. The strongest water absorption (as computed from the HITRAN molecular database for a 600 K temperature) occurs below 1.49μm, at significantly bluer wavelengths than the CFBDS0059 absorption feature.

3 Conclusion

Ammonia absorption thus seems by far the best explanation for the flux decrease observed in the blue wing of the H-band peaks of both ULAS 0034 and CFBDS 0059. If that association with a NH_3 band is confirmed, and if, as we expect, the band deepens at still lower effective temperatures, its development would naturally define the scale of the proposed Y spectral class. ULAS 0034 and CFBDS 0059 could then become the prototypes of the Y class. Weak near-infrared absorption by ammonia has been tentatively detected by Saumon et al. (2000) in the T7 dwarf Gl 229B, but this analysis of CFBDS0059 and ULAS0034 provides the first robust evidence of a strong near-infrared NH_3 band in brown dwarf spectra.

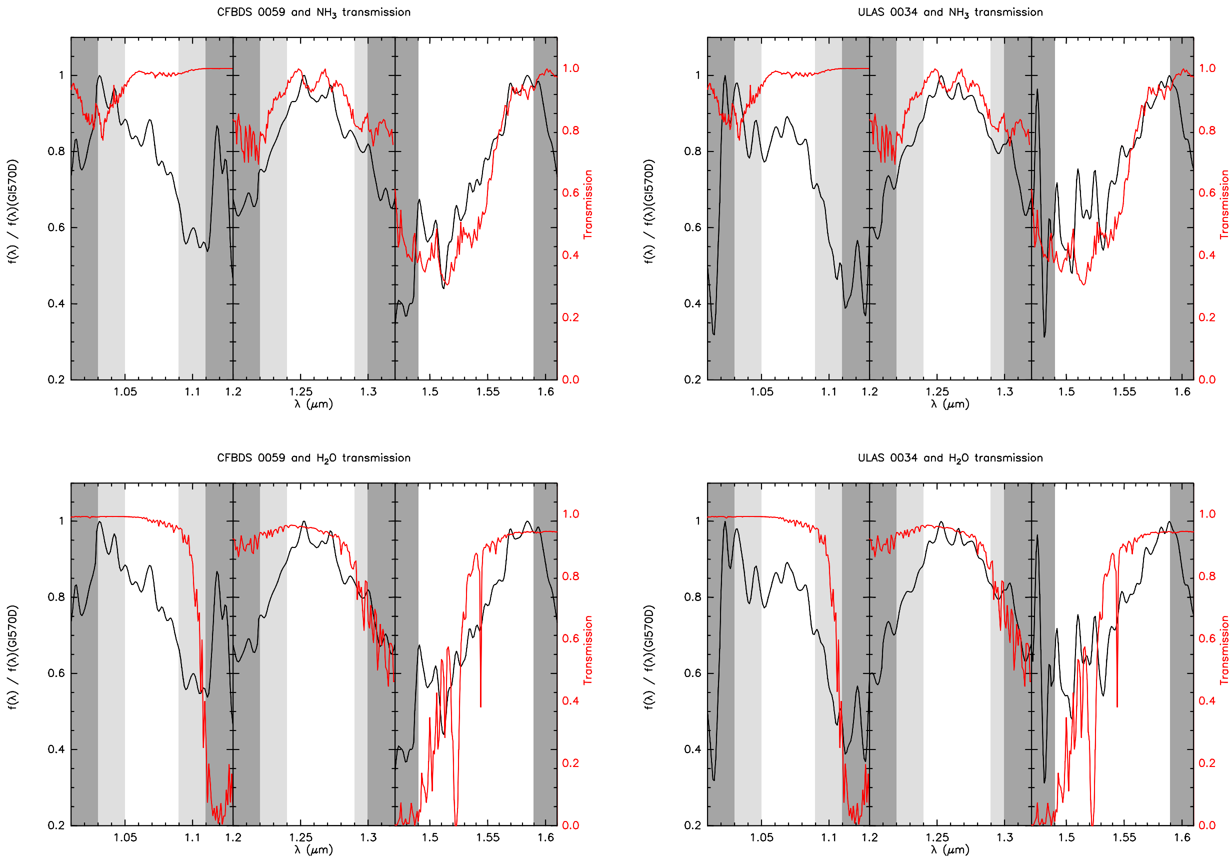

Fig. 3. Left panel: Flux ratio between CFBDS0059 and Gl570 (black), together with the 300K transmission spectrum of NH_3 (Irwin et al. 1999) (red, top panel) and the 600 K H_2O transmission spectrum (red, bottom panel). Grey bands mark the parts of the spectrum affected by strong (dark grey) or moderate (light grey) CH_4 absorption. Right panel: same overlays for the flux ratio between ULAS0034 and Gl 570D (black). From Delorme et al. (2008a).

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