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A SIGNATURE OF CHROMOSPHERIC ACTIVITY IN BROWN DWARFS: A RECENT RESULT FROM NIRLT MISSION PROGRAM

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ABSTRACT

We present the latest results from the Mission Program NIRLT (PI: I.Yamamura), the near-infrared spectroscopy of brown dwarfs using the AKARI/IRC grism mode with the spectral resolution of $\sim$ 120. The near-infrared spectra in the wavelength range between 2.5 and 5.0 μm are especially important to study the brown dwarf atmospheres because of the presence of major molecular bands, including CH_4 at 3.3 μm, CO_2 at 4.2 μm, CO at 4.6 μm, and H_2O around 2.7 μm. We observed 27 sources, and obtained 16 good spectra. Our model fitting reveals deviations between theoretical model and observed spectra in this wavelength range, which may be attributed to the physical condition of the upper atmosphere. The deviations indicate additional heating, which we hypothesize to be due to chromospheric activity. We test this effect by modifying the brown dwarf atmosphere model to artificially increase the temperature of the upper atmosphere, and compare the revised model with observed spectra of early- to mid-L type objects with Hα emission. We find that the chemical structure of the atmosphere changes dramatically, and the heating model spectra of early-type brown dwarfs can be considerably improved to match the observed spectra. Our result suggests that chromospheric activity is essential to understand early-type brown dwarf atmospheres.

Key words: astronomy — astrophysics — journals: individual: PKAS — brown dwarfs — stars: atmospheres — stars: chromospheres

1. INTRODUCTION

Brown dwarf atmospheres have previously been studied with ground-based photometric/spectroscopic observations in the near-infrared wavelength range shorter than 2.5 μm. Such data are sensitive to the inner atmospheric structure including dust effects. Almost all brown dwarf atmosphere models have been able to explain these observed near-infrared spectra. In Figure 1(a) we compare the spectra synthesized from the best-fit model (green line), which is determined by 1.0–2.5 μm observed spectra using Unified Cloudy Model (Tsuji, 2002) to the observed spectra (black lines) for L4.5 brown dwarf, 2MASS J2224–0158, as an example. We overplot continuous spectra between 2.5 and 5.0 μm obtained with AKARI (Murakami et al., 2007). This is the first time such spectra have been obtained in this wavelength range. The model does not show perfect fits to the AKARI observed spectra (Yamamura et al., 2010; Sorahana & Yamamura, 2012).

2. NEW ATMOSPHERIC MODEL, "HEATING MODEL"

This discrepancy implies that we are missing an important process in the upper atmospheres of brown dwarfs when constructing model atmospheres. Hα emissions, $L_{\mathrm{H}\alpha}$, are detected in some brown dwarfs (Mohanty &

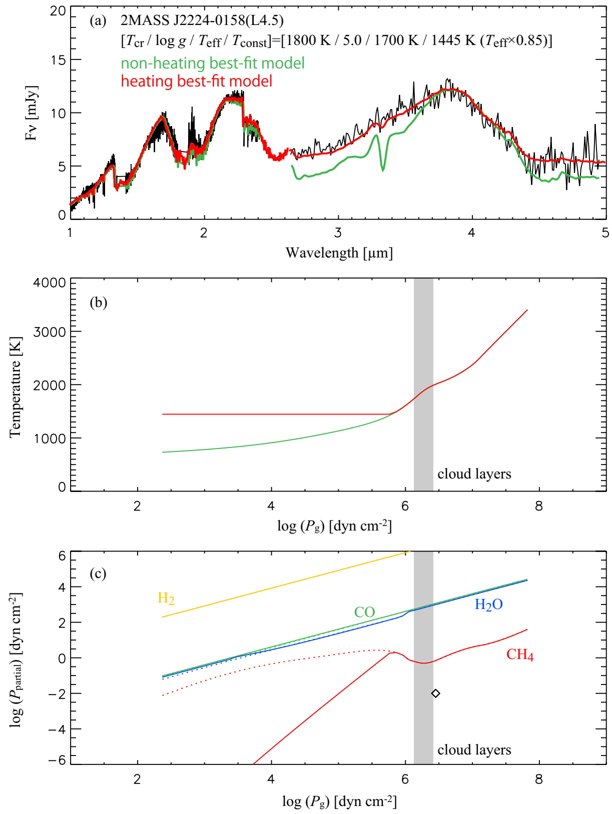

Figure 1. (a) Comparison of model spectra with observed spectra for 2MASS J2224–0158 (L4.5). The black, green, and red lines correspond to the observed, the best-fit model, and the heating best-fit model spectra, respectively. This object is well explained by the "heating best-fit model" that includes heating in the upper atmosphere. (b) The variation of temperature from that of the non-heating model. Colours are as in (a). (c) Total pressure log P_g versus partial pressures of H_2 (∼ total logP_g), CO, H_2O and CH_4, molecules, which are shown by yellow, green, blue and red, respectively. The values of the non-heating model are depicted with dashed lines, and those of the heating model with solid lines. The grey region shows the dust layers.

Basri, 2003). These observations suggest that there is an additional heating source in their upper atmospheres; the brown dwarfs have chromospheres and/or hot coronae in their upper atmospheres. However, no previous brown dwarf atmosphere models have considered chromospheric activity. Thus we construct a simple model that includes heating effect for early- to late-L dwarfs.

We modify the temperature structures of the upper atmosphere of the best fit model (Figure 1b). We set a floor value, $T_{\rm const}$, for the temperature structure of each object in the following way:

$$T(r) = \max(T(r), T_{\rm const}) = \max(T(r), f_{\rm const}T_{\rm eff}), \quad (1)$$

where $f_{\rm const}$ is a constant which is tuned by comparing the observed spectrum of each object (Sorahana et al., 2014). This is the most simple approach to form a chromosphere and/or corona. Using this model, we solve for chemical equilibrium and then calculate the radiative transfer. We seek model atmospheres that give better fits to the observations by varying $f_{\rm const}$. We refer to the derived model atmospheres as "heating best-fit models".

3. RESULTS AND DISCUSSIONS

The heating model spectra of early-type brown dwarfs are considerably improved to match the observed spectra, even though the spectra shorter than 2.5 μm change little (Figure 1a for 2MASS J2224–0158 as an example). With this additional heating, we find that the chemical structure of the atmosphere, especially CH_4 abundance, dramatically changes (Figure 1c). This fact is reflected in the spectral feature around 3.3 μm; that is, the absorption feature of the 3.3 μm CH_4 band is diminishing. In addition, the absorption bands of 2.7 μm H_2O and 4.6 μm CO in the heating model spectra tend to become weak. In general, the strengths of the absorption bands are a result of radiative transfer, which is affected by many factors such as the number densities of molecules, excitation, velocity structure, and relation to the continuum source. Hence it is often difficult to identify a unique reason for the variation. In the current case, the higher temperature in the upper photosphere cancels the effects of increased abundance of the molecules and makes the absorption even weaker.

Other two objects, which are inferred to possess high chromospheric activity from their relatively large $L_{\rm H\alpha}/L_{\rm bol}$ ($L_{\rm bol}$: bolometric luminosity) are also well reproduced by our heating models. This result also shows that the wavelength range of AKARI (2.5–5.0 μm) is more sensitive to the upper atmospheric structure.

We also test the objects that have much lower $L_{\rm H\alpha}/L_{\rm bol}$, and find that they cannot be explained by any of our models even though temperature floors are adjusted. We should consider alternative effects for these objects.

We also present the theoretical aspects of atmospheres. We perform Magnetic Hydro Dynamics simulations of a brown dwarf atmosphere by extending a simulation code originally developed for the Sun (Suzuki & Inutsuka, 2005, 2006). The numerical results indeed show that the temperature remains almost constant in the atmosphere but eventually increases in the upper region. Although we do not give the increasing temperature with the increase in the altitude, the numerical results are consistent with our new temperature structure, which a floor value, T_{const}, is set as the most simplified case for giving an additional heating. Our results suggest that chromospheric activity is essential to understand the near-infrared spectra of brown dwarfs (Sorahana et al., 2014).

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