Brown Dwarf Atmospheres Revealed by 2.5-5.0 μm *AKARI* Spectra
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Introduction: Brown dwarfs play an important role as a bridge between stars and planets. The first detection of brown dwarf was reported by Nakajima et al. [1]. Since they are not sufficiently massive for core hydrogen burning, they simply cool off after deuterium burning ends [2]. The physical and chemical structures of brown dwarf atmospheres are complicated and cannot be understood with a simple extension of stellar atmospheres. Theoretical studies of brown dwarf atmospheres predict that such low temperature atmospheres are dominated by molecules and dust [3][4][5], and can be determined by simple radiative equilibrium under local thermodynamic equilibrium [6]. However, many previous observations in the near-infrared wavelength range find that the actual physical and chemical structures of brown dwarf atmospheres are more complicated and differ from such simple predictions [7][8][9][10].

By understanding brown dwarf atmospheres we will be able to investigate exoplanet atmospheres so that we can finally gain a comprehensive understanding of atmospheres from stars to planets.

***AKARI* Spectra of Brown Dwarfs:** We observed 27 brown dwarfs with *AKARI,* a Japanese infrared astronomical satellite [11], and for the first time obtained good continuous spectra with moderate-resolution (R～120) between 2.5 and 5.0 μm for 16 sources (Figure 1).

Analysis of *AKARI* Spectra: We investigate the appearance of the CH_4 (3.3 μm), CO_2 (4.2 μm) and CO (4.6 μm) molecular absorption bands in this new wavelength range along their spectral types, and attempt to interpret these results with the Unified Cloudy Model (UCM), a theoretical brown dwarf atmosphere model.

We find that the physical and chemical structures in the brown dwarf atmospheres deviate from theoretical predictions for local thermodynamic equilibrium (LTE) with solar metallicity [10].

Elemental Abundances of Brown Dwarfs: We discuss possible elemental abundance variations among brown dwarfs using model atmospheres and *AKARI* data to explain the deviations. We construct a set of models with various elemental abundances as a first trial, and investigate the variation of the molecular composition and atmospheric structure. From the results, we suggest that a possible reason for the CO_2 4.2 μm absorption feature in the late-L and T type spectra is the C and O elemental abundances being higher or lower than the solar values used in previous studies (Figure 1; see also [12]; [13]). Investigation of elemental abundances is important for exoplanets to understand their origin of formation.

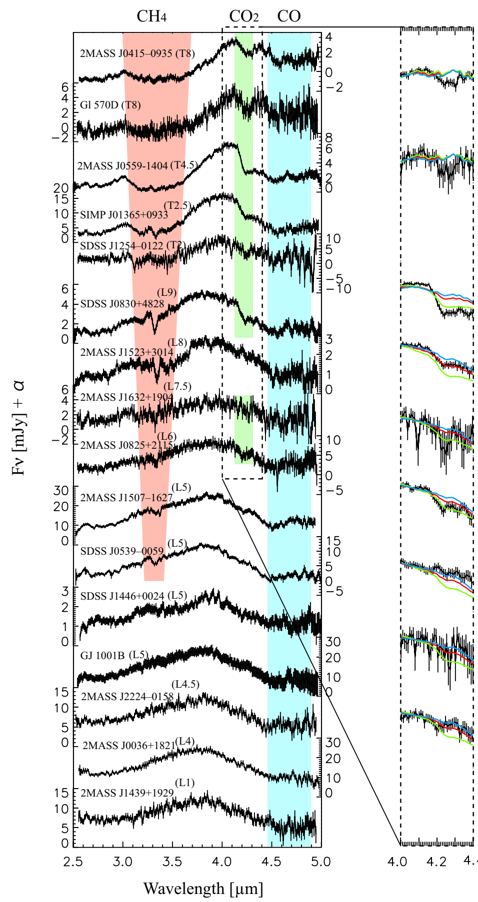

Figure.1 *AKARI* spectra of brown dwarfs with errors shown in black. 11 L dwarfs and 5 T dwarfs are successfully observed. The 3.3 μm CH_4, 4.2 μm CO_2 and 4.6 μm CO absorption bands are shown in red, green and blue, respectively in the left panel. We also enlarge the CO_2 absorption band region and show a comparison between observation and models with varying elemental abundances. We pick up 9 sources of our sample. They show the 4.2 μm CO_2 band, except for 2MASS J1523+3014. Three objects are better explained by the model with increased C and O elemental abundances (green), one object is well reproduced by the model with decreased abundances (blue), and the spectra of the other three sources are best explained by the solar abundance model (red). We are not yet able to explain the other two latest T-type sources that the CO_2 band appears.

Chromospheric activity in Brown Dwarfs: No previous brown dwarf atmosphere models have considered chromospheric activity. However, the deviations between theoretical model spectra and observed spectra in the wavelength range 2.5-5.0 μm indicate that there is additional heating in the upper atmosphere. If a brown dwarf has a chromosphere, the temperature in the upper atmosphere should be higher. We construct a simple model that includes heating due to chromospheric activity. With this additional heating, 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 the near-infrared spectra of brown dwarfs [14].

Our results are important for searching for signs of life in exoplanets orbiting brown dwarfs. NASA's Kepler space telescope has detected more than 1000 Earth-mass exoplanet candidates, and it is now estimated that at least 17 billion Earth-sized exoplanets reside in the Milky Way Galaxy. Since less massive, rocky planets tend to orbit around low mass stars, planets resembling our Earth are more likely to be discovered around brown dwarfs. Understanding chromospheric activity, such as flares, in brown dwarfs and its effects on the atmospheric structure of orbiting planets will be very important for investigating the potential for life on exoplanets.

References:

[1] Nakajima, T., et al. (1995) *Nature* **378**, 463-465. [2] Burrows, A., Hubbard, W. B., Lunine, J. I., and Liebert, J. (2001) *Reviews of Modern Physics*, **73**, 719-765. [3] Lord, III, H. ~C. (1965) *Icarus*, **4**, 279. [4] Larimer, J.~W. (1967) *Geochimica et Cosmochimica Acta*, **31**, 1215-1238. [5] Larimer, J.~W. and Anders, E. (1967) *Geochimica et Cosmochimica Acta*, **31**, 1239-1270. [6] Tsuji, T., et al. (1997) *Astrophys. J.*, **320**, L1-L4. [7] Cushing, M. C., et al. (2008) *Astrophys. J.*, **678**, 1372. [8] Geballe, T.~R., et al. (2009) *Astrophys. J.*, **695**, 844-854. [9] Yamamura, I., Tsuji, T. and Tanabe, T. (2010) *Astrophys. J.*, **722**, 682-698. [10] Sorahana, S. and Yamamura, I. (2012) *Astrophys. J.*,**760**, 151-167. [11] Murakami, H., et al. (2007), *PASJ*, , 59, S369. [12] Tsuji T., Yamamura, I., and Sorahana, S. (2011) *Astrophys. J.*, 734, 73. [13] Sorahana, S. and Yamamura, I. (2013) submitted to *Astrophys. J.* [14] Sorahana, S., Suzuki, T. K. and Yamamura, I. (2013) submitted to *MNRAS*.