Analysis of CH_4 Q-branch absorption at 3.3μm in brown dwarf spectra with AKARI

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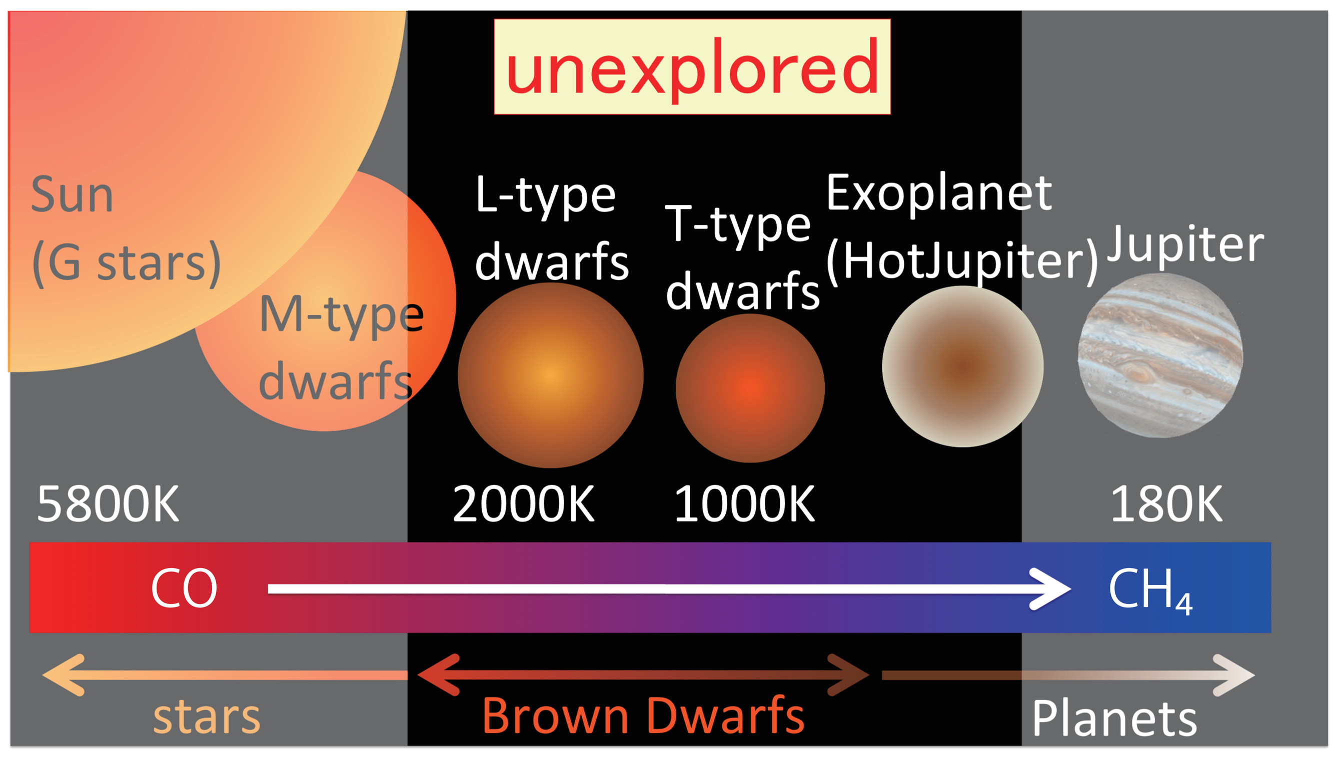
Summary. We present the result of our analysis about the appearance of 3.3 μm CH_4 band in the spectra of brown dwarfs with the Japanese infrared astronomical satellite, AKARI. We obtained good quality spectra for 13 objects that enable us to have a better understanding of the atmospheric structure and onset of the CH_4 band. We confirm that the 3.3 μm CH_4 fundamental band starts appearing at L5. The band is seen in two of four L5-dwarfs in our sample. We derive the physical parameters of the photosphere of the objects by applying the Unified Cloudy Model. We find that the abundance of CH_4 depends on the critical temperature (T_{cr}) and the surface gravity (log g) rather than the effective temperature (T_{eff}). We suspect that the two groups with/without 3.3μm CH_4 band are different in mass and age.

1 Introduction.

Brown dwarfs are too light to maintain hydrogen fusion in their cores. They **bridge** between stars and planets. Carbon in the brown dwarf atmosphere is transferred from CO to CH_4 as the temperature decreases. We can investigate how the atmosphere changes from stars to planets by CH_4 as a probe.

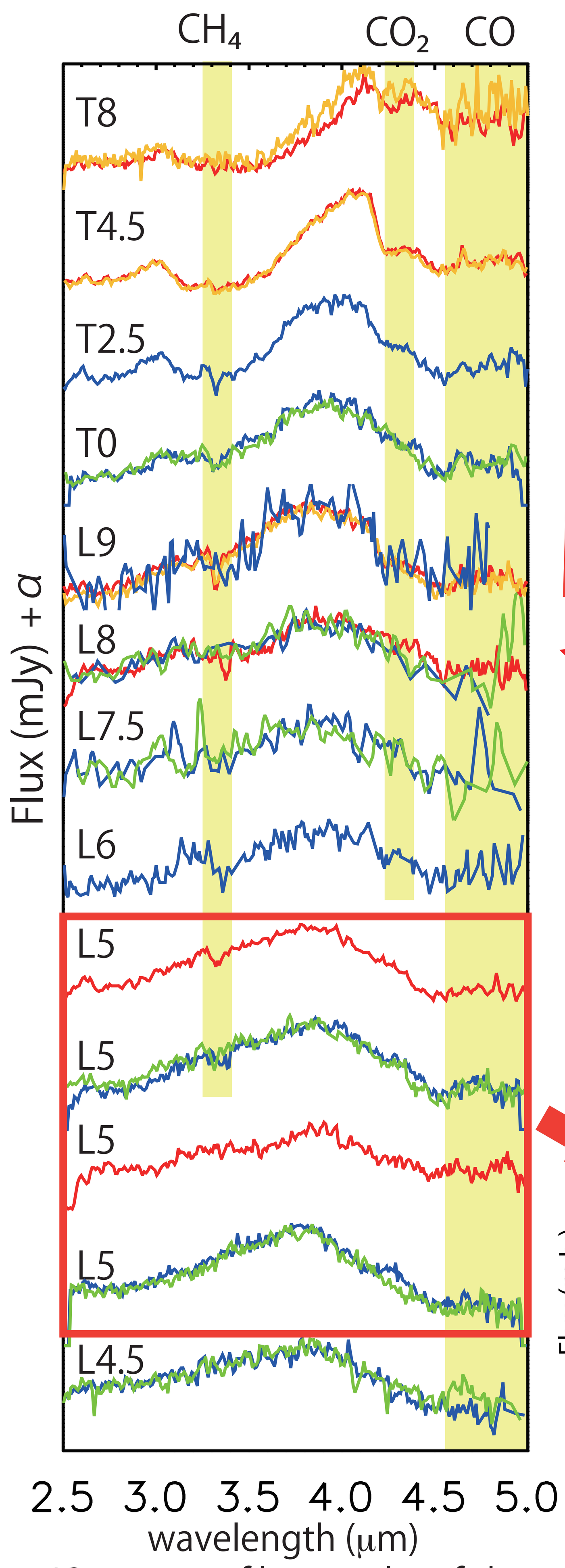
Mass	≦ 0.08M$_\odot$
T_{eff}	600-2000 K
spectral type	L T



The CH_4 bands at 1.6 and 2.2 μm have been regarded as a key indicative features for classification of T-type (i.e. cooler) brown dwarfs, while the 3.3 μm CH_4 band has been detected in the dwarfs as early as L5. This implies that **the presence of CH_4 does not simply rely on the effective temperature**, and that we need more investigation to understand how the 3.3 μm CH_4 absorption band appears in the infrared spectra of brown dwarfs.

The **AKARI** data including 3.3μm region should push forward our understanding of the CH_4 molecule behavior in the photosphere of mid to late-L dwarfs. **Our purpose of this study is, therefore, to confirm the onset of 3.3μm CH_4 band in L-type dwarfs and to discuss the relation between the spectral feature and properties of the objects.**

2 Spectroscopy by AKARI/IRC (The Japanese infrared astronomical satellite)



13 spectra of brown dwarfs by observed by AKARI/IRC

Launched in February 2006

Two instruments : IRC (1.8–26μm), FIS(50–180μm)

Observation

2006 – 2007 cold phase (with liquid He) (Phase2)

2008 – 2009 warm phase (without liquid He) (Phase3)

IRC spectroscopy

spectral resolution R ~ 120

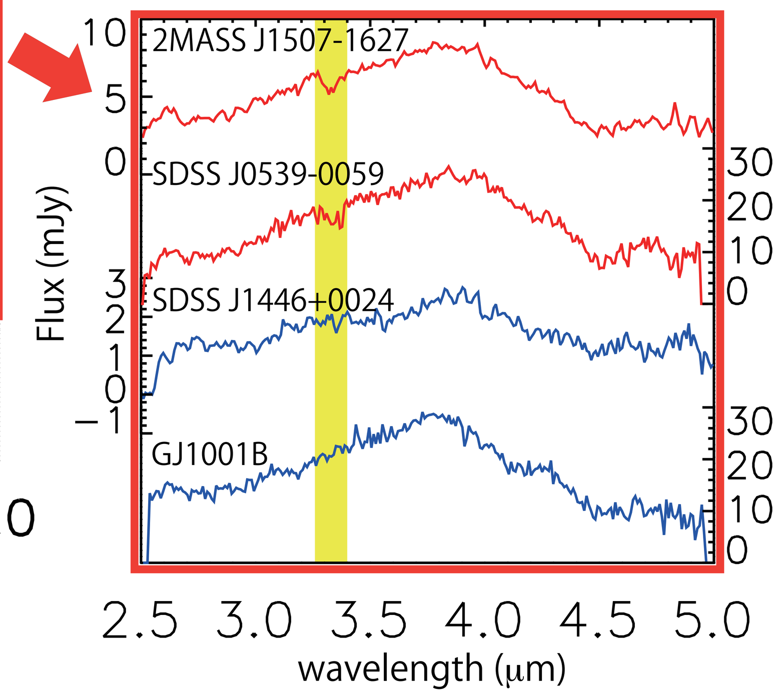
wavelength range 2.5-5.0μm

Important molecular bands (CO, CH_4 , CO_2) for investigating the atmospheres of brown dwarfs locate in this wavelength.

3 Molecular absorption bands in brown dwarfs

We investigate the onset of CH_4 band. We calculated the ratio ***EW*/Δ*EW*** between the equivalent width ***EW*** at position of the 3.3 μm CH_4 Q-branch band and the standard deviation **Δ*EW*** at nearby off-band wavelengths. We regard that the detection is significant when the *EW*/Δ*EW* is larger than 3.

Results



object	$EW/\Delta EW$
2MASS J1507–1627	3.17
SDSS J0539–0059	3.14
SDSS J1446+0024	0.77
GJ 1001b	0.73

①We find that the CH_4 3.3 μm Q-branch feature starts appearing at L5-type.

②We detect the band in only two sources out of four L5 dwarfs in our AKARI sample.

4 Comparisons of the observed and model spectra

To interpret the spectra, we apply the Unified Cloudy Model (**UCM**) by Tsuji (2002; 2005). In this model, condensation and sedimentation of dust spices are considered. The sedimentation process is parameterized by the critical temperature T_{cr} . Thus model parameters are:

chemical composition, ξ(~1km/s), T_{eff} , log g, T_{cr}

→solar metallicity (Allende Prieto et al. 2002)

Fitting evaluation

①We constrain the parameter set by using AKARI data only.

②We add the 2MASS J, H and K data to find the final solution.

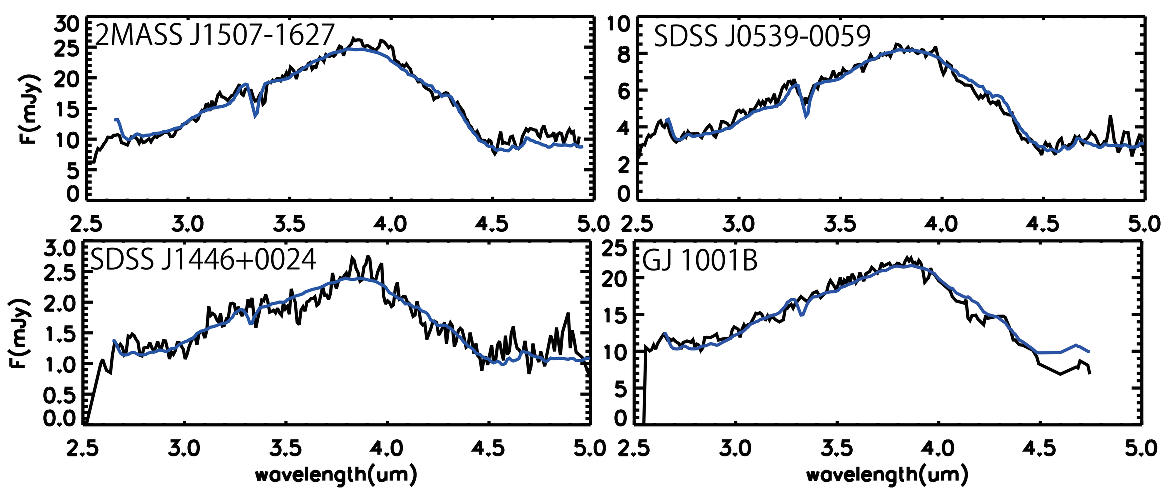
The parameter space (total 24×4×3 cases)

700≦T_{eff}≦2000 K in 100 K grid

T_{cr}=1700, 1800, 1900 K and T_{cond} (no dust layer)

log g=4.5, 5.0 and 5.5

Results



The L5 dwarfs with and without 3.3 μm CH_4 band are distinguished by the UCM parameter set (T_{eff}/log g/T_{cr}).

object name	CH_4	T_{eff}	log g	T_{cr}	C_k
2MASS J1507–1627	Y	1800	5.5	1800	1.82 ×10^7
SDSS J0539–0059	Y	1800	5.5	1800	6.48 ×10^6
SDSS J1446+0024	N	1700	4.5	1700	2.07 ×10^6
GJ 1001B	N	1700	4.5	1700	1.76 ×10^7

5 Discussion and conclusion

Generally, CH_4 band is expected to become deep as the effective temperature decreases. However, **our result is contradictory**. It is indicated that **the abundance of CH_4 molecule depends on other parameters, namely T_{cr} and log g** rather sensitively.

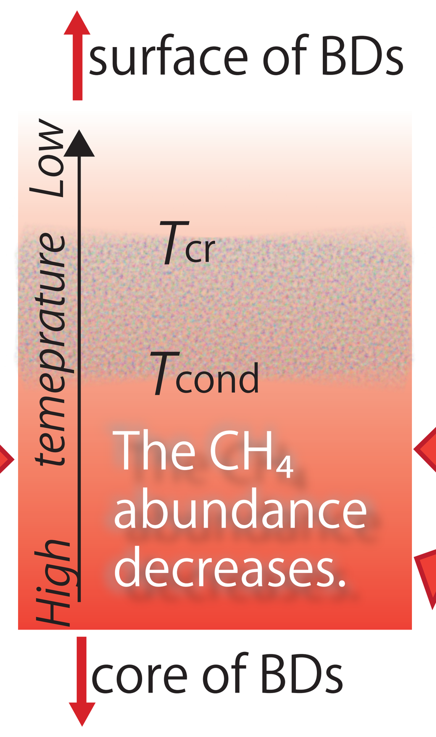
Dependence of T_{cr}

Lower T_{cr} results in the thicker dust layer.

↓

Temperature in the photosphere increases due to the green house effect

The opaque dust layer masks the CH_4 band features.



Dependence of log g

Total pressure increases as the gravity increases under the hydrostatic equilibrium

↓

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O.$$

(The CH_4 abundance is proportional to the square of total pressure)

The UCM shows that the temperature in the photosphere is higher in the small log g than large log g.

The properties of the objects

The model fits to the observed spectra on an absolute scale enable us to estimate the radii of the individual objects with the use of the known parallaxes (Vrba et al. 2004).

object name	Sp.T	radius [$R_{Jupiter}$]
SDSS J0539–0059	L5	0.804
SDSS J1446+0024	L5	0.763
2MASS J1507–1627	L5	0.764
GJ 1001B	L5	1.417

We find that the radii of the four L5 dwarfs are almost the same except for the possible binary, GJ 1001B (e.g., Leggett et al. 2002). Our result implies that **the objects with CH_4 band are more massive than the objects without the CH_4 band.** The similar radius of the different mass object may indicate that **they are different in age.**

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