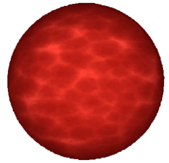
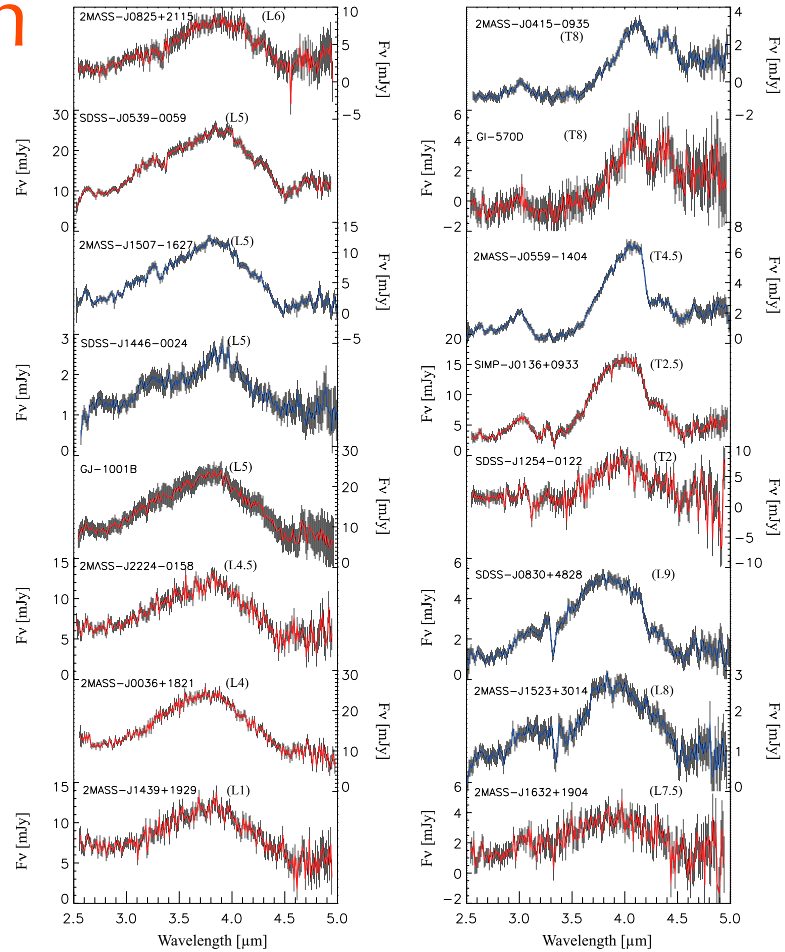


Brown Dwarf Atmospheres Revealed with 2.5 - 5.0 μm *AKARI* Spectra



Sorahana & Yamamura 2012

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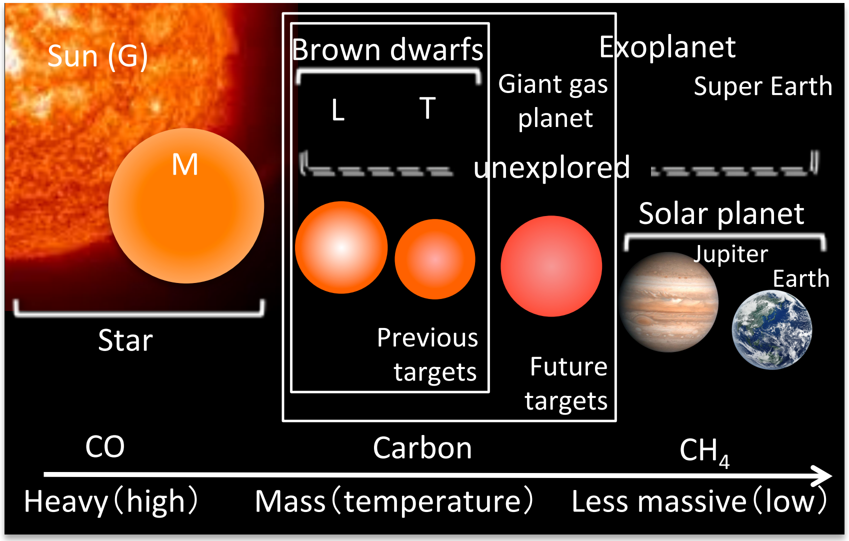
Takeru Suzuki (Nagoya Univ.)

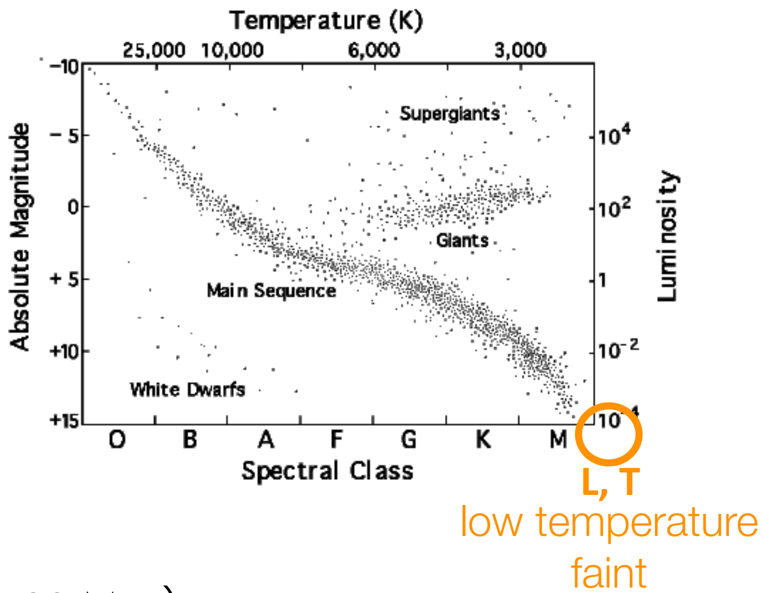
IAW2013 at ISAS

Our Motivation

- We want to know whether there is life on other planets.
- How can we explore such life?
- Molecular bands, CH_4 and CO_2, in observed spectra are important for understanding the environment of planets.
- Direct observations of exoplanets are much more difficult than those of brown dwarfs.
- Studies of brown dwarf atmospheres are a foundation for the study of exoplanet atmospheres and biology.
- I will present analyses of molecular bands in brown dwarf spectra taken by AKARI.

Introduction:
Brown Dwarfs

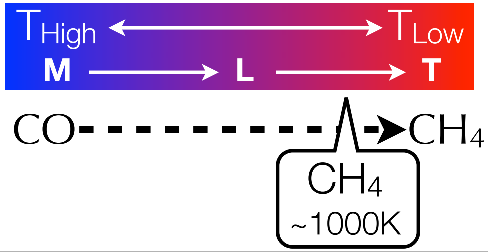


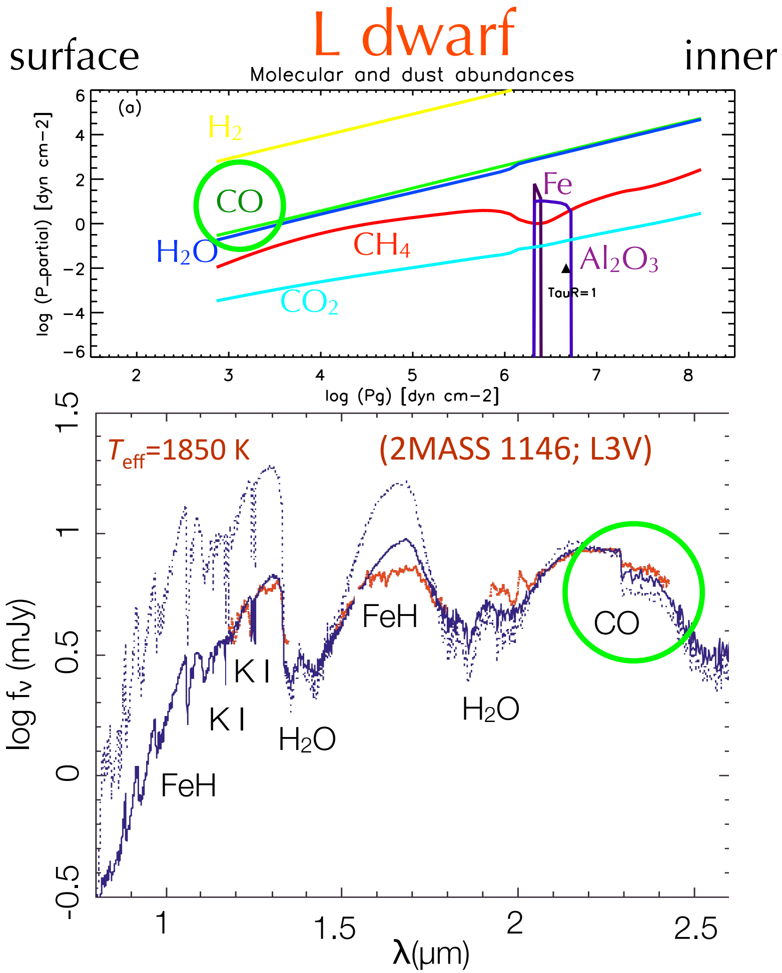


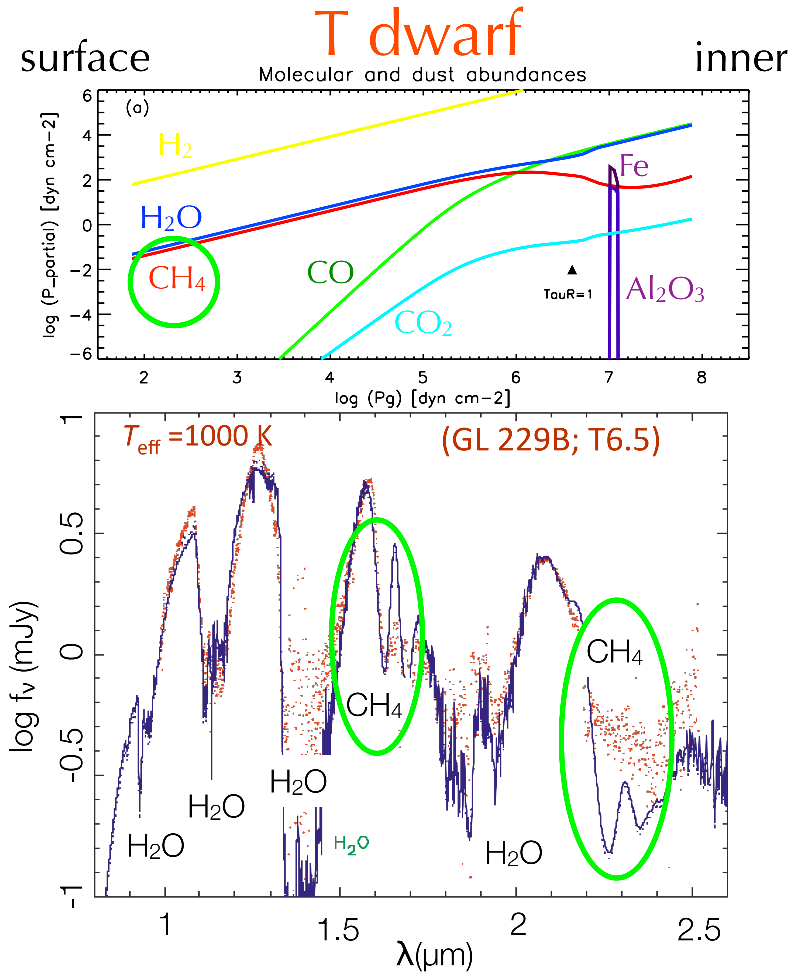
- too light to sustain hydrogen fusion （mass < 0.08 M_{sun})
- Spectral type：L, T type
  (Defined by strength of molecular absorption bands in optical and near-infrared range)
- First observation in 1995（Nakajima et al. 1995）=> not yet fully understood
- recent observations of exoplanets => discover a large variety of planets.
  => Temperature overlap between BDs and exoplanets
  => BD and exoplanet atmospheres could potentially be similar.

Introduction : Atmosphere

Molecular Atmosphere





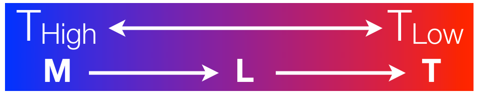


There are many molecular absorption bands.

=> They characterize brown dwarf spectra.

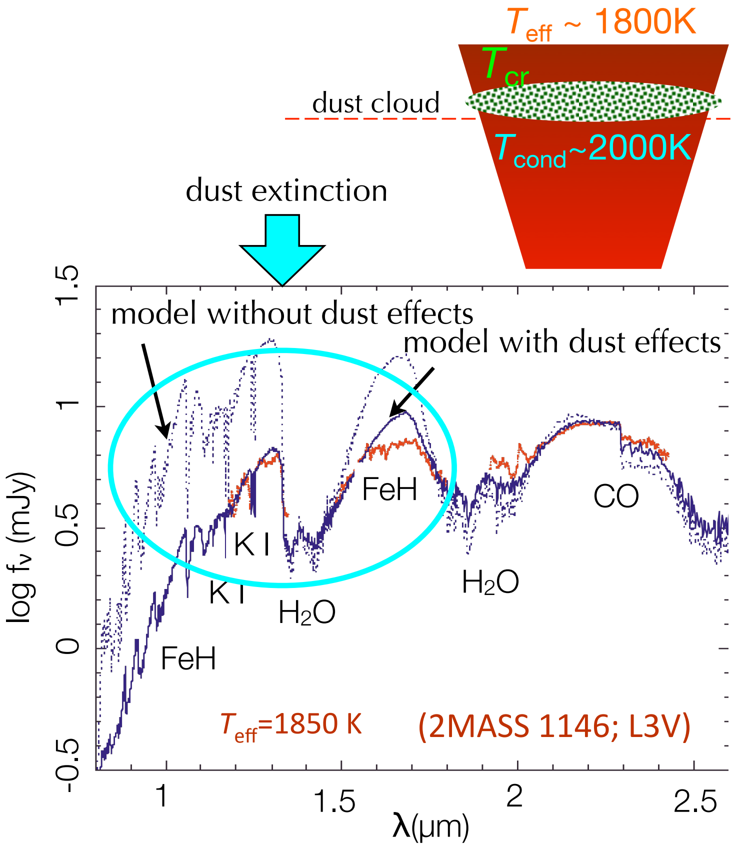
Introduction : Atmosphere

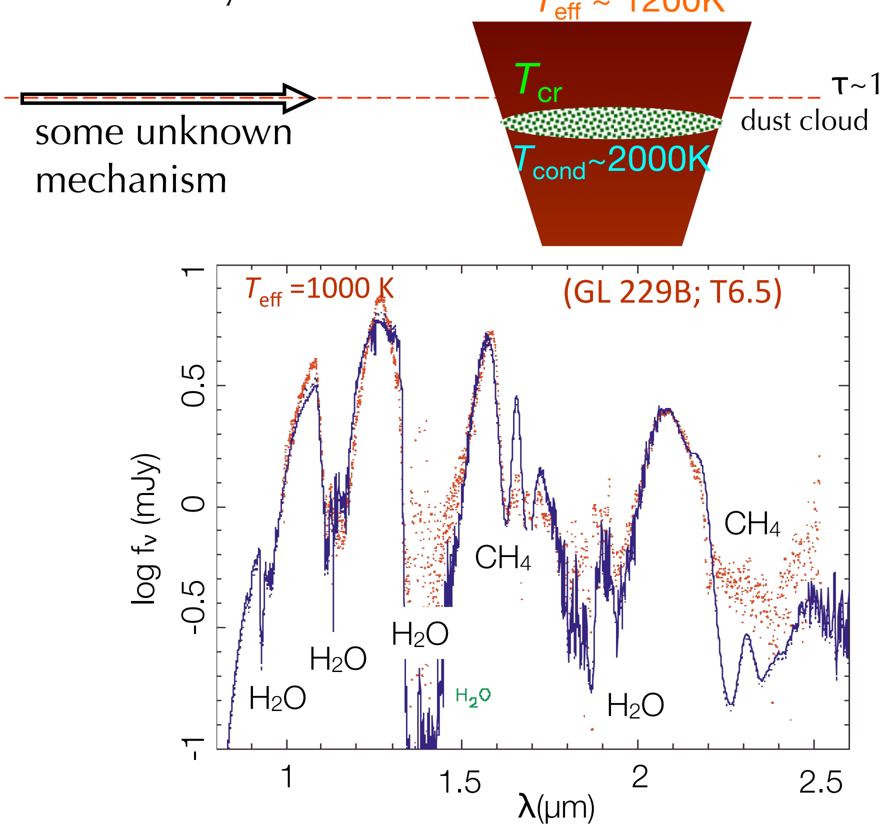
Atmosphere with dust



L type : Dust layer in upper photosphere. Dust extinction appears in the spectrum.

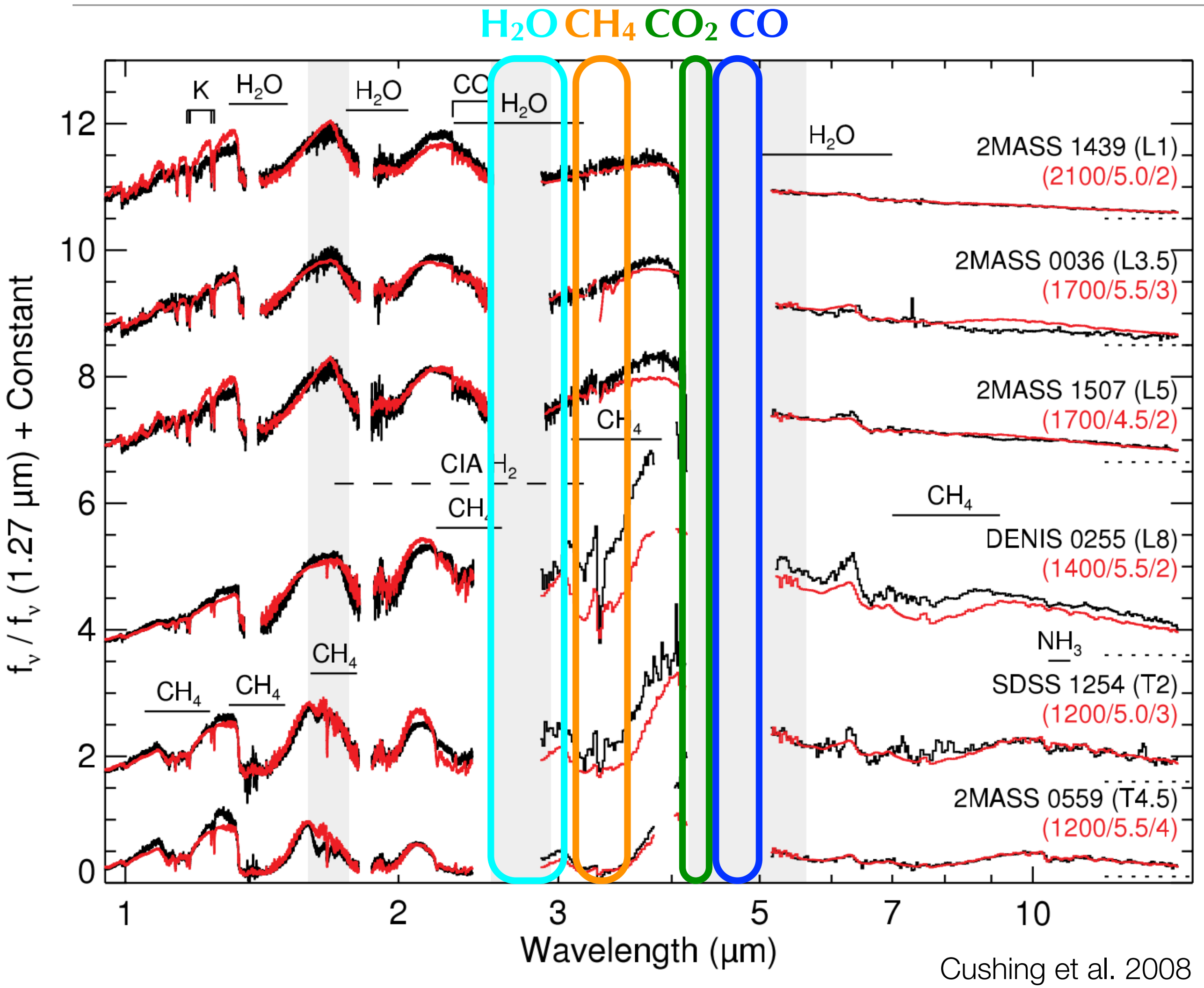
T type : Dust has little effect on the spectrum because the dust layer presents only at τ >1.





Brown dwarf atmospheres including the effects of dust are not yet understood.

Problem:
We cannot yet understand entire spectrum



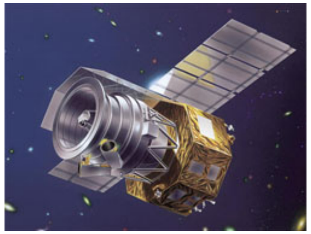
There are some deviations between models and observations.

2.5-5.0um
=> H_2O, CH_4, CO_2, CO
(fundamental bands
non-blended bands)

=> lack of data because of Earth's atmosphere.

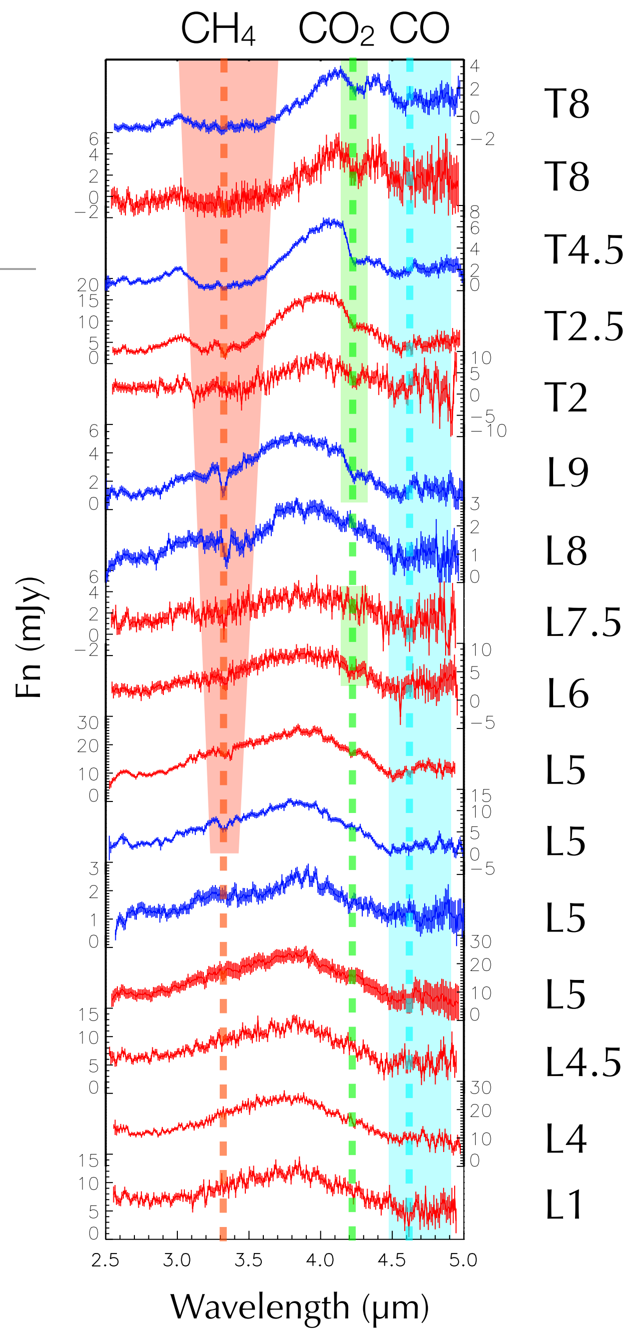
We observed 2.5-5.0 μm spectra of BDs with AKARI.

AKARI/IRC



- Launched in February 2006
- Observations continued until February 2010
- Reflecting telescope (Φ68.5cm)
- Two instruments （IRC, FIS）
  - InfraRed Camera (IRC) : 1.8 - 26 μm
    - NIR : 1.7 - 5.5 μm
    - ★ grism (R=λ／Δλ=120)
  - Wavelength range：2.5-5.0 μm

SpT.	targets	Phase2	Phase3	total	for analysis
L	17	5	10	15	11
T	14	5	6	11	5
total	31	10	16	27	16



Unified Cloudy Model (UCM, Tsuji 2002, 2005)

UCM ： B.D. atmosphere model (calculate radiative transfer based on hydrostatic equilibrium)

account for dust formation (condensation) and sublimation/sedimentation
(Fe, Mg_2SiO_3, Al_2O_3)

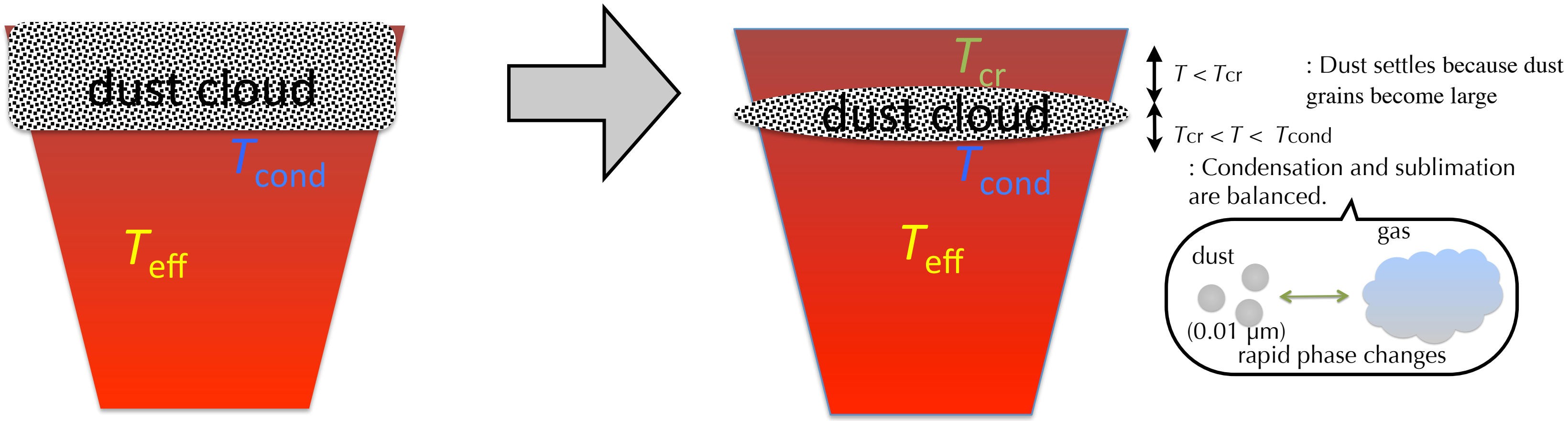
Physical parameters of model atmosphere:

- T_{eff} (700-2200K, grid=100K),
- log g (4.5, 5.0, 5.5),
- solar chemical composition,
- solar ξ_{micro} (~1km/s)

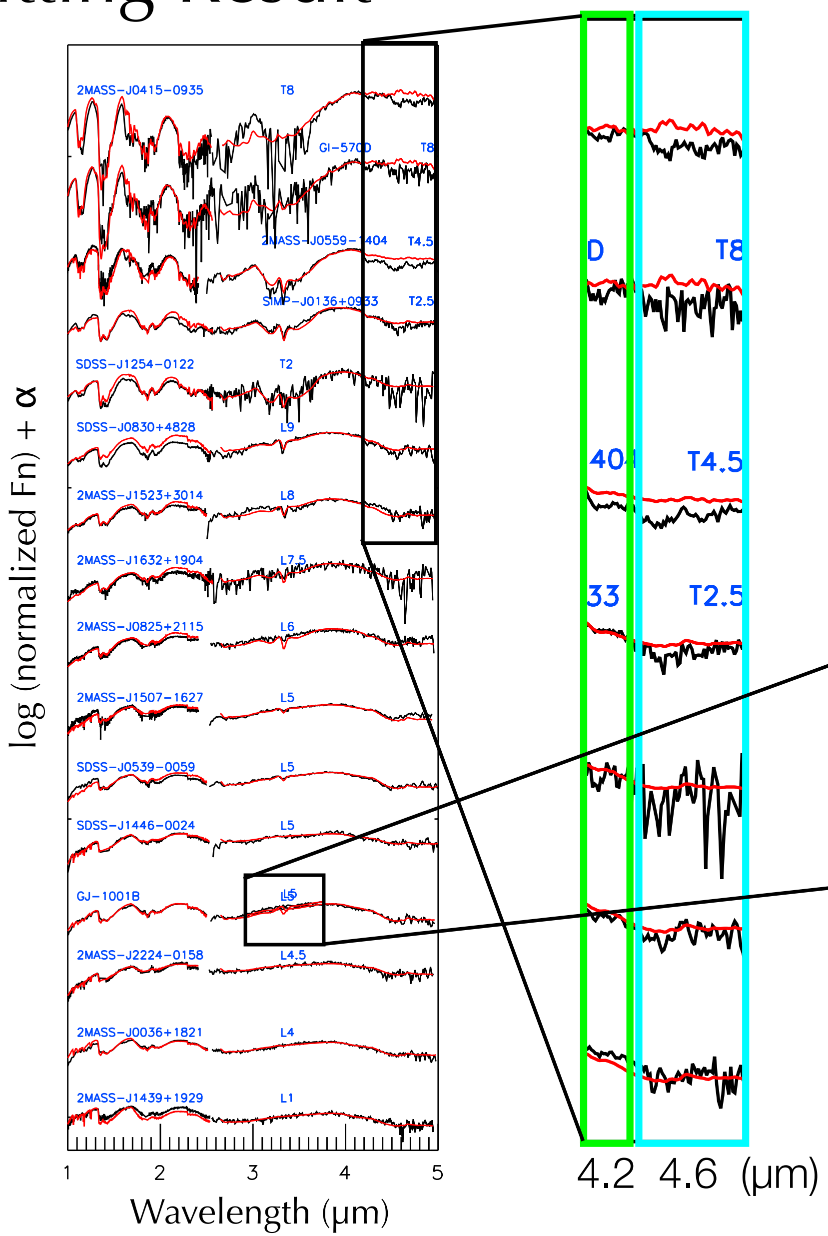
+

UCM for B.Ds

5th parameter:
T_{cr} (1700K, 1800K, 1900K, T_{cond})
(critical temperature; thickness of dust)



Fitting Result

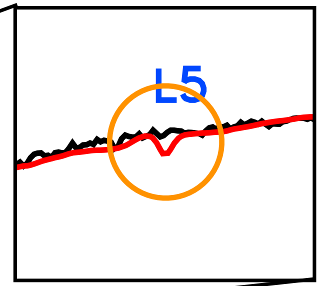


We use supplementary shorter wavelength spectra in our analysis in the model fitting.

UCM explains AKARI spectra in principle, but not the entire spectrum.

There are deviations in the CO/CO_2 bands between observations and model spectra.

There are deviations in the CH_4 band between observations and model spectra.



New approach 1: for deviations in the CO/CO_2 bands
C and O elemental abundances

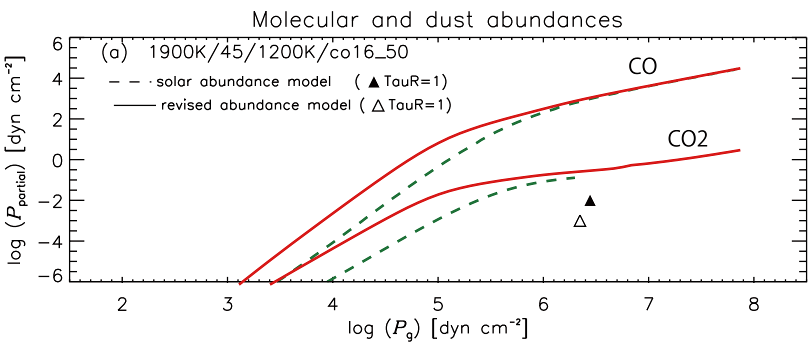
Tsuji Yamamura, Sorahana 2011
Sorahana et al., 2013 submitted to ApJ

- In our previous studies : solar metallicity (Allende et al. 2002)

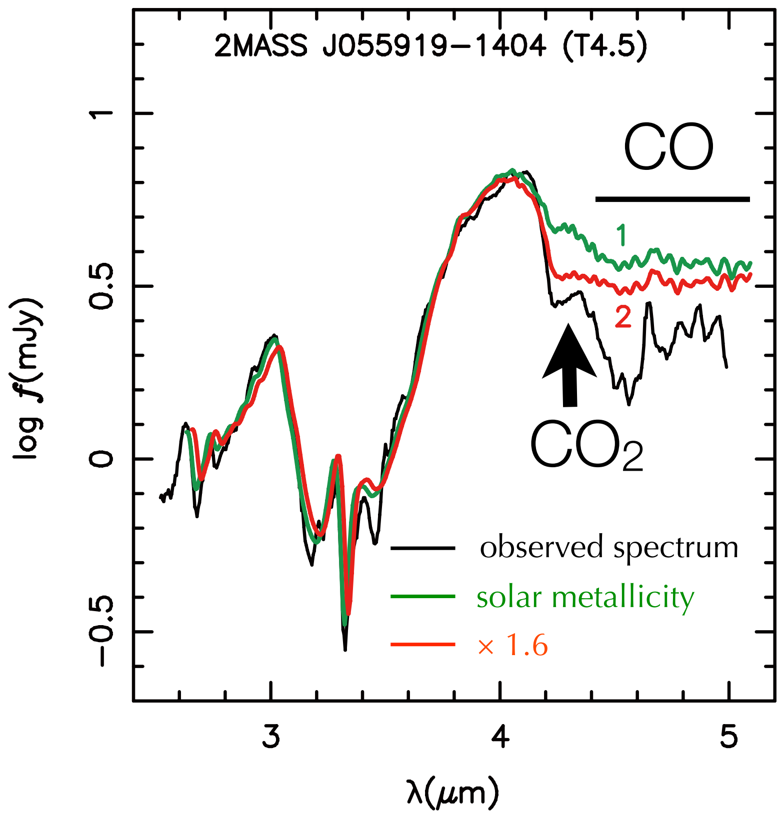
logAc = 8.39
logAo = 8.69
(solar metallicity)

C×1.6
O×1.6

logAc = 8.60
logAo = 8.92



(Tsuji, Yamamura, Sorahana 2011)



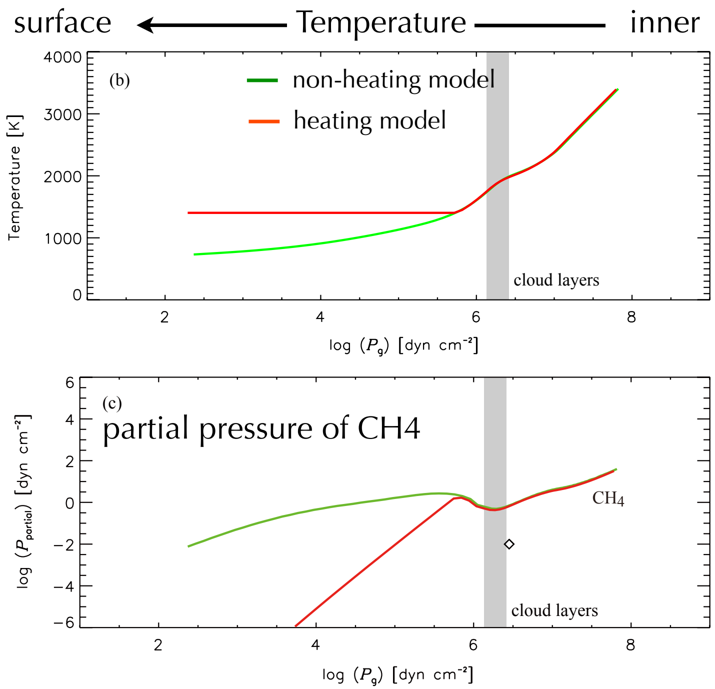
"C & O" abundances are different in each object
(Deviation of the CO abundance is future work).

=> These analyses can lead to the derivation of elemental abundances of exoplanets, which are important for understanding their origin and formation.

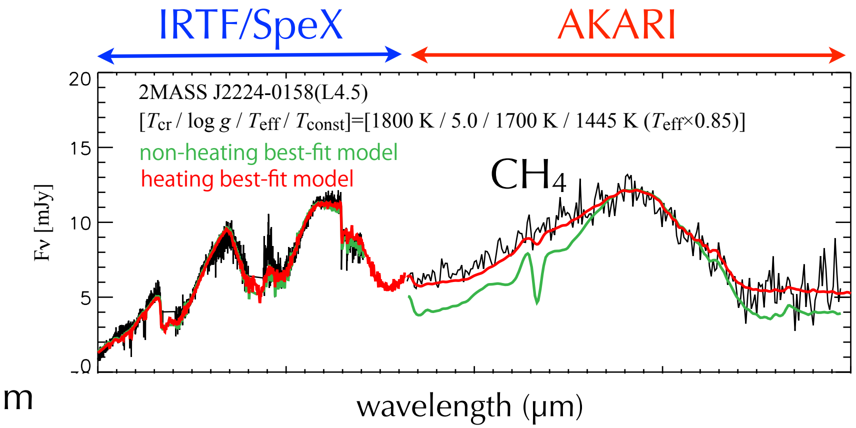
New approach 2: for deviations in CH_4 band

Signature of Chromospheric Activity

Sorahana and Suzuki 2013
submitted to MNRAS



Object Name	Sp.T	log($L_{H\alpha}/L_{bol}$)	C. activ.	Heating
2MASS J2224–0158	L4.5	-6.48	High	possible
GJ 1001B	L5	-7.42(-5.23)	High	possible
2MASS J1507–1627	L5	-8.18	Weak	impossible
2MASS J0825+2115	L6	-8.18	Weak	impossible
2MASS J1632+1904	L7.5	-6.23	High	possible



Temperature structure based on radiative equilibrium
=> monotonically decreases
New temperature structure including chromospheric activity
=> surface temperature should increase.
=> we put floor value $T(r) = \max(T(r), T_{const}) = \max(T(r), f_{const}T_{eff})$
=> CH_4 decreases.

New model fits better than previous attempts.
=> may need to consider chromospheric activity when modeling early L dwarfs or young planets

Summary of Analyses of AKARI Spectral Data

- Studies of brown dwarf atmospheres are a foundation for the study of exoplanet atmospheres and biology.
- We construct a spectral data set of brown dwarfs that continuously covers a new wavelength range, 2.5–5.0 μm.
    - We investigate CO, CH_4 and CO_2 absorption bands against spectral types.
- "C & O" abundances are different in each object.
    - These analyses can lead to the derivation of elemental abundances of exoplanets, which are important for understanding their origin and formation.
- Thus we conclude that chromospheric activity should be accounted for when modeling early L dwarfs or young planets.
    - Our result is important for investigating life on exoplanets orbiting around BDs.

Thank you very much for your attention.