

Condensate Clouds of Cool Objects

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Uniqueness of Low T Atmosphere

- Complex chemistry and molecules
- Condensation and cloud formation

Condensate species:

MgSi_3 , Mg_2Si_4 , ...

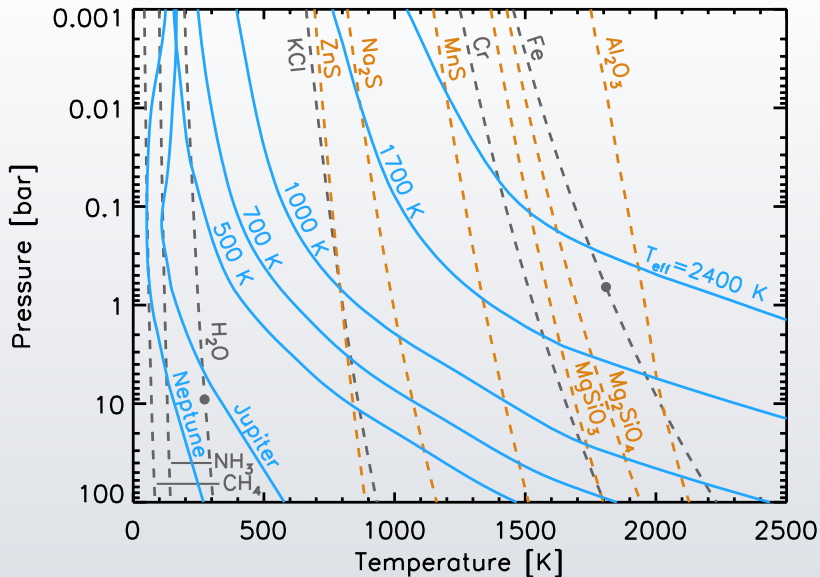
to H_2O , NH_3 ,...

Cloud Keynotes

WHAT DOES CLOUD MEAN?

- Solid/Liquid particles formed by condensation

Cloud Keynotes



Marley & Robinson 2014

SCHEME OF CONDENSATION

- A parcel of gas rises
- Partial pressure exceeds saturation vapor pressure
- Gas condenses, cloud base is determined
- Sedimentation

CLOUD OPACITY

$$\tau_{\lambda} = 75 \epsilon Q_{\lambda}^{\text{ext}}(r_c) \varphi \left(\frac{P_c}{1 \text{ bar}} \right) \left(\frac{10^5 \text{ cm s}^{-2}}{g} \right) \left(\frac{1 \text{ } \mu\text{m}}{r_c} \right) \left(\frac{1 \text{ g cm}^{-3}}{\rho_c} \right)$$

r_c – particle size

$Q_{\lambda}^{\text{ext}}(r_c)$ – extinction efficiency

Marley & Robinson (2014)

DIFFICULTIES

- Chemical equilibrium and condensation are entangled with each other
- Model the phase transition is difficult
- to calculate cloud opacity

Model Approaches

TSUJI MODEL

- Precipitation described by critical temperature T_{cr}
- Cloud thickness varies with T_{cr}

Model Approaches

ALLARD SETTL MODEL

- mixing, condensate, coagulation, and sedimentation time scales are bonded by particle size and condensate fraction
- particle size and condensate fraction are calculated to balance those time scales

Model Approaches

ACKERMAN & MARLEY

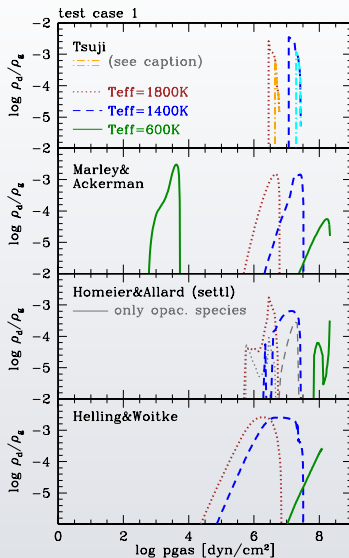
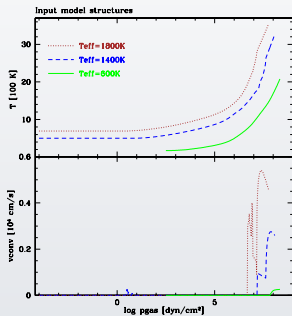
- using a scaling factor to describe the relationship of sedimentation velocity and turbulent mixing
- prescribing a particle size distribution

Model Approaches

HELLING & WOITKE

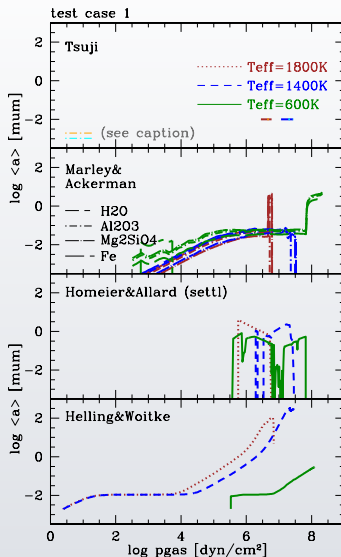
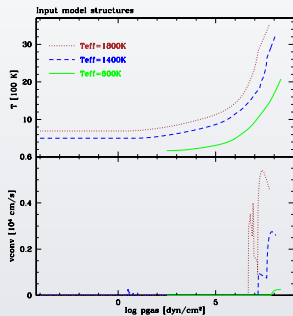
- Condensation starts with formation of seed particles
- seeds growing by gas-solid surface reaction

Comparison



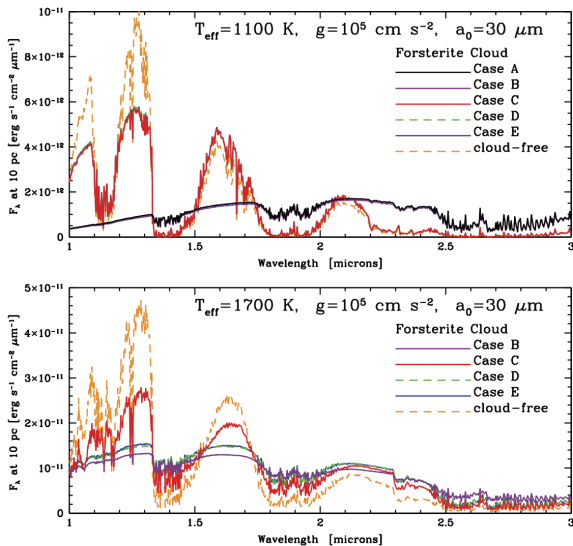
Helling et. al. (2008)

Comparison



Helling et. al. (2008)

Spectrum

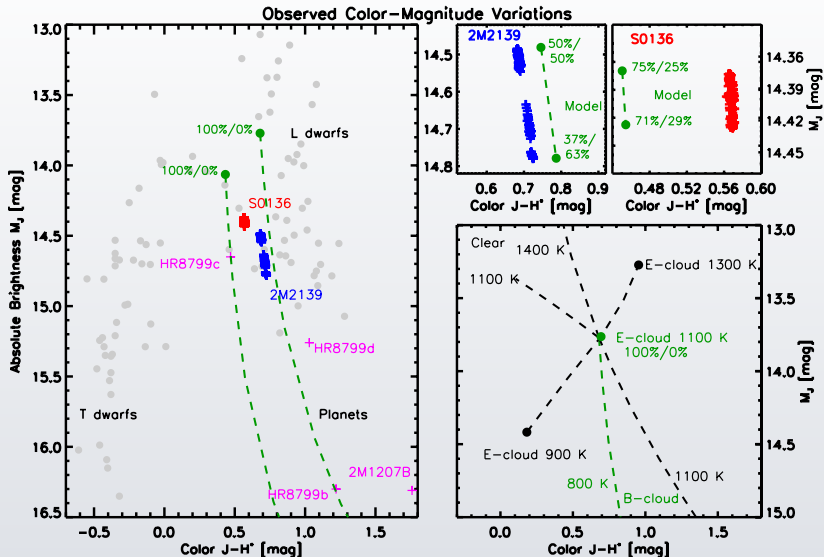


Burrows et. al. (2006)

Patchy Cloud

- Variability of brown dwarfs
- under-luminosity of direct imaged exoplanets and brown dwarfs.

Time resolved observation



Apai et. al. (2013)

