Condensate Clouds of Cool Objects

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Uniqueness of Low T Atmosphere

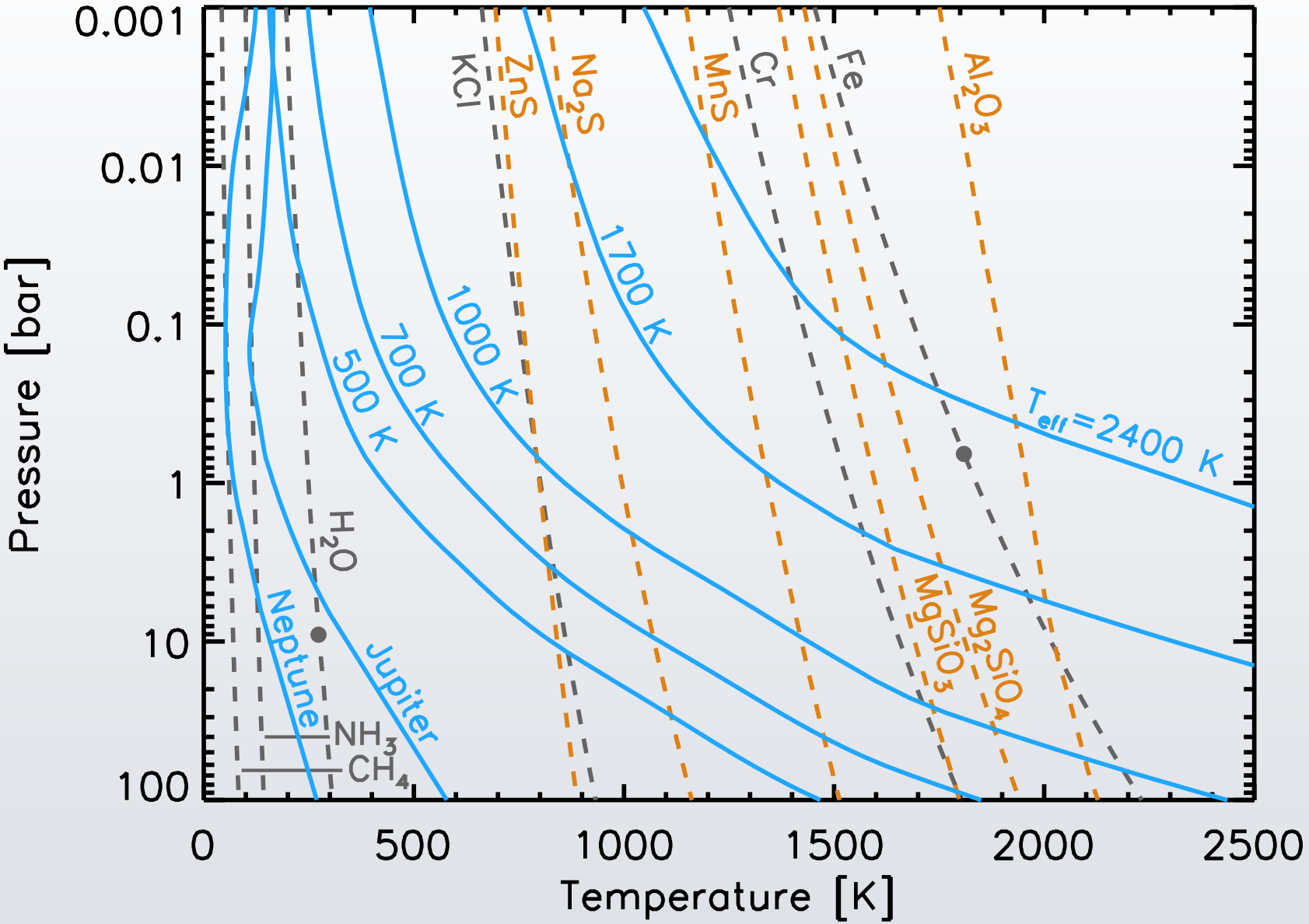
- Complex chemistry and molecules
- Condensation and cloud formation
  Condensate species:
  $MgSi_3$, Mg_2Si_4, ...
  to H_2O, NH_3,...

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
- Sentimentation

Cloud Opacity

$$\tau_\lambda = 75\epsilon Q_\lambda^{\rm ext}(r_{\rm c})\varphi\left(\frac{P_{\rm c}}{1\ {\rm bar}}\right)\left(\frac{10^5\ {\rm cm\,s^{-2}}}{g}\right)\left(\frac{1\ \mu{\rm m}}{r_{\rm c}}\right)\left(\frac{1\ {\rm g\,cm^{-3}}}{\rho_{\rm c}}\right)$$

$r_{\rm c}$ – particle size

$Q_\lambda^{\rm ext}(r_{\rm c})$ – extinction efficiency

Marley & Robinson (2014)

Cloud Keynotes

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

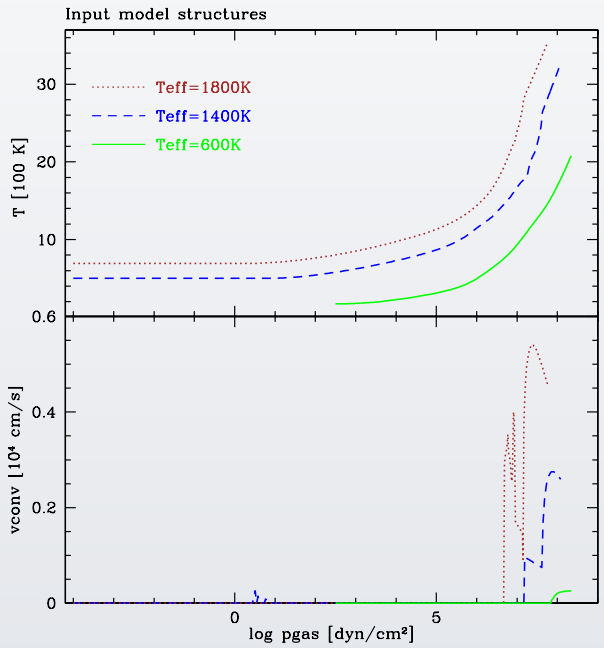
- using a scaling factor to describe the relationship of sedimentation velocity and turbulent mixing
- prescribing a particle size distribution

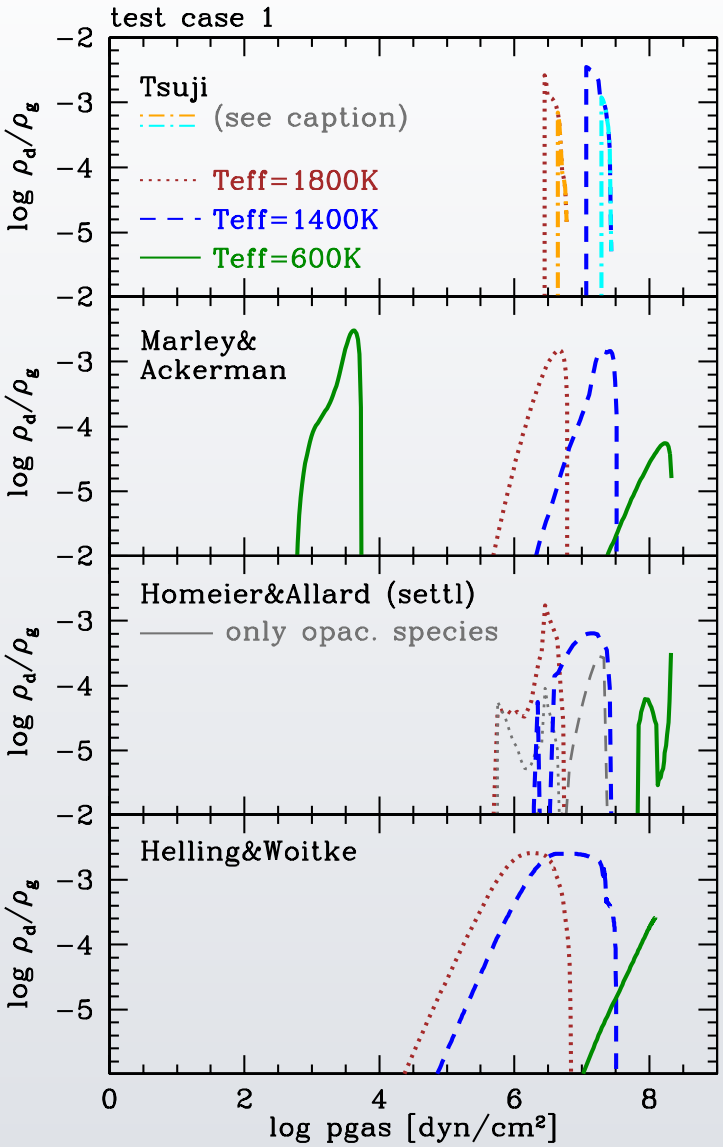
Model Approaches

Helling & Woitke

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

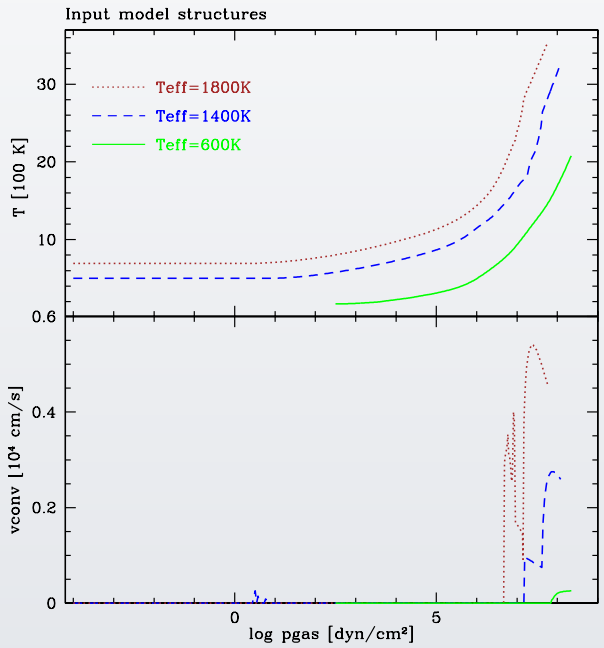
Comparison

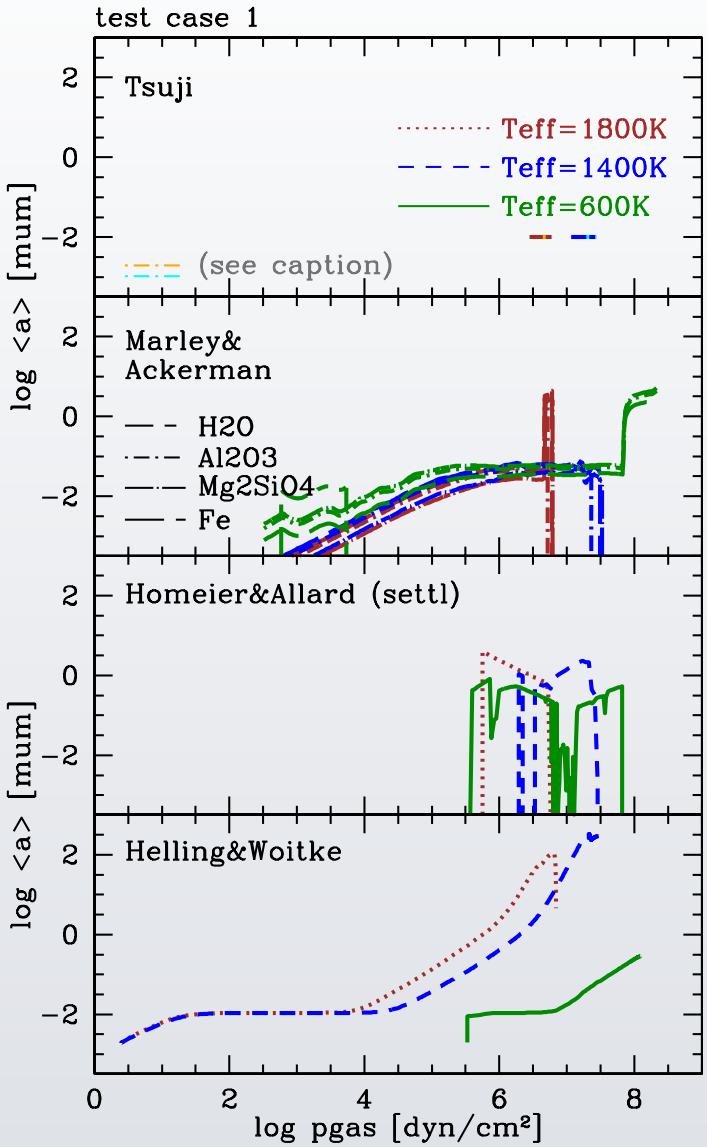




Helling et. al. (2008)

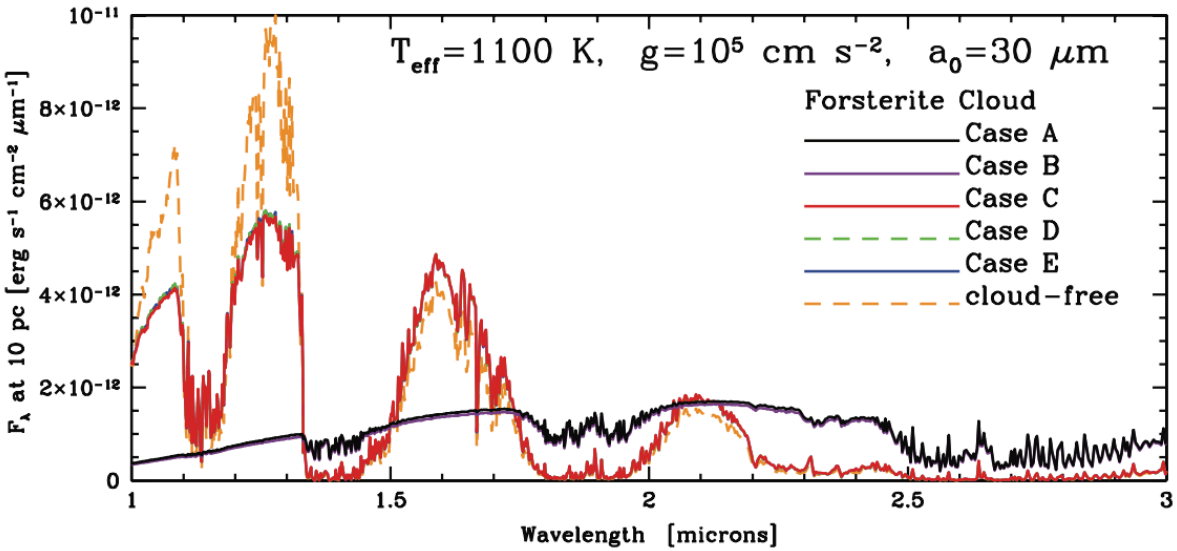
Comparison

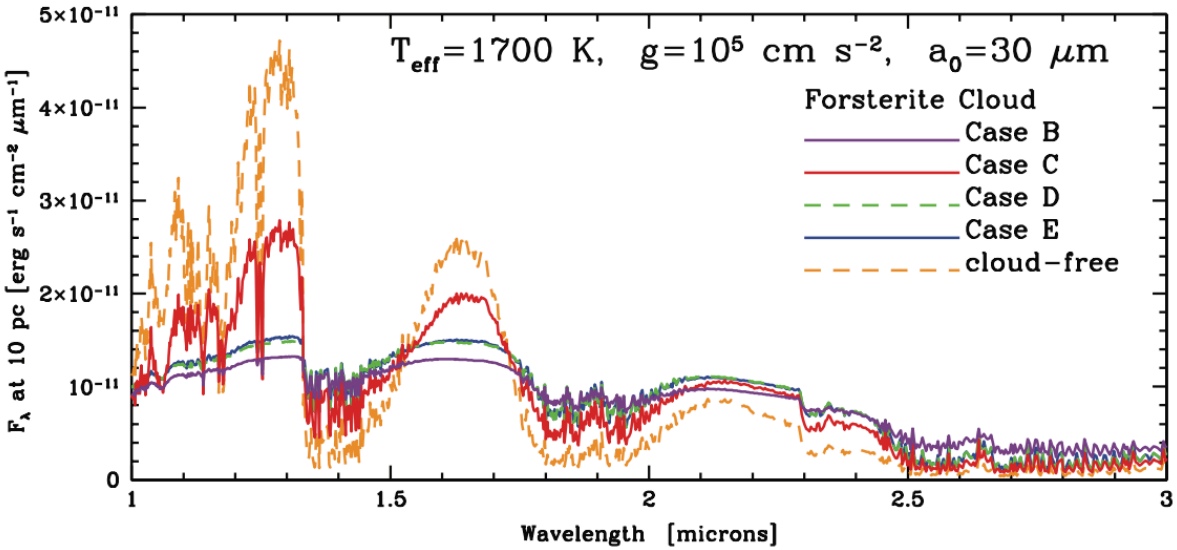




Helling et. al. (2008)

Spectrum



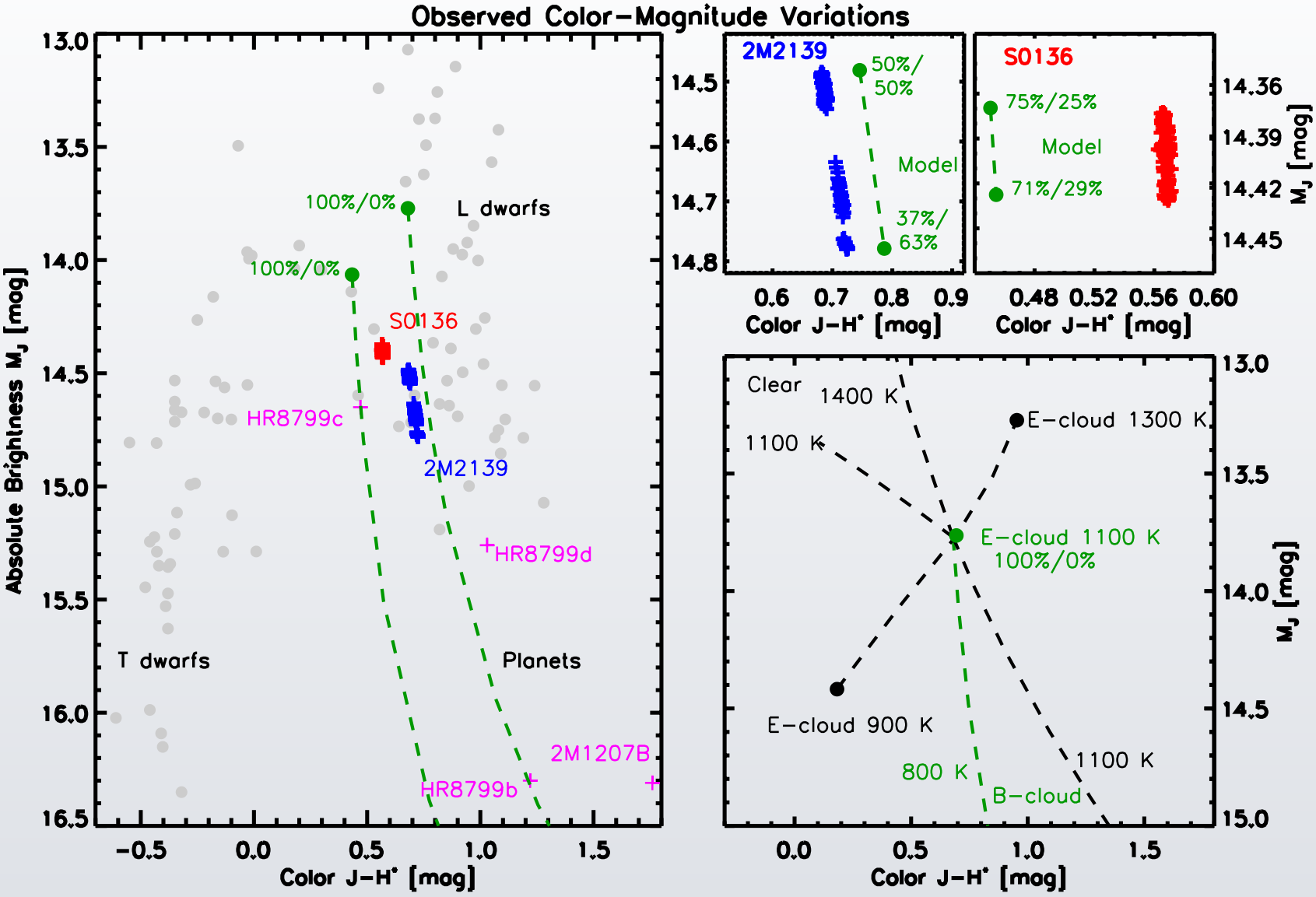


Burrows et. al. (2006)

Patchy Cloud

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

Time resolved observation



Apai et. al. (2013)