Atmospheres of Rocky Exoplanets
Stability of liquid water and cloud predictions

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NOVO Nordisk Meeting - 24.07.2020

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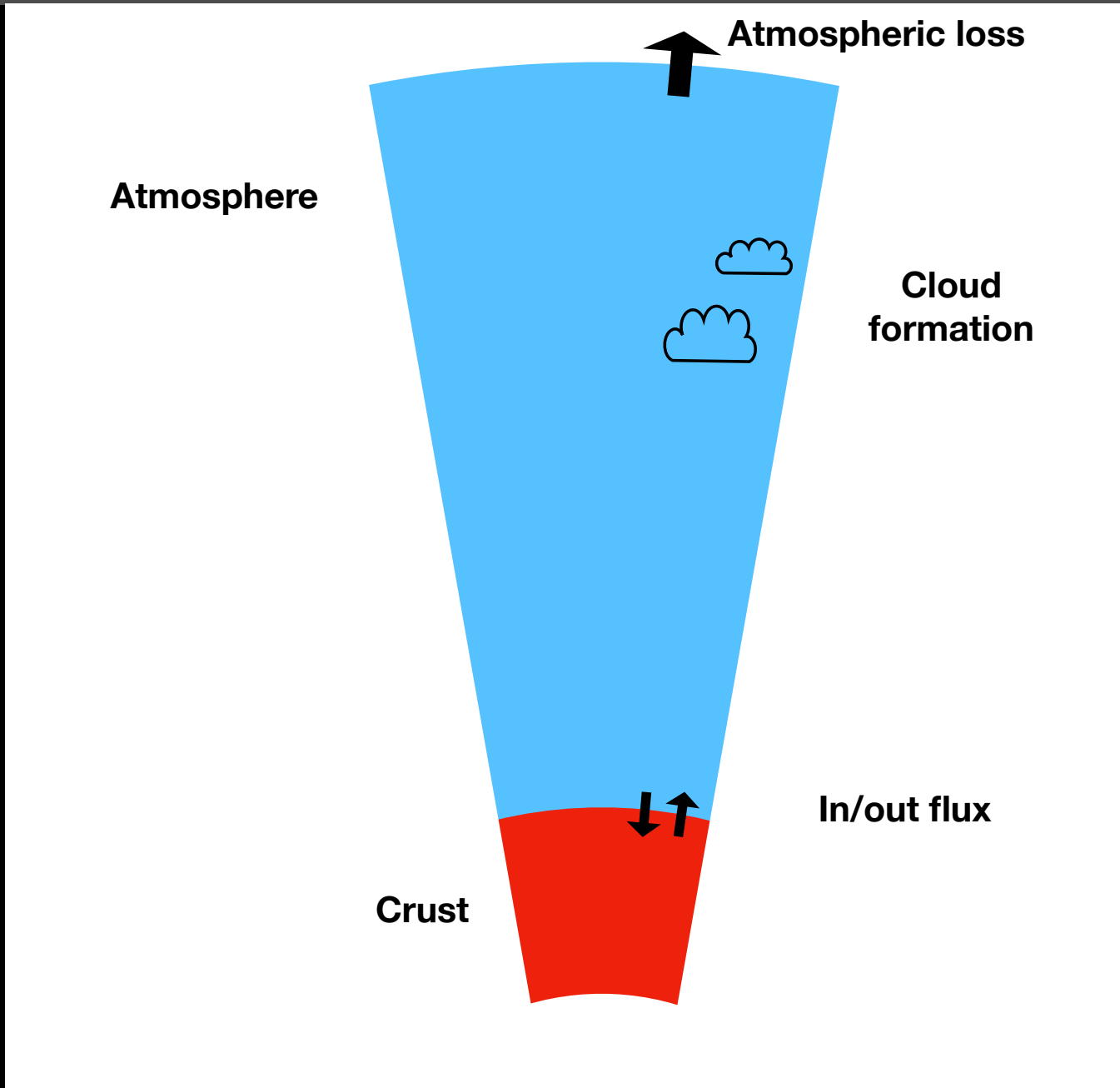
Contact layer between atmosphere and crust

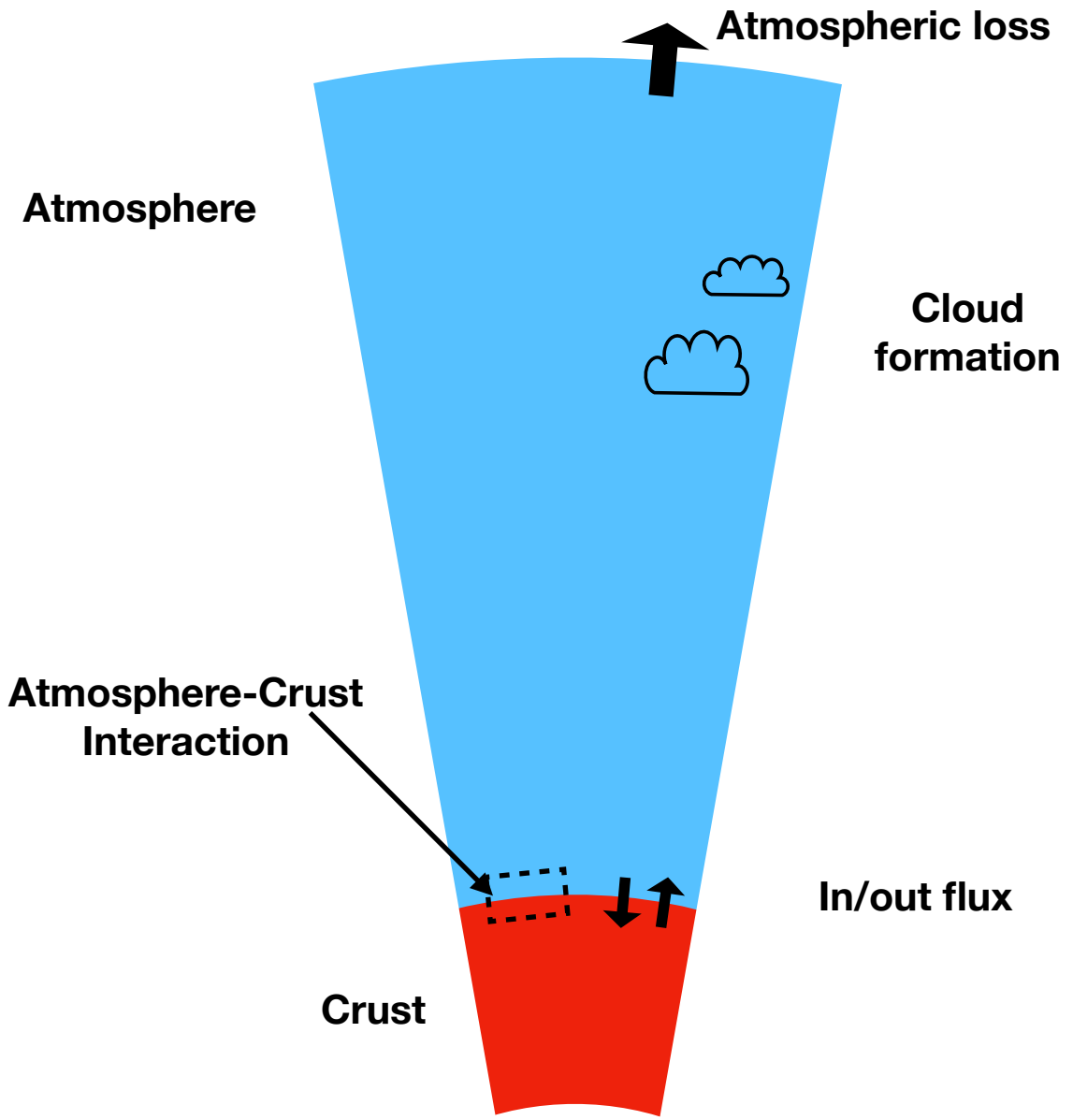
Rocky exoplanet



Contact layer between atmosphere and crust

Rocky exoplanet

Provide insight to: surface conditions preconditions for cloud formation



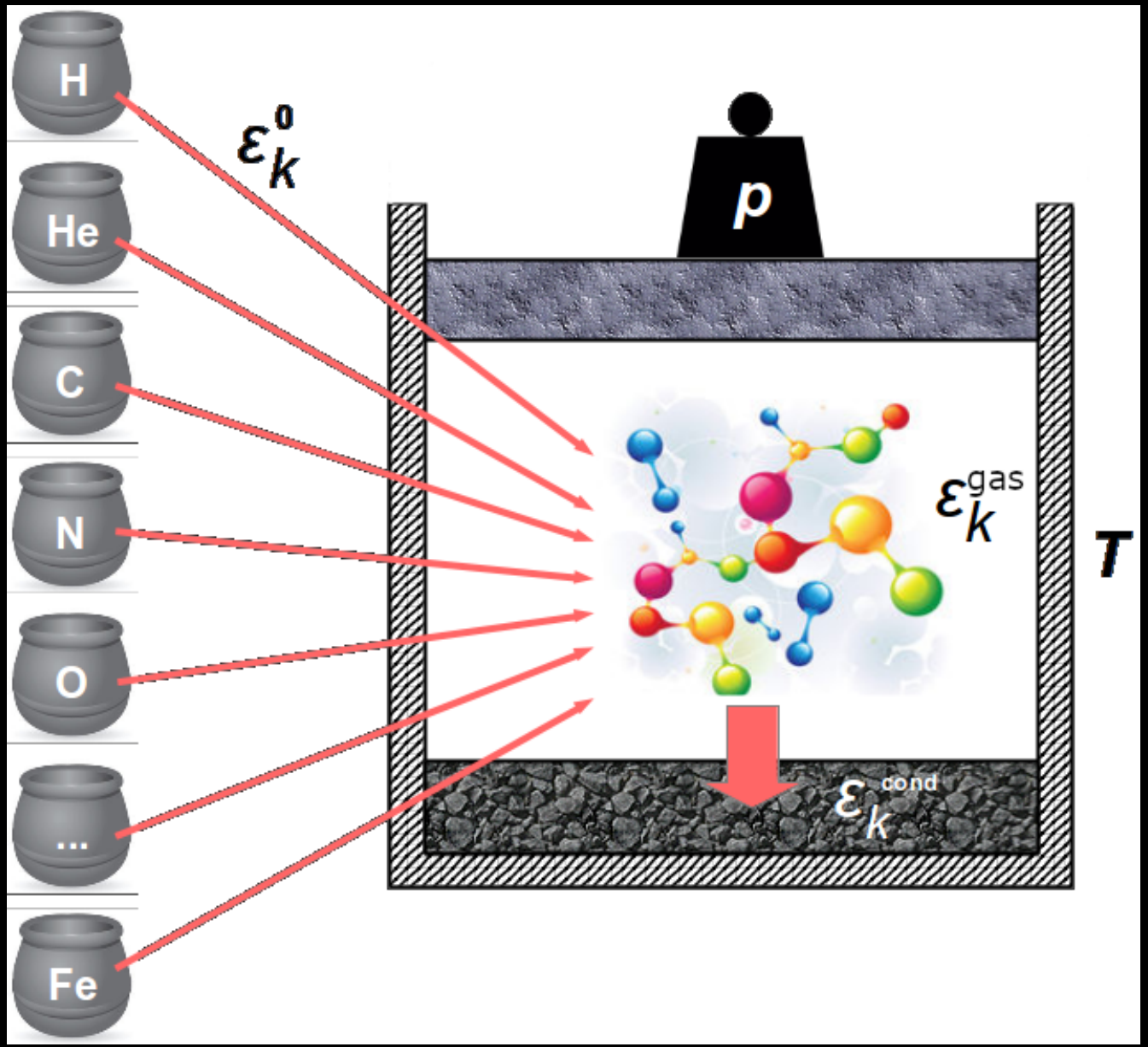
Equilibrium condensation model

GGCHEM
Woitke et al. (2018)

minimisation of
Gibbs free energy

condensation if
saturated, i.e. $S = 1$

$\epsilon_k^0 = \epsilon_k^{\rm gas} + \epsilon_k^{\rm cond}$



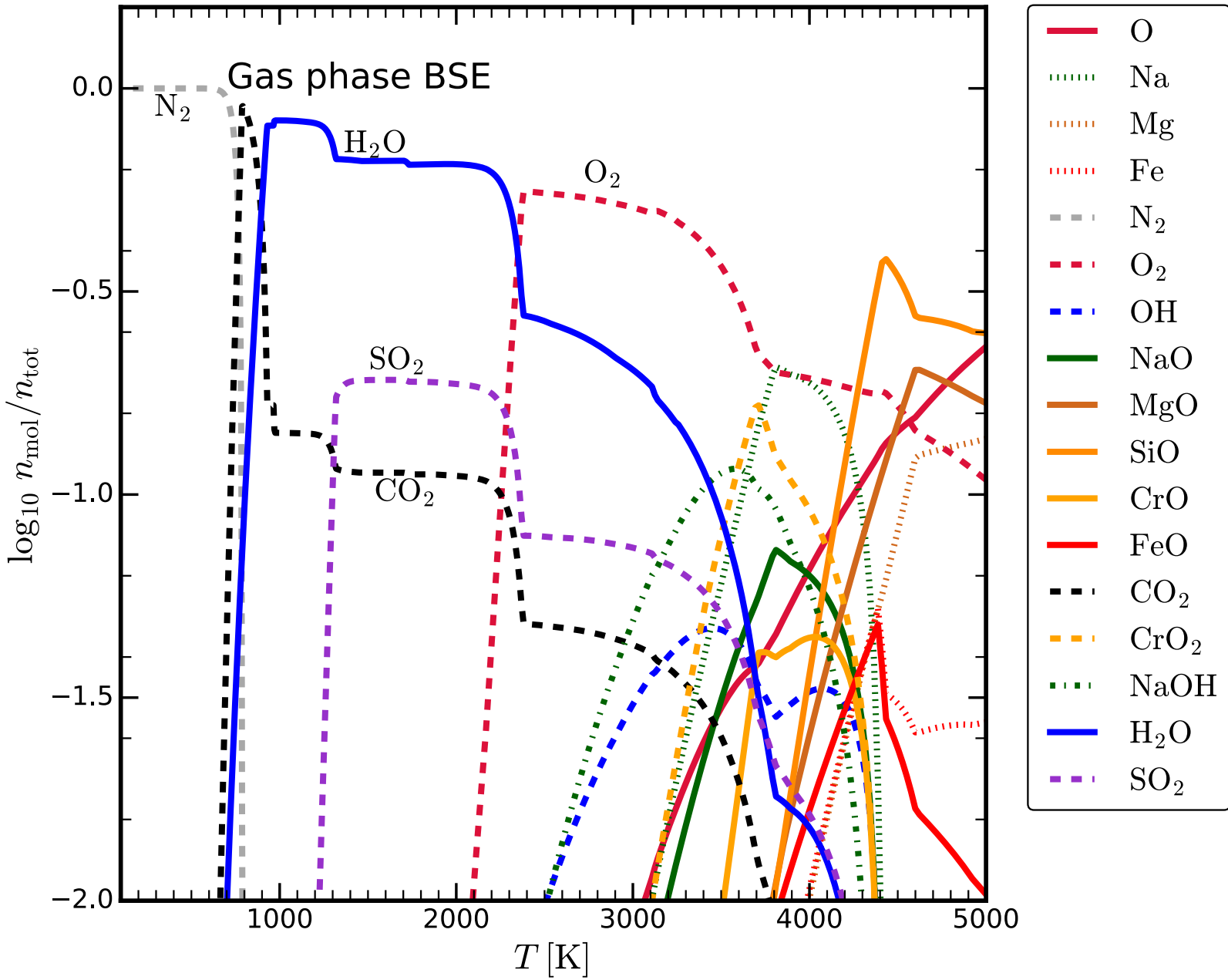
Near crust atmospheric composition

Element abundance: Bulk Silicate Earth

(Schaefer et al., 2012)

Pressure: 100 bar

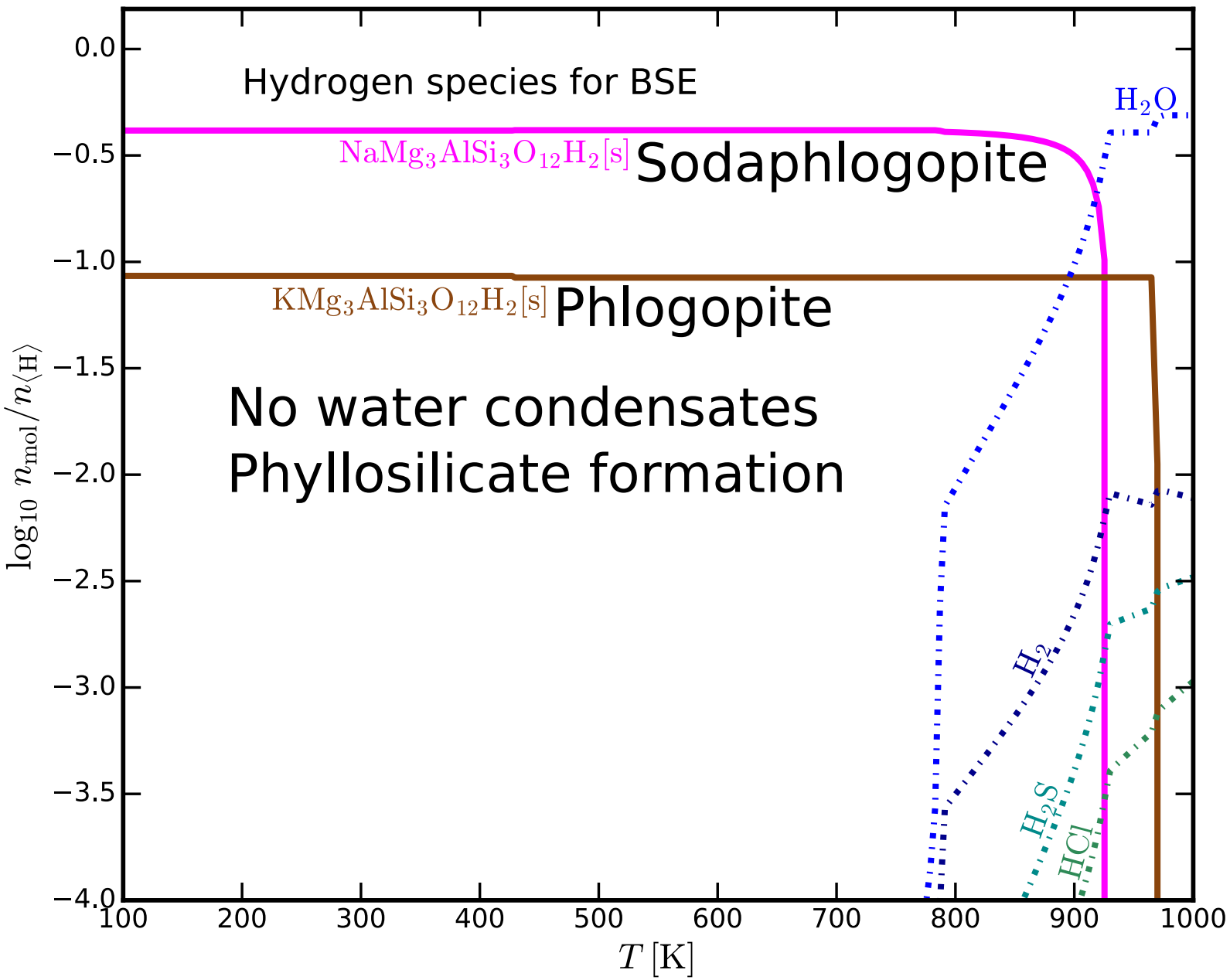
Herbort et al. (2020)



Where is the water?

Only phyllosilicates for $T \lesssim 750\,\mathrm{K}$

Herbort et al. (2020)

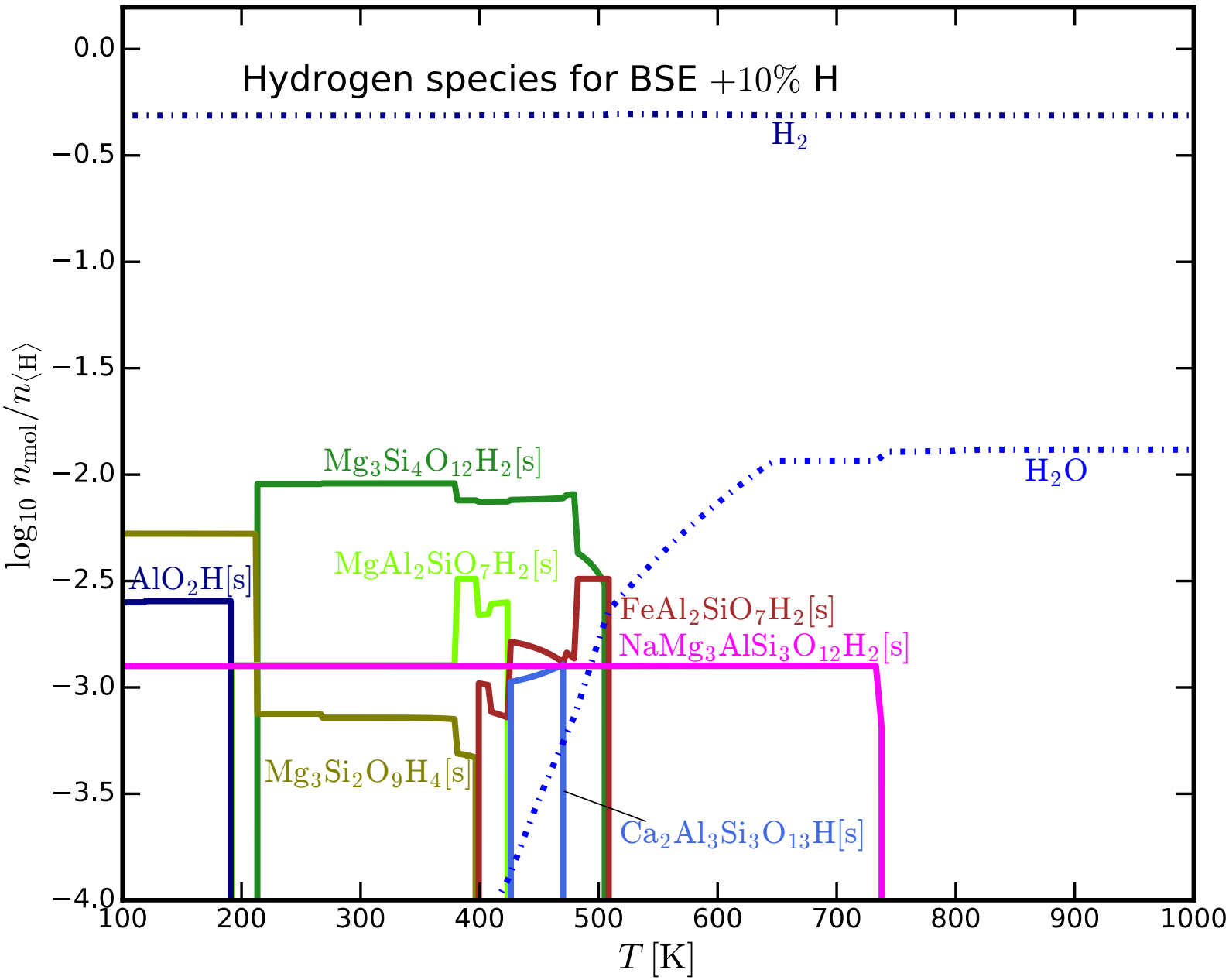


What do we need to form water?

Element abundance: BSE + H

Various phyllosilicates & H_2[g]

Herbort et al. (2020)

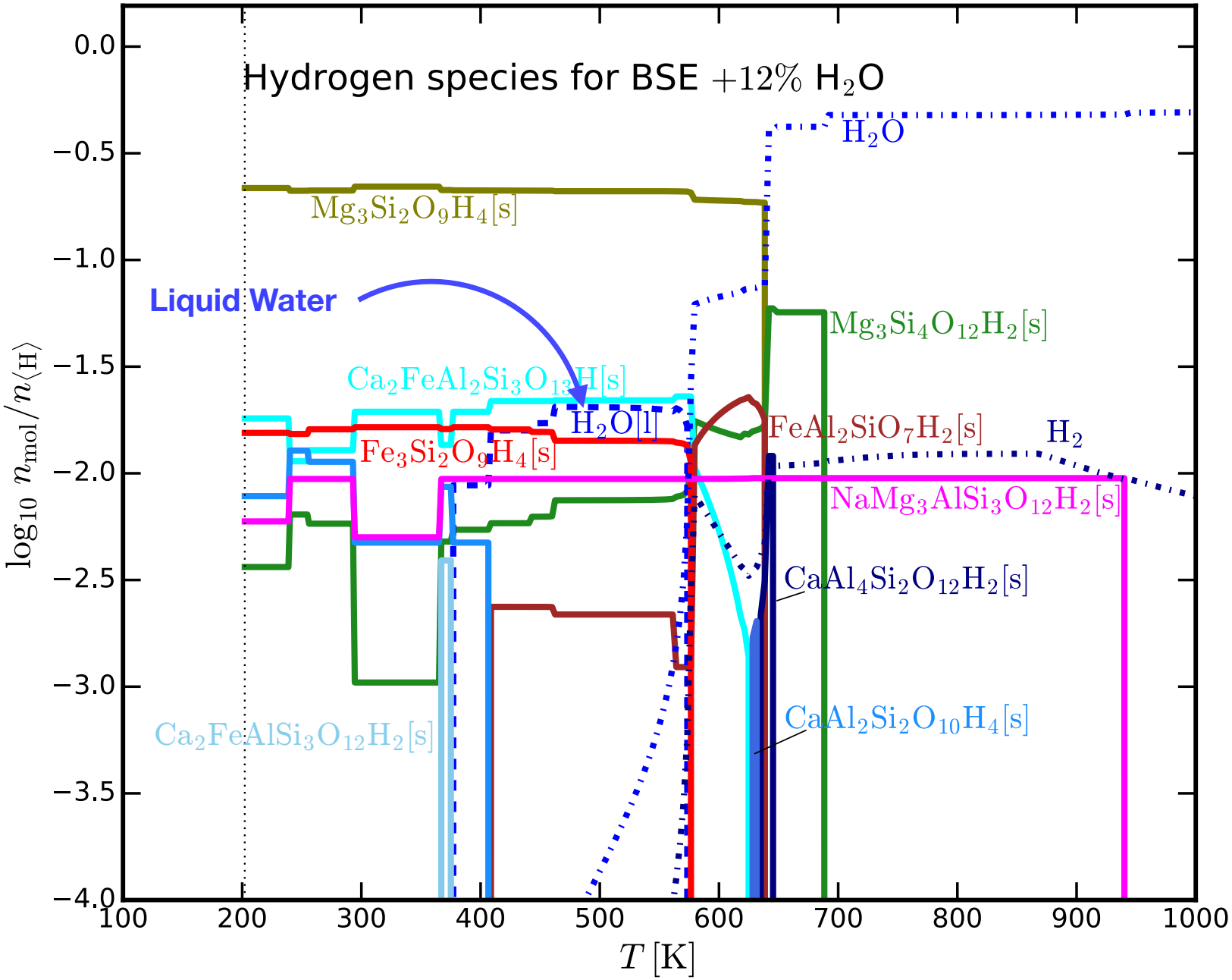


What do we need to form water?

Element abundance: BSE + H & O

Various phyllosilicates & H_2O[l]

Herbort et al. (2020)

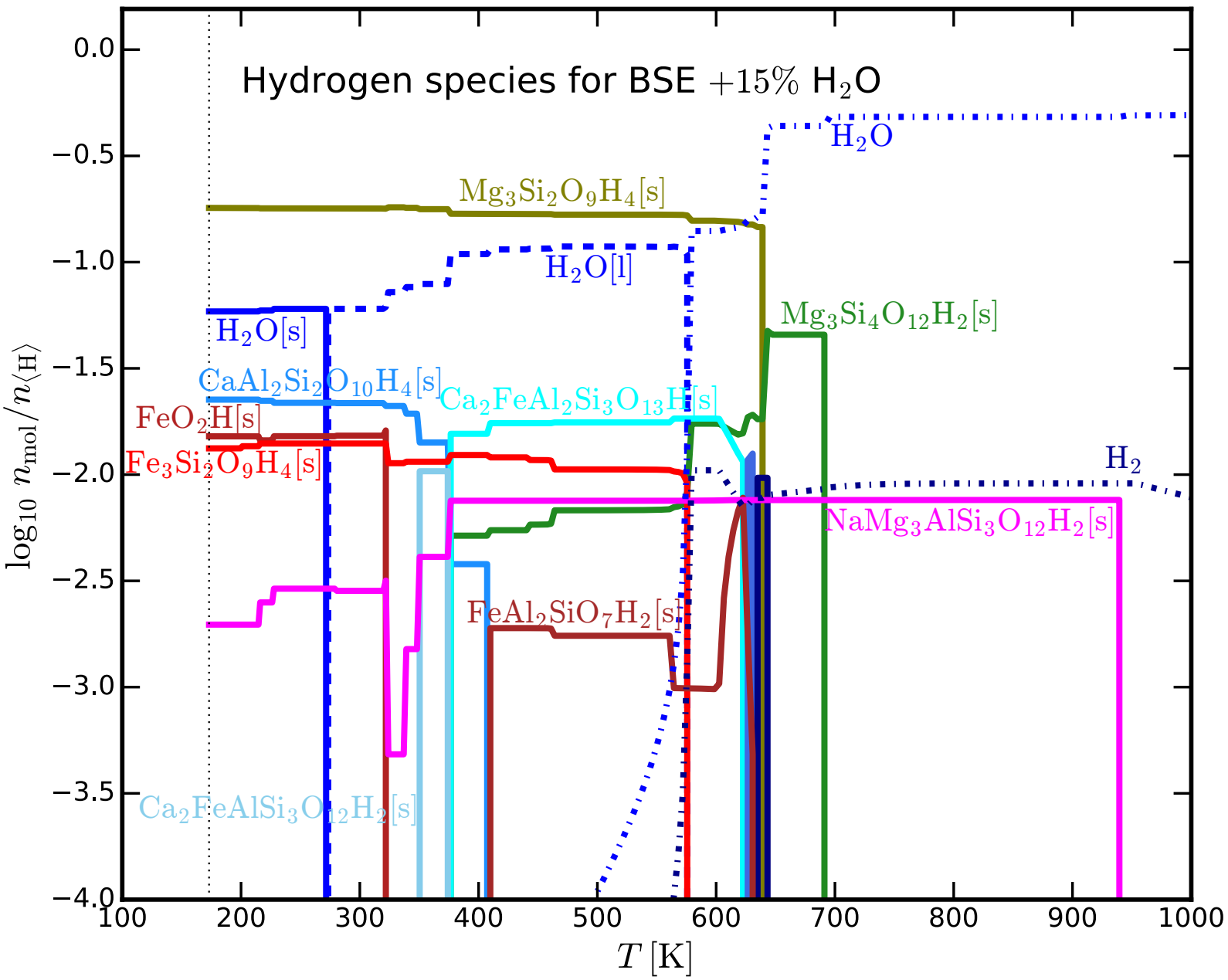


What do we need to form water?

Element abundance: BSE + more H & O

Various phyllosilicates & H_2O[l], H_2O[s]

Herbort et al. (2020)

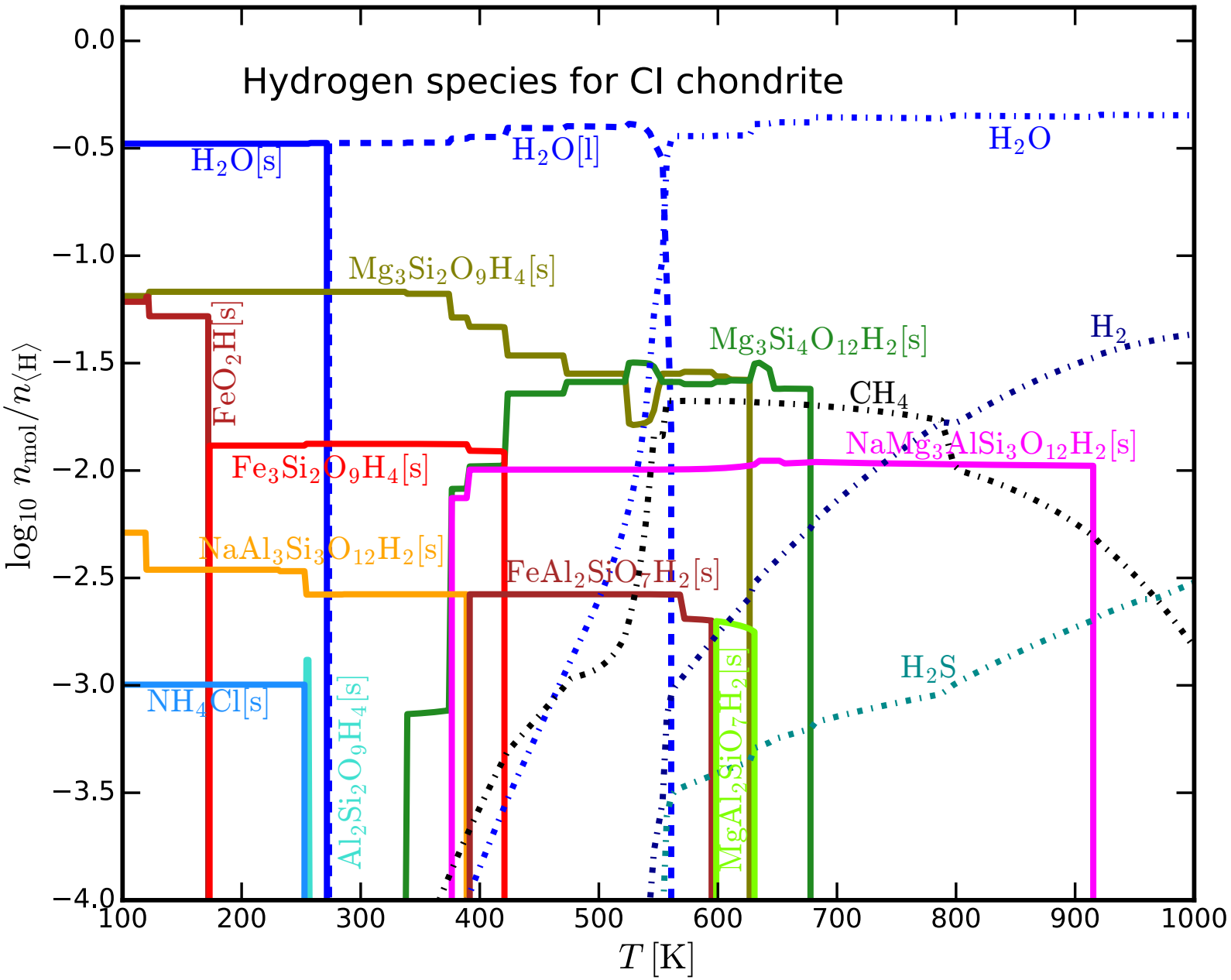


Natural rock resulting in water condensates

Element abundance: CI chondrite

(Lodders et al., 2009)

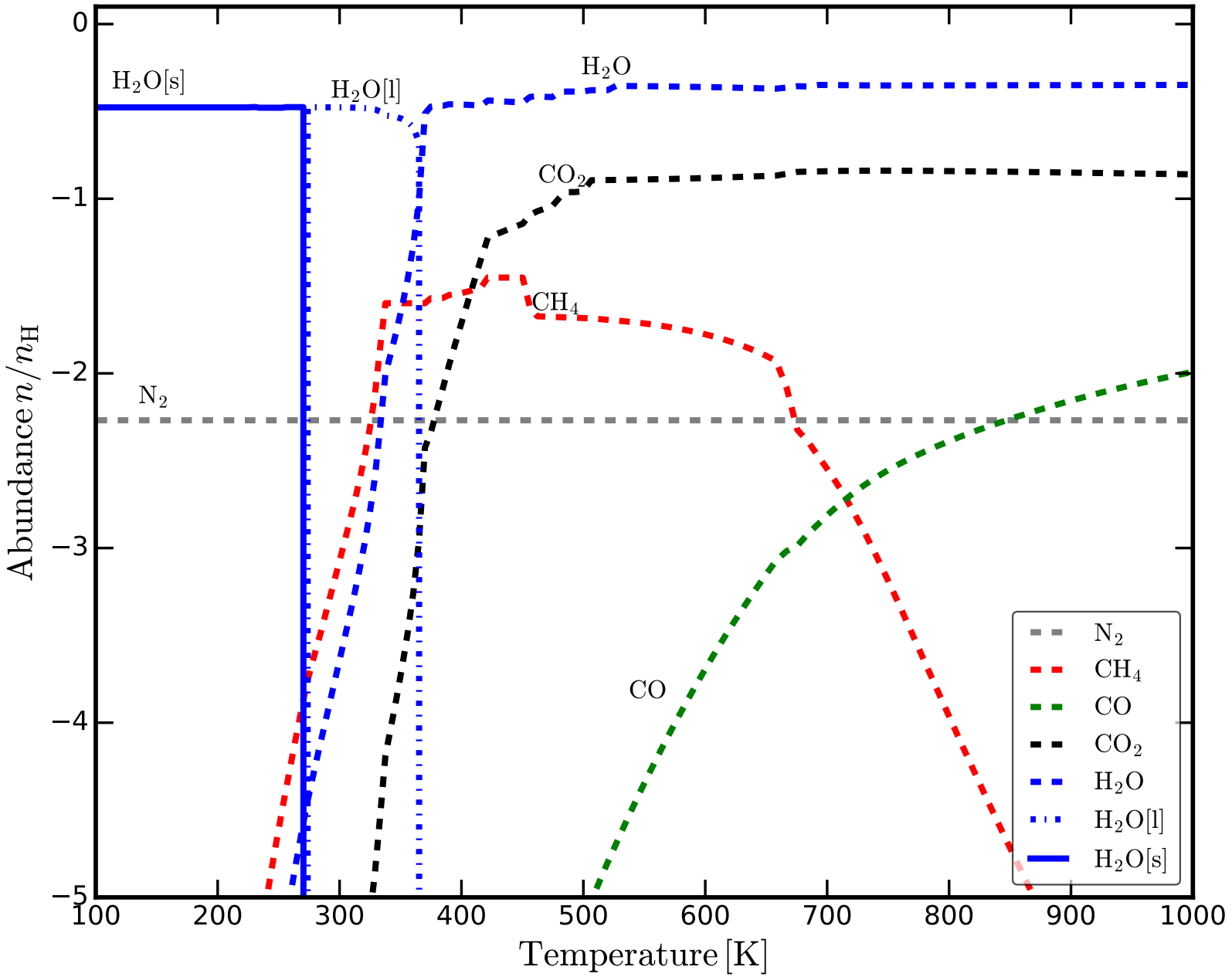
100 bar



Signatures of biology

Relevant species
CI chondrite
1 bar

CH_4 & CO_2 coexisting

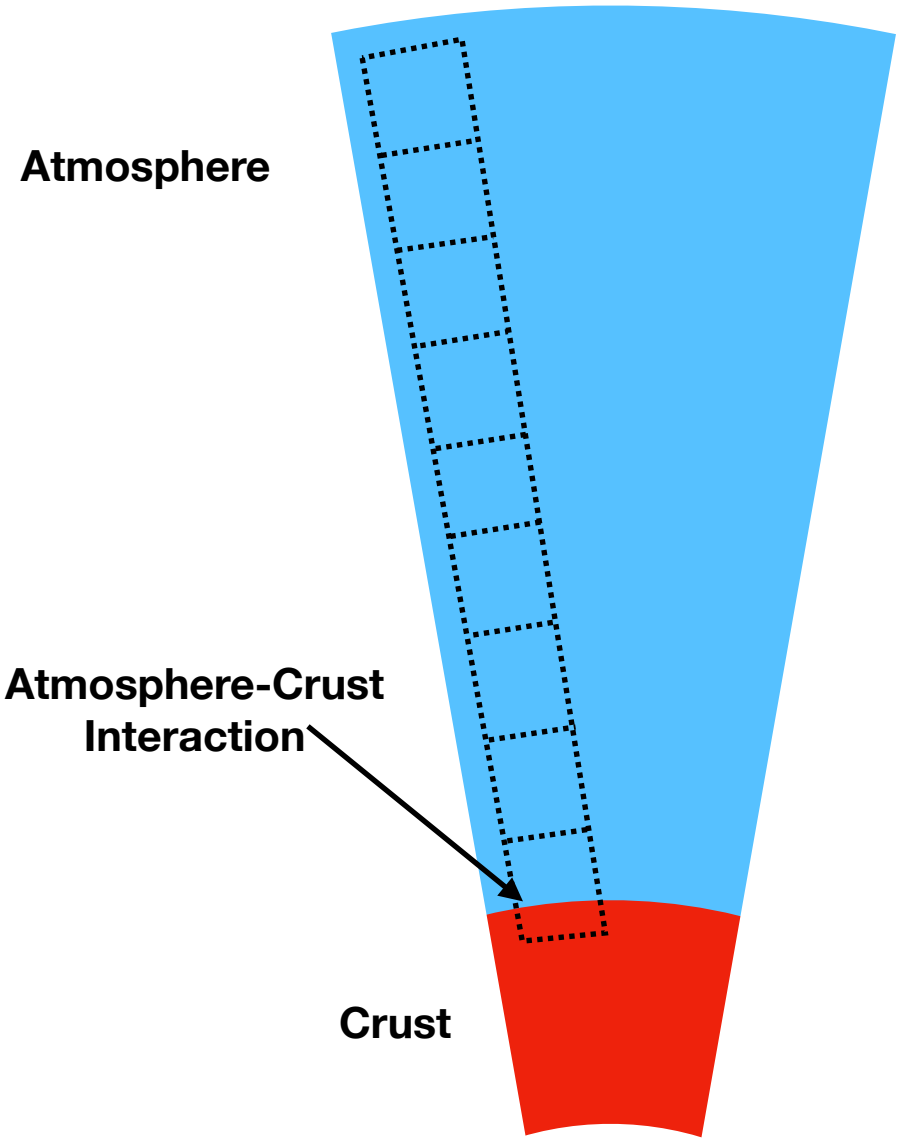


Building an atmosphere bottom to top

Equilibrium chemistry solved in each layer

hydrostatic equilibrium
Polytropic index

$$\frac{\mathrm{d}T}{\mathrm{d}z} = \frac{1+\gamma}{\gamma} g \frac{\mu}{k_\mathrm{B}}$$



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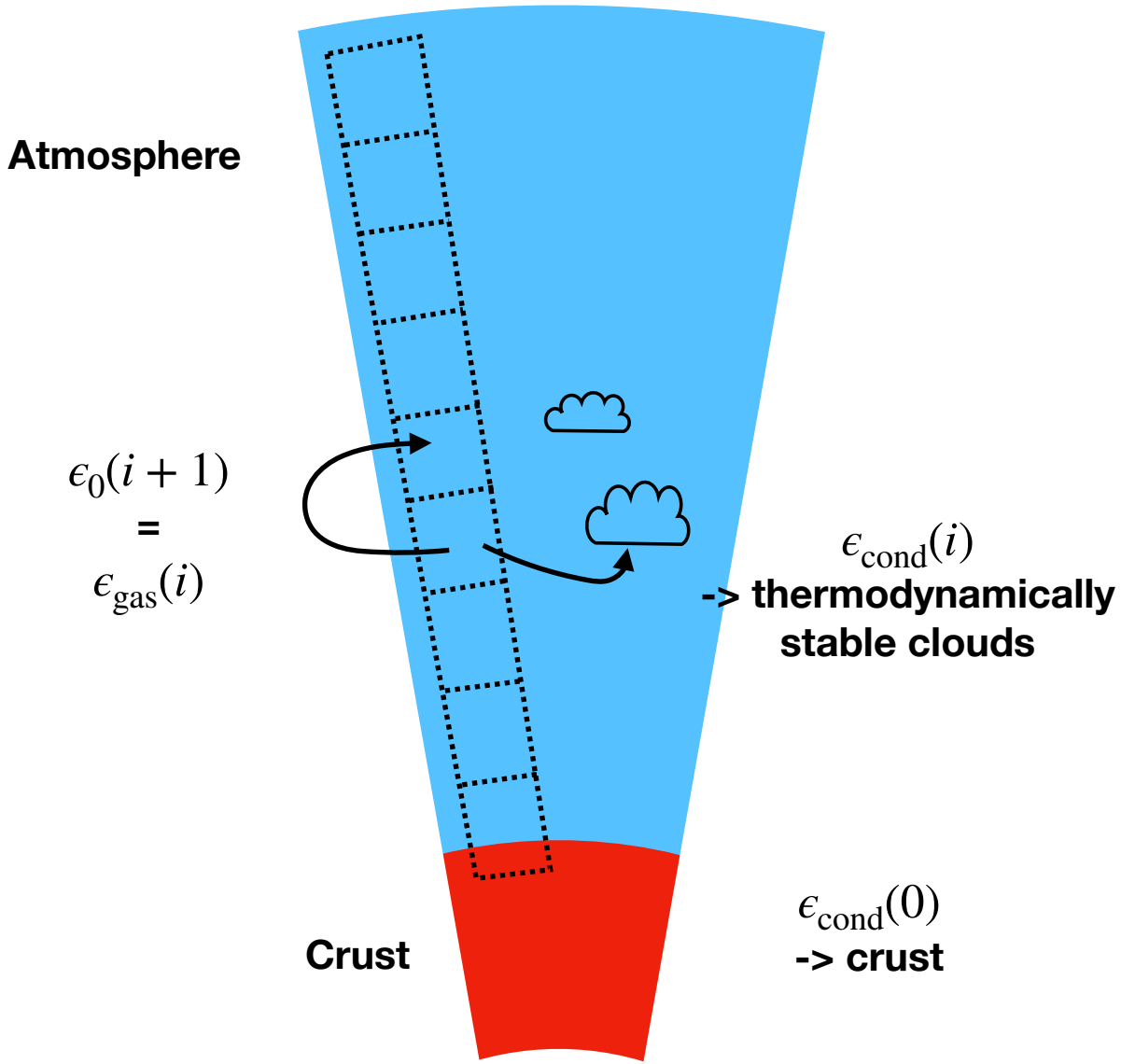
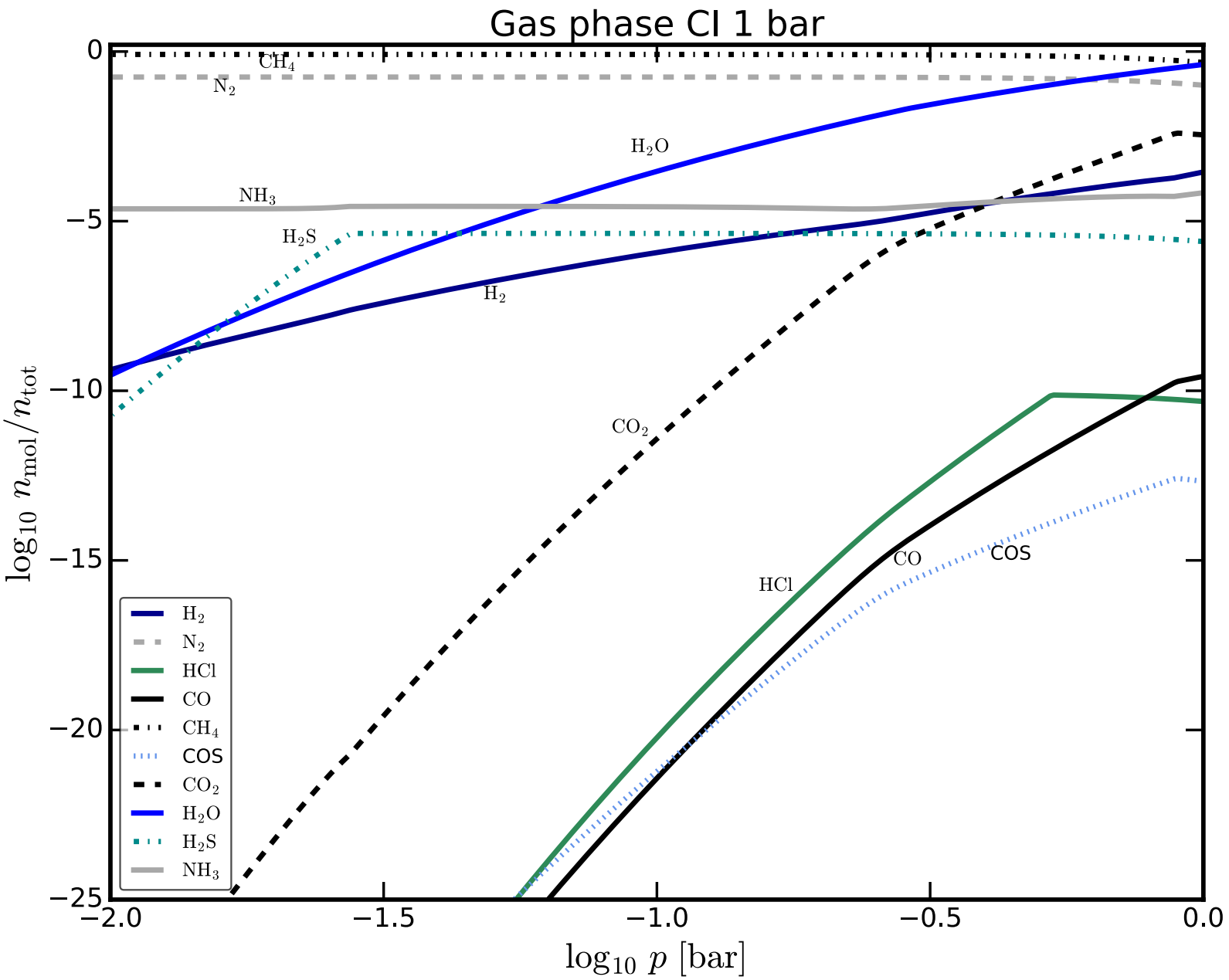


Atmosphere based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

Surface :
1 bar
350 K



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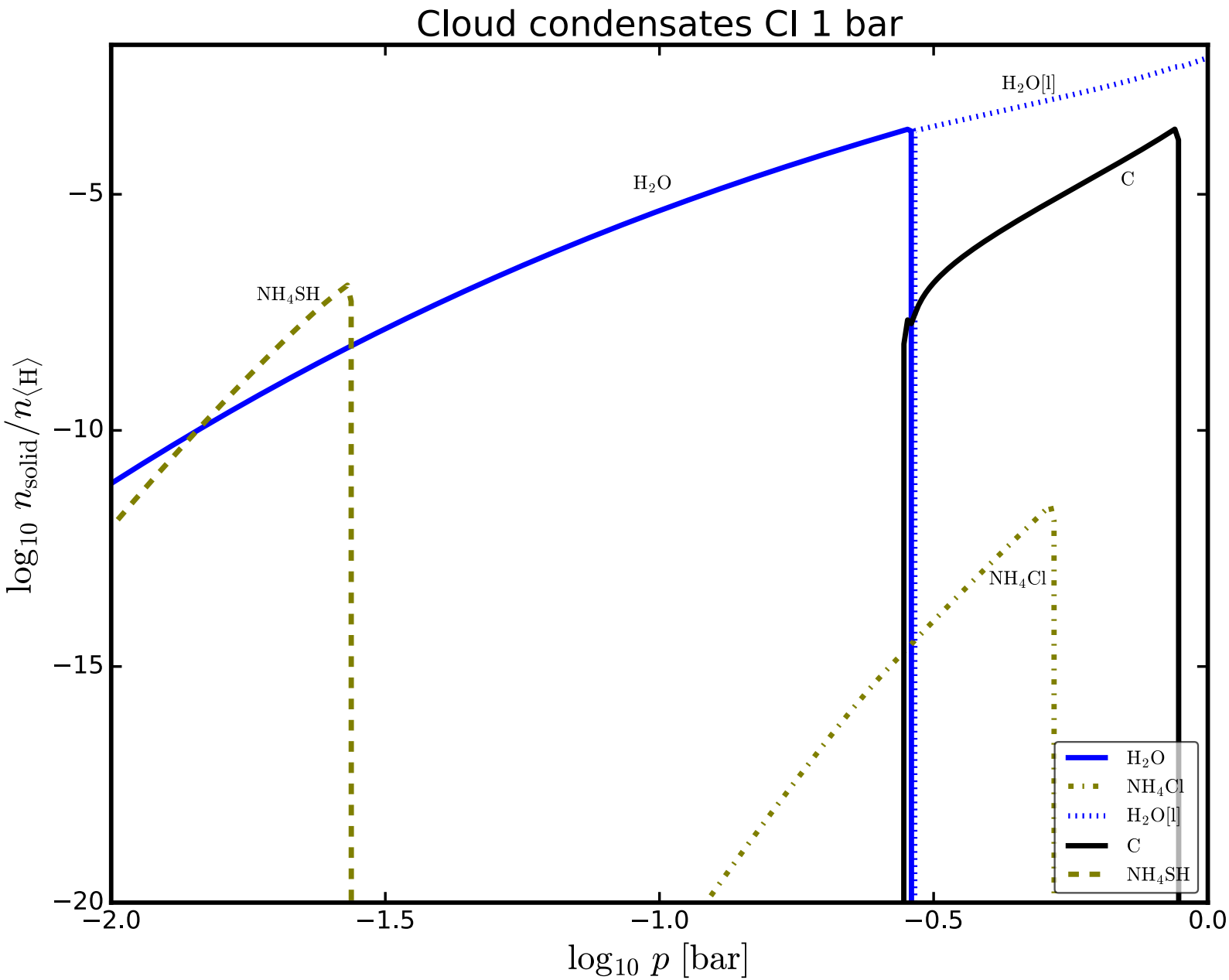
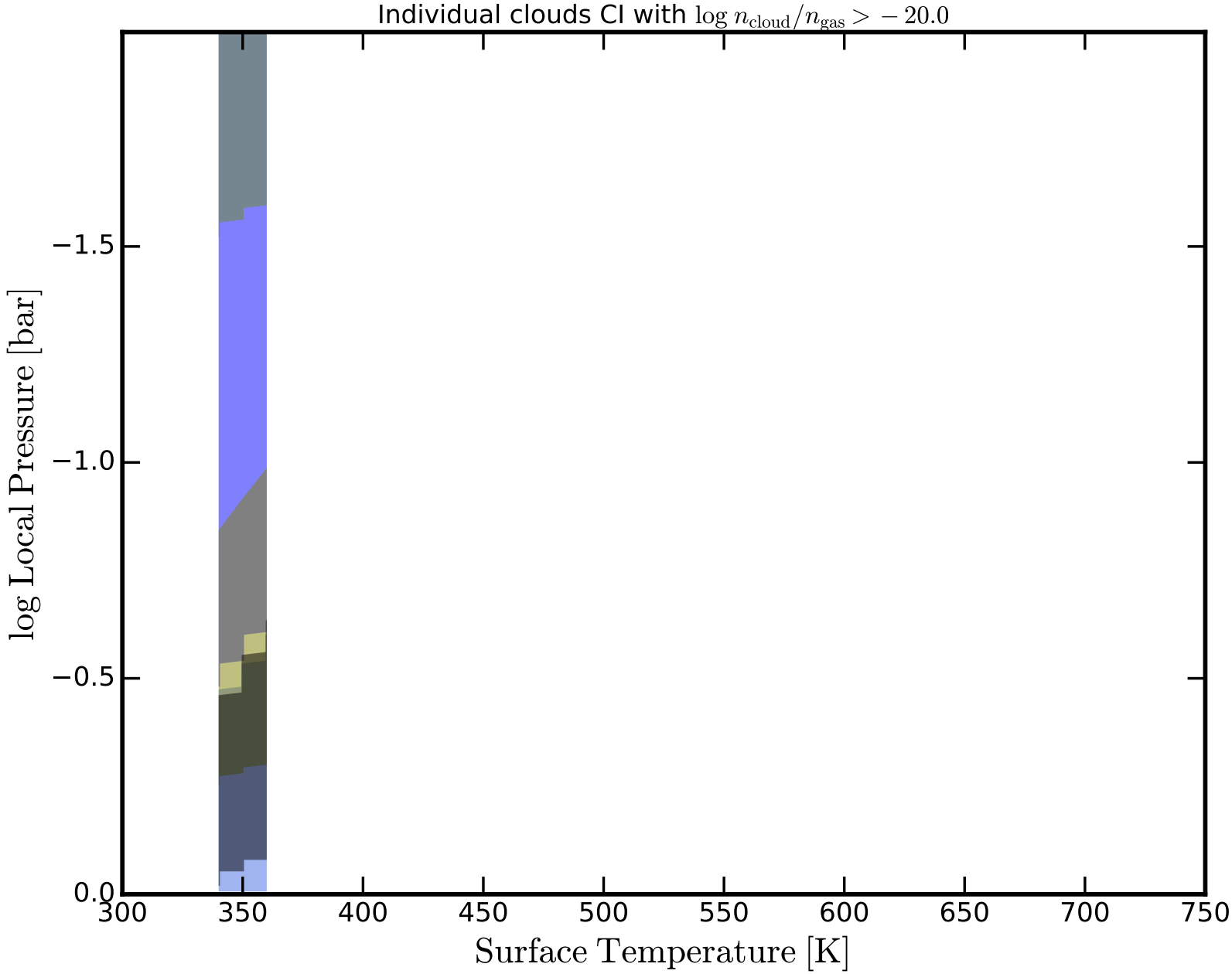


Cloud diversity based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

Surface : 1 bar

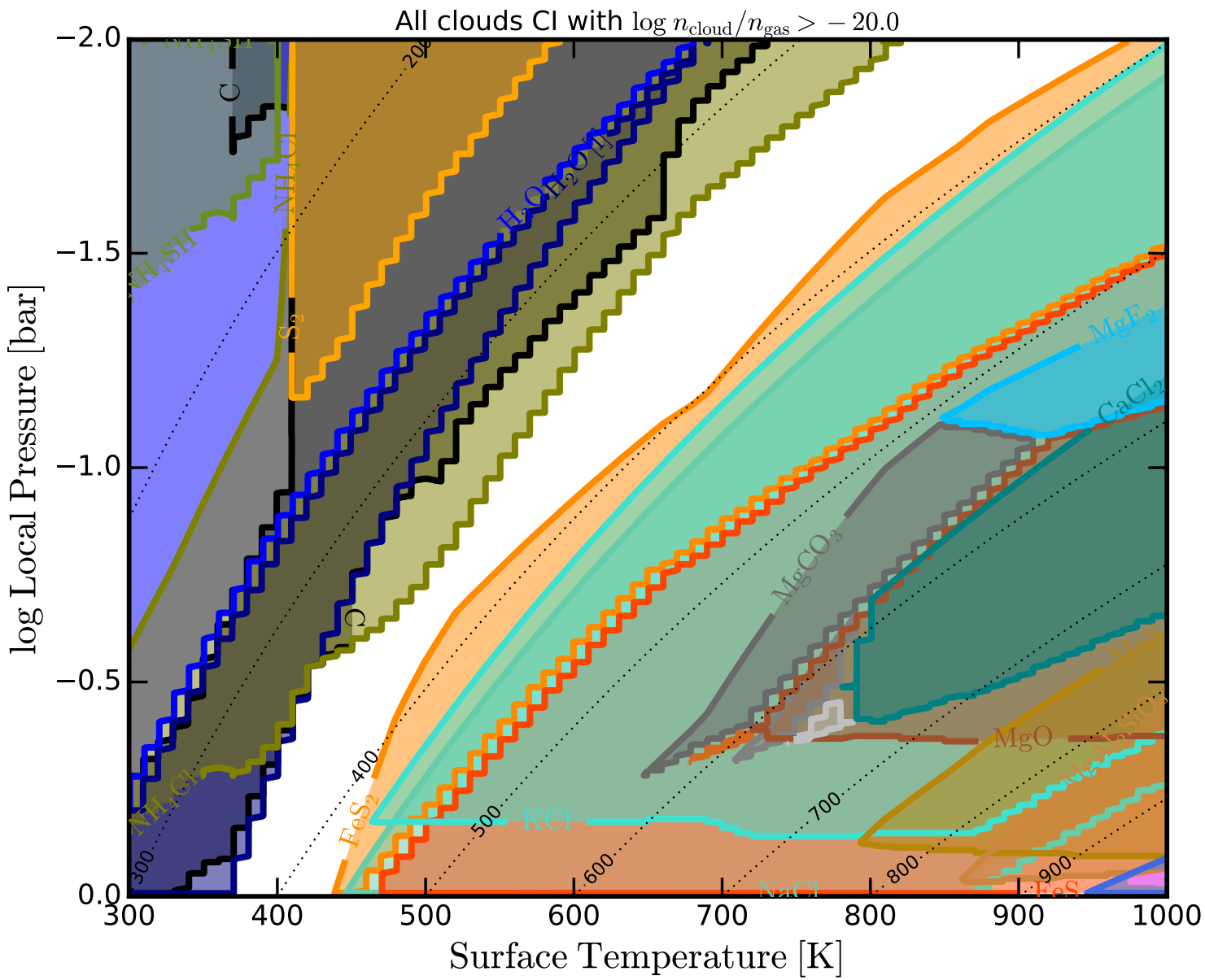


Cloud diversity based on CI chondrite

Element abundance: CI chondrite (Lodders et al., 2009)

Surface : 1 bar

All cloud species



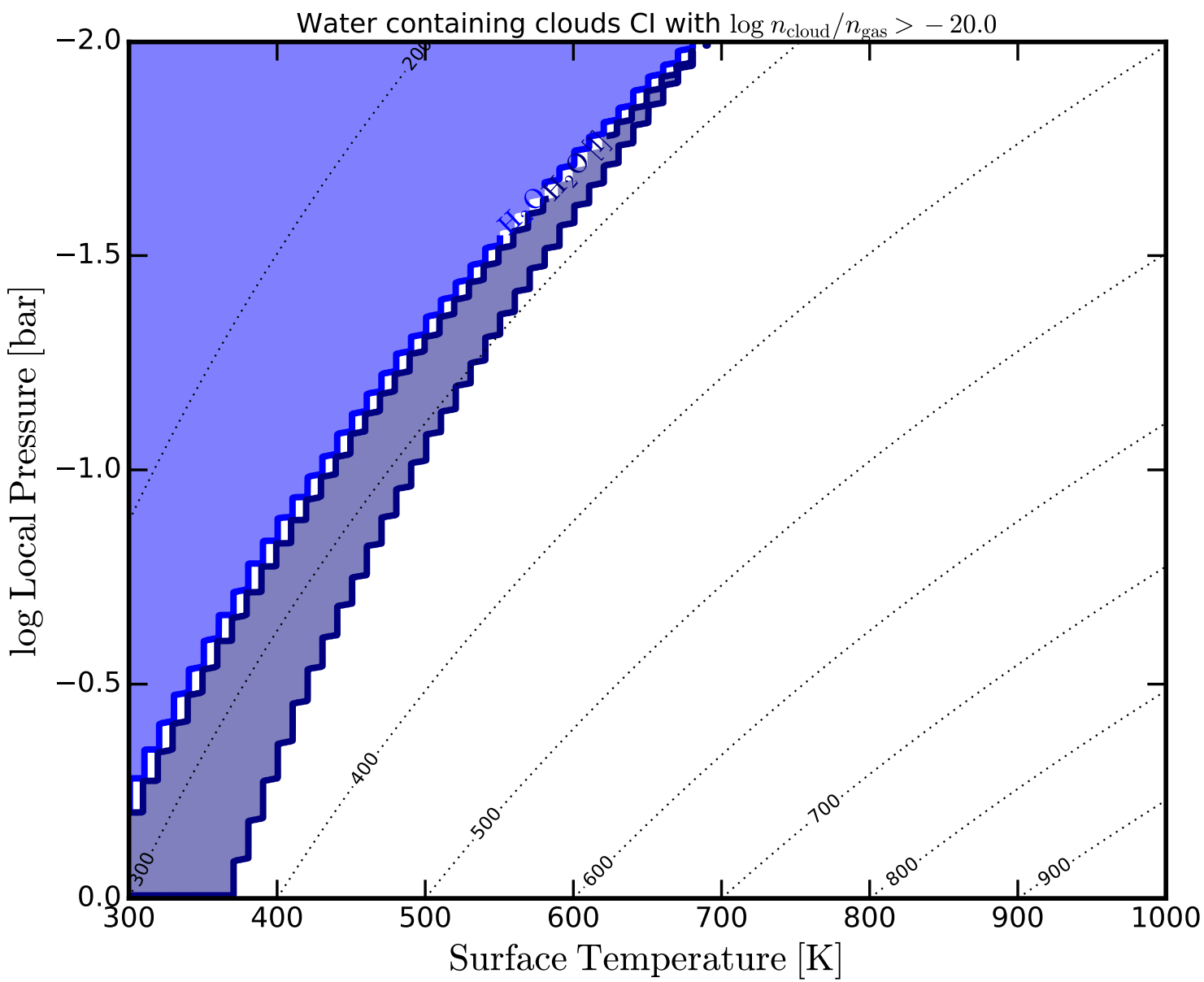
Cloud diversity based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

Surface : 1 bar

Water



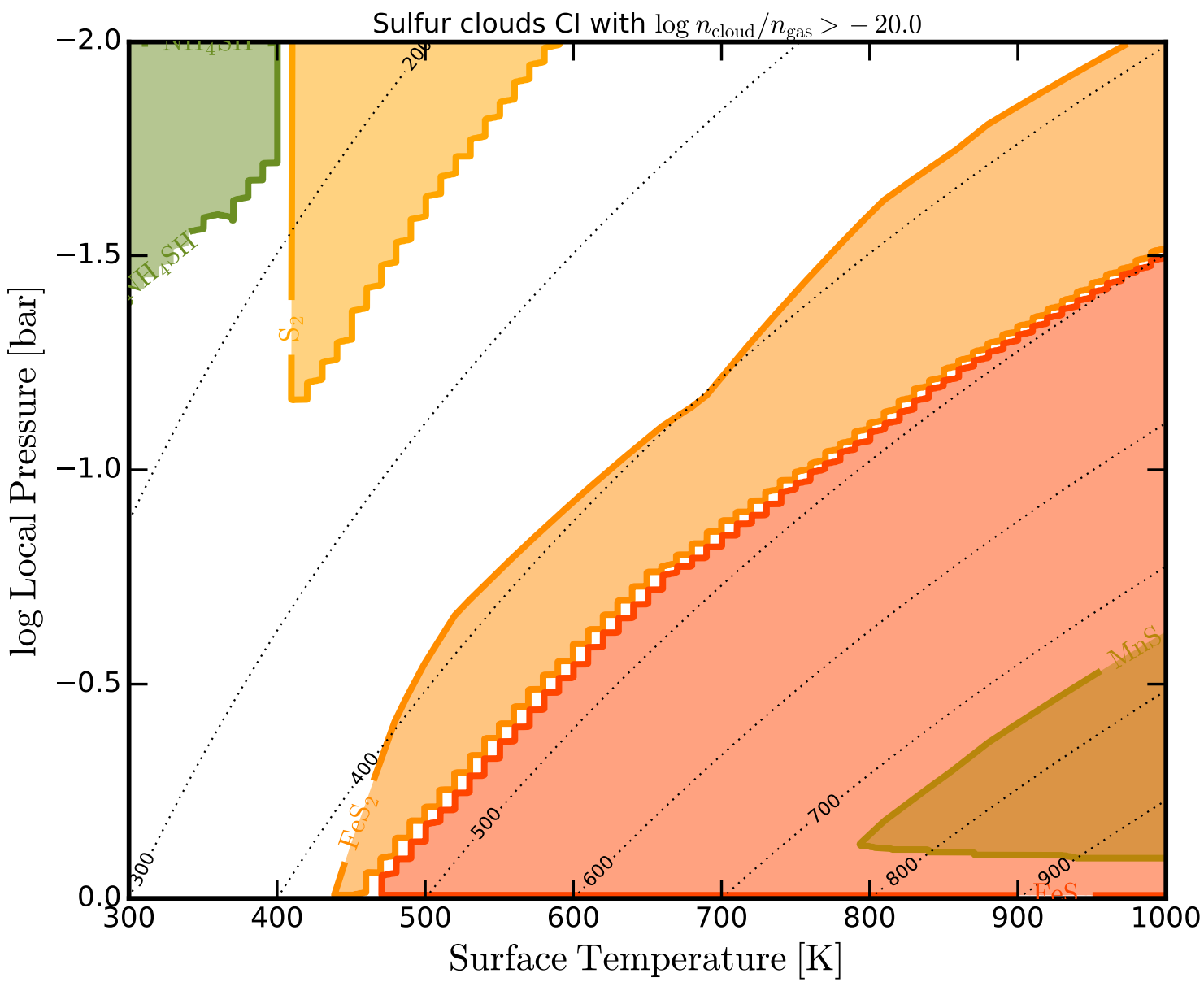
Cloud diversity based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

Surface : 1 bar

Iron Sulfur transitions



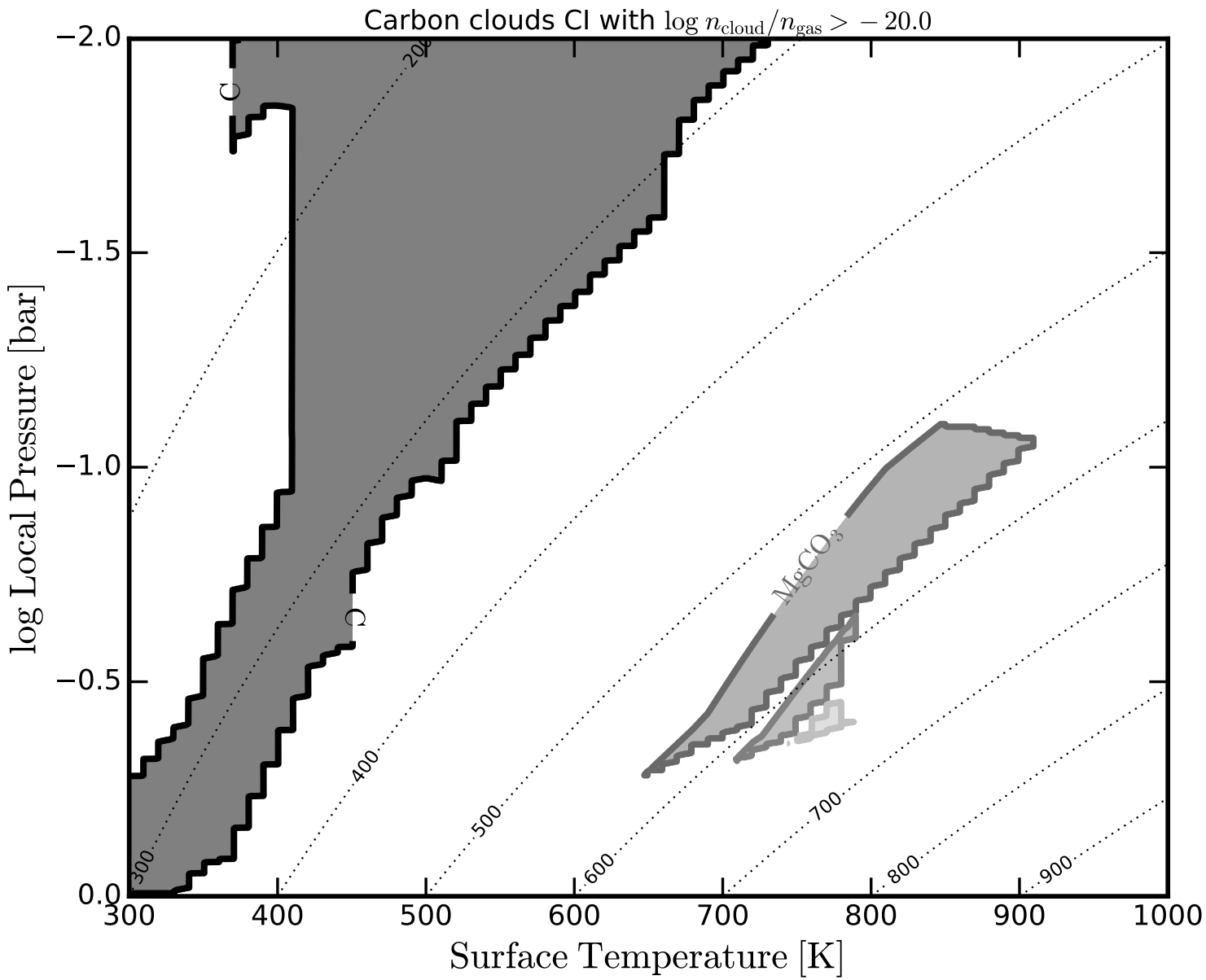
Cloud diversity based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

Surface : 1 bar

Carbon



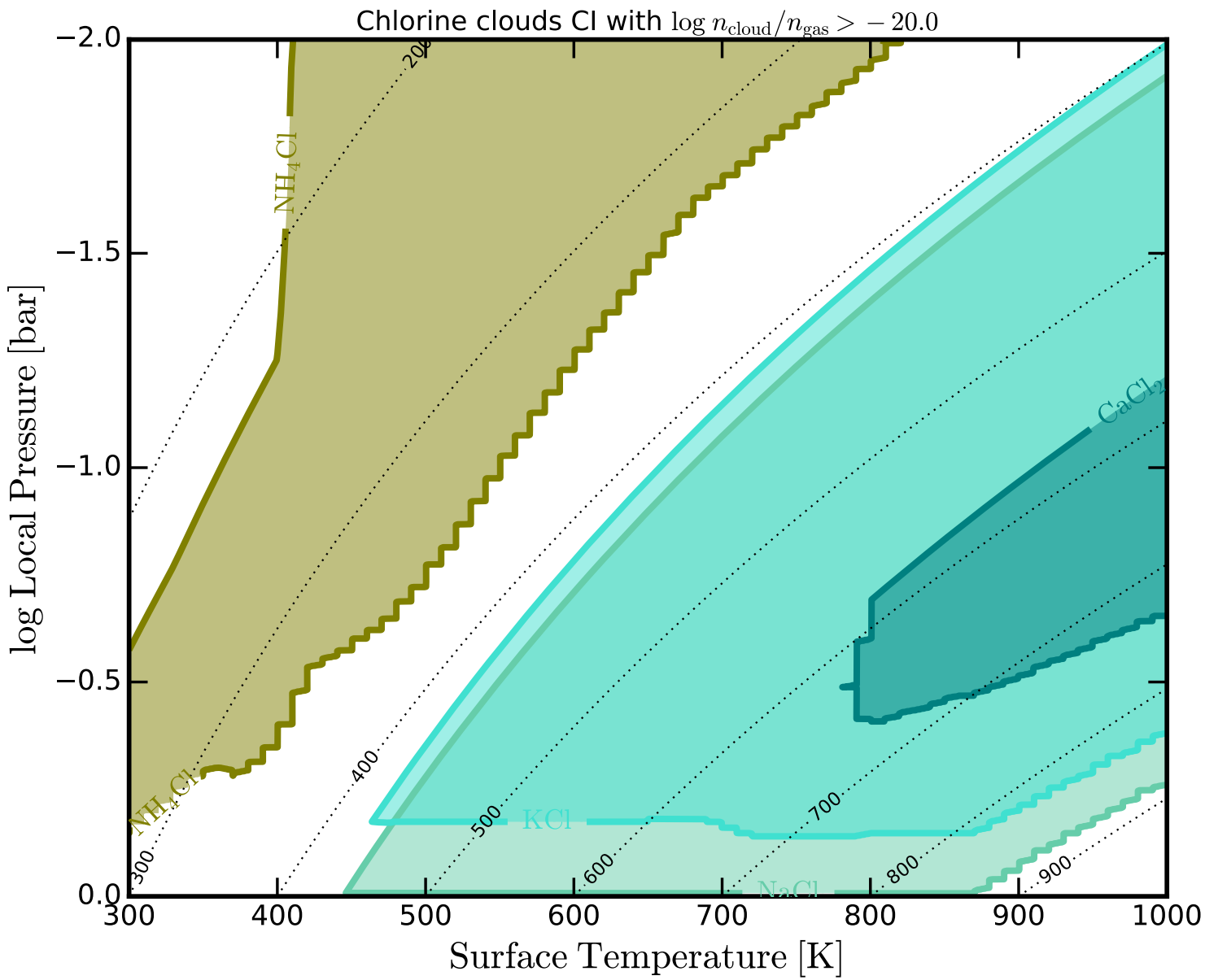
Cloud diversity based on Cl chondrite

Element abundance: Cl chondrite

(Lodders et al., 2009)

Surface : 1 bar

Halides + NH_4Cl



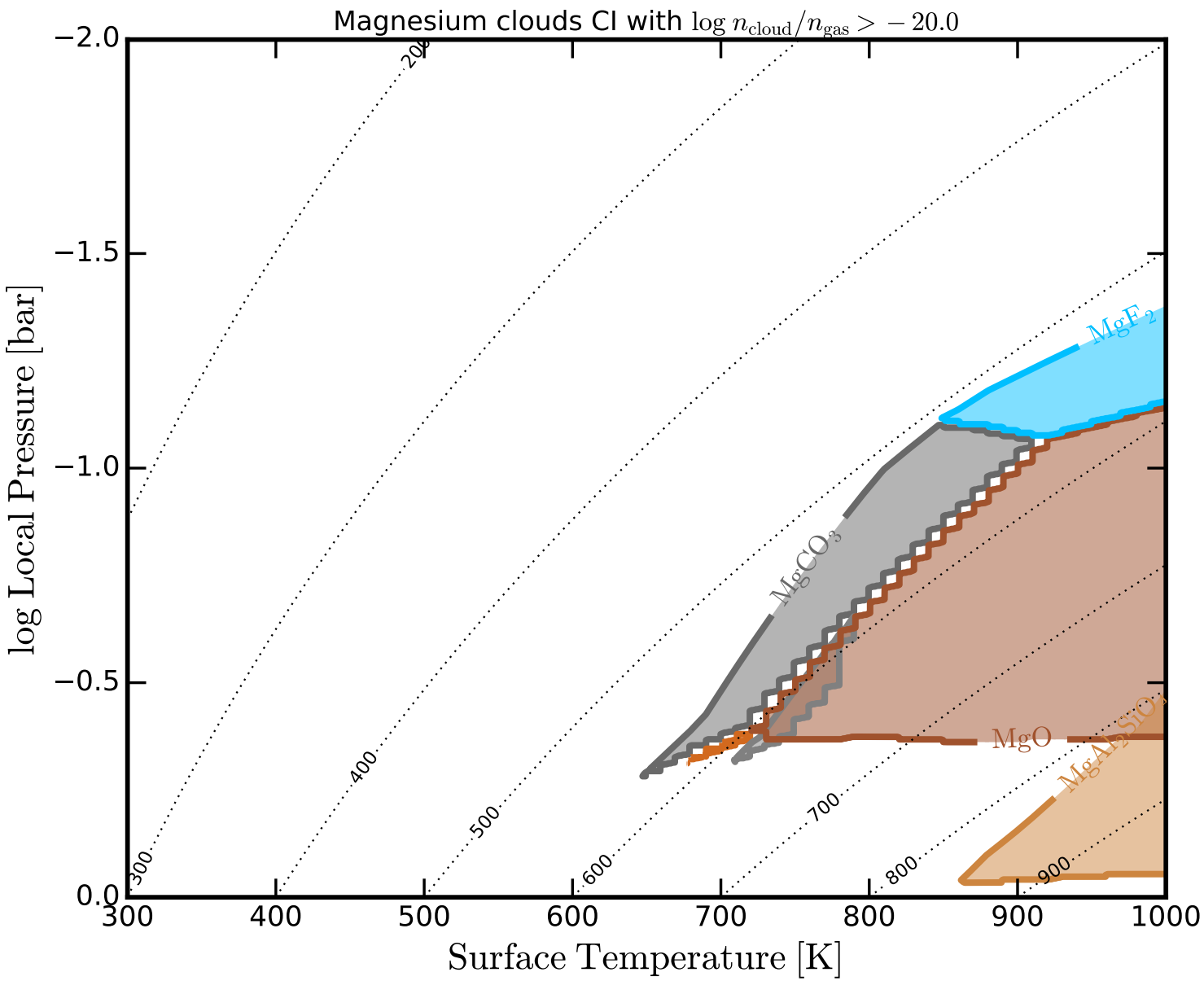
Cloud diversity based on CI chondrite

Element abundance: CI chondrite

(Lodders et al., 2009)

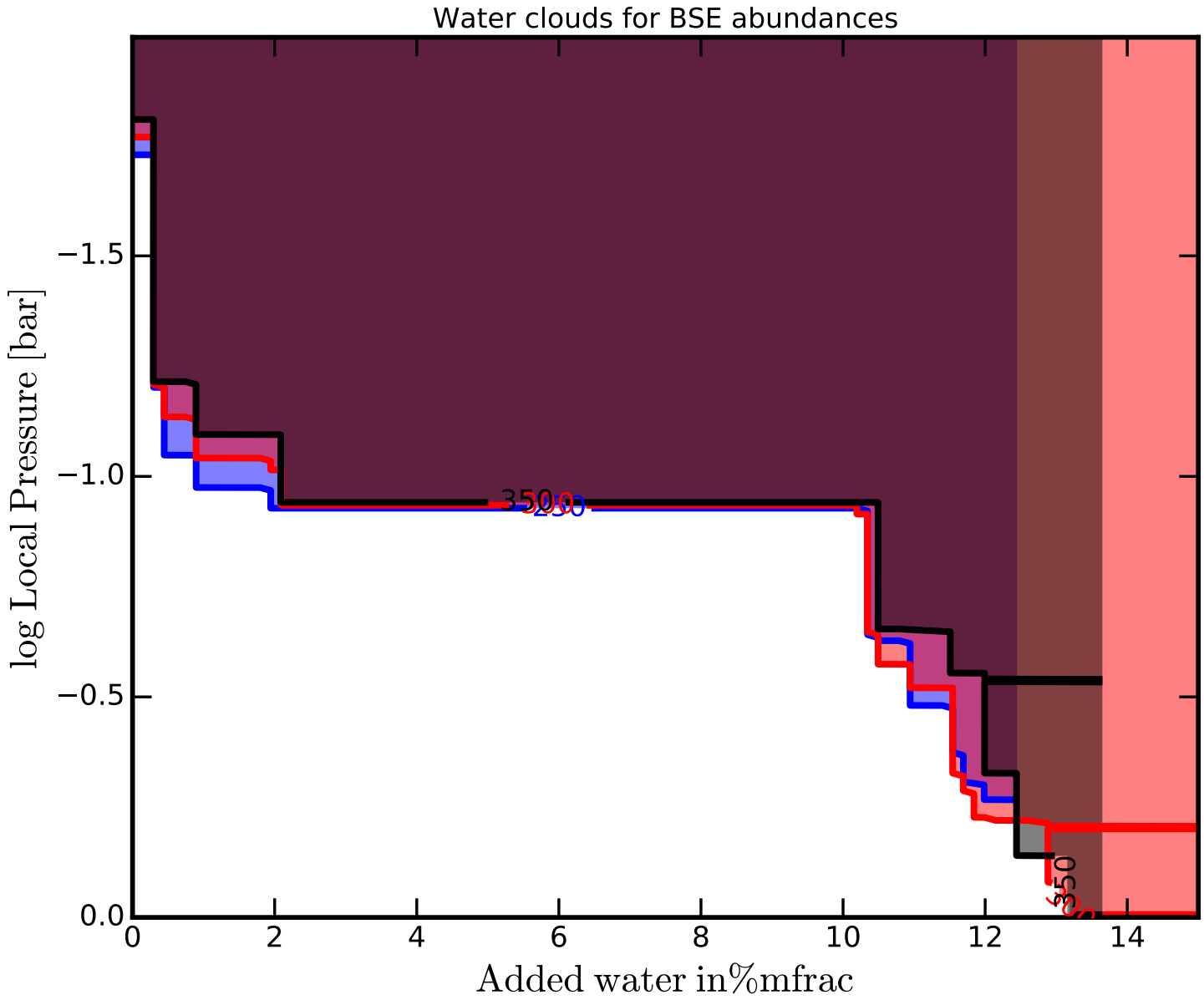
Surface : 1 bar

Magnesium



Link between clouds and surface water

Water clouds for added H and O to BSE models



Take home messages

- Only oversaturation of phyllosilicates can result in stable water as a condensate

  $\rightarrow$ Herbort et al. (2020)

- Our models show the possible coexistance of CH_4 and CO_2

  $\rightarrow$ Woitke et al. (submitted)

- Crust composition constrains cloud composition and location

  $\rightarrow$ Use clouds to determine surface conditions

Timescale

Relaxation time towards chemical equilibrium

$$\tau_{\mathrm{cond}} = \left(v_{\mathrm{th}} \frac{A}{V} V \alpha \right)^{-1}$$

Solid diffusion for a length Δa
Duschl et al. (1996), Gail & Sedlmayr (1999)

$$\tau_{\mathrm{annealing}} = \frac{(\Delta a)^2}{\frac{1}{3} \lambda^2 \nu \exp\left(\frac{-E_{\mathrm{a}}}{k_{\mathrm{B}} T} \right)}$$

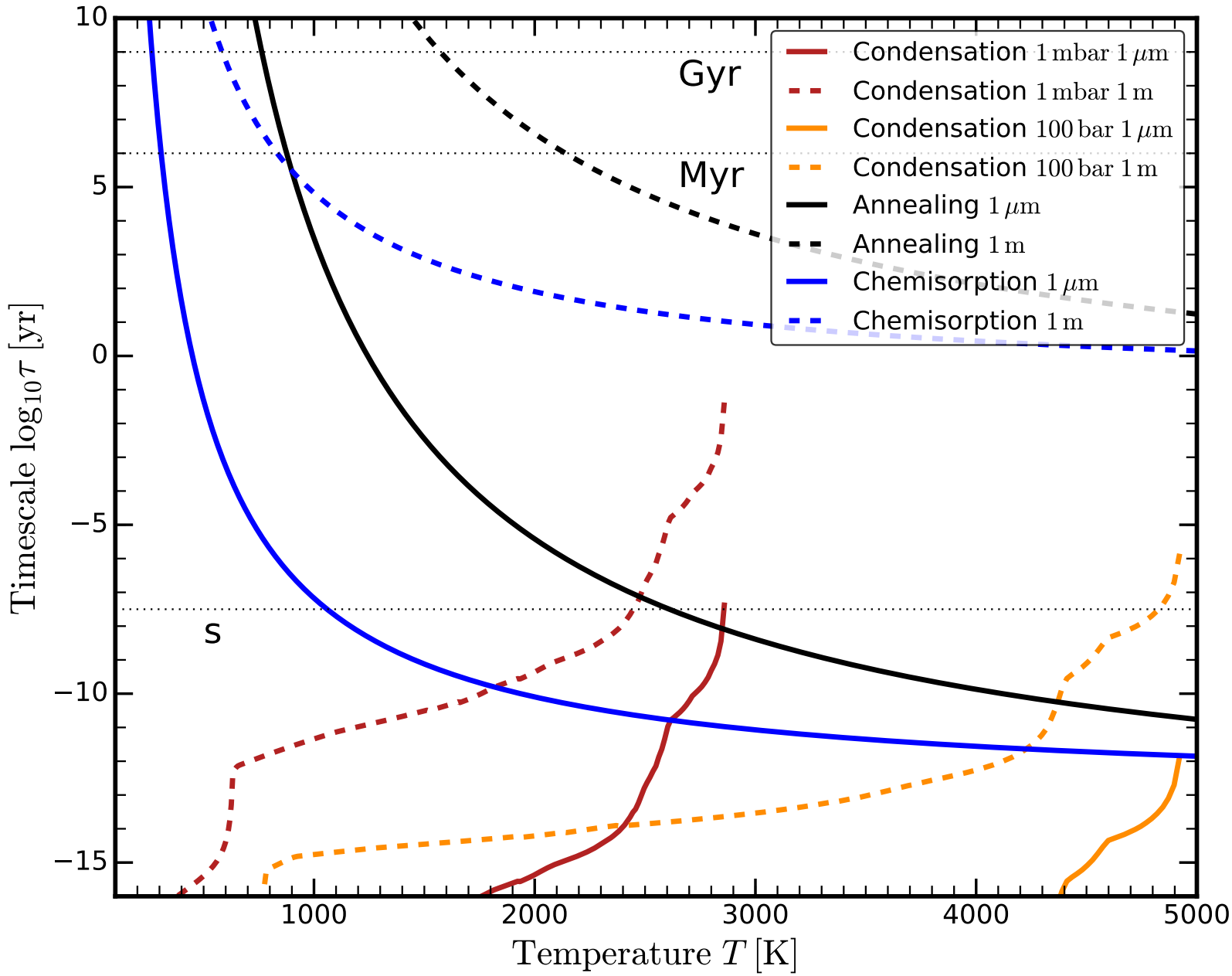
Rearrangement in the lattice structure
Chemisorption of surface water (Thi et al., 2018)

Timescale

Conden-
sation

Annealing
(Solid dif-
fusion)

Chemisorp-
tion
(water incor-
poration)



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