Warming of early Mars induced by CO_2 ice clouds

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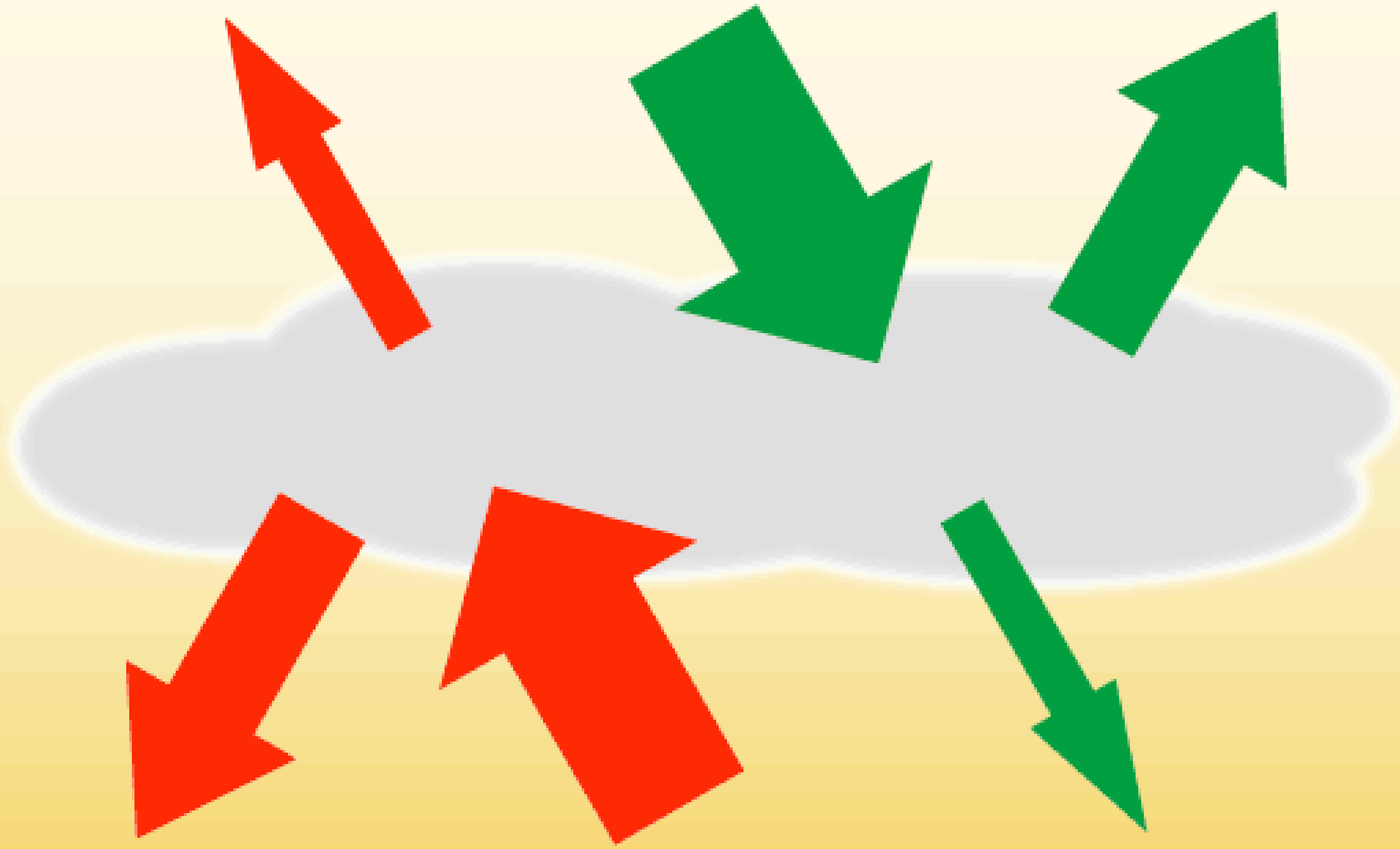
The faint young Sun paradox on Mars

- Early Mars (-- 3.8 Ga)
  - wet and warm climate?

- The warm climate cannot be sustained (Kasting, 1991)
  - CO_2-H_2O atmosphere
  - Solar Luminosity 75 % as present
  - neglect radiation processes of cloud

Valley networks (Carr, 1996)

Scattering greenhouse effect of CO_2 ice cloud



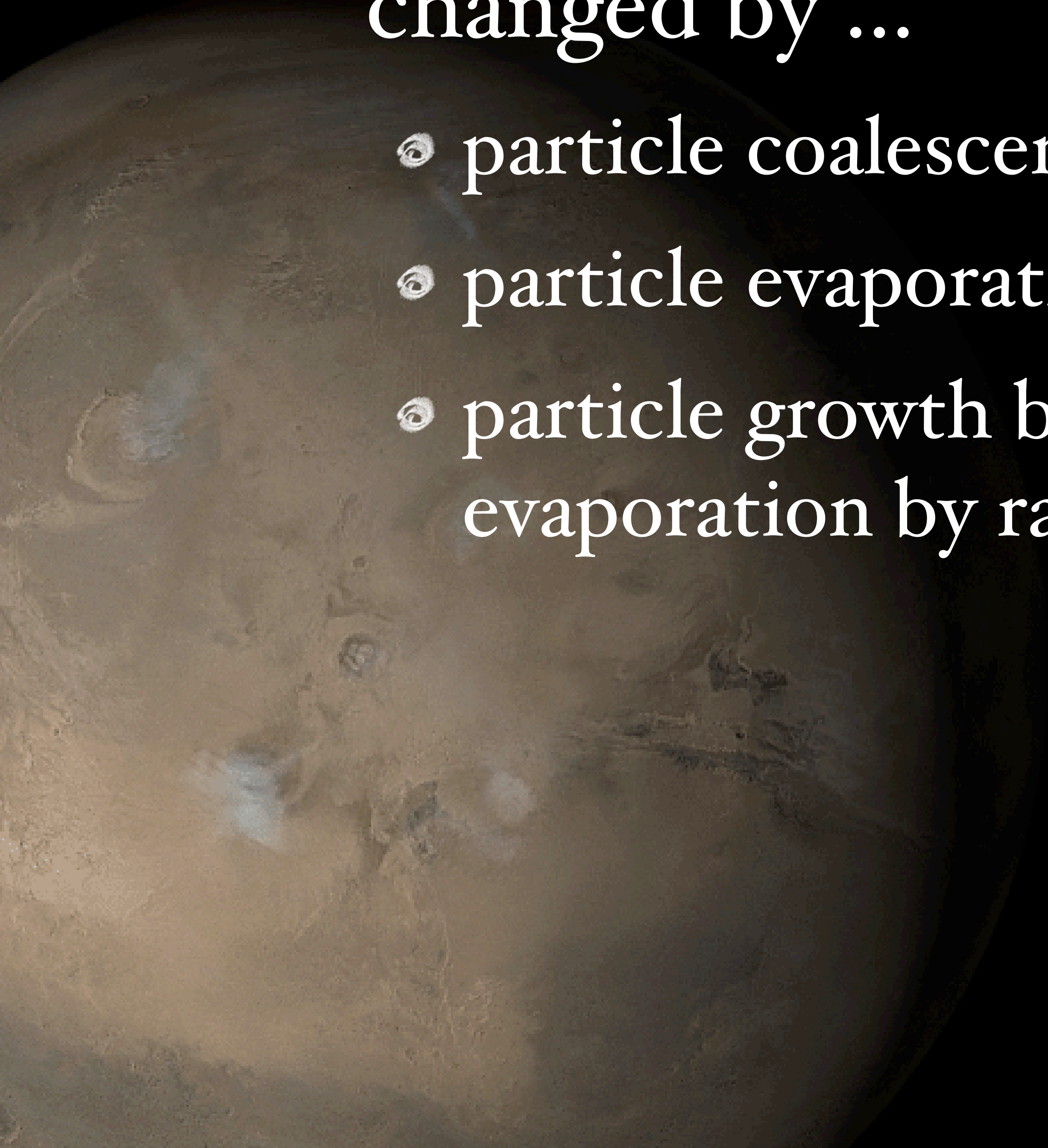
cloud reflects IR rafiarion > Solar radiation

Scattering greenhouse effect of CO_2 ice cloud

- Previus studies have shown
  - The strength of greenhouse effect depends on cloud parameters such as particle size and optical depth(e.g. Pierrehumbert and Erlick 1998)
  - Climate can become warm when cloud has optimal parameters(e.g. Mischna *et al*, 2000)
- Mechanisms determining these values have not been examined.

mechanisms of cloud parameters change

- Cloud particle size and optical depth are changed by ...
  - particle coalescence by collision
  - particle evaporation as getting out of the cloud
  - particle growth by radiative cooling or evaporation by radiative heating in cloud layer



mechanisms of cloud condition change

- Cloud particle size and optical depth are changed by …
  - particle combination with collision
  - particle evaporation as getting out of the cloud
  - particle growth by radiative cooling or evaporation by radiative heating in cloud layer

This study:
Estimation the greenhouse effect of stable CO_2 ice cloud

1-D radiation model

Solar luminosity:
0.75 times of today
(Gouth, 1981)

Two-stream approximation
(cloud layer: δ-Eddington approximation)

CO_2-H_2O atmosphere

Albedo: 0.216
(Kieffer et al. 1977)

Cloud particle:

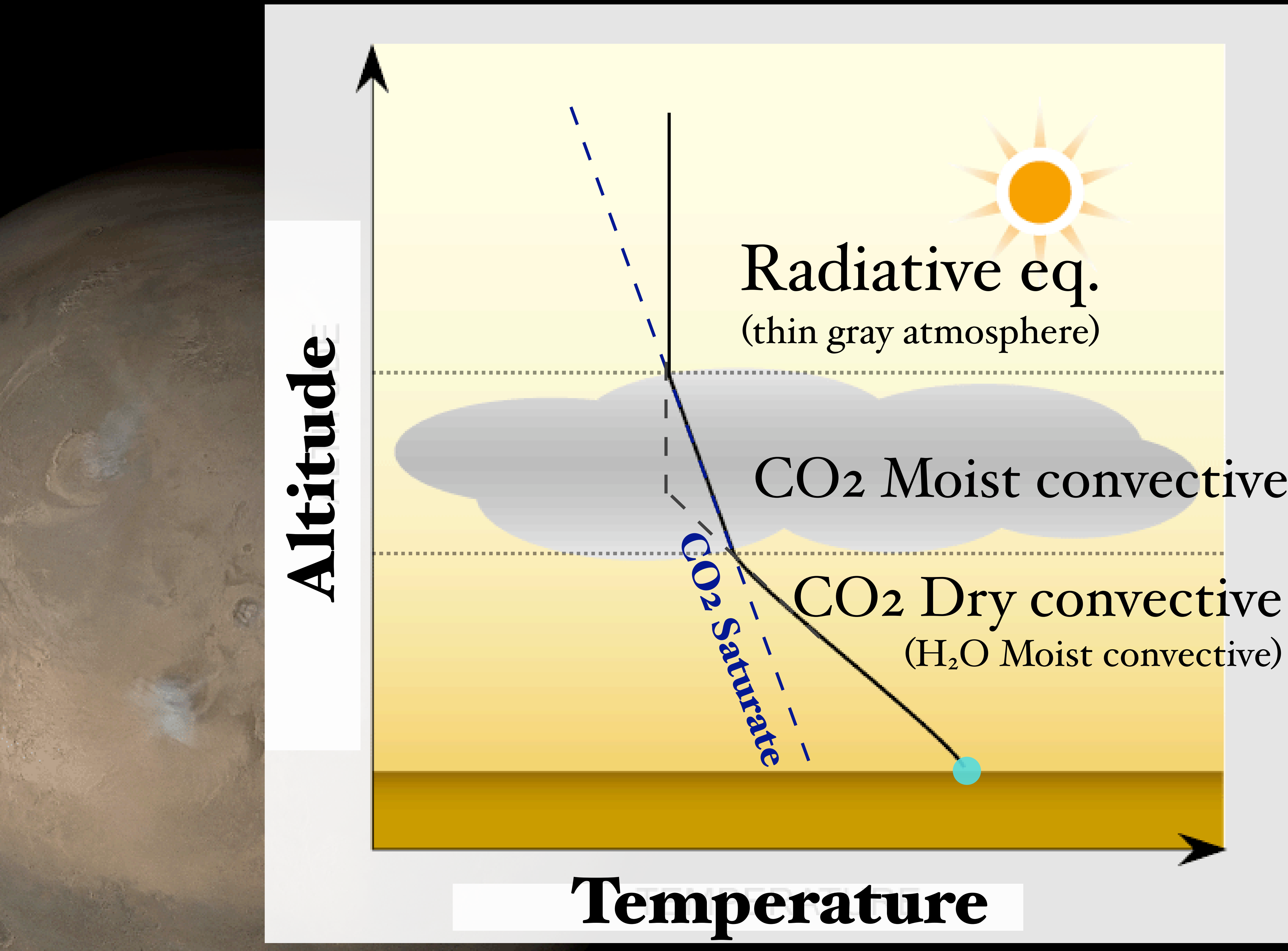
* Mie theory
  Complex indices of CO_2 ice (Warren,1986)

Gas (for IR radiation only):

* Line-by-line method
  absorption line parameters (HITRAN2000)

* At cloud layer, Ramdom model
  band parameter (Houghton, 2002)

Vertical temperature profile



1-D radiation model

Solar luminosity:
75 % current value
(Gouth, 1981)

Two-stream approximation
(cloud layer: δ-Eddington approximation)

latent heat of CO_2 condensation
= net cooling energy in cloud layer

CO_2-H_2O
atmosphere

regolith Albedo: 0.216
(Kieffer et al. 1977)

Cloud particle:

* Mie theory
  Comples indices of CO_2 ice (Warren,1986)

Gas (for IR radiation only):

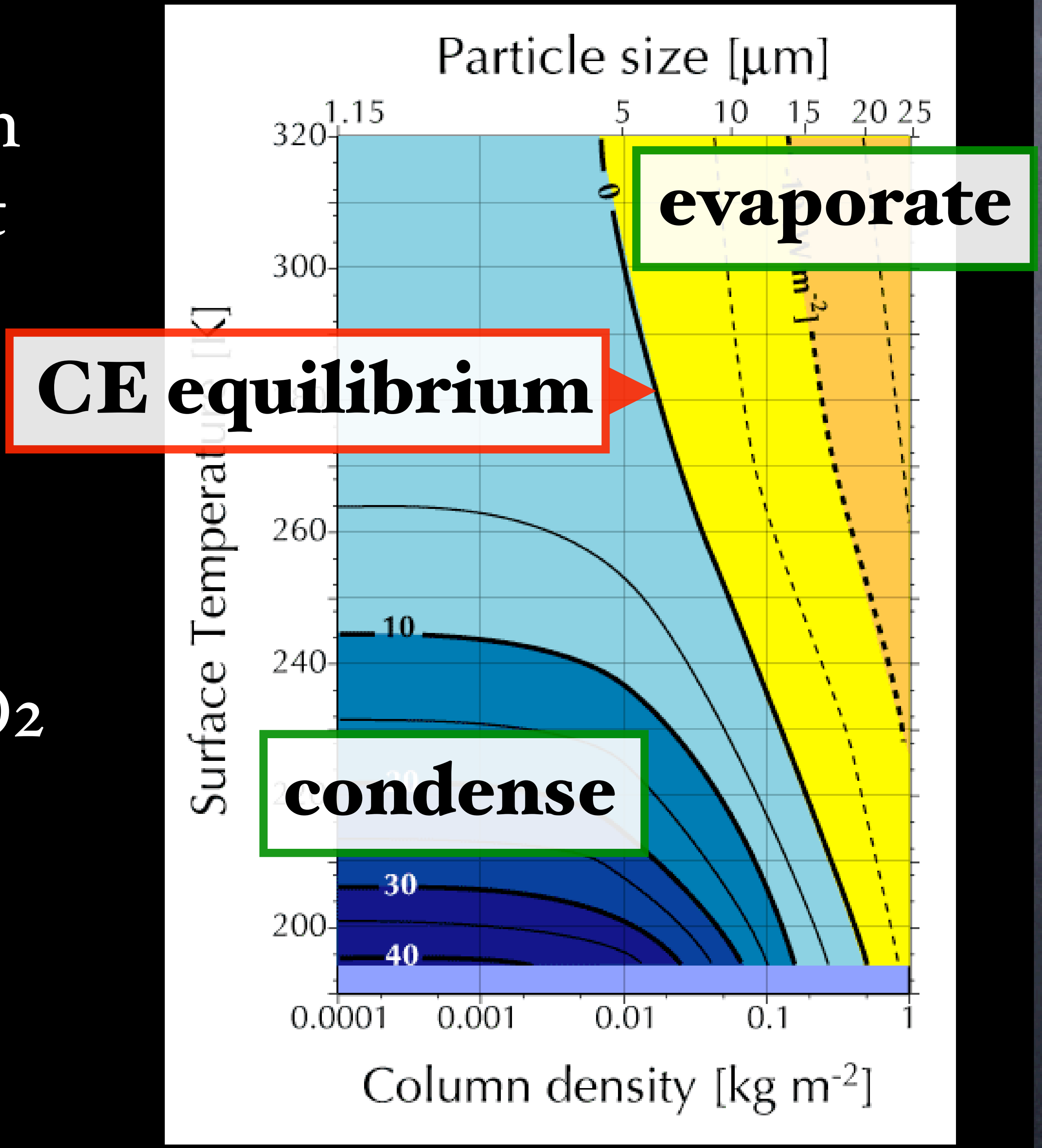
* Line-by-line method
  absorption line parameters (HITRAN200

* At cloud layer, Ramdom model
  band parameter (Houghton, 2002)

Latent heat of CO_2 condensation

atmospheric pressure: 1 bar ; condensation nucleus: 10^{10} m^{-2}

- Inverse correlation between particle size and latent heat is important
- By a negative feedback, the particle size change to the CE-equilibrium value if CO2 condensate and evaporate quickly.



Estimation of temperature

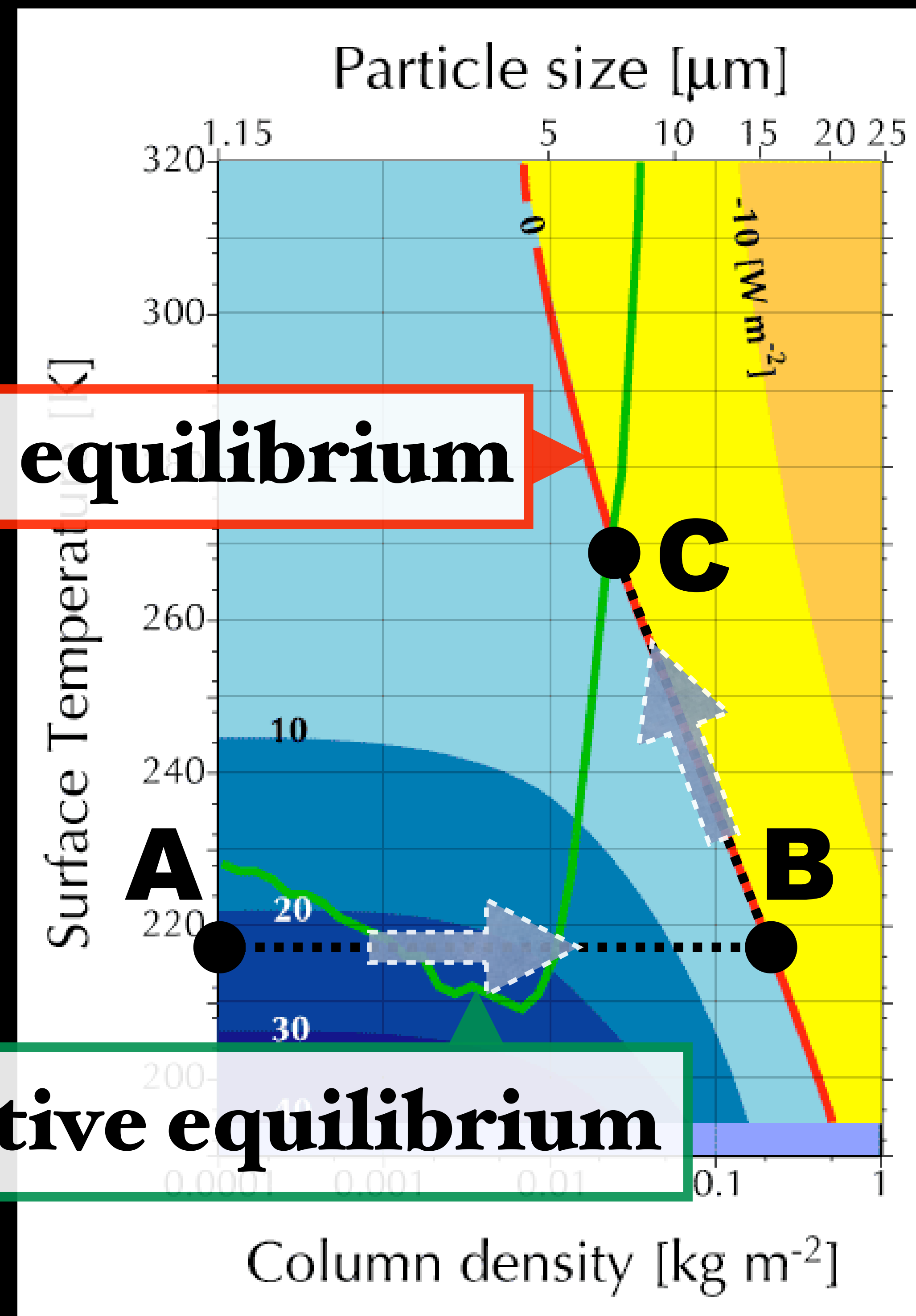
atmospheric pressure: 1 bar ; condensation nucleus: 10^{10} m^{-2}

time scale

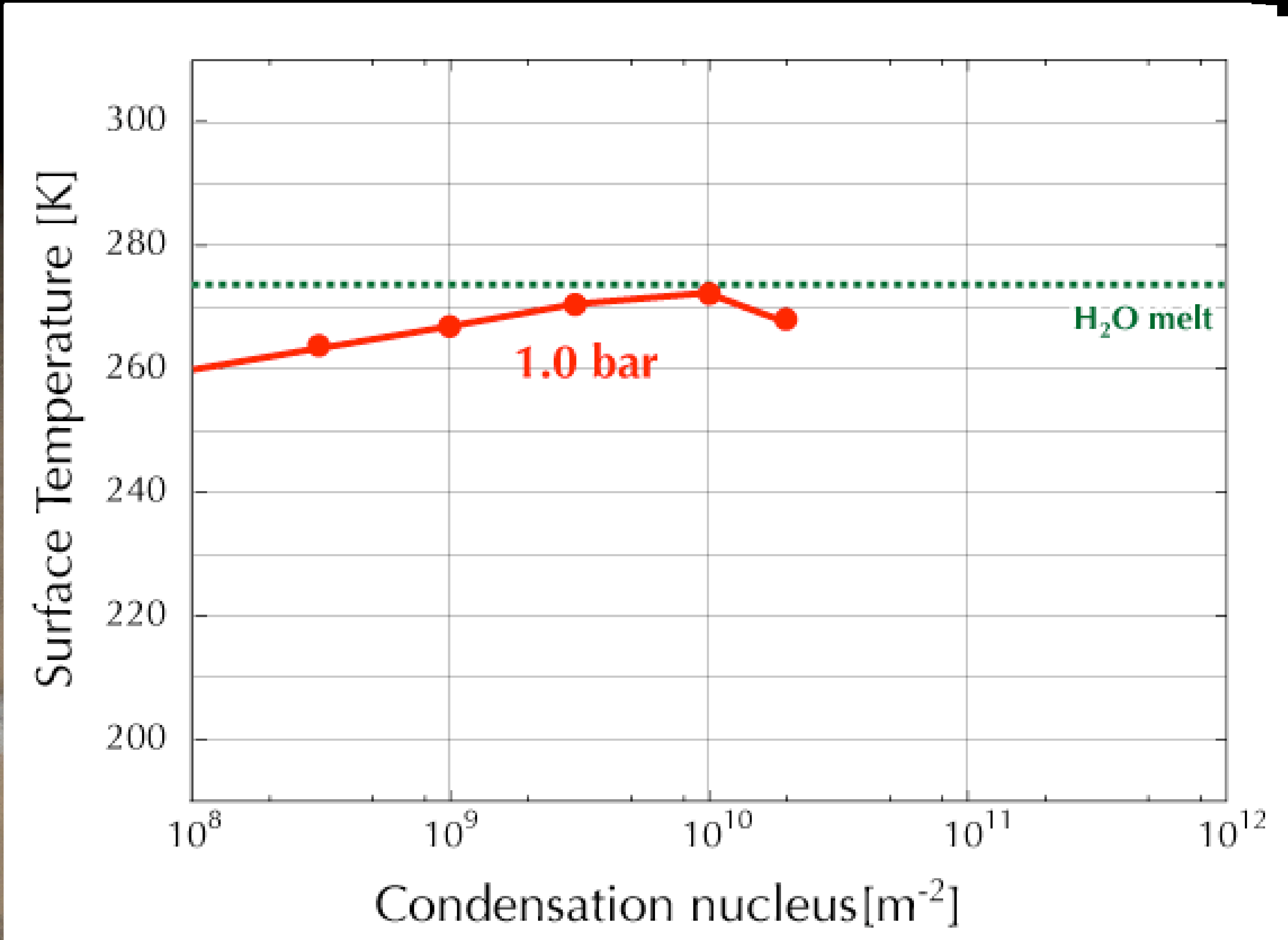
CE equilibrium(hour)

<< **R equilibrium**(week)

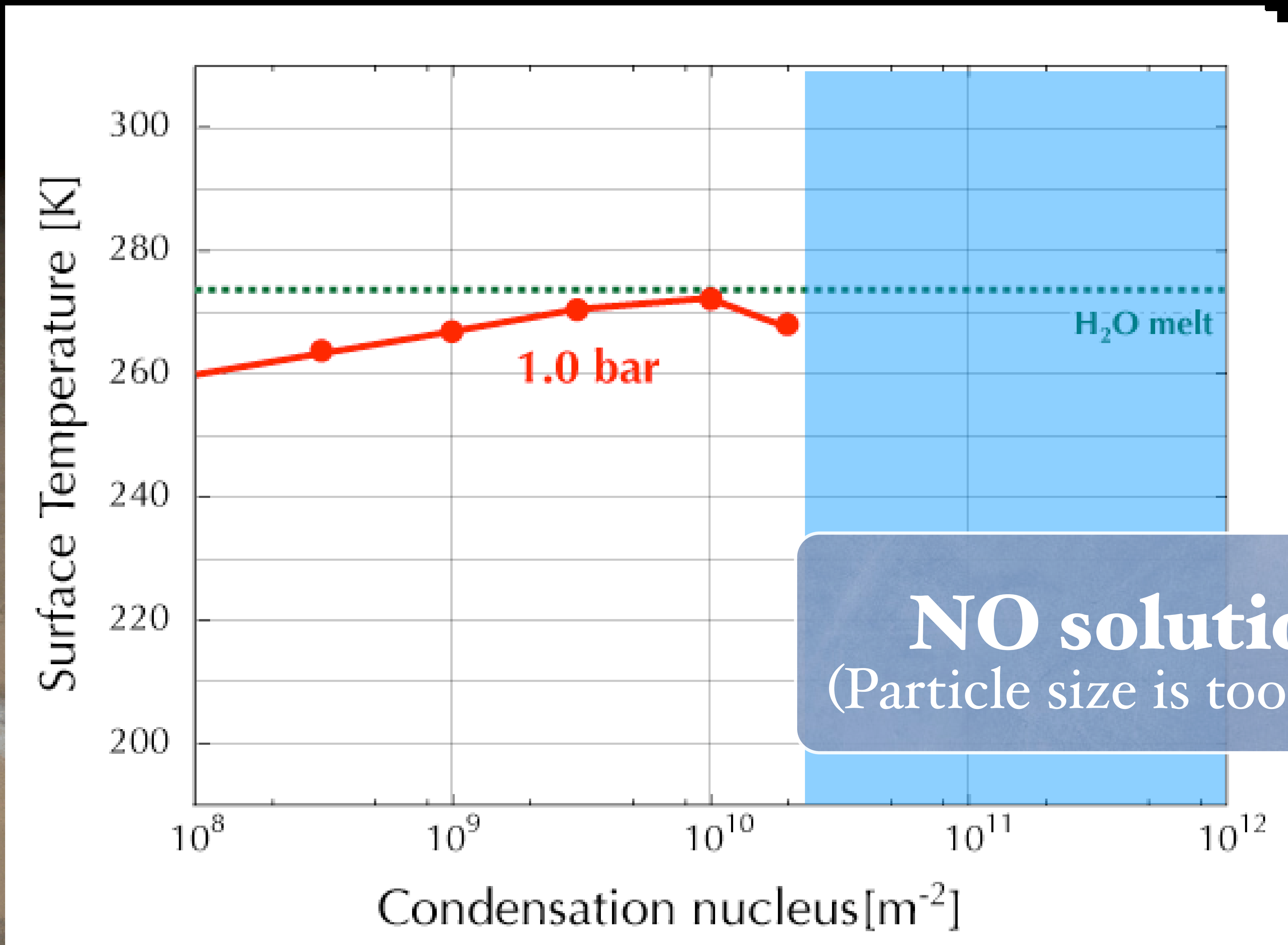
Surface temperature change to point C, in which these two equilibriums are archived.



Estimation of surface temperature

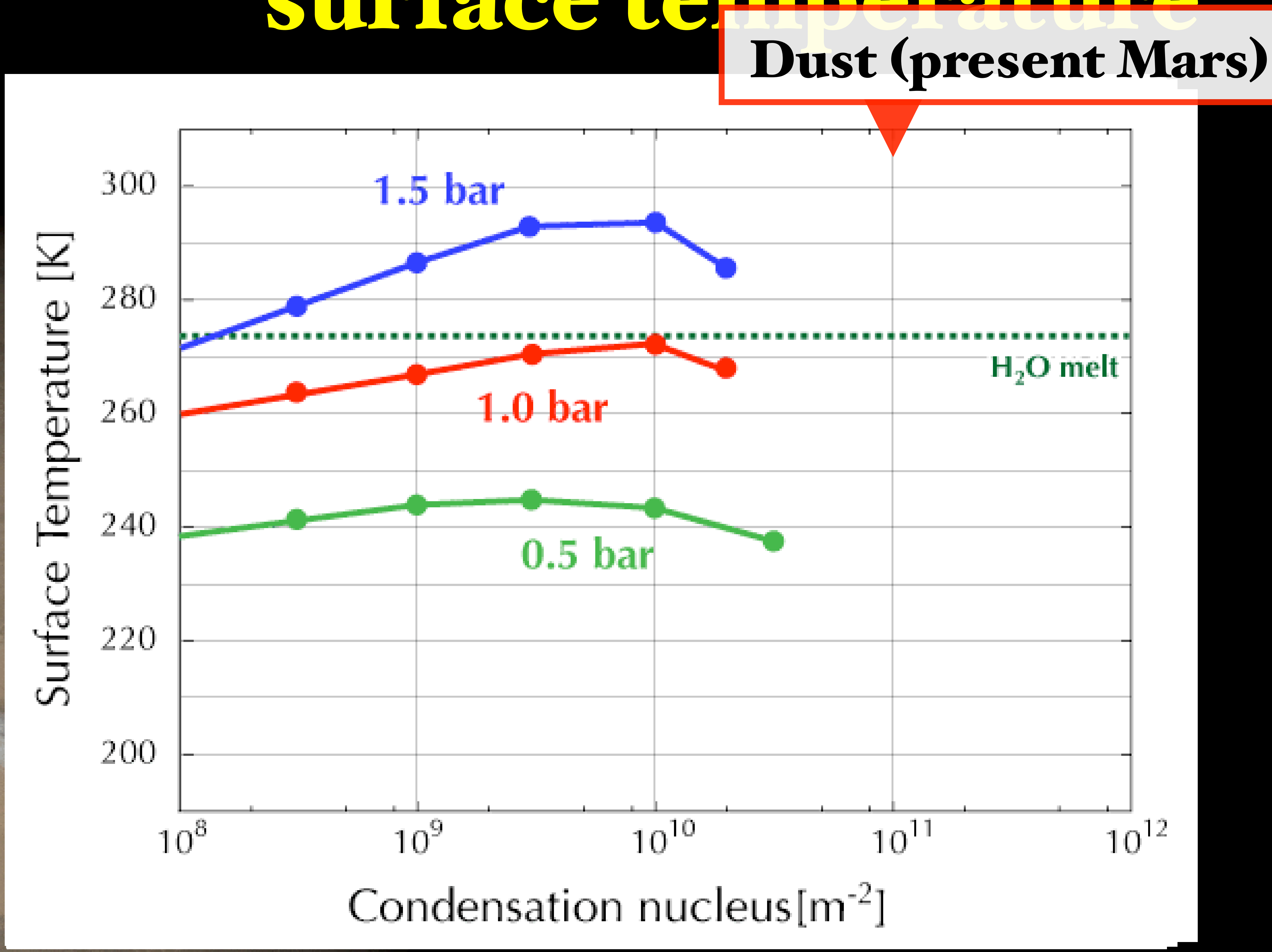


Estimation of surface temperature



NO solution
(Particle size is too small)

Estimation of surface temperature



Conclusion

- We construct simple 1-D radiation model and estimate surface temperature when atmospheric pressure and number of condensation nuclues are fixed.
  - the atmospheric pressure more than about 1 bar is necessary condition of the warm and wet climate on Early Mars.

- By the negative feedback of changes of the particle size and latent heat of condensation, the clouds may stabilize warm climate on early Mars.

References

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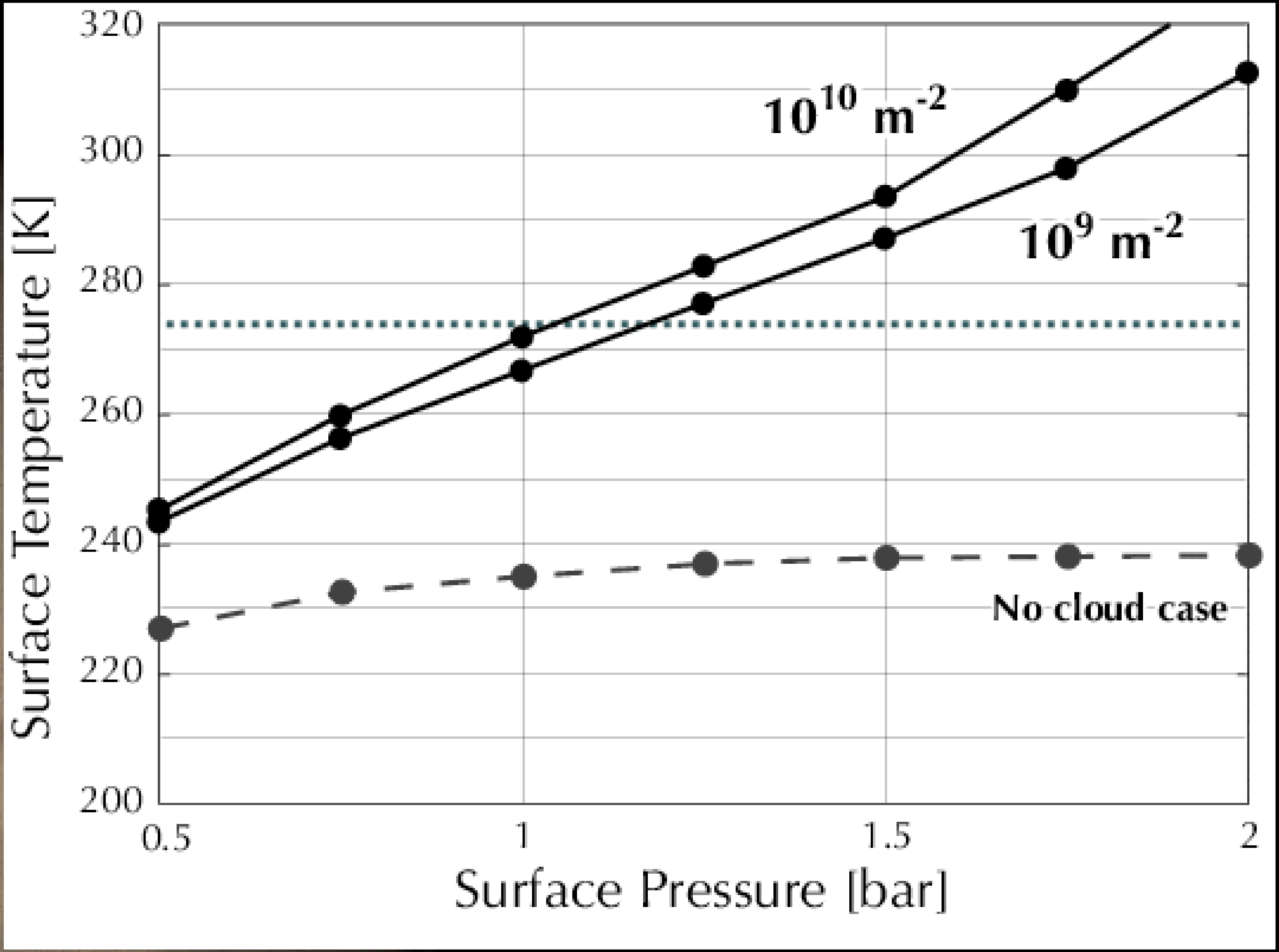
質問, コメント

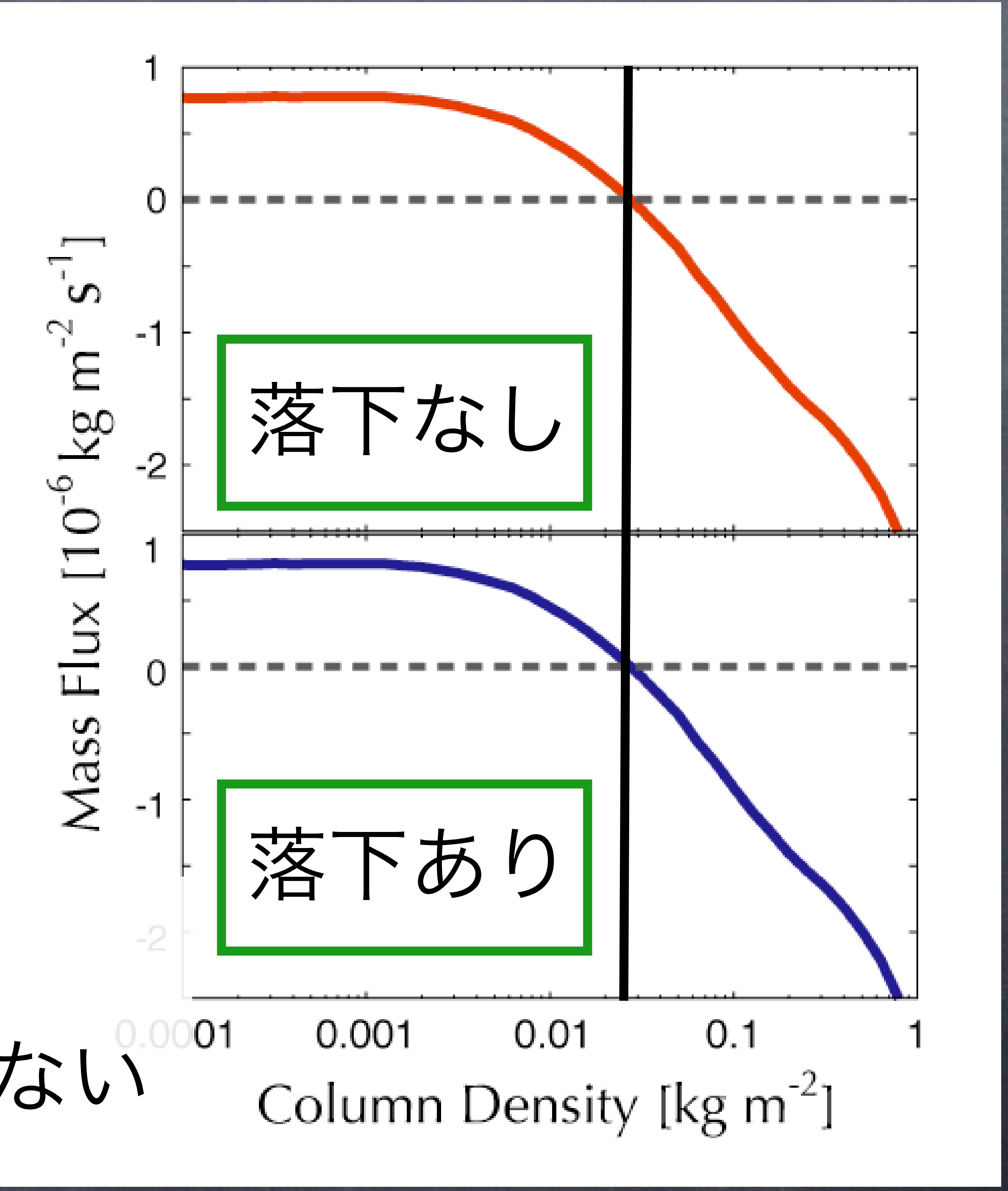
- 凝結核の見積もり方法としてアイデアは? 現在の地球の凝結核は, 海の水しぶきが主である. 過去の火星に海が存在していたならば, 火星の凝結核もそうなることが想像されるので, 地球の凝結核個数の比較はしてみましたか? (じょーじさん)
  - うーん, やってません... やってみます.
- メタンが存在している場合にはどうかわるのか? (Bullock さん)
  - メタンの温室効果も強まるが, おそらく対流圏の上層は放射冷却が効いて冷えるためにより厚い雲が生じるために雲による温室効果も強まり, より気候は暖まると考えている.
  - 要するにメタンが増えたら大気圧が増えた(一層あたりの透過率が下がった)ことと等価なわけで, 地表面温度はあがるのでは? (じょーじさん)
- でもメタンが有ったら成層圏の温度があがるよ(by 大朝さん)
  - 実際に計算してたしかめてみます...(はて? なんでそうなるかは不明, メタンは太陽放射を吸収して地球のオゾンのような役割を果たすとか?? 赤外にしか吸収帯をもっていなければ放射冷却がより強く効くはずなのに...??)
- 凝結核が存在しない場合にも凝結は生じるはずでは?(今村さん)
  - 今回は凝結核がたくさん有る場合を考えているので, その効果は無視できる程度だと考えている.

地表面温度の大気圧依存



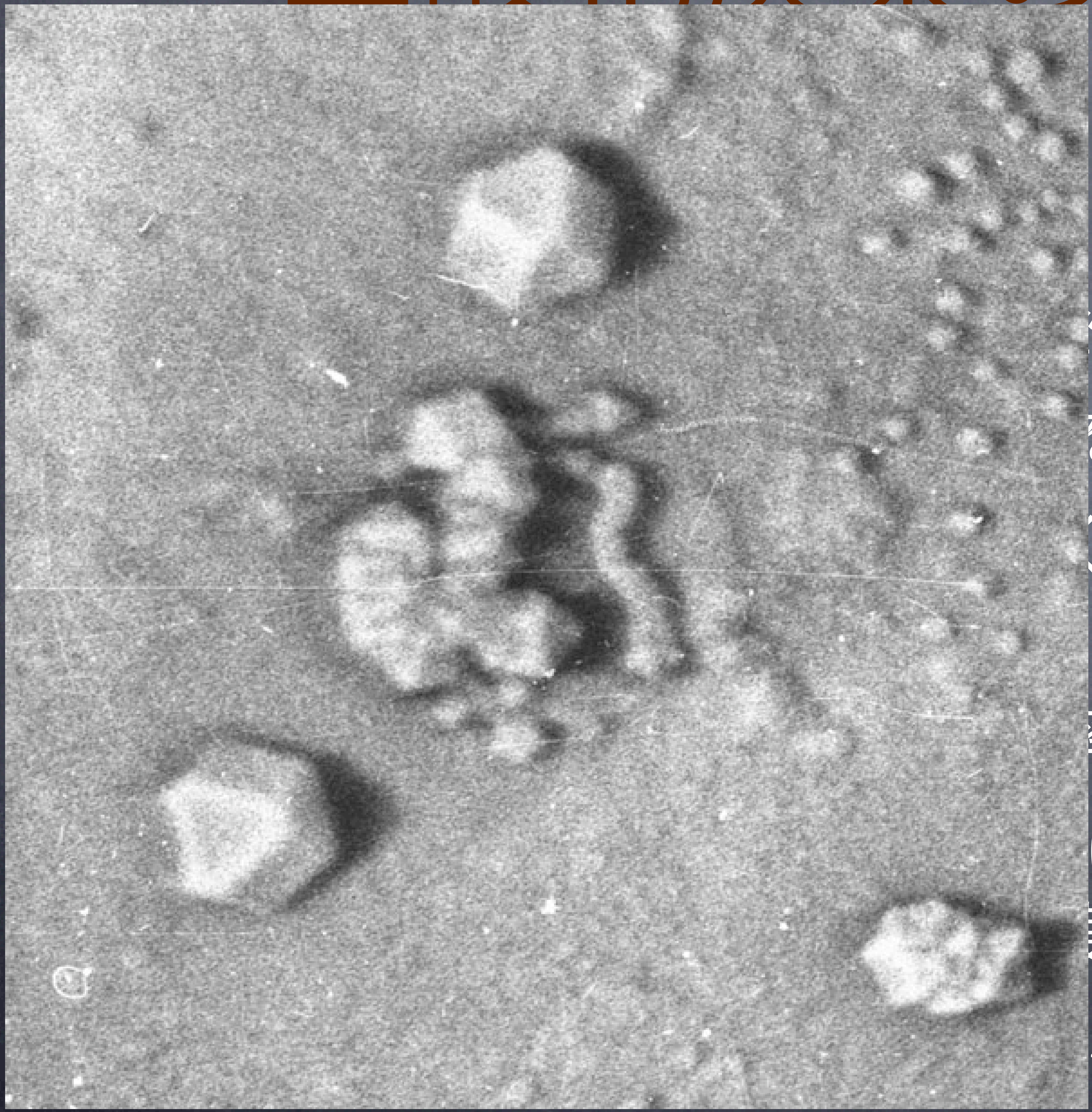
議論: 雲粒落下の影響

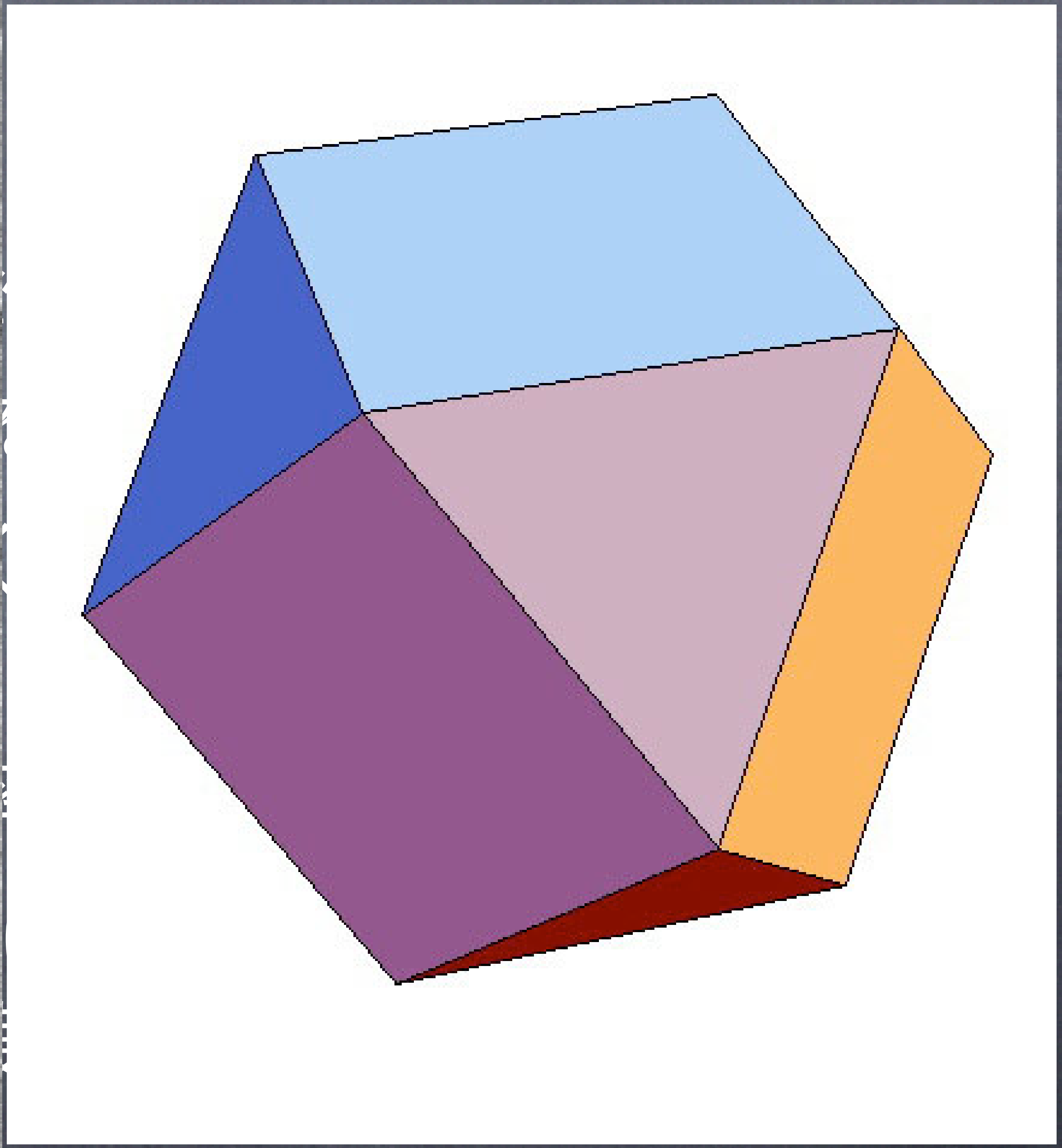
- 落下量の見積もり
  - ストークス沈降速度
  - 雲の鉛直構造は一様
  - 雲層外に出た雲粒は蒸発



雲粒落下を考慮しても
雲面密度の見積もりは変わらない

二酸化炭素の結晶構造

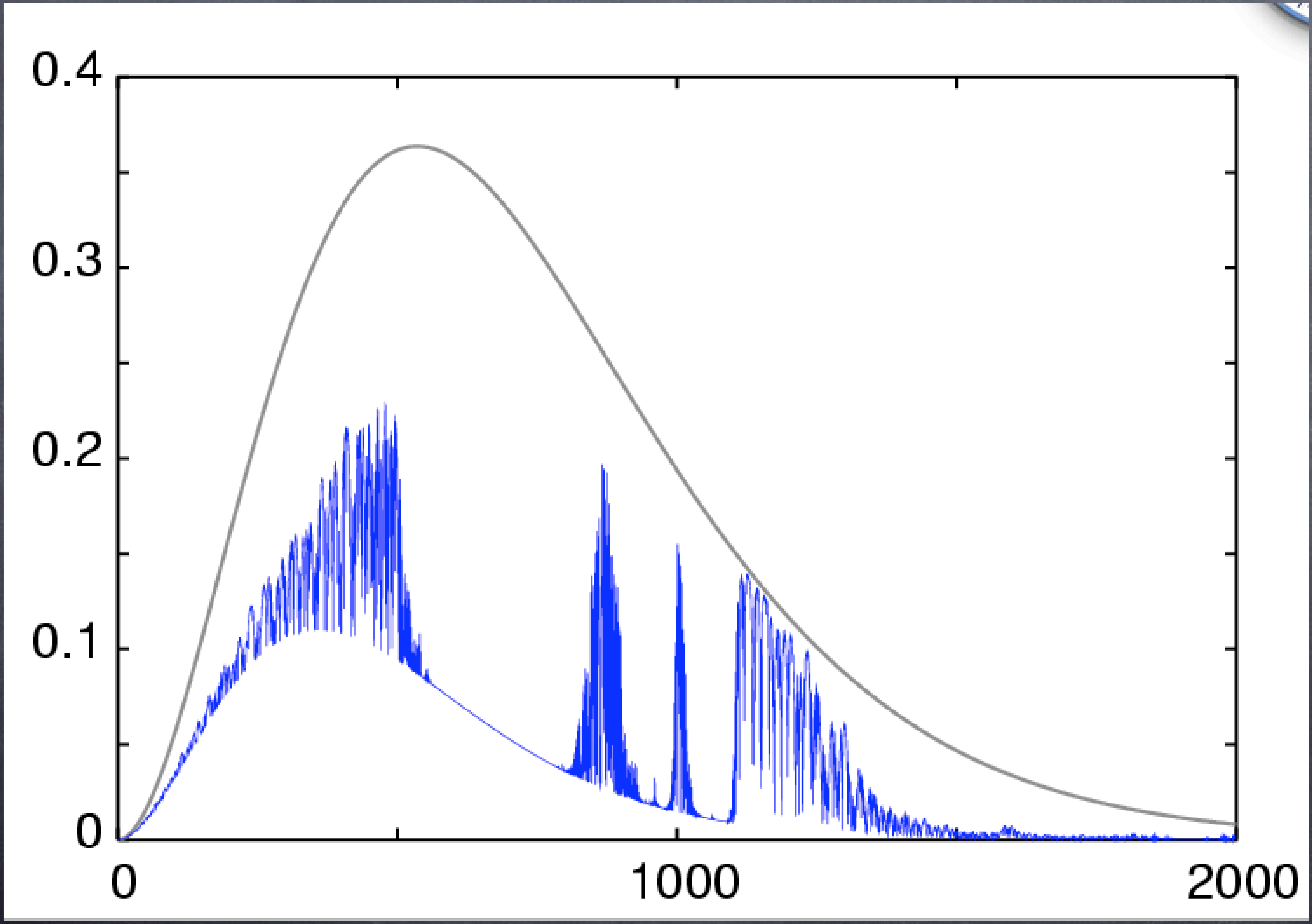




4snowflakes/cuboctahedronrh400.jpeg

http://www.exo.net/~pauld/Mars/4snowflakes/snowflakes200.jpeg

雲への入射スペクトル



地球型惑星の比較

	火星	地球	地球 (堆積岩)	金星
大気組成 N2 O2 Ar CO2	 2.7 - 1.6 95.3	 78.1 20.9 0.9 0.035	 1.0 - 0.01 99.0	 1.8 - 0.02 98.1
CO2 分圧 [bar]	6x10^-3	10^-4	80	90