Radiative constraints on the habitability of exoplanets Gliese 581c and d

Feng Ding

Advisor: Yongyun Hu

Dept. of Atmospheric Sciences

Peking University

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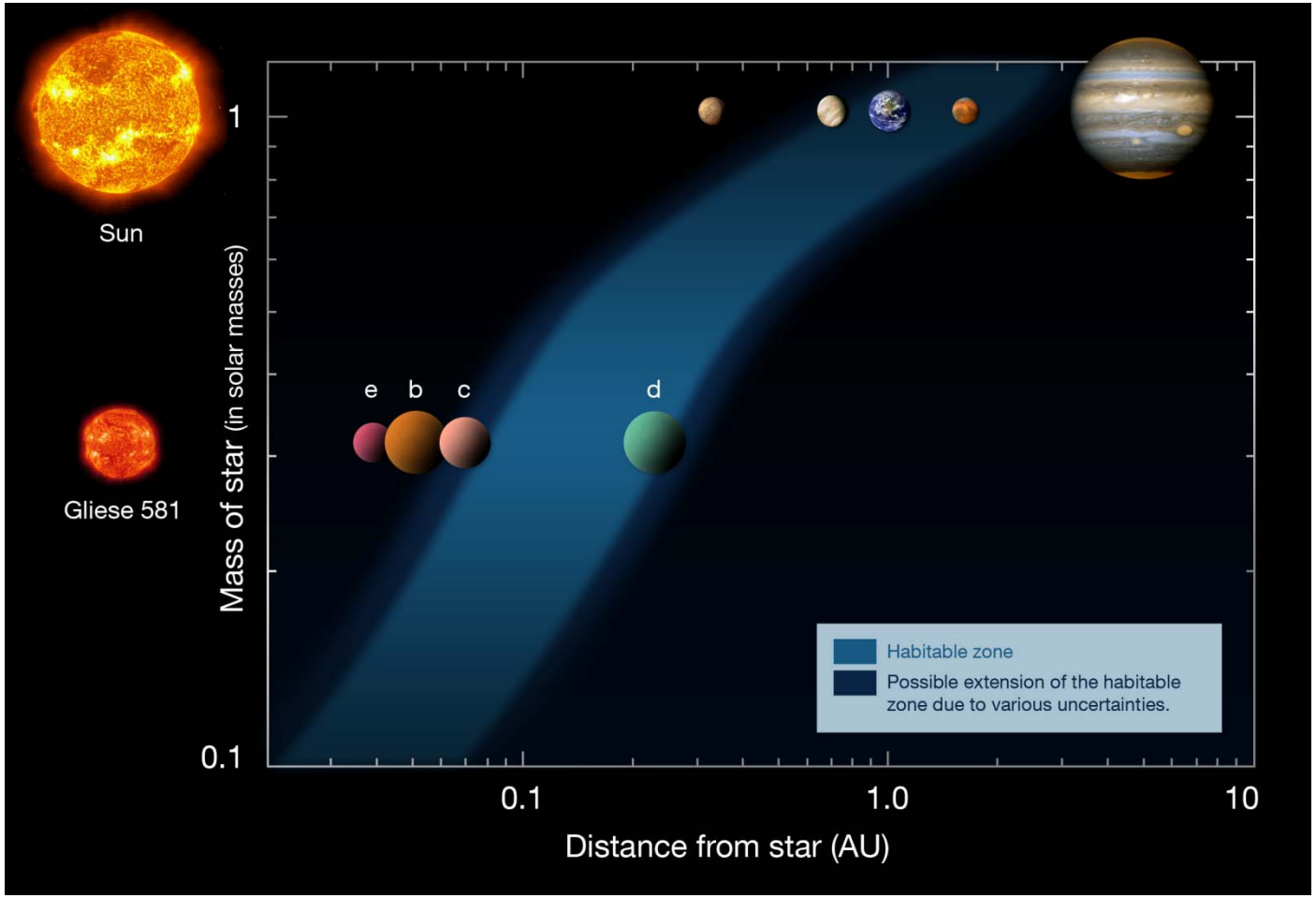
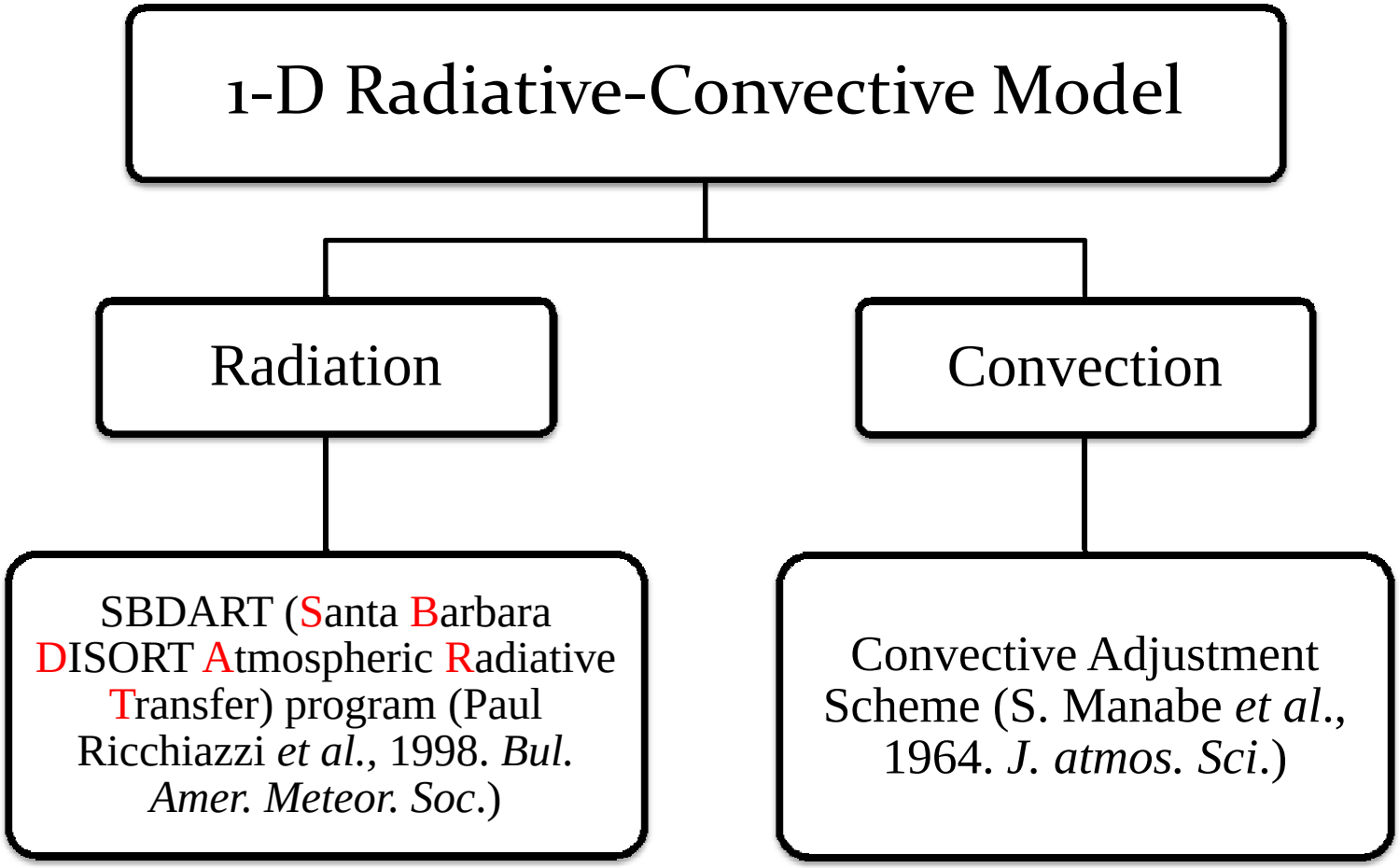
Habitable Zone in the Solar System and Gliese 581 System & Two Super-Earths



Based on a diagram by Franck Selsis (University of Bordeaux)

Surface Habitability

- Permanent liquid water can exist on the planet's surface (Ts, subsurface…)
- Planetary mass: 0.5~10 $M_{\oplus}$ (geophysical process, outgassing of **CO_2** and **H_2O**)
- Average stellar flux (tidal locking, high eccentricity…) $< d > = a\sqrt{1-e^2}$



Simple but practical

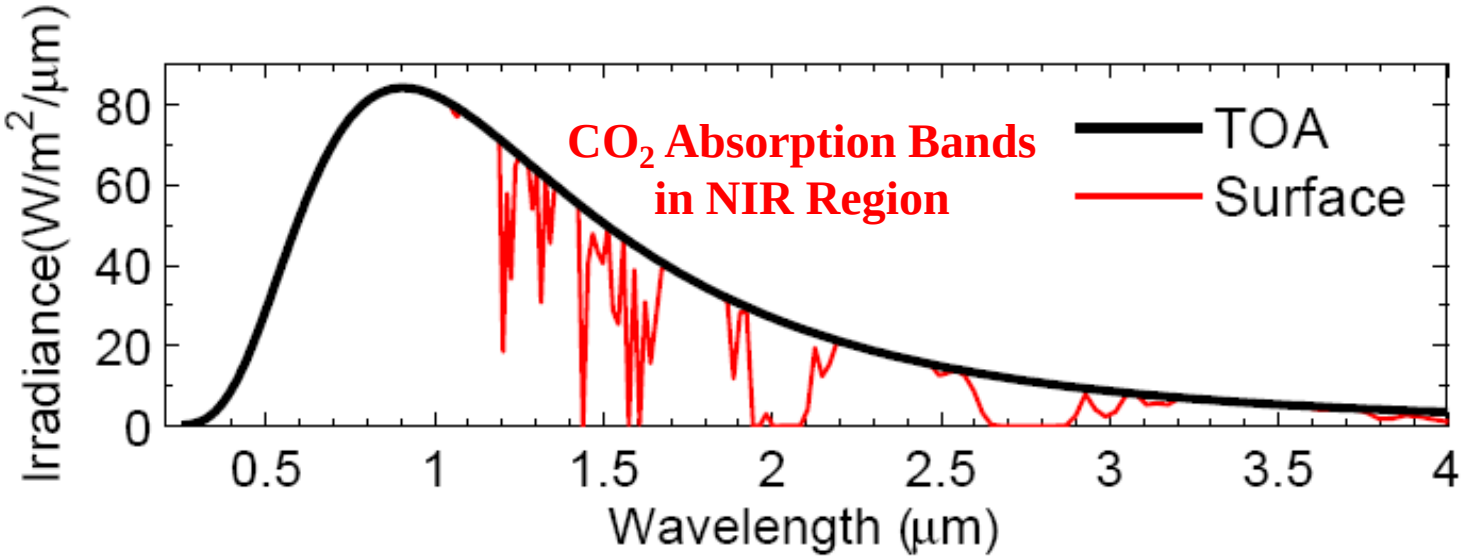
Part I: The case of Gliese 581d

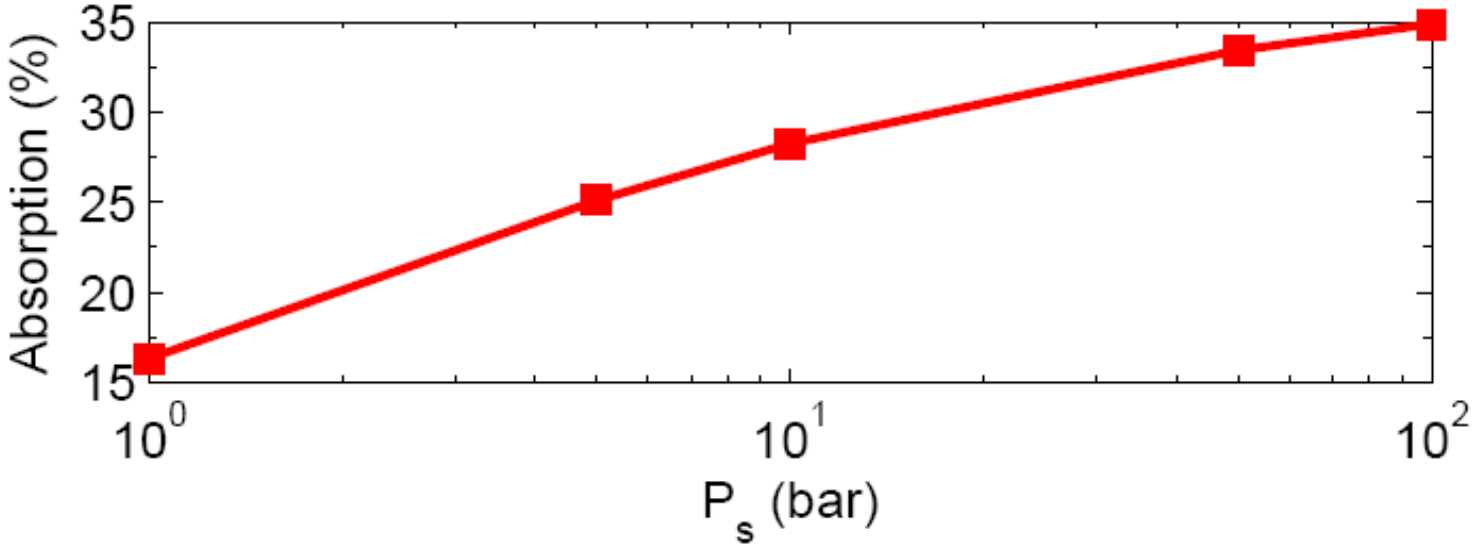
Planet	$M_{min}/M_{\oplus}$	$R_{min}/R_{\oplus}$	a (AU)	e
Gl 581d	7.09	1.8-2.2	0.22	0.38±0.09

F. Selsis *et al.*, 2007 & M. Mayor *et al.*, 2009

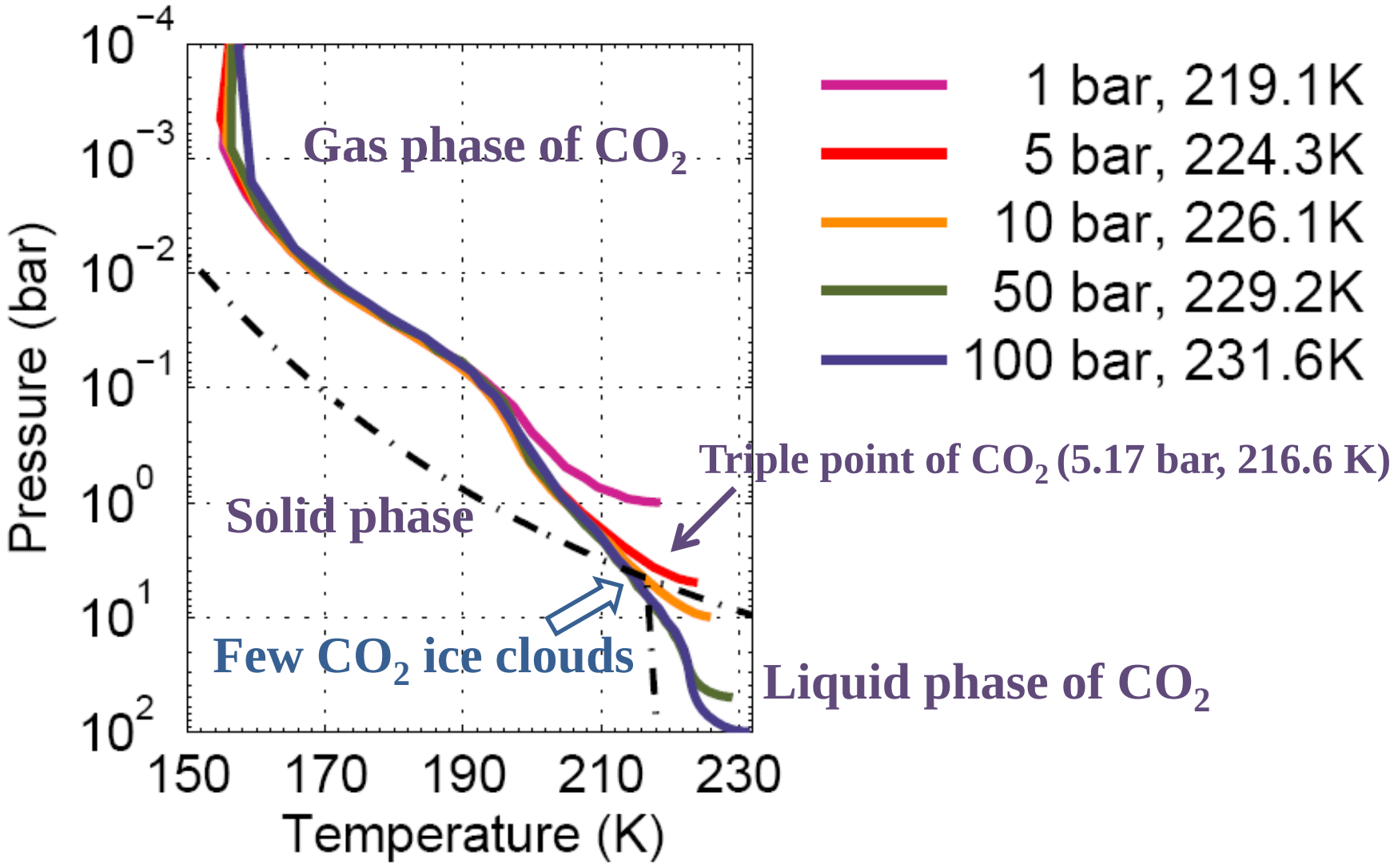
- Average stellar flux: ~112.18 W/m^2
- Strong greenhouse effect – high level of CO_2…

Anti-greenhouse effect of CO_2(1)

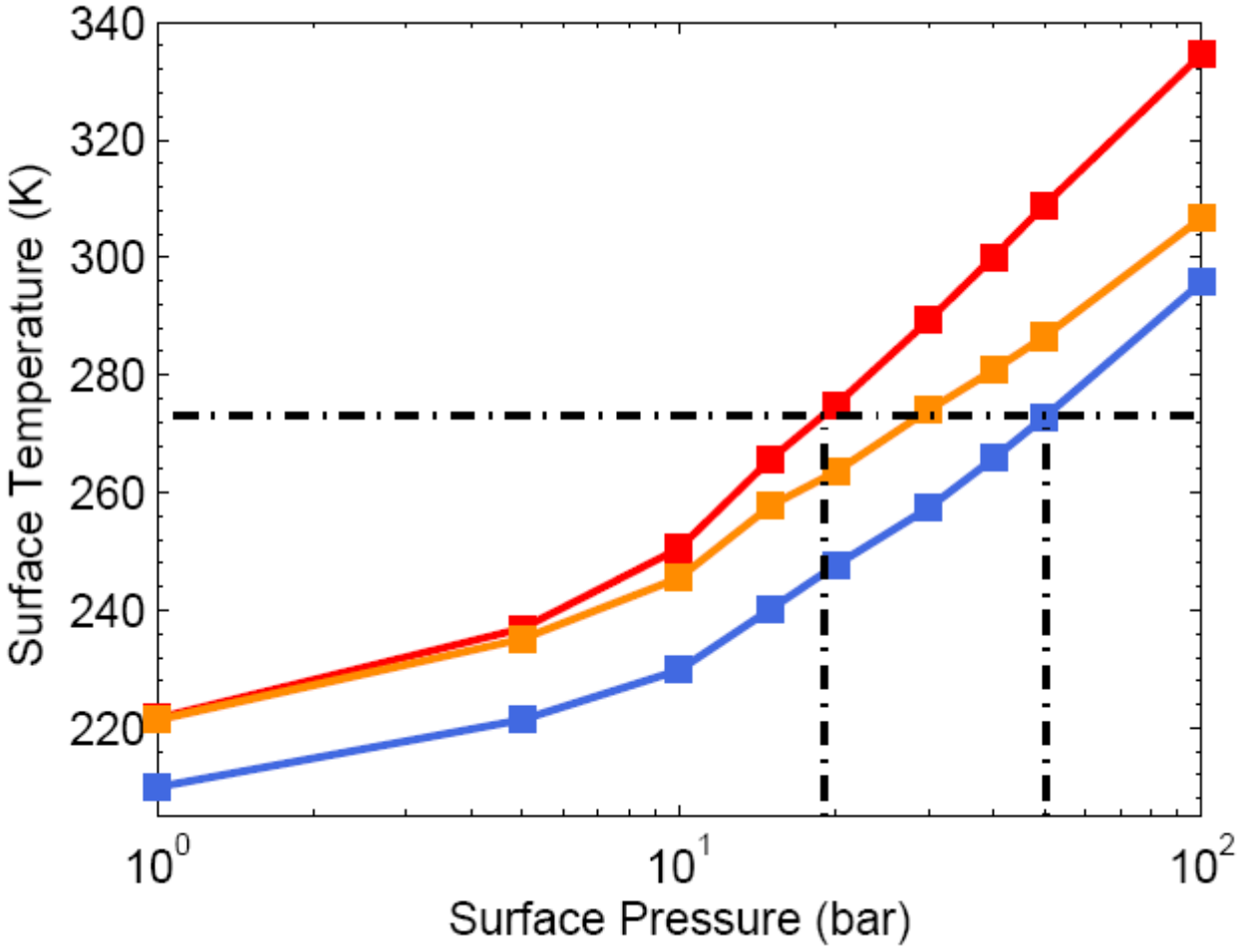




Anti-greenhouse effect of CO_2(2)



Fixed relative humidity following Manabe & Wetherald (1967)



Red line: dry adiabatic lapse rate + 0.15 surface albedo

Orange line: empirical adiabatic lapse rate + 0.15 surface albedo

Blue line: empirical adiabatic lapse rate + 0.30 surface albedo

18.24 ~ 48.81 bar CO_2 are required to raise the surface temperature above freezing point

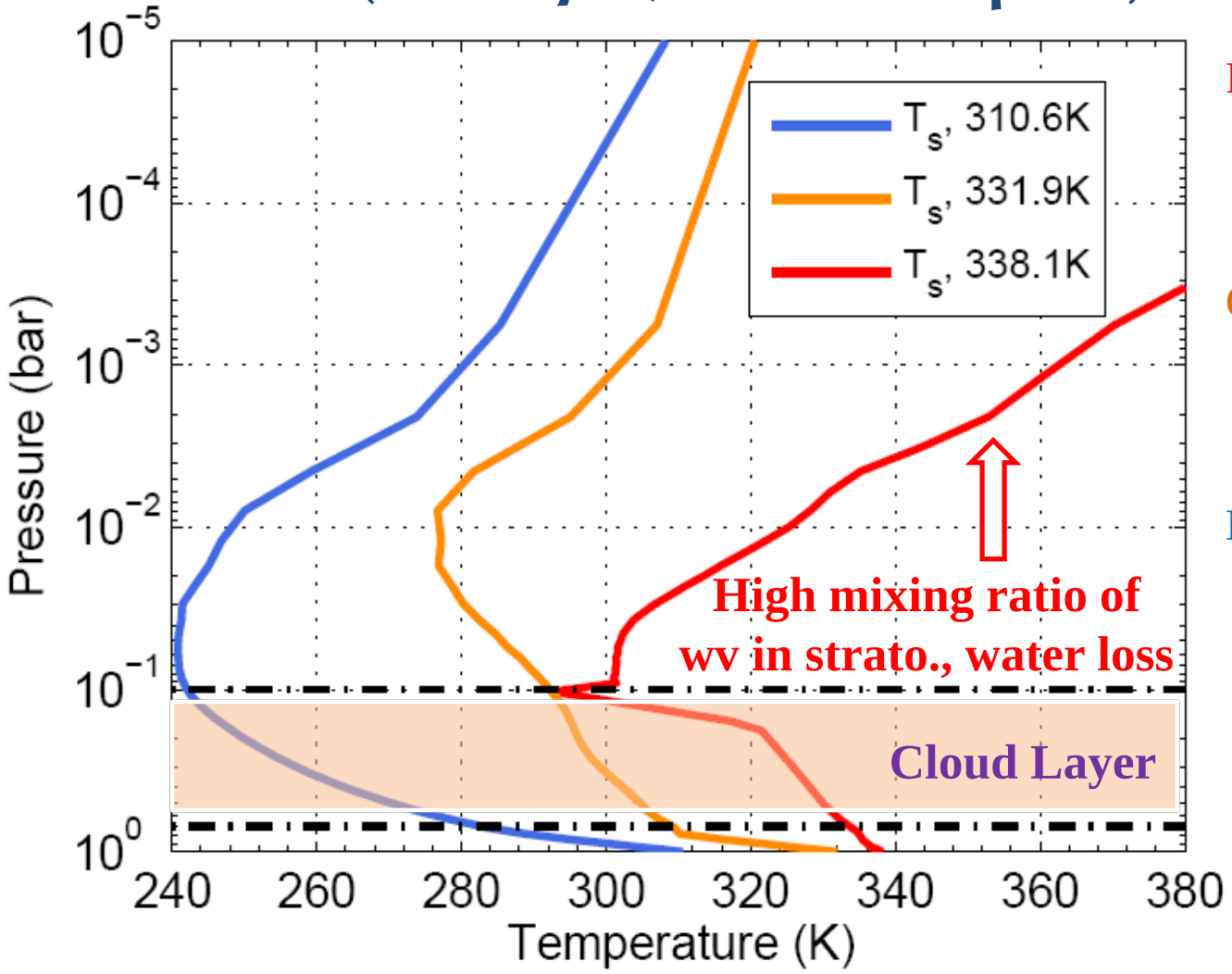
Part II: The case of Gliese 581c

Planet	$M_{min}/M_{\oplus}$	$R_{min}/R_{\oplus}$	a (AU)	e
Gl 581c	5.36	1.6-2.0	0.07	0.17±0.07

F. Selsis *et al.*, 2007 & M. Mayor *et al.*, 2009

- Average stellar flux: ~ 976.30 W/m^2
- Weak greenhouse effect, high planetary albedo
  - low level of CO_2, thick convective clouds …

High planetary albedo, due to thick clouds (τ =270, r = 20 μm)



Red line: 50ppmv CO_2 + fixed relative humidity profile + Cloud Layer

Orange line: 50 ppmv CO_2 + same amounts of water vapor as in Earth's atmosphere

Blue line: 50ppmv CO_2 only

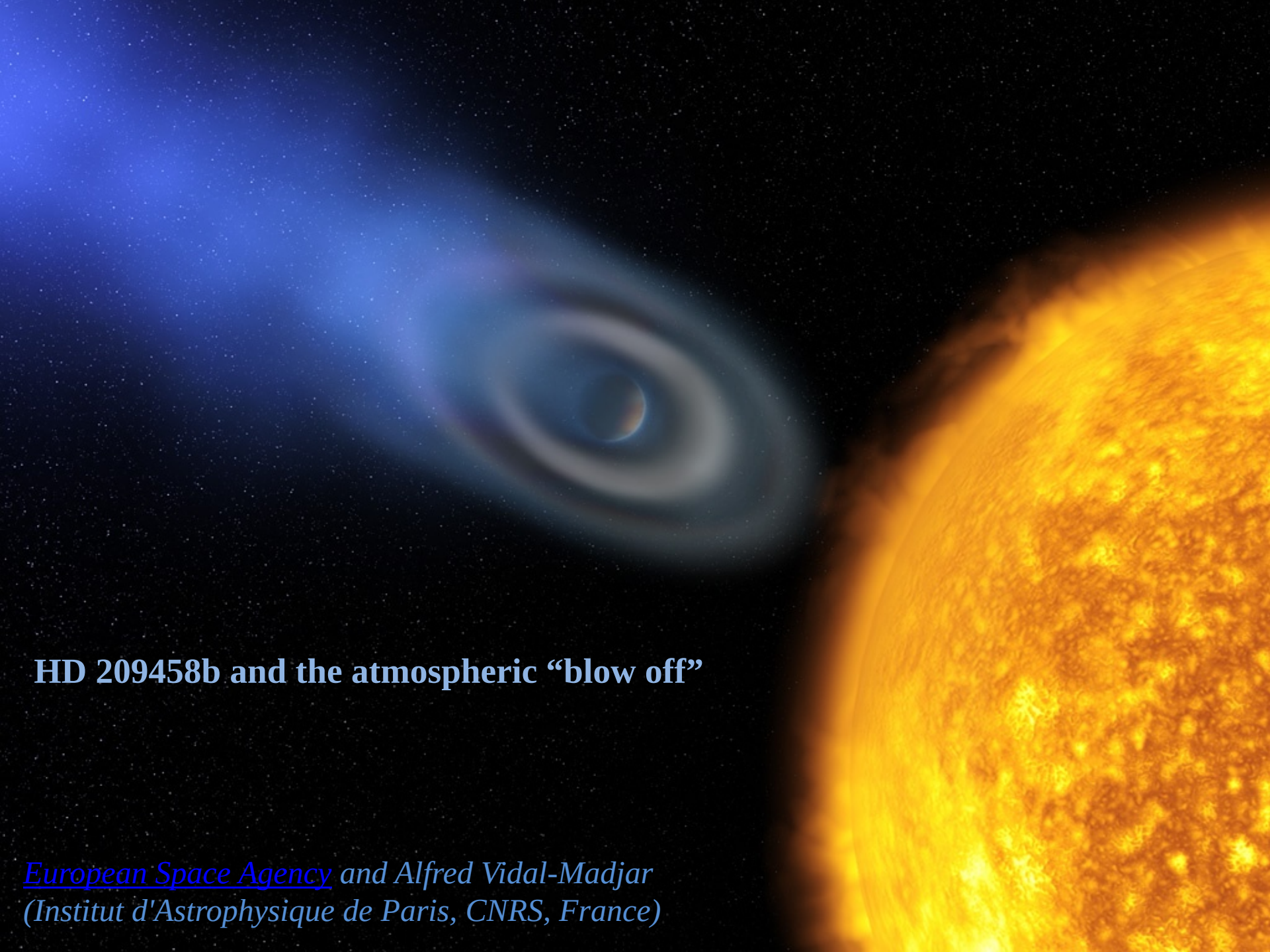
Ts > ~340 K, the runaway greenhouse effect may be triggered

Conclusion & Discussion

1. For Gl 581d, at least 18.24 bars of CO_2 are required. How such high-level CO_2 can be maintained remains an unanswered question.

   Aqua-planet? Oscillating state?

2. For Gl 581c, it is very likely that the planet had undergone runaway greenhouse like Venus because of the implausibility of high planetary albedo due to extremely thick clouds, and the ineffectiveness of the cold trap to prevent the loss of water.
3. Will the prediction of the models be justified by observations?



HD 209458b and the atmospheric “blow off”

European Space Agency and Alfred Vidal-Madjar
(Institut d'Astrophysique de Paris, CNRS, France)