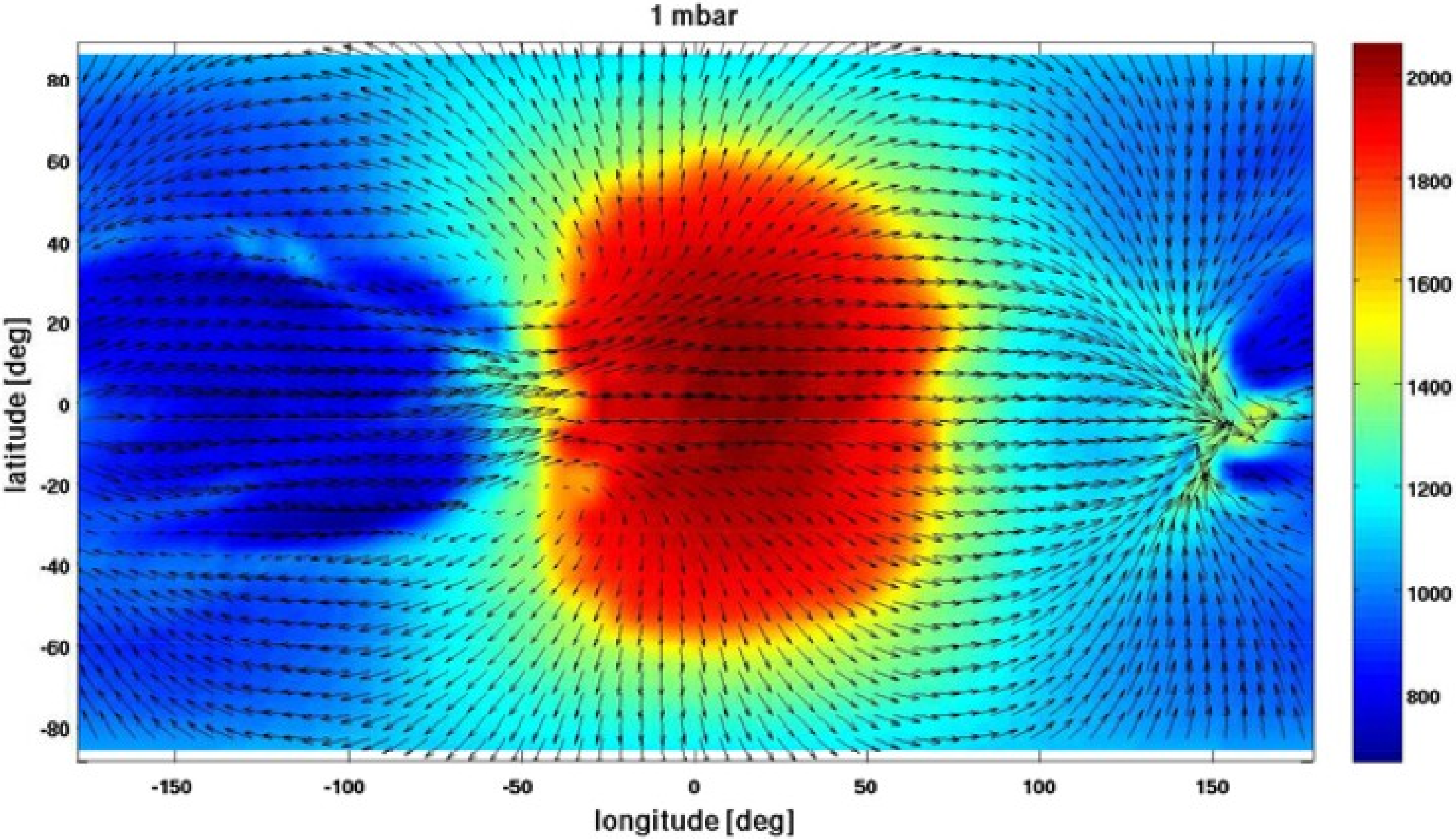
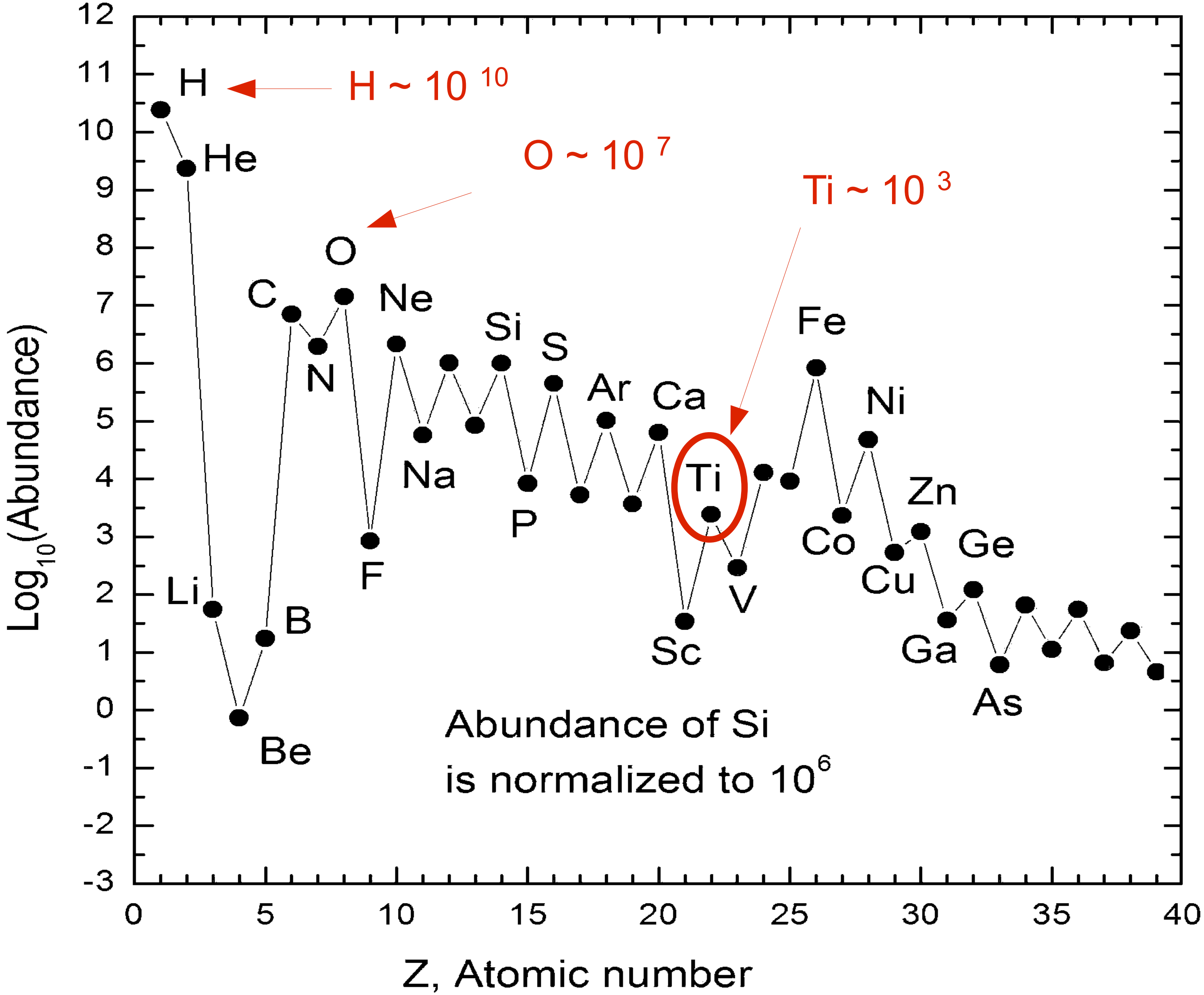
Day/night cold trap of TiO in hot Jupiters atmospheres

Vivien Parmentier
with Adam Showman



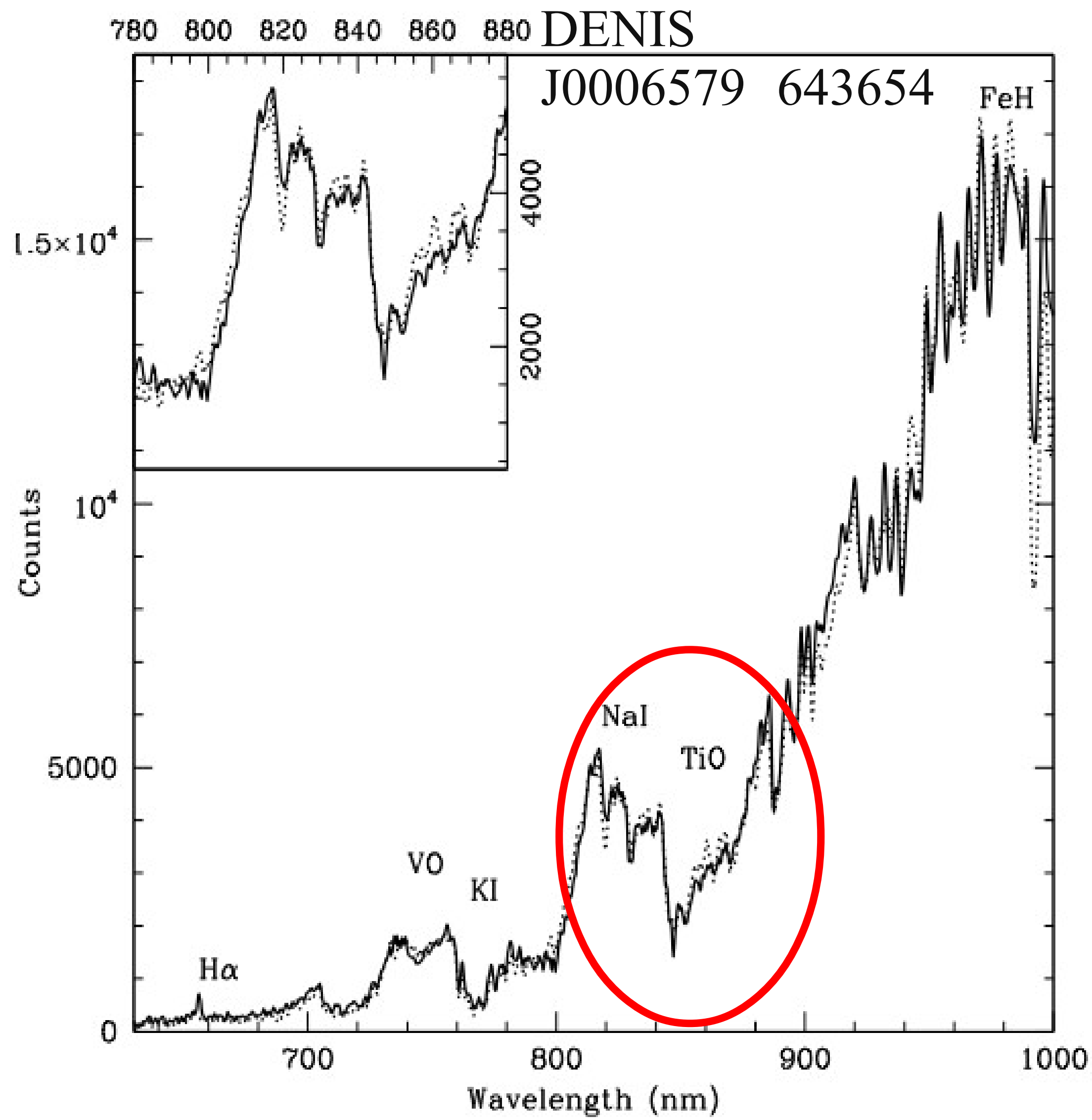
Background : Abundance of Ti the solar nebula.



Background : presence of TiO/VO in brown dwarf

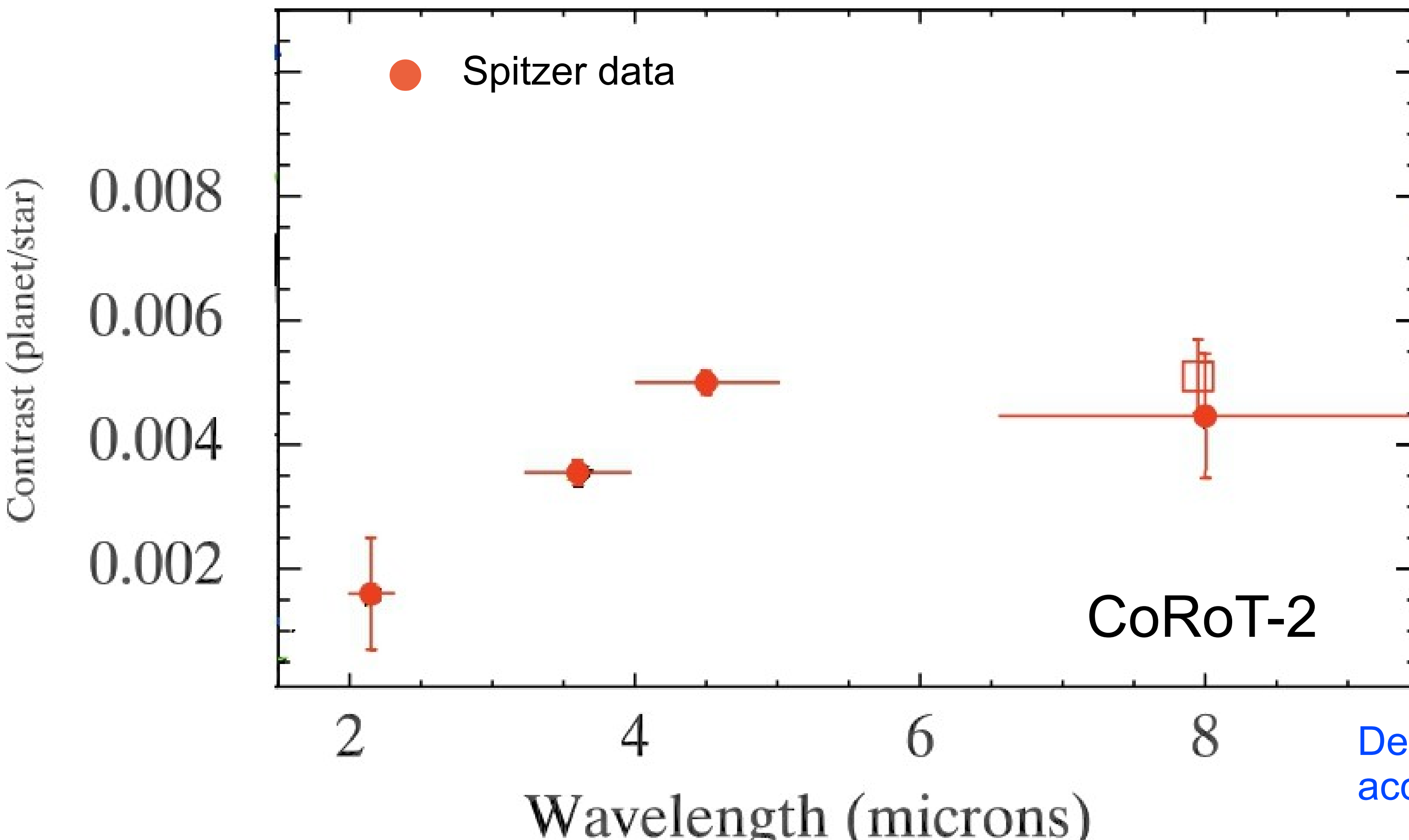
TiO : Titanium oxyde

The presence of the TiO absorption band define the separation between M dwarf and L dwarf.



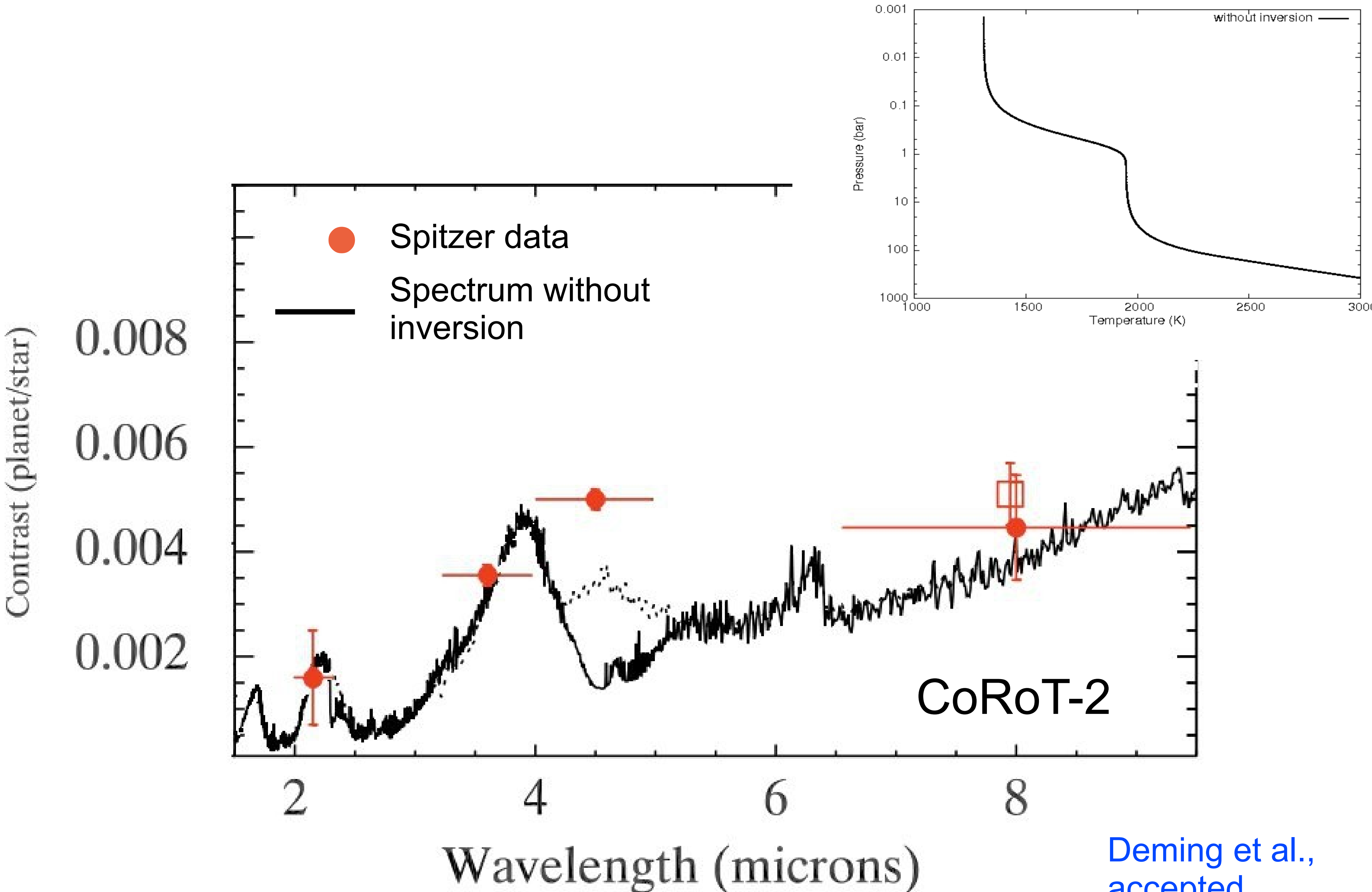
Martin et al. 2010

Background : presence of TiO in hot Jupiter atmospheres ?



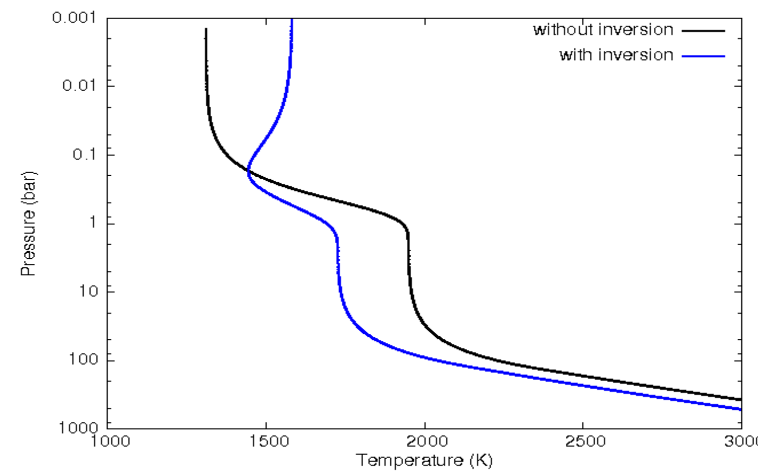
Deming et al., accepted

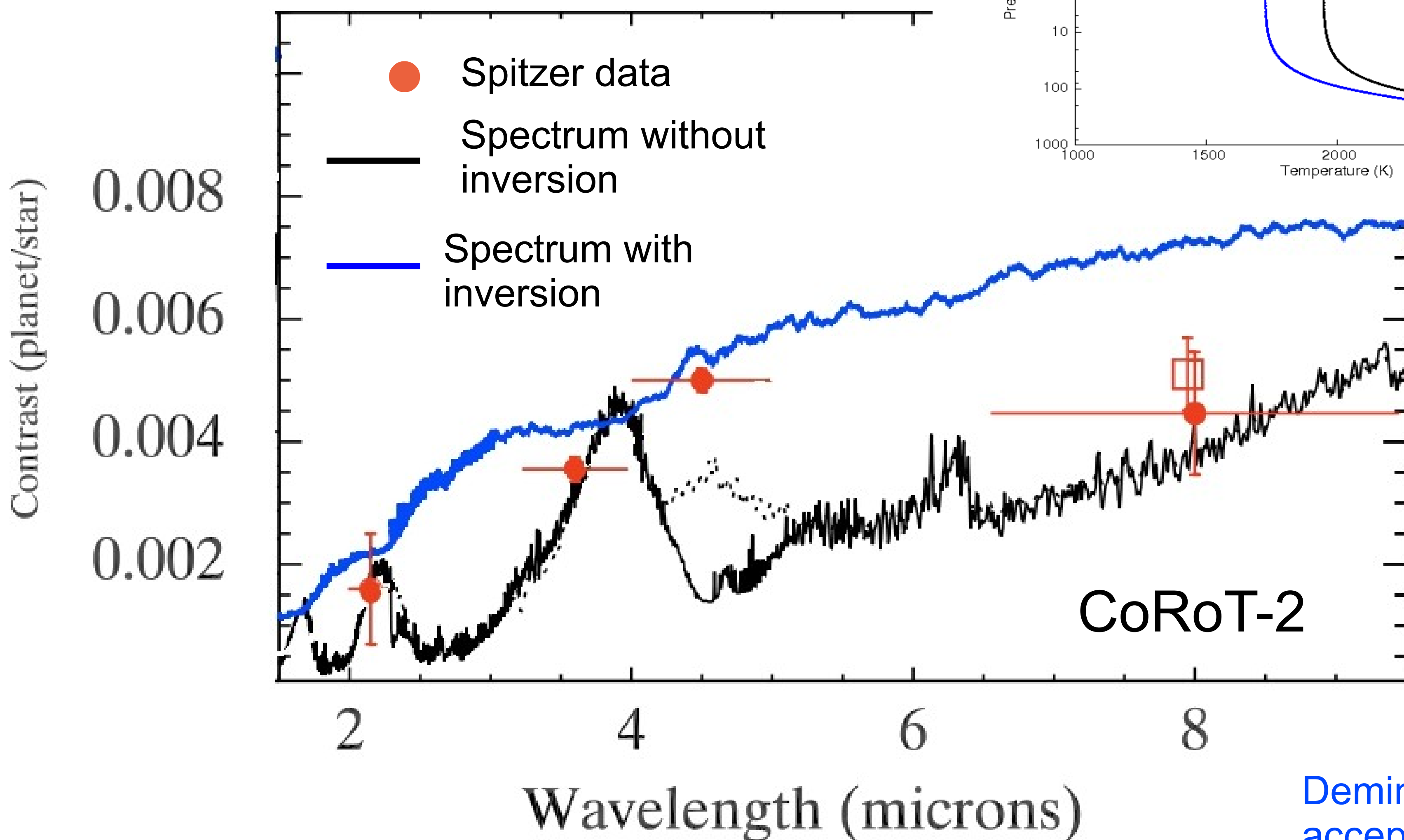
Background : presence of TiO in hot Jupiter atmospheres ?



Deming et al., accepted

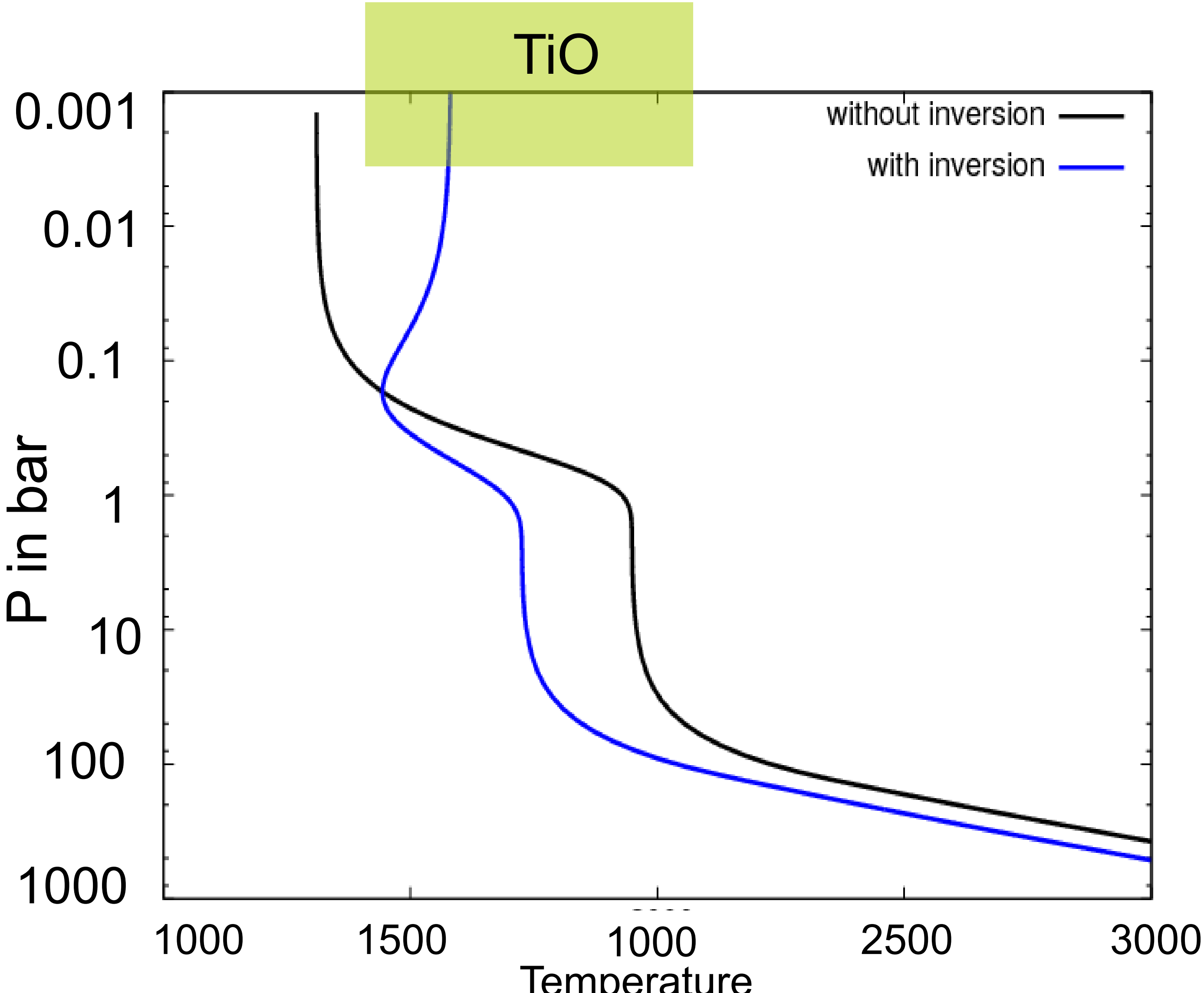
Background : presence of TiO in hot Jupiter atmospheres ?





Deming et al., accepted

Background : Temperature inversion due to TiO



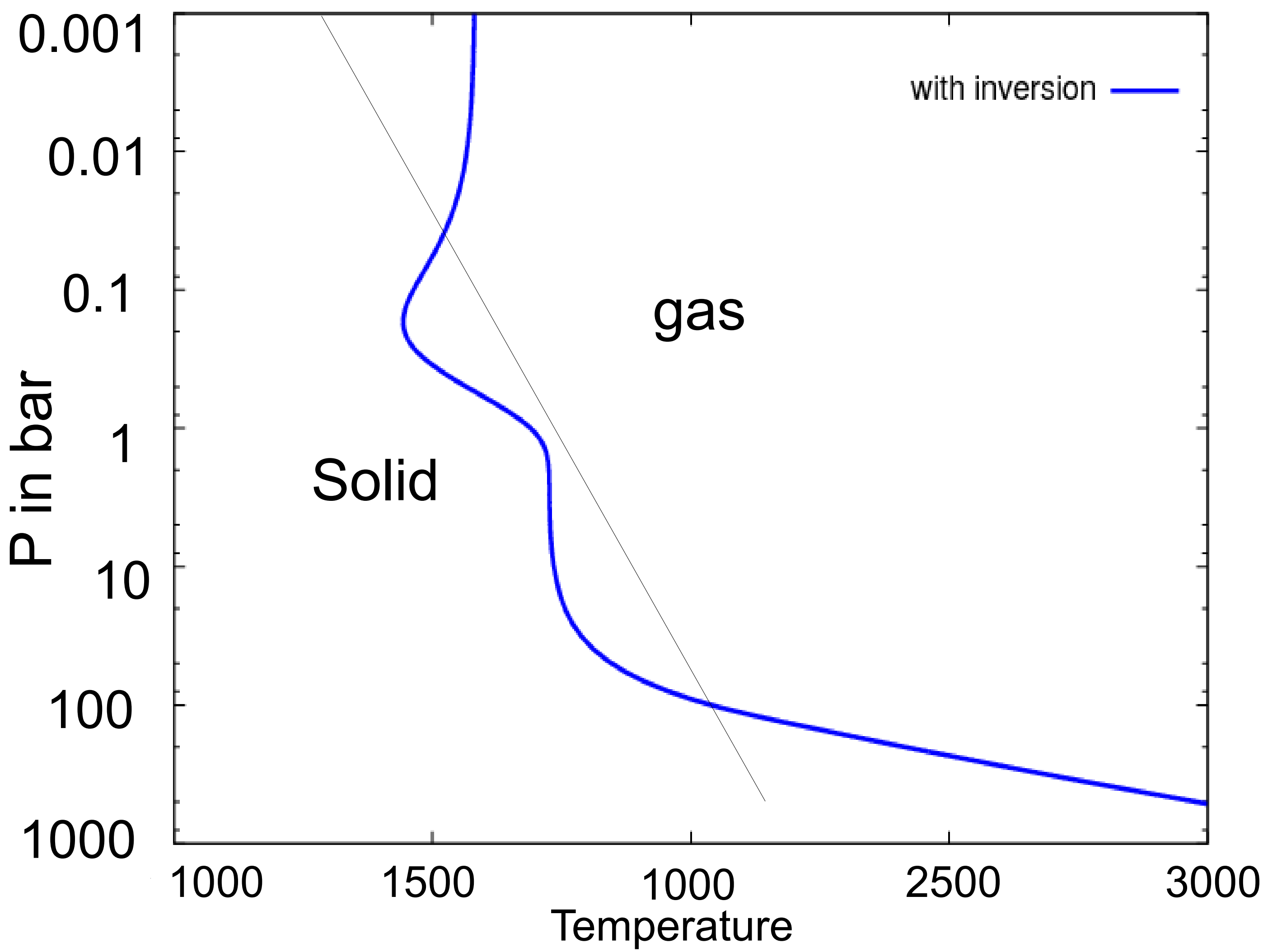
The presence of a visible absorber in the upper atmosphere warm it and create a temperature inversion

→ Condition : f_{TiO}= 0.5 f_0 between 1mBar and 0.1mBar

(Spiegel et al. 2009)

Background : Vertical cold trap

Particles diffuse to the cold region, condense and settle down.



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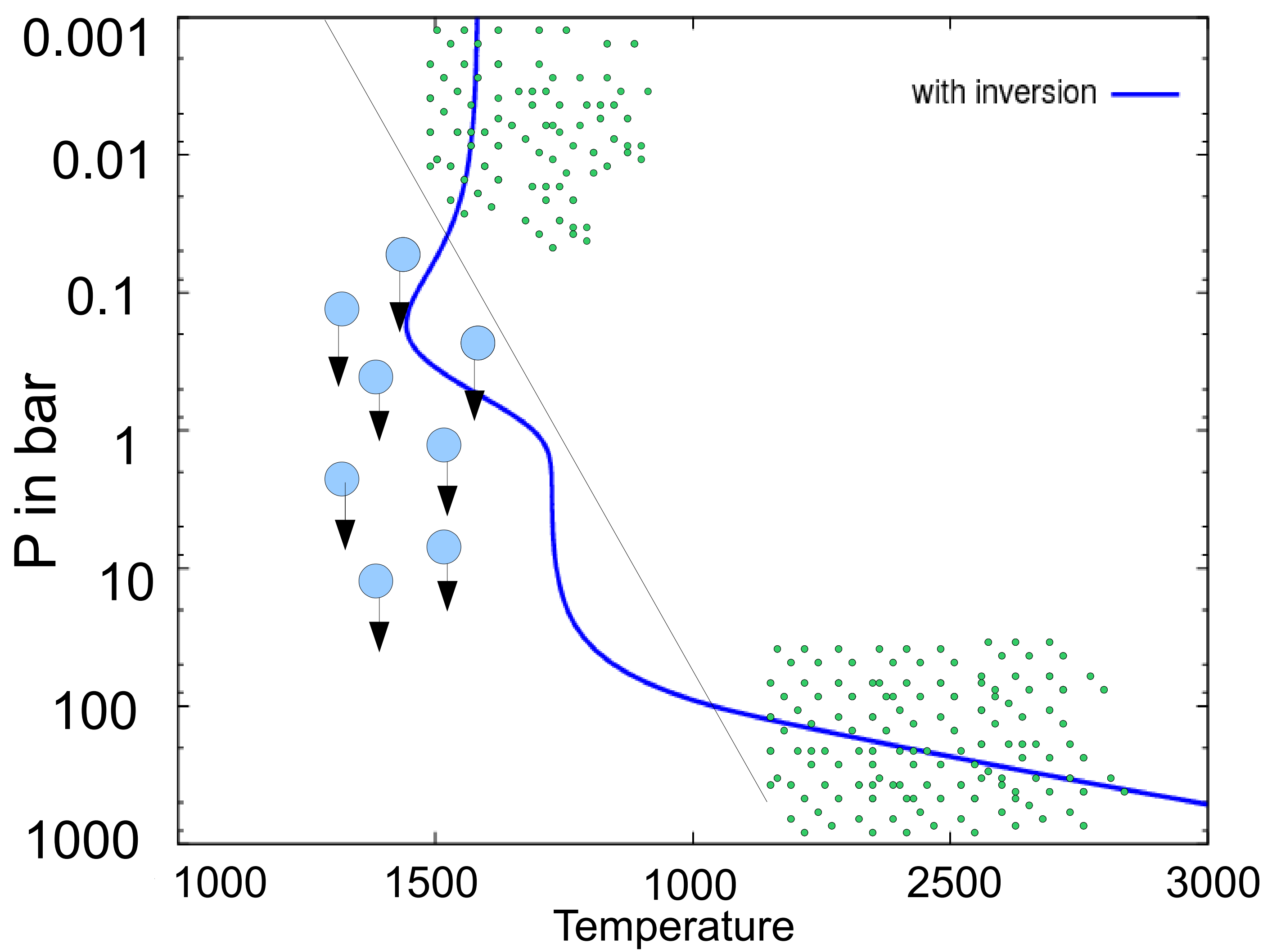

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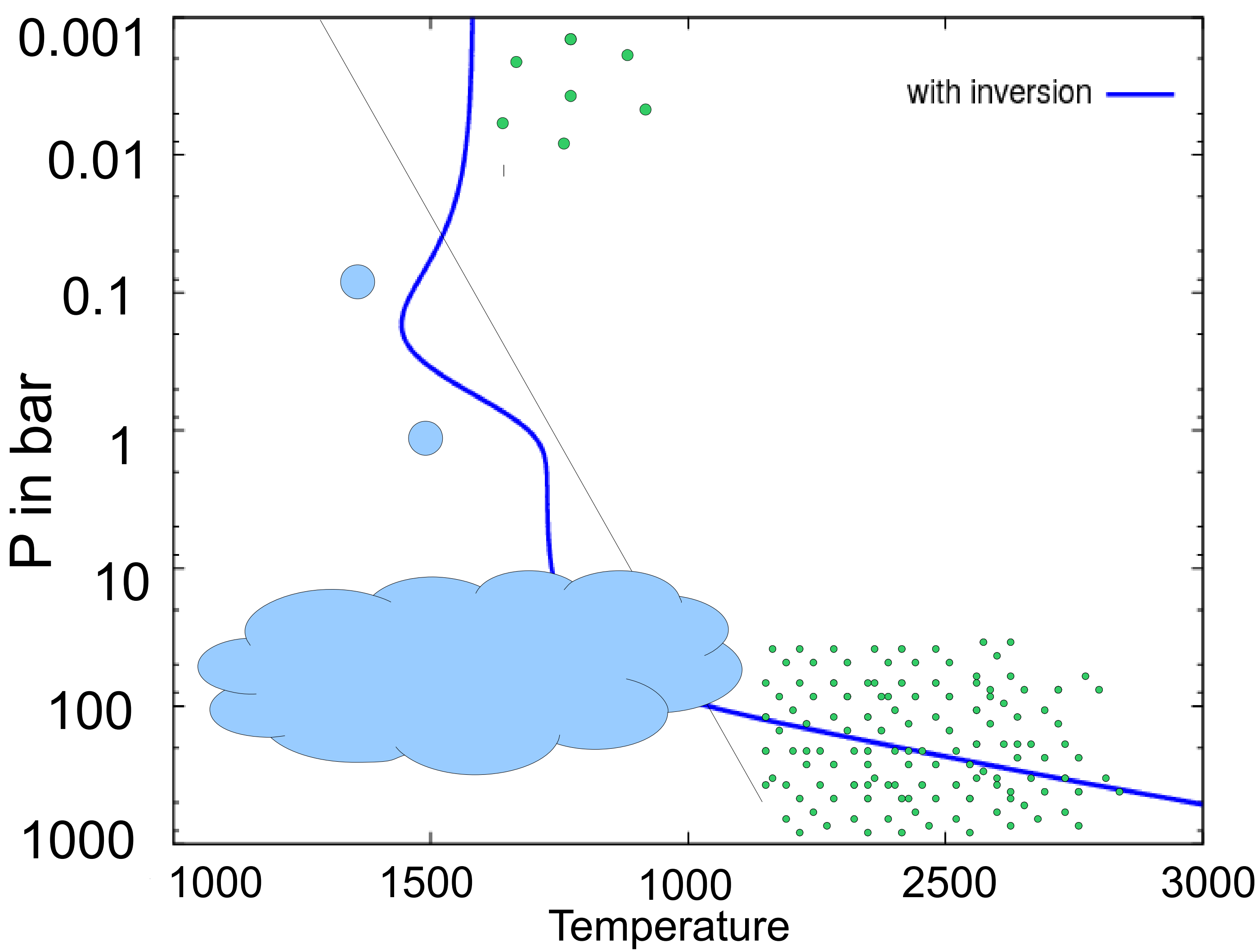
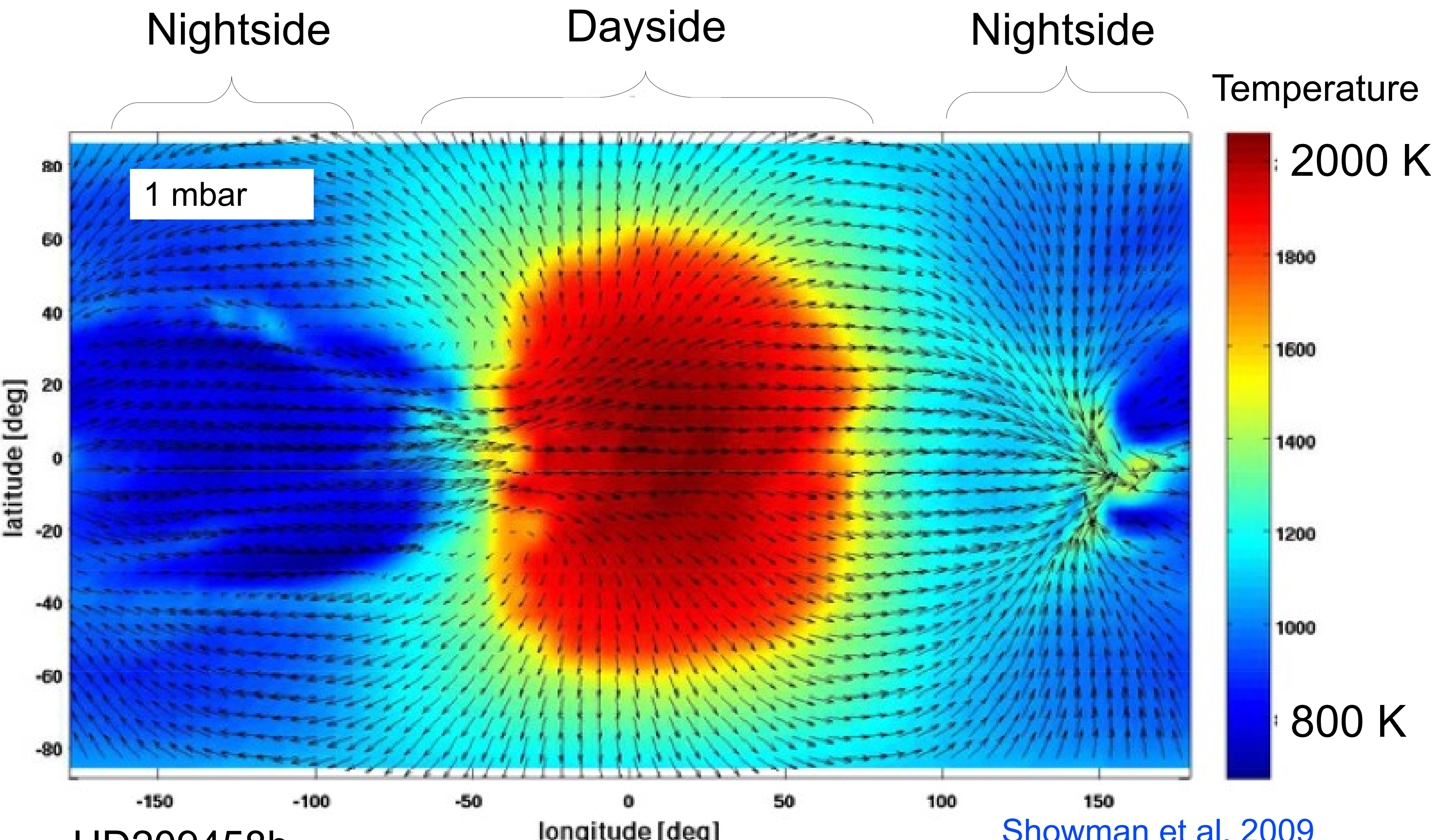


→ The hight atmosphere is depleted in the species.

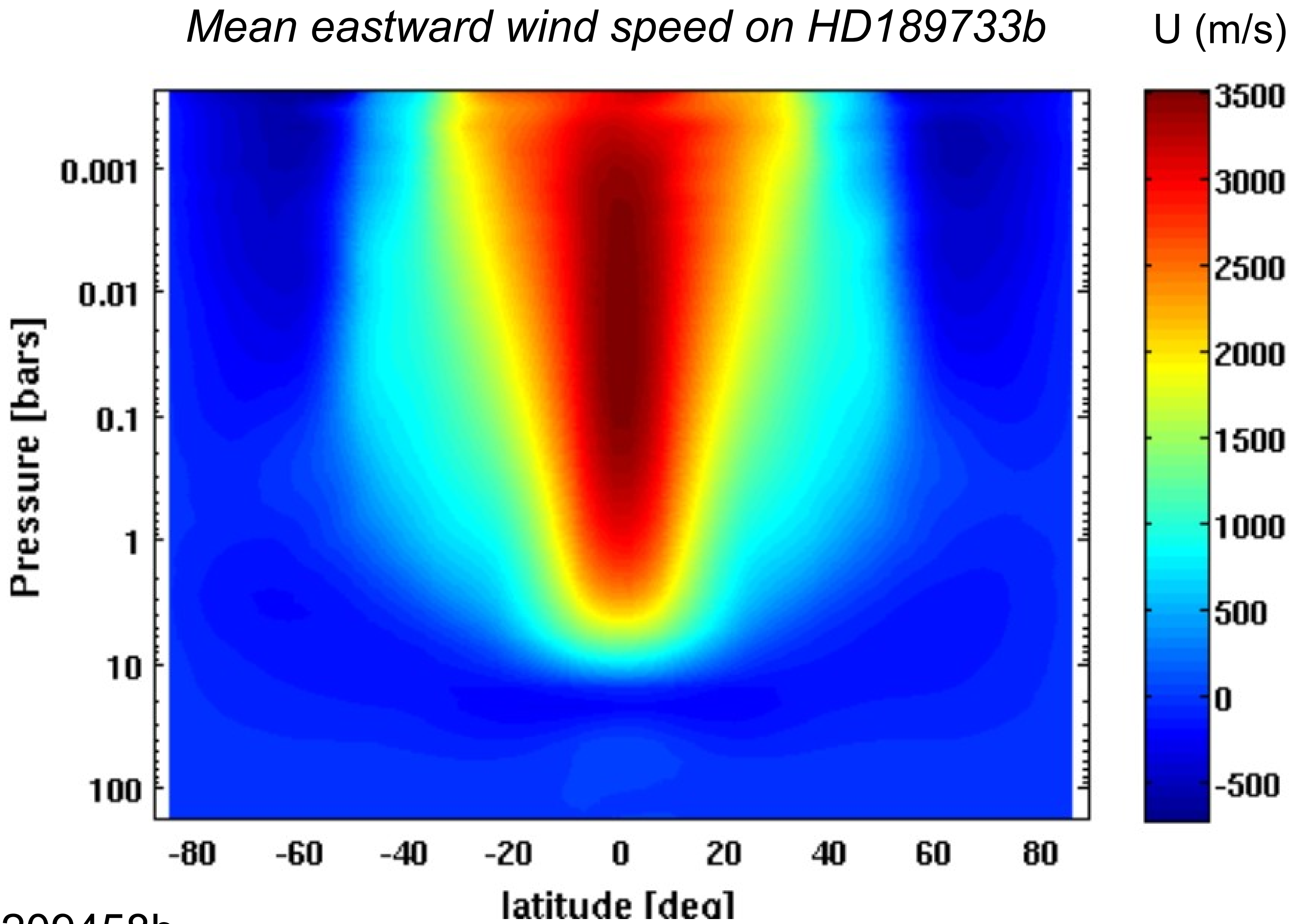
Background : Day/night temperature contrast on hot Jupiter



HD209458b

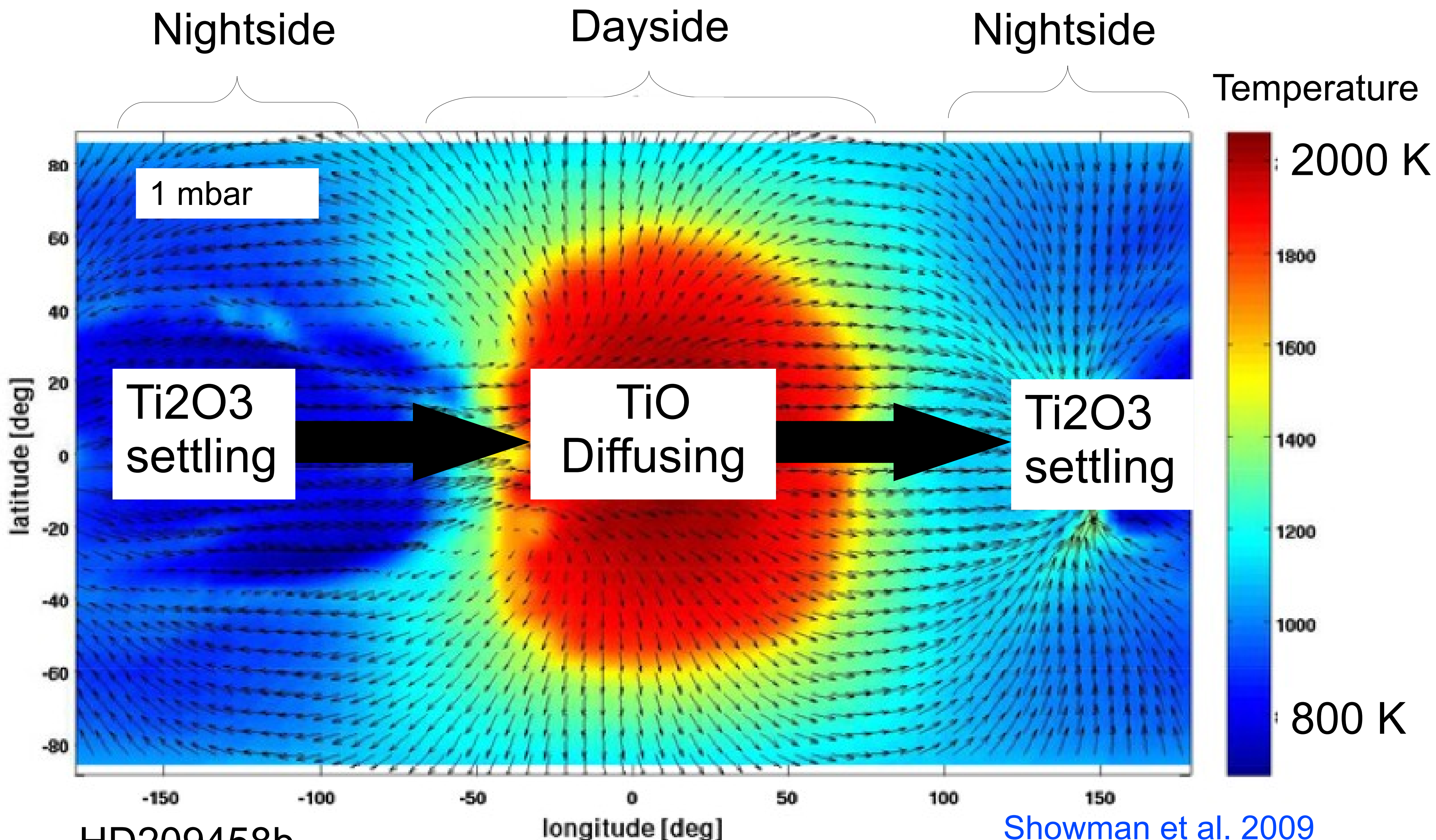
Showman et al. 2009

Background : Superrotation on hot Jupiter



HD209458b

Background : Day/night cold trap on hot Jupiter



HD209458b

Showman et al. 2009

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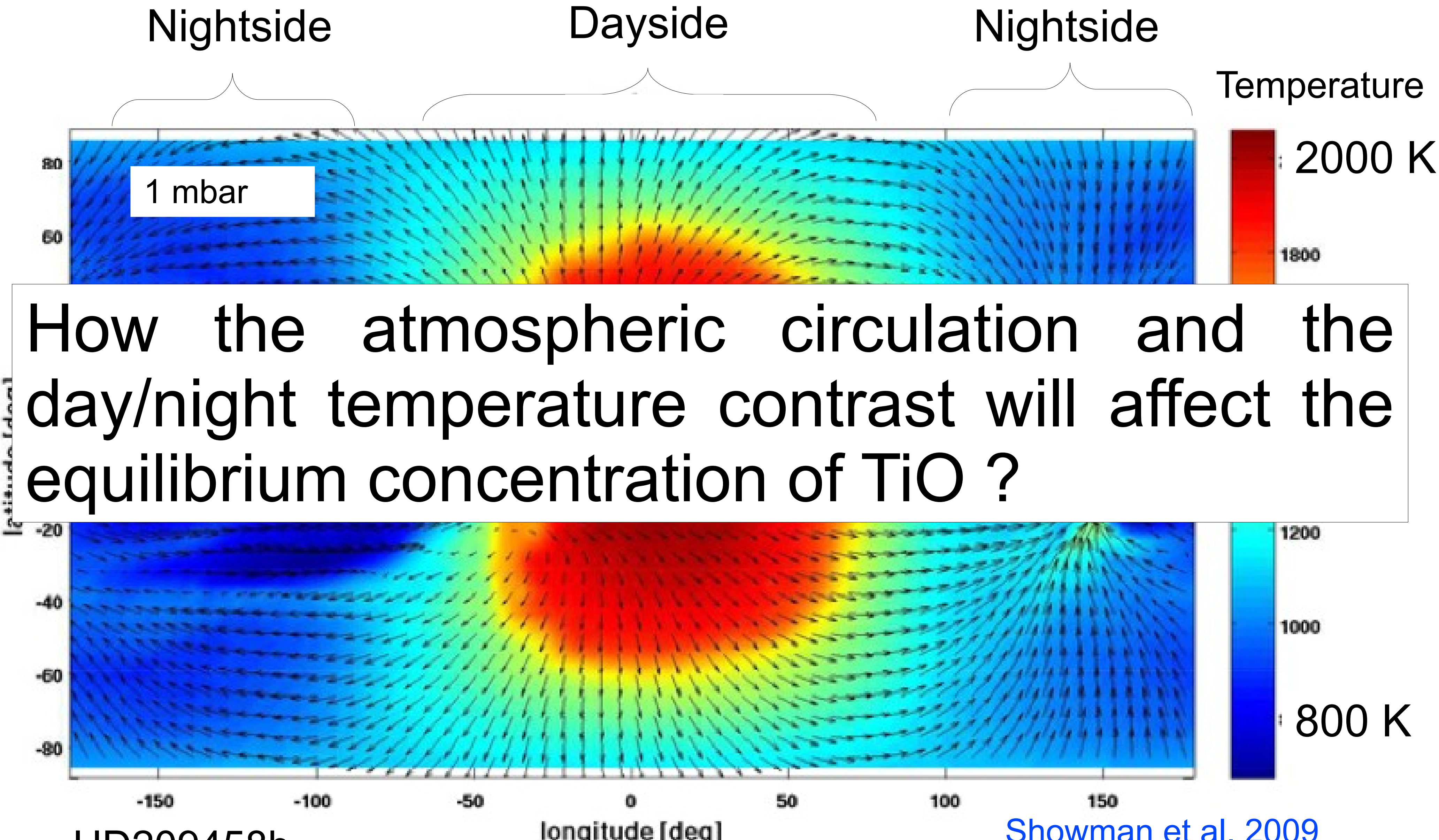


How the atmospheric circulation and the day/night temperature contrast will affect the equilibrium concentration of TiO ?

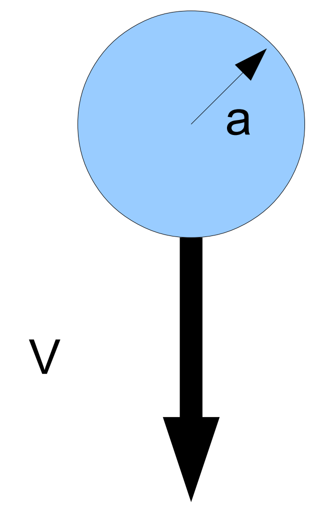
HD209458b

Showman et al. 2009

Settling : final velocity of a droplet in the atmosphere

Sphere of radius a falling in the fluid have a final velocity of :

$$V_{stokes} = a^2 \frac{2g\Delta\rho}{9\eta} \qquad \Delta\rho = \rho_{particle} - \rho_{fluid}$$



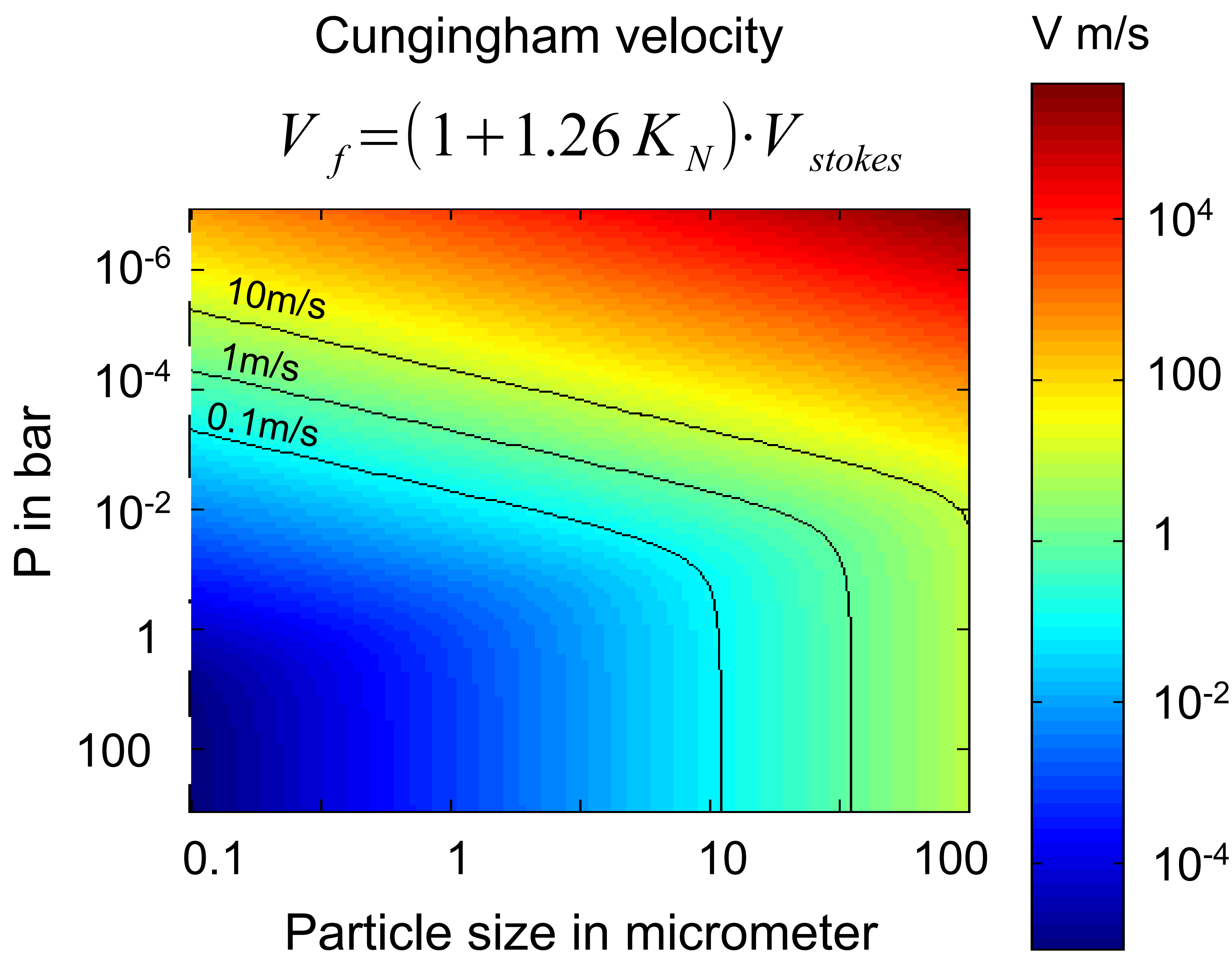
When the mean free path of the molecules becomes bigger than the size of the particle :β

$$V_f = (1 + 1.26\, K_N) \cdot V_{stokes}$$

$$K_N = \frac{\lambda}{a} \qquad \lambda = \frac{k_B T}{\sqrt{2}\,\pi d^2} \cdot \frac{1}{P}$$

$$\longrightarrow \quad V_f \propto \frac{a}{P}$$

Settling : final velocity of droplets in the atmosphere



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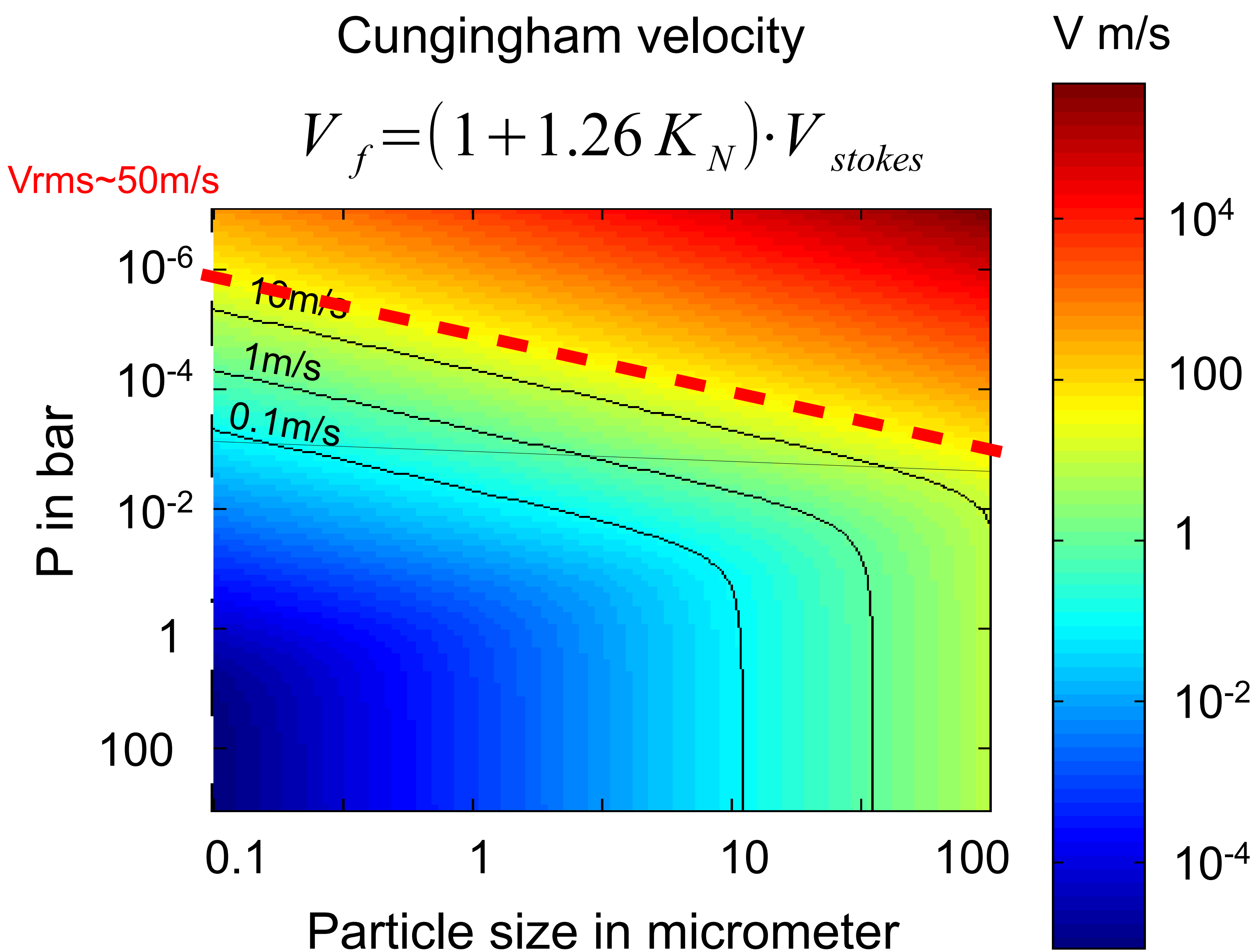


Diffusion : equations

$$\frac{D\chi}{Dt} = \frac{1}{\rho}\frac{\partial \rho V_z \chi}{\partial z}$$

3D – model big simulations

...

A lot of approximations and simplifications

...

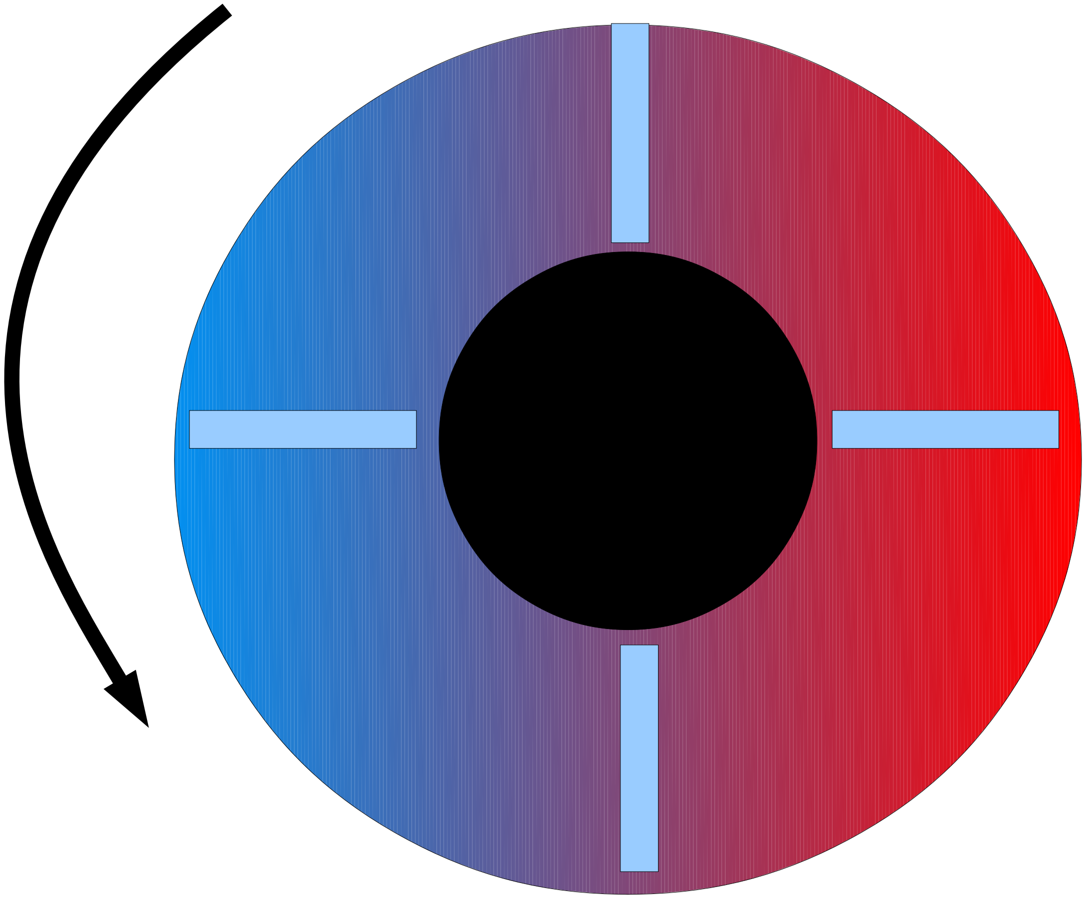
$$\frac{\partial \chi}{\partial t} - \frac{\partial}{\partial P}\left(K_P \frac{\partial \chi}{\partial P}\right) = \frac{\partial V_P \chi}{\partial P}$$

1D – highly idealized toy model

Numerical model

Night side :

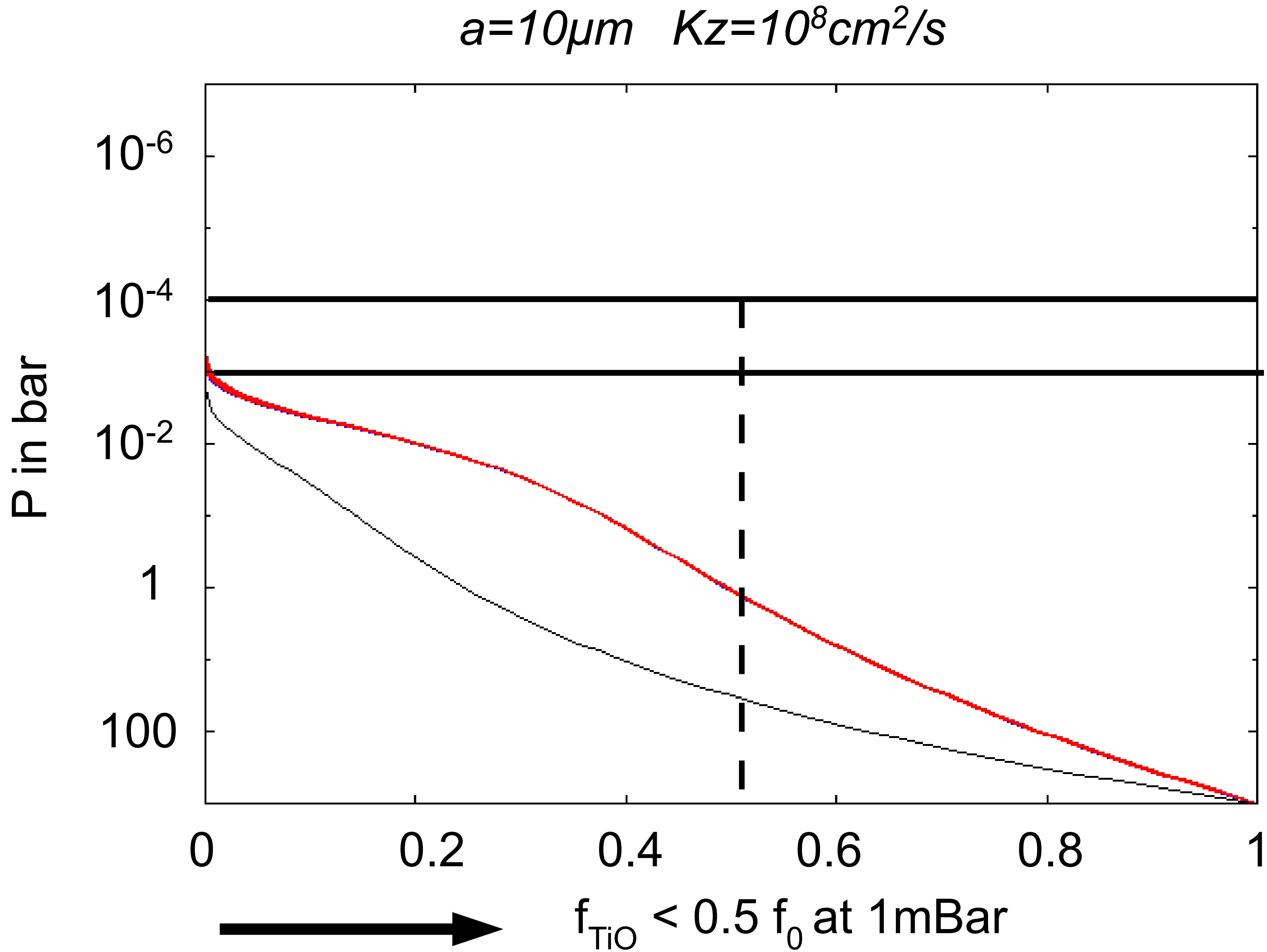
Settling and diffusion



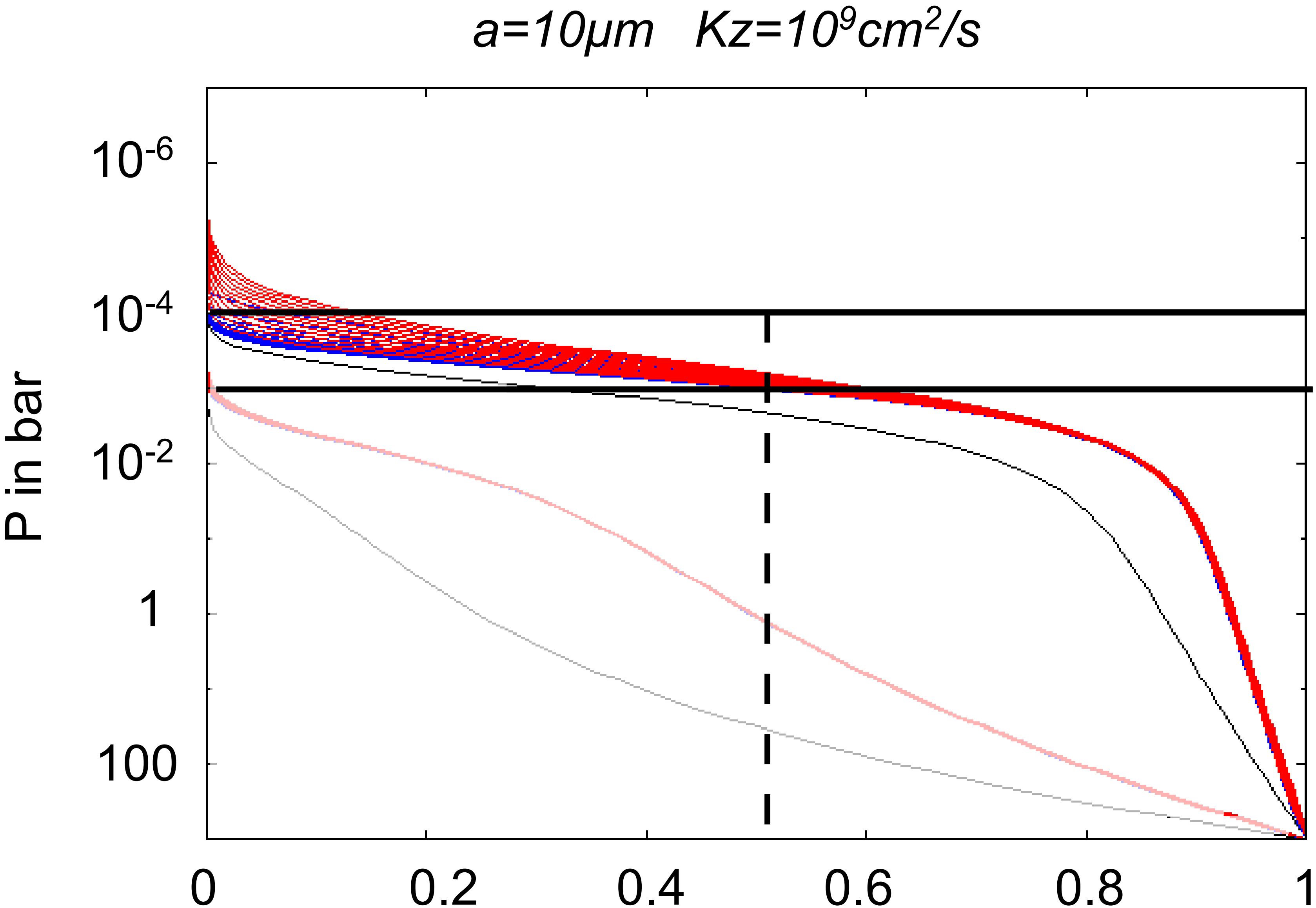
Day side :

Diffusion only

Results : abundance profiles

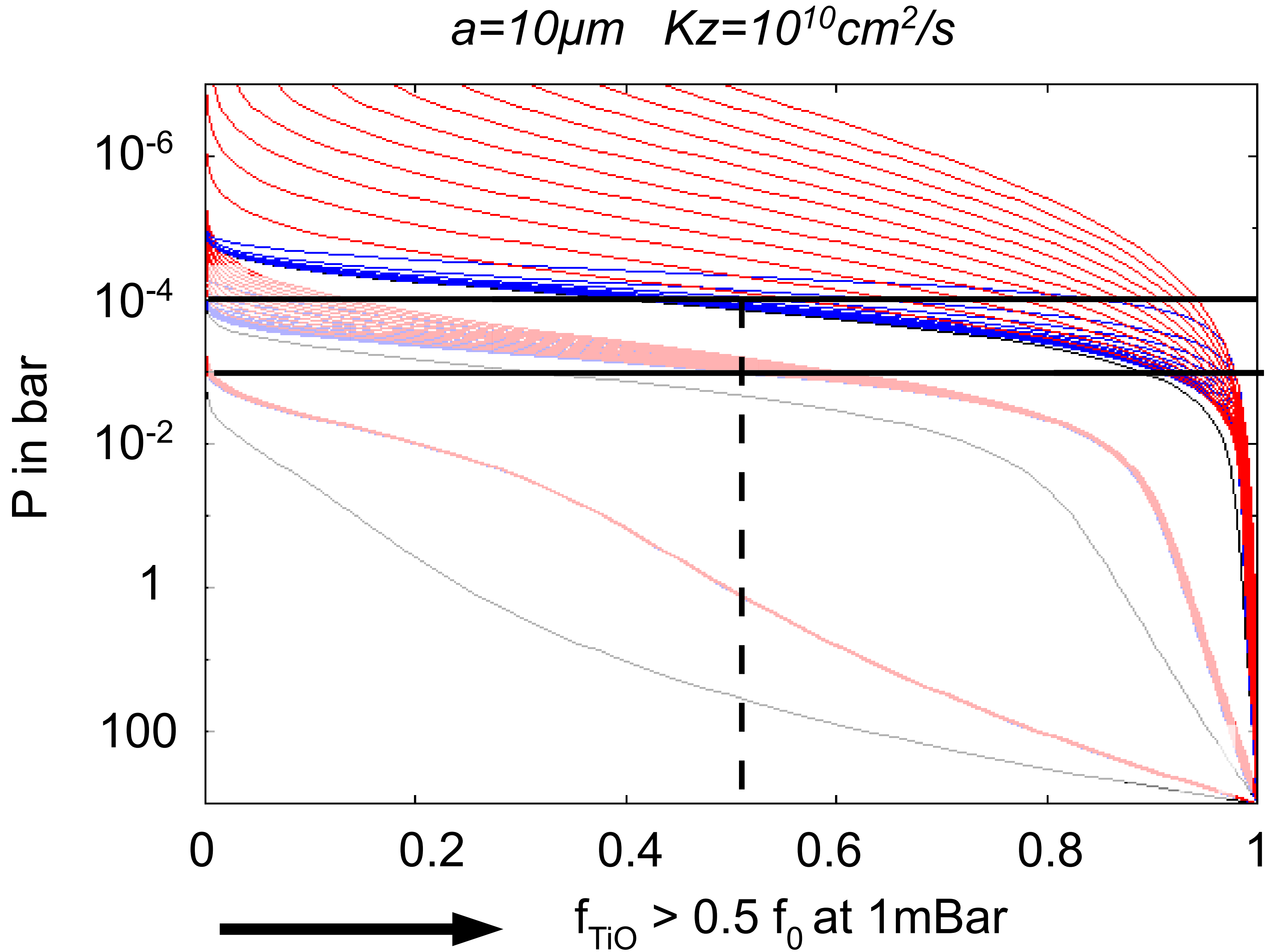


Results : abundance profiles

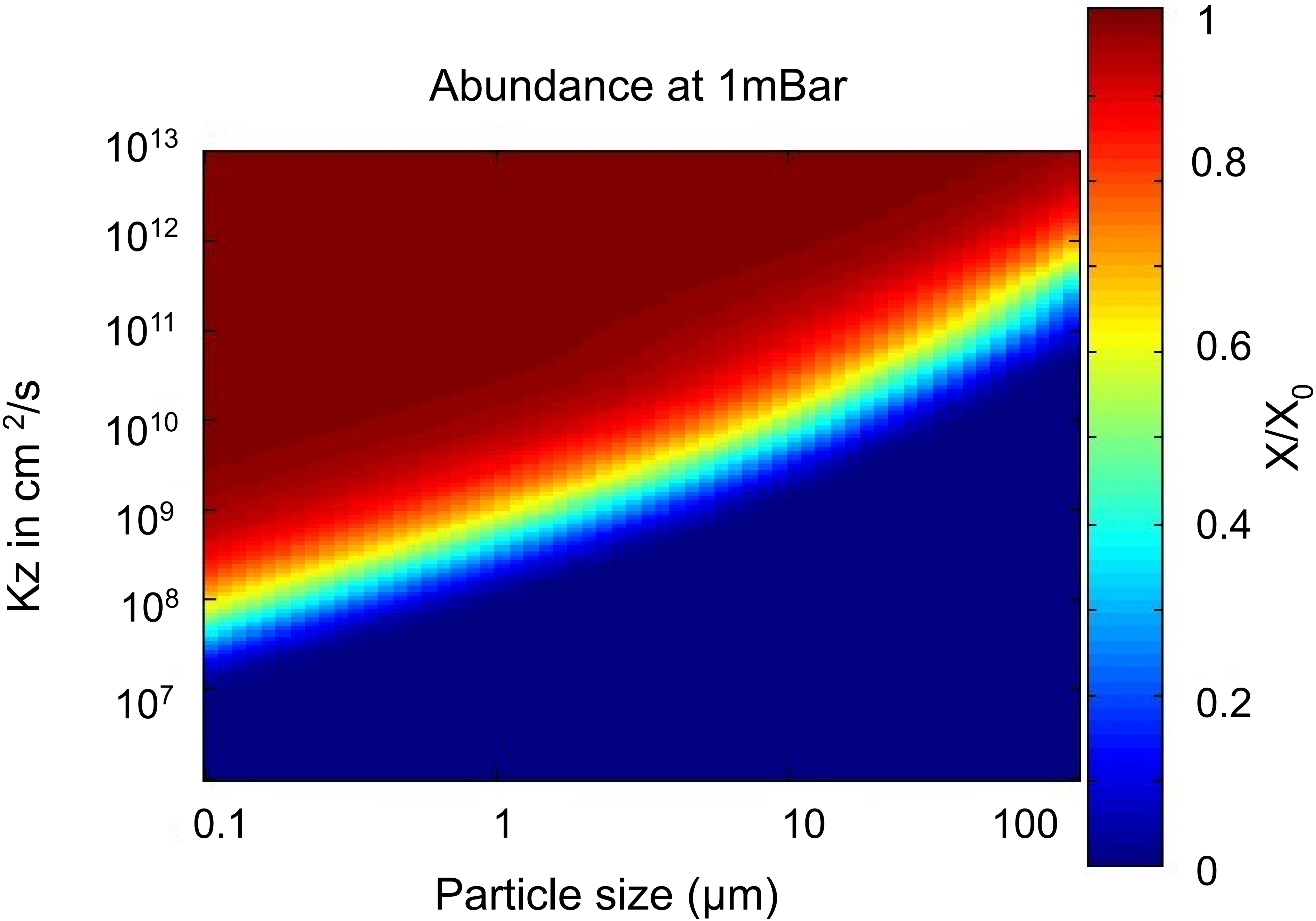


$f_{TiO} \sim 0.5\ f_0$ at 1mBar

Results : abundance profiles

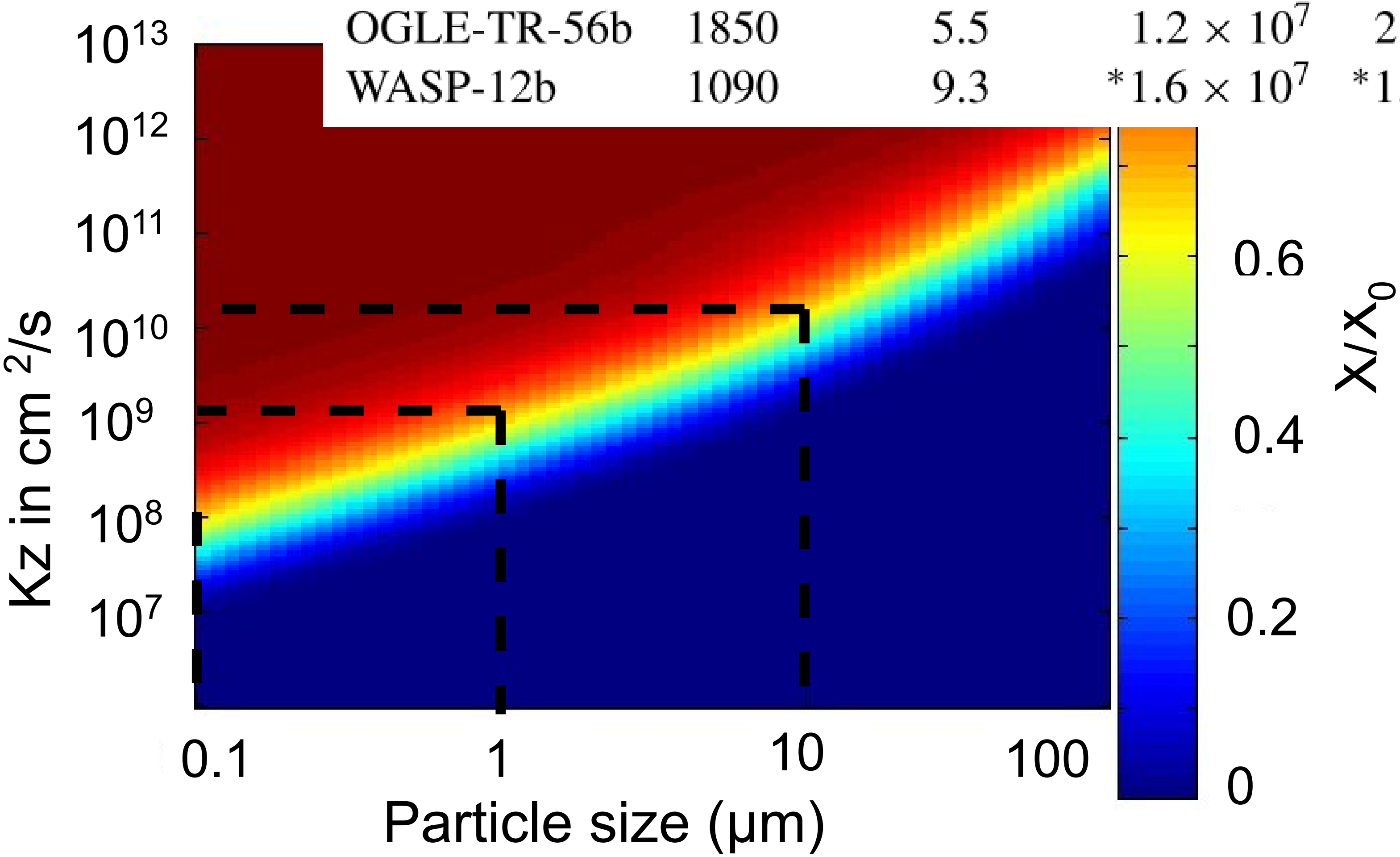


Results: constrain on Kz



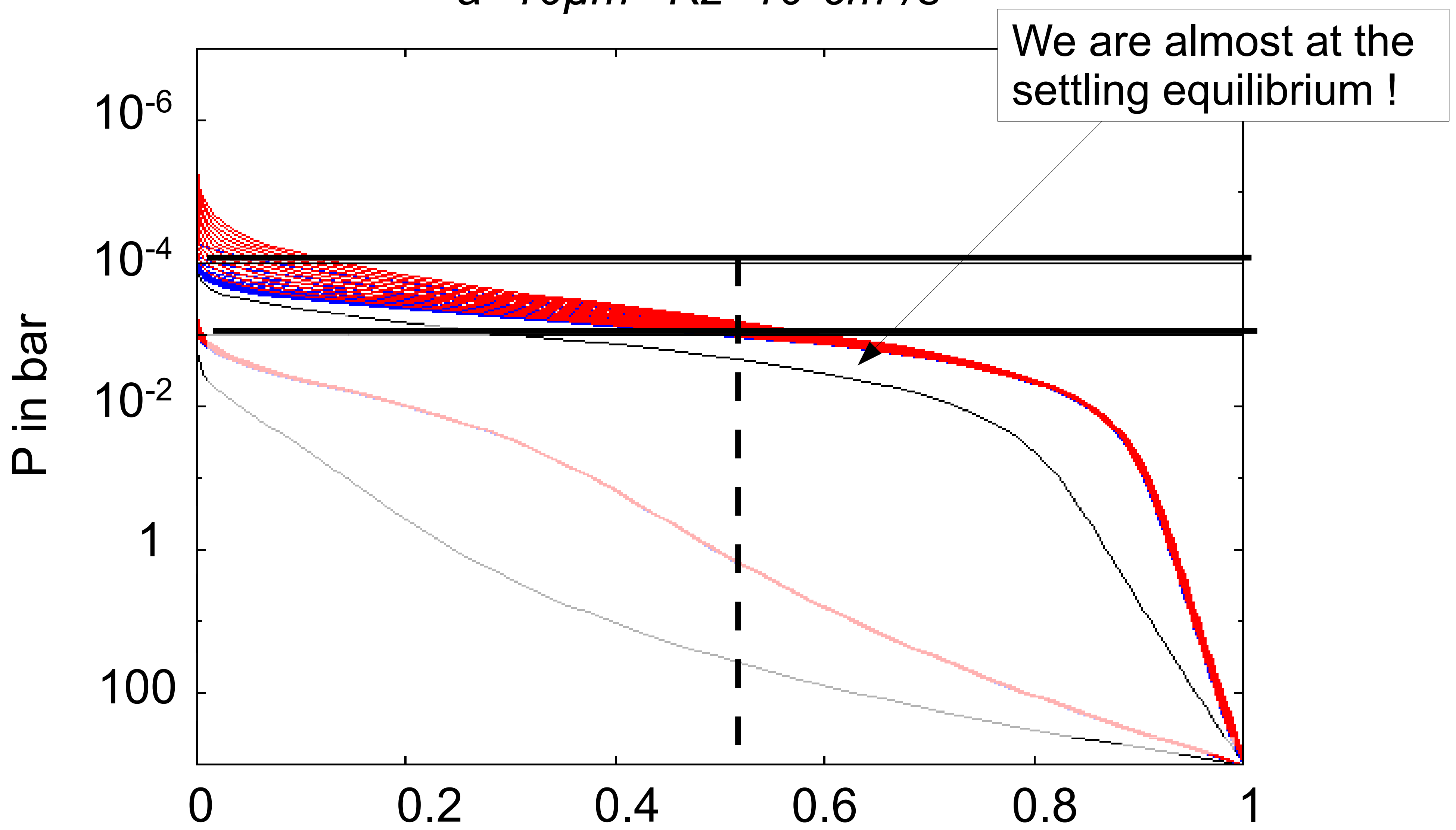
Results: comparison with the vertical cold trap

Planet	g (cm s^{-2})	F_* (erg cm^2 s^{-1})	Required K_{zz} $a = 0.1\ \mu$m	1 μm	10 μm
HD 209458b	1000	1.0	6.2×10^8	6.2×10^9	6.5×10^{10}
HD 149026b	1560	2.2	2.4×10^8	2.3×10^9	2.6×10^{10}
TrES-4	721	2.4	2.7×10^8	2.7×10^9	3.0×10^{10}
OGLE-TR-56b	1850	5.5	1.2×10^7	2.1×10^7	8.7×10^8
WASP-12b	1090	9.3	$^*1.6 \times 10^7$	$^*1.6 \times 10^7$	$^*1.6 \times 10^7$



Results : abundance profiles

a=10µm   Kz=10⁹cm²/s



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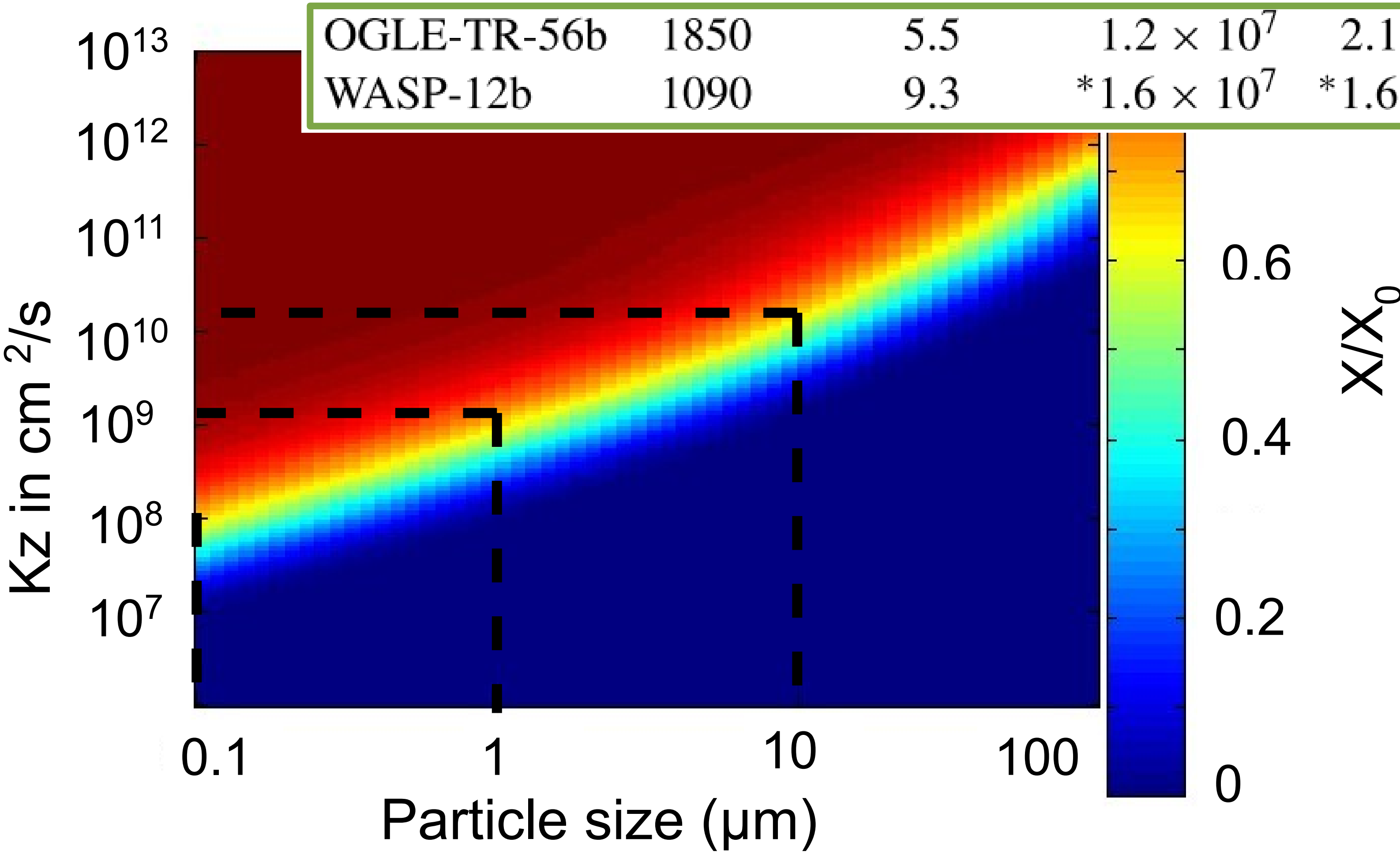

Results: comparison with the vertical cold trap

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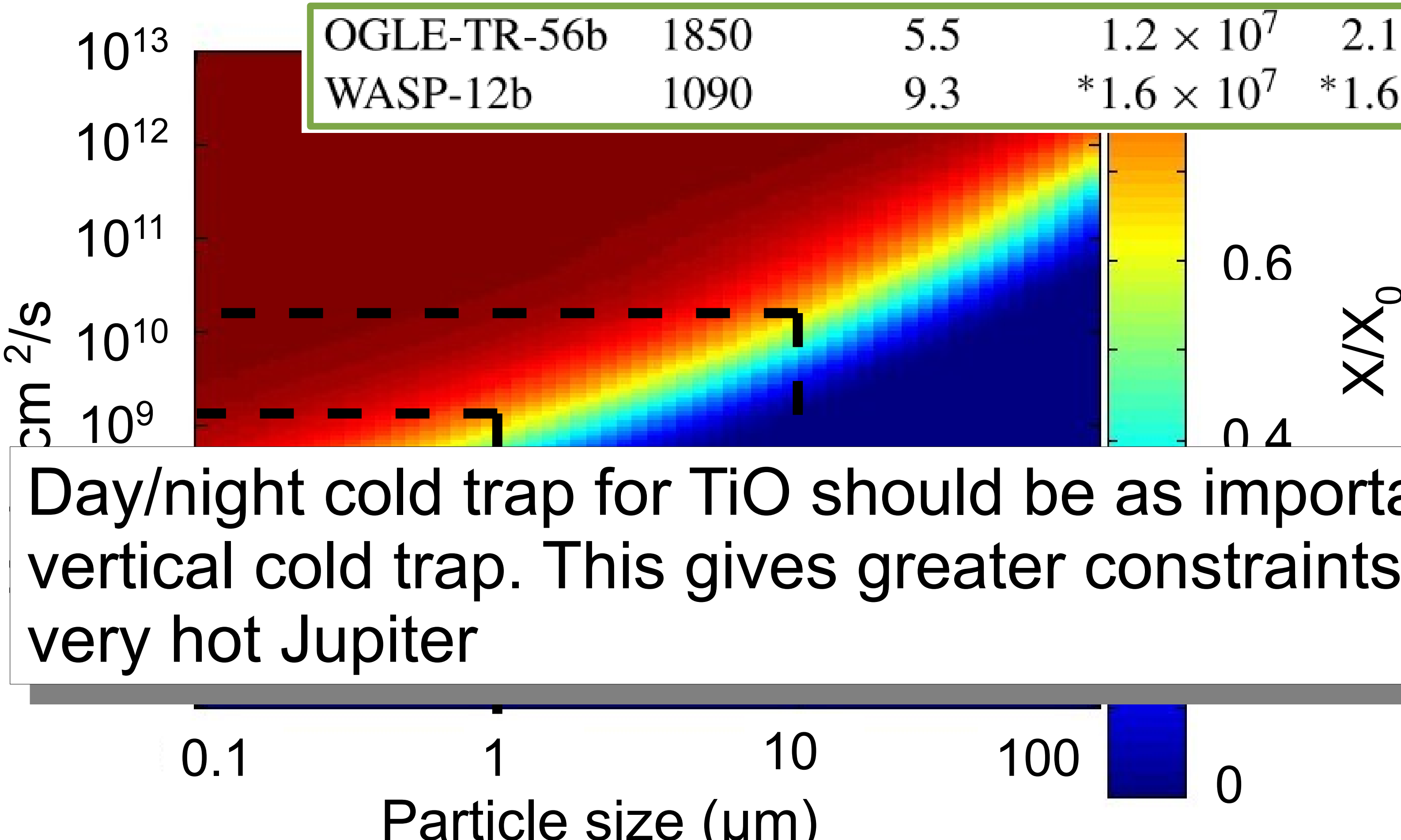
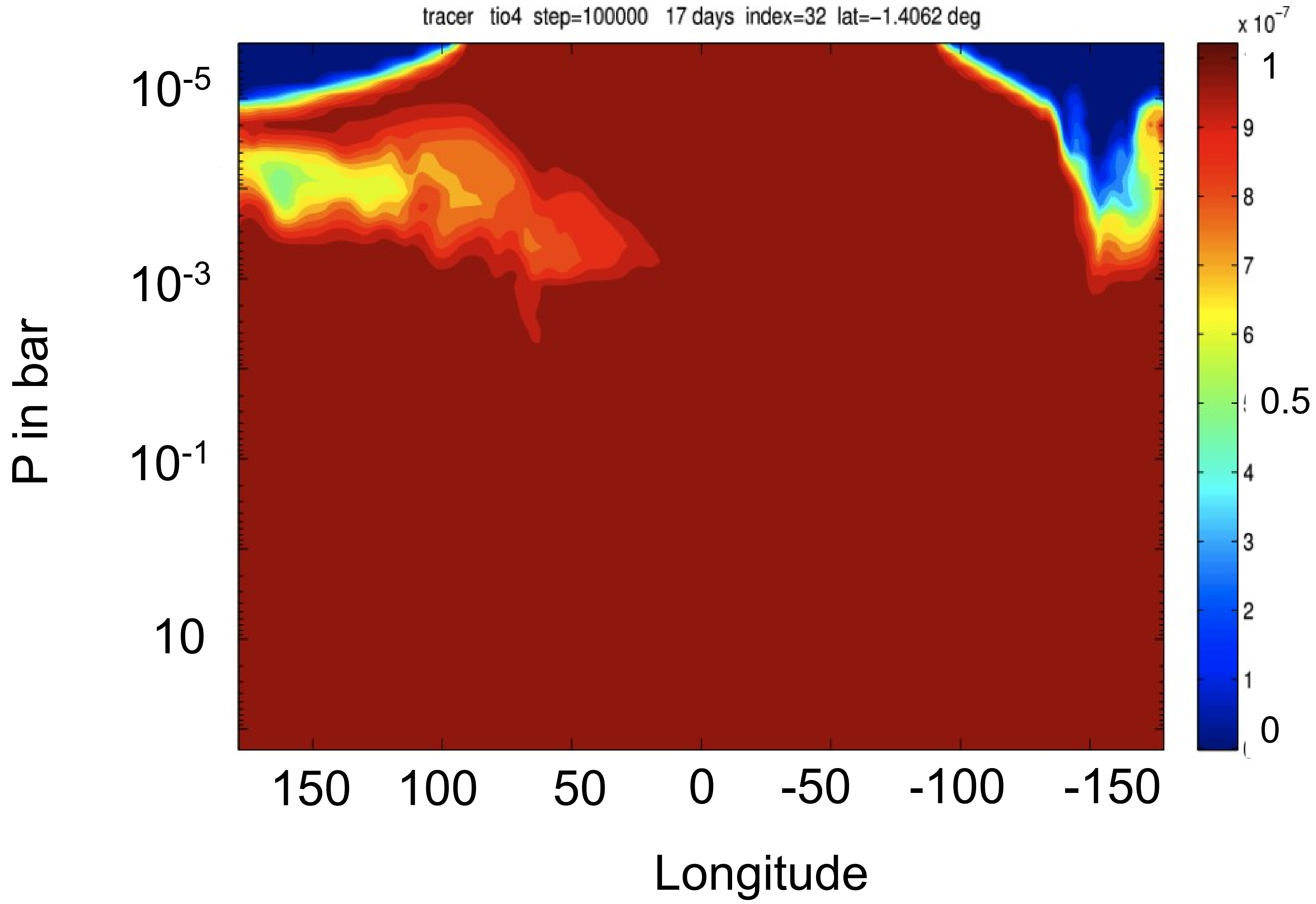


Day/night cold trap for TiO should be as important as vertical cold trap. This gives greater constraints on Kz for very hot Jupiter

Results : 3D simulation !

Thank you Adam !



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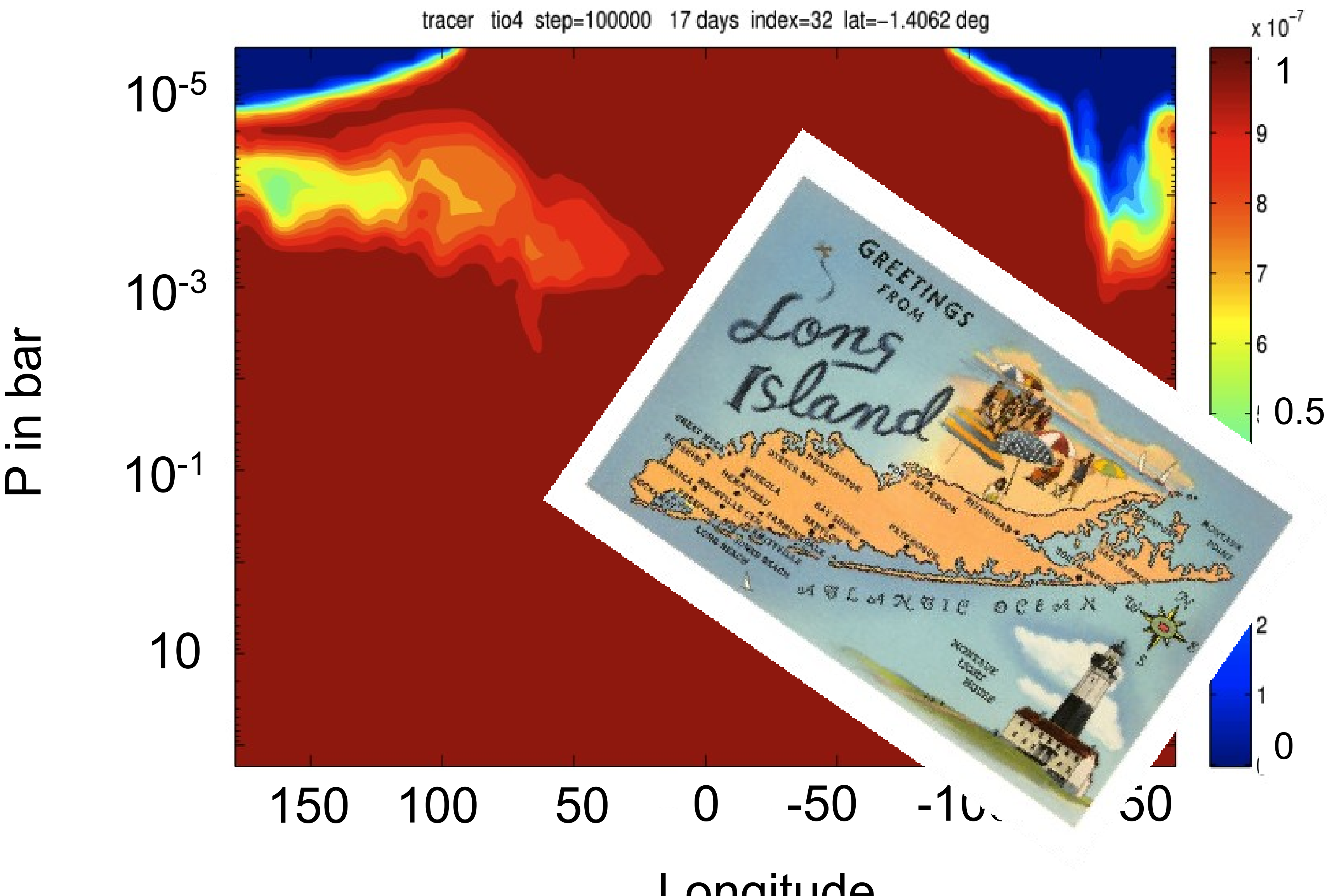

Future work

The presence or absence of TiO in hot Jupiter atmosphere depends strongly on the diffusivity of the flow

→ Measure the effective vertical mixing of the flow using tracers on a 3D simulation. Is the 1D mixing really diffusive ?

→ Different planets must have different conditions. We have to extend our work to hotter planet where the vertical cold trap is no more effective.

→ **Run more simulations !**