Characterizing cloudy atmospheres with space photometry at optical wavelengths.

Observatoire de la CÔTE d'AZUR

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→ Sagan fellow at UCSC in Sept.

LAGRANGE

3D clouds in irradiated exoplanets

Atmospheric composition and planet evolution

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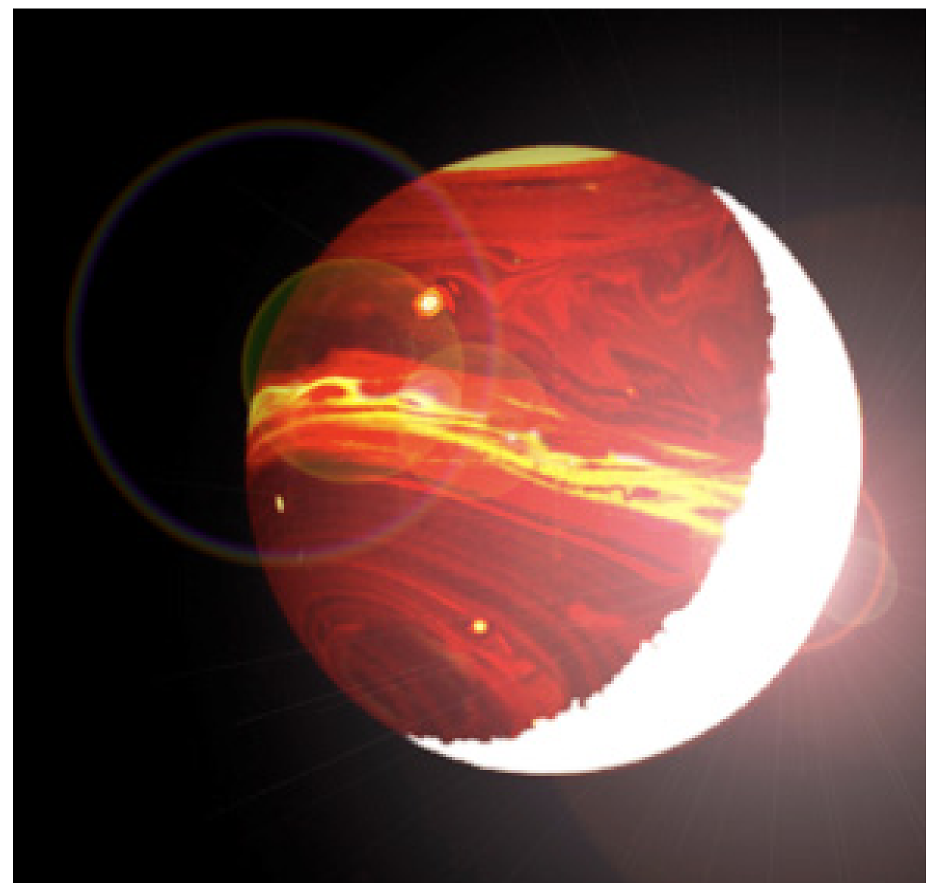
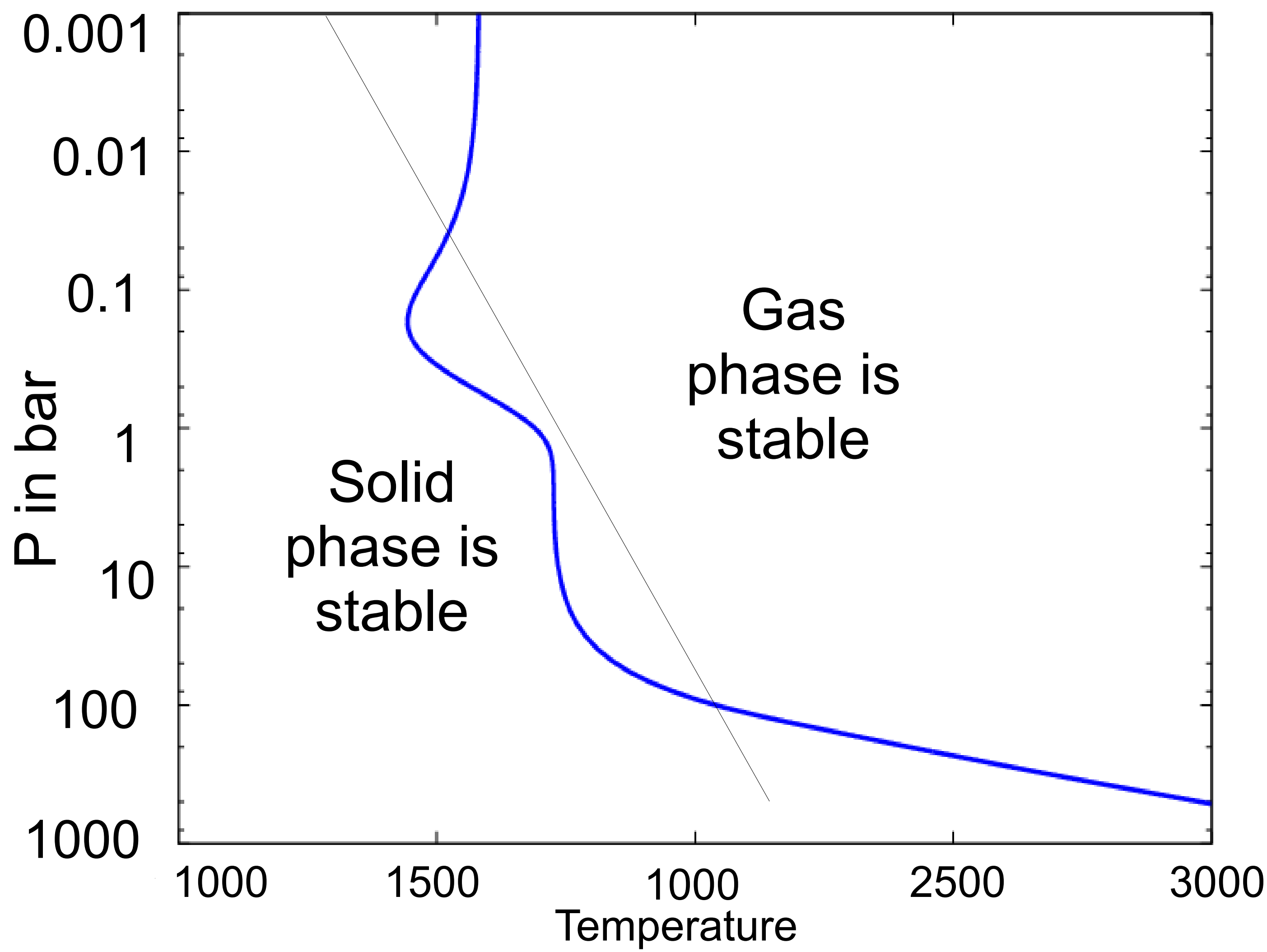
Julien de Wit MIT (Boston, US)
Nikole Lewis MIT (Boston, US)
Mark Marley NASA Ames (Mountain view, US)
B-O.Demory Cambridge (UK)



3D clouds in irradiated exoplanets

Cloud formation: simplistic view

If the temperature profile crosses the condensation curve of a minor specie



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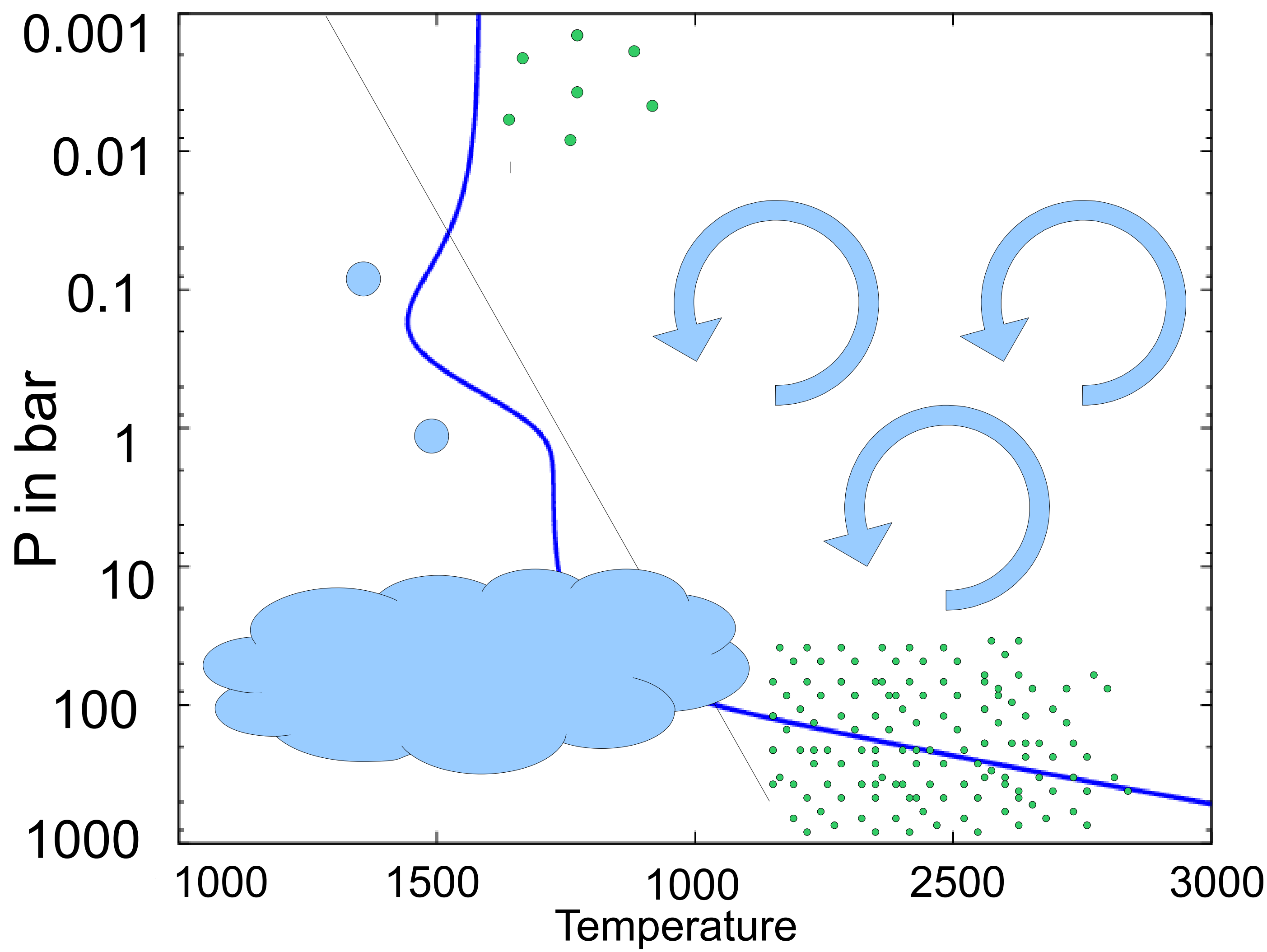
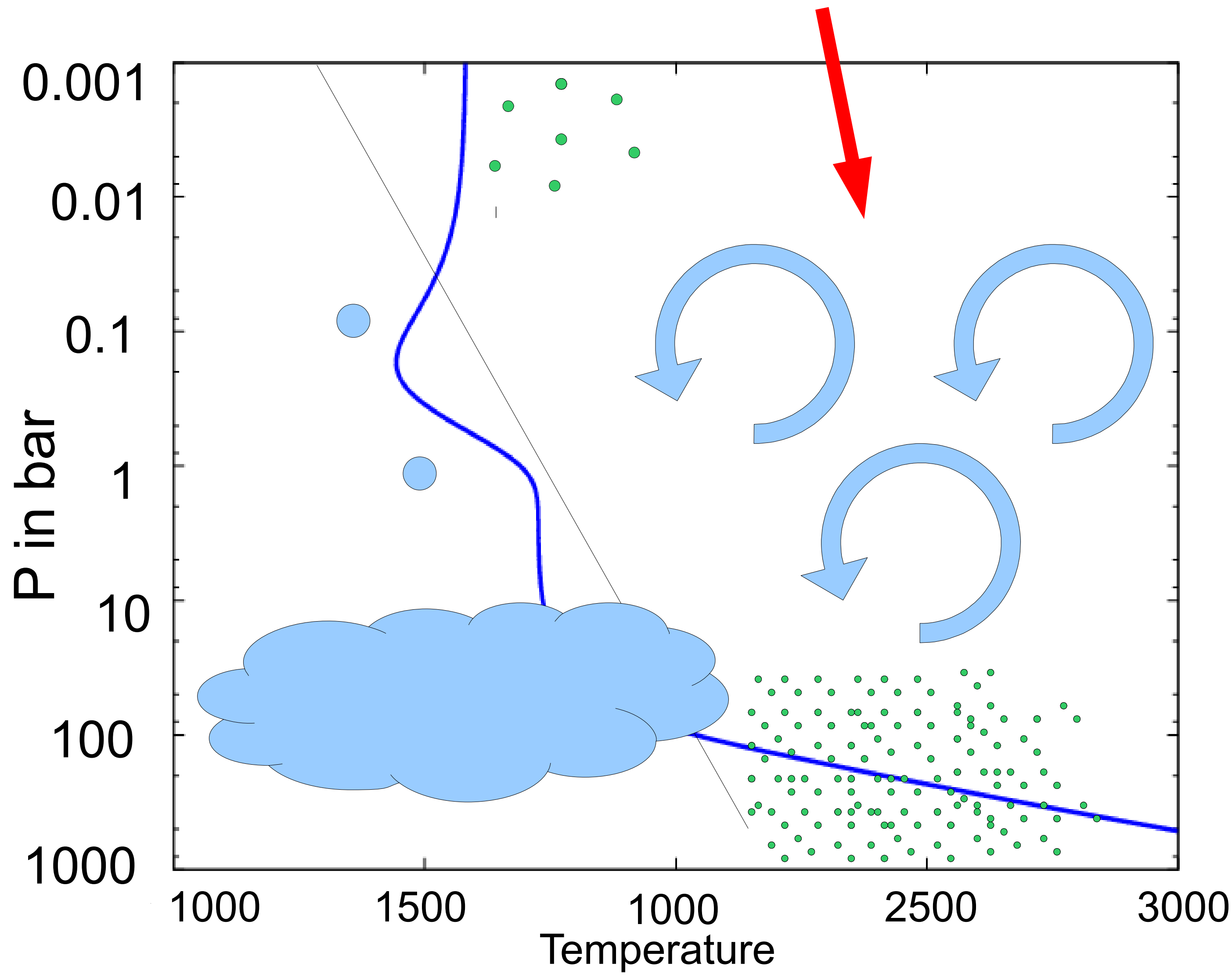


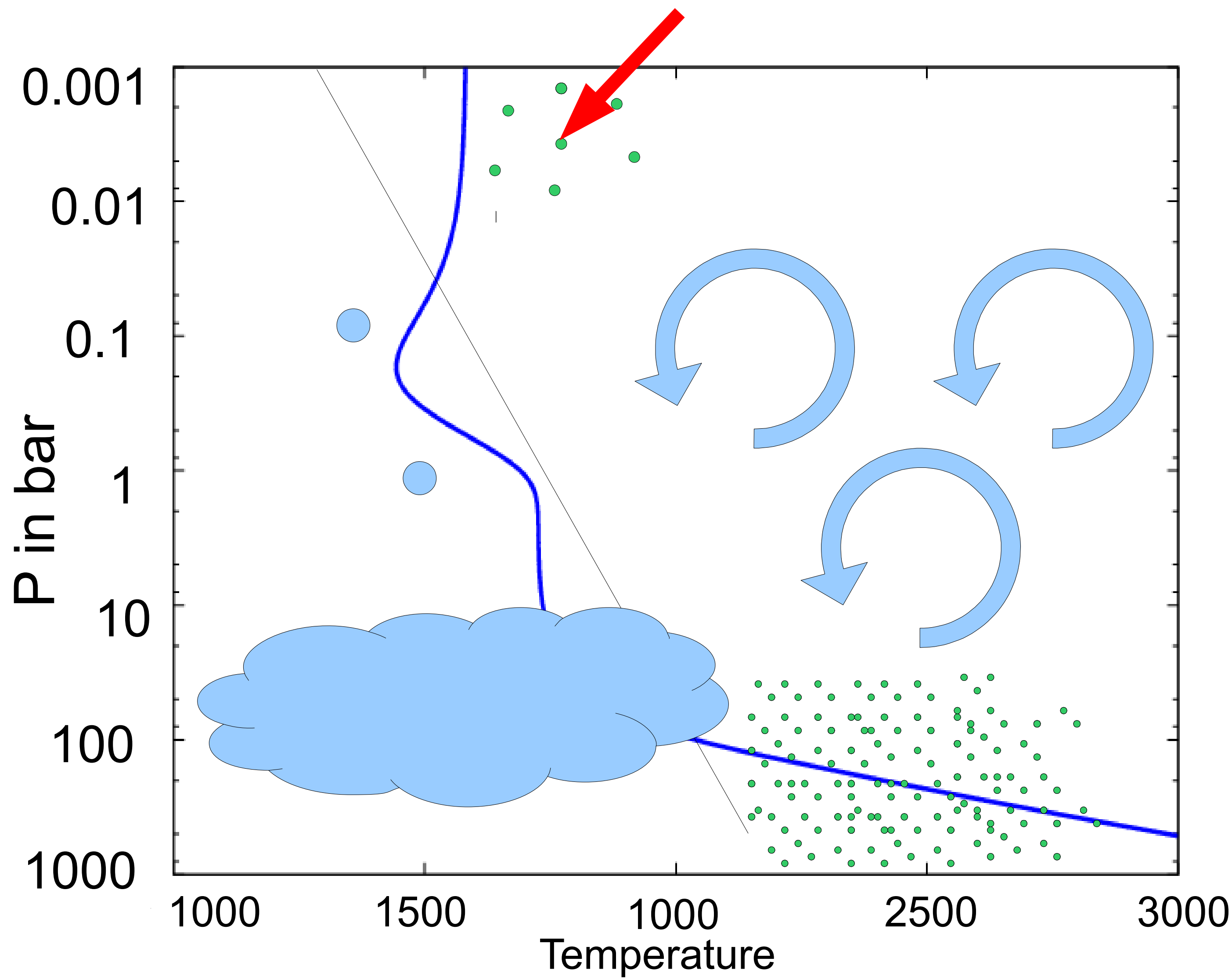
Cloud formation: simplistic view

Clouds are tracers of the atmospheric circulation



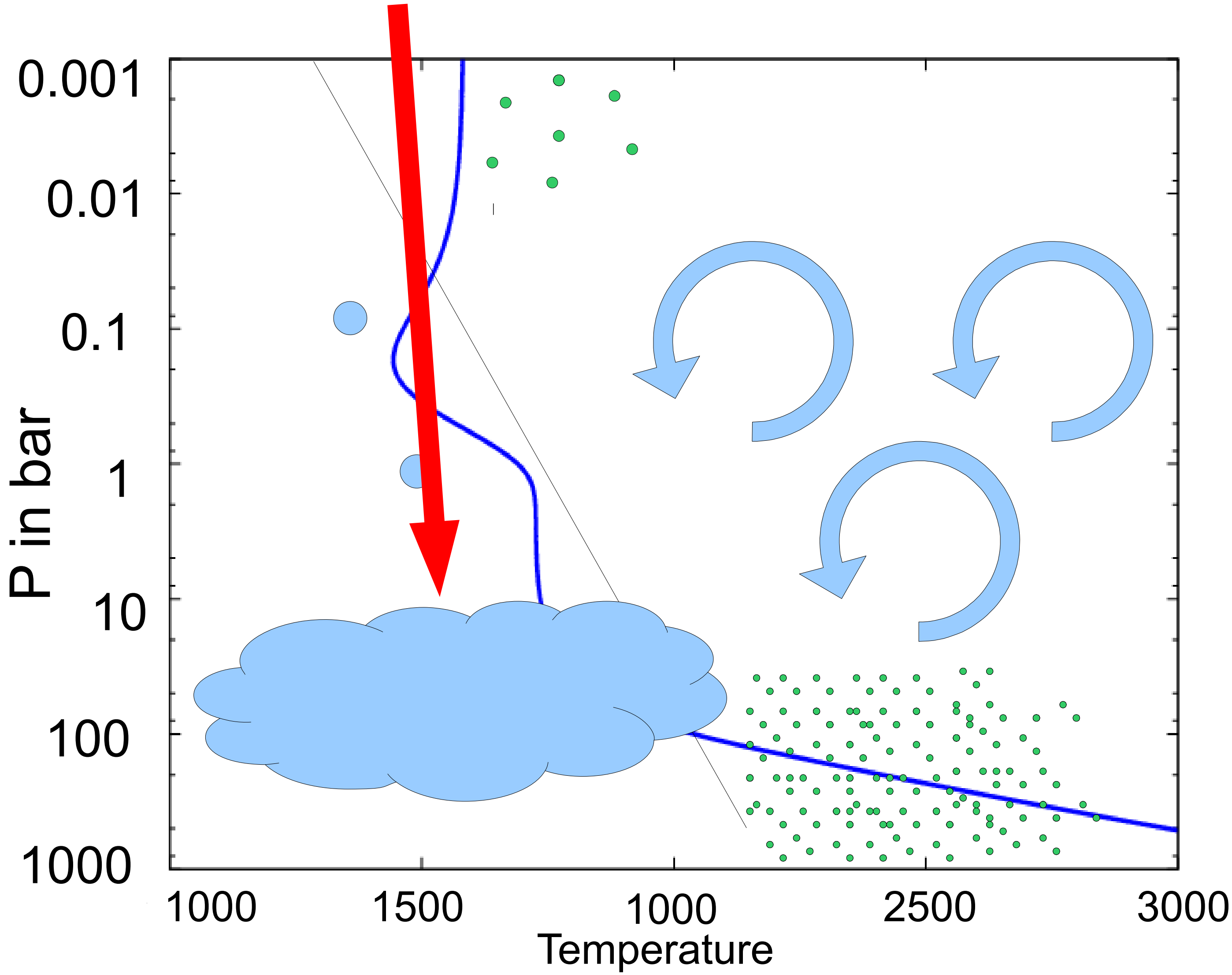
Cloud formation: simplistic view

Clouds affect the chemical abundances



Cloud formation: simplistic view

Clouds hide species in the deep atmosphere
→ bias in the retrieved bulk chemical abundances



3D clouds in irradiated exoplanets

→ **HD209458b** T_{eq0}~ 1500K

Deming et al. 2013 (transmission spectrum)

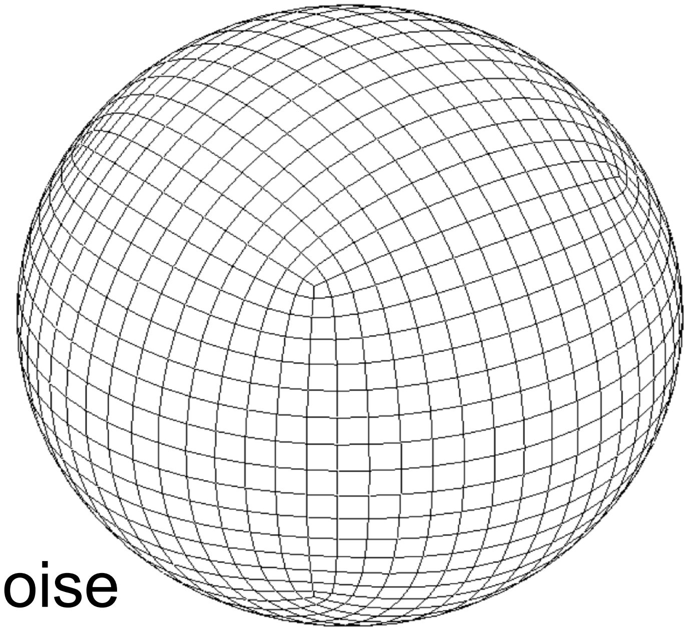
→ **Kepler-7b** T_{eq0}~ 1500K but A_g~0.35 T_{eq}~1300K

Demory et al. 2011, 2013 (albedo, optical phase curve)

→ **HD189733b** T_{eq0}~1200K

Lecavelier des etangs 2008a, Sing et al. 2009, Berdyugina et al. 2011, Sing et al. 2011b, Gibson et al. 2013, Pont et al. 2013, Evans et al. 2013 (transmission, albedo)

3D-model with the MITgcm



- Cubic sphere grid Nx=128 Ny=64 Np=53
- Domain 2µbar-200bars
- Shapiro filter smooths the horizontal grid noise
- Radiative transfer : correlated-k method

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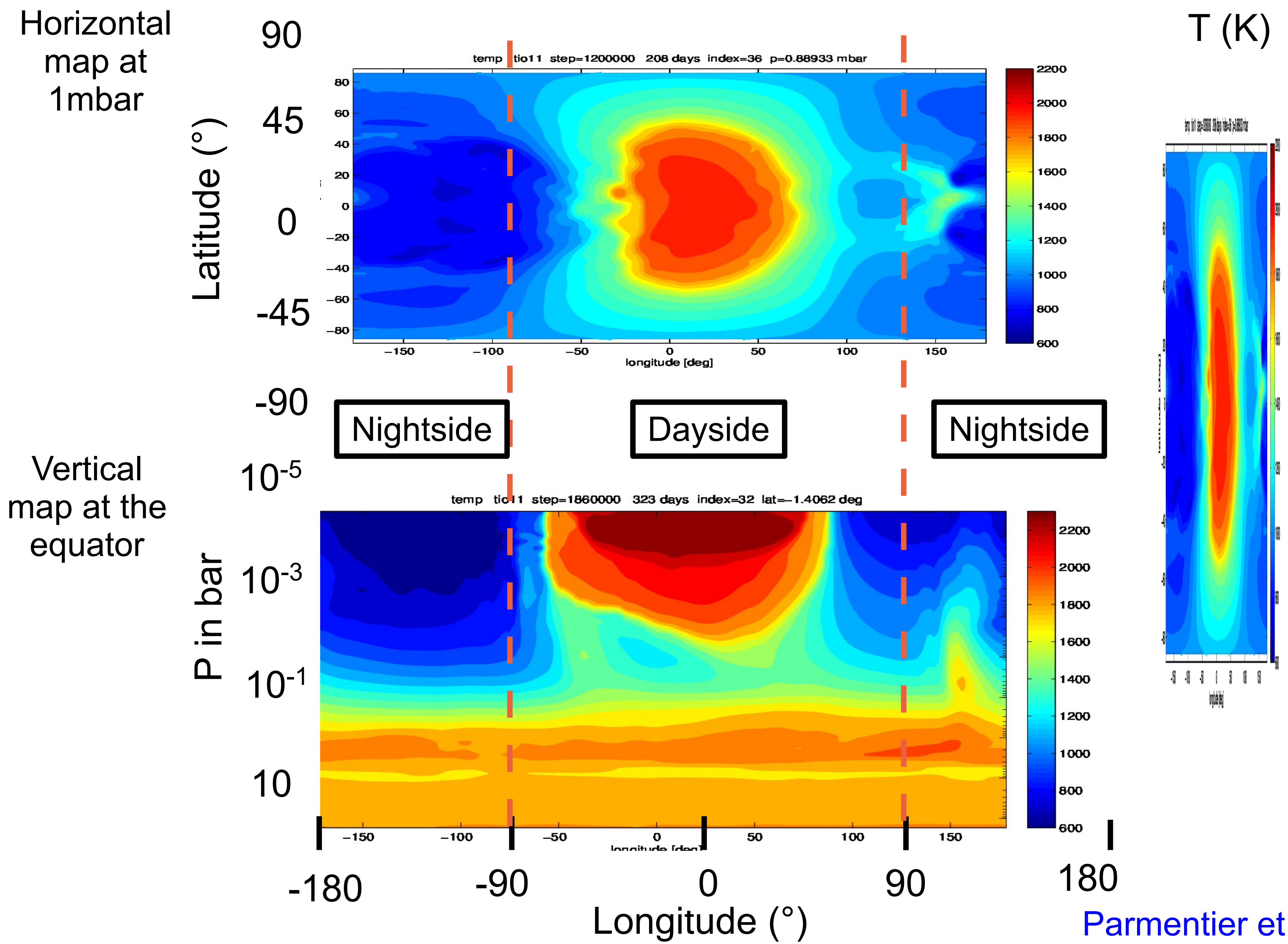
Temperature field of HD209458b



Parmentier et al. 2013

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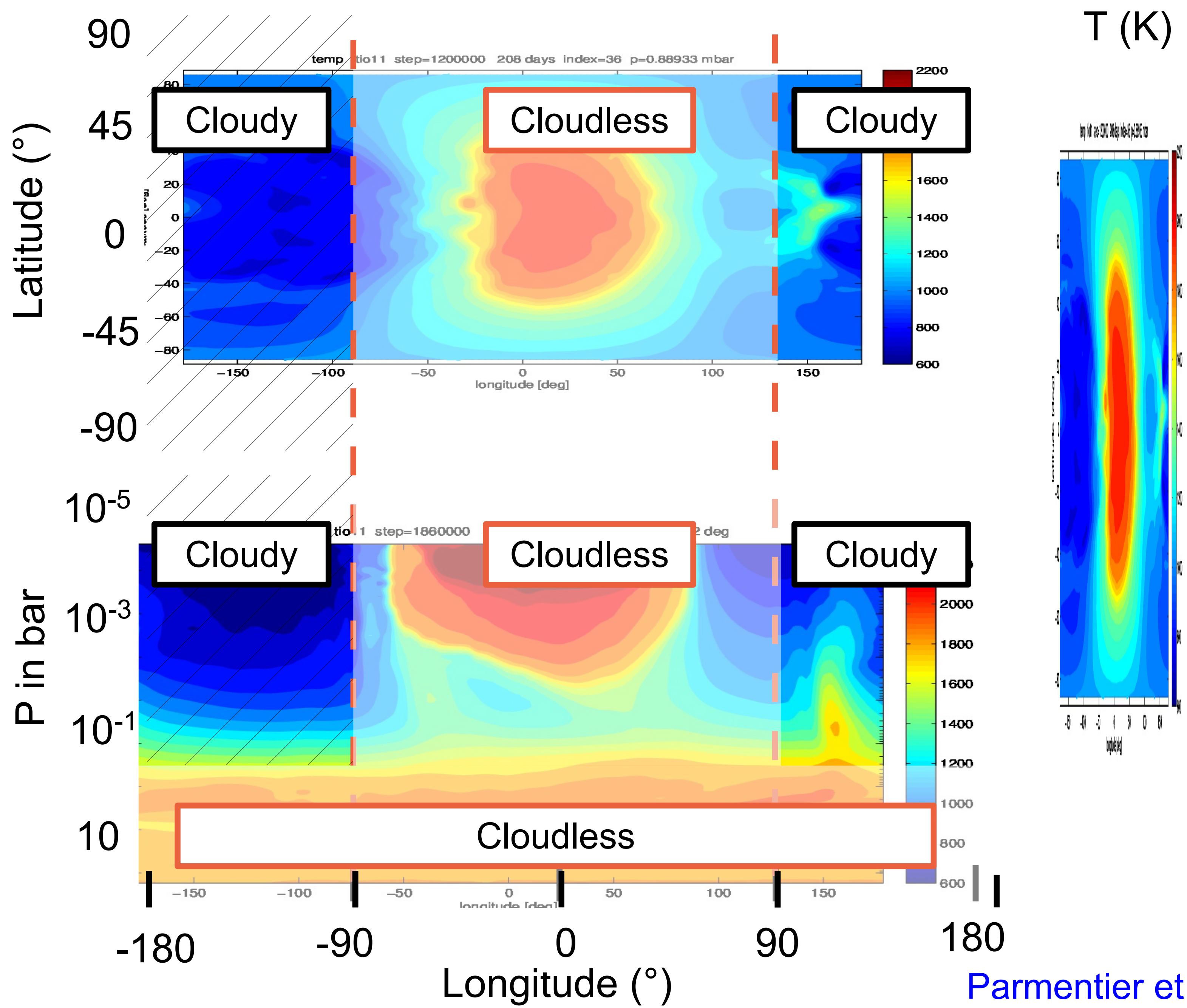
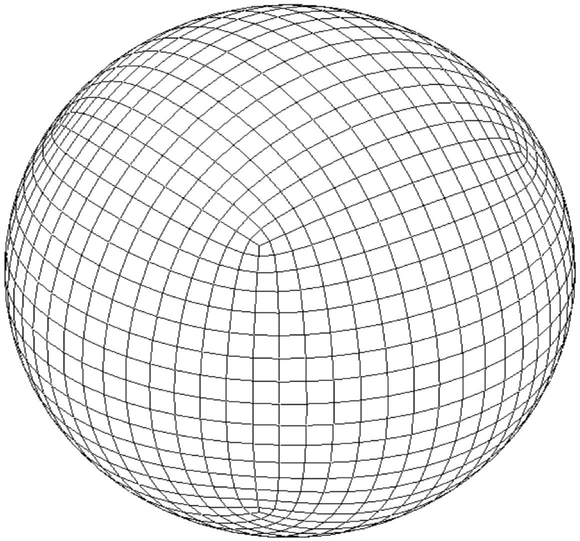


Parmentier et al. 2013

3D model : modified MITgcm



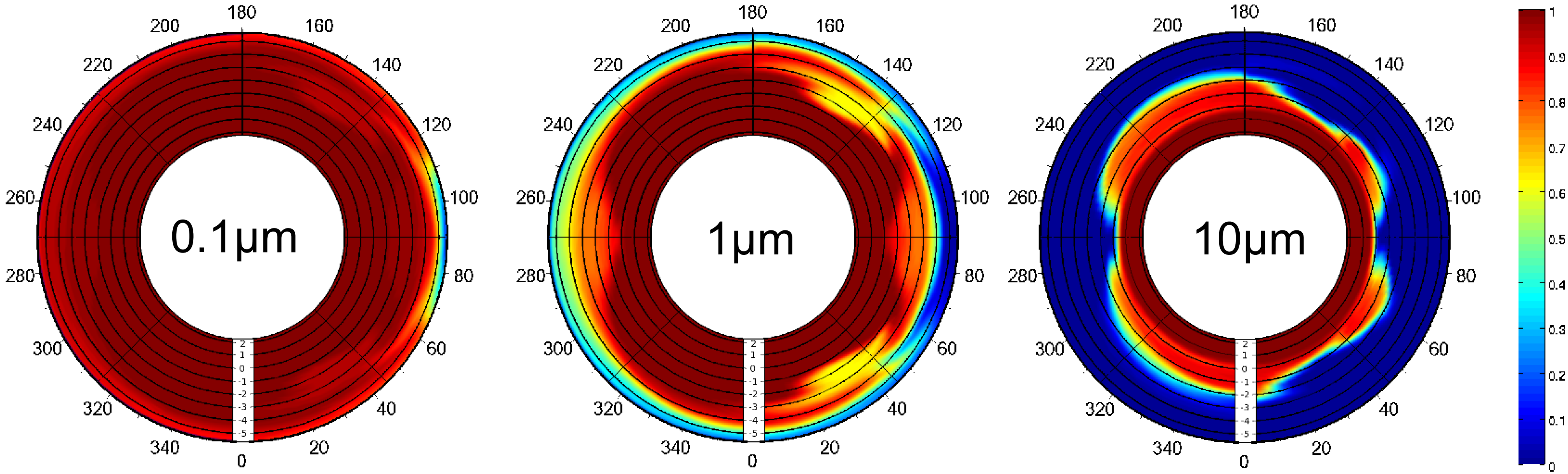
- We implemented passive tracers in the MITgcm
- In “cloudless” areas they follow the fluid
- In “cloudy” area they additionally rain
- The settling timecale is given by the size of the condensates (0.1/0.5/1/2.5/5/10μm)

→ Concerns many planets (day/night contrast inrcreases with T_{eq})

→ Concerns many species (TiO, Fe, $MgSiO_4$ ...)

Parmentier et al. 2013

Cloud abundance at the limb



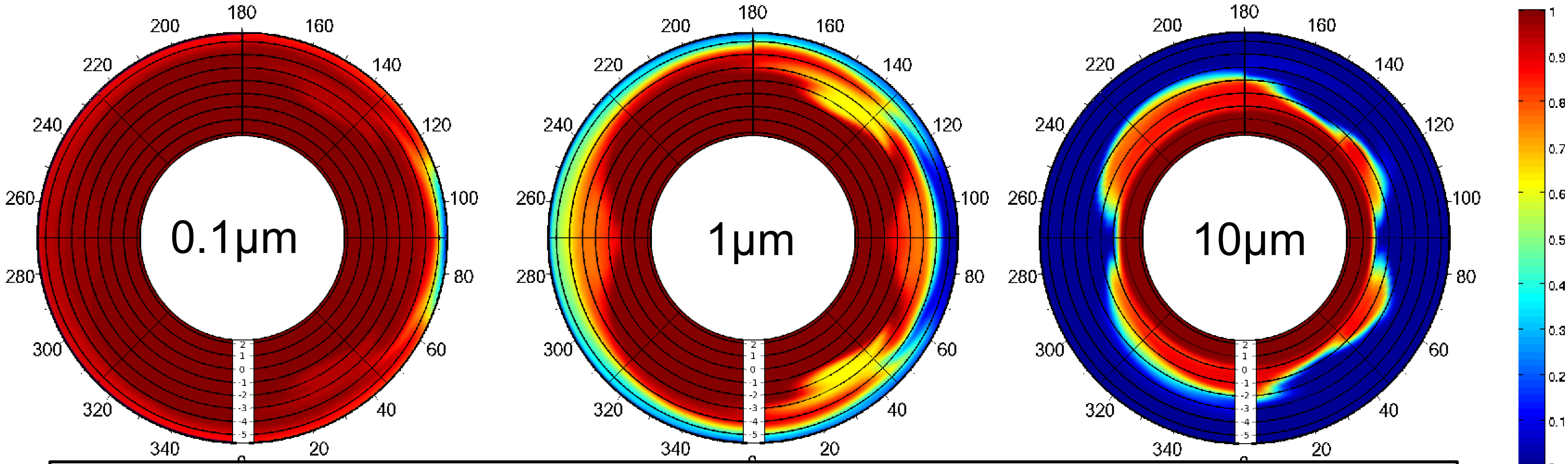
We expect clouds to be spatially variable

Top cloud pressure is fundamental to quantify the molecular abundances

We predict maximum particle size of ~1μm

Parmentier et al. 2013

Cloud abundance at the limb



Is the gas really condensed at the limb ?

Phase mapping of the dayside albedo is necessary

Parmentier et al. 2013

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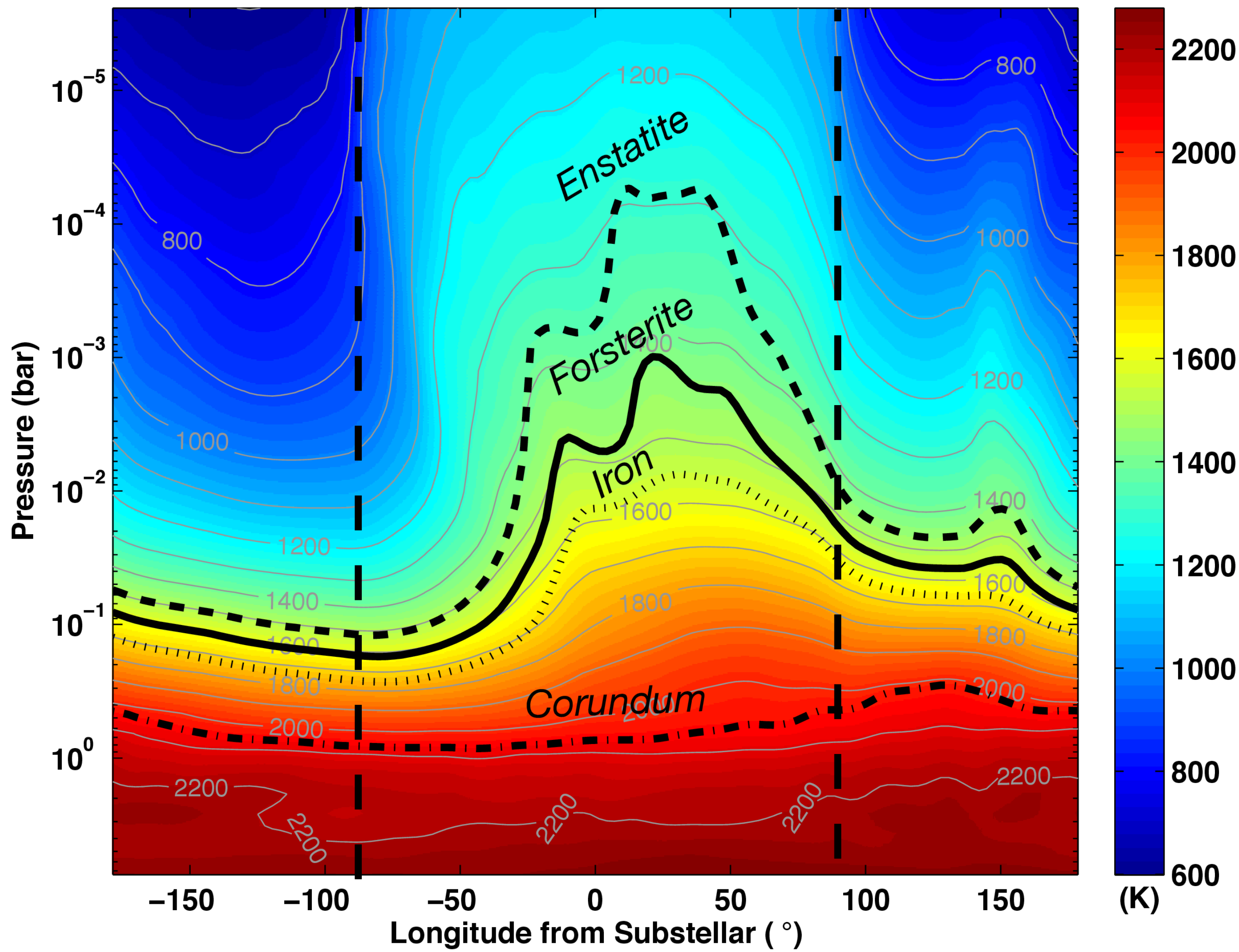
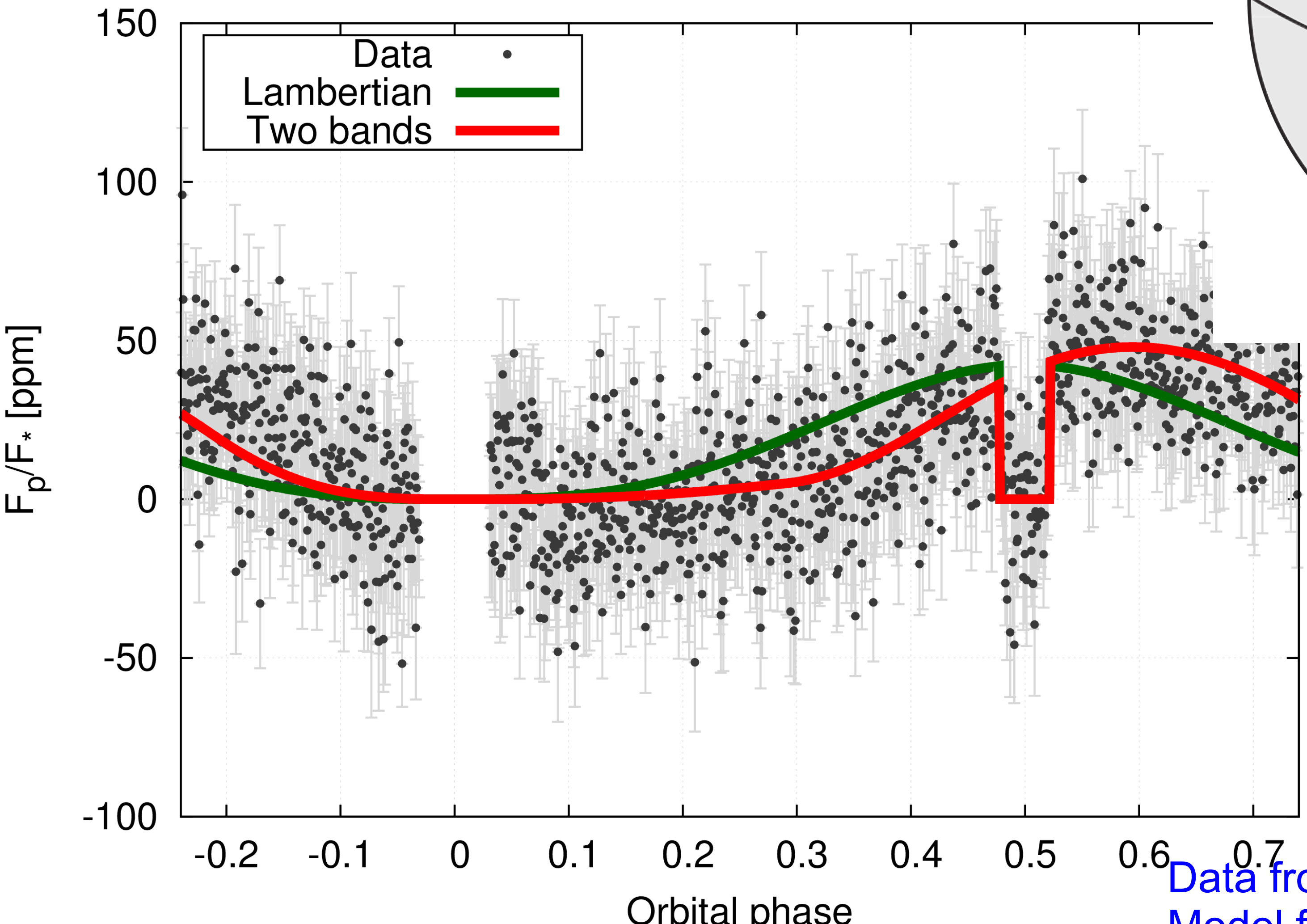
Partially cloudy Kepler-7b

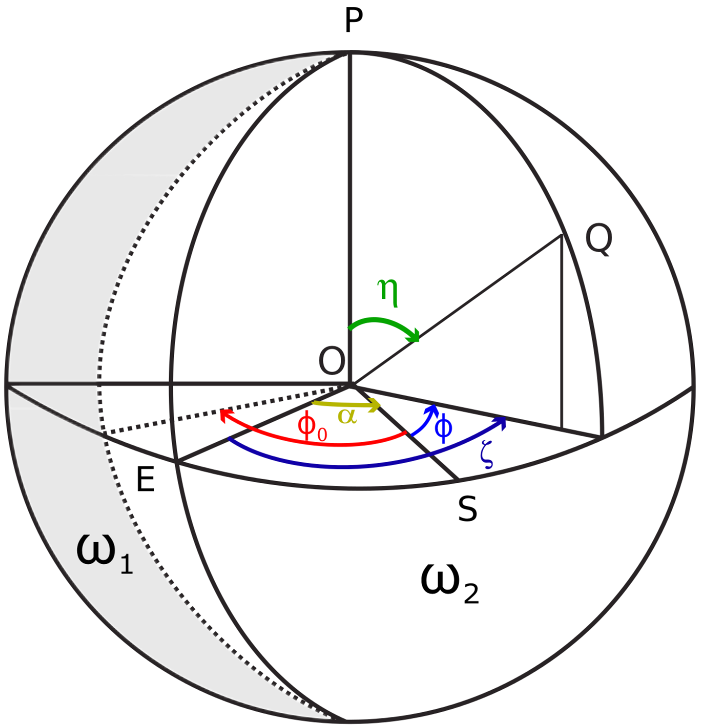


Lewis, Parmentier et al. in prep

Partially cloudy Kepler-7b

Analytical model for the phase curve of a partially cloudy planet.

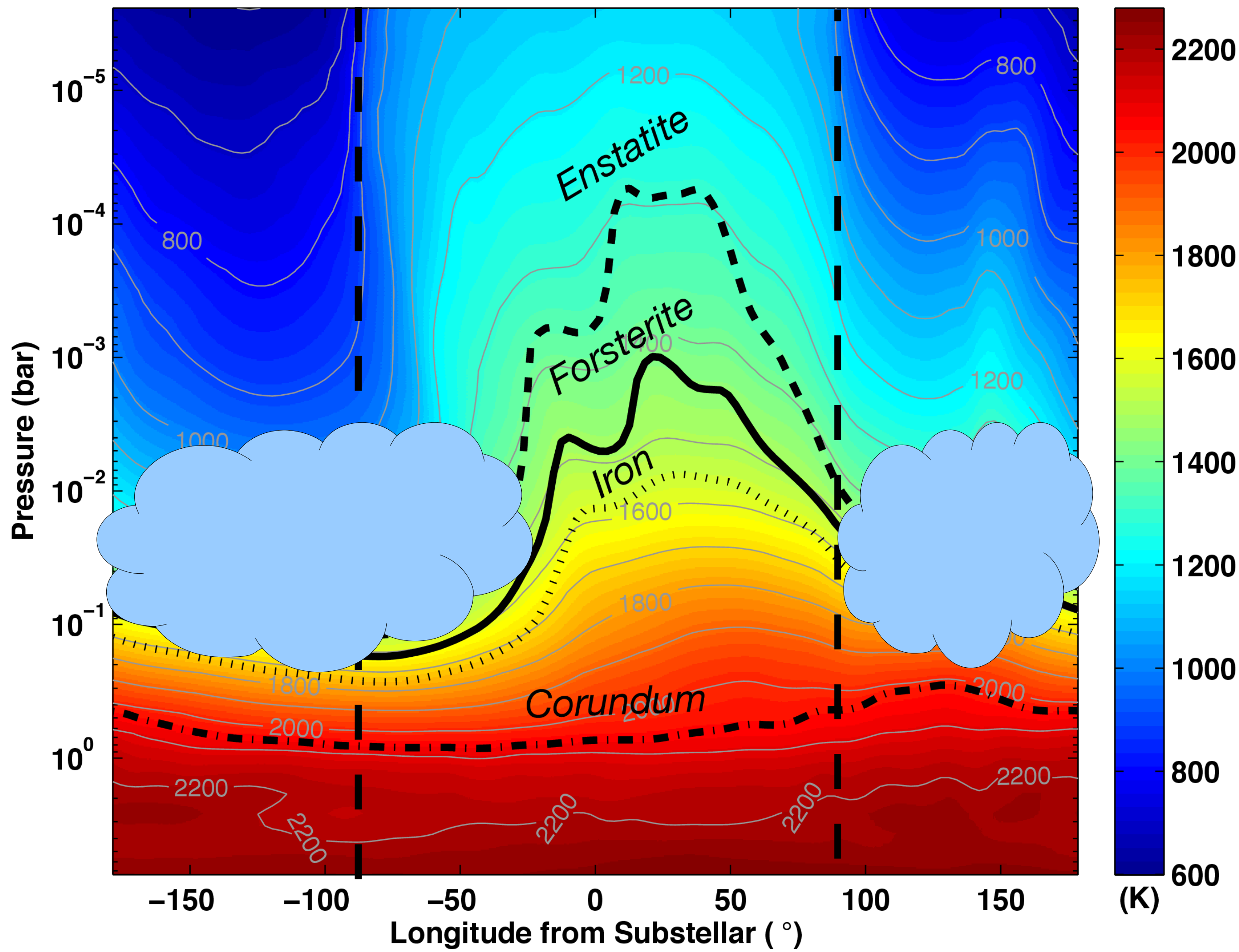




$\omega_1 \sim 1$
$\omega_2 \sim 0.1$
$\varphi_c \sim -14°$

Data from Demory et al. 2013
Model from Parmentier (unpublished)

Partially cloudy Kepler-7b



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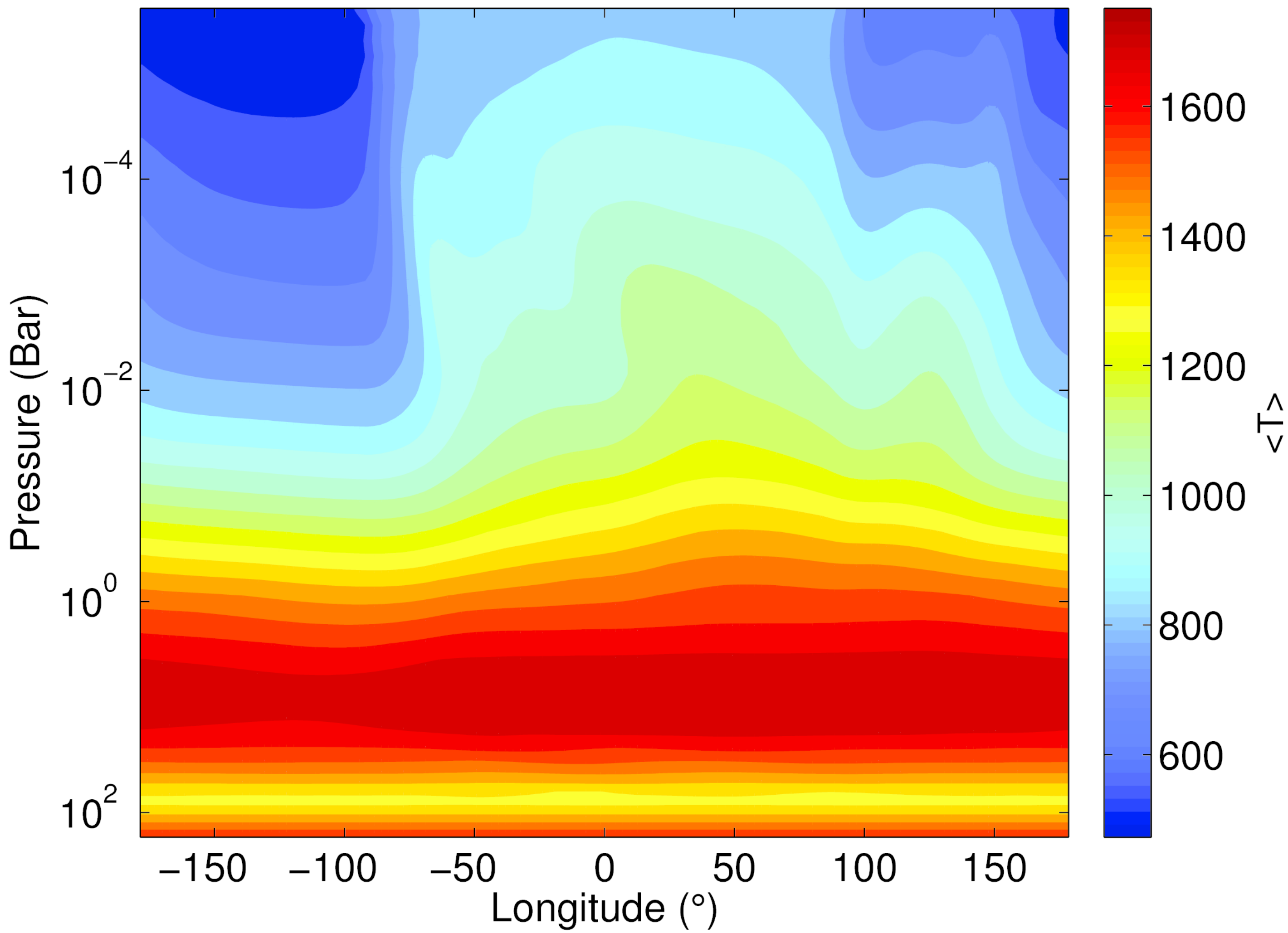
HD189733b : covered by clouds ?



Parmentier et al. in prep

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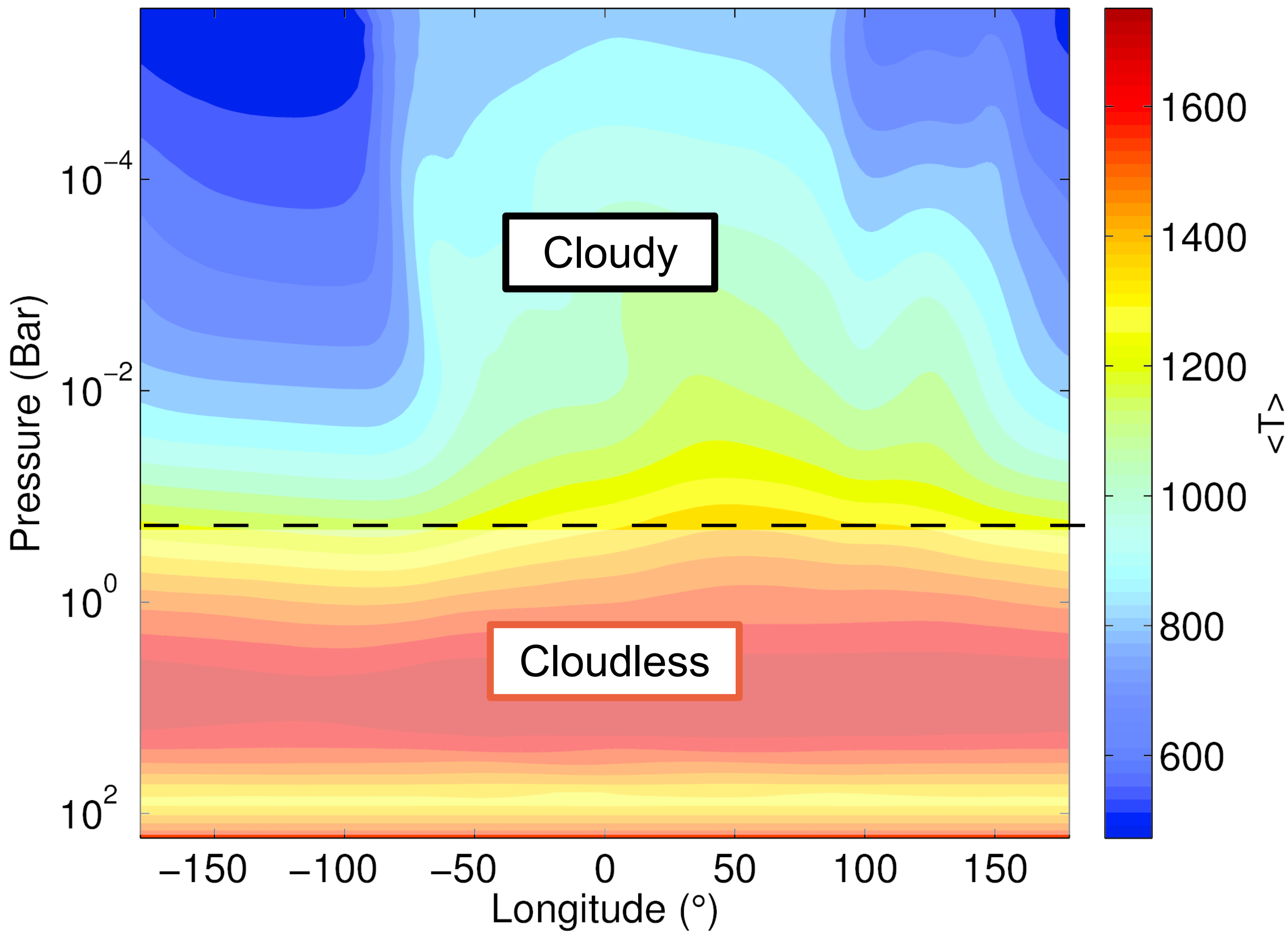
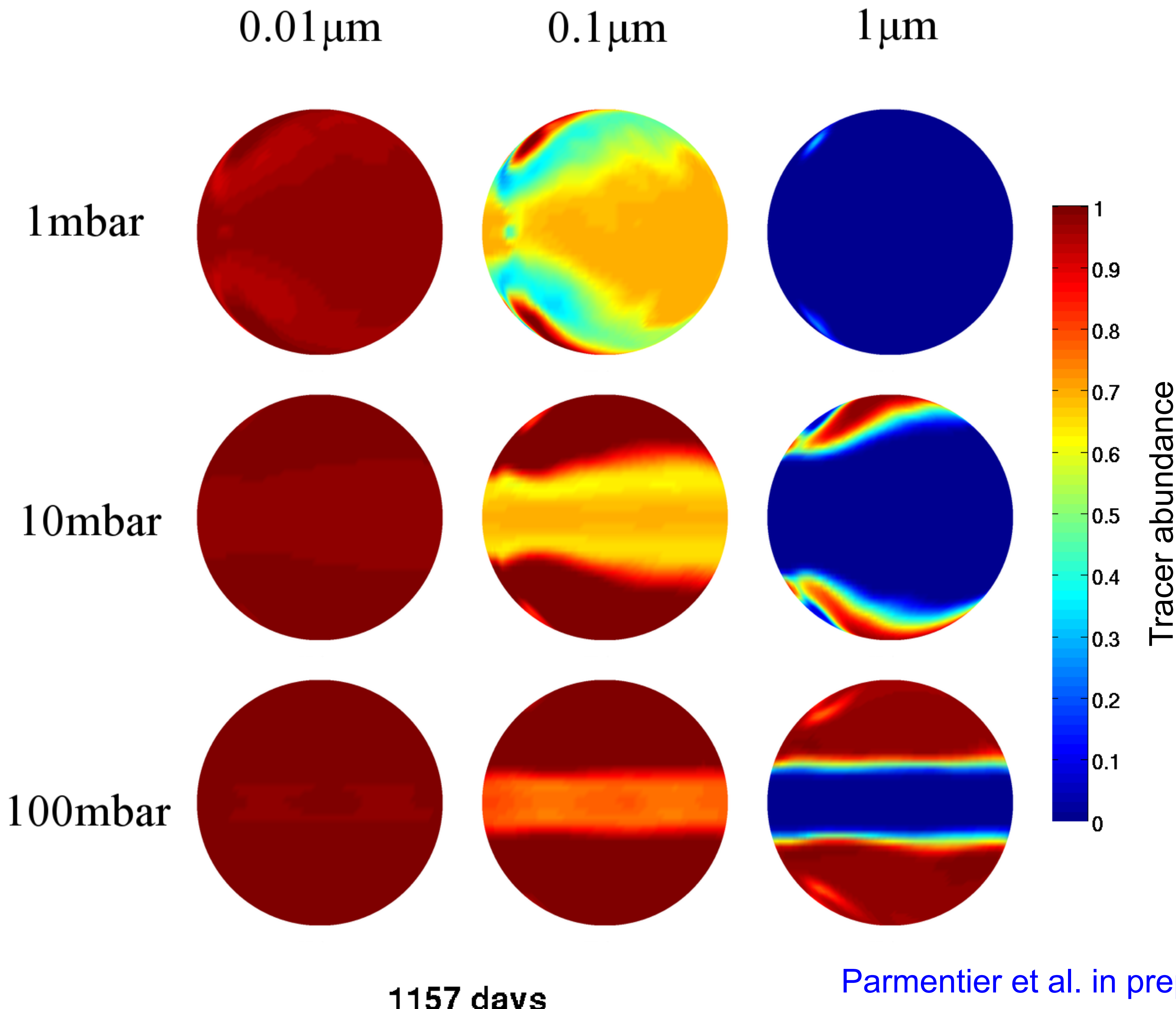
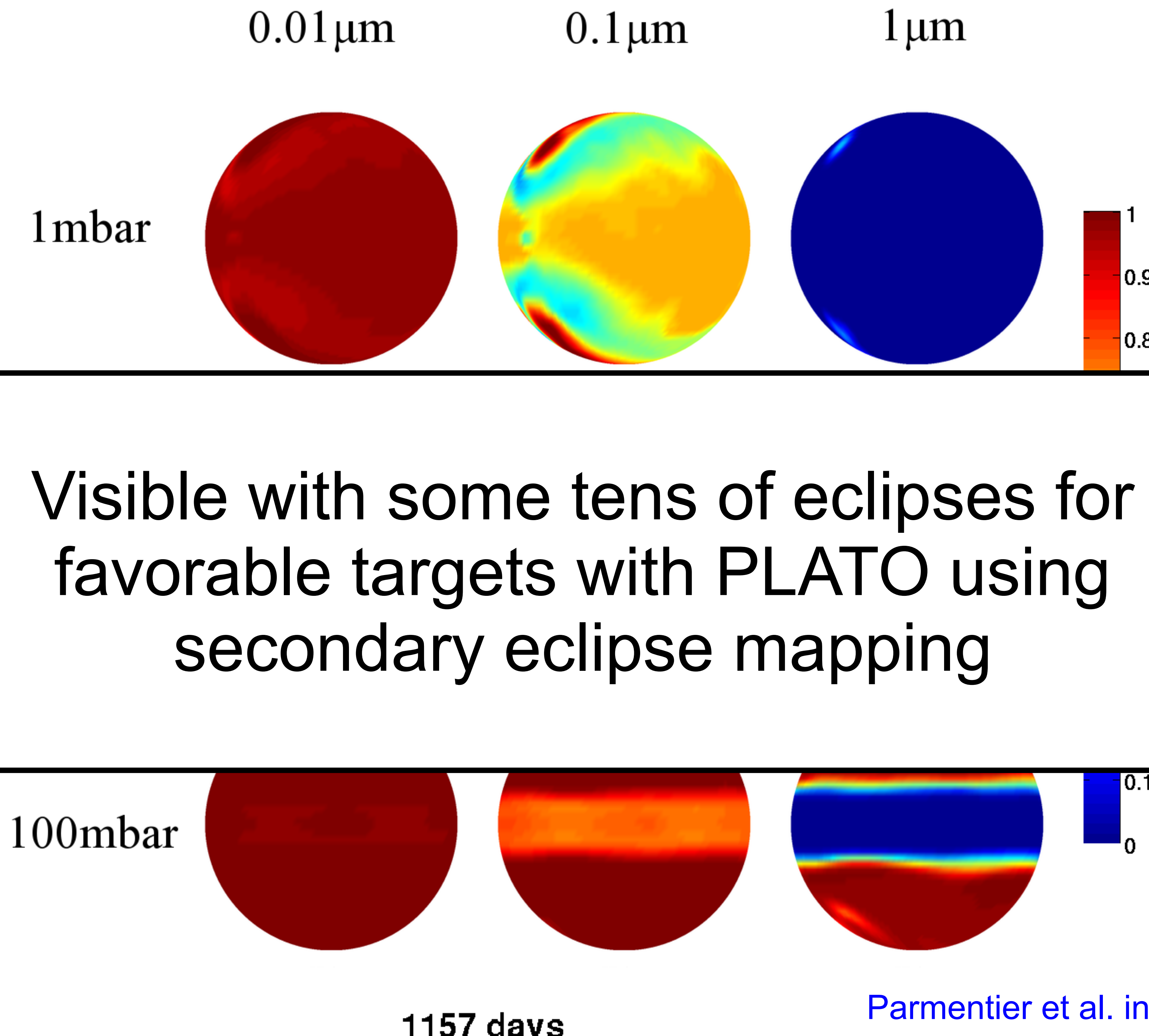


Parmentier et al. in prep



Parmentier et al. in prep



Visible with some tens of eclipses for favorable targets with PLATO using secondary eclipse mapping

Parmentier et al. in prep

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Clouds at the limb ? → important for transit observations

→ **Kepler-7b** T_{eq0}~ 1500K but A_g~0.35 T_{eq}~1300K

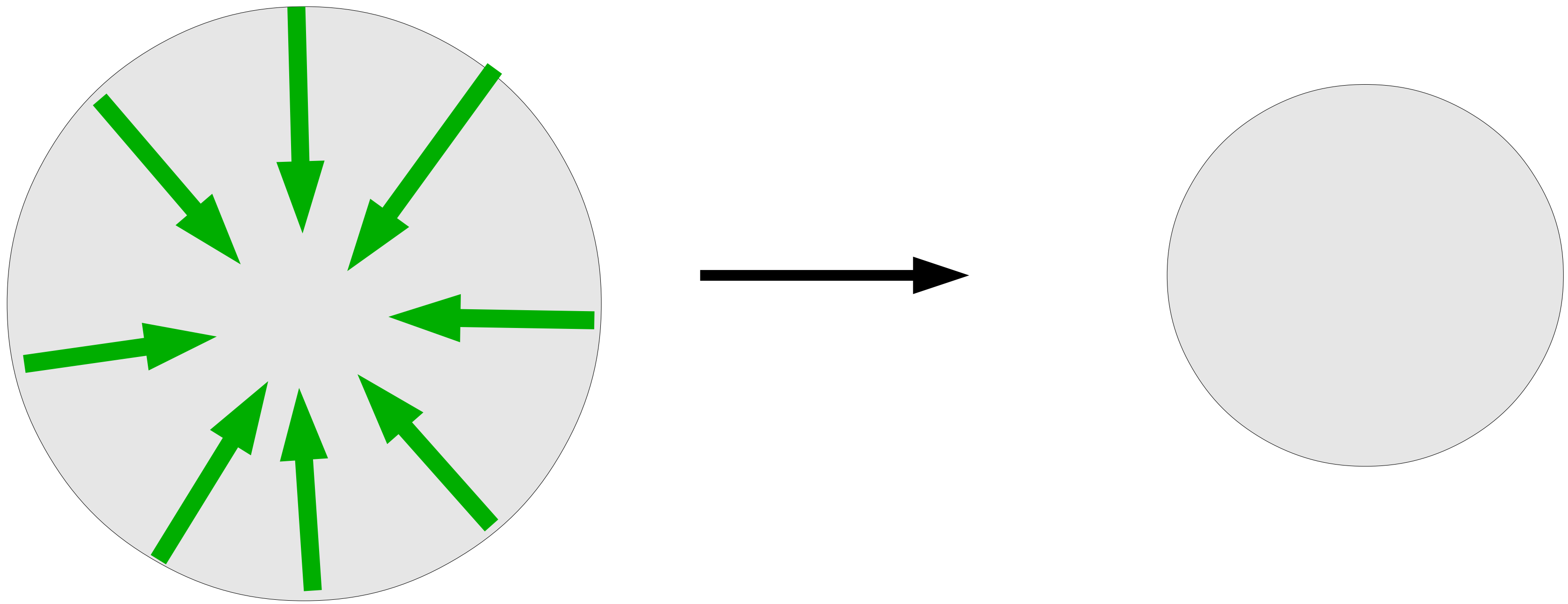
Partly cloudy dayside → longitudinal variations

→ **HD189733b** T_{eq0}~1200K

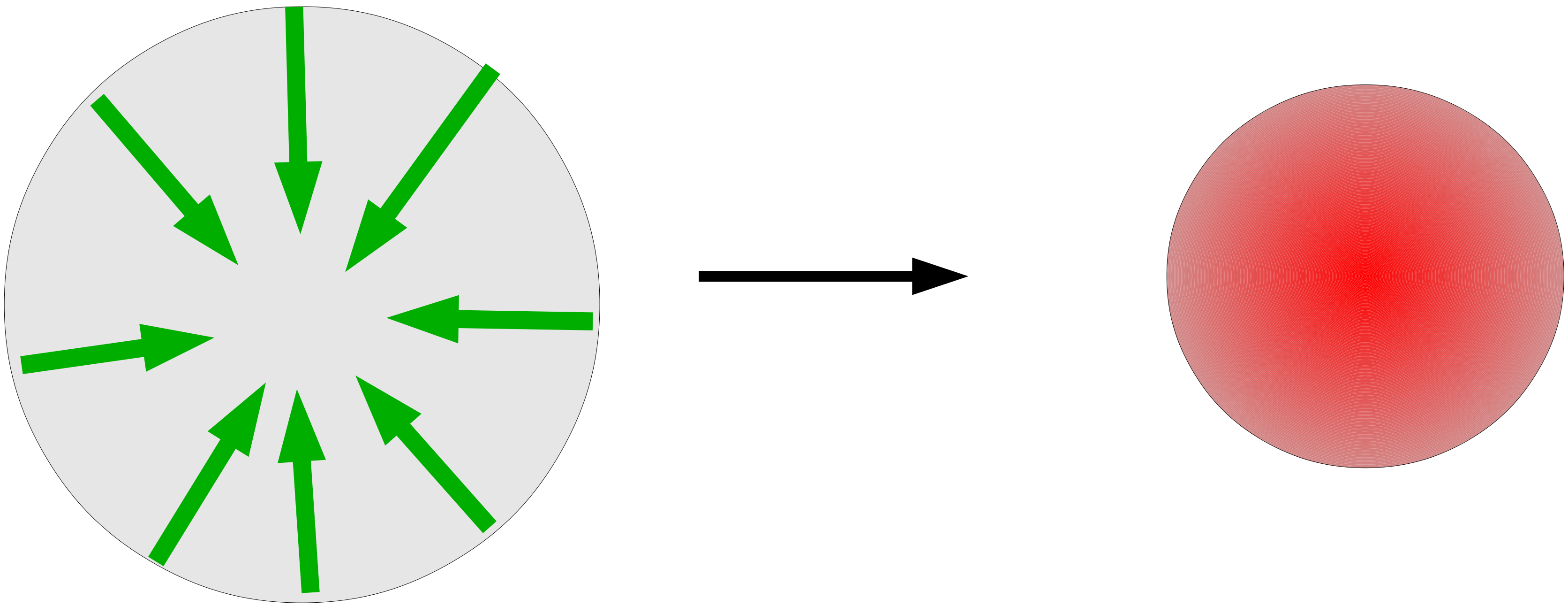
Partly cloudy dayside → latitudinal variations

Atmospheric composition and planet evolution

Evolution of a gaseous planet



Evolution of a gaseous planet



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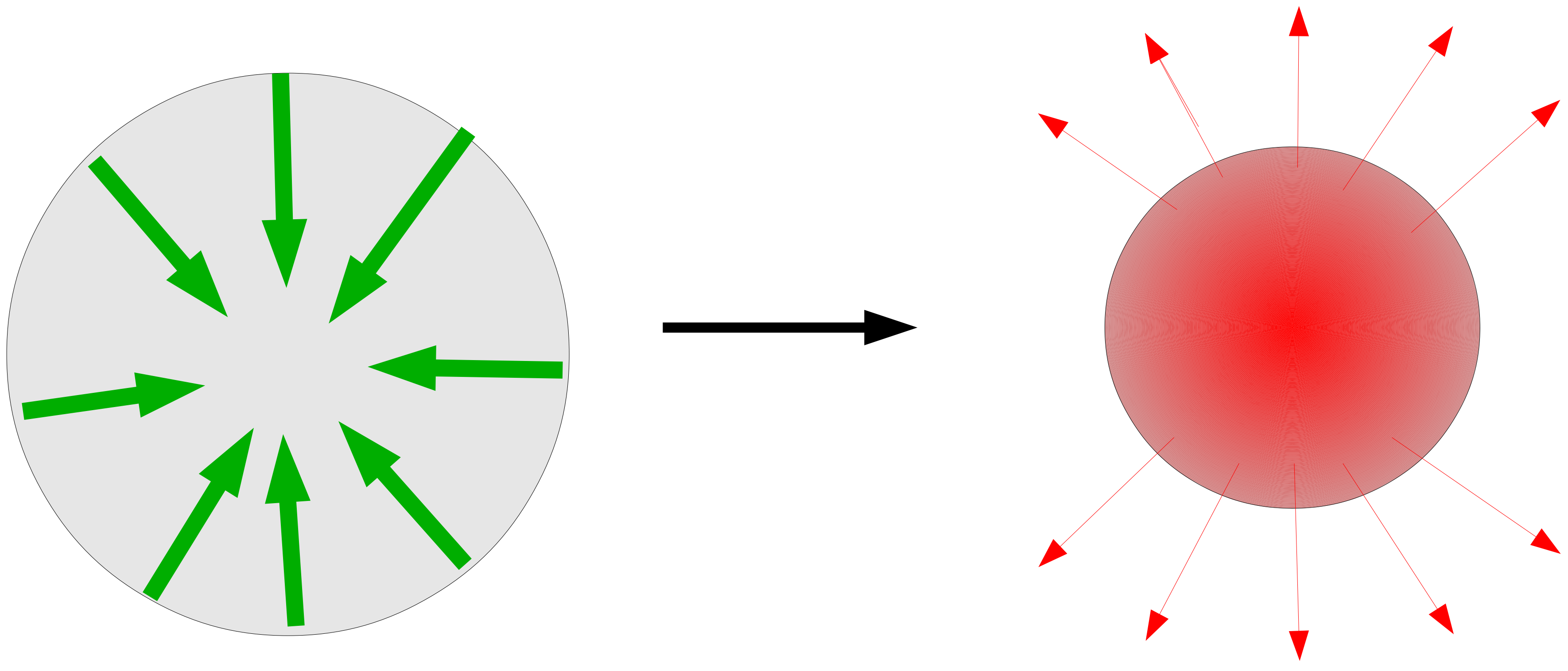

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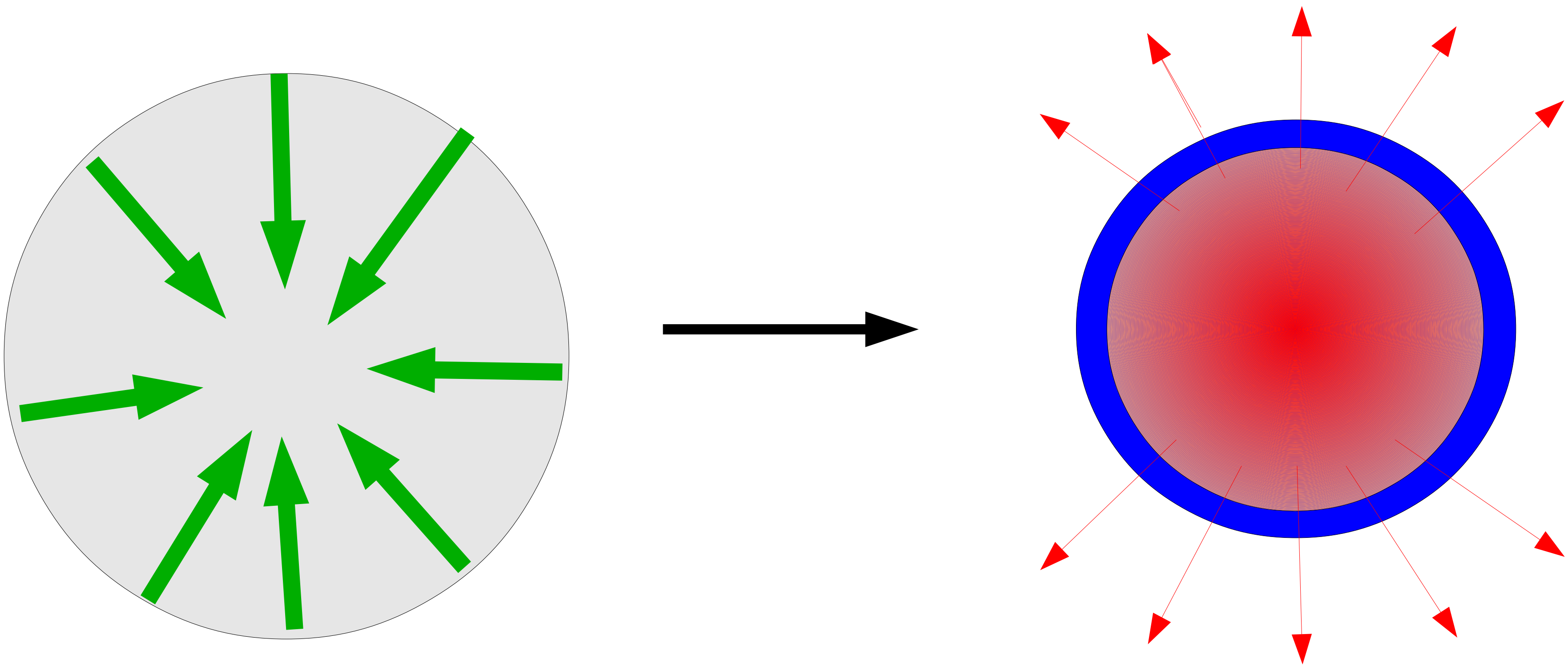
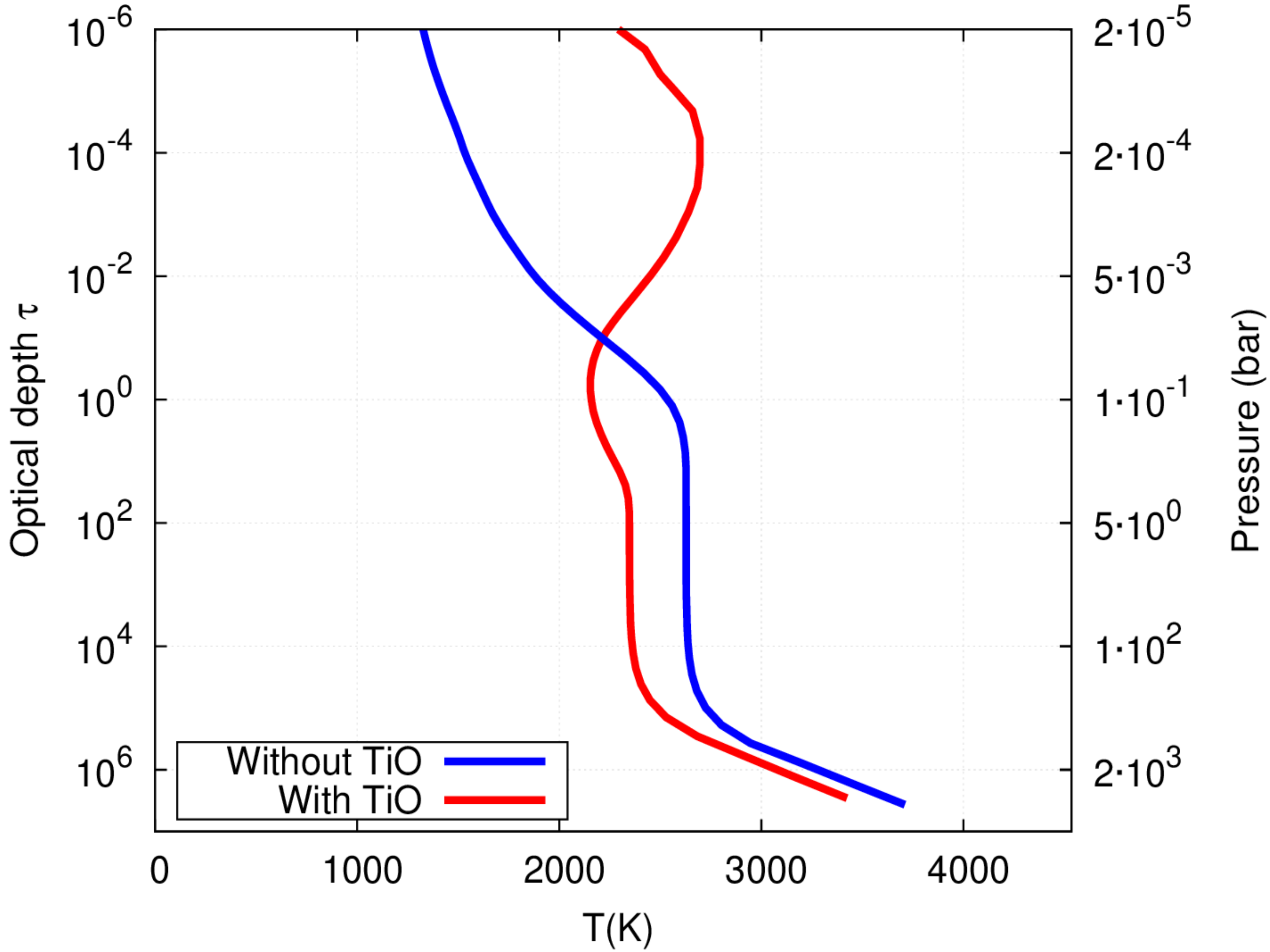


The atmosphere is a valve that determines how much energy can escape from the planet

Temperature profiles : the exemple of TiO



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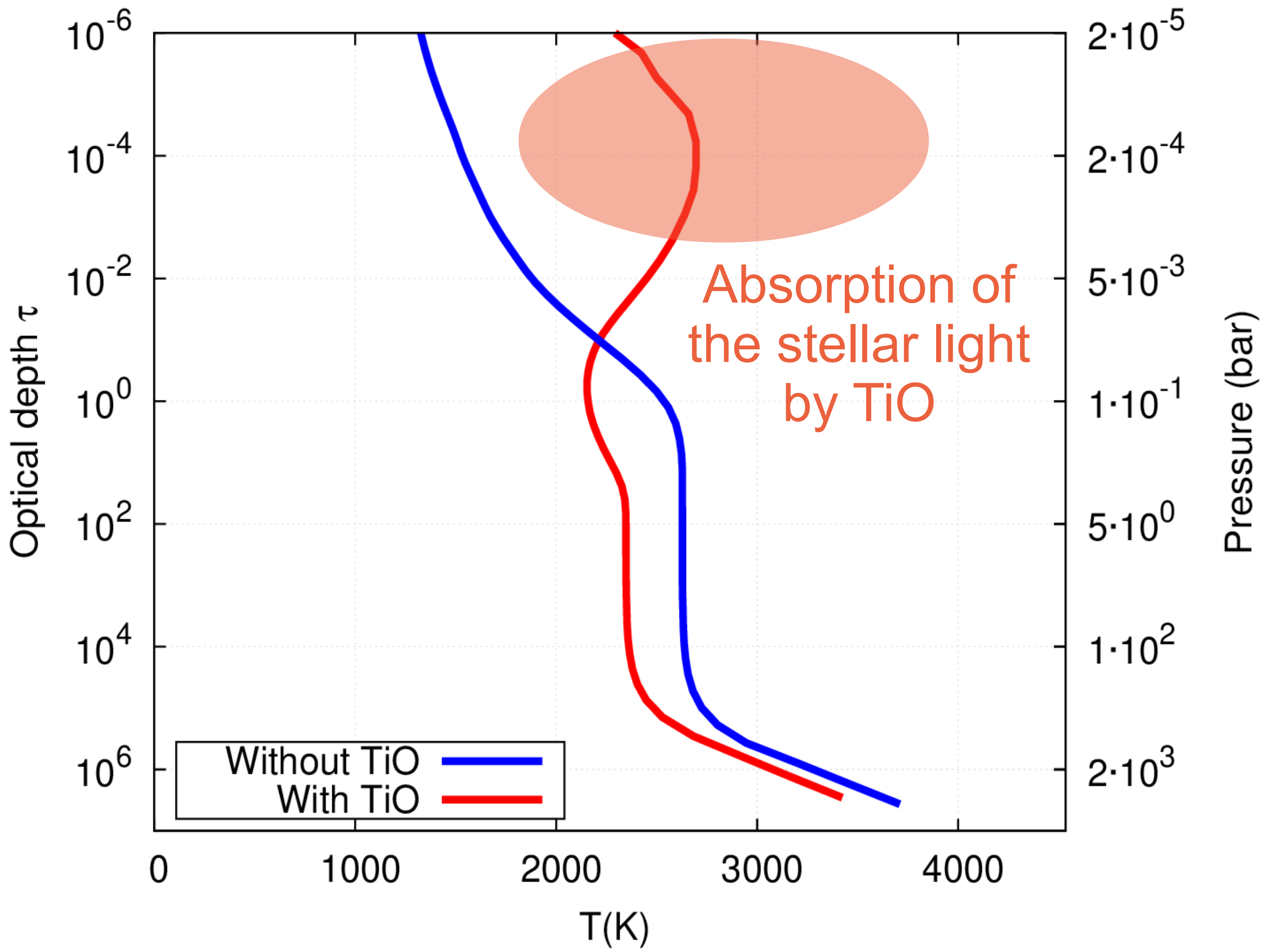
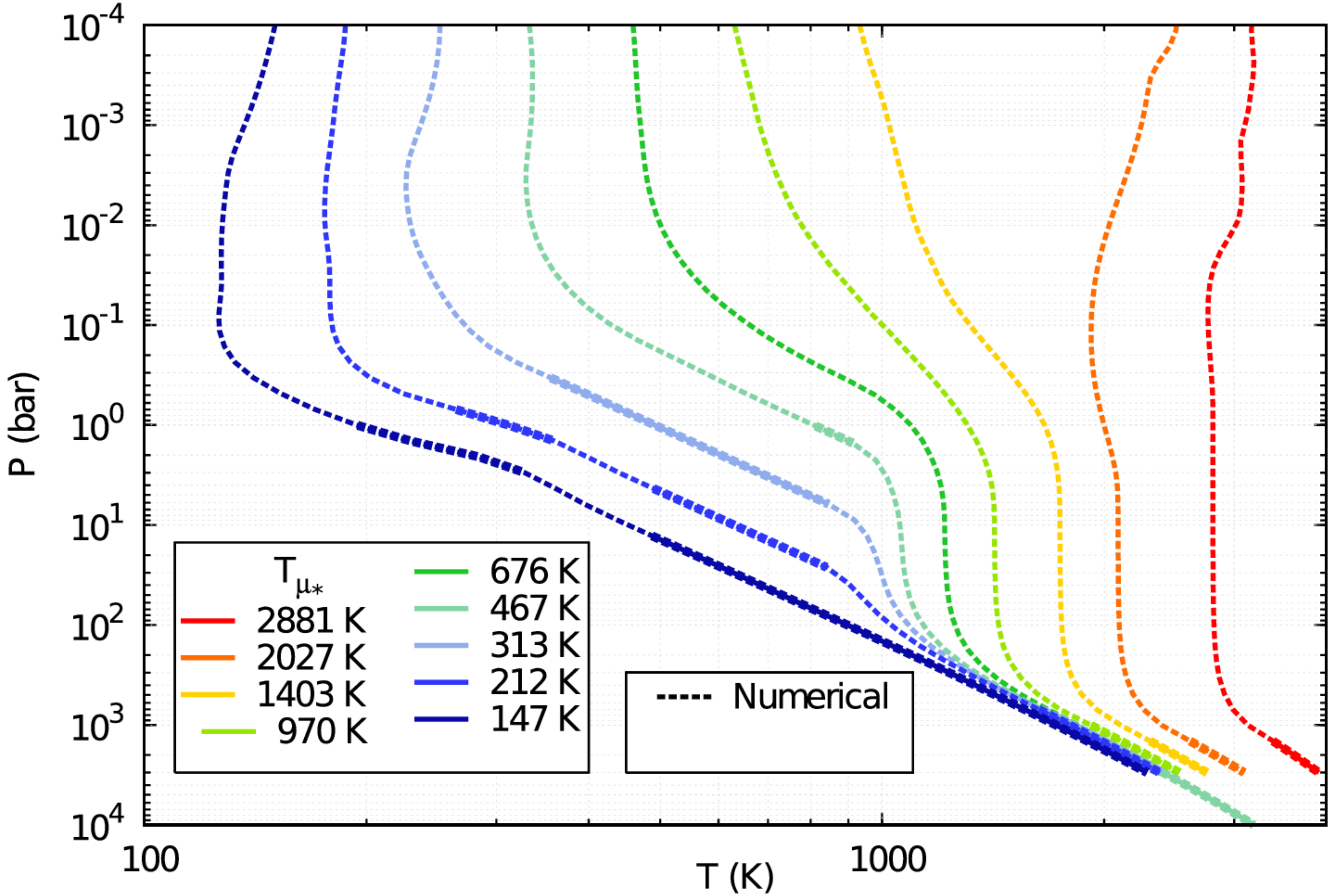


Temperature profiles : numerical

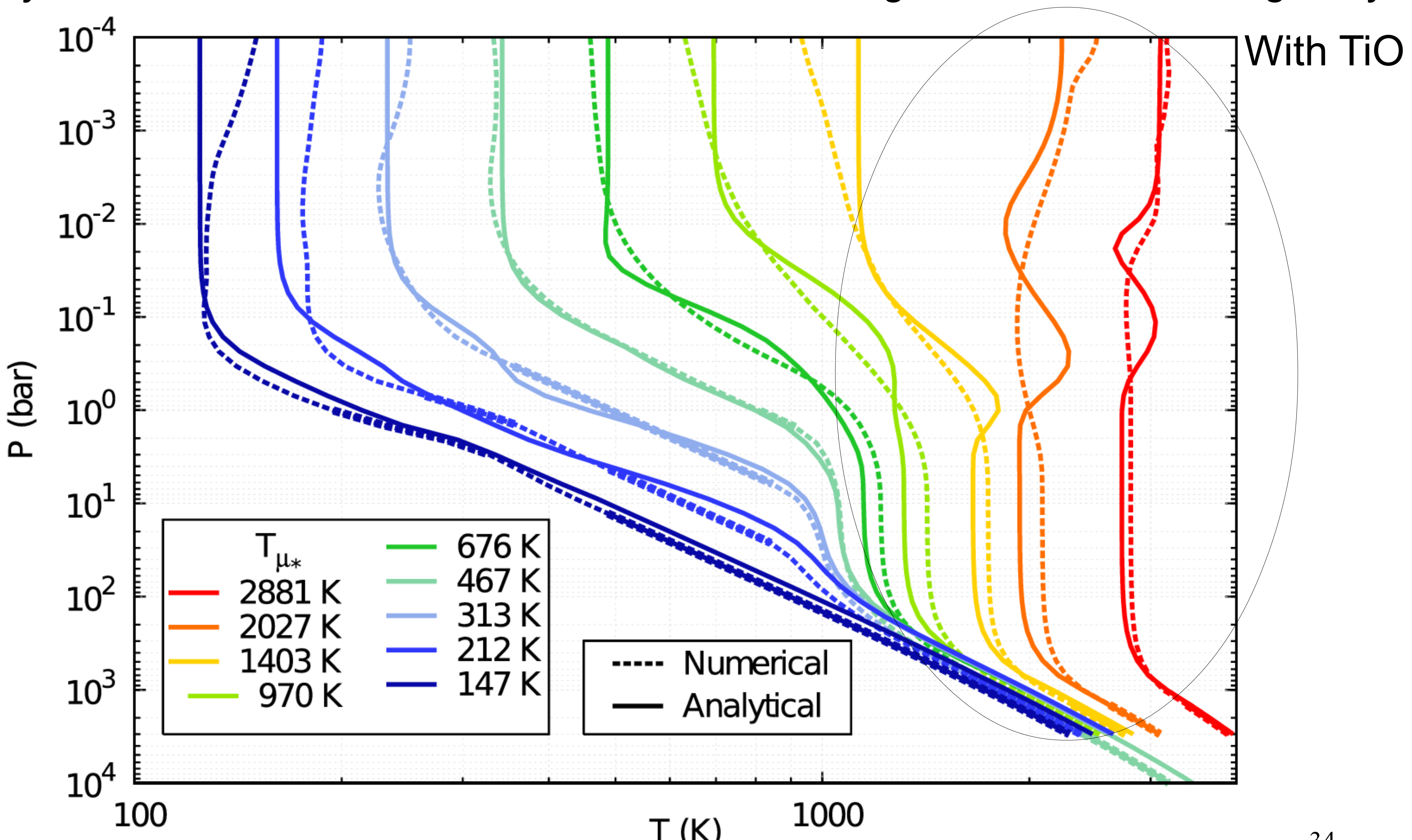
Grid of numerical model using the code of Fortney, Marley, McKay



Parmentier et al. 2014c – sub.

Temperature profiles : numerical vs. analytical

Analytical solution valid within 10% over a wide range of irradiation and gravity



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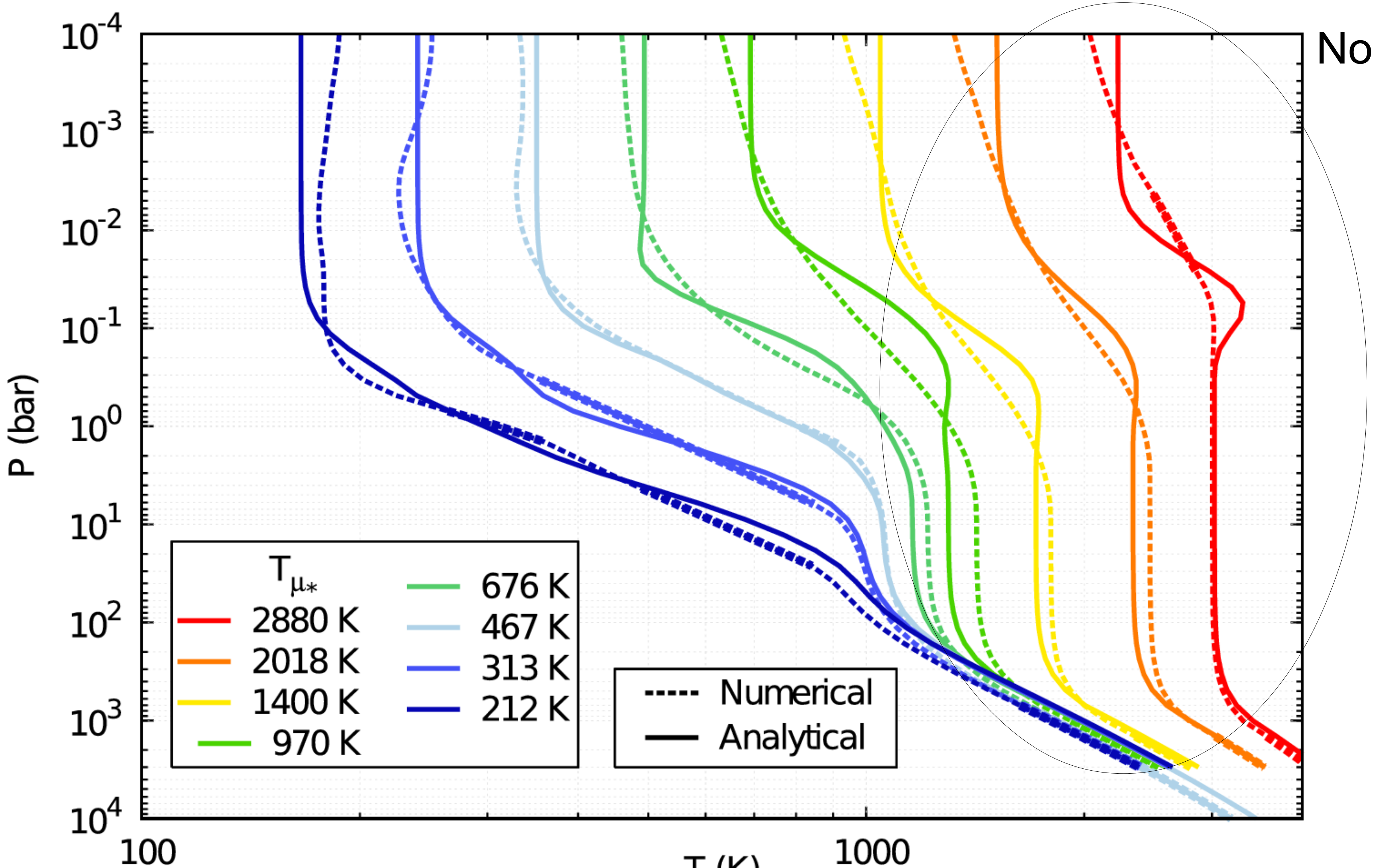

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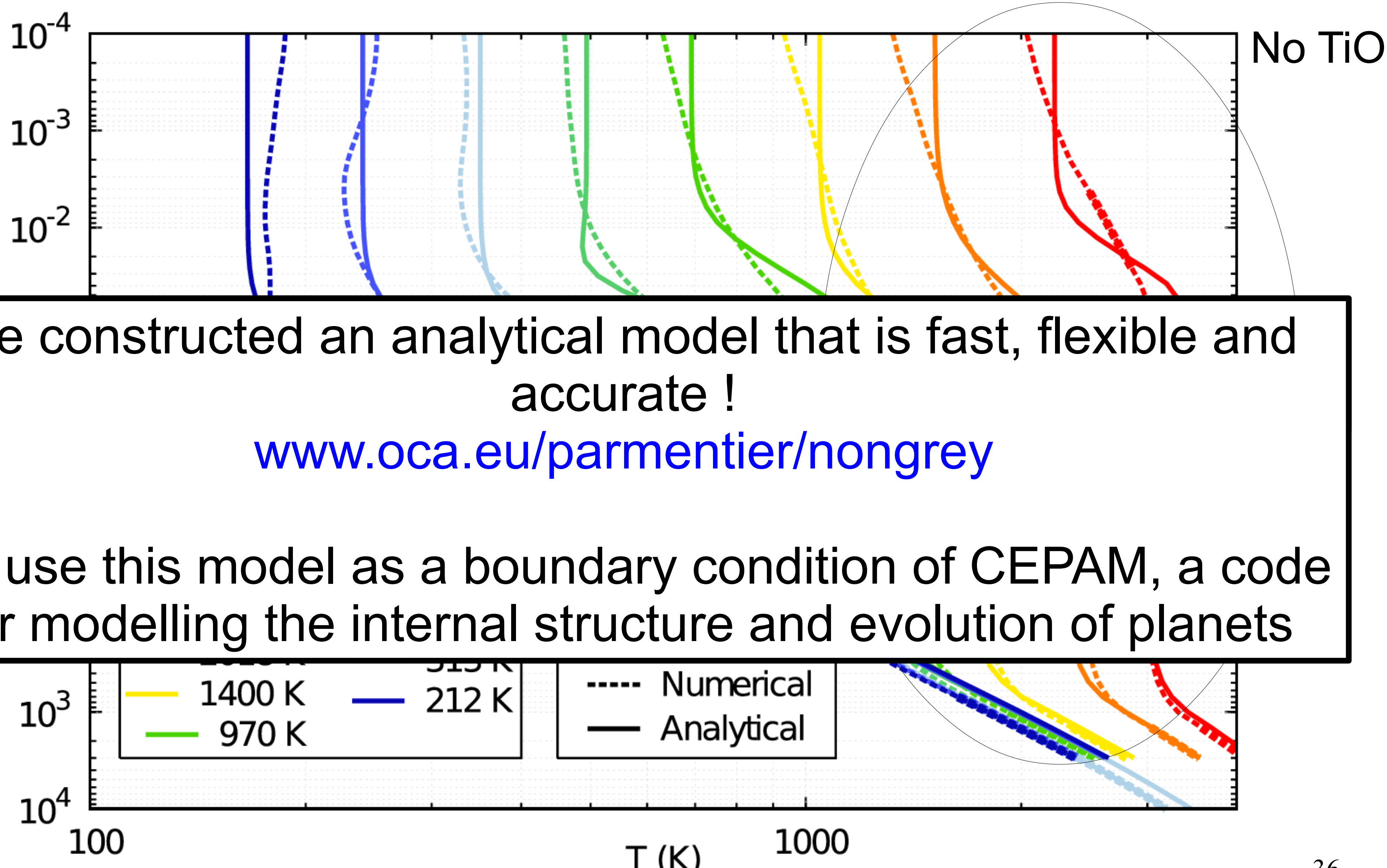
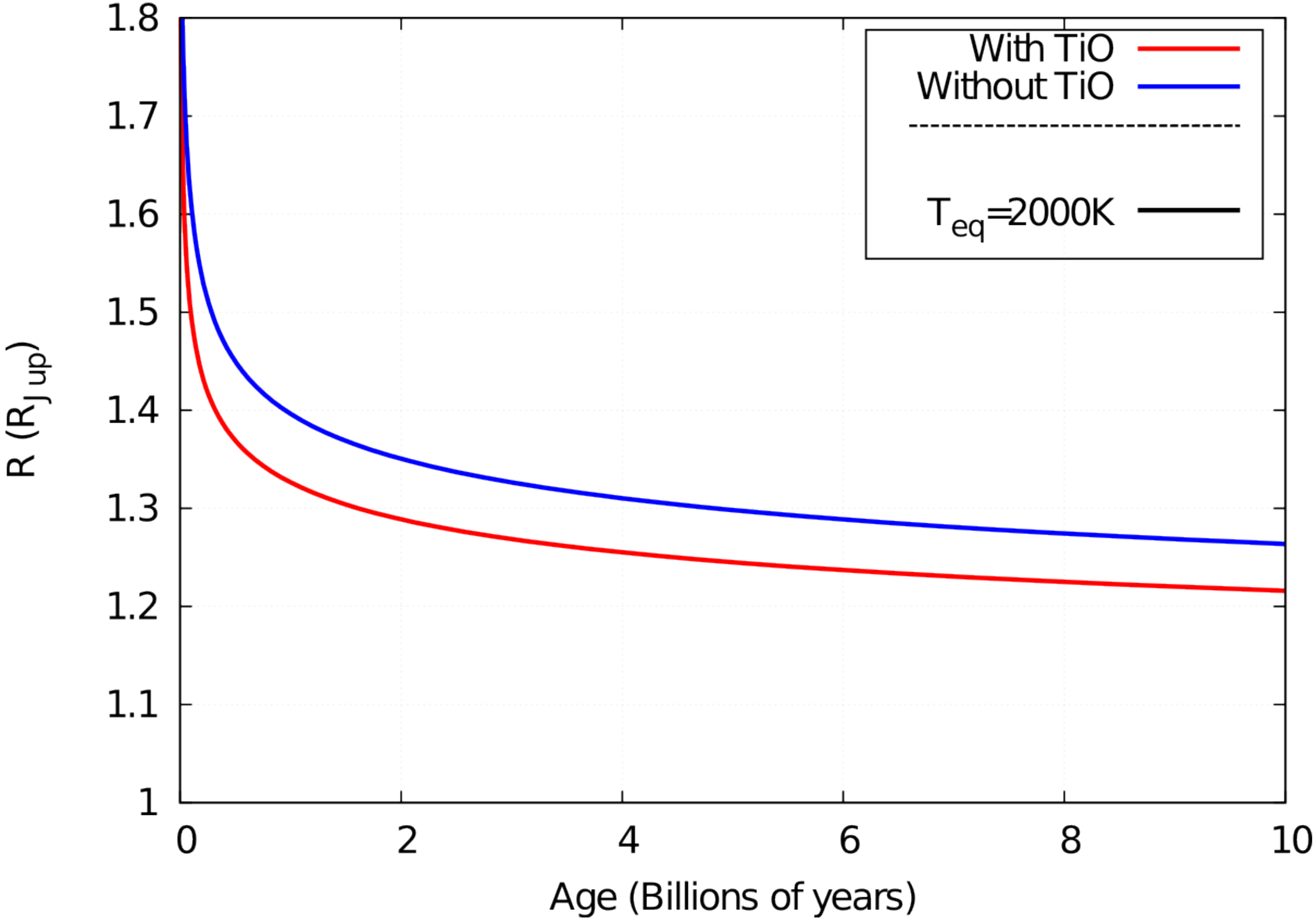


We constructed an analytical model that is fast, flexible and accurate !
www.oca.eu/parmentier/nongrey

We use this model as a boundary condition of CEPAM, a code for modelling the internal structure and evolution of planets

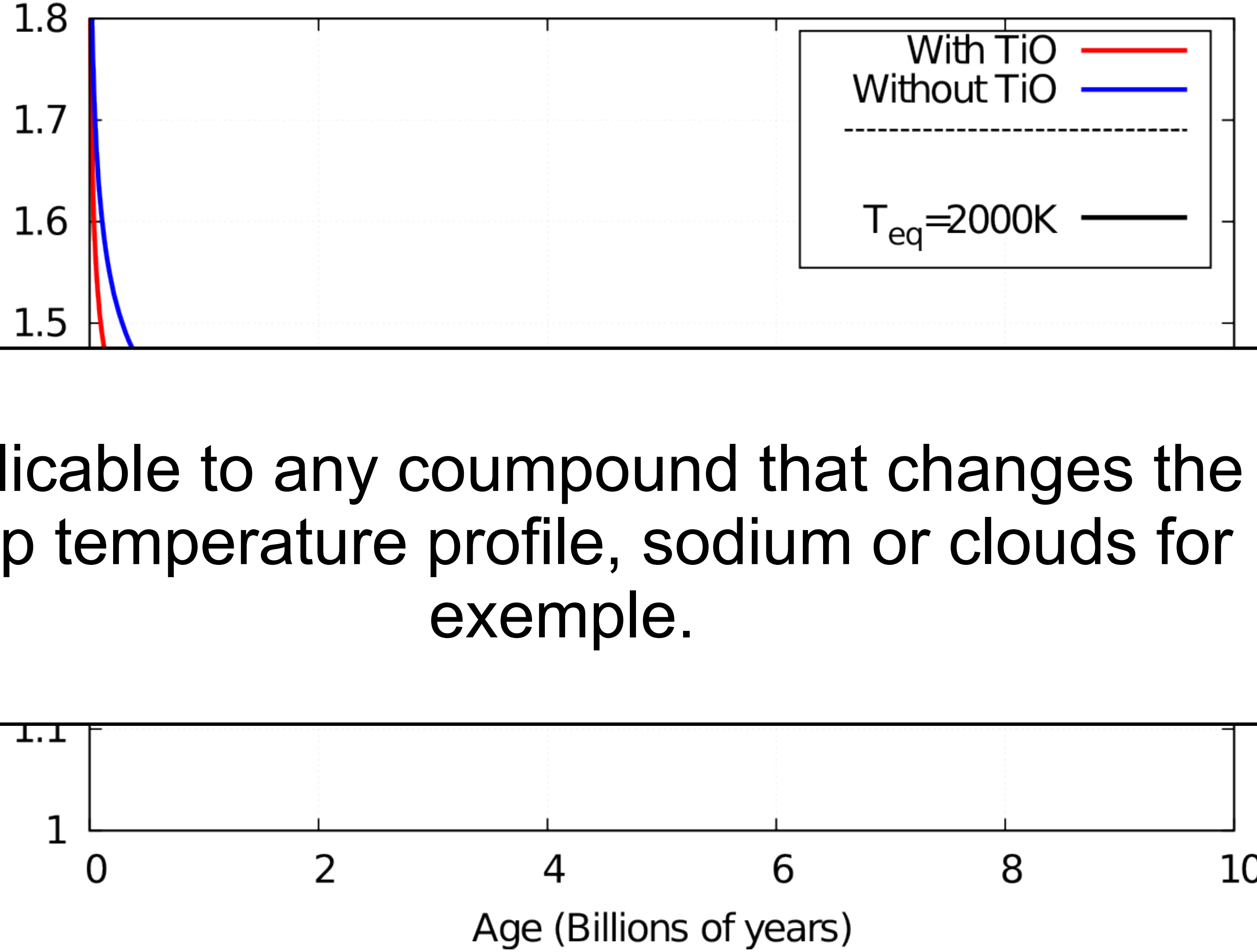
Parmentier et al. 2014c – sub.

Radius evolution: TiO vs No TiO



All things being equal, planets with TiO in their atmosphere should be smaller than planets without it.

Radius evolution: TiO vs No TiO



Applicable to any coumpound that changes the deep temperature profile, sodium or clouds for exemple.

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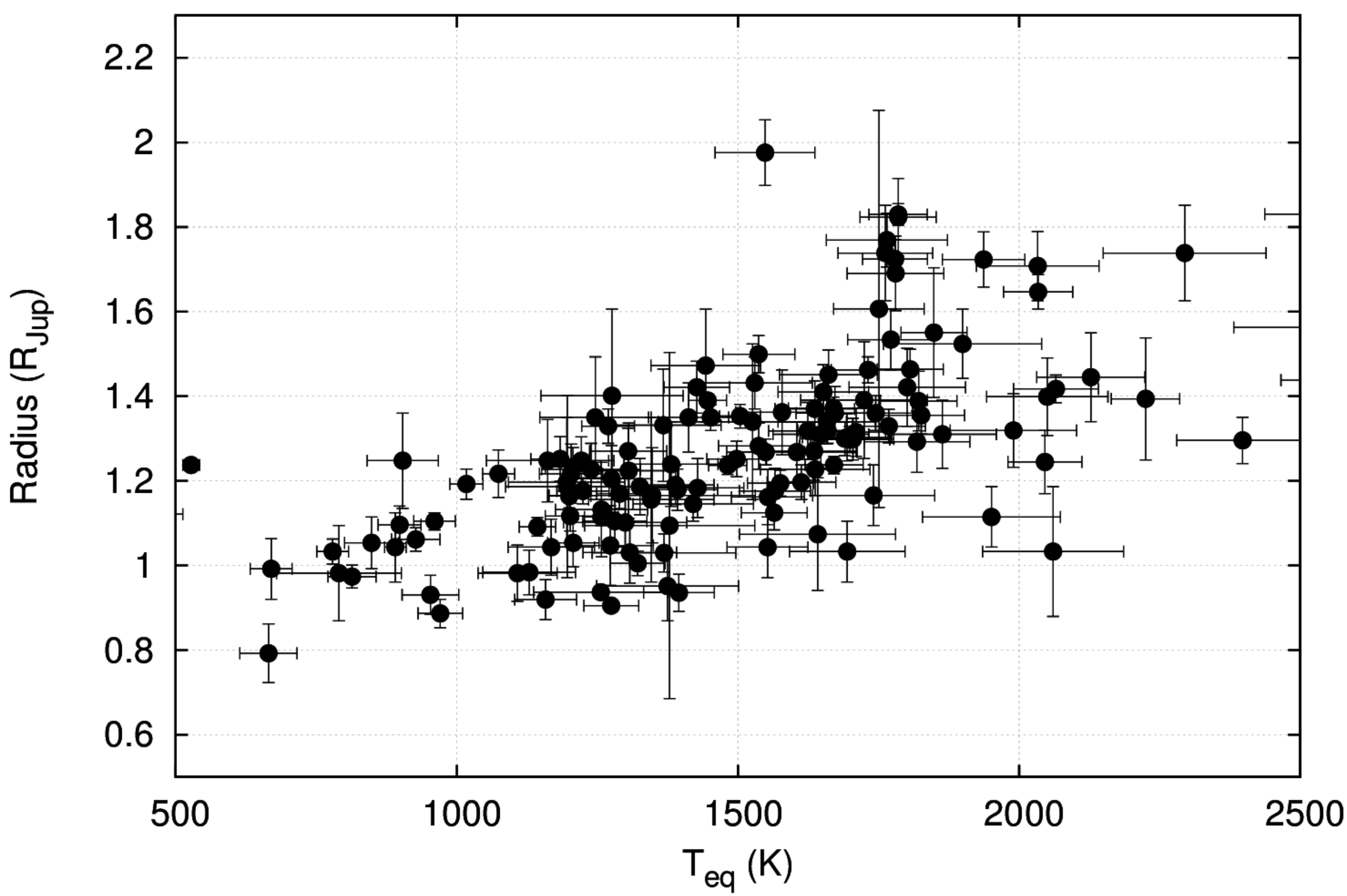
Are planets with TiO really smaller ?



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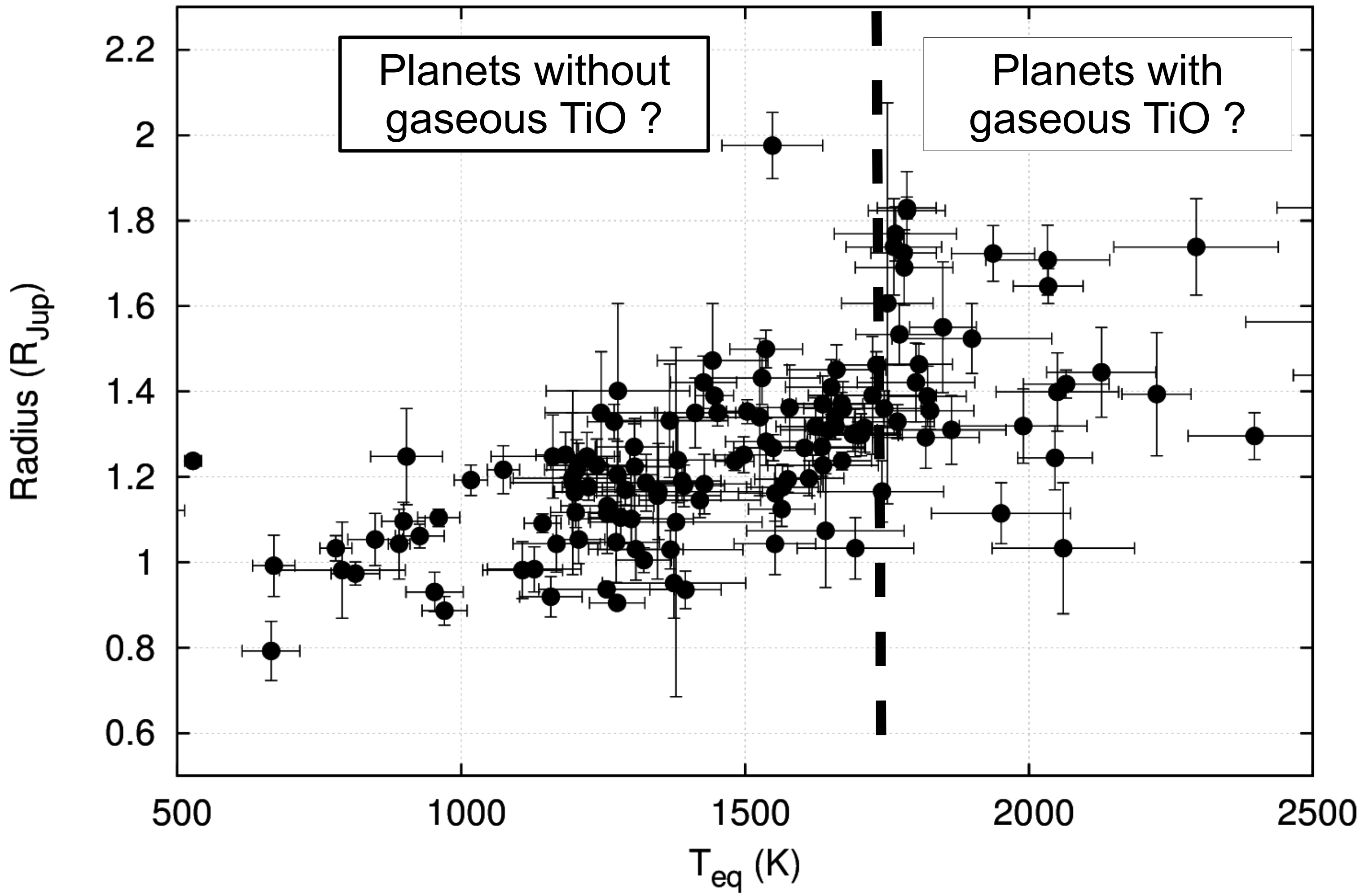

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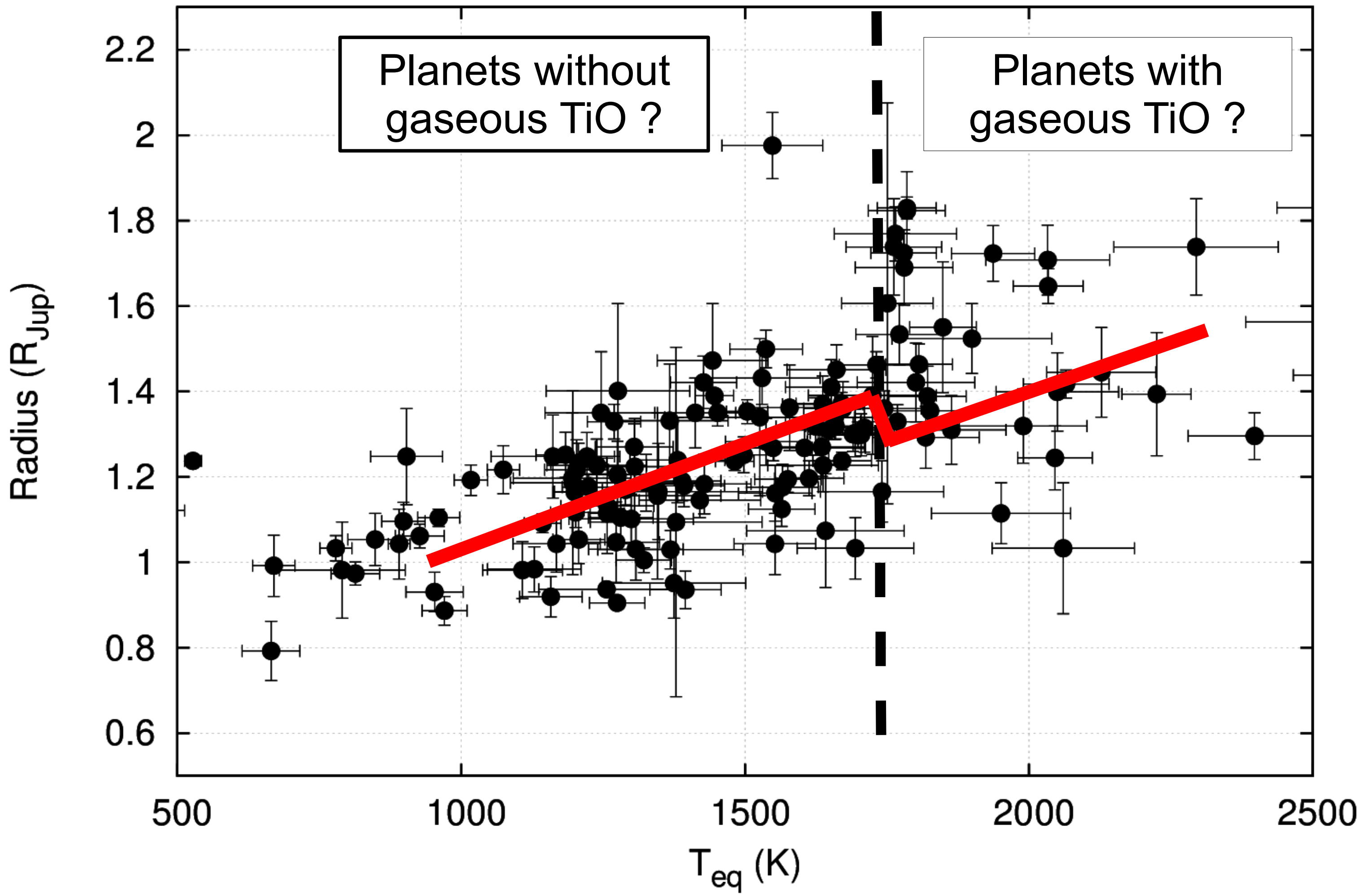
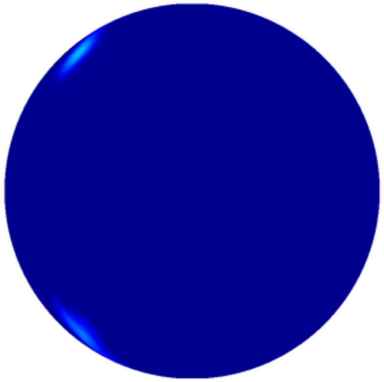


We need better statistics to see this signature

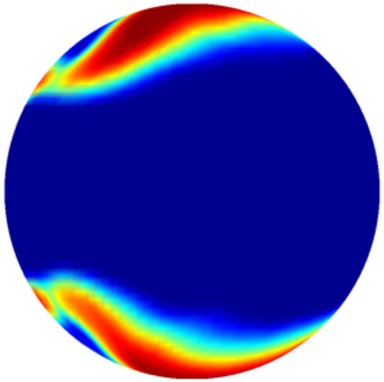
Conclusion

Atmospheric circulation shapes the clouds in a planet atmosphere.
→ *In hot Jupiters the patterns are global and thus observable by photometric missions.*



The atmospheric composition affects the long-term evolution of the planet.

→ Statistical studies are needed, photometric missions are necessary.



1D analytical atmospheric model available at:
www.oca.eu/parmentier/nongrey