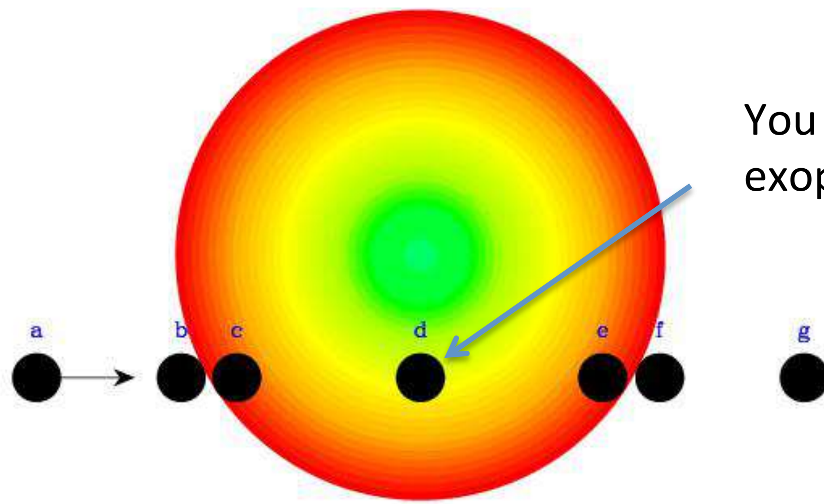
Global circulation models of hot jupiters with Dynamico: solving the radius inflation puzzle

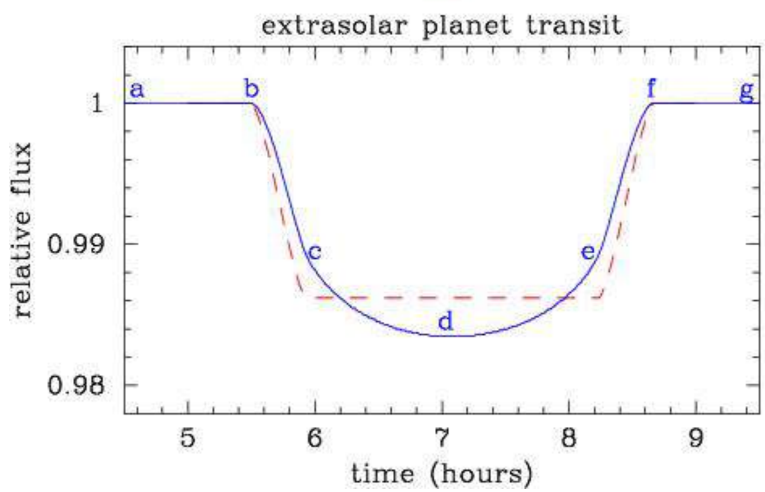
P. Tremblin, S. Fromang & collaborators

A bit of history… the transit method

- To confirm the 1995 radial velocity detection of an exoplanet, Astronomers were looking for a second undirect detection technique: the transit method

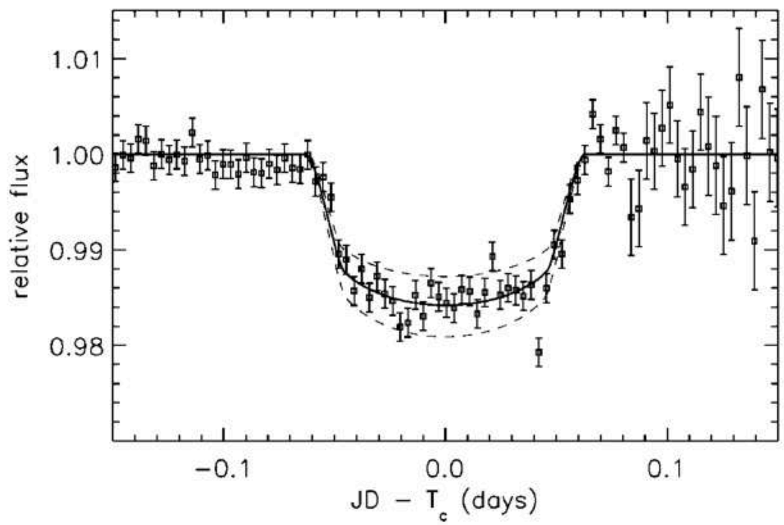


You get the radius of the exoplanet



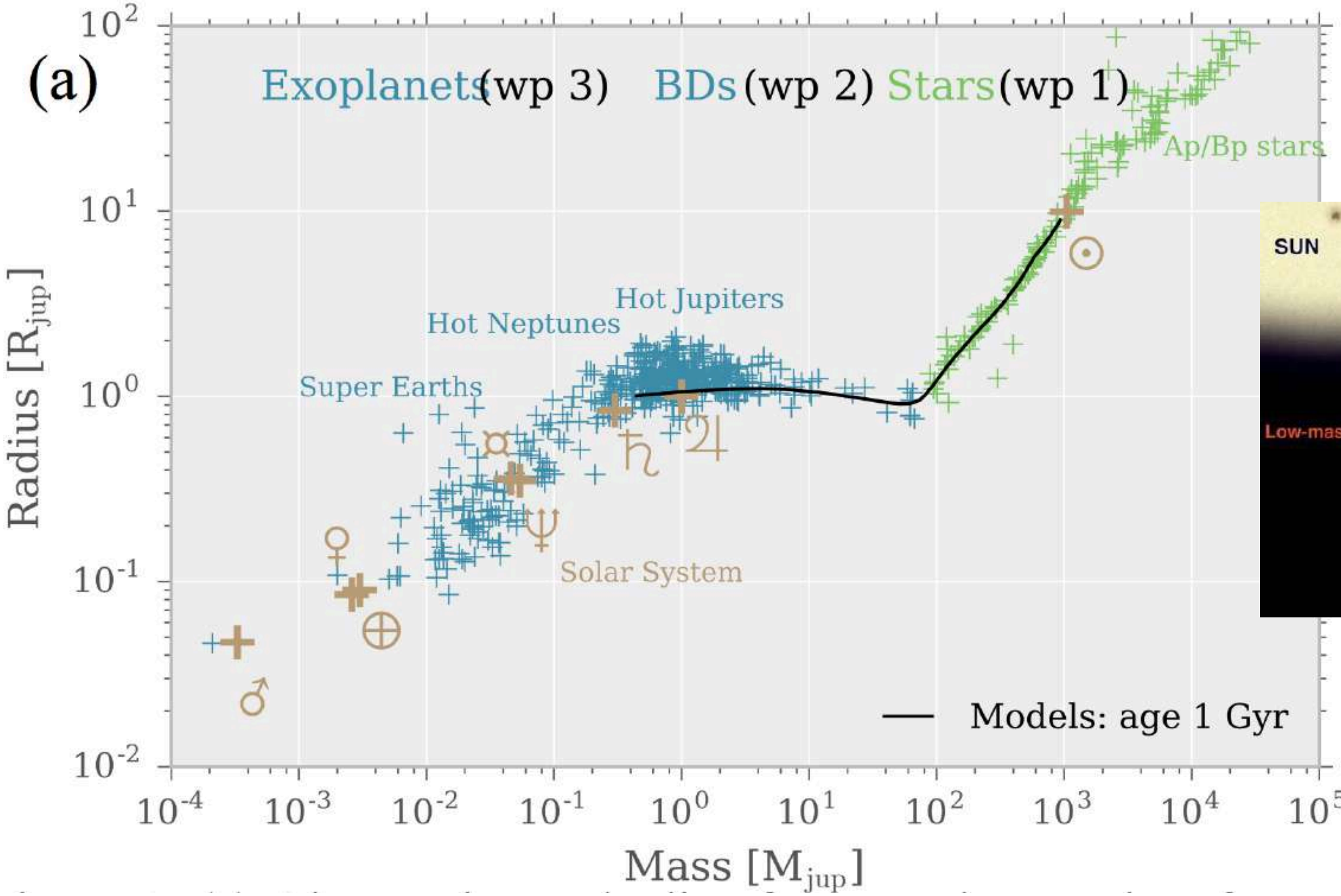
➢ A bit of history… the transit method

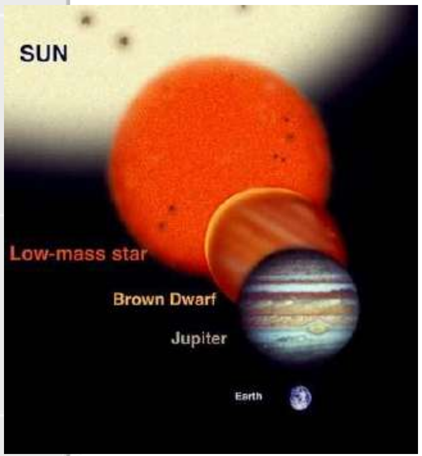
– In 1999 Charbonneau et al. got the first detection by this method, a 0.7 Jupiter-mass hot jupiter called HD209458b



– Finally fully confirming the existence of exoplanets !

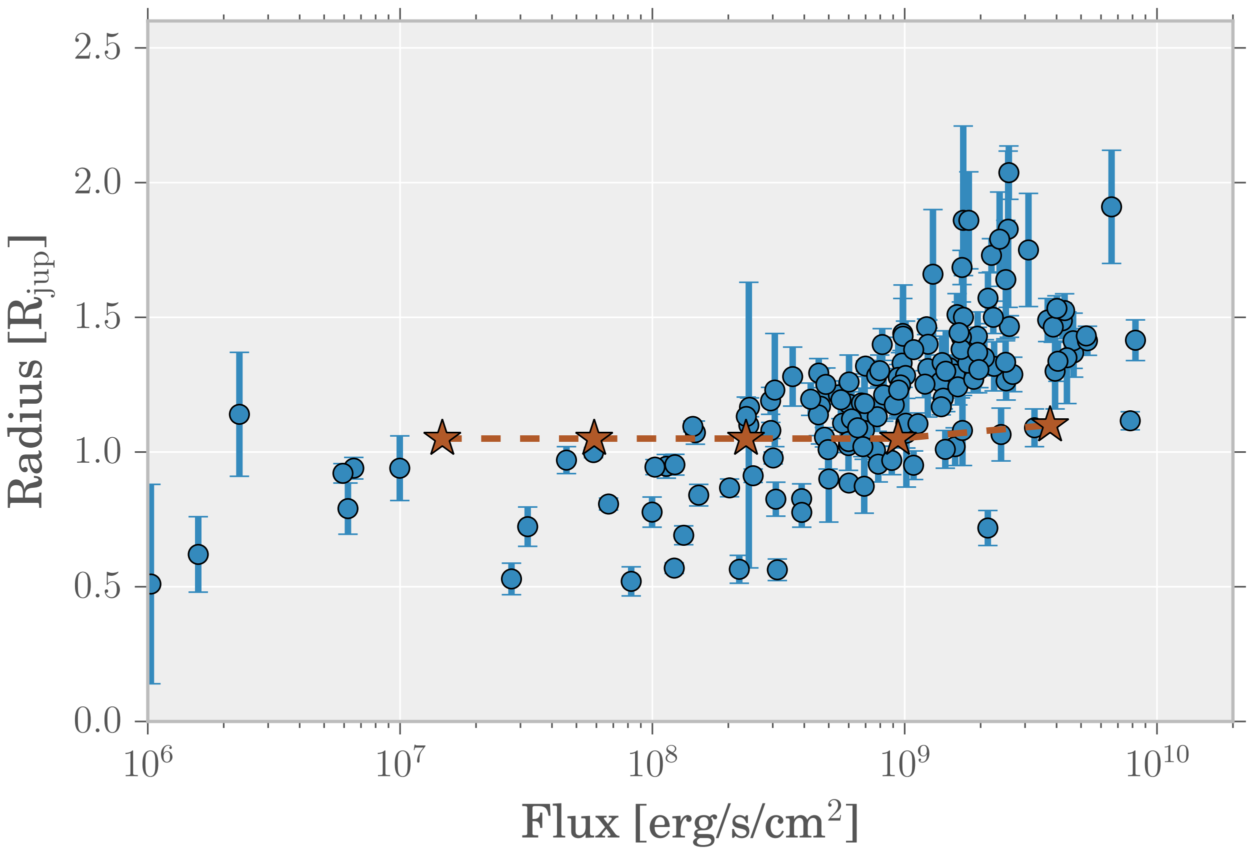
➢ Problem… the planet is inflated!





➢ Problem… the planet is inflated!

- We know very well what the radius of ball of gas should be
- And we do not know why irradiated hot jupiters are bigger with increasing irradiation

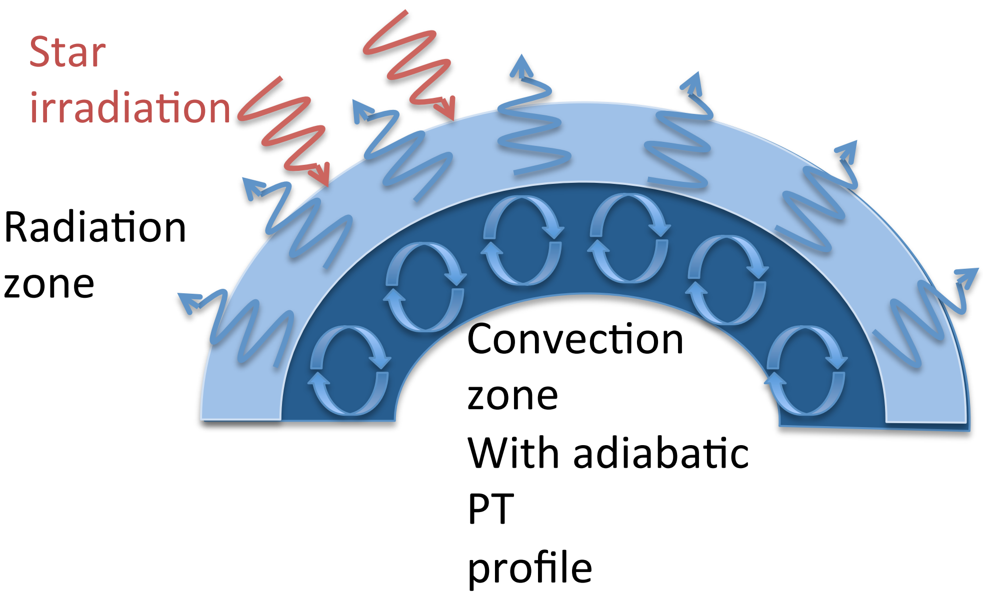


Why is it a challenge?

- We do not know why irradiated hot jupiters are bigger with increasing irradiation
- 1D atmospheric models

What you want to get:
- Pressure P
- Temperature T

What you need to solve (steady state):
- Hydrostatic balance
- Energy conservation



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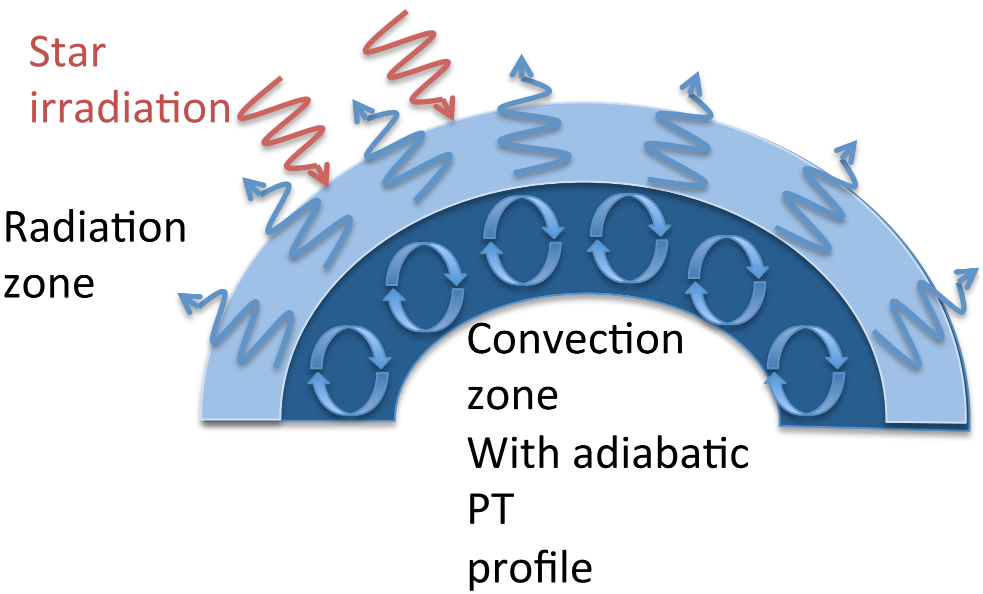
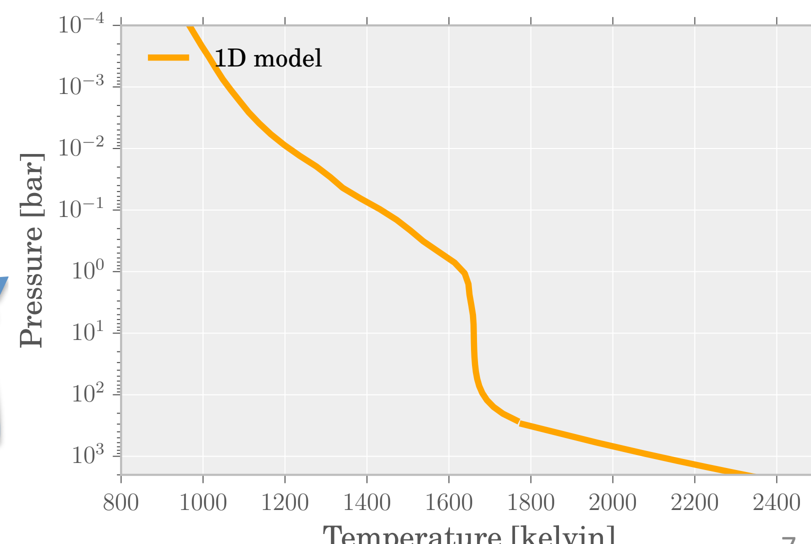
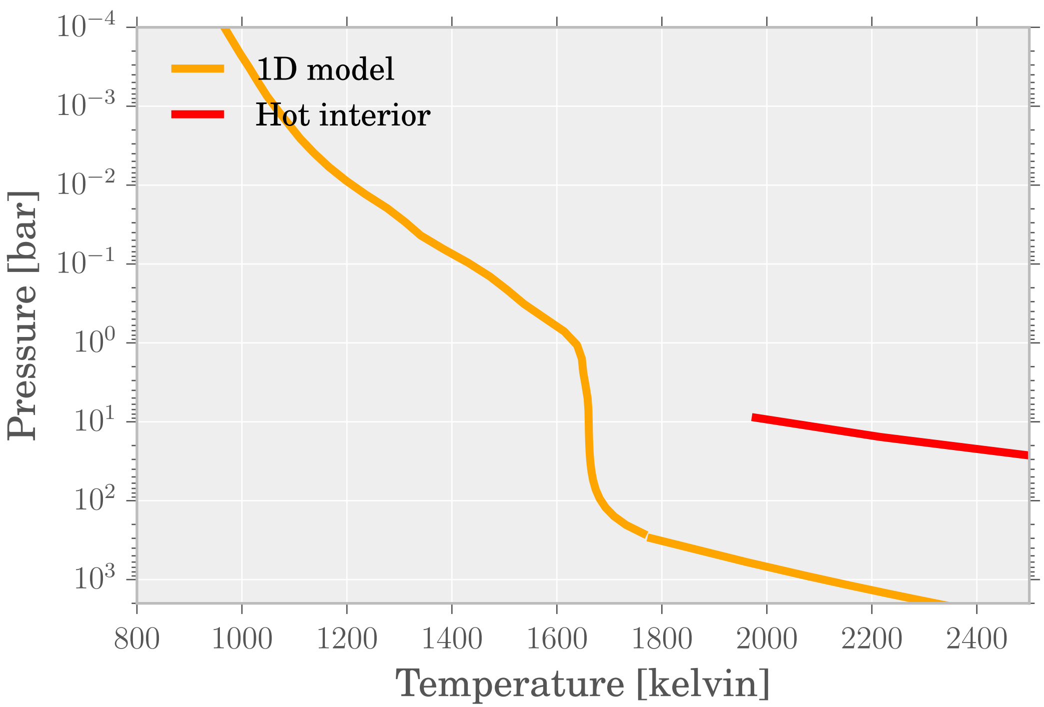
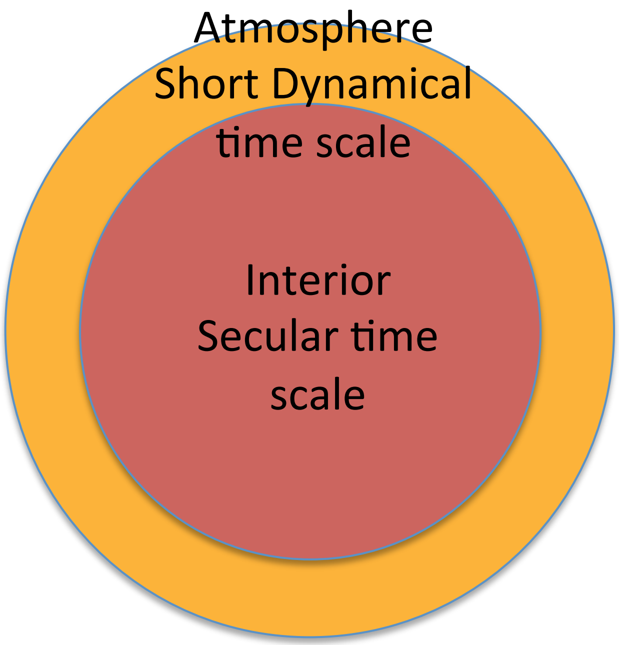




➢ Why is it a challenge?

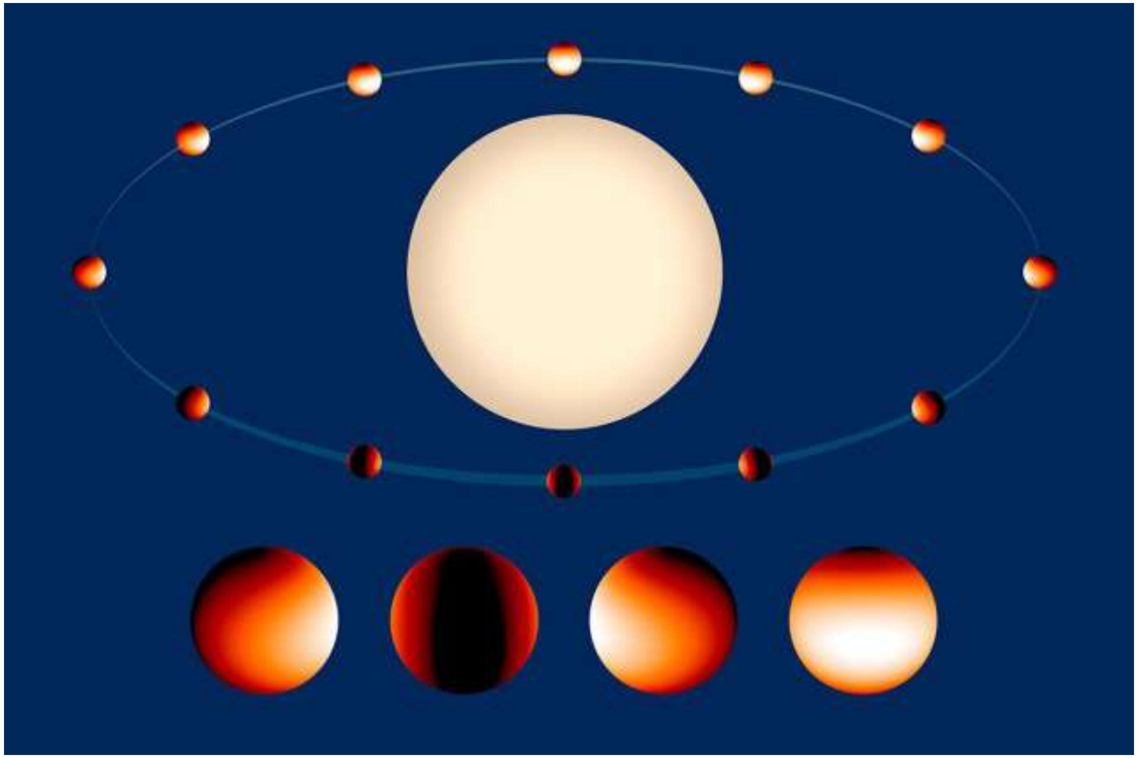
- We do not know why irradiated hot jupiters are bigger with increasing irradiation
- 1D atmospheric models do not work, too cold in the deep atmosphere





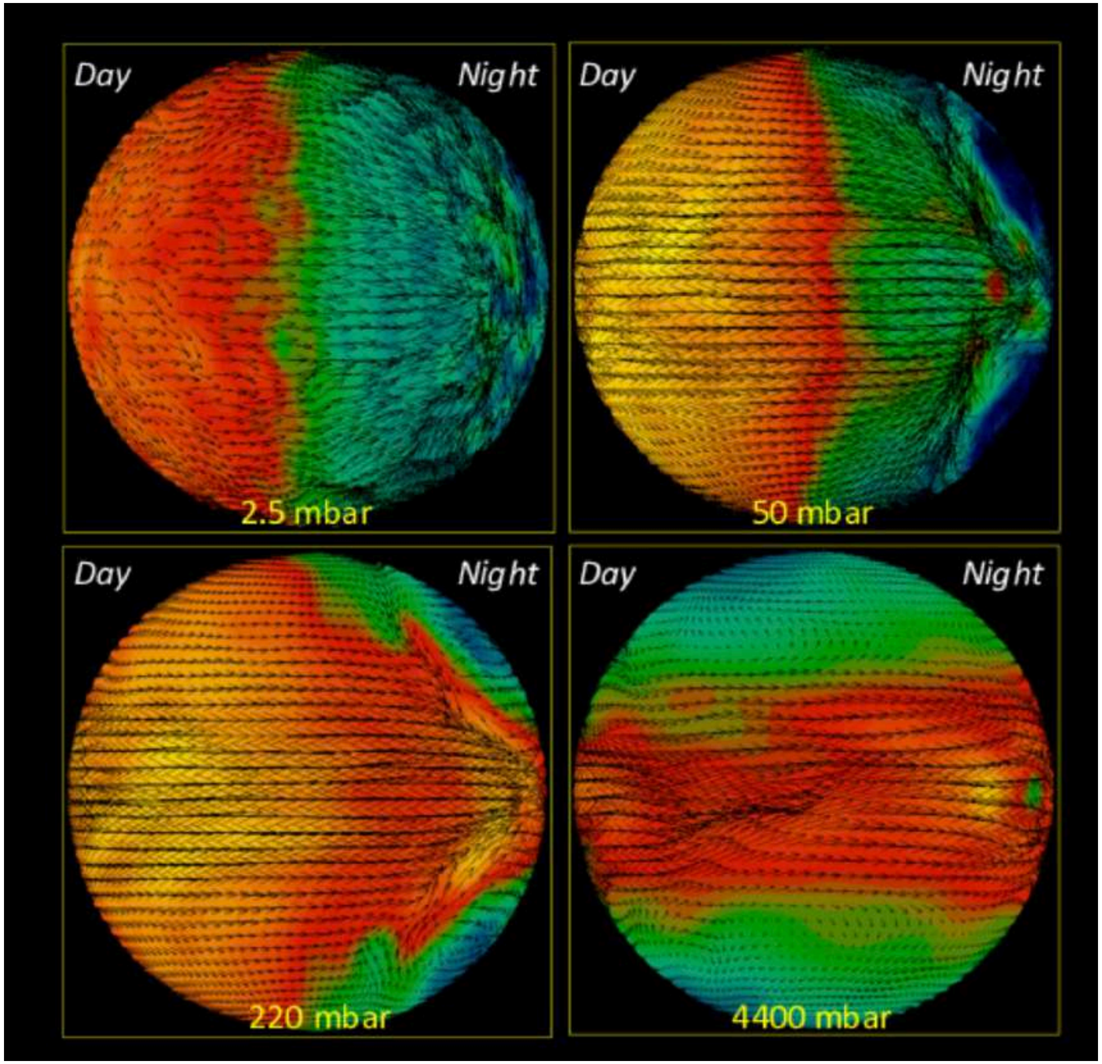
➢ Asymetric irradiation of tidally locked hot jupiter

- A hot dayside and a cold nightside implies pressure gradients and winds
- 3D atmospheric models to study the circulation



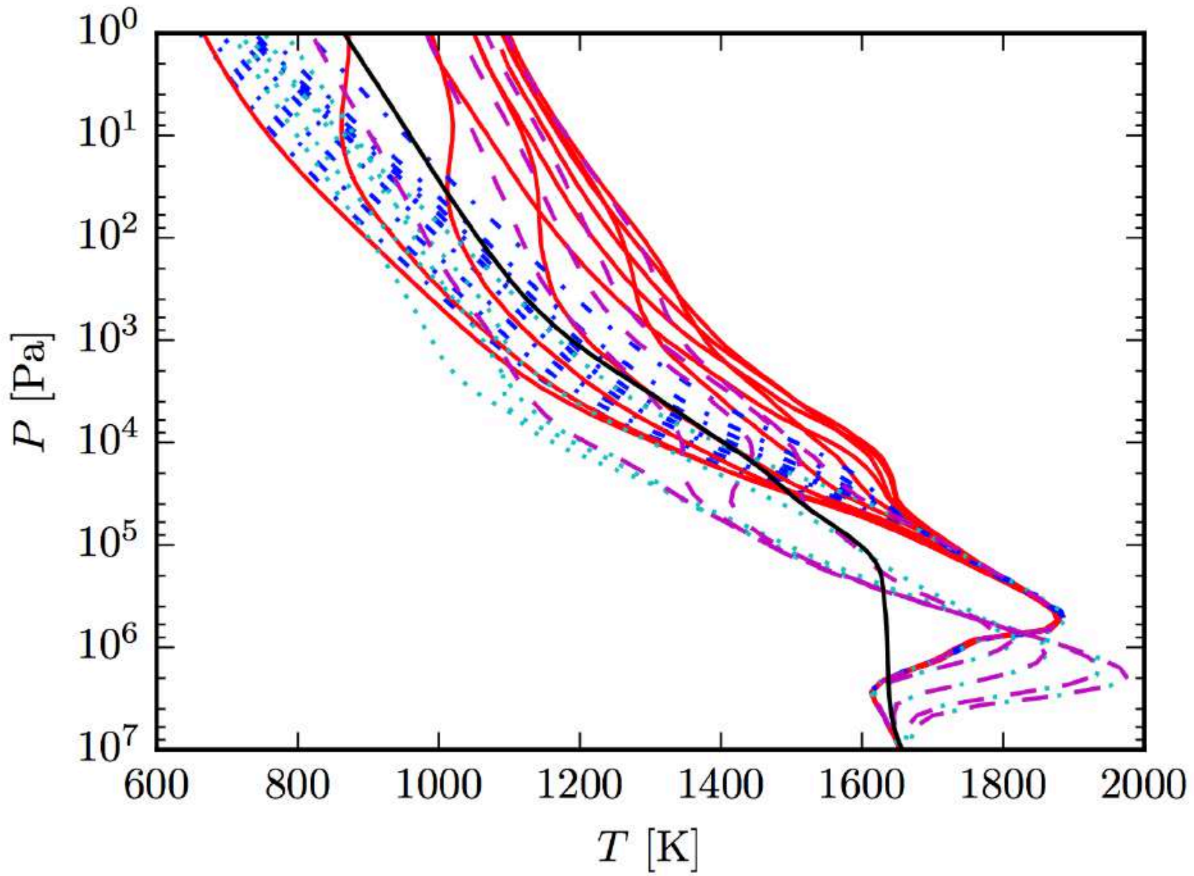
➢ Asymetric irradiation of tidally locked hot jupiter

- 3D atmospheric models to study the circulation, evolution in time to get the steady state



➢ Asymetric irradiation of tidally locked hot jupiter

– Does it work ? No…



– Can you guess why ?

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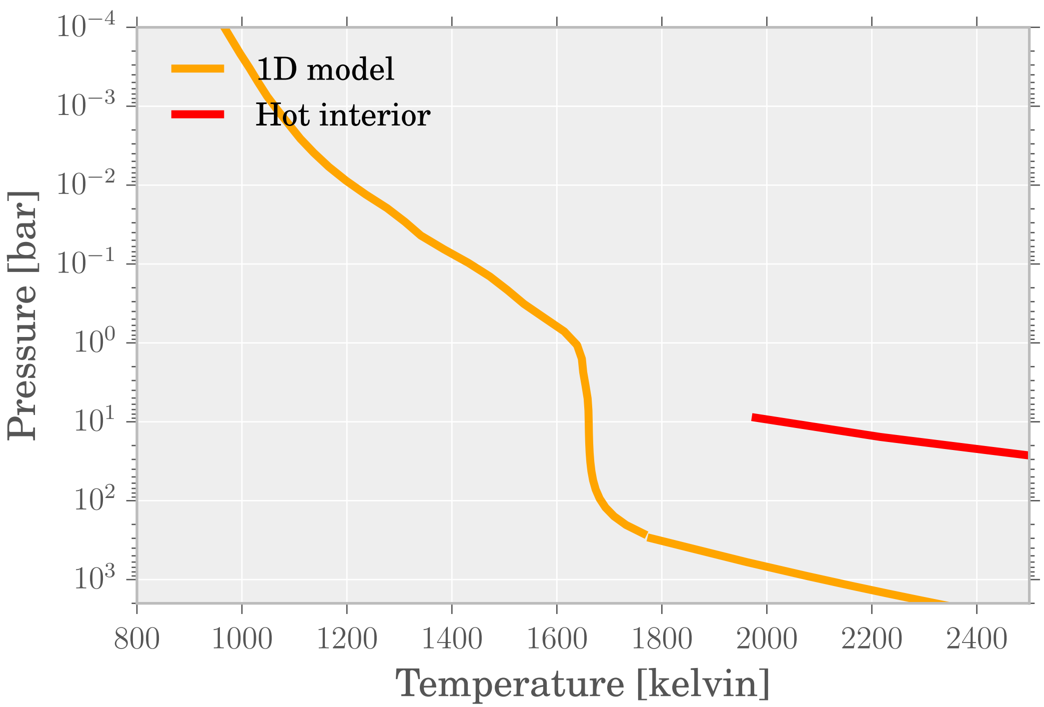
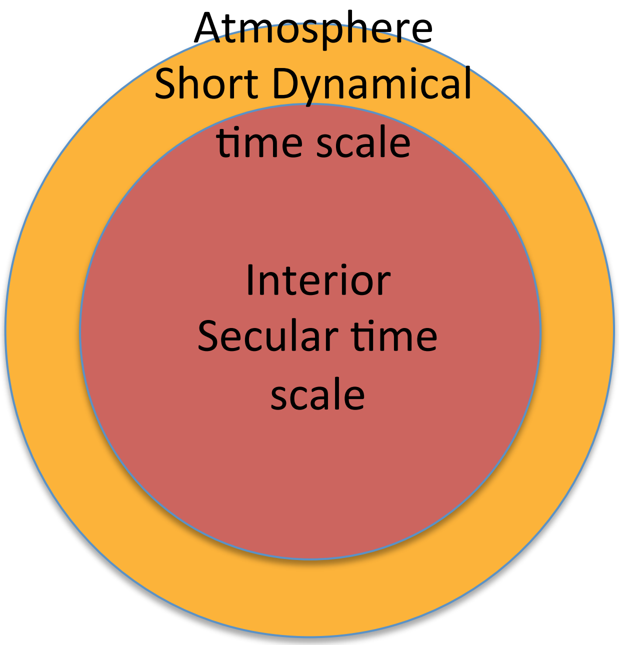
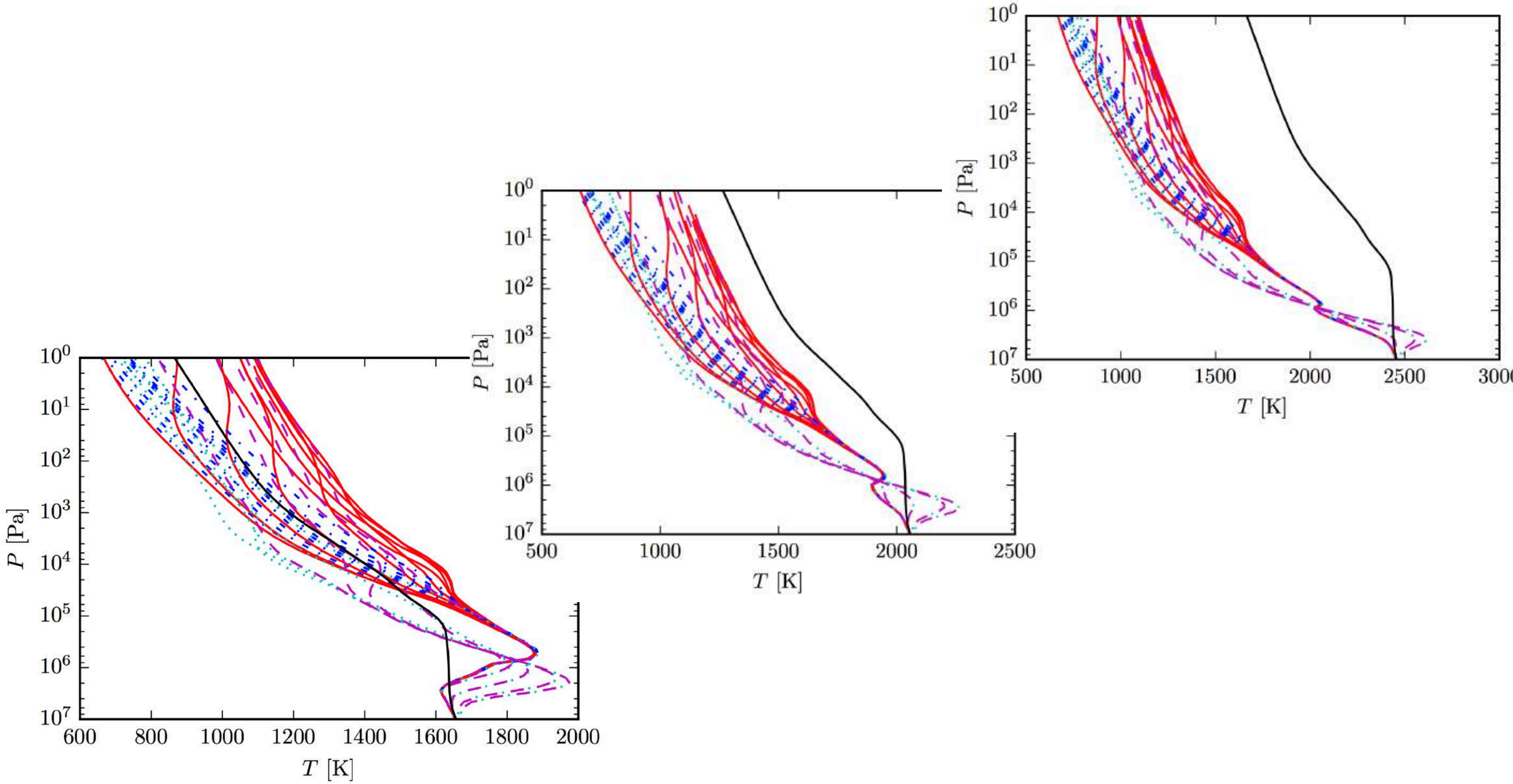




➢ Asymetric irradiation of tidally locked hot jupiter

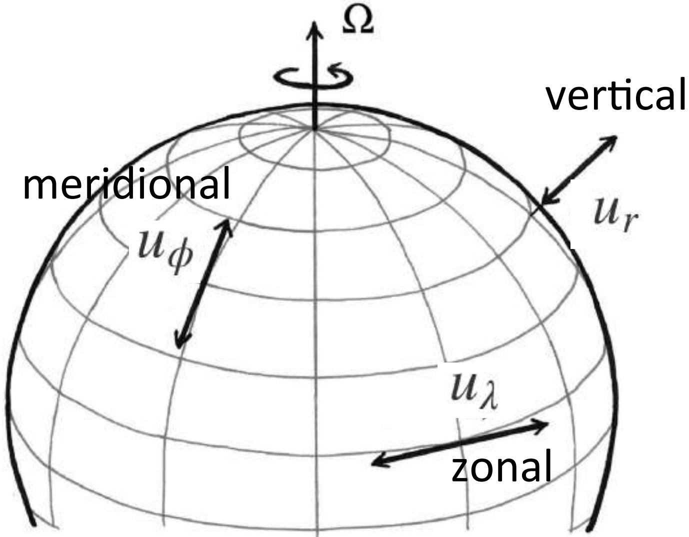
– The deep atmosphere is not converged in time because of computation limitation



Asymetric irradiation of tidally locked hot jupiter

- Need to construct a 2D steady state circulation model at the equator
  - Keep the steady state nature of the 1D model
  - Can take into account the asymetric irradiation as a 3D model

- Problems:
  - The meridional wind u_ϕ is zero at the equator by north/south symetry but not its derivative $\partial u_\phi / \partial \phi$
  - The meridional momentum equation vanishes at the equator and we lack one equation to close the system…



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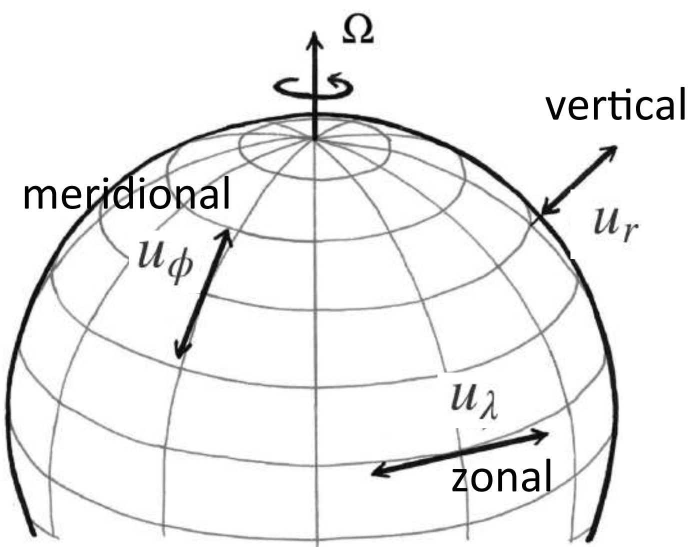


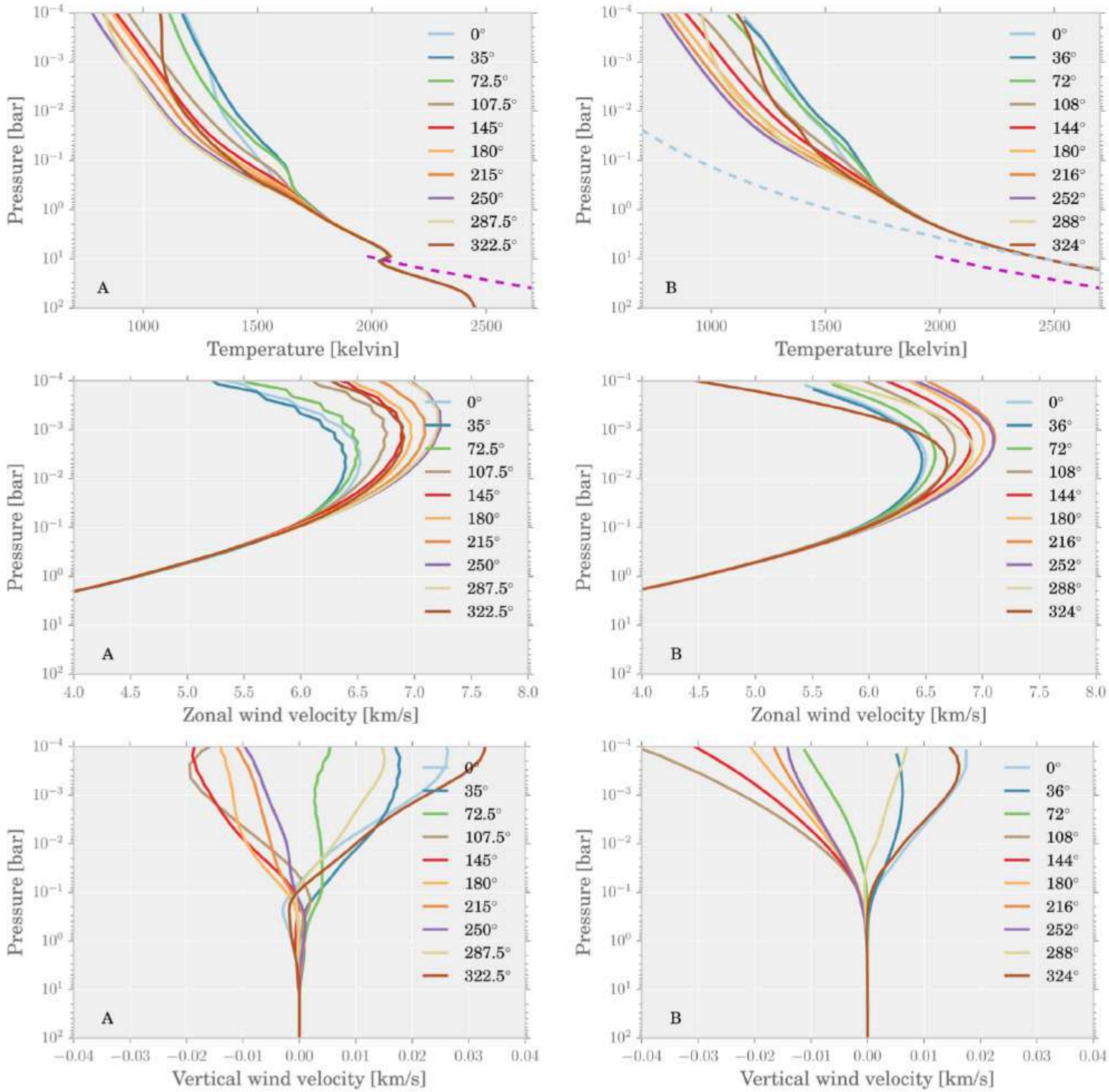
Just assume that transverse mass fluxes are proportional with a constant

$$\frac{1}{r^2}\frac{\partial r^2 \rho u_r}{\partial r} = \frac{1}{r\alpha}\frac{\partial \rho u_\phi}{\partial \phi}$$

$\alpha \to 0$ Zonal, vertical wind

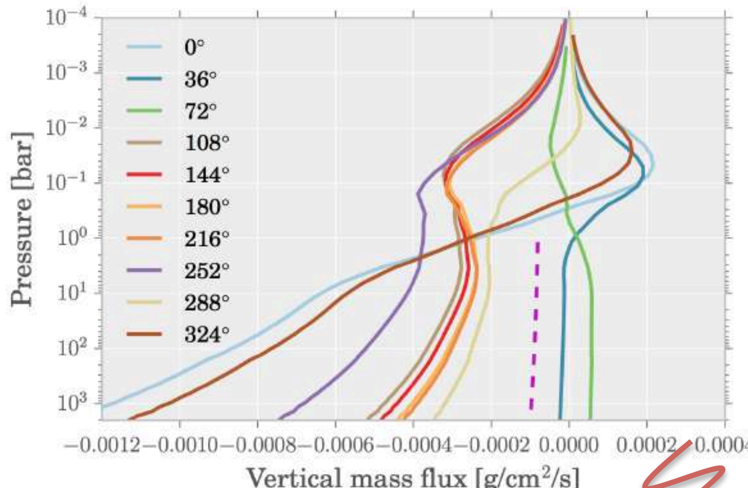
$\alpha \to \infty$ Zonal, meridional wind

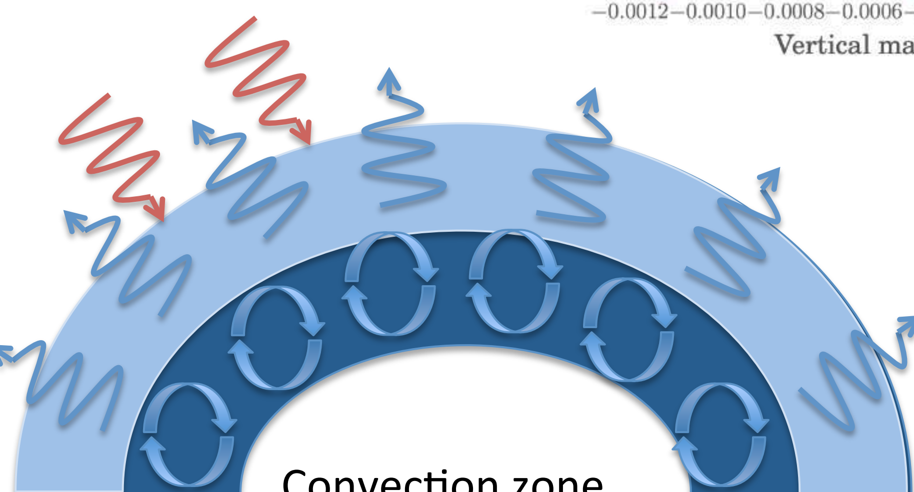
➢ Asymetric irradiation of tidally locked hot jupiter



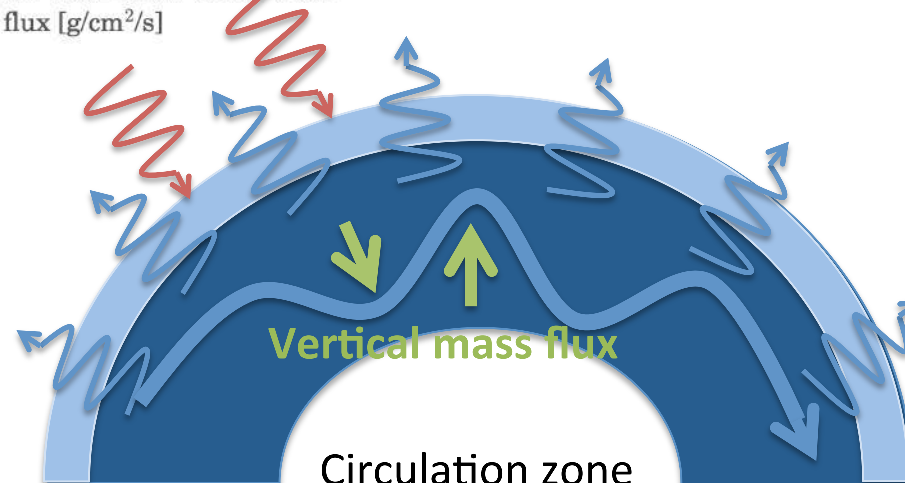
➢ Asymetric irradiation of tidally locked hot jupiter

– Get a hot deep interior because of vertical mass flows !





Convection zone
With small-scale motions
adiabatic PT profile



Circulation zone
With large-scale motions
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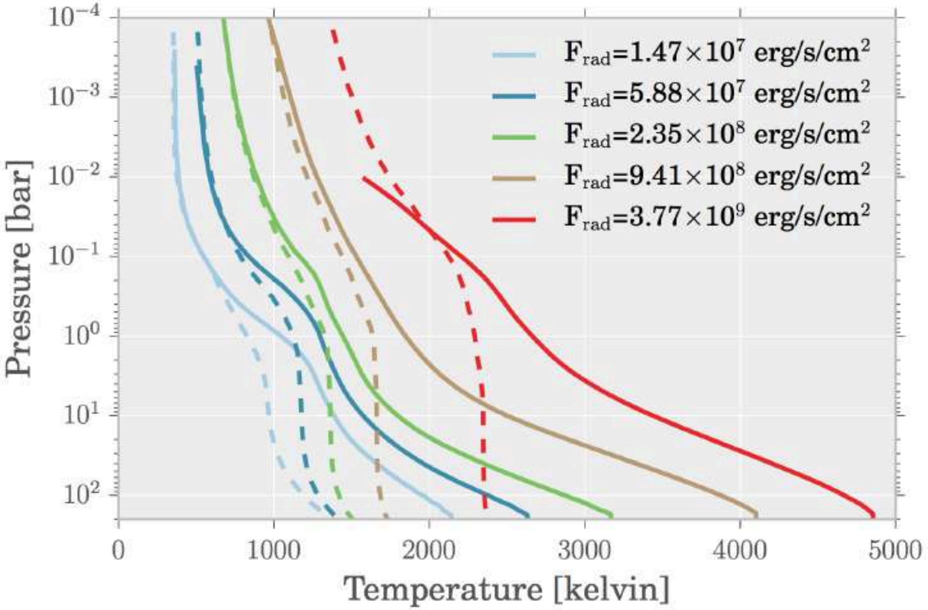
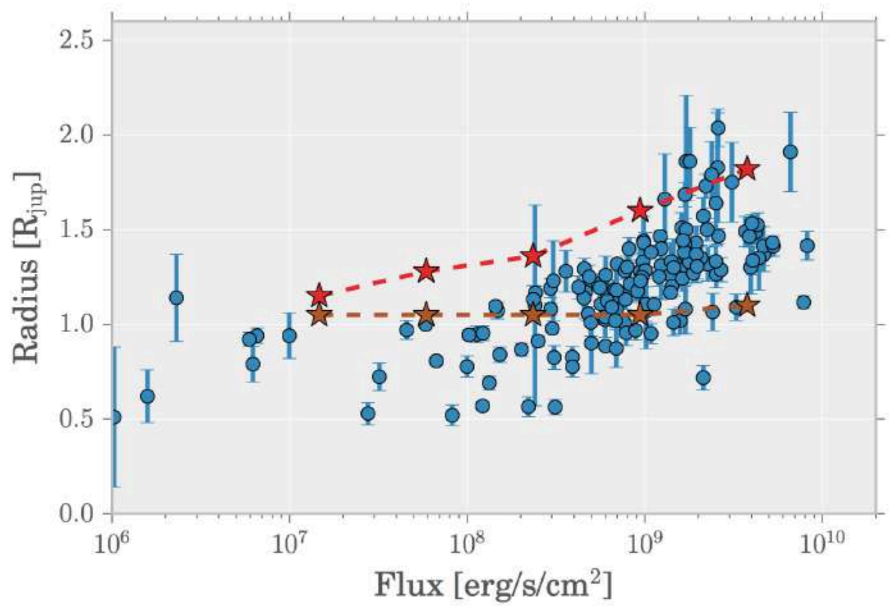
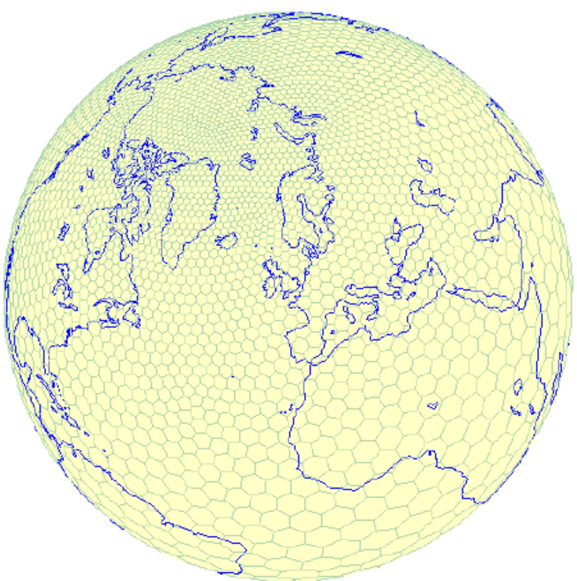


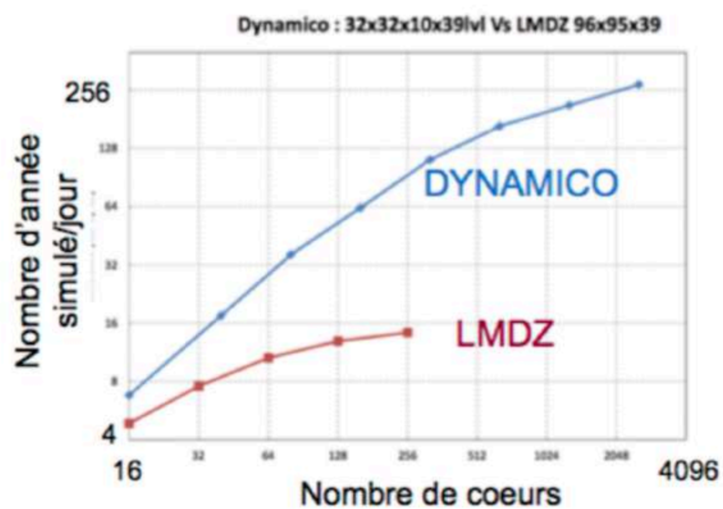


➢ Asymetric irradiation of tidally locked hot jupiter

- But the solution is only 2D at the equator… what happen at other latitudes ?? Still need 3D simulations but need efficient HPC to reach the steady state

- Efficient new dynamical core for atmospheric circulation: Dynamico
  - Following the adaptation to hot Jupiters done by Sébastien
  - Develop a newtonian cooling parametrization to probe the deep vertical advection of entropy





Thanks!

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