INTERIOR OF JUPITER IN THE CONTEXT OF JUNO AND GALILEO

SIGNATURE OF A DECOUPLING BETWEEN THE ATMOSPHERE AND THE INTERIOR

Florian Debras

Gilles Chabrier

European Research Council

Established by the European Commission

Overview

I. *Constraints of the models*

II. *New models of the interior of Jupiter*

III. *Implications*

I. Constraints of the models

Galileo's observations (Von Zahn et al. 1998, Wong et al. 2004):

- $Z_{ext} > Z_{sun} \approx 0.02$ (Li et al. 2017, 2020)

- 165 K, 1 bar - assume convection (! Guillot)

Juno's gravitational moments (Bolton et al. 2017, Iess et al. 2018)

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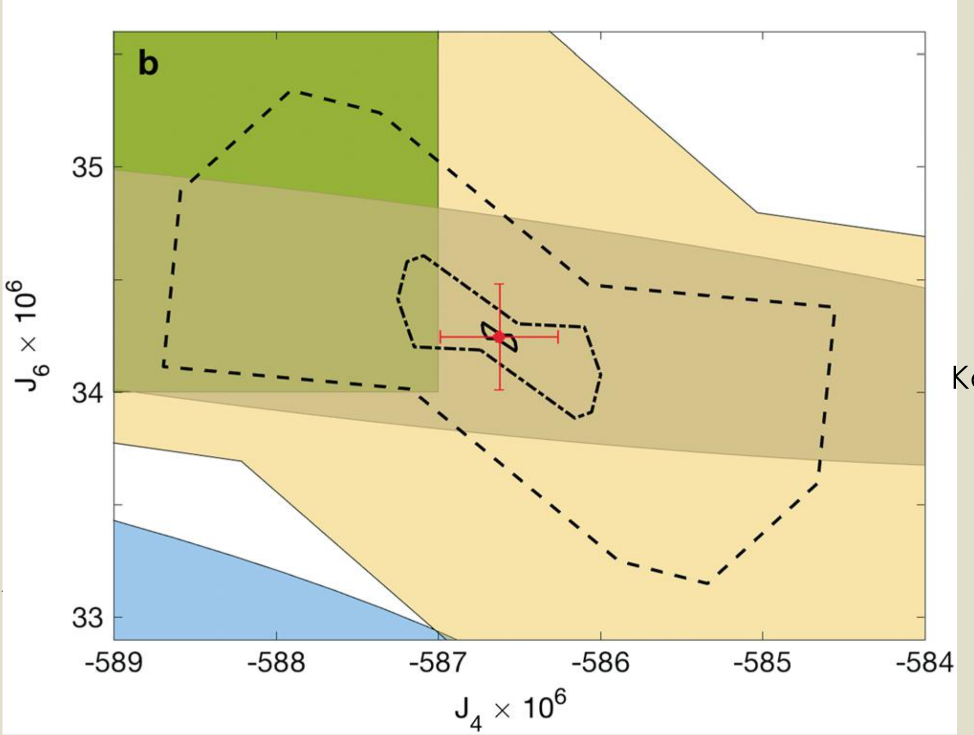
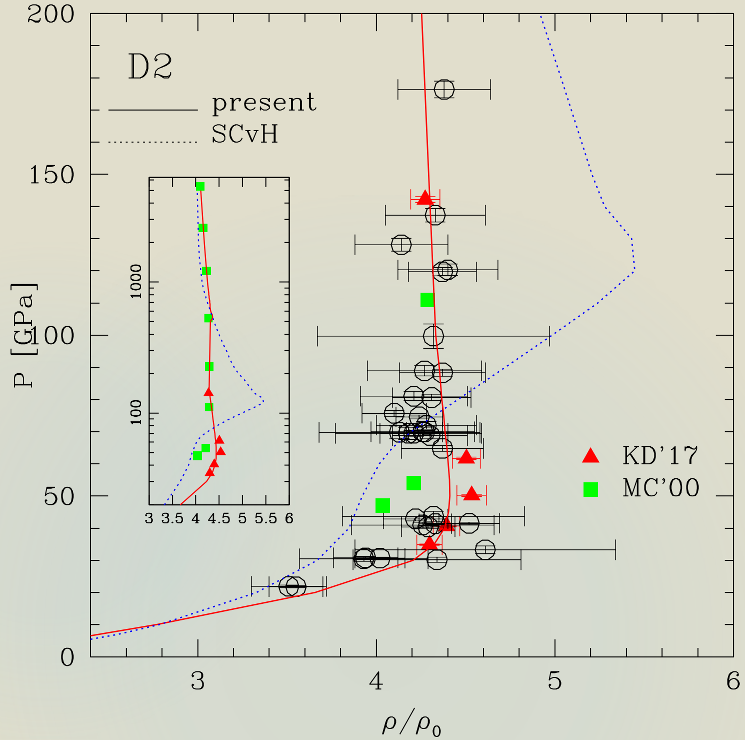
Winds: Kaspi et al. 2017 or Kaspi et al. 2018

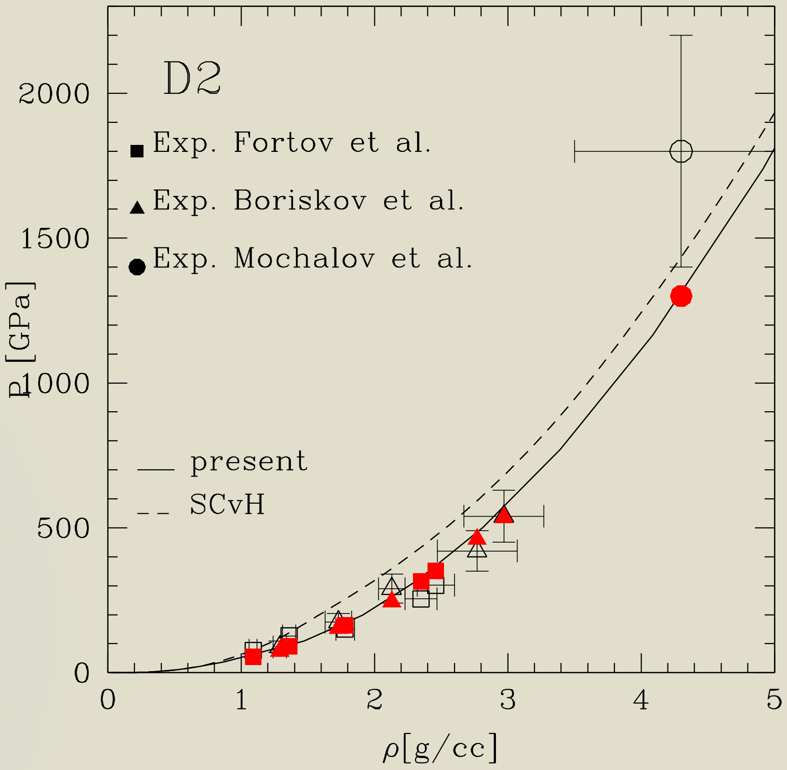


Kaspi et al. 2017

I. Constraints of the models

Equations of state





Comparison with experiments
Chabrier, Mazevet & Soubiran 2019

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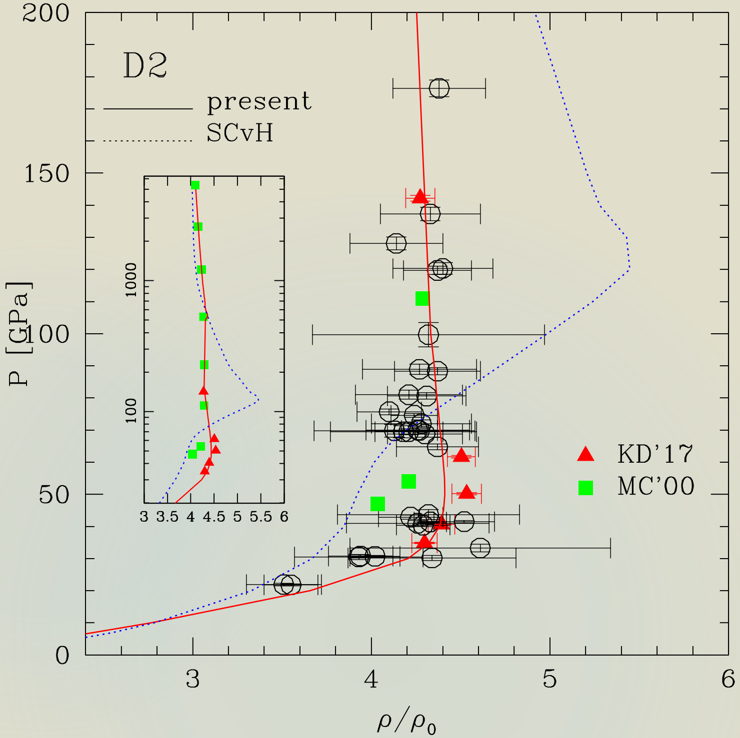

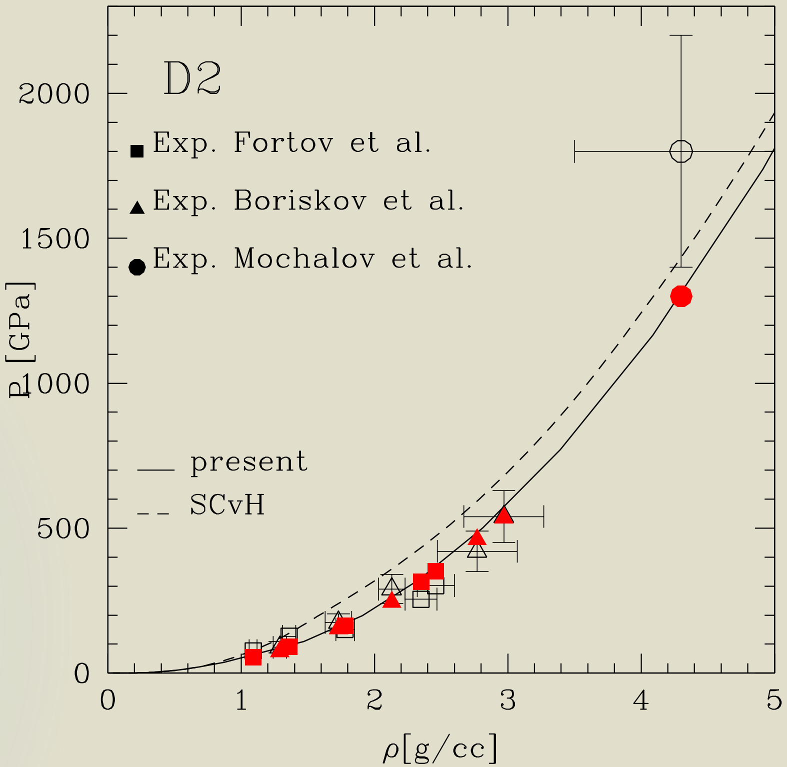

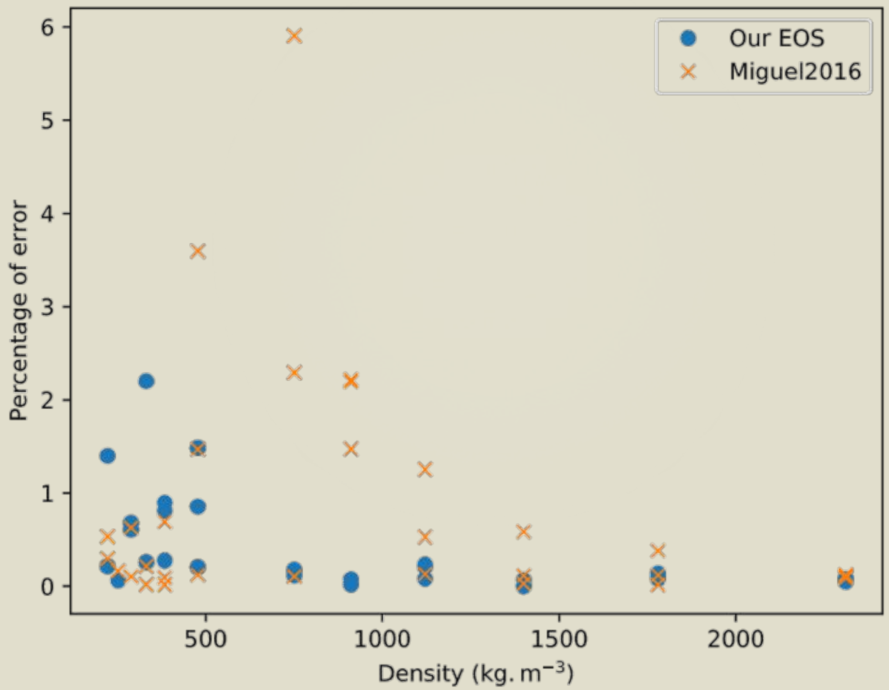

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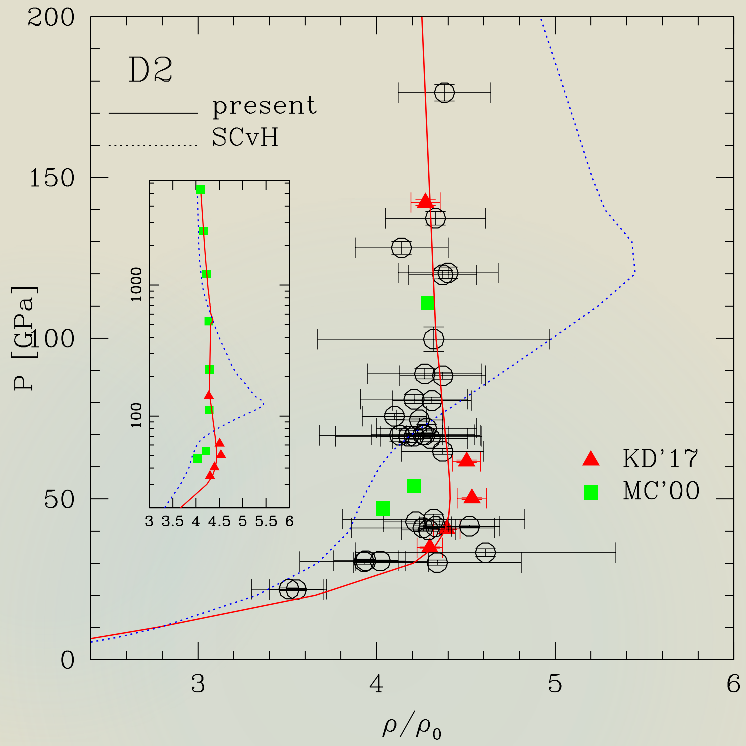

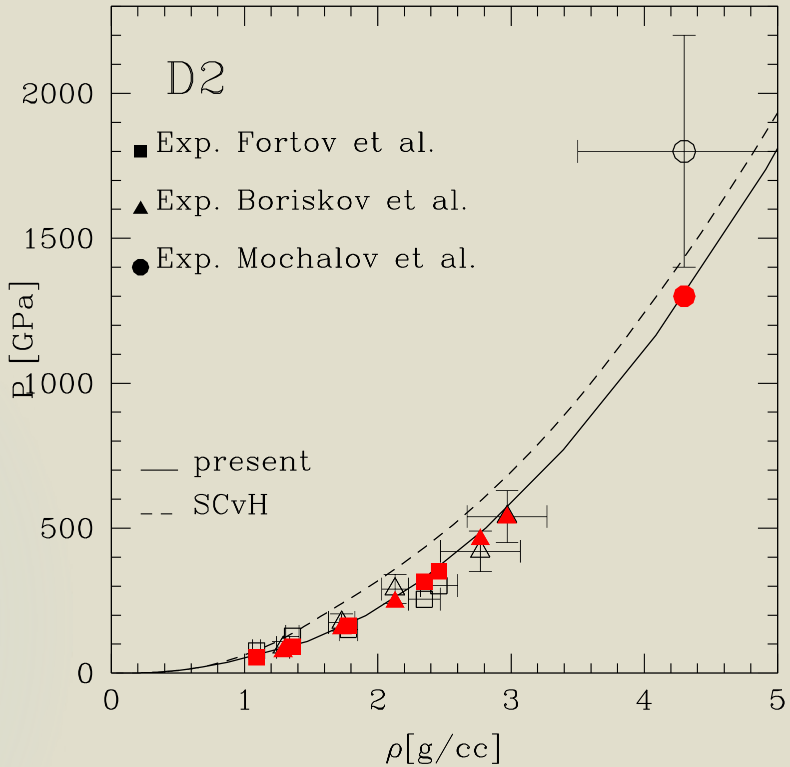

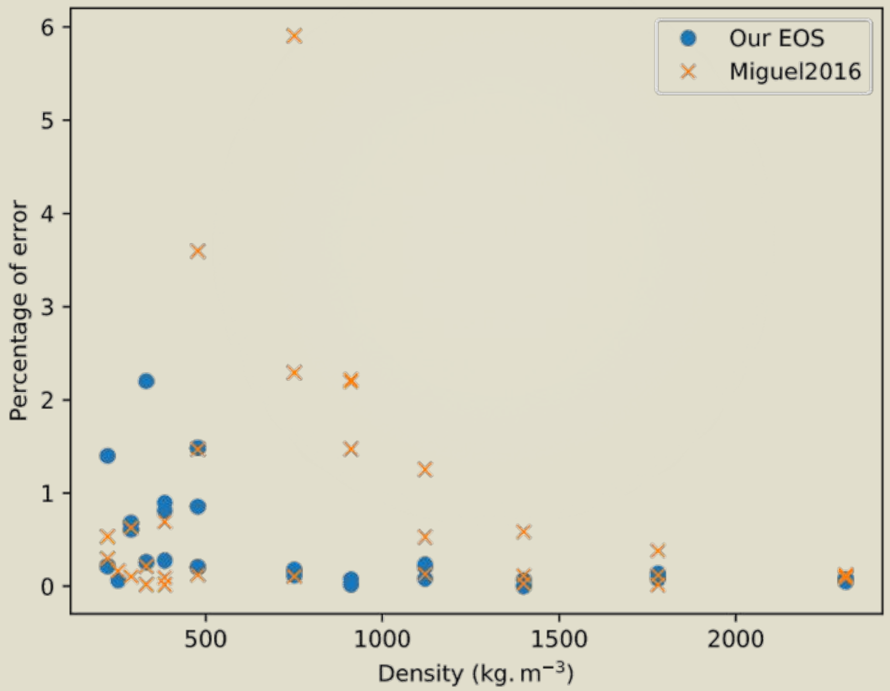

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Water: Mazevet et al. 2019, **Soubiran & Militzer 2016**

Other: drysand (Lyon & Johnson 1992)

II. New models of the interior of Jupiter

The issue

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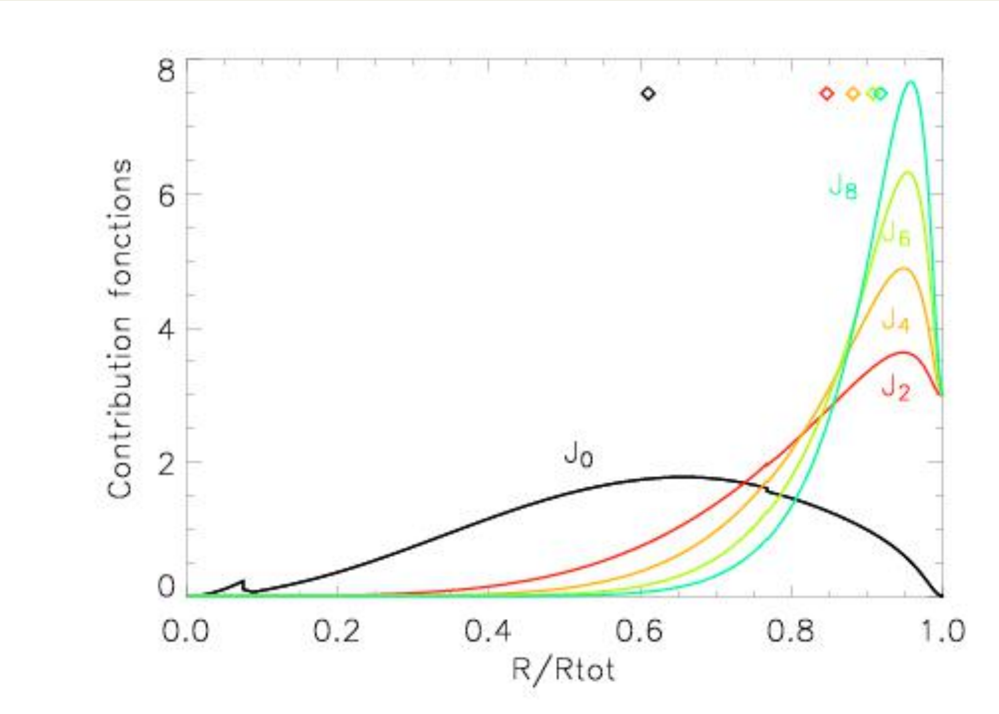
➡ Outer layers not very dense



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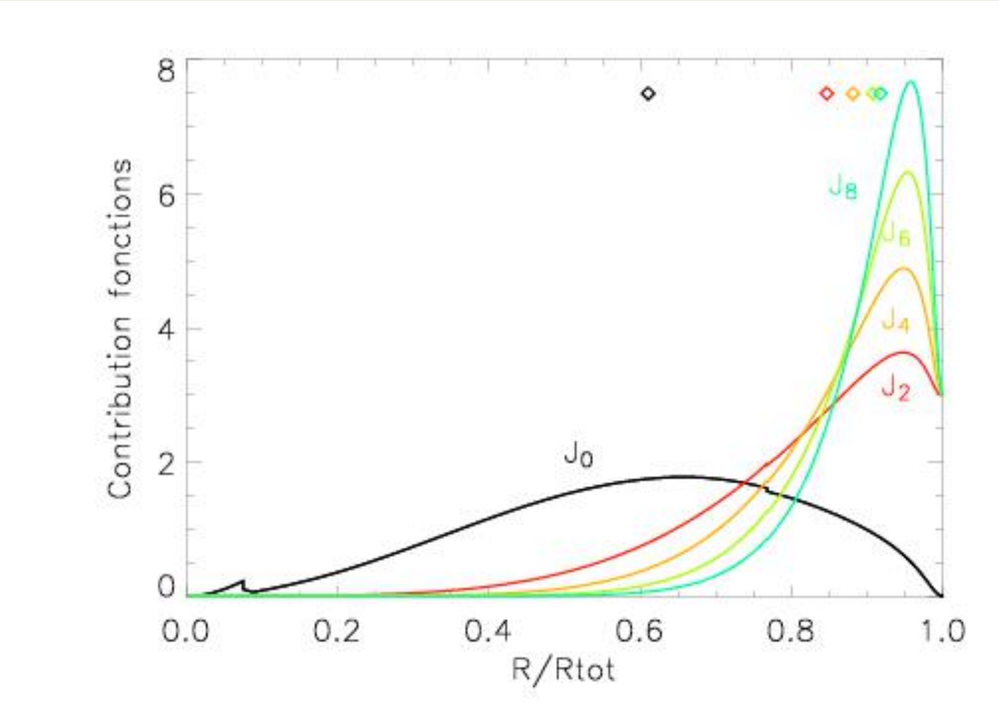

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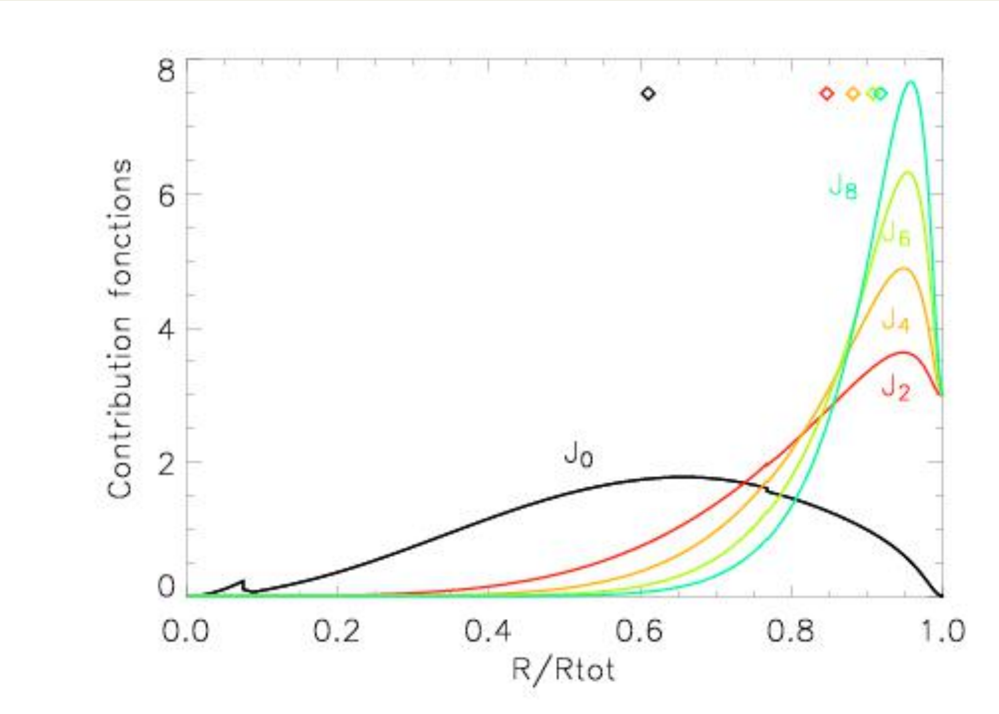

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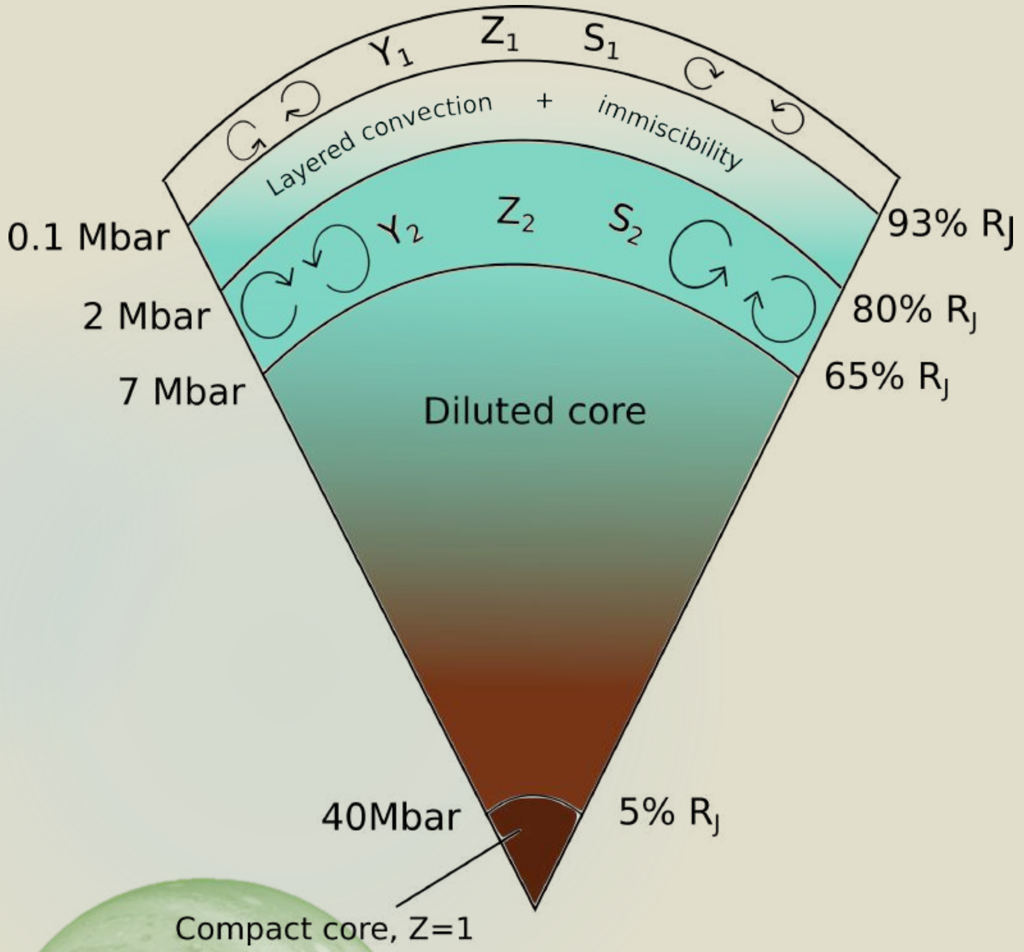

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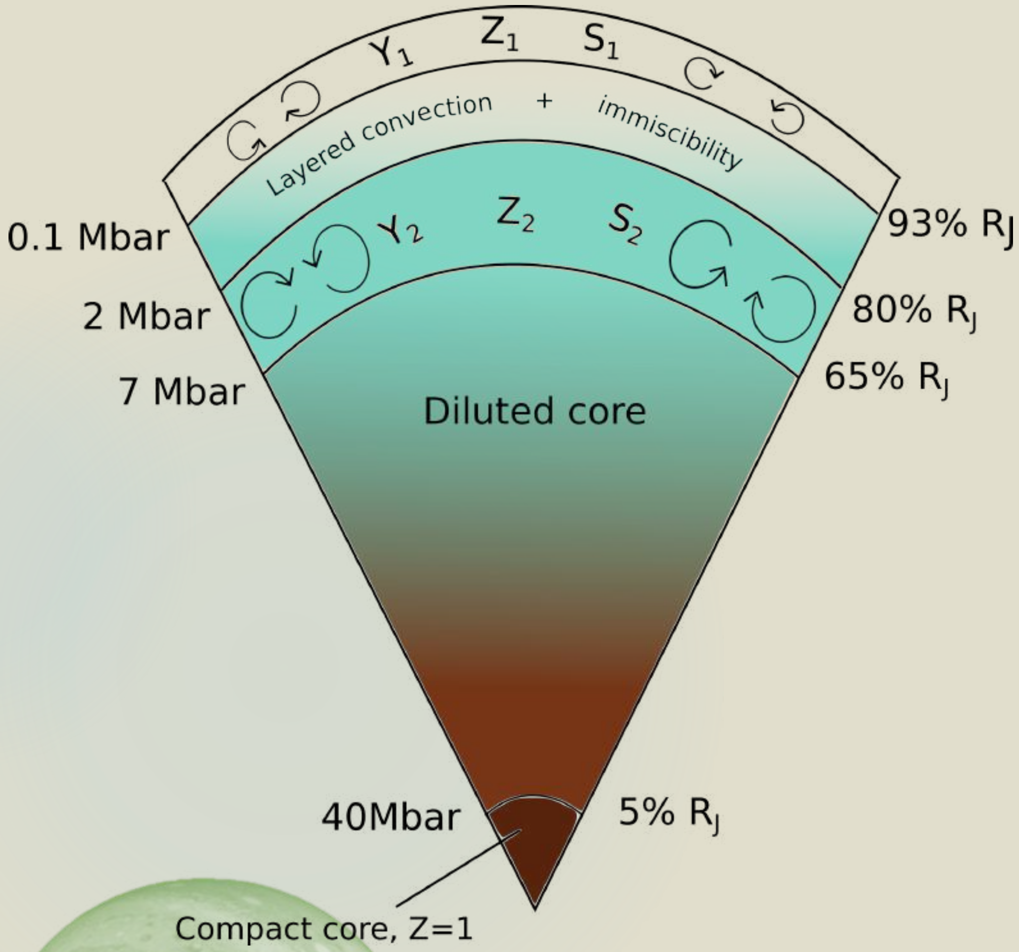

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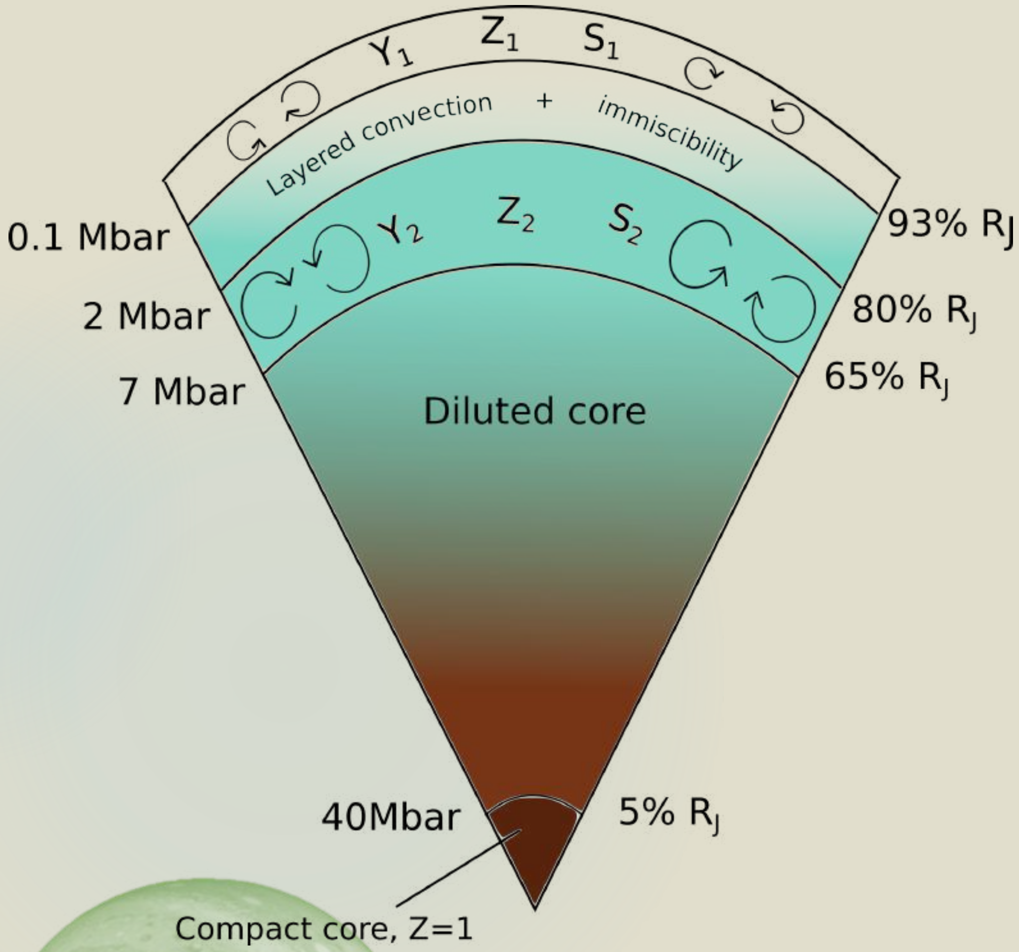

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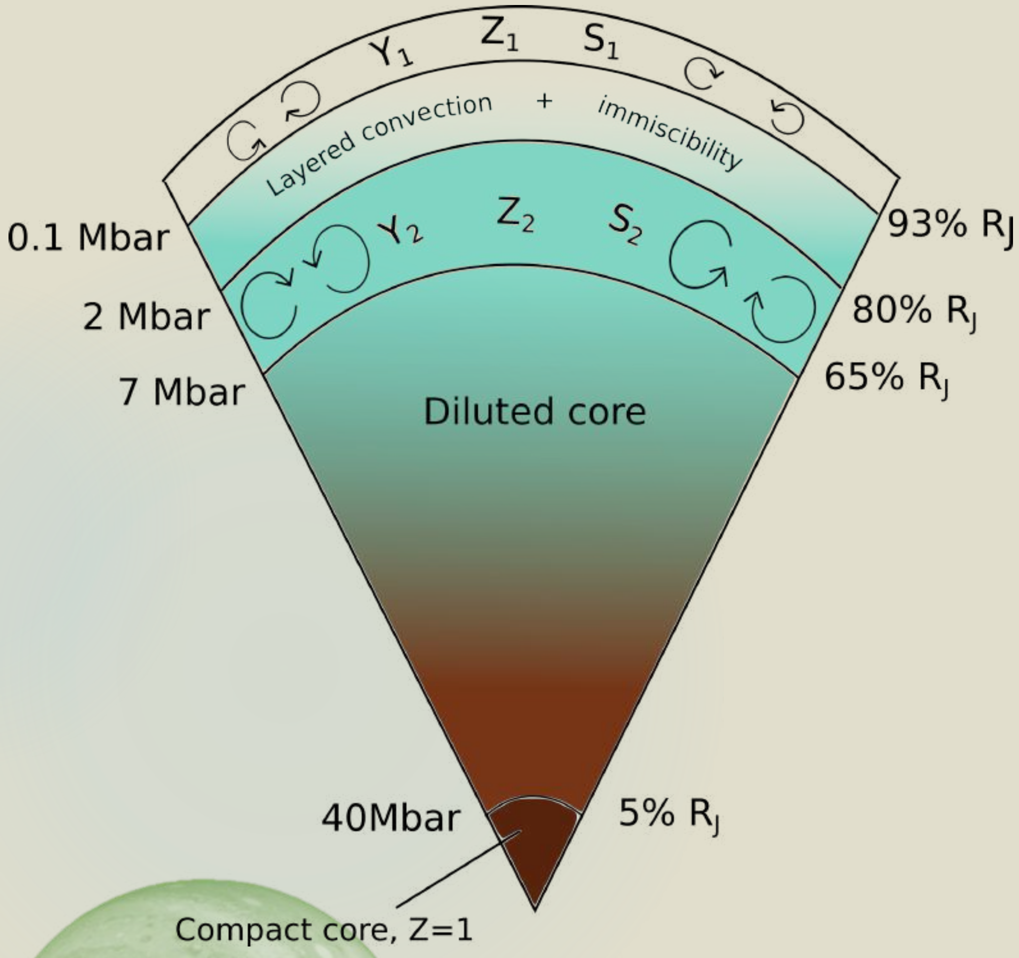

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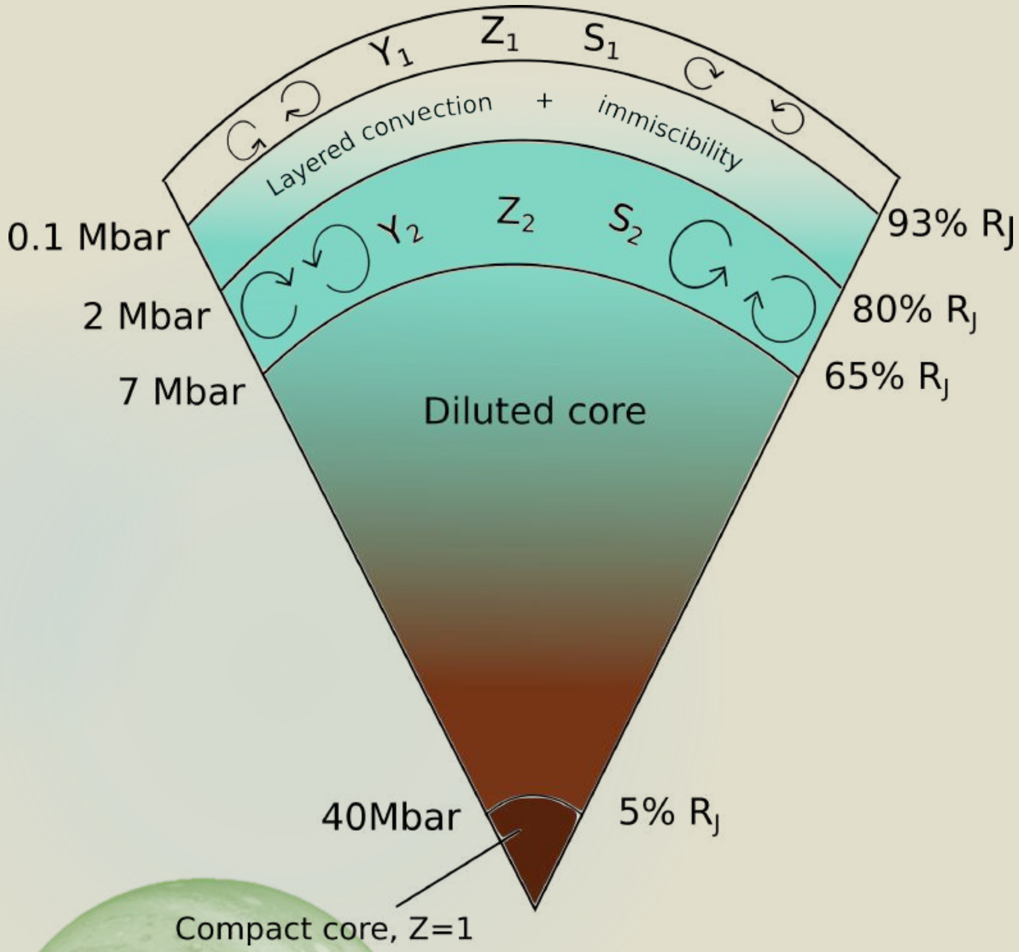

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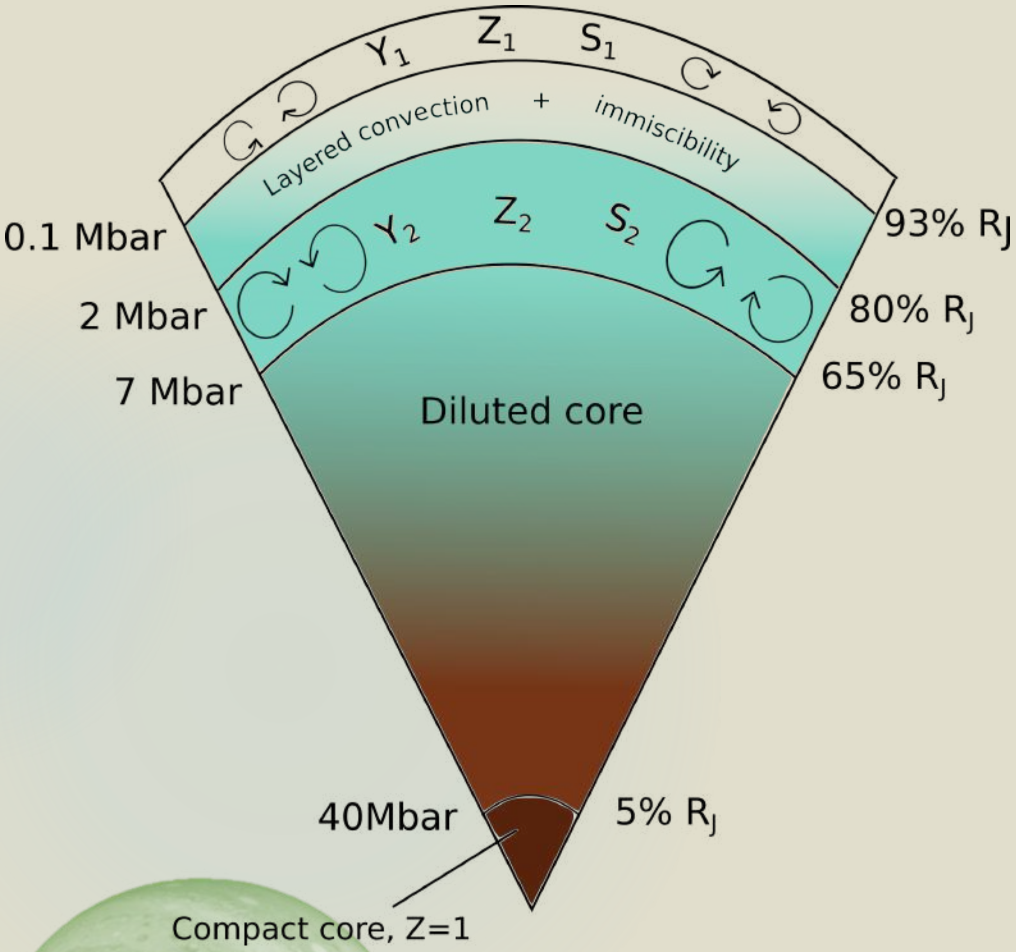

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Maximum mass of compact core: 5 Earth masses
(Total metal mass 25 $M_T < M_Z < 45\ M_T$)

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Entropy increase and heavy element decrease

H/He immiscibility:

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Need for semi-convection

(potentially triggered by immiscibility, Schubert et al. 1975, Earth)

II. New models of the interior of Jupiter

Condition for semi-convection

Small Prandt and inverse Lewis numbers :

$$0 < \frac{\mathrm{dln}T}{\mathrm{dln}P} - \left(\frac{\mathrm{dln}T}{\mathrm{dln}P}\right)_S < \frac{\alpha_\mu}{\alpha_T}\frac{\mathrm{dln}\mu}{\mathrm{dln}P}$$

$$\alpha_\mu = \left(\frac{\partial \ln \rho}{\partial \ln \mu}\right)_{P,T} \quad , \alpha_T = \left(\frac{\partial \ln \rho}{\partial \ln T}\right)_{P,\mu}$$

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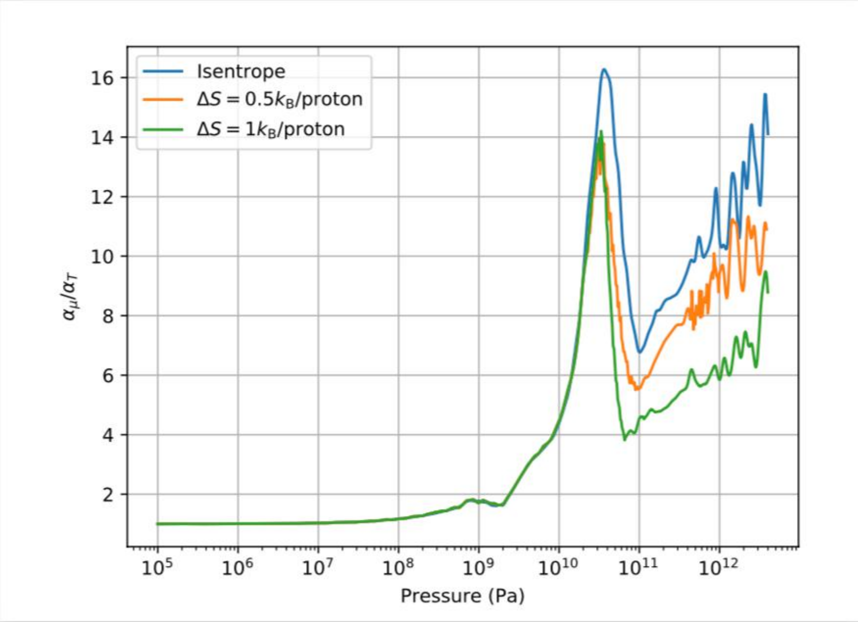

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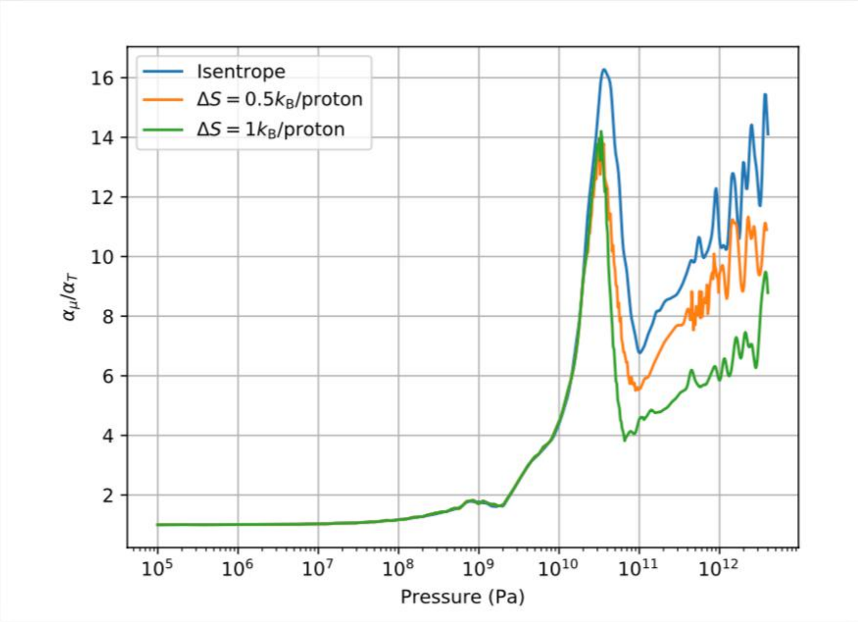


Debras & Chabrier 2019

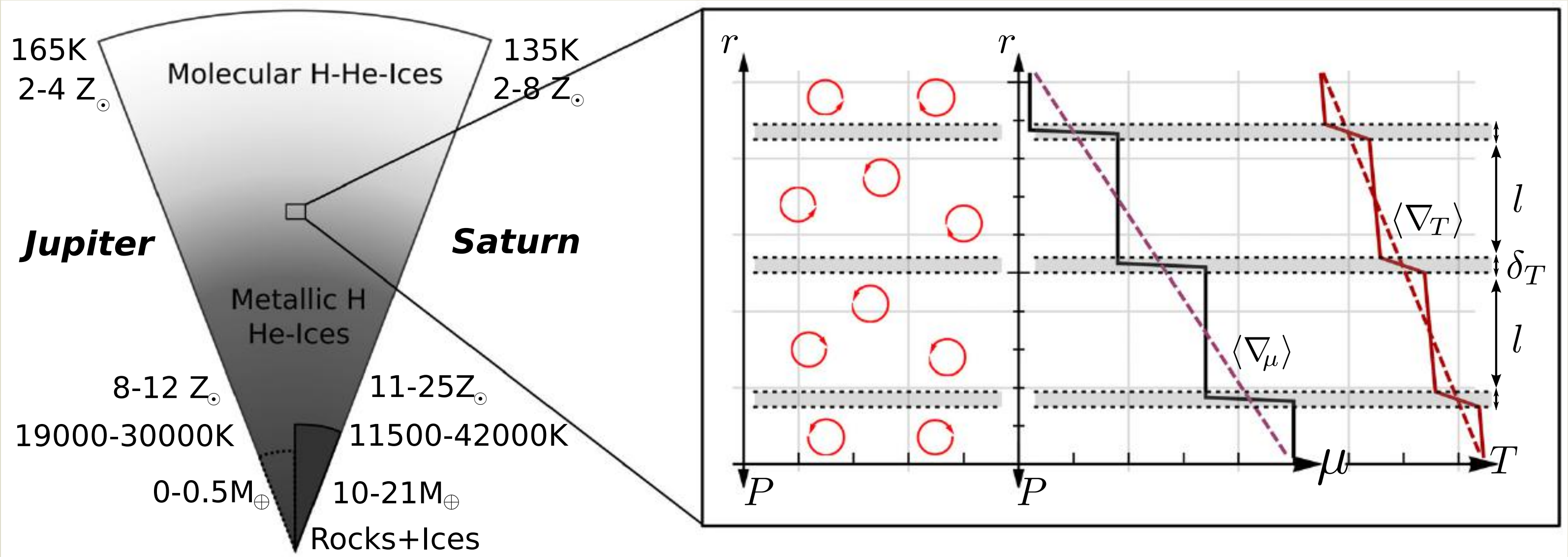
Semi-convection thermodynamically favoured deeper than 0.1 Mbar

II. New models of the interior of Jupiter

Effects of semi-convection

ΔS coherent with our models (~ 0.5 k_B/proton)

Possible to sharply decrease the metal content



Leconte & Chabrier 2012

II. New models of the interior of Jupiter

Summary

	J4, J10 + Kaspi 17	J4, J10 + Kaspi 18	J6, J8 + Kaspi 17	J6, J8 + Kaspi 18	Galileo	EOS	ΔS
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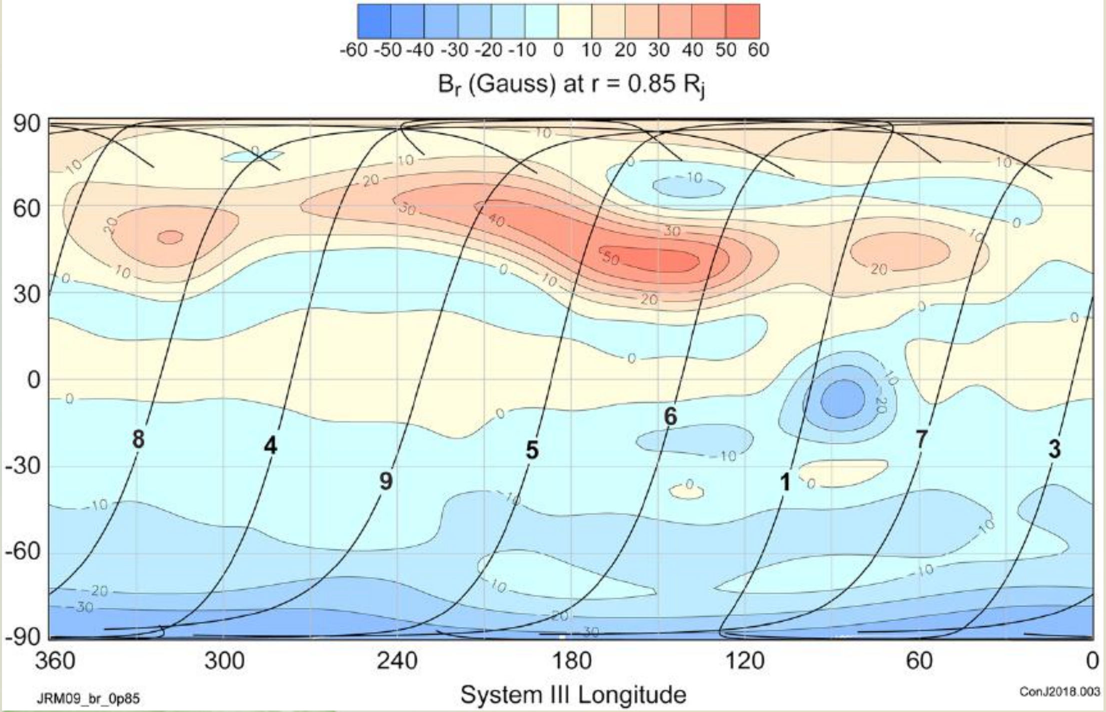
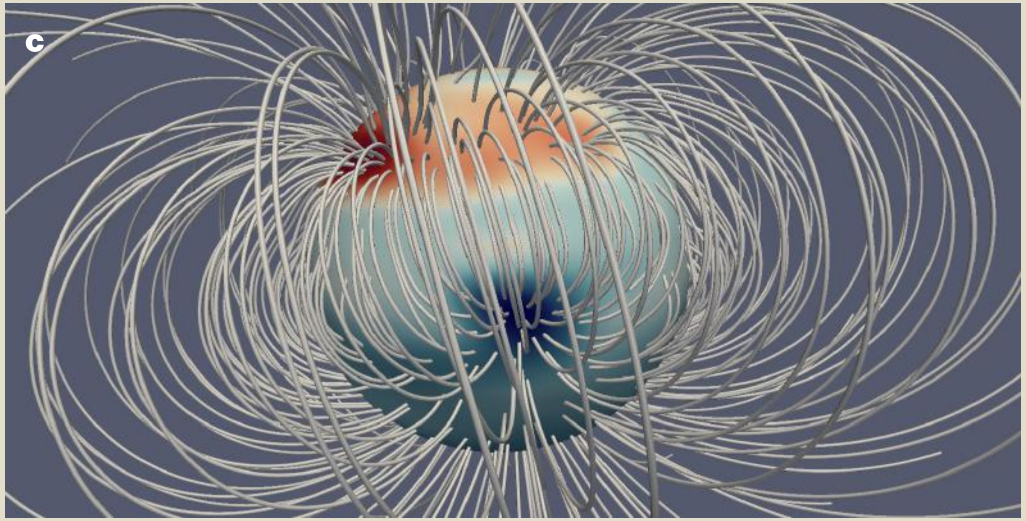
Dinamic Self Gravity effects : Wicht et al. 2020, Dietrich et al. 2021
Kong, Zhang & Schubert 2017, Li et al. 2020

III. Implications

Magnetic field: Moore et al. 2018, sign of two dynamo regions ?



Connerney et al. 2018



Moore et al. 2018

Deep dipolar dynamo and shallow multipolar dynamo ?

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Metal decrease

Large metal decrease possible if:

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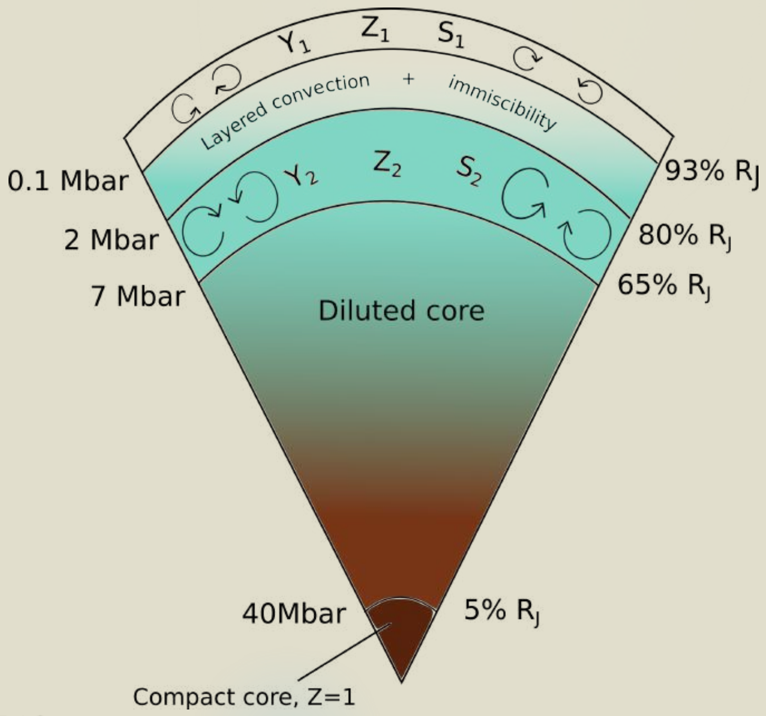
2) Layered convection triggers sharp decrease in metals. Doubtful



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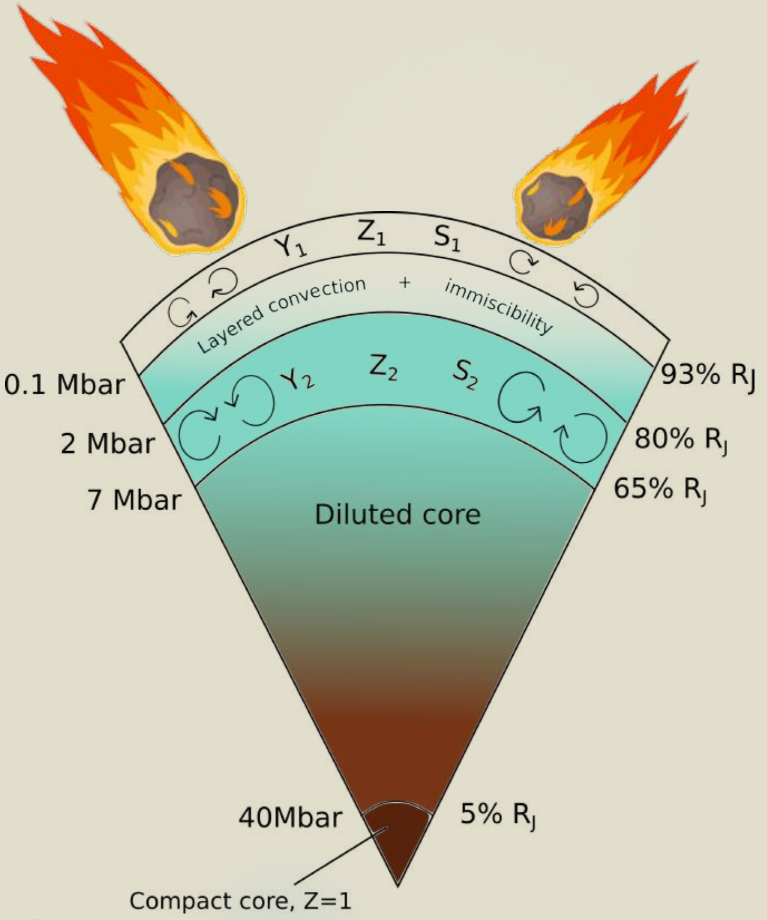

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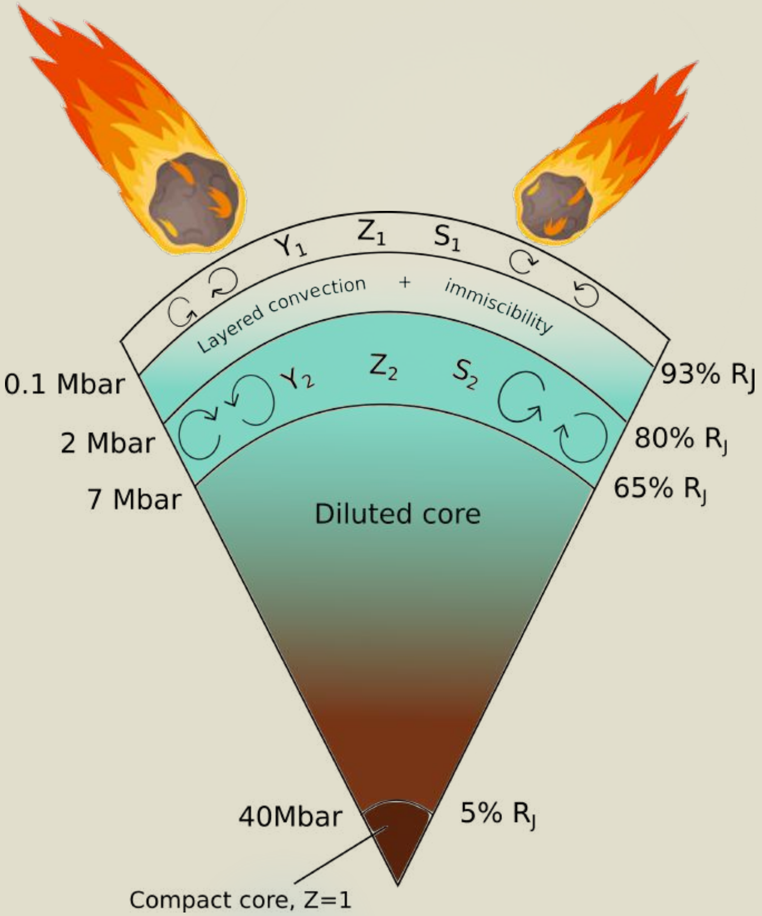
Crucial consequences on formation models !!



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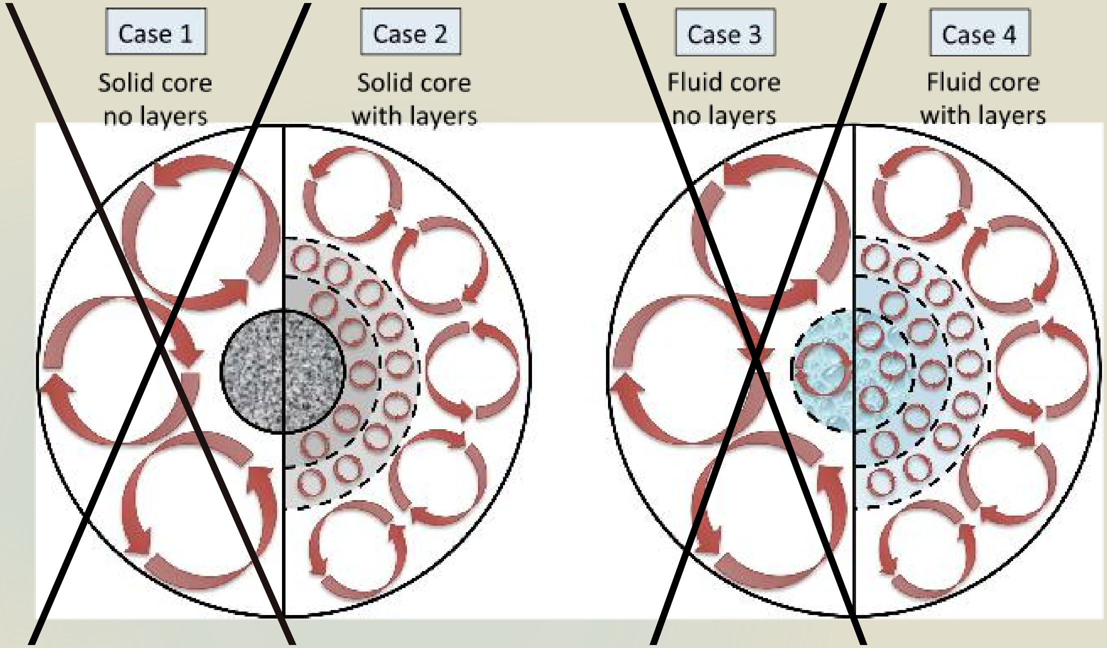
Long term survival of a diluted core ?

Moll et al. 2017



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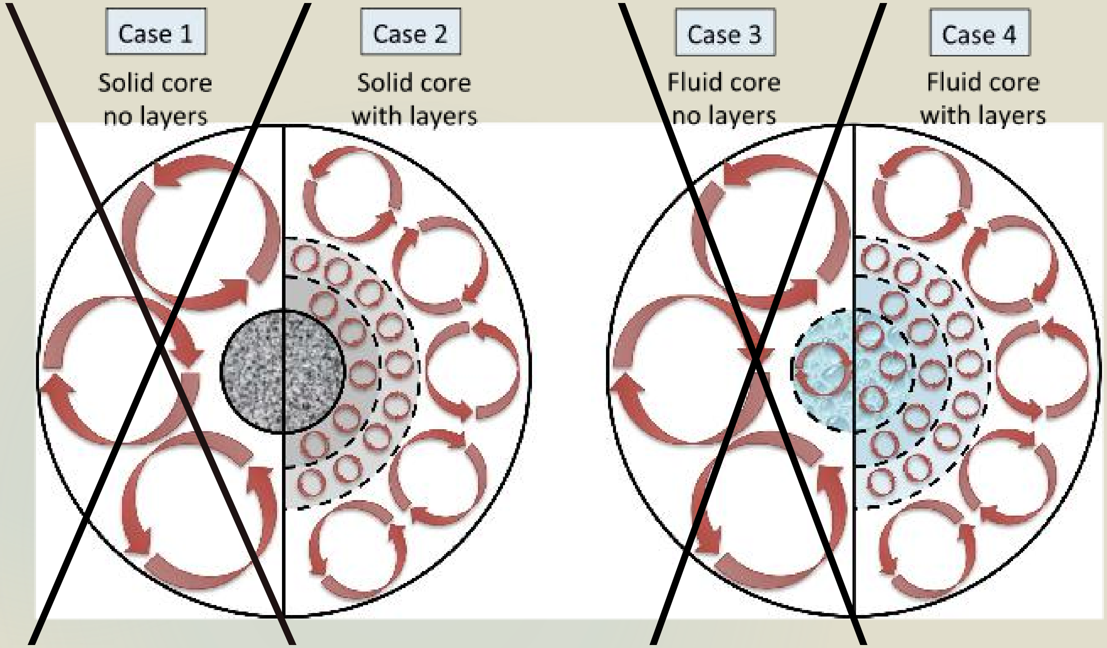
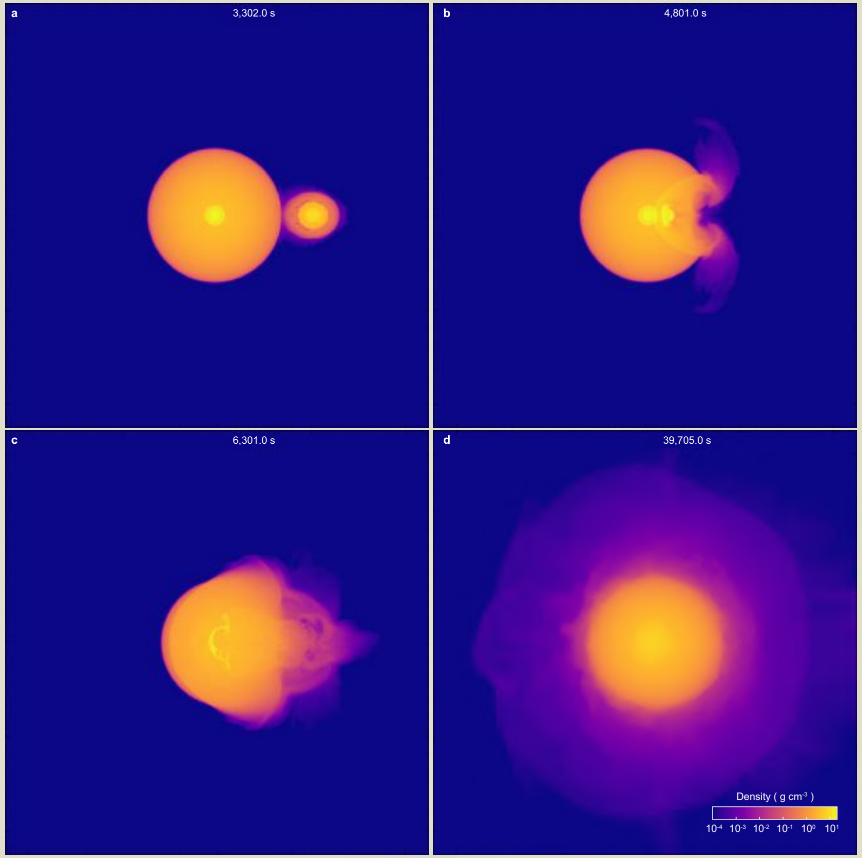


Giant impact: Liu et al. 2019



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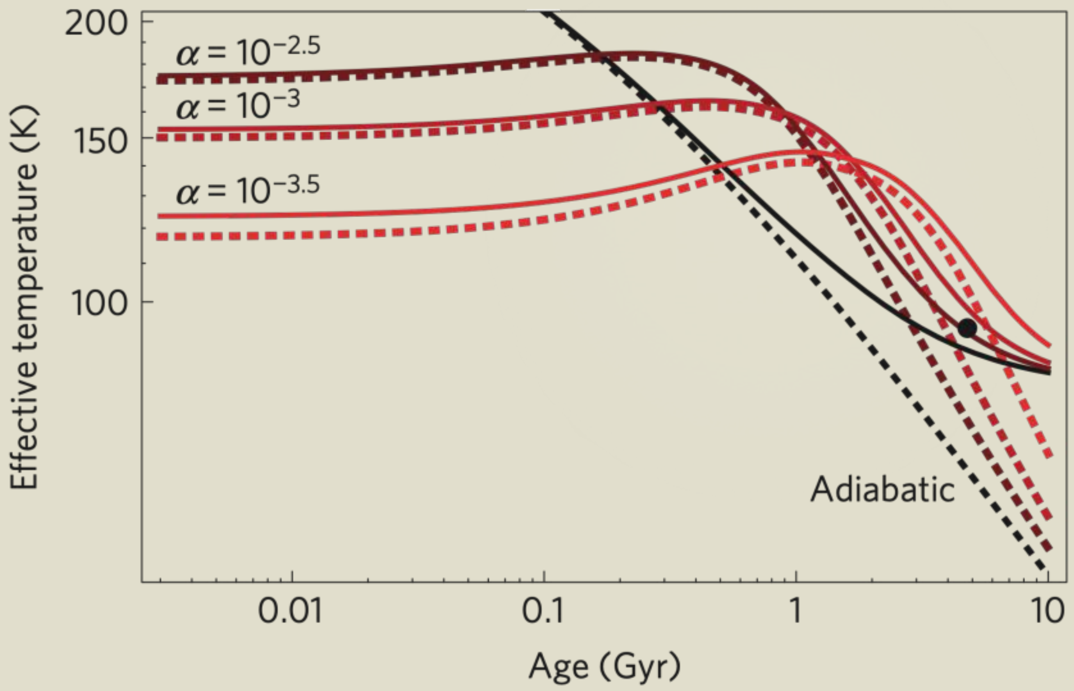

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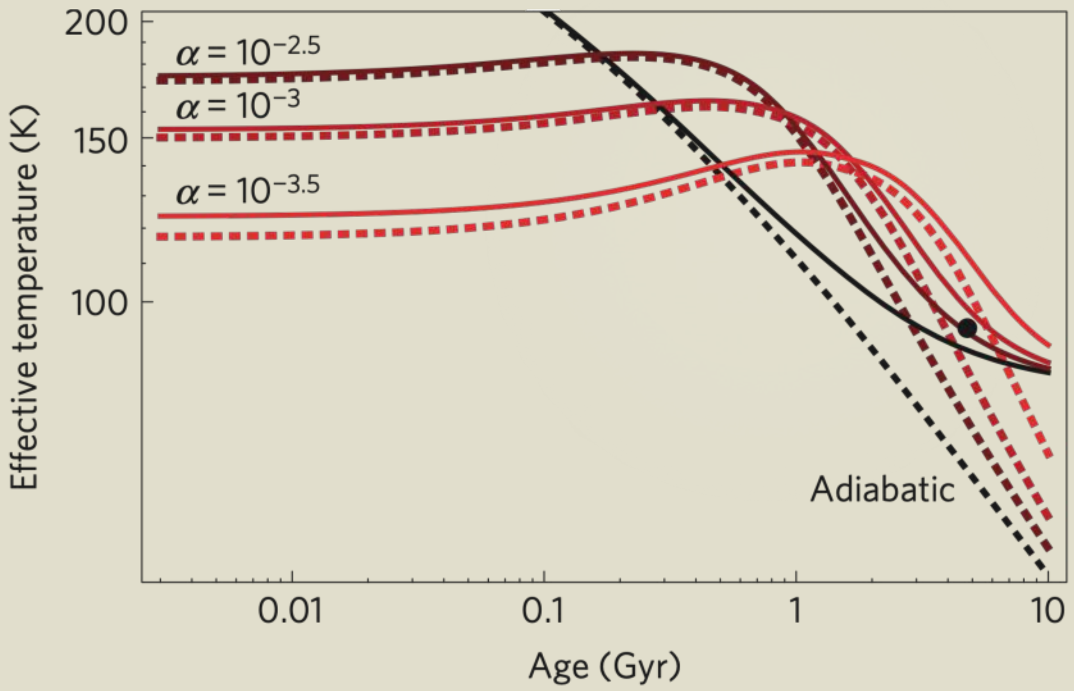

Leconte & Chabrier 2013

Evolutionary models must be taken with extreme care !

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Extrasolar planets

Atmospheric composition is NOT easily linked with bulk composition

Jupiter and Saturn are NOT adiabatic, maybe from several Gyrs. Factor of ~3 on the total metal mass

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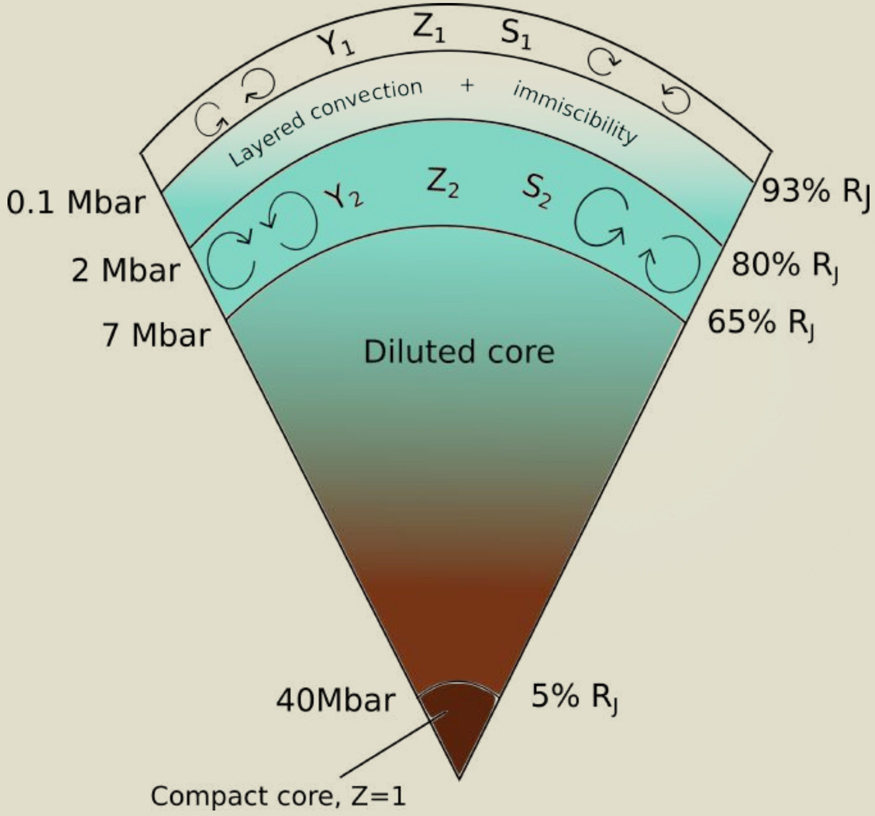
Careful with over simplifications !

Summary and prospects

Juno provided new data excluding older models

Need for diluted core, extended immiscibility and/or layered convection

Strong constraints on core mass



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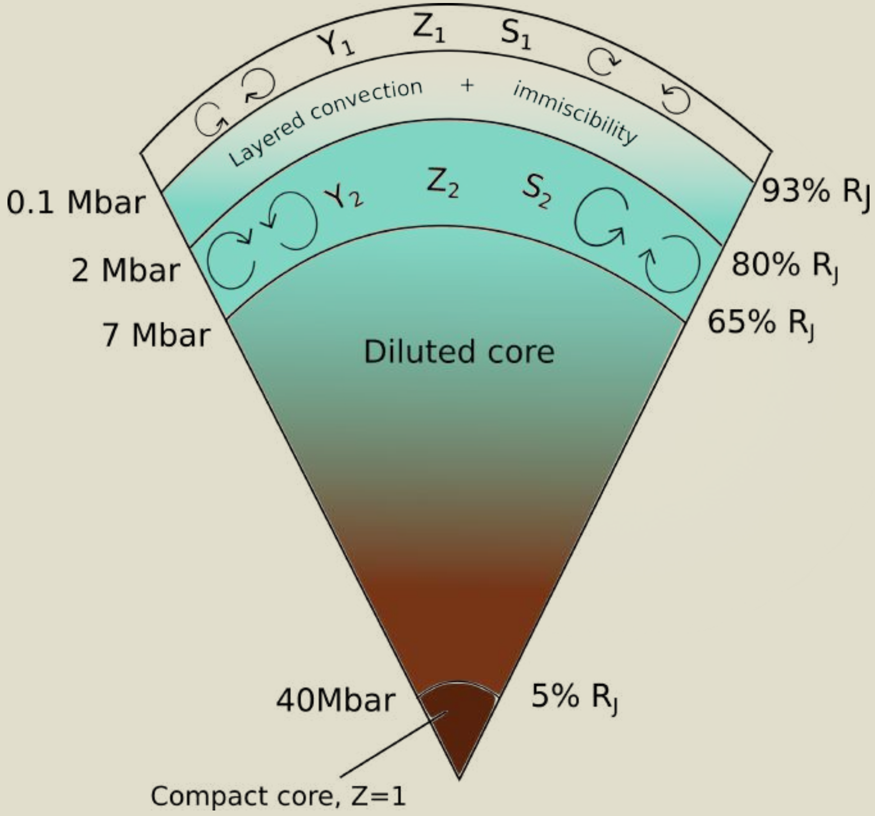

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Prospects

Oscillations are the necessary next step

Understanding the generation of magnetic fields in semi-convective regions is also key

Thank you !