Ab initio equations of states for planetary and exoplanetary modeling

S. Mazevet

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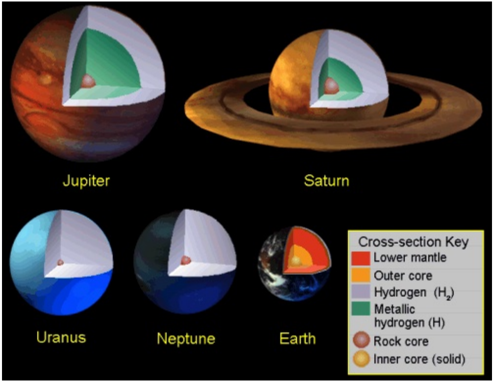
From Super Earth to Brown dwarfs: who's who, Paris June 2015

Motivations

Planetary interiors: 1-D hydrostatic modeling + EOS of a few elements



- **Jupiter, Saturn**: H, He
  40Mbar, 20000K, Fe/$MgSiO_3$
  70Mbar, 20000K
- **Neptune, Uranus** : H_2O, NH_3, CH_4 6Mbar-7000K, $MgSiO_3$ 10Mbar-7000K
- **Mercury, Venus, Earth, Mars**: Fe 5Mbar-7000K, $MgSiO_3$ 1Mbar-3000K

These EOS are mostly unknown over this large (P,T) domain

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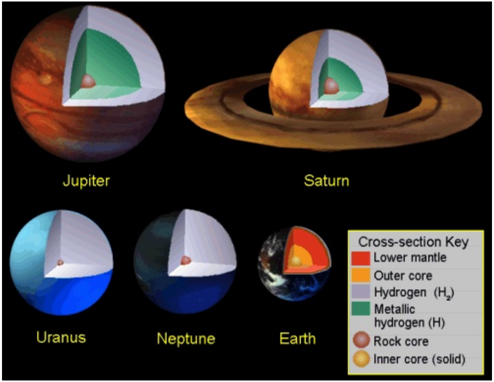

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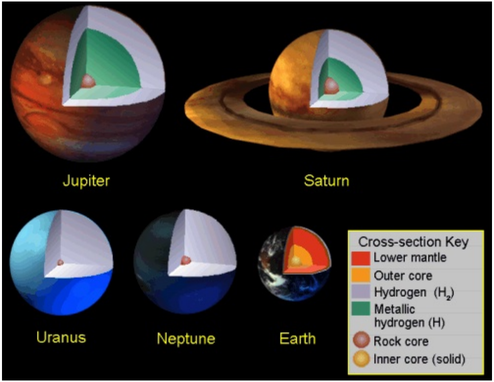

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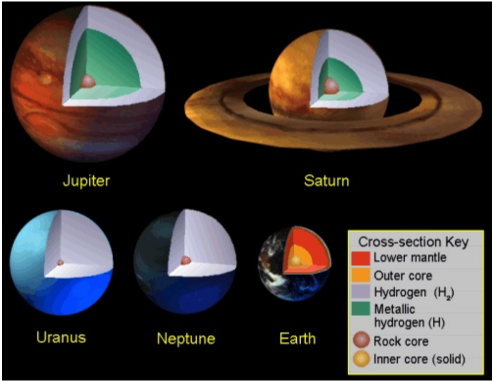

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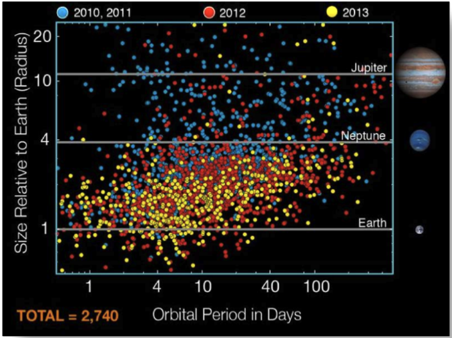

- Only mass en radius
- Some exoplanets are bigger than Jupiter or Earth: factor of 10 or more
- CHEOPS, PLATO: Neptune and Earth like planets
- New EOS for H_2O, Fe, $MgSiO_3$ up to 20Mbar
- Core of giants: 1000Mbar range

Need the phase diagrams of a few key elements up to 1000Mbar

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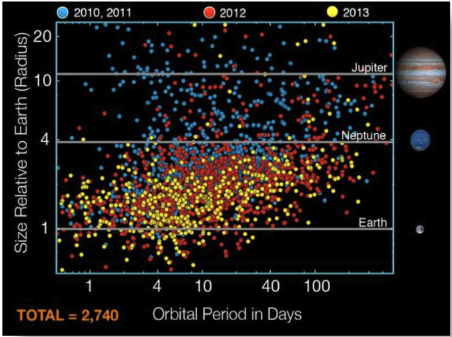

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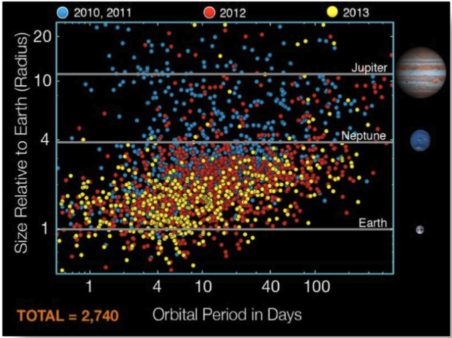

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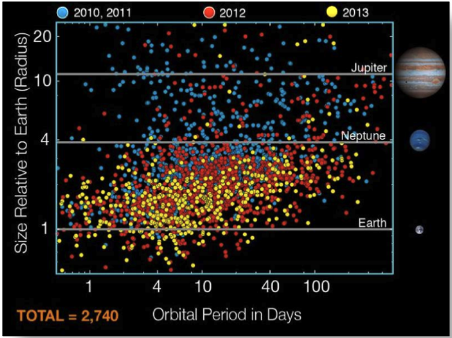

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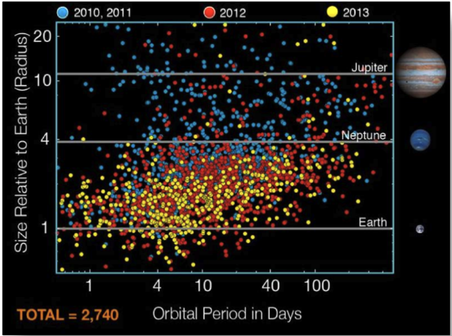

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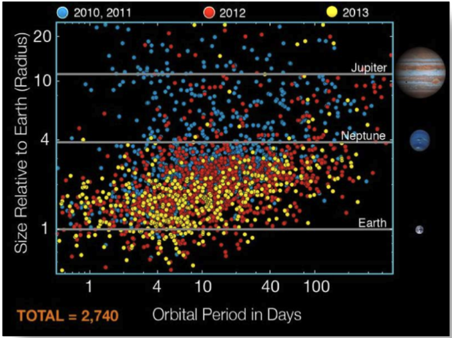

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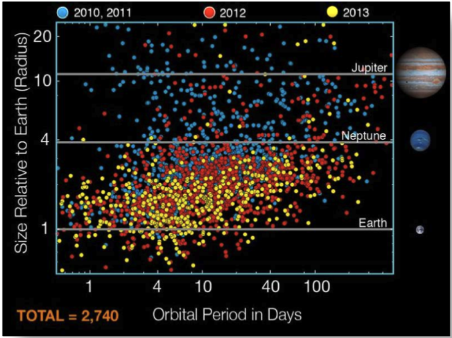

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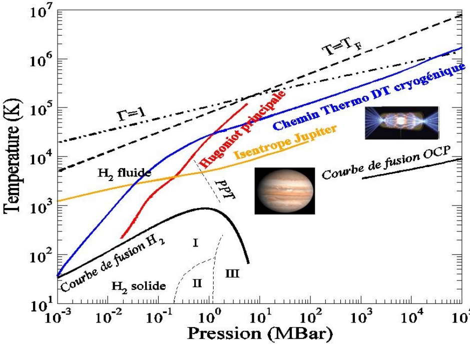
Why is this difficult: looking at hydrogen

In Jupiter's atmosphere, hydrogen is a molecular gas



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- In P and T hydrogen dissociates and ionizes,...
- First prediction for metallic hydrogen in 1920 (15GPa)
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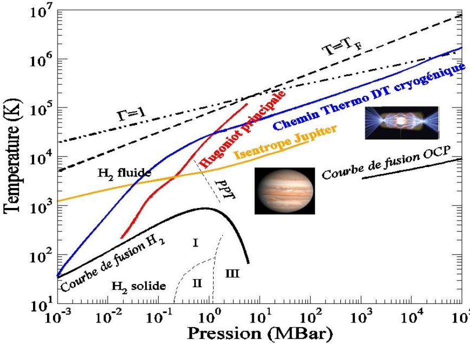

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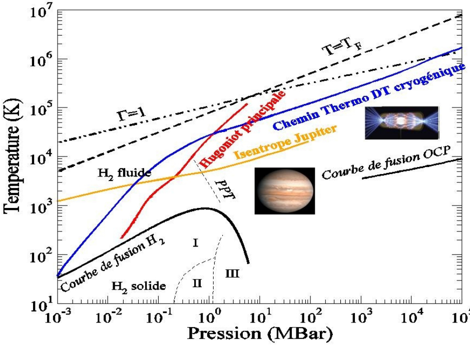

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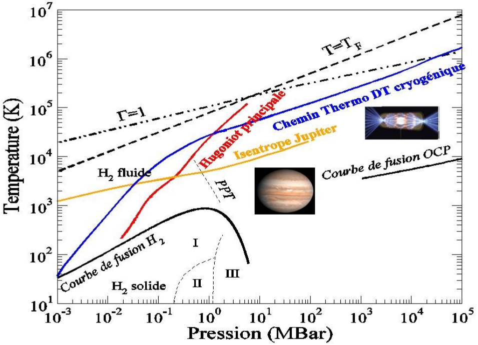

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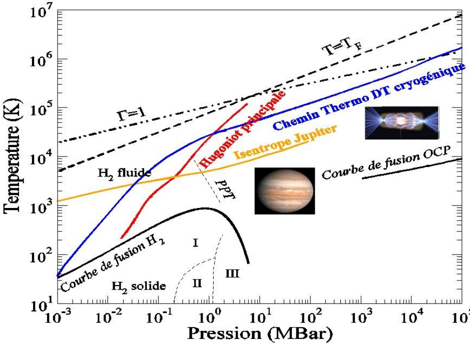

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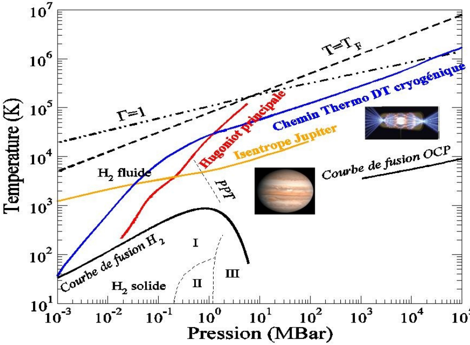

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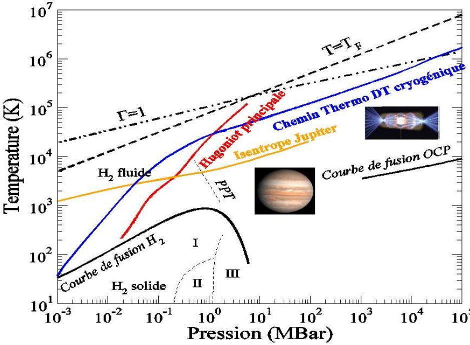

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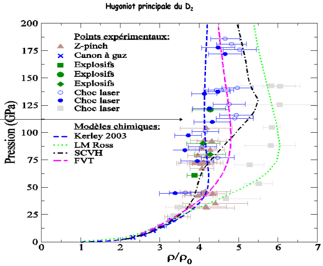
Hydrogen/Helium update: pure elements

Complete EOS for H and He up to 1000Mbar



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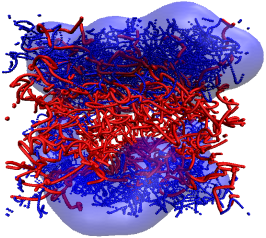
- No grid for varying H-He concentrations
- Direct simulations of demixing



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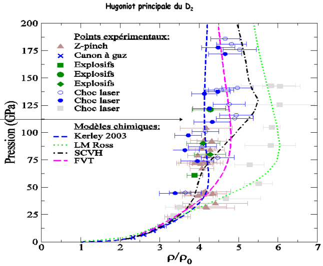

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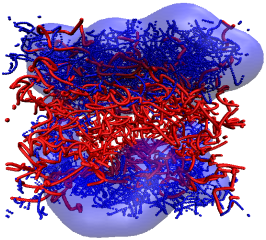

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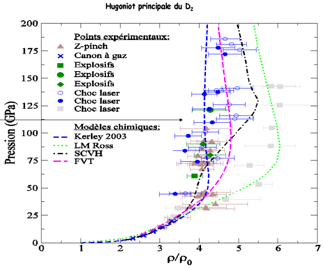

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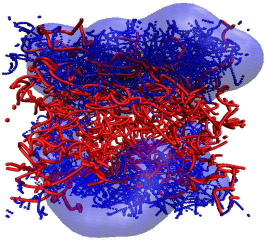

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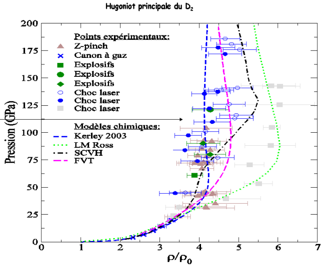

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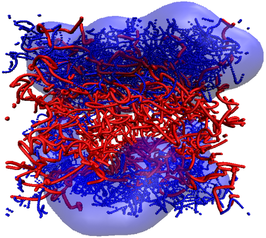

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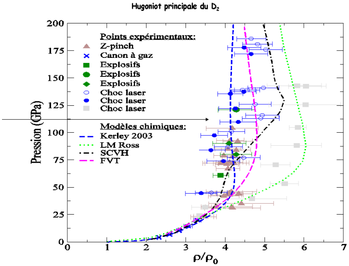

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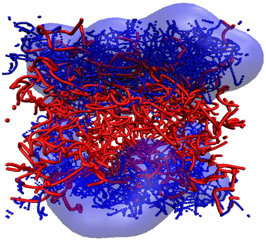

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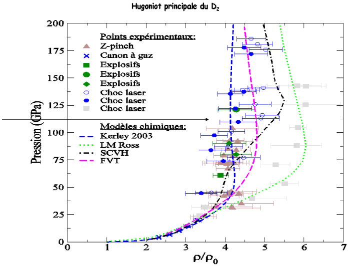

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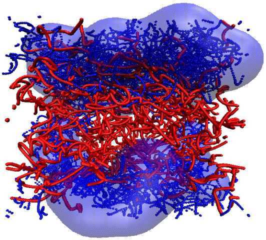

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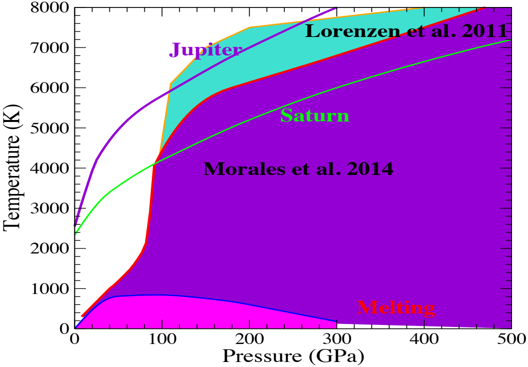
Saturn luminosity and Jupiter's He abundance



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- Demixing in Saturn but enough to explain luminosity? (Salpeter 1973)
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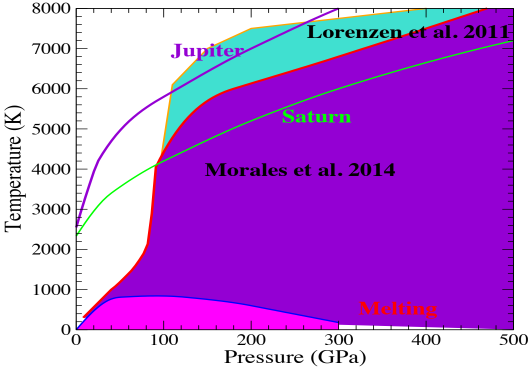

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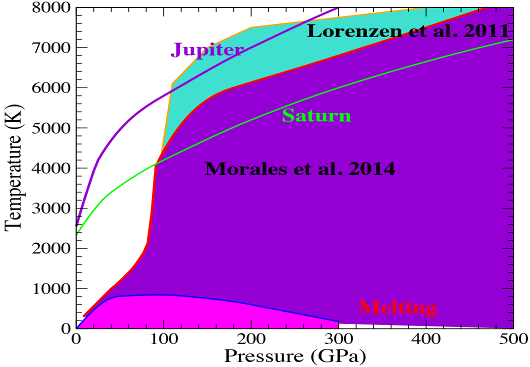

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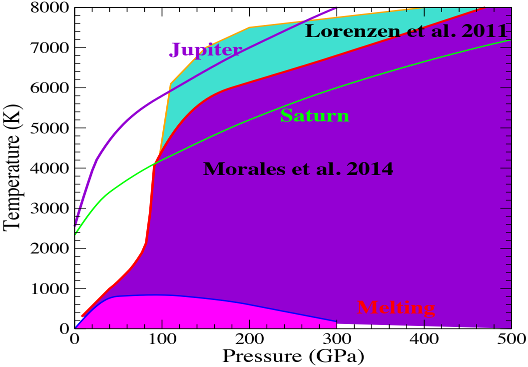

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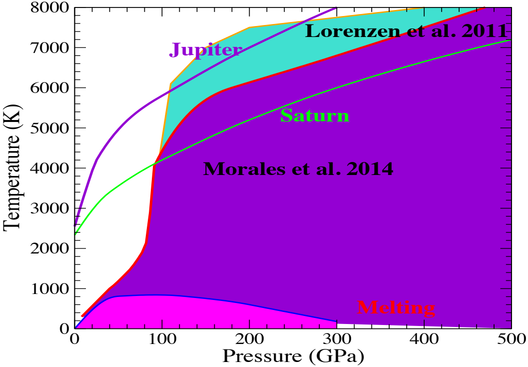

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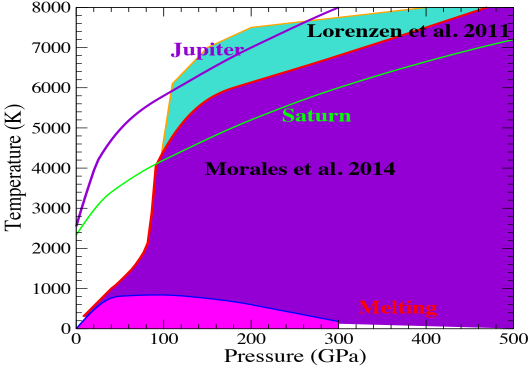
Unresolved issues for metallic elts and 2 or 3 layers models

H-He mixtures: Thesis F. Soubiran (CRAL Lyon)

Saturn luminosity and Jupiter's He abundance



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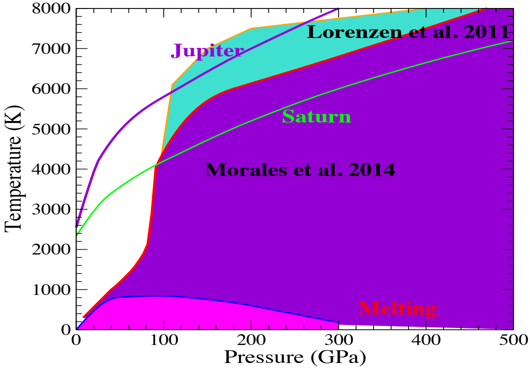

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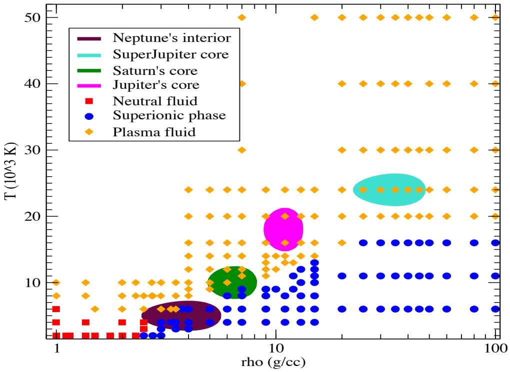

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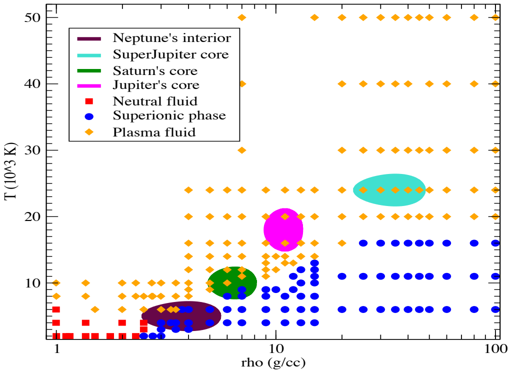

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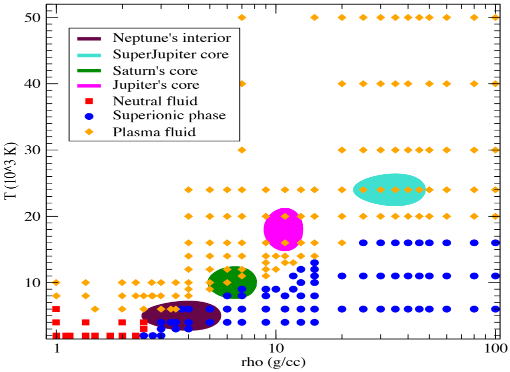

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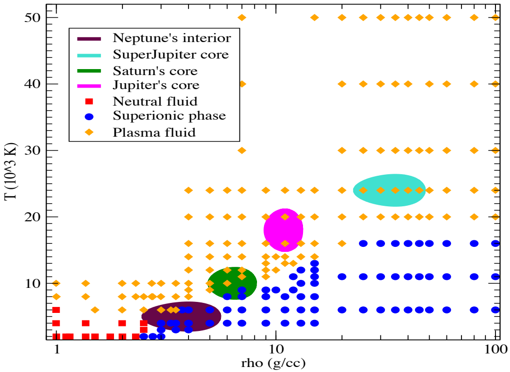

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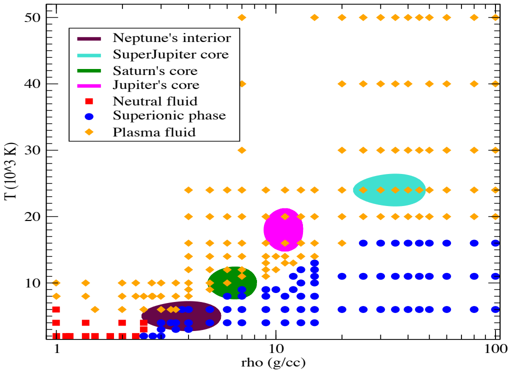

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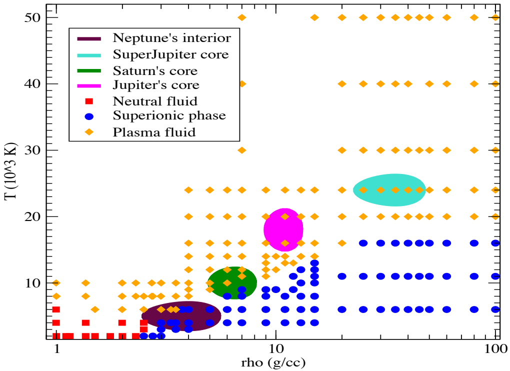

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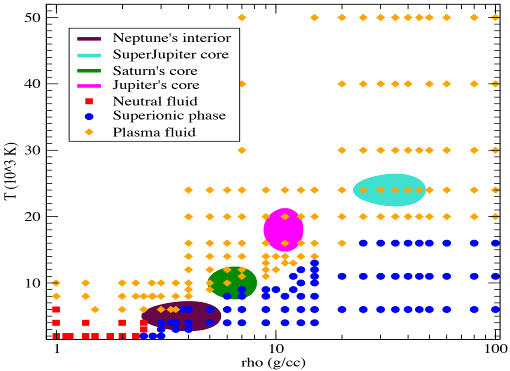

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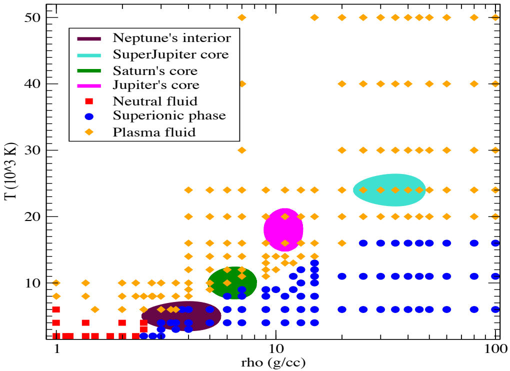

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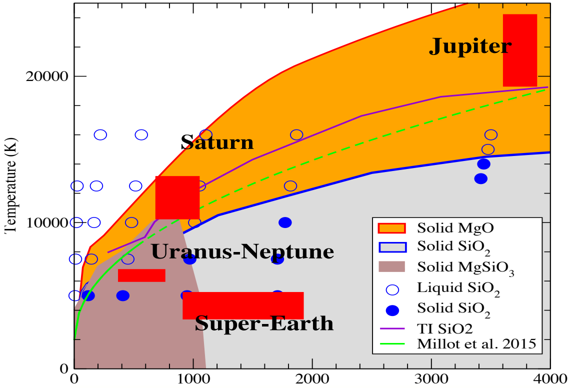
MgO-SiO_2: super-earth and giant cores (thesis R. Musella)

$MgSiO_3$ dissociates into MgO and SiO_2 above 10Mbar



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Liquid SiO_2 favors mixing: implications for tidal and evolution models

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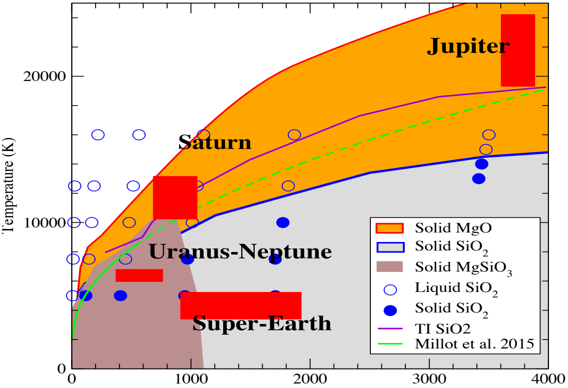

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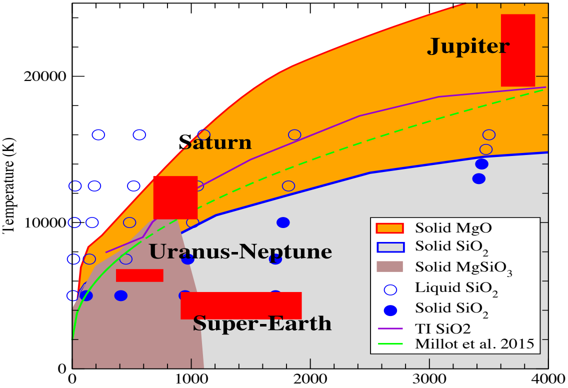

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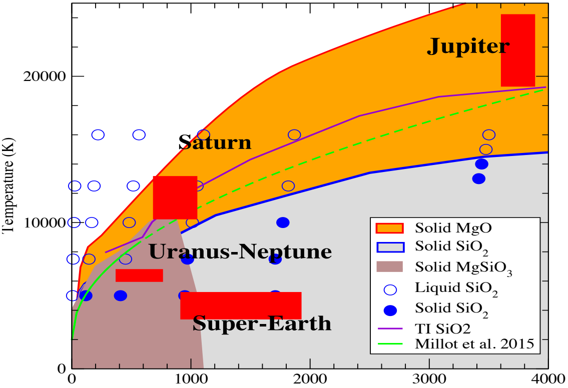

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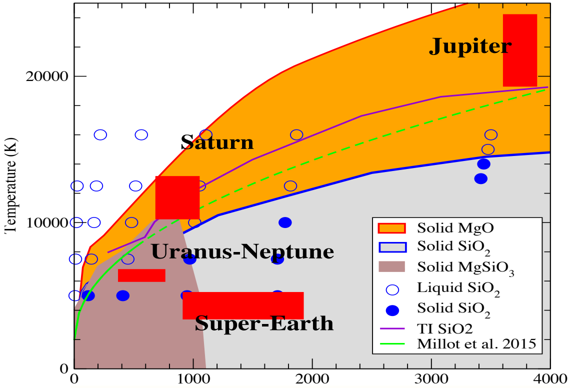

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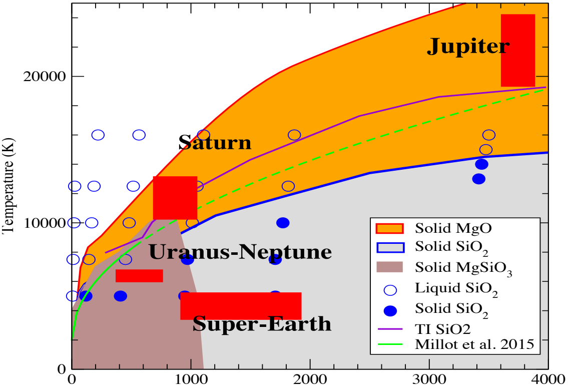

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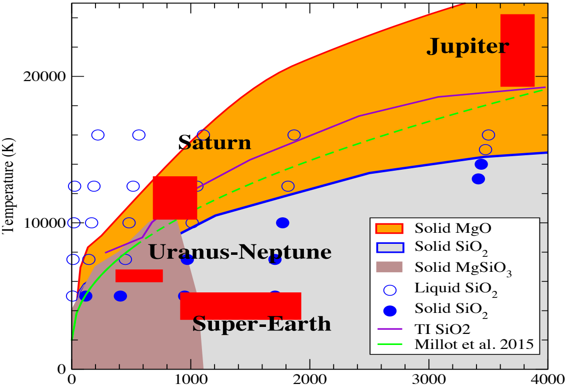

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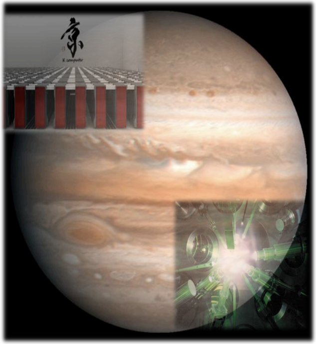
Summary

Complete planetary models based on ab initio results



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- Goal: provide benchmark EOS and 1D-models

Will be made available throught exoplanet.eu

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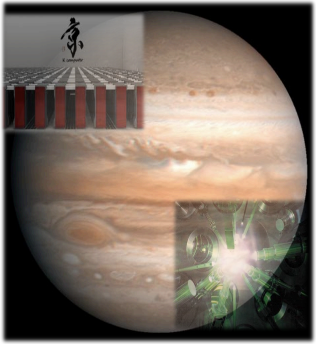

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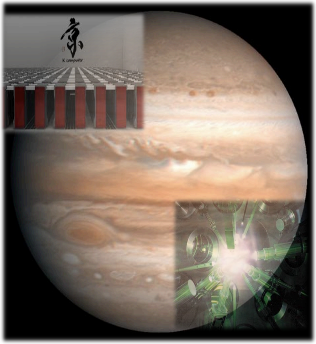

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l'Observatoire de Paris

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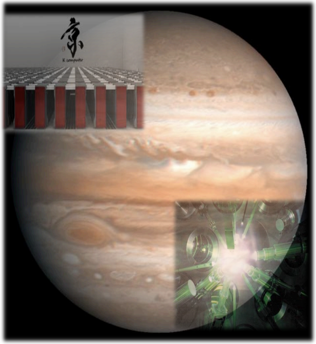

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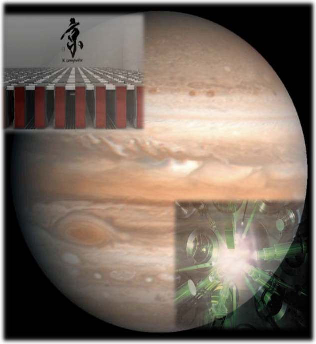

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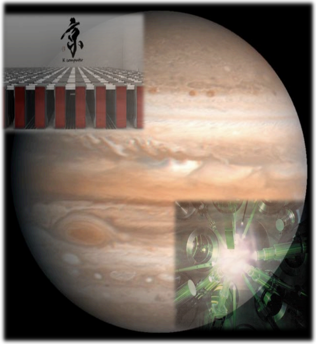

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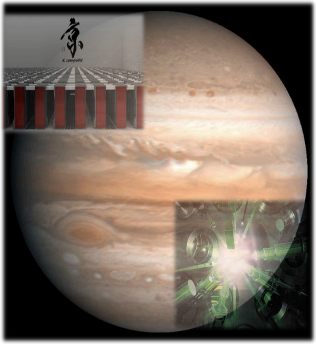

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Collaborators

Theory side

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  LUTH, Observatoire de Paris, 92195 Meudon
- V. Recoules, J. Bouchet
  CEA, DAM, DIF, F91297 Arpajon
- G. Chabrier, C. Winisdoerffer, F. Soubiran, A. Licari
  CRAL, Ecole Nationale Supérieure, 69180 Lyon

Experimental side

- A. Benuzzi-Mounaix, A. Denoeud, M. Koenig, A. Ravasio
  LULI, Ecole Polytechnique, 91128 Palaiseau
- F. Dorchies
  CELIA, Université Bordeaux 1, 33405 Bordeaux
- F. Guyot, G. Morard
  IMPMC, Université Paris VI Jussieu, 75006 Paris

ANR Planetlab: 4 years funding started in 2012