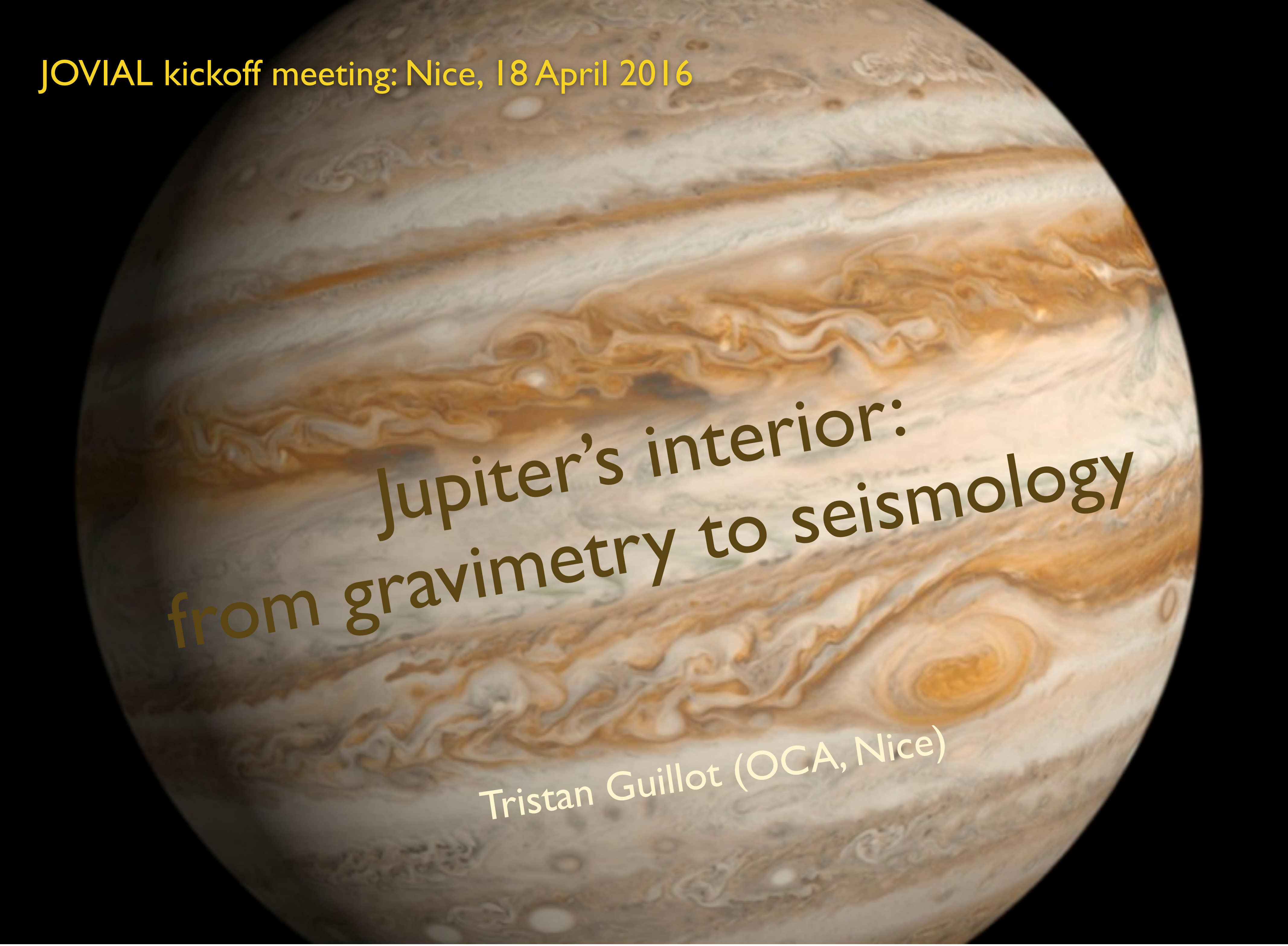
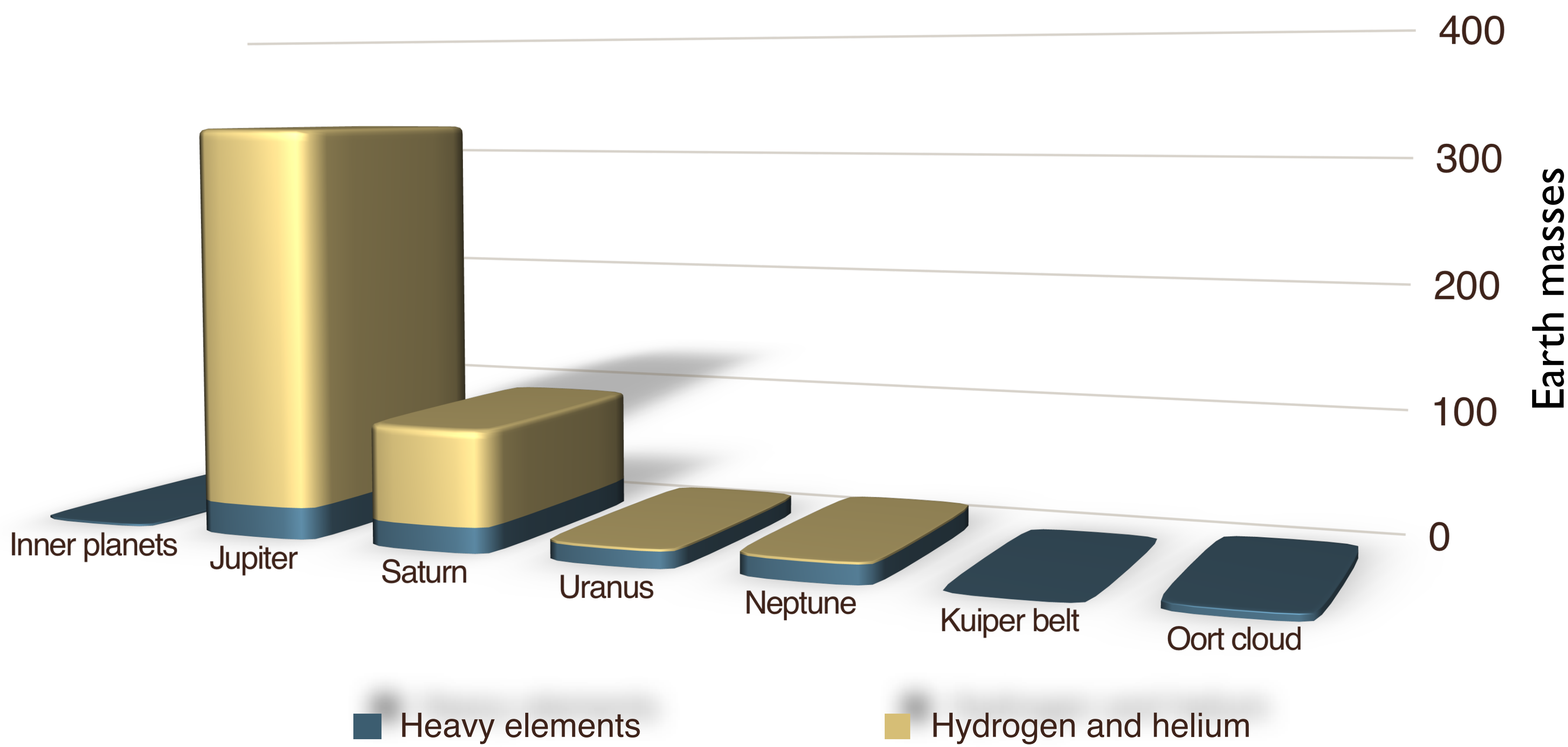
JOVIAL kickoff meeting: Nice, 18 April 2016



Jupiter's interior: from gravimetry to seismology

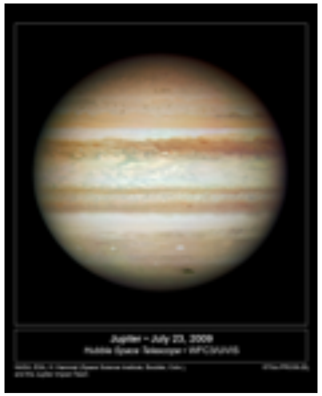
Tristan Guillot (OCA, Nice)

Completing the inventory



Giant planets possess 99.5% of all the mass in the Solar System except the Sun

Flattening & interior structure



Hydrostatic equilibrium with rotation:

$$\frac{\nabla P}{\rho} = \nabla V - \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r})$$

If the interior rotation derives from a potential

$$\nabla P = \rho \nabla U.$$

$$U = V + W \qquad V(\mathbf{r}) = G \int \frac{\rho(\mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|} d^3\mathbf{r}' \qquad W(\mathbf{r}) = \frac{1}{2}\omega^2 r^2 \sin^2\theta$$

$$\begin{aligned} V &= \frac{G}{r} \sum_{n=0}^{\infty} \left(r^{-2n} D_{2n} + r^{2n+1} D'_{2n} \right) P_{2n}(\cos\theta), \\ D_{2n} &= \int_{r' \le r} \rho(r', \cos\theta') r'^{2n} P_{2n}(\cos\theta') d^3\mathbf{r}', \\ D'_{2n} &= \int_{r' > r} \rho(r', \cos\theta') r'^{-2n-1} P_{2n}(\cos\theta') d^3\mathbf{r}'. \end{aligned}$$

Measured:

$$V_{\text{ext}}(r, \cos\theta) = \frac{GM}{r} \left[1 - \sum_{n=1}^{\infty} \left(\frac{a}{r} \right)^{2n} J_{2n} P_{2n}(\cos\theta) \right]$$

$$J_{2n} = -\frac{1}{M a^{2n}} D_{2n}.$$

Jupiter & Saturn: input data

Gravitational field

Table 5.1: Characteristics of the gravitational fields

	Jupiter		Saturn	
	measured[a]	adjusted[c]	measured[b]	adjusted[c]
$M/M_\oplus$	317.83		95.147	
$R_{eq}/10^9$ cm	7.1492(4)		6.0268(4)	
$\omega/10^{-4}\,s^{-1}$	1.76		1.64	
$J_2/10^{-2}$	1.4697(1)	1.4682(1)	1.6332(10)	1.6252(10)
$J_4/10^{-4}$	−5.84(5)	−5.80(5)	−9.19(40)	−8.99(40)
$J_6/10^{-4}$	0.31(20)	0.30(20)	1.04(50)	0.94(50)

Atmospheric temperatures

@1 bar: 165+/-5 K for Jupiter, 135+/-5K for Saturn

Atmospheric abundances

In Jupiter: Y=0.238+/-0.007 in the atmosphere, Z~3 times solar (?)
In Saturn: Y=0.06-0.21 in the atmosphere, Z~7 times solar (based on C/H)

Protosolar Y=0.275+/-0.05

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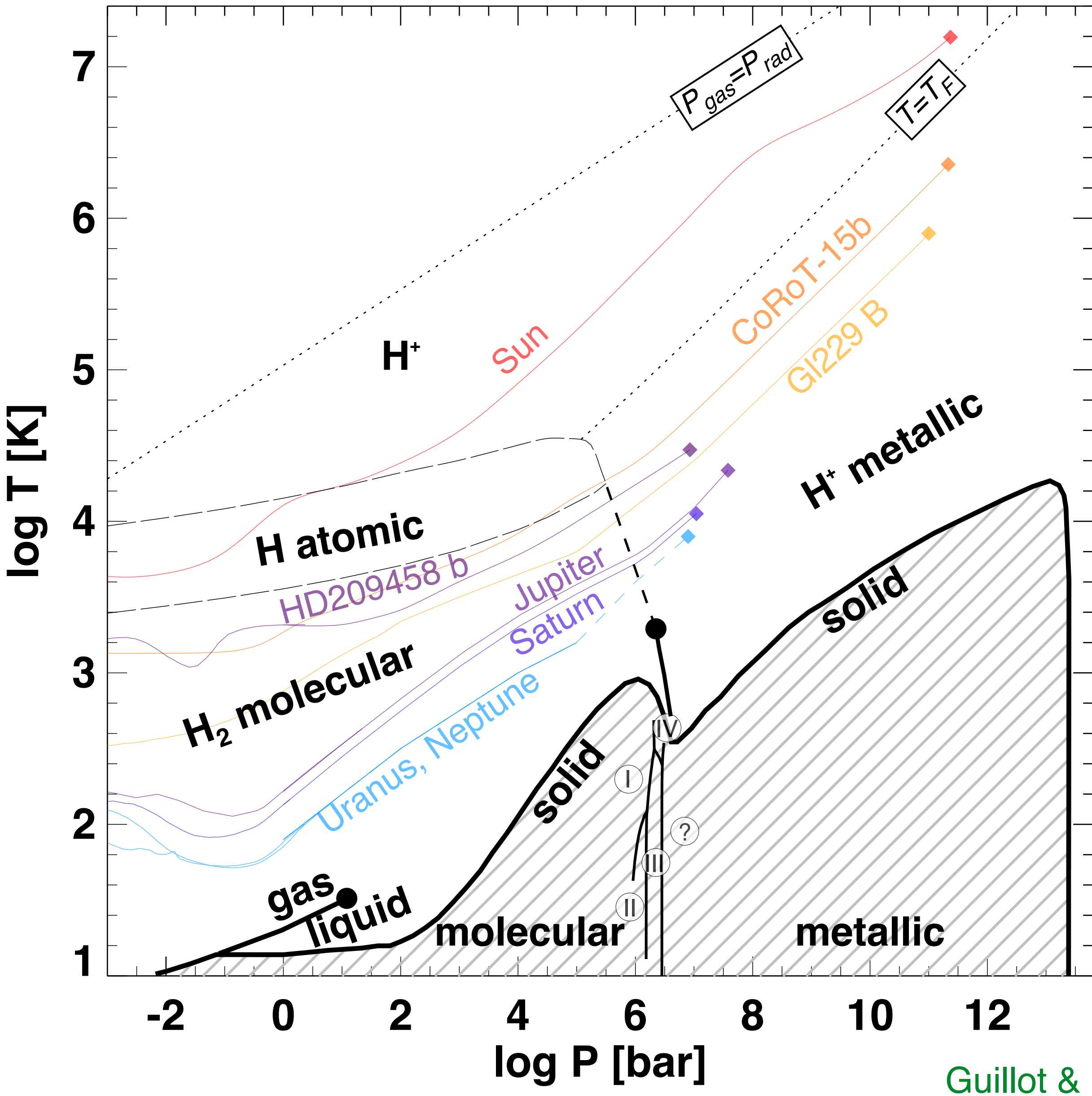
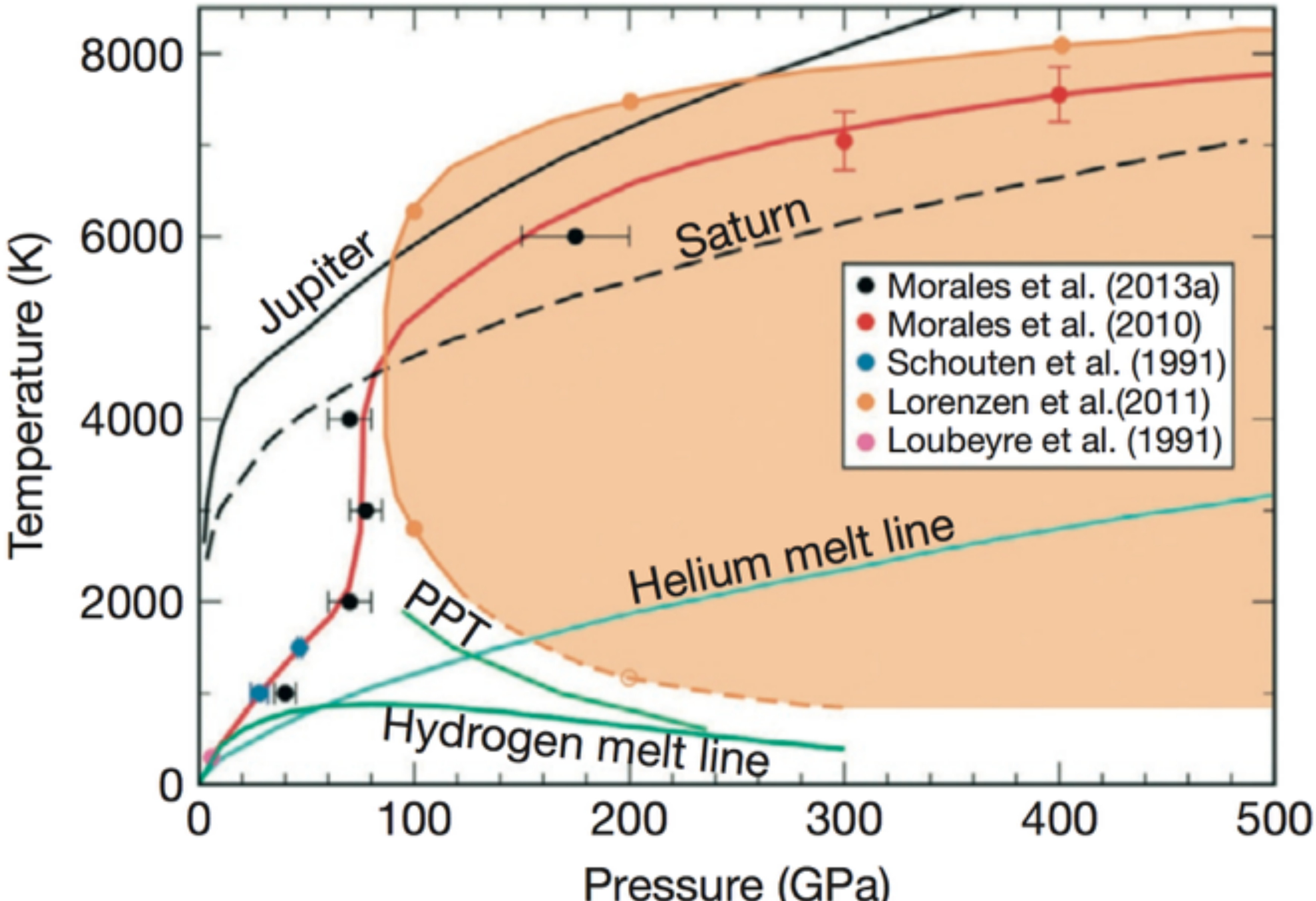
Hydrogen phase diagram

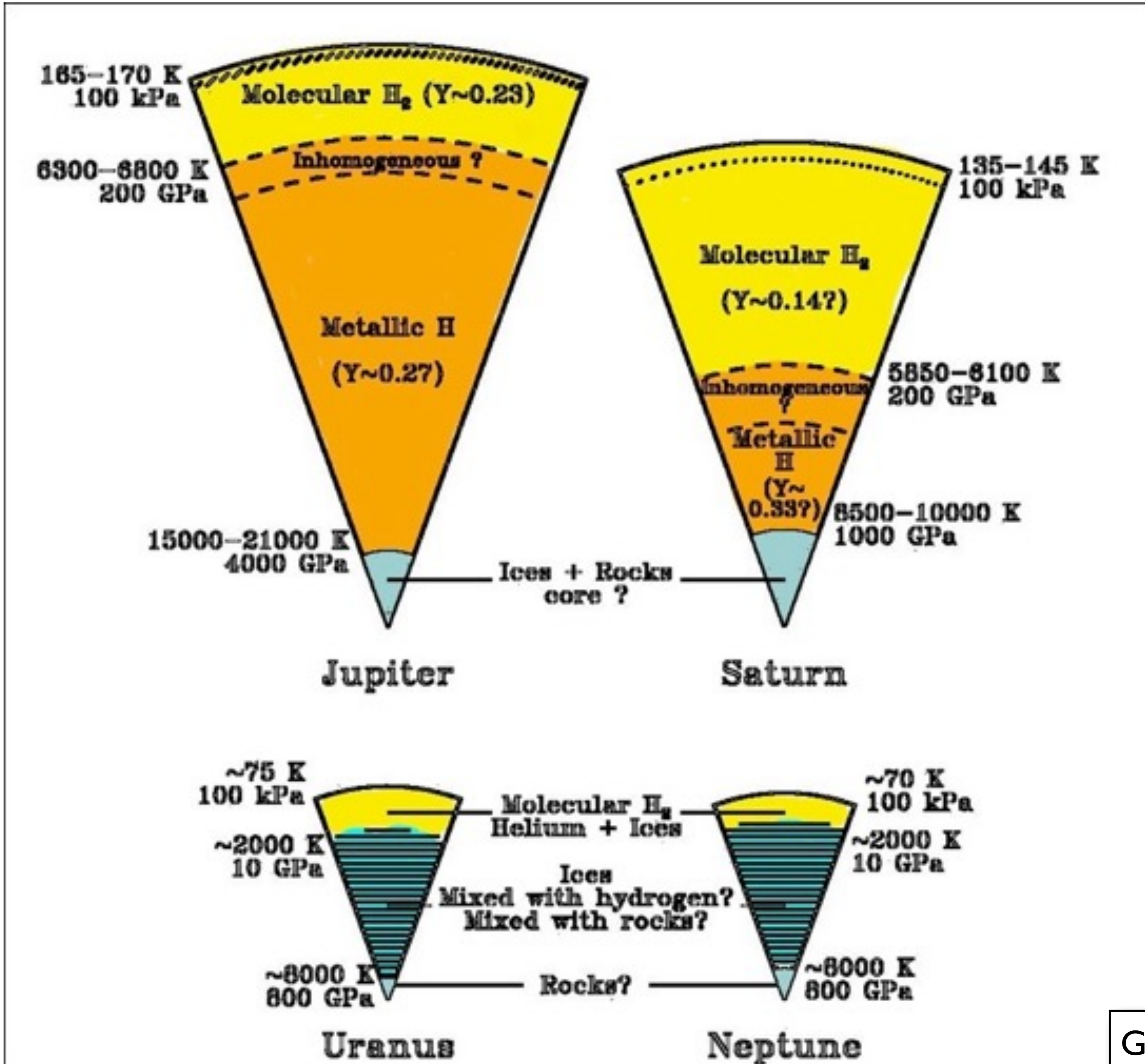


Guillot & Gautier (2015)
see also McMahon et al. (2012)

Hydrogen-helium phase separation



Three-layer models



Guillot (1999)

Construction of models

Equations of state

Opacities

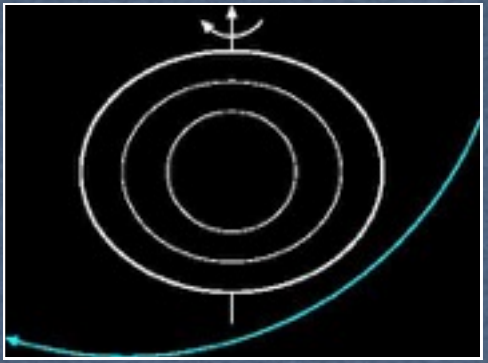
Mass,
surface temperature…etc.

Hydrostatic equations
(rotation to 4th order)

Theoretical gravitational
moments: J2, J4, J6,J8

Measured gravitational
moments: J2, J4, J6

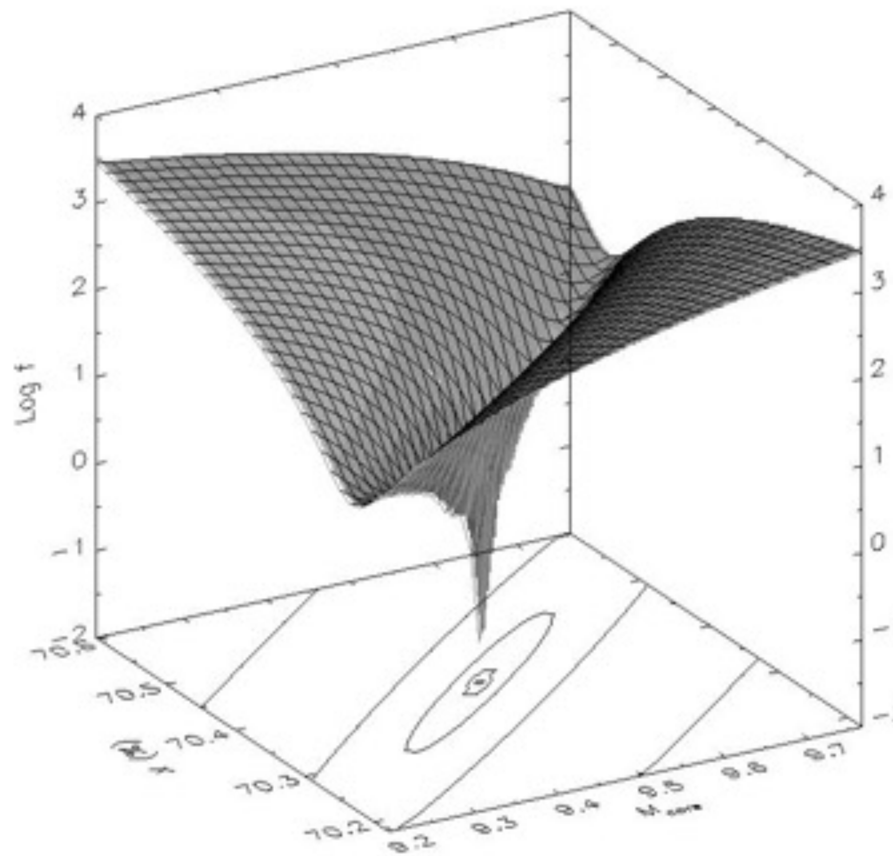
Mass of the rock/ice core
Y+Z in the metallic region
Y+Z in the molecular region



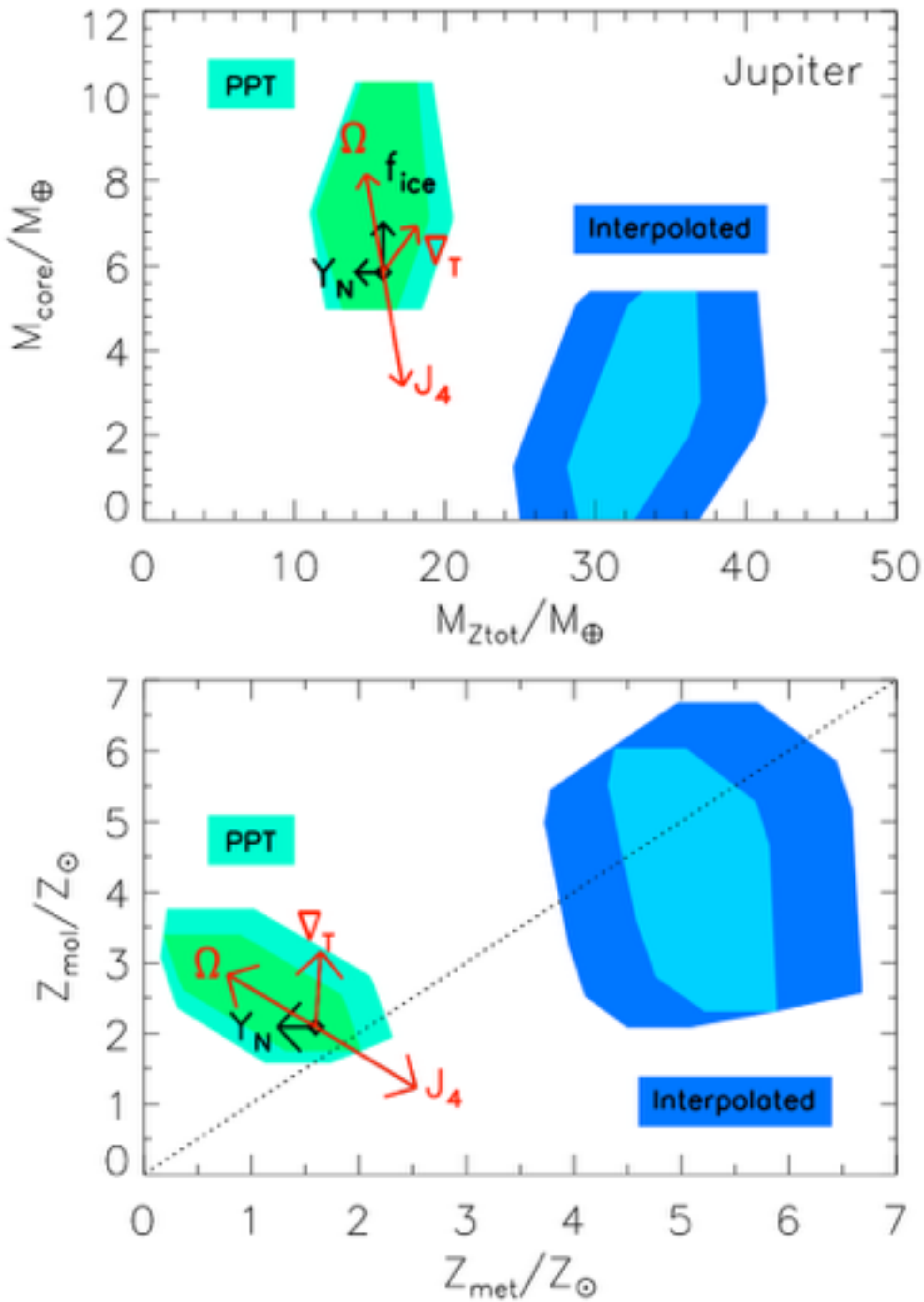
Construction of models

- A minimization technique is used to converge to models fitting the observational constraints within the error bars

$$\chi^2(Z_{\rm mol}, Z_{\rm met}, M_{\rm core}) = \frac{1}{4}\left[\left(\frac{\Delta R_{\rm eq}}{\sigma_{R_{\rm eq}}}\right)^2 + \left(\frac{\Delta J_2}{\sigma_{J_2}}\right)^2 + \left(\frac{\Delta J_4}{\sigma_{J_4}}\right)^2 + \left(\frac{\Delta J_6}{\sigma_{J_6}}\right)^2\right]$$

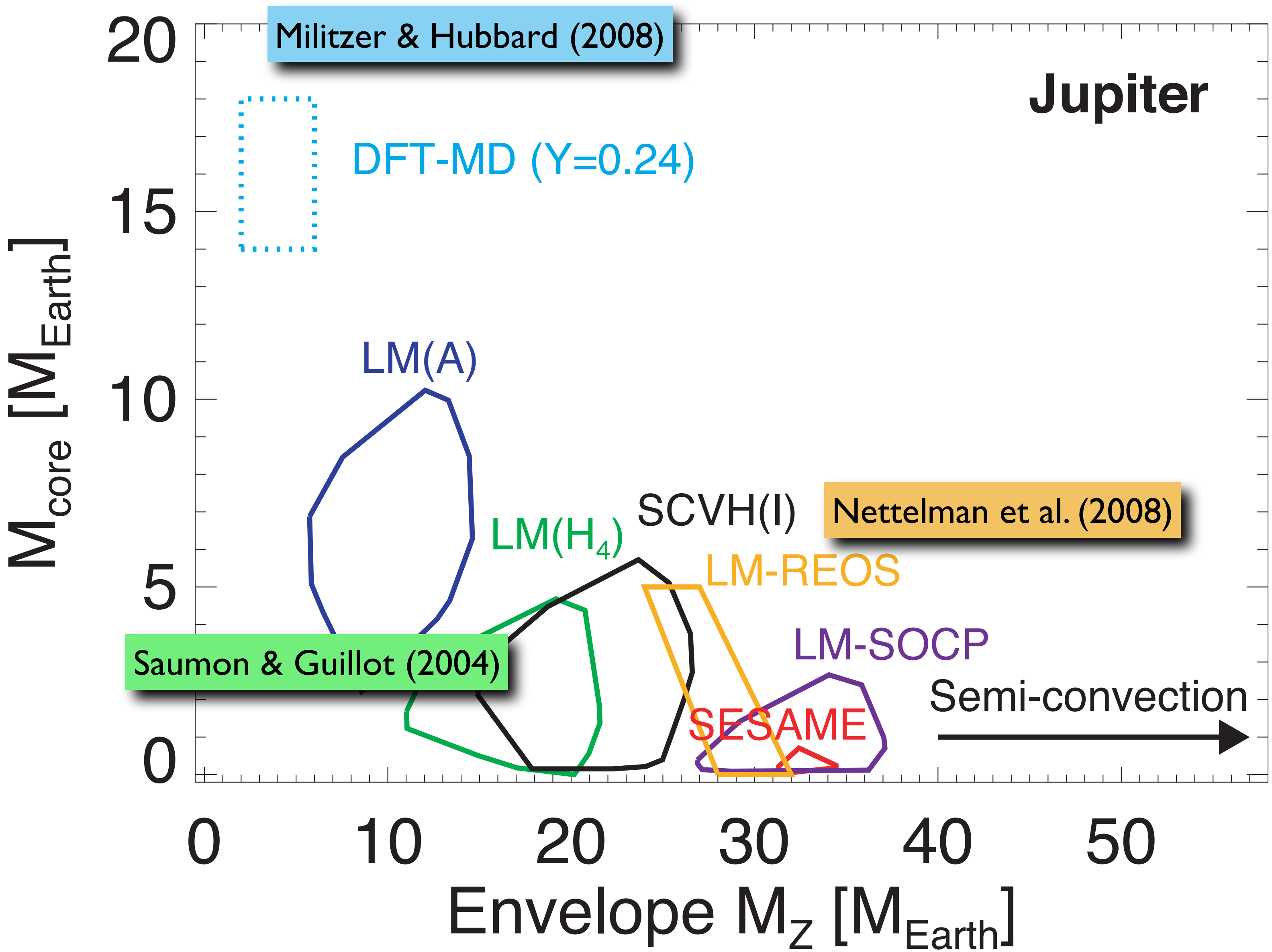


Results for Jupiter



Guillot 1999

Results for Jupiter



Jupiter Orbit Insertion: 4 July 2016

Juno project overview

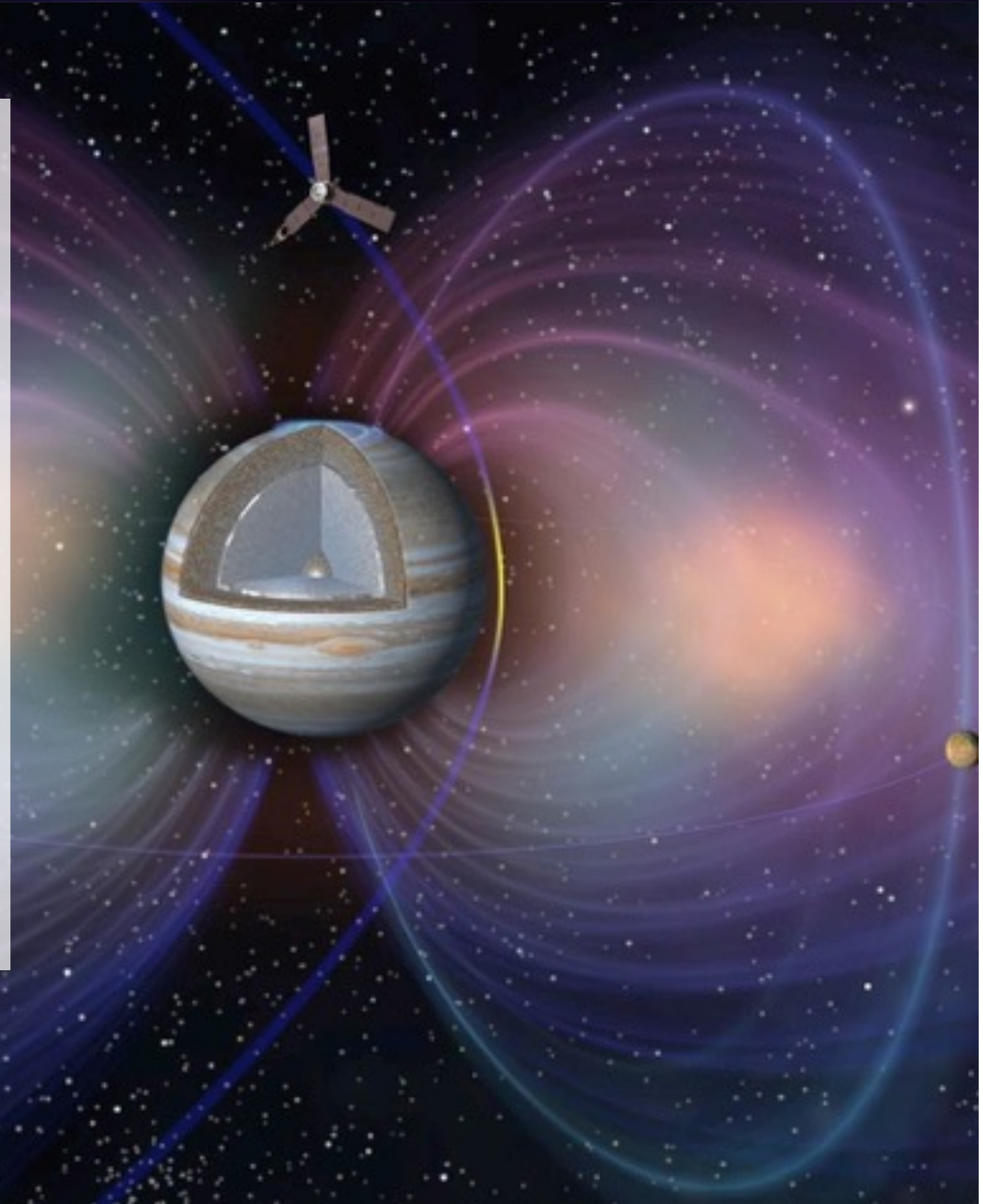
Spacecraft:

- Spinning, polar orbiter spacecraft launches in August 2011
  - 5-year cruise to Jupiter, JOI in July 2016
  - 1 year operations, EOM via de-orbit into Jupiter in 2017
- Elliptical 11-day orbit swings below radiation belts to minimize radiation exposure
- 2nd mission in NASA's New Frontiers Program First solar-powered mission to Jupiter
- Payload of eight science instruments to conduct gravity, magnetic and atmospheric investigations, plus a camera for E/PO

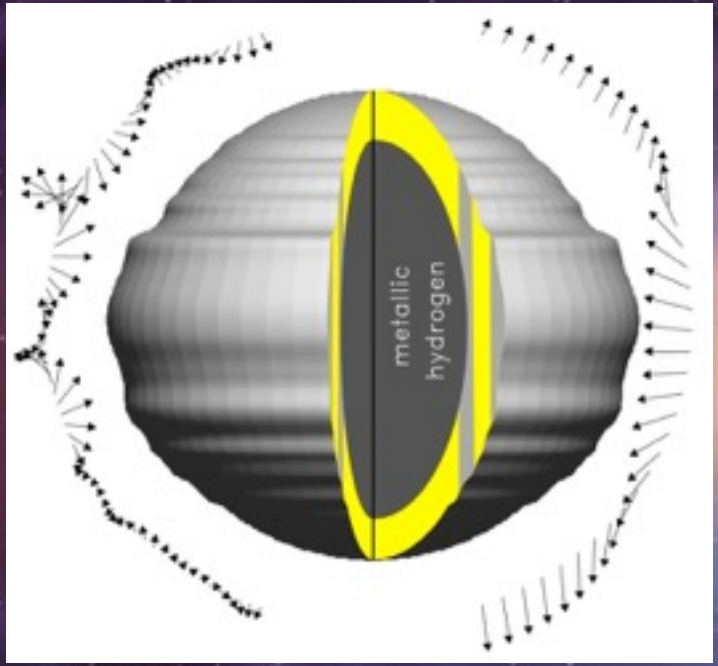
Science Objective: Improve our understanding of giant planet formation and evolution by studying Jupiter's origin, interior structure, atmospheric composition and dynamics, and magnetosphere

Principal Investigator: Dr. Scott Bolton

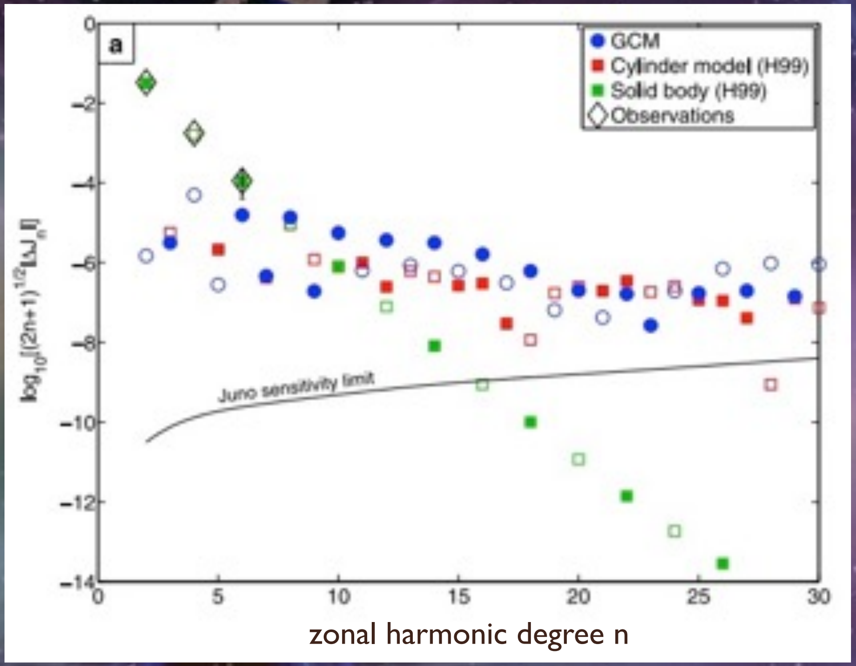
Southwest Research Institute



Deep atmosphere & Interior structure



Guillot et al. (2004)

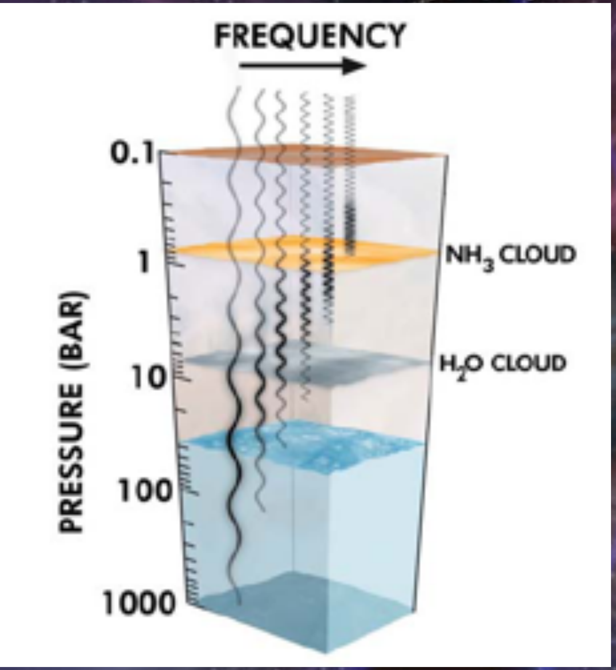


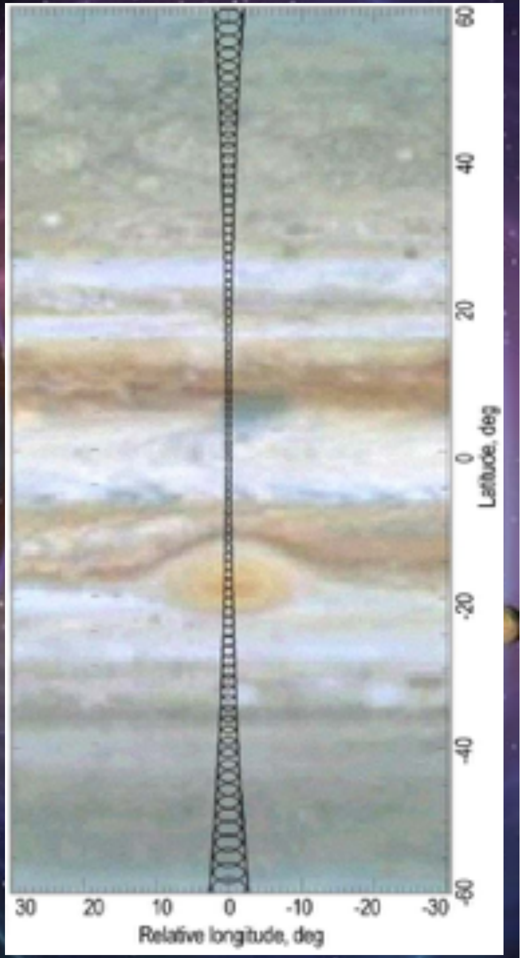
Kaspi et al. (2010)

Radiometry

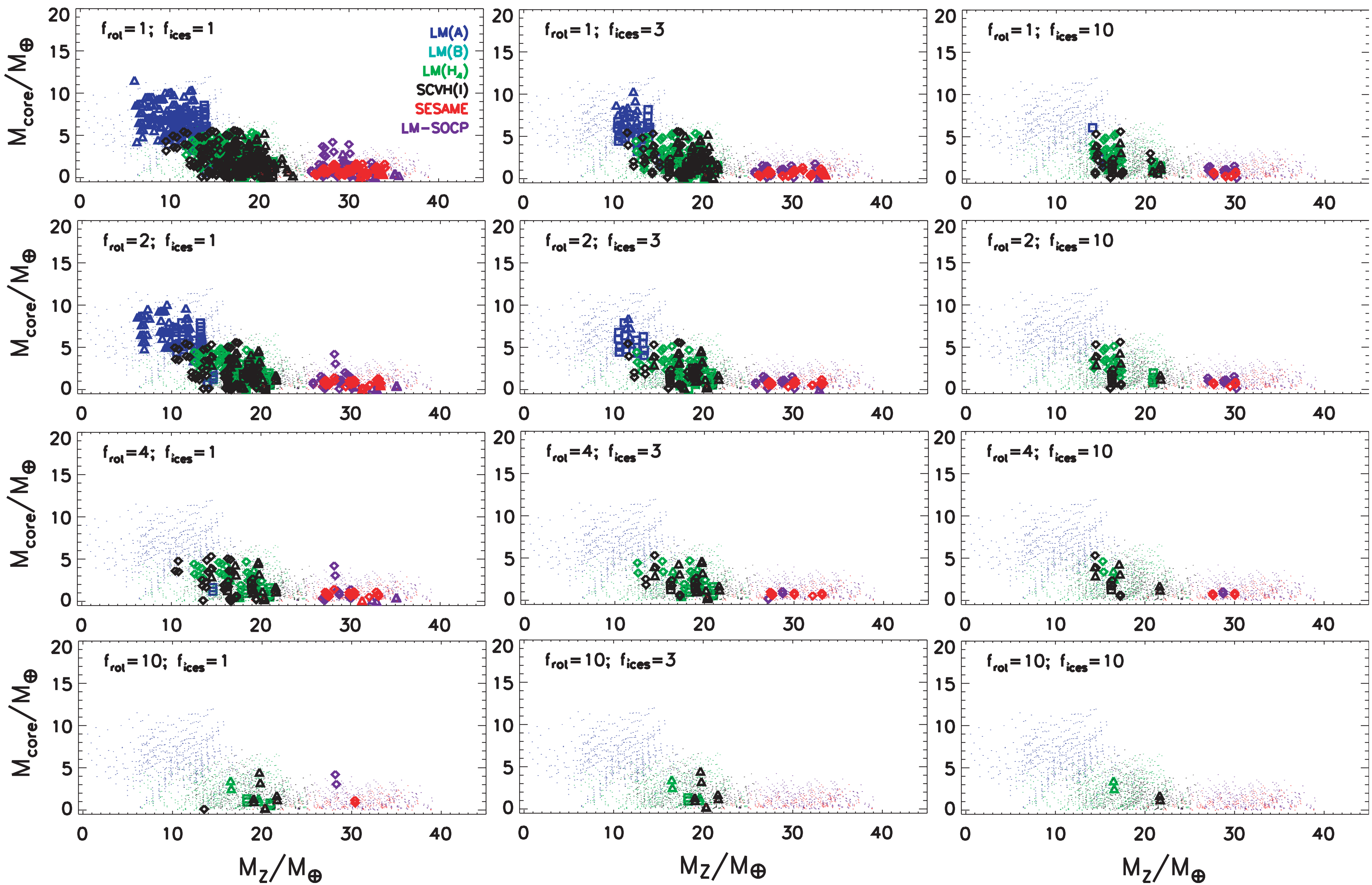
Radiometry probes deep into meteorological layer

Determines and maps the water and ammonia abundances

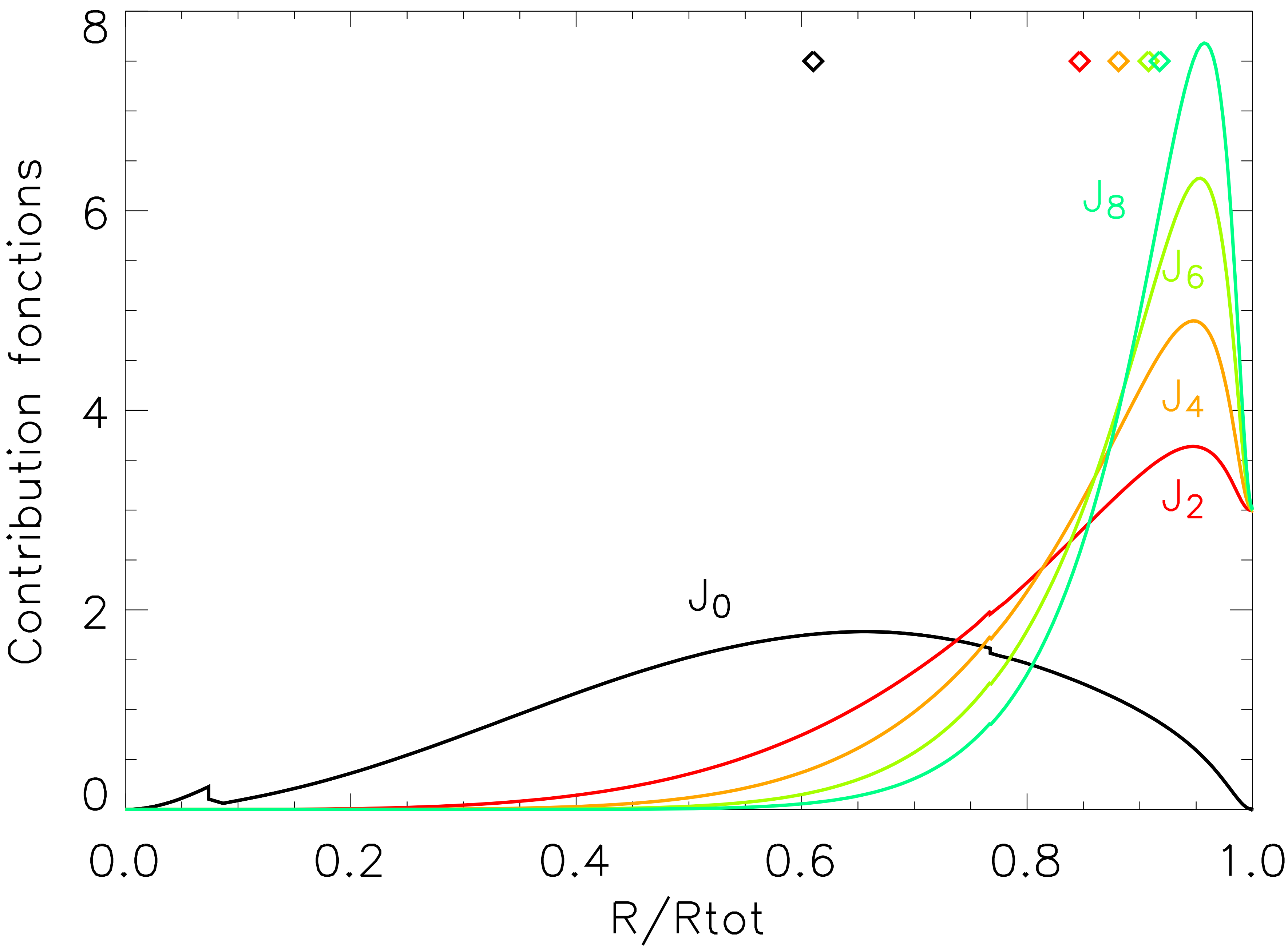




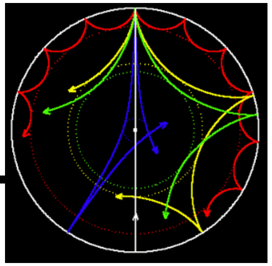
Three-layer model approach with Juno



Limitations of gravimetry

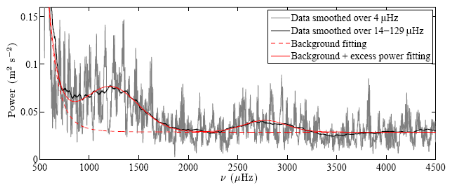


Seismology!



Jupiter

Gaulme et al. (2011)

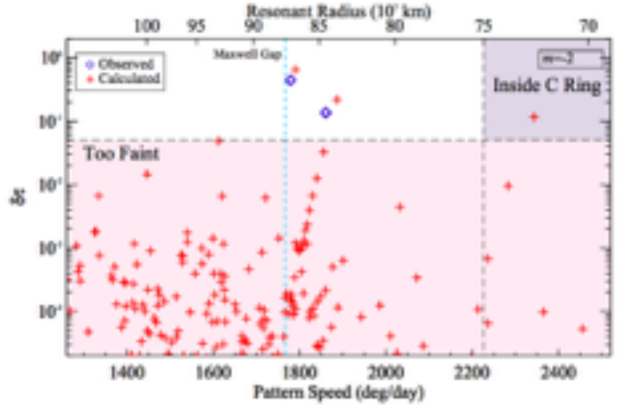


- p-modes detected
- low-degree (l~1)
- power excess: 1-3mHz (15-5mns)
- amplitudes: ~30cm/s

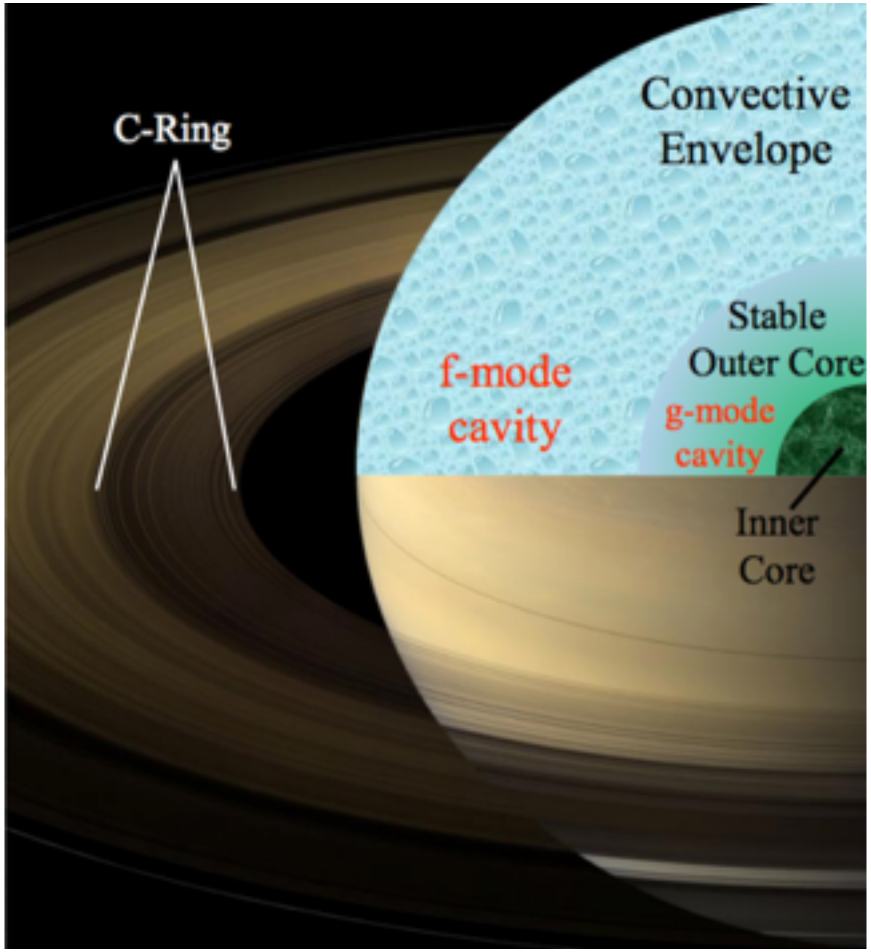
Saturn

Hedman & Nicholson (2013)

- f-modes identified
- low-degree (l=2-4)
- frequencies: 0.7-1.3 mHz
- amplitudes: ~1m



Fuller (2014)



Where are the heavies?

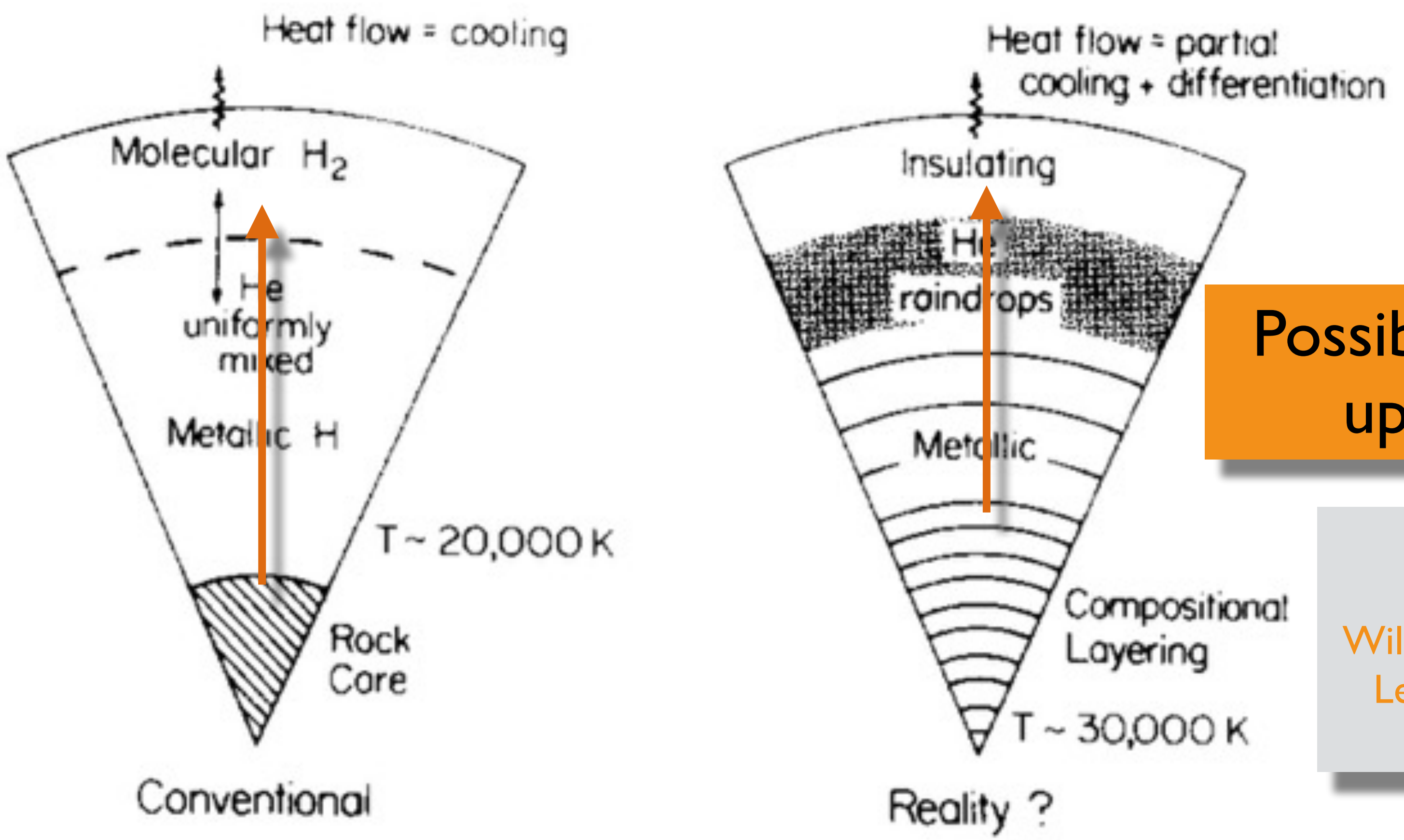


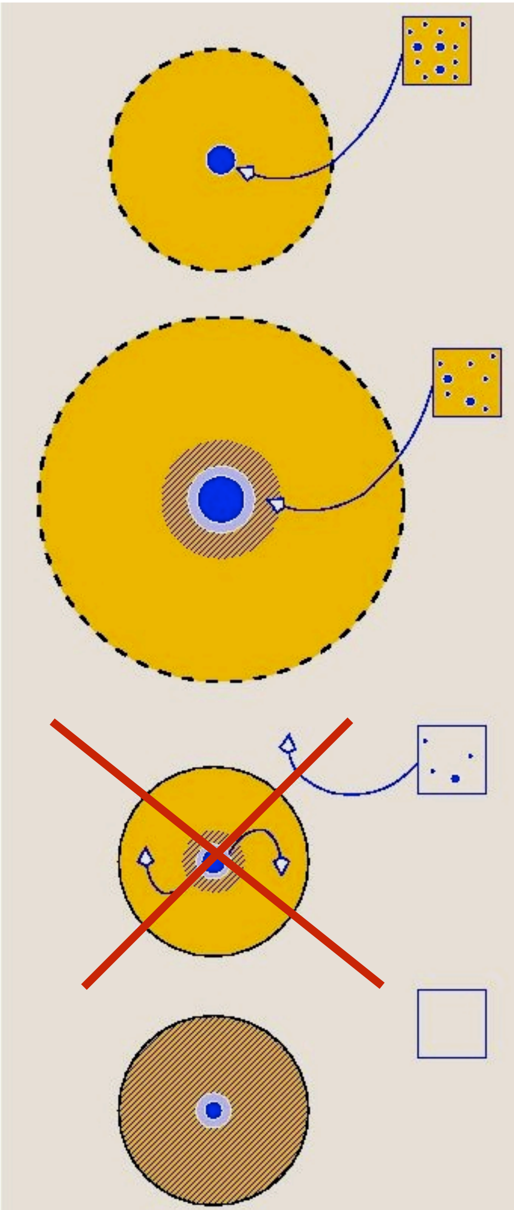
FIG. 3. Comparison of interior models for Jupiter according to the conventional view and in reality (similar to Table 1).

Possibility of erosion/ upward mixing

e.g. Stevenson 1981,
Guillot et al. 2004,
Wilson & Militzer 2011, 2012,
Leconte & Chabrier 2012,
Vazan et al. 2015

Stevenson (1985)

Was the primordial envelope metal-poor?



- Core accretion: planetesimals are delivered onto the central core.
- Core accretion: planetesimals cannot reach the core intact. (Podolak et al. 1988; Pollack et al. 1996)
- Envelope capture: accretion efficiency drops (Guillot & Gladman 2000): core erosion (see Guillot et al. 2004)?

or

- Heavies are accreted with the envelope because the feeding zone expands (e.g., Alibert et al. 2005; Lissauer et al. 2009)

- Present: enriched atmosphere.

Questions

- Can we go beyond 3-layer models?
  - Predictions from formation models
  - Learning from Saturn's seismology
- How are the oscillations excited?
  - Comparison to the Sun
  - Interactions between weather & waves
  - Saturn vs. Jupiter
- Juno & JIVE/JOVIAL
  - Oscillations in Juno's data?
  - Schedules?

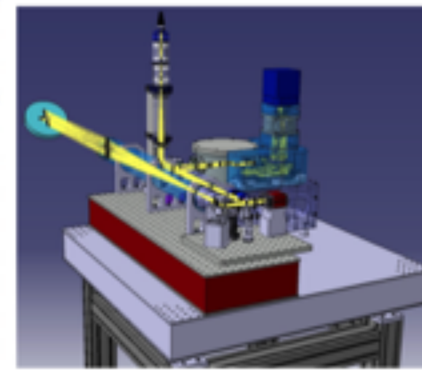
JOVIAL

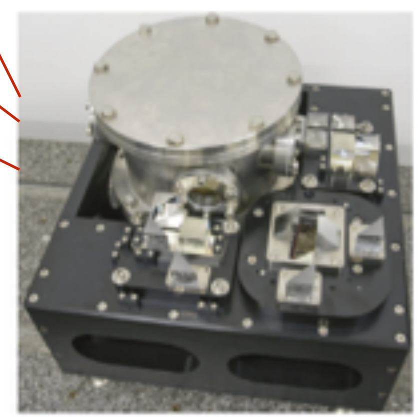
A network of Doppler Imagers to study Jupiter's and Saturn's global oscillations

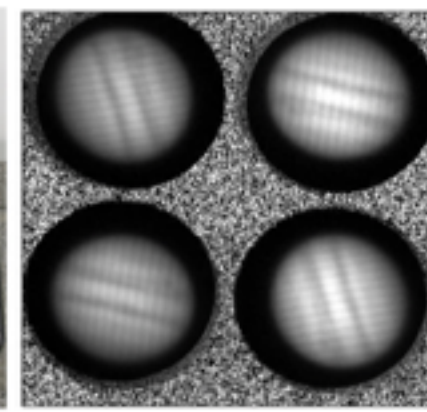
Kickoff meeting: Nice, 18-20 April 2016

A solid base: a prototype developed and built in Nice, France

JIVE will measure the velocity of the cloudy "surface" of Jupiter, to look for tiny fluctuations due to the seismic oscillations. The instrument principle is based on high-resolution spectro-imaging in the visible domain. The optical design as well as a prototype weres developed in Nice in the frame of a study for a instrument to be placed on an ESA space-mission. It was successfully tested from the ground early 2014.







Prototype instrument and preliminary observations. The top panel shows the whole design of the instrument. The bottom left shows the components of the prototype corresponding to the interferometer. On the bottom right are the four output images of Jupiter used to compute velocity maps from the interferometric fringes (barely seen in this image rendering). The two main bands in each image at about 45 are zonal features of Jupiter's clouds.