Séminaire Lagrange
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Jupiter's internal structure and the first Juno results

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Motivation why study Giant planets?

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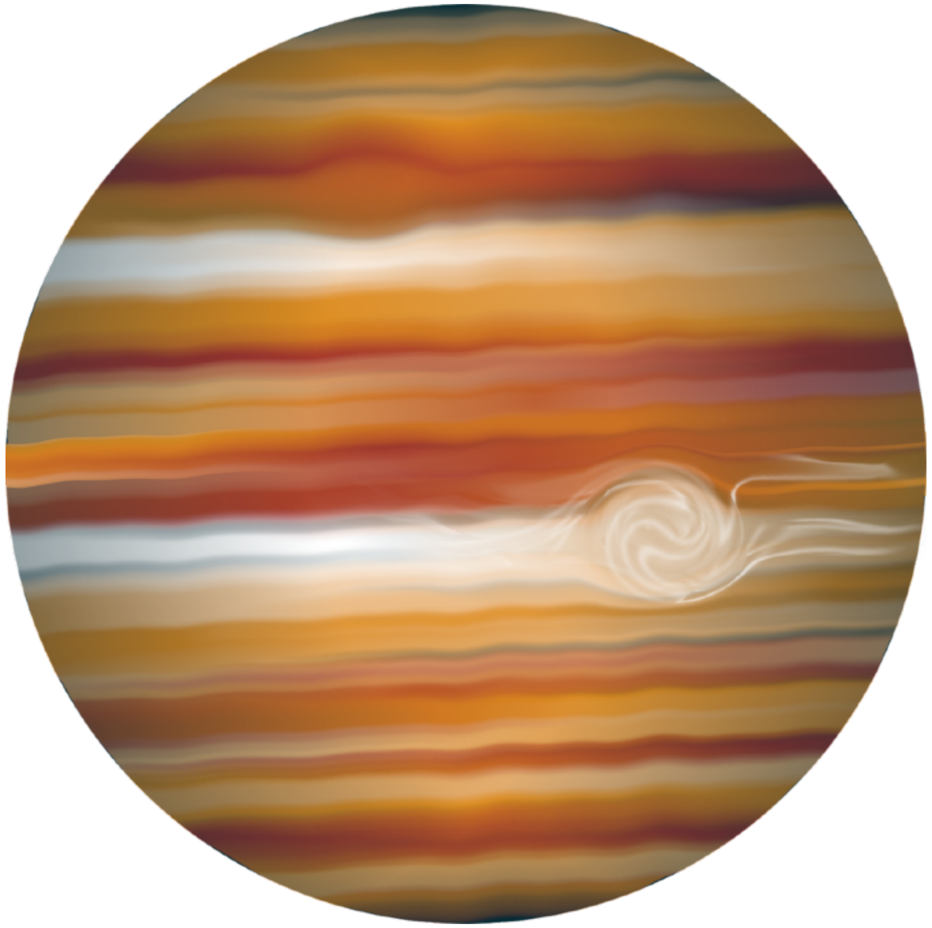
MOTIVATION WHY STUDY JUPITER?

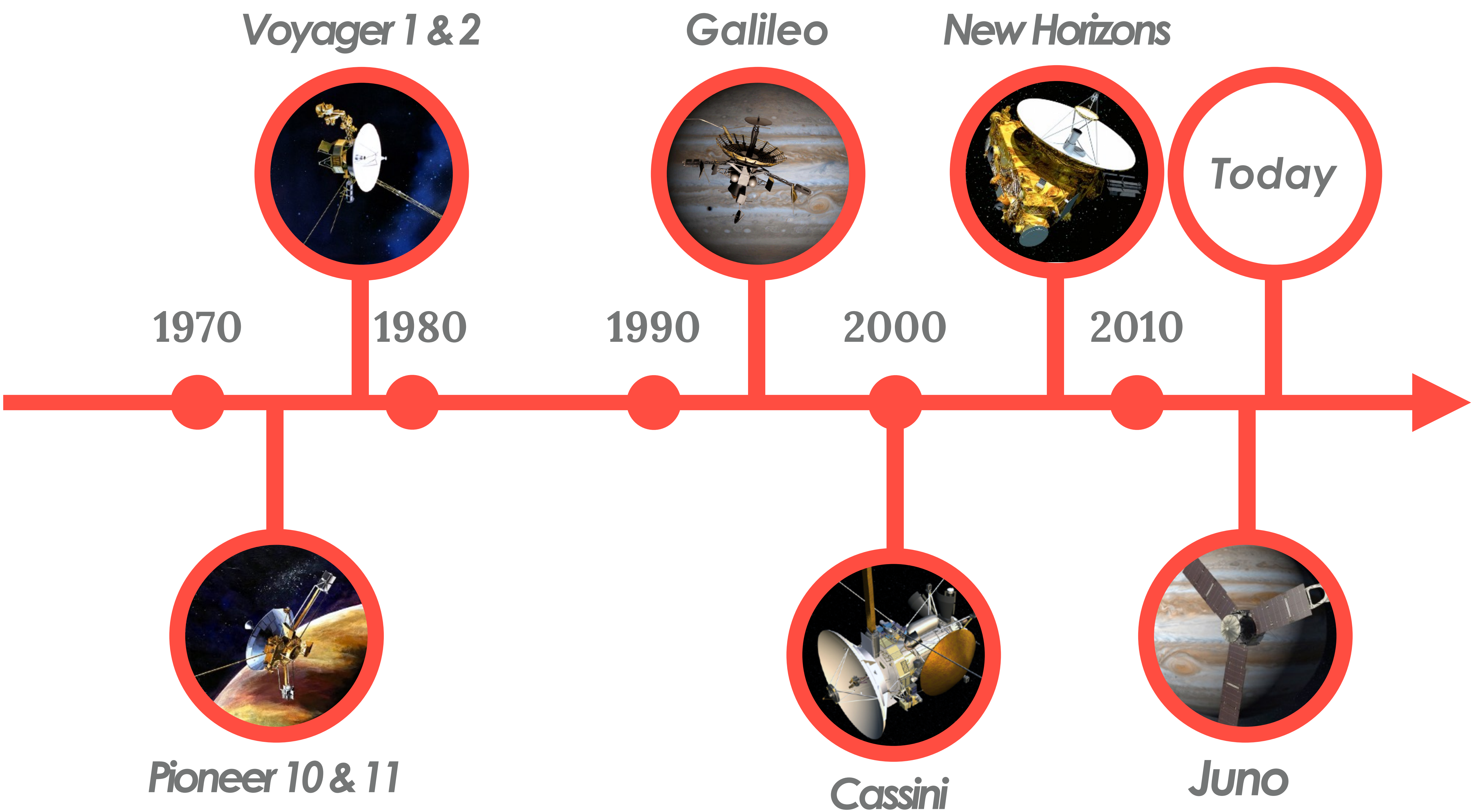
- Jupiter is the biggest giant in the Solar System
- It highly influenced the history of our Solar System

Understanding Jupiter we will know more about the history of our own Solar System



- What is it made of?
- Does it have a core?

Other missions: Pre - Juno results



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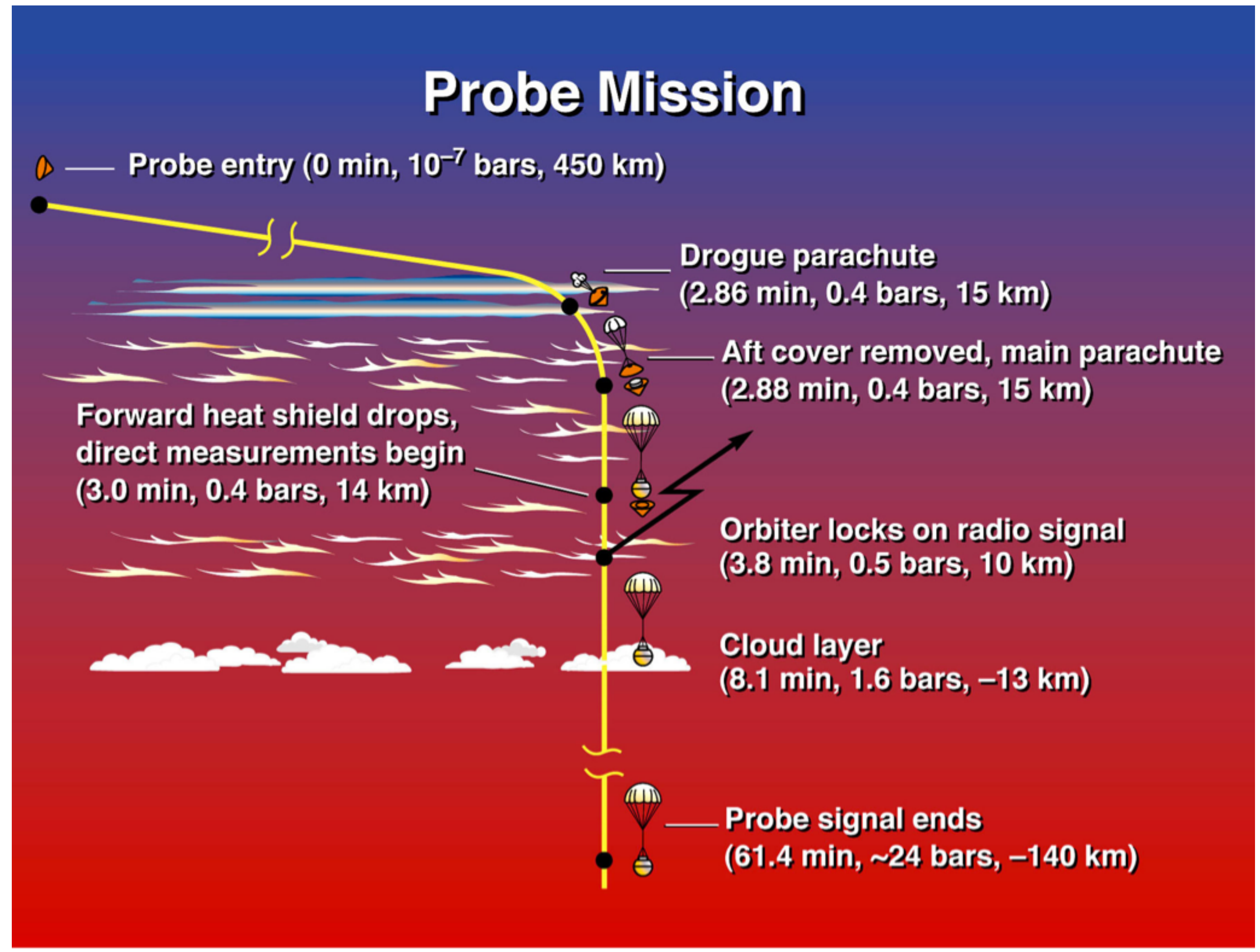
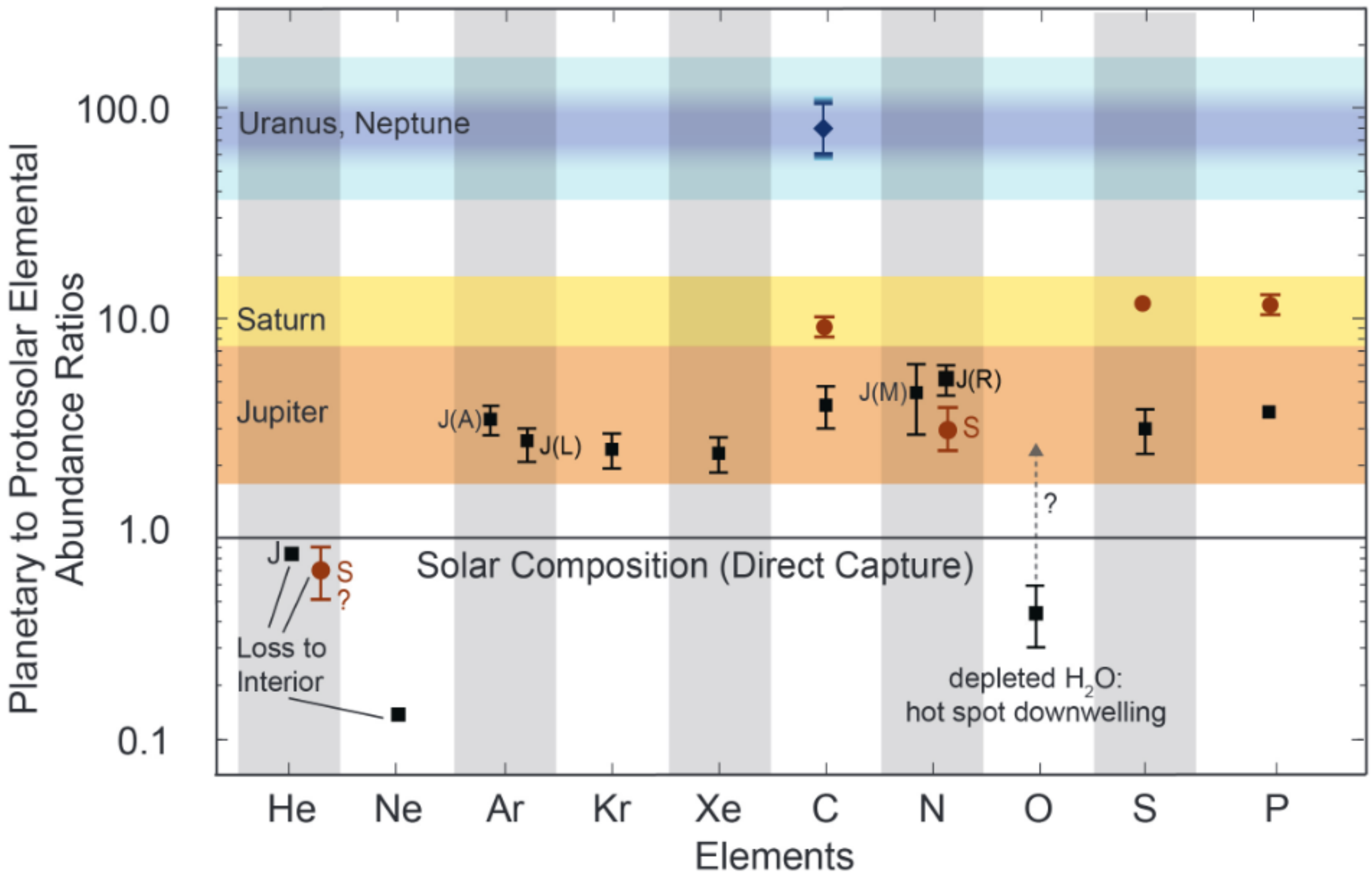
What do we know?: atmosphere



Atreya+2016

What do we know?: atmosphere

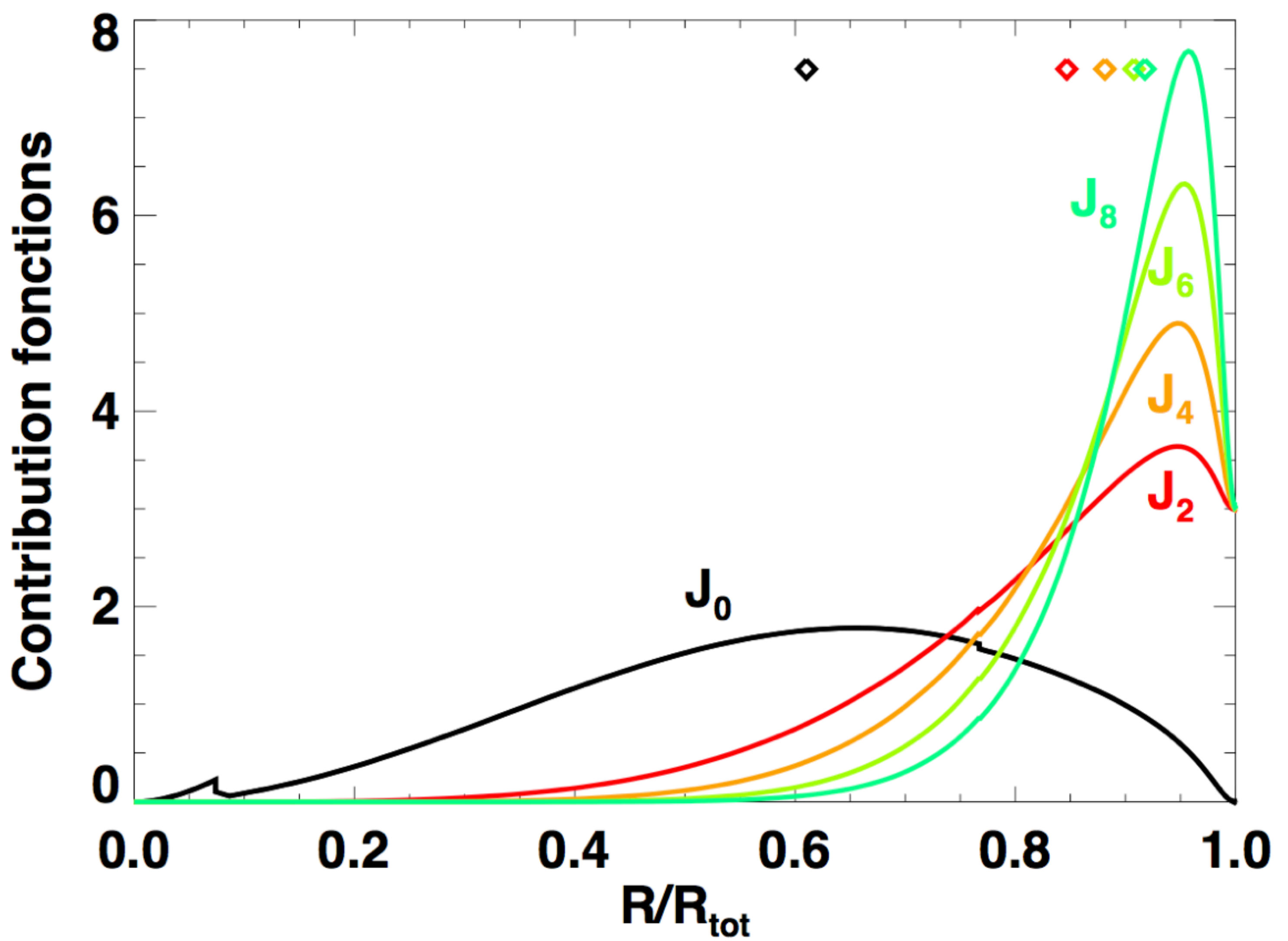


Atreya+2016

What do we know?: Js

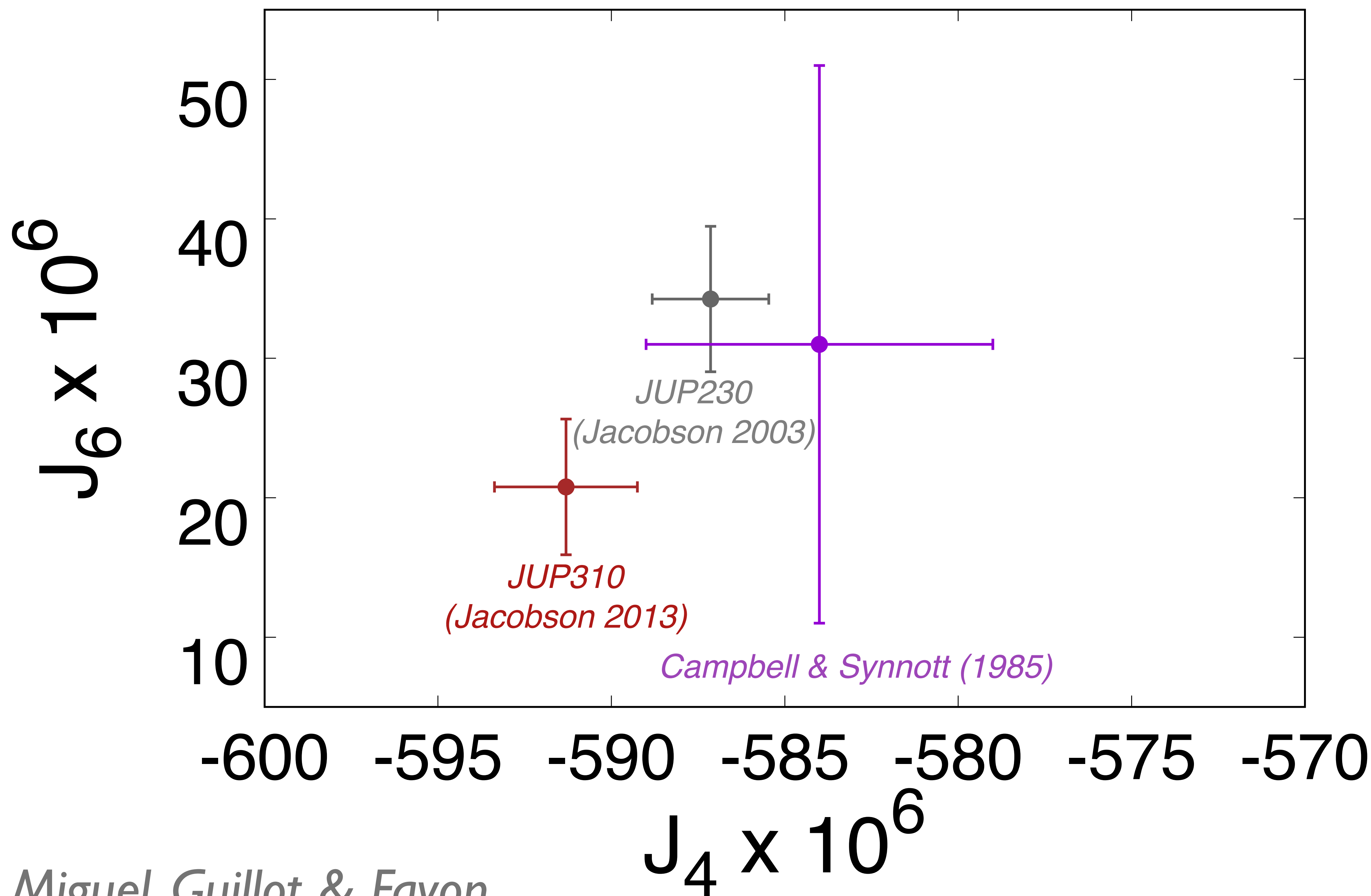
$$U(r,\theta) = \frac{GM}{r}\left\{1 - \sum_{i=1}^{\infty}\left(\frac{R_{\rm eq}}{r}\right)^{2i} J_{2i}P_{2i}(\cos\theta)\right\}$$

$$J_{2i} = -\frac{1}{MR_{\rm eq}^{2i}}\int \rho(r) r^{2i} P_{2i}(\cos\theta) d\tau$$



Guillot & Gautier 2014

What do we know?: Js



Miguel, Guillot & Fayon (A&A 2016)

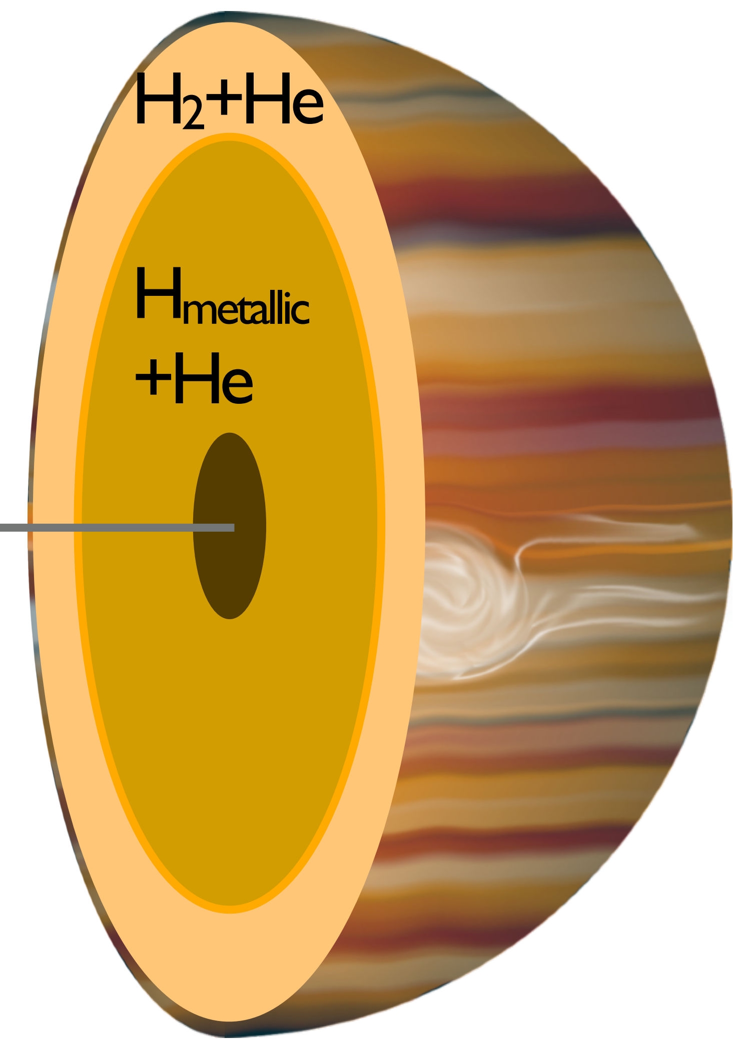
What do we know about Jupiter?

Jupiter's interior Juno!

$M_{core} = 0 - 17\ M_{Earth}$

M_z up to 40 M_{Earth}

(Saumon & Guillot 2004,
Nettelmann + 2008, 2012, Helled & Guillot 2013,
Hubbard & Militzer, 2016, Miguel + 2016)



R, M, J_2, J_4, J_6, Y, ...

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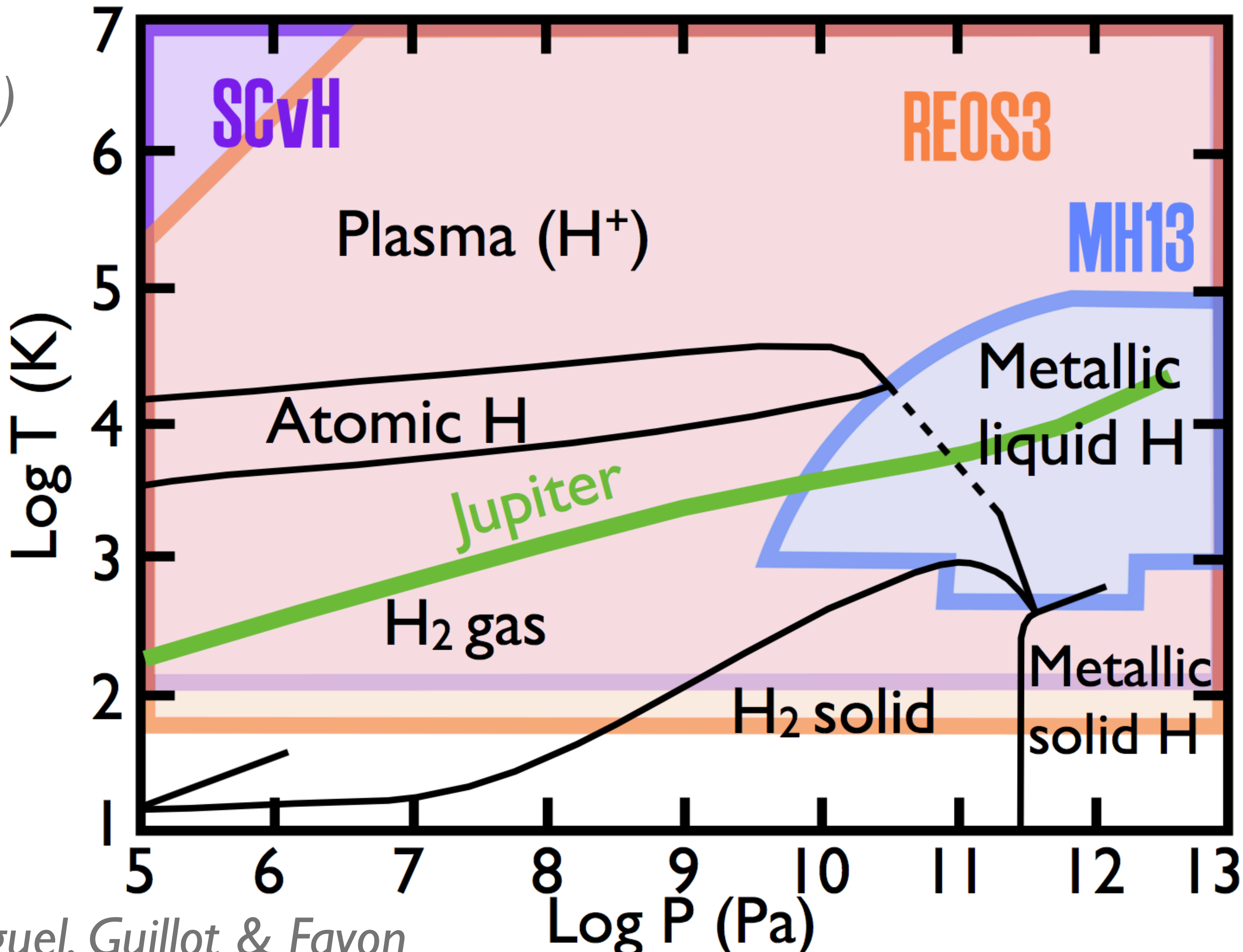
MODELING JUPITER'S INTERIOR: EOS

Saumon + (1995)



Becker+ (A&A 2014)

Militzer & Hubbard (ApJ 2013)

Miguel, Guillot & Fayon (A&A 2016)

Modeling Jupiter's interior

CEPAM (Guillot & Morel 1995)

$$\frac{\partial P}{\partial r} = -\rho g,$$

$$\frac{\partial T}{\partial r} = \frac{\partial P}{\partial r}\frac{T}{P}\nabla_T,$$

$$\frac{\partial m}{\partial r} = 4\pi r^2 \rho,$$

$$\frac{\partial L}{\partial r} = 4\pi r^2 \rho\left(\dot{\epsilon} - T\frac{\partial S}{\partial t}\right),$$

MODELING JUPITER'S INTERIOR: OPTIMISATIONS

Initial parameters: Mcore, Yatm, Zatm, Ydeep, Zdeep…

↓ *CEPAM (Guillot & Morel 1995)*

Radius, J2, J4

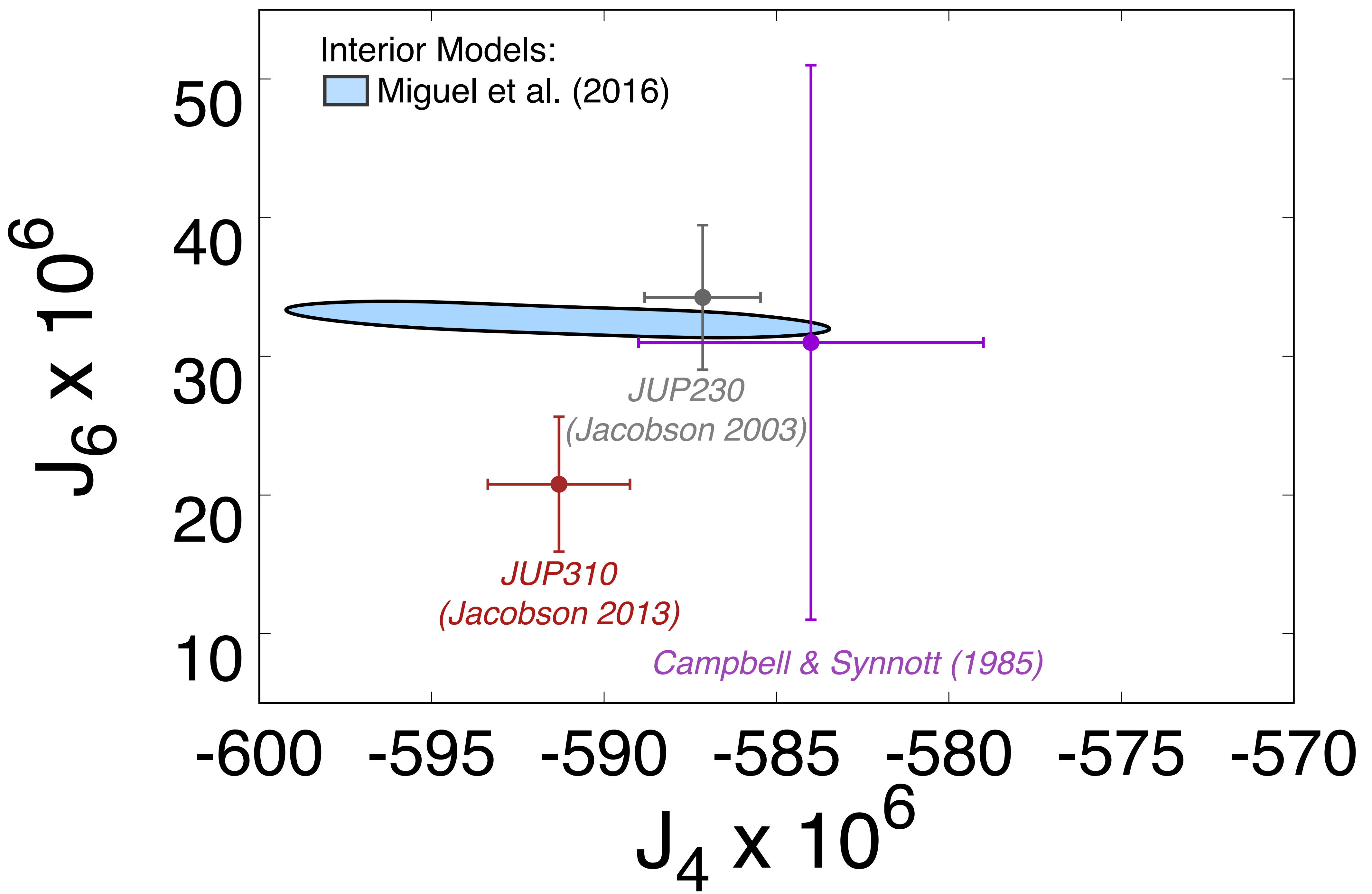
↓

$$f = \left(\frac{R_{cepam} - R_{obs}}{\sigma(R)}\right)^2 + \left(\frac{J2_{cepam} - J2_{Juno}}{\sigma(J2)}\right)^2 + \left(\frac{J4_{cepam} - J4_{obs}}{\sigma(J4)}\right)^2$$

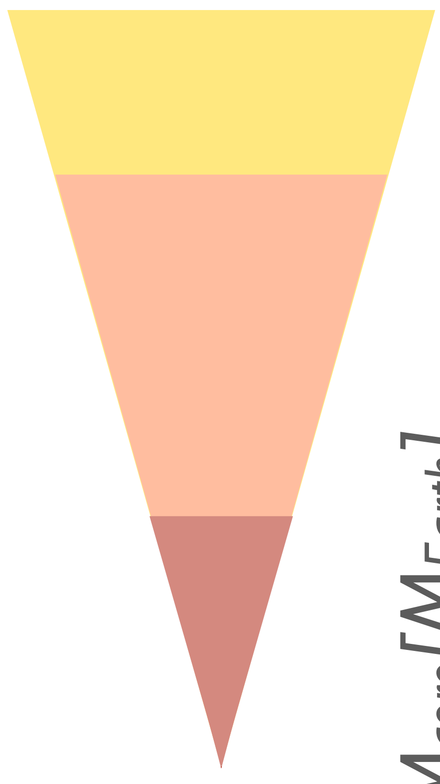
↓

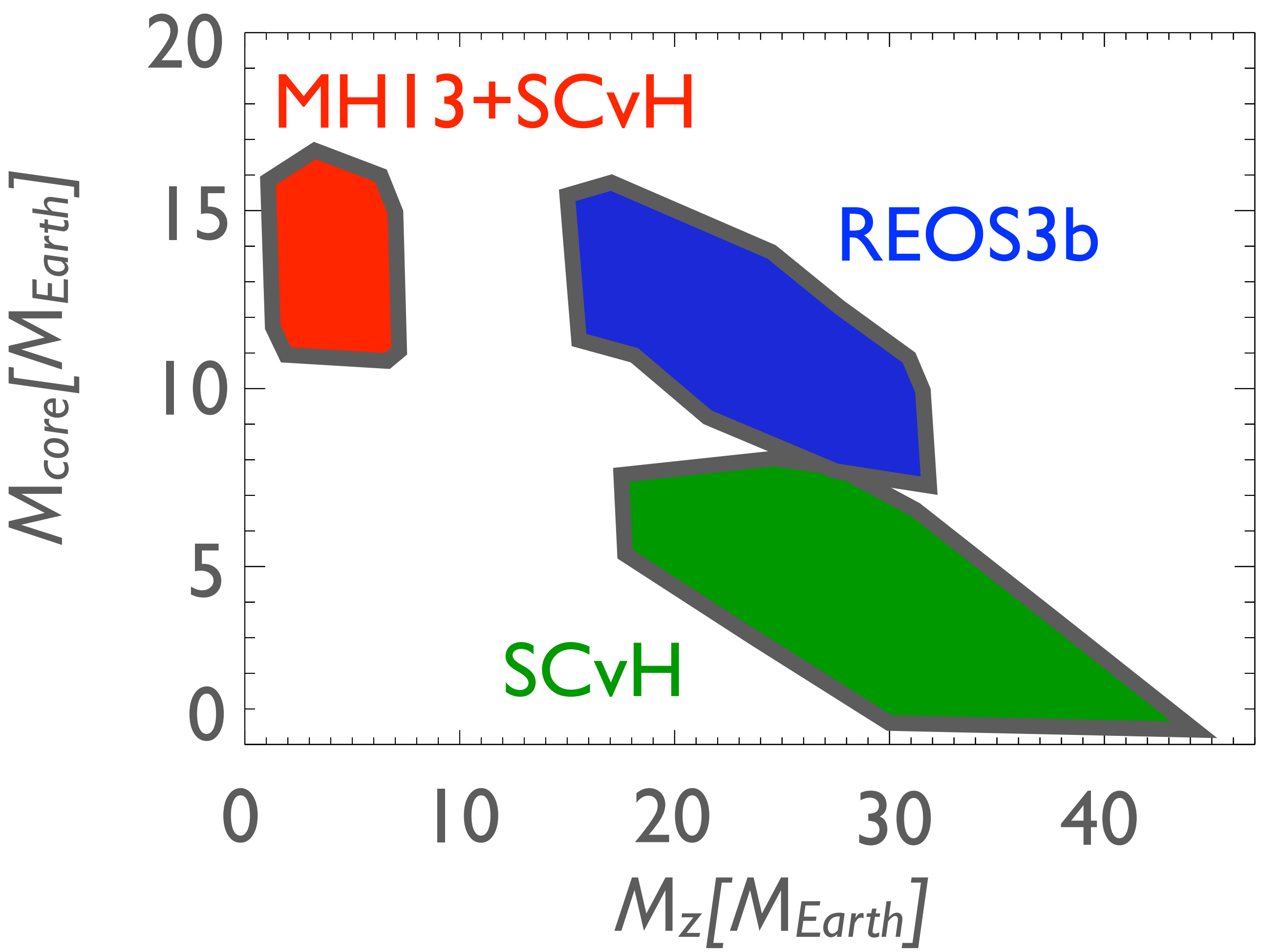
We find a solution!

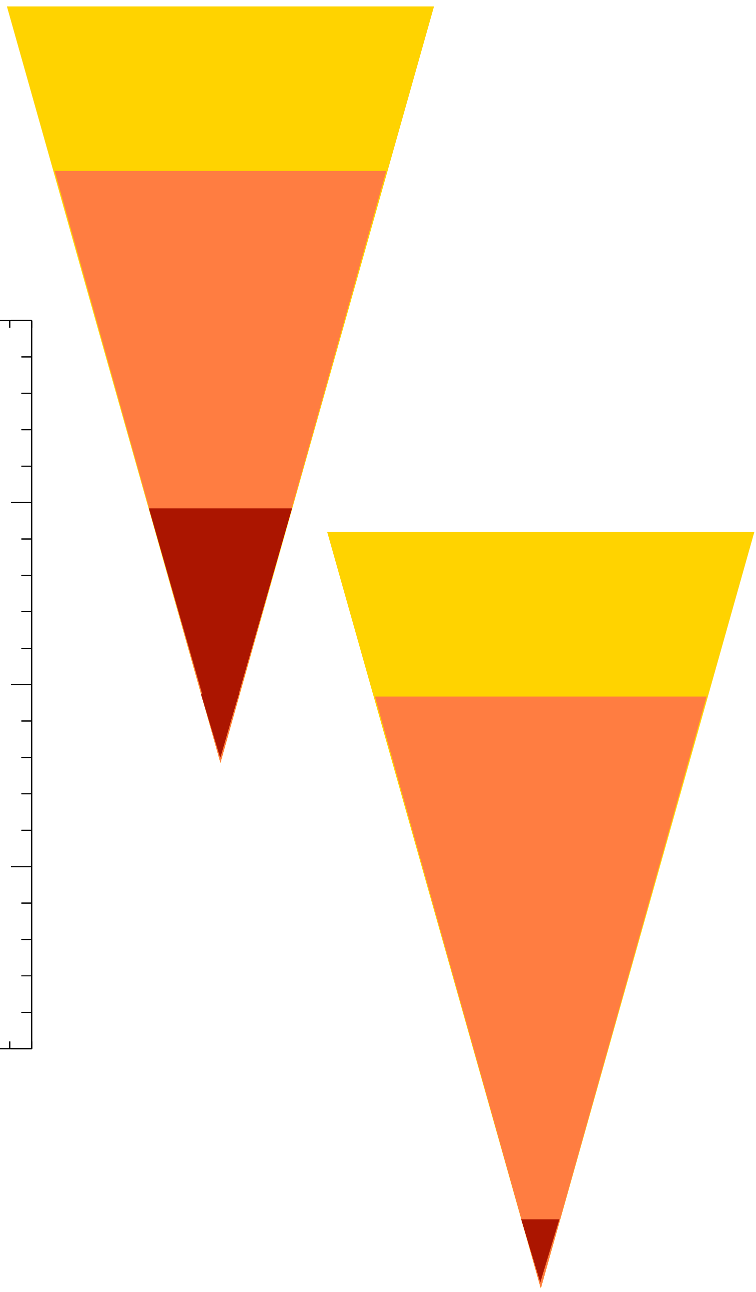
Jupiter's interior : pre - Juno results



JUPITER'S INTERIOR : DIFFERENT EOS







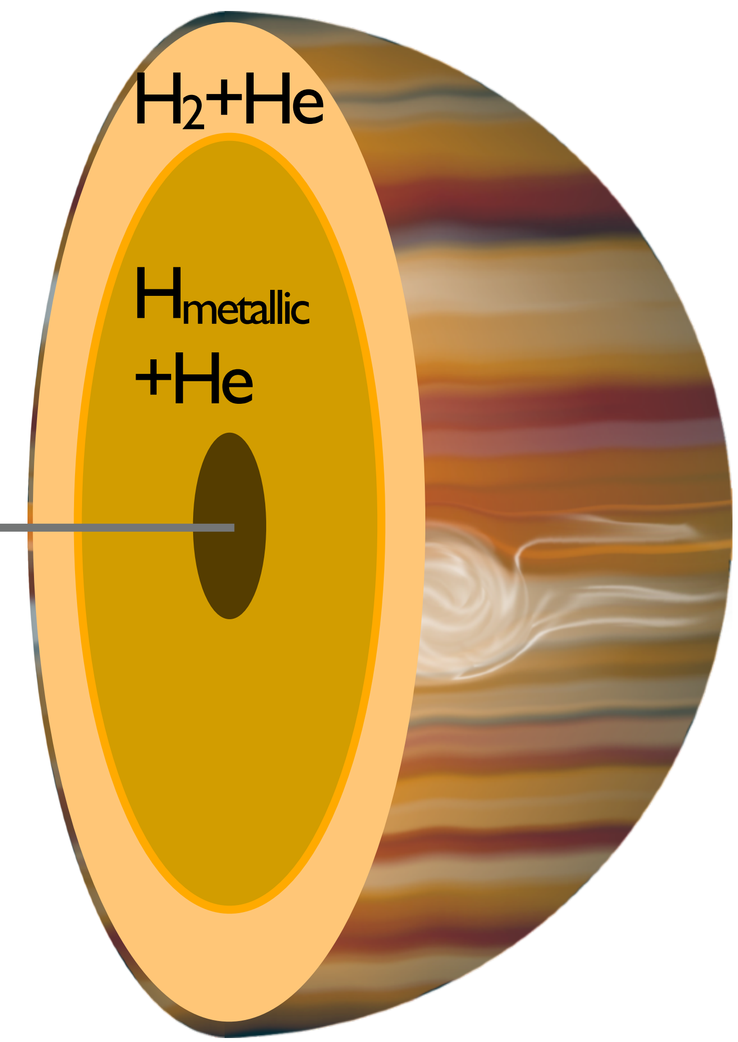
Miguel, Guillot & Fayon (A&A 2016)

Jupiter's interior : pre - Juno results

Recent EOS lead to large core masses

M_{core} = 7- 17 M_{Earth}

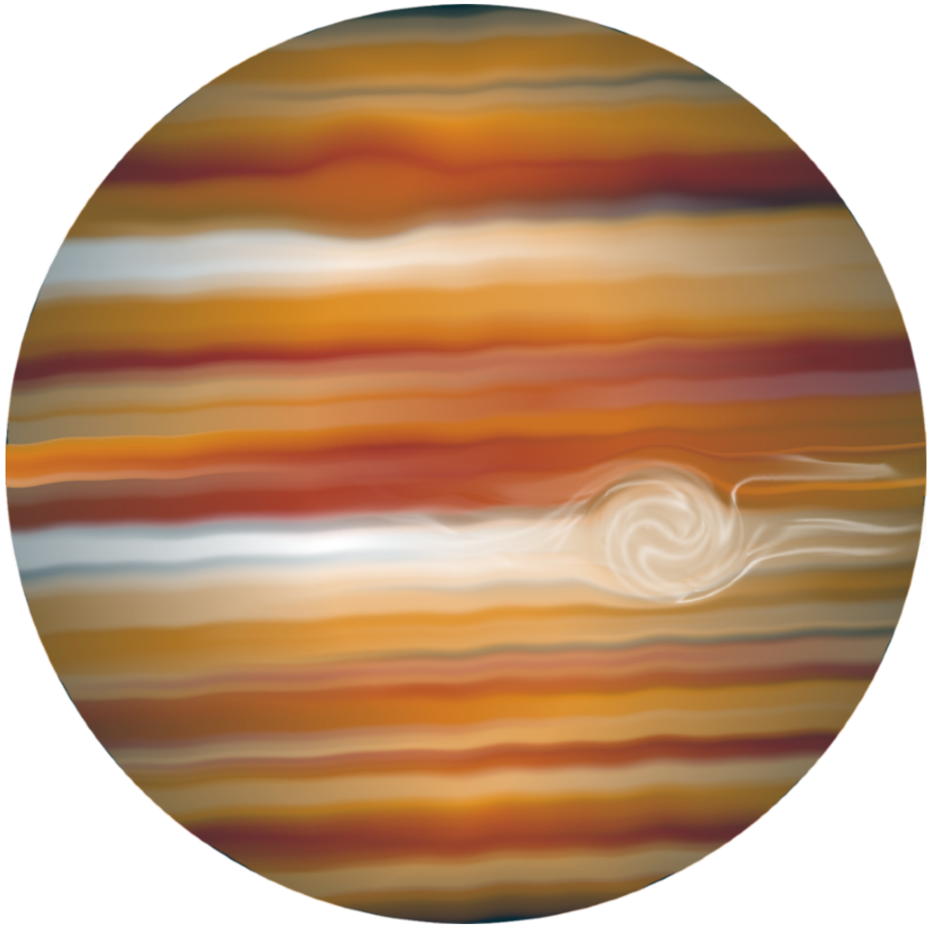
M_Z up to 33 M_{Earth}



R, M, J_2, J_4, J_6, Y, ...

Miguel, Guillot & Fayon (A&A 2016)

Jupiter interior: First Juno results



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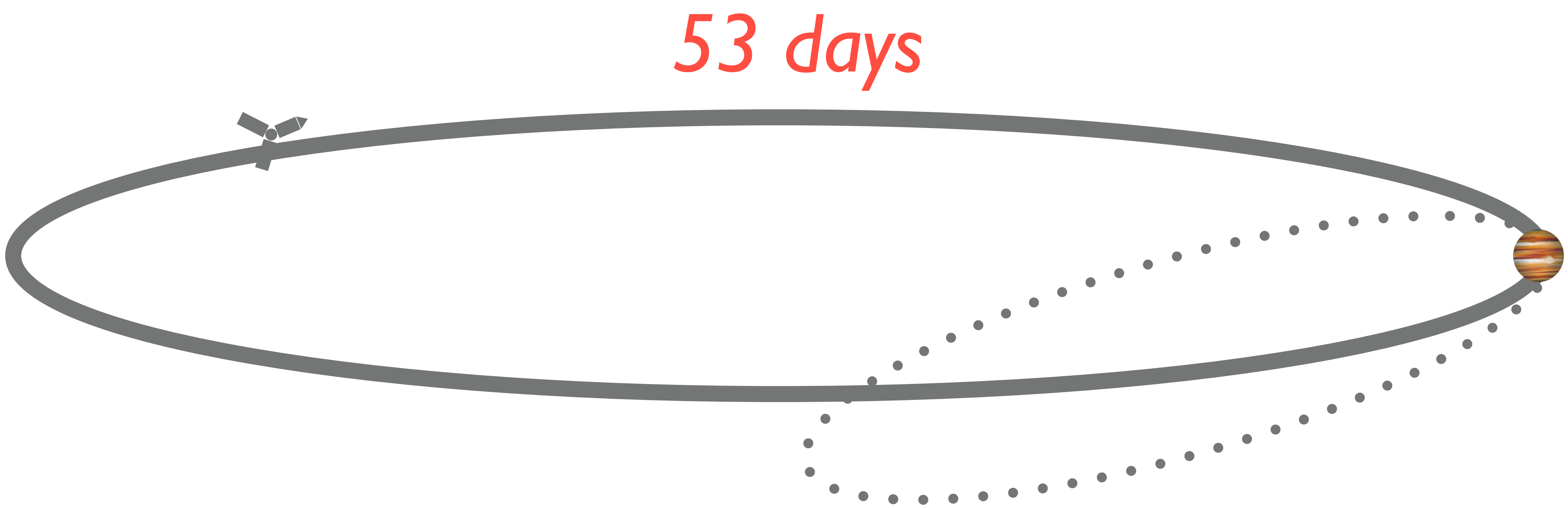
Juno Mission : Orbit



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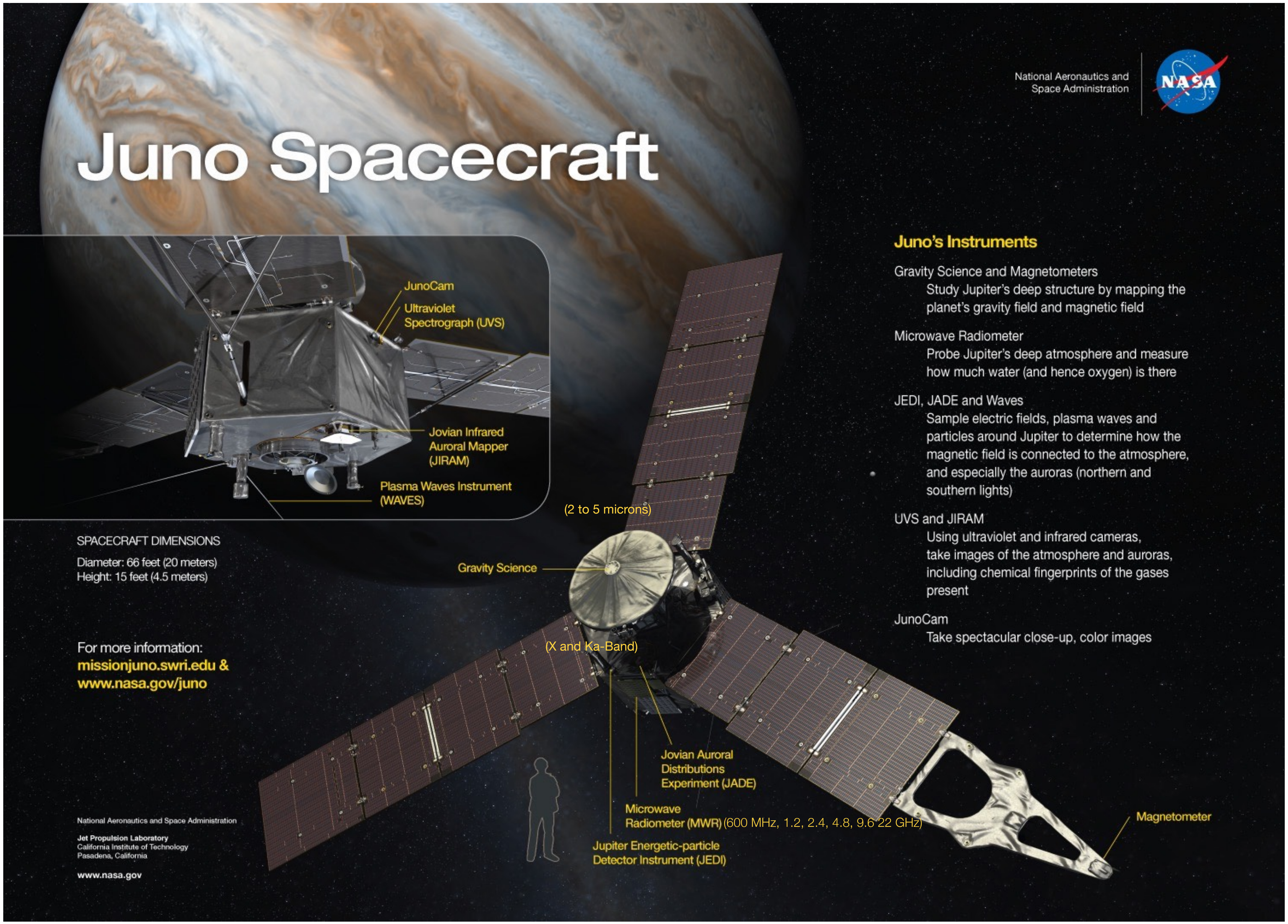
Juno Mission : Instruments



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Juno Mission : Orbit

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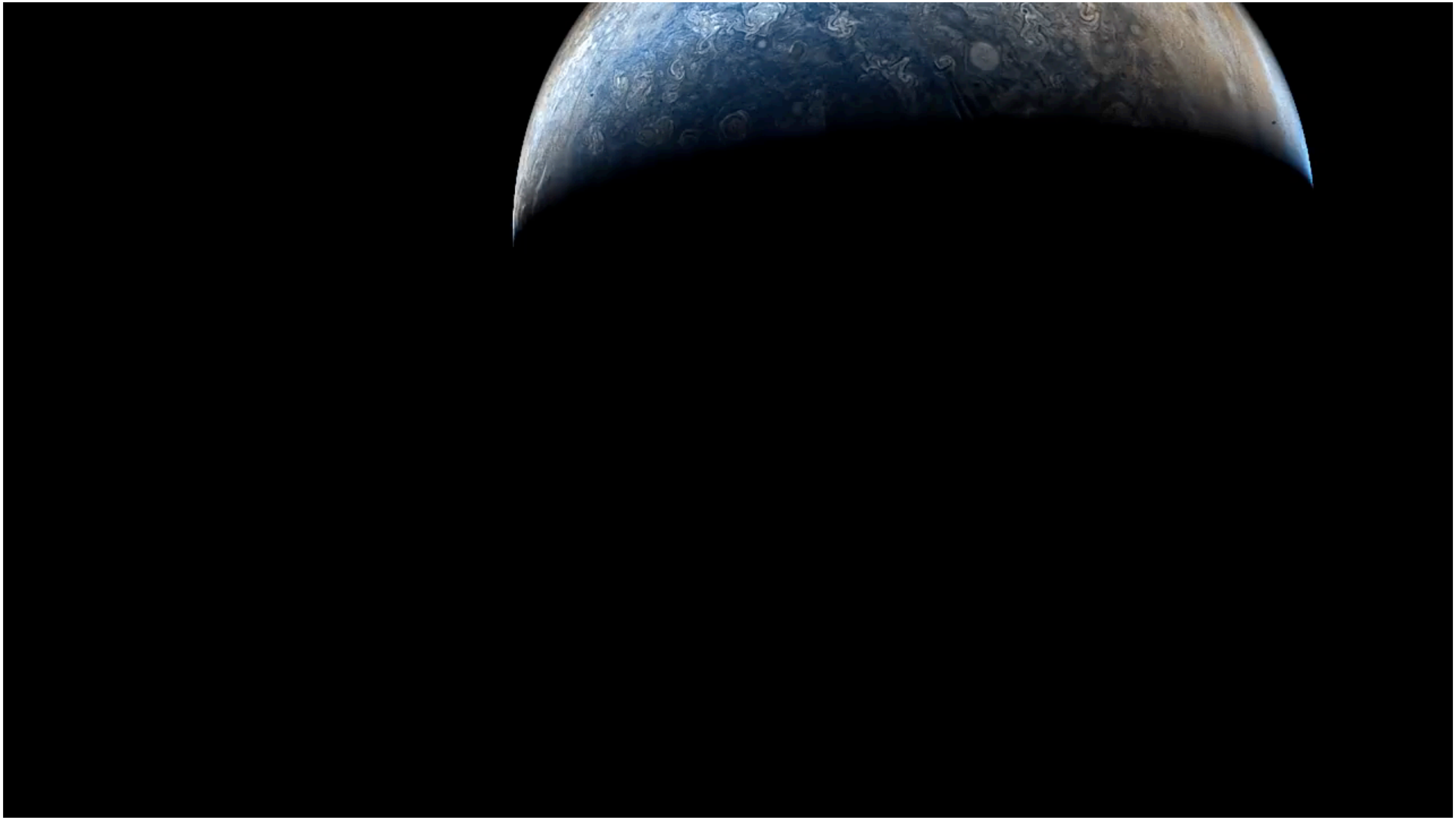
Juno Mission : Some photos



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Juno Mission : Some photos

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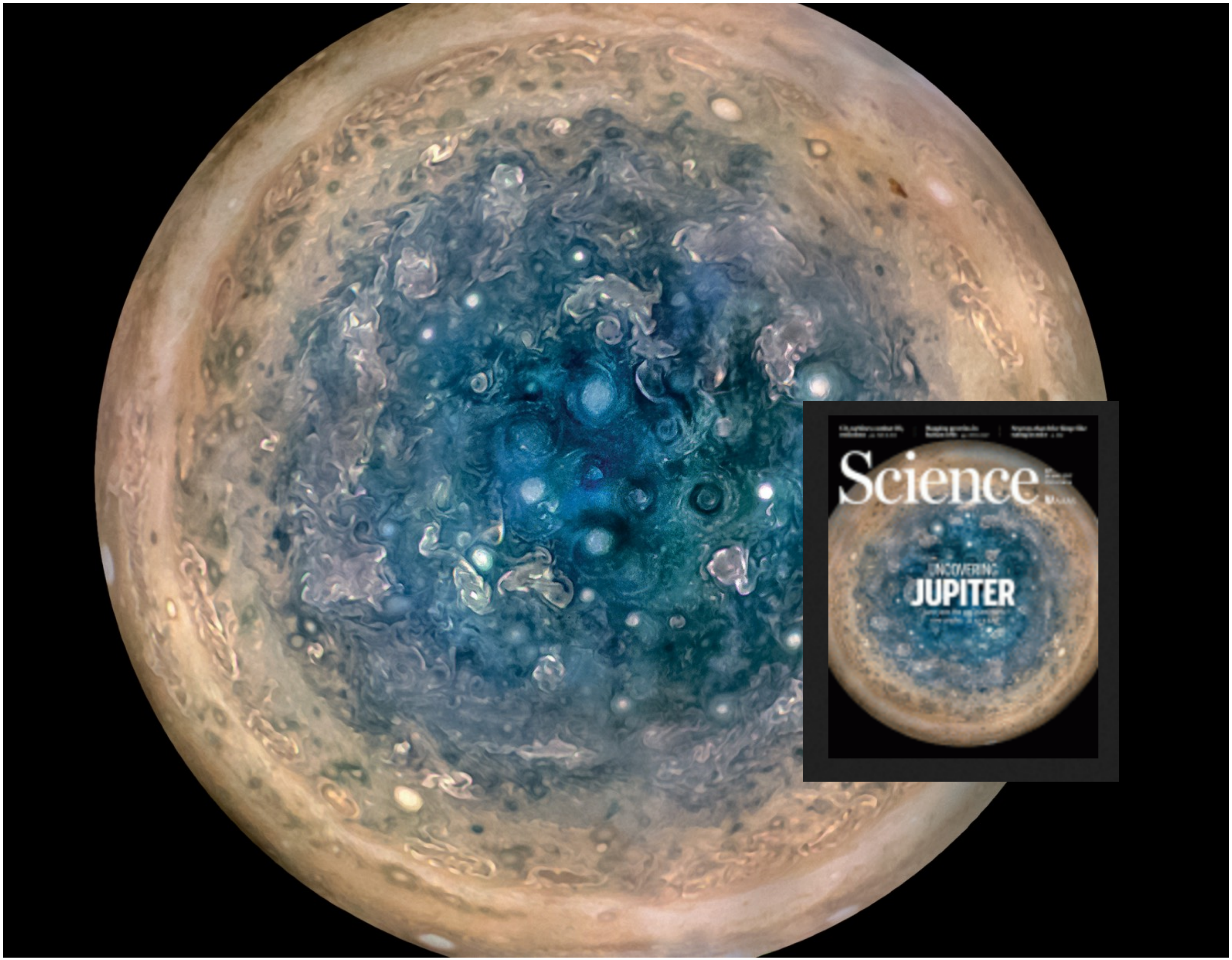
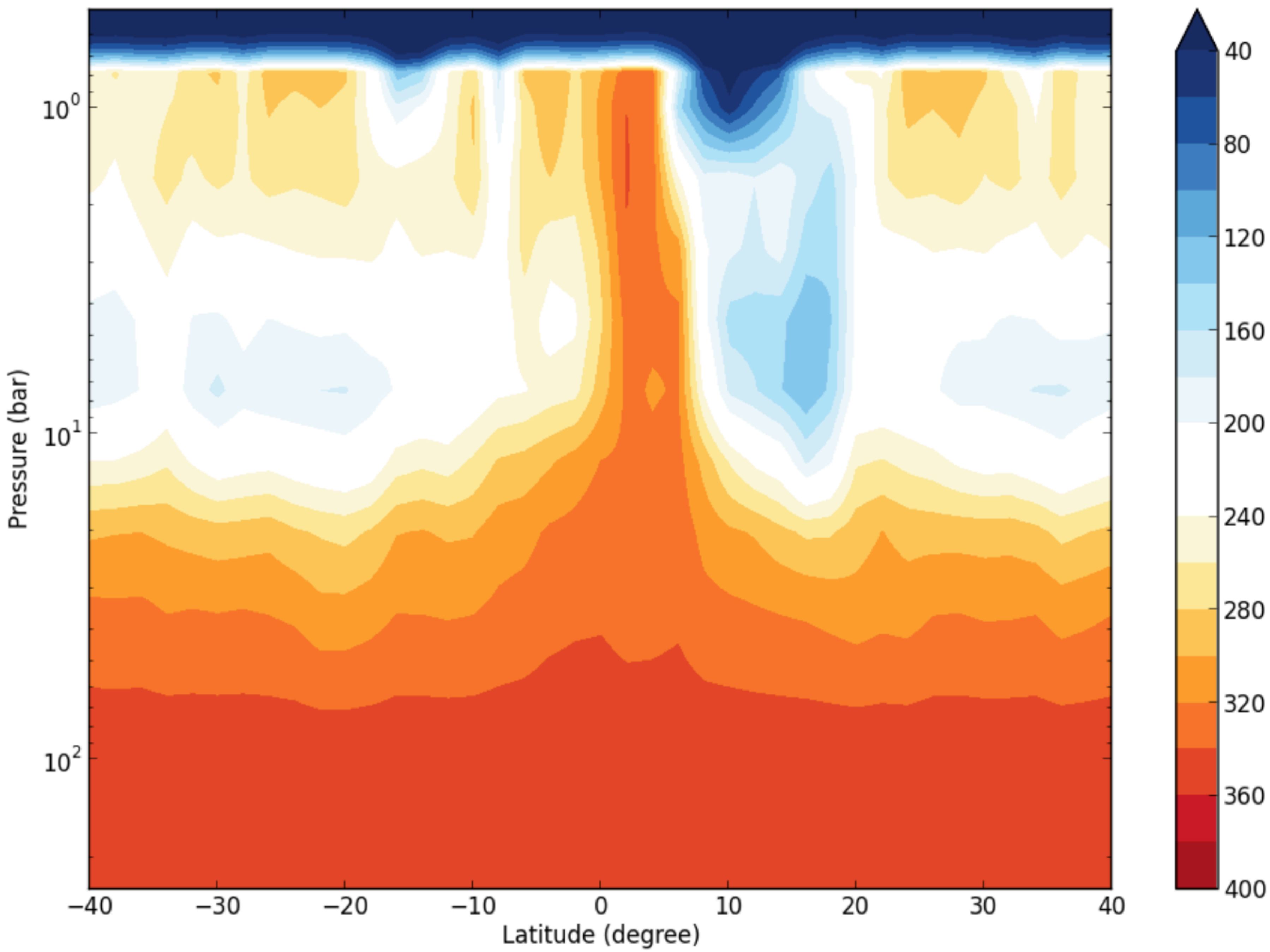
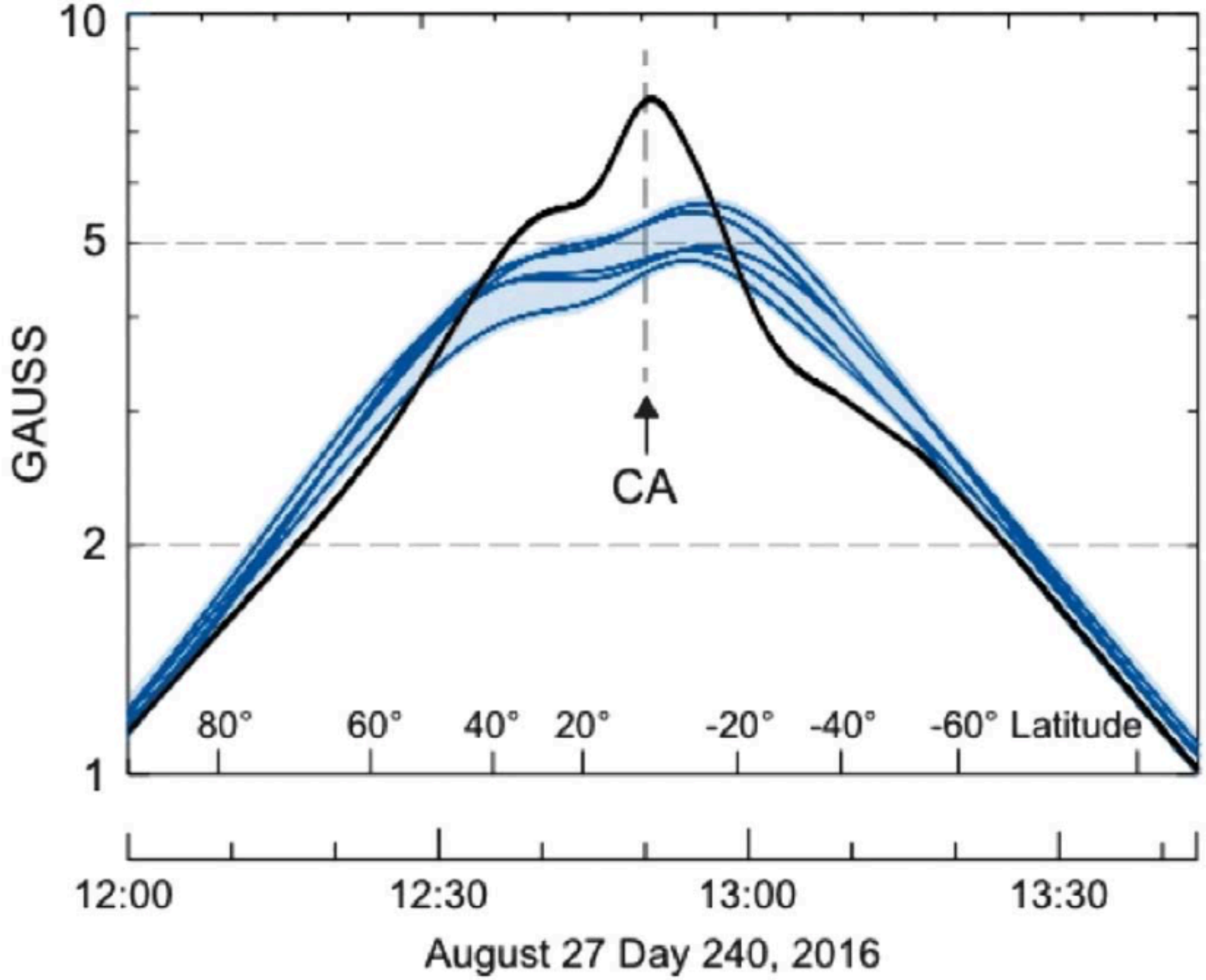


Juno Mission : First results



Bolton+(Science, 2017)

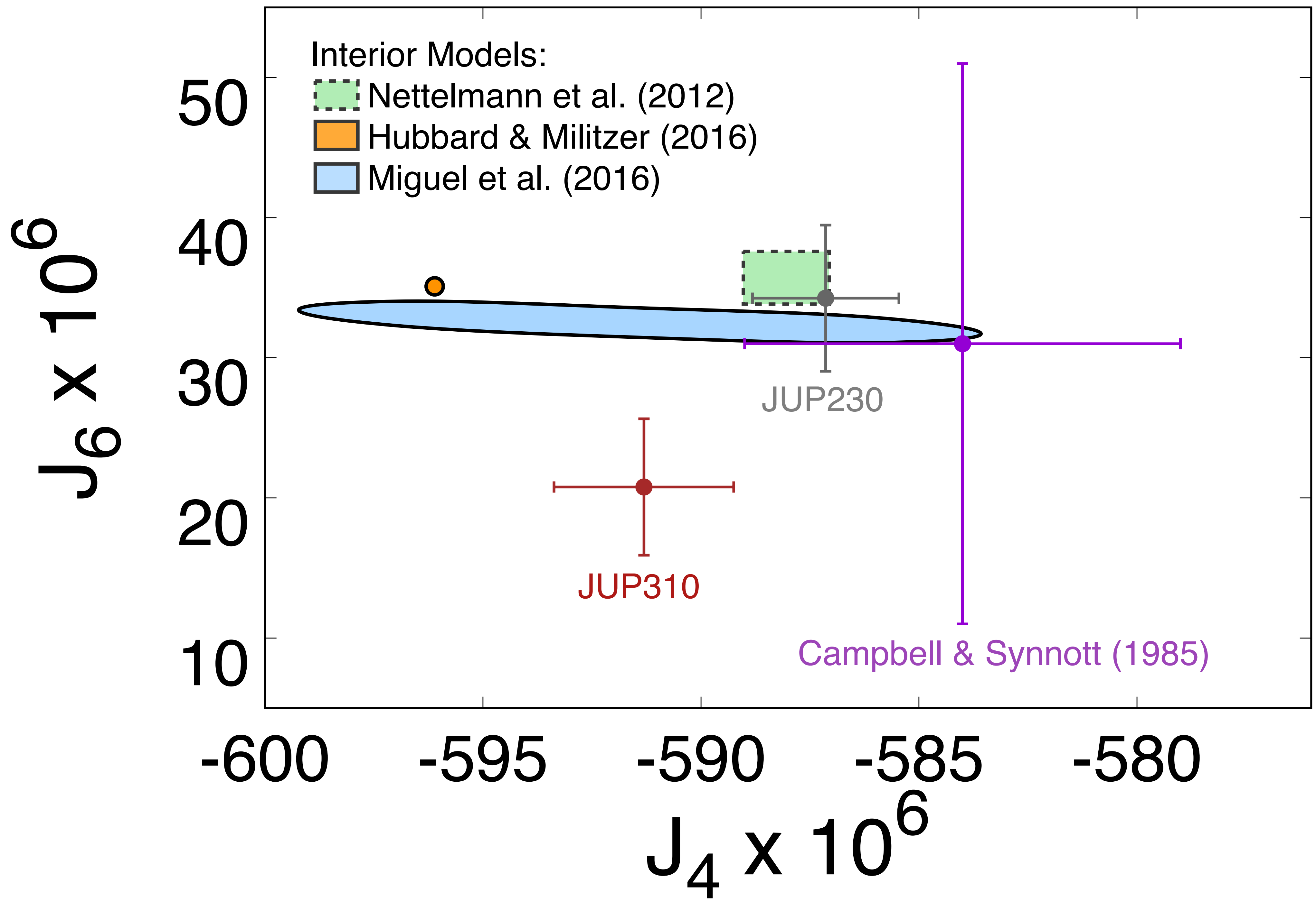
Juno Mission : First results



The maximum magnetic field observed was 7.766 G, more than an order of magnitude greater than Earth's.

Dynamo generation region not far beneath the surface.

Juno Mission : First results



Bolton+ (Science, in press 2017), Folkner + (GRL, in press 2017)

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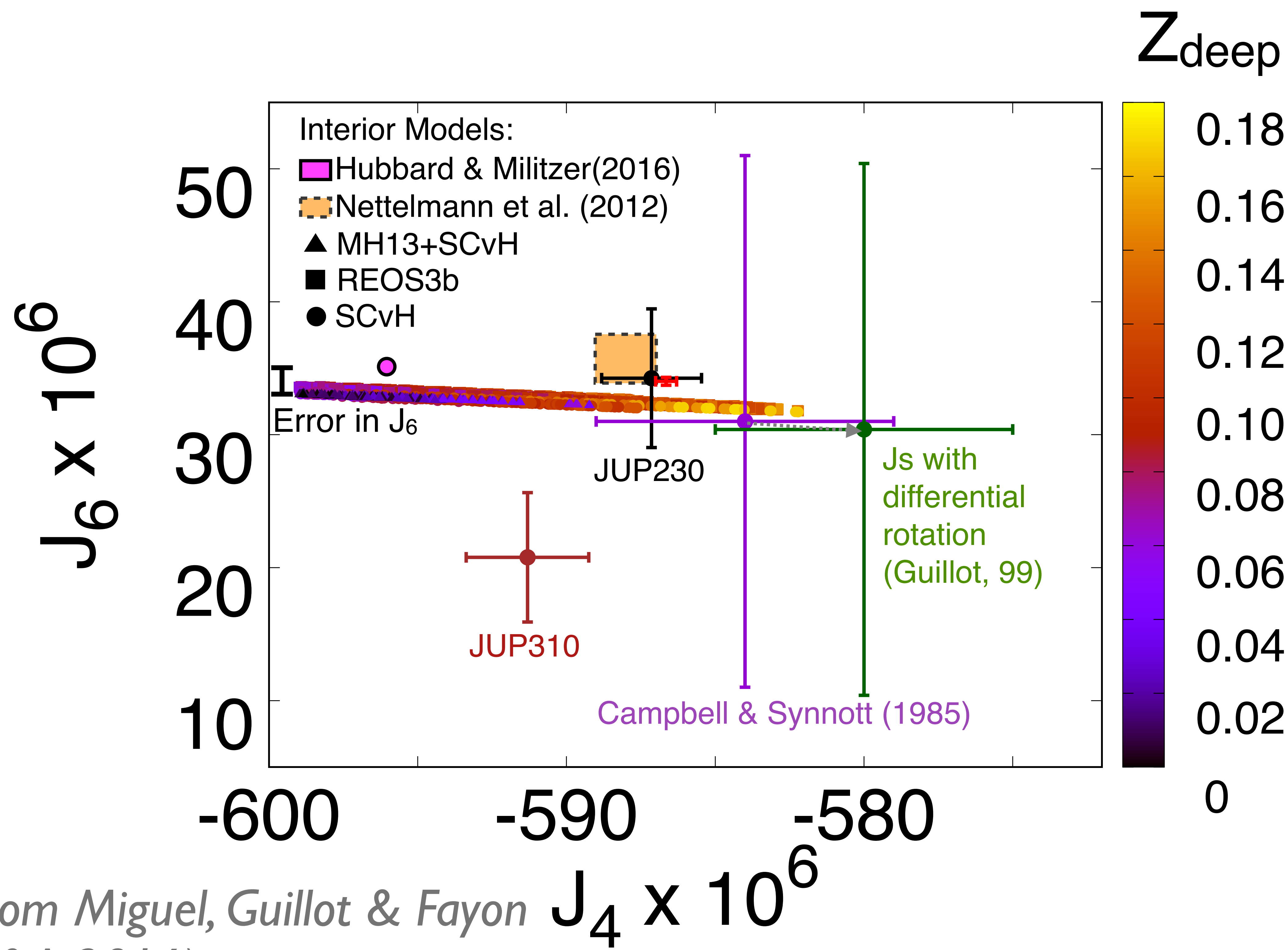
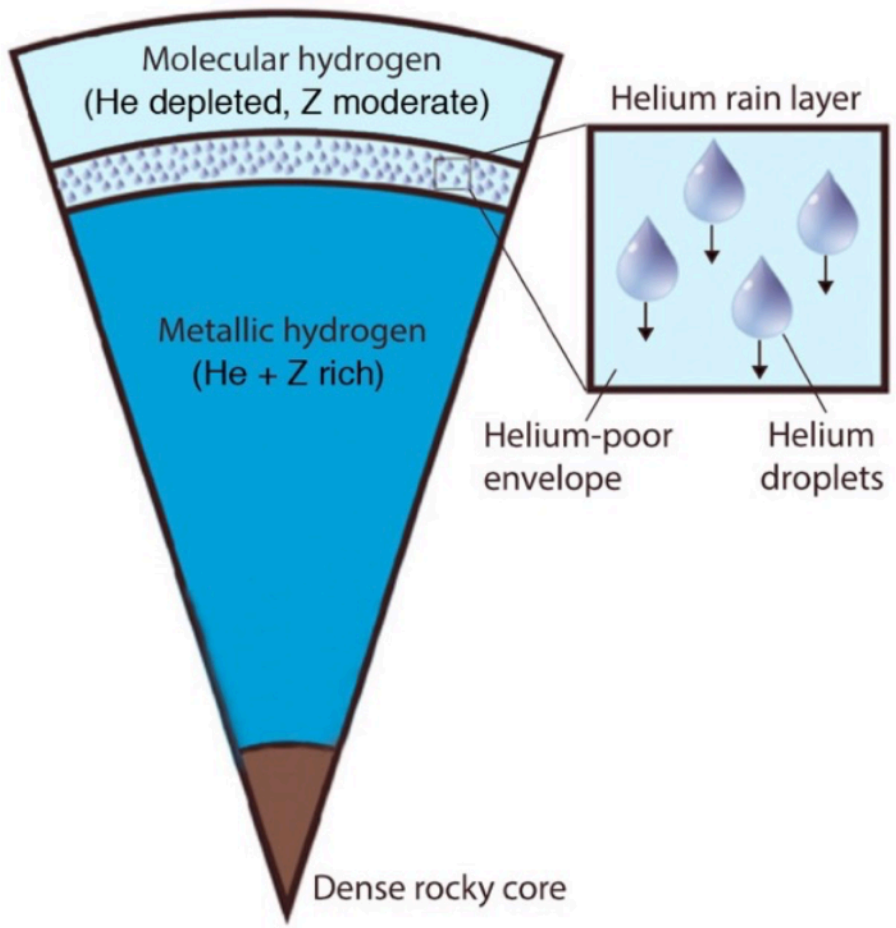
Juno Mission : First results



From Miguel, Guillot & Fayon (A&A 2016)

Juno Mission : First results

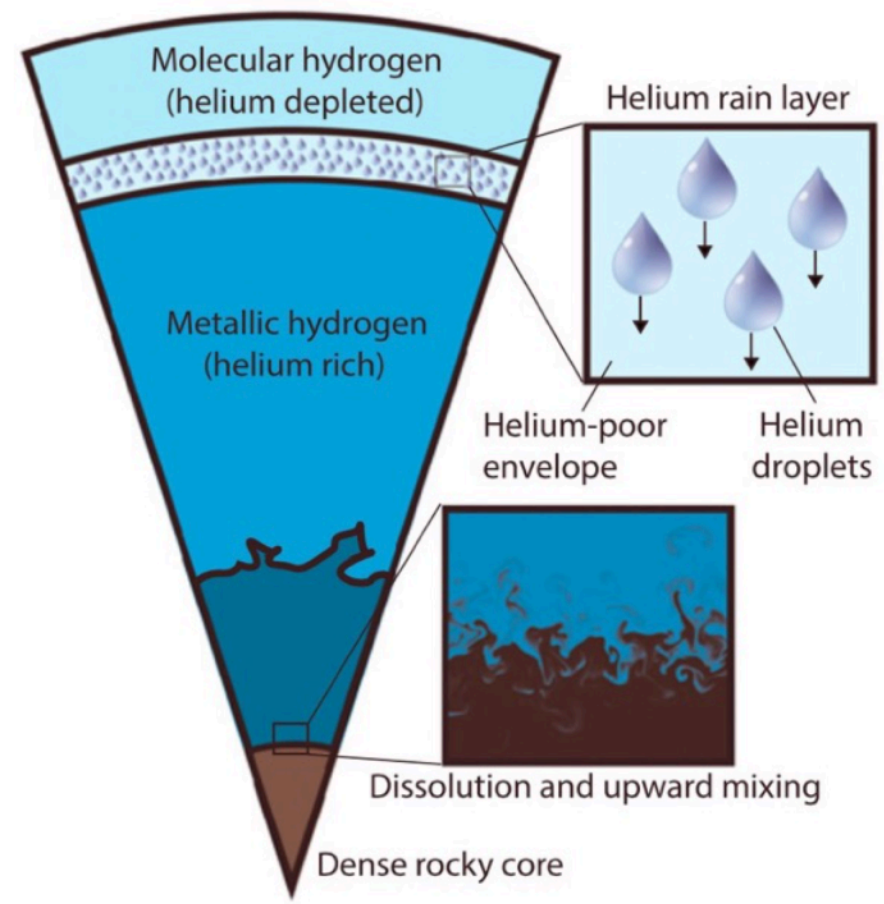
Standard



REOS3 ✓

MH13 ✗

Dilute core

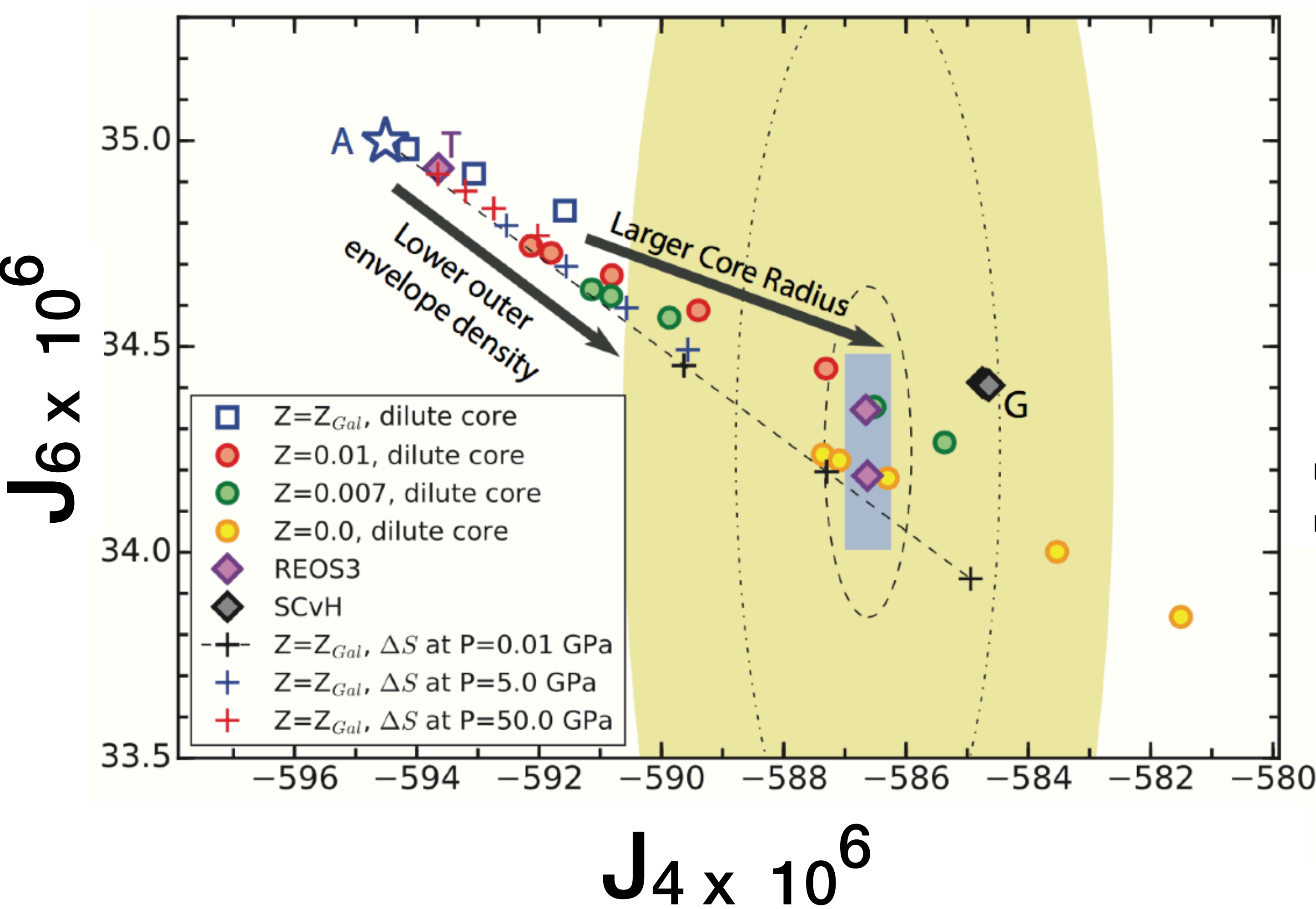


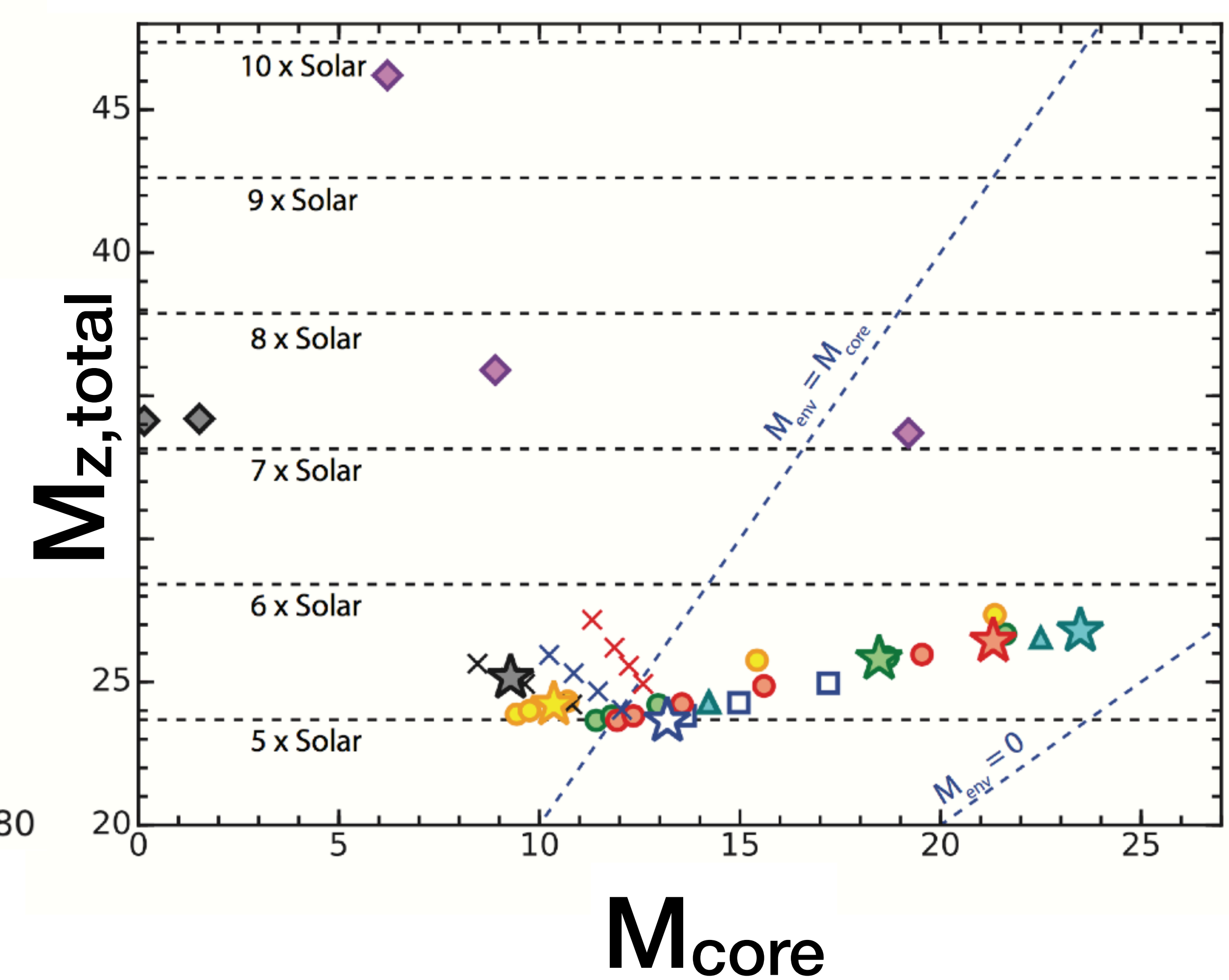
REOS3 ✓

MH13 ✓

Wahl + (GRL, 2017 in press)

Juno : Effect of a dilute core





Wahl + (GRL, 2017 in press)

Standing Questions

Models:

Knowledge of H-He EOS is crucial to determine giant planets interior structure.

Heavy elements EOS, mixtures of heavies with H and He?

Distribution of heavy elements in the interior and energy transport

Differential rotation

Observations & Experiments:

Water measurements in the deep atmosphere of Jupiter

Hugoniot experiments for better constrains on EOS

Take home message

Juno *first 2 passages greatly improved accuracy of Js*

New interior models have a higher concentration of heavies in the metallic region (independently of the EOS!) & larger cores!

This implies that mixing was not complete in Jupiter's envelope

$20 < M_{z,total} < 45\ M_{\oplus}$ - $6 < M_{core} < 25\ M_{\oplus}$

Some more questions:

A barrier at the He/H phase separation region?

Stable (conductive) zones inherited from the formation era?

Double-diffusive convection (with e.g. an eroding core)?

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