

*Séminaire Lagrange*  
*June 2017*

# JUPITER'S INTERNAL STRUCTURE AND THE FIRST JUNO RESULTS

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*Yamila Miguel*

*Tristan Guillot, Sean Wahl, William B. Hubbard, Burkhard Militzer, Yohai Kaspi, Naor Movshovitz, Daniel Reese, Ravit Helled, Eli Galanti, William Folkner, Luciano Iess, Daniele Durante, Marzia Parisi, David J. Stevenson, Steve Levin, Jack Connerney, Scott Bolton*

*CNES postdoctoral fellow*

# MOTIVATION WHY STUDY GIANT PLANETS?

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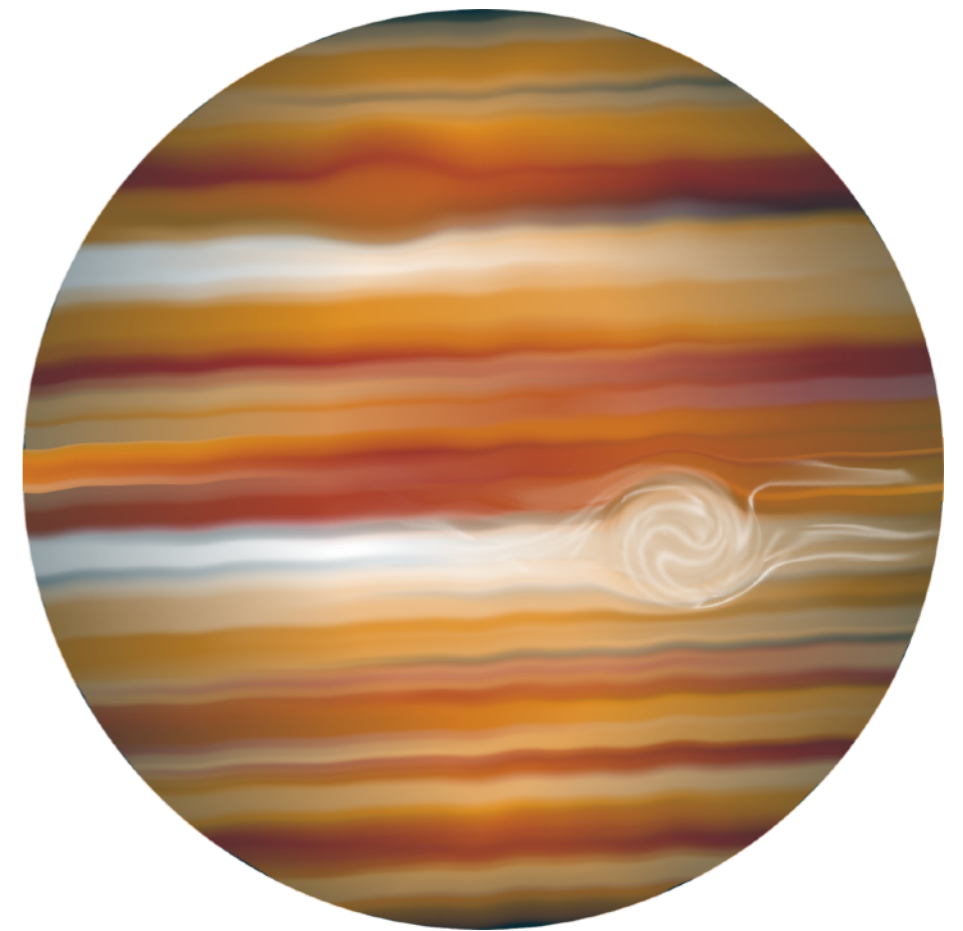


# MOTIVATION WHY STUDY JUPITER?

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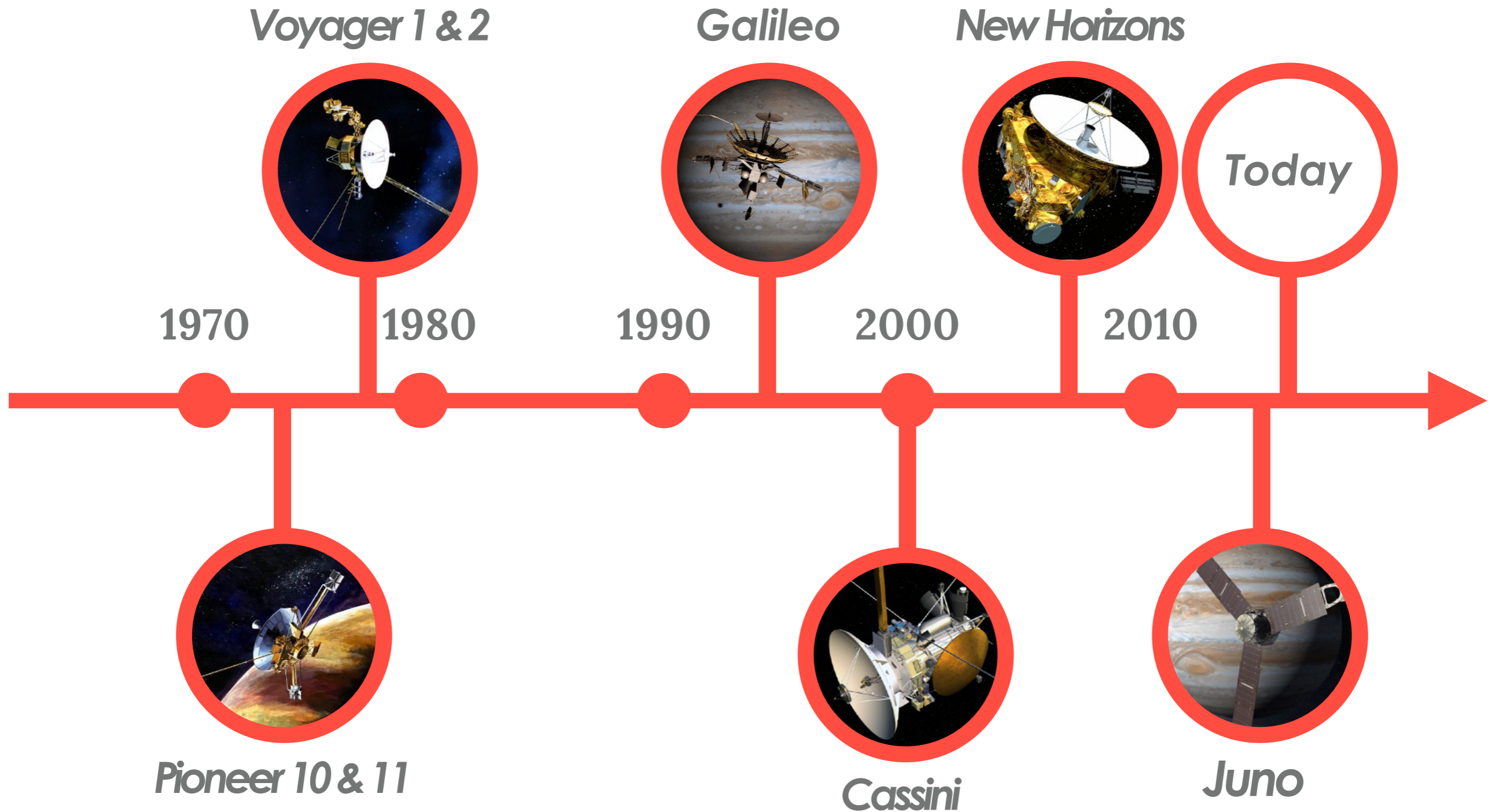
- Jupiter is the biggest giant in the Solar System
- It highly influenced the history of our Solar System

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

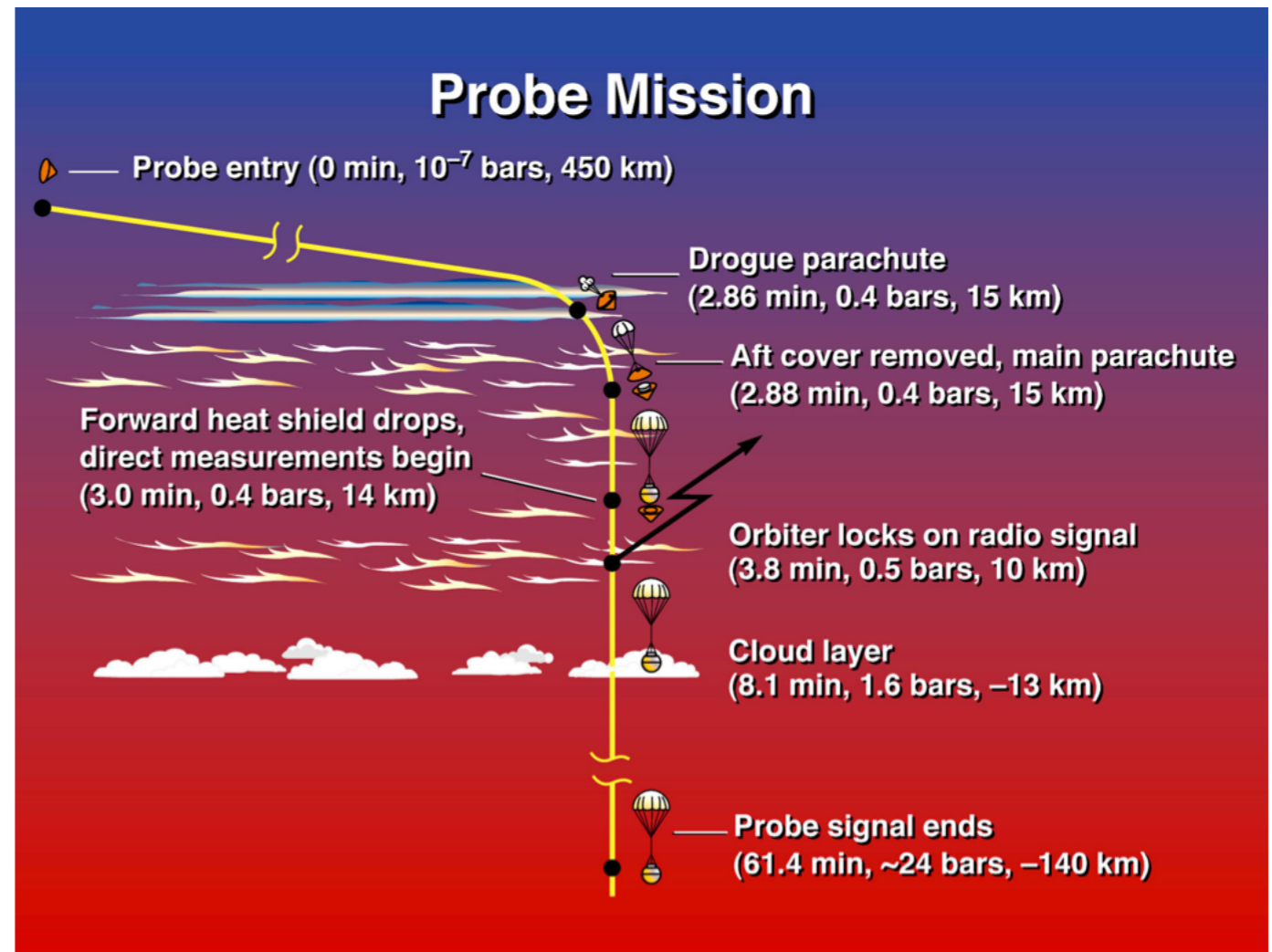


- What is it made of?
- Does it have a core?

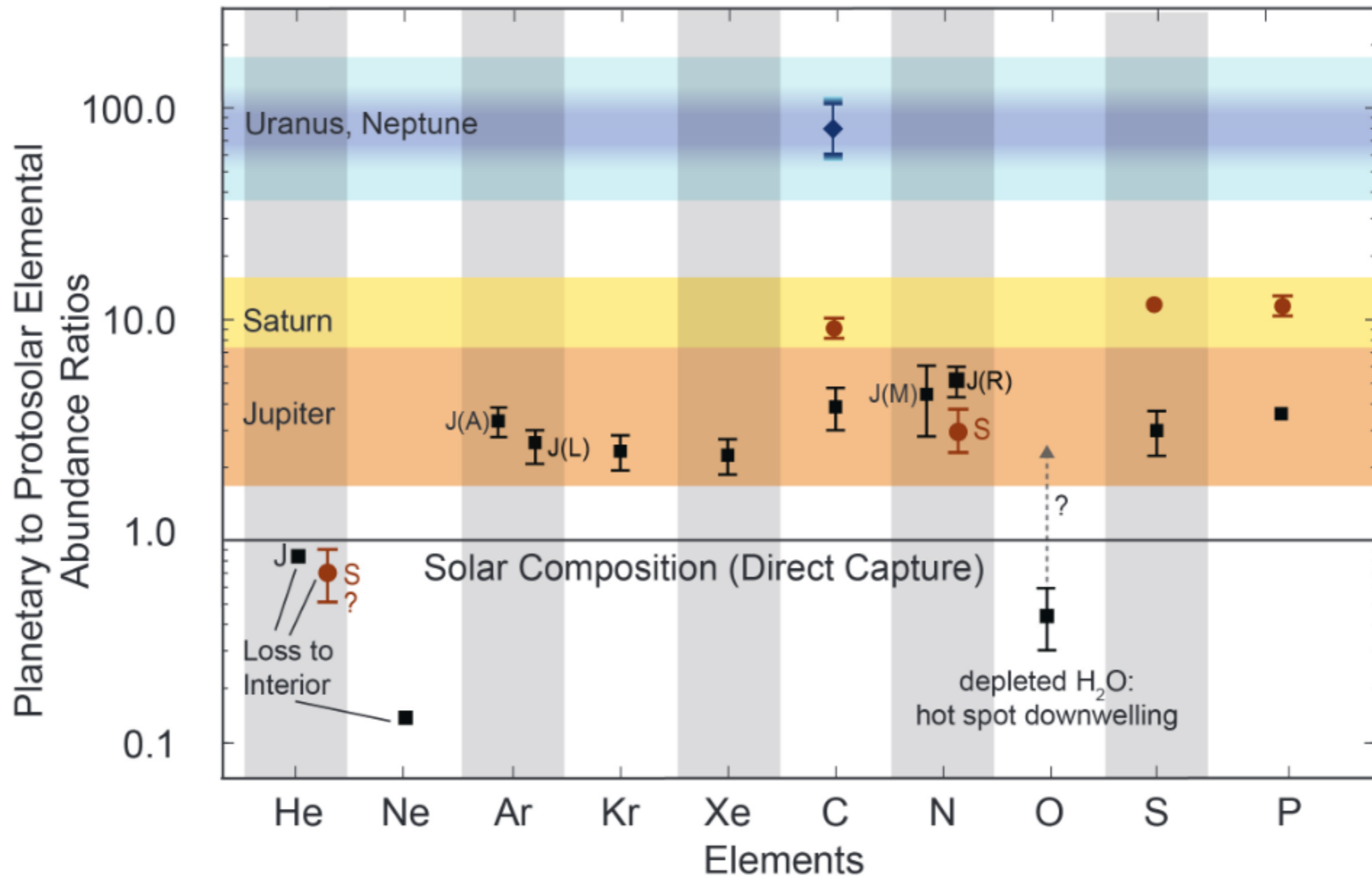
# OTHER MISSIONS: PRE - JUNO RESULTS



# WHAT DO WE KNOW?: ATMOSPHERE



# WHAT DO WE KNOW?: ATMOSPHERE

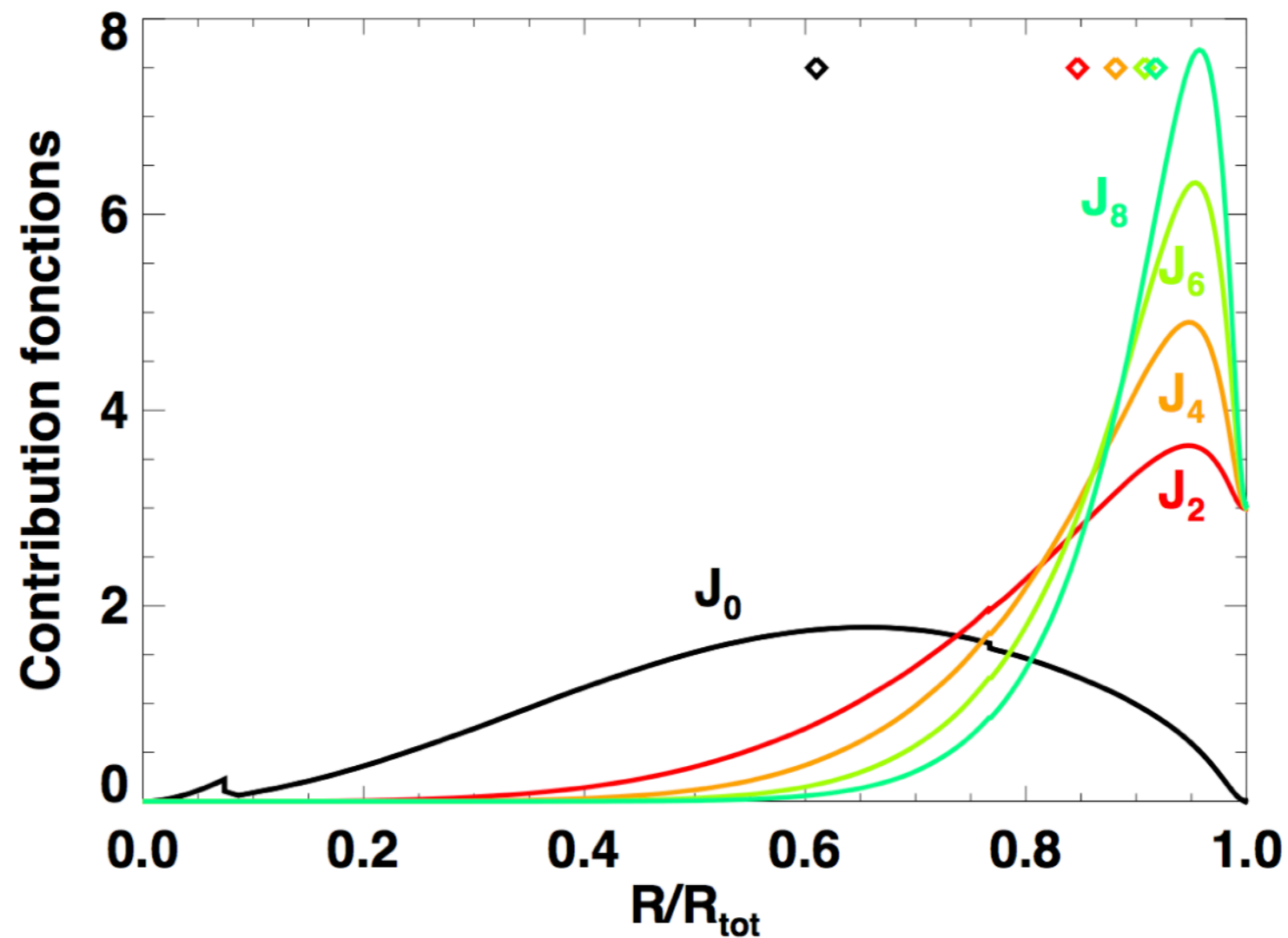


Atreya+2016

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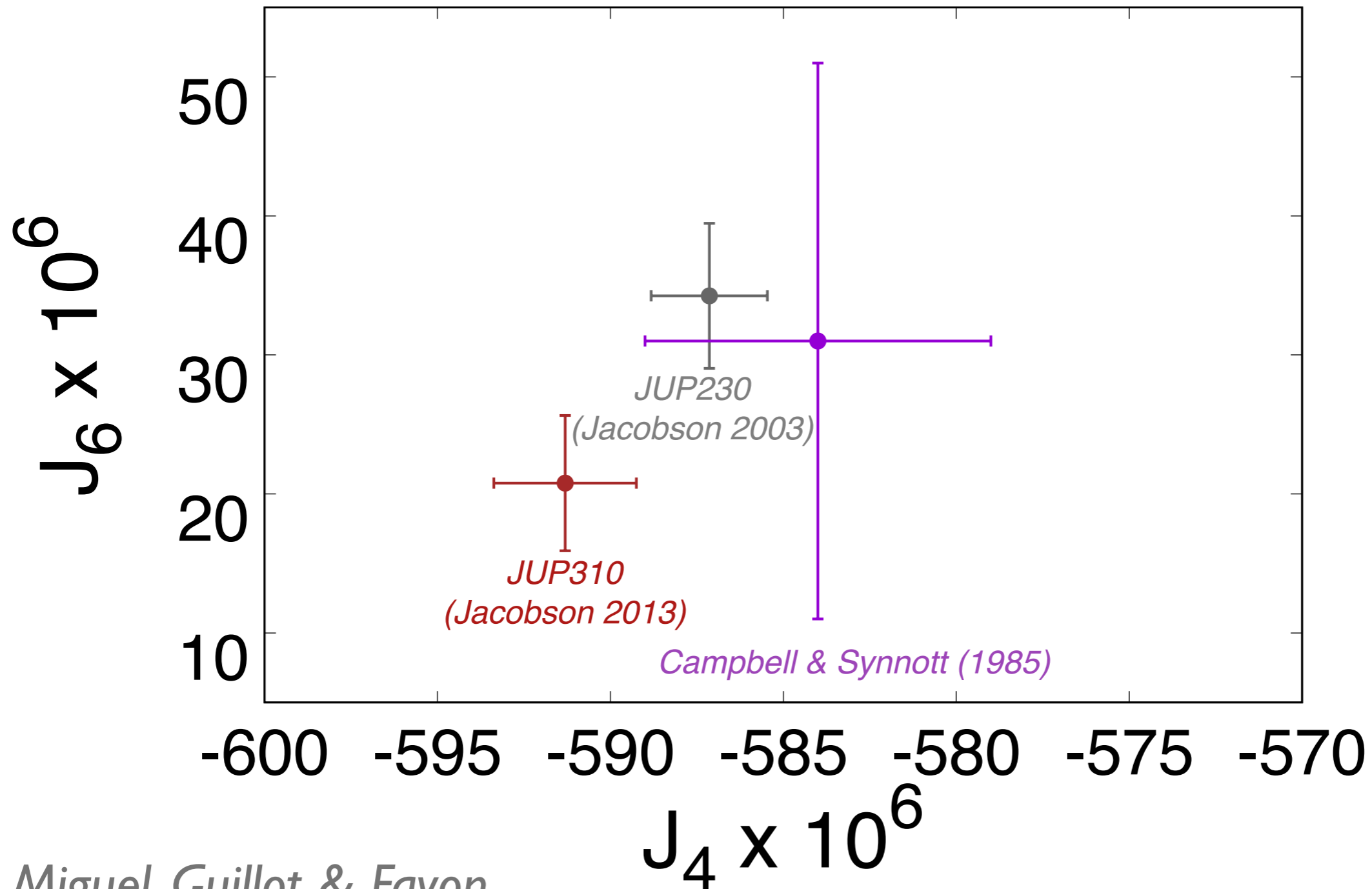
# WHAT DO WE KNOW?: Js

$$U(r, \theta) = \frac{GM}{r} \left\{ 1 - \sum_{i=1}^{\infty} \left( \frac{R_{\text{eq}}}{r} \right)^{2i} J_{2i} P_{2i}(\cos \theta) \right\} \quad J_{2i} = -\frac{1}{MR_{\text{eq}}^{2i}} \int \rho(r) r^{2i} P_{2i}(\cos \theta) d\tau$$



GUMUL & GUTIER 2014

# WHAT DO WE KNOW?: Js



Miguel, Guillot & Fayon  
(A&A 2016)

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# WHAT DO WE KNOW ABOUT JUPITER?

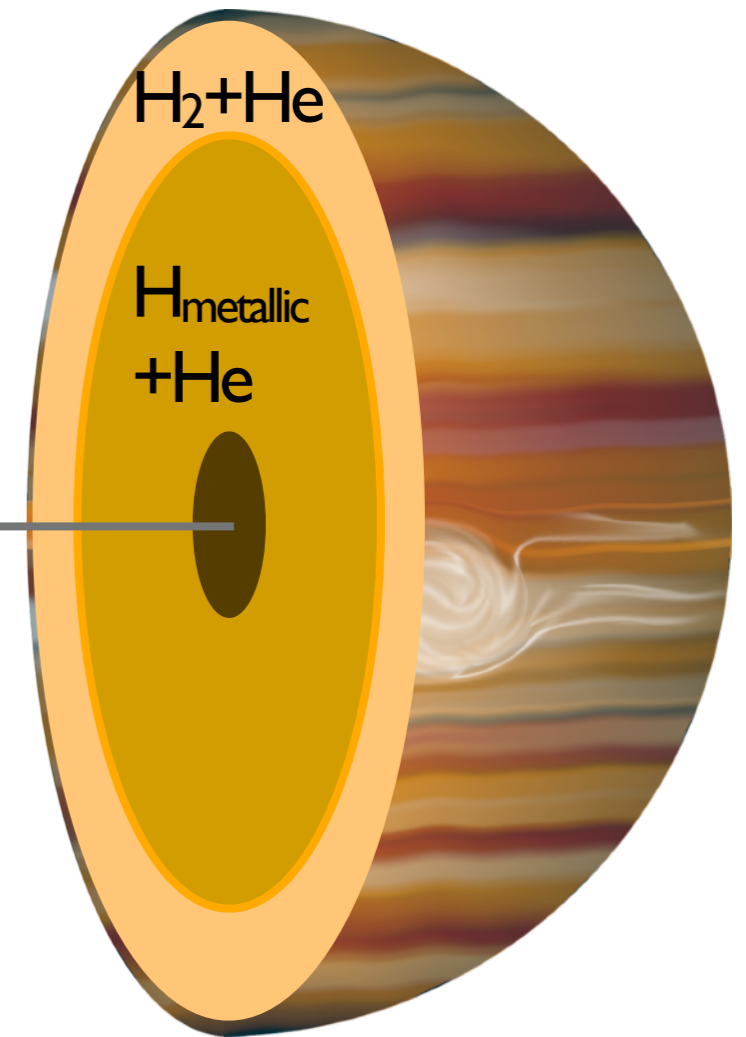
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## JUPITER'S INTERIOR JUNO!

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

$M_z$  up to  $40 M_{\text{Earth}}$

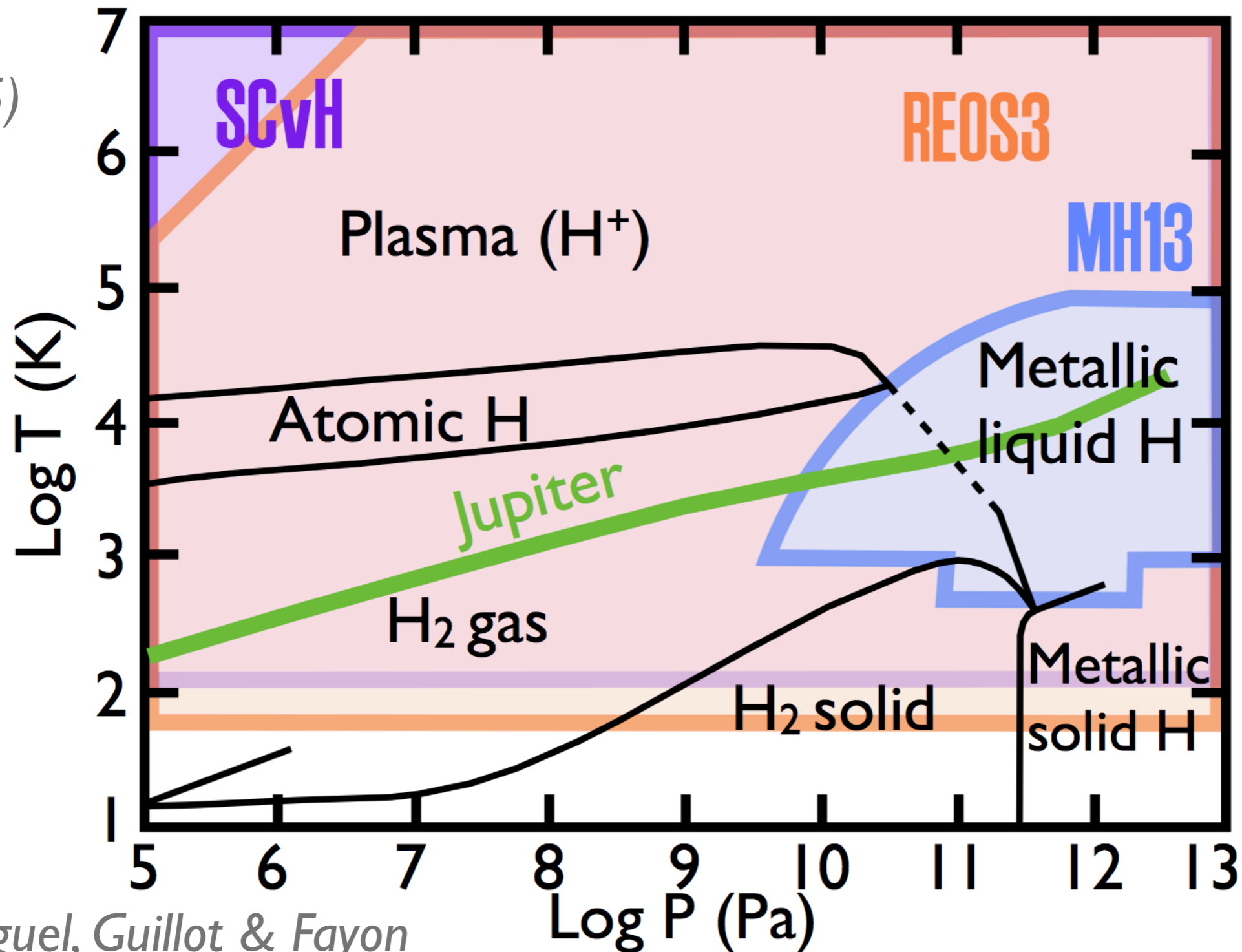
(Saumon & Guillot 2004,  
Nettelmann + 2008, 2012, Helled & Guillot 2013,  
Hubbard & Militzer, 2016, Miguel + 2016)



R, M, J<sub>2</sub>, J<sub>4</sub>, J<sub>6</sub>, Y, ...

# MODELING JUPITER'S INTERIOR: EOS

Saumon  
+ (1995)



Becker+  
(A&A 2014)

Militzer &  
Hubbard  
(ApJ 2013)

Miguel, Guillot & Fayon  
(A&A 2016)

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# MODELING JUPITER'S INTERIOR

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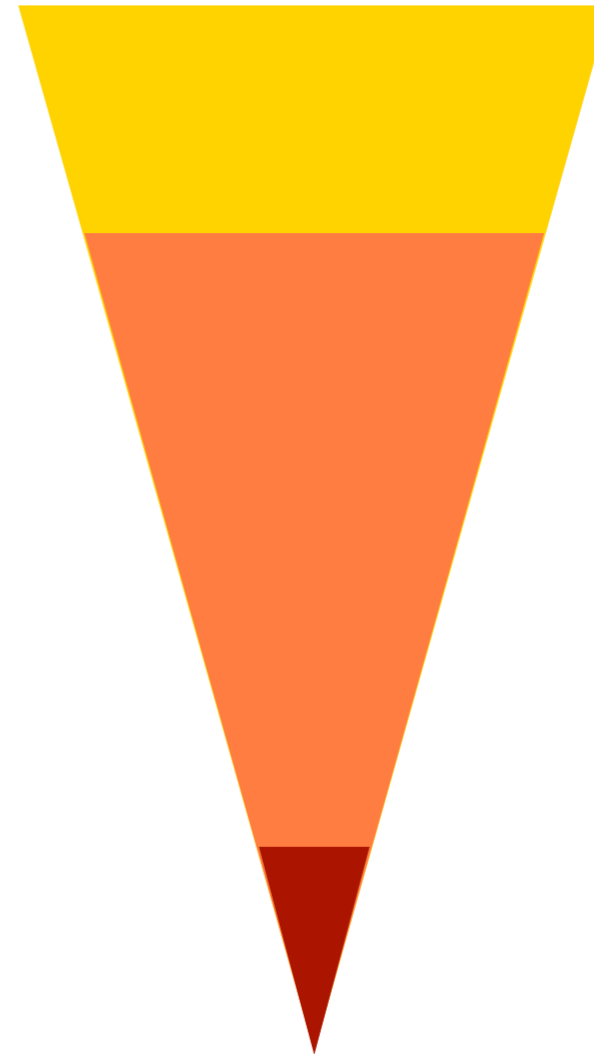
CEPAM (Guillot & Morel 1995)

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

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

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

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



# MODELING JUPITER'S INTERIOR: OPTIMISATIONS

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*Initial parameters:  $M_{core}$ ,  $Y_{atm}$ ,  $Z_{atm}$ ,  $Y_{deep}$ ,  $Z_{deep}$ ...*

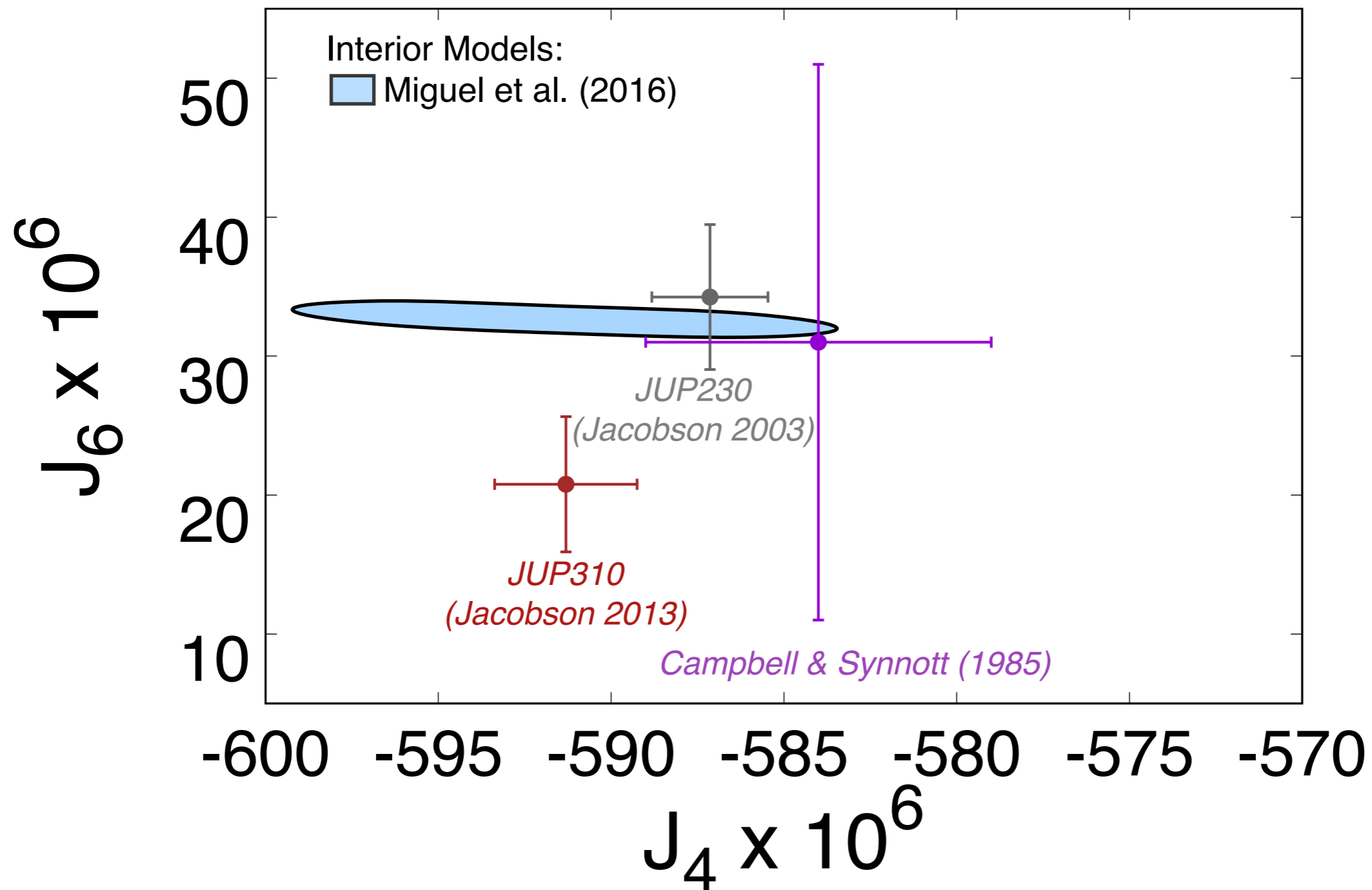
CEPAM (Guillot & Morel 1995)

*Radius,  $J_2$ ,  $J_4$*

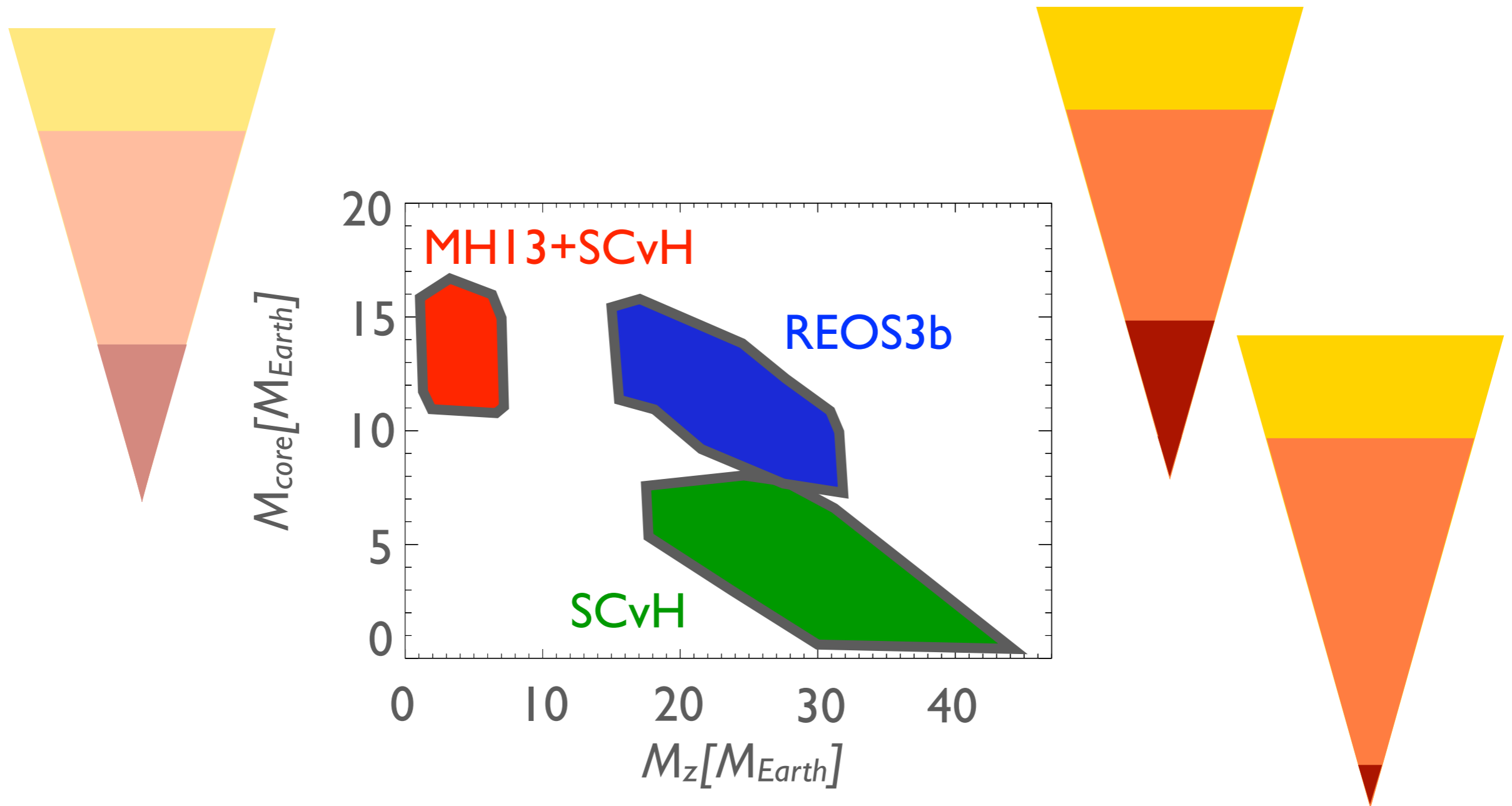
$$f = \left( \frac{R_{cepam} - R_{obs}}{\sigma(R)} \right)^2 + \left( \frac{J2_{cepam} - J2_{Juno}}{\sigma(J2)} \right)^2 + \left( \frac{J4_{cepam} - J4_{obs}}{\sigma(J4)} \right)^2$$

*We find a solution!*

# JUPITER'S INTERIOR : PRE - JUNO RESULTS



# JUPITER'S INTERIOR : DIFFERENT EOS



Miguel, Guillot & Fayon  
(A&A 2016)

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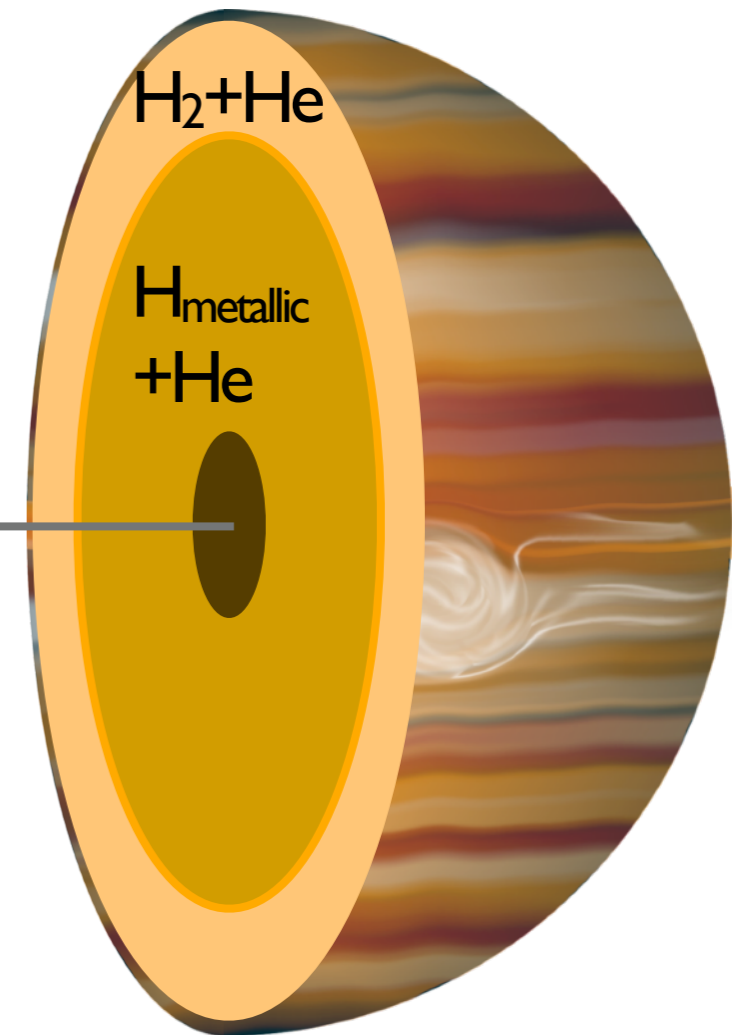
# JUPITER'S INTERIOR : PRE - JUNO RESULTS

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Recent EOS lead to large  
core masses

$$M_{\text{core}} = 7 - 17 M_{\text{Earth}}$$

$$M_z \text{ up to } 33 M_{\text{Earth}}$$



R, M, J<sub>2</sub>, J<sub>4</sub>, J<sub>6</sub>, Y, ...

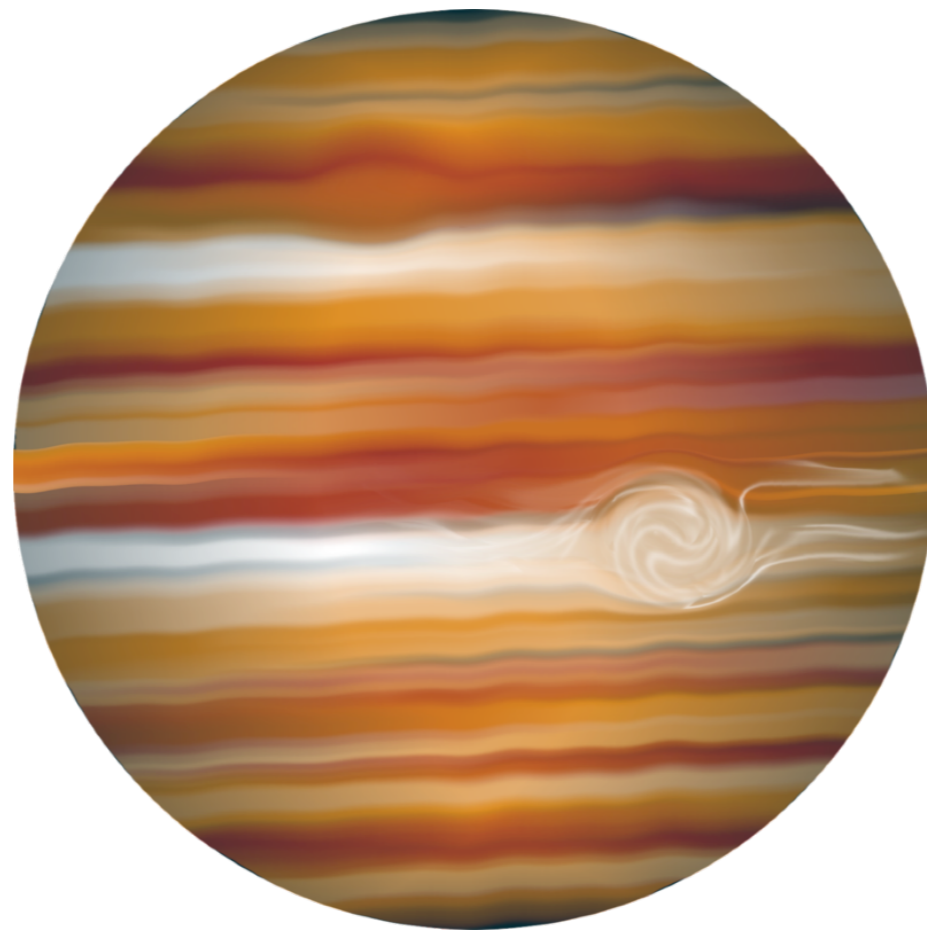
*Miguel, Guillot & Fayon (A&A 2016)*

*Yamila Miguel*

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# JUPITER INTERIOR: FIRST JUNO RESULTS

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*Yamila Miguel*

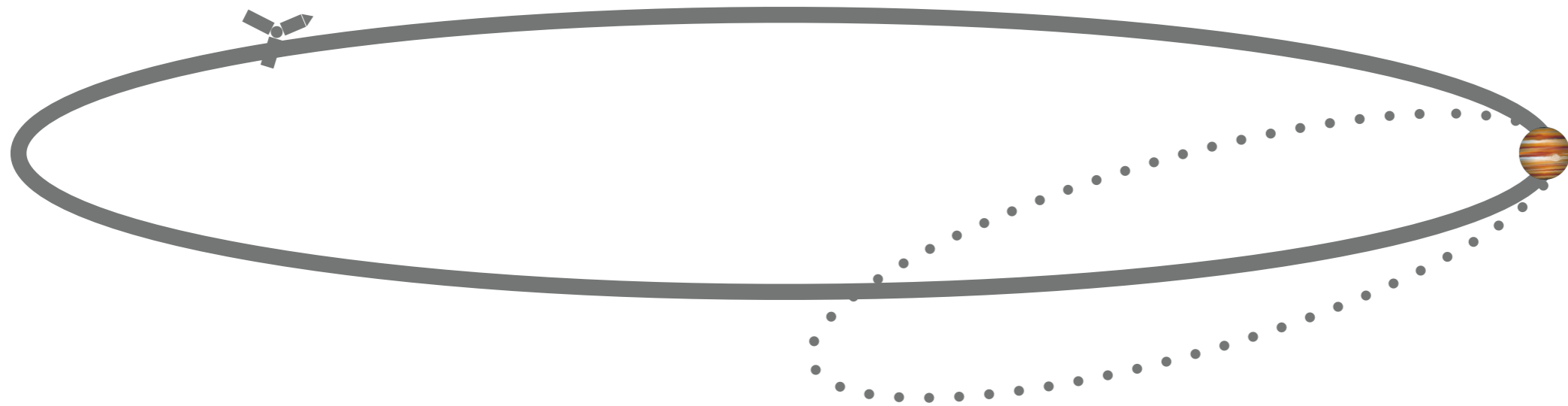




# JUNO MISSION : ORBIT



*53 days*

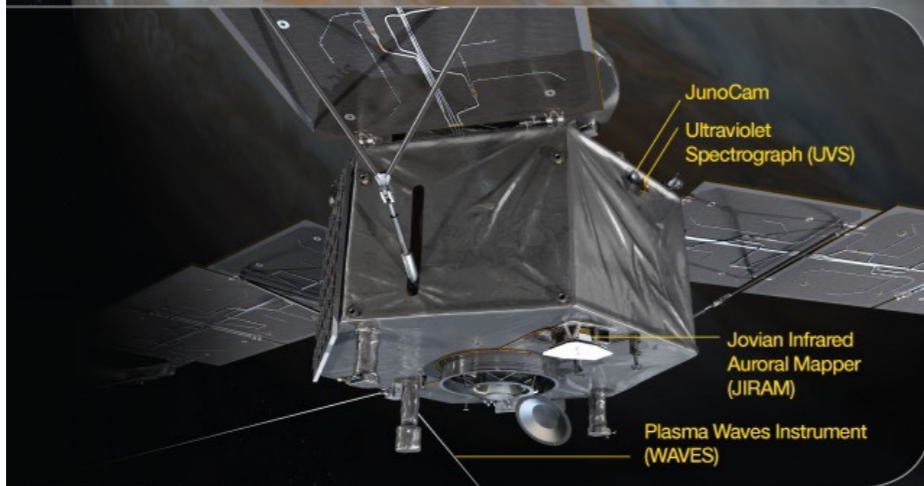


# JUNO MISSION : INSTRUMENTS

National Aeronautics and Space Administration



## Juno Spacecraft

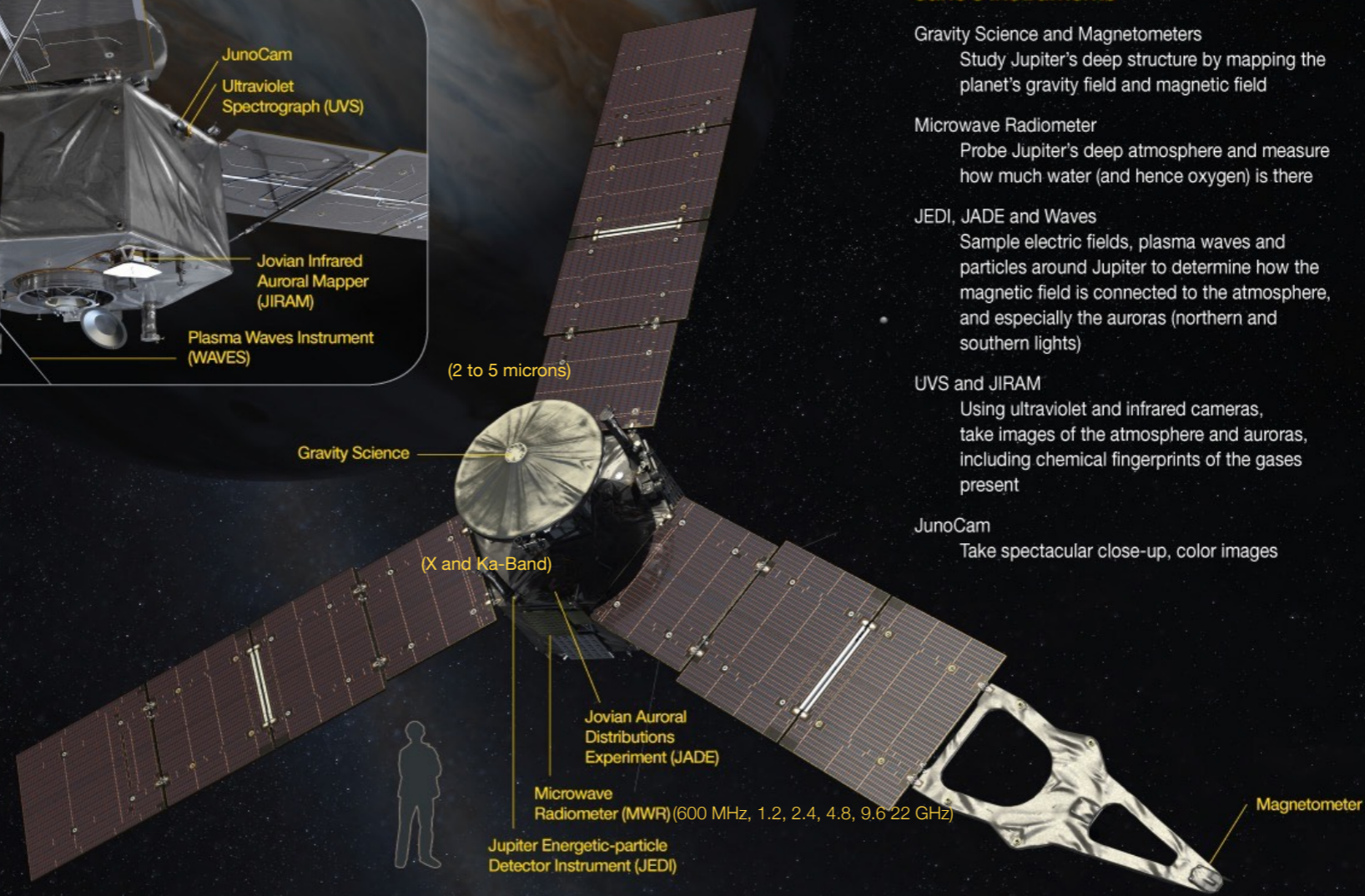


### SPACECRAFT DIMENSIONS

Diameter: 66 feet (20 meters)  
Height: 15 feet (4.5 meters)

For more information:  
[missionjuno.swri.edu](http://missionjuno.swri.edu) &  
[www.nasa.gov/juno](http://www.nasa.gov/juno)

National Aeronautics and Space Administration  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California  
[www.nasa.gov](http://www.nasa.gov)



### Juno's Instruments

#### Gravity Science and Magnetometers

Study Jupiter's deep structure by mapping the planet's gravity field and magnetic field

#### Microwave Radiometer

Probe Jupiter's deep atmosphere and measure how much water (and hence oxygen) is there

#### JEDI, JADE and Waves

Sample electric fields, plasma waves and particles around Jupiter to determine how the magnetic field is connected to the atmosphere, and especially the auroras (northern and southern lights)

#### UVS and JIRAM

Using ultraviolet and infrared cameras, take images of the atmosphere and auroras, including chemical fingerprints of the gases present

#### JunoCam

Take spectacular close-up, color images



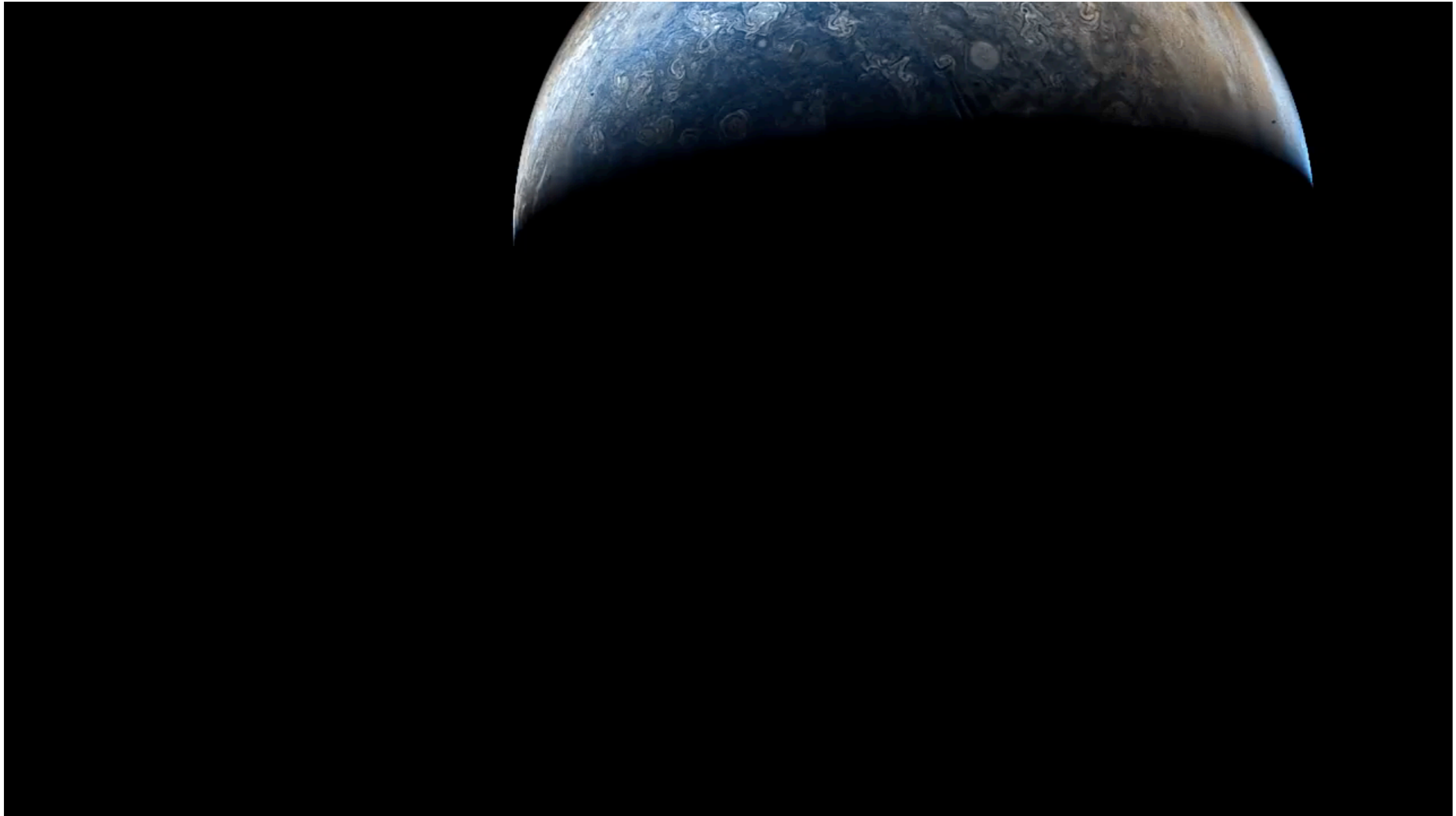
# JUNO MISSION : ORBIT

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 **JUNO MISSION** : **SOME PHOTOS**

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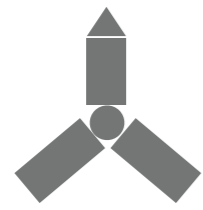
*Yamila Miguel*

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 **JUNO MISSION** : **SOME PHOTOS**



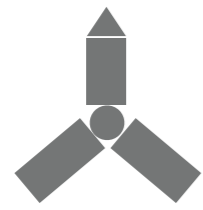
*Yamila Miguel*



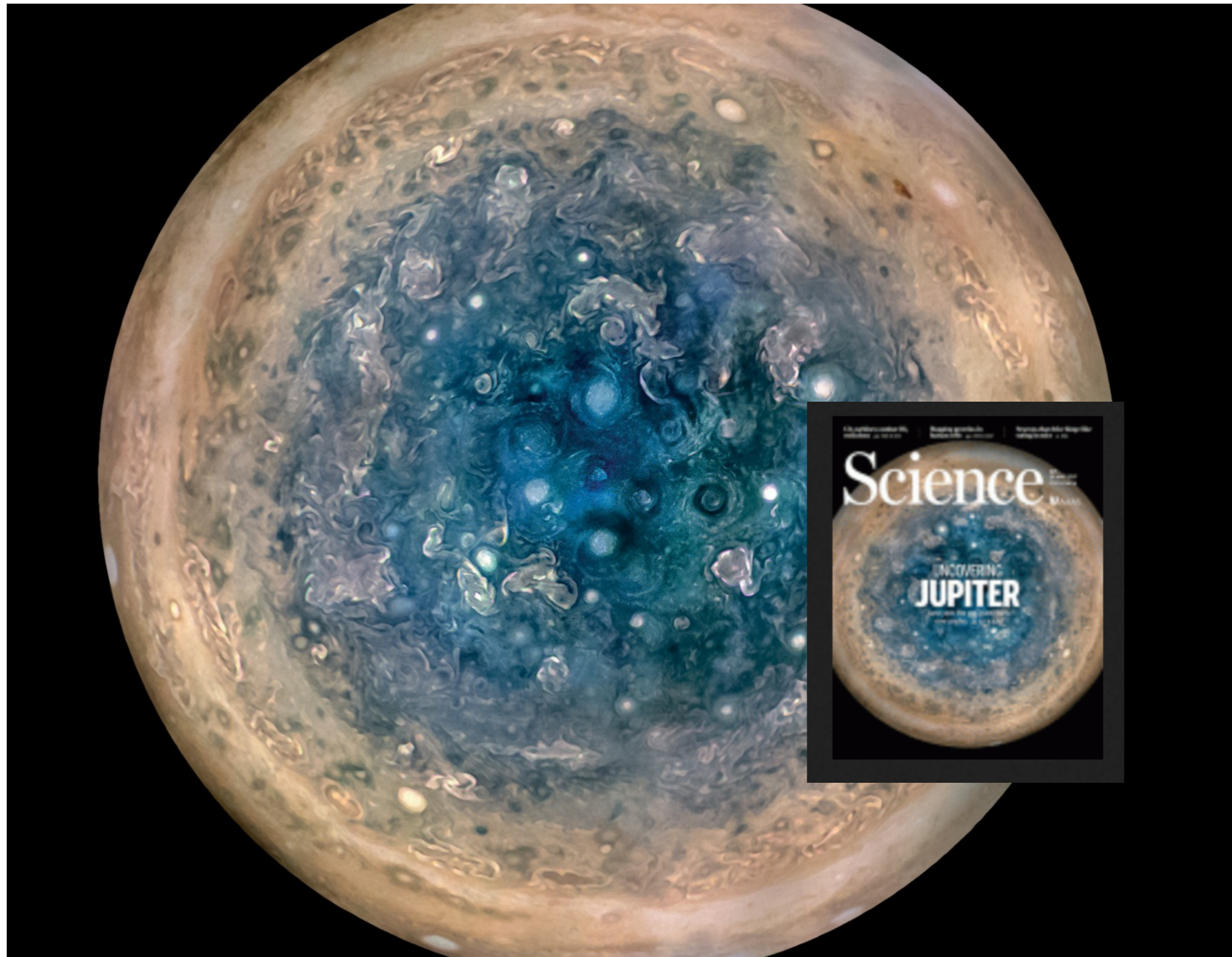
# JUNO MISSION : SOME PHOTOS



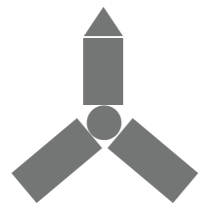
*Yamila Miguel*



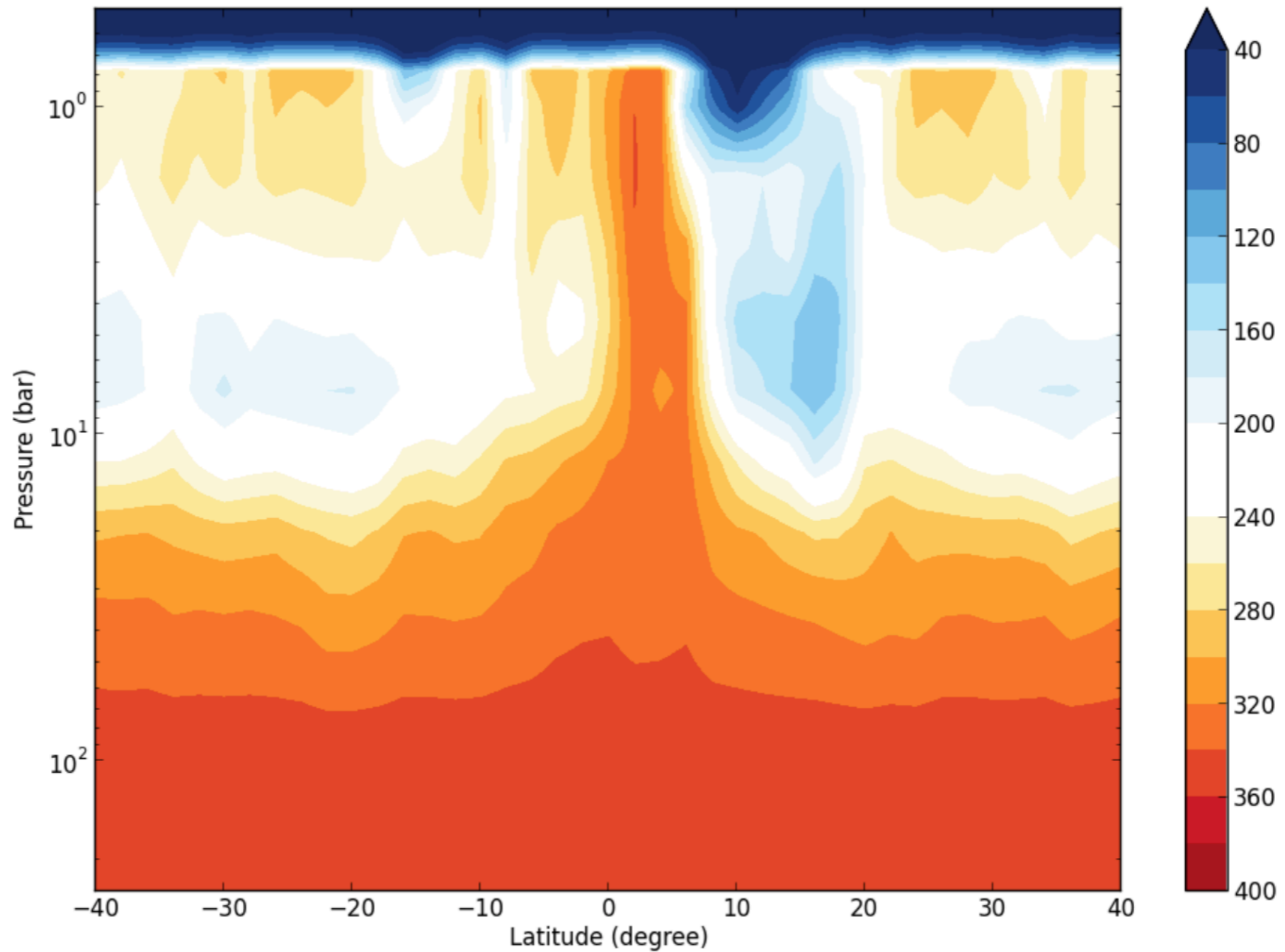
# JUNO MISSION : SOME PHOTOS



*Yamila Miguel*



# JUNO MISSION : FIRST RESULTS

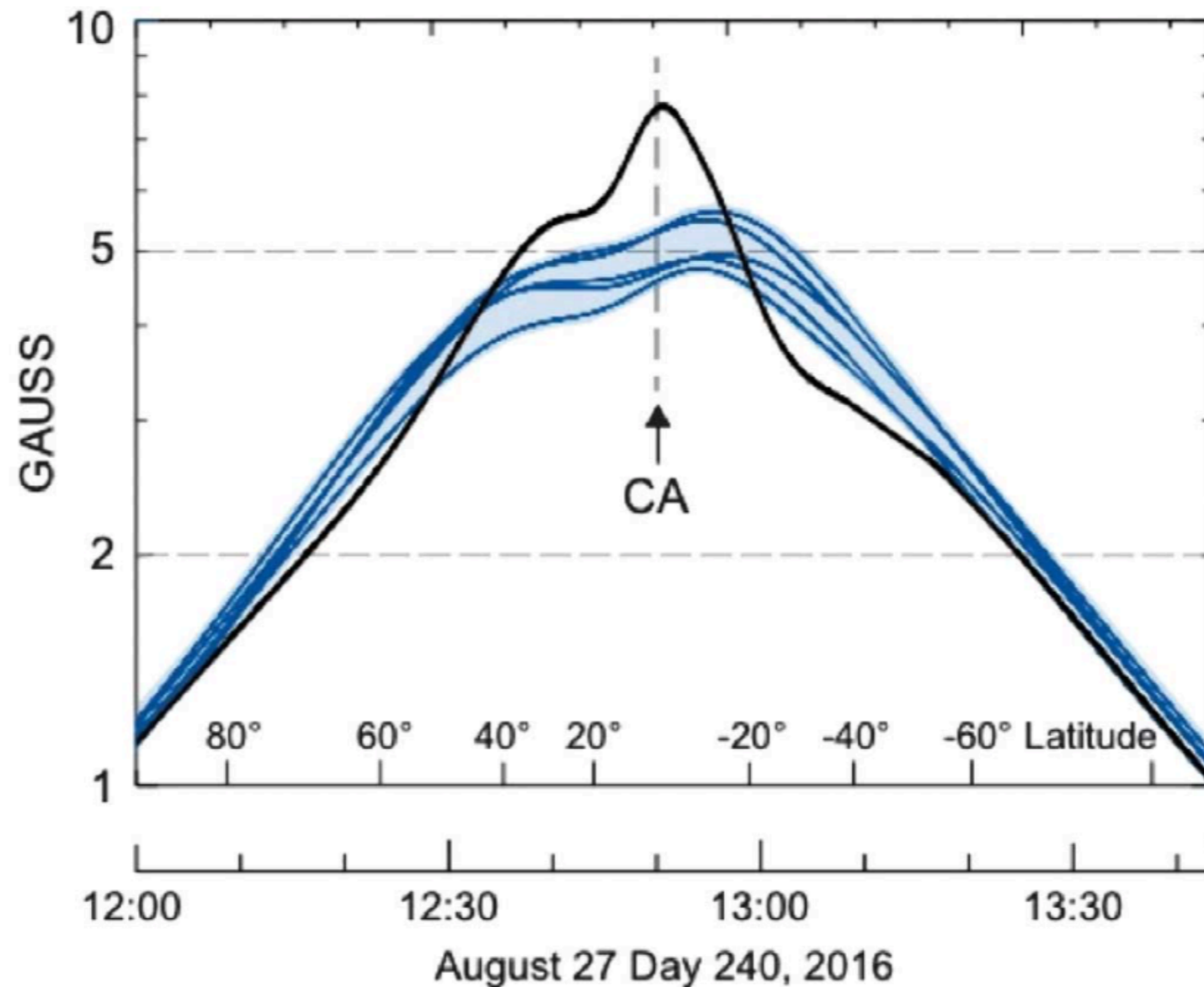


Bolton+(Science, 2017)

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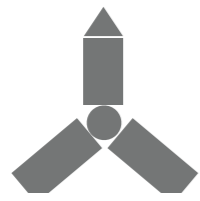


# JUNO MISSION : FIRST RESULTS

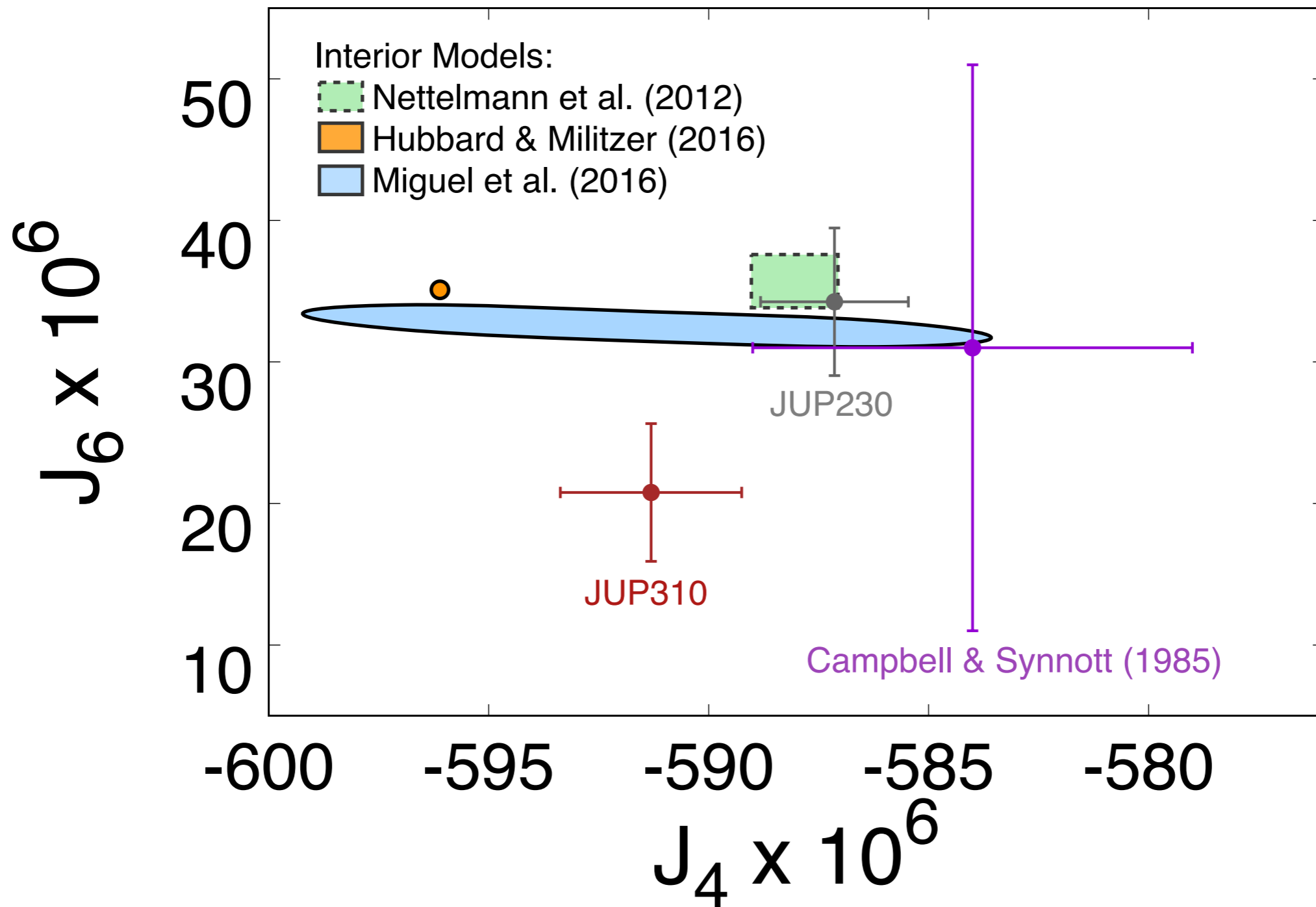


*The maximum magnetic field observed was 7.766 G, more than an order of magnitude greater than Earth's.*

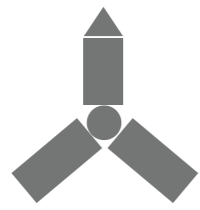
*Dynamo generation region not far beneath the surface.*



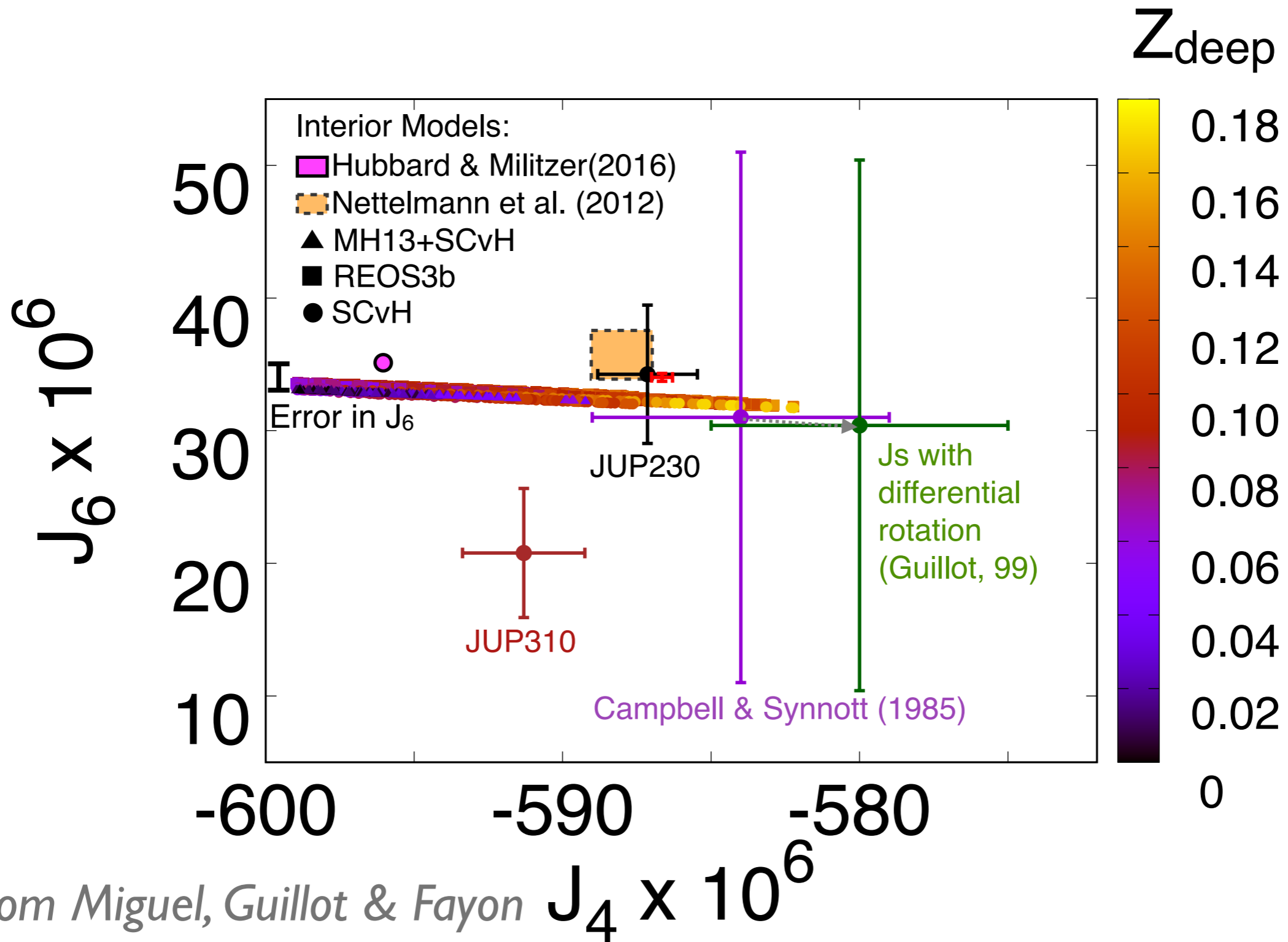
# JUNO MISSION : FIRST RESULTS



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

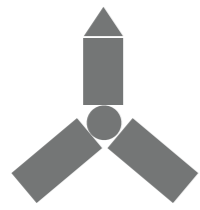


# JUNO MISSION : FIRST RESULTS



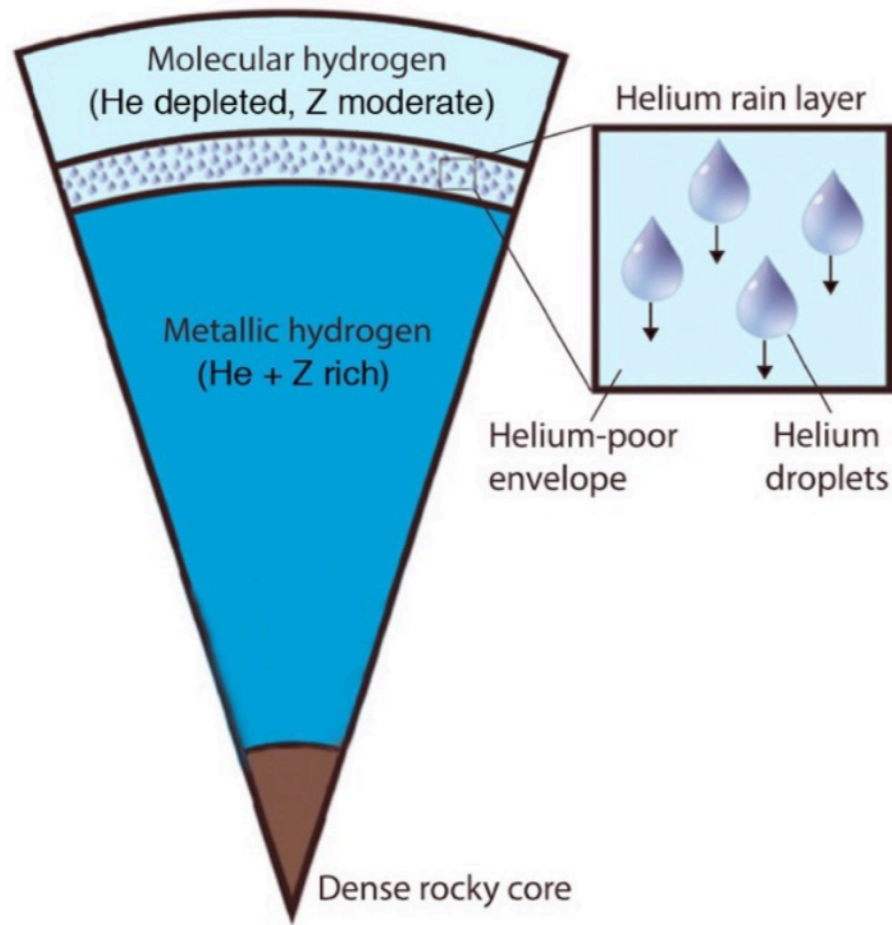
From Miguel, Guillot & Fayon (A&A 2016)

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# JUNO MISSION : FIRST RESULTS

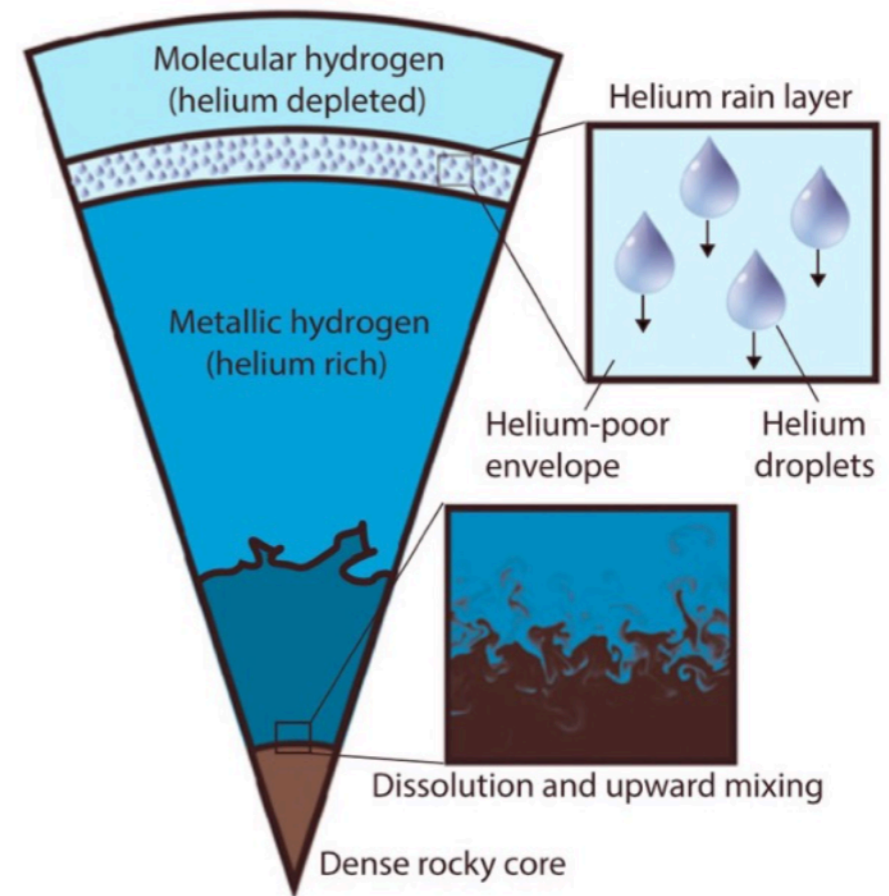
## Standard



REOS3 ✓

MHI3 ✗

## Dilute core

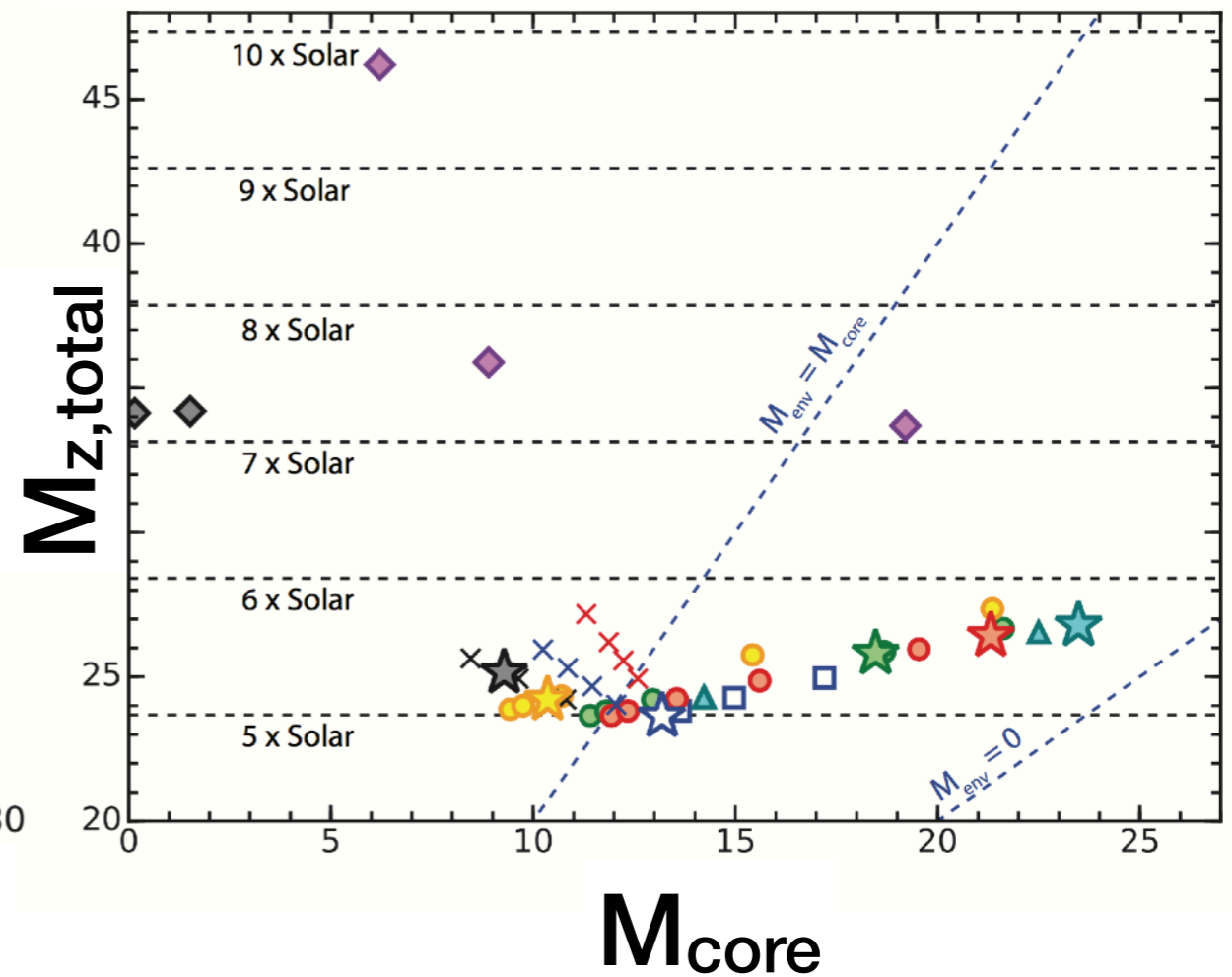
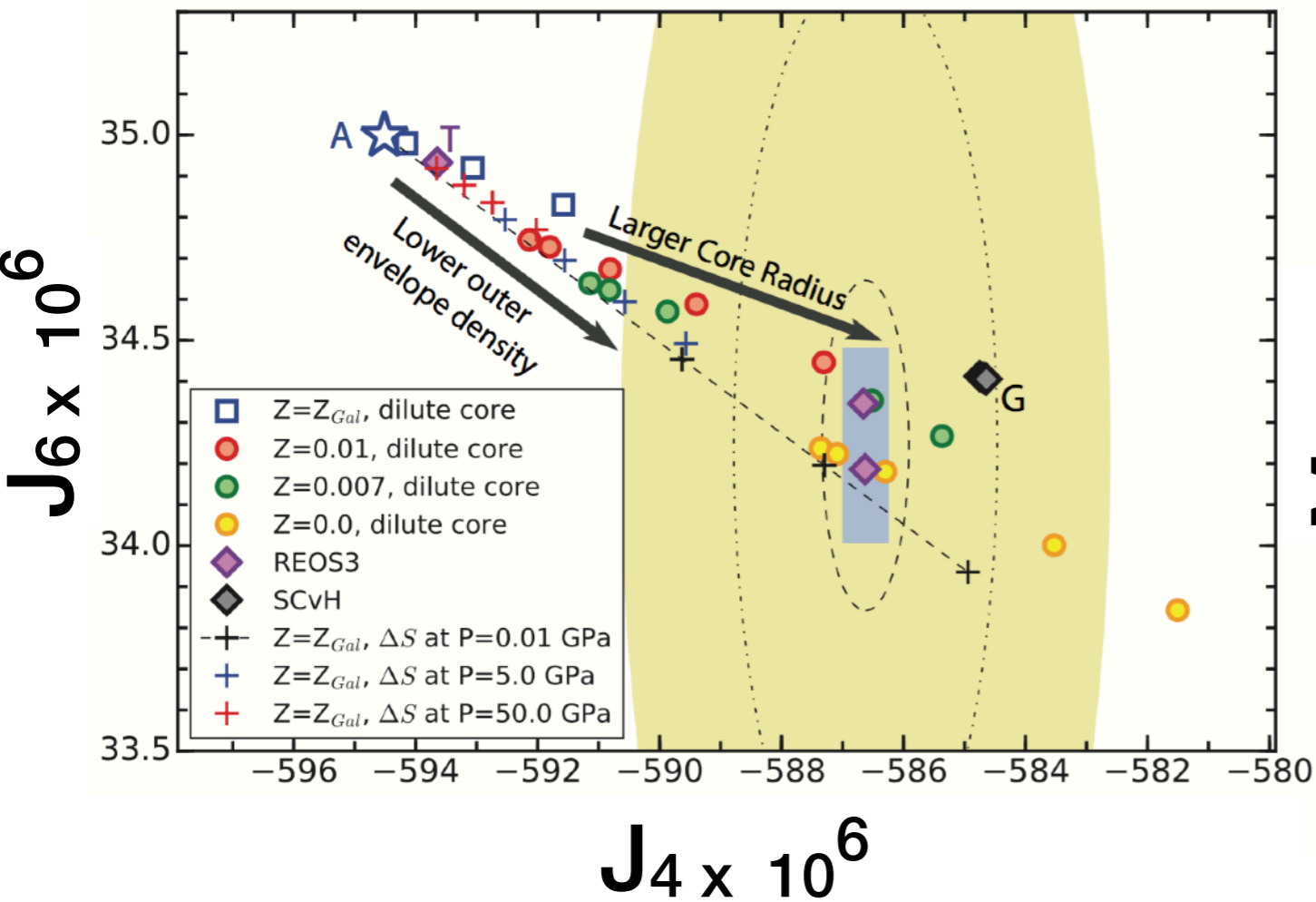


REOS3 ✓

MHI3 ✓

Wahl + (GRL, 2017 in press)

# JUNO : EFFECT OF A DILUTE CORE



Wahl + (GRL, 2017 in press)

Yamila Miguel

# STANDING QUESTIONS

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## **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  $J_s$

*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*

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



**Juno team!**

**July 3rd 2016**

*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)?*