

*Nordita PTA Program
May 2017*

Yamila Miguel

Tristan Guillot, Sean Wahl, William B. Hubbard, Burkhard Miltzer, 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

Observatoire de la Côte d'Azur

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INTERNAL STRUCTURE OF JUPITER AND FIRST JUNO RESULTS

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

Observatoire de la Côte d'Azur

MOTIVATION WHY STUDY GIANT PLANETS?



MOTIVATION WHY STUDY GIANT PLANETS?



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**



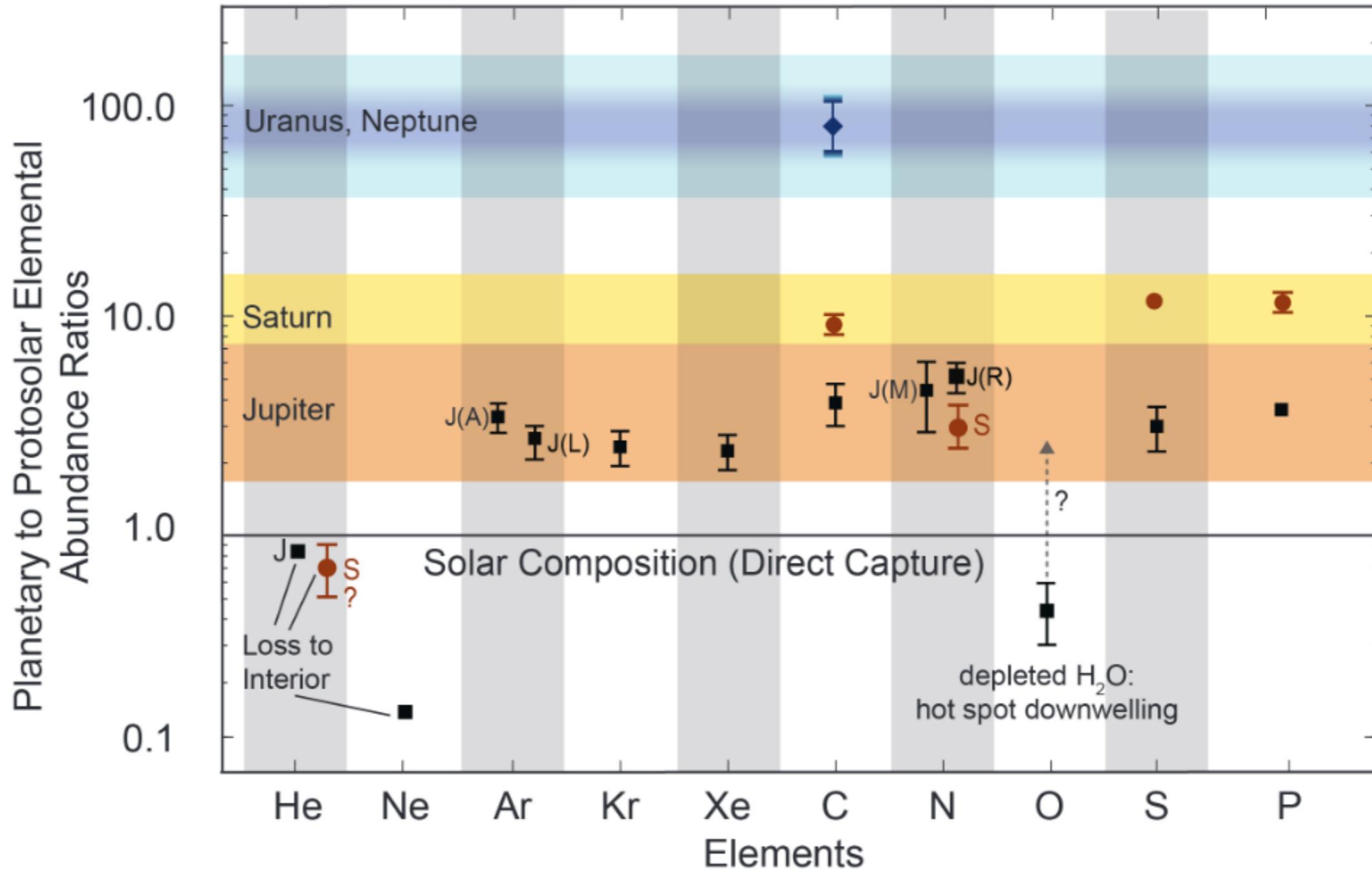
- What is it made of?
- Does it have a core?

JUPITER INTERIOR: PRE - JUNO RESULTS



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WHAT DO WE KNOW?: ATMOSPHERES



Atreya+2016

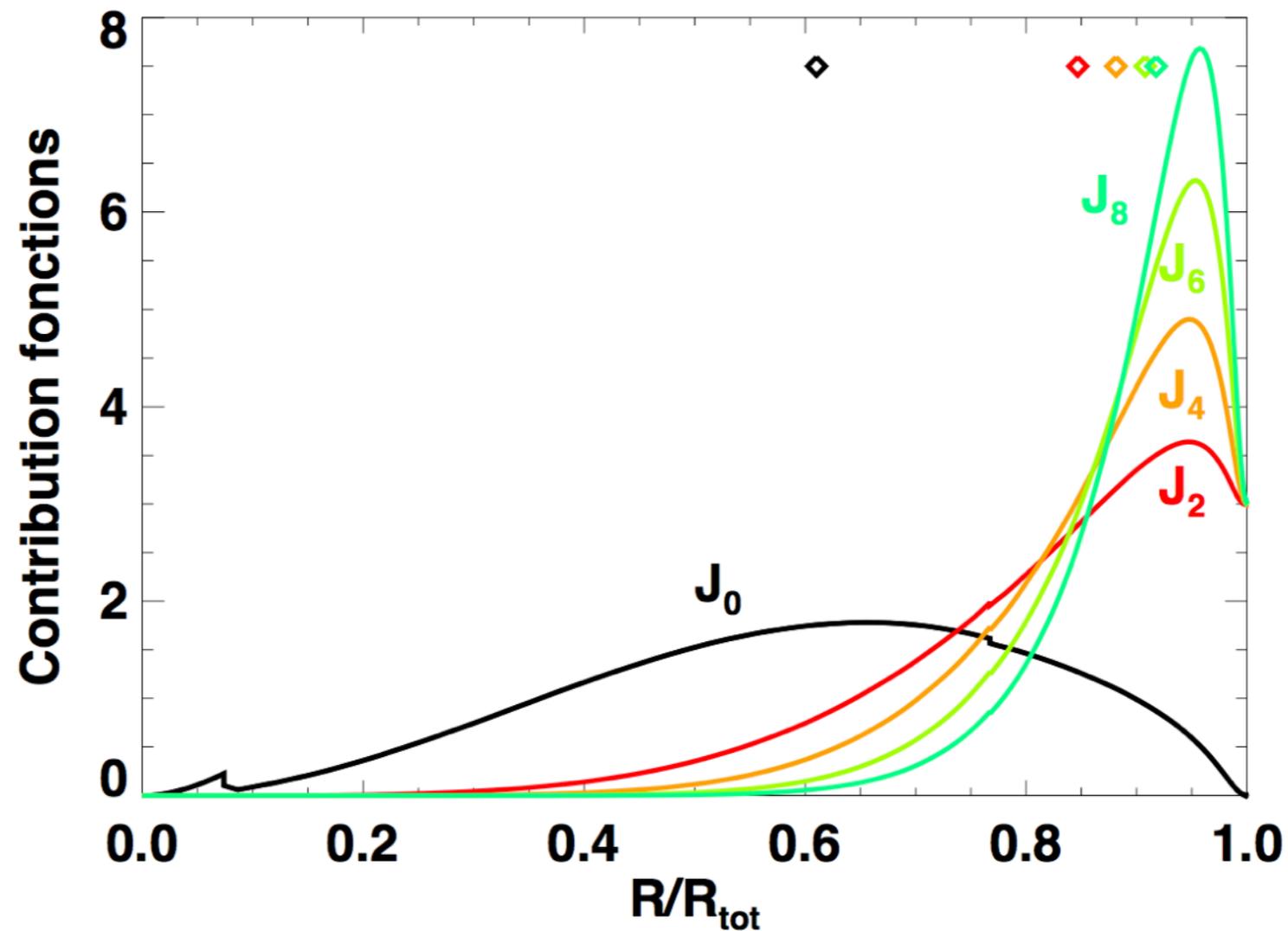
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WHAT DO WE KNOW?: Js

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

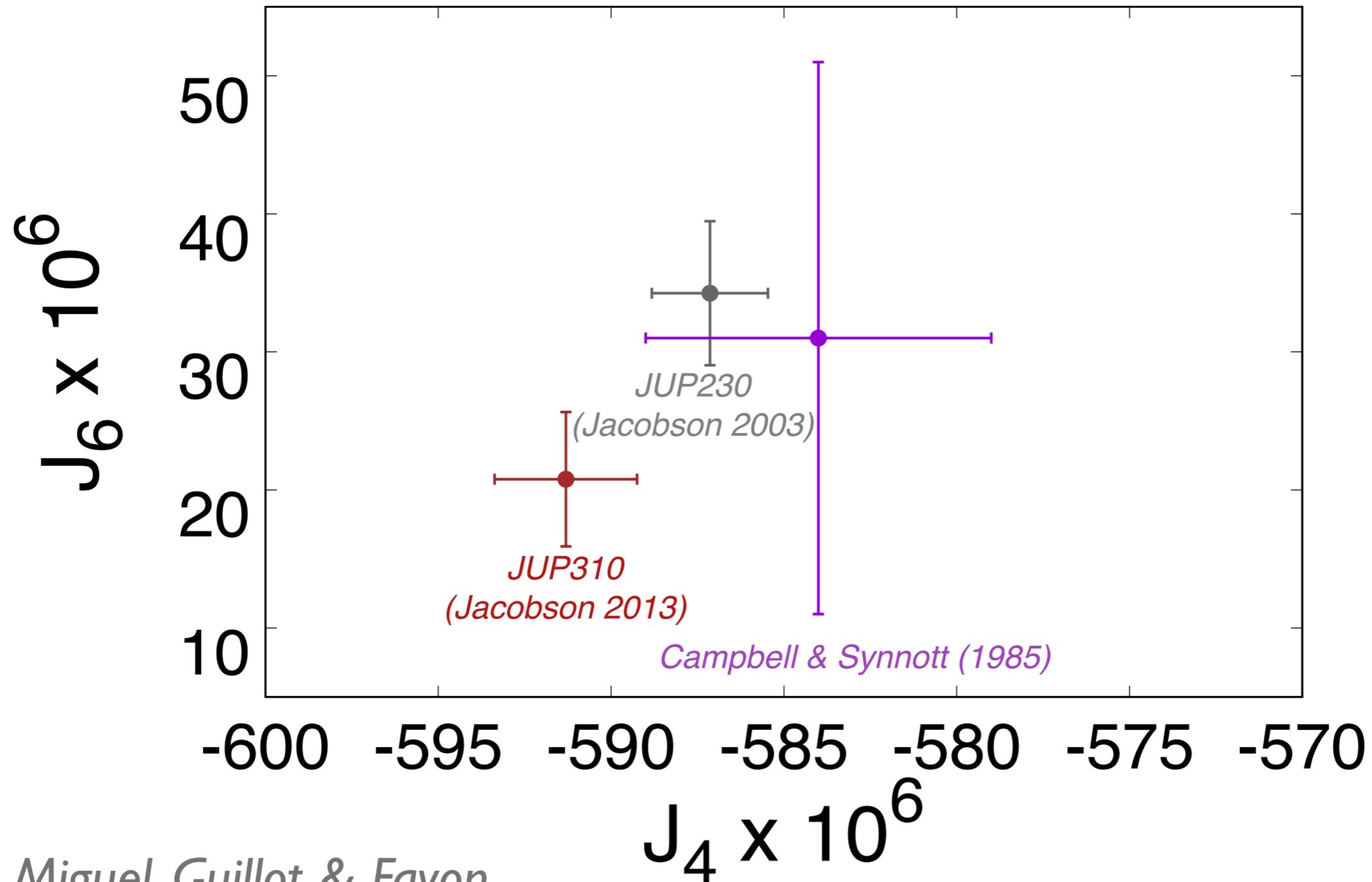
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Guillot & Gautier 2014

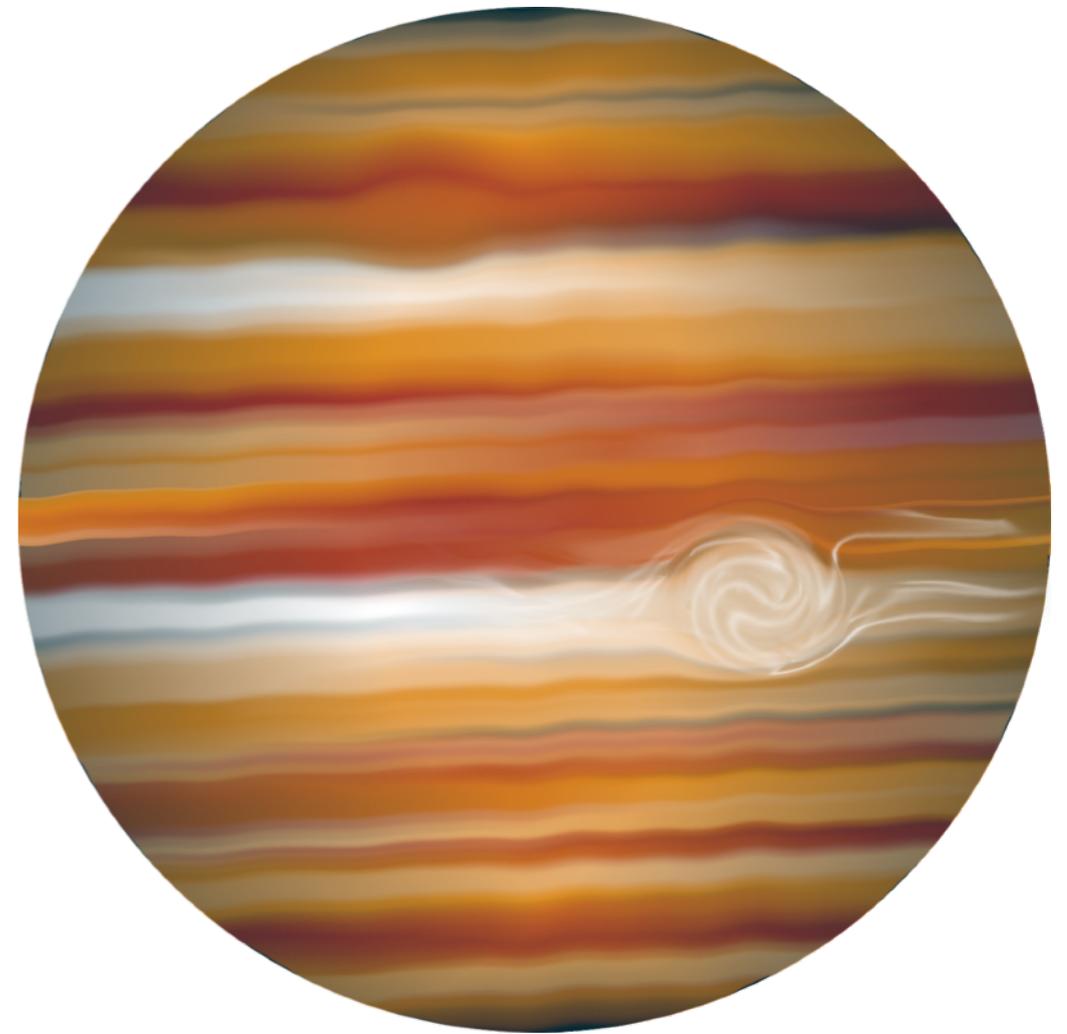
WHAT DO WE KNOW?: Js



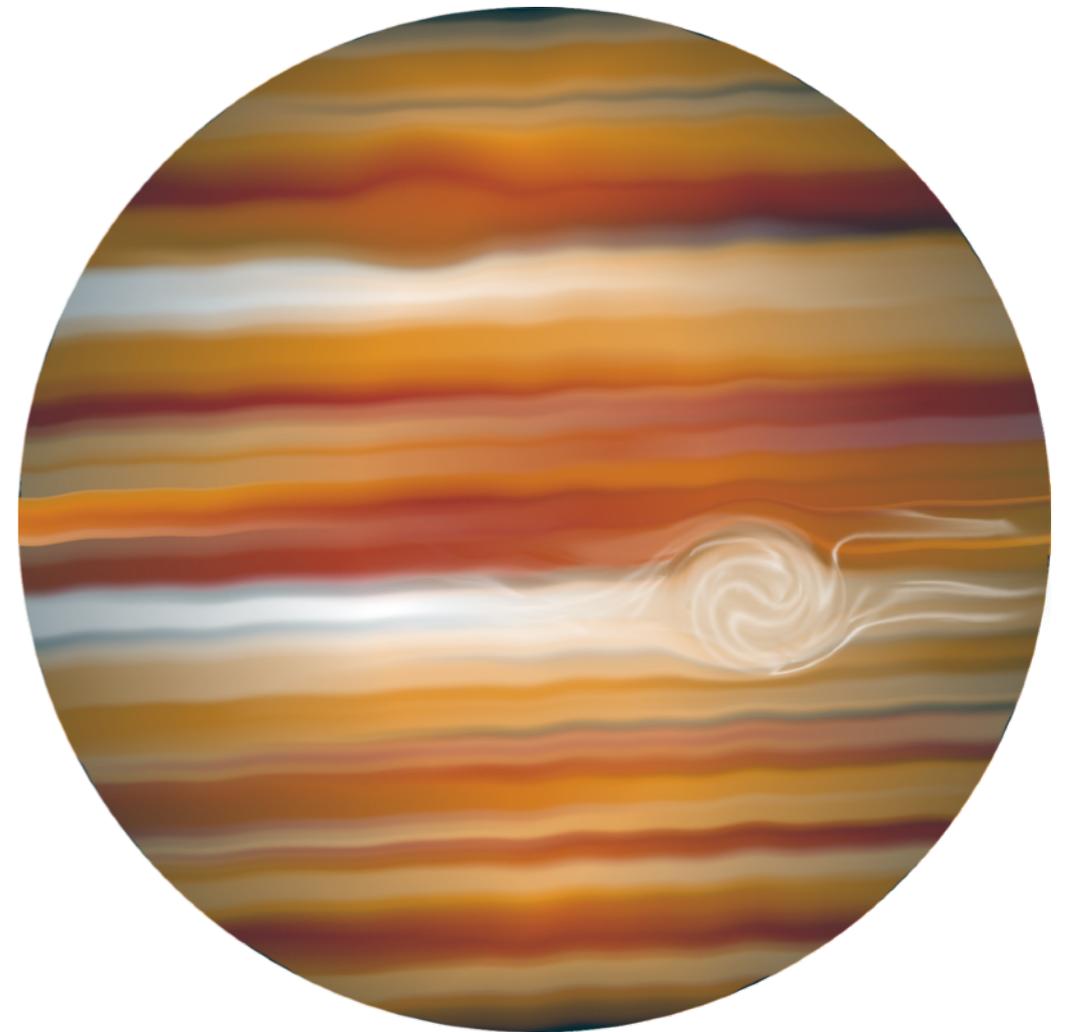
Miguel, Guillot & Fayon
(A&A 2016)

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WHAT DO WE KNOW ABOUT JUPITER?

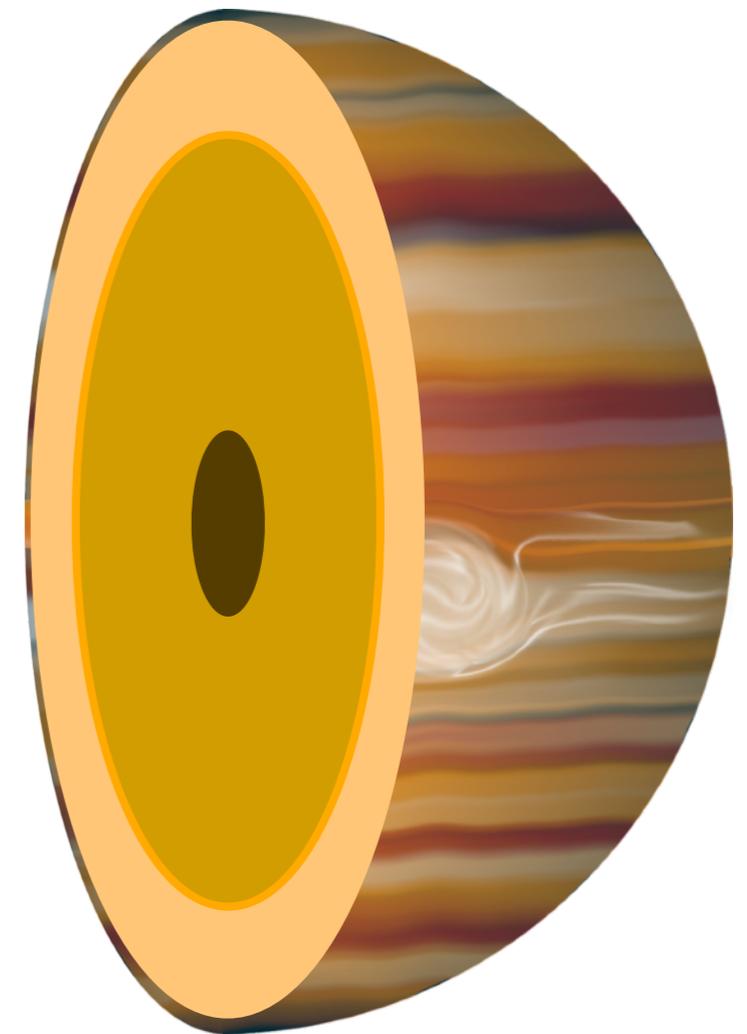


WHAT DO WE KNOW ABOUT JUPITER?



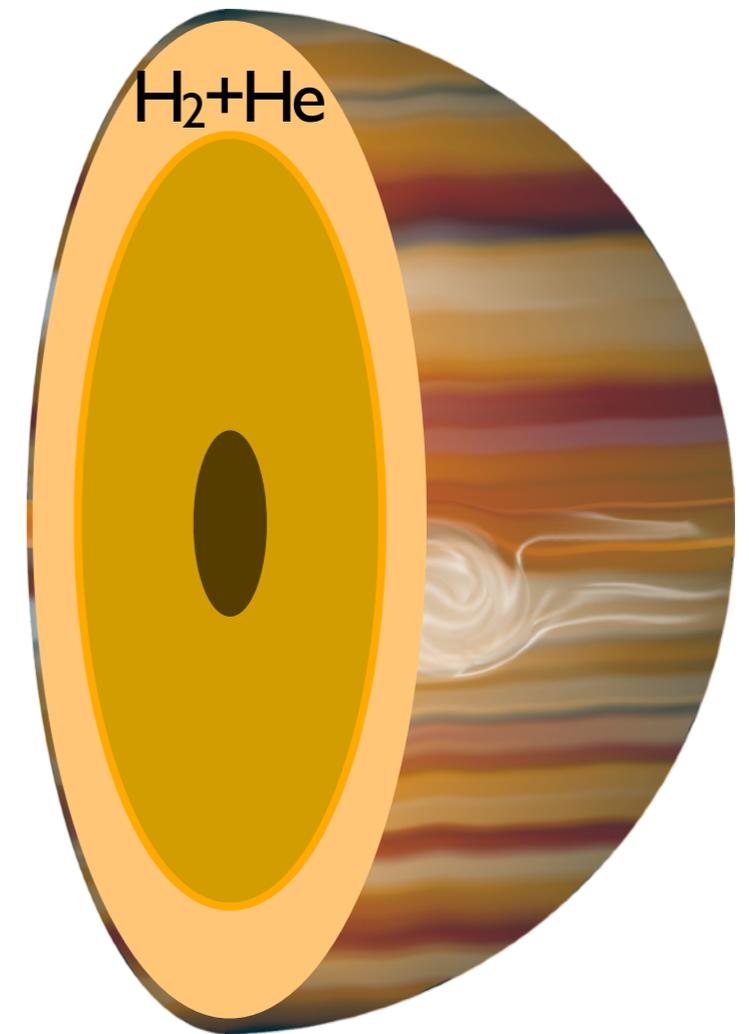
R, M, J₂, J₄, J₆, Y, ...

WHAT DO WE KNOW ABOUT JUPITER?



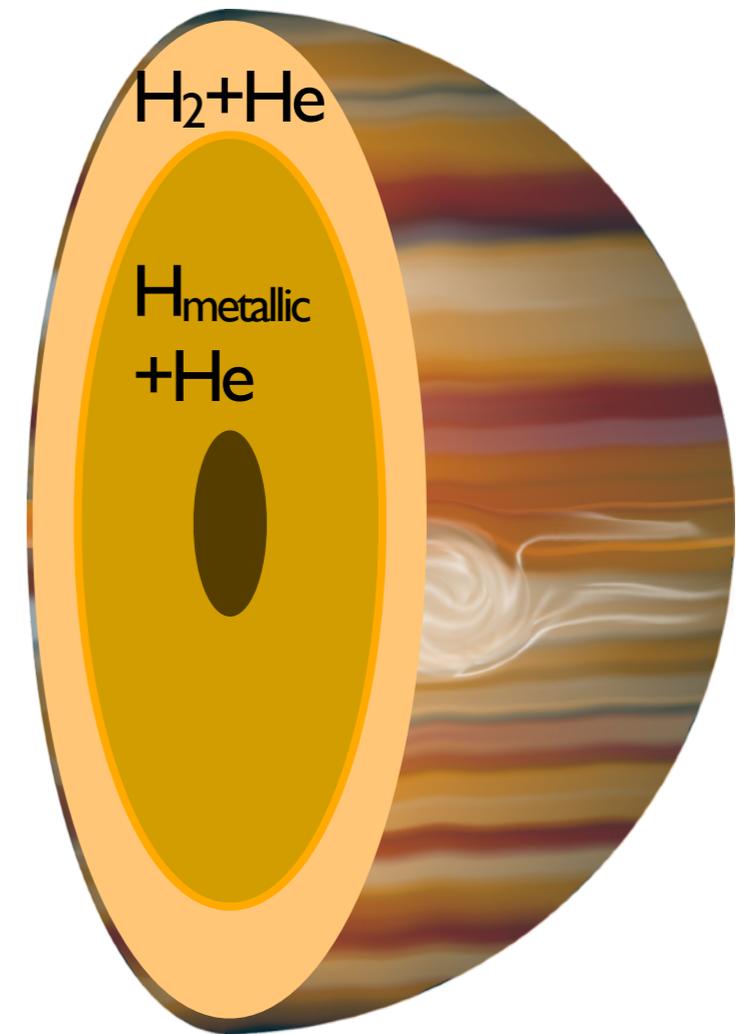
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WHAT DO WE KNOW ABOUT JUPITER?



R, M, J₂, J₄, J₆, Y, ...

WHAT DO WE KNOW ABOUT JUPITER?



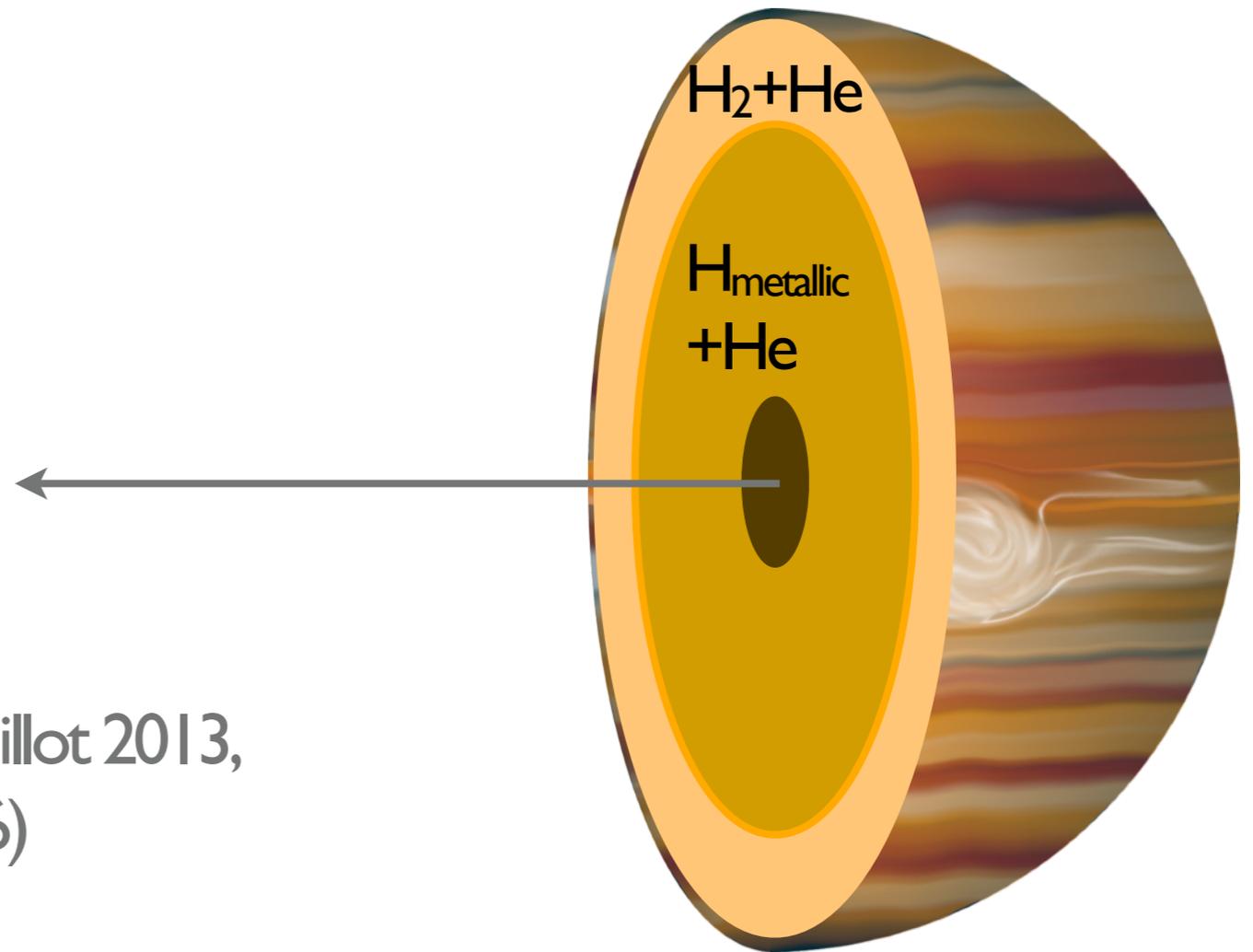
R, M, J_2 , J_4 , J_6 , Y, ...

WHAT DO WE KNOW ABOUT JUPITER?

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

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

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



R, M, J₂, J₄, J₆, Y, ...

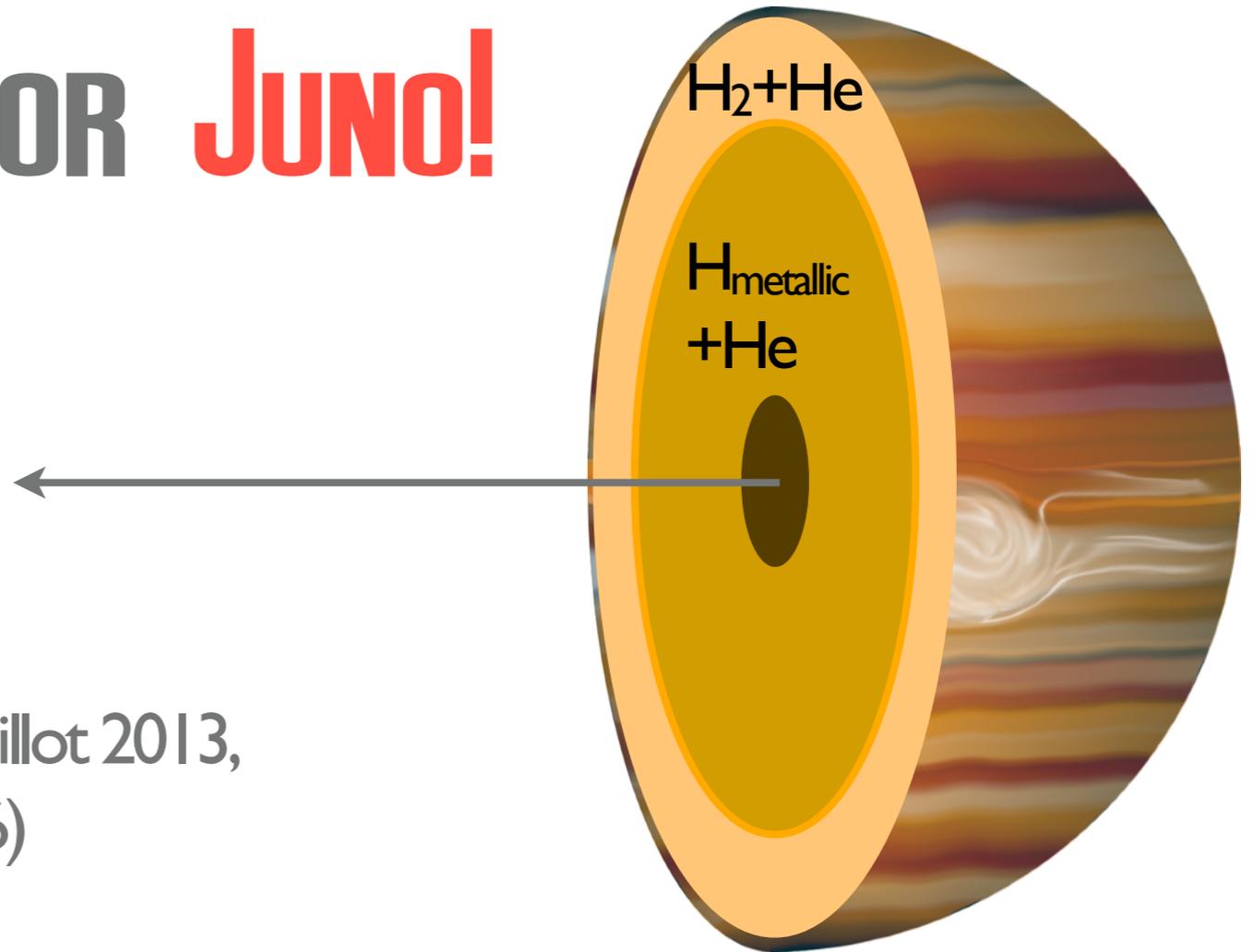
WHAT DO WE KNOW ABOUT JUPITER?

JUPITER'S INTERIOR JUNO!

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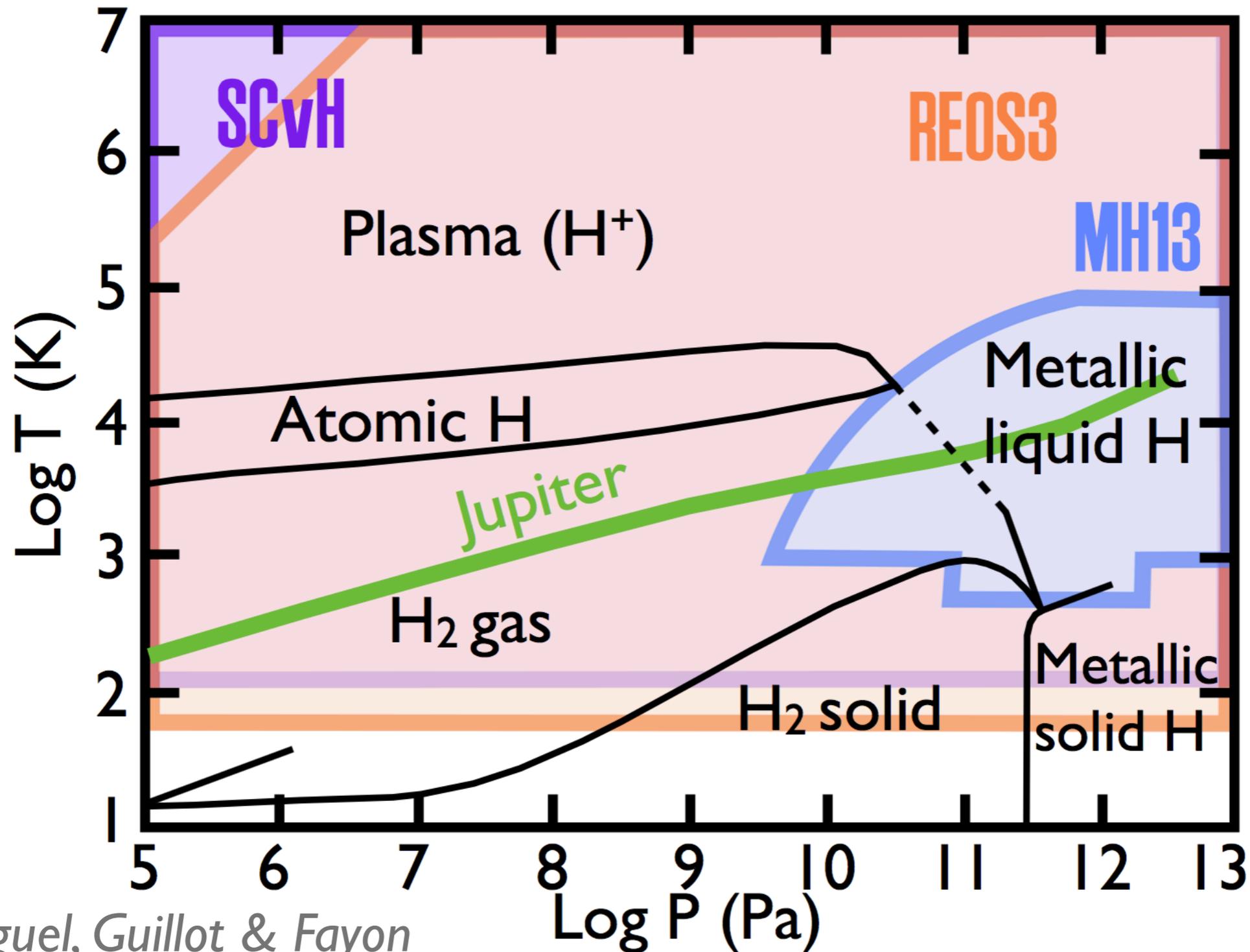
R, M, J₂, J₄, J₆, Y, ...

MODELING JUPITER'S INTERIOR: EOS

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

Yamila Miguel

MODELING JUPITER'S INTERIOR: EOS

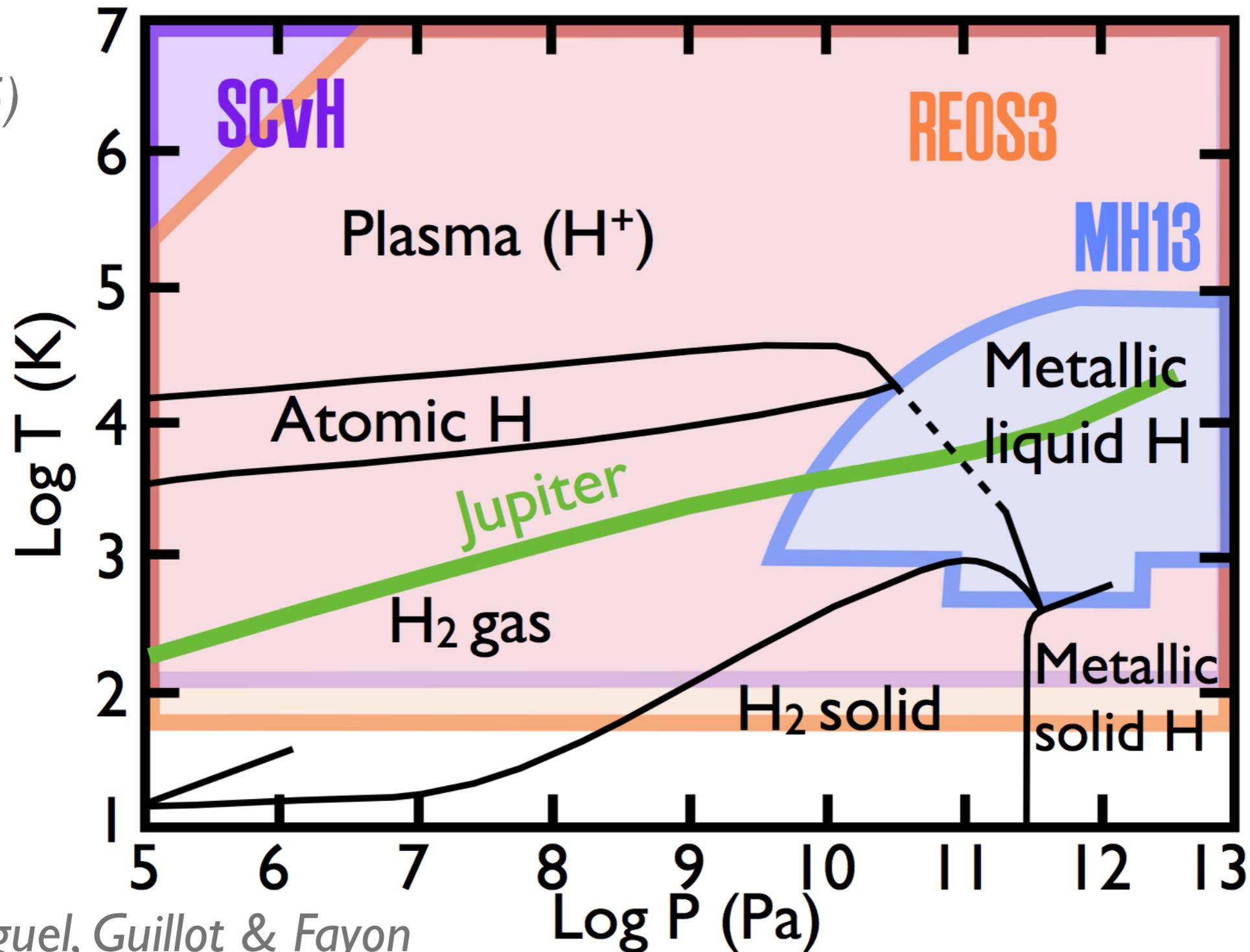


Miguel, Guillot & Fayon
(A&A 2016)

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MODELING JUPITER'S INTERIOR: EOS

Saumon
+ (1995)

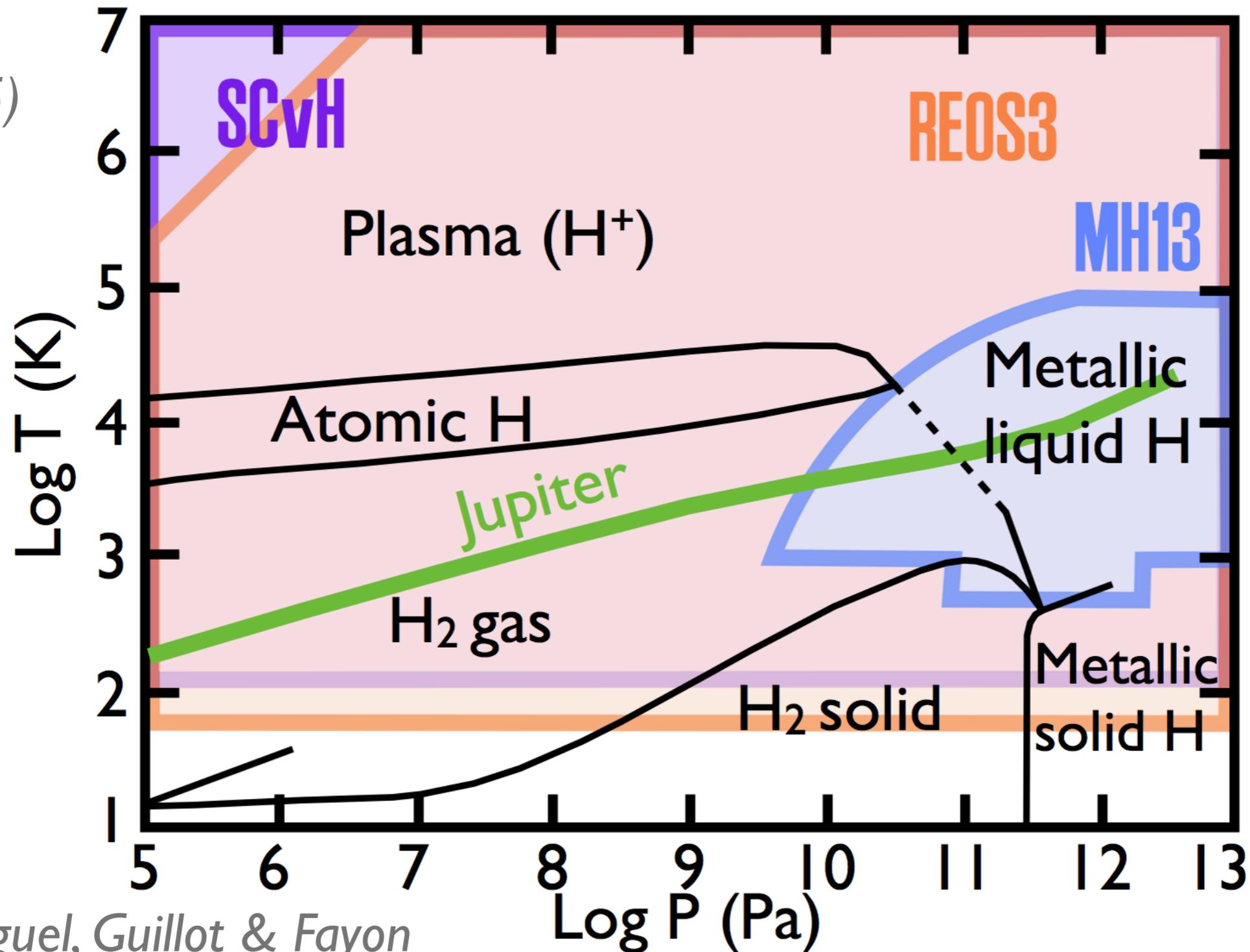


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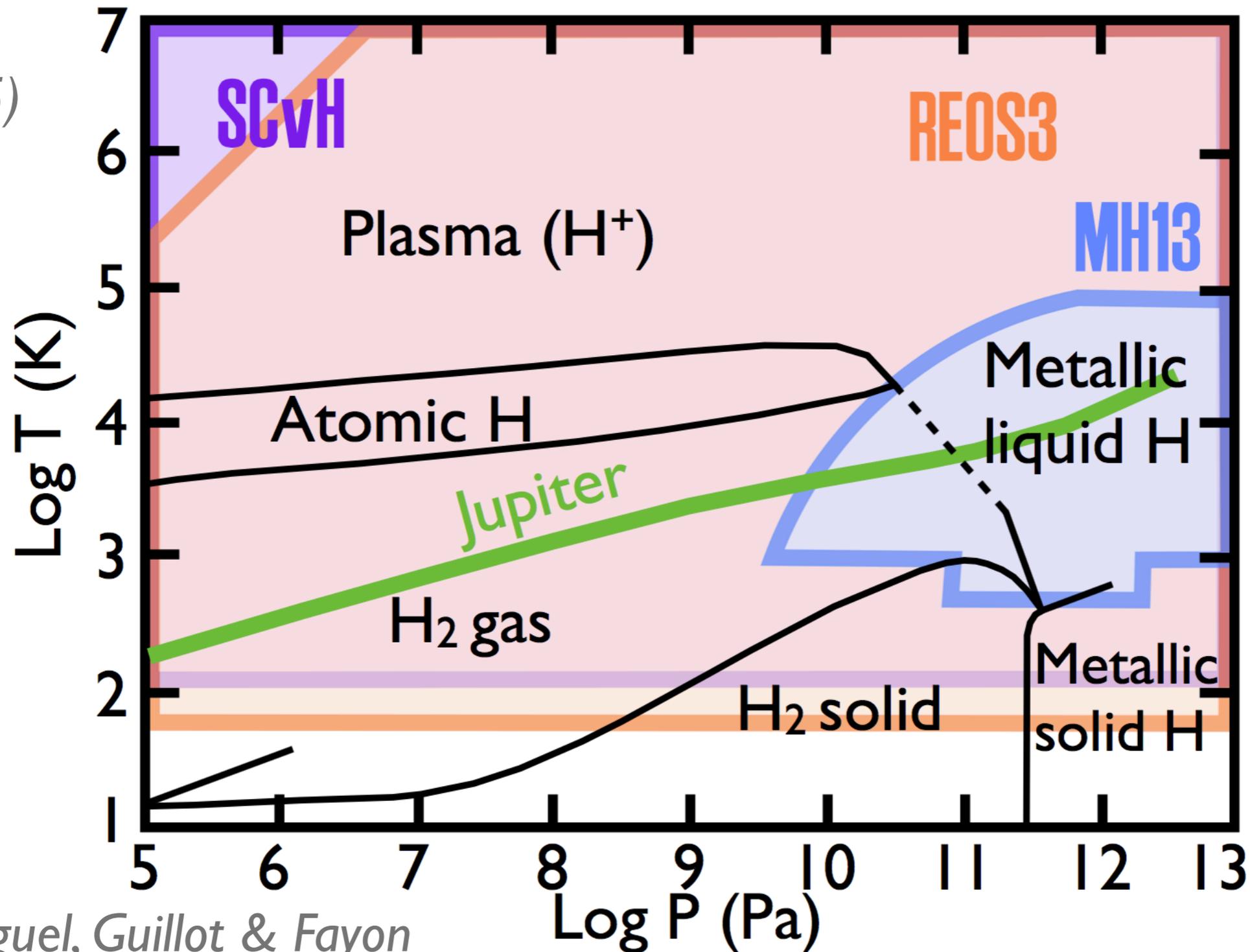
Becker+
(A&A 2014)

Miguel, Guillot & Fayon
(A&A 2016)

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MODELING JUPITER'S INTERIOR: EOS

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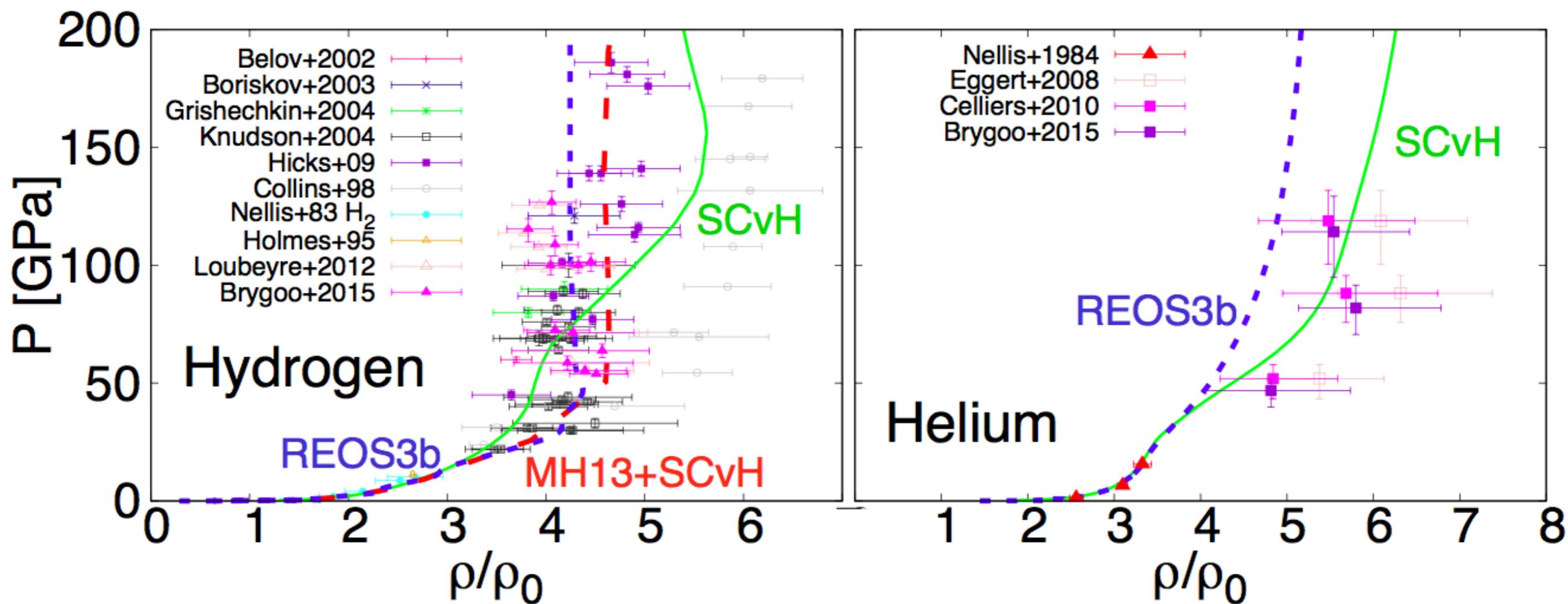
Becker+
(A&A 2014)

Militzer &
Hubbard
(ApJ 2013)

Miguel, Guillot & Fayon
(A&A 2016)

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EOS : COMPARISON WITH EXPERIMENTS



MODELING JUPITER'S INTERIOR

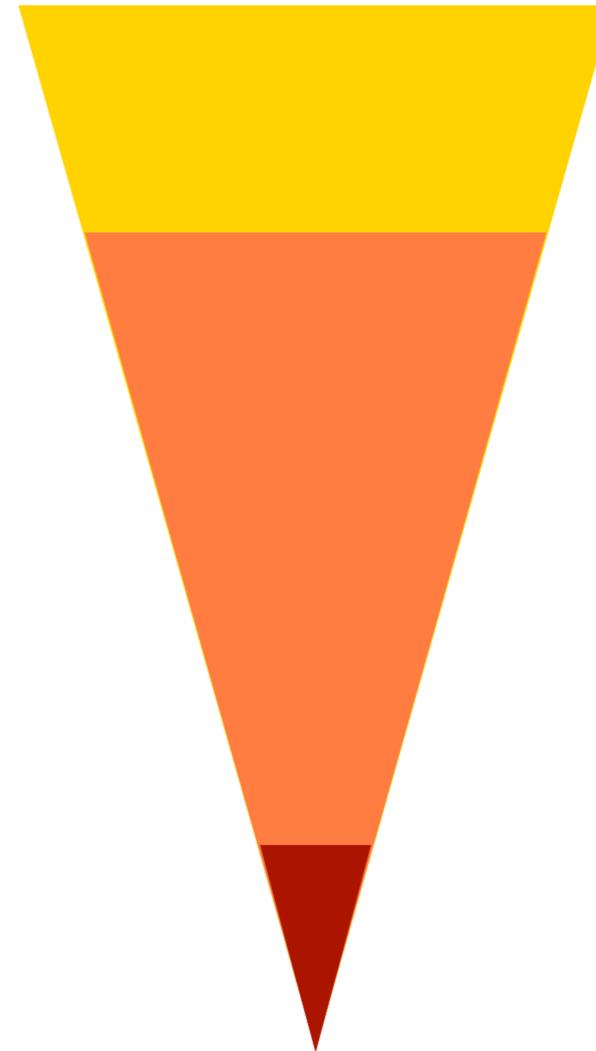
CEPAM (Guillot & Morel 1995)

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

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

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

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



MODELING JUPITER'S INTERIOR: OPTIMISATIONS

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

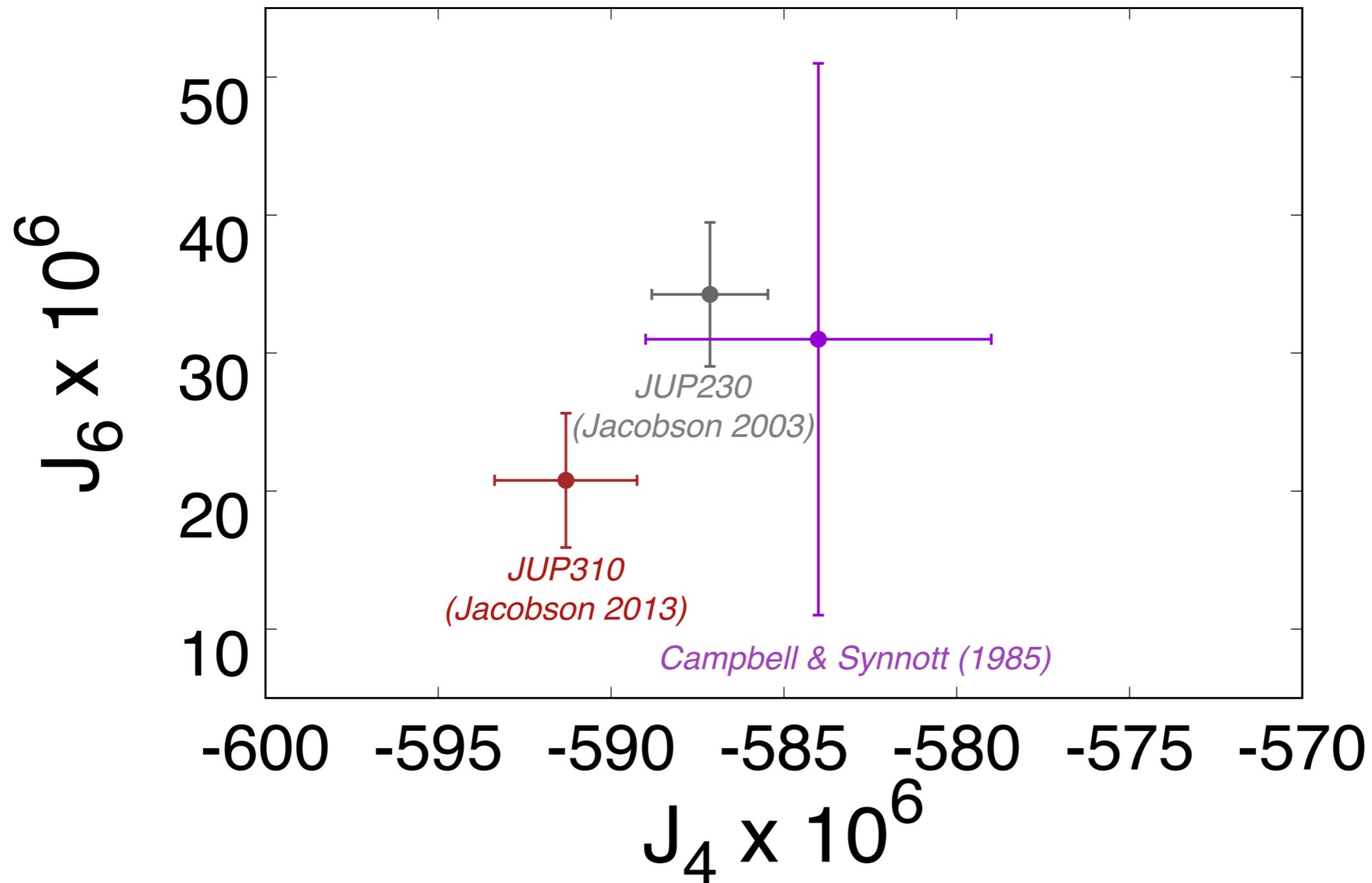
CEPAM (Guillot & Morel 1995)

Radius, J_2 , J_4

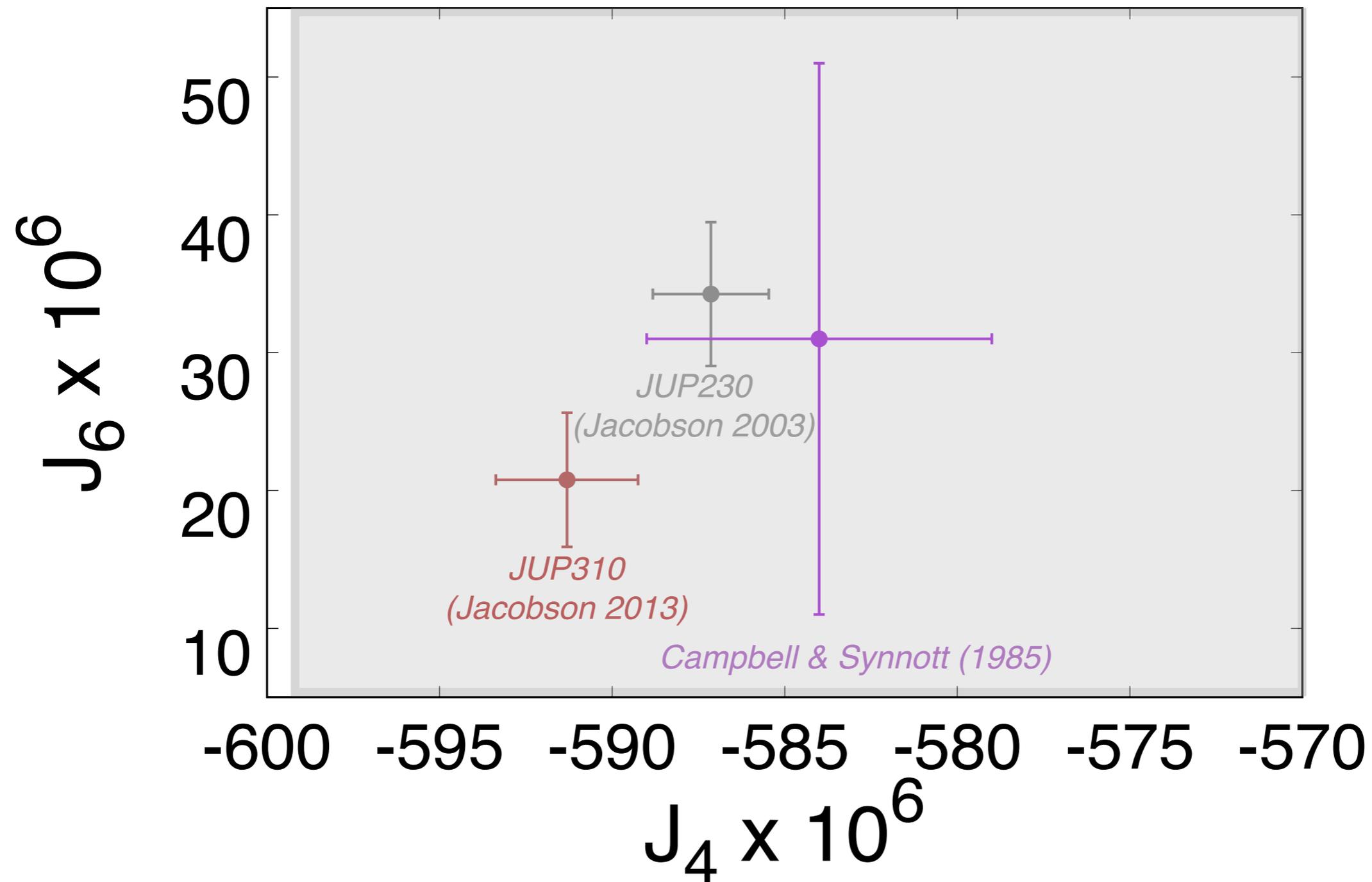
$$f = \left(\frac{R_{cepam} - R_{obs}}{\sigma(R)} \right)^2 + \left(\frac{J2_{cepam} - J2_{Juno}}{\sigma(J2)} \right)^2 + \left(\frac{J4_{cepam} - J4_{obs}}{\sigma(J4)} \right)^2$$

We find a solution!

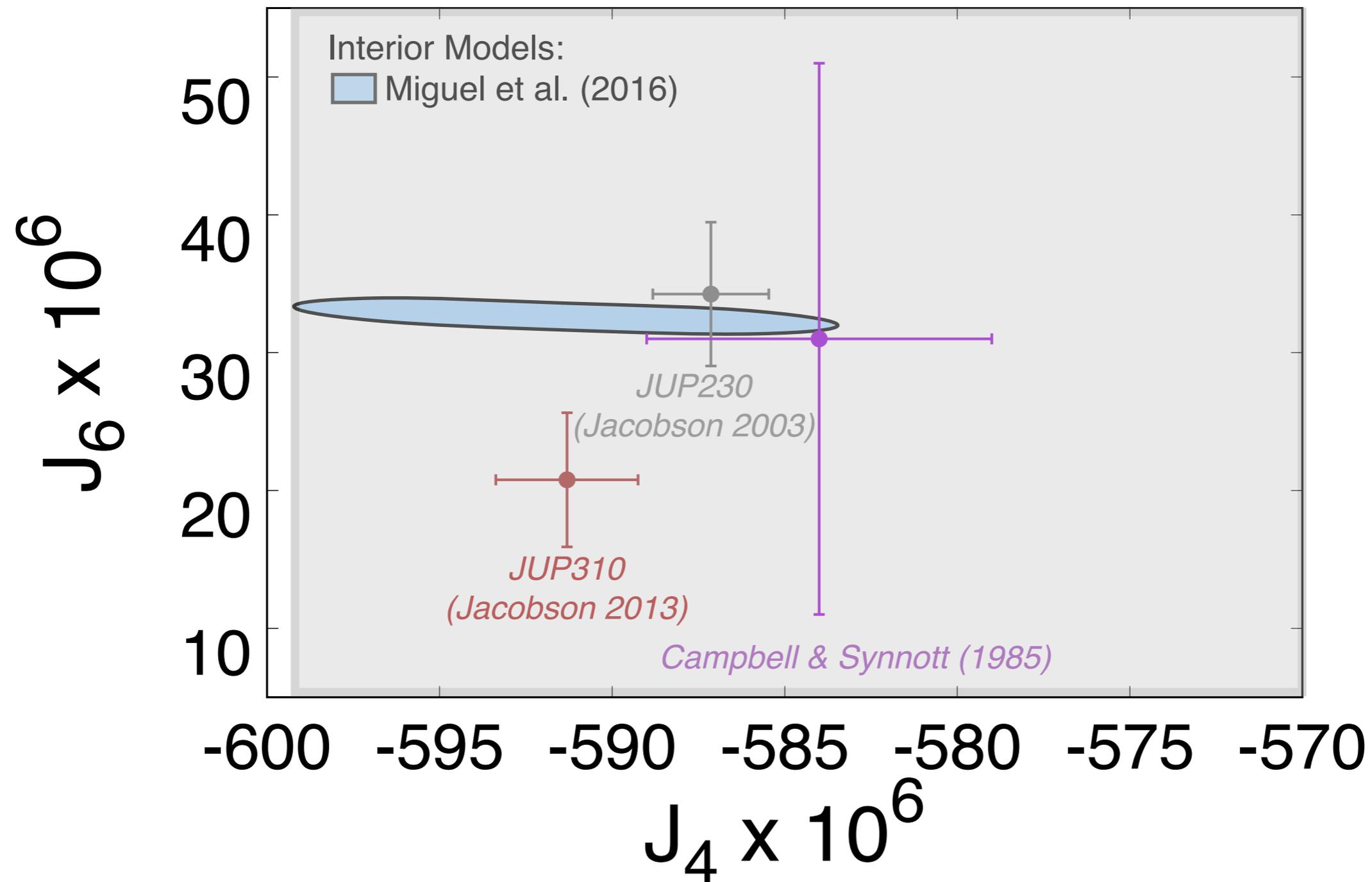
JUPITER'S INTERIOR : PRE - JUNO RESULTS



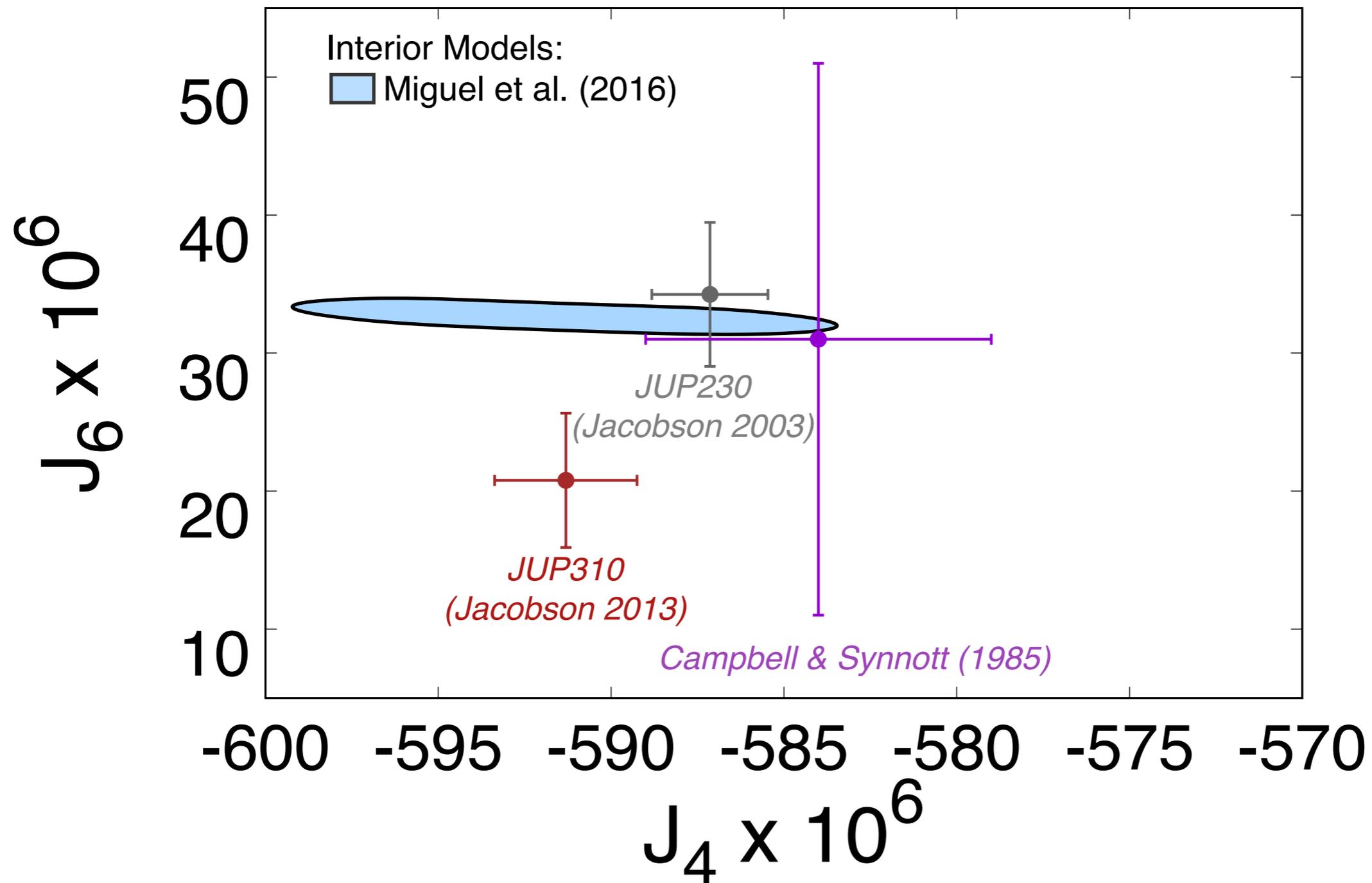
JUPITER'S INTERIOR : PRE - JUNO RESULTS



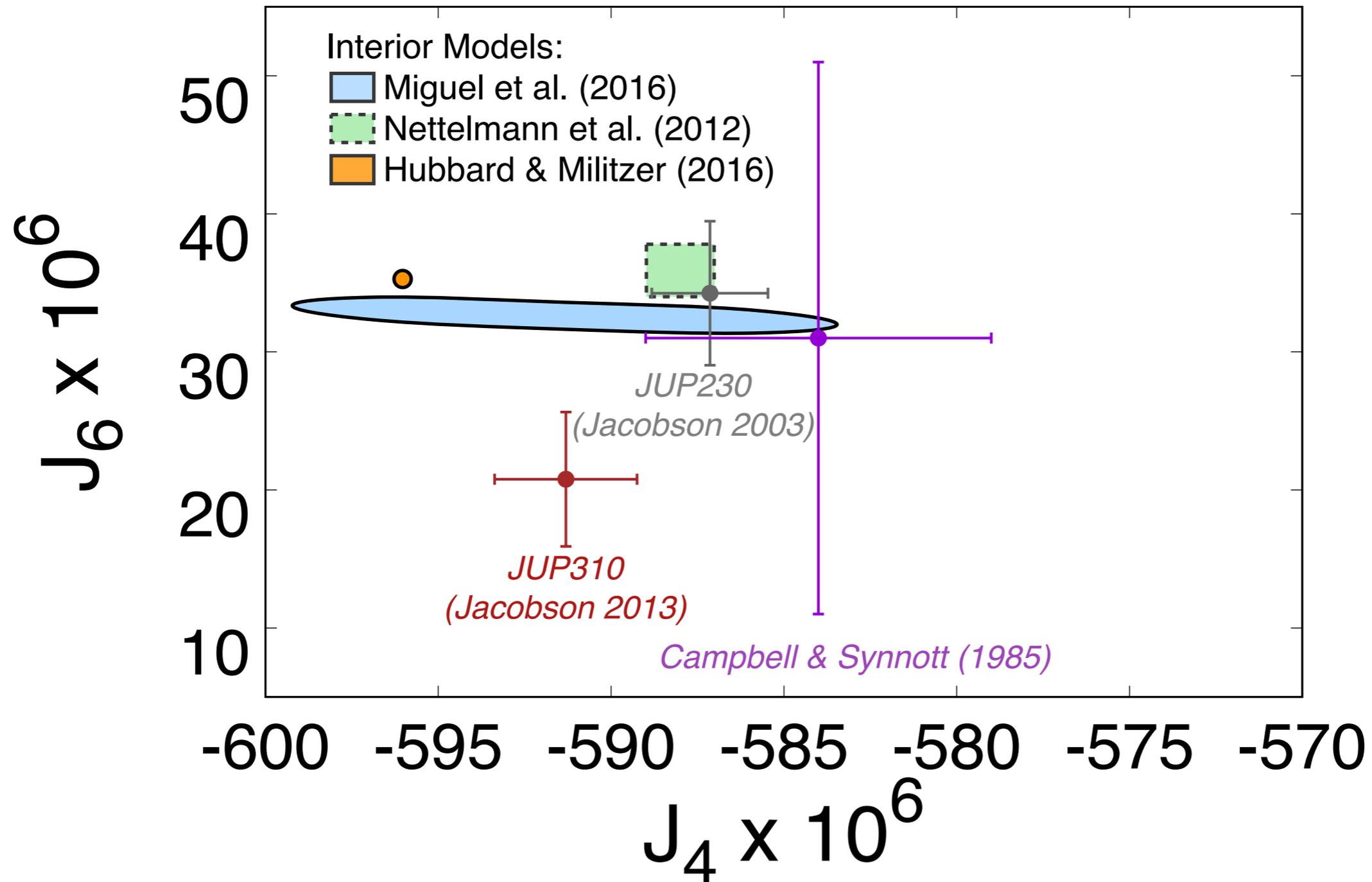
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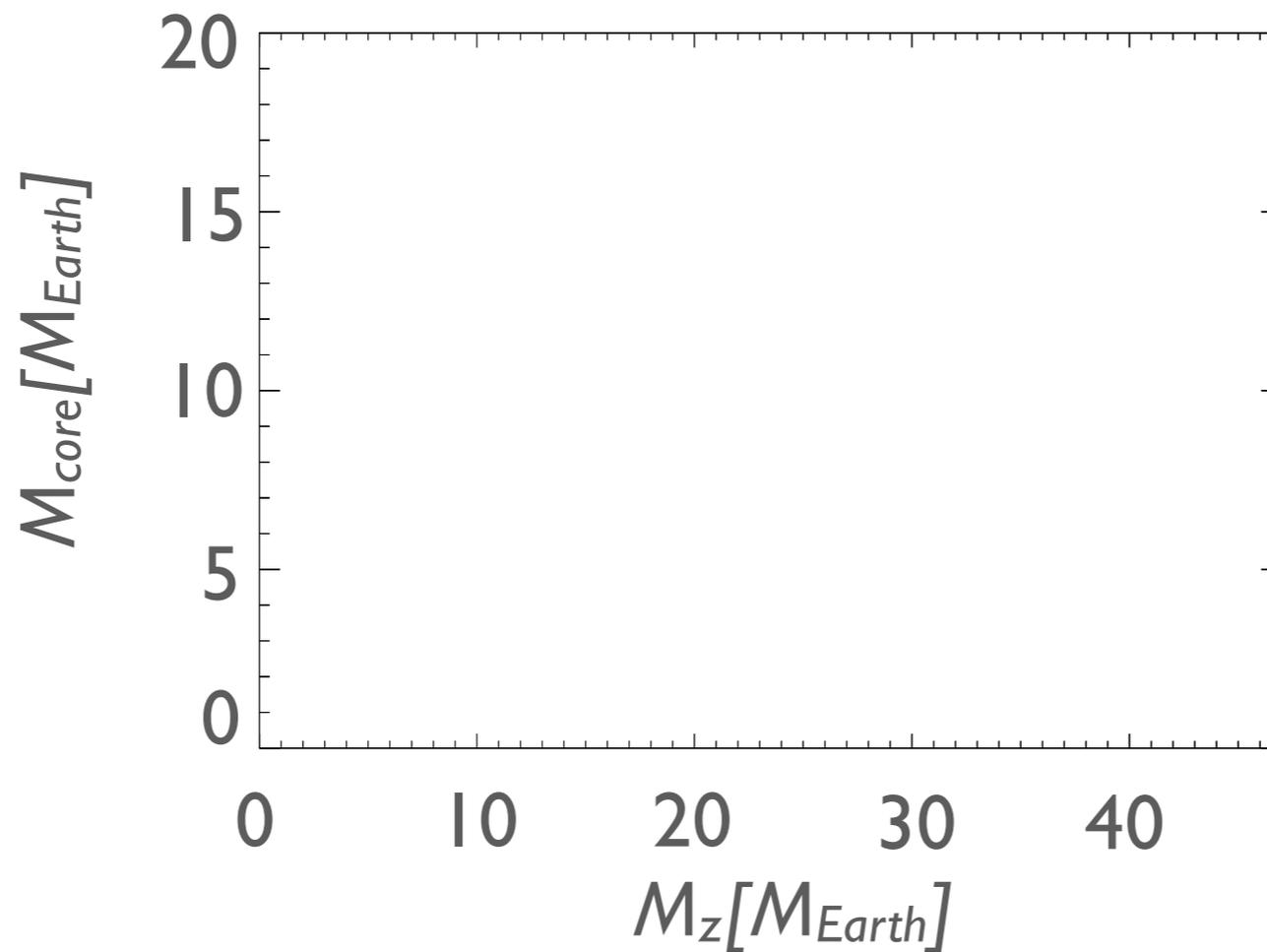
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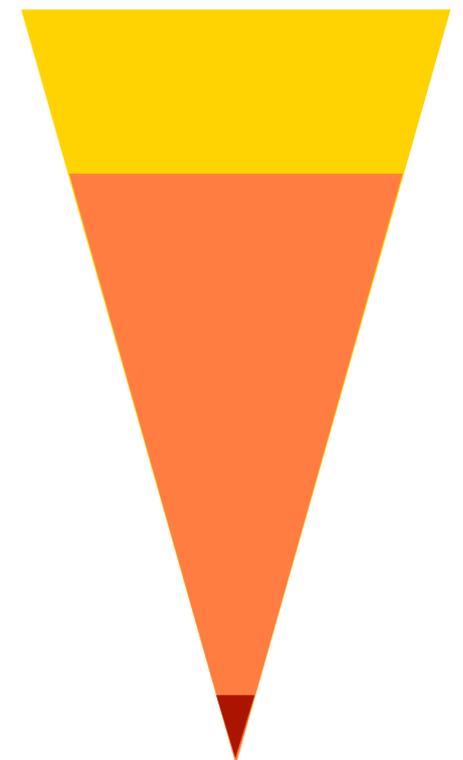
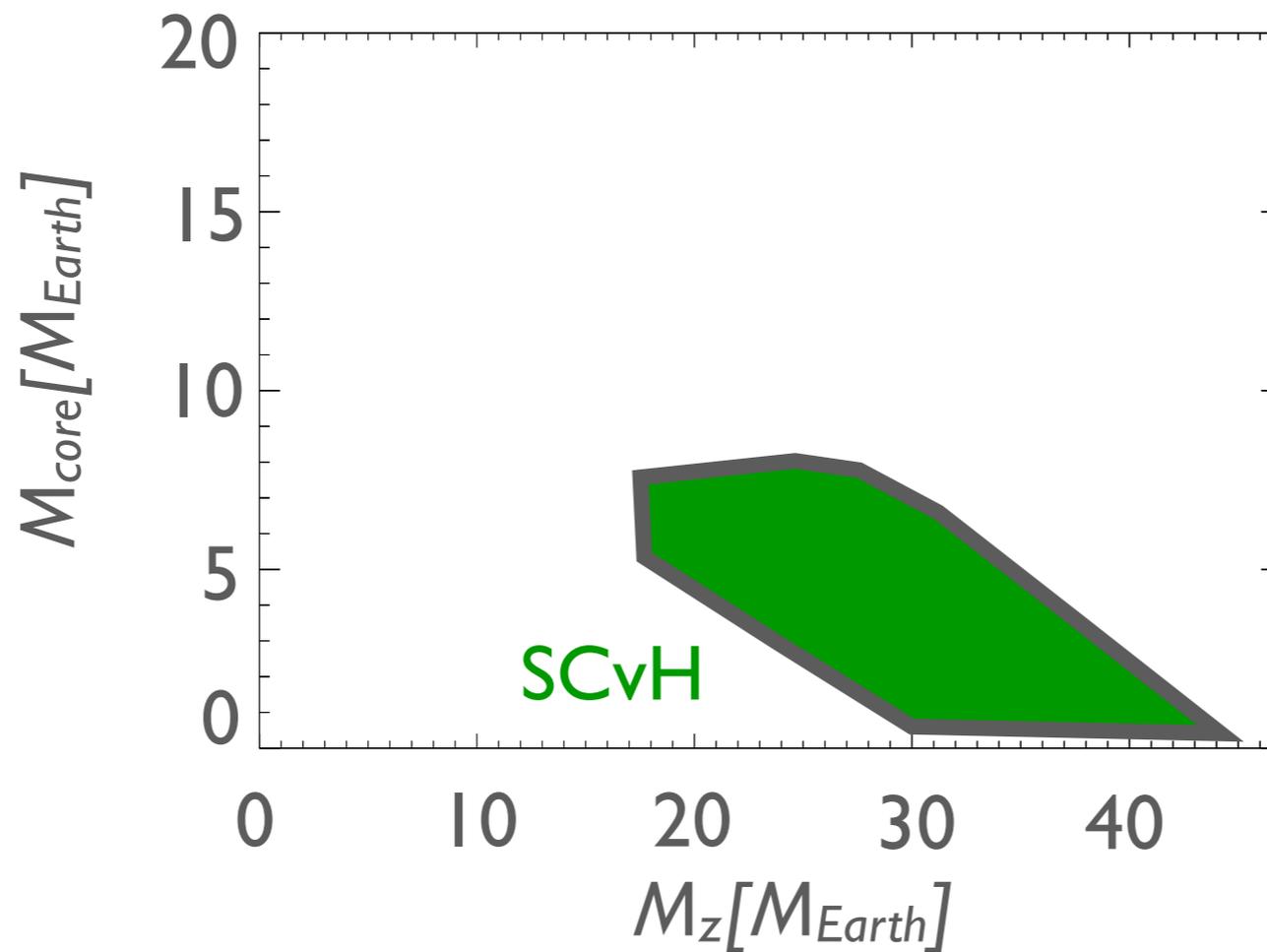
JUPITER'S INTERIOR : DIFFERENT EOS



Miguel, Guillot & Fayon
(A&A 2016)

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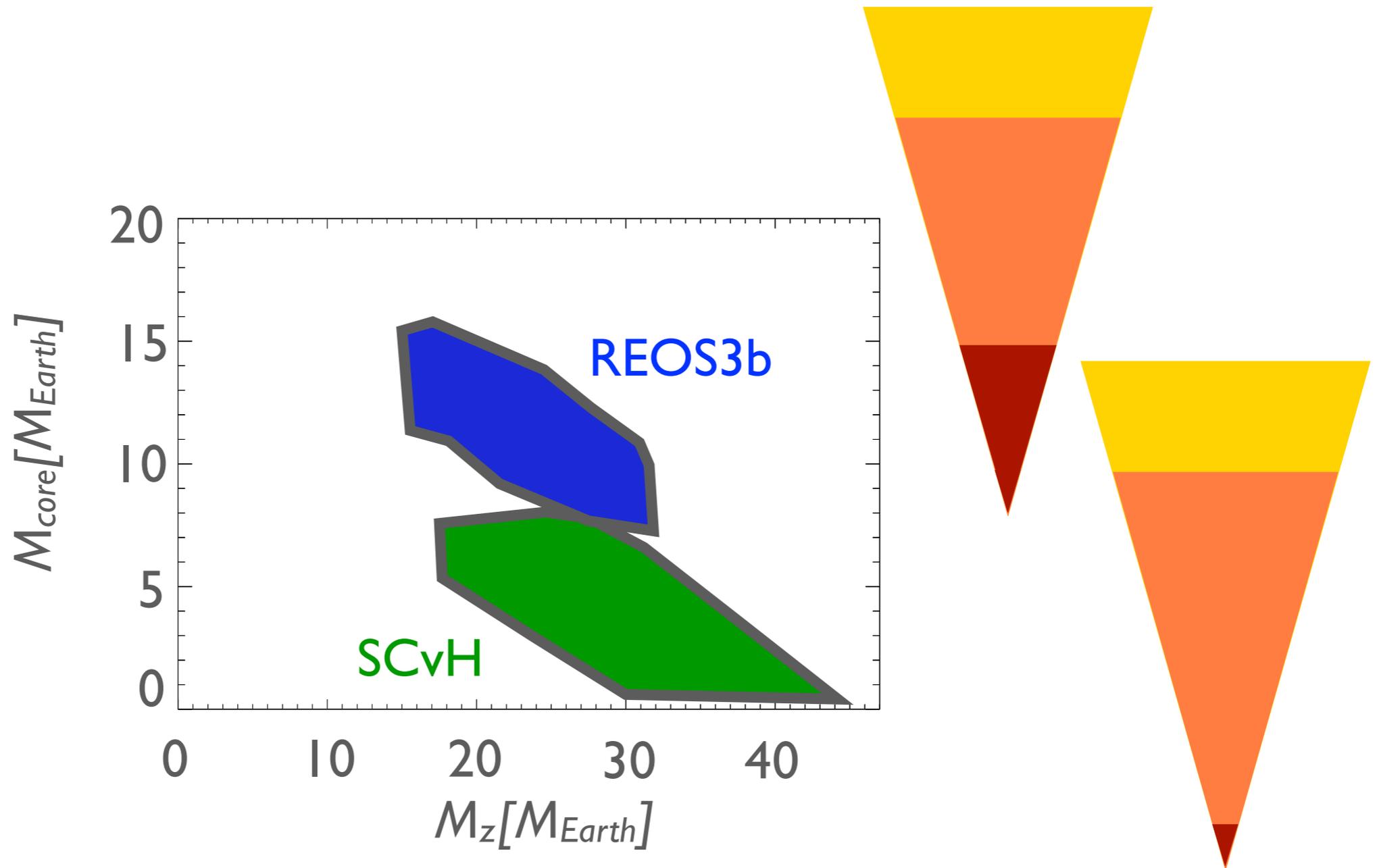
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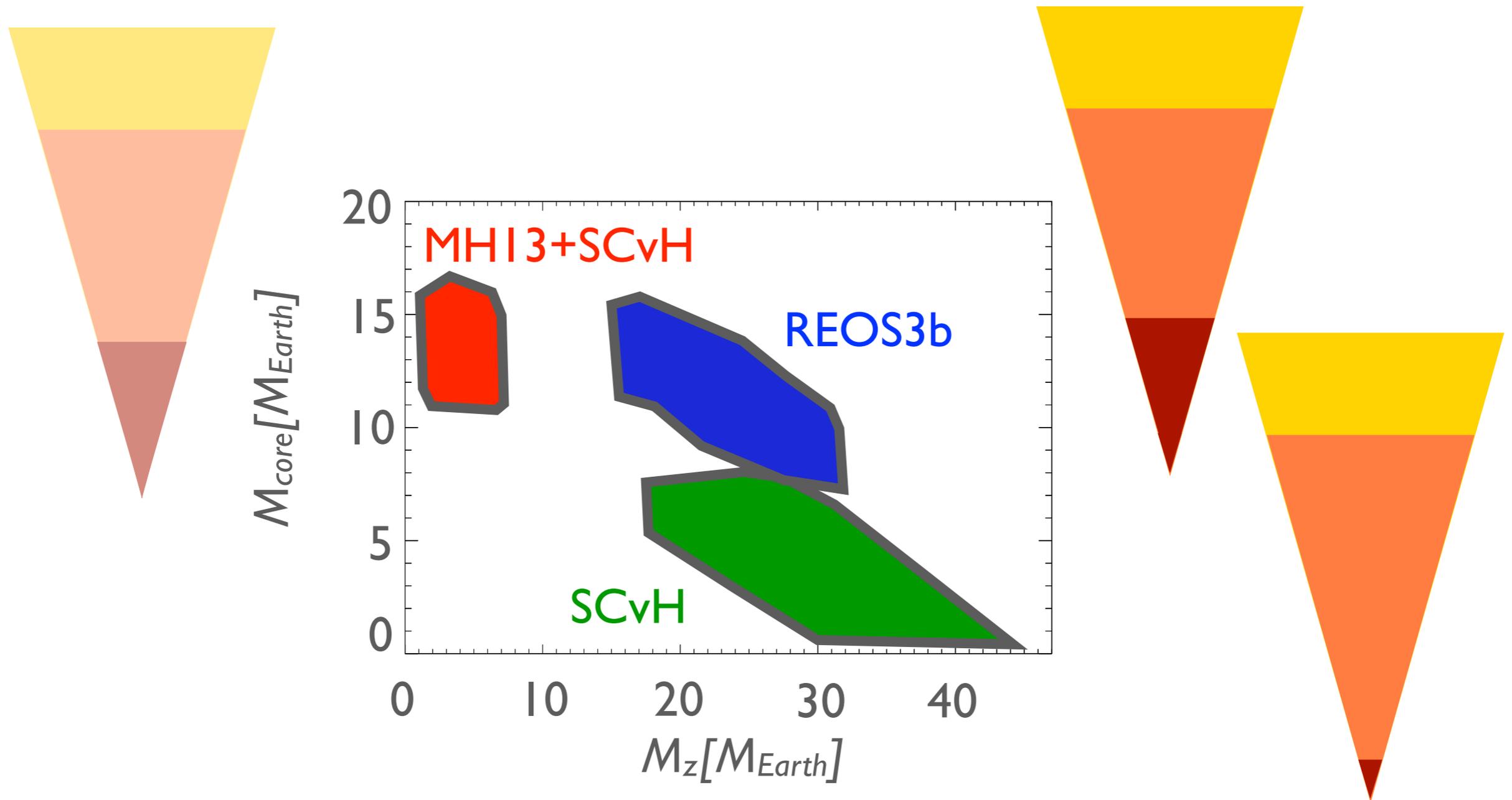
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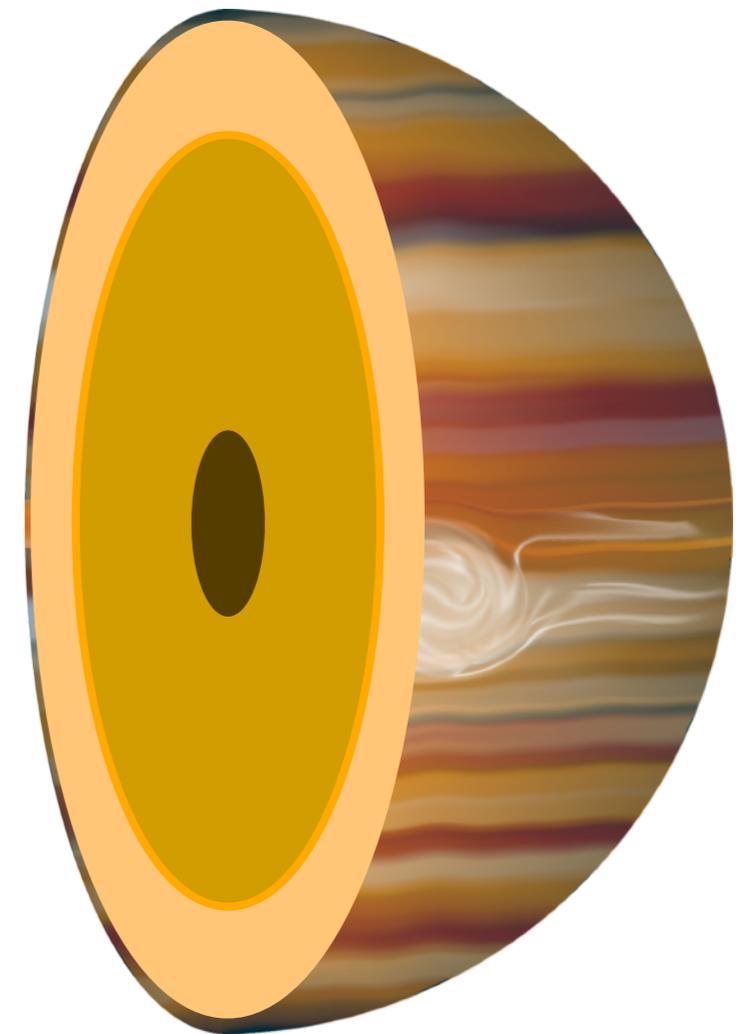


R, M, J₂, J₄, J₆, Y, ...

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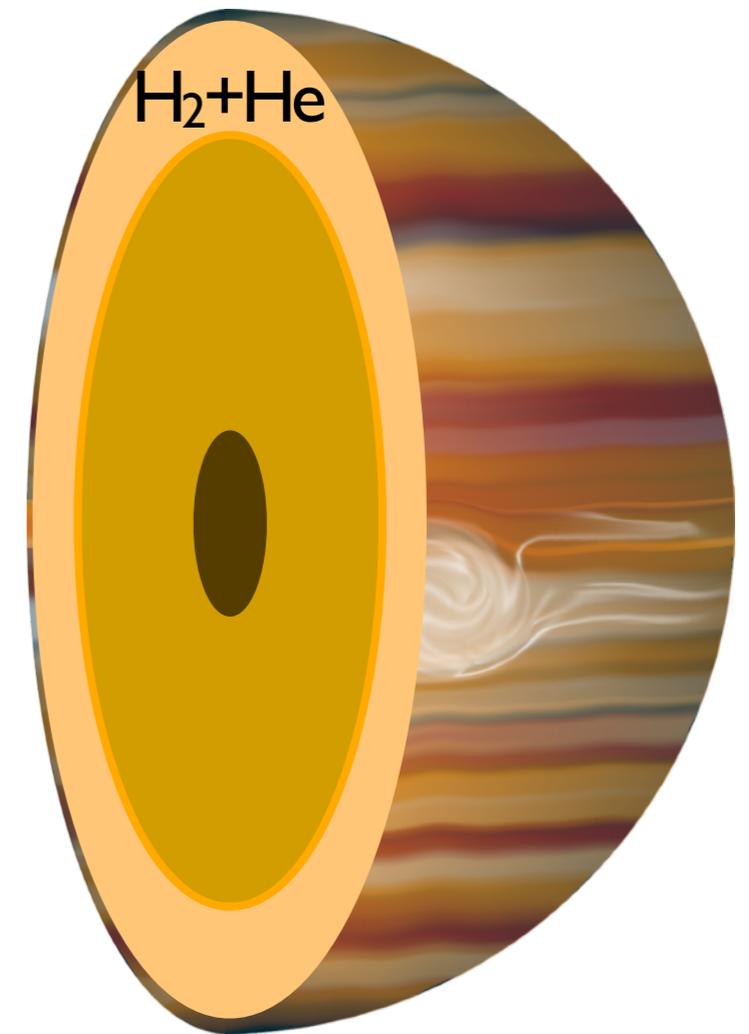


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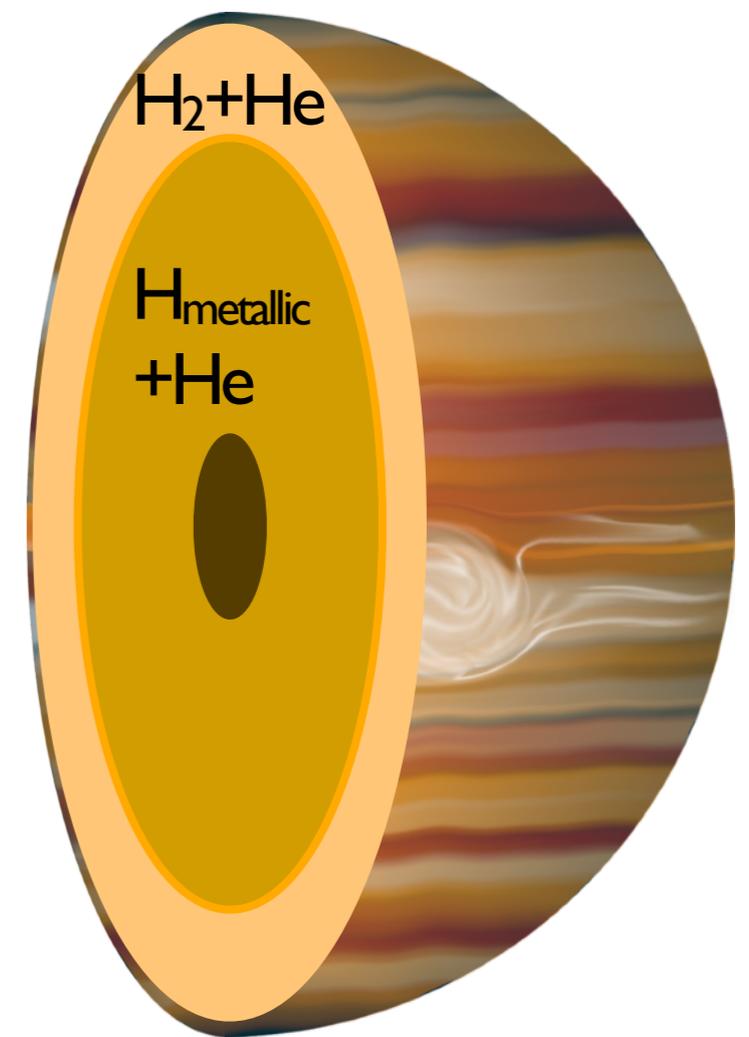


R, M, J₂, J₄, J₆, Y, ...

Miguel, Guillot & Fayon (A&A 2016)

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JUPITER'S INTERIOR : PRE - JUNO RESULTS



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

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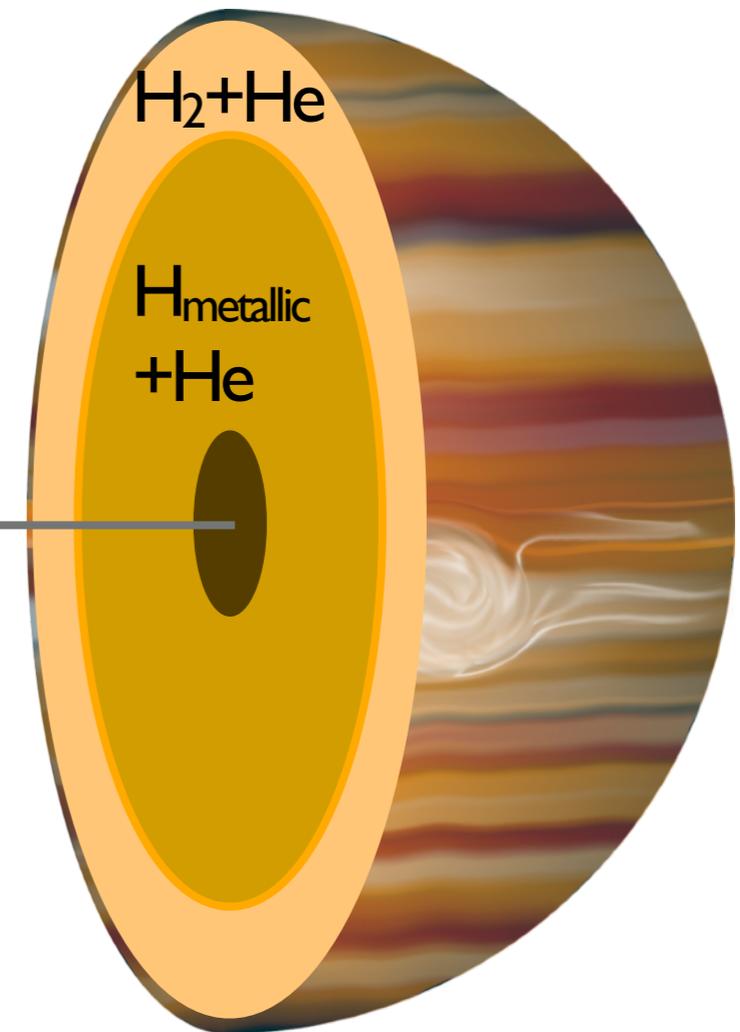
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JUPITER'S INTERIOR : PRE - JUNO RESULTS

Recent EOS lead to large
core masses

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

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



R, M, J₂, J₄, J₆, Y, ...

Miguel, Guillot & Fayon (A&A 2016)

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JUPITER INTERIOR: FIRST JUNO RESULTS



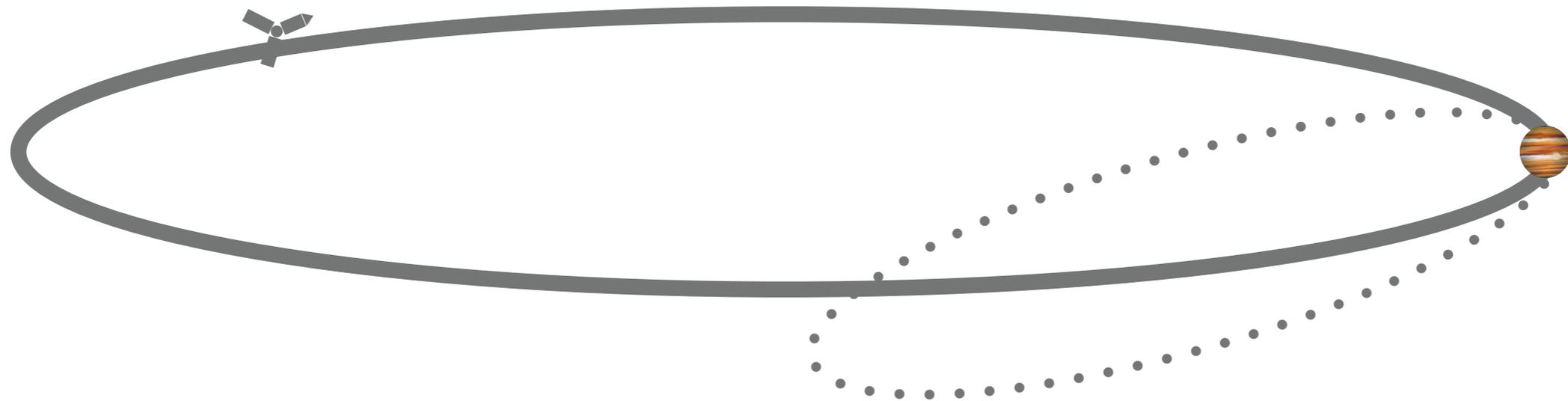
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JUNO MISSION : ORBIT



53 days

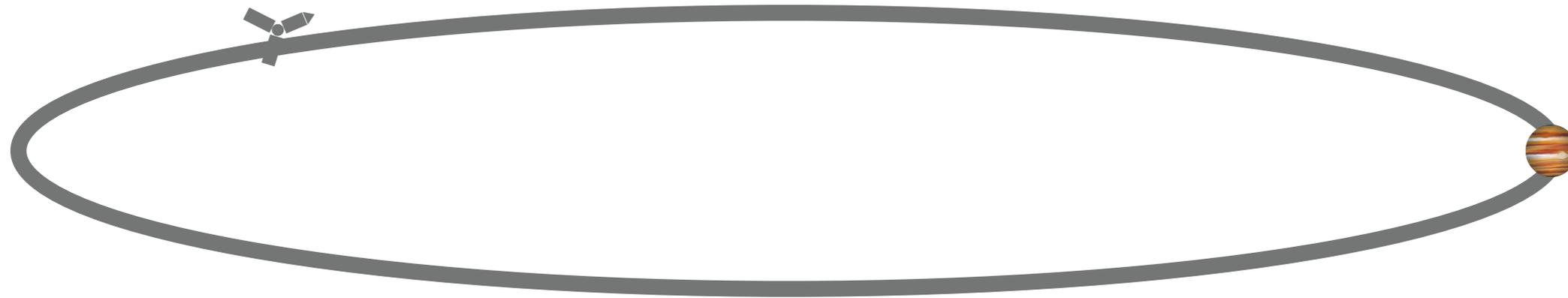




JUNO MISSION : ORBIT



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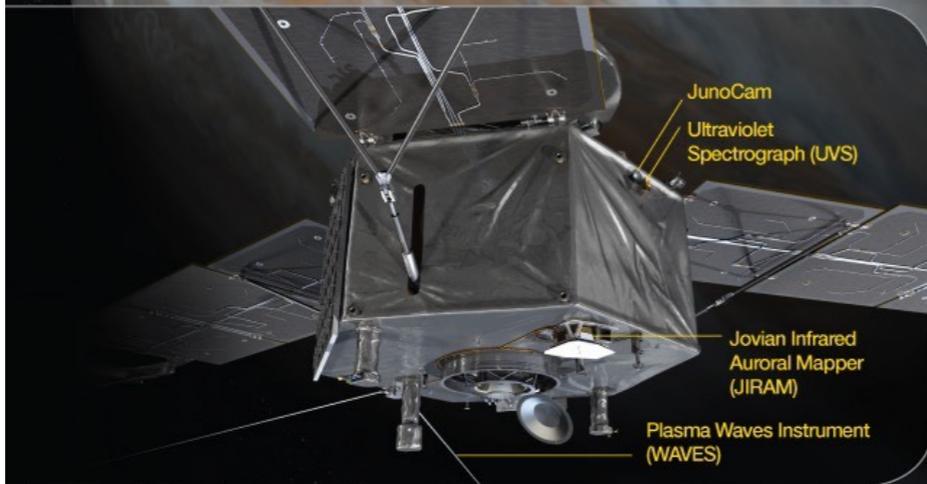


JUNO MISSION : INSTRUMENTS

National Aeronautics and
Space Administration



Juno Spacecraft



SPACECRAFT DIMENSIONS

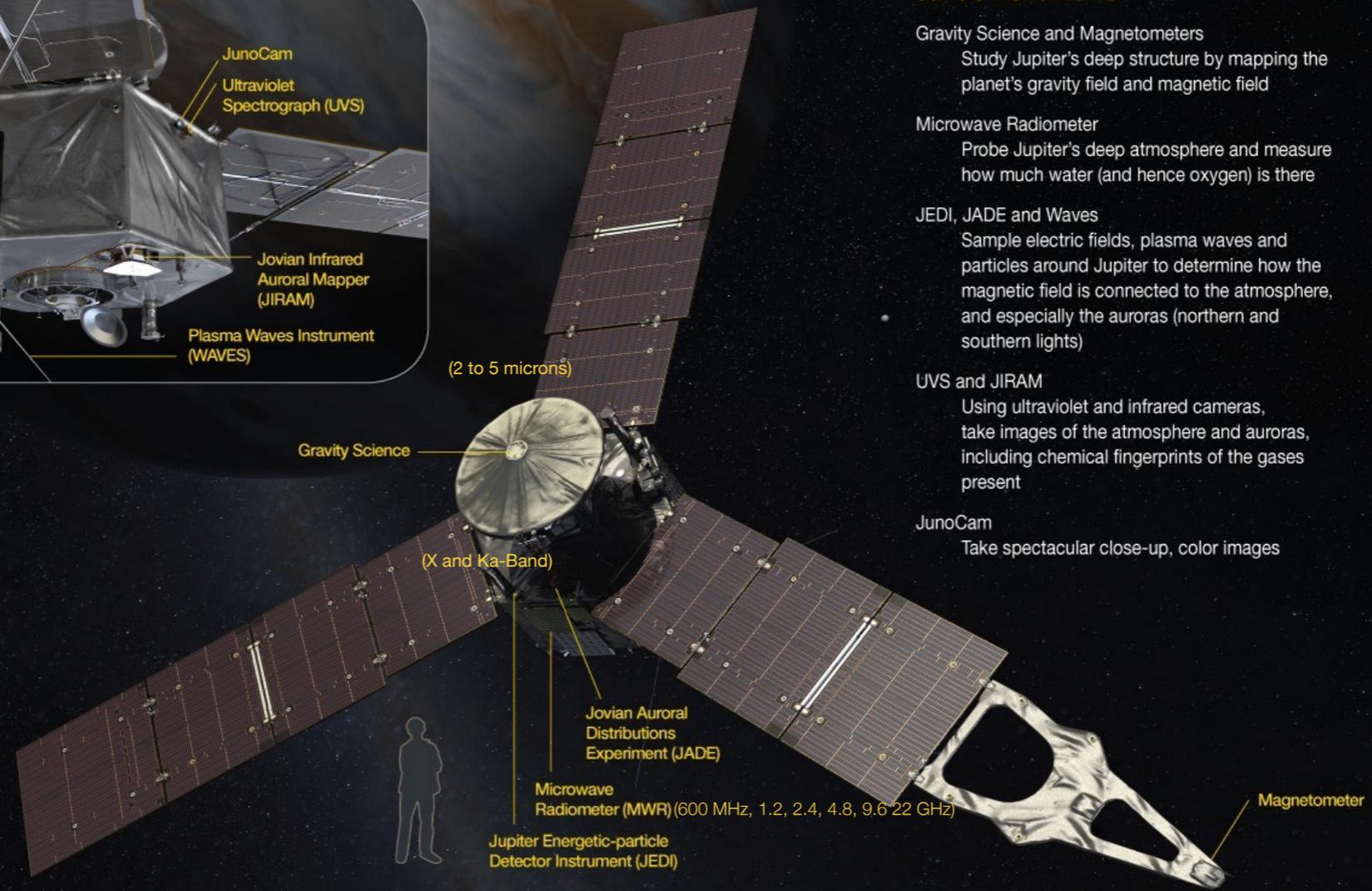
Diameter: 66 feet (20 meters)
Height: 15 feet (4.5 meters)

For more information:
missionjuno.swri.edu &
www.nasa.gov/juno

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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)

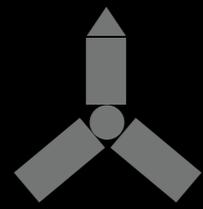
UVS and JIRAM

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

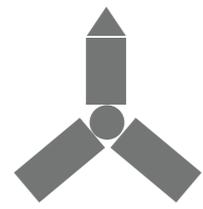
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JUNO MISSION : SOME PHOTOS



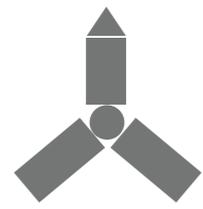
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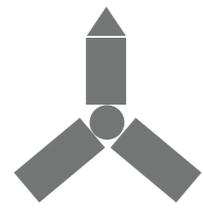
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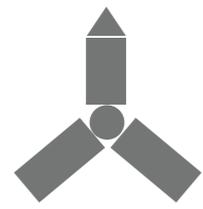
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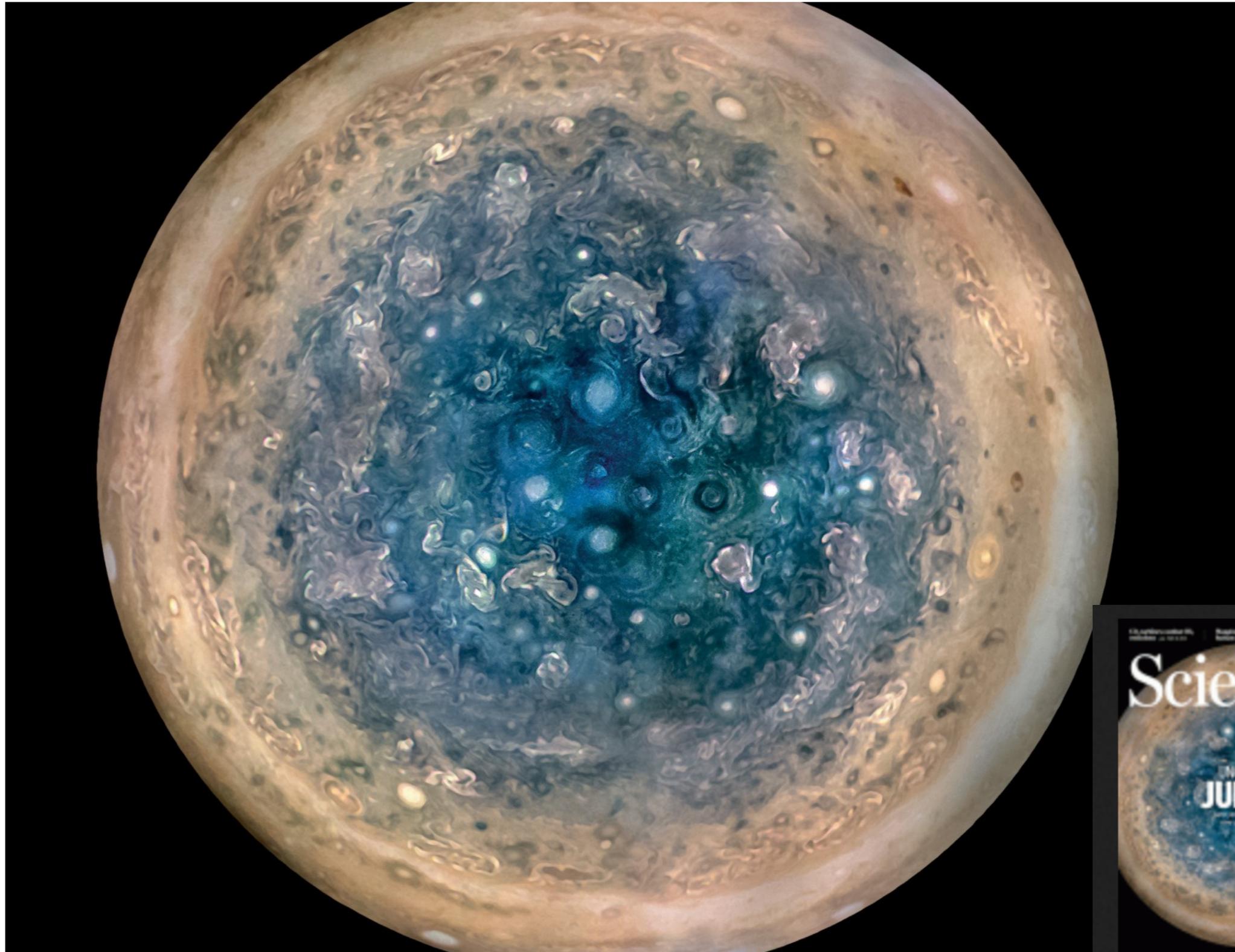
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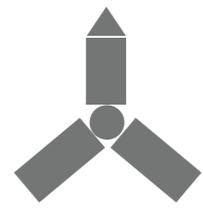
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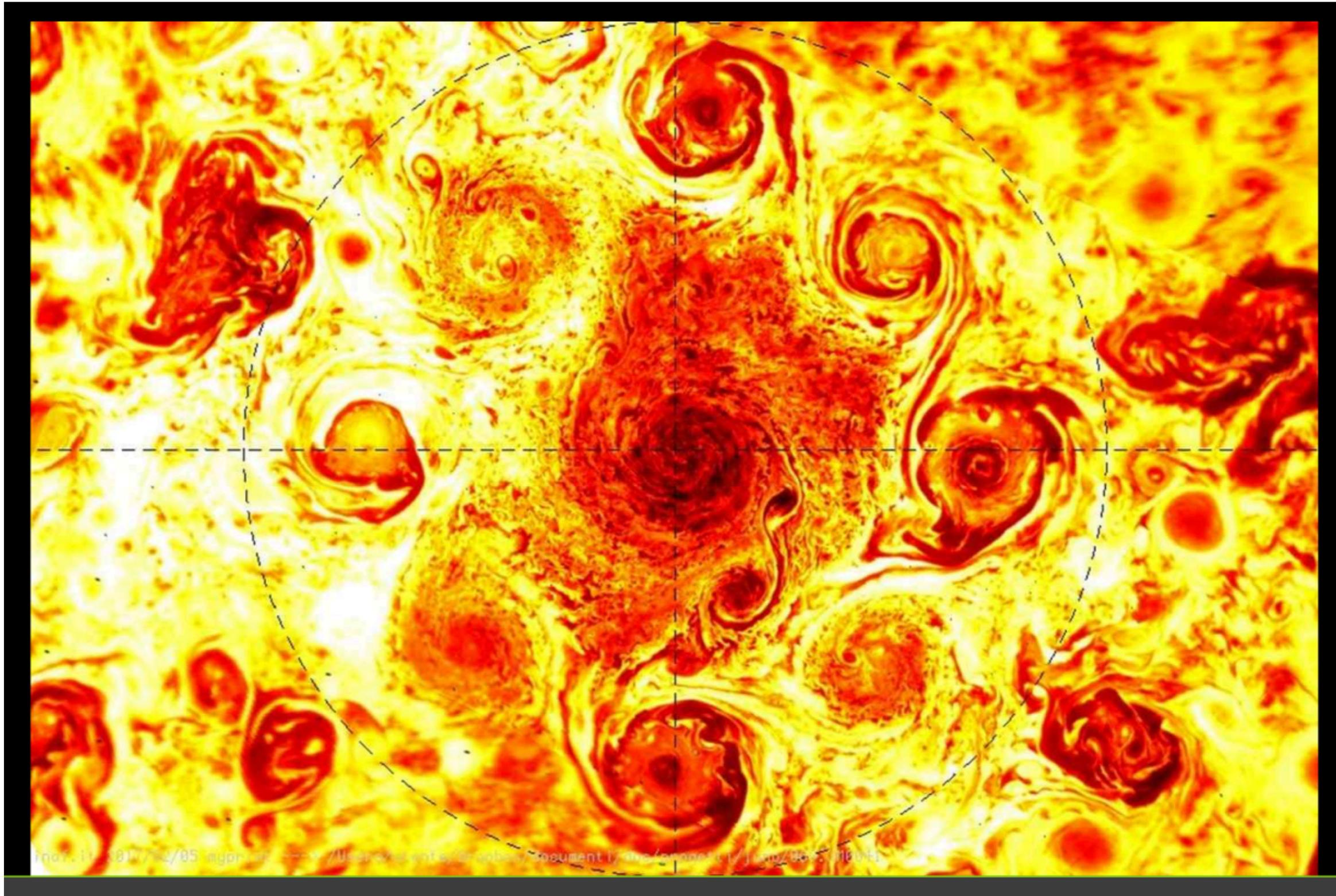
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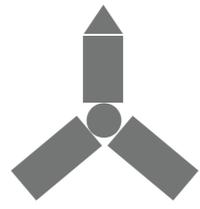
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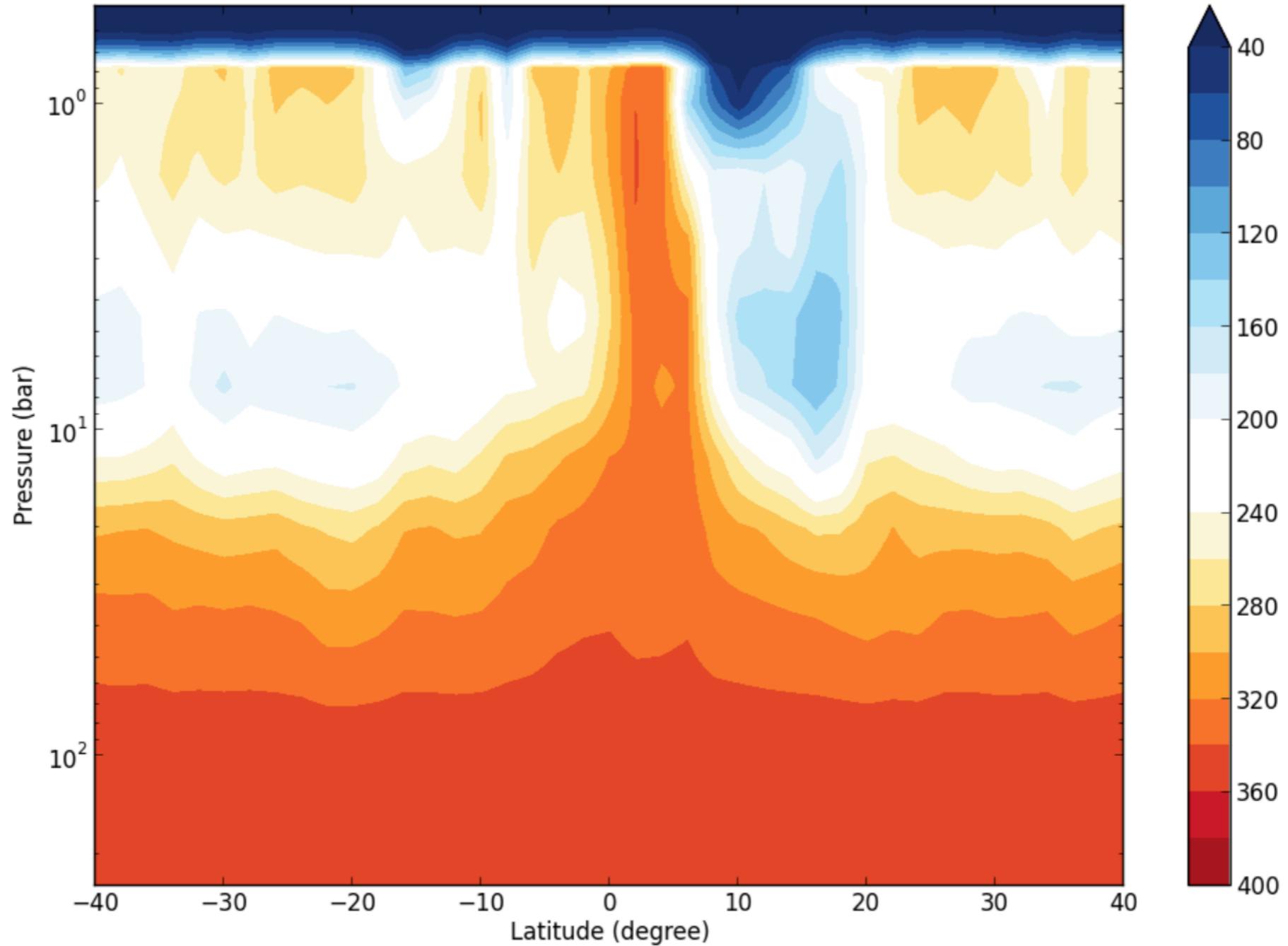
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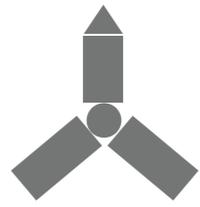
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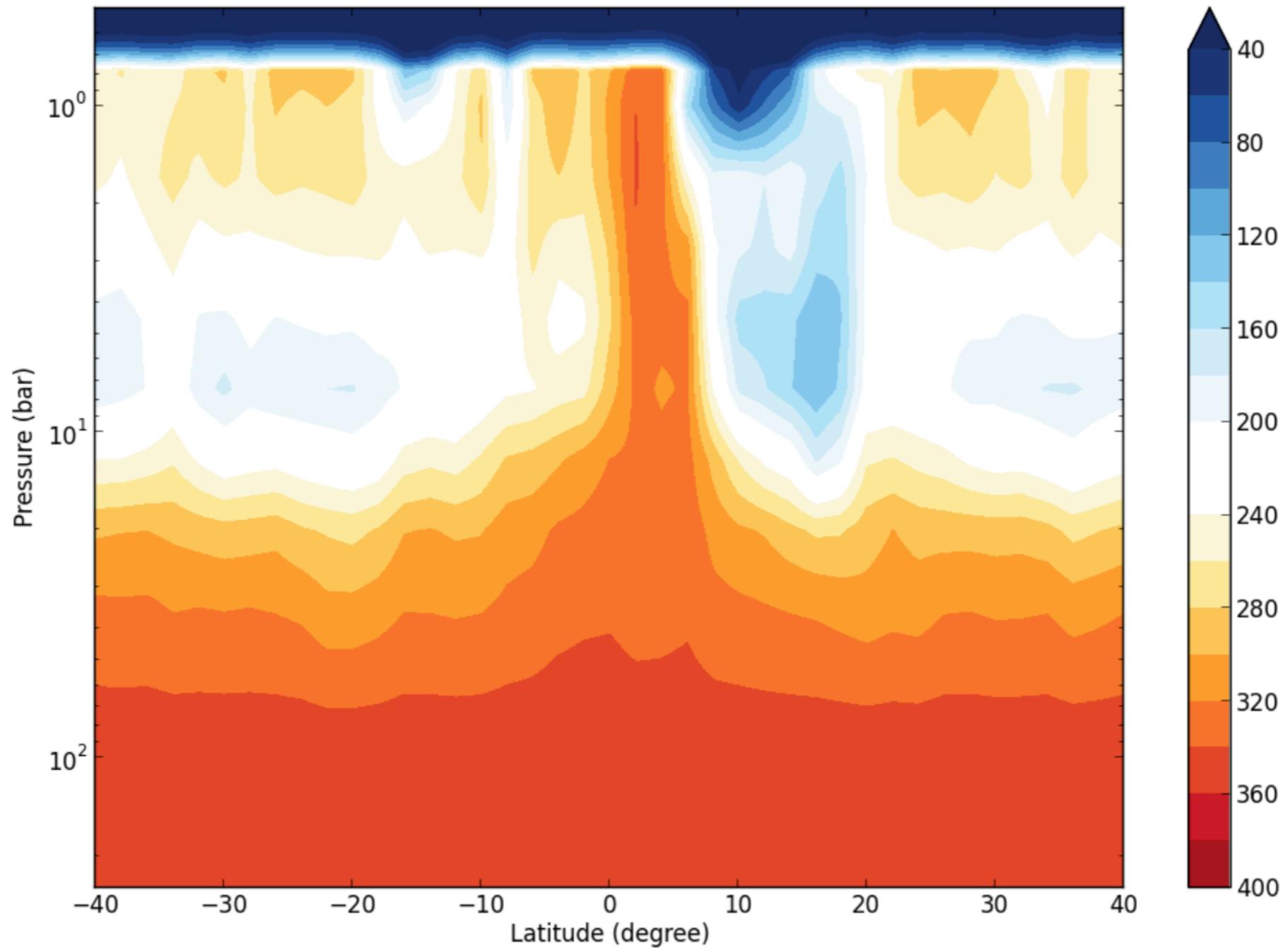
JUNO MISSION : FIRST RESULTS



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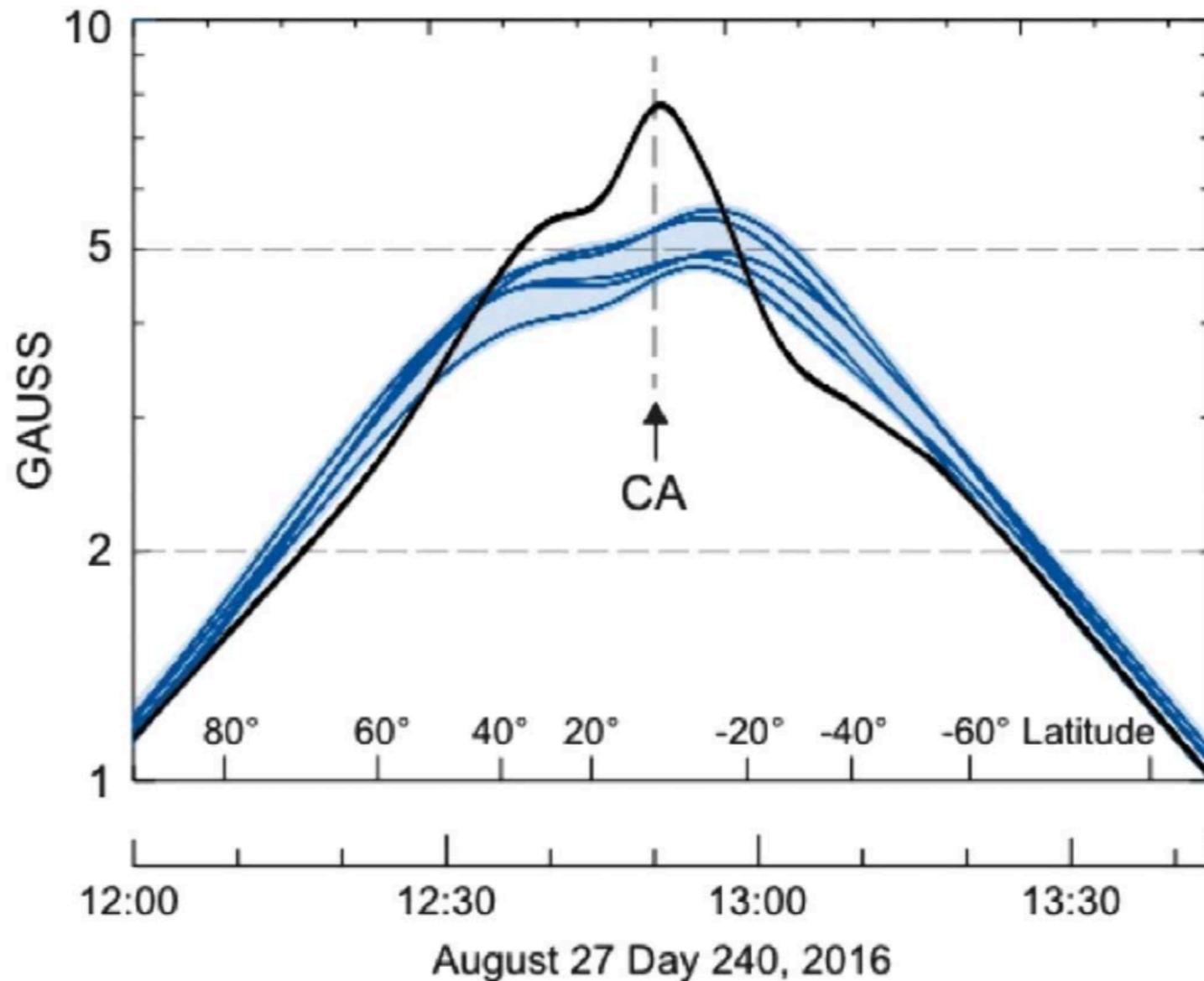
JUNO MISSION : FIRST RESULTS



Bolton+ (Science, in press 2017)

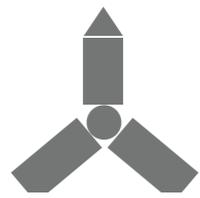
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JUNO MISSION : FIRST RESULTS

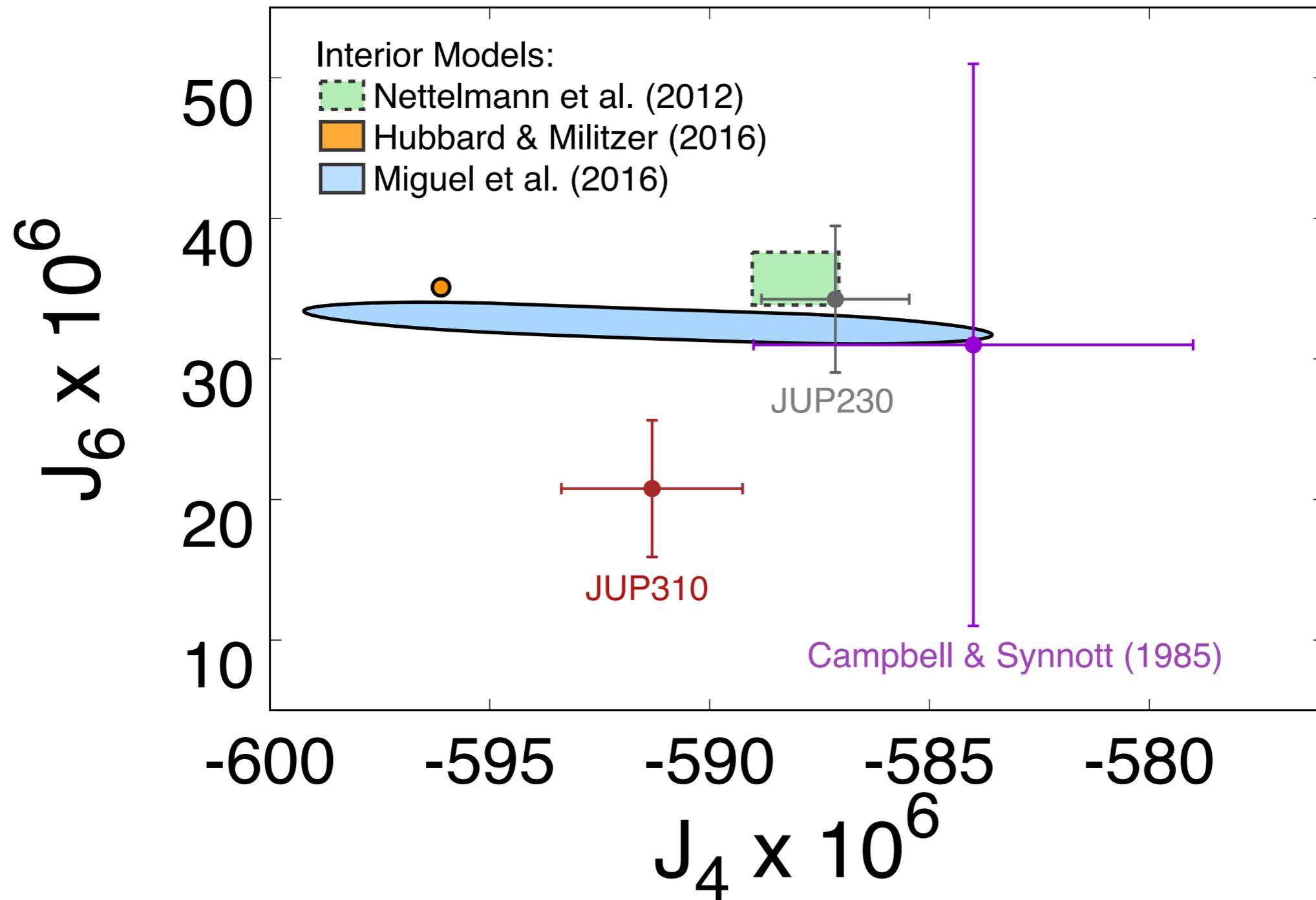


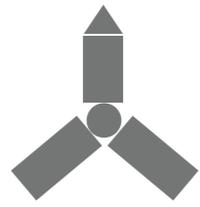
The maximum magnetic field observed was 7.766 G, more than an order of magnitude greater than Earth's.

The rich harmonic content indicated a dynamo generation region not far beneath the surface.

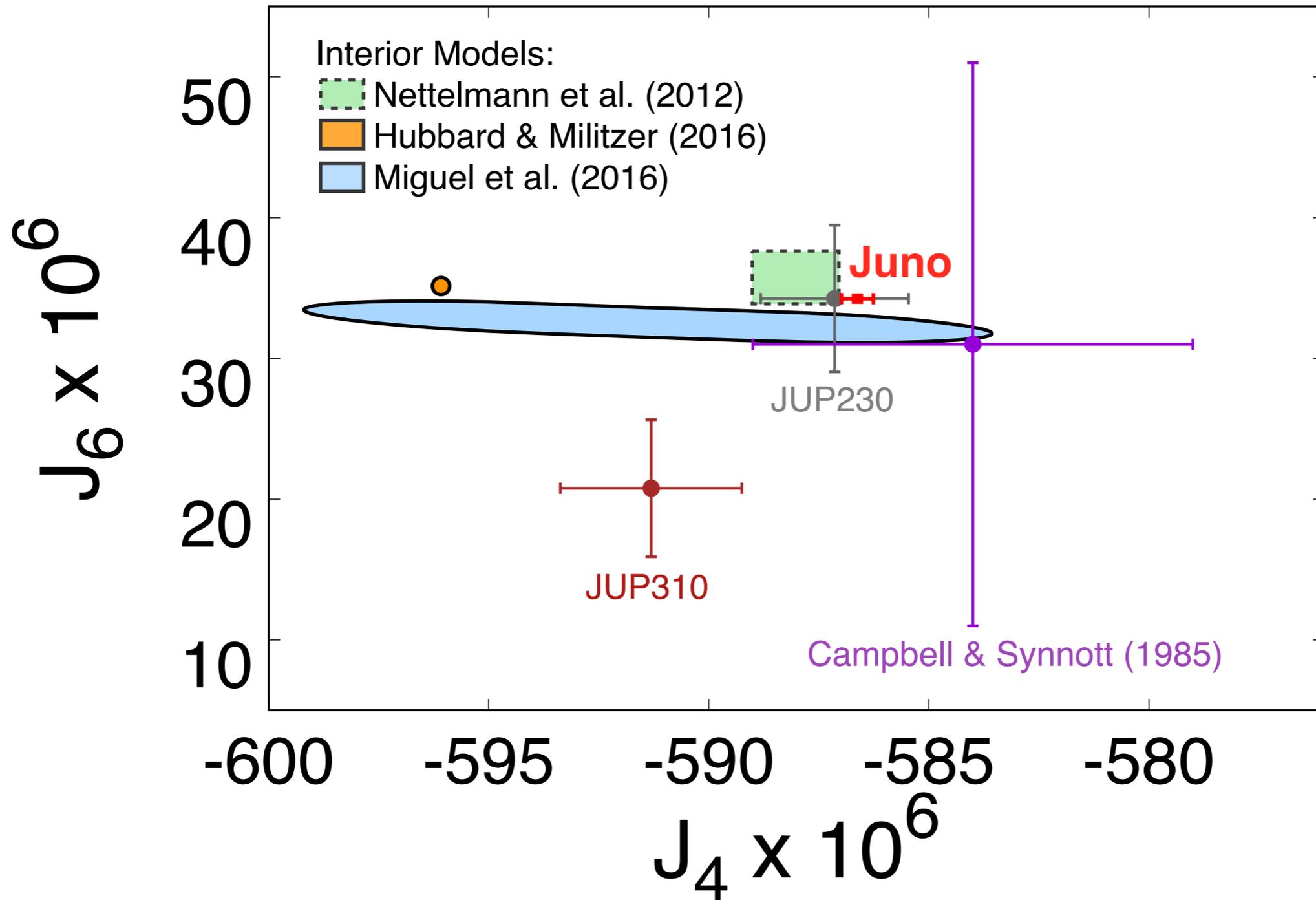


JUNO MISSION : FIRST RESULTS

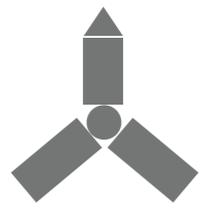




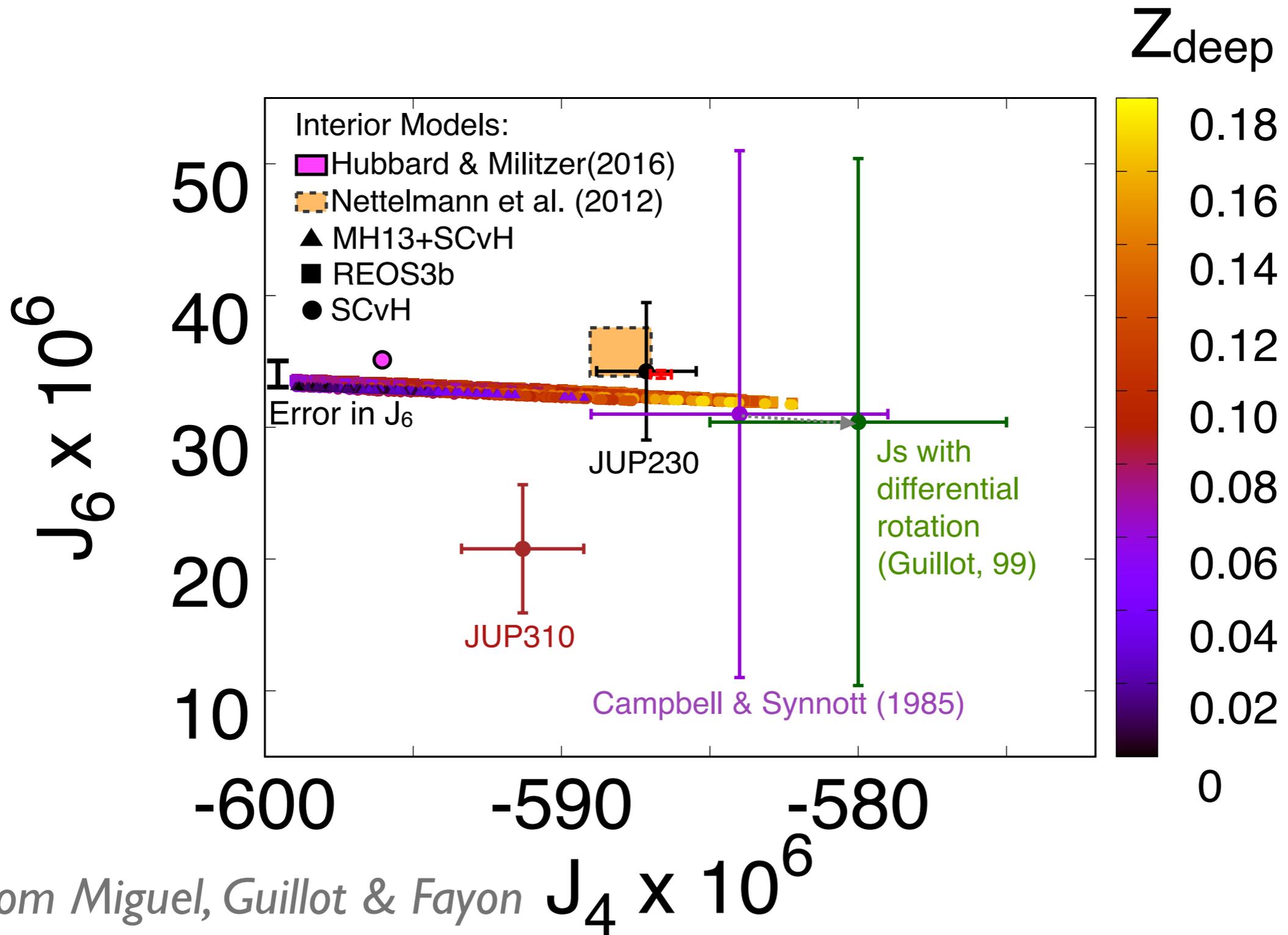
JUNO MISSION : FIRST RESULTS



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

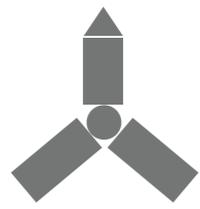


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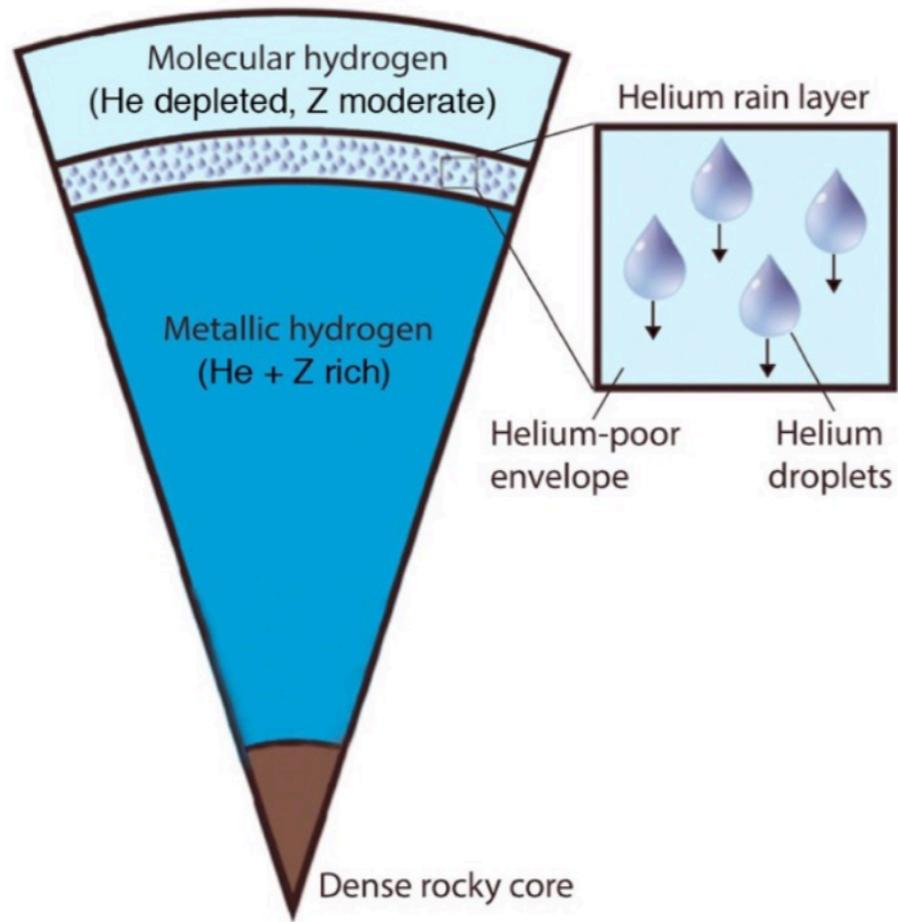
From Miguel, Guillot & Fayon (A&A 2016)

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JUNO MISSION : FIRST RESULTS

Standard

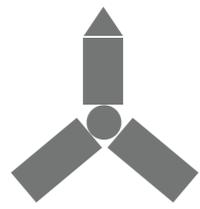


REOS3 ✓

MHI3 ✗

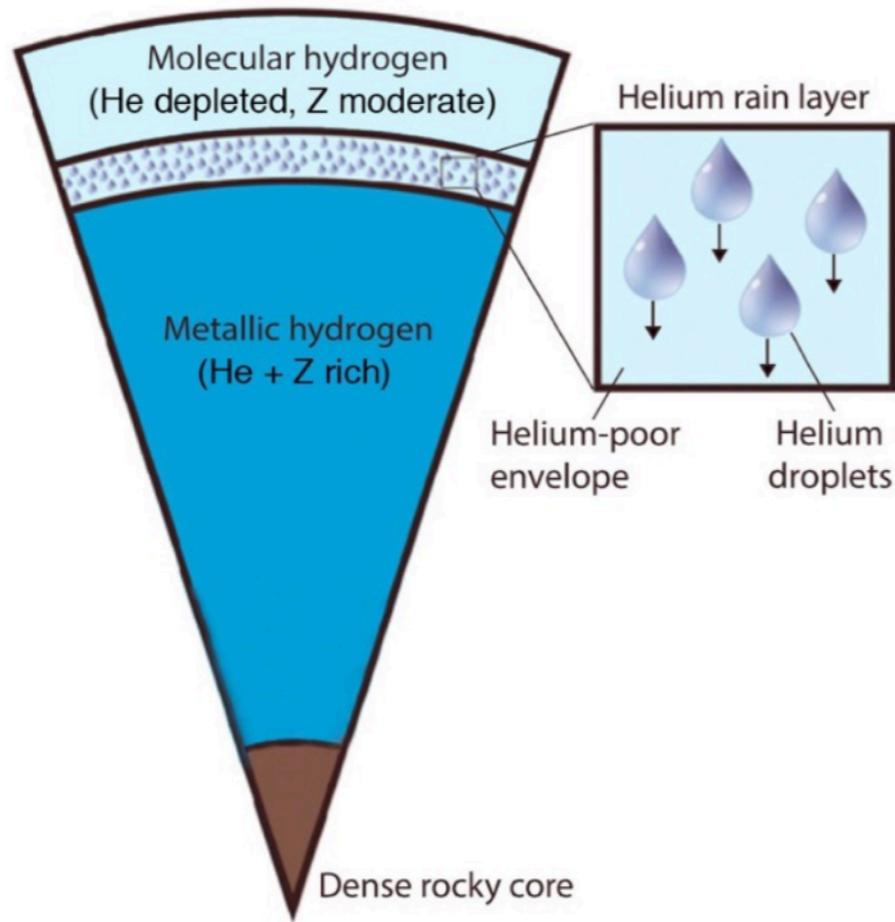
Wahl + (GRL, 2017 in press)

Yamila Miguel



JUNO MISSION : FIRST RESULTS

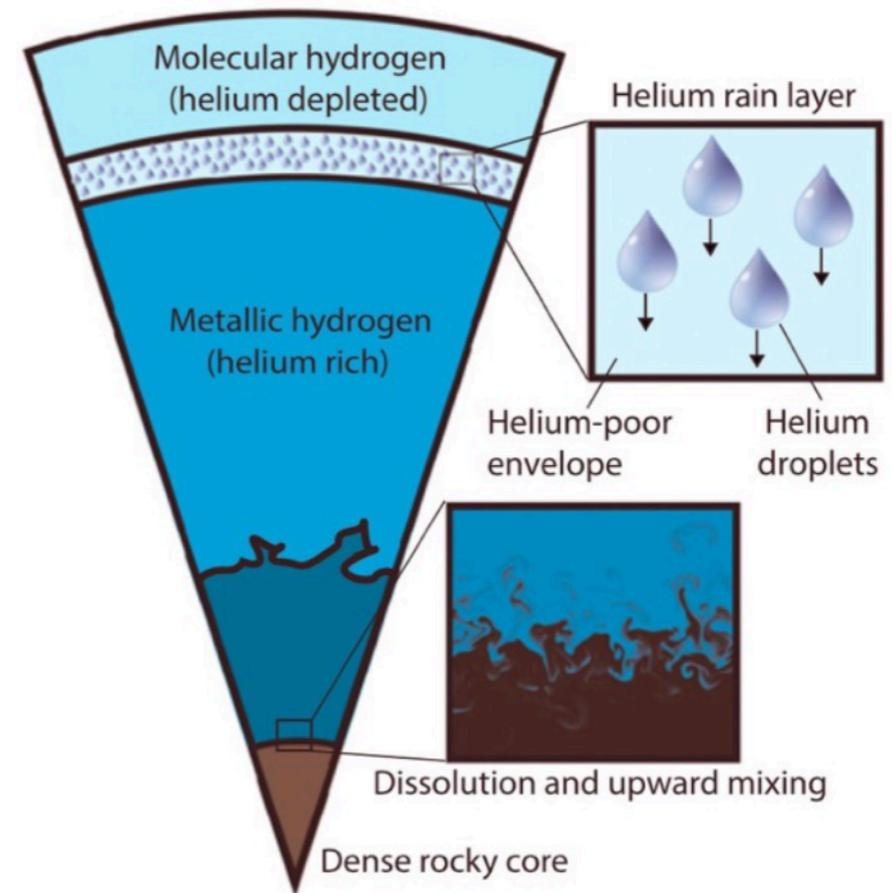
Standard



REOS3 ✓

MHI3 ✗

Dilute core

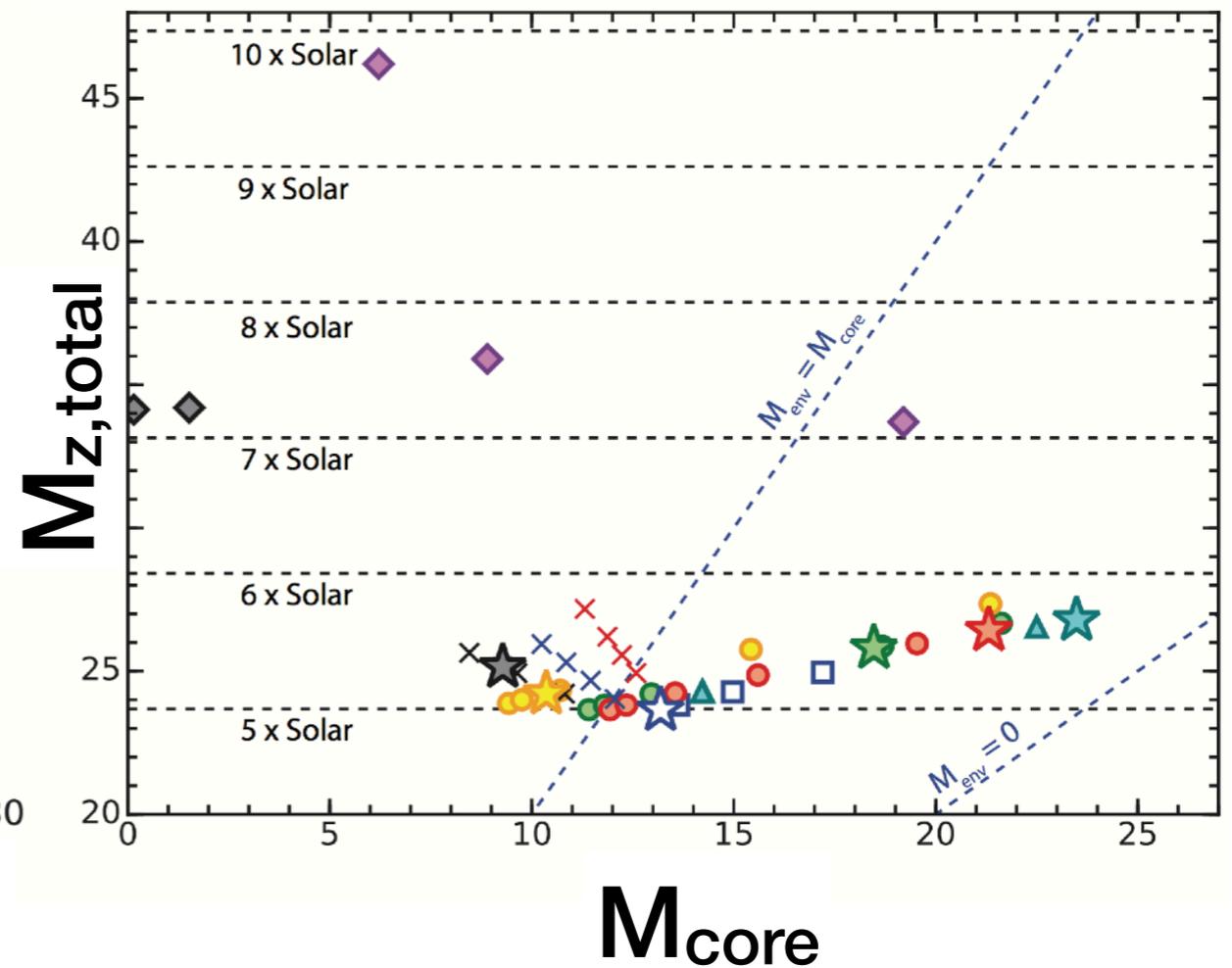
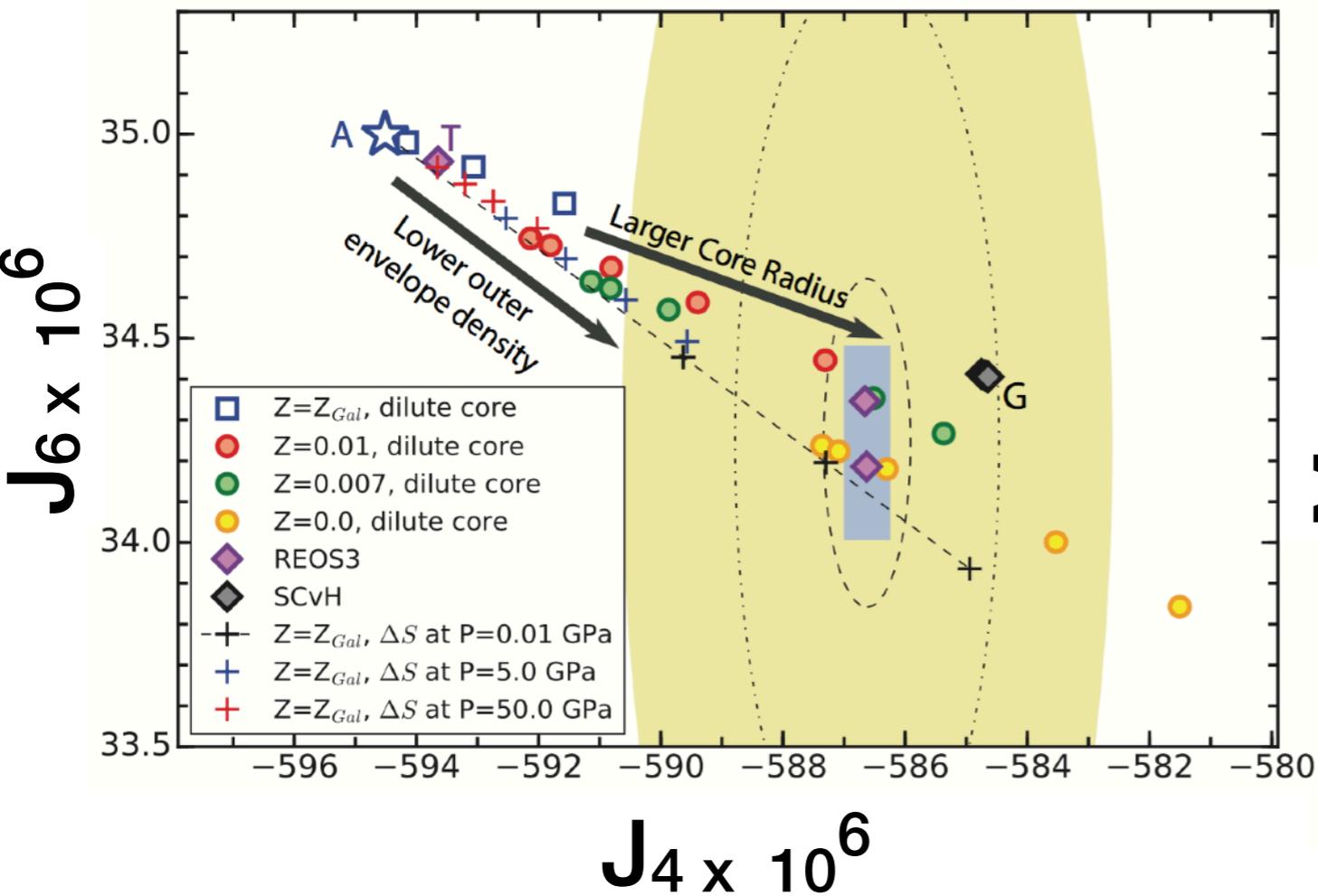


REOS3 ✓

MHI3 ✓

Wahl + (GRL, 2017 in press)

JUNO : EFFECT OF A DILUTE CORE



Wahl + (GRL, 2017 in press)

Yamila Miguel

STANDING QUESTIONS

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

Oscillations?

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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Juno team!

July 3rd 2016

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