Tsinghua University

Yamila Miguel
Leiden Observatory
SRON

UNVEILING THE SECRETS OF JUPITER

with the Juno mission

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Motivation

WHY STUDY THE GIANT PLANETS?

credit: NASA/GSFC

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Motivation

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CASSINI

Introduction: Solar System Exploration

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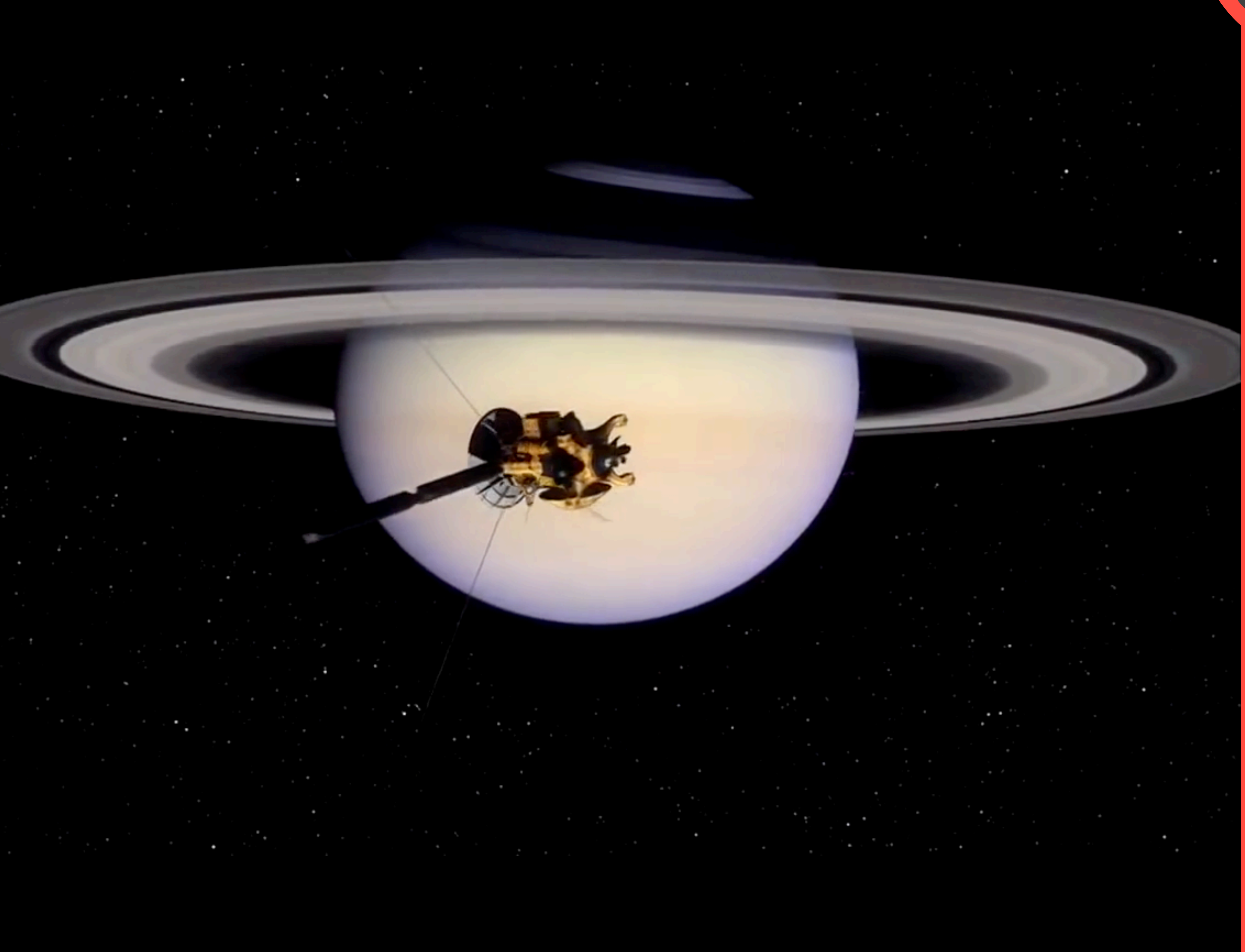
CASSINI



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Introduction: Solar System Exploration

JUNO

EXOPLANETS > 4000

Introduction

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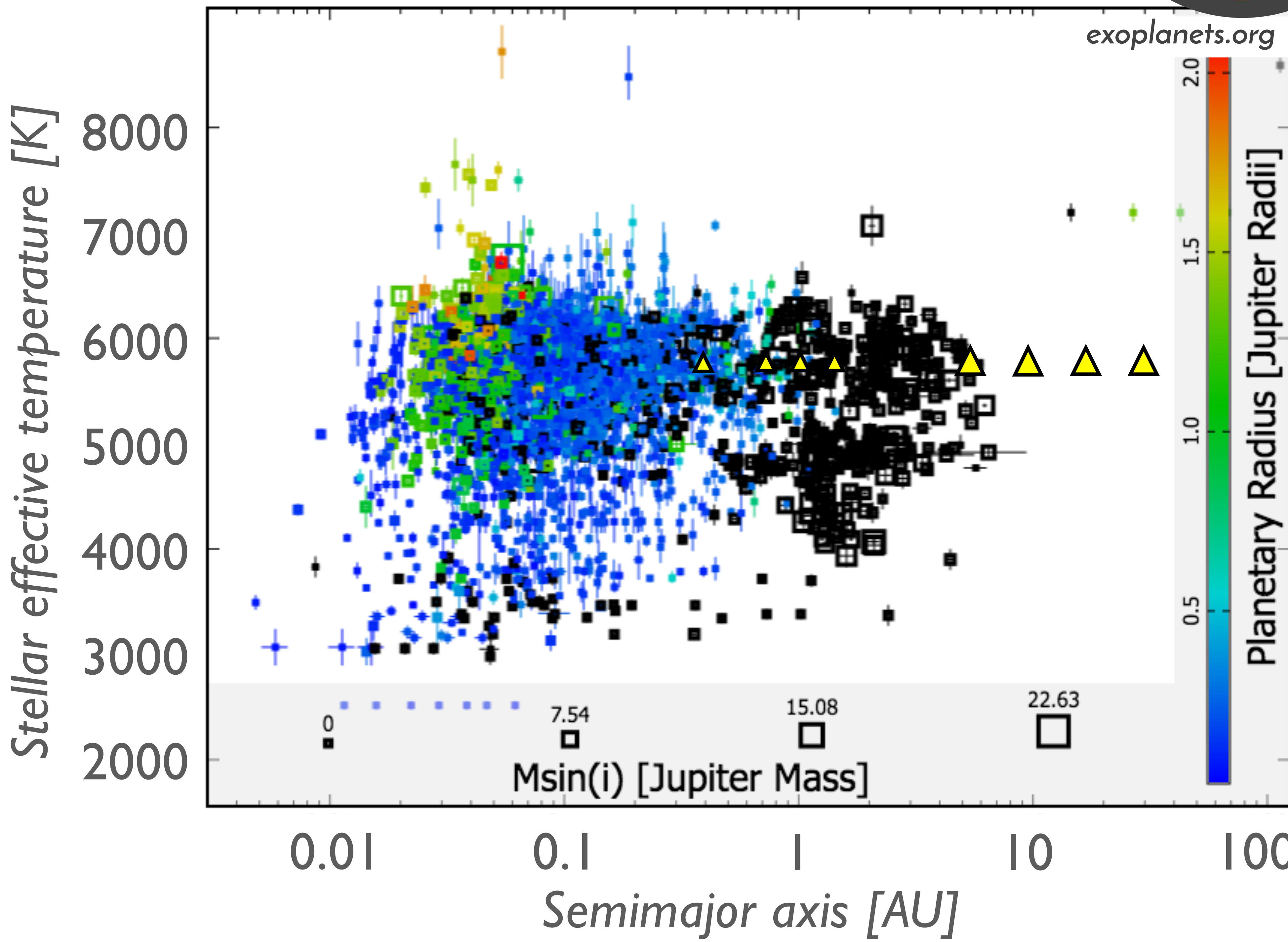

EXOPLANETS > 4000

Introduction

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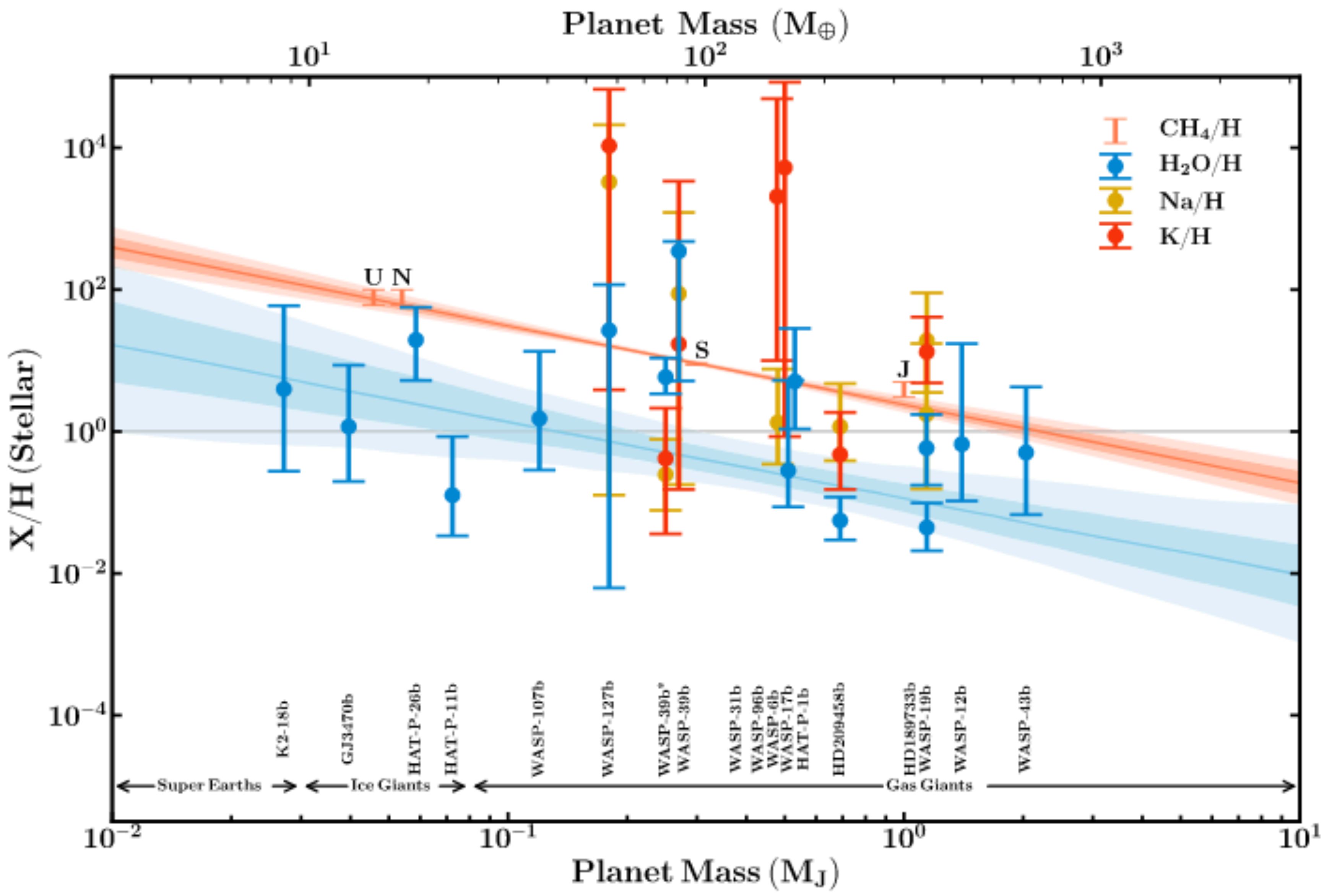

Welbanks+(ApJL,2019)

Motivation

WHY STUDY THE GIANT PLANETS?

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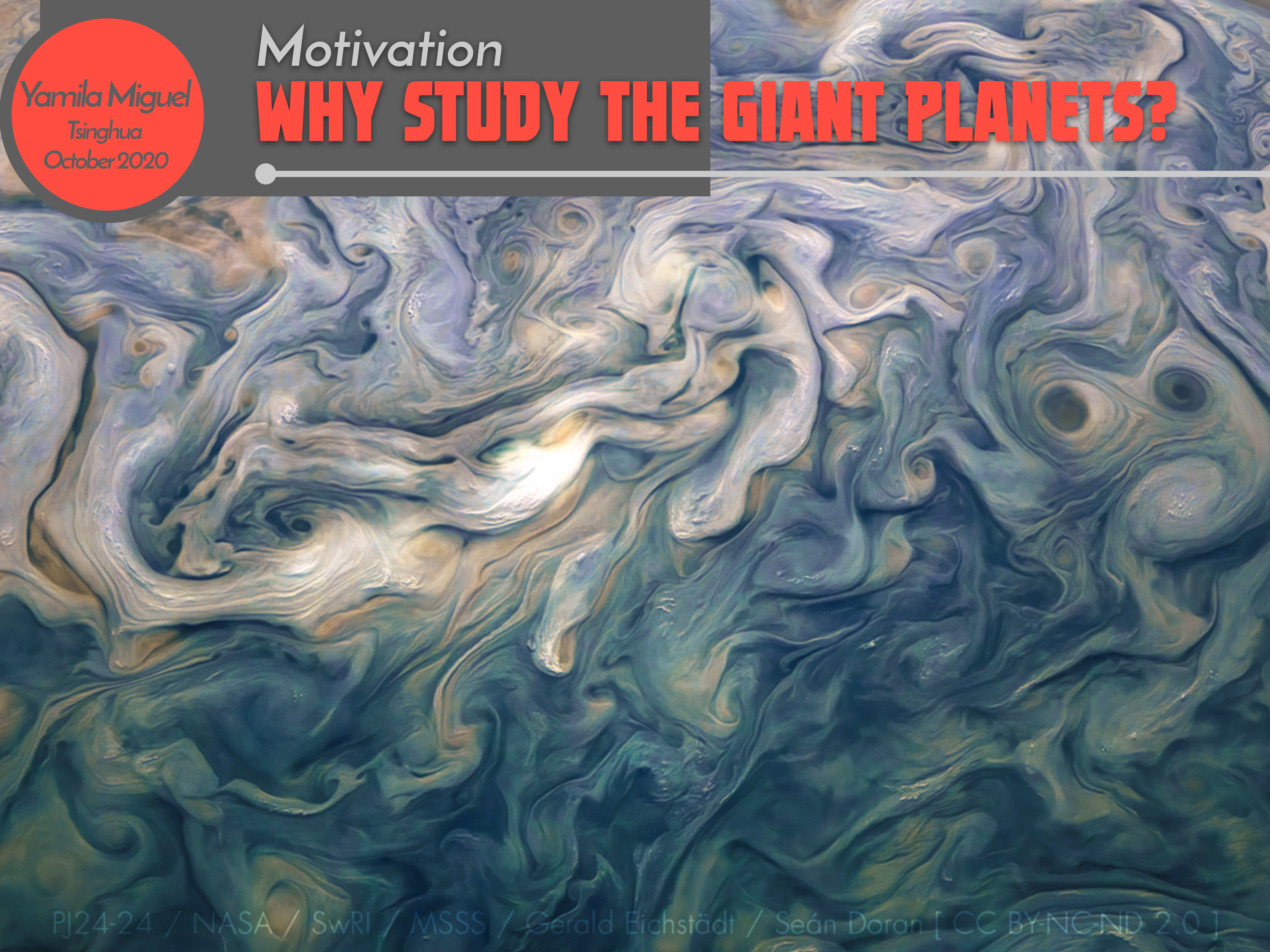
Motivation

WHY STUDY THE GIANT PLANETS?



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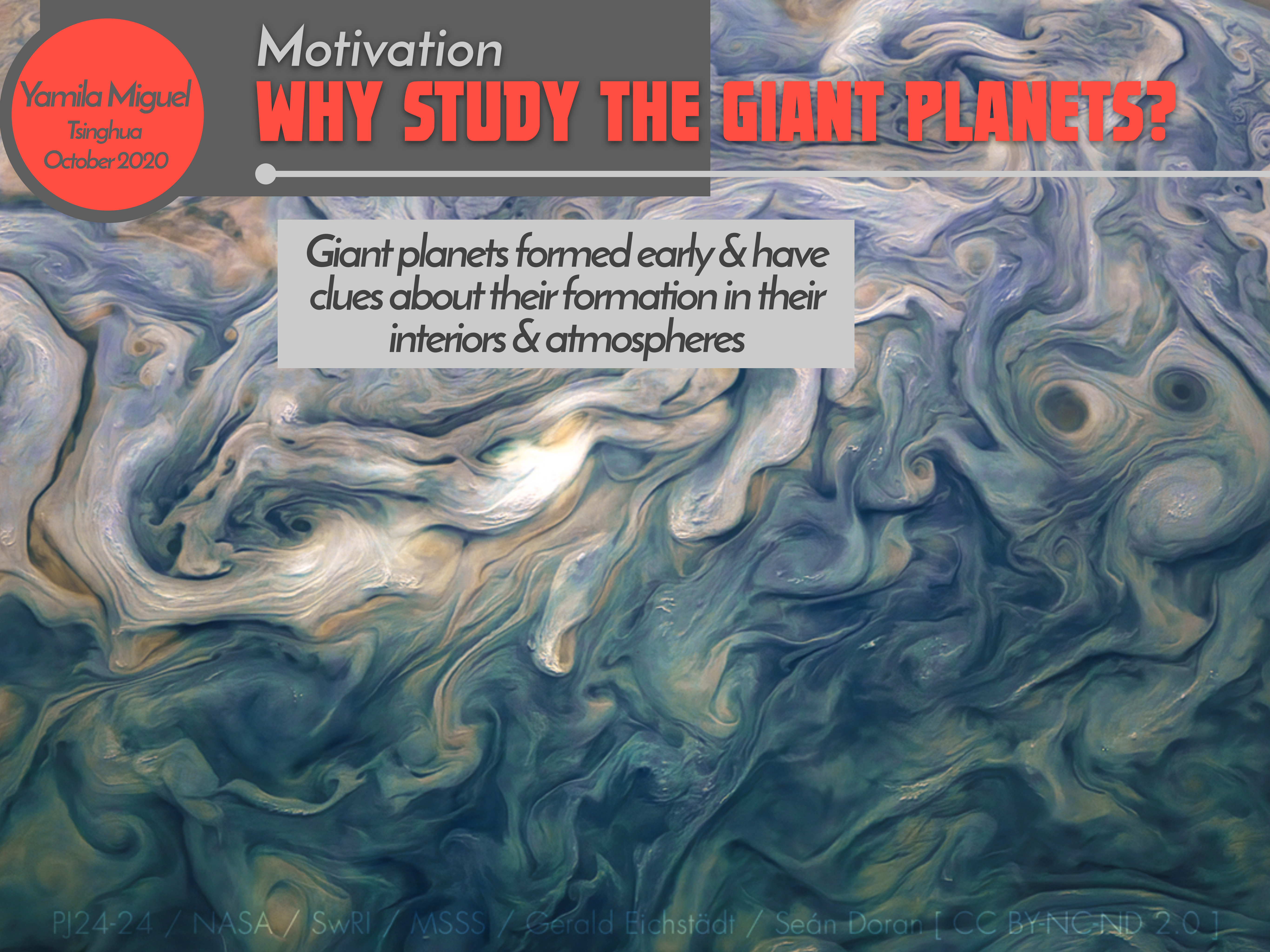
Motivation

WHY STUDY THE GIANT PLANETS?

Giant planets formed early & have clues about their formation in their interiors & atmospheres



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Motivation

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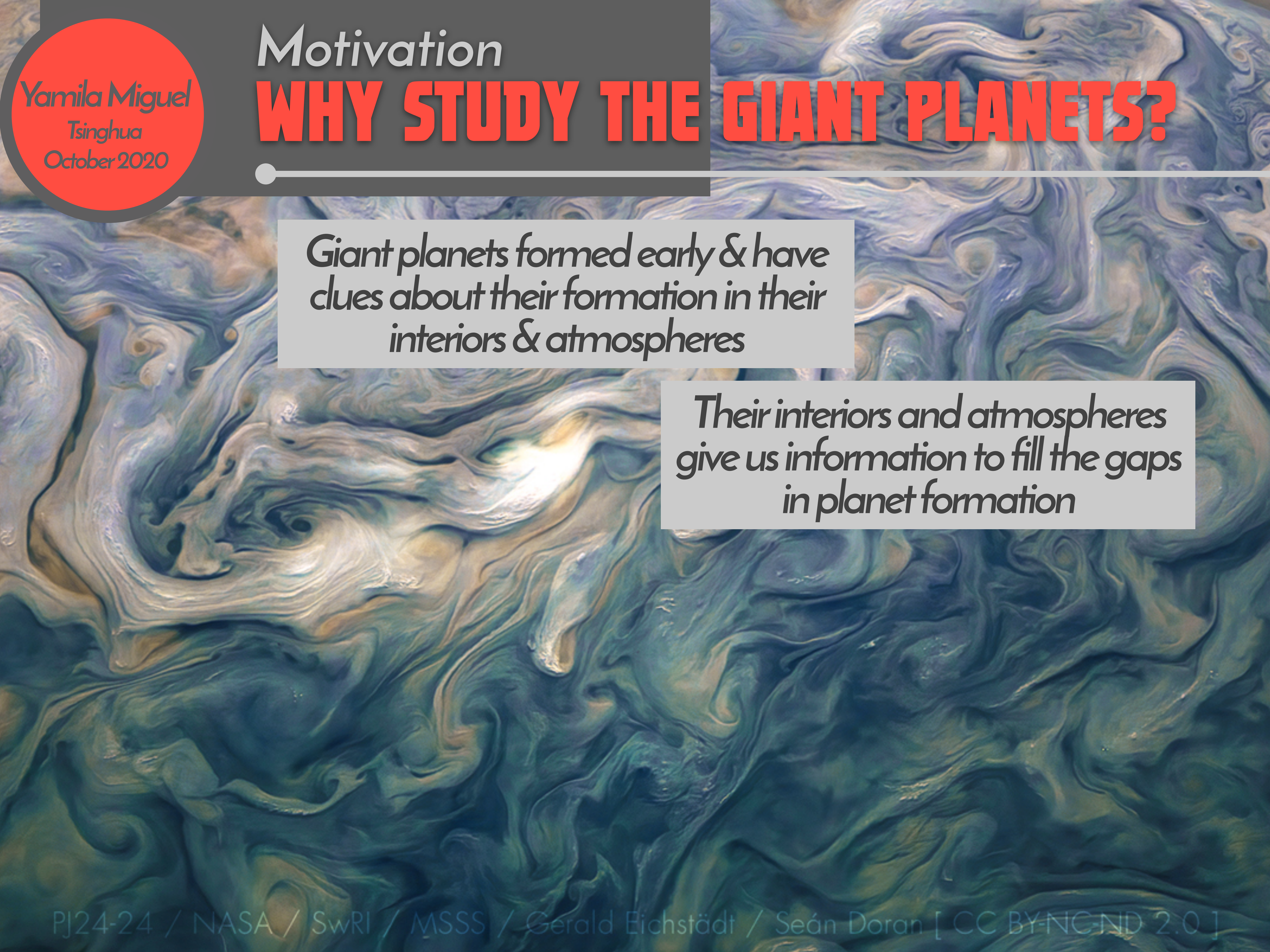
Their interiors and atmospheres give us information to fill the gaps in planet formation



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Motivation

WHY STUDY THE GIANT PLANETS?

Giant planets formed early & have clues about their formation in their interiors & atmospheres

Highly influenced the dynamics of small planets

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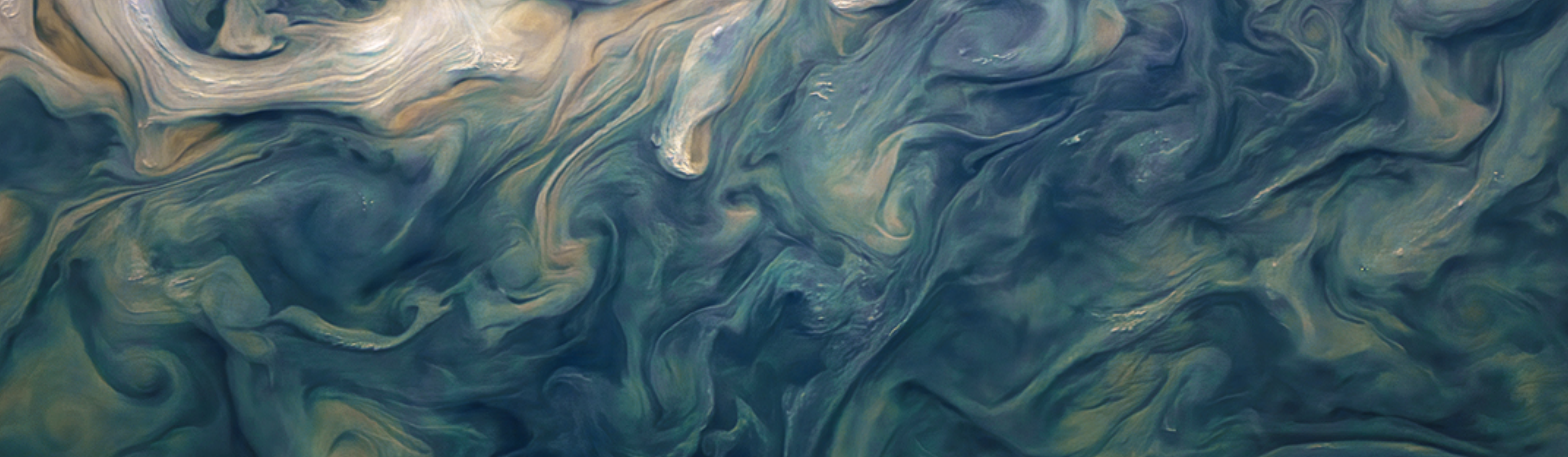

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Their interiors are natural laboratories to understand physics and chemistry

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Their interiors are natural laboratories to understand physics and chemistry

Understanding Jupiter we will know more about the history of our own Solar System (e.g. Bosman+2019; Öberg &Wordsworth 2019)

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

WHAT IS JUPITER MADE OF?

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

HOW ARE THE HEAVIES DISTRIBUTED?

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

credit of all Juno images during the talk: NASA/SwRI/SeanDoran

Complexity of the problem

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JUPITER'S INTERIOR

Complexity of the problem

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1. We don't know very well what is the amount of heavies

Complexity of the problem

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1. We don't know very well what is the amount of heavies
2. We don't know the size and composition of its core

JUPITER'S INTERIOR

Complexity of the problem

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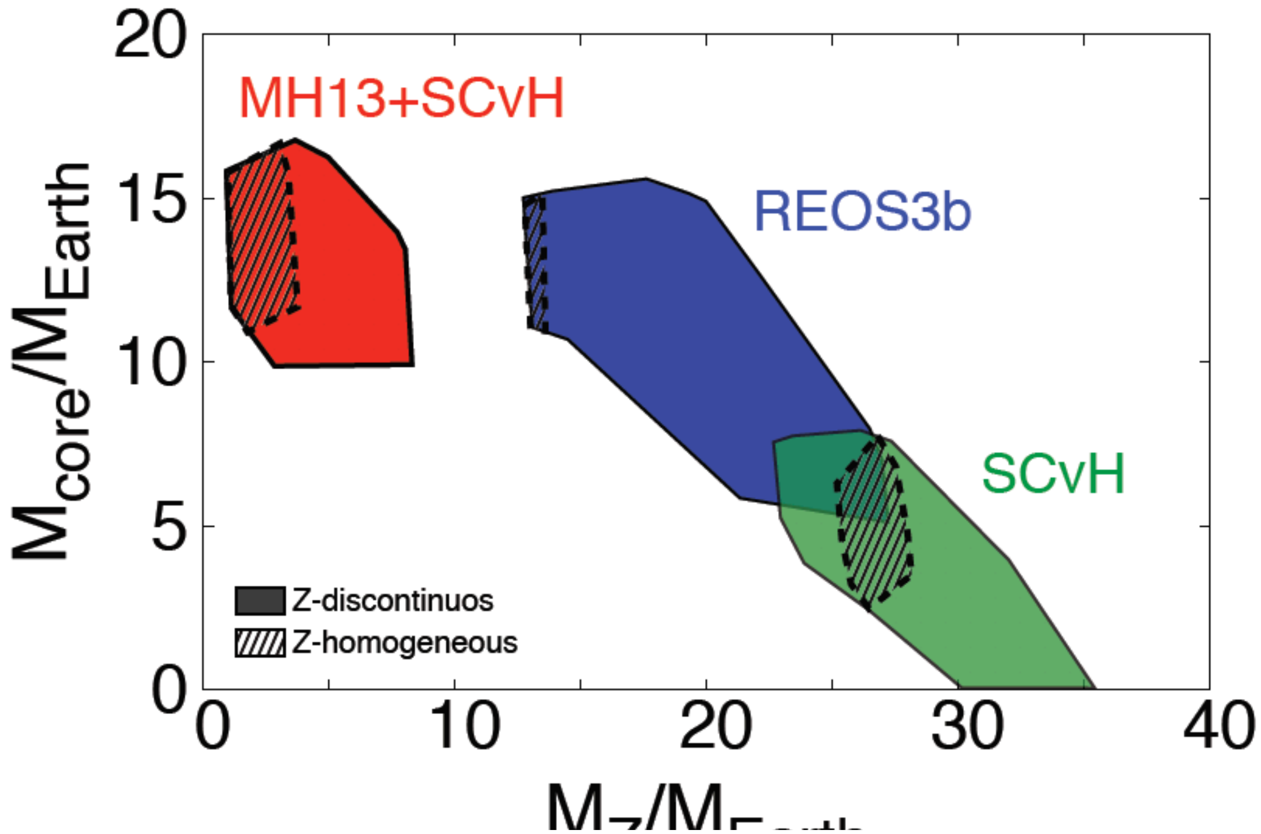
1. We don't know very well what is the amount of heavies
2. We don't know the size and composition of its core
3. It is made (mostly) of H and we don't know H very well



Miguel+(A&A, 2016)
also Saumon & Guillot (ApJ, 2004), Baraffe+(PPVI, 2014)

Complexity of the problem

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1. We don't know very well what is the amount of heavies
2. We don't know the size and composition of its core
3. It is made (mostly) of H and we don't know H very well
4. It (most likely) has a He phase transition

JUPITER'S INTERIOR

Complexity of the problem

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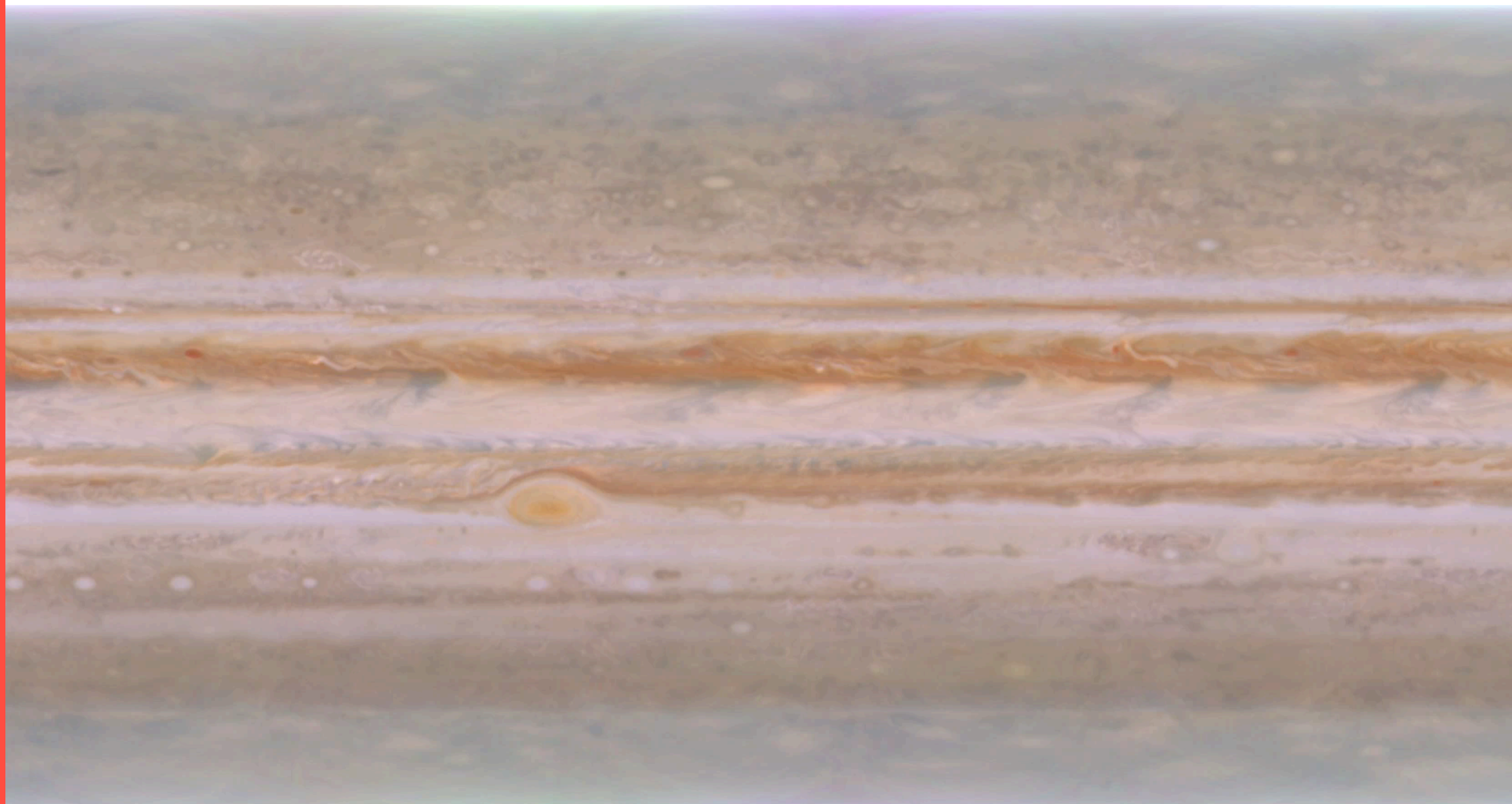

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6. It might have a compositional gradient that inhibits convection

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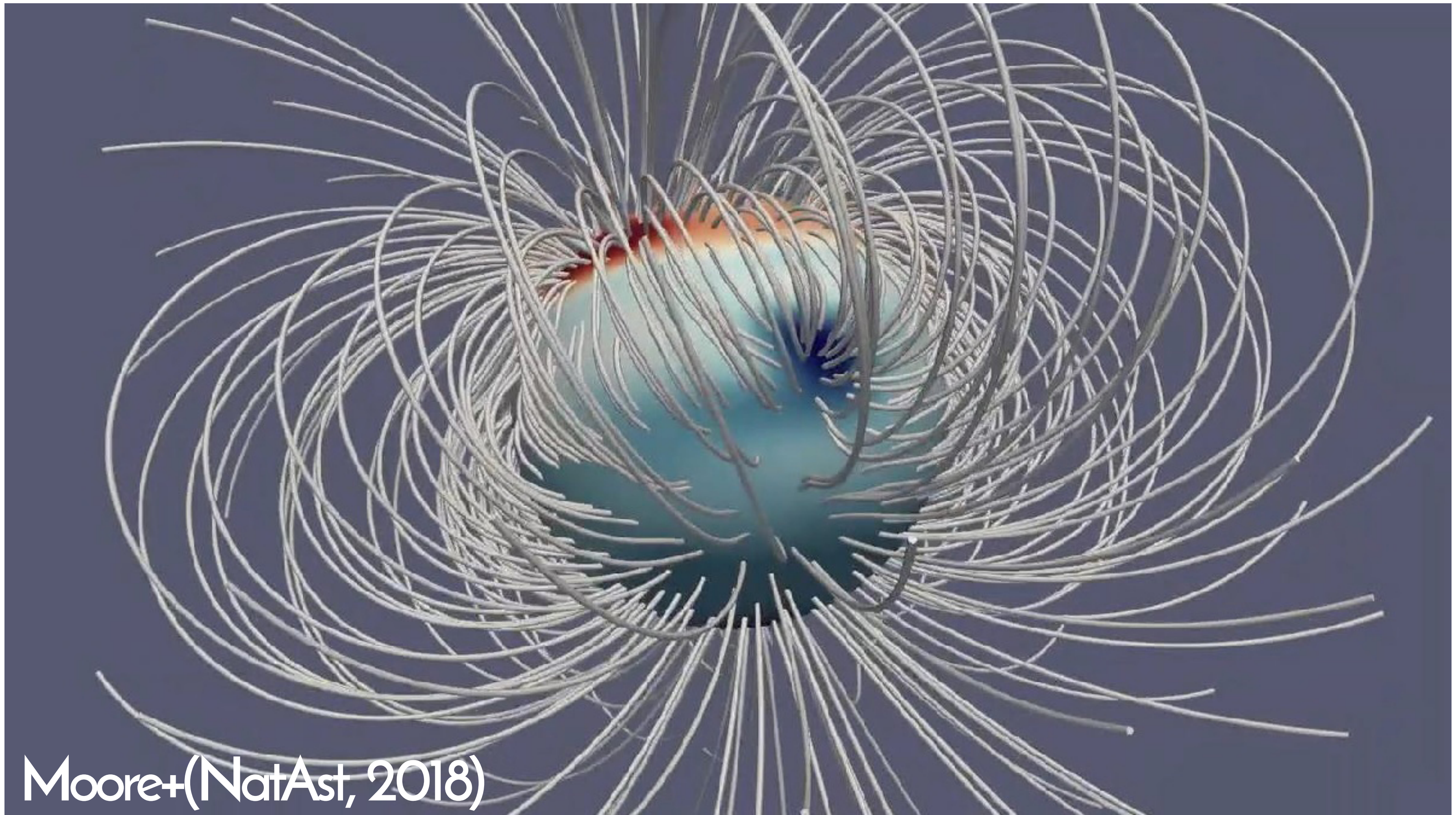
7. It has magnetic fields



Moore+(NatAst, 2018)

JUPITER'S INTERIOR

Complexity of the problem

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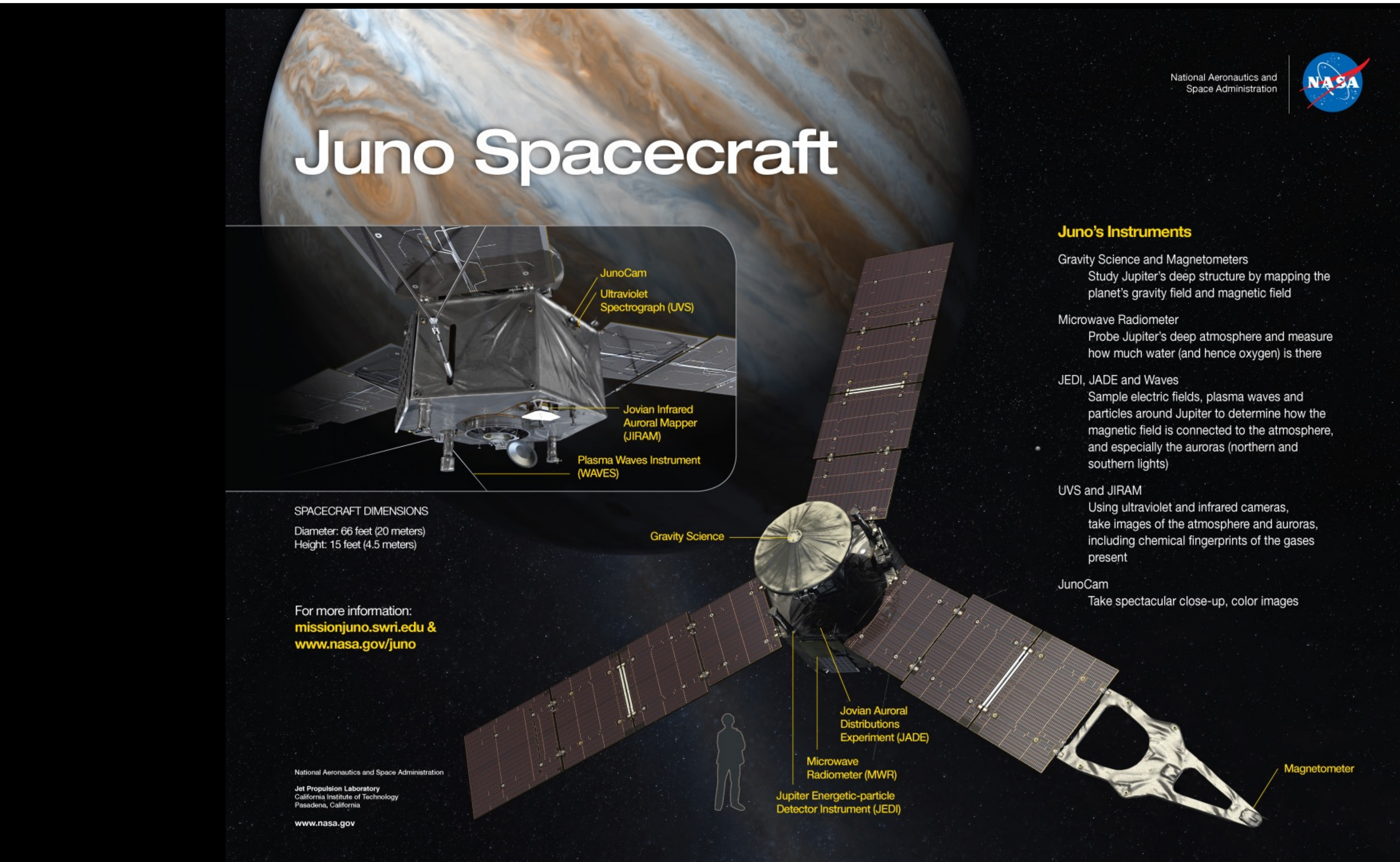
3. It is made (mostly) of H and we don't know H very well
4. It (most likely) has a He phase transition
5. It has a differential rotation
6. It might have a compositional gradient that inhibits convection
7. It has magnetic fields
8. We can not go inside the planet to make measurements!


National Aeronautics and
Space Administration
NASA
Juno Spacecraft
JunoCam
Ultraviolet
Spectrograph (UVS)
Jovian Infrared
Auroral Mapper
(JIRAM)
Plasma Waves Instrument
(WAVES)
SPACECRAFT DIMENSIONS
Diameter: 66 feet (20 meters)
Height: 15 feet (4.5 meters)
Gravity Science
For more information:
missionjuno.swri.edu &
www.nasa.gov/juno
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
Jovian Auroral
Distributions
Experiment (JADE)
Microwave
Radiometer (MWR)
Jupiter Energetic-particle
Detector Instrument (JEDI)
Magnetometer
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

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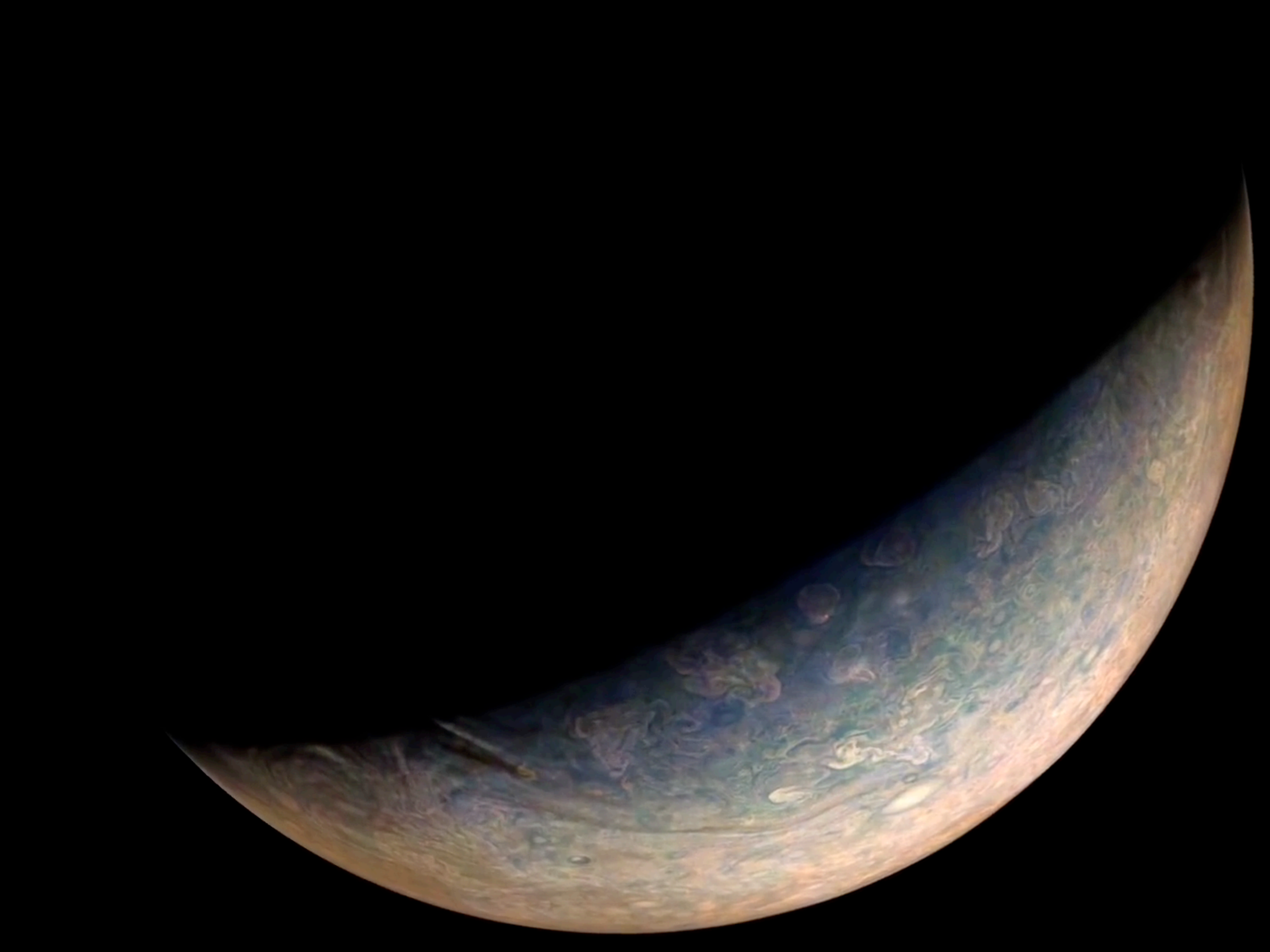
Data



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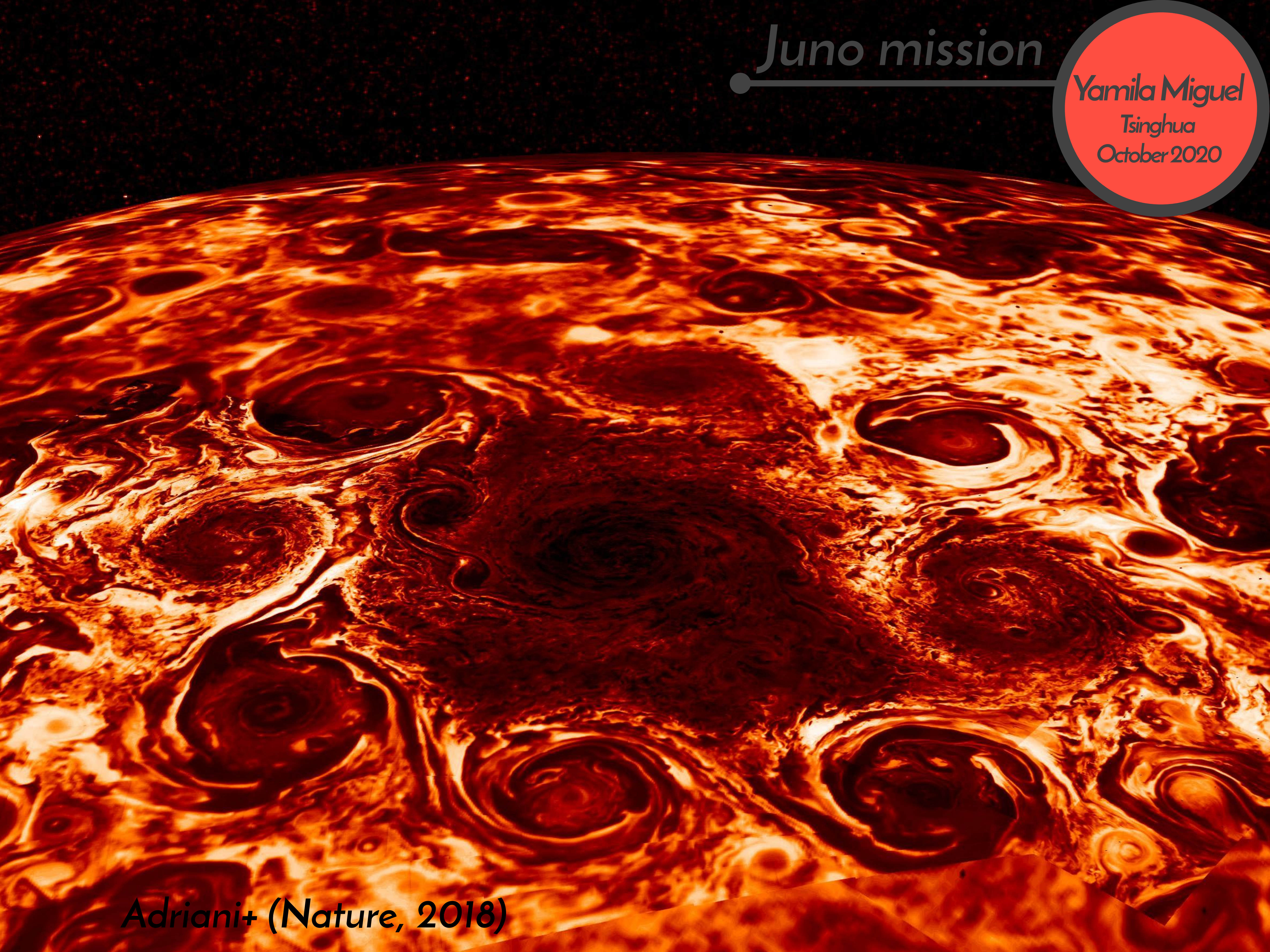

Adriani+ (Nature, 2018)

Methods

GRAVITY FIELD: EVEN Js

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GRAVITY FIELD: EVEN Js

Methods

GRAVITY FIELD: EVEN Js

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

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

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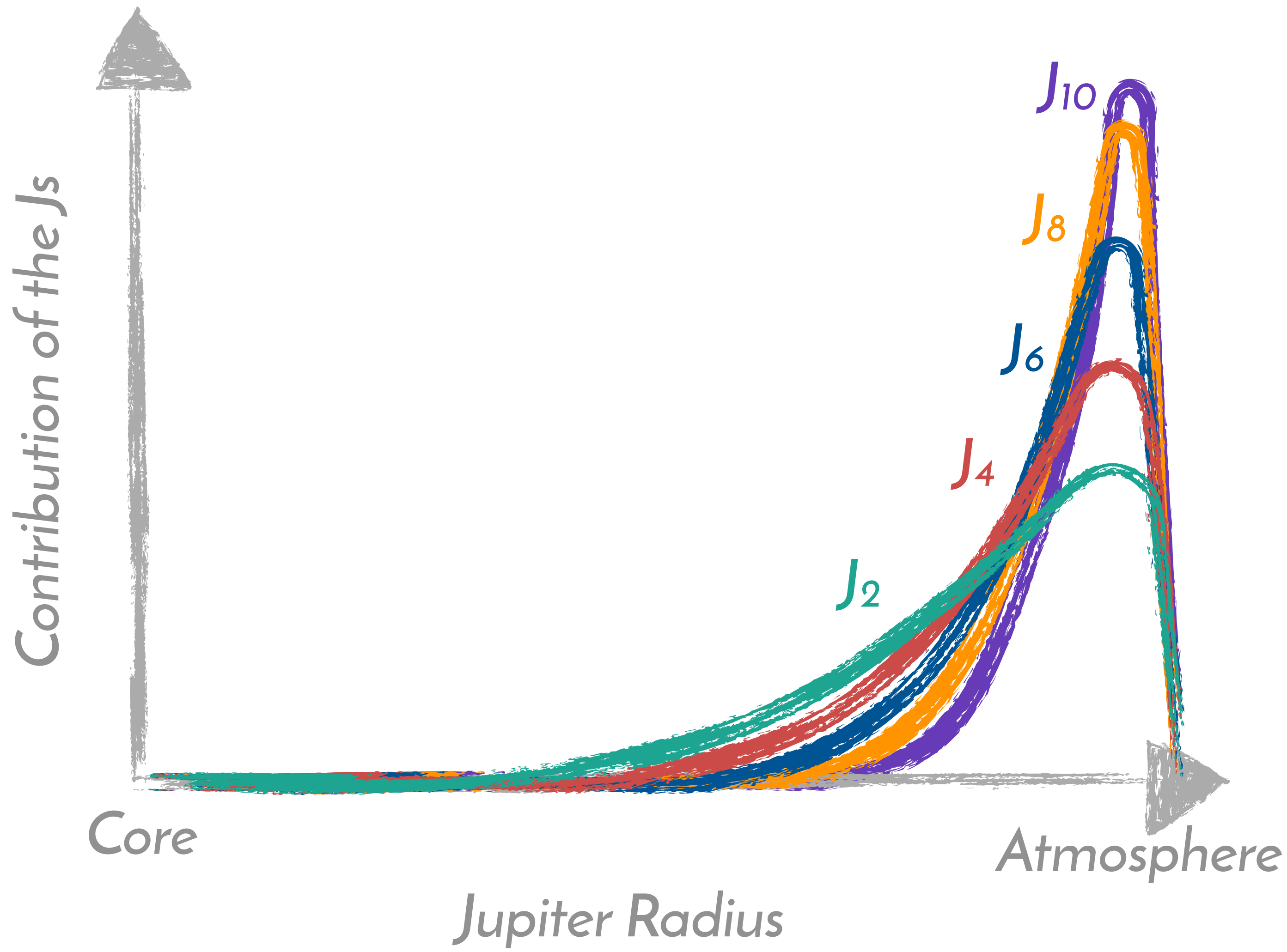
Methods

GRAVITY FIELD: EVEN Js



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Methods

GRAVITY FIELD: EVEN Js

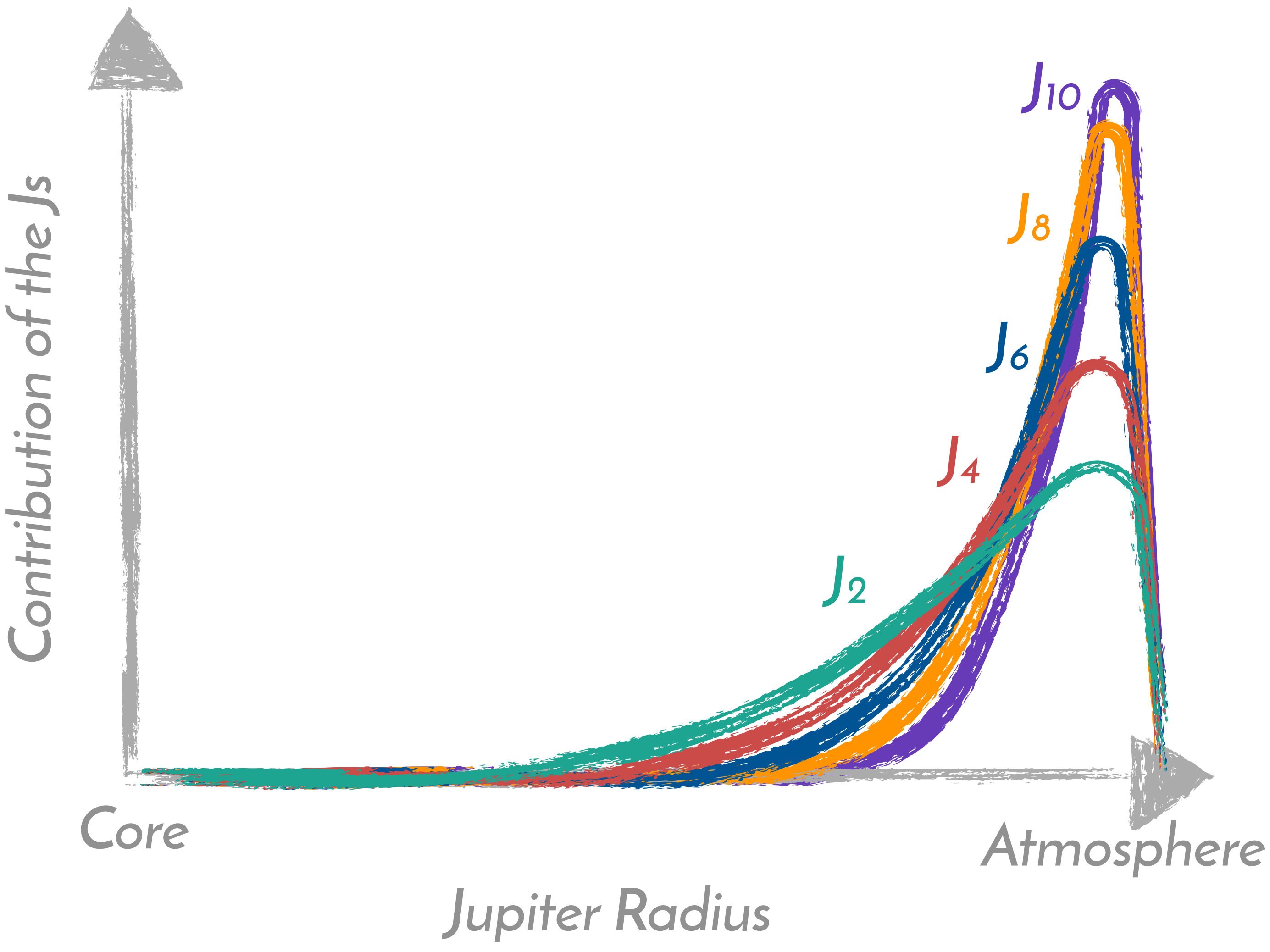
Even gravity harmonics

J_2
J_4
J_6
J_8
J_{10}

J_2, J_4, J_6 } Internal structure

J_6, J_8, J_{10} } Atmospheric & interior dynamics

Static (rigid body) +
Dynamic (differential rotation)



Methods: Gravity Field

BEFORE & AFTER JUNO

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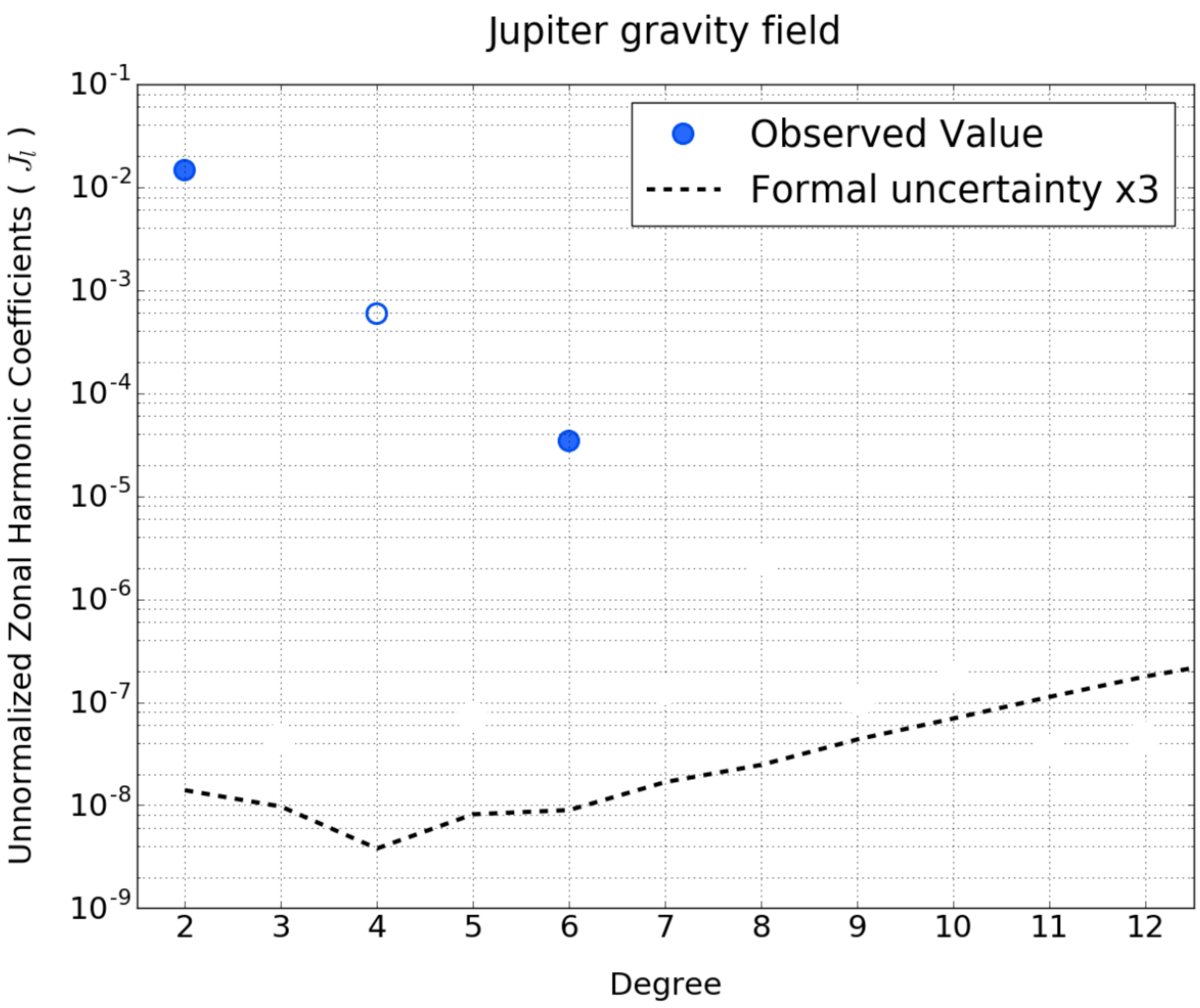
Methods: Gravity Field
BEFORE & AFTER JUNO



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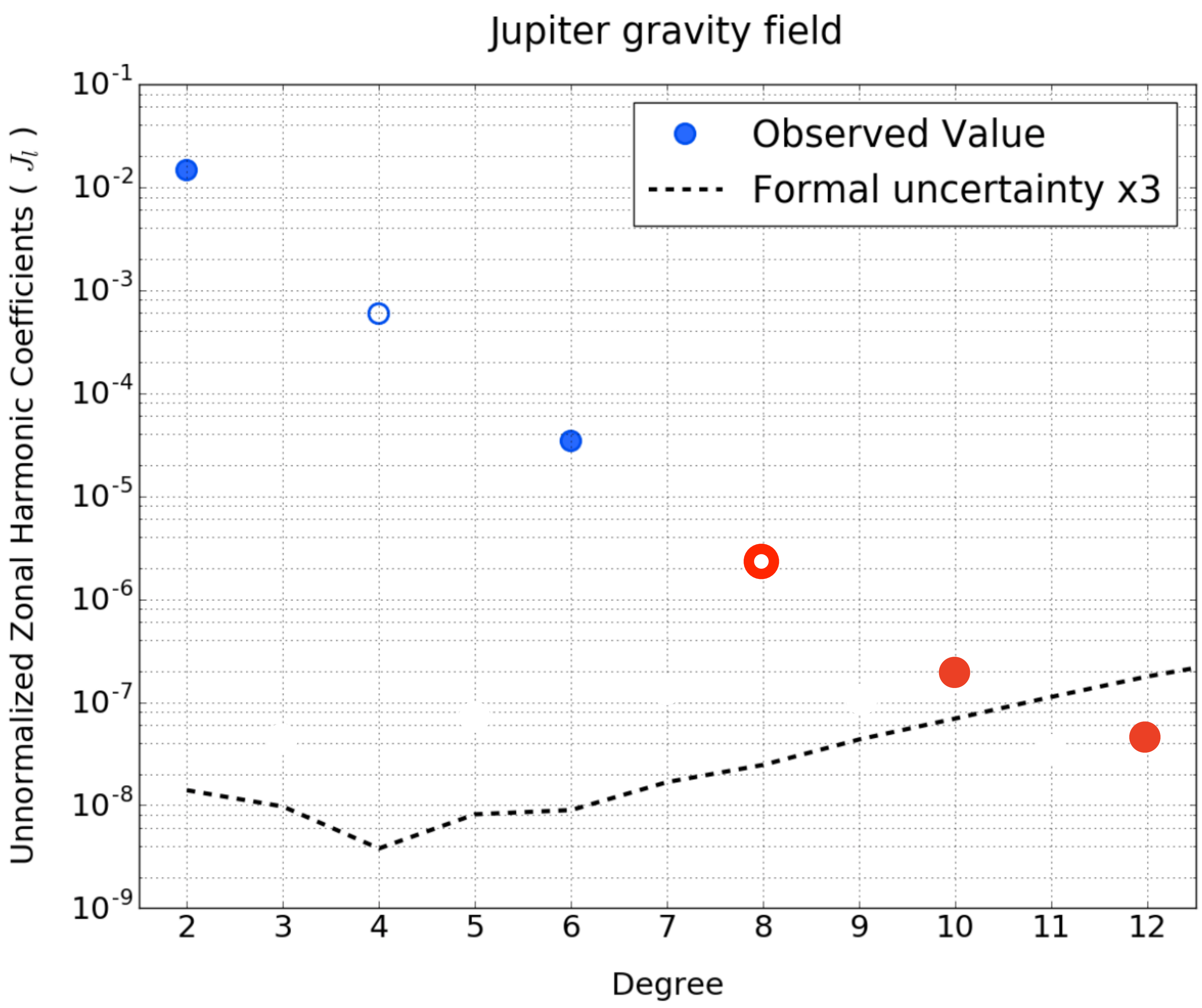
BEFORE & AFTER JUNO



Bolton+(Science, 2017), Folkner+(GRL, 2017), Iess +(Nature,2018)

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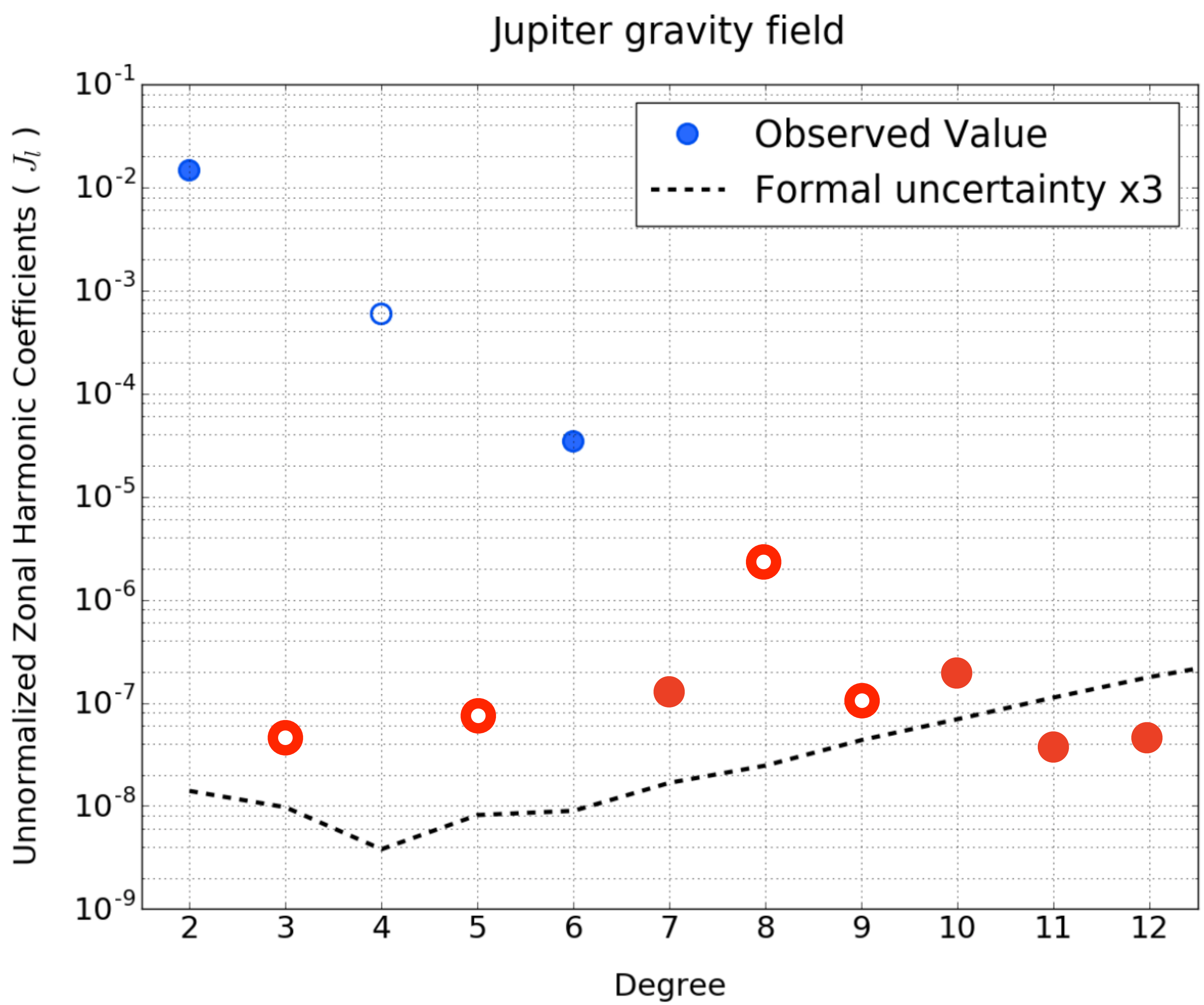
Methods: Gravity Field
BEFORE & AFTER JUNO



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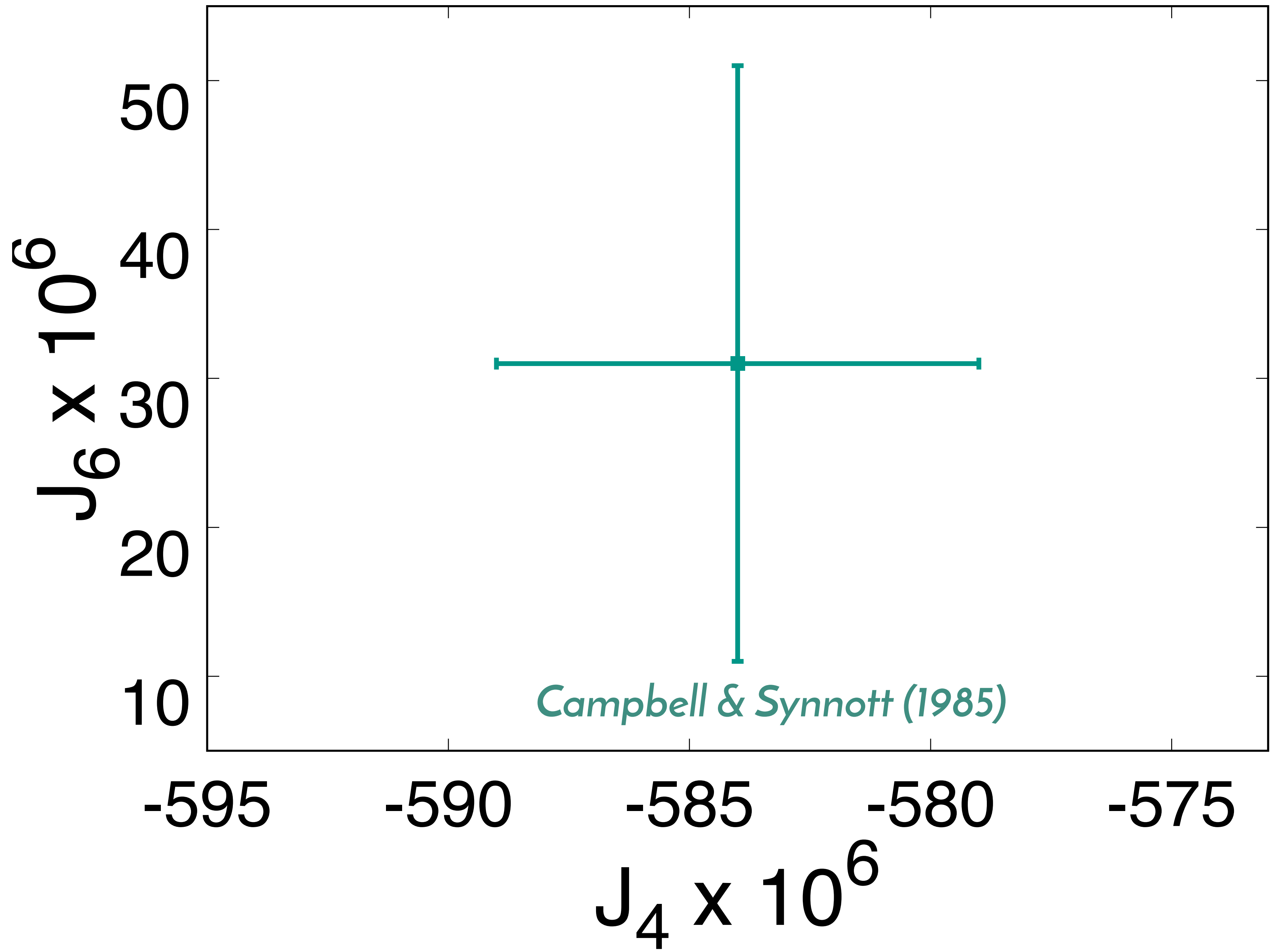

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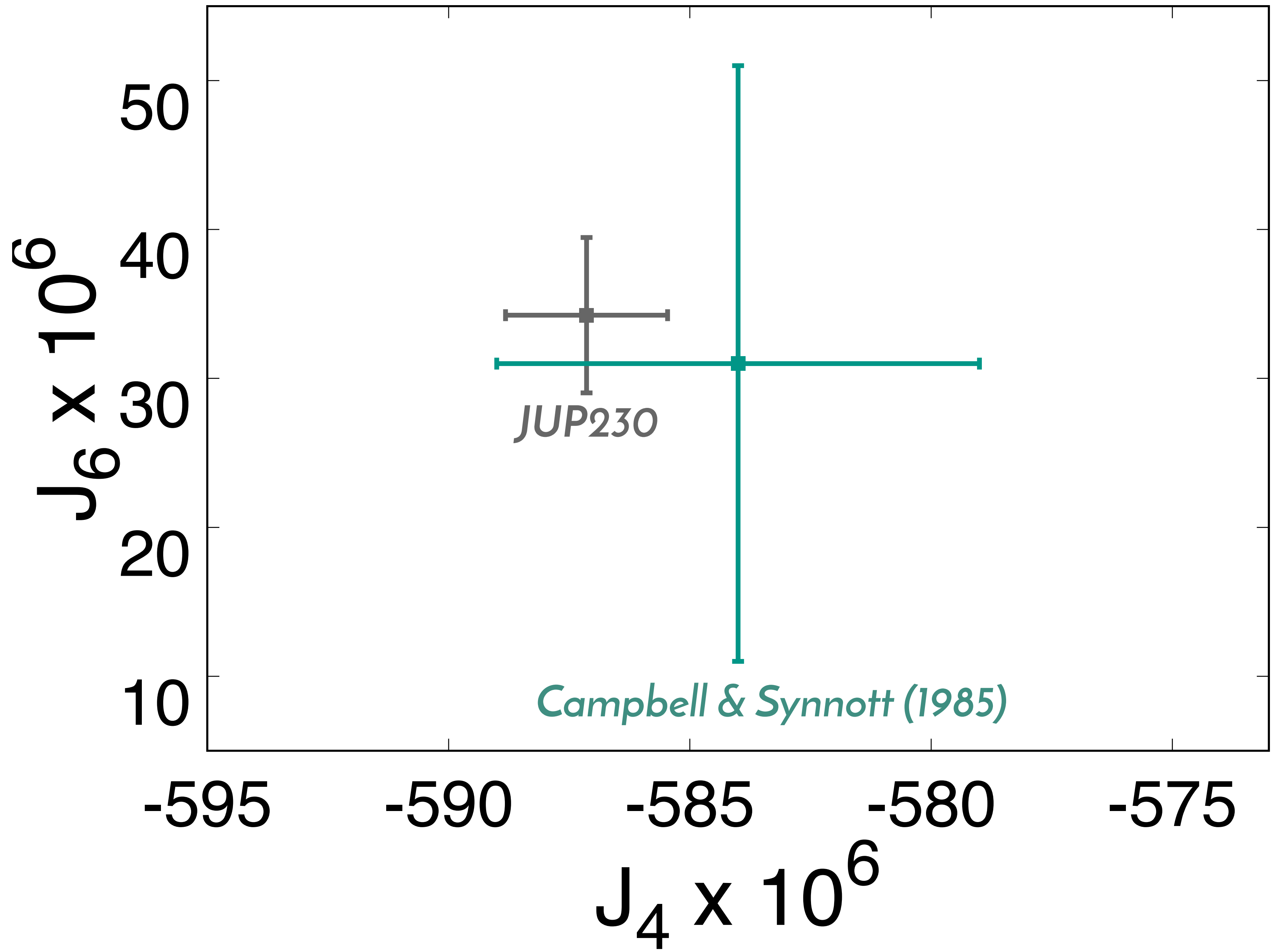

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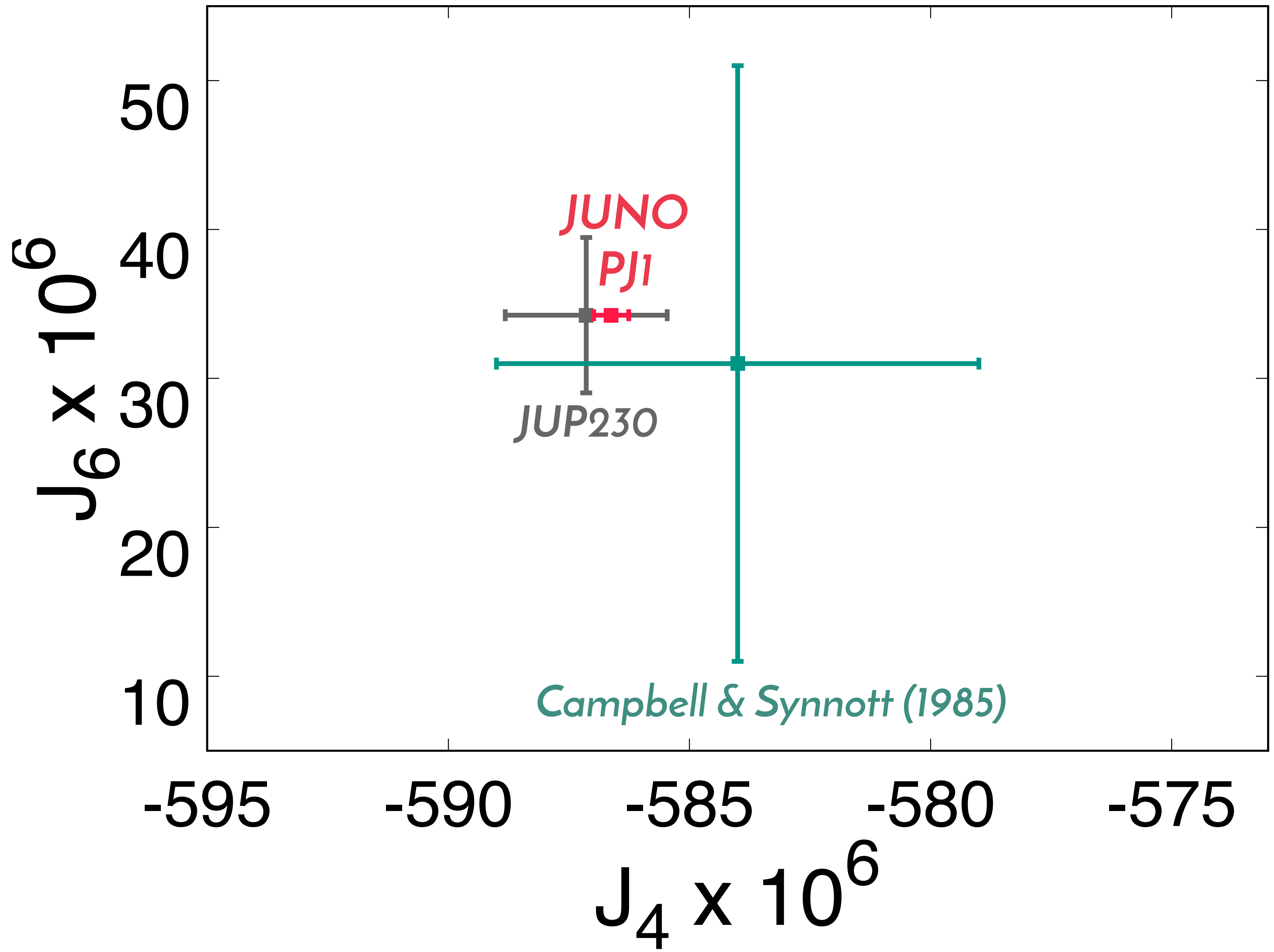
Methods: Gravity Field

BEFORE & AFTER JUNO



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Methods: Gravity Field

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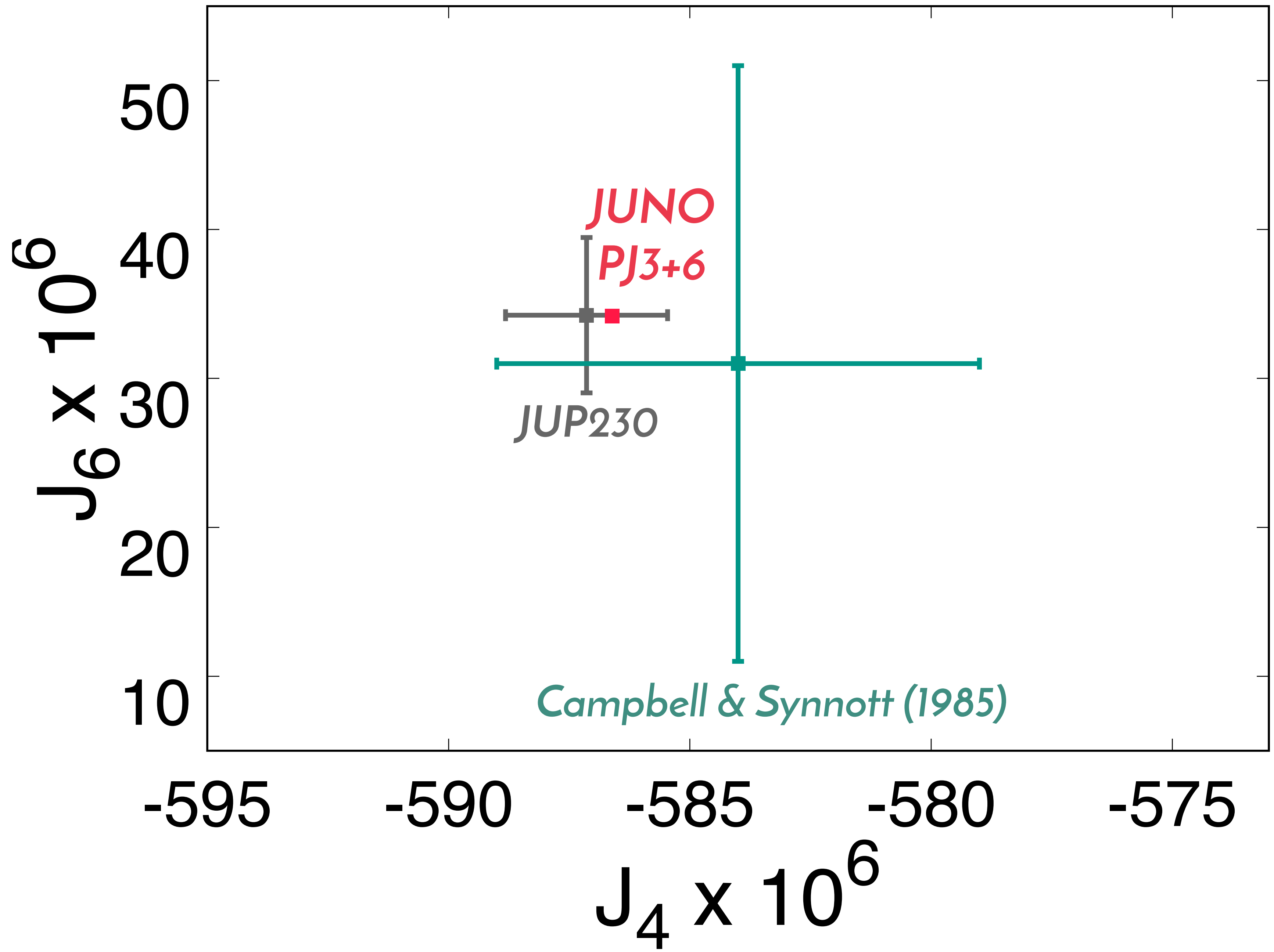

Miguel+(A&A, 2016); Bolton+ (Science, 2017)

Observational data

ATMOSPHERE

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Observational data

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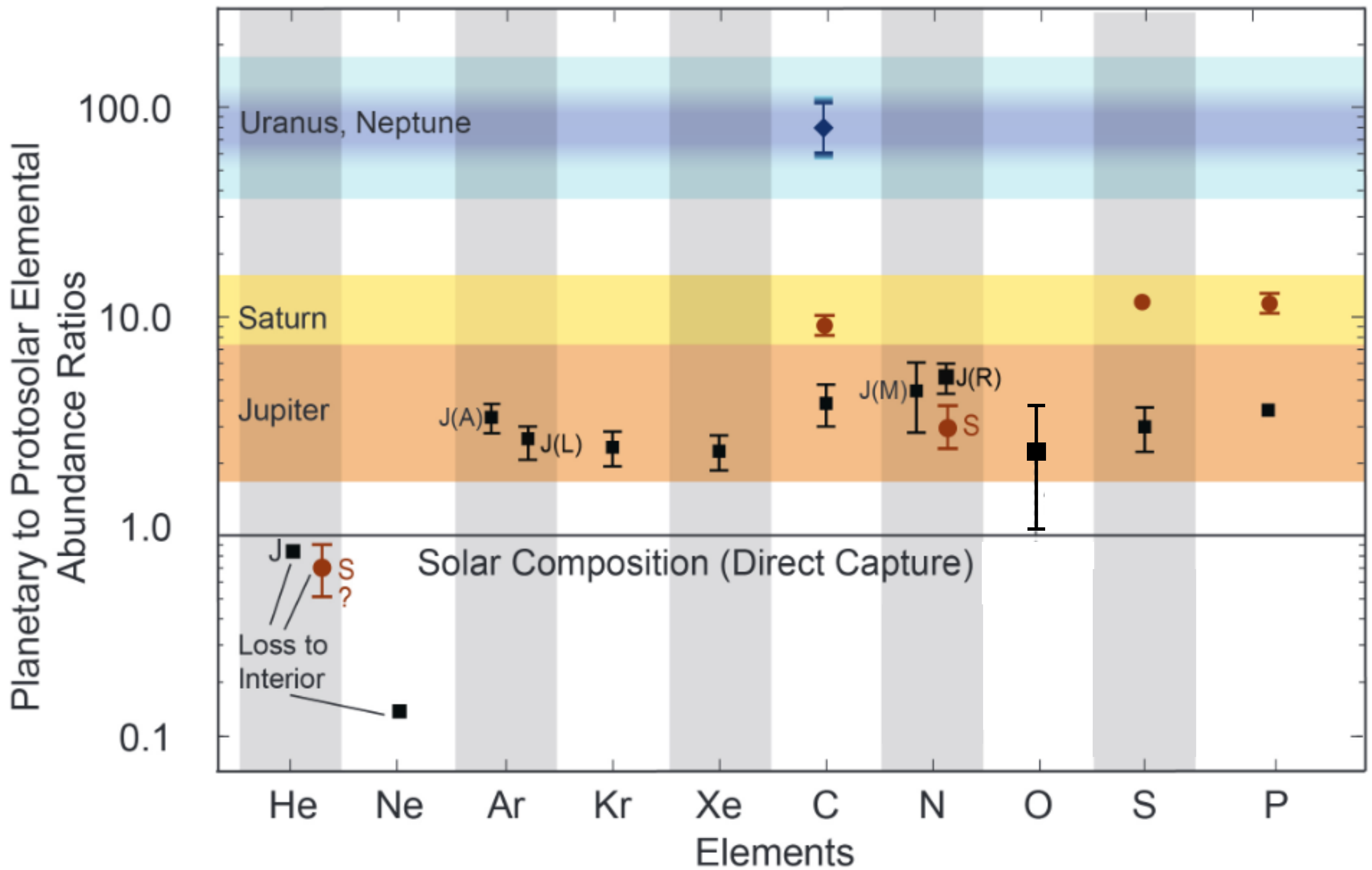
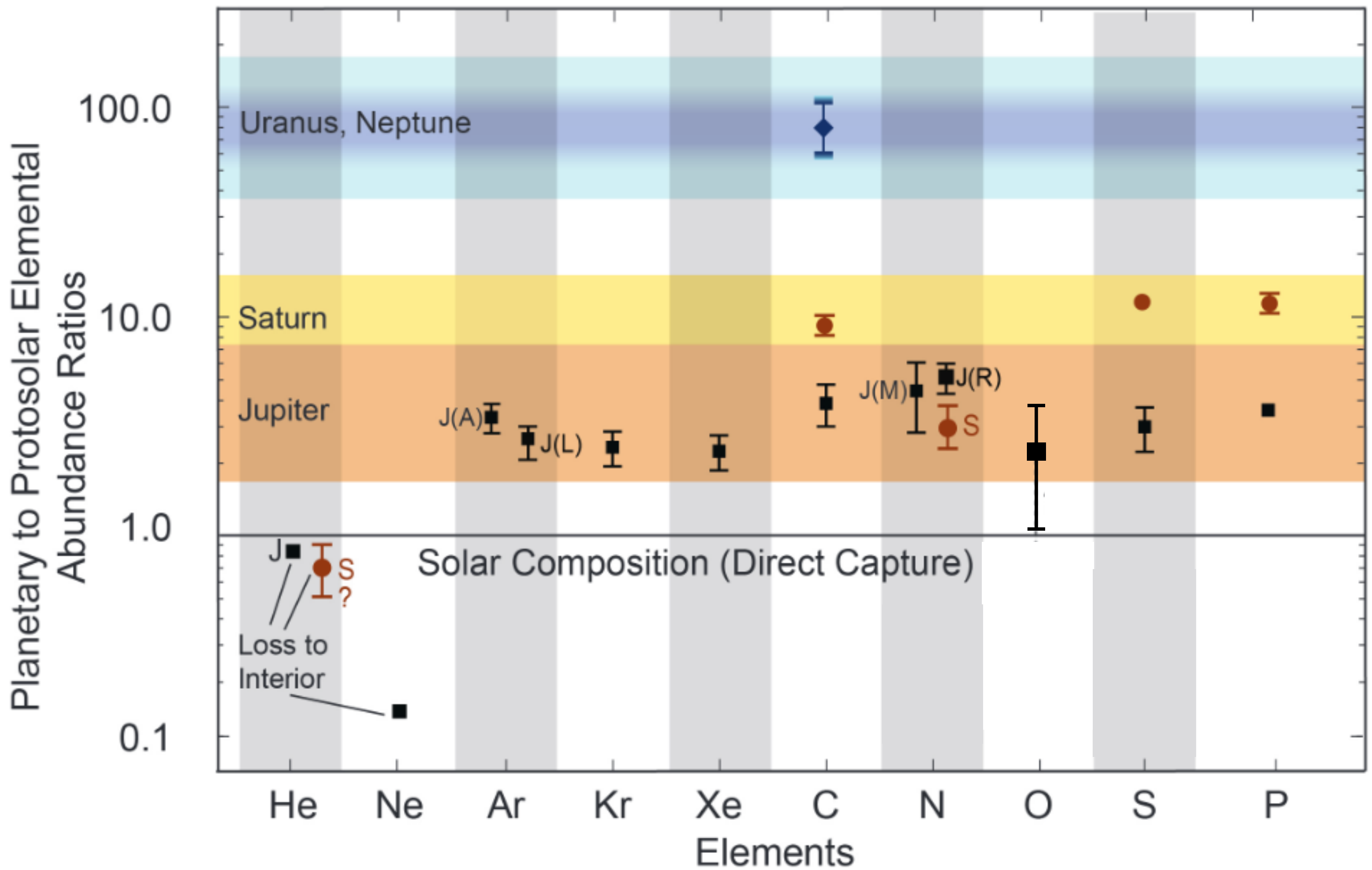
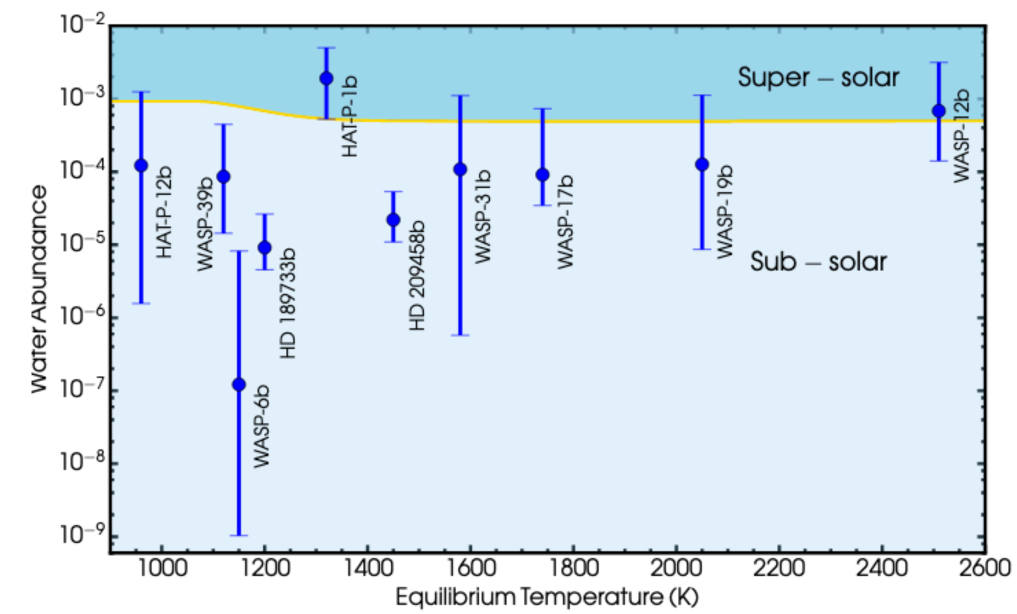
Observational data
ATMOSPHERE



Atreya+2016
Li+(Nature Astronomy,2020)

Observational data
ATMOSPHERE





Atreya+2016
Li+(Nature Astronomy,2020)

Pinhas+(mnras,2019)

also: Spake+2018; Tsiaras+2018; Fraine+2014; McCullough+2014; Wakeford+2013; Deming+2013; Damiano+2017; Evans+2016; Kreidberg+2014; Kreidberg+2015; Sing+2015; Knutson+2014

Methods

MODELING JUPITER'S INTERIOR

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MODELING JUPITER'S INTERIOR

Methods

MODELING JUPITER'S INTERIOR

Observational constrains :
R, M, J_2, J_4, J_6, Y, ...

+

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

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

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

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

Results using Juno data

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JUPITER'S INTERIOR

Results using Juno data

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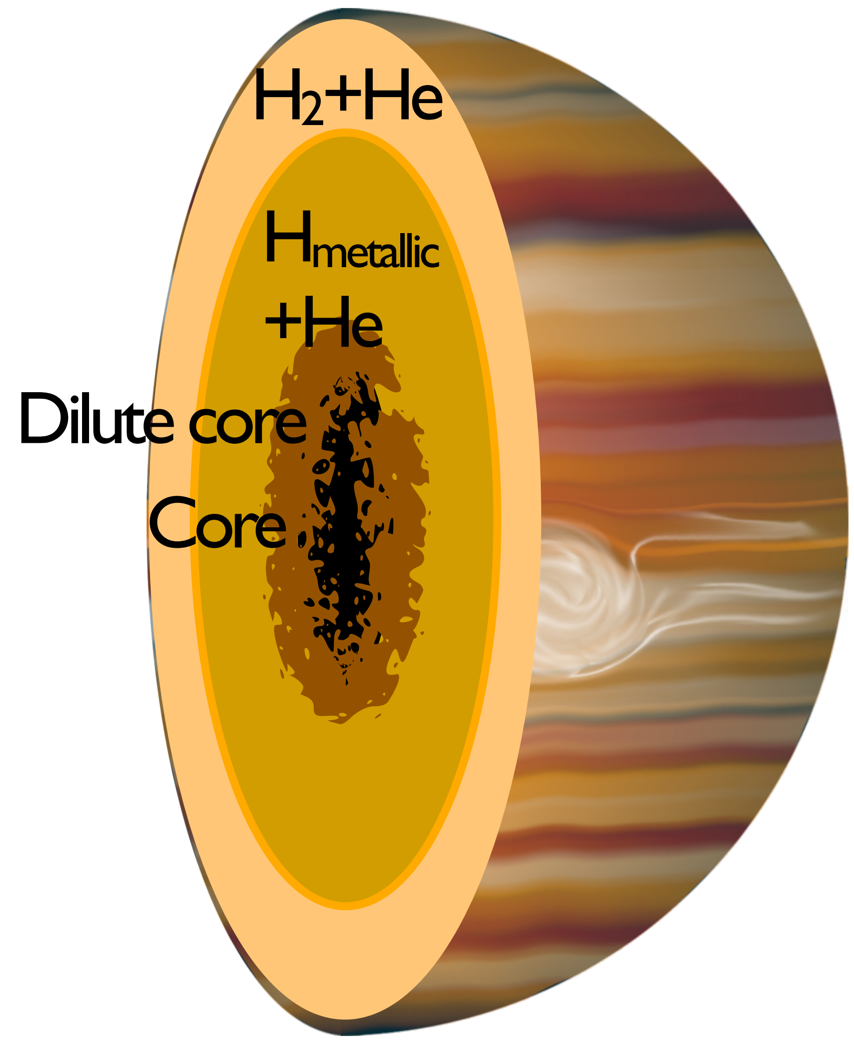

Altieri+(review on Jupiter to appear in 2020)
also: Wahl+ (GRL, 2017), with Mz approx. 25 MEarth
Dilute core formation & evolution: Lozovsky+2017, Vazan+2016
Alternative models: Debras & Chabrier (2019)

JUPITER'S INTERIOR

Results using Juno data

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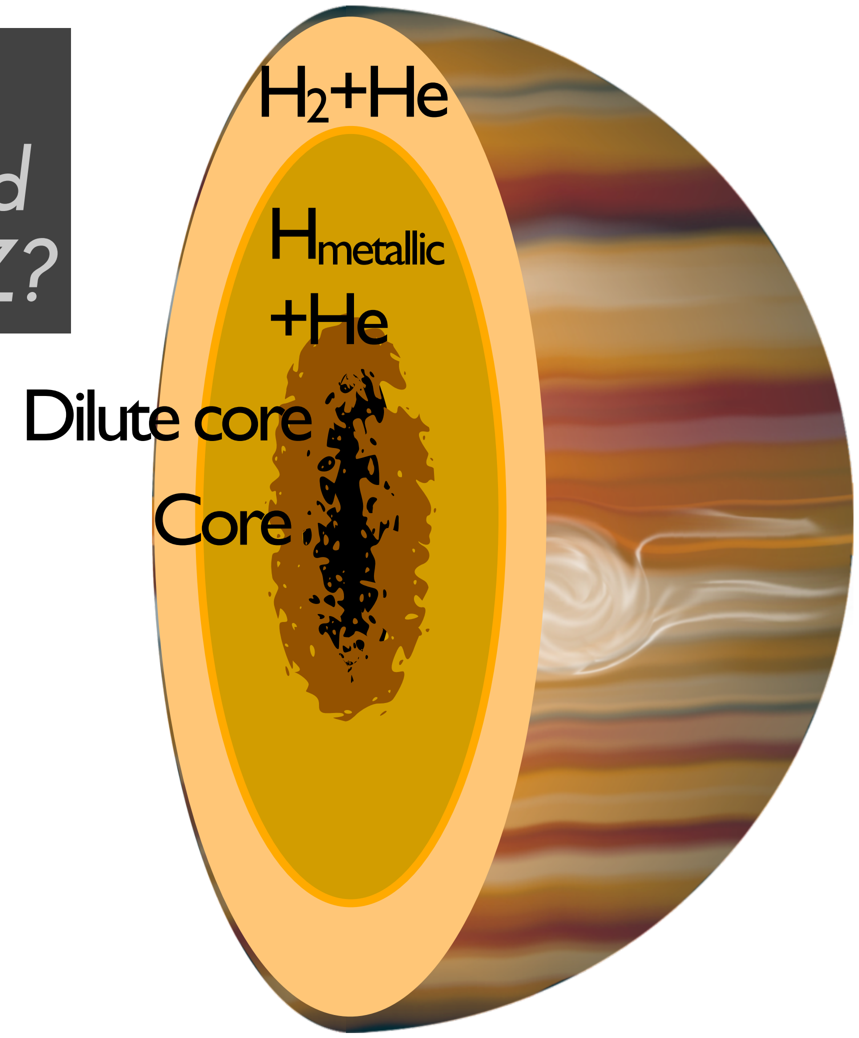
Are the H_2- and $H_{metallic}$-dominated Homogeneous in Z?



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Dilute core formation & evolution: Lozovsky+2017, Vazan+2016
Alternative models: Debras & Chabrier (2019)

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

↓ CEPAM

Radius, J2, J4

↓

Are the ones observed with Juno?

↓

We find a solution!

JUPITER'S INTERIOR

Method

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

▼ CEPAM

Radius, J2, J4

▼

Are the ones observed with Juno?

▼

We find a solution!


JUPITER'S ROTATION

Juno mission

JUPITER'S ROTATION

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Methods

GRAVITY FIELD

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Methods

GRAVITY FIELD

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Methods

GRAVITY FIELD

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Juno mission

JUPITER'S ROTATION

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JUPITER'S ROTATION

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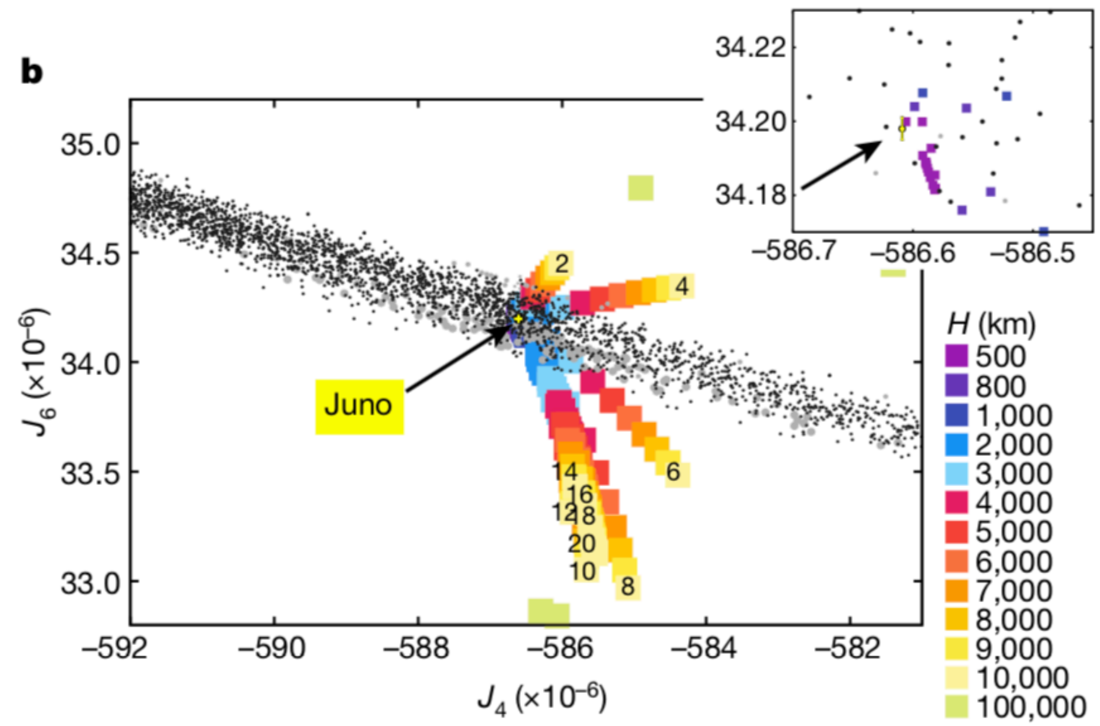

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JUPITER'S ROTATION

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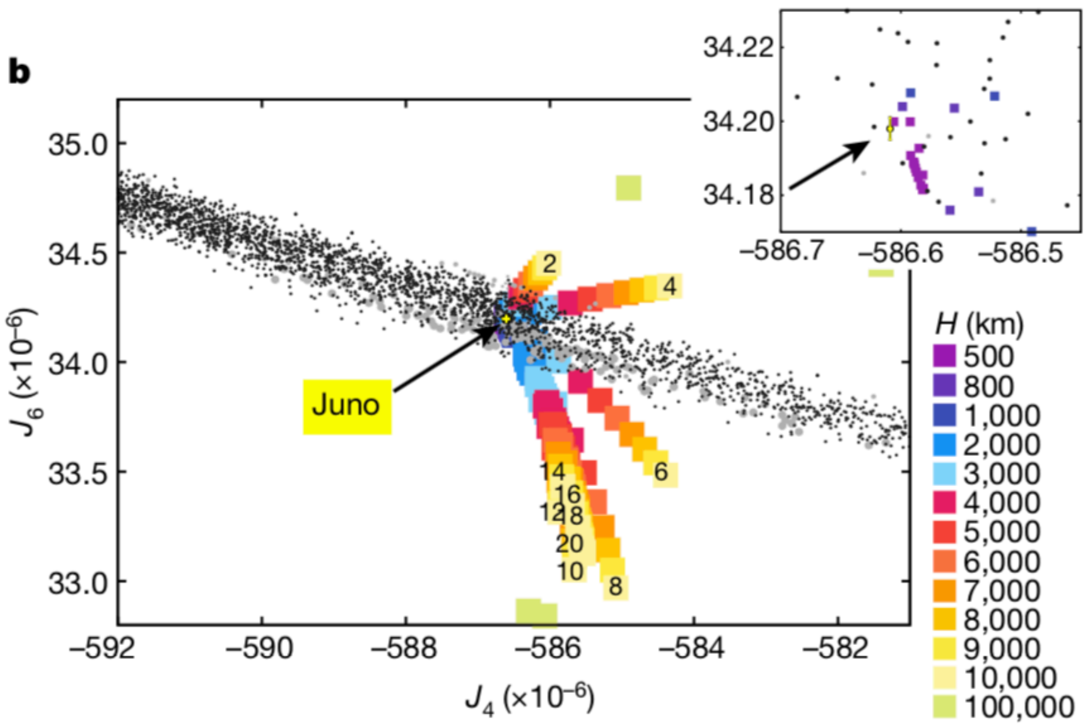

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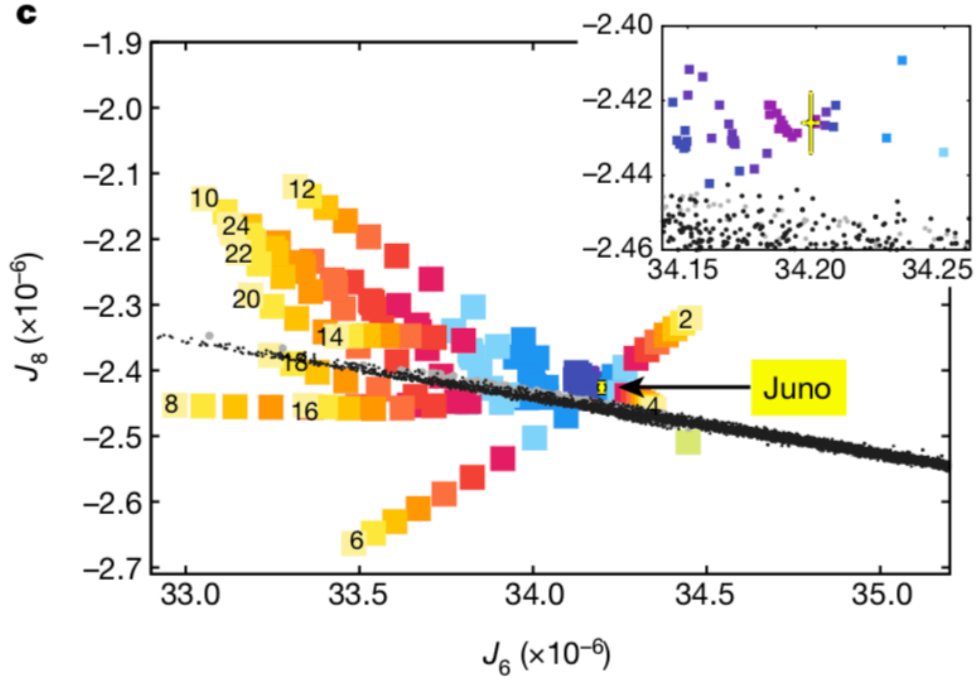

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JUPITER'S ROTATION

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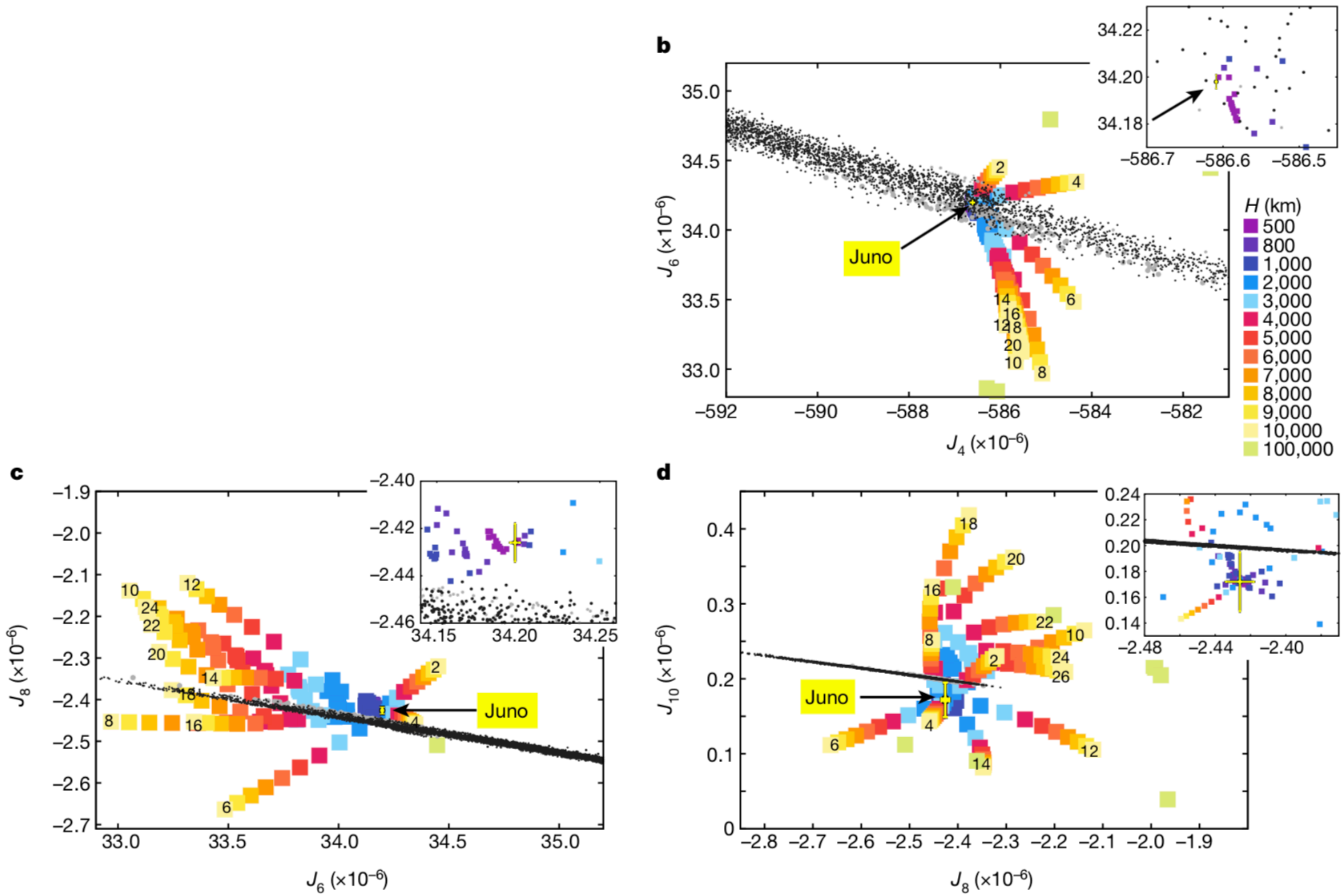

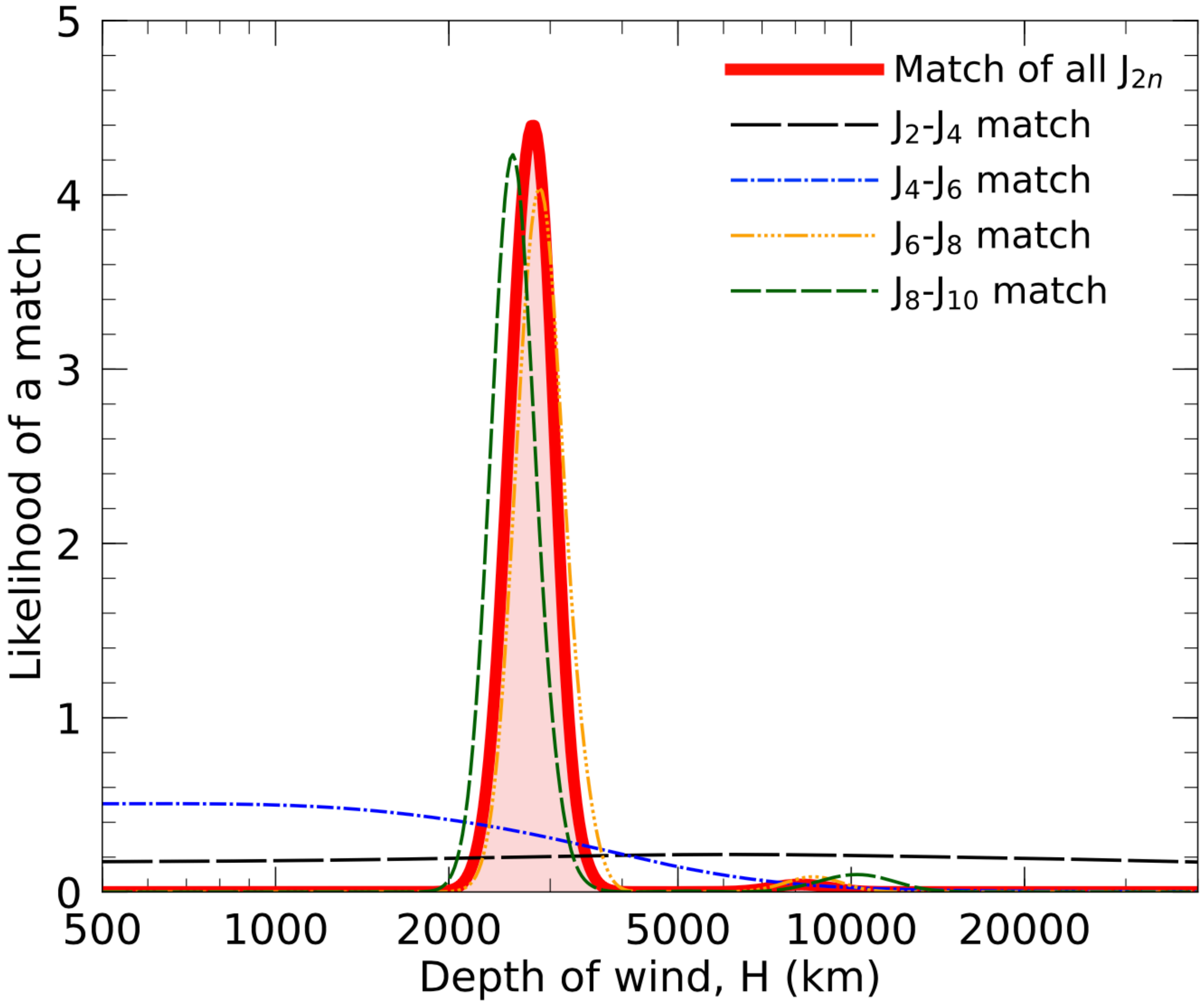

Guillot, Miguel + (Nature, 2018)

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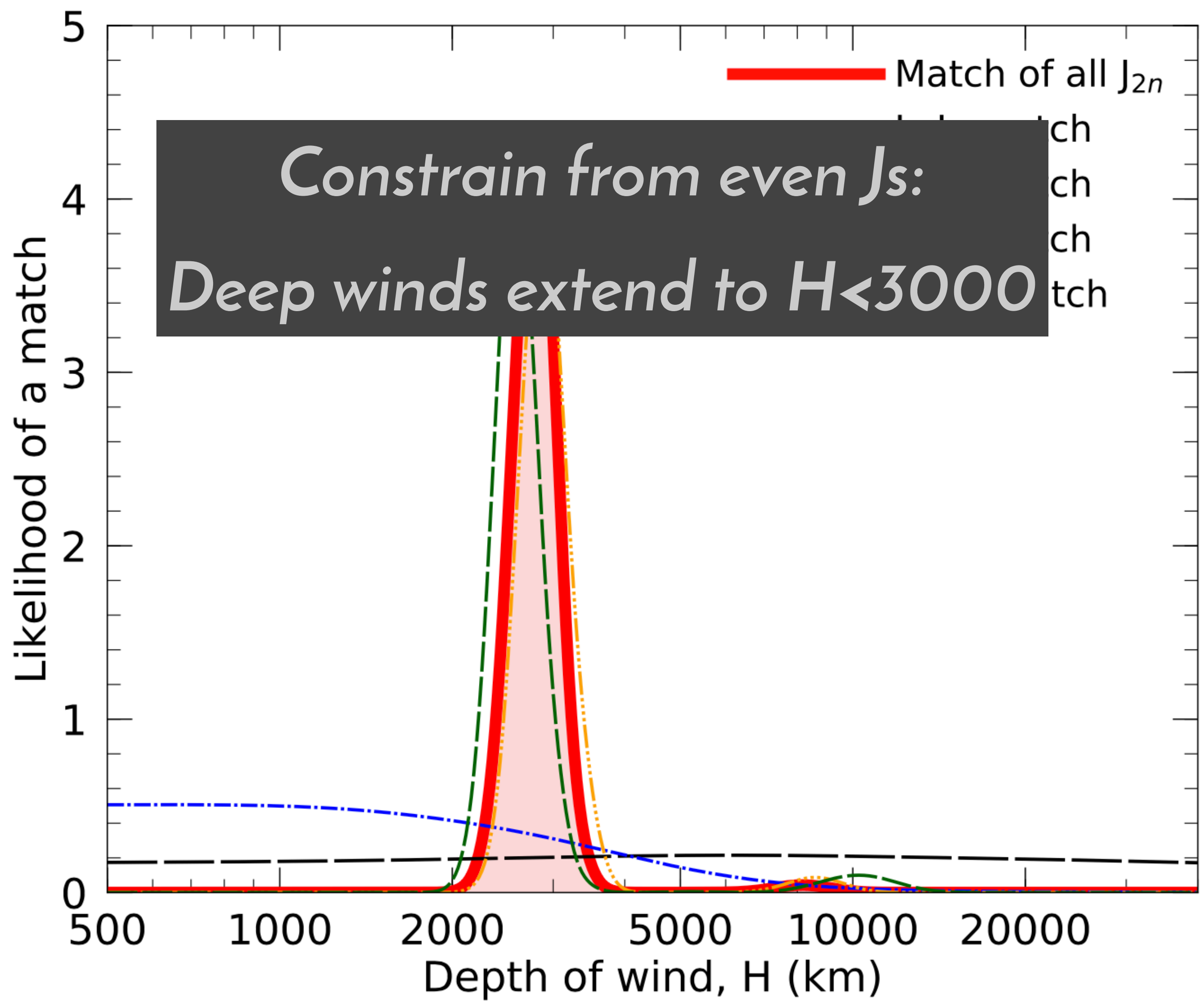

Constrain from even Js:

Deep winds extend to H<3000

Guillot, Miguel + (Nature, 2018)

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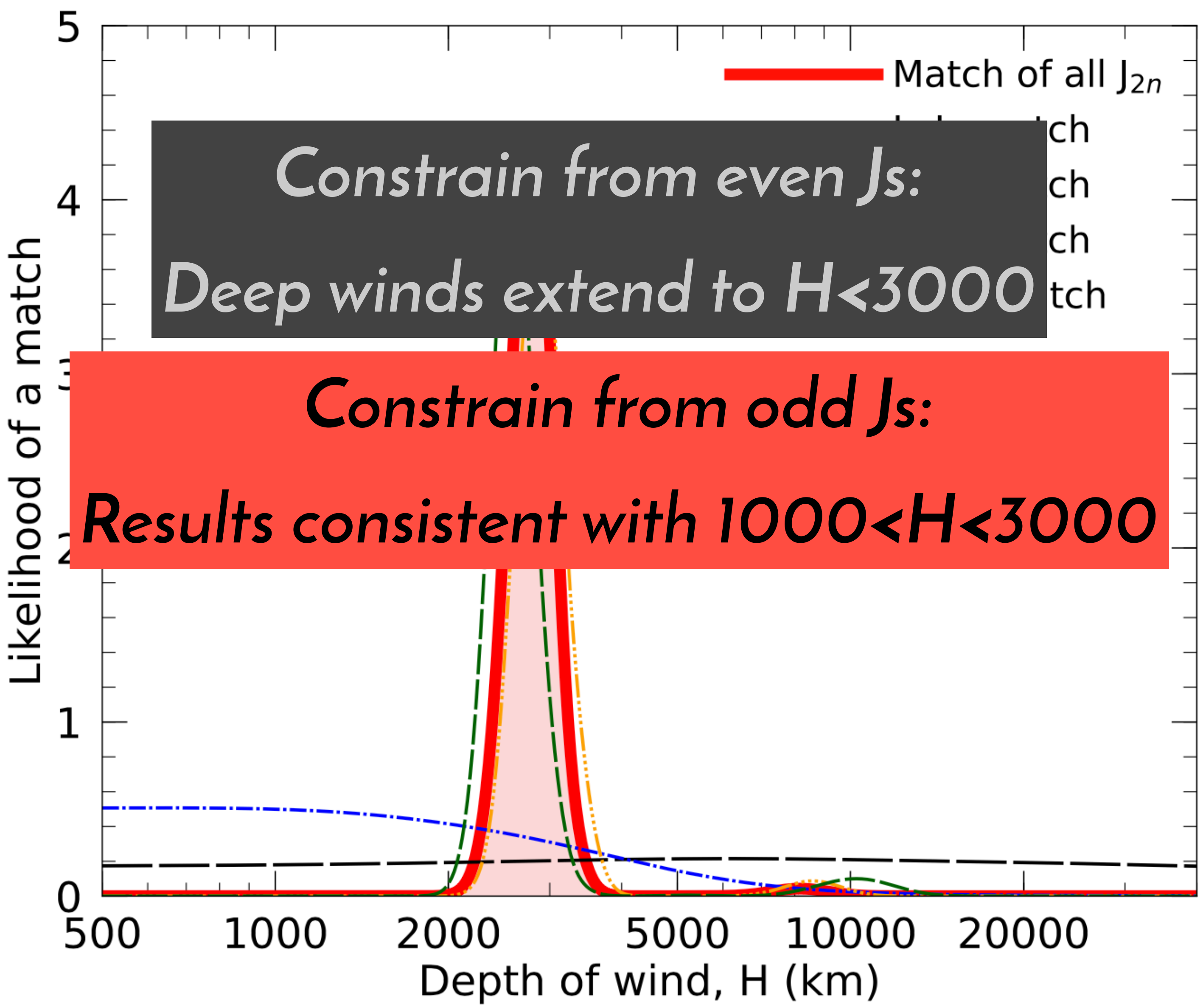


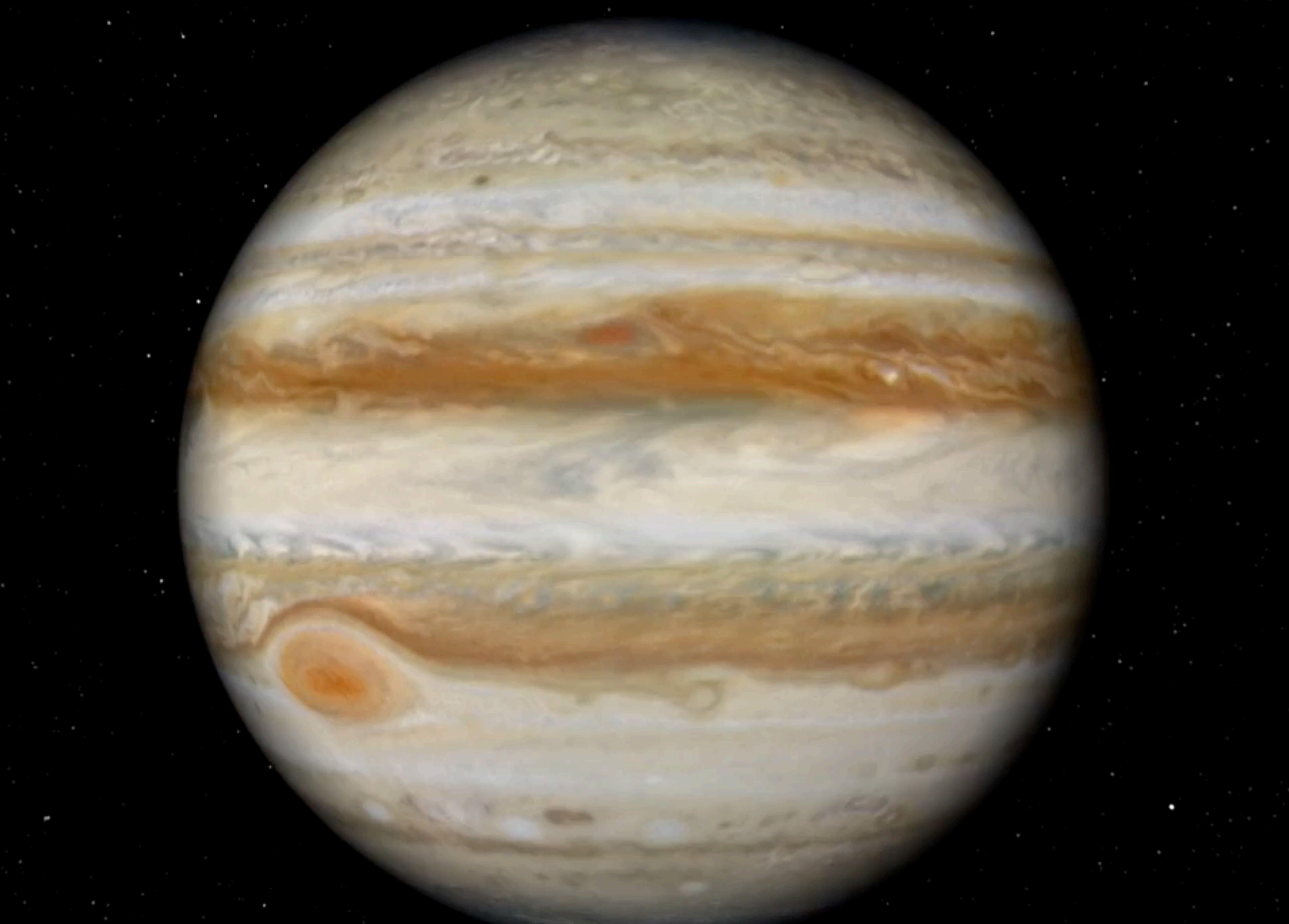
Constrain from even Js:

Deep winds extend to H<3000

Constrain from odd Js:

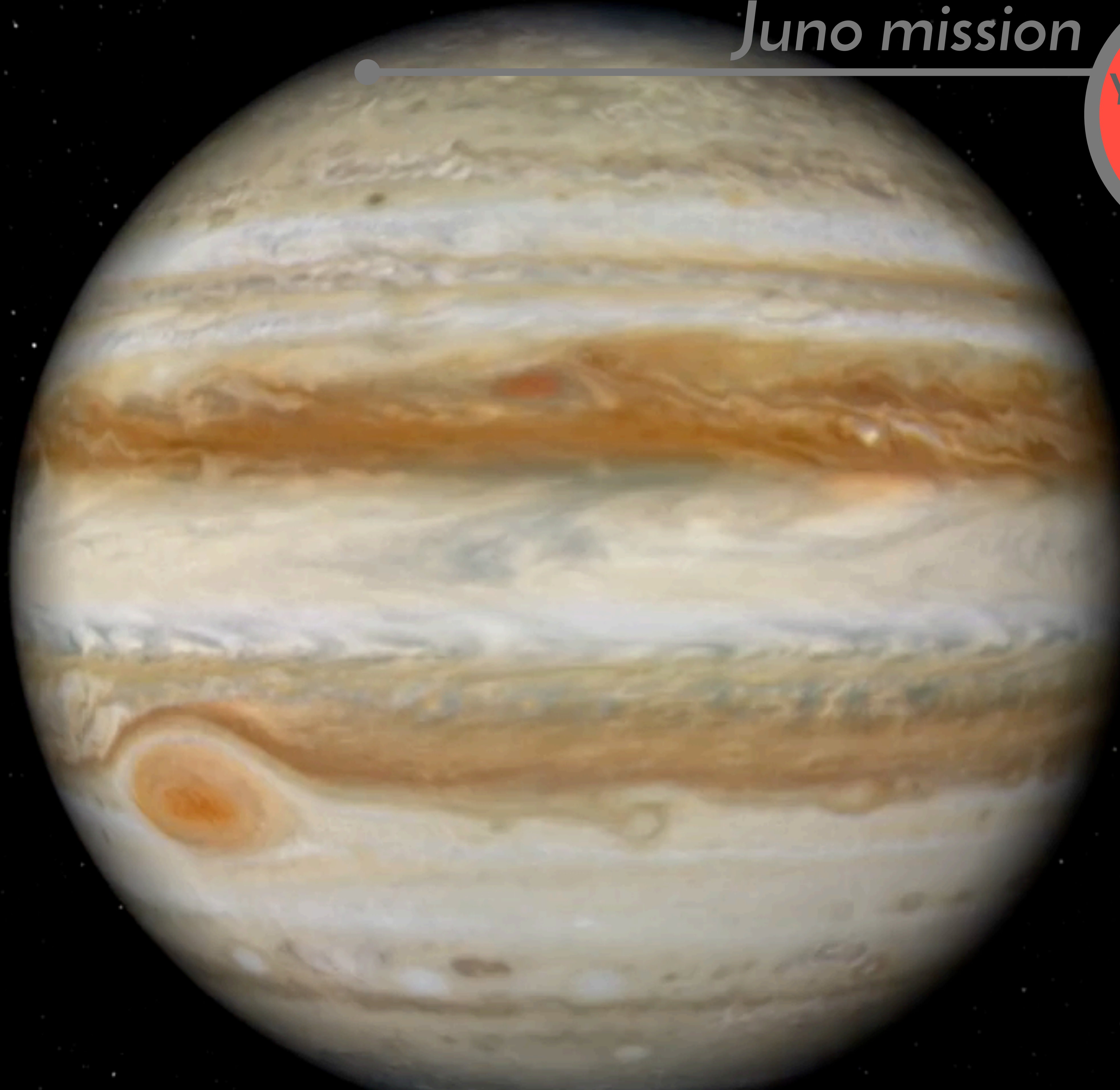
Results consistent with 1000<H<3000

Guillot, Miguel + (Nature, 2018), Kaspi + (Nature, 2018)



NASA press release for our papers: Guillot, Miguel+(Nature, 2018), Kaspi+(Nature, 2018) and Iess+(Nature+2018)

Juno mission



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NASA press release for our papers: Guillot, Miguel+(Nature, 2018), Kaspi+(Nature, 2018) and Iess+(Nature+2018)

TAKE HOME MESSAGE

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TAKE HOME MESSAGE

JUNO GRAVITY DATA

Juno greatly improved accuracy of Js

Including measurements of J8 and J10 and the odd Js for the first time

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@AstroYamila - www.YamilaMiguel.com

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JUPITER'S ENVELOPE

Interior models have a higher concentration of heavies in the metallic region:
Jupiter's envelope is not homogeneous
Mixing was not complete in Jupiter's envelope

JUNO GRAVITY DATA

Juno greatly improved accuracy of Js

Including measurements of J8 and J10 and the odd Js for the first time

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TAKE HOME MESSAGE

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JUNO IWG

Tristan Guillot, William B. Hubbard, Yohai Kaspi, Burkhard Militzer, Sean Wahl, William Folkner, Luciano Iess, Ravit Helled, Eli Galanti, Daniele Durante, Marzia Parisi, Hao Cao, Daniel Reese, Jonathan I Lunine, Scott J Bolton, David J. Stevenson

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