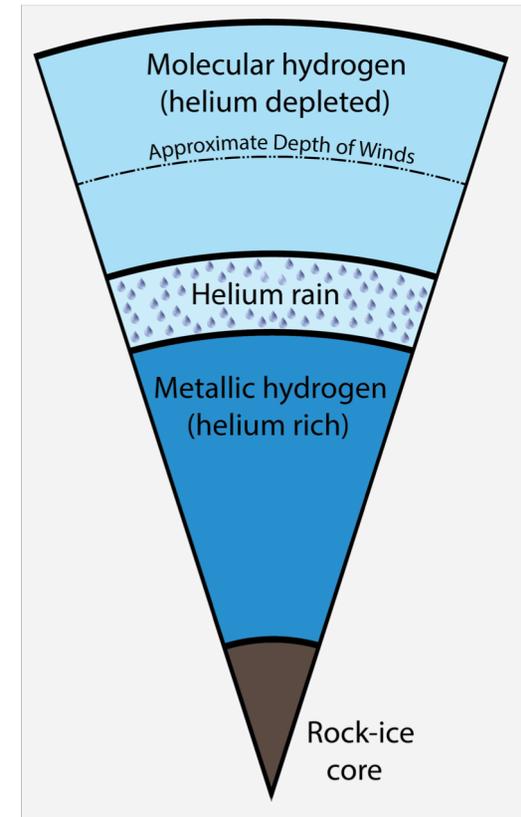
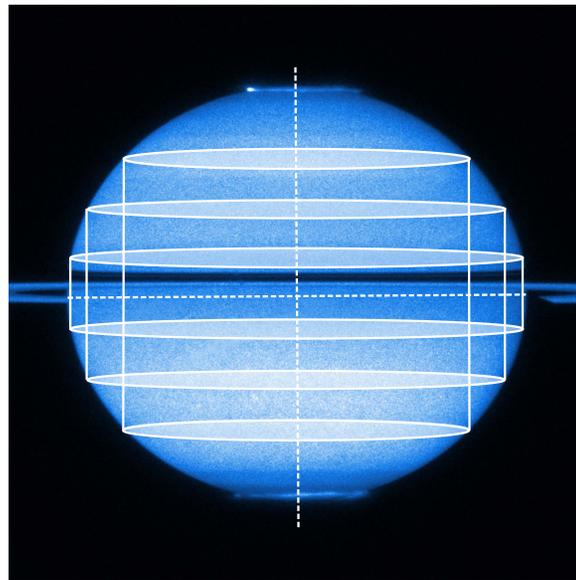
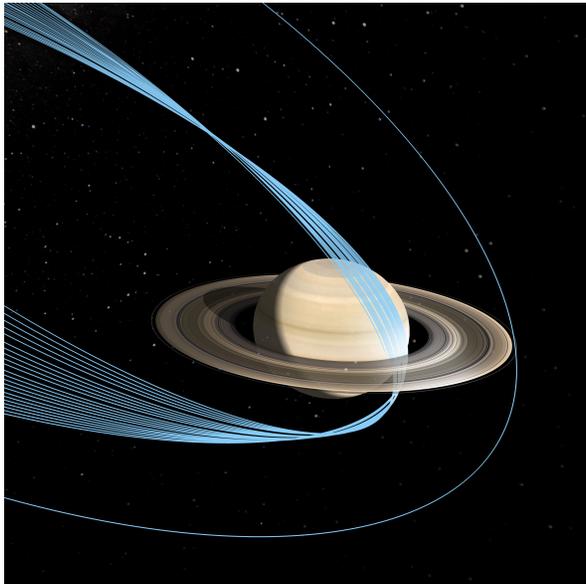


# Measurement and Implications of Saturn's Gravity Field and Ring Mass



Presentation prepared by

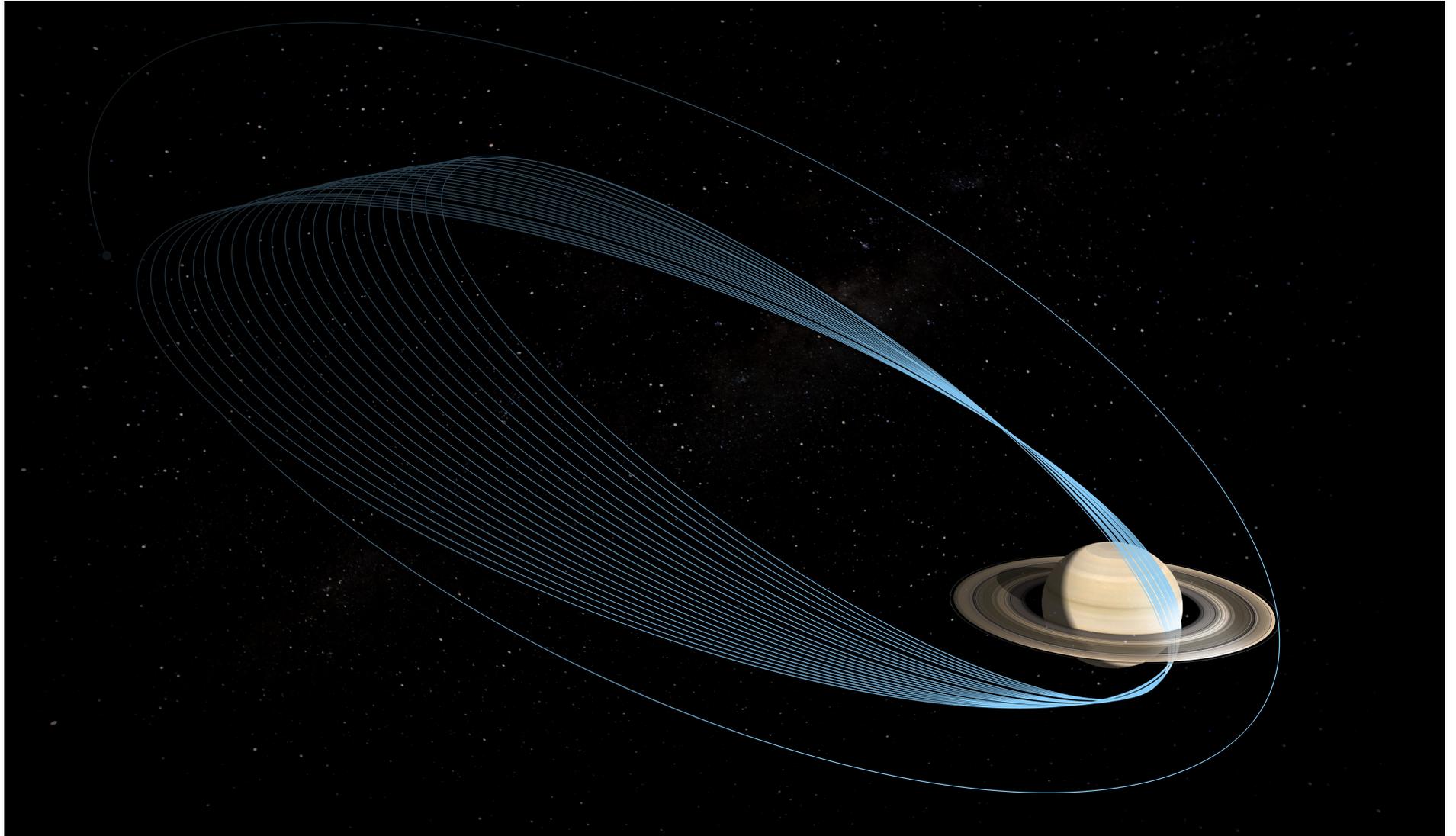
**Burkhard Militzer**

UC Berkeley

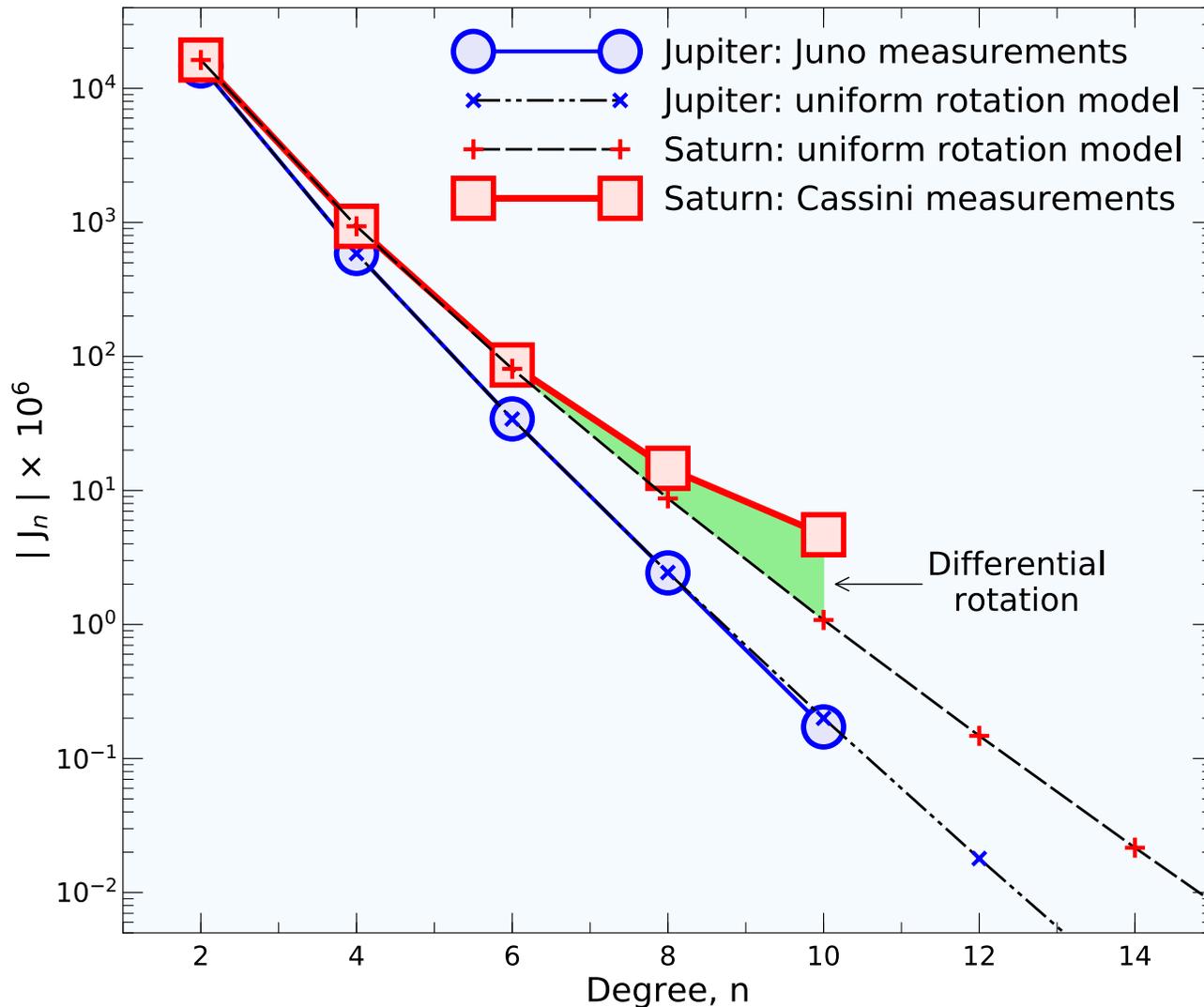
**Authors of the article in Science:** L. Iess, B. Militzer, Y. Kaspi, P. Nicholson, D. Durante, P. Racioppa, A. Anabtawi, E. Galanti, W. Hubbard, M. J. Mariani, P. Tortora, S. Wahl, M. Zannoni

# **1. Saturn's Gravity Field**

# The Cassini Spacecraft Measured Saturn's Gravity Field when it dove inside its rings before eventually burning up in its atmosphere



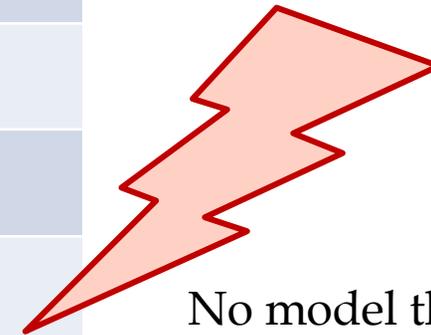
# Saturn's Gravity is highly unusual, cannot be matched with Uniform Rotation Models



# Puzzling Cassini Gravity Data with unusually large $J_6$ , $J_8$ and $J_{10}$

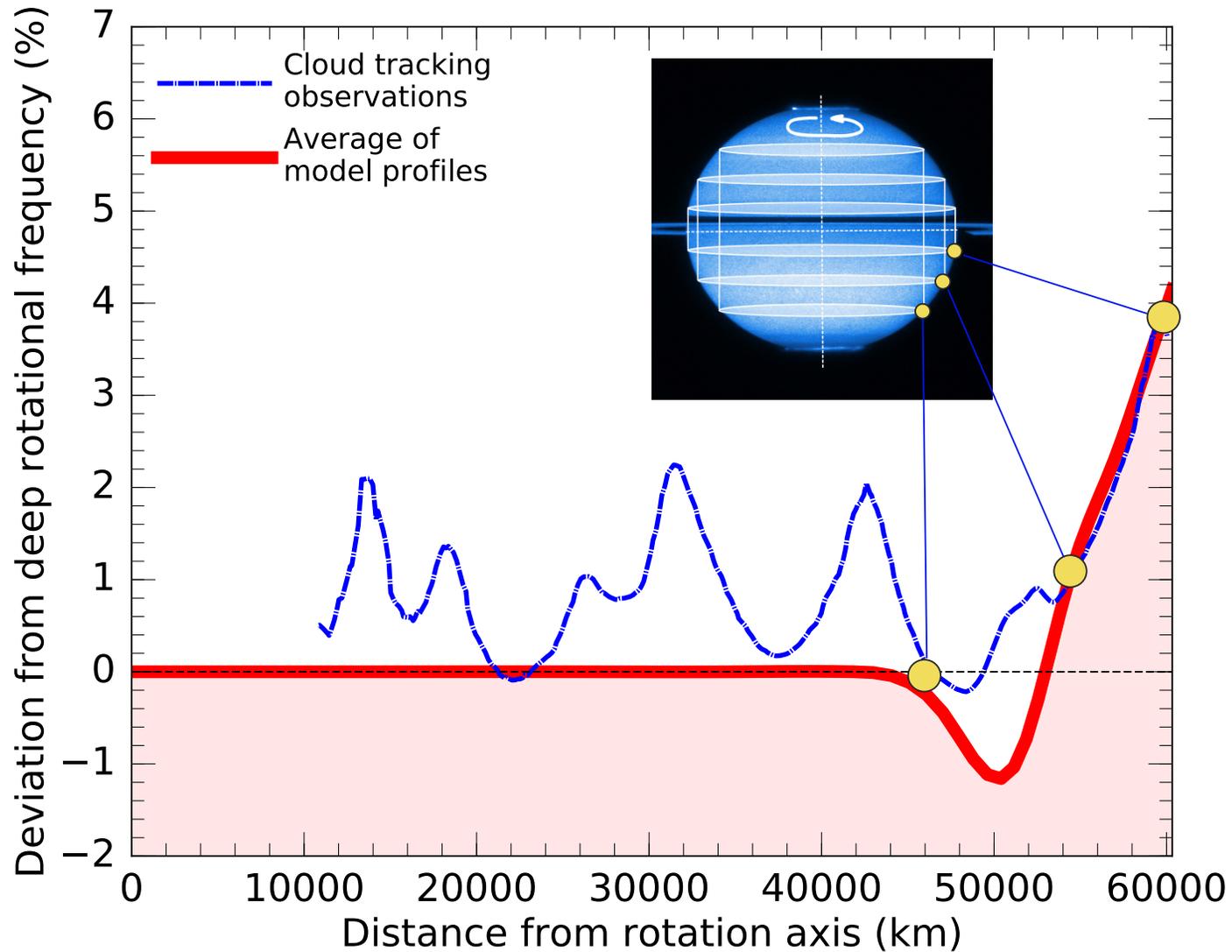
Models match mass, radius, and  $J_2$  from Jacobson solution. All  $J_{2n}$  multiplied by  $10^6$ .

	Range of Model Predictions assuming Uniform Rotation		Cassini Data Rev 273+274 solution
	May 1, 2017		May 19, 2017
$J_4$	-938.619	-933.187	-934.5792
$J_6$	80.532	81.737	<b>86.5215</b>
$J_8$	-8.950	-8.680	<b>-14.3704</b>
$J_{10}$	1.076	1.129	<b>4.9910</b>
$J_{12}$	-0.157	-0.147	-0.6670
$J_{14}$	0.0215	0.0234	0.5332



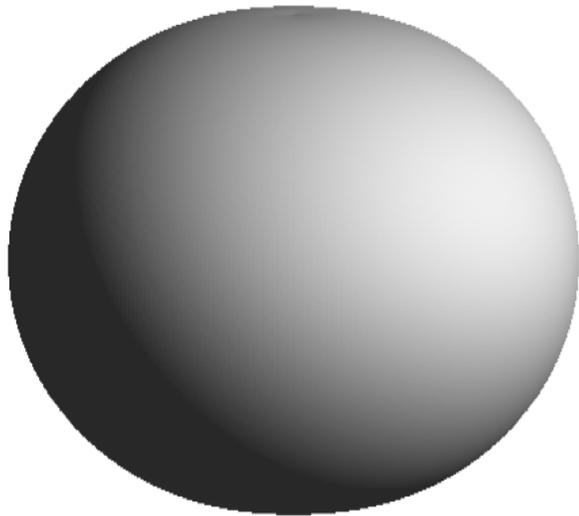
No model that assumed uniform rotation (no winds) could match the observations.

# Effects of Differential Rotation

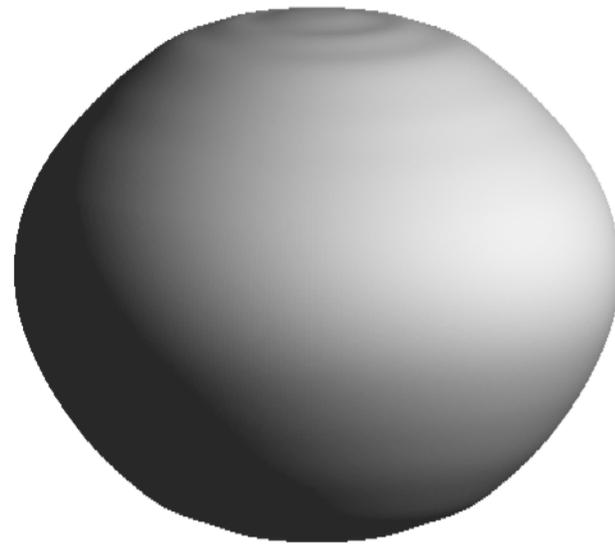


# Effects of Differential Rotation

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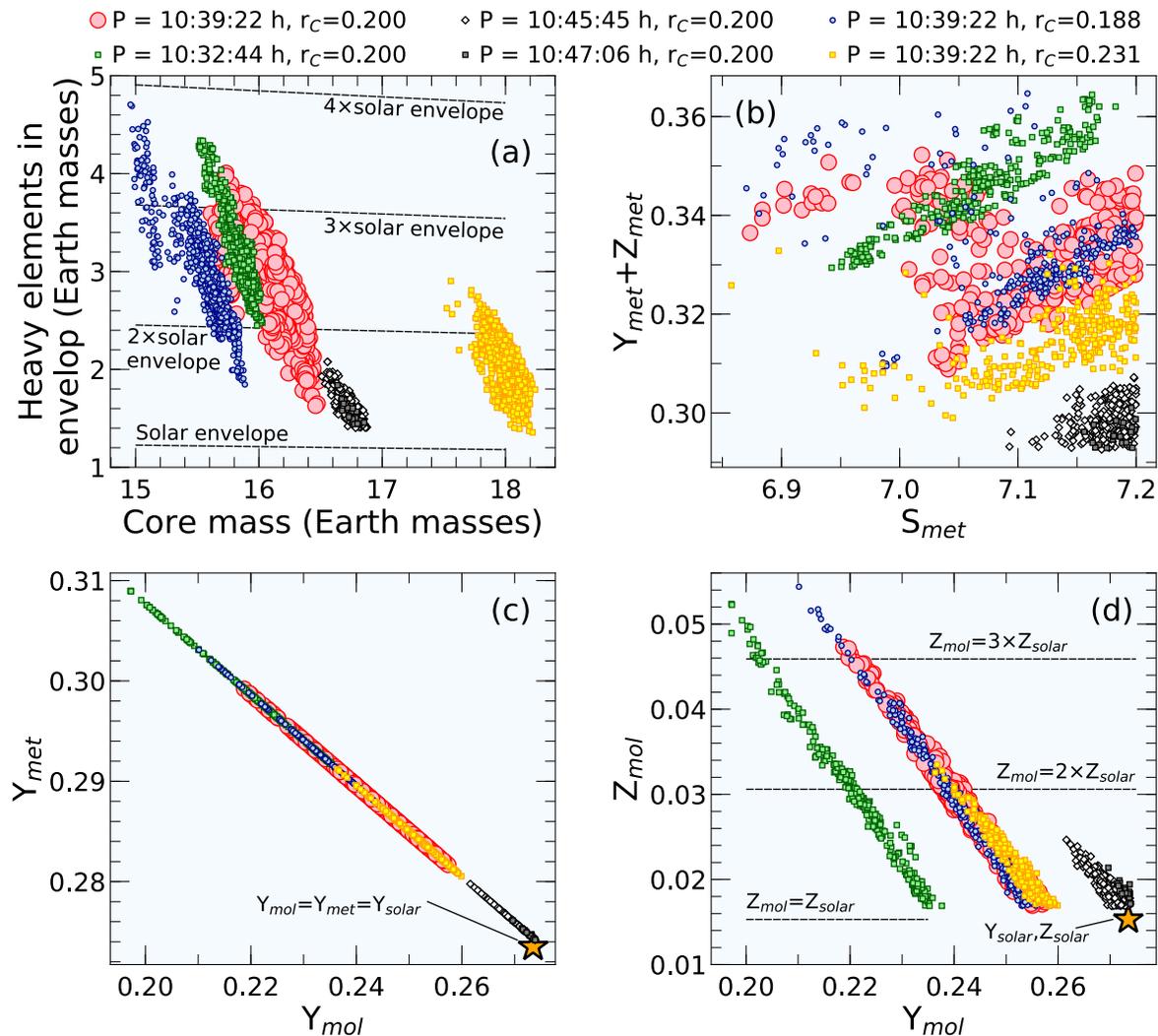


Rotational flattening from uniform, solid-body rotation



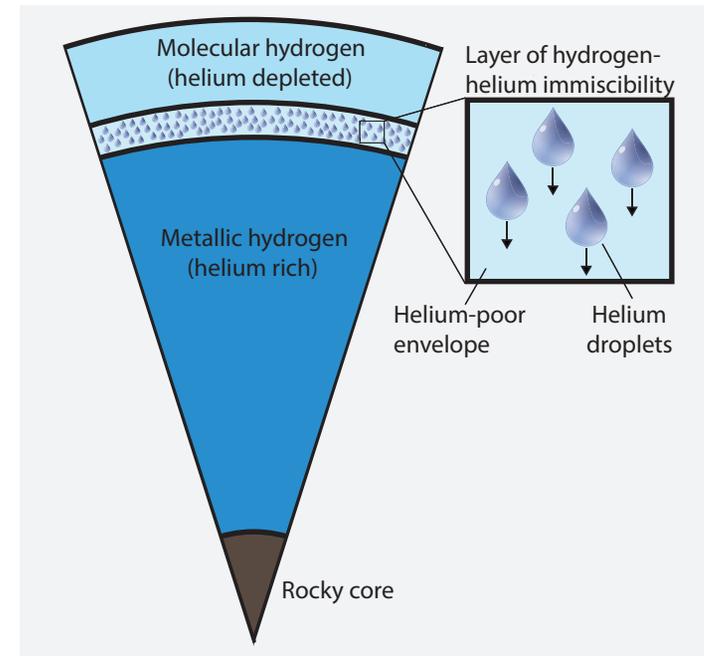
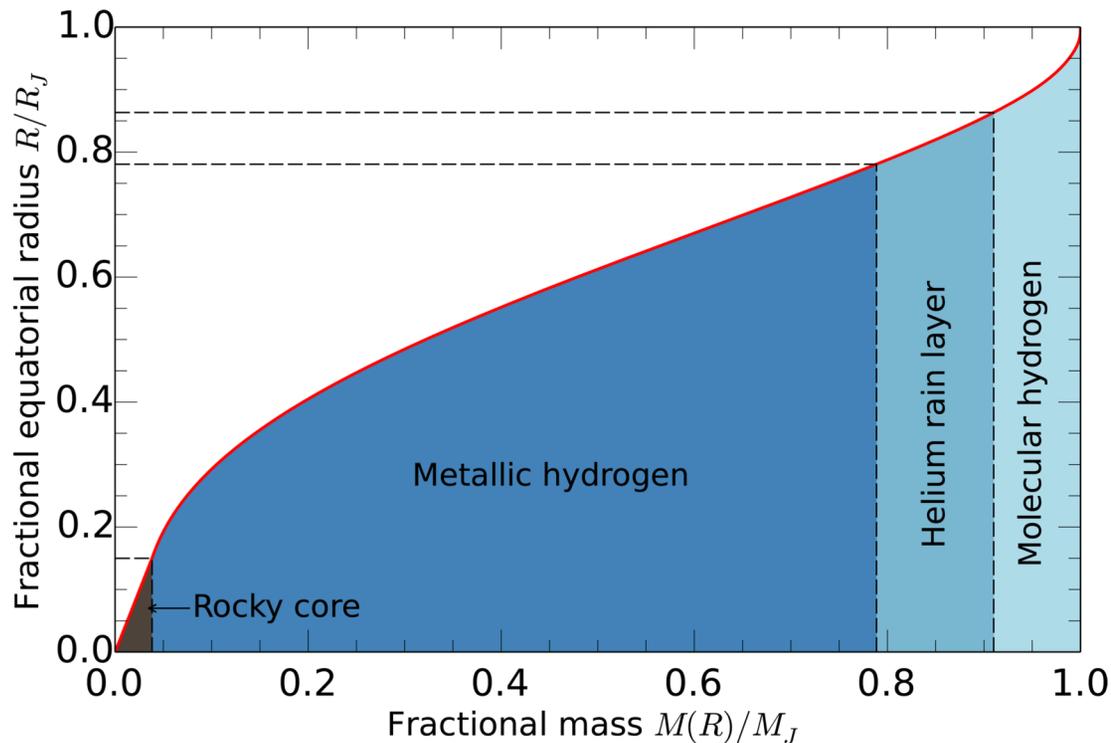
Flattening from differential rotation (exaggerated).

# Parameter Ranges in our Models that are consistent with the Spacecraft measurements



Saturn is predicted to have a rock-ice core worth 15-18 Earth masses.

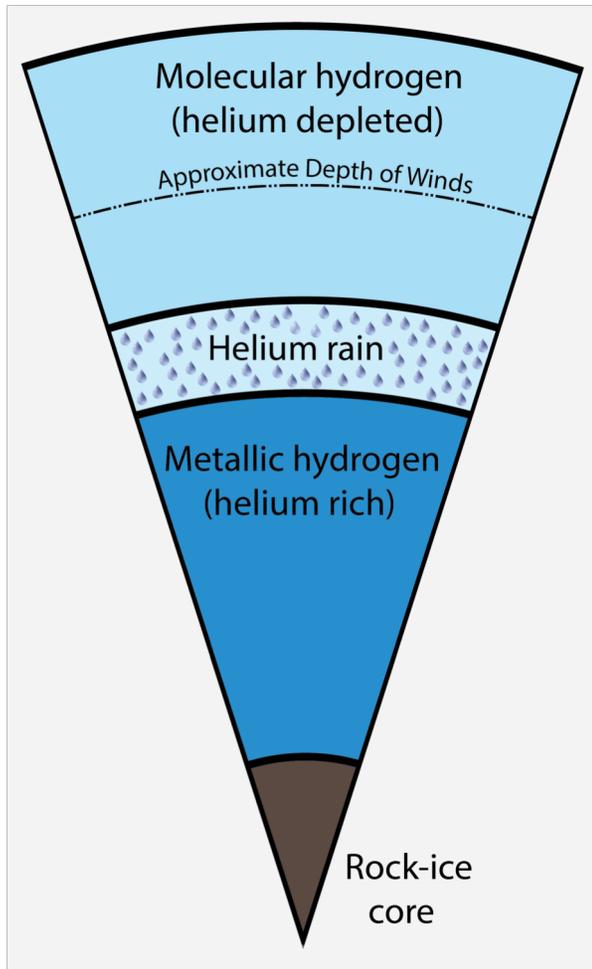
# Typical for Giant Planet Interiors Take Jupiter as an Example



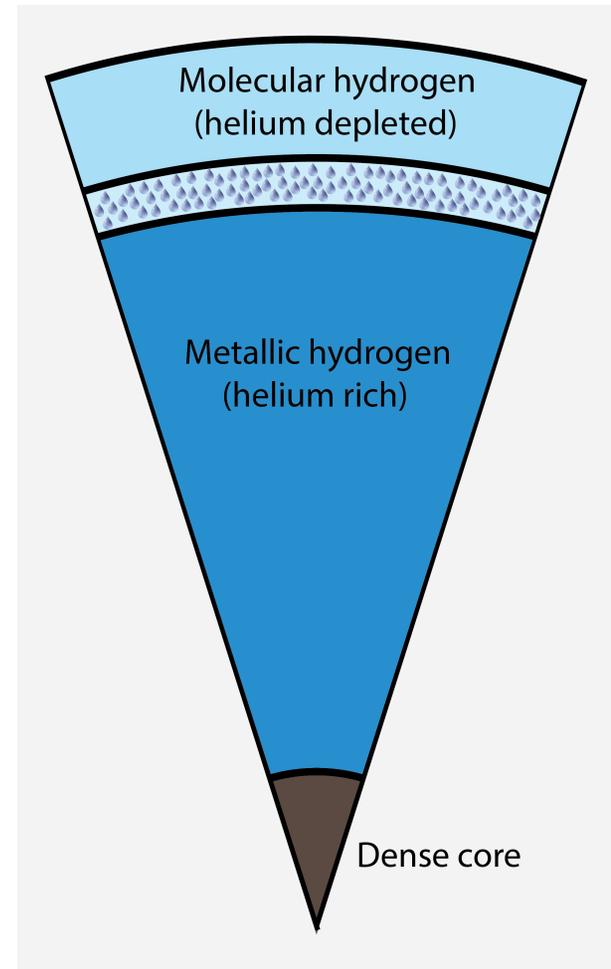
**Jupiter model**

Militzer et al. (2016) JGR, 121.

# Comparison of Saturn and Jupiter



Saturn's interior



Jupiter's interior

# **2. Mass of Saturn's Rings**

# How Do we Relate our Ring **Mass** Measurement to the **Age** of the Rings?

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1. Assume rings started as pure water ice and have been steadily darkened by the infall of meteoroid material (Cuzzi, Estrada, 1998). The meteoroid flux (mass/year) is known. The color of the rings tell us about today's rock-ice ratio. Our new mass measurements thus tell us when the rings formed and for how long meteoroids have polluted them.
2. Rate of recession of the small satellites from the rings due to gravitational torques (Borderies et al, 1984)
3. Evolution of unconfined edges such as the inner edges of the A and B rings (Estrada *et al.* 2015)

All these estimates depend on the total ring mass.

# “Pre-Cassini” Ring Mass Estimate

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The estimated total ring mass was

$2.8 \times 10^{19}$  kg or 0.75 Mimas masses

and became the standard pre-Cassini value.

*However, it was argued that substantially more mass might be hidden in the opaque parts of the B ring.*

Mimas: moon of Saturn, mass =  $6.3 \times 10^{-6} M_{\text{earth}}$ .

2000 Mimas masses  $\sim$  1 lunar mass.

16000 Mimas masses  $\sim$  1 Earth mass.

$1.5 \times 10^7$  Mimas masses  $\sim$  1 Saturn mass.

# Cassini observations of density waves

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Cassini observations of density waves have led to local surface density estimates in the A, B and C rings.

The B ring density is surprisingly low, with a mean value of  $\sim 600 \text{ kg/m}^2$ .

Likely total ring mass of **0.40 Mimas masses**.

*However, it is conceivable that some mass in the rings does not contribute to the density waves.*

# First Determination of Saturn's Ring Mass from Gravity

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Directly from the gravity signal, we determined a total mass of the main rings A, B and C =

**0.41±0.13 Mimas masses.**

Mass of diffuse D, F, G, and E rings assumed to be negligible.

An indication that the rings are young, were formed only 10-100 million years ago.

# Possible Origin of Saturn's Rings

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- The rings weigh 0.41 Mimas masses today but were **much more massive earlier**.
- Rings possibly came about from the capture and following gravitational disruption of a **comet or Centaur** (Dones, 1991; Dones et al. 2007)
- Alternatively they came from an earlier **population of mid-sized icy satellites** (Ćuk, ApJ, 2016). Their orbits became unstable and there was at least one giant collision that products the guzzilion of ring particles that we see today

# Conclusions

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- **Saturn is predicted to rotate differentially** based on even gravity coefficient. The equatorial regions rotate about 4% faster than the deep interior.
- Winds are at least 9000 km deep.
- Saturn rings have a low mass and are young (10-100 million years). This points to a dramatic collision in our recent solar system history.