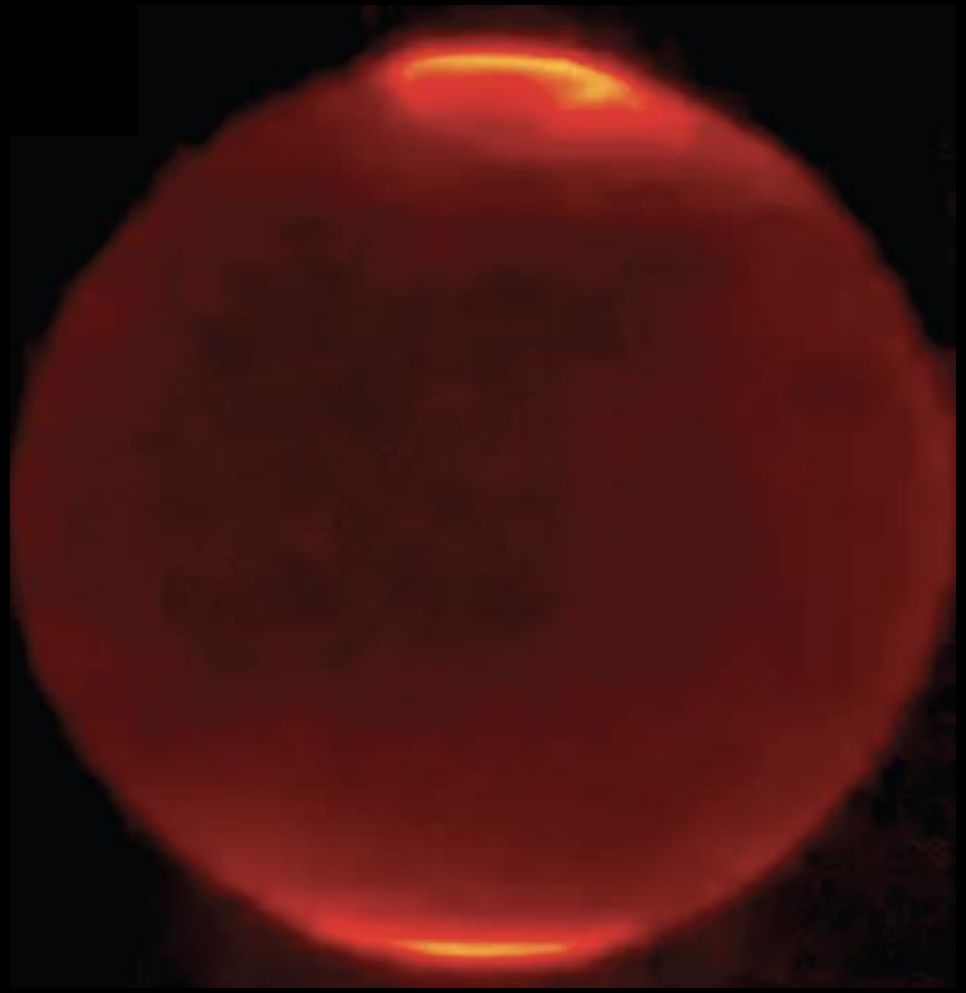
Probing the Most Revealing Layers of the Giant Planets

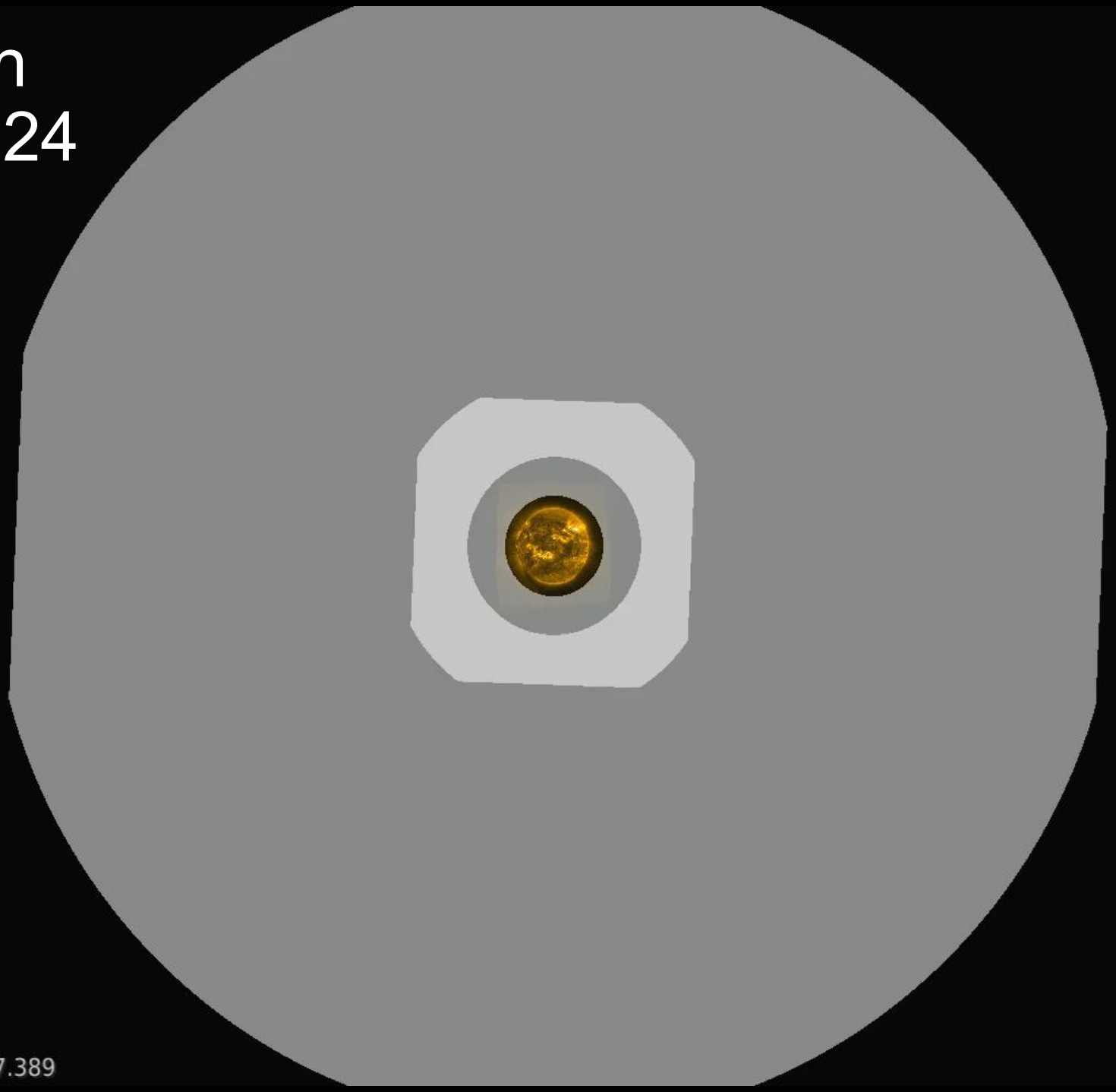
Dr James O’Donoghue



Spectroscopy of Exoplanets: Over All Wavelengths, June 2025

University of Reading

The Sun on 8-10 May 2024



SOHO

2024-05-08T00:06:07.389

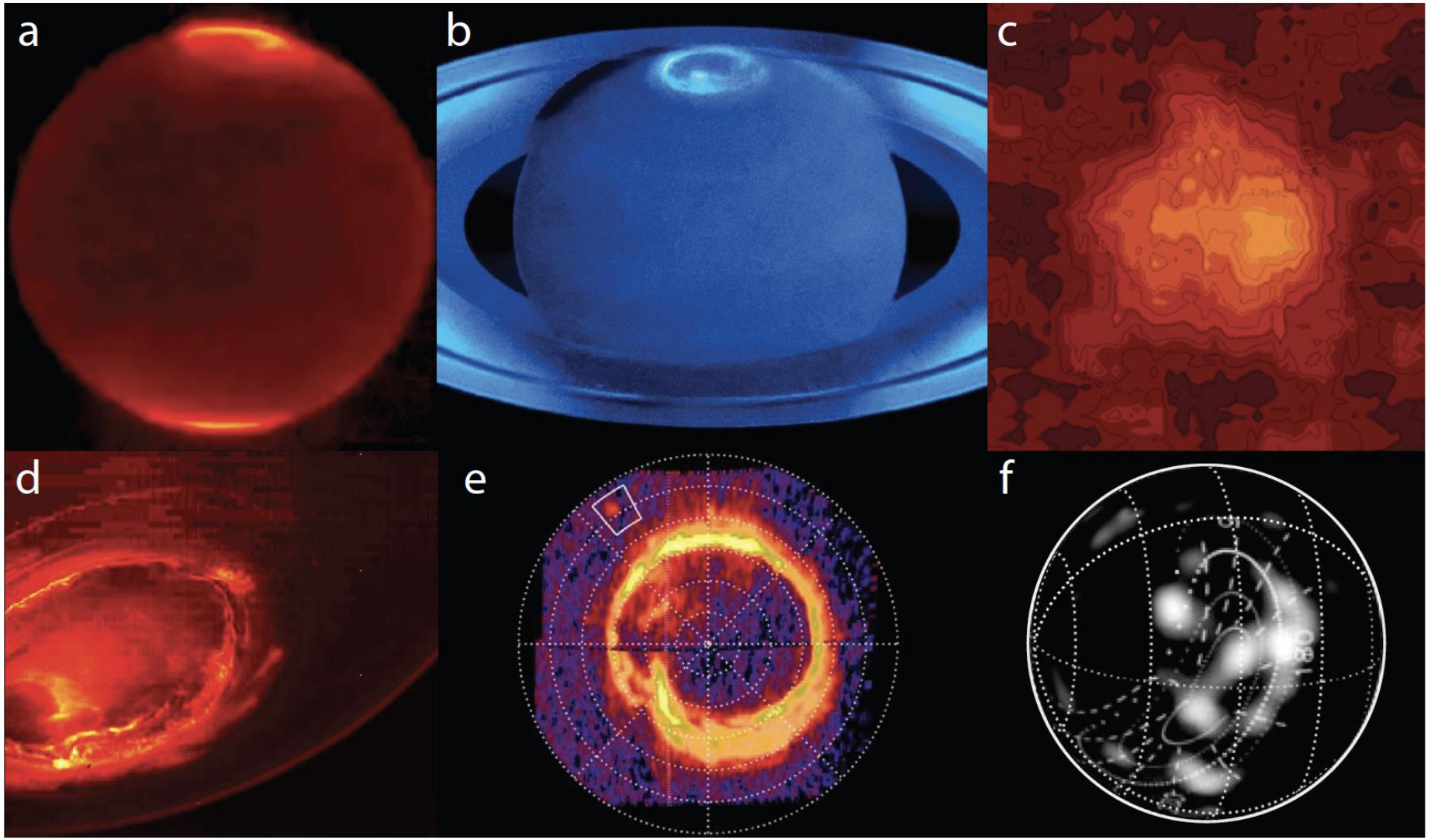
Brighton
Credit: Mel Ades

Giant planet upper atmospheres

JUPITER SATURN URANUS

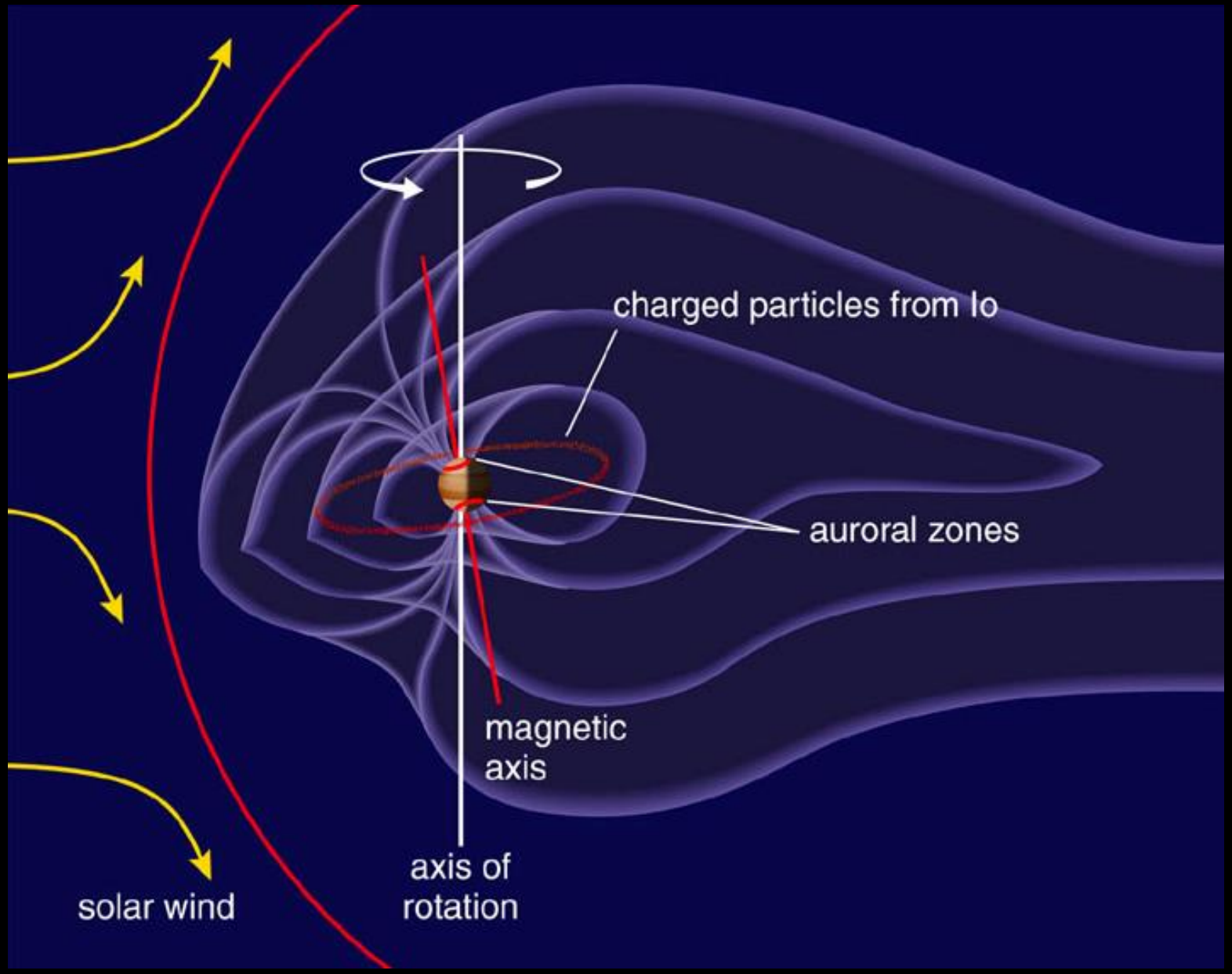
Earth-based telescopes

Spacecraft

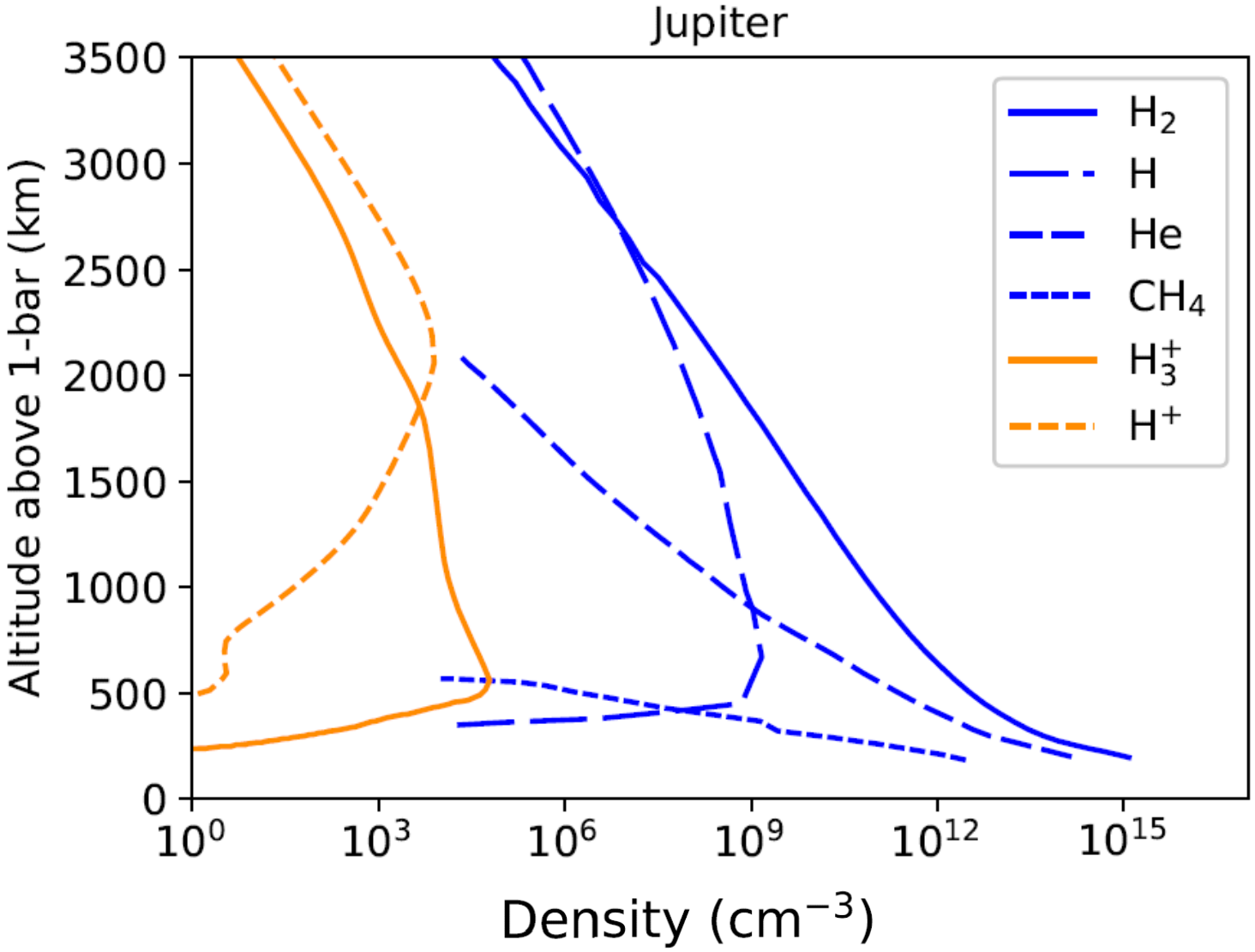


O'Donoghue and Stallard, 2022 (review)

Jupiter's magnetosphere



Giant planet upper atmospheres – Thermosphere and Ionosphere



O'Donoghue and Stallard, 2022 (review)

Major probe of the upper atmosphere: H_3^+

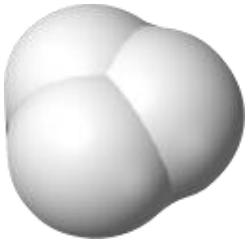
Production: first, ionise H_2

$$H_2^+ + H_2 \longrightarrow H_3^+ + H$$

Loss examples

$$H_3^+ + e^- \longrightarrow H_2 + H$$

$$H_3^+ + H_2O \longrightarrow H_2 + H_3O^+$$

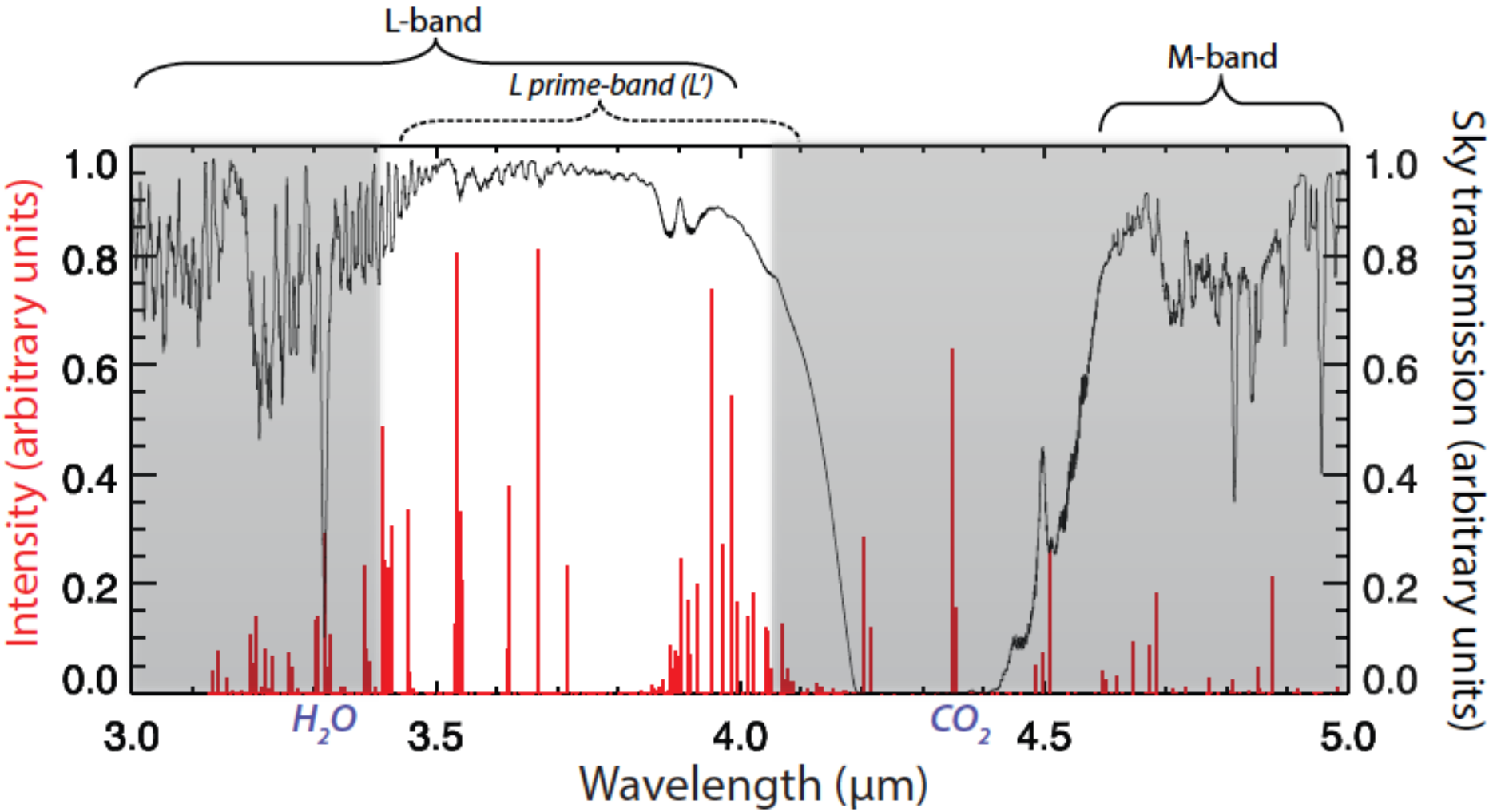


emitting in IR (~0.1sec)

Life time ~1000 s…

- Temperatures, $T(H_3^+)$
- Densities, $N(H_3^+)$
- Radiance, $E(H_3^+)$

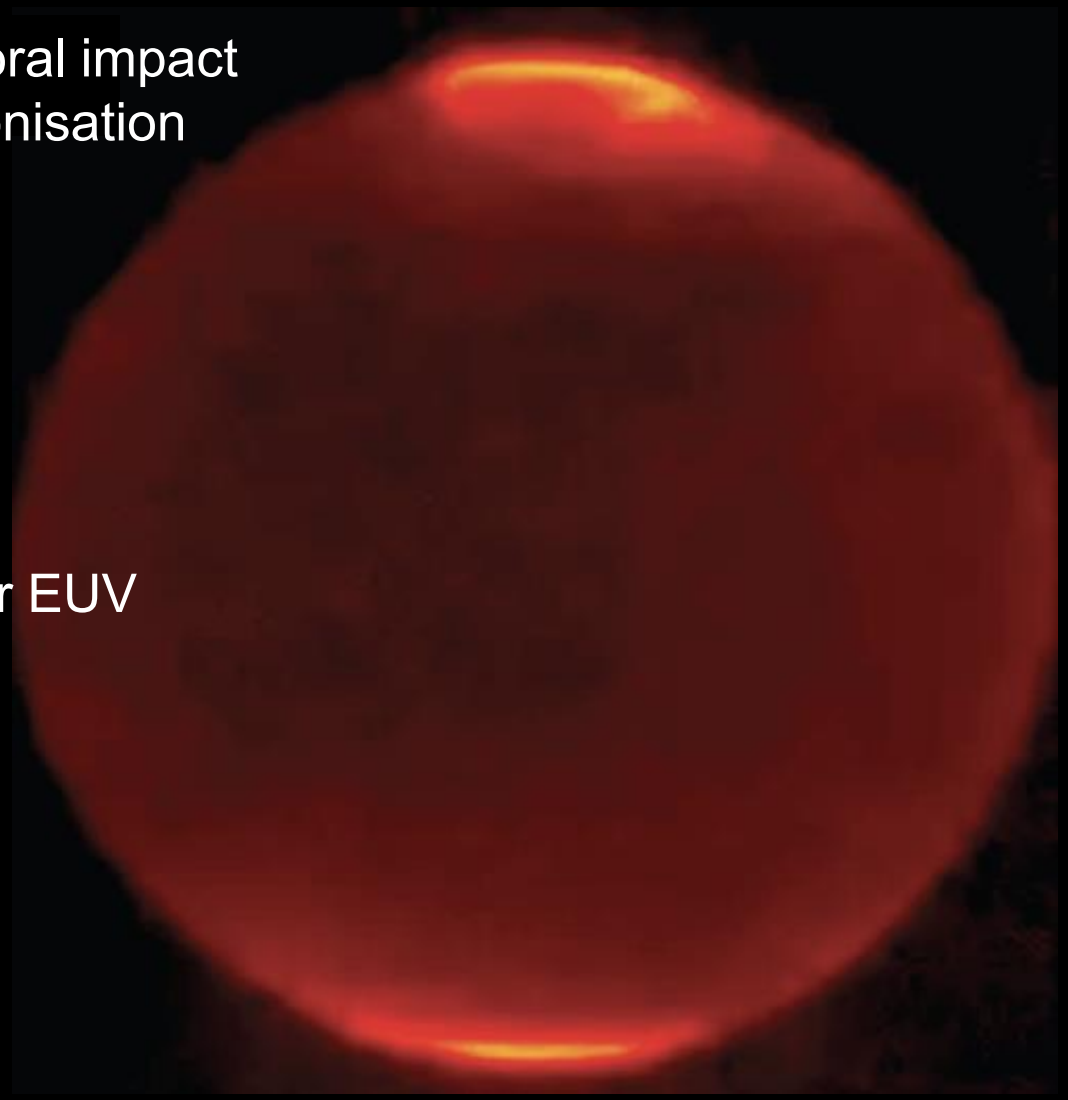
Emission lines of H_3^+



Jupiter’s upper atmosphere

Auroral impact ionisation

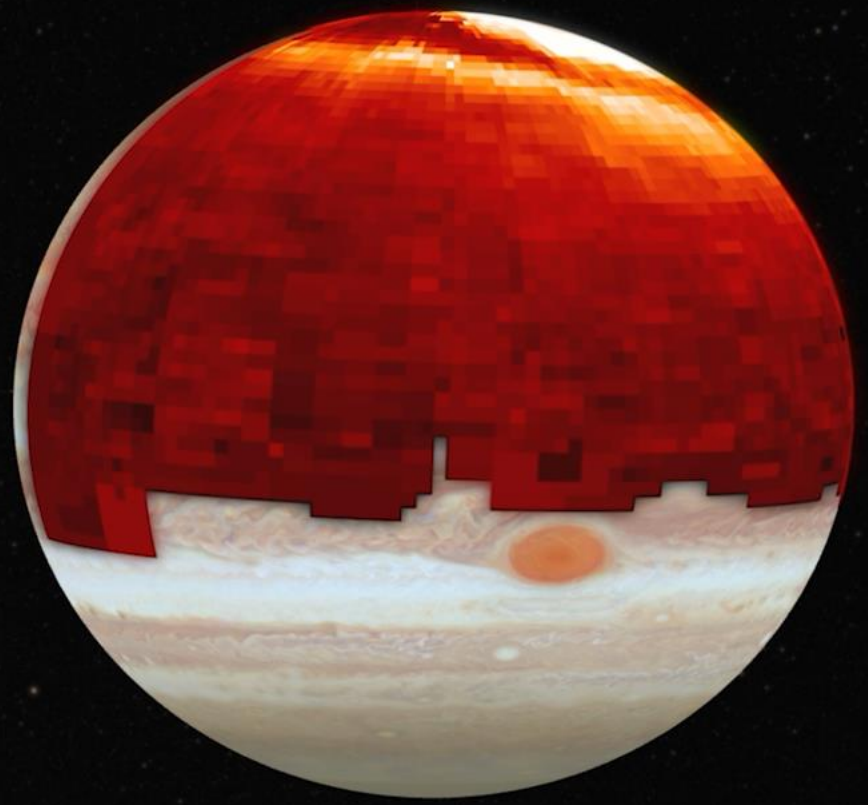
Solar EUV

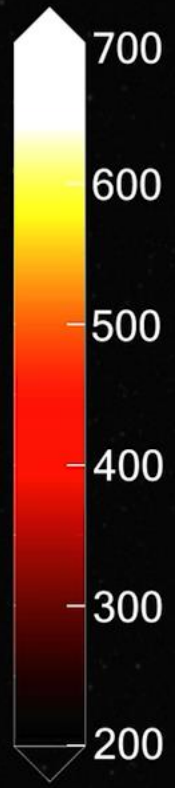


Real image (infrared)

NASA IRTF

A unique event in January 2017

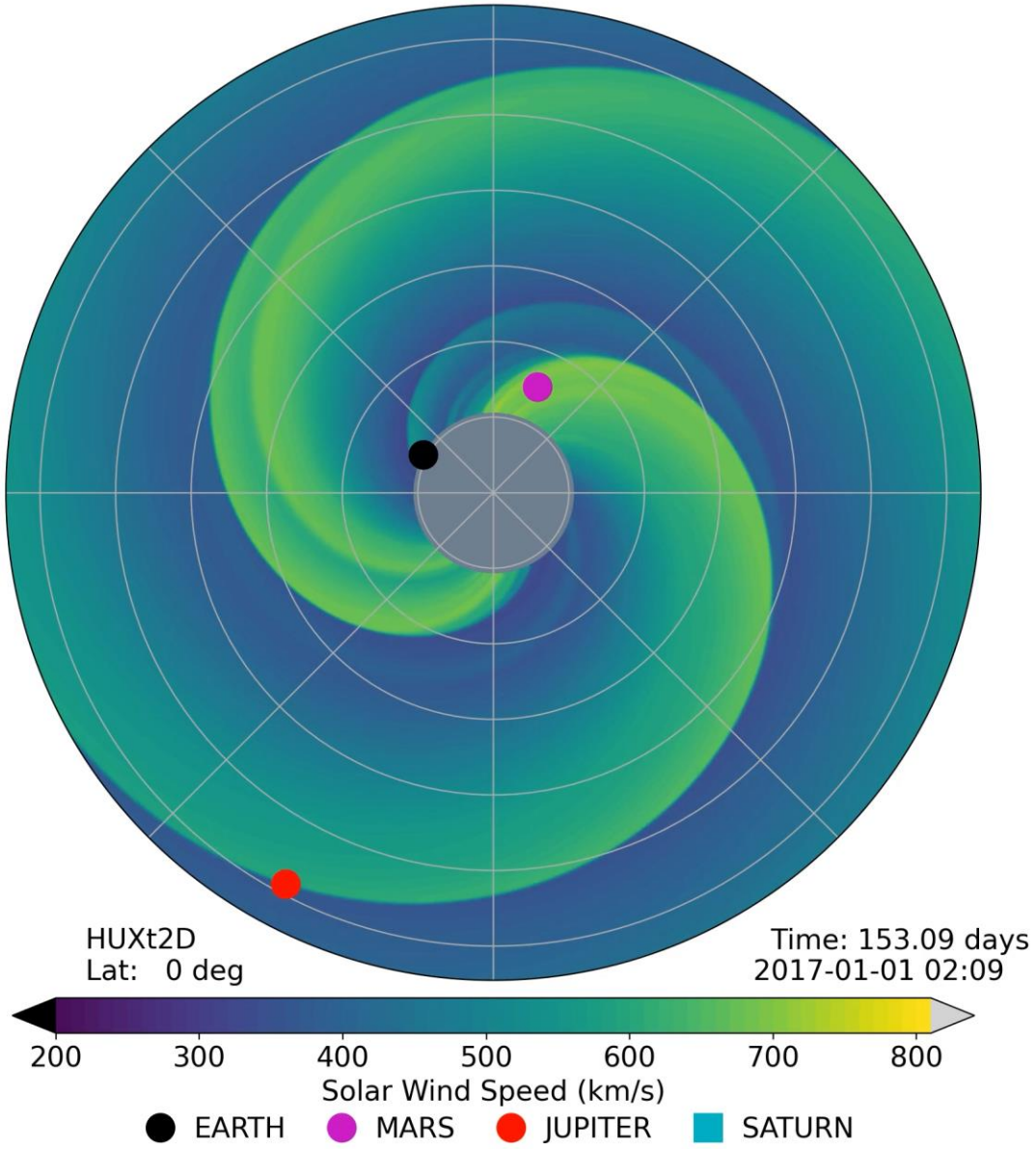




James O'Donoghue *et al.*
@physicsJ

Visible Jupiter Image:
Hubble / NASA / ESA /
A. Simon (GSFC) / J. Schmidt

HUXt2D model run, Mathew Owens + Luke Barnard (UoR)



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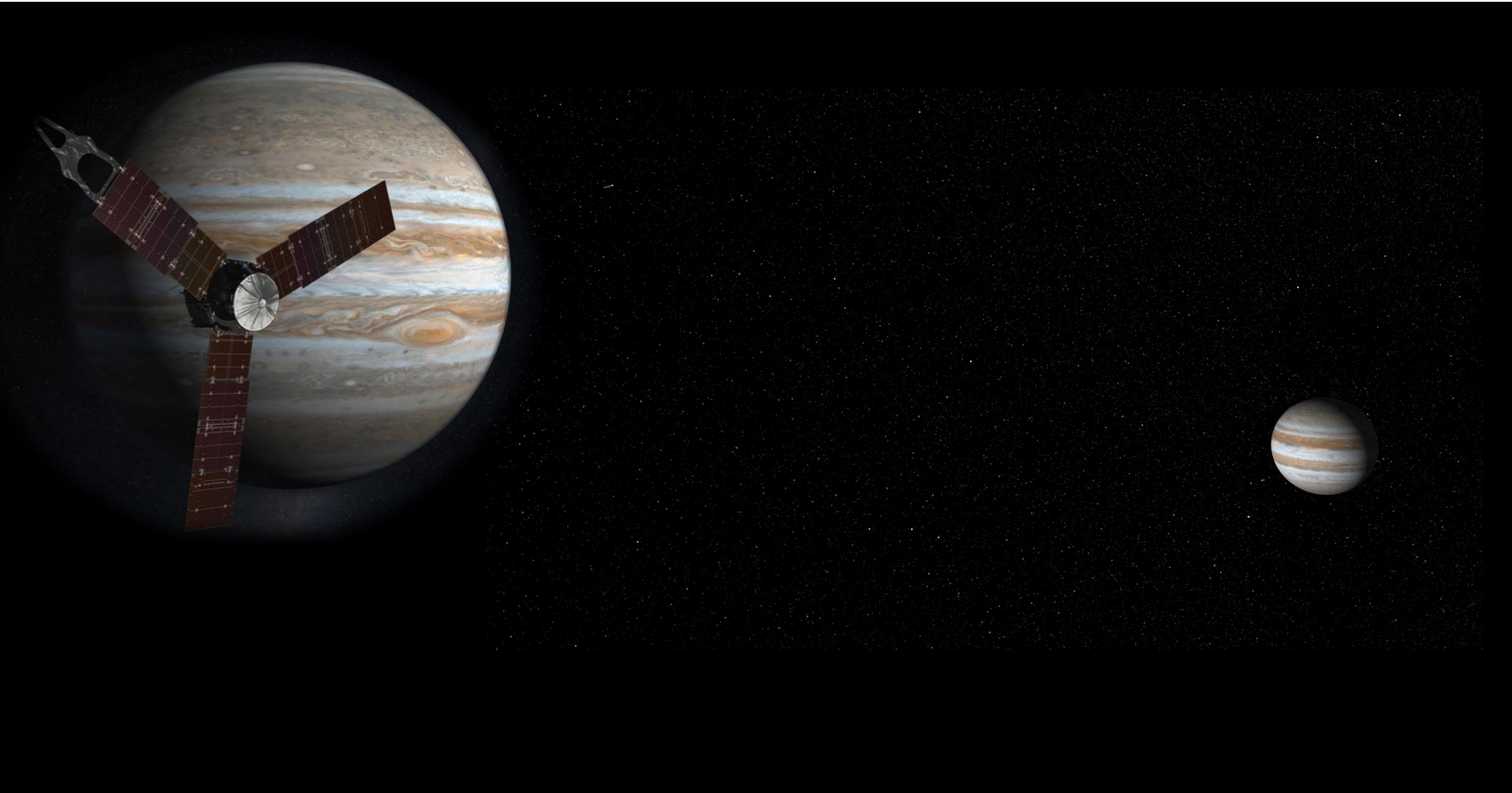
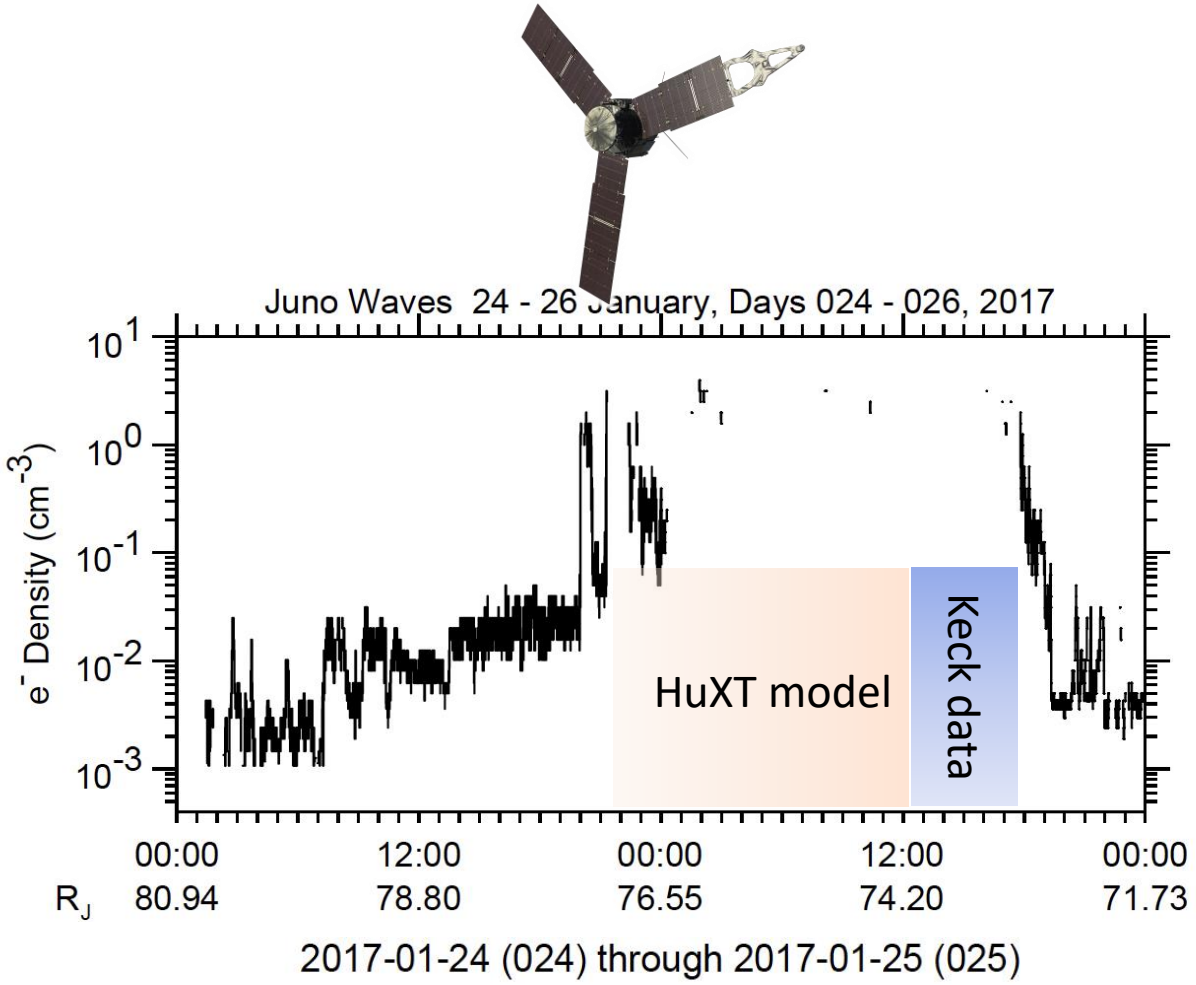
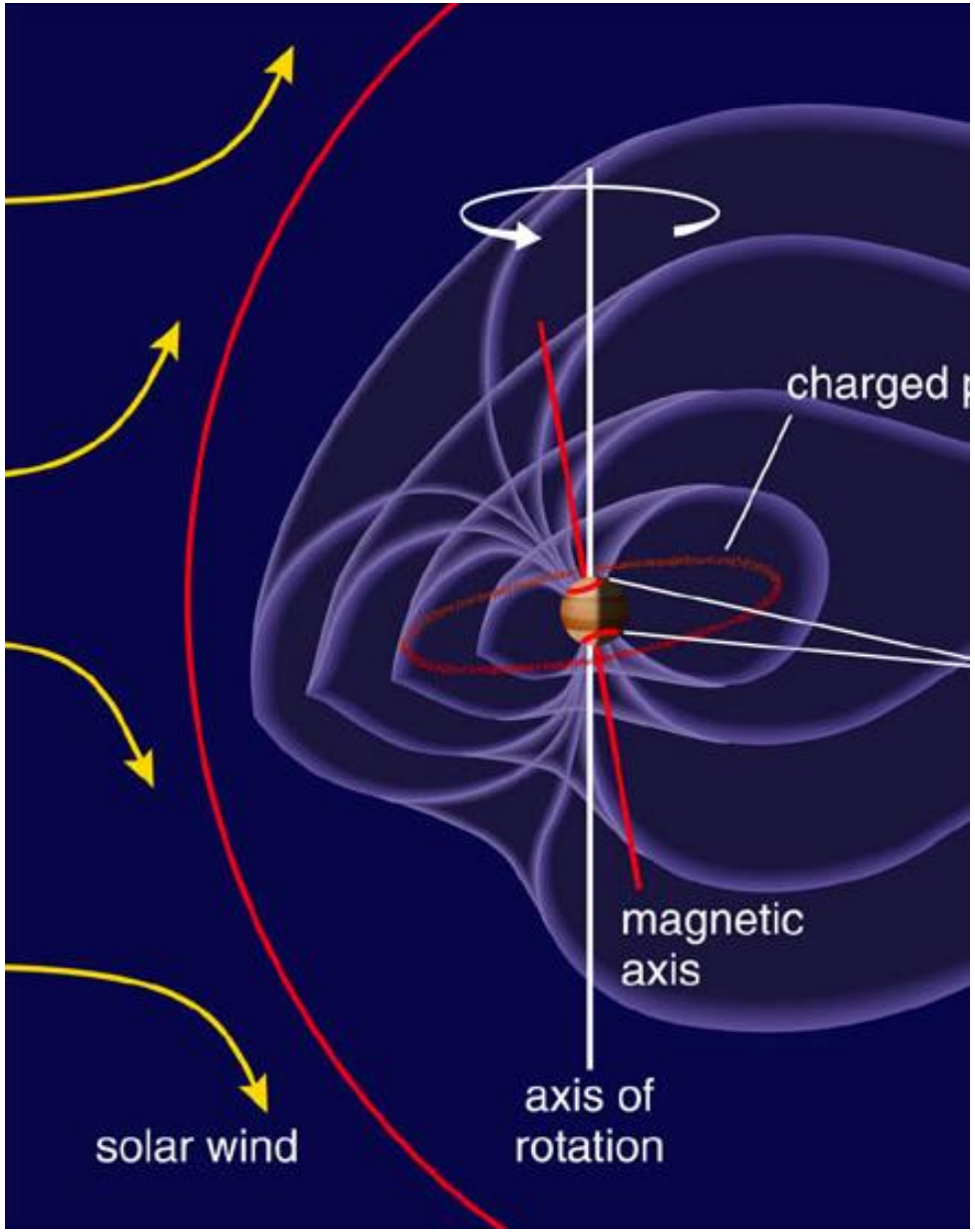
The **only** spacecraft at Jupiter: Juno (2016-present)



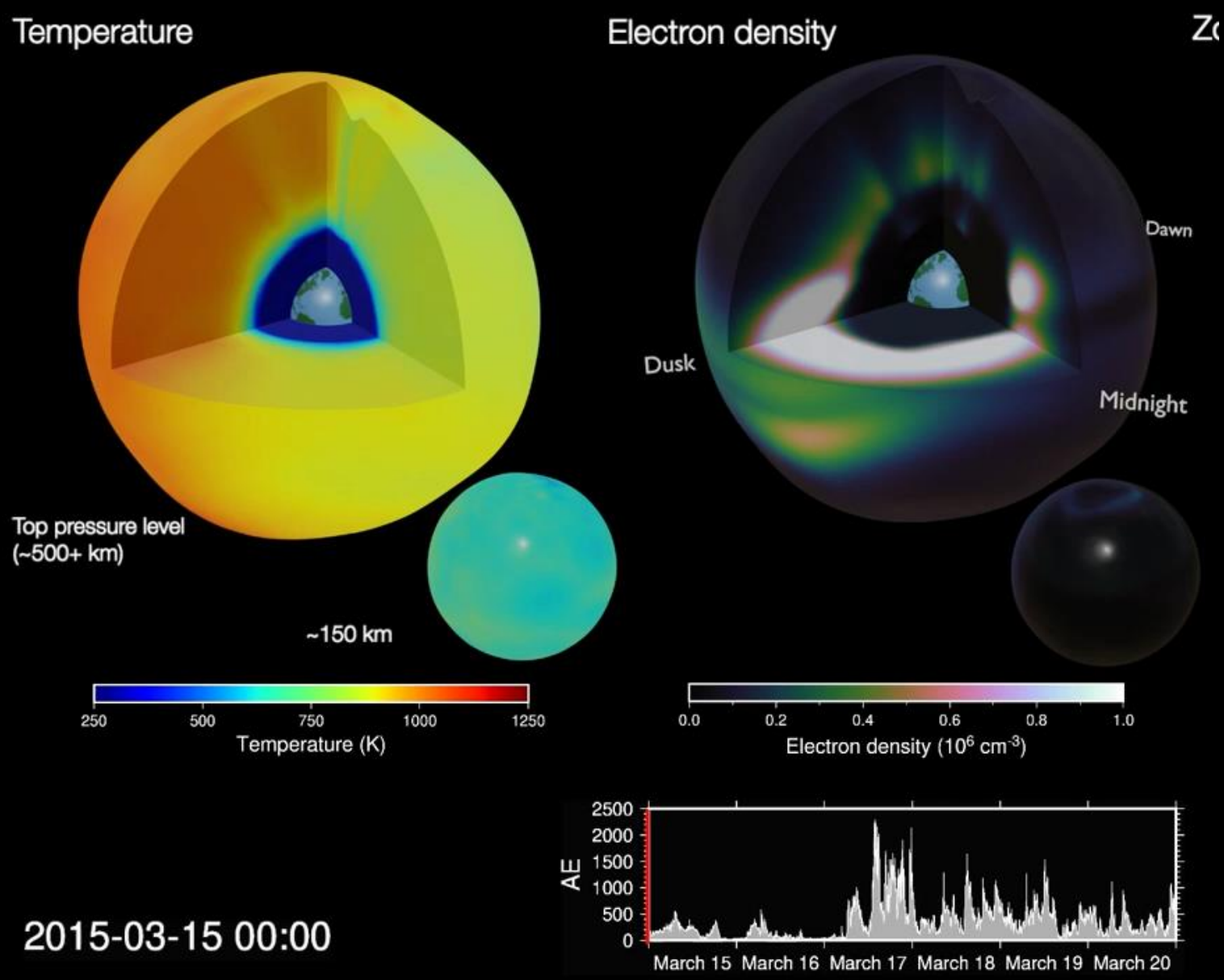
Inside Jupiter's magnetosphere at the same time (Juno)





(Credit: Bill Kurth)

Auroras as a global heat input on Earth



Temperature, electron density from WACCM-X model on two pressure level slices (150 & 500+ km)

By Federico Gasperini (NCAR/HAO), AMIE by Gang Lu (NCAR/HAO), AE index data WDC for Geomagnetism Kyoto, animation by Eelco Doornbos (KNMI)

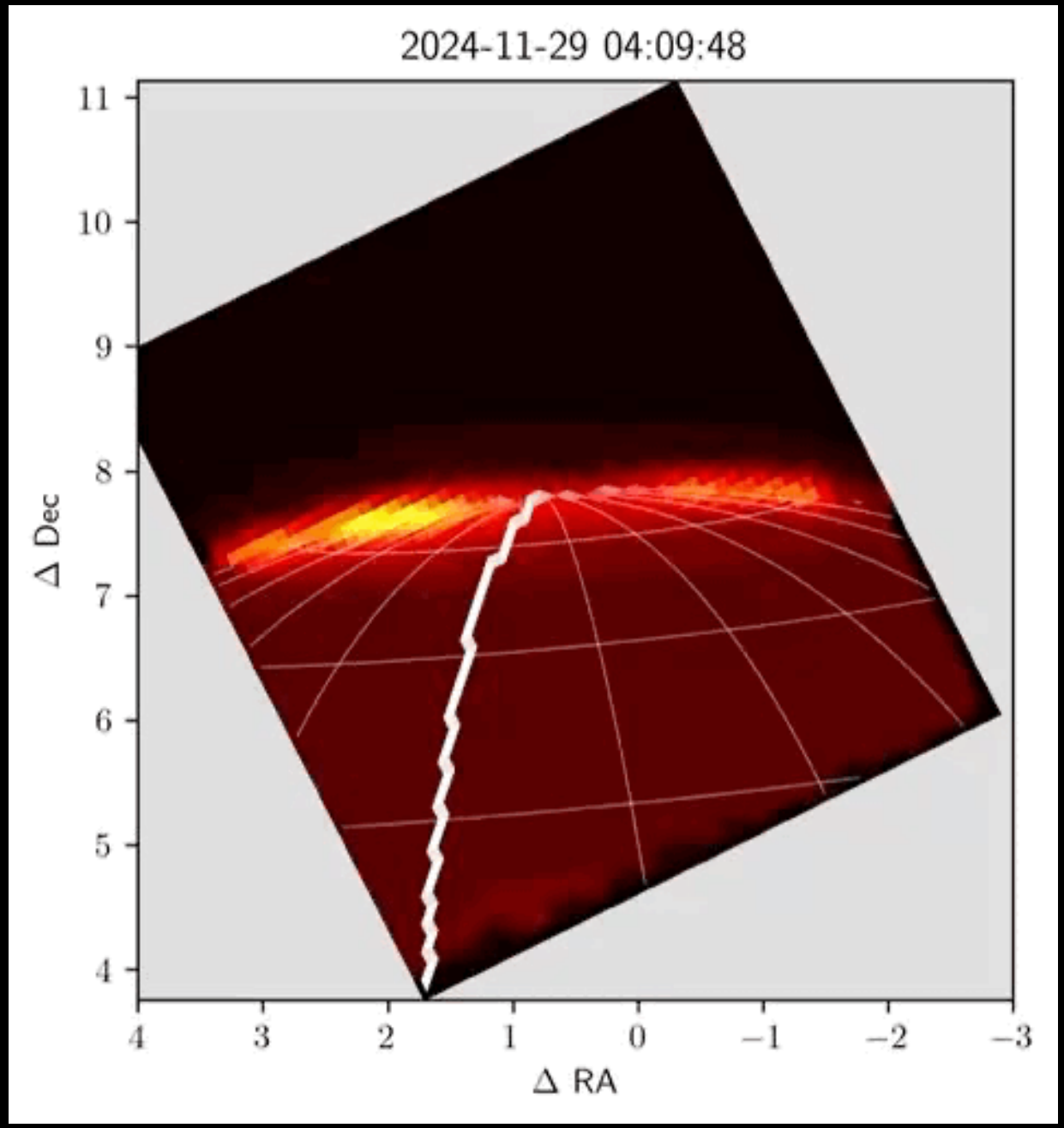
JWST – Auroras on Jupiter

James Webb Space Telescope
Nichols *et al.*, 2025

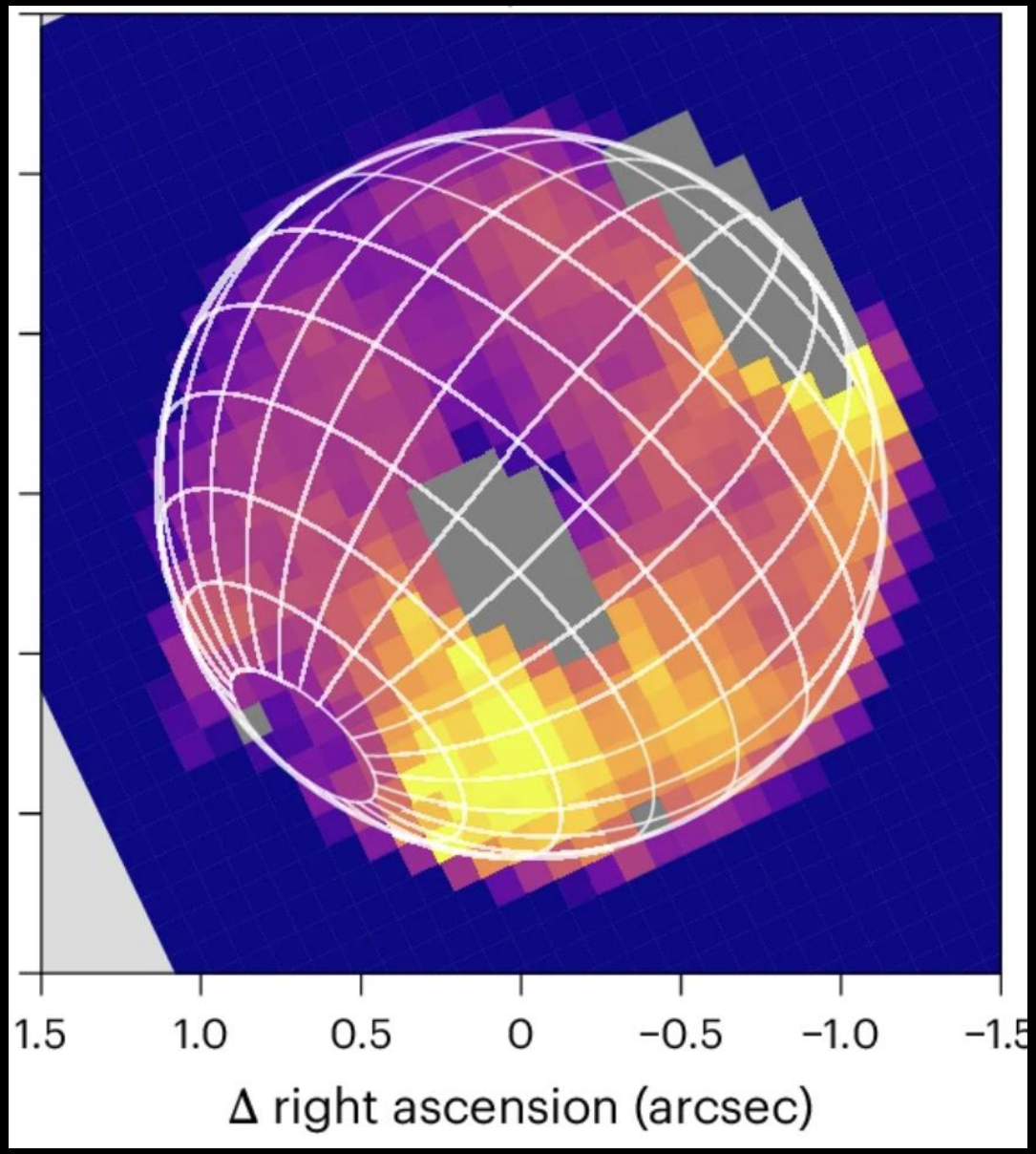
08:16:47 UTC
25 Dec. 2023

Earth to scale

JWST – Auroras on Saturn



JWST – Auroras on Neptune



nature astronomy

Article

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Discovery of H_3^+ and infrared aurorae at Neptune with JWST

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Check for updates

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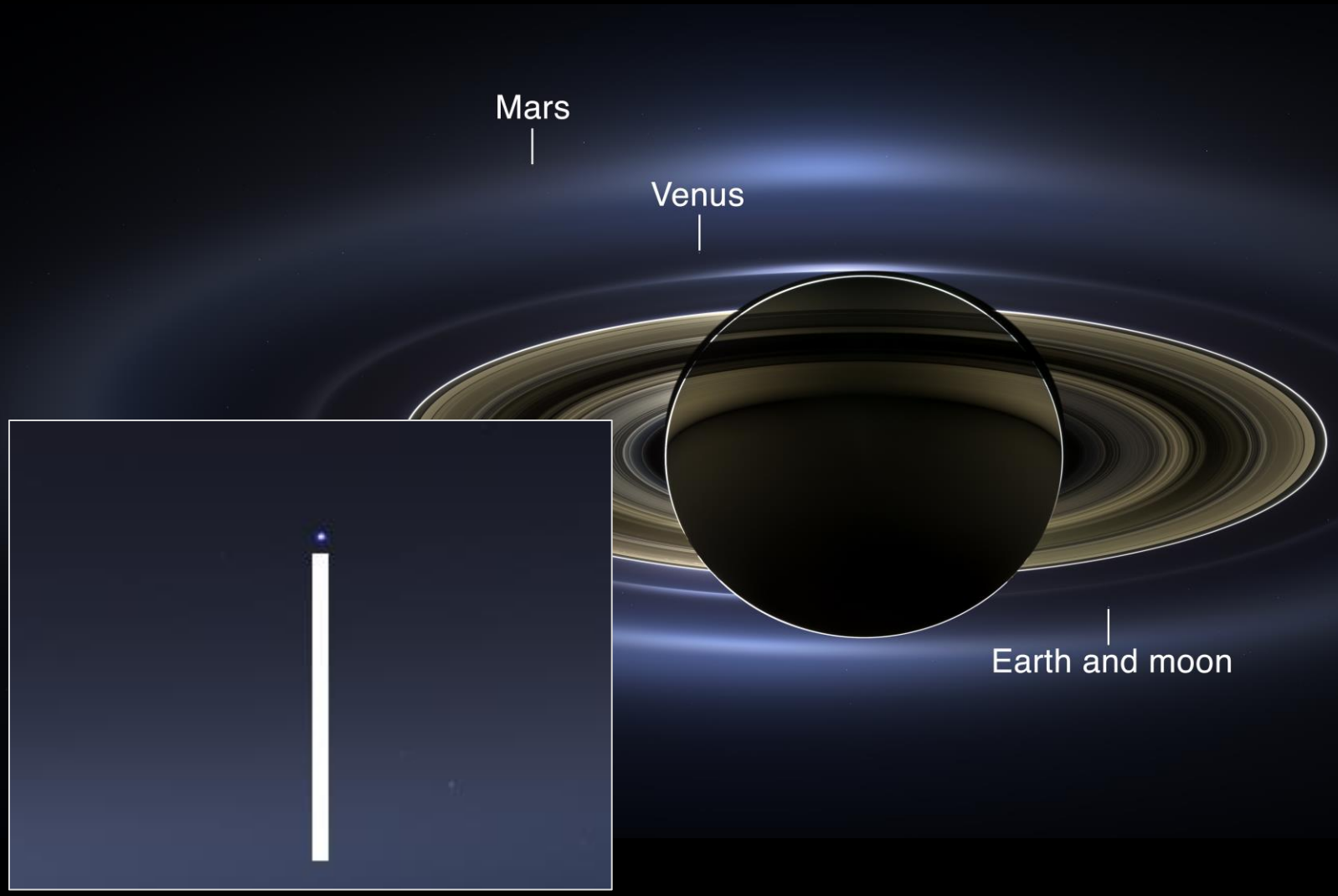
Saturn’s Eroding Rings

Saturn from the Cassini spacecraft (2004 – 2017)



NASA JPL / Cassini

How old are the rings?

Space.com
https://www.space.com › ... › Solar System › Saturn

Saturn's rings could be much older than scientists first ...

16 Dec 2024 — "All together, I say that Saturn's rings are likely to be very old — **about 4.5 billion to 4 billion years old**," Hyodo said.

Space.com
https://www.space.com › ... › Solar System › Saturn

Saturn's rings are much younger than we thought

15 May 2023 — The findings set a new age for the solar system's most impressive and famous ring system of **no older than 400 million years**. This is compared to ...

Space.com
https://www.space.com › ... › Solar System › Saturn

Saturn's Rings May Be Younger Than the Dinosaurs

17 Jan 2019 — The researchers suggest the rings formed between **10 million to 100 million years ago**. In comparison, the age of dinosaurs ended about 66 million years ago.

Space.com
https://www.space.com › ... › Solar System › Saturn

Age of Saturn's Rings Revealed

13 Dec 2013 — Saturn's iconic rings likely formed **about 4.4 billion years ago**, shortly after the planet itself took shape, a new study suggests.

Saturn’s rings have an uncertain past

How are they evolving today?

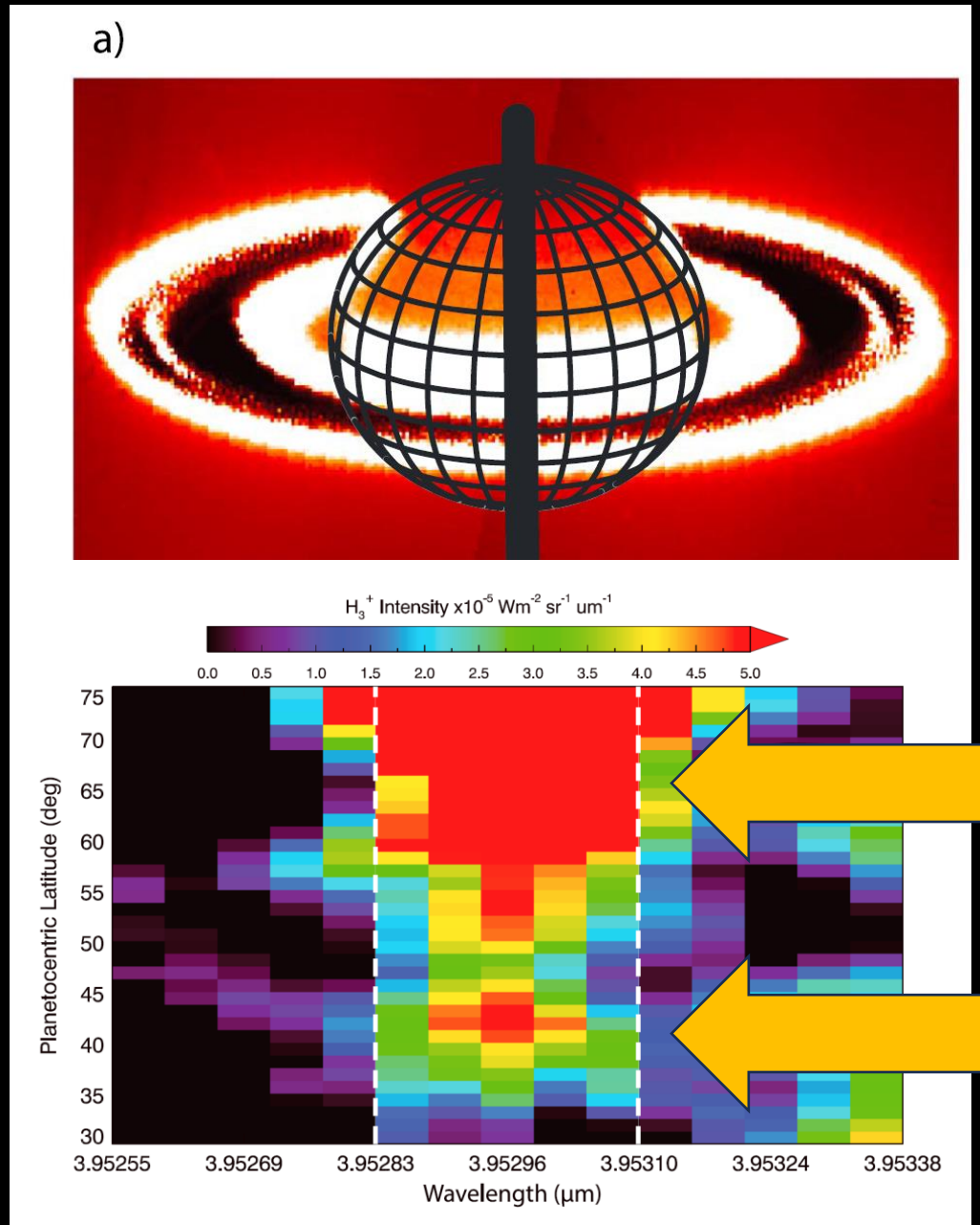
…what is their fate?

Grains fall in along the magnetic field

Animation: NASA GSFC press release

Ring rain: the electromagnetic erosion of the rings

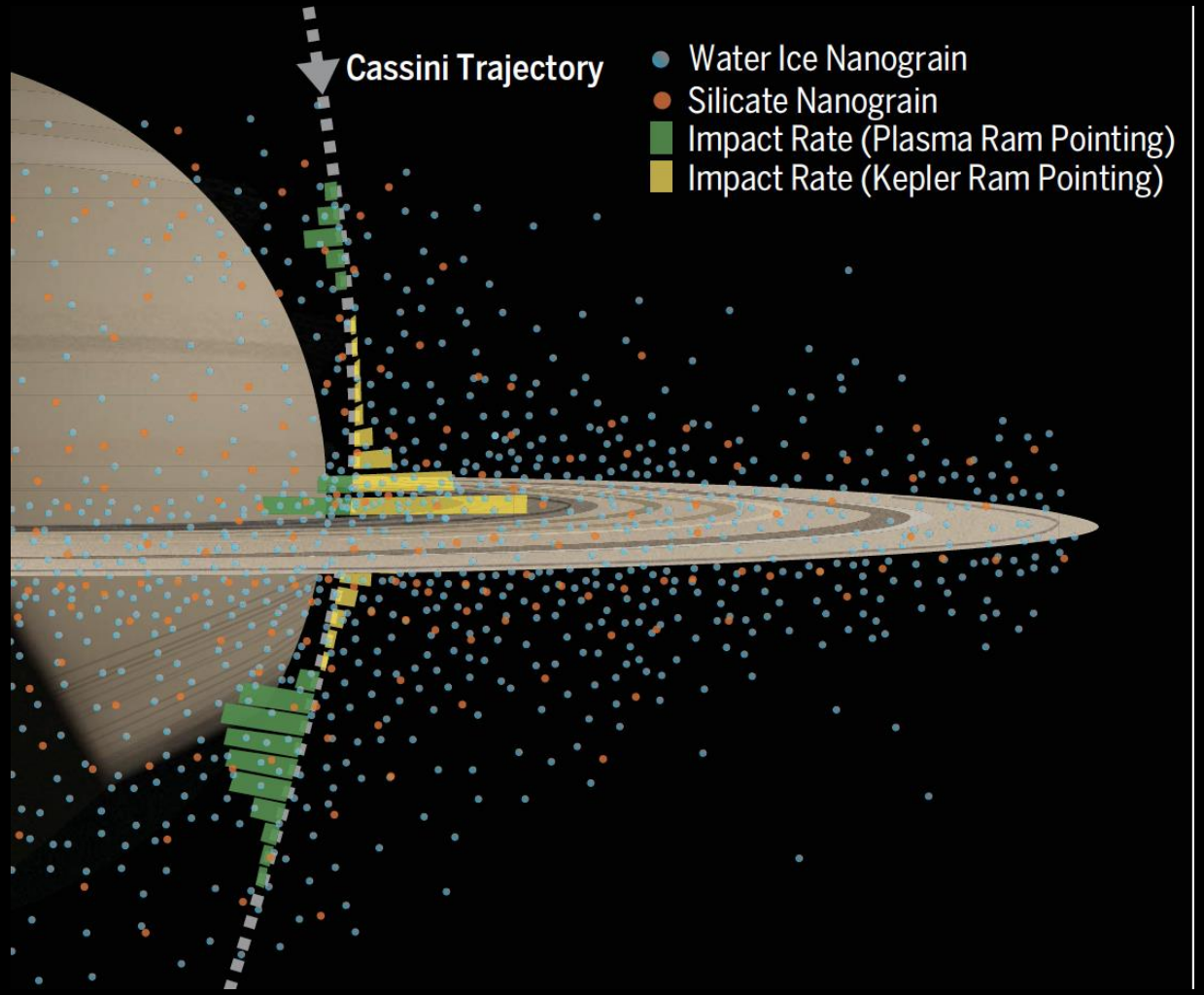
Saturn observations with Keck



Aurora

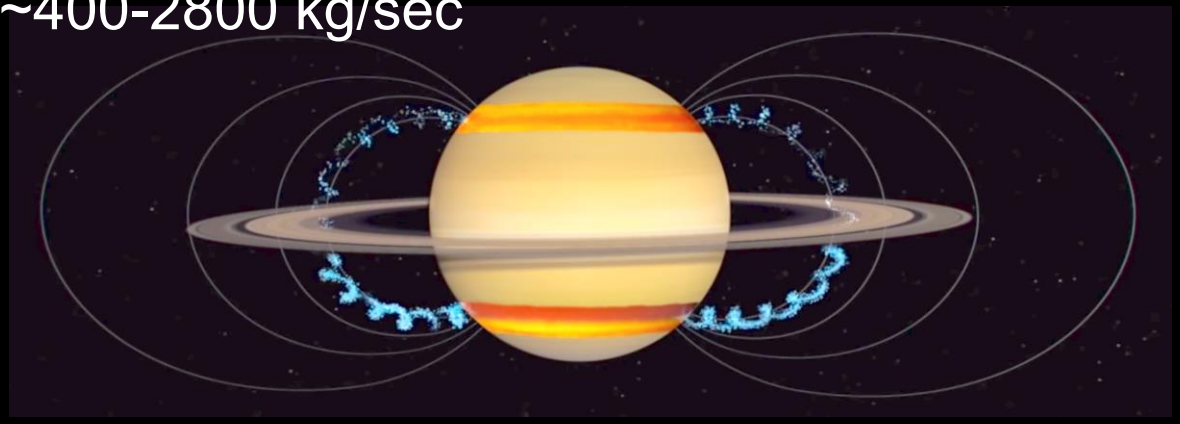
Ring Rain

Cassini spacecraft confirmed ‘ring rain’ and more



Quantifying Saturn's eroding rings

~400-2800 kg/sec

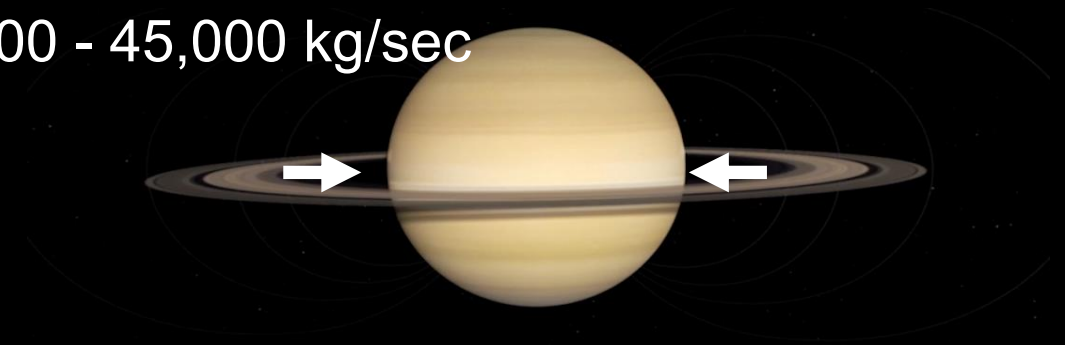


Mid-latitude ring rain alone:

~300 Million years to go

(really: 290-1,100 million)

4800 - 45,000 kg/sec

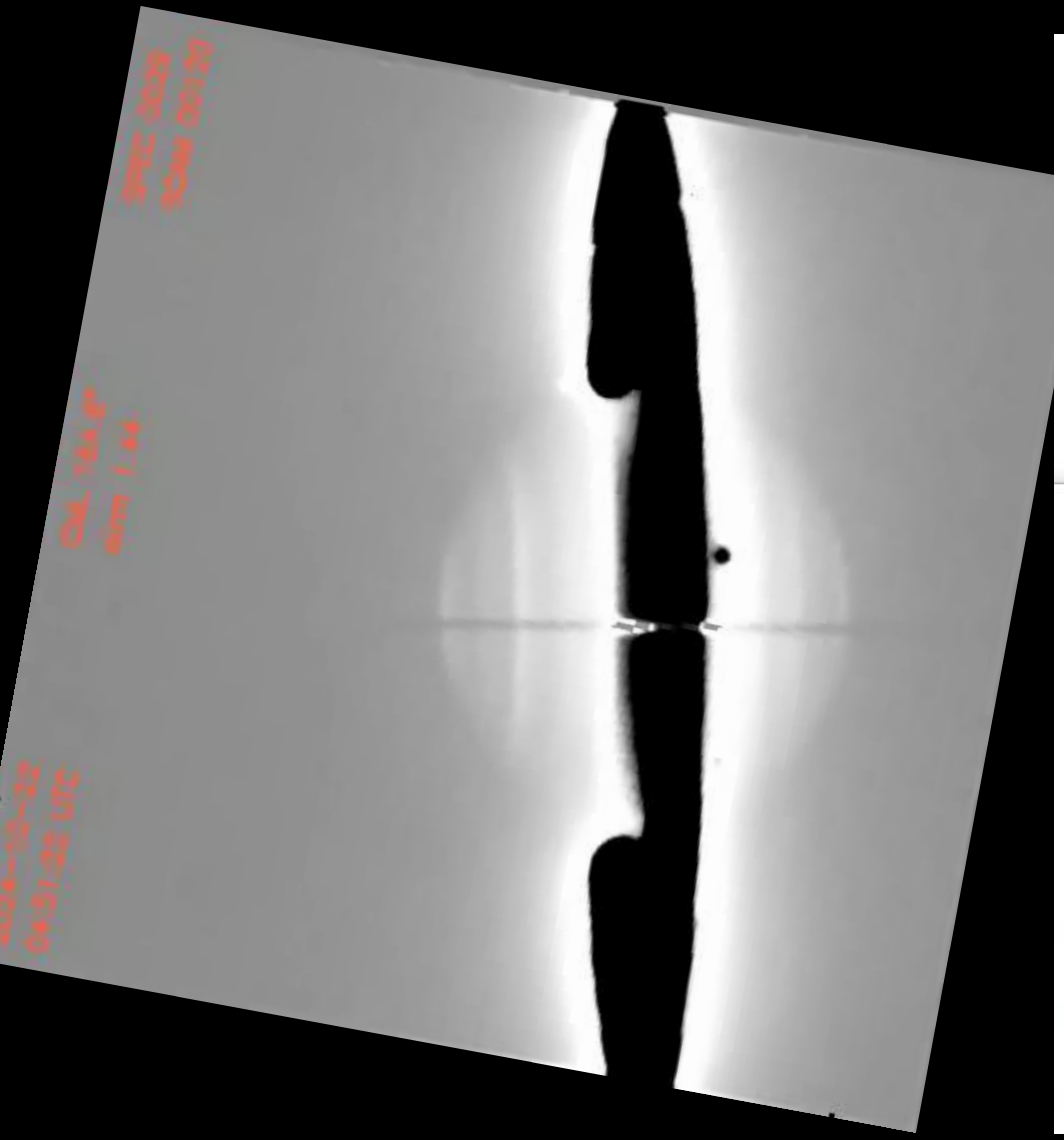


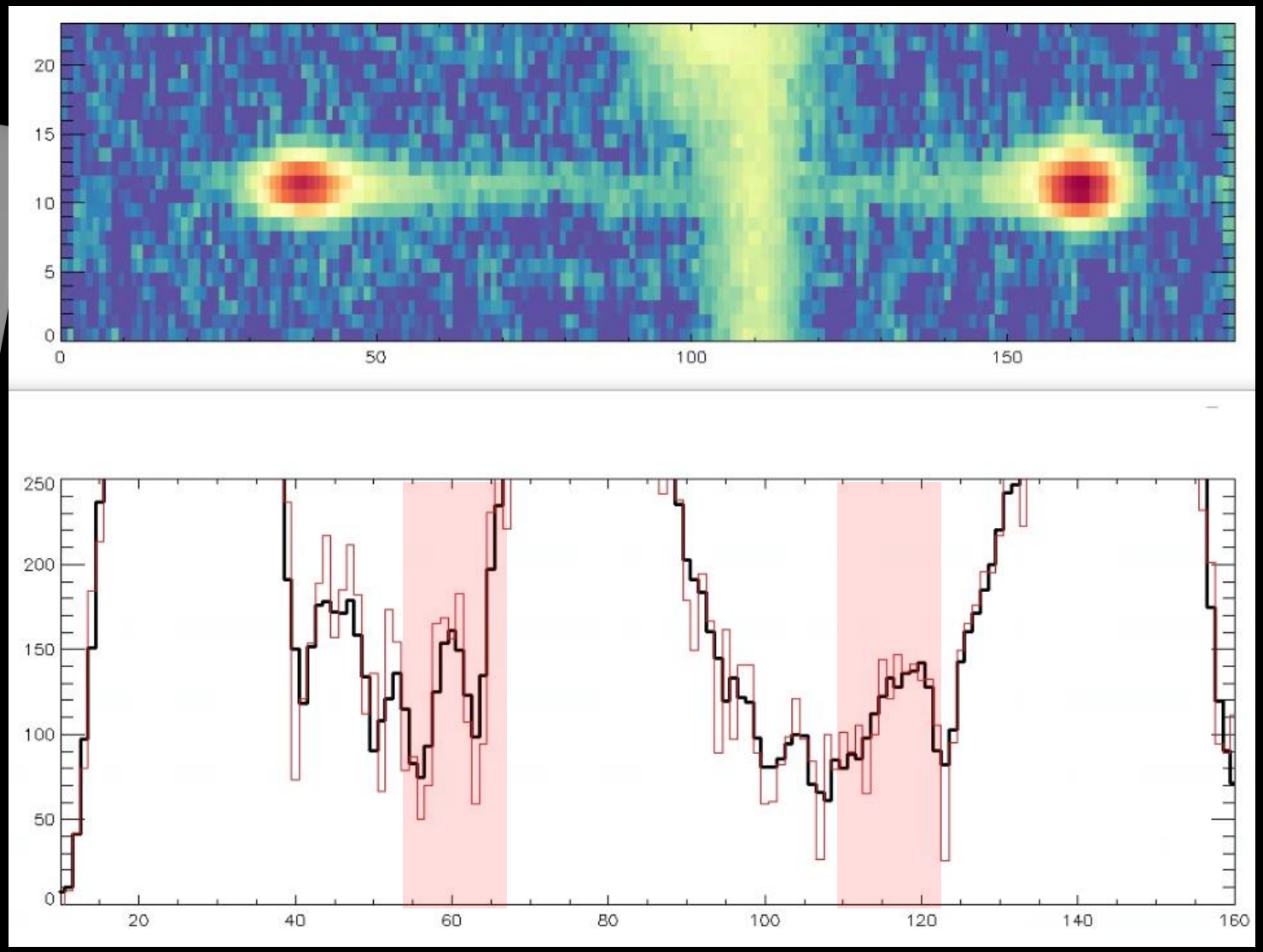
Plus equatorial influx :

<100 Million years

(but we don't know if it's constant!)

New – 2024/5 Keck Observations





Probing the Most Revealing Layers of the Giant Planets

Solar system upper atmosphere knowledge is expanding rapidly

Jupiter's aurorae spectacularly respond to changing solar wind conditions, causing planet-wide heating

Saturn's ring decay readily observable from ground-based telescopes

Long-term measurements of temperatures and wind speeds will enable weather and climate of upper atmospheres to be understood

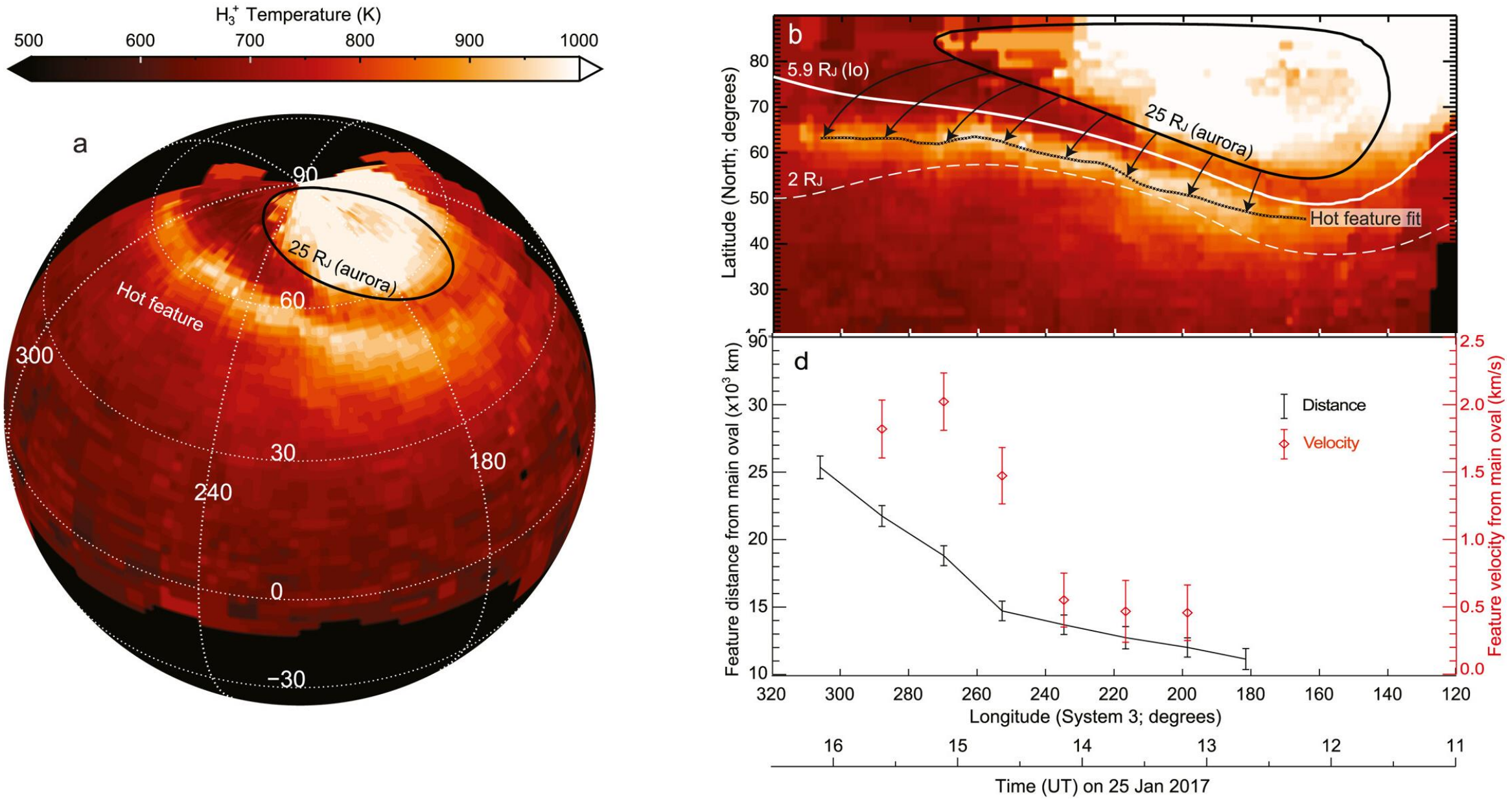
James O'Donoghue, University of Reading,

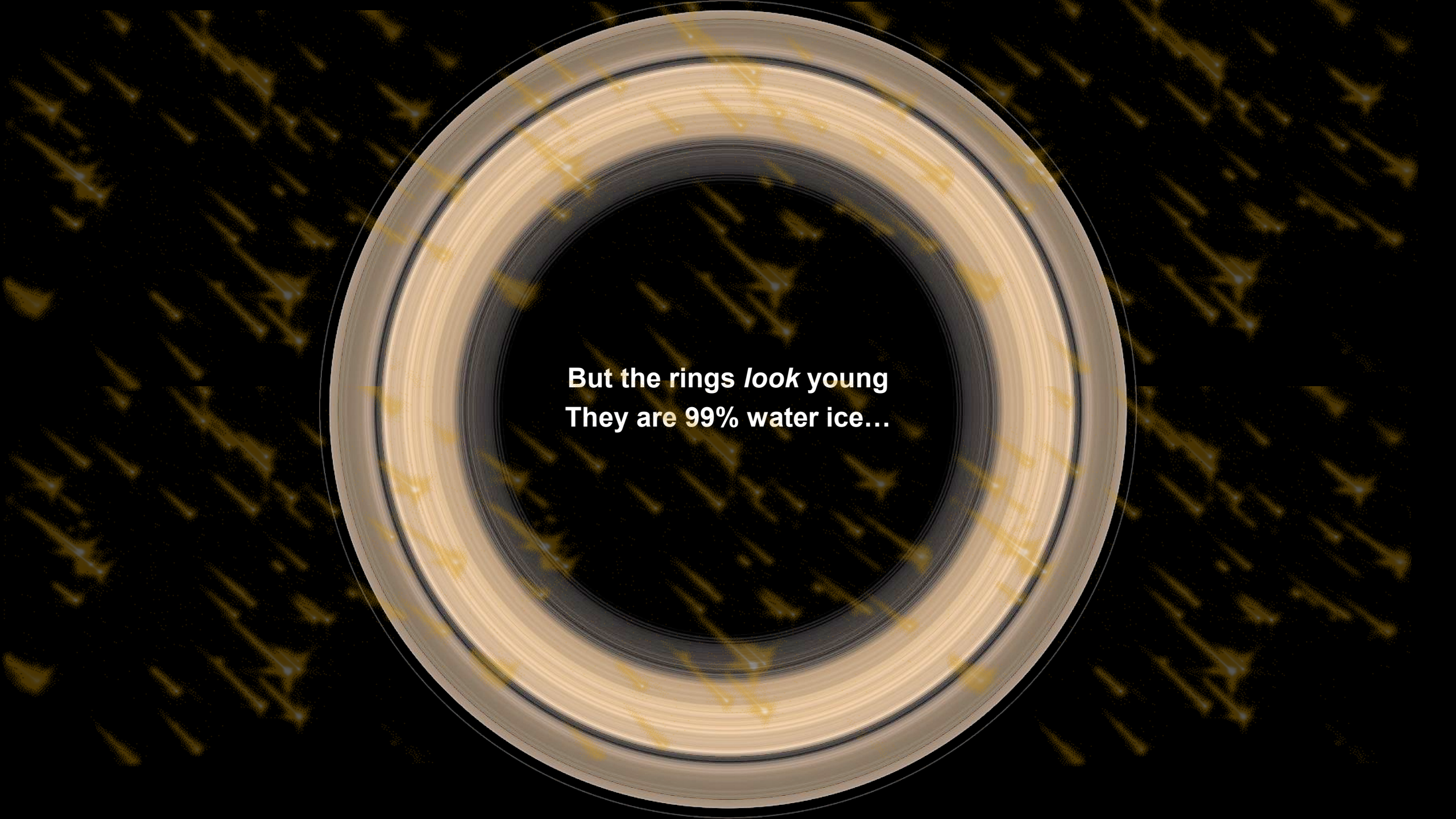
james.odonoghue@reading.ac.uk

Image credits – J: NASA / Hubble / Amy Simon / Judy Schmidt / O'Donoghue. S: NASA / JPL / SSI / Cassini. U&N: NASA / JPL-Caltech / Björn Jónsson. **To scale, approx. true colour**

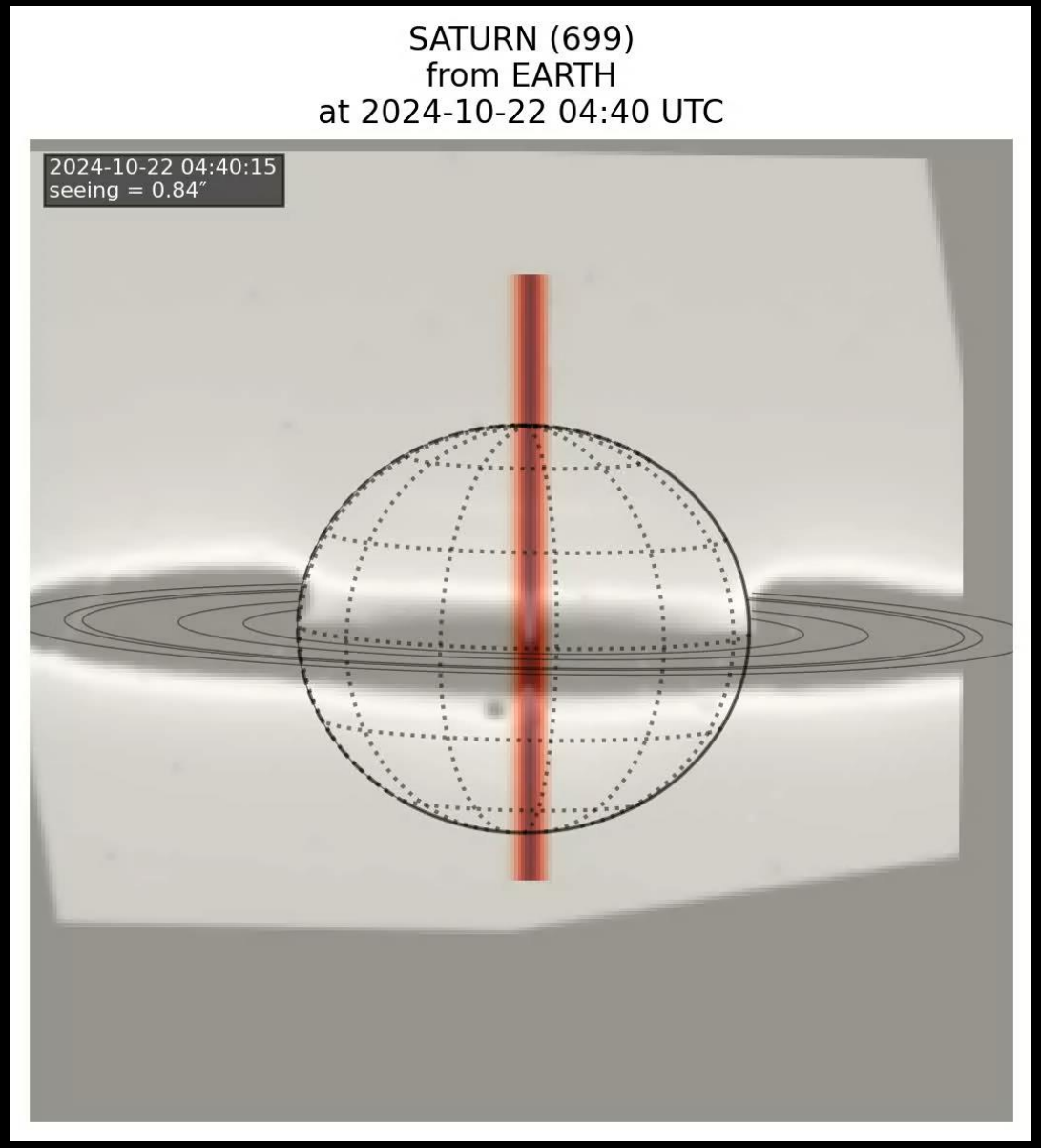
Extras

Velocity of the hot feature



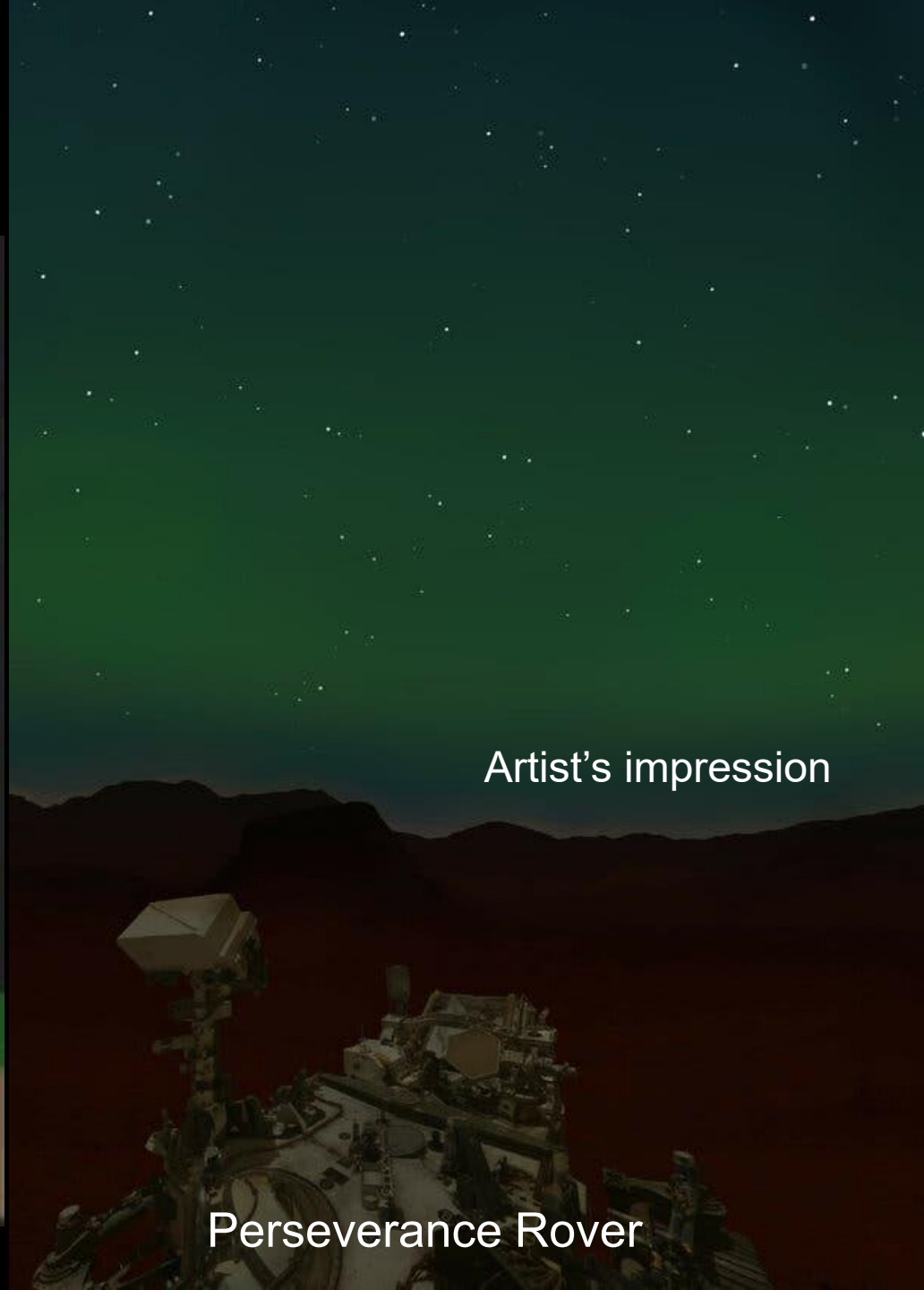

But the rings *look* young
They are 99% water ice…

New – 2024/5 Keck Observations



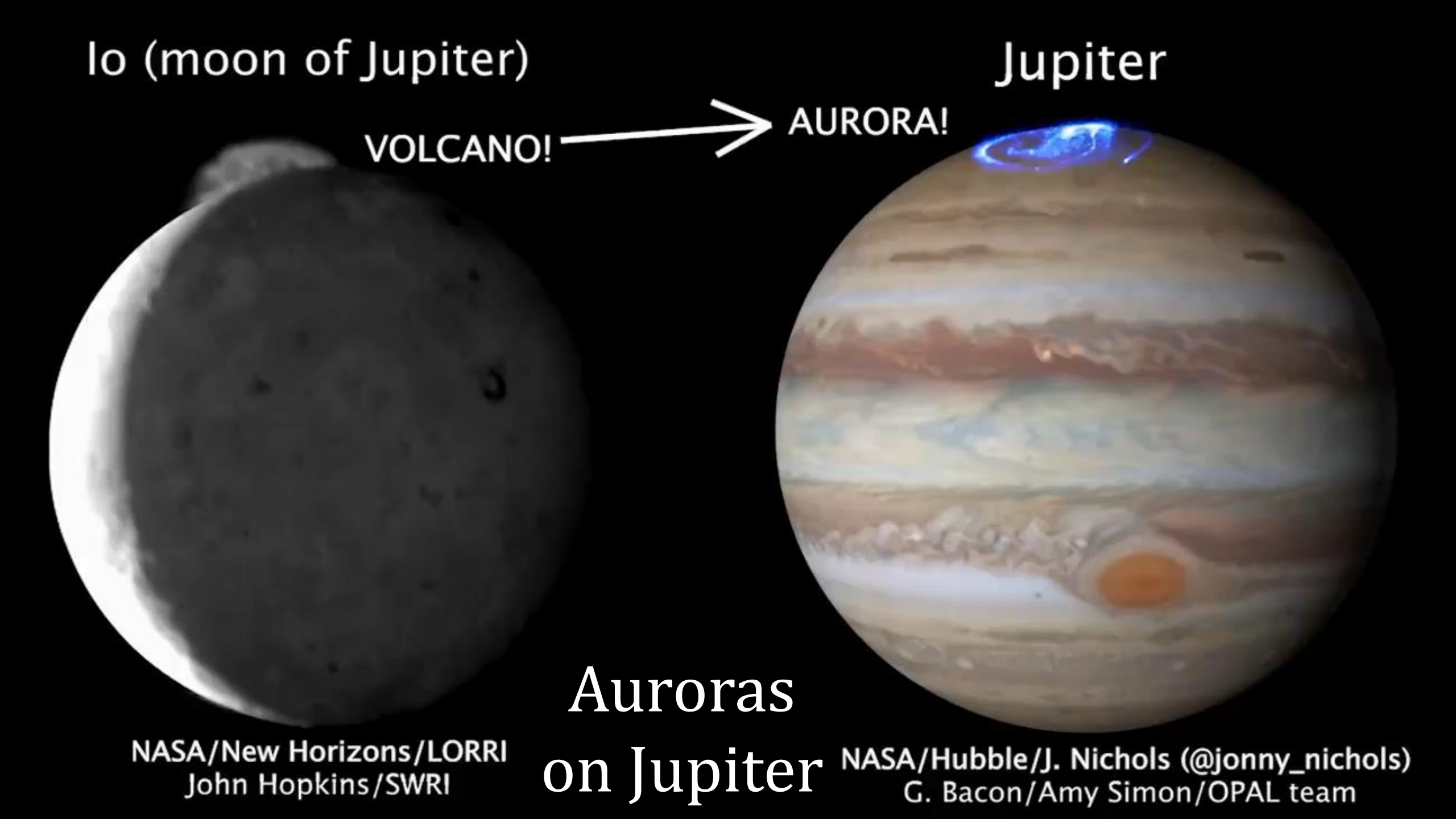
Green Auroras on Mars

March 2024



Artist’s impression

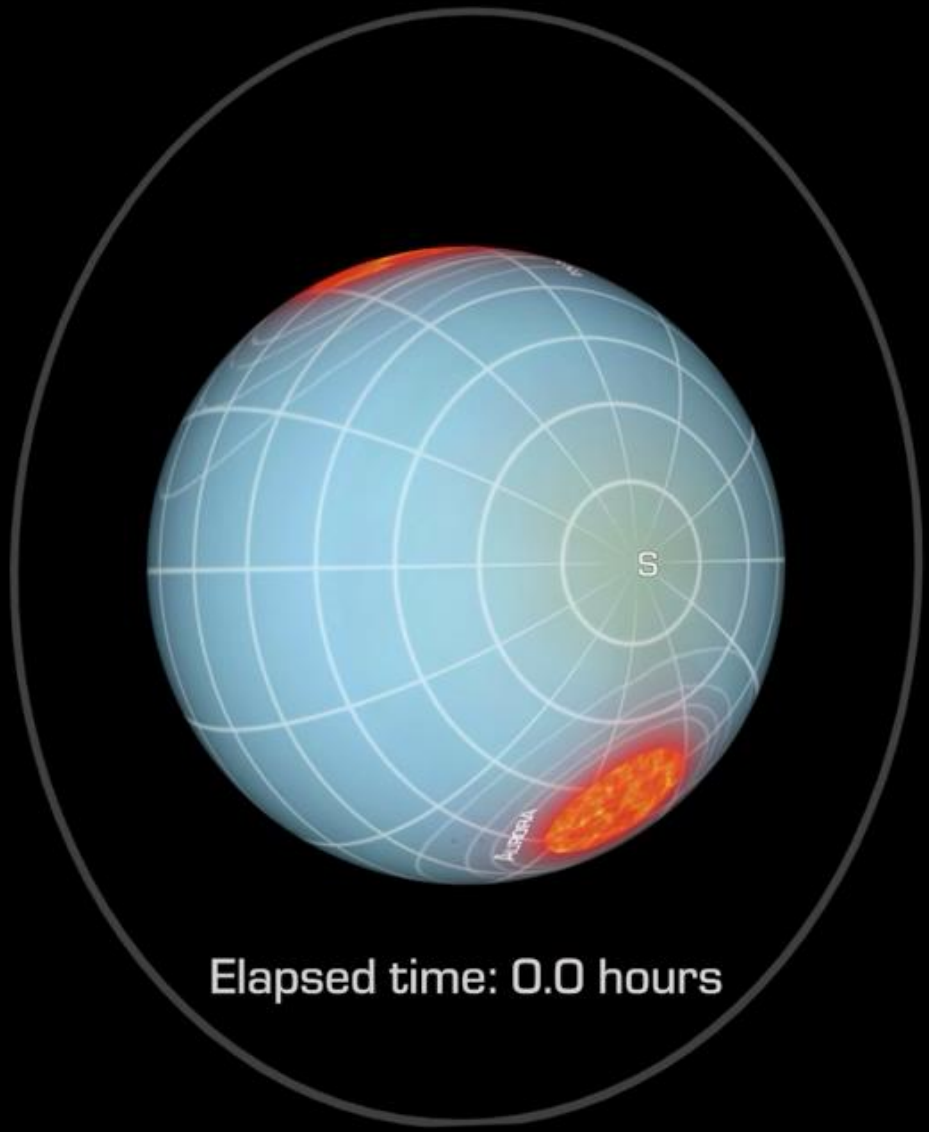
Perseverance Rover



Auroras on Jupiter

Auroras on Uranus

“Artist” impression



Uranus day 17hr 14min

NASA/ESO imagery
@physicsJ render

Probing the Most Revealing Layers of the Giant Planets

The upper atmospheres of Jupiter and Saturn, located several hundred kilometers above the planet's visible cloud decks, are extraordinarily thin, with number densities below 1012 cm−3. Being "basically space", however, is not a weakness, but a strength; it makes the region highly sensitive to physical and chemical processes on the planet and to interactions between the planet and its space environment. In this talk, I will focus on two major processes that shape these upper atmospheres: the **polar aurorae**, which dominate the planet's global upper-atmospheric energy balance, and **Saturn's eroding rings**, which deposit material into the atmosphere and dominate chemistry. The latter has interesting implications for the evolution and ultimate fate of Saturn's rings. By the end of this talk, I hope to convince you that, if it can be detected, this most revealing layer is worth investigating outside of the solar system.