JUPITER'S H_3^+ AURORAE AS A LABORATORY FOR COMPARATIVE AURORAL PHYSICS

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IX CHIANTI TOPICS

International Focus Workshop - **Atmospheres**

9 - 11 June 2026

What is the Aurora?

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“A luminous phenomenon that consists of streamers or arches of light appearing in the upper atmosphere of a planet's magnetic polar regions and is caused by the emission of light from atoms excited by electrons accelerated along the planet's magnetic field lines”

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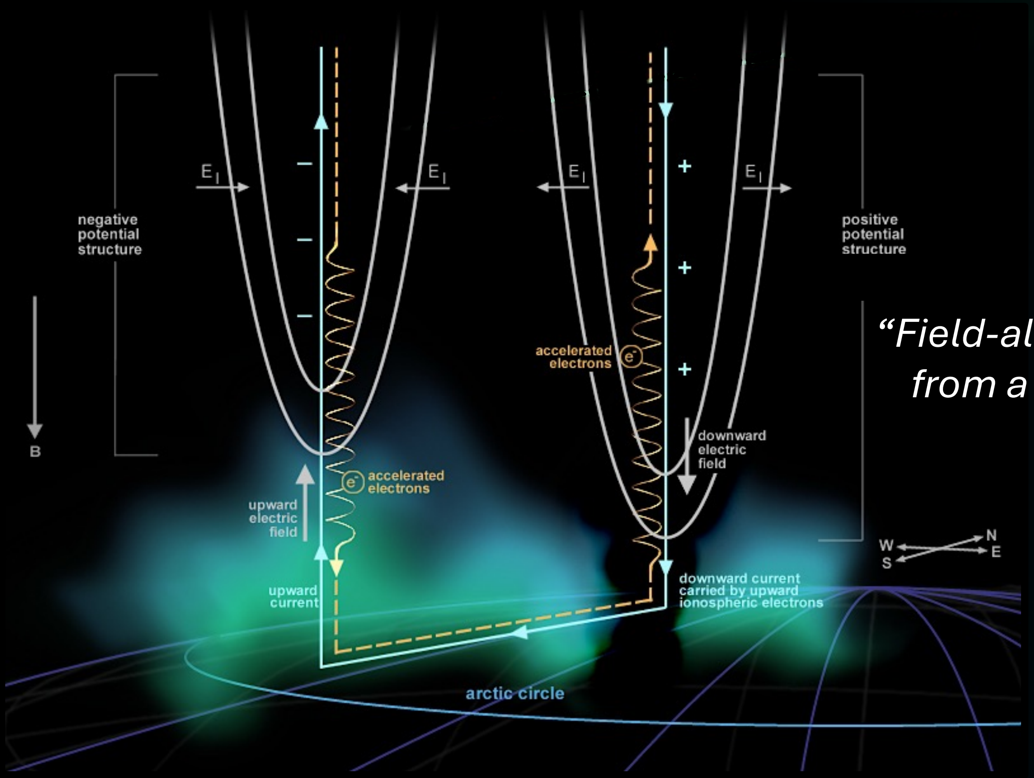

“Field-aligned potentials resulting from a specific magnetosphere-ionosphere interaction”

cit. some guy at a conference

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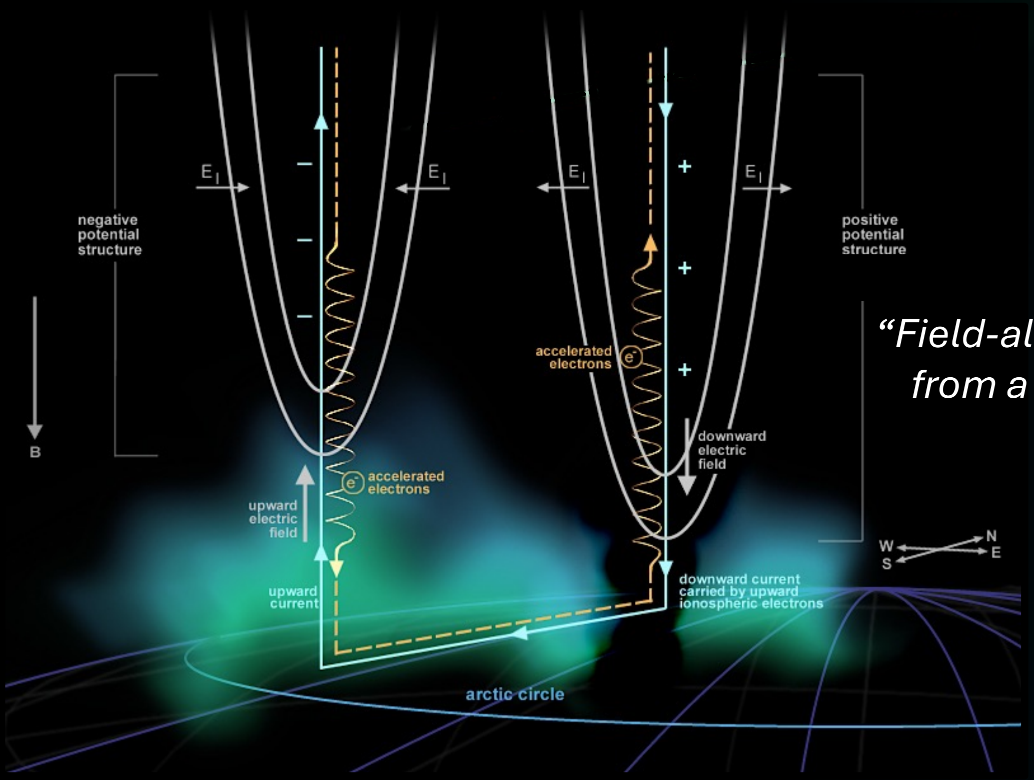

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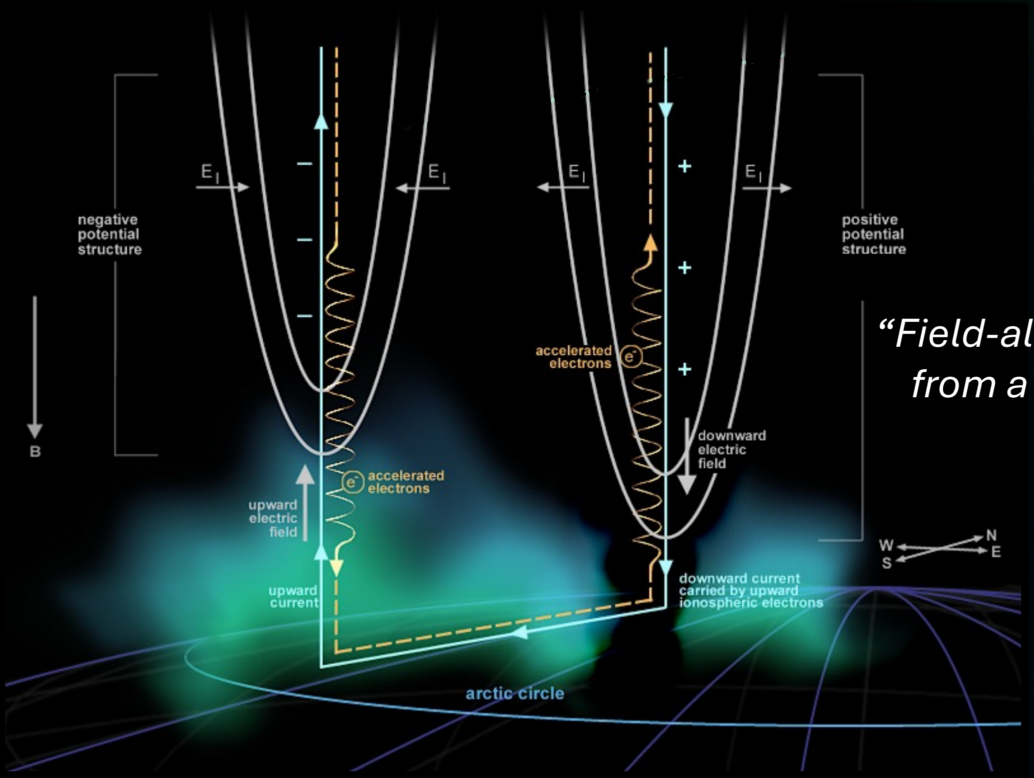

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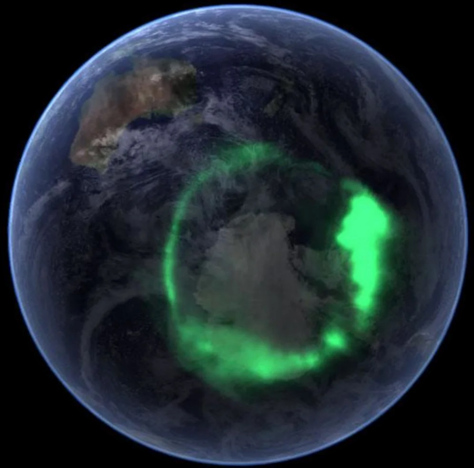
Should we define the aurora by what we see, or by how it is produced?

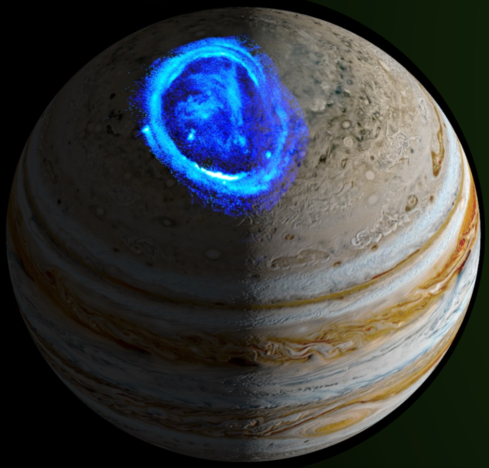
- ✓ A purely observational definition of aurora is unambigous and provides a cross-planetary definition.
- ✓ The physical description of auroral acceleration depends on
  - particle sources → ***What is the origin of the particles being accelerated?***
  - plasma environment and dominant acceleration mechanisms → ***Where and how are the particles accelerated?***

and varies between planetary systems therefore, it is not uniquely transferable as a universal definition.

Aurorae: More Than a Probe of the Upper Atmosphere

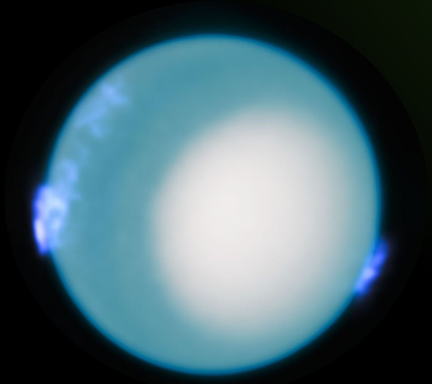


Earth



Jupiter

Saturn



Uranus

- Differences in magnetospheric environments and ionosphere–magnetosphere (M-I) coupling processes are reflected in auroral emissions and morphology.

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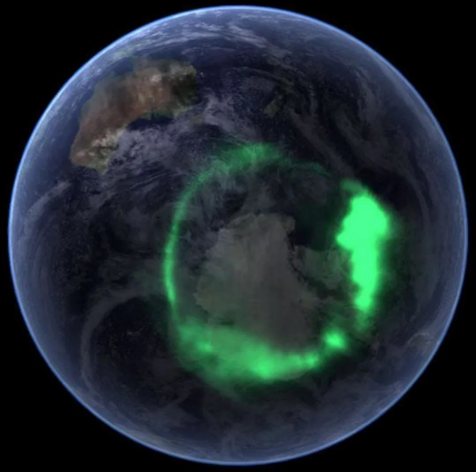

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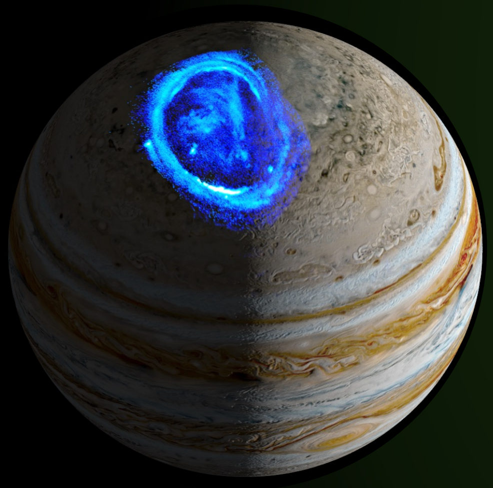

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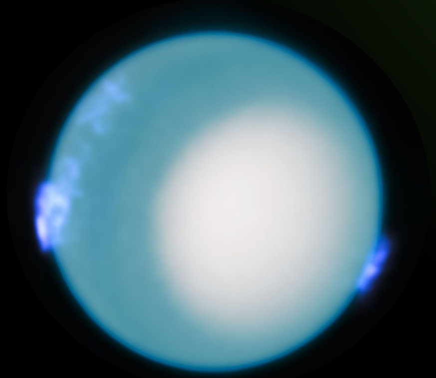


Uranus

- Differences in magnetospheric environments and ionosphere–magnetosphere (M-I) coupling processes are reflected in auroral emissions and morphology.

- Aurorae act as an indirect but powerful diagnostic of the magnetosphere.

- Aurorae can be repeatedly observed from both ground and space at multiple wavelengths, providing strong constraints on

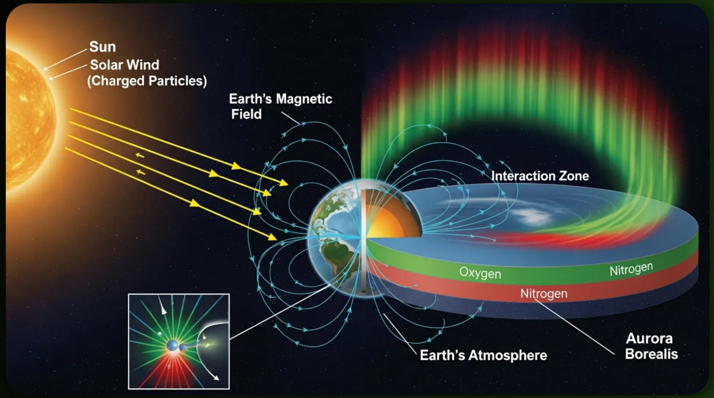
  - ✓ **precipitating particle populations** → species and energy spectra

  - ✓ **atmospheric response to energy deposition** → heating, chemistry, and dynamics

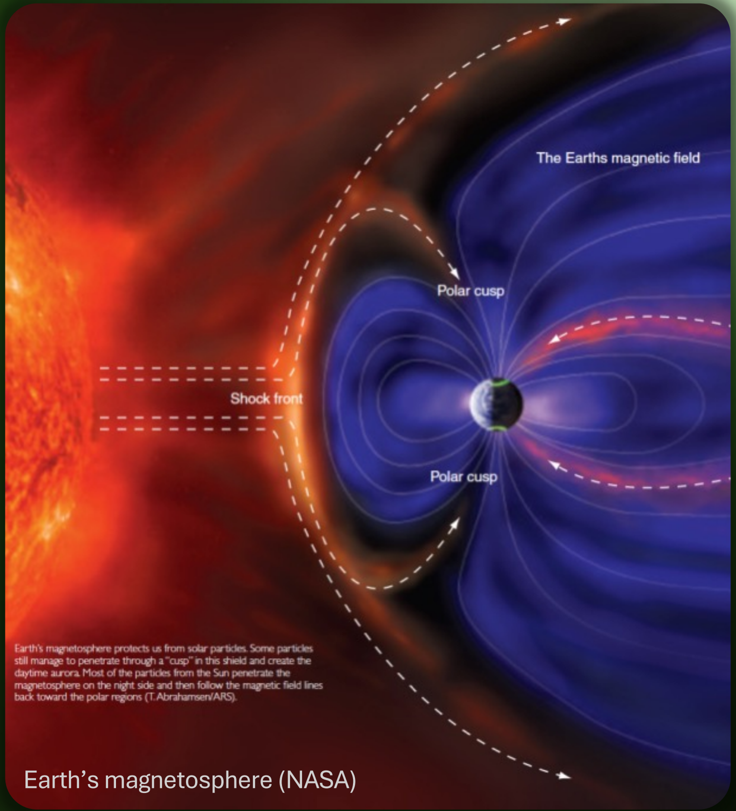
  - ✓ **magnetospheric processes driving auroral activity** → field-aligned currents, magnetic reconnection, and wave–particle coupling

From Earth’s auroral legacy to Jupiter’s aurora

- **Earth’s aurorae** are well characterized and are primarily driven by interactions between the **solar wind** and the terrestrial magnetosphere.



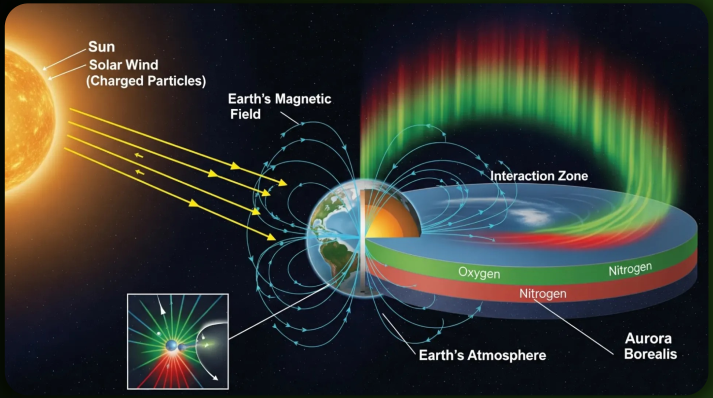

Earth’s aurora (ESA/NASA)



Earth’s magnetosphere (NASA)

From Earth's auroral legacy to Jupiter's aurora

- **Earth's aurorae** are well characterized and are primarily driven by interactions between the **solar wind** and the terrestrial magnetosphere.
- Jupiter's aurora is not simply a scaled-up verson of Earth's aurora.
- Jupiter exhibits the most energetic and brightest aurorae in the Solar System, primarily driven by the **planet's rapid rotation**.



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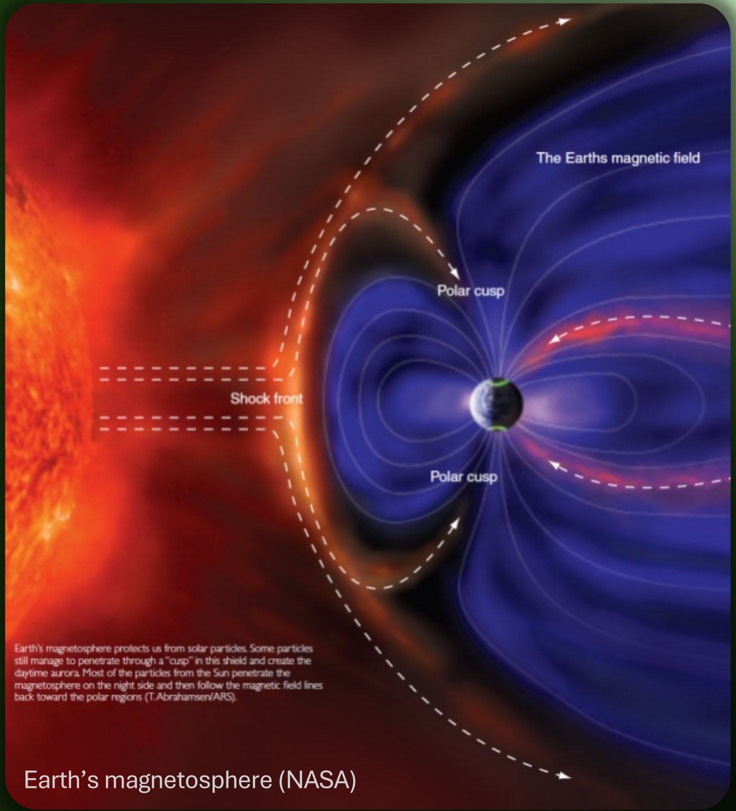

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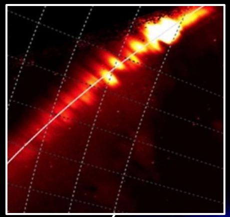
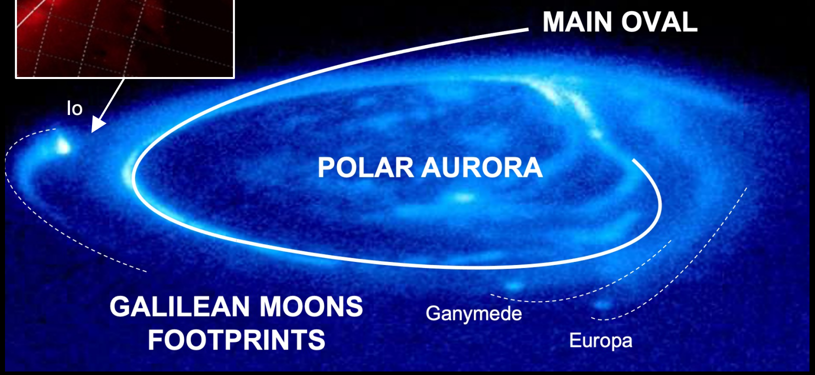


Io's IR footprint (A. Mura)



Jupiter's UV Aurora (Credits: HST/STIS/NASA/J. Clarke)

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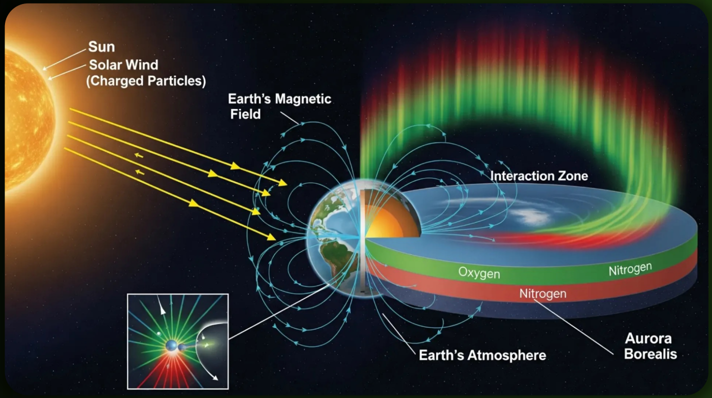


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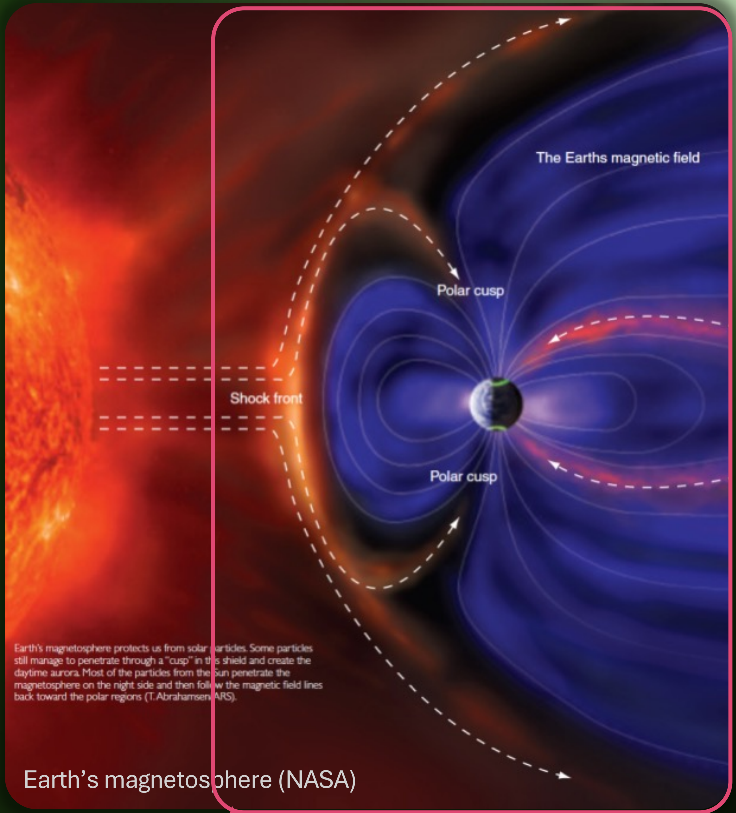

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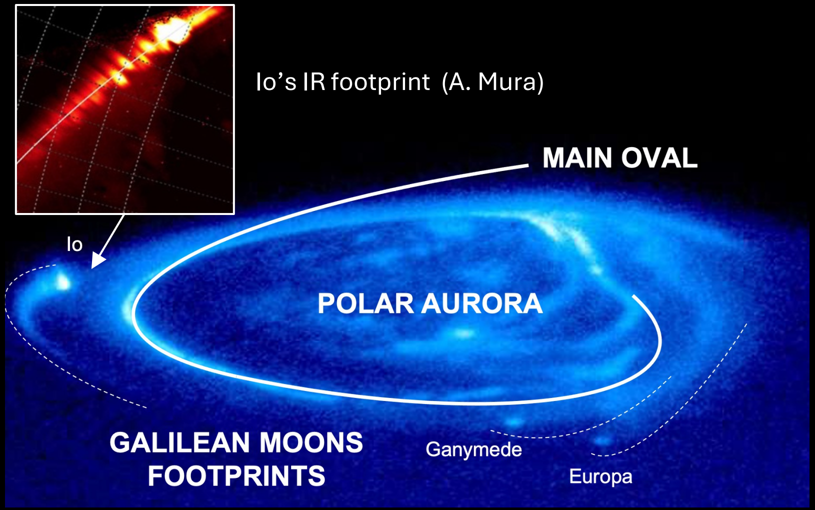

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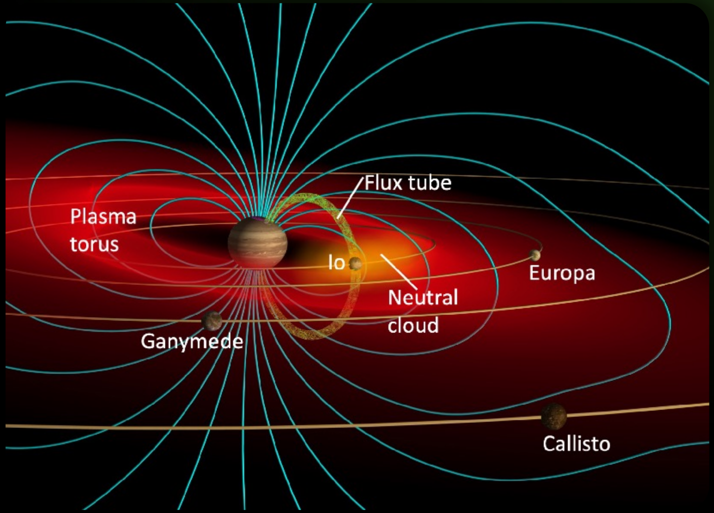
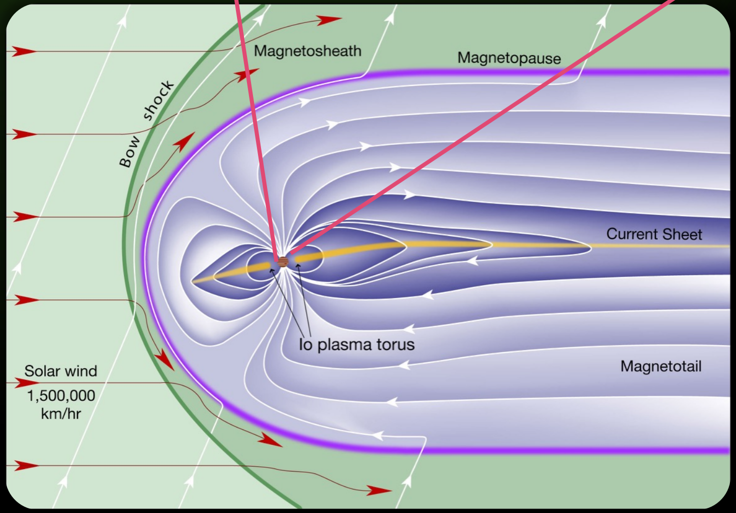


(John Spencer, SWRI)

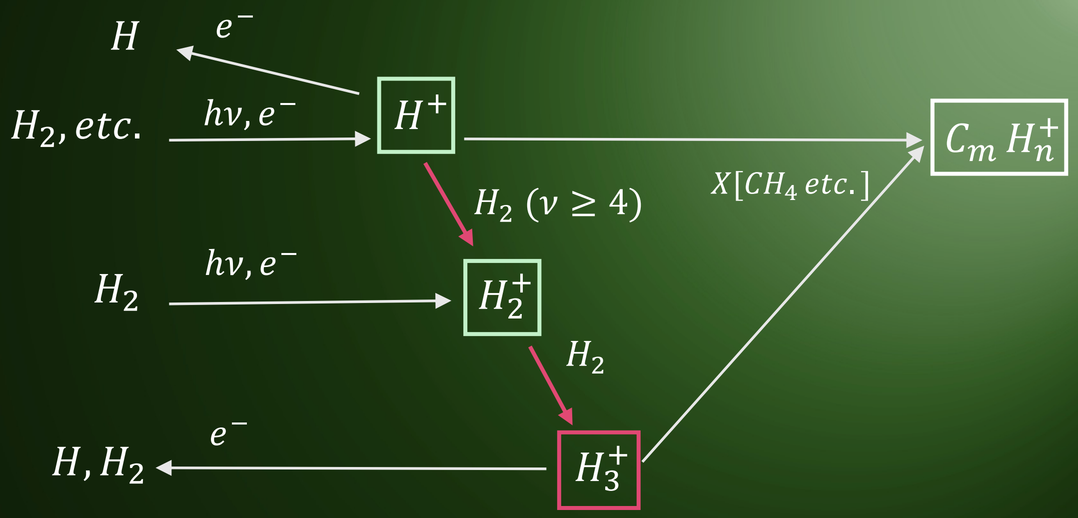


Jupiter's magnetosphere (Fran Bagenal & Steve Bartlett)

Jupiter's Infrared Aurorae

- **Infrared auroral emissions on giant planets are primarily produced by H_3^+** ions formed through particle-driven ionization of molecular hydrogen in the upper atmosphere.

- Infrared H_3^+ auroral emissions can be used to probe the **composition** and **thermal structure** of a planet's upper atmosphere.



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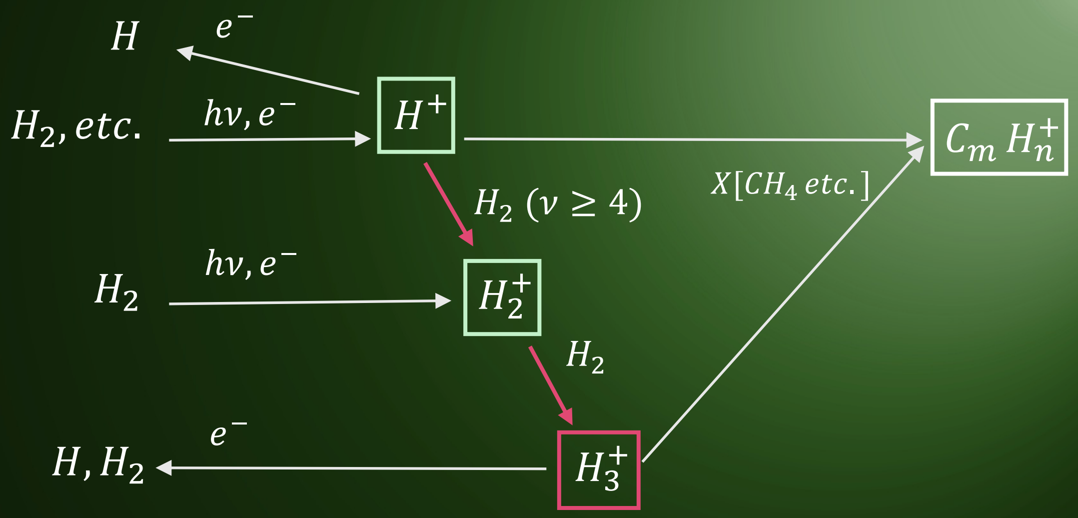

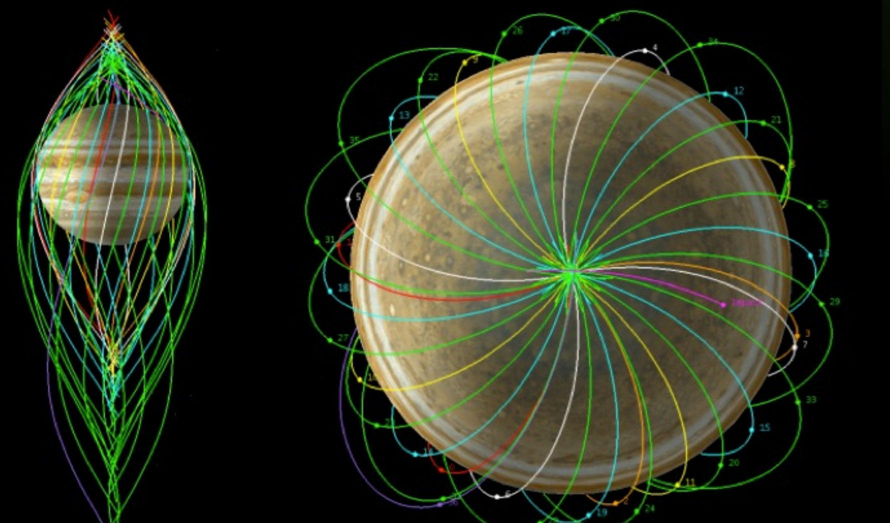

(S. Bolton)

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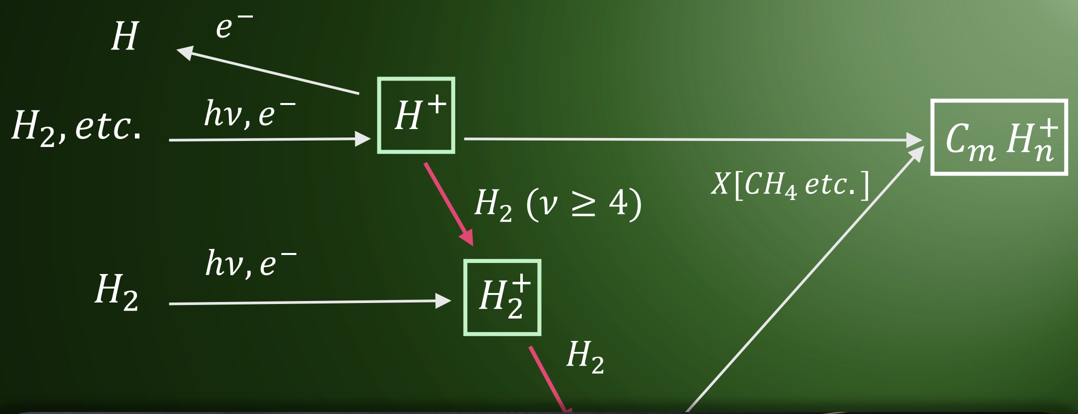

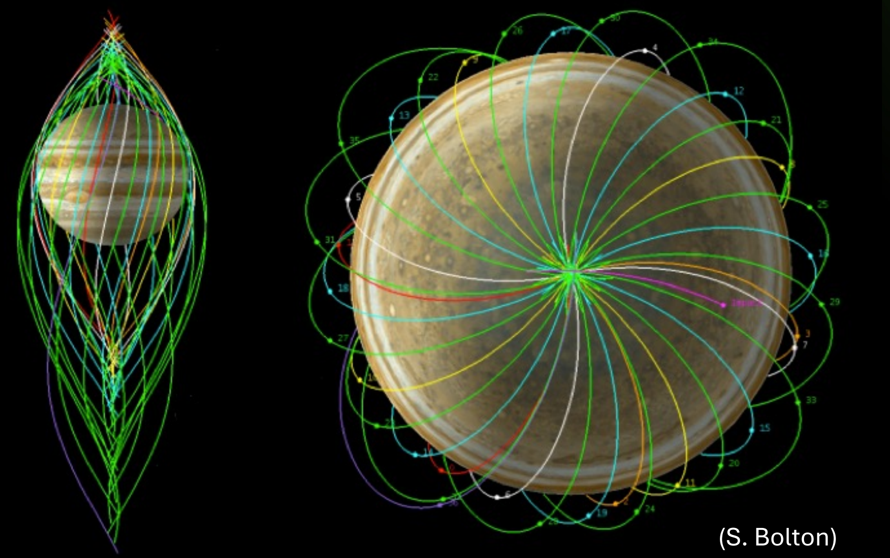

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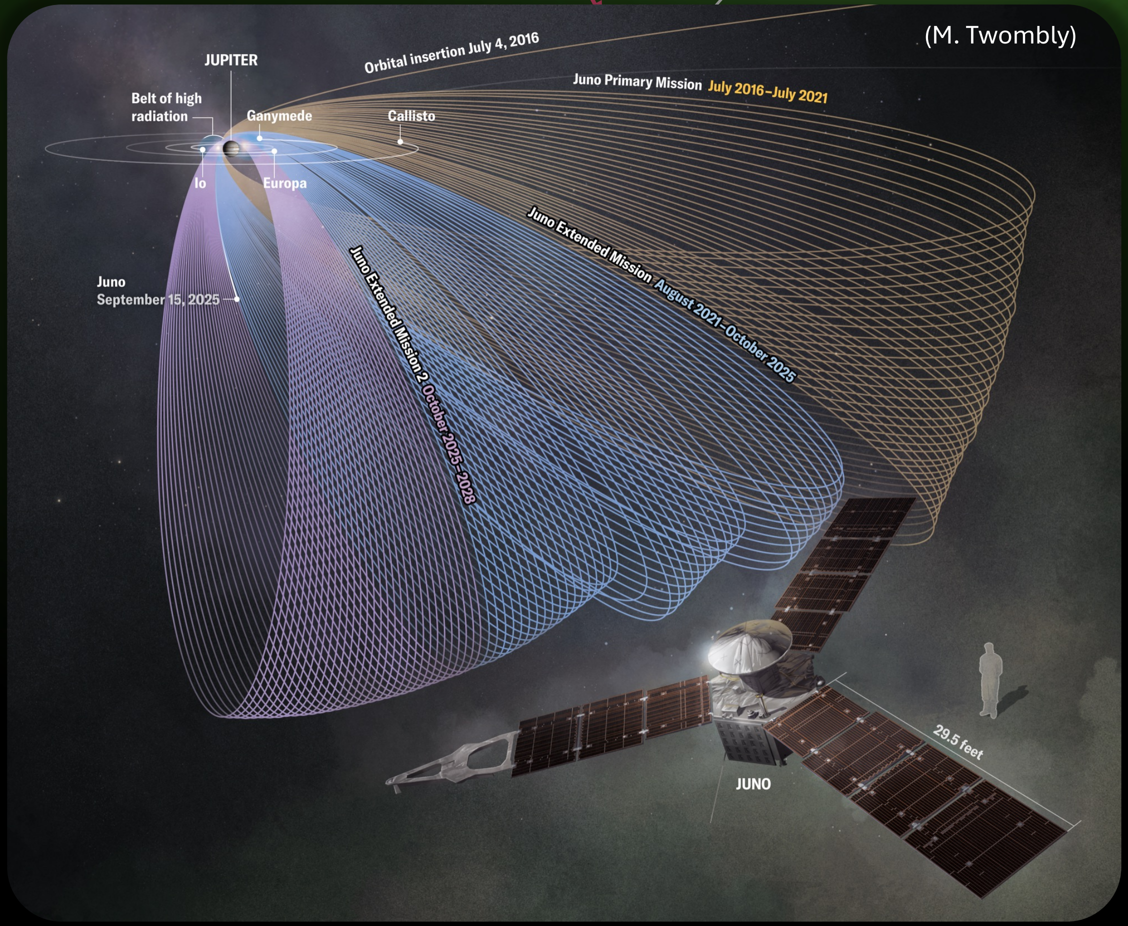

(M. Twombly)

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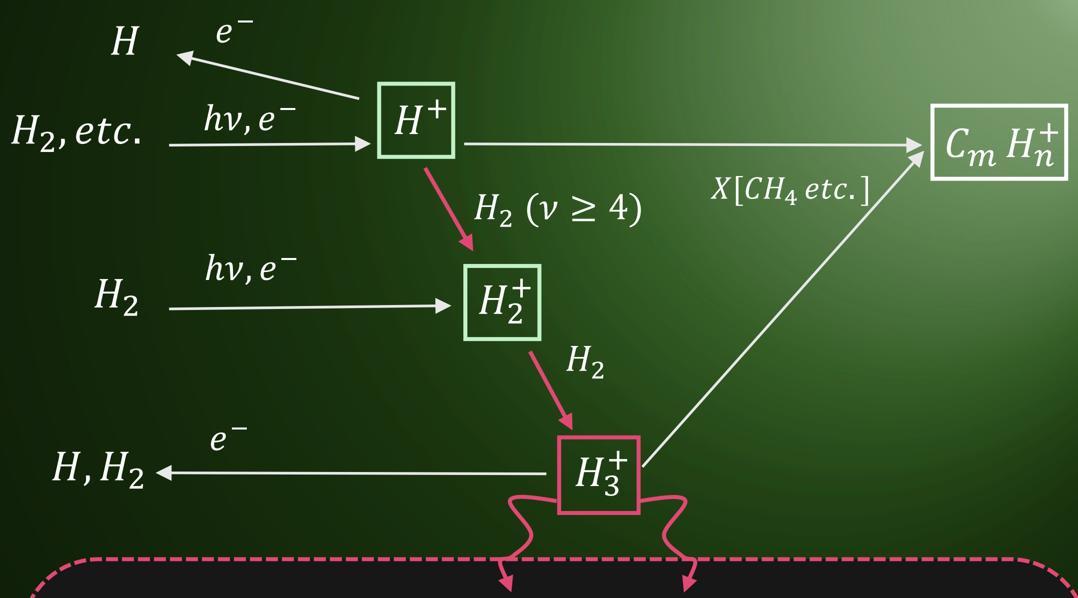
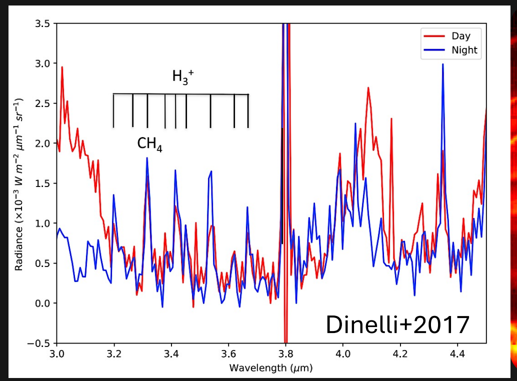
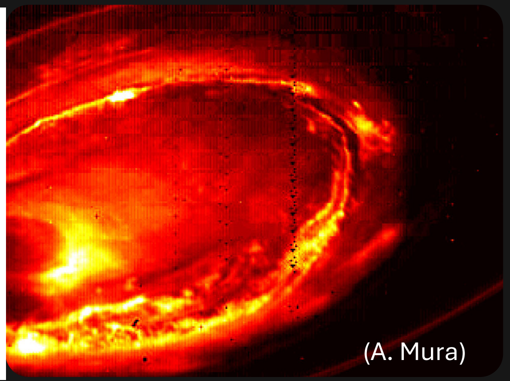
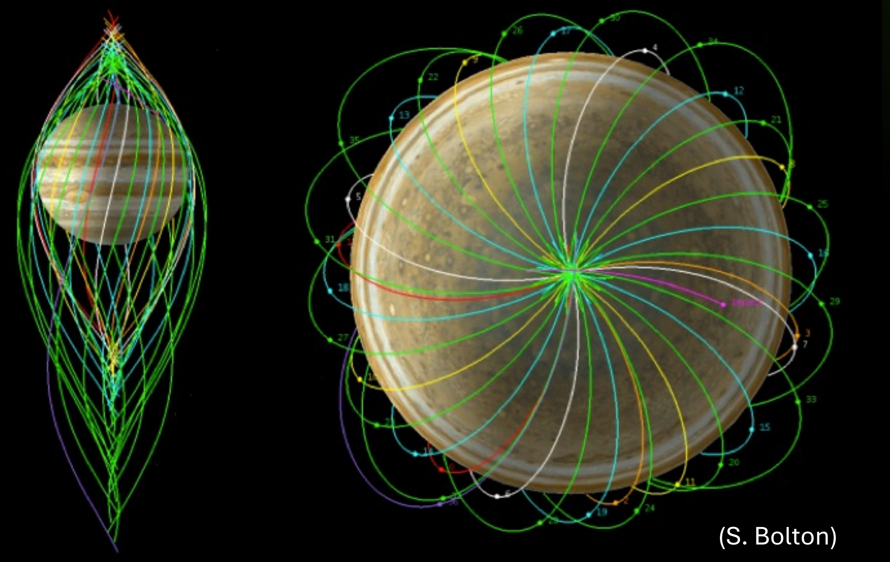






(A. Mura)



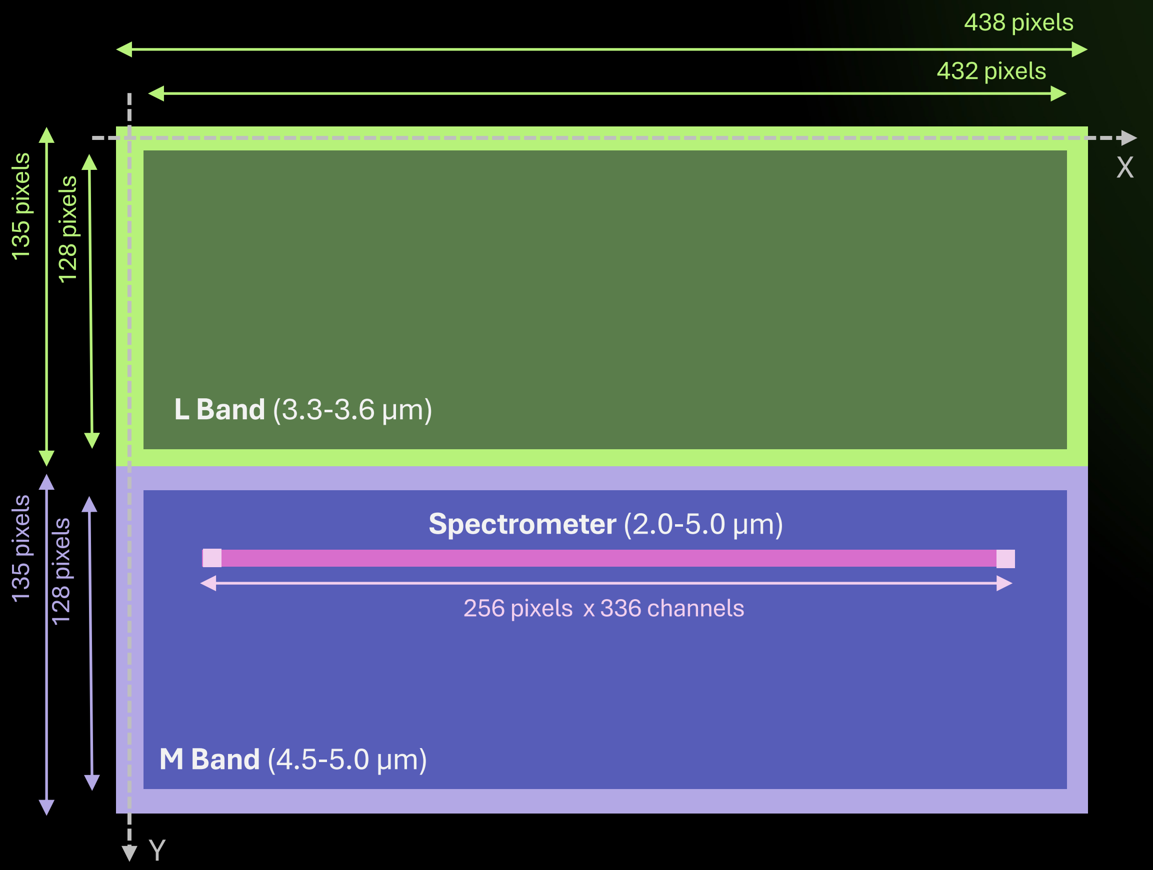
(S. Bolton)

- In the IR, the **Jovian InfraRed Auroral Mapper** (**JIRAM**), on board Juno, has obtained L-band (3.3–3.6 μm) images and spectra in the 2–5 μm range, where H_3^+ auroral emissions are detected.

The Jovian Infrared Auroral Mapper (JIRAM)

- JIRAM constits both in an **imager** and a **spectrometer**.

- The contrast of high-altitude H_3^+ auroral emissions is significantly enhanced in the 3 – 4 μm interval, where strong methane absorption effectively suppresses background light reflected from the deeper atmosphere.



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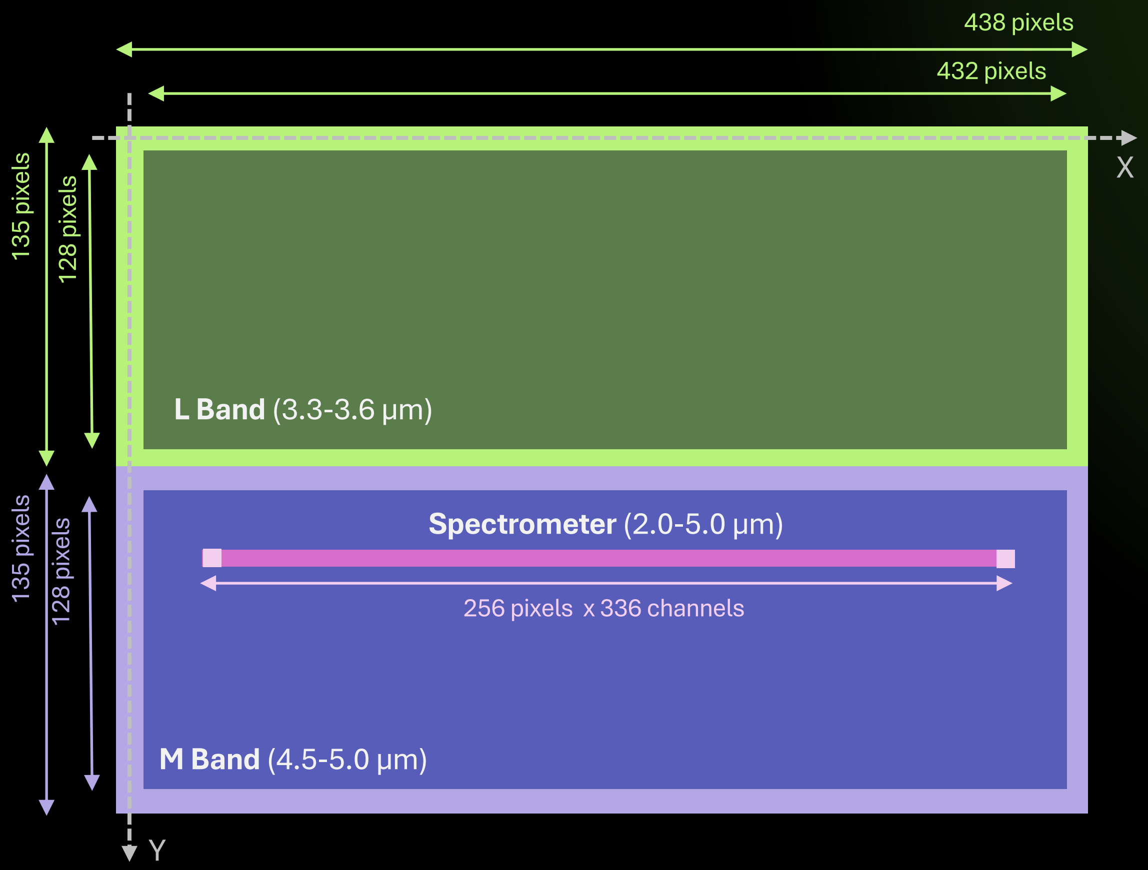

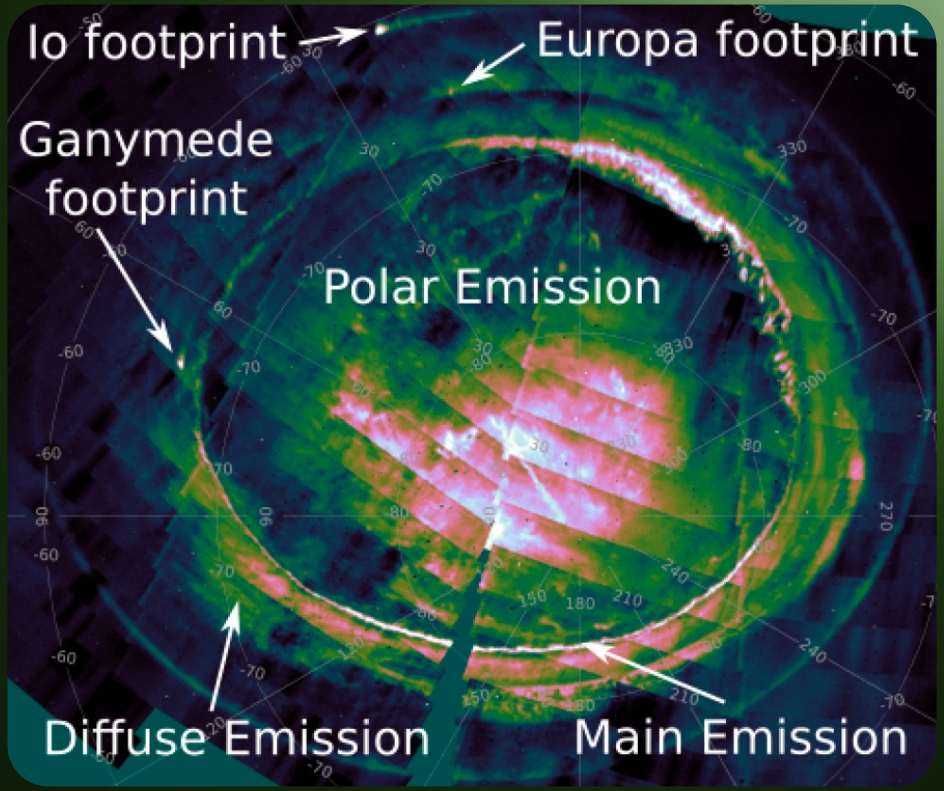

A. Moirano

- Using **L-band imaging** allows to study the morphology of H_3^+ auroral emissions by mapping their spatial distribution in planetary ionospheres.
- The morphology of H_3^+ emission links magnetospheric dynamics, including particle injections and solar wind forcing, to the ionospheric response.

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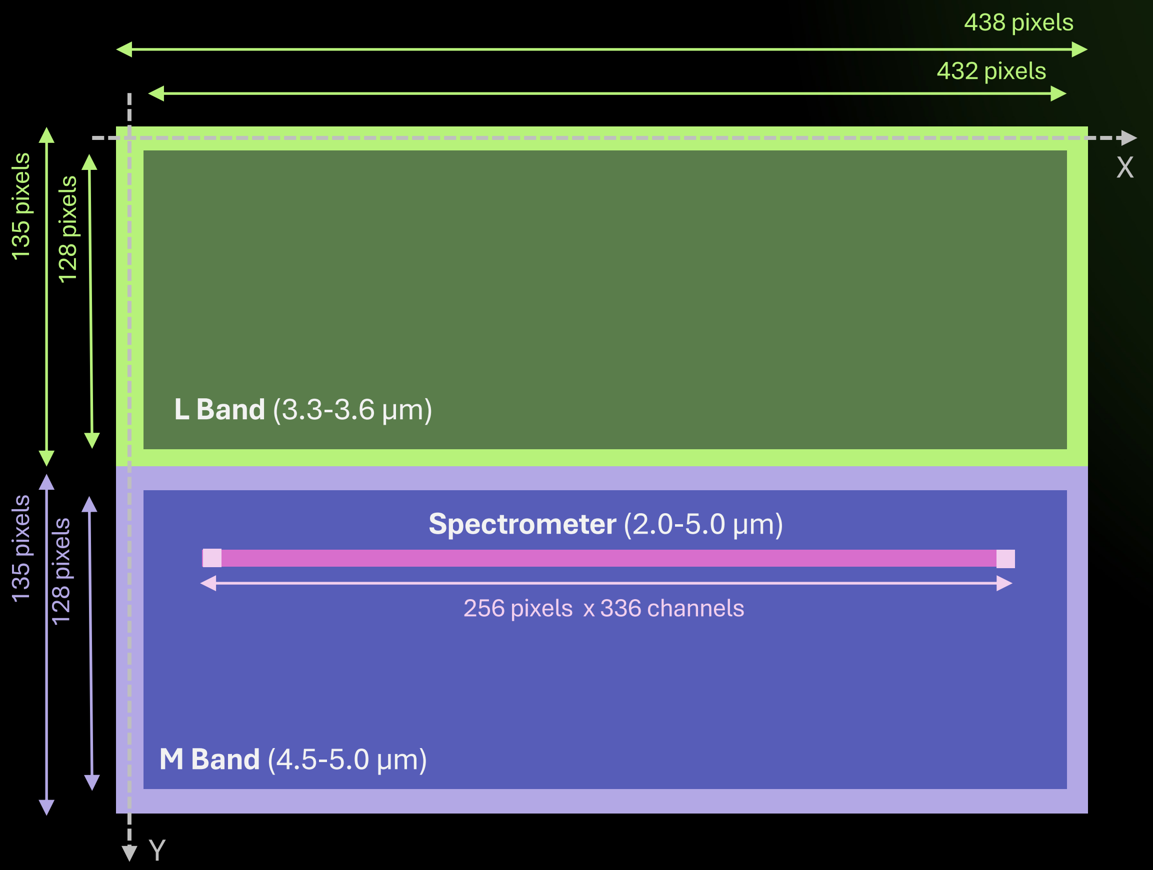

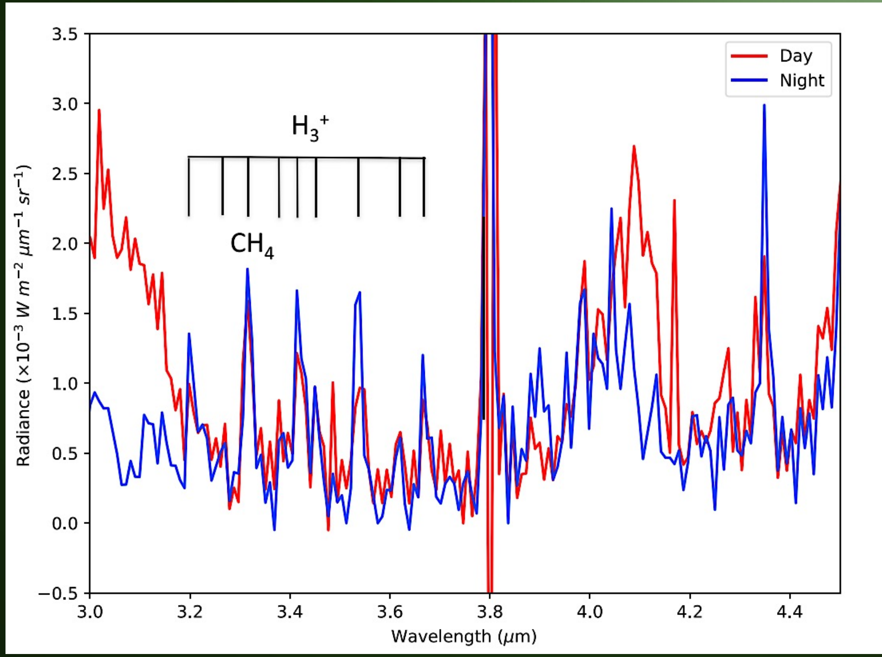

Dinelli+2017

- Compared to radiance images, **spectroscopy** enables identification of the emitting species and retrieval of physical parameters such as temperature and abundance.
- For H_3^+, which can be reasonably assumed to be in **local thermodynamic equilibrium** at the altitude of peak emission (~500 km above the 1-bar level), meaning spectroscopic measurements directly constrain ionospheric composition and temperature.

Retrieval Method

- **Assuming optically thin auroral emissions**, the forward model computes the intensity of each spectral transition using the following expression. The synthetic spectrum is then obtained by convolving the calculated line intensities with the instrumental spectral response function.

$$I_{im} = N_m(2J_{im}+1)g_{im}A_{im}hc\nu_{im}\frac{\exp(-hcE_{im}/KT_m)}{4\pi Q_m(T_m)}$$

I_{im}: intensity of the i–m transition.
N_m: column density of the emitting molecule m along the line of sight (cm^{-2}).
T_m: effective temperature of molecule m (K).
J_{im}: rotational quantum number of the upper level of the considered transition.
ν_{im}: frequency of the transition (cm^{-1}).
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$Q_m(T_m)$: partition function of molecule m at temperature Tm.

- The retrieval model fits the spectra through a **Bayesian approach**, minimizing the χ^2 with the Gauss-Newton iterative procedure.

Retrieval Method → *Analysis*

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✓ JIRAM **nadir spectra** from PJ1 (27 August 2016) to PJ40 (25 February 2022), acquired at latitudes > 50°, are analyzed, focusing on orbits with the most complete auroral coverage for inter-orbit comparison.

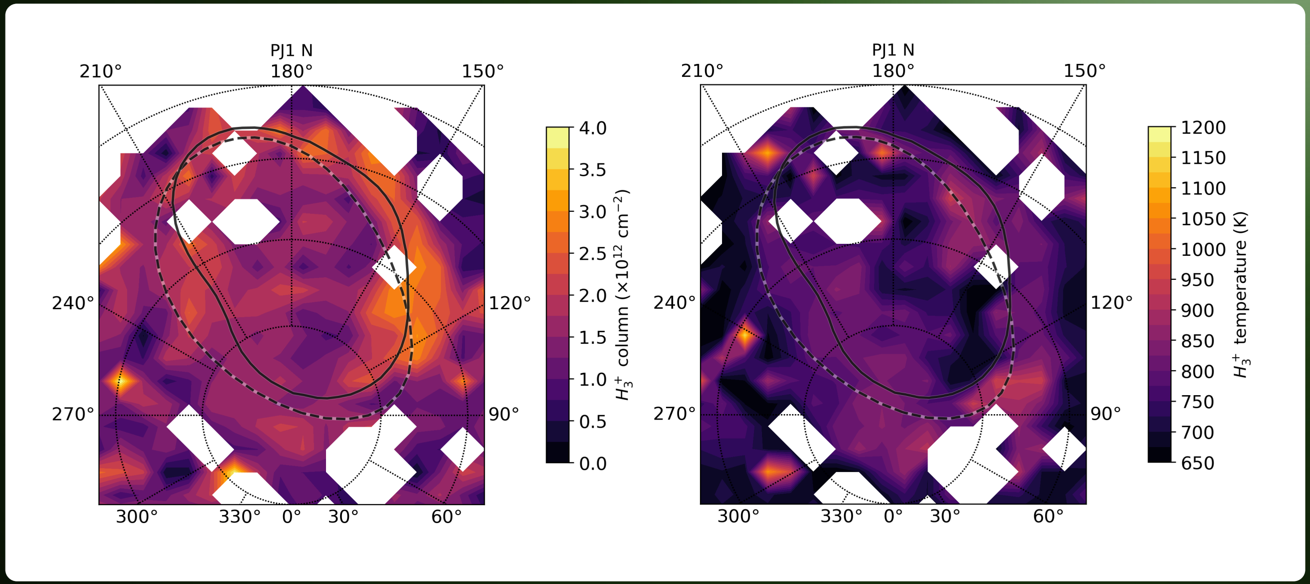
✓ **H_3^+ temperature** and **column density**, along with the **CH_4 relative abundance.**

✓ The analysis is restricted to the **3.2–3.8 μm** spectral range.

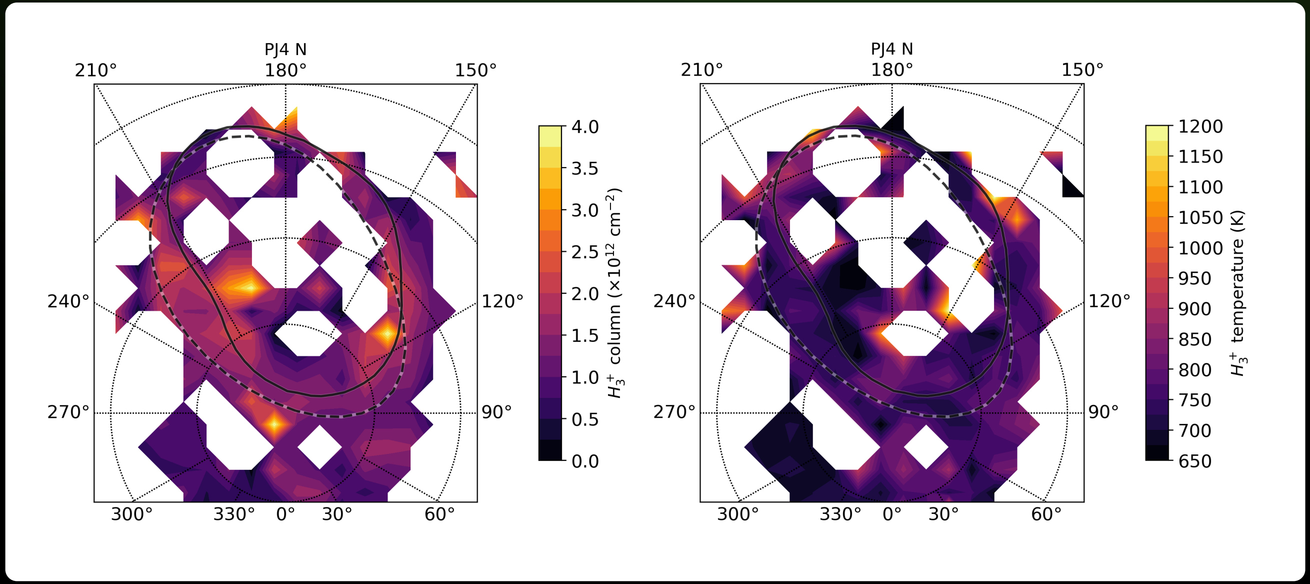
✓ The results are used to generate spatial distribution maps to investigate the spatial and temporal variability of auroral emissions.

Variability of H_3^+ emissions: North Aurora

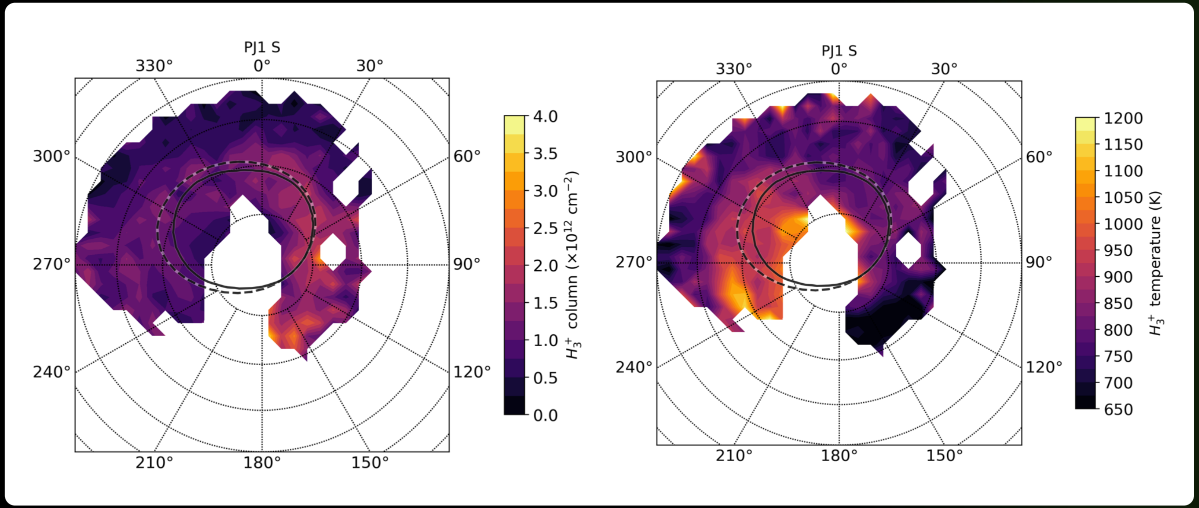
- ✓ H_3^+ emission traces the auroral oval, with enhanced concentration and temperatures of 750–950 K, while emission at lower latitudes is too faint or noisy for reliable retrieval.

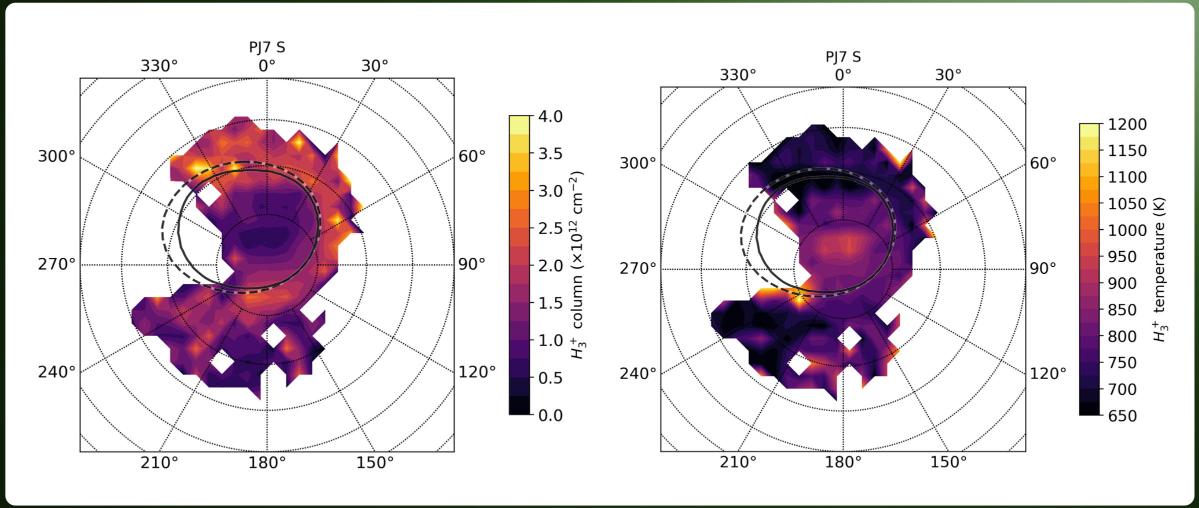


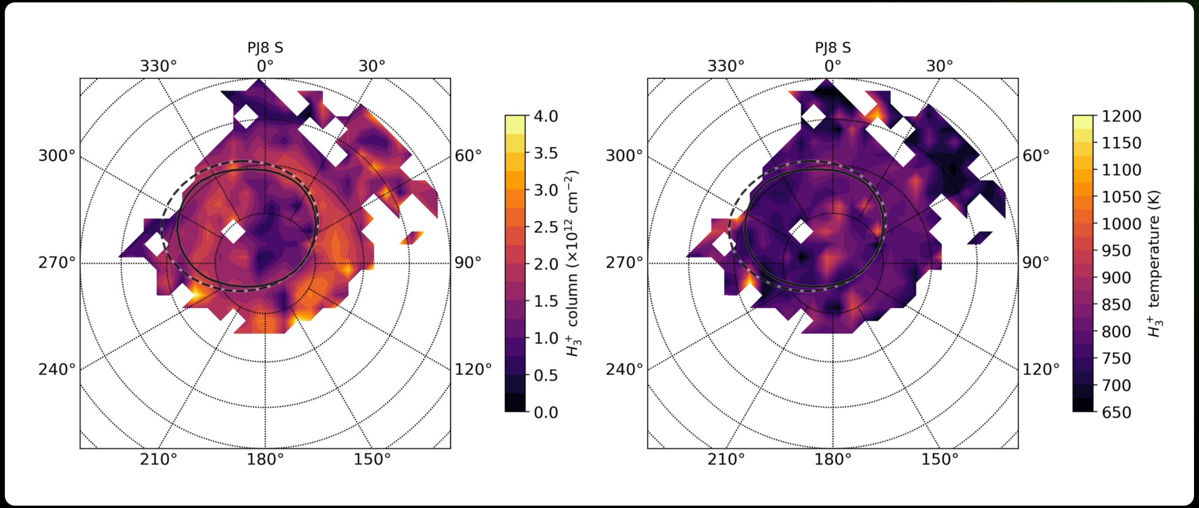
- ✓ Relative to PJ1, H_3^+ intensity is reduced, with a more confined auroral arc and lower temperatures (~ 700-800 K)

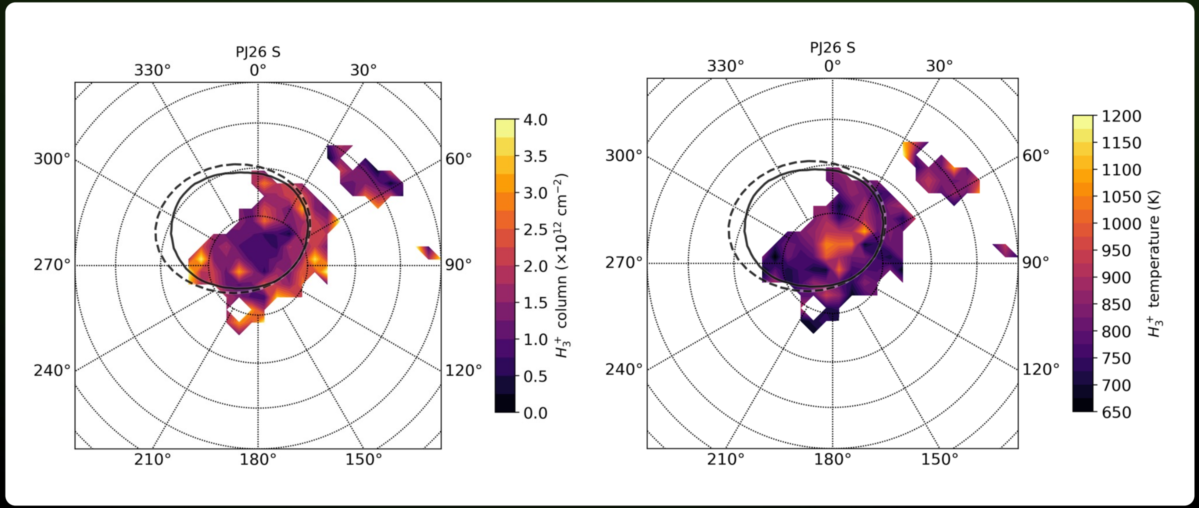


Variability of H_3^+ emissions: South Aurora



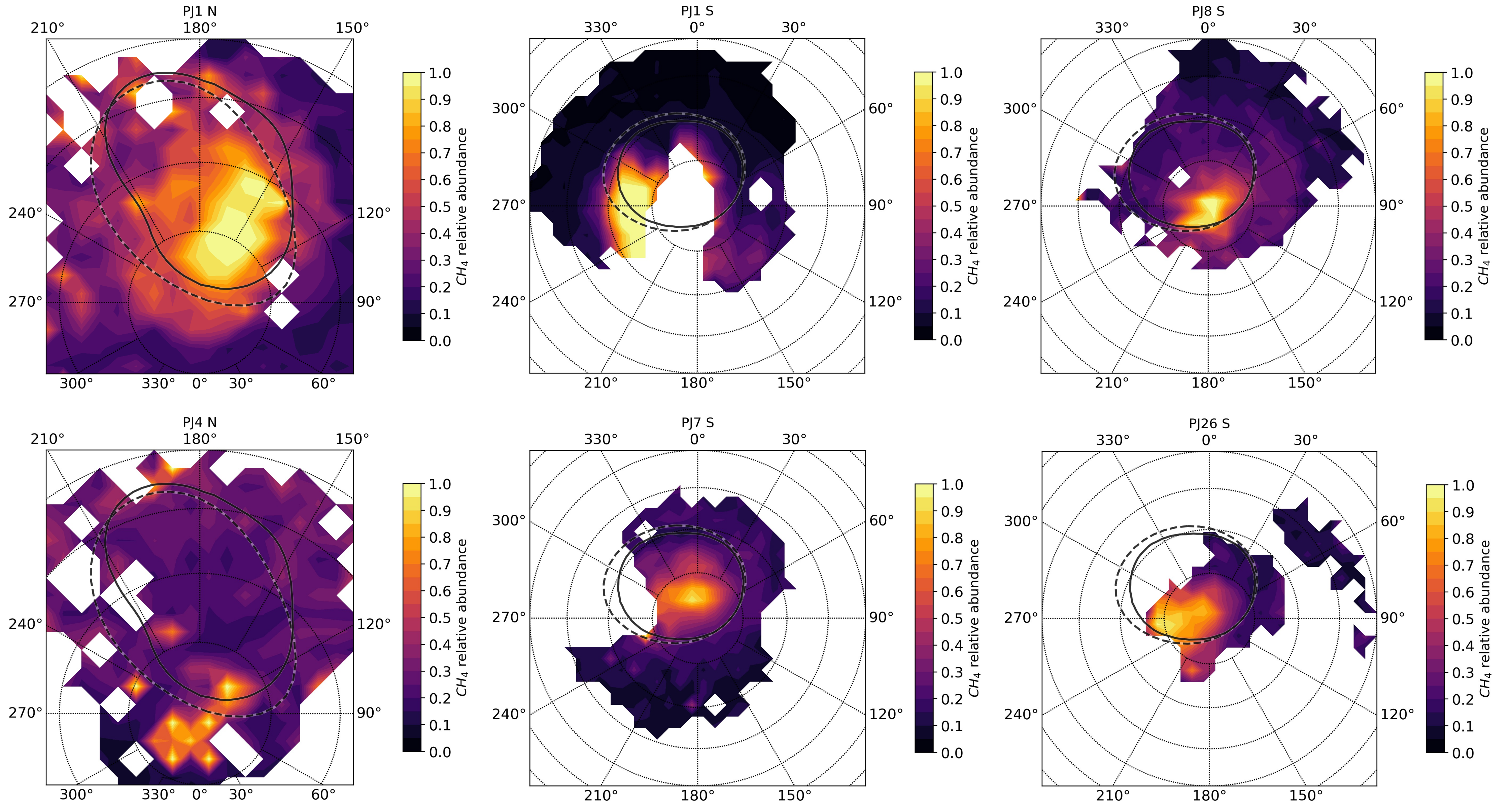






- ✓ The H_3^+ emission oval is well captured by the measurements due to the large concentration of the
- ✓ H_3^+ temperatures reach ~1200 K during PJ1, while they are mostly confined between 600-900K in the later orbits.
- ✓ Highest H_3^+ temperatures are observed in correspondence with the CH_4 polar hot spot.

Variability of H_3^+ emissions: CH_4 Polar Hot Spots



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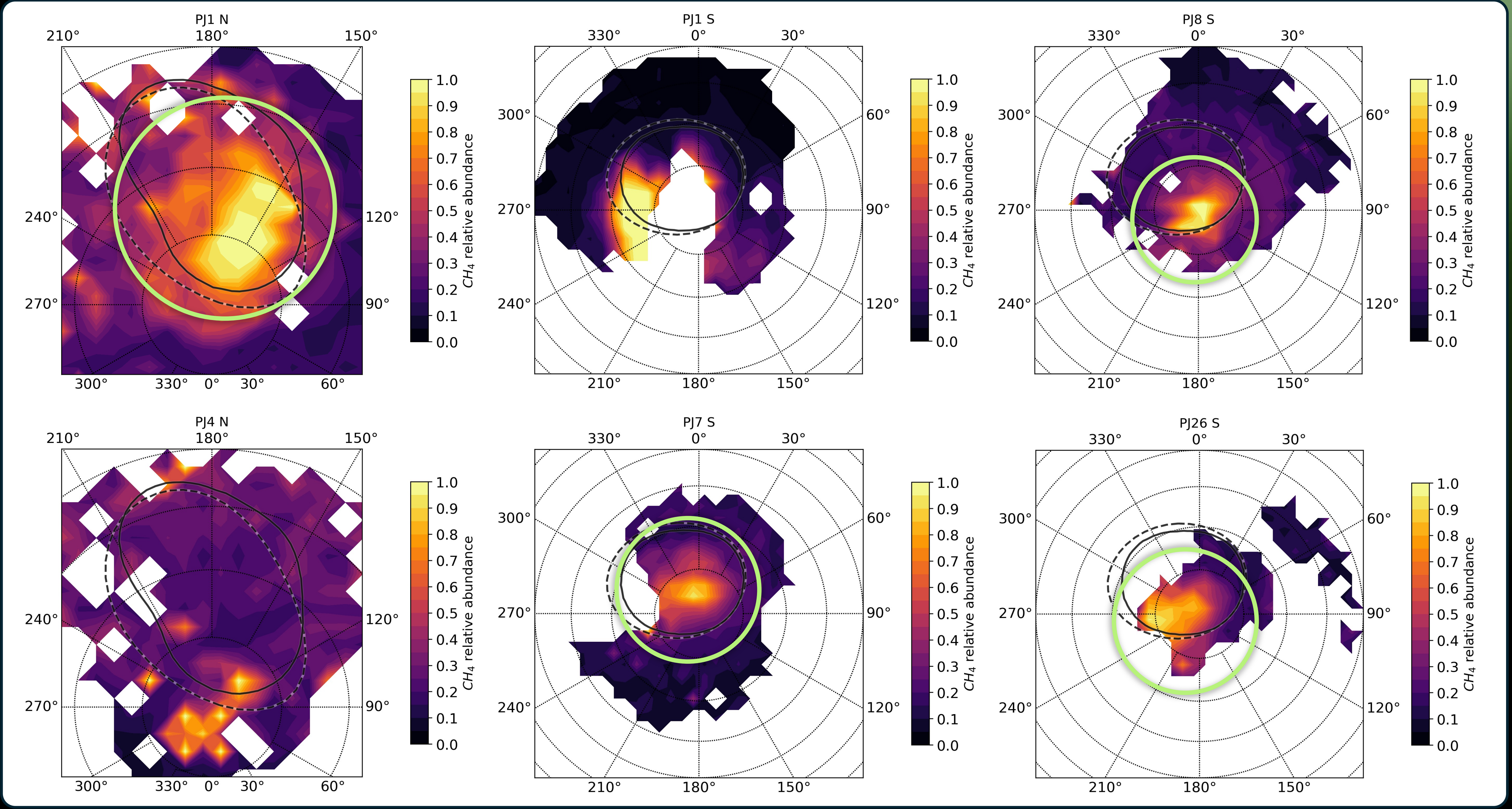
✓ CH_4 polar hot spots are mainly confined within the main auroral



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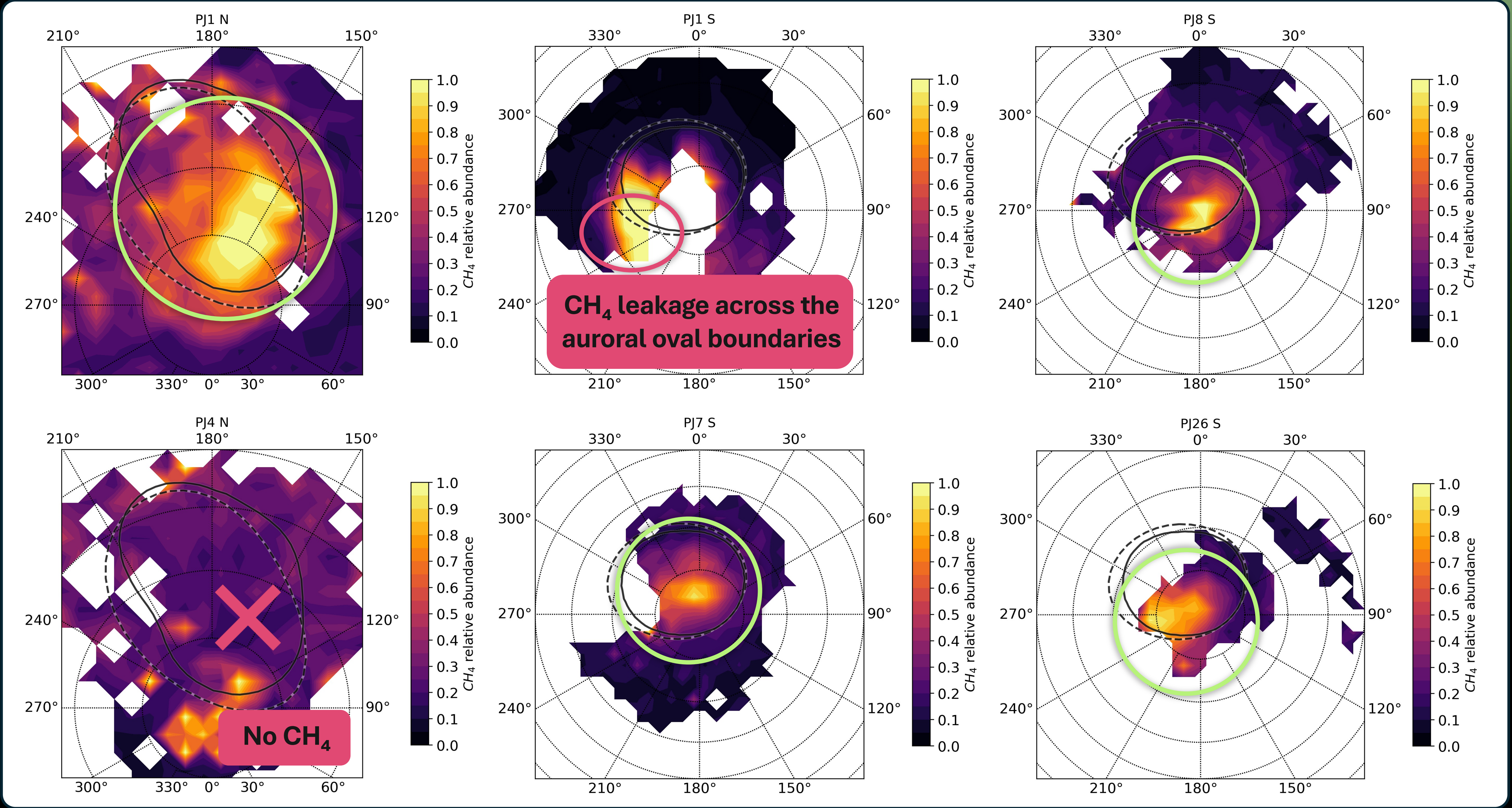
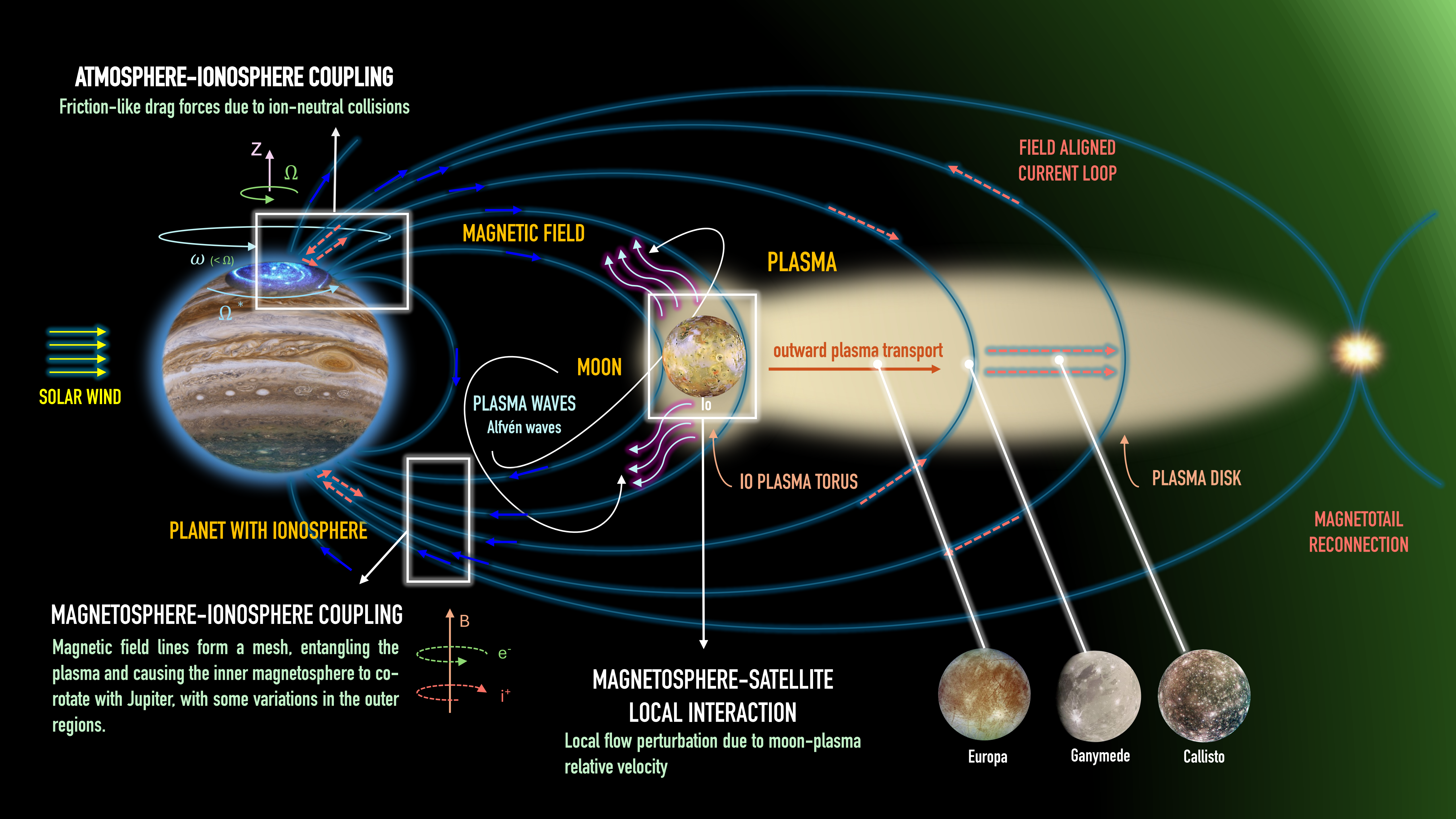


Conclusions

- ✓ The maps reveal significant variability in auroral emissions, including a longitudinal displacement of the southern aurora over time.
- ✓ The 3.3-μm methane hot spots are primarily confined within the auroral oval, with occasional indications of emission extending beyond its boundary, suggesting that they are likely driven by auroral processes.
- ✓ These results highlight the dynamic nature of Jupiter’s infrared aurora, consistent with variable atmospheric response to time-varying magnetospheric forcing.
- ✓ Nevertheless, the coupling between magnetospheric forcing and Jupiter's atmospheric response remains to be fully characterized.



ATMOSPHERE-IONOSPHERE COUPLING
Friction-like drag forces due to ion-neutral collisions
Z
Ω
ω (< Ω)
Ω*
SOLAR WIND
MAGNETIC FIELD
PLASMA
FIELD ALIGNED
CURRENT LOOP
MOON
PLASMA WAVES
Alfvén waves
Io
outward plasma transport
IO PLASMA TORUS
PLASMA DISK
MAGNETOTAIL
RECONNECTION
PLANET WITH IONOSPHERE
MAGNETOSPHERE-IONOSPHERE COUPLING
Magnetic field lines form a mesh, entangling the plasma and causing the inner magnetosphere to co-rotate with Jupiter, with some variations in the outer regions.
B
e-
i+
MAGNETOSPHERE-SATELLITE
LOCAL INTERACTION
Local flow perturbation due to moon-plasma relative velocity
Europa
Ganymede
Callisto

Beyond Jupiter

- ✓ Saturn's H_3^+ emission is much weaker than Jupiter's because Saturn receives less auroral particle precipitation and its upper atmosphere is cooler.
- ✓ For Uranus and Neptune, the auroral H_3^+ signals are even weaker and less well-constrained, with limited heating, distinct magnetospheric geometries, and sparse observations all contributing to the challenge.
- ✓ Consequently, **Jupiter's H_3^+ aurora serves as a key benchmark for comparative planetology**.
- ✓ Characterizing the Jovian auroral system provides a reference framework for interpreting magnetosphere–ionosphere coupling and the more elusive auroral environments of the other giant planets.


THANK YOU