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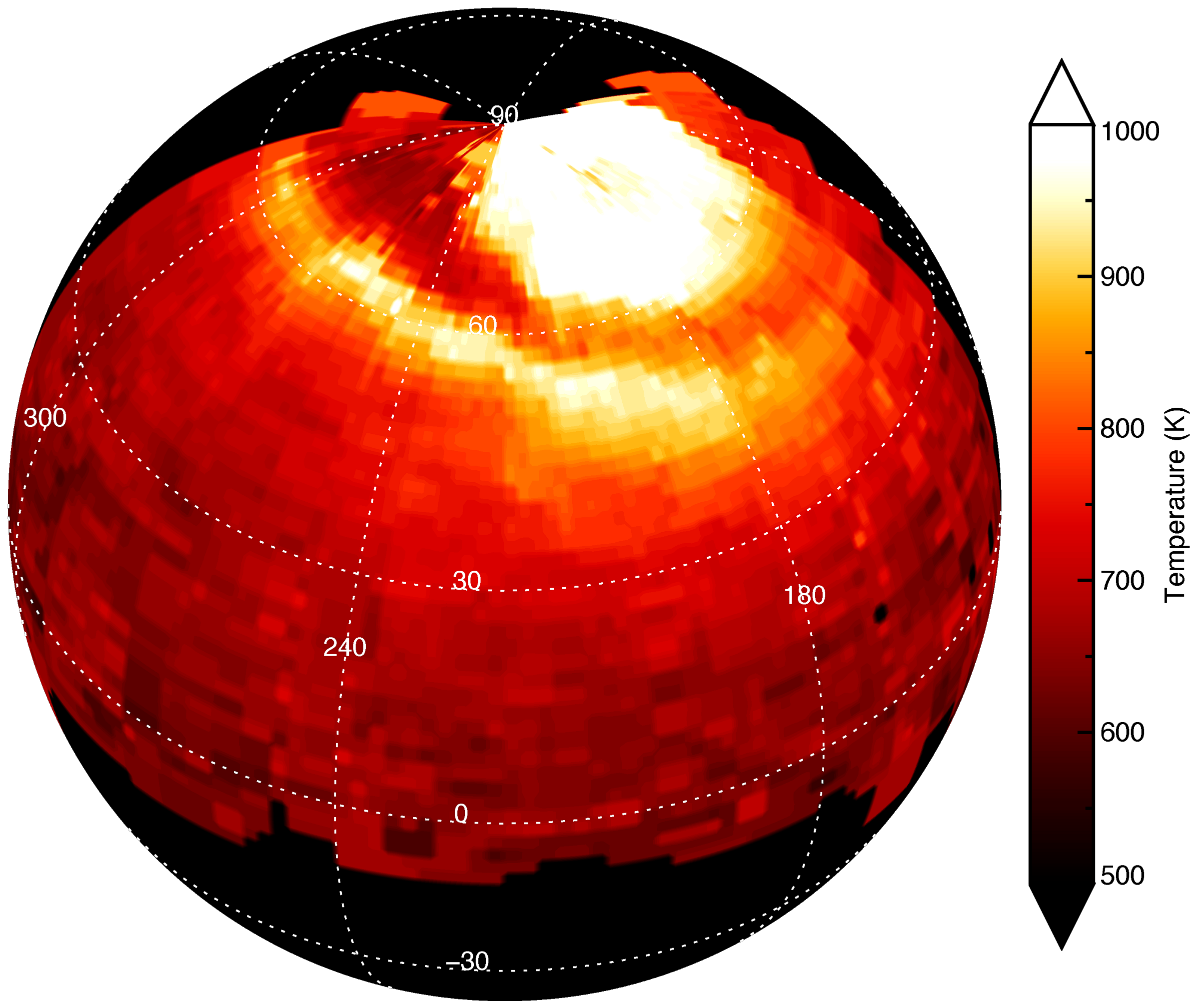
A planetary-scale heat wave in Jupiter's upper atmosphere



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The Giant Planet 'Energy Crisis'

Earth's non-auroral upper atmosphere is around 800 K

Jupiter is 5 times farther from the Sun than Earth, so it receives 4% the amount of Solar heating. However, both are similar in temperature.

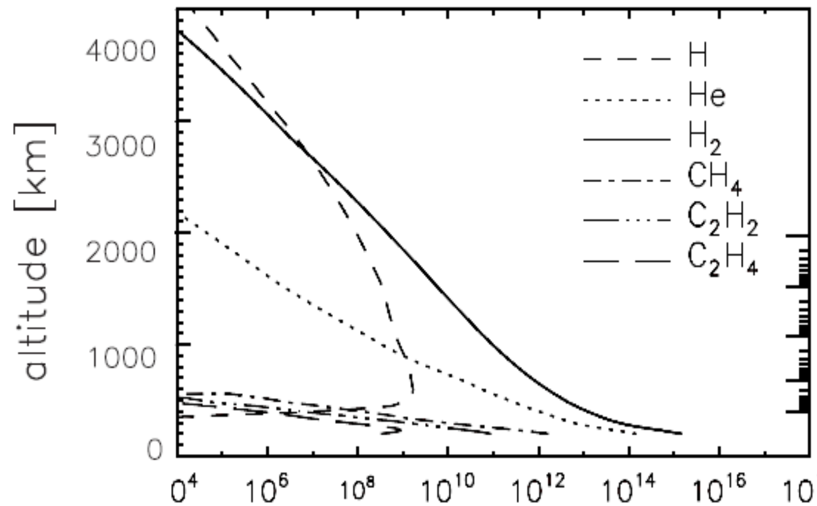
Table – Yelle and Miller 2004
Earliest understanding of a 'crisis' – Strobel et al., 1973

Planet / Upper atmos. temperature	Observed (Kelvin) non-auroral values	Model (Kelvin) by solar heating alone	Difference (Kelvin)
Earth	800	800	0
Jupiter	700	160	+460
Saturn	420	180	+240
Uranus	700	140	+560
Neptune	600	130	+470

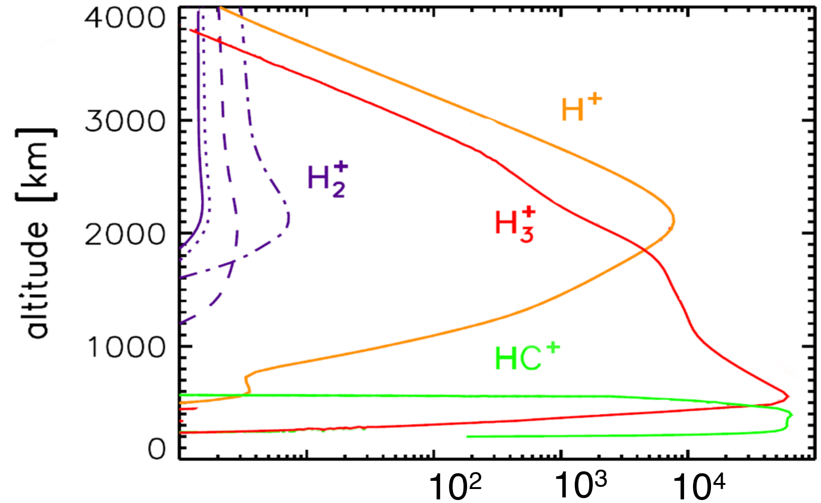
Motivations: find missing heating sources and characterise the weather and climate of Giant Planet upper atmospheres

Jupiter's upper atmosphere

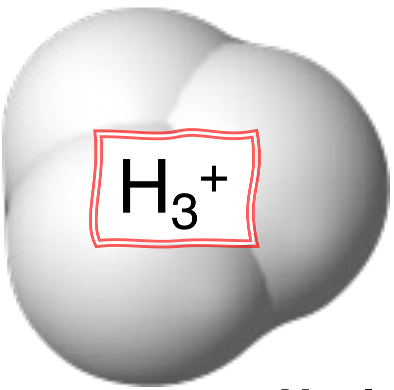
Thermosphere (neutrals)



Jupiter's co-located ionosphere



Model by Tao *et al.*, 2011



emits in IR (~0.1sec)

Life time ~1000 sec

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

H_3^+ is in thermal equilibrium with surroundings, so its temperature is a proxy for the upper atmosphere

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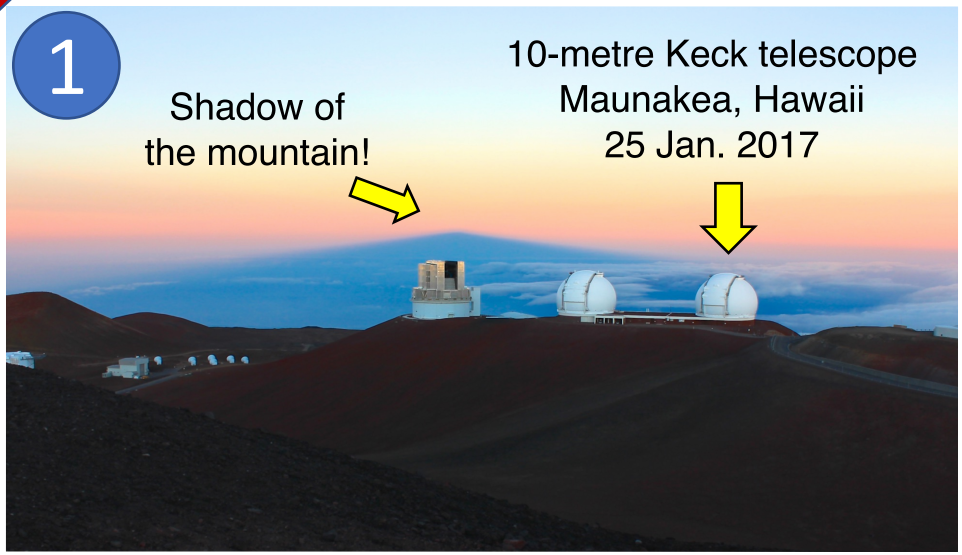
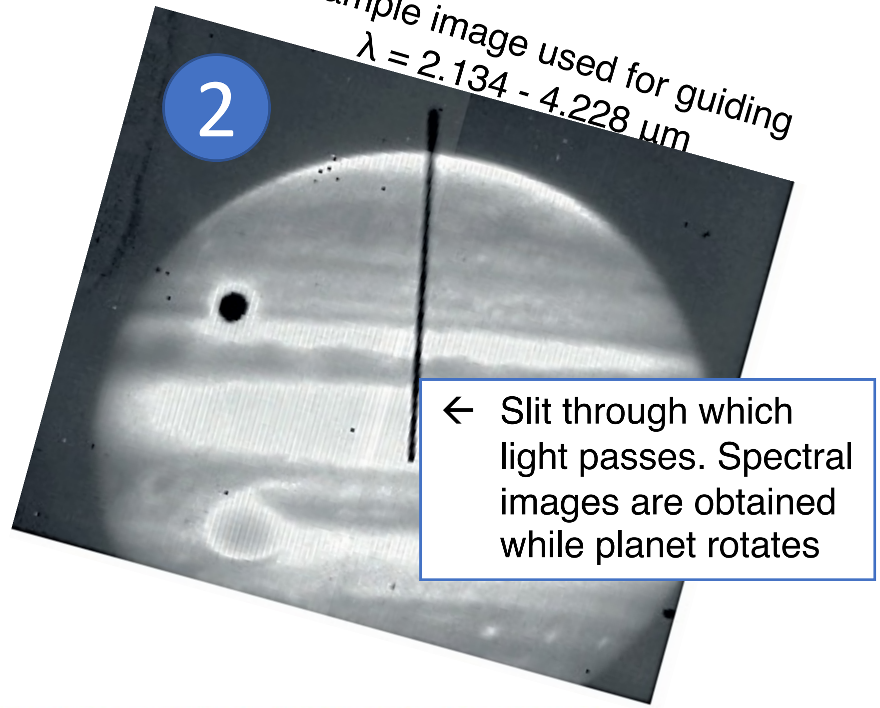
Observations

1



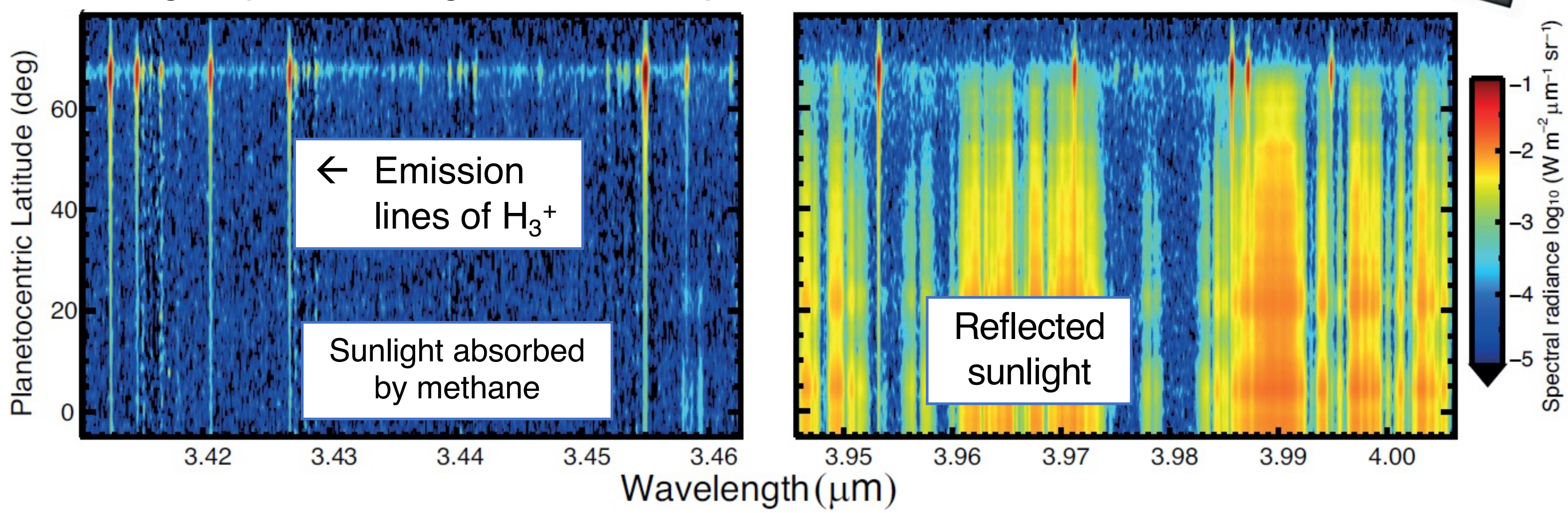
Example image used for guiding
λ = 2.134 - 4.228 um

2



A single spectral image (~60 sec exposure)

3



O'Donoghue *et al.*, *Nature*, 2021

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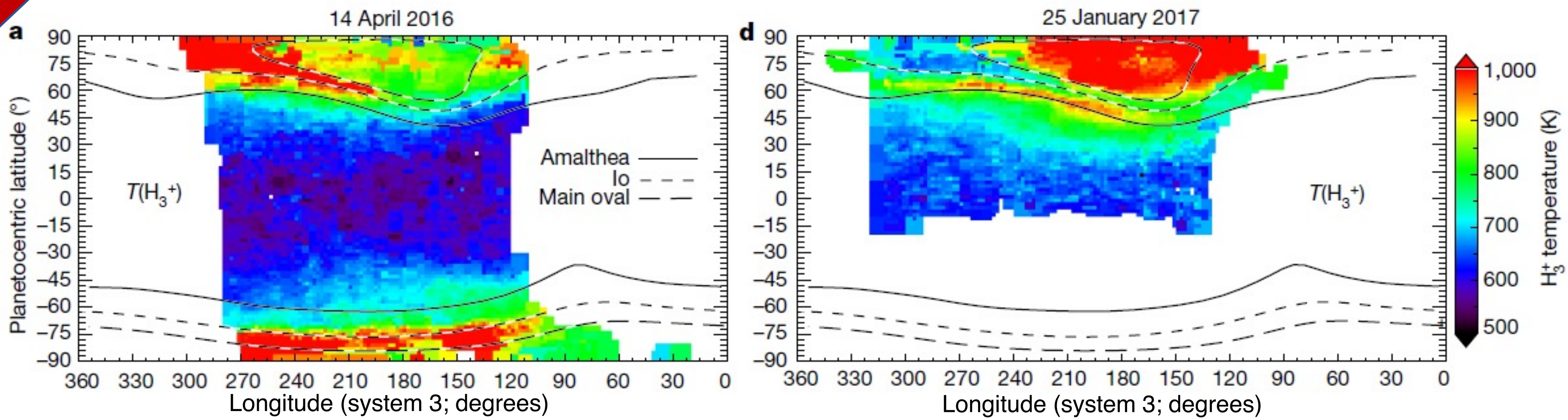
Results: Jupiter temperature maps

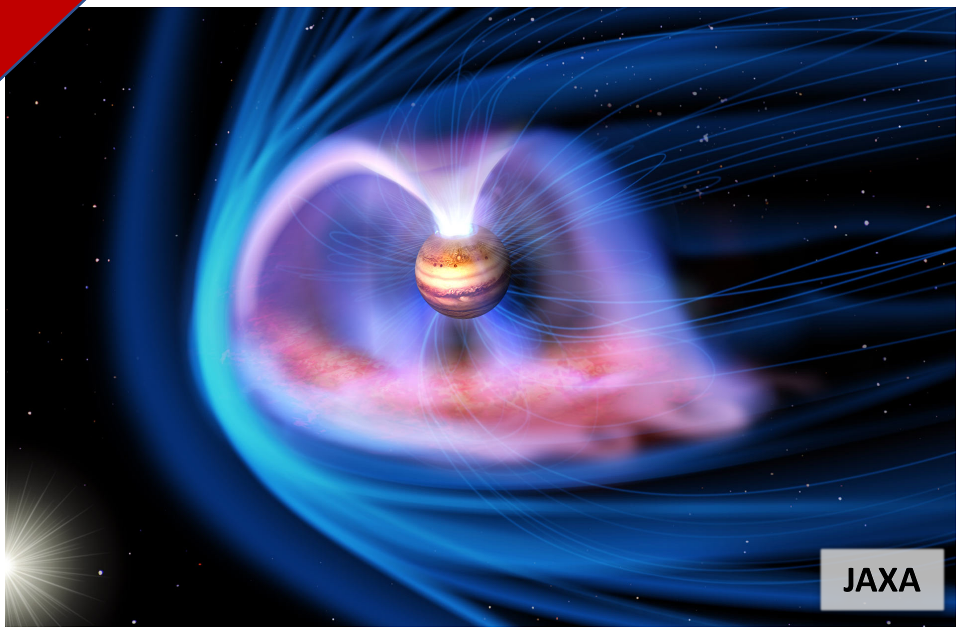


These near-global maps of Jupiter's upper atmosphere temperature were reported in O'Donoghue *et al*., 2021. The auroral "main oval" and the mapping of magnetic field lines which connect the planet to moons Io and Amalthea are overplotted for reference

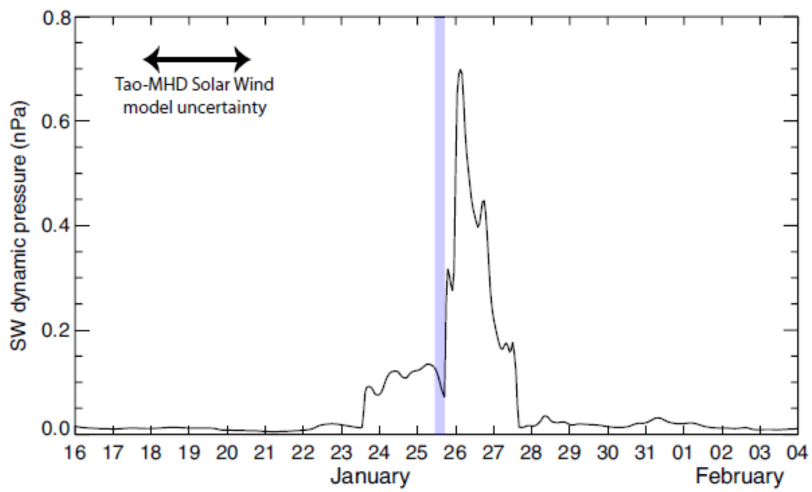
Temperatures between the auroras ('main oval') and the equator exhibit a gradient, indicating the auroras are the major source of global heating, at least on the days recorded

In the present study, we examine in detail a never-before-seen planetary heat wave outside of the main oval, on 25 Jan. 2017

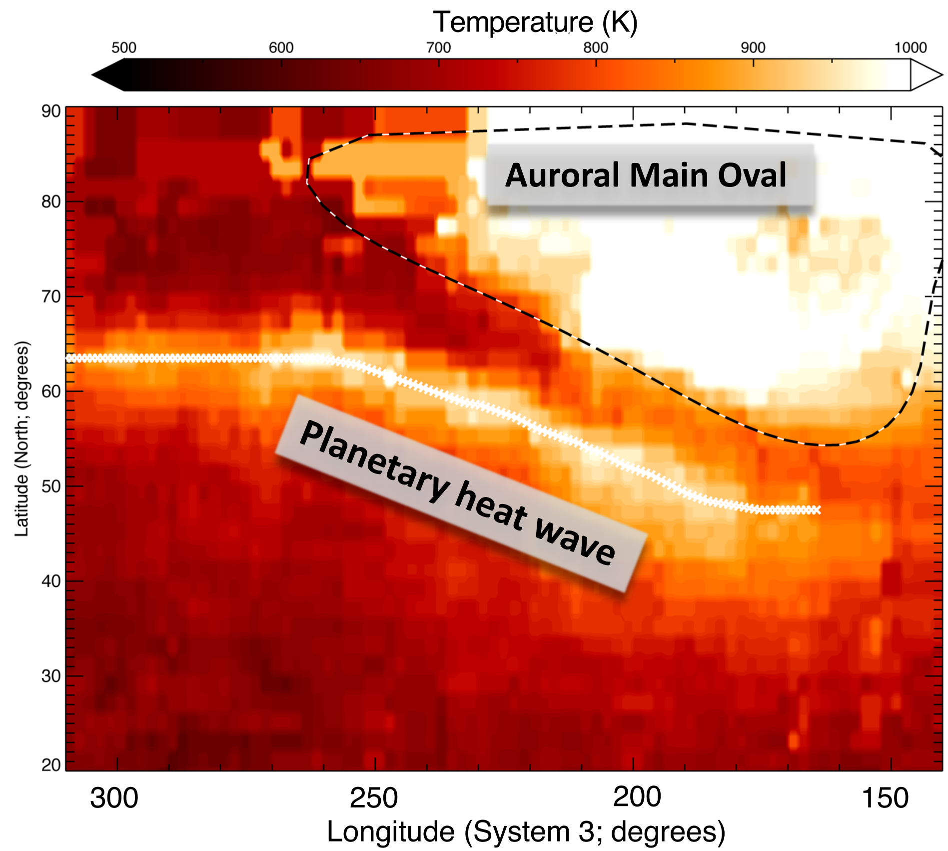
6 Planetary heat wave induced by solar wind



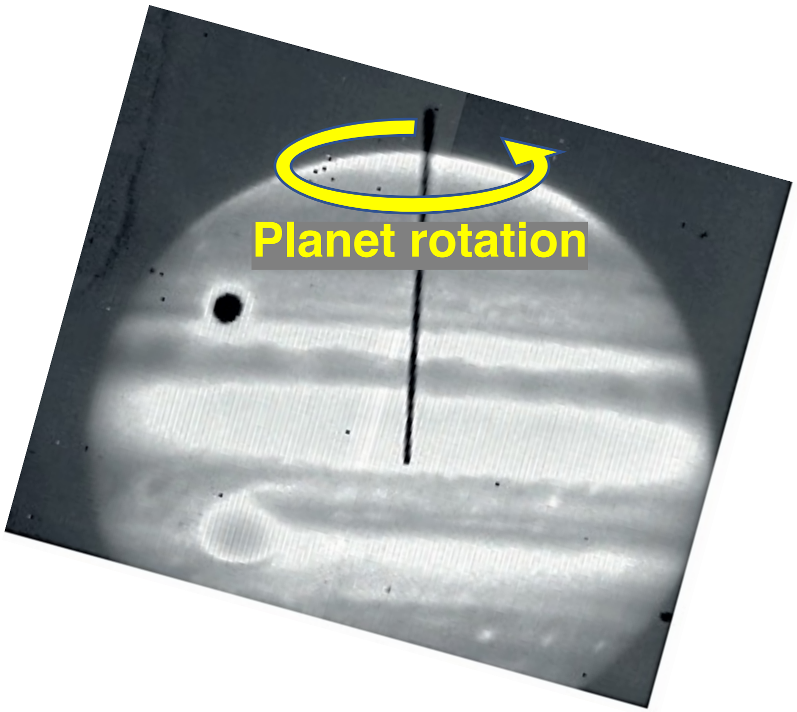
Jupiter was impacted by a dense stream of solar wind during the observations, increasing the precipitation of charged particles (originating from volcanic moon Io) inside the Jovan magnetosphere (left) into the polar regions. Auroral emissions and heating are enhanced, causing the atmosphere to thermally expand and spill both equatorward and poleward



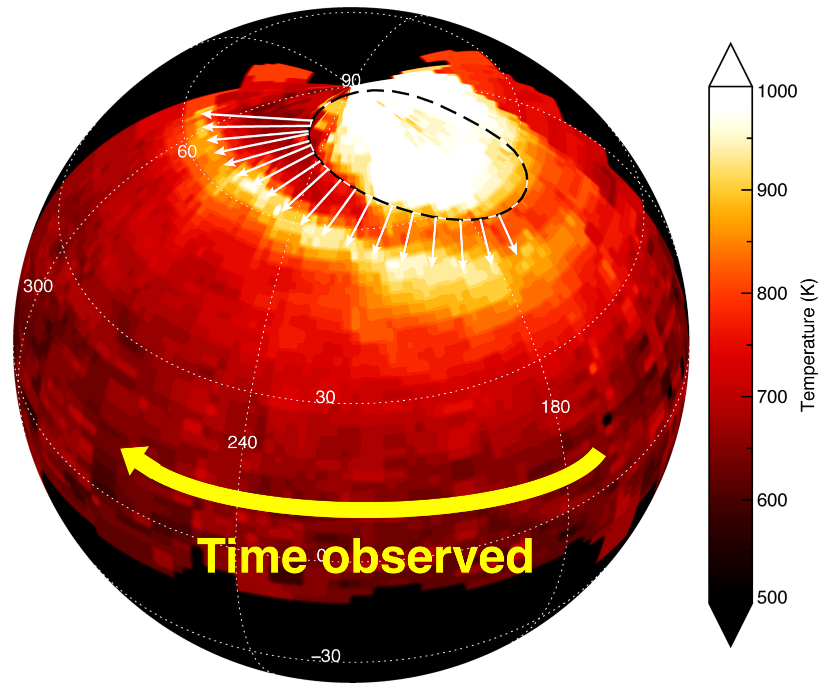
'Tao-MHD' model of solar wind incident at Jupiter. **Tao et al., 2004**



Characteristics of the heat wave



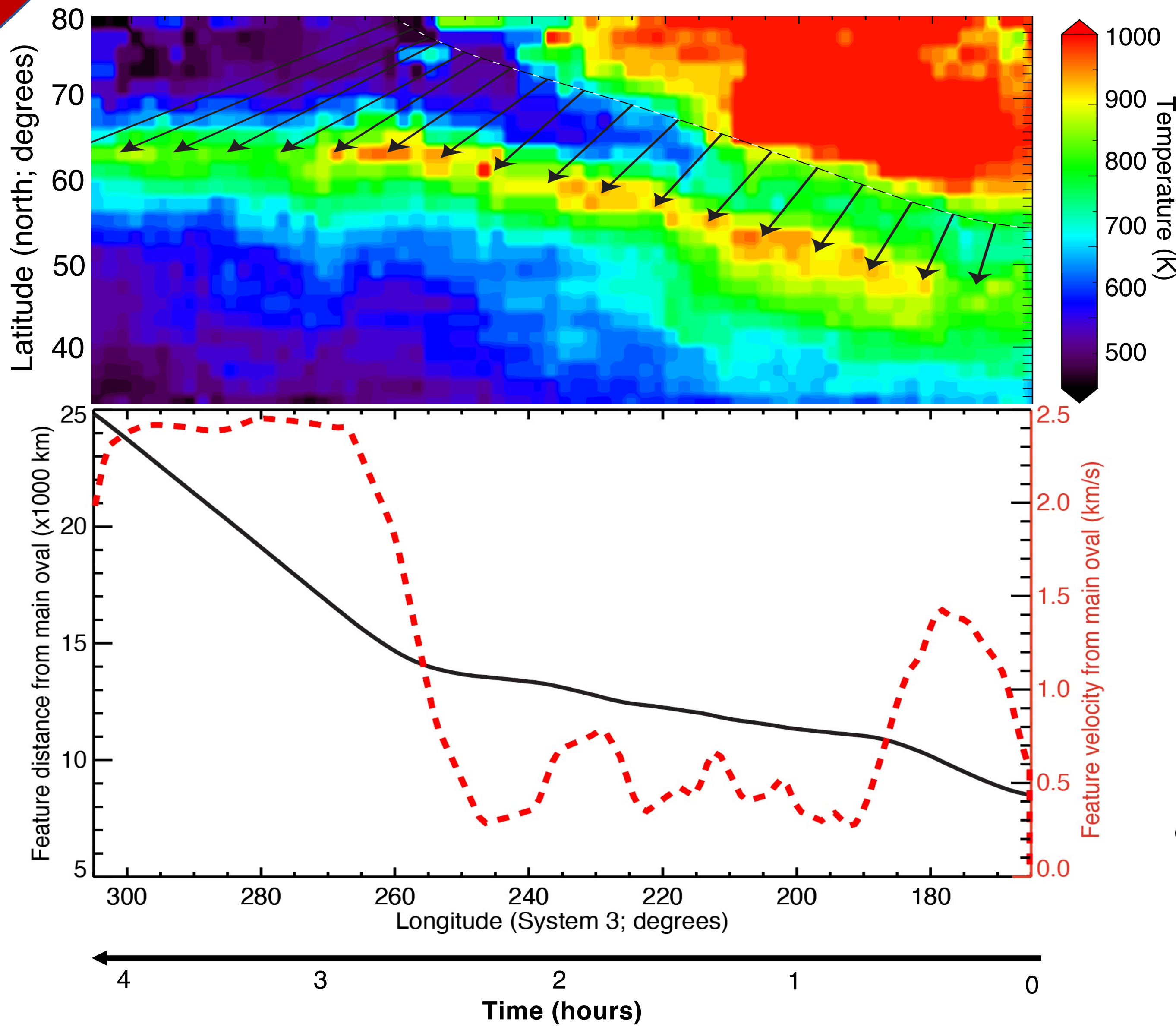
Observations were record by looking at the central meridian (local noon) and allowing the planet to rotate beneath the slit



During the ~6 hour of observations, we observed Jupiter in the order above

Assuming a main auroral oval origin, we can therefore find the velocity of the wave by measuring the distance from the main oval over time

Velocity of the heat wave



Median wave velocities

165 – 305° longitude
= 750 ms^{-1}

190 – 250° longitude
= 400 ms^{-1}

Velocities calculated from total displacement ±1 degrees of each longitude

Conclusions

The non-auroral upper atmospheres of giant planets are hundreds of degrees warmer than expected based on solar heating alone, motivating a search for missing heat sources

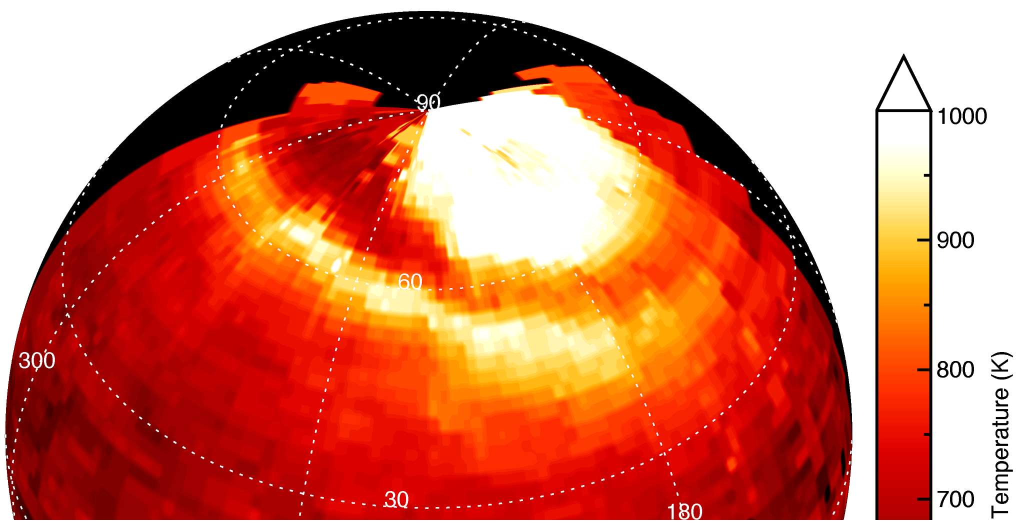
In 2021 we showed that Jupiter's auroras are the main heat source in the upper atmosphere

In the present work, we performed a new and detailed analysis of a giant planetary-scale 'heat wave', which we argue must emanate from the aurora

We found that it moves 400 – 2400 ms^{-1} with a median velocity of 750 ms^{-1}. This compares well with velocities found in Earth's ionosphere (300–1,000 ms^{-1}) but much higher than equatorward velocities reported at Saturn (up to 100 ms^{-1}) and modelled for Jupiter (~180 ms^{-1})

While the auroras continuously deliver heat to the rest of the planet, these heat wave 'events' represent an additional, significant energy source

These findings add to our knowledge of Jupiter's upper-atmospheric weather and climate, greatly helping to solve the 'energy crisis' plaguing the giant planets



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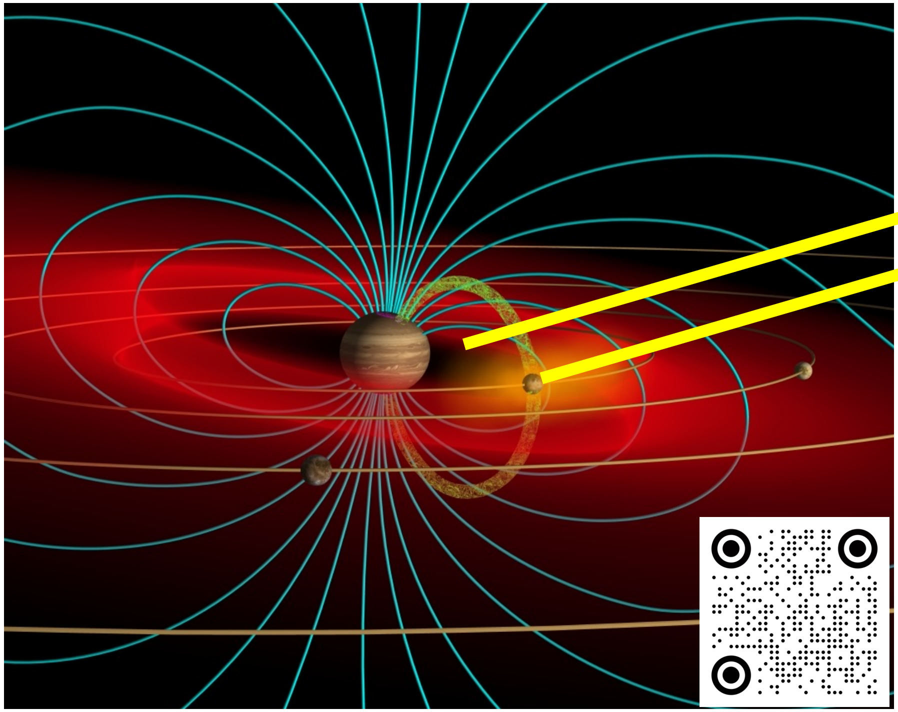
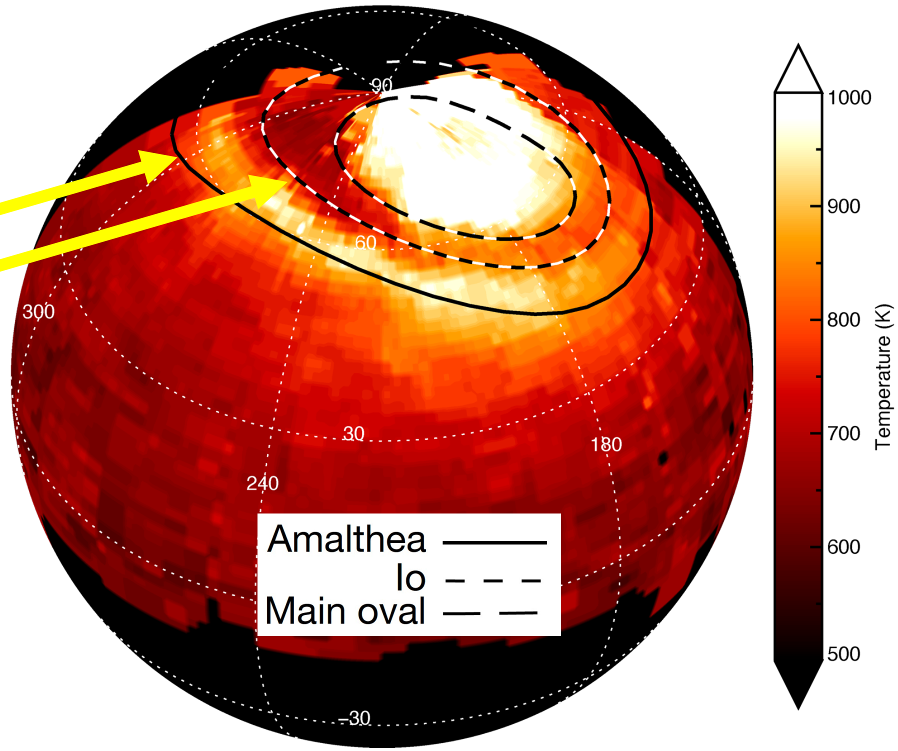
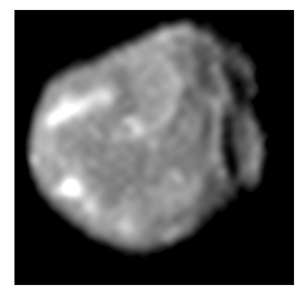
Extra – Could there be a new source inside the *inner* magnetosphere?



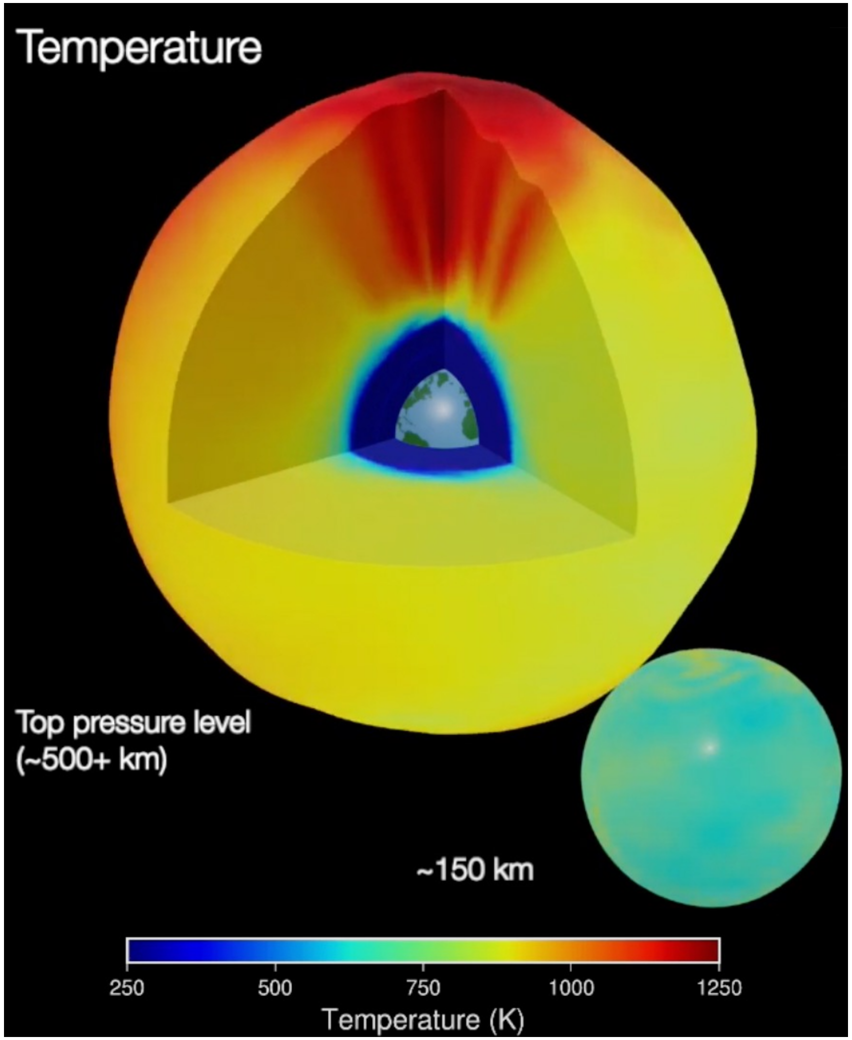


Magnetic mapping shows the heat wave largely intersects with the footprint of Amalthea, however, no electromagnetic connection between expected, since the moon is tiny and dormant

Therefore, the most likely cause of the heat wave is the solar wind, which through a compression and rarefaction of Jupiter's magnetosphere causes additional plasma to be liberated into the polar regions

(
Amalthea. Radius ~84 km)

Extra – Comparative planetology
Heat waves seen on Earth



Earth's non-auroral upper atmosphere is also heated by the auroras, takes on a wave-like appearance (seen on the left)

Temperature, electron density and zonal wind speed from the WACCM-X model on two pressure level slices (150 and 500+ km) and three vertical slices. Height above the Earth's surface is exaggerated 50 times. By Federico Gasperini (NCAR/HAO), AMIE assimilation of ionospheric electrodynamics by Gang Lu (NCAR/HAO), AE index data from WDC for Geomagnetism Kyoto, animation by Eelco Doornbos (KNMI).

Please see simulation video here, it's really cool: