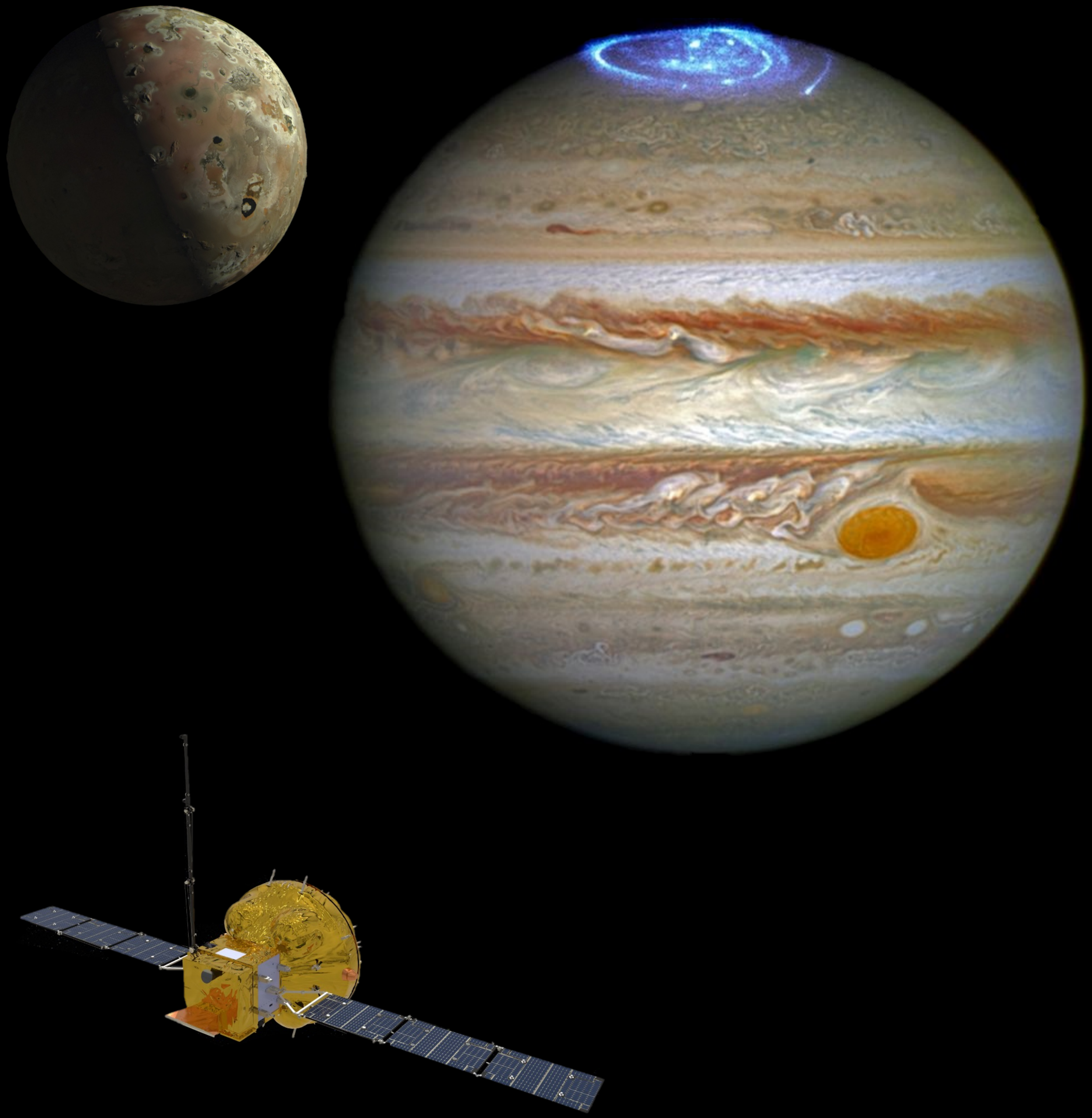

Can we Observe Jupiter’s Magnetosheath with a SMILE-Like Mission?

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CXU – Volos – 21st June 2024

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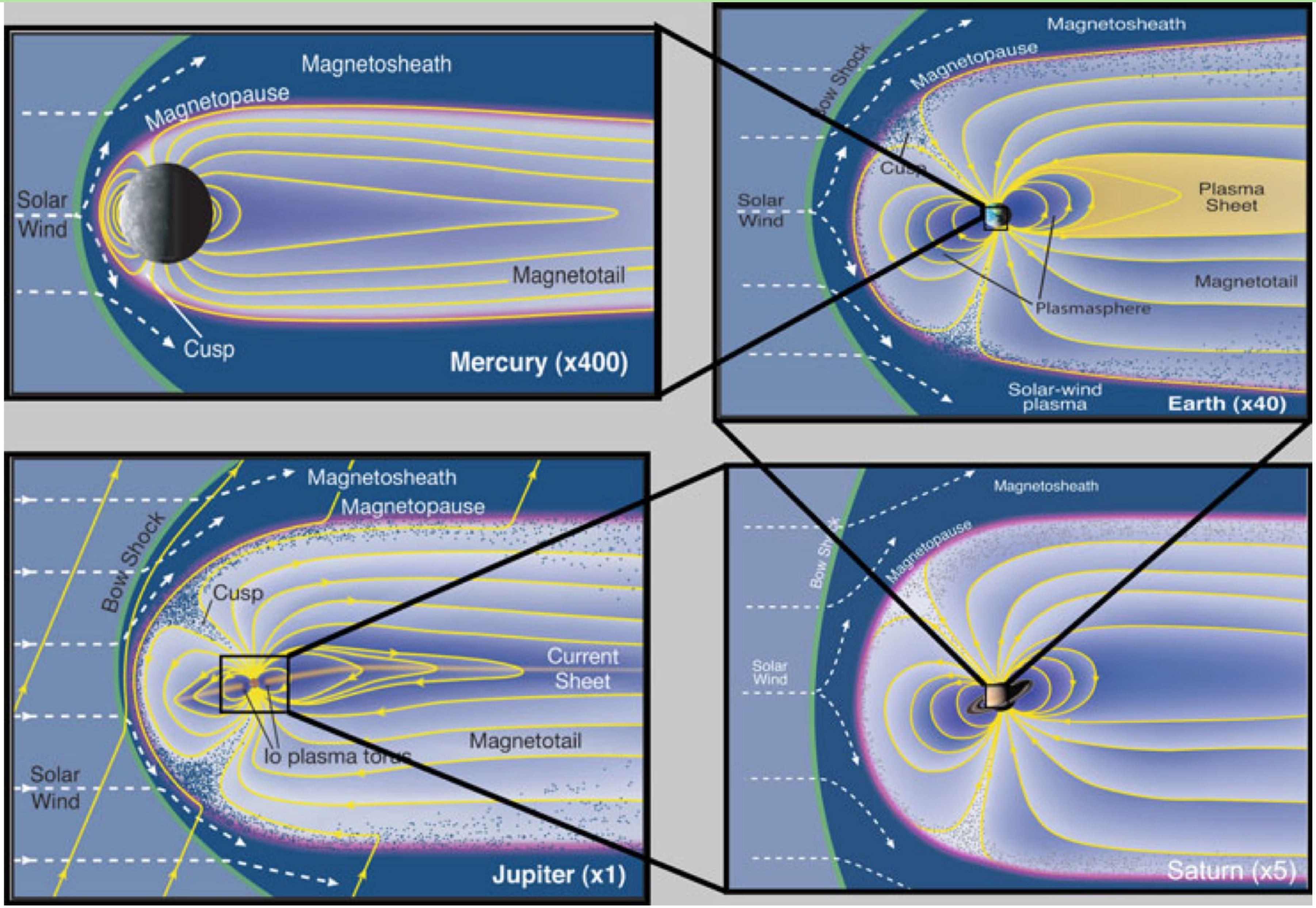
Jupiter and its Magnetosphere



Comparison of Planetary
Magnetospheres.
Credit: Fran Bagenal

Jupiter and its Magnetosphere

- Jupiter’s magnetosphere acts as a natural laboratory for high energy plasmas.
- The magnetosphere is the ”region of influence” – a cavity in the solar wind formed by the magnetic field.
- The magnetopause is the outer boundary, defined by the balance of internal and external pressure.
- Bow shock is a shock front formed by the super-sonic solar wind deflecting and decelerating around the magnetopause

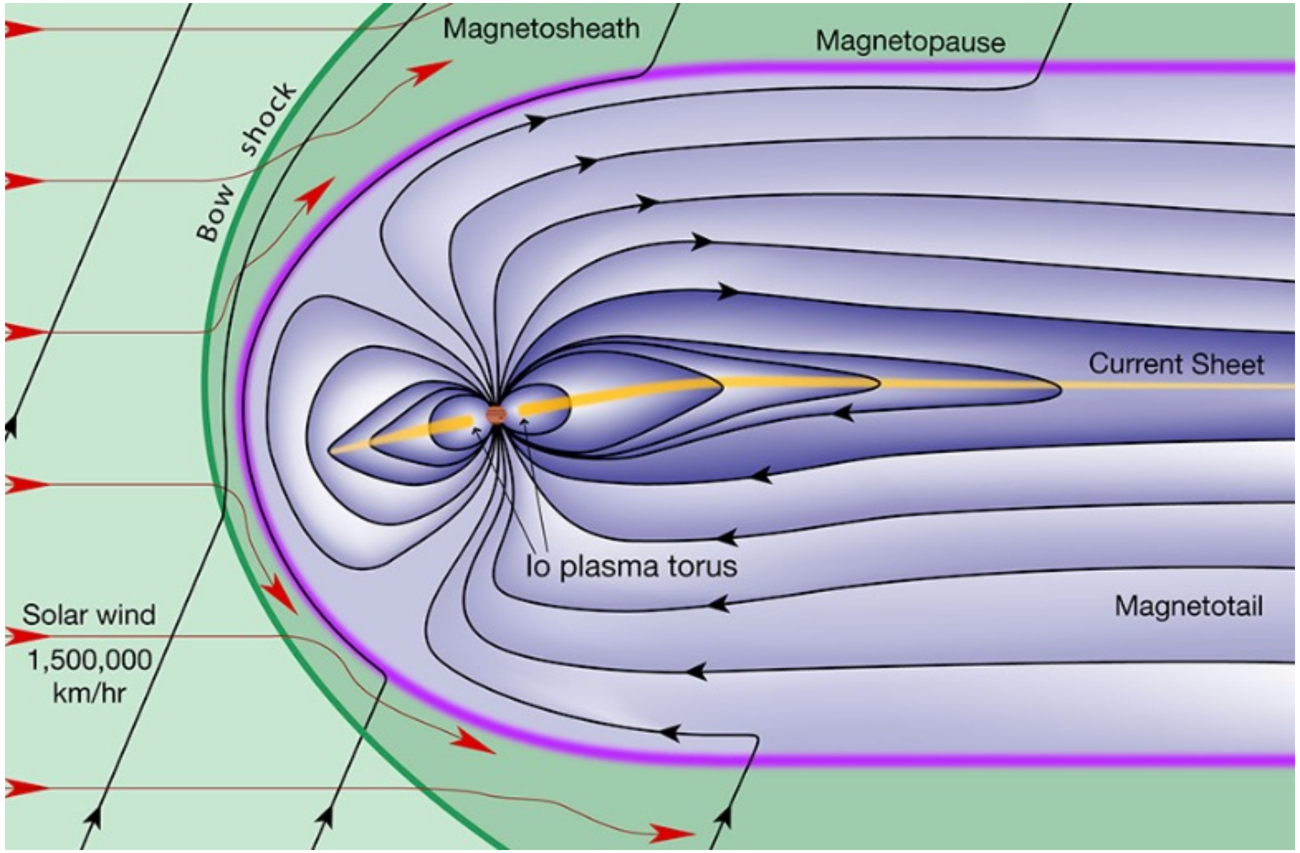
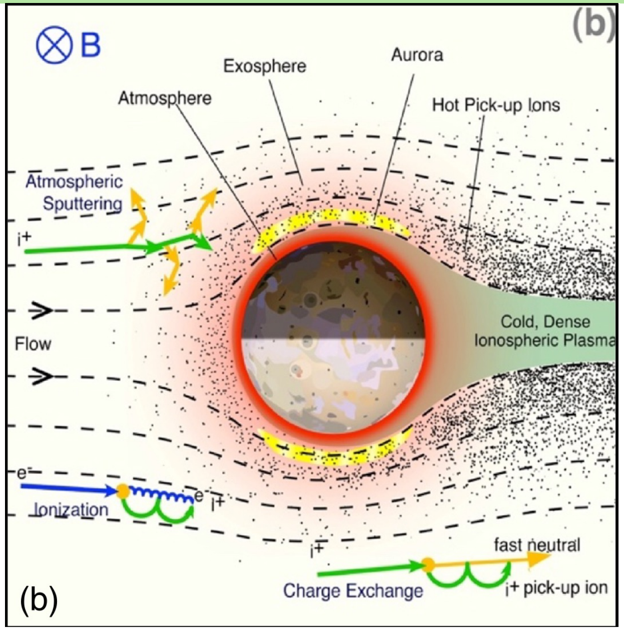


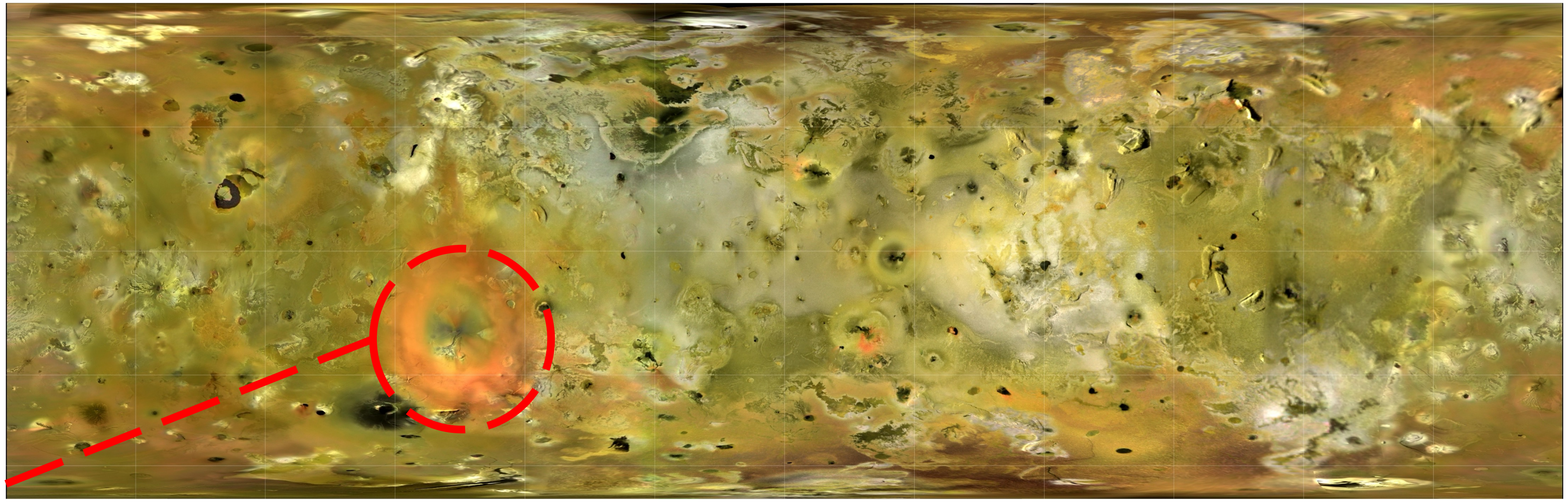
Illustration of Jupiter’s magnetosphere. Credit: Fran Bagenal and Steve Bartlett

Io’s Role in the Jovian Magnetosphere

- Most geologically known object in the solar system due to strong tidal heating as it is pulled between Jupiter and the other Galilean moons
- Several volcanoes produce plumes of Sulphur and Sulphur Dioxide that climb as high as 500 km above the surface.
- Volcanic activity produces an extensive atmosphere and corona around Jupiter. Through collisions and photoionisation, these neutrals and ionised and form the Io Plasma Torus
- Io loses 1000 kg/s to the magnetosphere



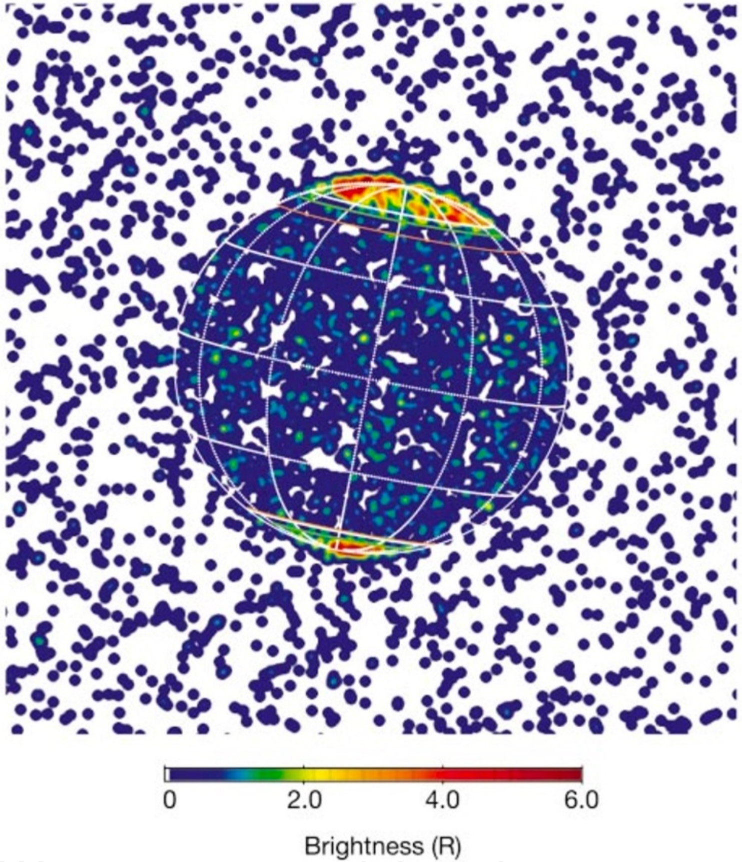
Schematic of interaction between the surrounding plasma and Io. Credit: Schneider & Bagenal, 2007

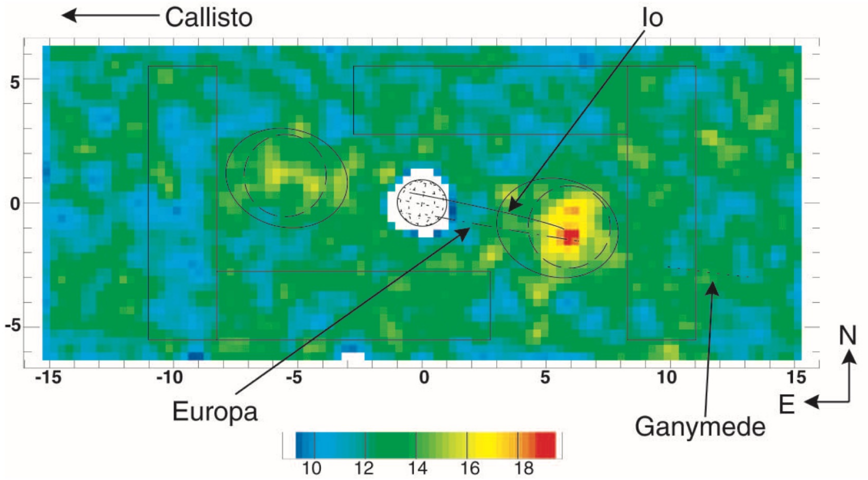


Pele Volcano

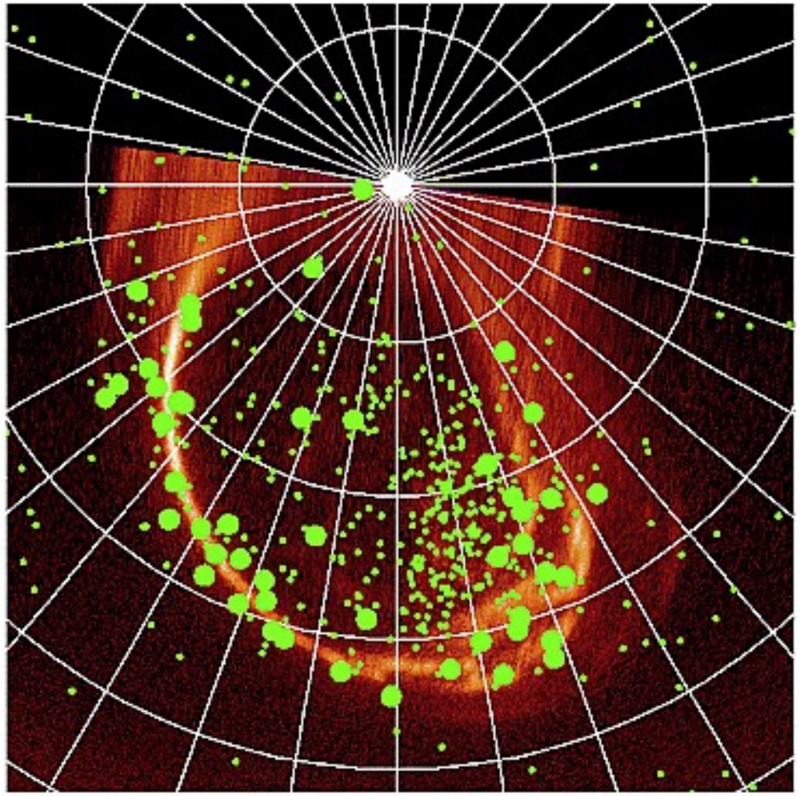
Surface map of IO from Galileo and Voyager missions. Credit: NASA

Production of X-rays at Jupiter





Soft X-ray emissions from the Io plasma torus. Credit: Elsner et al., 2002



Auroral X-ray emissions at Jupiter. Credit: Branduardi-Raymont et al. 2008

We are yet to model or observe x-ray emissions from Jupiter's magnetosheath.

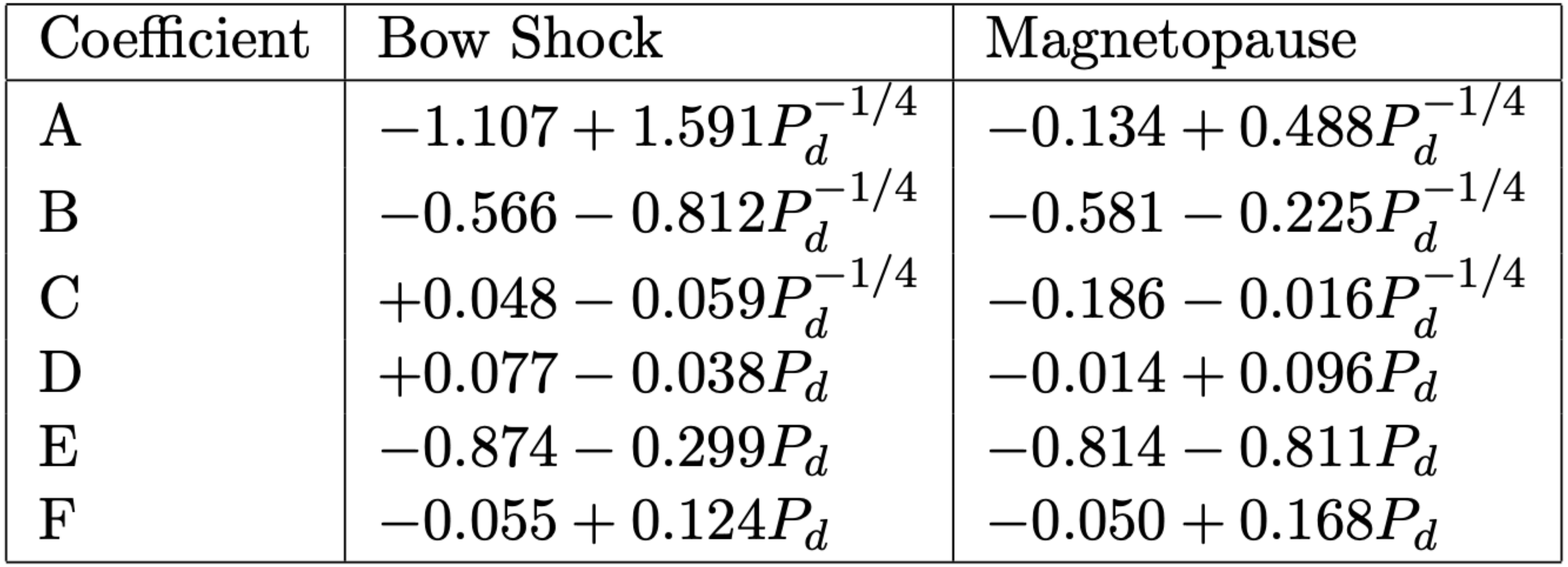
Thus, we should model SWCX emissions to see if a mission similar to SMILE could be achieved at Jupiter. Especially when many structures which will not be able to be observed by SMILE due to their small scale are significantly more prominent at Jupiter

Auroral x-rays are produced by Io torus ions (sulphur and oxygen) precipitating into the atmosphere at high energies. Likely accelerated by a megavolt potentials found in the polar region.

Development of The Magnetosheath Model

- Using a probabilistic model derived by Joy et al, [2002] from a combination of the Ogino-Walker MHD model and spacecraft observations we can construct the Magnetosheath onto a 3D grid.
- Bow shock and Magnetopause are independently defined by polynomial surfaces parameterised by the solar wind dynamic pressure.

$$z^2 = A + Bx + Cx^2 + Dy + Ey^2 + Fxy$$



Coefficient	Bow Shock	Magnetopause
A	$-1.107 + 1.591P_d^{-1/4}$	$-0.134 + 0.488P_d^{-1/4}$
B	$-0.566 - 0.812P_d^{-1/4}$	$-0.581 - 0.225P_d^{-1/4}$
C	$+0.048 - 0.059P_d^{-1/4}$	$-0.186 - 0.016P_d^{-1/4}$
D	$+0.077 - 0.038P_d$	$-0.014 + 0.096P_d$
E	$-0.874 - 0.299P_d$	$-0.814 - 0.811P_d$
F	$-0.055 + 0.124P_d$	$-0.050 + 0.168P_d$

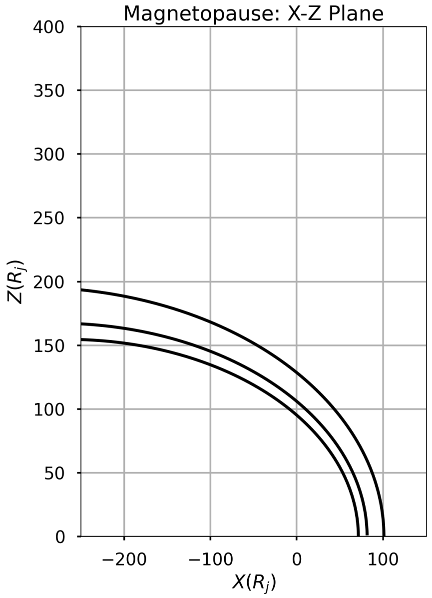
Development of The Magnetosheath Model

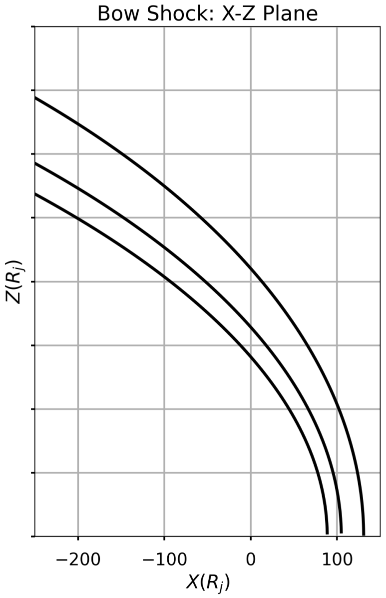
Computed for two solar wind dynamic pressure scenarios:

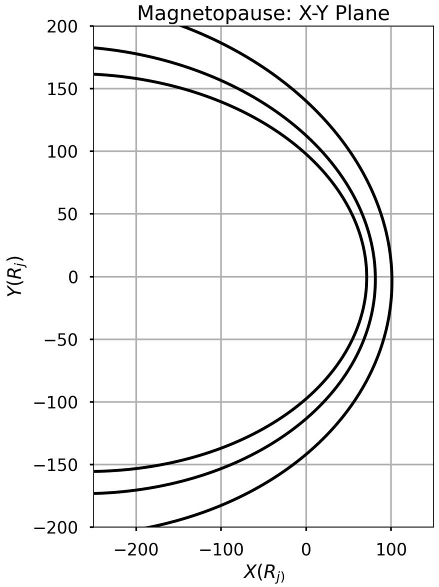
- High dynamic pressure: 0.167 nPa
- Low dynamic pressure: 0.021 nPa

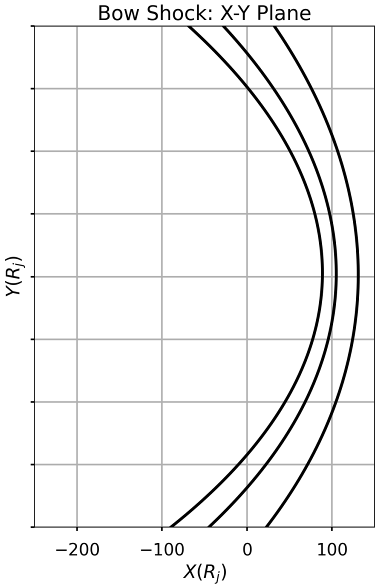
Correspond to the 10th and 90th Percentiles from Ulysses solar wind measurements at 5.2 AU

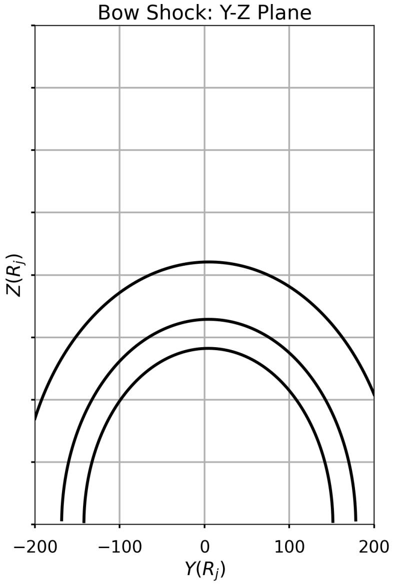
Shows the dawn-dusk asymmetry in the Jovian magnetosphere.











Development of The Magnetosheath Model

Intensity of SWCX emissions is calculated using:

$$I_j = \int P_{sqj} dl = \sum_n \int n_n n_q v_{rel} \sigma_{sqn} b_{sqj} \, d\Omega dl/4\pi$$

n_q is assumed to be constant (in 3D model) with a value of $7.01\times10^{-5}\ \mathrm{m}^{-2}$ by scaling the magnetosheath proton count of $0.98\ cm^{-2}$ from Juno by abundances and charge state ratios measured by ACE.

v_{rel} is calculated using

$$v_{rel} = \left(\mathrm{v}_\mathrm{r}^2 + \mathrm{v}_\mathrm{T}^2\right)^{1/2}$$

where the bulk rotational flow is $v_r = 348\ km\ s^{-1}$ and thermal velocity $v_T = 239\ kms^{-1}$ ($T = 198\ eV$). Therefore, $v_{rel} = 422\ kms^{-1}$.

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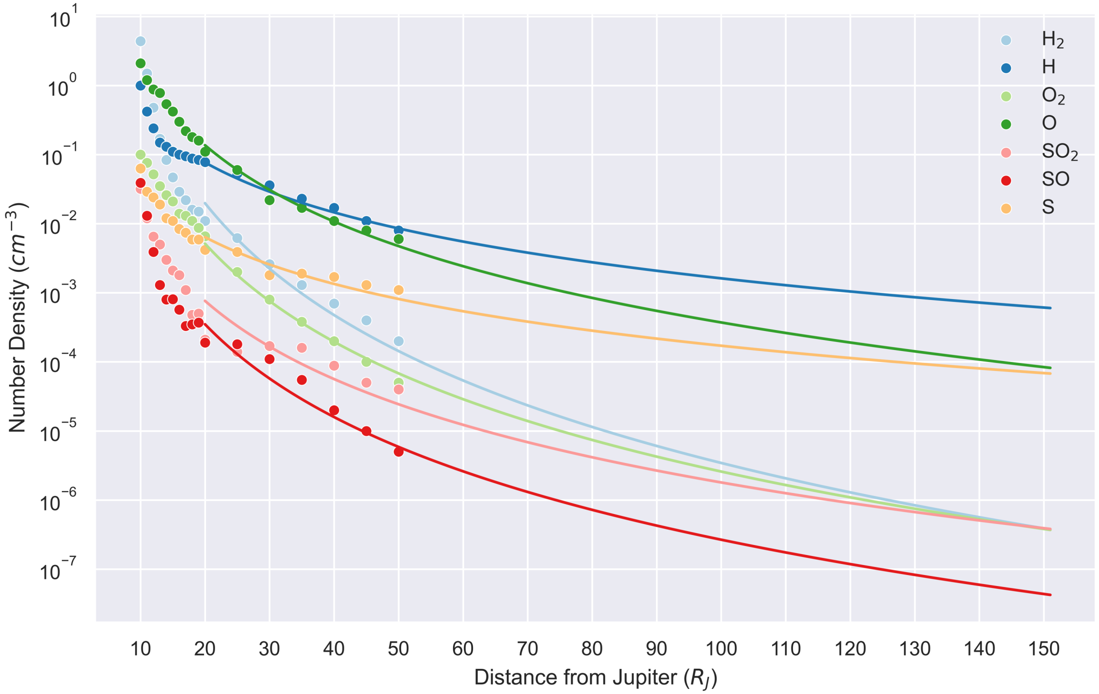
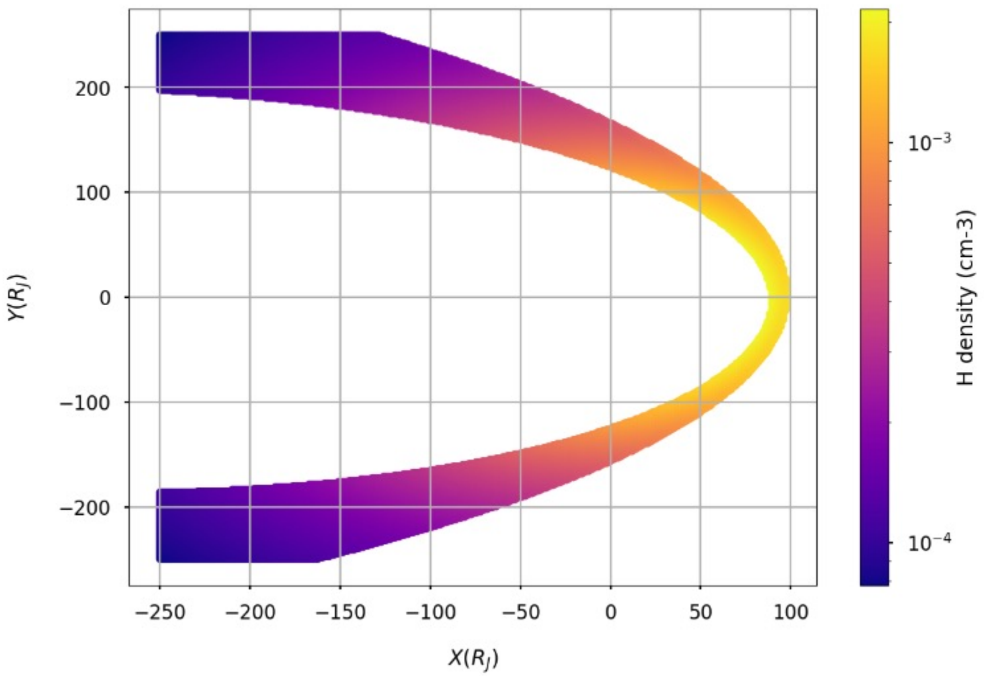
Development of The Magnetosheath Model

n_n is fitted using a density profile derived from a validated 3D Monte Carlo self-consistent neutral particle computational model developed by Todd Smith, the model accounts for the gravitational effects of Jupiter and major satellites, as well as particle interaction processes including charge exchange.

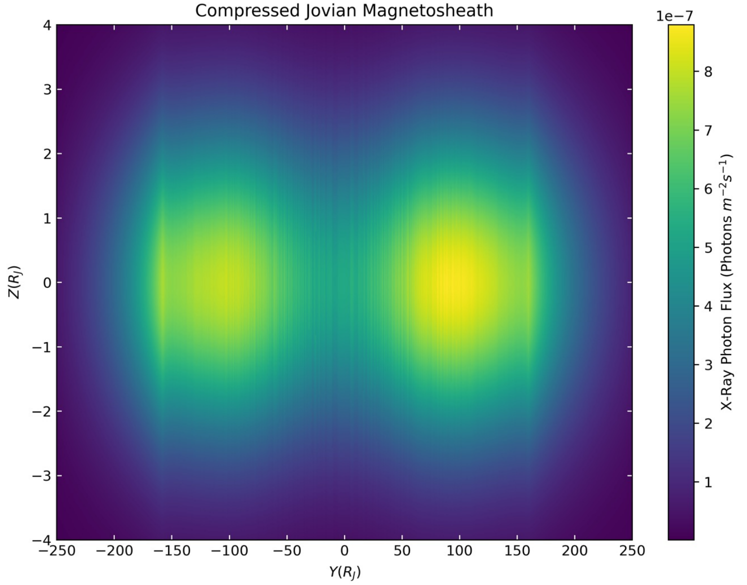
These are extrapolated to 150 R_J and constrained to the equatorial plane through considerations of the plasma disc scale height as most neutrals in the magnetosheath will be generated by CX with the plasma disc.

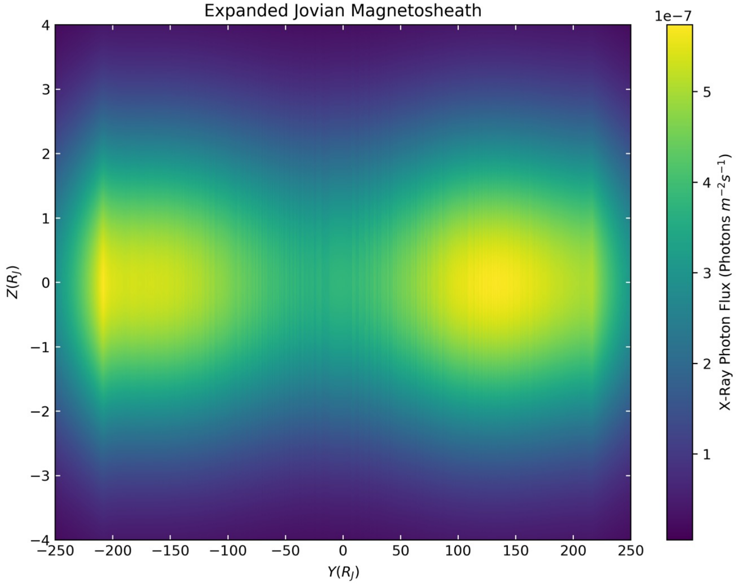
$$n_H(r,z) = 102.1 r^{-2.4} \exp\left(-\left(\frac{z}{2.0}\right)^2\right)$$

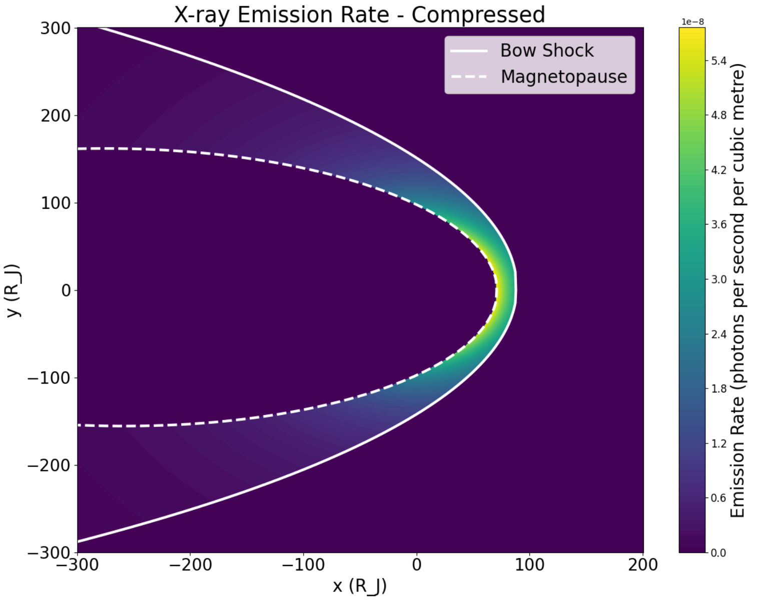


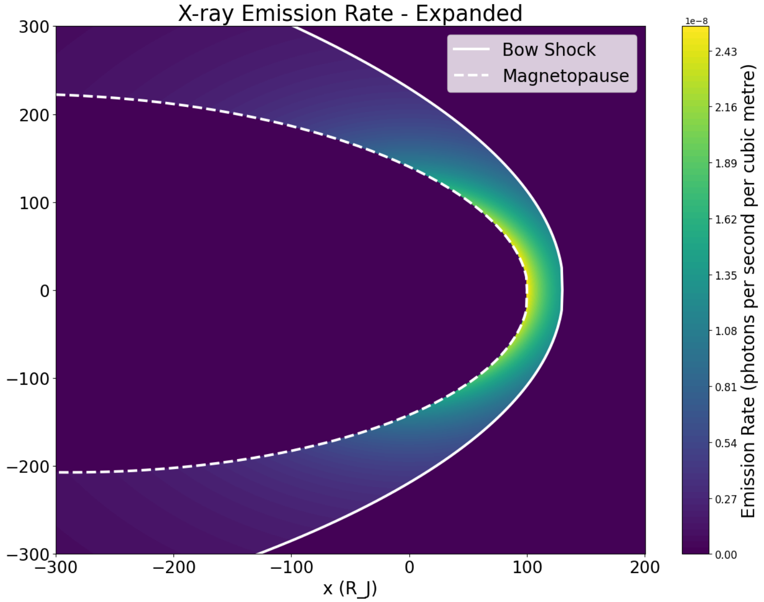


Magnetosheath Study Results









2D Model also varies density, temperature and velocity across the magnetosheath based on the Juno dawn survey

Parameter	Equation
Proton Density (m^{-3})	$\rho = 5r + (0.98 \times 10^6)$
Ion Temperature (eV)	$T = -0.07r + 197$
Bulk Velocity (m/s)	$v_B = -250r + 348000$

The SMILE SXI has a FOV of 16.5° x 26.5°, the minimum distance for the emission region to be visible is ~744 R_J upstream.

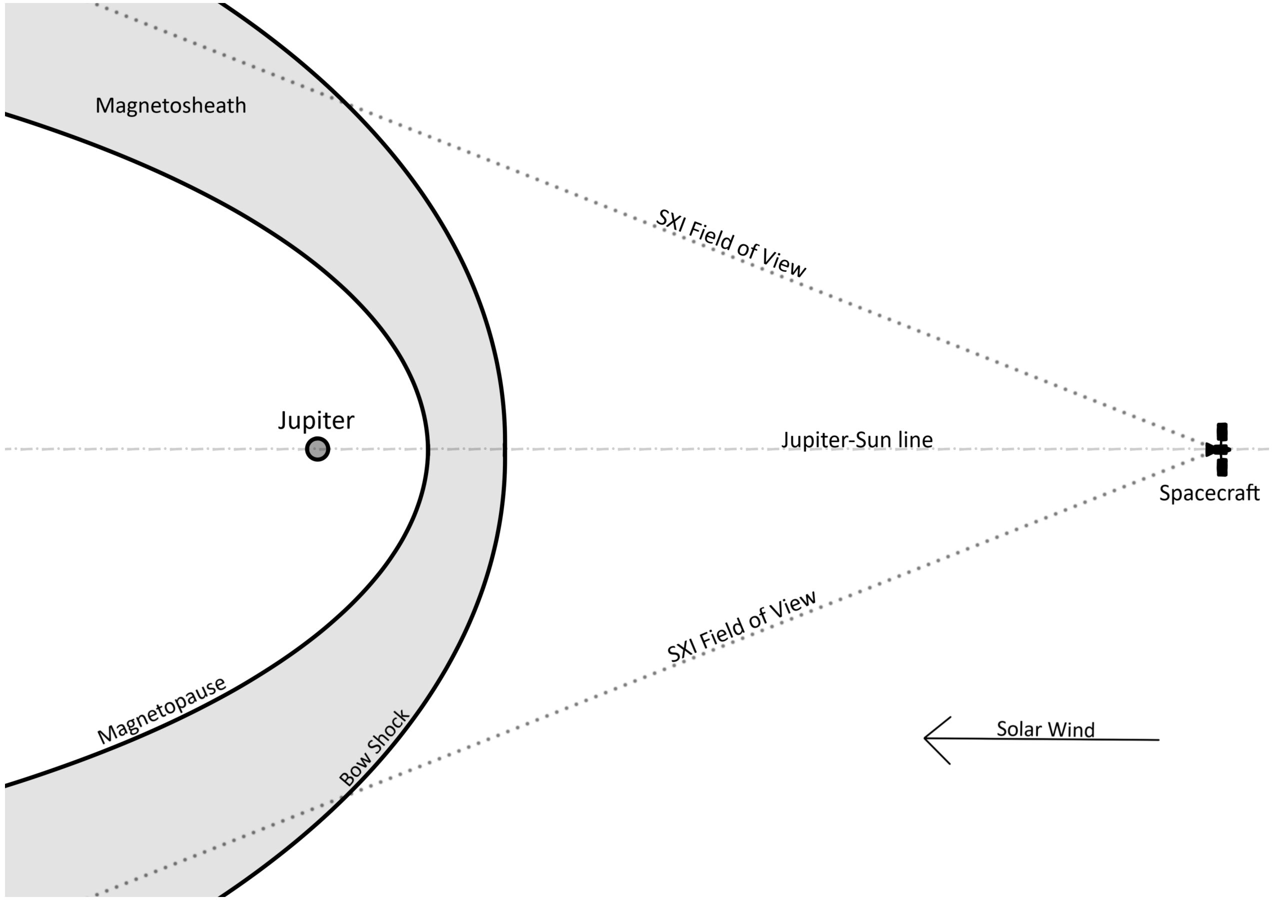
Peak emissions from a plane tangential to the nose of the bow shock are ~ $8 \times 10^{-7}\ m^{-2}s^{-1}$

This gives an observation time of:

Observation Time	Seconds	Jovian Rotations*
Expanded	1.1×10^8	3000
Compressed	5.6×10^7	1500

* 1 Jovian Rotation is about 10 hours

Magnetosheath Study Results

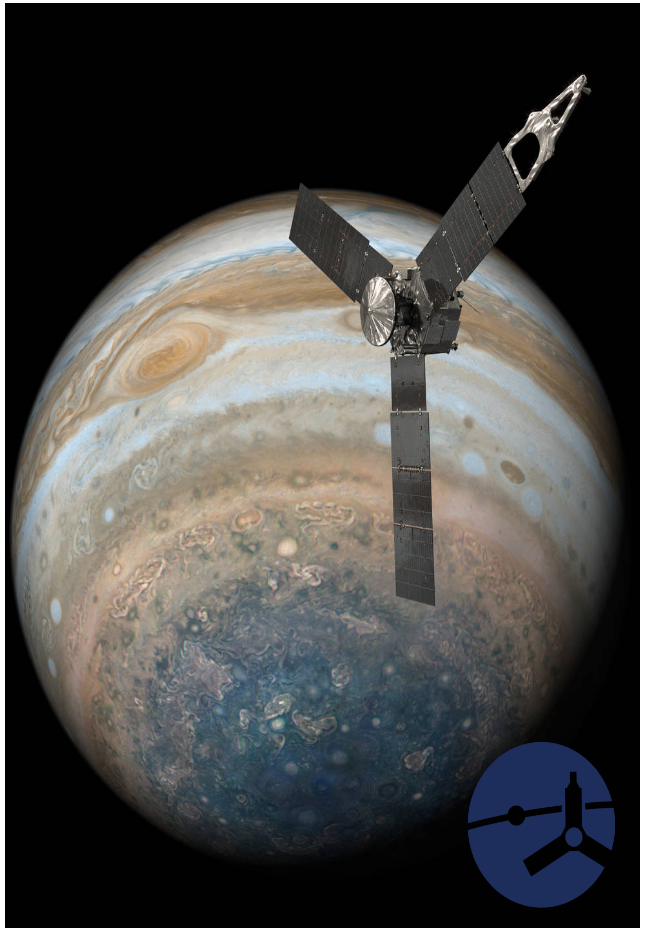


These observation times are too long and not practical, thus Jupiter's magnetosheath should not be the target of a dedicated soft x-ray mission.

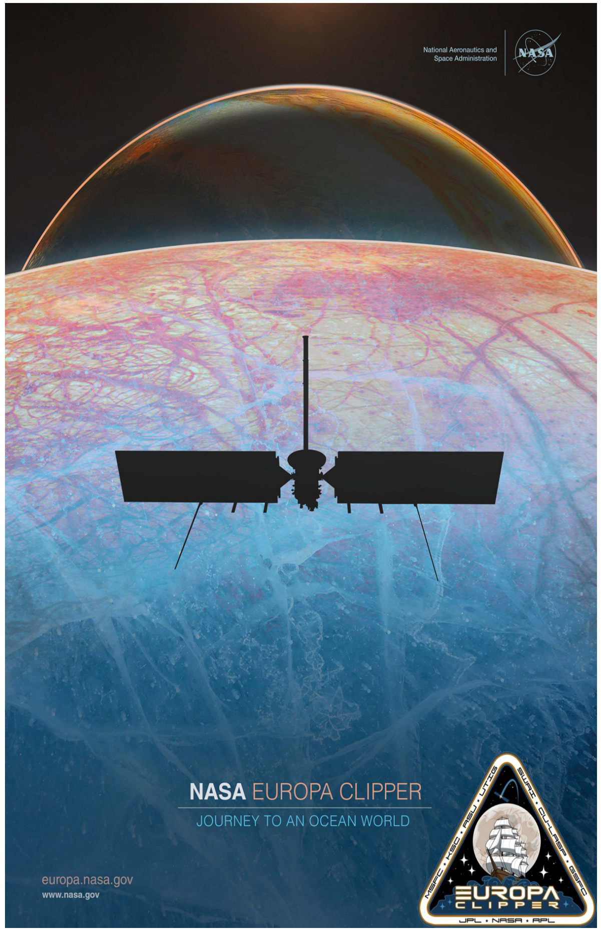
- Emission rates extremely low (~10^{-7} $m^{-2}s^{-1}$) mostly due to the lack of neutrals in the magnetosheath
- Spacecraft would move significantly during this time
- For a semi-stable viewing point, e.g. L1, the distance is 1625 R_J upstream.
- Any structures inside the magnetosheath would not be visible on timescales this long

The Future is Bright… in X-rays!

2030s will be an exciting decade for Jovian science



NASA Juno - 2016-2025



NASA Europa Clipper- 2030

ESA Juice – 2031

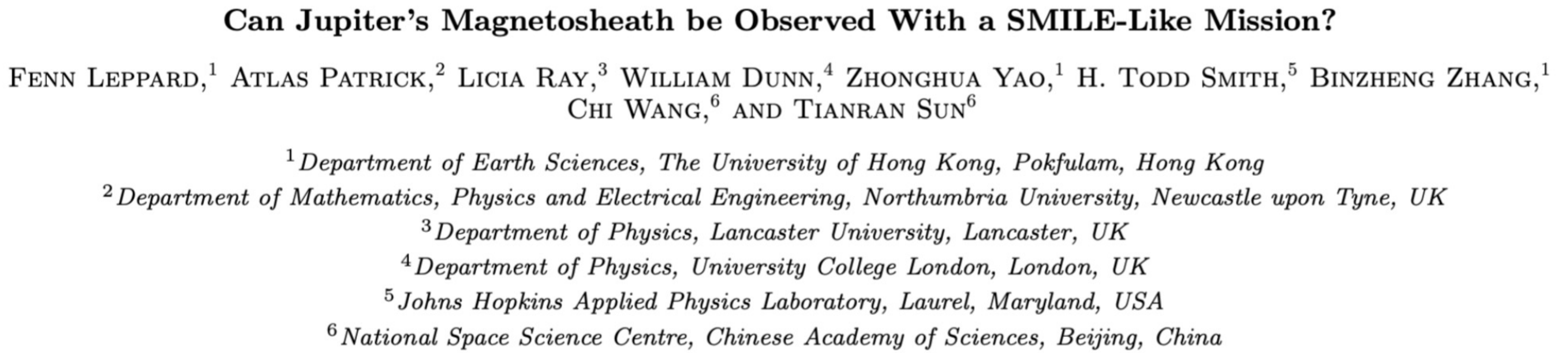
China – Tianwen-4: Soft X-ray instrument to Jupiter!
Late 2030s

More X-ray photons in ~ seconds than in the last 40 years of observations!

Image Credits: NASA and ESA

Summary

- Construct a model of SWCX emissions in Jupiter’s magnetosheath based on a combination of in-situ measurements from Juno, ACE, and Ulysses; and simulations.
- Compute the model for two solar wind scenarios corresponding to a high and low dynamic pressure.
- Determine peak volumetric emission rates of $\sim 5\times10^{-8}\ m^{-3}s^{-1}$ for the OVII triplet.
- Peak photon flux through the bow shock surface of $\sim 8\times10^{-7}\ m^{-2}s^{-1}$
- Estimate observation times for the SMILE SXI instrument observing from a minimum distance to capture the emission region (744 R_J) as 1500-3000 Jovian rotations (~10^8 s).
- Despite limitations of the model, we expect a more comprehensive study to only achieve one order of improvement, not the 4+ needed for a SMILE-like mission to be achievable.



Can Jupiter’s Magnetosheath be Observed With a SMILE-Like Mission?

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