What Can X-Rays Tell Us About Uranus's Unusual System?

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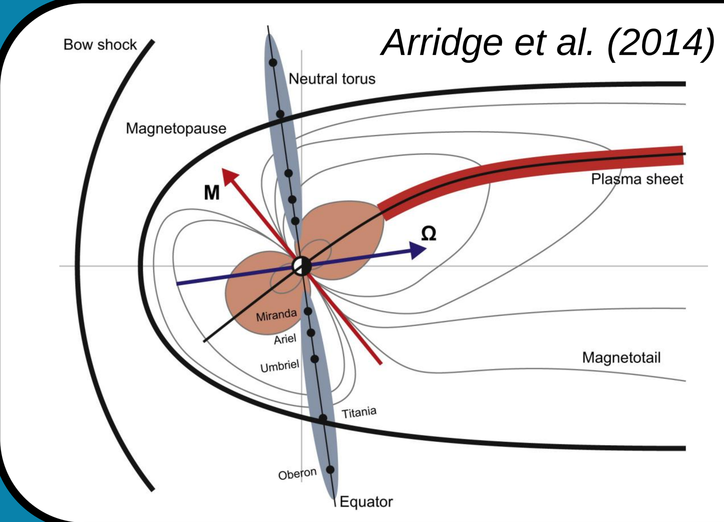
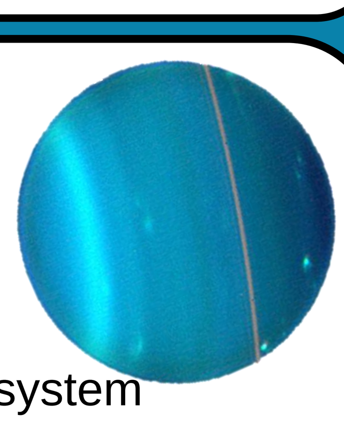


1. Why are we interested in Uranus and its space environment?



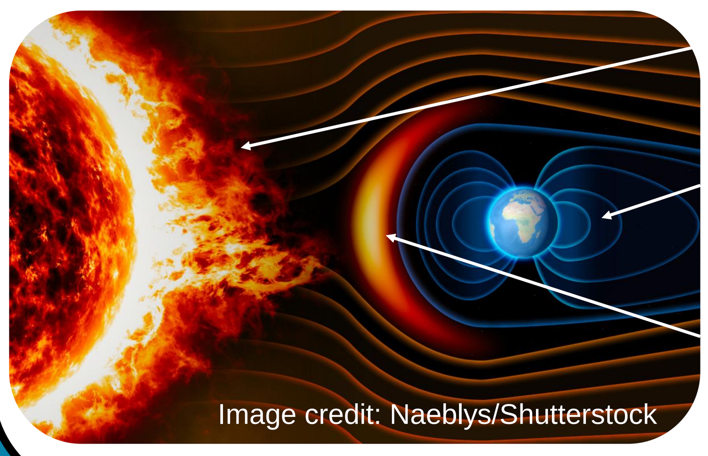
Uranus has an **extremely unusual space environment**

It orbits the Sun almost entirely on its side, its magnetic field is tilted and offset from the centre of the planet

Uranus has only been visited once, by Voyager 2 in 1986. There are lots of open questions about the true nature of the system

Uranus orbiter mission is NASA's next flagship planetary mission priority – can X-ray imaging be a useful tool for exploring the system?

2. How do planets interact with the Sun?



The Sun constantly ejects a stream of magnetised, charged particles known as the **solar wind**

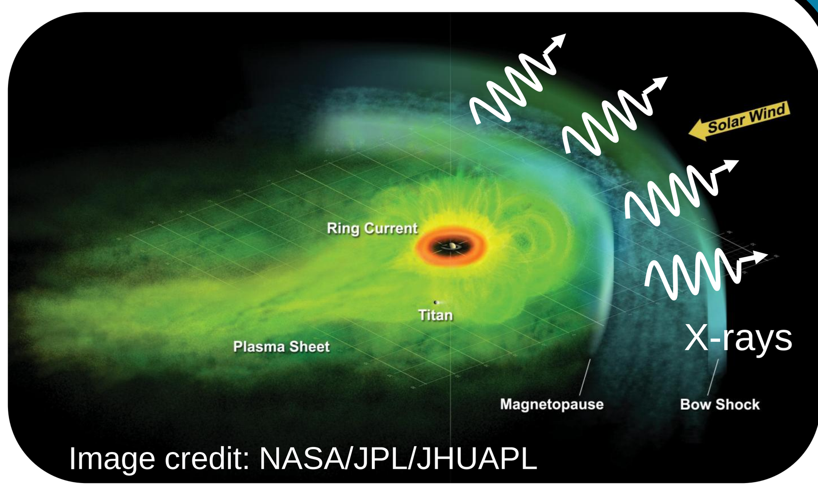
Planetary magnetic fields carve cavities in the solar wind known as a **magnetosphere**

The **magnetosheath** lies just outside the magnetosphere and is filled with slowed, heated solar wind

3. Where are X-rays generated?

Highly charged solar wind ions and neutral particles interact within the magnetosheath – produces soft X-ray emission

Imaging the soft X-rays gives a dynamic view of the sheath region – explore the driving of the magnetosphere by solar wind



SMILE mission aims to image Earth's magnetosheath with a soft X-ray imager (SXI)

4. What dictates X-ray volumetric emission rate, P?

$$P = \Sigma_n n_n n_q v_{\text{rel}} \sigma$$

$$v_{\text{rel}} \sim \left(v_{\text{bulk}}^2 + v_{\text{thermal}}^2\right)^{1/2}$$

n_n = Neutral Density

n_q = Ion Density

σ = Cross Section

v_{rel} = Collision Velocity

Cross sections from Bodewits (2007) (H-like) and Schwadron and Cravens (2000) (O-like)

Solar wind speed, density, dynamic pressure vary continuously – affects magnetosphere size and emission rate

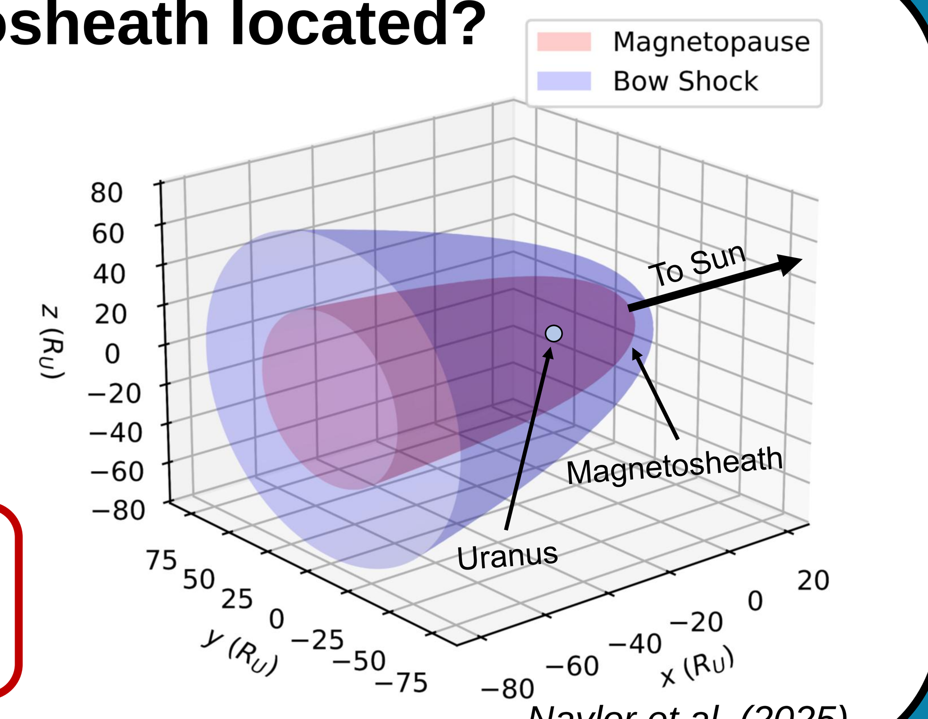
Voyager 2 solar wind data samples tested with composition initially simplified to O^{7+}

5. Where is the magnetosheath located?

Impose Lin et al. (2010) magnetopause – outer boundary of the magnetosphere

Edge of magnetosheath is the bow shock (where solar wind slows and heats) – location estimated using Voyager 2 crossings

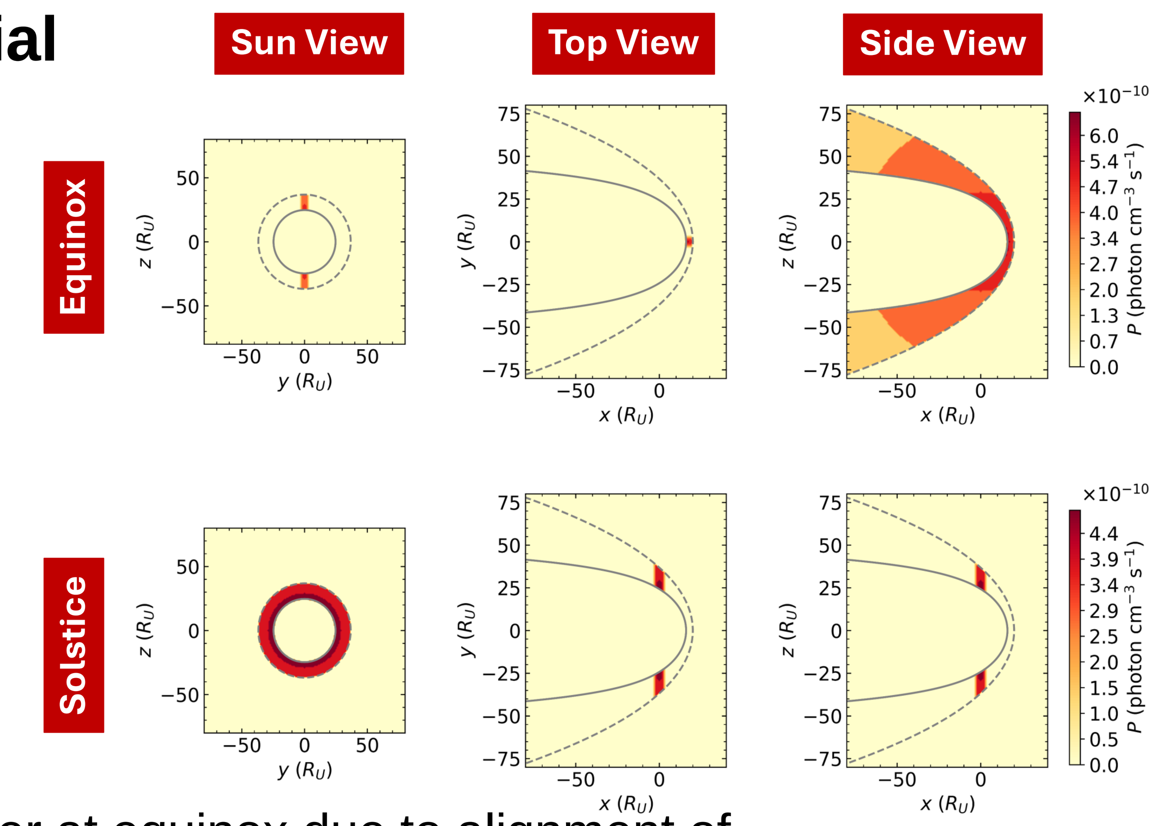
The magnetosheath is the region between the magnetopause and bow shock!



Naylor et al. (2025)

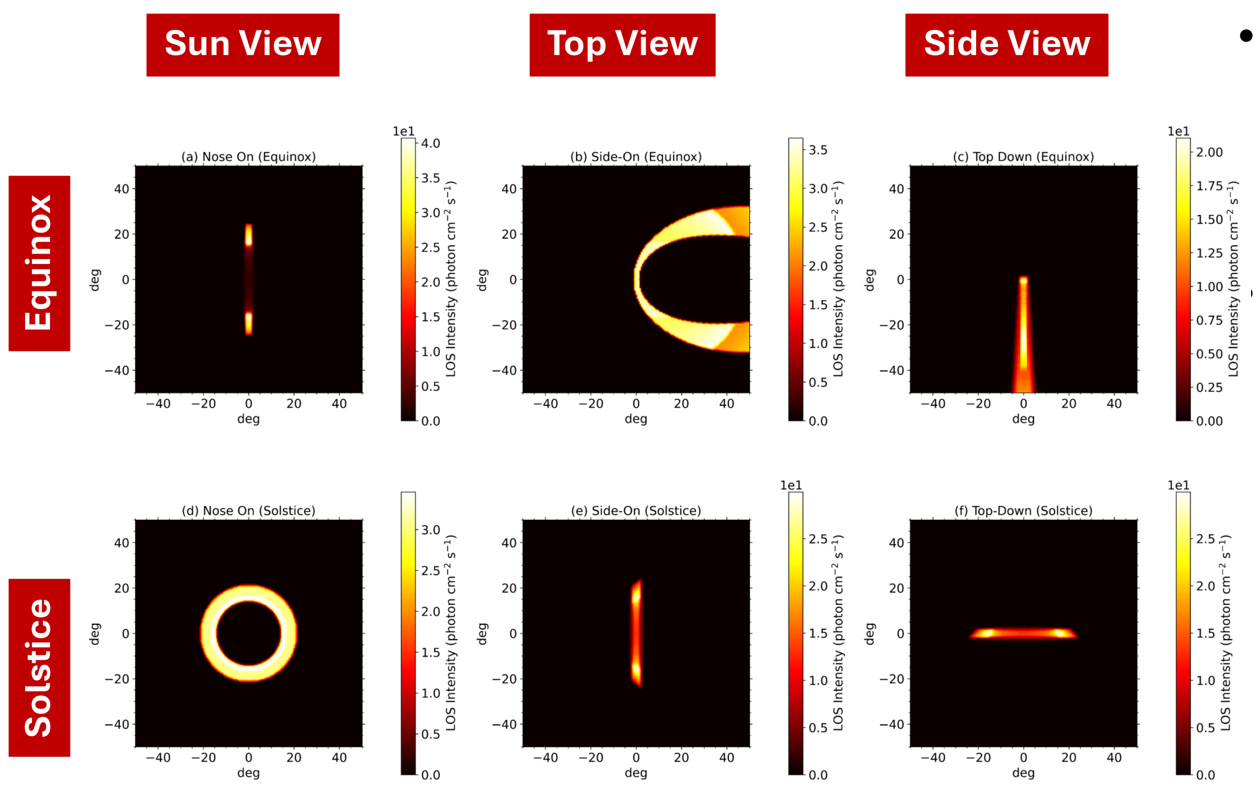
6. What did the initial results suggest?

- Neutral density main driver of emission rates
- Full solar wind chemistry important – emission may be 4x higher with full range of solar wind ions
- Variations with:
  - Season – emission higher at equinox due to alignment of neutral tori with magnetosheath
  - Solar wind conditions – emission lower for fast solar wind due to decreased proton density and O^{7+} abundance



Naylor et al. (2025)

7. Could we detect the emission?

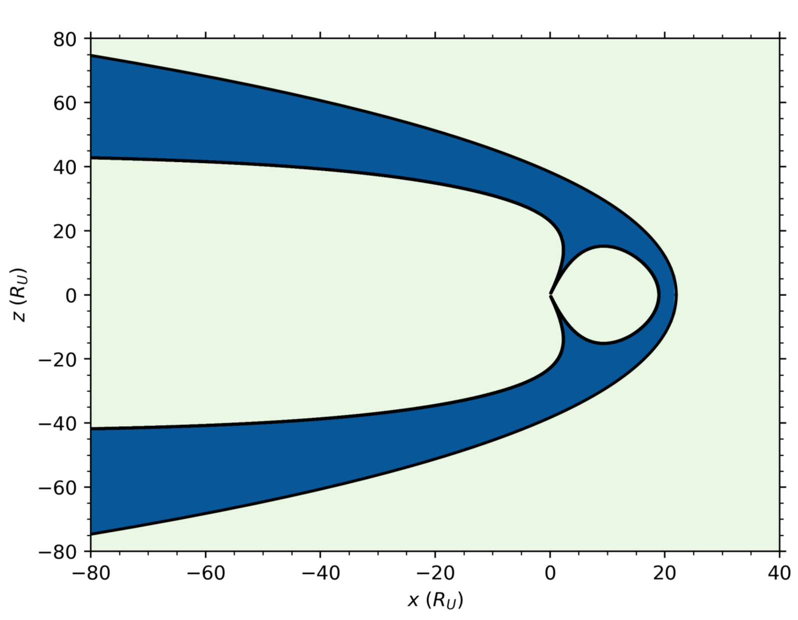


- SMILE-like SXI may detect ~100 photons in ¼ planetary rotation at 260 R_U

Orbital considerations:

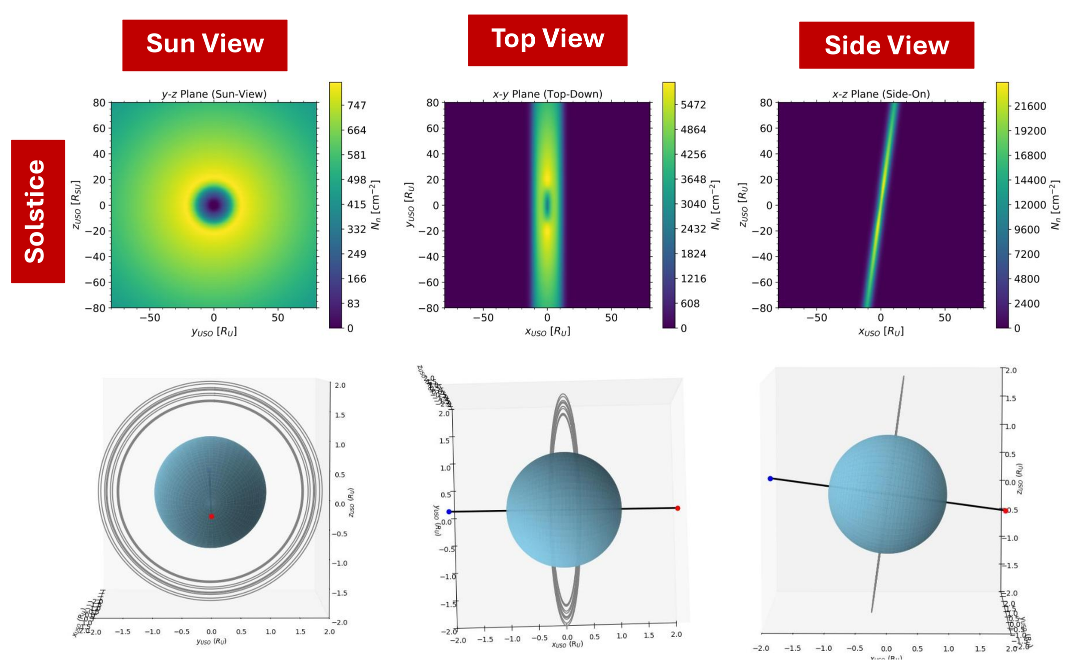
- Order of magnitude difference between different viewing geometries
- Sun view may be contaminated with reflected solar X-rays
- Side-on view at equinox gives full magnetosheath view

8. Creating an advanced model

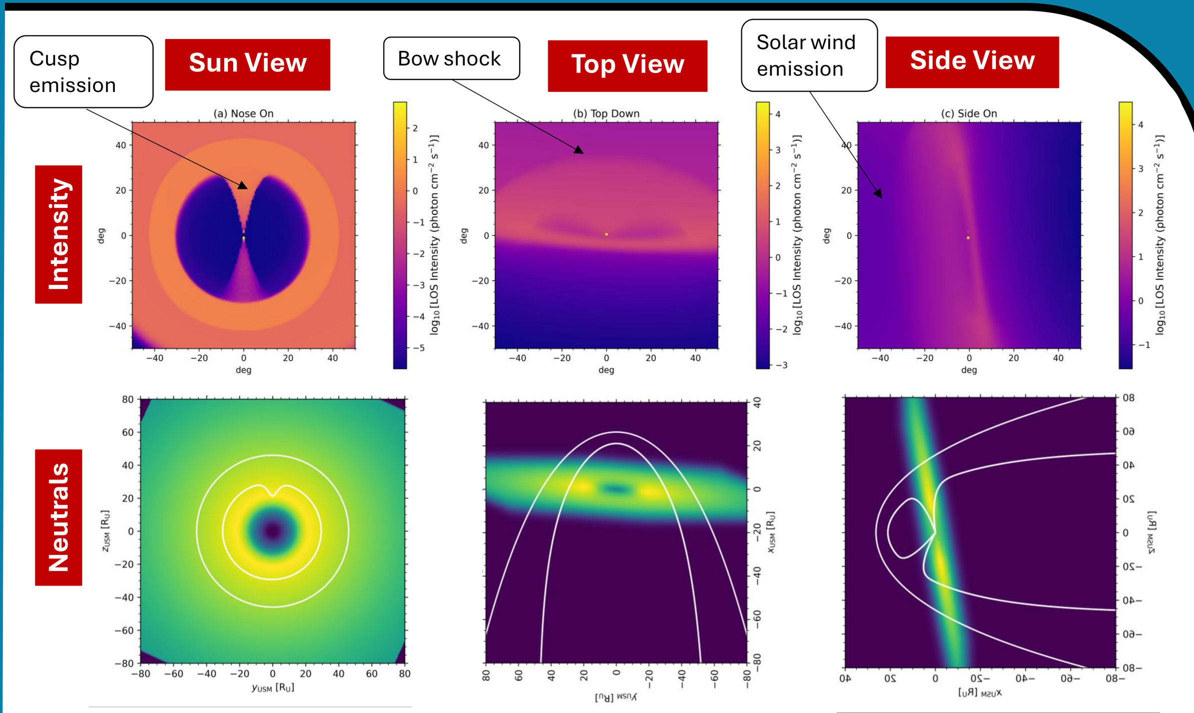


- Cusps are regions of solar wind entry deep into the magnetosphere
- Cusps at Uranus have many different configurations
- Atmospheric neutrals expected to drive higher emission rates near planet

Bright X-ray cusps!



- Smoother neutral particle distributions to more realistically represent a torus
- Consider complete system geometry



- Implement ray tracing to calculate line-of-sight X-ray intensities
- Synthetic detector images – can set instrument position, pointing, FOV

9. Conclusions

- Initial model provided some promising results
- New developments include improved system physics and ability to generate realistic X-ray images
- Initial analysis suggests intensity of X-rays higher than initial model – X-ray imaging may be useful tool to explore the Uranian system

10. Where next?

- Use MHD model-derived data to set realistic cusp positions
- Analyse changes in emission over a Uranian day
- Realistic magnetosheath ion density profiles
- Full range of solar wind ions included in charge exchange calculation