Soft X-Ray Emission from Uranus's Magnetosheath

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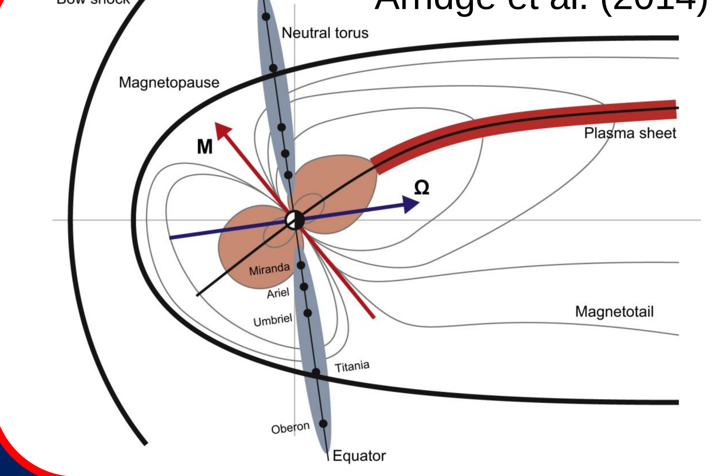
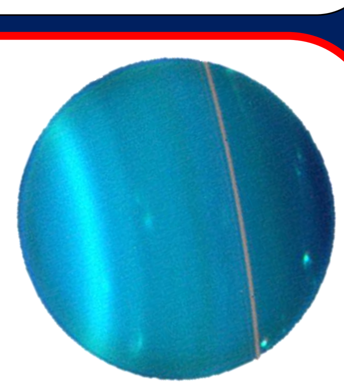
Arridge et al. (2014)



What can X-rays tell us about Uranus's unusual system?



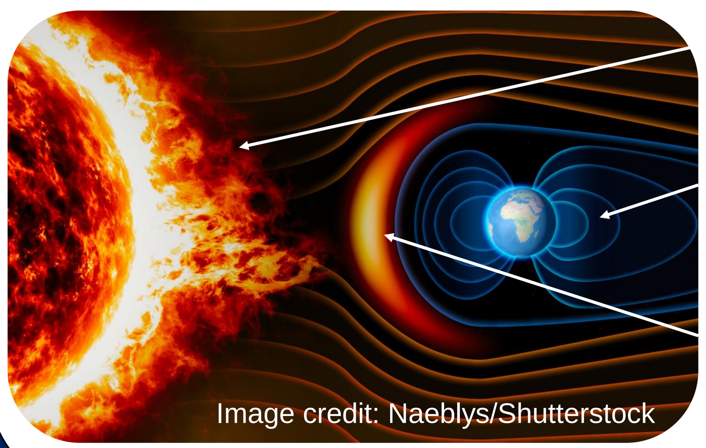
Uranus has an **extremely unusual space environment**

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?

How do planets interact with the Sun?



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

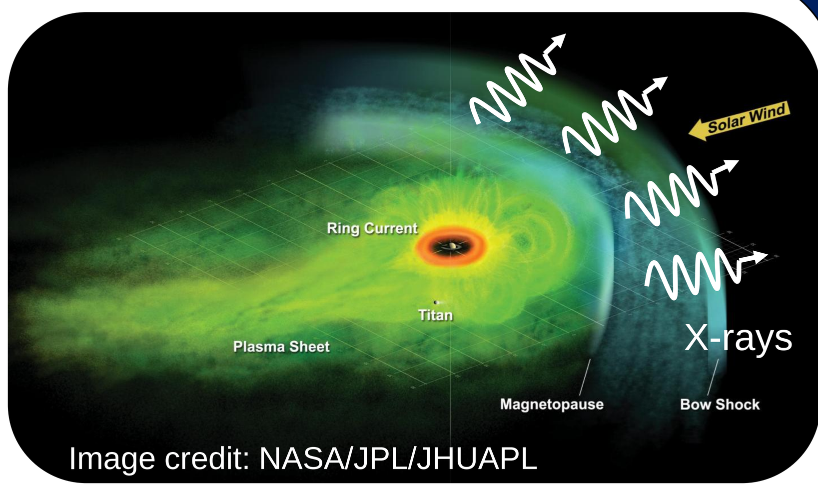
Planetary magnetic fields carve cavities in the solar wind known as a **magnetosphere**

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

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)

What dictates X-ray volumetric emission rate (VER), P?

$$P = \Sigma_n n_n n_q v_{\text{rel}} \sigma_{sqn} b_{sqj}$$

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

σ_{sqn} = Cross Section b_{sqj} = Branching Ratio n_n = Neutral Density
n_q = Ion Density 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 VER and magnetosphere size

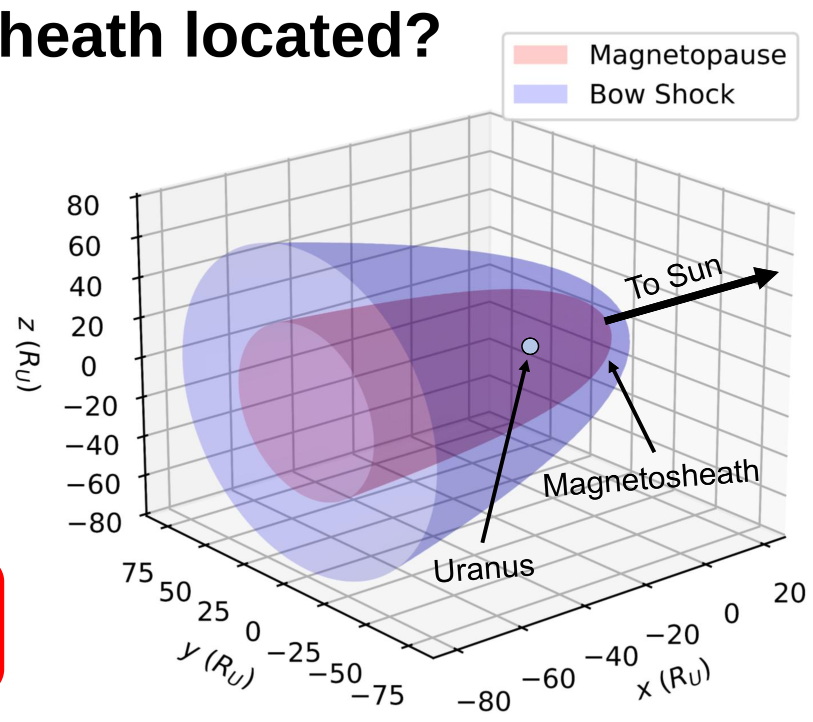
Simple Voyager 2 solar wind data samples tested

Where is the magnetosheath located?

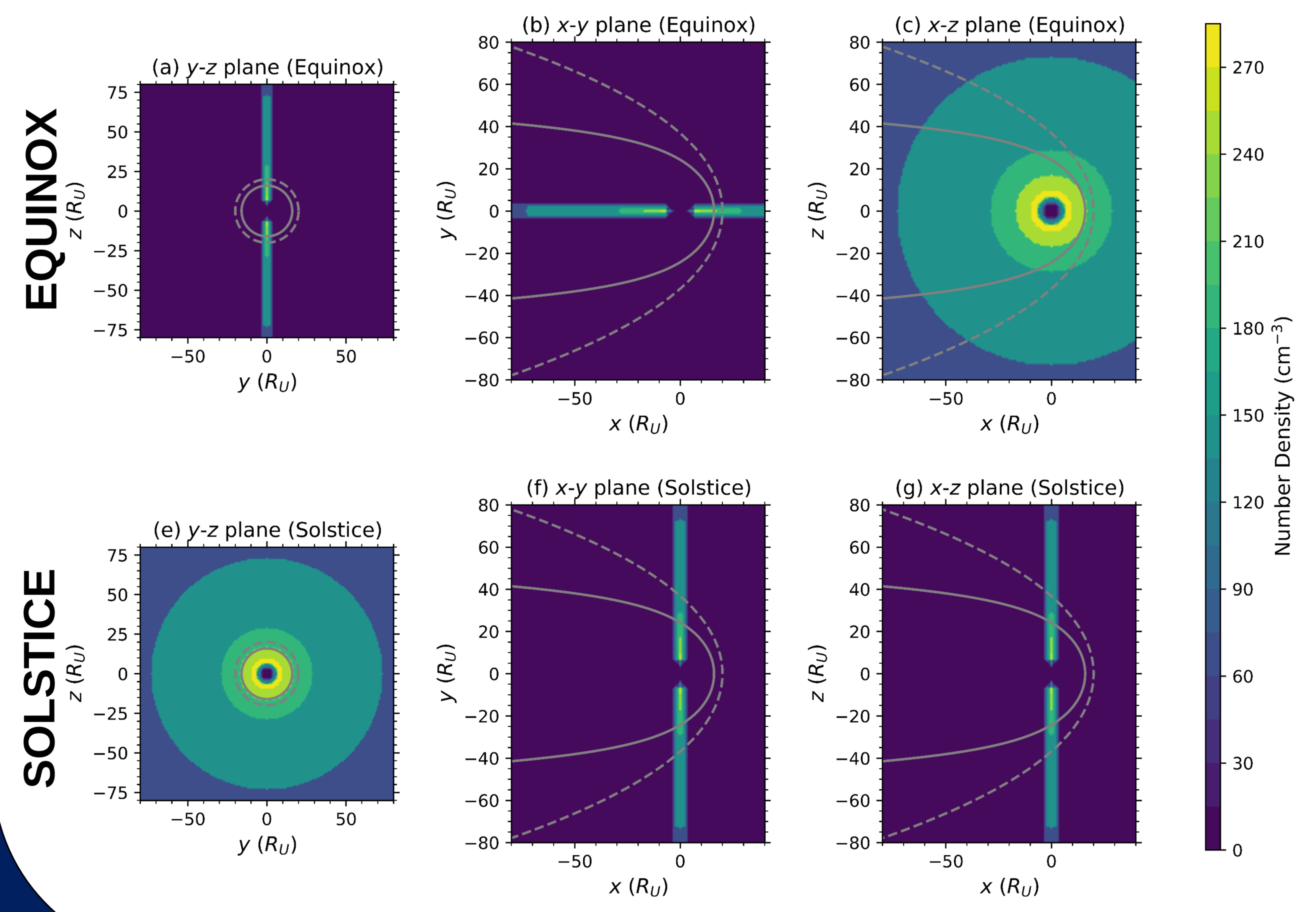
Impose simplified bullet-shaped magnetopause (Shue et al., 1997) – outer boundary of the magnetosphere

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

Magnetosheath is the region between the magnetopause and bow shock!



Neutral particles in the magnetosphere



Water-group neutrals sourced from icy moons form tori in the system

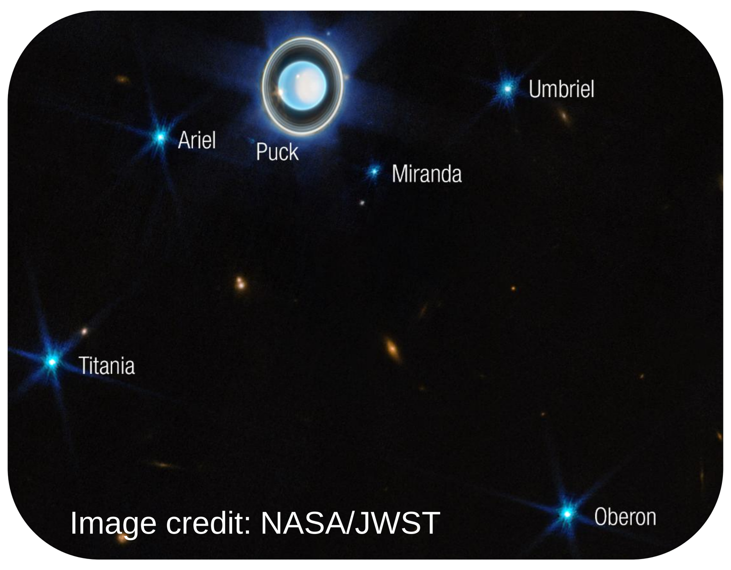
Neutrals at Uranus not well understood. Two models:

1. Eviatar & Richardson (1986) – pre-Voyager estimates based on Saturn moons, minimal and maximal estimates
2. Cheng (1987) – based on Voyager 2 plasma measurements

Tori shown at equinox (edge-on from Sun) and solstice (disk-on from Sun)

Herbert et al. (1987) exosphere also included – but negligible in this model

How does varying neutral density affect emission?



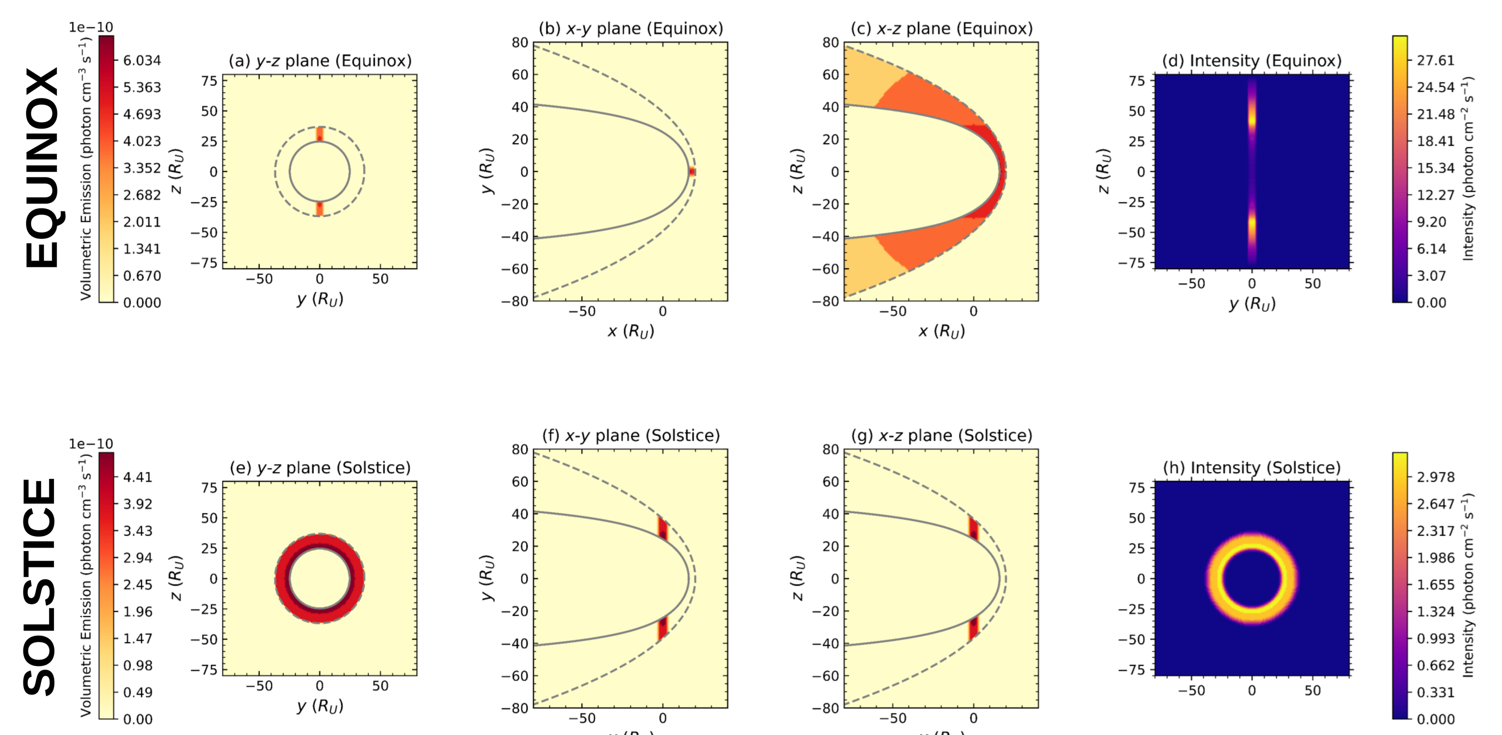
Emission on the order of 10^{-13} photon cm^{-3} s^{-1} for Cheng neutrals – unfavourable integration times for SXI.

Jasinski et al. (2024) suggests magnetosphere was plasma depleted during V2 flyby. So Cheng neutrals based on likely rare measurements

Emission on the order of 10^{-10} photon cm^{-3} s^{-1} for Eviatar & Richardson neutrals – fast integration times for both minimal and maximal densities (~3 mins at equinox for max)

Favourable emission rates within range of possible neutrals!

Do solar wind variations affect emission?



Emission on same order of magnitude for several different solar wind conditions

Sample of low density solar wind obtains emission 1 order of magnitude lower – imaging likely not possible in this case

Emission rates higher at equinox than solstice – due to the neutrals acting through sheath region being higher

Higher spatial distribution of flux detection at solstice

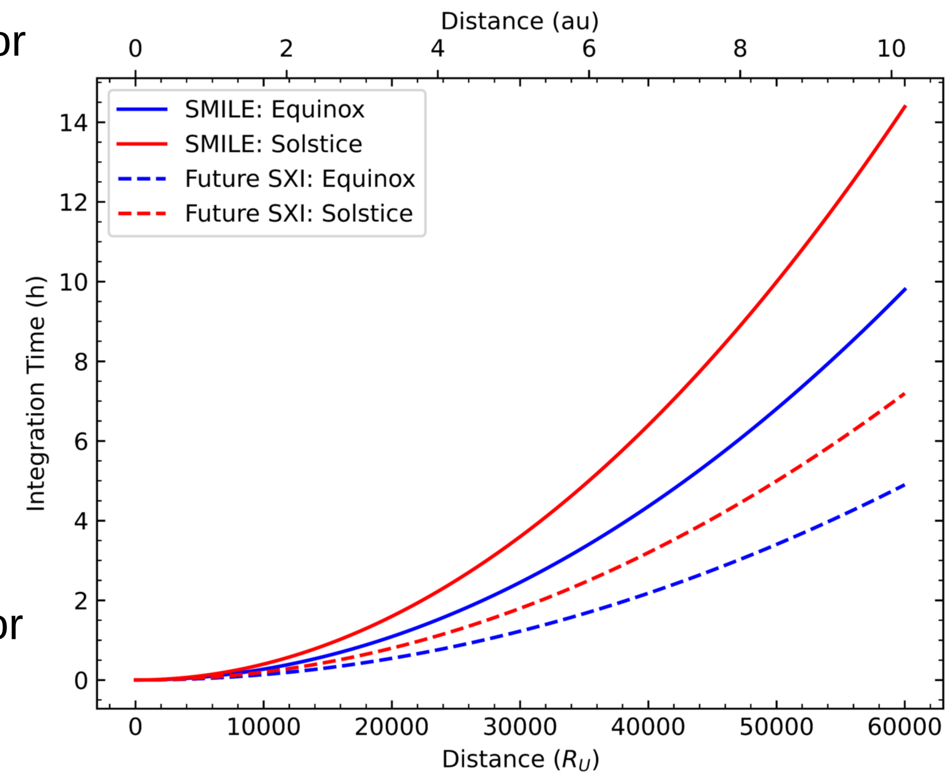
Can the X-ray emission be detected by a spacecraft?

SMILE SXI potentially sufficient for imaging

'Future' SXI considered – improvements to FOV and effective area

Photon detection possible within rapid solar wind timescales!

Point source approximation considered - detection possible for over a year before arrival at Uranus



Optimistic outlook for imaging – may be possible before the orbiter reaches the system!

Conclusions – will soft X-ray imaging help us explore Uranus?

- Neutral density is the strongest driver of emission – soft X-ray imaging could be used to better understand the spatial distribution of neutrals in the system
- Solar wind variations can affect emission significantly – more investigation needed
- The SMILE SXI provides opportunities to image the system within system timescales
- Emission rates estimated in this model are likely an underestimate

Promising results that justify further development of the model!

Where next?

Asymmetrical magnetopause – more realistic structure including cusps – funnel regions that allow solar wind to get close to the planet where exospheric density may drive emission rates up significantly

Time-varying model – use Voyager 2 data to look at solar wind variations over continuous timescales

Developing more realistic neutral tori – currently discrete