Estimating Soft X-Ray Emission from Uranus's Magnetosheath

Space & Planetary Physics | Lancaster University

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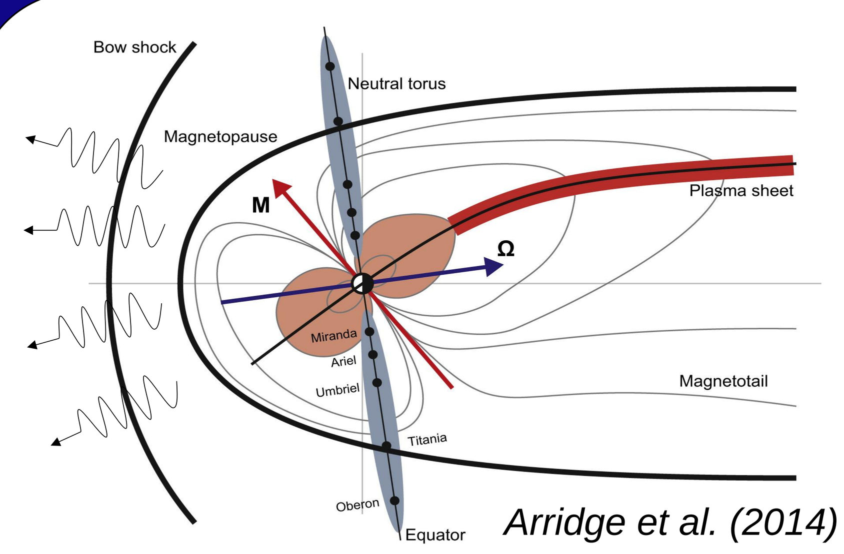
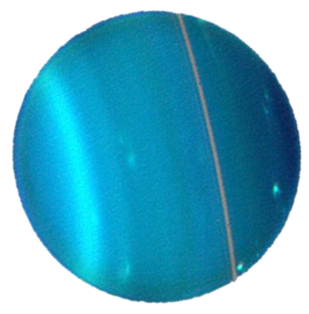


Arridge et al. (2014)

1. Can We Detect Soft X-Rays from Uranus's Magnetosheath?



- Uranus's magnetosphere is an unusual and complex environment
- Seasonal and diurnal variations
- Moon-sourced plasma and neutral rates debated – single Voyager 2 flyby in 1986
- Charge exchange between solar wind ions and magnetospheric neutrals in the magnetosheath generate soft X-rays
- Potentially provides global, dynamic view of system

2. Volumetric Emission Rate, *P*

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

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

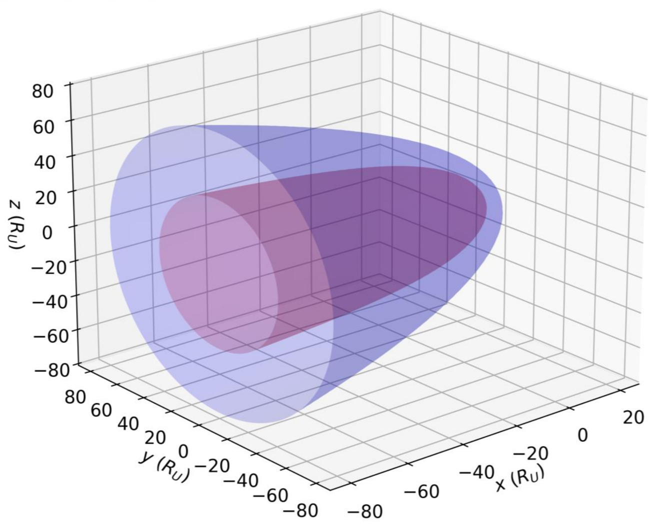
σ = Cross Section $\quad n_n$ = Neutral Density $\quad n_q$ = Ion Density $\quad v_{\text{rel}}$ = Collision Velocity

H-like and H_2O-like cross sections (Bodewits, 2007; Schwadron & Cravens, 2000)

Branching ratios wrapped into cross sections

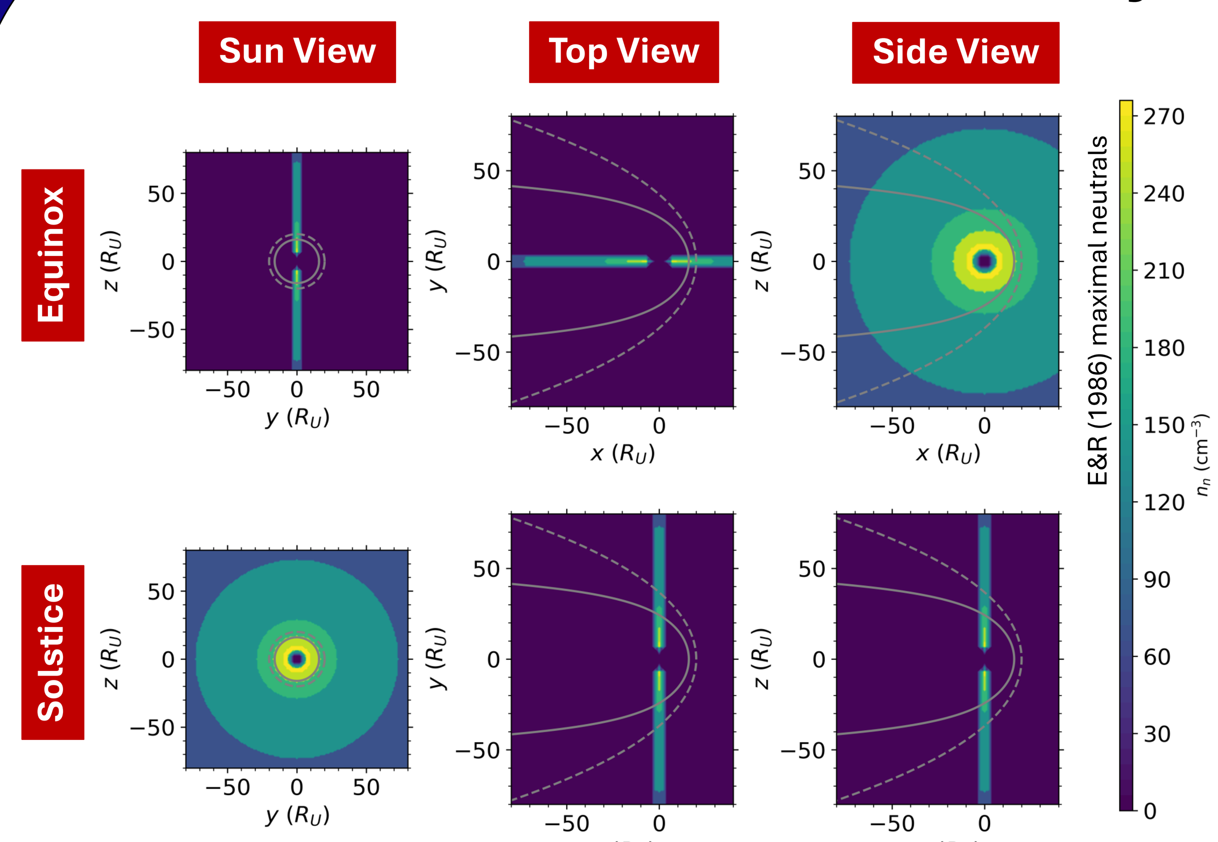
3. Magnetosheath Properties

- Shue et al. (1997) model for magnetopause and bow shock
- MP standoff distance ($r_0 = 16\ R_U$) and flaring parameter ($K = 0.6$) estimated from Voyager 2 flyby
- Magnetosheath density = 0.4 cm^{-3}
- O^{7+} CX considered, velocity-dependent abundances from Whittaker & Sembay (2016)



Naylor et al. (2025)

4. Neutral Density



Naylor et al. (2025)

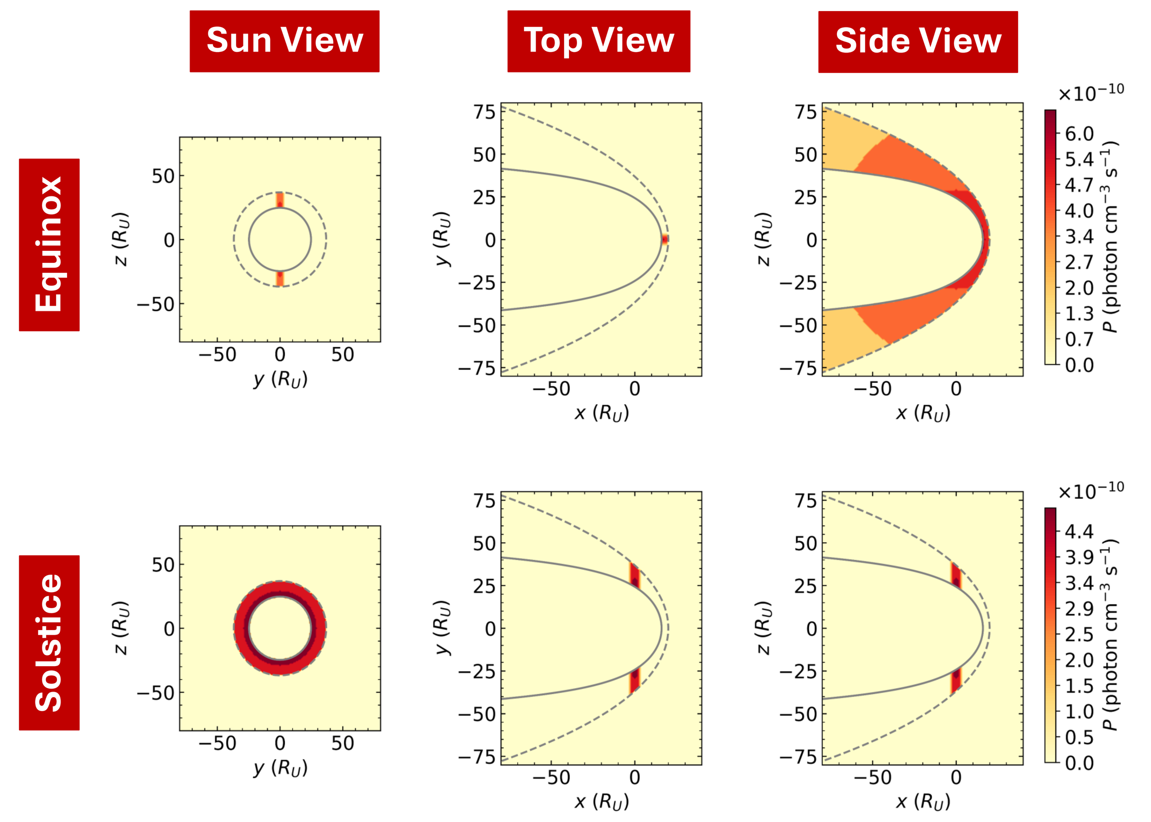
Three models for moon-sourced neutrals:

- Pre-Voyager 2 estimates: Eviator & Richardson (1986), *minimal & maximal*
- Post-Voyager 2 inferences: Cheng (1987)

- System potentially plasma-depleted (Jasinski et al., 2024)
- Exosphere (Herbert et al., 1987) included
- Assume best case neutral densities

5. Predicted Emission Rates

- Varies between 10^{-10} and 10^{-13} photon cm^{-3} s^{-1} between neutral models
  - Moon sources vital
- Only includes O^{7+} CX – may be up to 4x higher with full range of SW ions



Naylor et al. (2025)

- Variations with:
  - Season – emission higher at equinox due to alignment of neutral tori with magnetosheath
  - Solar wind conditions – emission lower for fast SW due to decreased proton density and O^{7+} abundance

6. Calculating Intensity and Flux

Sum emission along a line of sight for intensity

$$I = \int P \frac{d\Omega}{4\pi} dl = \frac{1}{2} \int P dl$$

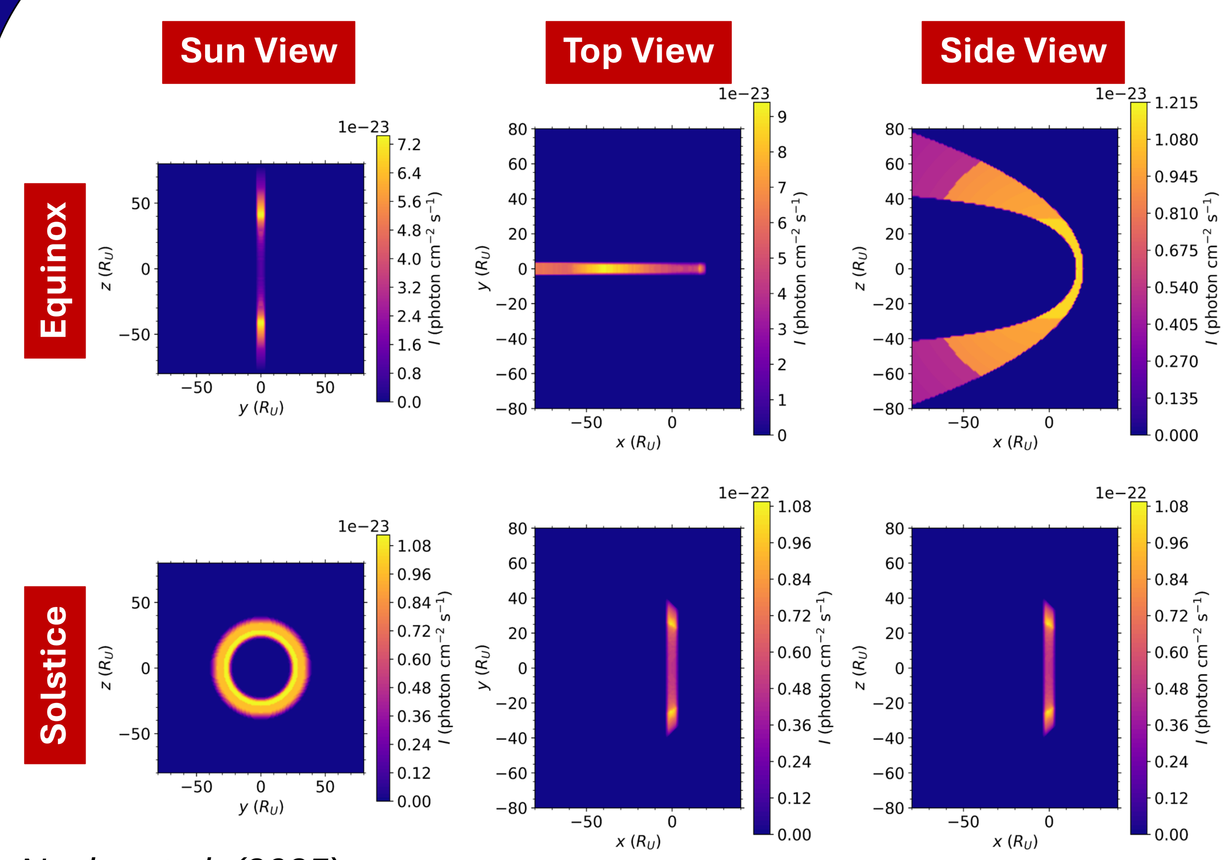
and approximate by collapsing along an axis

Credit: ESA

Scale to spacecraft for flux - consider three soft X-ray imagers (SXIs) informed by terrestrial investigations

SXI	FOV	$A_{effective}$ (cm^2)	Imaging Distance (R_U/au)
SMILE−like	26.5° × 15.5°	9.6	260/0.630
LEXI −like	9.1° × 9.1°	44.18	925/1.87
Future	53° × 31°	100	100/0.297

7. Could We Detect the Emission?



Naylor et al. (2025)

- SMILE-like SXI may detect ~100 photons in ¼ planetary rotation at 260 R_U
- Future SXI has ~3 s detection time per photon
- Can move detector closer

Implications for an orbiter:

- 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

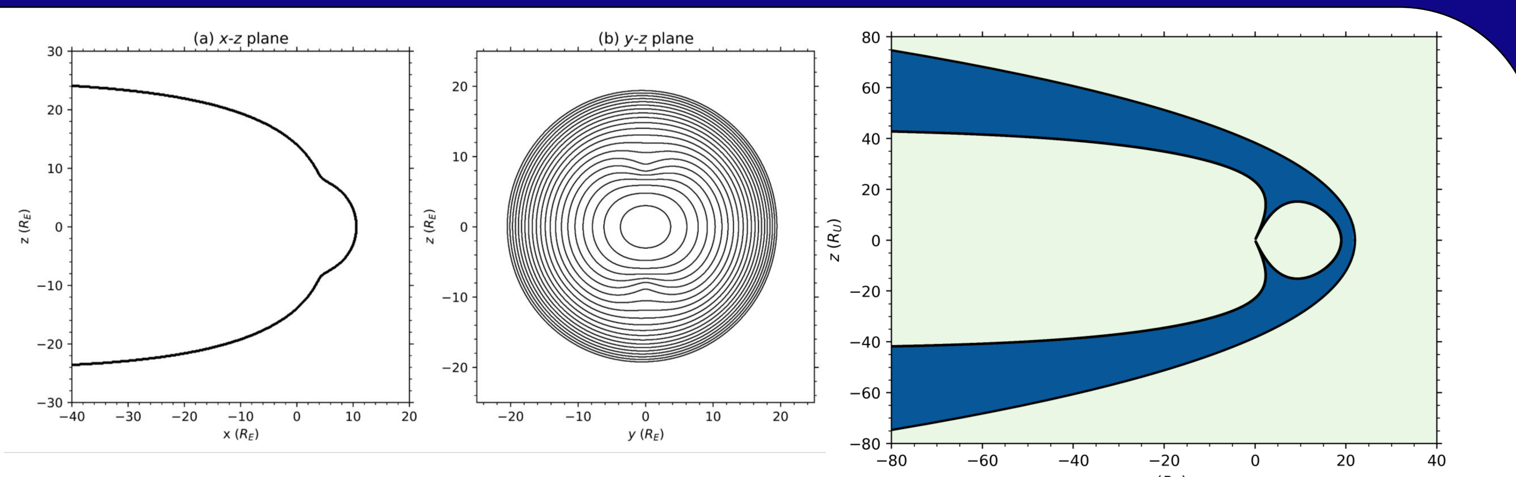
8. Conclusions

Promising results that justify further model development!

- Moon-sourced neutral density is key factor in producing emission
- Seasonal variation: increased emission at equinox
- Emission rates vary with SW conditions & potentially underestimated due to simplified chemistry
- Current technology may be sufficient but significant advancements possible

9. Where Next?

- Adapting Lin et al. (2010) Earth magnetopause model to Uranus to add cusps
- Cusps are predicted to be beacons of soft X-ray emission



- Improved neutral distributions for smoother emission signatures
- Adding true tilt of the neutral tori to represent Uranus's 98° obliquity

Look out for Naylor et al. (accepted), Estimating Soft X-Ray Emission from Uranus's Magnetosheath, in JGR Space Physics