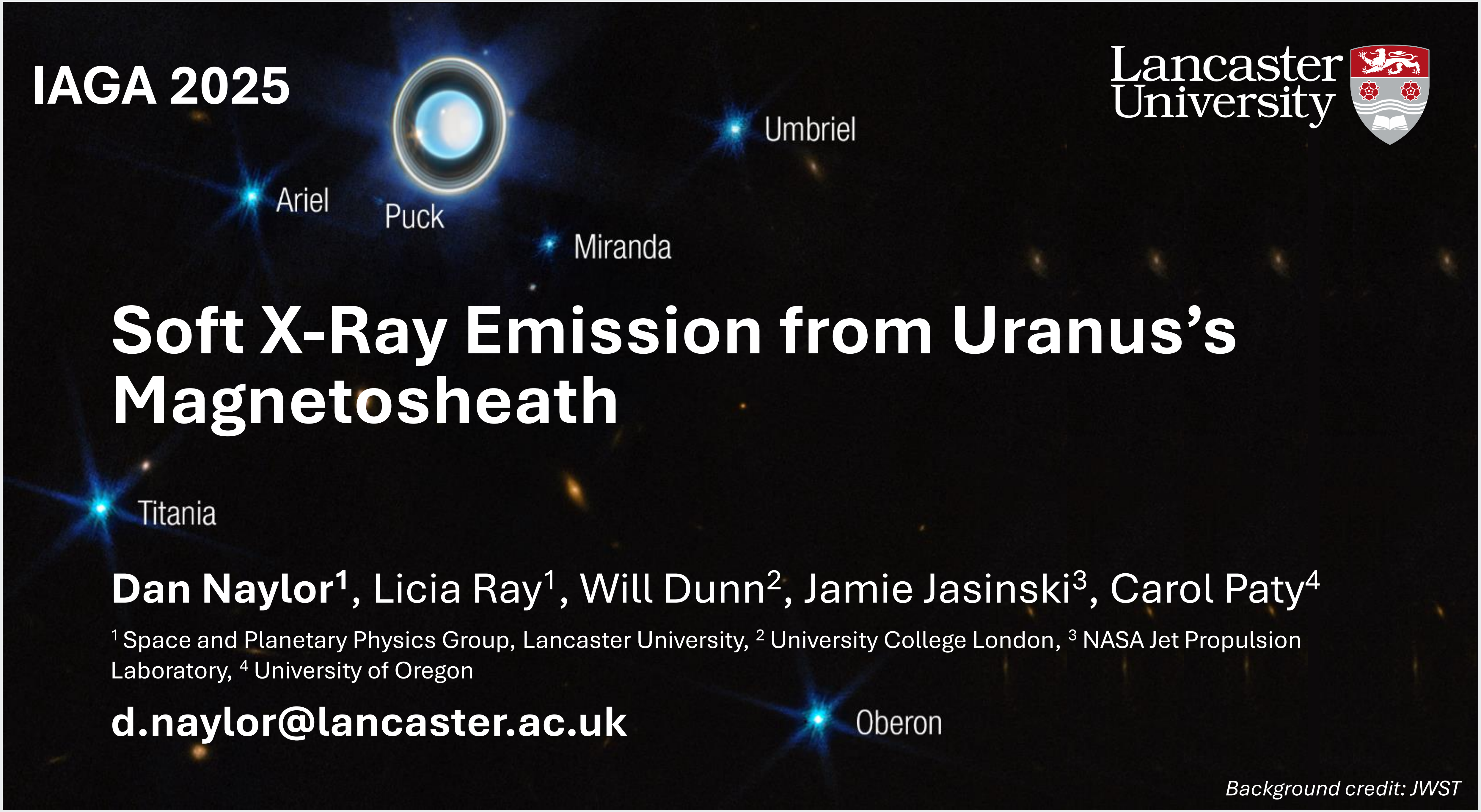


IAGA 2025

Soft X-Ray Emission from Uranus's Magnetosheath

Dan Naylor[1], Licia Ray[1], Will Dunn[2], Jamie Jasinski[3], Carol Paty[4]

[1] Space and Planetary Physics Group, Lancaster University, [2] University College London, [3] NASA Jet Propulsion Laboratory, [4] University of Oregon

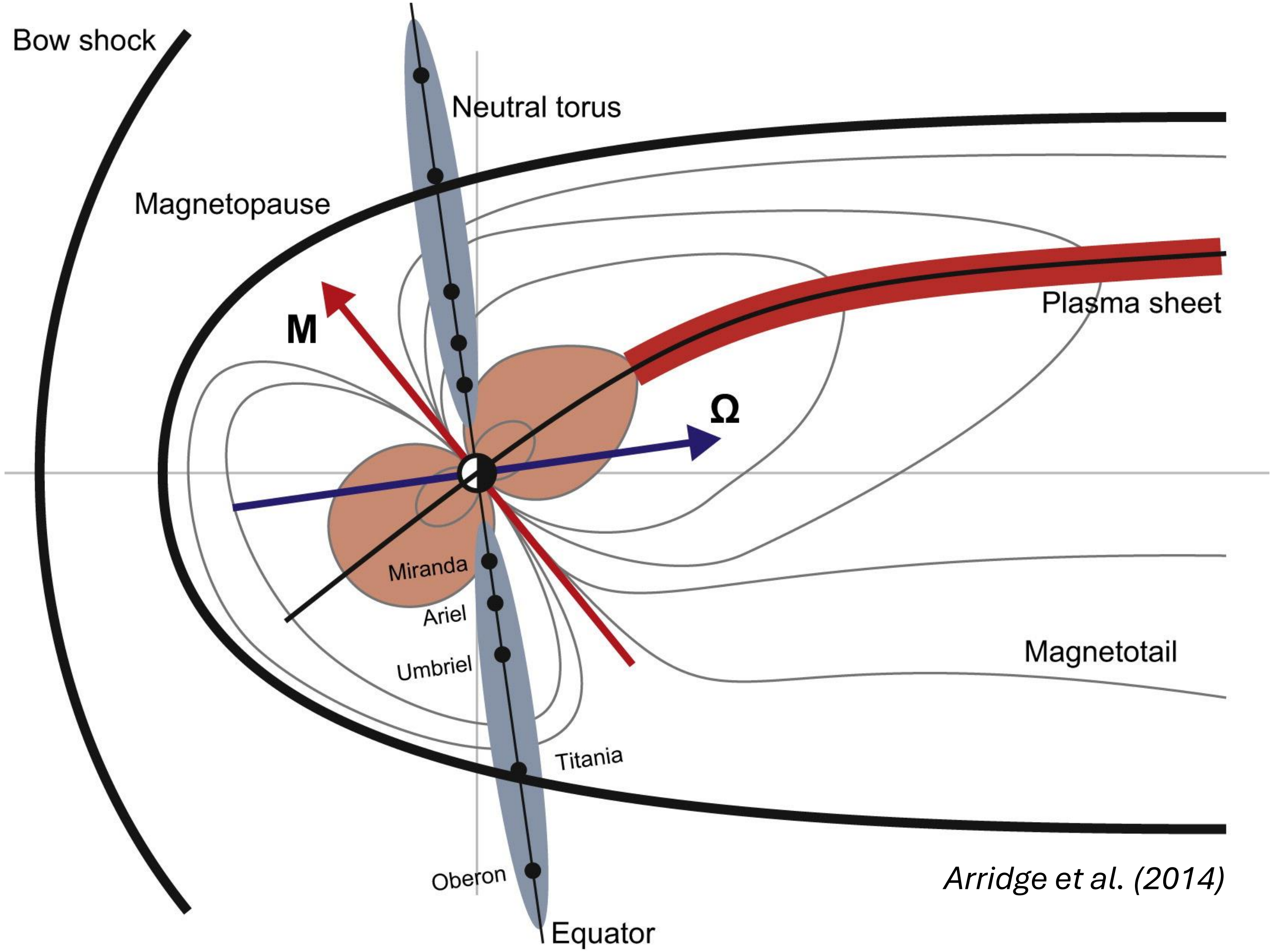
d.naylor@lancaster.ac.uk

Background credit: JWST

Uranus's Magnetosphere

Space & Planetary Physics | Lancaster University

- Unusual and complex environment
- Seasonal and diurnal variability
- Moon-sourced neutrals and plasma debated
- Single Voyager 2 flyby



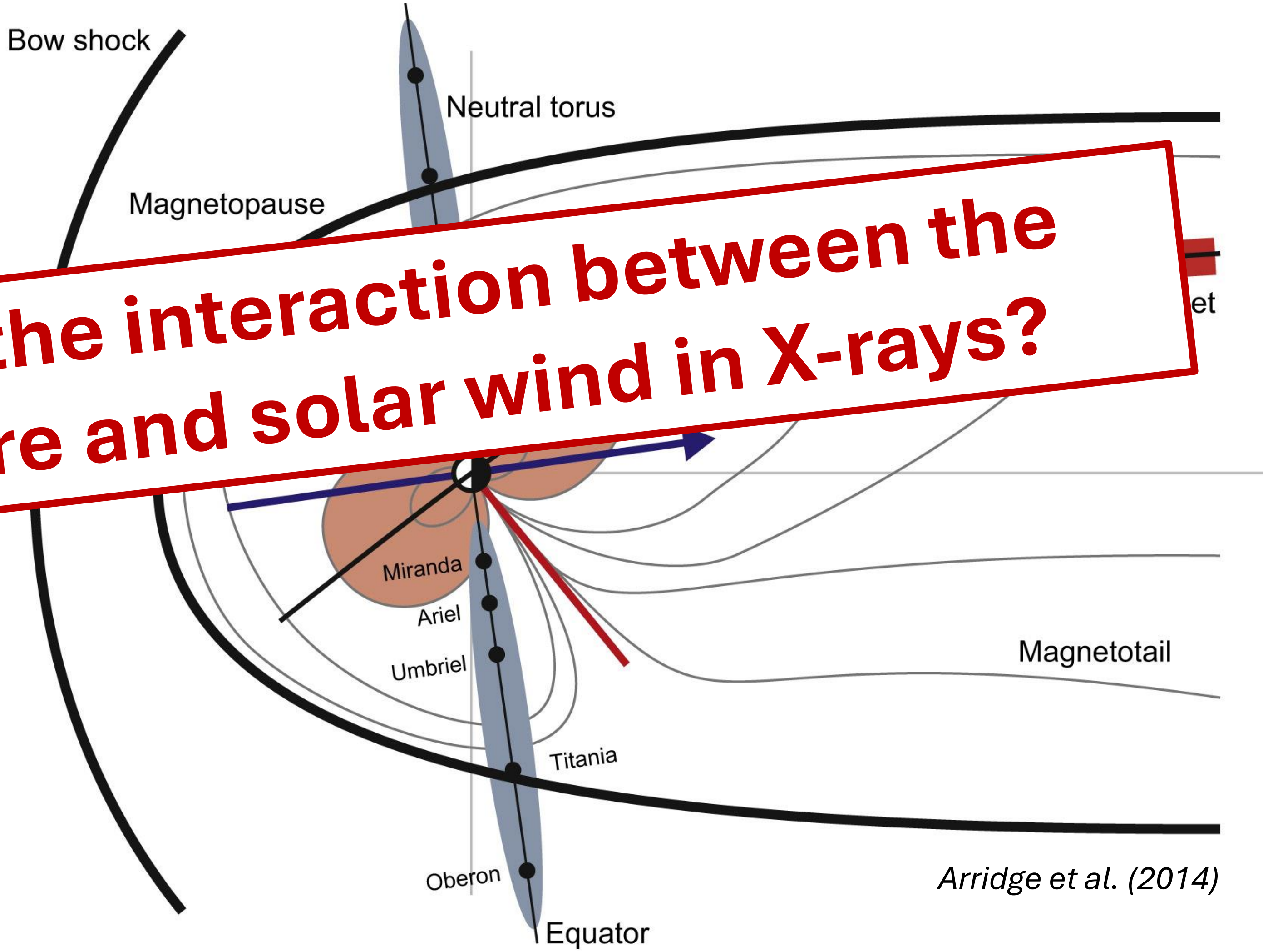
Arridge et al. (2014)

Uranus’s Magnetosphere

Space & Planetary Physics | Lancaster University

- Unusual and complex environment
- Seas… varia…
- Moon-sourced neutrals and plasma debated
- Single Voyager 2 flyby

Can we image the interaction between the magnetosphere and solar wind in X-rays?

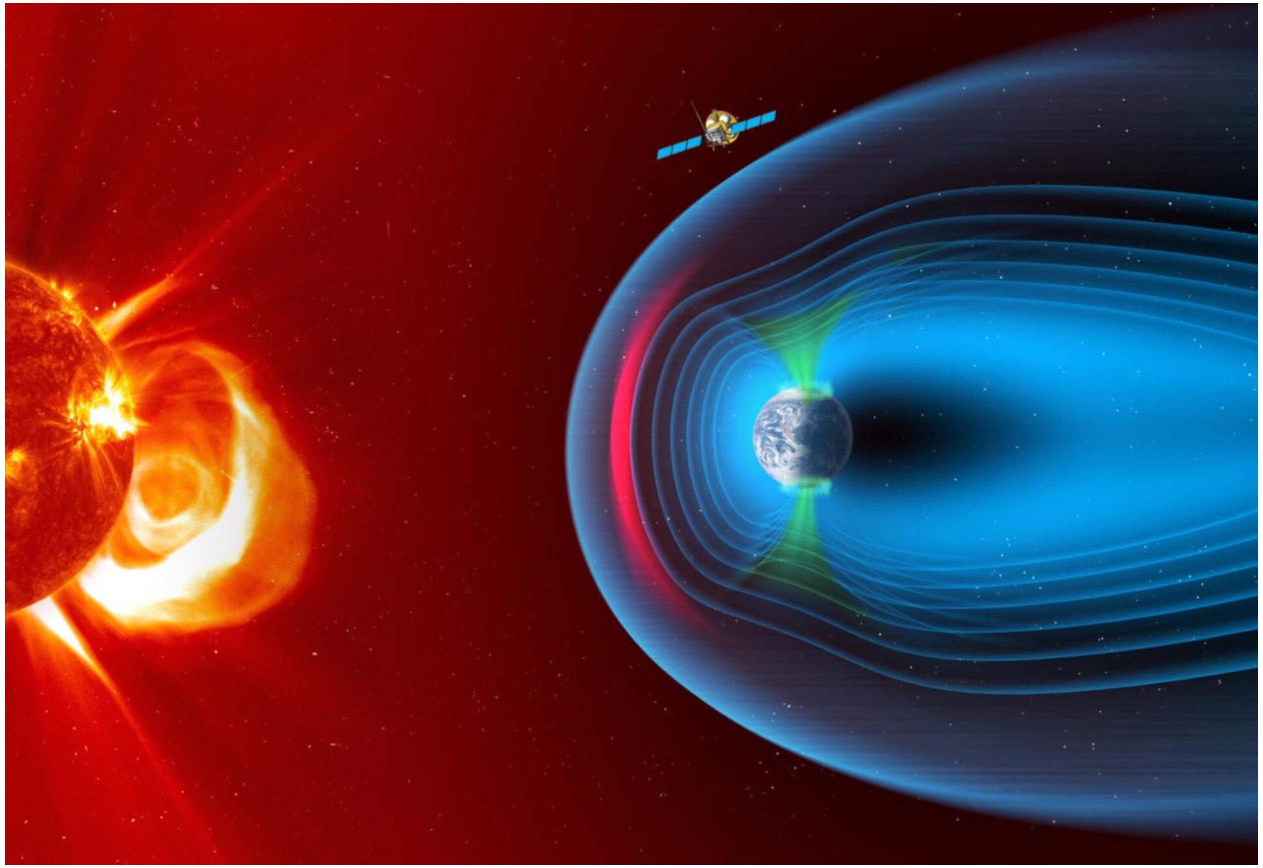


Arridge et al. (2014)

Soft X-Ray Emission & Imaging

Space & Planetary Physics | Lancaster University

- CX between highly charged ions and neutrals generates soft X-rays
- Dynamic, global view of system
- SMILE and LEXI missions aim to image terrestrial magnetosheath



Credit: ESA

What Dictates X-Ray Emission?

Space & Planetary Physics | Lancaster University

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

Emission given in photon cm^{-3} s^{-1}

Neutral density: Sum over n reflects different species

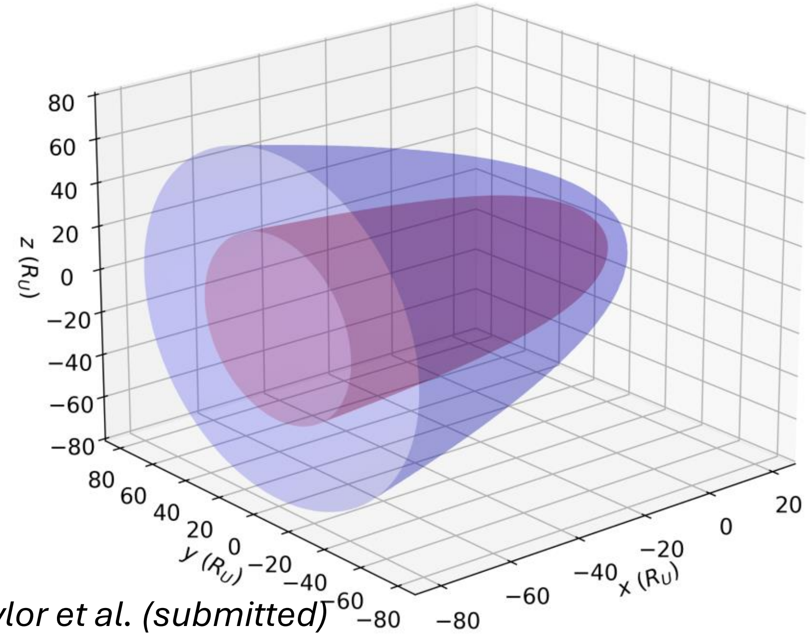
Magnetosheath ion density

Relative velocity between ions and neutrals

Cross sections – hydrogen-like and oxygen-like. Contains branching ratio term

Magnetosheath Properties

Space & Planetary Physics | Lancaster University

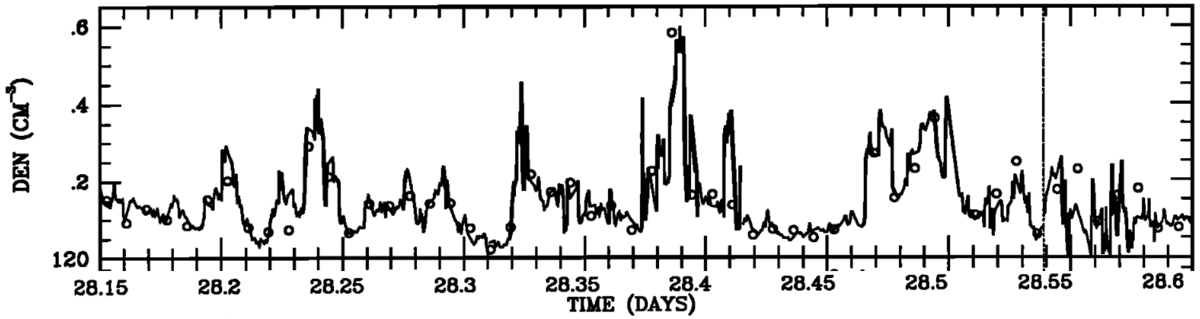


Naylor et al. (submitted)

- Apply Shue et al. (1997) model for magnetopause and bow shock:

$$r_{\mathrm{MP}} = r_0 \left(\frac{2}{1 + \cos\theta} \right)^K$$

- MP standoff distance ($r_0 = 16\ R_U$) and flaring ($K = 0.6$) estimated from Voyager 2 flyby

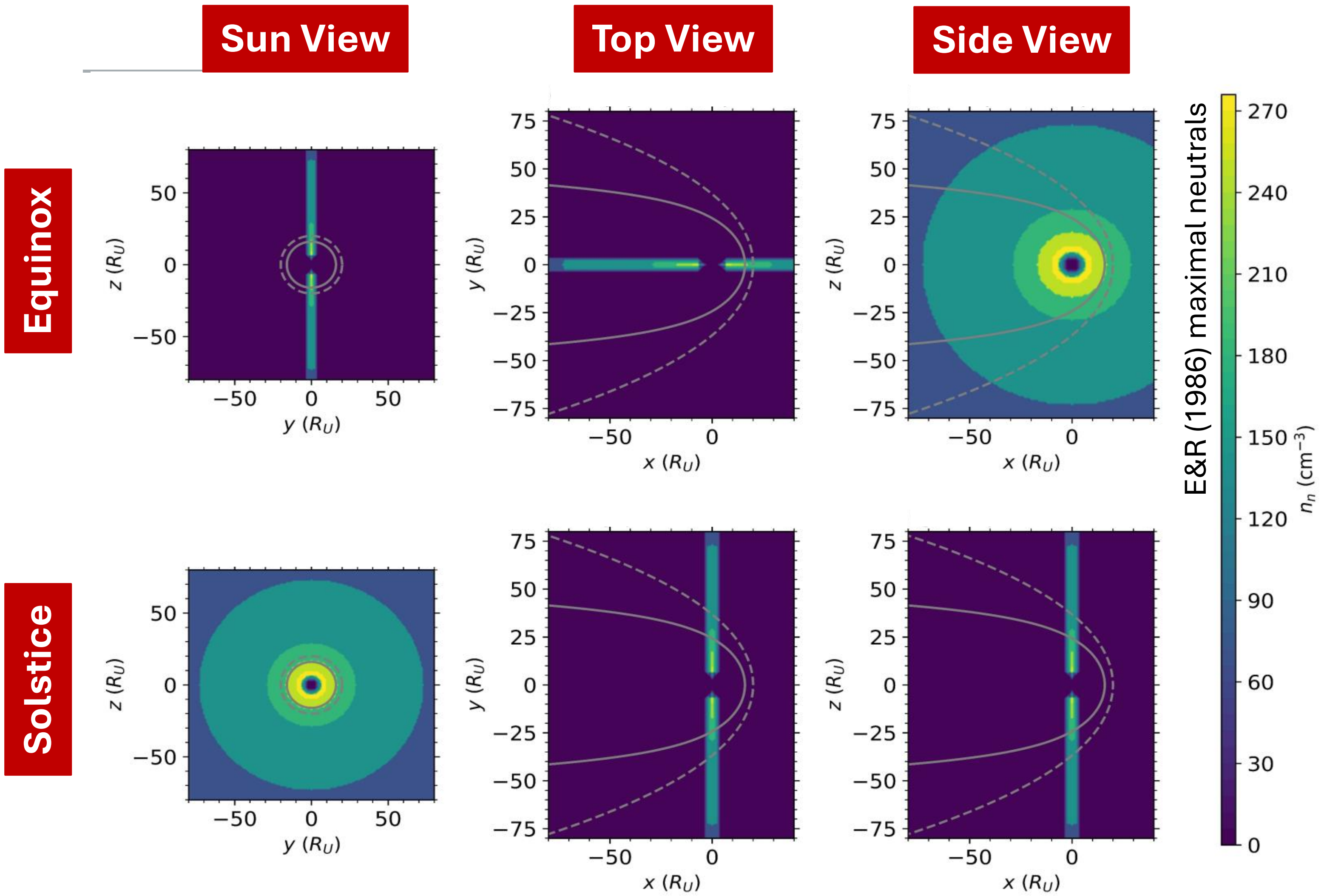


Richardson et al. (1990)

- Magnetosheath density: 0.4 cm^{-3}
- O^{7+} CX considered
- Velocity-dependent abundances from Whittaker & Sembay (2016)

Neutral Densities

Space & Planetary Physics | Lancaster University

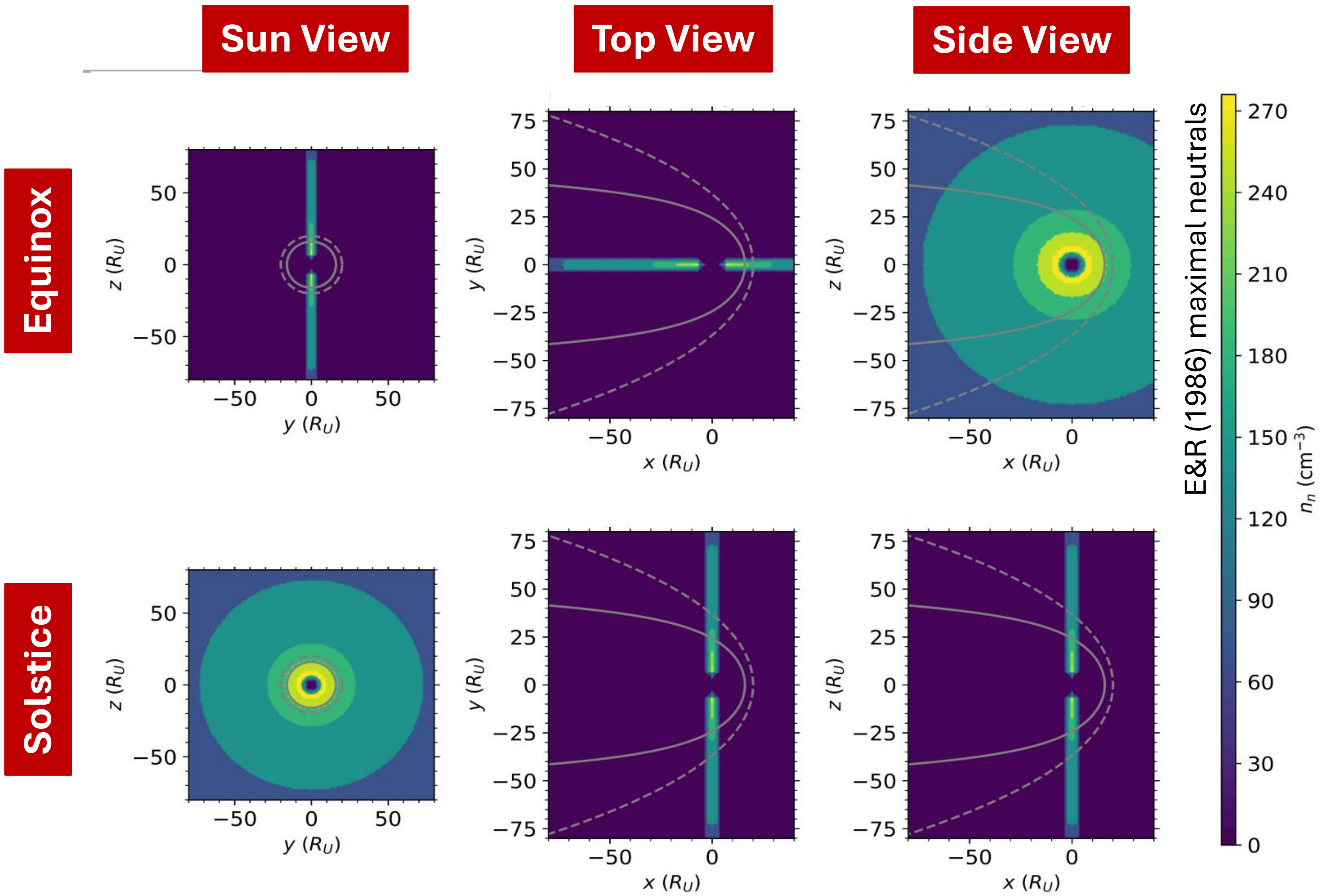


Naylor et al. (submitted)

- Exosphere included (Herbert et al., 1987)
- Three models:
  - Pre-Voyager 2 estimates: Eviator & Richardson (1986), *minimal & maximal*
  - Post-Voyager 2 inferences: Cheng (1987)
- System potentially plasma-depleted (Jasinski et al., 2024)

Neutral Densities

Space & Planetary Physics | Lancaster University

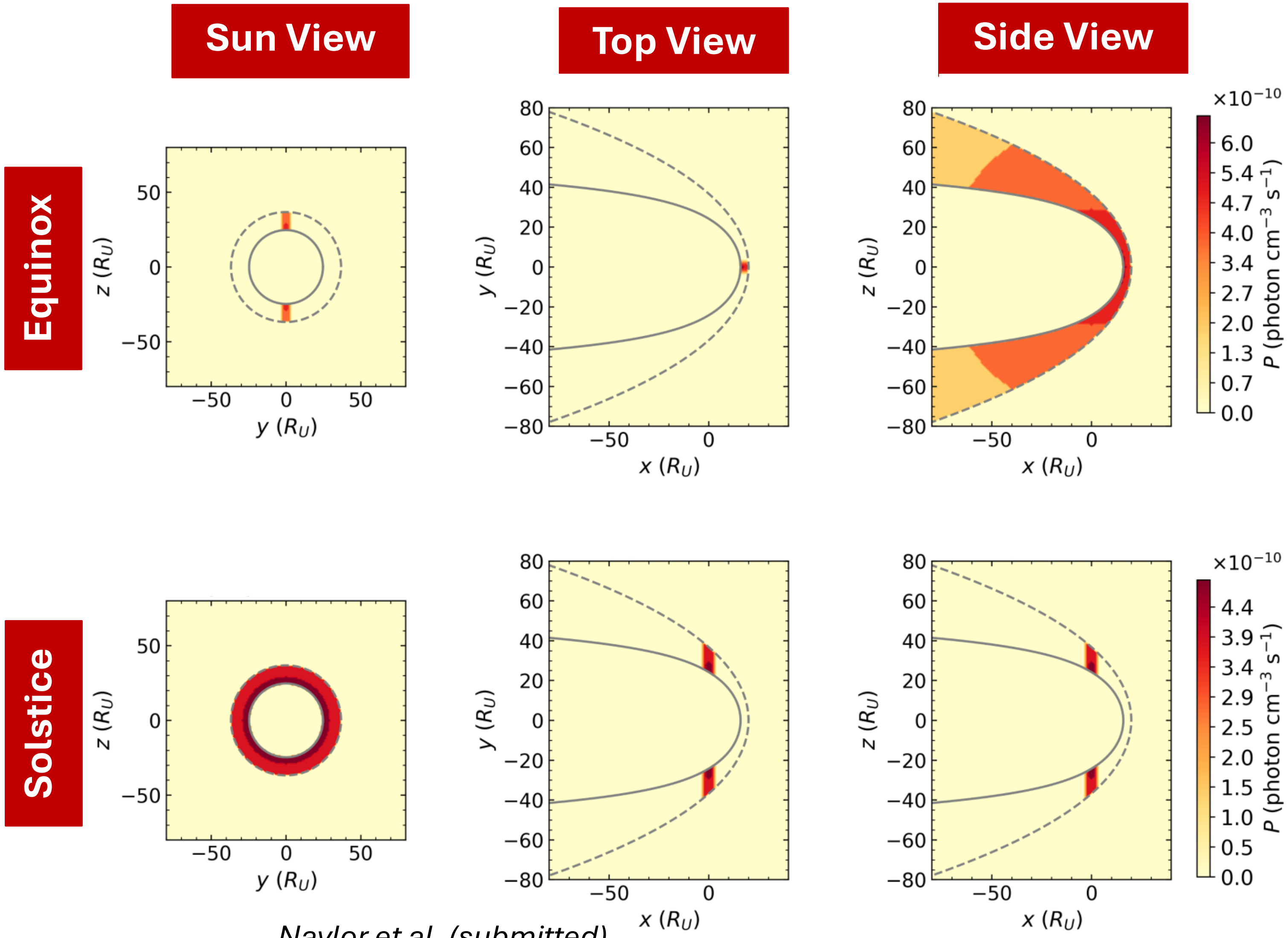


Naylor et al. (submitted)

- Exosphere included (Herbert et al., 1987)
- Three models:
  - Pre-Voyager 2 estimates: Eviator & Richardson (1986), *minimal* & *maximal*
  - Post-Voyager 2 inferences: Cheng (1987)
- System potentially plasma-depleted (Jasinski et al., 2024)

Predicted Emission Rates

Space & Planetary Physics | Lancaster University



Naylor et al. (submitted)

- Varies between 10^{-10} and 10^{-13} photon cm^{-3} s^{-1}
  - Moon sources vital
- Varies with:
  - Season
  - Solar wind driving
- Only includes O^{7+} CX

Detecting the Emission

Space & Planetary Physics | Lancaster University

- Sum emission along a line of sight for intensity:

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

Intensity given in photon cm^{-2} s^{-1}

- Consider 3 soft X-ray imagers (SXIs):

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

Naylor et al. (submitted)

Detecting the Emission

Space & Planetary Physics | Lancaster University

- Sum emission along a line of sight for intensity:

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

Intensity given in photon cm^{-2} s^{-1}

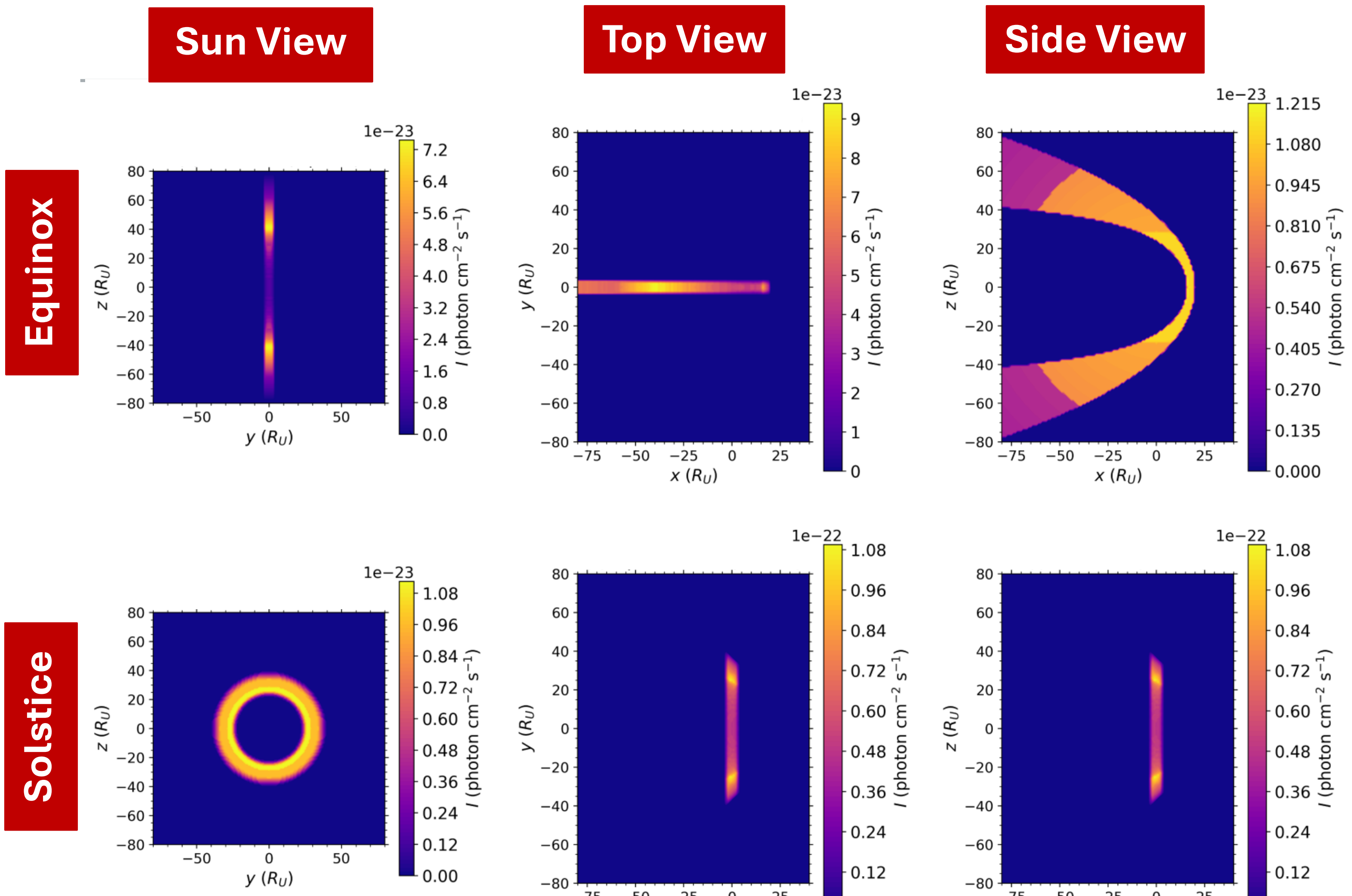
- Consider 3 soft X-ray imagers (SXIs):

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

Naylor et al. (submitted)

Can We Detect the Emission?

Space & Planetary Physics | Lancaster University



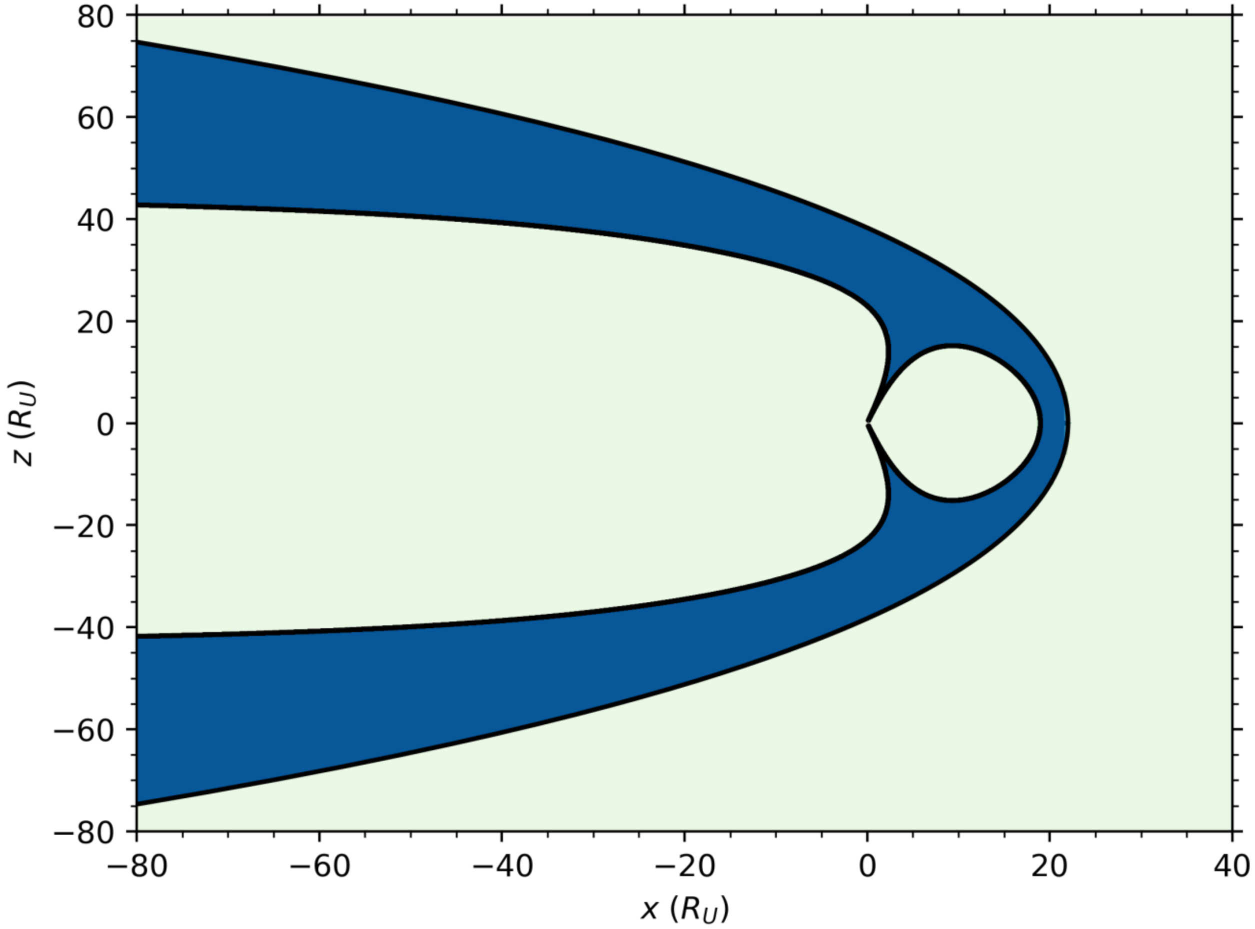
Naylor et al. (submitted)

- SMILE detects ~100 photons in ¼ planetary rotation at 260 R_U
- Future SXI has ~3 s detection time per photon
- Implications for an orbiter

Next Steps: Magnetospheric Cusps

Space & Planetary Physics | Lancaster University

- Predicted to be soft X-ray beacons:
    - Allow solar wind to reach deep into magnetosphere
    - Exospheric density important
    - Pole-on configurations at ice giants
- Adapting Lin et al. (2010) magnetopause model to Uranus



Conclusions

Space & Planetary Physics | Lancaster University

- Neutral density is key factor in determining magnetosheath emission, which is dependent on moon-sources
- Emission higher at equinox and varies with solar wind changes
- Emission rates potentially underestimated
- Current technology may be sufficient but technology advancements important to consider

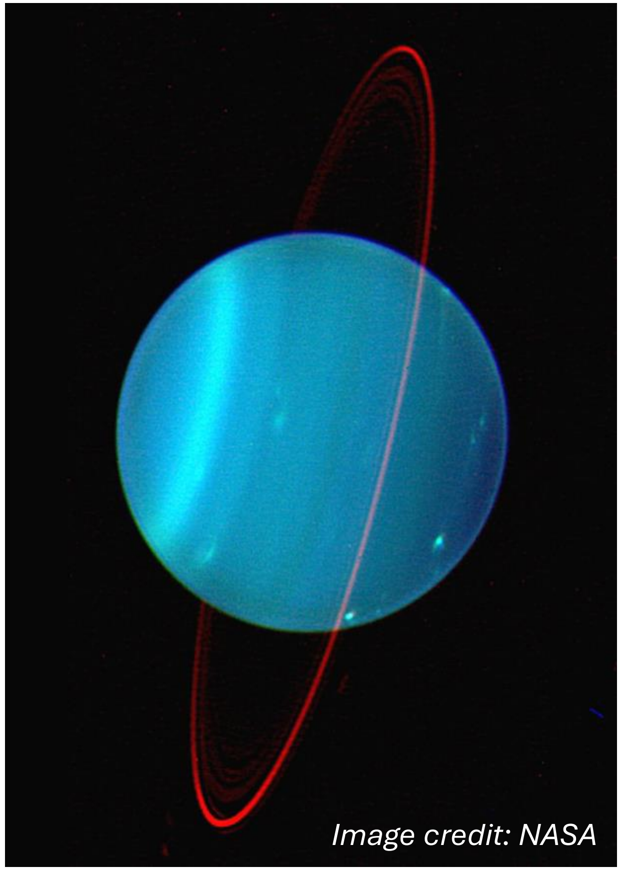


Image credit: NASA

Conclusions

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

Space & Planetary Physics | Lancaster University

- Neutral density is key factor in determining magnetosheath emission, which is dependent on moon-sources
- Emission higher at equinox and varies with solar wind changes
- Emission rates potentially underestimated
- Current technology may be sufficient but technology advancements important to consider

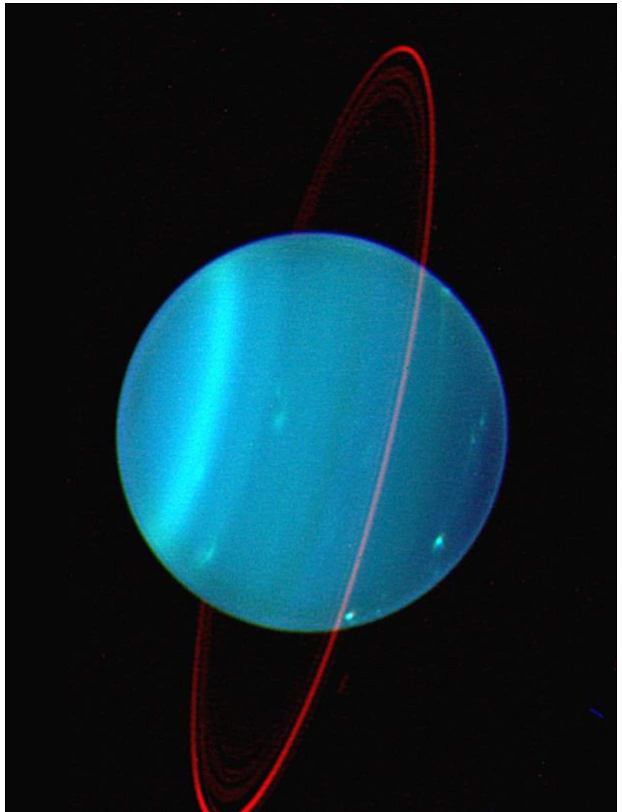


Image credit: NASA

Simple model with promising results that justify further development!

Extra Slides: Neutral Model Effect on Emission

Space & Planetary Physics | Lancaster University

Neutral Model	Equinox			Solstice		
	P (photon cm^{-3} s^{-1})	τ_{int} (h)	$N_{1/4}$	P (photon cm^{-3} s^{-1})	τ_{int} (h)	$N_{1/4}$
Cheng	6.71×10^{-13}	68.5	0	3.78×10^{-13}	75.7	0
ER Min	2.76×10^{-10}	0.0785	54	2.54×10^{-10}	0.0740	58
ER Max	6.64×10^{-10}	0.0482	89	4.85×10^{-10}	0.0416	103

Naylor et al. (in review)

Extra Slides: Solar Wind Variations

Space & Planetary Physics | Lancaster University

SW State	Equinox			Solstice		
	P (photon cm^{-3} s^{-1})	τ_{int} (h)	$N_{1/4}$	P (photon cm^{-3} s^{-1})	τ_{int} (h)	$N_{1/4}$
Fast Wind	3.98×10^{-10}	0.0829	51	2.91×10^{-10}	0.0762	56
V2 1	1.00×10^{-10}	0.222	19	7.83×10^{-11}	0.174	24
V2 2	5.64×10^{-10}	0.0569	75	4.12×10^{-10}	0.0506	85

Naylor et al. (in review)

Extra Slides: SXI Configurations

Space & Planetary Physics | Lancaster University

SXI Configuration	Equinox		Solstice	
	τ_{int} (h)	$N_{1/4}$	τ_{int} (h)	$N_{1/4}$
SMILE	0.0482	89	0.0416	103
LEXI	0.102	42	0.0793	54
Future SXI	7.94×10^{-4}	5428	8.89×10^{-4}	4848

Naylor et al. (in review)