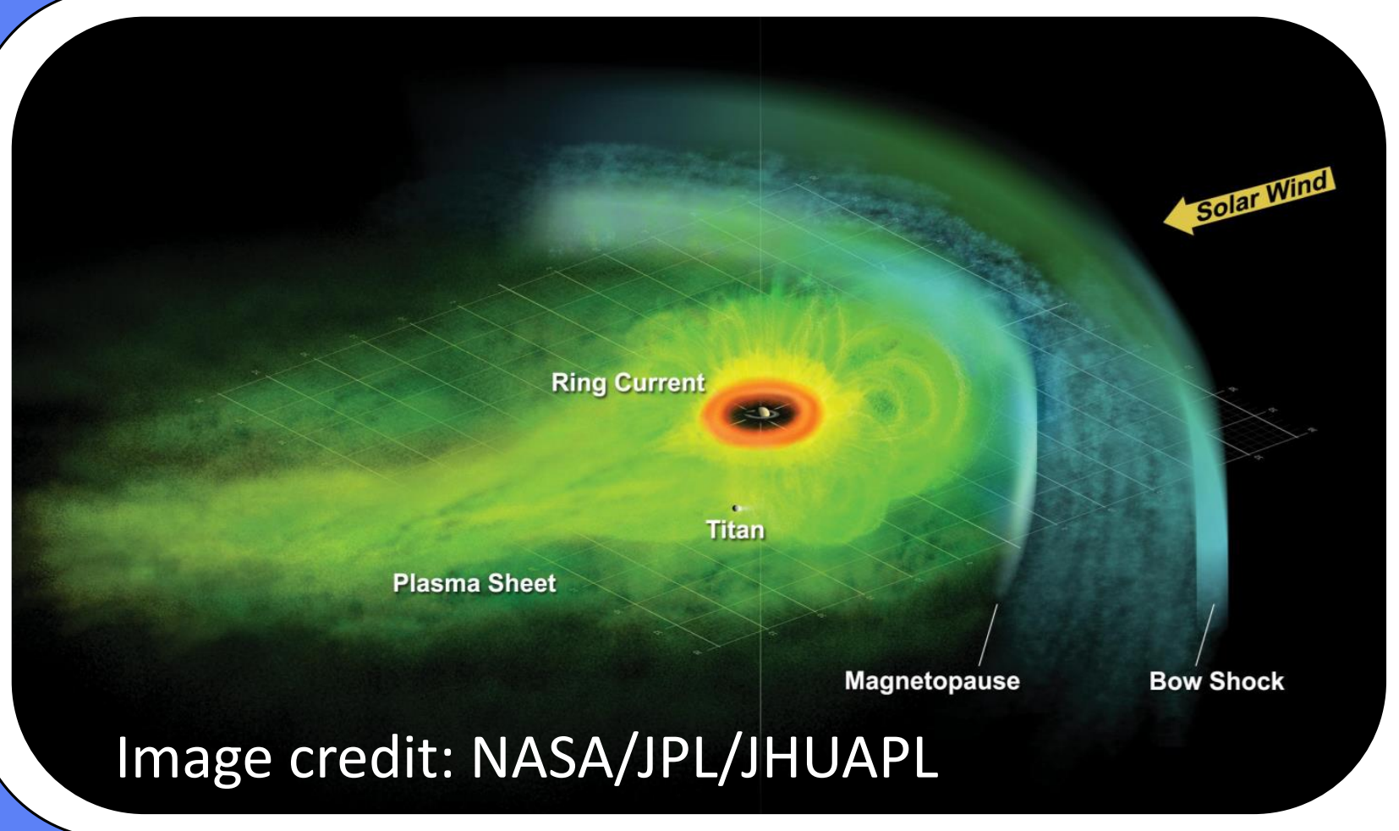
Soft x-ray emission from Saturn's magnetosheath: A comparison of two models

Patrick Rogan*†1, Dan Naylor†1, Licia Ray[1], Todd Smith[2], Will Dunn[3], Ali Sulaiman[4], Xianzhe Jia[5]

1: Lancaster University Department of Physics, **2:** Johns Hopkins University Applied Physics Laboratory, **3:** UCL Department of Physics and Astronomy, **4:** University of Minnesota, **5:** University of Michigan

* : Speaker, †: Corresponding authors: p.rogan@lancaster.ac.uk & d.naylor@lancaster.ac.uk



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Can x-ray emission from Saturn's magnetosheath be detected?

- Saturn's magnetosphere is filled with neutral particles sourced from the cryovolcanic moon Enceladus that form an extended cloud
- Charge exchange between Enceladus-genic neutrals and heavily stripped solar wind ions occurs within the magnetosheath
- Apply two models to simulate charge exchange rates within the magnetosheath, testing the viability of a SMILE-like SXI imaging the interaction between Saturn and the solar wind
  - ➢ **Model 1** uses **MHD simulation data** to describe the properties of the magnetosheath.
  - ➢ **Model 2** uses empirical models to explore **solar wind driving** of x-ray emission

Common Model Parameters

Magnetopause location

- Magnetosheath lies between the bow shock and magnetopause
- Bow shock varies between Model 1 and Model 2
- Use Kanani at al. (2010) magnetopause model based on Cassini data:

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

a_1	10.3
a_2	0.2
a_3	0.73
a_4	0.4

r_0 magnetopause nose distance, D_P dynamic pressure,
$r_0 \;=\; a_1 D_P^{-a_2}, \quad K \,=\, a_3 \,+\, a_4 D_P$

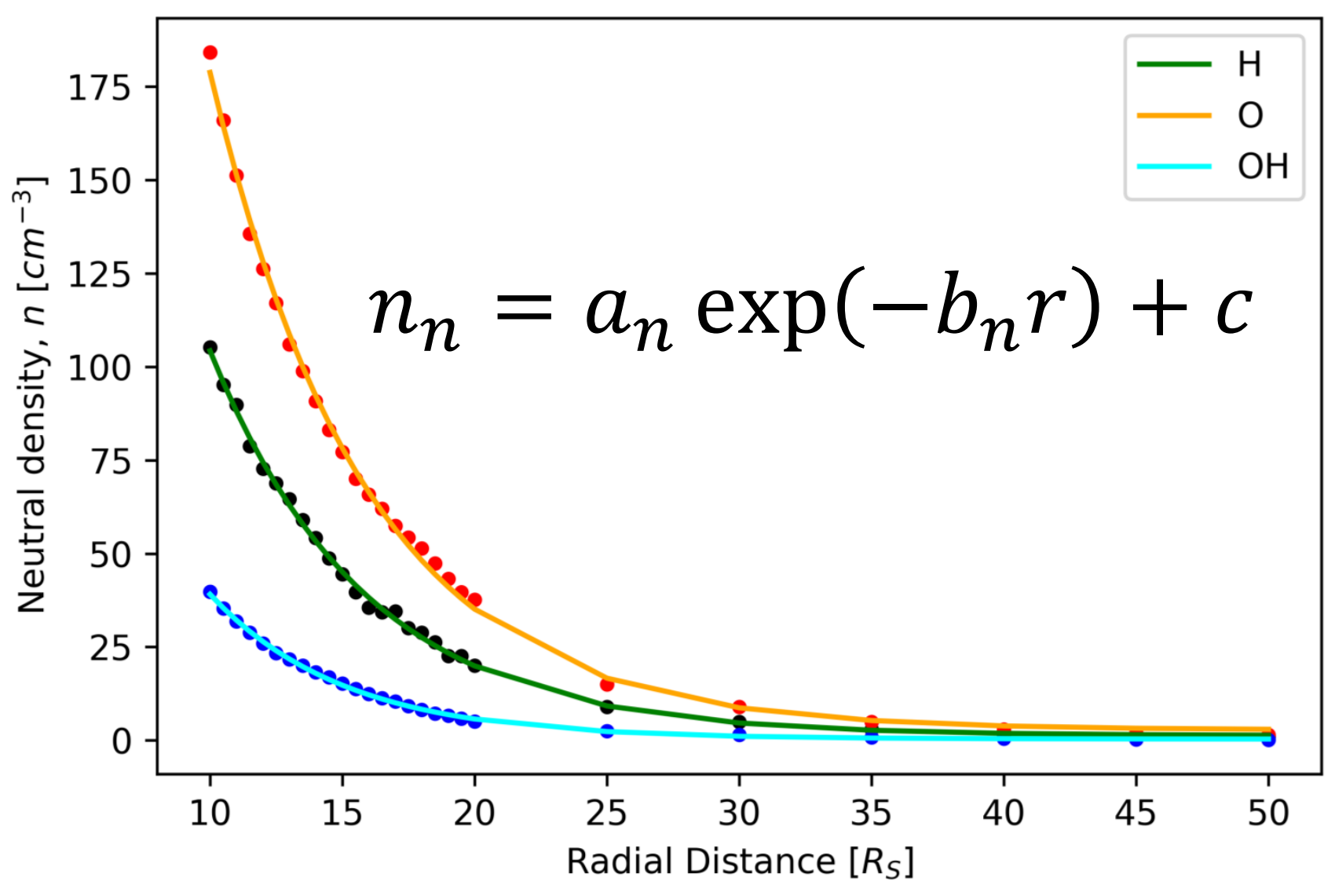
Volumetric emission rate (VER), *P*

$\mathrm{P} = \sum_n n_n n_q v_{\mathrm{rel}} \sigma_{sqn} b_{sqj}$ $\boldsymbol{n_n}$ = Neutral Density $\boldsymbol{n_q}$ = Ion Density

$\boldsymbol{\sigma_{sqn}}$ = Cross Section $\boldsymbol{b_{sqj}}$ = Branching Ratio $\boldsymbol{v_{rel}}$ = Collision Velocity

Neutral density

- Enceladus' geysers provide neutral H_2O-based material for system
- Expelled water disassociates into OH, O, and H, diffusing into extended clouds
- Density extrapolated from models informed by Cassini data (e.g. Smith & Richardson, 2021)
- Assume H-like cross sections for all species (Bodewits et al., 2007)

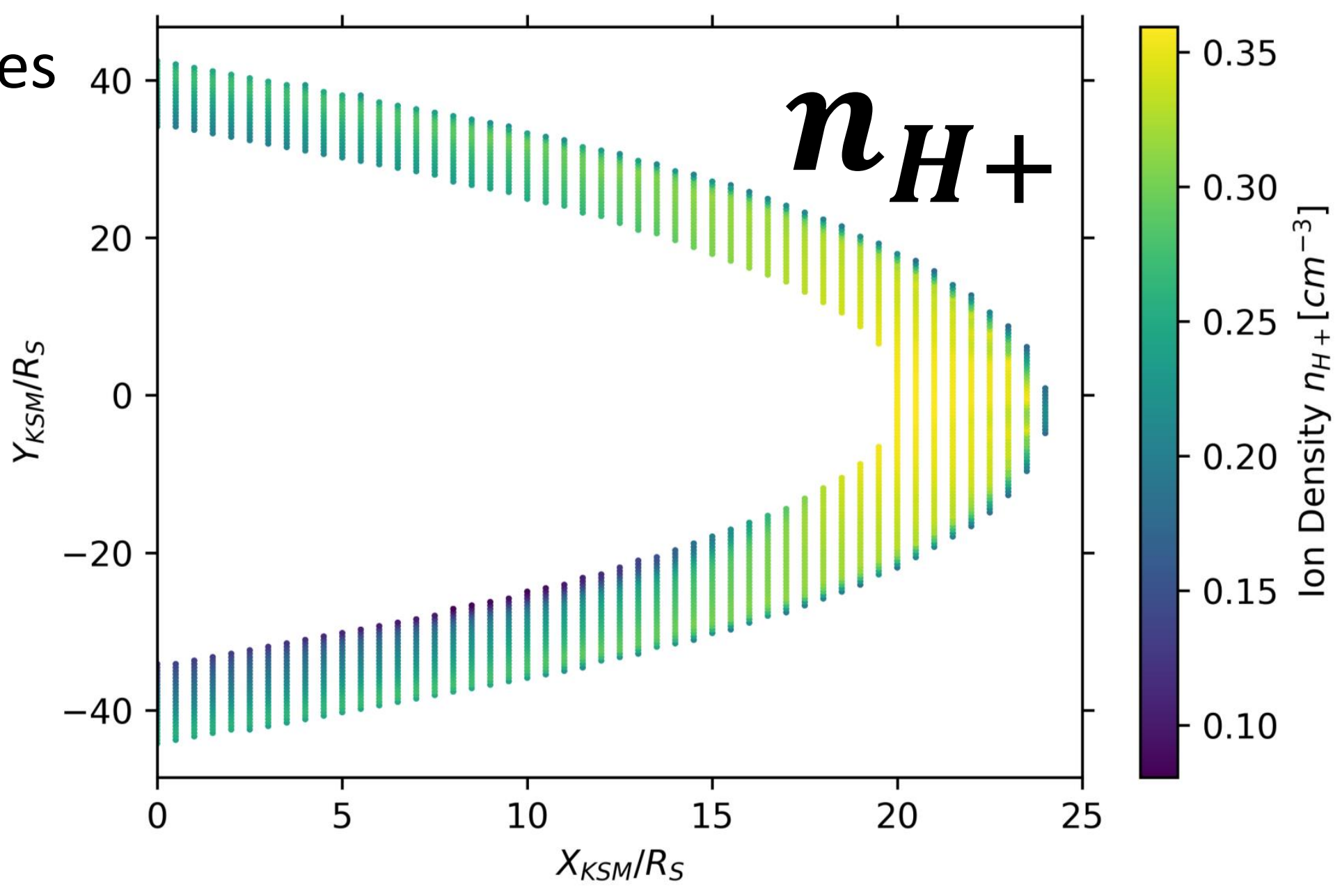


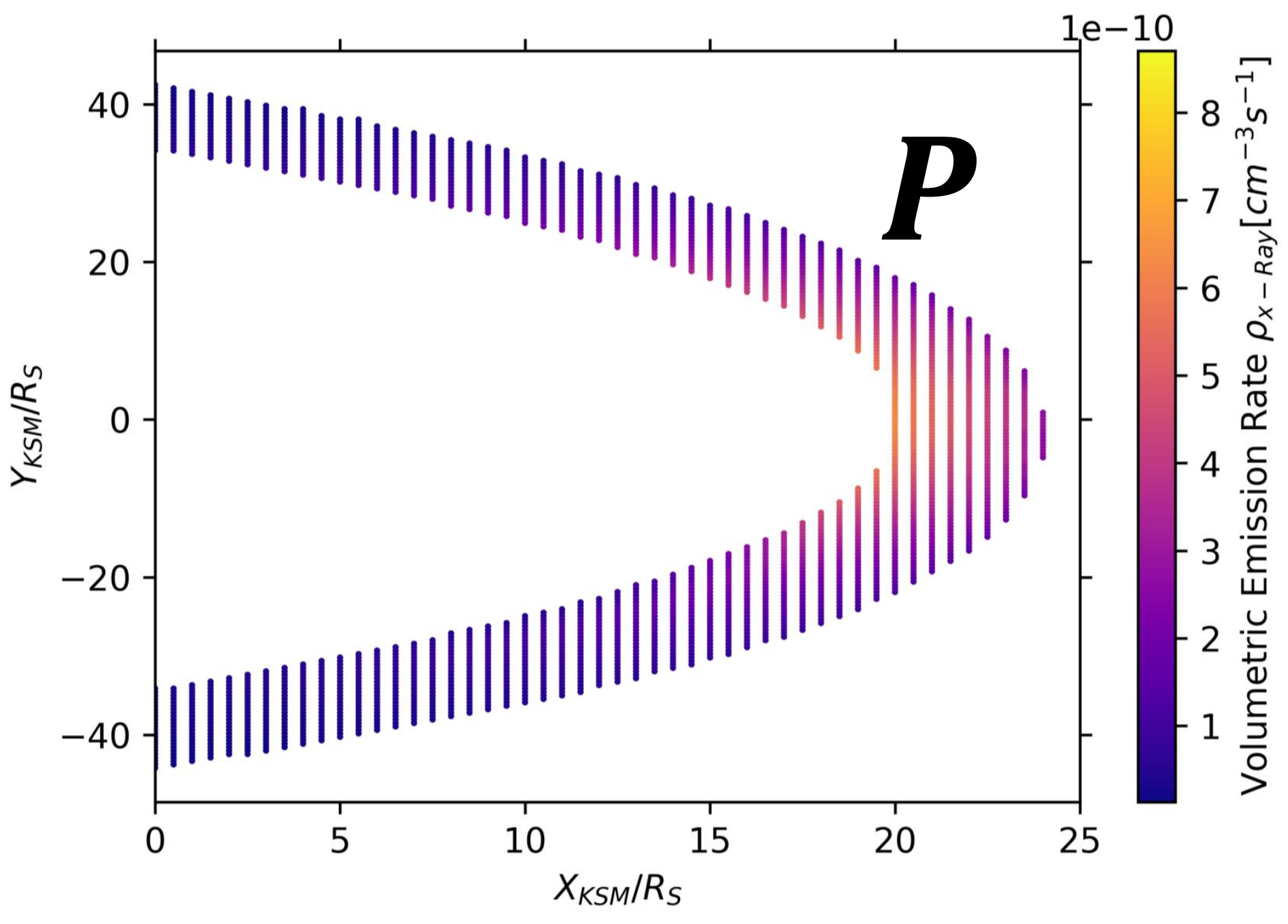
Cloud	a_n	b_n	c
H	5.46×10^2	1.66×10^{-1}	0
O	9.57×10^2	1.69×10^{-1}	2.77
OH	2.80×10^2	1.98×10^{-1}	3.55×10^{-1}

Model 1 Specifics and Results

Magnetosheath ion densities and velocities from 3D MHD simulation (Jia et al., 2012)

- Bow shock location defined by discontinuity in magnetic field
- Dynamic pressure calculated from flow velocity; magnetopause imposed
- Assume sheath ion temperature of 300 eV (Thomsen et al., 2018)
- $\boldsymbol{n_H, n_O, n_{OH}}$ calculated at each point



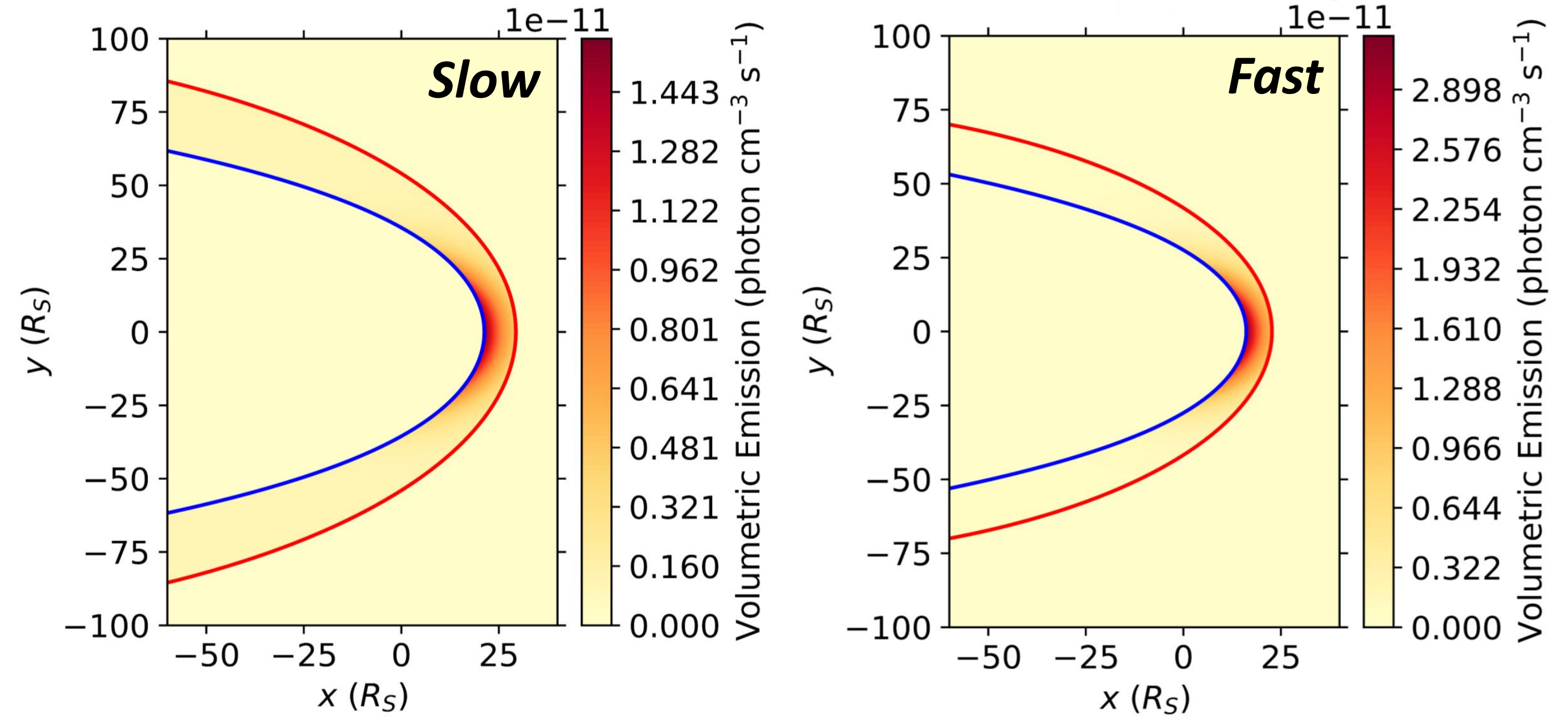


VER calculated for each point to create spatial map:

- **Significant emission region** likely exists; highest intensity at nose
- **Neutral density** is strongest predictor of VER; Hydrogen contributes most as more widely distributed
- **Collision velocity** plays reduced role; inflates VER at flanks
- **Ion density** mostly stable across region

Model 2 Specifics and Results

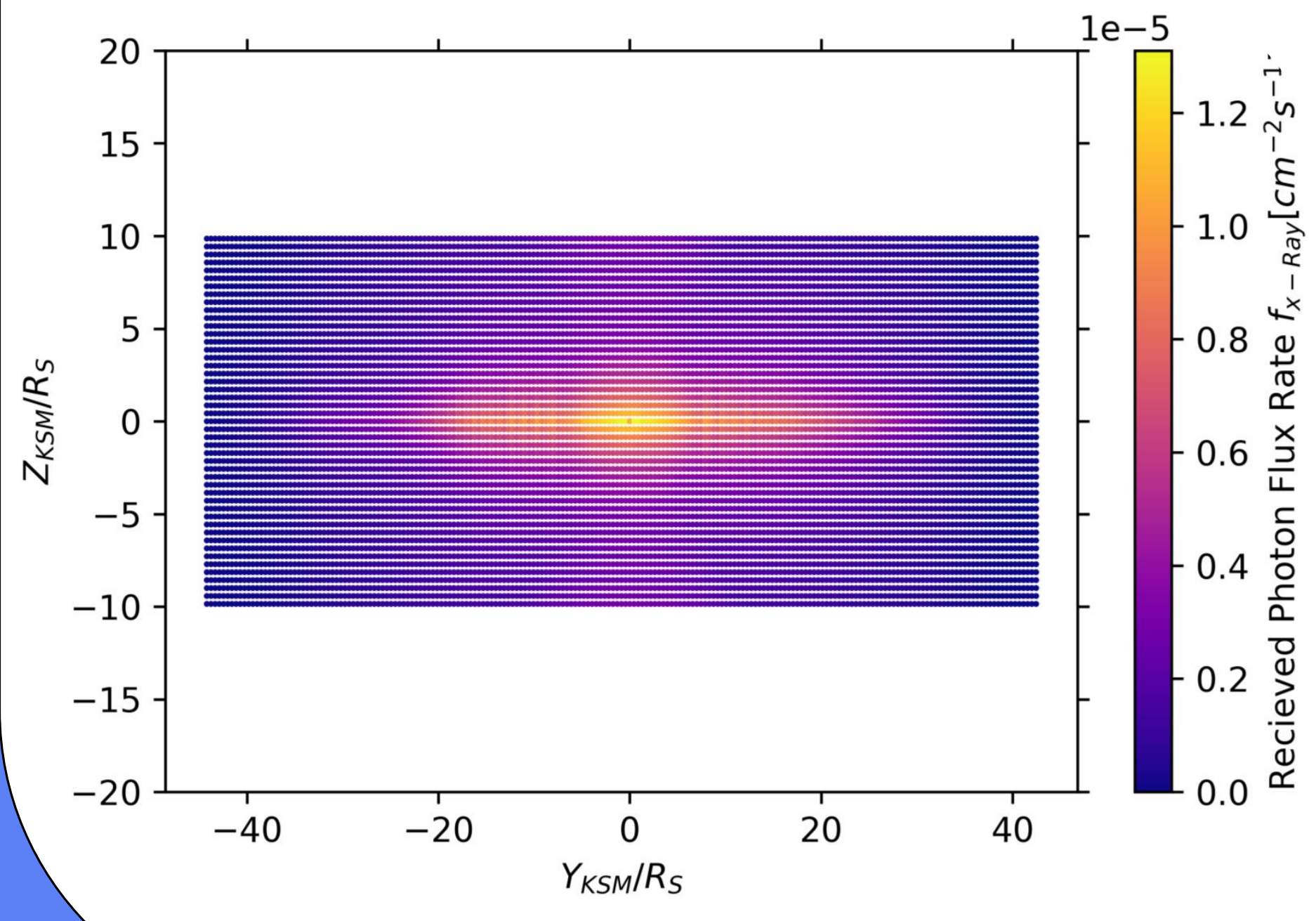
- Impose Went et al. (2011) bow shock
- Assume magnetosheath density of $n_{\mathrm{H+}}$ = 0.1 cm^{-3} (Sergis et al., 2013)
- Consider fast and slow wind conditions
  - Use O^{7+} abundances from Whittaker & Sembay (2016)
- Slow (v_{SW} = 400 km s^{-1}, D_P= 0.02656 nPa) and fast (v_{SW} = 800 km s^{-1}, D_P= 0.10624 nPa) solar wind considered; Dynamic pressure given by $D_P = n m_p v_{sw}^2$



- VER **peaks at the nose** of the magnetopause for slow and fast winds
- VER on the **order of 10^{-11} photon cm^{-3} s^{-1}**
  - **Higher for fast wind** – peak emission ~2 × that of slow wind
  - Compressed magnetosphere leads to **more neutral material within magnetosheath** and larger v_{rel}

Imaging the Region

Both models assume a SMILE-like instrument at 303 R_S to determine if the magnetosheath can be imaged in a reasonable timeframe
SMILE SXI field of view (FOV): 15.5° × 26.5° (Sembay et al., 2016).

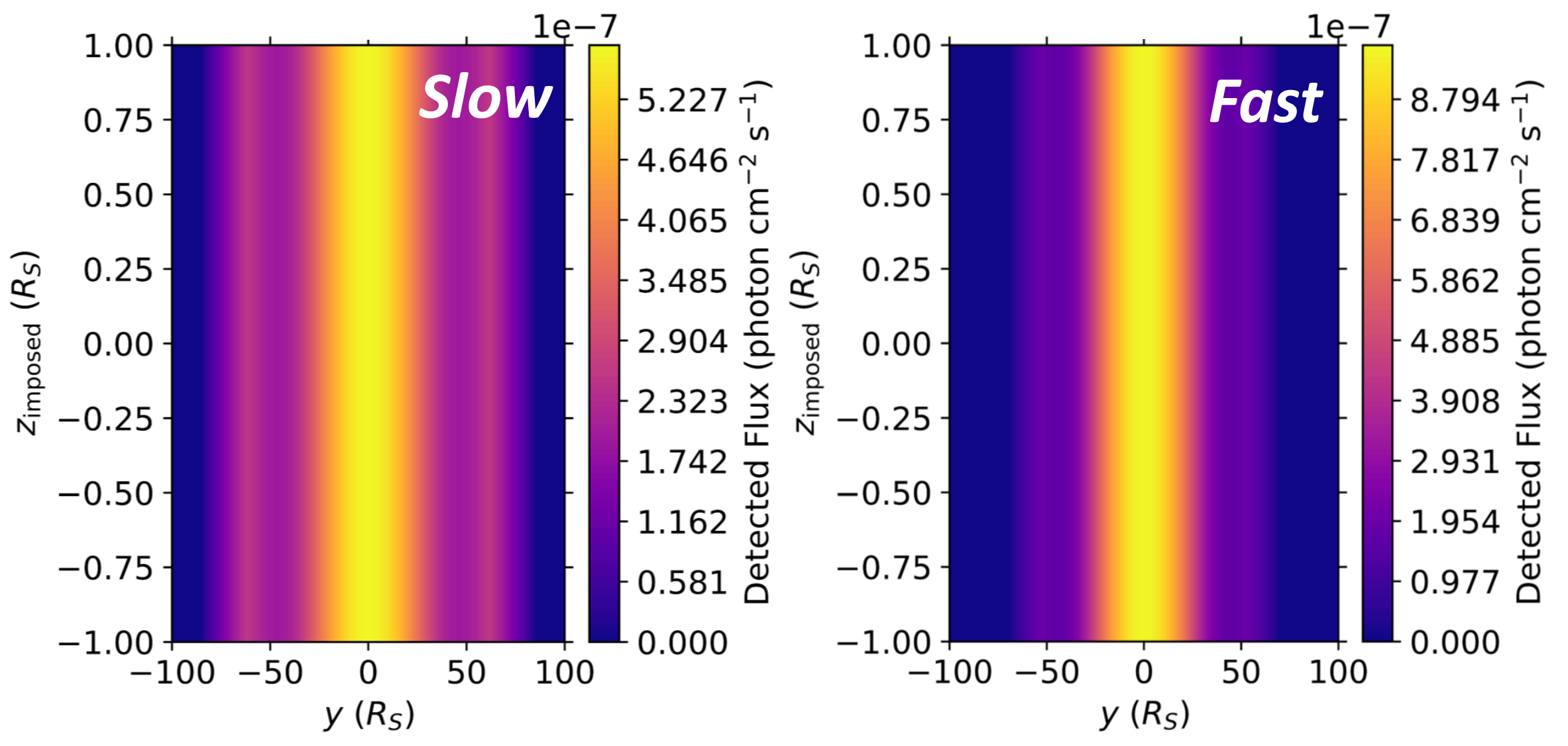


Two imaging methods explored:

- **LOS** directly in front of region
- Approximate region as **point source**

For point source approx. :

	Count Rate [s^{-1}]	**Integration time [s] (detector)**	**Integration time [hrs] (per pixel)**
303 R_S	9.77	0.102	1158
170 R_S	34.1	0.029	333



- Scale height of $\pm 1\ R_S$ imposed
- Different SXI configurations tested

	Slow (h)	**Fast (h)**
$\sim 303\ R_S$	55.3	32.9
$\sim 170\ R_S$	16.3	10.2
Double FOV	5.21	3.38

Shorter integration times required to pick out magnetospheric variability – need a closer or larger detector!

Conclusions & Future Work

Both models confirm the likely existence of a **significant emission region**; brightest emission is at the nose and reduced emission is present at the flanks:

- Neutral density is the greatest predictor of emission rate, and strongly influences spatial distribution of VER
- Higher collision velocity enhances emission rate e.g. at flanks
- Overall emission rates likely underestimate for physical system

VER comparable under fast and slow solar wind conditions

- Fast wind leads to a higher peak emission rate, but concentrated spatially
- Slow winds results in broader emission region across magnetosheath at a lower emission rate

Magnetosheath imaging possible for current generation of SXI instruments, e.g. SMILE:

- Integration times feasible for broad characterisation of magnetosheath
- Under point source approximation, flux is too low to image short-period variable behaviour; moving close enough restricts viewing picture, but allows spatial resolution

Future work to develop the model should include:

- Consideration of non-Enceladus neutral sources
- Implementation of more species-specific cross-sections
- Apply ray tracing analysis for imaging