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.

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

\[
\tau_{MP}(\theta) = \tau_0 \left( \frac{2}{1 + \cos \theta} \right)^K \quad a_1 = 10.3, \quad a_2 = 0.2, \quad a_3 = 0.73, \quad a_4 = 0.4
\]

\(\tau_0\) magnetopause nose distance, \(D_p\) dynamic pressure, \(\tau_0 = a_1D_p^{a_2}, \quad K = a_3 + a_4D_p\)

**Neutral density**
- Enceladus’ geysers provide neutral \(\text{H}_2\text{O}\)-based material for system.
- Expanded water dissociates into \(\text{OH}, \text{O}, \text{and H}\), 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).

<table>
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<tr>
<th>Model Specifics and Results</th>
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<tr>
<td><strong>Model 1</strong> Specifics and Results</td>
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- 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 \(n_{H2} = 0.1 \text{ cm}^{-3}\) (Sergis et al., 2013).
- Consider fast and slow wind conditions.
  - Use \(^{16}\)O abundances from Whittaker & Sembay (2016).
  - Slow \((v_{sw} = 400 \text{ km s}^{-1}, D_p = 0.02656 \text{ nPa})\) and fast \((v_{sw} = 800 \text{ km s}^{-1}, D_p = 0.10624 \text{ nPa})\) solar wind considered; Dynamic pressure given by \(D_p = \frac{1}{2} \rho D_p v_{sw}^2\).

- VER peaks at the nose of the magnetopause for slow and fast winds.
- VER on the order of \(10^{31} \text{ photon cm}^{-2} \text{ s}^{-1}\)
  - Higher for fast wind – peak emission ~2 \times 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).

**Conclusions & Future Work**
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.

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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.