Solar wind charge exchange X-ray imaging of the magnetosphere: comparison of the MHD and test-particle approaches

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Solar Wind Charge eXchange (SWCX) X-ray imaging of magnetospheres

Solar Wind (SW) ions charge-exchange with planetary neutrals, illuminating the magnetosheath region in X-rays.

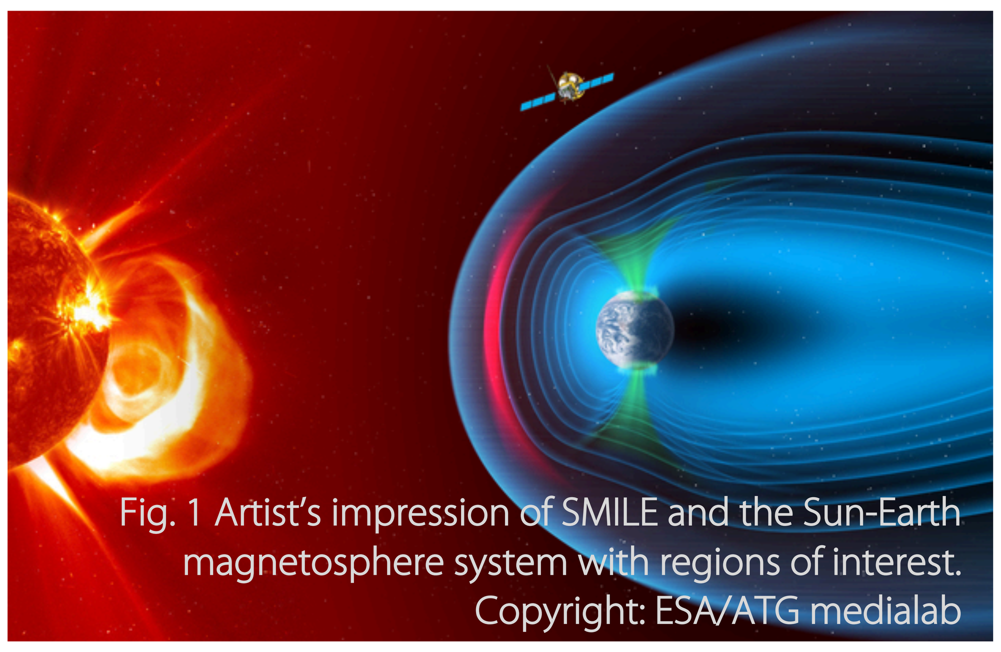
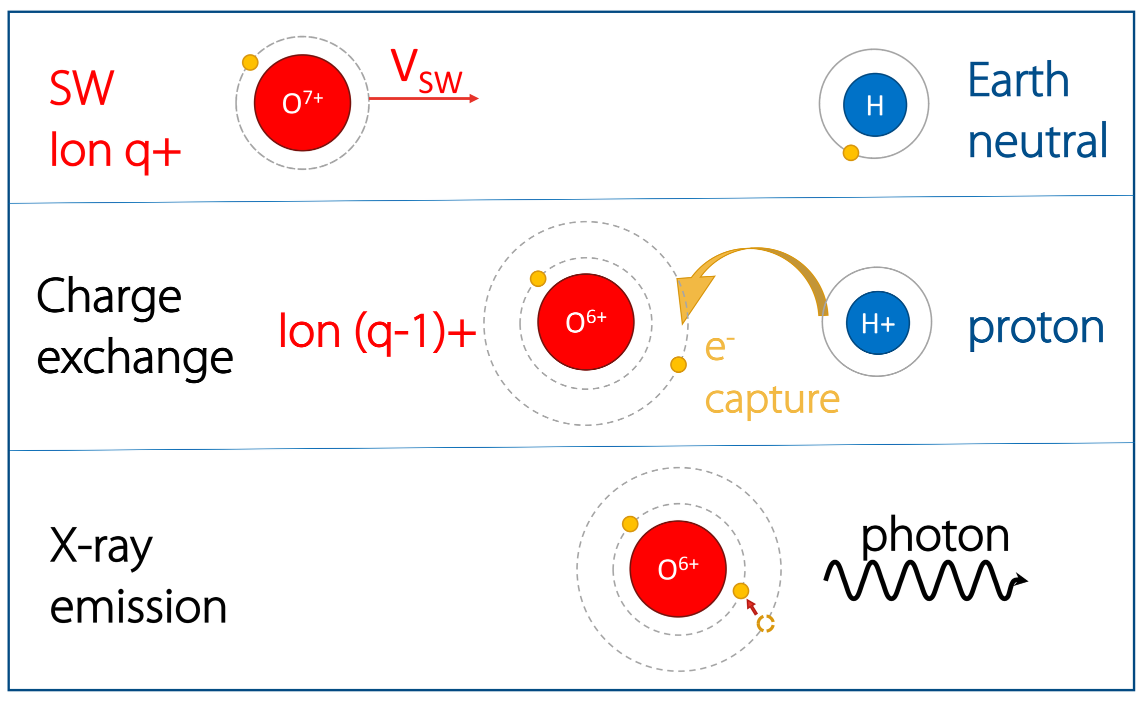
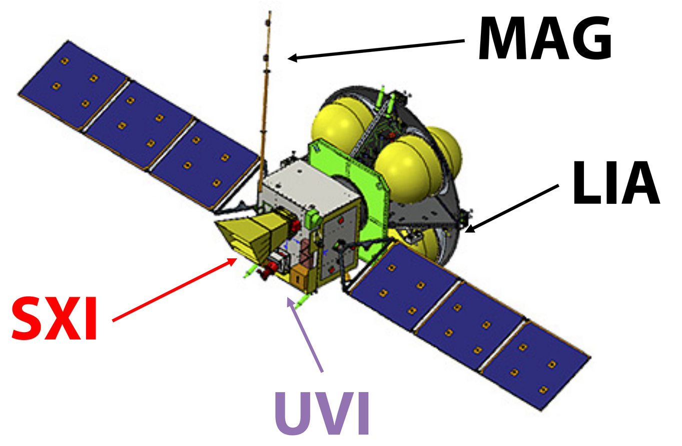


Fig. 1 Artist's impression of SMILE and the Sun-Earth magnetosphere system with regions of interest. Copyright: ESA/ATG medialab



The Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)



SMILE[a] is the first mission to investigate the solar-terrestrial interaction globally. It will combine soft X-ray imaging (SXI) of the **dayside magnetopause** and **polar cusps**, with simultaneous UV imaging (UVI) of the **auroras**, and in-situ monitoring of the SW and magnetosheath plasma conditions (LIA, MAG).

Modeling efforts

LATMOS contributes to the SMILE Modeling Working Group (MWG[b]) activities, by complementing commonly used MHD models with test-particle (TP) simulations of the near-Earth SWCX emission.

Using E/B field grids derived from OpenGGCM[c] runs, we perform TP simulations to calculate the SWCX emissivity Q and showcase the kinetic effects introduced by the ion gyromotion in the TP approach.

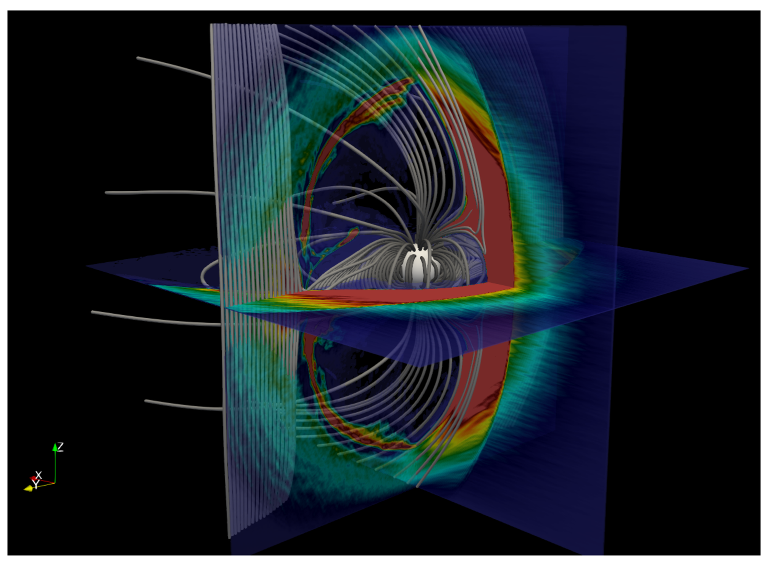
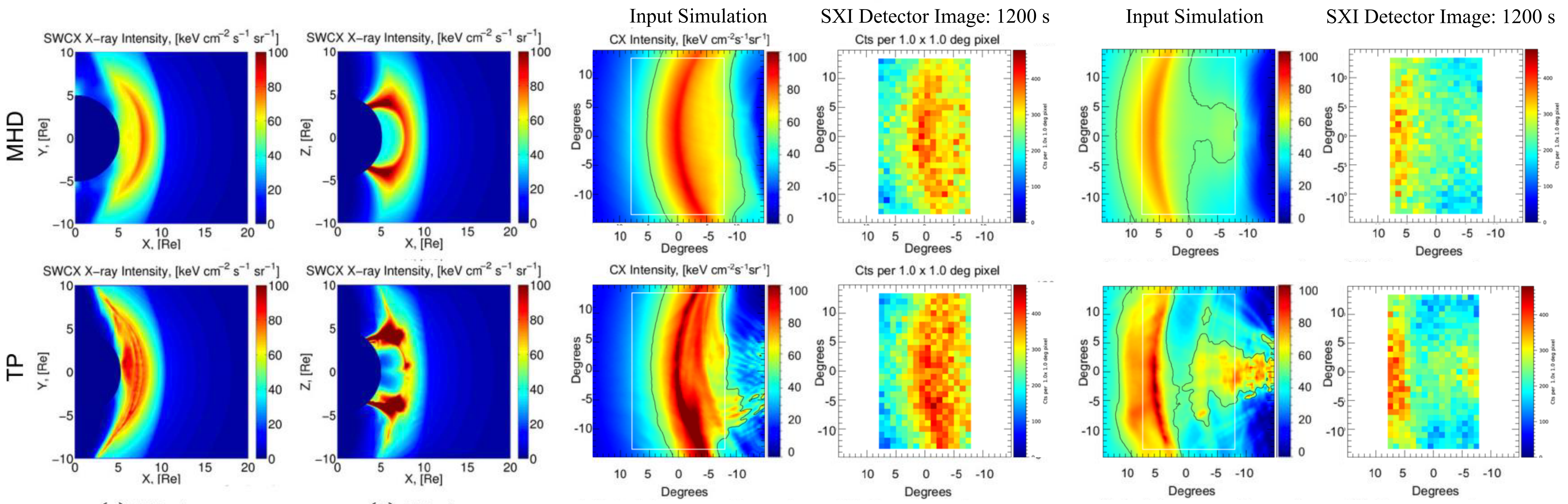


Fig. 2 SWCX emissivity cuts calculated with a TP model, traced along the Earth's magnetic field lines.

MHD / Test-Particle Results comparison[d]

Fig. 3 X-ray intensity maps for MHD (top) and TP (bottom) simulations in various generic projections (a, b) and simulated images from SMILE orbit (c, d).



(a) *XY plane* (b) *XZ plane* (c) *Orbit Position 3.76, 7.46, 17.97 GSE, Aim Point 8.04, 0, 0 GSE* (d) *Orbit Position 1.03, 0.04, 15.29 GSE, Aim Point 6.66, 0, 0 GSE*

MHD	Test-Particle (TP)
Single-fluid description	Collision probability of ion TP with Maxwellian distribution.
Self-computed E&B fields (solar & planetary origin)	Requires external E&B field input
Cross-section (C.S.) $\sigma_{X^{q+}} = const$	Separate ion cross–sections (C.S.) $\sigma_{X^{q+}} = \sigma(v_{X^{q+}})$
Compound C.S. $\alpha_H = \sum_{X^{q+},E} \sigma_{X^{q+}} Y_{X^{q+},E}(E) \left[\frac{X^{q+}}{p}\right]$	No compound C.S.
Velocity: $v_p^2 = u^2 + v_{th}^2$	Velocity $v_{X^{q+}}$ is from the Maxwellian distribution
No separate ion calculations	$Q_{TP}^{X^{q+}} \propto N_{X^{q+}}(t)\left(1 - exp(-\sigma_{X^{q+}} n_H v_{X^{q+}} \Delta t)\right)$
Total Emissivity: $Q_{MHD} = \alpha n_H n_p v_p$	Total Emisivity: $Q_{TP} = \sum_{X^{q+},E} Q_{TP}^{X^{q+}} Y_{X^{q+},E}(E) \left[\frac{X^{q+}}{p}\right]$

Discussion:

- TP results consistent with MHD input barriers (Fig. 3a, b).
- TP exhibits more complex structure, highlighting kinetic effects (re-acceleration in subsolar region - Fig. 3b).
- TP soft X-ray emission more intense, especially in the cusps (Fig. 3b, d).
- SXI synthetic images suggest that observations may grasp such effects (Fig. 3c, d).

[a] Branduardi-Raymont et al., 2020, EGU Conference Abstracts, 10783
[b] https://smile.alaska.edu/, [c] Raeder et al., 1998, JGR, 103, 14787
[d] Tkachenko et al., 2021, Proceedings of the SF2A-2021.

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