EPSC Abstracts
Vol. 8, EPSC2013-142, 2013
European Planetary Science Congress 2013

Exospheric solar wind charge exchange (SWCX): XMM-Newton observations, and modelling

J. A. Carter (1), S. Sembay (1), A. M. Read (1) and M. Palmroth (2)
(1) Department of Physics and Astronomy, University of Leicester, Leicester, U.K., (2) Finnish Meteorological Institute, Helsinki, Finland (jac48@le.ac.uk / Fax:+44-116-2522770)

Abstract

We will discuss evidence of exospheric solar wind charge exchange (SWCX) X-ray emission, as observed by the observatory XMM-Newton[1]. We will also discuss efforts to model this emission, using inputs from global hydrodynamical simulations of the plasma conditions in the vicinity of the Earth.

1. Introduction

As the world becomes more dependent on complex technology, both in space and on the ground, it becomes more exposed to the vagaries of space weather; the conditions on the Sun and in the solar wind, magnetosheath and magnetosphere that can influence the performance and reliability of technological systems and endanger human life and health. Current techniques for monitoring space weather, via the transportation of plasma in the Earth's environs, rely on insitu measurements. These measurements are limited by the number of spacecraft taking them, and cannot provide the global view which is necessary to understand the overall behaviour of the plasma. However, it is possible to image the Earth's near environment, through X-ray emission emitted via SWCX. Current space-based X-ray telescopes provide valuable constraints on this technique and ground-truth for proposals for purpose-built wide-field instruments designed to image large areas of the Earth's magnetosheath (the region between the magnetopause and bow shock boundaries; [1]; [3]).

SWCX occurs when high charge-state ions (e.g. C5+, C6+, N6+, N7+, O7+, O8+ and other heavier elements) in the solar wind collide with neutral atoms or molecules to produce a characteristic line emission spectrum at soft X-ray (and ultraviolet) wavelengths ([7]). SWCX occurs at many locations in the solar system (see [4] for a review), including in the Earth's exosphere. Observations with current astronomical X-ray observatories, although not optimised or designed to view this phenomenon, have provided evidence of exospheric SWCX, both spectrally and temporally. A systematic search for signatures of SWCX, using observations taken with the European Photon Imaging Camera (EPIC)-MOS instruments onboard the European Space Agency's XMM-Newton observatory ([6]), identified a set of SWCX-affected data sets ([2] and references therein). The data used covered a period from launch (1999) up to and including August 2009, from the peak of solar cycle number 23 to the beginning of solar cycle 24. The study looked for short term variability (timescale of minutes to hours) of the diffuse signal within a soft X-ray band (0.5 to 0.7 keV; the oxygen band). Variability in the diffuse signal on short timescales is a key signature of SWCX of an exospheric origin. 103 XMM-Newton observations were found to contain indications of a time-variable exospheric SWCX enhancement. Figure 1 shows the fraction of XMM-Newton observations containing SWCX plotted as a function of observation date. For comparison we show over the same period the sunspot number, which can be used as a measure of solar activity.

[1]Based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and NASA.

2. Modelling

Around the Earth the X-ray emissivity of SWCX at any point in space is directly related to the density and velocity of the solar wind/magnetosheath plasma and the density of the neutral atoms (mainly hydrogen) in the Earth's exosphere. An empirical model of exospheric X-ray emission was developed and compared with the observations ([2]). This model was limited by relatively crude estimations of the solar wind input parameters, the neutral hydrogen density in the exosphere, and the positions and shape of the magnetopause and bow shock boundaries. The Grand Unified Magnetosphere Ionosphere Coupling Simulation (GUMICS, version 4) is a global simulation code

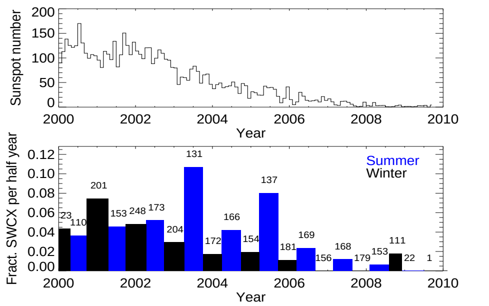

Figure 1: XMM-Newton observations affected by SWCX, and the sunspot number, versus time.

which solves the MHD equations in the solar wind and magnetosphere, developed at the Finnish Meteorological Institute (FMI; [5]). The outputs from the code are the plasma and electromagnetic field parameters in space and time (such as plasma density and pressure), in a box about the Earth. Figure 2 shows a 2-D snapshot of a GUMICS-4 simulation. The GUMICS-4 simulations will make a significant improvement to our understanding of the solar wind parameters in the vicinity of the Earth and will be used to develop the SWCX emissivity model.

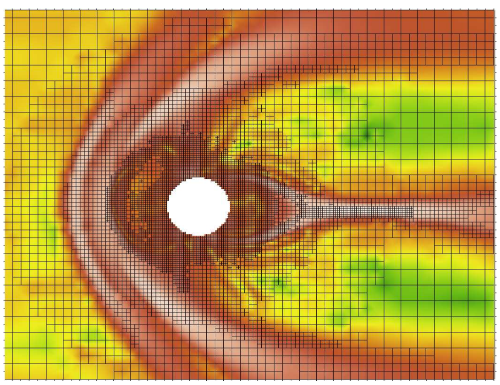

Figure 2: GUMICS-4 example snapshot of plasma density in 2-D. The Sun is to the left.

3. Summary and Conclusions

X-ray measurements of SWCX from current observatories provide a novel method of testing theoretical models of the global structure of the solar wind plasma and exospheric neutrals in geospace. They can provide proof-of-concept measurements for future ultra-wide field-of-view X-ray missions.

We will discuss how we will employ hydrodynamical simulations of the Earth's magnetic environment, under a variety of input conditions, to develop a model of emission in the vicinity of the Earth, comparing and verifying this model with the X-ray observations. The model will be used for feasibility studies for future missions, which set out to use charge exchange emission to image large areas of the Earth's magnetosheath, using wide-field X-ray optics.

References

[1] Branduardi-Raymont, G., Sembay, S.F., Eastwood, J. P. et al.: AXIOM: advanced X-ray imaging of the magnetosphere, Experimental Astronomy, Vol. 33, Issue 2-3, pp. 403, 2012

[2] Carter, J. A., Sembay, S., and Read, A. M.: Identifying XMM-Newton observations affected by solar wind charge exchange - Part II, Astronomy and Astrophysics, Vol. 527, pp. 939-947, 2011.

[3] Collier, M. R., Porter, F. S., Sibeck, D. G. et al.: Prototyping a global soft X-ray imaging instrument for heliophysics, planetary science, and astrophysics science, Astronomische Nachrichten, Volume 333, Issue 4, p.378, 2012

[4] Dennerl, K.: Charge Transfer Reactions, Space Science Reviews, Vol. 157, Issue 1-4, pp. 57-91, 2010

[5] Janhunen, P., Palmroth, M., Laitinen, T. et al.: The GUMICS-4 global MHD magnetosphere-ionosphere coupling simulation, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 80, Pages 48ó59, 2012

[6] Jansen, F., Lumb, D., Altieri, B. et al.: XMM-Newton observatory. I. The spacecraft and operations, Astronomy and Astrophysics, Vol. 365, p.L1-L6, 2001

[7] Schwadron, N. A., Cravens, T. E., Implications of Solar Wind Composition for Cometary X-Rays, The Astrophysical Journal, Vol. 544, Issue 1, pp. 558-566, 2000