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Planetary X-Ray Production by the Solar Wind Charge Exchange Mechanism

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Abstract

The most powerful x-ray source in the solar system is the solar corona, but x-ray emission has also been observed from Venus, Earth, Mars, Jupiter, Saturn, and comets. A broad review of x-ray sources in the solar system will be given in this talk, but the main emphasize will be on the solar wind charge exchange mechanism (SWCX). In particular, the talk will consider the potential for x-ray imaging to provide information on plasma structures and processes in the solar system including at Earth, Jupiter, and comets.

1. Introduction

Solar x-ray emission is associated with collisional ionization and excitation in the million-degree coronal gas. Planetary x-ray emission is due to several different mechanisms including bremsstrahlung in the terrestrial and Jovian aurorae, and scattering and fluorescence of solar x-ray photons in the atmospheres of Earth, Venus, Mars, Jupiter and Saturn. X-ray images and spectra of objects in the solar system can provide information on the solar wind and its heavy ion composition and on the distribution and flow of solar wind plasma around solar system bodies.

2. The Solar Wind Charge Exchange Mechanism

X-rays are produced by the SWCX mechanism when highly-charged solar wind ions (e.g., O^{7+}, C^{6+}, Fe^{12+},….) undergo charge transfer collisions with neutral atoms and molecules [1]. These ion species are formed in the hot solar corona and are carried out into interplanetary space. The charge exchange collision for such an ion species results in a highly-excited product ion that emits an x-ray photon. For example, O^{7+} ions colliding with atomic hydrogen produce excited O^{6+} ions, which then emit a 570 eV x-ray photon. X-ray emission by SWCX has been observed from comets (where it was first discovered, [1], [2]. [3]), from the terrestrial geocorona, and from the heliosphere. A brief review will be given of the atomic physics relevant to the SWCX mechanism.

3. Cometary X-Ray Emission

X-rays or extreme ultraviolet radiation has been detected from all comets observed in this spectral range, with x-ray luminosities often about 1 GW. For active comets this emission extends to cometocentric distances greater than 10^5 km because the cometary neutral coma does. Cometary x-ray images have been used to map out plasma morphology including the location and shape of the bow shock [4].

4. X-Ray Emission from the Terrestrial Magnetosheath

The SWCX mechanism is also known to be operating in the terrestrial magnetosheath and cusp [5]. The time-varying soft x-ray intensities measured by the Roentgen satellite are correlated with the measured solar wind proton flux just outside the magnetopause. Solar wind ions charge exchange with H-atoms in the extensive geocorona and the x-ray volume emission rate is particularly large downstream of the bow shock. This emission presents an opportunity to image the solar wind plasma surrounding the terrestrial magnetopause and to study how this important region evolves during the course of a magnetic storm. Plans are underway to build an x-ray imager to measure these emissions and use them to help understand how the solar wind interacts with the Earth's magnetosphere [6].

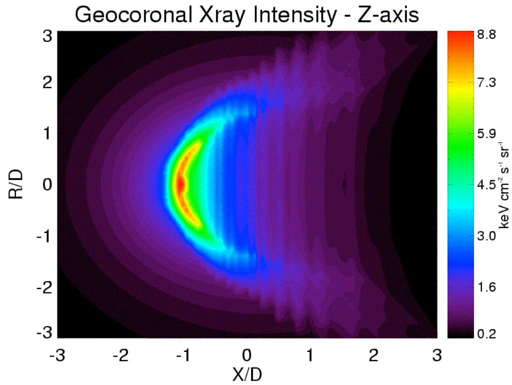

Figure 1: Simulated x-ray image of the terrestrial magnetosheath as viewed from the flanks. The magnetopause and bow shock are evident. From [5].

5. X-Ray Emission from Jupiter

X-Intense auroral emission has been observed from Jupiter across the electromagnetic spectrum (visible, ultraviolet, infrared, and x-ray) [7]. The emission from the main auroral oval is in the ultraviolet, but the x-rays are observed from the polar caps with a luminosity of about 1 GW. X-ray spectra measured by the Chandra X-Ray Observatory and by the XMM-Newton observatory include lines showing that precipitating magnetospheric oxygen and sulfur ions are responsible for this emission [8] [9]. Charge exchange collisions are thought to cause the x-rays but, unlike in the solar wind, these ions must be accelerated to MeV energies in order for collisions with Jupiter's neutral atmospheric gas to strip the incident ions of most of their orbital electrons. X-ray images provide information on magnetosphere-ionosphere coupling processes at Jupiter.

6. Summary

X-ray emission has traditionally been a diagnostic tool for hot plasmas (e.g., solar corona, supernova remnants, intragalactic medium…). X-ray emission from the solar wind charge exchange mechanism (or similar mechanisms) can be a diagnostic tool for the understanding and imaging of plasmas at the Earth, Jupiter, comets, and other solar system objects.

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