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【論文の内容の要旨】

Solar wind charge exchange (SWCX) is a ubiquitous phenomenon throughout our solar system. In the vicinity of Earth, solar wind plasma interacts with neutral materials in the Earth's exosphere or geocorona. Highly charged solar wind ions such as O^{7+} strip an electron from exospheric neutral atoms (mainly H atoms). The electron first enters into an excited state but soon cascades to the ground state by emitting soft X-ray photons. This phenomenon is called geocoronal SWCX. Similar phenomena to produce soft X-rays have also been observed from a number of comets and other solar system planets.

Geocoronal SWCX emission often contaminates astronomical signals of interest as temporally variable backgrounds, e.g., enhanced backgrounds with time scales of several hours to a couple of days as observed during the ROSAT All-Sky Survey (e.g., Snowden et al. 1994). Such signals have also been detected with X-ray CCDs onboard Chandra, XMM-Newton, and Suzaku (e.g., Wargelin et al. 2004; Snowden et al. 2004; Fujimoto et al. 2007). A spatial distribution of geocoronal SWCX emission is expected to be strong at the Earth's dayside magnetosphere, e.g., the nose of the magnetosheath and polar cusps. However, it remains difficult to predict some observational properties such as time series and overall flux levels for arbitrary spacecraft look directions.

The X-ray Imaging Spectrometer (XIS) onboard Suzaku has one of the highest

spectral sensitivities to geocoronal SWCX emission. The low-Earth orbit of Suzaku allows us to observe one of the strongest emitters, i.e., polar cusps. Making the most of such instrumental and orbital advantages, we analyzed five Suzaku detections of bright geocoronal SWCX events (Fujimoto et al. 2007; Ezoe et al. 2010; Ezoe et al. 2011; Ishikawa et al. 2013; Ishi et al. 2019). For each observation, we selected regions outside astronomical source(s) within the XIS field of view (FOV) and extracted X-ray light curves in the 0.5–0.7 keV band. This band contains O VII and O VIII emission lines. The 0.5–0.7 keV count rate showed a significant correlation with solar wind fluxes measured by WIND and ACE satellites. This is one of the most explicit signatures of geocoronal SWCX events. The enhanced spectra contained a series of emission lines from highly charged carbon, nitrogen, and oxygen ions. Some minor emission lines from highly ionized neon, magnesium, and silicon were also detected. Among them, we focused on the strongest oxygen emission lines, i.e., O VII and O VIII. These line fluxes reached several tens of photons s^{-1} cm^{-2} str^{-1}.

We then built an empirical model of geocoronal SWCX emission. The O VII emission lines are produced by O^{7+} ions undergoing charge exchange to become excited O^{6+} ions, while the O VIII emission lines are produced by O^{8+} ions. These ion densities and velocities were taken from ACE/SWICS. To describe neutral exospheric densities as a function of radial distances from the Earth, we adopted a simplified formula of Cravens et al. (2001). Charge exchange cross sections for each transition of O^{7+} (seven transitions) and O^{8+} (five transitions) ions were taken from tabled values of Bodewits et al. (2007). Magnetopause and bow shock positions were determined from empirical models of Shue et al. (1998) and Merka et al. (2005). To consider cusp geometries, we used magnetic field models of Tsyganenko & Sitnov (2005). Using the Rankine–Hugoniot equations, we took into account the effect that solar wind plasma slows abruptly and becomes denser and hotter when crossing shock fronts. We estimated the sum of model uncertainties to be a factor of 3–5.

Comparing observation and model results, we found that the modeled average intensities of O VII emission lines were consistent with the observed ones within a factor of three except for an event in which a line-of-sight direction was toward the night side of the Earth's magnetosphere and a major geomagnetic storm was observed. During such geomagnetic storms, more solar wind particles can penetrate into the Earth's magnetosphere and may be responsible for soft X-ray emitters. Those of O VIII emission lines were underestimated by a factor of three or more. Further uncertainties might exist in solar wind data concerning highly stripped ion states. We also found that the modeled O VII and O VIII light curves after scaling reproduced the observed ones including some spike behaviors due to line-of-sight directions passing through polar cusps during an orbital motion. This supports the idea that the strongest emitters are present in polar cusps and geocoronal SWCX emission is useful for capturing cusp geometries.

Future high-resolution X-ray spectroscopy missions such as XRISM and Athena will provide us with more fundamental information such as solar wind compositions, kinematics, and charge exchange processes. Future wide-FOV X-ray imaging missions like GEO-X will provide us with global views of the Earth's dayside magnetosphere, i.e., maps of geocoronal SWCX emission. The results described in this thesis will be quite valuable for such missions.