Suzaku Detection of Diffuse Hard X-ray Emission around Jupiter : Inverse Compton Scattering by MeV electrons ?

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Abstract

Our detection of diffuse hard X-ray emission around Jupiter with Suzaku XIS is reported. To investigate X-ray emission from Jupiter, Suzaku XIS observation data are analyzed. Thanks to the lowest particle background among all X-ray CCDs in orbit, diffuse X-ray emission around Jupiter is detected in 1–5 keV with the X-ray luminosity of $\sim 3 \times 10^{15}$ erg s^{-1}. Its emission spatially coincides with the Jupiter's radiation belts and Io's orbital path. Its spectrum is represented by a power law model with a photon index of ∼1.4. The emission is discussed in the context of the origin and emission mechanism.

Key words: planets and satellites: individual (Jupiter, Io) — X-rays

1. Introduction

Jupiter is the most luminous planet in the solar system in X-ray wavelength (Bhardwaj et al. 2007). It shows X-rays from auroral regions which is composed of bremsstrahlung emission and charge exchange emission lines. The Jovian disk also shows scattered radiation of solar X-rays. Temporal changes in the spectral shape and intensities have been observed in the past Chandra and XMM-Newton observations. A typical X-ray luminosity of Jupiter from the whole region reaches up to $\sim 10^{16}$ erg s^{-1}.

Jupiter is also known to host the largest magnetosphere in the solar system. Past in-situ measurements and ground-based radio observations revealed an existence of relativistic electrons with energies up to 50 MeV in the magnetosphere (e.g., Bolton et al. 2002). In order to investigate possible diffuse X-ray emission from these energetic particles, we analyzed Suzaku data of Jupiter.

2. Observation

Suzaku observed Jupiter on 2006 February 24-28. We analyzed archival data of the X-ray Imaging Spectrometer (XIS). During the observations, Suzaku repointed four times to follow the motion of Jupiter in the sky (∼ 1 arcmin per day). The net exposure of the FI (Front Illuminated) and BI (Back Illuminated) chips was 159 ks. Thanks to the low earth orbit of Suzaku and large effective area, the XIS has the lowest particle background among all X-ray CCDs in currently available X-ray observatories. Thus, the XIS data allows us to search for the possible diffuse X-ray emission around Jupiter with the highest sensitivity.

3. Data Analysis

3.1. Imaging analysis

In order to examine emission from the vicinity of Jupiter, we firstly checked 0.2–1 keV BI and 1–5 keV FI images without corrections of satellite and planetary orbital motions. Then, we found extended X-ray emission along the Jupiter's orbit in both 0.2–1 and 1–5 keV bands. Because bright spots of the emission moves following to the Jupiter's orbital path, we concluded that the emission is associated with Jupiter.

Next, we corrected the X-ray images for the satellite and Jupiter's orbital motions using the photon arrival time and CCD position. We utilized an ephemeris provided by the Jet Propulsion Laboratory. In addition, we removed unwanted contribution due to point sources from the 1–5 keV image. Using a point source detection program in the Chandra data analysis software package and checking the obtained source list by eye, we detected 20 point source candidates with 1–5 keV X-ray fluxes of $1 \sim 3 \times 10^{-14}$ erg s−1 cm^{-2}. The source number is consistent with the canonical cosmic X-ray background

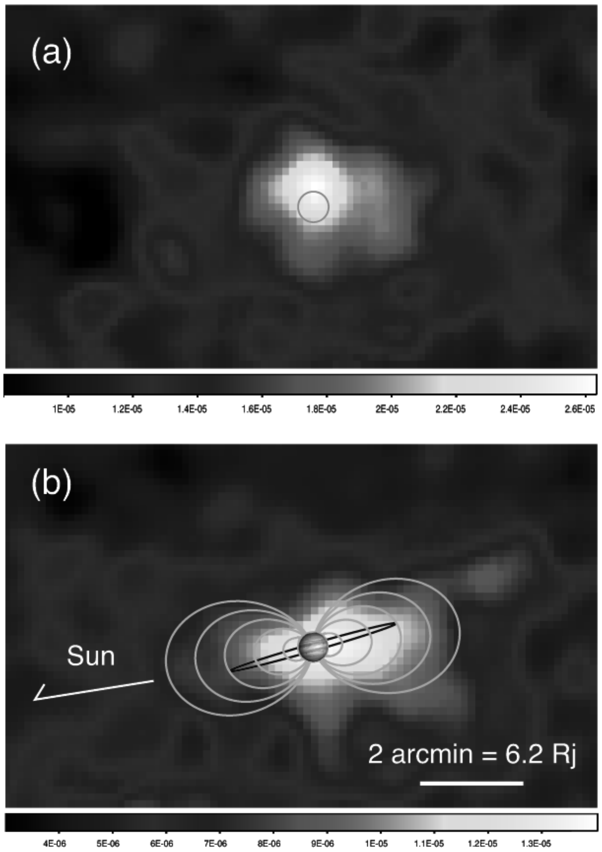

Fig. 1. (a) 0.2–1 keV BI and (b) 1–5 keV FI images of Jupiter. Vertical axes are count sec^{-1} pix^{-1}. The satellite and planetary orbital motions are corrected. In the 1–5 keV image, unwanted point sources are removed before the orbital motion correction. Grey lines are the equatorial crossing of magnetic field lines at 2, 4, 6, and 8 $R_{\rm j}$ (Jovian radius). In the panel (a), a circle shows the size and position of Jupiter. In the panel (b), a photograph of Jupiter taken by Cassini is overlaid. A black line indicates the Io's orbit.

model (Giacconi et al. 2001).

Figure 1 shows the obtained X-ray images after the corrections of the orbital motions and point sources. We detected significant extended 1–5 keV emission associated with the Jupiter's magnetosphere and Io's orbit. Its morphology is totally different from that in the soft X-ray band, whose spatial distribution is consistent with the emission from a point source or Jupiter. The X-ray luminosity of the extended emission is $(3.6\pm0.4)\times10^{15}$ erg s^{-1} in 0.2–1 keV and $(3.3\pm0.5)\times10^{15}$ erg s^{-1} in 1–5 keV. Here errors are 1σ.

3.2. Spectral analysis

To know the characteristics of the extended X-ray emission, we investigated its X-ray spectrum by extracting photons from the vicinity of the extended emission (r3 arcmin). For simplicity, we used event files without the orbital motion corrections. As a background, we extracted counts from the surrounding region with an outer radius of 6 arcmin. In these procedures, the possible point source regions are excluded. The obtained spectrum showed a featureless power-law continuum with a photon index of 1.4±0.2 in the 1–5 keV band. An absorption component was unnecessary.

4. Discussion

We detected significant extended hard X-ray emission around Jupiter. Using a projected profile and a point spread unction of the XIS, we estimated that a contribution from Jupiter to the extended emission is at most about half. Hence, at least about half of the emission should arise from a truly diffuse component.

We considered possible contamination of faint background point sources which were missed in our point source detection procedure. Because we have corrected the image for the Jupiter's orbital motion, any undetected point sources near the Jupiter's orbital path can be seen as the extended emission in the orbital motion corrected image. Due to the almost symmetric morphology of the emission against Jupiter, this requires symmetric spatial distribution of the sources. We concluded that this is rather unlikely, because, even if we assume one source in the path and extract it from the image, there still remains the extended emission. Thus, the emission can be truly diffuse.

The possible emission mechanism to explain the diffuse emission with the flat continuum is nonthermal processes such as synchrotron, bremsstrahlung, and/or inverse Compton scattering. The synchrotron emission can be rejected because it requires TeV electrons under a relatively weak magnetic field around Jupiter ($\sim$ 0.01 G at 6 $\rm R_j$). The bremsstrahlung emission is also difficult because the X-ray spectrum should be accompanied with strong emission lines from logenic O and S ions, which are main ion constitutions of the plasma.

The only possible mechanism is thus inverse Compton scattering. It is possible in terms of photon energy because the known MeV electrons can kick solar photons to be X-rays. However, the electron number density should be more than an order of magnitude larger than the empirical charged particle model of Jovian magnetosphere (Divine & Garret 1983), in order to explain the observed X-ray luminosity from the apparent volume. We need further X-ray observations with high sensitivity to know the characteristic of the emission.

References

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