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Effects of Auroral Ion Precipitation at Jupiter

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Abstract

Auroral emissions from Jupiter have been observed across the photon spectrum including ultraviolet and x-ray wavelengths. UV observations suggest an input flux power of 10^{13} – 10^{14} W for the aurora in each hemisphere. The Einstein Observatory, the Roentgen satellite, the Chandra x-ray Observatory (CXO), and XMM-Newton have observed x-ray emissions with a total power of about 1 GW. Previous theoretical studies have shown that precipitating energetic sulfur and oxygen ions can produce the observed x-rays. This study focuses on the ion precipitation of the polar region and its effects in the ionosphere. We present the results of a hybrid Monte Carlo model of oxygen ion precipitation at high latitudes that calculates the secondary electron production due to the oxygen ion precipitation for the first time. We analyze the secondary electron fluxes due to the ion aurora, estimate their effects on the ionosphere, calculate the downward current carried by ions and electrons, and estimate airglow emissions due to these secondary electrons. We find that the secondary electrons originating from energetic ion aurora affect the ionosphere similarly to auroral electrons responsible for the diffuse UV aurora and are therefore important for the magnetospheric dynamics and our better understanding of the ionosphere-magnetosphere coupling.

1. Introduction

Jupiter's powerful x-ray aurora was first observed by the Einstein X-ray Observatory in 1979 and 1981[17], when emissions were detected for photon energies from 0.2 to 3.0 keV. Observations carried out over an extended period of time have shown that there are two sources of x-rays coming from Jupiter: a high latitude source from the aurora [17, 19] (see [2] for a review) and a low latitude source due to scattering of solar x-rays. For the high latitude x-ray source [17] proposed a K-shell emission mechanism caused by heavy ions (mainly oxygen and sulfur) precipitating into the upper atmosphere. Observations by the Chandra X-ray Observatory (CXO) advanced CCD imaging spectrometer (ASIS) [9, 8] as well as observations by XMM-Newton [3, 4, 5] indeed showed a predominantly line emission spectrum instead of a continuum.

The heavy ion model proposed was further developed [10, 6, 13, 14, 15, 11, 12, 18] to more accurately model the observed data and to investigate the collisional and acceleration mechanisms needed to produce x-rays. In particular, [6] explained that electron removal collisions (i.e., stripping collisions) produce high-charge state ions (e.g., O^{7+} and O^{8+}), which collide with atmospheric H_2 emitting x-rays. Recently, [18] modeled the x-ray emissions due to high-charge state oxygen and sulphur ions and found that energies between 1 – 2 MeV/u are most efficient in producing the observed x-ray emissions and that opacity and quenching effects are significant to model the observed spectra for the observation geometries (see Figure 1).

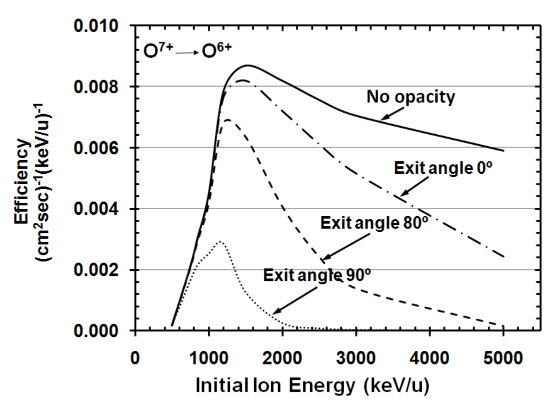

Figure 1: Outgoing x-ray photon flux efficiency as a function of initial beam energy for O^{6+} production with different opacities.

2. Secondary electrons from ion precipitation

Ionization and stripping collisions from ion precipitation will also produce secondary electrons as they are ejected either from the target atmospheric neutral or from the projectile ion. [10] calculated the energy distribution of secondary electrons due to oxygen ion precipitation. However, at that time there was insufficient information regarding the single differential cross sections needed for this calculation. Therefore, they used the single differential cross section for secondary electron production in a proton collision with H_2 as an approximation. This cross section is not expected to accurately simulate the behavior obtained with a heavier oxygen ion instead of the proton.

Since their work, not much progress has been made in modeling the secondary electrons from the ion aurora at Jupiter. Therefore we find our present work to be a significant contribution to the area. We have performed for the first time comprehensive calculations of the single differential cross section for secondary electron production in a collision between an energetic oxygen ion and H_2, covering all ionization stages and channels (single ionization, double ionization, single stripping, double stripping, transfer ionization, DCAI). We use the Monte Carlo method developed by [18] and the new single differential cross sections for ionization and stripping processes to model the auroral ion precipitation and calculate the secondary electron production rate due to oxygen ion precipitation in Jupiter's auroral region at different altitudes (see Figure 2).

3. Results

From our model we find that the bulk of the secondary electrons has energies smaller than 100 eV and that the electrons originate mostly from ionization collisions. The stripping collisions give rise to a high energy "tail" in the electron energy distribution. In order to estimate the overall effect of the ion aurora, we calculate the electron fluxes due to an ion precipitation of 10^6 oxygen ions/cm^2/s, required to obtain the observed 1 GW of x-ray power, given an x-ray efficiency of 10^{-4} [18]. We use the calculated electron production rates to calculate upward and downward electron fluxes along a radial magnetic field line at the auroral region using the two-stream approach [1]. We find that the escaping electrons from the ionosphere carry a downward current of $\sim$0.5 MA. Together with the

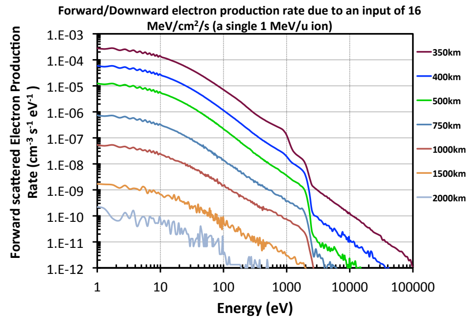

Figure 2: Secondary electron production rates for forward scattered electrons at different altitudes in the atmosphere due to precipitation of a single oxygen ion/cm^2/s

precipitating ions this would imply a total downward current of $\sim$1 MA. This value is in agreement with estimates of currents needed to accelerate the ion to MeV/u energies needed for the x-ray production [7]. We use our modeled secondary electron fluxes to calculate the airglow emissions. We find that the secondary electrons due to 2 MeV/u oxygen ions with the above-mentioned flux should produce emissions in the UV Lyman and Werner bands with an intensity of 10 – 20 kR. This is much smaller than the bright emission seen at the oval. However, it is comparable to fainter emissions that have been observed due to diffuse electron aurora. Although we have not yet calculated opacity effects to the airglow emissions, some of the emission due to the secondary electrons should be observable.

4. Summary and Conclusions

We calculate for the first time the secondary electron production due to energetic ion precipitation at high latitudes in Jupiter responsible for the observed x-ray aurora. We find that the secondary electron effects in the ionosphere are significant and of interest to possible future observations. We estimate that airglow emissions due to the secondary electrons should be observable, even if opacity is considered. We also calculate the electron fluxes in the ionosphere and estimate that the upward escaping electrons may carry a downward current of about 0.5 MA.

Acknowledgements

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