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On a source of electron impact ionization in Io's upstream atmosphere

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Abstract

A mechanism for the ionization of Io's atmosphere due to the moon's motion through the Jovian magnetic field is considered. Attention is paid to the important role of charge separation in the upstream part of Io's ionosphere and accumulation of electrons and positive ions on the low and top ionospheric boundaries which results in (a) the creation of longitudinal component (with respect to the Jovian magnetic field lines) of polarization electric field, (b) the driving of Bounemann plasma turbulence, and (c) the heating of electrons and the ionization of neutrals. Estimations show that the proposed mechanism can essentially heat the electrons and increase the electron density. The increase with the plasma density and the electron temperature can result in an ionospheric plasma distribution and overcomes the difficulty with generation of the most bright part of UV emission of the Io's equatorial spots.

1. Introduction

In the present report we would like to pay an attention to the important consequence of electromagnetic interaction of the Jovian magnetic field and the Io's plasma environment. In the upstream side of Io's ionosphere the electron temperature and the plasma density can be higher than compared to modern MHD models of the interaction between Io and Jovian magnetosphere (see, for example [1, 2]). The point is that in the upstream side of Io's ionosphere there is a polarization electric field created by electrons and positive charges which are accumulated on the low and top ionospheric boundaries, respectively. This electric field has a longitudinal component (with respect to the Jovian magnetic field lines) which is ignored in the MHD models.

2. Model

When the layer of partially ionized ionospheric plasma moves through the Jovian magnetic field, an electric field $\vec{E}_{\rm i} = \frac{1}{c}[\vec{V} \times \vec{B}_0]$ is induced in the Io's ionosphere (Fig. 1). Due to anisotropic conductivity of Io's ionosphere this electric field $E_{\rm i}$ drives a system of electric currents. The Pedersen current flows parallel to Io's equator (in the *y* direction on Fig. 1) and closes, for example, via Alfven wings in the Jovian ionosphere (see, for example [3]). The Hall current flows upward

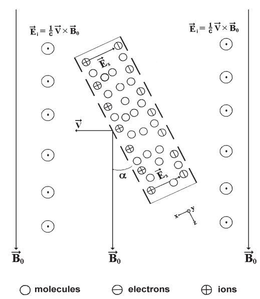

Figure 1: Schematic illustration of motion of a two-dimensional layer of partially ionized plasma through the external magnetic field [4].

in the *x* direction (Fig. 1), causing a charge separation in the ionosphere with accumulating electrons on its low boundary and positive charges on the top boundary. This charge distribution creates a charge separation electric field $E_{\rm s}$ (polarization electric field) which is directed from the top boundary of ionospheric layer to the low. This phenomenon is strongest when the electrons are magnetized and the ions are not [4]. In reality, in this case the electrons try to move along with the Jovian magnetic field but the ions move along with neutral particles in the opposite direction (in the $\vec{V}$ direction). The polarization electric field $E_{\rm s}$ has its projection $E_{{\rm s},\parallel}$ on the direction of the planetary magnetic field with a value reaching almost the value of induced electric field $E_{\rm i}$ [4]. The longitudinal electric field shifts the electron distribution function relative to the ion one by a value exceeding the thermal velocity of electrons. In this case, Bunemann instability with a very large growth rate is developed. This results in the excitation of turbulent pulsations at frequency close to the ion-sound frequency and the occurrence of anomalous resistance to the electric current. The latter causes a heating of Io's ionosphere electrons. As soon as the electron temperature T_e exceeds the threshold temperature, T_min, of electron impact ionization of neutrals, the heated electrons create secondary electrons which subsequently are heated and ionize additional neutrals. For SO_2 gas which is the main species of Io's atmosphere, $T_\mathrm{min} \simeq 12.5$ eV. The electrons lose their energy due to inelastic collisions and elastic collisions (electron thermal conductivity). Estimations of characteristic timescales of different cool processes show that the most effective channel for electron cooling in the considered region is thermal conductivity along the magnetic field.

From a balance between the heating rate due to the Bunemann instability and the cooling rate due to the electron thermal conductivity we find the connection between the parameters in the heating region [5]

$$n_\mathrm{e} \simeq (3 \times 10^5)^{-1} T_\mathrm{e}^{-3} n_\mathrm{n}^2 L_\|^2 E_{\mathrm{s},\|}^4 \qquad (1)$$

where T_e is the electron temperature, $n_\mathrm{e,n}$ is the density of electrons (e) and neutrals (n) in the heating region, and $L_\|$ is a characteristic scale of change of the electron temperature along the magnetic field.

To obtain an estimation of n_e and T_e we assume the following. Close to Io where the heating region is situated the radial distribution of the atmosphere gas is poorly understood. In accordance with atmospheric models (see, for example [5]) we assume the neutral density is a globally averaged neutral atmosphere density $n_\mathrm{n} \simeq 4 \times 10^8$ cm^{-3}. The longitudinal component of the polarization electric field reaches the highest value when the magnetic field lines are almost tangential to Io's surface. As the angle between the magnetic field lines and Io's surface increases, the electric field sharply decreases [4]. The topology of the magnetic field lines and, therefore, the electric field distribution in the heating region are uncertain. To be specific we assume that the electric field in the heating region is equal approximately to $(1/4)E_{\mathrm{s},\|}^{\max} \simeq 4 \times 10^7$ CGS units, and the characteristic scale of the electron temperature change is equal to the characteristic scale of Io's ionosphere, $L_\| \simeq 10^7$ cm. It follows from (1) that an increase of the electron density causes a decrease of the electron temperature steady in the heating region. When the electron temperature is decreased to the threshold temperature of ionization of the SO_2 molecules, T_min, the electron impact ionization of neutrals is stopped and the electron density reaches the greatest value. Assumed the steady-state electron temperature in the heating region is approximately equal to the threshold temperature of ionization of the SO_2 molecules, $T_\mathrm{e} \sim T_\mathrm{min} \simeq 12.5$ eV, we obtain from equation (1) that under the above atmospheric conditions, the electron density in the heating region can be estimated as $n_\mathrm{e} \simeq 8 \times 10^5$ cm^{-3}. These electron density and electron temperature exceed the values assumed in the known MHD models. The increase with the plasma density and the electron temperature can result in an ionospheric plasma distribution and, besides, overcomes the difficulty with generation of the most bright part of UV emission of the Io's equatorial spots.

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