EPSC Abstracts
Vol. 5, EPSC2010-36, 2010
European Planetary Science Congress 2010

Io's ultraviolet equatorial spots: Theory

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Abstract

A model for explanation for Io's ultraviolet (UV) aurora is presented. A mechanism for heating of electrons of Io's ionospheric plasma up to sufficient energies for the excitation of Io's atmospheric oxygen and emitting of observed UV emission is proposed. The mechanism operates by the effect of the different magnetization of the electrons and ions in Io's ionosphere which in the course of Io's motion through the Jovian magnetic field causes the creation of a charge-separation electric field in the frontal part of the ionosphere. This field has a component parallel to the magnetic and shifts the electron distribution function relative to the ion distribution function by a value exceeding the thermal velocity of electrons. In this case, a 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 heating of Io's ionospheric electrons up to a temperature of about 50 eV. Atmospheric oxygen molecules excited due to collisions with the heated electrons of Io's ionosphere, whose density is about $6x10^4$ cm^{-3} can ensure the observed UV brightness. The proposed model permits one to explain the correlation of UV brightness with Io's magnetic longitude and the different brightness between the anti-Jovian equatorial UV spots and the sub-Jovian spots as well.

1. Introduction

Observations of ultraviolet (UV) emission from Io's atmosphere show that brightest sources are near Io's equator (Fig. 1), about 200 km above Io's limb, which is designated "equatorial spots" [2-4]. These spots shift their position with the Jovian magnetic field orientation at Io, and the anti-Jovian equatorial spots are ~20% brighter than the sub-Jovian equatorial spots [3,4].

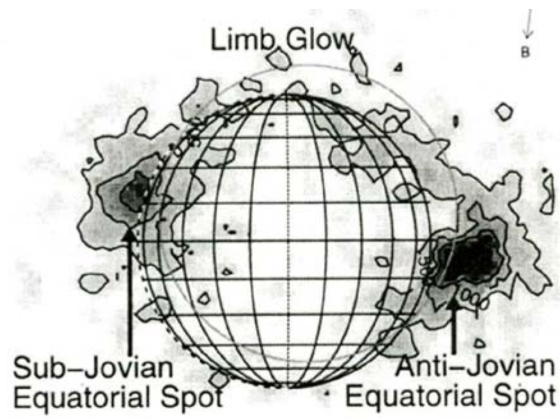

Figure 1: Image of UV emission (1356 Å) with Io, October 14, 1997. This picture was taken from [1].

It is also found that the brightness of the emissions is correlated with Io's distance from the plasma torus centrifugal equator [3]. Sauer et al. [5] proposed a model for explaining the features of the equatorial spots. According to their model, the electrons from Io's plasma torus are convected into Io's atmosphere and excite neutral oxygen due to inelastic collisions. The maximum number of collisions and maximum UV emission take place at Io's flanks where the atmospheric density is the maximum. Their model also gives an acceptable explanation for why the anti-Jovian equatorial spots are brighter than the sub-Jovian equatorial spots and why the equatorial spots are correlated with the Jovian magnetic fields orientated at Io. However, they could not explain the observed brightness of the equatorial spots.

2. Model of UV aurora

Our model is the development of the model proposed in [5]. We think that exactly the Io ionospheric electrons heated up to a temperature significantly exceeding the temperature of the equilibrium ionosphere are responsible for the excitation of neutral oxygen in the atmosphere. The general scheme of the proposed model is as follows. When Io passes the Jovian magnetic field, an electric field is induced in the satellite ionosphere, namely $\vec{E}_i = \frac{1}{c}[\vec{V} \times \vec{B}]$, where V is Io's velocity with respect to the co-rotating Jovian magnetospheric plasma, B is the magnetic field near Io, and c is the light speed. Due to the conductivity anisotropy of Io's ionosphere, the electric field $\vec{E}_i$ causes not only Pedersen currents along $\vec{E}_i$ in Io's ionosphere, but also tends to generate Hall currents whose direction in the frontal part of the ionosphere is approximately orthogonal to the moon surface. Hall currents cannot be closed through the surface due to the neutral atmosphere near the surface. Therefore, a considerable separation of charges takes place in the Io's ionosphere, which results in the creation of a charge-separation electric field, E_s. This field has its projection on the direction of the magnetic field, and its value is comparable with induced electric field E_i [6]. The charge-separation electric field shifts the electron distribution function relative to the ion distribution function by a value exceeding the thermal velocity of electrons. In this case, a Bunemann instability with a very large growth rate develops in the region where E_s acts. This results in the excitation of turbulent pulsations at a frequency close to the ion-sound frequency and the occurrence of the anomalous resistance to the electric current. Our estimates show that the ionospheric plasma in this region is heated up to a temperature of about 50 eV. According to [1], the ionospheric plasma density is assumed to be $6 \text{x} 10^4$ cm^{-3}. Since the heated electrons are magnetized, they are entrained by the Jovian magnetic field and are convected downstream, streamlining the satellite. At the flanks of Io's atmosphere (from the observer sight point), the number of collisions of electrons with neutral oxygen is the maximum; hence, we observe the brightest UV radiation, whose value, according to our estimates, can reach $3 \text{x} 10^3$ R. According to [6], the charge-separation field and therefore, the electron heating are determined by the magnetic field near Io, whose magnitude is varied with the variation in Io's magnetic longitude. Moreover, the electric field of charge separation is the maximum in the region where the Jovian magnetic is tangential to the satellite surface. This stipulates the correlation of the UV brightness with Io's magnetic longitude and the Jovian magnetic field's orientation at Io. The existence of an electric field of charge separation causes the charged particles to drift in the direction determined by the vector product $\vec{V}_d \propto [\vec{E}_s \times \vec{B}]$. As a result, the charged particles of the sub-Jovian hemisphere drift away from the satellite, i.e., towards the more rarefied atmosphere, while in the anti-Jovian hemisphere, conversely, the heated electrons drift towards the denser atmosphere. Thus, in the sub-Jovian hemisphere, the number of collisions with neutral oxygen is smaller than that in the anti-Jovian hemisphere, and the anti-Jovian equatorial spots are brighter than the sub-Jovian equatorial spots.

Acknowledgements

The work was supported by the Russian Foundation for Basic Research (project Nos. 08-02-00119-a and 09-02-90406-Ukr-f-a).

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