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Auroral ionosphere Joule heating by the magnetosphere-ionosphere slippage in the Jupiter and Saturn systems

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Abstract

All giant planets in the Solar System and particularly Saturn and Jupiter are known to have an upper neutral atmosphere far hotter than it is expected from solar extreme ultraviolet heating alone. While the measured exospheric temperatures on Saturn and Jupiter are close to 500 K and to 1100 K – 2000 K, respectively, the solar heating alone can provide an exospheric temperature only about – 200 K. Two main energy deposition mechanisms are discussed in the literature to resolve this contradictions: (1) the gravitation wave dissipation in the upper atmosphere, and (2) the auroral thermosphere Joule heating by the Pedersen ionospheric currents [1,2]. The ionospheric currents are associated with the field-aligned currents generated due to the magnetosphere-ionosphere slipping. Here we focus on the second mechanism.

1. Short description

To improve the accuracy of the numerical estimations we derived the analytic formulas which describe the dependence of the auroral energy flux on the planetary magnetic field strength, as well as on the solar wind plasma ram pressure, and on the breaking of magnetospheric plasma corotation. The last effect is essential for Jupiter, where the main oval is driven internally at Alvenic radius. We pay attention to the general physical phenomena which may be only slightly influenced/modified by the specific atmospheric composition and photochemical ionospheric reactions. A comparison with recent Cassini and Galileo data supports the importance of the polar region energy deposition for understanding of the Jupiter and Saturn dynamics.

The paraboloid model of the magnetosphere has a modular structure. The scaling relations enable to adapt the magnetopause and the tail current systems developed for the Earth's magnetosphere for the case of Jupiter and Saturn. However, there is no analogy for the currents caused by rapid planetary rotation (i.e. magnetodisk currents by Jupiter and Saturn) in the terrestrial magnetosphere. Magnetodisk is the main source of the Jupiter magnetospheric magnetic field. Its effective magnetic moment exceeds the Jupiter's dipole magnetic moment (in about 2.6 times).

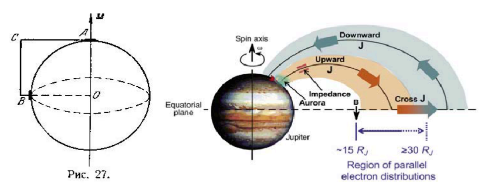

Figure 1: (Left) Generation of an electromotive force by unipolar generator: the rotating magnetized sphere with unmoved wires attached to a pole and equator by slipping contactor *Landay and Lifshitz*, [1959]. (Right) Mauk et al. [2002] : electric scheme in the concept of Hill [1979].

Unipolar generator scheme in case of Jupiter (Saturn) magnetosphere are shown in Figure 1. The relationship between observed equatorial electron field-aligned enhancements reported by Toma´s et al. [2004a, 2004b] and the circuit of electric currents that connects Jupiter's middle magnetosphere to the auroral ionosphere. The auroral circuit structure is based on concepts of Hill [1979] and Vasyliunas [1983] as replotted by Mauk et al. [2002]. It takes into account that the shape of the field lines in the actual Jovian system are substantially stretched away from the dipolar configuration

Here we investigate various flaring of the planetary magnetopause and generalize the geodipole screening current field for the case of Jupiter and Saturn. From the known boundary conditions, a solution of Laplace equation for the scalar potential of the magnetopause current magnetic field has been obtained. One of the most important energy inputs to the polar upper atmosphere is Joule heating by the ionospheric Pedersen currents. We estimate it to be ~3.0 TW for Saturn and about 1000 times more (3500 TW) for Jupiter. That represents a significant energy input to Saturn's and Jupiter's thermosphere. It is more than an order of magnitude larger as compared to the globally averaged solar input. Therefore, Joule heating may be reasonably appealed for the explanation of the observed high thermosphere temperatures by Saturn (~400–600 K) and Jupiter (1200 K).

Table 1: Planetary Magnetosphere System Parameters

Parameters (units)	Jupiter	Saturn
Heliocentric distance (AU)	5.2	9.5
Magnetic moment ($T{\cdot}km^3$)	150.	4.6
Equatorial magnetic field (μT)	420.	20.
Angular velocity (10^{-4} rad/s)	1.8	1.6
Unipolar generator *EMF* (MV)	367.	12.2
Dipole magnetic flux (TWb)	13.45	0.456
Open field line flux (GWb)	450.	11.4
Polar oval radius (degrees)	15	13
Average IMF magnitude (nT)	0.67	0.37
Solar wind ram pressure (nPa)	0.07	0.015
Subsolar magnetic field (nT)	14.3	7.8
Solar wind potential drop (kV)	720.	85.
Solar irradiance flux (10^{17} W)	5.3	1.1
Polar oval conductivity (mho)	1.	3.
Field-aligned currents (MA)	100.	12.
EUV flux in polar cap (TW)	3.6	1.3
Polar cap Joule heating (TW)	3700.	3.

6. Summary and Conclusions

The most important input in thermosphere energy budget of planets is the globally averaged solar energy flux. However our study indicates that Joule heating by the dissipating ionospheric Pedersen currents is also able to make a significant contribution. It may be in particular addressed for explanation of the observed high thermosphere temperatures by Saturn and Jupiter.

We estimate it to be ~3.0 TW for Saturn and about 1000 times higher (3500 TW) for Jupiter.

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