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Formation of magnetodisk-type current system in the escaping plasma flow of a Hot Jupiter

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Abstract

Formation of a stationary ring current system localized near the equatorial plane of a quasi-dipolar magnetic configuration is considered. As a driver for this current system, appears the expanding radial flow of partially ionized plasma. Obtained analytical solutions, numerical simulation and laboratory experiments confirm a possibility of similar effect in the inner magnetosphere of a Hot Jupiter in the presence of an expanding flow of the escaping upper atmosphere of the planet.

1. Introduction

More than a half of known exoplantes have orbits around their host stars shorter than 0.6 AU. By this, a clear maximum in the orbital distribution of exoplanets takes place in the vicinity of 0.05 AU. A close location of planets to their host stars means that they are exposed to intensive stellar radiations and plasma flows, which are stronger near a star. The stellar X-ray/EUV (XUV) radiation and the stellar wind result in ionization, heating, chemical modification, and slow erosion of the planetary upper atmospheres throughout their lifetime. The closer the planet is to the star, the more efficient are these processes. Hydrodynamic expansion of an exoplanetary upper atmosphere, heated by stellar XUV, with the consequent photo-ionization of the expanding atmospheric gas [1,2] leads to the formation of an extended, essentially dynamical planetary ionosphere and magnetosphere [3,4]. Of crucial importance in that respect appears formation of plasma *magnetodisks* around the close-orbit exoplanets resulted from the planetary rotation and hydrodynamic escape of the partially ionized upper atmospheric material [4]. The interaction of these expanding planetary partially ionized plasma envelopes with the intrinsic planetary magnetic fields and the stellar winds, as well as creation of magnetodisks, lead to the development of a new type of magnetospheres, not typical for the solar system planets [5,4]. Investigation of the structure of such exoplanetary magnetospheres, driven by the expanding planetary partially ionized plasma flow, and specifics of their interaction with the stellar winds, as well as their possible observational manifestations appears an actual task for the modern space physics.

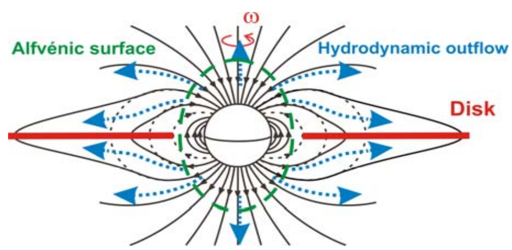

Figure 1: Schemetic view of the magnetodisk, formed by escaping upper atmospheric plasma of a Hot Jupiter.

2. Magnetodisk formation

A key effect under consideration consists in taking into account of the major specifics of the Hot Jupiter conditions, such as intensive thermal escape of the planetary atmospheric material heated and ionized by the stellar X-ray/EUV radiation and the presence of a rotating intrinsic magnetic dipole field of the planet. This leads to the formation of an equatorial current-carrying plasma disk which strongly influences the size and topology of the planetary magnetospheres [4]. Two major mechanisms for the magnetodisk formation are usually considered in the case of Hot Jupiters (Fig. 1). One mechanism is connected with the centrifugal inertial escape of the sub-corotating magnetospheric plasma at the radial distances beyond the planetary Alfvénic radius, R_A, at which the equality of energy of the planetary magnetic dipole field and of the co-rotating plasma kinetic energy is achieved. Beyond the surface limited by R_A, the rotating magnetic field of a planet can not drive the inner magnetospheric plasma in a rigid co-rotation, and a centrifugal inertial outflow of material begins. Another mechanism is directly connected with the thermal outflow of the expanding partially ionized material of the upper atmosphere of a Hot Jupiter. Even without significant centrifugal acceleration, the hydrodynamically escaping partially ionized plasma, moving below the Alfvénic surface (i.e. $r < R_A$), interacts with the background planetary magnetic dipole field deforming it and resulting in the radial stretching of the field lines with the creation of a disk-type current sheet in the equatorial region. By this, the effects of different interaction of the ionized and neutral components of the escaping plasma with the background magnetic field and each other play crucial role in the formation of the self-consistent magnetic field current system of the inner magnetosphere of a Hot Jupiter. This inner magnetodisk-type current system appears a kind of an "inner magnetospheric root" of the global planetary magnetodisk extended beyond R_A.

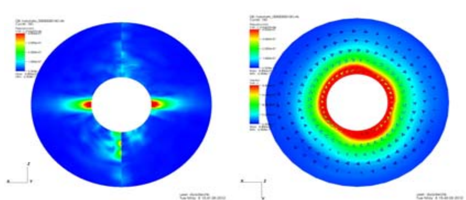

Figure 2: Numerically simulated ring current system formed during the interacttion of an expanding plasma radial flow with a dipole type magnetic field. The self-consistent ring current concentrated near the equatorial plane distorts the dipolar magnetic field structure by increase of the radial component near equator.

The presented study is aimed at development of a self-consistent description for the formation of an inner magnetospheric part of an exoplanetary current-carrying magnetodisk as a result of interaction of an expanding partially ionized plasmasphere of an exoplanet with the intrinsic planetary magnetic field. The analytical treatment of the problem enables definition of specific limiting cases and asymptotic solutions. Besides of that, the results of a hybrid model (Fig.2) numerical simulation and laboratory experiment which confirm the possibility of a plasma outflow-driven magnetodisk, will be presented.

3. Summary and Conclusions

1. It is shown that thermal expansion of the partially ionized upper atmospheric material itself, even without the centrifugal acceleration in the co-rotation region may lead to the build up of a current-carrying magnetodisk in the inner magnetosphere ($r < R_A$).

2. Correct and self-consistent modelling of these processes in the expanding magnetized and partially ionized plasmaspheres of close-orbit exoplanets and their contribution to the shaping of the exoplanetary magnetospheres, requires further study which may include numerical and laboratory experimental simulations.

Acknowledgements

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