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Parametric study of sizes of Hot Jupiter magnetospheres with magnetodisks

M.L. Khodachenko (1), I.I. Alexeev (2), E.S. Belenkaya (2), H.Lammer (1)

(1) Space Research Institute, Austrian Acad. Sci., Graz, Austria (maxim.khodachenko@oeaw.ac.at / Fax: +43-316-4120690);
(2) Inst of Nuclear Phys., Moscow State University, Moscow, Russia

Abstract
The scaling of Hot Jupiter's magnetospheres, containing magnetodisks, is considered for different values of the intrinsic planetary magnetic dipole moment, different orbital distances, and parameters of the stellar wind. The paraboloid model of a planetary magnetosphere is used for this study. In all cases the presence of magnetodisk results in larger magnetospheres, than those caused by just a planetary magnetic dipole alone.

1. Introduction

The constantly growing number of discovered exoplanets and accumulation of data regarding their physical and orbital characteristics provide an empirical platform for a more detailed study of general principles and major trends of the planetary evolution (including the planetary potential habitability aspect). The questions regarding evolutionary paths of exoplanets and their influencing key factors are nowadays under continuous tackling. Among these questions a prominent position belongs to the problem of stellar-exoplanetary interactions, including consideration of influences of stellar radiation and plasma flows (e.g., stellar winds and CMEs) on the planetary near-by plasma and atmosphere environments. Magnetic fields and related with them exoplanetary magnetospheres are widely recognized to play here an important role [1,2]. Magnetosphere acts as an obstacle (magnetospheric obstacle), which interacts with the stellar wind, declining it, and protecting planetary ionosphere, upper atmosphere against the direct impact of stellar plasmas and energetic particles (e.g., cosmic rays).

2. Importance of magnetodisks

Hydrodynamic expansion of an exoplanetary upper atmosphere, heated by stellar XUV, with the consequent photo-ionization of the expanding atomospheric gas [3,4] leads to the formation of an extended, essentially dynamical planetary ionosphere/plasmasphere. 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 [5]. Magnetodisks have been shown to play a crucial role in defining the magnetopause stand-off distance R_S of a close-orbit Hot Jupiter, and therefore, the size of the whole magnetosphere of the planet [1].

Two major physical factors contribute the formation of magnetodisk in the case of Hot Jupiters. On one hand, this is 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. On the other hand, even without significant centrifugal acceleration, the hydrodynamically escaping partially ionized upper atmospheric material (due to thermal mass loss) it-self provides the expanding plasma flux. The outflowing plasma, moving along the field lines inside the Alfvénic surface is concentrated near the equatorial plane and provides the material source for creation of magnetodisk. The plasma, escaping along the filed lines, penetrating beyond the Alfvénic surface, deforms the original planetary magnetic dipole field, resulting in the radial stretching of the field lines [6] and the creation of a thin disk-type current sheet in the equatorial region [5]. The situation with the magnetodisk formation and confinement is essentially non-stationary, characte-rized by continuous load of plasma to the disk, as well as to the entire magnetosphere and simultaneous loss of the expanding material from the system by the non-thermal mechanisms at the boundary of magnetosphere. This comprises the major specifics of the magnetodisk beyond R_A.

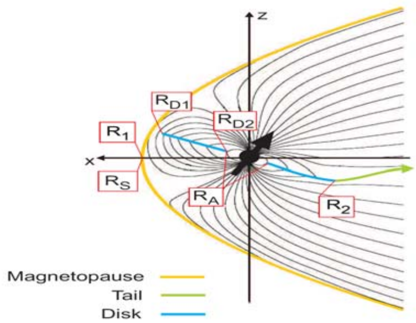

Figure 1: Schemetic view of the main current systems and magnetic field structure in the paraboloid model of a Hot Jupiter magnetosphere.

3. Paraboloid model of Hot Jupiter magnetosphere

A more complete view of the 'Hot Jupiter' magnetosphere structure is based on the Paraboloid Magnetospheric Model (PMM). PMM is a semi-analytical approach to the modelling of planetary magnetosphere structure [7]. The name of the model is derived from its key simplifying assumption that the magnetopause of a planet may be represented by a paraboloid surface co-axial with the direction of the ambient stellar wind plasma. The PMM calculates the magnetic field generated by a variety of current systems located on the boundaries and within the boundaries of a planetary magnetosphere. Besides of the intrinsic planetary magnetic dipole and magnetopause currents, the PMM has among the main sources of magnetic field also the electric current system of the magnetotail, and the induced ring currents of the magnetodisk (see Fig.1). The model works without any restrictions imposed on the values of interplanetary medium parameters, enabling therefore the description of the whole variety of possible magnetosphere configurations caused by different intrinsic magnetic fields of exoplanets and various stellar wind conditions.

The size of magnetosphere depends significantly on the stellar wind dynamic pressure and the parameters of the magnetodisk. At the same time, the last depend in their turn on the orbital distance of the planet towards its host star, the intensity of stellar XUV radiation and the value of intrinsic planetary magnetic dipole. By means of the paraboloid model of a planetary magnetosphere it was possible to perform the parametric study of possible sizes of the magnetospheres of Hot Jupiters at different orbital locations and to conclude about the cases when the contribution of magnetodisc to the scaling of a Hot Jupiter's magnetosphere may be the most prominent.

4. Summary and Conclusions

Due to certain extension of the plasma disks around close-in exoplanets, the sizes of their magnetodisk-containing magnetospheres are usually larger than those, followed from the traditional estimations based on the account of only the screened planetary magnetic dipoles. In general the role of magnetodisk may be formulated as expansion of a part of the dipole magnetic flux from the inner magnetosphere regions outwards and resulting increase of the magnetosphere size. Such larger magnetospheres provide better protection of close-in planets against of the erosive action of extreme stellar winds.

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References

[1] Lammer, H., et al., Astrobiology, 7, 185, 2007.
[2] Khodachenko, M.L., et al., PSS, 55, 631, 2007.
[3] Yelle, R. V., Icarus, 170, 167, 2004.
[4] Penz, T., et al., PSS, 56, 1260, 2008.
[5] Khodachenko, M.L., et al., ApJ, 744, 70, 2012.
[6] Mestel, L, MNRAS, 138, 359, 1968.
[7] Alexeev, I.I., Belenkaya, E.S., Ann. Geophys., 23, 809, 2005.