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On magnetosphere specifics of close-orbit giant exoplanets

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Abstract

A more generic view of the 'Hot Jupiter' magnetosphere structure, based on the Paraboloid Magnetospheric Model (PMM) is provided. Due to the outflow of ionized particles from the hydrodynamic-cally expanding upper atmosphere, 'Hot Jupiters' should have extended magnetodisks. The magnetic field produced by magnetodisk ring currents, dominates above the contribution of intrinsic magnetic dipole of a 'Hot Jupiter' and finally determines the size and shape of the whole magnetosphere.

1. Introduction

Investigation of exoplanetary magnetic fields and their role in evolution of planetary systems forms a new and fast developing branch. This topic is closely connected with the study of the whole complex of stellar - planetary interactions, including consideration of influences of stellar radiation and plasma flows, e.g., stellar wind, coronal mass ejections (CMEs), on the planetary environments, and, therefore, represents an important aspect of modern exoplanetology. Magnetic fields, those connected with the planetary intrinsic magnetic dipole, as well as the magnetic fields associated with the electric current systems induced in the close planetary plasma surroundings, form the planetary magnetosphere. 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). The closer the planet is to the star, the more important becomes magnetospheric protection of a planet.

The weak intrinsic magnetic dipole moments of tidally locked close-orbit giant exoplanets (Hot Jupiters) have been shown in previous studies to be unable to provide an efficient magnetospheric protecttion of their expanding upper atmospheres against the stellar plasma flow, leading to significant non-thermal mass loss of the planets [1]. On the other hand, the detection of a large number of such exoplanets indicates that Hot Jupiters nevertheless survive in the extreme conditions of their close-in orbits and are probably better protected, than the present-day theories predict. This stimulates further investigations of the magnetic and plasma environments of Hot Jupiters aimed at resolving the planetary survival paradox at close orbits.

2. Magnetodisk - a key element of a Hot Jupiter magnetosphere

A key element of the developed approach 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 and, therefore, has to be consequently taken into account.

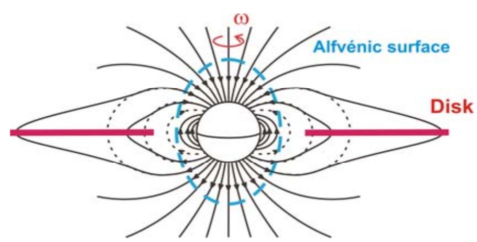

Fig.1 Schemetic view of the Magnetodisk, formed beyond the Alfvénic surface due to plasma escape in the rotating planetary dipole field.

The formation of magnetodisk may be explained in the following way. It is well known that the field of a rotating planetary magnetic dipole can drive the inner magnetospheric plasma to rigid corotation with a planet only inside of the so-called Alfvénic surface, where the strength of magnetic field is high enough

[2]. The equatorial boundary of the Alfvénic surface, R_A, is determined by the equality of energy densities of the plasma rotational motion and the dipole magnetic field. Beyond the Alfvénic surface, i.e. in the area where the rotating planetary dipole magnetic field becomes too weak to drive the plasma in rigid co-rotation, a centrifugal outflow of the sub-corotating material begins. Therefore, the inner edge of the disk may be taken as approximately equal to R_A. 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 [2] and the creation of a thin disk-type current sheet in the equatorial region (see Fig.1).

The situation with the magnetodisk formation and confinement is essentially non-stationary, characterrized 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. In such a dynamical situation the traditional force balance approach is inapplicable.

3. Magnetosphere model of a Hot Jupiter

We propose a more complete view of the Hot Jupiter magnetosphere structure, based on the Paraboloid Magnetospheric Model (PMM) [3]. Besides of the intrinsic planetary magnetic dipole, PMM considers among the main magnetic field sources also the electric current system of magnetotail, magnetopause currents, and the ring current of magnetodisk. The electric currents induced in the plasma disk produce an essential effect on the overall magnetic field structure around the planet, resulting in the formation of a magnetodisk-dominated magnetosphere of a Hot Jupiter. Due to certain extension of the plasma disks around close-in exoplanets, the sizes of their magnetodisk-dominated magnetospheres (see Fig.2) are usually larger than those, followed from the traditional estimations based on the account of only the screened planetary magnetic dipoles [4]. 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.

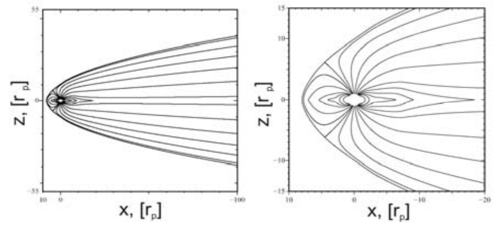

Fig.2 Typical view of a magnetodisk dominated magnetosphere.

6. Results and Conclusions

- Magnetodisks of close-in Hot Jupiters strongly influence the structure and character of their magnetospheres, leading to a new type of a magnetodisk-dominated magnetosphere.
- A slower, than the dipole-type decrease of magnetic field with the distance comprises the essential specifics of magnetodisk-dominated magnetospheres of Hot Jupiters. This results in their 40 - 70 % larger scales, as compared to those traditionally estimated with taking into account of only planetary dipole. Such larger magnetospheres provide better protection of close-in planets against of the erosive action of extreme stellar winds.

Acknowledgements

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