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'Hot Jupiter' magnetodisks – an important factor for planetary protection

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Abstract

A more generic view of a 'Hot Jupiter' ('HJ') magnetosphere structure, based on the Paraboloid Magnetospheric Model (PMM) is provided. The primary attention is paid to the fact that 'HJs' are likely to have massive magnetodisks created by thermally expanding planetary hydrogen atmosphere heated and ionized by stellar XUV.

1. Introduction

The magnetic fields, those connected with the planetary intrinsic magnetic dipole ***M***, as well as the fields associated with the electric current systems induced in the planetary close surroundings, play an important role in stellar - planetary interactions and evolution of planets. The magnetic and related electric current ambience of a planet forms the planetary magnetosphere. It appears as a sort of an obstacle, connected with a planet, which interacts with stellar wind, declining it and protecting the internal planetary environments (ionosphere, atmosphere, surface) against of direct impact of stellar plasmas and energetic particles. The topic of planetary magnetospheric protection has been addressed in several studies in the context of a non-thermal mass loss of a planet caused by the interaction between the expanding planetary atmosphere heated by stellar XUV radiation and the stellar wind / CMEs plasma flow [1], [2].

2. 'HJ' magnetospheric protection

For the efficient magnetospheric protection of a planet the size of magnetosphere characterized by the magnetopause stand-off distance $\boldsymbol{R_s}$ should be much larger then the height of the thermosphere base. In the opposite case the expanding planetary atmosphere penetrates beyond the magnetospheric boundary at which the ionization and pick-up of the atmospheric gas by the stellar wind plasma flow take place. The value of $\boldsymbol{R_s}$ is determined from the balance condition between the stellar wind kinetic ram pressure and the planetary magnetic field pressure at the substellar point [1], [3].

So far the most of work on magnetospheric protection of exoplanets was made within a highly simplifying assumption of a planetary ***dipole dominated magnetosphere***. This means that only the intrinsic magnetic dipole ***M*** of a planet has been considered as a magnetosphere forming factor [1], [3]. In this case the bigger ***M*** is, the more extended is the magnetosphere, and in order to have an efficient magnetic shield, the planet needs a strong intrinsic magnetic dipole.

Widely employed scaling laws for the planetary magnetic moment yield rapid decrease of ***M*** with decreasing planetary angular rotation rate ω_p [3]. In view of that, short orbit 'HJs', due to their slow rotation caused by tidal locking to the host stars, should have reduced values of ***M*** as compared to the fast rotating Jupiter type planets at larger orbits [3]. Weak magnetic dipoles of 'HJs' result in rather small magnetospheres (i.e., small $\boldsymbol{R_S}$) compressed by the stellar winds and stellar CMEs down to several planetary radii above the surface (Table 1) [1], [2]. Small magnetospheres have been shown to be unable to provide an efficient protection of the planetary environments against of stellar winds and coronal mass ejections, leading to the strong non-thermal mass loss of 'HJs' (up to several planetary masses during a planet life time) [1], [2]. However, the existence of multiple close-in giant exoplanets, comparable in mass and size with the solar system Jupiter, indicates that such planets may nevertheless be rather well protected by their magnetospheres.

In that respect we pay attention to the fact that in general case better magnetospheric protection not always requires a bigger ***M***. For example, a large-scale ***induced*** magnetosphere supported by the electric current system built in the extended plasma envelope around a planet may also serve as an efficient magnetic shield.

3. Paraboloid model for the 'HJ' magnetosphere

The present work makes a step forward on the way of exoplanet magnetosphere study and provides a more generic view of the 'HJ' magnetospheric structure. In particular, we pay attention to the fact of a significant mass loss of the close-in 'HJs'. The upper layers of an expanding planetary atmosphere ionized by stellar radiation contribute the formation of an extended plasma disk around the planet. By this, the rotation of a planet and presence of even a small intrinsic magnetic dipole play a crucial role in the shaping of the disk. The electric currents induced in the plasma disk produce an essential contribution to the overall magnetic field structure around a planet, resulting in formation of a specific for 'HJs' ***magnetodisk dominated magnetosphere***.

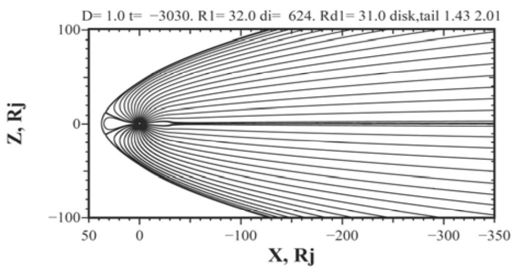

Figure 1: An example of the magnetodisk dominated magnetosphere of a 'HJ' calculated with PMM.

We build up a semi-analytical approach to model 'HJs' magnetospheres on the basis of a Paraboloid Magnetospheric Model (PMM) proposed and developed in [4]. 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, PMM has among the main sources of magnetic field also the electric current system of magnetotail, magnetopause currents, and the induced ring currents of magnetodisk. Figure 1 shows an example of the magnetodisk dominated magnetosphere of a 'HJ' calculated with PMM. The size of such magnetosphere may be essentially bigger then the size of a traditionally considered dipole dominated magnetosphere (see Table 1).

Table 1: 'HJ' magnetopause stand-off distance for a dipole- and magnetodisk- dominated magnetosphere

Orbital distance	M $[M_{\mathrm{Jup}}]$	R_S^{dipole} $[R_{\mathrm{Jup}}]$	R_S^{disk} $[R_{\mathrm{Jup}}]$
0.045 AU (tidally locked)	0.12…0.3	4.3…6.2	14.4
0.1 AU (possibly locked)	0.04…1	3.8…12	12.4
0.3 AU (tidally not locked)	1	16…16	28.4

4. Summary and Conclusions

In the most cases the bigger size of the magnetodisk dominated magnetosphere of 'HJs' appears sufficiently large for protection the planets against of erosive action of the stellar radiations and stellar winds. This sheds further light on the problem of 'HJ' and stellar wind interaction and the planets magnetospheric protection.

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