EPSC Abstracts
Vol. 5, EPSC2010-105, 2010
European Planetary Science Congress 2010

Solar system planets magnetospheres as prototype of the 'Hot Jupiter' magnetodisc magnetosphere

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Abstract

A short review of the Solar system planetary magnetospheres has been presented. It included the Mercury, Earth, Jupiter and Saturn magnetospheres. The universal features of these objects have been established during numerous spacecraft flybys by all abovementioned planets [1], [2], [3].

1. Solar system planet and exoplanet magnetospheres

Mercury. The "paraboloid" model of Mercury's magnetospheric magnetic field is used to determine the best-fit magnetospheric current system and internal dipole parameters from magnetic field measurements taken during the first and second MESSENGER flybys of Mercury on 14 January and 6 October 2008. From our model formulation and fitting procedure a Mercury dipole moment of 196 nT·R_M^3 (where R_M is Mercury's radius) was determined. The dipole is offset from Mercury's center by 405 km in the northward direction. The root mean square (rms) deviation between the Mariner 10 and MESSENGER magnetic field measurements and the predictions of our model for all four flybys is 10.7 nT. We analyzed the contributions of two magnetospheric current systems to the magnetic field measured along the MESSENGER flyby trajectories: (a) the magnetopause and (b) the tail currents.

Jupiter. Measured by Ulysses the jovian magnetospheric magnetic field dependent on the radial distance r (Cowley et al., 1996) is marked by solid curve (Figure 1). For comparison there are also shown magnetic field strength calculated by present model (heavy curve). It have been presented a global model of the jovian magnetosphere which is valid not only in the equatorial plane and near the planet, as most of the existing models are, but also at high latitudes and in the outer regions of the magnetosphere. The model includes the jovian dipole, magnetodisc, and tail current system. Tail currents are combined with the magnetopause closure currents. All inner magnetospheric magnetic field sources are screened by the magnetopause currents. It guarantees a zero

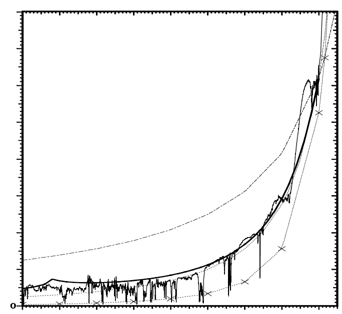

Figure 1. Jovian magnetospheric magnetic field radial dependence as measured by Ulysses [1],[4].

normal magnetic field component for the inner magnetospheric field at the whole magnetopause surface. By changing magnetospheric scale (subsolar distance), the model gives a possibility to study the solar wind influence on the magnetospheric structure and auroral activity. A dependence of the magnetospheric size on the solar wind dynamic pressure p_{sw} (proportional to power low -0.23) is obtained. It is more strong dependence than in the case of the dipole-type Earth's magnetosphere (-0.16).

Exoplanet. Based on comparison of the Jupiter and Saturn magnetospheric models with spacecraft data we have established the main sources of the giant planets magnetospheric field. Knowing the general features of the mechanism of the magnetosphere generation, we proposed that the main contribution to the magnetospheric plasma arrived from the magnetospheric equatorial plasma disk. This disk has been generated because the dipole magnetic field can drive the magnetospheric plasma to the rigid corotation with the planet only inside of the "Alfvenic" sphere. The "Alfvenic" sphere radius will be determined below from the equality of the dipole magnetic field pressure and the plasma corotation flow pressure. Next condition is connected with the conservation of the latitudinal component of the total pressure. From this condition the disk radial magnetic field outside the plasma disk has the same pressure as the plasma pressure at the plasma disk center. We will use the disk model for which the magnetic flux outside the disk is independent on the distance. Such situation have been happened if the disk plasma conductivity is very high (go to infinity). All abovementioned propositions gave us the disk field and plasma disk pressure as functions of the planetocentric distance.

The equation on Alfvenic radius, R_A (see 7th column in Table 1):

$$\varepsilon_B = \frac{B_{H0}^2 R_J^6}{2\mu_0 R_A^6} = \varepsilon_{mp} = \frac{\rho_A {\omega_H}^2 R_A^2}{2}.$$

Here ε_B . is the magnetic dipole pressure, ε_{mp} is the plasma disk pressure, B_{H0} is the dipole field at the equator, $B_{H0} = B_{J0} \cdot \sqrt{\omega_H / \omega_J}$ (B_{J0} = 420000 nT is the Jovian equatorial field) ω_H and ω_J is the Hot Jupiter and Jupiter angular rotation velocities, $\omega_J = 1.76 \cdot 10^{-4}$ s^{-1}. In Table 1 the chosen stellar wind pressure at Hot Jupiter orbits are given. For comparison in the bottom row of the Table 1 are shown the solar wind parameters at the Jupiter's orbit. The first column of the Table is marked the radius of the Hot Jupiter's orbit around the star. The second column included we are placed the stellar wind pressure, p_{sw}, at the nose of the Hot Jupiter magnetosphere. In the third column one can find the calculated strength of the nose magnetospheric magnetic field B_{ss} ($B_{ss} = \sqrt{2\mu_0 m\, n_{sw}}\, V_{sw}$) which balanced by the stellar wind pressure p_{sw}, the next column shown the magnetic field at the planet equator B_{H0} , 5th column marked the size of the magnetosphere, 6th column shown the loss rate which determined the plasma input in the equatorial disk region. As one can see from last right column of the Table the contributions of the planet dipole field at substellar point are around 0.187 – 0.2 from the strength of the plasma disk field.

Table 1. Parameters of Hot Jupiter magnetospheres

Orbit [AU]	p_{sw} [nPa]	B_{ss} [nT]	B_{H0} [nT]	R_{SS} [R_J]	Loss [kt/s]	R_A [R_J]	B_{disks}/B_{dips}
0.045	1341	1841	144574	11.4	49.5	2.3	5.0
0.1	271	828.	79645	10.4	7.43	3.3	3.0
0.3	35.7	300.	420000	28.4	0.720	5.3	5.3
5.2	0.08	14.1	420000	71.2	0.001	20.	3.6

2. Summary and Conclusions

We described the measurements which have been made by spacecraft in the environment of the Solar system giant planets. We propose a prototype of the exoplanet ("Hot Jupiter" magnetosphere. The plasma disk in the equatorial magnetosphere is most important factor and it play a key role in the magnetosphere phenomena.

Acknowledgements

This work was supported by FWF project P21197-N16. The authors are thankful to the JRA3/EMDAF (http://europlanet-jra3.oeaw.ac.at) - a subdivision of the Europlanet-RI for the support of their research communication and collaboration visits.

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