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Magnetic field amplification out of the magnetopause of a rapidly rotating magnetized planet and just beyond the heliopause

E. Belenkaya
Federal State Budget Educational Institution of Higher Education M.V.Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics (SINP MSU), 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation
(elena@dec1.sinp.msu.ru/ Fax: +7-495-939 0896)

Abstract

A possible mechanism of magnetic field generation in a flow of the magnetized plasma just beyond the magnetopause of a rapidly rotating planet with intrinsic magnetic field or the heliopause is considered. When the conductivity of this boundary is high, but less than the field-aligned conductivity out of it, the rotation transferred along the open field lines from the central body to the magnetopause/heliopause smoothly brakes down beyond this surface. If the main necessary conditions for dynamo are fulfilled in a thin layer outside the boundary, the magnetic field amplification could exist. The toroidal magnetic field could be generated there from the background poloidal magnetic field (interplanetary or interstellar) due to the differential rotation and magnetic diffusion. The alpha-effect, in principle, can regenerate the poloidal magnetic field there from the toroidal one. The necessary conditions for the dynamo mechanism are analyzed and checked.

1. Introduction

Magnetic field amplification out of the magnetopause of a quickly spinning magnetized planet or exoplanet, and beyond the heliopause is a very significant and actual astrophysical problem. In the Solar system it is important for Jupiter [1]. It is also related to the extrasolar planets like "Hot Jupiters", for example, which are similar to Jupiter, but located much closer to the host star (0.015 - 0.5 AU) and have an orbital period of a few days. It is supposed that tidal forces cause a synchronous rotation of "Hot Jupiters" with their host star.

Observations of Voyager 1 on 25 August 2012 showed that the spacecraft crossed the heliopause and measured magnetic field, which was twice more in the very local interstellar medium (VLISM) than in the inner heliosheath . The direction of the magnetic field did not change at the heliopause [2]. We suppose that this unusual behavior of magnetic field at the heliopause can be explained by the action of hydromagnetic dynamo.

2. Conditions at the magnetopause/heliopause

When the interplanetary magnetic field (IMF) is parallel to magnetic moment of the planet, the angular velocity of the planet is high and ionospheric conductivity is large, but less than the field-aligned magnetospheric conductivity, the corotation is transferred from the planet to the ionosphere, magnetosphere and its boundary along the open field lines. During this process the azimuthal speed lags gradually from rigid corotation. If the magnetopause conductivity is high, but less than the field-aligned conductivity in the other regions, than in a thin layer beyond the magnetopause, the rotation damps, and its energy can be used for amplification of the background IMF. There are several necessary conditions for realization of this process. One of them is prevailing of induction over diffusion on the large scales, which is realized for the great value of magnetic Reynolds number. Generation of toroidal field from the initial poloidal IMF is possible due to the differential rotation in a thin layer with effective dissipation out of the magnetopause. The next necessary condition is a request that the thickness of a layer (outside the magnetopause) where velocity changes should be larger than the thickness of a layer where magnetic field magnitude changes [3]. This is equivalent to condition that the magnetic Prandtl number exceeds unit. For the α-effect of dynamo the violation of a mirror and axial symmetry is necessary. All these conditions are fulfilled at the Jupiter's magnetopause [1].

The Voyager 1 measurements show that the thickness of a layer (outside the heliopause) where magnetic field strength changes is also less than the thickness of a layer where velocity changes. Beyond the heliopause the spiral magnetic field, character for the heliosphere, is still observed [2], thus, the angular momentum is transferred from the Sun outside up to the VLISM.

We show that all preconditions of dynamo action are realized out of the heliopause and give an energetic estimation of the ability of this process. We conclude that dynamo, in principle, could work just beyond the heliopause, because the differential rotation must exist there, in the layer where electric conductivity is less than the field-aligned conductivity in the heliosphere and in the local interstellar medium. In this layer the rotational kinetic energy density is comparable with the observed magnetic energy density. The equidistribution between the different types of energy determines the upper limit of the possible magnetic field amplification.

3. Summary and Conclusions

For a quickly spinning magnetized planet with dense atmosphere and large conductivities of ionosphere and magnetopause which are less than the field-aligned conductivity out of them, the dynamo mechanism can act just out of the magnetopause in the magnetosheath. The same concerns the nearest vicinity of the outer heliosheath close to the heliopause. Energetic estimations made for these regions show that the rotation energy of the planet and Sun is enough for a possible amplification of the background interplanetary and interstellar magnetic fields. The necessary conditions for dynamo action are checked and verified.

References

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