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Bow shock: Power aspects

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Abstract

It is clear that the primary energy source for magnetospheric processes is the solar wind, but the process of energy transfer from the solar wind into the magnetosphere, or rather, to convecting magnetospheric plasma, appears to be rather complicated. Bow shock is a powerful transformer of the solar wind kinetic energy into the gas dynamic and electromagnetic energy. A jump of the magnetic field tangential component at front crossing means that the front carries an electric current. The solar wind kinetic energy partly transforms to gas kinetic and electromagnetic energy during its passage through the bow shock front. The transition layer (magnetosheath) can use part of this energy for accelerating of plasma, but can conversely spend part its kinetic energy on the electric power generation, which afterwards may be used by the magnetosphere. Thereby, transition layer can be both consumer (sink) and generator (source) of electric power depending upon special conditions. The direction of the current behind the bow shock front depends on the sign of the IMF Bz-component. It is this electric current which sets convection of plasma in motion.

Keywords: Solar wind; Bow shock; Magnetosheath; Energy flux; Geomagnetosphere

1. Introduction

The solar wind is the supersonic flow of the solar coronal plasma. When colliding with the Earth's magnetic field, the solar wind forms a comet-like cavity of rather complex structure, isolated from interplanetary space by the bow shock front. This cavity is of considerable dimensions. The distance from the Earth to the bow shock front subsolar point is 10–12 Earth radii, and more than 20 radii along the dawn–dusk line. On the night side, the magnetospheric tail can be followed well out of the Moon's orbit. However, at long distances the magnetotail loses its continuity breaking up into separate jets of magnetospheric matter, which are blown round by the solar wind plasma.

The Perreault-Akasofu formula (Perreault and Akasofu, 1978), which adequately described the relation between the solar wind parameters and geomagnetic disturbance, indicated that the electromagnetic part of the total solar wind energy is used. The Perreault-Akasofu formula is still successfully used (although is criticized) in power estimations. In this case many researchers ignored the fact that the bow shock is a powerful transformer of the solar wind kinetic energy into the gas dynamic and electromagnetic energy. When the solar wind flows round the magnetosphere, its flow structure and interplanetary magnetic field (IMF) lines are affected. This indicates the appearance of an electric current system in near-Earth space. The magnetized solar wind plasma moving at the solar wind velocity in the coordinate system of near-Earth bow shock (BS) induces an electric field in this system. When crossing the bow shock front at the nose point, the tangential magnetic field component increases nearly four times, and the magnetic field density – 15 times (Korobeinikov, 1985). The physics of the phenomenon implies that the Earth in the solar wind stream disturbs the stream supersonic for the Earth. This suggests that a

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BS front is formed, the upstream wind plasma is undisturbed, and new scales of fluctuations appear downstream, where the minimum scale is the front thickness.

Since early 1960s many experimental and theoretical investigations of the supersonic and super-Alfvenic solar wind flow past the Earth considered the highly dynamic bow shock boundary upstream of the planetary magnetopause (Beard, 1960; Spreiter et al., 1966; Fairfield, 1971; Cairns and Lyon, 1995; Brecht, 1997). Research on processes in the BS has increased recently (see Fig. 1 (Balogh et al., 2005)). In Verigin et al. (2001) the location and shape of the terrestrial bow shock was analyzed using MAGION 4 (sub satellite of INTERBALL 1) crossings of this boundary and upstream solar wind parameters measured by the WIND spacecraft. Different crossing points were mapped to the Sun–Earth line using an analytical model of the planetary bow shock previously developed for the Martian bow shock investigation.

A relevant review of pertinent studies can be found in the paper by Peredo et al. (1995) presenting the empirical model of the Earth's bow shock.

In Verigin et al. (2003a) a direct approach for determining the asymptotic MHD Mach cone was formulated and solved. An implicit analytical solution enables the calculation of the asymptotic downstream slope of MHD Mach cones at any clock angle. The solution obtained includes all previously known symmetric cases. The elongation and shift of the asymptotic fast mode shock cross-section were studied for a wide range of upstream plasma parameters as well as its unusual 'chopped' shape under certain conditions. The results of (Verigin et al., 2003a) may be useful for planetary shock modeling and MHD numerical codes verification. In Verigin et al. (2003b) a new analytical model of the bow shock surface was suggested for reasonably accurate and fast prediction of this boundary's position near obstacles of different shape.

Features of blast-wave and piston shocks are in detail stated in Eselevich et al. (2013).

In Lu et al. (2013) a three-dimensional adaptive magnetohydrodynamic (MHD) model is used to examine the energy flow from the solar wind to the magnetosphere. Using this model, authors directly compute fluxes of mechanical and electromagnetic energy across the magnetopause surface. In this paper, authors investigated energy transfer through the magnetopause by using a global MHD code SWMF. According to the authors this is not the first study to consider energy transfer from the solar wind into the magnetosphere in a global MHD simulation. However, it is the first time that the mechanical energy and electromagnetic energy have been mapped quantitatively.

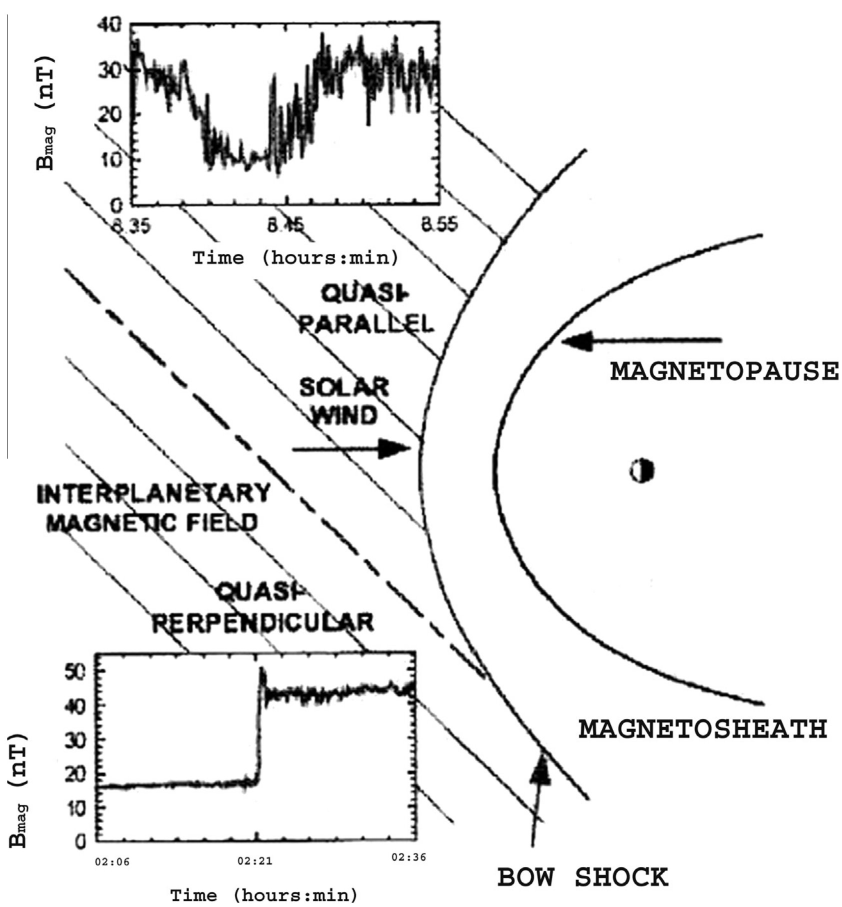

Fig. 1. Data of CLUSTER-II in the region of bow shock (Balogh et al., 2005).

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