"Physics of Auroral Phenomena", Proc. XXVIII Annual Seminar, Apatity, pp. 123-125 , 2005

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INFLUENCE OF THE IMF ON THE SHOCK STAND–OFF DISTANCE OF INTERPLANETARY MAGNETIC CLOUDS

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Abstract

We examine a set of magnetic clouds and model several values using a constant alpha force–free configuration of cylindrical symmetry, which allows us to make correction on the size of the cloud. For the stand–off distance of a shock driven by the cloud, a comparison with a hydrodynamic theory of a shock ahead a cylindrical object of circular cross–section is done. We find a rather wide distribution if we relate the diameter of the tube and the shock stand–off distance to the Alfvén Mach number. This can be explained if the orientation between the axis and the IMF is regarded, which influences the response of the magnetic barrier on the magnetized flow around the tube.

1. Introduction

Magnetic clouds (MCs) are a subset of interplanetary coronal mass ejections (ICMEs) in which a strong magnetic field rotates smoothly through a large angle in a low beta plasma, Burlage et al. (1981). In a very popular and successful approach MCs have been modelled as solutions of the force–free equation $\nabla \times \mathbf{B} = \alpha\mathbf{B}$ in a cylindrical geometry, Goldstein (1983), Marubashi (1986). Burlaga (1988) considered the case of constant α an exact solution of which was given by Lundquist (1950) in terms of Bessel functions. Burlaga showed that this model reproduces approximately MC profiles at 1 AU. This force–free model has been used to least–squares fit **B** data and thus obtain important parameters of the cloud such as the diameter of the object and the axial field strength, Lepping et al. (1990).

Few studies to date have however been devoted to the magnetosheath, by for example trying to predict its thickness and how it changes as the ejection propagates from Sun to Earth (but see Erkaev et al. (1995), Russell & Mulligan (2002), and references therein), or obtaining the stand–off distance of the shock fast MCs drive as a function of heliospheric distance. This information is important however because the sheath can elicit important geomagnetic effects, Gosling (1990), Gosling et al. (1991).

Recently (Leitner et al. 2005) we have shown that if comparing the ratio of the stand–off distance to the diameter of the tube with the Sonic and Alfvén Mach number, there exist deviations, which we tried to explain by deviations of the perfect circular cross section of MCs. Here we want to show another factor which influences the thickness of the sheath. This influence on the size of the sheath is due to the response of the magnetic barrier on the magnetized flow around MCs, and therefore we regard the angle between the axis of the cloud and the interplanetary magnetic field (IMF).

2. Influence of IMF orientation on the magnetic barrier

An angle χ is defined as the angle between the axis of the cloud and the IMF. First is a result of a least–square fit of the Lundquist solution to the three components of the magnetic field. Figure 1 shows the ratio of the size of the sheath (d) to the diameter of the cloud (D) versus the inverse squared of the Alfvén Mach number, and is obtained in the same way as described in Leitner et al. (2005). In addition the data is grouped according to the angle χ. Stars mark events for which the two vectors are perpendicular to each other, $\chi = 90° \pm 10°$. Furthermore we also regard the helicity of the cloud (H), such that plus signs are events with $\chi < 80°$ and $H = 1$ or with $\chi > 100°$ and $H = -1$. Thus, diamonds are events where $\chi < 80°$ and $H = -1$ or with $\chi > 100°$ and $H = 1$. General these are the parallel and anti–parallel cases.

The angle χ is affecting the size of the magnetic barrier. This is those region in the sheath where the magnetic pressure is comparable to, or greater than, the plasma pressure, and especially for MCs the magnetic barrier is an important part of the sheath, Erkaev et al. (1995). From Figure 1 we can see, that the group where IMF is perpendicular to the axis (stars) are above the group where IMF is more parallel or anti–parallel to the axis of the tube (diamonds and plus signs). Thus, for the same Alfvén Mach number, the sheath is bigger for the perpendicular case.

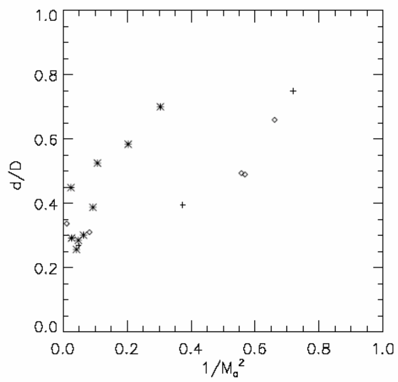

Figure 1. The ratio d/D, where d is the size of the sheath and D the diameter of the magnetic cloud, versus the inverse squared of the Alfvén Mach number. The perpendicular case of χ is represented by stars.

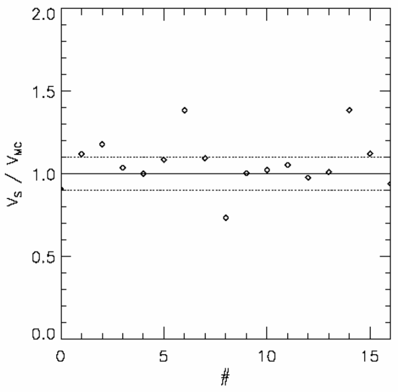

Figure 2. Ratios of the velocities of the shock to the velocities of the magnetic clouds. Solid line represents equality, dotted lines are 10 percent differences from equality.

3. Velocity of the shock

From the Rankine–Hugoniot equations we use the jump relation

$$\rho_1 \tilde{U}_{n1} = \rho_2 \tilde{U}_{n2}, \tag{1}$$

where subscripts 1 and 2 denote the properties before and after the discontinuity, and n indicates the normal component (t the tangential). Quantity $\mathbf{U} = (U_n - V_s; \mathbf{U}_t)$ is the velocity where V_s is the velocity of the shock.

$$\rho_1 (U_{n1} - V_s) = \rho_2 (U_{n2} - V_s) \tag{2}$$

$$V_s = \frac{\rho_1 U_{n1} - \rho_2 U_{n2}}{\rho_1 - \rho_2} \tag{3}$$

Average values of one hour before and behind the shock are used to obtain values of V_s, which are then compared with the velocity of the MC itself, Figure 2. For most cases V_s is bigger than $V_{MC,}$ thus the shock is propagating away from the obstacle. There are just a few cases where the shock velocity is less than the magnetic cloud velocity.

4. Discussion

We have shown by an selection of MCs that the orientation between the axis of the cloud and the magnetic field vector of the IMF can be an important factor if examining the size of the sheath region. The magnetic barrier is responding actively to the property of the magnetized plasma ahead, thus the shock in front of magnetic clouds is not in a static equilibrium. The sheath region is expanding, because of the expansion of MCs but also because the magnetic barrier can grow steadily for the perpendicular case of χ. Last reason is also increasing the size of the sheath if the MC is not expanding.

We have examined the velocity of the shock according to the velocity of the MCs. We found that on average the velocity of the shock is higher than the MC velocity, and an average difference of about 50 km/s was found. It would be a future topic to compare this with results of an expanding magnetic field model, to reveal better the influences due to expansion effect and growing magnetic barrier effect.

Acknowledgments. Support was given from the Austrian Academy of Sciences, “Verwaltungsstelle für Auslandsbeziehungen” while ML was on a visit in Apatity and in Krasnoyarsk. We thank R.P. Lepping for the Wind magnetic field data used in this study. This work is supported by the “Austrian Fonds zur Förderung der wissenschaftlichen Forschung” under project P17100-N08, NASA Grant NNG05GG25G, NASA Wind Grant, and by grants 04–05–64088, 03–05–20014 BNTS a from the Russian Foundation of Basic Research.
In memory of Yuri Maltsev, whose hospitality during the Apatity seminar 2005 will be kept in our minds.

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