ON THE FIELD CONFIGURATION IN MAGNETIC CLOUDS

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ABSTRACT

Interplanetary magnetic clouds are represented by cylindrically symmetric equilibrium solutions of the MHD-equations. The radial magnetic pressure gradient of the force-free field is balanced by the curvature stress. The field inside is essentially parallel to the cylinder axis, far outside it is oriented in azimuthal direction. These configurations therefore differ from the non-selfconsistent model proposed by Klein and Burlaga (1982), where the field lines are tightly wound even near the axis.

1. Introduction

Interplanetary magnetic clouds are defined as extended regions ($\sim$ 0.25 AU at 1 AU) in which the magnetic field strength is higher than average, the magnetic pressure exceeds the ion pressure and the field vector rotates parallel to a plane (Klein and Burlaga, 1982). A unique model for the magnetic field does not exist, but a number of different configurations seem to be consistent with the results of a minimum variance analysis (Burlaga and Behannon, 1982). However, these models were not required to be solutions of the MHD-equations so far. In this paper we present such selfconsistent configurations, which for simplicity are cylindrically symmetric as in the model proposed by Klein and Burlaga. Two observational facts can then be understood in a different way as before. Firstly, in most cases the direction of minimum variance is essentially the radial direction. Secondly, the higher (magnetic) pressure inside the cloud does not imply a rapid expansion, but the observed flow-velocity v in the comoving frame is smaller than the Alfvén-velocity v_A.

2. The Model

We start out from the momentum equation in a frame moving with the cloud, which is assumed to be a time-independent configuration.

$$\rho\, \underline{v} \cdot \nabla\, \underline{v} = -\nabla p + \frac{1}{c}\, \underline{j} \times \underline{B} \qquad (1)$$

Since $c|\rho\, \underline{v} \cdot \nabla\, \underline{v}|/|\underline{j} \times \underline{B}| \sim v^2/v_A^2 \ll 1$ and $c|\nabla p|/|\underline{j} \times \underline{B}| \sim p\,/(B^2/8\pi) \ll 1$. the convective term and the pressure gradient can be neglected in first approximation, such that the magnetic field is force-free, i.e. $\underline{j} \times \underline{B} = 0$ or by Ampere's law:

$$-\nabla B^2 + 2\,(\underline{B} \cdot \nabla)\, \underline{B} = 0. \qquad (2)$$

For our model we use cylindrical coordinates r, ϕ, z and assume that the magnetic field depends only on r:

$$-\frac{d}{dr}\left(B_\phi^2 + B_z^2\right) - \frac{2\,B_\phi^2}{r} = 0 \qquad (3)$$

The radial component B_r is zero because of $\nabla \cdot \underline{B} = 0$. The general solution can be given in terms of a generating function $F(r) = B_\phi^2 + B_z^2$ (Schlüter, 1957):

$$B_\phi^2 = -\frac{r}{2}\frac{dF}{dr} \qquad B_z^2 = \frac{1}{2r}\frac{d(r^2\,F)}{dr} \qquad (4)$$

Since B_ϕ^2 and B_z^2 are not negative, F(r) has to be chosen such that $0 \geq \frac{dF}{dr} \geq -\frac{2F}{r}$. Therefore the magnetic field strength has a maximum on the axis. Equation (3) shows that the gradient of the magnetic pressure is balanced by the curvature stress. If the current density and the total current are finite, the field is oriented along the axis near the center and directed in azimuthal direction far outside. Therefore the field lines cannot be tightly wound near the axis as proposed by the model of Klein and Burlaga.

It is interesting to study the consequences for a minimum variance analysis. Figure 1 shows a configuration with its axis in the equatorial plane perpendicular to the radial direction $\underline{R}$. During the passage of this cloud a spacecraft would observe a rotation of the magnetic field vector $\underline{B}$ from a southward to a northward direction in a plane perpendicular to $\underline{R}$ so that $\underline{R}$ is the direction of minimum variance. The cylinder axis is oriented along the direction of medium variance. These results fully agree with the observations as summarized by Burlaga and Behannon, however, we give a different interpretation here.

3. Summary and Conclusion

Magnetic clouds can be represented by cylindrically symmetric equilibrium configurations, which are force-free solutions of the MHD-equations. The magnetic pressure gradient is balanced by the curvature stress of the field lines. The results of a minimum variance analysis as reported by Klein and Burlaga (1982) and by Burlaga and Behannon (1982) are consistent with configurations where the cylinder-axis is oriented parallel to the ecliptic plane and perpendicular to the radial direction. However, the search for magnetic clouds was restricted so far to cases where the field vector rotates from a northward to a southward direction or vice versa. Therefore it can be expected that different orientations of the cylinder-axis are possible. Probably,thick sector boundaries (Klein and Burlaga, 1980) may be understood as magnetic clouds with their axis normal to the ecliptic plane.

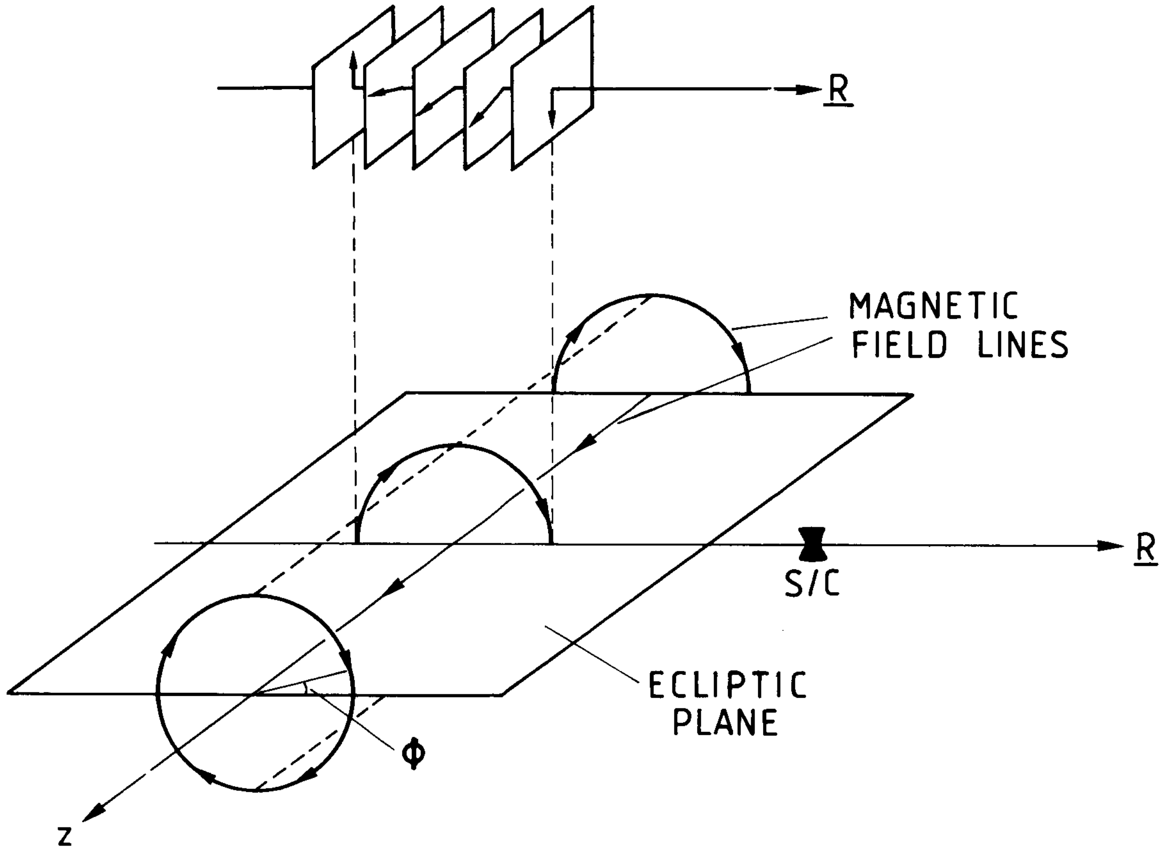

Figure 1. Cylindrical magnetic cloud with its axis in the equatorial plane perpendicular to the radial direction R. The magnetic field lines are circular far outside and straight lines parallel to the z-axis inside. When this configuration passes a spacecraft (S/C) a rotation of the field vector in a plane perpendicular to R is observed. This is illustrated in the upper part of the figure (compare with the observations sketched in figure 7 in Burlaga and Behannon (1982)). R is the direction of minimum variance and the axis is oriented parallel to the direction of medium variance.

References

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