Recent Insights into the Physics of the Sun and Heliosphere: Highlights from SOHO and Other Space Missions
IAU Symposium, Vol. 203, 2001
P. Brekke, B. Fleck, and J. B. Gurman eds.

Helical Magnetic Structure of White Light Polar Plumes

A. N. Zhukov, I. S. Veselovsky

Institute of Nuclear Physics, Moscow State University, Moscow, 119899 Russia

S. Koutchmy

Institut d'Astrophysique de Paris – CNRS, 98 bis bd Arago, 75014 Paris, France

A. Llebaria

Laboratoire d'Astronomie Spatiale – CNRS, Allée Peyresc, Marseille Cedex 12, France

Abstract. We describe the fine structure of white light polar plumes observed using SOHO/LASCO C2 coronagraph. The evolving helical structures of different scales are clearly seen on processed images (the processing is made to reveal the faint contrast objects). The observed structures trace the magnetic field lines, so the electric currents flow along the axes of plumes. An MHD model of a plume which takes into account field-aligned electric currents is developed. The model permits to understand the existence of high-density plasma inside the plume due to the balance between the magnetic forces and the transverse pressure gradient.

1. Observations, Interpretation and Results

In Fig. 1 we present four processed LASCO C2 images made on April 16, 1996 showing multi-thread helical structure of the plumes, which could be also observed in EUV by SOHO/EIT (Veselovsky et al. 1999). The details of observations and the image processing were reported earlier (Lamy et al. 1997).

The observed structures presumably trace the magnetic field lines, hence, the magnetic field in plumes has a helical shape. Such a magnetic structure necessarily implies that the electric currents flow in the radial direction along the plume axis. The force balance providing the equilibrium of the plume (or one of its threads) could be represented in the simplest model as follows. The electric current I is distributed homogeneously over the plume (cylinder with the radius R_0) cross section. The magnetic field $\vec{B}$ is created by the current I and the external homogeneous magnetic field parallel to the current direction. The pressure gradient $\vec{\nabla}p$ acting on plasma inside the plume is directed outwards, because the plume is an order of magnitude denser and about two times cooler than the interplume plasma (Suess 1998). The magnetic force $\frac{1}{c}\left[\vec{j} \times \vec{B}\right]$ compresses the plume. The balance between these two forces providing the

https://doi.org/10.1017/S0074180900219748 Published online by Cambridge University Press

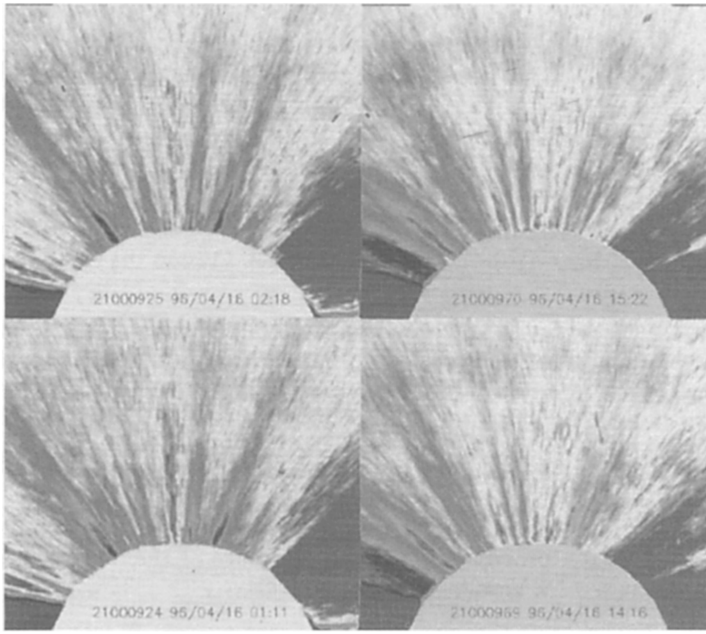

Figure 1. LASCO C2 images of the solar corona (northern polar coronal hole) taken on April 16, 1996. The regions with higher density are represented by darker colors.

plume transverse equilibrium could be written in the MHD approximation as $-\frac{\partial p}{\partial R} + \frac{1}{c}\left[\vec{j} \times \vec{B}\right]_R = 0$, where $j = I/4\pi R_0^2$ is the current density, c is the speed of light, R is the radial coordinate in the cylindrical geometry. For the sake of simplicity we assume the plasma temperature $T = const$ inside and outside the plume and, considering the fully ionized hydrogen plasma as an ideal gas, solve the force balance equation. The solution gives the expression for the electron number density n inside and outside the plume:

$$n(R) = \begin{cases} n_0 - \dfrac{1}{\pi c^2 kT}\dfrac{I^2}{R_0^2}\left(\dfrac{R}{R_0}\right)^2, & R < R_0; \\[2ex] n_0 - \dfrac{1}{\pi c^2 kT}\dfrac{I^2}{R_0^2}, & R > R_0. \end{cases} \tag{1}$$

Here $n_0 = n(R_0)$, k is the Boltzmann constant. For the quantitative calculations we take typical values of parameters for $1.1 R_\odot$ (where the MHD approximation is valid): $n_0 = 5\ 10^7\ \mathrm{cm}^{-3}$, $T = 10^6$ K, and the values obtained by Veselovsky et al. (1999) for the helical magnetic field of EUV plume: $R_0 = 1.6\ 10^4$ km, $I = 2\ 10^9$ A (which corresponds to the azimuthal field $B_\varphi = 0.5$ G). We obtain the good agreement with the independent observations (Koutchmy

https://doi.org/10.1017/S0074180900219748 Published online by Cambridge University Press

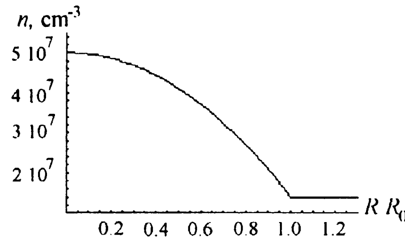

Figure 2. The dependence of the electron number density on the distance R from the center of the plume at 1.1 $R_{\odot}$. R_0 is the plume radius.

1988) of the electron number density outside the plume and a plausible radial profile (Fig. 2).

Some imlications of the helical magnetic structure of the plumes for the solar wind acceleration process and for the structure of the heliospheric current circuit were discussed by Veselovsky et al. (1999).

2. Conclusions

Investigating the thread-like fine structure of white-light polar plumes observed by LASCO C2 coronagraph onboard SOHO, we found helical magnetic field configuration in the polar plumes. The theoretical consequences are:

field-aligned electric currents are responsible for the formation of helical structures there;

the plume is maintained by the balance of the pressure gradient and the Ampère forces acting in the transverse direction.

References

Koutchmy, S. 1988, in Proc. Ninth Sacramento Peak Summer Workshop, Solar and Stellar Coronal Structure and Dynamics, ed. R. C. Altrock, Sunspot, New Mexico, 208

Lamy, P., Llebaria, A., Koutchmy, S., Reynet, P., Molodensky, M., Howard, R., Schwenn, R., & Simnett, G. 1997, in Proc. Fifth SOHO Workshop, The Corona and Solar Wind near Minimum Activity, ESA SP–403, Oslo, Norway, 487

Suess, S. T. 1998, in Proc. of an International Meeting on Solar Jets and Coronal Plumes, ESA SP–421, ed. T.-D. Guyenne, 223

Veselovsky, I. S., Zhukov, A. N., Koutchmy, S., Delannée, C., & Delaboudinière, J.-P. 1999, in Proc. 8th SOHO Workshop, Plasma Dynamics and Diagnostics in the Solar Transition Region and Corona, ESA SP–446, ed. B. Caldeich-Schurmann, 675

https://doi.org/10.1017/S0074180900219748 Published online by Cambridge University Press