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Magnetic field and the ionic tail of comet Halley†

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Abstract. The space missions to comet Halley have reported an increase of the magnetic field from 12–15 × 10^{-5} gauss characteristic of the interplanetary solar wind to a peak field strength of 70–80 × 10^{-5} gauss within the environment of comet Halley. The large magnetic field if characteristic of tail would lead to the growth of plasma instabilities excited in the cometary tail containing twisted magnetic fields, resulting in helical structures inclined at small angles to the tail boundary.

Key words : comet Halley—ion tail—instabilities

1. Introduction

Fine structures, like kinks and helices, seen in the ionic tails of comets hold forth valuable information on the physics of the interaction between the cometary ionosphere and the solar wind plasma. These structures have been interpreted in terms of kink instability and Kelvin-Helmholtz instability in the cometary plasma (Ershkovich 1980). Krishan & Sivaraman (1982) have shown that the multiple helical structures seen in the tail of comet Ikeya-Seki can be explained in terms of another type of magnetohydrodynamic instability arising through spatial resonance between magnetic field lines and wavelength of the mode. Further strong hydromagnetic turbulence associated with comet Giaccobini-Zinner has been observed by Tsurutani & Smith (1986). However, no direct measurement of the magnetic fields in the cometary tails has been available, even though their existence is accepted by all.

2. Observational features of comet Halley

For the first time space missions to comet Halley enabled direct measurements of the mangetic field strength and structures in the environment of the comet

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(Riedler *et al.* 1986; Saito *et al.* 1986). These showed a peak field strength of 70–80 gamma (Reidler *et al.* 1986), and helical structures in the streamers near the coma (Saito *et al.* 1986). These helical structures in the streamers near the comet Halley are shown in figure 1 (Saito *et al.* 1986). However these features are very close to the cometary coma. On the other hand a magnetic pile up region has been identified by Giotto spacecraft inside 1.35 × 10^5 km, inbound, and 2.63 × 10^5 km, outbound with fields up to 57 and 65 gamma respectively (Neubauer *et al.* 1986). This is very close to the tail of the comet. Helical features in the tail are very clearly resolved in the image intensified picture of comet Halley (figure 2) taken using the Anglo-Australian telescope (Malin 1986). These observational features clearly point out that the cometary plasma acquires the form of the field in the presence of twisted magnetic fields in the tail. This kind of behaviour of the plasma was first discussed by Dungey & Loughhead (1954). However, their treatment suffered from some invalid assumptions as was pointed out by Tayler (1957). Krishan & Sivaraman (1982) applied the model (removing the invalid assumptions) to the ionic tail of comet Ikeya-Seki and the theoretical treatment here closely follows this analysis. Of course, the plasma and magnetic field conditions of comet Halley are very different from those of Ikeya-Seki and hence the need to investigate new plasma instability for comet Halley.

3. Theoretical model

The system under investigation consists of the following components (Krishan & Sivaraman 1982) :

(i) Cometary tail plasma of electron density varying from 10 cm^{-3} to 100 cm^{-3} which is permeated by a uniformly twisted magnetic field of the form (0, $H_\theta(r)$, H_z), where H_θ and H_z are the azimuthal and axial components of the magnetic field.

(ii) The cometary tail plasma is surrounded by the solar wind plasma with its own magnetic field, which has also been assumed to be of the twisted form.

We make use of the ideal magnetohydrodynamic equations to investigate the response of the comet-solar wind plasma to a perturbation of the form $f(r) \exp(i(\omega t + qz + m\theta))$ where (r, θ, z) are the cylindrical coordinates; m is an integer; ω and q are the frequency and the wave vector. The boundary conditions to be satisfied are the continuity of the radial component of the velocity and discontinuity in the pressure across the boundary. The dispersion relation is (Krishan & Sivaraman 1982) :

$$\frac{(4\pi\mu_1\omega_1^2 - K_1^2)\dfrac{I'_m}{I_m}X_1 - 2A_1K_1m}{(4\pi\mu_1\omega_1^2 - K_1^2)^2 - 4A_1^2K_1^2}$$

$$= \frac{(4\pi\mu_2\omega_2^2 - K_2^2)\dfrac{K'_m}{K_m}X_2 - 2A_2K_2m}{(4\pi\mu_2\omega_2^2 - K_2^2)^2 - 4A_2^2K_2^2 + \dfrac{[2A_2K_2m - X_2(4\pi\mu_2\omega_2^2 - K_2^2)K'_m/K_m]}{[X_2(A_1^2 - A_2^2)]^{-1}}} \quad \ldots(1)$$

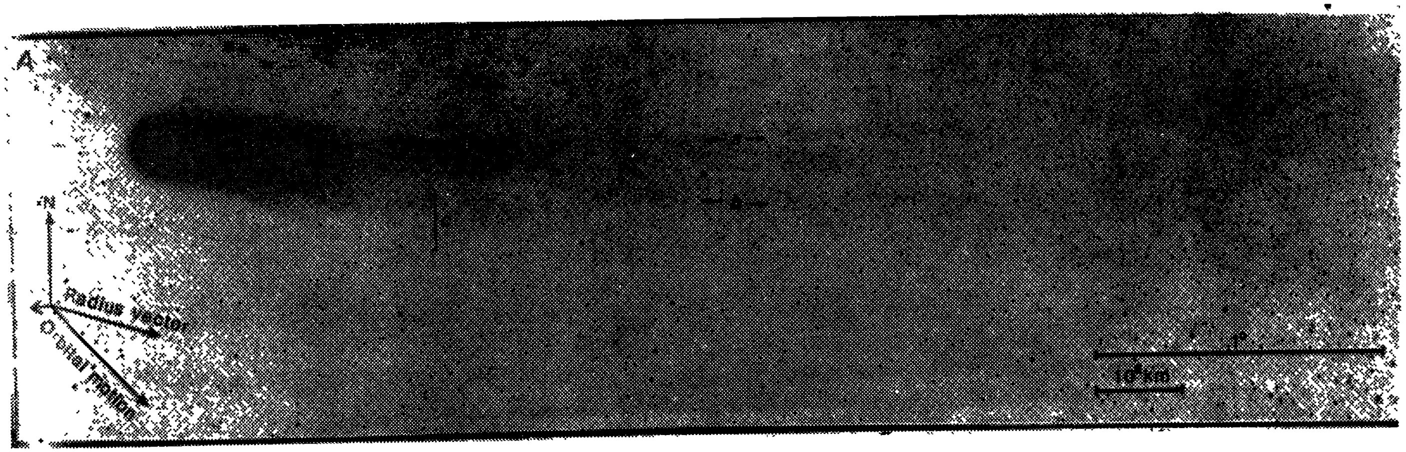

Figure 1. A photograph of comet Halley taken on 1986 March 11 showing the helical features in the streamers near the coma of comet Halley.

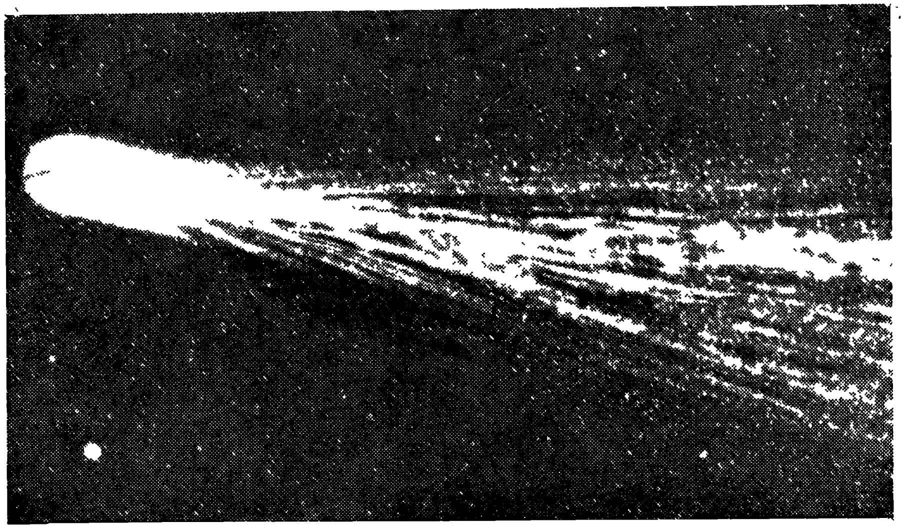

Figure 2. Image intensified picture of comet Halley's tail.

where the index 1 refers to the cometary plasma parameters and 2 to those of the surrounding solar wind plasma. Here μ is the mass density; $\omega_1 = \omega + \vec{q}.\vec{U}_c$; $\omega_2 = \omega + \vec{q}.\vec{U}_s$; U_c and U_s are the comet tail and solar wind velocity respectively; $A = H_\theta/r$; $K = qH_z + mA$; I_m and K_m are modified Bessel functions with I'_m and K'_m their derivatives; and

$$X_1 = q\left\{1 - \frac{4K_1^2A_1^2}{(4\pi\mu_1\omega_1^2 - K_1^2)^2}\right\}R$$

$$X_2 = q\left\{1 - \frac{4K_2^2A_2^2}{(4\pi\mu_2\omega_2^2 - K_2^2)}\right\}R \qquad \ldots(2)$$

are the arguments of the Bessel functions. Equation (1) is solved for complex roots such that

$$\omega \simeq qu_c - i\gamma_0 \qquad \ldots(3)$$

and the value of the growth rate γ_0 determined. In dealing with Ikeya-Seki, we assumed that the cometary magnetic field is of the same order as the interplanetary magnetic field. If the magnetic field is as large as is reported for Halley, a situation arises in which the instability has a larger growth rate. At the surface, where the helicity of the magnetic field is equal to that of the perturbation, the conditions $K_1 = K_2 = 0$ for the instability must be satisfied. This is possible only when $H_{1\theta} > H_{2\theta}$ since $H_{1z} > H_{2z}$ (whereas in Ikeya-Seki case $H_{1\theta} = H_{2\theta}$). Under these conditions, the growth rate is given by

$$\gamma_0^2 = \frac{\mu_2}{\mu_1}\omega_2^2 \frac{[I_1'(qR)/I_1(qR)]}{[K_1'(qR)/K_1(qR)]}\left[1 + \frac{\{K_1'(qR)/K_1(qR)\}(A_1^2 - A_2^2)}{4\pi\mu_2\omega_2^2}\right]. \qquad \ldots(4)$$

The growth rate of this instability for Ikeya-Seki with magnetic field of the interplanetary value was found to be $3 \times 10^{-4}\ \mathrm{s}^{-1}$. In contrast for comet Halley for a field of 75γ, the growth rate increases to a value of $10^{-3}\ \mathrm{s}^{-1}$. The large growth rate is the direct result of the increase of the azimuthal component of the cometary magnetic field and this further brings out the role of the twisted nature of the magnetic field in producing helical features in the ionic tail. The numerical estimate of the growth rate has been made using $\mu_1 = 2.8 \times 10^{-22}$ gm cm^{-3}, $\mu_2 = 5 \times 10^{-24}$ gm cm^{-3}, $U_c = 235$ km s^{-1}, $U_s = 540$ km s^{-1}, $H_{1\theta} = 75\gamma$, the radius R of the tail $\sim 2.5 \times 10^5$ km. These values have been compiled from the measurements of the recent space missions to comet Halley (Mckenna-Lawlor *et al.* 1986) as also from the typical values for the comets (Krishan & Sivaraman 1982). Further the value of 75γ for the magnetic field is taken as a representative value. As already mentioned the measurements of Giotto mission indicate a magnetic pile up region with fields much larger than the interplanetary fields over regions of several times 10^5 km and the radius has been taken here as $\sim 2.5 \times 10^5$ km which is very close to the pile up region. The pitch of the cometary magnetic field for $m = 1$ mode turns out to be equal to the radius of the tail. This can be seen to be true for some of the features in figures 1 and 2. Another important feature to be noted is the inclination angle θ of the helical structures to the tail boundary. If the cause of the twist (it need not be !) in the cometary magnetic field is the rotation of the nucleus, this angle is given by

$$\tan\theta = 2\pi R/U_c T,$$

For the measured rotation period $T \sim 2.2$ days for comet Halley (Sagdeev *et al.* 1986; Sekanina 1987; Wilhelm 1987), this angle turns out to be about 2°. This agrees with the inclination of some of the features present in figures 1 and 2. Again, this may be contrasted with the angle of about 15° obtained for comet Ikeya-Seki.

In the above analysis, the magnetic field has been assumed to be of uniform pitch. In a magnetic field with nonuniform pitch varying across the tail as for example for a field of the form $H_{1z} \sim J_0(\alpha r)$ and $H_{1\theta} \sim J_1(\alpha r)$ where α^{-1} is a characteristic length in the system, the conditions $K_1 = K_2 = 0$ can be satisfied only locally. The growth rate is a function of the radial coordinate. It is found that the growth rate decreases towards the boundary but is still larger than in the case of comets with magnetic fields of the order of interplanetary magnetic field.

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References

Dungey, J. W. & Loughhead, R. E. (1954) *Aust. J. Phys.* **7**, 5.

Ershkovich, A. I. (1980) *Sp. Sci. Rev.* **25**, 3.

Krishan, V. & Sivaraman, K. R. (1982) *Moon & Planets* **26**, 209.

Malin, D. (1986) reproduced in *Nature* **320**, 577.

McKenna-Lawlor, S., Kirsch, E., O'Sullivan, D., Thompson, A. & Wenxel, K. P. (1986) *Nature* **321**, 347.

Neubeauer, F. M. *et al.* (1986) *Nature* **321**, 352.

Riedler, W., Schwingenschuh, K., Yeroshenko, Ye. G., Styashkin, V. A. & Russell, C. T. (1986) *Nature* **321**, 288.

Sagdeev, R. Z. *et al.* (1986) *Nature* **321**, 262.

Saito, T., Yumoto, K., Hirao, K., Nakagawa, T. & Saito, U. (1986) *Nature* **321**, 303.

Sekanina, Z. (1987) *Nature* **325**, 326.

Tayler, R. J. (1957) *Phil. Mag.* **2**, 22.

Tsurutani, B. T. & Smith, E. J. (1986) *Geophys. Res. Lett.* **13**, 259.

Wilhelm, K. (1987) *Nature* **327**, 27.