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SMALL SCALE IRREGULARITIES IN COMET HALLEY'S PLASMA MANTLE: AN ATTEMPT AT SELF-CONSISTENT ANALYSIS OF PLASMA AND MAGNETIC FIELD DATA

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Abstract. VEGA-1 measurements of the plasma density and magnetic field in the coma of Comet Halley show characteristic signatures over a significant portion of the outbound pass. It is found that the assumption that there is a balance between the thermal and magnetic pressures in these features can be used to obtain estimates of the plasma temperature as a function of distance from the nucleus. These estimates indicate that the ions cool from $\sim 1.5 \times 10^6$ °K at 10^5 km to 2×10^5 °K at 5×10^4 km. The technique used here represents a novel approach whereby temperature measurements can be made in situations where only plasma density and magnetic field data are available.

Introduction

The BD-3 plasma detector on VEGA-1 (cf. Zastenker et al.;1986, Vaisberg et al., 1987) measured heavy cometary ions at high (~1s) time resolution at comet Halley in March 1986. One collector, which responded to ions in the energy range of ~600 eV to 1 keV, provided a detailed record of small-scale variations in the mantle of heavy ions. Contemporaneous magnetic field data from the MISCHA experiment (cf. Riedler et al., 1986) were also obtained at high time resolution.

Here the dual (plasma and field) high time resolution data sets are used to establish a relationship between irregularities in the cometary plasma density in Halley's coma and a particular type of magnetic structure identified earlier in magnetic field data by Yeroshenko et al. (1986), Galeev et al. (1986b) and Russell et al. (1987). These structures are particularly prevalent in the outbound portion of the VEGA-1 trajectory. The behavior of the plasma densities suggests that there is pressure balance between the plasma and magnetic field. This assumption is used to calculate the plasma temperatures as a function of distance from the nucleus. The temperatures so obtained compare favorably with what is expected from an MHD comet model. In addition to telling us about comet Halley's temperature, the present study adds to our understanding of the physical nature of the small scale magnetic structures in the cometosheath and illustrates how these structures can be used for plasma diagnostics.

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Observations

The operation of the BD-3 plasma detector on VEGA-1 is described elsewhere (Zastenker et al., 1986, Vaisberg et al., 1987). The one collector and mode which proved to be the most useful for the detection of cometary ions was the high voltage step of full plane collector 4 which is sensitive to ion energies between 600 eV and 1 keV. The collector is sampled once per second for 12 seconds with a "dead time" of 36 s between sampling intervals as the sensor is cycled through the other three voltages. The detected flux or current is proportional to the density of water group ions which are stationary in the comet frame compared to the spacecraft. Although vector magnetic field measurements were obtained on VEGA-1 (cf. Schwingenschuh et al., 1986), only the total field magnitude is used because of the nature of the magnetic structures discussed here. The sampling rate for the magnetic field data was 0.1 s.

Figure 1 shows the time series of the BD-3 heavy ion number densities, together with the magnetic field magnitude, for the hour surrounding the VEGA-1 closest approach to comet Halley's nucleus. (The ion density has been obtained from the measured current by multiplication by a factor of 7×10^{12}.) The magnetic field data are distinguished by the long segment of the outbound leg exhibiting quasiperiodic depressions. When examined at high time resolution as shown in Figure 2, these depressions appear as individual symmetric dips. Such dips in the field were first discussed in the literature by Yeroshenko et al. (1986) and Galeev et al. (1986). Russell et al. (1987) later noted their similarity to mirror mode waves observed in the terrestrial magnetosheath and studied their magnetic characteristics. These structures appear to cause only slight rotations of the magnetic field direction; thus, only the magnetic field magnitude is of primary interest here. One can suppose that they are associated with the observed enhancements in plasma density (cf. Galeev et al., 1986) which create diamagnetic cavities in their place. In other words, one can presume that pressure balance between the magnetic field and the observed cometary plasma prevails.

If pressure balance is assumed to exist in the region where the small scale structures are present, one can calculate the plasma temperature in that region from the observed relationship between the magnetic pressure and the plasma analyzer current. Pressure balance:

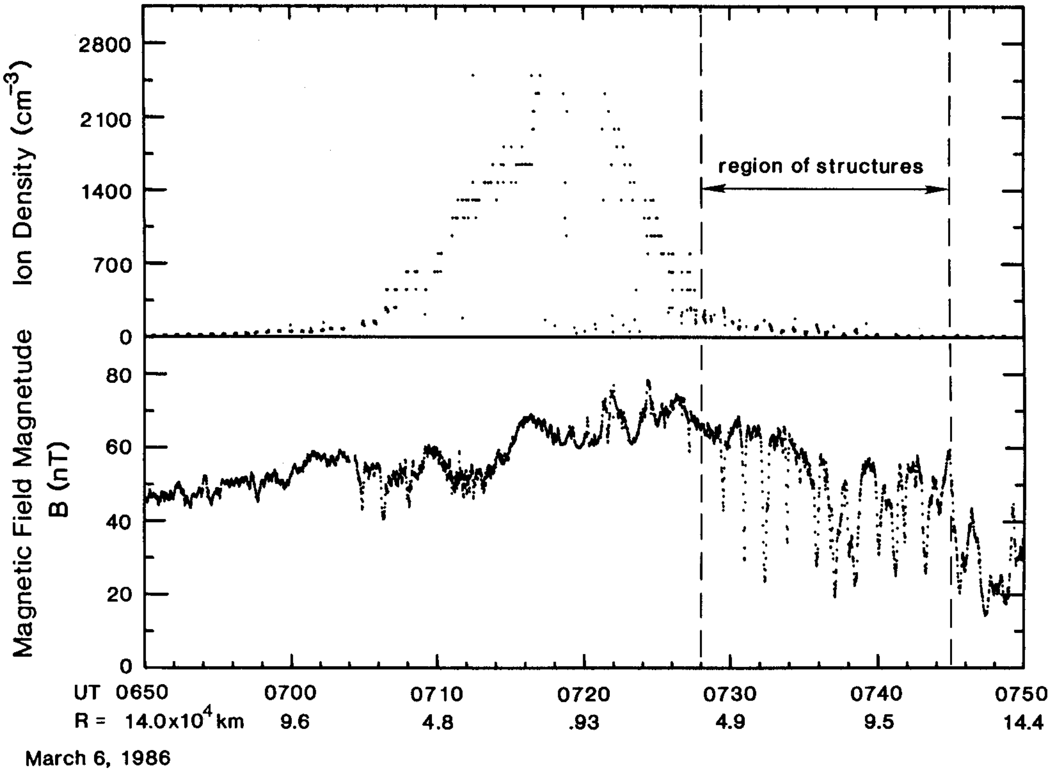

Fig. 1. (Top panel) Time series of heavy ion number densities measured within the hour of closest approach to comet Halley by the BD-3 plasma detector on VEGA-1. (Bottom panel). Simultaneously obtained magnetic field magnitude from the MISCHA experiment.

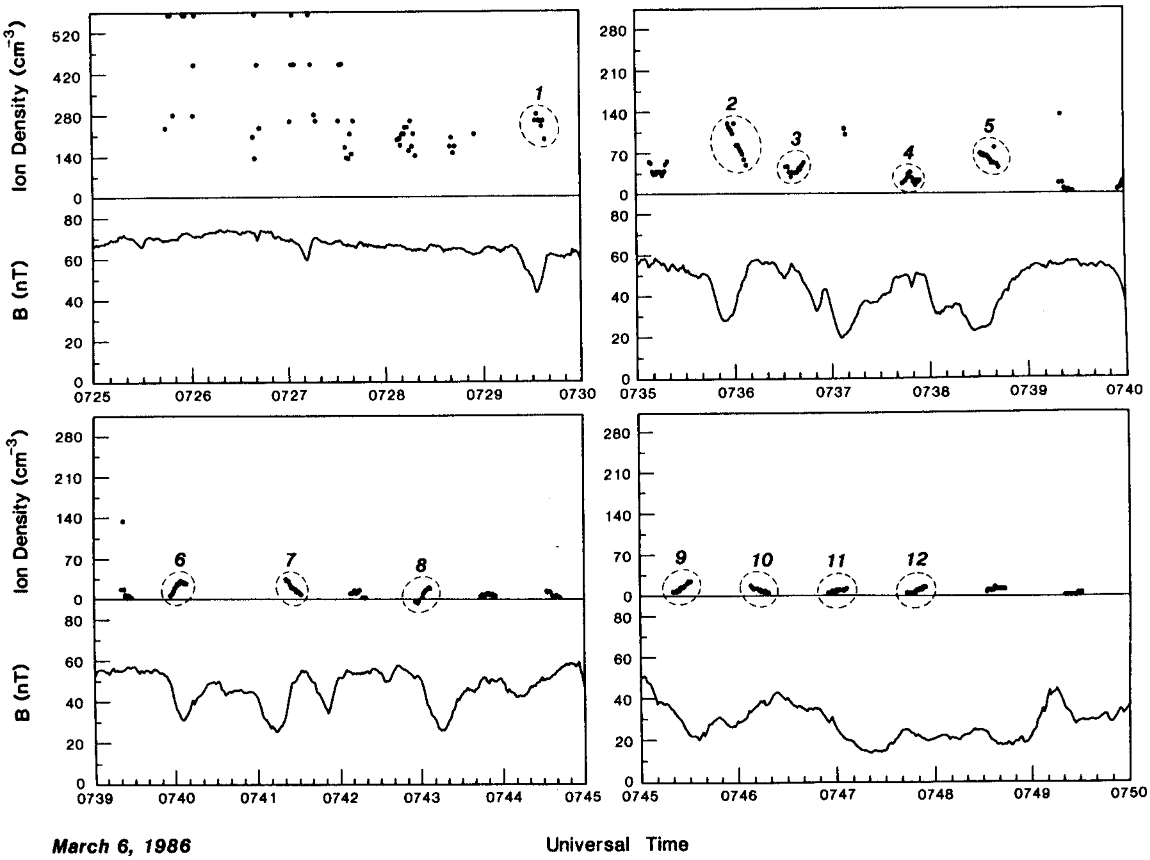

Fig. 2. Magnifications of sections of Figure 1 showing the small scale structures used in the present study.

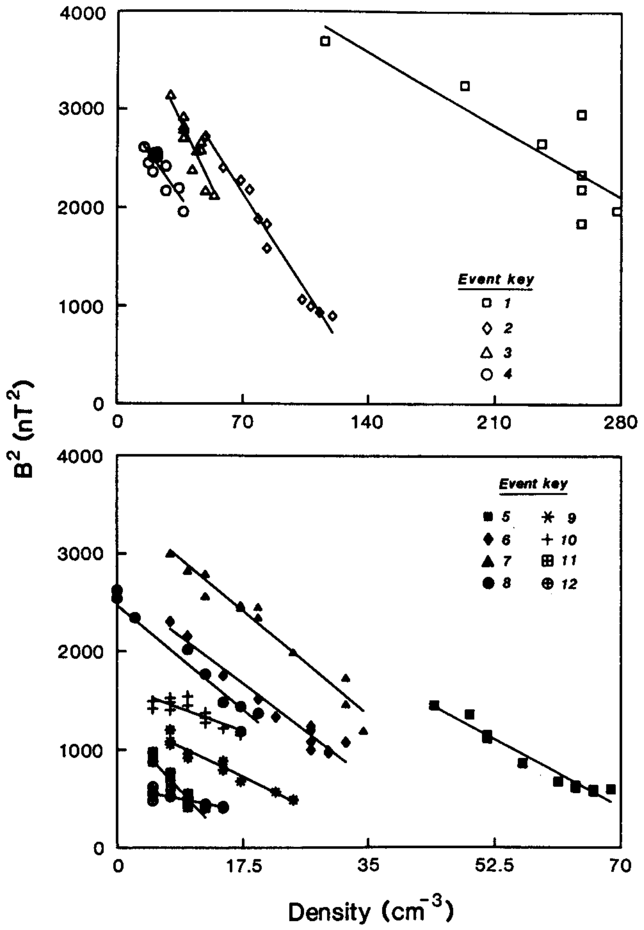

Fig. 3. Plots of magnetic field squared versus density obtained from the numbered structures in Figure 2. The lines are least squares fits to the data.

$$\frac{B^2}{8\pi} + nkT = \text{constant}$$

where B is the field magnitude and nkT is the thermal plasma pressure, implies that the plasma temperature T is proportional to the slope of a magnetic pressure versus density curve or $d(B^2/8\pi)/dn$ (n = density) provided that T is constant within a magnetic structure. Figure 3 shows plots of field magnitude squared (proportional to magnetic pressure) versus ion density obtained from a selected subset of the structures in Figure 2. The lines are least-squares-fits to data from the numbered individual structures for which the pressure-density relationship appeared monotonic. The variations in the slopes $d(B^2/8\pi)$ /dn of the lines in Figure 3 reflect differences in the temperatures of the different mirror mode structures.

The evolution of the slope, and related effective temperature derived from the small scale structures, as VEGA-1 receded from Halley is shown in Figure 4. The effective temperature is estimated to be accurate within a factor of 1.5. As one might expect, the temperature increases with distance from the nucleus. Comparison with the single fluid plasma temperature predicted by an MHD numerical model of Halley (cf. Schmidt et al., 1986) shows basic agreement in average value, but the model temperature does not vary as sharply as the temperature inferred from the observations. Note that the assumption of pressure balance fails in the outermost part of the region analyzed where the magnetic structures are no longer clearly defined. (Structures numbered 11-14 in Figure 2). If it is assumed that the electron temperature is equal to twice the ion temperature, the ion temperature ranges from about ~1.5 x 10^6°K at ~10^5 km cometocentric distance to ~2 x 10^5 °K closest to the nucleus (at ~5 x 10^4 km).

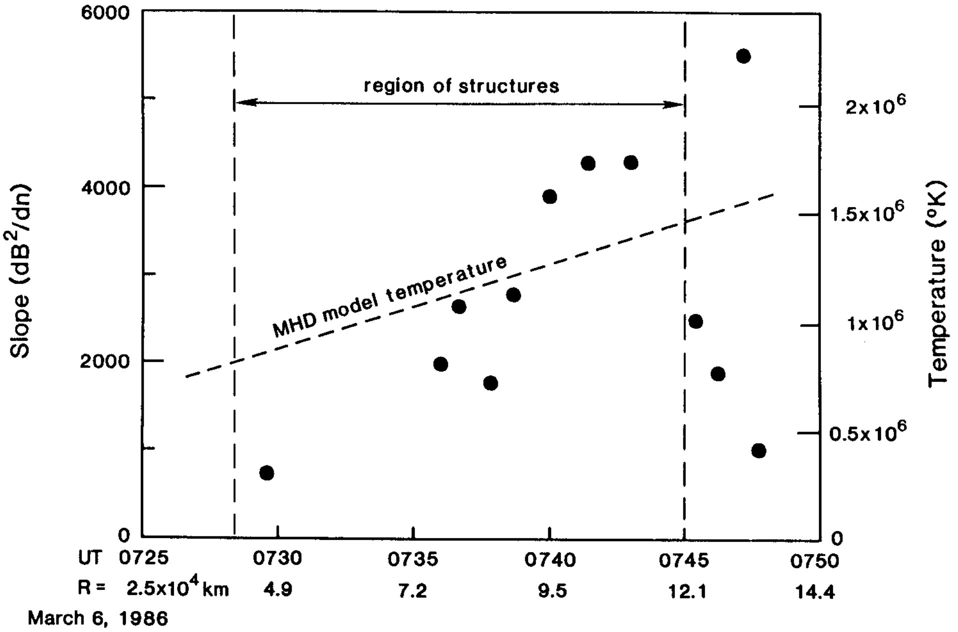

Fig. 4. The slopes $d(B^2/8\pi)/dn$ obtained from the data in Figures 3 and 4 as a function of time. A conversion to a temperature scale is given on the right. Plasma temperatures from the Schmidt et al. (1986) MHD model are shown for comparison.

Conclusions

Simultaneous VEGA-1 BD-3 plasma detector measurements and MISCHA magnetic field data show evidence of a special class of correlated magnetic pressure and density fluctuations during the outbound leg of VEGA-1's encounter with comet Halley. The magnetic fluctuations are of the type described by Russell et al. (1986) as mirror mode structures. A characteristic of these structures is a symmetric depression in the magnetic field magnitude with practically no rotation of the field direction. If it is assumed that there is pressure balance between magnetic and thermal pressures within these structures, and that the plasma temperature is practically constant throughout an individual magnetic field depression, the temperature can be computed for the region where these structures were observed. These temperatures are qualitatively consistent with those expected from MHD numerical modeling of comet Halley, thus lending credence to both the comet model and to our assumption that pressure balance approximately holds in these small-scale structures.

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References

Galeev, A. A., K. I. Gringauz, S. I. Klimov, A. P. Remizov, R. Z. Sagdeev, S. P. Savin, A. Yu. Sokolov, M. I. Verigin, and K. Szego, Crtical ionization velocity effects in the inner coma of comet Halley: Measurements by VEGA-2, Geophys. Res. Lett., 13, 845, 1986b.

Riedler, W., K. Schwingenschuh, Ye. G. Yeroshenko, V. A. Styashkin, and C. T. Russell, Magnetic field observations in comet Halley's coma, Nature, 321, 288, 1986.

Russell, C. T., W. Riedler, K. Schwingenschuh, and Ye. Yeroshenko, Mirror instability in the magnetosphere of comet Halley, Geophys. Res. Lett., 14, 644-647, 1987.

Schmidt, H. U., R. Wegmann, and F. M. Neubauer, MHD-Model for comet Halley, Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, 43, ESA SP-250, 1986.

Schwingenschuh, K., W. Riedler, G. Schelch, Ye. Yeroshenko, V. A. Styashkin, J. G. Luhmann, C. T. Russell, and J. A. Fedder, Cometary boundaries: VEGA observations at Halley, Adv. Space Res., 6, 217, 1986.

Vaisberg, O. L., G. Zastenker, V. Smirnov, B. Khazanov, A. Omelchenko, A. Federov, and D. Zakharov, Spatial distribution of heavy ions in comet P/Halley's coma, Astron. Astrophys., 187, 183, 1987.

Zastenker, G., O. Vaisberg, V. Smirnov, A. Federov, and A. Omelchenko, Distribution of cometary ions and flow properties in Halley comet, Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, 183, ESA SP-250,1986.

Yeroshenko, Ye. G., V. A. Styashkin, W. Riedler, K. Schwingenschuh, and C. T. Russell, Magnetic field fine structure in Comet Halley's coma, Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, 183, ESA SP-250, 1986.

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