CONFIGURATION, STRUCTURE, AND DYNAMICS OF MAGNETIC CLOUDS FROM SOLAR FLARES IN LIGHT OF MEASUREMENTS ON BOARD VEGA 1 AND VEGA 2 IN JANUARY–FEBRUARY 1986

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Abstract. Simple models of flare-generated magnetic clouds are considered in the light of magnetic measurements on board Vega 1 and Vega 2 during the solar-interplanetary events in January–February 1986. The models are in approximate accordance with the experimental data if the following conditions are satisfied: (1) the clouds are force-free finite aspect ratio toroids; (2) the large radius of each cloud is parallel to the magnetic axis of the nearest bipolar group; (3) the magnetic buoyancy, gravity, and hydrodynamical deceleration are taken into consideration.

1. Introduction

Several series of solar flares occurred in January–February 1986 (*Solar Geophysical Data*, 1986; *Solnechnye Dannye*, 1986). Space probes Vega 1 and Vega 2 passed through interplanetary shock waves and magnetic clouds generated by some of these flares. This paper presents the development of simple models of the geometry, structure and dynamics of magnetic clouds (Ivanov, 1987) in the light of the magnetic measurements made by Vegas 1 and 2.

2. Solar Flares as the Sources of Clouds

Spacecraft Vega 1 and Vega 2 have passed through three interplanetary magnetic clouds. The three solar flares shown in Table I can be the most proper sources of these clouds.

TABLE I

Solar flares and bipolar groups

Date	Start time (UT)	Position		IMP		North pole		South pole	
		φ_f (deg)	Λ_f (deg)	Opt.	X-ray	φ_N (deg)	Λ_N (deg)	φ_S (deg)	Λ_S (deg)
16 Jan., 1986	07 : 38	− 10	+ 90	1n	?	− 08	+ 70	− 12	+ 77
14 Feb., 1986	09 : 09	+ 03	+ 82	2b	M6.4	0	+ 80	− 2.5	+ 71
15 Feb., 1986	09 : 55	− 02	+ 83	SN	C7.4?	0	+ 80	− 2.5	+ 71

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Table I shows the time of the beginning of the flares, their importance and heliographic coordinates – heliolatitude φ_f (north is positive) and heliolongitude Λ_f (west is positive). The time of the flare on February 15 is determined by a radio type II burst. Since the data on this last flare are less definite than on the first two, question marks have inserted. Table I also includes coordinates of the magnetic poles of bipolar groups as the closest to the flares φ_N, Λ_N, φ_S, Λ_S.

Table II displays the solar-ecliptical coordinates of the Vega 1 and Vega 2 at the moments of boundary crossings as well as the normals to the boundaries of the magnetic clouds. φ is latitude with respect to the ecliptical plane, and Λ is longitude, relative to the autumnal equinox. The direction cosines of the normals are given in the right Cartesian coordinates with the origins on Vegas and the x- and z-axes directed to the centre of the Sun and along the perpendiculars to the orbital planes of the spacecraft correspondingly.

TABLE II

Spacecraft and normals to magnetic clouds

Space craft	Date	Time (UT)	$R \times 10^6$ (km)	Position		l_N	m_N	n_N
				deg	deg			
Vega 1	18 Jan., 1986	22 : 23	140.45	4.57	187.4	– 0.76	0.16	0.63
Vega 2	19 Jan., 1986	02 : 10	148.71	2.86	185.6	– 0.81	0.36	0.45
Vega 1	16 Feb., 1986	03 : 19	127.12	3.51	219.8	– 0.60	– 0.62	– 0.51
Vega 2	16 Feb., 1986	06 : 53	135.82	1.81	214.3	– 0.98	0.17	– 0.07
Vega 1	16 Feb., 1986	18 : 36	126.82	3.47	220.5	– 0.68	0.01	– 0.73
Vega 2	16 Feb., 1986	23 : 05	135.47	1.77	215.1	– 0.70	0.56	– 0.44

Figure 1 represents (by hatching) the regions of the necessary occurrence of shock waves generated by these flares on a sphere of 1 AU radius that were plotted by the procedure proposed earlier (Ivanov, Harshiladze, and Mikerina, 1983; Ivanov, 1984) using data of Table I. It is seen that Vegas 1 and 2 have entered the regions of the necessary occurrence of shock waves generated by these flares, and shock waves have been actually observed in all three cases. Herein, we would like to carry out a quantitative analysis of these disturbances, using the data obtained from the locations of the space vehicles located almost in an optimal way, as far as the geometry, structure and dynamics of magnetic clouds are concerned.

3. The Configuration of Magnetic Clouds

We propose the following simple method to estimate some of the geometric characteristics of magnetic clouds.

We assume the boundary of the magnetic cloud to be a regular surface of the second order. In the Cartesian coordinate system fixed to the cloud, it has the form of $f(x, y, z) = \text{const}$. Let us assume that during the time interval Δt, when no significant changes occur in the dimensions of this surface, n space vehicles cross it at n different points, and that the outside normals **N** to the surface are determined at these points. Then from

$$f(x_i, y_i, z_i) = \text{const.}, \qquad \textit{grad}\, f/|\text{grad}\, f| = \mathbf{N}_i(x_i, y_i, z_i), \tag{1}$$

where $i = 1, 2, \ldots,$ we have a nonlinear system of $3n$ algebraic equations.

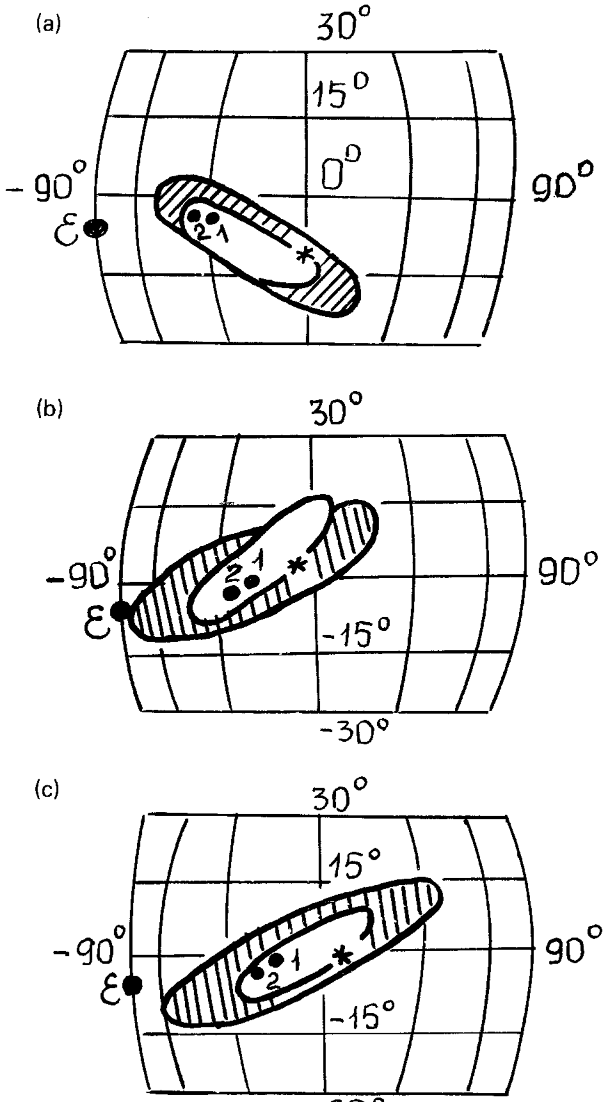

Fig. 1. Cross-sections of the nterplanetary shock waves (hatched) and of the magnetic clouds from the solar flares in January–February 1986 (* – flare position: 1 and 2 – Vega 1 and Vega 2 positions; ε – Earth's position). (a) 18–19 January, 1986; (b, c) 16 February, 1986.

Having approximated $f(x, y, z)$ by a particular surface of the second-order, we get a concrete form of that system the solution of which helps us to find some of the geometric characteristics of the cloud within the frames of this approximation. Having approximated the boundary of the cloud by half of the oblate spheroid with semi-axes b and c, we get a system of three equations for Vega 1:

$$\begin{aligned}
&((x_1 - R_{c_1})^2 + y_1^2)/b^2 + z_1^2/c^2 = 1\,, \\
&(x_1 - R_{c_1})/y_1 = l_{N_1}/m_{N_1}\,, \\
&(y_1 n_{N_1})/(z_1 l_{N_1}) = (b/c)^2\,.
\end{aligned} \tag{2}$$

Coordinates x, y, z of the space probes, and normals l_N, m_N, n_N are recorded in the coordinate system the origin of which is located in the Sun's centre. The axis x is oriented towards the centre of the cloud, whereas the axes y and z are oriented along the major and minor semi-axes of the cloud, respectively. If φ_a, Λ_a are the latitude and longitude of the apex of the cloud and θ_a is the angle of the inclination of the major semi-axis to the meridian, then the transition to such coordinate system from the heliographic one is performed with the aid of the matrix

$$\begin{aligned}
&c = \{c_{ii}\}, \qquad c_{11} = \cos\varphi_a \cos\Lambda_a\,, \\
&c_{12} = -\cos\theta_a \sin\Lambda_a + \sin\theta_a \sin\varphi_a \cos\Lambda_a\,, \\
&c_{13} = -\sin\theta_a \sin\Lambda_a - \cos\theta_a \sin\varphi_a \cos\Lambda_a\,, \\
&c_{21} = \cos\varphi_a \sin\Lambda_a\,, \\
&c_{22} = \cos\theta_a \cos\Lambda_a + \sin\theta_a \sin\varphi_a \sin\Lambda_a\,, \\
&c_{23} = \sin\theta_a \cos\Lambda_a - \cos\theta_a \sin\varphi_a \sin\Lambda_a\,, \\
&c_{31} = \sin\varphi_a, \qquad c_{32} = -\sin\theta_a \cos\varphi_a, \qquad c_{33} = \cos\theta_a \cos\varphi_a\,.
\end{aligned} \tag{3}$$

A similar system of three equations can be derived for the second space vehicle. Each of these systems allows the values b, c and R_c to be determined independently. The coordinates of the flare φ_a, Λ_a, and the angle θ_a were selected to reach the minimum for the expression

$$(c_2 - c_1)^2 + (b_2 - b_1)^2 + (R_{c2} - R_{c1} + D)^2\,;$$

here b_1, c_1, R_{c1} are values of the semiaxes and the location of the centre of the cloud determined from the data for Vega 1, and b_2, c_2, R_{c2} are the same values determined from the data for Vega 2. D is an assumed distance between the centres of the cloud at the moments of crossing the boundary of the latter by the two vehicles, $D = v_c \tau$, where v_c is the cloud's velocity, τ is a time interval between the moments of crossing the boundary by the vehicles. In our case $D = 10^7$ km, but its value does not significantly affect the results of the numerical solution. It is also worth noting that, due to the ambiquity, the solutions (2) were chosen as corresponding to oblate spheroids with semiaxes ratios that ranged from of $c/b = 0.2$ to 1.

In practice, the solution (2) was reduced to the exhaustion of the possible coordinates of the cloud apex in the square of 10° × 10° by heliographic coordinates and the values of θ_a by which the above-mentioned condition was reached. The geometric and kinematic characteristics of magnetic clouds obtained as a result of the solution of (2) are as follows: the coordinates of the apexes (φ_a, Λ_a) and the angles of the inclination of minor semiaxes to the heliographic meridian θ_a (Table III), the semiaxes of clouds 'b' and 'c' (Table IV), the position of the cloud centres (R_c) and the velocity of their travel between the vehicles (V_c) (Table V).

In Table III the results of the determination of the clouds apexes and the angles θ_a are compared by two independent methods. The first method is the one described above based on the magnetic data from the advantageous locations of the space vehicles. The other method is mentioned in the previous section (Ivanov, Harshiladze, and Mikerina,

TABLE III

Heliographic coordinates of magnetic clouds and angles of inclination determined by two independent methods

Number of cloud	Apex		Inclination	Apex		Inclination
	φ_a (deg)	Λ_a (deg)	θ_a (deg)	φ_a' (deg)	Λ_a' (deg)	θ_a' (deg)
1	−9.7	+76.6	110	−10	+80	118
2	+1.2	+72.4	47	0	+68	72
3	+2.8	+81.9	54	0?	+86	72

TABLE IV

Semi-axes of oblate spheroidal clouds

Number of cloud	B_1 10^6 (km)	c_1 10^6 (km)	b_1/c_1	b_2 10^6 (km)	c_2 10^6 (km)	b_2/c_2
1	37.0	10.8	3.4	35.8	7.2	5.0
2	62.1	16.9	3.7	57.8	16.3	3.5
3	34.8	8.4	4.1	40.0	8.9	4.5

TABLE V

Cloud distances from the Sun, velocities and propagation times between Vega 1 and Vega 2

Number of cloud	R_2 (km)	R_1 (km)	τ (hour)	v (km s^{-1})	v_φ (km s^{-1})
1	118.8	109.9	3.8	650	690
2	79.3	69.5	3.6	760	840
3	110.8	97.5	4.5	820	1100

1983) which uses the data on the coordinates of the flares and the magnetic poles of corresponding bipolar groups (Table I) as well as the mean geometric characteristics of the shock wave obtained from the statistics of the sudden commencements of magnetic storms generated by isolated flares (Ivanov, Evdokimova, and Mikerina, 1982). According to the latter, the coordinates of the shock wave apex $\varphi_a' = \varphi_f$, $\Lambda_a' = \Lambda_f - 10°$ and the angle θ_a' is determined from the inclination to the meridian of the surface of the great circle crossing the flare in parallel to the magnetic axis of a nearby bipolar group. Table III and Figure 1 show that there exists good agreement between φ_a and φ_a', Λ_a and Λ_a', θ_a and θ_a', determined by these two independent methods.

As follows from Table IV and Figure 1, the clouds are oblate with the semiaxes ratio of $b/c = 3.5$–5. Table V shows that the velocities of the travel of clouds between the vehicles determined due to $v_c = (R_2 - R_1)/\tau$ are in good agreement with the mean velocities v_a of the travel from the Sun to the vehicles.

Thus, a number of the geometric characteristics of the clouds has been estimated, and a mutual tie-in between flares, clouds and space vehicles has been performed. Within the frames of this simple model, the leading part of the cloud can be considered to be half of an oblate spheroid, the major semi-axis of which is almost parallel to the plane of the great circle passing through a flare in parallel to the magnetic axis of a nearby bipolar group.

4. Structure of Magnetic Clouds

Using the case of the magnetic cloud of February 16, 1986 (No. 2 in Table II), let us compare the theoretical profiles B_x, B_y, and B_z of the magnetic field components calculated for the trajectories determined from Tables II and III data:

$$\begin{aligned} &X_1 \neq \text{const.}, \quad Y_1 = -16 \times 10^6\ \text{km}, \quad Z_1 = 0.5 \times 10^6\ \text{km}, \\ &X_2 \neq \text{const.}, \quad Y_2 = -4 \times 10^6\ \text{km}, \quad Z_2 = -6.4 \times 10^6\ \text{km}, \end{aligned} \tag{4}$$

with the profiles obtained experimentally from Vegas 1 and 2.

The solutions of the equation of a force-free magnetic field were used as tentative theoretical models:

$$\operatorname{rot} \mathbf{B} = \lambda \mathbf{B}, \tag{5}$$

where $\lambda = \text{const.}$, respectively:

(a) In the coordinates of an oblate spheroid η, ξ, φ (Ivanov and Harshiladze, 1985):

$$\begin{aligned} &\mathbf{B} = \mathbf{z} \times \nabla\psi + [\nabla \times (\mathbf{r} \times \nabla\psi)]/\lambda, \\ &\psi = A_{00}[\sin(c_0\eta)]/c_0\eta - A_{01}(c_0\eta\cos c_0\eta - \sin c_0\eta)\xi/(c_0^2\eta^2), \end{aligned} \tag{6}$$

where

$$c_0 = \lambda(b^2 - c^2)^{1/2}, \qquad 0 \le \eta \le \infty, \qquad -1 < \xi < 1.$$

(b) In toroidally-distorted cylindrical coordinates r, θ, z (Miller and Turner, 1981):

$$
\begin{aligned}
B_r &= B_0[aF - y_0(\lambda r)] \sin\theta/(\lambda R_0)\,, \\
B_\theta &= B_0\left[y_1(\lambda r) - \left(y_0(\lambda r) - a\frac{\mathrm{d}F}{\mathrm{d}r}\right)\cos\theta/(\lambda R_0)\right], \\
B_z &= B_0[y_0(\lambda r) - aF\cos\theta]\,,
\end{aligned}
\tag{7}
$$

where

$$F = ry_0(\lambda r)/2a + y_0(\lambda a)y_1(\lambda r)/2y_1(\lambda a)\,,$$

a, R_0 are radii of a compact toroid with the final ratio; $a/R_0 \leq 1$, and y_0, y_1 are Bessel functions.

The theoretical solution of (6) or (7) for trajectories (4) optimally satisfying the experimental profiles B_x, B_y, and B_z components was found in the following way. The computeraided calculation of theoretical values B_{ijk}, where $1 \leq i \leq 3$, $1 \leq j \leq N$, $k = 1.2$ was made for different sets of free parameters A_∞, A_{01}, λ, b, c (in case (6)) and B_0, a, λ, R_0 (in case (7)). Here B_{1jk}, B_{2jk}, B^T_{3jk} are three components of the field at the jth point of the trajectory, $k = 1, 2$ is the number of the space vehicle. The total of $N_1 = N_2 = 64$ points for each trajectory was used. The corresponding experimental values of components (the mean ones for $\Delta t = 10.2$) are B^e_{ijk}. The trajectory step was chosen on the assumption that $\Delta X_1 = \Delta X_2 = v\Delta t = 760\ \mathrm{km\ s^{-1}} \times 10.2\ \mathrm{min} = 0.55 \times 10^6\ \mathrm{km}$.

The optimal solution was obtained with fairly small values

$$\alpha = \cos^{-1}(s^{eT}/\sqrt{s^e s^T})\,, \tag{8}$$

where

$$
\begin{aligned}
s^{eT} &= \sum_{k=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{N} B^e_{ijk} B^T_{ijk}\,, \qquad s^e = \sum_{k=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{N} (B^e_{ijk})^2\,, \\
s^T &= \sum_{k=1}^{2}\sum_{i=1}^{3}\sum_{j=1}^{N} (B^T_{ijk})^2\,.
\end{aligned}
\tag{9}
$$

In case of (6), α remained great with all reasonable values of parameters. In case of (7), the value $\alpha = 28.^\circ5$ was achieved with $\lambda = 0.17 \times 10^{-11}$ cm, $B_0 = 35.8$ nT, $a = 10 \times 10^6$ km, $R_0 = 25 \times 10^6$ km. Figures 2 and 3 illustrate experimental points in comparison with theoretical profiles.

The value α and Figures 2 and 3 indicate a certain degree of agreement between theory and experiment. Qualitatively, theoretical and experimental profiles are similar, though there are considerable divergences, in particular, at the ends of the profiles, and they are greater for Vega 2 than for Vega 1. These divergences could be explained by an error due to the neglect of the dynamical interaction between the cloud and the interplanetary medium, which might be shown by the 3-D MHD modeling of Dryer, Wu, and Han (1986) and Han (1988). Such an interaction generated currents on the cloud's boundary, violating the cloud's axial symmetry. However, the consideration of this important circumstance is outside the framework of this paper since the objective of the latter is to find the solution of Equation (5) which could be used as a basis for further development of the theory of clouds. The divergences of the theoretical and experimental profiles in Figures 2 and 3 could occur also as a result of an error in the plural cloud's tie-in to heliographical coordinates of the trajectory (4) fulfilled in the previous section of the paper (Table III).

In the final analysis, the correlation of theory and experiment agrees well with the concept of the cloud as a compact force-free oblate toroid, the equatorial plane of which

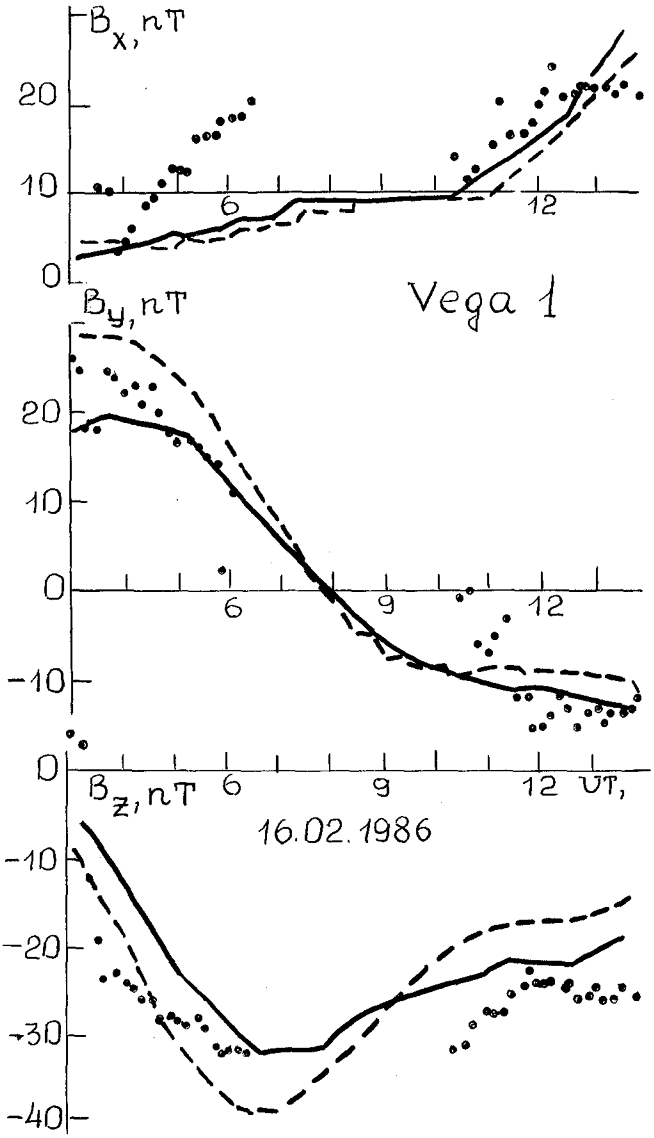

Fig. 2. Experimental (points) and theoretical profiles of IMF for the Vega 1 trajectory through the magnetic cloud from the solar flare on February 14, 1986.

is parallel to the plane of the great circle that passes through the flare along the magnetic axis of the bipolar group which is the closest to the flare.

5. Dynamics of Magnetic Clouds

Given the definitions and estimations made earlier from the data of Vegas 1 and 2, we can discuss the dynamics of magnetic clouds generated by a doublet of the considered

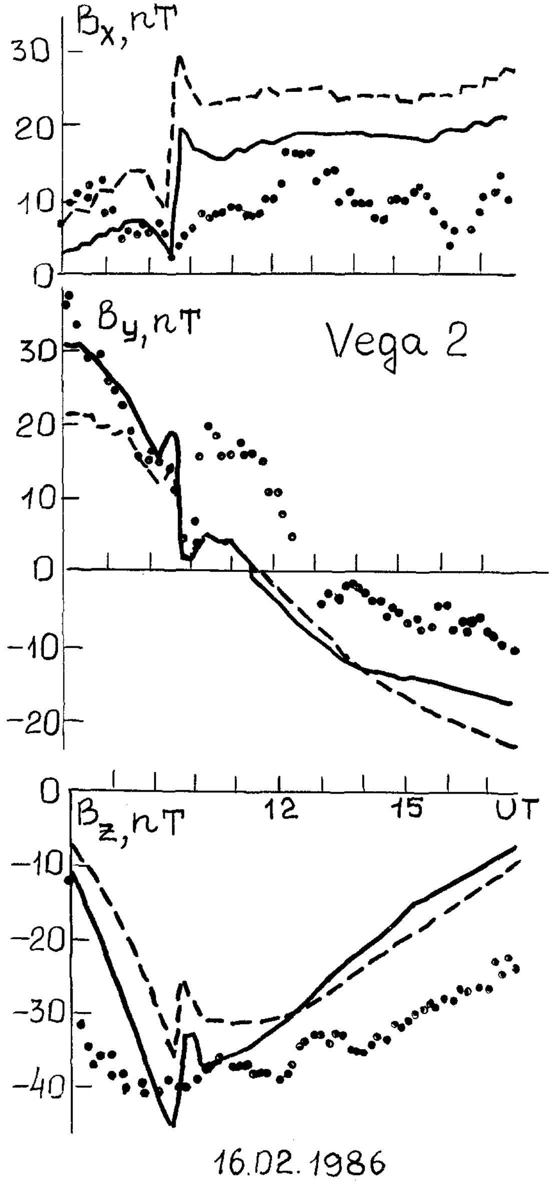

Fig. 3. Same as Figure 2 but for the Vega 2.

solar flares in February 1986 (Table I) in the light of the theory presented in studies by Ivanov and Harshiladze (1984) and Ivanov *et al.* (1987). In calculating forces acting upon a cloud, as well as its kinematic and geometric characteristics, we shall not differentiate the oblate ellipsoid, for which the above-mentioned theory has been developed, from a compact toroid. This assumption will lead to an insignificant error for the estimations presented below.

(1) Let us estimate to what extent one of the cloud's typical cross dimensions obtained in the previous section ($a = 10^7$ km, $b = a + R_0 = 35 \times 10^6$ km with the position of the centre of mass at a distance of $r = 110 \times 10^6$ km from the Sun) agrees with the theoretical ones. For that, we pass to the cloud's dimensions at a point of its origin c_0, b_0. If

$$c = c_0(B_0/B)^{1/2}, \quad B = B_0(r_0/r)^3 \quad \text{with} \quad r = (1.125\text{–}3)R_\odot, \quad R \sim r^{-2},$$

with $r > 3\,R_\odot$ as it is adopted in the paper by Ivanov *et al.* (1987), then $c_0 = 4 \times 10^9$ cm, $b_0 = 1.4 \times 10^{10}$ cm for the cloud generated by the flare on February 14, 1986, agreeing well with values $c_0 = 5 \times 10^9$ cm, $b_0 = 10^{10}$ cm assumed earlier while discussing the dynamics of the magnetic clouds generated by the doublet on August 10, 1979 (Ivanov *et al.*, 1987). This result is somewhat larger than $c_0 = 2 \times 10^9$ cm, $b_0 = 7 \times 10^9$ cm in the study by Ivanov and Harshiladze (1984) for the cloud generated by the flare on August 18, 1979.

(2) Let us plot the velocities of both the magnetic clouds $v_1(r)$, $v_2(r)$ on the path from the Sun to the encounter with Vega 2. For this purpose, we use solution of the equation (Ivanov and Harshiladze, 1984)

$$\mathrm{d}z/\mathrm{d}r = Q(r) + R(r)z^{1/2} - P(r)z, \tag{10}$$

$$Q(r) = \frac{4Bc^3}{3\alpha^2(1+\alpha^2)^{1/2}Q_1^{1\prime}(i\alpha)M}\frac{\partial B}{\partial r} - \frac{2GM_\odot}{r^2} - \frac{2\chi\pi cb\rho v_q^2}{M},$$

$$R = 4\chi\pi bc\rho v_q/M, \qquad P = 2\chi\pi bc\rho/M,$$

where $z = v^2$, $\alpha = c/(b^2 - c^2)^{1/2}$, M is the mass of the cloud, $\rho(r)$ is the profile of the density in the corona and the interplanetary medium (Athay, 1973), v_q is the velocity of the quiet solar wind assigned by the theoretical solution with $V_{qe} = 380$ km s^{-1} at the Earth's orbit (Hundhausen, 1972) and $\chi \approx 1$ is a coefficient taking into account the magnitude of the dynamic pressure on the cloud.

For the first cloud let us plot the profile $v_1(r)$ to provide the velocity of the cloud's centre of mass to be between 07–17 UT on February 16, 1986 at a distance of $R_e \approx 10^8$ km from the Sun during the period of its crossing by Vega 2 in agreement with the experimental data and estimates in the previous section. Let us also assume that the cross sectional dimensions of the cloud are equal to the ones of the previous section, i.e., $b = R + a = 35 \times 10^6$ km. $c = 10^7$ km and $\alpha = 0.3$. If we accept the profile $B(r)$ to be the same as in evaluating c_0, b_0 we shall have at least three free parameters. Choosing them in such a way that $M_1 = 10^{15}$ g, $B_0 = 15$ G, $\chi \approx 1.1$, we get the profile $v_1(r)$ (Figure 4) satisfying the abovementioned experimental data and estimates.

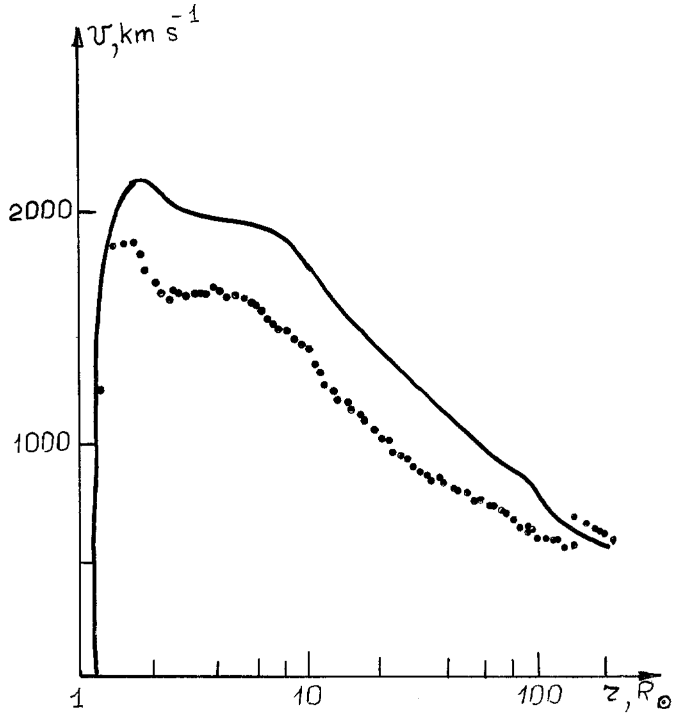

Fig. 4. Theoretical velocities of magnetic clouds from the solar flares on February 14 (dotted line) and February 15, 1986 (solid line). The jump at $r \approx 100\,R_\odot$ is probably produced by cloud-cloud collision (Ivanov *et al.*, 1987).

The profile of the velocity of the second cloud $v_2(r)$ (Figure 4) is plotted according to (10) from the Sun to the moment of the collision with the first cloud t_c. The estimate is as follows:

$$t_c = t_s - (2b - v_1(t_s - t_m))/v_s\,,$$

where $t_s = 17$ UT, $t_m \simeq 7$ UT on 16 February, 1986 – the moment of crossing the shock front generated by the second flare and the boundary of the first magnetic cloud on Vega 2, $b = 35 \times 10^6$ km, and $v_s = 1000$ km s^{-1} is the velocity of the shock wave. The profile $v_2(r)$ is plotted assuming that characteristics of both clouds and the medium are identical, with the exception of $M_2 = 1.5 \times 10^{15}$ g, $\chi = 0.83$.

These profiles provide theoretical values for the moment of the cloud's collision $t_c^* = 4.5$ UT on 16 February, 1987, and the position of the centre of mass of the first cloud at that moment $R_{c1}^* = 111 \times 10^6$ km which are close to the independent estimates presented above: $t_s = 6$ UT on 16 February, 1987 and $R_{c1} \approx 10^8$ km. It should also be noted that the cloud's velocities at the moment of the collision $v_1 = 550$ km s^{-1}, $v_2 = 803$ km s^{-1} agree well with those obtained by the independent estimation (Table V).

6. Conclusion

The magnetic measurements carried out on the two Vega 1 and Vega 2 space probes confirm the idea on the flare-generated magnetic cloud as a compact oblate force-free toroid, the equatorial plane of which is parallel to the plane of the great circle passing through a flare parallel to the magnetic axis of the bipolar group of solar spots which is the closest to the flare. This main conclusion has been drawn proceeding from the following results of this study:

(1) An independent method which is introduced and implemented for determining the geometric characteristics of a magnetic cloud uses magnetic measurements from the positions of two, conventiently located space vehicles. Applying this method we have been able: (a) to obtain an agreement in determining the geometric characteristics of clouds and shock waves by this new method and by the independent method proposed earlier (Ivanov, 1984; Ivanov, Harshiladze, and Mikerina, 1983) based on indirect data; (b) to confirm the notion (Ivanov, Mikerina, and Evdokimova, 1980; Ivanov, Evdokimova, and Mikerina, 1982) that the cross section of a flare interplanetary disturbance is oblate to the plane of the great circle passing through the flare in parallel to the magnetic axis of the bipolar group; and (c) to implement the mutual tie-in of the flares, clouds and trajectories of space vehicles.

(2) It is shown that if space vehicles pass through a magnetic cloud strictly along the above-mentioned trajectories, agreement of theory with experiment is achieved when a cloud is assumed to be a compact force-free toroid with the final aspect ratio and the equatorial plane parallel to the above-mentioned specific plane of the great circle. Thanks to this approach: (a) a theoretical solution serving as a basis for further studies of clouds and coronal transients (Dryer, 1982) is found; (b) another independent argument in favour of an oblate magnetic disturbance, located especially with respect to the magnetic axis of the corresponding bipolar group is found.

(3) It is established that the geometric and kinematic characteristics of magnetic clouds derived from the measurements by Vegas 1 and 2 and the corresponding estimates could, in principle, agree with the theory of the movement of these clouds from the Sun under the effect of the forces of magnetic buoyancy, gravitation and hydrodynamic deceleration (Ivanov and Harshiladze, 1984; Ivanov *et al.*, 1987).

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