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STRUCTURE OF THE SOLAR CORPUSCULAR STREAM AND ITS INTERACTION WITH THE EARTH'S MAGNETOSPHERE

by

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STRUCTURE OF THE SOLAR CORPUSCULAR STREAM AND ITS INTERACTION WITH THE EARTH'S MAGNETOSPHERE *

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by Yu. D. Kalinin
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SUMMARY

Basing themselves upon various "probe" and ground observations with particular reference to the results of observations by Mariner-2 IMP-1 and other artificial satellites, the authors clearly establish the determinant role of corpuscular stream's magnetic field in the transfer of perturbations to Earth's magnetosphere. These comparisons suggest the existence of a direct correlation between the D_i-variations of the geomagnetic field and the field variations beyond the limits of the Earth's magnetosphere. It is to be noted that these peculiarities of stream's magnetic field interaction with the Earth's magnetosphere may, at further quantitative development, be explained by the scheme earlier considered by one of the authors [28], just as would be the case for the part or entire plasma acceleration of the upper magnetosphere, attending the geomagnetic variations. At the same time the properties of the strongly magnetized collisionless plasma of the magnetosphere, allowing the penetration and the progress of the solar flux in the form of a magnetic piston, external relative to magnetosphere field, must be taken into account.

Author

* * *

1. - When attempting to answer the question as to how the solar corpuscular stream yields its energy to the Earth's magnetosphere and

* STRUKTURA SOLNECHNOGO KORPUSKULYARNOGO POTOKA I VZAIMODEYSTVIYE YEGO S MAGNITOSFEROY ZEMLI.

for the understanding of "probe" measurements of the magnetic field and plasma in the interplanetary and near-Earth space by means of rockets and satellites, one must have a representation of the structure of the corpuscular stream. In the solar atmosphere, that is, in the active region, where the geoeffective corpuscular stream is generated, in the interplanetary medium and in the greater part of the Earth's magnetosphere, the number

$$A = \frac{\varepsilon_M}{\varepsilon_K} = \frac{H^2}{4\pi\rho V^2} > 1 \text{ or } \gg 1.$$

This means, that the dynamics of the plasma are determined by the field; at the same time, this is done not only by its magnitude, but by its structure, its geometry in the entire volume and by its possible variations.

For the substantiation of the two positions, we utilized the observations in the basic magnetic vector, obtained on Mariner-2, IMP-1 and other probes.

a) The magnetic field (and probably the plasma) of the geoeffective corpuscular stream corresponds to a model of stream consisting of a series of discrete large-scale plasmoids ("M-elements"), having their proper, quasi-force-free magnetic field (which, for brevity, we shall subsequently call the force-free field). Such stream structure is a direct consequence of the observed magnetic fields in the Sun and the generation mechanism of the corpuscular stream in the active regions.

b) The existing schemes of solar corpuscular stream interaction with the Earth's magnetosphere must be revised, for the "probe" measurements of magnetic vector at magnetosphere periphery and in the nearest vicinity of the Earth point to a substantial, if not determining role of the magnetic field of the stream in the process of corpuscular stream's action upon the magnetosphere.

2.- Measurements of magnetic fields in active regions on the Sun at chromosphere level have shown [1, 2], that there exists between the field vector H and the velocity V the correlation

$$H = \beta(r)\,V. \qquad (1)$$

Its analysis leads to the conclusion that if the parameter β is

$$\beta = \frac{a}{H} \exp\left(-\frac{\lambda^2}{2} r\right), \tag{2}$$

the field in the chromosphere has a force-free structure, that is,

$$[\mathrm{rot}\, \mathbf{H}, \mathbf{H}] = 0.$$

Pointing to the validity of the correlation (2), the observations lead to the conclusions that the force-free fields in the chromosphere may be connected with the photosphere by a tube of force, where the field is basically a force field. Observed also are isolated force-free fields having no connection with the photosphere field. The examination of the generation mechanism of corpuscular streams leads to the concept, that only discrete plasmoids with proper force-free magnetic fields (M-elements) can emerge from the active region.

It should be also clarified in what context there is question here and subsequently of force-free magnetic fields. It is estimated in all cases that there exists in a specific, bounded and usually small volume (or on a specific surface) a magnetic field of force and a current with a source. In case of a standard chromospheric (coronal) force-free magnetic field, the force source is located under the photosphere, while for an isolated plasmoid with a nearly infinite conductivity one may consider on a specific surface a slowly decreasing current and a field of force having formed earlier, at plasmoid field break-away from the field of active regions *. In the bounded volume (or surface) there is a direct link between this force field and force-free magnetic field $\mathbf{H}$, so that in the entire remaining bounded volume of plasma the correlation $[\mathrm{rot}\,\mathbf{H}, \mathbf{H}] = 0$ takes place. Being the most stable, the force-free magnetic field still necessarily disintegrates, remaining, however, still force-free. The disintegration of the force-free magnetic field may be linked with dissipation processes (Joule current losses and so forth), as well as with the onset of convective and other instabilities. Thus, for the case $\mathbf{H} = \alpha \mathbf{H}$, where $\alpha =$ const, the field, according to [5], is unstable and the time of instability rise

* Note that the formation of such broken-away and often large magnetic fields with plasmoids is often observed during chromospheric flares [3] and in active prominences [4].

is estimated by the correlation

$$t_o \approx 3 \cdot 10^{-9}\, l_o n^{1/2} H^{-1} \text{ sec}$$

where l_o is the characteristic dimensions of the volume considered (where the field H is force-free); n is the plasma concentration in cm^3. It is easy to see that in the scale of solar activity events in the chromosphere and corona, where $l_o \gtrsim 10^{9}$-10 cm, $n \lesssim 10^{11} \div 10^{8}\ cm^{-3}$, $H \sim 10^{2} \div 10$ oe, the time of instability accretion t_o (in this unfavorable case) is of the order $\gtrsim 10^5$ sec. For the M -elements, t_o increases in the interplanetary medium by at least two orders. Therefore, if the characteristic time $\underline{t}$ of the events under consideration [generation and egress of M-elements in the chromosphere and corona ($t \lesssim 10^3$ sec), the motion of M-elements of corpuscular streams from Sun to Earth ($t \lesssim 10^5 - 10^6$ sec) is less than t_o, we may approximately consider the magnetic field as a stationary, force-free formation.

3.- The entire macroscopic structure of the corpuscular stream, consisting of separate M- elements, has the following peculiarities.

a) Each plasmoid with its proper magnetic field is an independent element of the flux, which moves radially preserving the angular moment of Sun's rotation. That is why the chain of M-elements is disposed along the isochrone, that is along the Archimedes spiral, the tangent inclination of which is determined by the magnitude of radial velocity. The dimensions of each element increase with time so that the magnetic field of the flux spreads into the surrounding rarefied collisionless plasma mostly in the direction of the magnetic lines of force of the associated plasma flux with a velocity $V \simeq \langle V_A \rangle \simeq 2{,}5 \cdot 10^{7}$ cm sec^{-1}.

Ahead of the boundary of the M-element there will propagate a supersonic shock (impact) magnetic piston, whose dimensions may be estimated at (see [6])

$$\delta \simeq \frac{m_i}{m_e} \frac{c}{\Omega_i} (M_A - 1)^{1/2},$$

where m_i is the mean ion mass of the flux (in our case $m_i \simeq 3/2\, m_H$); m_e is the mass of the electron; $\Omega_i = \left(\frac{4\pi n e^2}{m_i}\right)^{1/2}$ is the ion plasma frequency; M_A is the Mach-Alfvén number. In our case $\delta \lesssim 2 \cdot 10^{11}$cm. The question of existence of collisionless shock wave (and not the magnetic piston), moving ahead of the corpuscular flux's plasma, has been discussed in the works [7, 8].

b) The interplanetary medium, surrounding the M-elements, such as the quiet solar wind linked with temperature dissipation or continuous expansion of solar atmosphere, moves radially from the Sun with a velocity $\lesssim 3 \cdot 10^7$ cm sec^{-1} $< V_{r,\ stream} \simeq 4 \div 6 \cdot 10^7$ cm sec^{-1}, carrying along, according to [9], the total magnetic field of the Sun. Owing to the presence of the orthogonal component of the field, there sets in between the two magnetized fluxes, moving with relative velocity, an interaction reminding one of that occurring in the plasma flow between two cylindrical walls in a magnetic field having a field component perpendicular to the direction of plasma flow (see [10]). The problem is made more complex by the fact that the motion is sub-Alfvén at close distance from the moving boundary of the M-element, where the field is relatively great ($H \gtrsim 15$–20γ) ; at greater distances the number $M_A < 2$ and in the remote periphery it may become > 2. The second complicating circumstance consists in that it is necessary to account for conductance anisotropy (as the Hall currents become here substantial). For the estimate of the distribution of the transverse velocity component of the carried surrounding quiet wind, we utilized the method of calculation of gas hydrodynamic flow [10]. The final result is brought out in Fig. 1, from which it follows that the maximum radial velocity in the carried plasma medium is attained at a significant distance from the M-elements. There is a clear asymmetry in the distribution of carried plasma velocity, qualitatively coinciding with the distribution pattern of radial plasma and magnetic field velocity according to Mariner-2 measurements. Note that in the standard model of a corpuscular stream (the so-called "magnetic bubble" [11 – 13] or the continuous "magnetized plasma jet" [14 - 16]) such distribution of the field and of plasma velocity is difficult to obtain. The kinetic energy, transferred by the M-element by means of the magnetic field to the associated plasma over the entire path from Sun to Earth (for $t \approx 3.7$ days at $V_r \approx 5 \cdot 10^7$ cm sec^{-1}), does not exceed ten percent (10%) of the energy of the M-element, equal to $\gtrsim 10^{29}$ erg.

c) In the entire, broad ($\gtrsim 2 \cdot 10^{13}$ cm cross section), "peripheral" part of the corpuscular stream beyond the limits of M-elements, there must apparently be a magnetic field, bent along the isochrone, the direction of of which must correspond to the magnetic polarity of the sequence of M--elements, provided the considered model is valid. The latter preserve their polarity corresponding to that of the effective magnetic dipole of the active region correspondingly with the considered scheme of flux's generation in the Sun. Thus, the direction of the magnetic lines of force

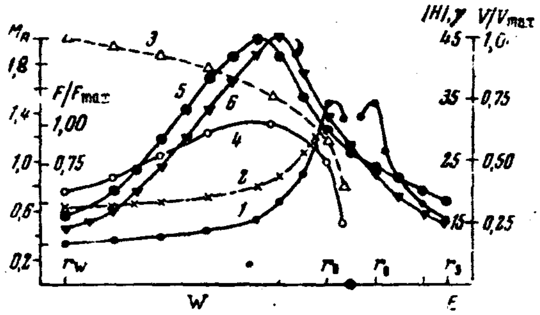

Fig. 1. - Distribution of the basic parameters of the corpuscular stream according its cross section.

The distances from the axis of the stream are given along the horizontal and are denoted by double circles; r_0 is the characteristic dimension of the M-element; E is the eastern part of the stream, W – the western one; $|H|$ is the module of the force-free field; 1 – undistorted field, 2 – taking into account the deformation associated with the plasma; M_A is the Mach-Alfvén number (3); F/F_{max} is the relative force linked with the magnetic viscosity and occurring at increase of associated plasma (4); V/V_{max} is the relative radial velocity of the plasma (5 – computed, 6 – average curve for four corpuscular streams observed on Mariner-2).

in the entire periphery of the stream may be either from the Sun (if the corpuscular stream moved in the given solar cycle (No. 19) from the active region of the N-hemisphere), or toward the Sun (if the corpuscular stream was generated in the S-hemisphere).

According to the second, more complete publication of measurement data of the magnetic vector on Mariner-2 during the perturbed period from 7 to 10 October 1962 [17], analysis of the structure of the field of the solar corpuscular stream was conducted (see below). We shall note now only that, (as may be seen from Fig. 2), the projection of the field vector on the ecliptic is directed toward the Sun everywhere in the entire initial (from 13 30 hours – beginning of available information to 14 40 hrs – boundary of the forward moving magnetic piston) and vast peripheral regions (from 07 50 hours of 8 October to 1120 hours on the 9th — end of information), and is disposed along the isochrone corresponding to $\langle V \rangle \sim 3.6 - 6 \cdot 10^7$ cm sec^{-1}. Comparison of the geomagnetic disturbance from 7 to 9 October with the active regions in the Sun [18] indicate that in this case the corpuscular stream could move only from the active region ($\varphi_0 = 8^\circ$ N, $L_0 = 258^\circ$) of the Sun's Northern hemisphere, which corresponds to direction of the lines of force at periphery of the stream with S — N polarity of stream's M-elements.

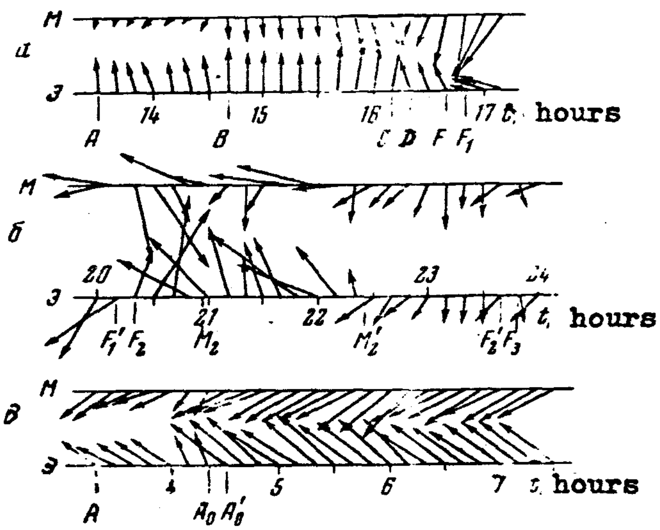

Fig. 2. - Vector of the magnetic field observed on Mariner-2 (M — in a plane perpendicular to the ecliptic, Э in the ecliptic plane; the direction at the Sun is to the right) for 3 periods.

a — 7 October 1962; A — beginning of information, BC — assumed shock front; DF — intermediate zone, F_1 - boundary of the first M-element; б - 7 Oct. 1962: F'_1 -bound. of the 1st M-element, M'_2 - region above the core of the M-element, F_3 boundary of the third M-element. $F_2 - F'_2$ - boundaries of the second M-element, $F_2 - M_2$ - region of the force boundary field. в — 9 Oct. 1962: region of the western periphery of the stream: A - beginning of the period, A_0, A'_0 — characteristic variations of the direction of the vector oriented along the isochrones in the maximum region of plasma's maximum velocity. The time is UT.

The prolonged (for several days) preservation of the direction of the magnetic lines of force at the periphery of corpuscular streams, and the changeover in field direction (from the Sun or at the Sun) depending upon from what hemisphere the corpuscular stream moves (N or S), may be determined by the observations of the magnetic vector on "IMP-1", when it was beyond the limits of the magnetosphere and of the shock wave front. Noting the

the direct connection between the interplanetary field and the magnetic fields in the Sun, the authors of [19] establish the prevalent direction of the interplanetary field from the Sun or toward the Sun, along the isochrone; this is the result of processing of vast observation material covering numerous months. The duration of preservation of one direction of the magnetic field ($\gtrsim 4$ days) is also concluded in that work from cross-modulation analysis (see Fig. 2 of [19]) of the direction of the interplanetary field relative to the selected polarity of the magnetic fields in the Sun. It is easy to see that the prolonged preservation of the direction of the interplanetary field cannot, in any way (as asserted by the authors) correspond to the usual, about daily changeover in the polarity of the magnetic fields of active regions in the center of the solar disk (and by no means not greater).

For all the 13 days when magnetic observations on IMP-1 wer published (more tham 3000 determinations of the magnetic vector) [20, 21], the directions of the magnetic vector in the interplanetary medium were examined by us. By the strength of low solar activity during the period of these observations (December 1963 — February 1964), the prevalent directions of the magnetic fields according to observations on IMP-1 may be almost unambiguously compared with the active regions in the N- or S-hemisphere, which are responsible for the so-called M-fluxes. One may estimate in nearly all these cases that the Earth was situated in the remote or nearby periphery of corpuscular streams. At the same time, the rule is confirmed that in the periphery of the corpuscular stream from the N-hemisphere the magnetic lines of force are directed from the Sun, while from the regions of the S-hemisphere they are directed toward the Sun. This is seen from the data brought out in Fig. 3.

It should be noted that the change in the direction of field's lines of force to the reverse, which may be expected according to the "expanded bubble-type" corpuscular stream [11 — 13], does not agree with the indicated observations on IMP-1. The change in the directions must, according to this model, be taking place no more seldom, than at every $0.5 \div 1$ day (at radial velocity of the stream of $400 \div 800$ km sec^{-1}), which is in sharp contradiction with the observations. For a "continuous jet"-

type stream no such magnetic field's direction changeover can, generally speaking, be expected. Therefore, the experimental data on the peripheral region of the stream are in a satisfactory agreement with the model considered by us. As already noted [22], the entire outer region of the corpuscular stream with the rarefied plasma associated with the motion of M-elements, where the magnetic field has a quasicylindrical form, with field amplitude modulation reflecting the closed fields of the chain of remote M-elements, constitutes what is usually called the "perturbed solar wind".

The fact that the magnetic field at stream's periphery is not simply a field, elongated and linked with the Sun, follows also from the stability of such type plasma flux. Near the Sun, where the standard magnetohydrodynamic approximation is applicable, the magnetized corpuscular stream is necessarily perturbed already at a distance of $2 \div 3 R_{\odot}$, as this was shown in the work [23]. Far from the Sun, the jet plasma flow in the external field (field of the active region) must necessarily be endowed with rotational instability. [24]. However, observations on Mariner-2 in the period from 7 to 9 Oct.1962 point to the modulation of the value and direction of the field vector at stream's periphery (and not to the rotation!), which reflects closed magnetic fields of remote M-elements. In this case (direct connection between the stream's periphery field and M-elements), there can be no instability.

4. - According to the first incomplete publication of measurement data of Mariner-2 [25] of the magnetic vector for seven hours of observations on 7 October 1962 during a perturbed period, a spatial model was built of the central part of the corpuscular stream [26]. It was then possible to ascertain two stream's structural M-elements in which the magnetic field had a force-free nature. An analogous analysis according to more complete publications of field and plasma measurements on Mariner-2 [17] allows to represent the field structure of separate M-elements. At the same time, the "nonaxial" passage of Mariner-2 through the corpuscular stream was taken into account [7]. Taking this circumstance into account, it is possible to separate three portions of field registration (from 1650 to 2010 hours, from 2020 to 2340 hours on 7 October and from 2350 hours on the 7th to 0250 hours on the 8th.), where the field structure corresponds to a force-free toroidal field.

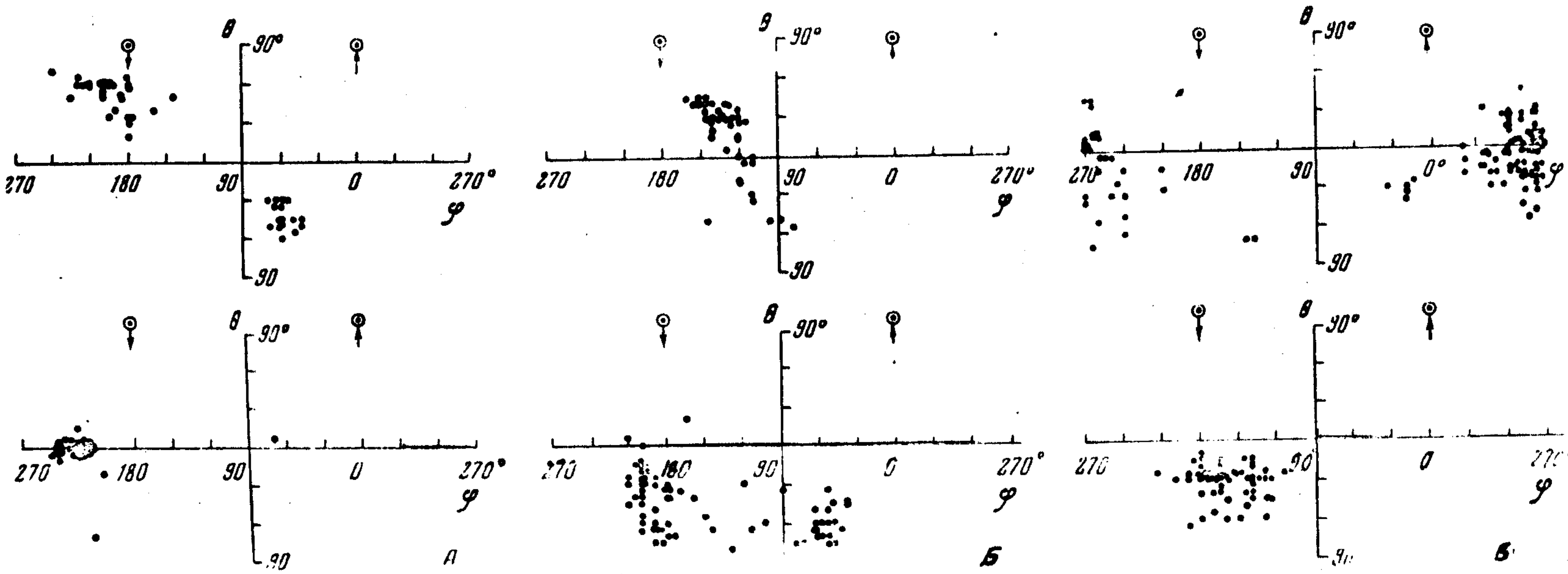

Fig. 3. - Correlation of determining field vector angles on IMP-1.
(θ — in a plane, perpendicular to the ecliptic, φ — in the ecliptic plane)

$\theta = 0^\circ$, $\varphi = 0^\circ$ — directions at the Sun; $\theta = 0^\circ$, $\varphi = 180^\circ$ — direction from the Sun; $\theta > 0$ — to the North; $\theta < 0$ — to the South. The upper range corresponds to 19 - 20 December 1963., the lower — 20 - 21 January 1964; **A** — at the boundary and inside the magnetosphere, **Б** — in the transitional region between the magnetosphere boundary and the shock wave front; **B** — in the interplanetary medium, at corpuscular stream's periphery. The same denotations are brought out in Figs. 7 through 11.

The data plotted in Fig. 4 have served as a verification of the above. Converted for the mean values of the $H_{\parallel}$ and $H_{\perp}$ components for the three plasmoids (in relative values), these were compared with the theoretically computed values of the force-free field components. The satisfactory agreement of the computed and experimental values of field components (just as the energetic criterion applied for that purpose in the work [26]) may serve as a corroboration of the fact that M-elements with force-free magnetic fields are observed in the solar flux. The values of the field at M-elements' boundaries were not taken into account in these calculations, for, judging by the sharp rotation of the field vector, (see for example the F_1F_2 region in the Fig. 2), a boundary force current must be present in these spots. This may also be corroborated by analysis of detailed measurements of the radial component of plasma velocity at eight energy levels of plasma's electrostatic analyzer. Utilizing the course of plasma velocity registration during the considered perturbation from 14 00 hours on 7 October to 06 00 hours on 8 October 1962, plotted in Fig. 11 of thr work [25], it is possible to construct the relative "spectrum" of velocities (energy) of the plasma for the moments of time corresponding to peripheral regions of the stream, and for the region corresponding to the boundary of M-elements. The appearance of the second maximum on the curve for the "spectrum", may serve as an indication of the presence of a "force current" in that region.

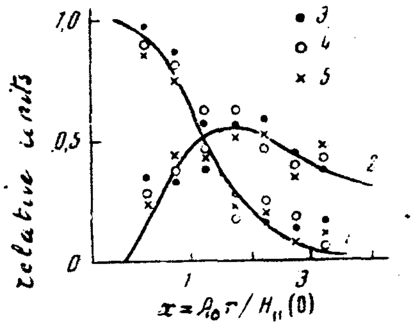

Fig. 4. - Comparison of the calculated model of a force-free field with the values of the field components $H_{\parallel}$ and $H_{\perp}$ measured on Mariner-2.

The relative distances from the axis of M-elements are given in abscissa, and the relative values are plotted in ordinates.- 1 - $H_{\parallel}/H_0(0)$; a — $H_{\perp}/H_{\parallel}(0)$; 3 — First element; 4 — second element ; 5 — third element.

The assumption was made in the works [7, 8] that the magnetic field in the zone of its maximum value according to measurements on Mariner-2, is simply a turbulent field of the stream. Such an interpretation of measurements on Mariner-2 is beset with a series of difficulties and it contradicts the results of observations, at least, as this would seem to us.

Taking advantage of the concepts of turbulence of interstellar gas [27], which are to a significant degree applicable to the interplanetary medium, it is possible, for instance, to estimate the inner scale of turbulence, that is the extremely small characteristic dimension of the considered ionized gas beyond the limits of which the motion (flow) is turbulent. Applying the well known correlations [27], we obtain that at concentration $n \sim 10$ cm^{-3} the field is $H \sim 10^{-4}$ oe, with the reduced magnetic viscosity $\nu'_m \simeq 10^{19}$ cm$^2 \cdot$ $\cdot$ sec^{-1} (as is well known, we should then take the greatest value of the magnetic viscosity in a direction perpendicular to the field), at gas flow velocity $\sim 5 \cdot 10^7$ cm sec^{-1}, the characteristic inner scale of turbulence is $\gtrsim 10^{13}$ cm.* This exceeds by nearly three orders the dimensions of field inhomogeneities in the corpuscular stream provided we consider them as a result of turbulence. If all the observed variations of the magnetic field were linked with turbulence, we should obtain for the characteristic functional $L = H_\perp^2 - H_\parallel^2$ a constant value along measurement trajectory $|L| \simeq H_\parallel^2$ and $\delta L < 0$ (assuming a developed isotropic turbulence), which precisely determines the turbulent instability. For a force-free magnetic field, satisfying the condition $j = \alpha H$, where $\alpha =$ const, the values of L must be zero everywhere. The estimate, conducted for the considered three M-elements, noted by Mariner-2, has shown that $0 \lesssim L < H_\parallel^2$. This points to the fact that the field is not turbulent (for $\delta L > 0$), is unsteady as an average, and at force-free structure of the field the parameter α is a function of coordinates **. The large-scale structure of the magnetic field within the bounds of M-elements does not in any way exclude the appearance of instability of the field in a collisionless plasma of the corpuscular stream. Then it is necessary to take into account that within the limits of M-elements, where $\beta = \varepsilon_M / \varepsilon_K > 1$ (in the system of coordinates linked with the M-element), the determining factor of instability and of the general structure of the plasmoid is the geometry of the magnetic field of the M-element. That is why the continually occurring field instabilities, inherent to magnetized rarefied plasmas [6], will appear and spread along the field, without changing the general macroscopic structure inherent to the corpuscular stream.

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[*] .- [The entire original Russian sentence is extremely foggy and hardly intelligible. Translation is made with this reservation].
** Such an assumption was precisely made in the calculation of the force-free field in ref. [26], during the analysis of measurements on Mariner-2.

Incidentally, by this is also determined the approach to the solution of the problem of the structure of the corpuscular stream (by experimental data), where the main, determining parameter is the measured vector of the magnetic field. Note that in all the conducted "probe" measurements in the interplanetary medium, the most informative are the magnetic measurements, providing at the given point the total magnetic vector, whereas for the plasma, only parameters of mainly one of the radial components are measured. These premises remain to a significant degree in force when analyzing the measurements on IMP-1.

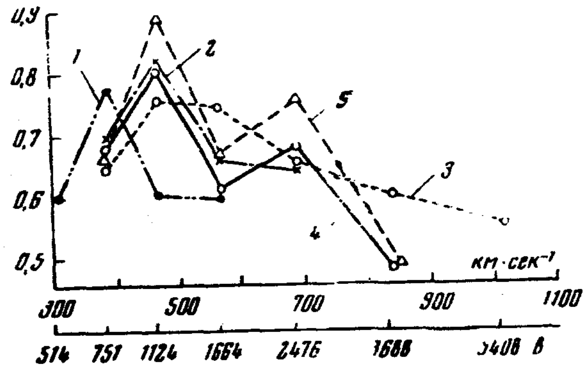

Fig. 5. - "Spectra" of radial plasma velocities according to measurements on "Mariner - 2".

The velocities (in km sec^{-1}) and the corresponding values of the electrostatic analyzer potential (in volts) are plotted in abscissa; the relative values are plotted in ordinates.

1 — for 1400 hrs on 7 Oct.; 2 — for 1600 hrs on 7 Oct.; 3 — for 0200 hrs on 8 Oct.; 4 — for 2015 hrs on 7 Oct.; 5 — for 1645 hrs on 7 Oct.1962.- The curves 1 — 3 are related to stream's periphery; the curves 4 — 5 — to the boundaries of M-elements, where the force currents are flowing.

5. - From the above representations of the structure of a solar corpuscular stream, it follows that in the process of energy transfer from solar flux to magnetosphere, the essential, if not the determining role must be played by the stream's magnetic field, by means of which part of the energy of the moving solar plasma is precisely transferred to the magnetosphere. This circle of questions was discussed in the works [22, 28, 29]. Unfortunately in the vast literature about the interaction of solar corpuscular streams with

the Earth's magnetosphere the question of the role in this process of stream's magnetic field interaction is not considered. This question is still made more complex by the fact that a series of events, observed by rockets and satellites (such as the standing shock wave from the daytime side, the nonlinear events and plasma heating etc. between the shock wave front and the boundary of the magnetosphere and others) may be explained by plasma supersonic flow past the Earth, as well as by "incursion" (or relatively rapid variation at magnetosphere boundary) of the magnetic field with rarefied plasma (see, for example, the laboratory works [30] on the magnetohydrodynamic squeezing and heating of plasma). However, the available "probe" measurements of the magnetic field at Earth's boundaries and inside the magnetosphere are difficult to understand if one fails to account for the determining role of the magnetic field in the process of interaction solar flux — magnetosphere. This may be seen from the following.

a) We may compare the deflections from the mean positions of the observed magnetosphere boundaries and of the shock wave front determined on IMP-1 [20], with the index of geomagnetic disturbance A_p at the moments of time, close to intersection by the satellite of boundaries over ascending or descending parts of the convolution. Such a comparison, brought up in Fig. 6, shows that the variation of the magnetosphere boundary correlates with the geomagnetic state of disturbance, whereas for the position of the shock wave front there is an anticorrelation (see convolutions No. 5 ÷ 14) for the azimuths of satellite's trajectory axis, which are close in the ecliptic plane to the average (along the isochrone) direction of the stream's magnetic field. In our opinion, the latter is evidence of the specific role of stream's magnetic field, defining the position of the shock wave front, for all the remaining parameters of the interaction process in these azimuths have no peculiarities of any sort.

b) On the IMP-1 magnetograms, published for a few geomagnetically perturbed periods [20], one may see a very characteristic event : at time of arrival of the stream's magnetic field (when the magnetic field of the interplanetary medium is increased by 2 — 3 times) there appears instead of the shock wave a characteristic tangential break and the "turbulent" transitional zone disappears. This is clearly seen, for example, from the comparison of data from IMP-1 for 20 December 1963 and 21 January 1964 (see Fig. 7, a and 7, б). Hence it follows, that at arrival of the magnetic field of the stream there takes place a sub-Alfvén flow past the Earth's magnetosphere. Since the plasma will not pass through the tangential break, the determining role at energy transfer to magnetosphere must be played by the stream's magnetic field.

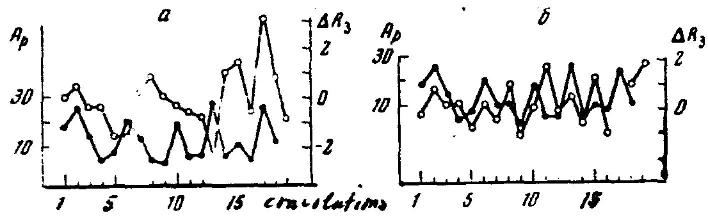

Fig. 6. - Relationship between the deflections of magnetosphere boundary and shock wave front positions from the corresponding average positions with the level of the state of geomagnetic disturbance.

a — according to data related to IMP-1 entry from without into the turbulent region; б — according to data related to IMP-1 entry from the turbulent region into the magnetosphere. ΔR_3 (clear circles) — deflections of the corresponding boundary from its average position, shown in Fig. 28 of the work [20], the scale being in Earth's radii — on the right; A_p (dark circles) — values of the index of geomagnetic state of disturbance, the scale being in units of A_p — to the left. The numerals below denote the convolutions of IMP-1 according to the work [20].

c) The correlations of magnetic vector angles with the line AES - SUN (θ and φ) according to measurements on IMP-1, brought out in Figs. 3 and 8 a and 8 б), show the dependence of these angles in the transitional zone at magnetosphere boundary on the direction of stream's magnetic field (this dependence is traced for all the available days of observations).

For the two characteristic days (19 December 1963 and 21 January 1964) according to which it is possible, from comparisons with solar events and observations far beyond the limits of the magnetosphere, one may derive the presence of the Earth's magnetosphere at the periphery of the corpuscular streams, having arrived from the active regions N (for 20 January 1964) and S- (for 19 — 20 December 1963) hemispheres, we presented the measured magnetic field vectors according to the entire magnetogram (see Fig.s 8, a and 8, б).

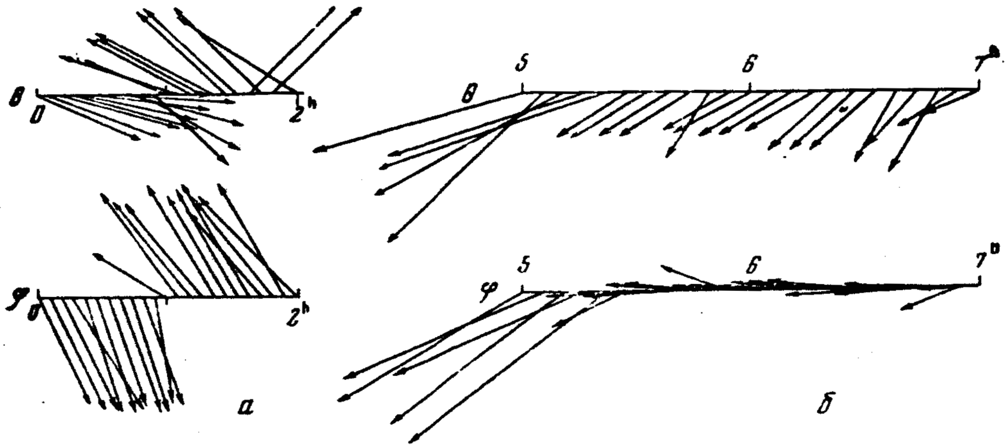

Fig. 7. - Field Vectors on "IMP-1".

The hours are given along horizontal axes (UT). a — 20 Dec 1963. The Earth is situated in a stream from the active region in Sun's S-hemisphere (region of the tangential break); б — 21 Jan. 1964.- The Earth is situated in the flux from the active region in the N-hemisphere of the Sun (region of the standing shock wave). - The Sun is to the right.

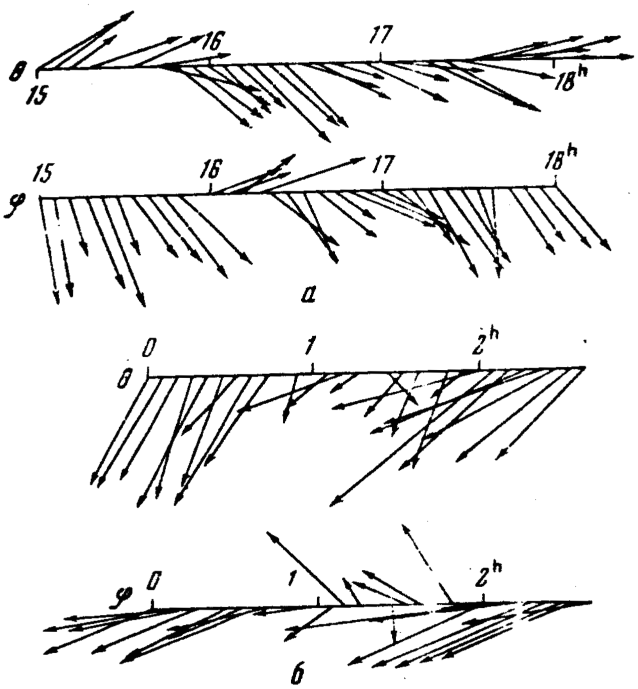

Fig. 8.- Field Vectors according to data from IMP-1 in the in the region between the magnetosphere boundary and the shock wave front.

The hours are given along the horizontal axes (UT).- a — 19 December 1963. The Earth is situated in the stream from the active region of the S-hemisphere of the Sun; б — 21 January 1964.- The Earth is situated at the periphery of the stream from the active region of Sun's N-hemisphere. (The Sun is to the right), It follows from these figures a distinction in the effects at magnetosphere boundary (Figs. 9 a and 6), rendering evident the deep penetration of the stream's field. At the same time it may be seen that in the transitional zone and near the magnetosphere boundary there takes place a characteristic rotation of the field vector. This is close to what should be observed at magnetic piston motion in a magnetized plasma (simple Alfvén waves of rarefaction, rotational break and shock waves). At the same time, simple compression waves, that should be present at determining role of stream's incident plasma, are absent. This preliminary but important conclusion on the character of instability in the transitional zone requires corroboration by complementary data of field and plasma observations in the transitional zone, particularly at time of geomagnetic disturbances.

d) A great number of observations of the magnetic field in the interplanetary space and at magnetosphere boundary are currently already available. They point to the direct correspondence of field variations observed in the interplanetary medium and on the Earth's surface. This has been established from observations on Pioneer-5 [31], Explorer-12 [32], Mariner-2 [22] and other probes. From this viewpoint it is of interest to consider one of the observations of SC of the geomagnetic disturbance of 2 December 1963, noted on IMP-1 at a distance of $\sim 2 \cdot 10^9$ cm (that is, far beyond the limits of the magnetosphere) and after ~ 3 min. on ground observatories.

One may attempt, as is often done, to explain the correspondence (in any case of relatively rapid variations of the field with frequencies $\omega \gtrsim 10^{-2}$ sec^{-1}) of extraterrestrial and terrestrial field variations by the propagation from magnetosphere boundaries to Earth of transverse hydromagnetic s h o c k waves. However, a simple propagation to Earth of hydromagnetic waves may be made complex by the following circumstances:

a) because of disintegrating instability of Alfvén waves in the magnetosphere and beyond its limits [33], the possibility of complete correspondence (with phase preservation) between the extramagnetospheric and terrestrial field variations becomes improbable ;

b) according to calculations of the work [34], hydromagnetic waves may reach the Earth's surface only under strongly limited conditions. The presence of Alfvén velocity maximum in the lower magnetosphere rules out the possibility of propagation toward the Earth of "oblique" beams of low-frequency hydromagnetic waves.

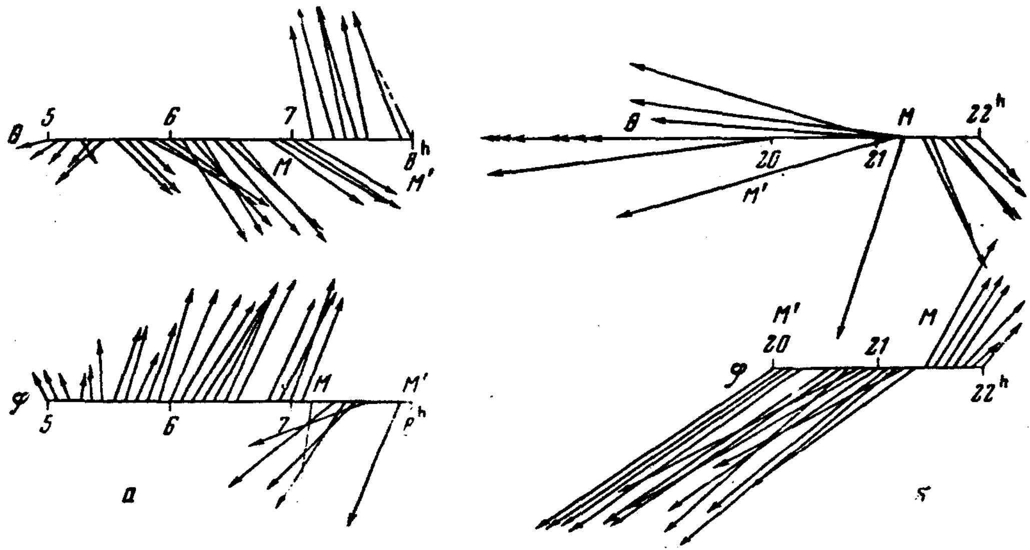

Fig. 9. - Field Vectors on IMP-1 in the region between the boundary of the magnetosphere (M) and the shock wave front and in the magnetosphere (MM')

Time is given on horizontal axes (UT); a — 20 Dec 1963 (vector lengths have been reduced four times by comparison with the lengths of vectors in Fig. 9 б). The Earth is located in the stream from the active region in the S-hemisphere of the Sun; б — 21 January 1964. The Earth is situated at periphery of the emerging from the active region in the N-hemisphere of the Sun. (The Sun is to the right).

The observations of field variations on IMP-1 allow, at comparison with the registrations of the field by magnetic observatories, to obtain additional data on the correspondence, in feebly-perturbed periods of D_1--variations and on bay-like perturbations, to the variations of the field registered by IMP-1.

For example, on 19 December 1963, during the period 22 18 — 22 42 hrs there were registered on IMP-1, which at that time was located a distance of nearly 18 R_E, that is, far beyond the limits of the magnetosphere and of the shock wave front, variations of the angles θ and φ (Fig. 10). These may be interpreted as a passage by IMP-1 of the boundary of a corpuscular stream. Sharp variations of the elements of terrestrial magnetism were noted in ground observatories with a lag of a few minutes. On 7 January 1964, when IMP-1 was at about 30 R_E, that is, in the interplanetary medium, the variations of the angles θ and φ (Fig. 10) (and the simultaneous small variations of the module of the field vector F) were in good agreement with the variations of the geomagnetic elements according to the data from ground observatories.

Therefore, comparison of ground and "probe" observations point sufficiently clearly to the determining role of the magnetic field of the stream in the process of disturbance transfer to Earth's magnetosphere. These comparisons suggest the existence of a direct congruence of D_i-variations of the geomagnetic field with field variations beyond the limits of the Earth's magnetosphere. Note that the scheme of stream's magnetic field interaction with the Earth's magnetosphere, considered in the work by one of us [28],

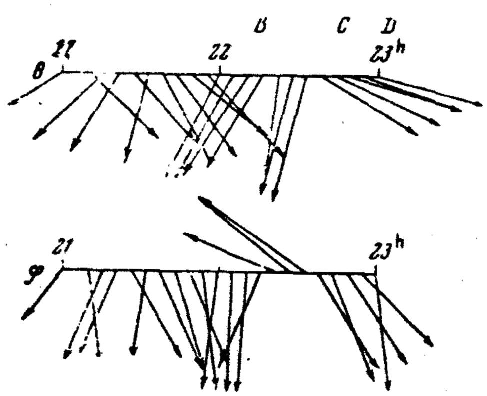

Fig. 10.- Field Vectors according to data from IMP-1 on 19 December 1963 in the interplanetary medium (AB) in the assumed stream boundary (BC) the stream originating in the active region of the Sun in the S-hemisphere, inside the stream (CD)

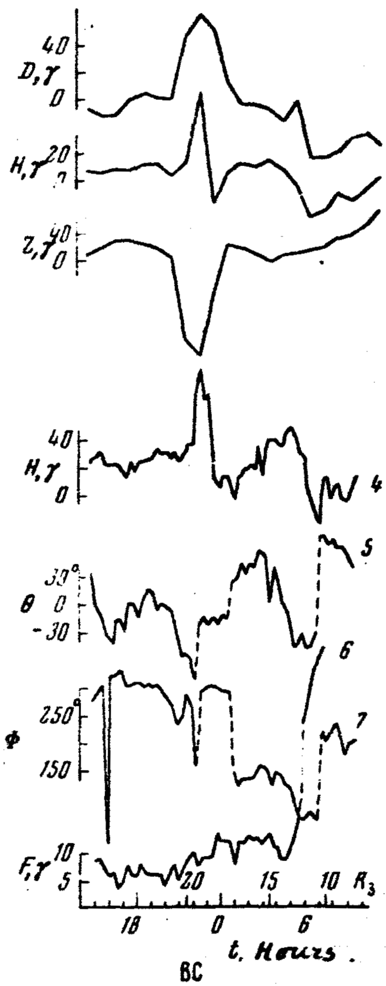

Fig. 11. - Reflec*ion in ground magnetograms of Earth's magnetosphere passage through the boundary of the stream (BC).
1-3-Data from the Murmansk Observ.
4 — Variations of H at Leningrad Observatory. 5—7 — copy of part of the IMP-1 magnetogram. Time is U.T.

can explain, after further quantitative development, the above peculiarities of the influence of the stream's field, as well as of the acceleration of the whole, or part of the upper magnetosphere plasma accompanying the geomagnetic variations.

At the same time, account must be taken of the properties of the strongly magnetized collisionless plasma of the magnetosphere, allowing the penetration and further push in the form of magnetic piston of solar flux's field, external relative to the magnetosphere.

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***** THE END *****

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