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ESTIMATE OF PROTON TEMPERATURE OF INTERPLANETARY PLASMA ACCORDING TO DATA OBTAINED ON SPACECRAFT "VENERA-3"

by

T. K. Breus
K.I. Gringauz

(USSR)

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K. I. Gringauz

SUMMARY

The estimates of proton temperature of interplanetary plasma on VENERA-3 are in fairly good agreement with the results obtained on MARINER-2, EXPLORER-10 IMP-2 and OGO-1. The authors attribute these temperatures to solar plasma proton perturbations rather than to conditions in the solar corona.

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One of the experiments conducted aboard spacecraft "Venera-3" launched in November 1965, was devoted to the study of solar wind parameters with the aid of a modulation trap of charged particles [1]. Energy spectra in the region from 0 to 3600 ev were obtained during the experiment; their analysis allowed us to estimate the temperature of protons in the solar wind. One of the most characteristic examples of spectra used for such estimates is shown in Fig.1 (obtained on 24 November 1965 at 12 h.09 min). Plotted in ordinates are the values of partial ion fluxes in each energy interval N, and in abscissa the values of energy E (on lower axis) at the boundary of each interval and the values of proton velocities v corresponding to these energies (upper axis).

As indicated in [1], spectra, in which fluxes were present in numerous energy intervals and analogous to the spectrum of Fig.1, were observed rather frequently, just as the spectra, where the flux was present only in a single interval (see Fig.2, this being obtained on 19 December 1965 at 13 h. 15m. 13s.). Alongside with them were observed spectra, when fluxes close in magnitude were registered in two neighboring intervals. It was noted in [1] that one of the possible explanations of spectra of the latter type may be the penetration of the more rapid plasma flux into the flux, moving more slowly.

(*) OTSENKA TEMPERATURY PTOTONOV MEZHPLANETNOY PLAZMY PO DANNYM POLUCHENNYM NA KOSMICHESKOM APPARATE "VENERA-3"

We shall limit ourselves to the consideration of spectra of two types and we shall postulate that they reflect the distribution by velocities of particles in the solar wind. For spectra in which flux was registered only in one interval, we may consider that in intervals adjacent to it fluxes did not exceed the trap's threshold response equal to $\sim 10^7$ cm^{-2} sec^{-1}.

In a system of coordinates linked with the spacecraft and so chosen that the axis z coincide with the direction of the incoming ion flux, the spectra obtained may be described by the following expression:

$$N \sim v_z f(\vec{v}, \vec{v_0}),$$

where N is the flux of protons with energy equal to the average energy in each spectral interval; v_z is the mean value in each spectral interval of the projection on the axis z of the velocity $\vec{v}$ of particles relative to the device; $f(\vec{v}, \vec{v}_0)$ are the values of the distribution function averaged by each spectral interval; $\vec{v}_0$ is the directed velocity of plasma motion.

Hence

$$f(\vec{v}, \vec{v_0}) \sim \frac{N}{v_z} \sim \frac{N}{\sqrt{\varepsilon_z}},$$

where $\varepsilon_z = mv_z^2/2$ is the mean energy of particles in the given interval.

We shall assume that the distribution of particles in the solar wind in a system of coordinates moving with velocity $\vec{v}_0$ (in which the directed plasma motion is absent), may be considered as Maxwellian.

The experiment was set up in such a way that it was not possible to take into account the anisotropy of temperature introduced by the magnetic field frozen in the solar wind plasma. (According to the latest estimates made in the works [2, 3], $T_\parallel / T_\perp$ cannot be $\sim 2-5$). Despite this, the estimate of the temperature of protons brought out below appears to be appropriate from our own viewpoint, for it provides the possibility of comparing the data obtained with analogous estimates made from the results of other experiments.

In the assumption that the distribution of particles by velocities is isotropic, we shall have

$$f \sim \frac{N}{\sqrt{\varepsilon_z}} \sim \exp - \left\{ \frac{m\,[v_x^2 + v_y^2 + (v_z - v_0)^2]}{kT} \right\},$$

where T is the temperature of solar wind protons, k is the Boltzmann constant, m is the mass of the protons.

For fixed v_x and v_y function $f(\vec{v}, \vec{v}_0)$ has a maximum at $v_z = v_0$, then the directed motion velocity of protons of solar wind corresponds to the mean value of velocity in the spectral interval with maximum value $f(v_x, v_y, v_z = v_0, \vec{v}_0)$. Let us denote this quantity by $N(v_0) / \sqrt{\varepsilon_0}$ or $f(\vec{v}_0)$. Then

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$$\ln\frac{f(\vec{v}_0)}{f(\vec{v},\vec{v}_0)} \sim \ln\frac{N(v_0)\sqrt{\varepsilon_z}}{\sqrt{\varepsilon_0}\,N(v_z)} \sim \frac{(\sqrt{\varepsilon_z}-\sqrt{\varepsilon_0})^2}{kT}, \qquad T=\frac{(\sqrt{\varepsilon_z}-\sqrt{\varepsilon_0})^2}{k\ln\dfrac{N(v_0)\sqrt{\varepsilon_z}}{\sqrt{\varepsilon_0}\,N(v_z)}} .$$

In this way the distribution function f was constructed by the spectra of the type shown in Fig.1, and then the temperature T was estimated with the aid of formulas for T. Inasmuch as the values of the distribution function

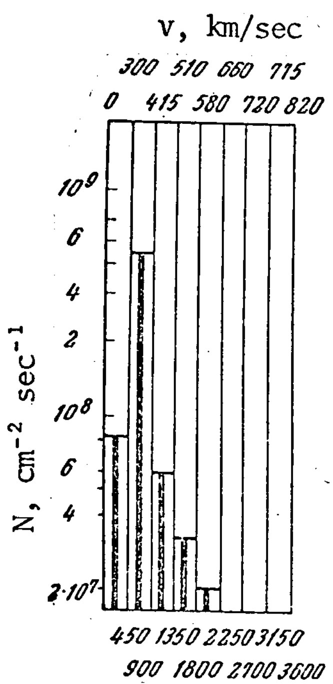

Fig.1

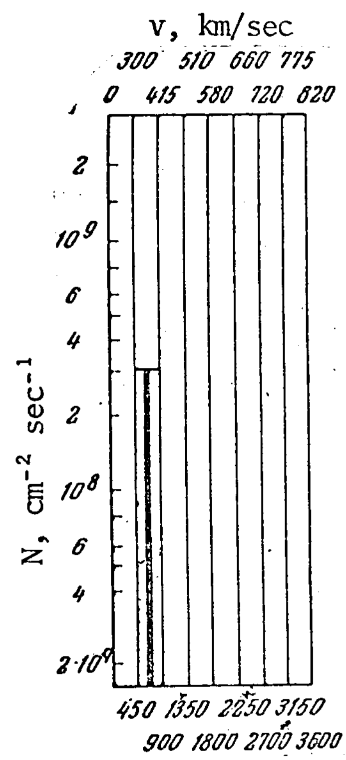

Fig.2

in each interval were computed for the average energy, as was shown above, the error in the in the determination of ε_z and ε_0 was equal to the half of the interval value. Then the error in the estimate of T can be computed by the formula

$$\frac{\Delta T}{T}=\frac{\Delta\varepsilon}{\sqrt{\varepsilon_z\varepsilon_0}}\left\{1-\frac{kT}{2\sqrt{\varepsilon_z\varepsilon_0}}\,\frac{(\sqrt{\varepsilon_z}+\sqrt{\varepsilon_0})}{(\sqrt{\varepsilon_z}-\sqrt{\varepsilon_0})}\right\}.$$

Only the upper temperature limit was determined by the spectra of the type shown in Fig.2, inasmuch as the estimate could be made only by considering that the value of the flux in the energy interval adjacent to the interval containing the registered flux was equal to threshold $\sim 10^7$ cm^{-2} sec^{-1}. In reality in this interval the flux could be lesser.

For spectra shown in Fig.2 and 2, the estimated temperature was found to be equal to respectively $4 \cdot 10^5$ °K and $2 \cdot 10^5$°K. The temperature estimated by the spectra obtained for the period from 16 February 1965 to 7 January 1966 at distances from the Earth ∿ 10 million km is included in the interval of values of about 1 to $5 \cdot 10^5$ °K. The maximum error at determination of T was 15 to 20 percent.

The values obtained for T are not in contradiction with the well known [4] estimates by Neugebauer and Snyder from data obtained on MARINER-2 ($3 \cdot 10^4$ to $5 \cdot 10^5$ °K); nor do they contradict the data by Bonetti et al [5] according to data of EXPLORER-10 (∿ 10^6 °K), or the results of Wolfe, Silva and Myers on IMP-2 and OGO-1 ($2 \cdot 10^5$ °K) [6].

It obviously can not be said, whether this temperature, determined by velocity dispersion, will or will not be the measure of the true chaotic thermal motions in the plasma and the characteristic of conditions existing in the solar corona, which is the source of the solar wind.

In connection with the existence of solar plasma proton perturbations in interplanetary space (hydromagnetic oscillations, collisionless shock waves occurring in the cases when the high-velocity flux is met with a slower one) the temperature evaluated apparently characterizes to a greater degree these perturbations rather than the conditions in the solar corona.

*** THE END ***

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VOLT TECHNICAL CORPORATION
1145 - 19th St.NW
WASHINGTON D.C. 20036.
Telephone: 223-6700 (X-36)

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