HYDROMAGNETIC EMISSION OF INTERPLANETARY PLASMA

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We report observation of hydromagnetic emission in the 0 — 2 Hz band; a distinguishing feature of this emission is deep carrier modulation. It is suggested that this emission is excited in the interplanetary plasma.

1. It is known that the pressure of the interplanetary plasma (solar wind) is anisotropic, with $p_{\parallel} > p_{\perp}$ near the earth's orbit. The anisotropy is the consequence of the radial expansion of the flux of solar plasma [1].

When $p_{\parallel} > p_{\perp}$, hose instability can set in and lead to growth of the long-wave hydrodynamic perturbations ($\Omega << \Omega_p$) and to cyclotron short-wave instability ($\omega \sim \Omega_p$, where $\Omega_p = eB/m_p/c$) [2 - 4]. The threshold of cyclotron instability is lower, and the growth increment of the amplitude is higher than for hose instability. The cyclotron instability apparently limits the anisotropy of the pressure and equalizes the temperatures of the electrons and protons in the solar wind. Thus, experimental investigation of cyclotron instability is of great importance for the understanding of the physics of the inerplanetary medium.

We report here an attempt to observe from the earth's surface magnetosonic waves excited in the interplanetary medium as a result of cyclotron instability.

2. A great variety of hydromagnetic emissions is observed on the earth's surface [6]. In our attempt to separate the emission of interplanetary origin, we have started from the expected properties of this emission, which distinguish it from the well known types that originate inside the magnetosphere.

In the coordinate system connected with the earth, the wave frequency is

$$\omega = \mathbf{k}\mathbf{U} + \omega', \qquad (1)$$

where ω' is the frequency of the wave in the system connected with the solar wind, and $\vec{U}$ is the velocity of the solar wind. In the interplanetary plasma ($\beta \sim 1$, $T_{\perp p} \leq T_{\parallel p}$) we have growing magnetosonic waves with an increment $\gamma \sim \omega' \sim \Omega_p$ at $k_{\perp} = 0$ and $k_{\parallel} \sim \omega_{0p}/c$, where $\omega_{0p}^2 = 4\pi e^2 N/m_p$ [5]. At typical values of the parameters we have $\Omega_p << (U/c)\omega_{0p}$, so that

$$\omega \approx \omega_{op} \frac{U}{c} \cos\psi, \qquad (2)$$

where ψ is the angle between $\vec{U}$ and $\vec{B}$.

The variations in the concentration and velocity of the solar wind should lead to modulation of the emission frequency. The largest contribution to the modulation, however, is expected from changes in the orientation of the interplanetary magnetic field. These changes are due to motion of the elements of wavelike structure of the interplanetary field relative to the observer. Figure 1 gives an idea of the variations of the direction of $\vec{B}$ relative to the sun-earth line, namely, $|\cos\psi|$ changes from ~ 1 practically to ~ 0 in an interval of about one hour. Accordingly, the emission frequency should change from $\omega_{max} \sim (U/c)\omega_{0p}$ to $\omega_{min} \sim \Omega_p$, with $\omega_{max} >> \omega_{min}$. (At

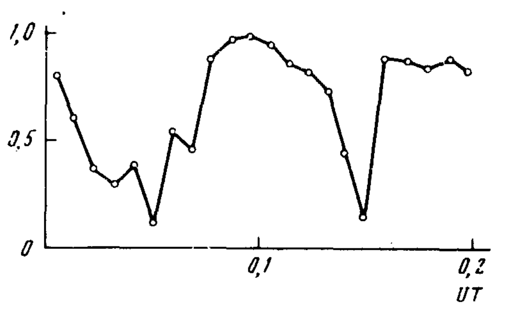

Fig. 1. Variation of the angle ψ between the interplanetary magnetic field and the earth-sun line. The abscissas represent the time in hours (IMP-3 satellite, 8 August 1965).

$U \sim 400$ km/sec, $N \sim 5$ cm^{-3}, and $B \sim 5\gamma$ we have $\omega_{max} \sim 4$ sec^{-1} and $\omega_{min} \sim 0.5$ sec^{-1}.) Thus, we expect deep modulation of the frequency of the received emission. In addition, the emission should be quasicontinuous, since the anisotropy of the pressure is a constant property of the solar wind.

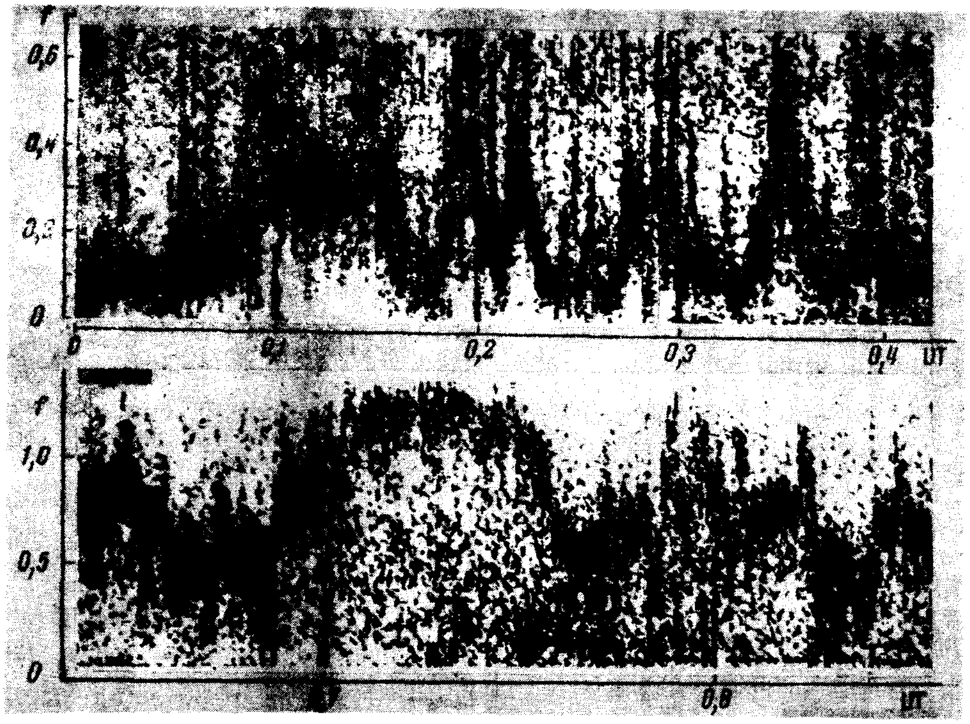

Fig. 2. Dynamic spectrum of serpentine emission of 20 April 1968. Ordinates — frequency in Hz, abscissas — time in hours; the spectral density is proportional to the degree of blackening.

3. The geomagnetic pulsations have been recorded regularly on the earth's surface for many years, but no oscillations having the indicated properties have been detected so far [6]. Starting from the assumption that under usual conditions the weak emission of the interplanetary medium is masked by intense noise originating inside the magnetosphere, we have chosen for the analysis the rare intervals during which the magnetosphere was exceedingly quiet (perturbation index $K_p = 0$). A sonograph was used to analyze the 1966 - 1968 pulsations recorded on magnetic tape at the station Vostok. As a result we were able to observe in the $\sim 0 - 2$ Hz band geomagnetic pulsations whose properties give grounds for assuming that they are excited in the interplanetary medium.

A sonogram (dynamic spectrum) of the emission is shown in Fig. 2. The emission has the form of a winding dark strip of width $\Delta f \sim 0.2$ Hz. We have arbitrarily called this new type of emission "serpentine emission."

The most important distinguishing feature of serpentine emission is deep modulation of the carrier: in typical cases f ranges from $f_{max} \sim 1$ Hz to $f_{min} \sim 0.1$ Hz with a quasiperiod ~ 10 - 60 min. The permanency of the emission and the modulation of the frequency agree with the expected properties indicated in the preceding section. It is therefore reasonable to assume that the emission penetrates to the earth's surface from the interplanetary medium. According to estimates, the spectrum of the observed emission coincides with the spectrum of the cyclotron instability of the interplanetary plasma.

The hypothesis concerning the nature of the serpentine emission can be verified either by direct observations of the hydromagnetic emission in the solar wind, or by comparing the earth's surface data on the modulation of the emission frequency with satellite data concerning the variations of the direction of the interplanetary magnetic field.1) It is desirable to perform such experiments, in view of the role played by cyclotron instability in the kinetics of solar wind.

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[1] According to the data possessed by us, a remarkable correlation is observed between the mean hourly values of f and |cos ψ|. It is obvious, however, that more detailed information on the interplanetary magnetic field is necessary to verify the hypothesis.

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VELOCITY OSCILLATIONS OF A FREELY ROTATING VESSEL WITH HELIUM II

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Experiments with free rotation of vessels with helium-II show that the perturbations of the vortex lattice lead to oscillations of the rotation velocity. These data serve as a certain confirmation of the premise that Tkachenko oscillations of the vortex lattice play a role in the behavior of pulsars.

A detailed analysis of the behavior of gradually-decelerating freely-rotating helium II shows that the damping of its rotation is an oscillating function of the time, unlike that of a classical liquid, the motion of which should be damped gradually in a similar situation.

There are several causes of the oscillations of the angular velocity of freely-rotating helium II [1], but principal among them is apparently the action exerted on the walls of the rotating vessel by the oscillating lattice of Onsager-Feynman vortices [2]. These oscillations were theoretically studied by Tkachenko [3].

Naturally, experimental observation of this effect calls for a very sensitive instrument with a vessel having a small moment of inertia and with low damping of the rotation.

We used a magnetic bearingless suspension[1] having minimal friction. The vessels used for the helium were: 1) An organic-glass beaker of diameter 64 ± 0.05 mm, height 50.0 mm, and wall thickness 0.2 mm, with smooth inner surfaces; 2) The same beaker but with rough bottom and cover. The roughness was produced with sand particles of 0.01 mm linear dimensions; 3) A glass sphere with smooth inner surface and with diameter 68 ± 1.5 mm. The ratio of the moments of inertia of the superfluid component of the helium II (at $T = 1.46^\circ$K) to that of the vessel was 0.89, 2.38, and 2.0 for vessels 1, 2, and 3, respectively.

The rotating vessels were placed inside a copper screen in contact with a liquid-helium bath. The instrument was filled with liquid from a special beaker and a device that made it possible to move this beaker up and down. Just as in the previous experiments [1, 4], the procedure was the following: The instrument was set to revolve and the driving force was removed after a definite velocity was reached. We measured the dependence of the rotation velocity on time.

The setup was connected on line to an M-1000 computer and the experimental results were reduced automatically[2].

The figure shows preliminary results obtained in the experiment with the beaker with the smooth surfaces. It is clearly seen from an examination of curve a that immediately after acceleration of the initially immobile instrument its damping drops sharply (owing to the transfer of