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From the Current Literature

DISCOVERY OF PULSED SOURCES OF COSMIC RADIO EMISSION WITH STRICTLY PERIODIC VARIATION OF THE FLUX

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AT present the astronomers' attention is focused on an outstanding discovery, recently made by British radioastronomers. We refer to the discovery of the so-called "pulsars"—pulsed sources of cosmic radio emission with a strictly periodic flux variation. This discovery was made after a new radio telescope, operating at 81.5 MHz and intended for the investigation of scintillations of the radio emission flux from sources with small angular dimensions, due to interplanetary plasma, was started up at the Mallard Radioastronomical Observatory. With the aid of this large radio telescope, the sky is periodically scanned every week in the declination zone $-08^\circ < \delta < 44^\circ$. During the course of such observations, four sources were observed, the properties of which were unprecedented. More or less detailed data have so far been published concerning only one such source[1].

Systematic observations of this source, which began in November of last year, yielded the following results. The signal is a series of regularly repeating pulses of ~ 0.3 sec duration, and the time interval between two pulses is strictly constant at 1.337 sec. The observations made during many months have made it possible to obtain a more accurate value for this period, namely $t_0 = 1.3372795 \pm 0.0000020$ sec. Such a high accuracy is attained because the instant of the pulse could be calculated beforehand with accuracy to 0.1 sec several months ahead of time. Although the variability of the flux from certain sources of cosmic radiation has been observed frequently in recent years, a strictly periodic variation of the flux was revealed here for the first time.

Further observations have shown that the amplitudes of the pulses change in rather considerable limits. The maximum value of the spectral radio-emission flux density (averaged over a receiver bandwidth of approximation 1 MHz) reaches $\sim 20 \times 10^{-26}$ W/m^2 Hz, while the value averaged over a time of about one minute is $\sim 1.0 \times 10^{-26}$ W/m^2-Hz. A quasiperiodicity is observed in the amplitude of the pulses, namely, the pulses "follow each other" within approximately one minute, although their amplitudes change somewhat (this can be more readily attributed to scintillations due to the passage of the signal through the interplanetary plasma). Then the amplitudes decrease sharply, for three-four minutes, and the signal frequently becomes unobservable. This is followed again by a series of 40–50 pulses without any "collapse" of the phase.

To investigate the spectral composition of the signals, two receivers were employed with identical bandwidths, but centered at slightly different frequencies, 81.5 and 80.5 MHz. It was observed that in "lower-frequency" receiver the signal arrives with a delay of 0.2 sec. It follows therefore that the signal should be relatively monochromatic, and the frequencies in the signal bands drift with a velocity of approximately 5 MHz. Additional investigations have shown that the width of the signal band "drifting" at the indicated velocity is 80 ± 20 kHz.

Observations made at the Arecibo (Puerto Rico) Radioastronomical Observatory show that the "pulsar" emission covers a broad spectral region from 40 to 240 MHz*, and the maximum of the spectral dissipation is near 110 MHz[2]. The observed delay of the radiation from one pulse at a frequency of 40 MHz relative to the frequency 240 MHz is approximately 10 sec. Information is available indicating that the radio emission of the "pulsar" was investigated also in Canada and in Australia. At the present time the coordinates of the source of this puzzling radiation has been determined with high accuracy, namely, $\alpha = 19^h 19^m 37^s$, and $\delta = 21^\circ 47' 02''$ (epoch 1950.0). The source was located in the Vixen constellation in the milky way. A weak blue star of 18th magnitude is observed near it.

These are essentially the scanty information available to us at the present time (30 March 1968) concerning this surprising source. What can be said concerning its nature? The lack of information on three other analogous sources discovered by the British makes it even more difficult to present even an approximate analysis of this question. Nevertheless, something can be said. First, the source is located far beyond the limits of the solar system. It follows from the observation that its parallax is smaller than $2'$; consequently, the distance to this source is at least 1,000 times larger than the distance from the earth to the sun[1]. From the observed width of the signal band (~ 80 kHz) and the drift rate (-5 MHz/sec) it follows that the duration of the process of emission at a fixed frequency does not exceed 0.016 sec. The linear dimensions of the radiation source therefore cannot exceed $\sim 5 \times 10^8$ cm (i.e., 5,000 km, approximately the radius of the earth's sphere!).

The observed drift of the signal band and the relative narrowness of the latter can be attributed most naturally to the phenomenon of group delay in the interstellar plasma[1]. As is well known, the group velocity of radio waves in the plasma is $v_{gr} = nc$, where $n(\nu) < 1$ is the refractive index (see[3]). If the distance to the source in which the broadband pulse is emitted is r, then after substituting $n(\nu)$ we can easily obtain an expression for

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*According to other American data, the "pulsar" emission can be traced at least to a frequency of 1600 MHz.

the delay of a signal at two close frequencies separated by $\Delta\nu$:

$$\Delta t \approx \frac{2\cdot 10^8 r N_e}{c}\frac{\Delta\nu}{\nu^3},$$

where N_e is the average concentration of the free electrons in interstellar space (it is assumed here that the delay in the source itself is relatively small, as is apparently the case). It was assumed in[1] that $N_e = 0.2\ \mathrm{cm}^{-3}$, and therefore r = 65 psec. We assume that actually $N_e \approx 10^{-2}\ \mathrm{cm}^{-3}$ in this direction of the galaxy, and therefore r ~ 1,000 psec. Some confirmation of such a large distance to the source is its location in the milky way, although there is a ~ 10% probability that this may be accidental. The problem will become immediately clarified when the coordinates of other "pulsars" are published.

Assuming that the distance to the source is ~ 1,000 psec, we can find that the energy radiated during the time of one pulse (assuming that the source is isotropic) is $\sim 3 \times 10^{29}$ erg, whereas the power in the pulse is $\sim 3 \times 10^{31}$ erg/sec, amounting to about 1% of the power of the solar radiation at all the frequencies.

Knowing the upper limit of the dimensions and the distance to the source, we can estimate its so-called "brightness temperature." The angular dimensions of the source are $< 10^{-7}$ seconds of arc (this is perhaps a record), and the brightness temperature at 81.5 MHz ($\lambda \approx 3.5$ m) is $T_b > 3 \times 10^{25}$ degrees!

In addition to the trivial conclusion that the radio emission of the "pulsar" cannot be thermal, we can also say that it cannot be synchrotron radiation (since the energy of each of the relativistic particles should be $> 3 \times 10^{21}$ eV, and the magnetic field is unbelievably small).

If we disregard the intriguing possibility of an artificial origin of the signal, only coherent radiation mechanisms (such as plasma oscillations) can explain the radio emission from the "pulsars." It is known that such mechanisms are decisive in the case of radio emission of the active sun. In this case, however, the maximum registered brightness temperature was $\sim 10^{16^\circ}$K.

Perhaps the main question is the cause of the surprisingly regular periodicity of the pulses. There can be three natural causes of such a strict periodicity:

a) The orbital motion of the source in a binary system with a revolution period equal to t_0.

b) Rotation of the source around its axis with period t_0 in the presence of a relatively small radio-emitting region on its surface.

c) Pulsation of the source (such as the pulsation of the Cepheids) with period t_0.

The first possibility seems highly unlikely, if only because t_0 is quite small. The possibility b) (proposed by Ya. B. Zel'dovich[4] by way of a hypothesis) calls for a rather high directivity of radiation: the cone in which the main part of the radiation is concentrated should have an angle $< 1^\circ$. Such a possibility, of course, cannot be excluded, although the difficulties arising in the development of a corresponding theory are quite large. A value $t_0 \approx 1^s$ denotes that the dimensions of the rotating body should be quite small (neutron star?)

Hypothesis c) was proposed in most general form in[1]. According to a recent theoretical investigation, white dwarfs have a minimum pulsation period ~ 8 sec. This occurs at an average star density 10^7 g/cm³. When the density increases, the period begins to increase. On the other hand, a pulsation period $\sim 1^s$ can be expected from neutron stars with average density $\sim 10^{13}$ g/cm³. It should be borne in mind, however, that these calculations are quite preliminary. One thing is clear: if we assume that the original cause of the radiation are pulsations of stars, these stars should be small and very dense, i.e., they should have properties intermediate between "ordinary" white dwarfs and the hypothetical neutron stars.

One can propose the following mechanism of radio-wave generation in such pulsations. Let us assume that the pulsating star is a component of a tight binary system. Under such conditions, a jet of gas can be incident on the pulsating star.

Such jets are observed in many double stars that are very close to each other. When such a jet is incident on the pulsating star, strong shock waves will be continuously produced in the gas, and their energy is drawn from the pulsation energy.

When a "fresh" shock wave is produced (one closest to the surface of a pulsating star), powerful plasma oscillations can arise, and these are transformed with sufficiently high efficiency into electromagnetic waves. From the fact that predominantly meter waves are radiated, it follows that $N_e \approx 10^8\ \mathrm{cm}^{-3}$ in the jet. An estimate shows that such a mechanism is quite effective from the energy point of view. On the other hand, shock waves can arise in a pulsating atmosphere of a star even without an "external" gas jet.

There is no doubt that information on "pulsars" will appreciably increase in the nearest future and the question of their nature will become clear.

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[1] A. Hewish, S. Bell, J. Pilkington, P. Scott and R. Collins, Nature **217**, 709 (1968).

[2] W. Sullivan, New York Times, 10 March 1968.

[3] V. L. Ginzburg, Teoriya rasprostraneniya radiovoln v ionosfere (Theory of Radio Wave Propagation in the Ionosphere), Gostekhizdat, 1949.

[4] Ya. B. Zel'dovich, Izvestiya, 22 March, 1968.

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