# Letters to the Editor

## *METHOD OF FINDING LOCAL SOURCES OF HIGH-ENERGY PHOTONS*

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DATA on processes connected with cosmic rays in many astronomical objects are of great importance to the solution of many astrophysical problems. Such data can be obtained from the high-energy photons arriving at the earth without being deflected.

Cocconi [1] proposed to locate on the celestial sphere sources of photons with $E \sim 10^{12}$ ev by measuring the relative delay in the passage of a front of a developing air shower through scintillators. [2]

It seems to us that showers from primary photons with energy $E \sim 10^{12}$ ev, in a solid angle $\Omega \sim 10^{-3}$ sr, can be registered more reliably and with much simpler means by using the Cerenkov radiation produced by the shower in the atmosphere. For this purpose, the light flash should be registered with a photomultiplier placed at the focus of a large parabolic mirror. The angular resolution of such a system can be reduced to $\pm 1°$.

It is advisable to use several paraboloids with parallel orientation to distinguish between separate showers by the time coincidences of the pulses. It is possible in this case to register showers for which the number of light quanta gathered on the photocathode is greater than 200. [3] Calculations of the intensity of Cerenkov glow of a sea-level shower produced by a primary $10^{12}$-ev photon yields a flux of $\sim 50$ quanta/m$^2$. To register such showers the area of the parabolic mirror should be 4 m$^2$. In spite of many shortcomings (the observations can be made only in moonless and cloudless nights) the proposed procedure seems more promising than that of Cocconi,[1] at any rate when searching for photons from known radioastronomical objects.

If the apparatus is located on a mountain and if large-area mirrors are used, primary photons of lower energy can be registered. At high energies, the ratio of the photon effect to the cosmic-ray background can be improved by using penetrating-particle detectors connected for anticoincidence.

An advantage of the proposed method, in addition to the possibility of placing the apparatus at sea level, is the relatively large effective area of shower registration (on the order of $10^5$ m$^2$), so that high statistical accuracy can be attained; the latter is very important, since the optimistic estimates given in [1] for the intensity of the high-energy photons from radioastronomical objects are highly overestimated. A likely estimate can be made by counting the number of neutral pions generated when cosmic-ray particles collide inside an object with atomic nuclei of disperse matter (gas or dust).

Using the experimental data on cosmic rays in the atmosphere and assuming that the cosmic rays in radio nebulae have an energy spectrum similar to that of the particles incident on earth [i.e., $F_c(E)dE = AE^{-(\gamma+1)}dE$ with $\gamma \cong 1.7$ when $E > E_{min}$ and $F_c(E) = 0$ when $E < E_{min}$], we can write for the number of photons produced by passage of the cosmic rays through a layer of matter of thickness dx

$$dF_{ph}(E) = K_{ph}F_c(E)\,dx/\lambda_0, \qquad K_{ph} \approx 2\cdot 10^{-2},$$

$$\lambda_0 = 1.5\cdot 10^2 \text{ g/cm}^2$$

Therefore, integrating over the volume of the entire object and expressing the constant A in terms of the cosmic-ray energy density $\epsilon_c$,

$$\varepsilon_c = 4\pi c \int_{E_{min}}^{\infty} EF_c(E)\,dE,$$

we can obtain in simple fashion the following estimate for the intensity of the flux of photons with energy greater than E at a distance R from the object:

$$I_{ph}(>E) \sim 10^{-5} E_{min}^{\gamma-1} E^{-\gamma} c R^{-2} \bar{\varepsilon}_c M,$$

where $E_{min}$ ($\sim 10^{-3}$ erg) is the minimum energy of the cosmic-ray particles in the object, c is the velocity of light, while $\bar{\epsilon}_c$ and M are the energy density of the cosmic rays and the mass of the gas in the object, determined from the relation

$$\bar{\varepsilon}_c M = \int \varepsilon_c(\mathbf{r})\,\rho(\mathbf{r})\,dV,$$

where $\rho$ is the density of the gas and integration is over the entire volume of the object.

The flux of cosmic-ray particles at the earth is $I_c(>E) = 5\times 10^{-5} E^{-\gamma}$ erg-cm$^{-2}$ sec$^{-1}$ sr$^{-1}$. The expected fraction of showers from the photons inside a solid angle $\Omega = 10^{-3}$ is

$$\Delta = (I_{ph}/I_c)\cdot 10^3 = 5\cdot 10^{10}\bar{\varepsilon}_c MR^{-2} \approx 2\cdot 10^9 \overline{H^2} MR^{-2}$$

(if it is assumed that $\bar{\varepsilon}_c = \overline{H^2}/8\pi$, where H is the intensity of the magnetic field). If, for example, we assume for the Crab nebula $H = 3\times 10^{-3}$ oe, $M = 10^{33}$ g, and $R = 10^{22}$ cm, then $\Delta = 2\times 10^{-7}$. If (as in the center of the galaxy) $H = 10^{-3}$, $M = 10^{38}$, and $R = 2\times 10^{22}$, then $\Delta = 5\times 10^{-4}$.

Thus, even the most favorable estimates yield rather low values for the photon intensity. Recognizing, however, that the cosmic-ray spectrum in many objects can be richer in high-energy particles than is the spectrum on earth, and also that only the order of magnitude of most astrophysical quantities is known, it seems advantageous to investigate by the above-described method the most promising objects (such as the center of the galaxy or the radio nebulae).

[1] J. Cocconi, Trans. Intl. Conf. on Cosmic Rays, vol. 2, AN USSSR, 1960, p. 327.

[2] B. Rossi, ibid. p. 16.

[3] Chudakov, Nesterova, Zatsepin, and Tukish, ibid. p. 36.

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## *TUNNEL EFFECT BETWEEN THIN LAYERS OF SUPERCONDUCTORS*

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As is well known, the chemical potentials of the electrons of metals in electrical contact are equalized. Contact can also be accomplished by tunneling transfer of electrons through a layer of insulator separating the metals. If a potential difference is applied to the layer of insulator, the current produced depends not only on the dimensions of the insulator, but also on the distribution of electron states near the energy corresponding to the chemical potential. According to the present theory of superconductivity,[1,2] the transition of a metal from the normal into the superconducting state is accompanied by a change in the distribution density of electrons $\rho$; if $\rho = N(0)$ in the normal state, then in the superconducting state the density of "unpaired" electrons (for $E > 0$) or holes (for $E < 0$)*

$$\rho_s(E) = N(0)\,|E|\,[E^2 - \Delta^2]^{-1/2}, \quad E \geqslant \Delta,$$
$$\rho_s(E) = 0, \quad E < \Delta, \tag{1}$$

where E is the energy, measured from the chemical potential, and $\Delta(T)$ is the width of the gap in the energy spectrum of the electrons of the superconductor. A change in the electron density distribution will, evidently, produce a change in the current when the applied voltage is less than $\Delta/e$. This effect has recently been found[3] and also confirmed.[4] In these experiments, however, the measurements were carried out in a temperature region where the smearing out of the electron distribution, due to the influence of temperature on the Fermi distribution, affects the results appreciably.

In the present paper we report on a study of the tunnel effect at temperatures down to $\sim 0.1°$ K. The specimens were metal films of thickness $\sim 10^{-5}$ cm, condensed at 300° K onto a glass surface in the form of a $\sim 1$ mm wide strip. The measurements were made on the overlap regions of strips of successively condensed metals. An oxidized aluminum layer, or in some experiments a $BaF_2$ film, was used as insulator. The resistance of the specimens was $10^4 - 10^6$ ohm. The tunneling transfer between Al and Al, In, Sn, and Pb was mainly studied. The temperature of the specimens was reduced by adiabatic demagnetization of a paramagnetic salt.[5] It was possible with the apparatus to achieve brief heating of the specimen to $\sim 4°$ K before the measurements.† In an experiment, current-voltage characteristics were measured between metals in the normal $(J_n - V)$ and superconducting $(J_s - V)$ states. The dependence of the current on temperature and on a magnetic field parallel to the plane of the specimen was measured.

The $J_n - V$ characteristic is linear up to $\sim 10^{-3}$ v for the tunneling transfer of electrons between metals in the normal state (at a temperature above the transition temperature or in a field greater than the critical magnetic field).

*The paired electrons are only important in the equalization of chemical potentials. Their contribution in the tunneling current is negligibly small.

†The heating served to remove the frozen-in fields from the specimens. These fields, frozen-in during the adiabatic demagnetization, led to a spreading of the $\sigma(V)$ dependence.