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Abstract

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Possible Influence of Supernova Outbursts on the Evolution of Life on Earth

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At the present time it appears to be proven that both the radio emission and the optical emission (with a continuous spectrum) of the Crab Nebula are due to relativistic electrons moving in magnetic fields ([1],[2]). It is therefore necessary to take into account the fact that this nebula—the remnant of the supernova outburst of 1054—contains an enormous number of relativistic particles, i.e., primary cosmic rays. The same should be said of all other nebulae that are remnants of supernova outbursts. Indeed, the remnants of such outbursts as the supernova of 1572 and the supernova of 1604 are sources of radio emission ([3],[4]). Recently radio emission has also been detected from the filamentary nebulae in Cygnus—undoubted remnants of a supernova that exploded several thousand years ago ([5]). According to ([6]), in the Crab Nebula the mean concentration of relativistic electrons with energy $E > 10^9$ eV is $N(E > 10^9) \simeq 3 \cdot 10^{-7}$ cm^{-3}. It may be expected that the concentration of relativistic protons will be of the same order. When the radius of the Crab Nebula, owing to its expansion, becomes equal to ~ 5 parsecs, the concentration of relativistic particles will become $\sim 3 \cdot 10^{-9}$ cm^{-3}, i.e., it will still be approximately thirty times greater than the concentration of primary cosmic rays in the vicinity of the Earth.

Such a comparatively "old" nebula, formed as the result of a supernova outburst, is IC443, whose linear dimensions are 7-10 parsecs, and the concentration of relativistic particles in it, as follows from radio-astronomical data, is 50-100 times greater than in the vicinity of the Earth.

The question arises whether the Sun, together with the planets surrounding it, while moving in the Galaxy, could have entered such regions of interstellar space where the density of primary cosmic rays is tens or even hundreds of times greater than at present. We can answer this question in the affirmative. This occurred when supernova stars exploded in the immediate vicinity of the Sun.

Until recently the frequency of supernova outbursts in the Galaxy was determined from averaged data for other galaxies. However, it has been shown ([6]) that the frequency of such outbursts is at least an order of magnitude higher. In this respect our Galaxy is similar to the galaxies NGC 3184, 6946, and 4321, in which the frequency of supernova outbursts is anomalously high. Indeed, during the last thousand years in our Galaxy at least 5 supernova outbursts have been observed (1006, 1054, 1572, 1604, and 1843; the last was Nova Carinae, see ([7])). All of them were very bright; consequently, the distances to them did not exceed 2-2.5 kpc, especially if one takes interstellar absorption of light into account. From this one may conclude that approximately every 1000 years a supernova explodes at a distance of no more than 1000 pc. Assuming that supernovae form a strongly flattened distribution in the Galaxy—

a system of thickness $\sim$ 100 pc, we find that, for example, every 200 million years a Supernova explodes at a distance of less than 8 parsecs. This means that during the existence of the Earth the stars closest to the Sun have exploded as Supernovae several times ($\sim$ 10).

The brightness of the exploded star scarcely exceeded -20^m, i.e., the radiation flux from the star was thousands of times smaller than that from the Sun. It is not excluded, however, that the flux of hard (for example, X-ray) radiation from the star and from the nebula in the very earliest phases of its development could substantially exceed the flux of hard radiation from the Sun. This could have serious consequences (see below). The gaseous shell expanding with a velocity $\sim 10^8$ cm/sec, formed as a result of the Supernova outburst, will pass through the solar system. Taking into account, however, the negligible gas density in this shell ($\sim 10^{-22}$ g/cm^3), this is unlikely to entail any consequences.

It is very significant, however, that in such epochs, for several thousand years, the flux of cosmic radiation on the Earth will exceed the average level by several tens of times. It must also be taken into account that the relativistic particles in the expanding nebula—the remnant of the Supernova outburst—will be distributed very nonuniformly. Thus there may be periods, lasting many hundreds of years, when the flux of primary cosmic rays on the Earth will be hundreds of times greater than the present one.

It is not excluded that this may entail serious biological and, above all, genetic consequences. It is known that the process of evolution of living organisms on Earth is determined by natural selection under the influence of diverse physical conditions of the environment. However, up to the present time such an important factor as the general level of hard radiation has never been taken into account. Meanwhile, in view of what has been said, it must be admitted that this latter factor, at certain stages of evolution, may have had an important, if not decisive, significance.

According to existing data (see, for example, (8)), the radioactivity of the air in the near-ground layer caused by cosmic rays at present amounts to 0.04 r per year, i.e., about 1/3 of the total level of natural radiation. The genetic significance of hard radiation, as is known, is at present the subject of very intensive investigations. Although much in this important problem is still not sufficiently clear, the principal conclusions may be summarized as follows.

An increase in the mutation frequency over the natural level even by a factor of two may, for some forms, entail serious genetic consequences. For species with a short reproductive cycle, in a number of cases a hundred- and thousandfold increase in the intensity of cosmic radiation is required to double the mutation frequency. However, for long-lived forms, a doubling of the mutation frequency requires an increase in the dose of irradiation by cosmic radiation by only 3–10 times.

It follows from this that a prolonged, millennia-long exposure to a level of cosmic-ray intensity increased by tens of times may entail catastrophic consequences for many relatively long-lived specialized animal species with limited population size. One may, for example, put forward the hypothesis that the so-called “great extinction” of reptiles at the end of the Cretaceous period was caused by this reason.

On the other hand, for other species of animals, as well as plants, a considerable increase in the intensity of cosmic rays may prove to be a factor favoring their further evolution. It is not excluded, for example, that the luxuriant flourishing of vegetation in the Carboniferous period was to a considerable extent caused by an increase in the level of hard radiation.

Drawing attention to the biological and genetic consequences of a significant increase in the intensity of cosmic radiation in certain

epochs of the past history of the Earth, we must note that this factor could, in its time, have stimulated the formation, from simple organic compounds, of complex complexes from which life on Earth could have developed.

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