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THE SURVIVAL OF HEAVY NUCLEI IN COSMIC RAY SOURCE ENVIRONMENTS

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The study of the composition and energy distribution of high-energy cosmic rays could be used to understand phenomena connected with the acceleration and propagation of cosmic rays near possible source regions. In Figure 1, the results from the Goddard balloon spectrometer and the results reported by Soviet Scientists using the Proton series of satellites are summarized.

The important experimental results related to this discussion which have come from the Goddard balloon spectrometer experiment are as follows:

(1) On a total-energy scale, protons constitute only a minor proportion of the cosmic rays. They account for only 20 percent. The rest of the cosmic rays are complex nuclei.

(2) All the nuclei have the same power low spectrum in total energy and so the composition seems to be independent of energy.

In Figure 1 the continuous curve is the balloon data from Goddard. The points indicate the results of the experiment from Grigorov et al. from the Proton series of satellites. We believe that the agreement between the two measurements is quite good. Thus, the independence of the composition could be extended to much higher energies than has been possible with the balloon results.

Pulsars have been considered as possible sources of cosmic rays. The evidence for particle acceleration has been demonstrated from the radiation detected from them. They have also been associated with large magnetic fields. Also, large energy releases from pulsars have been detected.

Julian and Goldreich and Gunn and Ostriker have developed theories regarding the electromagnetic environment of pulsars and acceleration of cosmic rays.

In Figure 2, a schematic representation of the pulsar environment relevent to the acceleration of cosmic rays is shown. The period of rotation of the pulsar is approximately 30 ms. The velocity-of-light circle is shown with the dashed line, and the outer circle is a schematic representation of the supernova surface material blown off. In one form of Gunn and Ostriker's theory,

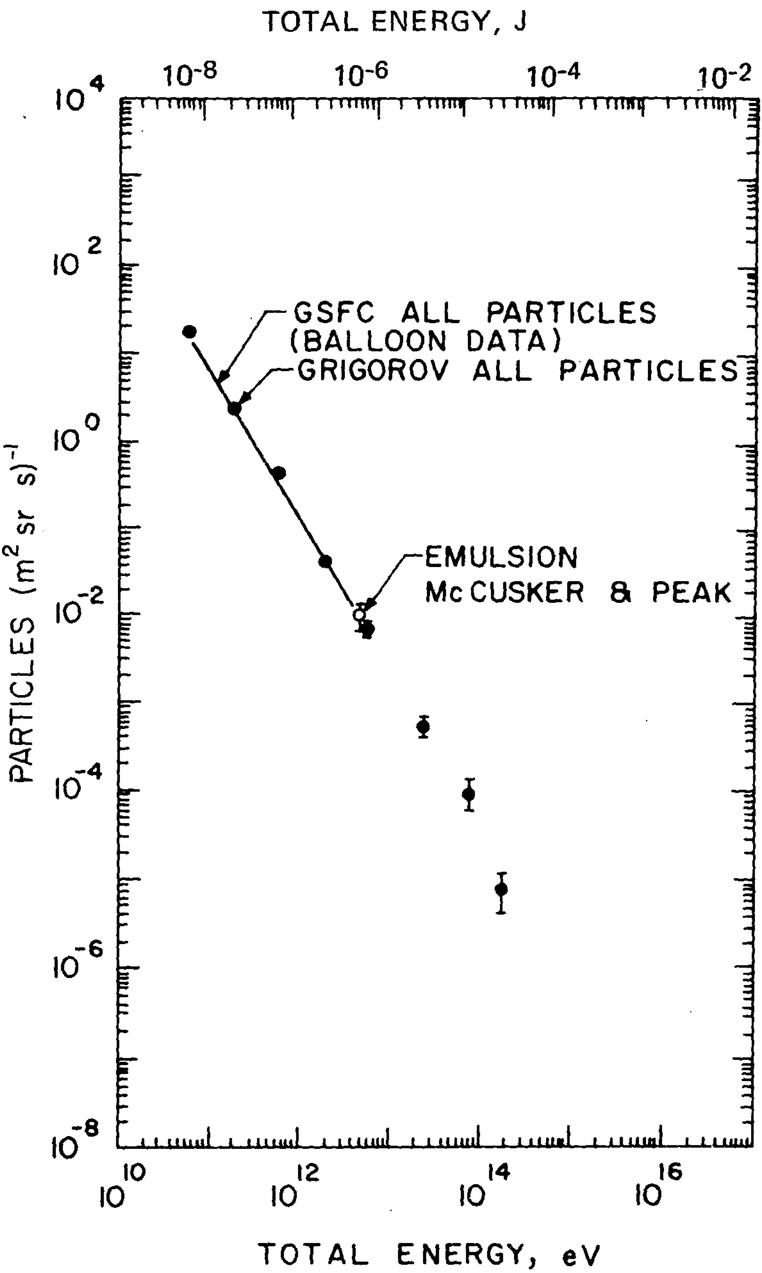

Figure 1–Balloon spectrometer results.

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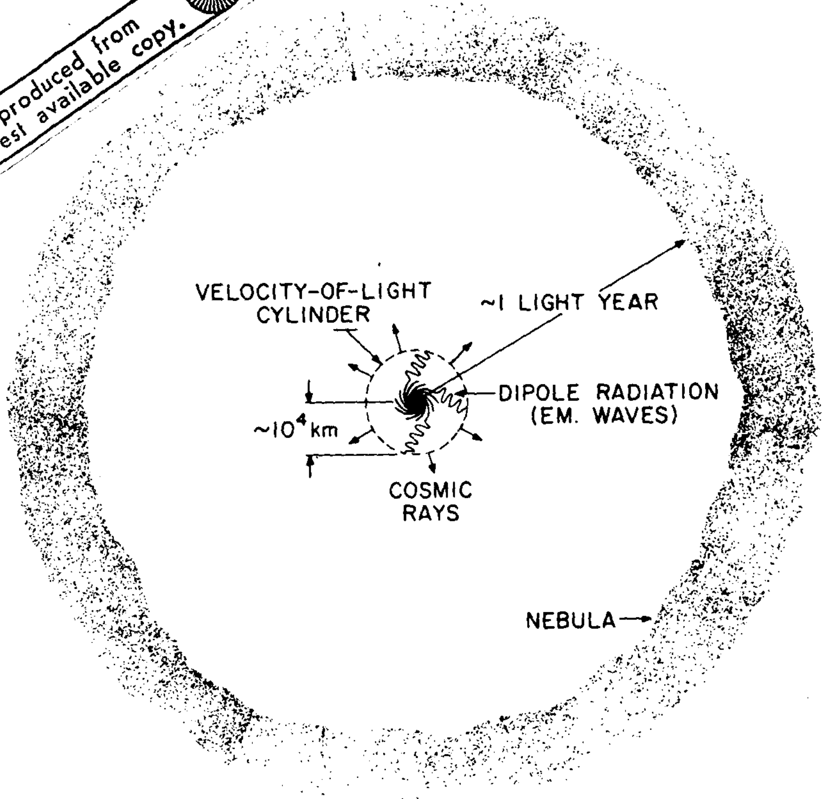

Figure 2–Pulsar environment.

the dipole radiation from the rotating pulsar produces low-frequency electromagnetic rays which accelerate cosmic rays near the velocity-of-light circle.

Another experimental observation, which has come from X-ray experiments on the study of NPO532 is the enormous density of X-ray photons around the pulsar. It will be interesting to see whether all these physical facts we know about the pulsar are consistent with the acceleration of heavy cosmic rays of high energy near the pulsar.

In the case of X-rays, a 100-kV X-ray, for example, appears to be a gamma ray of 1.6 pJ (10 MeV) when seen from the frame of reference of a nucleus with a velocity of 16 nJ (100 GeV) nucleon^{-1}. A gamma ray of 1.6 pJ energy can photodisintegrate the heavy nucleus through the giant dipole resonance with a cross-section that is quite large, namely 10^{-25} cm^2.

Photonuclear interactions remove neutrons preferentially from nuclei. In the region of iron nuclei, if you remove three neutrons from any nucleus, the nucleus becomes unstable and quickly breaks down to lighter nuclei. So the composition would become drastically altered if photonuclear reactions were to take place in any preferential manner.

Using the observed X-ray fluxes, the number of interactions suffered by an iron nucleus and a carbon nucleus have been calculated and are shown in Table I. We see that right up to 200 yr, it is very difficult to accelerate complex nuclei. They will all be broken down by the photonuclear reactions.

TABLE I. Number of Photodisintegrations of a Nucleus of Energy 16 nJ (100 GeV) Nucleon^{-1}

Time after supernova explosion, yr	Iron	Carbon
10	16798	2154
100	183	24
200	46	6
500	7.4	1.0
700	3.7	0.5
1000	2	–

So our conclusion from our experimental observations that composition is independent of energy up to a few-tens of nanojoules (a few hundred giga-electron volts) per nucleon, and also that it is strictly similar to the observed composition at nonrelativistic energies, is that it is very difficult to accelerate heavy cosmic rays, using the Gunn and Ostriker model near the velocity-of-light circle.

I would conclude with the following observation: If acceleration takes place through low-frequency electromagnetic waves, it takes place much farther from the velocity-of-light circle – probably in the nebula.

CHAIRMAN:

Are there any questions?

MEMBER OF THE AUDIENCE:

What effect would the plasma around the pulsar have on the acceleration?

DR. BALASUBHRAHMANYAN:

The Gunn and Ostriker calculations are done for a vacuum. Basically, the arguments for the existence of a plasma around the pulsar come from Goldreich and Julain and they are fairly general. The electrostatic field is so large compared to the gravitational field that there is bound to be a plasma environment. There has been a recent paper published in Astronomy and Astrophysics in which corrections for the existence of the plasma have been made. The mechanism essentially holds but it slightly affects the upper limit to which you can accelerate the particles.