JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-3-5. Anisotropy of High Energy Cosmic Rays in the Galactic Arm

S. FUKUI, S. HAYAKAWA, H. NISHIMURA and H. OBAYASHI

Physical Institute, Nagoya University
Nagoya, Japan

Theoretical investigation by Davis[1] and the observations of extensive air showers[2] have shown that the anisotropy of the arrival direction of high energy cosmic rays is so small as to be essentially isotropic.

In "Primary" session of this conference the interesting results concerning the arrival direction of air showers were presented.[3] Just as commented by Greisen, those data must be carefully interpreted but there may exist the possibilities of anisotropy.

The arrival direction of typical air showers reported[3] seems to be distributed non-uniformly. Those showers are the showers having relatively more μ-mesons than others and having very high particle numbers, say, more than 5×10^8. Concerning the energies of primary particles which initiate those showers, it seems that the primaries are possibly heavy nuclei with energies as high as 10^{17} ev.

As is well known, the isotropy of cosmic rays in the Galaxy is due to the fact that charged particles are sufficiently stirred by magnetic fields in the galaxy. This may be true for particles of the long enough age as 10^8 years.

On account of rather short mean free paths of their nuclear interactions, heavy nuclei cannot be of too old age, so that they may not be well stirred by interstellar magnetic fields. And heavy nuclei can hardly be accelerated to such high energies as 10^{17} ev by the Fermi mechanism, because they should rapidly break up into light nuclei in their cource of acceleration.

Therefore, the presence of heavy nuclei of such high energies indicates the existence of an acceleration mechanism other than Fermi's.[4] Assuming that the sources of cosmic rays are supernova, the particles are accelerated in the source to such high energies by an efficient acceleration mechanism. Considering the dimension of a supernova remnant and the intensity of magnetic field of about 10^{-3} gauss, the upper limit of rigidity is estimated to be 10^{18} volt. Whatever the acceleration mechanism may be, the existence of high energy heavy primary and its possible anisotropy are very important, if the observed results are taken for granted.

The observed anisotropy may be under stood, if it is assumed that there is a strong source which is mainly responsible for these heavy primaries. Such a source probably lies in the Galactic arm, so that the earth is connected to the source by a magnetic line of force. It may be quite possible that both the source and the earth lie in a common magnetic bottle. The particle's motion is restricted by this magnetic field. The thickness of the interstellar matter through which the particles traverse is sufficiently small, even if the particles go back and forth many times between two mirror points.

This model is essentially the same as the motion of electrons in our magnetic mirror device.[5] A perturbation for particles is considered as due to the collision of electrons with gas molecules in our experiment and as due to the scattering by magnetic irregularities in the Galactic arm. Since this perturbation gives rise to a change in a pitch angle, particles whose pitch angles decrease drift away from the bottle and particles whose pitch angles increase can be still trapped in the magnetic bottle. From a simple calculation, the trapping time is shown to increase with increasing pitch angles, hence the relative population of particles moving with large pitch angles become large as time goes on.

The particles of large pitch angles which hit the earth are expected on the plane nearly perpendicular to the axis of the magnetic bottle, that is, the high energy heavy nuclei hitting the earth are on the plane nearly perpendicular to the Galactic arm.

In order to explain the reason why the anisotropic component is stronger for heavier nuclei, it is assumed for the sake of definiteness that 10^{50} particles are injected from a source with the average energy of 0.1 erg on account of the Crab evidence. The pressure of these particles can be balanced by the magnetic pressure of the Galactic field, if they are trapped in the bottle of 10^{61} c.c.. The magnetic bottle of this size may be of length of about 1000 l.y. and of radius of about 100 l.y., large enough to store the particles with rigidity as high as 10^{17} ev.

Particle density in the bottle is, therefore, estimated as about 10^{-11} per cm,^{3} about the one-tenth of the cosmic ray density we observe. If it can be assumed that the charge spectrum at a source is independent of energy, and that the fragmentation of heavy nuclei does not occur for the particles trapped in the bottle,[*] the relative contribution of heavy nuclei from this particular source is nearly equal to that of general cosmic rays, because in the bottle the intensity of heavy and very heavy nuclei has decreased to about the one-tenth of the original value.

Finally, the following remarks must be added ; (1) no anisotropy can be expected for low energy particles, because they are well stirred by magnetic irregularities of small scale, (2) the identification of the source concerned would be difficult, because it would have existed more than 10^4 years ago, (3) the acceleration of particles in a supernova remnant is not impossible, on account of the high acceleration efficiency which is responsible for accelerating electrons by compensating the rapid energy loss due to the synchrotron radiation, and (4) our model seems to be supported by the paper presented by Oda,[6] although it is concerned with a different source.

References

1) L. Davis: Phys. Rev. **96** (1954) 743.
2) For instance, Proc. Moscow Conference, 1959.
3) K. Greisen (Cornel. EAS exp.), M. Oda (INS EAS exp.) (Osaka City Univ. Underground exp.) and J. Linsley (MIT EAS exp.): Lectures at Kyoto Conference, III-2.
4) V. L. Ginzburg and S. I. Syrovatsky: Prog. Theor. Phys. Suppl. **20** (1961) 1.
5) Lecture at Kyoto Conference, II-2-9.
6) M. Oda and H. Hasegawa, III-3-6.

* Light nuclei may be produced by the nuclear interaction of heavy nuclei with the interstellar matter, indeed. Therefore the intensity of very heavy nuclei may decrease to less than the one-tenth of the original value. In our hypothetical consideration we discuss with the order of magnitude.

Discussion

Simpson, J.A.: What are your arguments for believing that heavy nuclei can be accelerated to $\sim 10^{17}$ ev/nucleon in the supernova "shell" without break up, but cannot be brought up to such energies by the Fermi mechanism in interstellar space?

Hayakawa, S.: Even if the Fermi acceleration is operative in the interstellar space, it requires a rather long age to accelerate a heavy nucleus to such a high energy. This should result in the break-up of a heavy nucleus. The necessary path length in the supernova shell is quite small compared with the interaction mean free path.

Sarabhai, V.A.: What interstellar density, and how many reflections between the mirror points do you take so as to still permit the survival of heavy nuclei?

Hayakawa: The lifetime in the bottle should not be longer than 10^7 years. This is much shorter than the collision mean free time with the conventional density of 1/c.c..