On the Origin of Cosmic Rays

The accumulating evidence that a major part of the cosmic rays comes from beyond the Milky Way suggests a renewed examination of the consequences of Lemaitre's hypothesis of their origin as a part of the explosion of the primeval concentration of matter from which the present world system has developed. This hypothesis deserves renewed attention also because of the support given by Hubble's recent observations[1] to this particular model of the Friedmann universe.

The difficulty of obtaining any satisfactory alternative explanation of the origin of cosmic rays is becoming more and more apparent. The measurements by Millikan and Regener of the ionization by cosmic rays from high altitudes down to depths where they are completely absorbed have shown that the cosmic rays bring to the earth about the same amount of heat as does starlight. But, as these authors have noted, the earth, being within a local star cluster which is itself a part of a major galaxy, receives much more than a fair sample of the heat radiated by stars. If the cosmic rays come from beyond the Milky Way, at a really typical place in intergalactic space the density of cosmic-ray energy would be of the order of 10^2 times as great as that of starlight. It is thus apparent that either the source of the rays must be a radiator which is very powerful compared with stars as a source of light, or the cosmic rays once emitted must be retained by the metagalactic system instead of being lost as is starlight.

None of the attempts to interpret cosmic rays as arising from stellar electric or magnetic fields would seem adequate to deliver energy in the required amounts. If the electromotive forces are due to the motion of the stars in the magnetic fields of the star system, the maximum energy that could thus be supplied would be that of the kinetic energy of the stars which form the system. Even such a kinetic energy as that of the sun as a part of the galactic rotation is small compared with the energy radiated by the sun as light in 10^9 years. Likewise, if we consider the electric field between concentric clouds of matter surrounding an exploding nova, the work done by these clouds in pulling ions from the interior cannot be greater than the kinetic energy of the clouds themselves. Also, if these clouds are driven by radiation pressure, the work done by this radiation is necessarily much less than the energy of the radiation itself, whence the radiation emitted must be of much greater energy than the electric particles that may arise as a secondary consequence. Similar considerations make the other hypotheses of this type also difficult to defend.

Although nuclear processes occurring in interstellar space might result in an adequate total energy, it appears that such processes are inadequate to account for the great energies of the individual cosmic-ray particles. Latitude effect studies show that the average energy of the primary particles is of the order of 10^{10} electron volts, whereas burst studies indicate occasional rays with energies as great as 10^{12} ev. Since the mass of a hydrogen atom is equivalent to only 10^9 ev, this means that even nuclear sources are inadequate as an origin for cosmic rays.

A primeval explosion of the type imagined by Lemaitre could supply the necessary amount of total and individual energy for the cosmic rays, if merely because no limit is assigned to the amount of energy available, and no specific mechanism is postulated for the ejection of the individual particles.

If only gravitational fields are effective in bending the paths of the particles, the cosmic rays which we observe in our galaxy must have come out of the primeval explosion with our neighboring galaxies, while particles originating in our galaxy are permanently lost to us, but may be observed on the extra-galactic nebulae around us. This picture would immediately explain the isotropic origin of the cosmic rays as observed in our galaxy. For in a homogeneous isotropic universe of relativistic cosmology, an observer on any nebula (or galaxy) would observe the same phenomenon of expansion of other nebulae around him. Hence, we should expect an isotropic type of cosmic-ray phenomenon to be observed not only by us but also by observers situated on any other nebula in space (condition of homogeneity).

This hypothesis leads, however, to a serious difficulty regarding the composition of the rays. From such a violent cataclysm we should expect particles of all types to be ejected—if electrons, then certainly photons, and presumably also protons, alpha-particles and ions of all types. Our cosmic-ray studies have, however, revealed in the primary cosmic rays only positive and negative electrons and electrical particles of higher mass (the more penetrating component), which may be either protons or the "heavy electrons" recently suggested by Street and Stephenson. According to present evidence, few if any photons, neutrons or alpha-particles seem to enter the earth as cosmic rays.

Is it possible that electrically-charged rays emitted by the initial explosion may be deflected by stellar or galactic magnetic fields just as a cosmic-ray electron is deflected by the earth's magnetic field? If so, those particles which would be most probably retained by the metagalactic system would be those with the highest ratio of e/m, i.e., in order, electrons, protons, etc., whereas all neutral rays might be forever lost.

If the magnetic fields of the earth and sun are typical, a strong deflection of a cosmic-ray particle on traversing a galaxy would be an event of low probability. Thus the cosmic rays should not acquire any considerable part of the motion of the star streams through which they pass, and their spatial distribution should remain sensibly isotropic. Since most of their time would thus be spent in intergalactic space, however, such cosmic-ray electrons should be subject to the same "red-shift" decay of energy as would photons. If this is true, the energies of the cosmic rays now striking the earth must be much less than those of the rays in the early history of the earth.

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[1] E. Hubble, Astrophys. J. **84**, 270 and 517 (1936).