Cosmic rays lose dramatic quality

The discovery of cosmic rays was a dramatic event early in this century, but the resolution of the problems then posed is turning out to be a quieter (but nonetheless interesting) affair.

THE question of where cosmic rays come from has been with us for most of this century, ever since C. T. R. Wilson's device for simulating the formation of clouds in the laboratory happened also to reveal a previously unsuspected flux of charged particles of whose origin the only certainty was that it could not lie in the Solar System. For much of the time since then, the origin of cosmic rays has been as much in doubt as at the beginning. But now there seems to be a chance — within the foreseeable future, perhaps by the end of the century — that the issue will be so clarified that many will regard it as settled.

The reasons why the cosmic-ray problem is so difficult are so plain that they are most often overlooked. The most obvious, and thus the most distracting, is the sequence of processes by which whatever particles constitute the primary flux of cosmic rays are successively converted into others. There is, for example, the atmosphere of the Earth, which ensures that all particles but a sizeable proportion of neutrons and all neutrinos, will be converted into other mixtures of the constituents of the primary flux. But the stream of particles reaching the top of the Earth's atmosphere will have reached there only by travelling at relativistic speed through interstellar matter, interacting (among other things) with nuclei to produce the nuclear fragments recognized over the past thirty years as significant components of the cosmic-ray flux collectable by balloons.

The Earth's atmosphere and interstellar matter are but two of the screens standing between observers and the true primary flux.

By any reckoning, the primary particles — whatever they are and wherever they come from — travel the Galaxy for intervals of time comparable with its age, so that there is plenty of opportunity for even the least likely interactions between cosmic-ray particles and others to set their stamp on the composition of the cosmic rays eventually observed. If, as now seems likely, at least some primary-cosmic ray particles come from other galaxies than our own, their interaction with the ubiquitous microwave radiation background must also be taken into account.

That interaction is, for example, one of the distinctive features of an article by J. Wdowczyk, from the Institute of Nuclear Studies at Lodz in Poland, and A.W. Wolfendale, from the University of Durham, in the United Kingdom (*Astrophys J.* **349**, 35-40; 1990), which is chiefly concerned with spelling out tests of the possibility that a fraction of primary cosmic-ray particles may be extragalactic, but which is in passing a neat summary of how the conundrum of the origin of cosmic rays has been particularized into a manageable string of apparently answerable questions.

The issue of whether cosmic rays are confined to the Galaxy (and, presumably, to other galaxies as well) or are a supragalactic phenomenon has not been much debated since the 1950s. Plainly, the flux of energy in the cosmic rays reaching the surface of the Earth cannot be representative of the Universe as a whole, for the amounts of energy involved are comparable with those locked up in the cosmic microwave radiation background — itself a substantial fraction of the energy of the Universe in any view of the mechanism of its formation. If cosmic rays were truly ubiquitous, it would be necessary on those grounds alone to rewrite the "Big Bang" script — but the cosmic rays would also interact with the background radiation so effectively that the properties of both would be transformed.

But if the distribution of cosmic rays cannot be uniform throughout the Universe (so that their origin cannot lie in some event characteristic of the whole Universe rather than of its parts), it is unthinkable that all galaxies would be impervious to the escape of a fraction of the cosmic-ray fluxes which they contain. So there will be some intergalactic flux of cosmic-ray particles, where that term must be taken to include γ-rays as well as protons, neutrons and electrons. As things stand, nobody can be in a position to tell how the present leakage of cosmic rays from galaxies compares with the creation of new volume in the Universe on account of its expansion.

The other long-standing conundrum is the mechanism by which particles are accelerated to high energy. Since the 1920s, the goalposts have been moved repeatedly, in such a way that the gap between them has been steadily enlarged, chiefly by the development of techniques for the measurement of the energy of energetic particles.

In retrospect, this has been a curiously empirical process. From the outset, it must have been plain that measures of the energy of a particle provided by the thickness of lead or other metal plate it would traverse would be at once rough and ready and incapable of providing information about the most energetic particles of all. Plainly, there are also (and will remain) limitations on what can be done by estimates of the energy of charged particles among the cosmic rays by their deflection by powerful magnetic fields; of necessity, instruments to accomplish that would have to be comparable in size with the scale on which particle accelerators are constructed, but the interest in cosmic-ray physics and because substantial part of the primary flux consists of particles which are several orders of magnitude more energetic than can be produced by accelerators.

Wdowczyk and Wolfendale take the view that there is nothing in the measurements to suggest a fixed upper limit on the energy of cosmic rays. Extensive showers of secondary particles in the Earth's atmosphere have been able to verify that there are primary particles with energies as great as 10^{20} electron-volts (eV), but that is largely a function of the size of shower detectors so far constructed. Whether larger and more sensitive detectors will uncover the footprints of still more energetic particles will depend on whether the underlying processes that generate the energetic cosmic rays are theselves inherently limited in the energy they can impart to particles.

So where do these energetic particles come from? The passage of time has made this seemingly crucial question seem less and less important. But just as it may be unreasonable to expect a black-and-white answer to the question as to whether cosmic rays are a galactic or extragalactic phenomenon, so it is likely that there is no unique source of cosmic rays. In some respect, that must be so. Some of the particles flung off from the Sun in the course of solar flares, for example, must eventually contribute to the general flux of cosmic rays. Other main-sequence stars will presumably behave in the same way, but active neutron stars and supernovae (past as well as present) will be more prolific sources of more energetic particles. Yet objects such as those do not account for the most energetic particles of all — whence interest in what are called γ-ray bursters, whatever they may be. The conclusion that there is no unique source may of course be a disappointment. How can such a dramatic discovery as that of cosmic rays have such an anticlimactic denouement? That, sadly, is often how it is.

John Maddox