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# Cosmic Rays and the Aurora

**D A Bryant**

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# Cosmic Rays and the Aurora

Duncan A Bryant

It is suggested that the acceleration of cosmic rays and auroral electrons may be dynamically equivalent

There is a growing awareness of the potential of random or stochastic processes to shape natural phenomena. Here, the possibility is discussed that solutions to the two long standing, apparently unconnected problems of the acceleration of cosmic rays and auroral electrons might be dynamically equivalent.

Fermi suggested that high energy cosmic rays might have been accelerated by scattering from magnetic irregularities moving at random through interstellar space [1]. Energy gains from head-on reflections would exceed losses from overtaking because the former were statistically more likely. Cosmic ray protons and other ions would thus be energized systematically. The process is, though, considered to be too slow to achieve the required energization before most particles escape from the galaxy. Preoccupation with the systematic effect seems, however, to have diverted attention from the crucial role of the accompanying statistical spread in energy [2,3]. Although only a small proportion of cosmic rays could be expected to experience by sheer chance many more energy gains than losses, only a small proportion is required to do so in order to account for the observed steeply falling spectrum. Small scale (sub parsec) regions of very strong magnetic field (approaching 0.1 gauss) with speeds of around 1,000 km/s could in fact accelerate ions to around the required $10^{20}$ eV within the constraints set by current knowledge of the random component of the galactic magnetic field[3,4]. The resulting mean magnetic energy density, at several orders of magnitude greater than that of the cosmic rays, would normally be considered unacceptably high, but a recent finding demonstrates that a marked imbalance can occur in active galaxies and that there is no compelling justification for the assumption of energy equipartition [5].

In the equivalent auroral theory [6,7], the moving reflecting barriers are electrostatic rather than magnetic. The electrons responsible for the brighter and more highly structured types of aurora, such as auroral arcs, are found to be accelerated during the final 10,000 km of their journey of precipitation into the atmosphere from above. Typically this acceleration takes the form of the appearance of a sharp peak in the 1 to 10 keV range and a high energy tail being added to an initial power law distribution. Acceleration is predominantly parallel to the magnetic field. Low energy electrons are apparently little affected, suggesting at once that a resonant process is at work. Landau [8] showed that a particle distribution could become energized through the effect of absorbing or damping electrostatic waves of resonant velocities. The process is often likened to surfing on ocean waves. Since the auroral acceleration region is a region of strong electrostatic turbulence it was natural to ask whether the waves could be responsible for the energization. A mathematical model of the process, in which wavepackets act as moving electrostatic barriers, similar in effect to Fermi's magnetic scattering centres, shows that the features observed in auroral electron distributions should indeed be expected. Again, it is only by allowing for the different behaviour of individual particles in the random process of energy gain from encounters with faster wavepackets and losses to slower ones that the full intricacy of the stochastic process is revealed. A key feature is the initial rush of large numbers of electrons at the lower limit of resonance to higher energies where they congregate in a peak. The steeply falling initial distribution ensures that fewer electrons undergo the reverse change. If the process were to continue indefinitely the distribution would level off to give the familiar plateau predicted by Landau. It appears not to proceed to this extent in the terrestrial aurora. New support for this interpretation comes with the recent discovery that lower-hybrid waves are an important constituent of auroral-zone turbulence[9]. The properties of these waves, in particular the high phase velocity parallel to the magnetic field, make these waves very effective agents for accelerating electrons. Indeed these waves have long been used to drive currents and heat plasmas in experimental devices for controlled nuclear fusion [10].

A vital common factor in the above cosmic ray and auroral electron acceleration mechanisms is the fact that the scattering centres and wavepackets are in motion. In this both are applications of Newton's third law. Stationary magnetic- and electric-field configurations (including those of potential wells and double layers) would , in common with all other systems of unchanging central forces have no net effect on particles traversing them [11,12]. Theories and models based on static (or quasi-static) potential differences seem, with which the literature abounds, seem unable therefore to offer an alternative explanation. Proposal for dynamos driven, for example, by the solar wind or the Earth's rotation are not yet specific enough to be evaluated.

It seems, therefore, that the newly realised powers of stochastic processes could be the key to these two major problems in space plasma physics. It is conceivable that further study of these and other natural phenomena could be of practical benefit in the drive to harness similar processes in the laboratory.

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