ENERGY LOSSES OF GALACTIC COSMIC RAYS
IN THE INTERPLANETARY MEDIUM

I. H. URCH and L. J. GLEESON
Monash University, Clayton, Australia

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Abstract. Using realistic models of cosmic-ray propagation in interplanetary space we present, for electrons, protons and helium nuclei of a given energy near Earth, calculations of their distribution in energy before entering the solar cavity and their mean energy loss. Interplanetary conditions appropriate for the epochs 1965 and 1969 have been used. Cosmic-ray energies in the range of 20 MeV/nucleon to 1000 MeV/nucleon have been considered.

1. Introduction

Since the first formulation of the appropriate equation of transport by Parker (1965) it has been increasingly accepted that galactic cosmic rays with energies \( \lesssim 20 \text{ GeV/nucleon} \) and propagating through the interplanetary medium lose energy due to adiabatic deceleration in the expanding magnetic field irregularities as well as undergoing transport by convection and diffusion. For some years it was thought that we would be able to associate the differential intensity \( j(r, T) \) at a heliocentric distance \( r \) (near Earth, say) at kinetic energy \( T = T_e \) with the differential intensity in the interstellar region at some kinetic energy \( T'_e \) with \( T_e < T'_e \). In an attempt to obtain the relationship between \( T_e \) and \( T'_e \) for nuclei, calculations were made to determine the mean kinetic energy \( \langle T \rangle \) near Earth of a mono-energetic galactic source spectrum of protons and helium nuclei (Goldstein et al., 1970b; Gleeson and Urch, 1971). However in making these and associated calculations with realistic galactic spectra it was shown that at kinetic energies \( \lesssim 80 \text{ MeV/nucleon} \) (solar minimum value) protons and helium nuclei are virtually excluded from near Earth and that the intensity observed arises from a range of galactic energies. Hence the mean energy losses computed from mono-energetic galactic spectra are not appropriate for low energy nuclei.

In this paper we will present a quantitative determination of the contributions from different portions of the galactic spectrum to the near-Earth differential intensity at an energy \( T_0 \) and, for the first time, determine the mean energy losses of cosmic rays from these distributions. As noted above such calculations are necessary to determine the extent of the energy losses experienced by low-energy galactic nuclei in diffusing to near Earth, but they are also of general interest at higher energies and for other cosmic ray species. Hence distributions and mean energy losses are given for protons, helium nuclei, and electrons with \( T_0 \) in the range 20 MeV (/nucleon) to 1000 MeV (/nucleon) for each of 1965 and 1969.
The model assumed for the propagation of cosmic rays in the interplanetary medium is that described in Urch and Gleeson (1972a) and the reader is referred to that paper for a complete description and references. In the context of the model the steady-state cosmic-ray equation of transport appropriate to the ecliptic plane and which takes into account the Archimedean-spiral interplanetary magnetic field, anisotropic diffusion, convection, and adiabatic deceleration is

\[
\frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 UV - r^2 K \frac{\partial U}{\partial r} \right) = \frac{1}{3r^2} \frac{\partial}{\partial r} \left( r^2 V \right) \frac{\partial}{\partial T} (\alpha TU),
\]

where \( U(r, T) \) is the differential number density, \( \alpha = (T+2E_0)/(T+E_0) \) with \( E_0 \) the rest mass, \( K(r, T) \) is the effective diffusion coefficient, and \( V(r) \) is the solar-wind speed which we take to be 400 km s\(^{-1}\) at \( r = 1 \) AU (Note that the differential intensity \( j = vU/4\pi \), \( v \equiv \) particle speed).

The diffusion coefficients and galactic spectra assumed have been taken from a recent paper (Urch and Gleeson, 1972b) in which we used numerical solutions of (1) to select parameters with which the spectra of electrons, protons, and helium nuclei observed at several times during the period 1965–1970 could be reproduced. In particular the effective diffusion coefficients followed from the requirement that modulation of the known galactic electron spectrum (see Figure 1; Burger, 1971; and Goldstein et al., 1970a) reproduced the observed near-Earth electron spectra. We found with the boundary of the solar cavity at \( r = 10 \) AU, suitable galactic spectra to be

\[
U_G(T) = A (T + aE_0)^{-2.5},
\]

Fig. 1. Showing a comparison between the observed and calculated electron and proton spectra at \( r = 1 \) AU for the epochs 1965, 1968, 1969, and 1970. The galactic spectra used are also shown.