DRIFT MOTION AND PERPENDICULAR DIFFUSION OF ENERGETIC PARTICLES IN INTERPLANETARY SPACE BASED ON SPACECRAFT DATA

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Abstract. A realistic model of the interplanetary magnetic field (IMF) is constructed based on measurements taken by Pioneer 10 magnetometer at 5 AU. Energetic particle (0.1-100 MeV) propagation in this field is studied by a computer simulation of its motion in order to calculate $K_\perp$, the perpendicular diffusion coefficient, and $\langle V_D \rangle$ the average drift velocity of an ensemble of particles. Determinations of $K_\perp$ lie in the range $3 \times 10^{19} - 8 \times 10^{20}$ cm$^2$ s$^{-1}$ for the energies considered and they show that perpendicular diffusion may be an important process at these heliodistances when compared with parallel diffusion results obtained by similar techniques, contrary to what was previously thought.

Drift velocity calculations are very close to predictions of guiding centre theory (within 30%) suggesting that this theory can be applied in the IMF. This result shows that gradient and curvature drifts can be present even in a highly perturbed field and thus they can have some influence in cosmic ray modulation.

1. Introduction

Current interest in the ability of the solar wind to modulate the intensity of cosmic rays is focussed on the evaluation of the importance of particle drift motion in exchanging particles between solar equatorial and solar polar latitudes (Levy, 1976; Jokipii and Levy, 1977; Moraal et al., 1979). Although the drift flux, consisting of the contributions from curvature and gradients drifts in an inhomogeneous magnetic field was included in the original formulations of modulation theory (Axford, 1965; Parker, 1965), the observed sector structure of the interplanetary magnetic field (IMF) was thought to cause the associated terms to cancel. With the recognition of the importance of off-ecliptic effects and the disappearance of the sector structure (Smith et al., 1978) the necessity of taking drift terms into account becomes apparent. The existence of off-ecliptic gradients were discussed by Subramanian and Sarabahi (1967) and Lietti and Quenby (1968) in connection with the second harmonic of the diurnal variation. The latter authors first demonstrated that the Parker spiral geometry naturally gave rise to an off-ecliptic gradient, but in a further publication, Quenby and Hashim (1969), only $K_\perp$ due to scattering was employed in a calculation of off-ecliptic flow patterns.

Use of conventional guiding centre theory for drifts has demonstrated that the magnitude of the latitudinal gradients in cosmic ray intensity can be profoundly altered.
depending on the phase of the cycle of solar magnetic field. The solar magnetic cycle wave in the diurnal variations of cosmic rays as measured by neutron monitor and meson telescopes has also been explained on these grounds (Levy, 1976). Isenberg and Jokipii (1979) have suggested an analytical demonstration in the weak scattering, near isotropy limit that guiding centre or first order orbit theory applies for arbitrary spatial variation fields. However, doubt exists both as to whether the drift formulation is correct for the conditions of large scale magnetic turbulence found in the solar wind, and also if the demonstration given by Isenberg and Jokipii can be valid in particular field configurations (Lee and Fisk, 1981).

2. A Critical Review of Current Theory and Data

In a series of papers Jokipii and his co-workers (Jokipii et al., 1977; Isenberg and Jokipii, 1978; Jokipii and Kopriva, 1979; Jokipii and Thomas, 1981) have provided numerical solutions of the modulation equations including drift motion which yield a positive gradient towards higher latitudes if the northern solar field is predominantly outwards while the gradient is negative if the general solar field is reversed. Protons drift towards lower latitudes for the outward northern field but to higher latitudes for the inward field situation. One implication of such a model is that experiments on the galactic spectrum to be carried out by the International Solar Polar Mission are less likely to find near galactic spectral conditions at about 1 AU over the solar poles than if diffusion along field lines dominate because in the Jokipii et al. model most of the modulation must occur at greater radial distances. A full 3-dimensional model for solar modulation including drifts has been provided by Moraal et al. (1979). Their results show that the particles seen at the earth cross the boundary of the modulation cavity at very different heliolatitudes, depending on the sign of the IMF. However the off ecliptic gradient is always positive towards the poles, probably suggesting that diffusion versus convection and energy loss competition acting far out remains the main reason for modulation.

There have been efforts to assess the importance of drifts by analysing the evolution of cosmic ray intensity in different solar cycles. Erdős and Kota (1978) studied the high energy diurnal variation using the spiral field model with oppositely directed B north and south of the equatorial plane and with the region of magnetic flux change restricted to the sector boundary layer. Numerical trajectory integrations together with an application of Liouville's theorem led to an explanation of the 1969 diurnal variation phase changes, thus suggesting that scattering throughout the heliosphere is important at least at high energies. Antonucci et al. (1978) studied the symmetrical and antisymmetrical variation in cosmic ray flux with heliolatitude at a few GeV and find a higher cosmic ray intensity at the equator pre-1967 and a higher intensity towards the solar poles after 1967. This agrees with the calculations of Jokipii and Kopriva (1979). Newkirk and Lockwood (1981) essentially put forward a correction to the Antonucci et al. work by employing a latitude defined by K-coronameter data and found that the cosmic ray gradient does not change sign but that the intensity is always higher at the equator.