Cosmic Ray Transport in Turbulent and Periodic Velocity Structures

G.M. Webb[1], G.P. Zank[2], J.R. Jokipii[1] & C.M. Ko[3]
[2]IGPP, University of California Riverside, CA 92506,
[3]Dept. of Physics, National Central University Chung Li, Taiwan, 32054, ROC

Abstract

Multiple scales perturbation methods are used to study the transport and acceleration of cosmic rays in two different, but related fluid velocity structures. The analysis is based on the diffusive transport equation for cosmic rays derived by Parker (1965) and Skilling (1975), in which the particles are transported by convection and diffusion, and undergo energy changes due to adiabatic compression of the background flow, and due to second order Fermi acceleration due to Alfvén waves. In the first example, we consider particle transport in a turbulent medium upstream of a high Mach number cosmic ray modified shock, in which the turbulence has scale length ℓ_u, which is much less than the characteristic diffusive scale length $\ell_d = \kappa/u_0$ of the shock transition, where κ is the cosmic ray diffusion coefficient and u_0 is the shock speed. For the case of compressible turbulence, the fluid velocity perturbations can be thought of as sound waves. The perturbation parameter used in the analysis $\epsilon = \ell_u/\ell_d$ is assumed to be a small parameter, and the Mach number M of the upstream flow is a large number of order $1/\epsilon$. The net upshot of the analysis is that by averaging over the small scale length ℓ_u and time scale t_u characteristic of the velocity perturbations, one obtains a modifed transport equation for the cosmic rays on the long space scale ℓ_d and on the long time scale $t_d = \kappa/u_0^2$. The modified transport equation contains a modified spatial diffusion tensor consisting of the original diffusion tensor $\mathbf{K}_m$, plus a further diffusion tensor component $\mathbf{K}_{turb}$ due to the turbulent velocity fluctuations (this is commonly known as turbulent diffusion). Furthermore, the new transport equation contains terms representing the acceleration of the particles by the turbulent velocity fluctuations, which depend on the correlation tensor of the velocity fluctuations, and a modifed convection speed for the particle transport. A second example of the use of multiple scales analysis is also discussed, in which the background fluid velocity profile consists of a quasi-periodic, one dimensional structure of scale length ℓ_u in which ℓ_u is much smaller than the diffusive scale length $\ell_d = \kappa/u_0$ (this structure could for example represent a sequence of multiple, smoothed cosmic ray shocks). As in the first example, we obtain a modified transport equation on the long space and time scales, in which the particles are accelerated by the diffusive-compression acceleration mechanism, due to the compressible velocity variations. These results are related to those obtained by Jokipii, Kota and Giacalone (2002) on diffusive-compression acceleration in periodic velocity structures. The results are also related to those obtained by Bykov and Toptygin (1993) on particle acceleration and transport in turbulent media and multiple shocks.

References

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