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Superdiffusive shock acceleration and short acceleration times at interplanetary shocks

Silvia Perri and Gaetano Zimbardo
Università della Calabria, Dipartimento di Fisica, Arcavacata di Rende (CS), Italy (silvia.perri@fis.unical.it)

The analysis of time profiles of particles accelerated at interplanetary shock waves has shown evidence for superdiffusive transport in the upstream region. Superdiffusive transport is characterized by a mean square displacement that grows faster than linearly in time and by non Gaussian statistics for the distribution of the particle jump lengths. In the superdiffusive framework it has been shown that particle time profiles upstream of a planar shock decay as power laws, at variance with exponential particle time profiles predicted in the case of diffusive transport. A large number of interplanetary shocks, including coronal mass ejection driven shocks, exhibit energetic particle time profiles that decay as power laws far upstream.
In order to take this evidence into account, we have extended the standard theory of diffusive shock acceleration to the case of particle superdiffusive transport (superdiffusive shock acceleration). This has allowed us to derive both hard energy spectral indices and short acceleration times. This new theory has been tested for a number of interplanetary shock waves, observed by the Ulysses and the ACE spacecraft, and for the termination shock. The superdiffusive shock acceleration leads to a strong reduction of the acceleration times (even of about one order of magnitude) with respect to the diffusive shock acceleration.
Thus, this new framework provides a substantial advancement in the understanding of the processes of particle acceleration and particle transport, which are among the main objectives of the new Solar Probe and Solar Orbiter space missions.