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Propagation of a Strong Shock through Upstream Turbulence

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We consider effects of pre-existing, large-scale turbulence, upstream of a shock, on the magnetic field and the acceleration of charged particles. Turbulent density fluctuations upstream of the shock have a large effect on the magnetic field downstream (Giacalone and Jokipii, Ap. J., 633, L41, 2007). For high Alfven Mach number shocks, the downstream magnetic field is amplified considerably above the value obtained from the shock jump conditions. These effects may provide a robust and natural understanding of recent observations at supernova shocks.

The magnetic-field amplification implied by our simulations should exceed factors of 100, consistent with observed X-rays from supernova remnants, which require magnetic fields of 100 mu G. These are much larger than expected from the shock jump conditions. The upstream field is not amplified, so cosmic-rays with energies approaching the “knee” in the spectrum require rapid acceleration, which can occur at the quasi-perpendicular part of the supernova blast wave, where the turbulent field-line mixing plays a large role.

We have carried out a global test-particle simulation of acceleration at a spherical blast wave propagating into a uniform magnetic field. We find that although most of rapid particle acceleration occurs in the "equatorial" band, where the upstream magnetic field is quasi-perpendicular, the ongoing temporal evolution of the shock brings most of the particles to the quasi-parallel "polar" part of the shock.

This is in agreement with the observational constraints reported by Rothenflug, et al (A & A, 4225, 121, 2004), and allows the rapid acceleration at the quasiperpendicular shock.

We conclude that a model in which the magnetic-field amplification occurs because of the upstream turbulence and rapid acceleration to the knee occurs at the quasi-perpendicular part of the shock is consistent with the observations. Amplification of the upstream magnetic field is not necessary in this model.