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Field aligned accelerations by plasma shock waves

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High energy distributions have been observed along the shock front in supernova remnants (SNR). To account for this phenomena we proposed here a model of the particle acceleration parallel to the magnetic field of the shock propagating through the interstellar magnetic field (IMF), namely it is the field aligned acceleration by the plasma shock wave. A reasonable formula of the highest energy gain is derived from theoretical analysis of the relativistic equations of motion. The energy gain obtained by a test particle is given by the mutual product between four parameters: the shock velocity, the cross angle between IMF and the magnetic field of the shock, the magnitude of IMF and the acceleration time.

Strong shocks in SNR have been remarkable as a candidate of the high energy accelerator of cosmic rays. The mechanism of particle acceleration is explained by the diffusive shock acceleration (DSA) in which there exist two types of acceleration. One is the perpendicular shock where the direction of IMF is perpendicular to the shock normal and the other is the parallel shock where the direction of IMF is parallel to the shock normal. We show here a model of the perpendicular shock where the direction of IMF is perpendicular to both the shock normal and the direction of the wave magnetic field.

We firstly consider the plasma shock wave propagating through the uniform and stationary IMF. The magnetic field of the shock is parallel to IMF, whereas the electric field of the shock is perpendicular to IMF. In laboratory frame, there is no electric field along the magnetic field of the shock, then it is so difficult to predict the field aligned acceleration. Next, let us consider the electric and magnetic fields experienced by the particles on the wave frame of the shock. The electric field of the shock disappears on the wave frame, however the electric field of IMF is generated because IMF moves in the direction of the shock. The direction of the electric field is the same as that of the magnetic field of the shock. As a result, the test particle located near the shock front is accelerated by the electric field parallel to the magnetic field of the shock.

The highest energy gain obtained by the test particle depends on the cross angle between IMF and the magnetic field of the shock. When the angle is smaller than 90 degree, the gain becomes small. Whereas, if the angle is greater than 90 degree, then the magnetic neutral sheet is created in front of the shock. Once the test particle is trapped by the neutral sheet, the particle never escape from the trap[1]. Furthermore, in the vicinity of the neutral sheet, there exists the electric field along the magnetic field. The particle trapped is accelerated by this electric field indefinitely.

Some narrow filament structures in the vicinity of the shock front in SN 1006[2] and extremely fast accelerations[3] also have been observed in another supernova remnant. These phenomena could be explained by the field aligned acceleration presented here.

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