Nonstochastic particle acceleration by magnetosonic shock waves

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Acceleration of charged particles in plasmas has been demonstrated with laboratory experiments and astrophysical observations. Also, particle simulations have shown that a magnetosonic shock wave can promptly accelerate many kinds of particles to high energies with nonstochastic mechanisms; hydrogen ions, heavy ions, electrons, nonthermal energetic ions, and positrons (as a very brief review, see, for instance, Ref. [1] and references therein). We briefly describe these simulation results and discuss the acceleration mechanisms.

The sharp rise in the electric potential and magnetic field in a shock wave can reflect some of the thermal hydrogen ions; they then have high energies. If the external magnetic field is rather strong so that the electron gyrofrequency Wce is greater than the plasma frequency Wpe, these ions can have relativistic energies.

The presence of multiple ion species introduces interesting phenomena in particle acceleration, wave propagation, and energy transport [2]. If, as space plasmas, the plasma contains minor heavy ions as well as the major hydrogen ions, a shock wave can accelerate all the heavy ions with its transverse electric field. These accelerated heavy ions have nearly the same speed; the maximum speed is independent of particle species. Accordingly, the elemental composition of high-energy heavy ions is the same as that in the background plasma.

Shock waves propagating obliquely to an external magnetic field can accelerate some electrons to ultrarelativistic energies such that the Lorentz factor g exceeds 100 [3]. This acceleration is strong when the magnetic field is strong (Wce is geater than Wpe) and is particularly enhanced when the shock propagation speed Vsh is close to c cosq, where q is the angle between the external magnetic field and the wave normal.

Quite recently, it has also been found that electrons can gain ultrarelativistic energies immediately behind a small pulse, which is generated in a nonstationary shock wave [4]. This acceleration process can occur in weak magnetic fields (Wce is smaller than Wpe) as well as in strong magnetic fields. In addition, it does not require the condition that Vsh is close to c cosq.

These show that the magnetosonic wave can produce relativistic ions and ultrarelativistic electrons in times much shorter than one second.

Furthermore, nonthermal energetic particles can be accelerated to much higher energies by the transverse electric field; ion acceleration from g = 4 to g=160 was observed in test particle simulations [5]; where we obtained the wave fields from a particle simulation, and assuming stationary propagation, we calculated motions of test particles in these fields. If the shock propagation speed Vsh is close to c cosq, energetic ions can move with the shock wave for much longer times than their relativistic gyroperiods. These particles incessantly suffer the acceleration.

In a three component plasma containing electrons, ions, and positrons, oblique shock waves can accelerate positrons as well as ions and electrons. Particle simulations demonstrate positron acceleration to energies g=2000 by the time the simulation is finished (Wpe t = 5000). Accelerated positrons stay in the shock transition region for long periods of time. Unlike the surfatron acceleration [6], however, these accelerated positrons move nearly parallel to the external magnetic field [7].

[1] Y. Ohsawa, Physica Scripta T107, 32 (2004).

[2] M. Toida and Y. Ohsawa, Solar Physics 171, 161 (1997); M. Toida, T. Yoshiya, and Y. Ohsawa, Phys. Plasmas 12, 102306 (2005).

[3] N. Bessho and Y. Ohsawa, Phys. Plasmas 6, 3076 (1999); ibid. 9, 979 (2002).

[4] M. Sato, S. Miyahara, and Y. Ohsawa, Phys. Plasmas 12, 052308 (2005).

[5] S. Usami and Y. Ohsawa, Phys. Plasmas 9, 1069 (2002); ibid. 11, 3203 (2004).

[6] R. Z. Sagdeev and V. D. Shapiro, JETP Lett. 17, 279 (1973).

[7] H. Hasegawa, K. Kato, and Y. Ohsawa, Phys. Plasmas 12, 082306 (2005).