Particle acceleration by a relativistic collisionless shock with alternating magnetic field inflow

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The Crab nebula is driven by the rotational energy of the central pulsar. However the detailed mechanism of energy transfer between pulsar wind and nebula remains an open question.

Pulsars are rapidly spinning and strongly magnetized neutron stars. With a typical radius of r_{NS} ~10 km, magnetic field strengths of 10^{12} G are reached on the surface. Rotation periods are in the range of tens of milliseconds and co-rotation of the pervasively dipolar magnetic field extends towards the light cylinder at ~158 r_{NS}. Extreme conditions in the inner magnetosphere cause the generation of secondary lepton pairs; therefore the pulsar wind consists pervasively of pair plasma. Beyond the light cylinder the pulsar outflow is forced into a spiral topology within the equatorial plane. Consequently the pulsar wind is well approximated within the model of a strongly magnetized pair plasma with alternating magnetic polarity.

The Crab Nebula is well observed in broad band and in high resolution due to the comparatively small distance of 2 kpc. Chandra X-ray observatory shows us the double ring structure. The inner ring is located about 0.1 pc from the center and generated by the interaction between the pulsar outflow and the supernova remnant.

C.F. Kennel and F.V. Coroniti(1984) proposed a one-dimensional spherical MHD model (KC model) suggesting that the ratio of magnetic field energy flux to kinetic energy flux at the shock upstream region, the so-called sigma parameter, is $3*10^{-3}$. This means that the kinetic energy is dominant near the shock, in contrast to the situation close the pulsar where the contribution of magnetic field energy prevails.

The spectrum of the Crab Nebula exhibits highly non-thermal features which is indicative for the presence of some particle acceleration process. An essential point is that the toroidal magnetic field is perpendicular to the direction of the plasma flow. The perpendicular components of the magnetic field are relativistically boosted, and the magnetic field must be parallel to shock surface. In this case Fermi acceleration, the standard theory of particle acceleration, is not an efficient mechanism of particle acceleration.

One of the solutions to this problem is to investigate the shock direct acceleration. The presence of this process in pair plasmas is shown in particle simulations where the sigma parameter is less than 1/100 (M.Hoshino 2001). In such a case the magnetic field is constant in the upstream flow. The KC model also neglected the magnetic field structure. However, the magnetic field polarity is alternating around the equatorial plane due to the magnetic pole precession of the pulsar.

We investigate the particle acceleration by taking into account the upstream alternating magnetic field in one-dimensional particle simulations. The magnetic field and the current sheet structures are prescribed within the constraints of the Harris solution. We find that the acceleration is stronger in comparison to the non-alternating case in certain parameter ranges. We present simulation results and the acceleration mechanism caused by the interaction between the Harris current sheet and the shock, respectively.