A PIC Simulation for Break-up of the Closed magnetic field of the Pulsar Magnetosphere

Mitsuhiro Umizaki[1], Shinpei Shibata[2], Shinya Yuki[1]

[1] School of Science and Engineering, Yamagata University
[2] Department of Physics, Yamagata University
E-mail(MU): mumizaki@ksirius.kj.yamagata-u.ac.jp

ABSTRACT

We investigate the magnetic dissipation in the pulsar magnetosphere, in particular, around the Y-point, which is the boundary region between the closed magnetic flux of the dead zone and the open flux in the wind zone, via axisymmetric particle-in-cell (PIC) method in the cylindrical coordinates. We find that magnetic reconnections occur around the Y-point and magnetic islands are repeatedly formed and ejected outward, which suggests that the magnetic energy converts to the kinetic and thermal energy. It is possible that high-energy emission is radiated from this region. It is also possible that the plasma pressure accelerates the pulsar wind. A polar cap radiation may be emitted by falling particles into the neutron star.

KEY WORDS: magnetic fields — MHD — pulsars: general — stars: neutron

1. Introduction

Pulsars are the bright sources in the gamma-ray sky, however the emission mechanism remains open question. Recently, the current sheet in the pulsar magnetosphere is regarded as a candidate of the new radiation source. The aim of our study is to examine the possibility of the high-energy emission around the Y-point (Y-type current sheet) via axisymmetric particle-in-cell (PIC) method in the cylindrical coordinates.

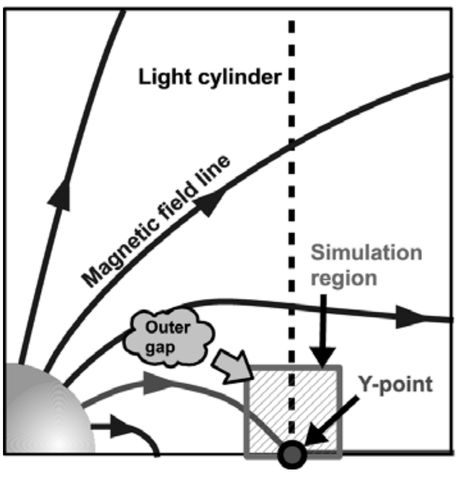

Fig. 1. The meridional plane of the pulsar magnetosphere.

2. Simulation method

The boundary condition (fig.2) is of great importance for the simulation of the Y-point. The inner (left and top) boundary condition is the force-free solution (fig.3) given by Uzdensky (2003). The outer (right-side) boundary may be crossed by super-fast wind. Then we impose free boundary for the right-side boundary. The lower boundary can be treated as reflection symmetry.

As for the initial condition we also use the Uzdensky's solution. Lorentz factor and number density of the inflow from the outer gap are free parameters. $R \times z = 64 \times 64$ grids, $dR = dz = 2c\omega_p^{-1}$, $dt \approx \Omega_{\max}^{-1}$. The simulation continues until the system becomes quasi steady state.

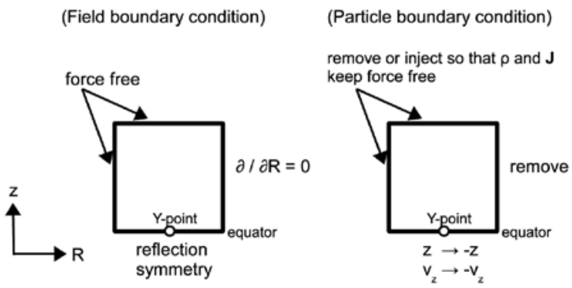

Fig. 2. The boundary condition. The left and top boundary condition is the force free. The right boundary condition is free boundary. The lower boundary condition is reflection symmetry.

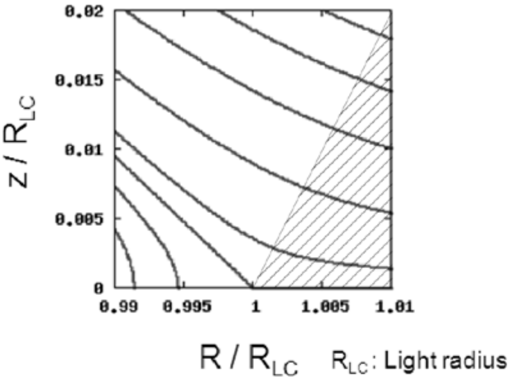

Fig. 3. The force-free solution (magnetic field line) given by Uzdensky (2003). In the shaded region, force free is broken and magnetic dissipation is expected.

3. Results

We have performed a test run with the boundary and initial condition which are described in the previous section. After a time of 1/60 rotations, we find that magnetic reconnections occur around the Y-point, which suggests that the magnetic energy converts to the kinetic and thermal energy. We see that a magnetic island is formed, goes outward, and merges with the dead zone (fig.4, 5). It is possible that high-energy emission is radiated from this region. It is also possible that the plasma pressure accelerates the pulsar wind. A polar cap radiation may be emitted by falling particles into the neutron star.

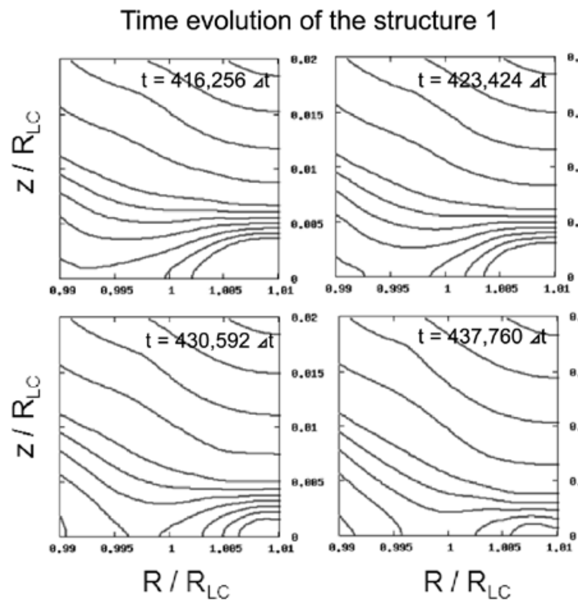

Fig. 4. Time evolution of the structure 1. The solid lines represent poloidal magnetic field line. Magnetic reconnections occur around the Y-point and the magnetic island goes outward.

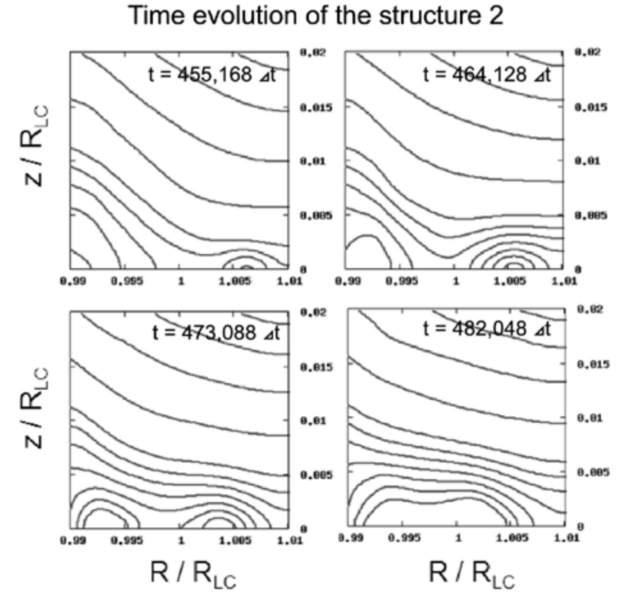

Fig. 5. Time evolution of the structure 2. The solid lines represent poloidal magnetic field line. The magnetic island comes back and merges with the dead zone.

4. Summary

The current sheet in the pulsar magnetosphere is regarded as a candidate of the new radiation source. In order to examine the possibility of the high-energy emission, we perform a PIC simulation around the Y-point in the pulsar magnetosphere. We find that magnetic reconnections intermittently occur in the pulsar wind, which suggests plasma heating. there are possibilities of high-energy emission and pulsar wind acceleration in this region. It is also possible that a polar cap radiation is emitted by falling particles into the neutron star. In the next step, we will examine the possibilities of high-energy emission and wind acceleration in detail by large scale simulation.

References

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