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Turbulent Magnetic Reconnection in Pulsar Wind Nebula
パルサー星雲における乱流リコネクション

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The pulsar wind Nebula is a post shock region generated by the interaction of pulsar wind and supernova ejecta. It is well-known that in this region the energy is dominated by the particle energy. However, the theoretical research indicates that the upstream flow, that is, pulsar wind, is Poynting energy dominated plasma, and the resulted post shock region is also Poynting energy dominated plasma. The mechanism that can convert Poynting energy into particle thermal energy effectively has been still unknown. In this presentation, we study the effect of turbulence on the dissipation of magnetic energy.

1. Introduction

In many astrophysical phenomena, the magnetic field plays important roles. In particular, Poynting-dominated plasma models have recently been studied extensively as a probable model of many high energy astrophysical phenomena. Among these phenomena, the physical system of the pulsar wind and the pulsar wind nebula of Crab pulsar is one of the most famous and accurately observed system of Poynting dominated plasma. The pulsar wind Nebula is a post shock region generated by the interaction of pulsar wind and supernova ejecta. However, the theoretical research indicates that the upstream flow, that is, pulsar wind, is Poynting energy dominated plasma, and the resulted post shock region is also Poynting energy dominated plasma. This result contradicts to the observation that indicates the nebula region is particle energy dominated, and some dissipation process has to exist. It is well-known that it is very difficult to dissipate the electromagnetic energy sufficiently during the characteristic time of phenomena if one considers the ordinal dissipation coefficient, and this problem, often called “σ- problem”, has been unsolved for more than thirty years.

Related to this problem, Petri and Lyubarsky [1] has recently shown that the magnetic dissipation rate is increased by the interaction of the shock waves and current sheet. They performed the one-dimensional particle-in-cell (PIC) simulation, and reported that this enhancement of dissipation is purely kinetic effect. Though they consider homogeneous upstream, it is natural that turbulence exists in the post shock region. It can be expected that the turbulence stretches the current sheets, and increases the dissipation rate of magnetic energy. This effect will accelerate the magnetic dissipation in addition to the above kinetic dissipation, and we can advances to the solution of the effective dissipation mechanisms.

In this presentation, we perform two-dimensional numerical simulation considering the turbulence in the post shock region, and report the enhancement of the dissipation of magnetic energy.

2. Numerical Setup

We model the interaction of the turbulence and current sheet in the post shock region as two dimensional resistive relativistic magnetohydrodynamics (RRMHD). This calculation includes relativistically hot phenomena, turbulence, and magnetic dissipation. We use multi-dimensional extension of new RRMHD scheme developed by Takamoto and Inoue [2]. This scheme uses appropriate characteristic velocities for calculating numerical fluxes, and it can solve problems including turbulence accurately. Since the main purpose of this research is studying the enhancement of dissipation rate of current sheet stretched by the turbulence, we assume the electric conductivity σ is a constant, and consider that the resistivity is a parameter of this calculation.

In this calculation, we model turbulent flow in post shock region generated by the moderately Poynting energy dominated upstream flow. When magnetic energy is strong enough, magnetic tension force impedes the turbulent motions completely, and the turbulence evolves only in the plane perpendicular to the magnetic field. Thus, we study 2-dimensional turbulence, and we assume the magnetic field is perpendicular to the numerical plane.

For the initial condition, we consider the post shock region generated by the Poynting dominated cold upstream flow whose plasma. Then, this post shock region becomes relativistically hot; the magnetic energy density is much larger than the rest mass energy density, and the plasma β is very low. In order for the numerical stability, we assume β = 4. More realistic set up will be studied in our future work. In this study, we consider the velocity dispersions as the initial perturbation. This enables us to study the effect of turbulence on the dissipation rate independent of driving sources of the turbulence. We consider the following form of velocity fluctuation

$$\gamma v_i = \sum_{k_x,k_y} P_i(k)^{1/2} \sin(k_x x + k_y y + \phi_{k,i}), \quad (1)$$

where $\phi_{k,i}$ is a random phase depending on the wave number and the component. We consider the following three cases: $\Delta v / c_s$ = 0.01, 0.05, 0.1, 0.5, 0.9 where c_s is the sound velocity. These parameters are motivated by the Richitmyer-Meshkov instability [3] since this instability results turbulence whose velocity dispersions are lower than the sound velocity.

3. Results

Fig. 1 is the snapshots of the profile of perpendicular magnetic field B_z at t = 75 t_0.

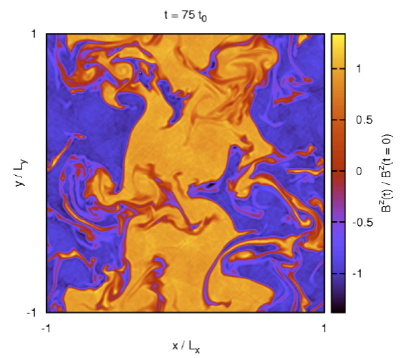

Fig. 1 Snapshot of Bz

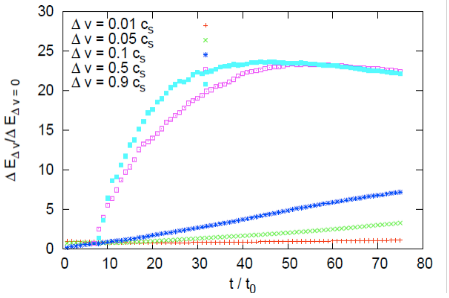

Fig. 2 Enhancement of dissipation

These figures show that the initial current sheets are stretched by the turbulence, and the eddies smaller than the dissipation scale are fully dissipated. You can see that the two current sheets gradually mixed by the turbulence. Though this may be partly because we consider slightly large scale initial perturbation, the main reason is that the turbulence is two-dimensional and the energy inversely cascade, and this results in more large eddies.

Fig. 2 is the enhancement of the dissipation rate with respect to various velocity dispersions. The vertical axis is the dissipated energy with turbulence comparing to that without turbulence. Fig. 2 shows that the dissipation energy is increased as the velocity dispersion is increased. Especially, in the cases of $\Delta v / c_s$ = 0.01, 0.05, 0.1, dissipated energy is proportional to the velocity dispersions.

4. Conclusion

In this presentation, we report on the enhancement of the dissipation of magnetic energy by the 2-dimensional turbulence in the post shock region where magnetic energy is much larger than the rest mass energy. The numerical results show that when the velocity dispersions are increased, the current sheet is bent, and the total dissipated energy is nearly proportional to the velocity dispersions. In addition, when velocity dispersions are larger than 50 % of sound velocity, the turbulence is fully evolved rapidly, and the enhancement of dissipation reaches to the upper limit in this letter's parameter.

References

[1] Petri, J., & Lyubarsky, Y. 2007, A&A, 473, 683.
[2] Takamoto, M., & Inoue, T. 2011, ApJ, 735, 113
[3] Goodman, J., & MacFadyen, A. 2008, Journal of Fluid Mechanics, 604, 325.