MAGNETOSPHERIC STRUCTURE FILLED WITH RELATIVISTIC PLASMA JETS/WINDS

SHIN-YA NITTA
Research Center for Advanced Energy Conversion, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-01, Japan
e-mail: snitta @satio.phys.nagoya-u.ac.jp

1. Introduction

Recent observations revealed that many kinds of astrophysical outflows have very similar structure, i.e. bipolar jets are surrounded by an equatorial (disk-shaped) wind or an expanded wind as in the outflows from YSO's, post AGB stars, pulsars or AGN's. One might think that this is very queer because the species of the central objects and the spatial scales are quite different among these objects. However this similarity is a result of self-organized magnetospheric equilibrium. In these systems, the rotating magnetic field plays an important role for the structure formation. In such systems, two components of the Lorentz force (the electrostatic force and the magnetic force arising from the toroidal component) dominate other forces in the region far distant from the rotation axis in spite of the difference of the acceleration mechanism of the flows. We can understand that such similarity of the structures is a nature of the plasma outflows itself.

We suppose relativistic, pressure-free, inviscid, resistive-less, stationary and axisymmetric MHD flows. In this case, MHD equations reduce to well known basic equations: the Bernoulli equation and the Grad-Shafranov equation. We should note that the special relativistic treatment is necessary to discuss the structure far beyond the light cylinder, even if the flow speed is not close to the light velocity.

2. Asymptotic Structure

In this paper, our scope is focused to the asymptotic region (far distant from the central object) in which we can observe the structure. The asymp-

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totic region should be divided into two regions depending on the dominated forces, i.e. the asymptotic polar (AP) region (Nitta '95, '97) and the asymptotic lower latitude (AL) region (Nitta '94).

In AP, the Lorentz force and the centrifugal force arising from the rotation of the flow are in balance. We can obtain the structure of the highly collimated cylindrical jet having clear outline with finite cylindrical radius ($\sim R_L$: the light cylinder radius) as M87 jet.

In AL, the solution is restricted to the conical class, and the electrostatic force and the magnetic pinching force are in balance. We can obtain the general solution of the conical class. Note that this solution can explain various asymptotic structures (both of the jet-like and the equatorial-wind-like structure) depending on the parameters (the terminal velocity, the angular velocity of the central object, the total poloidal magnetic flux and the amount of the polar current determined by the equilibrium at AP).

The jet solution obtained in AL is the 'conical' jet with very narrow polar angle. We should distinguish the 'cylindrical' jet in AP and the 'conical' jet in AL, because the dominated forces are different in these two cases.

3. Discussion

In many literature, thin jets and expanded winds are treated as different kinds of outflows. However the author would mention that these structures can be made by common mechanical process as discussed above.

We should divide the entire process of the outflows into, at least, three stages. The first is the acceleration stage with the scale $\sim R_L$, the second is the structure formation stage ($\gg R_L$) discussed in this paper, and the third is the propagation stage where the influence of the ambient medium is essential. Here we present a unified scheme for the structure formation stage: the Lorentz force equilibrium can explain various self-organized structures, e.g. the conical jet, the equatorial wind, the expanded wind or the hybrid (jet+wind) flow.

However some parameters, e.g. the terminal velocity and the mass injection rate are still 'free' in the asymptotic analysis. They should be determined by the connection with the acceleration region. The author is now trying to solve this remaining problem in order to discuss what is the difference in the inner region among the thin-jet-dominated case, the equatorial-wind-dominated case and the hybrid (jet+wind) case.

References

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