MHD MODELS OF GALACTIC CENTER LOBES, SHELLS, AND FILAMENTS

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ABSTRACT. Magnetohydrodynamic (MHD) mechanisms producing radio lobes, shells, and filaments in the Galactic center as well as in the gas disk of the Galaxy are studied by using two-dimensional MHD code: (a) the explosion in a magnetized disk, (b) the interaction of a rotating disk with vertical fields, and (c) the nonlinear Parker instability in toroidal magnetic fields in a disk. In all cases, dense shells or filaments are created along magnetic field lines in a transient state, in contrast to the quasi-equilibrium filaments perpendicular to magnetic fields.

Recent high resolution radio observations of the Galactic center region revealed many fine structures suggesting the presence of strong magnetic fields, such as filaments in the radio arc and bridge (Yusef-Zadeh *et al.* 1984) and the Galactic center lobe (Sofue and Handa 1984). In fact radio polarization measurement confirmed the existence of strong magnetic fields of order of $10 - 100\ \mu$G (Inoue *et al.* 1984; Tsuboi *et al.* 1986). It has also been revealed by high resolution HI observations (e.g., Heiles 1984) that the gas disk of our Galaxy is filled with many filamentary structures, such as shells, loops, and worms. Although some of the shells correlate with SNRs or superbubbles including OB associations, there are many shells or filaments which are not associated with them. Recently, Heiles (1989) suggested that the formation of a filament in an expanding HI shell is related to the existence of the magnetic field, because magnetic pressure dominates gas pressure in the filament. In this paper, we study three MHD mechanisms producing filamentary structures in the Galactic center as well as in the gas disk of our Galaxy, by using two-dimensional nonsteady MHD numerical simulations.

(a) *Explosion in a magnetized gas disk*: Umemura *et al.* (1988) studied the propagation of an MHD shock wave originating from a single adiabatic explosion occurring in the center of a gas disk with a vertical magnetic field, and found that the cylindrical flow with a dense shell appears after the shock propagates into the halo. It is also found that the shell is not a shock front but a contact surface of the ejecta from the disk. The density contrast between the halo and the shell mainly originates from the initial density contrast between the halo and the disk. However the density at the shell increases with increasing the field strength, because the ejecta is more compressed between an expanding flow and a magnetic "wall" when the field strength is larger. Similar shells (filaments) are created even if initial magnetic fields are horizontal (Mineshige *et al.* 1989).

(b) *Interaction of poloidal magnetics field with a rotating gas disk*: Uchida *et al.* (1985) and Shibata and Uchida (1987) studied this process assuming parameters suitable for the Galactic center region, and found that a jet is created which has a hollow cylindrical shell structure. The physical mechanism producing the shell is similar to that in the above case (a), although the acceleration of the gas is not due to gas pressure in a hot gas, but due to magnetic pressure in a magnetic twist created by winding-up of poloidal fields by a differentially rotating gas disk.

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(c) *Parker instability*: Matsumoto *et al.* (1988) and Shibata *et al.* (1990) studied the nonlinear evolution of the Parker instability in a gas disk suitable for an accretion disk or a galactic disk. They found that transient dense loops are created when the magnetic loops expand into the halo or corona (Fig. 1). The mechanism is again similar to the previous one, though the accelerating force of a loop is the nonlinear magnetic pressure gradient force. The lifetime of the loop is of order of a free fall time at the loop height. The loop density increases if a neutral sheet is created just above the loop through the interaction with anti-parallel magnetic fields in the halo. It is also found that a shock wave is formed at the footpoint of the loop for low $\beta(= p_g/p_m < 1)$ disks. The shock wave front is nearly perpendicular to the field lines, and the gas is significantly compressed after passing through the shock, which may lead to the formation of molecular clouds. The configuration of the magnetic fields and shock fronts (molecular clouds) in simulation results is similar to the morphology of the Orion molecular cloud complex and the associated magnetic field (e.g., Maddalena *et al.* 1986). The quasi-equilibrium filament perpendicular to the field lines resembles the 300 pc thermal spur observed by Müller *et al.* (1987).

As a concluding remark, we would like to stress that filamentary structures along magnetic field lines are easily created if we consider a transient state.

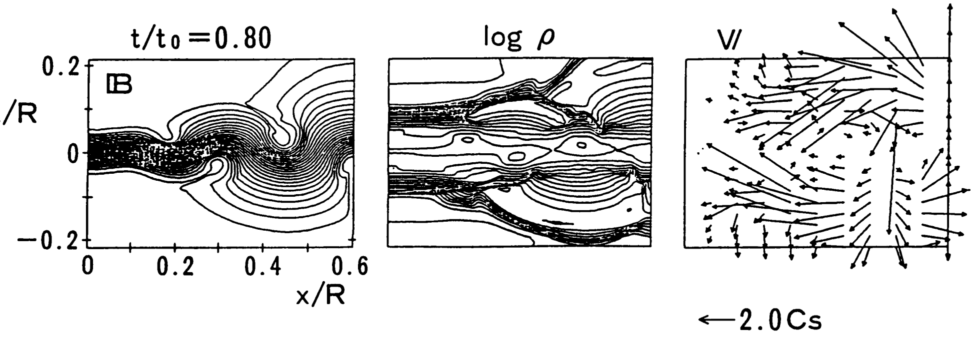

Figure 1. The nonlinear expansion of magnetic loops as a result of the Parker instability in an isolated magnetic flux in a disk (Shibata *et al.* 1990): magnetic field lines (**B**), density (ρ), and velocity vectors (**V**). Here, x and z are in the azimuthal and vertical directions, and R is the radius of the disk.

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