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Magnetic instabilities and magnetic activities in accretion disks

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We carried out global three-dimensional magnetohydrodynamic simulations of accretion disks. When the initial magnetic field is weak and toroidal, magnetic energy is amplified exponentially owing to the growth of the magnetorotational instability. The system approaches a quasi-steady sate with beta=Pgas/Pmag=10. Magnetic turbulence developed in the disk efficiently transports angular momentum. When the disk is optically thin, magnetic reconnection generates 1/f noise-like X-ray time variations. When the magnetic energy is comparable to the thermal energy, magnetic flux buoyantly escapes from the disk. When the magnetic loop connecting the central star and the disk is twisted by the rotation of the disk, hard X-ray flare takes place.

Accretion disks are thought to be the energy source of various activities in active galactic nuclei, black hole candidates, and in star forming regions.. Magnetic fields play essential roles in these activities. In this talk, I review the results of three-dimensional global magneto-hydrodynamic simulations of the nonlinear growth of magnetic instabilities in accretion disks.

In the conventional theory of accretion disks, phenomenological parameter, alpha, is introduced for the efficiency of angular momentum transport. Since molecular viscosity is too small, it has been thought that turbulent transport is essential. However, it became clear that purely hydrodynamical turbulence cannot provide large enough alpha. Balbus and Hawley (1991) pointed out the importance of magneto-rotational instability which grows in dynamical time scale in differentially rotating disks.

Several authors have reported the results of local 3D MHD simulations of accretion disks (Hawley et al. 1995; Matsumoto and Tajima 1995; Brandenburg et al. 1995). When the initial magnetic field is weak and toroidal, magnetic energy is amplified exponentially and saturates when beta=Pgas/Pmag=10-30. However, local simulations have limitations that numerical results depend on the size of the simulation region. Thus we carried out global simulations by adopting an equilibrium model of shear rotating torus as an initial condition (Matsumoto 1999). We found that the magnetic energy is amplified exponentially and saturates when beta=10. Owing to the efficient angular momentum transport, matter accretes to the central object. The effective value of alpha is found to be between 0.01 and 0.1. Inside the disk, filamentary shaped, low-beta regions are created. Magnetic energy release in strongly magnetized regions may lead to sporadic X-ray time variations. We found that the power spectral density of time variation shows 1/f noise-like spectrum similar to that in black hole candidates (Kawaguchi et al. 2000).

When the initial toroidal field is nearly equipartition strength (beta =1), magnetic flux escapes from the disk due to the buoyancy. The emerging magnetic flux creates loop-like structures similar to those in the solar corona(Machida et al. 2000). Twist injection from the disk into closed magnetic loops may lead to flaring activities. We carried out numerical simulations of the magnetic loops connecting the central star and the disk and showed that magnetic reconnection taking place in the loop heats the plasma and creates hot, X-ray emitting plasmoids. This mechanism can explain the X-ray flares and optical jets observed in protostars (Hayashi et al. 1996).