Global Simulations of Turbulence and Dynamos in Differentially Rotating Astrophysical Plasmas

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We present the results of global three-dimensional resistive magnetohydrodynamic (MHD) simulations of astrophysical plasmas rotating around a gravitating object. When the initial magnetic field is weak (i.e., $\beta = P_{\rm gas}/P_{\rm mag} \gg 1$), differential rotation enables the growth of the magneto-rotational instability (MRI) , which amplifies azimuthal magnetic fields and generates MHD turbulence in the disk. Angular momentum transport due to the Maxwell stress of the turbulent magnetic field leads to the infall of the disk plasma. The gravitational energy of the plasma released during this infall is believed to be the energy source of accretion powered objects such as black hole candidates.
We found that the direction of equatorial mean azimuthal magnetic field reverses with time scale about 10 rotation period at the characteristic radius of the disk. Formation of the bisymmetric magnetic fields and the buoyant rise of the magnetic flux from the disk to the disk corona enables the amplification and reversal of azimuthal magnetic field in the disk. The appearance of global mean azimuthal magnetic field with net azimuthal flux in the disk elevates the saturation level of magnetic energy. The quasi-periodic reversal of azimuthal magnetic field is similar to the 11 year cycle of the reversal of the polarity of solar magnetic fields.
When we adopt the gravitational potential of our galaxy, numerical results indicate that the mean azimuthal magnetic field is amplified up to μG. The interval of the reversal of the azimuthal magnetic field is about 1Gyr at 5kpc from the galactic center. The mean magnetic fields are mainly azimuthal in the outer disk but vertical component becomes important near the galactic center, consistent with the observations of our galactic center.
In black hole accretion disks, sawtooth-like oscillations of magnetic energy appears when the accreting matter forms an inner torus near the black hole. In such tori, the magnetic energy approaches $\beta \sim 1$ and is released by magnetic reconnection. Such dynamo-driven quasi-periodic activities can explain low-frequency(1-10Hz) quasi-periodic oscillations (QPO) observed in galactic black hole candidates. We found that during the growth of the magnetic field, the accretion disk deforms itself into a crescent shape. Such non-axisymmetric structure can excite higher frequency oscillations in the disk.