Magnetohydrodynamic Simulations of Cosmic-Ray Modified Magnetic Buoyancy Instabilities in Disk Galaxies

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In disk galaxies, magnetic fields can be amplified and maintained. For galactic gas disks, Nishikori et al. (2006) and Machida et al. (2013) showed by three-dimensional global magnetohydrodynamic simulations that the mean magnetic fields inside the disk reverse their direction quasi-periodically. [1][2] This cyclic dynamo is driven by magnetic fields amplification due to magneto-rotational instability and the buoyant escape of the magnetic flux by Parker instability.

However, their simulation did not consider cosmic-rays (or the non-thermal particles) whose energy density is comparable to the magnetic energy density. Since the pressure of the non-thermal particles becomes dynamically important, we need to include cosmic rays to study the evolution of galactic magnetic fields.[3] Cosmic-Rays modify the growth rate and the critical wavelength for the growth of the undulating mode of the magnetic buoyancy instability because the cosmic-ray diffusion along the magnetic field lines enhances the buoyancy around the loop top of the undulating magnetic field lines. This instability, which we call the Magneto-Cosmic-Ray instability (MCI), is similar to the magneto-thermal instability (MTI) driven by the thermal diffusion along the magnetic field lines.

Additionally, Supernovae are important for galactic dynamo because they inject energy into thermal plasmas and cosmic-rays.[5][6] We carried out local two-dimensional and three-dimensional magnetohydrodynamic (MHD) simulations of the cosmic-ray modified magnetic buoyancy instabilities. We found that unlike the Parker instability which only drives nonlinear oscillations when the magnetic field is weak, short wavelength magnetic loops buoyantly escape from the disk when MCI grows. We also present the results of simulations including the source term of cosmic-rays.