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Magnetohydrodynamic Simulations of the Formation of Galactic Prominence

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Interstellar matter consists of hot plasma (T>10^5K), warm gas (6000K<T<10000K), and cool (T<1000K) neutral gas. In dense, cold regions where the number density exceeds 100cm^{-3}, the neutral gas becomes molecular gas.

By NANTEN CO observations, Fukui et al. (2006) found molecular loops in the central region of our galaxy. The height of the molecular loops exceed 100pc above the galactic plane, and the length of the loop is around 600pc. Fukui et al. (2006) pointed out the importance of strong magnetic fields (>30 μ G) necessary to support the dense loop against gravity. They also observed line of sight velocity of molecular gas exceeding 40km/s, which exceeds the sound speed in the warm medium. Fukui et al. (2006) explained the velocity by sliding motion of molecular gas along a magnetic loop formed by Parker instability. Machida et al. (2009) carried out three-dimensional global MHD simulations of the central region of galactic gas disks and showed that magnetic loops are formed and that warm gas slides down along the magnetic loops. In order to explain the formation of molecular loops, dense, cool gas should be levitated against gravity before they slide down along the magnetic loops. The dense, cool gas levitating in the warm medium is similar to solar prominences, in which dense, cool gas is condensed in the hot solar corona

According to the model of inverse-polarity solar prominences (e.g., Kuperus and Raadu 1974), the prominences are confined in the flux rope formed by magnetic reconnection taking place in magnetic arcades inflating by injection of energy through the motion of the footpoints of the magnetic arcades. Kaneko and Yokoyama (2015, 2017) carried out MHD simulations of rising magnetic arcades in the solar corona by taking into account the cooling/heating and thermal conduction. They showed that after magnetic flux ropes are formed, the coronal plasma falling along the closed magnetic fields accumulate around the bottom of the flux rope. When the density of the region exceeds the threshold for the cooling instability, cool, dense filament is formed.

Peng et al. (2017) applied this "reconnection-condensation model" of prominence formation to galactic gas disks and carried out two-dimensional simulations by taking into account the cooling/heating of the interstellar medium. They showed that cool (<400K) dense filaments with mass exceeding 10^5 solar mass can be levitated in the warm interstellar medium. The height of the cool, dense filament exceeds 100pc when the initial disk is dominated by magnetic pressure.

In the model studied by Peng et al. (2017), however, they did not consider the rotation of the galactic disk. In rotating disks, Coriolis force can prevent accumulation of the gas. Furthermore, Peng et al. (2017) did not consider the spacial variation of gravity in the vertical direction. We have to take into account the increase of vertical gravity with height from the galactic plane.

Here we report the results of two-dimensional and three-dimensional magnetohydrodynamic simulations of prominence formation in rotating galactic gas disks. We consider a local region of the disk and carry out simulations in a frame co-rotating with the galactic gas disk. We adopt the heating/cooling function by Inoue et al. (2006). The vertical gravity is approximated by Miyamoto and Nagai potential modified by Sofue (1996). Initial magnetic field is a solution of force-free magnetic arches. We incorporate anomalous resistivity which onset when the current density exceeds a threshold. Shear motion is imposed at the foorpoints of the magnetic arches. The time evolution is computed by using a magnetohydrodynamic code CANS+ (Matsumoto et al. 2016). Figure 1 shows the density distribution for a model with β =0.2, where β is the ratio of gas pressure to magnetic pressure. Dense filament is formed around the midpoint of the loop. The height of the center of the flux rope is 150pc. The total mass of the filament exceeds 10^5 solar mass.

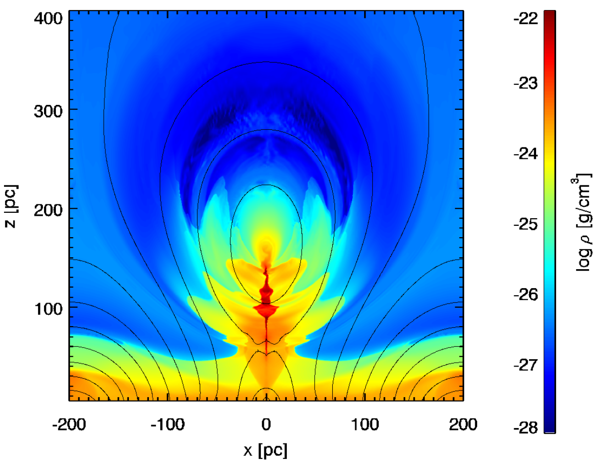

Figure 1: Density distribution for β =0.2 at 48Myr,

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