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On the Long-term Evolution of Our Galaxy: Importance of the Diffuse X-ray Emitting Plasma

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The evolution of galaxy over cosmic time (~1 Gyr) is related to many astrophysical subjects such as the formation of stellar objects, the origin of cosmic particles and radiations, and environmental evolution for life on the planes, and has been widely studied. Nevertheless, our current understandings are far from sufficient. Our galaxy's long-term star formation, which continues with an almost constant rate of several Mo/yr during the cosmic age of 14 Gyr [1], is a representative puzzle. If the constant star formation resulted from the similar Galactic disk conditions during 14 Gyr, the gaseous matter as the fuel of star formation with a mass of 10^9 Mo was depleted within ~1 Gyr. This puzzle can be translated by the cosmological context. Supposing the cosmic density fraction ratio of the baryon (usual matter) to dark matter (DM), ~0.1 [2], the total baryon mass of our galaxy is estimated as ~10^11 Mo, while the total mass of stars is 4-6x10^10 Mo [3]. Therefore, we must find the reason why half of the gaseous matter is converted to the stars leaving ~1 % of mass at the Galactic disk.

The galactic wind (outflow from the disk) is invoked to explain the observed metal absorption lines at the circumgalactic medium (surrounding gaseous matter around the Galaxy with a radius of ~100 kpc, [4]). Note that the metal (elements heavier than helium) is created inside the stars which are formed in the disk. Therefore, the existence of the metal at ~100 kpc distant from the disk should be explained by the outflow. We showed [5] that the diffuse X-ray emitting plasma (DXEP) can escape from the disk as the wind due to the effects of cosmic-rays (CRs). The CRs are non-thermal, relativistic particles whose observed energy density of ~1 eV/cc is comparable to the other components such as the energy density of thermal particles and the magnetic field in the Galactic disk. They can heat the background plasma via the generation and dissipation of the Alfven waves. We found that this heating rate is comparable to the radiative cooling rate of the DXEP, resulting in a sufficiently high temperature of the DXEP to escape the Galactic system. Note that the gravitational virial temperature for our galaxy is ~0.3 keV, the plasma with such temperature is bright at the X-ray band. The mass transfer rate of the wind is several Mo/yr, comparable to the gas depletion rate due to the star formation. Such comparable mass loss is preferred to keep the small mass of the gaseous matter in the disk.

To explain the long-term star formation, the gas accretion onto the Galactic system is a must. The DM accretion rate can be estimated from the cosmological N-body simulations. According to the results given by [5], our galaxy suffers the DM accretion with a rate of ~70 Mo/yr at the current time. We can estimate the gas accretion rate by multiplying the cosmic baryon fraction as ~7 Mo/yr. Then, if a tenth of the supernovae explosion energy is consumed to form the DXEP with a temperature of 0.3 keV, the outflow rate becomes ~4 Mo/yr. To reproduce the quasi-steady state of the disk, the remaining gaseous matter should be consumed for the star formation with a rate of ~7 Mo/yr – 4 Mo/yr ~ 3 Mo/yr. Hence, the existence of the Galactic wind can be essential to understand the long-term evolution of the Galactic system. Constructing the time-dependent model of the Galactic system including the accretion, wind, star formation, CRs, metal produced by stars, and stellar dynamics, we confirm that our picture can be consistent with the observed star formation history and other Galactic conditions. In this talk, we review the long-term evolution of our galaxy according to this scenario and the results of our model.

References

[1] Heywood et al. 2016, A&A 589, A66
[2] Planck Collaboration 2020, A&A, 641, A6
[3] Bland-Hawthron & Gerhard 2016, ARA&A, 54, 529
[4] Tumlinson et al. 2017, ARA&A, 55, 839
[5] Shimoda & Inutsuka 2022, ApJ 926, 1, 8

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Note: Abstract should be in (full) double-columned one page.