Thermal States of HI gas and Dust properties in The Galactic Halo: Towards Understanding Circum-Galactic Medium and Cosmic Star Formation in The Galaxy

Izumi Seno[1], Shu-ichiro Inutsuka[1], Jiro Shimoda[2]

[1]*Nagoya University, Japan,* [2]*Institute for Cosmic Ray Research, The University of Tokyo, Japan*

The star formation rate in our Galaxy has been maintained at the level of several $M_{\odot}$ yr^{-1} for about 10^{10} yr. However, if star formation continues at the current rate, the current amount of gas in the galactic disk should be depleted in less than 10^{9} yr. Recently, large amounts of metal-enriched gas, exceeding $10^{10} M_{\odot}$, have been observed in the halo. From these observations, it is expected that the gas supply and circulation between the disk and the halo are responsible for long-sustained star formation. The gas transport mechanism from the disk to the halo has been re-examined by Shimoda & Inutsuka (2022). Their detailed theoretical calculations have shown that cosmic ray heating suppresses radiative cooling, allowing the gas to be transported out of the disk over 100 kpc. In contrast, the gas supply mechanism from the halo to the disk, including the thermal condensation process in the halo and the infall process from the halo to the disk, remains to be studied, which is the purpose of this work. This line of work should include the analysis of Intermediate- and High- High-velocity clouds (IVCs / HVCs), which are the HI gas objects in the halo whose origins are still under debate.

On the other hand, a map of the dust-to-HI ratio in the whole sky is recently provided by Hayakawa & Fukui (2024). They show that the metallicity of IVCs/HVCs is universally less than several $Z_{\odot}$ in our Galaxy. However, the properties of dust grains in the halo are still unknown, so there are many open questions. For example, it is unknown whether dust can survive in hot regions such as Circum-Galactic Medium.

In this study, we analyze the thermal state of the halo gas in detail. We have performed a linear stability analysis of the thermal gas in the halo that is gravitationally stratified and in thermal equilibrium, considering thermal instability, gravitational dynamics, and the effect of cosmic rays. One of our results shows that the lower layer of the halo is thermally and convectively unstable, which may correspond to the mixing layer of multi-phase gases. We also compare the expected condensations in the halo as a result of the present analysis with observations of HVCs/IVCs.