【Grant-in-Aid for Scientific Research (S)】

The Evolution of Our Galaxy: Disk/Halo Interaction and Star Formation over Cosmic Time

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Project Information	Project Number : 25H00394 Keywords : Milky Way, Galactic Halo, Spiral Arm, Interstellar Medium, Star Formation	Project Period (FY) : 2025-2029

Purpose and Background of the Research

● Outline of the Research

We will conduct unified research on (1) the star formation process in the disk of our Milky Way Galaxy, including its outer edges and central regions; (2) the origin and evolution of the Galactic spiral arms; and (3) the evolution of the entire Galaxy as a system, including the Galactic Halo, to explain our Galaxy's evolution over almost the age of the Universe. In the Galactic Disk, many old supernova remnants form a connected system of bubbles that sweep up gas, with Giant Molecular Clouds formed where bubbles collide. These clouds are the main sites of star formation, with massive stars and clusters born in so-called "hub-filament" structures within them. However, the gas present in the Galactic disk alone can only sustain star formation for less than 10% of the age of the Universe. Therefore, gas must be supplied to the disk by the cooling and infall of the ionized gas present in the Galactic Halo. We will establish a new picture of star formation and the maintenance and evolution of Galactic spiral arms, with the gas circulation process in the Galactic Disk and Galactic Halo as an essential element.

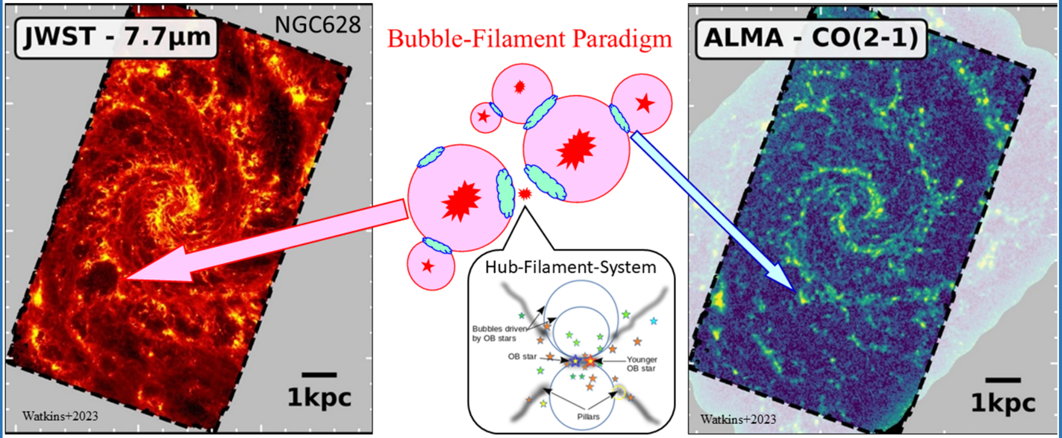

Figure 1. The left panel shows numerous bubble structures in the extra galaxy NGC628 observed with JWST at 7.7um (Watkins et al. 2023). As predicted, the distribution of giant molecular clouds in NGC628 observed by ALMA (right panel) confirms that the regions where bubbles collide are the formation regions of giant molecular clouds.

● Background and Purpose

Figure 1 shows a distant galaxy revealed by the JWST space telescope. Its bubbly disk closely resembles the picture predicted by the new star formation theory (Inutsuka et al. 2015) proposed by the principal investigator (hereafter the PI). The PI studies the interaction between the gas in the Galactic halo and star formation in the Galactic disk with special emphasis on magnetic fields and cosmic rays. If the gas in the Galactic disk (~1 billion solar mass) were to be converted into stars at the current star formation rate (~2 solar masses per year), the gas would be exhausted in about 500 million years. Yet observations of low-mass old stars remaining in the galaxy have shown that the Galaxy's star formation activity has been continuing at its present rate for about 9 billion years. To sustain star formation activity for such a long period, gas needs to be continuously supplied to the Galactic Disk, and this can only be supplied from the Galactic Halo. In fact, recent observations have shown that there is a large amount of ionized gas in the Galactic Halo, as much as 20 billion solar masses. If mass accretes from this gas to the Galactic Disk at the current star formation rate, the quasi-steady star formation activity on the scale of the age of the Universe can be explained without contradiction. However, the gas in the Galactic Halo is not just primordial hydrogen and helium, but also contains heavy elements. These can only be supplied if there is also a flow of matter *from* the Disk *to* the Halo. The principal investigators quantitatively analyzed the Galactic Disk wind, which is the key to the circulation of material between in the Galactic Halo and Galactic Disk, and showed for the first time that even the currently observed frequency of supernova explosions is sufficient to drive the Galactic Disk wind. In this process, turbulent magnetic fields and the effective pressure of cosmic rays play a crucial role, and this research requires the use of various disciplines of astrophysics. In addition to understanding the Galactic wind, if we can quantitatively understand the process by which cooled gas in the Galactic Halo rains down onto the Disk (Figure 2), we should be able to understand the star formation process that has been going on for about 9 billion years – equivalent to two-thirds of the age of the Universe. This research is an attempt to understand the evolution of our Milky Way Galaxy by understanding the interaction between the abundant gas in the Galactic Halo and the molecular cloud formation and star formation processes regulated by the magnetic field in the Galactic disk.

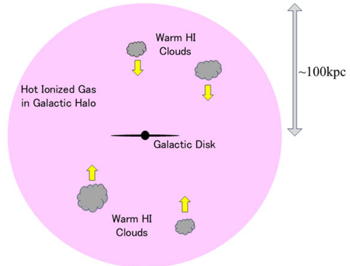

Figure 2. A schematic picture of gas supply from Galactic halo to disk.

Expected Research Achievements

● Star Cluster Formation in Hub-Filament Systems

Statistical research on molecular clouds using the Herschel Telescope has revealed that all high-mass star-forming regions within 5 kpc of the Solar System are molecular clouds with a shape known as hub-filament systems. We will determine the formation and evolution of hub-filament molecular clouds, which will lead to an understanding of the main star formation process in the Galaxy.

● Effect of Gas and Star Formation on Spiral Structures in Galactic Disk

We will conduct a unified study of spiral arm structure, including star formation in the disk and gas supply from the halo, and determine the mechanism that maintains the spiral arms of the Galactic disk.

● Verification of Theory and Galactic Archaeology

We will comprehensively describe the evolution of the Milky Way including the migration of stars and heavy element distribution. We will verify this theory through galactic archaeological analysis that makes full use of observational data from Gaia and Subaru (Figure 3).

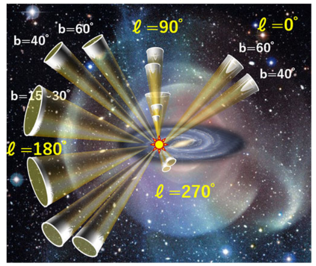

Figure 3. Observations for the Galactic Archaeology by the *Subaru Telescope*. The observational directions are shown with respect to the position of Solar System.

Homepage Address	PI: https://www.astro-th.phys.nagoya-u.ac.jp/~inutsuka Present Grant: https://www.astro-th.phys.nagoya-u.ac.jp/~inutsuka/S