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学 位 論 文 内 容 の 要 旨
Abstract of Doctoral Dissertation

博士の専攻分野の名称	博士 (理学)	氏名　藤本 裕輔
Degree requested	Doctor of Science	Yusuke Fujimoto

学 位 論 文 題 名
Title of Doctoral Dissertation

Formation and evolution of giant molecular clouds in a barred spiral galaxy
(棒渦巻銀河における巨大分子雲の形成と進化)

Understanding where and how gas is converted into stars in a galaxy is important for understanding a galaxy's formation and evolution through each epoch of the universe. Which physical processes control the star formation in a galaxy is heavily debated.

We are now at a stage where it is possible to investigate the giant molecular clouds (GMC) and star formation, while also taking global galactic dynamics into account. Thanks to high resolution and sensitive observations from sources such as the millimeter/submillimeter observations by ALMA and infrared observations by Spitzer and Herschel, it is becoming possible to statistically explore GMC and star forming regions through observations in nearby galaxies. In theoretical works, we can also now investigate the formation and evolution of individual GMCs using hydrodynamical isolated galaxy simulations with a self-consistent multiphase interstellar medium (ISM) thanks to developments of super-computer and effective algorithms.

Recent observations (high resolution, but not enough to resolve down to GMC scale yet) have shown the star formation activity changing between galactic-scale environments. The star formation efficiencies (SFEs) have systematic variations larger than one order of magnitude between different galaxy types and between different regions within a galaxy. This means that the gas density is not the only factor that determines the star formation activity in a galaxy. In particular, observations of barred galaxies showed that a central bar region has a lower SFE than that in the spiral arm regions even when the gas surface densities are almost the same.

Why does the star formation activity differ depending on the galactic structure's different environments? This question is key to understanding the galactic-scale star formation and has been the focus of my doctoral research. To understand this, it is important to investigate how the formation and evolution of GMCs is affected by the galactic structures. This is because the GMCs are the star formation spots in a galaxy; they are formed from the cold phase of the ISM, and their densest pockets are the birth place of stars.

In our first work, we performed three-dimensional hydrodynamical simulations of an M83-type galaxy; M83 is a nearby barred spiral galaxy. The simulations were run using a three dimensional adaptive mesh refinement (AMR) hydrodynamics code. We used eight levels of refinement, giving a limiting resolution of 1.5 pc. As the typical size of the GMC is 20 pc, the 1.5 pc resolution is sufficient to investigate the bulk cloud's properties.

We showed that the GMC distributions and properties are different between the three galactic regions (central bar, spiral arms, and outer-disc regions), primarily due to different cloud interaction rates. In the central bar region, massive giant molecular associations are formed due to a high cloud number density from the elliptical motion boosting interactions between clouds. The violent cloud-cloud interactions form dense tidal filamentary structures around them, which produce gravitationally unbound transient clouds in the filaments. In the outer-disc regions, clouds are more widely spaced and lack filament structures due to the absence of the grand design potential to gather gas and produce less cloud-cloud interactions. Spiral regions have intermediate features.

In our second work, we investigated a physical origin of the observed lower SFE in the bar region than that in the spiral arms (Momose et al. 2010; Hirota et al. 2014). We focussed on triggered star formation by cloud-cloud collisions. We hypothesised that the environmental dependence of star formation might be related to the different cloud interactions between galactic environments that was shown in our first work. A cloud-cloud collision is thought to be one of the triggering mechanisms of massive star formation; the compressed shocked region caused during the collision can form massive cloud cores where massive star formation would occur (Habe & Ohta 1992; Takahira et al. 2014).

We showed the variation in relative velocity of cloud collisions in different regions of the simulated galaxy performed in our first work; the collision velocity shows a clear dependence on galactic environment. Using this, we proposed a new model based on the triggered star formation model developed by Tan (2000) that varied the effectiveness of star formation from cloud collisions based on the collision speed. Clouds formed in the bar region typically collide faster than those in the spiral. Such speeds can be unproductive, as the collision is over too quickly for gas to collapse. The unproductive collisions in the bar region lower the SFE to put it below the maximum efficiency in the spiral region, as seen in observations.

In our final work, we included a stellar feedback effects into our simulations, and investigated the effects on GMCs, that was not included in our first simulations. Massive star larger than 8 $M_{\odot}$ ejects huge energy into the ISM as a supernova in the end of its life. The effect of stellar feedback on the ISM, GMCs, and star formation has been heavily debated, but a consensus has not been reached yet. We showed that the stellar feedback disperses part of the cloud gas, and the ISM density in the inter-cloud region increases. The high inter-cloud density causes angular momentum loss of clouds due to hydrodynamical drag. Massive clouds lose their angular momentum due to the torque from the hydrodynamical drag. They inflow toward the galactic centre, and then the total gas density in the central bar region rises. This gas supply would be important for evolution of the galaxy centre.

Through my doctoral research, we clarified that galactic environments and stellar feedbacks affect GMC formation and evolution, and that could explain the different star formation activities in a barred spiral galaxy. For my future work, I would like to investigate more complex stellar feedback models and different types of galaxy such as Milky-Way and starburst galaxies.