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The Impact of the Group Environment on the Molecular Gas and Star Formation Activity

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Abstract. At least half of the local galaxies reside in galaxy groups, which indicates that the group is the common environment where galaxies evolve. Therefore, it is important to probe how significantly galaxies are affected by group environmental processes, in order to obtain a better understanding of galaxy evolution. We carried out a new CO imaging survey for 31 galaxies in the IC 1459 and NGC 4636 groups, using the Atacama Compact Array, to study the effect of the group environment on the molecular gas properties and the star formation activity. With our resolved CO data, combined with high-resolution H I images, we find asymmetric CO and H I distributions in the group galaxies. Compared to isolated galaxies, group members have relatively low molecular gas fraction and low star formation rate. These results suggest that

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the group environment can change the properties of cold gas components and star formation in group galaxies.

Keywords. Molecular gas, Galaxies, Galaxy groups, Galaxy evolution

1. Introduction

Galaxy groups are common places where at least 50% of a whole population of galaxies in the local universe live and evolve. In particular, many galaxies experience external perturbations for the first time in the group environment before they join larger structures such as galaxy clusters. To begin with, tidal interactions among group galaxies are expected to commonly occur due to the low velocity dispersion of the group. In addition, the detection of X-ray in some groups indicates that a hot intragroup medium (IGrM) can also affect galaxies, mostly the interstellar medium (e.g., Cortese, Catinella, & Smith 2021). Those environmental processes can change the physical properties of group galaxies, making their color redder, and stopping their star formation. The combination of these processes can also account for many quenched galaxies at the outskirts of a cluster (known as "preprocessing", Morokuma-Matsui et al. 2021). Therefore, probing the influence of the group environment on member galaxies is a key to better understanding galaxy evolution in general. Recently, we carried out a CO imaging study of group galaxies to investigate how the group environment affects the cold molecular gas content and star formation processes. In this work, we present CO images of group members showing signs of external perturbations, together with H I images. We also compare the global properties (e.g., star formation rate (SFR), H_2 gas fraction) of group galaxies with those of isolated galaxies. The details of this work are presented in Lee et al. (2022).

2. Sample and Observations

From the Group Evolution Multiwavelength Study (GEMS)-H I survey (Kilborn et al. 2009) with the Parkes radio telescope, we selected 31 target galaxies with H I detections from the IC 1459 (I1459G) and NGC 4636 (N4636G) groups. Recent H I observations with the Australian Square Kilometre Array Pathfinder (ASKAP, Serra et al. 2015; Koribalski et al. 2020) covering these two groups provide high-resolution imaging data which we use to identify the environmental effects. Our sample includes dwarf and spiral galaxies with stellar masses ranging from $1.6 \times 10^6 - 4.9 \times 10^{10}\ M_\odot$. Using the Atacama Compact Array (ACA), we observed ^{12}CO(J=1–0) of 31 group members from October 2019 to December 2019. To detect the edge of the molecular disk, we aimed to reach a 5σ gas surface density sensitivity of 4 $M_\odot$ pc^{-2}.

3. Results

3.1. *Peculiar CO and* H I *structures*

Sixteen out of the 31 galaxies in these two groups observed were detected in CO, such that imaging data could be obtained at ∼1 kpc scale. Figure 1 displays both CO (color scale) and H I (contours) distributions of two interesting cases (IC 5264 and NGC 4632) that show signs of violent external perturbations (for other group members, see Lee et al. 2022). IC 5264 (1459G) has an asymmetric CO distribution with CO disk size of 6.5 kpc in the west and 7.5 kpc in the east. The CO disk is also more extended toward the south. The H I morphology is similar to the CO morphology, showing an extended H I tail-like structure in the east and a marginally truncated H I disk in the west. IC 5264 is thought to be experiencing both ram pressure stripping and tidal interaction. NGC 4632

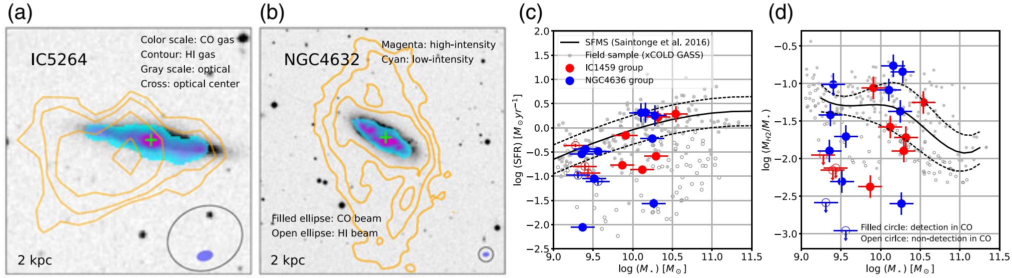

Figure 1. (a) & (b): CO (color scale) and H I (contours) distributions of two group members (left: IC 5264 (I1459G) and right: NGC 4632 (N4636G)) overlaid on the DSS2 blue images. (c) & (d): comparisons of SFR and H_2 gas fraction ($M_{H2}/M_\star$) between our group sample and the field sample. In panel (c), the star-forming main sequence (Saintonge et al. 2016) and the 0.3 dex scatter are shown in a solid line and dashed lines, respectively. In panel (d), a solid line and dashed lines indicate the median trend and the 1σ standard deviation, respectively, which are derived from the field sample. This figure is reconstructed from results presented in Lee et al. (2022).

(N4636G) has a large H I polar ring-like structure. Its CO distribution is irregular with a more extended disk in the east and a local peak. For this galaxy, tidal interaction or a minor merger may cause these complex structures of H I and CO.

3.2. *Comparisons of SFR and H_2 gas fraction between group and isolated galaxies*

We compare the SFR and H_2 gas fraction ($M_{H2}/M_\star$) of our group members with those of 240 isolated galaxies (i.e., the field sample) from the extended CO Legacy Database for GASS (xCOLD GASS; Saintonge et al. 2017). In Figure 1(c), the fraction (48%) of the star-forming galaxies in our group sample is similar to that (50%) in the field sample. However, many low-mass members (log $(M_\star/M_\odot) < 10$) in our group sample have suppressed SFRs (i.e., below the star-forming main sequence). For the H_2 gas fraction (Figure 1(d)), our group sample shows a high fraction (57%) of H_2 deficient galaxies compared to the field sample (26%). In particular, most low-mass group galaxies tend to be deficient in H_2. Interestingly, these low-mass galaxies are not deficient in H I. One possible scenario is that the conversion of H I to H_2 in the low-mass members is severely suppressed due to the environmental effects, resulting in low SFRs of the low-mass group galaxies. Further discussion of this is given in Section 5.2.1 of Lee et al. (2022).

The results in this work indicate that the group environmental effects can change not only the cold gas (CO and H I) distribution but also the global properties (e.g., SFR and H_2 gas fraction) of group members. This is particularly true for the N4636G, which is falling into the Virgo cluster. Our findings from the N4636G seem supporting evidence for the group preprocessing, but this study has been conducted with a small sample (only 31 galaxies). Follow-up studies observing various group members are required to obtain a more concrete and robust result of group environmental effects. In particular, more CO imaging observations with the ACA will be very helpful to reveal the environmental effects on the molecular gas of group galaxies.

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