

PRE-PROCESSING OF GALAXIES IN THE FILAMENTS AROUND THE VIRGO CLUSTER

HYEIN YOON¹, AEREE CHUNG^{†1}, CHANDREYEE SENGUPTA², O. IVY WONG³, MARTIN BUREAU⁴, SOO-CHANG REY⁵, AND J. H. VAN GORKOM⁶

¹Department of Astronomy, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Korea

²Korea Astronomy and Space Science Institute, 776 Daedeokdae-ro, Yuseong-gu, Daejeon 305-348, Korea

³International Centre for Radio Astronomy Research, M468, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia

⁴Sub-Department of Astrophysics, Department of Physics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK

⁵Department of Astronomy and Space Science, Chungnam National University, Daejeon 305-764, Korea

⁶Department of Astronomy, Columbia University, New York, NY 10027, USA

E-mail: hiyoon@galaxy.yonsei.ac.kr, achung@yonsei.ac.kr

(Received November 30, 2014; Revised May 31, 2015; Accepted June 30, 2015)

ABSTRACT

Galaxies can be “pre-processed” in the low-density outskirts by ambient medium in the filaments or tidal interactions with other galaxies while falling into the cluster. In order to probe how early on and by which mechanisms galaxies can be affected before they enter high-density cluster environments, we are carrying out an atomic hydrogen (H I) imaging study of a sample of galaxies selected from three filamentary structures around the Virgo cluster. Our sample consists of 14 late-type galaxies, which are potentially interacting with their surroundings. The H I observations have been done using the Westerbork Synthesis Radio Telescope, the Giant Metrewave Radio Telescope, and the Jansky Very Large Array with column density sensitivity of $\approx 3\text{--}5 \times 10^{19} \text{ cm}^{-2}$ in 3σ per channel, which is low enough to detect faint H I features in the outer disks of galaxies. In this work, we present the H I data of two galaxies that were observed with GMRT. We examine the H I morphology and kinematics to find the evidence for gas-gas and/or tidal interactions, and discuss which mechanism(s) could be responsible for pre-processing in these cases.

Key words: galaxies: evolution — galaxies: individual (IC 3908, MCG-01-33-059) — galaxies: interactions — galaxies: kinematics and dynamics

1. INTRODUCTION

Galaxies in the periphery of clusters may fall into the high-density regions as a group or along filamentary structures. The infalling galaxies may already be affected by their surroundings before they reach the core of the cluster (“pre-processing”; Fujita, 2004). As the build-up of evidence increases with recent studies (e.g. Cortese et al., 2006; Mahajan, 2013), pre-processing of galaxies has become an important subject to be probed to understand galaxy evolution in the frame of the hierarchical structure formation of the Universe.

Filaments around galaxy clusters are ideal places to find candidates which are undergoing pre-processing. Tidal interactions between galaxies are expected to be common outside clusters. In addition, a significant number of H I-poor galaxies are found well outside clusters (Solanes et al., 2001; Rines et al., 2001), indicating that gas stripping can still take place far out from the cluster

center as suggested by Tonnesen et al. (2007). In addition, galaxies moving along the filament can accrete gas from ambient medium (Sancisi et al., 2008).

In order to probe how and by which mechanisms galaxies are pre-processed before they arrive in the cluster, we were carrying out an H I imaging study of galaxies which are carefully selected in filaments around the Virgo cluster. We search for evidence that galaxies are tidally disturbed, gas-stripped and/or accreting gas by/from the filament.

2. SAMPLE AND H I OBSERVATIONS

A number of filamentary structures are present around the Virgo cluster (Tully, 1982). Among those, we have selected 14 galaxies from two most well-defined filaments in the north of Virgo and one infalling group in the south (Tully, 1982; Karachentsev & Nasonova, 2013). Aiming to sample the galaxies that are potentially undergoing gas accretion or ram pressure stripping, we have chosen galaxies which are either extremely H I-rich (by $3.4 \sim 6.9$ times richer) or extremely H I-poor (poorer a factor of

[†]Corresponding author: A. Chung

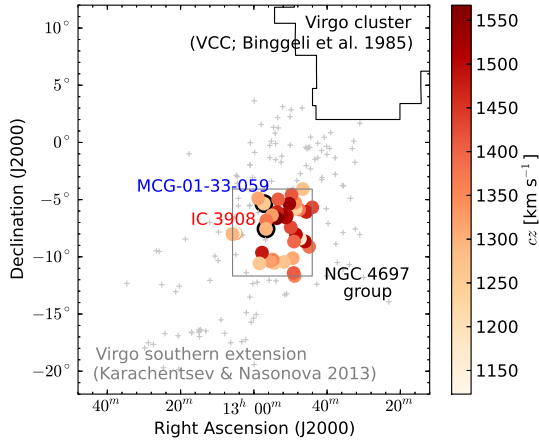


Figure 1. An infalling group in the south-east of Virgo. Karachentsev & Nasonova (2013) identify members of the group based on the position and the radial velocity. MCG-01-33-059 is HI-rich and IC 3908 is HI-poor for its size and environment.

1.2 \sim 1.7) compared to other late-type galaxies with similar size based on single-dish data from LEDA (Paturel et al., 2003), HIPASS (Meyer et al., 2004) and ALFALFA (Haynes et al., 2011).

The observations were done using the Westerbork Synthesis Radio Telescope 72 m configuration (WSRT, 96 hours for the NW filament), the Giant Metrewave Radio Telescope (GMRT, 20 hours for the SE group) and the Jansky Very Large Array D configuration (JVLA, 7.5 hours for the NE filament). To detect diffuse HI gas in the outer disks of galaxies, we aimed to reach a 3σ column density sensitivity of $\sim 10^{19} \text{ cm}^{-2}$.

3. RESULTS

We present preliminary results of two galaxies, MCG-01-33-059 and IC 3908, selected from the infalling galaxy group in the south-east of Virgo (Fig. 1). They have HI masses and optical colors suggestive of gas interactions with the surrounding IGM. The HI distributions of the galaxies are presented in Figure 2.

MCG-01-33-059 shows a very extended HI disk, ~ 4 times larger than its stellar disk. It contains 65% more HI gas compared to other field galaxies with a similar size. The HI peak shows an offset from the optical center to the west by $\sim 35''$ and the HI distribution becomes quite asymmetric in the outer part. The GMRT HI images and velocity field suggest gas accretion. Based on the fact that there are no obvious companions within 200 kpc radius and $\Delta v = 500 \text{ km s}^{-1}$, the filament is likely to be the source of the accreted gas (Kereš et al., 2005; Sancisi et al., 2008). The gas accretion might be responsible for star-forming knots that are optically identified throughout the disk.

IC 3908 shows a very sharp HI cutoff in the outer disk with a short one-sided gas tail in the south. Although the total HI mass is quite comparable to what is expected in field late-type galaxies with similar size

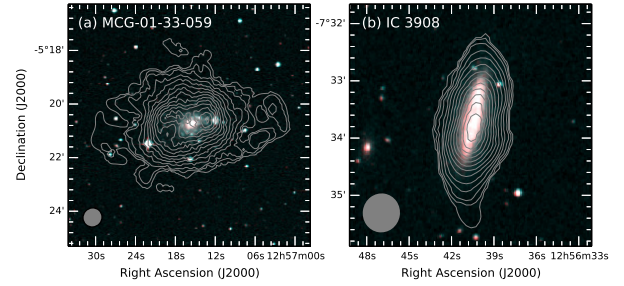


Figure 2. HI distributions overlaid on the optical DSS images of (a) MCG-01-33-059 and (b) IC 3908. The contour levels are (a) (3.4, 6.8, 10.2, 17.0, 23.8, 30.6, 37.4, 44.2, ...) $\times 10^{19} \text{ atoms cm}^{-2}$ and (b) (3.5, 7.0, 14.0, 28.0, 42.0, 63.0, 84.0, 105.0, ...) $\times 10^{19} \text{ atoms cm}^{-2}$.

and its HI disk is not (yet) truncated within the stellar disk, its HI properties are suggestive of HI stripping in the outer part, which might be related to its red optical color. This might be a good example of a galaxy being ram pressure stripped in the low-density outskirts of the cluster before falling into the cluster center as suggested by Rines et al. (2001) or Tonnesen et al. (2007).

ACKNOWLEDGMENTS

This work has been supported by the Center for Galaxy Evolution Research (the SRC program of the National Research Foundation of Korea) and Science Fellowship of POSCO TJ Park Foundation. We thank the staff of the GMRT that made these observations possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.

REFERENCES

- Binggeli, B., Sandage, A., & Tammann, G. A., 1985, Studies of the Virgo Cluster. II - A Catalog of 2096 Galaxies in the Virgo Cluster Area, *AJ*, 90, 1681
- Cortese, L., Gavazzi, G., & Boselli, A., et al., 2006, Witnessing Galaxy Preprocessing in the Local Universe: the Case of a Star-bursting Group Falling into Abell 1367, *A&A*, 453, 847
- Fujita, Y., 2004, Pre-processing of Galaxies before Entering a Cluster, *PASJ*, 56, 29
- Haynes, M. P., Giovanelli, R., & Martin, A. M., et al., 2011, The Arecibo Legacy Fast ALFA Survey: The $\alpha 40$ HI Source Catalog, Its Characteristics and Their Impact on the Derivation of the HI Mass Function, *AJ*, 142, 170
- Karachentsev, I. D. & Nasonova, O. G., 2013, Intense Look at Virgo Southern Extension, *MNRAS*, 429, 2677
- Kereš, D., Katz, N., Weinberg, D. H., & Davé, R., 2005, How Do Galaxies Get Their Gas?, *MNRAS*, 363, 2
- Mahajan, S., 2013, Evidence for Galaxies being Pre-processed before Accreted into Clusters, *MNRAS*, 431, L117
- Meyer, M. J., Zwaan, M. A., & Webster, R. L., et al., 2004, The HIPASS Catalogue - I. Data Presentation, *MNRAS*, 350, 1195
- Paturel, G., Theureau, G., & Bottinelli, L., et al., 2003, HYPERLEDA. II. The Homogenized HI Data, *A&A*, 412, 57

- Rines, K., Mahdavi, A., & Geller, M. J., et al., 2001, X-Ray-emitting Groups in the Infall Region of Abell 2199, *ApJ*, 555, 558
- Sancisi, R., Fraternali, F., Oosterloo, T., & van der Hulst, T., 2008, Cold Gas Accretion in Galaxies, *A&ARv*, 15, 189
- Solanes, J. M., Manrique, A., & García-Gómez, C., et al., 2001, The H I Content of Spirals. II. Gas Deficiency in Cluster Galaxies, *ApJ*, 548, 97
- Tonnesen, S., Bryan, G. L., & van Gorkom, J. H., 2007, Environmentally Driven Evolution of Simulated Cluster Galaxies, *ApJ*, 671, 1434
- Tully, R. B., 1982, The Local Supercluster, *ApJ*, 257, 389