ENVIRONMENTAL EFFECTS ON GASEOUS DISKS OF VIRGO SPIRAL GALAXIES

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ABSTRACT

We present the results of ^{12}CO($J = 1 - 0$) observations of five Virgo spiral galaxies obtained with the Nobeyama 45-m telescope equipped with a multi-beam receiver, BEARS. We combined the CO data with H I data to address environmental effect on gaseous disks. We investigated a relationship between the molecular fraction ($f_{\rm mol}$) and the total gaseous density (H I plus H_2 density, $\Sigma_{\rm HI+H_2}$). We found that three of our samples display unusually larger $f_{\rm mol}$ than that expected for the field galaxies, while the rest two galaxies show the normal $f_{\rm mol}$. It implies that the ram-pressure stripping occurs at the inner disks to result in unusually large $f_{\rm mol}$ as one possibility.

Key words: galaxies: clusters: individual (Virgo), galaxies: ISM, ISM: molecules, radio lines: ISM.

1. INTRODUCTION

The 21-cm line observations showed that the HI gas is deficient for galaxies near the center of the Virgo cluster (e.g., Cayatte et al. 1990). This is interpreted to be a result of the ram-pressure stripping. However, even such HI deficient galaxies still contain a little amount of HI gas in their inner regions as well as a wealth of molecular gas. Hence, it is not clear if the ram-pressure stripping has occurred even in the central regions, or it affected only the outer HI disks.

We mapped spiral galaxies in the Virgo cluster in the CO($J = 1 - 0$) line using the 45-m telescope of the Nobeyama Radio Observatory (NRO) equipped with a multi-beam array receiver, which is called BEARS (25-BEam Array Receiver System). By comparing the CO and HI data, we investigated stripping of HI gas has occurred even in the inner disks of the galaxies.

2. OBSERVATIONS AND DATA

The CO observations of the Virgo cluster spirals were made from December 2002 to April 2004 with the Nobeyama 45-m radio telescope. Spatial and velocity resolutions were 15″ and 1.3 km s^{-1}, respectively.

We mapped five Virgo galaxies with a grid spacing of 10.″3. The number of total observed points for each galaxy was 576 or 1056, and the mapped area was 4.′12 × 4.′12 or 4.′12 × 7.′55.

To compare with the distribution of CO, we used the HI data of the target galaxies mapped with the Very Large Array (VLA). The HI data were adopted from Phookun, Vogel, & Mundy (1993) for NGC 4254, from Cayatte et al. (1990) for NGC 4402, NGC 4569, and NGC 4579, and from Phookun & Mundy (1995) for NGC 4654.

Figure 1 shows the distribution of the CO integrated intensity, $I_{\rm CO} \equiv \int T_{\rm MB} dv$ [K km s^{-1}], (gray) and the HI intensity (contours) of the five galaxies. The CO emissions distribute in the inner disks, and the extensions are typically up to the radii of $\sim$ 1.′5 (7 kpc).

3. UNUSUALLY LARGE MOLECULAR FRACTION OF THE GASEOUS DISKS

3.1. Molecular Fraction as a Function of the Surface Density of the Total Gas

The fraction of the molecular gas to the total gas (HI gas plus H_2 gas), $f_{\rm mol}$, is determined by the

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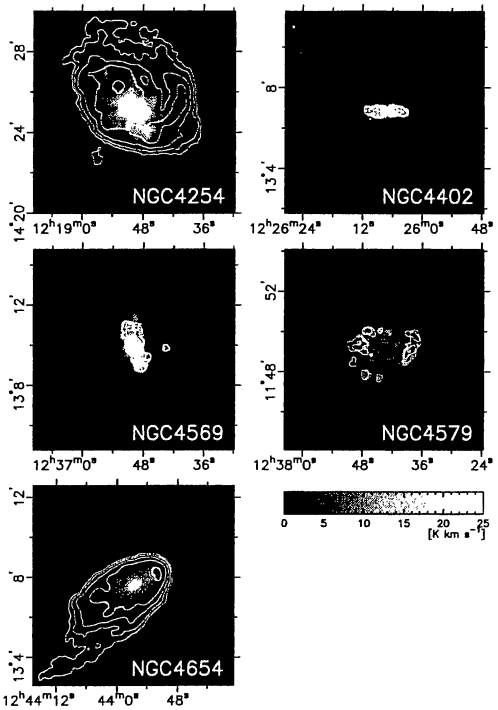

Figure 1. The integrated CO intensity maps (gray) and the integrated HI intensity maps (contour). The contour levels are 100, 200, 400, 800, 1600 K km s^{-1}.

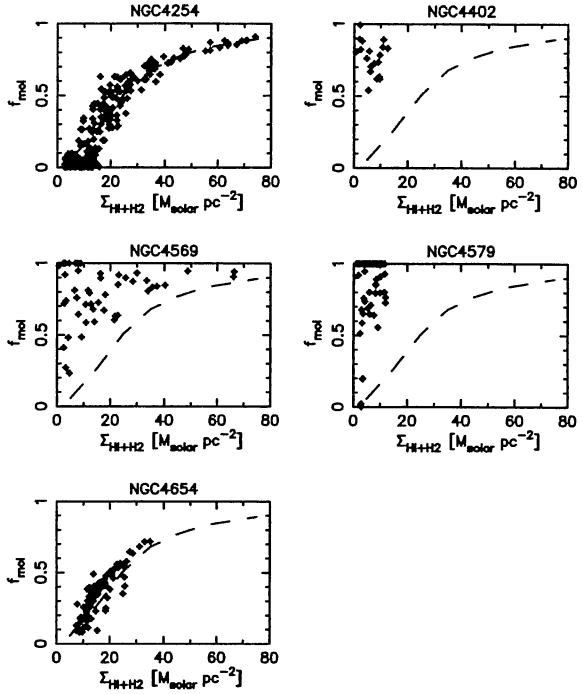

Figure 2. The molecular fraction $f_{\rm mol}$ against the surface density of the total gas $\Sigma_{\rm HI+H_2}$. Dashed lines indicate averaged $f_{\rm mol}$ of NGC4254 and NGC4654. The data of $\Sigma_{\rm HI} > 3.8 \times 10^{20}$ H cm^{-2} or $\Sigma_{\rm H_2} > 7.0 \times 10^{19}$ H_2 cm^{-2} (3σ) are plotted.

ISM pressure P, metallicity Z, and UV radiation U (Elmegreen, 1993). Here, the molecular fraction $f_{\rm mol}$ is defined as $f_{\rm mol} \equiv \Sigma_{\rm H_2}/(\Sigma_{\rm HI} + \Sigma_{\rm H_2})$ with $\Sigma_{\rm HI}$ and $\Sigma_{\rm H_2}$ being the surface mass densities of HI and H_2, respectively.

Figure 2 shows $f_{\rm mol}$ against $\Sigma_{\rm HI+H_2}$ for each observed point of the five galaxies, where the CO-to-H_2 conversion factor was adopted to be $X_{\rm CO} = 1.0\times10^{20}$ H_2 $\rm cm^{-2}$ $\rm K^{-2}$ $\rm km^{-1}$ (Nakai & Kuno, 1995). The molecular fractions $f_{\rm mol}$ in NGC 4254 and NGC 4654 are similar to that of a field galaxy (e.g., Kuno et al. 1995; Sorai et al. 2000). On the contrary, the other three galaxies, NGC 4402, NGC 4569, and NGC 4579 present larger molecular fractions than the model curve. NGC 4402 shows extraordinarily large $f_{\rm mol}$ in spite of the small surface density of the gas.

3.2. Origin of the Unusual Molecular Fraction in the Virgo Spirals

We can consider the ram-pressure stripping as one possibility of making the unusually large $f_{\rm mol}$. When the ram-pressure acts on a gaseous disk, the HI gas would be selectively stripped from a galaxy and the molecular gas may remain in the galaxy. In this case, the molecular fraction $f_{\rm mol}$ in the $\Sigma_{\rm HI+H_2}$–$f_{\rm mol}$ diagram moves toward the upper-left side of the $\Sigma_{\rm HI+H_2}$–$f_{\rm mol}$ curve of the field galaxies.

As another possibility, differences of the condition (metallicity or UV radiation) of the inner disks may make unusually large $f_{\rm mol}$. Since NGC 4254 and NGC 4654 are later type than the others, the conditions of the two galaxies may largely differ from the others. The large $f_{\rm mol}$ may indicate that the metallicity is large or the UV radiation is small in the three galaxies.

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