

# New HI Observations Toward the NGC 5055 Galaxy Group with FAST

Xiao-Lan Liu<sup>1,2,3</sup>, Ming Zhu<sup>1,2,3</sup>, Jin-Long Xu<sup>1,2,3</sup>, Peng Jiang<sup>1,2,3</sup>, Chuan-Peng Zhang<sup>1,2,3</sup>, Nai-Ping Yu<sup>1,2,3</sup>, Jun-Jie Wang<sup>1,2,3</sup>, and

Yan-Bin Yang<sup>4</sup>

<sup>1</sup>National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China; liuxiaolan@bao.ac.cn

Guizhou Radio Astronomical Observatory, Guizhou University, Guiyang 550000, China

<sup>3</sup> CAS Key Laboratory of FAST, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China

GEPI, Observatoire de Paris, Universite PSL, CNRS, Place Jules Janssen, 92195 Meudon, France Received 2024 February 27; revised 2024 May 8; accepted 2024 May 22; published 2024 July 8

# Abstract

We report a new high-sensitivity HI mapping observation of the NGC 5055 galaxy group over an area of  $1^{\circ}.5 \times 0^{\circ}.75$  with the Five-hundred-meter Aperture Spherical radio Telescope (FAST). Our observation reveals that the warped HI disk of NGC 5055 is more extended than what was previously observed by WSRT, out to 23/9 (61.7 kpc). The total HI mass of NGC 5055 is determined to be  $\sim 1.1 \times 10^{10} M_{\odot}$ . We identified three HI clouds with H I masses of the order of  $\sim 10^7 M_{\odot}$  at the southeastern edge of the H I disk, as well as a candidate high-velocity cloud with an H I mass of  $(1.2 \pm 0.5) \times 10^6 M_{\odot}$  to the north of NGC 5055. The H I content of UGCA 337 is robustly detected for the first time by the FAST observations. It has a narrow HI linewidth of  $W_{50} = 17.4 \pm 3.8$  km s<sup>-1</sup> with a total H I mass of  $(3.5 \pm 0.3) \times 10^6 M_{\odot}$ . Comparing the gas content and g-r color of UGCA 337 with typical low-mass dwarf galaxies, UGCA 337 appears relatively gas-poor despite its blue color. This suggests that UGCA 337 may have undergone gas stripping in the past. We also analyzed the possible origin of the diffuse HI clouds located at the outskirts of NGC 5055, and speculate that they might be the remnant features of a merger event in the past.

Key words: galaxies: evolution - galaxies: structure - galaxies: individual (NGC 5055) - galaxies: kinematics and dynamics – galaxies: interactions

# 1. Introduction

Understanding how massive galaxies, such as our Milky Way, accumulate mass to support their almost constant star formation rates over billions of years is crucial to understanding how galaxies evolve. According to the  $\Lambda$ -Cold Dark Matter paradigm of cosmology, galaxies are expected to form in a hierarchical manner. Gas and dark matter accumulate in dark matter halos, merging and condensing into larger structures, which leads to the formation of stars and the growth of the galaxy. High-sensitivity observations of massive disk galaxies have the potential to provide new insights into the history of their formation and evolution.

NGC 5055, also known as the Sunflower Galaxy M63, is a Milky Way-type SAb(c) galaxy with an optical disk size of about 5.'5 ( $R_{25}$ ) (de Vaucouleurs et al. 1976). The spiral galaxy NGC 5055 is located at a distance of 8.87 Mpc (McQuinn et al. 2017) and is accompanied by approximately 20 dwarf galaxies, as identified by the deep optical observations (e.g., Karachentsev et al. 2020). This group is a relatively isolated galaxy group, with no large galaxies in the surrounding  $3^{\circ} \times 3^{\circ}$  region (Müller et al. 2017; Karachentsev et al. 2020). Within the group, only a few dwarfs were identified with radial velocities in the range of  $\pm 300$  km s<sup>-1</sup> with respect to that of NGC 5055, among which UGC 8313 and UGCA 337 were determined as

the real satellites of NGC 5055 through the measurement of their distances (Carlsten et al. 2022). However, most of the other faint dwarfs in the group lack velocity or distance information (Karachentsev et al. 2020; Carlsten et al. 2022), making it difficult to determine their roles in the evolution of NGC 5055.

NGC 5055 has been extensively studied using highresolution HI line observations at 21 cm carried out by the Westerbork Synthesis Radio Telescope (WSRT) (Battaglia et al. 2006; Kamphuis et al. 2022). These observations revealed a significantly more extended HI disk with pronounced kinematic warps beyond the inner optical disk. Deep optical observations have found very faint stellar loops across NGC 5055, some of which had no HI associations detected (Chonis et al. 2011; Karachentsev et al. 2020). Kamphuis et al. (2022) reported three HI sources on the outskirts of NGC 5055 through analyzing the deep WSRT Hydrogen Accretion in LOcal GAlaxieS (HALOGAS) Survey<sup>5</sup> (Heald et al. 2011), including a possible cloud candidate located to the northeast of NGC 5055 and two HI counterparts of the nearby dwarf galaxies UGC 8313 and UGC 8365.

<sup>&</sup>lt;sup>5</sup> https://www.astron.nl/halogas/data.php

Interferometer arrays have the advantage of resolving small structures of galaxies in principle, but can suffer from the socalled "negative bowl" artifacts indicating the loss of shortspacing information (Wang et al. 2023). In contrast, single-dish radio telescopes can compensate for this deficiency. In recent years, radio telescopes with large collecting areas, such as the Five-hundred-meter Aperture Spherical radio Telescope (FAST), have detected faint gas in or around several large spiral galaxies (e.g., Zhu et al. 2021; Xu et al. 2021; Wang et al. 2023; Yu et al. 2023). These findings have cast new light on the formation and evolution of galaxies. In this paper, new HI observations have been carried out toward the NGC 5055 galaxy group using FAST. We describes the observation and data reduction in Section 2. The results and the kinematic analysis of NGC 5055 are presented in Section 3. Section 4 discusses the possible origin of the observed HI around NGC 5055, while Section 5 provides a summary of the main results

## 2. Observation and Data Reduction

in this paper.

We carried out a high-sensitivity H I observation of NGC 5055 and its surroundings over an area of  $1.^{\circ}5 \times 0.^{\circ}75$  in 2022 July, as part of the FAST All Sky H I survey (FASHI, Zhang et al. 2024). We adopted the multi-beam on-the-fly (MultiBeamOTF) observation mode with the 19-beam array receiver which provides a halfpower beamwidth (HPBW) of 2.'9 at 1.4 GHz per beam (Nan et al. 2011; Jiang et al. 2019, 2020). The on-sky scanning speed was set to 15'' per second with an integration time of 1 s. Spectra were observed in the dual polarization mode of the front end, and digitized by the backend Spec(W) in 65 536 channels over a bandwidth of 500 MHz. The latter provides a frequency resolution of 7.629 kHz at 1.4 GHz, corresponding to a velocity resolution of  $1.611 \,\mathrm{km \, s^{-1}}$ . During the observation, the mean system temperature was 20 K. The pointing accuracy of FAST is better than 8". We observed NGC 5055 twice with a total observation time 1.28 hr. For calibration, a standard noise signal,  $T_{cal}$  (typically 10 K), was regularly injected into the signal path every 32 s with a duration of 1 s. The raw data were reduced using the Pythonbased pipeline HIFAST (Jing et al. 2024). The reduced data cube has a pixel scale of  $1' \times 1'$  and a channel resolution of  $1.611 \text{ km s}^{-1}$  for a spectrum. The final data cube has a mean noise of about  $1.04 \text{ mJy beam}^{-1}$  per channel, corresponding to a  $3\sigma$  HI column density of  $5.2 \times 10^{17}$  cm<sup>-2</sup> in a linewidth of  $20 \text{ km s}^{-1}$  (Wang et al. 2023).

In addition, we utilized SOFIA (Serra et al. 2015) to create a detection mask for the H I emission in the final data cube, which was applied during the analysis of the H I moment maps. The smooth+clip source-finding algorithm was implemented by applying a  $5\sigma$  threshold and smoothing kernels of 0, 3, and 5 pixels in both space and velocity dimensions. The final detection mask was generated by ensuring a detection reliability of 0.99.

### 3. Results

# 3.1. HI Map of the NGC 5055 Galaxy Group

Figure 1(a) presents H I column density map in contours of the NGC 5055 galaxy group, which is overlaid on the SDSS *g*-band optical image. The column density is derived from its moment-0 map integrated over the velocity range of 276.0–718.8 km s<sup>-1</sup>. There are three dwarf galaxies located adjacent to NGC 5055. UGC 8313 and UGCA 337 had been recognized as the satellites of NGC 5055 (Carlsten et al. 2022) at projected distances of ~61.7 kpc to the northwest of NGC 5055 and ~90 kpc to the southwest respectively. UGC 8365 is located on the east of NGC 5055, and has a system velocity of 1260 km s<sup>-1</sup> (van Driel et al. 2016; Kamphuis et al. 2022). We estimated the distance of UGC 8365 to be  $20.8 \pm 2.1$  Mpc using the Cosmicflows-3 method (Kourkchi et al. 2020), which is not associated with that of NGC 5055. Thus, we suggest that UGC 8365 is a background galaxy of NGC 5055.

Figure 1(b) shows an H I column density overlay map of NGC 5055, obtained from the FAST observation data and the HALOGAS survey data. Compared to the HALOGAS survey data, we found that the FAST observations reveal more extended H I structures around NGC 5055. It makes the observed H I disk of NGC 5055 out to 23'.9 (i.e., 61.7 kpc), which is corrected for resolution utilizing the expression of  $r_{\rm eff} = \sqrt{R_{\rm HI}^2 - R_{\rm B}^2}$ , where R<sub>HI</sub> is the length of the semimajor axis measured from the H I column density map in the H I disk over  $3\sigma$  and R<sub>B</sub> is half of the HPBW of FAST. This H I disk measured by FAST is ~25% larger than that of the full WSRT data observed by Battaglia et al. (2006).

Figure 2 compares the total HI flux of NGC 5055 from FAST observation (black line) and the primary beam(pb)corrected HALOGAS survey (blue line). We find the pbcorrected HALOGAS survey revealed much less HI flux, by 22.4%  $\pm$  0.6%, compared to that observed by FAST (see Table 1). Taking into account the ~10% systematic difference between the two telescopes and the ~10% flux calibration uncertainty (Wang et al. 2023), our observed HI flux for NGC 5055 is still in excess of the HALOGAS survey. This is because the HALOGAS survey was performed with the interferometer array WSRT, which could suffer from the zero-spacing problem and miss some fluxes from the extended gas component. This effect has been studied in detail in the case of NGC 4631 (Wang et al. 2023).

#### 3.2. HI Kinematics of NGC 5055

In Figure 3, we explore the position–velocity (PV) slices along five directions, i.e., the cyan dashed arrows from a to e (the same names apply for the panels). The slice thickness is taken as 3 spaxels, i.e., 3<sup>(1)</sup>, corresponding to the beamsize. In each PV, the position axis is chosen to be centered on the center of NGC 5055, and increasing along the arrow direction.



**Figure 1.** H I column density contours in the velocity range of 276.0–718.8 km s<sup>-1</sup> superimposed on the SDSS *g*-band optical image of the NGC 5055 galaxy group (a) and the HALOGAS survey data (b). The contours are 0.1 (3 $\sigma$ ), 0.3, 0.6, 1.0, 3.3, 6.8, 12.8, 20.6, 31.4, 41.2, 55.5, 82.4, 123.4, 156.0 × 10<sup>19</sup> cm<sup>-2</sup> respectively. The plus symbols indicate the optical centers of galaxies NGC 5055, UGC 8313, UGCA 337 and UGC 8365, as labeled respectively. The beamsizes of FAST and WSRT are shown in the bottom-left corner of panel (b).



**Figure 2.** Comparison of the integrated H I profile over NGC 5055 from the FAST map (black line) and the pb-corrected HALOGAS map (blue line). The red lines represent the fittings from the busy function code (Westmeier et al. 2014).

These slices were selected to investigate the kinematic behaviors of dwarf galaxies and some possible substructures ( i.e., c1, 2, 3, and H1) in the HI map around the main (inside an elliptical radius of 0°.3) H I disk of NGC 5055. Panel (a) shows a slice of PV passing a possible substructure of c1, which seems to be a detached substructure with a noticeable smaller velocity compared to that of the main H I disk emissions. In the positive part of the PV, c1 shows some broad connections in space to the main HI disk over a wider velocity range. One may also notice the counterpart (i.e., at the same symmetric distance) of c1 in the negative part of the PV, which appears not detached from the main H I disk, but with strong lagging in velocity (over about  $50 \text{ km s}^{-1}$ ). Although these spatial and kinematic features of these lagging HI emissions and c1 could result from the beam smearing effect at high inclination, it is important to note that the ridge line of the disk flux in panel (a) points to c1, indicating that they are likely to be tidal gas

Source	$\log(M_{\rm HI})$ $(M_{\odot})$	$\frac{S_{\rm H I}}{(\rm mJy \ km \ s^{-1})}$	S <sub>peak</sub> (mJy)	$\frac{v_{\rm sys}}{(\rm km~s^{-1})}$	$     W_{50}     (km s^{-1}) $	$W_{20}$ (km s <sup>-1</sup> )	Velocity Range (km s <sup>-1</sup> )
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			FAST				
NGC 5055	10.03(0.01)	$574.8(17.3) \times 10^3$	2390.0(131.2)	492.8(0.4)	346.7(0.5)	383.5(0.5)	276.0-718.8
UGCA 337	6.55(0.04)	194.7(17.5)	10.8(1.7)	550.0(1.0)	17.4(3.8)	25.3(5.6)	533.7-557.8
c1	7.43(0.01)	1449.0(43.2)	35.3(1.8)	564.5(0.8)	39.3(1.9)	58.2(2.5)	536.9-601.3
c2	7.36(0.01)	1239.0(36.2)	33.0(1.3)	621.6(0.6)	37.0(1.4)	51.1(1.9)	583.6-651.2
c3	7.09(0.02)	661.6(35.0)	27.2(2.5)	616.5(0.9)	23.6(2.9)	34.0(4.4)	590.0-657.7
H1	6.09(0.17)	66.0(25.5)	2.9(1.1)	322.8(3.7)	21.5(11.3)	33.0(17.0)	316.3-329.2
			HALOGAS (after b)	p correction)			
NGC 5055	9.94(0.02)	$469.6(19.8)  imes 10^3$	1727.0(134.1)	497.9(0.6)	354.2(2.7)	389.1(1.9)	276.0-718.8

 Table 1

 The Observed Parameters for H I Sources in the NGC 5055 Galaxy Group

around NGC 5055. In panel (b), UGC 8313 is seen at a counter-rotating velocity with respect to the disk of NGC 5055, and well detached. The possible substructure c2 seems more connected to the main H I disk, and its counterpart appears well as a continuity of the main H I disk. Panel (c) demonstrates that the possible substructure c3 has similar properties as c2. Panel (d) depicts the clear detection of H I gas associated with the low surface brightness (LSB) galaxy UGCA 337. In the panel (e), we see that the substructure H1 appears not only as an extra structure from the main H I disk, but also separated in velocity by  $\approx -170 \text{ km s}^{-1}$  with respect to the systemic velocity of NGC 5055. This suggests that it is either a satellite or a high velocity cloud (HVC) of NGC 5055 (Westmeier et al. 2008; Hess et al. 2009; Chynoweth et al. 2011b).

Figure 4 presents the velocity field of NGC 5055 by excluding UGC 8313, as it is superimposed in position with the disk but at a different velocity. Similar to the PV slices in Figure 3, the main HI disk of NGC 5055 presents a regular warped velocity field. At the outskirts of NGC 5055, c1, 2, and 3 exhibit velocity continuity with the main HI disk of NGC 5055 on the whole, however, there appears to be a slightly perturbed velocity field at the junctions between them. In addition, a velocity gradient is presented between the isolated H1 and the northern edge of the HI disk of NGC 5055, possibly due to the projection effect.

# 3.3. Integrated HI of HI Clouds

Using the associated velocity ranges from the PV diagrams (see Table 1), we created HI column density maps and integrated fluxes of the HI substructures c1, 2, 3, and H1, which are presented in Figure 5. The HI column density maps over  $3\sigma$  were superimposed on the SDSS *g*-band optical images to identify the optical counterparts. In Figure 5, each of the four HI substructures exhibits a coherent structure with a Gaussian component, and appears to lack any visible optical counterparts. Therefore, we can conclude that the HI substructures c1,

2, 3 and H1 are probably coherent gas clouds (Chynoweth et al. 2011a) located on the outskirts of the extended gaseous disk of NGC 5055. We compute their total HI mass through the following equation:

$$M_{\rm H\,I} = 2.355 \times 10^5 D^2 \int S_{\nu} d\nu, \tag{1}$$

where *D* is the distance in Mpc and  $\int S_{\nu} d\nu$  is the integrated H I flux in Jy km s<sup>-1</sup>. Assuming the same distance as the host galaxy NGC 5055, clouds c1, 2, 3 and H1 are determined to have a total H I mass of  $(2.7 \pm 0.06) \times 10^7 M_{\odot}$ ,  $(2.3 \pm 0.05) \times 10^7 M_{\odot}$ ,  $(1.2 \pm 0.06) \times 10^7 M_{\odot}$ , and  $(1.2 \pm 0.5) \times 10^6 M_{\odot}$  respectively, as shown in column (2) of Table 1. Their total H I mass contributes to less than one percent of that of NGC 5055, which is about  $1.1 \times 10^{10} M_{\odot}$  as derived from the integrated H I flux presented in Table 1.

# 3.4. Integrated HI of the LSB Dwarf Galaxy UGCA 337

Figure 6 shows the H I column density contours overlaid on the SDSS g-band optical image and integrated HI spectrum (including the fitting from the busy function code) for UGCA 337. From the fitting results obtained from the busy function code of the integrated H I spectrum in Table 1, FAST detected a narrow single-Gaussian HI component with a system velocity of  $550.0 \pm 1.0$  km s<sup>-1</sup> and a linewidth of  $W_{50} \sim 17.4 \pm 3.8$  km s<sup>-1</sup>. It is in agreement with the optically heliocentric radial velocity of  $529 \pm 40$  km s<sup>-1</sup> (Alam et al. 2015) and therefore can be identified as the counterpart of UGCA 337. This HI component is missing from the HALOGAS survey. However, in the previous studies of UGCA 337, Huchtmeier et al. (2009) reported a double-horn H I counterpart with a system velocity of  $460.0 \pm 5.0 \text{ km s}^{-1}$  and a linewidth of  $W_{50} = 234 \text{ km s}^{-1}$ , observed by the 100 m radio telescope Effelsberg with a spatial resolution of 9'. Given the facts that UGCA 337 is comparable to the beamsize of FAST but much smaller than that of Effelsberg and the HI component detected by FAST exhibits a higher



**Figure 3.** Five PV plots along different directions. The top-left frame shows H I column density maps (black contours+color map) of the NGC 5055 galaxy group. The H I contour levels and symbols are the same as those in Figure 1. The five cyan dashed arrows indicate the orientation along which the PV diagrams are made in panels (a), (b), (c), (d), and (e), respectively. The dashed red ellipses and circles in each panel represent the possible H I substructures c1, 2, 3, and H1, as well as the possible H I component of UGCA 337. The blue contours in panels (a)–(e) are  $3\sigma$ ,  $5\sigma$ ,  $10\sigma$ ,  $15\sigma$ ,  $35\sigma$ ,  $55\sigma$ ,  $75\sigma$ ,  $95\sigma$ ,  $115\sigma$ ,  $175\sigma$ ,  $235\sigma$ ,  $295\sigma$ ,  $355\sigma$ ,  $415\sigma$ ,  $475\sigma$ ,  $535\sigma$ ,  $595\sigma$ ,  $655\sigma$ ,  $715\sigma$ , respectively. The mean  $1\sigma$  value is equal to 0.78 mJy beam<sup>-1</sup> for the slices taken within the 3' width centered on the paths a-e.

signal-to-noise ratio, we believe that the H I results of UGCA 337 from the FAST observation are more reliable, which means we procured a clear H I detection of this galaxy for the first time. As for the H I detection performed by Huchtmeier et al. (2009), it might have been affected by the H I emission from NGC 5055

that has leaked in through an Effelsberg sidelobe (Reich et al. 1978), and thus give the impression of a double-horned profile.

Cold gas  $(M_{\rm gas}/M_{\star} > 1)$  typically dominates the baryon content in low-mass dwarfs (Lelli 2022). We have determined the total H I mass of UGCA 337 to be  $(3.5 \pm 0.3) \times 10^6 M_{\odot}$ 



**Figure 4.** H I intensity-weighted velocity field (i.e., the first moment map) of NGC 5055. UGC 8313 has been excluded in this calculation. Velocity contours start from 297.8 to 672.8 km s<sup>-1</sup> in steps of 15 km s<sup>-1</sup>. The red solid line signifies the system velocity of NGC 5055. Dashed ellipses/circles and pluses represent the same features as those in Figure 3. The beamsize of FAST is displayed in the bottom-left corner.



**Figure 5.** Top: H I column density contours superimposed on the SDSS *g*-band optical image for clouds c1, 2, 3, along with the candidate HVC H1. Black contour levels for cloud c1 are 1.2 ( $3\sigma$ ), 2.0, 4.5, 7.1, 9.7, 12.3, 14.8, 17.4, 20.0 × 10<sup>18</sup> cm<sup>-2</sup>, for cloud c2 are 1.2 ( $3\sigma$ ), 2.0, 4.6, 7.1, 9.7, 12.3 × 10<sup>18</sup> cm<sup>-2</sup>, for cloud c3 are 2.0 ( $3\sigma$ ), 5.0, 8.0, 10.9, 13.9, 16.9, 19.9, 22.0 × 10<sup>18</sup> cm<sup>-2</sup>, and for cloud H1 are 0.6 ( $3\sigma$ ), 0.9, 1.0, 1.2, 1.3 × 10<sup>18</sup> cm<sup>-2</sup>. The beamsize of FAST is displayed in the bottom-left corner in each panel. Bottom: The corresponding integrated H I spectra lines. The red lines represent the fittings from the busy function code (Westmeier et al. 2014).

using Equation (1) and the integrated HI flux of  $194.7 \pm 17.5 \text{ mJy km s}^{-1}$ . The total gas mass, denoted as  $M_{\text{gas}}$ , can be calculated as  $(4.7 \pm 0.4) \times 10^6 M_{\odot}$ , after accounting for helium's contribution, by multiplying the above estimated value by a factor of 1.33. The stellar mass  $(M_{\star})$  of UGCA 337 is determined to be  $(1.7 \pm 0.5) \times 10^8 M_{\odot}$  after correcting for distance to 8.87 Mpc (Carlsten et al. 2022). The obtained  $M_{\text{gas}}/M_{\star}$  in UGCA 337 is about  $0.03 \pm 0.008$ , implying that this dwarf galaxy is extremely gas-poor. Additionally, the dwarf galaxy

exhibits a *g*-*r* color of  $0.61 \pm 0.13$  (Carlsten et al. 2022) and a star formation rate of  $4.8 \times 10^{-5} M_{\odot} \text{ yr}^{-1}$  as estimated from the H $\alpha$  observation,<sup>6</sup> indicating a rather low level of star formation despite its blue color. Such findings differ from the usually low-mass dwarfs (Lisker et al. 2006; Lelli 2022), suggesting that UGCA 337 might have been stripped of gas in the past.

<sup>&</sup>lt;sup>6</sup> http://www.sao.ru/lv/lvgdb/object.php?name=UGCA337&id=696



**Figure 6.** Left: H I column density contours in the velocity range of 533.7–557.8 km s<sup>-1</sup> superimposed on the SDSS *g*-band optical image for UGCA 337. The cyan contour levels are 1.0 (3 $\sigma$ ), 1.4, 1.7, 2.4, 3.5 and 4.5 × 10<sup>18</sup> cm<sup>-2</sup>. The magenta plus marks the optical center of the galaxy. The beamsize of FAST is displayed in the bottom-left corner. Right: The corresponding integrated H I spectrum for UGCA 337. The red line represents the fitting from the busy function code (Westmeier et al. 2014).

## 4. Discussion

# 4.1. Origin of the Possible Tidal Gas

Our new high-sensitivity HI mapping observations with FAST toward NGC 5055 reveal faint HI clouds (clouds c1, 2, 3, and H1) at the edges of the HI disk of NGC 5055. Clouds c2 and H1 were detected for the first time by us, and cloud c3 was identified for the first time as well. These four HI clouds have a total HI mass of  $\sim 6.3 \times 10^7 M_{\odot}$ , contributing to less than one percent HI mass of NGC 5055. In terms of kinematics, clouds c1, 2, and 3 look like extensions of the spiral arms of NGC 5055 as shown in Figures 3 and 4, resembling the tidal tails observed in other galaxies (e.g., Xu et al. 2021; Zhou et al. 2023). In this section, we will mainly discuss their possible origins.

Tidal features generally indicate recent or past gravitational interactions/disruptions of galaxies (Sancisi et al. 2008; Xu et al. 2021; Zhou et al. 2023). However, UGC 8313 and UGCA 337 seem to lack the necessary mass to extract gas from their host galaxy NGC 5055, as indicated by the significant stellar mass ratios between NGC 5055 and UGC 8313 and UGCA 337 of about 274 and 306, respectively, since NGC 5055 and UGC 8313 have a total stellar mass of  $5.2 \times 10^{10} M_{\odot}$  and  $1.9 \pm 0.6 \times 10^8 M_{\odot}$ at the distance of 8.87 Mpc respectively (Carlsten et al. 2022). In addition to UGC 8313 and UGCA 337, Chonis et al. (2011) proposed a minor interaction that NGC 5055 may have disrupted a missed dwarf galaxy in the last few Gyr, because they found a faint and huge arc-loop coherent stellar stream with a dim break at the north and northeast of NGC 5055. Chonis et al. (2011) roughly estimated a total mass of approximately  $10^8 M_{\odot}$  for this disrupted dwarf satellite. This mass appears also insufficient to extract gas from the host galaxy NGC 5055. Clouds 1, 2, and 3 appear to be

unlikely outcomes resulting from the minor interaction between the disrupted dwarf galaxy/UGC 8313/UGCA 337 and NGC 5055.

Alternatively, the tidal tails of NGC 5055 might be remnants of a past merger event that formed the galaxy NGC 5055. This is supported by the presence of the notable warped features, which may have resulted from a merger event (Barnes 2002). In addition, it has been also discovered that the HI kinematic features in NGC 5055 resemble those observed in M94 (Zhou et al. 2023). Specifically, a central, isolated host galaxy is surrounded by diffuse HI tidal(s) and isolated HI cloud(s). This similarity appears to suggest a common origin for the diffuse HI features outside the host galaxy, that the clouds could be part of the remnant of a major merger event in the past.

### 5. Conclusions

We have performed a high-sensitivity HI mapping observation toward the NGC 5055 galaxy group over an area of 1.°  $5 \times 0.^{\circ}75$  with FAST. We discovered a more extended gaseous disk of NGC 5055 compared to the HI mappings of the WSRT. The FAST observation allows us to probe the HI disk of NGC 5055 out to 23'.9 (61.7 kpc), and find a total HI mass of  $\sim 1.1 \times 10^{10} M_{\odot}$ . The latter is almost 22.4% larger than that revealed by the pb-corrected HALOGAS survey, which is due to the fact that FAST is a single-dish telescope that does not suffer from the zero-spacing problem, and then missing fluxes. We identified three HI clouds with tidal features on the southeastern edge of the H I disk of NGC 5055. They have total H I masses of  $\sim 2.7 \times 10^7 M_{\odot}$ ,  $\sim 2.3 \times 10^7 M_{\odot}$  and  $\sim 1.2 \times 10^7 M_{\odot}$  respectively, and might be the remnants of a merger event in the past. A candidate HVC, H1, is confirmed to the north of NGC 5055 and near the minor axis. It has a total HI mass of  $\sim 1.2 \times 10^6 M_{\odot}$ . In addition, the H I content of the dwarf galaxy UGCA 337 is robustly determined by the FAST observation for the first time, which has a narrow HI linewidth of  $W_{50} = 17.4 \pm 3.8 \text{ km s}^{-1}$  with a total H I mass of  $(3.5 \pm 0.3) \times$  $10^6 M_{\odot}$ . Comparing the gas content and g-r color of UGCA 337 with typical low-mass dwarf galaxies, it appears relatively gas-poor despite its blue color, suggesting that UGCA 337 may have undergone gas stripping in the past.

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