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HIPASS study of southern ultradiffuse galaxies and low surface brightness galaxies

Yun-Fan Zhou,[1,2] Chandreyee Sengupta,[1⋆] Yogesh Chandola,[1] O. Ivy Wong,[3,4] Tom C. Scott,[5]
Yin-Zhe Ma[1,6,7⋆] and Hao Chen[1,8,9]

[1] *Purple Mountain Observatory (CAS), No. 10 Yuanhua Road, Qixia District, Nanjing 210034, China*
[2] *School of Astronomy and Space Science, University of Science and Technology of China, Hefei, Anhui 230026, China*
[3] *CSIRO Space & Astronomy, PO Box 1130, Bentley, WA 6102, Australia*
[4] *ICRAR-M468, University of Western Australia, Crawley, WA 6009, Australia*
[5] *Instituto de Astrofísica e Ciência do Espaço (IA), Rua das Estrelas, P-4150-762 Porto, Portugal*
[6] *School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Private Bag X54001, Durban 4000, South Africa*
[7] *NAOC-UKZN Computational Astrophysics Centre (NUCAC), University of KwaZulu-Natal, Durban 4000, South Africa*
[8] *Research Center for Intelligent Computing Platforms, Zhejiang Laboratory, Hangzhou 311100, China*
[9] *Department of Astronomy, University of Cape Town, Private Bag X3, 7701 Rondebosch, South Africa*

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马寅哲

ABSTRACT

We present results from an H I counterpart search using the HI Parkes All Sky Survey (HIPASS) for a sample of low surface brightness galaxies (LSBGs) and ultradiffuse galaxies (UDGs) identified from the Dark Energy Survey (DES). We aimed to establish the redshifts of the DES LSBGs to determine the UDG fraction and understand their properties. Out of 409 galaxies investigated, none were unambiguously detected in H I. Our study was significantly hampered by the high spectral rms of HIPASS and thus in this paper we do not make any strong conclusive claims but discuss the main trends and possible scenarios our results reflect. The overwhelming number of non-detections suggest that (a) Either all the LSBGs in the groups, blue or red, have undergone environment aided pre-processing and are H I deficient or the majority of them are distant galaxies, beyond the HIPASS detection threshold. (b) The sample investigated is most likely dominated by galaxies with H I masses typical of dwarf galaxies. Had there been Milky Way (MW) size (R_e) galaxies in our sample, with proportionate H I content, they would have been detected, even with the limitations imposed by the HIPASS spectral quality. This leads us to infer that if some of the LSBGs have MW-size optical diameters, their H I content is possibly in the dwarf range. More sensitive observations using the SKA precursors in future may resolve these questions.

Key words: galaxies: dwarf – galaxies: evolution – galaxies: groups: general – radio lines: galaxies.

1 INTRODUCTION

A relatively unexplored area of extragalactic astronomy is the study of low mass (dwarf) and low surface brightness galaxies (LSBGs). Understanding the fainter end of the galaxy mass spectrum holds the key to questions related to galaxy formation, evolution, mass budgets in these structures and thus improving cosmology models. Since their reporting in 2015, a class of fainter LSBGs, called the ultradiffuse galaxies (UDGs; van Dokkum et al. 2015) have become a topic of interest to the astronomy community. To qualify as an UDG, a galaxy has to meet two criteria: they must have a central surface brightness (μ_g) of $\geq$24 mag arcsec^{-2} and an effective radius[1] (R_e) $\geq$ 1.5 (van Dokkum et al. 2015). While faint, LSBGs are not a recent discovery (Impey, Bothun & Malin 1988; Dalcanton et al. 1997; Conselice 2018), the 1000 + UDGs found projected around the Coma cluster (Koda et al. 2015) indicated for the first time their relative ubiquity in a dense environments (van der Burg et al. 2017). This fact suggested that UDG studies had the potential to add new insights to knowledge of galaxy and structure formation. Despite the relatively large number of reported UDGs, little is known about their properties and formation. Various secular and environmentally driven formation scenarios have been proposed but detailed observations are needed to determine which ones are valid.

UDGs, and LSBGs in general, are optically faint galaxies with mostly low star formation rates (Wyder et al. 2009). As a result, establishing their optical/UV and infrared (IR) properties is observationally expensive. They are typically metal poor, limiting the practicality of molecular gas observations. However, outside cluster cores, UDGs and LSBGs are usually H I rich, making H I line observations a high priority tool to study these galaxies. Despite this, very few UDG H I studies exist in the literature mainly because the field is new. Single dish targeted H I UDG surveys, yielding statistically significant results are so far limited to only a handful of studies (i.e. Leisman et al. 2017; Karunakaran et al. 2020). A few more H I studies of UDGs are focused on H I in isolated

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[⋆] E-mail: sengupta.chandreyee@gmail.com (CS); ma@ukzn.ac.za (YZM)
[1] The effective radius of a galaxy is the radius at which half of the total light is emitted

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UDGs (Papastergis, Adams & Romanowsky 2017), H I-rich field UDGs (Leisman et al. 2017), and UDGs in groups (Spekkens & Karunakaran 2018; Poulain et al. 2022). There are even fewer resolved H I studies of UDGs (Sengupta et al. 2019; Mancera Piña et al. 2019; Scott et al. 2021; Gault et al. 2021; Mancera Piña et al. 2022). More extensive H I studies of these galaxies is thus timely and relevant as their abundance in different environments has important implications for our knowledge of galaxy and large-scale structure formation.

Using optical imaging from the Dark Energy Survey (DES; Abbott et al. 2018), Tanoglidis et al. (2021) reported a large number ($\sim$23 790) LSBGs in an area $\sim$ 5000 deg^2 mainly from the Southern hemisphere sky with a fraction of them being UDG candidates. The Tanoglidis et al. (2021) LSBG catalogue was based on imaging data and thus lacked the essential redshift information necessary to determine the UDG fraction in the catalogue. Unlike the Northern hemisphere where a number of H I surveys have been carried out, principally with the Arecibo 305m telescope, the H I Parkes All Sky Survey (HIPASS) single dish survey is the only extensive southern H I survey available. Thus, HIPASS provides an excellent opportunity to search for H I counterparts to LSBG/UDGs in the Tanoglidis et al. (2021) catalogue and determine their redshifts. In this paper, we present the results of our search on a subset of Southern hemisphere Tanoglidis et al. (2021) catalogue LSBGs using H I spectra extracted from HIPASS data cubes (Barnes et al. 2001; Meyer et al. 2004; Zwaan et al. 2004; Wong et al. 2006). We aim to understand what fraction of our sample had detectable H I and their H I properties, and most importantly the fraction of the H I-detected LSBGs that qualify as UDGs.

2 SAMPLE AND METHODOLOGY

2.1 Sample selection

Our sample was selected from the southern LSBGs in the (Tanoglidis et al. 2021) LSBG catalogue compiled from DES optical imaging. According to the authors' definition, galaxies qualified as LSBGs if they had g-band effective radii $\geq$ 2.5 arcsec and a mean surface brightness (in g band) $\geq$24.2 mag arcsec^{-2}. While Tanoglidis' LSBGs were found to be distributed all across the southern sky, they also showed projected clustering around prominent known galaxy groups and clusters. About 80 such concentrations were reported in Tanoglidis et al. (2021). On the assumption that the clustering of the LSBGs around known galaxy groups is also true in velocity space, and not just in projection, we selected the LSBGs associated with groups and clusters. Assuming a large dwarf population dominated this catalogue, we selected primarily nearby groups. We expect that selecting the groups/clusters would provide approximate constraint on the distance to our targets. While a fraction of LSBGs projected around the groups and clusters could be foreground or background galaxies, choosing nearby groups and clusters increases the probability that the targeted galaxies would be at a similar redshift. As the H I detection threshold increases with redshift this approach tends to maximize the probability of detecting H I in the LSBGs, while minimizing the search distance. A fraction of the reported Tanoglidis et al. (2021) LSBGs in nearby groups and clusters are also UDG candidates. In defining their UDG sample, those authors followed the standard definition of an UDG, i.e. g band $R_{\rm e} \geq 1.5$ kpc and the central surface brightness $\mu_{\rm g} \geq$24.0 mag arcsec^{-2} (van Dokkum et al. 2015). Tanoglidis et al. (2021) used the distances to the groups or clusters with which they were presumed to be associated with, to estimate the $R_{\rm e}$ of the UDG candidates. Detection of an H I counterpart to these optical candidates would thus allow us to determine whether these are truly UDGs.

We used the HIPASS spectra extracted from the online data release (https://www.atnf.csiro.au/research/multibeam/release/) to search for H I counterparts in a sample 409 of Tanoglidis et al. (2021) LSBG candidates with the aim of estimating the H I content of the LSBGs. The same exercise was repeated using spectra extracted directly from the HIPASS cubes as a cross check. Given the HIPASS spectral rms $\sim$13 mJy beam^{-1}, velocity resolution of 18 km s^{-1} (Meyer et al. 2004) and assuming the H I emission appears over at least three consecutive channels, a galaxy with an H I mass $\sim 1.9 \times 10^8$ M$_\odot$, at a distance of 20 Mpc, should be detected at 3σ significance with HIPASS. However, had we restricted our sample to distances $\leq$ 20 Mpc, our sample size would have been very small. Therefore, we increased our distance limit, being aware that with increasing distance, possibility of detecting galaxies with dwarf H I masses significantly reduces. However, not all LSBGs are dwarf galaxies and several LSBGs are known to be H I rich and relatively optically extended galaxies (Sprayberry et al. 1995; de Blok, McGaugh & van der Hulst 1996; Impey et al. 1996) and we therefore extended our search to groups with luminosity distances $\leq$ 70 Mpc. At 70 Mpc, a galaxy with an H I mass of $\sim$2.4 $\times$ 10^{9}M$_\odot$, still in the dwarf galaxy H I mass range, would be detected at 3σ level in a HIPASS spectrum. Thus, even at 70 Mpc, a few LSBGs could potentially be detected and thus we included all Tanoglidis et al. (2021) LSBG candidates in clusters/groups and overdensities with distances $\leq$70 Mpc in our sample of 409 LSBGs. Using the archival HIPASS data, we searched for H I along the line sight for the 409 LSBGs associated with 18 groups and overdensities (15 known groups and 3 central galaxies) with luminosity distances $\leq$70 Mpc. Table 1 shows these group names, coordinates, redshift, luminosity distance as well as the number of associated LSBGs and UDGs (in brackets). The redshifts to these groups/galaxy clusters are taken from Tanoglidis et al. (2021).

2.2 Search for H I counterparts and comparison with spectra from the HIPASS cubes

Line-of-sight spectra were extracted from the HIPASS online archive for each of the 409 LSBGs in our sample in an attempt to detect H I in them. Caveats to this process need to be discussed. The full width at half-maximum (FWHM) of the HIPASS beam is large ($\sim$15 arcsec), and in most cases, the galaxy coordinates, although within the FWHM of HIPASS beam, differed significantly from the HIPASS beam pointing centre. Additionally, while the canonical rms for HIPASS is 13 mJy beam^{-1}, depending on sky position it varies from 13 to 20 mJy beam^{-1} (Zwaan et al. 2004). These rms variations are often convolved with baseline ripples. This fact can add to the difficulty in detecting galaxies with low H I mass. The pointing offset and presence of other large group galaxies in the same redshift range within the HIPASS FWHM leads to the risk that the H I signal from our intended target is confused with H I emission from other galaxies within or slightly beyond the HIPASS beam. To minimize this risk for targets associated with groups, we restricted our search to only nearby groups ($D \leq 70$ Mpc), while acknowledging that we may have missed several H I counterparts due to this restriction. Fig. 1 demonstrates the effect of the high spectral rms and baseline issues mentioned above. While NGC 7398 ($D = 67.4$ Mpc), the galaxy in the figure is not in our sample, but belongs to one of the groups we are investigating. It is a large H I-rich spiral in contrast to the dwarf dominated LSBG population of our sample. Thus, the figure indicates

Table 1. Groups searched for H I.

(1) Sl. no.[2]	(2) Group/cluster name	(3) RA[3] (h m s)	(4) Dec. (d m s)	(5) Redshift[4]	(6) Lum. dist.[5] (Mpc)	(7) No. LSBGs (UDGs)[6]
1	Abell S373 (Fornax)	03:38:30.0	−35:27:18.0	0.0046	19.0	59 (3)
2	NGC 1401	03:39:21.9	−22:43:29.0	0.0050	20.3	26 (1)
3	RXC J0152.9-1345	01:52:59.0	−13:45:12.0	0.0058	21.9	13(0)
4	RXC J0340.1-1835	03:40:11.4	−18:35:15.0	0.0057	23.4	45(1)
5	NGC 1316	03:22:41.8	−37:12:29.5	0.0059	24.4	17(1)
6	Abell 3820	21:52:32.0	−48:23:54.0	0.0064	25.6	14(0)
7	NGC 7041	21:16:32.4	−48:21:48.8	0.0065	26.0	14(1)
8	Abell S989	22:04:25.0	−50:04:24.0	0.0098	40.3	25(3)
9	NGC 1162	02:58:56.0	−12:23:54.8	0.0131	55.3	12(2)
10	NGC 145	00:31:45.7	−05:09:09.6	0.0138	56.0	10 (0)
11	NGC 829	02:08:42.2	−07:47:26.9	0.0135	56.1	17 (5)
12	NGC 1200	03:03:54.5	−11:59:30.7	0.0135	57.0	30 (10)
13	Abell 2964	02:01:06.4	−25:04:31.7	0.0144	60.3	18 (5)
14	NGC 1521	04:08:18.9	−21:03:07.3	0.0142	61.4	14 (4)
15	NGC 1208	03:06:11.9	−09:32:29.4	0.0145	61.6	18 (5)
16	NGC 199	00:39:33.2	+ 03:08:18.8	0.0154	62.8	39 (12)
17	NGC 7396	22:52:22.6	+ 01:05:33.3	0.0166	68.0	18 (7)
18	Abell S924	21:07:53.0	−47:10:54.0	0.0162	68.9	20 (8)

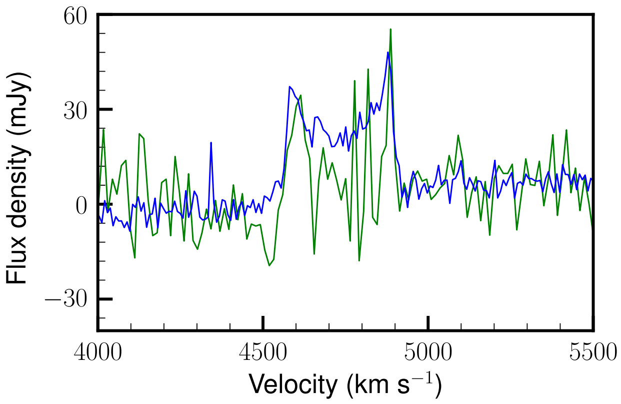

Figure 1. H Ispectra of NGC 7398, measured from HIPASS (green) and the Arecibo 305m telescope (blue) (Springob et al. 2005).

that there is a low probability of detecting our targets with HIPASS unless they are H I rich.

The HIPASS cubes cover a ∼8° × 8° sky area with each pixel covering an area of ∼4 arcmin × 4 arcmin and the HIPASS FWHM beam is ∼15 arcmin (Meyer et al. 2004). The spectra available from the website[7] are extracted using a single pixel box at the location of the source, where the pixel size is 8 arcmin × 8 arcmin. While extracting spectra directly from the HIPASS cubes, we used a 3 pixels × 3 pixels box (with pixel sizes of 4 arcmin), closer to the HIPASS FWHM, for each source. We compared the entire set of HIPASS spectra available from HIPASS website to the spectra extracted directly from the cubes. We found no significant difference, however, for our analysis we used the spectra from the 3 pixels × 3 pixels boxes, extracted from the HIPASS cubes.

3 RESULTS

Our search for H I in HIPASS cubes for the target galaxies along 409 lines of sight, associated with 18 groups/clusters, yielded no clear detection. There were four tentative detections, two associated with the Fornax cluster and one each with NGC 1316 and NGC 145 groups (see Figs 2–5). The rest were all clear non-detections. All four tentative detections had the following common features. They were all narrow line features, similar to 2–4 channels and appeared at velocities similar to 4500 km s^{-1} and 2600 km s^{-1}. The W$_{20}$ of our tentative detections ranged from 30 to 50 km s^{-1}. Narrow line signals at these frequencies can potentially be radio frequency interference (RFI). The HIPASS Data Release Help Page offers information on the frequencies, where known RFI signals can be seen. According to this page, the prime interfering line is the 11th harmonic of the 128 MHz sampler clock at 1408 MHz (cz = 2640 km s^{-1}). The page further states that while this is a narrow line, Doppler corrections may broaden this line by up to 30 km s^{-1}. Additionally, other residual narrow-band signals may be present in the HIPASS cubes, notably near 1400 MHz, or 4400 km s^{-1}. Since some of these RFI signatures match with our tentative detections, we carried out the prescribed RFI checking method suggested in the Data Release Help Page, i.e. by extracting several spectra from along a 1° radius from the candidate source position. Of our tentative sources Fornax-C1, Fornax-C2, and NGC 145-C1, had narrow signals from their 1° radii tests at the same velocity confirming the tentative detections were in fact RFI. Sometimes spectrometer saturation may cause a sign bit inversion. This could be a possible reason for seeing negative amplitudes at RFI frequencies. For NGC 1316-C1, we see no such feature. But NGC 1316-C1 was the weakest of the four tentative signals and barely a 2σ emission. Thus, we conclude we have complete non-detection of H I signals in this search for H I counterparts, using the HIPASS data. We note that a few groups in our sample overlap with the ALFALFA[8]

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[2] Serial number.

[3] All group co-ordinates are from SIMBAD, except RXC J0152.9-1345 and RXC J0340.1-1835 which are from Piffaretti et al. (2011).

[4] Redshift of the groups/clusters from Tanoglidis et al. (2021).

[5] Luminosity distance of the groups/clusters from Tanoglidis et al. (2021)

[6] Number of LSBGs (UDGs) in each group/cluster from Tanoglidis et al. (2021).

[7] https://www.atnf.csiro.au/research/multibeam/release/

[8] http://egg.astro.cornell.edu/alfalfa/data/

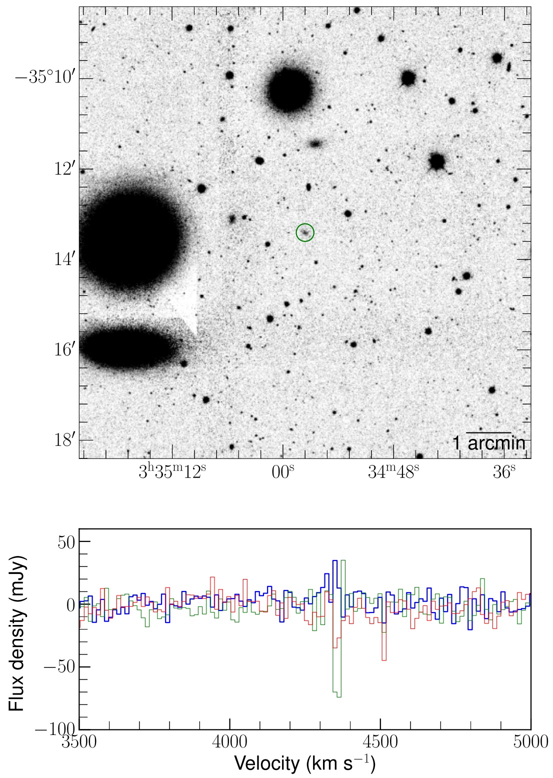

Figure 2. Fornax-C1 (RA 03:34:57.6 Dec. −35:13:24.5). *Top*: DES image with green circle indicating the galaxy. *Bottom*–HIPASS spectrum of the target galaxy in blue. Spectra in green and red are extracted from regions 1° away from the galaxy. The test indicates the peak in this spectrum is RFI.

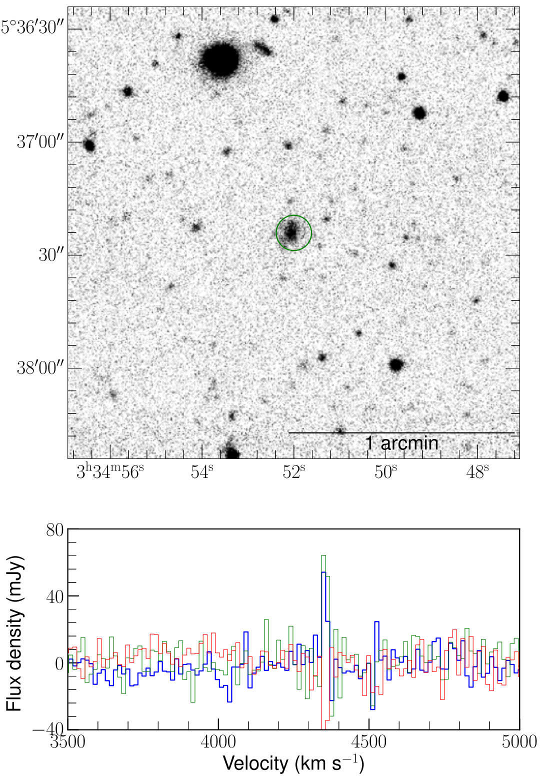

Figure 3. Fornax-C2 (RA 03:34:52.0 Dec. −35:37:24.1). *Top:* DES image with green circle indicating the galaxy. *Bottom*: HIPASS spectrum of the target galaxy. Spectra in green and red are extracted from regions 1° away from the galaxy. The test indicates the peak in this spectrum is RFI.

survey areas. Two of our groups (NGC 199 and NGC 7369) overlap with the ALFALFA sky coverage, but the LSBGs in those groups were H I non-detections in both HIPASS and ALFALFA.

Assuming the Tanoglidis et al. (2021) LSBGs to be group members, we next performed a spectral stacking experiment. Due to lack of redshifts for the LSBGs, we assumed all the LSBGs had velocities similar to the nearest group in projection. Additionally, we only stacked the spectra from the blue galaxies, because these are expected to be H I rich. The caveat here being that the groups can have H I velocity dispersions of up to 200 km s^{-1} with group members having a range of radial velocities, whereas the LSBGs are assumed to be at the group systemic velocity. Thus, stacking in this case is likely to miss a major fraction of the galaxies. However given that these are nearby groups where individual galaxies with H I masses $\geq 10^8$ M⊙ should be detected, the stacked signal would at least detect the LSBGs close to the systemic velocity of the group. Thus, the systemic velocity of the host group was considered the zero velocity for all the blue LSBG spectra and a ± 1000 km s^{-1} range about the zero velocity was extracted for stacking them. However, we did not detect any signal in the stacked spectra.

The Tanoglidis et al. (2021) LSBG catalogue is based on DES DR1 from the first 3 yr of data from the DES. Their paper contains a link (https://desdr-server.ncsa.illinois.edu/despublic/other_files/y3-lsbg/) to their LSBG catalogues. We used the original version of the catalogue for our analysis. But we note that the above website also contains a second version of the catalogue, possibly a recent update on their original version. Comparing the two catalogue versions for our sample showed that galaxies from six groups in our sample were reclassified as field LSBGs rather than group members in version two of the catalogue. The differences between the two versions of the Tanoglidis LSBG catalogues add additional uncertainties to group memberships. But, whether we include or exclude these six groups, our complete H I non-detection result remains unchanged as do the conclusions.

4 DISCUSSION

Analysis of imaging data from the DES provided a large sample of new LSBGs and UDGs mainly in the Southern hemisphere (Tanoglidis et al. 2021). They report a 2D clustering for the red LSBGs where the galaxies appear preferentially near to known groups and clusters. The authors report ∼80 such groupings. For a subset of that sample, 18 groups in total, we used the only available large-scale single dish H I survey in the Southern hemisphere, HIPASS, to search for H I counterparts. In absence of spectroscopic redshifts, projected proximity to a group or cluster provided the initial distance constraint for our sample. According to Tanoglidis et al. (2021), the majority of the LSBGs associated with over densities are redder than $g - i \geq 0.60$ and the redder LSBGs are more strongly clustered than the bluer ones. This situation introduces a bias in our sample as the bluer galaxies are more likely to be H I detected than the red ones (Leisman et al. 2017; Spekkens & Karunakaran 2018; Sengupta et al. 2019). However, as a first step, we chose to probe the groups because this provides a better redshift constraint on the sample. Though rare, it is not impossible for redder LSBGs or dwarfs to contain substantial H I (Leisman et al. 2017; Papastergis et al. 2017; Karunakaran et al. 2020; Poulain et al. 2022) and thus we did expect H I detections in at least a fraction of them. In addition, choosing groups does not

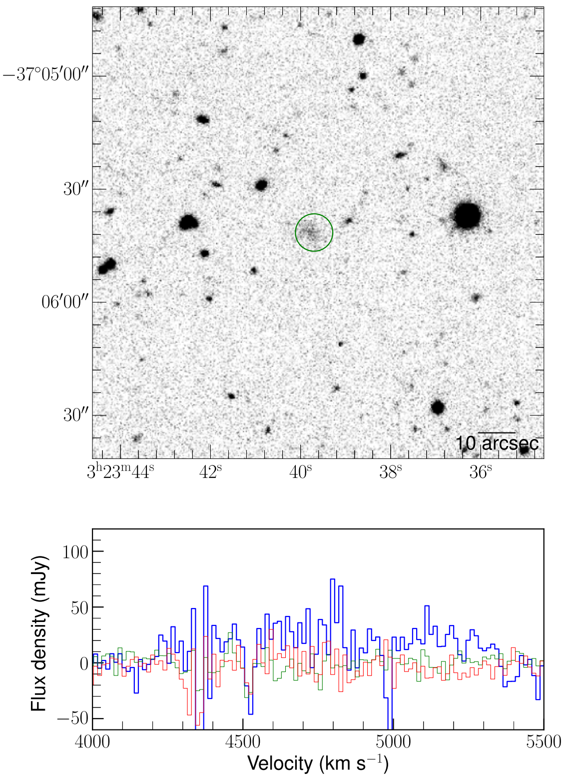

Figure 4. NGC 1316-C1 (RA 03:23:39.7 Dec. −37:05:41.5). *Top*: DES image with green circle indicating the galaxy. *Bottom*: HIPASS spectrum of the target galaxy. Spectra in green and red are extracted from regions 1° away from the galaxy. The spectrum is barely a 2σ signal and cannot be unambiguously claimed as a detection.

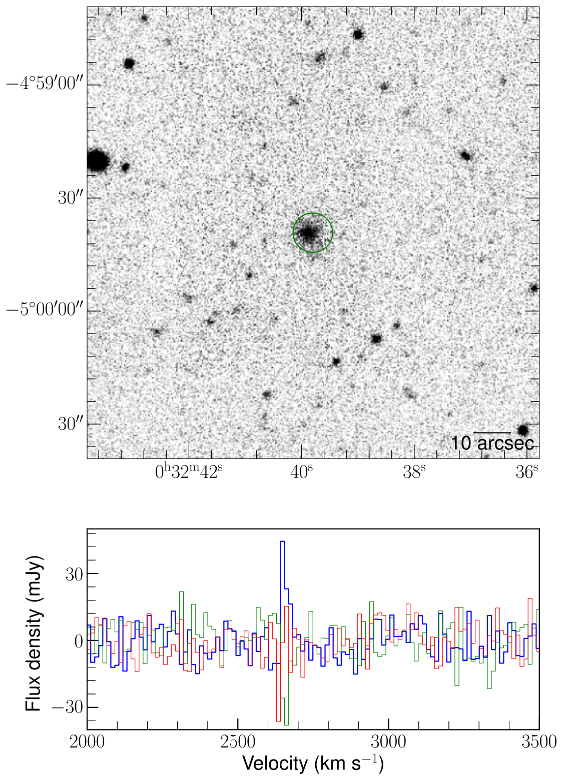

Figure 5. NGC 145-C1 (RA 00 32 39.8 Dec. −04 59 39.2). *Top*: DES image with green circle indicating the galaxy. *Bottom*: HIPASS spectrum of the target galaxy. Spectra in green and red are extracted from regions 1° away from the galaxy. The test indicates the peak in this spectrum is RFI.

imply that our sample is completely devoid of blue galaxies. While the dominant population in our 409 LSBG sample have a red colour, 108 are blue galaxies ($g - i < 0.6$).

Our study resulted in H I non-detection for all of the 409 lines of sight in 18 groups. For the HIPASS data, a galaxy's H I mass upper limits ranges from $\sim 1.9 \times 10^8\,\mathrm{M}_\odot$ (for 20 Mpc) to $\sim 2.4 \times 10^9\,\mathrm{M}_\odot$ (for 70 Mpc). Our 70 Mpc distance cut-off was chosen to ensure we do not miss higher H I mass but more distant LSBGs, if any. While our best candidates are projected close to the nearest six groups in our sample (Table 1), we extend our distance limit to 70 Mpc. Although, the recently reported UDGs (Sengupta et al. 2019; Scott et al. 2021) are predominantly dwarf mass galaxies, several LSBGs have been reported to be H I rich with moderate to large size stellar disks (Bothun et al. 1990; Sprayberry et al. 1993). So if such galaxies with proportionally large H I masses are present in the Tanoglidis et al. (2021) LSBG sample, extending the distance limit to 70 Mpc would help us detect them in those more distant groups. Here, we discuss a few factors that could explain the H I non-detections in our study.

According to Tanoglidis et al. (2021), of the 409 target LSBGs in our sample, 108 have blue DES colour ($g - i \leq 0.6$) and the majority, 301, are red ($g - i \geq 0.6$). While red galaxies can contain detectable H I mass (e.g. Leisman et al. 2017; Papastergis et al. 2017; Karunakaran et al. 2020; Poulain et al. 2022) at least in the nearby groups, the chances of H I detection in them are lower than bluer galaxies (Bouchard et al. 2005; Grossi et al. 2009; Karunakaran et al. 2020). Additionally, if these galaxies are genuinely group members, the chance of them being H I deficient is high. H I deficiency from galaxy pre-processing in groups is a known phenomenon and LSBGs with nominal stellar disc mass are more vulnerable to gas stripping physical processes like tidal interactions, harassment, and ram pressure stripping than higher mass galaxies (Verdes-Montenegro et al. 2001; Sengupta & Balasubramanyam 2006; Kilborn et al. 2009; Odekon et al. 2016). These group physical processes could make even the blue fraction of the LSBGs H I deficient. However, this scenario alone appears insufficient to explain the complete non-detection of the 108 blue galaxies in the sample. Even with preprocessing active in groups, at least a small fraction of the blue galaxies should have been detected at HIPASS sensitivity. H I deficient dwarf galaxies have been detected previously with HIPASS data in groups at similar distances (Sengupta & Balasubramanyam 2006).

An alternative explanation for this non-detections could be that LSBGs, while projected close to the groups, are in fact background galaxies which fall below the HIPASS detection threshold. HIPASS's H I sensitivity falls off rapidly with distance and if a large fraction of our sample are dwarfs and/or in the background of their Tanoglidis assigned group, they would not be detected in the HIPASS. The result from spectral stacking of the blue galaxies supports this hypothesis. If our LSBGs are group members, statistically at least a fraction of them could have had velocities close to the group systemic velocity. Since the groups are at various redshifts, the total blue stacked spectrum rms cannot be used to quote upper limits of H I masses for groups at different distances. Thus, individual group's stacked spectral rms was used to extract this number. Thus, the 3σ upper limit to the H I mass for the nearest ($\sim$20 Mpc) and the farthest ($\sim$70 Mpc) groups are $\sim 3.6 \times 10^7\,\mathrm{M}_\odot$ and $7.3 \times 10^8\,\mathrm{M}_\odot$, respectively. For individual galaxies, this limit varies from $\sim 1.9 \times 10^8 \mathrm{M}_\odot$ to $2.4 \times 10^9 \mathrm{M}_\odot$, for the nearest and the farthest groups respectively. These are normal H I masses for dwarf galaxies and should have been easily detected in HIPASS, either individually or in the stacked spectra.

While our study only results in non-detections, this exercise, carried out with the best available data at our disposal, provides a statistical trend for H I in the Tanoglidis et al. (2021) LSBGs. In that context, our results reveal two important trends.

Of our sample of 409 targets, 68 are designated as UDG candidates in Tanoglidis et al. (2021) and the rest as LSBGs. This classification, however, assumes that the galaxies are at the same distances as the groups or clusters they are projected near to. Our H I results suggest, a large fraction of our sample galaxies might not in fact be clustered near to the groups they are projected close to. This effect is almost certainly impacting the estimate of the true number of UDGs in the Tanoglidis et al. (2021) LSBG catalogue. Additionally, our work demonstrates the critical importance of spectroscopic observations for these galaxies since redshift confirmation is the only way to understand the true fraction of UDGs in this sample. This result together with the low H I detection rates of UDGs in clusters (Karunakaran et al. 2020) challenge our perceived idea of clustering property of UDGs. UDGs are optically selected galaxies and thus the UDG literature is dominated by optical imaging studies (van Dokkum et al. 2015; Koda et al. 2015; Yagi et al. 2016; Román & Trujillo 2017; Shi et al. 2017). They were first reported in the Coma cluster and subsequent reports of their discoveries also came mainly from groups and clusters giving the impression of an enhanced population of these galaxies in such overdensities (van der Burg et al. 2017). Tanoglidis et al. (2021) also reported a similar clustering for red LSBGs and UDGs in the southern sky. Our overwhelming number of non-detections, even for typical H I mass dwarf LSBGs or UDGs, raises doubts about the reported clustering properties. The 108 blue galaxies in our sample of 409 LSBGs have an even higher probability of being non-cluster or non-group members. This is because galaxies in groups will undergo pre-processing causing gas loss and also redder colour. Deeper spectroscopic, optical or H I observations are required to confirm or refute the association of UDGs and LSBGs with the groups/ clusters.

Our project was designed to detect H I-rich LSBGs of all sizes, including distant H I-rich dwarfs out to a distance of about 70 Mpc. The lack of even a single clear detection of a LSBG or UDG with the H I mass of the Milky way (MW) suggested our sample only contains dwarf H I mass galaxies. Among the reported UDGs in the recent years, a substantial fraction have $R_\mathrm{e} \geq 3.7$ kpc (similar to or larger than that of the MW) (Zaritsky et al. 2019). The stellar masses of these galaxies may be equivalent to small dwarfs, but their R_e mimics much larger galaxies. While these UDGs are considerably more extended than dwarf galaxies, it is not yet clear if the H I line widths, H I masses and the dark matter content are consistent with the dwarf or more massive galaxies. Recently, Gault et al. (2021) imaged H I in about ten UDGs and found the H I mass and the H I disc diameter to follow the correlation in Wang et al. (2016); however, the H I mass range covered in this work is less than $2 \times 10^9 \mathrm{M}_\odot$, in the range of dwarf galaxies. A scaling relation between the UDG R_e and the DM halo mass was proposed by Zaritsky (2017) and is consistent with a globular cluster count study of six Coma UDGs with $R_\mathrm{e} \geq$ 3 kpc by Saifollahi et al. (2022). However, the R_e–DM halo mass relation is yet to be confirmed with DM halo mass estimates based on H I rotation curves. Moreover, if this relation is established for cluster UDGs it is not clear if this would also hold for gas rich field UDGs, where the formation mechanism may also be different.

The lack of spectroscopically confirmed distances for our sample makes it impossible to ascertain how many of our target 409 LSBGs have an $R_\mathrm{e} \geq 3.7$ kpc. The LSBGs in our sample, with the largest angular R_e are in the range of 14–21 arcsec (Tanoglidis et al. 2021). In the absence of redshift measurements, these larger angular R_e LSBGs could be at any redshift along the line of sight. If these larger angular R_e galaxies, or a fraction of them, are at a distance of 70 Mpc then their R_e would be 4–7 kpc, i.e. larger than the MW. LSBs or more specifically UDGs with R_e larger than MW are not unusual and have been detected in H I in Leisman et al. (2017). Non-detection of even a single extended galaxy ($R_\mathrm{e} \geq 3.7$ kpc) in our study thus suggests two possible scenarios: (a) the sample is consists entirely of LSBGs with H I masses in the range dwarf galaxies and is devoid of any higher R_e galaxies; (b) if LSBGs with $R_\mathrm{e} \geq$ the MW are present in the sample, their non-detection in H I, suggests that they have dwarf like H I content and perhaps even dwarf like dark matter content.

Scenario (b) is consistent with recent results from H I studies of faint LSBGs and UDGs. For example Gault et al. (2021) studied a sample of UDGs with R_e ranging from 1.9 to 6.3 kpc. Irrespective of R_e, the detected H I mass was $\leq 2 \times 10^9 \mathrm{M}_\odot$ and the H I mass typically found in dwarf galaxies. The lack H I detections in our study is consistent with the low H I detection rates in other studies of UDGs and LSBGs. A recent H I study of moderately extended ($R_\mathrm{e} \geq 2.5$ kpc at the distance of Coma) UDGs from the SMUDGES survey (Karunakaran et al. 2020) resulted in a low detection rate for UDGs. In that study about 70 UDG candidates were observed using the Green Bank Telescope (GBT) and about 9 UDGs were detected in H I. The region surveyed was around the Coma cluster; however, none of the H I-detected UDGs was cluster members. All of them belong to the low density environment in the foreground or background of the Coma cluster which probably resulted in a better detection rate as opposed to a search inside a group or a cluster, where higher H I deficiencies are expected. Additionally the H I masses of the detected galaxies were $\leq 1.7 \times 10^9 \mathrm{M}_\odot$ irrespective of the R_e which again seems to reinforce our findings of Scenario (b) above. Compared our 409 targets, Gault et al. (2021) and Karunakaran et al. (2020) had smaller sample sizes; however, both of those studies show similar trend to our results with respect to the absence of H I rich and large R_e UDGs. While the sample is insufficient to make any strong claims, Scenario (b) combined with other studies in the literature showing irrespective of R_e the H I masses of UDGs are typical of dwarf galaxies (Gault et al. 2021; Karunakaran et al. 2020), most likely suggest that a scaling relation as suggested by Zaritsky et al. (2019) may not be valid for UDGs. However, we clearly need more data and a statistically significant sample to confirm this. The SKA precursors MeerKAT and ASKAP are located in the Southern hemisphere. Both telescopes offer higher sensitivity and resolution than HIPASS and therefore could be used in future studies of the LSBGs and UDGs with a higher probability of detecting H I.

5 CONCLUSIONS

Using archival HIPASS data, we searched for H I counterparts in 409 LSBGs from the Tanoglidis et al. (2021) catalogue of Southern hemisphere LSBGs. We found no convincing H I counterparts for any of the sample of 409 LSBGs.

While our study was significantly hampered by the high spectral rms of HIPASS, the non-detections are not entirely a result of this. Our project was designed to detect H I rich LSBGs of all sizes, including distant H I-rich dwarfs out to a distance of about 70 Mpc. For example, for a distance of 20 Mpc, the HIPASS data would allow us to detect H I mass $\sim 1.9 \times 10^8$ M$_\odot$ and for 70 Mpc, the farthest group in our sample, the detection limit would be $\sim$2.4 × 10^9M$_\odot$. These numbers represent typical dwarf galaxy, small LSBGs to gas rich small spiral's H I content. Thus a complete non-detection cannot be only due to the limitation of the HIPASS spectral rms.

Our non-detections suggest the following likely scenarios: (i) The majority of LSBGs are group members but nearly all of them are H I deficient due to preprocessing in those groups. While many of the red LSBGs could be highly H I deficient and thus below the HIPASS detection limit, this scenario cannot explain the non-detection of all of our sample's 108 blue galaxies. (ii) Is it possible that our perceived idea of UDG clustering is incorrect. The majority of Tanoglidis et al. (2021) LSBGs could be distant background galaxies to the groups and thus beyond the detection threshold of the HIPASS. Without more sensitive spectroscopic measurements this cannot be confirmed. Our study highlights the crucial need for spectroscopy, optical or H I, to estimate the redshifts and to understand whether LSBGs or UDGs are genuine groups members. (iii) The sample investigated by us appears to be dominated by galaxies with H I masses in the dwarf range. Had there been LSBGs or UDGs in our sample with ≥ MW R_e and proportional H I masses, even with the high spectral rms of HIPASS, the detection rate would have been higher. We did not even detect any MW R_e LSBG with an H I mass of the order of a few times 10^9M$_\odot$, typically seen in extended UDGs (Leisman et al. 2017; Karunakaran et al. 2020). This may imply, LSBGs or UDGs with stellar disks as extended as the MW probably have an H I content similar to dwarf galaxies. Clearly, more sensitive observations using the SKA precursors in future may answer these questions.

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DATA AVAILABILITY

This project has used publicly available archived data. Koribalski, Baerbel; Staveley-Smith, Lister (2004): The HI Parkes All Sky Survey (HIPASS) image cubes. v1. CSIRO. Data Collection. https://doi.org/10.25919/5c36de6d37141. The spectra can also be downloaded from https://www.atnf.csiro.au/research/multibeam/release/.

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