

LETTER TO THE EDITOR

Addition of the Local Volume sample of galaxies from the FAST HI survey

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ABSTRACT

We report the discovery of 20 new dwarf galaxies in the Local Volume identified as optical counterparts to the Five-hundred-meter Aperture Spherical radio Telescope (FAST) All Sky HI Survey (FASHI) sources. The galaxies have a median stellar mass of $7.8 \times 10^6 M_\odot$ and a median HI mass of $1.0 \times 10^7 M_\odot$. Most of them are field galaxies, while three are probable members of the M 101 and M 106 groups. We also found seven FASHI radio sources to be probable dark HI clouds in nearby groups. Together with four other known HI clouds in the local groups, their mean-square radial velocity difference of 49 km s^{-1} with respect to the host galaxies yields an average total mass of $(2.7 \pm 1.0) \times 10^{11} M_\odot$ for these groups on the projected scale of 90 kpc.

Key words. surveys – galaxies: dwarf

1. Introduction

A Local Volume (LV) of the Universe with a radius of 11 Mpc around the Milky Way is the most optimal sample for testing the results of N -body simulations performed within the framework of the standard cosmological paradigm, Λ cold dark matter. A unique feature of this sample is that it contains many faint dwarf galaxies that are essentially not observable at far distances. With distance and radial velocity measurements, the LV dwarf galaxies can be used as ‘test particles’ to trace a local field of peculiar velocities and to recover a distribution of dark matter in the LV. The radius of the LV sphere, 11 Mpc, is used because high-precision distances to galaxies can be measured by the *Hubble* Space Telescope from the tip of the red giant branch (TRGB) in one orbital turnover of the telescope.

The first sample of nearby galaxies within 10 Mpc was compiled by Kraan-Korteweg & Tammann (1979) and included 179. Systematic all-sky searches for nearby low surface brightness galaxies on images of the Palomar Observatory Sky Survey (Karachentseva & Karachentsev 1998, 2000; Karachentseva et al. 1999) and subsequent measurements of their radial velocities (Huchtmeier et al. 2000, 2001, 2003) increased the LV population to approximately 500 objects. Surveys of large sky regions in optical bands – from the Sloan Digital Sky Survey (SDSS; Abazajian et al. 2009) and the Dark Energy Spectroscopic Instrument (DESI) Legacy Imaging Surveys (Dey et al. 2019) – and in radio bands – from the HI Parkes All Sky Survey (HIPASS; Koribalski et al. 2004) and the Arecibo Legacy Fast ALFA (ALFALFA) survey (Haynes et al. 2011) – approximately doubled the number of known galaxies in the LV. Another significant addition to the LV sample resulted

from special deep searches for low surface brightness objects in the virial zones of nearby groups (Chiboucas et al. 2009; Müller et al. 2019; Carlsten et al. 2022). Summary data of the LV galaxies are presented in the Updated Nearby Galaxy Catalog (UNGC; Karachentsev et al. 2013), a regularly updated version of which is available online¹. To date, the LV sample comprises about 1400 objects with expected distances $D < 11$ Mpc.

We note that ‘blind’ sky surveys that use the HI 21 cm line have contributed significantly to the population of known late-type dwarf galaxies with star formation. However, the most extensive HI surveys (HIPASS and ALFALFA) cover predominantly the southern sky with declination $\text{Dec} < +38^\circ$. For the northern polar cap region, only one blind survey, of the Canes Venatici constellation, has been performed with the Westerbork radio telescope (Kovač et al. 2009). The new capabilities of the Five-hundred-meter Aperture Spherical radio Telescope (FAST; Jiang et al. 2020) promise to significantly reduce the existing asymmetry of the sky HI view.

According to Zhang et al. (2024), the FAST All Sky HI Survey (FASHI) will survey half the total sky (22 000 square degrees) in the declination interval between -14° and $+66^\circ$. With a median sensitivity of $0.76 \text{ mJy-beam}^{-1}$, a velocity resolution of 6.4 km s^{-1} , and a beam size of $FWHM = 2.9'$, the FAST telescope is capable of detecting significantly more radio sources than the 300 m Arecibo Telescope. The first release of the FAST survey covers close to 7600 square degrees. A list of 41 741 sources with redshifts $z < 0.09$ detected in this survey has recently been published by Zhang et al. (2024).

¹ <http://www.sao.ru/lv/lvgdb>

2. New Local Volume candidates

Among the radio sources from the Zhang et al. (2024) catalogue, there are 580 objects with heliocentric radial velocities $V_h < 1000 \text{ km s}^{-1}$. Many of them are identified with well-known LV galaxies. Inspecting this sample, we discovered 27 sources absent from the LV database. Seven of these radio sources are completely invisible in the DESI Legacy Imaging Surveys. They may be dark galaxies without any stellar counterpart or be equivalents to the high velocity clouds of the Milky Way.

Images of 20 galaxies, identified with the FAST sources, are presented in Fig. 1. The basic parameters of these galaxies are listed in Table 1: (1) the galaxy names, (2) their equatorial coordinates (in degrees; epoch J2000.0), (3) the heliocentric radial velocity (in km s^{-1}), (4) the width of the HI line at half intensity from the maximum (km s^{-1}), (5) the integrated HI line flux (in Jy km s^{-1}), (6) the distance to the galaxy (in Mpc) determined by its radial velocity and taking the local velocity field calculated according to the numerical action method (NAM) into account (Shaya et al. 2017; Kourkchi et al. 2020), (7) the apparent UV magnitude in the far-UV band from the Galaxy Evolution Explorer (GALEX; Martin et al. 2005; Gil de Paz et al. 2007), (8–9) the apparent g and r magnitudes from the DESI Legacy Imaging Surveys (Dey et al. 2019), (10) the integral apparent B magnitude determined by the relation $B = g + 0.313(g - r) + 0.227$ as recommended by Lupton², or taken from NASA Extragalactic Database (NED)³ when a galaxy is outside the DESI Legacy Imaging zone, (11) the galaxy hydrogen mass expressed as $\log(M_{\text{HI}}/M_{\odot}) = 5.37 + 2 \log(D_{\text{Mpc}}) + \log(S_{\text{HI}})$, (12) the galaxy stellar mass determined as $\log(M_*/M_{\odot}) = 12.23 + 2 \log(D_{\text{Mpc}}) - 0.4B$ with the apparent B magnitude corrected for Galactic extinction (to estimate the galaxy stellar mass via its V -band luminosity, we used the relation $M_*/M_{\odot} = 1.4(L_V/L_{\odot})$, as justified by McGaugh & Schombert 2014, and the average color $(B - V) = +0.37$ for late-type dwarf galaxies; Makarova et al. 1998), and (13) the galaxy distance determined by the Tully-Fisher (TF) relation between the HI line width and the absolute B magnitude, $M_B = -19.99 - 7.27(\log W_{50} - 2.5)$ (Tully et al. 2008). For some of the gas-dominated galaxies, we used the magnitude $m_{21} = 17.4 - 2.5 \log(S_{\text{HI}})$ instead of the B magnitude. We also include notes about surrounding galaxies (14). As can be seen from Fig. 1, the optical diameters of the galaxies, being less than the beam size of $FWHM = 2.9'$, do not exceed $1'$.

We also include the galaxy UGC 63 in Table 1. Its HI parameters were known previously, but it has not been considered before as a member of the LV.

We note that, in general, the NAM distance estimations agree well with those determined using the TRGB distance estimate method. However, in specific sky regions close to the radius of the zero velocity sphere of the Virgo cluster, for example in the region of the Coma I group around NGC 4278 (Karachentsev et al. 2011), the difference between D_{NAM} and D_{TRGB} is large. For our LV member candidates, we therefore selected from the FASHI catalogue (Zhang et al. 2024) only galaxies for which the D_{NAM} estimates do not differ greatly from the D_{TF} estimates.

3. HI clouds in the LV galaxy groups

Table 2 presents seven cases for which nearby HI sources from the FASHI catalogue are not identified with any optical counterpart in the g and r bands of the Legacy Imaging Surveys, nor in the UV (GALEX) or infrared (Wide-field Infrared Survey Explorer) wavebands. These sources are all located in well-known nearby galaxy groups. The first six columns of Table 2 are similar to those of Table 1. Columns (7) and (8) present the name and distance (in Mpc) from the main galaxy in these groups. Columns (9) and (10) give the difference between the radial velocities (in km s^{-1}) of the HI cloud and the central galaxy, as well as the projected separation between them (in kpc), assuming that the cloud is at the same distance as the host galaxy. Column (11) provides the hydrogen mass of the clouds calculated as described for Table 1. The bottom part of Table 2 presents the relevant data for four other known HI clouds in the LV groups: HIJASS1021+68 (Boyce et al. 2001), CVnHI (Kovač et al. 2009), M94-HIn 9 (Zhou et al. 2023), and GBT 1355+54 (Mihos et al. 2012).

We also identified in the FASHI catalogue 12 LV galaxies with known optical radial velocities for which HI parameters were absent. Their HI parameters are listed in Table 3: (1) a galaxy name, (2) equatorial coordinates, (3–5) HI galaxy parameters from FASHI (Zhang et al. 2024), (6) the galaxy distance (in Mpc) calculated via the NAM (Shaya et al. 2017; Kourkchi et al. 2020), and (7–8) estimates of hydrogen and stellar masses.

Appendix A contains the names of the galaxies presented in Tables 1–3 and the corresponding ID numbers of the radio sources from the FASHI catalogue (Zhang et al. 2024). Appendix B shows the profiles of all the new LV HI sources in the same sequence as given in Tables 1–3.

4. Discussion and conclusion

As seen from Table 1, all nearby FASHI sources have radial velocities $V_h < 850 \text{ km s}^{-1}$. They are star-forming dwarf galaxies of morphological types Irr, Im, or BCD with a median color index of $g - r = 0.21$. The ones that lie within the GALEX viewing area have significant fluxes in the far-UV band. More than half of the HI sources with optical counterparts have a hydrogen mass that exceeds their stellar mass. The gas-rich dIrr galaxy FASHI1206+45 has a hydrogen-to-stellar mass ratio of 5.6.

Table 4 presents the average hydrogen and stellar masses for three categories of the FASHI sources: new LV dwarfs with an optical counterpart, HI sources without an optical counterpart, and the known LV dwarfs with new HI redshifts. There is no significant difference in the mean HI mass between the three subsamples. However, the HI clouds have a noticeably greater standard deviation (s.d.) in HI masses. The characteristic hydrogen mass of the new LV objects is $1.0 \times 10^7 M_{\odot}$ with a typical ratio $M_{\text{HI}}/M_* = 1.3$. Assuming that HI sources with no visible optical counterpart have $g > 21.5$ mag, we estimate their average hydrogen-to-stellar mass ratio to be more than 80.

Most of these dwarf galaxies are located in the general field, though some of them are very isolated objects. Three dIrrs turned out to be peripheral members of known groups around M 101 and M 106 (also known as NGC 4258).

Estimates of distances to galaxies in Table 1, made according to the classic TF relation (Tully et al. 2008) or based on the galaxy's baryonic analogue under the assumption that the shape of a dwarf is described by a rotating ellipsoid with an axis ratio $b/a \approx 0.6$ (Karachentsev et al. 2017), are in satisfactory agreement with kinematic distance estimates (NAM), accounting for

² <https://www.sdss3.org/dr10/algorithms/sdssUBVRITransform.php#Lupton2005>

³ <https://ned.ipac.caltech.edu/>

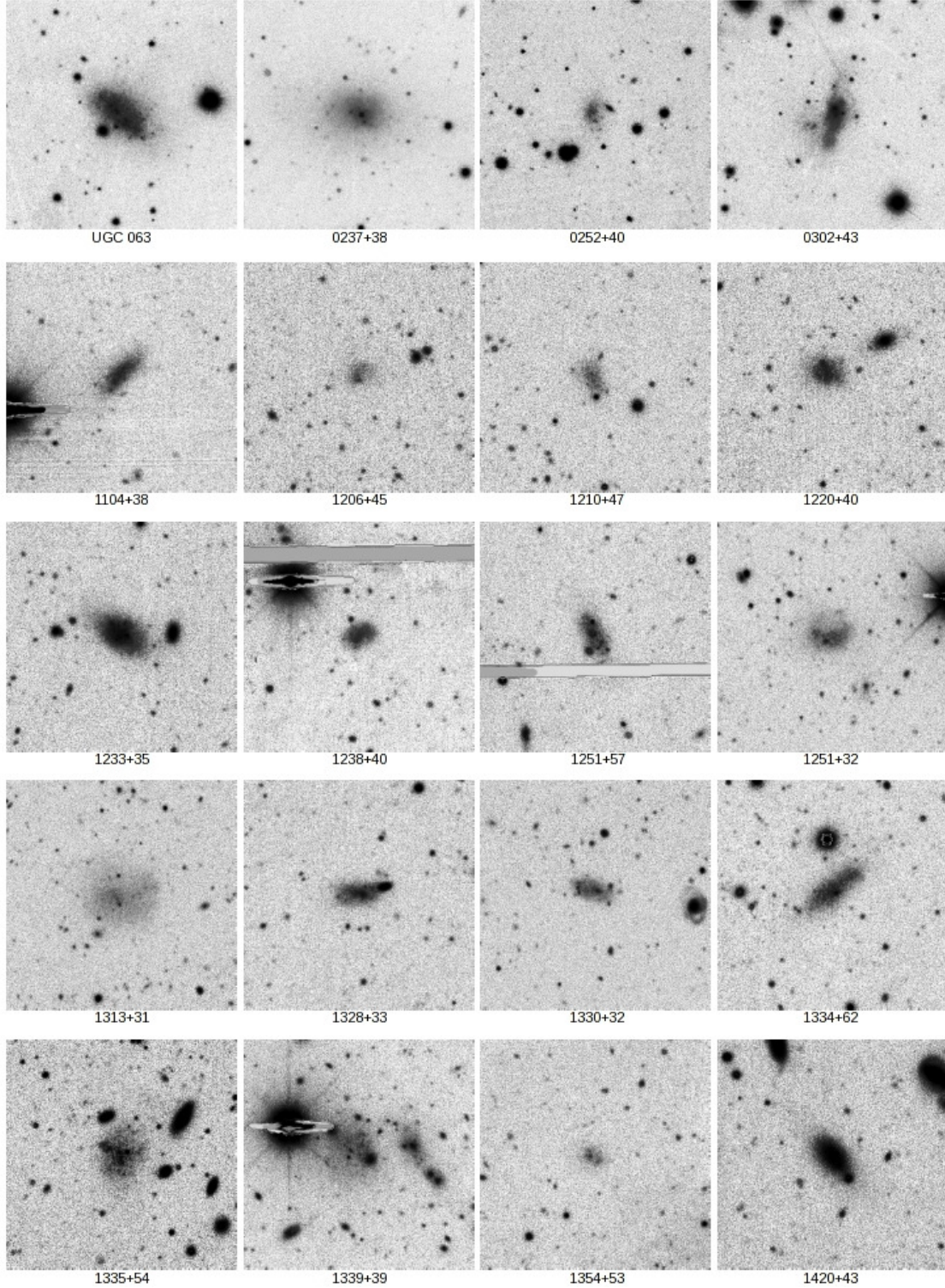


Fig. 1. Images of the 20 new dwarf galaxies identified with the FASHI radio sources. Most of the images are taken from the DESI Legacy Imaging Surveys. Each image side is $2'$. North is up, and east is to the left.

the local velocity field. The mean-square difference of the distance estimates is 2.1 Mpc, or 22% at the average distance of these objects, $D_{\text{NAM}} = 9.5$ Mpc.

Relatively isolated dark HI clouds in the LV groups, presented in Table 2, have parameters W_{50} and S_{HI} close to the parameters of usual dIrr galaxies. Their mean-square velocity difference relative to the host galaxies in the groups amounts to $\langle \Delta V^2 \rangle^{1/2} = 49$ km s $^{-1}$, and their average projected separa-

tion from the main galaxies, $\langle R_p \rangle$, is 90 kpc. These clouds can be considered test particles that characterise the groups' kinematics. The average virial mass of the groups is $M_v/M_\odot = 1.18 \times 10^6 \langle \Delta V^2 \times R_p \rangle$, where ΔV is expressed in km s $^{-1}$ and R_p in kpc (Karachentsev & Kashibadze 2021), and equals $(2.7 \pm 1.0) 10^{11} M_\odot$. The median K -band luminosity of the host galaxies in the groups under consideration is $6.2 \times 10^{10} L_\odot$, which is close to the Milky Way luminosity. For such luminous galaxies,

Table 1. LV galaxy candidates from FASHI DR1.

Name	RA (2000.0)Dec	V_h	W_{50}	S_{HI}	D_{NAM}	m_{FUV}	g	r	B	$\log M_{HI}$	$\log M_*$	D_{TF}	Note
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
UGC 63	001.962 +35.966	438	39	3.14	9.17	17.38	–	–	15.58	7.79	8.01	6.3	
FASHI0237+38	039.329 +38.930	420	34	0.76	9.76	–	–	–	17.8	7.23	7.20	11.4	
FASHI0252+40	043.042 +40.779	375	28	0.32	9.18	–	–	–	19.0	6.80	6.70	13.8	
FASHI0302+43	045.581 +43.663	289	21	0.43	8.15	19.31	16.97	16.53	17.33	6.83	7.38	5.8	
FASHI1104+38	166.148 +38.737	610	24	0.40	9.64	–	17.80	17.74	18.04	6.94	7.00	9.5	
FASHI1206+45	181.688 +45.494	610	24	0.23	9.69	21.28	20.39	20.17	20.68	6.70	5.95	–	(a)
FASHI1210+47	182.566 +47.574	408	23	0.44	7.06	20.91	18.89	18.68	19.18	6.71	6.30	8.2	(b)
FASHI1220+40	185.042 +40.878	520	21	0.21	7.26	21.02	18.50	18.09	18.85	6.41	6.44	10.9	
FASHI1233+35	188.313 +35.734	817	35	0.92	10.32	17.98	16.76	16.53	17.06	7.36	7.44	10.0	
FASHI1238+40	189.627 +40.863	644	22	0.24	9.21	18.90	17.93	17.75	18.21	6.68	6.89	9.0	(a)
FASHI1251+57	192.767 +57.379	426	21	0.59	9.03	–	17.76	17.59	18.04	7.05	6.95	7.6	
FASHI1251+32	192.914 +32.181	849	19	0.43	10.15	19.77	18.60	18.49	18.86	7.02	6.72	8.0	
FASHI1313+31	198.328 +31.415	801	20	0.44	9.69	21.09	18.03	17.70	18.36	6.99	6.88	8.3	
FASHI1328+33	202.144 +33.147	754	33	1.31	9.60	18.39	17.53	17.38	17.80	7.45	7.08	9.1	
FASHI1330+32	202.538 +32.287	744	24	0.72	9.38	18.62	17.45	17.44	17.68	7.17	7.11	8.0	
FASHI1334+62	203.578 +62.960	392	35	0.81	9.92	19.75	17.77	17.55	18.06	7.27	7.03	12.5	(a)
FASHI1335+54	203.982 +54.742	358	21	0.43	7.46	–	18.85	18.74	19.11	6.75	6.35	8.1	(c)
FASHI1339+39	204.938 +39.135	682	25	0.97	9.96	18.65	17.45	17.51	17.68	7.35	7.16	8.3	
FASHI1354+53	208.530 +53.787	297	22	0.30	6.43	–	19.73	19.35	20.07	6.46	5.84	–	(c)
FASHI1420+43	215.051 +43.020	628	32	0.48	10.86	18.65	16.97	16.73	17.27	7.12	7.41	10.0	

Notes. ^(a) An isolated dwarf; ^(b) a satellite of M 106; ^(c) a probable satellite of M 101.

Table 2. HI clouds in the LV groups.

Name	RA(2000.0)Dec	V_h	W_{50}	S_{HI}	D_{NAM}	Host	D_{host}	Δ_V	R_p	M_{HI}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
FASHI1219+46a	184.822 +46.738	403	48	6.84	6.89	M 106	7.66	−44	76	7.88
FASHI1219+46b	184.962 +46.503	391	35	3.56	6.57	M 106	7.66	−56	109	7.56
FASHI1219+46c	184.969 +46.632	388	36	3.41	6.54	M 106	7.66	−59	92	7.53
FASHI1231+41	187.770 +41.141	629	36	6.16	9.10	NGC 4490	8.91	43	79	8.08
FASHI1243+32	190.846 +32.723	617	46	5.74	7.21	NGC 4631	7.35	34	41	7.84
FASHI1250+41	192.601 +41.520	328	31	0.32	4.39	M 94	4.41	20	32	6.16
FASHI1251+41	192.814 +41.594	235	43	0.69	3.17	M 94	4.41	−73	37	6.21
HIJASS1021+68	155.251 +68.700	46	50	10.0	2.75	M 81	3.70	84	151	7.25
CVnHI	185.181 +46.209	420	20	0.28	6.58	M 106	7.66	−27	152	6.45
M94HIin9	192.967 +40.291	298	20	0.23	3.80	M 94	4.41	−10	65	5.89
GBT1355+54	208.711 +54.647	210	27	1.10	4.54	M 101	6.95	−30	151	6.73

Table 3. New HI data for the known LV objects.

Name	RA(2000.0)Dec	V_h	W_{50}	S_{HI}	D_{NAM}	$\log M_{HI}$	$\log M_*$
	hh mm ss .oo " " "	km s ^{−1}	km s ^{−1}	Jy·km s ^{−1}	Mpc	$M_\odot$	$M_\odot$
MCG+06-27-017	12 09 56.4+36 26 07	325	48	1.43	4.26	6.78	7.56
LVJ1218+4655	12 18 11.1+46 55 01	396	62	3.11	6.83	7.53	7.10
SBS1224+533	12 26 52.6+53 06 19	291	31	1.46	6.36	7.14	7.29
PGC4074723	12 40 29.9+47 22 04	523	20	0.46	8.53	6.89	6.73
dw1303+42	13 03 14.0+42 22 17	449	33	0.25	6.48	6.39	6.37
Dw1311+4051	13 11 41.3+40 51 47	604	21	0.46	9.32	6.97	6.36
CGCG 217-018	13 12 51.8+40 32 35	565	65	4.88	9.01	7.97	7.97
dw1313+46	13 13 02.0+46 36 08	388	27	0.75	6.22	6.83	6.50
CGCG 189-050	13 17 04.9+37 57 08	334	27	2.14	4.20	6.95	7.06
PGC2229803	13 27 53.1+43 48 55	434	30	0.41	6.55	6.62	7.20
MCG+08-25-028	13 36 44.8+44 35 57	488	30	1.03	7.87	7.17	7.50
LVJ1342+4840	13 42 20.1+48 40 57	434	22	0.54	7.59	6.86	7.29

Table 4. Average parameters of the HI sources.

Category	N	$\log \frac{M_{\text{HI}}}{M_{\odot}}$	s.d.	$\log \frac{M_{*}}{M_{\odot}}$	$\log \frac{M_{\text{HI}}}{M_{*}}$
New LV	20	7.00 ± 0.08	0.34	6.89	0.11
HI-clouds	11	7.05 ± 0.24	0.75	< 5.15	> 1.90
Known LV	12	7.01 ± 0.12	0.46	7.08	-0.07

the virial radius of their dark halo amounts to $R_v \sim 300$ kpc. Consequently, the subsystem of HI clouds is concentrated predominantly in the central part of the groups, with a characteristic radius three times less than R_v . In this volume, the ratio $M_v/L_K = (4.4 \pm 1.7)M_{\odot}/L_{\odot}$, estimated via the kinematics of HI clouds, is in line with the average ratio of $\langle M_v/L_K \rangle = 17.4 \pm 2.8(M_{\odot}/L_{\odot})$ obtained for halos of major spiral galaxies in the LV on the scale of their virial radius as based on the kinematics of satellites (Karachentsev & Kashibadze 2021).

It should be noted that for FASHI, the lower radial velocity limit is $V_h = 200 \text{ km s}^{-1}$. However, there are about known 200 galaxies in the LV with radial velocities $V_h < 200 \text{ km s}^{-1}$. Hence, some fraction of the LV population will remain undetected by this survey. Obviously, the establishment in FASHI of a lower radial velocity limit is due to the difficulty in detecting the HI signal of a galaxy against the bright local HI background from the Milky Way.

Our identification of radio sources from the first FASHI release with optical objects led to the detection of 20 new dwarf galaxy candidates in the LV, as well as 7 HI clouds in nearby groups without signs of a stellar population. The upcoming completion of FASHI promises to increase the sample of LV galaxies.

The new LV candidates have radial velocities measured with a typical error of about 1 km s^{-1} . Using new objects to trace the local field of peculiar velocities, determined by local attractors, requires high-precision TRGB distances that need to be obtained with space telescopes.

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Appendix A: Cross-identification with the FASHI catalogue

Table A.1.

Galaxy name	FASHI ID
UGC 063	20230057537
FASHI0237+38	20230057540
FASHI0252+40	20230021207
FASHI0302+43	20230025382
FASHI1104+38	20230017803
FASHI1206+45	20230027281
FASHI1210+47	20230029574
FASHI1220+40	20230021454
FASHI1233+35	20230058904
FASHI1238+40	20230021429
FASHI1251+57	20230038542
FASHI1251+32	20230058517
FASHI1313+31	20230007323
FASHI1328+33	20230061148
FASHI1330+32	20230008631
FASHI1334+62	20230064037
FASHI1335+54	20230036458
FASHI1339+39	20230018394
FASHI1354+53	20230063286
FASHI1420+43	20230024668
FASHI1219+46a	20230028812
FASHI1219+46b	20230028556
FASHI1219+46c	20230028794
FASHI1231+41	20230021838
FASHI1243+32	20230058573
FASHI1250+41	20230022318
FASHI1251+41	20230022402
MCG+06-27-017	20230013995
LVJ1218+4655	20230028964
SBS1224+533	20230034659
PGC4074723	20230029371
dw1303+42	20230023590
Dw1311+4051	20230021424
CGCG 217-018	20230020782
dw1313+46	20230028693
CGCG 189-050	20230061751
PGC2229803	20230025576
MCG+08-25-028	20230026440
LVJ1342+4840	20230062806

Appendix B: HI profiles of the new Local Volume objects

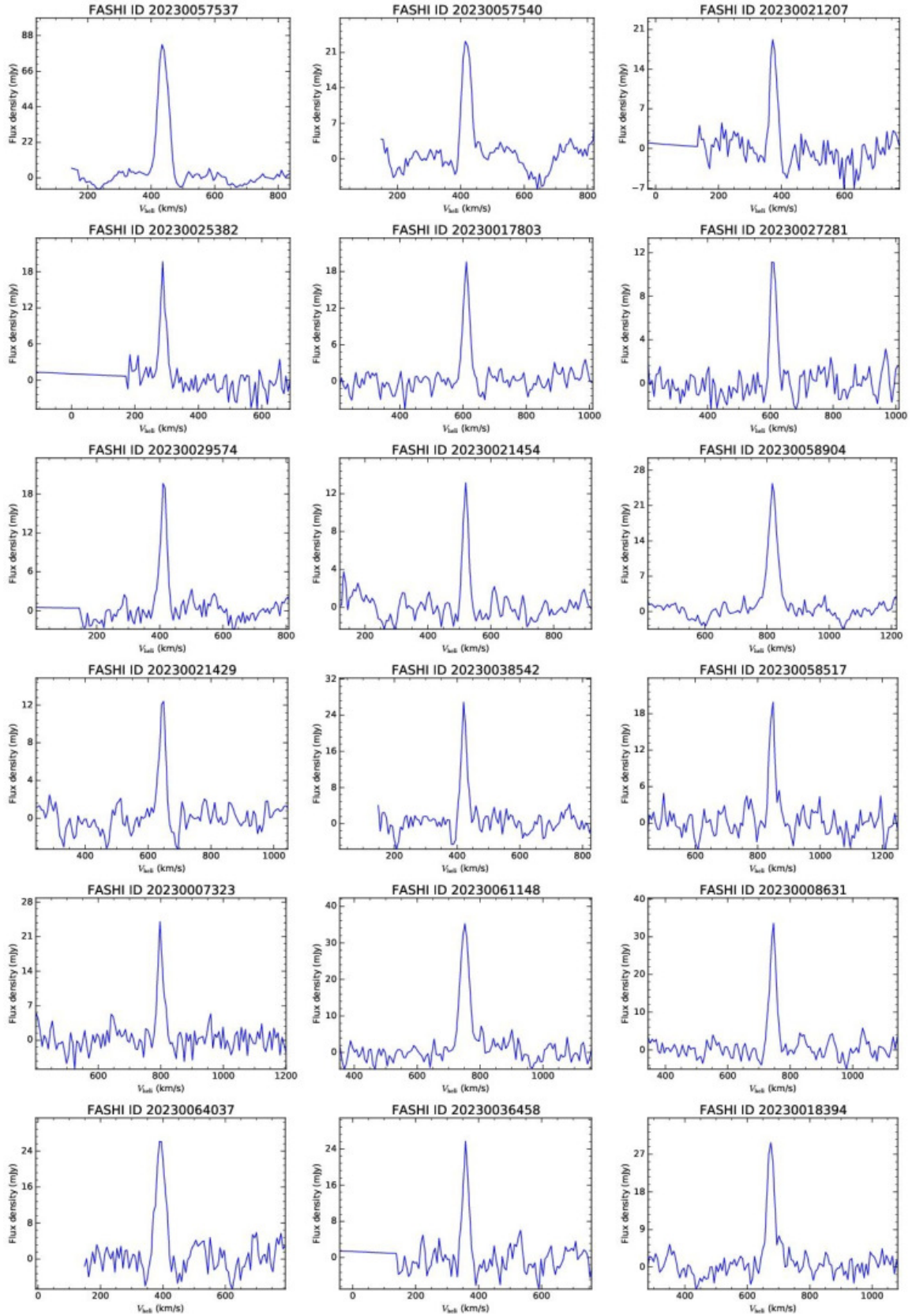


Fig. B.1. Profiles of 39 new LV HI sources from FASHI given in the same sequence as in Tables 1–3.

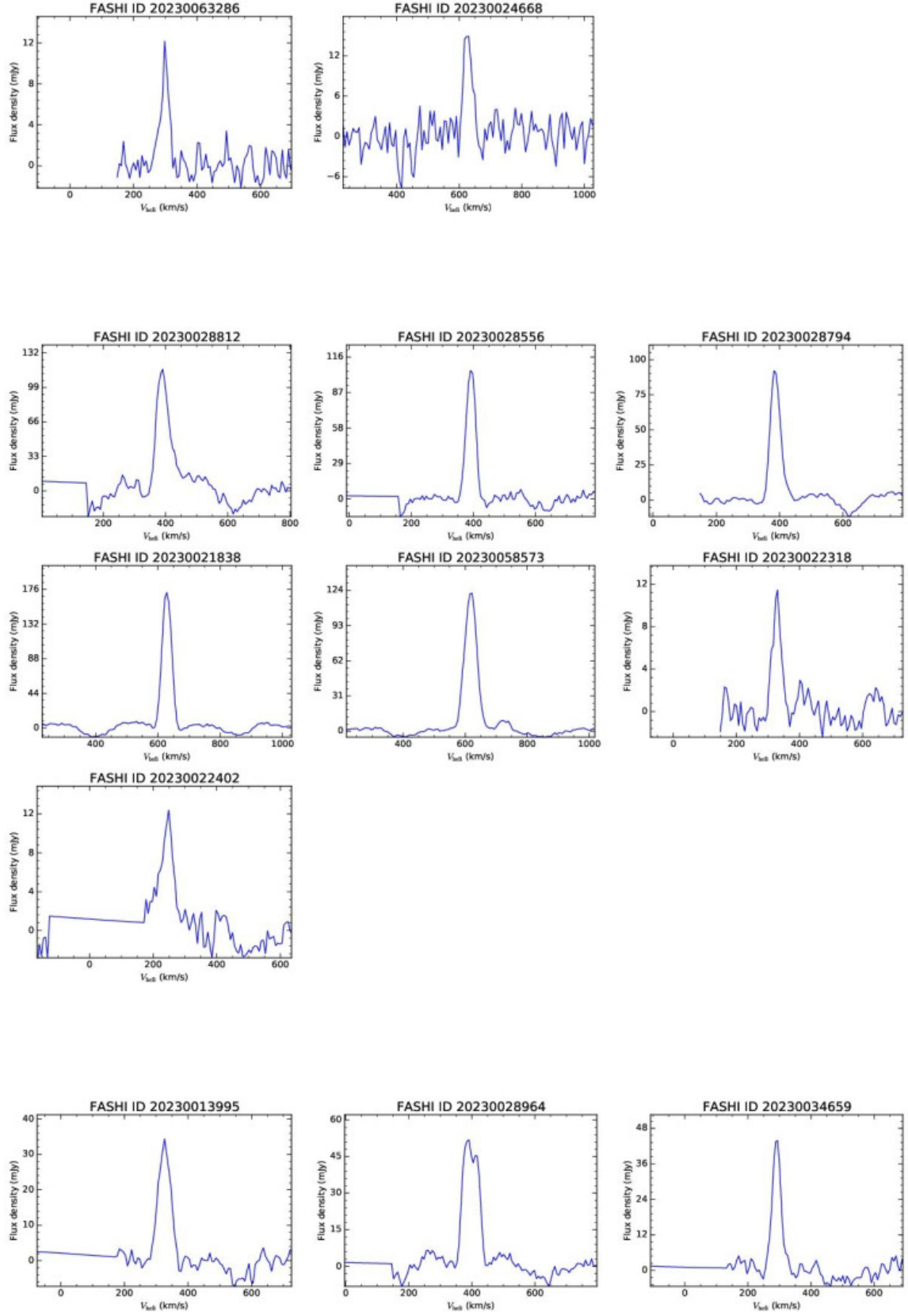


Fig. B.2. Continued.

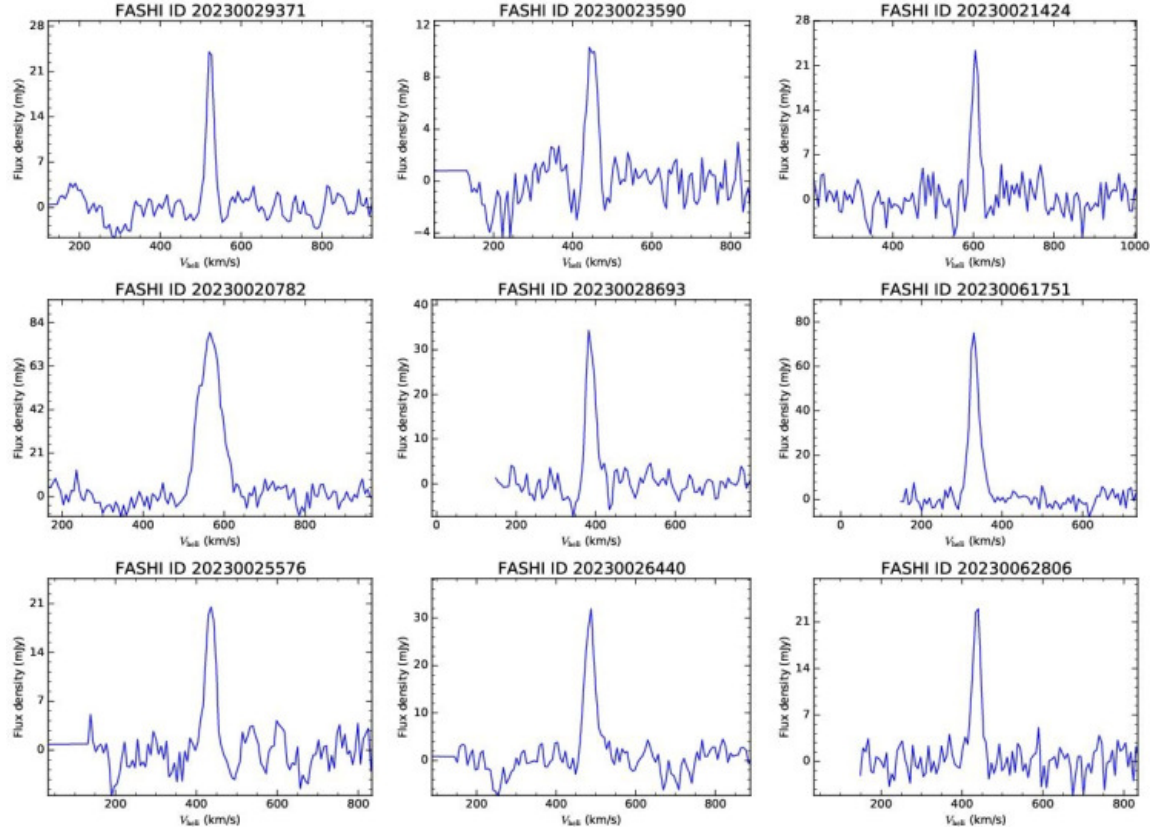


Fig. B.3. Continued.