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Wide-field Imaging of the Environments of LITTLE THINGS Dwarf Irregular Galaxies

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Abstract

We have obtained wide-field images of 36 of the 41 LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes, The H I Nearby Galaxy Survey) nearby (<10.3 Mpc) dwarf irregular and blue compact dwarf galaxies. Although the LITTLE THINGS galaxies were chosen to be non-interacting and no companions were found in H I imaging, the purpose of this imaging was to search for optical companion galaxies that had been missed in imaging with smaller fields of view and that might indicate an external factor in ongoing star formation. The limiting magnitudes of the images range from 19.7 to 28.3 mag arcsec^{-2}, with a median value of 25.9 mag arcsec^{-2}. We did not find any unknown companions. Two of the LITTLE THINGS galaxies, NGC 4163 and NGC 4214, and the fainter dwarf, UGCA 276, lie potentially within 100 kpc of each other, but our imaging does not reveal any stellar bridge between the galaxies. This project was part of the Lowell Amateur Research Initiative.

Key words: galaxies: irregular – galaxies: star formation

Supporting material: extended figure

1. Introduction

LITTLE THINGS[13] (Local Irregulars That Trace Luminosity Extremes, The H I Nearby Galaxy Survey; Hunter et al. 2012a) is a multiwavelength survey of 37 dwarf irregular (dIrr) galaxies and 4 blue compact dwarfs (BCD) aimed at understanding what drives star formation in tiny systems. The LITTLE THINGS galaxies were chosen to be nearby (⩽10.3 Mpc), contain gas so they could be forming stars, and cover a large range in dIrr galactic properties.

In order to concentrate on internal processes, the LITTLE THINGS galaxies were also chosen to be non-interacting. That is, they are not companions of giant galaxies and show no obvious signs of currently undergoing an interaction with another galaxy. One of the LITTLE THINGS data sets includes H I emission maps over a moderately large field of view (FOV; 30′), and these data did not reveal any nearby companions containing gas.

However, in 2012 several groups announced the discovery of a stellar dwarf companion to the irregular galaxy NGC 4449 (Martínez-Delgado et al. 2012; Rich et al. 2012). The companion had not shown up in the H I maps because it has been stripped of its gas by NGC 4449. Although the optical companion was noticed previously on Digitized Sky Survey (POSS-II) plates (Karachentsev et al. 2007), its significance was not realized and it was not caught in subsequent imaging of NGC 4449 because it was outside of the FOV of the typical astronomical imagers. Thus, it became clear that wide-field imaging of the LITTLE THINGS sample to search for stellar companions would be important in determining the current isolated status of the LITTLE THINGS galaxies.

At the Society for Astronomical Sciences conference in 2012 May, Lowell Observatory launched the Lowell Amateur Research Initiative (LARI). LARI is designed to bring amateur and professional astronomers together in collaborative research projects. This was an excellent opportunity to obtain the needed images of the galactic environments of LITTLE THINGS, and so this became one of the LARI projects (for another example of a survey of dwarf galaxies by amateurs, see Henkel et al. 2017). In this paper we present the results of imaging 36 of the LITTLE THINGS galaxies by 10 dedicated amateur astronomers with an expertise in deep sky imaging.

2. Observations

The observing team's telescope and camera facilities, image FOV, and pixel scales are given in Table 1 and the observations are listed in Table 2. One observer, Leshin, used two different telescopes with different FOVs, and both are listed in Table 1, and in Table 2 the images obtained with the larger FOV are labeled as "Leshin-TEC" under "Observer." The distances to the galaxies and the FOVs in kpc at the galaxy are also given in Table 2. The FOV ranges from 5 to 166 kpc with a median of 41 kpc. For comparison the dwarf companion to NGC 4449 is 10 kpc from NGC 4449, measured center to center. We also

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Table 1
Observers and Facilities

Observer	Location	Telescope	Camera	Field of View (degree × degree)	Pixel Scale (arcsec)
Stephen Leshin	Sedona, AZ, USA	14.5-in f/9 Ritchey-Chrétien Cassegrain	STL 11000XM CCD	0.6 × 0.4	0.56
		5.5-in f/7 refractor	QSI 583wsg	1.02 × 0.75	1.09
Alson Wong	Landers, CA, USA	14-in f/10 Schmidt Cassegrain	STL 11000M	0.6 × 0.4	1.09
Maurice Clark	Lubbock, TX, USA	20-in f/6.8 Cassegrain	SBIG 1001E CCD	0.4 × 0.4	1.44
Jerald Kamienski	Aguanga, CA, USA	14-in f/7.2 Dall-Kirkham astrograph	Appogee F16M Large Format CCD	0.65 × 0.60	0.72
Netzer Moriya	Mitzpe Ramon, Negev, Israel	17-in f/6.8 Dall-Kirkham Cassegrain	FLI Proline PL16803 monochrome CCD	0.65 × 0.54	0.65
Burley Packwood	Green Valley, AZ, USA	4.2-in f/5 Refractor	SBIG STT-8300M CCD	1.95 × 1.5	2.10
Bob Birket	Pie Town, NM, USA	12.5-in Ritchey-Chrétien Cassegrain	STL11000M CCD	0.60 × 0.45	0.88
William Edwards	Crawfordville, GA, USA	12-in f/8 Schmidt Cassegrain	SBIG ST10-XME CCD	0.20 × 0.25	0.67
Mervyn Millward	George Town, Tasmania, Australia	3.35-in Refractor	QSI 583wsg CCD	2.28 × 1.72	2.47
Ian Wheelband	Toronto, Canada	12.5-in Ritchey-Chrétien Cassegrain	SBIG STL1100M CCD	0.72 × 0.54	1.29

give the size of the FOV in units of R_{25}, the radius of the galaxy at a B-band surface brightness of 25 mag arcsec^{-2}.

The images are shown in Figure 1. Most images were centered on or near the LITTLE THINGS galaxy and a single image was taken. However, NGC 4214 and NGC 4163 were imaged by Leshin in a mosaic because both LITTLE THINGS galaxies are fairly near each other. Also, Haro 36 was placed at the northern edge of the FOV in order to include NGC 4707, a galaxy that had been suggested as interacting with Haro 36, at the southern edge. In addition some galaxies were observed twice with different FOVs and depths: NGC 2366, NGC 4214/NGC 4163, WLM, UGC 8508, and Haro 36. Both of the sets of images are included here.

In order to maximize throughput, all of the observations were made through a luminance filter that cuts off light in the UV (below about 3900 Å) and the IR (above about 7000 Å). Most of the images have been flat-fielded, and some were flat-fielded using the images themselves (DDO 52, DDO 133, DDO 154, DDO 155, IC 10, NGC 2366-Wheelband, UGC 8508-Clark, and Mrk 178). Images of DDO 216, NGC 1569, and possibly DDO 63 also contain Milky Way cirrus that is seen as large-scale filamentary structure across the FOV. We have rotated the images so that north is up and east is to the left.

We have calibrated the photometry of each image to the Johnson V filter using V-band images obtained of the galaxies by Hunter & Elmegreen (2006). We calculated a limiting magnitude as 3×rms, where the rms is the standard deviation of the background in the image. We then calculated a surface brightness limit as this magnitude per arcsec^{-2}. The limiting magnitude and surface brightness of each image are given in Table 2. The limiting magnitudes range from 19.7 mag arcsec^{-2} to 28.3 mag arcsec^{-2}, with a median value of 25.9 mag arcsec^{-2}. For comparison the central surface brightness of the dwarf companion to NGC 4449 is about 25.5 mag arcsec^{-2} in V (Rich et al. 2012).

3. Results

We examined each image for extended objects that were likely to be galactic in nature, and used the NASA/IPAC Extragalactic Database (NED) to determine the radial velocity of the cataloged galaxies. Most of the objects that we found in the images were cataloged galaxies at significantly higher radial velocities than our object galaxies, placing them in the background. In most cases, we have not identified these background objects in Figure 1.

Galaxies of special note:

DDO 154. DDO 154 is also known as NGC 4789A, which implies that it is associated with NGC 4789. However, NGC 4789 has a recessional velocity of 8365 km s^{-1}, while the velocity of DDO 154 is 374 km s^{-1}, so they are not physically close. Many of the other galaxies in the FOV of DDO 154 are at velocities of 6000–8000 km s^{-1}.

NGC 3738. NGC 3756 is relatively nearby in angular separation. However, its distance is placed at about 19.7 Mpc by various studies listed by NED. NGC 3738, on the other hand, is placed at 4.9 Mpc by Karachentsev et al. (2003).

Haro 36. Haro 36 and NGC 4707 are only 30.″2 apart on the sky. However, Haro 36 is at a radial distance of approximately 9.3 Mpc (Hunter et al. 2012a), and NGC 4707 is measured from the tip of the red giant branch to be at a distance of 6.5 Mpc (Tully et al. 2013). Thus, unless one of the distances of these objects is wrong, the two galaxies are likely of order 2.8 Mpc apart and are unlikely to have gravitationally interacted.

Mrk 178. The object 3.″3 to the northwest from Mrk 178 is UGC 6538, which has a radial velocity of 3077 km s^{-1}, while the radial velocity of Mrk 178 is 250 km s^{-1}. In the FOV of our image there are also 32 objects with redshifts from −98 to 61 km s^{-1}, but these objects are identified as stars. There are also other objects with very high redshifts in the NED catalog, and other faint galaxies without radial velocities that look like background spirals or ellipticals.

NGC 4214/NGC 4163. There are two LITTLE THINGS galaxies, NGC 4163 and NGC 4214, that are close to each other and to the faint dwarf UGCA 276. NGC 4163 is at a radial distance of 2.87 ± 0.03 Mpc (Tully et al. 2013), NGC 4214 is at 2.94 ± 0.18 Mpc (Maíz-Apellániz et al. 2002), and UGCA 276 is at 2.96 ± 0.10 (Jacobs et al.

Table 2
Observations

Galaxy	Observer	R.A. (2000) (h m ss.s)	Decl. (2000) (d ′ ″)	Exposure (hr)	Date	D (Mpc)[a]	FOV (kpc)[b]	R_{25}[c] (kpc)	FOV(R_{25})[d]	3×rms[e] (mag per pixel)	μ_V[f] (mag per arcsec^2)
CVnIdwA	Leshin	12 38 40.2	+32 46 14	24.7	2017 May	3.6	38 × 25	…	…	27.2	25.9
DDO 43	Leshin	07 28 29.2	+40 45 57	25.0	2015 May	7.8	82 × 55	1.39	59 × 40	27.3	26.0
DDO 46	Leshin	07 41 19.2	+40 07 56	26.0	2016 Mar	6.1	64 × 43	1.31	49 × 33	27.7	26.4
DDO 47	Wong	07 41 48.1	+16 46 31	19.7	2014 Feb	5.2	54 × 36	1.08	50 × 33	22.3	22.4
DDO 50	Wong	08 19 08.7	+70 43 25	24.3	2013 Feb	3.4	36 × 24	2.92	12.3 × 8.2	24.6	24.8
DDO 52	Moriya	08 28 26.1	+41 53 47	11.0	2017 Apr	10.3	117 × 97	1.35	87 × 72	25.5	24.6
DDO 63	Wong	09 40 15.9	+71 07 43	14.0	2015 Apr	3.9	41 × 27	1.47	28 × 18.4	25.7	25.9
DDO 69	Wong	09 59 28.3	+30 44 56	26.0	2014 Apr	0.8	8 × 6	0.31	26 × 20	25.5	25.7
DDO 70	Wong	10 00 00.0	+05 19 50	20.3	2013 Apr	1.3	14 × 9	0.80	17.5 × 11.2	23.9	24.1
DDO 75	Leshin	10 10 57.9	−04 40 10	25.7	2017 Apr	1.3	14 × 9	0.90	15.6 × 10.0	27.4	26.1
DDO 87	Leshin	10 49 36.5	+65 31 50	32.0	2017 Feb	7.7	81 × 54	…	…	27.2	26.0
DDO 101	Leshin	11 55 55.9	+31 32 09	8.3	2015 Jun	6.4	67 × 45	1.28	52 × 35	26.4	25.1
DDO 126	Wong	12 27 03.3	+37 07 29	27.7	2014 May	4.9	51 × 34	1.17	43 × 29	19.5	19.7
DDO 133	Moriya	12 32 31.5	+31 29 37	12.5	2016 Aug	3.5	40 × 33	1.08	37 × 30	25.5	24.6
DDO 154	Kamienski	12 54 10.2	+27 06 24	40.0	2017 Apr	3.7	42 × 39	0.96	39 × 36	25.2	24.5
DDO 155	Packwood	12 59 30.0	+14 07 45	37.0	2016 Apr–May	2.2	75 × 58	0.40	188 × 146	25.2	26.8
DDO 165	Leshin	13 06 25.3	+67 42 25	30.3	2013 Jun	4.6	48 × 32	1.89	25 × 17	27.1	25.8
DDO 167	Birket	13 13 17.8	+46 18 09	10.5	2014 Apr–May	4.2	44 × 33	0.60	73 × 55	26.6	26.3
DDO 168	Wong	13 14 27.2	+45 55 46	20.0	2013 Jun	4.3	45 × 30	1.78	25 × 17	26.4	26.6
DDO 187	Leshin	14 15 56.7	+23 03 19	36.0	2012 Jul	2.2	23 × 15	0.44	52 × 34	27.2	26.0
DDO 210	Millward	20 46 52.0	−12 50 57	18.0	2015 Jun	0.9	36 × 27	0.12	295 × 221	24.1	26.1
DDO 216	Wong	23 28 35.0	+14 44 30	32.3	2012 Aug	1.1	12 × 8	0.42	29 × 19	25.1	25.3
IC 10-HI blob	Leshin	00 15 37.0	+60 15 47	25.0	2013 Nov	0.7	7 × 5	…	…	…	…
IC 10	Clark	00 20 17.3	+59 18 36	2.4	2012 Jul	0.7	5 × 5	…	…	25.1	25.9
IC 1613	Wong	01 04 49.2	+02 07 48	22.0	2013 Nov	0.7	7 × 5	1.03	7 × 5	23.1	23.3
LGS 3	Wong	01 03 55.3	+21 52 03	34.0	2012 Oct	0.7	7 × 7	…	…	26.4	26.6
NGC 1569	Leshin	04 30 49.8	+64 50 51	37.0	2014 Jan	3.4	36 × 25	…	…	27.4	26.1
NGC 2366	Edwards	07 28 45.7	+69 12 46	51.7	2015 Feb	3.4	12 × 15	2.92	4.1 × 5.1	29.2	28.3
NGC 2366	Wheelband	07 29 20.5	+69 11 47	5.0	2012 Nov	3.4	43 × 32	2.92	15 × 11	25.7	26.3
NGC 3738	Kamienski	11 35 48.8	+54 31 26	40.0	2017 Apr	4.9	56 × 51	2.17	26 × 23	26.1	25.4
NGC 4163/NGC 4214	Leshin	12 14 17.2	+36 15 50	14/8/6.3[g]	2014 Apr	2.9	82 × 31	2.99	27 × 10	26.0	24.8
NGC 4163/NGC 4214	Packwood	12 15 20.0	+36 09 49	35.8	2016 Mar–Apr	2.9	99 × 76	2.99	33 × 25	25.8	27.4
NGC 6822	Leshin	19 44 57.9	−14 48 11	37.0	2012 Oct	0.5	5 × 3.5	…	…	27.2	26.0
SagDIG	Leshin	19 29 58.9	−17 41 25	22.7	2014 Oct	1.1	12 × 8	0.51	23 × 16	27.6	26.3
UGC 8508	Leshin	13 30 50.8	+54 54 54	31.7	2014 Jul	2.6	27 × 18	0.63	42 × 28	27.6	26.3
UGC 8508	Clark	13 30 42.4	+54 54 13	1.7	2012 Jul	2.6	18 × 18	0.63	28 × 28	24.8	25.6
WLM	Leshin	00 01 59.2	−15 27 41	38.7	2012 Nov	1.0	10 × 7	1.02	10 × 7	27.4	26.1

Table 2
(Continued)

Galaxy	Observer	R.A. (2000) (h m ss.s)	Decl. (2000) (d ′ ″)	Exposure (hr)	Date	D (Mpc)[a]	FOV (kpc)[b]	R_{25}[c] (kpc)	FOV(R_{25})[d]	3×rms[e] (mag per pixel)	μ_V[f] (mag per arcsec^2)
WLM	Leshin-TEC	00 01 59.2	−15 27 41	11.5	2012 Nov	1.0	18 × 13	1.02	18 × 13	25.4	25.6
Haro 29	Leshin	12 26 16.7	+48 29 38	36.3	2013 May	5.8	61 × 41	0.81	75 × 50	27.8	26.5
Haro 36	Leshin	12 48 13.3	+51 27 48	45.0	2013 Mar	9.3	97 × 65	1.95	50 × 33	27.0	25.7
Haro 36	Leshin-TEC	12 48 13.3	+51 27 48	9.8	2013 Mar	9.3	166 × 122	1.95	85 × 63	26.0	26.2
Mrk 178	Kamienski	11 33 28.4	+49 13 59	28.0	2017 Jul–Aug	3.9	44 × 41	0.70	63 × 59	25.9	25.2

Notes.
[a] Distance to the galaxy. See references in Hunter et al. (2012a).
[b] FOV at the galaxy as $x \times y$ dimensions before the image was rotated to put north up.
[c] R_{25} is the radius of the galaxy to a surface brightness limit of 25 mag arcsec^{-2} in B, from Hunter & Elmegreen (2006). R_{25} are not available for CVnIdwA, DDO 87, and LGS 3 because the central point in the B-band surface brightness profile is fainter than 25 mag arcsec^{-2}. R_{25} is missing for IC 10, NGC 1569, and NGC 6822 because the B-band surface brightness profile does not extend as faint as 25 mag arcsec^{-2}.
[d] FOV of the image in units of R_{25}.
[e] rms is the standard deviation of the background of the image, calibrated to the Johnson V-passband and given as a magnitude.
[f] Surface brightness corresponding to 3×rms of sky in the image, calibrated to the Johnson V-passband.
[g] Individual exposure times for each part of the mosaic.

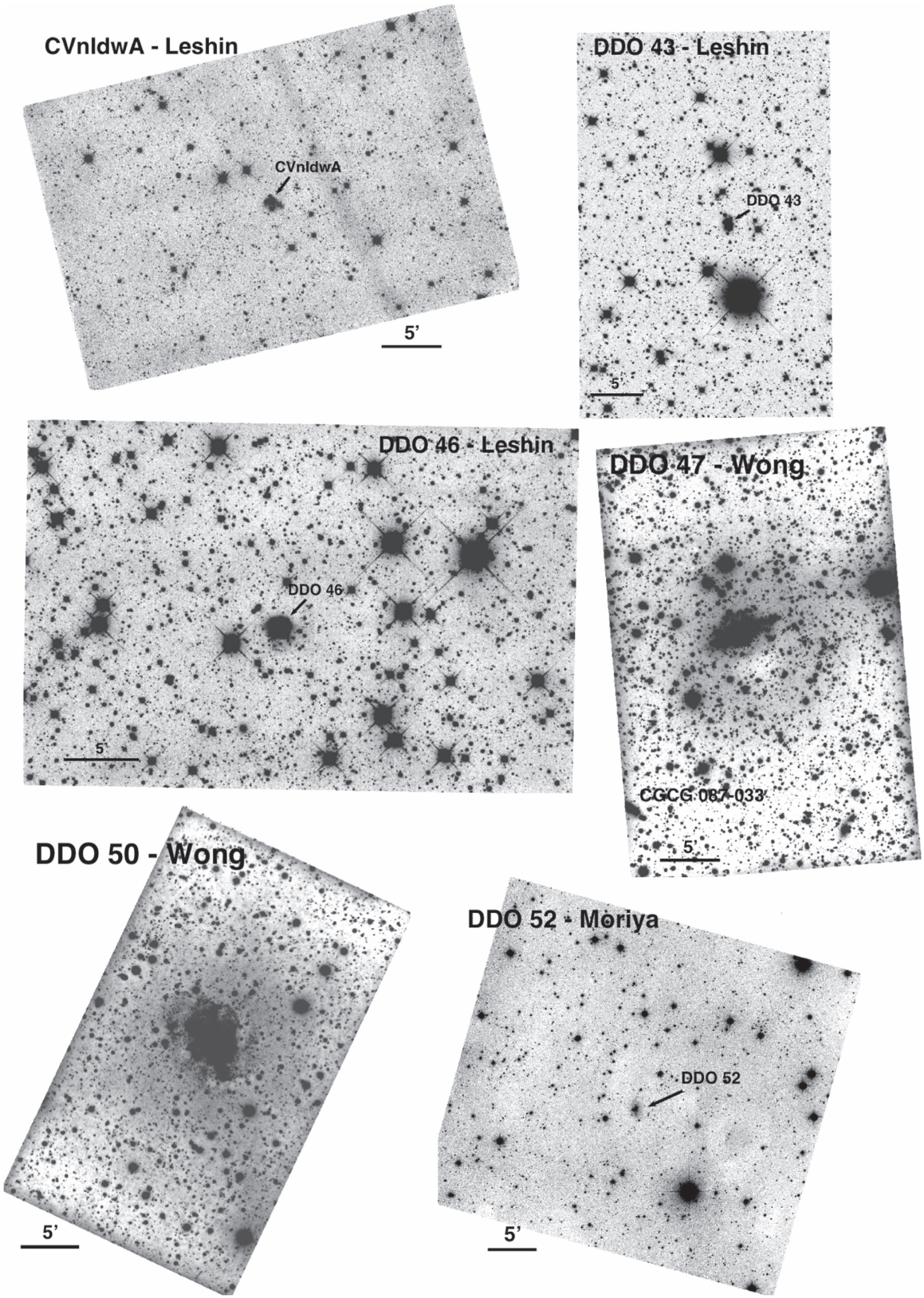

Figure 1. Images through luminance filters of fields surrounding LITTLE THINGS galaxies. There are many background galaxies, most of which are not labeled, but NGC 4163 and NGC 4214 have a nearby galaxy, UGCA 276. NGC 4707 in the field of Haro 36 is 2.8 Mpc in the foreground, and NGC 4789 in the field of DDO 154 is about 90 Mpc in the background. "IC 10 H I blob" refers to the gas cloud at the end of a long H I filament extending from IC 10 that could be an interacting companion. The center of the H I cloud is indicated by a circle on the image. No stellar component of the H I cloud was found.

(An extended version of this figure is available.)

2009). NGC 4214 and UGCA 276 are 10.′6 apart on the sky and at the same distance, so their angular separation is about 9.1 ± 0.3 kpc. The uncertainty in the distances give an uncertainty in the radial separation of 200 kpc. NGC 4163 and UGCA 276 are 34.′2 apart on the sky for a separation of 29 ± 1 kpc and they are 90 ± 104 kpc apart in radial distance, so their separation is about 95 ± 104 kpc. Although we see no obvious signs of an interaction in the optical or H I, the distances between them are small enough that it is plausible that gravitational effects between these three galaxies occurred at some time in the past.

IC 10. IC 10 was imaged as part of this program, but no optical companions were found in the FOV. However, an H I survey of a large region around IC 10 has revealed an H I blob at the end of a long filament (Nidever et al. 2013). This structure could be what is left of an interacting companion or could be a filament resulting from a merger of IC 10 with another dwarf (Ashley et al. 2014). The H I object is off the image centered on IC 10 and shown in Figure 1. Another image was taken centered on the H I blob, also shown in Figure 1, but no stellar counterpart was detected.

4. Summary

We obtained images in the optical broad band of 36 of the LITTLE THINGS nearby dwarf irregular and BCD galaxies. The purpose was to search for previously unknown optical companion galaxies that might be interacting with these galaxies that were chosen to be fairly isolated. No objects had been found in H I radio interferometric imaging, but optical companions without gas could not be ruled out. The concern was that galaxy–galaxy gravitational interactions would introduce external influences to the star formation processes. We found no new stellar companions to these galaxies. However, we note that NGC 4163 and NGC 4214, two of the LITTLE THINGS galaxies, appear to lie within 100 kpc of each other and the tiny dwarf UGCA 276, which is close enough for interactions to be possible, although we did not detect any stellar bridges between the galaxies.

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