An Inventory of Supershells in nearby Galaxies: First Results from THINGS

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ABSTRACT

The H I Nearby Galaxy Survey (THINGS), is a 21-cm H I line survey of a sample of 34 nearby ($2-15$ Mpc) galaxies. The observations were carried out with the VLA and have a velocity resolution of 5 $\mathrm{km\,s^{-1}}$ or better and an angular resolution of $6''$ which at this distance range corresponds to a linear resolution of $60-440$ pc. One of the primary goals of THINGS is to look at the fine-scale structure of the Interstellar Medium (ISM) and examine how it varies as a function of Hubble type, star formation rate, galaxy mass, metallicity, etc. Previous studies have shown that the morphology of the neutral ISM is greatly affected by massive stars through the combined effects of stellar winds and supernova explosions. Because massive stars tend to form in associations they will end their lives within the same, relatively short time span and within a small volume, which leads to the formation of expanding bubbles of coronal gas in the ISM. These structures compress the neutral gas and can trigger secondary or induced star formation on their rims where presumably molecular clouds are formed. We present an inventory of more than 1000 holes and shells in 20 nearby galaxies, and some first results from a comparison between these galaxies as far as the properties of their H I holes are concerned. These properties include the size of the holes, their expansion velocities, energy requirements and kinematic ages.

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1. Introduction

Studies of H I in nearby galaxies using powerful synthesis instruments such as the Westerbork Synthesis Radio Telescope (WSRT) and the Very Large Array (VLA) have revealed the effects of star formation on the interstellar medium in nearby galaxies. Holes, shells, bubbles, filaments and other such features characterize the gas distribution of the Galaxy and nearby galaxies. These features represent a deficiency of interstellar matter and are usually bordered by regions of higher density that may be neutral or ionised. Their shape is roughly circular and they are, in most cases, the result of strong localized depositions of energy into the interstellar medium. Stellar winds and supernovae from OB associations are considered the main driving forces behind the creation of holes and shells (Weaver et al. 1977; McCray & Kafatos 1987). Other proposed mechanisms include turbulence (Hatzidimitriou et al. 2005, Dib & Burkert 2005), gamma-ray bursts (Loeb & Perna 1998; Efremov, Ehlerová & Palouš 1999; Perna & Raymond 2000) and collisions of High-Velocity Clouds with the disc of the galaxy (Tenorio-Tagle & Bodenheimer 1988; Santillan et al. 1999).

So far only about ten galaxies have been observed at an adequate spatial and velocity resolution that would allow the detection of such structures. In the Milky Way, Heiles (1979, 1984) was the first to detect supershells and since then hundreds of shells have been identified. In order to fully understand these structures and their impact on their surrounding ISM, we need to investigate them in a systematic way and thus we need a larger sample that will cover a wide variety of Hubble types.

2. Data

The present study is based on observations carried out within the framework of "The H I Nearby Galaxy Survey" (THINGS) project. THINGS is based on a sample of 34 nearby systems ($2 - 15$ Mpc) observed at high angular ($\approx 6''$) and velocity ($2.6 - 5.2$ $\mathrm{km\,s^{-1}}$) resolution (Walter et al. 2008, submitted). The observations were carried out with the NRAO[1] VLA in B, C, and D configurations, totalling ~ 500 hours. THINGS was designed

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[1] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Table 1. Properties of selected galaxies

Name (1)	Alt (2)	α(J2000) h m s (3)	δ(J2000) $^\circ$ $'$ $''$ (4)	Type (5)	D Mpc (6)	Incl. deg (7)	PA deg (8)	H I Mass 10^8 $M_\odot$ (9)	$\log(D_{25})$ $\log(0.1')$ (10)
NGC 628	M 74	01 36 41.8	+15 47 00.0	SA(s)c	7.3	7	20	38.0	1.99
NGC 2366	DDO 42	07 28 53.4	+69 12 51.1	IB(s)m	3.4	64	40	6.5	1.64
NGC 2403		07 36 51.1	+65 36 02.9	SAB(s)cd	3.2	63	124	25.8	2.20
Holmberg II	DDO 50	08 19 05.0	+70 43 12.0	Im	3.4	41	177	5.9	1.82
DDO 53		08 34 07.2	+66 10 54.0	Im	3.6	31	132	0.6	0.89
NGC 2841		09 22 02.6	+50 58 35.4	SA(r)b	14.1	74	153	85.6	1.80
Holmberg I	DDO 63	09 40 32.3	+71 10 56.0	IAB(s)m	3.8	12	50	1.4	1.52
NGC 2976		09 47 15.3	+67 55 00.0	SAc	3.6	65	335	1.4	1.90
NGC 3031	M 81	09 55 33.1	+69 03 54.7	SA(s)ab	3.6	59	330	36.3	2.33
NGC 3184		10 18 17.0	+41 25 28.0	SAB(rs)cd	11.1	16	179	30.6	1.87
IC 2574	DDO 81	10 28 27.7	+68 24 59.4	SAB(s)m	4.0	53	55	14.7	2.11
NGC 3521		11 05 48.6	−00 02 09.2	SAB(rs)bc	10.7	73	340	80.2	1.92
NGC 3627	M 66	11 20 15.0	+12 59 29.6	SAB(s)b	9.2	62	173	8.2	2.01
NGC 4214		12 15 39.2	+36 19 37.0	IAB(s)m	2.9	44	65	4.1	1.83
NGC 4449		12 28 11.9	+44 05 40.0	IBm	4.2	60	230	11.0	1.67
NGC 4736	M 94	12 50 53.0	+41 07 13.2	(R)SA(r)ab	4.7	41	296	4.0	1.89
DDO 154	NGC 4789A	12 54 05.9	+27 09 09.9	IB(s)m	4.3	66	375	3.6	1.29
NGC 5194	M 51	13 29 52.7	+47 11 43.0	SA(s)bc	8.0	42	172	25.4	1.89
NGC 6946		20 34 52.2	+60 09 14.4	SAB(rs)cd	5.9	33	243	41.5	2.06
NGC 7793		23 57 49.7	−32 35 27.9	SA(s)d	3.9	50	290	8.9	2.02

Note. — Col 1: Galaxy Name; Col 2: Alternative Name; Col 3 and 4: RA and DEC; Col 5: Hubble Type; Col 6: Distance; Col 7: Inclination; Col 8: Position Angle; Col 9: H I Mass; Col 10: Isophotal Diameter

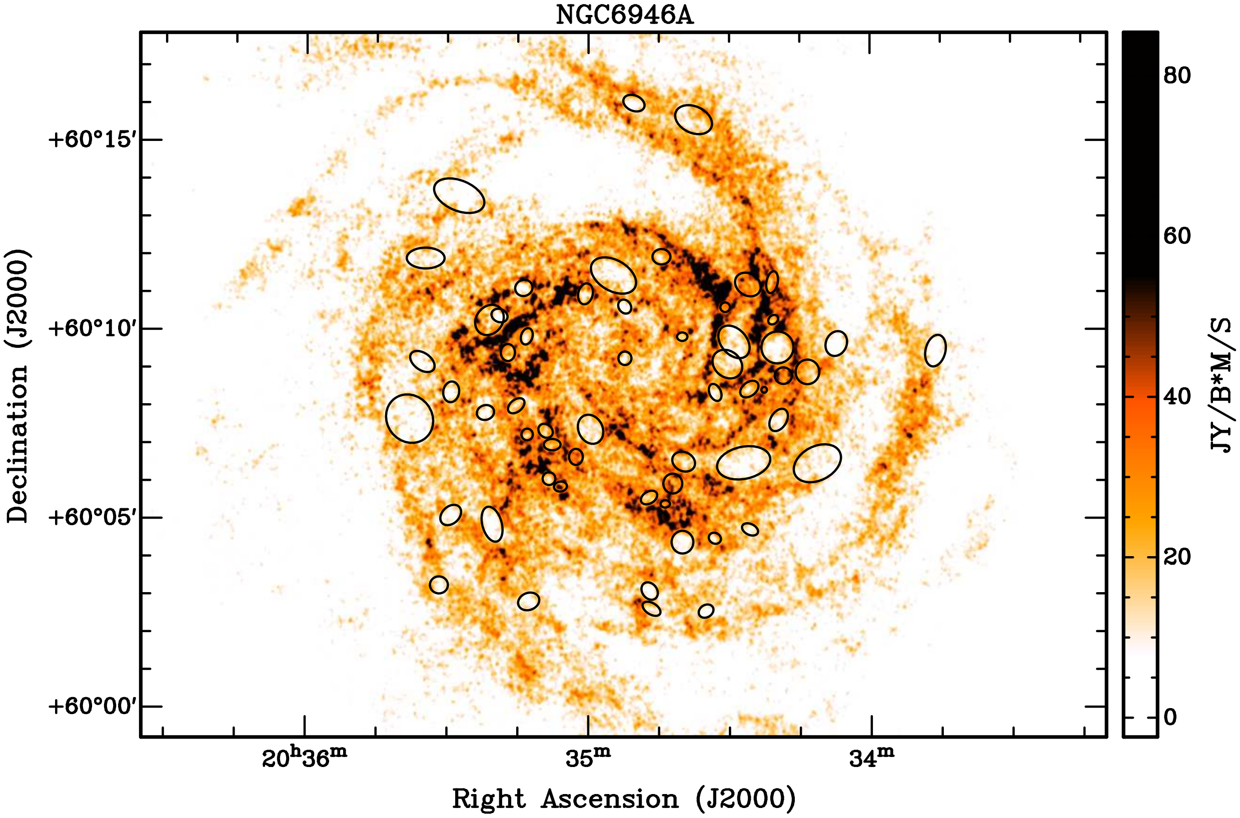

Fig. 1.— H I holes in NGC 6946 overlaid with the H I integrated map.

to complement the Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al. 2003) and the *GALEX* Nearby Galaxies Survey (NGS; Gil de Paz et al. 2007) therefore providing us with multi-wavelength coverage of these galaxies.

For our analysis we selected 20 galaxies from the THINGS sample (Table 1). The basic criterion was to include at least one pair of galaxies from each Hubble type in order to be able to make a comparative study of H I holes across all Hubble types. The galaxies in each pair were also selected to vary substantially in their star formation rates and H I masses. Care was taken to select galaxies for which the H I channel maps had sufficiently high signal-to-noise ratios.

3. Results

Initial results from the THINGS project include the detection of some 1000 H I holes in 20 THINGS galaxies. Working under the hypothesis that these structures originate from stellar winds and SN explosions we have measured and derived their physical properties (such as size, expansion velocity, dynamical age and energy requirements) and we are now performing a comparative analysis based on those properties. We will also explore if there are any connections between the properties of the H I holes and those of the host galaxies (SFR, mass, metallicity, Hubble type among others).

Figure 1 shows the H I surface brightness map of NGC 6946. Note the wealth of structure visible in this map. Overlaid are the approximate locations and outlines of H I holes identified by us. The location of the holes in the discs of the host galaxies is illustrated in Figure 2. The horizontal axis represents galactocentric distance normalized to the maximum extent of the H I disc, R_{max}. From this figure it is evident that wherever there is H I, holes are found, even in the outskirts of galaxies. The vertical line in the figure indicates the location of R_{25}, confirming the finding that holes are found well beyond the main optical body of a galaxy.

Figure 3 shows the distribution of kinematic ages of the H I holes grouped according to galaxy type. It appears that early-type spirals have younger holes (or rather a lack of old holes) which can be understood in terms of the stronger shear these galaxies exhibit. Shear (and spiral density waves) tend to deform and destroy HI holes which also explains why dwarf galaxies (where shear is negligible) have a broader age distribution and show holes with dynamical ages up to 150 Myr.

Under the hypothesis that the H I holes are the result of massive star formation we can determine the star formation rate of the host galaxies based on the number of supernovae needed to create the observed H I holes. Our spatial resolution allows for the detection of holes larger than 100 pc, thus missing out on holes smaller than this value, and therefore our star formation rate estimates will be a lower limit.

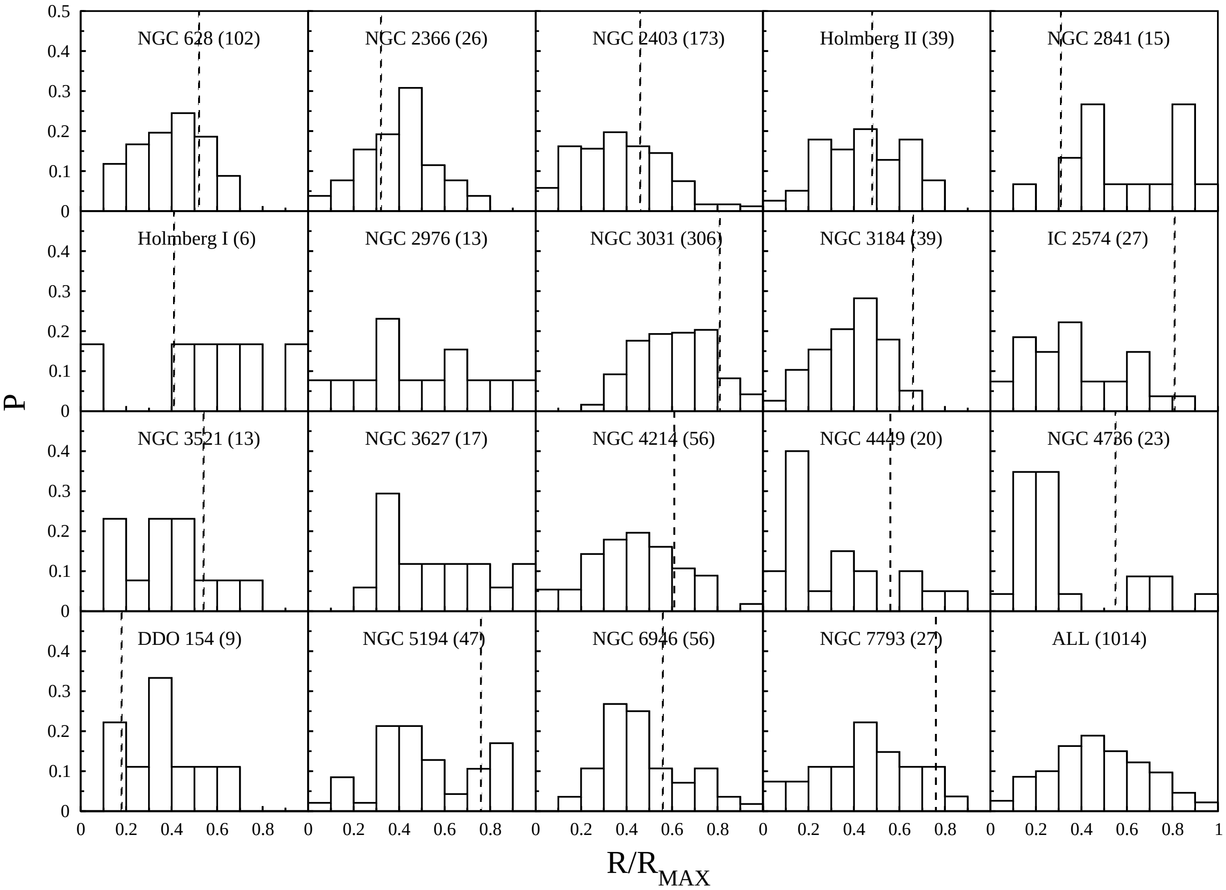

Fig. 2.— Relative radial number distribution, P, of the H I holes. The x axis represents the relative galactocentric radius of an H I hole with respect to the largest extent of the H I disc of the host galaxy, $R_{\rm max}$. The numbers in parenthesis are the numbers of holes detected in each galaxy and the last panel shows the distribution of all holes found in all galaxies. The dashed vertical line indicates for each galaxy the corresponding location of R_{25}. Overall 77% of the holes are located within R_{25} and 23% outside.

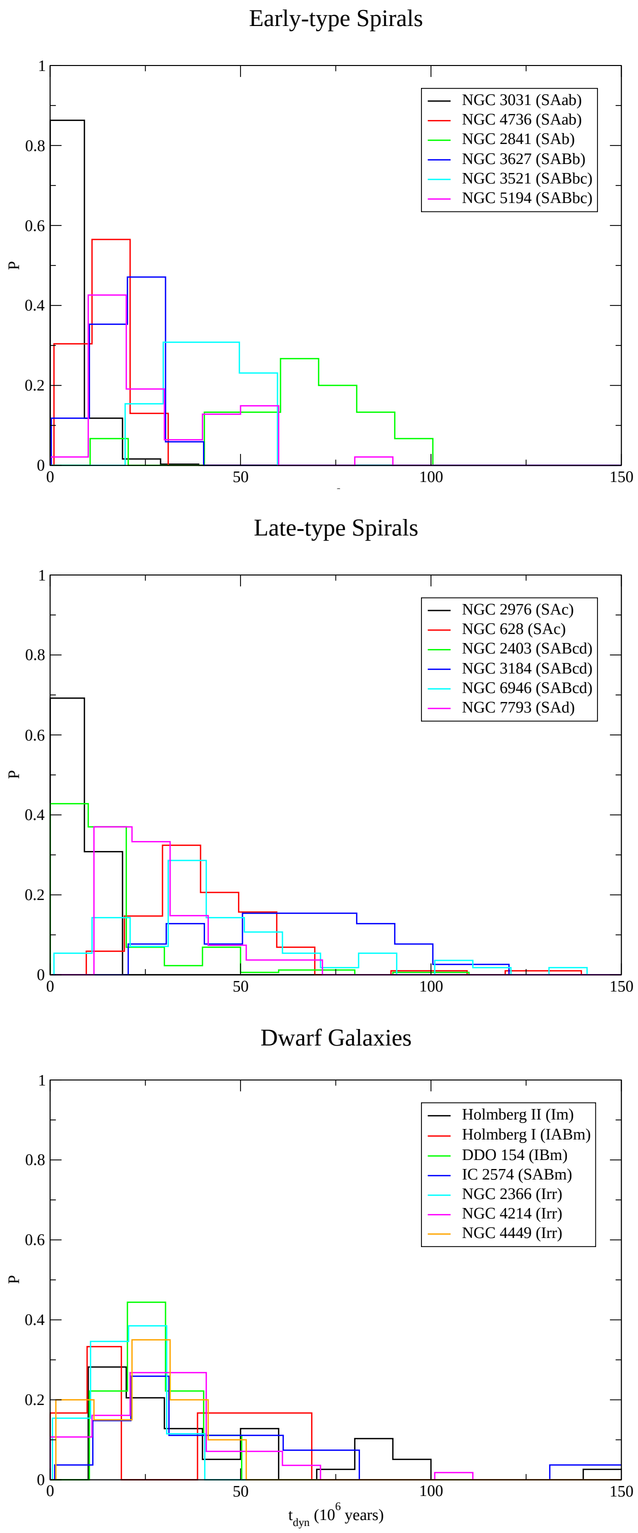

Fig. 3.— The distributions of the kinematic ages of the HI holes divided into 3 different groups of galaxies (from early-type spirals to dwarf galaxies). The $y-$axis shows the relative number distribution, P.

4. Summary

We report on the detection of ~ 1000 holes in the H I distribution of 20 nearby galaxies. The number of holes found in each galaxy and their properties vary greatly across our sample. This is due to a combination of effects. The spatial resolution and orientation of each galaxy is different which influences the efficiency with which holes are detected. And, of course, there are intrinsic differences from galaxy to galaxy, as illustrated in Figure 3. Overall, the diameter of the holes ranges from 100 pc to 2 kpc and their expansion velocity from 4 to 36 $\mathrm{km\,s^{-1}}$ with energy requirement from 2×10^{49} to 8×10^{54} erg. One surprising result is that the holes are distributed across the entire H I layer sometimes well outside the optical disc. The diversity of our sample of galaxies has enabled us to make a comparative study on the properties of the H I holes. With respect to the kinematic age of the holes we found that in dwarf galaxies holes tend to be older compared to the ones found in early and late type spirals.

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