Star Formation at the Lower Mass End of Dwarf Galaxies — The Impact on the Neutral Gas

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Abstract

Theoretical models for low–mass dwarf irregular galaxies predict the partial ("blow–out") or even total ("blow–away") loss of interstellar medium due to supernova explosions within massive star forming regions. We present optical and HI data for two members of the M 81 group, Ho I and M 81 dw A, which exhibit masses in the regime predicted to lose material to the surrounding intergalactic space. We see evidence for blow–out taking place in a visible mass range between $\sim 10^8\,\mathcal{M}_\odot$ and $\sim 10^7\,\mathcal{M}_\odot$.

1 Introduction

The interstellar medium (ISM) of galaxies in general shows a wealth of large and small scale structure. Next to global patterns like spiral arms, one also finds smaller, local structures such as bubbles, shells, supergiant shells, or rings (see e.g., Heiles 1979, 1984; Brinks & Bajaja 1986; Walter & Brinks 1999). In the standard picture, massive stars within star formation (SF) regions provide the kinetic energy to shape the ISM (for a review see e.g. Tenorio–Tagle & Bodenheimer 1988). Strong stellar winds and subsequent supernovae (SNe) explosions release some $\sim 10^{53}$ erg within a stellar cluster of $10^4\,\mathcal{M}_\odot$ over 4×10^7 yr, the longest period for massive stars to exist which share the fate of SNe (Leitherer et al. 1999).

To first order at least, a region of massive SF is oblivious to its environment, dumping the same amount of energy into the ISM whether it finds itself in a large spiral galaxy or in a dwarf irregular galaxy (dIrr). Therefore, going down in overall galaxy mass, the impact of SF and its aftermath becomes proportionally more and more important. This, and the lack of substantial shearing forces, causes the shells to grow to much larger radii in dIrrs (Walter & Brinks 1999).

Once the velocity of an expanding structure exceeds the escape velocity given by the gravitational potential of its host, the shell might break out of the disk and lose part of the material to the surrounding intergalactic space ("blow–out"). This is predicted by recent theories (De Young & Heckman 1994; Mac Low & Ferrara 1999; Ferrara & Tolstoy 2000) for galaxies with visible masses below $\lesssim 10^9\,\mathcal{M}_\odot$. Beyond $\mathcal{M}_{visible} \lesssim 10^6\,\mathcal{M}_\odot$ dIrrs may loose all of their ISM due to the described effects ("blow–away").

It should be noted, though, that observational evidence for a stellar origin of superbubbles or supergiant shells is circumstantial. Only in very few cases are stellar clusters found within giant holes (Stewart & Walter 2000). In most cases these structures do not seem to host remnant stellar clusters, as was pointed out by Rhode et al. (1999).

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2 The dIrrs Ho I and M 81 dw A

The dIrrs Ho I and M 81 dw A are members of the M 81 group of galaxies at a distance of 3.6 Mpc (Freedman et al. 1994). Here we present high velocity and spatial resolution observations in the 21 cm line of neutral hydrogen (H I) performed with the NRAO[1] Very Large Array (VLA) in different configurations (see also Ott et al. 2001). Furthermore, we carried out optical UBVRI observations with the 2.2 m Calar Alto telescope[2].

Ho I and M 81 dw A represent galaxies in the H I mass range of $\sim 10^8\,\mathcal{M}_\odot$ down to $\sim 10^7\,\mathcal{M}_\odot$. With an optical mass which is similar to the gaseous content, we reach visible masses where blow–out should take place, if the theoretical models mentioned in the Introduction hold true. The integrated H I maps, as well as an overlay with the optical counterpart is shown in Fig. 1. The H I morphology of Ho I and M 81 dw A is quite similar, as both galaxies appear with a huge H I ring surrounding most of their optical counterpart.

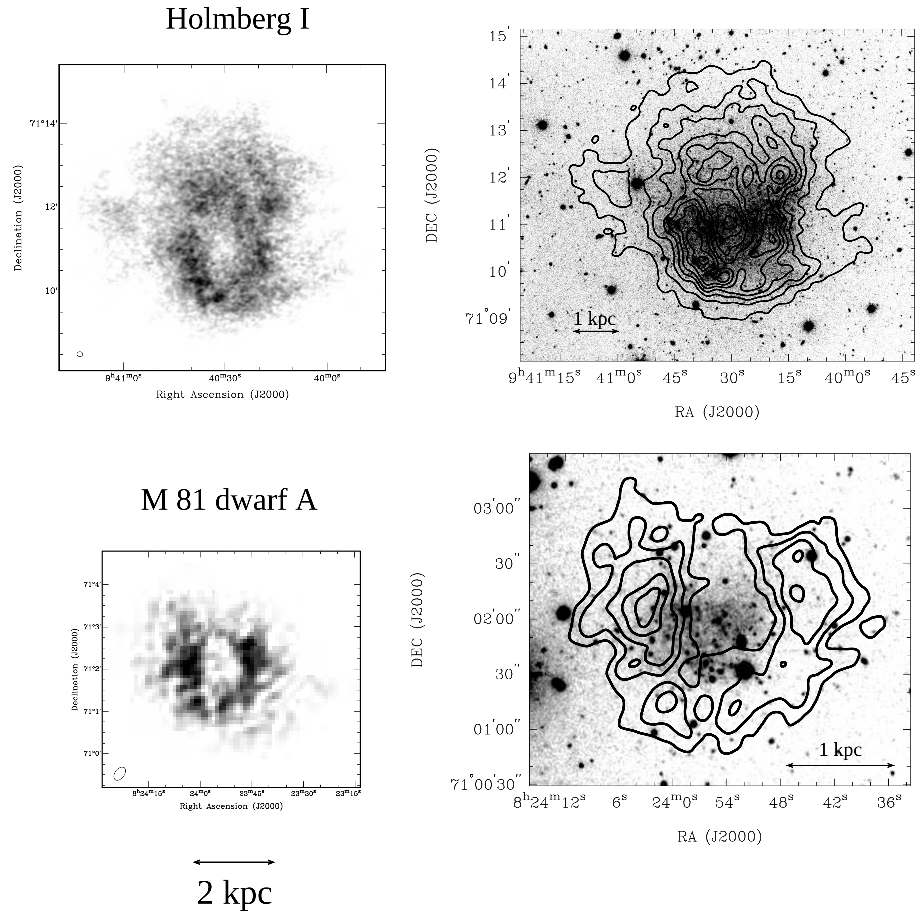

Figure 1: *Left:* 21 cm H I images of Ho I ($\mathcal{M}_{\rm HI} = 1.1 \times 10^8\,\mathcal{M}_\odot$) and M 81 dw A ($\mathcal{M}_{\rm HI} = 8.4 \times 10^6\,\mathcal{M}_\odot$). The images are on the same scale, as indicated by the marker at the bottom. The beam is plotted the lower left corner of each map. *Right:* Optical images of both galaxies. The H I maps are overlaid as contours on our R–band images. Note the difference in linear scale used.

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

[2]The Calar Alto Observatory is operated by the Max–Planck–Institut für Astronomie (Heidelberg) jointly with the Spanish Comisión Nacional de Astronomía.

3 Indications for blow–out in Ho I and M 81 dw A

Since the H I rings of Ho I and M 81 dw A are centered on their optical counterparts, it is suggestive that these structures were created by SF. This is supported by a flat and rather blue surface brightness profile in the optical. Judging from their ring–like morphology, it is likely that the shell in Ho I has broken out of the disk and entered the "snowplow" phase, i.e. an expansion with conservation of momentum. Furthermore, the 1σ scaleheight of the H I layer of Ho I is with $250\,\mathrm{pc} \lesssim h \lesssim 550\,\mathrm{pc}$ considerably less than the radius of the H I ring ($\sim 850\,\mathrm{pc}$). We modelled a post–Sedov expansion phase of a supernova driven shell (Sedov 1959; Mac Low & McCray 1988; Ehlerová et al. 1997) to the H I morphology of Ho I for a range of ages at which break–out might have occurred (see Fig. 2). If the shell indeed suffered break–out right at the maximum of the 1σ scaleheight, than this must have taken place when the age of the shell was some 15 Myr. Silich & Tenorio–Tagle (2001) mentioned, that if the radius of a supergiant shell in a dIrr indeed reaches the 1σ scaleheight of a Gaussian halo, then neither the pressure of the intergalactic medium nor the gravity of the host galaxy is able to retain the swept–up gas. This is exactly the "blow–out" scenario which was alluded to in the Introduction. Different approaches for deriving an age of the shell lead to 80 ± 20 Myr (for details see Ott et al. 2001). The situation in M 81 dw A is similar to Ho I (also regarding the physical properties).

4 Summary

Since the stellar body of Ho I and M 81 dw A is surrounded by a ring–like H I morphology, we assume that SF and subsequent SNe explosions are responsible for the shape of the neutral gas. Table 1 lists the main characteristics of the shells. The dimensions of the shells require an energy input equivalent to ~ 120 and ~ 50 SNe, for Ho I and M 81 dw A respectively. In neither galaxy do we detect any expansion velocity of the shell which might be due to the rather low inclination or that implies that the shell has already stalled. The most likely explanation is that the shell has broken out of the disk at which moment the internal pressure must have dropped rapidly. Hence, there is evidence that these dIrrs with visible masses between $\sim 10^8\,\mathcal{M}_\odot$ and $\sim 10^7\,\mathcal{M}_\odot$ have lost part of their ISM, suffering blow–out.

	Ho I	M 81 dw A
Radius [kpc]	0.85	0.73
FWHM width [kpc]	1.26	1.00
H I mass [$\mathcal{M}_\odot$]	$\sim 8 \times 10^7$	$\sim 8 \times 10^6$
Central H I column density [cm^{-2}]	6×10^{19}	$< 10^{19}$
Average H I column density on the rim [cm^{-2}]	1.2×10^{21}	1.8×10^{20}
Peak H I column density on the rim [cm^{-2}]	2.0×10^{21}	2.6×10^{20}
Energy [erg]	$1.2 \times 10^{53} \mathrel{\hat{=}} 120$ SNe	$4.7 \times 10^{52} \mathrel{\hat{=}} 47$ SNe

Table 1: Properties of the central supergiant H I shells.

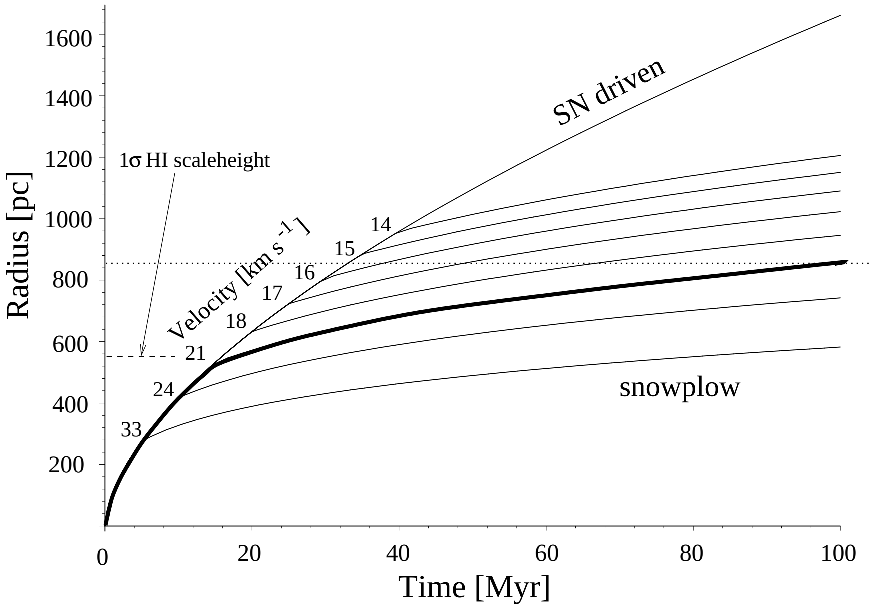

Figure 2: Evolution of the supergiant HI shell which dominates Ho I. After a certain period of SN–driven expansion (post–Sedov phase) the shell enters the "snowplow" phase, due to break–out or cooling. The turn–off points are plotted for critical times t_c=5–40 Myr in steps of 5 Myr. The *dotted line* indicates the observed present–day radius of the supergiant shell. The dashed line represents the 1σ scaleheight of the HI layer of Ho I. Expansion velocities are given at the time of the break–out. We assume that the evolution of the supergiant shell in Ho I followed the thick line.

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