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Starbursts and Extra-planar Hα from SINGG

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Abstract. The NOAO Survey for Ionization in Neutral Gas Galaxies (SINGG) is the largest star formation survey of an H I selected sample. Since the selection is made without regard to optical morphology, it is not biased toward or against "interesting" types of galaxies; thus SINGG is an ideal sample for studying galaxy demographics. Of a sample of 90 extra-galactic sources observed in photometric conditions, all are detected in Hα. This indicates that dormant galaxies, those containing an appreciable ISM but no star formation, are at best rare. We have made first pass morphological surveys for starbursts, as judged by Hα surface brightness, and outflows as judged by extra-planar Hα. We find that about 15% of the sources contain starbursts, with little dependence on the neutral hydrogen mass $\mathcal{M}_{\rm HI}$. Nearly one half of a sample ~ 35 edge-on galaxies show evidence for extra-planar Hα having a scale size of 0.5 Kpc or larger, while nearly one quarter have extra-planar Hα features 1.0 Kpc in size or larger. There is a hint that high $\mathcal{M}_{\rm HI}$ systems preferentially have displaced outflows (chimneys, or fountains) while central outflows (galactic winds) preferentially occur in low $\mathcal{M}_{\rm HI}$ systems. However, a larger sample (e.g. the full SINGG survey) is needed to confirm this trend.

1. Introduction to SINGG

Here I present preliminary morphological results from *SINGG* - the Survey for Ionization in Neutral Gas Galaxies. SINGG is an approved and ongoing survey project of the National Optical Astronomy Observatory (NOAO). It is a follow-up survey to HIPASS - the H I Parkes All Sky Survey (Staveley-Smith *et al.* 1997). HIPASS has surveyed the entire southern sky for neutral hydrogen emission out to nearly 13000 $\rm km\,s^{-1}$. SINGG is intended to look for star formation, as traced by Hα emission, in this H I selected sample.

The primary motivation for SINGG is to measure the star formation rate density of the local universe, $\dot\rho_{\rm SFR}(0)$. The selection by 21cm emission bypasses all the common *optical* selection biases (e.g. dust content and surface brightness), which should allow a more complete and representative survey of local star formation. The planned incorporation of ultraviolet data from *GALEX* and infrared data from *IRAS* and *SIRTF* will allow a multi-wavelength determination of $\dot\rho_{\rm SFR}(0)$, addressing issues of dust extinction and the initial mass function. SINGG is also intended to examine the H II region luminosity function, determining how it varies as a function of morphology and H I mass, $\mathcal{M}_{\rm HI}$.

In this paper I address some of the morphological questions that motivate SINGG. In particular (1) What fraction of gas rich galaxies are dormant? That is, what fraction contains no detectable star formation? (2) How common are starbursts? And, (3) how common are galactic winds? Addressing these questions will give us a better understanding of the life-cycle of star formation, and how star forming galaxies enrich the inter-galactic medium.

After presenting a few more details of the SINGG survey in §2, I discuss the Hα detectability of HIPASS sources in §3. In §4 I present plans for making an objectively defined starburst sample and estimate the starburst incidence rate. In §5 I summarize a morphological survey for extra-planar Hα. Finally §6 summarizes these preliminary results.

2. The SINGG survey: more details

The SINGG sample is selected from the HIPASS survey completely blind to the UV through infrared properties of the sources. A total of 471 targets with a peak H I flux density $f_\nu \geq 0.05$ Jy in the Parkes 21cm spectrum were chosen by $\mathcal{M}_{\rm HI}$ so as to have a flat distribution in $\log(\mathcal{M}_{\rm HI})$. This is impossible at the lowest and highest masses, where the HIPASS sample is volume limited. Otherwise, we have preferentially selected the nearest galaxies in each $\mathcal{M}_{\rm HI}$ bin so as to better resolve H II regions. Figure 1 shows the $\mathcal{M}_{\rm HI}$ distribution of the final sample.

The observations with the CTIO 1.5m typically comprise three exposures in a narrow band filter (matched to the wavelength of Hα at the target's velocity) and a broad band R filter, for total exposure times of 30 and 6 minutes respectively. We use specialized software from the high-z supernova group to align the images, combine the images within each filter and subtract the scaled R-band image to produce the net Hα image. The final images typically have $1.5''$ seeing. The 5σ point source detection limit is typically $F_{\rm H\alpha} \sim 4 \times 10^{-16}\,{\rm erg\,cm^{-2}\,s^{-1}}$. On scales $\gtrsim 15''$ the images are typically flat to better than 1% of the sky level allowing large scale features with $S_{\rm H\alpha} \gtrsim 3 \times 10^{-18}\,{\rm erg\,cm^{-2}\,s^{-1}\,arcsec^{-2}}$ (0.6 Rayleigh) to be discerned at the 5σ level after sufficient smoothing.

3. Star formation in H I selected galaxies

We find that all extra-galactic HIPASS targets display Hα emission. This result is based on data from four observing runs, comprising 90 extra-galactic HIPASS targets (this excludes two frames which targeted High Velocity Clouds and one frame strongly affected by twilight sky). The result is summarized in Fig. 2. All HIPASS targets are comprised of at least one Hα emitting galaxy, defined as a spatially extended and distinct source in the Hα and/or R image having readily detected net Hα emission. In all cases, much of the Hα emission is organized into knots or high surface brightness concentrations – H II regions or starbursts. Hence, all targets are undergoing some star formation.

While extra-galactic H I imaging surveys often turn up sources that were previously uncataloged in optical surveys, free-floating H I sources with no op-

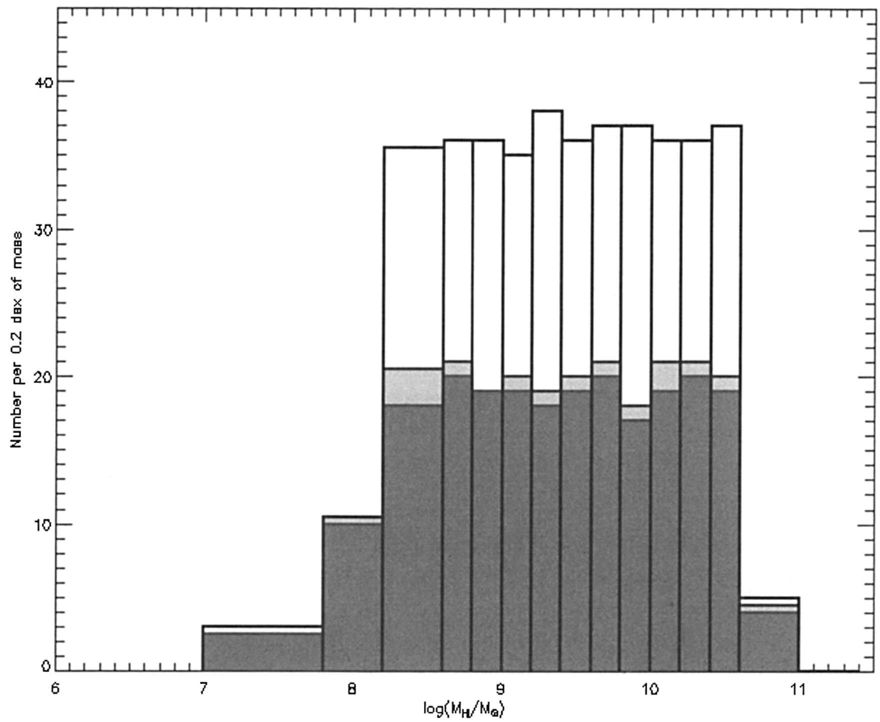

Figure 1. The H I mass histogram of the final SINGG sample. Shading indicates the portion observed in Hα as of July 2003. Lighter shading indicates sources that need further observations.

tical counterpart are rare (Zwaan *et al.* 1997; Ryan-Weber *et al.* 2002). One possible exception is HIPASS J1712-64 (Kilborn *et al.* 2000). However, even in this case the possibility that this may be an extreme version of an HVC bound to our galaxy has not been ruled out. The dearth of free-floating extra-galactic H I may be due to the fact that when there is sufficient H I for a gas cloud to be self gravitating, it is gravitationally unstable until some stars form so that they can heat the ISM enough to arrest further star formation. Low mass H I clouds that are not self-gravitating would have low column density and are susceptible to ionization by the UV background (Zwaan *et al.* 1997). So H I is either associated with stars or destroyed.

Our results allow a stronger statement - dormant galaxies are rare or do not exist. That is, if a galaxy has an ISM with $\mathcal{M}_{\rm HI} \gtrsim 3 \times 10^7 \mathcal{M}_\odot$ it also has *recently* (within 10 Myr) formed high mass stars. The gravitational instability in the ISM is not halted by feedback from evolved stellar populations. Instead new stars continue to form, including the massive stars that ionize H II regions.

While some star formation is always found, the range of star formation morphologies is wide. We find low surface brightness dwarfs with a few faint H II regions, giant spirals with morphologies ranging from flocculent to grand-design,

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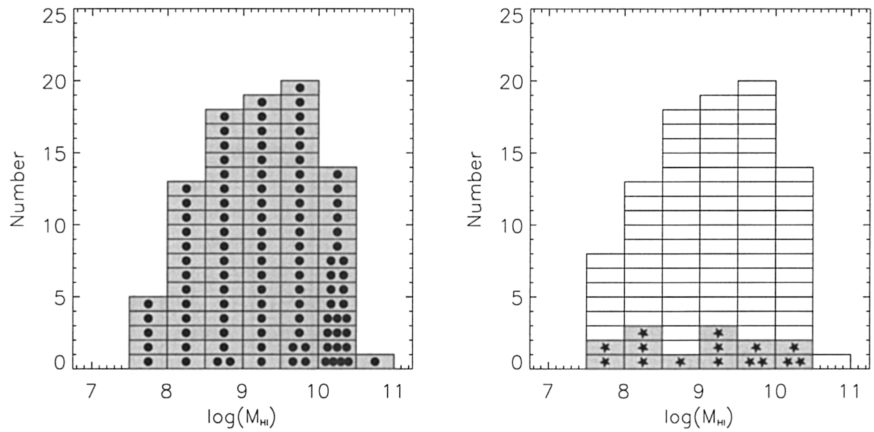

Figure 2. a (left). The H I mass histogram of 90 SINGG targets observed over four observing runs. Each rectangle represents one HIPASS target, while each dot within a rectangle represents an Hα emitting galaxy. b (right), the same histogram, marking the targets containing starburst galaxies. Each starburst galaxy is indicated with a $\star$.

high central surface brightness starbursts (discussed below), and residual star formation in early type disk galaxies. SINGG also finds many multiple sources, particularly for $\mathcal{M}_{\rm HI} > 10^{9.5}\mathcal{M}_\odot$ (Fig 2a.). The higher multiplicity fraction, may in part be due to the generally larger distance of the highest mass sources and thus larger projected field. In many cases the companions are obvious, having similar angular extent and a merging, colliding or interacting morphology. In other cases the companions are less obvious small sources, easily mistaken for field galaxies, save for their Hα emission. I conclude that narrow band imaging is an effective means to locate companion galaxies.

The SINGG images also frequently reveal unresolved emission line sources projected far from the primary Hα source on the frame. The images alone are incapable of discriminating what these emission line dots, or "ELdots" are. Possibilities include outer disk or halo H II regions (Ferguson, *et al.* 1998), very faint companion galaxies (e.g. similar to those proposed by Blitz *et al.* 1999), or background emission line galaxies (Boroson, Salzer & Trotter 1993). In her contribution, Emma Ryan-Weber presents results from our first spectroscopic follow-up observations of ELdots.

4. Starbursts with SINGG

Starburst galaxies are systems which are experiencing a short duration episode of intense star formation. Beyond this statement the term starburst is not really well defined in the literature. The SINGG sample selection has netted many well known galaxies which have been called starbursts. These include M83, NGC 1705, NGC 1808, and NGC 5253. All have high central surface brightness, and frequently have a galactic wind morphology.

One goal of SINGG is to provide an objectively defined starburst sample. We will look at three quantities often used to define starbursts: Hα equivalent width, EW(Hα), effective Hα surface brightness, $S_e(H\alpha)$, and gas consumption timescale, $\tau_{\rm gas}$. A high EW(Hα) indicates a large SFR compared to the past average. High values of $S_e(H\alpha)$ indicates currently intense star formation. A short $\tau_{\rm gas}$ indicates that star formation can not continue for long at its present rate. Hence the three measures of star formation are complementary. Our plan is to use the well known starbursts in the sample as a training set to determine the best cuts in these quantities for our objectively defined starburst sample.

Currently we have defined a sample of starbursts by $S_e(H\alpha)$. The incidence of these starbursts as a function of $\mathcal{M}_{\rm HI}$ is given in Fig. 2b. The sample includes well known starbursts, and sources selected to have similar surface brightness. This yields a a first pass starburst incidence rate of $13/90 \sim 15\%$ of SINGG targets containing at least one starburst galaxy.

5. Extra-planar Hα

To address the incidence rate of extra-planar Hα, or outflows, we have compiled a database of the largest possibly expanding structures in each galaxy. These have morphologies including bubbles, rays or chimneys, and edge-brightened and filled fans with or without caps. The database notes whether the source is in the center (i.e. a galactic wind) or outer regions (e.g. a fountain or chimney) of the galaxy, the source's radius r and orientation relative to the host's minor axis, its morphology and finally whether the source is seen in Hα emission (almost all cases) or continuum absorption (just a few cases). In order to focus on extra-planar ISM we limited ourselves to structures with a minor axis extension, and with hosts having axial ratio $a/b > 2$. We considered two samples, structures having $r > 0.5$ Kpc, and those with $r > 1.0$ Kpc. We limit ourselves to sources with $r > 5''$ so that the structures are well resolved, hence the two samples are distance limited to within 21 and 42 Mpc respectively ($H_0 = 70\,{\rm km\,s^{-1}\,Mpc^{-1}}$).

Figure 3a and 3b show $\mathcal{M}_{\rm HI}$ histograms of the Hα emitting galaxies meeting the distance and a/b cuts for the two samples. Sources are distinguished by whether the largest expanding structure is central or in the outer regions of the galaxy. Nearly half of the hosts have extra-planar structures with $r > 0.5$ kpc, while about a quarter have structures larger than 1.0 Kpc. The galaxies with extra-planar Hα are not all starbursts. This is true even if we limit ourselves to just the cases with central outflows, which are also found in galaxies with modest values of $S_e(H\alpha)$.

The histograms imply that the central outflows tend to be in lower $\mathcal{M}_{\rm HI}$ hosts, while larger mass systems tend to host fountains. However, we have found high H I mass Hα emitting galaxies that have strong galactic winds that just don't quite make our distance and a/b cuts. One case is the well known central starburst in NGC 1808 ($\log(\mathcal{M}_{\rm HI}/\mathcal{M}_\odot) = 9.4$) which is one of the two cases where the outflow is best traced by dust lanes. However, its $a/b \approx 1.5$, is too round to make our selection. The three galaxies with the largest galactic winds ($r = 6$ to 12 Kpc) seen in the database are all contained within a single Hickson Compact Group (HCG 16, combined $\log(\mathcal{M}_{\rm HI}/\mathcal{M}_\odot) = 10.3$). However, with $D = 54$ Mpc, it does not make our distance cut. These examples show that

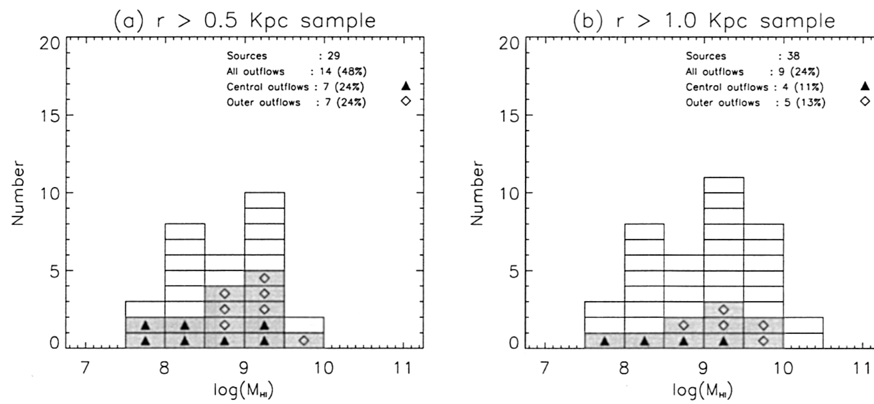

Figure 3. Mass histograms showing the incidence of central and outer outflows having scale sizes (a) $r > 0.5$ Kpc, and (b) $r > 1.0$ Kpc. Central outflows are marked with filled triangles while outer outflows are indicated with diamonds.

there are indeed high mass systems with central galactic winds, however we need a larger sample to find them in statistically significant quantities.

6. Summary

The strategy of SINGG is to survey for star formation in the galaxies known to contain its essential ingredient, interstellar hydrogen, i.e. we know where the fuel is; that's where to look for the fire. This has proven to be a very effective approach, since we find that there are no dormant galaxies: when a galaxy has $\mathcal{M}_{\rm HI} > 3 \times 10^7 \mathcal{M}_\odot$ it is observed to be undergoing some star formation. The amount of H I does not prove to be a good predictor of star formation morphology which varies greatly at fixed $\mathcal{M}_{\rm HI}$. About 15% of H I selected galaxies are starbursts. Extra-planar Hα also appears to be a common phenomenon with half of edge-on galaxies having features with a radius ≥ 0.5 Kpc, and about a quarter having a radius ≥ 1 Kpc.

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