

The Fate of Ionizing Photons in Starbursts: A Local Perspective

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Abstract We present new results from the SINGG $H\alpha$ survey of nearby galaxies, which show that starbursts have a lower fraction of diffuse, warm ionized gas than other star-forming galaxies. We discuss the possible causes of this effect, including a decrease in field star contributions, absorption of ionizing radiation by dust, and the escape of ionizing radiation from the galaxies.

Keywords galaxies: evolution, galaxies: ISM, galaxies: starburst, H II regions, intergalactic medium, ISM:evolution

1 Introduction

The previous speaker discussed issues related to mechanical feedback from starbursts, and here, we now focus on radiative feedback in these systems. Assuming that ionizing radiation from the massive stars is absorbed within the host galaxy, it must be absorbed by either in classical H II regions or the diffuse, warm ionized medium (WIM). Most work in the literature suggests that the WIM comprises about half of the total $H\alpha$ luminosity in star-forming galaxies (e.g., Walterbos 1998). The specific source of the WIM's power

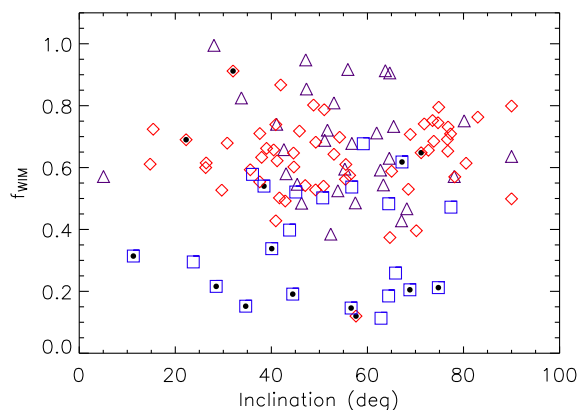


Fig. 1 Fraction of diffuse $H\alpha$ emission as a function of galaxy inclination. Squares, diamonds, and triangles respectively show starbursts, normal galaxies, and galaxies with sparse star formation. Objects shown with a central dot have nuclear-dominated star formation. (Figures are from Oey et al. 2007)

is thought to originate roughly equally from both field stars and Lyman continuum radiation escaping from classical H II regions (e.g., Oey & Kennicutt 1997; Hoopes & Walterbos 2000; Oey et al. 2004). However, we caution that our most recent work suggests that there may be a problem with the total ionizing photon budget for the WIM, when adopting the most recent stellar atmosphere models (Voges et al. 2008). Nevertheless, photoionization from massive stars is undoubtedly a dominant powering source for the WIM.

We used observations from the Survey of Ionization in Neutral Gas Galaxies (SINGG; Meurer et al. 2006) to evaluate the properties of the WIM in starbursts and other classes of galaxies. SINGG is an $H\alpha$ survey of H I-selected galaxies from the HIPASS survey (Barnes et al. 2001), selected to uniformly sample the mass range $7 \leq \log M(\text{HI}/M_{\odot}) \leq 11$. Our study of

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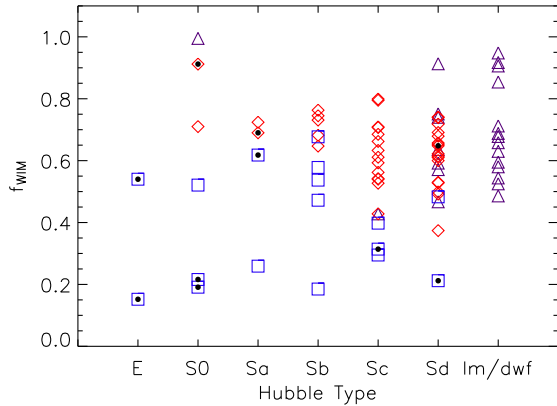


Fig. 2 Fraction of diffuse $H\alpha$ emission as a function of galaxy Hubble type. Symbols are as in Figure 1

the WIM is based on the SINGG Release 1 dataset of 109 galaxies, which reveals a wide range of star-formation properties. We categorized the galaxies according to star-formation intensity (SFI), defined as the $H\alpha$ luminosity per unit area within the $H\alpha$ half-light radius. “Normal” galaxies are those with SFI in the range $38.4 < \log \Sigma_{H\alpha} / \text{erg s}^{-1} \text{ kpc}^{-2} \leq 39.4$; galaxies with SFI above this range we define as “starbursts”, and those with SFI below this range we categorize as “sparse” star formation. We also note that many galaxies show star formation or $H\alpha$ emission exclusively in a nuclear morphology, which we also note as a separate category in addition to those defined by SFI.

The algorithm used to determine the boundaries between classical $H\text{ II}$ region and the WIM emission plays a critical role in defining the relation between these components. We adopted the HIIphot software by Thilker et al. (2000), which is based on a radial surface brightness gradient for the objects. It also interpolates a varying background, which is especially important in estimating the WIM emission. Figure 1 shows WIM fraction vs galaxy inclination for the sample, which tests the effect of line-of-sight crowding. The three SFI categories show no systematic effects as a function of i , suggesting that crowding effects are adequately addressed by HIIphot.

Anecdotally, the work in the literature suggests that the WIM fraction is independent of galaxy Hubble type. This is largely confirmed by Figure 2, although the latest galaxy types show the largest scatter in the fraction of diffuse $H\alpha$ emission. Galaxies dominated by nuclear star formation (shown with central dots) appear to be less confined by the parameter space and are found in a variety of conditions.

Both Figures 1 and 2 show that starburst galaxies have lower WIM fractions than galaxies in the “normal”

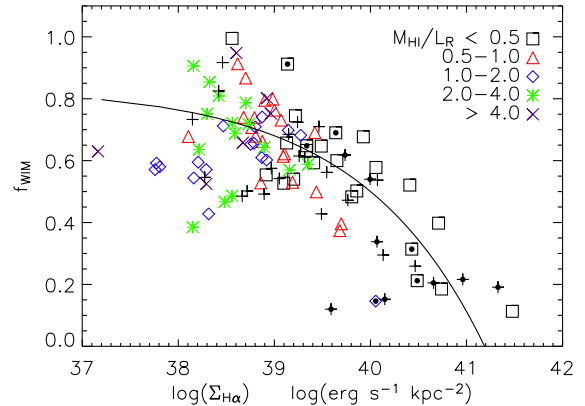


Fig. 3 Fraction of diffuse $H\alpha$ emission as a function of $H\alpha$ surface brightness, a measure of star-formation intensity. Symbols indicate $H\text{ I}$ mass relative to R -band luminosity, a measure of the $H\text{ I}$ gas fraction, as shown.

or “sparse” SFI categories. Figure 3 indeed reveals a strong anticorrelation between the WIM fraction and SFI, which is especially manifested by the objects having $\log \Sigma_{H\alpha} > 39.4$, namely, the starburst galaxies. The effect is confirmed by the $H\alpha$ surface brightness distributions, which are flatter for starbursts than for the other galaxies (Figure 4).

2 Possible explanations

Why do starbursts show lower fractions of diffuse WIM than other galaxies? One possibility is that the source(s) of ionizing photons is reduced in starburst galaxies. As mentioned above, the WIM is thought to be ionized by both field OB stars and radiation leaking from $H\text{ II}$ regions. If one or both of these sources

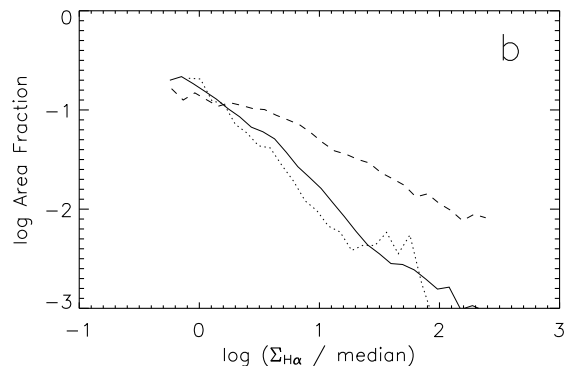


Fig. 4 Composite $H\alpha$ surface brightness distributions for starburst galaxies (dashed line), normal galaxies (solid line), and galaxies with sparse star formation (dotted line)

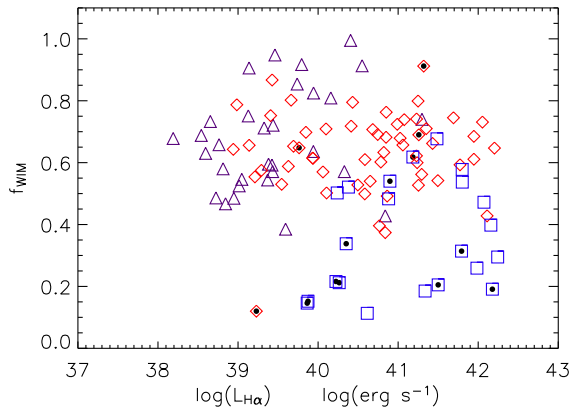


Fig. 5 WIM fraction as a function of total H α luminosity, a measure of total star-formation rate. Symbols are as in Figure 1

is greatly reduced, then the WIM fraction will decrease accordingly.

We can evaluate the possibility that there is a lower fraction of field OB stars in starbursts. Oey et al. (2004) showed that the clustering law for the Small Magellanic Cloud shows a smooth N_*^{-2} power law all the way down to individual field OB candidates, where N_* is the number of OB stars per cluster or associated group. If field and cluster massive stars are related by this power law relation, as discussed several times in these Proceedings, then the fraction of field massive stars is simply given by,

$$f_{\text{field}} \simeq (\ln N_{*,\text{up}} + 0.5772)^{-1}, \quad (1)$$

where $N_{*,\text{up}}$ is the number of massive stars in the richest cluster of the ensemble (Oey et al. 2004). Since this parameter increases with star-formation rate (SFR), we indeed expect a somewhat lower fraction of field stars in galaxies with the highest absolute SFR. Figure 5 shows WIM fraction vs total SFR as indicated by the total H α luminosity. There is only a slight inverse trend with SFR, not the strong anticorrelation as seen in Figure 3, and so this strongly suggests that a decrease in field stars is not the dominant effect in explaining that trend.

It remains possible that a strong decrease the other source of WIM ionization, the radiation leaking from H II regions, could be responsible for the lower fraction of diffuse H α emission in starbursts. This might be caused by much greater extinction, for example, than is seen in normal galaxies. We plan to examine this possibility with *Spitzer* and *GALEX* observations.

There is a different scenario that could explain the lower WIM fraction in starbursts: it could be that almost all of the ISM is associated with the star formation, leaving very little neutral gas to be ionized into

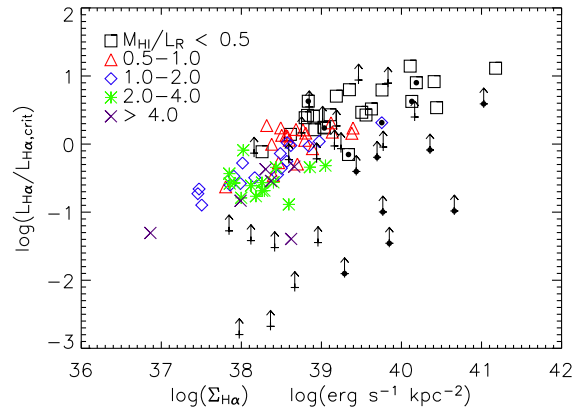


Fig. 6 Total star-formation rate relative to the critical value for dominating feedback, as given by H α luminosity. Symbols are as in Figure 3

a WIM component. This therefore predicts that most such galaxies have an ionized ISM that is essentially density-bounded, allowing ionizing radiation to escape altogether. This model is similar to that proposed by Clarke & Oey (2002), in which we predicted that as the SFR per unit ISM mass increases, a threshold SFR_{crit} is reached at which the ISM is shredded by feedback, allowing Lyman continuum radiation and hot superwinds to emanate from the host galaxies. For local starbursts, we found that $\text{SFR}_{\text{crit}} \lesssim 1 M_{\odot} \text{ yr}^{-1}$ from our crude prediction, whereas the observed SFR in such galaxies is typically at least that value. Thus, local starbursts are generally predicted to exceed the threshold criterion.

Figure 6 shows the observed total SFR relative to the critical value in our sample of galaxies, again as represented by the H α luminosity, as a function of SFI. All the starburst galaxies meet the threshold criterion. We do see that, overall, a surprisingly large fraction of galaxies are above the threshold, so it is likely that our crude model needs calibration and refinement. However, the qualitative behavior of the data is consistent with the model and the possibility that ionizing radiation is escaping from the starburst galaxies.

Moreover, Figure 6 also shows that galaxies that most strongly meet the threshold criterion and have the highest SFI, are also those that have the *lowest* H I gas fractions. This effect is also seen in Figure 3, where we see that the inverse trend of WIM fraction with SFI is essentially seen only in galaxies with the lowest H I gas fractions. This again suggests that such galaxies are allowing ionizing radiation to escape. The curve in Figure 3 shows a crude general analytic relation for ISM density bounding.

In summary, our sample of 109 H I-selected galaxies show that starburst galaxies have lower fractions

of diffuse H α emission than normal star-forming galaxies. We see an inverse relation between star-formation intensity and WIM fraction that is exhibited in particular by galaxies having the lowest H I gas fractions. A lower fraction of field OB stars is unlikely to explain this pattern, although high extinction may be a factor. However, these results are also consistent with our earlier predictions that starburst galaxies exceed a critical threshold star-formation rate above which ionizing radiation and galactic outflows are predicted. In this case, the central regions of the galaxies are essentially density-bounded, which would have vital implications for their gaseous halos and intergalactic environments.

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