The local environment of H\textsubscript{II} galaxies

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A B S T R A C T

We have carried out an investigation of the environments of low redshift H\textsubscript{II} galaxies by cross-correlating their positions on the sky with those of faint field galaxies in the Automatic Plate Measuring Machine (APM) catalogues. We address the question of whether violent star formation in H\textsubscript{II} galaxies is induced by low-mass companions by statistically estimating the mean space density of galaxies around them. We argue that even if low-mass companions were mainly intergalactic H\textsubscript{i} clouds, their optical counterparts should be detectable at faint limits of the APM scans.

A significantly positive signal is detected for the H\textsubscript{II} galaxy±APM galaxy angular cross-correlation function, but the amplitude is poorly determined. The projected cross-correlation function has a higher signal-to-noise ratio, and suggests that the amplitude is slightly lower than for normal field galaxies. This implies that these bursting dwarf galaxies inhabit slightly lower density environments than those of normal field galaxies, consistent with other studies of emission-line galaxies. This suggests that in these dwarf starburst galaxies, star formation is not always triggered by tidal interactions, and a significant fraction must have a different origin.

Key words: galaxies: clusters: general – galaxies: starburst – galaxies: statistics.

1 INTRODUCTION

The starburst phenomenon is observed in a large number of extragalactic objects from giant H\textsubscript{II} regions in irregular galaxies and late-type spirals, to galaxies entirely dominated by the violent massive star formation region as in the case of starburst galaxies. The class of starburst galaxies comprises a large range in luminosity, mass, heavy element and dust content, as well as morphology. Classical starburst or nuclear starburst galaxies typically have an intense region of violent star formation in the nucleus of an otherwise normal spiral galaxy (Balzano 1983). At the high luminosity end of starburst galaxies, ultraluminous IRAS galaxies (Soifer et al. 1987) are strongly interacting giant systems (Melnick & Mirabel 1990) where most of the radiation is emitted in the far-infrared owing to reprocessed ultraviolet (UV) radiation by the large content of dust particles. H\textsubscript{II} galaxies, on the other hand, are dwarf galaxies in a bursting phase of star formation of low luminosity and mass, low heavy element abundance and low dust content where the triggering mechanism of the present episode of violent star formation is not as obvious (Telles & Terlevich 1995).

Earlier searches for bright galaxies near to H\textsubscript{II} galaxies found a deficit of $L > L^*$ galaxies within 1 Mpc (Campos-Aguilar & Moles 1991; Campos-Aguilar, Moles & Masegosa 1993; Vilchez 1995; Pustilnik et al. 1995; Telles & Terlevich 1995). H\textsubscript{II} galaxies are not associated with giant galaxies, therefore they are not tidal debris of strongly interacting systems. Autocorrelation analyses of strong emission-line galaxies (Iovino, Melnick & Shaver 1988; Rosenberg, Salzer & Moody 1994; Loveday, Tresse & Maddox 1999) find a low clustering amplitude, suggesting that H\textsubscript{II} galaxies tend to populate regions of low galactic density.

Their optical properties are dominated by the massive star-forming region, as shown by their strong emission-line spectra superposed on a weak blue continuum. The properties of the underlying galaxies in these systems are similar to late-type dwarf galaxies such as dwarf irregulars or low-surface-brightness dwarfs (Telles & Terlevich 1997). The most luminous H\textsubscript{II} galaxies, classified as Type I by Telles, Melnick & Terlevich (1997), show signs of disturbed morphology such as distorted outer isophotes, tails or irregular fuzz, while the low luminosity Type IIs are regular and compact. Although there is a clear case for a morphology–luminosity relation, neither type of H\textsubscript{II} galaxies shows conspicuous evidence of bright companions in their neighbourhood. The few H\textsubscript{II} galaxies found to have a bright neighbour (maybe by chance) are all Type IIs of regular morphology, contrary to what one would expect if interactions...
caused the morphological disturbances as seen in Type Is (Telles & Terlevich 1995).

A popular hypothesis is that interactions between galaxies are the triggers of starbursts and they may also cause the current burst of star formation in H\textsc{ii} galaxies. Giant galaxies, however, are not found in the immediate vicinity of H\textsc{ii} galaxies, thus are improbable candidates for triggering agents. A possible and appealing alternative was presented by Melnick (1987), who proposed that high-resolution 21-cm maps were needed to investigate the role of collisions between intergalactic neutral hydrogen clouds in the formation of these objects. Brinks (1990) also hypothesized that other dwarfs or intergalactic H\textsc{i} clouds could be the triggering agents. Taylor et al. (1995, 1996a,b), using the Very Large Array (VLA), detected 12 H\textsc{i} companions around 21 H\textsc{ii} galaxies, while only four H\textsc{i}-rich companions were detected around a control sample of 17 quiescent low-surface-brightness dwarfs (Taylor 1997). As also pointed out by these authors, this leaves some intriguing questions: why are the nine out of the 21 H\textsc{i} galaxies with \textit{no} companions, violent forming stars now (‘bursting’)? Why are the four out of the 17 LSBGs with companions \textit{not} ‘bursting’?

H\textsc{i} surveys find that all the H\textsc{i} detections have an optical counterpart. That is, all the sources found in 21-cm surveys are nothing other than normal galaxies (cf. Zwaan et al. 1997; Zwaan 1999; Hoffmann 1999). No free floating intergalactic H\textsc{i} clouds were detected in such surveys. Thus, we have carried out a further investigation of the galaxy environments of a sample of over 160 low-redshift H\textsc{ii} galaxies by cross-correlating their accurate position in the sky to faint field galaxies (15 < \textit{b}_\textit{J} < 20.5) in the Automatic Plate Measuring Machine (APM) galaxy catalogue. The completeness and representativeness of a sample of H\textsc{ii} galaxies have been discussed by Salzer (1989) and apply here. Random incompleteness has no effect at all on the cross-correlation function. Systematic biases may change the result. If, for example, there are systematic differences between different H\textsc{ii} galaxy types, and our sample were biased towards one particular type then the results could be affected. The spectral, morphological and photometric properties of our sample are representative of H\textsc{ii} galaxies. Therefore, our sample is unbiased in the sense that it is not chosen to have any particular observational properties apart from the selection from objective prism surveys. For the mean redshift of our H\textsc{ii} galaxy sample, we detect galaxies down to \textit{M}_B \sim -15. Using the relation between optical magnitude \textit{M}_B and H\textsc{i} mass \textit{M}_\textsc{hi}, for late-type galaxies, given by Rao & Briggs (1993) \[ \log \textit{M}_\textsc{hi} \textit{M}_\odot = 2.72 - 0.36 \textit{M}_B \], we estimate that we are not missing any cloud with mass greater than \textasciitilde 10^8 \textit{M}_\odot. This is comparable to the lower limits of H\textsc{i} companions found by Taylor et al. (1995, 1996a, 1996b). Hence our present study should detect possible candidates to act as tidal triggers to this low-mass limit.

In Section 2 we describe in more detail the data sets used in the present work and we present the details of our calculations in Section 3. Finally, we show some of our conclusions in Section 4.

2 DATA

2.1 H\textsc{ii} galaxy sample

The H\textsc{ii} galaxy sample used in this paper is taken from the Spectrophotometric Catalogue of H\textsc{ii} Galaxies (SCHG; Terlevich et al. 1991). Most of the objects in this data base have been selected from the Tololo survey (Smith, Aguirre & Zemelman 1976), and the University of Michigan survey (MacAlpine & Williams 1981). The catalogue also contains a number of objects that are not classified as Seyfert galaxies selected from the Markarian list of galaxies with strong ultraviolet continuum (Markarian, Lipovetskii & Stepanyan 1981 and references therein), as well as some blue objects from Zwicky’s catalogue of compact galaxies (Zwicky 1971). The total catalogue contains spectra of over 400 emission-line objects found in objective prism surveys using IIIa-J emulsion through their [O\textsc{iii}]\lambda4959, 5007 and/or [O\textsc{ii}]\lambda3726, 3729 lines. From these, about 300 are H\textsc{ii} galaxies. The remainder are giant H\textsc{ii} regions, and starburst nuclei or emission-line objects classified as Seyfert nuclei from their position in the emission-line-ratio diagnostic diagrams.

Most of the objects in this sample cover only two specific regions of the sky. For instance, the Michigan survey covers a 10° band around the celestial equator, while the Tololo survey concentrates in the region \(-27° < \delta < -43°\). This is illustrated in Fig. 1, which shows the distribution of our H\textsc{ii} galaxies in the sky. For the present study we ended up with 163 H\textsc{ii} galaxy centres for which there are APM-scanned UK Schmidt plates. The actual centre for each APM field was carefully identified, thus assuring that the H\textsc{ii} galaxy is not counted as a companion of itself.

The redshift distribution of these galaxies is plotted in Fig. 2, which also shows the best-fitting model redshift distribution of the form

\[ N(z) \propto \frac{z_c}{z_c^3} \exp \left[ -\left( \frac{z}{z_c} \right)^{3/2} \right], \]  

where \(z_c\) is used as a fitting parameter, with \(z_{\text{median}} = \sqrt{2}z_c\) and \(z_{\text{mean}} = 5/3(5/3)z_c = 1.5z_c\). The mean redshift is 0.03. The typical absolute magnitude is \(M_B \sim -18\). Throughout this paper we use the current value of \(H_0 = 65 \text{ km s}^{-1} \text{Mpc}^{-1}\) (Suntzeff et al. 1999).

2.2 APM galaxy sample

Our sample of faint field galaxies was selected from the APM Galaxy Survey, which is described in detail by Maddox et al. (1990). The sky covered by the APM galaxy survey has been extended since the original publication of the survey: the south galactic pole part of the survey now covers a solid angle of 6250 deg\(^2\), and is based on 269 UKS J plates scanned by the APM machine; the north galactic cap area covers 750 deg\(^2\) from scans of 30 UKS plates centred with \(\alpha = 15^h\) and \(-5° < \delta < 0°\). The fields covered are shown by the dotted squares on Fig. 1.

The data consist of positions accurate to \(\pm 1\text{arcsec}\) and magnitudes accurate to \(\pm 0.1\text{mag}\) for over 50 million images brighter than a magnitude limit of \(b_J = 21.9\). The galaxy photometry has been corrected for several systematic effects and has no detectable systematic errors more than \(\pm 0.04\text{mag}\). The galaxy sample selected from the survey data at a magnitude limit of \(b_J = 20.5\) has a completeness \(\sim 90-95\text{per cent}\), stellar contamination \(\sim 5\text{per cent}\) and negligible dependence of the galaxy surface density on declination or galactic latitude (Maddox, Efstathiou & Sutherland 1996). At this magnitude limit the redshift distribution is well described by equation (1) with the mean \(z = 0.16\) (Maddox et al. 1996).

We extracted APM measurements for a 2 deg\(^2\) area around each of the H\textsc{ii} galaxies. For the central 10-arcmin square we visually cross-checked the APM catalogue list against images from the
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Digitized Sky Survey (DSS), and rejected multiple detections and noise images. This provides a reliable galaxy catalogue around each H II galaxy.

3 ANALYSIS

3.1 The angular cross-correlation function

We have measured $w_{hg}(\theta)$, the angular cross-correlation function between the H II galaxies and an apparent magnitude limited sample of neighbouring galaxies. We estimated $w_{hg}$ by counting the number of galaxies $N_{bg}$ as a function of angular radius $\theta$ from the central H II galaxy, and comparing this with the number $N_{hr}$ counted for a catalogue of uniform random positions. We used ten times as many random points as galaxies in order to reduce their contribution to the counting errors, and then rescaled the count down by a factor of 10. The cross-correlation function is then given by

$$w_{hg}(\theta) = \frac{N_{bg}(\theta)}{N_{hr}(\theta)} - 1.$$  (2)

We also used the simpler direct estimate using the mean surface density of field galaxies, $\bar{N}$, and the area of each annulus,

$$w_{bg}(\theta) = \frac{N_{bg}(\theta)}{n_{cen} \bar{N} \pi[(\theta - \Delta)^2 - \theta^2]} - 1,$$  (3)

where $n_{cen}$ is the number of H II galaxies used as centres, and $\Delta$ is the angular width of each annulus used in counting the galaxy pairs.

The main results are shown in Fig. 3. The filled circles show $w$ from equation (2) and the open triangles from the direct estimator, equation (3). This gave essentially indistinguishable results, showing that there are no significant systematic biases in our sample. The error bars are estimated from the Poisson noise in each radial bin, scaled by the integral of $w$, $\epsilon_w = [1 + 2\pi \bar{N} J_2(\theta)]/\sqrt{N_{bg}}$, where $J_2 = \int_0^\theta \psi(\theta) d\theta$. This is analogous to the error estimate for the spatial correlation function $\xi$ suggested by Kaiser (1986), and is a reasonable approximation for a weakly clustered distribution (see Hamilton 1993 for an extensive analysis of errors in correlation functions). It can be seen that $w_{bg}$ is significantly positive for angles $\theta \leq 30$ arcmin, corresponding to an excess of galaxies near the H II galaxy.

Figure 1. The distribution of H II galaxies and APM data on the sky in an equal area projection in equatorial coordinates. The solid circles are the positions of the H II galaxies. The square fields are the APM scans of the UK Schmidt plates. The dashed lines show lines of constant RA and Dec.

Figure 2. The distribution of redshifts for the H II galaxies (histogram) and the model distribution (equation 1) used to calculate the model correlation function (dashed line).
positions with a uniform distribution. This would be expected for any sample of galaxies, because we know that galaxies are clustered.

We have calculated the expected cross-correlation function assuming that HII galaxies cluster in the same way as normal galaxies, and this is shown by the line in Fig. 3. This prediction is based on the APM correlation function for galaxies, and this is shown by the line in Fig. 3. This prediction is consistent, although slightly lower than the predictions. This slight discrepancy can be interpreted as a reflection of the fact that the amplitude of the autocorrelation function for HII galaxies is lower than for normal galaxies. Iovino et al. (1988) find $r_0 = 2.7 h^{-1}$ Mpc for the HII galaxy sample used here; the corresponding $\Xi_{\text{bg}}$ is shown as the dashed line in Fig. 4. If HII galaxies and normal galaxies follow the same underlying mass distribution with differing bias levels, the cross-correlation function should be the geometric mean of the two autocorrelation functions, so $\hat{\xi}_{\text{bg}} = \sqrt{\hat{\xi}_{\text{gg}} \hat{\xi}_{\text{dd}}}$. The dotted line in Fig. 4 shows the equivalent $\Xi_{\text{bg}}$.

Our measurement of $\Xi_{\text{bg}}(\sigma)/\sigma$ is shown by the points in Fig. 4. It is possible for $\sigma \lesssim 1$ Mpc, showing that HII galaxies have more neighbouring galaxies than a uniform distribution: they are not isolated systems. As discussed in Section 3.1, we expect any sample of galaxies to have more neighbours than a random distribution, so we have calculated the expected $\Xi/\sigma$ assuming that HII galaxies are clustered in the same way as normal galaxies. Our prediction is given by equation (8) with $\hat{\xi}_{\text{bg}}(r) = (r/5.1 h^{-1})^{-1.71}$, which is a good approximation to the APM correlation function on small scales (Maddox et al. 1996). We have also subtracted a constant from the power law to allow for the integral constraint which applies to the data points. This is shown as the solid line in Fig. 4. The observed values are consistent, although slightly lower than the predictions. This slight discrepancy can be interpreted as a reflection of the fact that the amplitude of the autocorrelation function for HII galaxies is lower than for normal galaxies. Iovino et al. (1988) find $r_0 = 2.7 h^{-1}$ Mpc for the HII galaxy sample used here; the corresponding $\Xi_{\text{bg}}$ is shown as the dashed line in Fig. 4. If HII galaxies and normal galaxies follow the same underlying mass distribution with differing bias levels, the cross-correlation function should be the geometric mean of the two autocorrelation functions, so $\hat{\xi}_{\text{bg}} = \sqrt{\hat{\xi}_{\text{gg}} \hat{\xi}_{\text{dd}}}$. The dotted line in Fig. 4 shows the equivalent $\Xi_{\text{bg}}$.

The resulting projected cross-correlation function, $\Xi_{\text{bg}}$, is an integral over the spatial correlation function $\xi_{\text{bg}}$.

$$\Xi_{\text{bg}}(\sigma) = \int_{-\infty}^{\infty} \xi_{\text{bg}}(x^2 + \sigma^2)^{1/2} \, dx.$$  \hfill (5)

We estimate $\Xi_{\text{bg}}$ using a method similar to that described by Saunders, Rowan-Robinson & Lawrence (1992). For each HII galaxy we count the excess neighbours compared with a random distribution using

$$X_{\text{bg}}(\sigma) = \frac{N_{\text{bg}}(\sigma)}{N_{\text{bg}}(\sigma)} - 1. \quad (6)$$

This is related to $\Xi$

$$\Xi(\sigma) = \frac{n(x) \, dx}{n(y)} \, X(\sigma). \quad (7)$$

where $n(x)$ is the average number of field galaxies per sr per Mpc along the line of sight in the background catalogue at distance $x$, and the distance to the central HII galaxy is $y$. The approximation is essentially the small-angle approximation, but also involves several subtleties, as discussed by Saunders et al. (1992). Note that the different distance to each HII galaxy means that the relation between $\sigma$ and $\theta$ is different for each centre, and also the $1/n(y)$ leads to a different weighting of the pair count from each centre. This means that $\Xi_{\text{bg}}$ is not simply a rescaling of $w_{\text{bg}}$.

If $\hat{\xi}_{\text{bg}}$ is a power law in $r$, $\hat{\xi}_{\text{bg}} = (r/r_0)^{-\gamma}$, then the projected correlation function is given by $\Xi_{\text{bg}}(\sigma) = (\sigma/r_0)^{1-\gamma}$ where $\sigma_0^{-2} = r_0 \Gamma(\frac{1}{2}) \Gamma(\frac{2-1}{2})/\Gamma(\frac{3}{2})$. Hence

$$\Xi_{\text{bg}}(\sigma)/\sigma = \hat{\xi}_{\text{bg}}(\sigma) \Gamma(\frac{1}{2}) \Gamma(\frac{2-1}{2})/\Gamma(\frac{3}{2}). \quad (8)$$

3.2 The projected cross-correlation function

As we know the redshift to each HII galaxy, we can estimate the correlation function using the projected physical separation, $\sigma$. The angular cross-correlation between the HII galaxies and the faint APM field galaxies. The filled circles show the results using equation 2, and the open triangles are from equation 3. The error bars are estimated from $\sigma_n = (1 + 2\pi N J_2(\theta)/\sqrt{N_{\text{bg}}}$, the line is the cross-correlation function predicted assuming that the HII galaxies are a random subsample of APM galaxies.

\[ \text{Figure 3. The angular cross-correlation between the HII galaxies and the faint APM field galaxies. The filled circles show the results using equation 2, and the open triangles are from equation 3. The error bars are estimated from } \sigma_n = (1 + 2\pi N J_2(\theta)/\sqrt{N_{\text{bg}}}. \text{ The line is the cross-correlation function predicted assuming that the HII galaxies are a random subsample of APM galaxies.} \]
galaxies to separate the Taylor et al. H\textsubscript{ii} maps is about 4.5 \textit{h}\textsuperscript{-1}kpc.

ii Faint, low-mass neighbours. The resolution of the Taylor et al. H\textsubscript{ii} galaxies, which is about 9 arcsec at a magnitude limit of \(M_{B_J} \approx -14.5\), which correspond to very low-mass galaxies and H\textsubscript{ii} clouds (\(\sim 10^8 M_\odot\)). Our results are in agreement with the earlier studies, with the additional conclusion that H\textsubscript{ii} galaxies do not have preferentially faint, low-mass neighbours.

It is also worth comparing our results with the analyses of Taylor et al. (1995, 1996a, 1996b), who searched for low-mass H\textsubscript{i} companions around samples of H\textsubscript{ii} galaxies and low-surface-brightness dwarf galaxies. The resolution of the Taylor et al. H\textsubscript{i} maps is about 4.5 \textit{h}\textsuperscript{-1}kpc. Galaxy pairs in the APM survey are reliably resolved down to separations equal to the size of the galaxies, which is about 9 arcsec at a magnitude limit of \(b_J = 20.0\). [This can be seen from the correlation function of galaxies to \(b_J = 20\) (fig. 1 of Maddox et al. 1996) which is a power law at scales \(\geq 10\) arcsec, but drops below the power law at smaller separations, where pairs of galaxies are not resolved.] At the mean distance to the H\textsubscript{ii} galaxies in our analysis (90 \textit{h}\textsuperscript{-1}Mpc), this corresponds to a resolution of about 4 \textit{h}\textsuperscript{-1}kpc, which is very similar to the Taylor et al. sample. The mean separation of the Taylor et al. H\textsubscript{i} companions is 59.5 kpc, which is comparable to the scale of the smallest bin in our estimated \(\Xi(\sigma)\) (see Fig. 4). Most of the clustering signal in our analysis comes from excess pairs at these small scales, although we also see evidence for correlated pairs extending out to several hundred kpc.

The Taylor analysis suggests that H\textsubscript{ii} galaxies have a slightly higher clustering amplitude than LSB dwarves. Our measurements show that H\textsubscript{ii} galaxies have a clustering amplitude slightly lower than average optically selected galaxies. There is observational evidence that shows that both emission-line galaxies and low-mass galaxies have weaker clustering than average optical galaxies (Loveday et al. 1995, 1999). Therefore, our measurements are not in conflict with the Taylor et al. result.

In conclusion, we find that H\textsubscript{ii} galaxies do not have more companions than an average galaxy, so that tidal interactions cannot be the only factor that triggers their burst of star formation. This does not rule out the possibility that tidal interactions are necessary to produce a starburst, but suggests that interactions alone are not sufficient. Other factors must be important in triggering a burst, such as the formation and evolution of super stellar clusters in starbursts, as observed in the UV (Vacca 1994; Meurer et al. 1995; Ho 1997) and in the near-IR (Telles et al. 1999).

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4 CONCLUSIONS
Our main results are:

(i) Both the angular and projected correlation functions are significantly positive, so H\textsubscript{ii} galaxies are significantly clustered. This is what you expect to find for any sample of galaxies.

(ii) The angular measurements have large uncertainties, but are consistent with the predictions expected for a sample of normally clustered galaxies.

(iii) The projected measurements are marginally lower than the predictions expected for a sample of normally clustered galaxies, and lie between the autocorrelation functions of normal galaxies and H\textsubscript{ii} galaxies.

Telles & Terlevich (1995) found that the space density of bright galaxies within 1 Mpc\(^3\) of H\textsubscript{ii} galaxies is a factor \(-4\) times higher than expected for a random distribution, but \(-2\) times less than for a control sample of sample of Sc galaxies. These results showed that H\textsubscript{ii} galaxies are more clustered than a random distribution, but slightly less clustered than normal galaxies. The present work extends this analysis to much fainter apparent magnitudes, but slightly less clustered than normal galaxies. The present work extends this analysis to much fainter apparent magnitudes, but slightly less clustered than normal galaxies. The present work extends this analysis to much fainter apparent magnitudes, but slightly less clustered than normal galaxies. The present work extends this analysis to much fainter apparent magnitudes, but slightly less clustered than normal galaxies.

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Figure 4. The projected cross-correlation between the H\textsubscript{ii} galaxies and the faint APM field galaxies, \(\Xi_p(\sigma)/\sigma\). The points show our measurements, with error bars estimated from the scatter between centres. The solid, dotted and dashed lines show the predicted \(\Xi\) for \(r_0 = 5, 1, 3.7\) and \(2.7 h^{-1}\)Mpc, respectively.

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