Astronomy & Astrophysics manuscript no. HII˙Koulouridis
June 8, 2018
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arXiv:1304.0777v1 [astro-ph.CO] 2 Apr 2013

The Environment of HII Galaxies revisited

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June 8, 2018

ABSTRACT

We present a study of the close ($\lesssim 200h_{75}^{-1}$kpc) environment of 110 relatively local ($z\lesssim 0.16$) HII galaxies, selected from the Sloan Digital Sky Survey (SDSS; DR7). We use available spectroscopic and photometric redshifts in order to investigate the presence of a close and possibly interacting companion galaxy. Our aim is to compare the physical properties of isolated and interacting HII galaxies and investigate possible systematic effects in their use as cosmological probes. We find that interacting HII galaxies tend to be more compact, less luminous and have a lower velocity dispersion than isolated ones, in agreement with previous studies on smaller samples. However, as we verified, these environmental differences do not affect the cosmologically important $L_{H\beta} - \sigma$ correlation of the HII galaxies.

Key words. Galaxies: Starburst, Galaxies: interactions, Galaxies: Star formation, Galaxies: Evolution, Cosmology: Large-Scale Structure of Universe

1. Introduction

HII galaxies are compact dwarf objects with massive star formation bursts. They are characterized by a high luminosity per unit mass, concentrated mostly in a few strong emission lines in the optical rest frame, a fact that makes them visible at very large redshifts. This, together with the observed correlation between the luminosity of recombination lines, e.g. $L(\mathrm{H}\beta)$ and the ionized gas velocity dispersion σ (see Terlevich & Melnick 1981; Melnick, Terlevich & Moles 1988; Fuentes-Masip et al. 2000; Telles et al. 2001; Bosch, Terlevich & Terlevich 2002; Siegel et al. 2005; Bordalo and Telles 2011) renders them alternative cosmological distance probes. In Plionis et al. (2011) we presented a thorough investigation of the viability of using HII galaxies to constrain the dark energy equation of state and they indeed appear to be a prominent cosmological probe (see also Melnick, Terlevich & Terlevich 2000; Siegel et al. 2005). This was clearly verified by using them to estimate the Hubble constant, finding a value $H_0 = 74.3 \pm 4.3$ km s^{-1} Mpc^{-1} (Chávez et al. 2012), in excellent agreement with, and independently confirming, the most recent SNIa based results (Riess et al. 2011; Freedman et al. 2012).

The cosmological importance of the HII galaxies forces us to investigate all possible sources of systematic effects that could affect the observed $L(\mathrm{H}\beta) - \sigma$ correlation. One such systematic could well be related to the effects of the close environment of HII galaxies. It is widely accepted that interactions between two galaxies are capable of triggering starburst events by driving gas and molecular clouds from the outskirts toward the center of each galaxy (e.g. Li et al. 2008; Ellison et al. 2008; Ideue et al. 2012). These events enhance greatly the star formation rate of the galaxies and consequently they appear intensely blue because of their abundance in young stars. The idea of the interactions-starburst connection was greatly supported by the studies of ultraluminous infrared galaxies (e.g. Sanders & Mirabel 1996; Surace et al. 1998) which were found to be strongly interacting and by definition highly star forming. In addition, supportive evidence of interaction-induced star formation, at lower infrared luminosities, was given by Koulouridis et al. (2006).

On the other hand, regarding HII galaxies, previous studies on the environmental dependence of their properties concluded that they appear to be less clustered than "normal" galaxies (e.g. Iovino, Melnick & Shaver 1988; Loveday, Tresse & Maddox 1999; Telles & Maddox 2000) and to have a deficiency in bright neighbours (Campos-Aguilar & Moles 1991; Campos-Aguilar, Moles & Masegosa 1993). These results questioned the efficiency of interactions as the starburst's triggering mechanism at least for the specific objects. However, Noeske et al. (2006) argued that since ∼30% of their sample's star forming dwarf galaxies (SFDGs) have mostly dwarf neighbours, this percentage is a lower limit because of the poor completness of the NED[1], which they used to conduct their search. In addition, numerical simulations (Bekki, 2008) also showed that some compact star forming galaxies can be the result of dwarf-dwarf merging. We should note however, that although faint dwarf neighbours (in projection) were also probably found in a sample of SFDGs by Brosch et al. (2006), they were considered as non-interacting, because of their large distance, and rather as a sign of synchronized star formation over a large area. Interestingly, Telles & Terlevich (1995) found, by investigating the environment of 51 HII galaxies, that only ∼ 10% of their sample had a luminous neighbouring galaxy

[1] NASA/IPAC Extragalactic Database is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

and they tend to be those of lower Hβ luminosity, lower velocity dispersion and regular morphology, while on the contrary the majority of luminous objects seem to be irregular, disturbed and isolated (see also Telles, Melnick & Terlevich 1997). Similar results were also reported in Vilchez (1995) where the SFDGs in low density regions have larger Hβ equivalent widths and higher Hβ luminosities.

Most of these studies however, investigated the effects of what could be called the large scale environment, since their radial limit for the identification of a possible neighbour was at least 1 h_{75}^{-1}Mpc. In addition they were relatively "shallow" because of the low magnitude limit of the available redshift surveys at the time and as a result they were sensitive only to the more luminous and massive neighbours.

The aim of the present study is to investigate the environment of a larger sample of 128 HII galaxies, selected from the SDSS, which enables us to perform a consistent environmental analysis using a fixed magnitude difference between the HII galaxies and their neighbours, while reaching fainter magnitudes. More importantly, we would like to investigate the already mentioned trend reported by Telles & Terlevich (1995) which, if confirmed, could introduce a systematic effect in the use of the HII galaxies as cosmological probes. Throughout our paper we use $H_0 = 75$ km s^{-1} Mpc^{-1}.

2. Sample Selection & Methodology

We consider the original sample of 128 HII galaxies, used to estimate the Hubble constant in Chávez et al. (2012) which was selected from the SDSS DR7 spectroscopic data within a redshift range $0.01 < z < 0.2$. The sources were chosen for being compact ($D < 5$ arcsec) and having large Balmer emission line fluxes and equivalent widths. A lower limit of 50 Å for the Hβ equivalent width (W) was chosen in order to avoid more evolved starbursts, that would present underlying absorptions due to an older stellar population component, thus affecting the emission lines flux [cf. Melnick, Terlevich & Terlevich (2000)].

High resolution echelle spectroscopy was performed at 8 meter class telescopes (Subaru & VLT) and long slit spectrophotometry at the 2.1m telescope of the Observatorio Astronómico Nacional (OAN) in San Pedro Mártir and at the 2.1 m telescope of the Observatorio Astrofísico Guillermo Haro (OAGH) in Cananea, both in Mexico. Full details of the sample selection, observations and data reduction and analysis are given elsewhere (Chávez et al., 2012; Chávez et al. 2013 in preparation).

In order to identify neighbours around each HII galaxy, within the Sloan Digital Sky Survey (SDSS; DR7), we apply a projected rest-frame maximum radius separation of $< 200h_{75}^{-1}$kpc, as well as radial velocity limit separation of $\Delta u <$ 600 km/sec (similar to the pairwise galaxy velocity dispersion; e.g. Jing, Mo & Boerner 1998), when spectroscopic redshifts are available, or $\Delta z < 0.025$ (ie., the rms error of the SDSS photometric z's) when only photometry is available. Even though there is no general concensus on the maximum radial separation of a galaxy pair, most of the recent studies use a search radius between $20h^{-1}$kpc (e.g. Patton et al. 2005) and $200h^{-1}$kpc (e.g. Focardi et al. 2006; see also relevant discussion in Deng et al. 2008). We choose the limit of 200 h_{75}^{-1}kpc considering that it is a reasonable distance for a satellite galaxy in a massive halo (e.g. Bahcall et al. 1995; Zaritsky et al. 1997), while this limit is also a compromise between having enough "isolated" and "paired" HII galaxies. Had we increased its value we would reduce greatly the number of isolated galaxies and vice versa.

In addition, we limit our neighbour search to a maximum SDSS m_r-band magnitude difference between the HII galaxy and its companion of $\Delta m_r = +1$ since the SDSS completness limit is $m_r \sim 20.5$ while our HII galaxy sample is limited to $m_r < 19$, reducing our sample to 110 objects.

Our aim is to separate the isolated HII galaxies from those with at least one neighbour within the specified angular and velocity limits, and then compare their physical properties, i.e. their velocity dispersion σ, Hβ emission line luminosity[2] $L_{H\beta}$ and metallicity Z (defined as O/H abundance).

In our initial analysis we choose to use only the HII galaxies which have neighbours with spectroscopic redshifts (ie., we exclude all HII galaxies that have neighbours based only on photometric z's, due to the known relatively large photo-z uncertainty). Note that although the above exclusion of photo-z pairs is expected to reduce the noise in our results, it could introduce a bias towards brighter pairs since the spectroscopic SDSS catalogue is complete only to an r magnitude of 17.77. This bias manifests itself also as a redshift distribution difference between the HII galaxies having a neighbour and the isolated ones. Nevertheless, we will use these results as a starting point. Ideally, we would like to compare subsamples matched in redshift and with available spectroscopy. This is possible at present only for a redshift limited sample of $z = 0.05$, below which there is no redshift distribution difference of the two subsamples. However, in this case the size of the sample is greatly reduced which may affect the significance of our results.

Therefore, we choose also to use the photo-z based pairs in our analysis, since their inclusion (at the expense of additional noise) eliminates the problem of the uneven redshift distribution between isolated and paired HII galaxies without reducing the respective subsamples. Our goal for the future is to obtain spectroscopic redshifts of all the photo-z based neighbours and confirm our results.

Telles & Televich (1995) concluded that their sample of HII galaxies with a close companion tends to be more compact and less disturbed than the respective sample of isolated ones. Because of the faint magnitudes and compactness of the majority of our sample galaxies we are not able to reach a definite conclusion on the latter. We will however investigate the possible role of interactions in the compactness of the HII galaxies. To this end we use the physical diameters of the HII galaxies which are derived from the apparent SDSS isophotal diameters (at 25.0 r-mag arcsec^{-2}). The data and calculation method are available in the NED. We should note here that the Petrosian radius is a better measure of the size of extended sources, but for compact objects the isophotal diameters can also be used. To test the different definitions, we compared the Petrosian to the isophotal diameters of a small random subsample of our HII galaxies and found that they are completely consistent.

3. Results

In Fig.1 we plot the luminosity and velocity dispersion distributions of 62 isolated and 17 paired (using spec-z's and $\Delta m_r = +1.0$) HII galaxies. The KS test indicates that the luminosity and velocity dispersion distributions are significantly different, the former more than the latter (see Table 1), in the sense that isolated HII galaxies exhibit higher luminosities and higher velocity dispersions with respect to those having close neighbours. Considering neighbours with $z < 0.05$ (Fig.2) supresses the

[2] Throughout when referring to luminosity we will always imply Hβ luminosity.

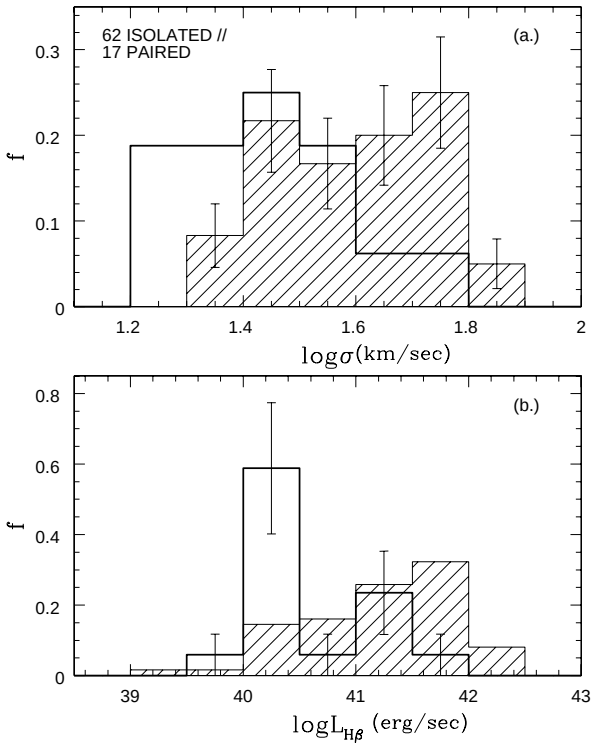

Fig. 1. Velocity dispersion (panel a.) and luminosity (panel b.) distributions of HII galaxies with (plain) and without (hatched) spectroscopically confirmed neighbours. Uncertainties are 1σ Poisson errors.

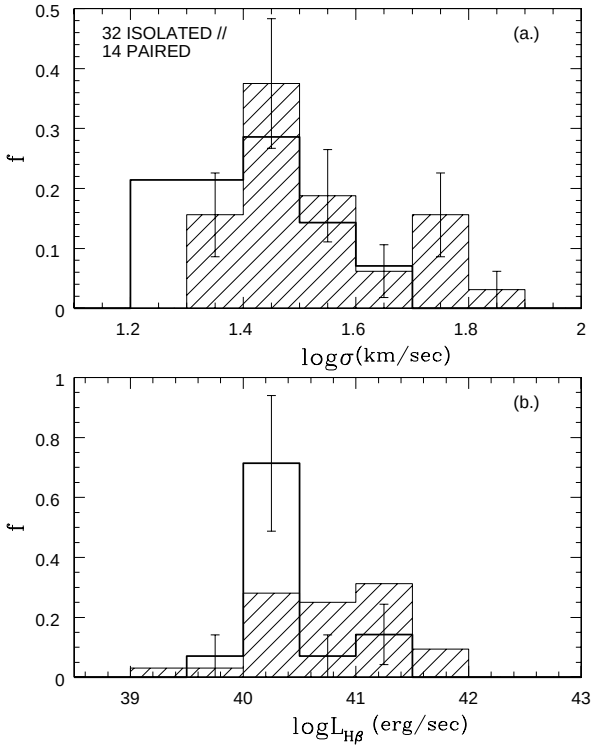

Fig. 2. Velocity dispersion (panel a.) and luminosity (panel b.) distributions of the volume limited HII galaxy sample ($z < 0.05$) with (plain) and without spectroscopically confirmed neighbours. Uncertainties are 1 σ Poisson errors.

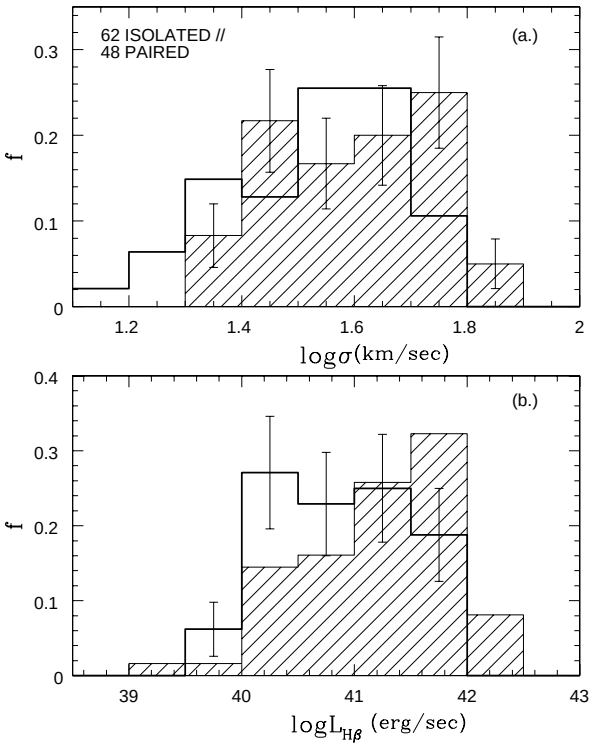

Fig. 3. Velocity dispersion (panel a.) and luminosity (panel b.) distributions of HII galaxies with (plain) and without (hatched) spectroscopically or photometrically confirmed neighbours. Uncertainties are 1 σ Poisson errors.

problem of the uneven redshift distribution between isolated and paired HII galaxies (last column of Table 1) at the cost of reducing greatly the number of isolated HII galaxies. The results remain practically the same, even though less statistically significant (especially for the velocity dispersion). We should note however that this is probably due to the small number of available objects.

By considering in the previous analysis only the spec-*z* based pairs, in order to avoid projection effects due to unreliable photometric redshifts, we have excluded more than half our HII galaxy sample resulting in less significant statistical results. Furthermore, by not imposing a redshift limit in Fig.1, we may have also introduced a bias towards brighter HII galaxy neighbours, as we have discussed earlier.

We now relax the above conditions and we add neighbours with available photometric redshift within the limit $\Delta m_r = +1.0$, considering all photometrically confirmed neighbours as "true" neighbours (Fig.3). This increases considerably (almost triples) the number of paired HII galaxies (from 17 to 48). Despite the fact that we surely contaminate the subsample of paired HII galaxies with a number of isolated ones because of the greater photometric redshift uncertainty of faint objects, we can see that the luminosity and velocity dispersion distributions can be considered statistically different, but the former at a reduced confidence level with respect to the Fig.1's case (see Table 1). In addition, we cannot reject the hypothesis that the redshift distributions of the two subsamples are drawn from the same parent population at any significant statistical level.

We should note here that excluding all galaxies with redshift above $z = 0.05$ from the analysis, presuming that the photometric redshifts of low *z* galaxies are more reliable, the trends remain practically the same as for the whole sample.

Table 1. Results of Kolmogorov-Smirnov statistical tests.

z confirmation	*Fig.*	z	N_i	N_p	KS_σ	KS_L	*KSz*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
spectroscopy	1	0.15	62	17	0.011	0.003	0.005
spectroscopy	2	0.05	32	14	0.098	0.030	0.129
spec. & photometry	3	0.15	62	48	0.067	0.011	0.952

Notes. *(1)* Redshift confirmation, *(2)* respective figure number, *(3)* upper limit of HII galaxy redshift, *(4)* Number of isolated HII galaxies, *(5)* Number of HII galaxies with at least one neighbour within 200 h_{75}^{-1}kpc, *(6)* probability that the null hypothesis that the samples are drawn from the same parent population can not be rejected for velocity dispersion distributions, *(7)* same as column *6* for luminosity distributions, *(8)* same as column *6* for redshift distributions.

In all cases the metallicity distributions of the two subsamples are statistically equivalent and therefore we do not present any extra plots.

Returning to the issue of the compactness of the HII galaxies we apply a KS test on the diameter distributions of a low redshift volume limited subsample, where all pairs are spectroscopically confirmed (Fig.4a), and of the whole parent sample using in addition photometrically confirmed neighbours (Fig.4b). Once more, we use volume limited subsamples to avoid introducing any distance dependent bias. We conclude that although we cannot reject the null hypothesis that the two aforementioned distributions are drawn from the same parent population at any significant confidence level, we observe a difference between the two subsample distributions which mainly arises from a visible shift between the distributions. This shift is due to the more compact objects being mostly HII galaxies with neighbours, while the more extended ones are isolated. We should note here that by investigating the diameter distributions of the HII galaxies in a small number of narrow redshift bins, we find that this effect persists in each bin. This partially confirms the results of Telles & Terlevich (1995) who found a weak trend where the most compact HII galaxies tend to have a close neighbour, whereas the most extended ones tend to be isolated. However, this trend between the two subsamples is not highly significant and a larger sample would be necessary in order to confirm this trend.

We now wish to investigate whether the particular systematic effect that we have identified, ie., the environmental dependence of both the $H\beta$ luminosity and the velocity dispersion, affects the cosmologically relevant $L_{H\beta} - \sigma$ correlation. Qualitatively one should not expect any important effect on the correlation since the existence of a close neighbour affects both the $H\beta$ luminosity and σ in the same direction; ie., they both decrease following the monotonic trend of the observed correlation. Nevertheless, in order to be more quantitative we fit the above correlation separately for the isolated or the paired HII galaxies, and we compare the slopes of the correlation with that of the whole sample together. In Fig.5 we plot the three lines which best fit each sample (black line for the parent sample (all points), red line for the paired HII sample (open squares) and green line (triangles) for the isolated sample). The hatched lines define the confidence band at 2σ confidence level of the parent sample's regression line, taking into account the joint distribution of the slope and the intercept.

For the case of isolated HII galaxies we find a relative difference of the slopes of the $L_{H\beta} - \sigma$ relation $\delta a/a_T = (a_{isol} - a_T)/a_T = -0.06 \pm 0.10$, while for the case of paired HII galaxies, $\delta a/a_T = 0.08 \pm 0.13$, where a_T is the slope of the correlation based on the parent sample of HII galaxies.

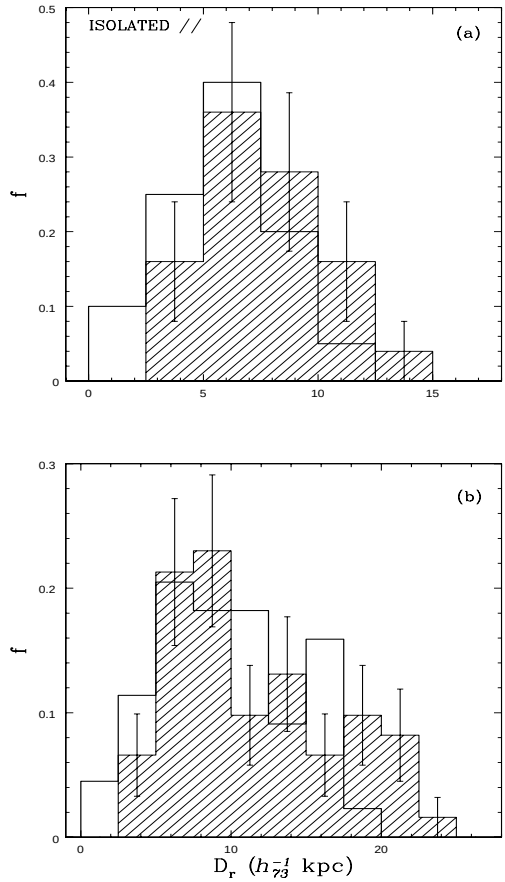

Fig. 4. Isophotal r-SDSS diameter distribution of isolated (hatched area) and paired HII galaxies of (a) a low redshift ($z < 0.05$) volume limited subsample of HII galaxies with spectroscopically confirmed neighbours, and (b) of the whole parent sample using also photometrically confirmed neighbours. Uncertainties are 1σ Poisson errors.

In an attempt to determine if any discrepancies can also arise due to random sampling of 62 or 48 objects drawn from the parent population independently of their properties, the errors were calculated by applying the bootstrap method i.e. by resampling randomly each subsample from the parent sample. Indeed, in both cases, we find no significant difference.

This is indeed a very important result, indicating that although environmental effects do influence the dynamics of the starburst they do not affect the cosmologically important $L_{H\beta} - \sigma$ correlation. Given the size of the sample, the possibility remains that these small differences between the slopes of the two subsamples are intrinsic. However, to verify if such small slope differences are real, we would need at least to triple the number of objects, a difficult task considering the expensive observational requirements for this kind of studies. Furthermore, such a difference in the slope of the relation is not found even at much higher densities, as shown by the similarity of the slope of the L-sigma relation for Giant HII regions in the disks of massive spirals (see conclusions & discussion section).

4. Conclusions & discussion

We have studied a sample of 110 HII galaxies which was selected from the SDSS DR7 spectroscopic data within a redshift

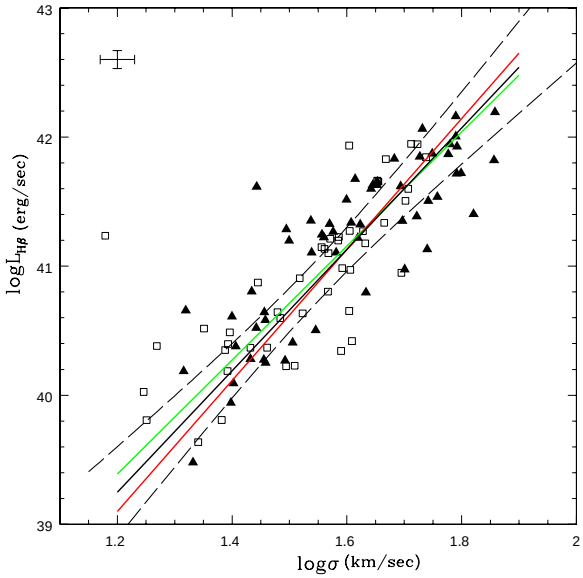

Fig. 5. L-$\sigma_{H\beta}$ diagram. The red line denotes the linear regression fitting of the isolated HII galaxies (triangles), while the green line denotes the fitting of those that have at least one spectroscopically or photometrically confirmed neighbour within 200 h_{75}^{-1}kpc (squares). The black line is the fitting of the parent sample and the hatched lines define the 2σ confidence band of the regression line. Typical 1σ errors are shown on the upper left corner of the plot.

range $0.01 < z < 0.16$ and $m_r < 19$. Our results indicate that there is a connection between the existence of a companion and the size of the starforming region.

In particular we find that both The Hβ luminosities and velocity dispersions of the HII galaxies with neighbours (within a projected rest-frame radius separation of $< 200h_{75}^{-1}$kpc and radial velocity separation of $\Delta u < 600 km/sec$) tend to be significantly lower than those of the isolated ones.

Importantly, the $L_{H\beta} - \sigma$ correlation and distance estimator is not affected by the environmental or host galaxy differences of the isolated and paired HII galaxies. One would like to understand the physical mechanism by which the environmental dependence of $L_{H\beta}$ and σ is such as to leave unaffected the correlation. If this correlation is a manifestation of the virial theorem, it is evident that the mass of the molecular cloud, progenitor of the massive starburst, is influenced by the environment, i.e. more massive clouds, producing more massive starbursts and therefore higher values of $L_{H\beta}$ and σ, are developed in lower density environments, while the lower mass clouds are characteristic of higher density environments, where more frequent interactions can limit the growth of the molecular clouds. This is even more evident when including in the discussion the results of Giant HII regions in the disks of massive spirals. Giant HII regions are massive bursts of star formation in a much higher density environment than that of HII galaxies. As can be seen from the analysis of Melnick, Terlevich & Moles (1988) or Chávez et al. (2012), Giant HII regions and HII galaxies define a tight $L_{H\beta} - \sigma$ correlation where Giant HII regions occupy the lower end of the relation; i.e. they tend to be much smaller than HII galaxies while independently verifying the same tight relation between $L_{H\beta}$ and σ of the more luminous HII galaxies notwithstanding the fact that they are formed in a much denser environment.

Our results are in agreement with previous studies showing that HII galaxies are less clustered than normal galaxies (e.g. Iovino, Melnick & Shaver 1988; Loveday, Tresse & Maddox 1999; Telles & Maddox 2000), and that they lack massive neighbours (Campos-Aguilar & Moles 1991; Campos-Aguilar, Moles & Masegosa 1993). Even considering all photometrically confirmed neighbours (faint neighbours) as real neighbours, more than half of our sample galaxies remain isolated. Our results therefore concur with the view where star formation in HII galaxies is not necessarily triggered by interactions (Telles & Terlevich 1995; Telles & Maddox 2000); they do appear however to play an important role in the confinement of the total mass of the progenitor molecular cloud that gives birth to an HII galaxy. Although the triggering mechanism of the enhanced star-forming activity of HII galaxies is still debated, star formation is probably bound to happen when even an isolated molecular cloud fulfills the requirements (see discussion in Telles 2010). Alternatively, and since older stellar populations have been found to be present (e.g. Papaderos et al. 1996; Telles & Terlevich 1997; Cairós et al. 2003), implying that not all HII galaxies are young formations, it could also be a manifestation of cosmic downsizing; less massive structures are unable to efficiently form stars in the past and they are doing so in later epochs, when most massive structures are already quiescent (e.g. Neistein, van den Bosch & Dekel 2006). Thus, given that star formation in most HII galaxies happens spontaneously and depends only on the mass of the already virialised system, the $L_{H\beta} - \sigma$ relation should be expected as well.

Not all HII galaxies should be expected to verify the $L_{H\beta} - \sigma$ relation with a small scatter. Already Melnick et al. (1988) had recognised that systems with $\log\sigma > 1.75$ show a flattening of the relation, probably indicating the onset of rotation for larger starforming regions, and that limiting the sample to objects with 10 km/s $< \sigma <$ 60 km/s, equivalent widths $W_{H\beta} > 50$Å and gaussian profiles in their emission lines, produces a tight $L_{H\beta} - \sigma$ relation, suggesting that we are dealing with young massive bursts that dominate the luminosity of the galaxy and that they are gravitationally bound and pressure supported. The biases introduced by multiplicity, rotation and contamination by the underlying galaxy (e.g. Overzier et al. 2008; Amorin et al. 2012) are minimised by selecting only objects with emission lines of high equivalent width and line profiles that are well fitted by a single gaussian.

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