The Environmental Dependence of Star Formation in the Nearby Universe

Laerte Sodré Jr.

Departamento de Astronomia, IAG, Universidade de São Paulo, Brazil

Abílio Mateus Jr.

Departamento de Astronomia, IAG, Universidade de São Paulo, Brazil

Abstract. We have investigated how the incidence of star-forming galaxies varies with the environment using a volume-limited sample of nearby galaxy spectra extracted from the 2dF Galaxy Redshift Survey. The environment is characterized by the local number density of galaxies, corrected for sample incompleteness and border effects. Using the equivalent widths of [O II]λ3727 and Hδ we discriminate the star-forming galaxies in two classes, starbursts and ordinary star-forming galaxies, and evaluate their properties as a function of the local density. We show that the fraction of ordinary star-forming galaxies decreases regularly with increasing density, indicating that star formation is sensitive to the environment for all range of densities present in the sample. The fraction of starbursts is approximately independent of the density and, consequently, the fraction of starbursts relative to star-forming galaxies increases with local density. This suggests that a mechanism that acts everywhere, like tidal interactions, is the responsible for triggering starbursts. We also show that while the mean EW(Hδ) of ordinary star-forming galaxies is progressively reduced as density increases, for starbursts it suffers a strong decrease at densities corresponding to scales of $\rho^{-1/3} \sim 2.5 \ h^{-1} \ Mpc$. A visual inspection of starburst images in the Digital Sky Survey reveals that this corresponds to a change in the morphology of starburst galaxies, from mainly apparently normal spirals and galaxies with apparently compact morphologies at low densities, to tidally distorted spirals at high densities.

1. Introduction

Studies of the effects of the large scale environment around a galaxy on the properties of its star formation are essential for understanding how galaxies evolve. It is well known since long time that galaxies with large star formation rates avoid dense environments, and many recent works have confirmed that star formation is lower for galaxies in clusters and groups than for those in the field (e.g., Ellingson et al. 2001, Martínez et al. 2002). Several different process have been proposed to explain why and how star formation is affected by the environment, like mergers, ram pressure, and tidal interactions. While all of
them may take place in some form or another, the main process that affects star formation in galaxies is not clear yet.

In the current era of large redshift surveys, enormous amounts of homogeneous data on nearby and distant galaxies are becoming available and may be used to study statistically many aspects of star formation in galaxies. Here we use the first 100k Data Release of the 2dF Galaxy Redshift Survey (2dFGRS; Colless et al. 2001) to examine some properties of star-forming galaxies in the nearby universe.

2. A Nearby Galaxy Sample

The sample analyzed here was extracted from the 2dFGRS. We adopt a volume limited sample because, in this case, the selection function is in principle uniform and the variations in galaxy number density are due to galaxy clustering only. We have considered galaxies with velocities between 600 km s\(^{-1}\) and 15000 km s\(^{-1}\) brighter than the extinction corrected magnitude \(b_J = 18.50\) (corresponding to \(M_{b_J}^{lim} = -17.38 + 5 \log h\)) and located within the SGP and NGP strips covered by the survey. Galaxy distances were computed from the redshifts, neglecting peculiar velocities and \(k\)-corrections.

The redshift completeness and its magnitude dependence vary over the area of the survey but, nevertheless, they can be represented by a mask that gives the selection function at each position in the survey area (Colless et al. 2001, Norberg et al. 2001). We have used numerical simulations to study how the survey geometry and its current incompleteness affect our estimates of the galaxy density (Mateus & Sodré, in preparation). These simulations allowed us to estimate the mean local correction factor, \(C\), that should be applied to the observed density to correct it of local incompleteness and border effects (\(C \geq 1\)). To minimize these corrections and, at the same time, to have a sample as large as possible, we have considered only regions for which \(C \leq 2.5\).

3. Determination of the Local Galaxy Density

We characterize the environment of a galaxy by the three-dimensional galaxy number density in its neighborhood. This density is calculated from the distance \(r\) to its 5\(-\)th nearest neighbor in the sample and corrected with the local value of \(C\). Since we are neglecting peculiar velocities, galaxies in dense environments, where the velocity dispersion is high, will probably have their local densities underestimated. However, only one of the cataloged galaxy clusters in the survey region (De Propis et al. 2002), S0006, is inside our selected volume. Hence, our sample is more representative of the field than of the cluster galaxy population.

The local densities (of galaxies brighter than \(M_{b_J}^{lim}\)) were computed for all the galaxies in the sample above. It can be shown that our results are not affected, qualitatively, by the density corrections.
4. Spectral Classes

Spectra obtained in modern redshift surveys like the 2dFGRS have much more information than that needed to obtain just redshifts, and can be used to provide informations on the galaxy type or star formation activity. The use of equivalent widths (EWs) of certain spectral features are particularly useful in the study of survey data because they are not affected by reddening and are relatively insensitive to the instrumental resolution.

Following Balogh et al. (1999), we use the EWs of the [O II]λ3727 doublet and of Hδ to classify galaxies in distinct spectral classes. The EW of [O II] measures the activity of star formation, whereas the EW(Hδ) is sensitive to the age of star formation bursts. EWs in the rest-frame of the objects were computed and 146 of them that presented bad quality spectra or were classified as AGN (i.e., with EW(Hα) > 10 Å and EW([N II]) > 0.55 EW(Hα); Lewis et al. 2002) were removed from the analysis. The remaining sample, with \( N_{ALL} = 1234 \) galaxies, will be analyzed hereafter.

We consider star-forming galaxies those with EW([O II]) larger than 5 Å, roughly the detection limit of this spectral feature in the survey spectra. Notice that we adopt here positive and negative values for the EW of emission and absorption lines, respectively. The spectral classes defined in the plane EW(Hδ) vs. EW([O II]) and discussed in this work are:

- non star-forming galaxies (P: EW([O II]) ≤ 5 Å) passive galaxies, without evidence of current significant star formation (in general E or S0);
- starburst galaxies (SB: EW([O II]) > 5Å, EW(Hδ) > 0) galaxies where a large fraction of the light comes from a starburst that started less than \( \sim 200 \) Myr ago; these galaxies are called SSB (short starburst) by Balogh et al. (1999);
- ordinary star-forming galaxies (SF: EW([O II])>5Å, EW(Hδ)<0) includes most normal spirals and irregulars, that have been forming stars for several hundred million years.

With these definitions, the total number of galaxies with star formation is \( N_{TSF} = 635 \), of which \( N_{SB} = 66 \) and \( N_{SF} = 569 \), and of those without evidence of ongoing star formation is \( N_{P} = 599 \). Considering only galaxies with star formation, SBs correspond to 10.4% of the total.

5. Type vs. Local Density

Our main results are summarized in Figure 1. In all plots the data of each class was divided in six density bins with approximately the same number of galaxies per bin. Fig. 1a shows that the fraction of star-forming galaxies decreases steadily with increasing local density. At the same time, the fraction of non star-forming galaxies increases with increasing density. These trends may be seen as a consequence of the well-known density - morphology relation proposed by Dressler (1980). The fraction of SBs, however, is essentially independent of
local density. Since the fraction of star-forming galaxies decrease with increasing density, in dense environments SBs become relatively more frequent among star-forming galaxies.

The relation between the mean value of $\text{EW}(H\alpha)$ and local density, shown in Fig. 1b, also provides interesting information about the behavior of star formation in distinct environments. Passive galaxies do not have significant $H\alpha$ emission, as expected. For ordinary star-forming galaxies the $\text{EW}(H\alpha)$ is essentially constant with density. For the SBs, however, the $\text{EW}(H\alpha)$ presents a clear decrease at $\rho \sim 0.06 h^3 \text{ Mpc}^{-3}$. At lower densities these galaxies have mean $\text{EW}(H\alpha)$ larger than those of SF galaxies. For higher densities, however, it drops from $\sim 30 \text{ Å}$ to $\sim 10 \text{ Å}$, below the mean value of SFs, $\sim 20 \text{ Å}$.

6. Discussion

In the hierarchical scenario, as galaxy clustering evolves, the density around a galaxy tends to increase, in all environments. Higher density probably means more interactions. Our results give support to this broad view because star formation seems to be affected by the environment in all range of densities covered by our sample, as evidenced by the decrease in the fraction of star-forming galaxies with increasing local density shown in Fig. 1. Lewis et al. (2002), analyzing a different sample extracted from the 2dFGRS, find a density threshold, below which the star formation is insensitive to the galaxy environment. This is in variance with our results, which suggest that the processes that affect the star formation activity in a galaxy do act everywhere, although they may be different in distinct environments.

Most of star-forming galaxies have their star formation activity inhibited or even interrupted as density increases, but the fraction of SBs seems to be roughly independent of local density, contrarily to the expectation that denser environments favor the triggering of a starburst. However, since the fraction of star-forming galaxies decreases in dense regions, the fraction of SB galaxies relative to all star-forming galaxies is actually enhanced. This behavior have been noticed already in a sample of galaxies in the Shapley supercluster (Cuevas 2000). From a study of 8 Abell clusters, Moss & Whittle (2000) have also concluded that the fraction of SBs among spirals increases from regions of lower to higher local galaxy surface density. They noticed that in most starbursts the $H\alpha$ emission is circumnuclear and the galaxy morphology is disturbed, indicating the action of tidal interactions; these galaxies are the local counterparts of the Butcher-Oemler objects. Here we have shown that the fraction of SBs is essentially the same in all environments. This favors mechanisms like tidal interactions for triggering starbursts because they act everywhere, and not only in high-density environments, like ram-pressure stripping or high-speed interactions between galaxies (‘harassment’).

We have also found that the $\text{EW}(H\alpha)$ of starbursts suffers a strong reduction in high density regions. This reduction occurs at a characteristic intergalactic distance ($\rho^{-1/3}$) of $\sim 2.5 h^{-1} \text{ Mpc}$. This is a quite large separation, when compared with the distances between the members of our Local Group.

We have inspected visually the sample of starburst galaxies using Digital Sky Survey images. A clear trend with morphology is present: at low densi-
ties most of the starbursts are apparently normal spirals or galaxies with an apparently compact morphology, whereas at high densities the starburst class contains a large fraction of tidally distorted spirals. In the lowest density bin only 1 out of 11 galaxies is clearly a tidally distorted spiral; in the highest density bin, however, 6 out of 11 are galaxies of this kind. This suggests that tidal interactions in dense environments may indeed favor the triggering of starbursts in spiral galaxies.

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Figure 1. Some properties of the sample as a function of the local galaxy number density. For each class, the density was divided in 6 bins with approximately the same number of galaxies per bin. a) Fractions of galaxy classes; the error bars assume Poisson statistics. b) EW(Hα), with the errors of the mean.