Tracing the Ancestry of Galaxies (on the land of our ancestors)
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The Environments of Luminous IR Galaxies

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Abstract. We have studied the star formation vs. environment connection of local LIRGs by characterising their environment using number densities of galaxies as well as halo masses. It is found that LIRGs preferentially live in group environments and that they also exhibit a relation where their star formation rate increases with their environmental density.

Keywords. galaxies: evolution, galaxies: starburst

1. Introduction

Luminous Infrared Galaxies (LIRGs) are defined in terms of their infrared luminosity ($L_{IR} = L_{8-1000\mu m}$) as galaxies with $10^{11} L_{\odot} \leqslant L_{IR} \leqslant 10^{12} L_{\odot}$. Locally, they are often products of major mergers between gas rich disk galaxies (e.g. Sanders & Mirabel 1996). They are much more numerous in the high redshift Universe ($z \sim 1$) than they are at $z \sim 0$ and this makes them potentially a useful laboratory to understand the star formation rate (SFR) vs. environment relationship, and its changes, at the two redshifts. This work addresses the relationship of SFR and the larger-scale environment of local IR galaxies, and specifically LIRGs, by characterising their environment with galaxy number counts (see Tekola *et al.* 2011a) as well as halo masses (Tekola *et al.* 2011b).

2. Results

We measured the local density around IR-galaxies, taken from the IRAS PSCz redshift survey, by counting PSCz and 6dF galaxies in a cylindrical volume with $2h^{-1}$ Mpc radius and $10h^{-1}$ Mpc length around each IR-galaxy. The radius of the cylinder is selected to include the immediate density field that affects galaxy star-formation (SF) (Blanton *et al.* 2006) and at the same time allows enough statistics at regions where the galaxy number count is small. The length of the cylinder is just greater than typical velocity dispersions ($\sim 800h$ km s^{-1}) inside clusters of galaxies. The density count is normalised by the mean number density of galaxies in the respective density field. The SFRs for the individual PSCz galaxies are derived from their L_{IR} (Kennicutt 1996) and stellar masses are derived using the absolute K magnitudes found by cross-matching PSCz with 2MASS.

Using the density estimates, stellar masses, and SFR, we explored the connection between these three quantities for local IR galaxies. Figure 1 shows the correlation between L_{IR} (i.e. SFR) and the environment of IR galaxies, where densities are measured from 6dF and PSCz in the left and right panels, respectively. In both cases we note that there is a clear difference in the environments of LIRGs and non-LIRG IR (those with $L_{IR} \leqslant 10^{11} L_{\odot}$) galaxies. Based on halo mass estimation (see below) of the galaxy systems

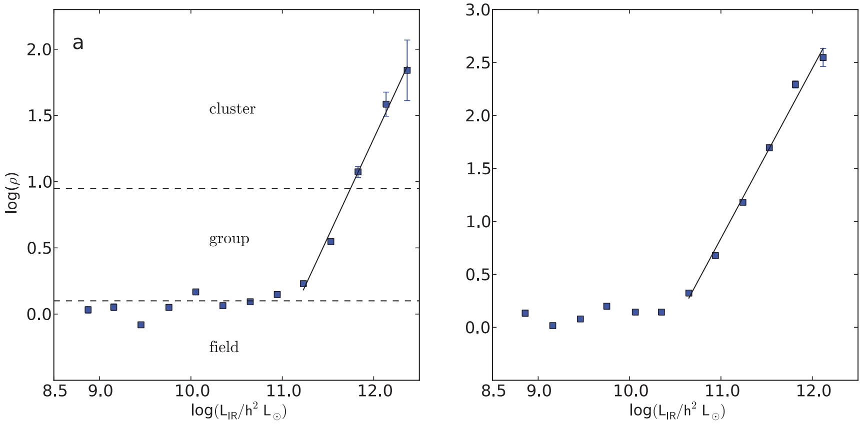

Figure 1. The relationship between L_{IR} and the mean local densities for IRAS galaxies. The densities are estimated using 6dF (left panel) and PSCz (right panel) galaxies. The data points show the mean density in $\log(L_{IR})$ bins of width 0.3. The horizontal dashed lines mark the transition from field to group and from group to cluster.

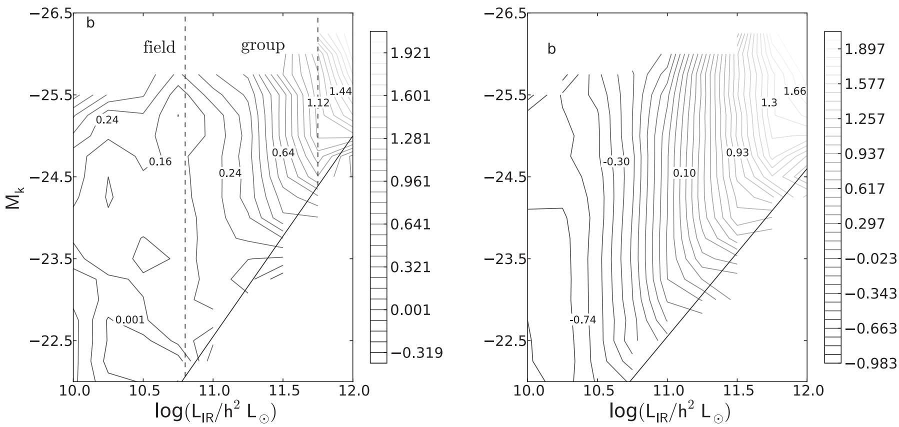

Figure 2. Local density (6dF in panel a) and PSCz in panel b)) as a function of both stellar mass (M_K) and SFR (L_{IR}). Both panels show contours of constant density, with the values of $\log\rho$. The vertical dashed lines in panel (a) denote the approximate transition between field, group, and cluster environments. The solid diagonal lines in both panels highlight that there is a maximum SFR that grows with stellar mass.

the PSCz galaxies are associated with, we have defined field, group, and cluster environments, and it is seen that the transition happens in the group environment, where LIRGs typically live.

Figure 2 shows the joint dependence of local density on both stellar mass and SFR. In the LIRG regime, the density contours show a clear trend in both panels: they are almost perfectly vertical, with each density contour corresponding to a specific value of SFR. The diagonal lines in both panels of Figure 2 highlight that there is a minimum stellar mass that can support the existence of IR galaxies at a given L_{IR}, and this minimum mass grows with L_{IR}. This limit must be related to gas-fractions and velocity dispersions of the galaxies, and will be studied separately in the future.

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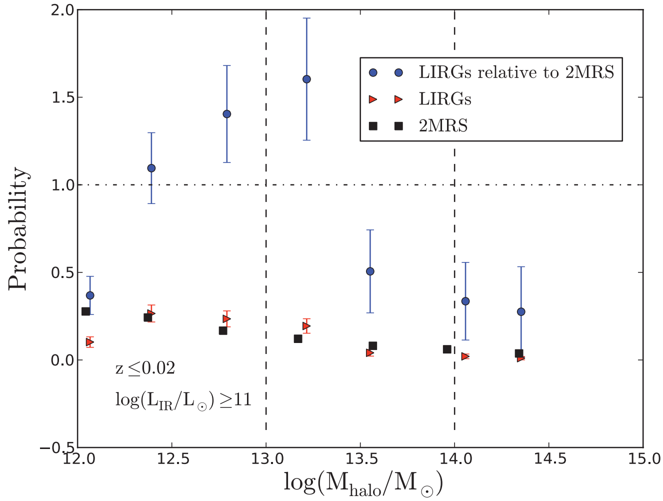

Figure 3. The probability of finding non-LIRGs and 2MASS galaxies in a certain range dark matter halo mass. The triangles represent the probability for non-LIRGs, the squares for 2MASS and the circles for relative probability of Non-LIRG infrared galaxies in relative to 2MASS galaxies. The dashed vertical lines again demarcate regions for field, group, and cluster halo sizes, from left to right, respectively. All the error bars are calculated from Poisson statistics.

In addition to number counts of galaxies, halo masses are used to characterise the environments of low-L_{IR} LIRGs from three volume-limited PSCz samples. For each of these PSCz volume-limited samples, we constructed a corresponding 2MRS (2MASS redshift survey) volume-limited sample with the same redshift limit. For each of the three volume-limited 2MRS samples, galaxy systems are identified using the Berlind *et al.* (2006) Friends-of-Friends algorithm which groups together galaxies that live in the same dark matter halo. By matching the measured space density of the identified systems to the theoretical space density of dark matter halos, we assign a virial halo mass to each system. Finally, each of the LIRGs in the PSCz volume-limited sample are matched with galaxy systems identified from the corresponding 2MRS sample in order to find the galaxy system the LIRGs belong to and get the size of the halo mass. Therefore, ultimately each of the galaxies in both the PSCz and 2MRS volume-limited samples has a halo mass estimate.

In each of the PSCz volume-limited samples, the LIRGs are binned in a halo mass range of 0.4 dex and the number in each bin is divided by the total number of galaxies from their respective volume-limited sample. This determines the probability of finding the PSCz LIRGs in a certain halo mass range. The same is done for 2MRS galaxies to get the probability of finding 2MRS galaxies in a certain mass range. The different panels in Figure 3 represent the results for the different volume-limited samples, squares represent 2MRS and triangles PSCz galaxies.

What we are really interested in is the *relative* probability of finding PSCz galaxies with respect to 2MRS galaxies, essentially the K-selected control sample, and the blue circles in Fig. 3 show this. The relative probability of finding LIRGs in cluster and field environments appears to be small, while the highest relative probability, though the error bars are significant, occurs at a halo mass near the transition between field and group and group sizes.

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3. Discussion

It is found that the $L_{IR} \sim 10^{11} L_{\odot}$ luminosity corresponds to an important environmental break point among IR galaxies. Above this luminosity (LIRGs and ULIRGs), the SFR (or L_{IR}) is strongly correlated with the large scale environment (Fig. 1). In terms of the traditional density classes (field, group and cluster), LIRGs live in groups while ULIRGs (IR galaxies defined as $L_{IR} \geqslant 10^{12} L_{\odot}$) live in cluster environments. This result seems to indicate that the large scale environment has an important effect in the SF mechanism of LIRGs, perhaps through tidal fields of large scale structures. The correlation shows a SF-environment relation which is not "normal" (where SFRs tend to drop with increasing densities among the general galaxy population) in local Universe, but is rather similar to what is claimed at $z \sim 1$ by some works (see e.g. Elbaz *et al.* 2007). This suggests that local IR-luminous and higher redshift SF galaxies might have formed through similar processes.

According to Figure 2, LIRGs exhibit a correlation between their SFR and environment at constant M_K (used as a proxy for stellar mass) but they do not show any clear correlation between stellar mass and density at constant SFR. No matter what the stellar mass is, local LIRGs in a similar density environment tend to have the same total SFR. The implication is that the SFR of local LIRGs is controlled by their environment, or by the effect of the environment on characteristics other than the stellar mass, such as gas fractions, SF efficiencies, etc. There is a minimum stellar mass threshold which galaxies have to have in order to be LIRGs at a certain environment, but above that stellar mass threshold, the stellar mass increase does not have a consequence on their IR activity.

Using an estimate of the dark matter halo masses, it was found that LIRGs, as compared to the general NIR selected galaxy population, are slightly more likely to live in environments close to the transition region between field and group size haloes. The result is consistent with what was found when densities were quantified using number counts of galaxies.

4. Conclusions

We have studied the star formation-environment connection of local LIRGs by characterising their environment using both number densities of galaxies and halo masses, based on different redshift surveys. It was found that the IR luminosity point $10^{11} L_{\odot}$ marks an important environmental difference among IR galaxies. We also found that LIRGs live in group environments, or close to the transition dark matter halo mass scale to groups, and they exhibit a star formation-density relationship where the SFR increases with environmental density. The latter pattern is similar to what has been found for higher redshift star forming galaxies.

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