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Article

Interactions, Starbursts, and Star Formation

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Abstract: We study how interactions between galaxies affect star formation within them by considering a sample of almost 1500 of the nearest galaxies, all within a distance of $\sim$45 Mpc. We use the far-IR emission to define the massive star formation rate (SFR), and then normalise the SFR by the stellar mass of the galaxy to obtain the specific star formation rate (SSFR). We explore the distribution of (S)SFR with morphological type and with stellar mass. We calculate the relative enhancement of SFR and SSFR for each galaxy by normalising them by the median SFR and SSFR values of individual control samples of similar non-interacting galaxies. We find that both the median SFR and SSFR are enhanced in interacting galaxies, and more so as the degree of interaction is higher. The increase is moderate, reaching a maximum of a factor of 1.9 for the highest degree of interaction (mergers). While the SFR and SSFR are enhanced statistically by interactions, in many individual interacting galaxies they are not enhanced at all. Our study is based on a representative sample of nearby galaxies and should be used to place constraints on studies based on samples of galaxies at larger distances.

Keywords: galaxies: general, galaxies: interactions, galaxies: starbursts

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1. Introduction

Galaxy-galaxy interactions and mergers are an important factor in the dominant cosmological model of galaxy evolution, in which mergers between dark matter haloes and/or luminous galaxies occur frequently, increasing their mass and ultimately shaping them into the galaxies that we observe at the current epoch. A frequent assumption is that interactions and mergers lead to star formation rates (SFRs) that are temporarily increased, often by very large amounts. We know from observations that this can and does happen, in the most extreme form as Ultra-Luminous InfraRed Galaxies (ULIRGs), and numerical simulations can also produce much enhanced SFRs (e.g., [1,2]).

A question that is vital is whether any galaxy-galaxy interaction or merger is accompanied by a significant increase in the SFR, and whether this increase is always so large that it can be classified as a so-called "starburst". From various observational and modelling studies we have strong indications that indeed there is such a general increase, but also that this is limited to around a factor of two in the SFR (e.g., [3–7] and references therein, [8,9]).

We summarise here the results of our statistical study of the SFR and the specific SFR (SSFR; SFR normalised by stellar mass) of a sample of some 1500 galaxies in the very local Universe, within a distance of ∼45 Mpc ([7,10]). This sample is unique because it covers galaxies down to stellar masses of around $10^8\,M_\odot$ and of all morphological types, and should be considered as a local analogue for studies of galaxies at higher redshifts.

2. Data and Analysis

For a sample of 1478 nearby galaxies ($D < 45\,$Mpc) selected from the *Spitzer* Survey of Stellar Structure in Galaxies (S^4G; [11]) we use the SFR (from a combination of IRAS 60 and $100\,\mu$m fluxes; from [12]), the SSFR (SFR divided by stellar mass, the latter from the dust emission-corrected *Spitzer* $3.6\,\mu$m images from the S^4G; also from [12]), and whether the galaxies are interacting (Classes A—merging; B—highly distorted; C—with minor distortions; from [13]). As few of our sample galaxies have powerful AGN emission, we do not expect AGN activity to affect the SFRs in a statistically significant way (see [7]). Figure 1 shows an example of one of our Class B galaxies: NGC 4438.

We then calculate, for each sample galaxy, the enhancement in its SFR and SSFR, $E(\mathrm{SFR})$ and $E(\mathrm{SSFR})$, by dividing these parameters by the median values for a control sample. The control sample is created for each galaxy individually, and consists of all those galaxies which are not interacting and which are close in morphological type (within ± 1 numerical class) and stellar mass (within ± 0.2 in $\log(M/M_\odot)$; see [7]).

We can use the values of $E(\mathrm{SFR})$ and $E(\mathrm{SSFR})$ to define which galaxies are starbursts: namely those which have values of E above a certain level, in particular $E(\mathrm{SFR}) > 5$ and $E(\mathrm{SSFR}) > 4$. As we show in [7] (see also [8]), these choices are reasonable, but in any case the main results obtained do not depend on the exact values of the cut-off used to define starbursts.

Figure 1. False-colour image of the galaxy NGC 4438, one of our sample galaxies classified as Class B in [13]—recognising its highly distorted morphology indicative of the galaxy undergoing an interaction. Image courtesy of DAGAL, Nik Szymanek, SDSS, and S^{4}G, www.dagalnetwork.eu.

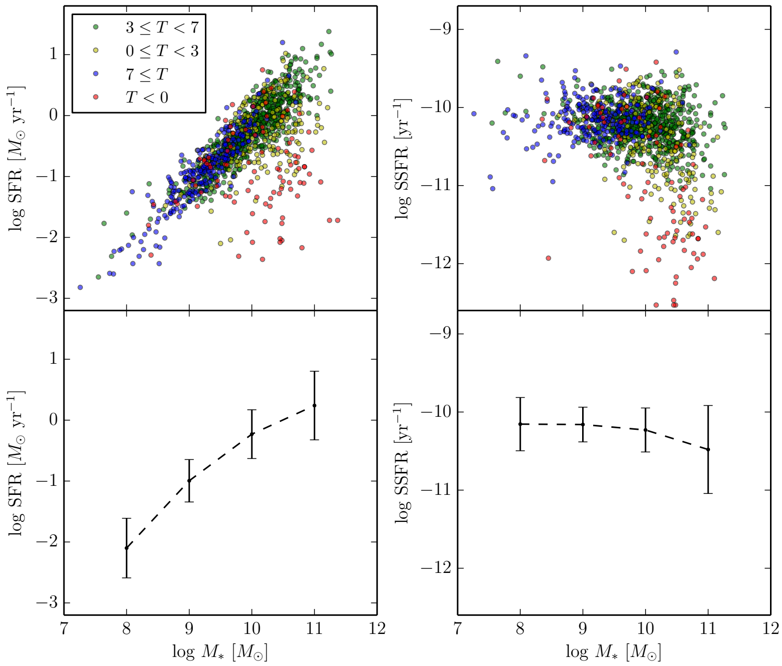

Figure 2. Log of the star formation rate (SFR) (**left** panels) and the specific star formation rate (SSFR) (**right** panels) as a function of stellar mass. **Top** panels show the individual galaxies, colour-coded by morphological type, while the **lower** panels show the median values, with the $1\,\sigma$ spread indicated by the error bars. The dashed curve connects the points. Morphological type is given as de Vaucouleurs' T-type, where $T < 0$ correspond to lenticulars and ellipticals, spirals have $0 < T < 8$, with Sa $T = 1$, Sb $T = 3$, *etc.*, and late-type and irregular galaxies are $T > 8$. From [7].

3. Results

In Figure 2 we show how the SFR and the SSFR vary with stellar mass and with morphological type (the latter colour-coded in the top panels). This is a well-known plot (often referred to as the "galaxy main sequence") but nicely illustrates a number of important points, such as that our (S)SFR determinations seem correct, and that our sample spans a large range in both type and mass. We claim that our sample is a much better representation of at least the nearby Universe than what a typical galaxy main-sequence plot from the literature might lead one to believe.

Figure 3 shows the enhancement of the SFR (left panels) and the SSFR (right panels) for each galaxy individually (top panels) and in the median (lower panels) for the sample galaxies as a function of their interaction class (see Section 2), where the most strongly interacting galaxies are category A on the left, and the non-interacting control sample galaxies are Class N on the right. We can derive a number of main results from this figure, as highlighted in the following short Sections.

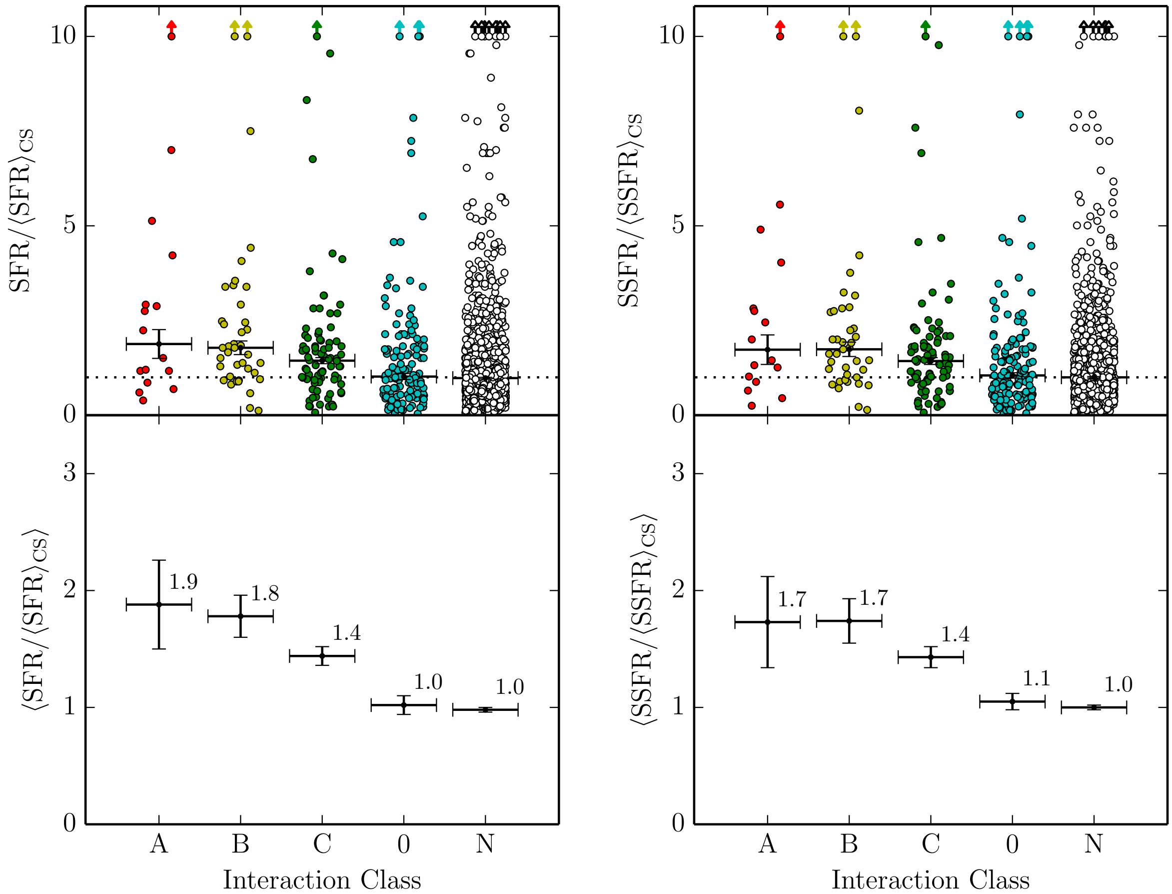

Figure 3. The SFR (**left** panels) and SSFR (**right** panels) enhancement, defined as the (S)SFR of a galaxy normalised by the median (S)SFR for its control population, separated by interaction class (where A is the most extreme class, of mergers, and N contains non-interacting galaxies). Values larger than 10 are indicated by lower limits. The median values per class are indicated in both top and lower panels, but are amplified in the lower panels where the values are indicated next to the data points. Error bars indicate $1\,\sigma$ uncertainties. From [7].

3.1. Extreme Star Formation Is Not Limited to Interacting Galaxies

Extreme values of SFR and SSFR, of more than 10 times that of the control sample, are indicated in the individual values for galaxies (top panels in Figure 3) with arrows. These are seen to occur across the board, in all categories, and are not limited to interacting galaxies. It is thus not correct to state that extreme values of (S)SFR, indicative of the most extreme starbursts, must occur in interacting galaxies. As shown in Table 1 of [7], many of these galaxies are early-types, including ellipticals. Their raw SFRs (not normalised by control sample) are sometimes, but not always, rather modest, but their (S)SFR enhancement may be high compared to the SFRs of the similar galaxies in their control samples.

3.2. Many Interacting Galaxies Do Not Have Enhanced Star Formation at All

Values below unity also occur across the board, and in particular we note that a good number of interacting and merging galaxies (Classes C, B and A) form stars at a lower rate than might be expected from their mass and type. We thus see that many interacting galaxies have no enhanced (S)SFR at all.

3.3. Interactions Do Increase the (S)SFR, but Not by Much

The median SFR and SSFR enhancement values, as shown in the lower panels of Figure 3, shows that the median (S)SFR is indeed increased in interacting as compared to non-interacting (class N) galaxies. This enhancement is relatively modest, however, at just below a factor of two. Our work, using a larger sample galaxy with well-defined parameters, thus confirms earlier claims in the literature (see references in Section 1) of a moderate increase of the (S)SFR due to interactions.

3.4. Stronger Interactions Induce More Star Formation

The figure shows that the increase in (S)SFR is more pronounced as the interaction gets stronger, towards Class A, or towards the left in the plots. This shows that the excess in (S)SFR as compared to control galaxies increases as the interaction gets progressively more pronounced; from the minor distortions which give rise to our Class C, via the major distortions in morphology, indicative of more pronounced gravitational effects, in Class B, to the merger galaxies of Class A. This indicates that indeed the degree of interaction is related to the excess (S)SFR, keeping in mind what we noted above, that even for Class A the enhancement is at most a factor of two, and that this is a statistical effect, with many galaxies in all classes not having enhanced (S)SFR at all.

3.5. Effective Control Sample Technique

Finally, our results indicate that our control sample technique works. This is shown by the fact that the median values for Class N (the non-interacting galaxies) are 1.0. This is exactly what they should be, considering that every control sample galaxy has also been analysed with its own control sample.

4. Conclusions

Using a sample of 1500 nearby galaxies from the S^{4}G we quantify the role of galaxy-galaxy interactions in enhancing the star formation. To do this, we measure SFRs from *IRAS* fluxes, and use stellar masses determined from 3.6 μm S^{4}G images corrected for emission from young stars and dust. We normalise the SFR by galaxy mass (yielding the SSFR), and explore the distribution of the SFR and SSFR with morphological type and galaxy stellar mass. For each galaxy we calculate the SFR and SSFR enhancement by normalising them to the values obtained for a specific and individually constructed control sample, consisting of all galaxies within a morphological type range of ± 1, and a stellar mass range of ± 0.2 in $\log(M/M_{\odot})$.

We find that both the median SFR and SSFR are enhanced in interacting galaxies, and more so as the interaction becomes stronger. The increase is, however, moderate, of at most a factor of two, and driven by an overall enhancement of the (S)SFR rather than by highly enhanced values in a very small number of galaxies. We can use the SFR and SSFR enhancements to define galaxies as starbursts. The largest values of (S)SFR enhancement, indicative of the most extreme starbursts, occur in all classes, not just among the interacting galaxies. Many interacting galaxies have SFRs and SSFRs that are not enhanced at all with respect to a control population, and in several cases their (S)SFR is even lower. As this study is based on a representative sample of nearby galaxies, we argue that it should be used to place constraints on studies based on samples of galaxies at larger distances.

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Author Contributions

Both co-authors have contributed equally to this work.

Conflicts of Interest

The authors declare no conflict of interest.

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