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ENHANCED STAR FORMATION IN GALAXY MERGERS AT THE PERIPHERY OF CLUSTERS

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Abstract. Observations show that a large part of the stars seen today formed during bursts of star formation, which in the Local Universe appear to be mostly triggered by galaxy mergers. Yet, simulations of galaxy mergers rarely induce starbursts as intense as those observed, in particular at high redshift. Moreover, observations suggest that large-scale structures could trigger the star formation at $z \simeq 1$ and above.

We have then investigated the influence of the proximity of a cluster on star formation. We performed a large set of numerical simulations, in which clusters were modeled by analytical potential wells. We mainly focused on galaxies located in the periphery of these potentials. We show that, while the potentials of clusters do not directly trigger starbursts in single galaxies, merger-induced starbursts are on average twice more intense when the mergers take place in the vicinity of such large structures. This enhancement affects not only the instantaneous SFR, but also the total stellar mass formed during these events.

We thus demonstrate a significant effect of the large-scale environment on star formation in galaxies, caused by the tidal field of large structures.

1 Introduction

In the Local Universe as well as at $z \simeq 1$, starbursts often take place in interacting or merging systems (Sanders & Mirabel 1996, Conselice et al. 2003, Bridge et al. 2007), and in particular in major mergers (involving two galaxies of comparable masses).

This is explained by theoretical and numerical studies (Barnes & Hernquist 1991, Mihos & Hernquist 1996) that show that the tidal forces during mergers trigger a gas inflow toward the center of the galaxy, thus increasing the gas density and the star formation rate (SFR).

Nevertheless, a statistical study of a large number of galaxy interactions (thanks to numerical simulations) allowed di Matteo et al. (2007) to conclude that the SFR in galaxy mergers is not as high as expected considering the observations (the mean SFR is rather low, and so is the frequency of intense starbursts). Thus, there might exist unkown factors that trigger the most intense starbursts.

Moreover, observations by Elbaz et al. (2007) and Cooper et al. (2007) showed that at $z \simeq 1$ there is a reversal of the SFR-density relation : in the Local Universe, the star formation is quenched in dense environments and it seems to be the contrary at $z \simeq 1$ (where the highest SFRs are found in dense environments). Cosmological models predict that this reversal should only take place at $z > 2$, so the Elbaz et al. observations are still unexplained : an unkown mechanism must trigger starbursts in dense environments, and this mechanism must be linked with galaxy mergers since the bulk of star formation occurs in interacting galaxies even at $z \simeq 1$.

We thus decided to investigate the influence of the tidal field of a large structure like a galaxy cluster on the star formation rate during major mergers. We will describe the method used for numerical simulations in Section 2 and the results in Section 3. Our conclusions are summarized in Section 4.

2 Method

We performed simulations using the code described in Bournaud & Combes (2002), and in which galaxies are modeled with stars, gas and dark matter particles (2.2×10^5 particles per galaxy). The gas dynamics is

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treated with the sticky-particles algorithm with β_r=0.7 and β_t=0.5. Star formation is computed according to the Schmidt law : the star formation rate is proportional to the local gas density to the exponent 1.5 (Kennicutt 1998).

The galaxies have a total visible mass of 1.4×10^{10} $M_\odot$, with a bulge:disk mass ratio of 0.24 and a gas mass fraction in the disk of 15%.The disk has a Toomre profile with a radial scalelength of 1.6 kpc for stars and 4.6 kpc for gas (truncated at 5.6 kpc). The dark halo has a mass of 5.4×10^{10} $M_\odot$. It is represented by a Plummer profile of scale-length 60 kpc truncated at 200 kpc. This give a circular velocity in the model galaxies of $V_{\rm circ} \simeq 100$ km s^{-1}.

The initial conditions for the binary mergers are then chosen so as to explore different configurations leading to mergers. We fix the relative inclination of the two galaxies to 33 degrees, we vary the relative velocity (V) between 0.2 and $0.8V_{\rm circ}$, the impact parameter (b) between 3 and $7R_{\rm disk}$, and the orientation of each of these orbits is varied to prograde and retrograde. It finally gives us 32 orbits to simulate. Nevertheless all these orbits do not have the same likelihood and since we intend to perform a statistical study, we weight the results obtained for each orbit by its likelihood, which is linked to the collision rate. For a uniform galaxy distribution, the collision rate is proportional to $b^2Vf(V)$ where $f(V)$ is the velocity distribution of the galaxies and we present here the results obtained with $f(V) = 1$ (this corresponds to a conservative approach since the real $f(V)$ shoul be increasing with V, at least in the velocity range we are interested in, and we observed that an increasing $f(V)$ enhanced the effect of the cluster on the SFR).

Each galaxy merger is simulated both with and without the cluster potential. The latter is modeled by a Plummer potential with a total mass of 10^{15} $M_\odot$ and a radial scale-length of 400 kpc (it could for instance represent the Virgo cluster). The galaxy pair is initially at 400 kpc of the center of the cluster (galaxies in the core of clusters do not have gas anymore and we are not interested in them). What is more, the galaxies have no initial velocity with respect to the cluster (of course, during the simulations the galaxies are free to move in the cluster field) since we performed tests and concluded that this initial speed has no influence on the SFR.

Four different possibilities have been studied for the position of the galaxy pair with respect to the cluster :

- configuration 1: the cluster center is in the orbital plane, in the same direction as the initial relative velocity of the two galaxies
- configuration 2: the cluster center is in the orbital plane, in a direction perpendicular to the one of configuration 1
- configuration 3: the cluster center is in the orbital plane, along the bisector of the two previous directions.
- configuration 4: the cluster center is 45 degrees above the orbital plane and in projection in this plane this configuration is identical to configuration 3.

Each galaxy pair orbit described previously has been studied without the cluster and with the cluster in each of the four configurations.

3 Results

We study here the relative SFRs, i.e. SFRs divided by the SFR of an isolated galaxy without cluster.

We first interested ourselves in the SFR of a single galaxy situated near a cluster. The relative SFR is in this case slightly greater than 1 and never greater than 1.25. This shows that the gravitational potential of a cluster cannot trigger starbursts in isolated galaxies.

On the contrary, the presence of a cluster can strongly influence the SFR during a galaxy merger. We show on Fig. 1 the evolution of the SFR during a merger (with $V = 0.6V_{\rm circ}$, $b = 4R_{\rm disk}$ and a prograde orbit) without the cluster and with the cluster in configurations 1, 2 and 3. We observe that the intensity of the SFR peak can be strongly affected (and so is the instant at which this peak occurs). The cluster can strongly increase the SFR (for example the maximum SFR is multiplied by 3 when the cluster is in configuration 1). In other cases, the cluster can also inhibit the star formation.

The diversity of the behaviours observed justifies the statistical approach we decided to adopt. Figure 2 shows the statistical distribution of the maximum relative SFR (which is defined as the ratio between the additional SFR in the star formation peak during a merger and the SFR in a single galaxy. See Fig. 1 for a definition of these quantities). The most important result is that the maximum relative SFR is increased for

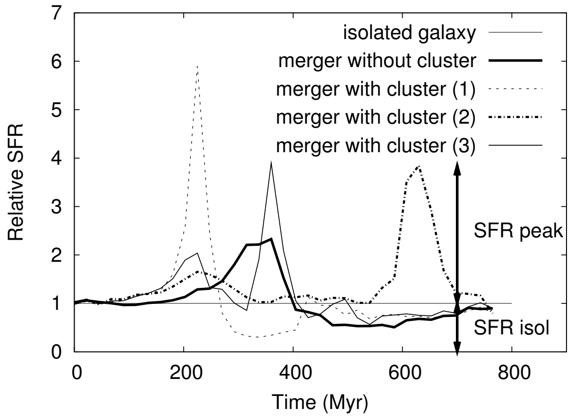

Fig. 1. Relative SFRs for mergers without and with the cluster in three different configurations. The two galaxies have initially a relative speed of $0.6V_{\rm circ}$, an impact parameter of $4R_{\rm disk}$ and the orbit is prograde.

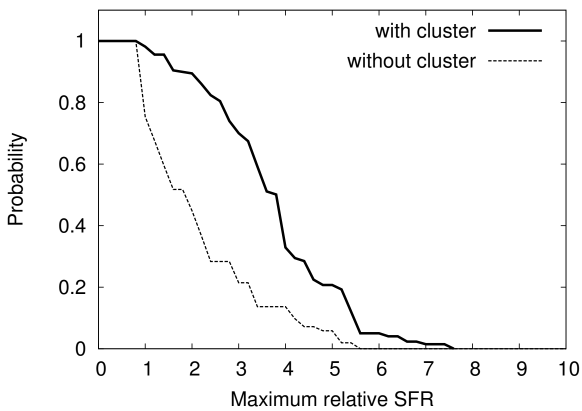

Fig. 2. Probability to have a maximum relative SFR greater than the value specified on the x-axis for mergers with and without a cluster

mergers taking place in the gravitational field of a galaxy cluster with respect to mergers of isolated galaxies. In particular, a maximum relative SFR of 2 and more is reached in 90% of major mergers taking place near a cluster and in only 40% of isolated mergers. The presence of a cluster even allows us to observe a few intense starbursts (maximum relative SFR>6), which was not possible without the cluster. Finally, the average maximum relative SFR is multiplied by a factor 1.7 for mergers near clusters.

It is also important to notice that not only the cluster increases the maximum SFR but also the SFR integrated over the duration of the burst, which is linked with the total stellar mass formed during the burst.

4 Conclusion

A first conclusion we can draw from our study is that galaxy mergers that take place out of the gravitational field of a cluster are generally not very efficient to trigger intense starbursts : only 40% of these mergers form more than twice more stars than an isolated galaxy. This result is comparable to the one di Matteo et al. (2007) obtained with a different code (with a SPH model).

On the other hand, we have shown that the presence of a cluster significantly increases the star formation rate during a merger : in average, the maximum relative SFR is multiplied by a factor 1.7 for mergers near clusters with respect to isolated mergers. The integrated SFR is also increased.

Of course, the values obtained depend on the mass and radius chosen for the cluster. Nevertheless, we expect the same kind of results for every cosmological structure having a divergent tidal field in its outer regions (like groups or filaments). The galaxies concerned by this increasement are necessarily those that still contain gas, i.e mainly galaxies in the periphery of clusters beginning to form at $z \simeq 1$. In particular, at $z \simeq 1$ our results could contribue to explain the reversal of the star formation-density observed by Elbaz et al. (2007) and Cooper et al. (2007).

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References

Barnes, J. E. & Hernquist, L. E. 1991, ApJL, 370, L65

Bournaud, F. & Combes, F. 2002, A&A, 392, 83

Bridge, C. R., Appleton, P. N., Conselice, C. J., et al. 2007, ApJ, 659, 931

Conselice, C. J., Chapman, S. C., & Windhorst, R. A. 2003, ApJL, 596, L5

Cooper, M. C., Newman, J. A., Weiner, B. J., et al. 2007, ArXiv e-prints

di Matteo, P., Combes, F., Melchior, A.-L., & Semelin, B. 2007a, A&A, 468, 61

Elbaz, D., Daddi, E., Le Borgne, D., et al. 2007, A&A, 468, 33

Kennicutt, R. C., Jr. 1998, ApJ, 498, 541

Mihos, J. C. & Hernquist, L. 1996, ApJ, 464, 641

Sanders, D. B. & Mirabel, I. F. 1996, ARA&A, 34, 749