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Properties and environment of compact starburst galaxies in cosmological hydrodynamical simulations

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Abstract. The investigation of Compact Starburst Galaxies (CSBGs) in the local universe ($z \lesssim 0.1$) allows us to explore the processes responsible for triggering intense star-formation activity. In addition, we can compare the evolution of these galaxies with the past, when they were more abundant and active. This analysis is essential for understanding how galactic interactions and mergers influence star-formation activity at different epochs in the universe. In this study, we use the TNG50-1 cosmological simulation from the IllustrisTNG project to investigate the mechanisms that drive this star-formation activity. A sample of 151 CSBGs and a corresponding control sample with 151 galaxies, paired by stellar mass and half-mass radius, were selected, and we observed that major merger events in the last 3 Gyr and interactions with close neighbours ($\leq$ 50 kpc) are significantly more frequent among CSBGs, occurring in 23.2% of them, compared to only 8% in the control sample. This difference, with p-value = 0.0004, reinforces the role of galactic interactions in triggering bursts of star formation, in agreement with previous studies.

Resumo. A investigação de Galáxias Starburst Compactas (CSBGs) no universo local ($z \lesssim 0.1$) permite explorar os processos responsáveis pela intensa atividade de formação estelar. Além disso, podemos comparar a evolução dessas galáxias com o passado, quando eram mais abundantes e ativas. Essa análise é essencial para entender como interações e fusões galácticas influenciam a atividade de formação estelar em diferentes épocas do universo. Este estudo utilizou a simulação cosmológica TNG50-1 do projeto IllustrisTNG para investigar os mecanismos que impulsionam essa atividade estelar. Uma amostra de 151 CSBGs e uma amostra de controle correspondente com 151 CSBGs, pareadas por massa estelar e raio de meia massa foram selecionadas, e observamos que eventos de major merger nos últimos 3 Gyr e interações com vizinhos próximos ($\leq$ 50 kpc) são significativamente mais frequentes entre as CSBGs, ocorrendo em 23.2% delas, em comparação a apenas 8% na amostra de controle. Essa diferença, com p-valor = 0.0004, reforça o papel de interações galácticas no desencadeamento de surtos de formação estelar, em concordância com estudos anteriores.

Keywords. Galaxies: dwarf – Galaxies: interactions – Galaxies: starburst

1. Introduction

Compact Starburst Galaxies (CSBGs) are objects characterized by intense star formation activity, with high specific star formation rates (sSFR $\gtrsim 10^{-9}$ yr^{-1}), small effective radii ($r_e \cong 1$ kpc) and typically low stellar masses, with $\log(M_\star/M_\odot) \lesssim 9.5$. Although they are more common at high redshifts (Barro et al., 2013; Zolotov et al., 2015), the mechanisms that trigger this intense star-forming activity in the local universe are still unclear.

By analyzing the deep images from the Hyper-Suprime Cam Subaru Strategic Survey, we identified that a significant fraction of CSBGs shows clear signs of recent mergers and interactions (Chervinski, in prep.). In this work, we seek to understand the processes responsible for the high Specific Star Formation Rate (sSFR) at low redshifts ($z \lesssim 0.1$), with special attention to the role of galactic interactions and mergers, to compare observations with predictions from state-of-the-art simulations.

2. Methods and data

We investigated the evolution of CSBGs using the set of cosmological hydrodynamic simulations of the IllustrisTNG project, in particular, the high-resolution TNG50-1 simulation (Nelson et al., 2019; Pillepich et al., 2019).

From the TNG50-1 simulation, we sought to identify galaxies that are both starburst and compact. To select starburst galaxies (SBGs), we determined the log(SFR) vs. $\log(M_\star)$ relation through a linear fit and defined as SBGs those galaxies that lie one standard deviation above the established relation, as illustrated in panel (a) of Fig. 1. Next, to identify the compact galaxies (CGs), we determined the stellar surface density measured within one stellar half-mass radius ($\Sigma_\star$) for each galaxy, separating those that are in the top 10% with the highest surface stellar mass density (see panel (b) of Fig. 1). This ensured that the galaxies were, in fact, starbursts and compact, and matching these selections resulted in a sample of 204 CSBGs, as shown in panel (c) of Fig. 1.

Additionally, for a comparative analysis, we selected a sample of control galaxies with "normal" SFR (i.e., within 0.5 σ of the established relation), which were paired by stellar mass and stellar half-mass radius. This resulted in a control sample with 151 normal galaxies and a corresponding sample of 151 CSBGs (see panel (d) of Fig. 1), ensuring that comparisons between the samples are consistent in terms of mass and size.

3. Results

Analyzing the merger tree of the 302 galaxies considered, we observed that 81 galaxies underwent a major merger, of which 45 are CSBGs, and 36 belong to the control group, as indicated in Fig. 2. In addition, major mergers occurred in the last 3 Gyr and were observed in only 8 CSBGs.

Motivated by previous studies indicating that dwarf-dwarf galaxy interactions can trigger bursts of star formation, in particular when interacting galaxies are closer than 50 kpc (Stierwalt et al., 2015; Privon et al., 2017), we investigate the role of these interactions in CSBGs. These studies suggest that not only merg-

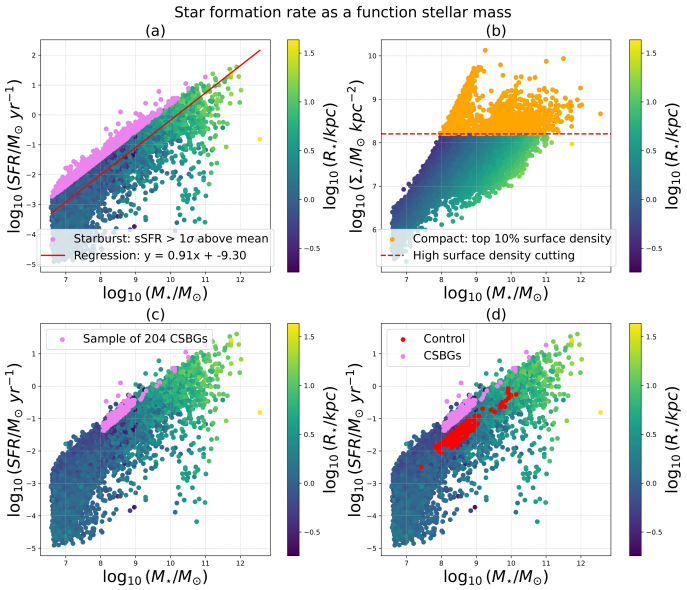

Figure 1. The figure shows the star formation rate as a function of the stellar mass of the galaxies in the IllustrisTNG simulation, highlighting different samples. (a) Galaxies with sSFR above one standard deviation of the log(SFR) vs. log($M_\star$) relation are indicated by magenta symbols. (b) Objects with the 10% highest values of surface stellar mass density are shown in orange. (c) The sample of ∼ 200 CSBGs (in magenta) includes galaxies that meet both criteria of high sSFR and high surface stellar mass density. (d) The control sample with 151 normal galaxies (in red) and a corresponding sample of 151 CSBGs (in magenta) of the same mass and size.

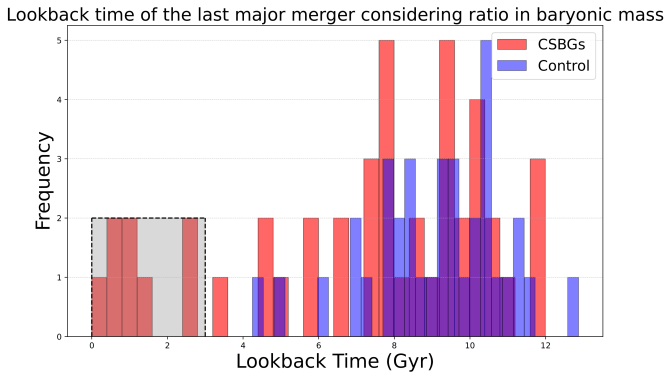

Figure 2. Histogram of the time when the last major merger occurred, considering the baryonic mass ratio of 1:4 hide ($\frac{1}{4}$). The grey shaded area highlights the 8 CSBGs that have undergone major mergers in the last 3 Gyr.

ers, but also interactions may be responsible for the intense star-forming activity observed in CSBGs. We found that a non-negligible fraction of CSBGs have closer neighbours than galaxies in the control sample, as shown in Fig. 3. By calculating the fraction of galaxies that have undergone a recent major merger in the last 3 Gyr and/or that have close neighbours at distances < 50 kpc, we found that approximately 23.2% of the CSBGs satisfy this condition, which is ∼ 3 times higher than the fraction of approximately 8% found in the control sample. By applying Fisher's test, we found that this difference is statistically significant, assuming a significance level of 5% (p-value = 0.0004).

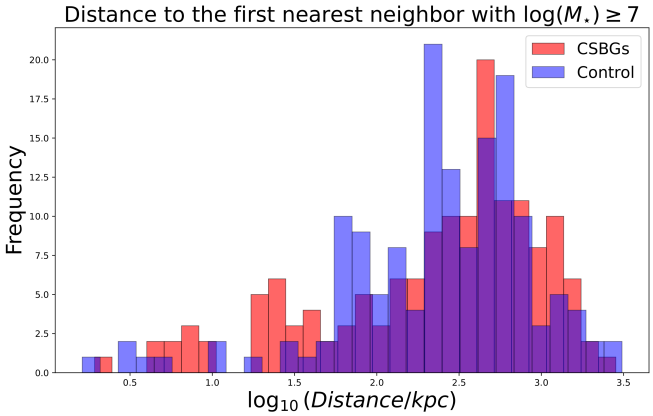

Figure 3. Logarithm of the distance in real 3D space to the first nearest neighbor whose stellar mass $M_\star \geq 10^7$.

4. Discussion and conclusion

Our results indicate that CSBGs at low redshifts ($z \lesssim 0.1$) are more likely to have close companions and/or to have undergone recent major mergers compared to control galaxies (of the same stellar mass and radius). These results align with previous observational studies (Stierwalt et al., 2015; Privon et al., 2017) and numerical studies (Flores-Freitas et al., 2024), highlighting the important role of interactions in triggering starburst episodes in low-mass galaxies.

Finally, our next steps include continuing to investigate the interaction with close neighbours and exploring the role of supermassive black holes and the feedback associated with them in CSBGs.Through a detailed analysis of the history, properties, and environments of simulated CSBGs, we aim to complement observational studies by offering potential physical explanations for the enhanced star formation observed in compact galaxies.

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