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*M. Brescia, S.G. Djorgovski, E. Feigelson,*
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# Effects of mergers on non-parametric morphologies

**Lucas A. Bignone[1], Patricia B. Tissera[2,3], Emanuel Sillero[4], Susana E. Pedrosa[1], Leonardo J. Pellizza[5] and Diego G. Lambas[4]**

[1]Instituto de Astronomía y Física del Espacio (IAFE, CONICET-UBA), C.C. 67 Suc. 28, C1428ZAA Ciudad de Buenos Aires, Argentina
[2]Departamento de Ciencias Físicas, Universidad Andres Bello, Av. Republica 220, Santiago, Chile
[3]Millennium Institute of Astrophysics, Av. Republica 220, Santiago, Chile
[4]Instituto de Astronomia Teórica y Experimental (CONICET-UNC), Laprida 925, Cordoba, Argentina
[5]Instituto Argentino de Radioastronomía, CONICET, Camino Gral. Belgrano km 40, Berazategui, Prov. de Buenos Aires, Argentina

**Abstract.** We study the effects of mergers on non-parametric morphologies of galaxies. We compute the Gini index, $M_{20}$, asymmetry and concentration statistics for $z = 0$ galaxies in the Illustris simulation and compare non-parametric morphologies of major mergers, minor merges, close pairs, distant pairs and unperturbed galaxies. We determine the effectiveness of observational methods based on these statistics to select merging galaxies.

**Keywords.** galaxies: formation, galaxies: interactions, methods: numerical

## 1. Introduction

Non-parametric morphologies are an attractive method to quantify the morphologies of galaxies. Unlike other techniques, such as the computation of Sérsic profiles (Sérsic *et al.* 1963), non-parametric morphologies do not assume an underlying model for the light distribution of a galaxy and are therefore specially well suited to study mergers.

Several non-parametric statistics have been developed throughout the years. Each encode a different aspects of galaxy morphology. Concentration (C) (Bershady *et al.* 2000; Conselice *et al.* 2000) measures the degree of light concentration, asymmetry (A) (Abraham *et al.* 1996; Conselice *et al.* 2000) measures the degree of rotational asymmetry, clumpiness (S) (Isserstedt & Schindler 1986; Takamiya 1999; Conselice *et al.* 2003) measures the amount of small scale structure present, Gini index (G) (Lotz *et al.* 2004) measures how evenly distributed is the light from the galaxy and $M_{20}$ measures the second-order moment of the brightest 20 per cent of the galaxy light.

Combinations of these statistics have been used to identify mergers in galaxy samples and to determine the merger rate, a crucial, but poorly constraint quantity. Conselice *et al.* (2003) found that interacting galaxies tend to have higher asymmetries and determined a threshold value of A = 0.35 to separate normal from disturbed galaxies. Similarly, Lotz *et al.* (2004) found that Ultra-Luminous Infra-red Galaxies (ULIRGs), which are often associated with mergers, can be separated from normal galaxies by a demarcation line in G-$M_{20}$ space determined by

$$G = -0.115\, M_{20} + 0.384. \tag{1.1}$$

In order to properly derive the merger rate an observability time-scale is required (i.e. the average time during which a merging system can be identified as such by its non-parametric morphologies). Previously, isolated merger simulations have been used to compute observability time-scales for different criteria (Lotz *et al.* 2011). While much has been learned from these studies, they explore a limited parameter space of merger properties. In this work we propose the use of cosmological scale simulations to study non-parametric morphologies of mergers and to ascertain the effectiveness of empirically derived demarcation criteria to select galaxies undergoing mergers. To do so, we use the mock galaxy images generated for the Illustris simulation at $z = 0$ to compute non-parametric morphologies (C, A, S, G, $M_{20}$) and compare the results for galaxy samples containing major merger remnants, minor merger remnants, close pairs, distant pairs as well as unperturbed galaxies.

Finally, it is worthwhile to point out that the correct understanding of the information provided by automatic classification of mergers events are crucial in light of future large sample surveys such as LSST that will possess the depth, volume, and wavelength coverage to greatly improve our knowledge of merger events and rates. Non-parametric morphologies also constitute a rich field for the implementation of machine learning algorithms applied to the classification of galaxies. Large volume numerical simulations, like the one we used in this work, can constitute powerful tools for the testing, training and understanding of such algorithms.

## 2. Numerical Methods

Mock images for Illustris $z = 0$ galaxies with stellar mass ($M_*$) greater than $10^{10}$ $M_\odot$ where computed by Torrey *et al.* (2015). They include not only light from the selected galaxy, but also light from other galaxies in the same halo that fall within the camera field-of-view (FOV), this makes them specially well suited to study mergers. These images are idealized in the sense that they do not contain background noise nor the effects of seeing or telescope point spread function (PSF). We convolve g-band mock images by a PSF of 1 arcsec and add background noise to achieve a constant S/N ratio of 25. Also, we rescale the images to a pixel scale of 0.24 arcsec. We follow these steps in order to approximate observations by the SDSS main galaxy survey at $z = 0.05$.

We obtain segmentation maps using similar methods to Lotz *et al.* (2004) and finally we compute non-parametric morphologies C, A, S, G, $M_{20}$ for all galaxies in each of the four random camera angles available.

We use the SubLink merger trees compiled by Rodriguez-Gomez *et al.* (2015) to obtain a subsample of major merger remnants composed of galaxies at $z = 0$ that experienced at least one major merger in the previous 2 Gyr. We consider a merger as major if the stellar mass ratio ($\mu_*$) is greater than 0.25. Similarly, we define a subsample of minor merger remnants from galaxies that experience a merger with $0.001 < \mu_* < 0.25$ in the previous 2 Gyr.

We also utilize the subfind catalogue to produce a close pair subsample of galaxies having a companion with $M_* > 10^8$ $h^{-1}$ $M_\odot$ at a distance $d \leqslant 20$ $h^{-1}$ kpc and a distant pair subsample composed of galaxies having a companion with $M_* > 10^8$ $h^{-1}$ $M_\odot$ within the range $20 < d \leqslant 100$ $h^{-1}$ kpc.

## 3. Results

### 3.1. *G-$M_{20}$ morphologies*

Figure 1 shows G-$M_{20}$ morphologies for all galaxies and camera angles in the major remnants, minor remnants, close pairs and distant pairs subsamples. In agreement with

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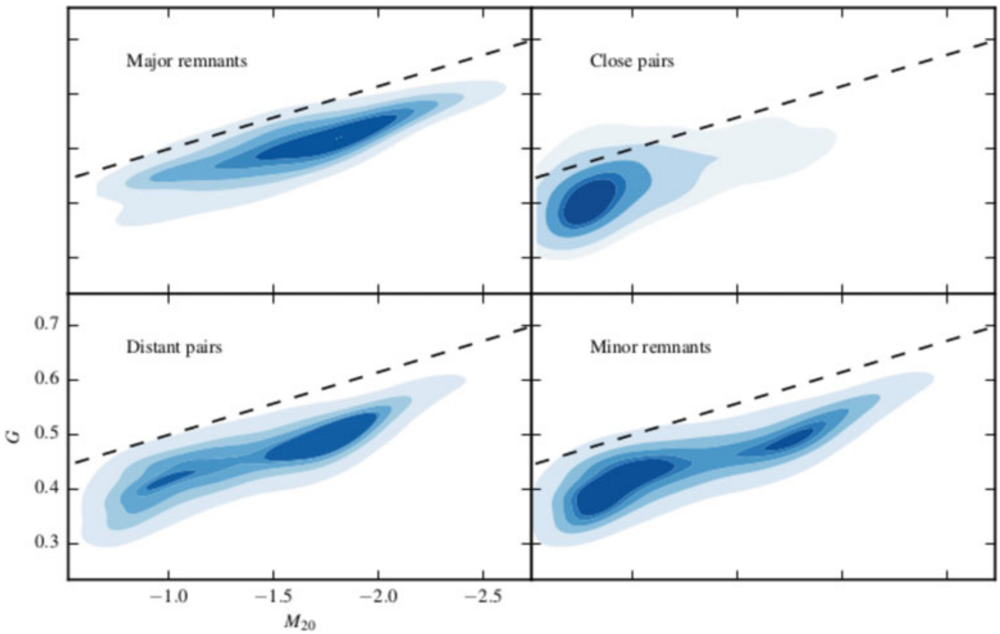


**Figure 1.** G-$M_{20}$ morphologies for each of the four subsamples. The shaded contours mark regions which enclose 90, 70, 50, 30 and 20 percent of galaxies (from light to dark blue, respectively). The dashed line represents the merger demarcation line defined by equation 1.1

Snyder *et al.* (2015) we find that Illustris galaxies occupy a similar location in the G-$M_{20}$ plane than observed galaxies and that early type galaxies are located in the upper right corner of the distribution while late type galaxies occupy the lower left region. We also display the demarcation line defined by equation 1.1 and that is expected to separate normal from merging galaxies. We find that only a small number of such galaxies is found above the demarcation line, while most lay below.

We find that Close pairs present the highest percentage of galaxies above the demarcation line (10.1%), follow by major mergers remnants (7.0%), minor merger remnants (4.2%), and distant pairs (3.0%). As we can see, the demarcation line is better at selecting close pair galaxies that are more likely to be mergers, but only a relative small percentage of close pairs is actually above the demarcation line

### 3.2. *Asymmetry*

Similarly to our previous approach with G-$M_{20}$ morphologies, Figure 2 shows asymmetry and concentration statistics for major remnants, minor remnants, close pairs and distant pairs. In this case, we also display a vertical line corresponding to the $A = 0.35$ criteria of Conselice *et al.* (2003) separating mergers from unperturbed galaxies. We found that the criteria is again more effective at separating close pairs than the other samples, but a large number of galaxies in every subsample is actually found with $A > 0.35$. This indicates that while asymmetry is being sensitive to potential mergers, it is not a very pure indicator, this is probable related to numerical resolution effects of the simulations, where star particles that have a much higher mass than typical star forming regions can severely impact the light distribution of the galaxy as interpreted by the asymmetry statistic. The effect is specially notorious on lower mass galaxies where the light from these young stellar particles can dominate. In contrast G-$M_{20}$ morphologies appear much more robust to numerical resolution effects.

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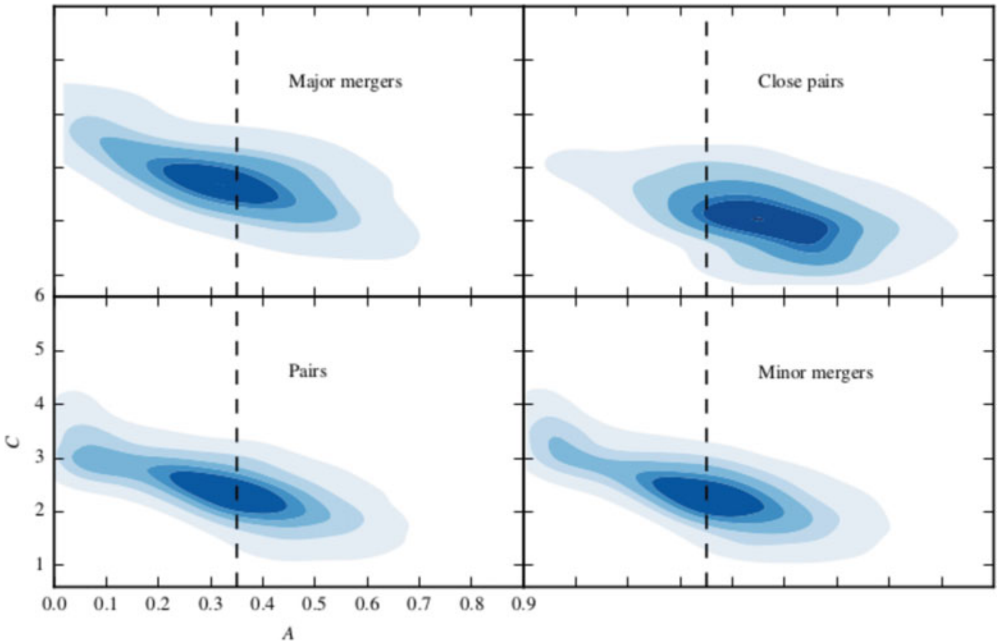


**Figure 2.** Concentration vs. asymmetry for each of the four subsamples. The dashed line represents the A = 0.35 criteria of Conselice *et al.* (2003). The contours represent the same as in figure 1

## 4. Conclusion

We find that both G-$M_{20}$ morphologies and asymmetry are sensitive to mergers, specially when considering close pairs. It is therefore possible to utilize the same techniques and demarcation lines used observationally, to study the effects of mergers on morphologies in the Illustris simulation. Also, given that the simulation merger rate is a known quantity, it would be possible to study the biases present when deriving the merger rate using non-parametric morphologies. However, some care must be taken to consider possible resolution effects, specially in the case of asymmetry.

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