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Exploring the Impact of Galaxy Interactions over Seven Billion Years with CAS

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Abstract. We explore galaxy assembly over the last seven billion years by characterizing "normal" galaxies along the Hubble sequence, against strongly disturbed merging/interacting galaxies with the widely used CAS system of concentration (C), asymmetry (A), and 'clumpiness' (S) parameters, as well as visual classification. We analyze Hubble Space Telescope (HST) ACS images of ~4000 intermediate and high mass ($M/M_\odot > 10^9$) galaxies from the GEMS survey, one of the largest HST surveys conducted to date in two filters. We explore the effectiveness of the CAS criteria [$A > S$ and $A > 0.35$] in separating normal and strongly disturbed galaxies at different redshifts, and quantify the recovery and contamination rate. We also compare the average star formation rate and the cosmic star formation rate density as a function of redshift between normal and interacting systems identified by CAS.

1. Introduction

Galaxy mergers and interactions are believed to have a profound impact on the structural evolution and star formation activity of galaxies. The recent advent of large space-based surveys with thousands of galaxies, such as GEMS, GOODS, COSMOS, and AEGIS, has led to the use of different methods for identifying interacting/merging galaxies, such as detailed visual classification, and quantitative codes like CAS (Conselice et al. 2000). However, detailed assessment of the results from different methods has been altogether lacking.

2. CAS

We quantify the concentration, asymmetry, and high-spatial frequency clumpiness of the sample galaxies using the CAS concentration (C) (Bershady et al. 2000), asymmetry (A) and clumpiness (S) indices (Conselice et al. 2000). The concentration index (C) is the ratio of the two radii containing 80% and 20% of the total flux, which is then normalized logarithmically. The asymmetry index (A) is found by rotating the original image of the galaxy by 180 degrees, and then subtracting this image from the original. The residual flux of this subtracted image is then normalized by the original galaxy's flux. The clumpiness index (S) is computed by reducing the original galaxy's effective resolution to create a new image that is smoothed so that the high-frequency structure has been

washed out. The original image is then subtracted from the smoothed image to produce a residual map, which then contains only the high frequency part of the original galaxy's light distribution. The flux of this light is then summed and divided by the sum of the original galaxy's flux to obtain the S index. The CAS criteria for identifying distorted/interacting systems ($A > S$ and $A > 0.35$) are empirically derived from nearby galaxies (Conselice et al. 2003).
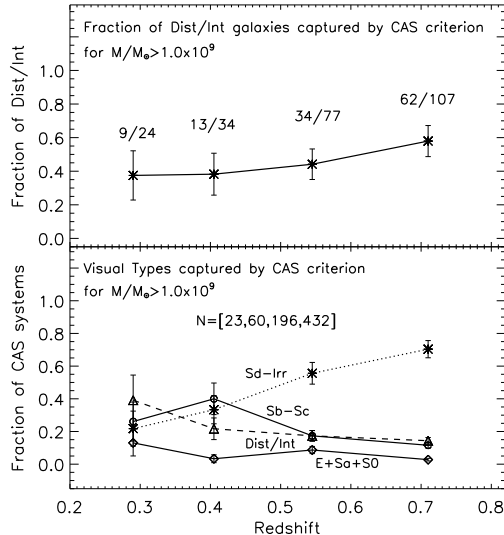

Figure 1.   The top panel shows, by redshift, the fraction of visually-classified, strongly distorted/interacting systems that the CAS criteria also identify as distorted/interacting. The bottom panel shows which visually-classified systems CAS is identifying as distorted/ interacting. Notice the large fraction of Sd-Irr type galaxies as redshift increases, in agreement with Jogee et al. (2008).

3.   Conclusions

1. The CAS criteria ($A > S$ and $A > 0.35$) captures 38% to 58% (Fig. 1) of the galaxies visually classified as interacting. This is not unexpected, given that on average, the $A > 0.35$ criterion is only satisfied for one third of the major merger timescale in N-body simulations (Conselice 2006).

2. We inspected the morphologically distorted galaxies, which the CAS merger criteria fail to capture and find the following. The criteria do not pick up systems where the externally-triggered tidal features (e.g., light bridges between galaxies, tidal tails, arcs, shells, ripples) and tidal debris (e.g., small accreted satellite in the main disk of a galaxy), contribute less than 35% of the total light (e.g., Fig. 3, cases 1 and 3). In addition, in galaxies with close double nuclei where the center is assumed to be between the two nuclei, the resulting low A value will prevent the system from satisfying the CAS criteria (e.g., Fig. 3, case 2).

3. The CAS criteria suffer from contamination by relatively undistorted, so-called 'normal' galaxies. The contamination rate (i.e. fraction of 'normal'
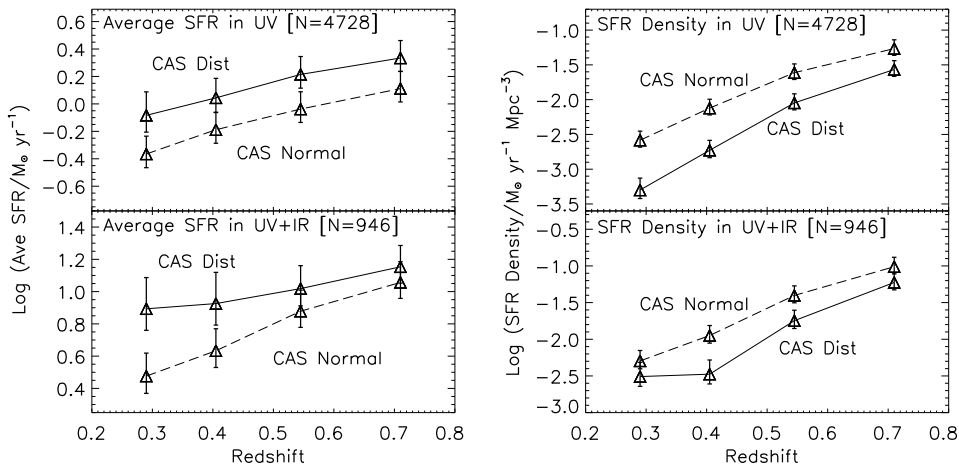
Figure 2. The average star formation rate (*Left*) and the cosmic star formation rate density (*Right*) as functions of redshift between the systems that the CAS criteria [$A > S$ and $A > 0.35$] identify as normal and identify as distorted/interacting systems. According to the CAS criteria, the severe decline in the cosmic SFR density we observe between $z \sim 0.2$–0.8 (Madau et al. 1996) is driven primarily by the shutdown of star formation in normal undisturbed systems rather than distorted/interacting systems.
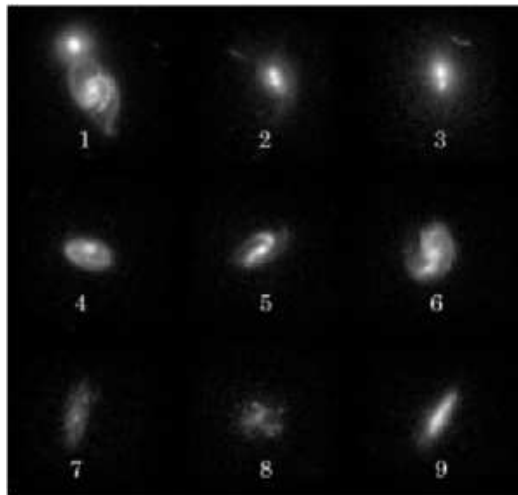

Figure 3. Galaxies 1-3: Visually classified as strongly distorted/interacting, but CAS criteria identify as normal. Galaxies 4-9: Visually classified as normal types, but CAS criteria identify as distorted/interacting.

galaxies misidentified by CAS as distorted/interacting) increases with redshift (Fig. 1). This is due to several factors:

(a) S (clumpiness) and A (asymmetry) values are higher in systems with increased star formation. Small-scale asymmetries due to stochastic star formation can be separated from truly interacting systems by visual classification. However, CAS (designed in rest-frame optical)

may identify high star-forming systems as interacting (e.g., Fig. 3, cases 4 and 6) at bluer/UV wavelengths as in $z \sim 0.6$–0.8. (Fig. 1)

(b) Galaxies whose outer parts look irregular (e.g., Fig. 3, cases 7 and 8), whether intrinsically or due to cosmological surface brightness dimming, can be picked by the CAS criteria.

(c) In systems without a clear center (e.g. dusty bright galaxies, local and distant Irrs, and distant Sds that are dimmed to resemble Irrs) the A (asymmetry) parameter can be high (e.g., Fig. 3 cases 4 and 8).

(d) In edge-on systems and compact systems, where the light profile is steep, small centering inaccuracies can lead to large A (asymmetry) values. (e.g., Fig. 3 case 9)

4. In Jogee, Miller, Penner, et al. (2008), we reported the following from visual classification. The average SFR of strongly disturbed/interacting systems is only modestly enhanced, by a factor of 2–3, with respect to normal undisturbed galaxies. Contrary to common lore, large order of magnitude enhancements in the SFR are rare in strongly disturbed systems. In fact, such systems contribute below 20% of the cosmic SFR density over $z \sim 0.2$–0.8. Thus, the decline over this regime is driven primarily by a shutdown in the star formation of relatively undisturbed galaxies. Our results are consistent with earlier findings, over a narrower redshfit bin ($z \sim 0.65$–0.75), that relatively undisturbed galaxies produce most of the UV (Wolf et al. 2005) and IR (Bell et al. 2005) luminosity density.

A certain element of uncertainty and subjectivity is inherent in visual classification. However, the robustness of the results can be illustrated by an independent analysis based on the CAS system, yielding the same conclusions. In particular, we show that the cosmic SFR density is dominated by systems classified as 'Normal' by CAS, rather than as distorted (Fig. 2). The interpretation here is complicated due to the fact that the CAS 'Normal' class includes a small number of distorted galaxies missed by the CAS merger criteria, while the CAS 'Distorted' class is contaminated by a number of Irregular systems. Nonetheless, it is encouraging that the same conclusions are reached with CAS.

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