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The contribution of major mergers to the creation of spheroidal galaxies and the build up of stellar mass at z≃2

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Abstract. We investigate the contribution of major mergers to star formation in spheroidal galaxies at z $\sim$ 2. Galaxies are visually classified from a sample of massive galaxies in CANDELS. At the redshifts used, the observed morphological disturbances are due to recent major mergers as minor mergers are too faint. The percentage of blue spheroids showing morphological disturbances is 21 $\pm$ 4%, indicating that major mergers are not the dominant star formation mechanism in these galaxies. Thus, minor mergers or cold accretion are likely to be the main drivers of star formation. We investigate the U-band luminosity emission of the sample and find that only a small fraction of the cosmic L(U) is from galaxies involved in a major merger, $\sim$30%. Using the ratio of specific star formation rate for LTGs to mergers and combining this with the results for the luminosity budget shows that only $\sim$6% of the total L(U) emitted at z $\sim$ 2 is due to the major merger process.

Keywords. Galaxy: evolution, galaxies: high-redshift, galaxies: interactions

1. Introduction

The processes which drive star formation and the morphological transformation of galaxies are still unclear, particularly at higher redshifts. The cosmic star formation rate (SFR) has been observed to peak at z $\sim$ 2 (Madau *et al.* 1998). Therefore, a significant proportion of the stellar mass in local massive galaxies formed at this time. Various processes have been considered to be causing this high SFR including starbursts induced by major mergers (mass ratio >1:5), minor mergers (mass ratio <1:5) or cold accretion.

Major mergers were previously thought to be significant drivers of galaxy evolution, triggering star formation and causing the morphological transformation which created spheroidal galaxies (Negroponte *et al.* 1983). This would explain the changing morphological mix of the Universe which is occuring rapidly at z $\sim$ 2 (Lee *et al.* 2013).

Recent work has begun to indicate that the contribution from major mergers may not be as significant, favouring other mechanisms such as minor mergers or cold accretion. For example, theoretical work by Dekel *et al.* (2009) and the lack of observed major mergers to account for the high SFRs (Genzel *et al.* 2008). Kaviraj *et al.* 20013 found that $\sim$50% of blue spheroids do not form most of their stellar mass via major mergers and those which do have only modest increases in their specific SFRs. The contribution of different mechanisms to the creation of spheroidal galaxies is still uncertain so a larger study into the mechanisms driving this evolution is needed.

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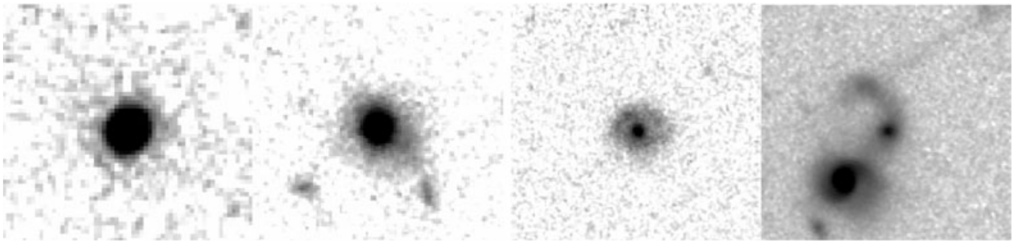

Figure 1. Example H(F160W) images. from HST WFC3 camera, of the different morphological classes in our sample. *From left to right:* relaxed spheroids, Disturbed spheroids, Non-interacting late-types, major mergers.

2. Fraction of blue spheroids with morphological disturbances

A sample of 625 galaxies is selected with H<23, $M_* > 10^{10} M_\odot$, and 1.5<z<2.5, from the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS; Grogin *et al.* (2011), Koekemoer *et al.* (2011)). Stellar masses are derived from a spectral energy distribution (SED) fitting technique using a combined best-fit and Bayesian approach (Mortlock *et al.* 2015). Photometric redshifts are produced from EAZY (Brammer *et al.* 2008) by fitting template spectra to the optical and NIR bands (Hartley *et al.* 2013).

Images taken by WFC3 in the NIR are used which trace the restframe optical properties at $1.5 < z < 2.5$. This allows the study of the overall morphological structure of the galaxy giving reliable morphological classifications. The H-band images are visually classified into non-interacting spheroidal galaxies (154 galaxies) non-interacting late-type galaxies (LTGs, 287 galaxies), mergers (117 galaxies) and disturbed spheroids (37 galaxies), which show tidal features indicating a recent major merger.

Kaviraj *et al.* (2013) used a hydrodynamical cosmological simulation to model the surface brightness of tidal features in CANDELS images, for galaxies with various mass ratios. If a major merger has occurred within ~0.3-0.4 Gyr, morphological disturbances will be observed at the depth of our images. However, tidal features from a minor merger will not be observed and therefore all the galaxies in the disturbed spheroids class have experienced a recent major merger.

We know that the timescale over which tidal features fade (Lotz *et al.* 2008) is comparable to the timescale over which galaxies redden (Kaviraj *et al.* 2013). Additionally, spheroids are known to form their stars quickly due to the observed high stellar [α/Fe] ratios, with a star formation timescale shorter than ~1 Gyr (Trager *et al.* 2000) Therefore, when we look at blue (U-V<1.2) spheroids, the star formation we are seeing is likely to be the main star formation episode which produced most of the stellar mass in these systems and created the spheroidal morphology.

In our sample, 21 ± 4% of blue spheroids show morphological disturbances. The low number of disturbed systems indicates that a significant amount of star formation does not originate from major mergers and that they are not respponisble for forming a large fraction of spheroid. This is in agreement with recent theoretical work e.g. Dekel *et al.* (2009) and observations such as the low number of observed major mergers (Genzel *et al.* 2008) and studies of morphology of blue spheroids by Kaviraj *et al.* (2013). Figure 2 shows the fraction of disturbed blue spheroids as a function of redshift. This shows a possible increase in the fraction of blue spheroids with tidal debris to higher redshift.

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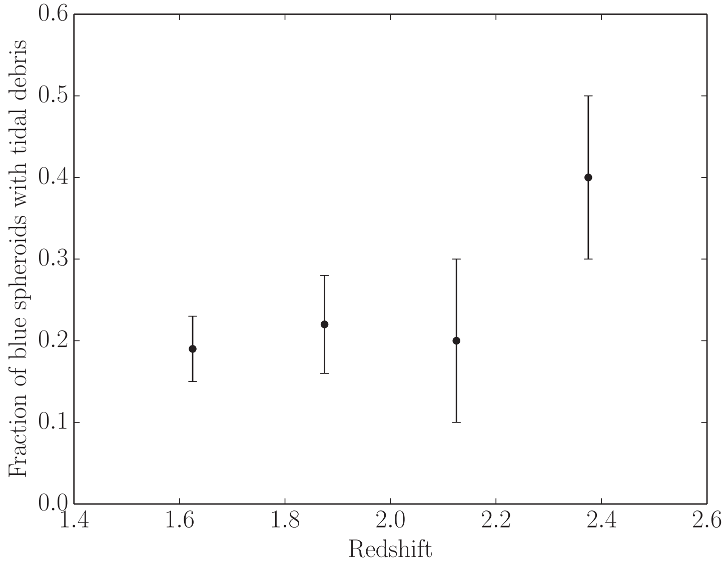

Figure 2. Fraction of blue spheroids with tidal debris as a function of redshift. The points are plotted at the mid-point of each bin with errors calculated via standard error propagation equations.

3. U-band Luminosity Budget

Dust-corrected U-band luminosities, L(U), for each galaxy are stacked by morphology: LTGs, spheroids, major mergers and disturbed spheroids. The percentage of total luminosity for each morphological type is shown in Figure 3. Of the total L(U), 70% is emitted by non-interacting galaxies (LTGs and spheroids). The remaining ∼30% is from galaxies which are currently undergoing a major merger (23 ± 4%) or disturbed spheroids due to a recent major merger (5.8 ± 0.9%). These results argee with those previously published on the distribution of star formation in different morphologies, (Kaviraj *et al.* 2013).

To investigate whether the L(U) budget shows any variation by mass or redshift, we split the sample into 4 bins combining low and high redshifts and masses (1.5<z<2 and 2<z<2.5, ($10^{10} M_{\odot}$ < M_* < $10^{10.5} M_{\odot}$ and M_* > $10^{10.5} M_{\odot}$), see Figure 3. In the higher redshift range there is a larger percentage of luminosity in major mergers and a lower percentage in spheroids. The higher percentage of luminosity at lower redshifts can be explained by the changing morphological mix of the Universe over cosmic time. At higher masses the percentage of luminosity from LTGs is lower while the percentage in both non-interacting spheroids and disturbed spheroids is higher. This is likely due to the higher number fraction of spheroids at high masses.

4. Enhancement due to major mergers

Our results have shown that major mergers are not the main source of L(U) emission. This could be due to the lower number of these systems compared to LTGs or because major mergers may not significantly increase the SFR. To check this we calcuate the ratio of average L(U) for all merging galaxies to LTGs which is ∼1.25:1. This shows that there is little enhancement in the L(U), and hence SFR, in a major merger. This ratio is an upper limit on the amount of star formation caused by the merger as the galaxy will still contain ongoing star formation caused by the same processes as in non-interacting galaxies. By combining this ratio (i.e. the amount of star formation in the

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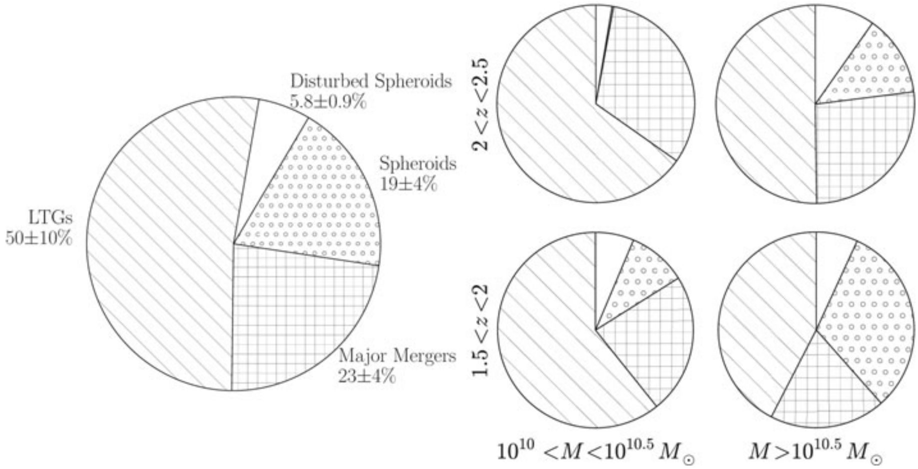

Figure 3. *Left:* the distribution of the L(U) budget by morphological type. Over half of all L(U) is in LTGs, ∼53% with only ∼29% in mergers. *Right:* The L(U) budget is split into two mass bins and two redshift bins. Diagonal line = LTGs, solid = Disturbed spheroids, dots = spheroids, squares = major mergers. At higher redshifts, the percentage of star formation hosted by major mergers increases while the percentage hosted by spheroids decreases. On the other hand, moving to higher masses shows a lower percentage from the spheroid population.

merging galaxies which is trigerred by the merger) with the result that ∼30% of the total cosmic L(U) is in mergers, we find that only ∼6% ($30 * 0.25/1.25$) of the cosmic L(U) at z ∼ 2 is due to the major merger process.

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