Evolution of the galaxy major merger fraction since z ~ 6 in the MUSE Hubble Ultra Deep Field Survey

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1 Context

How do galaxies grow over cosmic time ? The processes that govern the evolution of baryons, and thus the mass assembly of galaxies in dark matter haloes, are still unclear. Do galaxy mergers, one of the main driving mechanisms behind the growth of galaxies, played a key role in their evolution at significant look-back time ?.

Due to the difficulty to identify these violent interactions between galaxies at high redshifts, the major merger fraction, involving two galaxies of similar masses, was constrained so far up to redshift z ~ 3 from previous studies of spectrocopic pair counts (eg. Lopez-Sanjuan et al. 2012, Tasca et al.2015). Thanks to its wide field-of-view and unprecedented sensitivity, **MUSE** allows us to perform spectroscopic deep fields **without any pre-selection** of galaxies, the main drawback of previous spectroscopic surveys. This new and powerful instrument is thus perfectly suited to identify close pairs of galaxies with **secure spectroscopic redshift.**

We provide, for the first time, robust observational constraints on the galaxy major merger fraction over the last 12 billion years, i.e., extending up to redshift z ~6, and over a large range of galaxy masses.

2 MUSE data set

This analysis is based on MUSE observations over **two deep fields**, the UDF10 and HDF-S with an average in exposure time of **30hr**, and **one medium deep** (**10 hr**) mosaic covering the entire HUDF.

The combined fields result in a **parent sample** of **1801** galaxies with **spectroscopic redshift**.

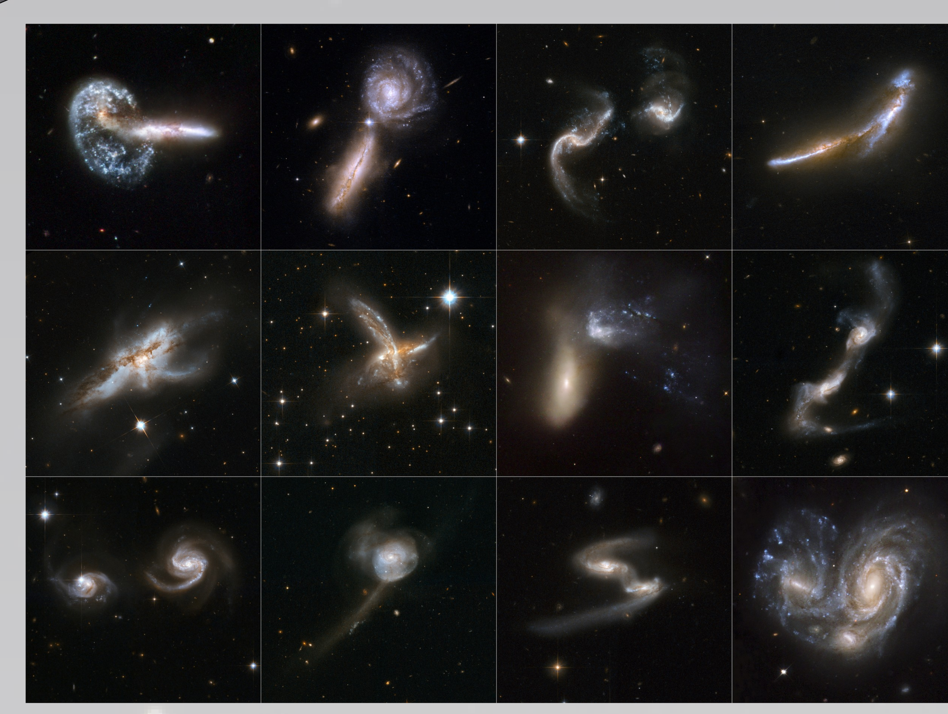

Figure 1: Hubble images of galaxies undergoing a merging process.

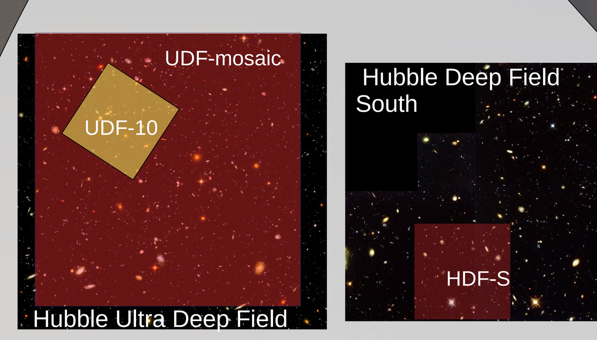

Figure 2: The HUDF and HDFS region observed with MUSE, resulting in one medium deep mosaic of 9 fields and two single deep fields (UDF-10 and HDF-S).

3 Detection of close pairs of galaxies

We searched for **close kinematic pairs of galaxies** within the following Projected separation distance and rest-frame relative velocity criteria :

Projected separation distance : $5 < r_p \leq 30\,kpc$

Difference in relative velocity : $D_V \leq 500\,km\,s^{-1}$

We identified **113 secure close pairs** of galaxies spread over **a large redshift range** (0.2<z<6) and **stellar masses** (10^{7}-10^{11} Msun), see Fig 4. Stellar masses are estimated from **SED fitting** over the extensive UV-to-NIR HST photometry available, adding Spitzer IRAC bands to better constrain masses for high-redshift (z>4) galaxies.

Defining **major mergers** as having a mass ratio of 1:1-1:6, we found **56 major close pairs**, among this sample, **23 pairs** are identified at high redshift (**z>3**) through their Lya emission.

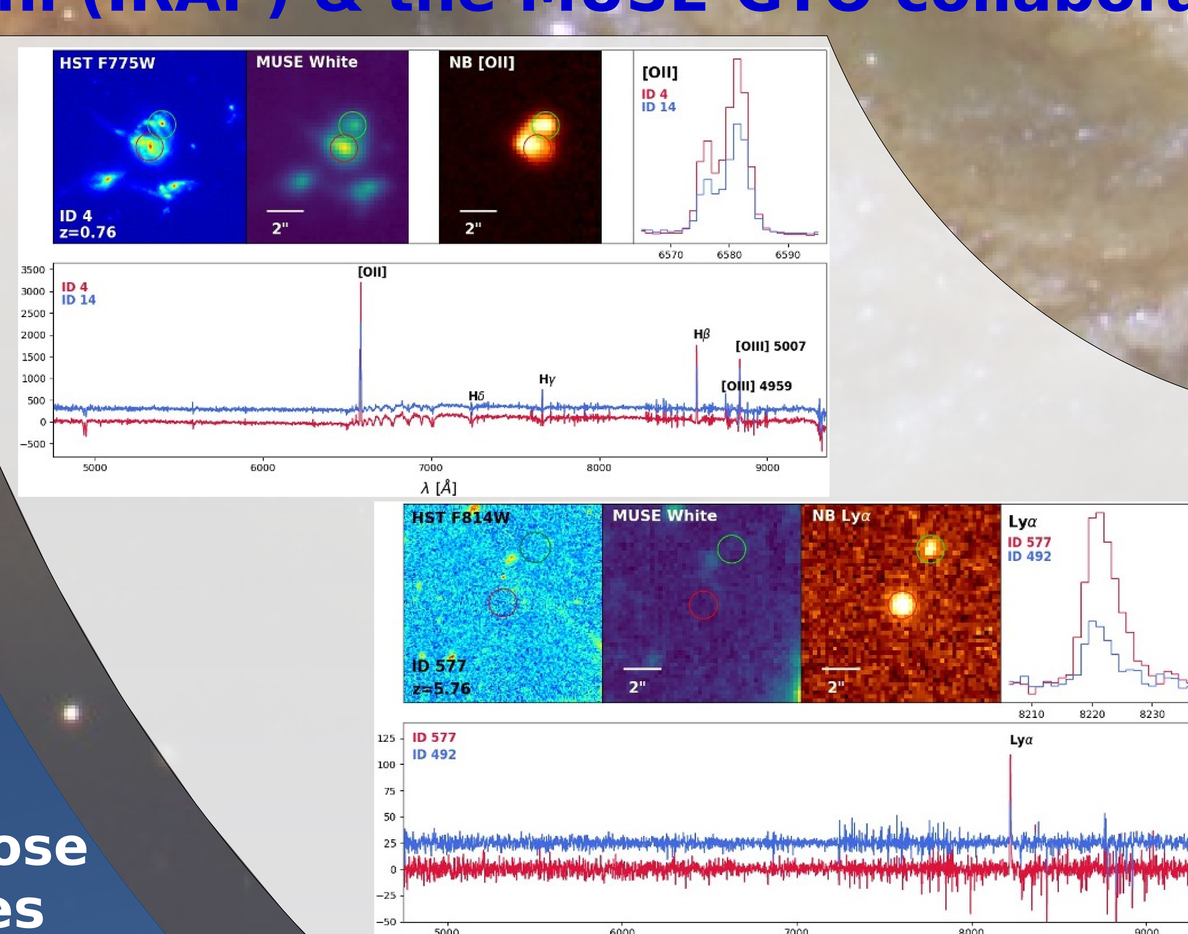

Figure 3: HST image, MUSE reconstructed white light and narrow band images and spectra of two close pairs. The most massive galaxy is circled in red and its companion in green.

Top : A low redshift pair, z=0,76 with rp=10 kpc and Dv= 6 km/s.

Bottom: The highest redshift pair of our sample, z=5,76, with Rp=19 kpc and Dv= 25 km/s.

4 First results

The major merger fraction is estimated over 5 redshift bins from z=0,2 to z=6 and is defined (with correction from selection effect) as:

$$F_{MM} = C_1 * \frac{\sum_{k=1}^{N_p} \frac{W_c^{k_1}}{C_2} * \frac{W_c^{k_2}}{C_2} * W_A}{\sum_{i=1}^{N_g} \frac{W_c^{i}}{C_2} * W_A}$$

where Ng and Np is the number of galaxies in the parent sample and the number of major close pairs, C_1 accounts for the missing companions due to our limit in spatial resolution ,W_C takes into account the confidence in the z measurement, W_A takes into account that some galaxies are located on the border of the MUSE field-of-view, and finally C_2 is a correction term for the redshift incompleteness.

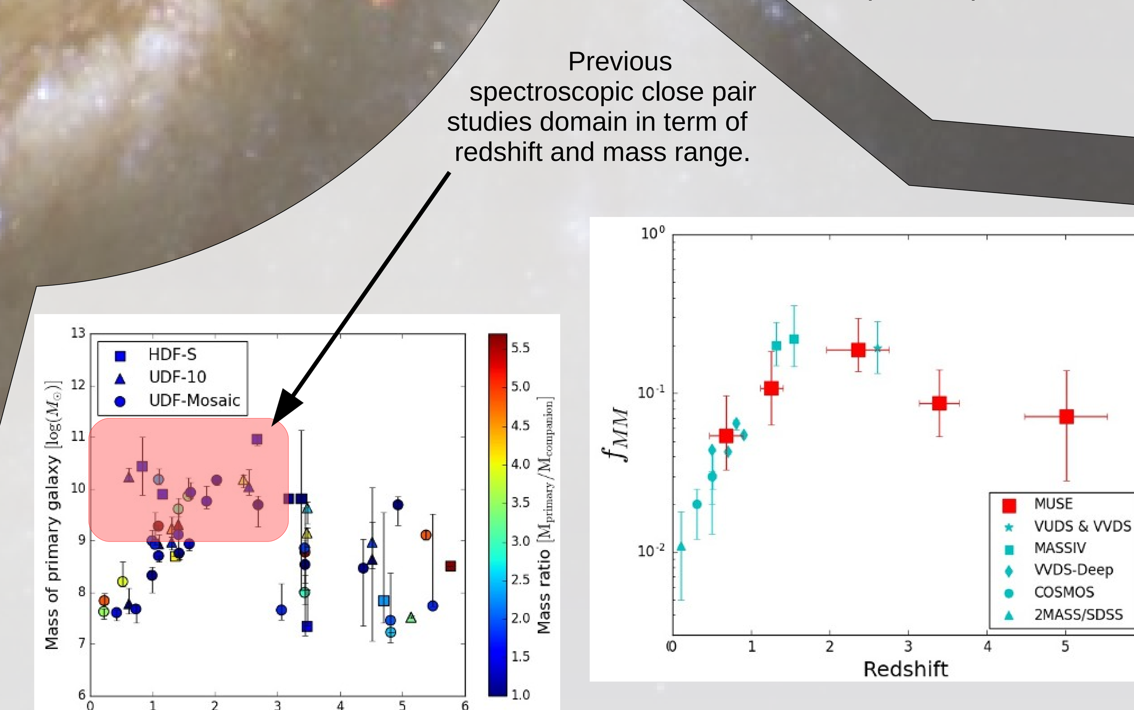

Figure 4: Left : Stellar mass of the primary galaxy as a function of redshift for our major close pairs sample, color coded with respect to the galaxy mass ratio in the pair. It shows the broad stellar mass and redshift distribution of our 56 major close pairs.

Right : The **major merger fraction evolution** over cosmic time. Estimates from MUSE data (red squares) are compared to previous estimates (light blue symbols).

The major merger fractions estimated in the MUSE fields are in good agreement with those derived from previous analyses at similar redshifts, with a **constant increase** of the merger fraction with look-back time up to **z~3** (Fig 4, Right). At higher redshift, we show **for the first time** that the fraction **slowly decreases or flattens** down to about 10% at z~6.

An attempt to separate our sample of close pairs in stellar masses is shown in Fig 5 (Bottom). We use the stellar mass of the primary galaxy to discriminate the pairs. The major merger fractions estimated for the **massive sample** is, within uncertainties, consistent with previous works, with an **increase** of the fraction up to 23% and 19% at z~1.3 and 2.7. The major merger fraction evolution of the **low-mass** sample seems to **follow the same trend**, with a **monotonically increases up to z~ 1.3-3** where it reaches a maximum of 11%, and then **flattens or slightly decreases** to 8-9% between 3< z< 6.

5 Comparison with simulations

We can compare our merger fractions to predictions from **hydrodynamic simulations** which model the dark matter and baryonic components of a cosmological volume consistently. Fig 5 (Top) compares the predictions from HORIZON-AGN (Kaviraj et al.2015), EAGLE (Qu et al.2017) and ILLUSTRIS (Snyder et al.2017) simulations, to our major merger fraction estimates.

The **trend** of our major merger fraction evolution is **in good agreement** with the trend of these **simulations**, with a slow increase of the merger fraction up to z~3 and then a **decrease toward higher redshift**.

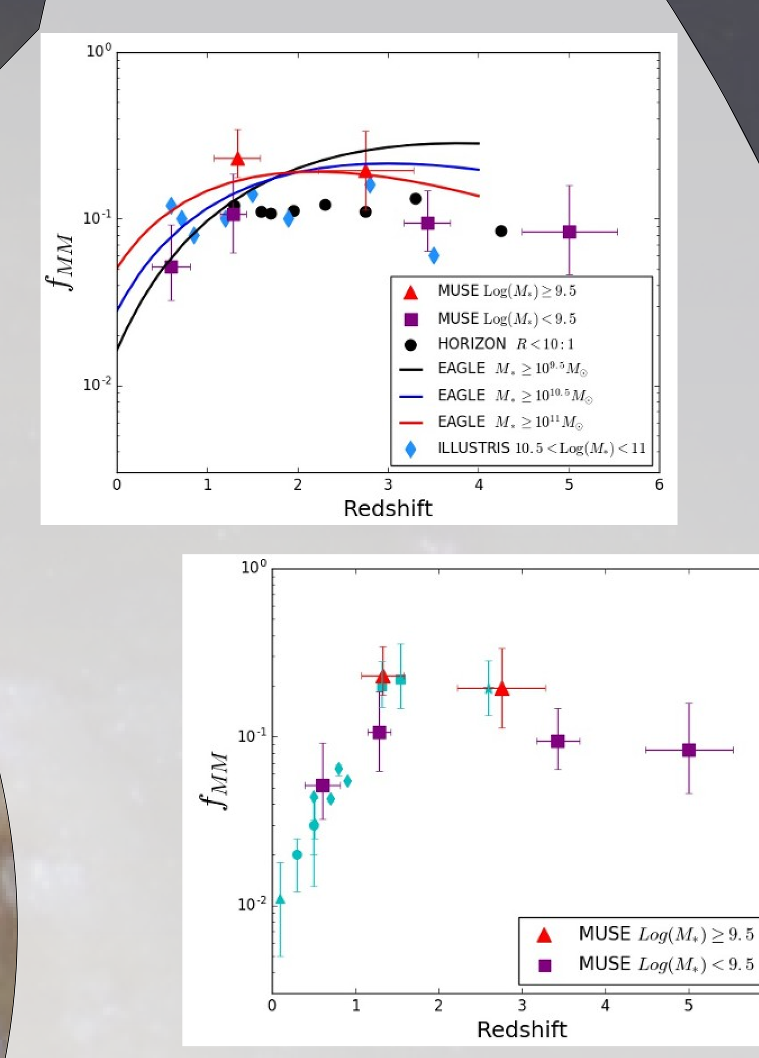

Figure 5: Evolution of the major merger fraction for two ranges of stellar mass, assuming a constant separation limit of $M = 10^{9.5}$ Msun. MUSE estimates for our low-mass (Purple squares) and massive galaxies (red triangles) samples are compared to previous estimates from the literature (Bottom) and simulations (Top).

NEXT STEP

Extend such analysis to other MUSE fields, to obtain even more statistically robust results and decrease the cosmic variance effect.

Convert the merger fraction into a merger rate.