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# The Galaxy Merger Rate History (GMRH) since $z \simeq 3$

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**Abstract.** Here we present new measurements of the pair fraction at redshifts from z=1 to $z \simeq 3$ using physical pairs identified from spectroscopic redshift measurements, and we derive the evolution of the galaxy merger rate combining these data with our previous measurements at $z < 1$. We use 3D spectroscopy from the MASSIV survey at $z \sim 1.05 - 1.55$, the VVDS ultra-deep survey at $z \sim 2.3$ and the new VUDS survey at $z \sim 2.7$ to identify major mergers ($\mu > 1/4$) and measure the merger fraction. The Galaxy Merger Rate History (GMRH) shows an increase from $z = 0$ to $z \sim 1$ with a peak at $z \simeq 1.5$ followed by a plateau or a slight decrease to $z \sim 3$, reminiscent of the Star Formation Rate History. From the GMRH we infer that major mergers contribute more than $\sim 30\%$ of the mass increase of a galaxy with $M \geq 10^{10.5} M_\odot$ since $z \sim 3$. Combined with estimates of the contribution of minor mergers, merging processes are therefore a major contributor to mass assembly in galaxies.

## 1. Introduction

How and when galaxies assemble their mass is still a major unknown of the galaxy formation and evolution scenario. In the hierarchical picture of galaxy assembly, it is expected that, as dark matter halos merge to form increasingly larger halos, galaxies in these halos are also merging along cosmic time. In addition to merging, several physical processes could also contribute to mass build-up. Star formation is a secular process transforming gas into stars, therefore increasing the stellar mass with time. Cold or hot gas accretion can replenish the gas reservoir, fueling the star formation activity and stellar mass increase. On the other hand, feedback processes from AGN or supernovae could contribute to mass loss. Gas accretion along the cosmic web and secular evolution has been claimed to be the dominant factor in the mass growth of galaxies at $z \sim 2$, efficiently forming disks and bulges (Genzel et al., 2008). However, the relative contribution of these different processes to mass assembly remains poorly constrained. In particular, the role of mergers in the early phases of galaxy assembly, the frequency of major and minor merger events, and the total amount of mass accretion onto galaxies by merging is still poorly known.

Here we present a first attempt to measure the cosmic galaxy merger rate history (GMRH) since $z \sim 3$ or over more than 12 billion years. We present new measurements of the merger rate from physical galaxy pairs identified from the VIMOS VLT Deep Survey (VVDS), the Mass Assembly in VVDS survey (MASSIV) and the VIMOS Ultra-Deep Survey (VUDS).

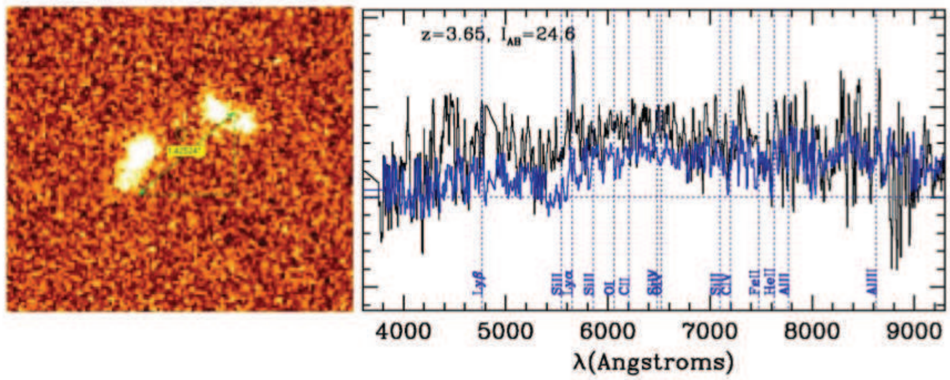


Figure 1. A high redshift pair at $z = 3.65$: (left) HST I-band imaging from the COSMOS survey, (right) VIMOS Ultra-Deep Survey spectra of the two components.

## 2. Major spectroscopic pairs at $1 < z < 3$ from the VVDS, MASSIV and VUDS spectroscopic redshift surveys

One of the main difficulties in measuring the impact of mergers on galaxy evolution is to identify merging systems at different epochs. The most straightforward is to identify galaxy pairs using redshift (velocity) and projected distance criteria, available from deep galaxy redshift surveys. This has been successfully used on the VVDS and zCOSMOS surveys by de Ravel et al. (2009, 2011) to derive the evolution of the pair fraction since $z \sim 1$.

In this paper, we use the VVDS, MASSIV and VUDS surveys, which are all spectroscopic redshift surveys, providing a direct identification of physical pairs, and therefore eliminating the contamination problem present when using photometric pairs. The MASSIV survey is a 3D spectroscopy survey with SINFONI on the VLT targeting $\sim 80$ galaxies with $1 < z < 1.8$ from the VVDS (Contini et al., 2011). Galaxy pairs can be easily identified in MASSIV from the 3D velocity field, with the mass ratio derived from the deep photometry in the field. From the VVDS Ultra-Deep survey (Le Fèvre et al., in prep.) we have observed 7 pairs at $z \sim 2$. Finally, we have used preliminary results from the on-going VIMOS Ultra Deep Survey (VUDS) to identify pairs with $z \sim 2.3 - 2.7$. Although the number of pairs is still low and will increase as we get more observations, it is already possible to measure the merger fraction with an accuracy of $\sim 20\%$ at $z \sim 2 - 3$. The main uncertainty comes from cosmic variance as the field sampled is small, so these measurements are to be refined from our larger upcoming VUDS sample from 3 different fields in the VVDS-02h, COSMOS and ECDFS.

We use a mass ratio $\mu = M_{companion}/M_{primary} \geq 1/4$ as the definition of a major merger, combined to $\delta v \leq 500 km/s$ and $\delta r_p \leq 25 h^{-1}$kpc for the physical separation between the two components. From the identified pairs we derive the pair fraction as the ratio of the number of pairs to the total number of galaxies in the parent sample.

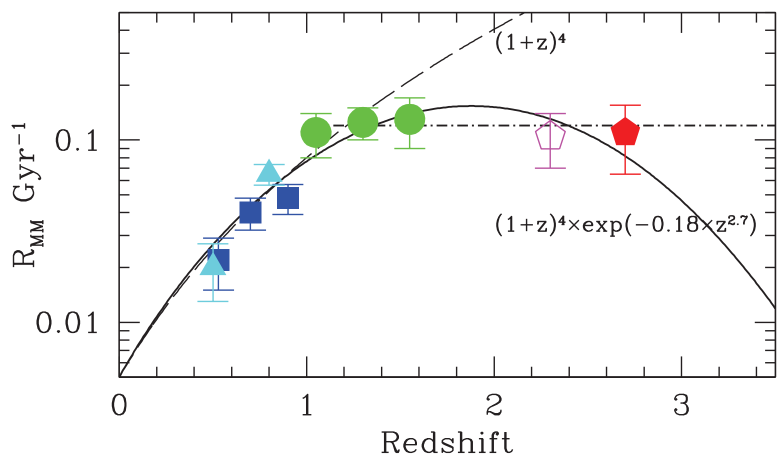


Figure 2. Galaxy Merger Rate History (GMRH) since $z \sim 3$. Squares and triangles are from the VVDS at $z < 1$, filled circles are from MASSIV, the open pentagon is from the VVDS-UltraDeep, and the filled pentagon is from the VUDS (see text).

## 3. Merger rate measurements

From the pair fraction one can derive the merger rate by making assumptions on the timescale upon which a pair will merge, as well as on the probability for the pair to merge. A pair with less than $25h^{-1}$kpc had been classically assumed to merge in a timescale of order 500Myr. In a recent paper, Kitzbichler and White (2008) find merging timescale about twice larger at the same separation. This is similar to Lotz et al. (2011) once the probability of merging has been made similar (Lopez-SanJuan et al., 2011). Even if the merger timescales may still be a matter of debate, we point out that changing the timescales by a scale factor would only affect the absolute merger rate values, not the shape of the merger rate evolution.

Using the Kitzbichler and White prescription on the pair fraction, we find preliminary major merging rates of $R_{MM}(z = 1.05) = 0.110 \pm 0.030$, $R_{MM}(z = 1.3) = 0.125 \pm 0.025$, $R_{MM}(z = 1.55) = 0.130 \pm 0.040$ from MASSIV, $R_{MM}(z = 2.3) = 0.105 \pm 0.035$ from VVDS, and $R_{MM}(z = 2.7) = 0.110 \pm 0.045$ from VUDS. These values are being iterated upon as we finalize the analysis of these datasets.

## 4. GMRH since $z \sim 3$

We combine these new measurements with results from the VVDS-Deep in $0 < z < 1.2$ (de Ravel et al., 2010, Lopez-SanJuan et al., 2011). The GMRH is presented in Figure 2. We find that the GMRH is rising rapidly from z=0 to z=1 with $(1+z)^m$ and $m \simeq 3$, it is becoming flatter from z=1 to z=1.55 from the MASSIV data and then slightly decreases going up to $z \sim 2.3$ (VVDS) and $z \sim 2.7$ (VUDS). The merger rate history therefore seems to go through a peak in merging activity around $z \sim 1.5-2$. This shape is comparable to the star formation rate history, possibly with the merger rate activity peaking at a somewhat earlier cosmic time than the star formation peak.

## 5. Conclusion

Our results indicate that major mergers contribute at least 30% of the mass growth of galaxies with $M \geq 10^{10.5} M_\odot$ since $z \sim 3$. Minor mergers $1/10 < \mu \leq 1/4$ are also expected to contribute significantly to the mass assembly, as is now being quantified up to $z \sim 1$ (Lopez-SanJuan et al., 2011). It is therefore evident that galaxy mergers are a major contributor to the mass assembly of galaxies.

The complete knowledge of the total contribution of merging to galaxy mass assembly will require extending the measurements of the major merging rate beyond $z = 3$, as well as that of minor mergers only constrained to z=1 today. Spectroscopic pairs will remain a major tool in this context.

### References

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