The minor merger history of massive galaxies ($M_\star \geq 10^{11}\ M_\odot$) since $z \sim 1$

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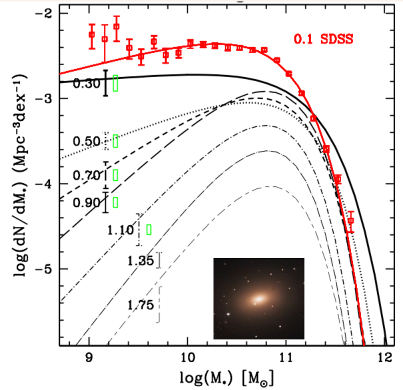
Red sequence growth since $z \sim 1$

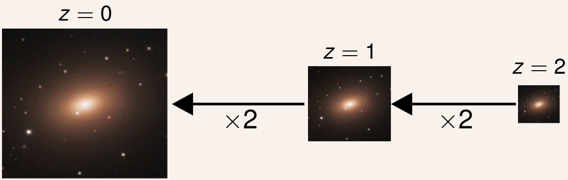


Ilbert et al. 2010

The most massive galaxies were the first to reach the red sequence: the so called "downsizing".

Cowie et al. 1996, Bundy et al. 2006, Pérez-González et al. 2008, Ilbert et al. 2010, Pozzetti et al. 2010, ...

Evolution of massive galaxies since $z \sim 1$



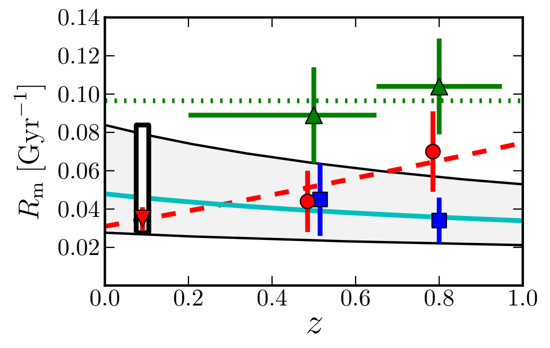
Trujillo et al. 2006, 2007, Buitrago et al. 2008, van der Well et al. 2008, van Dokkum et al. 2010, Williams et al. 2010

$M_\star \gtrsim 10^{11}\ M_\odot$

Major mergers can explain the nuber density evolution of the massive galaxies since $z = 1$ (Eliche-Moral et al. 2010a,b, Oesch et al. 2010, Robaina et al. 2010).

Minor mergers could explain the size evolution (e.g., Bezanson et al. 2009, Naab et al. 2009) and the recent star formation episodes in massive galaxies (Kaviraj et al. 2007,2009; Fernández-Ontiveros et al. 2010).

Minor mergers in VVDS-Deep



$\mu \equiv L_{B,2}/L_{B,1}$

- Major merger rate ($\mu \geq 1/4$)
- Minor merger rate ($1/10 \leq \mu < 1/4$)
- Major + minor merger rate ($\mu \geq 1/10$)

- We measure the minor merger rate of bright galaxies in VVDS-Deep survey ($M_B \leq -20$; López-Sanjuan et al. 2011, A&A, 530, A20).
- Only $\sim$ 100 sources with $M_\star \gtrsim 10^{11}\ M_\odot$.
- We need more fields to confirm our results and to study massive galaxies.

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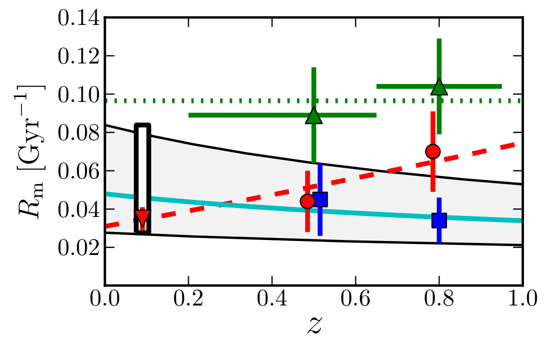

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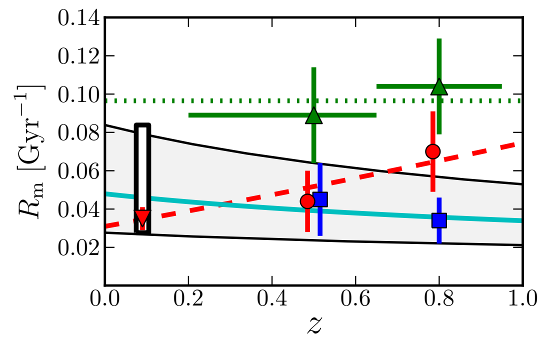

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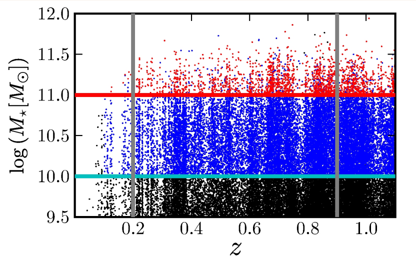
Close pairs in COSMOS field

Measure the minor merger fraction and rate of massive galaxies ($M_\star \gtrsim 10^{11}\ M_\odot$) since $z \sim 1$

Selection	Area	Spectroscopy	Sources
$I_{\rm AB} \leq 25$	1.6 deg^2	30% ($I_{\rm AB} \leq 22.5$)	$\sim 300k$ ($\sim$2000)
Ilbert et al. 2009		zCOSMOS, Lilly et al. 2009	$z < 1.1$



$$\mu \equiv M_{\star,2}/M_{\star,1}$$

- Major mergers: $\mu \geq 1/4$ ($\Delta M_B \leq 1.5$ in $B-$band)
- Minor mergers: $1/10 \leq \mu < 1/4$ ($1.5 < \Delta M_B \leq 2.5$ in $B-$band)

Close pairs in COSMOS field

We need to rely on photometric redshifts when search for close pairs (López-Sanjuan et al. 2010 methodology)

- Better statistics. ✓
- We work with complete samples. ✓
- We need high quality photometric redshifts. ✗ ✓
- Reliable measurement of merger fraction, but we need spectroscopy to define secure close pairs. ✗

Projection effects are important for $r_p \geq 30h^{-1}$ kpc.

Maximum $\sigma_z/1+z \sim 0.04$.

Systematic error of 10% in the merger fraction.

$$10h^{-1}\ \mathrm{kpc} \leq r_p \leq 30h^{-1}\ \mathrm{kpc}$$
$$\Delta v \leq 500\ \mathrm{km\ s^{-1}}$$

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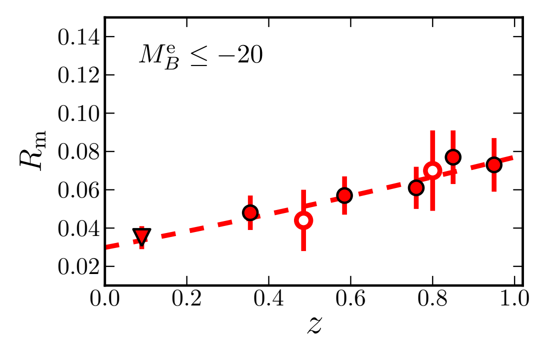
The minor merger rate

$$R_{\rm m} = f_{\rm m}\, T_{\rm m}^{-1}$$

- $T_{\rm MM}$ from cosmological simulations (Kitzbichler&White 2008). This time scale takes into account that some close pairs will never merge.
- $T_{\rm mm} = 1.5 \times T_{\rm MM}$ from $N-$body/hydrodynamical simulations (Lotz et al. 2010a,b).
- The time scale depends on the stellar mass of the principal galaxy and on the separation of the close pair, but slightly on z (Kitzbichler&White 2008) and on the gas fraction of the galaxies (Lotz et al. 2010b).

The minor merger rate of bright galaxies ($M_B \leq -20$)



VVDS-Deep
COSMOS
Major merger rate,
$R_{\rm MM}$ ($\mu \geq 1/4$)
MGC ($z = 0.09$)
Minor merger rate,
$R_{\rm mm}$ ($1/10 \leq \mu < 1/4$)
Major + minor merger rate,
$R_{\rm m}$ ($\mu \geq 1/10$)

The major merger rate increases with z, $R_{\rm MM} \propto (1+z)^{1.4\pm0.1}$

Le Fèvre et al. 2000; Conselice et al. 2003,2008,2009; Rawat et al. 2008; de Ravel et al. 2009; López-Sanjuan et al. 2009a,b, 2011; Bridge et al. 2010;...

The minor merger rate decreases with z, $R_{\rm mm} \propto (1+z)^{-0.7}$
A local estimation of the minor merger rate is needed.

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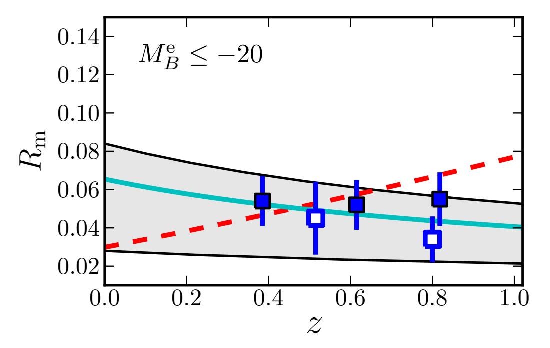

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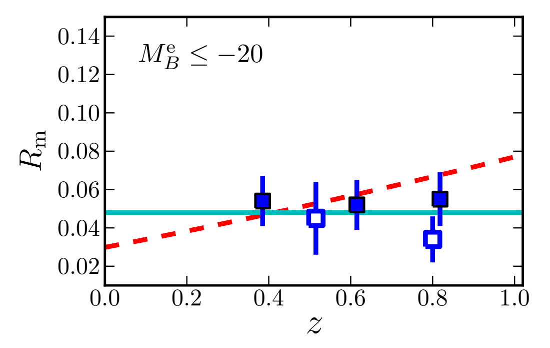

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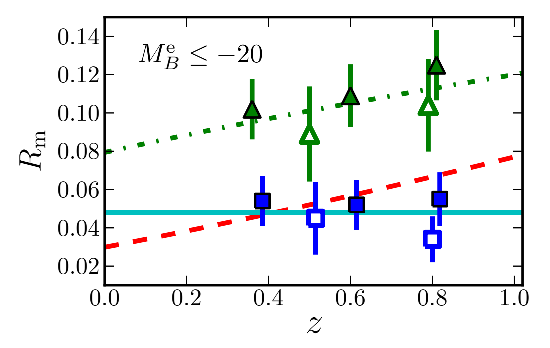

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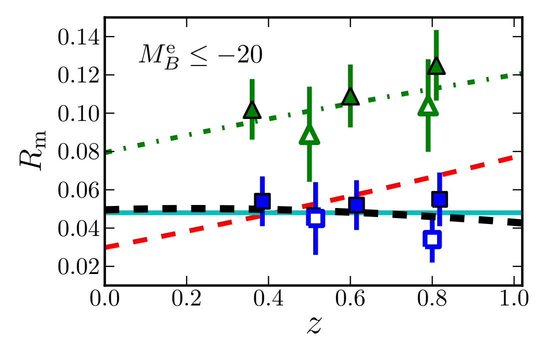

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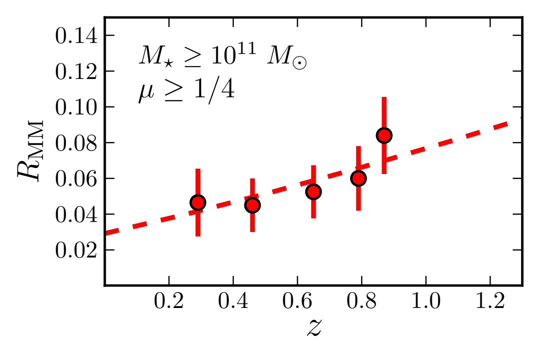

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Good agreement with previous works
(△ zCOSMOS 10k, de Ravel et al. 2011;
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The minor merger rate is roughly constant, $R_{\rm mm} \sim 0.050$ Gyr^{-1}
The total merger rate increases with z, $R_{\rm m} \propto (1+z)^{0.8\pm0.2}$.

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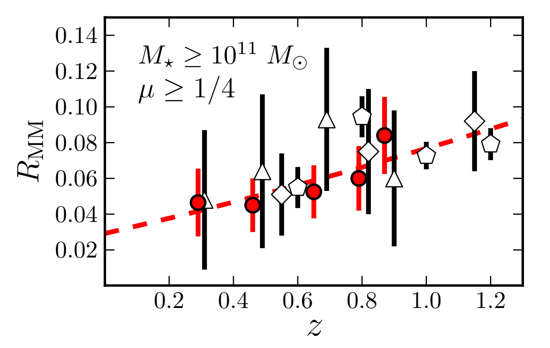

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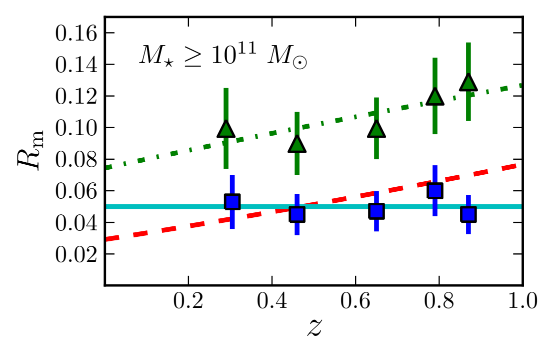

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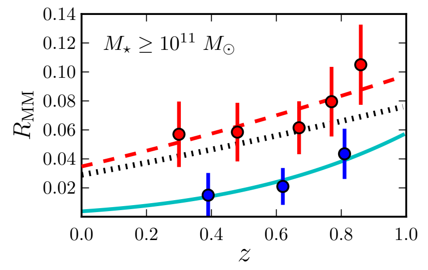
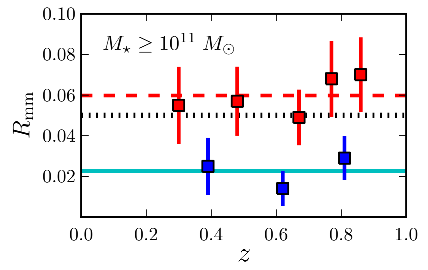
We split our massive galaxies into early types (2/3 of the sample) and spirals (1/3) following Tasca et al. 2009.

Major mergers ($\mu \geq 1/4$)



● $R_{\rm MM}$(early types) $\propto (1+z)^{1.5\pm0.3}$
● $R_{\rm MM}$(spirals) $\propto (1+z)^{3.9\pm0.5}$

Minor mergers ($1/10 \leq \mu < 1/4$)



■ $R_{\rm mm}$(early types) ~ 0.060 Gyr^{-1}
■ $R_{\rm mm}$(spirals) ~ 0.023 Gyr^{-1}

The major and the minor merger rate of early-type galaxies are $\sim$ 20% higher than for the global population, while those of spirals are a factor of two lower.

Minor mergers and the evolution of massive galaxies

- Early-type galaxies with $M_\star \geq 10^{11}\ M_\odot$ have undergone $\sim$0.9 mergers (0.45 major and 0.45 minor) since $z = 1$.
- Mergers may increase the mass of massive early-type galaxies by $\sim$ 30%.
- Regarding size evolution, mergers can account for $\sim$ 60% of the observed evolution (we assume $r_e \propto M_\star^{1.5}$). An extra $\sim$ 20% is due to the progenitos bias (Van der Wel et al. 2009), while the remaining $\sim$ 20% should come from other physical processes (e.g., adiabatic expansion or very minor mergers).
- The relative contribution of major and minor mergers to the previous evolution is 75%/25%, in good agreement with cosmological models' predictions (Hopkins et al. 2010, Cattaneo et al. 2011).

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Conclusions

The major and minor merger rate of bright ($M_B \leq -20$) galaxies in COSMOS agree with those in VVDS-Deep spectroscopic survey.

The minor merger ($1/10 \leq \mu < 1/4$) rate of massive galaxies with $M_\star \geq 10^{11}\ M_\odot$ is roughly constant with redshift, while major merger ($\mu \geq 1/4$) rate increases with redshift.

Mergers (major + minor, $\mu \geq 1/10$) increase the stellar mass of massive early-type galaxies by $\sim$30% and account for $\sim$ 60% of their size evolution since $z \sim 1$.
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