Do close pairs always merge? How long does it take?
Calibrating observational estimates of the galaxy merger rate.

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The Issue

- We believe that galaxy mergers occur, inducing AGN and star-formation activity while transforming galaxy morphology.
- How can we estimate the rate of such mergers observationally?

The Idea

- All mergers must appear as close pairs of galaxies shortly before they merge.

\[ \dot{n}_{\text{merge}} = n_{\text{close_pair}} \times F_{\text{merge}} / T_{\text{merge}} \]

The Problem

- How do we estimate \( F_{\text{merge}}(z) \) and \( T_{\text{merge}}(z) \)?
The Trouble with Morphology

- Morphology can give a clear indication that a dynamical interaction is occurring, and so would seem to offer the chance to construct uncontaminated catalogues of merging pairs.
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...BUT...

• The detectability of interaction signatures in an image depends
  (i) on the morphology of the interacting systems (E, S, Irr...);
  (ii) on the viewing angle;
  (iii) on the time when the interaction is seen;
  (iv) on the redshift of the system; and
  (v) on the sensitivity, resolution and waveband of the observation.
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...AND SO...

• Since the abundance of morphologically detected interacting systems depends on all these highly uncertain factors, so also must the effective values of $F_{\text{merge}}(z)$ and $T_{\text{merge}}(z)$. 
Our Solution

● Use the Millennium Simulation to create virtual samples of close pairs directly analogous to real observed surveys

● Measure \( n_{\text{merge}}(z) \) and \( n_{\text{close pair}}(z) \) in the mock survey

● Use these to estimate \( F_{\text{merge}}(z) \) and \( T_{\text{merge}}(z) \)

● Do not require any morphological signatures of interaction in either the simulated or the observed catalogues
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Caveat

- Dynamical evolution in the Millennium Simulation must be realistic on the relevant scales (30 to 50 kpc).
Does the MS produce the right number of faint galaxies?

Counts agree in the optical but not in the K-band.

Redshift distributions are approximately OK but numbers high at all $z$. 
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Too many faint red galaxies \rightarrow galaxy formation too early?
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Evolution of the mass function of galaxies in the MS compared to observation
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Comparison with VVDS survey $w_p(r_p)$

Meneux et al 2007

$\langle z \rangle \sim 0.6$

The Millennium Simulation approximately reproduces the observed abundance of pairs on scales $\sim 200$ kpc at $z \sim 0.6$
Small-scale correlations in the MS versus SDSS

Kitzbichler & White 2008
Small-scale correlations in the MS versus SDSS

\[ 11 < \log M_* < 11.5 \]
Small-scale correlations in the MS versus SDSS

$W_p(r_p)r_p^{0.8}$ vs $r_p$ [Mpc/h] for $10.5 < \log M_\star < 11$
Small-scale correlations in the MS versus SDSS

\[ W_p(r_p) \sim r_p^{-0.8} \]

\[ 10 < \log M_* < 10.5 \]
Small-scale correlations in the MS versus SDSS
Small-scale correlations in the MS versus SDSS

- The Millennium Simulation reproduces the observed abundance of pairs on 30 to 50 kpc scales at $z \sim 0.1$
- The "orphan" galaxies are critical to getting this right
Small-scale correlations in the MS versus SDSS

According to the simulation (and the data!) the small-scale shape of the correlation function depends strongly on stellar mass
What constitutes a merger in the simulation?

- When two dark halos merge into a single halo?
- When the DM (sub)structure of one galaxy is disrupted within the halo of the other?
- When the code thinks dynamical friction has brought the visible galaxies together?

Kitzbichler & White 2008
Merger rates as a function of stellar mass and redshift

- Halo merger and disruption rates $\propto (1 + z)^{1.5}$ at low $z$, but galaxy merger rates are independent of $z$.
- Halo merger rates are more than twice (sub)halo disruption rates.
Merger rates as a function of stellar mass and redshift

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Do observed close pairs actually merge?

Most close pairs merge but they take a long time to do it!
How long do close pairs take to merge?

The median merger time is about 2Gyr with a broad distribution.
**Timescale for converting close pair counts into merger rates**

\[ T_{\text{merge}} = \frac{\text{(Abundance of projected close pairs)}}{\text{(Merger rate of such pairs)}} \]

\[ \propto r_p M^{-0.3} (8 + z) \]

Kitzbichler & White 2008

For pairs with \( r_p < 30 \text{ kpc} \) and \( \Delta v < 300 \text{ km/s} \)
How to estimate merger rates from pair counts

1. Count close pairs ($r_p < 50$ or $30$ kpc) with well defined criteria on magnitude difference, stellar mass, etc.

2. Make completeness and background corrections to estimate abundance of pairs of chosen type at known $z$.

3. Divide close pair abundance by the merger timescale to get merger rate (per unit volume) of the chosen pair type. E.g. for pairs of $\sim 10^{10}$ $M_\odot$ galaxies at $z \sim 1$ with $r_p \leq 30$ kpc/h (physical) and $\Delta v < 300$ km/s

$$T_{\text{merge}} = 2.0 \text{ Gyr/h}$$
IN CONCLUSION

- Do NOT use morphologically selected samples to estimate merger rates
- Most close ($r_p < 50$ kpc) pairs will merge
- The time they take to merge varies widely
- The appropriate average time is around 2 Gyr
- Merger rates are not expected to vary much with $z$
- Most previous observational estimates are too high