The role of galaxy merging in the life of massive galaxies

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+ Sune Toft, Andrew Zirm

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Finding galaxy mergers — why and how?
Why study galaxy mergers?

Galaxy merging is...

- the backbone of LCDM cosmology
- related to the most spectacular phenomena in the Universe

Enhanced star formation
- de Propris+05; Engel+10; Kartaltepe +10; Patton+11, +13

Active galactic nuclei
- Treister+12; Ellison+13

Disks → elliptical
- Toomre & Toomre 72; Barnes & Hernquist 96; Hopkins+10

Credit: Hooper & Wolf @ WISC

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Finding galaxy mergers

1. Morphologically disturbed galaxies
   - Visual classification of merger stages
     - Kartaltepe+10, +12, +14; Hung+13
   - CAS – Concentration, asymmetry & clumpiness
     - Conselice+03
   - Gini-M_{20}
     - Lotz+04

Credit: HST Great Observatories of All-sky LIRG Survey (GOALS)

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Finding galaxy mergers

Morphologically disturbed galaxies

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Gini-M
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What z~2 galaxies look like...
- Lower surface brightness
- Coarser resolution

Credit: Kartaltepe+14, HST/WFC3 CANDELS

Credit: HST Great Observatories of All-sky LIRG Survey (GOALS)

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2. Galaxy pairs

- Within projected separation threshold (e.g. 30 kpc/h)
- Consistent line-of-sight distance
  - If no redshift info: statistical correction
  - Photometric redshift
  - Spectroscopic redshift
- Merger fraction / Timescale = Merger rate

Zepf & Koo 89; Le Fevre+00, Patton+00, 08; Lin+04, 08; de Propris+05, Kartaltepe+07; Ryan+08; Bluck+09; Bundy+09; de Ravel+09; Robaina+10; Williams+11; Xu+12; Lopez-Sanjuan+11, +12, +13; Man+12, +14; Newman+12; Xu+12; Tasca+14

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## Pros & Cons of merger selection

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<td>- Less dependent on imaging resolution &amp; depth $\rightarrow$ push to higher $z$</td>
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**Galaxy pairs**

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#### Which one to use?

- **Galaxy pairs** → better for galaxy merger rate measurements
- **Morphological classification** → better for measuring merger fraction of AGN / starburst / favorite population

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Measuring galaxy merger rate at z=0-3 w/ galaxy pairs

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Lotz+11 find consistency across observations & theoretical predictions up to $z=1.5$ if parent sample are selected the same way.

Major merger rate (Lotz+11)

- Observations
- Theoretical predictions

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Discrepant merger fractions at $z \sim 2$

- **Increase strongly with $z$**
- **No evolution with $z$**
- **Decrease with $z$**

Based on different data ($HST$ vs ground-based) & selection ($H$-band flux ratio vs stellar mass ratio)

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Galaxy merger fraction – method & data

- Largest sample of photometrically selected mergers at z>1 from stellar mass-complete samples

<table>
<thead>
<tr>
<th>Survey</th>
<th>Ref</th>
<th>Area [deg²]</th>
<th>Depth (5σ)</th>
<th>FWHM</th>
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<tr>
<td>UltraVISTA / COSMOS</td>
<td>Muzzin+13</td>
<td>1.62</td>
<td>K=23.8</td>
<td>0.75”</td>
</tr>
<tr>
<td>CANDELS</td>
<td>Skelton+14</td>
<td>0.25</td>
<td>H=26.9</td>
<td>0.18”</td>
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- Merging massive \( (M_\star \geq 10^{10.8} M_\odot) \) galaxies are identified by pairs:
  - Projected separations 10-30 kpc/h
  - Photo-z's overlap within 1σ uncertainties
  - Stellar mass or H-band flux ratio
    - 1:1 – 1:4 (major)
    - 1:4 – 1:10 (minor)

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Galaxy merger fraction - results

- **Observed H-band flux ratio**
  - Bias towards gas-rich satellites
  - Increasing trend

- **Stellar mass ratio**
  - Bias against gas-rich satellites
  - Diminishing trend
Galaxy merger rates – observed vs predicted

If only stellar mass ratio is considered, we miss out on the gas-rich mergers at $z>2$ that have the right baryon ratio (Stewart+09)

- Gas-poor merger rate ✔
- Gas-rich merger rate
- Diverge at $z>2$
A massive galaxy doubles its stellar mass from $z \sim 3$ to 0.3 by accreting stars via major & minor mergers.
Average sizes of quiescent galaxies need to increase their sizes ~3-5 times 
(Newman+12, van der Wel+14)

Major + minor mergers can at most double the size from $z \sim 2.5$ to 0

→ Need other mechanisms to explain the observed size evolution
Conclusions

- Discrepant merger fraction at $z \sim 2$ due to merger definition
  - Stellar mass ratio $\Rightarrow$ bias against gas-rich satellites $\Rightarrow$ diminishing merger fraction
  - Observed H-band flux ratio $\Rightarrow$ bias towards gas-rich satellites $\Rightarrow$ increasing merger fraction

- Which ratio to used? Depends on science questions.

- Merging is enough to explain the stellar mass assembly of the most massive galaxies at $z \sim 0$-2.5, but additional mechanisms are needed to explain the rapid average size evolution of quiescent galaxies

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