Constraining Merger Morphologies and Timescales with Simulations

Jennifer Lotz - NOAO

P. Jonsson (UCSC), TJ Cox (Harvard)
J. Primack (UCSC)
(see also G. Novak’s talk)
Galaxy mergers and interactions --

transform star-forming disks to ‘dead’ spheroids

trigger massive starbursts (ULIRGS)

fuel AGN + grow SMBHs

Want to be able to track ‘galaxy merger rate’ as a function of time, mass, environment....
Galaxy merger rate ==
number of mergers/ Gyr / unit volume

“Mergers” identified via
morphology
-- visual classification
tails, double nuclei, shells
-- quantitative measures
asymmetry, concentration
Gini coefficient, M20

or close kinematic pairs
(10 < drproj < 50 kpc, dv < 500 km/s )
Quantitative Merger Classification

Lotz, Primack, & Madau 2004, Conselice 2004
Merger Timescale:

time during which a merger can be identified (i.e. ‘duty cycle’)

-- poorly constrained for disturbed morphologies
  (Conselice 2005, Iono, Yin, & Mihos 2004, Bell et al 2005)

-- depends on merger conditions:
  gas fraction, orbital parameters, SFR/feedback, mass ratio

-- depends on observations:
  wavelength, viewing angle, S/N, resolution

⇒ calibrate with simulations!
GADGET: nparticles > 200,000
spatial resln ~ 100 pc, particles ~ $10^6$ Msun
dark matter + stars + gas, SF + SN feedback
(Cox 2005, 2006)

SUNRISE: Monte Carlo radiative transfer
assign SEDs to star particles,
dust-to-gas ratio, metallicity gradient
images in UV-optical-IR, w/ dust, 11 cameras
(Jonsson 2005, 2006)

morphology code: Gini, M20, Concentration, Asym,
projected radius for SDSS g-band images
(Lotz 2004, 2006)
Gas-Rich Equal Mass Merger Simulations

Sbc-Sbc: \( M_{\text{tot}} = 8 \times 10^{11} \, M_{\odot} \)
- gas/baryons = 50%
- bulge stars/baryons = 10%
- \( R_{\text{disk}} = 3 \, \text{kpc} \); \( R_{\text{gas}} = 3 \, R_{\text{disk}} \); \( R_{\text{bulge}} = 0.2 \, \text{kpc} \)
- high SN feedback
- prograde-prograde, \( R_{\text{peri}} = 11 \, \text{kpc} \)

- \( N_{\text{particles}} \): 4x, 10x
- Gas fraction: 10% gas
- Orbits: retro-pro, retro-retro, \( R_{\text{peri}} = 5, 44 \, \text{kpc} \)
- Feedback: low SN feedback
Sbc-Sbc simulation;
Camera 0  u-r-z  color composite
Sbc-Sbc simulation;
1.5 Gyr remnant u-r-z color composite
Sbc-Sbc simulation:
merger properties v. time

-Time (Gyr)
-Rproj (kpc)
-SFR/object
-log10[L(IR)/object]
-L(Ha)/object
-Gini
-Asym
-M20
Are we resolved?
1x v. 10x nparticles

scatter because different sims

initial galaxies high A, high M20 -- unresolved star clusters?

~0.1 offset in A
good agreement for merger/remnant
Are we resolved?
1x v. 10x nparticles
Are we resolved?
1x v. 10x nparticles
Merger Stage v. Merger Classification

- first pass
- high SN feedback, all orbits, with dust, high gas fraction
Merger Stage v. Merger Classification

- high SN feedback
- all orbits
- with dust
- high gas fraction
Merger Stage v. Merger Classification

**final pass/merger**

- **Gini** vs. **M20**
- **Asym** vs. **C**

- **mergers**
- **high SN feedback, all orbits, with dust, high gas fraction**
Merger Stage v. Merger Classification

Post merger: high SN feedback, all orbits, with dust, high gas fraction
Merger Stage v. Merger Classification

>1 Gyr remnant

Gini - M_20

mergers

high SN feedback, all orbits, with dust, high gas fraction
Merger Stage v. Merger Classification

G-M20, Asym identify mergers during 1st pass - final merger

Mergers

Initial gals
1st pass apart merger
Post-merger remnant
<table>
<thead>
<tr>
<th>Merger Time:</th>
<th>dt(G-M20) Gyr</th>
<th>dt(Asym) Gyr</th>
<th>dt(pair) Gyr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sbc-Sbc</td>
<td>0.35</td>
<td>0.83</td>
<td>0.51</td>
</tr>
<tr>
<td>no dust</td>
<td>0.35</td>
<td>0.80</td>
<td>0.52</td>
</tr>
<tr>
<td>npart x10</td>
<td>0.18</td>
<td>0.33</td>
<td>0.73</td>
</tr>
<tr>
<td>low feedback</td>
<td>0.43</td>
<td>0.54</td>
<td>0.60</td>
</tr>
<tr>
<td>Sb-Sb, low gas</td>
<td>0.49</td>
<td>0.78</td>
<td>0.58</td>
</tr>
<tr>
<td>pro-retro</td>
<td>0.23</td>
<td>1.37</td>
<td>0.56</td>
</tr>
<tr>
<td>retro-retro</td>
<td>0.48</td>
<td>1.11</td>
<td>0.59</td>
</tr>
<tr>
<td>small $R_{peri}$</td>
<td>0.41</td>
<td>0.59</td>
<td>0.53</td>
</tr>
<tr>
<td>large $R_{peri}$</td>
<td>1.31</td>
<td>1.53</td>
<td>0.91</td>
</tr>
<tr>
<td>&lt;Average&gt;</td>
<td>0.5 ± 0.4</td>
<td>0.8 ± 0.4</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>Remnants:</td>
<td>Gini</td>
<td>M20</td>
<td>C</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Sbc-Sbc</td>
<td>0.54</td>
<td>-1.77</td>
<td>3.2</td>
</tr>
<tr>
<td>no dust</td>
<td>0.58</td>
<td>-1.95</td>
<td>5.1</td>
</tr>
<tr>
<td>npart x10</td>
<td>0.54</td>
<td>-1.89</td>
<td>3.4</td>
</tr>
<tr>
<td>low feedback</td>
<td>0.59</td>
<td>-2.27</td>
<td>4.5</td>
</tr>
<tr>
<td>Sb-Sb, low gas</td>
<td>0.55</td>
<td>-1.79</td>
<td>3.2</td>
</tr>
<tr>
<td>pro-retro</td>
<td>0.54</td>
<td>-1.78</td>
<td>3.1</td>
</tr>
<tr>
<td>retro-retro</td>
<td>0.54</td>
<td>-1.60</td>
<td>3.1</td>
</tr>
<tr>
<td>small $R_{\text{peri}}$</td>
<td>0.53</td>
<td>-1.74</td>
<td>3.1</td>
</tr>
<tr>
<td>large $R_{\text{peri}}$</td>
<td>0.52</td>
<td>-1.46</td>
<td>3.0</td>
</tr>
<tr>
<td>&lt;Average&gt;</td>
<td>0.54 ± 0.02</td>
<td>-1.77 ± 0.25</td>
<td>3.3 ± 0.5</td>
</tr>
</tbody>
</table>
$>1$ Gyr Merger Remnants

- all orbits, high feedback, with dust
- pro-pro, high feedback, no dust
- pro-pro, low feedback, with dust

Many remnants are disky, dusty, and ‘green’: $u-r \approx 2.0$ (red seq $u-r \approx 2.5$)
Star-formation + IR luminosity

>90% of ultra-luminous galaxies in nearby universe are mergers (e.g. Sanders 1988, Borne et al 2001)

IR-luminous galaxies (>10^{11} L_{sun}) dominate global SF at z>1 but most classified as spirals visually + quantitatively (Bell et al 2005, Melbourne et al 2005, Lotz et al 2006)
L(IR) v. morphology

- First pass

Graphs show the relationship between L(IR) and various morphological features (Gini, Asym, M) across different values.
L(IR) v. morphology

Gini vs. L(IR)/object

M20 vs. L(IR)/object

Asym vs. L(IR)/object

C vs. L(IR)/object

apart
L(IR) v. morphology

(final pass/merger)
L(IR) v. morphology

post merger
L(IR) v. morphology

>1 Gyr remnant

Asym
Gini
M
C

>1 Gyr remnant

>1 Gyr remnant
L(IR) v. morphology

L(IR) does not correlate closely with morphology!

high SN feedback, all orbits

initial gals 1st pass apart merger
post-merger remnant
Sbc-Sbc simulation: merger properties v. time

peak in SFR/L(IR) occurs after peak in morphology disturbances
reaches ULIRG L(IR)

low SN feedback, prograde-prograde

initial gals
M20 1st pass apart merger post-merger remnant
low SN feedback simulation
merger properties v. time

1st starburst is stronger; better correlation between morphology + SFR
Summary

Gas-rich equal mass mergers, g-band morphologies for range of orbits, SN feedback, gas-fraction

- merger timescales NOT strong function of feedback, gas-fraction, orbit (except $R_{peri}$)

\[
dt (G-M20) \sim 0.5 \text{ Gyr} \\
dt (\text{Asym} > 0.4) \sim 0.8 \text{ Gyr} \\
dt (\text{close pair } 10 < r_{proj} < 50 \text{ kpc}) \sim 0.7 \text{ Gyr}
\]

- $\sim 1$ Gyr merger remnants are disky, dusty, and ‘green’
  - need AGN/ modified SN feedback to remove/use gas?

- IR luminosity not always closely correlated with high Asym, high G-M20 (except for low SN feedback sim)