Merger relics in galaxy clusters

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Dark haloes grow through mergers

DMH merger tree from an N-body simulation

Wechsler et al. (02)

Courtesy: Jay Lee
mass, star formation, morphology, black hole activities, etc

~50% of field bulge-dominant galaxies show merger features in deep ($\mu=28$) images (van Dokkum 2005).
Deep images help.

Kaviraj et al. 2010

SDSS short exp
$\mu_r \sim 25$

SDSS long exp
$\mu_r \sim 27$
Indeed.
Clusters at z~0.1

- FOV covers $R_{\text{virial}}$
  - A389 $R_{\text{virial}} = 2.3$ Mpc
  - A3330 $R_{\text{virial}} = 1.9$ Mpc
  - A2670 $R_{\text{virial}} = 1.6$ Mpc
  - A119 $R_{\text{virial}} = 1.0$ Mpc

- $R_{\text{vir}} \sim$ CTIO Blanco 4m MOSAIC FOV (36‘x36’)

- exposure ~ 2hr

- All with deep GALEX images
also exhibit many post-merger features
**High post-merger fraction**

<table>
<thead>
<tr>
<th>Class</th>
<th>Cluster</th>
<th>Field (a)</th>
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</thead>
<tbody>
<tr>
<td>PM</td>
<td>38 *</td>
<td>49%</td>
</tr>
<tr>
<td>Bulge-dominated</td>
<td>I</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21%</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>70%</td>
</tr>
</tbody>
</table>

\(a\) van Dokkum 2005


* N.B.

\(~10-20\%\) on ETGs (CFHTLS)
Merger timescale in a “frozen halo”

Chandrasekhar merger timescale (Lacey & Cole 1993)

\[ t_{\text{merge}} = \frac{1}{2} \frac{f(\epsilon)V_c r_c^2}{CGm_{\text{sat}} \ln \Lambda} \propto \frac{V_c r_c^2}{m_{\text{sat}}} \propto \frac{r_c V_c^2}{m_{\text{sat}} V_c} \propto \frac{m_{\text{host}}}{m_{\text{sat}}} \rho^{-1/2} \propto \frac{m_{\text{host}}}{m_{\text{sat}}} t_{\text{dyn}} \propto \frac{m_{\text{host}}}{m_{\text{sat}}} \]

In a large halo, galaxy density is high but spatial velocity is also high and galaxy merger becomes highly unlikely!
Merger relics

- build halo merger history from DM simulations
- semi-analytic tracking of subhalos in dense regions (Binney & Tremaine GD; Jiang et al. 2008)
- build model galaxies using SAM
- estimate “post-merger feature time” from galaxy merger simulations
- calculate the number of merger relics showing post-merger features in each halo
Subhalo tracking tough!

GADGETII

M = 8.64E+09 M☉  BoxSize = 0.60 Mpc

z = 7.70
Post-merger feature time

First Passage

Final Coalescence

for $\mu_r = 28$

Post Merger
~ 3 FC

equal-mass disc+disc merger

< FP  FP  FP - FC  FC  FC - PM  PM
Post-merger features

Abell 2670 (z~0.076)

SDSS

CTIO r'

Courtesy of Y.K. Sheen
Subhaloes with a resident galaxy with PM feature
red: bulge-dominant
blue: disc
Merger Relic Fraction

$t_{PM \text{ feature}} = 2-4 \ t_{merge} \ (\text{fiducial 3})$

discs show merger features less frequently (c.f., Ferguson)
Summary

• caveats
  - merger feature, mass ratio determination subjective
  - baryon effects on halo merger tree
  - post-merger feature time (larger parameter space to explore)

• galaxy mergers
  - found to be frequent in clusters too
  - some may be merger relics from previous halo environments

• cluster deep imaging campaign: 20 clusters with CTIO/Magellan/CFHT

• full hydrodynamic simulation
Deep imaging campaign continued:
16 clusters using Magellan and CFHT
(e.g. A3574)
A3574  Rank 13  id= 15_23  Mr= -19.840491  g-r= 0.38863495  re= 48.5950  field= good  Morphology= S

A3574  Rank 14  id= 28_403  Mr= -19.705012  g-r= 0.67966970  re= 37.4830  field= saturation  Morphology= Perturbed S

A3574  Rank 15  id= 41_365  Mr= -19.664509  g-r= 0.61515550  re= 37.4830  field= good  Morphology= S

A3574  Rank 16  id= 24_24  Mr= -19.572514  g-r= 0.50471290  re= 26.2410  field= good  Morphology= Merger
Cluster zoom-in simulations

6.4 Gyr

120 kpc

Hoseung Choi