Dry minor mergers and size evolution of early-type galaxies
In high density environments  Taira OOGI, Asao HABE (Hokkaido University)

Abstract

- To study size evolution of early-type galaxies, we simulate dry major and minor mergers between early-type galaxies with N-body simulations.
- In minor merger simulations, we perform continuous mergers and synchronized mergers. Furthermore, we assume compact, less massive galaxies and diffuse, less massive objects as satellite galaxies.
- We compare the remnant properties: size, density, and velocity dispersion.
- We derive efficiencies of size growth and of velocity dispersion decrease of ETGs from a set of simulations.
- Our results indicate that minor mergers, in particular continuous ones are very efficient way to size evolution of ETGs.

N-body simulations

Model galaxies

Two-component (stellar system + dark matter halo) Hernquist model

- Stellar system
- We assume compact massive ETGs as the main galaxy.
- Effective radius: 1 kpc, stellar mass: 10^11 M_⊙
- Dark Matter (DM) halo
- We associate the Hernquist profile with a corresponding NFW halo with the same dark matter mass within r_0 at ζ=2.
- The scale radius is ζ = r_0 * (1 + (r/r_0) - 1)

Compact massive ETGs

<table>
<thead>
<tr>
<th>Galaxy ID</th>
<th>Dark Matter halo</th>
<th>Stellar bulge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxy M1</td>
<td>10^12 M_⊙</td>
<td>10^11 M_⊙</td>
</tr>
<tr>
<td>Galaxy S1</td>
<td>10^11 M_⊙</td>
<td>10^10 M_⊙</td>
</tr>
</tbody>
</table>

Compact less massive ETGs

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<thead>
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</thead>
<tbody>
<tr>
<td>Galaxy C1</td>
<td>10^11 M_⊙</td>
<td>10^10 M_⊙</td>
</tr>
<tr>
<td>Galaxy C2</td>
<td>10^10 M_⊙</td>
<td>10^9 M_⊙</td>
</tr>
</tbody>
</table>

Diffuse less massive ETGs

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<th>Dark Matter halo</th>
<th>Stellar bulge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxy D1</td>
<td>10^10 M_⊙</td>
<td>10^9 M_⊙</td>
</tr>
<tr>
<td>Galaxy D2</td>
<td>10^9 M_⊙</td>
<td>10^8 M_⊙</td>
</tr>
</tbody>
</table>

Initial conditions

- Assumption of spherical and isotropic structure
- We reproduce particle position & velocity consistently from the density profile and the distribution function.
- We use analytical phase-space distribution function in Ciotti 1996 to make a component-Hernquist profile.
- Distribution function of each component:

\[ f(R, \theta, \phi) = \frac{4}{\pi} \frac{\sigma}{M} \left( \frac{R}{R_*} \right)^{3-\beta} e^{-\left( \frac{R}{R_*} \right)^{\beta}} \]

Initial state (−1Gyr after)

Density profile

Surface density profile

We confirm that model galaxy’s stellar profile in the range of ζ=0.29kpc in −30yr.

Analysis

Effective radius, Sersic index

Sersic profile

Fitting remnant bulge’s projected profile to a Sersic profile on the range of [0.2−10] kpc

Calculating the properties for 3 angles, and averaging

Surface density weighted velocity dispersion

Comparison of the results with observations (Bezanson+ 2009)

Observation

- Black: High-z ETGs
- White: Local ETGs

Simulation results

- Yellow: Initial
- Blue: Simulation A
- Green: Simulation B
- Pink: Simulation D

Logarithmic slopes

\[ k_s = M' \cdot \sigma_n^3 \]

Simulation A: S1, S2

Simulation B: S1, S2

Simulation D: S1, S2

Simulation results

Initial: 1.00×10^12 1.00×10^12
Simulation A: 1.49×10^12 1.49×10^12
Simulation B: 1.37×10^12 1.37×10^12
Simulation D: 1.40×10^12 1.40×10^12

Change of energies of DM, star particles

- The orbit of energy of massive galaxies are transferred to the internal energy of main galaxy.
- Star particles of main galaxy gain internal energy by minor mergers.

Summary

1. We derive efficiencies of size growth and of velocity dispersion decrease of ETGs by dry major/minor mergers.
2. Minor mergers cause more efficient size growth and velocity dispersion decrease than major mergers.
3. In particular, continuous minor mergers cause more efficient size growth and velocity dispersion decrease than synchronized minor mergers.
4. We show that continuous minor mergers that are cosmologically expected are important process to explain observed size evolution of ETGs.

Future work

1. In future work, we will study the size evolution through realistic simulation using cosmological simulation in high density environment.