Numerical simulations of cosmic structures

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A third key component: satellites vs. centrals
Smaller satellite galaxies can orbit for a time within larger halos without merging onto the central galaxies.

Taken from S. Faber
The universal mass accretion history of dark matter haloes
Choosing proper variables for modeling

- Given cosmology and power spectrum, after extrapolated linearly to $z=0$, linear mass variance of given volume $\sigma$ is determined by $M$, and

$$\sigma(M) \equiv \sigma'(M, z) / D(z)$$

linear critical collapse overdensity $\delta_c$ by $z$.

$$\delta_c(z) \equiv \delta'_c(\Omega_m(z), \Omega_\Lambda(z)) / D(z)$$
Universal differential relation

$w-p$ determines growth rate of halo of mass $M$

• **LCDM**

Much more accurate than van den Bocsh (2002) or Wecshler et al. (2002)
- SCDM

&

OCDM
Evolution of halo density profile

- Combined with MAHs model we presented in part I, c-t correlation can be used to predict the evolution of halo density profile.

- LCDM1-3
Merging of galaxies
A third key component: satellites vs. centrals
Smaller satellite galaxies can orbit for a time within larger halos without merging onto the central galaxies.
We employed a parallel version of the SPH code GADGET 2 (Springel 2005). The box is $100h^{-1}Mpc$ on a side, with $512^3$ dark matter particles and $512^3$ gas particles. Gravity is softened with a spline, roughly equivalent to a Plummer force softening of $4.9h^{-1}$ comoving kpc. There are totally 177 snapshots from $z=19$, among which 28 are before $z=3.5$, and 149 are at $z \leq 3.5$. Present time $z = 0$ with an equal logarithmic scale factor interval $\Delta \ln a = 0.01$ between two consecutive outputs. The large number of the outputs enables us to accurately sample orbits of satellites within massive haloes, with about 8 outputs for one dynamical crossing time. Both the good force resolution and the dense sampling of snapshots are crucial for the current study.
Two types of merger timescales in literature

• The time duration for a satellite falling into the central galaxy from the first crossing of the virial radius of host DM halo; important of theoretical modeling, such as in SAMs;
• The time duration for a close pair of galaxies at a fixed separation (small) to merge; important for observations
Fitting formula

\[ T_{\text{fit}} = \frac{0.90 \epsilon^{0.47} + 0.60}{2C} \frac{m_{\text{pri}}}{m_{\text{sat}}} \frac{1}{\ln[1 + \left(\frac{m_{\text{pri}}}{m_{\text{sat}}}\right)]} \frac{\sqrt{r_{\text{vir}}/r_c}}{V_c}, \]

Corrections:

1) Mass loss: a factor of 2 longer

2) Motion of the central galaxies and dynamical evolution: weak dependence on \( \epsilon \) (orbital circularity)

3) Dependence on the DM mass of the primary and satellite: the Coulomb logarithm

4) Scatter: 40% reflecting hierarchical formation and diversity of host halos

Jiang et al. 2008
The second merger timescale

- A merger time for close pairs of certain mass (luminosity) and separation, related to measure the merger rate from the counts of close pairs in observations
- (Jiang, YPJ, Han, 2013, astroph/1307.3322)
Theoretical framework for understanding evolution of galaxies and dark matter halos

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Some scaling considerations

\[ T_{\text{fit}} = \frac{0.90 \epsilon^{0.47} + 0.60}{2C} \frac{m_{\text{pri}}}{m_{\text{sat}}} \frac{1}{\ln[1 + \left( \frac{m_{\text{pri}}}{m_{\text{sat}}} \right)]} \frac{\sqrt{r_{\text{vir}} r_c}}{V_c}, \]

Considering \( v_c \approx \sqrt{\frac{G m_{1,v}}{r_{1,v}}} \) in the primary halo,

\[ T_{\text{mg}} \propto \frac{m_{1,v}^{1/2} r_p^2}{G^{1/2} m_2 \ln \Lambda r_{1,v}^{1/2}}. \]

The volume merger rate can be written as

\[ \Phi = C_{\text{mg}} n_1 n_p(< r_p)/T_{\text{mg}}, \]

Replacing \( T_{\text{mg}} \) in equation (1) with equation (2), obtain

\[ \Phi = A_* \frac{G^{1/2} m_2 r_{1,v}^{1/2} n_1 n_p(< r_p)}{m_{1,v}^{1/2} r_p^2}. \]
More scaling considerations

• The retained mass of the satellite: \( m_{2,v} \frac{r_p}{r_{1,v}} \).
  – Correct when DM halo is an isothermal sphere of; but good for real DM halos
• With the definition of halos (200 critical density) and cosmological parameter relations, we have

\[
T_{mg} \propto \frac{m_{1,v}}{m_{2,v}} \left[ m_{1,v} G H_0 E(z) \right]^{-1/3} r_p \\
\Phi = B_* \frac{m_{2,v} n_1 n_p(< r_p) [m_{1,v} G H_0 E(z)]^{1/3}}{m_{1,v} r_p}.
\]

\[ E(z) = \Omega_\Lambda + \Omega_m (1+z)^3 \text{ : dimensionless Hubble parameter (i.e. } H(z) \text{ in unit of } H_0) \]
When the retained mass is considered for the satellites:
1) For different masses of central and satellites
2) For different redshifts
for the different separations

\[ r_p = \frac{50}{1+z} \ h^{-1}\text{kpc}^{10} \]

\[ r_p = \frac{150}{1+z} \ h^{-1}\text{kpc} \]
Applications to observations

• Measure the pair count per unit volume of stellar masses \( m_{1,s} \) and \( m_{2,s} \) (or luminosities)

\[
N_p(< r_p) = n_1 n_p(< r_p)
\]

– \( n_1 \) is the density of galaxy 1 and \( n_p \) is the number count within projected \( r_p \) (corrected for the background) of galaxies 2 around galaxy 1

• Volume merger rate: \( \Phi = N_p(< r_p)/T_{mg} \)

• Merger rate of G 1 and G 2: \( n_p(< r_p)/T_{mg} \)

\[
T_{mg(< r_p^{proj})} = \frac{10^{-0.23}}{0.66} \frac{m_{1,v}}{m_{2,v}} \frac{[m_{1,v} GH_0 E(z)]^{-1/3}}{r_p}
\]