The Merger Times of High-Redshift Dark Matter Halos

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Overview

- Why are accurate merger times important?
- Merger times – What has been done previously?
- Our methodology
  - Our simulations
  - Mergertree
  - Defining Mergertime
- Results
- Conclusions
Why are accurate merger times important?

Galaxy formation and evolution
* Galactic gas flows/accretion rates
* Star formation rates
  - Disruption of disks
  - Ram pressure stripping
* Metallicities
* Build up of stellar mass in galactic cores.
* Transitions of galactic morphologies.

Black Hole Growth
- Gas flows onto accretion disks/ accretion rates
- Binary formation and populations
- Activation of the AGN duty cycle
What has been done previously?

Chandrasekhar 1943 - His most cited paper (438 citations)

Formula
- Retarding Force = \[ \frac{d}{dt}v_{\text{orb}} = -4\pi G^2 \ln(\Lambda) M_{\text{sat}} \rho_{\text{host}}(\frac{v_{\text{orb}}}{\eta}) v_{\text{orb}}, \]
- Time of merger = \[ t_{\text{merge}} = \frac{1.17 r_i^2 v_M}{\ln \Lambda \frac{v_{\text{orb}}}{GM}}. \]

What it means?

Where does it apply?

Example .........
What has been done previously?
Numerical (N) and Semi Analytical (SA) ............... well a sample

Binney and Tremaine – Galactic Dynamics – derivation and excellent introduction

Tremaine 1975 – SA – Applying Dynamical Friction to globular clusters in M31
Dynamical Friction responsible for Galactic Nuclei


Tormen et al 1998 – N – Cosmological N-body. z=1 to z=0 (8 outputs).
N=20,000

van den Bosch et al 1998 – N - Extended host N=50,000, Point mass Satellite.
Does not circularize!

Orbital Energy  Eccentricity  Mass Ratio
What has been done previously?

......of particular interest

Boylan-Kolchin et al 2008 – N
• Merging 2 self consistent Hernquist halos.
• Multiple runs varying mass ratio, orbital energy and circularity
• $N_{\text{host}} = 2 \times 10^5$ and $N_{\text{sat}} = (M_{\text{sat}}/M_{\text{host}}) \times N_{\text{host}}$
• Simulated in isolation and independent of Cosmology

Jiang et al 2008 – N
• Cosmological N-body simulation (DM $512^3$ and Gas $512^3$ in 100 Mpc $h^{-1}$)
• $z=2$ to $z=0$
• FOF group finder with a 2 scale hierarchy for substructure
• Tracing substructure between snapshots
Our Research

Aim – Measure merger times for numerous of halos using a cosmological N-body simulations.

Simulation

Post Simulation Analysis
  Group finding
  Merger tree
  Defining merger time

Results
Cosmological N-body simulation

- $512^3$ Dark Matter Particles
- 10 Mpc$^3$ Box
- Mass resolution $\sim 7.05 \times 10^5$ M$\odot$ h$^{-1}$
- 101 Snapshots from $z=19$ to $z=0$

ΛCDM cosmology based on WMAP3

- $\Omega_M = 0.24$
- $\Omega^\Lambda = 0.76$
- $\sigma_8 = 0.74$
- h = 0.73
Post Simulation Analysis

P-Groupfinder Springel (2000)

- FOF
- Subfind

Linking length = 0.2 (physically 3.9 kpcs)
Post Simulation Analysis

Mergertree

- Link halos in adjacent snapshots by tracing particles
- 2 snapshots at a time
  ....... not so great
Defining Merger Time
When does it start?

Touching

\[ \frac{\text{separation}}{R_{vir_h} + R_{vir_s}} \leq 1 \]

or

\[ \frac{\text{separation}}{R_{vir_h}} \leq 1 \]

Negative Energy

\[ 0 \geq \frac{v^2}{2} - \frac{\mu}{r} \]
Defining Merger Time
When does it end?

Specific Angular Momentum

\[ \leq \text{Boylan-Kolchin et al 2008} \]

Ok but........
So angular momentum works perfectly in an isolated system but not so well in an open one.
Defining Merger Time
When does it end?

Unbinding

- Spherical potential approximation
- Iterative removal of unbound particles
- When bound subset falls to less than 5% of the initial set
Merger Time vs Starting Redshift

\[ T_{\text{merge}} = 8.07 z_s^{-1.22} \]
Results – Density profiles at different Redshifts
Results – not so peachy
Conclusions

• We use high resolution cosmological N-body simulations to measure the time of merger for a many mergers betweens redshifts $z=19$ to $z=0$.

• We found that the time of merger is correlated to the redshift at which the merger starts.

• At this stage we suggest that this effect is due to the steepening of the density profile at lower redshifts. However further investigation is needed to confirm this result.

• Further study into correlations (or lack of) with previously found dependencies such as orbital energy, orbital circularity and mass ratio is needed.