Successive Merger of Multiple Massive Black Holes in a Primordial Galaxy

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# How SMBHs@z~6 form ?

- Gas accretion
  - From debris of first stars (~100M⊙)
  - From direct gas collapse (> 10<sup>4</sup>M<sub>☉</sub>)
- Merger of massive black holes (MBHs) in dense environments

We investigate the growth of SMBHs through their merger.

## But, can MBHs merge easily ?

- Two MBHs in one galaxy
  - Approach down to a few pc.
  - Loss cone depletion (Begelman et al. 1980; Makino, Funato 2004).
- Three MBHs in one galaxy
  - Two MBHs sometimes merge (Iwasawa et al. 2006; Hoffman, Loeb 2007).





## This work



- By means of N-body simulation
  - Orbits of MBHs down to 3 times Schwarzschild radii
    3rsch
    3rsch
    Merge
    Not merge

## Method - N-body model

- 10 MBHs in one galaxy
  - Galaxy
    - Distribution function : Hernquist's model
    - The number of stars: N=5×10<sup>5</sup>
    - escape velocity ~1000 km/s
  - MBHs
    - Total mass : 0.1 % of the galaxy mass
    - Mass function : equal mass
    - Spacial distribution :
      - within 1/3 virial radius of the galaxy
    - Merger condition :
      - 3 times Schwarzschild radii





### Equation of Motion



## N-body Code

- Time integration
  - 4th-order Hermite scheme with individual timestep
- Calculation of gravitational force
  - 64 Blade-GRAPE on FIRST
- Special treatments for binary MBHs
  - Coordinate transformation to
    - Center of mass
    - Relative motion
  - Ahmad-Cohen neighbor scheme
- From scratch

#### Results - Orbits of MBHs



## MBH growth



- Growth of one dominant MBH
  - Five MBHs merge to one MBH.
  - No merger of the other MBHs
- Formation and merger of binary MBHs
  - No direct collision

# Growth of one dominant MBHs to merge



- One binary MBH at each time
  - Prevent other binaries from forming
- The binary always including the most massive MBH
  - Not easy to be replaced by smaller MBHs
- $\rightarrow$  Growth of one dominant MBH

#### Growth mechanism (1) Formation of binary MBHs



- Dynamical friction of stars is important.
  - No formation of binary MBHs in a fixed potential
- Dynamical friction of stars
  - Falling into MBHs into the galaxy center
  - Increase of the number density of MBHs at the galaxy center



## Summary

- We follow the evolution of multiple MBHs by means of N-body simulation.
- Multiple MBHs evolve to one dominant MBH.
- The key process for the growth
  - Dynamical friction
  - Binary-single interactions
  - Gravitational wave radiation
- SMBHs can form through the system of multiple MBHs in the early universe.