Formation of Hypermassive Star Clusters and Mass Supply to Galactic Center in Merging Galaxies

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Project Milkyway
Coevolution between supermassive black holes (SMBHs) and galaxies

- Correlation between $M_{\text{bulge}}$ and $M_{\text{SMBH}}$

$\rightarrow$ Coevolution between a galaxy and a SMBH

- Theoretically, a SMBH grows through
  - coalescence between SMBHs
  - gas accretion to SMBHs in wet merger

$\rightarrow$ Galaxy - galaxy merging plays a key role in the growth of SMBHs.

Marconi & Hunt 2003
Previous Numerical Simulations of Merging Galaxies with SMBHs
(e.g., Springel et al. 2005, Kazantzidis et al. 2005, Di Matteo et al. 2007)

- Gas falls into galactic central region (~hundreds of pc scale).
- The SMBHs grows through the accretion of gas.

Numerical results reproduce the observational relation.

\[ M_{\text{SMBH}} \]

\[ \sigma: \text{velocity dispersion} \]

Kazantzidis et al. 2005
Previous Numerical Simulations of Merging Galaxies with SMBHs
(e.g., Springel et al. 2005, Kazantzidis et al. 2005, Di Matteo et al. 2007)

- Resolution
  - Mass resolution (SPH mass) $10^{5-6} \, M_{\odot}$
  - Spatial resolution (gravitational softening) $\sim 100$ pc

- Interstellar medium (ISM) model
  - Isothermal gas ($T \sim 10^4 \, K$) or gas ($T > 10^4 \, K$)

Individual molecular clouds and star-forming regions are not resolved.

→ Cannot reproduce the starbursts in observed mergers.
→ Behaviour of gas in previous simulations might be completely different from that in actual mergers.
Our Simulations of a Merging Galaxy

~ Simulation Method ~

- Simulation Code
    - Parallel Tree+GRAPE N-body/SPH code
- ISM Model
  - SPH (mass: $7 \times 10^3$ Msun)
  - Radiative cooling ($10 \text{ K} < T < 10^8 \text{ K}$)
  - Star Formation ($n_H > 100 \text{ cm}^{-3}, T < 100 \text{ K}$)
  - Feedback by Type II supernovae
  - Gravitational softening length $\sim 20 \text{ pc}$

The mass and spatial resolutions in our simulations, at least, one order of magnitude better than those in previous simulations.

Wide range of gas temperature ($10 \text{ K} < T < 10^8 \text{ K}$).
Simulation Models

Disk (gas + old stars)

exponential disk

Disk (gas + old stars)

$M_{\text{disk}} \sim 10^{10} M_{\odot}$

$M_{\text{gas}} \sim 10^{9} M_{\odot}$

Dark halo (Dark matter)

$M_{\text{DM}} \sim 10^{11} M_{\odot}$

Particle Number

- SPH particles: 510,000
- Old star particles: 1,800,000
- Dark matter particles: 28,000,000

Mittwoch, 30. Juni 2010
### Collision Geometries

#### Inclination of Disks

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Results
Several massive star clusters form at the distance of a few kpc from the galactic centers.

The mass of formed star clusters is about $10^8$ M$_{\odot}$.

We should call them “Hypermassive star clusters” rather than super star clusters.

These multiple core structures are consistent with ULIRGs observed at $z \sim 0.1$. 
Observations of ULIRGs (z~0.1)

Borne et al. 2000
Mass Supply to the Galactic Center

Hypermassive star clusters sink into galactic center through dynamical friction.

→ Mass supply to galactic central region (~10 pc) takes place.
Result Summary

- Hypermassive star clusters form in the central kpc of the merger.
- These clusters sink into the galactic central region.
- Mass supply to the galactic nucleus is in the form of this HSCs, not in gas.
- These structures are consistent with "multiple nuclei" in ULIRGs.

Our numerical simulations have shown very different pictures with previous ones.
Discussions

How the central SMBH grows?

- Hypermassive Star Clusters are compact.
  - Mass: $\sim 10^8$ Msun
  - Half mass radius: < 20 pc

  IMBHs might be formed through runaway collisions of massive stars (Portegies Zwart et al. 2005).

- Hypermassive star clusters with IMBHs sink into galactic center through dynamical friction.

  A SMBH and IMBHs coalesce (Matsubayashi et al. 2007) and SMBH grows.

  Mass supply to a SMBH takes place.

Ebisuzaki et al. 2000
Summary

• We have performed high resolution simulations (mass resolution $\sim 7 \times 10^3$ Msun, spatial resolution $\sim 20$ pc,) of galaxy-galaxy merging.

• In the merging process, several hypermassive star clusters ($\sim 10^8$ M$_{\text{sun}}$) form in the galactic central a few kpc.

• These clusters explain the origin of "multiple nuclei" in ULIRGs.

• Hypermassive star clusters sink into the galactic central region because of the dynamical friction.

→ These processes may be important for growth of SMBHs.

If IMBHs formed in HSCs, they are brought to the GC by the parent cluster and merge with central SMBH. This might be the main growth path SMBHs.
High resolution simulations with multi-phase ISM model are important for understanding merging galaxies and growth of SMBHs.
Formation of IMBHs

- Hypermassive Star Clusters are compact.
  - Mass: \( \sim 10^8 \) Msun
  - Half mass radius: < 20 pc

Formation of intermediate mass black holes (IMBHs) via runaway collisions of massive stars (Portegies Zwart et al. 2005).
Simulations with Multi-phase Gas ($10 \, \text{K} < T < 10^8 \, \text{K}$) (Saitoh et al. 2009)

Global dynamics is very “different” with previous simulations.

First encounter

- Multiphase Gas Model ($10 \, \text{K} < T < 10^8 \, \text{K}$)
- Isothermal Gas Model ($\sim 10^4 \, \text{K}$)

created by Takeda & Saitoh
Formation Process of Hypermassive star clusters

1. Gas clumps ($\sim10^6$ Msun) form.

2. The clumps merge with each other.

3. Their mass grows and reaches to $>10^8$ Msun.
Mass evolution of hypermassive star clusters