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

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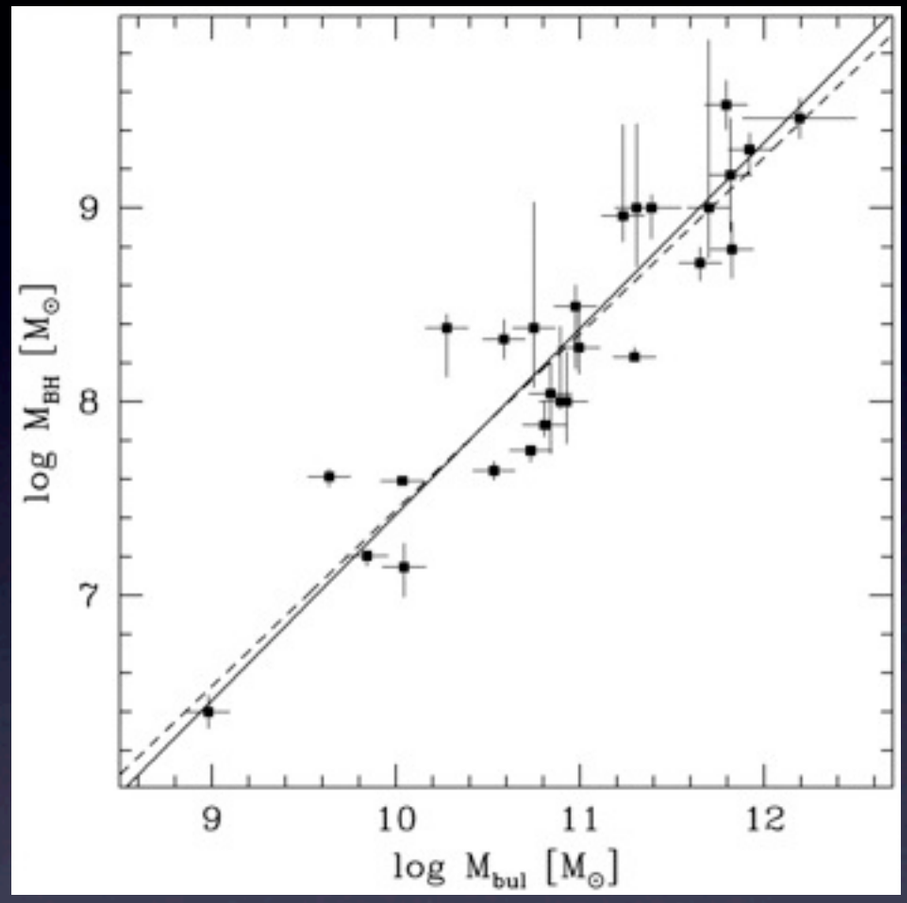
Project Milkyway

Coevolution between supermassive black holes (SMBHs) and galaxies

- Correlation between M_{bulge} and M_{SMBH}

➡ Coevolution between a galaxy and a SMBH

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



Mass of bulges

Marconi & Hunt 2003

➡ **Galaxy - galaxy merging plays a key role in the growth of SMBHs.**

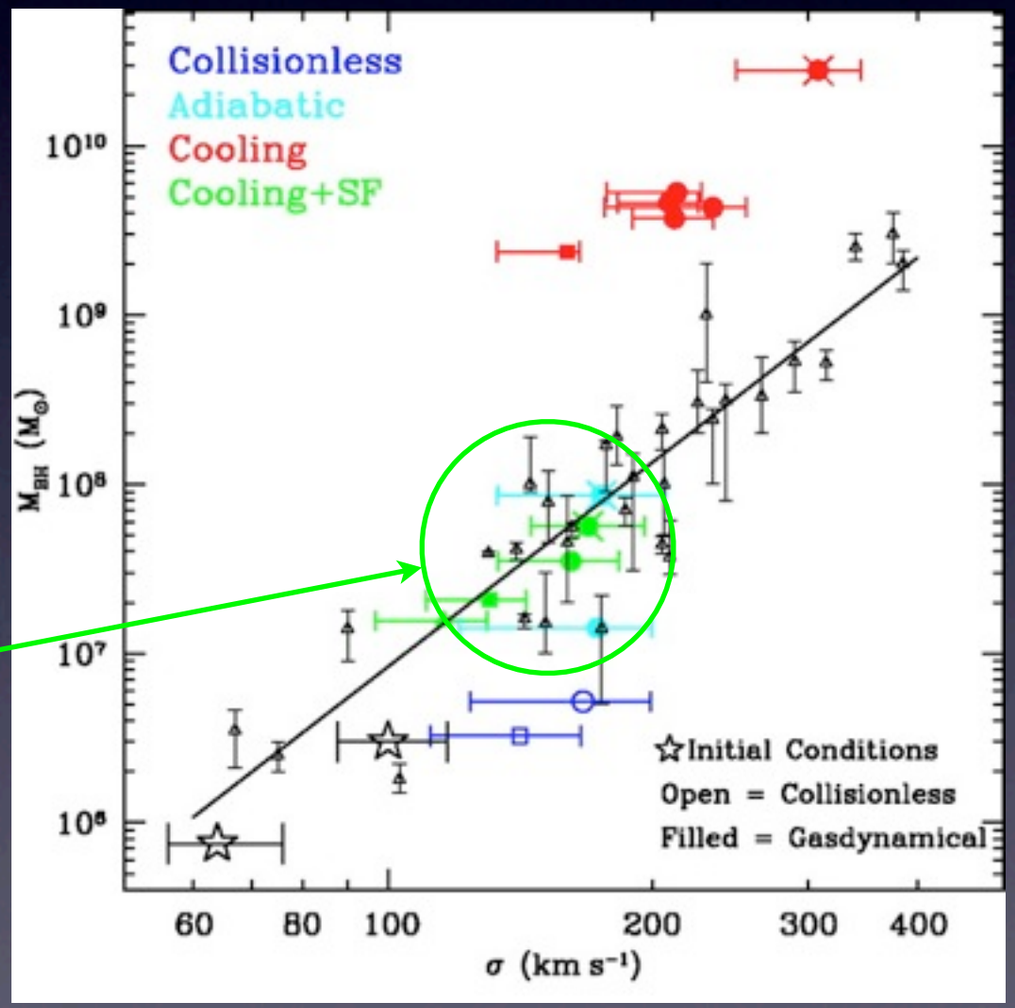
Previous Numerical Simulations of Merging Galaxies with SMBHs

(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.

M_{SMBH}

Numerical results reproduce the observational relation.



σ: 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) $10^{5\text{-}6}\ M_{sun}$
  - Spatial resolution (gravitational softening) ~ 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.

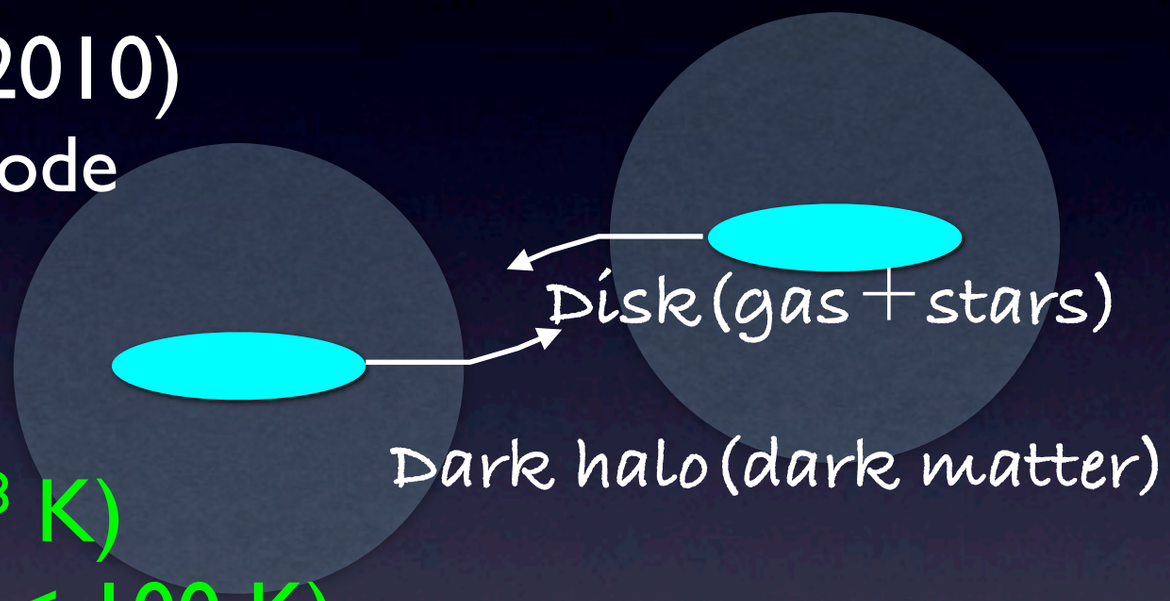
➡ Cannot reproduce the starbursts in observed mergers.

➡ Behaviour of gas in previous simulations might be completely different from that in actual mergers.

Our Simulations of a Merging Galaxy

~ Simulation Method ~

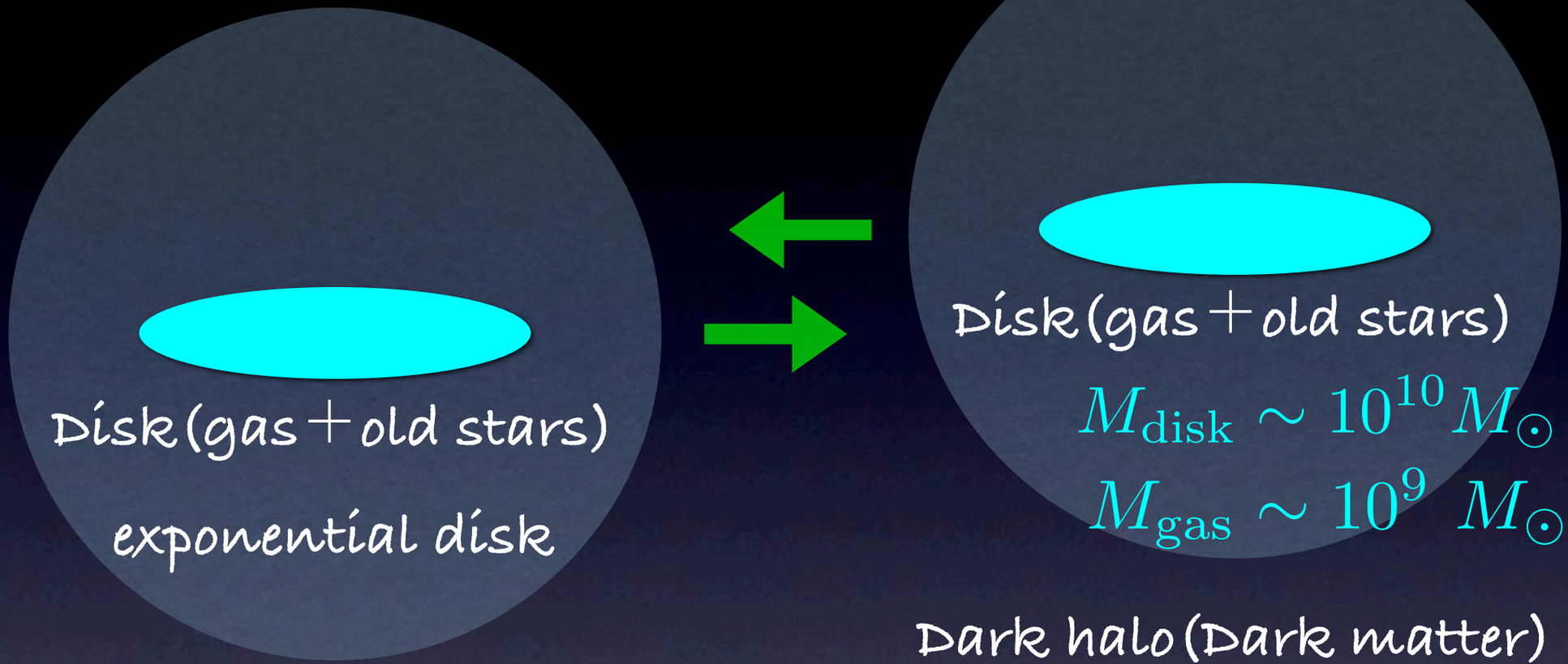
- Simulation Code
  - ASURA (Saitoh et al. 2008,2009,2010)
    - Parallel Tree+GRAPE N-body/SPH code
- ISM Model
  - SPH (mass : 7×10^3 Msun)
  - Radiative cooling ($10\ K < T < 10^8\ K$)
  - Star Formation ($n_H > 100\ cm^{-3}, T < 100\ K$)
  - Feedback by Type II supernovea
  - Gravitational softening length ~ 20 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 ($10\ K < T < 10^8\ K$).

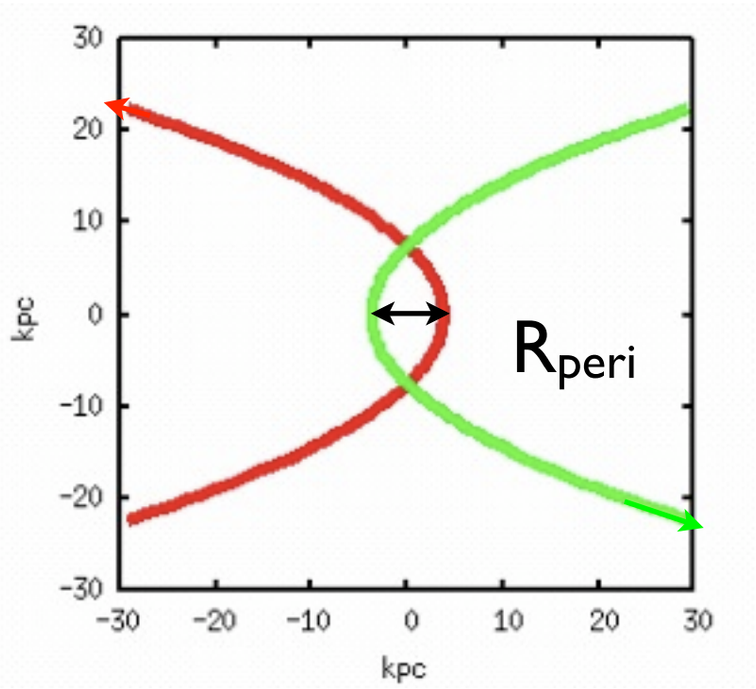
Simulation Models



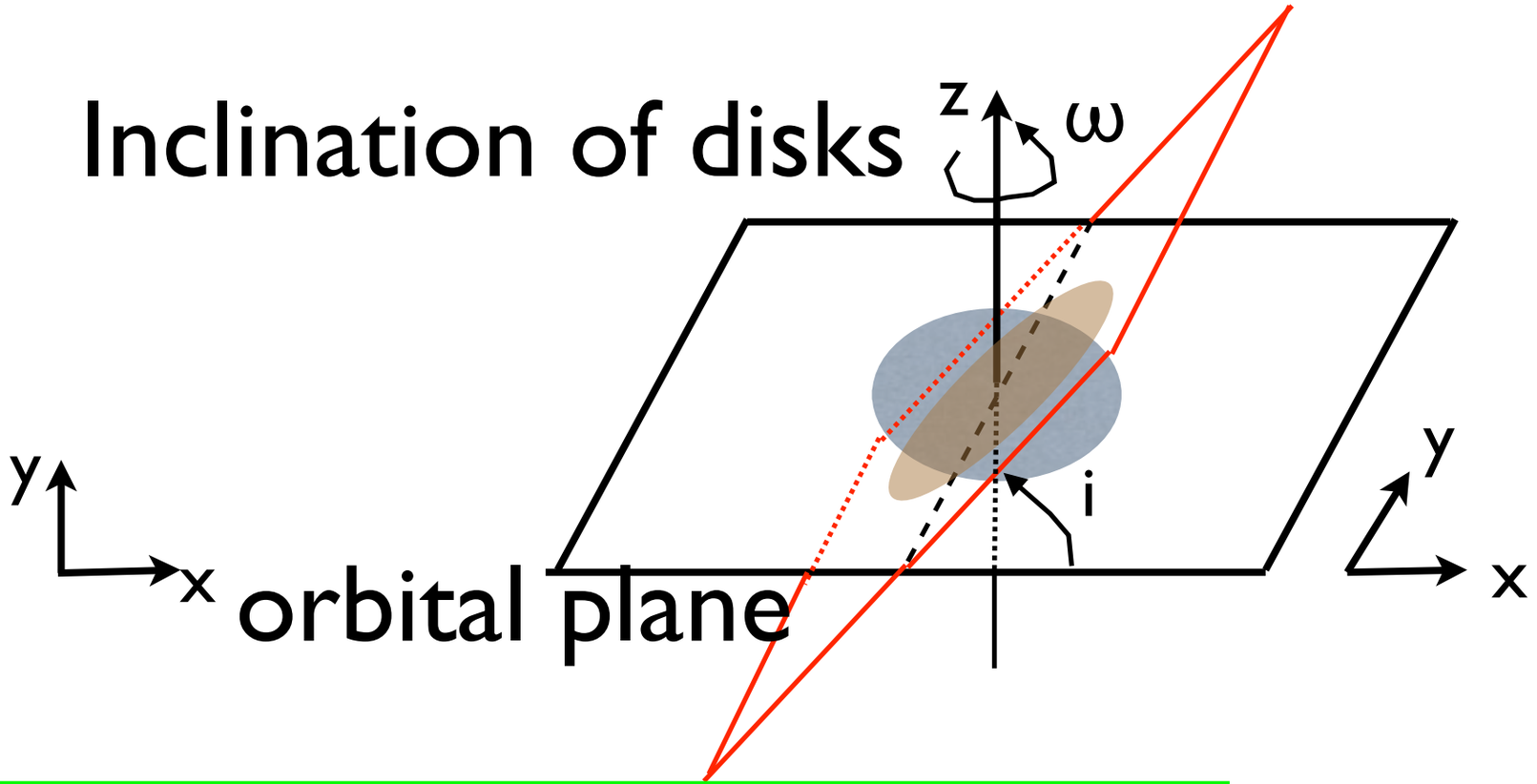
- Particle Number
  - SPH particles : 510,000
  - Old star particles : 1,800,000
  - Dark matter particles : 28,000,000

Collision Geometries

Orbit：Parabolic



Inclination of disks



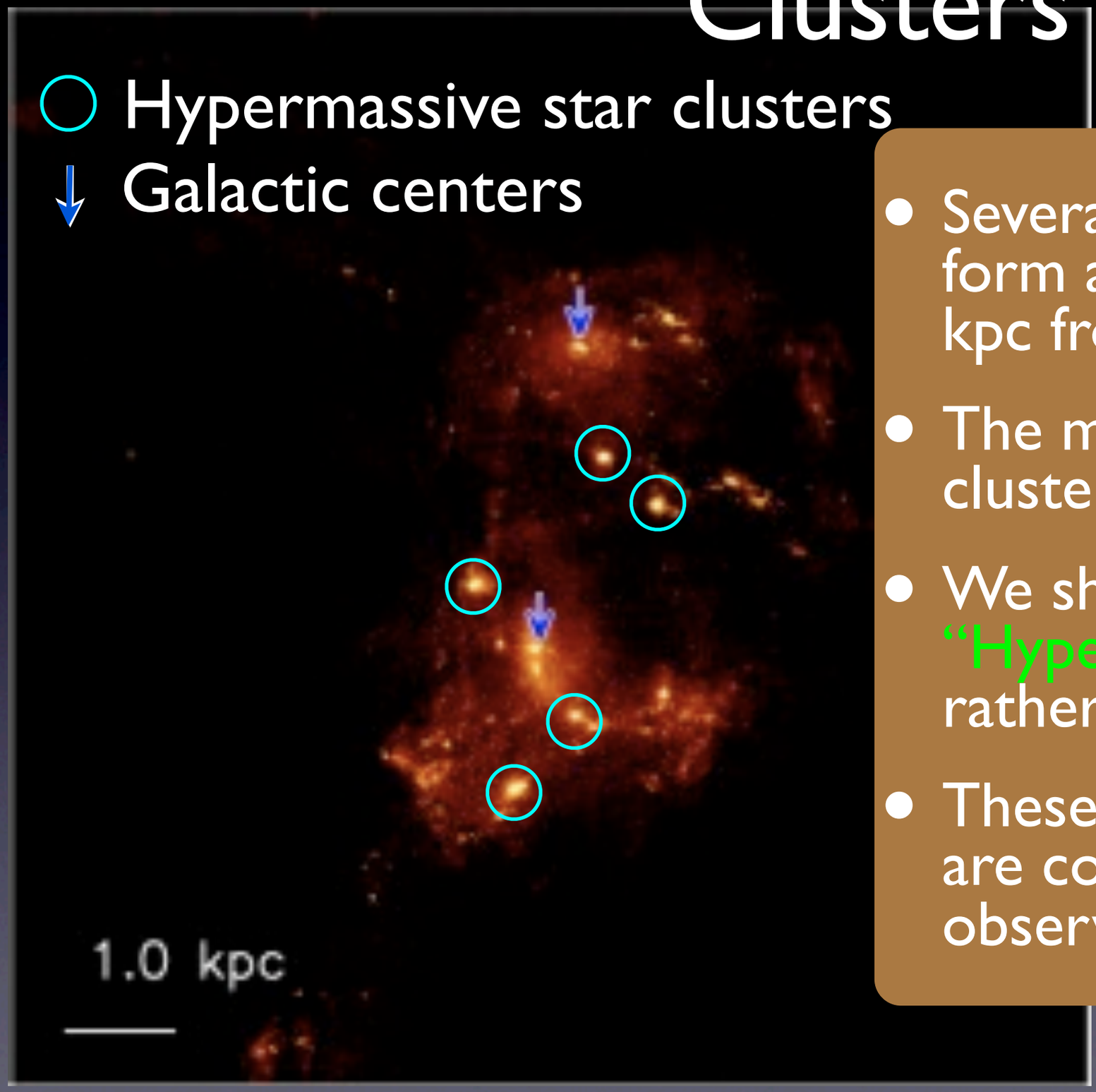
	R_{peri} (kpc)	i_1	ω_1	i_2	ω_2
tilt/tilt	7,5	-109	-30	71	-30

	R_{peri} (kpc)	i_1	ω_1	i_2	ω_2
pro/pro	7,5	0	-	0	-
pro/ret	7,5	0	-	180	-
ret/ret	7,5	180	-	180	-
pro/tilt	7,5	0	-	71	30
tilt/ret	7,5	109	30	180	-
tilt/tilt	7,5	-109	90	71	90

Results

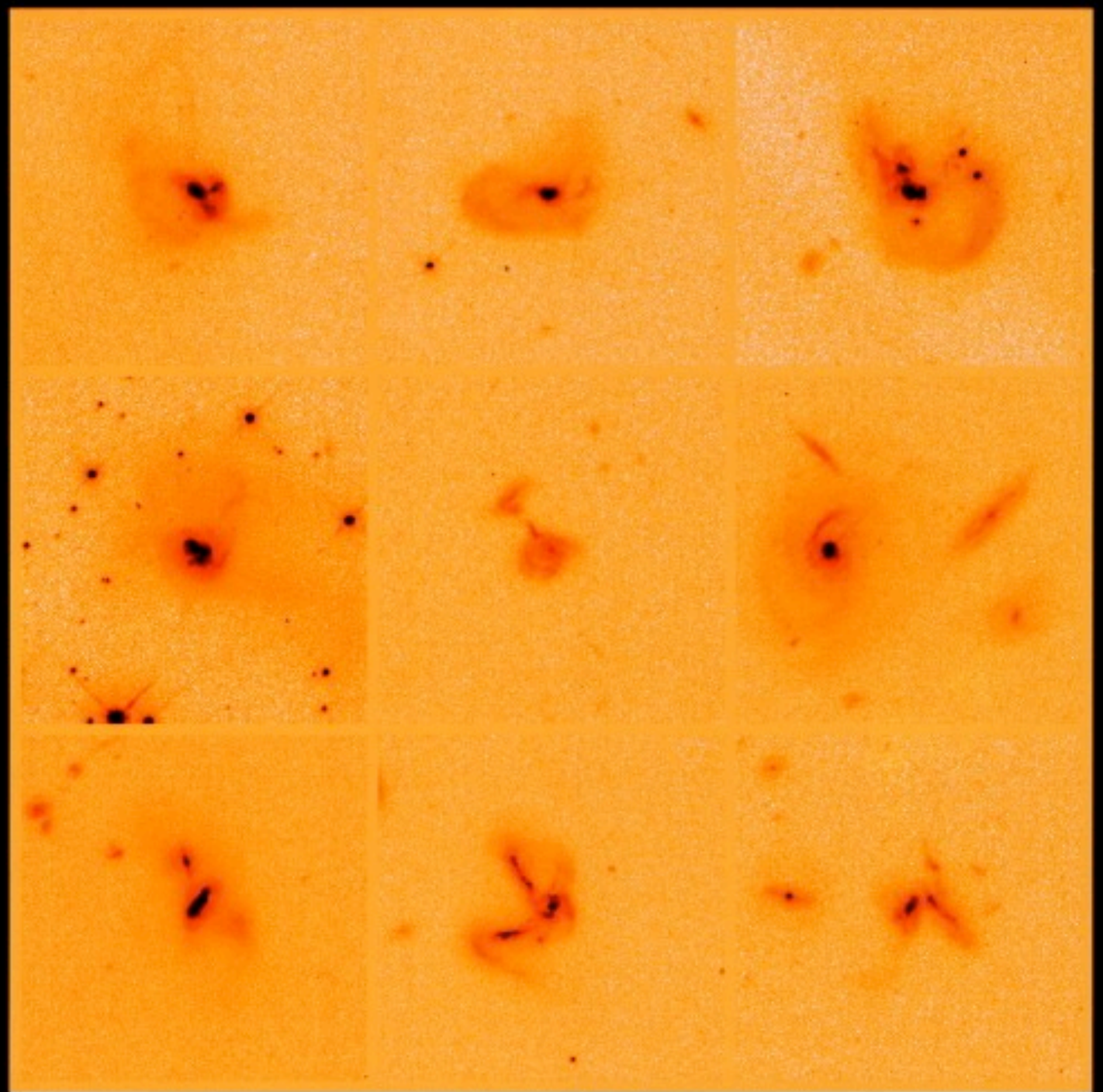
Formations of Hypermassive Star Clusters

○ Hypermassive star clusters
↓ Galactic centers



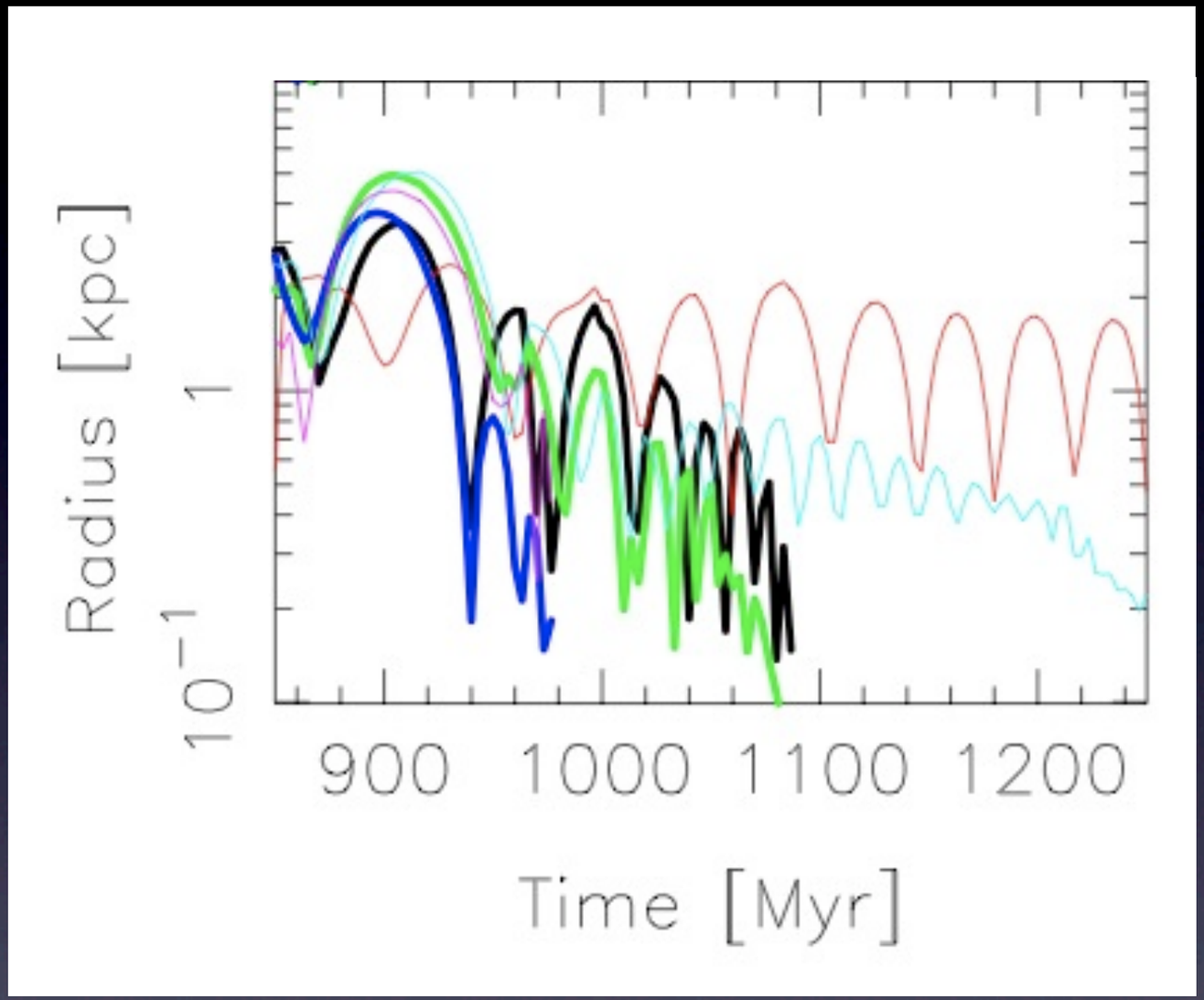
- Several massive star clusters form at the distance of a few kpc from the galactic centers.
- The mass of formed star clusters is about 10^8 Msun.
- We should call them "Hypermassive star clusters" rather than super star clusters.
- These multiple core structures are consistent with ULIRGs observed at z~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?

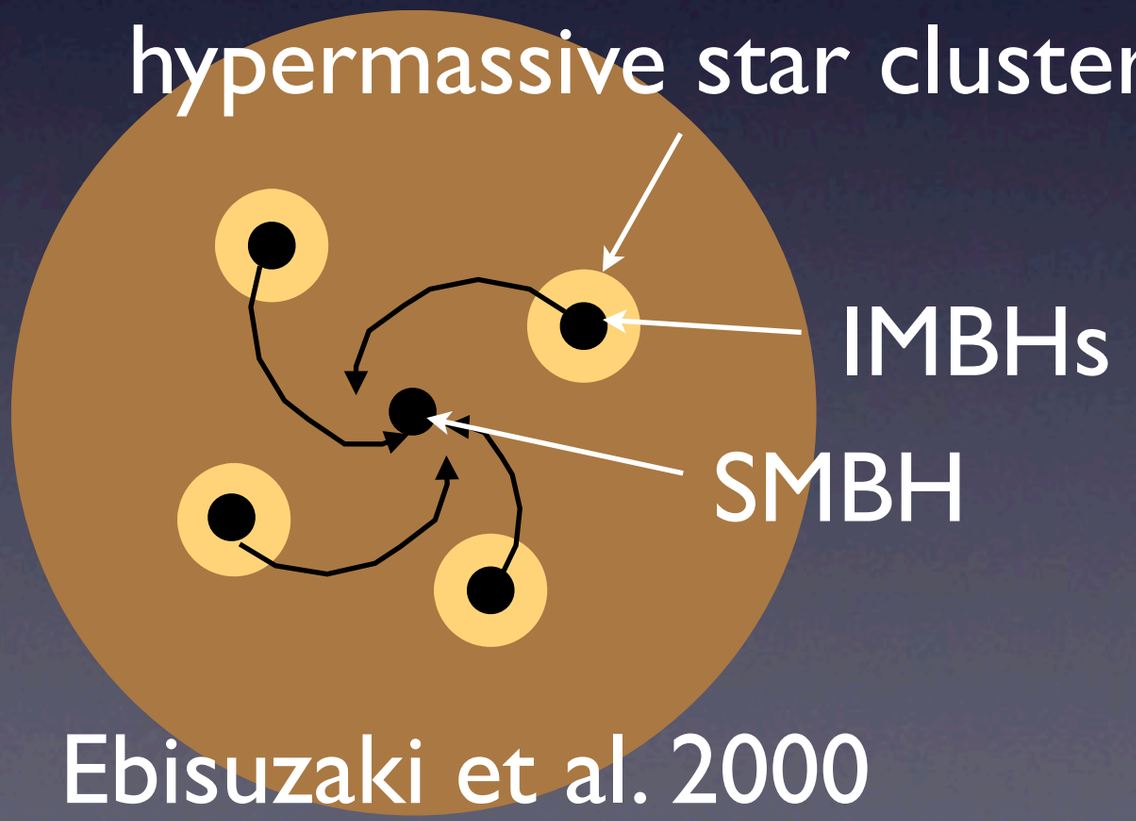
- Hypermassive Star Clusters are compact.
  - Mass: ~ 10^8 Msun
  - Half mass radius: < 20 pc

➡ 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 ~ 7×10^3 Msun, spatial resolution ~ 20 pc,) of galaxy-galaxy merging.
- In the merging process, several hypermassive star clusters (~10^8 M_{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.

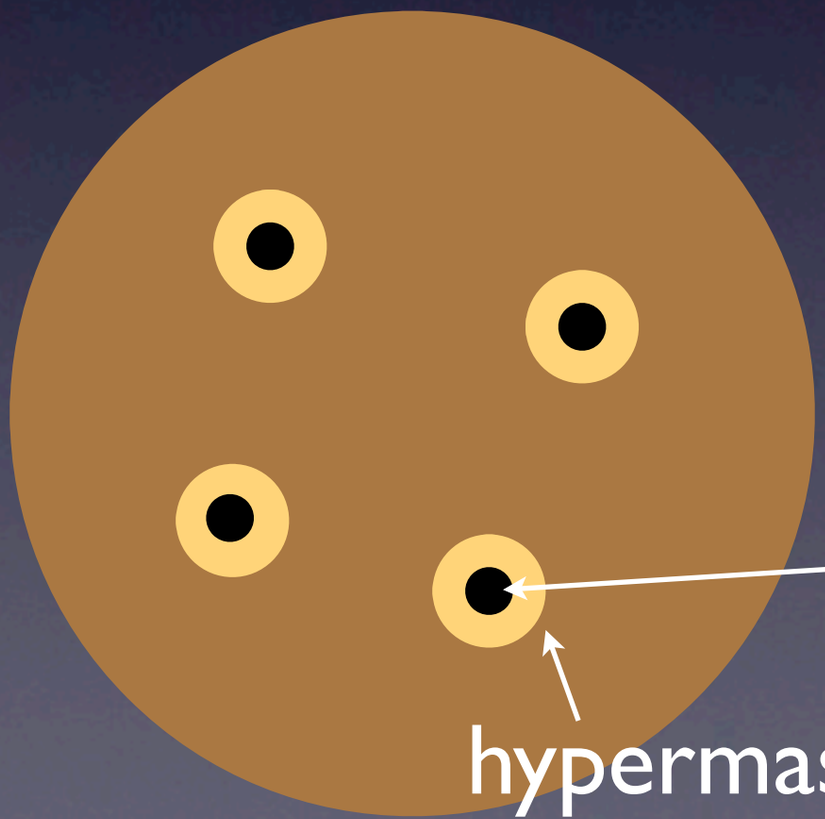
If IMBHs formed in HSCs, they are brought to the GC by the parent cluster and merge with central SMBH. This might be the main growth path SMBHs.

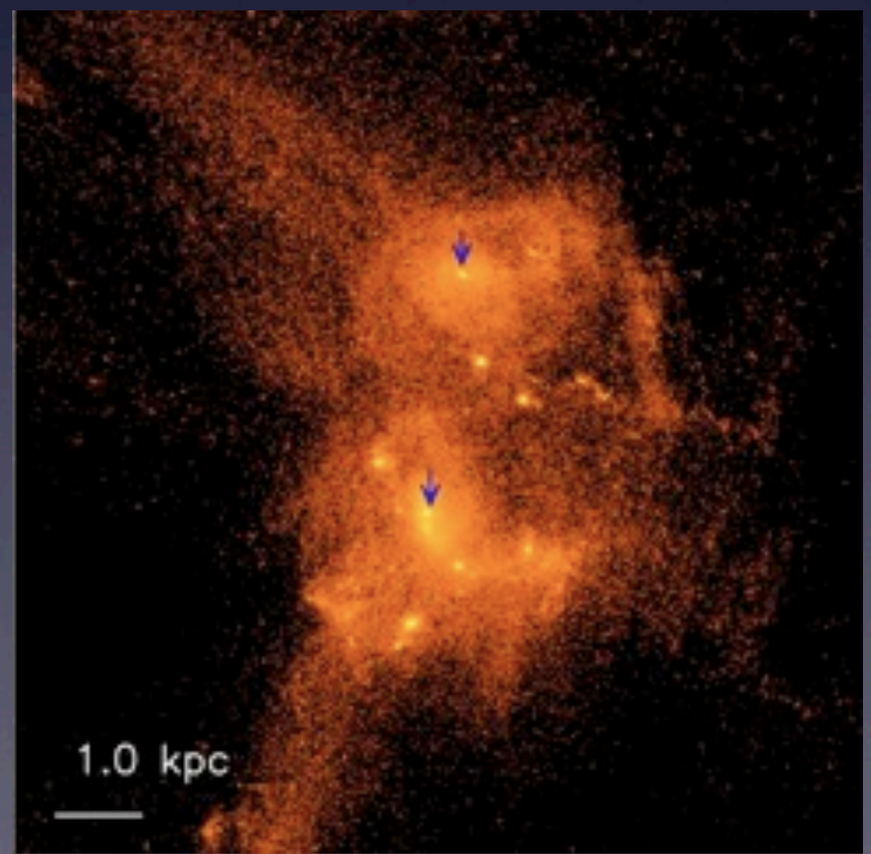
High resolution simulations with multi-phase ISM model are important for understanding merging galaxies and growth of SMBHs.

Formation of IMBHs

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

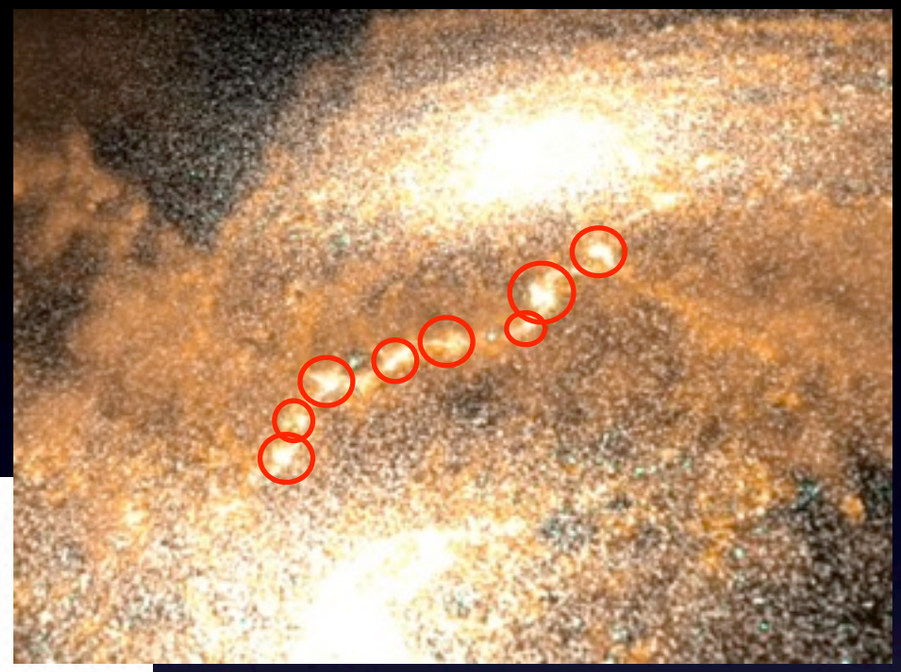
➡Formation of intermediate mass black holes (IMBHs) via runaway collisions of massive stars (Portegies Zwart et al. 2005).



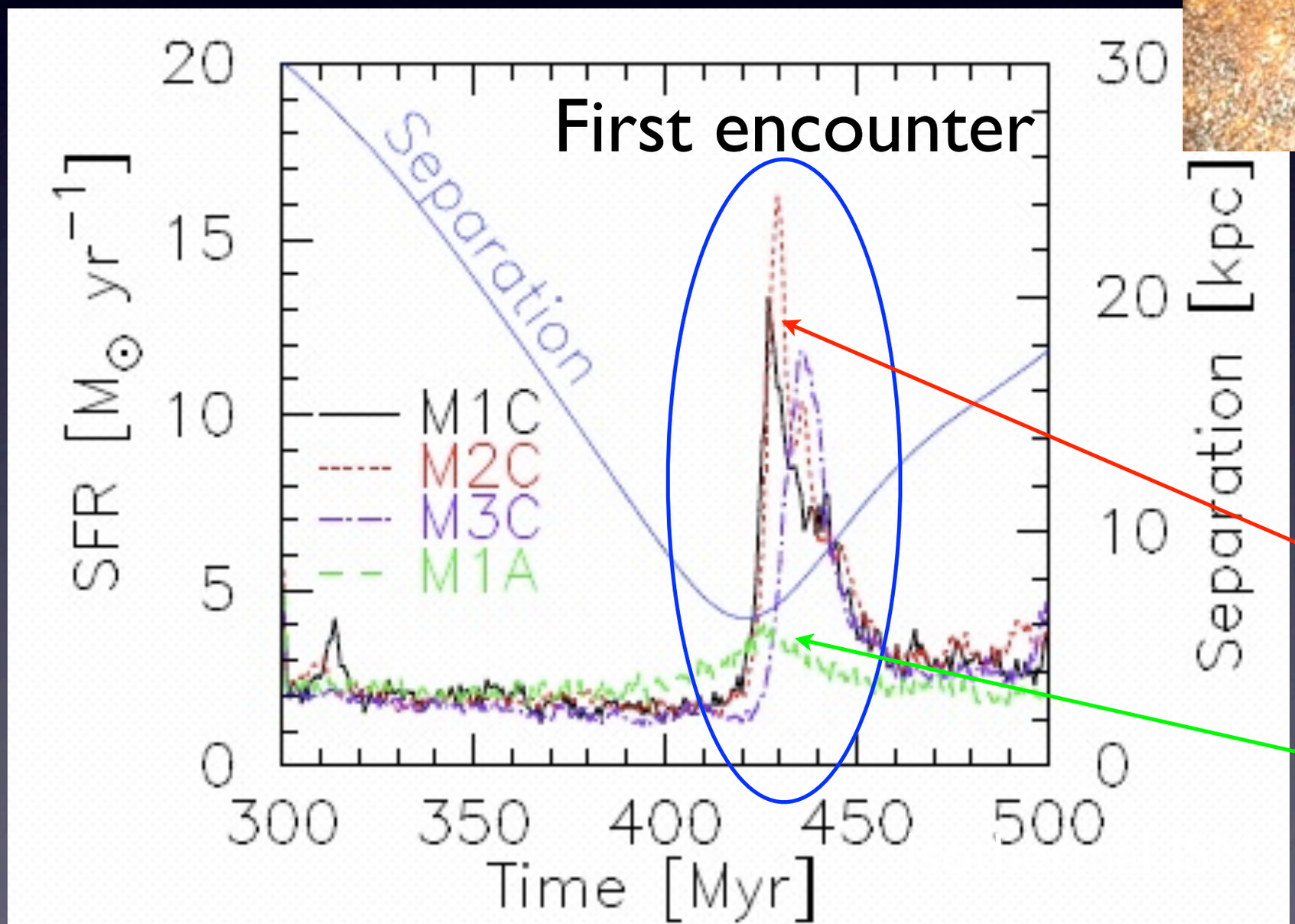


Simulations with Multi-phase Gas (10 K <T < 10^8 K) (Saitoh et al. 2009)

Global dynamics is very "different" with previous simulations.



created by Takeda & Saitoh

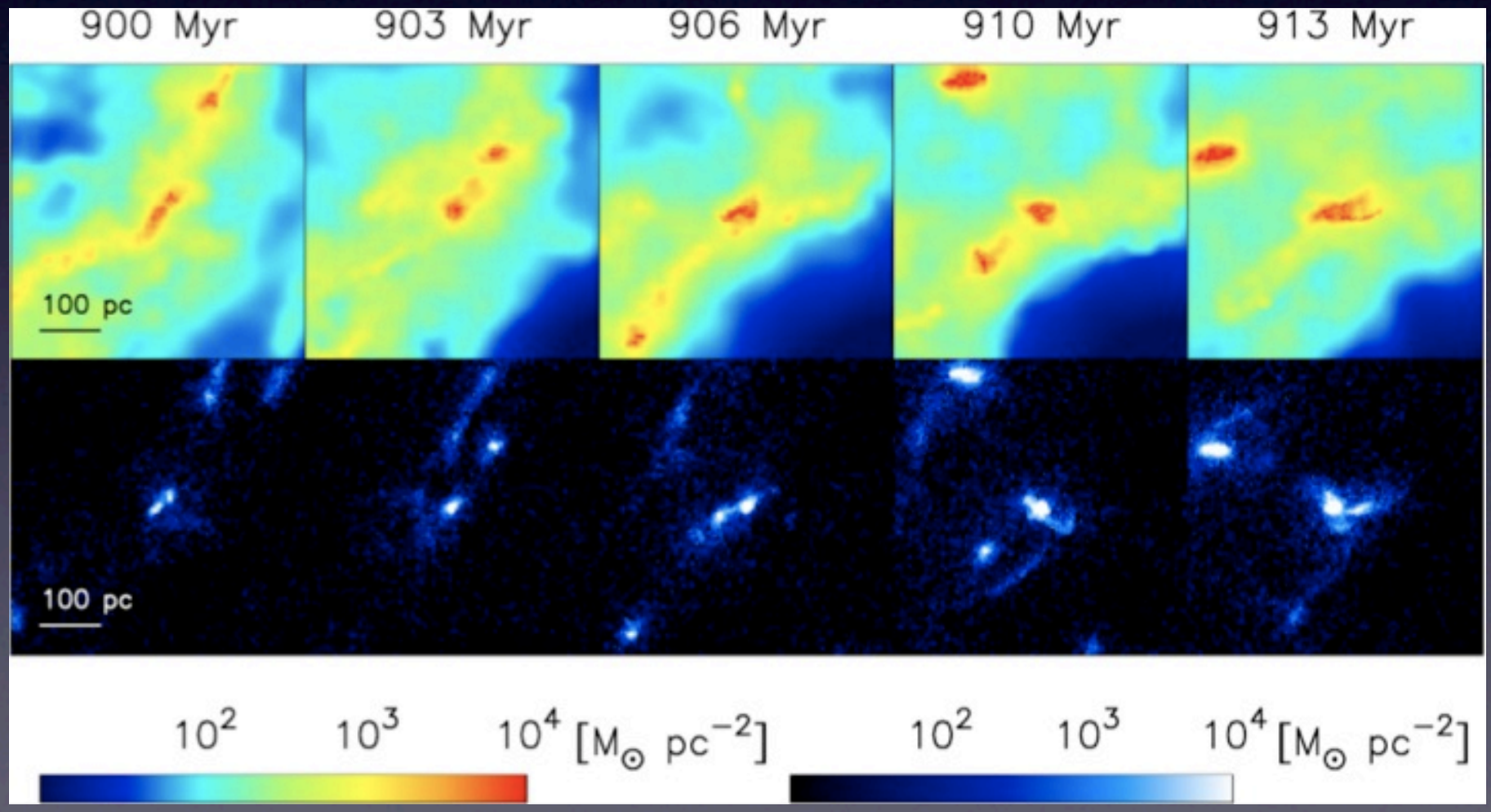


Multiphase Gas Model (10 K <T < 10^8 K)

Isothermal Gas Model (~10^4 K)

Formation Process of Hypermassive star clusters

1. Gas clumps （~10^6 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