The cosmic dance

Unveiling the dynamics of supermassive black holes in cosmological simulations

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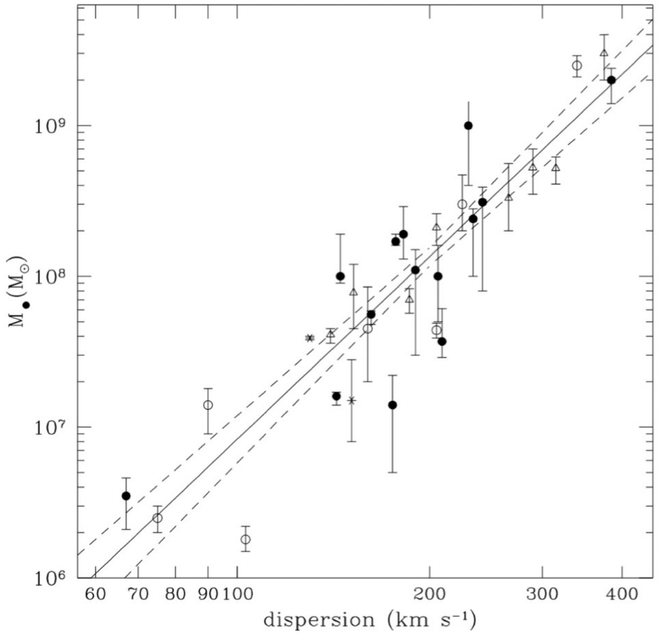
Part I

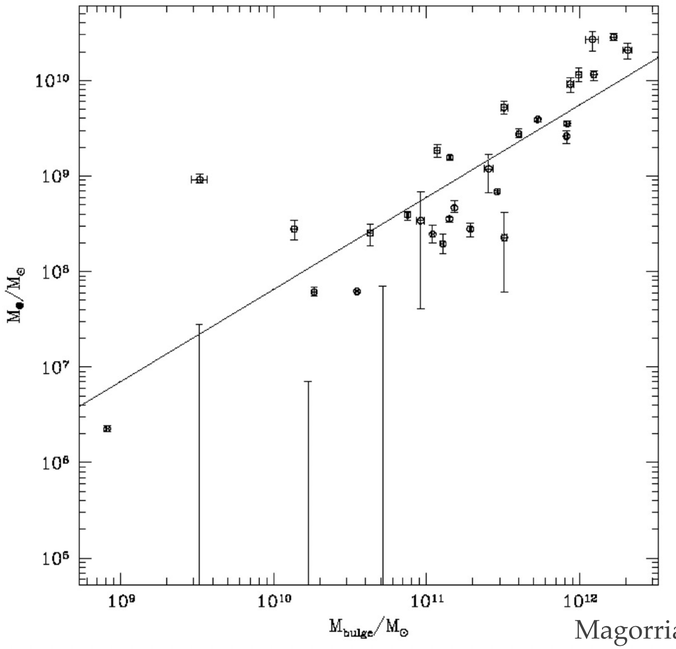
The importance of being a black hole

Active Galactic Nuclei, powered by Supermassive Black Holes, can solve the tension between the hierarchical structure growth and the $downsizingtrend$[1,2].



Tremaine et al.2000

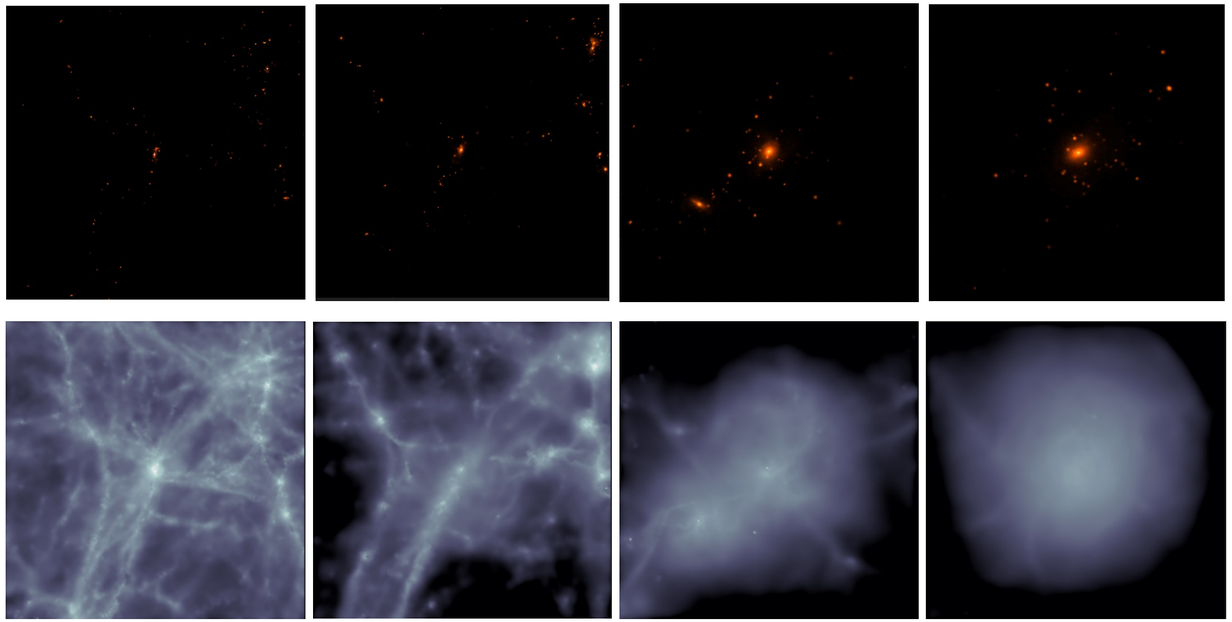
The growth of Supermassive Black Holes and their host galaxy seem to be intertwined, witnessing that BHs play a key role in galaxy evolution[3].



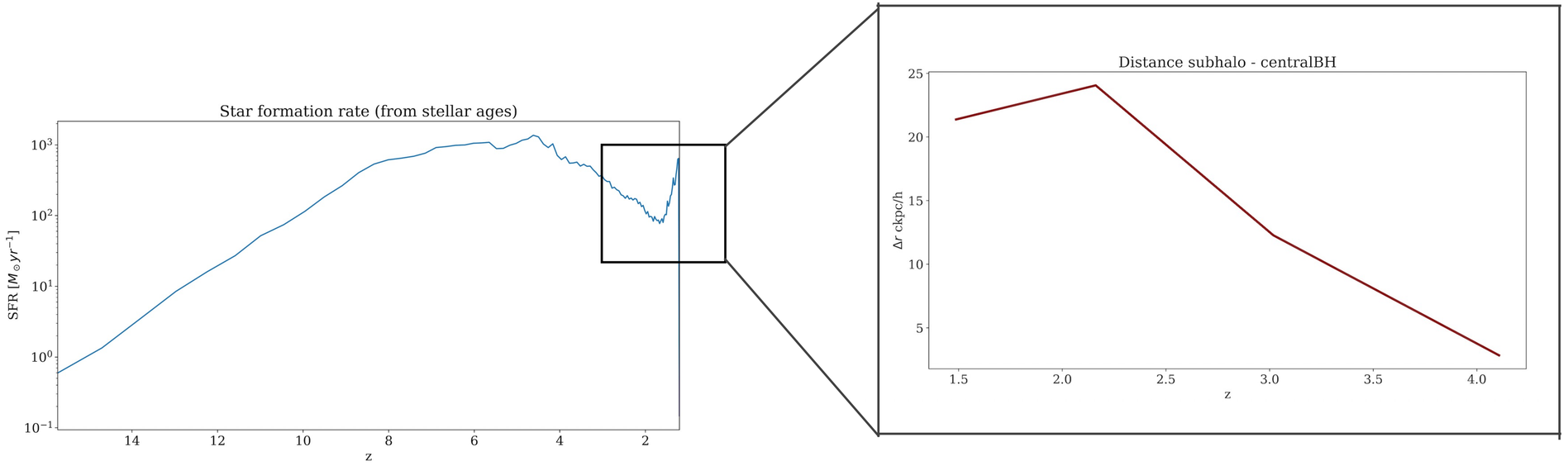
Magorrian 2000

1. Fontanot, F., De Lucia, G., Monaco, P., Somerville, R.S. and Santini, P., 2009. The many manifestations of downsizing: hierarchical galaxy formation models confront observations. *Monthly Notices of the Royal Astronomical Society*, *397*(4), pp.1776-1790
2. Bower, Richard G., et al. "Breaking the hierarchy of galaxy formation." *Monthly Notices of the Royal Astronomical Society* 370.2 (2006): 645-655.
3. Magorrian, John, et al. "The demography of massive dark objects in galaxy centers." *The Astronomical Journal* 115.6 (1998): 2285.

Part I How it all started



Zoom-in simulations of galaxy clusters belonging to the DIANOGA set using the lagrangian OpenGadget3 code (TreePM-SPH).



Part II

Dealing with black holes in cosmological simulations

Solve the dynamics of a collision less self-gravitating fluid by sampling the fluid with discrete tracer particles. The evolution of the fluid is then obtained by integrating their equation of motion in the collective gravitational field.

Due to the *sampling in mass*, simulations cannot be able to reproduce the dynamics of single particles.

The computation of the gravitational interactions is correct only above the *softening length*. In cosmological simulations it often relies on approximate methods.

$$\Phi(\vec{r_i}) = \sum_j \frac{G m_j}{(|\vec{r_i} - \vec{r_j}|^2 + \epsilon^2)^{1/2}}$$

One major obstacle is that becomes necessary to accurately follow the dynamics of one single object, the black hole, something that simulations with force resolution larger than a few pc are inherently not well equipped to do.

Tremmel, Michael, et al. "Off the beaten path: a new approach to realistically model the orbital decay of supermassive black holes in galaxy formation simulations." *Monthly Notices of the Royal Astronomical Society* 451.2 (2015): 1868-1874.

Part II

Black hole mergers

The two galaxies merge

HST image of NGC5331

The pairing phase is dominated by dynamical friction

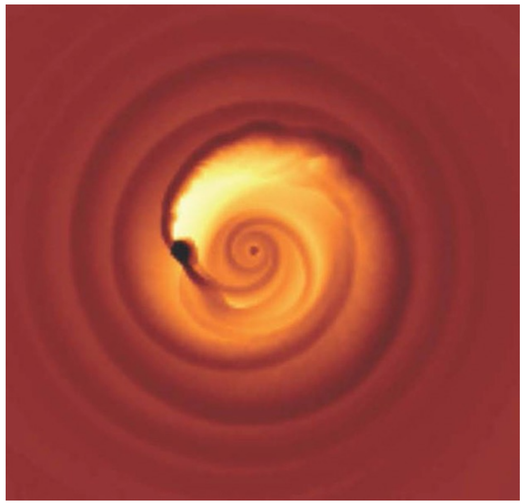


Image credit: Columbia University

Stellar hardening and GW emission drive the last stages

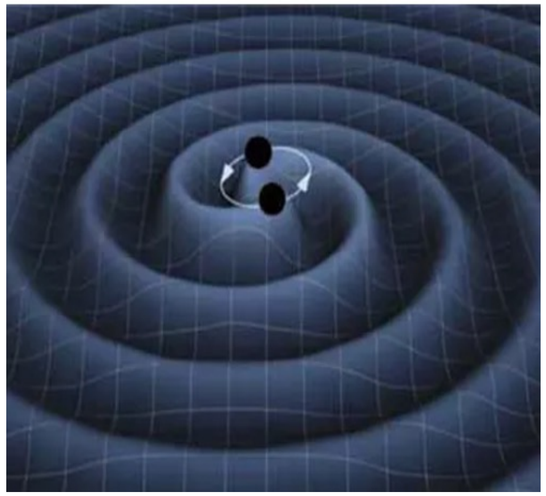


Image credit: K. Thorne (Caltech) and T. Carnahan (NASA GSFC)

$\sim 100kpc$ $\sim 10kpc$ $\sim 10pc$

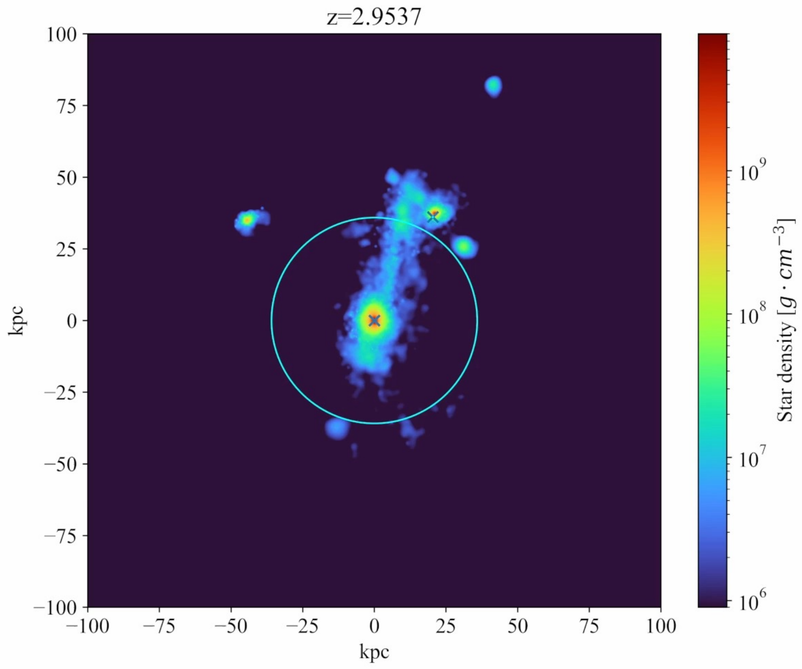
Cosmological simulations

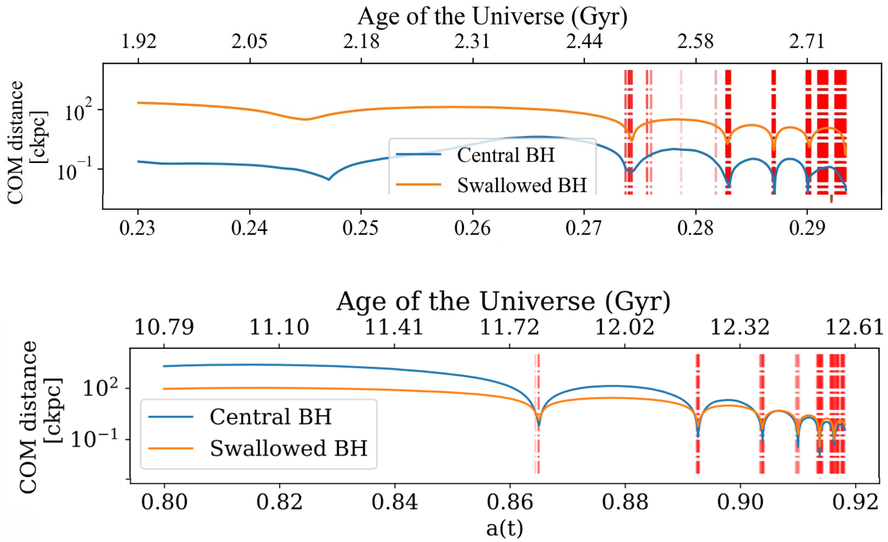
Part II

Introducing dynamical friction: our new prescription

The recipe

Add a correction to the gravitational interactions under the softening length to account for the unresolved dynamical friction force.

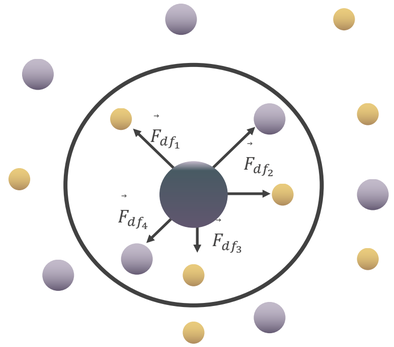




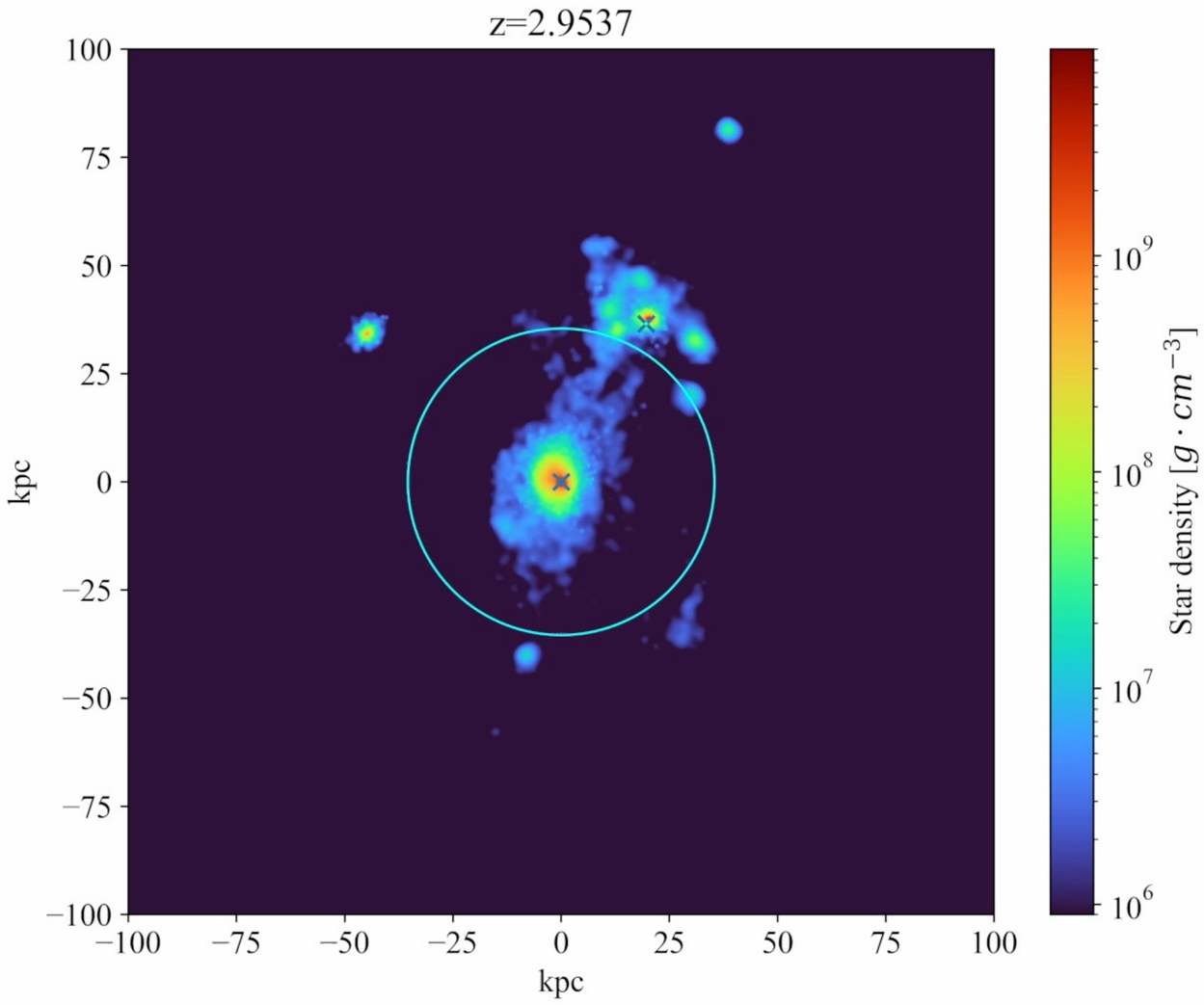
How it works

Every particle at a distance $< h_s$ adds a contribution that depends on its mass and its relative velocity.

$$\vec{F}_{BH} = \vec{F}_g + \sum_{i}^{N(<h_s)} \vec{F}_{df_i}(\vec{v}_{rel_i}, m_i)$$



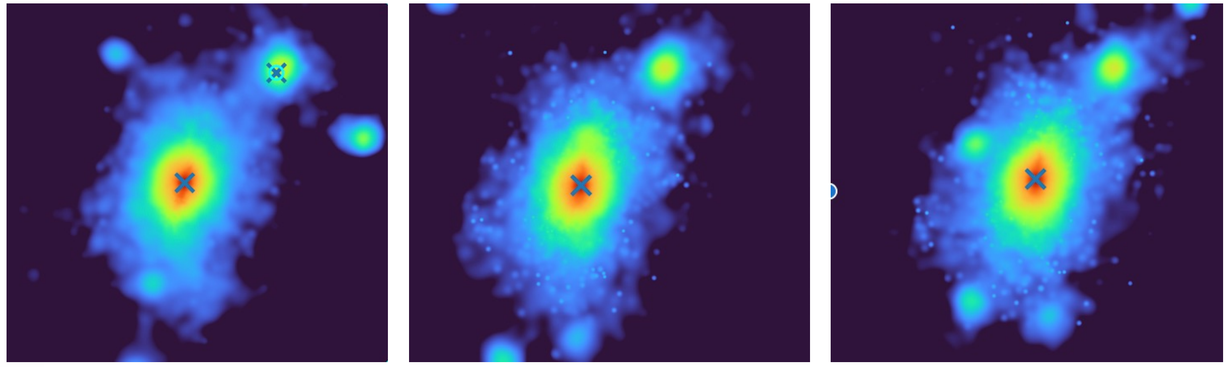
Part III Comparing with other implementations: the pinning prescription



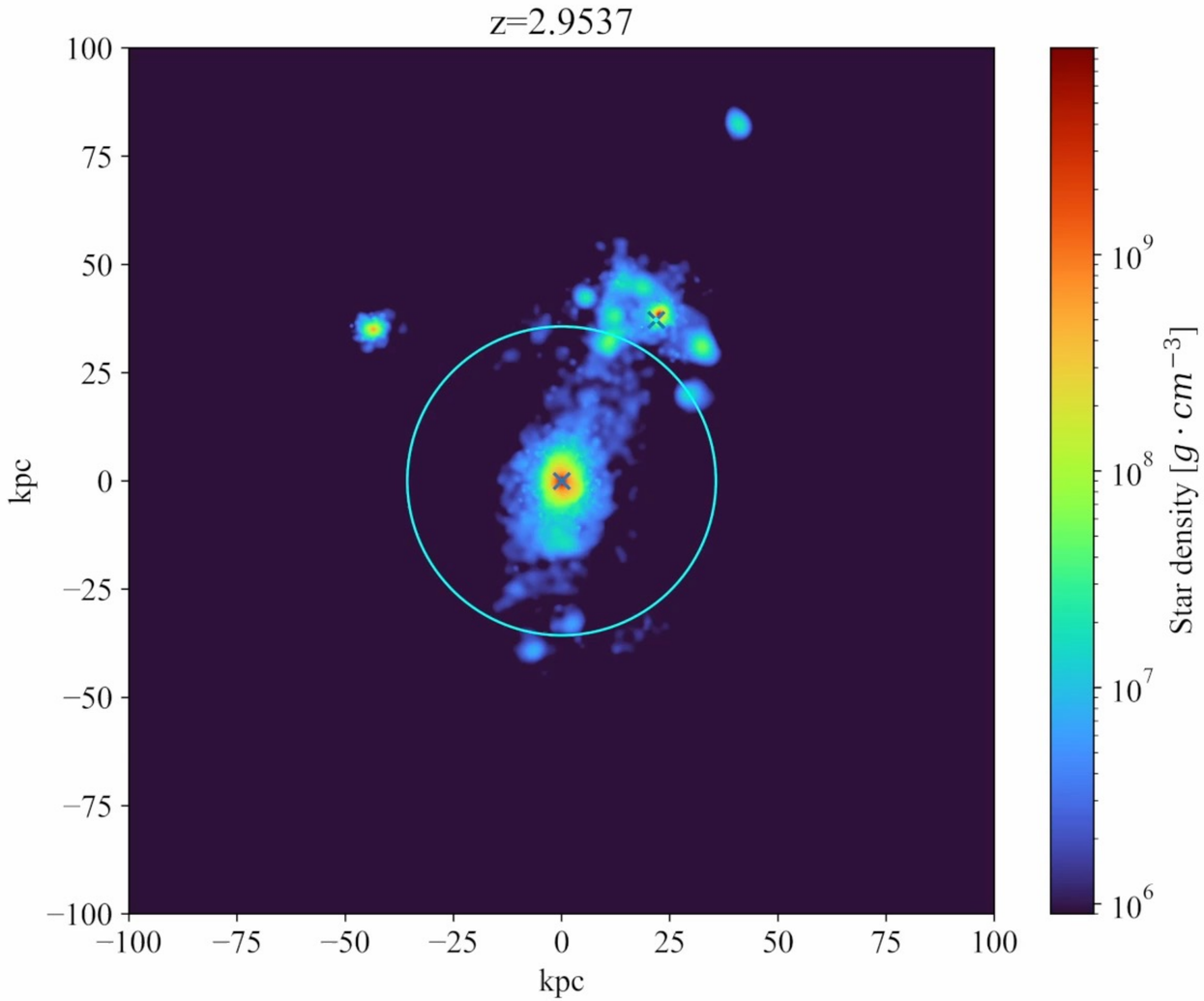
The recipe

Re-position the black hole in the position of the neighbour star particle having the minimum potential.

- The black holes are well centered into the hosting galaxies
- The merger events are extremely fast
- The dynamics of merger is not reproduced



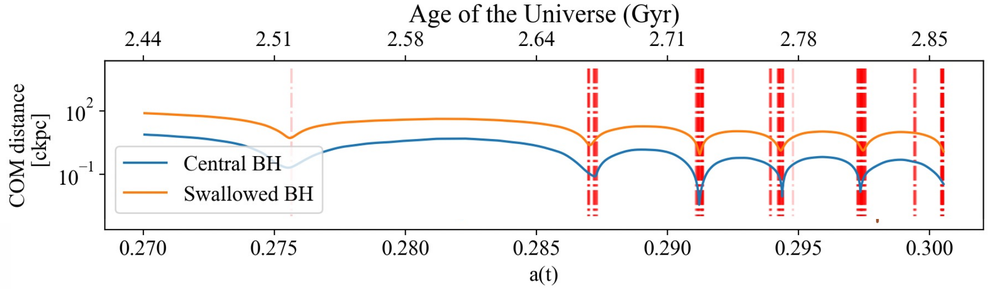
Part III Comparing with other implementations: the dynamical mass

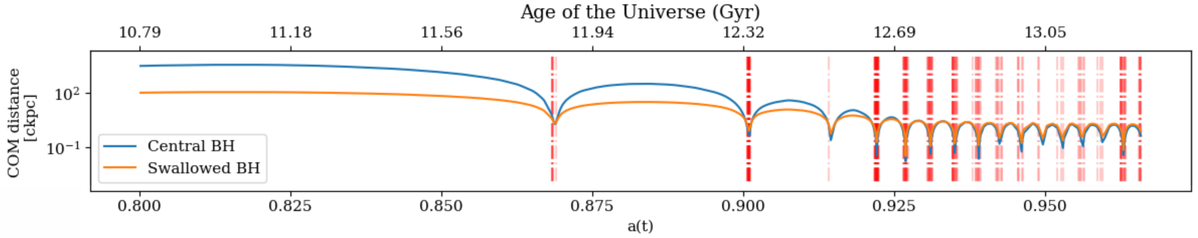


The recipe

The black hole particles have a second artificial boosted mass which account for gravitational interactions.

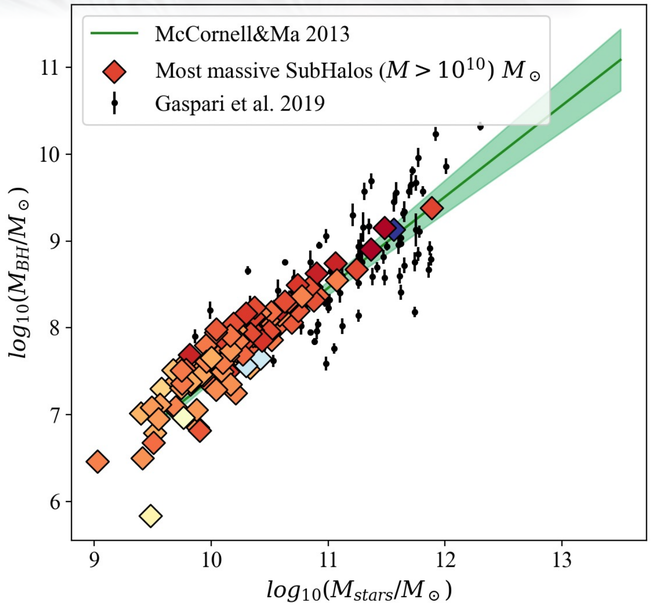
- Improves the modelization of the merger event
- Does not reproduce the loss of angular momentum shrinking the orbits of the merging black holes



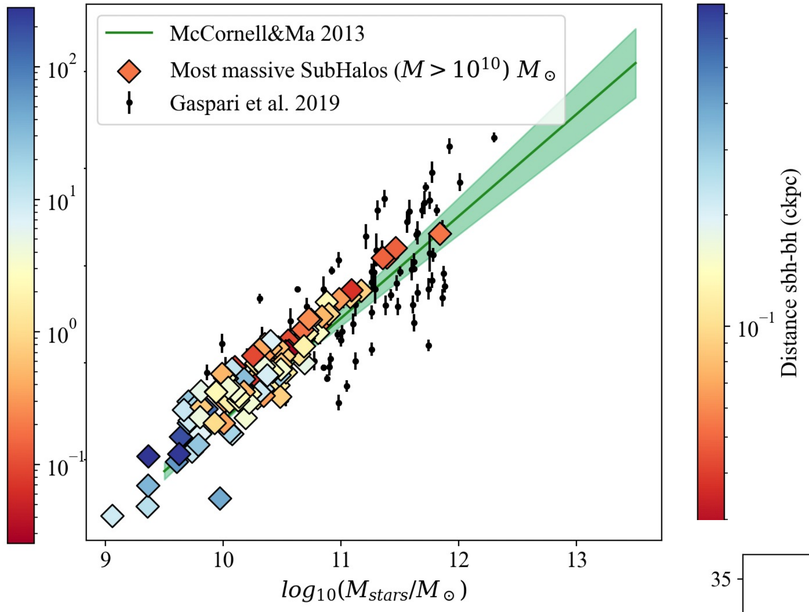


Part III Some results

Dynamical mass

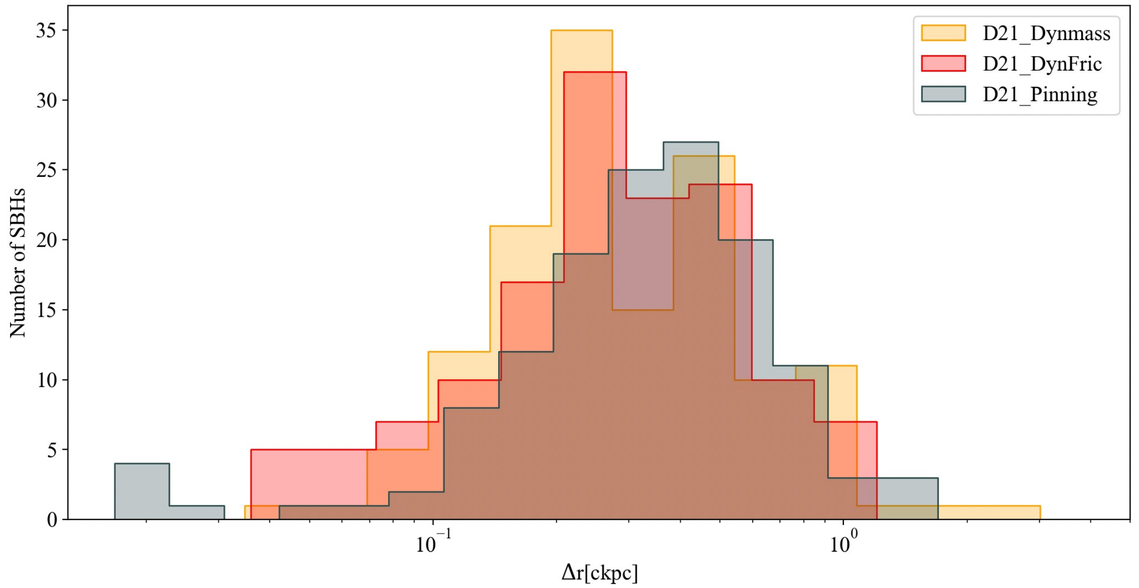


Dynamical friction

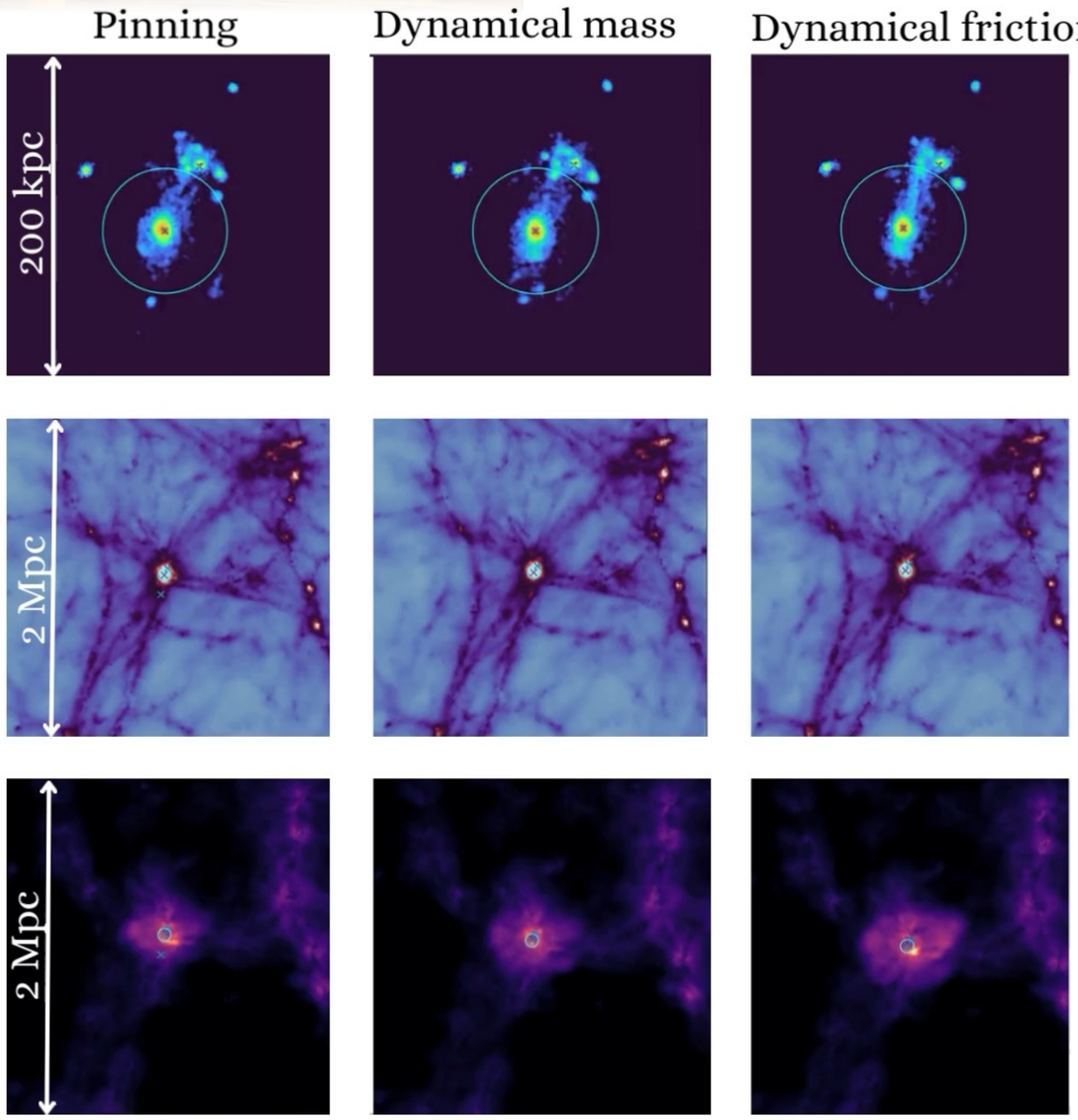


- Magorrian relation reproduced
- Decrease of SBH-BH distance
- No massive SBH without a central BH
- The wandering population decrease at lower redshift

The new implementation both centers the BHs and is capable to describe the dynamics of the merger event.



Current and future perspectives



Higher resolution galaxy cluster simulations to investigate the role of this new recipe on the AGN activity and galaxy population.

Study of the effect of the merging histories on higher-redshift protocluster regions.

Cosmological simulations to investigate the merger rate, the black hole mass function and predictions for PTA, LISA.

Part IV Not only physics

Running the code

The new implementation does not require the computation of the local potential of particles, neither requires SUBFIND running on the fly. As a result, it slightly reduces the computational cost of the simulations:

	Code speed-up
Dynamical mass	2.2%
Pinning	3.5%

Data analysis

On-going project: a GUI platform to study the role of SMBHs into the simulations including informations about mergers, BH growth, AGN feedback