# The Early Growth of Supermassive Black Holes in Cosmological Simulations:
## The Role of Advection

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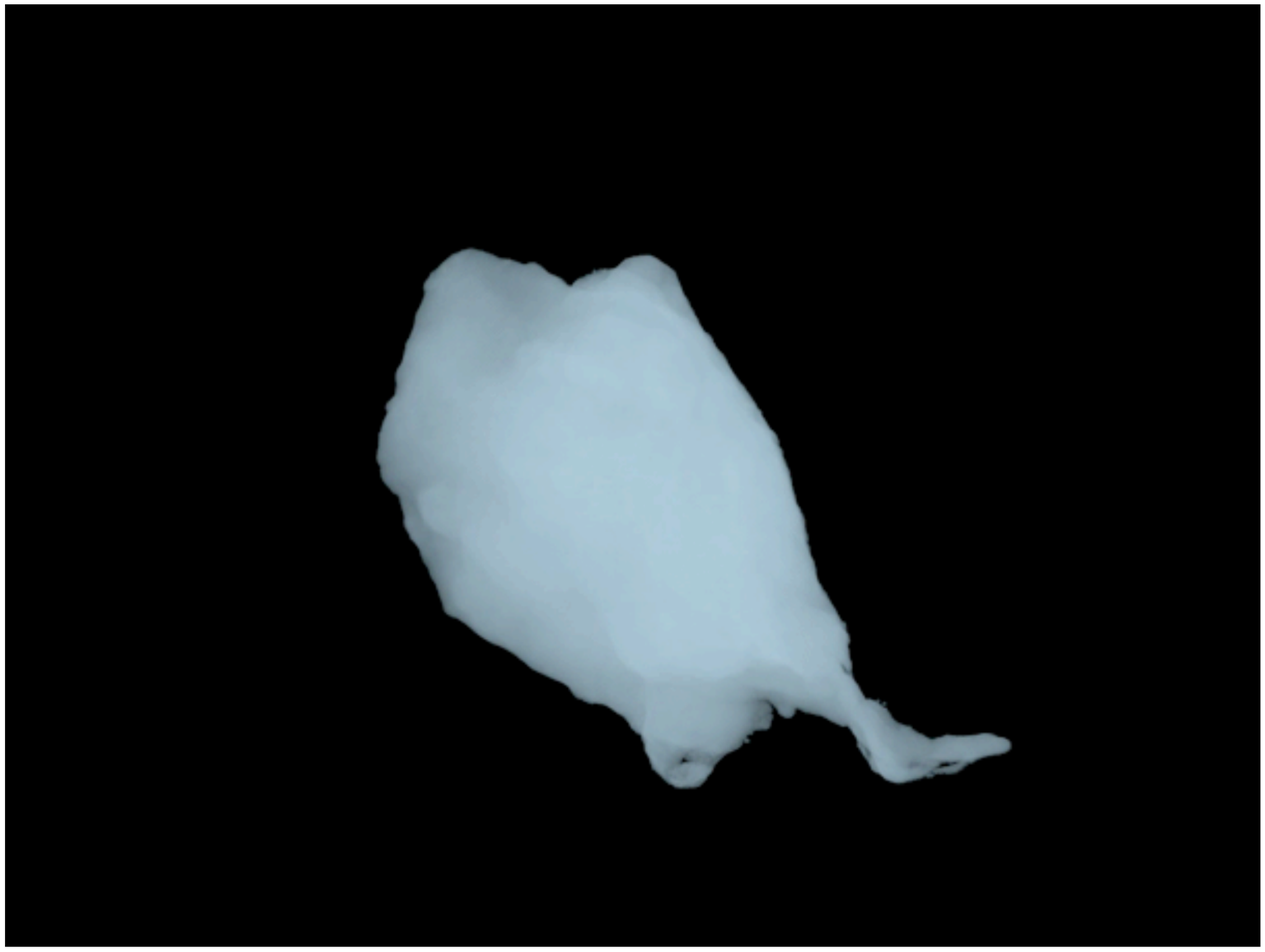
# Why Cosmological Simulations?

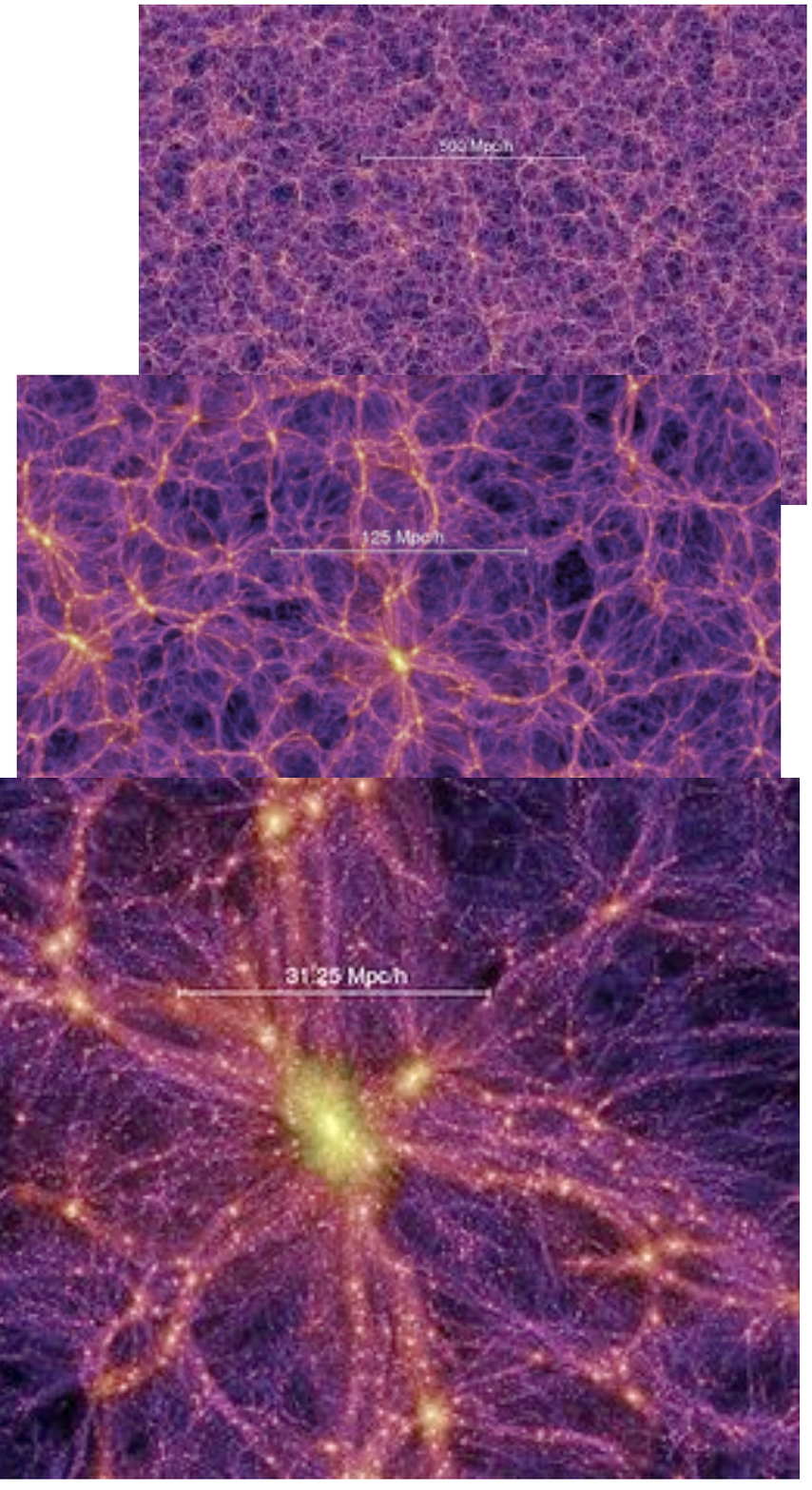
- Cosmological simulations allow us to model the environment in which a galaxy is evolving
  - Merger history
  - Gas accretion
  - Large scale gravitational torques
- *Need to simulate galaxies in a cosmological context if we want to understand the growth of SMBHs*



credit: Fabio Governato

# The Challenges of Modeling Black Holes

- Cosmological Volumes must model processes on a very large range of scales
- The Black Hole/Accretion Disk system will not be resolved
- All that physics must be inserted as analytical prescriptions and "Free" sub-grid parameters




Millennium Simulation

# The Challenges of Modeling Black Holes

- Formation of black hole seeds
    - Where, when, at what mass?
- Accretion Rate
    - Unresolved on cosmological simulation scales
- AGN Feedback
    - How do black holes radiate energy? How does this energy get coupled to surrounding gas?
- BH tracking (i.e. advection)

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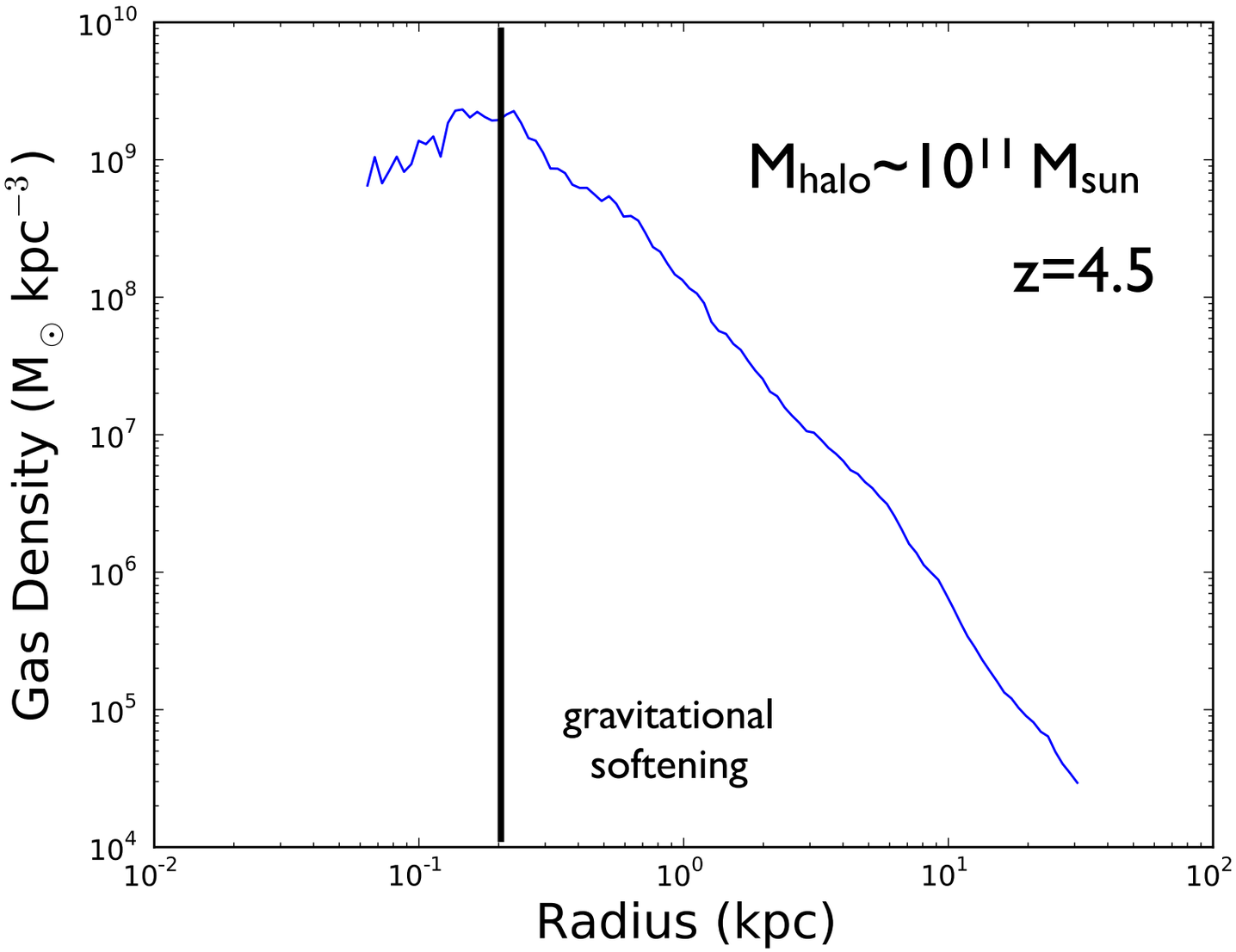
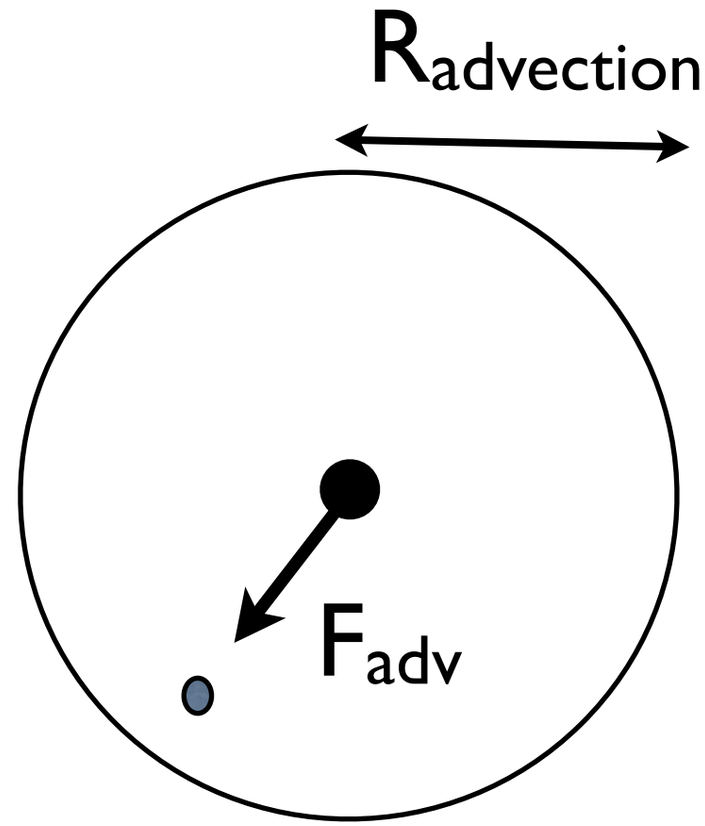
# The Challenges of Modeling Black Holes

- BH Tracking: The Problem
  - BH accretion sensitive to position
  - Dynamical heating caused by low resolution
  - Inefficient dynamical friction when particles are too similar in mass to BH mass



# The Challenges of Modeling Black Holes

- Different Advection Methods
  - Provide "advection force" in direction of
    - center of mass (Wurster & Thacker 2013, Okamoto et. al. 2008)
    - gas particle at the deepest potential (e.g. Springel et. al. 2005, Booth & Schaye 2009)
  - Force BH to have a high *dynamical* mass (Debuhr et. al. 2011)

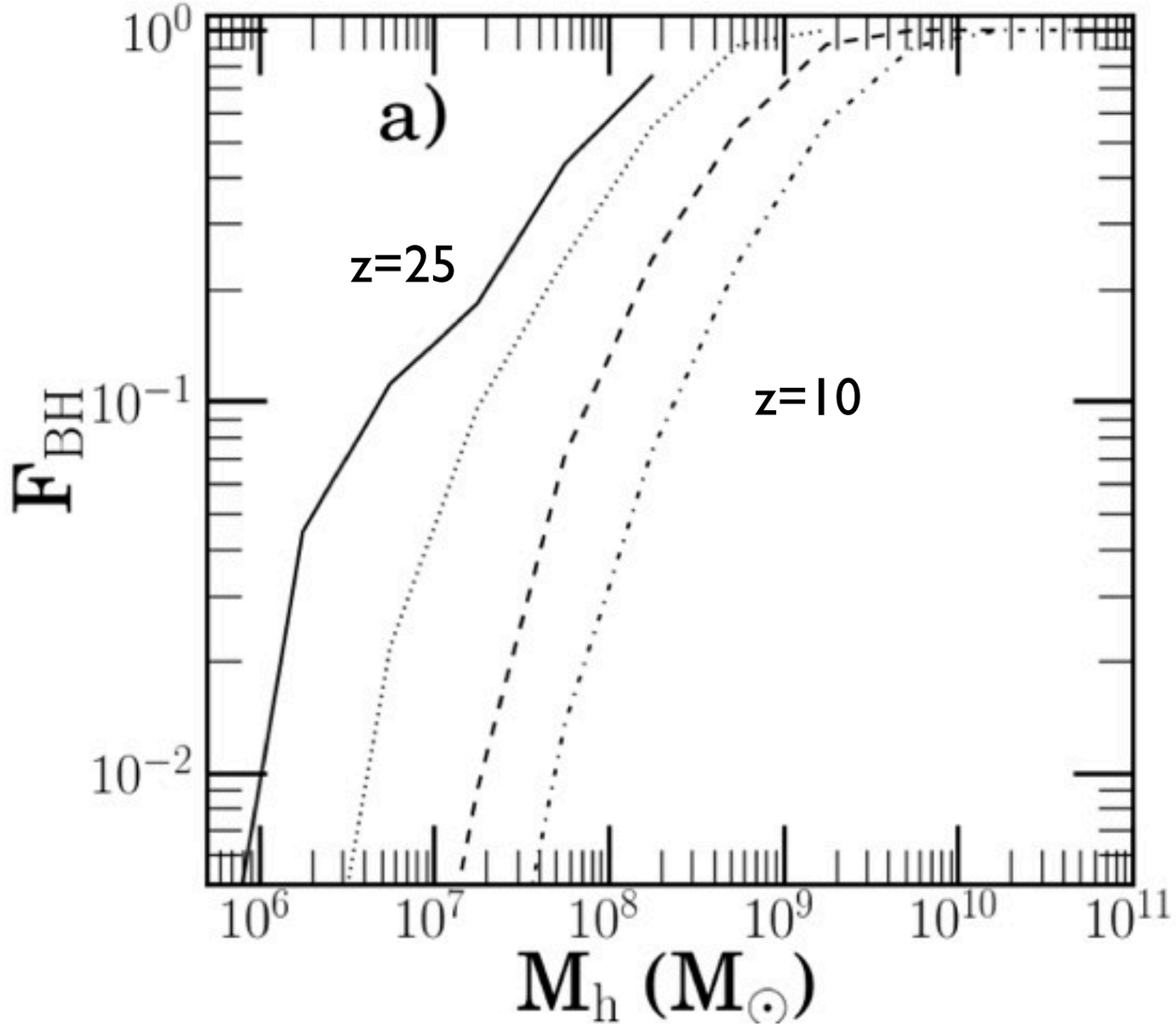


# Do We *Want* Advection?

- Disadvantages to Advection Methods
  - Artificial force can cause small, chaotic motions (Wurster & Thacker 2013)
  - Coupling to gas particles means the BH cannot exist in a void
  - Large dynamical masses affect the dynamics of the galaxy as well (Wurster & Thacker 2013)

# Do We *Want* Advection?

- Should we assume BHs always stay in the center of their halos?
  - Few dwarf galaxies found to host AGN
  - DM halos do not have a constant DM profile
    (Pontzen & Governato 2013)
  - DM profiles of small halos are highly cored
    (Governato et. al. 2010)
  - BHs can form in small halos in high density, dynamically interesting regions




Devecchi, Volonteri, et. al. 2012

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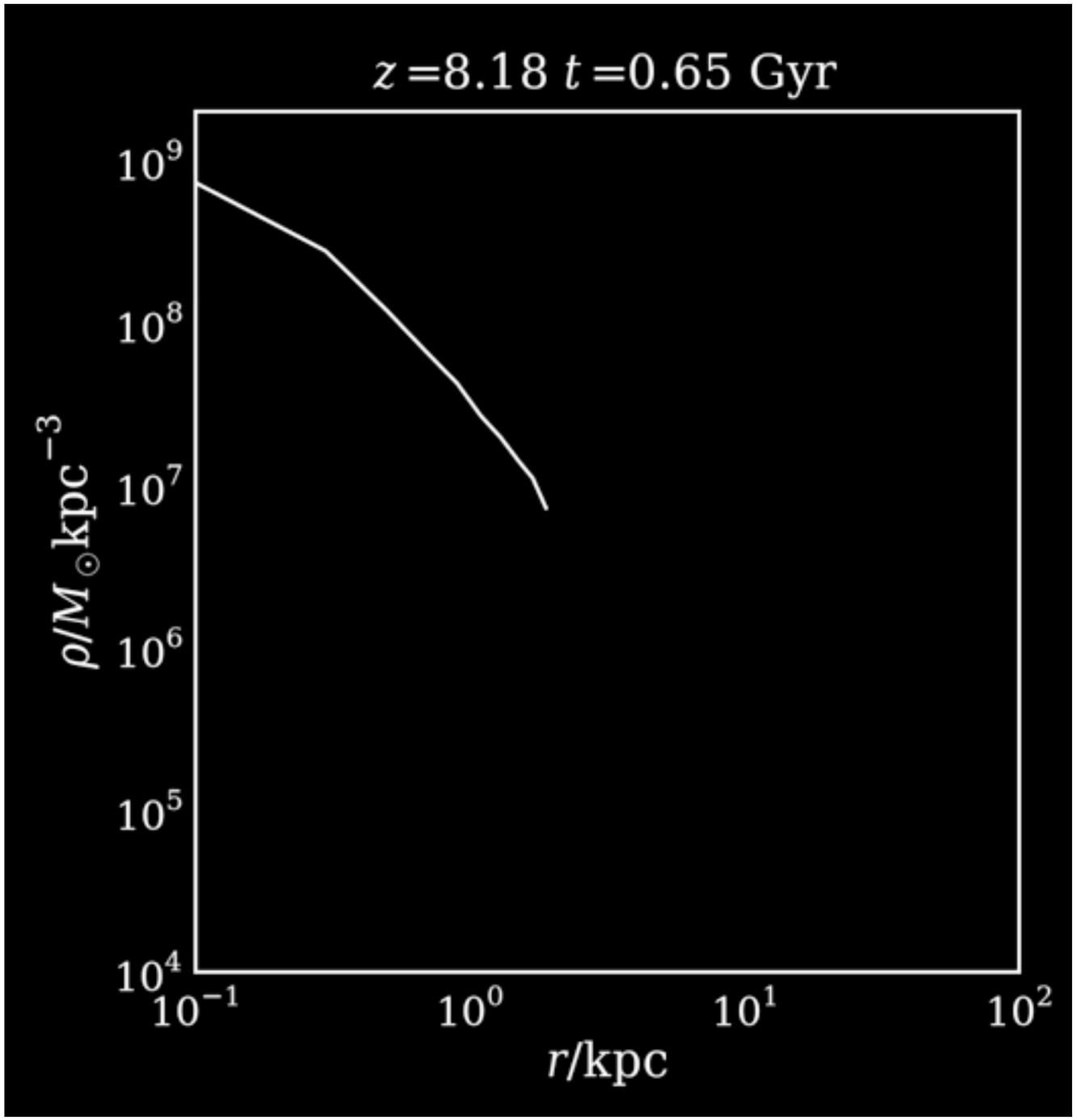
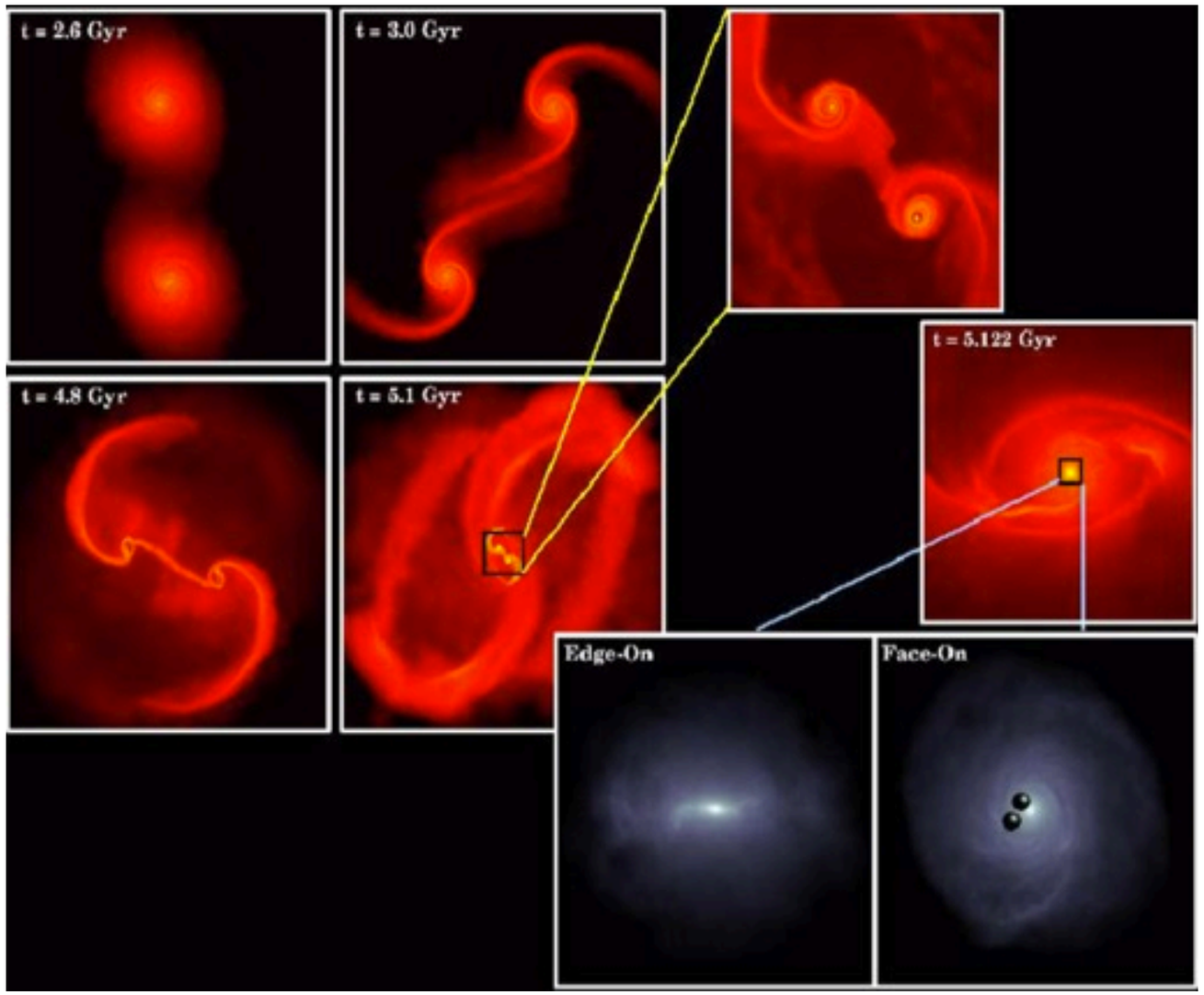


# Do We *Need* Advection?

- Unnecessary for high enough resolution simulations (e.g. Mayer et. al. 2007)
- Test Model: BH in an NFW halo with:
  - $M_{vir} = 10^{10} M_{sun}$
  - $M_{BH} = 10^{6} M_{sun}$
  - BH initially at the center (0,0,0)
  - $M_{DM} \sim 7 \times 10^{5} M_{sun}$ (low res)

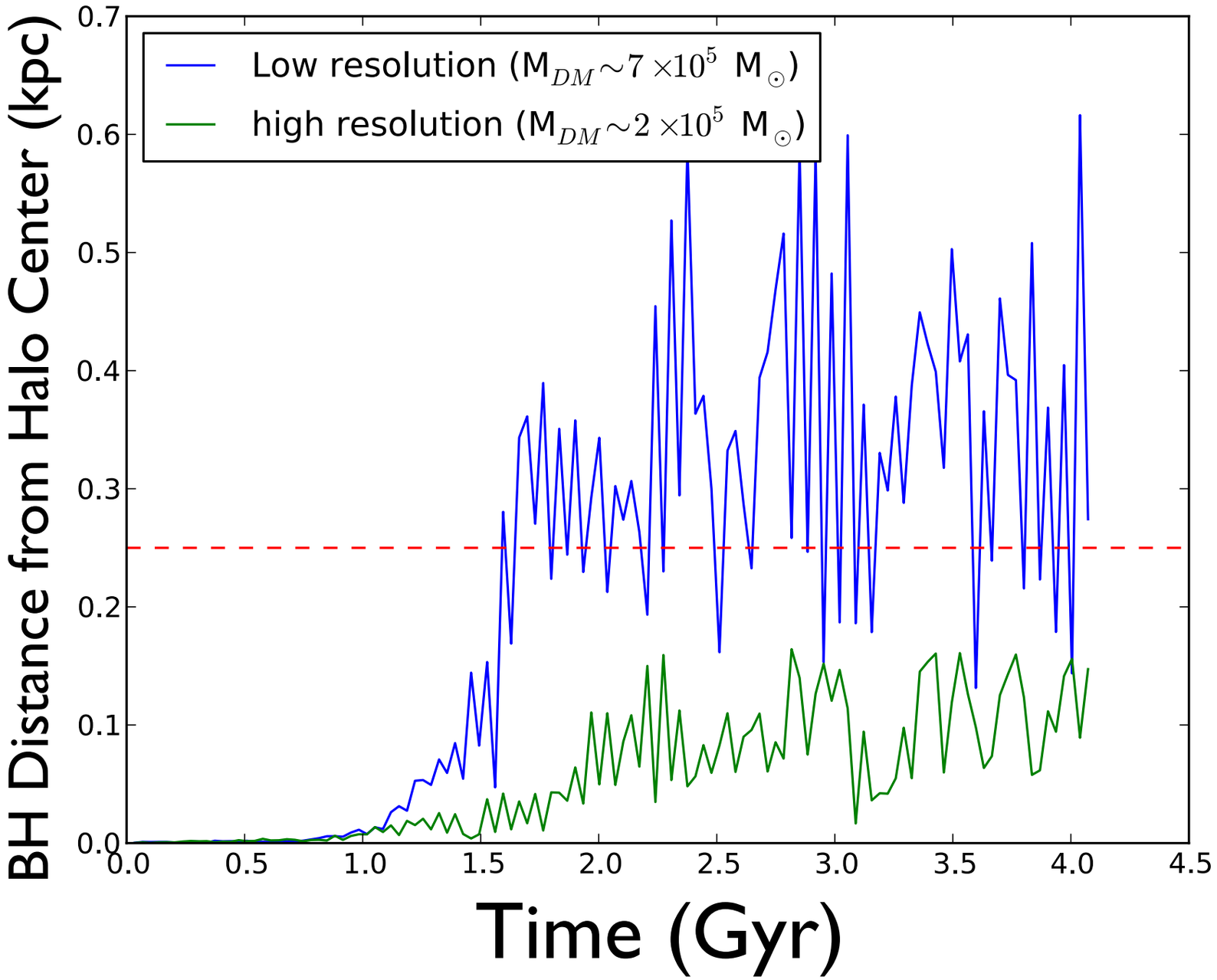
    $M_{DM} \sim 2 \times 10^{5} M_{sun}$ (high res)
  - BH velocity of 0, 10 km/s




Mayer et. al. 2007

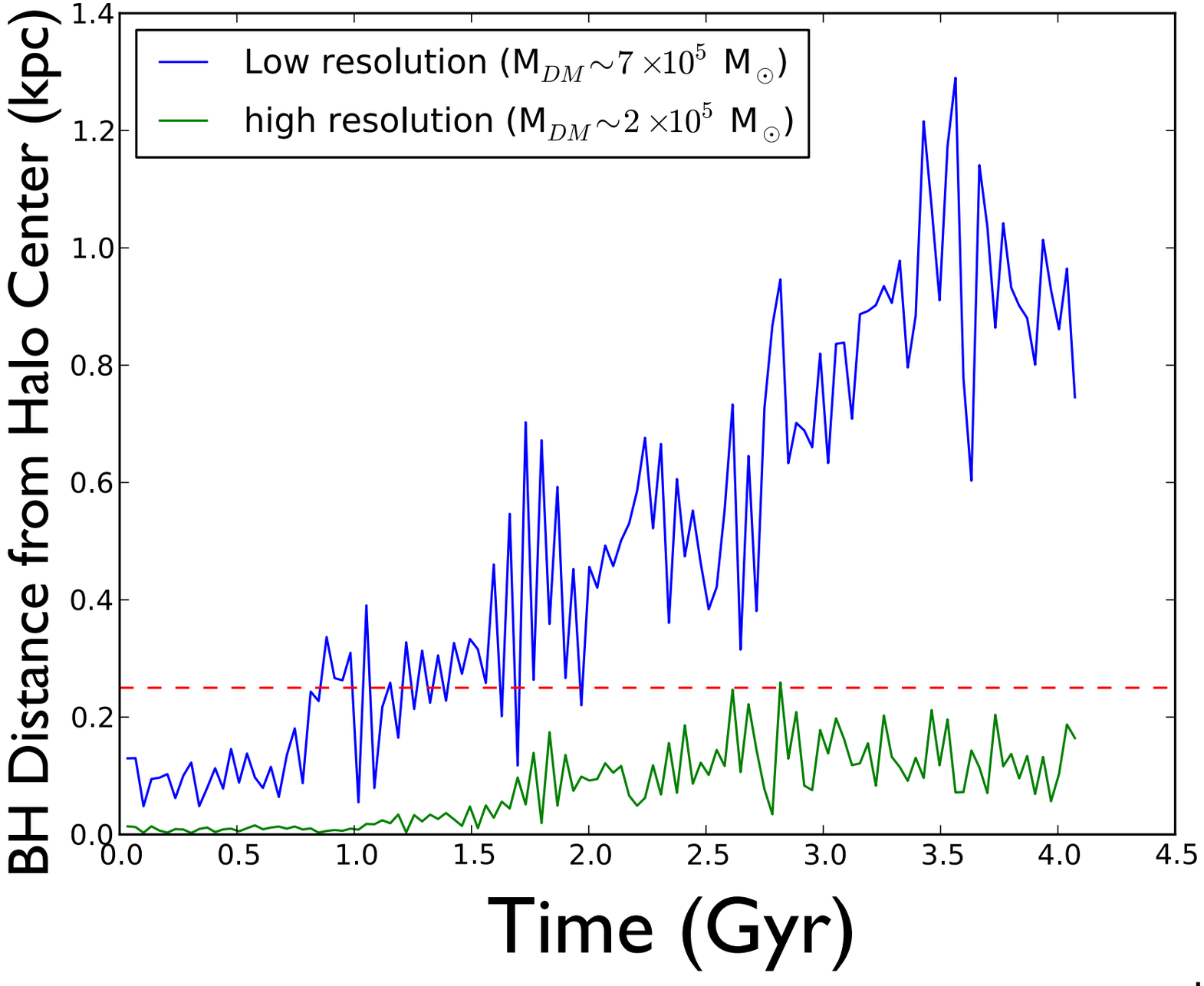
# Do We Need Advection?

$V_{initial} = 0$



# Do We Need Advection?

$V_{initial}$ = 10 km/s

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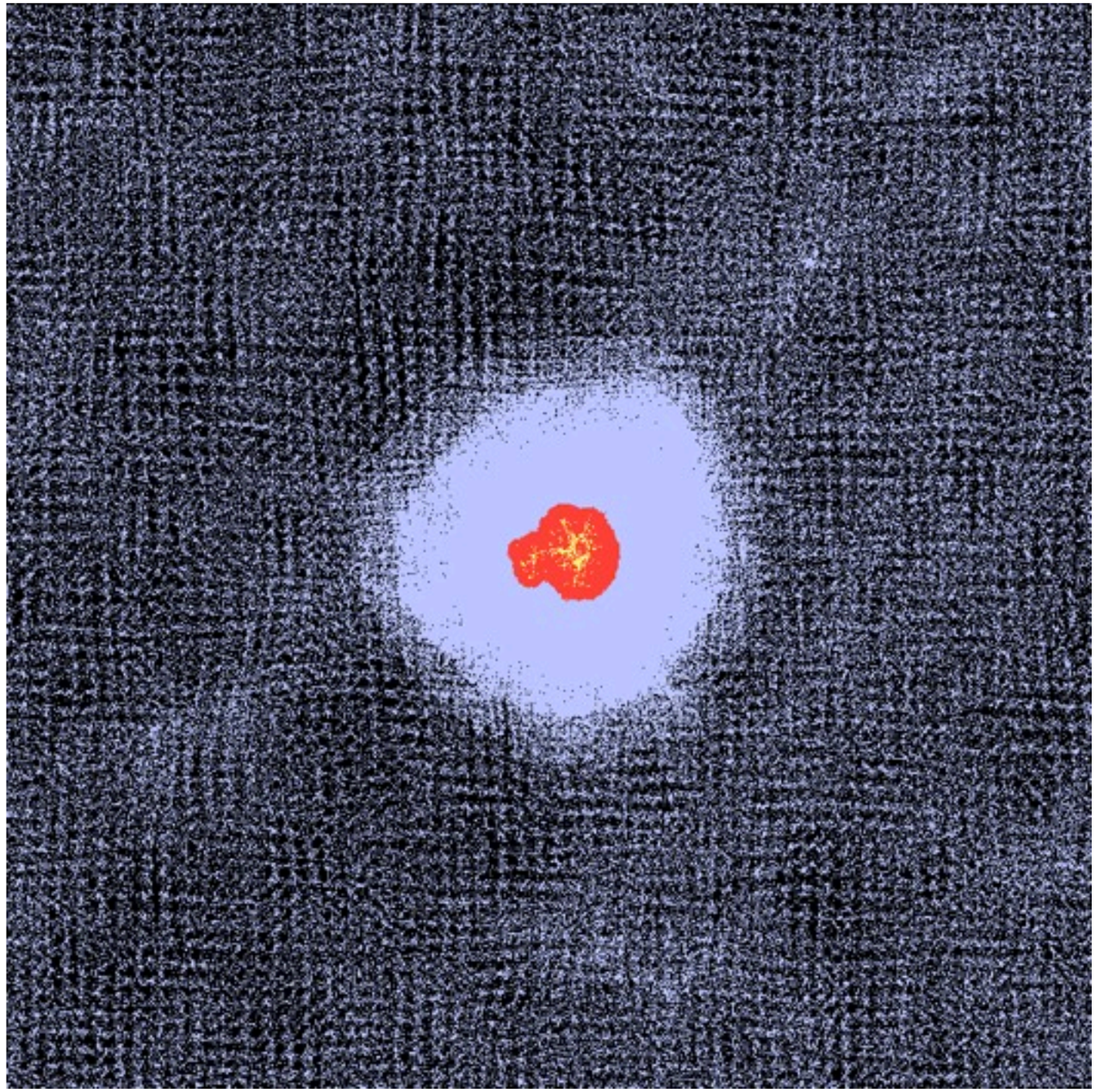
# Modeling Galaxies with ChaNGa

- Successor to the very successful N-body+Smoothed Particle Hydrodynamics code, **Gasoline**
  - Well tested code used to study a wide variety of problems, e.g
    - Formation and evolution of dwarf galaxies
    - Gas accretion onto galaxies
    - Effects of stellar feedback and tidal torques on dark matter halos
    - Formation of disks and bulges
- ChaNGa has all the important physics in Gasoline (UV background, star formation and feedback, $H_2$ formation, metal line cooling, etc) but *includes an updated SPH that resolves Kelvin-Helmholtz instabilities and achieves an order of magnitude higher scaling performance*

# Modeling Galaxies with ChaNGa

- "Zoomed-in" Simulations
  - Model a small piece of a larger volume at much higher resolution
  - Still get self consistent gas accretion and merger histories of galaxies
  - Keep the large scale dark matter distribution for tidal torques
- Advantage: Higher resolution
- Disadvantage: Won't get a very large statistical sample



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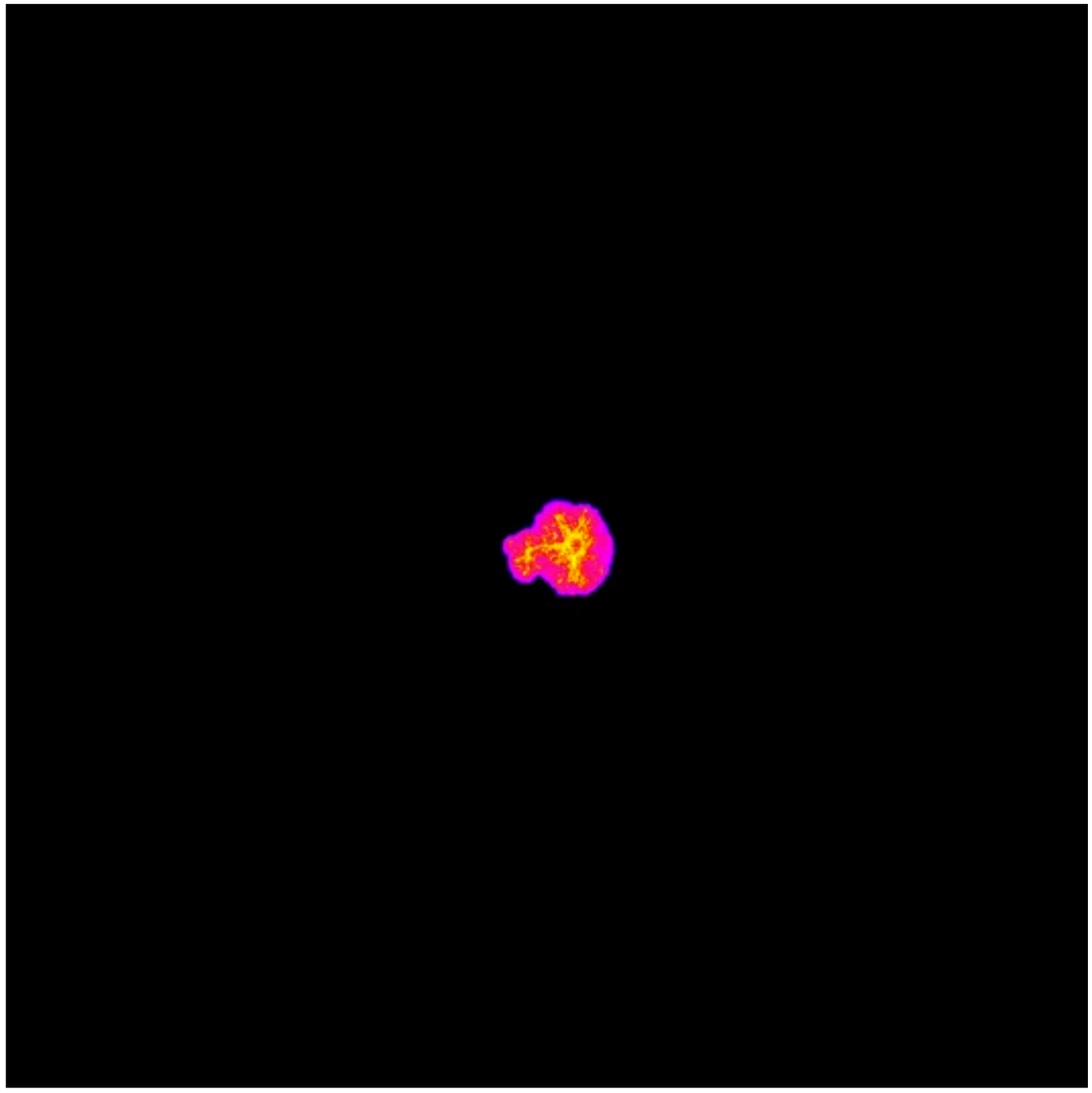

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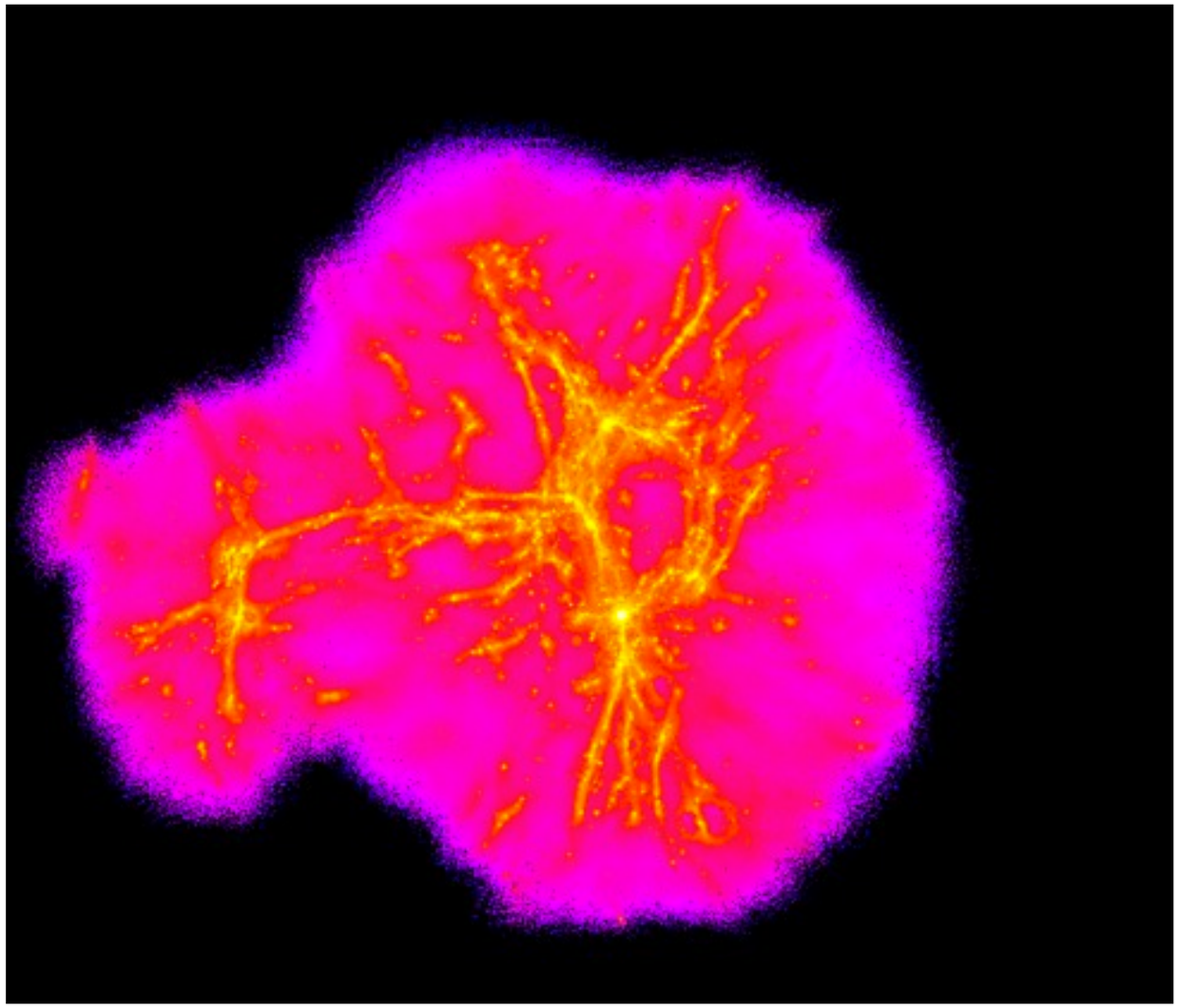
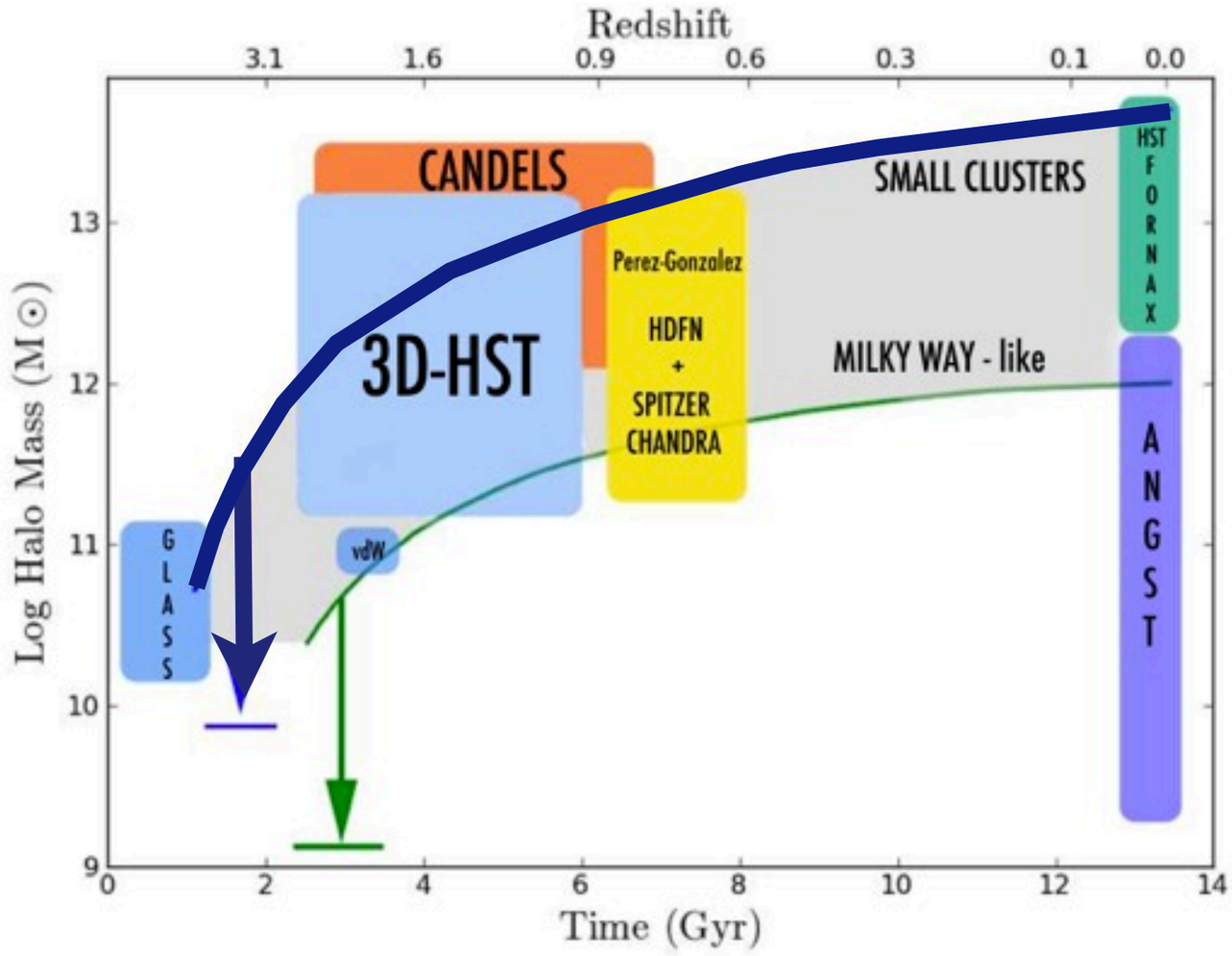


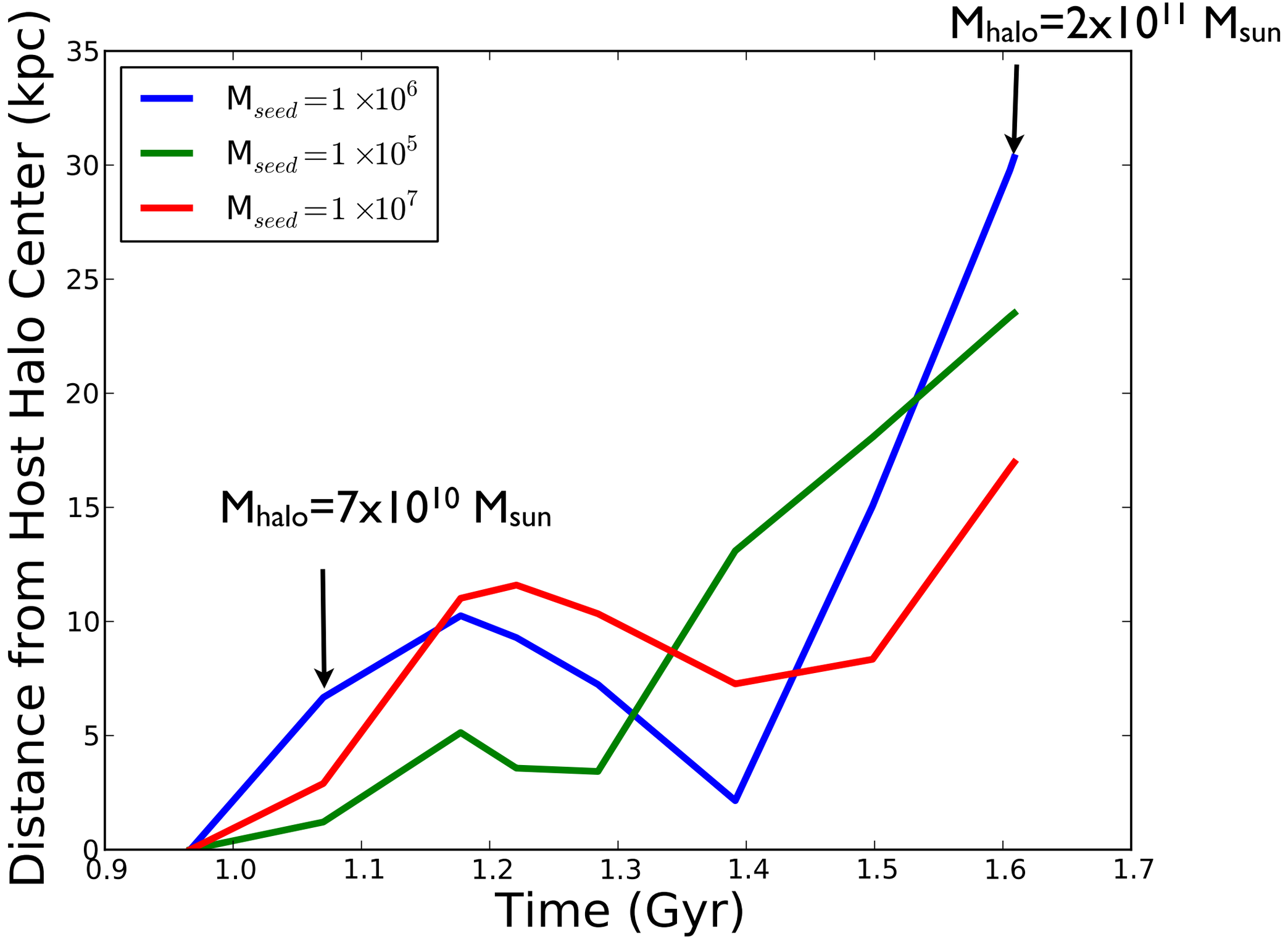
# The Simulation

- 10 BHs with mass $10^6$ $M_{sun}$ are placed at the center of the 10 largest halos at z = 6 (time ~ 1 Gyr)
- BHs accrete via Bondi-Hoyle accretion
- DM mass: 1.26 x $10^5$ $M_{sun}$




credit: Fabio Governato

# Do Our Black Holes Move?



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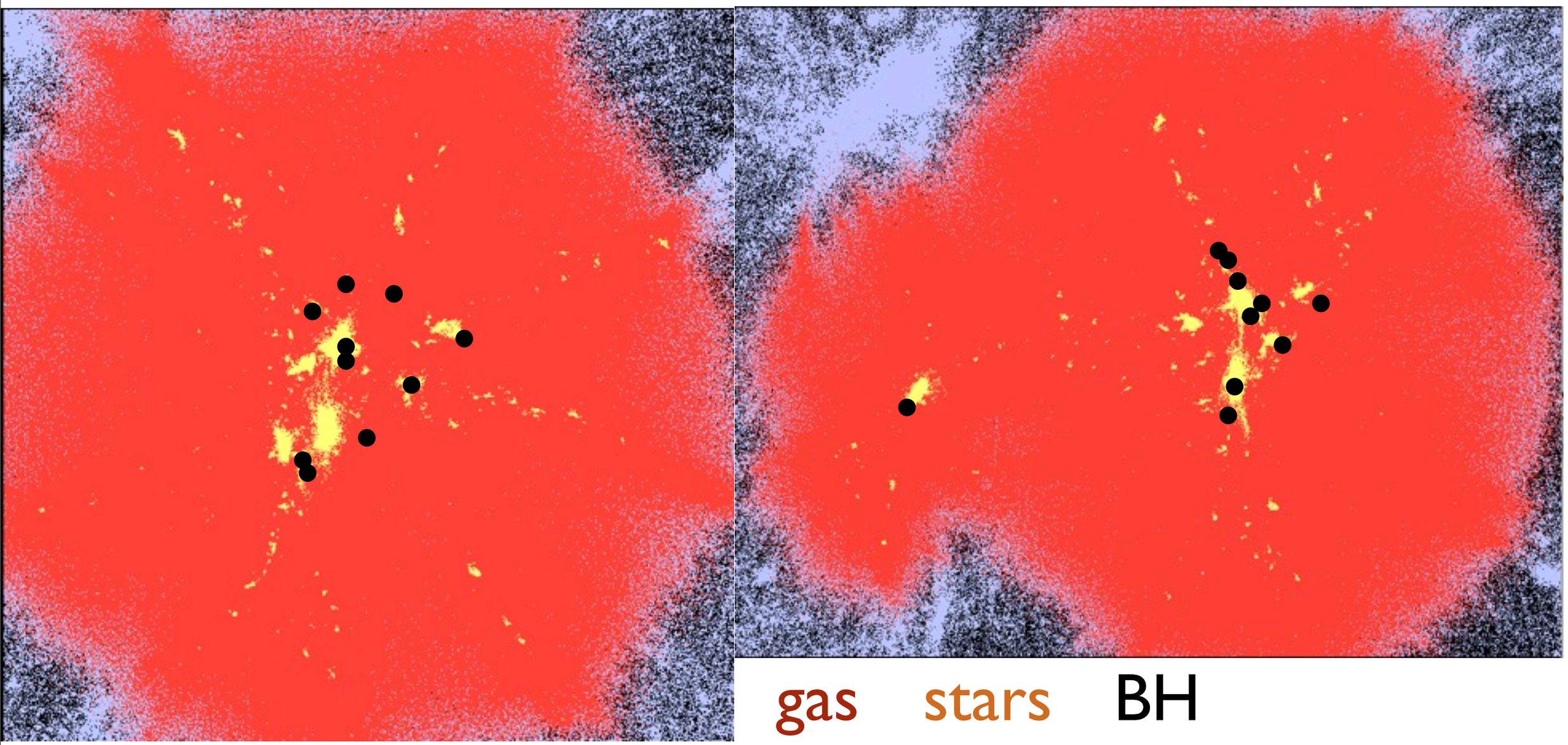

gas stars BH

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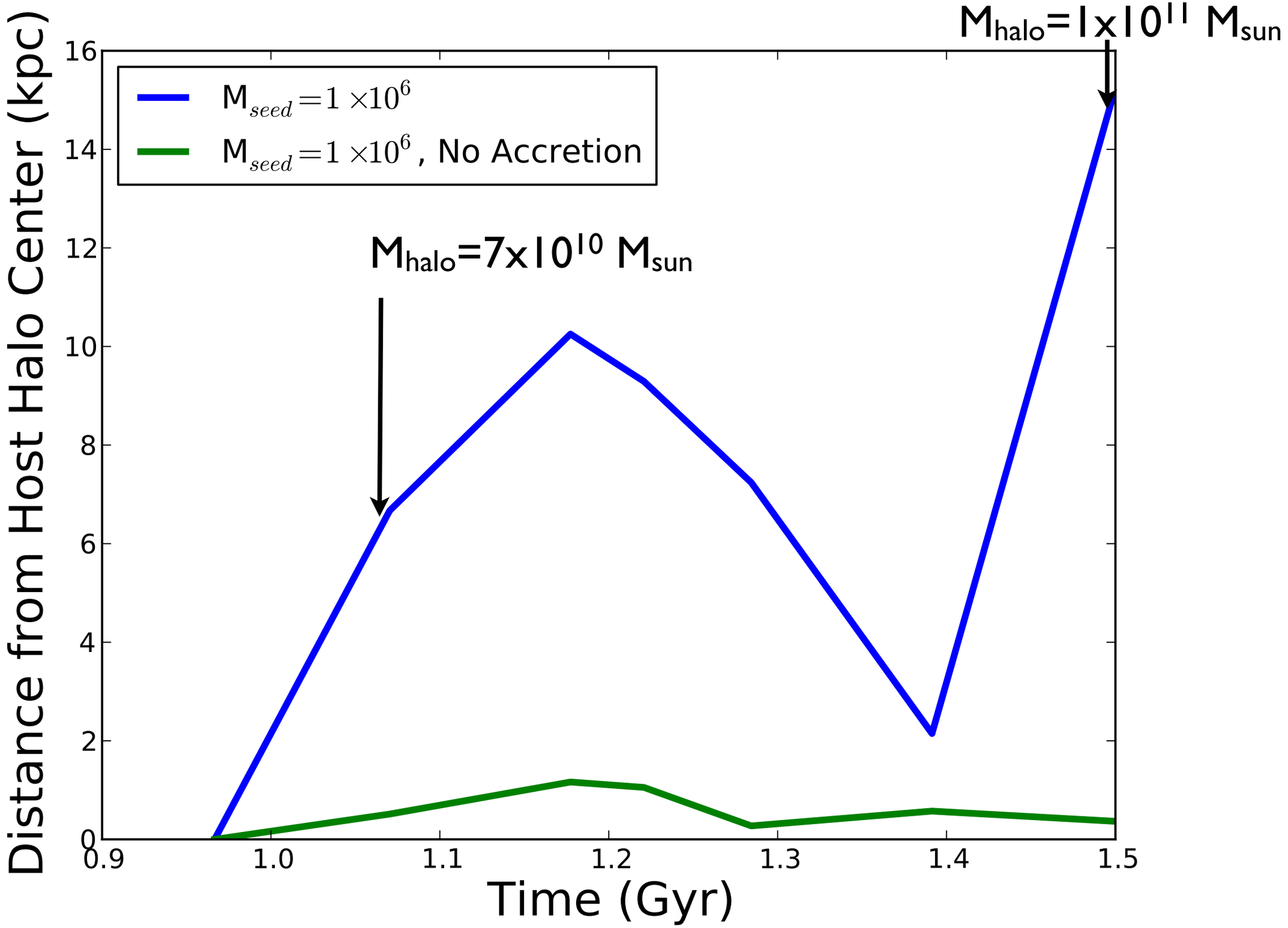


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# Open Questions and Future Work

- Look at the growth of black holes in a variety of different galaxies and environments
- Dynamics of black holes in galaxies
  - possible source of growth regulation in small halos?
  - What role is accretion playing?
- Seed Formation
  - When, where, and at what mass do black holes form? How does this affect early growth and dynamics of black holes?
  - Connect to early star formation (see: Bellovary et. al 2011)
- Explore new feedback and accretion algorithms

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