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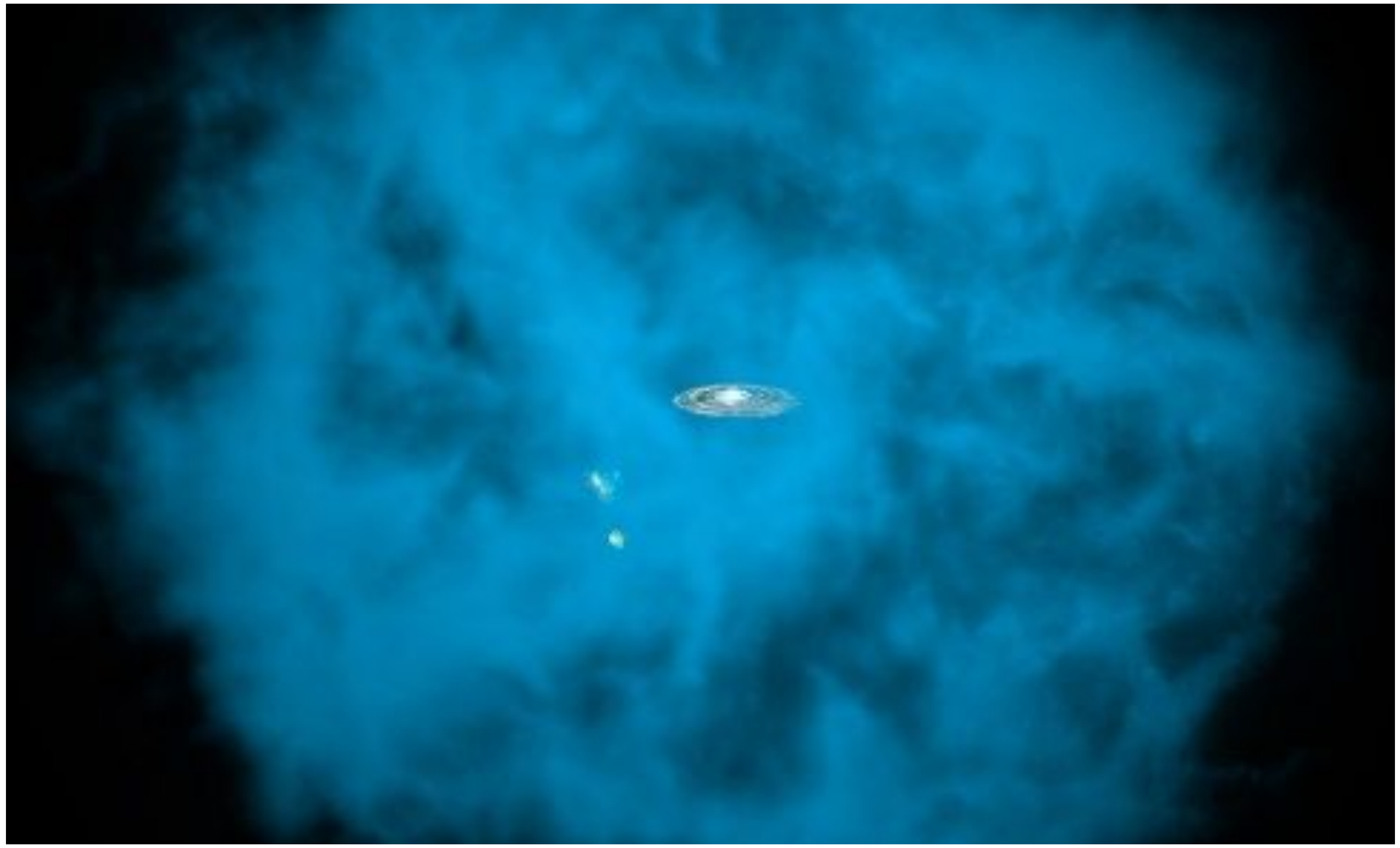

# Hot gas in accreting dark matter halos: A simple 1D model

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# Acknowledgements

**Prof. Dr. Guinevere Kauffmann**

**Dr. Prateek Sharma**

**And MPA, Garching for the kind hospitality during my long-term visit.**

**What is interesting about gas in accreting dark matter halos evolving over redshifts?**

# What is interesting about gas in accreting dark matter halos evolving over redshifts?

**New observations of galaxy clusters are giving high redshift information!**

## The Remarkable Similarity of Massive Galaxy Clusters from $z \sim 0$ to $z \sim 1.9$

M. McDonald[1], S. W. Allen[2,3,4], M. Bayliss[1], B. A. Benson[5,6,7], L. E. Bleem[6,7,8], M. Brodwin[9], E. Bulbul[1], J. E. Carlstrom[6,7,8,10], W. R. Forman[11], J. Hlavacek-Larrondo[12] Show full author list

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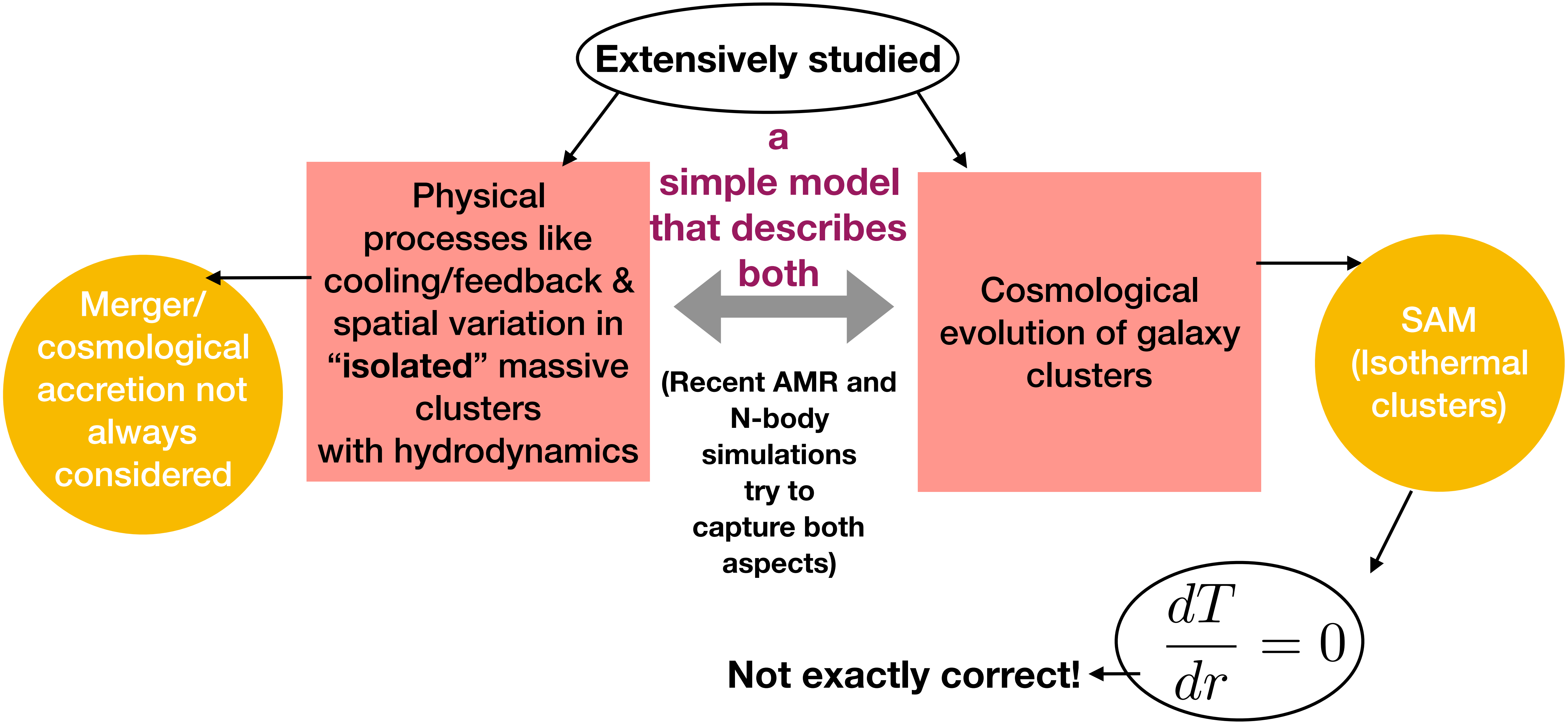
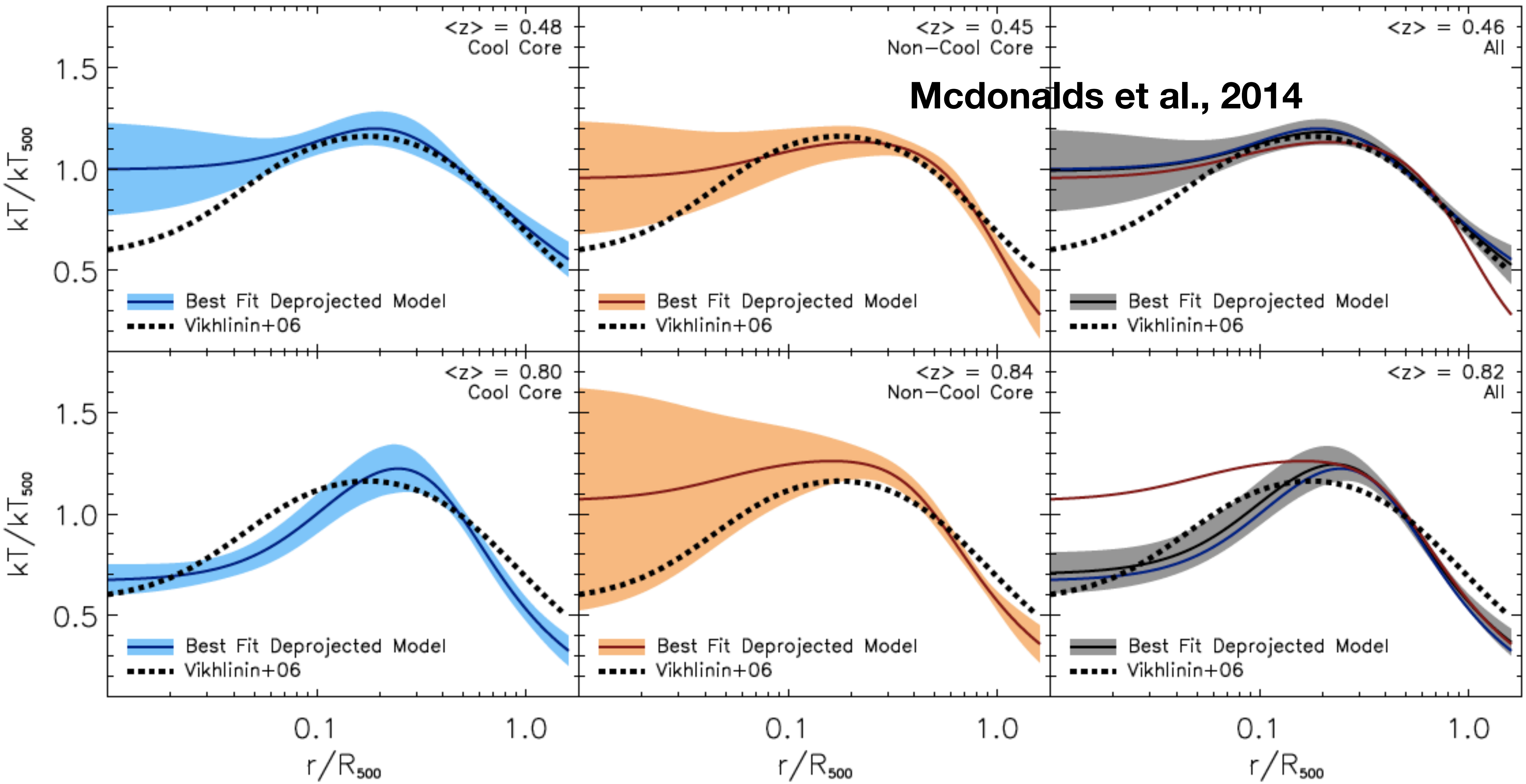
# Why do we look for 1D model of gas in accreting dark matter halos evolving over redshifts?



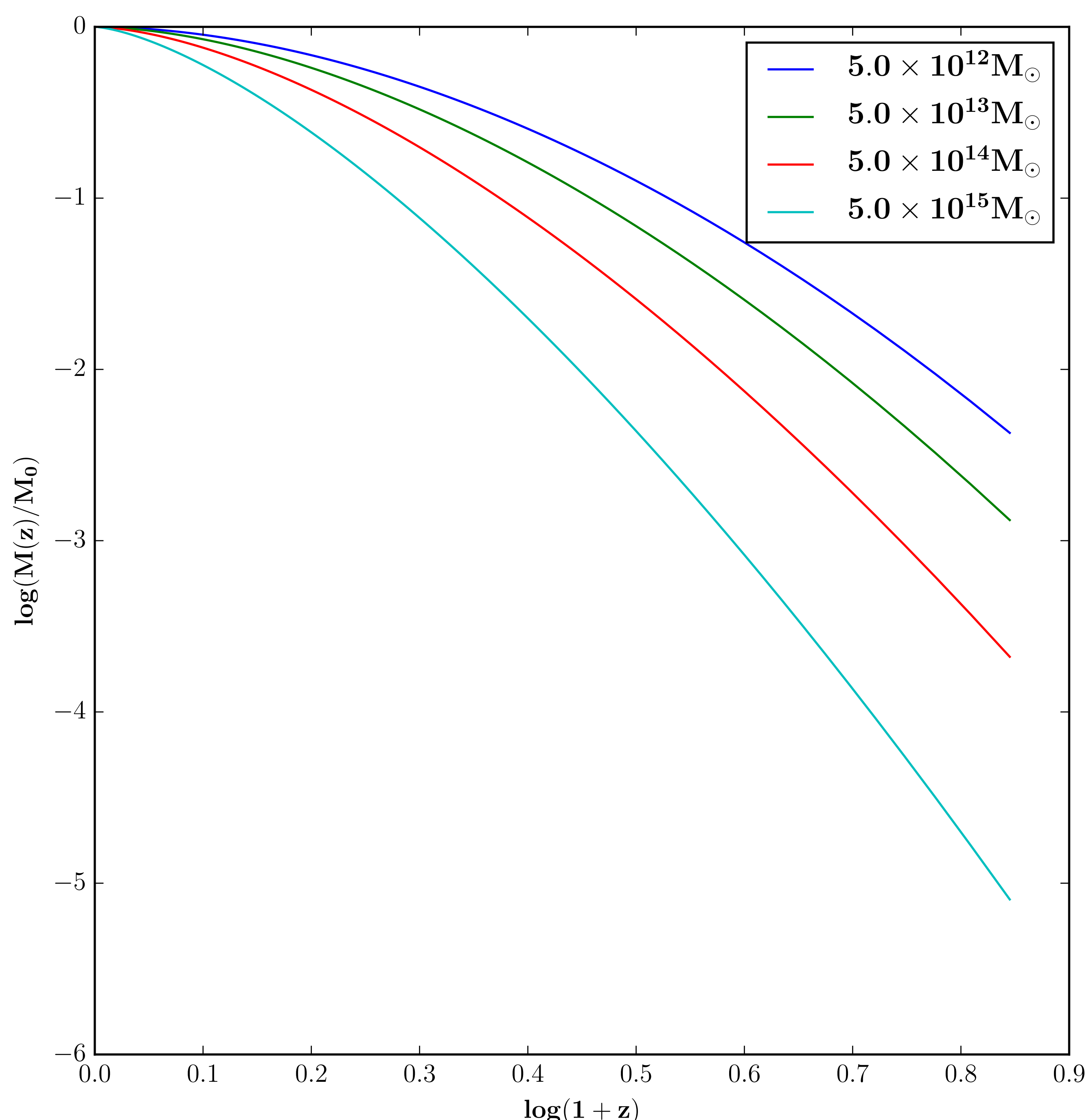
# Why do we look for 1D model of gas in accreting dark matter halos evolving over redshifts?




**What is the effect of a temperature gradient in ICM which evolves with redshift?**

# To start with: how to model the MAH of the DM halos that determine the gravitational potential for gas(Van den Bosch, 2002)

**They discuss an algorithm to follow the main trunk of the merger tree!**
**Or trace the most massive progenitor(MMP) as M(z)**



**Virial mass $M_{200}$ and $R_{200}$ can be calculated as a function of time!**

↓

**NFW potential, $\phi_{\rm NFW}$ can be calculated as a function of time!**

↓

$\frac{d\phi_{\rm NFW}}{dr} = g(r,t)$ **can be calculated as a function of time!**

**The information of the average history of merger and accretion encapsulated in g(r,t)-to be included in the momentum equation in hydrodynamics; assumption is dark matter comes to equilibrium faster than gas**

## Initial Conditions: the gas in the halo is in hydrostatic balance following the gravitational potential due to DM

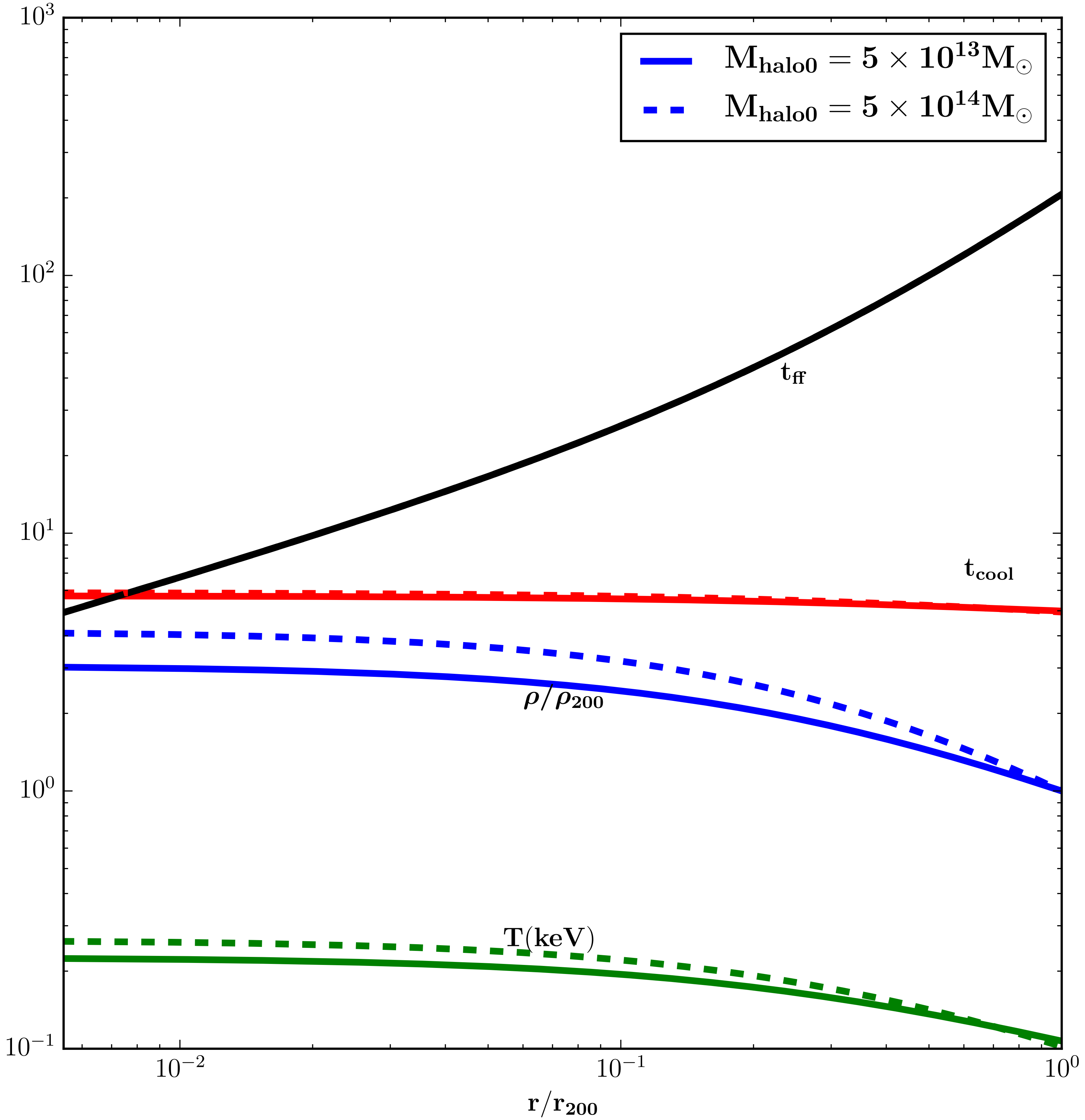
$$\frac{dp(r,t_0)}{dr} = -\rho(r,t_0)g(r,t_0)$$

$$p = K\rho^{\gamma}$$

$$T = \frac{p\mu m_p}{\rho k_B}$$

**The density at some given radius is a free parameter along with K(entropy parameter)**

# A typical initial condition at z=6



## Lagrangian shell hydrodynamics (algorithm taken from Thoul&Weinberg, 1995)

$$dm = 4\pi r^2 \rho dr$$

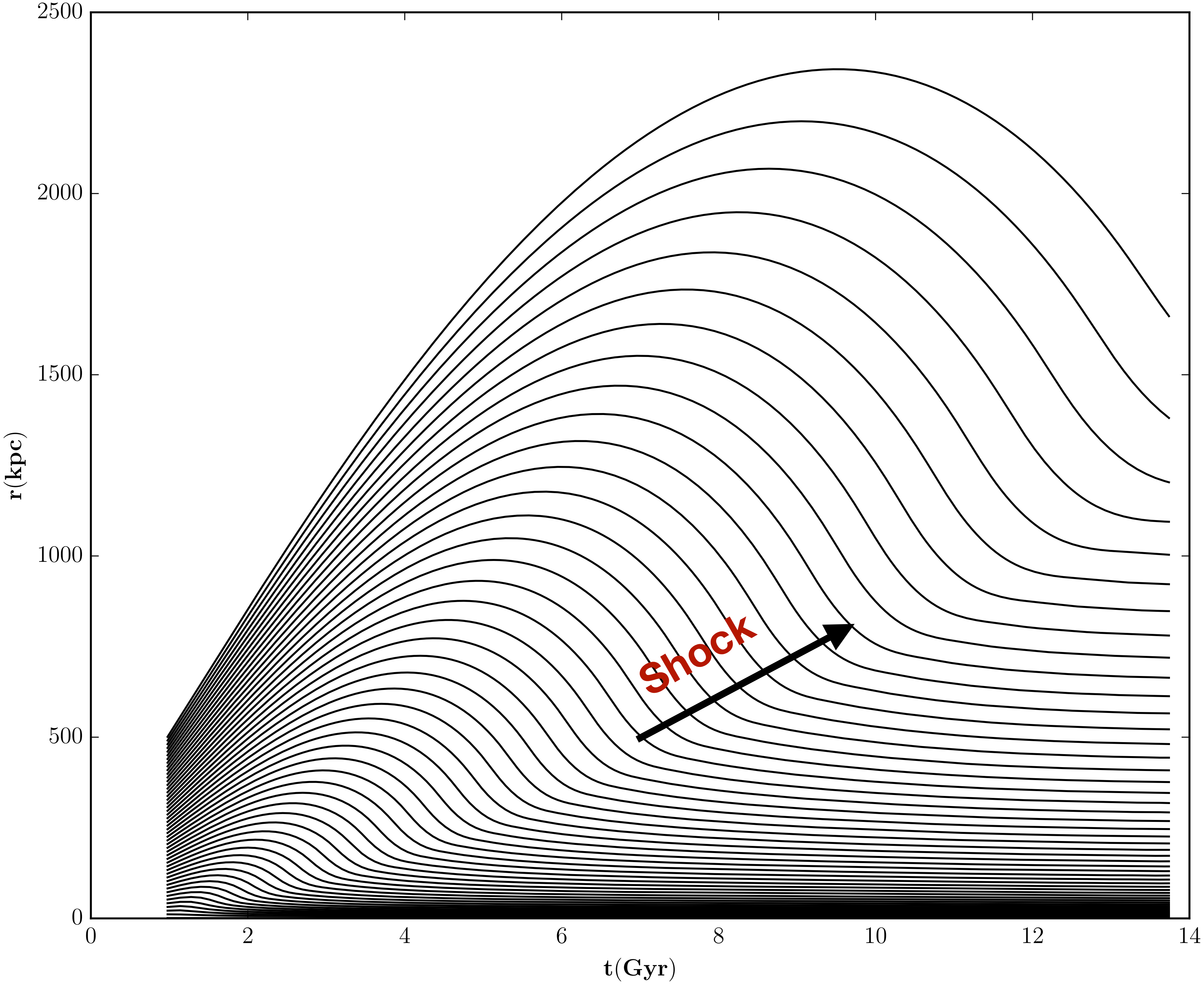
$$p = (\gamma - 1)\rho u$$

$$\frac{dv}{dt} = -4\pi r^2 \frac{dp}{dm} - g_{NFW}(r,t)$$

$$\Lambda_c = n^2 \Lambda(T)$$

$$\frac{du}{dt} = \frac{p}{\rho^2}\frac{d\rho}{dt} + \frac{\Gamma - \Lambda_c}{\rho}$$

# First trial run with no cooling and heating




**50 shells**

**Current halo mass**

$$M_{\rm halo} = 5 \times 10^{13} M_{\odot}$$

# First trial run with no cooling and heating: density evolution

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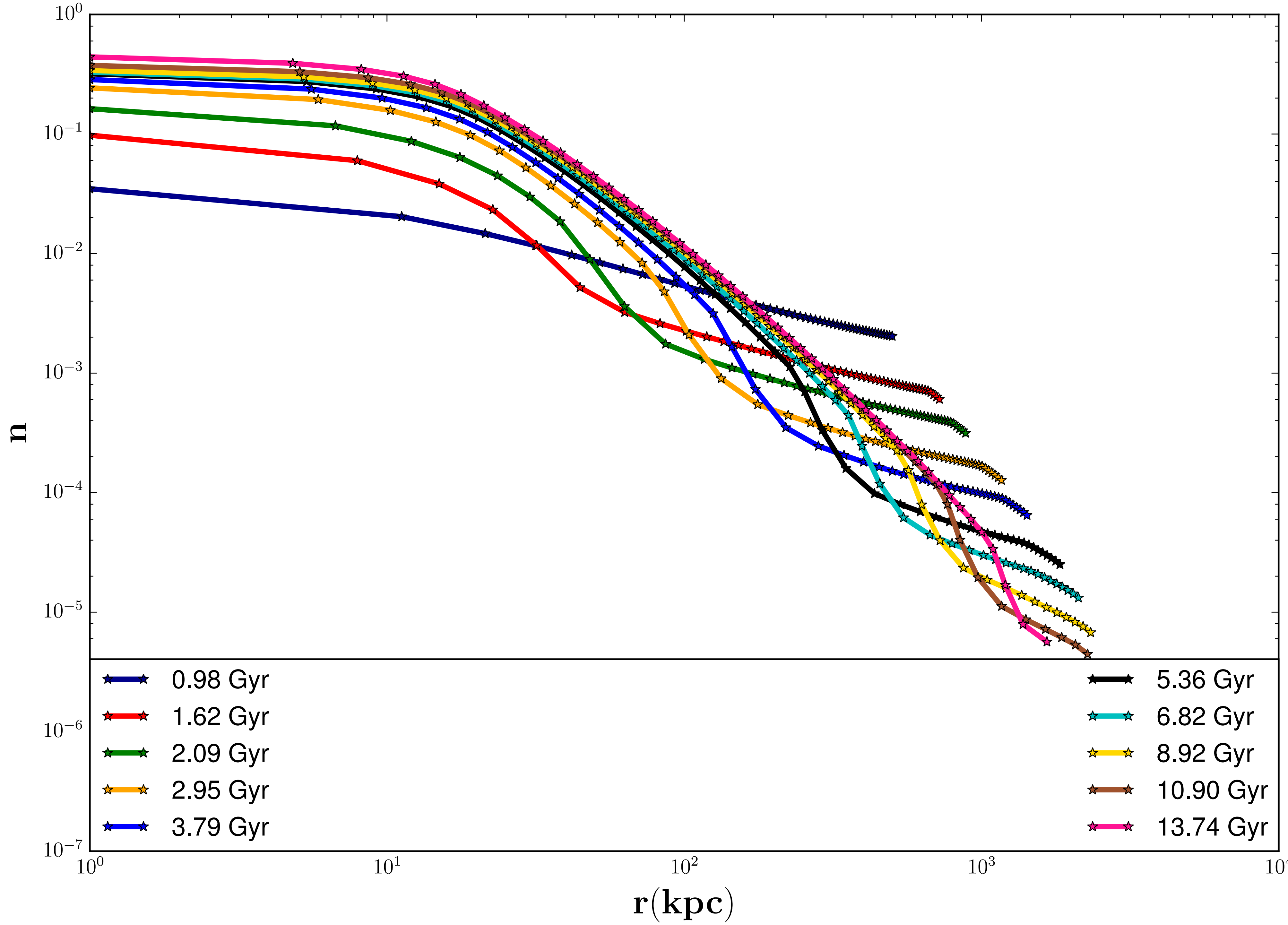

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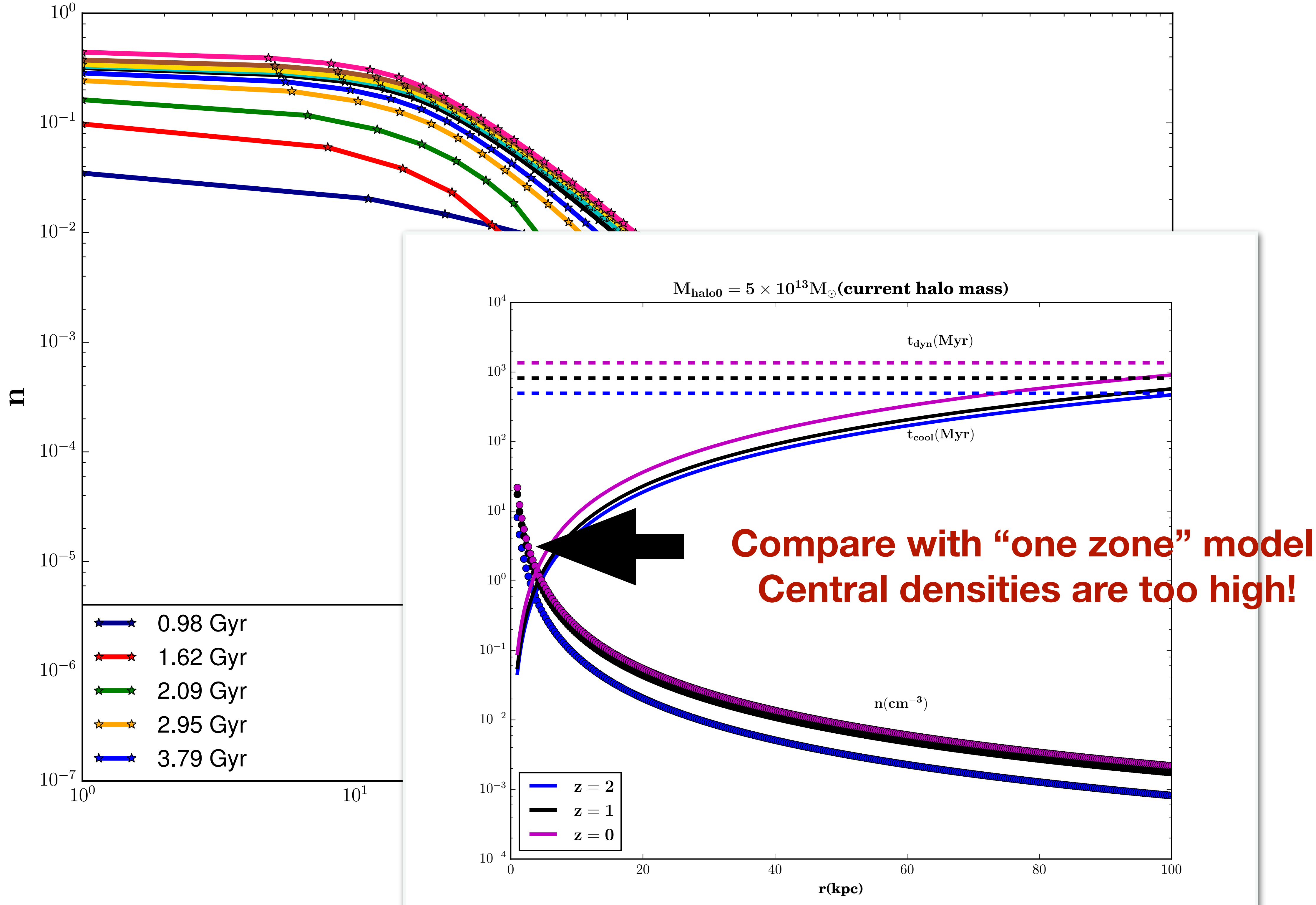

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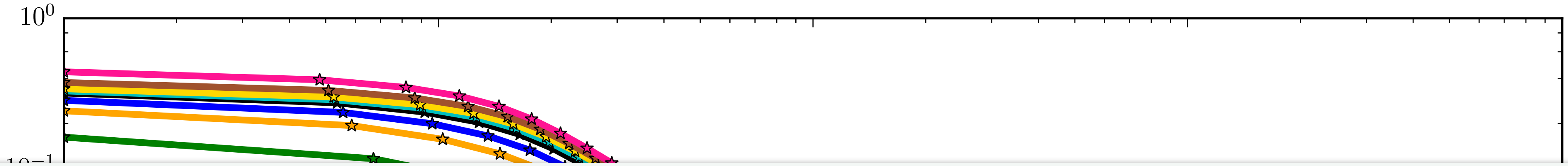
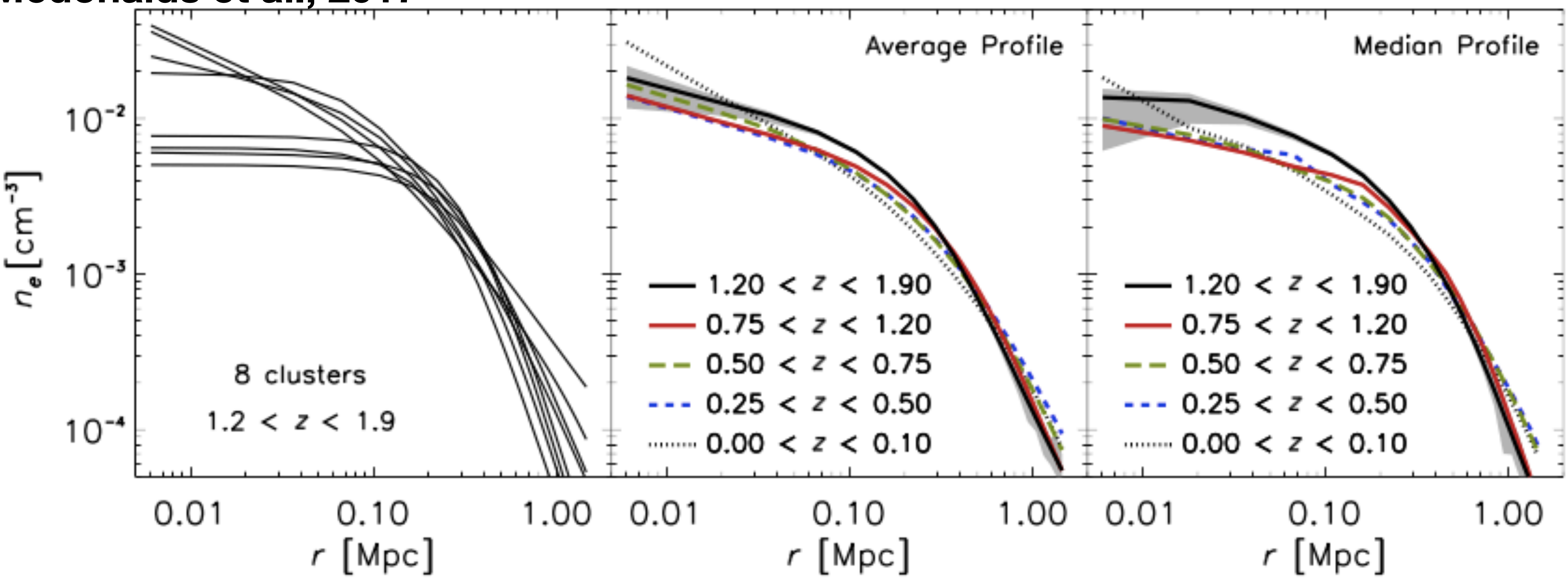
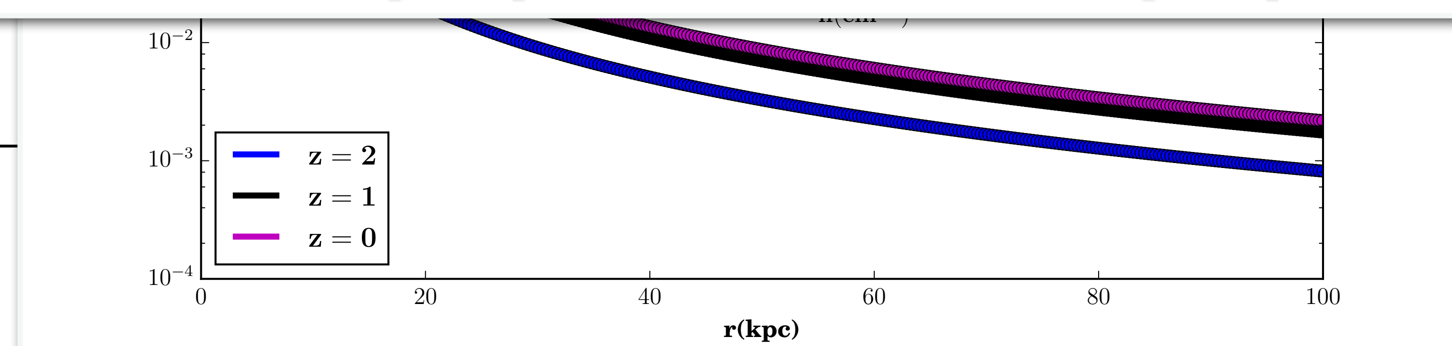
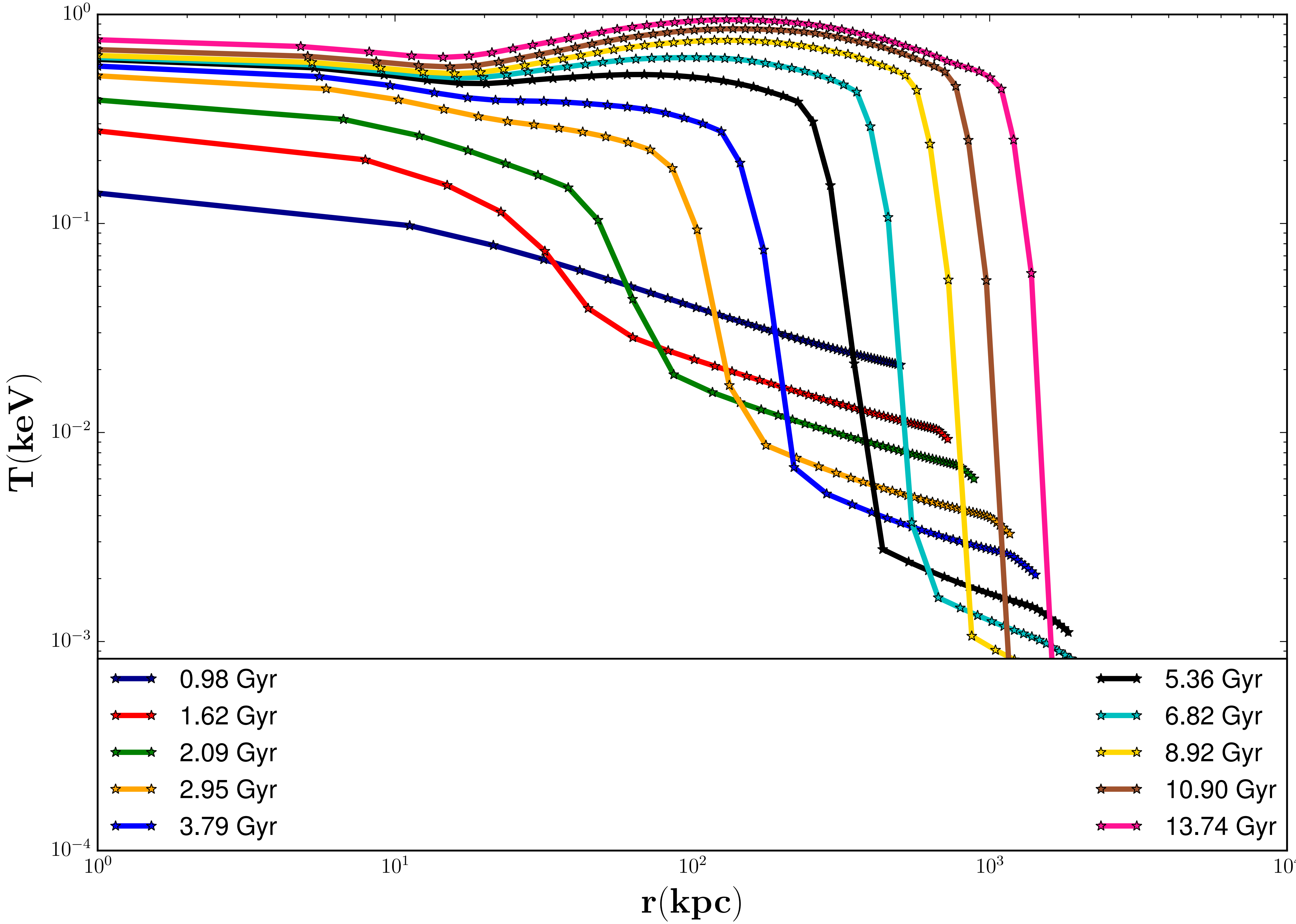



Mcdonalds et al., 2017



# First trial run with no cooling and heating: temperature evolution



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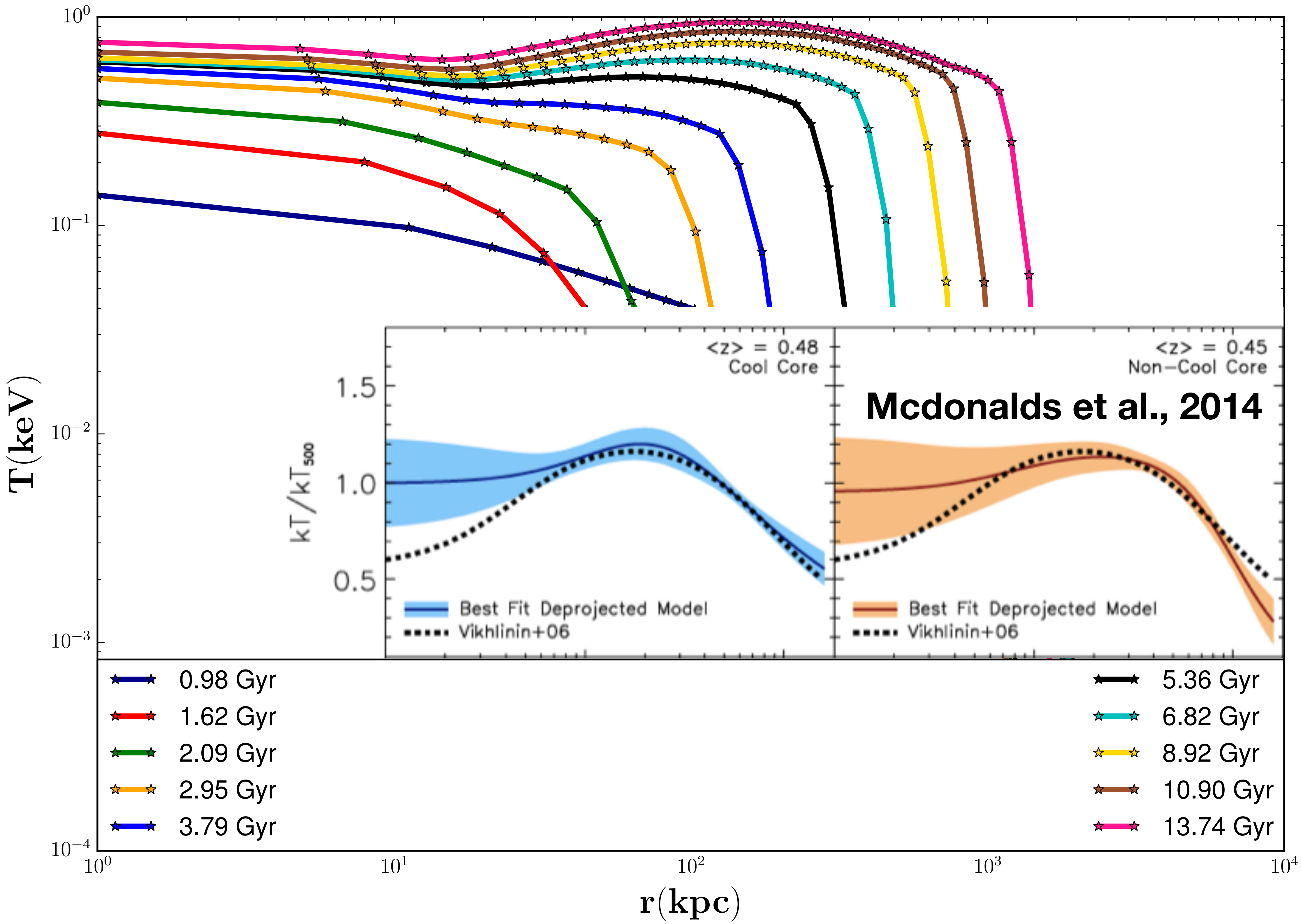
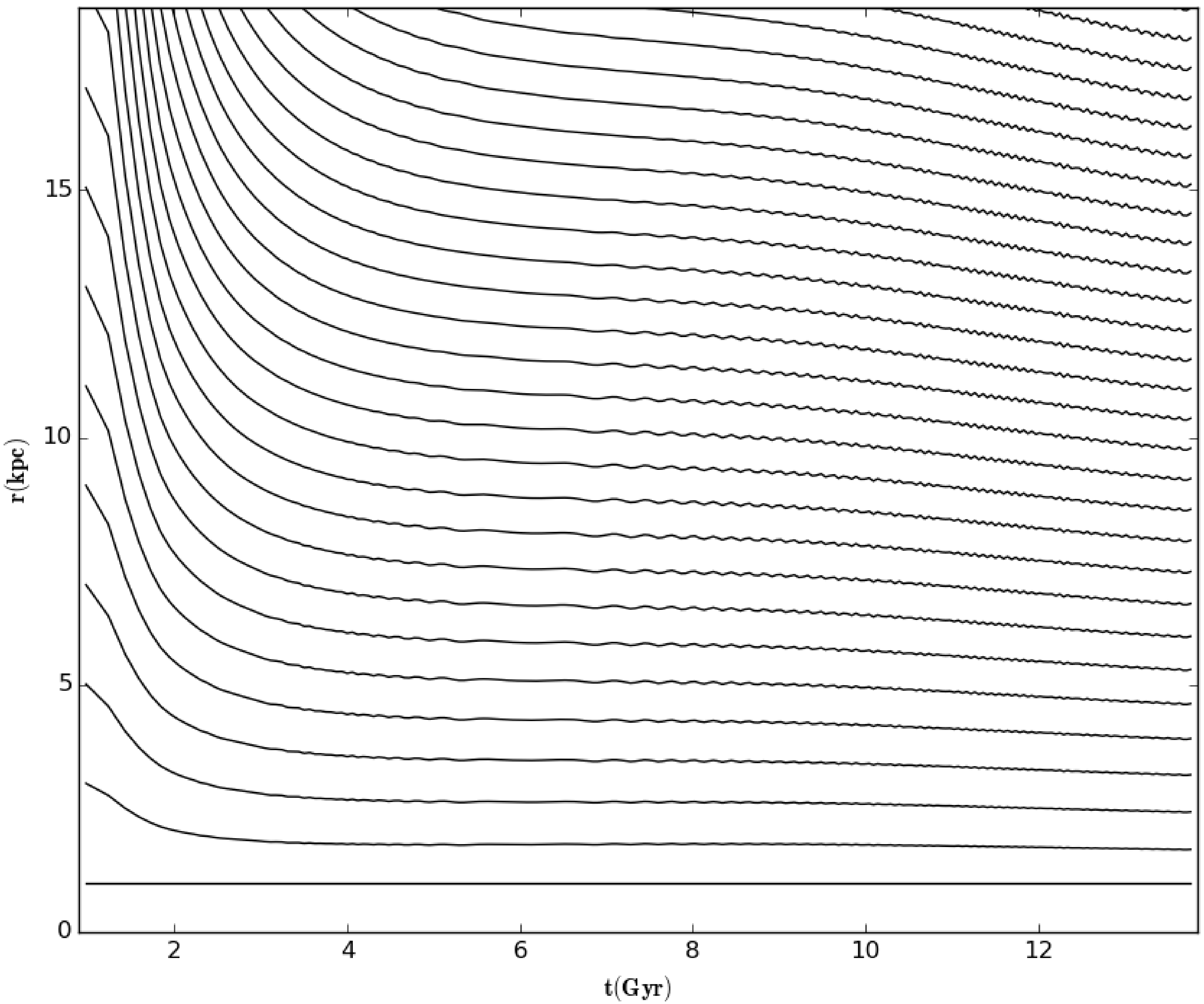


# The inner boundary and specific angular momentum

## Inner boundary condition for the first trajectory v=0, r=1 kpc

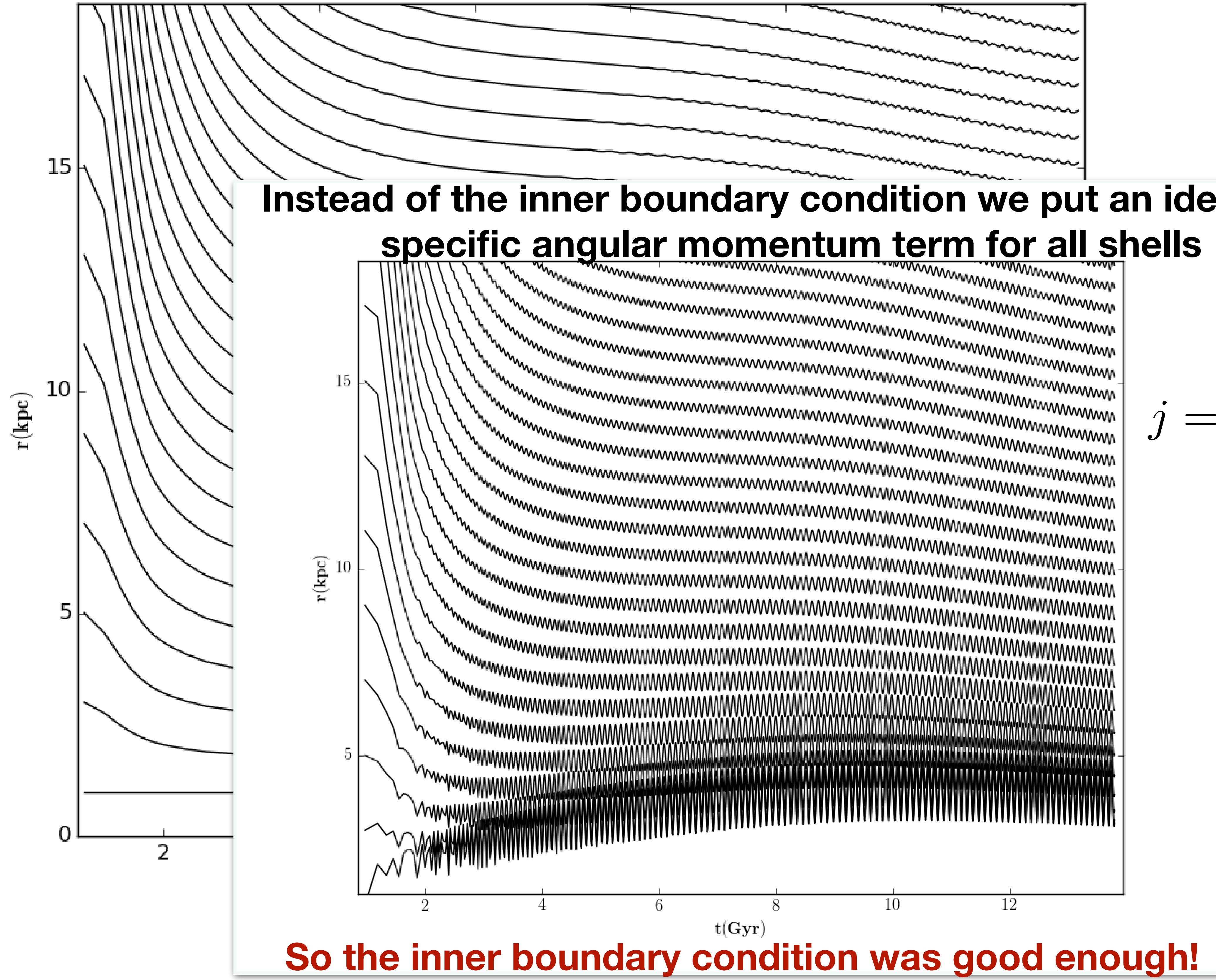



How accurate is that?

# The inner boundary and specific angular momentum

Inner boundary condition for the first trajectory v=0, r=1 kpc

Instead of the inner boundary condition we put an idealised specific angular momentum term for all shells




$$j = 2r_{\mathrm{d}}V_{200}$$

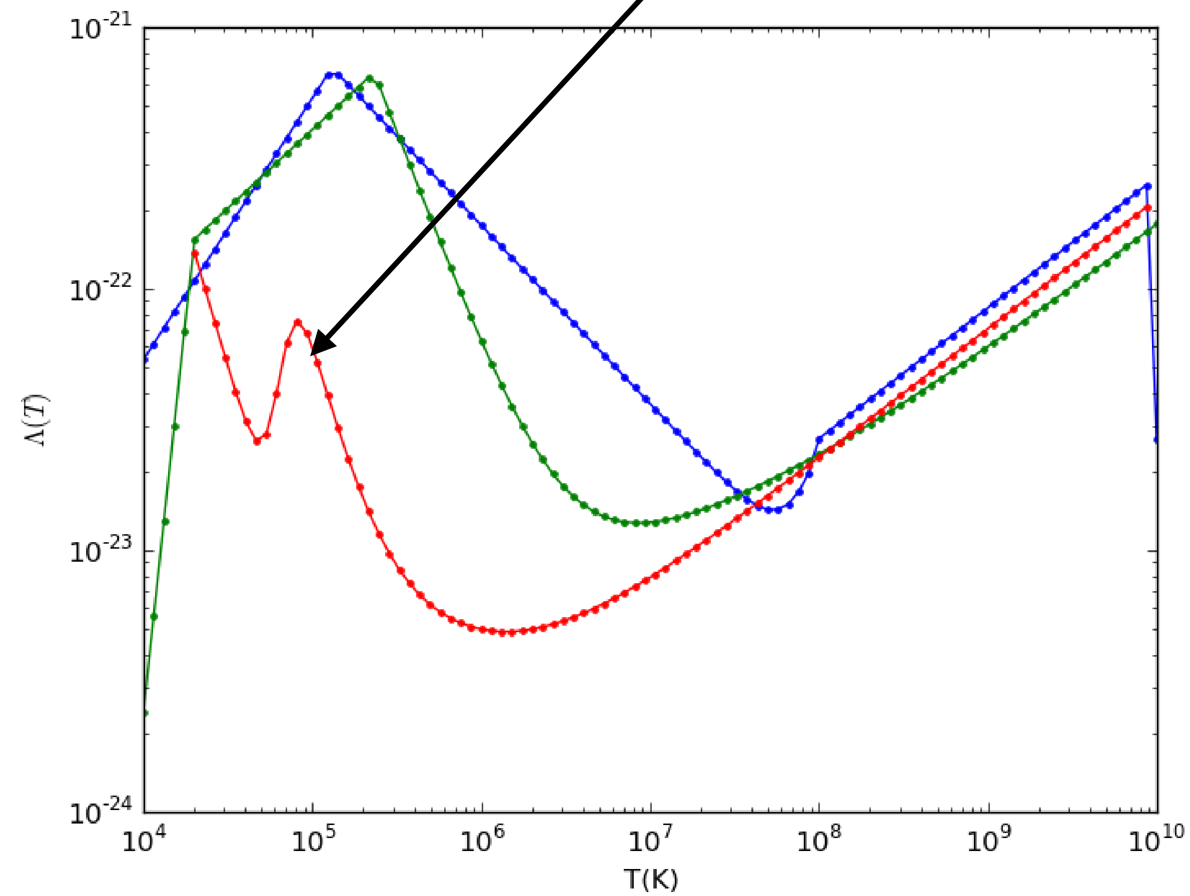
So the inner boundary condition was good enough!

# Including radiative cooling: tested with zero metallicity cooling curve

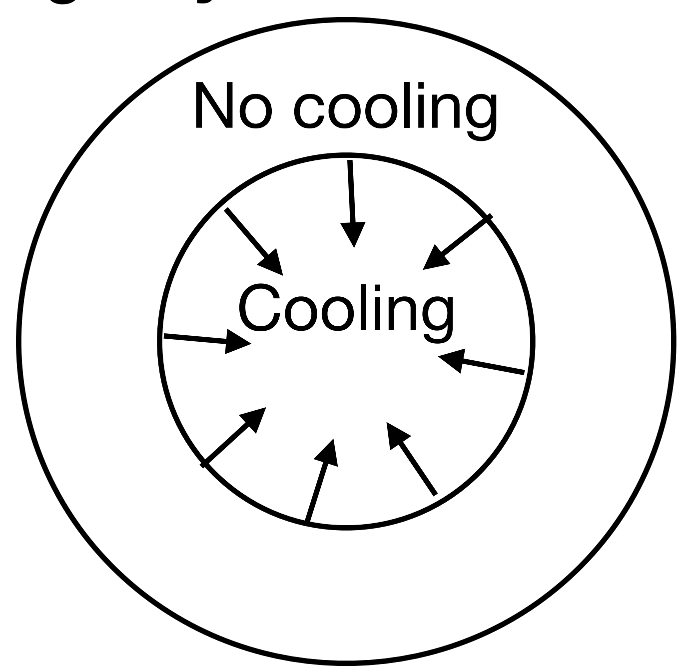
**Sub-cycling at each hydrodynamic step**

$$\frac{du}{dt} = \frac{\Gamma - \Lambda_c}{\rho}$$

**This is solved in cooling time-steps within each hydrodynamic time-step**




**Cooling only inside virial radius**

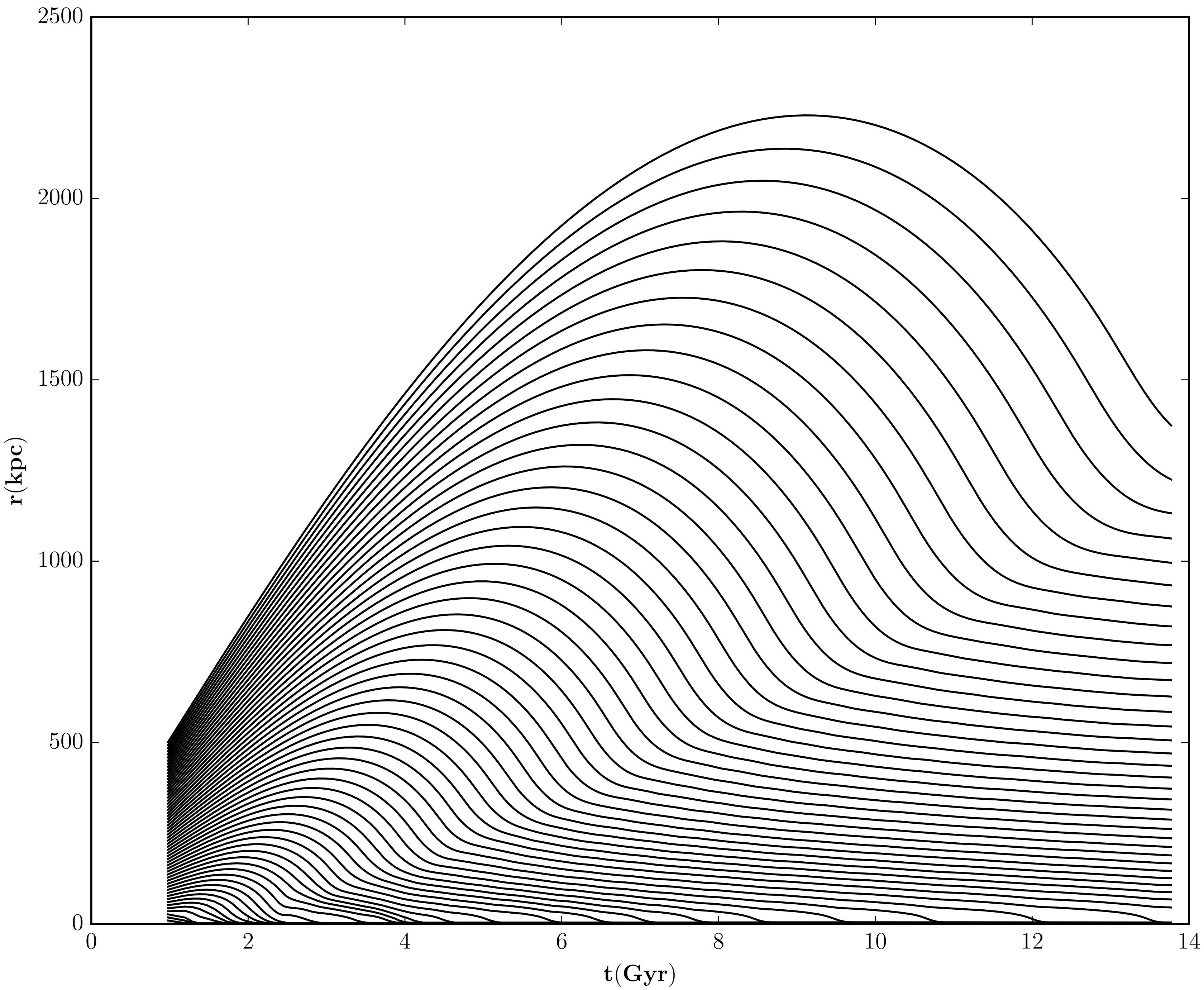


# Runs with cooling: a general initial condition for different halo evolution

**Fiducial case:** $M_{\mathrm{halo0}} = 5 \times 10^{13} M_{\odot}$ $\quad K_{\mathrm{ini}} = \frac{T_{keV}}{n^{\gamma-1}} = 2\ keV\, cm^2$

$$\rho_{2\mathrm{r_{vir}}} = 10\rho_{\mathrm{crit}}(t_0)$$

**Other cases:** $K_{\mathrm{ini}}(M_{\mathrm{halo}}) = K_{\mathrm{ini}}(M_{\mathrm{halo}}/M_{13})^{2/3}$



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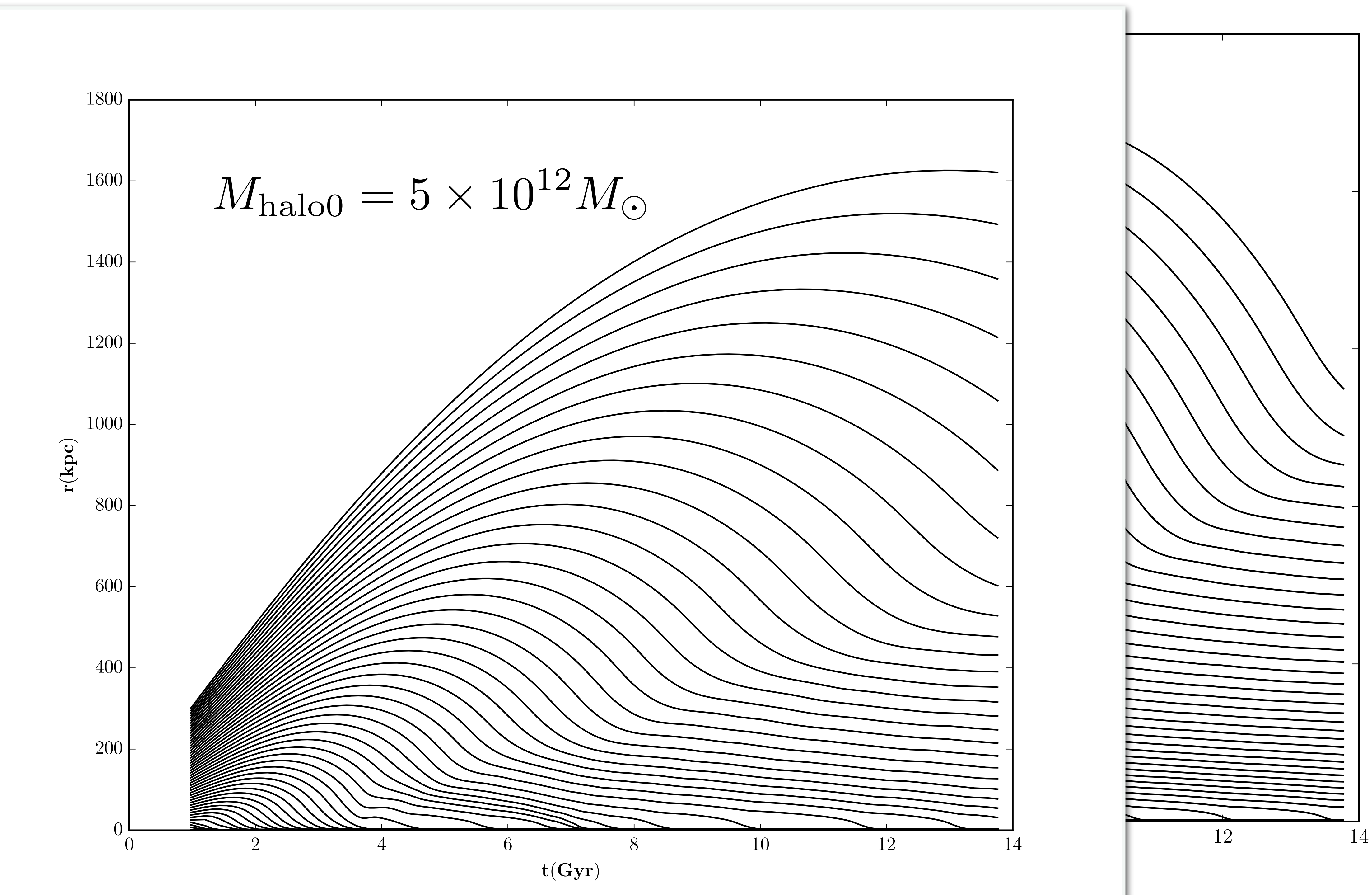

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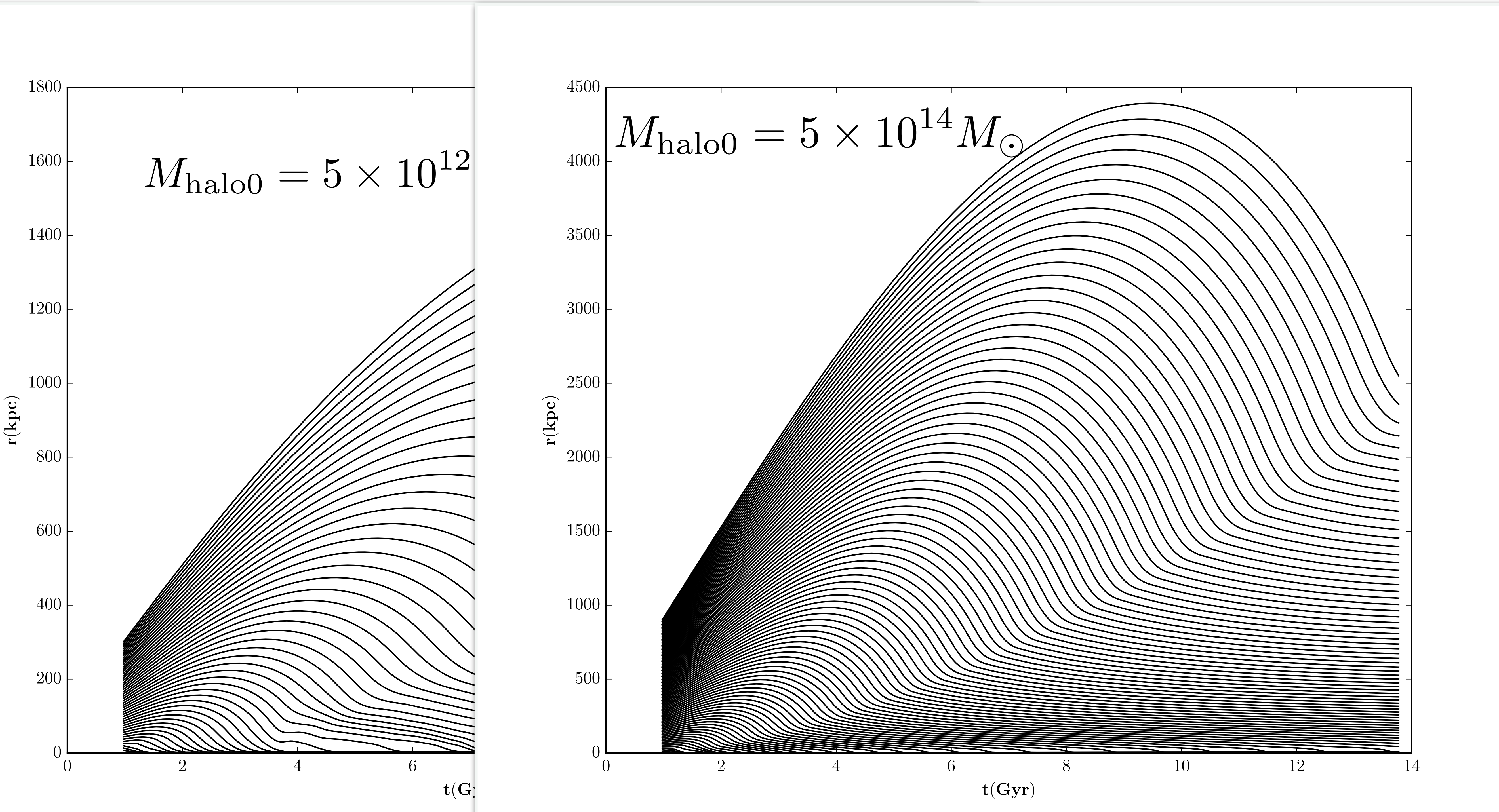
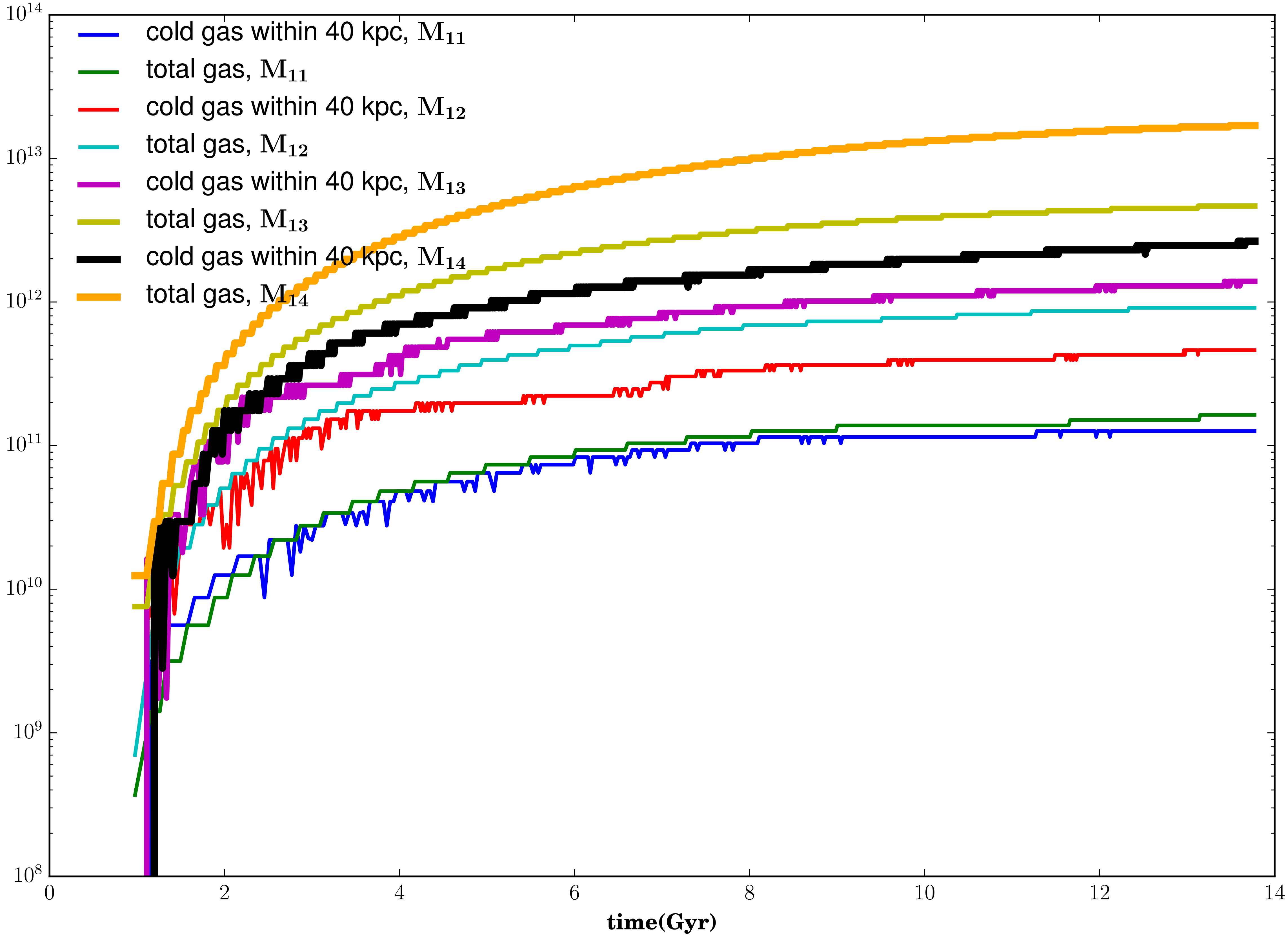
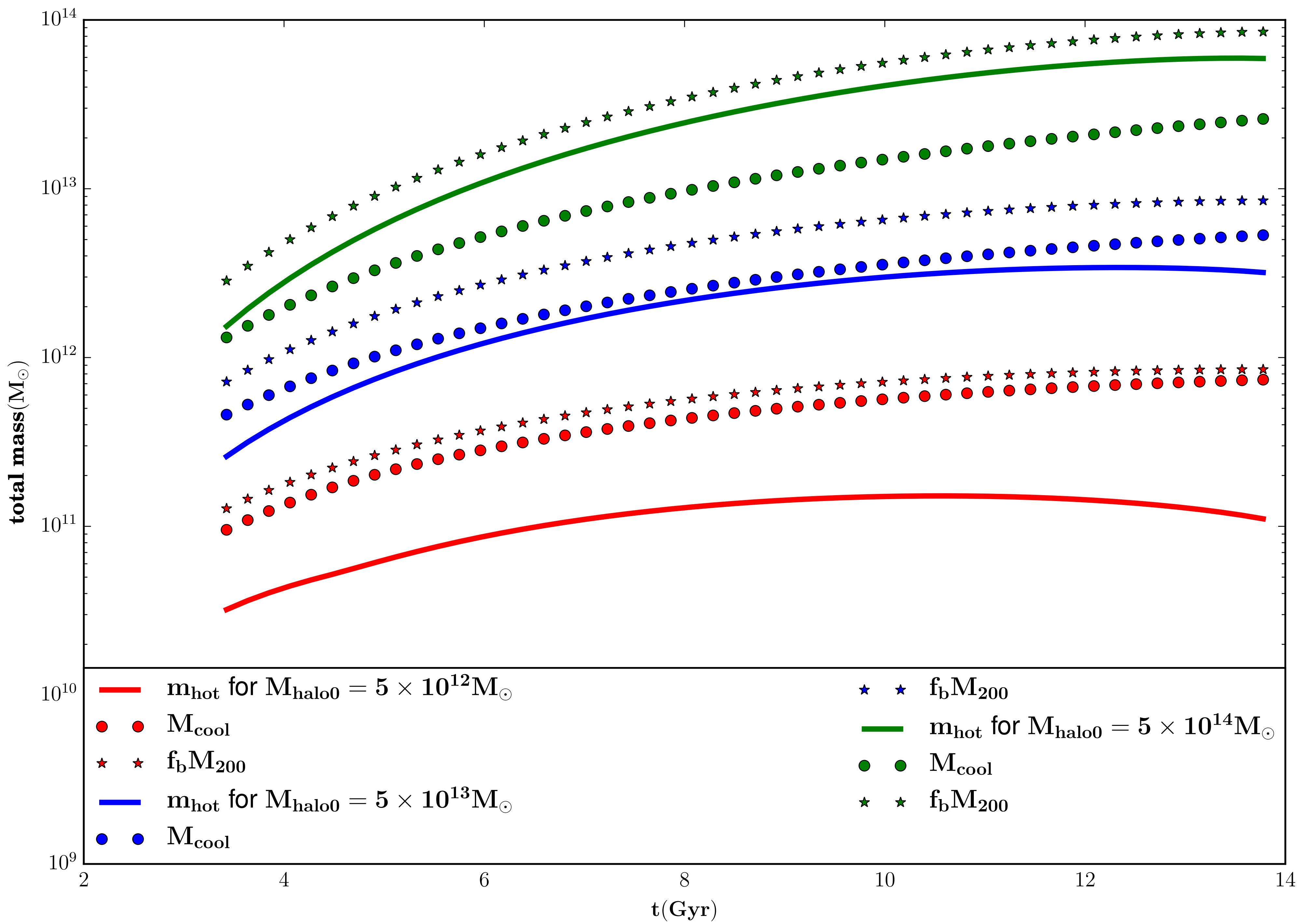


# Mass vs time: evolution for varying halo masses



# Mass vs time: evolution for varying halo masses

## Compare with one zone model!



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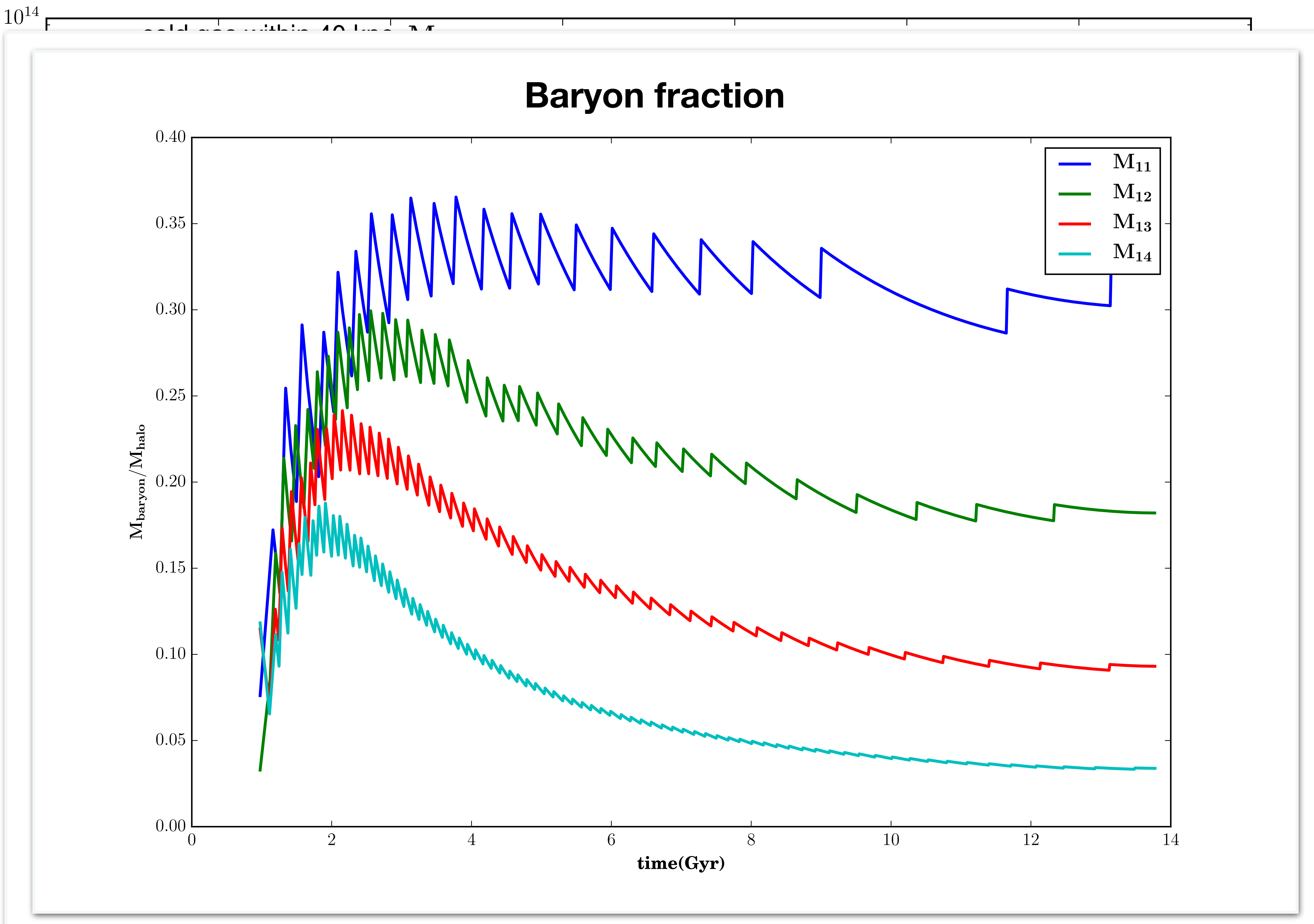


# Idealized heating: Bondi-Hoyle-Lyttleton accretion

**We use the first shell and second trajectory for ambient density and velocity**

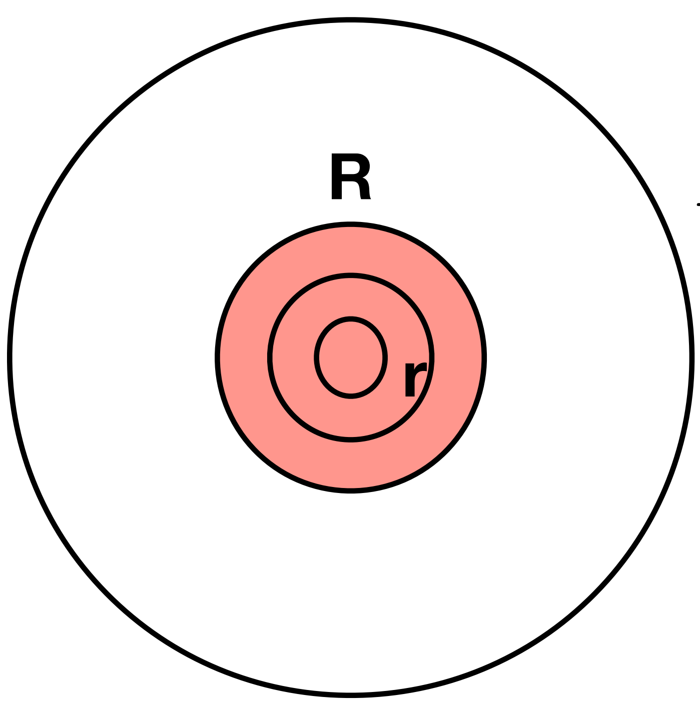
$$\dot{M}_{BHL} = \frac{4\pi\alpha G^2 M_{BH}^2 \rho}{(c_s^2 + v^2)^{\frac{3}{2}}}$$

$$\dot{M}_{Edd} = \frac{4\pi G M_{BH} m_p}{\epsilon_r \sigma_T c}$$

$$\epsilon_{\mathrm{r}} = 0.1$$

$$\dot{E}_{feed} = \epsilon_f min(M_{BHL}, M_{Edd})c^2$$

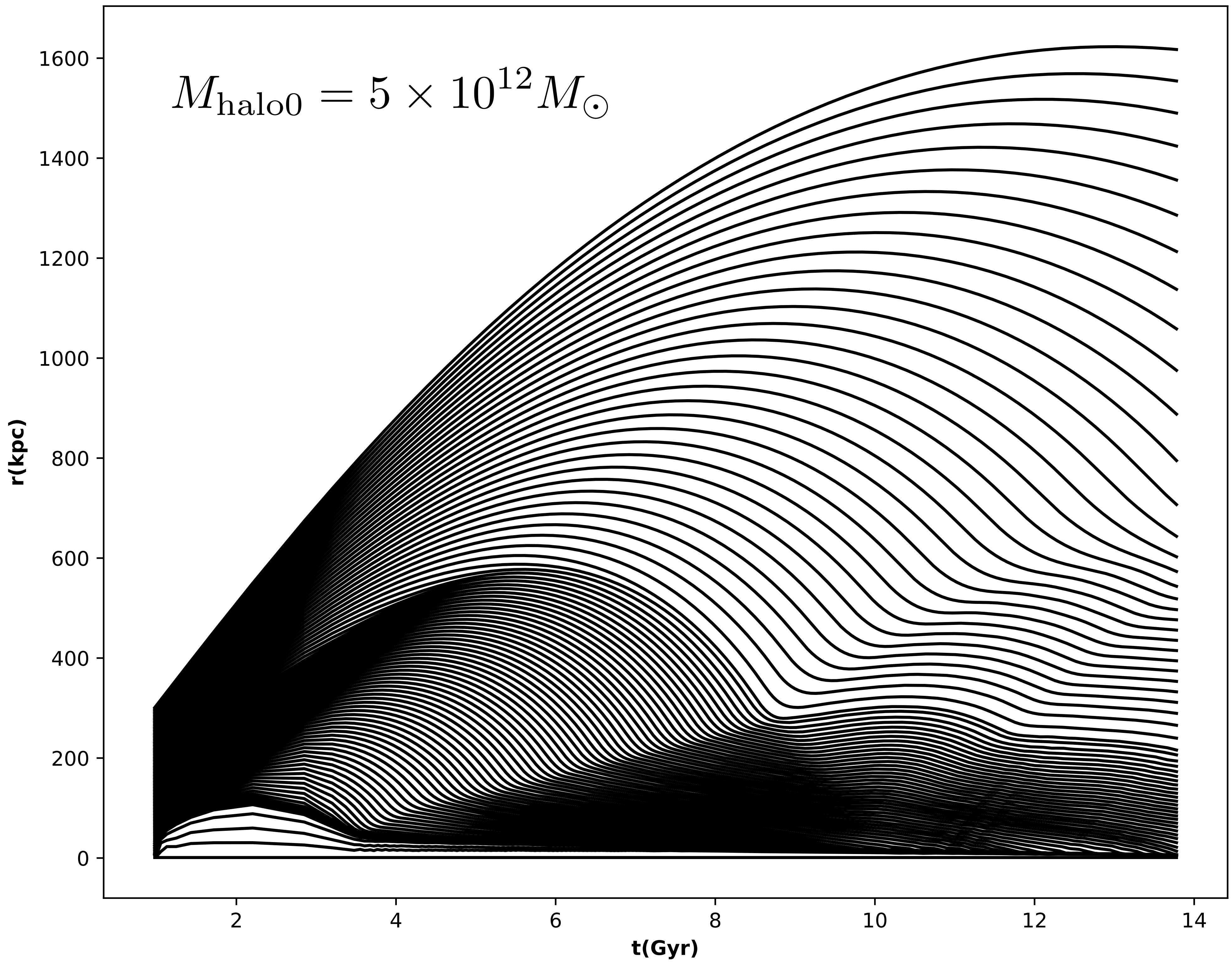
$$\epsilon_f = 0.005$$



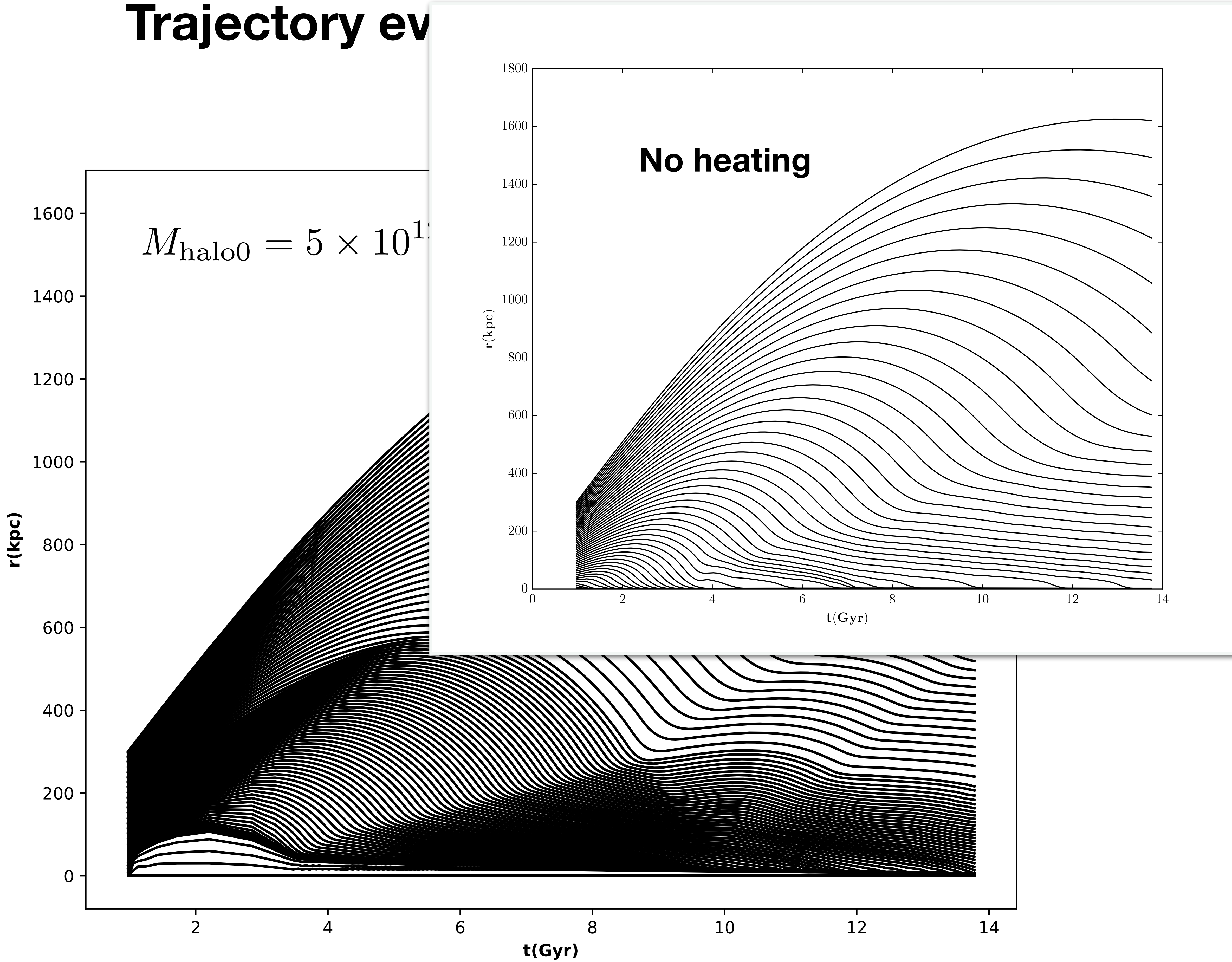

$$\dot{E}_{feed} 4\pi r^2 dr / \frac{4}{3}\pi R^3 = 3\dot{E}_{feed} r^2 dr / R^3$$

**Feedback energy only injected within R, assuming constant energy density**

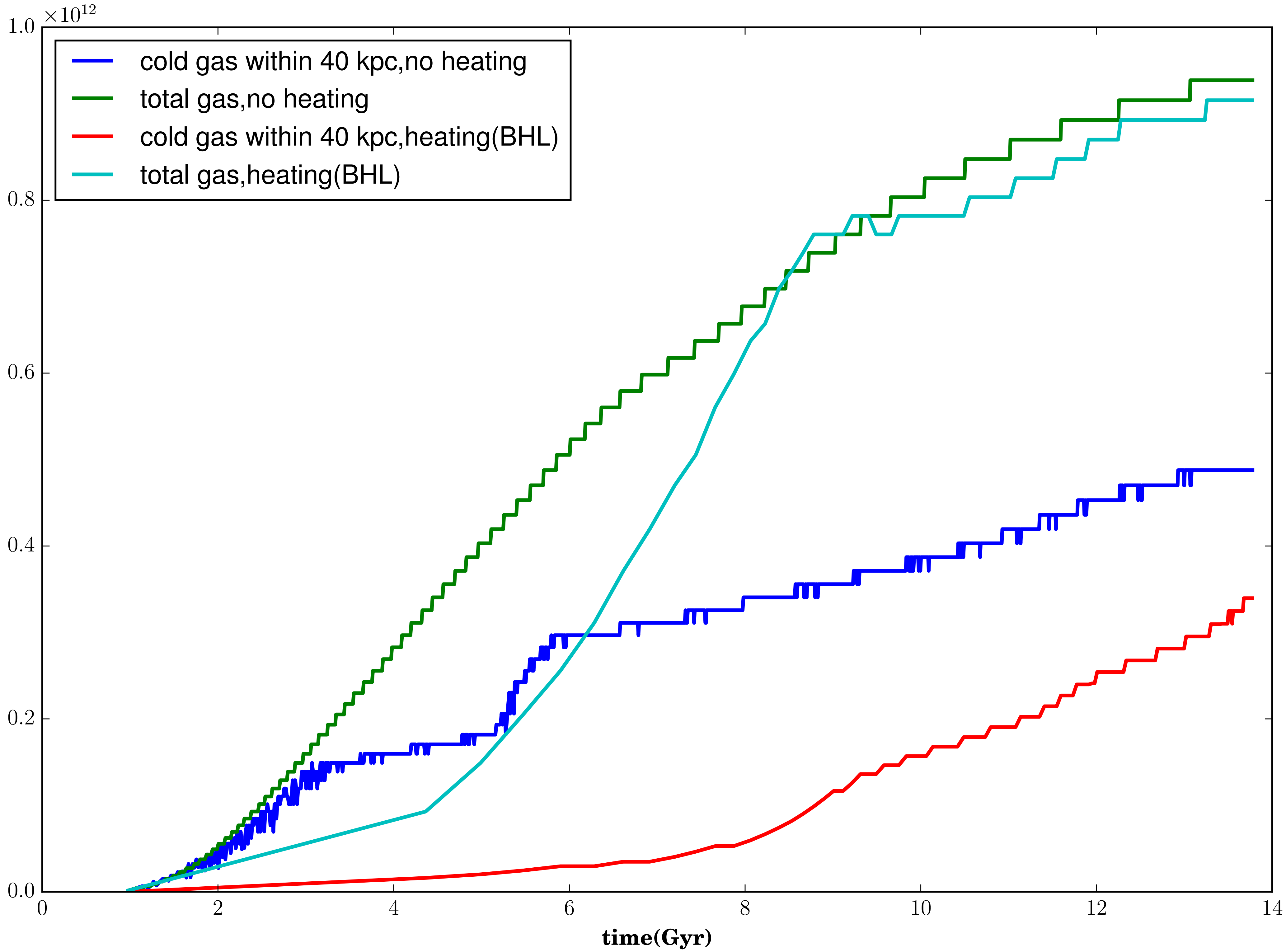
# Trajectory evolution with heating



# Trajectory ev



# Comparison of total mass accumulated and cold gas mass with and without heating



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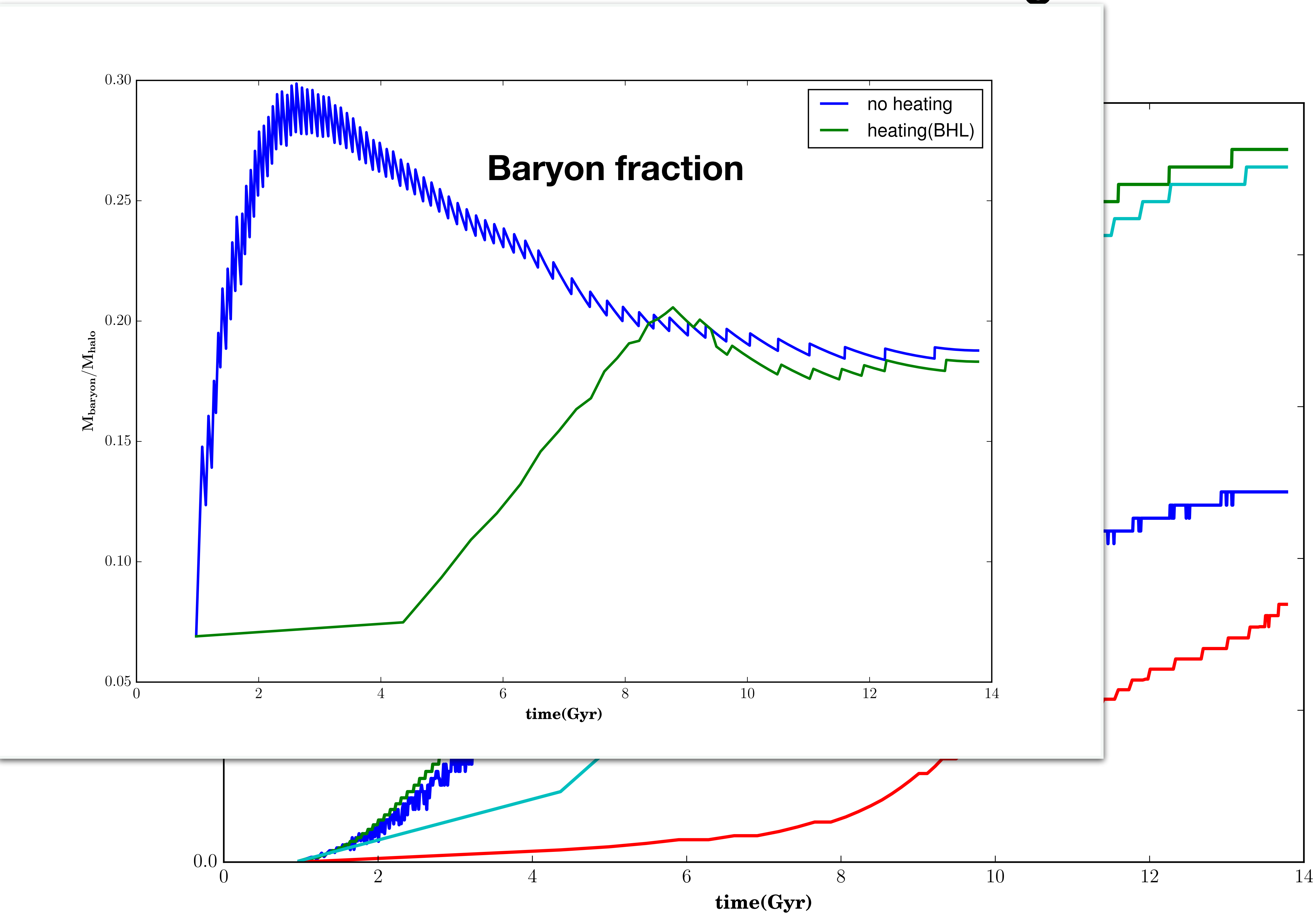
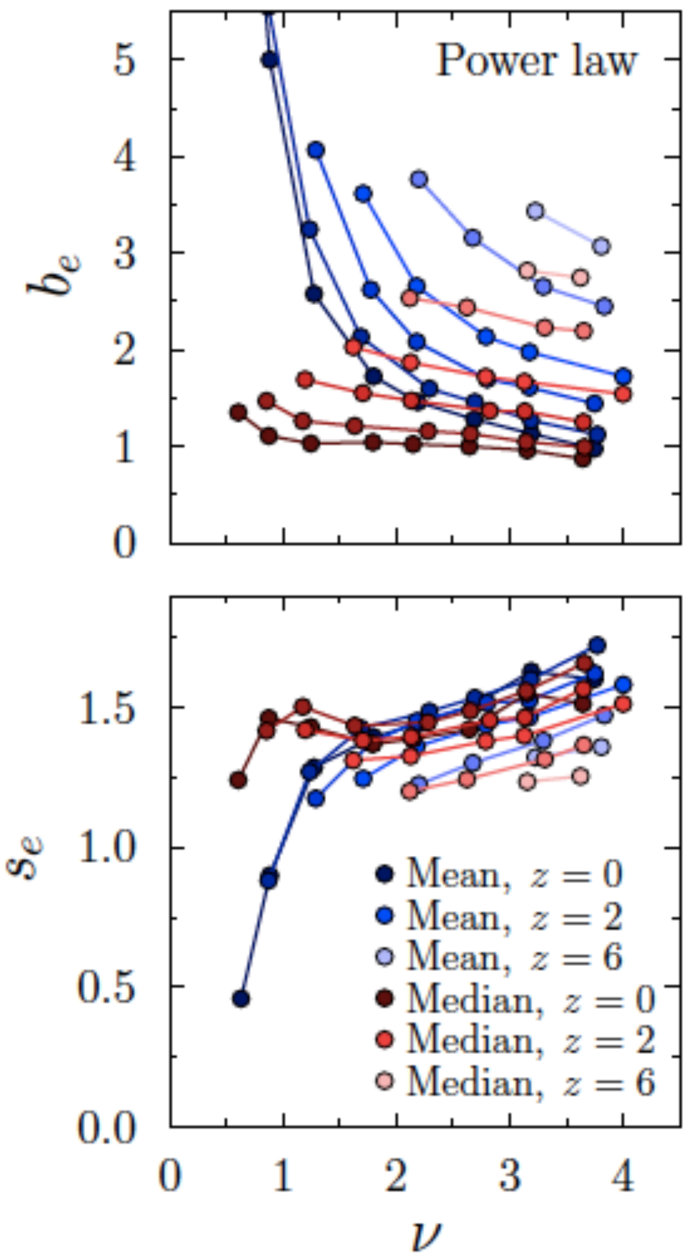


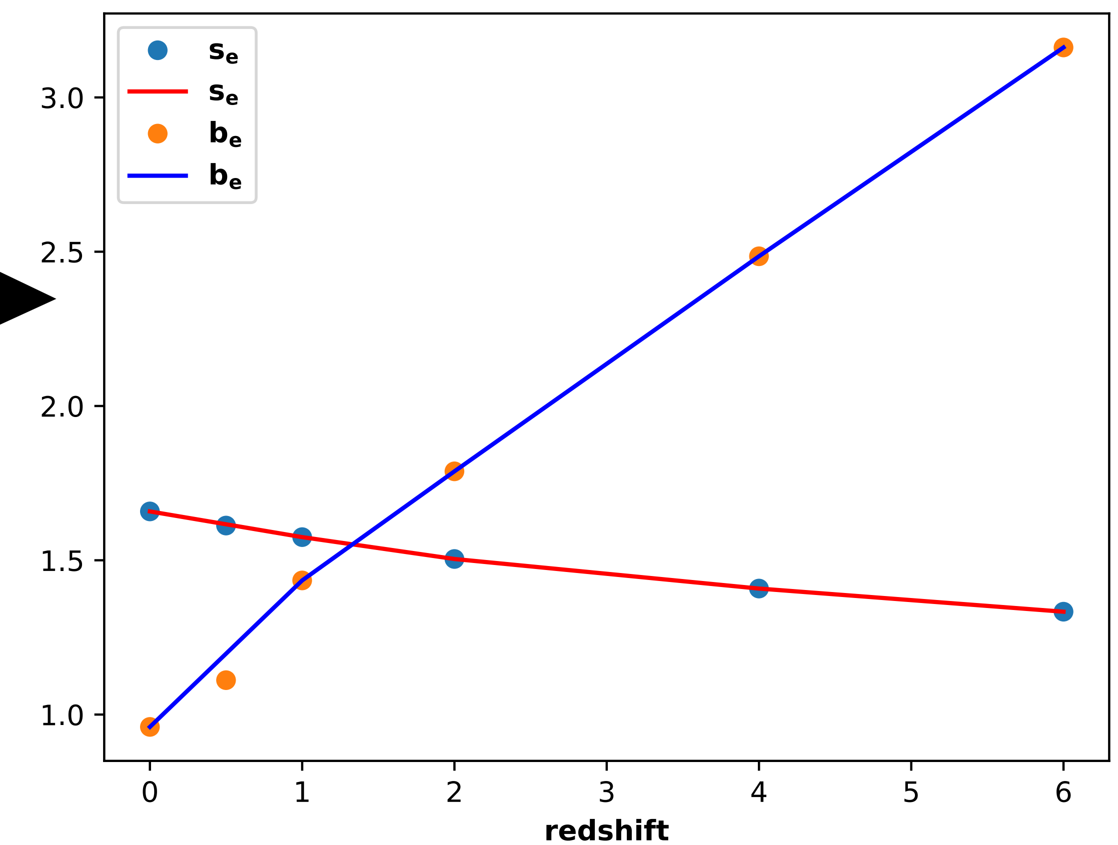
# New boundary and initial conditions following outer density fits of Diemer&Kravtsov,2014

$$\rho_{outer} = \rho_m(b_e(r/5R_{200m})^{-s_e} + 1)$$

**A fitting formula which along with a modified Einasto profile for the inner part of the cluster, makes the density profiles remarkably self-similar. We use the fit to the outer density profile only.**

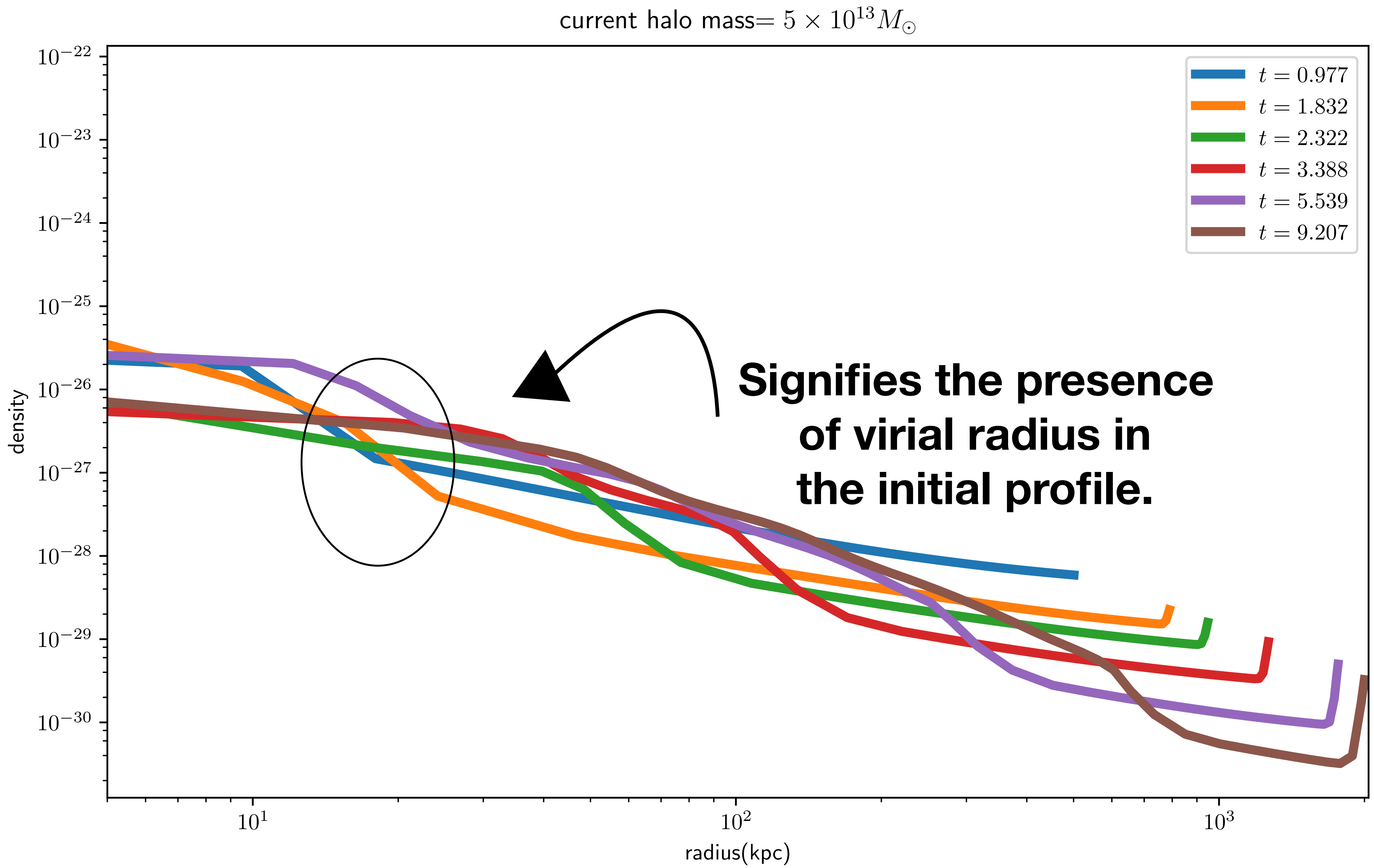


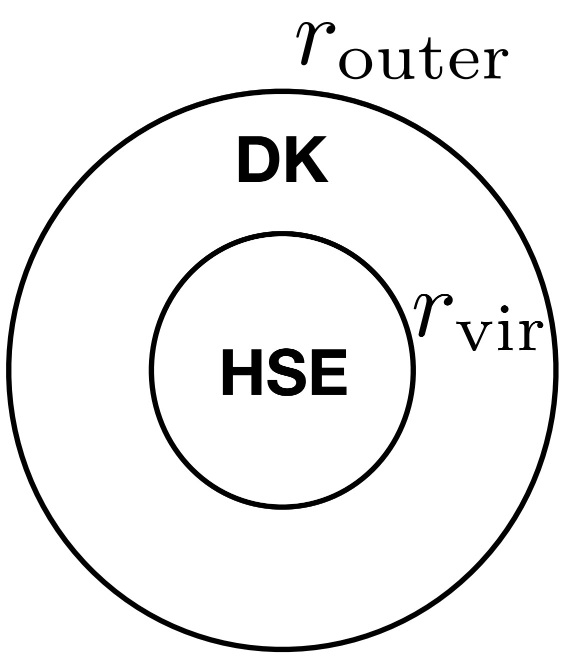

**A stronger variation with redshift. Hence we try to interpolate the parameters for a high value of peak height**



# New boundary and initial conditions following outer density fits of Diemer&Kravtsov,2014

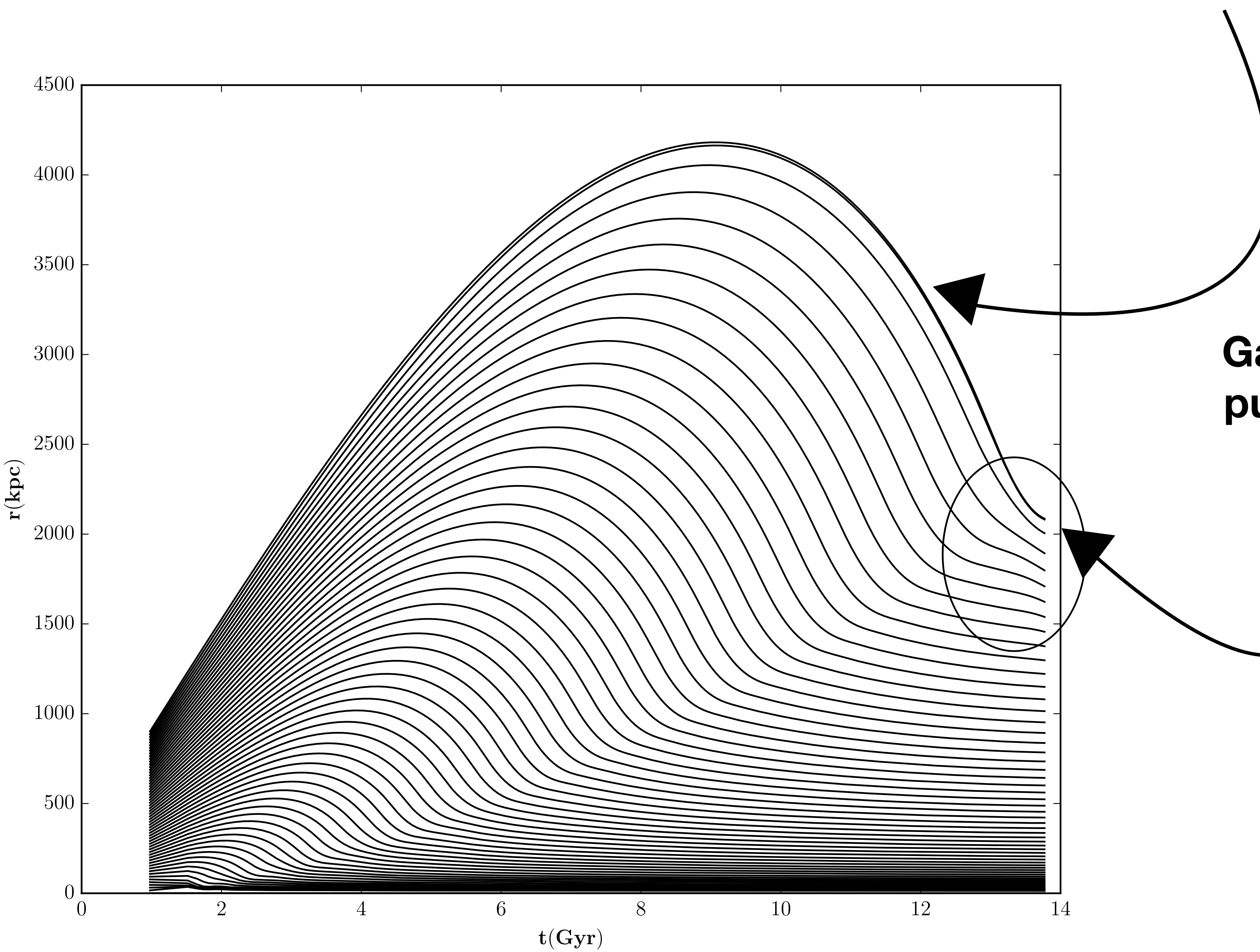
**Change in initial condition:** *Upto virial radius, hydrostatic profile, Beyond virial radius DK density profile multiplied by universal baryon fraction*
**Change in boundary condition:** *density in the outer boundary changes with time.*



# New boundary and initial conditions following outer density fits of Diemer&Kravtsov,2014

**How the trajectories evolve without cooling?**
**Only the outer shell seems to be denser than that without DK boundary.**




**Gas layers pushing in**

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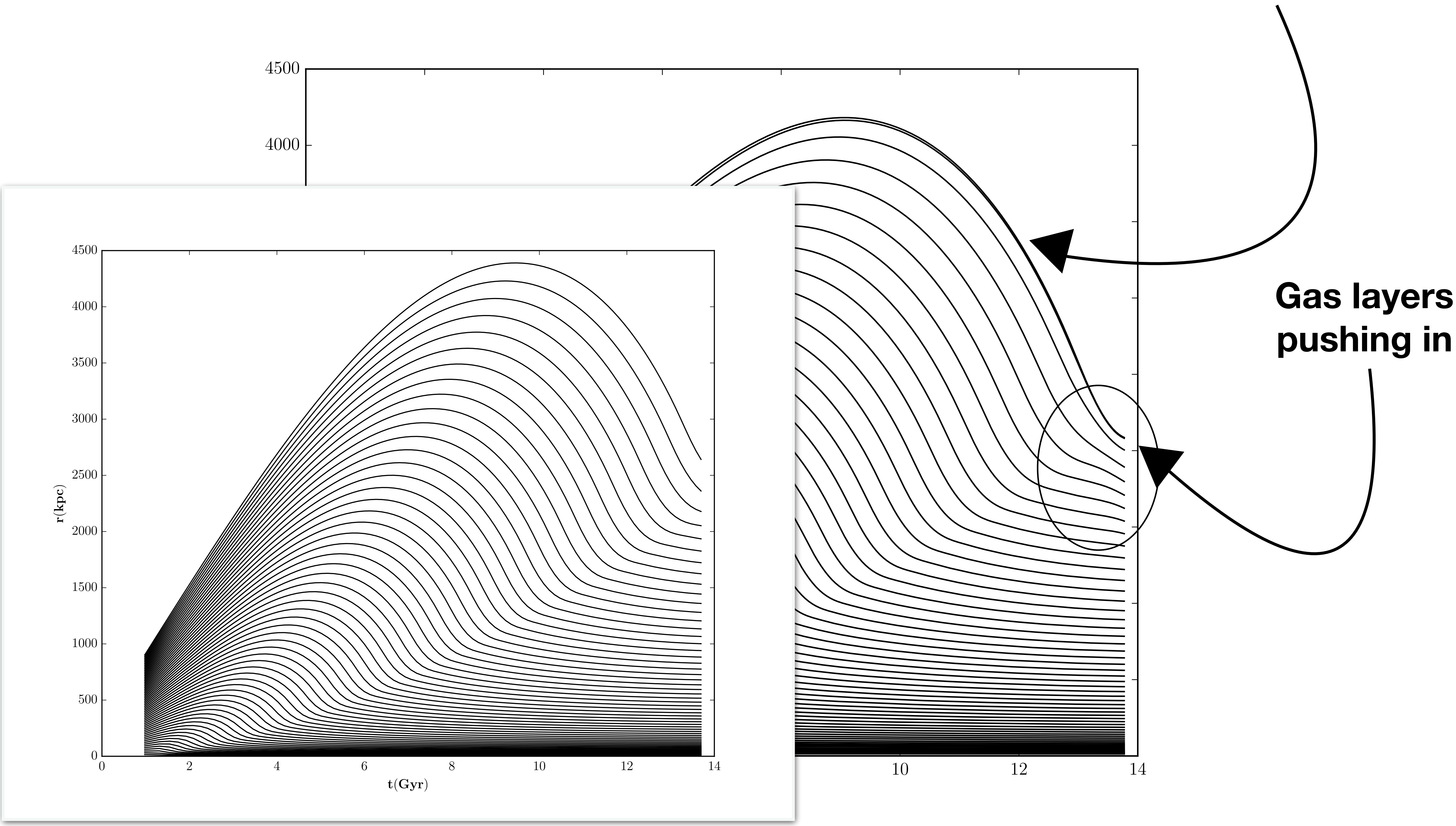
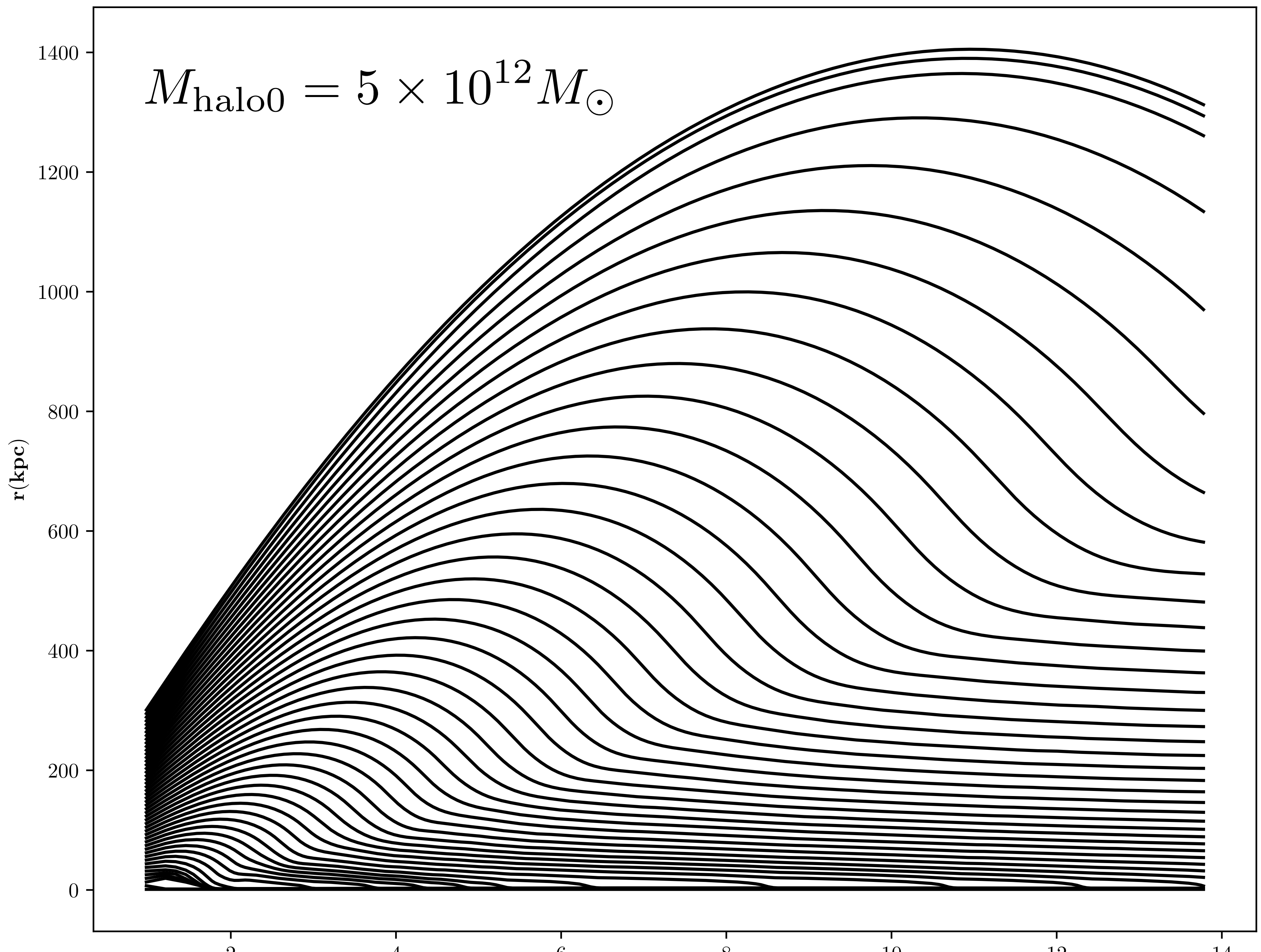


# New boundary and initial conditions following outer density fits of Diemer&Kravtsov,2014

## Trajectories with cooling



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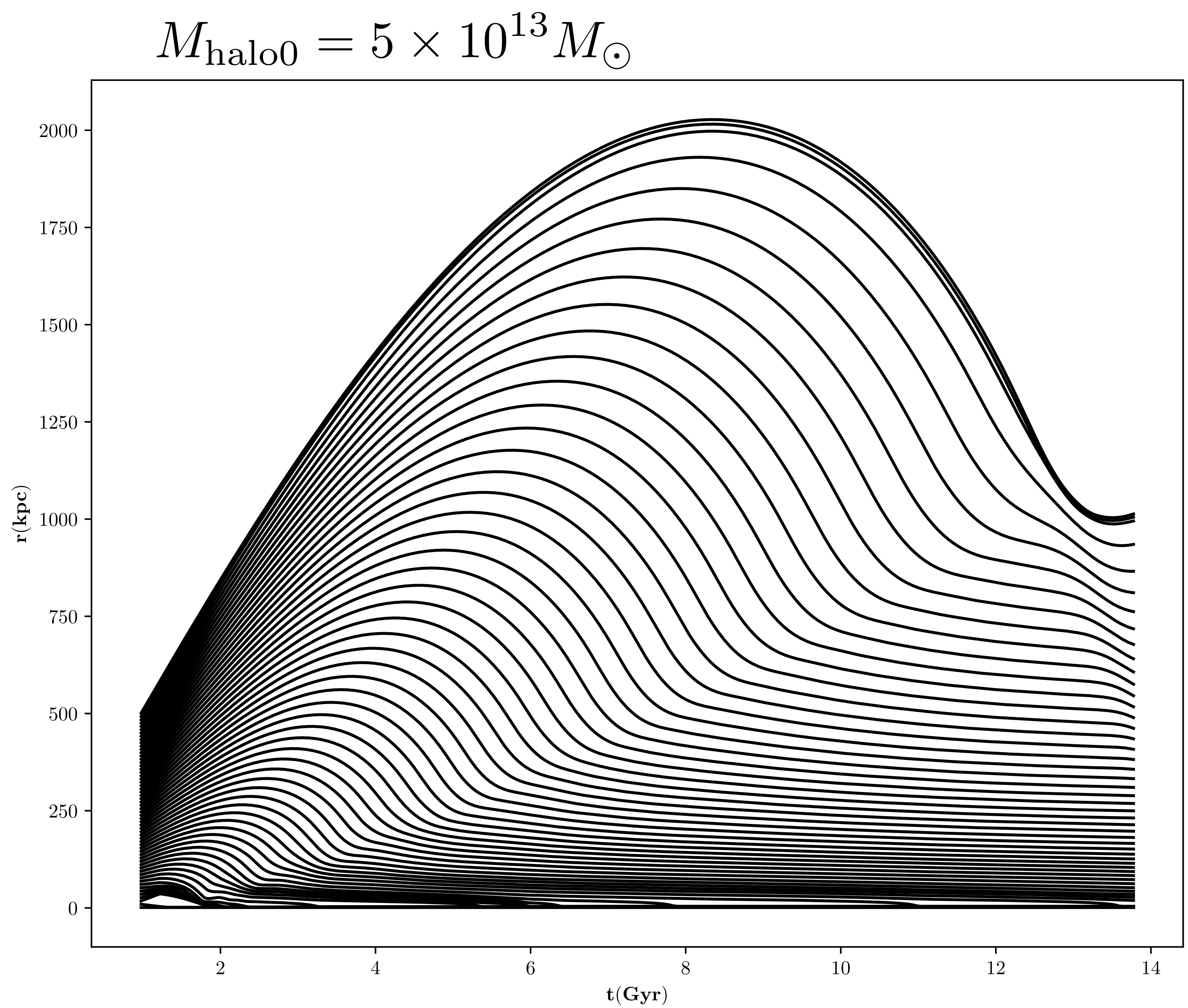


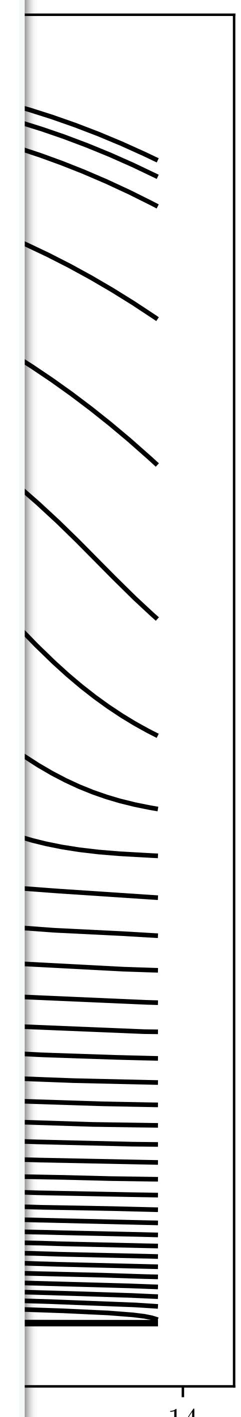

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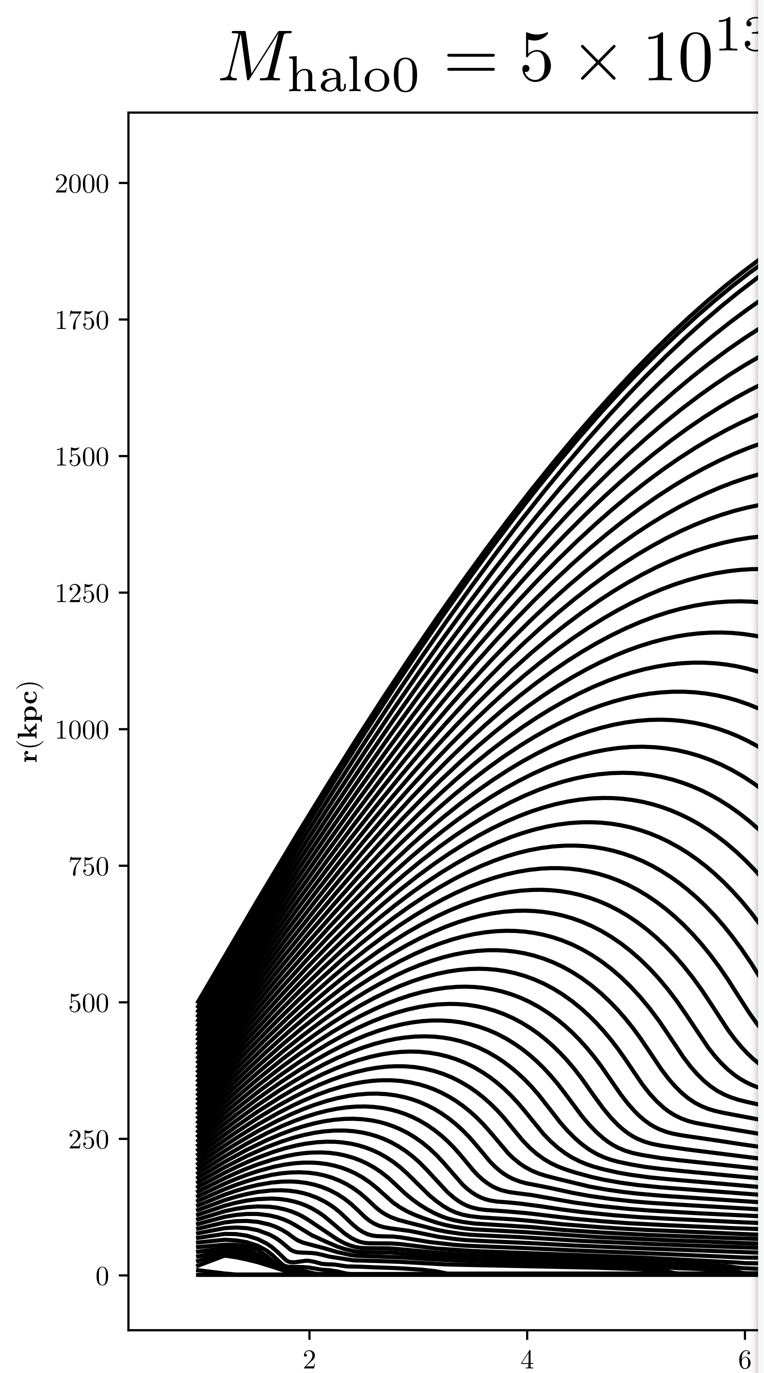


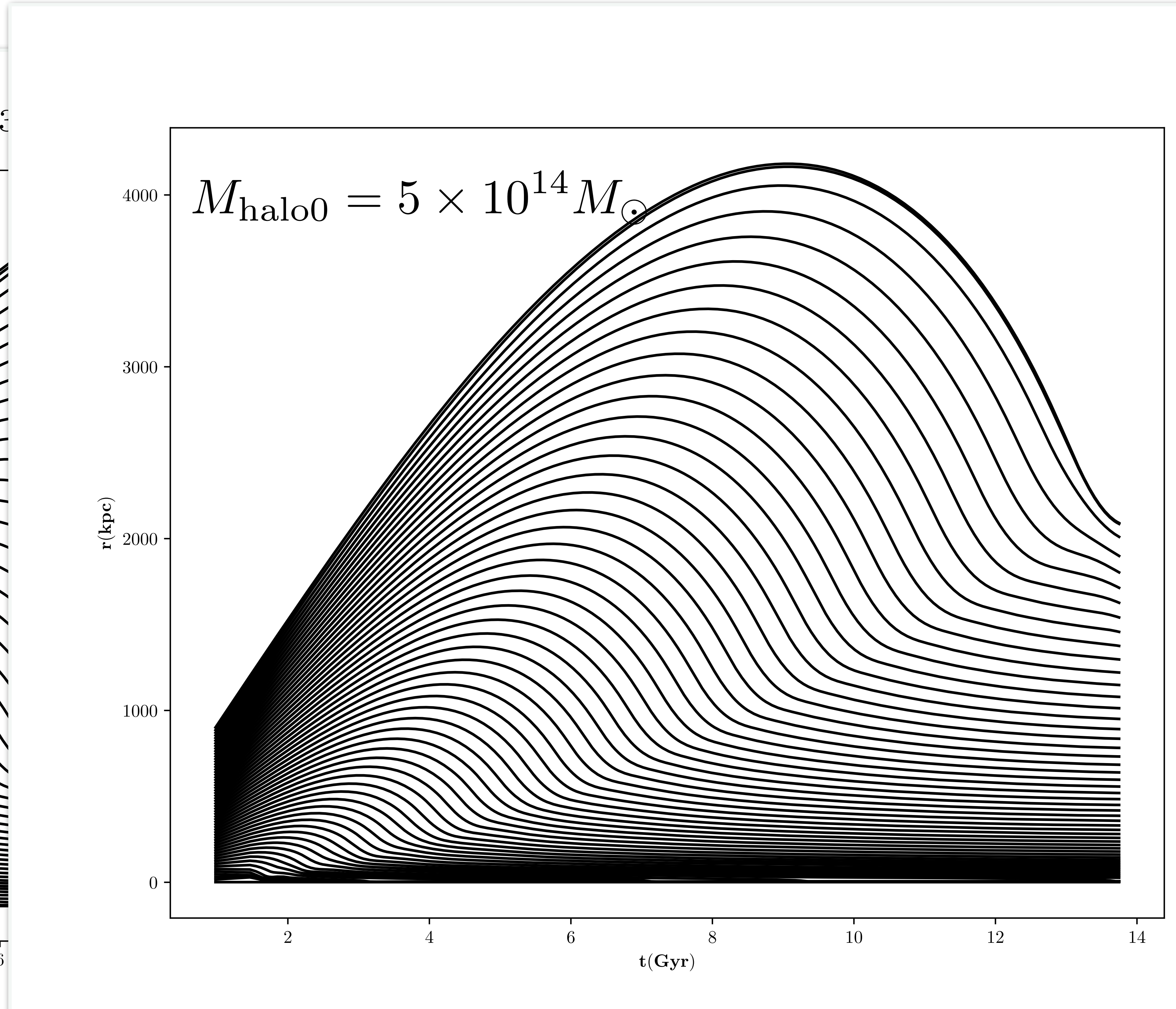

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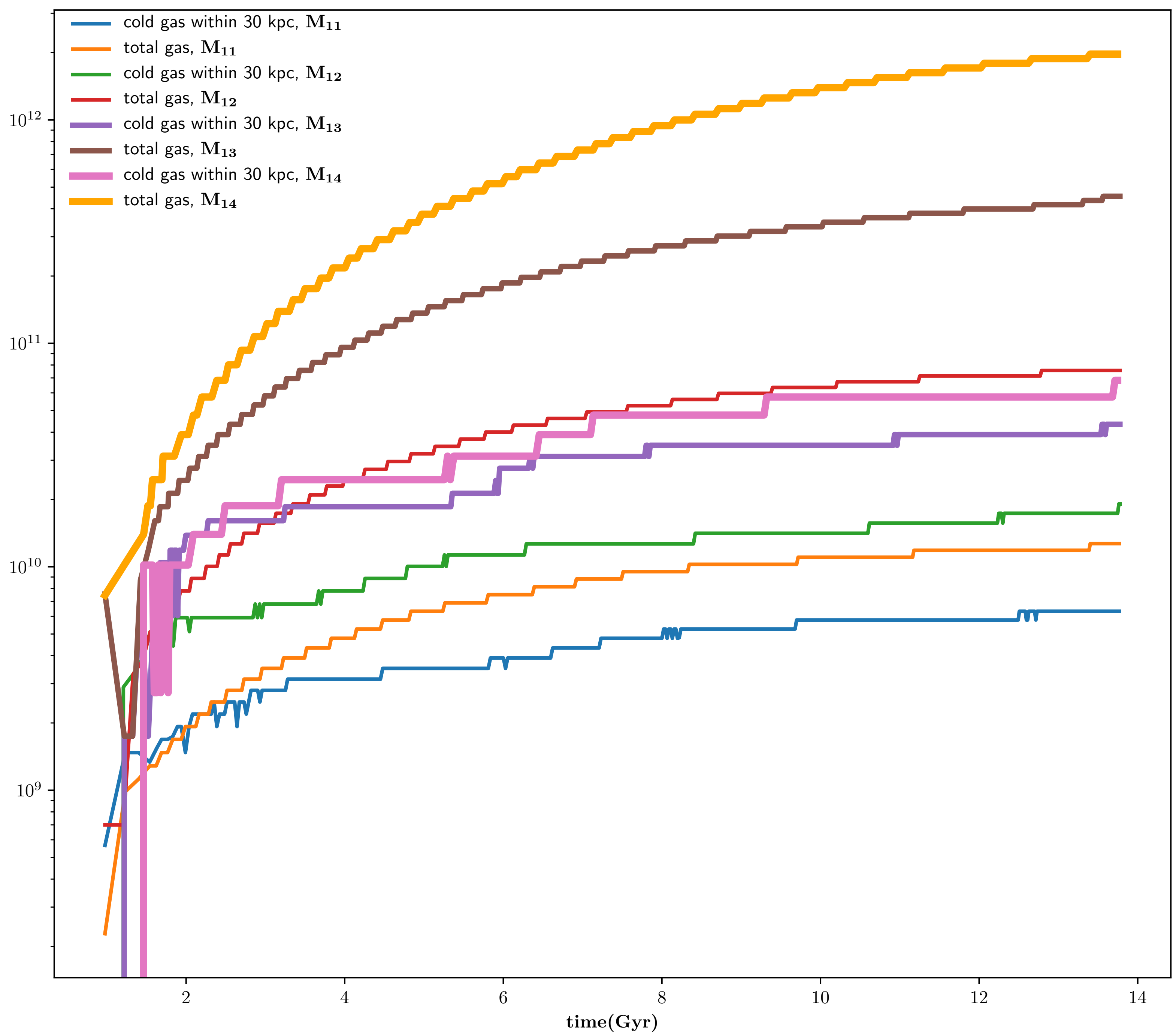

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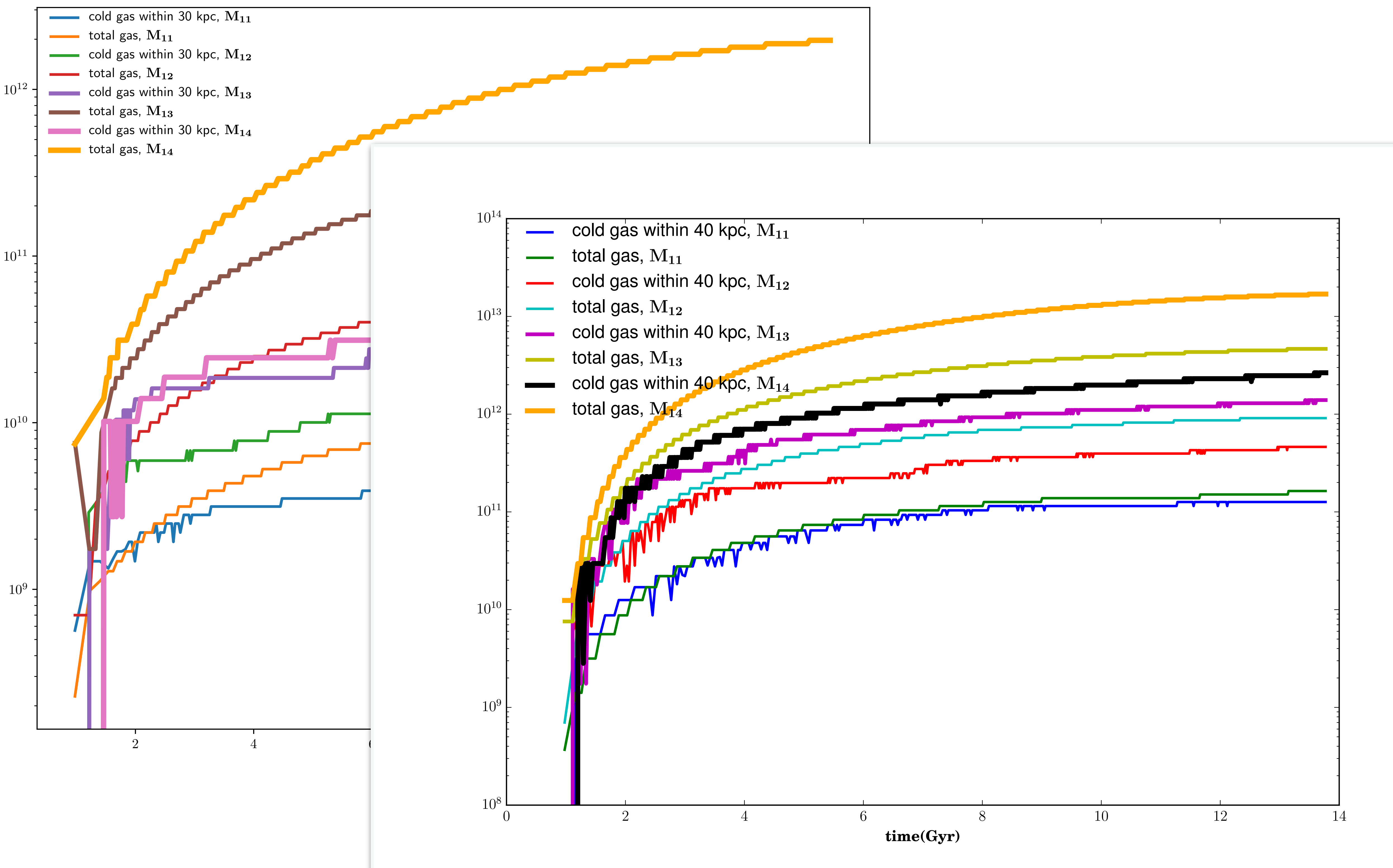

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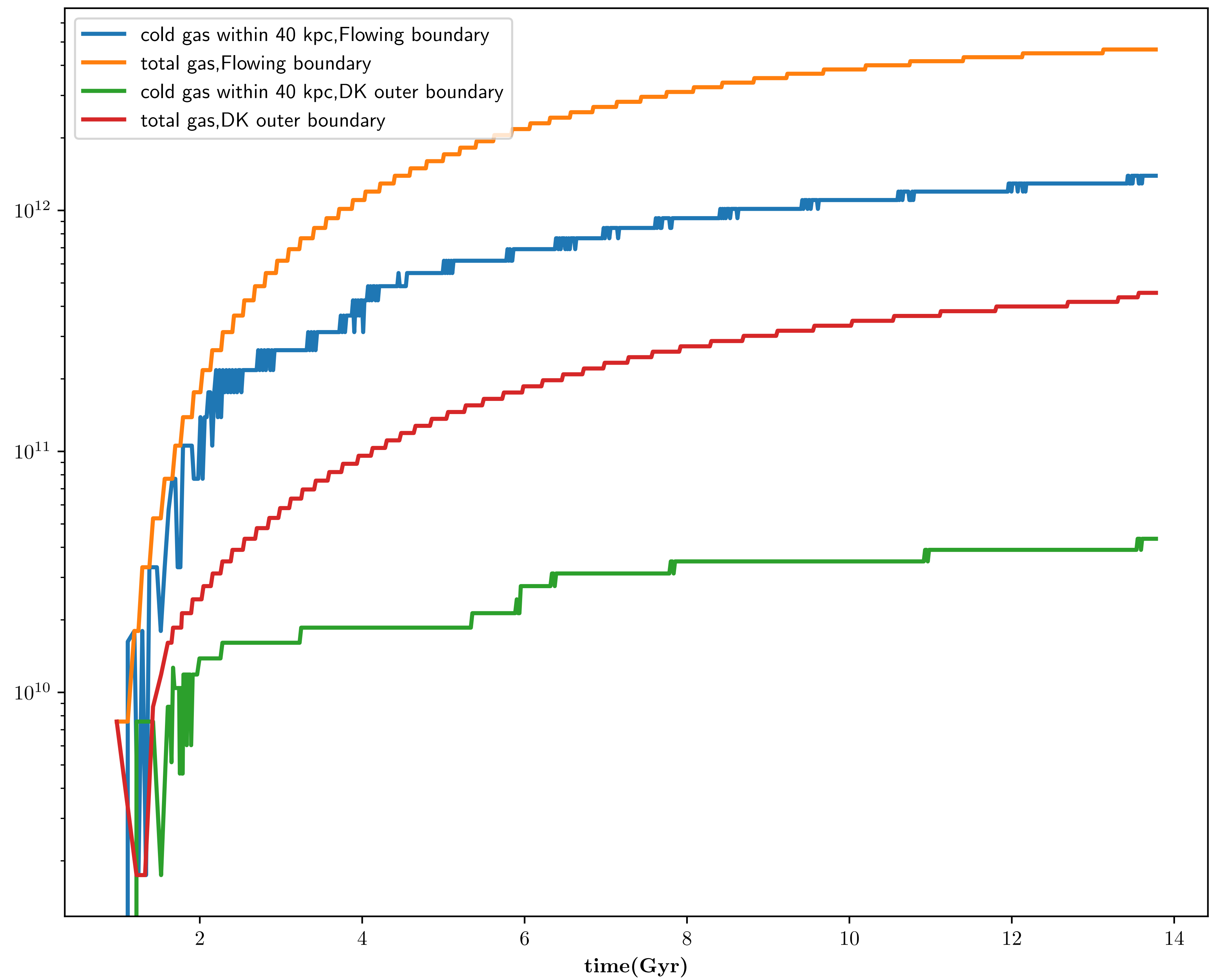

# On a final note

More experimentation with other heating mechanisms and some of the parameters could be done, like the radius within which feedback energy is driven in. Some mechanical energy could be injected as well in the form of feedback.

A transition from zero metallicity cooling to the cooling in the presence of metals could be added. That may not make a major difference in the low redshifts.

Some precise comparisons with observed data of the 1D profiles for cluster variables like density and temperature, are on the way.

Instead of incorporating an average history of DM halos, N-body simulations could provide the exact history for different halos. In such a situation it could be interesting to check if there is a difference in the total gas accreted or cold gas formed or find the CC and NCC dichotomy.