Master's thesis
Astrophysical Sciences

Supermassive black holes and the cosmological formation of massive early-type galaxies (title not final)

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Contents

1. Introduction

1.1 Information about galaxies, shortly

1.2 Aim of the thesis

2. Background

2.1 Cosmology

2.1.1 Hubble parameter, Friedmann equations and so on

2.1.2 Cosmological perturbations

2.2 Early-type galaxies

2.2.1 Types of ellipticals

2.2.2 Photometric and kinematic profiles

2.3 Feedback processes

3. GADGET-3 and KETJU

- Haven't really thought about the contents of this chapter yet

3.1 Overview of GADGET-3

3.2 Smoothed Particle Hydrodynamics

3.3 Gas cooling?

3.4 Feedback?

3.5 KETJU

4. Creating initial conditions for the cosmological simulations

This chapter focuses on the methods used to create the necessary configuration files for the high resolution cosmological simulations. First, we discuss the so-called zoom-in method, which allows us to have spatially large simulation boxes with high resolution regions. After this, we discuss the code MUSIC (MUlti-Scale initial conditions), which used to create a spatial volume with highly accurate velocity and density partuebations (the root-mean square (RMS) relative error being of the order 10^{-4}.) (SOURCE). The created initial conditions file is used for the performed GADGET3 simulations. As the runs performed with GADGET3 are the main focus of this thesis, the section for MUSIC is not as in-depth as the GADGET3 discussion in chapter 3. The last part of this chaper focuses on the setup of the cosmological setup of the simulations, and on the preliminary low resolution run needed for the higher resolution simulations.

4.1 Zoom-in technique

- Describe the technique ()
- benefits (takes cosmological environment into account, while also solving smaller sclae structure in a region we are interested in, computational power focused

in one region)

- figure showing multiple scales of refinement in a grid
- Maybe some information of earlier implementations of the technique/IC creation, leading up to MUSIC

4.2 MUSIC

4.2.1 Basic properties of MUSIC

4.2.2 Algorithms of MUSIC

- Short section on how MUSIC generates initial particle positions, velocity fields and so on (basically summary of the first few sections of the MUSIC paper)

4.2.3 Creating an IC-file with a zoom-in box

- Step by step explanation of creating the IC file with a zoom-in region

4.3 GADGET-3 setup for the zoom-in -simulations

4.3.1 Cosmological setup

4.3.2 Low-resolution run

4.3.3 Choosing the zoom-in regions

- FoF -algorithm
- Conditions of the chosen halos
- Figure showing the zoom-in regions from the low res run

4.3.4 Initial conditions

h_0	Ω_m	Ω_b	Ω_Λ	σ_8	ρ_{crit}
70.3	0.276	0.045	0.724	0.811	9.28×10^{-27} kg/m^3

Table 4.1: Cosmological parameters used for the simulations. If a simulation doesn't include baryons, the dark matter density parameter Ω_{DM} is equal to the matter density parameter Ω_{m}. If baryons are included, $\Omega_{\mathrm{DM}} = \Omega_{\mathrm{m}} - \Omega_{\mathrm{b}}$.

- Information from GADGET3 config files

5. Cosmological GADGET-3 simulations

5.1 Computational load of the simulations

- Quick overview: CPUs used, time elapsed, where simulations were run

5.2 Locating galaxy centers: the shrinking sphere -method

5.3 Properties of the galaxies

Simulation	$r_{\rm vir}$ (kpc)	M_* ($M_\odot$)	$M_{\rm V}$ (mag)	$M_{*,\rm gal}/M_{\rm vir}$	$M_{\rm bh}$ ($M_\odot$)
Med res, A	517	3.98×10^{11}	-22.4	0.025	5.82×10^{9}
Med res, B	574	5.16×10^{11}	-22.7	0.024	6.23×10^{9}
Med res, C	400	2.56×10^{11}	-22.0	0.035	3.96×10^{9}
High res, A	526	5.31×10^{11}	-22.6	0.032	3.64×10^{9}
High res, B	578	6.38×10^{11}	-22.8	0.029	4.54×10^{9}
High res, C	400	3.46×10^{11}	-22.2	0.047	2.80×10^{9}

Table 5.1: Properties of the zoomed-in galaxies at redshift $z = 0$.

5.3.1 Rotation curves

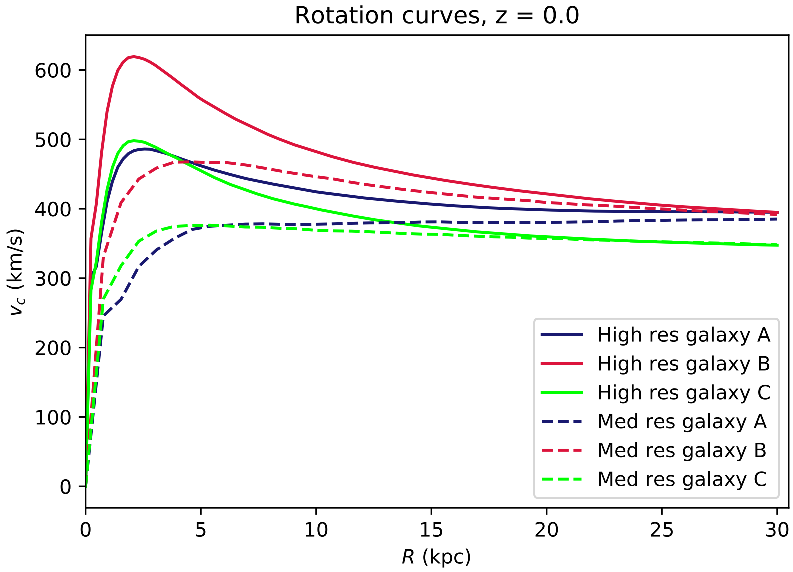

Figure 5.1: Rotation curves for each galaxy including baryons, at redshift 0. The continuous lines represent the high resolution simulations and the dasheld lines represent the medium resolution simulations.

- Med res galaxy A simulation is performed with single precision, I'm currently doing the simulation in double precision
- Rotation curves do not have the same limits on the y-axis

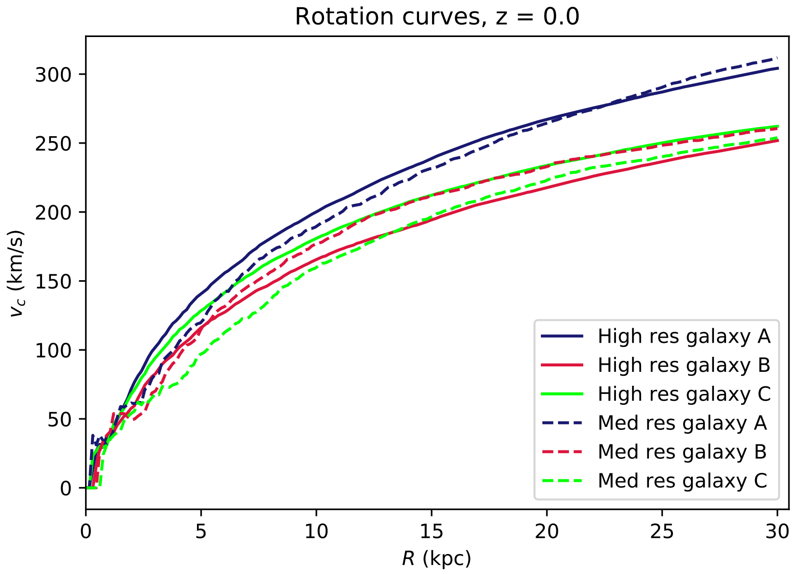

Figure 5.2: Rotation curves for each galaxy including only dark matter, at redshift 0. The continuous lines represent the high resolution simulations and the dasheld lines represent the medium resolution simulations.

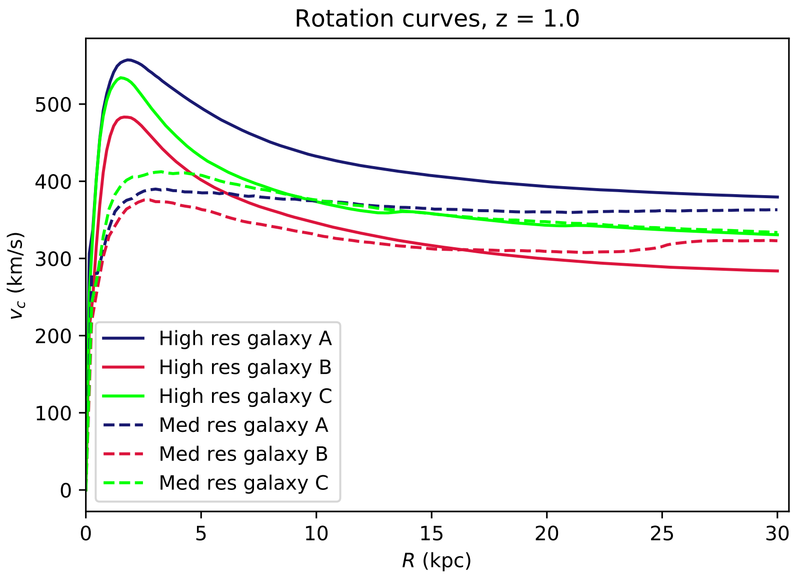

Figure 5.3: Rotation curves for each galaxy including baryons, at redshift 1. The continuous lines represent the high resolution simulations and the dasheld lines represent the medium resolution simulations.

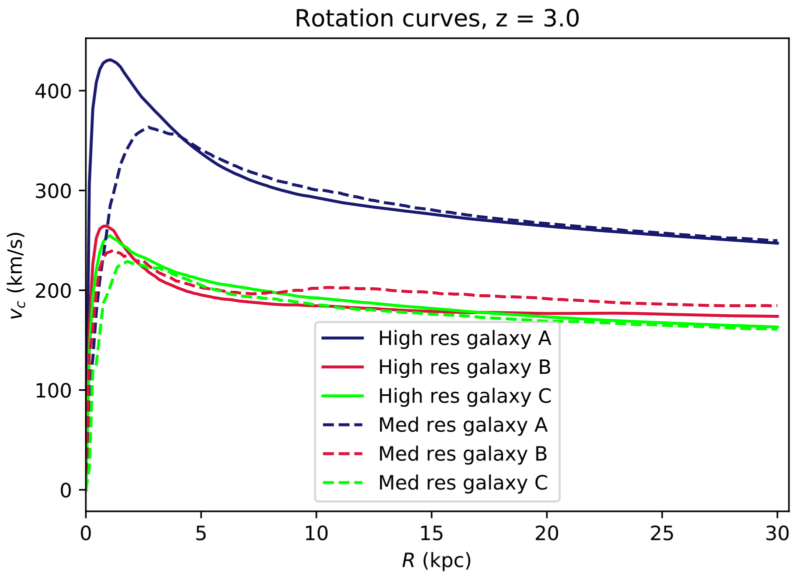

Figure 5.4: Rotation curves for each galaxy including baryons, at redshift 3. The continuous lines represent the high resolution simulations and the dasheld lines represent the medium resolution simulations.

5.3.2 Star formation history

- The stellar mass evolution plot is not yet done for high res simulations.
- Redshifts missing from the stellar mass evolution plot
- SFRs, also histograms?
- Again, med res A results will probably change a bit when double precision run is finished.
- Formation efficiencies, comparing to the cosmological parameter

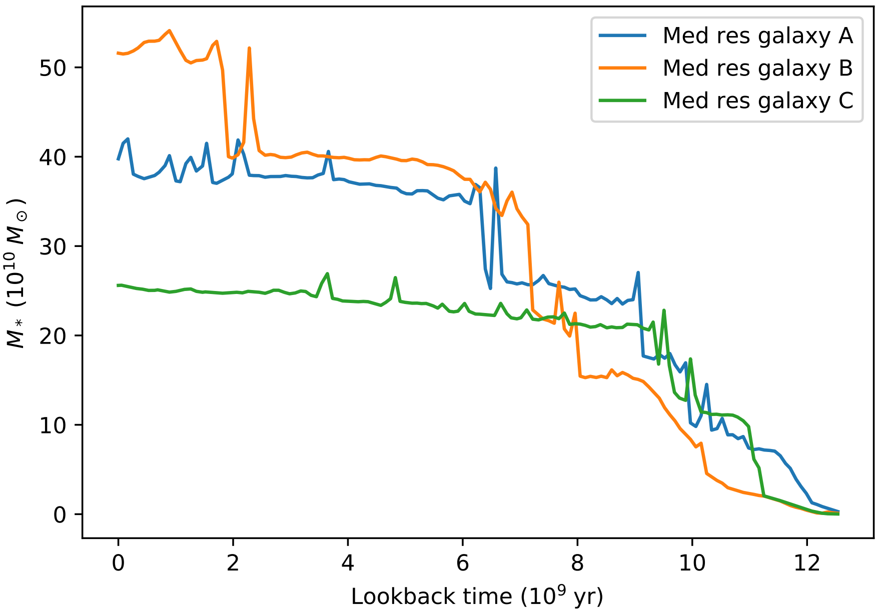

Figure 5.5: Stellar mass evolution for the medium resolution galaxies. The calculated stellar mass is the stellar mass within $r_{\text{gal}} = r_{\text{vir}}/10$.

5.3.3 Colors and magnitudes

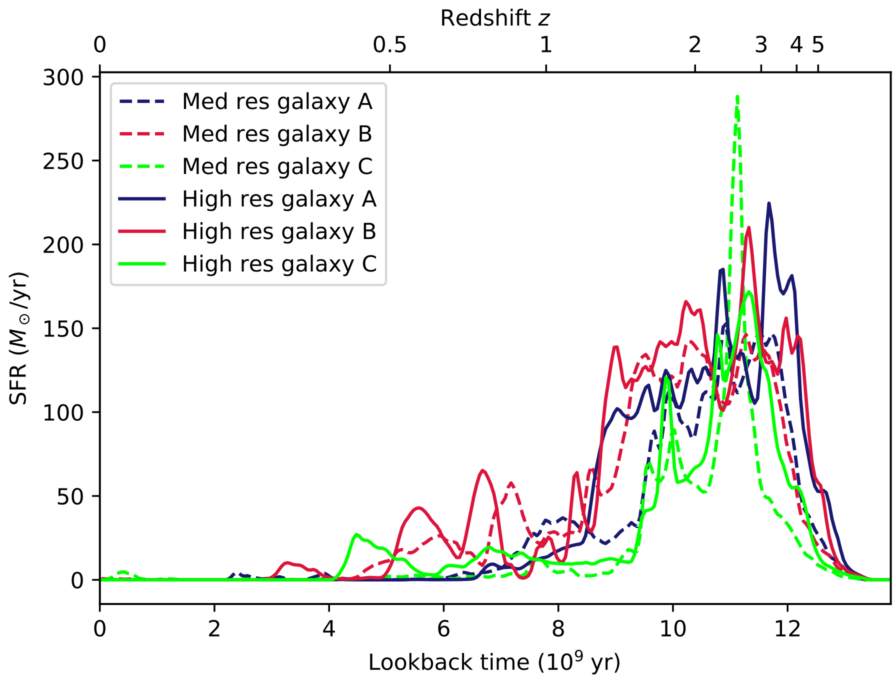

Figure 5.6: Stellar for mation rates for each zoomed-in galaxy, plottes ad a function of lookback time. The lines are created from histograms having a length of 5 Myr, which are then smoothed. The continuous lines represent the high resolution simulations and the dasheld lines represent the medium resolution simulations.

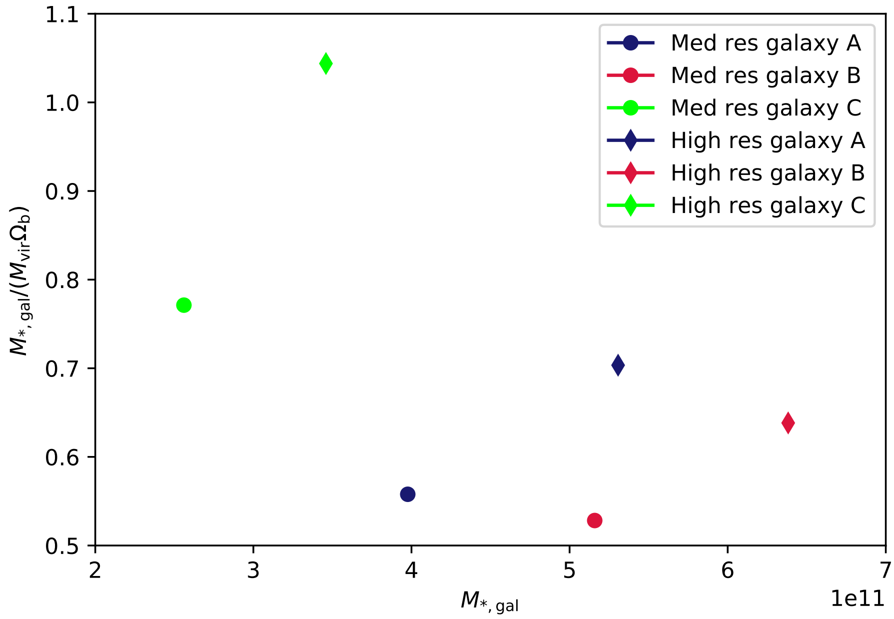

Figure 5.7: Galaxy formation efficiencies for each galaxy, plotted with their stellar masses. The cosmological baryon density Ω_{b} is set to 0.045 in the simulations. The diamond and circular markers show the results of the high resolution and the medium resolution zoom-in simulations, respectively.

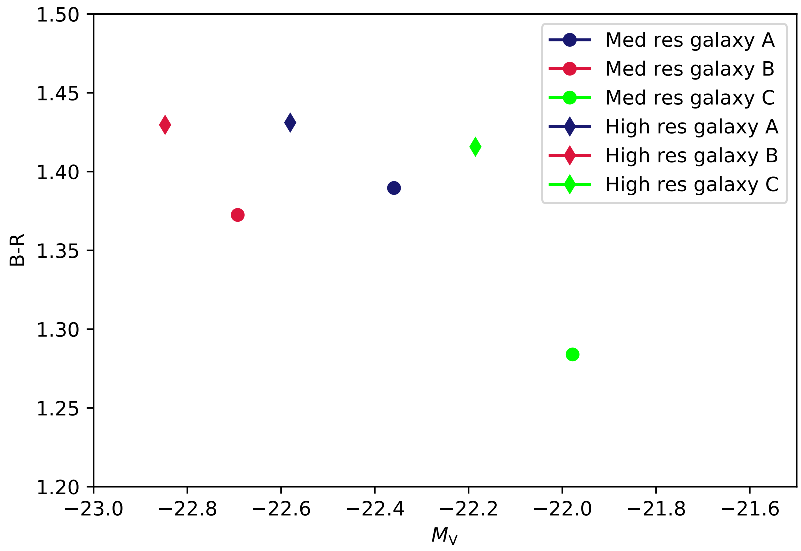

Figure 5.8: B-R colors for each simulated galaxy, plotted with each galaxy's absolute magnitude in the V-band. The diamond and circular markers show the results of the high resolution and the medium resolution zoom-in simulations, respectively.

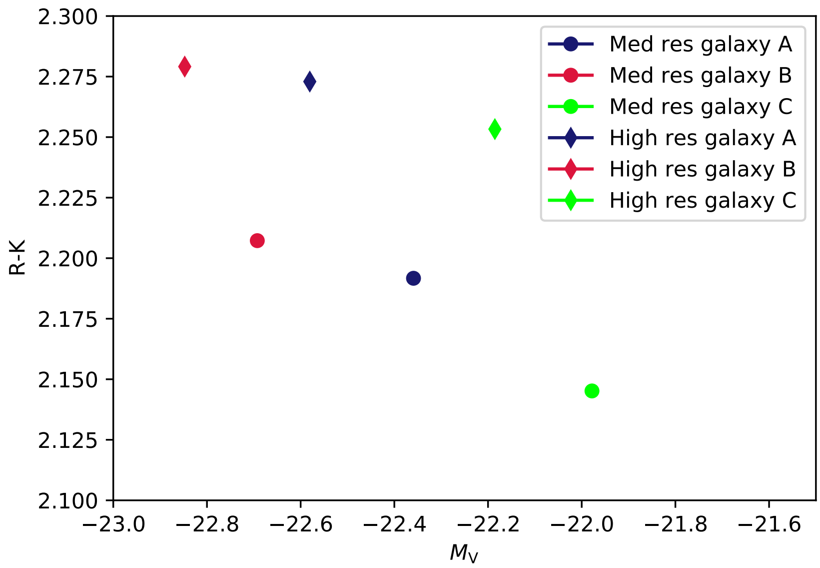

Figure 5.9: R-K colors for each simulated galaxy, plotted with each galaxy's absolute magnitude in the V-band. The diamond and circular markers show the results of the high resolution and the medium resolution zoom-in simulations, respectively.

6. Simulations with KETJU

7. Conclusions

- recap on what was written/studied
- more own thoughts on results
- future missions
- how could the simulations be more realistic (higher resolution, more feedback stuff?)