SURGE Numerical Analysis

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1 Introduction

Now that we are done with a preliminary exercise consisting of calculation of density profiles of concentric shells through a Random and Gaussian Distribution, we have moved on to analyzing real world numerical simulation data and extracting meaningful results from it. We have used the Sahaydri simulation data to determine halos and perform calculations on it.

2 Numerical Analysis

Using 2 files on the github repository of the simulation particularly **- out_200.trees** and **snapshot_200.hdf5** we identify the primary halos that are useful for us and then extract the number of point masses that exist within that particular halo.

2.1 Halo Identification

The file `out_200.trees` contains a wealth of information about halos identified in the simulation. Some of the key physical properties recorded for each halo include:

- **Virial Mass** (`Mvir`) – the total mass within the virial radius.
- **Virial Radius** (`Rvir`) – the radius enclosing the virial mass.
- **Scale Radius** (`rs`) – the characteristic radius from NFW profile fitting.
- **Maximum Circular Velocity** (`Vmax`) – the peak of the circular velocity curve.
- **Velocity Dispersion** (`vrms`) – a measure of the internal random motion of particles.
- **Position** (`x, y, z`) – the center of the halo in comoving coordinates.
- **Center-of-Mass Velocity** (`vx, vy, vz`) – the bulk velocity of the halo.
- **Angular Momentum** (`Jx, Jy, Jz`) – the total angular momentum vector of the halo.

We assumed a certain mass threshold = 10^{14} and filtered all the haloes based off of it, that is, consider only the halos that are above the mass threshold.
This gave us the following halos that meet our criteria :

Mvir	Rvir	x	y	z	vx	vy	vz
9.243	1976.273	189.25	136.15	120.90	276.29	-72.89	-23.05
6.868	1789.999	178.82	111.75	23.02	345.16	-75.54	362.27
6.476	1755.210	198.29	16.61	43.09	42.14	-398.44	-47.94
5.866	1698.362	8.12	135.75	83.85	-220.10	206.76	206.37
5.585	1670.795	149.33	174.44	99.42	55.66	-243.98	-193.63

Table 1: Virial mass, virial radius, position, and velocity components of selected halos.

2.2 Determining Points inside Halo

For this part we will only choose a halo from those detected, the one with **Mvir** $= 9.243$ and perform the calculation for it.
This halo has the following properties : The second file **snapshot_200.hdf5** has the information about

Property	Value
M_{vir}	$9.243\,M_{\odot}/h$
R_{vir}	$1976.273\,\text{kpc}/h$
x	$189.24596\,\text{Mpc}/h$
y	$136.15475\,\text{Mpc}/h$
z	$120.90205\,\text{Mpc}/h$
v_x	$276.29\,\text{km/s}$
v_y	$-72.89\,\text{km/s}$
v_z	$-23.05\,\text{km/s}$

Table 2: Properties of the selected dark matter halo.

various points in the numerical simulation, particularly their centre of mass and velocities. Assuming the halo to be a sphere with radius equal to virial Radius, we can check which points lie within the halo using a mask and we get the following :

```
Number of particles within radius: 131657
First 5 positions:
[[189.25424  136.34824  120.88043 ]
 [189.23906  136.35173  120.860435]
 [189.24187  136.37282  120.87555 ]
 [189.21852  136.36864  120.86115 ]
 [189.22015  136.36383  120.86505 ]]
First 5 velocities:
[[-331.90327744 -708.06733643 1205.3501709 ]
 [  14.22983643 -508.4672998   401.73969727]
 [1144.71427246  176.55889191 -170.10841675]
 [ 572.64530273  701.0596167  -924.98875732]
 [1133.83158203 -333.49882446  -54.72059174]]
```

Figure 1: List of points within a Halo

3 Density Calculation

Now that we have the various points within the halo, we create bins of varying radius to calculate the density of each concentric shell. We divide the total radial distance logarithmically, starting from a minimum value of 10^{-2} Mpc up to the virial radius. We know the mass of each particle in the simulation is equal to $4.15153252\ M_{\odot}$, so we can easily compute the density of each shell as follows: first, we count the number of particles within each radial shell. Then, we multiply this count by the mass per particle to obtain the mass contained in each shell. Finally, we divide the mass of each shell by its corresponding volume to obtain the density:

$$\rho_i = \frac{N_i \times m_{\text{particle}}}{\frac{4}{3}\pi \left(r_{i+1}^3 - r_i^3\right)}$$

where N_i is the number of particles in the i^{th} shell, m_{particle} is the mass of each particle, and r_i, r_{i+1} are the inner and outer radii of the shell respectively.

Using the above formula we get the following graph for the density plot, both the axes are in logarithmic scale.

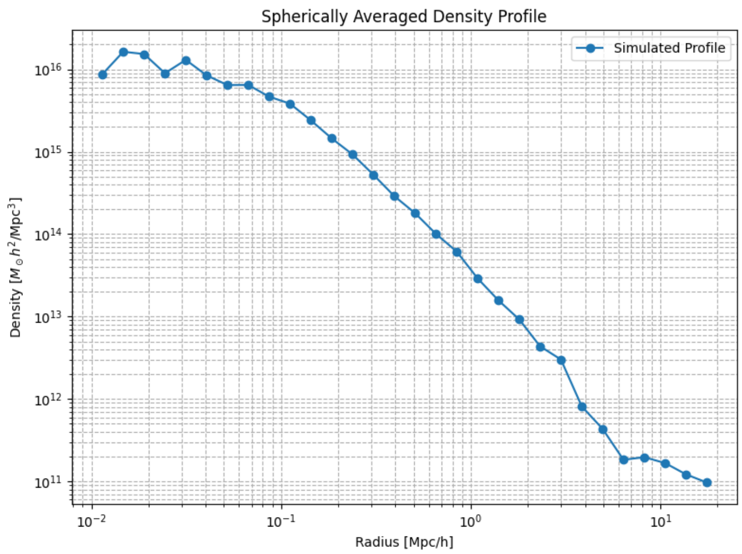
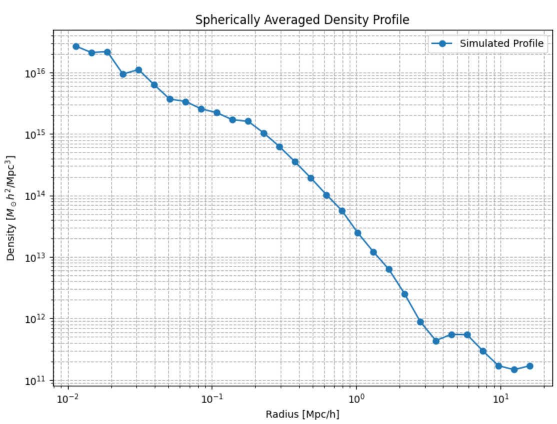
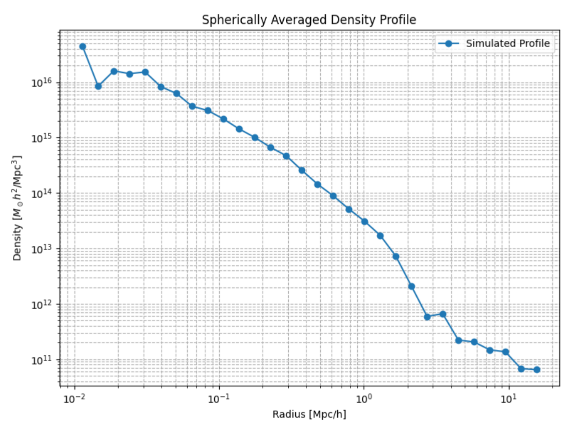


Figure 2: Density Plot for Halo 1

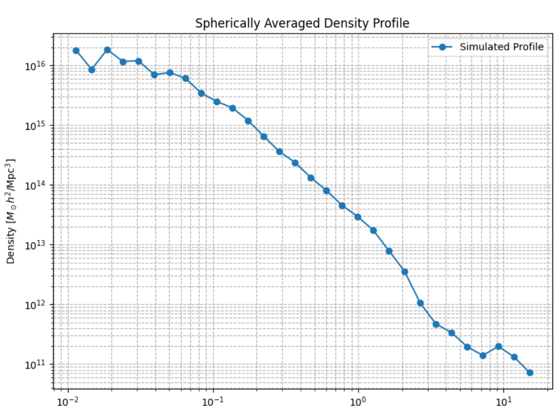
4 Plots for various Halos



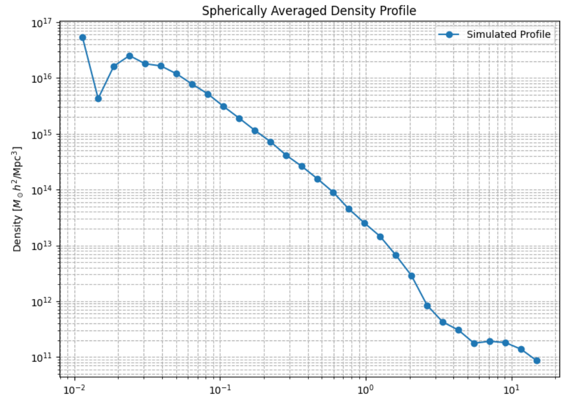
(a) Halo 2



(b) Halo 3



(c) Halo 4



(d) Halo 5

Figure 3: Spherical density profiles for four different halos.