Convergence Tests and Applications of SIDM Simulations

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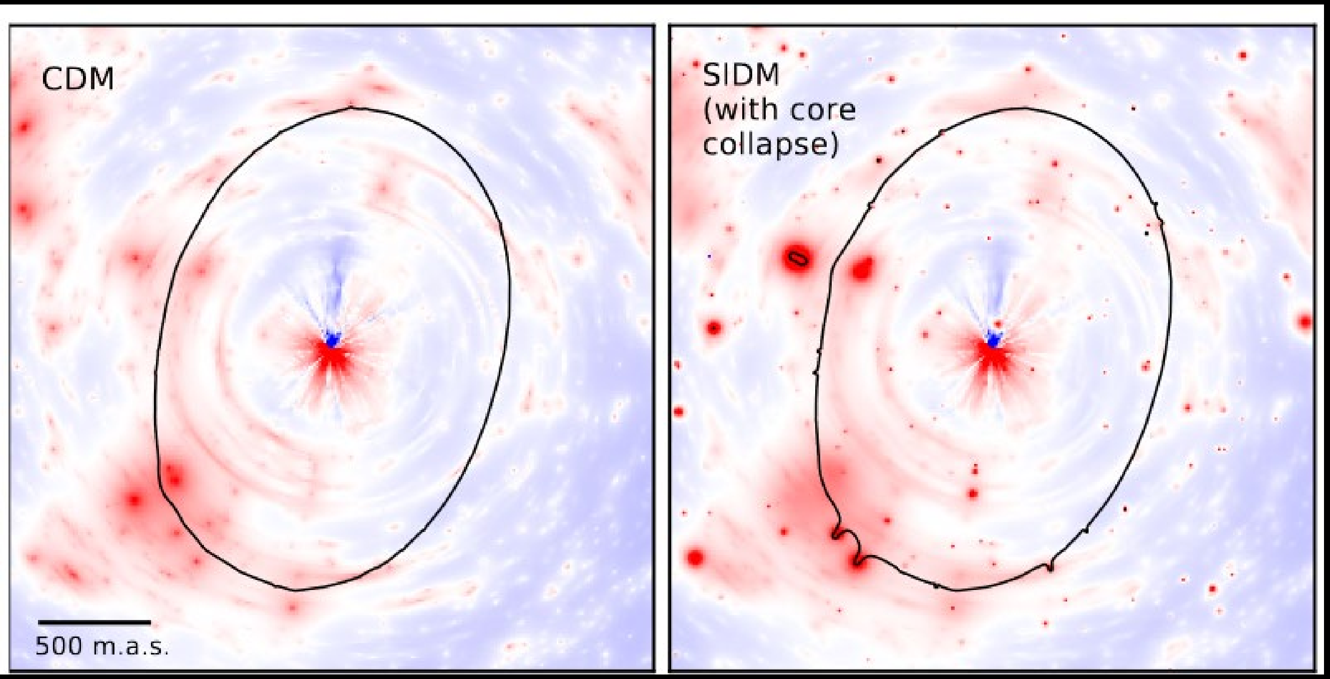
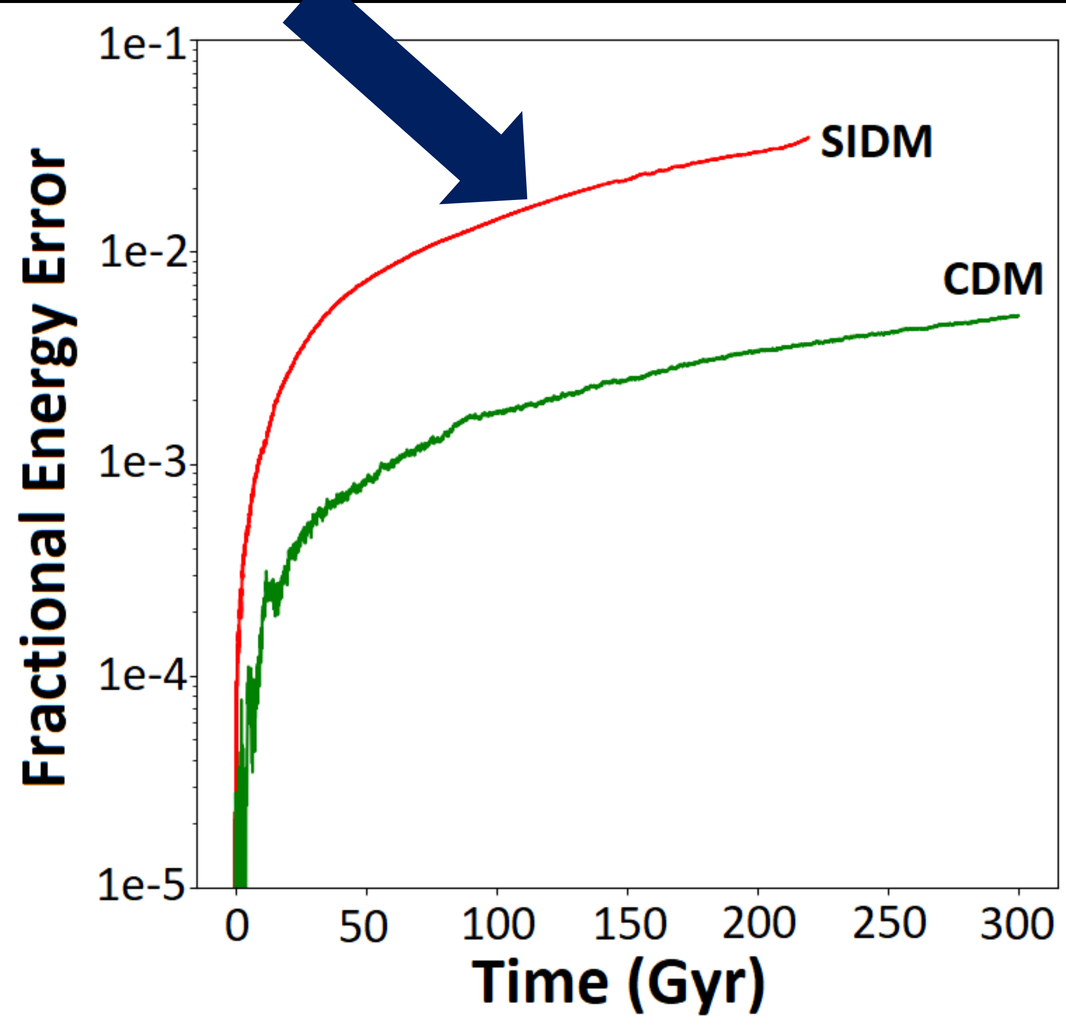
AAS 242

The Problem

D. Gilman et al. 2021



SIDM scattering introduces significant and unexplained energy non-conservation



Dark matter self interactions significantly alter lensing predictions

We cannot constrain SIDM without reliable simulations

Our Solution

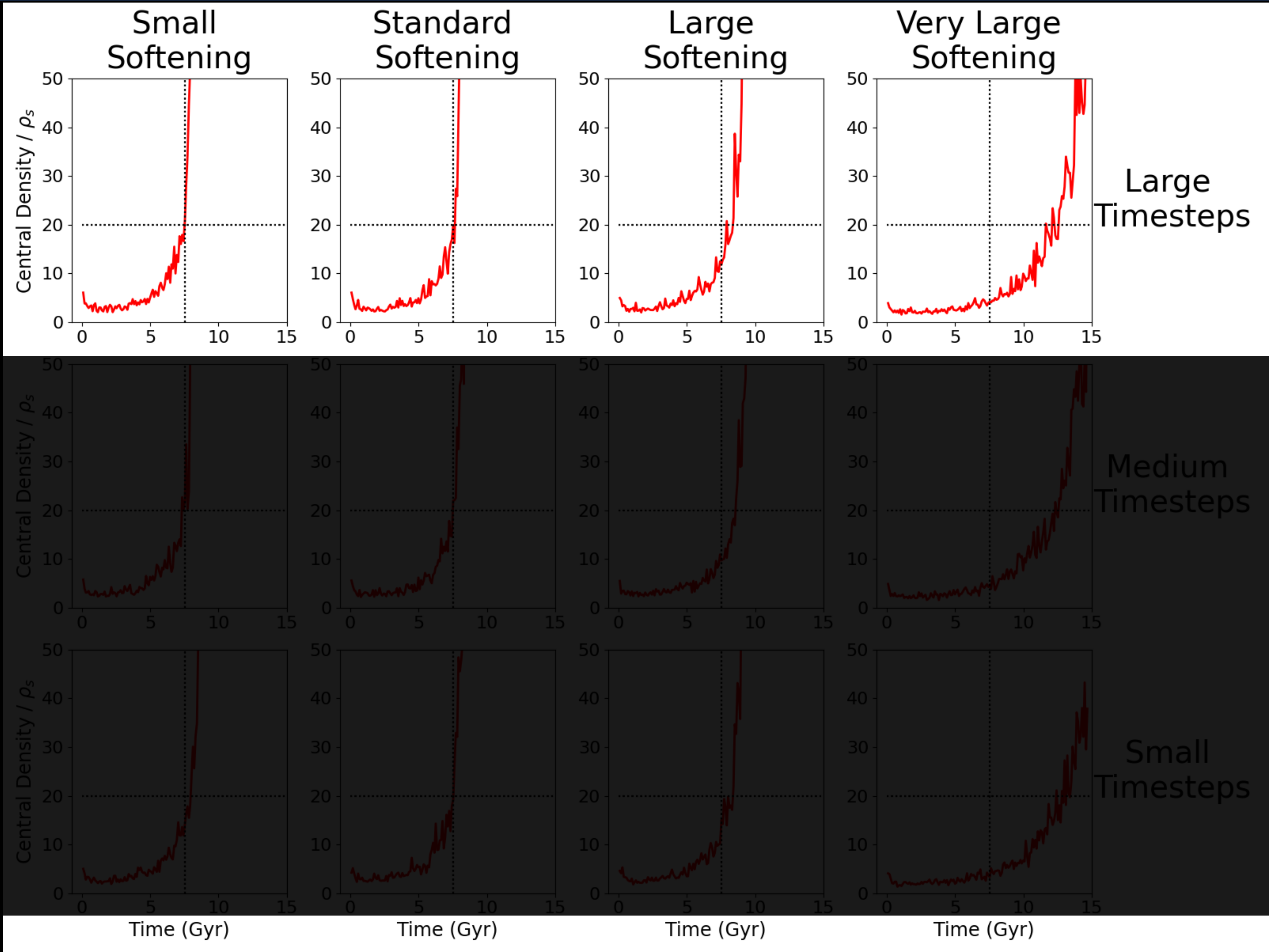
We perform convergence tests within a grid of numerical and physical parameters – total of 144 simulations!

Physical parameters:

1. Halo concentration
2. SIDM cross-section

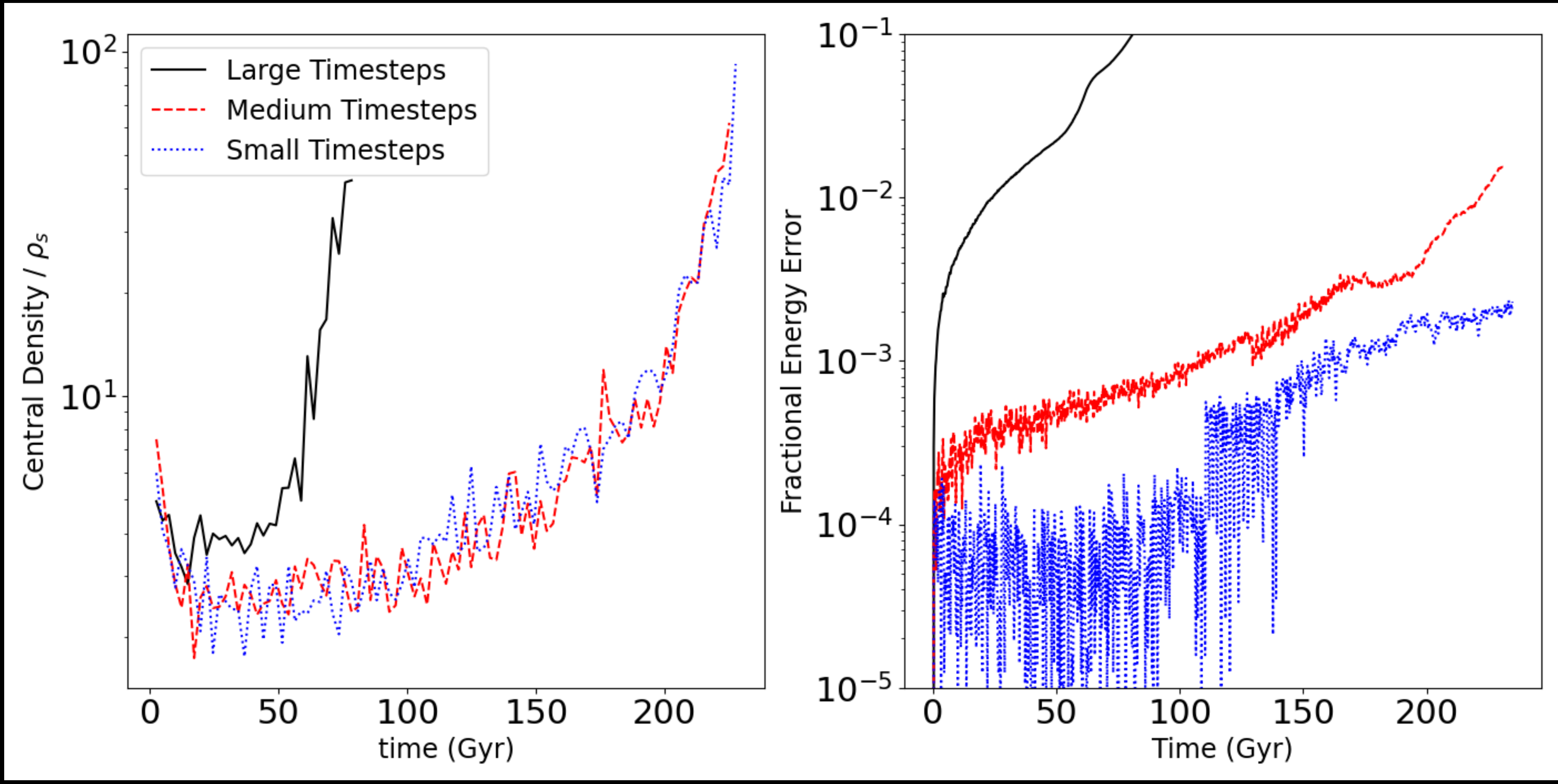
Numerical parameters:

1. Mass resolution
2. Softening length
3. Timestep size



Results

Decreasing the timestep size decreases the energy error, and the central density evolution converges



More analysis this Summer on:

- Softening
- Energy errors
- Resolution
- Halo concentration

Our goal: Detailed prescription for numerical parameters based on halo and SIDM cross-section

Questions?

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Extra Slides

Overview

Concentration

C10T9

Log(M200) = 10.5
Conc = 10
Sigma/m = 1892 cm^2/g
Collapse time = 9 Gyr
Status: Complete

C10T225

Log(M200) = 10.5
Conc = 10
Sigma/m = 17.65 cm^2/g
Collapse time = 225 Gyr
Status: Incomplete

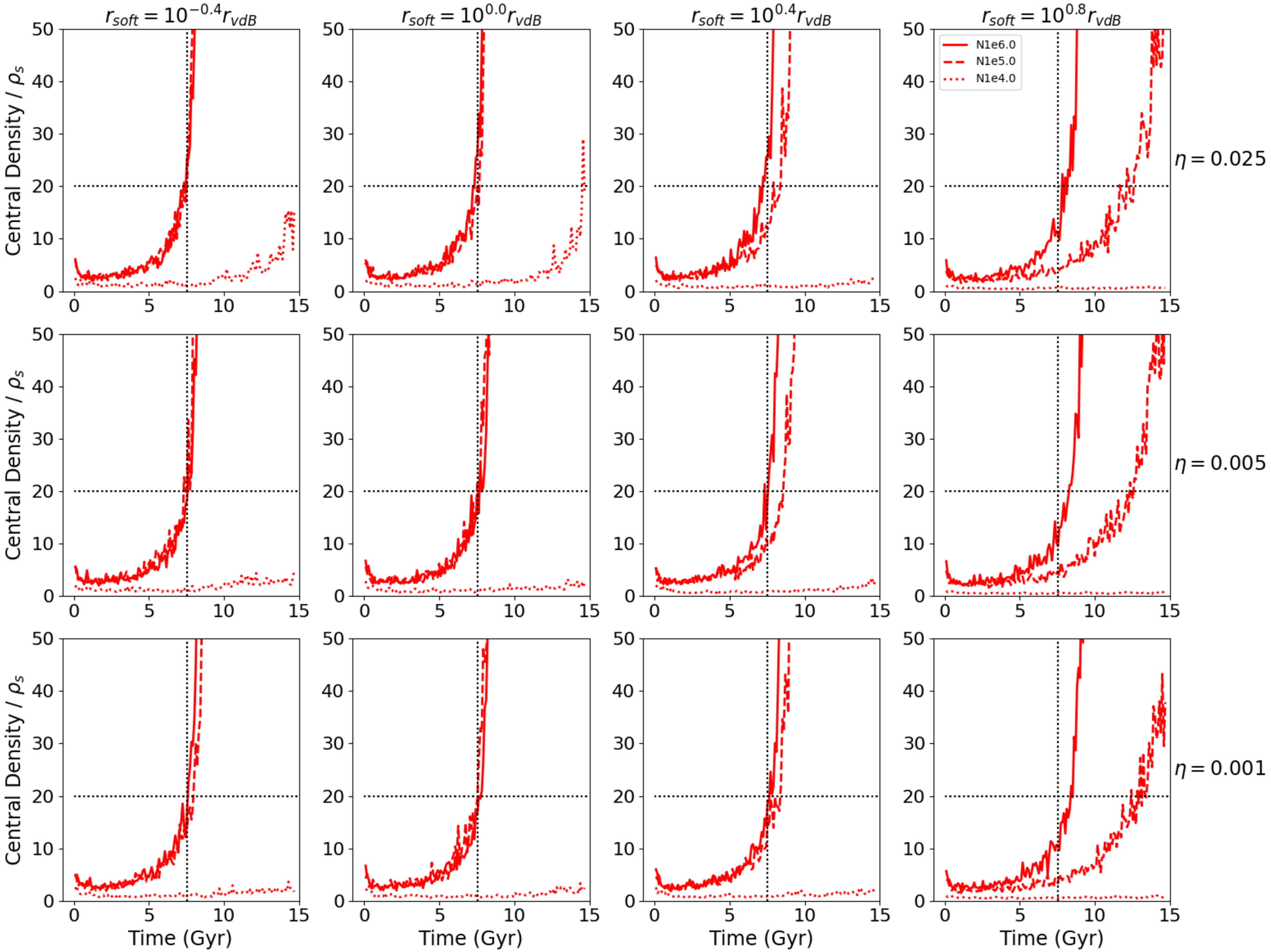
C50T9

Log(M200) = 10.5
Conc = 50
Sigma/m = 5.688 cm^2/g
Collapse time = 9 Gyr
Status: Complete

C50T225

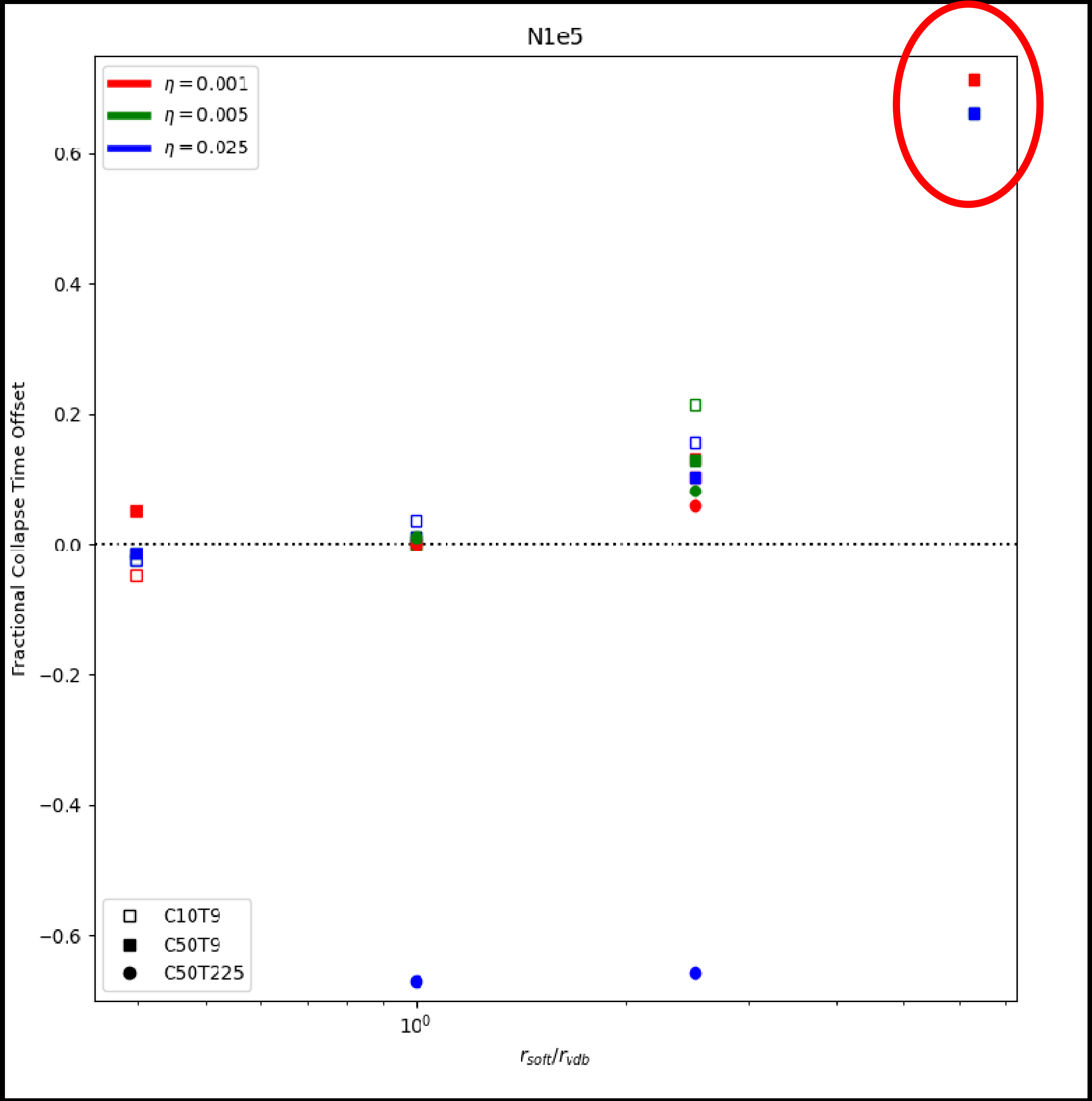
Log(M200) = 10.5
Conc = 50
Sigma/m = 0.1764 cm^2/g
Collapse time = 225 Gyr
Status: Mostly Complete

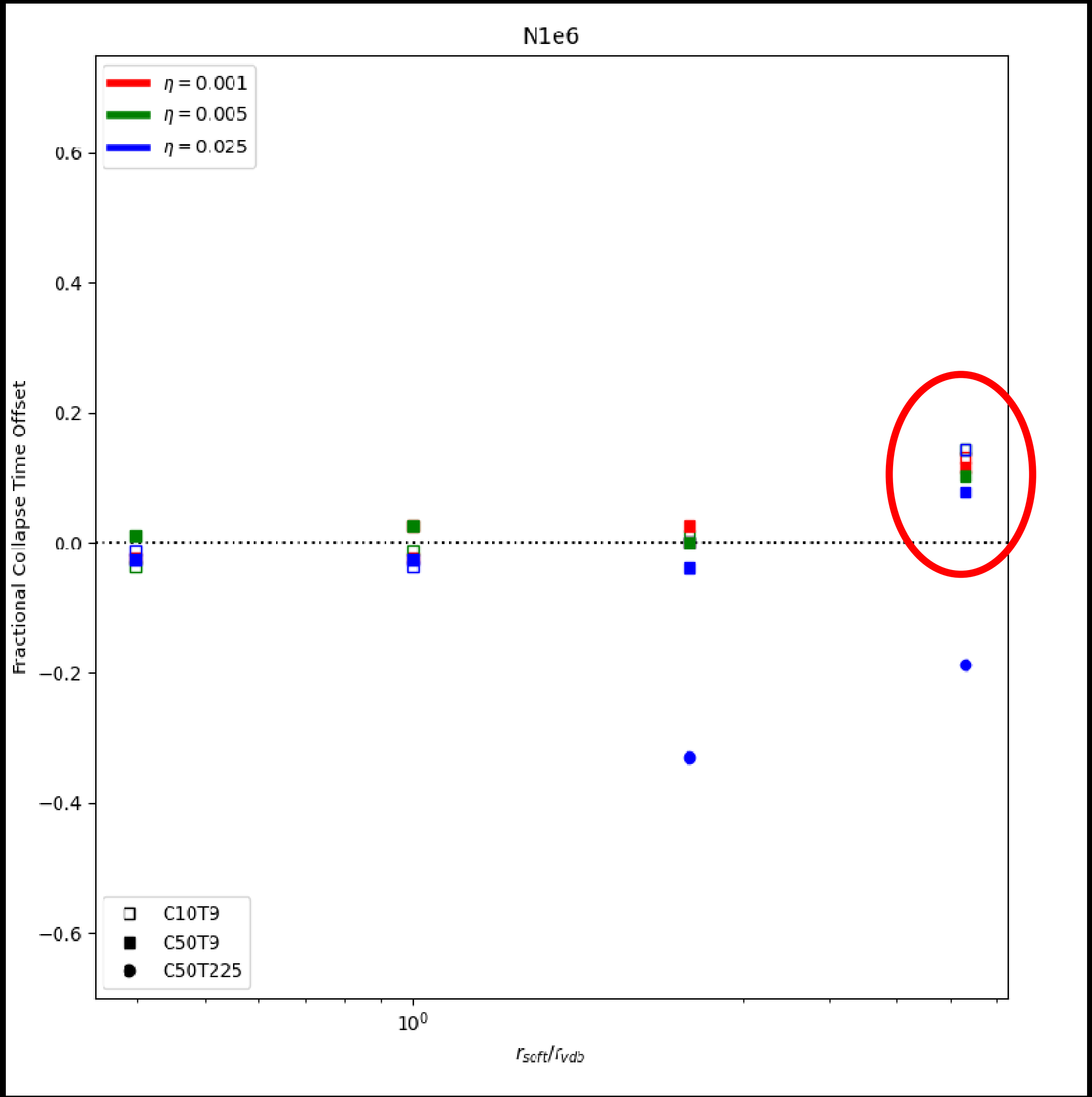
Collapse Time (via scattering cross-section)



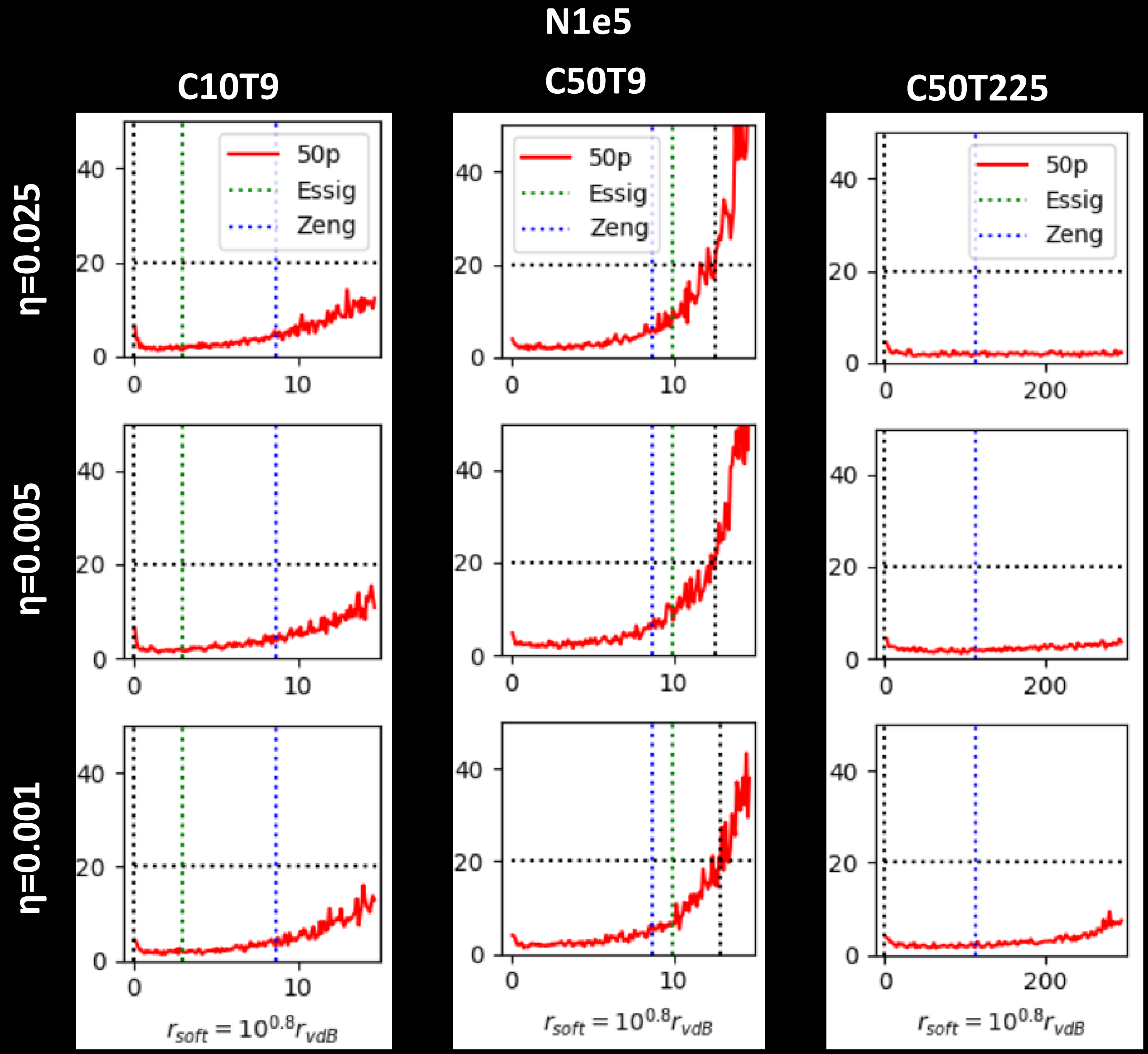
$r_{soft} = 10^{-0.4} r_{vdB}$
$r_{soft} = 10^{0.0} r_{vdB}$
$r_{soft} = 10^{0.4} r_{vdB}$
$r_{soft} = 10^{0.8} r_{vdB}$
N1e6.0
N1e5.0
N1e4.0
$\eta = 0.025$
$\eta = 0.005$
$\eta = 0.001$
Central Density / ρ_s
Time (Gyr)

Over-Softening





Over-Softening



Over-softening is the worst for C10T9 and C50T225, not as bad for C50T9

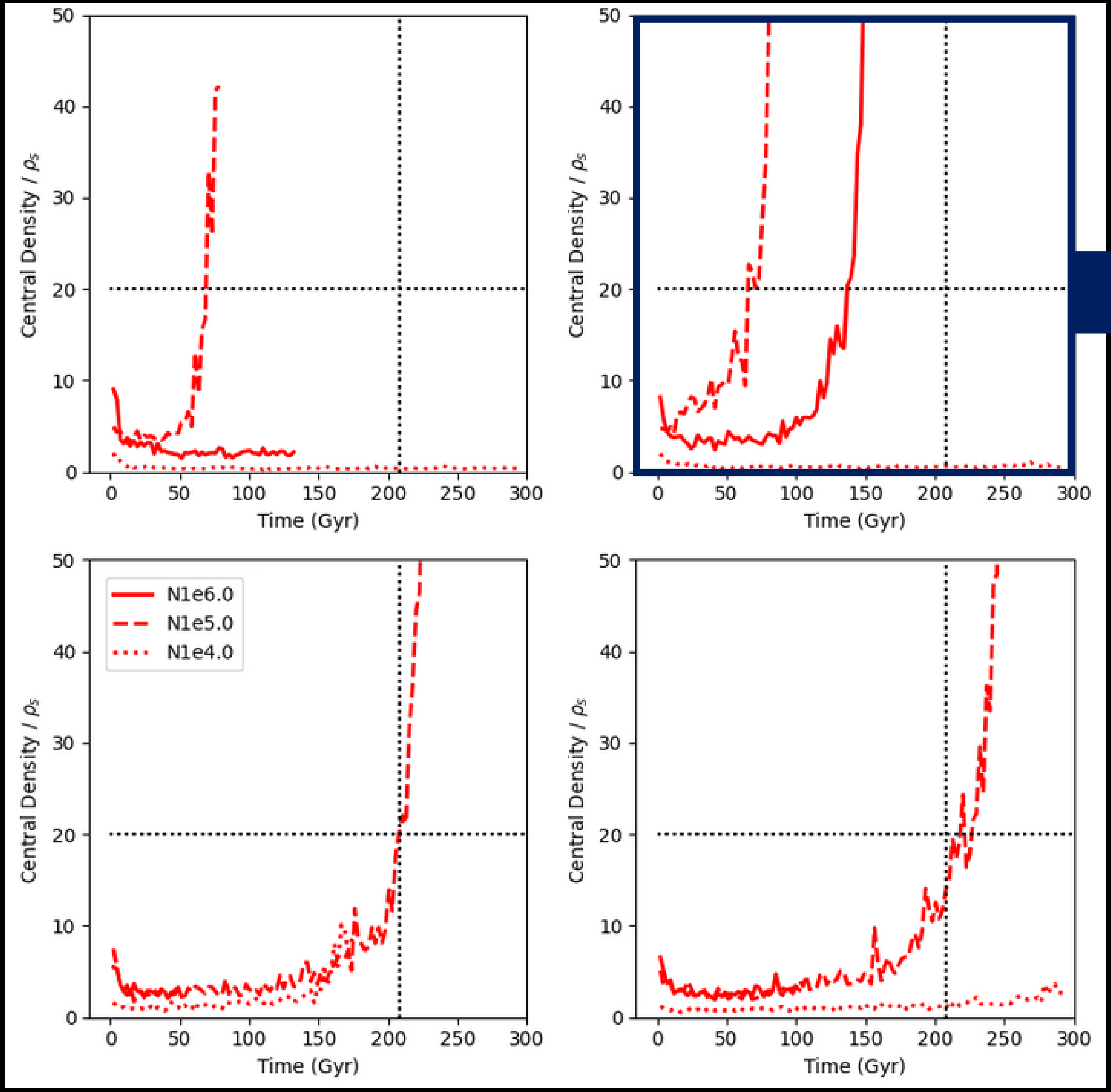
Currently running C10T9 longer to see actual collapse time, may run C50T225 longer as well

Accelerated Collapse

C50T225

η=0.025

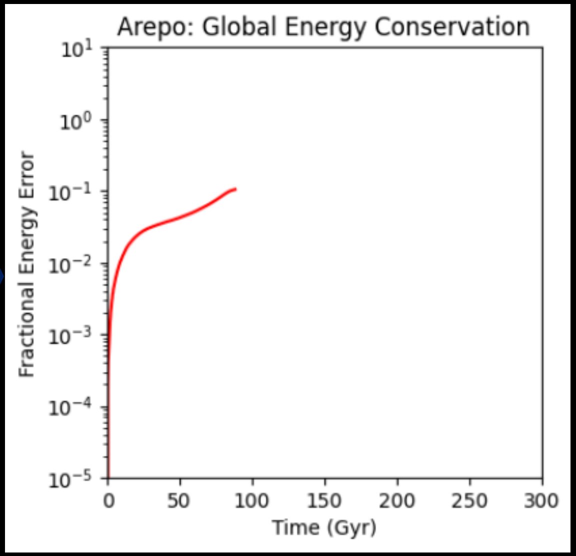
η=0.005



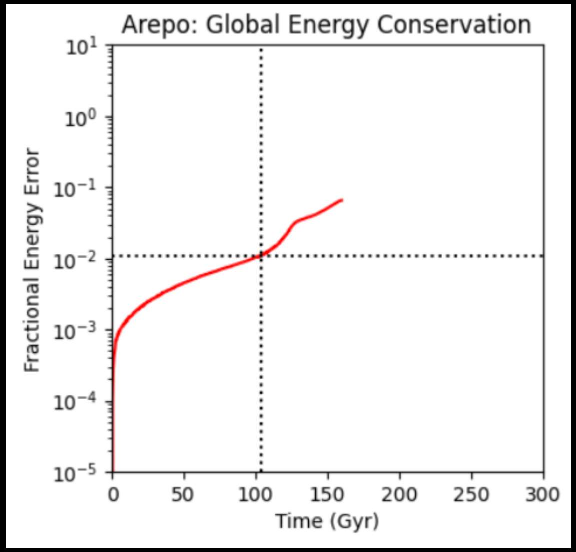
Standard Softening

2.5x Softening

N1e5



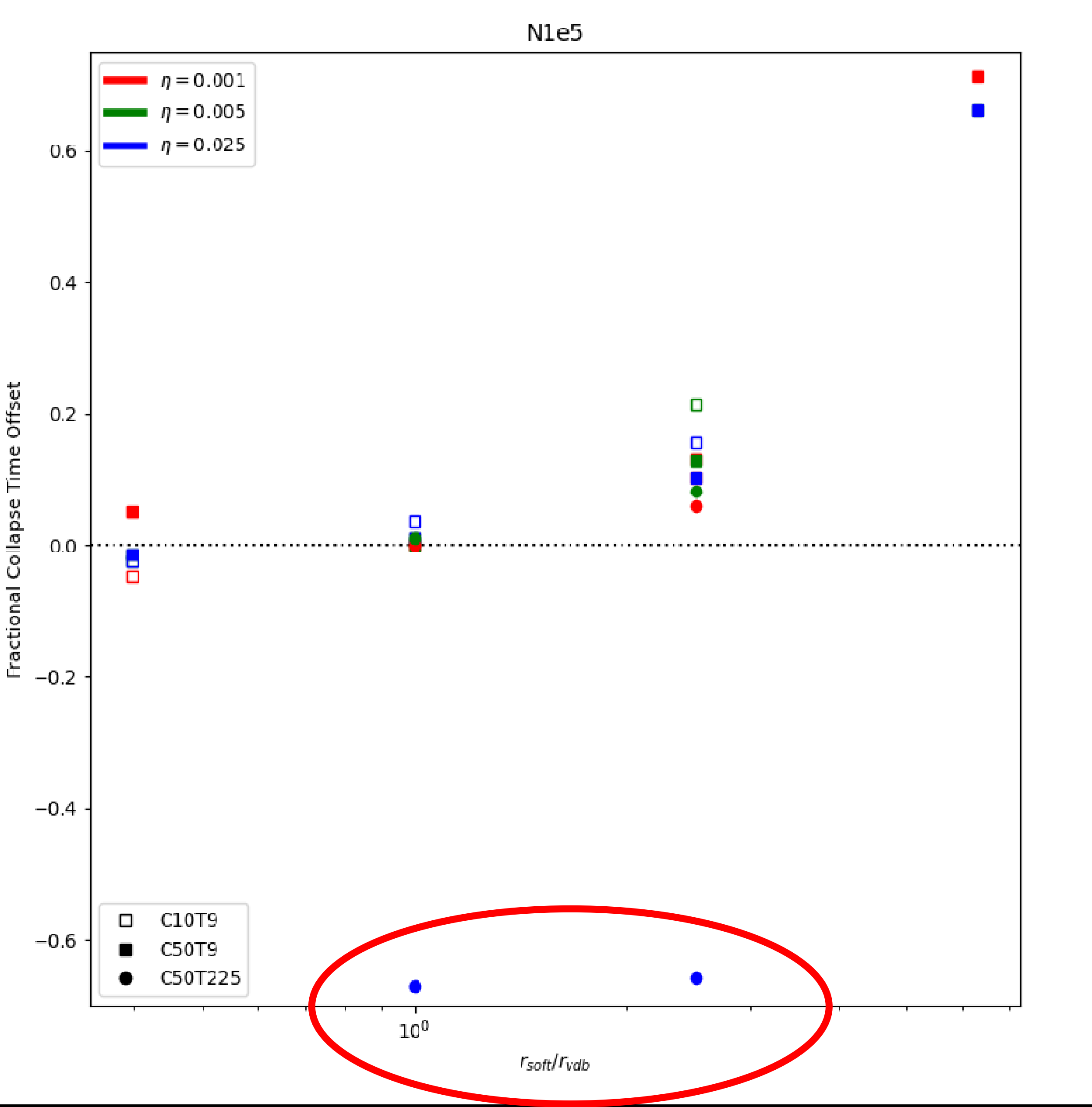
N1e6



Collapse acceleration is less significant at higher resolution

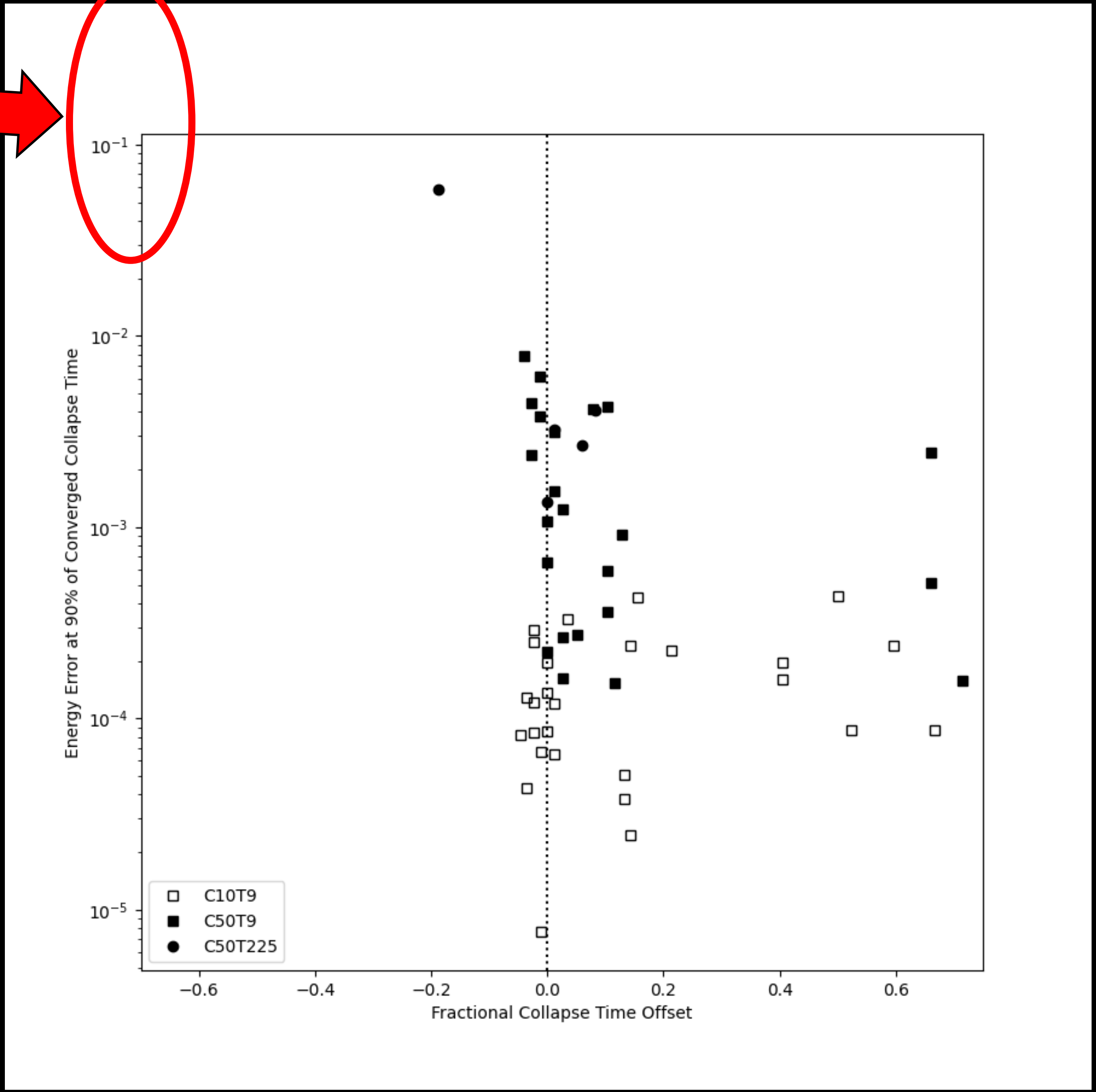
Accelerated Collapse

Collapse acceleration is only significant in long simulations



Accelerated Collapse

Accelerated cases would be here!



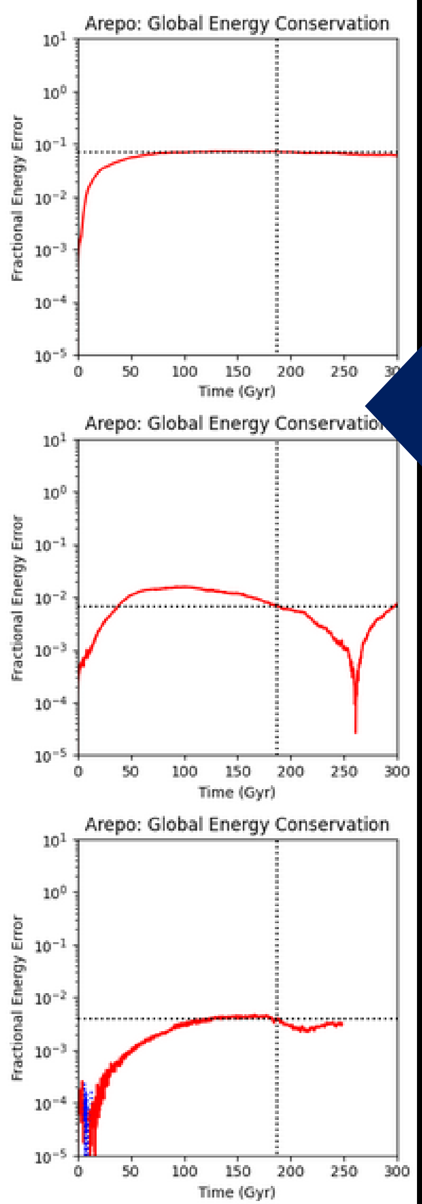
Energy error on accelerated collapsed cases is much larger than it is for all other simulations

Still a lot to investigate here:

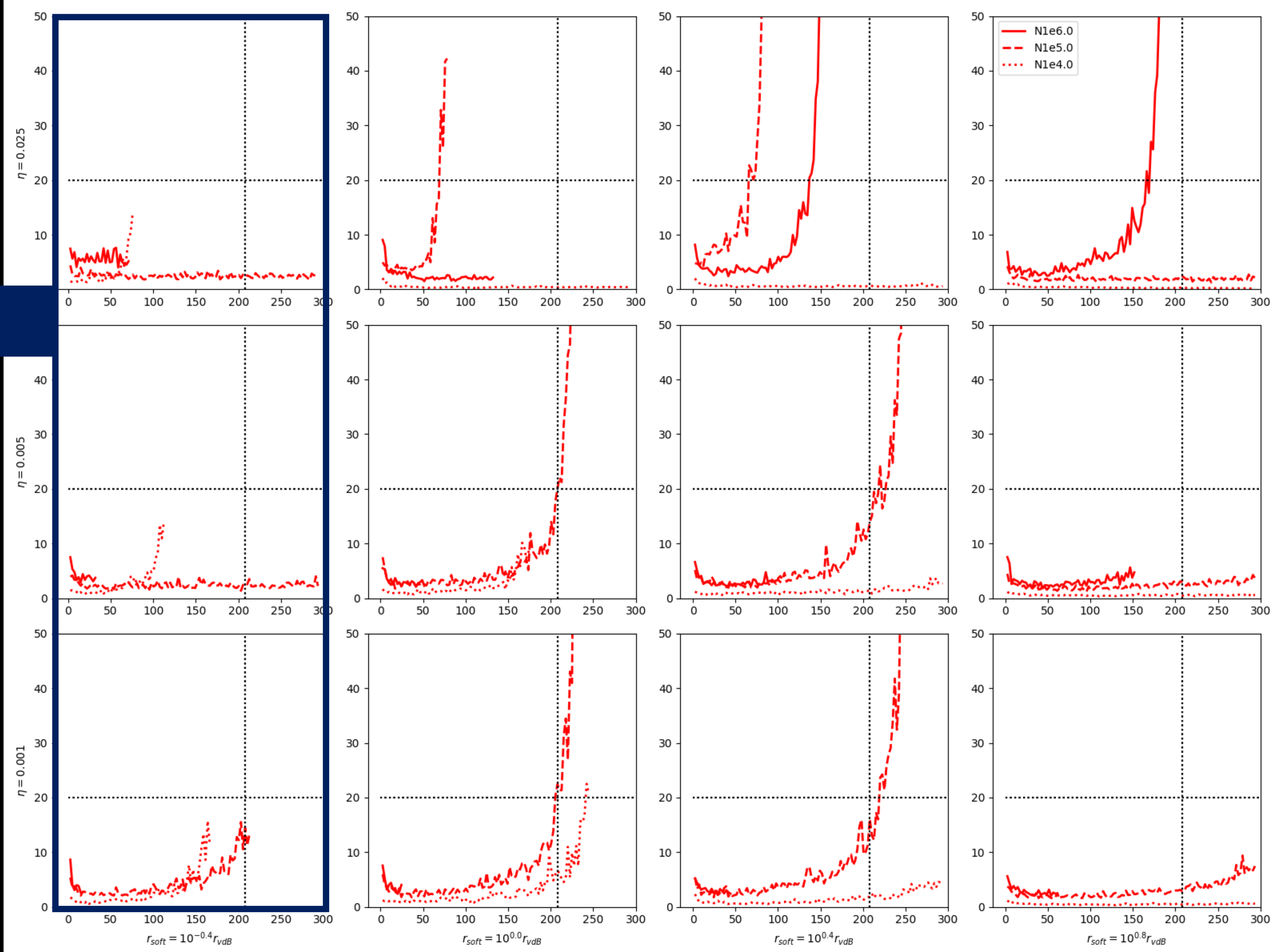
- Are the small energy errors significant?
- Is this a good way to quantify the energy error?
- Does the sign of the error correlate with anything?

Under-Softening

N1e5



C50T225



Delayed collapse at low softening + large η in new simulations

- Resolution dependence?
- Weird energy error plots?
- What if we decrease softening more, or lower η?

Summary

Low resolution

- Delays/prevents core collapse
- 100,000 particles seems sufficient for most cases
    - Are cosmological simulations underpredicting core collapse?

Over-softening

- Delays core collapse
- Worst for large softening and low resolutions
- Some halo parameter dependence to untangle

Accelerated Collapse

- System energy loss (or gain)
- Accelerates core collapse
- Worst for large η and low resolutions

Under-softening

- New and exciting error - only appears in C50T225
- Worst for small softening and large η

Tentative general result: $N > 1e5$, $\eta < 0.005$, and standard softening is sufficient to resolve isolated collapsing halos

Outside these bounds you may run into numerical issues, dependent on the specific halo and cross-section