Dark Matter Dynamics

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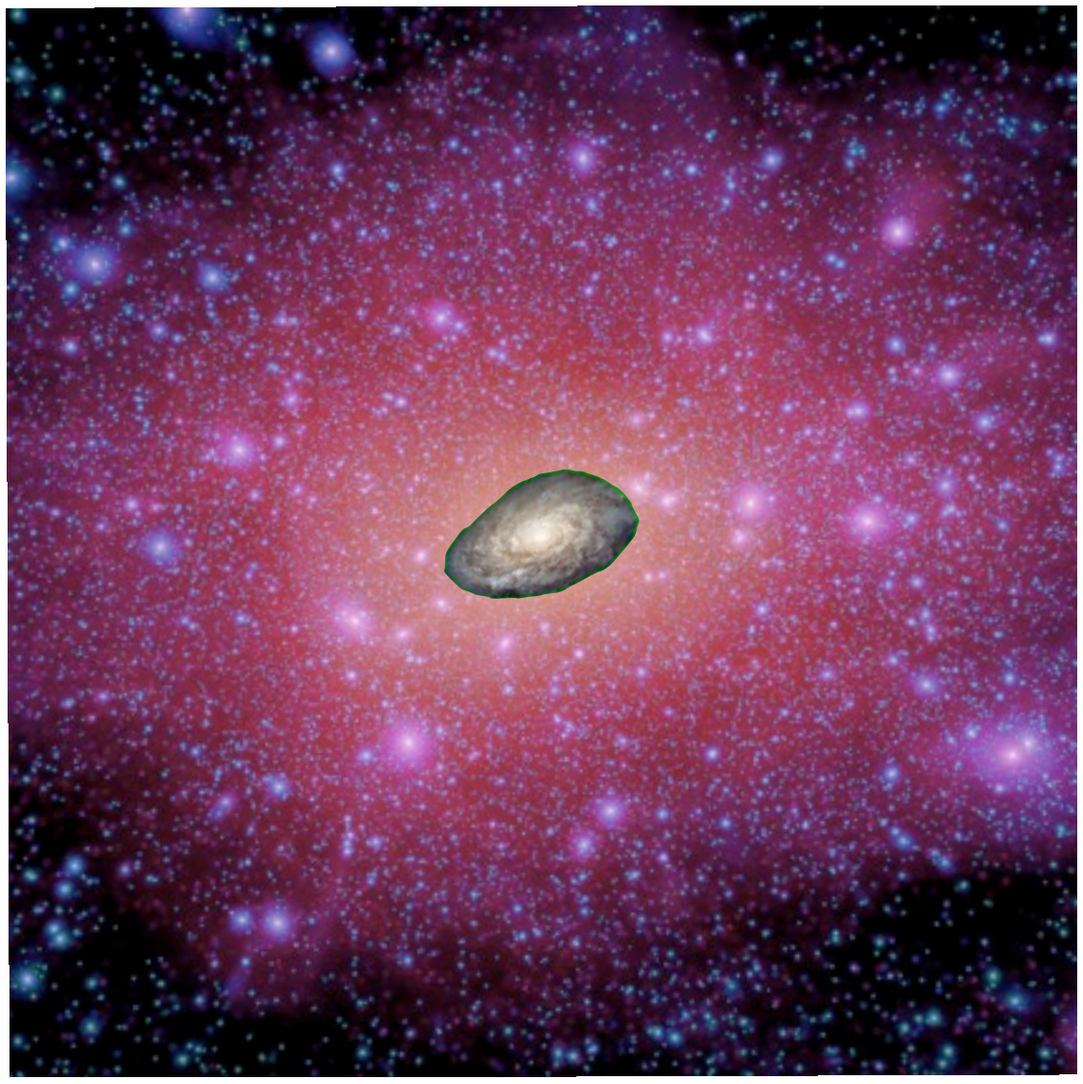
Newtonian Gravity

Newtonian Gravity in Galaxies (Prediction)

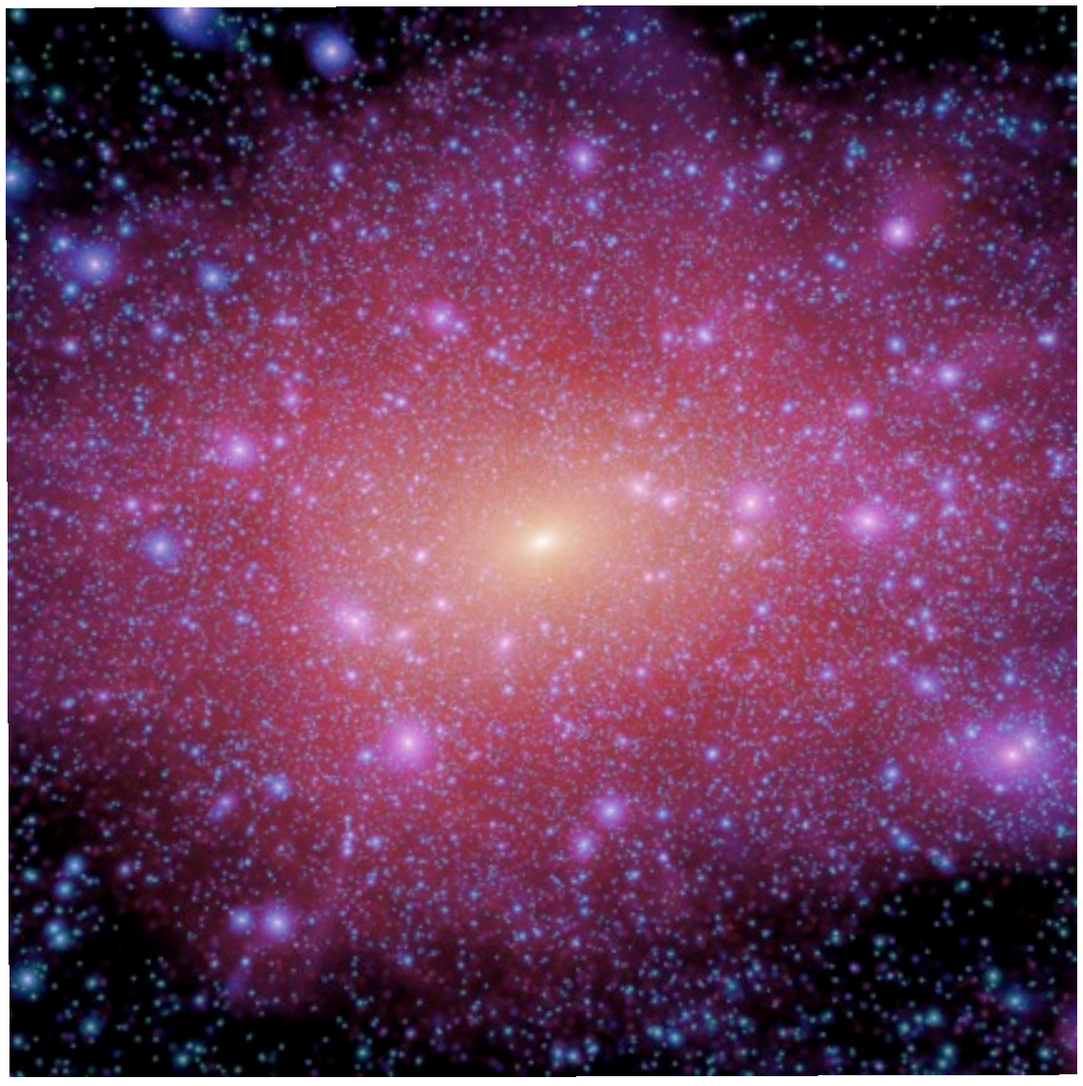
Newtonian Gravity in Galaxies (Actual)

DARK MATTER HALO

Galaxy Formation

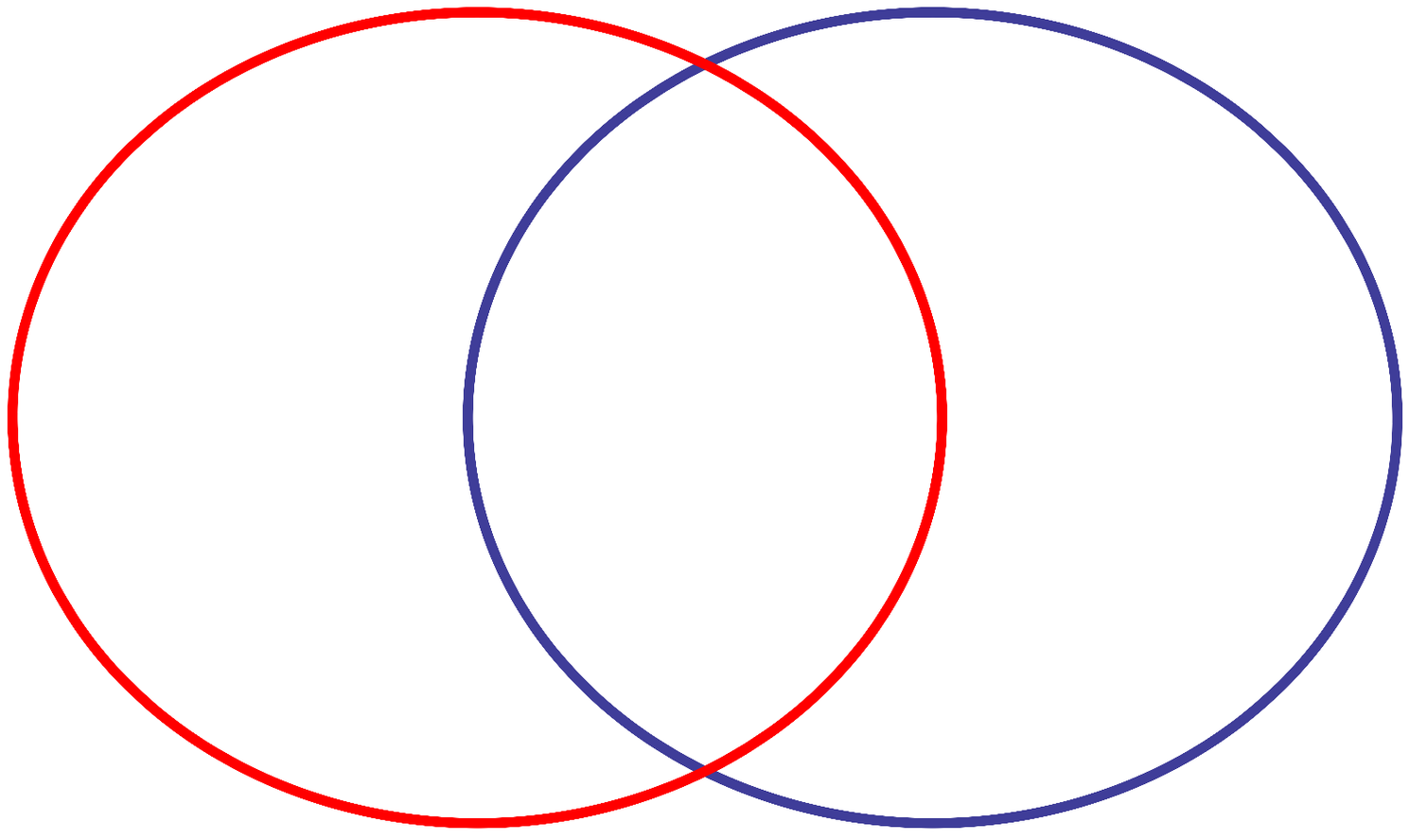


Dark Matter Dynamics (How do Halos form?)



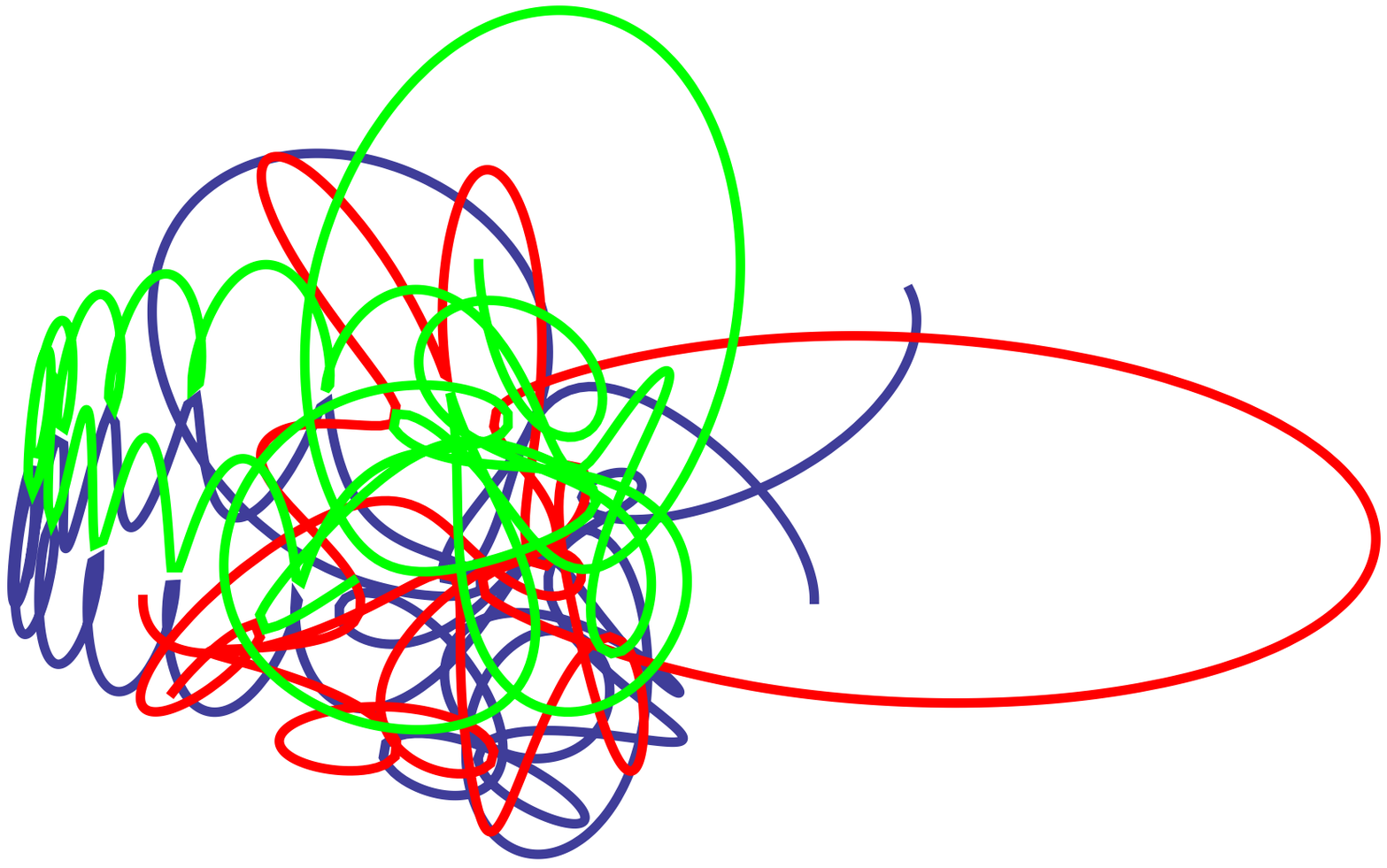
Two Body System

Two Body System

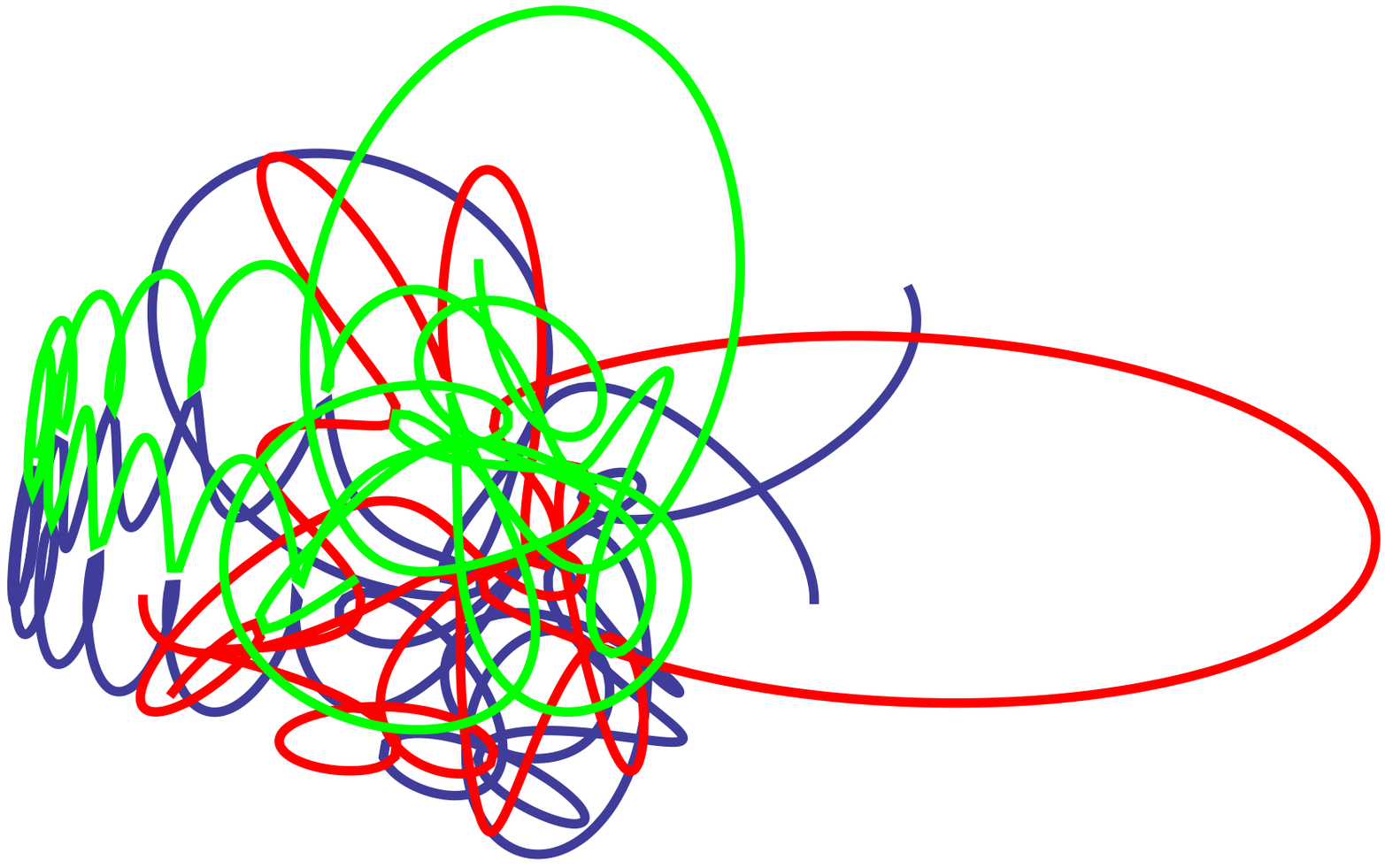


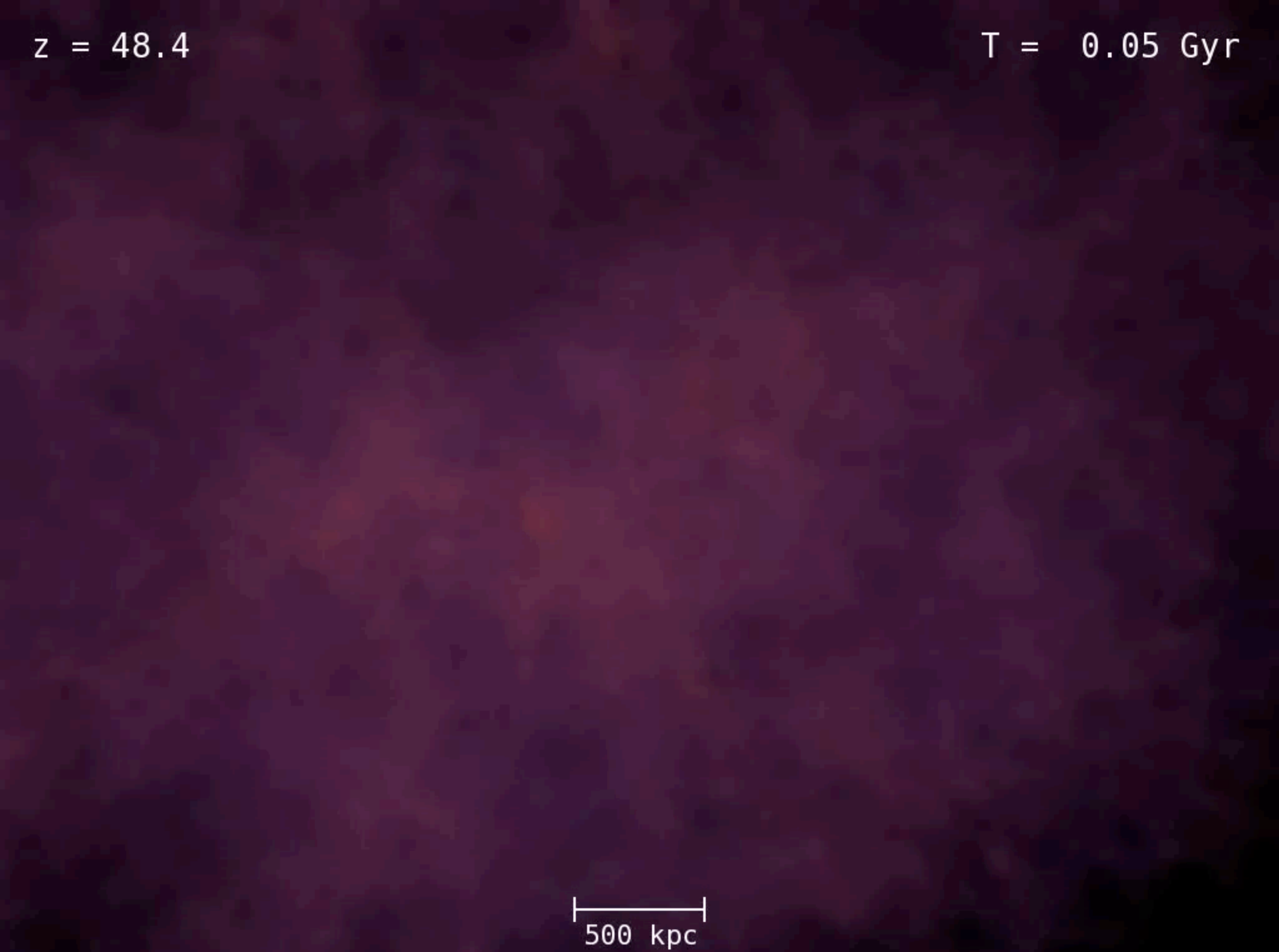
Three Body System

Three Body System



Three Body ~~System~~ Problem




z = 48.4
T = 0.05 Gyr
500 kpc

z = 2.0

T = 3.37 Gyr

500 kpc

z = 0.3

T = 10.33 Gyr

500 kpc

What do simulations tell us?

- Halos have specific (NFW) density profiles
- Halos have specific velocity profiles
- Halos have universal properties

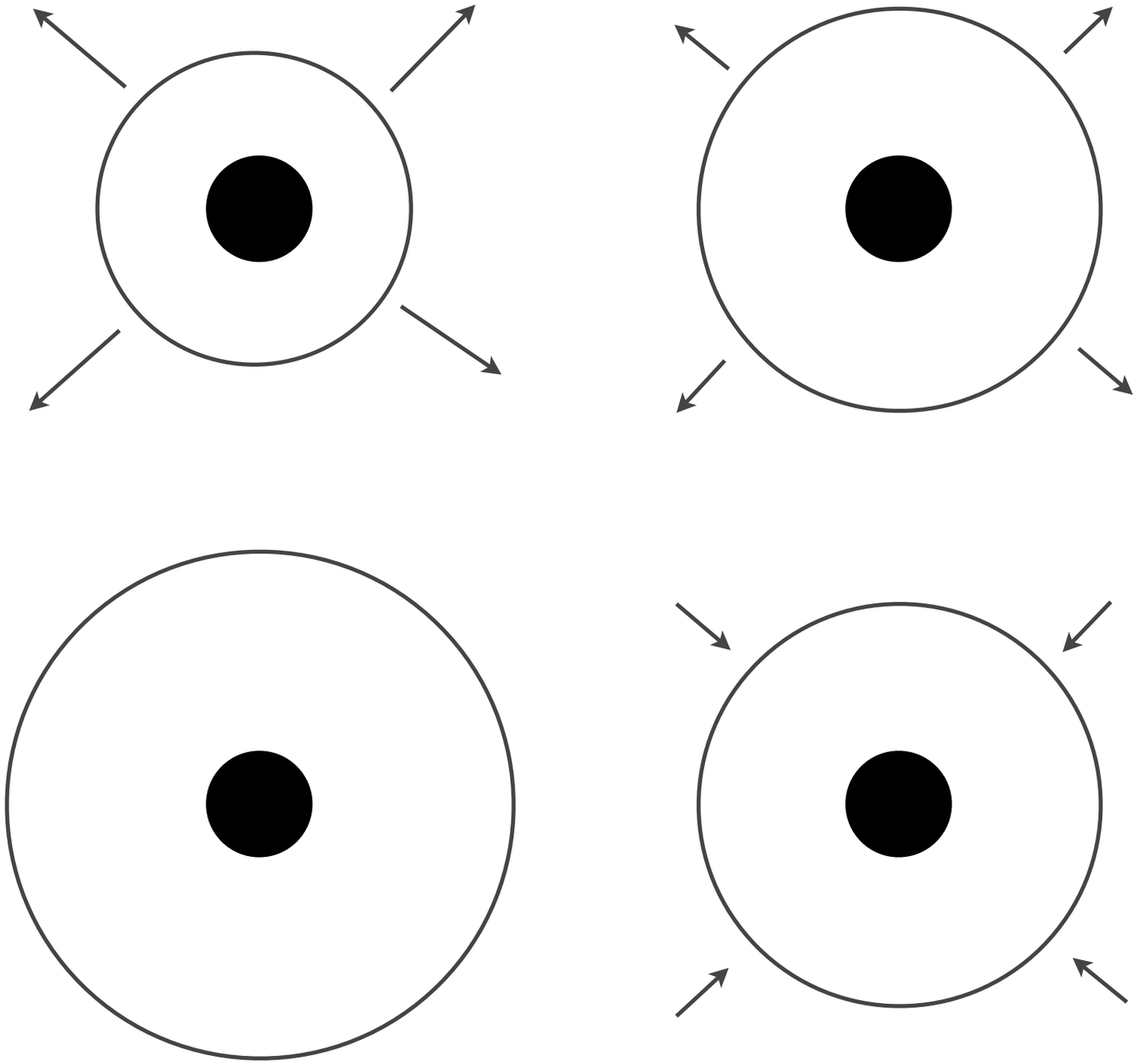
What do simulations tell us?

- Halos have specific (NFW) density profiles ⟶ Part 1
- Halos have specific velocity profiles ⟶ Part 2
- Halos have universal properties ⟶ Part 3

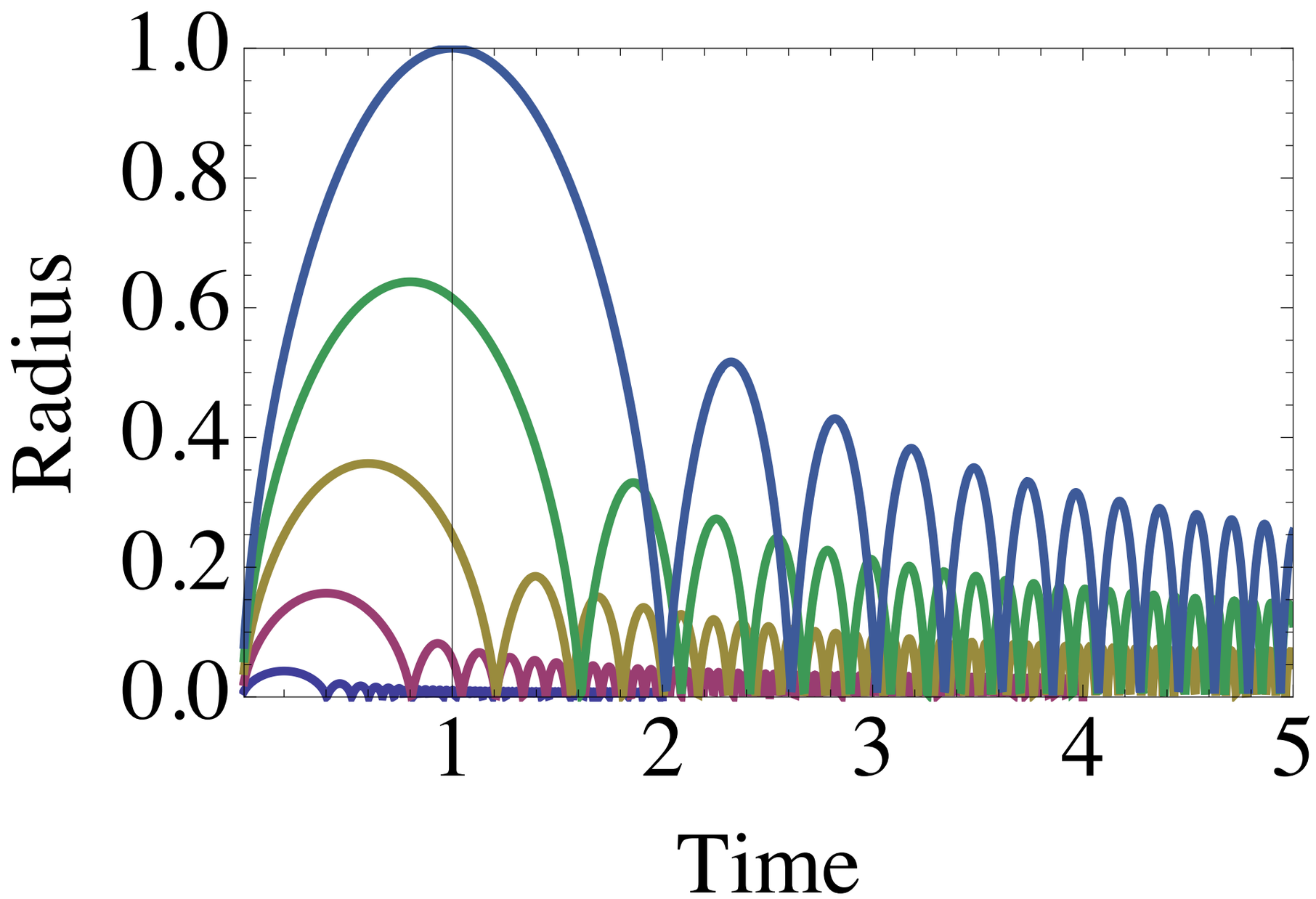
Part 1

Self Similar Secondary Infall

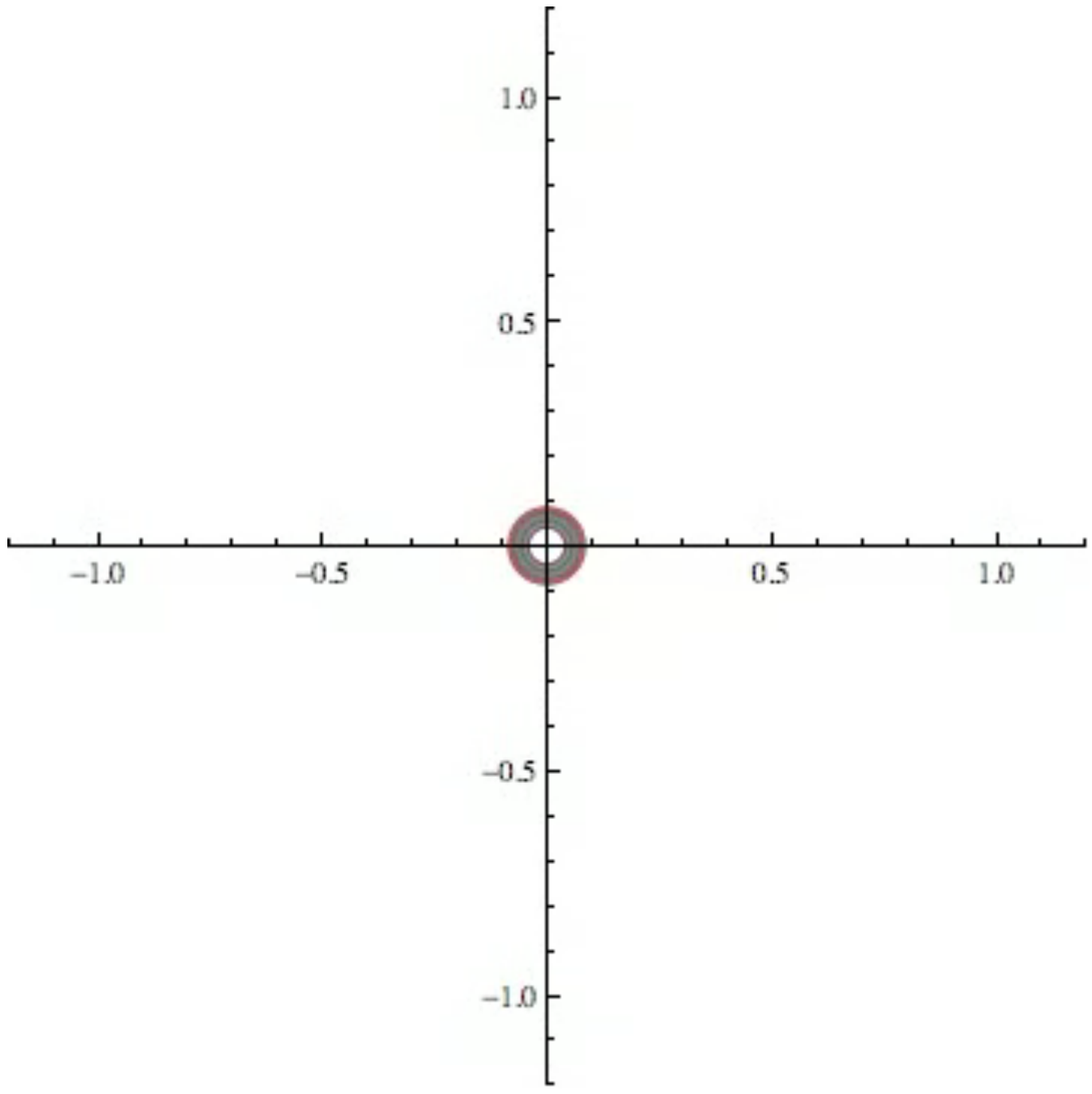
Secondary Infall



Self-Similarity



Self-Similar Secondary Infall

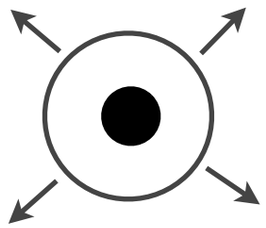


Why?

- Numerically (much) easier.
- Analytically tractable: $\frac{d\ln M}{d\ln r}$ $\frac{d\ln \sigma_r^2}{d\ln r}$ $\frac{d\ln \sigma_t^2}{d\ln r}$

Model

- Initial density perturbation: $\delta \propto r^{-n}$



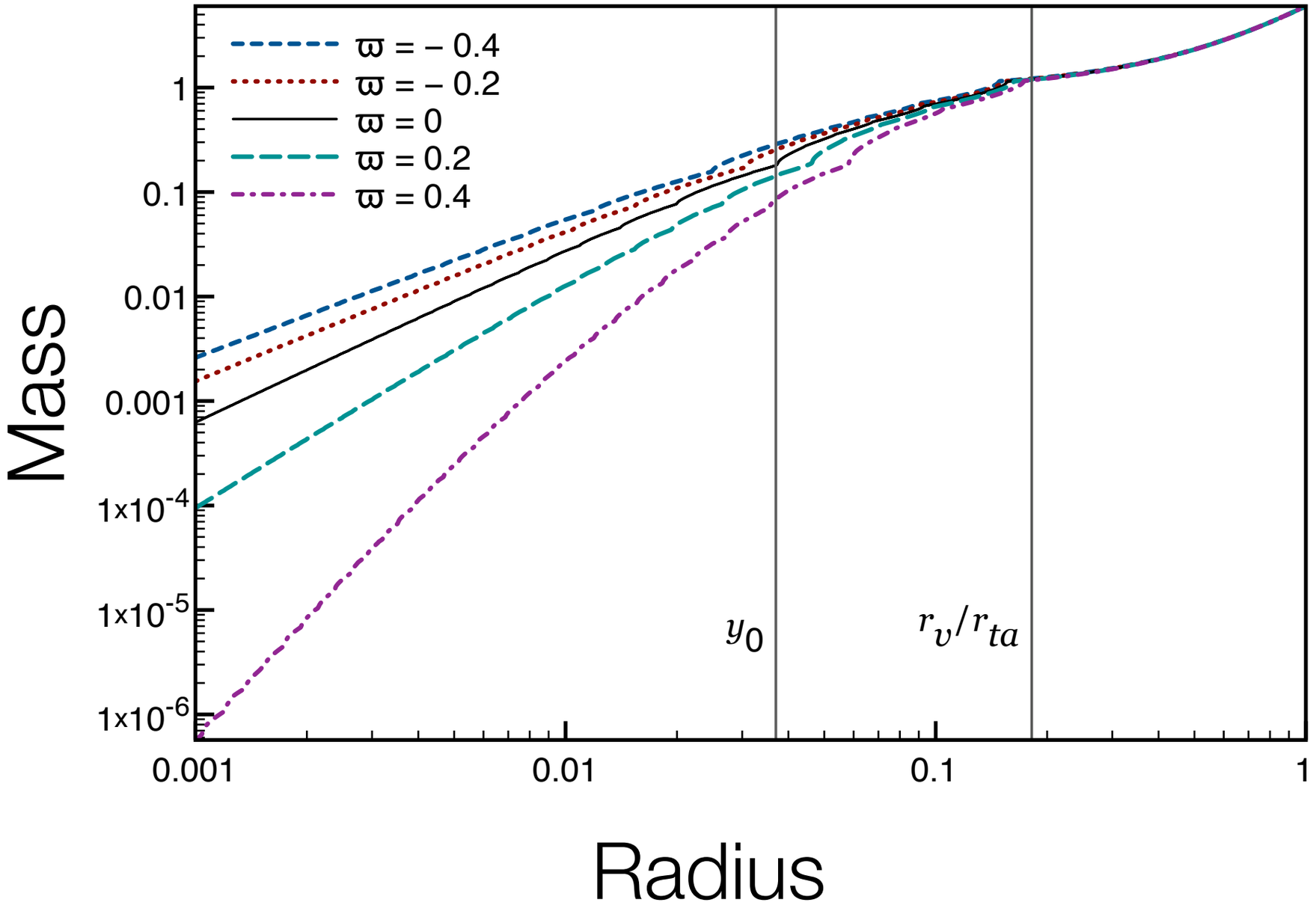
- Particles torqued throughout evolution.

$$L(r,t) = B\frac{r_{ta}^2}{t}\begin{cases}(r/r_{ta})^{-\gamma} & \text{if } t < t_*,\\ (t/t_*)^{\varpi+1-2\beta} & \text{if } t > t_*.\end{cases}$$

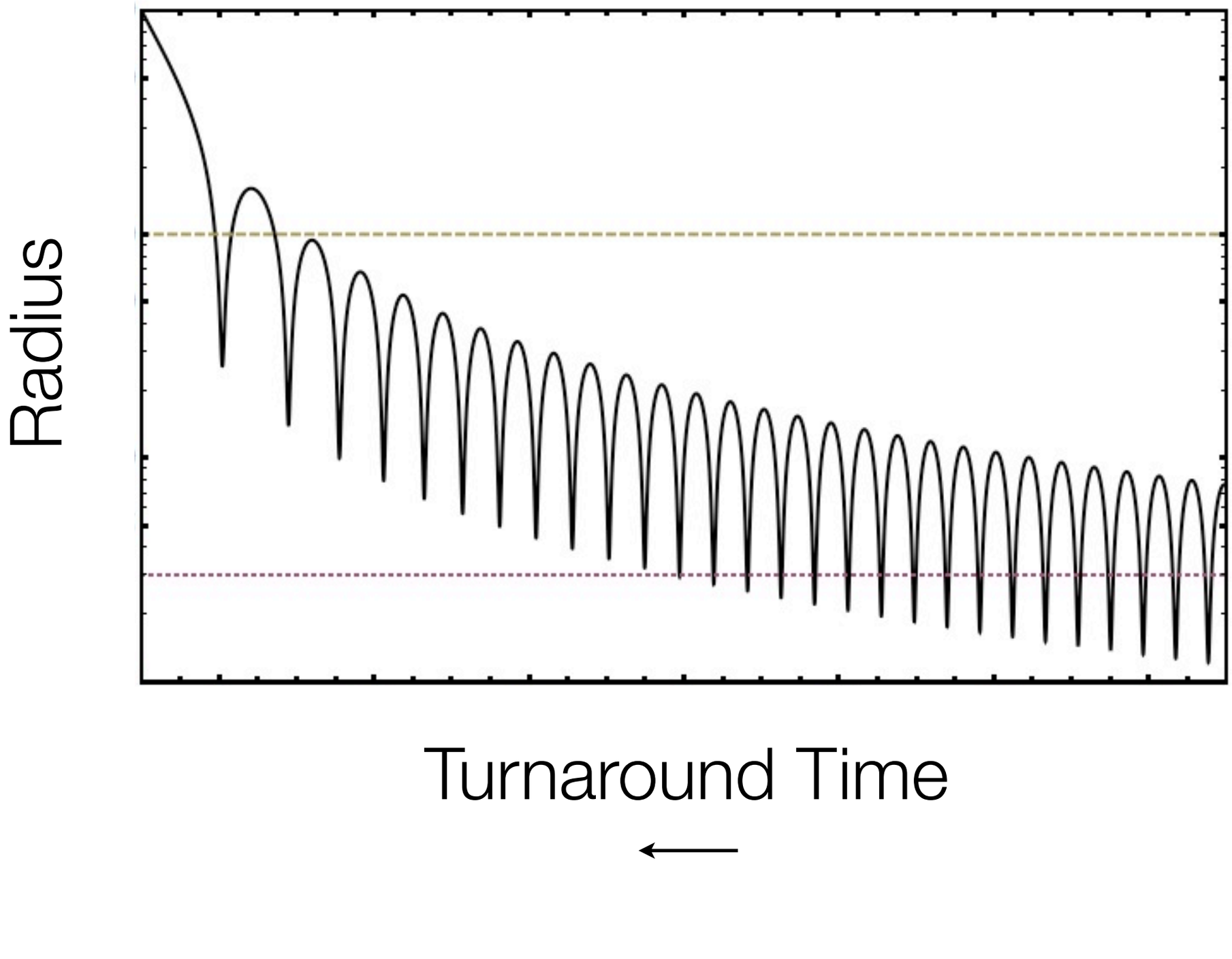
- Parameters n, B, γ set by halo mass

- ϖ difficult to constrain analytically.

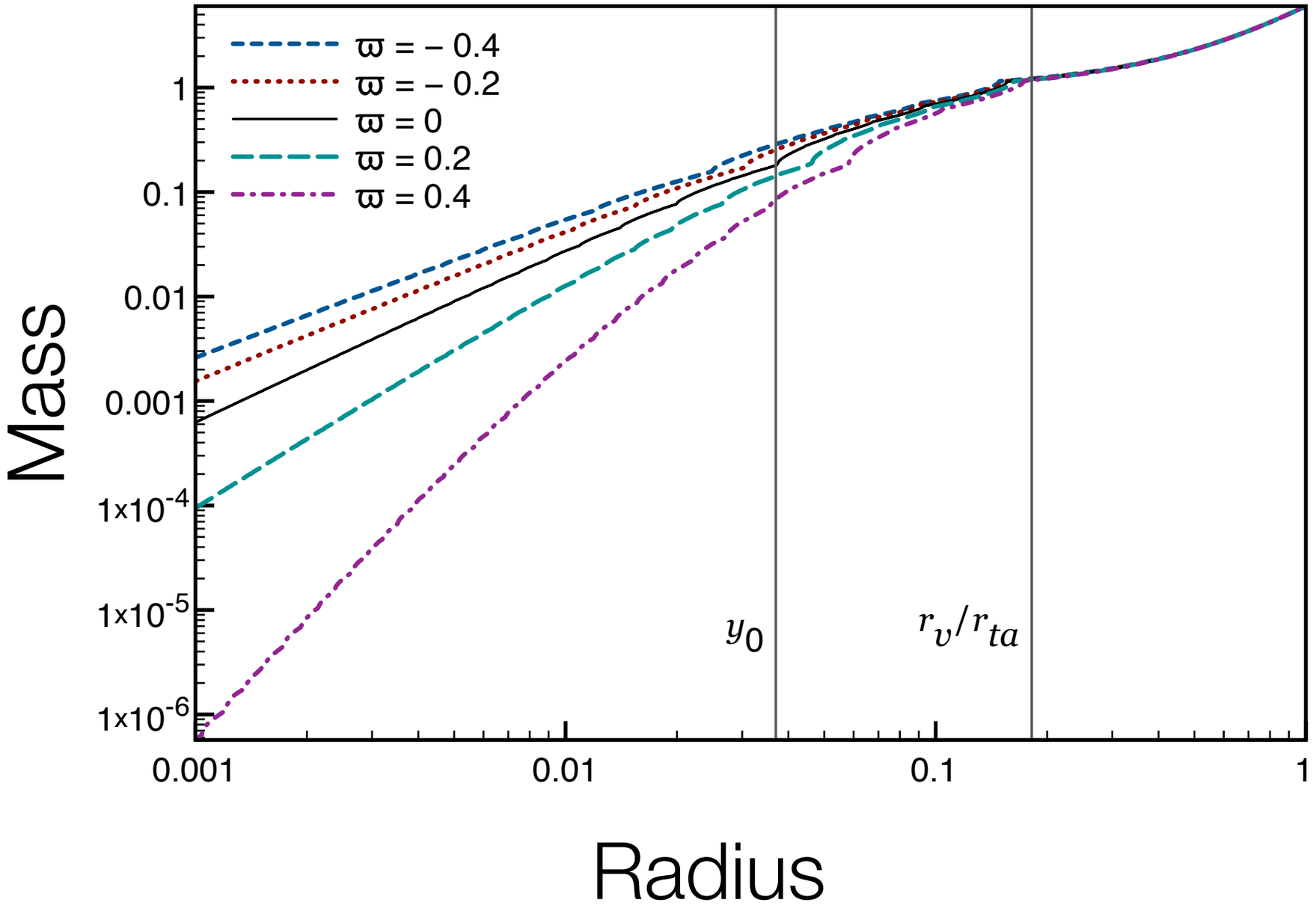
Model Results:
Mass Profile



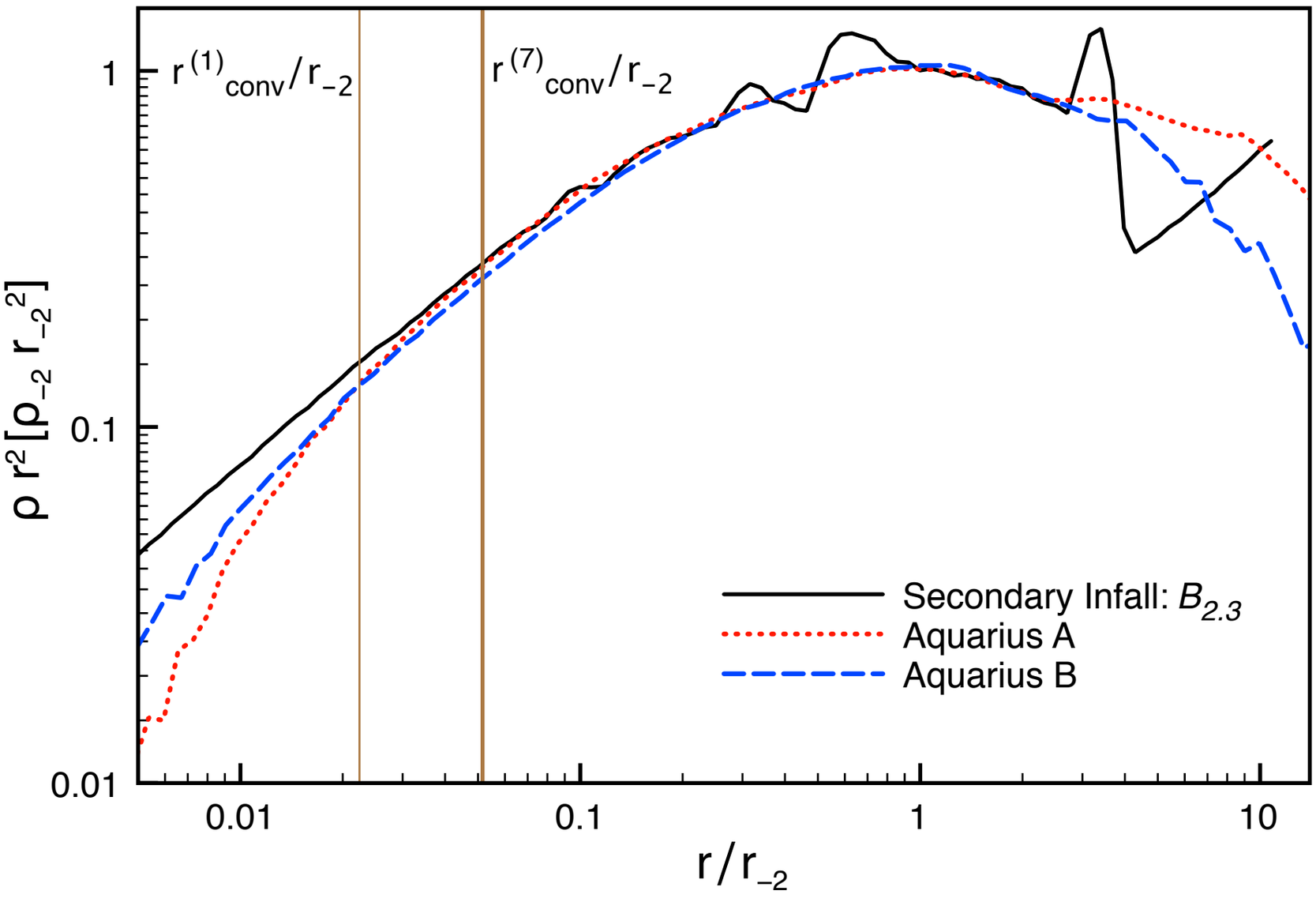
Location of Shells



Model Results:
Mass Profile



Model vs N-body



Part 1 Summary

- Angular Momentum determines inner structure of density profiles.
- Potentially gives insight to the Cusp/Core Problem
- Self Similar model does a good job, but is incomplete.

Chapter 2

Velocity Structure of Dark Matter Halos

Chapter 2 Summary

- Velocity analysis separates us from other treatments.

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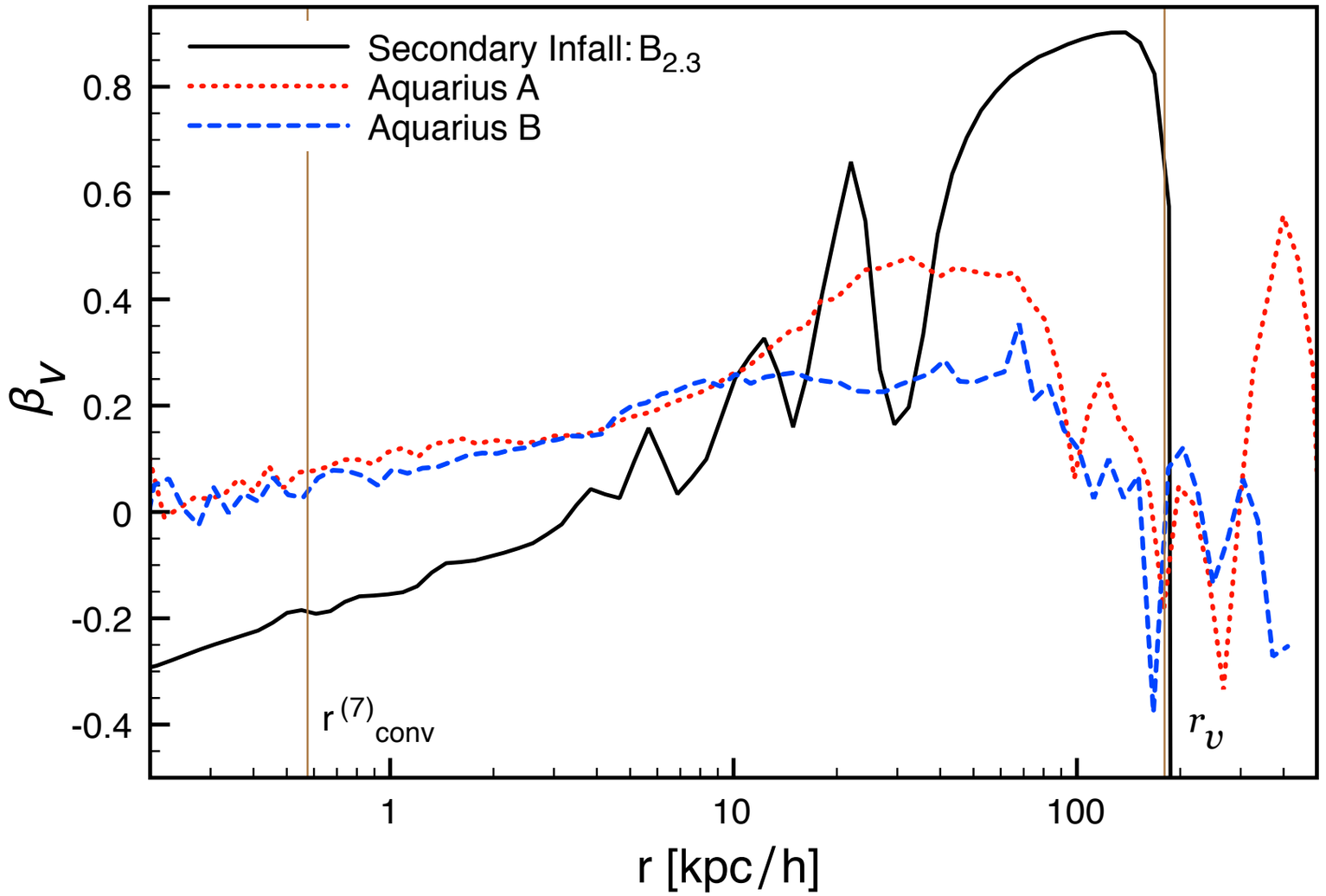
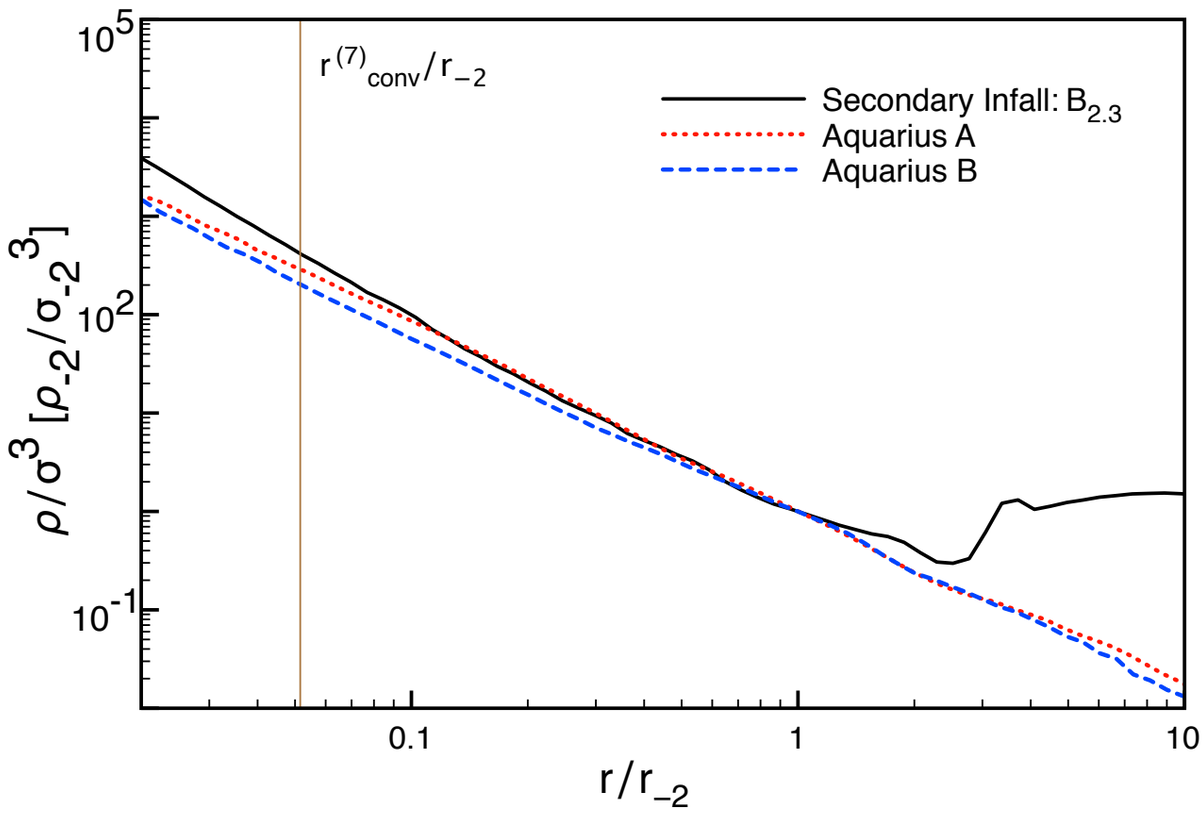
- Analytically derived the behavior of the velocity anisotropy profile.



Part 2 Summary

- Velocity analysis separates us from other treatments.
- Analytically derived the behavior of the velocity anisotropy profile.
- Predicted that higher resolution simulations should see deviations from a universal pseudo-phase-space density (ρ/σ^3) profile.



Part 3

Universality in Dark Matter Halos

Universality Implies Information is Lost

- Dynamically
- Post-processing

Background:
Brownian Motion (Langevin Equation)

$$\frac{dv}{dt} = -\gamma v + \Gamma(t)$$

drag

diffusion

$$\langle \Gamma(t) \rangle = 0$$

$$\langle \Gamma(t)\Gamma(t') \rangle = 2D\delta(t - t')$$

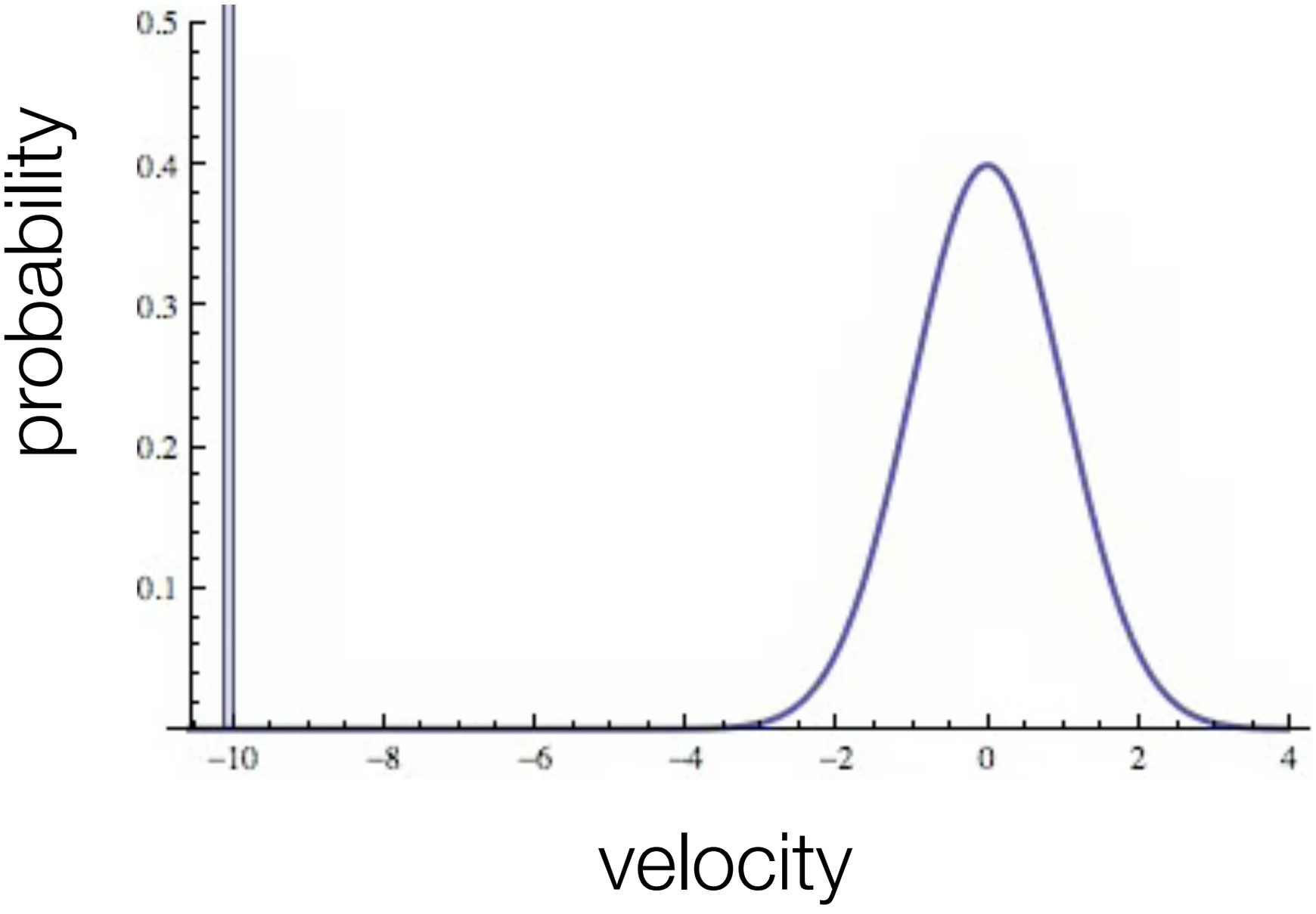
diffusion coefficient

Background:
Brownian Motion (Fokker-Planck Equation)

$$f(v,t) = \sum_i \delta(v - v_i(t))$$

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial v}\left(\gamma v f + D\frac{\partial f}{\partial v}\right)$$

Background:
Brownian Motion



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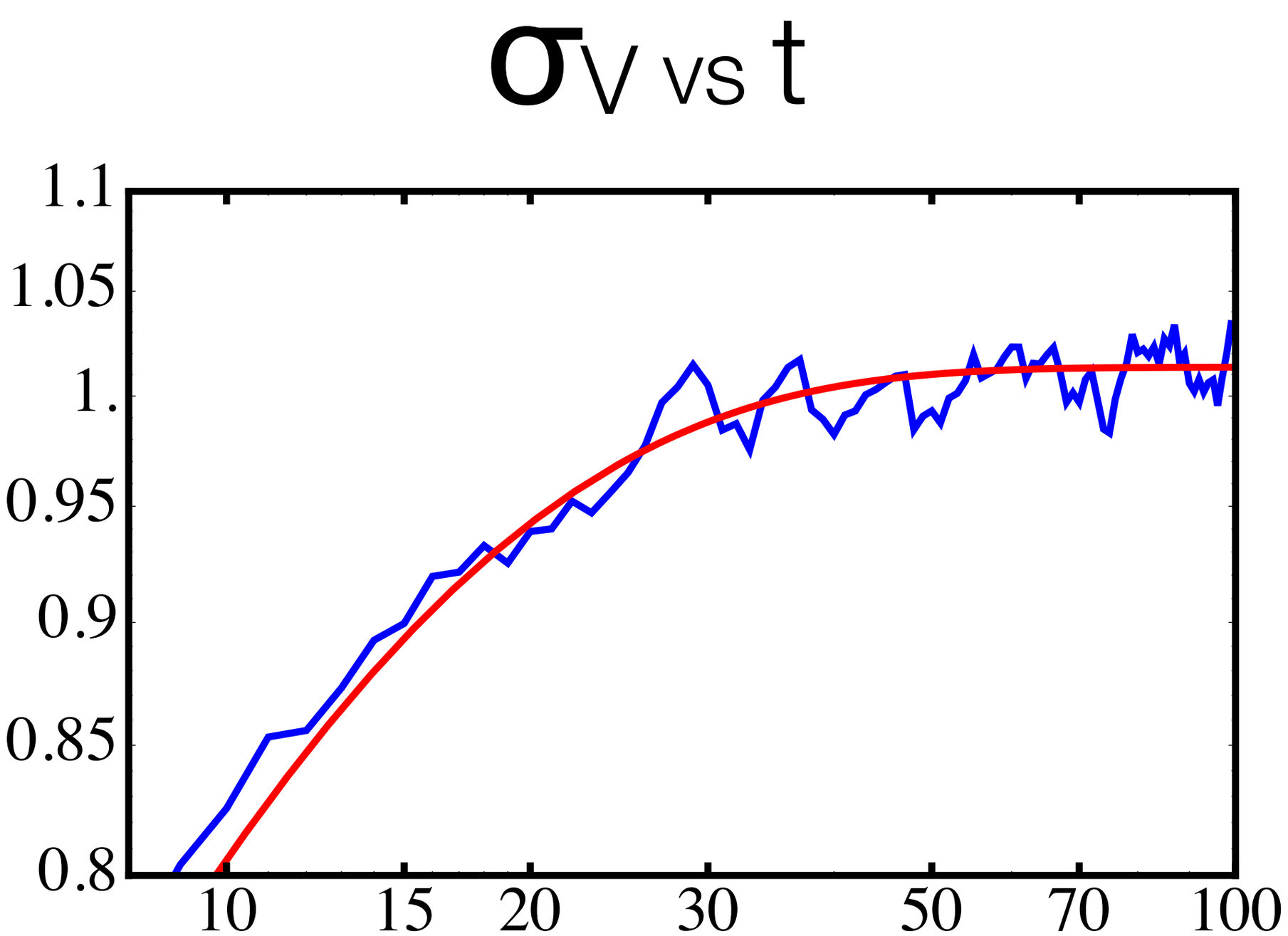
Brownian Motion



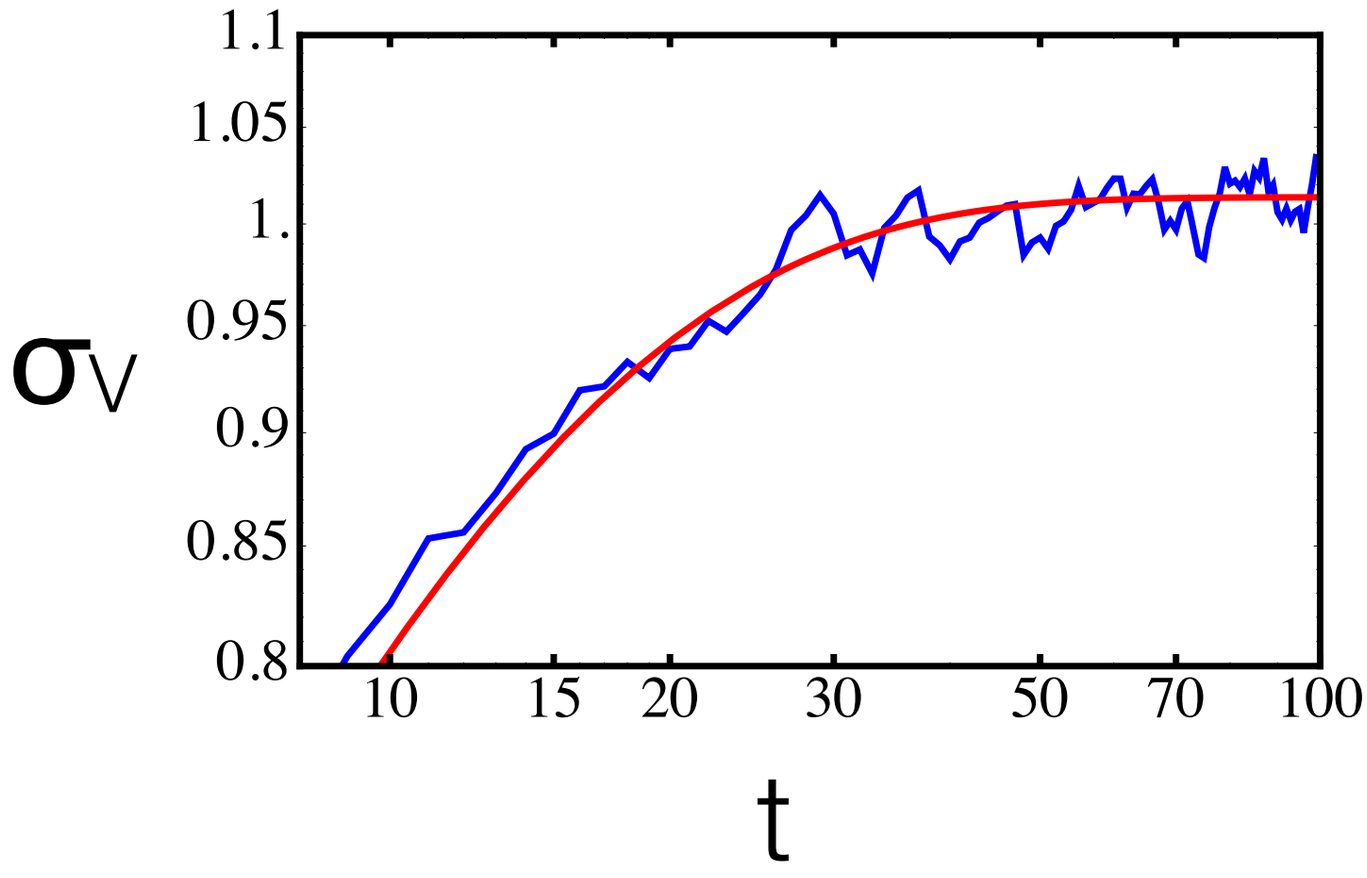
What I would like to know

- Is there an equivalent description for Dark Matter Halos?
- Do Halos undergo diffusion?
- Do Halos relax?

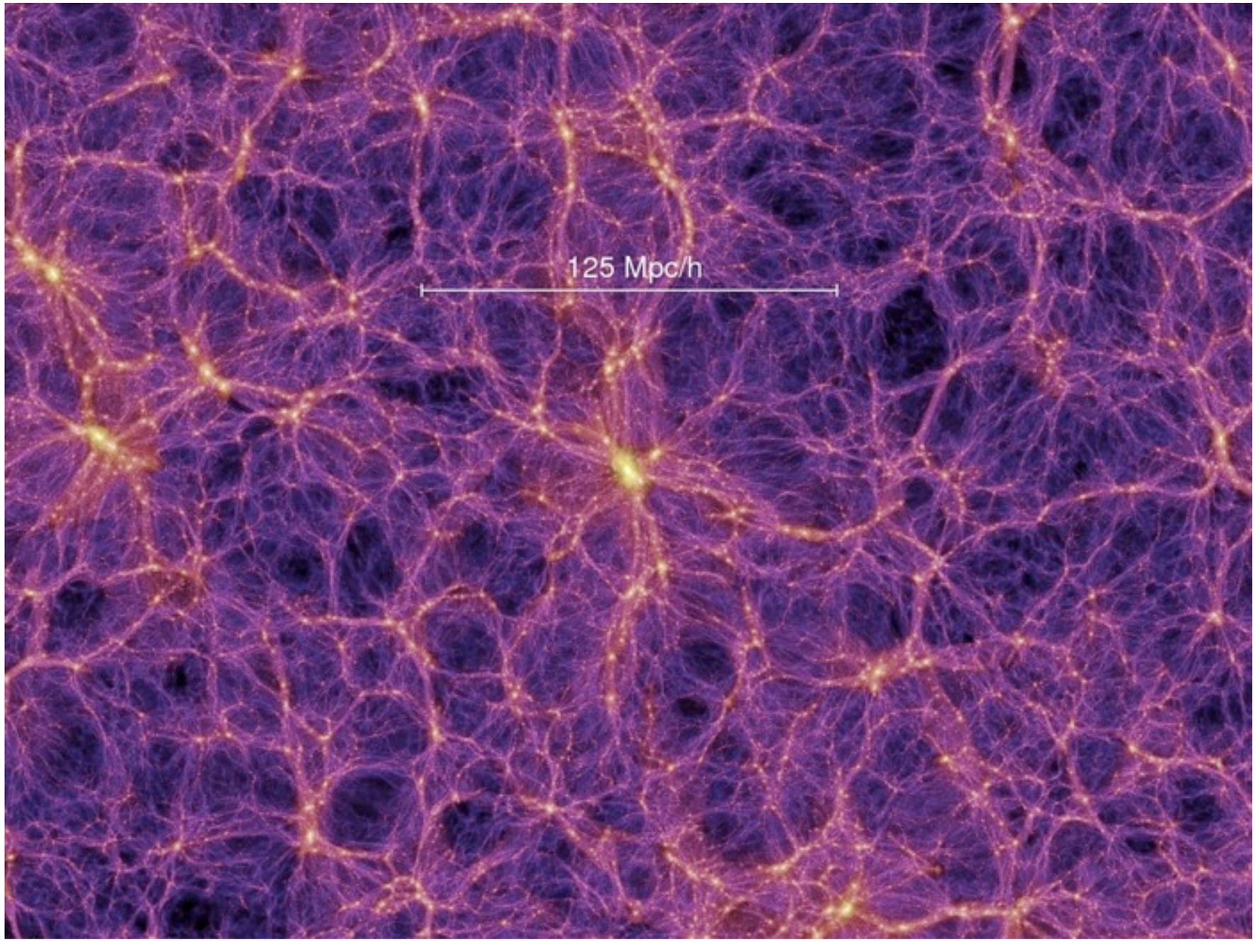
‘Measure’ Diffusion using N-body Simulations

- Sample f(E,L) and track the distribution’s evolution.

- If spread in distribution is proportional to $t^{1/2}$ initially ⟶ diffusion



How do we sample f(E,L)?



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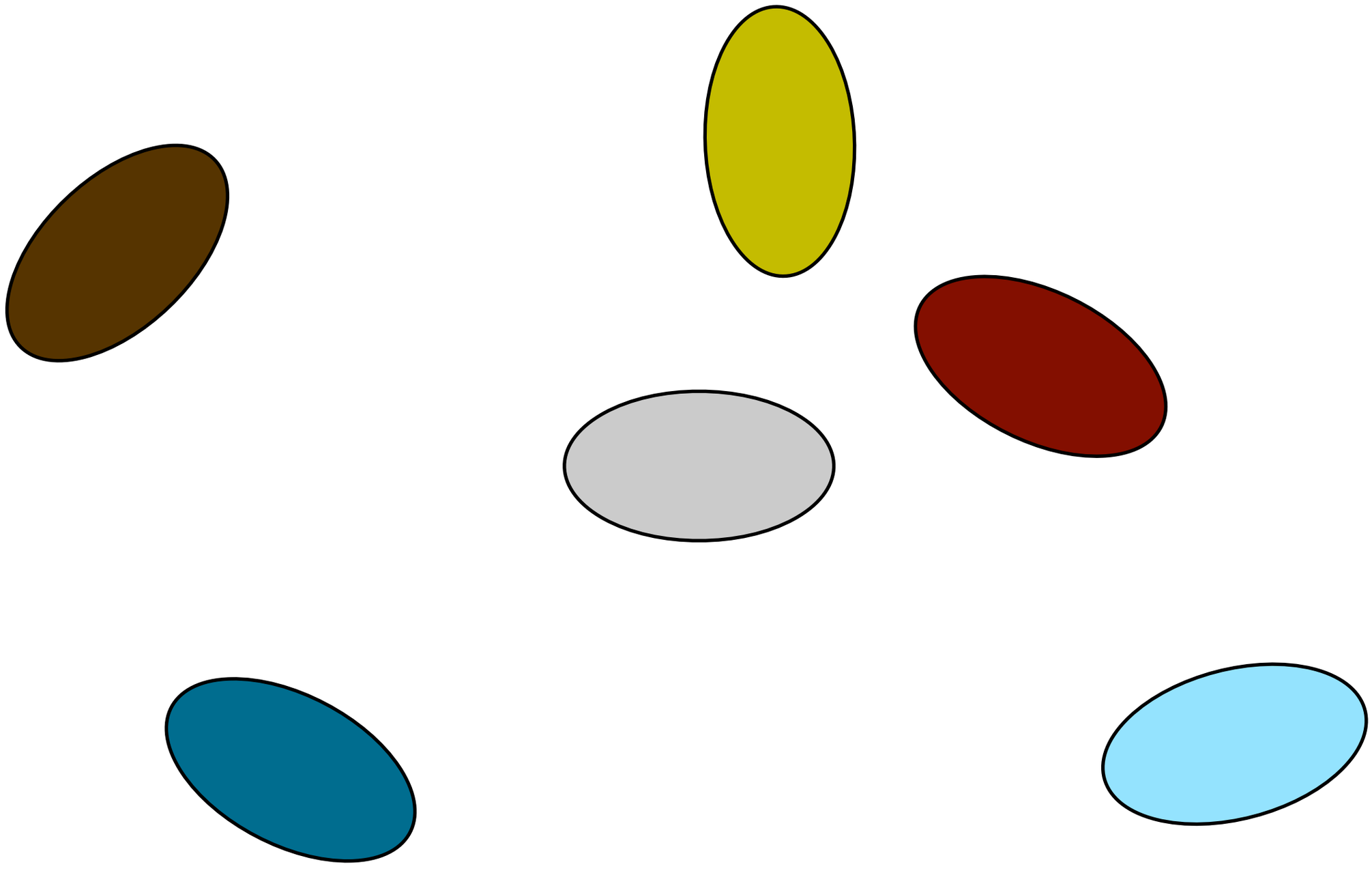

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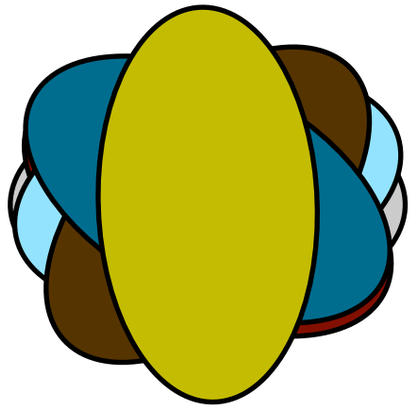

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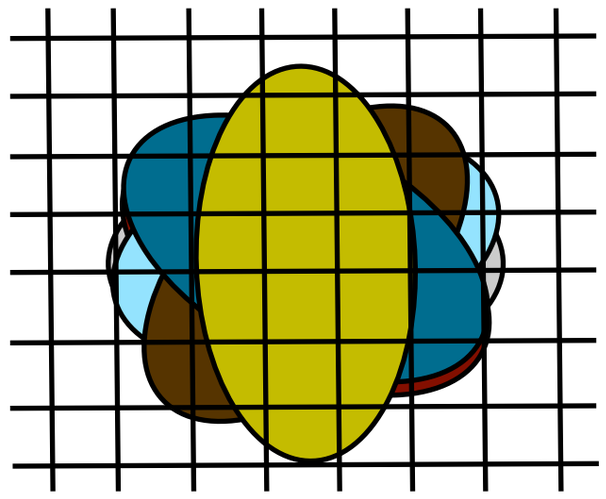
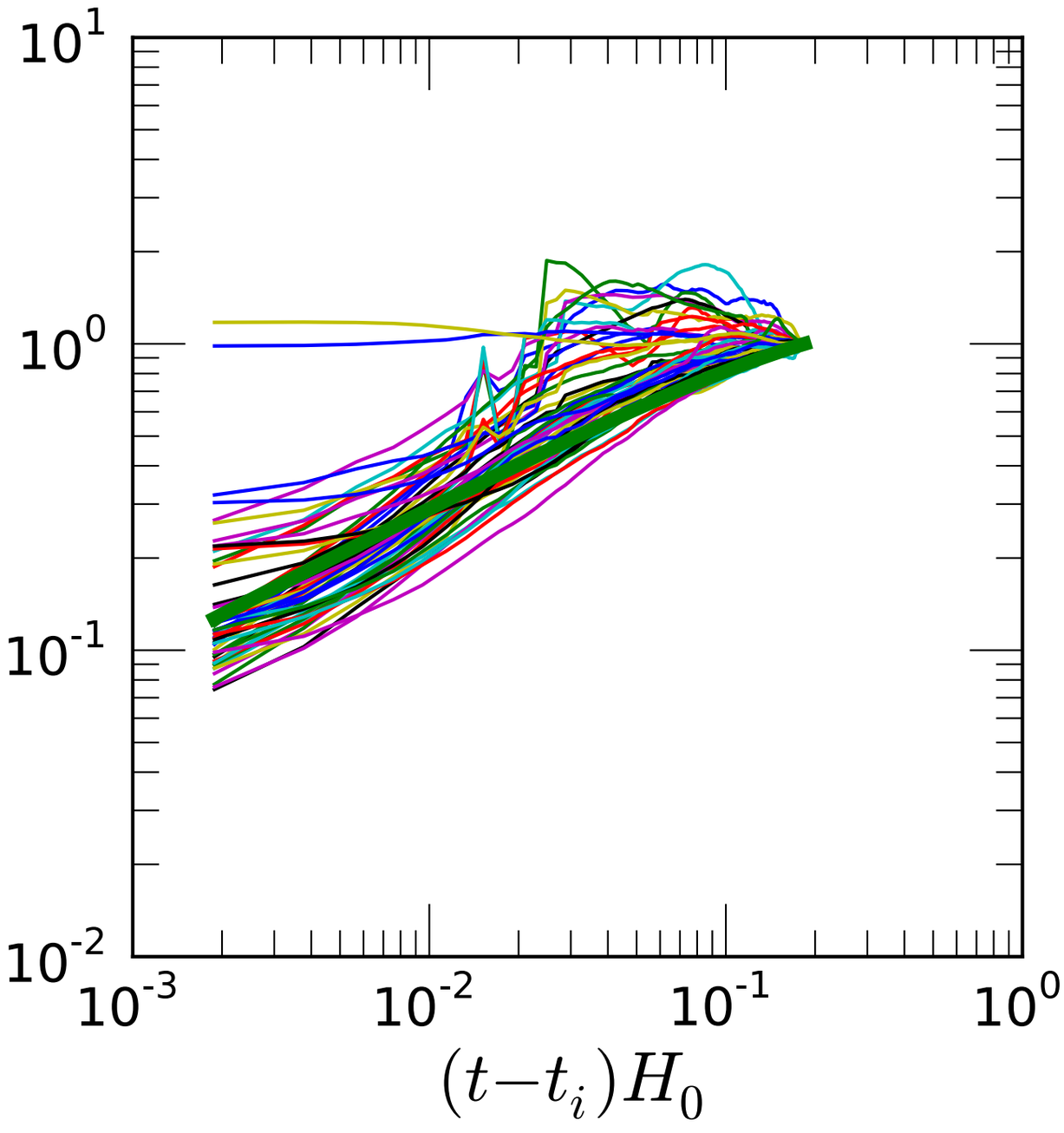
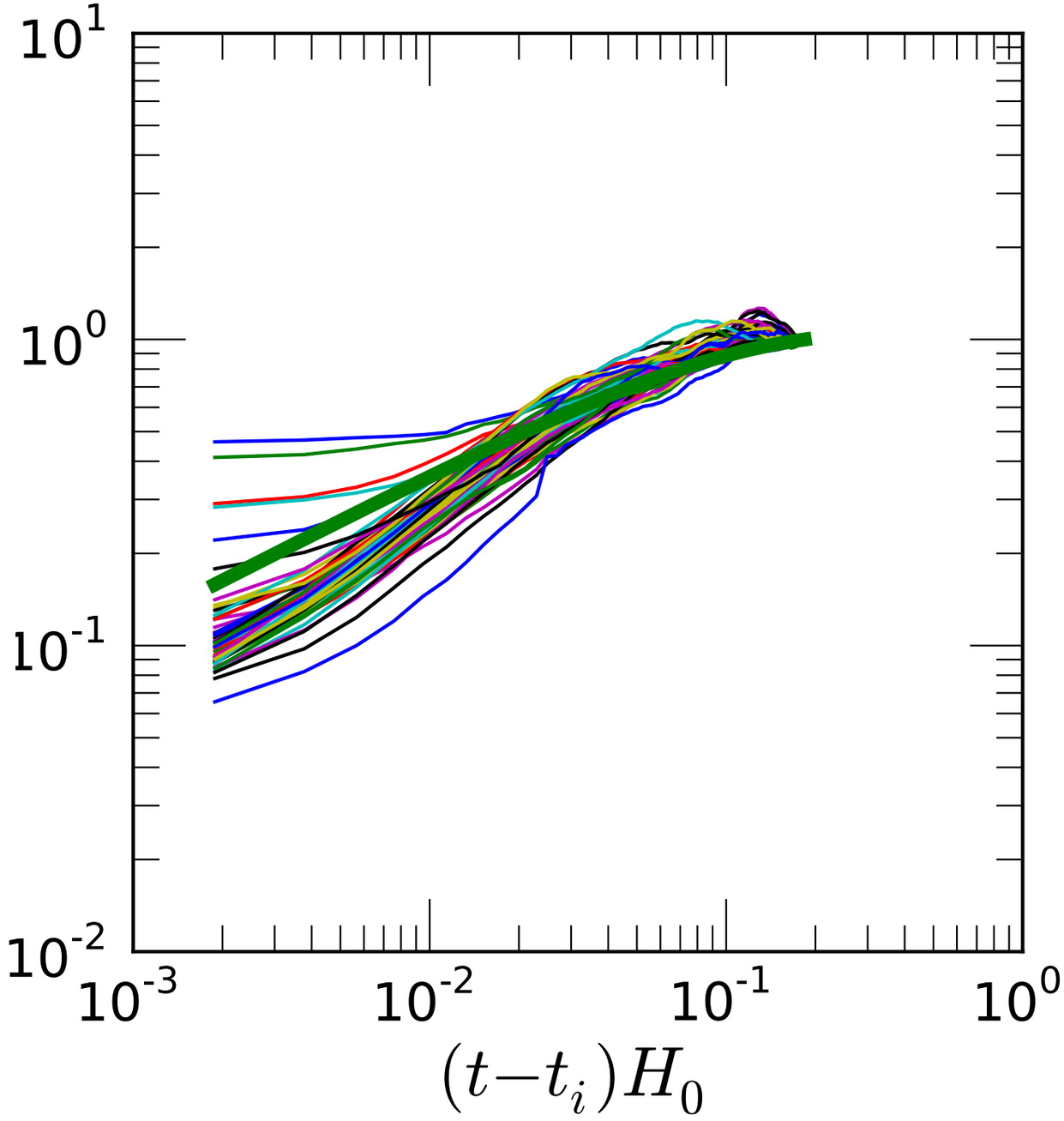


N-body simulations

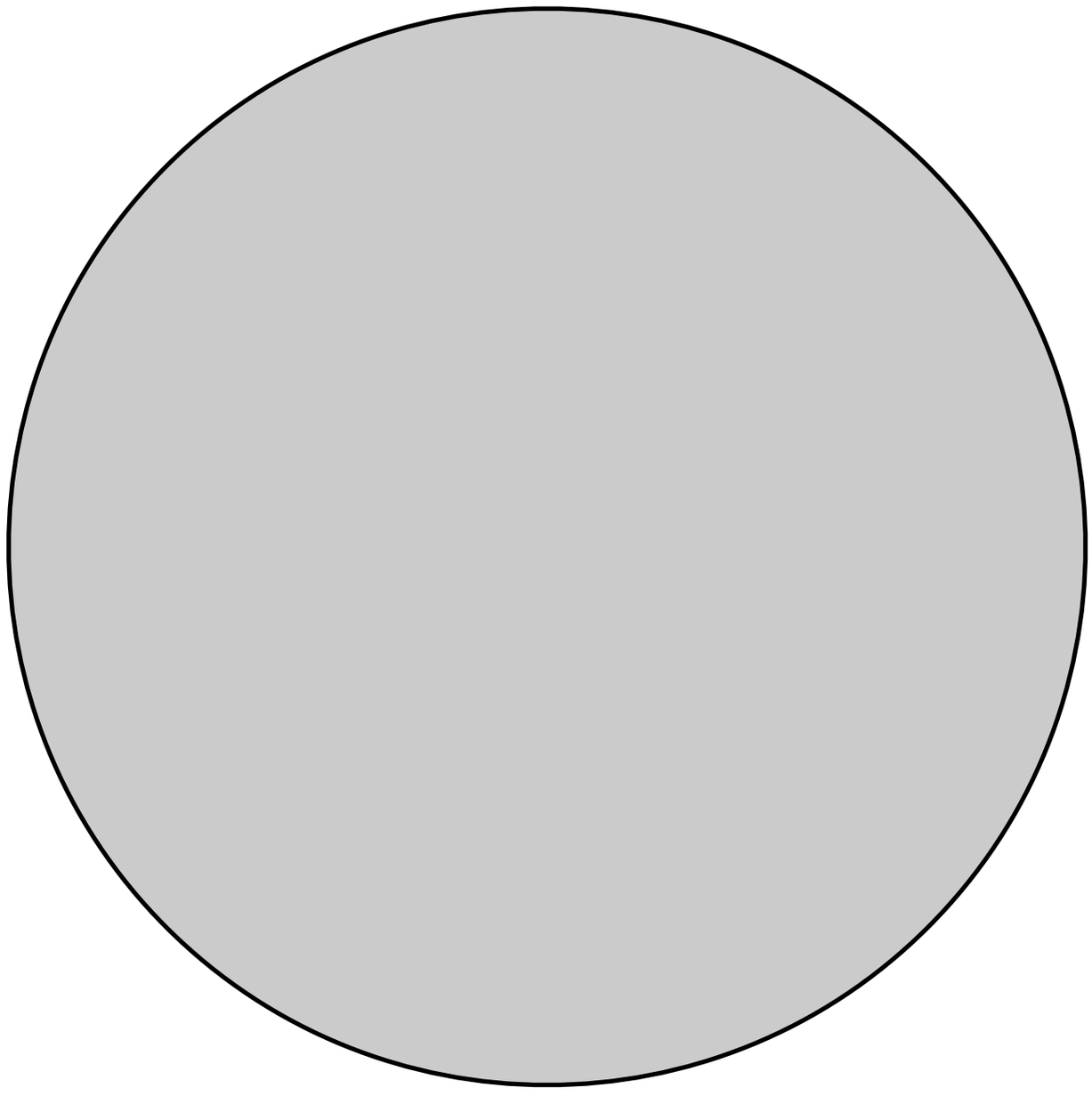
σ_L vs t



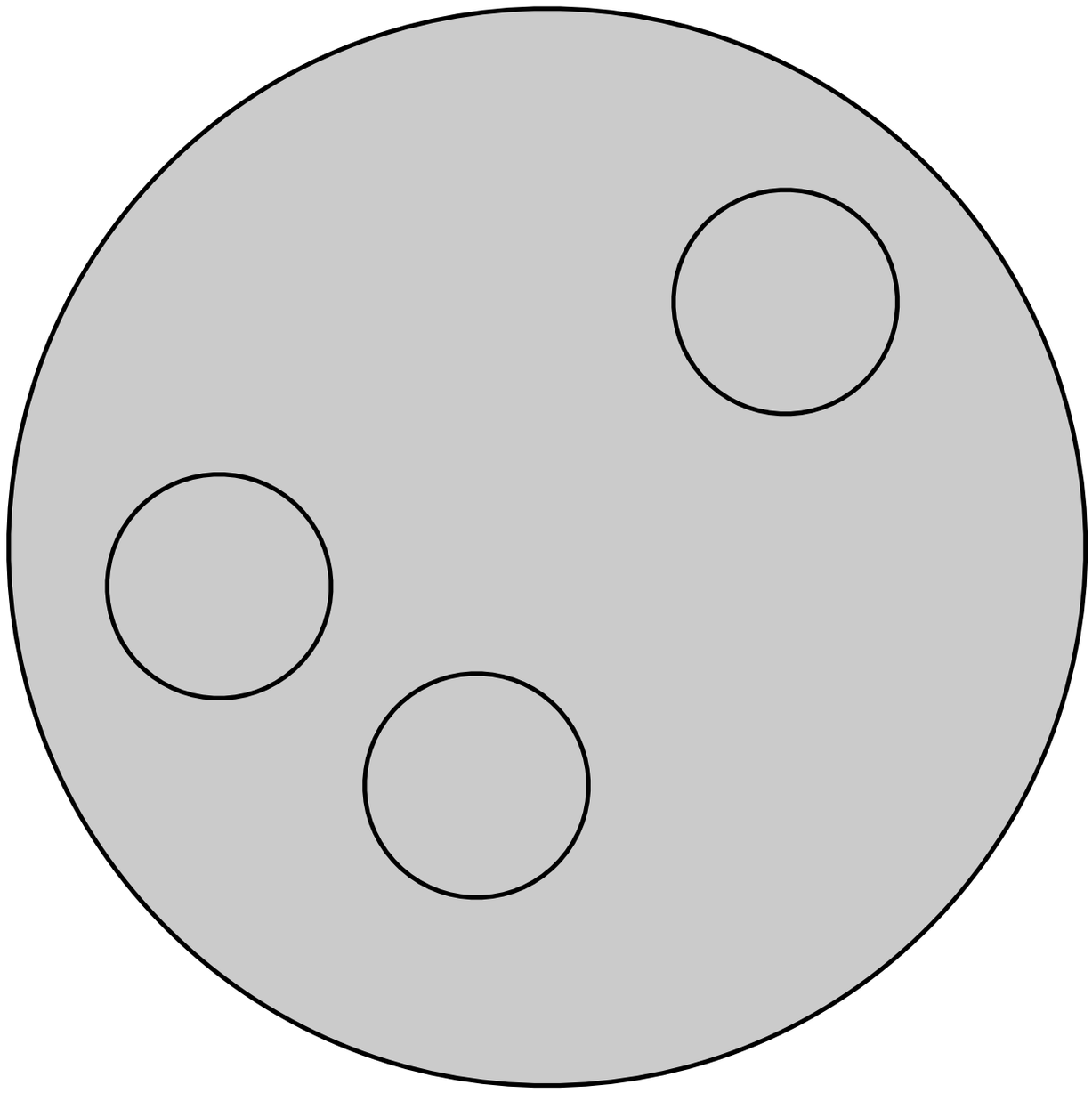
σ_E vs t



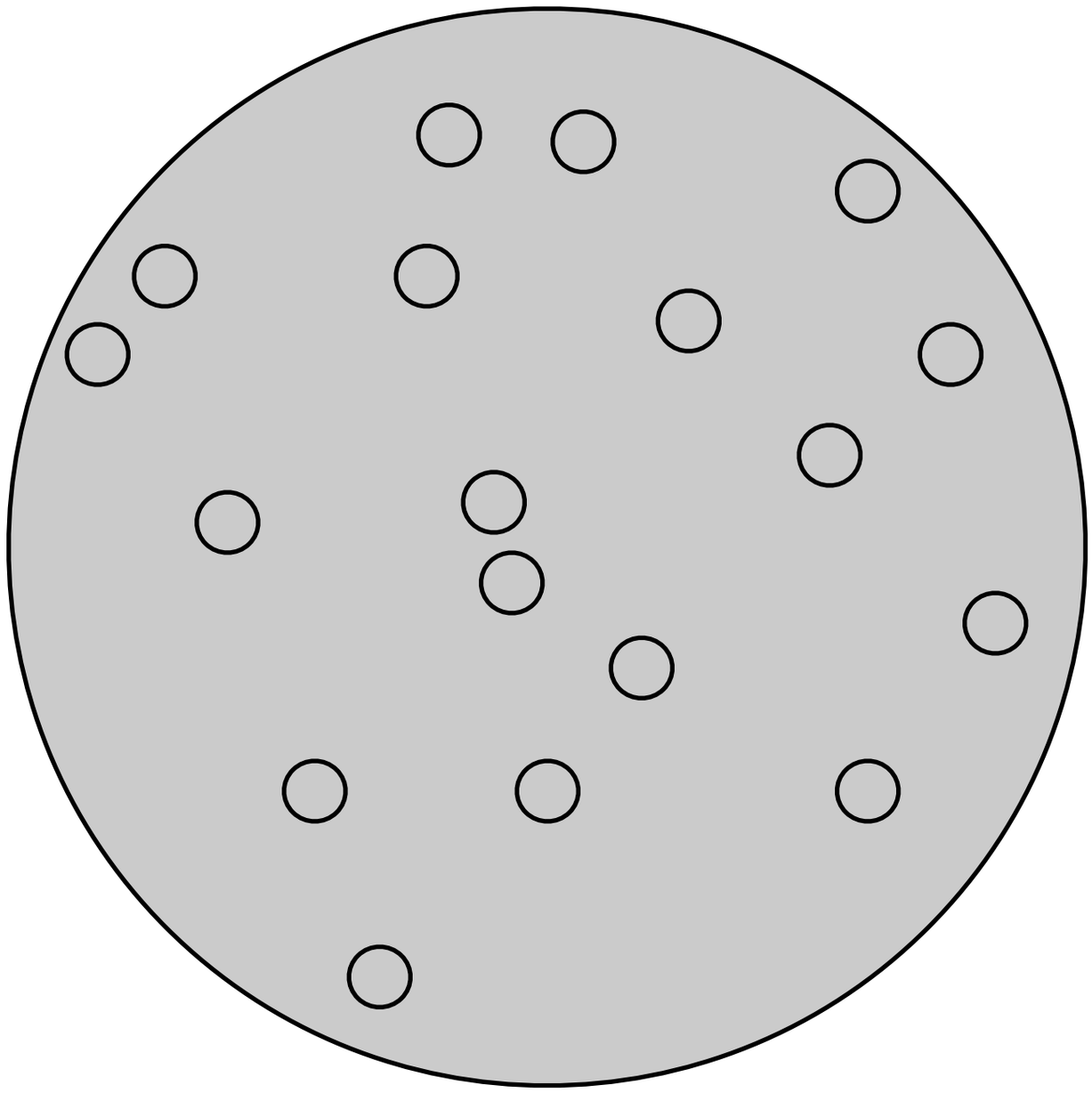
Simple Numerical Experiments: Spherical



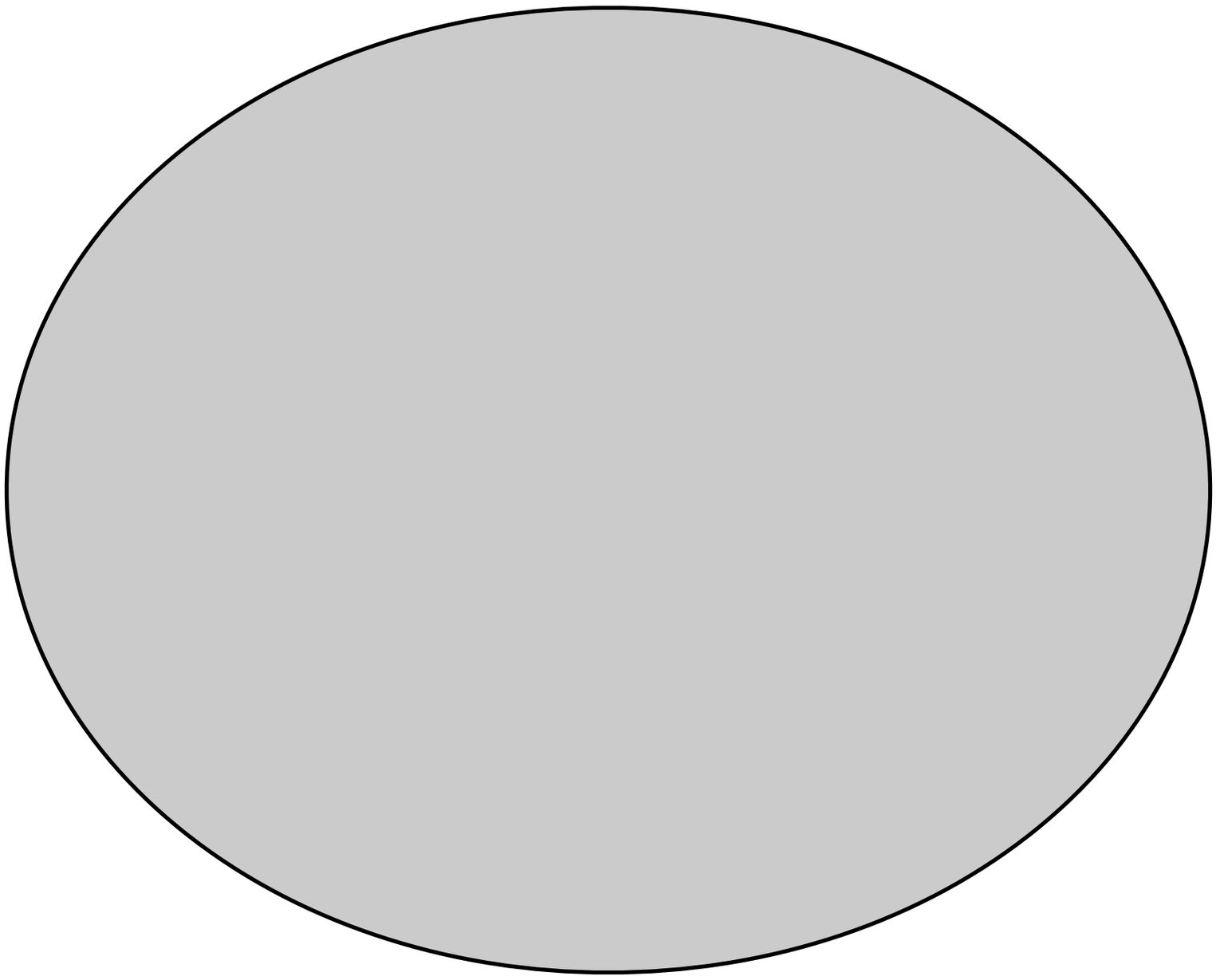
Simple Numerical Experiments: Spherical with Big Kicks



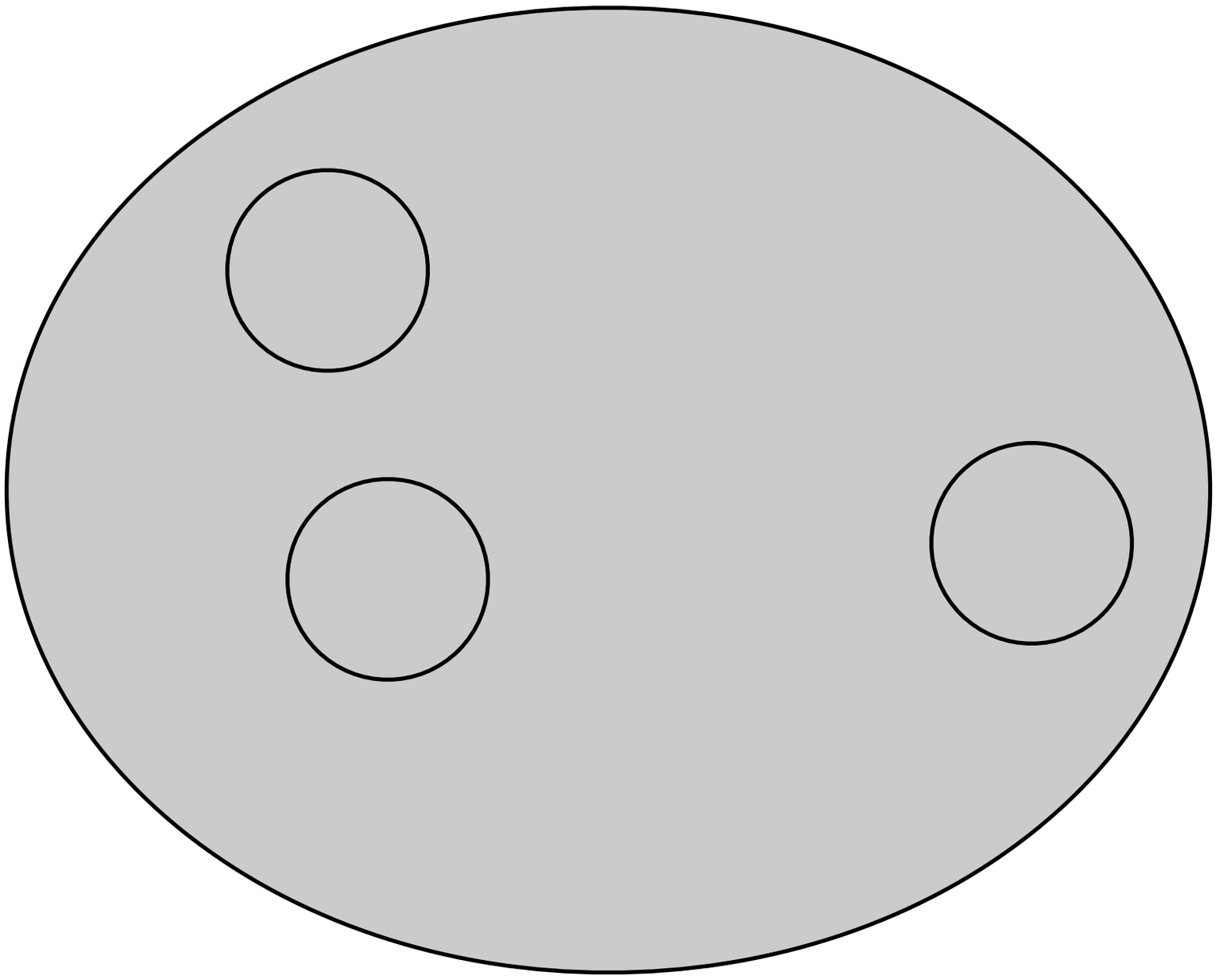
Simple Numerical Experiments: Spherical with Small Kicks



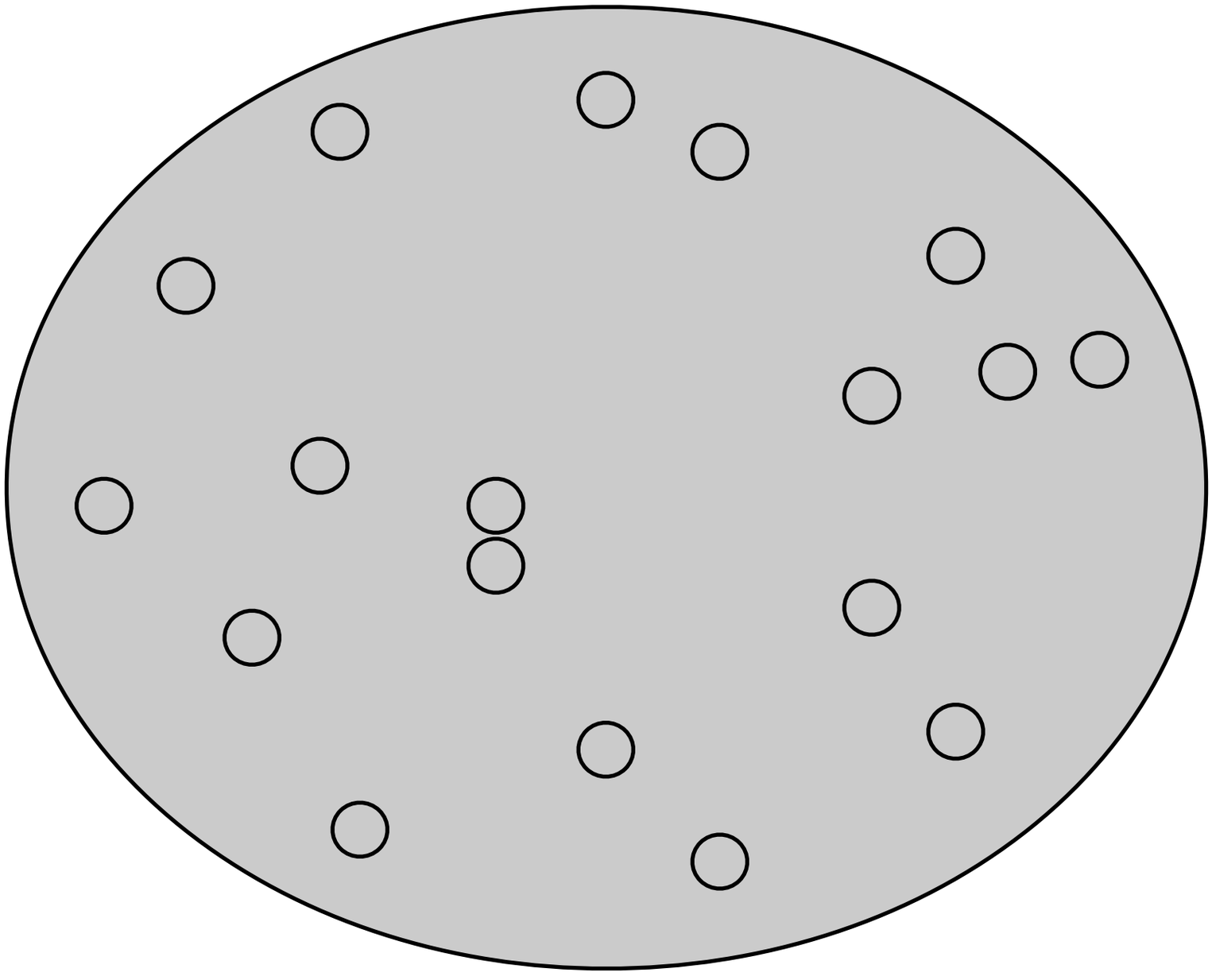
Simple Numerical Experiments: Triaxial



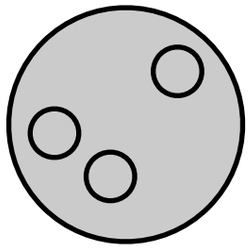
Simple Numerical Experiments: Triaxial with Big Kicks

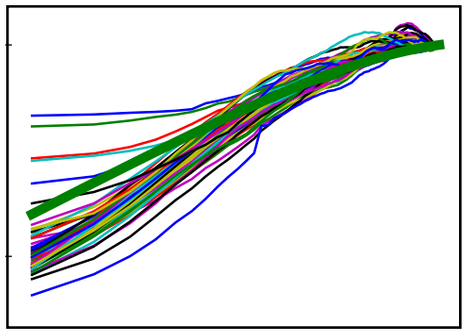


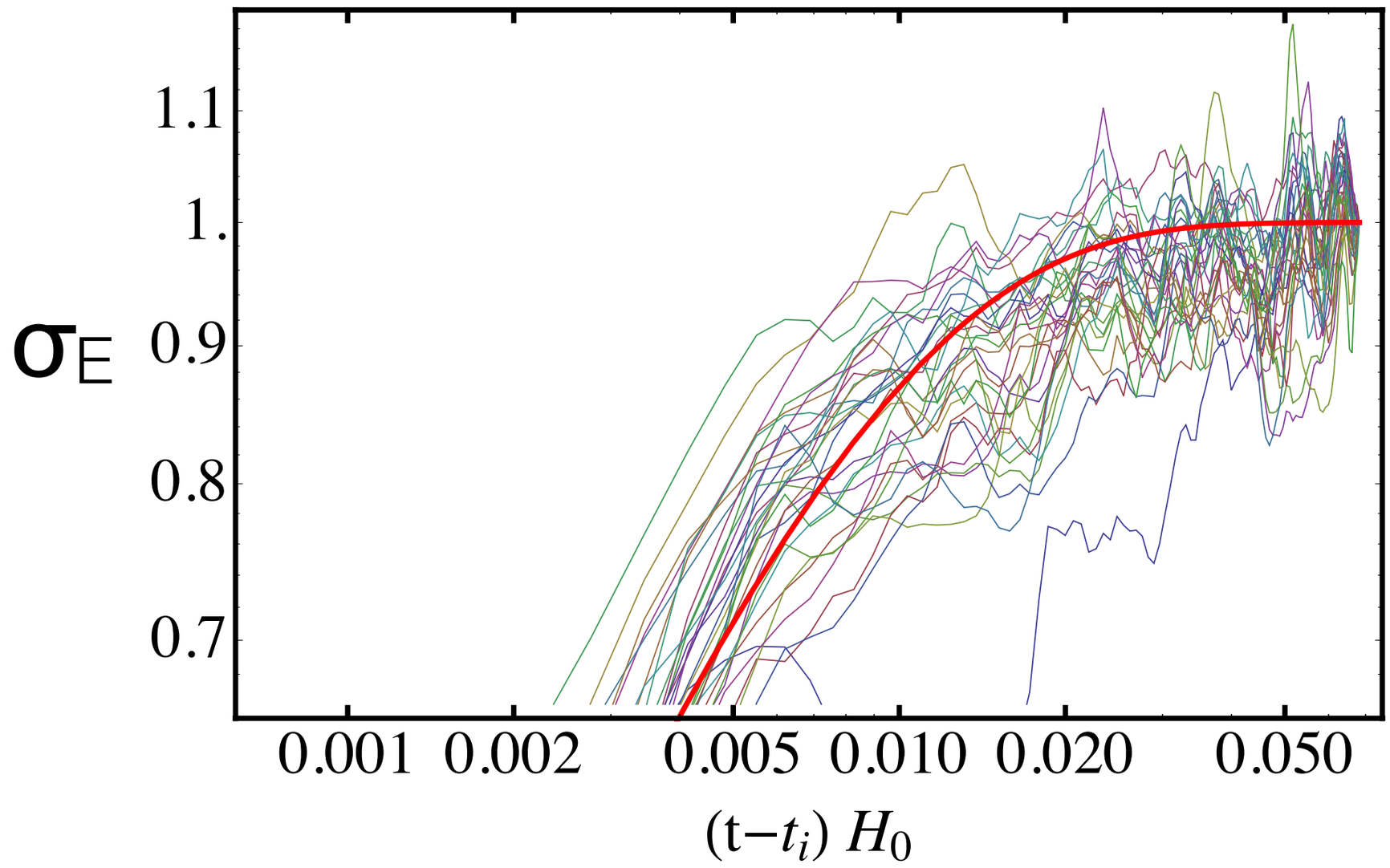
Simple Numerical Experiments: Triaxial with Small Kicks



Spherical with Big Kicks







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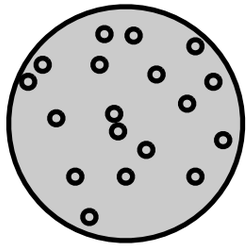
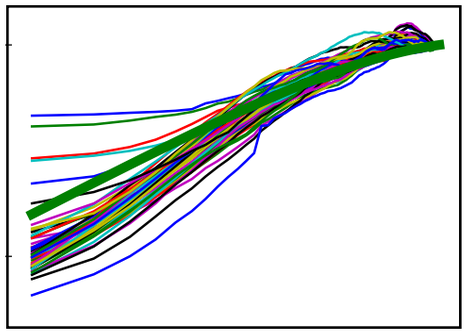
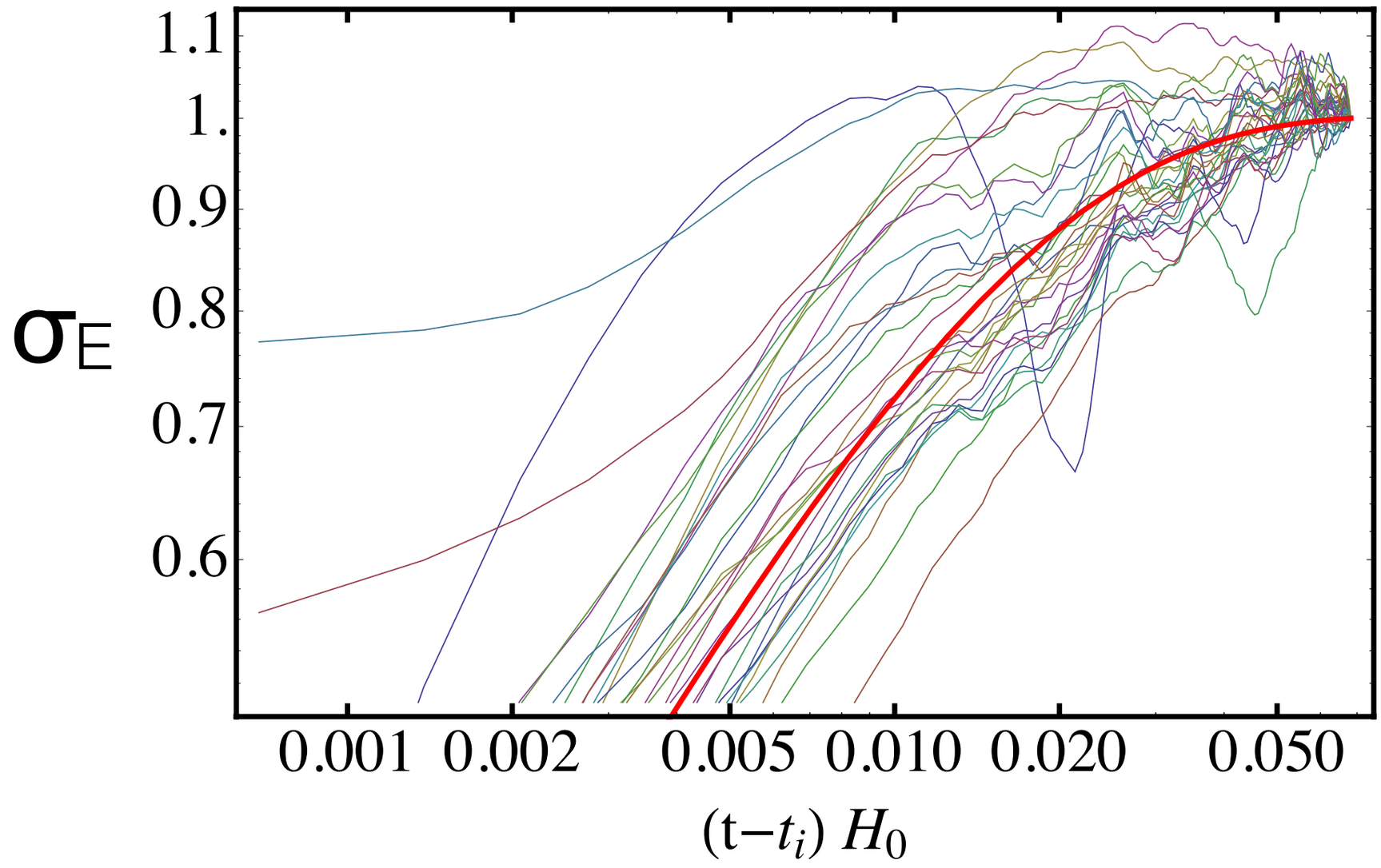
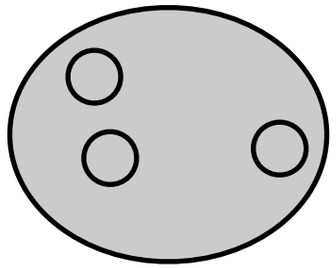
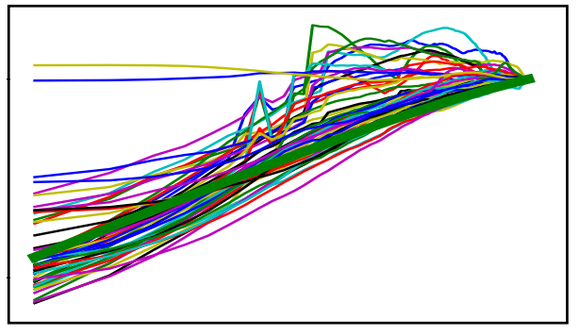


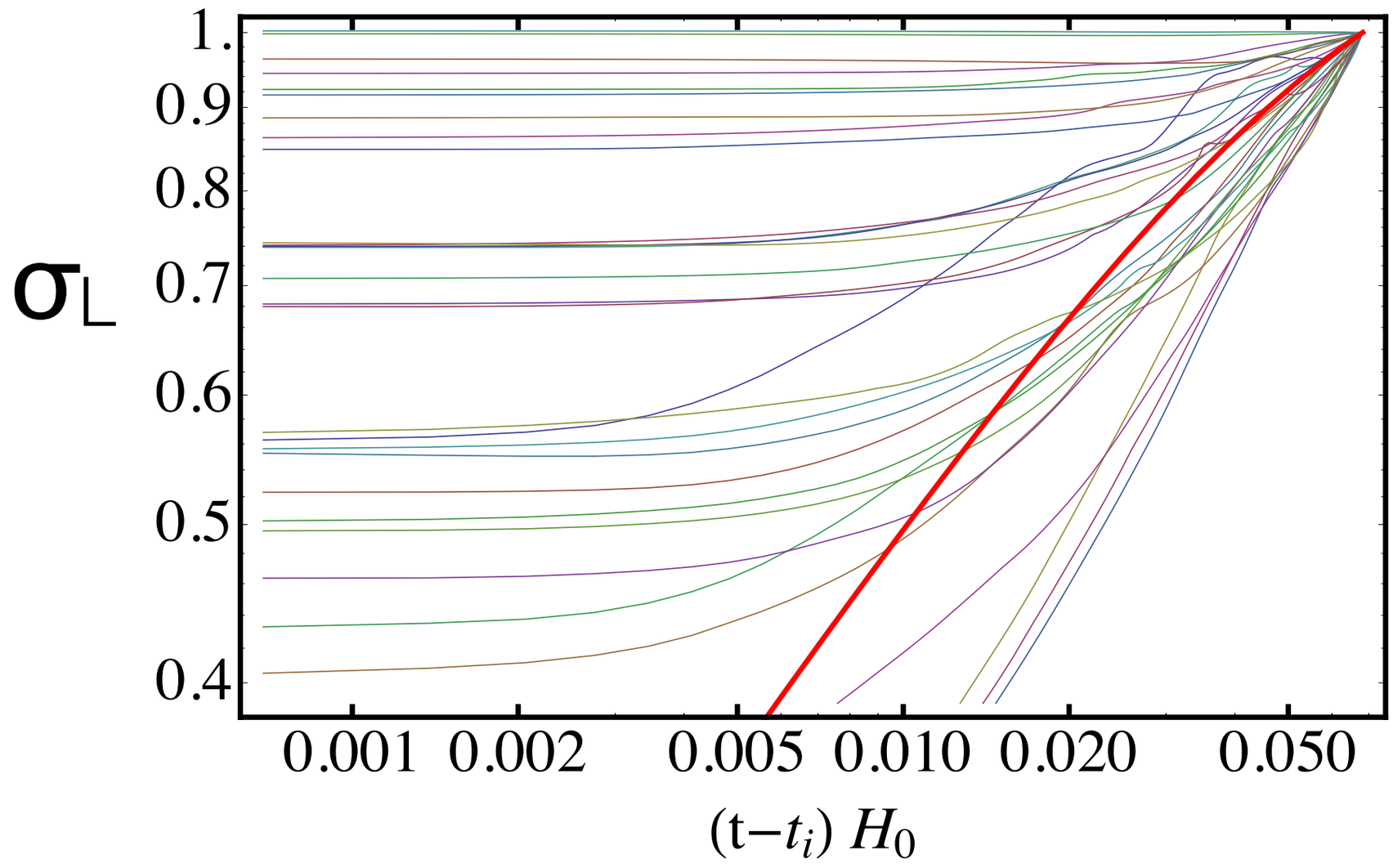




Triaxial with Big Kicks







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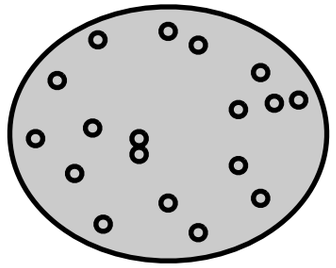

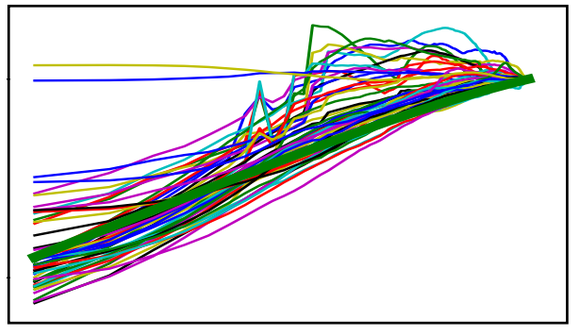

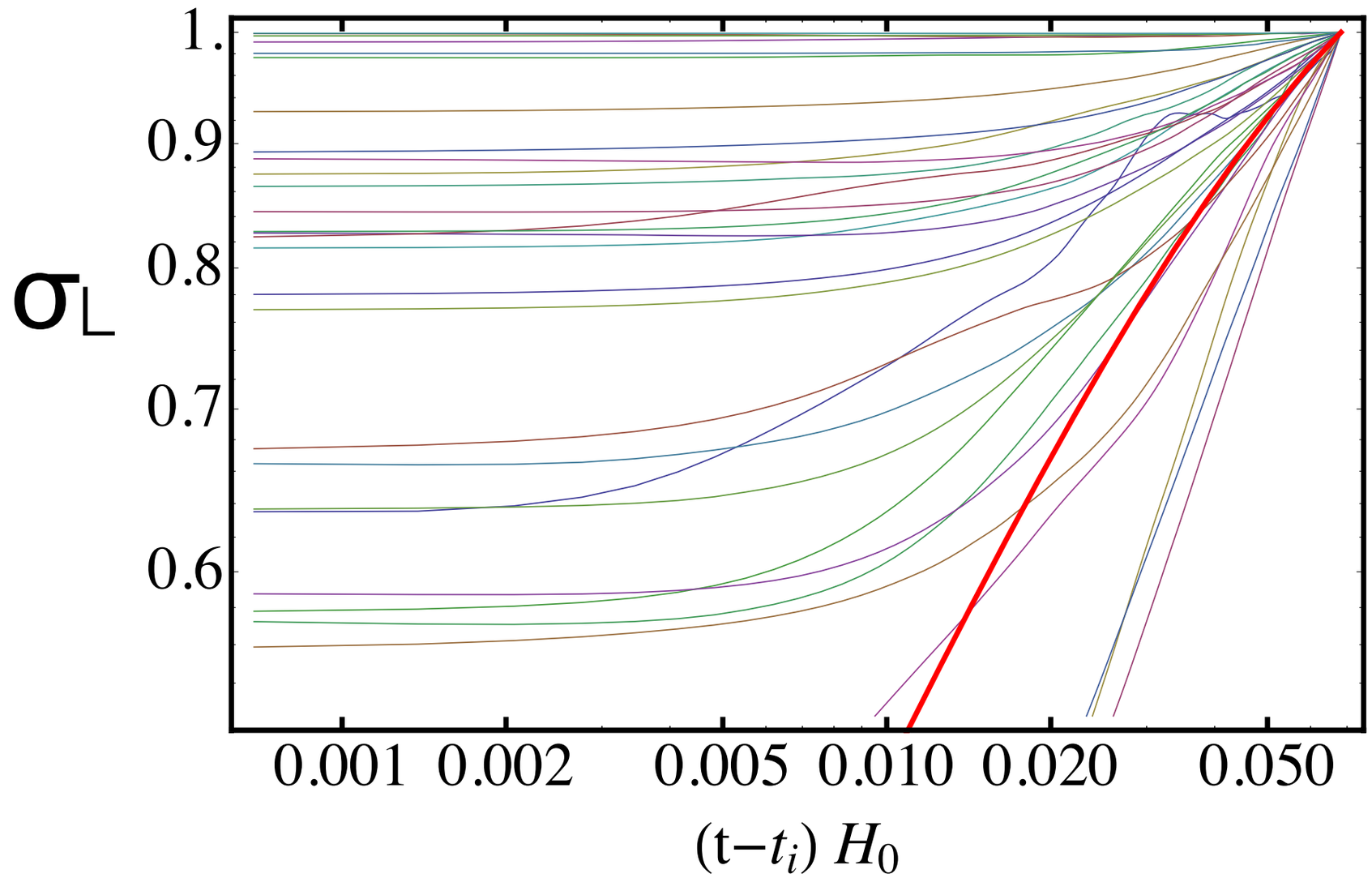

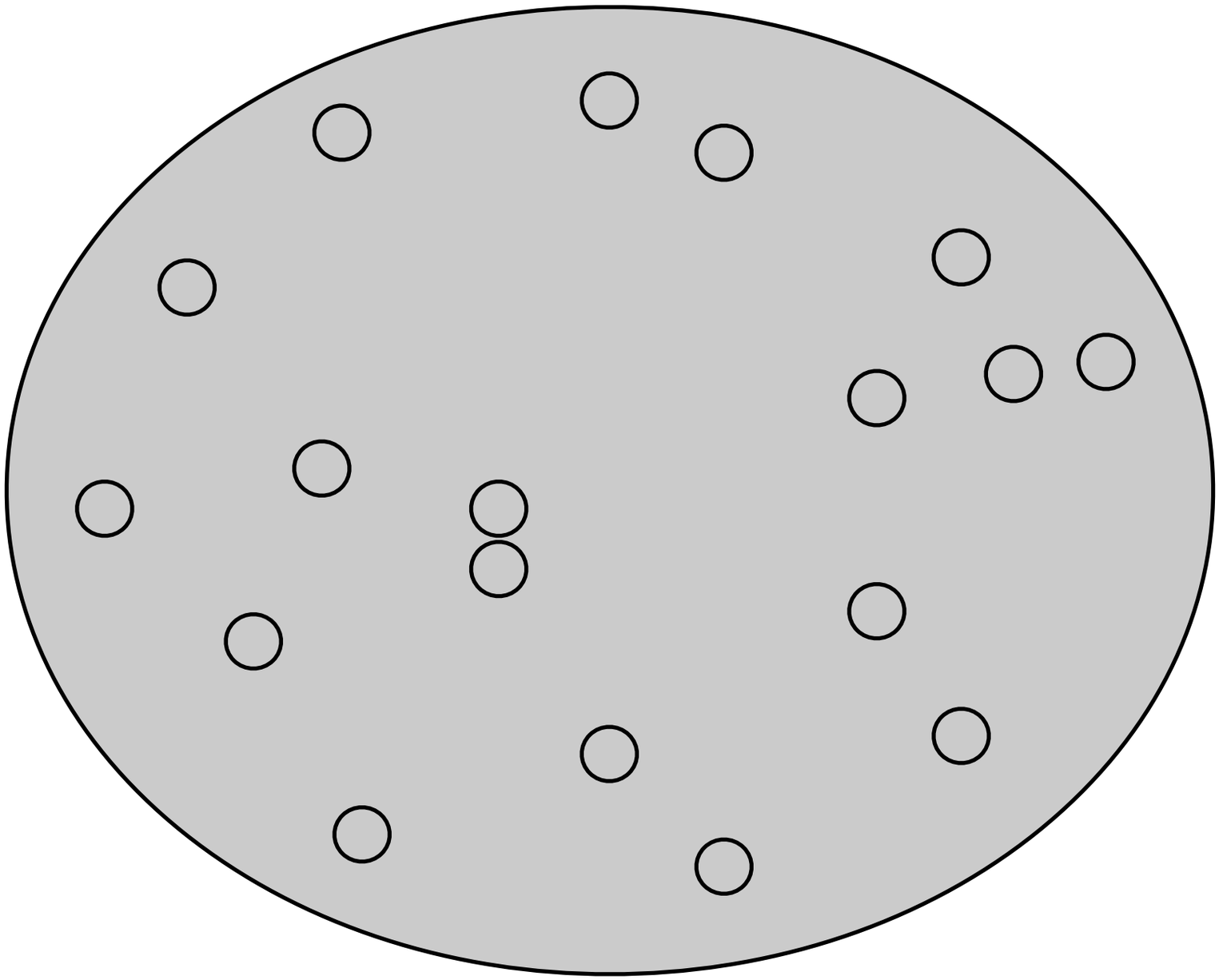

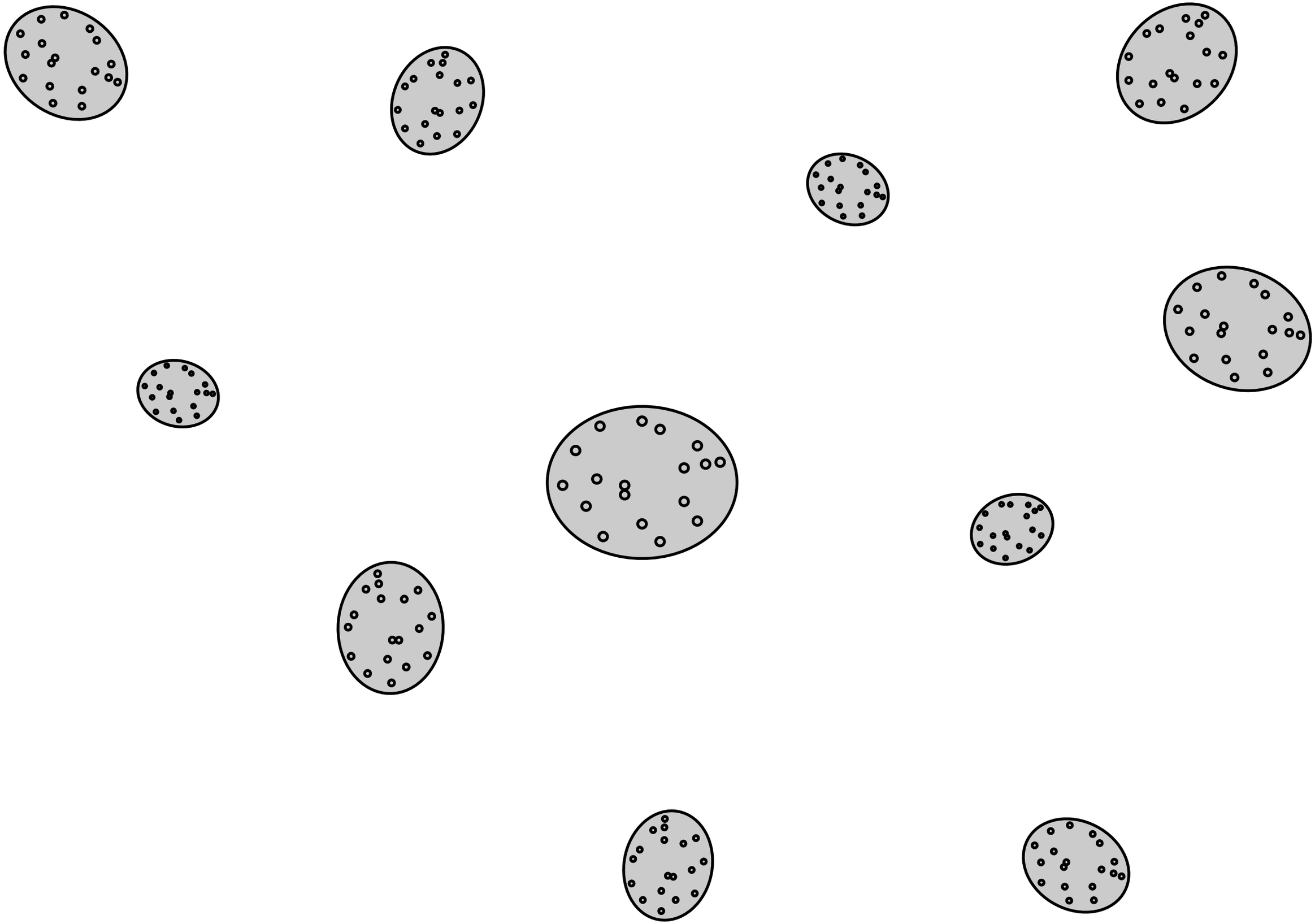

Chapter 3 Summary

- We’ve found evidence for diffusion during Halo evolution.
- Large scale tidal fields play an important role dynamically.
- Analytically putting the pieces together...

Conclusion

- We’ve gained intuition about the structure of Dark Matter Halos
- We’re gaining intuition about the formation of Dark Matter Halos
- Exciting times ahead...
- Thanks!!