Semester Thesis - Three Week Presentation

March 19, 2024

- Project Objective
- Methods
  - Electrostatic vs. Gravity
  - Initial Conditions (NGen-IC)
  - Implementation
- Current Work Status
- Next Steps
  - Implement Simulation Setup
  - Define Test Cases

Project Objectives

- Development of a Cosmology Mini App
  $\rightarrow$ simulation of cold dark matter to understand structure formation.
  $\rightarrow$ Include the expansion of the Universe
- Test the results $\rightarrow$ Comparison to existing simulations
- How far can we push it? (Number of Particles, mesh size)

Methods

- Define the physics of the simulation
  $\rightarrow$ set up the equations of motion for the particles
  $\rightarrow$ define the Poisson equation for the gravitational potential
- Define the initial conditions of the particles
- Run the simulations on a suitable grid size for a certain amount of time
  $\rightarrow$ Redshift z

Methods - Electrostatic vs. Newton Gravity

Electrostatic

- Poisson equation

$$\Delta\Phi(\mathbf{r}) = -\frac{\rho(\mathbf{r})}{\varepsilon}$$

- Electric Field

$$\mathbf{E}(\mathbf{r}) = -\nabla\Phi(\mathbf{r})$$

Gravity

- Poisson equation

$$\Delta\Phi(\mathbf{r}) = 4\pi G\rho(\mathbf{r})$$

- Gravitational Field

$$\mathbf{F}(\mathbf{r}) = -\nabla\Phi(\mathbf{r})$$

Methods - Electrostatic vs. General Relativity

Electrostatic

- Poisson equation

$$\Delta\Phi(\mathbf{r}) = -\frac{\rho(\mathbf{r})}{\varepsilon}$$

- Particle Motions

$$\frac{d\mathbf{x}_i}{dt} = \mathbf{v}_i$$

$$\frac{d\mathbf{v}_i}{dt} = -\frac{q_i}{m_i}\nabla\Phi|_i$$

Gravity (Expanding Universe)

- Poisson equation

$$\Delta_x\Phi = 4\pi G a^2(t)\left[\rho(\mathbf{x},t) - \bar{\rho}(t)\right]$$

- Particle Motions

$$\frac{d\mathbf{x}_i}{dt} = \mathbf{v}_i$$

$$\frac{d\mathbf{v}_i}{dt} = -\frac{1}{a^2(t)}\nabla_x\Phi|_i - 2H(t)\mathbf{v}_i$$

$\rightarrow$ use Leapfrog to update particle simulations

Methods - Initial Conditions

NGenIC is an initial conditions code for cosmological structure formation (based on power spectrum)

Developed at Heidelberg Institute for Theoretical Studies

- generates particles with positions, velocities
- ICs are compatible with GADGET (cosmological simulations code from Max-Planck-Institute for Astrophysics)
- NGenIC code is MPI parallel $\rightarrow$ suitable for large initial conditions

Methods - Implementation

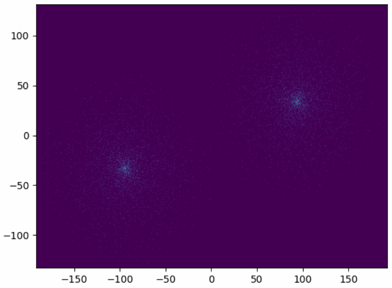
Implementation will be based on the structure of the Landau Damping Simulation

- collisionless dark matter particles
- Periodic boundary conditions
- FFT solver for Poisson equation (analogously to electrostatic)
- Leapfrog Integration (analogously to electrostatic)

What has been done so far?

- Download NGenIC and GADGET, install all dependencies
- Test of Generation of ICs with NGenIC
- First small simulation with GADGET
    - Collision of two galaxy clusters
    - large-scale structure formation

Animations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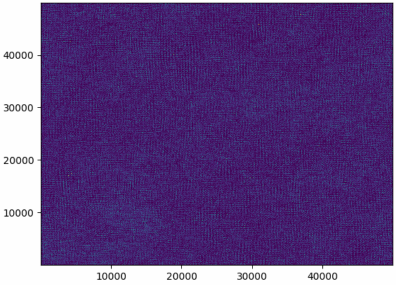
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Ongoing Tasks

- Get a feeling for IPPL
- read in ICs from NGenIC and initialise IPPL particles with it
- Understand the parameters of NGenIC

Next Steps

- derive correct equations for particle movements (comoving vs. physical distances)
- Change physics equations for the time evolution in IPPL
- set up simulation $\rightarrow$ compare/verify with GADGET
- scaling study
- Generate nice picures/movies :)

Questions

- Time attribute already implemented explicitly?