Osservatorio Astronomico di Trieste
Astronomical Observatory of Trieste

High-Performance Cosmology: the PINOCCHIO code

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Outline

- Overview of PINOCCHIO
- Time scale, Milestones and KPIs
- Future developments

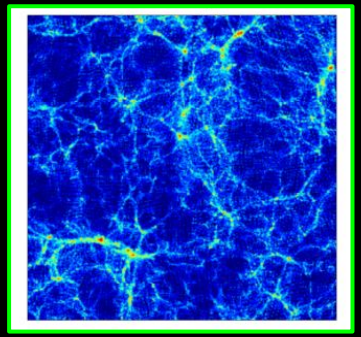
PINpointing Orbit-Crossing Collapses HIerarchical Objects: PINOCCHIO

PINOCCHIO is an algorithm, based on Lagrangian Perturbation Theory (LPT), for simulating Dark Matter halos in cosmological boxes and past light cones (*Monaco et al. 2002)*

- N-Body approach: calculating the gravitational forces acting on each particle due to all other particles

↓

Detailed and accurate for all-scale structure
Computationally very expensive



- LPT approach: calculating the displacements of particles from their initial position

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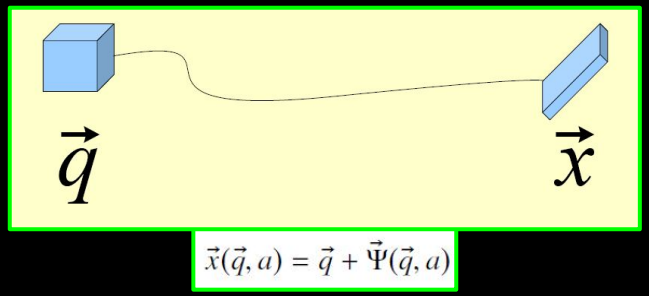
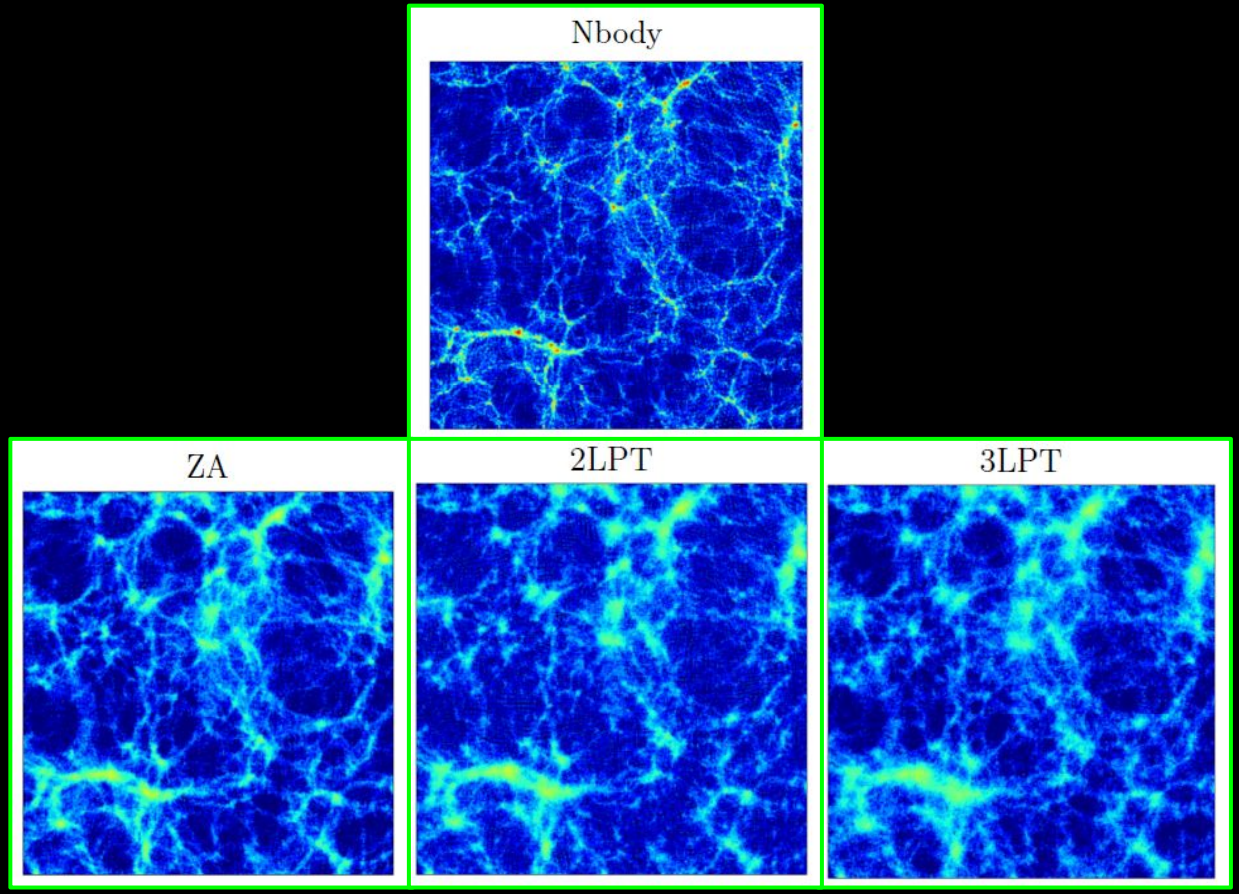
Fast approximation for large-scale structure





Only the displacements are not enough, we still need to identify halos ...

Collapse time for halo identification

The Lagrangian approach has a natural limit in the condition J = 0

$$\vec{x}(\vec{q},a) = \vec{q} + \vec{\Psi}(\vec{q},a)$$

$$J_{ij} = \frac{\partial x^i}{\partial q^j} = \delta_{ij} + \frac{\partial \Psi^i}{\partial q^j}$$

- Before this moment the Lagrangian-to-Eulerian mapping is single-valued

- When J = 0 the q → x mapping becomes multi-valued and the density goes to infinity: orbit crossing or shell crossing

$$1+\delta = \left|\frac{\partial \mathbf{x}}{\partial \mathbf{x_i}}\right|^{-1} = \frac{1}{(1-\lambda_1 D)(1-\lambda_2 D)(1-\lambda_3 D)},$$

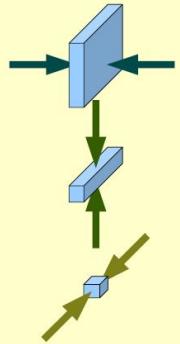
Eigenvalues λ_i for calculating collapse times of particles

$D(t) = 1/\lambda_1$: *pancake*

(ORBIT CROSSING)

$D(t) = 1/\lambda_2$: *filament*

$D(t) = 1/\lambda_3$: *knot*



Code structure

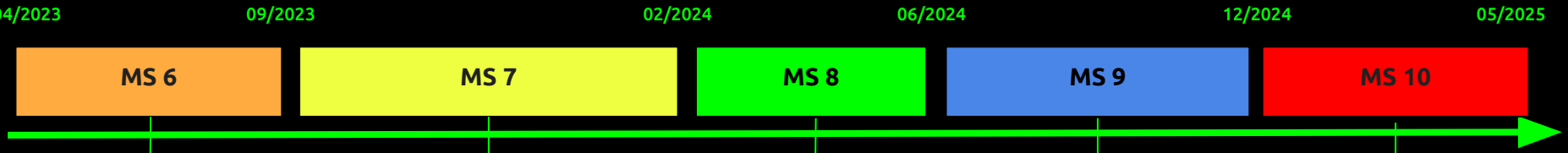
1. Generation of a linear density field on a regular grid

2. Computation of collapse time using an ellipsoidal model based on LPT up to 3rd order

3. Fragmentation of the collapsed medium performed with an algorithm that mimics the hierarchical build-up of DM halos

4. Creation of halo catalogs (box and light cones)

Time Scale, Milestones and KPIs



1. Familiarization with the code
2. Bug fixing
3. Identification off-loadable regions and bottleneck

1. Threadization of collapse time with OpenMP
2. GPU offloading of collapse times with OpenMP/OpenACC

1. Deploying stable code fully suited for LEONARDO with documentation
2. Re-engineering of the fragmentation code, the main actual bottleneck

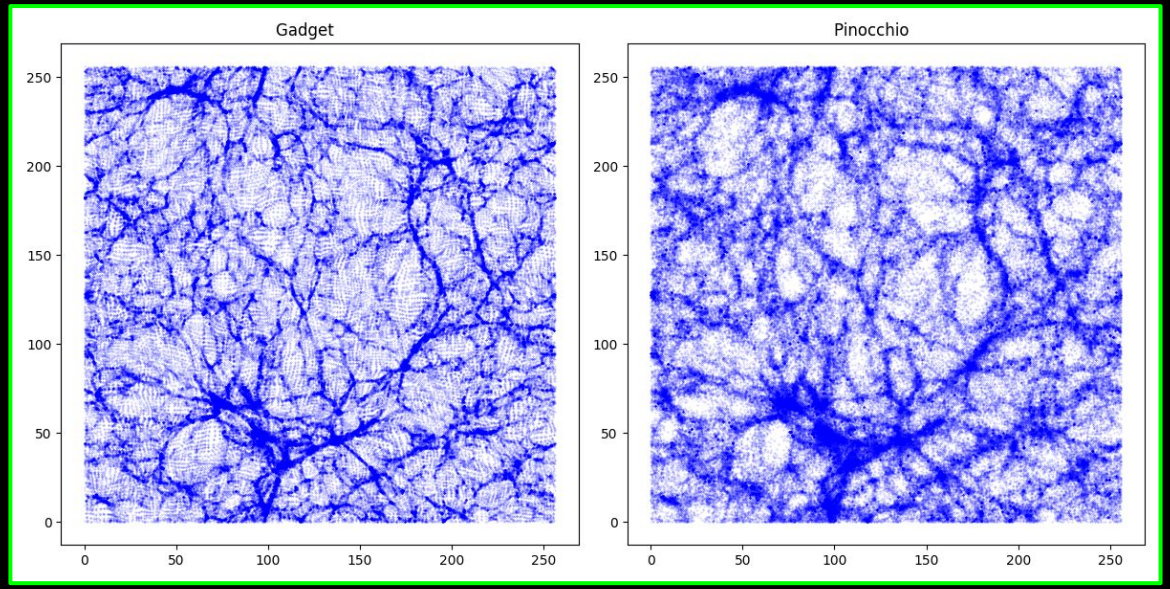
1. Set of demonstrative simulations with the new fragmentation and report

1. 100 simulations
2. Technical paper on the code

Computational capabilities v5.0: start of MS 6

Comparison with full N-body simulations:

- ~1000 faster
- Large Euclid Box (box ~ 4 Gpc, 4096^3 particles) computational time ~ 40 minutes
- Full MPI parallelization
- 5 – 10% accuracy in reproducing
  2-point statistics, mass function and bias



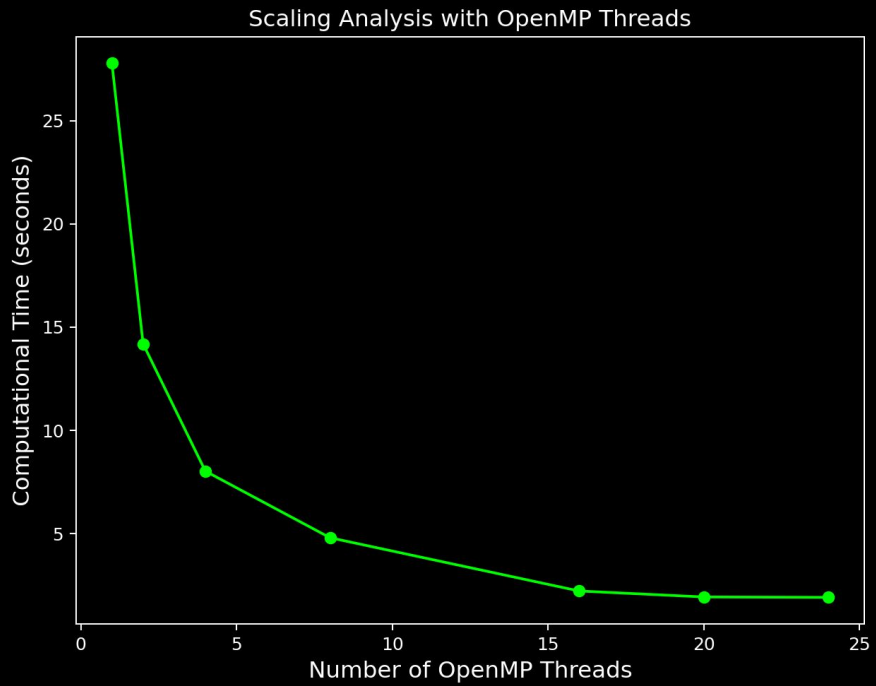
Key Performance Indicators: MS 6 & MS 7

Integration of OpenMP alongside the already-established MPI framework for the calculation of collapse times

- Nearly ideal scaling up to ~20 threads per single MPI Task
- Computational time improvement: ~ 9x speed-up
- Thousands of mocks: ~ 50 hours less

KPI : https://github.com/pigimonaco/Pinocchio.git branch Refactoring

Issues: halos final positions and velocities change by varying #OMP_NUM_THREADS



Key Performance Indicators: MS 6 & MS 7

Offloading of collapse times calculation on GPU with OpenMP/OpenACC

- Submission of proposal for GPU hours (ISCRA C): accepted
- Set up the environment to compile the code on LEONARDO
- Offloading implemented

KPI : https://github.com/pigimonaco/Pinocchio.git branch Refactoring_GPU

Issues: incompatibility offloading - GSL library both with OpenMP and OpenACC

CINECA ISCRA

Class C Projects

code: HP10CJLAHQ

Section 1: You and Your Group

Principal Investigator

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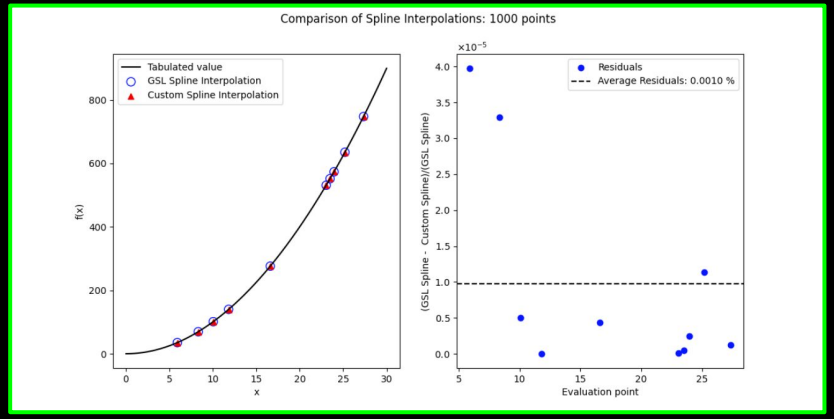
Key Performance Indicators: MS 6 & MS 7

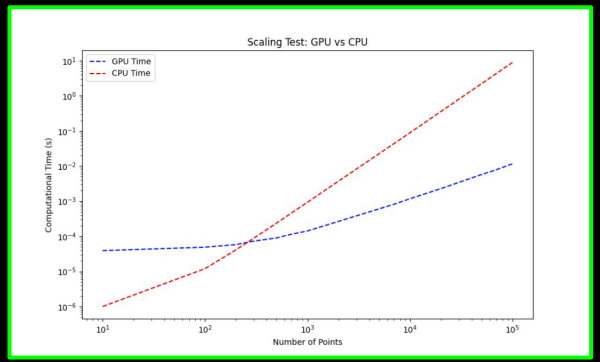
Offloading of collapse times calculation on GPU with OpenMP/OpenACC

- Implementation of a custom cubic spline interpolation
- GPU offloading test out of PINOCCHIO and comparison with GSL: done
- Integration in PINOCCHIO and test on CPU: done

KPI : https://github.com/pigimonaco/Pinocchio.git branch Refactoring_GPU

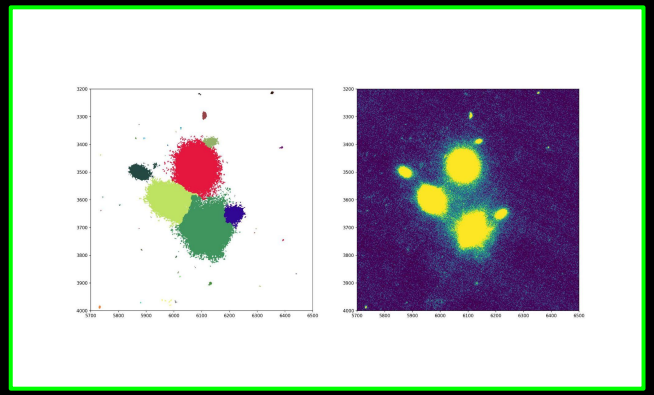
Issues: synchronization errors at run time for the GPU version of collapse times





Foreseen Key Performance Indicators: MS 8

- Release of a stable v5.1 of PINOCCHIO able to fully exploit LEONARDO computational capabilities with documentation
  KPI: https://github.com/pigimonaco/Pinocchio.git



- Re-engineering of the fragmentation part in a debleding-like flavour
  KPI: working code and report