Project 2: Simulating Realistic Star Clusters. Comparison between PeTar and nbody6++gpu

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Introduction

Direct N-body simulations for star clusters:

- Dense systems.
- Dynamics driven by close encounters:
  - High precision.
  - Short time-step.
- Hardware (GRAPE, GPU) and software (block time step, Barnes-Hut tree) improvements.

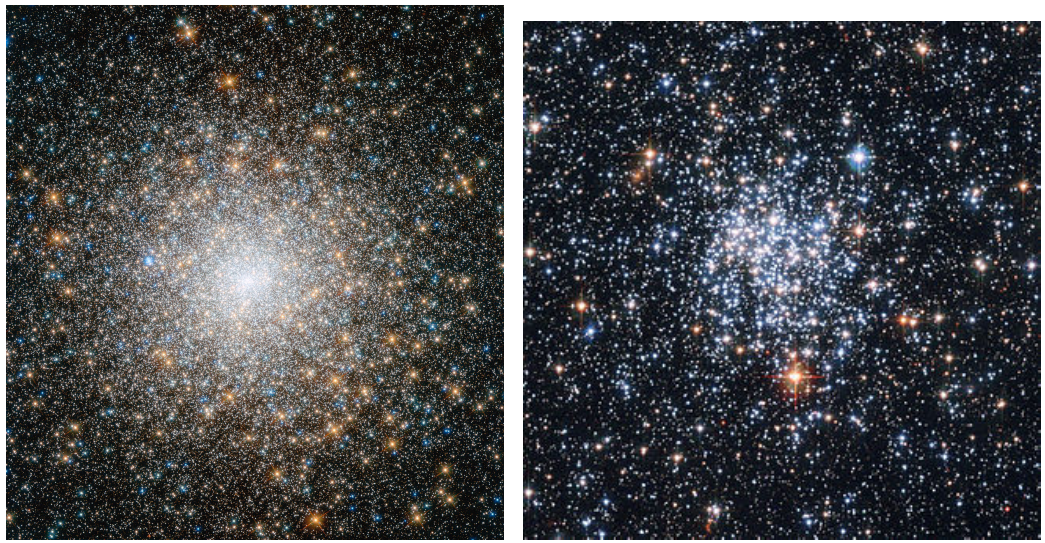


Figure: M15 (left) and NGC 265 (right). Credits: NASA/ESA/HST.

Aim of the Report

Compare the results of two simulations ran with NBODY6++GPU and PETAR from the same realistic initial conditions.

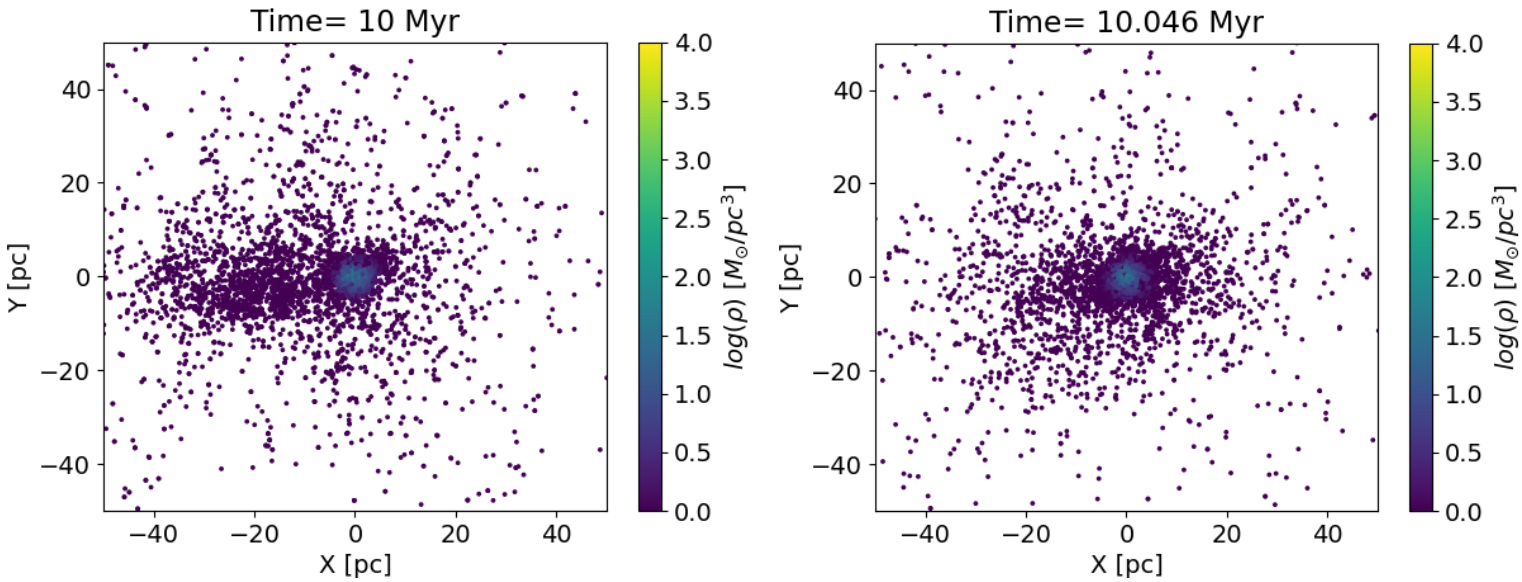


Figure: Stars positions at $t = 10$ Myr computed by PETAR (top) and NBODY6++GPU (bottom).

Initial Conditions

- Initial conditions influence some proprieties of star cluster.
- Star clusters form from molecular clouds collapse.
- Usually no spherical shape (e.g. Plummer sphere).
- Initial conditions from hydrodynamical simulation (Ballone et al. 2020).

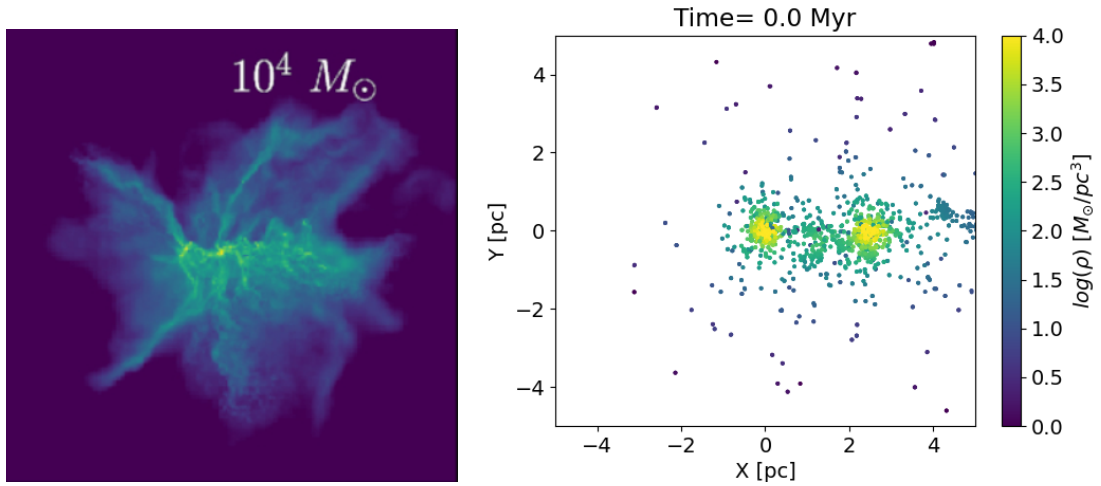


Figure: Gas density at the end of the hydrodynamics simulation (left), initial positions of the stars (right).

NBODY6++GPU and PETAR

NBODY6++GPU

- Hybrid parallelization.
- GPU acceleration.
- Fourth-order Hermite scheme + block time step.
- Can implement stellar evolution (MOBSE).
- Output printed every 0.201 Myr.
- [Fe/H] = 0.002, no tidal field.

PETAR

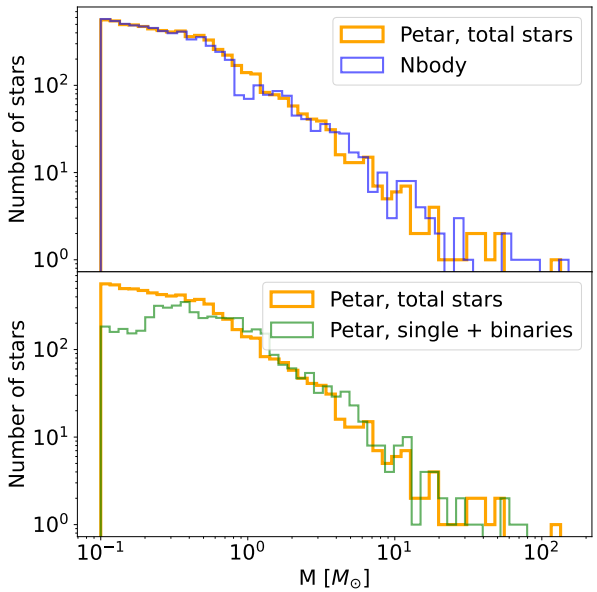
- Hybrid parallelization.
- P^3T (Particle Particle Particle tree).
- Can implement stellar evolution (MOBSE).
- [Fe/H] = 0.002, no tidal field.
- Best tree time-step: $t = 2.048 \times 10^{-5}$ Myr.
- Output printed every 1 Myr.
- `petar.data.process`: find binaries.

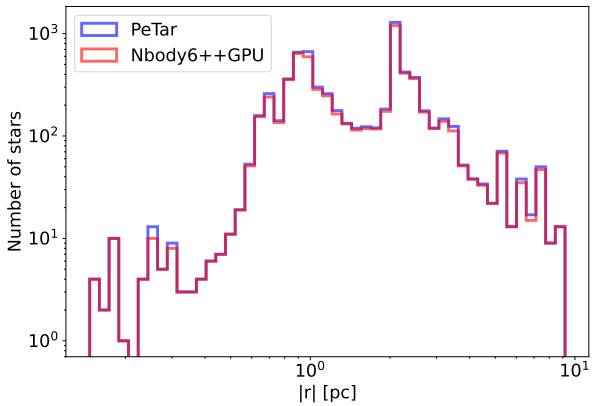
The scripts used

- Analysis made with `Python3`.
- Scripts can be found in GitHub.
- Comparison between:
  - Initial conditions.
  - Time evolution.
  - Mass segregation.
- For all the analysis: Re-scaling of coordinates to density center (function provided by dott. Stefano Torniamenti).

Initial conditions

- No systematic differences between NBODY6++GPU and PETAR.
- Differences between PETAR output files.





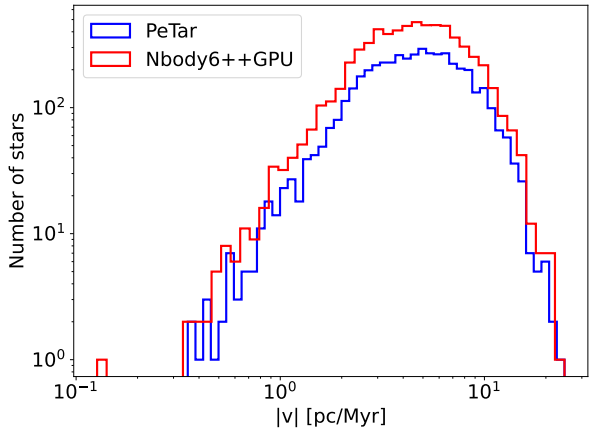
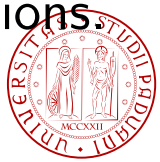
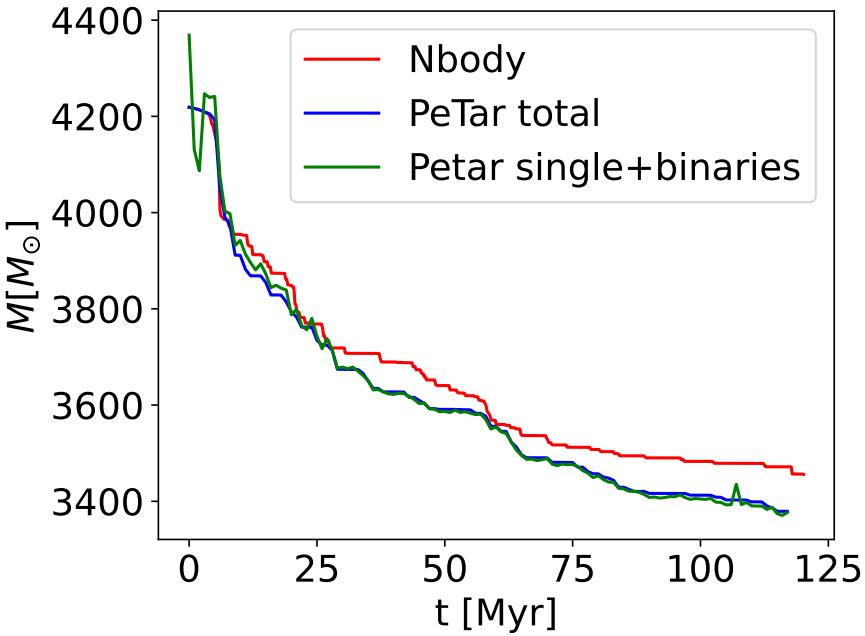


Figure: Masses (left), positions (center) and velocities (right) initial distributions.



Time evolution

- Movies with the positions and velocities.
- Differences in mass and half-mass radius evolution between the codes.
- Differences between PETAR outputs in total mass.



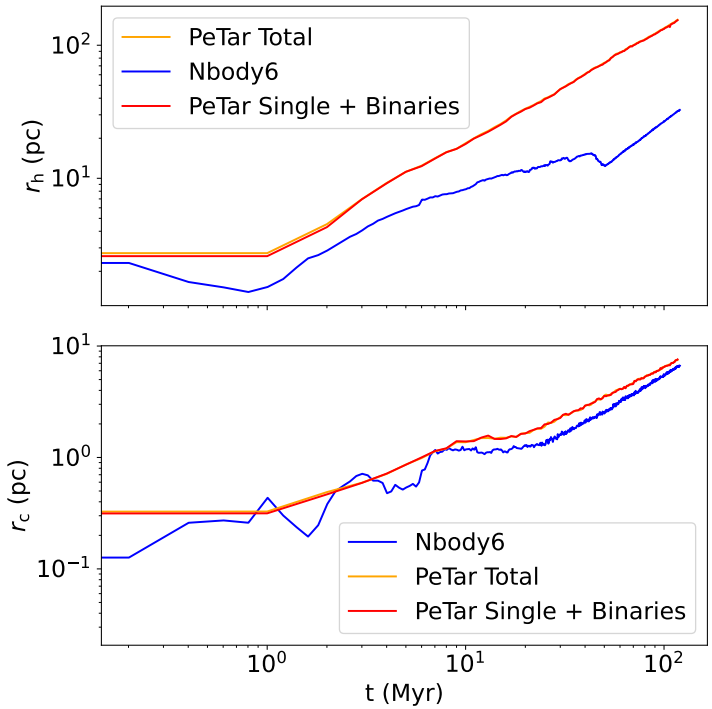


Figure: Total mass evolution (left); half-mass (top right) and core radius (bottom right) evolution.

Mass Segregation

- NBODY6+GPU shows mass segregation.
- PETAR high mass lagrangian radius diverge up to $\sim$ 650 pc.
- No differences between PETAR outputs.

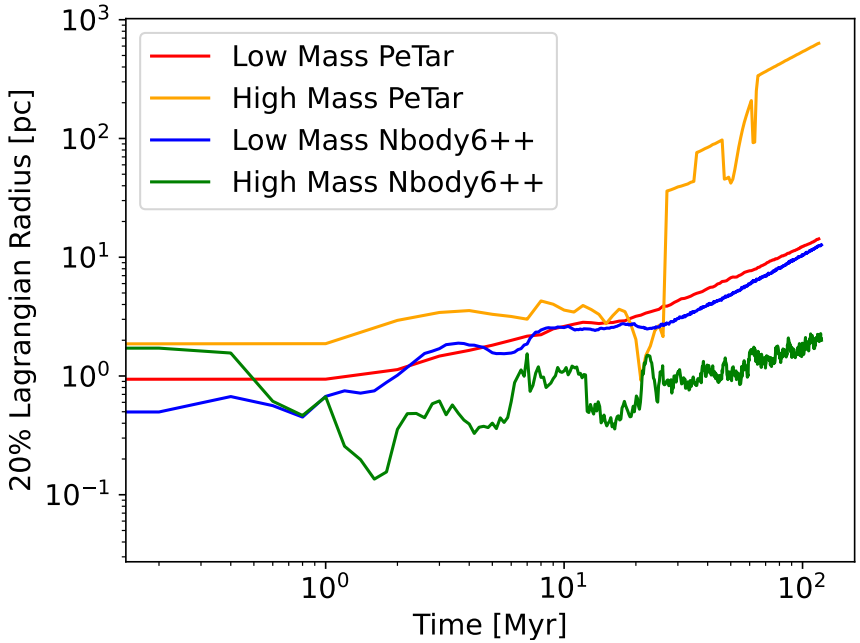


Figure: Mass segregation computed by the two codes.

Discussions

Total mass of the cluster

- Differences in total mass evolution.
- Contradiction between number of stars and total mass.
- `petar.data.process` presents some errors.

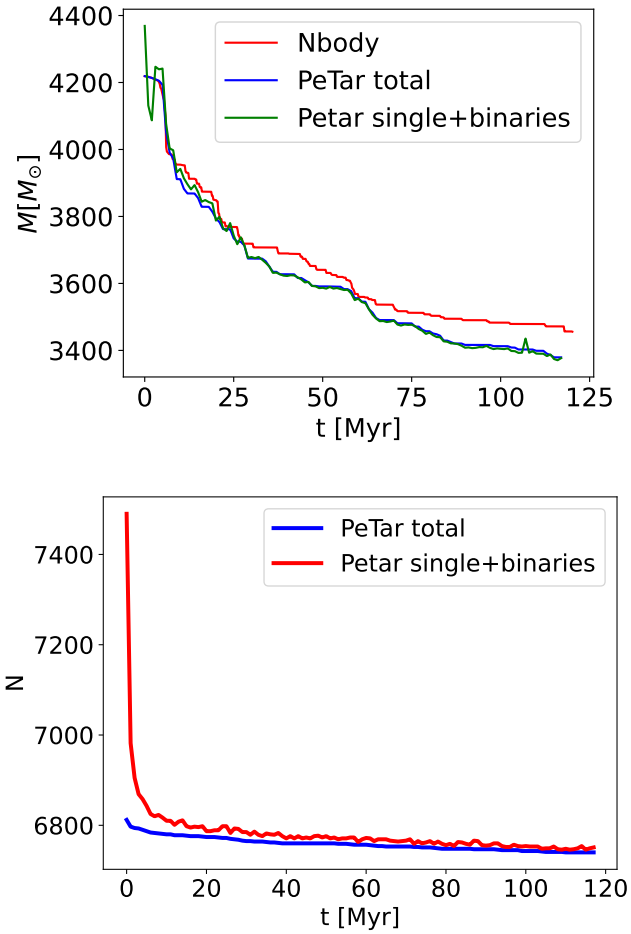


Figure: Total mass evolution of the cluster (top) and evolution of stars number (bottom).

Discussions

Half-mass radius

- Half-mass radius from PETAR $\neq$ observed values in star clusters.
- In PETAR more massive stars are distant from the center at $t = 117$ Myr.

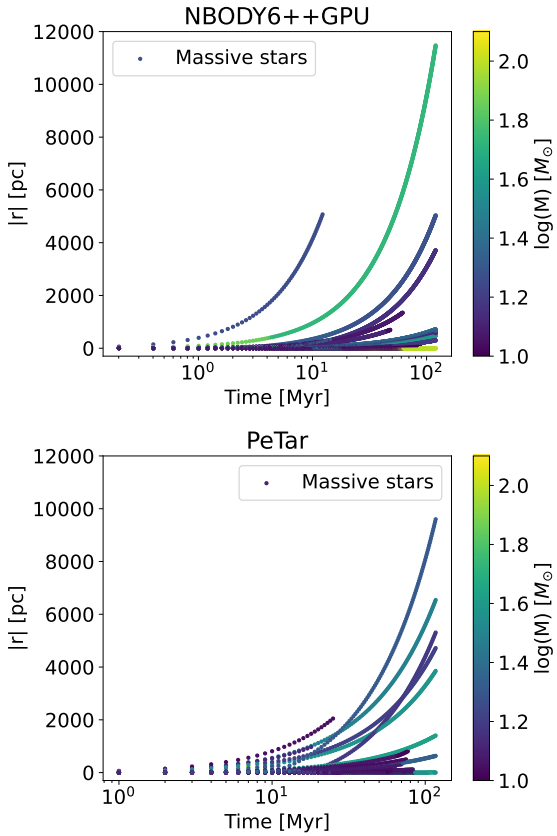


Figure: Massive star tracks for NBODY6++GPU (top) and PETAR (bottom).

Conclusions

- Differences between the codes seem present.
- Discrepancies between the PeTar output files.
- More simulations are needed.