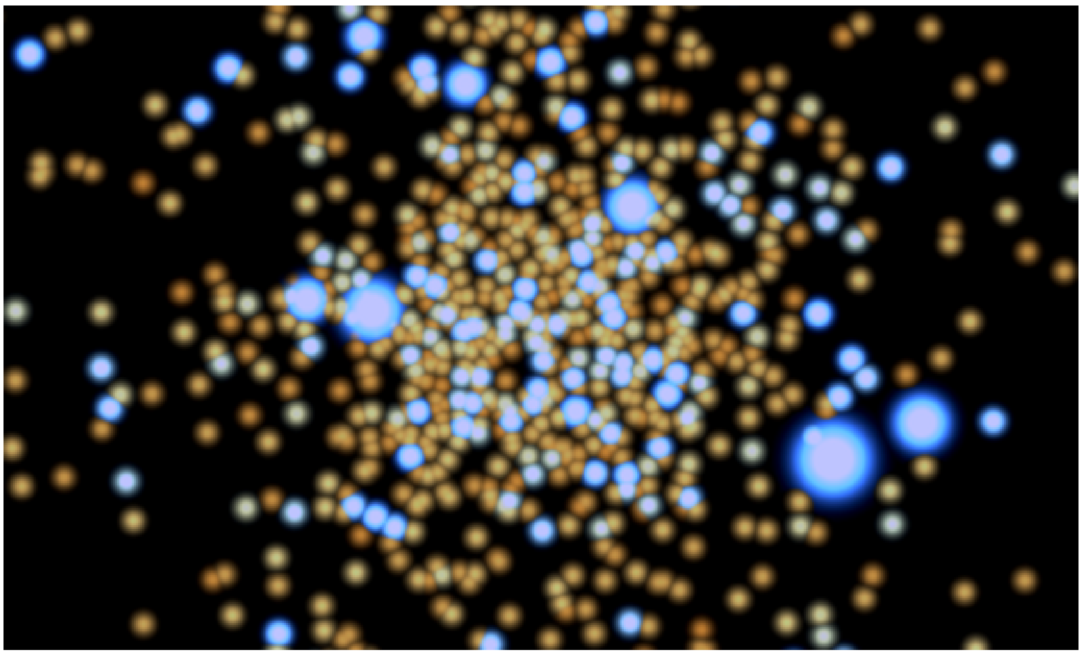
N-body techniques for astrophysics

Lecturer: Michela Mapelli

Numerical simulations are a powerful tool to investigate a plethora of astrophysical processes, ranging from stellar dynamics, star and galaxy formation, to the evolution of the early Universe and to the physics of gravitational wave sources. N-body codes are among the most common tools adopted in astrophysical simulations: they allow us to describe an astrophysical system (such as a molecular cloud, a star cluster or a cosmological box) as a system of N-particles, evolving under the effect of gravity and possibly other physical processes (e.g. gas cooling, radiative feedback, supernovae, star formation, etc).



The aim of this course is to discuss the main characteristics of state-of-the-art N-body techniques for astrophysics. We will discuss some of the main integration methods adopted by N-body codes (e.g. Leapfrog scheme, Hermite predictor-corrector scheme). We will present the differences between direct N-body techniques adopted for collisional systems and other schemes used to integrate the evolution of collisionless systems (e.g. tree codes). Finally, we will review the main schemes used to integrate the hydrodynamics of gas (particle-based and mesh-based algorithms) and we will address the concept of sub-grid physics. A special lecture will be devoted to the smart generation of initial conditions with Monte Carlo algorithms.

Each lecture (2 hours) will consist of a theoretical explanation (~1 hour) followed by exercises (~1 hour). The exercises will be solved directly by the students, with the help of the lecturer, and will be part of the final exam.

The students are warmly encouraged to bring their laptop (at least one every two students) to the classes. The only software which <u>needs</u> to be installed by the students on their laptops is ssh (or similar software to manage secure remote connections).

Lecture 1 (2 hour):
Definition of an N-body simulation; concept of computational complexity; N-body units; exercises on N-body units.

Lecture 2 (2 hours):
Examples of numerical algorithms: Euler, Leapfrog integrators; conservation of energy with Euler and with Leapfrog; exercises with Euler and Leapfrog (motion of a binary system and a small N-body system).

Lecture 3 (2 hours):
Monte Carlo methods to generate initial conditions: random generators; uniform deviates; transformation method (examples: exponential, Gaussian and Maxwellian deviates); rejection method (examples: uniform sphere, isothermal sphere). Exercises on transformation method and rejection method.

Lecture 4 (2 hours):
Direct N-body codes for collisional systems: Hermite scheme; exercises on the Hermite scheme.

Lecture 5 (2 hours):
Direct N-body codes for collisional systems: block time-step algorithm, regularization algorithms, stellar evolution recipes, special purpose hardware, graphics processing units; exercises on regularization.

Lecture 6 (2 hours):
Examples of direct N-body codes (STARLAB, Nbody6, ..); exercises with direct N-body codes.

Lecture 7 (2 hours):
N-body methods for collisionless systems (softening, tree codes, particle mesh and fast multipole codes, high performance computing architectures); exercises with tree codes (ChaNGa).

Lecture 8 (2 hours):
Algorithms for gas (smoothed particle hydrodynamics, mesh codes, adaptive mesh refinement codes); Sub-grid physics (star formation, supernovae, radiative transfer); exercises about hydrodynamics.