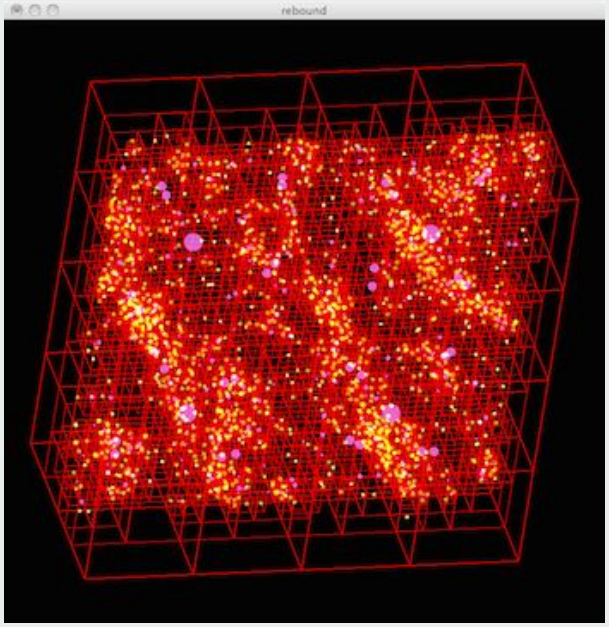
Introducing Rebound

An open-source multi-purpose N-body code



Ridlo W. Wibowo

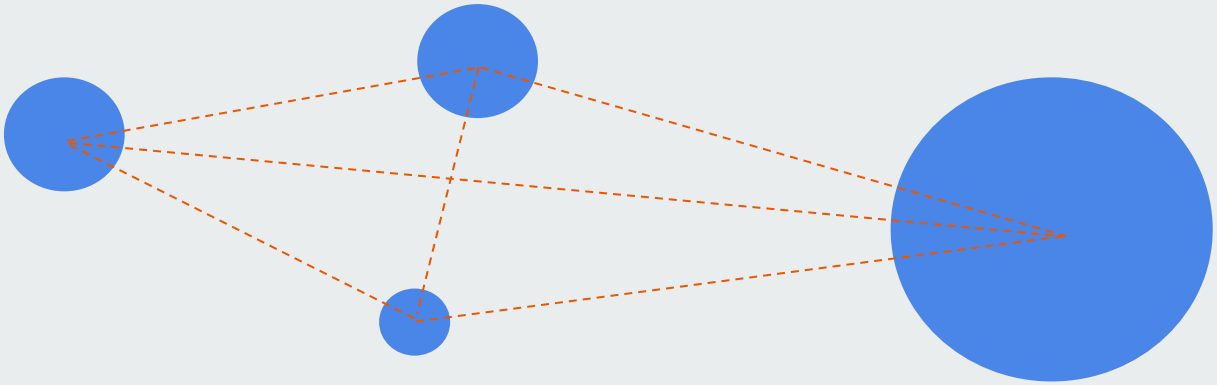
Python Coffee | @ ESO Vitacura | 11/10/2018

Overview

- N-body simulation
- What is Rebound?
- Examples

N-body simulation

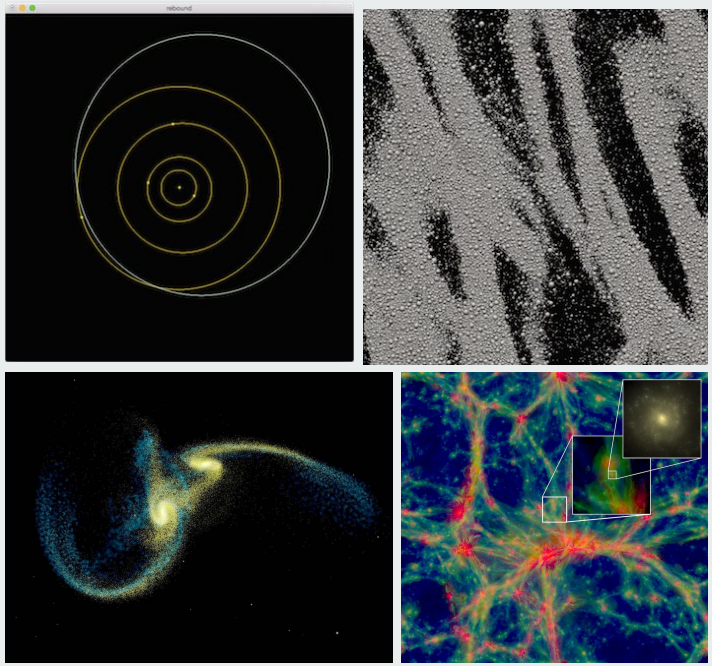
$N > 2$



“interaction/force”

N-body simulation

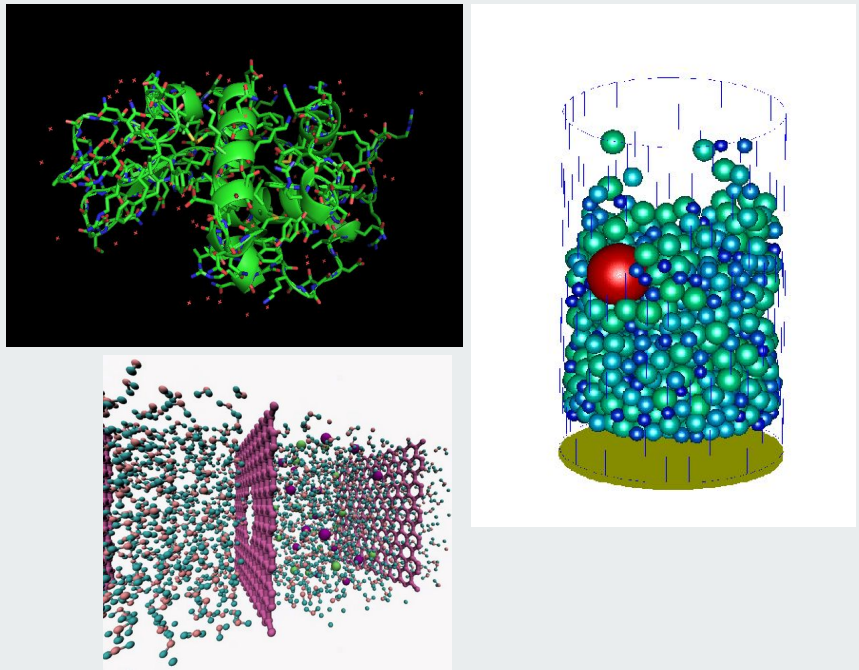
In astronomy/astrophysics



interaction: (Newtonian) gravitational force
++ relativity corr, radiation pressure, drag force, thermal effect, etc

#principle: how particle interact? boundary of system?
Mostly care about position & velocity only

In other fields: (similar principle)
Molecular dynamics (MD), atomic simulation, granular simulation, etc.



interaction: Coulomb force, normal force, Lennard-Jones potential, etc

-- sometimes we care about the potential (not the force)

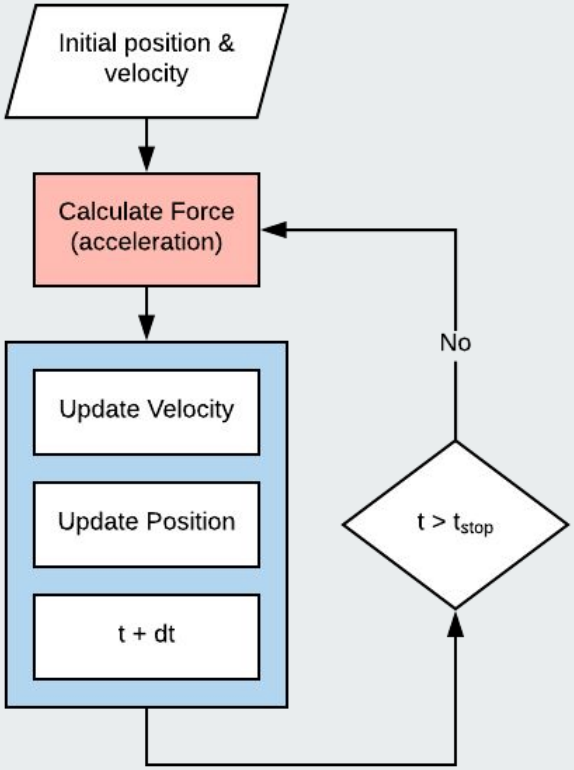
rocket and interplanetary flight

Initial Value Problem

Solving ODE

self-driving car

N-body simulation



How to calculate force?

e.g. direct summation, BH-Tree, ...

$$\ddot{\vec{r}}_i = \sum_{i=1, i\neq j}^{N} \frac{G m_j}{r^2} \hat{r} + \dots$$

Integration method

e.g. euler, leapfrog/verlet, RK, ...

$$\begin{aligned} x_{i+\frac{1}{2}} &= x_i + v_i \frac{\Delta t}{2}, \\ v_{i+1} &= v_i + a_{i+\frac{1}{2}} \Delta t, \\ x_{i+1} &= x_{i+\frac{1}{2}} + v_{i+1} \frac{\Delta t}{2}, \end{aligned}$$

Drift

Kick

Drift

Need to be considered:

- ❏ order (precision) of integrator vs number of particles vs timestep
- ❏ collision vs collisionless system

- ❏ symplectic vs non-symplectic integrator
- ❏ coordinate used, e.g. cartesian, jacobian, ...
- ❏ type of particles
- ❏ etc.. etc..

-> hard to make a “multi-purpose” N-body code!

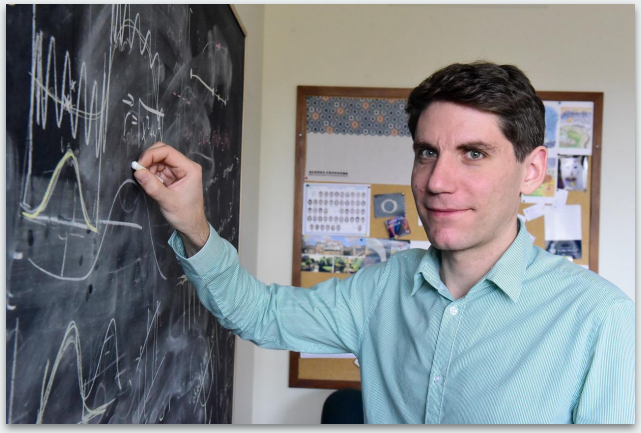
Boundary

e.g. open, closed, periodic, ...

Rebound

Rebound is an N-body integrator, i.e. a software that can integrate the motion of particles under the influence of gravity. The particles can represent stars, planets, moons, ring or dust particles.

- Multi-purpose N-body code ➡ *now mainly used for Solar System dynamics and planetary science.
- Written in C with easy-to-use Python 'interface'.



Prof. Hanno Rein

Installation:

```
pip install rebound
```

Source code:

http://github.com/hannorein/rebound

Doc:

https://rebound.readthedocs.io/en/latest/

current version: Rebound 3.6.6

Rebound

Main modules

Boundary/geometry

- None (default)
- Open boundary condition
- Periodic boundary condition
- Shearing-sheet (Hill's approx.)

Integrator

- Euler
- Leapfrog
- IAS15 (default)
- Wisdom-Holman Fast (WHFast)
- Symplectic Epicycle integrator (SEI)
- Janus (experimental)
- Mercurius (experimental)
- Hermes (experimental)

Gravity solver

- None (no self gravity)
- Direct sum (default)
- BH-Tree
- OpenCL (in progress)
- FFT (in progress)

Collision Detection

- None (default)
- Direct nearest-neighbor search
- BH-Tree
- Plane sweep algorithm

Rebound

Additional features

See complete list in API doc (for C and Python)

- `SimulationArchive` ➡ data analysis + enables fully reproducible simulations!
- Additional Force (native and also “widget” code: reboundx)
- Tools and Misc. functions:
  - Simple collision resolve function (merge or elastic)
  - Easy plot orbit (in python)
  - Coordinate conversion, e.g. convert Cartesion ⟷ Keplerian
  - OpenGL integration (you need to install it first), WebGL,..
  - JPL Ephemeris download
  - Particle ID (& hash)
  - ...

Examples

Provide **a lot of** examples in C and python: https://rebound.readthedocs.io/en/latest/examples.html

C: https://github.com/hannorein/rebound/tree/master/examples
Jupyter Notebook: https://github.com/hannorein/rebound/tree/master/ipython_examples

For this coffee talk:

1. Quick start
2. Small bodies & Solar System (how to set parameters)
3. Planetary Migration & Debris disk
   (additional effect/force, introducing ReboundX)
4. ...

Examples

Some papers:

- **Dynamical Stability of Imaged Planetary Systems in Formation: Application to HL Tau**, Tamayo, D., Triaud, A. H. M. J., Menou, K., & Rein, H. 2015, ApJ, 805, 100
- **No circumbinary planets transiting the tightest Kepler binaries - a possible fingerprint of a third star**, Martin, D. V., Mazeh, T., & Fabrycky, D. C. 2015, Mon Not R Astron Soc, 453, 3554
- **Gap Clearing by Planets in a Collisional Debris Disk**, Nesvold, E. R., & Kuchner, M. J. 2015, ApJ, 798, 83
- **Numerical simulation of tidal evolution of a viscoelastic body modelled with a mass-spring network**, Frouard, J., Quillen, A. C., Efroimsky, M., & Giannella, D. 2016, Mon Not R Astron Soc, 458, 2890
- **Stability of multiplanetary systems in star clusters**, Cai (蔡栩), M. X., Kouwenhoven, M. B. N., Portegies Zwart, S. F., & Spurzem, R. 2017, Mon Not R Astron Soc, 470, 4337

When you should/(not) try to use `Rebound`?
Please, you may want ask me about your N-body problem! :)

Thank you