Computational Astrophysics – HW #3

Answer the following questions. Hand in your (documented) code along with your solutions.

1. **Let's not be strangers!**

For this problem we will work with the N-body code *Rebound*: `https://rebound.readthedocs.io/en/latest/index.html`. This has the advantage of having implementations in both C and Python. Note the Python version works as a wrapper for the C code, so the functions aren't completely doubly implemented, e.g., digging into the details of the integrators code requires opening the C code.

Before running any problems, let's first get to know this code and how it works (happily, this is relatively clean code and fairly straight-forward to parse).

a) Look through the documentation and poke around in the code. Let's suppose we want to integrate the orbits for a 3 body system. Draw a flow chart for how the code initializes and evolves this interaction.

b) The code offers a variety of different choices of integrators. Make a table of the different options, list their order of accuracy (if documented), what problems they are best suited for, and note any tunable parameters.

c) Look at the leapfrog and symplectic epicyclic integrator code (see the repository src "source" directory). Make a flow chart for how these functions work. For production research you would want to read the method papers for each of the solvers to better understand their implementations, strengths and weaknesses. Here, this is not necessary unless you want to dig deeper into how the algorithms work.

2. **Hello Comets**

a) You may recall seeing articles about the ESA Rosetta mission that visited and then sent a probe to land on a comet. This was eponymously named 67P/Churyumov–Gerasimenko comet (see `https://en.wikipedia.org/wiki/67P/ChuryumovGerasimenko`). There is an example problem based on this comet, which we will use to get familiar with *Rebound*.

Set up and run the 67P/C-G example problem following the documentation (see Examples → Planetary systems → Just getting started → The comet 67P/Churyumov-Gerasimenko). Only include the Sun, Saturn and Jupiter for now. Include a plot of the 67P/C-G comet and two planet orbits evolved over 70 years in your solution set.

b) Experiment with the timestep and integrator choice (e.g., IAS15 vs WHFast). How does the result change with different integrators? What integrator(s) do you think work best for this problem? How does the result change as a function of the timestep? E.g., you can evaluate this by looking at energy conservation and the change in orbits. (Note IAS15 has adaptive timestepping so you have to set the minimum timestep.)

c) How does the orbit of 67PC-G change when you add the rest of the Solar System planets? Which is the larger source of error – the parameter choices such as the integrator and/or timestep or missing bodies?

d) Optional: If you completed part 3a in HW 1 or have your own N-body code that you wrote, you might be curious about how your Earth orbit integration compares with one run with *Rebound*. Compare the *Rebound* Sun/Earth orbit with your result from HW1 (or your own code). What do you notice?

3. **Finding Planet X (actually Planet Nine)**

There is a long history of speculation that another undiscovered planet might exist outside our Solar system. Originally this planet was known as "Planet X." A more recent 2016 study has hypothesized anew about the presence of a large planet beyond the Kuiper belt (now called "Planet nine"). You can read through a brief summary of the proposed planet here: `https://en.wikipedia.org/wiki/Planet_Nine`.

Set up a Solar System with all the planets and Pluto. Suppose Planet Nine has a semi-major axis of 460 au and eccentricity of 0.4. How massive would it need to be to perturb Pluto's orbit by 10% after 10 years of evolution? Given your answer, why do you think we haven't found any Planet Nine yet?