Exam Computational Astrophysics

8 December 2017 (duration: 3 hours, from 13.30–16.30)

You will earn at most 5 points for this exam. The other 5 points are for the assignments you already made. The maximum score for assignments + exam is 10 points.

Expected: Source codes (and comments), figures and answers to the questions can be uploaded to a new personal git account. You will have to create a new git repository for this, and invite Francisca Concha Ramirez: fconcha@strw.leidenuniv.nl and Simon Portegies zwart: spz@strw.leidenuniv.nl.

Only exams submitted before 16.30 on December 8 are considered.
Add a `README` to your uploaded directory with clearly state what each file means, your name and your student number.

Exam Computational Astrophysics 2017/2018

1I/'Oumuamua (1I/2017 U1) is a genuine interstellar object that was discovered on 19 October 2017 in the Pan-STARRS survey [1, 2]. The object was first classified as a comet due to its peculiar orbit but later reclassified as a *unusual minor planets.* Most notable orbital parameters are the distance at pericenter, $q = 0.254 \pm 0.002$, the eccentricity, $e = 1.1971 \pm 0.0013$ and the relative velocity at infinity $v \simeq 26\,\mathrm{km/s}$ [1, 2]. This makes the object unbound from the Sun on an en-passant orbit through the Solar System.

The relative velocity of 26 km/s seems rather low compared to the velocity dispersion in the Solar neighborhood. As objects orbit the Galaxy for a longer time they tend to be accelerated by structures in the Galaxy, either by spiral arms, star clusters or giant molecular clouds. The stellar density of the Galaxy is probably insufficient to accelerate Rama-like objects. In this exam, we will explore the effect of giant molecular clouds on the velocity distribution expected from interstellar objects as observed from the Sun.

In that sense, we wonder if this velocity can tell us something about the age of the object. For this, we will perform a small N-body calculation using the AMUSE framework.

The assumption will be that Rama is a true interstellar object that formed somewhere in the Galactic disk with a velocity consistent with the local Galactic velocity dispersion. At the same time the Sun, being born as part of a cluster also orbited the Galactic center.

0.1 The background Galaxy

Initialize a background Galaxy using the built-in semi-analytic `MWpotentialBovy2015` model for bulge, disk and halo. [3, 4].

0.2 The Sun's birth cluster

Initiate a Sun's birth cluster with $N = 100$ stars in virial equilibrium and with the stars distributed in a Plummer sphere with a characteristic radius of 10 pc. Choose the masses of the stars from a Salpeter mass function between $0.1\,M_\odot$ and $10\,M_\odot$. Give them a softening of 100 au. Position center of mass of the cluster at Cartesian coordinates:

$$x = (-7977, 2764, -106.4) \text{ parsec},$$

$$v = (88.45, 212.7, -2.788) \text{ km/s}.$$

0.3 Distributing the Rama particles

Now distributed $n = 10^3$ asteroidal-like Rama particles according to a thick disk between 6 and 11 kpc. You may want to use the built-in routine `ProtoPlanetaryDisk` or put the particles in Keplerian orbits around the Galactic center. Make sure that the disk particles rotate in the same direction as the Sun's birth cluster.

0.4 Constructing the code

Integrate the equation of motion for the cluster stars using a direct N-body code. But the Rama-like objects can be integrated using a simple drifter. Built a bridge in which the cluster stars feel the gravitational effect of the background Galaxy. The Rama-like particles should feel the force of the background Galactic potential and that of the stars in the Sun's birth-cluster.

0.5 Running the code

Integrate the equations of motion for 4.6 Gyr and write a final snapshot of the combined particles of the Sun's birth cluster as well as the Rama particles.

Question 1:

Plot the Sun's birth cluster (blue bullets) and the asteroidal Rama-particles (black points) in the x-y plane with the size of the bullets proportional to the mass of the stars. The axis limits should be 10 kpc on all sides.

0.6 Runtime processing

Perform the following analysis at every 0.1 Gyr. Find for each star in the Sun's birth cluster the nearest Rama particle, and calculate their relative velocity. This will result in a list of N velocities. Calculate the mean, median and the dispersion of these velocities.

Question 2:

Plot, as a function of time, the mean, median and dispersion velocities. Compare these with the observed velocity of 1I/'Oumuamua (a.k.a. Rama).

0.7 Post processing

Generate the same list of relative velocities for the last snapshot (at 4.6 Gyr) as you did in § 0.6, but accumulate the data for 10 runs each with a different random number seed (if you are running out of time use at least 2 runs). Make a histogram of these velocities and fit it with a Maxwellian velocity distribution (see `scipy.stats`).

Question 3:

Give the Maxwellian fit parameters. Plot the histogram as well as the fitted Maxwellian.

0.8 Final questions

Question 4:
How old to you think 1I/'Oumuamua is?

Question 5:
How would you improve on your calculations to make them more realistic?

References

[1] MPC, 'Iau minor planet center, u181' (2017).

[2] MPC, 'Iau minor planet center, u183' (2017).

[3] J. Bovy, 'galpy: Galactic dynamics package', Astrophysics Source Code Library (2014).

[4] J. Bovy, *ApJS* **216**, 29 (2015).