CAP - report of assignment 5

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December 7, 2017

1 Introduction

Most stars are born in open clusters. Therefore, it is likely the also Sun was also born in an open cluster somewhere in our Milky Way. In this assignment we will try to find the birthplace of the Sun. We will also investigate what happened to the stars born in the same cluster, the siblings of the Sun.

2 Methods

2.1 Finding the birthplace of the Sun

The birthplace of the Sun can be estimated by integrating the Sun's orbit around the Galactic center back in time. Currently the Sun is positioned at

$$\mathbf{x} = (-8400, 0, 17) \text{ pc} \tag{1}$$

with a velocity of

$$\mathbf{v} = (-11.35, -232.1, -7.41) \text{ km/s}. \tag{2}$$

We calculate the birthplace of the Sun by integrating it's orbit back in time for 4.56 Gyrs, the age of the Sun. This is done by flipping the current Solar velocity vector and integrating with the ph4 N-body integrator. The system with the Sun as a point particle is bridged with the Galactic potential. It is important to notice this assumes a smoothened Galactic potential: spiral arms are for example neglected. The parameters of the simulation are shown in Table 1.

To check the sensitivity of the birthplace upon the accuracy of which the current position and velocity are known we launched a cloud of 50 massless point particles with random positions and velocities within 1% of the values as in Equation 1 and 2. Since these massless point particles do not have any interactions with each other this is as if we launched 50 Suns from different current positions. However, now we initialize a cluster with 51 stars that follow a Kroupa mass distribution with a maximum mass of $100M_\odot$. After initialization of the open cluster we manually select one star and give it a mass and radius equal to the Solar mass and Solar radius. The center of mass of the cluster is given the initial Solar position and velocity. Integrating this cluster forward in time likely gives a different result since the interactions between the stars in the cluster will likely try to keep the system more bound. To integrate this system we use the BHTree tree-code N-body integrator with a smoothening length of 1 pc. For a larger smoothening length, the cluster is smoothened so much that it starts to behave basically as a point particle, neglecting the cluster dynamics. However, if the smoothening length becomes too small, we loose the advantage of the tree-code where we do not have to calculate the interactions between all the stars within the cluster, making it computationally very expensive.

Parameter	Value
t_{end}	4.56 Gyrs
Δt	0.01 Myr
N_{stars}	50

Table 1: Default parameters for all simulations described here.

After running the simulation we check how many stars are still close to the Sun by plotting their cumulative distance distribution. We also check typical velocities of Solar siblings to estimate if 1I/2017 U1 could have originated from the same open cluster as the Sun. For the final question, we redo the simulation with different total cluster sizes to check the dependency of the number of close Solar siblings on the total cluster size.

3 Results

Our results are summarized in the Figures below.

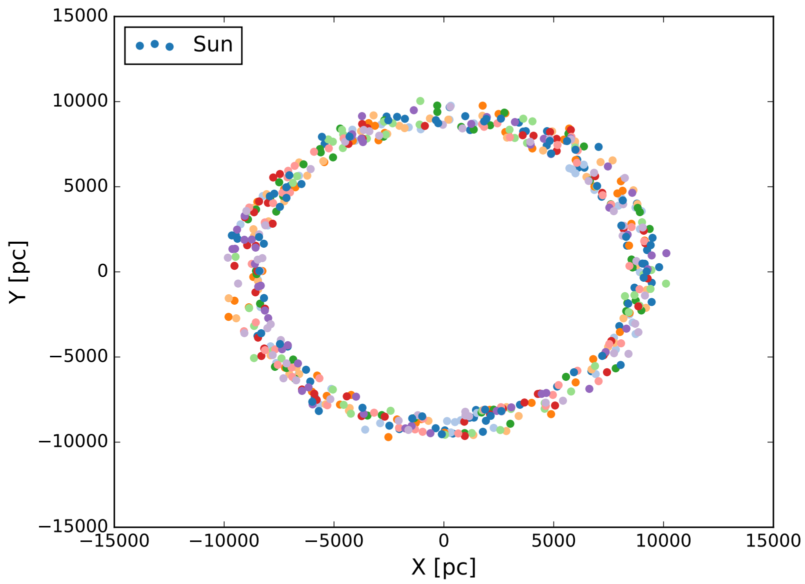

Figure 1: Some positions of the bodies as they orbit the Galactic center.

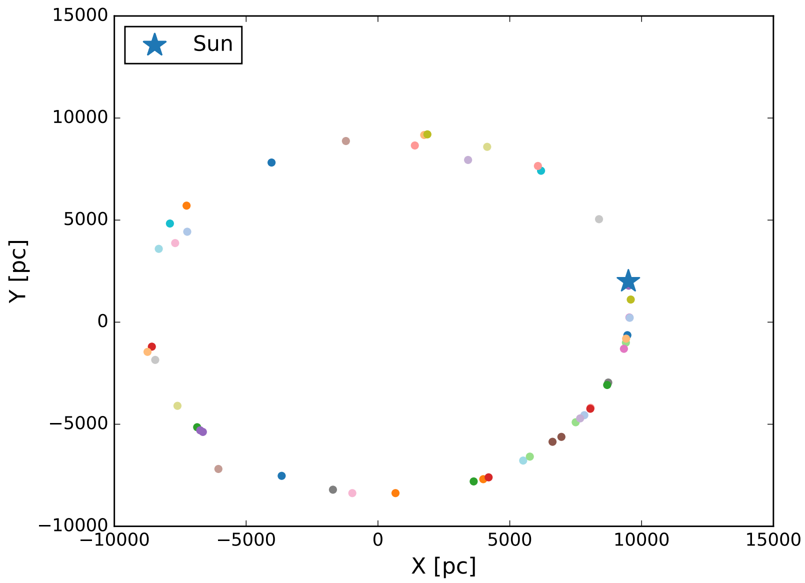

Figure 2: The final positions of the 50 bodies. The Sun is indicated as a blue star.

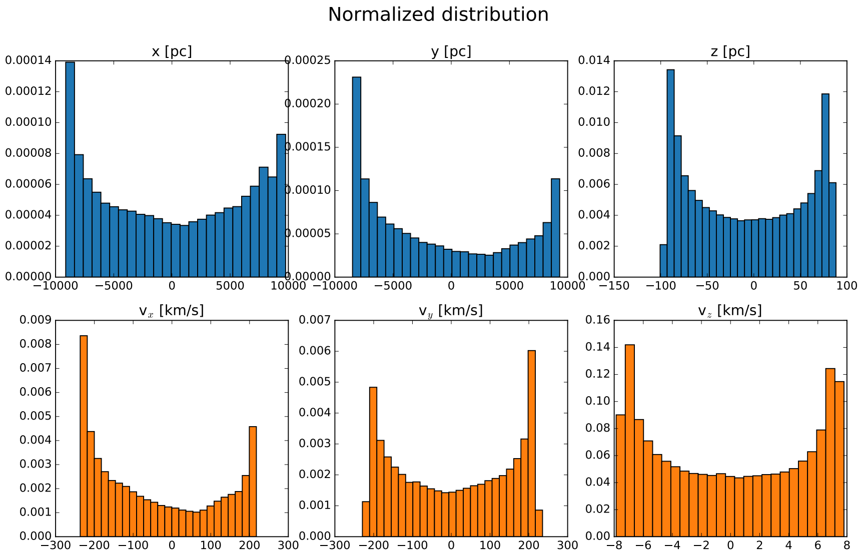

Figure 3: Normalized distributions of the position and velocity of the 50 initialized bodies.

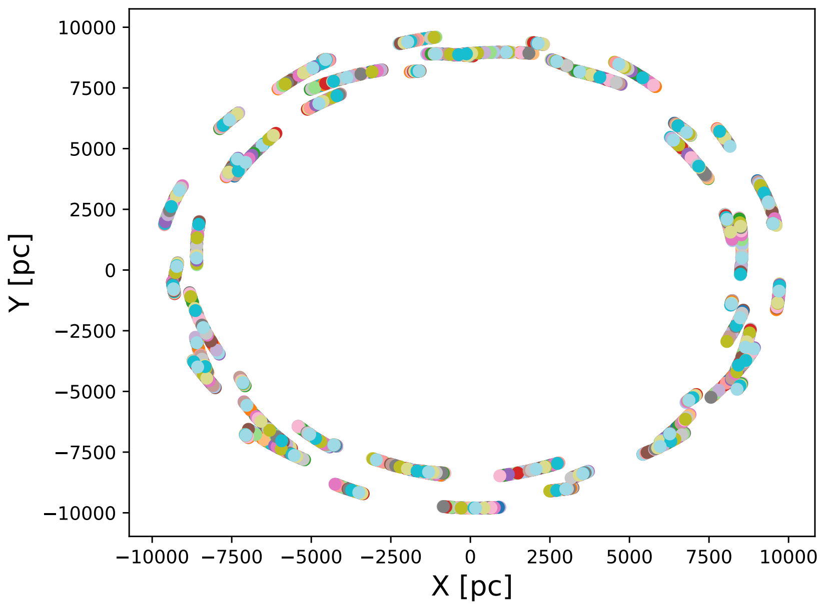

Figure 4: Some positions of the bodies as they orbit the Galactic center for the open cluster simulation with 50 stars.

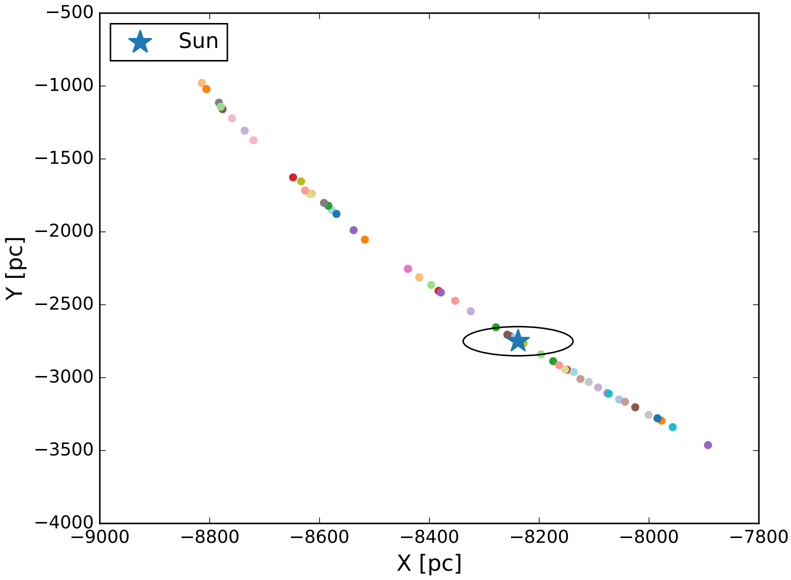

Figure 5: The final positions of the 50 bodies for the open cluster simulation. The Sun is indicated as a blue star. The black ellipse indicates the < 100 parsec region around the Sun in the xy-plane.

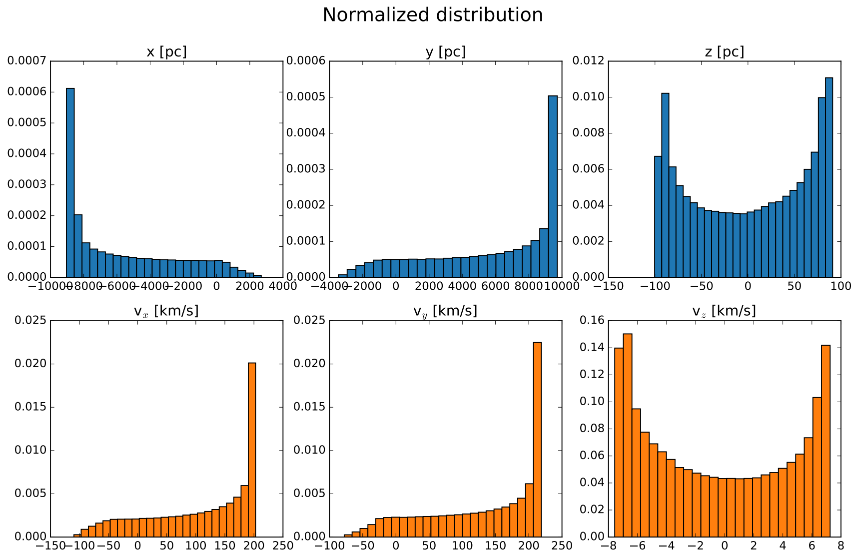

Figure 6: Normalized distributions of the position and velocity of the 50 initialized bodies for the open cluster simulation.

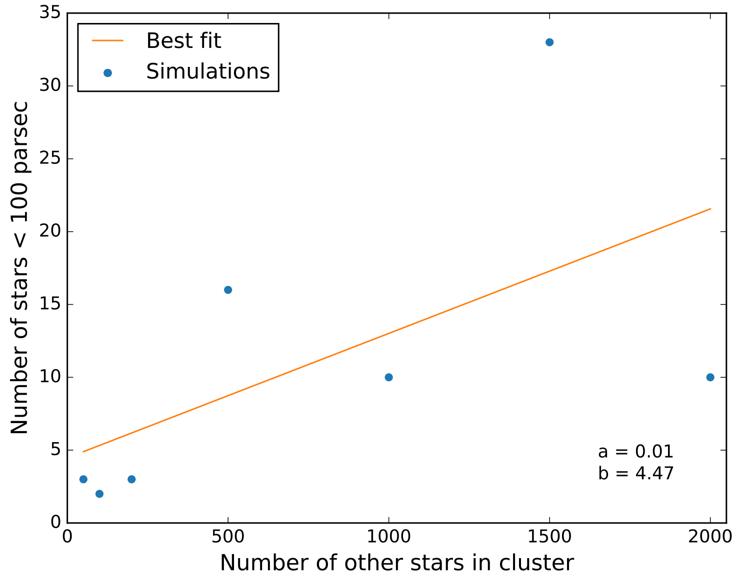

Figure 8: Number of stars within < 100 parsec nowadays as a function of the original cluster size. The blue dots are the obtained values from our simulations and the orange line indicates the best linear fit. The slope a and intercept b are also shown within the plot.

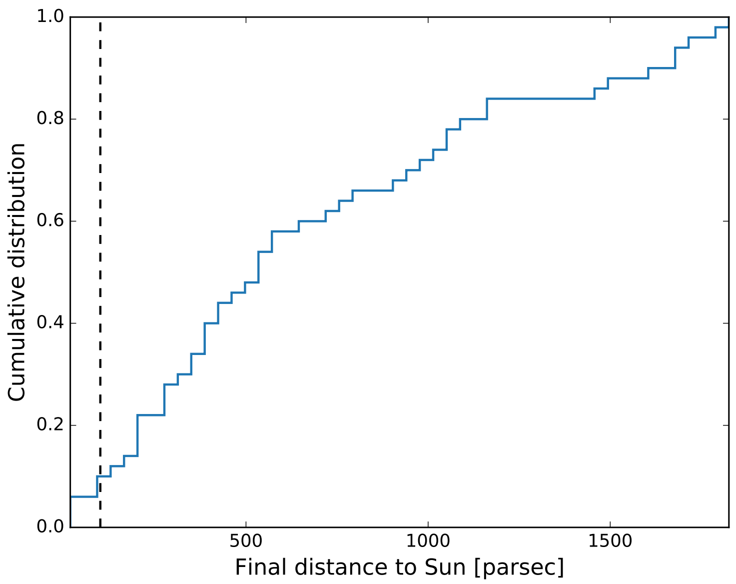

Figure 7: Cumulative distribution function of the distance to the Sun as at the final position of the simulation with the open cluster. The black intersected line indicates a 100 parsec.

4 Discussion

Figure 1 shows the positions of the orbiting bodies at a regular interval during the simulation. As expected all bodies integrate on approximately circular orbits around the Galactic center.
Figure 2 shows the final positions of the orbiting bodies and Figure 3 the normalized distribution of the position and velocity. The birthplace of the Sun is $\mathbf{x} = (9499, 2000, 80)$ pc with a velocity of $\mathbf{v} = (31, -201, 2.5)$ km/s. We see that slight deviations of only one percent have a big impact on

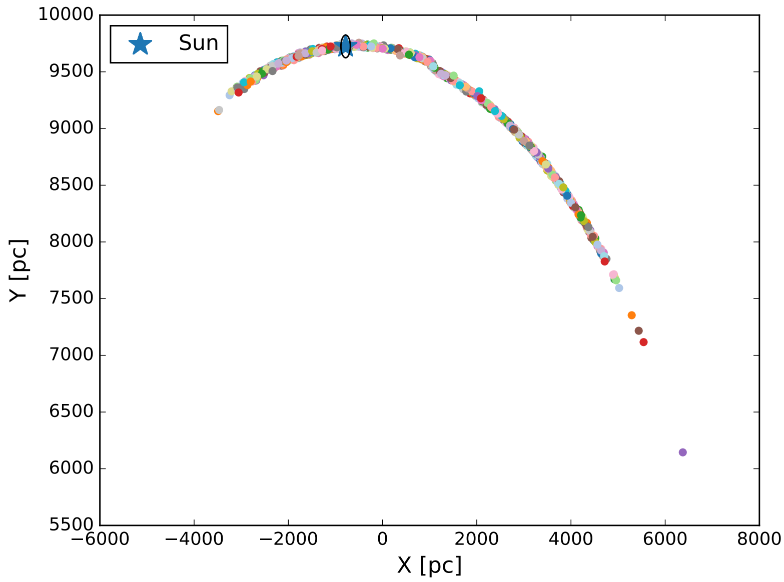

Figure 9: Number of stars within < 100 parsec nowadays as a function of the original cluster size. The blue dots are the obtained values from our simulations and the orange line indicates the best linear fit. The slope a and intercept b are also shown within the plot.

the final position of the objects. In Figure 2 we see most bodies end up in an arc about 45 degrees as seen from the Sun. However, many bodies end up at positions homogeneously distributed among the circular orbit around the Galactic center. This can also be seen in Figure 3 resulting in a funny U-like shape, because all bodies are distributed along a circle. This indicates the exact birthplace of the Sun is really sensitive to small errors in our current position and velocity. Additionally, we have neglected the Milky way's substructure and their might also be an uncertainty regarding the age of the Sun.

For the open cluster simulations we find different results. In figure 4 we see some positions that the stars have adopted during the integrated time. As expected, they are all around the galactic center. Figure 5 shows the final positions of the stars in the cluster. This time, the stars are grouped forming an arc. This result is different to the previous simulation where they were all spread, filling the circle around the galactic center. This clearly indicates that the cluster dynamics play a mayor role in the distribution of the stars. We can also see the different normalized distributions in Figure 6. The parameters are now highly inclined towards one of the two edges. Again, we plot the cumulative distribution of the final distances of the stars to the Sun in Figure 7. We see that the probability of finding a star within 100 pc of the Sun is $\sim$0.05. The relative velocities of those stars are minimal, $<$1.3 km/s,. Objects that were born in the same cluster and end up < 100 parsec from the Sun have relative velocities $\sim$1.67 km/s. Therefore, we can conclude that the interstellar asteroid 1I/2017 U1 was not originated in the Sun's birth cluster since it has a relative velocity of $\sim$26 km/s[1], much larger than expected if it was launched from a solar sibling.

Figure 8 shows how the number of stars within 100 parsec of the Sun nowadays changes as a function of the original cluster size. One can see the number of expected stars indeed grows as a function of the original cluster size, but not in a one-to-one way. This is shown by the linear fit which has a slope value $a \ll 1$. This can be explained by the fact that if the open cluster becomes bigger it distributes itself over a much wider arc around the Galactic center. Therefore, although more stars make it more likely one ends up near the Sun, they also spread more. This effect can be seen when one compares the final positions for the open cluster with 50 stars as in Figure 5 with the final positions for an open cluster with 1500 stars as in Figure 9. Another explanation might be that the final positions of the stars are very sensitive to the initial conditions of the cluster.

[1] https://en.wikipedia.org/wiki/Oumuamua

More simulations with small perturbations on the initial conditions might give some more insight if this is indeed the case or not.

5 Conclusions

Our main conclusions are:

- Our estimated birthplace of the Sun is $\mathbf{x} = (9499, 2000, 80)$ pc with a velocity of $\mathbf{v} = (31, -201, 2.5)$ pc. However, small deviations of the current positions and velocity of the Sun have a huge impact on these values, thus the exact birthplace of the Sun is still unknown.
- The gravitational dynamics of the open cluster in which the Sun was born affects the distribution of the Solar siblings nowadays, such that they lie in an arc-like structure. This implies there should still be several Solar siblings close to the Sun within 100 parsec.
- The extra-solar asteroid Oumuamua most-likely does not originate from a Solar sibling, because it's relative velocity is much higher than expected as for a Solar sibling.
- If the birth cluster of the Sun contained more stars it is more likely that Solar siblings are still nearby. However, the relation does not scale one-to-one: a much larger original open cluster only increases the expected number of stars within 100 parsec slightly.