A Potential Observer

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We were given initial positions and velocities of planets and a star, we then used Newtonian mechanics to calculate their paths over 11 years. We took into account the force the star has on the planets and the opposite, we did not however, take into account the force the planets have on each other. We then chose a line of sight from astronomically far away on the x-axis and an inclination angle $i = 75°$. We then plotted the relative velocity as seen from a potential observer. To make it even more realistic, and to stimulate atmospheric disturbances and such, we also added Gaussian distributed noise with $\mu = 0$ and $\sigma = \frac{1}{5}\vec{v}_{max}$ to the velocity.

I. INTRODUCTION

Our mission was to deepen our understanding of the process of discovering stars and exo-planets. To do that, we reverse-engineered the usual process of finding stars and ended up with data that a potential observer could use to find out information about our system. We had data on a solar system which included the initial positions, initial velocities, and the masses of the planets. The star had 0.81 solar masses and was at the origin and had no velocity at $t = 0$. We had calculated the orbits of the 4 most massive planets in the solar system. This time we took into account the gravitational pull the planets had on their star, so the system's center of mass is no longer at the origin. We did not, however, include the gravitational pull the planet's had on each other. We tried to imagine how an observer would discover our solar system, and where it would be best to observe our system from. That includes from what direction they would be looking at our system, and at what inclination the system is at in relation to them. We plotted the component of the velocity that would be best for the observer to see at that inclination we decided. We then added Gaussian noise to the plot to simulate how the observer would actually see it.

II. METHOD

We had the initial positions and velocities, we then used Euler-Cromer's method, which we described in 'Calculating Planet Orbits' (an earlier publication of ours), to find the positions, velocities, and accelerations of the planet's and the star over a certain time N. We chose to have $N = 365 * 11$, and each time-step to be $dt = 3600 * 24s$, which means we had data from over 11 years, and each time step was 1 day. We chose 11 years because all the planets go around at least once, and we could clearly see how the star was behaving.

Using the vectorized form of Newton's law of gravitation:

$$\vec{F} = G\frac{m_1 m_2}{|\vec{r}|^3}\vec{r}$$

($\vec{r}$ being the vector from the planet to the star), we calculated the force from the star on each planet, and all the planet's forces on the star, which is just to add them all up and make negative. We then used the calculated force and newton's second law:

$$\vec{F} = m\vec{a}, \quad \vec{a} = \frac{\vec{F}}{m}$$

to calculate the acceleration. We repeated this process N times. Once we had the positions of the planet's and stars over time, we plotted the orbits and the movement of the star over time. We looked closer at the star to see in which direction it moves the most and would be most useful for an observer to see, since an observer would be using the Doppler formula to measure the radial velocity of the star. It is based on the change in wavelength of photons depending on their velocity, it is explained in detail in another previous publication of ours 'Combing through noisy data'. We then decided on an inclination for the system to be at for the hypothetical observer. The inclination is at what angle the system is at in relation to the observer's line of sight and is important because it affects how much of the actual radial velocity one can record.

$$|v_r| = v \sin i$$

If $i = 90°$, then the system is parallel to the line of sight (as seen in figure 1), and the observed radial velocity is the real velocity.

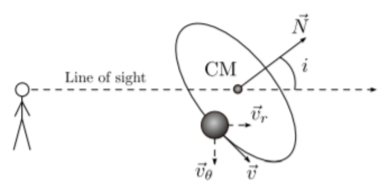

Figure 1.

Once we had the radial velocity in the direction and inclination we decided on, we then found the peculiar velocity and subtracted that to find the relative velocity.

After we had the relative velocity, we then added some artificial noise to that data. The noise would be Gaussian according to the Central Limit Theorem (Hansen, part 1a) which states that most distributions in nature are Gaussian, depending on some conditions of the distribution and that they are big enough distributions, (i.e. have enough values in them). With that in mind, we then added a random number from a set of numbers with Gaussian distribution and with $\mu = 0$ and $\sigma = \frac{1}{5}\vec{v}_{max}$ to each value of the velocity at each time-step, $\vec{v}_{max}$ being the maximum relative velocity. We chose $\sigma = \frac{1}{5}\vec{v}_{max}$ simply because it would make the data quite similar to what it would look like in reality.

III. RESULTS

When we plotted the orbits, we saw that the whole system was moving, i.e. had a peculiar velocity, as it would in reality.

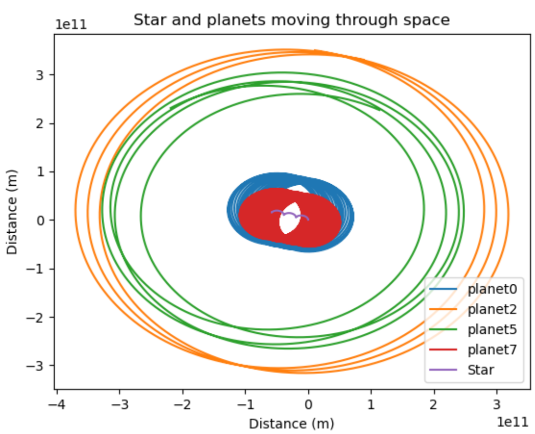

Figure 2.

We looked closer at the star's movement alone (see figure 3), and saw that it moves much more in the x-direction than it does in the y-direction, and decided that it would be optimal for a very distant observer to look at the star from the x-axis since they would be measuring the radial velocity of the star using the Doppler formula. We decided on the first number that came to our heads for which inclination the hypothetical observer would be seeing our system from, and that was $i = 75°$.

We then took the average of the velocity to find the peculiar velocity, which was $-161.21 m/s$, i.e. moving away from the observer. We then plotted the x-component of the relative velocity and observed that it is oscillating as it should, since the star is orbiting it's center of mass (see figure 4).

We then added the Gaussian distributed noise to the relative velocity and plotted that (see figure 5).

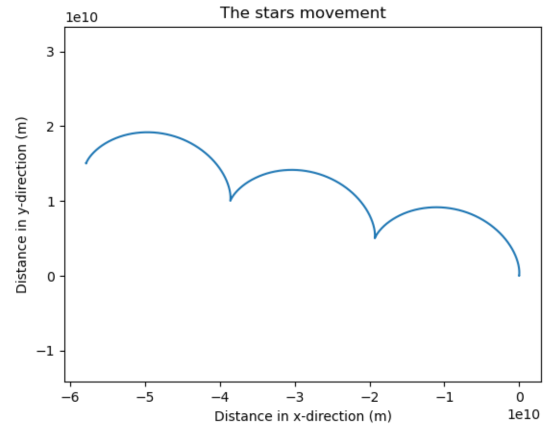

Figure 3.

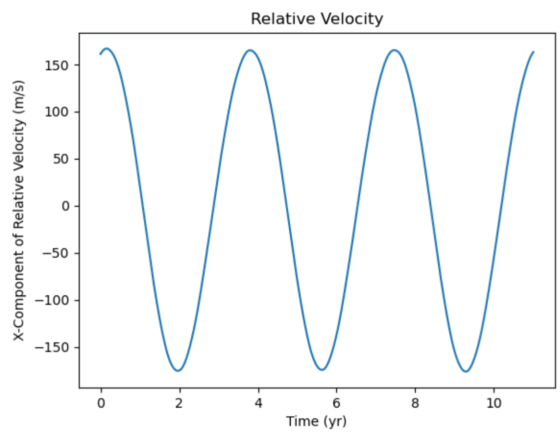

Figure 4.

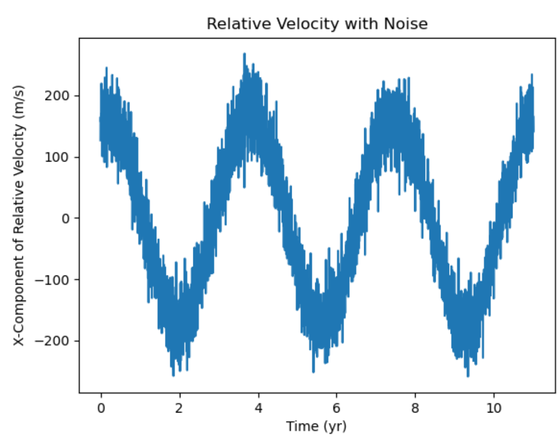

Figure 5.

IV. DISCUSSION

We did not take into account the gravitational forces the planets have on each other, so the orbits of the planet's would be different in reality, the system could in theory, fall into chaos. We also did not taking into account the fact that the observer will most likely be moving in relation to the star, so the radial velocity they would measure would be a little different. The peculiar velocity of our system is also very slow in comparison to our home system at $20,000m/s$, we couldn't figure out why this is the case, but it could just be that every system is different.

V. CONCLUSION

We have plotted the position of a star and the orbits of 4 planets rotating around it over 11 years using the Euler-Cromer method. We then plotted the relative velocity as seen from a potential observer that is astronomically far away on the x-axis, and seeing the system at an inclination angle of $i = 75°$. We added noise to the velocity, this noise had Gaussian distribution with $\mu = 0$ and $\sigma = \frac{1}{5}\vec{v}_{max}$ and ended up with data that an observer could use to discover properties about this system of ours.

REFERENCES

[1] Hansen, F. K., 2021, Forelesningsnotat 1b i kurset AST2000

[2] Hansen, F. K., 2021, Forelesningsnotat 1c i kurset AST2000

[3] Hansen, F. K., 2021, Forelesningsnotat 1a i kurset AST2000

[4] Kandidatnr:15293, 2021, Calculating Planet Orbits

[5] Kandidatnr:15293, 2021, Combing through noisy data