Starshot Mission and the Alpha Centauri System

Evan Manley[1]
[1] *Columbia University, New York, NY 10027*

INTRODUCTION

The Starshot mission is an engineering mission being developed by the Breakthrough Starshot Foundation. The mission has many important goals, but the basic idea is to send a large number of nanocrafts equipped with scientific instruments to the closest star system to us: the Alpha Centauri system. Equipped with spectrometers, the probes could tell us important information about the chemical constituents of planetary and stellar atmospheres. With magnetometers, they could tell us important information about magnetic fields in the system. With cameras, the probes could search for geological features which indicate life.

The nanocrafts will be propelled by laser beams and are expected to reach up to 20 percent of the speed of light. With Alpha Centauri being 4.37 light-years from Earth, the journey is therefore expected to take around 20 years. However, we will need to be more precise than this to have a successful mission. The questions this paper seeks to answer are:

- Exactly how long will these probes take to reach the Alpha Centauri system?
- What are the right ascension and declination coordinates at which we should send the probes?
- When is the optimal position of the Earth's orbit around the Sun to send the probes?
- What is the energy required to send the probes to the system?

PROBE AND PROXIMA CENTAURI DYNAMICS

To precisely calculate the probe travel time, I accounted for the relative motion of the Sun and Proxima Centauri. Here is relevant information about Proxima Centauri according to Gaia's third data release and other sources:

Right Ascension and Declination:
$(\alpha_0, \delta_0) = (217.393, -62.676)\ deg$
Proper Motion:
$(\frac{d\alpha}{dt}_0, \frac{d\delta}{dt}_0) = (-3781.306, 769.766)\ \frac{mas}{yr}$.
Radial Velocity:
$-22.2\ \frac{km}{s}$ (Kervella et al. 2017) [1].
Parallax:
$p = 768.500\ mas$

Using this information, I wrote a 2-Body motion integrator to calculate relative motion of Proxima Centauri and the Sun. Because the acceleration of Proxima Centauri relative to the Sun is so small, the coordinate system can be safely approximated as inertial even with the origin fixed to the center of the Sun. Here is relevant information I used to set up the integrator:

Initial Conditions:

$$\vec{r}_0 = \frac{1}{p}(\cos\delta_0\cos\alpha_0, \cos\delta\sin\alpha_0, \sin\delta_0)$$

$$\frac{d\vec{r}}{dt}_0 = (\frac{dx}{dt}_0, \frac{dy}{dt}_0, \frac{dz}{dt}_0)$$

$$\frac{d^2\vec{r}}{dt^2}_0 = \frac{-Gm_{sun}}{r_0^3}\vec{r}_0$$

Evolution:

$$\vec{r}_{i+1} = \frac{d\vec{r}}{dt}_i dt$$

$$\frac{d\vec{r}}{dt}_{i+1} = \frac{d^2\vec{r}}{dt^2}_i dt$$

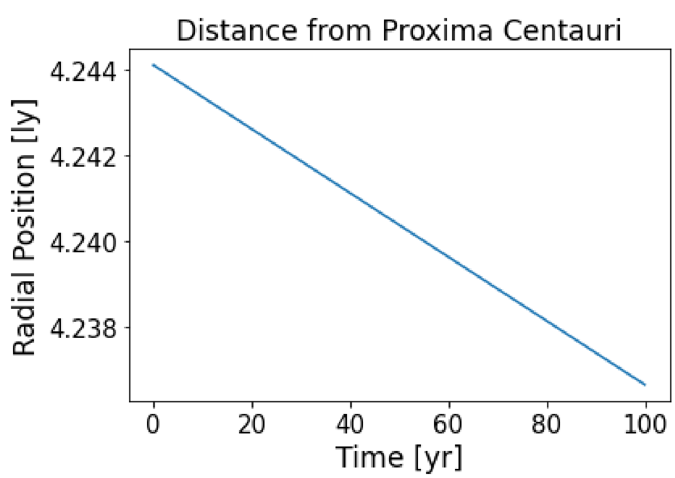

FIG. 1. Plots of the radial position of Proxima Centauri to the Sun as a function of time since the Gaia meaurements.

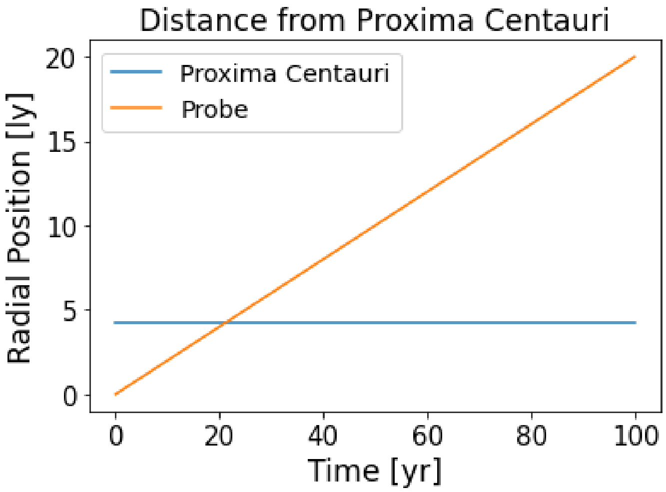

FIG. 2. Plots of the radial positions of Proxima Centauri and the Probe relative to the Sun as a function of time since the Gaia meaurements.

As seen in Figures 1 and 2, the relative velocity of Proxima Centauri is quite slow when compared to that of the probe, as expected. The exact time of the journey is $6.68648E8$ sec or 21.2 yr. After this amount of time since the Gaia measurements, the right ascension and declination coordinates of Proxima Centauri will be $(\alpha, \delta) = (217.371, 297.328)$ deg. However, as the amount of time since the Gaia measurements change, so will the journey time, as well as the right ascension and declination launch coordinates because of Proxima Centauri's relative motion. That is, we must lead our shot of the probes in order to properly hit the target. Figures 3 and 4 show the angular positions of Proxima Centauri as a function of time since the Gaia measurements, and Figures 5 and 6 show the lanuch angular positions as a function of time since the Gaia measurements.

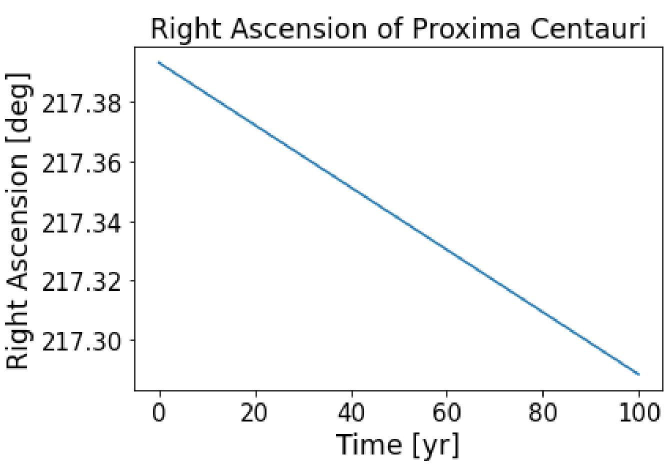

FIG. 3. Right Ascension of Proxima Centauri relative to the Sun as a function of time since the Gaia meaurements.

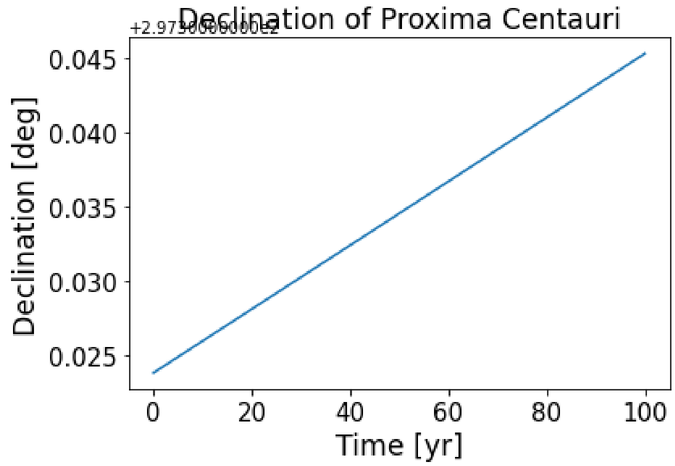

FIG. 4. Declination of Proxima Centauri relative to the Sun as a function of time since the Gaia meaurements.

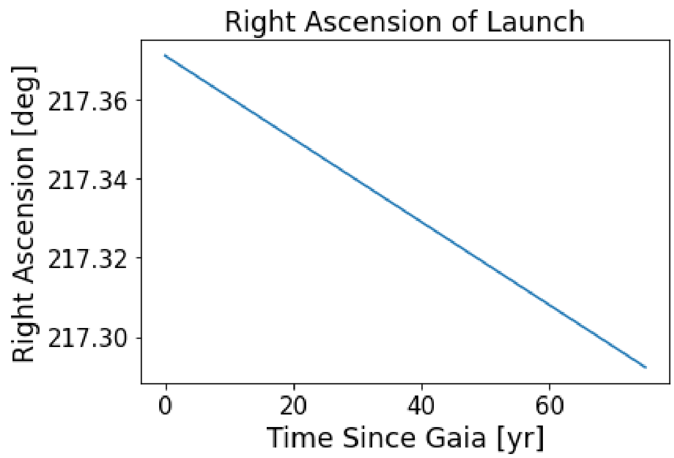

FIG. 5. The right ascension at which the probe should be launched as a function of time since the Gaia measurements.

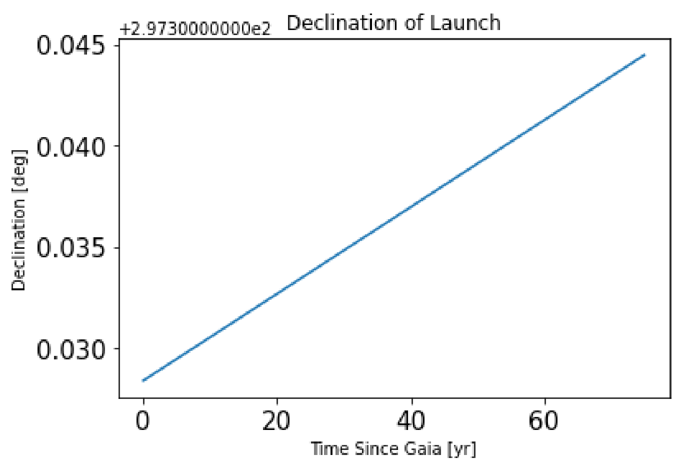

FIG. 6. The declination at which the probe should be launched as a function of time since the Gaia measurements.

WHEN TO SEND THE PROBES

Although the probes velocity is much greater than that of the Earth's orbital velocity, it doesn't hurt to know when we can get a boost from the Earth's orbital energy. When the angle between the velocity vector of the Earth relative to the Sun and the position vector of Proxima Centauri relative to the Earth is at a minimum, the boost from the Earth is at a maximum.

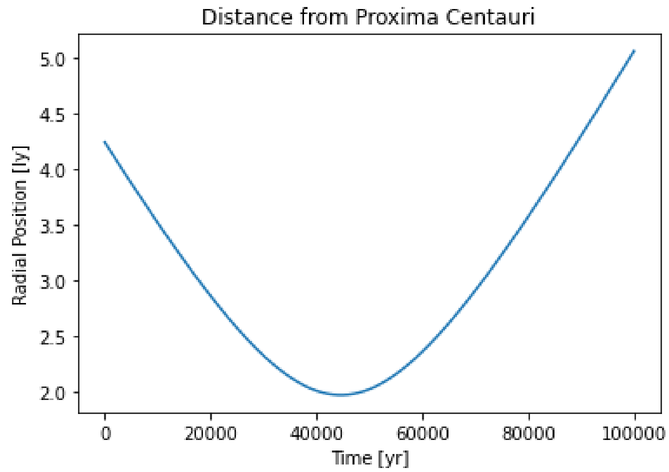

FIG. 7. The long-term behavior of the distance between the Sun and Proxima Centauri.

ENERGY REQUIRED PER PROBE

Because the gravitation potential energy component of the probe's total energy is negligible, only considering the kinetic energy requirements is an excellent assumption. In that case, $E = \frac{m_{probe} v_{probe}^2}{2}$. The mass of each probe is expected to be about .001 kg, and the velocity of the probe is $6E7$ $\frac{m}{s}$. So, the energy requirement per probe is about $3E12$ J.

LONG-TERM BEHAVIOR OF PROXIMA CENTAURI

To better visualize the motion of the Alpha Centauri system relative to the Solar System, we can simply extend the timescale of the integrator. A more accurate model can be made by refraining from assuming the sun is an inertial reference frame, taking into account the local distributions of mass which may affect the motion of Proxima Centauri, and using the center of mass of all the bodies considered to be the origin of the coordinate system. However, the qualitative conclusions of this simplified model are still correct. Proxima Centauri will take several tens of millenia getting closer to us before moving further away. More accurate models show that after 30000 years, Proxima Centauri system will come to 3 light years from the Sun before moving further away.

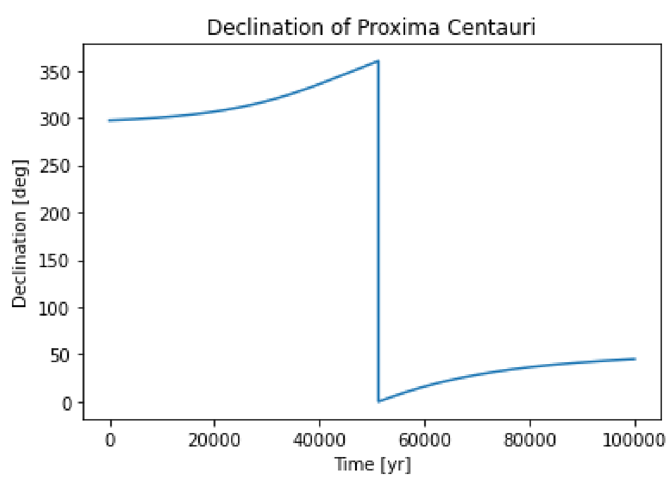

FIG. 8. The long-term behavior of the declination of Proxima Centauri.

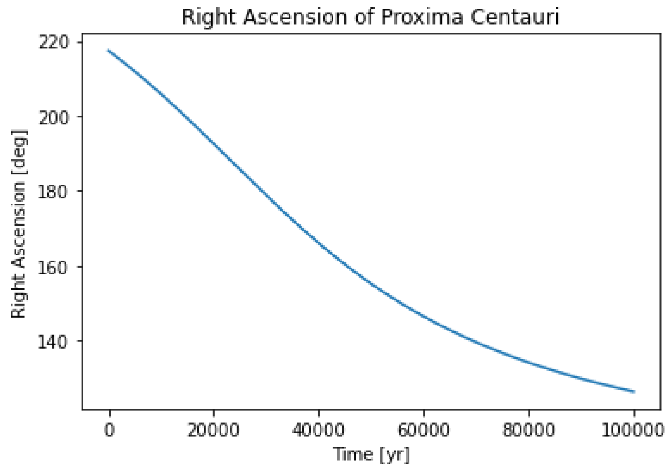

FIG. 9. The long-term behavior of the right ascension of Proxima Centauri.

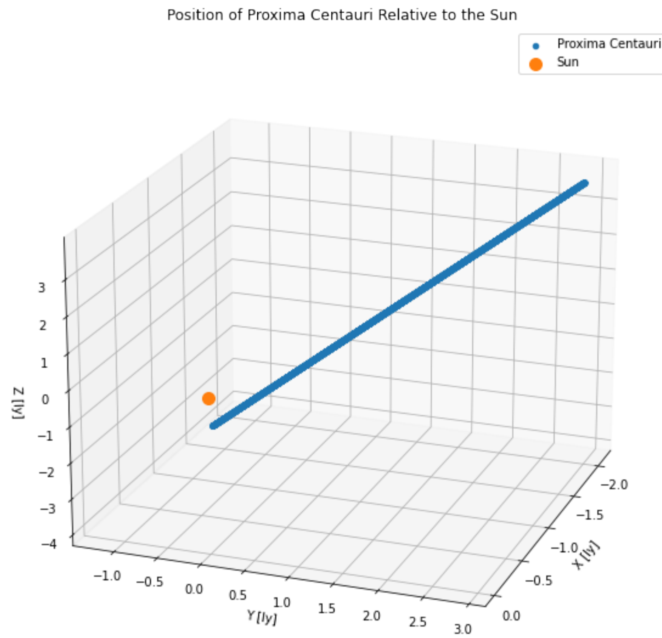

FIG. 10. A 3D visualization of the relative position of the Sun and Proxima Centauri.

[1] P. Kervella, F. Thé venin, and C. Lovis, Astronomy &amp Astrophysics **598**, L7 (2017).