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P6_5 Interstellar Space Pirates

Strachan-Deol, J.M.G., Knowles, K.L., Thompson, L.L. and Kelly, A.L.

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

The authors present in the following paper an analysis of the use of a solar sail on a typical pirate ship, and how long it would take to reach our nearest interstellar neighbour, Proxima Centauri. Using a ship with mass 1.270×10^5 kg, and a total sail surface area of $385.0\,\mathrm{m}^2$, it was found that from an initial velocity of $0.000\,\mathrm{ms}^{-1}$, the journey would take 8.422×10^{14} s or approximately 26.71 million years, and the ship would arrive travelling at a velocity of $95.49\,\mathrm{ms}^{-1}$. Also considered was the case where the ship started with an initial velocity equal to Earth's orbital velocity $v = v_{tang} = 2.798 \times 10^4\,\mathrm{ms}^{-1}$. The journey would take 1.350×10^{12} s or approximately 42,000 years. The sail is negligible in a system with a non-zero initial velocity.

Introduction

The use of solar sails to accelerate spacecraft to fractions of the speed of light was first demonstrated during the IKAROS mission that launched in 2010 [1]. The idea behind the technology is to use solar radiation pressure impacting on a highly reflecting surface, to accelerate the spacecraft. Over the course of a long journey, spacecraft can be accelerated up to incredible speeds not feasible with fuel propulsion.

The sail is a technology that was commonly used by pirates to propel their ships. This paper demonstrates the journey time and destination velocity achievable by a 'space' pirate ship using a solar sail to travel to the nearest star, Proxima Centauri.

Assumptions

This first paper assumes the solar sail material to be a perfect reflector, with no absorption. The ship is not gravitationally bound to the Sun or the Earth. The point of this analysis is to highlight the ineffectiveness of using a solar sail to transport a pirate ship interstellar distances. Due to this, the fact that the majority of the journey would take place in interstellar space and that the overall journey time is far beyond a human lifetime, it will be assumed that gravitational forces on the ship have a negligible effect on the journey. Furthermore, it will be assumed that the space between the solar system and Proxima Centauri is completely empty and free from any dust or objects that might slow the ship down. The mass of the ship is approximated as 1.270×10^5 kg [2]. The initial velocity of the ship is assumed to be zero. The ship in question is assumed to be a small Galleon ship, an example of which is the 'Golden Hind' with well documented measurements [2].

Method

To begin with, we use the solar radiation pressure (P) equation for a perfect reflector:

$$P = 2\frac{G_{sc}}{cR^2}\cos^2(\alpha) \tag{1}$$

where G_{sc} is the solar constant, equal to $1.361\,\mathrm{kWm}^{-2}$ [3], c is the speed of light, equal to $2.998 \times 10^8\,\mathrm{ms}^{-1}$, R is the distance from the Sun in astronomical units and α is the angle of the solar sail to the Sun, with $\alpha = 0°$ meaning the sail is completely facing the Sun.

The pressure will decrease the further the ship travels from the Sun, therefore Equation (1) can be expressed as an integral:

$$P = \int_{R_1}^{R_2} \frac{4G_{sc}}{cR^3}\cos^2(\alpha)dR \tag{2}$$

Performing the integral in Equation (2) over the distance from the Earth to Proxima Centauri, from

$R_1 = 1\,\mathrm{au}$ (Earth-Sun distance [4]) and $R_2 = 2.688 \times 10^5\,\mathrm{au}$ (Sun-Proxima Centauri distance [5]) gives us the total solar radiation pressure over the entire journey.

Using the following equation:

$$F = PA = ma \tag{3}$$

where A is the area of the sail, which for this scenario is assumed to be $385.0\,\mathrm{m}^2$ [2], F is the force exerted by the solar radiation on the sail, and a is the resultant acceleration in ms^{-2}.

Rearranging Equation (3) and substituting in Equation (2) we arrived at the equation:

$$a = \frac{A}{m} \int_{R_1}^{R_2} 4\frac{G_{sc}}{cR^3} \cos^2(\alpha) dR \tag{4}$$

Using a simple SUVAT equation:

$$s = ut + \frac{1}{2}at^2 \tag{5}$$

setting the initial velocity, $u = 0.000\,\mathrm{m}s^{-1}$, substituting in Equation (4) for a and rearranging for the journey time t, we arrive at the expression:

$$t = \sqrt{\frac{2(R_2 - R_1)}{a}} \tag{6}$$

We can also find the final velocity simply by:

$$v = u + at \tag{7}$$

Considering the case where the initial velocity is non-zero, but instead equal to the tangential velocity of the Earth, v_{tang} can use the quadratic solution to find the journey time:

$$t = \frac{-2v_{tang} \pm \sqrt{(2v_{tang})^2 + 8a(R_2 - R_1)}}{2a} \tag{8}$$

using only the positive solution.

Results

Using Equation (6), along with the various parameter values stated previously, the total journey time for the ship is $t = 8.422 \times 10^{14}\,\mathrm{s}$ or ≈ 26.71 million years. For context, it will take Voyager 2 another 40,000 years to pass within 1.700 light years of a small star called Ross 248, in the Andromeda constellation [6].

Using Equation (7), the final velocity of the ship, when starting from a stationary position, is $v = 95.49\,\mathrm{ms}^{-1}$. When considering the case with an initial velocity equal to the Earth's tangential velocity, $v_{tang} = 2.798 \times 10^4\,\mathrm{ms}^{-1}$, the journey time is $t = 1.350 \times 10^{12}\,\mathrm{s}$ or $\approx 42,000$ years. The final velocity would be practically equal to the initial velocity due to the minute acceleration of the ship of $a = 1.134 \times 10^{-13}\,\mathrm{ms}^{-2}$.

Conclusion

Clearly, the journey time is extensive and the final velocity is not particularly large for both the first and second case (relative to spacecraft such as Voyager), and the journey time is reduced by a factor of ≈100. However, in the second case, the sail provides a negligible increase in velocity. This is most likely due to the small sail surface area and relatively large mass of typical pirate ships. To expand upon this work, future papers could possibly consider a larger sail, which is more conceivable in space, along with an analysis without assuming the material is a perfect reflector. One could also consider which materials would be most suitable for such an endeavour.

References

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