Journal of Physics Special Topics
An undergraduate physics journal

A5_10 Solar Laser

T. Graham, F. Kaiser, C. Keany, R. Newland, K. Pankhania

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

December 6, 2022

Abstract

Following on from previous work, this paper aims to compare the effect on Earth's orbit that a solar laser would have (a laser with a power equivalent to that of the Sun), as opposed to the Sun's realistic forces on the Earth, ignoring all physical effects other than the radiation pressure. It is found by simulating this scenario that the realistic Earth's orbit is expanded at a rate of approximately 0.43 m/s. A Sun powered laser is then considered, although this is found to accelerate the Earth to relativistic speeds in an extremely short timeframe.

Introduction

In a previous paper A5_7 Laser Pool [1], it is derived that the force experienced by a spherical object from parallel light incident on one face is given by

$$F = \frac{\pi I R^2}{c}, \tag{1}$$

where I is the intensity of the light, in W/m^2, R is the radius of the object, and c is the speed of light. This prompted the thought of what effect the Sun has on Earth's orbit. Two scenarios are considered; one in which the solar flux incident on the Earth's surface is used, and the other in which the luminosity visible half of the Sun is focused onto the Earth's surface in the form of a laser. The Earth is assumed to be a perfectly smooth and reflective sphere.

Scenario One: the Realistic Solar System

The solar intensity on the Earth's surface is given as $1,360$ W/m^2 by NASA [2]. The radius of Earth is $6,371$ km [3], which provides a value of the force on the Earth's surface of $F = (\pi I R^2)/c = 5.78 \times 10^8$ N. A two-body gravitational simulation was run for one million iterations, up to a time of 2×10^9 s, or roughly 63 years. However, the flux on the Earth's surface is so low that there is zero noticeable change in the orbit. Therefore, we have increased the flux by a factor of 20, which is enough to determine an increase in the orbit over a small enough distance for our approximations to be applicable.

As can be seen in Figure 1, the orbit has changed from a starting value of 1.496×10^{11} m to a final value of $1.671 \times 10^{11} m$. Given the timescale of 10^9 seconds, this is therefore an average increase of 8.5 m/s. For the correct value of the solar flux it would therefore be twenty times slower, at 0.43 m/s. Assuming a constant rate of increase, this would put Earth at the distance of Neptune (4.516×10^{12} m [4]) in approximately 10^{13} seconds, or a little over 300,000 years. This value is however a very low one, as the solar flux would drop off according to the inverse square law. The rate of increase is so slow that the weakening of solar flux could not be considered in this paper.

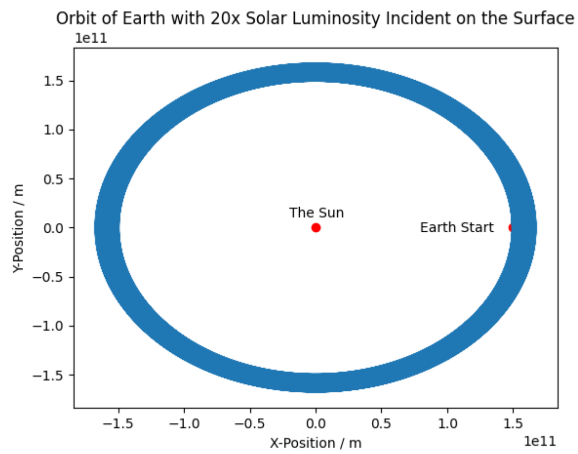

Figure 1: A diagram showing the increase in Earth's orbital radius over a period of 2×10^9 seconds (63 years). The position of the sun and the initial position of the Earth are shown as red circles. Individual orbits are not visible as there is so little difference between each successive one.

Scenario Two: the Solar Laser

The next scenario to be considered is: what if the Sun's power was to be focused entirely onto the Earth in the form of a perfectly collimated laser beam? The average solar luminosity is 3.828×10^{26} W. If we consider light only coming from the face visible from Earth, then 1.914×10^{26} W will be incident. This value is so much higher than in scenario one that the Earth is ejected from the system immediately. In order to grasp how fast the Earth is ejected, the luminosity is reduced by a factor of 10^{16}. This allows the same simulation as before to be run, and usable data to be obtained. Following the same method as in scenario one provides an average velocity of 23 m/s. This is $\sim$ 50 times higher than scenario one, and would put Earth out to Neptune's orbit in only $\sim 5,000$ years. This, of course, is for the reduced value of the luminosity. A solar laser would therefore send the Earth away at extremely relativistic speeds within this timeframe, when the 10^{16} factor in solar luminosity (removed earlier) is reintroduced. The details of this are not discussed here, as this model only looks at short term effects with low radial velocities.

Conclusion

In conclusion, we find that the influence of the Sun's radiation is extremely minimal. It would take approximately 300,000 years for the Earth to be pushed as far as Neptune given the assumptions that have been made. However, the real values for these can change drastically. The intensity of the solar radiation is obviously dependent on the inverse square law, and thus would drop off rapidly as the Earth drifted away. The value for how long the Sun would take to push Earth to Neptune is therefore much higher. The Earth is also assumed to be perfectly reflective, however the albedo of the Earth in the present day is around 0.3 (meaning 30% of incoming radiation is re-emitted into space). This value would also change as the Earth froze over, increasing to around 0.84 (both values from [5]). The effect of this would be to further increase the time it would take to be moved towards Neptune.

The significantly less realistic scenario of a Sun powered laser is also considered, but it is found that the Earth would be accelerated to relativistic speeds within seconds.

References

[1] T. Graham, F. Kaiser, C. Keany, R. Newland, K. Pankhania, *A5_7 Laser Pool*, PST 21, (2022)

[2] `https://earthobservatory.nasa.gov/features/EnergyBalance/page2.php` [Accessed 7 Nov 2022]

[3] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html` [Accessed 7 Nov 2022]

[4] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/neptunefact.html` [Accessed 7 Nov 2022]

[5] `https://earthobservatory.nasa.gov/images/84499/measuring-earths-albedo` [Accessed 7 Nov 2022]