Journal of Physics Special Topics
An undergraduate physics journal

S4_5 If You Liked It, You Should Have Put A Ring On It

J. T. Best, M. J. Duggan, S. M. B. Croxford

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

November 15, 2017

Abstract

In this paper, we explore the potential power to be harnessed by constructing a Dyson Ring, and produce a ball-park figure of the associated costs. We find that there is the possibility to collect approximately 6 $\times 10^{10}$ Watts of power, and that an initial investment of £50 billion could suffice to install such a structure.

Introduction

The Dyson Sphere was a concept popularised by Freeman Dyson in his 1960 paper "Search for Artificial Stellar Sources of Infrared Radiation". In it, he discussed the idea that any sufficiently advanced civilisation would have ever- increasing energy requirements which could be met by harnessing great proportions of the parent star's energy.

One of the more realistic and simplest configurations is the Dyson Ring. This is formed of a single circle of satellites that orbit the star, harvest its energy, and then beam it via LASER or MASER to the nearby civilisation. This paper attempts to quantify the potential power collection and the cost associated with constructing one Dyson Ring.

Theory

We propose a circular solar panel of diameter 1km, orbiting the Sun at 1 AU, with a spacing of 3°. The circumference of the orbit is 9.42×10^{11} m. A spacing of 3° correlates to a distance between panel centres of 7.85×10^9 m, so the ratio of the orbital circumference to the distance between panel centres results in 119 panels forming the circle.

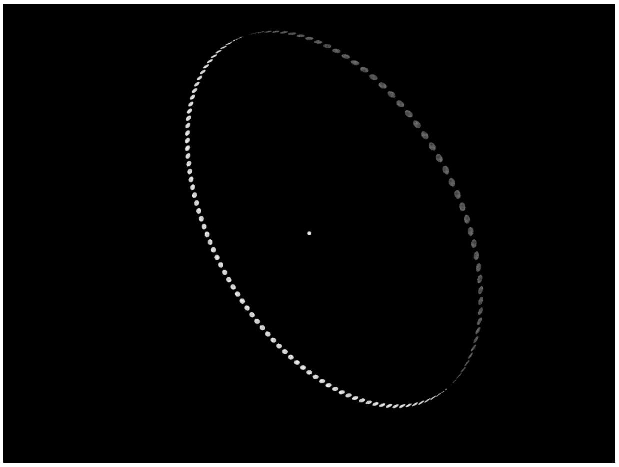

Figure 1: Visualisation of the Dyson Ring setup. [1].

At this distance of 1 AU, we can compute the solar intensity using the solar constant of 1,368 W m $^{-2}$ [2]. The area of each panel is given by 250,000 π. The total intensity captured by all 119 panels is therefore

$$119 \times 1368 \times 250,000\pi = 1.279 \times 10^{11} W. \quad (1)$$

Currently the world record for solar cell efficiency (multi-junction) is 0.46 [3], so the amount of useful wattage drops to 5.88 $\times 10^{10}$ W. This is equivalent to the Palo Verde nuclear reactors in Arizona, the most powerful in the USA, constantly running at 15 times maximum capacity [4].

We next estimate the total mass of solar panels to be put into orbit around the sun. Commercial solar panels are 1.95 m $\times$ 0.975 m rectangles, and they can have masses as low as 18kg [5]. This results in a panel with a mass per unit area of (in kg m^{-2})

$$\frac{18}{1.95 \times 0.975} = 9.45 \tag{2}$$

and therefore one Dyson solar panel would have a mass of 7.42×10^6 kg. Thus the total mass of Dyson solar panels is 119 times this value, equal to 8.83×10^8 kg. A value for the cost per kg of world-record grade solar panels could not be obtained, so here we have assumed that production cost scales with efficiency. The efficiency of domestic grade solar panels then is around 21.5 % [6], with a cost per kg of £19.80. Multiplying £19.80 by $\frac{0.46}{0.215}$, we estimate that the cost per kg of solar panels with an efficiency of 0.46 = £42.45. Thus the total production cost becomes

$$42.45 \times 8.83 \times 10^8 = \pounds 37.5 \text{ billion.} \tag{3}$$

We next consider the cost of launching this mass into a stable orbit around the Sun. Data are unclear on exactly where the satellites would be launched, but we know that they would not be orbiting the Earth and that they should be relatively uninfluenced by the Earth's gravity, so one possible approximation is to consider the cost of accelerating mass to escape velocity.

Results

We use the rocket equation, where the payload mass m_f, calculated in the previous section as the mass of a single solar panel, is equal to 7.42 $\times 10^6$ kg, escape velocity $\Delta v = 11.18$ kms^{-1}, and the exhaust velocity $v_e = 5$ km s^{-1}. The initial mass m_i is 6.94×10^7 kg. Thus the mass of the propellant is equal to

$$m_i - m_f = 6.2 \times 10^7 \text{ kg.} \tag{4}$$

NASA pays approximately £1.44 per kg of fuel, and so using this figure as a reference, the total cost for fuel equates to £89 million per launch of one solar panel [7], and thus for all 119 launches the total cost is £10.6 billion. Adding the production cost of £37.5 billion brings the total to £48.1 billion. In order to account for overheads regarding labour costs and underestimated quantities, this figure can be approximated to at least £50 billion.

Conclusion

While currently inaccessible to humans on an engineering front, the costs associated with a mission like this are neither unsurprisingly high nor leagues above the world's budget, assuming that this would be undertaken and funded by most countries on Earth. In addition, the energy saving would be huge, and would allow for cheaper installation of further Dyson structures in the future.

References

[1] https://goo.gl/j57M9R [Accessed 14 November 2017]

[2] https://goo.gl/C6mEV2 [Accessed 14 November 2017]

[3] https://goo.gl/eTJwpi [Accessed 14 November 2017]

[4] https://goo.gl/cdyYYy [Accessed 15 November 2017]

[5] https://goo.gl/DH9GgB [Accessed 15 November 2017]

[6] https://goo.gl/Fxk74Q [Accessed 15 November 2017]

[7] https://goo.gl/Pv97mX [Accessed 15 November 2017]