The Possibility and Consequences of a Second Sun

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April 24, 2012

Abstract

As the world population explodes there are more and more mouths to fill, our current predicament of celebrities and hippies guilt-tripping the developed world into propping up the uncontrollable population of the third world. There will come a time that food is so scarce that those with money and power will not feel so generous, potentially, civilised countries would commit crimes to keep their charges' hunger sated. This is a reason for considering a second Sun. Seasons could be altered so that crops could grow endlessly and solar power plants would have a much greater efficiency and could become more viable, there are a multitude of effects, some of which are discussed below.

1 Idea Genesis

Whilst Fusion is taking major steps towards viability, the uses for it are wide reaching and world changing. The greatest effects on our planet comes directly from the Sun, most of which are positive, and so more benefits could be reaped from a second Sun.

2 Possibilities

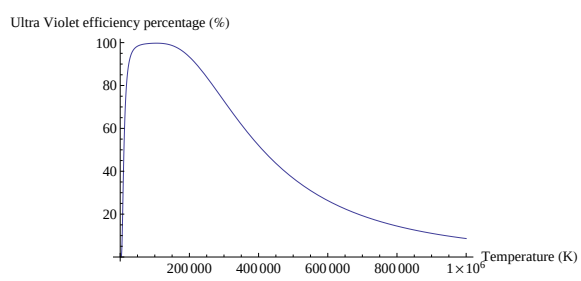
What the second Sun would be required to do and how it would be possible to achieve this.

2.1 Blackbodies

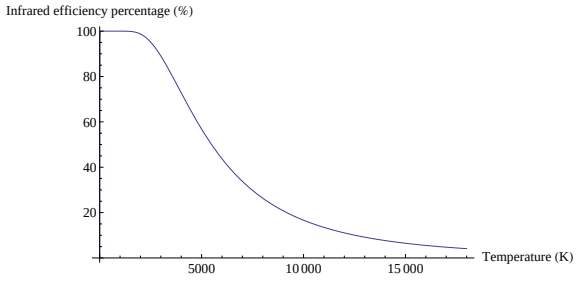
Before discussing fusion in any complexity we must first ascertain whether the basic ideas can even stand. As such, for now, let us take that there would be no issues with the power generating side of this idea. The basic concept would be to have a fusion reaction giving it's power to some radiator which would then act as a blackbody. The initial vehicle for this system was imagined to be a satellite and so the position could be controlled but after a few minor calculations this was deemed unsuitable. First was to decide what radiation would be favoured; when making a 'new Sun' choices can be made about what should be it's primary focus, the temperature of the blackbody radiator could be set such that there was a greater amount of radiation suitable for photosynthesis, visible light or wavelengths that could further enhance the use of photovoltaic cells. By using *Mathematica*, a series of spectra of different radiation types as a function of temperature were created, these can be found in Fig. 2.1 and were formulated using the following relation,

$$\text{Proportion of radiation emitted between } \lambda_1 \text{ and } \lambda_2 = \frac{\int_{\lambda_1}^{\lambda_2} \frac{2c^2h}{\lambda^5\left(e^{\frac{ch}{\lambda k_B T}}-1\right)}\,\mathrm{d}\lambda}{\int_0^{\infty} \frac{2c^2h}{\lambda^5\left(e^{\frac{ch}{\lambda k_B T}}-1\right)}\,\mathrm{d}\lambda} \tag{1}$$

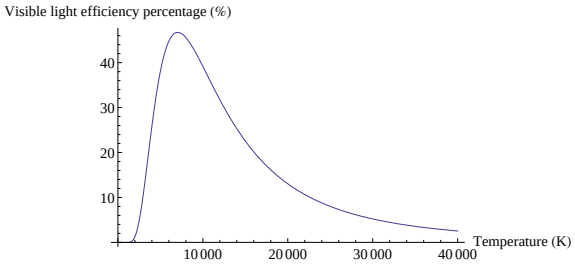
This can be evaluated for any values of λ_1 and λ_2, for example in the visible light interval, $\lambda_1 = 390\text{nm}$ and $\lambda_2 = 750\text{nm}$, which results in an expression for the efficiency of a blackbody at radiating visible light as a function of temperature. To evaluate other uses it was trivial to modify this relation to be relevant to the following efficiencies: Infrared, Ultra violet, wavelengths used in Photosynthesis and by photovoltaic cells. These relations could be visualised, however plotting them offered no real contribution to the matters at hand but were simply interesting and so have been included.



(a) Ultra violet



(b) Infrared



(c) Visible

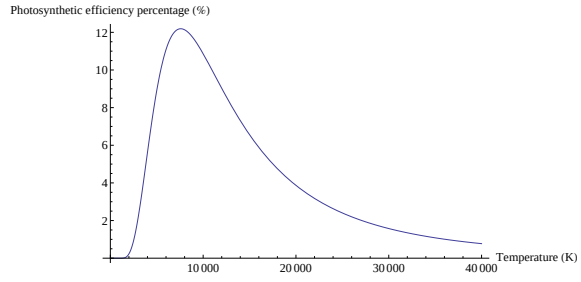
Figure 1: Percentage efficiency of a blackbody producing Ultra Violet (a), Infrared (b) and Visible (c) light as a function of temperature, K.

The plots showed that there are peaks in all spectra and that for a thorough evaluation it would be useful to determine the temperature at which these occurred,

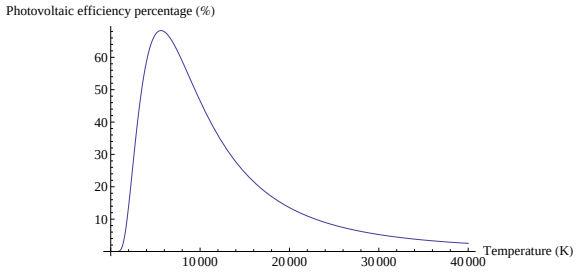
Radiation type	Temperature (K)	Efficiency (%)
Visible	7043.33	46.73
Ultra violet	105072.00	99.73
Infrared	774.68	100.00

Table 1: Optimum temperatures and efficiencies for sections of the electromagnetic spectrum to be emitted from a blackbody

Efficiency curves were also created for the wavelengths used by photovoltaic cells and in photosynthesis, by equation (1).



(a) Photosynthetic



(b) Photovoltaic

Figure 2: Percentage efficiency of a blackbody producing Photosynthetic (a) and Photovoltaic (b) light as a function of temperature, K.

It could be possible to choose where the greatest effects could be felt, by creating an algorithm which included several weighting factors, a compromise can be found that has a more even overall effect. The table below gives a breakdown of the most common radiation from three most favourable configurations of a Sun and the result of the weighted algorithm.

		Percentage type of radiation emitted (%)				
Emphasis of Sun	Temperature	Visible	Infrared	Ultraviolet	Photovoltaic	Photosynthetic
Existing Sun	5778	43.75	46.31	9.94	68.20	10.71
Visible	7043.33	46.73	33.36	19.90	64.17	12.08
Photovoltaic	5625.33	42.90	48.20	8.89	68.26	10.42
Photosynthesis	7583.98	46.33	29.13	24.53	61.27	12.19
Optimal Sun	6829.20	46.66	35.24	18.10	65.18	11.97

It seems from above that there is now an optimal temperature from the algorithm and that the weightings are suitable, although the value for photovoltaic light has been reduced, the reduction is only a difference of 4% of the total radiation output used in photovoltaic cells, which given a maximal efficiency of a solar cell to be 43% this corresponds to only a 1.73% change in useful solar cell output. The photosynthetic wavelengths have increased in proportion by 12% and the visible light has also proportionately increased by 6.6%. Until now it has not been clear as to why the infrared and ultra violet wavelengths have been discussed but from a second Sun we do not need more heat or harmful UV, hence these types of radiation were accounted for and the 'optimal' Sun offers a 31% decrease in infrared radiation but an increase in ultra violet by 82%. The effects of these will be discussed later and so ends the blackbody section.

2.2 The radiator: The Great Plate

Now a medium to act as the blackbody at $6829.20K$ is required and it's properties discussed, initially the primary thought was towards a ceramic material, some of which can already achieve well over $4000K$ [1], particularly due to the increase in research funding in this area due to NASA's hypersonic aerospace vehicle program [2]. But if a ceramic is not available with the necessary properties there exists a solution that is already a commercial product in many homes using the same principle, Plasma televisions; these are stimulated to act as a blackbody and produce light radiation.

The dimensions and arrangement of the radiator are crucial for making the new Sun comparable to the original Sun at ground level. The energy received by the Earth from the sun annually is $3850000EJ$ which is equivalent to an average power of 1.22×10^{17}Watts, by using the Stefan-Boltzmann law,

$$P/A = \sigma T^4$$
$$A = \frac{P}{\sigma T^4}$$

we can determine the area of the plate required to radiate this same power,

$$A = \frac{1.22 \times 10^{17}}{\sigma \left(6829.2\right)^4} \text{ where } \sigma = 5.67 \times 10^{-8} \text{ W}/(\text{m}^2\text{K}^4)$$

this gives,

$$A = 989900940\text{m}^2$$
$$A = 989\text{km}^2$$
$$A \approx 1000\text{km}^2$$

which is about 1/21 of Wales. This is the required size of the plate to radiate the same power as the incident solar radiation upon Earth with the spectrum we have chosen; given that all of the radiation from our blackbody is incident upon the Earth. The shape of the plate is also critical and can be chosen to suit our needs, the radiation emitted would be wasted if it were not to be incident upon the Earth's surface and so the plate must have the correct surface area and be shaped such that the radiation, if emitted at a normal to the plate, would fall in this region. From Fig. 3 and knowing the distances

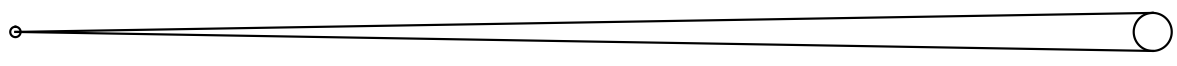


Figure 3: A diagram to scale of the Moon and Earth and the stream of light

involved an angle can be calculated,

$$\theta = \arctan\left(\frac{\text{Earth radius}}{\text{Average Moon orbit radius}}\right)$$
$$\theta = \arctan\left(\frac{6378100}{381550000}\right)$$
$$\theta = 0.0167$$

This angle, when using a plate that follows the curvature of the Moon's surface, the surface area of the spherical cap can be calculated. In Fig. 4 h is given by, $h = r\,(1 - \cos\theta)$ this gives $h = 242.7\text{m}$

$$S_{cap} = 2\pi r h$$
$$S_{cap} = 2649.\text{km}^2$$

which is too great, therefore a new design must be created, knowing the surface area required and the formula for the surface area of a spherical cap, h can be calculated as a function of r,

$$S_{cap} = 2\pi r h = 989\text{km}^2$$
$$rh = 1.57 \times 10^6\text{m}^2$$
$$h = \frac{1.57 \times 10^6}{r}\text{ meters}$$

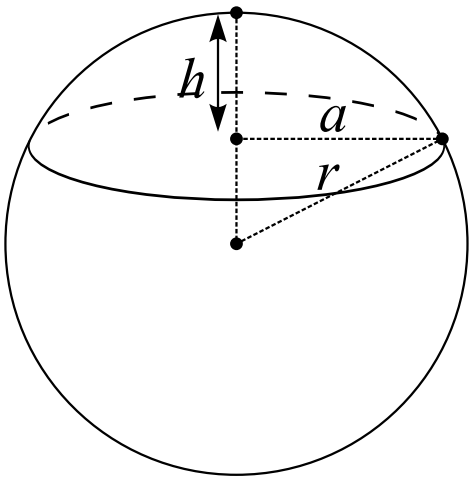


Figure 4: A diagram of a spherical cap. [4]

Once r has been found more details can be deduced, and can be found by solving two simultaneous equations, both involving the angle at the center of the new spherical cap,

$$\tan\theta = \frac{63738100}{381550000 + r}$$

the origin of this equation is the Earth's radius divided by the sum of the average Moon radius and the radius of the spherical cap that will be our radiator.

$$\cos\theta = \frac{r - h}{r}$$
$$\cos\theta = 1 - \frac{1.57 \times 10^6}{r^2}$$

thus the equation to solve is,

$$\arctan\left(\frac{63738100}{381550000 + r}\right) = \arccos\left(1 - \frac{1.57 \times 10^6}{r^2}\right)$$

luckily there exists *Mathematica* which gave r to be,

$$r = 1.06497 \times 10^6\text{m}$$

now the Moon with the theoretical sphere of the spherical cap can be visualised, see Fig. 5. Being a spherical plate and the light being radiated normally there will be an even spread of the power over the entire face of the Earth, which may not be an advantage. Those areas that are already too hot to be habitual, the tropics in particular, would receive not only the same portion as another more northern or southern region but also due to the refraction of light in the atmosphere, the radiation would be considerably greater, hence an inverted parabolic plate would be a ideal solution, the light could then be directed such that the proportion would increase as a function of distance from the center of the side of the Earth facing the Moon.

Computing the requirements of a non-spherical plate with the correct surface area and curvature in *Mathematica* was not trivial but achievable, once complete scaled models of the plate were produced, these can be seen in Fig. 6.

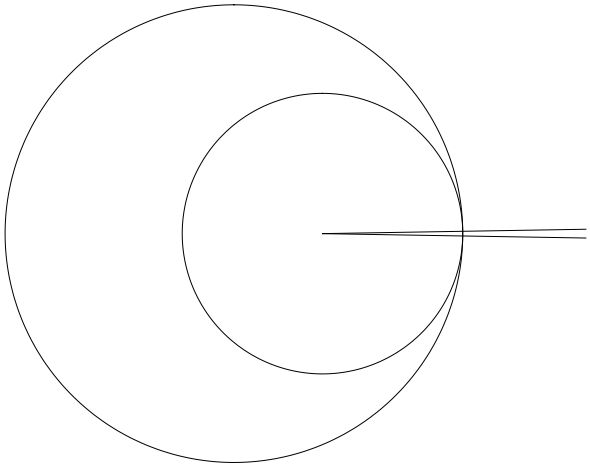
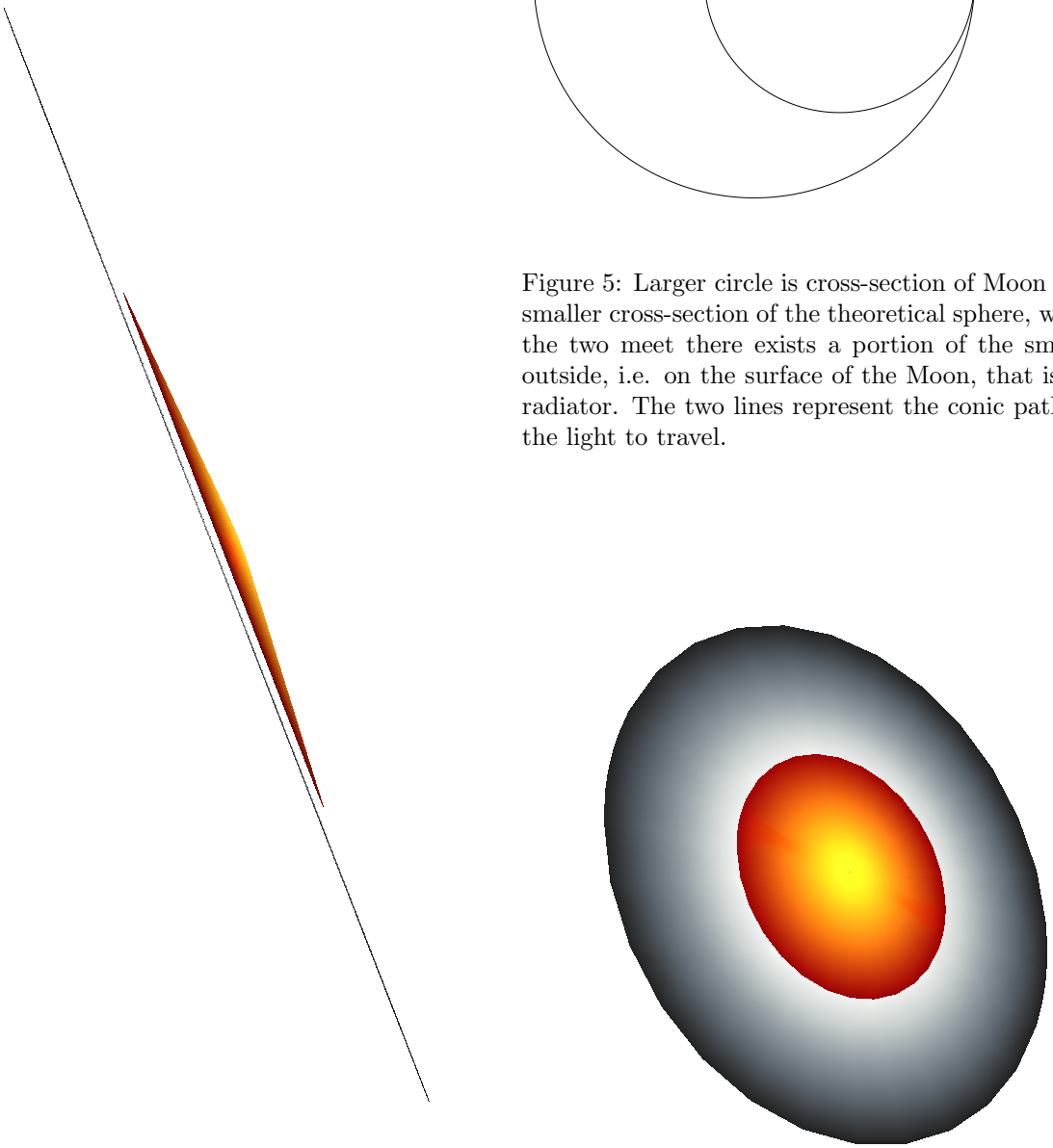


Figure 5: Larger circle is cross-section of Moon with smaller cross-section of the theoretical sphere, where the two meet there exists a portion of the smaller outside, i.e. on the surface of the Moon, that is the radiator. The two lines represent the conic path for the light to travel.



(a) Profile

(b) Angled

Figure 6: The profile model (a) is to show a comparison between the curvature of the Moon's surface and the plate, which, as can be seen the lunar curvature is approximately zero in contrast to the plate which has been modelled such that the perpendicular radiation is confined to falling upon the Earth. The angled (b) plot is for aesthetics only, the grey is the lunar surface and the plate is decorated with a *"SolarColors"* colour scheme available in *Mathematica*

The technicalities that have been dealt with thus far are:

- Calculation of the necessary wavelengths and hence the temperature of the Blackbody radiator
- Radiator material has been discussed.
- Size, shape and placement of the radiator.

The next point of contention is whether the power required can be generated, the only power technology, in all probability, that could achieve this is nuclear fusion.

3 Fusion: Power possibilities and He-3

In current fusion reactors, JET and ITER, the plasma is confined in a vacuum vessel using toroidal and poloidal magnets, with the fuel being Tritium and Deuterium. Since 1986 there have been thoughts towards the extraterrestrial mining of Helium-3, for our purposes this is an exciting prospect as He-3 can be used in nuclear fusion. The process of fusion in the stars begins with Hydrogen nuclei and ends with Helium-4 as the product. A fusion reactor using He-3 uses the same final reaction, as can be seen in Fig. 7, the advantage of mining and using Helium-3 as a fuel from the Moon is not only physically beneficial but also as a product of these fusion reactions, Hydrogen is formed, one side of the rocket fuel coin.

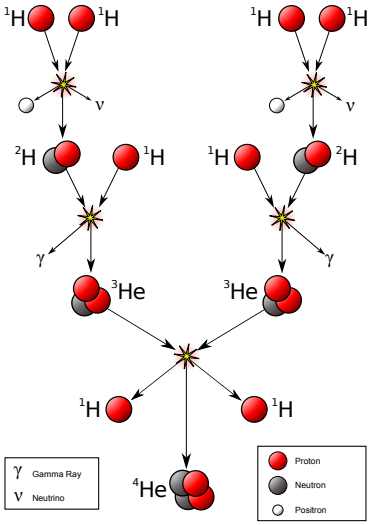


Figure 7: A diagram of the reactions continuously occurring in the Sun. [5]

3.1 Lunar mining

The initial race for the Moon was hotly contested and the cause was mostly just rivalry, but now we could be on the precipice of another competition and this time the stakes could be, potentially, much greater. In 1969 Neil Armstrong collected samples that fist showed the abundance of Helium-3 in the lunar soil, levels may range from 10-50ppb in undisturbed, continuously shady regions. This may not seem like a hugely impressive quantity, but as He-3 prices have risen to $5000/litre of late the viability is more likely.

NASA's Vision for Space Exploration has stated that there should be men back on the moon in 2020 and by 2024 a permanent base established although no official statements have been released from NASA concerning Helium-3 that is not so from other countries, in China, Ouyang Ziyuan head of the Chinese Lunar Exploration program has previously detailed that the mining of the precious resource would be a key goal [6]. Russia also is keen to explore this potential economic resource by 2020 [7]. India too, in a joint experiment with NASA, are trying to compete with the Chandrayaan-1 with one of the two instruments contributed by NASA being the Moon Mineralogy Mapper (M^3), an imaging spectrometer, giving a very detailed composition spectrum of the Moon's surface [8].

It could be that the mining effort could be done by automated machinery and the separation and purification of He-3 is comparatively simple and inexpensive

3.2 He-3 fusion

The dream of Helium-3 fusion is of a clean and efficient energy source, as can be seen from Fig. 7 the products of this reaction is a Helium-4 nucleus or alpha particle and two protons or Hydrogen nuclei. The key advantage lay with those two protons, employing electrostatic fields to control fuel ions and the fusion protons and using solid-state conversion materials a positively charged proton can be converted directly into electricity without the need for conventional turbines and steam, hence a much greater efficiency, up to 70%; this is the hope from which this entire project stems.

The basis upon which all nuclear reaction work is that the total mass of the products of a reaction is less that the sum of the reactants mass; this change in mass, Δm, is the energy released in the reaction according to Einstein's mass-energy relationship, $E = mc^2$. The energy released is given by,

$$Q = \left(\sum_i m_i - \sum_f m_f \right) c^2$$

This can be written differently if considered that an nucleus of mass m with atomic number Z and mass number A differs from the sum of the components by,

$$\Delta m = Z m_p + (A - Z)\, m_n - m$$

Stable nuclei have a positive Δm and so an amount of energy is required to dissociate the constituent parts of the nucleus, this is the binding energy, $B = \Delta m c^2$.

$$Q = \sum_f B_f - \sum_i B_i$$

By plotting B/A against A in Fig. 8, the binding energy per nucleon against nucleon number, we can see that fusion occurs for nuclei with fewer number of nucleons than Iron and fission for greater numbers This

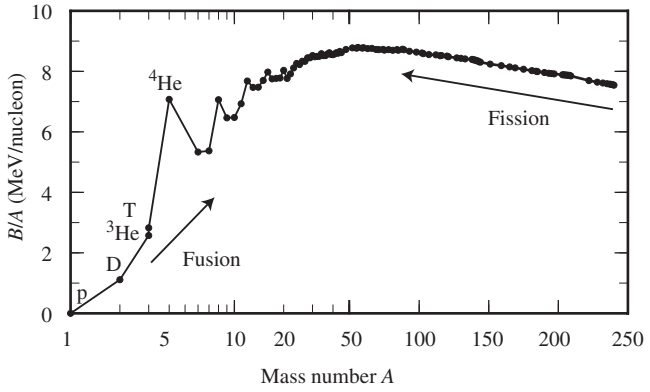


Figure 8: Binding energy per nucleon versus mass number A

plot shows the vast amount of energy released from fusing He-3 to He-4. But the medium that this energy is released in is the important factor, conventional power stations convert crude energy into electricity through a inefficient and inelegant method; as He-3 fusion reactions emit high energy ions, protons, there have been experiments that have shown that a blind like series of water cooled ion collectors converts these protons into electrical energy with very high efficiencies, much higher than Deuterium-Tritium reactors, at around 70%. The reaction above is the much sought after He-3 reaction, with the energy released being

$$^3_2\mathrm{He} + {}^3_2\mathrm{He} = {}^4_2\mathrm{He} + 2\ {}^1\mathrm{H} + 12.9\mathrm{MeV}$$

in the form of highly kinetic protons, which given the theoretical current efficiency of energy conversion should give 9.03MeV per reaction or 1.45×10^{-12} Joules. Now knowing the power output required for our plate as 1.22×10^{17} we can calculate the number of reactions per second,

$$\begin{aligned} \mathrm{N}^o \text{ of reactions per second required } &= \frac{1.22 \times 10^{17}}{1.45 \times 10^{-12}} \\ &= 8.43 \times 10^{28} s^{-1} \end{aligned}$$

This may seem like a massive number but Gerald Kulcinski, a professor of nuclear engineering at the University of Wisconsin-Madison maintains a Helium-3 fusion reactor, not of a tokamak design but spherical. The plasma is a sphere of radius approximately 5 cm and in this volume there occurs 200 million reactions per second; if we could scale this proportionately, if a volume of $5.236 \times 10^{-4}\mathrm{m}^3$ can support 200 million reactions per second then theoretically a volume of $4.215 \times 10^{20}\mathrm{m}^3$ is large enough

to contain enough plasma to power our second Sun. The volume calculated above is massive and equates to a sphere with a radius 2.6 times bigger than the Moon's radius, hence a problem. However if you look at the difference in the plasma volume sizes between ITER and JET, the energy output or number of reactions per second does not have a direct linear relationship with size. From the data of several fusion reactors a quadratic extrapolation can be calculated for the size required, the estimate for the needs of the plate from this extrapolation is $1.38 \times 10^{10}\text{m}^3$ which gives a diameter of less than three kilometres. This could be a possibility on the moon.

4 Global effects

As can be imagined the effects will be gargantuan and as such have been divided into subsections.

4.1 Environmental

The most obvious aspect would be the influence on vegetation, with a doubling of light suitable for photosynthesis there are going to be profound effects; Fig. 9 shows the various locations in which Chlorophyll exists. Humans release 27 billion tons of Carbon Dioxide a year through various means [11] with much being absorbed by the oceans, around 30%. If photosynthesis were to be able to occur for twice the amount of time and given that sufficient nutrients and water were available, the amount of biomass created as a result of photosynthesis would double. Each year, globally, 100-115 petagrams of carbon are converted into biomass, considering that doubling this value would become 2×10^{17}g which is more than enough to completely offset the current global CO_2 emissions at 2.7×10^{16}g. This would be using the current quantity of vegetation, however as you could imagine the number of photosynthetic organisms would explode, having a further positive effect.

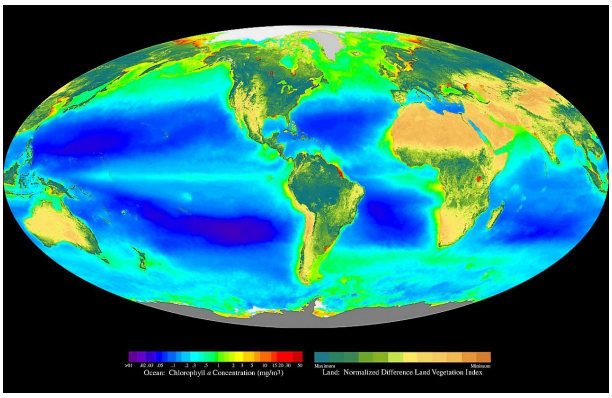


Figure 9: A global map of chlorophyll concentrations both in the oceans and on land. The colours that are closest to the middle of the legend have higher concentrations of Chlorophyll. [10]

A reduction in Carbon Dioxide would have many positive effects, including a reduction in greenhouse gases, but the place most to benefit from this would probably be the oceans. We already know the ocean absorbs a large portion of the World's CO_2, but much of it becomes a weak acid that decreases the alkalinity of the seawater and damages parts of the important infrastructure of sea life: Corals cannot build their skeletons as quickly, marine algae and zooplankton find protection difficult due to a reduction in their shells and the survival of larval marine organisms is reduced, some of which are commercial sea food. Our current dwindling stocks of fish and shellfish, which feed mostly on algae and plankton, would have a much greater food supply from these sources due to the ability to photosynthesise more and an ideal alkaline environment.

The weighting algorithm to determine the new Sun's radiation spectrum it was important to ensure that the Infrared levels were significantly lower than the current Sun to try and reduce the effect of warming even with lower levels of Carbon Dioxide. Although the worry with global warming is mostly the sea levels rising due to the melting of the ice caps, the worry could be somewhat reduced through the increase in photosynthesis also. Considering that up to 95% of a plant's mass is water, if the biomass production doubled with the correct irrigation, the water displacement could be met by the uptake into vegetation.

The effect upon wildlife would be devastating and would be tantamount to the genocide of many species and as such shall not be discussed as it serves no purpose.

4.2 Impact upon Humanity

First and foremost, globally, there is a higher incident of crime at night, which can be expected. A second Sun would have a two-fold increase on this; with no darkness those whom are currently not caught due to the indistinctness of the night would be brought to justice and act as a deterrent to those that may,

also most crime stems from depravity and disadvantages, often financially. With the advent of more vegetation and thus food, the cost of living will decrease, not necessarily uniformly, but to some degree; this too would help to combat crime.

The World could have a unified time zone, hence the global economy could be tuned to a higher level promoting prosperity, potentially, lowering crime. Lighting would also be a huge issue; with 20-50% of total energy in homes and offices being lighting [15], there are potentially massive savings that could be made. Also jet-lag would be a phenomenon known only in history books.

The main concern is the amount of Ultra Violet radiation that would be incident upon the surface due to the new Sun. With an increase in UV radiation of 82% there could quite possibly be the need to spend a minimal amount of time in direct sunlight at 'night', windows of buildings may need a Ultra Violet filter and other precautions may be needed. The consequences of over exposure to UV radiation can be: Skin cancer, immune suppression and cataracts [16].

Included in the weighted algorithm was an allowance for photovoltaic suitable radiation, transmitting energy through space may seem inelegant, but the light falling on our planet from the current Sun that would otherwise be unused is no different from the light that would be falling on our planet from the new Sun, it would increase the efficiency of solar panels, collecting energy from both Suns.

Safety could also be a factor, having such a massive reactor as would be needed for this project, placing it on the Moon would alleviate public concerns of a energy-related nuclear disaster; but furthermore, without the need of so much lighting and with the increased warmth from the second Sun the domestic and some business environment's power requirements would be so greatly reduced that the power required could be provided by photovoltaic cells, wind power or another renewable energy source.

5 Conclusion

Although nearly all of this article has been hypothesised, the object was to illustrate how it could be possible at some point, when great advances have been made, to create a second Sun; the effects would be unimaginable, with repercussions around the World. Humans have ransacked this planet's energy resources and change will be needed on a global scale.

Space exploration is going to become evermore important to find another habitable planet, the advantages of having a Moon base would be incredibly valuable; due to the lack of atmospheric hinderances and reduced gravitational potential, exploration missions would be easier and cheaper.

It is important to note that in this system the fusion reaction would not be continuous and would have a 'down-time' each day when the Moon is in front of the Sun and the extra solar power is not required.

It would be a dream to see a reality of human endeavour taken to such lengths, but for now the dream will have to wait.



Figure 10: One Sun rising as the other sets, Luke took it for granted. [17]

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