A study on Dyson Spheres and Dyson Swarms

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Abstract— Humanity has advanced considerably since the beginning, finding new ways to make life easier, but these advancements generally require increasing amounts of energy. A Dyson Sphere is a conceptual megastructure that a technologically superior civilisation might construct around a star to intercept most of the star's light and convert it to useful energy. This energy can be used by a civilisation to solve its energy crisis in order to develop further. It could also serve as the largest and the cleanest source of energy ever developed. The idea of a Dyson sphere, which was introduced by Freeman Dyson, will initiate our transition to the next stage of human civilization i.e. The Kardashev Type II Civilisation – which can utilize and control the entire energy of its planetary system's star. The Dyson Sphere was first envisioned as a giant shell encompassing the entirety of a star; however, this design poses few hindrances, which will be elaborated further in the paper. The hindrance led to the designing of Dyson Swarm, which is an alternative that solves most of the problems of the Dyson Sphere. It is a dense arrangement of independent constructions, such as solar captors, that orbit the star as a single layer. The scope of our study also includes the process of making a Dyson Swarm.

Keywords: Dyson Sphere, Dyson Swarm, Energy, Kardashev Type II Civilization

I. Introduction

The amount of energy needed generally increases as advancements are made in a civilization. It fundamentally means that the more advanced the technology and industries of a civilization are, the higher is their need for energy. Earth has sustained life for millions of years, and one of the main reasons being, our indirect reliance on the energy from the Sun. With rampant development taking place leading to globalization, industrialization, urbanization, etc. the natural resources that our planet once had in abundance are now depleting by the minute leading to the fear of scarcity of our resources over the next hundred to thousand years. Unlike fossil fuels, whose availability will reduce and will be replenished only through thousands and millions of years of natural processes, the Sun is effectively a long-term and constant source of energy. Given this availability of energy, it is important for us to identify how we can harness the power of the Sun more efficiently and channel the energy drawn from it towards the Earth. At present, the Earth's surface receives about $1360\,\mathrm{W/m^2}$ of energy every second [1], this amount is only a very small fraction of the total energy that can be gained from around the sun. A Dyson sphere can serve as a possible long-term solution to our energy crisis.

Freeman Dyson first introduced the idea of the Dyson Sphere in a 1960 article titled 'Search for Artificial Stellar Sources of Infrared Radiation' as a possible means to find extra-terrestrial intelligence that has the capability to communicate using radio transmissions [2]. However, through the years, as multiple researchers evaluated his idea, they figured that Dyson also implied that a Dyson Sphere could serve as a possible long-term solution to combat our energy crisis. Thus, the original thought experiment of Dyson gave birth to the idea of Dyson Spheres being used by an advancing civilization to meet its energy requirements when the requirements are greater than the amount that can be generated from its home planet's resources.

The Kardashev Scale, published in 1964 by Soviet astronomer Nikolai Kardashev, is a classification about the possible levels of technologically advanced civilizations based on their energy consumptions. There are 3 basic kinds of Kardashev Type Civilisations:

1) Type 1: A civilisation with technological levels that can manipulate energy resources of its home planet;
2) Type 2: A civilisation with the capability to harness the energy radiated by its home star and to manipulate the energy resources of its planetary system;
3) Type 3: A civilisation holding the capability to manipulate the energy resources of its entire home galaxy [3].

We are currently near the type 1 civilization, more precisely, our average energy consumption leads us to nearly 0.73 on the Kardashev scale [4]. The energy output of the Dyson Sphere, even if it is less than $1/100000^{\mathrm{th}}$ of the Sun's energy, is about 3.8×10^{21} W, which is extremely huge and will give us the edge we need to reach Type 2 on the Kardashev scale.

II. Dyson Sphere

Dyson sphere refers to a theoretical megastructure that can completely surround its parent star and use it as an energy source.[5]. It is the most optimum solution for living space and energy production and provides the ability to capture the radiation emitted from the parent star.

A. Different Designs Formulated for the Dyson Sphere

There were many structures and designs formulated for the Dyson Sphere. We will analyse some of the different designs formulated over the years and choose the best one in terms of its practicality, cost-efficiency and which can start construction in a few decades.

1) Dyson Shell –

Description: The Dyson Shell is a massive monolithic spherical shell which surrounds a Star and captures all the energy released out by it.

Advantages: It enables to capture almost all the energy from the star.

Disadvantages: Constructing a massive structure of this nature will require huge financial commitments and initial energy to build. The Chances of this massive structure collapsing cannot be ruled out.

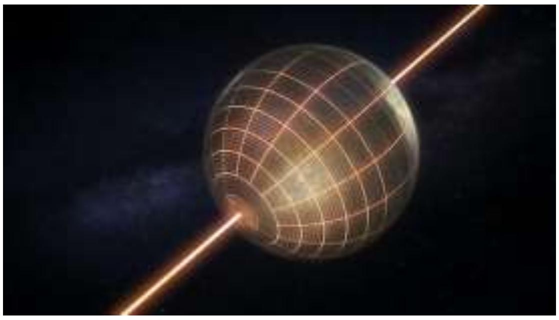

Fig. 1: Dyson Shell

2) Dyson Ring –

Description: A large circular structure comprising of Solar Captors that orbit around the star.

Advantages: A design that is simple and easy to create and has significant efficiency in operations.

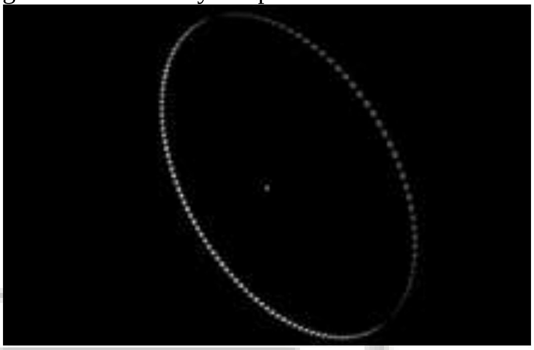

Fig. 2: Dyson Ring

Disadvantages: As the structure covers a relatively smaller area in comparison to the other Dyson structures, it can harness relatively less energy from the Star.

3) Dyson Swarm

Description: An arrangement of Solar Captors or Reflective panels in the general form of a cluster of Dyson Rings orbiting the Star.

Advantages: The construction is not subject to large internal forces, is simple to create, and the materials to be used are easily available. It is much cheaper to construct and though the efficiency is questionable, it still harnesses higher energy than any conventional method.

Disadvantages: The swarm needs precise calibration to ensure the captors and panels don't collide against each other and also to ensure that they are protected from external objects in space.

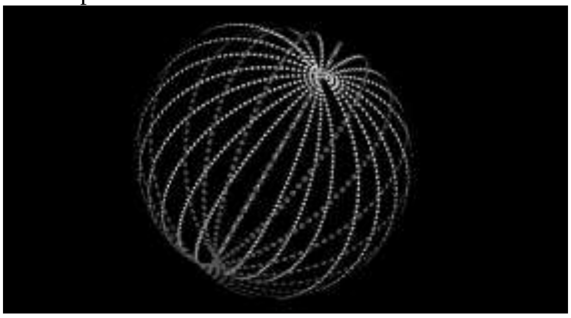

Fig. 3: Dyson Swarm

On understanding the advantages and disadvantages of each of the Dyson structures, we believe the best suited design is the Dyson Swarm, keeping in mind the ease of construction and the financial implications. The lack of perfect efficiency isn't an issue either, given the 3.8×10^{26} W of energy available.

III. DYSON SWARM

A. Structure of the Dyson Swarm

The initial stages of the Dyson Swarm's construction would resemble a Dyson Ring. The Swarm's radius could be equal to approximately the length of the Semi-Major axis of Mercury. This and various other factors have been assumed in the design of the Swarm's structure.

The bulk of the Dyson Swarm will be made out of hexagonal reflective panels with sides of roughly 620.40324m (3.1.3), to get a panel that has a total surface area of 1km^2. Each panel could be about 1.5km apart giving us a total of approximately $7.34112684 \times 10^{15}$ (3.1.5) hexagonal panels, which covers around 17.42047% of all the area that can be covered at the distance of circa 57.90905×10^6km from the Sun.

The semi-major axis of Mercury = 57,909,050 km

(3.1.1)

Surface area that the Dyson Swarm can cover if radius is equal to the length of the semi-major $= 4\pi r^2$

$$= 4 \times \pi \times (57909050)^2$$
$$= 4.2140797 \times 10^{16}\text{km}^2$$

(3.1.2)

Surface area of each hexagonal panel $= 1\text{km}^2$

Length of the sides of each panel $(s) = \sqrt{\frac{\text{Surface Area}}{1.5 \times \sqrt{3}}}$

$$s = \sqrt{\frac{1}{1.5 \times \sqrt{3}}}$$
$$s = 0.6204032394\text{km}$$
$$\therefore s = 620.4032394\text{m}$$

(3.1.3)

Apothem of each panel $(a) = \frac{s}{2\tan\left(\frac{180}{n}\right)}$

$$a = \frac{0.6204032394}{2\tan\left(\frac{180}{6}\right)}$$
$$a = 0.5372849659\text{km}$$

(3.1.4)

Total distance between each panel = 1.5km

Total number of panels required in the Dyson Swarm = $7.34112684 \times 10^{15}$

(3.1.5)

∵Each panel accounts for $\mathbf{1km^2}$ of area actually covered and there are $\mathbf{7.34112684 \times 10^{15}}$ panels in use, all the panels in total will cover an area of $\mathbf{7.34112684 \times 10^{15} km^2}$.

(3.1.6)

Of the total area available at a distance of $\mathbf{57,909,050km}$ ($\mathbf{4.2140797km^2}$ $(\mathbf{3.1.2})$), the Dyson Swarm covers circa $\mathbf{17.42047\%}$ $\left(\mathbf{7.34112684 \times 10^{15}km^2}\ (\mathbf{3.1.6})\right)$

B. Materials

At present, Earth does not possess sufficient amounts of useful material to construct a Dyson Swarm, as a result, the only other sources of material are the planets and asteroids in our planetary system. Out of the planets in our solar system, Mercury is the best candidate for planetary disassembly as it possesses huge amounts of the materials which would be required in the construction of the swarm, and its proximity to the Sun makes it easier to move machinery and the parts of the swarm towards and around the Sun.

The composition of Mercury is estimated to be primarily consisting of about $\mathbf{30}\%$ silicate and $\mathbf{70}\%$ metals, mainly Iron or Iron oxides [6]. The Iron extracted from Mercury will be utilized in constructing the parts of the Dyson Swarm such as reflective panels which will use polished Iron in their construction.

C. Setting-up the Infrastructure and Acquiring the Materials

To initiate the process of disassembly, there has to be a permanent infrastructure on the surface of Mercury. Prior to beginning the disassembly process, a satellite containing a rover will have to be sent to Mercury to scout for a large and mostly flat area for our main base to be set up. The satellite will initially orbit the planet in search for a landing spot which meets our requirements, following which the rover will be sent down to send detailed close-up images of the land for the prospective base and to transmit other essential details back to us. Considering that Mercury has minimal to no altitudinal variation in comparison to Earth and Mars, this initial process should not be heavily time consuming or cost intensive [7].

Once the land over which the base will be constructed has been decided, all the machinery required for the disassembly can be sent to Mercury. The process of disassembling Mercury and the production and launch of each panel is split into 4 stages of production namely Mining, Refining, Manufacturing and Launching [6]. The disassembly process begins with Mining by using fully automated robotic Miners which are programmed to strip-mine the surface of the planet and send the geological material obtained to the refiners. The refiners will refine the rocks and soil into purer forms of the required metals. The next stage of production is the manufacturing stage during which all the acquired materials will be combined to form the reflective panels and the solar captors which will be launched into orbit around the Sun using something similar to a mass driver. Every machinery has to be fully automated and has to use the geothermal energy from the core of Mercury as an energy source, even if the amount of energy needed to power all 4 stages, is more than what we can produce using geothermal energy alone, there is still a lot of solar energy that can be harnessed and used. This offers an added advantage of cooling the core of Mercury faster for smoother mining and even though the cooling effect to the core may initially seem negligible, it will add up over time to have a greater effect on the cooling of the core. We will use the energy from the reflective panels in the orbit of the Sun as a second and long-term method for gaining energy for the machinery, i.e., for producing more parts and launching the parts.

D. Launch

On Earth, we use rockets to send payloads to space since the escape velocity of Earth at exobase is $\mathbf{10.8}\,\boldsymbol{km/s}$ [8], however, on mercury the escape velocity is just $\mathbf{4.25}\,\boldsymbol{km/s}$ [9] at its surface, as a result it is probably better to use a more reusable and cost-efficient form of launch equipment such as a mass driver. Mercury's proximity to the intended position of the Dyson Swarm gives us another reason to use mass drivers instead of traditional rockets for launching the payloads into space.

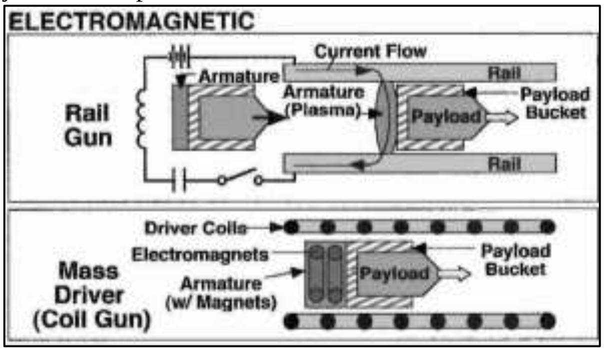

Fig. 4: Rail Gun and Mass Driver

There are other fixed launching system designs that work on the same principle as a mass driver, one of which being railguns [6]. A railgun is a linear motor device that uses electromagnetic waves to launch high velocity projectiles. The design involves the use of a pair of parallel conductors (rails) which are connected to an electrical power supply on one end, this forms the breech end of the gun. When a conductive projectile is inserted between the rails, it completes the circuit. Electrons flow from the negative terminal of the power supply up the negative rail, across the projectile, and down the positive rail, back to the power supply. This makes the railgun behave like an electromagnet, creating a magnetic field inside the loop formed by the length of the rails up to the position of the armature. The sliding armature is accelerated by the electromagnetic effects of the current which flows through it, as a result, launching the projectile forward at high velocities [10]. The mass driver is essentially the same as rail gun except the rails are replaced with driver coils which produce their own magnetic field once powered. The armature is made up of bars of magnets. The coils are powered in such a way that it creates a magnetic field possessing the same polarity as the rear end of the armature. The magnetic field created causes the armature to repel off of the driver coils on its rear end, forcing it to accelerate forward, thus gaining speed as it moves along the tube.

The railgun, due to its design, is limited to high-acceleration with small-payload projectiles, on the contrary, a mass driver is scalable to larger projectiles and higher or lower velocities by just changing the length of the barrel and number of coils on the gun [10]. Hence, the mass driver may be the most suitable option for launching the panels and other components of the Dyson Swarm to space from the surface of Mercury.

E. Transmission and Storage of Energy

Transmission of energy is a crucial aspect of the Dyson Swarm. The main system for transfer of energy will be through the reflective panels. Using the reflective panels, the energy captured will be concentrated and directed towards giant solar powerplants (in the form of Heat Engines) [6] which will act as collectors of energy. The ultimate goal will be to redirect the energy harnessed from the Sun towards mammoth Heat Engines located on the surface of the Earth.

Hence to ensure that there is a constant transmission of energy at every point in time and no complete failure is faced at any point of time, we will be using a second way of storing and transmission of energy which is by some Solar Captors orbiting Mercury. These Solar Captors will also manage and prevent the crashing of reflective panels by having the needed power and programs.

The process of transmission has to be conducted in a robust manner so that only a minimal loss of transmitted energy takes place and the consistency is maintained.

IV. Continuing the PROCES of development of the DYSON swarm

The Dyson Swarm is an enormous megastructure, and it cannot be solely developed by using materials exclusively derived from Mercury. We will have to find new sources for gaining the material for further progress of the Dyson Swarm. Asteroids possessing the necessary metals and minerals can be mined and bought to the base for production of more parts of the Dyson Swarm. These materials can be also used to maintain the Dyson Swarm as there are chances for there to be a collision with an asteroid or meteoroid along with the possibility of a solar flare or coronal mass ejection (CME) causing a failure and the crashing of a few panels. In order to recognise and instantly rectify these or any other failure that might occur, few satellites would have to be placed in orbit to monitor over different sections of the swarm.

V. Conclusion

Energy is the core requirement for any civilisation and as a result is one of the fastest depleting resources. The Sun is essentially a long-term and constant source of energy, multiple theories on how to harness and store the energy from the sun have been in the working, however with mixed successes. Given the abundant availability of the Sun's energy, it is important for us to identify how we can harness the power of the Sun more efficiently. Understanding this long-term need, Freeman Dyson introduced the theory of the Dyson Sphere and the concept of the Dyson Swarm, which is doable and a very practical long-term solution to the growing Energy requirements of any Civilisation.

References

[1] Fitch, Kemler, Kemler Katie, and Kemler Christine. "Solar Radiation and Photosynethically Active Radiation." Fundamentals of Environmental Measurement 2014. Fundamentals of Environmental Measurement. Web. https://www.fondriest.com/environmental-measurements/parameters/weather/photosynthetically-active-radiation
[2] Dyson, Freeman J. "Search for Artificial Stellar Sources of Infrared Radiation." Science 131.3414 (1960): 1667.
[3] Ćirković, M. M. "Kardashev's Classification at 50+: A Fine Vehicle with Room for Improvement." Serbian Astronomical Journal 2015.191 (2015): 1–15.
[4] Gray, Robert H. "The Extended Kardashev Scale." The Astronomical Journal 159.5 (2020): 228.
[5] Wright, Jason T. "Dyson Spheres." Serbian Astronomical Journal 200 (2020): 1–18.
[6] Armstrong, Stuart, and Anders Sandberg. "Eternity in Six Hours: Intergalactic Spreading of Intelligent Life and Sharpening the Fermi Paradox." Acta Astronautica 89 (2013): 1–13.
[7] Smith, W. B. et al. "Surface-Height Variations on Venus and Mercury." Radio Science 5.2 (1970): 411–423.
[8] Menzel, Donald H. "The Escape of Planetary Atmospheres." Exploration of the Planetary System. Springer Netherlands, 1974. 37–39.
[9] Schmidt, Carl A. et al. "Escape Rates and Variability Constraints for High-Energy Sodium Sources at Mercury." Journal of Geophysical Research: Space Physics 117.3 (2012).
[10] Frisbee, Robert H. "Advanced Space Propulsion for the 21st Century." Journal of Propulsion and Power 19.6 (2003): 1129–1154.