Image credit

Dyson Sphere

The megastructure of the future

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Brief history of energy advancements

Through human history events have happened that boosted our energy output as a species. We electrified the world with the industrial revolution and the discovery of nuclear power. Alan Turing invented the Computer and we entered the information age in the mid-1900s. Most likely, in the future, we'll gain complete control of the earth and become a Type I civilization. After that, the next step will be colonizing the universe. But for that we will need an unbelievable amount of energy.

Kardashev scale

The Kardashev scale, named after Russian astrophysicist Nikolai Semenovich Kardashev, is a scale meant to describe how advanced a civilization is. It is divided into types. The official Types of civilizations are Types I through III, although scientists have expanded it to Types IV and V.

Type I

A Type I civilization can harness all of the earth's energy, or 2.778×10^{9} kilowatt hours (kWh). It's relatively easy to get to Type I, since we are already making considerable progress in our energy output. For that, we simply need to transition to fusion, hydroelectric, renewable and antimatter energy. We would probably get there in 100-200 years.

Type II

A Type II civilization can store 2.778×10^{19} kWh [14], which means capturing the entire output of a STAR. To get there, we would need to either feed stellar mass into black holes, use star lifting, use antimatter, or collect parts of the energy of multiple stars. But the most viable option is a Dyson Sphere. Star lifting is where we remove some matter from a star to use it for other purposes. We might get here in a few thousand years

Type III

A Type III civilization will have to capture all the energy of a galaxy and would consume 2.778×10^{29} kWh. How could we get there? One option is to build multiple Dyson spheres around multiple stars. There are other options, too. We could use gamma-ray emissions or use a black hole bomb to collect the energy of a supermassive black hole and/or Quasar, giving us a galaxy's worth of energy. We could get here anywhere between 100,000 and 1,000,000 years.

Type IV

A Type IV civilization would capture the entire energy of the universe. Kardashev didn't even mention a Type IV civilization; he thought it was too advanced. A Type IV civilization would use 2.778×10^{39} kWh. I would think about continuing the pattern of advancement, by collecting the energy from multiple black holes, that is, building multiple black hole bombs around multiple black holes and quasars, or possibly, maybe harvesting dark energy and dark matter.

Type V

Type V earthlings would become literal gods, manipulating the multiverse as they please. It's very very unlikely that humanity will ever hit a Type V civilization. The only way I would think of doing it would be harvesting the dark matter and energy from multiple universes.

In fact, I'd say a very intelligent species can escape a real dying universe, trillions of trillions of years in the future, by using the energy from the Type IV civilization to artificially cause a big bang, creating a baby universe, a window to escape the dying universe.

The equation for Kardashev type

There is an equation that you can use to calculate the Kardashev type using the total wattage. Created by Carl Sagan, this is the equation:

$$K = \frac{log(P) - 6}{10}$$

Where K is the Kardashev type, and

$P$is the total amount of watts used.

What type are we?

In 2018, the human race used 5.1 million kWh of energy, which if we plug that into the equation means that humans are a Type 0.726481782300954 civilization or approximately Type 0.73. We're actually making noticeable progress, since in 2012, the wattage consumption was 4.87

million kWh. That was a Type 0.724402958903002 civilization, or around Type 0.72. That means that in only 6 years from 2012 to 2018, we increased our Kardashev type by 0.00207882339, or pretty much 0.002. That increase should not be so surprising with new technologies coming out. However, it's good to be able to prove that we're advancing as a species, especially when you consider that the Kardashev scale is logarithmic.

After we get to a Type I civilization, how will we get to a Type II civilization? The way we'll do that is by capturing not some of the Sun's energy, but all of it. How do we do that? With a Dyson Sphere!

What is a Dyson Sphere?

A Dyson sphere is a megastructure that surrounds a star, and captures as much of its energy as possible, turning it into useful energy. It was first mentioned in the 1930s, in a sci-fi novel, which first described a structure encompassing a star. Then, in the 1960s, Freeman Dyson described a Dyson Sphere, but didn't talk about how to build it (F. Dyson's short paper). It actually comes in different flavors. They are:

- Dyson Sphere: A plain old sphere of matter surrounding the Sun. (**Fig. 1**). However, it's physically impossible because there is no material strong enough to resist the solar radiation as it is right now.

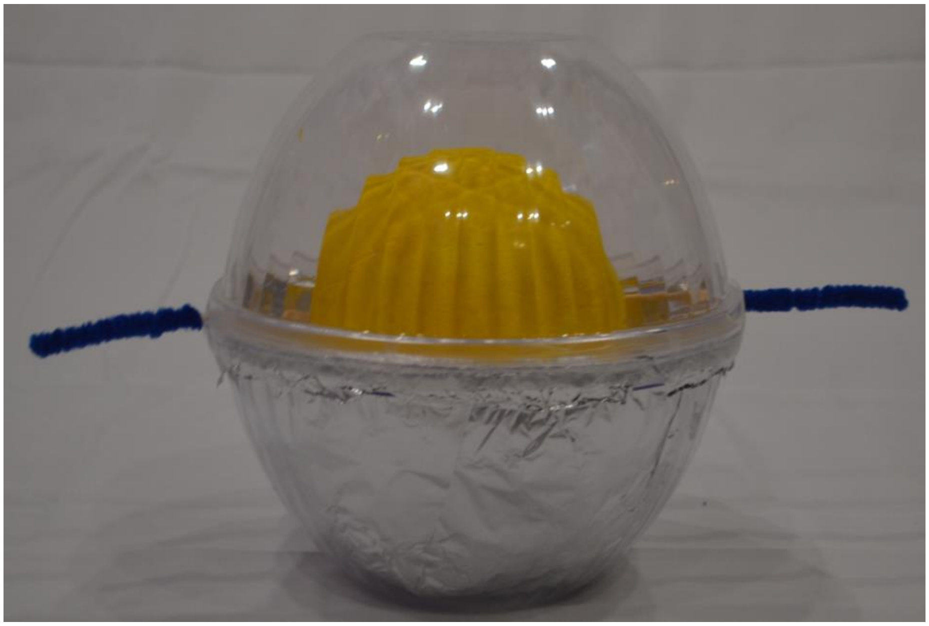

Fig. 1 Dyson Sphere home made model

- Dyson Shell: A uniform solid shell of matter (**Fig. 2**). It's also kind of impossible, for the same reasons as a Dyson sphere but additionally, it would be very vulnerable to impacts, and could crash into the Sun.

Fig. 2 Dyson Shell homemade model

- Dyson Belt and/or Dyson ring: A ring or multiple rings of independent energy-collecting satellites. A Dyson ring is a single ring of them (**Fig. 3**), and a Dyson belt is a set of rings that orbit at different distances (**Fig. 4**).

Fig. 3 Dyson Ring homemade model

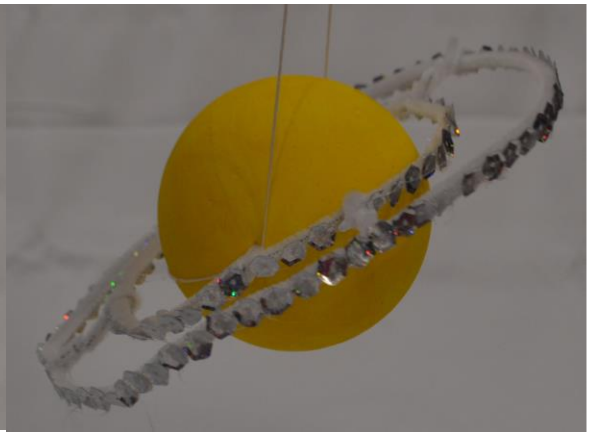

Fig. 4 Dyson Belt homemade model

- Dyson Swarm: A swarm of satellites that orbit the Sun and surround it. (Fig. 5).

Fig. 5 Dyson Swarm and Dyson Bubble homemade model

- Dyson Bubble: Like a Dyson Swarm, except the satellites don't orbit the Sun, but rather keep themselves stable (**Fig. 5**).

We believe that the most viable of all the types is probably the Dyson Swarm, since it seems to be easier to build, more durable, less vulnerable to impacts and more efficient. But even though it is believed to be easier than the rest, it will require an incredible amount of energy, and a lot of materials we don't have today as a type 0.726 civilization.

What would we need to build it?

If each satellite was 1 km^2, we'd need 30 quadrillion satellites to surround the Sun. We might leave tiny gaps to prevent freezing earth with too little Sunlight. But we need to consider the gravity in the swarm. We can make the satellites light enough that they are pushed by the solar radiation equally and opposite to gravity. This makes them float over the Sun and prevents them from smashing into it. If they're as light as possible, that would be a density of 2.744 kg/m^2, which is 2,744,000 kg for each panel, or 2,744 metric tons each. Since we need 30 quadrillion satellites, we'd need 2744 * $3x10^{16}$ that equals 82.32 quintillion metric tons of material.

How could we build it?

We'll divide the building process into three main categories. Materials, Design, and Energy.

Material

Where could we get the material?

We need a lot of material to build a Dyson sphere. To get the materials we'd most likely need to disassemble a whole planet. Of all the planets, Mercury is the best candidate, because it's close to the Sun, very metal-rich, has no atmosphere, and only one third of the earth's gravity, making it quite easy to launch things into space.

Unfortunately, mining on Mercury is not very easy since the dayside temperature is very high, reaching 430 degrees Celsius, along with unshielded ultraviolet and high energy radiation from the Sun, and the freezing nightside temperature of -180 degrees Celsius. It becomes obvious that building a Dyson sphere isn't easy. Mercury is too harsh. To achieve our purpose, we'll need to think of heat-resistant materials and thermal design, similar to the space probe MESSENGER.

Design

What could our design be like?

We need to keep in mind that we won't be able to go to the satellites and fix them if anything goes wrong with them. Because of that, we will need a design that has very long lifetimes and is inexpensive. The most viable design is most likely going to be huge mirrors that reflect light, similar to the mirrors on the James Webb. They'd be light, made of polished metal foil, bound to some supports. The mirrors will refocus Sunlight to central collecting stations potentially located at the moon, which will then beam the energy to earth potentially through hyper advanced microwave technology. The moon could be a space relay for the energy to reach earth. They will beam the energy using electromagnetic waves called microwaves. These collecting stations will turn photons from the Sun into useful energy.

The reason why we don't just put solar panels everywhere on earth to collect all energy from the Sun, is because the flux, which is the energy per unit area decreases during the journey to earth (Fig. 6). And then the earth's surface area also captures a small amount of the remaining energy.

And then from THAT energy, only 20% is turned into useful energy [10]. The rest is not useful for humanity.

With a Dyson Swarm, the flux decreases much less much less before reaching the mirrors, which reflect it to the moon, which has no atmosphere. Therefore, we will be capturing more of the energy, and sending it to earth, with much more of the Sun's energy being received (Fig. 7). And again, 20% of it is turned into useful energy.

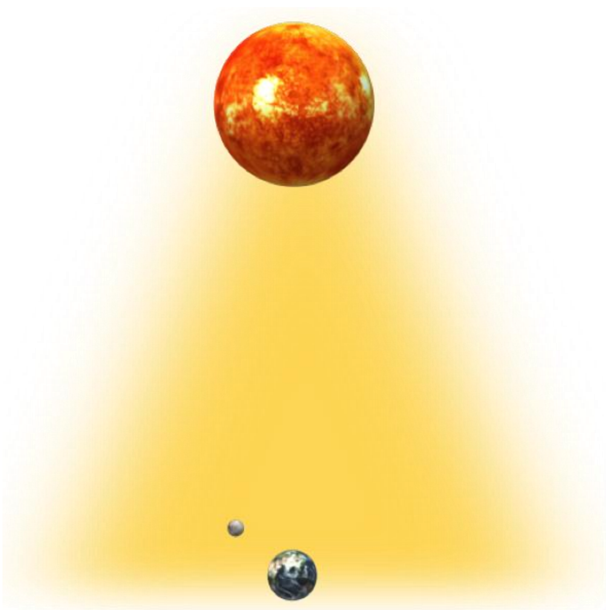

Fig. 6

Fig. 7

Energy

We'll need lots of energy to build a Dyson sphere, that you might as well almost need a Dyson Sphere to build one. We'd need to automate the most we can. Ideally, there could be a crew of people (or possibly artificial intelligence) that supervise all the machines doing the actual work. There are four pieces of technology needed. Solar collectors, miners, refiners, and launch equipment.

Solar Collectors

The solar collectors will collect the energy needed to do the work. Deploying 1 km^2 of solar collectors, either as mirrors or traditional solar panels, would be a good starting point to collect enough energy. The collectors will power the miners and refiners.

Miners

The objective of the miners is to strip mine the surface and look for the necessary materials. However, this leaves a question. WHAT are the necessary materials? To answer that, we need to know what the mirrors would be made of.

What materials could we use to make the mirrors?

Space mirrors, like the ones on James Webb are made of Beryllium, although we can instead look for magnesium on the surface, which can also do the trick. But what is Mercury's surface composition?

What is Mercury's surface composition?

Mercury is made of many elements, as revealed by the NASA space probe MESSENGER. The surface composition contains high proportions of Calcium (Ca), Oxygen (O), Potassium (K), Silicon (Si), and Sodium (Na). It also contains Thallium (Th), Uranium (U), Magnesium (Mg), Aluminum (Al), Sulfur (S), Titanium (Ti), Chromium (Cr), Manganese (Mn), Iron (Fe), Chlorine (Cl), and Carbon (C). The mantle is also made of some silicates. They are Silicon Dioxide (SiO_2), Titanium Dioxide (TiO_2), Aluminum Oxide (Al_2O_3), Iron Oxide (FeO), Magnesium Oxide (MgO), Calcium Oxide (CaO), Sodium Oxide (Na_2O), and Potassium Oxide (K_2O). The core is also made of Iron (Fe), Nickel (Ni), Carbon (C), Silicon (Si), and Sulfur (S). This means we can extract Aluminum (or Titanium), maybe carbon composite structures, and join silicon and oxygen to make silica or glass. We'll also be mining Magnesium to make the mirrors. The areas rich in magnesium were identified by the NASA probe MESSENGER, and are shown in **Fig. 8**

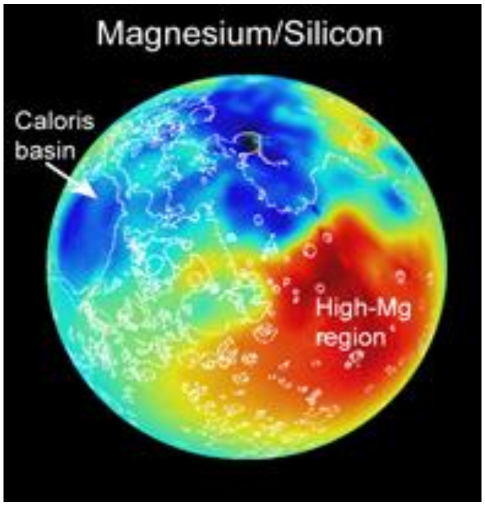

Fig. 8 Map of magnesium/silicon present on Mercury (credit)

This is the surface composition of Mercury, along with the ratios between two elements.

Elements in yellow will be needed to build a Dyson Sphere.

Element (ratio)	**XRS**	**GRS**	**NS**
K (ppm, average)		1288 ± 234	
K (ppm, range)		240–2500	
Th (ppm)		0.155 ± 0.054	
U (ppb)		90 ± 20	
K/Th		8000 ± 3200	
Mg/Si	0.436 (0.106)		
Al/Si	0.268 (0.048)	$0.29^{+0.05}_{-0.13}$	
S/Si	0.076 (0.019)	0.092 ± 0.015	
Ca/Si	0.165 (0.030)	0.24 ± 0.05	
Ti/Si	0.012 ± 0.001		
Cr/Si	0.006 ± 0.001		
Mn/Si	0.004 ± 0.001		
Fe/Si	0.053 (0.013)	0.077 ± 0.013	
Na/Si		0.12 ± 0.01	
Na/Si		0.107 ± 0.008	
Na/Si		0.198 ± 0.030	
Cl/Si		0.0057 ± 0.0010	
Cl/Si		0.0049 ± 0.001	
Cl/Si		0.014 ± 0.005	
O/Si		1.2 ± 0.1	
C		1.4 ± 0.9	~1–4

Refiners

We would need to build the refiners to extract the valuable elements from the Mercurian samples that the miners mined. The refiners will extract aluminum/titanium, Silica, and Magnesium. The refiners will also be in charge of fabricating the elements into the satellites.

Launch Equipment

For the launch we have to find a way of launching the satellites into space that is inexpensive and easy to reuse. The rockets we know today will not work for this. They're too expensive and difficult to reuse. A possibility to consider is using an electromagnetic track that launches the satellites at high velocity, taking advantage of Mercury's low gravity. Mercury's surface gravity is 3.7 m/s^2, which is divided by earth's gravitational acceleration, 9.8 m/s^2. That's about 37.7551020408163% or approximately 1/3rd of the earth's gravity, which multiplying that by the earth's escape velocity, 11.2 km/s, gives us the escape velocity of 4.228571428571429 km/s for Mercury. So, in conclusion, we'll only need to launch the satellites at 4.22 km/s.

But we also need to find an advantageous location on Mercury to launch the satellites. Mercury is tidally locked and therefore, we might choose the dayside to launch satellites, which never goes into nighttime and will give us the shortest path for launching.

The easier way to launch the satellites into space will be if they are packed tight for launch, unfolding while in space, similar to how the James Webb space telescope is expected to. An appealing shape could be a hexagon. And so, after they enter orbit, we can take advantage of exponential growth, using the energy the satellites already deployed will produce, to build more infrastructure on Mercury, and launch new satellites faster and faster. One panel will contribute to the construction of the next one. Then those two contribute to the construction of the next two, then continuing the pattern with powers of two.

After doubling 55 times, the Sun would be completely surrounded by 36 quadrillion satellites, 6 quadrillion more satellites than the 30 quadrillion that we need. And this process is surprisingly fast, compared to what you might think. If one panel takes 1 month to build, we could have finished the entire Dyson swarm in 55 months, or less than 5 years.

How much energy captured will be useful?

Solar panels today are typically 15-20% efficient, but the efficiency of solar cells can reach up to 42%. The Sun produces 1.068×10^{20} kWh per second. The panels will capture all of the Sun's energy, but since they are 20% efficient, at max efficiency, we could capture 1.068×10^{20} kWh*0.2, which is 2.137×10^{19} kWh of useful energy. But since solar cells can reach 42%, we might be able to get 1.068×10^{20} kWh*0.42 which is 4.487×10^{19} kWh.

The way the solar panels work is that the panels are made of silicon cells, a metal frame, a glass casing surrounded by a special film, and wiring. The panels are grouped into arrays to maximize efficiency and are placed on roofs. The solar cells absorb the Sunlight during the day.

In each solar cell is a thin semiconductor wafer made from two layers of silicon. One layer is negatively charged, and the other positively charged, forming an electric field. When light energy from the Sun strikes a solar cell, it energizes the cell and causes electrons to loosen from atoms within the semiconductor wafer. Those loose electrons are set into motion by the electric field surrounding the wafer, and this motion creates an electrical current.

After that there are now solar panels working efficiently to transform Sunlight into electricity, but the electricity generated is called direct current (or DC) electricity, which is not the type of electricity that powers most homes, which is alternating current (or AC) electricity. Fortunately, DC electricity can easily be changed into AC electricity by a gadget called an inverter. In modern solar systems, these inverters can be configured as one inverter for the entire system or as individual microinverters attached behind the panels.

Once the solar energy has been converted from DC to AC electricity, it runs through your electrical panel and is distributed within the home to power your appliances. It works exactly the same way as the electrical power generated through the grid by your electric utility company, so nothing within the home needs to change.

When would we be able to build this?

In order to keep progressing as a civilization, we would probably have to build this in the next few thousand years according to Michio Kaku (source). But will we have the technology by then? Well, today, we are starting to develop some of the technology. However, the governments are too focused on political issues that have no use in humanity's progress. We need leaders that are interested in harvesting the progress that we all dream of. Big Progress requires big ideas. Now, in one thousand years, we will most likely already be multiplanetary, living on mars and the moon.

We'd be able to control the weather, as a Type I civilization would do. For our population, there aren't many projections that go beyond 2100. But by the year 3000, the earth's population might be 12,951,226,948 people according to a video by Imperial Statistics about the world population by the top 25 countries from 1000 AD to 3000 AD. There will also of course be people on mars and the moon, although there will be obviously less than 13 billion people on either of these, since both of them are smaller than earth.

But a Dyson Sphere can also host living habitats, like what's called an O' Neil ladder state. Each O' Neil ladder state could have a trillion people, and another rotating habitat, called a McKendree Ladder state could have 100 trillion to 1 quadrillion. To surround the Sun that could use millions of O' Neil ladder states, or a few thousand McKendree ladder states. That would fit a few quintillion people in one Dyson Sphere. Of course, we'd need to be able to make all the oxygen, carbon and nitrogen so that our quintillion people can breathe, plant trees, and therefore control climate change in their habitat. We only need to make sure there is enough space and food for all of us. Using a spherical planet is mostly a waste of material and therefore, the O' neil and McKendree ladder states would be a good alternative.

Why is this an important leap?

This structure is really important, since it would explain how we can do many more amazing things, like colonizing planets and becoming multiplanetary, creating huge living spaces, like the ringworld, turning planets into another blue home, or even moving to other stars and becoming interstellar.

A Type II civilization would thrive after building such a structure. We can even dodge a danger, like supernovae, by moving the Sun using a stellar engine, which steers a star through the galaxy. And in fact, let's return to our good friend Kardashev and calculate the type of civilization. If we return to the power output of the civilization, $2.137\text{x}10^{19}$ kWh of energy we can plug that into the equation and determine that we'll become a Type 1.988603927556644 civilization, and if we can get 4.487×10^{19} kWh, that will be a Type 2.020825857030036 civilization. A mathematical proof that a Dyson Sphere can get us to a Type II civilization! Many astronomers think that because it is so important for any lifeform to expand beyond its home planet, there might be Dyson spheres out there in the universe. The big worry is: are there enough materials on Mercury?

Thankfully, even Mercury is so massive that it has 3 times more material than we need, that is, we'd need to disassemble 1/3rd of Mercury. That does require a lot of energy, but we can find a way to produce the energy using the Sun. We even got so close to detecting a Dyson Sphere around a star called KIC 8462852 (Tabby's star), when it was going through unusual fluctuations in brightness. Sadly, we later confirmed it was most likely just a set of asteroids and/or comets. It's not 100% that WE'LL ever build a Dyson Sphere, but it is still very much possible, and if we do it, we'll have complete control of the solar system.

Conclusion

Building a Dyson Sphere is hard, but worth it. It requires energy, but it's possible, It's costly, but useful, it requires big ideas, but it's a big progress, and most of all, it requires the mindset of mankind, but is the "yes" to long-term survival. If we do it, we'll embark on a Type II civilization that will thrive forever. Freeman Dyson would be proud.

Video Material

Here is a video of me explaining the Kardashev scale, what a Dyson Sphere is, and how to build it, and other details https://youtu.be/s1IBPX60JVU

Acknowledgements

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