The Dyson Sphere: A THEORETICAL APPLICATION APPLIED TO HYPOTHESES: THERMODYNAMICS & PHYSICAL LAW OF HEAT TRANSFER IN THE IMPERFECT VACUUM OF OUTER SPACE.

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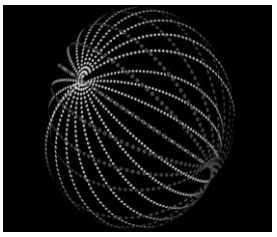

The Dyson Sphere

A THEORETICAL APPLICATION APPLIED TO HYPOTHESES: THERMODYNAMICS & PHYSICAL LAW OF HEAT TRANSFER IN THE IMPERFECT VACUUM OF OUTER SPACE.

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Introduction

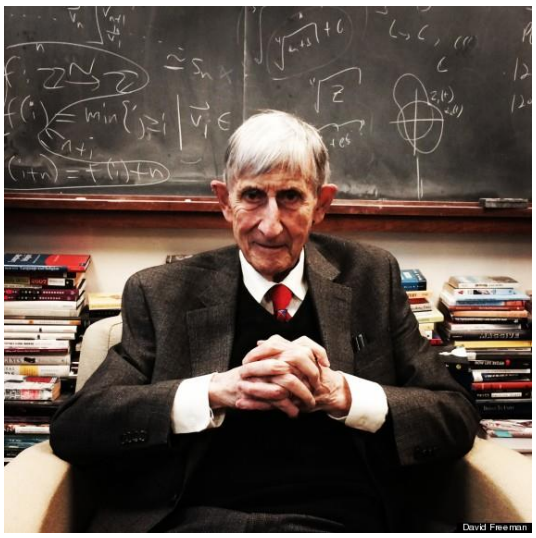
In 1960 the renowned physicist Dr Freeman Dyson proposed the idea that some civilisations outside of our solar system may not wish to be contacted (Dyson and Carrigan, 2009), then in 1964 the Russian physicist and astronomer Dr Nikolai Kardashev proposed and created the hypothesis and thought experiment that perhaps civilisations within the universe may fall into certain categories, categories of which that can be judged on their level of advancement according to their utilisation and collection of available energy. This treatise created by Dr Kardashev was published in the Russian science journal *Astronomicheskii Zhurnal* (Kardashev, 1962) and proposed that there are three states at which a civilisation may reach its pinnacle state of energy utilisation.

It makes perfectly logical sense that a sufficiently advanced enough civilisation will find a way to harness and utilise as much available energy afforded to them, and then transfer this energy into usable *work*.

This body of work aims to look at the propositions made in the hypothesis of Dr Kardashev and the scales of civilisation he devised, as well as subsequent additions by other scientists and examine their hypotheses and stipulations regarding the known thermodynamic laws whilst observing and applying the currently known thermodynamic laws in regards to the proposed levels in Kardashev's scale and the proposed megastructure known as *The Dyson Sphere.*

Regarding the hypotheses made by Dr Kardashev and the fact that this has not progressed from the level of hypothesis to theory, I validate this work to being a valid academic submission as much as a thought experiment by using the IRAS Space Telescope experiments made by SETI during the 1980's (Carrigan, 2014) and using the known laws of thermodynamics in the proposed scales stipulated in the subsequent hypotheses.

Dr Freeman Dyson



(Freeman, 2014)

The Kardashev Scale

As the laws that govern the universe and dimension we live in appear to be universal, it seems that the observed Earth bound laws should also apply when dealing with hypothetical ideas such as extra-terrestrial megastructures, perhaps it would be even more profound due to the large masses involved and the technical proficiency that would be required to make such objects exist.

In 1964 Nikolai Kardashev proposed the idea of three stages of advancement for a civilisation and based the level of technological advancement achieved according to the civilisations collective ability for energy containment and utilisation. As per Kardashev, the first two parameters of his scale are a prerequisite for any activity of a species to become a "super-civilisation".

In this way, Dr Kardashev suggested that the following classifications of civilizations can be by classified per the proposed civilisations energy usage, the propositions from zero to three proposed in *Astronomicheskii Zhurnal* are the following stipulations (neglecting state zero).

Type I Civilisation:

A level "near" contemporary terrestrial civilisation with an energy capability equivalent to the solar insolation on Earth, between $1 * 10^{16}\ Watts$ and $1 * 10^{17}\ Watts$.

Type II Civilisation:

A civilisation capable of utilising and channelling the entire radiation output of its star. The energy utilisation would then be comparable to the luminosity of our Sun, about $4 * 10^{26}\ Watts$ …*The Dyson Sphere*.

Type III Civilisation:

A civilisation with access to the power comparable to the luminosity of the entire Milky Way galaxy, in the region of $4 * 10^{37}\ Watts$.

(Lemarchand, 1992)

Further Additions to the Kardashev Scale

In order to give a rounded direction to this work and how the laws of thermodynamics relate to the proposition of megastructures, I feel it is also important to state the following additions to Kardashev's initial three postulations as they also conflict with the current working model and laws of thermodynamics.
Furthermore, the further the additions from the initial scale proposed in Kardashev's three postulations drift further from the realms of the laws of known thermodynamics and may involve other technologies, creations and advancements that somehow increase the efficiency made possible in the universal laws of heat transfer, in my closing arguments attempted advancements in technology currently in development will be referenced that may lean some credit to the possibilities of higher energy working civilisations.

Type IV Civilisation:

If the Kardashev scale is a measurement of the utilisation of power available to a civilisation, then the type four civilisation would be beings that may harness the power of the entire universe we inhabit, in our known universe the power available is believed to be in the magnitude of a few orders of $1 * 10^{45}$ Watts.

The quantum physicist and science advocate Dr Michio Kaku discussed that a type IV Civilisation may exist in his book *Parallel Worlds* (Kaku, 2006) via utilising dark matter, but this has no bearing within the boundaries I shall approach and the topic of the thermodynamic systems of a *Dyson Sphere* and its utilisation of total energy capture as proposed by the hypothesis.

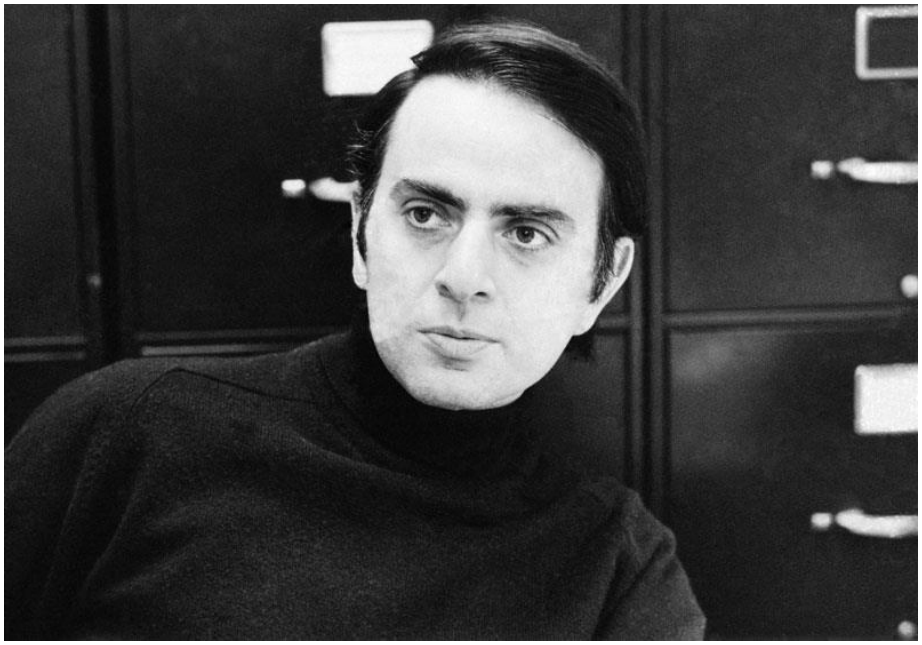
Dr Michio Kaku

(Kaku, 2015)

There exists other models and additions to the Kardashev scale that do not solely involve the utilisation of energy, but information as a level of judging a civilisations ability such as that proposed by Dr Carl Sagan in *Carl Sagan's Cosmic Connection* (Sagan, 2000), but as this work relates to heat transfer in thermodynamics and specifically the *Dyson Sphere*, this addition is arbitrary in approaching the scope of the proposition, though his measurement of intelligence for a civilisation and the energy required to store said information leads to a quite accurate result of Dr Kardashev's model in that the Earth's civilisation is at 0.723 on Kardashev's scale.

Perhaps Dr Sagan's result shows a correlation between energy and intelligence?

Dr Carl Sagan



(Associated Press, 1973)

What is the Temperature of Space?

Regarding the fact that space is part of space/time and they are inseparable, such a question asked as per this chapters titular is as useful as asking:

"How warm is quarter past three?"

So, I refer to "space" in the following further examples as a term for outer space *in vacuo* and extra-planetary events unless stated otherwise.

To investigate the thermal energy transfer possibilities of a *Dyson Sphere*, one must first ask:

"What is the temperature of the medium the heat is moving through?"

Following the zeroth law of thermodynamics, for a systems temperature to be measured, a thermometer works by being in physical contact with the matter being observed and then taking the temperature of the connected matter with either mercury in the system, thermal sensors or thermistors should electronic readings wish to be taken.

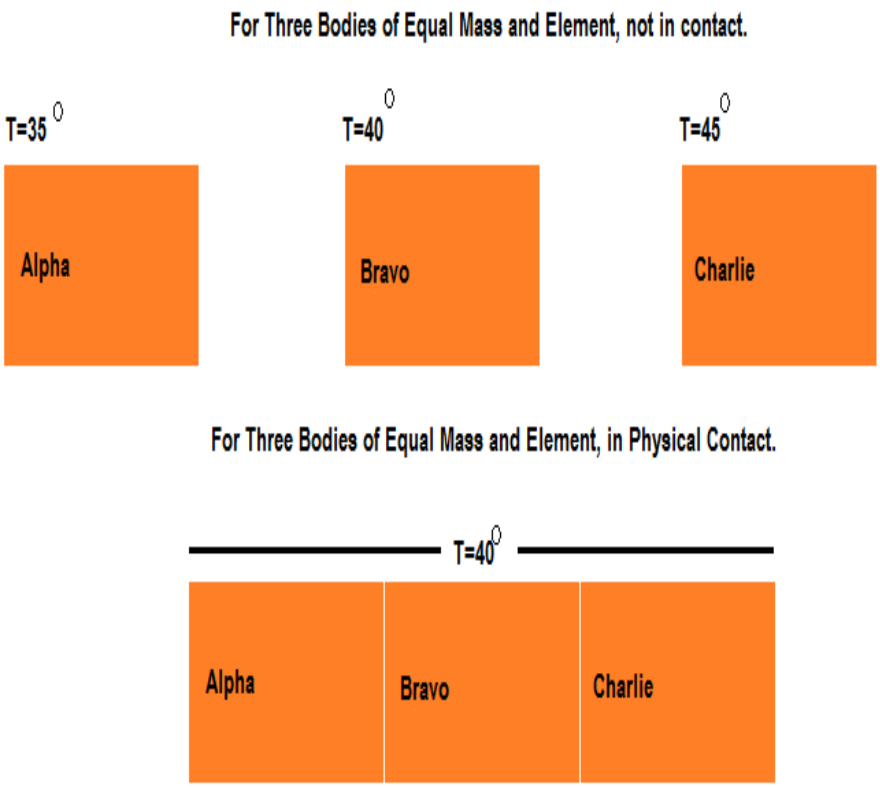
Essentially when using a thermometer or temperature sensor, the reading you obtain is the temperature of the thermometer/sensor itself when it has reached thermal equilibrium within an enclosed system, so to measure the temperature of "space" is quite nonsensical in its question (disregarding the occasional radiating particle collision).

As the zeroth law of thermodynamics states, heat can be transferred via a system of bodies that are within physical contact. I shall describe *The Zeroth Law* here in a basic model.

If you have a system of three bodies of mass, for this example we will call them "*Object Alpha"*, "*Object Bravo"* and "*Object Charlie"* for references sake, the following scenario shall describe the zeroth law in effect.

If "*Object Alpha"* is in physical contact with "*Object Bravo"*, but not in physical contact with "*Object Charlie"*, if "*Object Charlie"* is also in physical contact with "*Object Bravo"*, then eventually the system shall reach thermal equilibrium (the same temperature) as the thermal energy (heat) transverses via the atomic structure and molecules of each object and thermally excites the connecting molecules and thus transfers energy in the system, this zeroth law of thermodynamics is very easily observed on Earth but in the imperfect vacuum of open space, there is less solid matter combined in contact than here on Earth (in regard to the vastness of the known universe).

This diagram represents heat transfer via the zeroth law of thermodynamics to help visualise the zeroth law in motion:



Radiant Energy

Radiant energy is defined as the energy of gravitational radiation and electromagnetic sources, electromagnetic radiation is classified by its wavelength, it's frequency can also be taken and calculated using the speed of light in vacuo of:

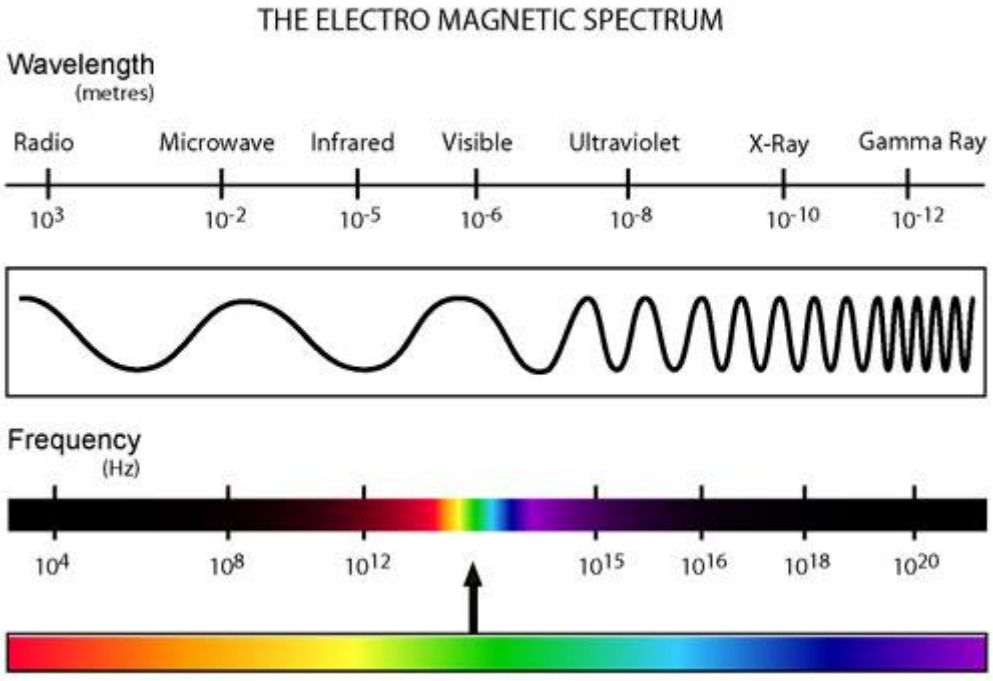
$$c = 3 * 10^8 m/s$$

This is then plugged into the wavelength and frequency formula of:

$$c = f\lambda$$

Where λ = wavelength in metres and f is equal to frequency in Hz.

Electromagnetic wave radiating behaviour is defined by its wavelength, where lower frequencies have longer wavelengths and the higher frequencies have higher tier wavelengths such as gamma rays and x-rays. This means that the rate of the wave is a lot more frequent the higher you go amongst the visible spectrum and beyond.



(Electromagnetic Spectrum, 2013)

Electromagnetic waves within the visible spectrum contain quanta (a measurement) of photons that can excite particles and molecules electronically that cause fluctuations within the bonding of the atoms, molecules or particles. Electromagnetic radiation in the infrared and upward wavelengths cause molecular vibration, and, in turn from this molecular vibration a radiant heat is emitted from the molecules themselves.

So, when calculating temperatures in outer space, this question of heat movement can be answered by looking at the Sun's rays, they carry a radiant energy from the star in all directions (some of the rays are visible light, and some is of the non-visible spectrum). If the solar rays collide with matter, the matter absorbs part of the energy from the ray and heats the matters temperature upwards.

Earth, Luna and other such celestial bodies are heated. A transparent object such as glass would be heated less than an object with a lower colour frequency (such as black). Refractive indices of the materials may also be a factor of heating in the medium through radiant energy. A white object will reflect much of the radiant energy of the ray and thus not be heated as much as a darker object, the darker objects will absorb much more of the available heat energy.

The space that is between the planets outside of our Sun is very nearly empty. It contains a very diluted or rarefied gas that absorbs essentially none of the star’s radiant energy and is thus quite transparent, though the vacuum of space is itself not a perfect vacuum, there exists matter within the “void”.

Per Dennis L. Mammana in *Interstellar Space* he states "On the average, this haze contains about one atom per cubic centimetre." (Mammana, 2000).

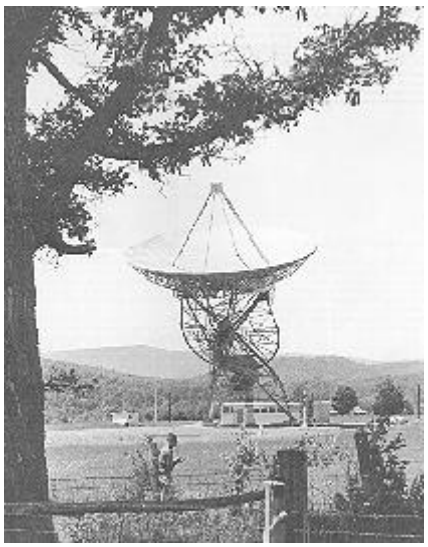
From this calculation it is possible to gauge the potentials of heat transfer using the kinetic theory of gases, though as these particles are sparse in their proximity, it is logical to assume the closer the measurement of matter taken closer toward the sun, this should suggest that more particles are within the cubic metre, and as such the temperature radiated from exited molecules will be greater due to the larger quantities available.

The Dyson Sphere

A Dyson Sphere is a hypothesised extra-terrestrial megastructure that was used to solve the question of “What if alien civilisations do not wish to communicate?”.

Two curious Professors Cocconi and Morrison at Cornell pondered this question and came to the conclusion that radio signals in space should be searched for (Morrison and Cocconi, 1959), and ultimately this lead to the creation of SETI (Search for Extra-terrestrial Intelligence) when Frank Drake at The Green Bank Observation began his search in a project he named *Project Ozma,* in Drakes words he wrote, "It is named for the queen of the imaginary land of Oz, a place very far away, difficult to reach, and populated by exotic beings" (Drake, 1959).

The Howard Tatel telescope

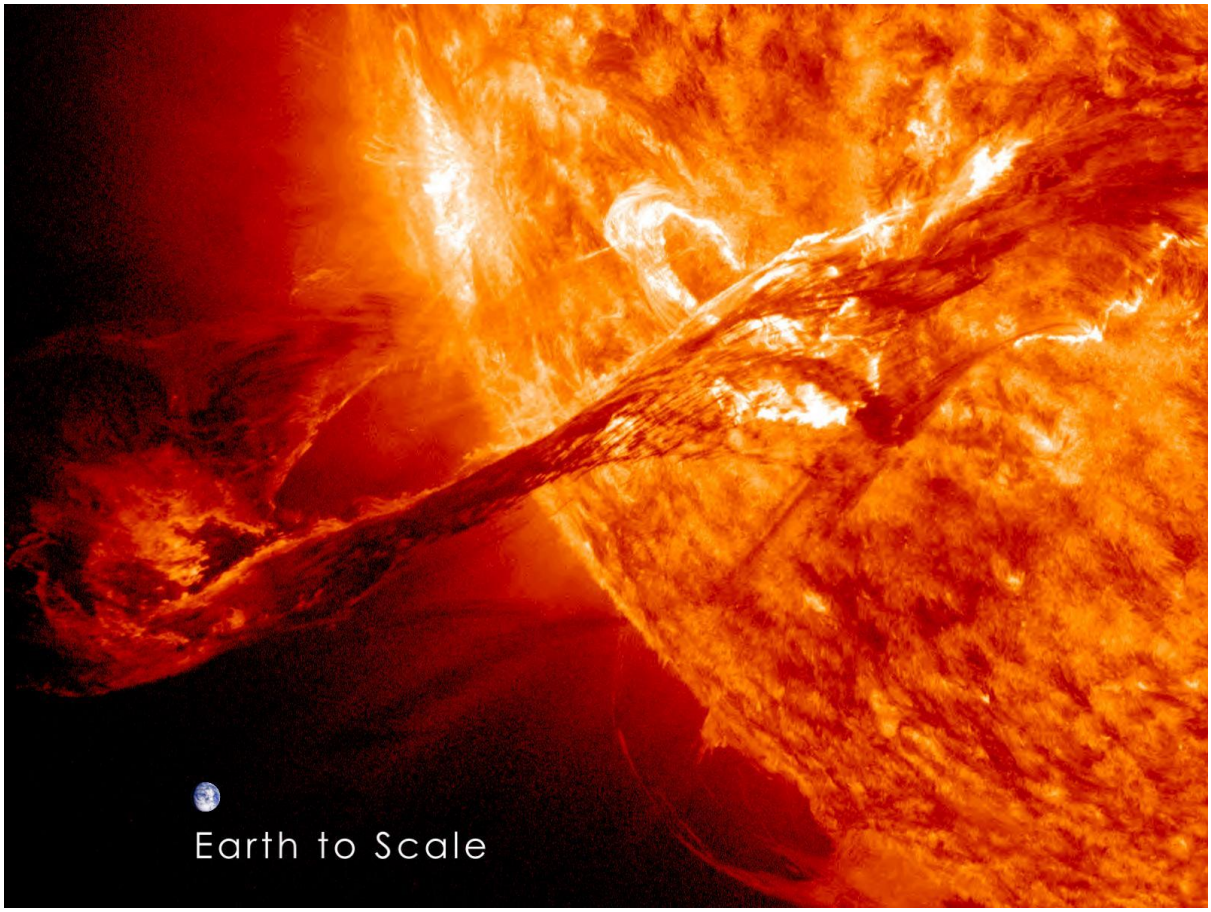


(National Radio Astronomy Observatory, 1959)

In 1960 Professor Freeman Dyson proposed that it was indeed possible, and if such a civilisation were to exist it would be one of extraordinary capability when it came to the use and harnessing of energy for *work*, also to contain radio emissions it must be an enclosed system for total isolation, but due to the laws of thermodynamics, the civilisation that created the hypothesised *Dyson Sphere* and using such large flows of energy, whether or not it wished to communicate with other species it would have no choice via the laws of thermodynamics but to dispose of waste heat, this heat must then be radiated into space in the form of infra-red radiation. Dyson then proposed that uncommunicative civilizations could possibly be detected from sources of infra-red radiation emitted from the gravitational wells surrounding the mass of a star if they used a flow of energy large enough when compared with natural infra-red sources in the same part of the sky.

Per Kardashev's Scale, a civilisation that can create a *Dyson Sphere* and harnessing all of a star's energy would be categorised as a Type 2 civilisation.

Sun to Earth Scale



(NASA, 2013)

Due to the tremendous scale of a living stars size and the energy output in its various states of nuclear fusion, the civilisation that created such a megastructure to encompass an entire star would need to use a dense material that is capable of supporting itself under the massive gravitational pull of the host star, as the amount of photons striking the inner surface of the sphere would also be contained, this will almost certainly require an outlet for such pressures and energy in order for the structure to maintain its integrity without collapsing.

There is also the factor of volumetric expansion per the material used in the spheres construction material, the formula:

$$\Delta V = \beta \Delta T$$

explains that per the materials coefficient of linear expansion (multiplied by 3 for volumetric expansion), when used in combination with the zeroth law of thermodynamics that there will be waste heat that leaves the structure itself, as it will eventually reach thermal equilibrium as this is what the universe strives for.

I will hypothetically speculate on the possibilities of heat transfer via the sphere, and apply the laws of thermodynamics to the hypotheses of Kardashev and propose that there may be other viable methods of detection, *should* such an object exist.

If there *is* a sealed *Dyson Sphere* with an area exact of our stars (taking the exact measurement and not leaving space in-between for a more direct measurement), the area of the star would be 6,078,747,774,547 km^2 and by using Dennis L. Mammana's pre-stated measurement that there is one atom per cm^3 in "empty" space, if we convert that to metres we reach:

$$1\ m^3 = 1{,}000{,}000\ cm^3$$

Now taking the area of an atom, using the model used mainly in particle and quantum physics of 1×10^{-12} m, or one trillionth of a metre (Mark Winter, 2014), and multiplying it by 1,000,000 cm^3 we have an area of space filled with $1x10^{-6}$ m of atoms per cubic metre, when this is multiplied by the area of the outside wall of the hypothetical *Dyson Sphere* it would mean that there are potentially…

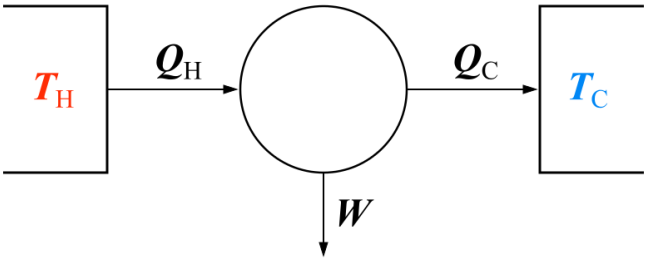
$$(1 * 10^{-6}) * (6{,}078{,}747{,}774{,}547) * (1000) = 6.07 * 10^{9}m$$

of the individual atoms combined area colliding with the outside sphere at any stage.

As heat flows from hot to cold, a cold reservoir must be maintained, if this were to be within a 100% sealed *Dyson Sphere*, eventually the gaseous content and energy within the sphere will reach thermal equilibrium, everything will be at the same temperature and no useful *work* could be performed, certainly not refrigeration.

If you think of a heat engine (or even electrical as there will be frictional heat) like water flowing down the side of a hill, energy flows from a higher temperature to the lower temperature. It is this flow that an engine converts into useable *work*.

The Carnot Engine



(Carnot Engine, 2014)

It does not matter how high the top of the hill is (using the hill height as an analogy to the temperature of the high temperature reservoir), you will only get the amount of work from the elevation of the reservoir (temperature of the sink reservoir (cold)) that the heat flows into.

As per the heat exchange of radiated energy via rays in space, if the star is completely covered by the structure, the radiated energy transferred within the sphere itself would be completely contained, the photosphere is the shell of a star in from which light is radiated, assuming that the *Dyson Sphere* itself may be just outside the perimeter of a star's photosphere (the deepest region of a luminous object).

The physicist and natural philosopher Ludwig Boltzmann along with the theoretical physicist Max Planck theorised that every physical body of mass will spontaneously and continuously emit electromagnetic radiation, this is known as *Black Body Radiation*, and as such Boltzmann theorised that the sun emits in the region of 5700 K at the photosphere (Ces.fau.edu, 2016), this is a very high temperature and as such, should a *Dyson Sphere* contain said energy, supporting life without a vent once it reached thermal equilibrium seems unfitting when the models for life are based on "The Goldilocks Zone", or "Not too hot, not too cold." (NASA, 2003).

Conclusion

Certainly, with the gravitational attraction of a dense star, using Newtons Universal Law of Gravitation and including the hypothetical mass of the materials composing the megastructure, it is plausible that the energy transferred from the medium may radiate into colliding particles on the outer walls of such a megastructure, once again following the zeroth law of thermodynamics and possibly emitting light via the heat exchange of the exited particle.

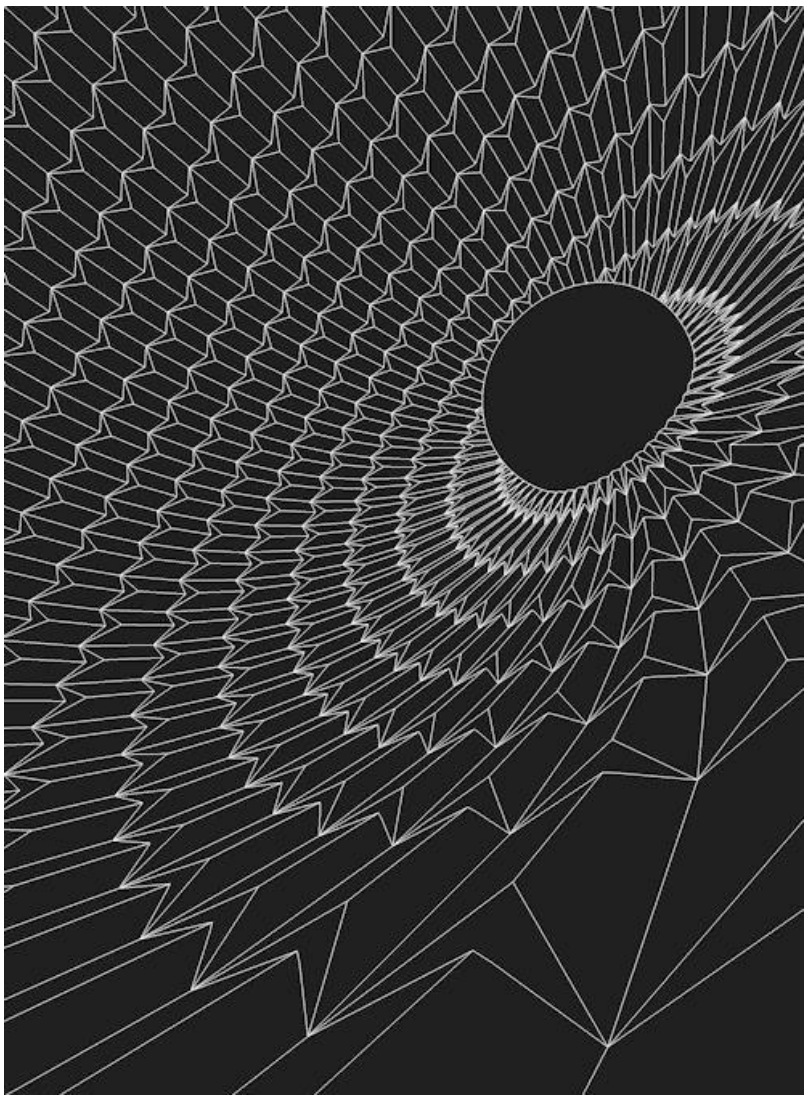
This conclusion leads me to believe that the second law of thermodynamics will come into play should a *Dyson Sphere* exist, as well as the Carnot Cycle system for any work to be performed within the sphere itself, it must have an exhaust.

For a heat engine to work it must have a cold reservoir for the working system to dump its heat, it is this postulate from which the second law of thermodynamics was formed.

Possible methods of energy collection and harnessing from within the sphere itself could take many forms, it could be from that of a photovoltaic system (solar panels), using electromagnetic radiation from exited particles in a type of collision engine or something a lot more advanced due to the very poor efficiency of photovoltaic systems.

A method already used by humans in outer space missions is the thermoelectric generator (TEG), using the imperfect vacuum of space to improve the Seebeck efficiency higher than the current 5-8% we can achieve at the moment would be a viable method, though the proposed *Thermal Diode* may also increase efficiency levels as a way of stalling the hot to cold transfer process observed in thermodynamics, such a device is currently being worked on at M.I.T in their nanotechnology department (Martínez-Pérez, Fornieri and Giazotto, 2017), until our efficiency levels can increase or further developments progress greatly, we may remain at 0.73 on Kardashev's Scale for some time (Sicoe, 2014).

Artist's Conception: Dyson Sphere



(Anon, 2015)

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