The Fermi-Hart Paradox – Perhaps Nothing is Out There (Right Now)

Essentially – where are they?

- Granted, it took 4.5 billion years from the development of life to develop intelligence (we think).
- After the development of spaceflight (from out own experience), it would take on average 1,000 light-years to travel to the nearest star with simple chemical rockets.
- Assuming stars are about 1 light-year apart, it would take "only" 100 million years to colonize the whole galaxy.
- If we suppose we are not so special (the conditions that led to our development, our evolution, etc.), then there should be evidence of extraterrestrial engineering on a VAST scale, throughout the history of the galaxy.
  - Think of stars being blown up, etc.
  - The "mining" of the interstellar medium.
  - Dyson spheres – the construction of shells around stars leads to the observations of characteristic (?) infrared radiation.
  - How come Jupiter isn't mined out? How come the sun hasn't been blown up? How come we are still here?
- People have proposed different ways to "resolve" this issue.
  - Perhaps intermittent "restart" events (neutron-star collisions – much worse than supernovae; the periodic "activation" of galactic cores) rendering the galaxy uninhabitable, and starting life all over.

- An interstellar “zoo” in which we reside, that is (somehow) kept free of poachers.
- A “great filter” – an insurmountable difficulty for intelligent life to develop.
- Intelligent killing machines that destroy any emergent intelligences?
- Sending things through space is too hard..
- Extremely different forms (passing the “information singularity”).

The problem with these and similar models is that it is believed by many that it would be too difficult to hide the evidence of these, some of them require perfect enforcement, or that there is no obvious purpose, or that they somehow kill ALL intelligent life before it can propagate through the galaxy.

- After all, it takes only ONE civilization to pass all these possible hurdles, and then within a galactic year, the galaxy is entirely colonized.

Thus, my opinion, is that given the “easiness” with which life can propagate through space after it has reached a certain threshold, and its quickness relative to the age of the galaxy (100 million years, tops, compared to 13 billion years for the galaxy), I don’t think there is anything out there.

Many of the arguments used to describe the properties of super-advanced civilizations can be used to describe our future – after all, a civilization that is supposedly 3 billion years old nowadays is simply “us” (or our direct descendants) some 3 billion years from now.

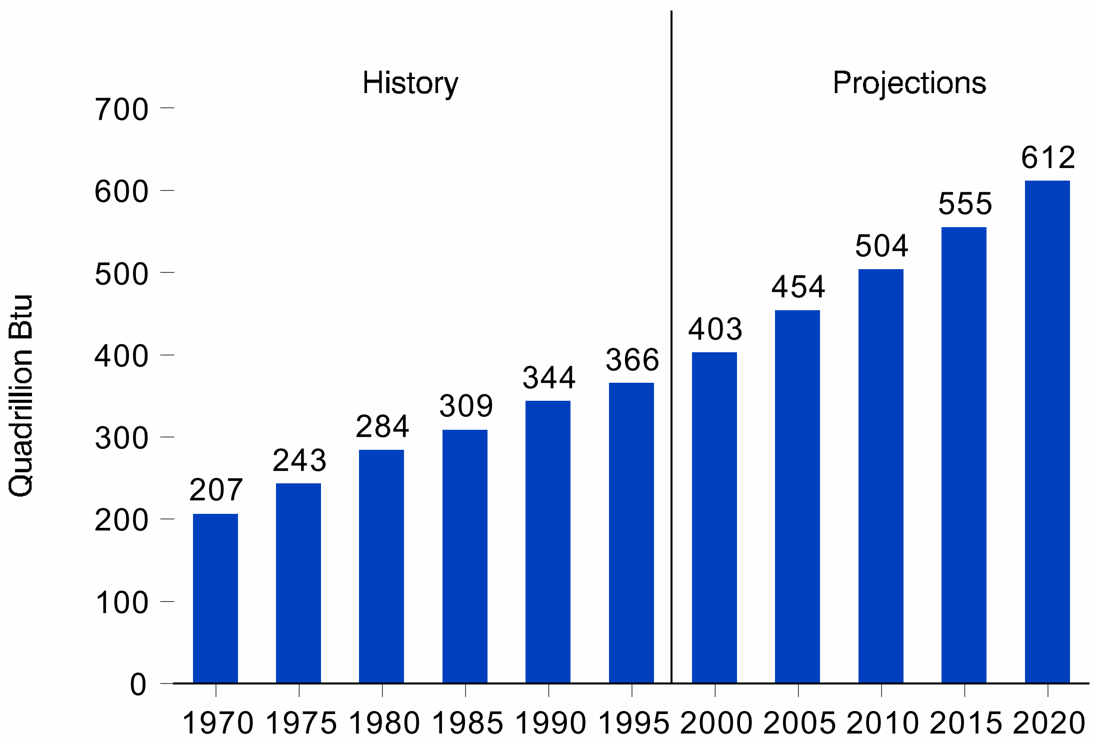
Current Energy Usage and the Trend Towards Space

The three laws of thermodynamics

- Energy cannot be created from nothing.
- Any kind of cyclical process (such as those that describe life processes) will result in some waste heat.
- The universe is headed towards increasing disorder.

However, first focus on our current civilization.

- As of 2001, we use up approximately 1.35×10^{13} Watts of power[1].



Shown is the trend in yearly energy usage from 1970 to the predicted usage in 2020.[2] One Btu (British thermal unit) = 1055 Joules. To

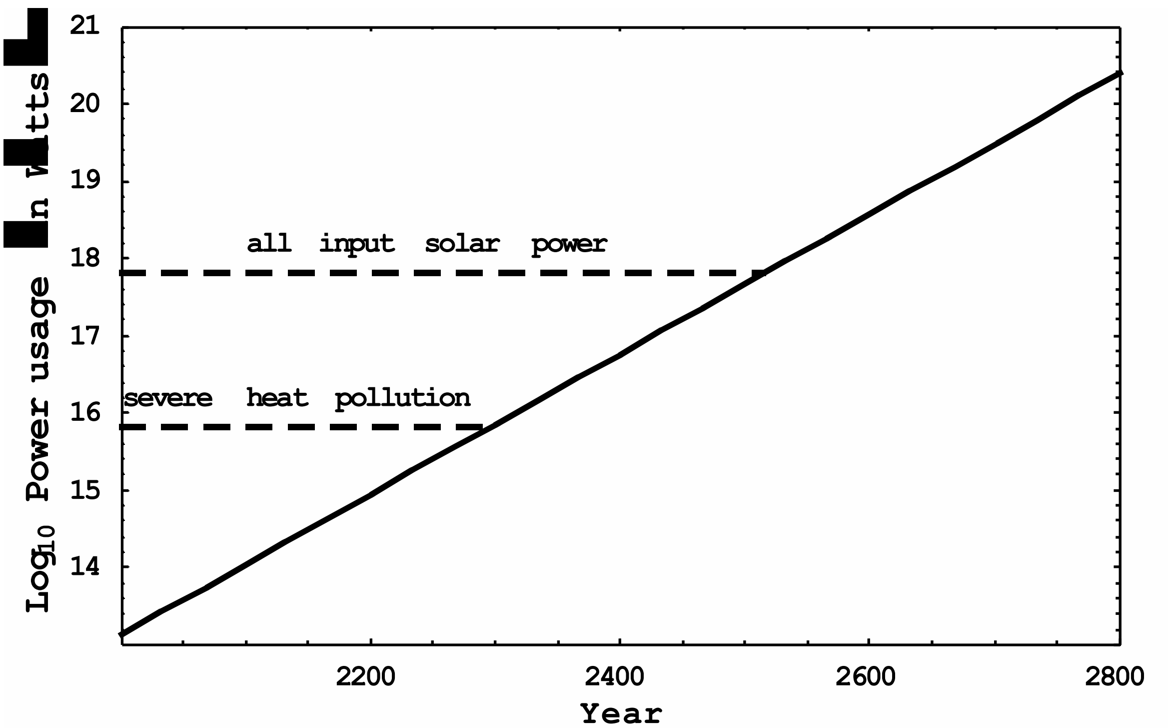
[1] Energy Information Administration (EIA), *International Energy Annual 2001*, DOE/EIA-0219(2001) (Washington, DC, February 2003), web site www.eia.doe.gov/iea/

[2] EIA, International Energy Outlook 1999.

calculate power in Watts, divide energy in Joules by the number of seconds in a year.

The total power received from sunlight on Earth = 6.4×10^{17} W, so power usage from industrial activity ~2.1×10^{-5} of total power striking Earth.

Assuming power usage rises at a constant rate of 2.1 percent per year (like compound interest) from 2000, then the rate of power usage as a function of time is shown below.



Currently, energy usage involves the creation of lots of CO_2, a greenhouse gas – it is the gas, rather than industrial activity, that leads to global warming.

Even if we created energy without "burning" (i.e., processes that create carbon dioxide), there is still the problem of **heat pollution** – any process will create waste heat.

One may expect that an input of 1% of total incoming solar power will result in severe climate changes.

- "ice ages" involved changes in thermal energy output of a few percent, at most.

- Runaway greenhouse may occur if we put in more than 5-10% of the total energy the earth receives.
- *Therefore, we might conservatively expect that our energy consumption will go up by a factor **of only a few hundred** only within the **next few centuries**.*

Thus, to get more energy usage without wrecking Earth's ecosystem through heat pollution, we would expect to move our civilization into space.

For the sake of curiosity, assuming our power consumption increases by 2.1% per year, we will start using ALL the sun's energy by AD 3500!

The Movement into Space

As our spacegoing civilization matures and its energy needs grow, they will move out into space-going habitats

- Very large surface area to volume ratio – easy to mine or exploit.
- Negligible energy requirements in transportation – easy to get there.

Each person requires at least 1 ton of supporting biomatter in order to live – supposing people live in an ecology of plants and animals. This is calculated from the fact that each rung of the food chain has a total mass of 10% (on average) of the rung below it – each person ~ 100 kg, so 1 ton each.

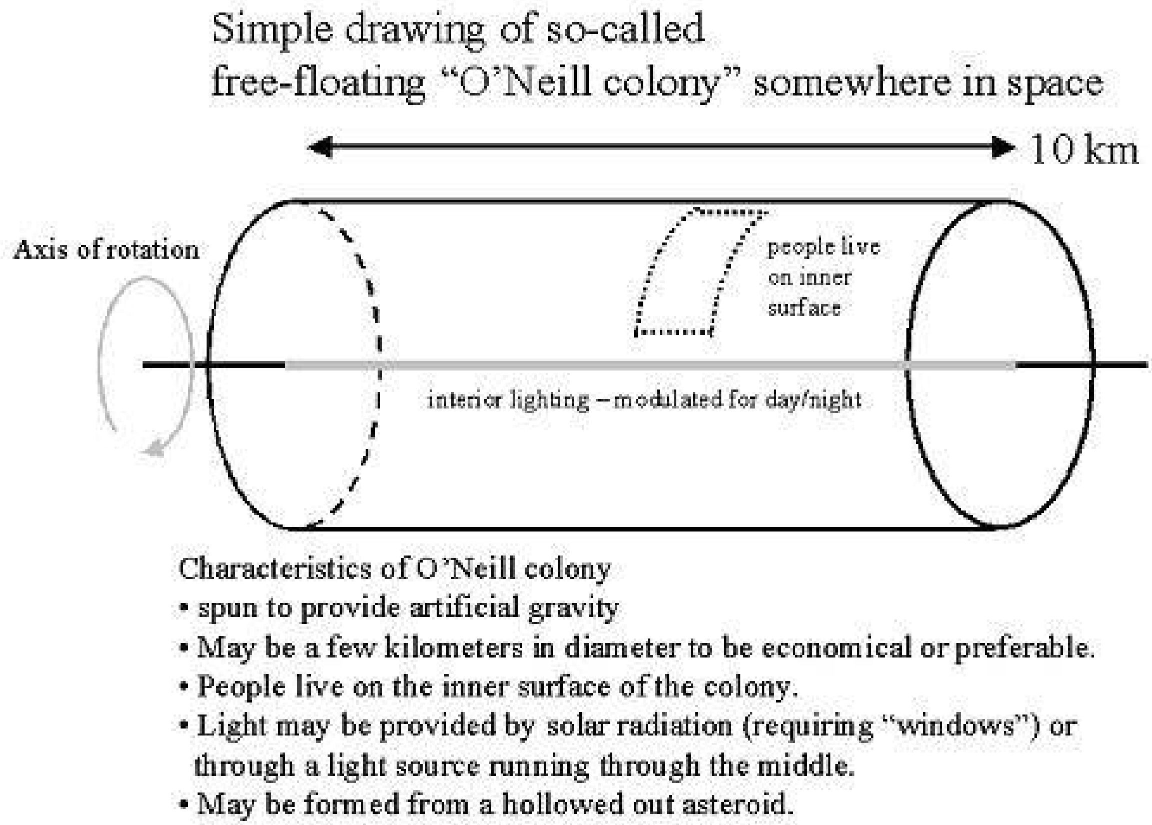
This assumption is made on the basis that people remain vegetarians in space – hence the smallest environmental impact.

A typical carbonaceous asteroid 10 km across – can sustain 10^{12} people.

The most lucrative resource could be comets. The total cometary mass of the halo bound to the sun is approximately 1/1000 the mass of Earth – can sustain 10^{18} people.

A typical habitat may be a hollowed out asteroid/comet, spun for gravity, lit either by the sun or through the central axis. People live on the inner surface of this asteroid.

A "Representative" Type of Space Colony



May have human civilization living in these space habitats – since they provide a much nicer volume (or mass) ratio to area ratio than planets. Of course, there several big problems:

1. Radiation hazards – Earth's magnetic field and atmosphere get rid of nearly all the harmful radiation from sun and space.
2. Collision hazards – things zip around in space about 20 times faster than bullets in our neighborhood. Easy to destroy something that's too big.

Kardashev Classification of Civilizations

Assuming that we or our descendants do not become extinct or summer from some irreversible catastrophe, we could expect that our power consumption would continue to grow over millions and billions of years.

Nikolai Kardashev defined three major evolutionary levels for civilizations[3].

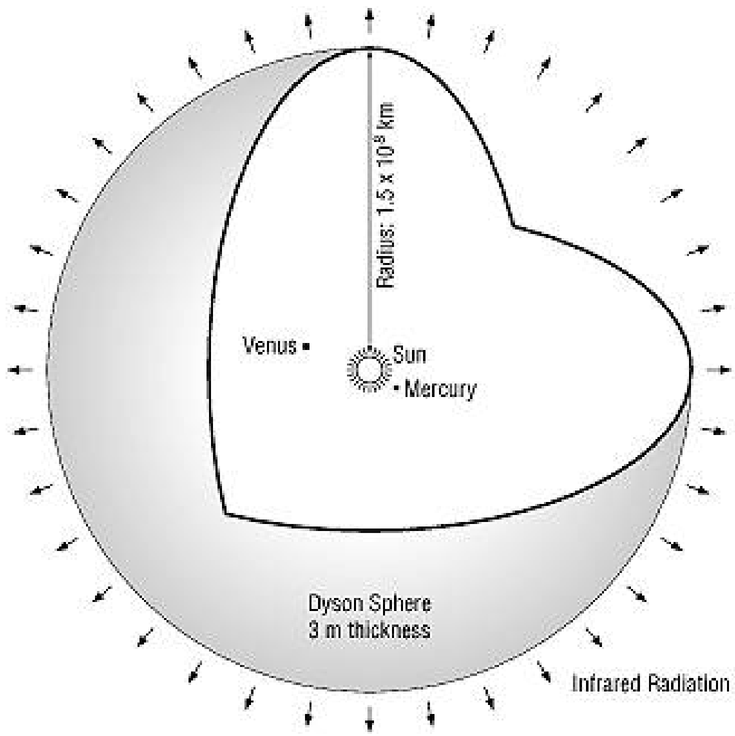
1. Type I – use all the power AND matter available to them on their home planet (or something comparable).
2. Type II – use all power and matter from their star.
3. Type III – all power and matter within a galaxy.

Table 3. Kardashev Civilization Types

Civilization Level	Energy Resource Utilization	Available Power	Available Mass
		Watts	kg
KT-I	planet	$\sim 10^{12}$	$\sim 10^{24}$
KT-II	star	$\sim 10^{23}$-10^{29}	$\sim 10^{30}$
KT-III	galaxy	$\sim 10^{37}$-10^{38}	$\sim 10^{42}$

These are, of course, speculative upper limits on the power and matter usage of various Kardashev civilizations.

[3] Kardashev, N. S., "Transmission of Information by Extraterrestrial Civilizations," *Astronomicheskii Zhurn.*, **41**:282 (1964). [*Soviet Astronomy* **8**(2):217-220 (1964).]



The Dyson Sphere – A Possible (Generic) Structure for Advanced Civilizations?

This is a sphere of matter that encloses a star, thus allowing for the total collection of energy from the star by a sufficiently advanced civilization.

A Kardashev II civilization might have one or a few of these structures in use.

A Kardashev III civilization might have most of the stars in a galaxy covered in Dyson spheres, in order to collect this energy.

1. Type I – collection of large (planet-sized or larger) orbiting elements that would not completely cover the star.
2. Type II – rigid shell of very strong matter that completely encircles the star.

Freeman Dyson predicted that a very advanced civilization would construct such an object, which could then be detected in the infrared (if the civilizations construct their Dyson sphere at a habitable radius from their parent star).[4]

For example, a Dyson sphere with the radius of Earth's orbit around the sun would emit in the infrared.

The available area would be enormous.

[4] Dyson, F. J., Search for Artificial Stellar Sources of Infrared Radiation, Science, vol. 131, pp. 1667-1668, 1959

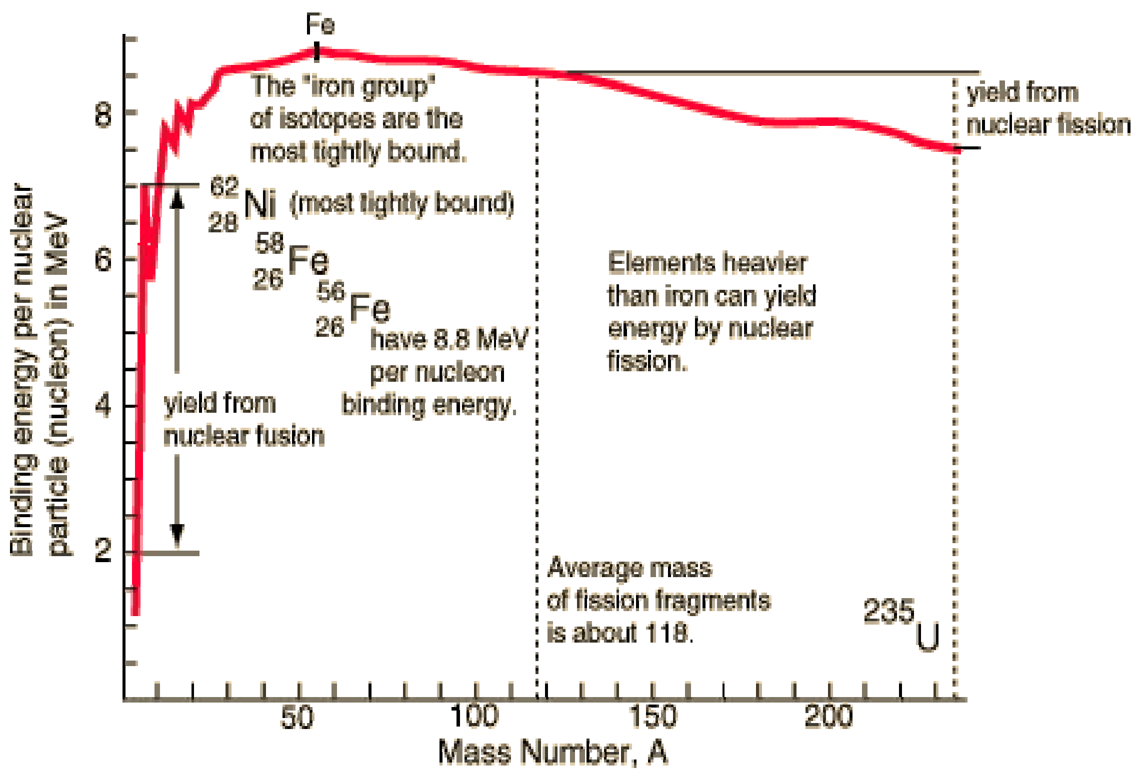
Other Types of Megastructures – New Places of Habitation

- **Hollow World**: An asteroid (or something similar) hollowed out and set rotating for artificial gravity, with landscaping on the inside. It may or may not be fitted with some form of propulsion system as well.
- **Orbital Tower**: In its simplest form, a very strong cable lowered from a synchronous satellite to the surface of the Earth (or another planet, of course). Usually a second cable extends outwards, with an asteroid or something similar on the end as a counterweight.
- **Topopolis**: A long, cylindrical object, rotating for gravity, and wrapped around a star in a spaghetti-like mass (or mess). The concept was invented by Pat Gunkel and mentioned by Larry Niven in "Bigger than Worlds."
- **Ringworld**: A circular ribbon, very strong, rotating for gravity, with a star at the centre. The idea was thought up by Larry Niven and first used in his novel _Ringworld_ (1970).
- **Alderson Disc**: A massive disc the size of a planetary system, with a small hole in the centre through which a star bobs up and down. Different intelligent species, with different temperature requirements, would live at various distances from the centre. Thought up by Dan Alderson and mentioned by Larry Niven in "Bigger than Worlds."

Other Methods of Energy Collection – Gravitational Collapse into Black Holes

A sufficiently advanced civilization (as we might become in the far future) would probably not be limited to the energy derived from simple stellar fusion alone. This is due to the following reasons:

1. Only 15% of hydrogen is burned within a typical solar-mass star.
2. Only 1% or less of the mass is converted into energy from the



fusion of hydrogen into iron, the most stable atomic nucleus.

One could liberate energy by collapsing the mass of an object (planet, star, galaxy) into a black hole. The total energy available can be that released from the collapse of the object into a black hole.

This usable energy is of order ~$0.15\ M\ c^2$ – much more efficient than fusion processes.

Thus, if a Kardashev III civilization derives its energy from gravitational collapse on the largest scales (say, galactic) – this is much larger than the energy available from normal stellar fusion.

Other Methods of Energy Collection – Fusion Husbandry

Method described by Criswell[5] that describes in detail how one can stretch out the life of a star and in essence get more energy from the star than from nuclear fusion.

A much easier way is to use energetics arguments.

1. Consider the total energy locked up gravitationally within the sun. This energy $E \sim GM^2/R$.
2. Now consider the TOTAL energy available from fusing all the elements in the sun into iron-56, which has a binding energy of 8.8 MeV per nucleon.
    a. Lightest hydrogen nuclei have a binding energy of 0 MeV per nucleon.
    b. The mass of a nucleon is approximately 980 MeV.
    c. Therefore, the maximum efficiency of a fusion process is to turn 8.8/980 = 0.00898 = 0.898% of the matter into energy!

So one can think of the following – it is economically feasible (in terms of pure energetics argument) to simply "blow up" a star and then simply fuse all its lighter elements into iron!

Of course, why have stars in the first place? Mine the interstellar gas before it can be put into stellar or other concentrated form!

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[5] Criswell, D. R., "Solar System Industrialization: Implications for Interstellar Migrations", pp 50-87 in *Interstellar Migration and the Human Experience*, Ben R. Finney & Eric M. Jones (Eds.), University of California Press, Berkeley, CA (1985).