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Rejuvenating the Sun and Avoiding Other Global Catastrophes

Springer

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This book is dedicated to Georgette
my past, present, and future.

About the Author

Dr. Martin Beech is an associate professor of astronomy and head of the Astronomy Department at Campion College, The University of Regina in Canada. His main research interests during the past decade have focused on the smaller objects within the Solar System (comets, asteroids, and meteoroids), but concomitant to this he has continued to perform research related to the structure and evolution of stars (the area of his doctoral studies). The material in this book was partly based on a series of research papers Dr. Beech has had published in scientific journals, and the topic was the focus of an article written for the May 2006 issue of *Astronomy Now* magazine.

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Introduction

This book is about an audacious idea: *asteroengineering*—literally, the physical engineering of a star, especially the star we call our Sun. It is an idea on the grandest of scales. Part science fiction, part science fact, asteroengineering is a response to a very definite and a very real problem, a problem that our distant descendants will one day have to face. It is also a universal problem that will be experienced – at some stage or other – by every extraterrestrial civilization that has or will exist. Indeed, the problem to be addressed resides within the parent stars of each and every life-supporting planetary system within our galaxy. In short, stars puff up to become luminous red giants as they age, and by doing this they vaporize those planets previously situated in the habitability zone where life can otherwise thrive. As their parent star ages and approaches the red giant phase, a civilization has two options open to it: stay at home, or pack up and leave. The latter option would require the hapless civilization to cocoon itself within giant spaceships and then set itself adrift in the uncharted depths of space. If a civilization chooses to stay put, however, then all life will end—unless, that is, something is done about the demise of its parent star.

The idea of star engineering was possibly first discussed in the mid-1980s in the book *Atoms of Silence: An Exploration of Cosmic Evolution* by Hubert Reeves (MIT Press, 1984). The blatant defiance of the idea was inspiring. That we might engineer the Sun – the hub of the solar system and steadfast provider of warmth for life on Earth – now that's an ambitious goal! It is a brazen and challenging notion, and one that sets the mind both searching and reeling. This book provides a preliminary examination of the solar rejuvenation options that may be realized and put into practice by our descendants in the deep future.

It is often said that science fiction is just pre-science fact. There are few, if any, science fiction stories about engineering stars to save a planetary system, but this is essentially the aim of asteroengineering. If nothing is done about the future evolution of our Sun, then it will destroy all life on Earth. This fiery destruction of Earth won't happen within our lifetime, however, and we are still many hundreds of millions of years away from potential destruction. Indeed, our distant descendants will have many long years of preparation time before even the first steps towards solar rejuvenation must be taken. Some of our galactic companions – assuming that they exist – will not, however, be as lucky as us. They may, in the here and now, be involved in the very process of altering their parent stars. As we shall argue in Chapters 1 and 6, asteroengineering may, in fact, be in common practice throughout the Milky Way galaxy (and other galaxies), and if so, this can be offered as a potential solution to the famous paradox, posed by physicist Enrico Fermi, which asks why are there no alien life forms in our solar system at the present time. Our suggested answer is that they are not here – that is, in the solar system – because they have had no reason to leave their home worlds. Indeed, it is our contention that advanced galactic civilizations will most likely choose to rejuvenate their parent stars into long-lived, non-giant forming states, than adopt a galactic colonization program.

Before our descendants have to worry about the effects of an aging and more luminous Sun, there are a multitude of terrestrial and astronomical disasters that they will have to guard themselves against first. Not just earthquakes, landslides, tornadoes, and tsunamis; our descendants will have to contend with comet and asteroid impacts, the explosion of nearby supernovae, and the close passages of wayward stars. All of these problems, however, just like the increase in size of the aging Sun, are potentially fixable by strategic planning and, in some cases, direct intervention. Asteroengineering is one of the direct intervention cases. We cannot possibly perform the required engineering at the present time—nor indeed, do we need to. But we can determine what must be done in principle, and that is half the battle. In the meantime, by learning how to tame and nullify the dangers posed to life on Earth by the heavens around us, humanity can begin to acquire the engineering skills that will eventually be needed to save the entire planet and all the life that resides on, in, and around it from the raging gigantism of an aging Sun.

Although you will find technical arguments and a good number of equations written in this book it is hoped and intended that the material presented is accessible to the non-specialist. The mathematics presented is no more advanced than that of a first-year university-level science course, and no detailed knowledge of physics is assumed. The general reader, though, need not worry about the mathematical and technical details too much; if you can't follow the equations then skip to the conclusions, where all should be made clear in words. Chapter 3 is by far the most difficult chapter with respect to its weight of mathematics and physics, but please don't be put off; have a go at trying to follow the arguments. Stars are indeed wonderful objects, whether described in the flowing lyrics of iambic pentameter or precisely described in an intricate web of mathematical detail.

Comments on Units and Notation

Astronomers are notoriously bad for their inconsistent use of physical units. Although we will ostensibly use the *SI* units of meters, kilograms, and seconds, there are times when other (i.e., non-*SI*) units are more conveniently adopted. Distances, for example, will typically be expressed in either astronomical units (AU) or in parsecs (pc), and occasionally as light-years (ly). Accordingly:

$$1 \text{ AU} = 1.496 \text{ x } 10^{11} \text{ m}$$

$$1\text{pc} = 206,265 \text{ AU} = 3.261 \text{ ly}$$

We will also use solar units (designated by the symbol $\odot$) where mass, size and energy output per unit time (luminosity) are expressed according to the measured quantities:

$$1 \ M_{\odot} = 1.9891 \text{ x } 10^{30} \text{ kg}$$

$$1 \ R_{\odot} = 6.96265 \text{ x } 10^{7} \text{ m}$$

$$1 \ L_{\odot} = 3.85 \text{ x } 10^{26} \text{ Watts.}$$

Temperatures will be expressed in Kelvins (K), where zero Kelvins (the convention is to say Kevins rather than degrees Kelvin) corresponds to the absolute zero point temperature. In the more commonly used Centigrade (°C) scale, absolute zero falls at $-273\,°C$. Among the mathematical symbols that you will commonly see: '$\sim$,' meaning to order of magnitude, and '$\approx$,' meaning approximately equal to. The symbols '<' and '>' are used to indicate the 'less than' and 'greater than' inequalities. In this manner, for example, $a > b$ means quantity 'a' is greater in magnitude than quantity 'b.'

1. A Universal Problem

Los Alamos Laboratories, New Mexico, 1945. It is lunchtime. Our gaze is directed towards a quiet corner of the otherwise busy refectory hall. A cluster of crop-haired physicists are seated around a large circular table. In twos and threes they huddle together in deep conversation. Snippets of their discourse drift into range. The discussion topics vary wildly: the weather, the ending of the war, a weekend hike, the solution to a particular integral equation, and the many other problems of their work. At some moment, no one is quite sure how or why it happened, one of the physicists, Enrico Fermi,[1] asks a question about extraterrestrial life. "What's that, Fermi?" a voice queries. "I was just thinking" repeated Fermi, "if the galaxy is full of extraterrestrial civilizations, then why are there no extraterrestrial beings on Earth—walking amongst us now?" "Don't be absurd Fermi," one of the group counters. "The galaxy is huge, and it would take longer than the age of the universe to colonize it—surely?"

"Are you so certain?" rejoins Fermi. "Let's do a back of the envelope calculation." There is a flurry of movement among our huddle of physicists. Fermi is famous for his order of magnitude calculations. "Let's assume that there are 10^{10} stars in our galaxy and that each star is on average, oh, say, 6 light years from its nearest neighbor," Fermi begins.[2] "Let's also assume that a spaceship has been developed that uses standard rocket power to propel it at speeds of, oh, let's say, 30 kilometers per second or one-ten-thousandth the speed of light.[3] So, travel time being distance divided by speed gives about 65,000 years to move from any one star to its next nearest companion. A long time by human standards for sure, but small fry compared to the age of the galaxy."

"Not an exactly profound result," someone mumbles, but a series of sharp glances and furrowed brows quells the interrupter.

"Now, as I see it," Fermi continues, ignoring the young upstart, "any reasonable colonization strategy would work like a fission process. One spaceship sets off from the home planet. When it reaches the next nearest star, two new spaceships are made, and these are sent off to the next two nearest stars, where the same doubling process continues. In this way, after 33 generations, every star in the galaxy should have been visited, since 2^{33} is about 10^{10}. So, as I see it, the total time required to visit every star in the galaxy should be of order 33 x 65,000, or 2 million years.[4] Two million years, why compared to the age of the Sun (which is something like 4.5 billion years old) this is a mere nothing. Even on a geological time scale, this is peanuts. A civilization that arose on a planet orbiting a star formed, say, a billion years before our Sun formed, could have easily colonized the entire galaxy. So, I ask again, where are they?"

A hush falls over his audience. Fermi has them in a bind. The younger physicists at the table are racking their brains in the hope of finding a loophole in the argument, hoping to score points with their companions. But no one can come up with a counter answer.

Dealing with Fermi

The lunchtime conversation as just described may never have actually happened, but it is loosely based upon a story recounted by planetary astronomer Carl Sagan. Real or not, however, it is an anecdote that has become encased in legend. Where and when Fermi first raised the topic is not so much the issue; the point is that Fermi's Paradox – as his question has become known – is a real problem that correspondingly requires a solution. A paradox, the dictionary indicates, is a statement that seems contradictory but contains an element of truth. In this manner Fermi's question does require a few points of qualification: it is only a paradox if extraterrestrial beings actually exist and are capable of, and of a mind to, explore and possibly attempt to colonize the galaxy. We shall argue later in this chapter and indeed throughout this book that Fermi's Paradox is answered, in fact, in terms of a no-need-to-colonize principle at work within the galaxy. Indeed, it is the viewpoint of this author that extraterrestrial civilizations will first engineer their parent stars into long-lived states, rather than—or, indeed, instead of—embarking on galactic colonization programs.

This being said, it seems worthwhile at this stage to spend a little time reviewing a few of the basic issues that arise from a consideration of Fermi's question in general.

As of the time of this writing, we do not know if any other life forms exist beyond Planet Earth—intelligent or otherwise. We do, however, have knowledge of one fact, and it is that there are currently no extraterrestrial intelligent beings making their presence clearly known to us on Earth. There is also no clear evidence for extraterrestrial beings ever having visited Earth in the past. This latter point, while true as it stands, should be tempered by recalling the well-known maxim: absence of evidence is not evidence of absence.

With these very limited facts to deal with, however, what might be said in answer to Fermi's question? Well, it is probably fair to say that a very impressive and a very diverse array of solutions have been offered over the years,[5] and they range from the extreme idea that there are absolutely no intelligent life forms, other than us, in the entire galaxy (and universe), to the idea that advanced civilizations are everywhere in the galaxy, but they are being very careful to avoid contact with us. There is also the idea that we happen to live in a very special epoch, which argues that the conditions necessary for a galaxy-colonizing civilization to emerge have not, as of yet, been satisfied. All such explanations are indeed possible solutions to Fermi's Paradox, although some of the arguments seem much more compelling than others.

Perhaps the most incredible and thought-provoking solution to the paradox is that no alien civilizations exist. As Stephen J. Gould once aptly put it, "Perhaps we are only an afterthought, a kind of cosmic accident, just one bauble on the Christmas tree of evolution."[6] The suggestion that we live in some special epoch is one in general to be wary of, no matter how compelling the argument might sound, since it runs against the basic tenant of the so-called Copernican Principle which, under admittedly different circumstances, many astronomers take to be an underlying axiom of their work. This principle, while sounding profound, is essentially a straightforward statement concerning special conditions. Just as Nicolaus Copernicus, in 1543, argued that Earth is not located at the center of the universe but is instead a planet in orbit around the Sun (which he believed was located at the center of the universe), the Copernican Principle in general says that we shouldn't assume that there is anything special about our existence or our location in the galaxy (and the universe). The point behind this principle is that the conditions that have resulted in our existence, while wholly remarkable and exceptionally special in their development, should operate elsewhere in the galaxy, and, consequently, there is no specific reason why other life forms shouldn't have come into existence on planets orbiting other stars within our galaxy (and in other galaxies).

There is a caveat to the Copernican Principle that is worth considering at this stage. Although it makes good scientific sense to avoid special-case explanations for any given observed phenomena, there are circumstances where special conditions must hold true for some specific phenomenon to be observable in the first place. This set of circumstances is often referred to as the Anthropic Principle.[7] Our existence as intelligent observers, for example, is special in that the convoluted set of events leading up to our emergence are not likely to have happened much earlier than they did. That is, the fact that we observe the Solar System to be 4.56 billion years old is in part a necessary reflection of the time required for us to appear. If the time for us to evolve on Earth is T_{us}, then we know $0 < T_{us} < T_{ms}$, where T_{ms} is the main-sequence lifetime of the Sun. We will define what is meant by the main-sequence lifetime, and why it is an upper time limit, more clearly in the next chapter. For the moment, suffice it to say that T_{ms} (Sun) $\approx 10^{10}$ years and that after this time the Sun's luminosity increases so much that Earth's oceans will boil away and all life will perish (see Chapters 3 and 4). The lower bound is clear enough in the sense that we did not evolve instantaneously. Indeed, our immediate ancestors, *homo sapien*, only emerged a few hundred thousand years ago. The so-called Weak Anthropic Principle explains why we observe $T_{us} < T_{ms}$ on the basis that if it wasn't so, then we wouldn't exist to make the observation. This is all rather trivial and self-evident, but the Anthropic Principle has also been used to argue that there are no extraterrestrial civilizations within our galaxy. In particular physicist Brandon Carter has presented the following argument: assuming that the average time T_{av} needed for an intelligent observer to appear on an Earth-like planet is typically much greater than the main-sequence lifetime of a Sun-like star (i.e., $T_{av} > T_{ms}$), but that the longer the evolutionary process proceeds the more likely it is that an intelligent observer is going to appear, then the appearance time T_{IN} for intelligent life should be $T_{IN} \approx T_{ms}$. In other words, intelligent observers are most likely going to appear at the exact same time that their parent star destroys their home planet. According to this line of reasoning the existence of extraterrestrial life forms is, in fact, highly unlikely. Carter suggests that our existence ($T_{us} < T_{ms} < T_{av}$) indicates that our presence is the result of a set of highly improbable evolutionary circumstances, not likely to be repeated anywhere else in the galaxy—ever! So, in some sense, we are special, albeit apparently improbable, after all.

The Drake Equation

When a physicist or mathematician writes down an equation, it is usually because it makes a very definite and precise statement about some particular set of circumstances. When we write down the Drake equation, however, which expresses the possible number of extraterrestrial civilizations N within our galaxy, we ultimately write down an equation that expresses our total ignorance. This statement is not made as an indictment of SETI pioneer Frank Drake,[8] who first discussed the equation now named after him, but a comment upon the fact that we simply don't know, even to order of magnitude, what actual numbers to place in the equation. (This is actually a counter example to Fermi's maxim discussed in Note 1.) There are at least seven terms that can be included in the Drake equation. The first term accounts for the formation rate of stars R^* in the mass range $\sim 0.5\ M_\odot$ to $\sim 1.3\ M_\odot$. We shall explain in Chapter 4 why this particular mass range is important. Having formed a star, there is then a term f_P that accounts for the fraction of those stars that actually have planets. A third term n_L then accounts for the number of planets that reside in the habitability zone (again, discussed in Chapter 4) where life might possibly exist. Three other fractional terms are then introduced: f_l, which accounts for those planets in the habitability zone that actually evolve life; f_I, the fraction of those life forms evolved that actually acquire an advanced 'intelligence,' and f_E, the fraction of those intelligent species that develop advanced technologies (such as radio transmitters producing signals that we might detect). A final term L is introduced to account for the lifetime of the civilization ended by natural or self-destruction. Drake's equation is the product of all these terms:

$$N = R^* f_P \, n_L \, f_L \, f_I \, f_E \, L \tag{1.1}$$

The simplicity of Equation (1.1) is, as mentioned above, deceptive. Surely, all we have to do now is plug in reasonable numbers for all of the terms, and we have our estimate for N. This would be true, of course, if we actually knew with any certainty what values to give for the various terms. The only term that astronomers can place a reasonably good value on is that for R^*, the star formation rate. The second astronomical term f_P is beginning to be constrained through the ever-increasing number of extrasolar planets being discovered. This latter constraint, however, is currently not especially helpful, since only gas and ice-giant Jupiter- to Neptune-like planets have been discovered with any certainty. As of this writing there is no clear idea how many of the presently detected planetary systems might contain terrestrial planets in a habitable zone.[9]

The available observations suggest that the star formation rate R^* has been decreasing ever since the formation of our galaxy (thought to be at least 13 billion years old). This has a number of interesting consequences. The metals (by which astronomers mean all the elements other than hydrogen and helium) that are vitally important for making terrestrial-like planets and ultimately allowing life to come about are all produced through fusion reactions (see Chapter 3) within the cores of massive stars and their end stages as supernovae. Most of the metals were produced, therefore, in a strong initial burst of star formation in the first few 100 million years of the galaxy forming. Consequently it is possible that at least some terrestrial planets may have formed very early on, allowing for the possibility that some extraterrestrial civilizations may have existed for billions of years prior to the formation of our Solar System. This is a thought-provoking possibility indeed, and one that makes the absence of extraterrestrials on Earth – here and now – all the more intriguing, as Fermi noted.

There is an interesting mix of terms in Equation (1.1), and these speak to its hidden complexity. Although the first three terms are essentially astronomical in nature, the terms f_L and f_I are determined according to biological constraints. The last two terms, f_E and L, depend upon the sociology of the intelligent life that has evolved. All we can say currently is that N is at least equal to one—i.e., philosophical issues aside, we exist. As to whether N, after a final tally is made (which begs the question, "how would we know?"), will still be equal to one or if it will be as large as, say, one million is completely unclear at the present time. Either way, even finding out that $N = 2$ would have profound effects upon human society.

"Hey! Over Here!"

A number of researchers have suggested that rather than the actual beings from an advanced extraterrestrial civilization exploring (or colonizing) the galaxy, they might send out self-replicating machines instead. These so-called von Neumann[10] machines are almost mythical beasts, endowed with superior engineering skills and an intelligence that far exceeds those of, say, a mere human being. With these machines we break with the traditional science fiction precedent and submit that just because such mechanisms can be dreamed of does not mean that they will ever be constructed (for galactic exploration, that is). If a civilization wants to actually communicate its existence or colonize the galaxy, then the use of self-replicating machines is an inherently difficult way of trying to do it. Highly advanced robotic and artificially intelligent systems will almost certainly be developed, and they will also probably be used to explore and help colonize a home planetary system, but only under circumstances where profits – commercial and social as well as scientific – can be extracted.

Having argued the above it should be noted, however, that there are actually good reasons for sending spacecraft into interstellar space. The difference between spacecraft and Von Neumann machines, however, are that the former are passive and relatively cheap, while the latter are invasive, arguably aggressive, and highly expensive. Neither object actually provides any return of information, but the simple, slow spacecraft method provides an exceptionally efficient means of providing a large amount of information, to any potential finder, in one simple dose. Indeed, when the speed at which any communication proceeds is not of overriding importance, Christopher Rose and Gregory Wright[11] argue that "inscribed matter" messages (Figure. 1.1) are far more

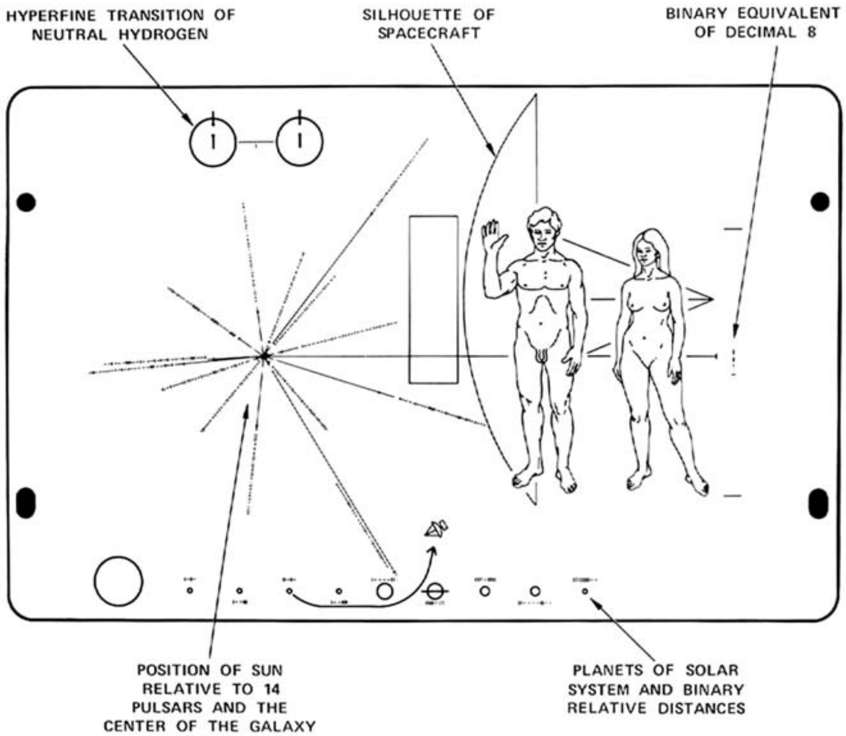

FIGURE 1.1. The plaque carried aboard the *Pioneer 10* and *11* spacecraft, both of which are now traveling into interstellar space. The plaque was designed by Frank Drake in collaboration with Carl and Linda Sagan and carries a wealth of 'inscribed' information. Two human figures are shown to scale by the spacecraft, and a diagram (to the lower right) shows which planet in our solar system the spacecraft came from. The set of 'star' lines towards the center right of the plaque indicate the position of our Sun with respect to nearby pulsars—each pulsar being identified by the binary value of its spin period. The two circles to the upper right of the plaque correspond to the atomic hydrogen molecule. The plaque is about 15cm x 23cm in size. While not actually aimed at any specific star system, *Pioneer 10* is currently heading in the direction of the constellation of Taurus. *Pioneer 11* is heading towards the constellation of Aquila. (Image courtesy of NASA)

cost-effective and efficient than any other mode of communication. Indeed, Rose and Wright comment that "Carefully searching our own planetary backyard may be as likely to reveal evidence of extraterrestrial civilizations as studying distant stars through telescopes."[12]

Caveat

One of the central tenets of the Fermi Paradox is that there is no evidence that extraterrestrial beings or, for that matter, autonomous extraterrestrial spacecraft (such as von Neumann machines) have ever visited our solar system. Although this last statement is true as it stands, there is, of course, the issue of recognition. How can we be sure that all the correct places have been searched when we don't actually know what it is we are looking for? Physicist Stephen Wolfram has recently argued, in fact, that recognizing extraterrestrial intelligence may even be impossible—at least, that is, with current search strategies.[12]

In spite of Wolfram's pessimism, various programs have been initiated in recent years to address the visitation issue. For example, Search for Extraterrestrial Artifacts (SETA) and Search for Extraterrestrial Visitation (SETV) programs have joined the multitude of Search for Extraterrestrial Intelligence (SETI) initiatives already in place. But to date no credible artifacts or visitation data have been found.

The ability to search for and potentially recognize extraterrestrial artifacts, such as spacecraft with inscribed, information-laden messages will, presumably, improve with time. As humans explore more of the Solar System in greater and greater detail, the chances of our finding any embedded artifacts will improve. Since longevity of survival is paramount for any inscribed message platform, Alexey Arkhipov of the Institute for Radio Astronomy in the Ukraine has suggested that the best first-place to look for such objects is our Moon.[13] The Moon, Arkhipov argues, provides shielding from a large fraction of the micro-meteoroid flux, a stable land mass (large impact cratering events aside) that has no atmospheric or biological factors to corrode or disturb equipment.

Arkhipov has also suggested that an "Astroinfect Principle" could be at play within our galaxy.[14] Specifically, Arkhipov notes that the winds associated with stars might eject space debris (literally, the small scraps of paint, fuel pellets, fecal matter, and exotic alloy flecks blasted by meteoroid impacts upon spacecraft in orbit around Earth) into interstellar space, and these alien scraps might just be detectable in, say, the lunar regolith. Ian Morrison writes that "For perhaps 7 billion years there have been enough heavy elements within the interstellar medium for planets to form and intelligent life to arise. If, in this period, one such civilization came into existence every 100,000 years, then 70,000 advanced civilizations might have come and gone. Could one of them have left any evidence of their existence?"[15] One can always argue about the numbers of possible extraterrestrial civilizations, but it is intriguing, and indeed sobering, to think that the past heights of advanced extraterrestrial intelligences within our galaxy might only be betrayed to us by the garbage that they left behind.

Types of Civilizations

Russian astrophysicist Nicolai Kardashev has proposed a three-tiered system of civilization classification. His scheme is based upon how much energy a specific civilization can draw upon.[16] Using Earth and the Sun as the basic measure of energy being consumed and energy potentially available, Kardashev suggests the following designations:

- **Type I** A civilization that can draw upon and consume $\sim 10^{17}$ joules of energy per second. Earth presently corresponds to just such a civilization.
- **Type II** A civilization capable of harnessing and using the entire energy output from its parent star. In the case of our Solar System, this would correspond to the consumption of about 4×10^{30} J/s worth of energy. A civilization capable of building a so-called Dyson sphere (discussed in more detail in the next chapter) about their parent star would correspond to a Type II civilization.