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Preface

Reflections on the Equation

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The Equation first appeared 51 years ago on a blackboard in a cozy residence hall at the new radio observatory at Green Bank, West Virginia. I had based it on the known history of our galaxy and the Earth, and the factors affecting the existence of intelligent, technology-using life on Earth and similar planets. It predicts the number of civilizations N like ours that we might detect with our instruments. The goal was to produce an estimate of the number of detectable civilizations, and thereby reveal the challenge to be faced by serious searchers. Twelve scientists from many disciplines were present, in response to a request from the National Academy of Scientists to convene a workshop on the possibilities of detecting extraterrestrial intelligent life, a potential discovery that had been made plausible by the recent development of high sensitivity radio telescopes. These, for the first time in history, could detect radio signals no stronger than we were then radiating, sent from the distance of nearby stars. One such telescope was only a few hundred feet away, and had actually been used in the first modern search about a year previously. The Equation served as a convenient and succinct agenda for the workshop – seven topics, seven sessions.

It has been gratifying that over the years the Equation has not been found erroneous – it is alive and well in in its original form. I do get suggestions quite frequently that some new factors should be added to the Equation. The most frequent one, drawn from our own history, has been that there should be a factor to account for uninformed, bad, decisions by politicians. Indeed, several times in the history of SETI in the US politicians have taken successful actions to eliminate governmental funding for SETI. Fortunately, private sources of funding have come forward to rescue the program. But maybe many other civilizations don't have that antidote for bad decisions. Actually, such episodes don't really change the value of N. They just reduce the number of worlds that have search activities. However, we don't need an additional factor for this – the activity can be subsumed into the value of the longevity of civilizations in a detectable state, L. The same is true of all the other suggestions I have received so far – they can all be subsumed into the existing seven factors.

The greatest advances in the Equation since its birth have certainly been the growing knowledge of the actual values of the factors in the Equation. When the Equation was first proposed, the actual values of the factors in the Equation were almost all just blanks. Only one factor, the rate of star formation in the Milky Way, was actually known fairly accurately from astronomical census studies. None of the rest had been established directly by any observational or empirical method. We had to use sometimes very indirect evidence, or what were ostentatiously called "subjective probabilities", or sometimes, less politely called, "informed guesses". An example was the fraction of the stars with planets. We had clear evidence for only one planetary system, ours. But attempts were made to establish the fraction of stars with planets from such things as the statistics, by mass, of the smaller stellar companions of binary stars, which suggested that there might be many undetected planetary mass companions. Other evidence was that the hottest, most massive stars, rotated very quickly, while stars like the sun rotated slowly, as though when they were formed angular momentum had been delivered to other bodies in the system. This was supported by theoretical studies that showed that all stars probably formed from a cloud with substantial angular momentum, and if a gaseous mass proceeded to contract under its own self-gravitation towards planetary size, the angular momentum would cause the mass to spin so rapidly that centrifugal force would stop the contraction before the star was formed. The answer to this was that the angular momentum was delivered to accompanying bodies in the form of orbital motion around the forming star.

The recent discoveries of large numbers of other planetary systems have been the most striking development related to the Equation. We owe these, of course, to the dedicated observers who search for miniscule changes in the observed wavelengths of stellar spectral lines, from which the existence, orbit, and mass of a companion, star or planet, can be deduced. This has been one of the most spectacular advances in the history of science, in my opinion. Thousands of other planetary systems have been found, and this is just a start. The prime result for the Equation of these discoveries is that a very large fraction of the stars have planetary systems, including the most common stars, the M Class stars, and even multiple star systems. There is still much to be discovered: many Earth mass and smaller planets, and planets with orbital periods of more than a few years. The data suggest that these exist in enormous numbers.

We have also learned that the so-called "habitable zone" of stars is much longer than thought even a few years ago. We find a very large liquid water ocean beneath the ice of Europa, a potential habit for life, but where surface temperatures far to low to support life. Similarly, the satellite Enceladus of Saturn has bodies of liquid water near the surface, again possible abodes of life. The large satellite Titan of Saturn has lakes of liquid hydrocarbons that might be abodes of life. It seems implausible to us that there might be technology-using life-forms in these places, but the power of evolution should not be underestimated in its ability to develop complex life forms in unlikely places. The average number of potential life bearing bodies per star is coming into focus.

Over the years, there have been a multitude of chemical experiments simulating processes on primitive planets, with the result that we know of a large number of chemical pathways to the chemical evolution of biologically relevant molecules. Only a few cosmically abundant elements are required. No unusual circumstances are required to produce these precursors to life. This suggests strongly that the development of life will be very common wherever conditions are right, and that a great abundance of life must exist in the cosmos. The actual problem now is to determine which of the many chemical pathways to life have actually been most productive in nature.

The fossil record on Earth has shown that evolution works to produce life forms that thrive in every ecological niche. In particular, brain size has continuously increased over the history of the Earth, leading after sufficient time, which may be variable, to intelligent brains. No special conditions are required except that resources must be limited so that there is a competition for resources, which is the driver for evolution. All planets have limited resources, which sounds simplistic, but is an important driver in the development of technology using creatures.

All in all, we have made enormous progress in finding the actual values of the factors in the equation, and this is both very satisfying and encouraging, and something we as humans can be proud of.

To many minds, there is still great uncertainty in the probability of evolution producing a creature like us that can build a technology detectable at interstellar distances. Perhaps they are making the common mistake of not appreciating the immensity of cosmic time, and that it may take a lot of time to produce creativity as an ability in the evolution of the brain and body. One argument that I know is false is arguing that, since there is only one species on Earth capable of creating high technology, after 4.5 billion years of evolution, such species are very rare. This mistaken idea derives from not recognizing that evolutionary lines will be progressing towards intelligence and technology, but they will not all arrive at a creative species at the same time. One will always be first, and it will look around and be mistakenly surprised that it is the only one on the planet. This is not improbable, it is the only possibility! There are many species in existence on Earth already which are intelligent, manipulate tools, and given enough time may well equal us in technological capabilities. If we let them!

To my mind, there is one remaining very uncertain factor in the Equation. What is the value of L? Our own experience does not really help us at all, except to suggest that the minimum value of L is about 100 years. We have been detectable about that long. But that is certainly not worthy of being taken as the real value of L. Clearly we will not be able to arrive at even a plausible estimate of L

until we have found other civilizations and seen how long L can be elsewhere. SETI has always been burdened with this chicken and egg problem: we won't know how much searching is required for success until we have succeeded! This situation is very off-putting to those people and organizations that might fund our searches.

However, there is something useful we can say, and is, as we will see, very encouraging.

When we actually insert in the Equation plausible values of the factors, it is immediately striking that the overall uncertainty in our estimate of the number of detectable civilizations is dominated by our almost total ignorance of the value of L. There is a demonstration I do in lectures, when time permits, to demonstrate how serious this is. At the beginning of the lecture I ask everyone present to tear off a piece of paper and write on it his or her own personal estimate of L. I then collect these and have someone construct the mean of all the values (it is interesting to do this twice, at the beginning and end of the lecture to see how much the lecture has changed people's ideas of L). The end result is usually quite surprising. Typically, many people (the pessimists!) estimate that L is about 100 years – that we are likely to destroy ourselves through some folly soon. (The fraction of responders who vote for a small value of L, has, over the years, reflected the political state of the world at the time, which is separately interesting). Some (the historians!) will estimate perhaps 2000 years – that is about how long we have had good recorded history, and these estimators are unconsciously reluctant to speculate what may happen over a time interval greater than our known experience. Nobody ever estimates ten thousand years. Then there are always a few (the optimists! – maybe cockeyed?) who think that our civilization will last and be detectable, say, a few billion years, the longevity limited really only by cosmic events like the evolution of the sun into its giant phase. To see what comes from such an exercise, assume, as an example, that of 100 people, 90 think that L is 100 years, 9 think L is 2000 years, and just 1 thinks that L is a billion years. The arithmetic mean of this set is, (you can compute this in your head) surprise! – About ten million years! In fact, the result is hardly affected by the short-lived civilizations, even though they may vary greatly as a percentage of responders. The end result will always be very large, and dominated by the few long-lived worlds, the outliers. We can't, as we might with many sets of scientific data, throw out the outliers on the basis that something was wrong with their measurement. Intelligent creatures are capable of unusual things, and an occasional billion-year longevity is not impossible, nor does it violate any law of physics or biology. They may occur, and even more often than we can imagine.

Beyond telling us that L may be larger than we imagine, this situation tells us something else important, which is that any civilization we detect will probably be much more advanced than our civilization. We will rarely, if ever, find peers!

Indeed, the probability of civilizations exhibiting very great longevity may derive from, of all things, the sociology of extraterrestrial civilizations. Is the practice of altruism ubiquitous in extraterrestrial civilizations? Is it a widespread characteristic of intelligent creatures? Altruism is a common human trait – are we typical? This may matter greatly because very advanced civilizations may quickly develop technology that avoids the release of energy to space, which would be wasted energy to them as it is to us. Thus they would produce only very weak, difficult to detect, signals. Our own civilization, presently easily detectable, is conspicuously on this path to undetectability already. Cable television, satellite-to-home televisions, cell phones, are examples of young technologies that are replacing older technologies that radiated copious amounts of energy into space. These young technologies radiate far weaker signals than the older systems they replace. Do mature civilizations realize the problem this creates for the newcomers such as us, and appreciate that they can tell us very useful things, and practice altruism by intentionally sending powerful signals to provide widespread sharing of knowledge to others? If so, the value of L is possibly enhanced greatly by this. Could this be? If so, L is very large, as is N. Again, we can't know the value of L until we have found intelligent life somewhere in space, and have an answer to the altruism question.

It has been fascinating to me to see how the Equation has taken on a life of its own. It is found routinely in many elementary astronomy textbooks now, gaining the status of being one of the important formulas in the lexicon of science. It has served as the agenda, again, of many workshops and symposia. It is often the basis of the syllabus in college courses in Astrobiology, one of the fastest growing subjects in college curricula, and one which works well to attract bright students into science. It has served to acquaint, without anxiety, mathematically queasy students to the power of equations. They are typically quite fascinated with the idea of extraterrestrial life, and this enthusiasm emboldens them to risk dipping their minds into a possibly perplexing equation so that they can learn of intelligent creatures elsewhere. The Equation makes it easy for them. I remember so well the times when I was giving a college lecture in an elementary course on the solar system, and came to Kepler's third law, which has both dreaded exponents in it, as well as something in the denominator. The room would fill with the rustling of papers and whispers of "Do we have to know that?" Well, the Equation has no exponents and nothing in the denominator! More than that, it has many probability factors in it, but none of them are joint probabilities, a concept that would have caused much consternation. The Equation is a joy to students of all abilities, including those who are unsure of their abilities to deal with mathematical science!

Indeed, people see the Equation in general as a very positive thing, producing knowledge about only good things. It has no ability to suggest or develop a new weapon system. It doesn't support activities or ideas that will contribute to global warming or other forms of environmental damage. It encourages people to study science because extraterrestrial life is so interesting. It even points out that altruism is a good thing, and may be more important than we ever imagined. That the general public appreciates this is expressed in surprising ways, such as the Equation being used on the sides of a multitude of U-Haul trucks to serve as an icon for the good things produced in the State of West Virginia! The importance of the Equation to some people is reflected in the photos I receive in the mail, or see at public science events, of the Equation being a tattoo on many arms and legs, and even across the forehead of one supporter. We may not have the answer to the Equation soon, but it already is doing good things. I believe it will become even much more important as we fill in the blanks still unfilled.