Introduction

The Drake Equation in context

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Abstract

The Drake Equation, a method for estimating the number of communicative civilizations in the Milky Way galaxy, was a product of its time in several important ways. After a period of several decades during which the idea of life on other planets had reached a low point due to rise of the "rare collision" hypothesis for planet formation, by the 1950s the nebular hypothesis was once again in favor, whereby planets would form as a common byproduct of stellar evolution. The Miller–Urey experiments in the early 1950s produced complex organic molecules under simulated primitive-Earth conditions, indicating life might easily originate given the proper conditions. And while little was known about the gap between primitive life and intelligent life, and a sophisticated understanding of intelligence was lacking, the Lowellian Mars still lingered in the cultural background and, along with contemporary astronomical advancements, stimulated the scientific imagination to consider aliens. The original emphasis on "radio communicative" reflected the new era of radio astronomy, exemplified by the radio telescopes under construction at the newly founded National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, where Frank Drake was working at the time when the equation originated as the meeting agenda for an informal conference there in 1961. Drake's ability to undertake such a controversial subject, including the first radio search for extraterrestrial intelligence in 1960, was aided by senior scientists Lloyd Berkner and Otto Struve. Assessments of the probabilities of extraterrestrial life and intelligence had been sporadically undertaken in the course of the twentieth century, but most particularly by former Harvard Observatory Director Harlow Shapley in his book *Of Stars and Men* (1958); Drake had recently graduated from the Harvard astronomy program, and had cited the book. Here we look at the origins and development of the

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equation over time, including significant variations in the equation; examine positive and negative views of its epistemological status and utility ranging from scientists to popular authors such as Michael Crichton; and attempt to tease out the scientific and metaphysical assumptions behind the equation. We conclude by discussing the future of the equation, and the cultural hopes and fears it embodies.

Origins of the equation

The Drake Equation was born during an informal conference on "Extraterrestrial Intelligent Life" held on November 1–2, 1961, at the nascent NRAO in Green Bank, West Virginia. The meeting, sponsored by the Space Science Board of the National Academy of Sciences, was held in the wake of the excitement generated by Project Ozma, the first search for interstellar communications, conducted at the NRAO by Frank Drake, a young astronomer on its staff (Figure I.1). The two-hundred-hour search, with the observatory's 85 foot Tatel radio telescope in April, 1960 (Figure I.2), targeted only two nearby Sun-like stars, Tau Ceti and Epsilon Eridani, around the 21 centimeter line of neutral hydrogen (Drake and Sobel 1992, chapter 2). Although it failed to detect any extraterrestrial civilizations, the project captured the imaginations of scientists and public alike. The Ozma search (though independently conceived by Drake) followed the landmark publication by Giuseppe Cocconi and Philip Morrison that argued on theoretical grounds that such a search should be undertaken (Cocconi and Morrison 1959). The Green Bank meeting was therefore the last in a troika of events from 1959 to 1961 that launched the modern SETI era (Dick 1996, 1998).

The standard story, even from Drake himself, is that press coverage of Project Ozma triggered the interest of the National Academy (Drake 1992, 14–15; Drake and Sobel 1992, 46). But National Academy records demonstrate that the immediate cause was actually a lecture Drake gave on the subject at the Philosophical Society of Washington on March 10, 1961 (Drake 1961a; Pearman 1961). In the audience was biologist J. P. T. Pearman of the National Academy's Space Science Board staff, who that night after the lecture discussed with Drake the possibility of such a meeting (Pearman 1961). By March 13, Drake replied to Pearman with a letter stating that NRAO Director Otto Struve not only approved such a meeting but also offered to hold it at NRAO. The observatory had living accommodations for about thirty people, Drake noted, and "the isolation of Green Bank would also help solve the problem of keeping the symposium quiet and scientific" (Drake 1961b).

The National Academy's records indicate Pearman immediately set to work, handling much of the logistics for the meeting. But the organization of the scientific content fell largely to Drake. Thinking in the days before the meeting about how to

Figure I.1 Frank Drake at the National Radio Astronomy Observatory, 1962, where he had conducted Project Ozma two years before. Drake, recently graduated from Cornell and Harvard, had been interested in extraterrestrial life from an early age, and had been influenced during his Cornell years by a lecture on planetary systems given by Otto Struve.
Credit: NRAO/AUI/NSF

proceed, Drake decided to arrange the discussions of extraterrestrial intelligence around an equation that concisely represented the relevant factors. Thus appeared for the first time the formulation that would be used repeatedly in the following decades in attempts to determine the likelihood of radio-communicative civilizations in our galaxy – and thus the likelihood of success in any such search.

The original form in which Drake wrote the equation was $N = R^* f_p n_e f_l f_i f_c L$, where each symbol on the right side of the equation represents a factor bearing on the number of radio-communicating civilizations in the galaxy (N) (Figure I.3). The first three factors were astronomical, estimating respectively the rate of star formation in the galaxy, the fraction of stars with planets, and the number of planets per star with environments suitable for life. The fourth and fifth factors

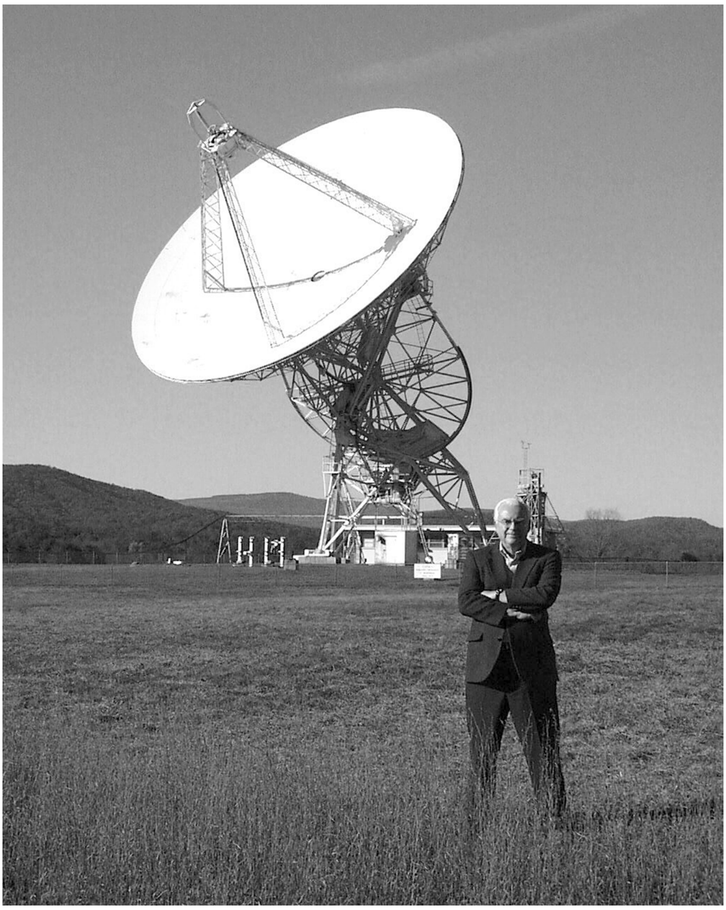

Figure I.2 Drake at the 85 foot Tatel telescope during his visit to give the October 1999 Jansky Lecture. The Tatel telescope was completed in early 1959 at the nascent NRAO.
Credit: NRAO/AUI/NSF

were biological: the fraction of suitable planets on which life developed and the fraction of those life-bearing planets on which intelligence evolved. The last two factors were social: the fraction of civilizations that were radio-communicative over interstellar distances and the lifetime of radio-communicative civilizations. The uncertainties, already shaky enough for the astronomical factors, nevertheless increased as one progressed from the astronomical to the biological to the social. Taken together, they represented cosmic evolution writ large.

Although Drake was the first to put these factors in simple equation form, he was not the first to ask the question in terms of probabilities. Assessments of the probabilities of extraterrestrial life and intelligence had been sporadically undertaken in the course of twentieth-century discussions of the subject. On the eve of

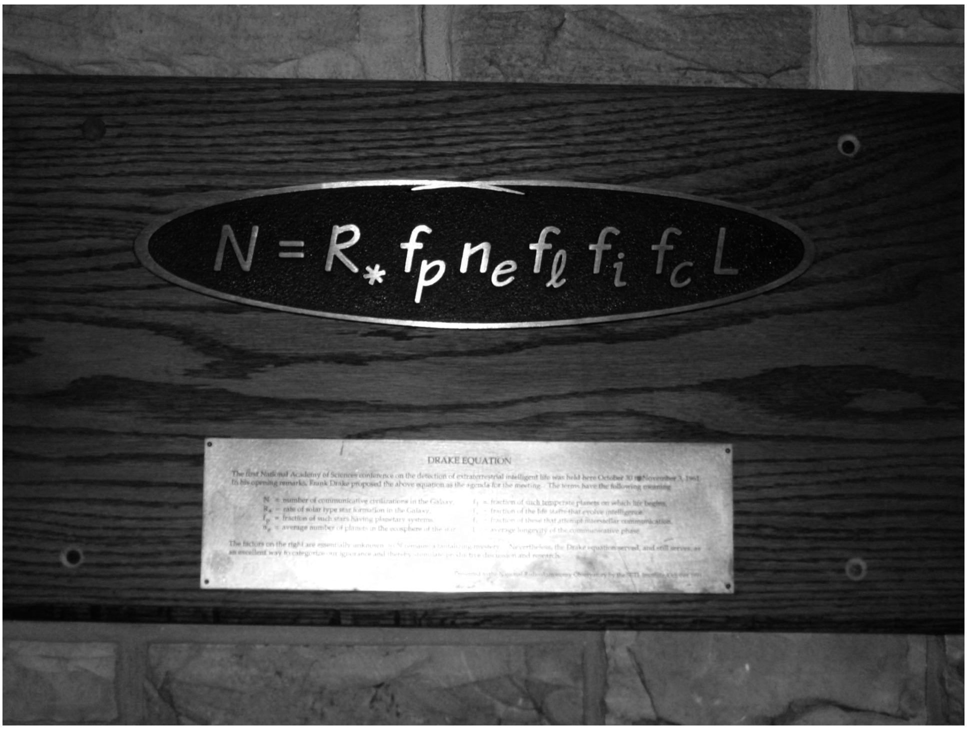

Figure I.3 The Drake Equation, inscribed on a plaque in the conference room at the National Radio Astronomy Observatory in Green Bank, West Virginia, where Drake first formulated the equation in 1961. N represents the number of technological communicating civilizations in the Milky Way galaxy, and the right side of the equation embodies various parameters of star and planet formation, the likelihood of the origin and evolution of life and intelligence, and the lifetimes of technical civilizations.
Photo courtesy of author

the events of 1959–61, former Harvard Observatory Director Harlow Shapley had calculated the number of intelligent civilizations in the universe based on probabilities, but had not discussed interstellar communication (Shapley 1958, 73–74). Drake had recently graduated from the Harvard astronomy program, and had cited Shapley's calculations prior to the Green Bank meeting (Drake 1959). Probabilities had also been used by radio astronomer Ronald Bracewell in another early discussion of the number of advanced communities in the Milky Way (Bracewell 1960, 670). Bracewell, however, had couched his discussion in graphical rather than equation form. And astronomer Sebastian von Hoerner had used probabilities to conclude that one in three million stars might have a technical civilization, but that the longevity of a technical civilization (a concept he credited to Bracewell) might be very limited (von Hoerner 1961).

When Drake began the Green Bank meeting by writing his equation on the board, he could not have known that he was establishing a paradigm for SETI discussions that would last into the twenty-first century. But by considering in turn astrophysical, biological, and social factors he did just that, and Green Bank was only the first of many occasions where experts would discuss the factors that Drake proposed. In the wake of the Green Bank meeting, discussions centered on the likelihood of communicative extraterrestrial civilizations using radio technology. The calculations of N varied wildly, over a range not seen before in the history of science (Dick 1996, 441; 1998, 217). One could take this as an indication of a very unsettled protoscience, though one that held promise for the future.

In the task of calculating the number of radio-communicative civilizations, the compelling nature of an equation – even one whose parameters were not well known – was not to be denied, since an equation is a symbol of science and lends authority to any scientific discussion. The meteoritic career of the Drake Equation, rather than one of the other probabilistic assessments, is evidence of such authority. Only a month after the Green Bank meeting in November 1961, Philip Morrison used a similar equation in a NASA lecture (Morrison 1962). The equation first saw print not in an article by Drake but in Pearman's account of the Green Bank conference published in a 1963 volume of collected articles on the subject entitled *Interstellar Communication* (Cameron 1963a; Pearman 1963). In the same volume its editor, the astrophysicist A. G. W. Cameron, used a similar equation (Cameron 1963b, 1963c). Sagan was also among the first to publish the equation (Sagan 1963), and Drake himself used it in a paper presented at a JPL symposium on exobiology in February 1963 (Drake 1965). Although not known at first as the Drake Equation, after a period of uncertainty when it was called the Sagan Equation or the Green Bank Equation, the originator was given due credit (Drake 1992). Perhaps the decisive events in the spread of the Drake Equation were Walter Sullivan's popularized account of it in *We Are Not Alone* (1964) and Sagan's incorporation of it into his translation and expansion of Russian astrophysicist Joseph Shklovskii's book *Intelligent Life in the Universe* (Shklovskii and Sagan 1966), which became the Bible of the SETI movement. These books assured the rapid diffusion of the Drake Equation to the public and interested scientists alike.

Although not immediately used in the Soviet Union, the Drake Equation, with its emphasis on radio communication, focused attention on the electromagnetic-radio search paradigm. Already by 1966 this concept and all of the assumptions that went with it were sufficiently entrenched that physicist Freeman Dyson labeled it the "orthodox view" of interstellar communication, characterized not by interstellar travel but by "a slow and benign exchange of messages, a contact carrying only information and wisdom around the galaxy, not conflict and turmoil" (Dyson 1966). As anyone who read science fiction knew, this was not the only possible view of the universe. But it was a practical method, a logical extension of the new field of radio astronomy, and one that at least some of its practitioners were keen to carry out. For these reasons, the discussion of rationale and strategy within the radio search paradigm continued its upward climb.

By 1971, ten years after its origin, the Drake Equation was the centerpiece for the first international SETI meeting, held at the Byurakan Astrophysical Observatory in Yerevan, the Soviet Union (Sagan 1973). This time the organizers of the meeting, sponsored by the Academies of Sciences of both the United States and the Soviet Union, included not only Drake, but also Carl Sagan and Philip Morrison of the United States, as well as Victor Ambartsumian, Nikolai Kardashev, Joseph Shklovskii, and V. S. Troitskii of the Soviet Union. Instead of the eleven participants at the Green Bank meeting in 1961, twenty-eight Soviets, fifteen Americans, and four scientists from other nations participated. They concluded that perhaps a million technical civilizations existed in the galaxy. SETI, though still a small endeavor by science standards, was growing, and the Drake Equation was its central icon.

The equation in context

The equation was a product of its time, triggered by the ability of radio telescopes to search for artificial signals from nearby stars (Drake and Sobel 1992, chapter 2). Drake has given us an inside look at the eleven participants as they gathered at the Green Bank meeting (Drake and Sobel 1992, chapter 3): Drake himself was the expert young radio astronomer. His boss, Otto Struve (Figure I.4), and Struve's former student Su-Shu Huang, were the experts on planetary systems. Other participants were recruited for their expertise in a particular factor in the Drake Equation. Collectively, they represented most but not all of the factors in the equation. Notably, no social science or humanities experts were present to discuss the number of civilizations or their lifetimes, in part a reflection of the gulf between the two cultures of science and the humanities in the early 1960s.

At the time of the Green Bank meeting, the idea of extraterrestrial life was gaining momentum. After a period of several decades, during which the idea of life on other planets had reached a low point due to rise of the "rare collision" hypothesis for planet formation, by 1960 the nebular hypothesis was once again in favor and held that planets would be a common by-product of stellar evolution. At the Green Bank meeting, Struve was enthusiastic about the number of planetary systems, based primarily on his work on stellar rotation, and was supported by Huang, who had concluded from his own research on habitable zones around stars that the number of planets in the galaxy suitable for life was indeed very large (Dick 1996).

Figure I.4 Otto Struve, director of the NRAO, July 1, 1959 through December 1, 1961. Neither Project Ozma nor the Green Bank meeting on Interstellar Communication could have been undertaken without his enthusiastic acceptance.
Credit: NRAO/AUI/NSF

In the wake of NASA's founding in 1958, planetary science was also on the upswing, with the real possibility of sending spacecraft to study planetary surfaces and atmospheres. Indeed, that is precisely what happened, with the search for life on Mars often in the forefront as a driver of space science. Although no one represented NASA at the meeting, the young planetary scientist Carl Sagan, already involved in many planetary projects, was in attendance and well aware of NASA's planetary efforts. Joshua Lederberg, who had just coined the word "exobiology," had some input to the meeting, but could not attend (Lederberg 1961).

The origin of life was also a hot topic at the time. The 1953 Miller–Urey experiments in simulating life under primitive-Earth conditions indicated life might easily originate given proper stimulus. Melvin Calvin, an expert on chemical evolution, argued at the meeting that the origin of life was a common and even inevitable step in planetary evolution, and his already formidable credentials were given another boost when he received notification during the meeting that he would be awarded the Nobel Prize for his work on the chemical pathways of photosynthesis. And while little was known about the gap between primitive life and intelligent life, or even the definition of intelligence, the

Lowellian Mars of artificially constructed canals still lingered in the background, stimulating imaginative scientists to think about aliens.

It was a very large step from the origins of life to intelligence, and the concept of "intelligence" was neither well defined nor understood, which is still the case today. Perhaps not surprisingly in this environment, the organizers looked for a participant doing practical research in the field. John Lilly, who had just come out with his controversial book *Man and Dolphin*, met that criterion and argued at Green Bank that dolphins were an intelligent species with a complex language, and that we might even be able to communicate with them. Dolphins thus became a kind of symbol for interspecies communication.

The equation's emphasis on "radio-communicative" reflects the new era of radio astronomy, exemplified by the radio telescopes being built at the newly founded NRAO. This early history and subsequent events are elaborated in Dick (1996, 1998), and there is no need to repeat it here. Summarizing the results of their discussions, the members of the conference concluded that, depending on the average lifetime for a civilization, the number of communicative civilizations in the galaxy might range from less than one thousand to one billion. Opting for the more optimistic figure (likely an unfounded bias based on their interest in the subject), most of the members felt the higher number was likely closer to the truth.

Hidden assumptions

Even as it grew in popularity, the Drake Equation embodied many hidden assumptions, perhaps responsible for both confusion and its enduring legacy. Nowhere is this truer than it its first and last factors, R* and L, which are the only parameters with dimensions (stars forming per year and number of years). It is often forgotten that Drake's formulation was an eminently practical exercise, driven by Project Ozma and the desire to estimate the chances of its success by estimating the number of communicative civilizations existing *now*. This explains why the first parameter in the equation was not simply the number of stars existing today in the galaxy, whose formation began some eleven or twelve billion years ago. Nor was it even the number of stars existing 4.5 billion years ago, since they were all in different stages of development; if those stars had spawned civilizations, they would all be in different stages of development. Rather, Drake was interested in civilizations that were communicating now and at about the same stage of development as ours. He therefore used as the first parameter of the equation a rate of star formation rather than a number of stars. And he used L because it was the bottleneck that restricted technological civilizations to those communicating *now*.

The rate of star formation in our galaxy was the best-known quantity in the equation, and by the evidence of the time, it was calculated in a straightforward, "quick and dirty" way, not taking into account current theories of star formation as discussed in Chapter 2. In Pearman's account of the meeting, the calculation went as follows:

> If stars of solar type only are considered, a rough estimate of R* is given by the total number of such stars in the galaxy divided by their average lifetime. Thus $R^* = 10^{10}/10^{10} = 1$ per year. This is perhaps a conservative estimate and less restrictive considerations permitting the inclusion of some Population II stars would give values as high as 10 stars per year. (Pearman 1963, 289)

In other words, estimating ten billion solar-type stars in the galaxy, each with a lifetime of about ten billion years, yields one star forming per year. Including Population II stars (still Sun-like stars but older than our Sun), one could raise this estimate to ten per year, thus the often-used estimate in the Drake Equation of one to ten stars forming in our galaxy per year.

Needless to say, this assumes a uniform rate of star formation over the lifetime of the galaxy, which we know today not to be the case. The same can be said for the calculation sometimes used that employs the number of solar-type stars in the galaxy divided by its age. Strictly speaking, R* today is defined not as the rate of star formation over the lifetime of the galaxy but as the rate of star formation 4.5 billion years ago when our Sun and its planets were formed. At least that is the way Drake defines it. Responding to an inquiry about his current usage of R*, Drake wrote,

> I prefer it because it more accurately quantifies the process by which current intelligent technology-using life came about. There are two versions of the equation which occur in various textbooks, etc. One uses number of stars/age of galaxy. The other uses R*. The first conceals a somewhat important aspect of the whole picture, since it implies that the relevant star formation rate is the mean rate during the existence of the galaxy. But that is not the one which applies to the calculation of how many technology civilizations are out there to be found *now*. That number is governed by not the mean rate of star formation, but the rate of star formation which existed at the time stars of about the same age as the Sun were formed, namely about 4.5 billion years ago. (Drake 2014a, emphasis in original)

This formulation assumes that extraterrestrial technological civilizations develop at about the same rate as on Earth, a very large assumption indeed. Drake fully recognizes the assumption, but finds it necessary considering our ignorance:

> What we really need to know is the statistics of star formation over a substantial period 4.5 billion years ago, since the process of producing an intelligent species will take some range of time intervals. We won't know that until SETI succeeds. However, the rate of star formation 4.5 billion years ago is the best estimate we can use in our current state of