In 1961 astronomer Frank Drake wrote the equation that put the search for alien civilizations on a scientific footing and launched the modern SETI movement. How do the equation's numbers look today?

By Govert Schilling

The Chance of
Searching for extraterrestrial life has become a hot topic in astronomy and biology, but few remember how the subject was jump-started almost 40 years ago. In September 1959, physicists Giuseppe Cocconi and Philip Morrison published a landmark article in the British weekly *Nature* with the provocative title, “Searching for Interstellar Communications.” Cocconi and Morrison argued that radio telescopes had become sensitive enough to pick up transmissions from civilizations orbiting distant stars. Such messages, they suggested, might be transmitted at a wavelength of 21 centimeters. This is the characteristic wavelength of radio emission by neutral hydrogen, the most common element in the universe. Aliens might see this as a logical landmark in the radio spectrum where searchers like us would think to look.

Seven months later, in April 1960, radio astronomer Frank Drake became the first person to carry out a systematic search for intelligent signals from the cosmos. Using the 25-meter dish of the National Radio Astronomy Observatory in Green Bank, West Virginia, Drake “listened in” on two nearby Sun-like stars: Tau Ceti and Epsilon Eridani. His Project Ozma (named after the main character in L. Frank Baum’s book *Ozma of Oz*) was cheap, simple, and unsuccessful.

Following the Ozma experience, Drake organized a meeting with a select group of scientists to discuss the prospects and pitfalls of the search for extraterrestrial intelligence (SETI). In November 1961, 10 radio technicians, astronomers, and biologists convened for two days at Green Bank. Young Carl Sagan was there, as was Berkeley chemist Melvin Calvin, who received news during the meeting that he had won the Nobel Prize in chemistry.

It was in preparing for this meeting that Drake came up with his famous equation:

\[
N = R \times f_p \times n_e \times f_i \times f_l \times f_s \times L
\]

Today this string of letters and symbols can be found on T-shirts, coffee mugs, and bumper stickers. It is simpler than it looks. It expresses the number \( N \) of “observable civilizations” that exist in our Milky Way galaxy as a simple multiplication of several, more approachable unknowns. \( R \) is the rate at which stars are born in the...
Milky Way each year, \( f_p \) is the fraction of these stars that have planets, \( n_p \) is the average number of “Earth-like” planets (reasonably suitable for life) in the typical solar system, \( f_l \) is the fraction of those planets on which life actually forms, \( f_i \) is the fraction of life-bearing planets where biological evolution produces an intelligent species, \( f_c \) is the fraction of those species that become capable of interstellar radio communication, and \( L \) is the average lifetime of a communicating civilization.

The Drake equation is as straightforward as it is fascinating. By breaking down a great unknown into a series of smaller, more addressable questions, the formula made the search for alien civilizations more realistic and promising. The Drake equation made SETI a tangible effort and gave the question of life elsewhere a basis for scientific analysis.

Astronomers and biologists alike have tried to “solve” the equation ever since. At first sight, deriving a good estimate for the answer might seem fairly straightforward, but in reality the number of communicating extraterrestrial intelligences can’t be computed easily. In recent years some of the variables in the equation have been firmed up. But most remain very unknown.

The rate of star formation in our galaxy is approximately one star per year, so \( R = 1 \). The next factor, \( f_p \), is probably smaller than one: not every star is accompanied by planets. On the other hand, if a star has a planetary system, it seems plausible that at least two or three of its planets and moons are potentially suitable for the origin of life, so maybe the product of \( f_p \) and \( n_p \) is not much smaller than 1.

Optimists would argue that life will form wherever it can \((f_l = 1)\), that the Darwinian process of natural selection eventually favors the evolution of intelligence \((f_i = 1)\), and that no intelligent civilization would exist for long without discovering electricity and radio and feeling the urge to communicate \((f_c = 1)\). In this most optimistic case, the Drake equation boils down to the simple observation that \( N = L \) (the average lifetime of an intelligent society in years). If \( L \) is, say, 10,000 years, there would be about 10,000 chatty civilizations in our galaxy, or about one per 20 million stars. If they were distributed at random through the Milky Way, the nearest would probably be about 1,000 light-years from us. A two-way conversation would require a time equal to a large part of recorded human history, but a one-way broadcast might be audible.

However, 35 years of SETI efforts have failed to find anything, even though radio telescope apertures, receiver techniques, and computational capabilities have increased enormously since the early 1960s. Granted, the “parameter space” of possible radio signals (the possible frequencies, locations on the sky, signal strengths, and so forth) is vastly larger than has yet been searched. But we have discovered, at least, that our galaxy is not teeming with powerful alien transmitters continuously broadcasting at us in the ways we have looked for. No one could say this in 1961.

Have we overestimated the values of one or more of the Drake parameters? Is the average lifetime of technological civilizations quite short? Or have astronomers overlooked some other, more profound aspect?

Let’s reevaluate the Drake equation by analyzing each term separately. \( R \), the number of stars born in the Milky Way each year, is indeed approximately 1 — astrophysicists are quite sure about that. (Of course this doesn’t apply to the fraction of these stars that have planets, \( f_p \), which is a matter of far more controversy.)

Above: Frank Drake has been convinced of the existence of extraterrestrial civilizations since his 1930s Chicago childhood. “I could see no reason to think that humankind was the only example of civilization, unique in the universe,” he writes in his 1992 book, *Is Anyone Out There?* (coauthored by David Sobel).

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mean there’s exactly one new starbirth every year, but the average rate is somewhere between 0.3 and 3.) However, astronomers and biologists are much less certain about subsequent terms in the equation.

**How Many Planets? \( f_p \)**

The second variable is \( f_p \), the fraction of stars that have planetary systems. Recent discoveries of young stars surrounded by planet-forming disks, along with detections of actual planets orbiting nearby Sun-like stars, confirm what astronomers had already come to suspect: planets are common.

So-called protoplanetary disks have been detected by various infrared observations and are seen directly in Hubble Space Telescope photographs of the Orion Nebula, a prolific star-forming region. Such observations seem to imply that at least 50 percent of all newborn stars are accompanied by planets. Although no one is sure how long the disks will survive, recent submillimeter-wave observations have shown more tenuous dust disks around a number of older stars, including Drake’s first target, Epsilon Eridani. Many of these disks are doughnut shaped. According to some theorists, the central holes can only be caused by planets accreting gas and dust from the inner portion of the disk.

In the arena of actual planet detections, the most productive teams of planet hunters (Michel Mayor and Didier Queloz in Europe, and Geoffrey Marcy and R. Paul Butler in California) found about 10 planetary systems in a search of some 200 single (nonbinary) Sun-like stars. This implies that about 5 percent of stars are accompanied by planets, so \( f_p \) would be 0.05. However, there’s a catch: the current search techniques are sensitive only to massive planets, especially those in very tight orbits. Replicas of our solar system cannot yet be recognized. Quite probably the real fraction of single Sun-like stars with planets of some kind is much higher than 5 percent. It could be as high as 50 or even 100 percent.

So what do these new observations tell us about \( f_p \)? Although we don’t yet have a final value, it’s now clear that \( f_p \) is very substantial and is not a bottleneck in the Drake equation.

**How Many Good Planets? \( n_e \)**

There’s less encouraging news when we turn to the equation’s next term, \( n_e \). This factor represents the average number of planets in other solar systems that have environments suitable for the origin of life (the “e” stands for “Earth-like”). In his 1992 book, *Is Anyone Out There?* Drake recalls that the participants at the Green Bank meeting estimated that the value of \( n_e \) lay between 1 and 3. In other words, every planetary system was expected to contain at least one minimally Earth-like planet (one where liquid water is possible), and that there might easily be three, four or five such worlds per system.

This optimistic view was based on the assumption that our own solar system is typical in its size and its number and distribution of planets. Today Mars and Jupiter’s moon Europa are being considered as sites of early biology, indeed making three possible “Earths” (by the Drake-equation definition) in our solar system. However, the extrasolar planets found in the last three years have taught us humans a humbling lesson. Our solar system, with lots of worlds and moons in nice, stable, nearly circular orbits, may be more the exception than the rule (S&T: March 1996, page 30).

**How Many Origins of Life? \( f_l \)**

In scientific circles there’s much more optimism now than in the past about the value of \( f_l \), the fraction of habitable planets on which life evolves. The molecular building blocks of life — complex organic hydrocarbons and even amino acids — are abundant in the universe. They have been discovered in meteorites, comets, and interstellar gas and dust. There are vastly more amounts of amino acids in interstellar space than in the Earth’s biosphere. Although hydrocarbons and amino acids are not living organisms, there’s little doubt that a lot of prebiotic evolution is going on in the dark galactic dungeons between the stars.

Most significant are the surprising recent discoveries...
that microorganisms appeared on Earth only moments (geologically speaking) after the last devastating impacts of the planet’s formation. Perhaps, given the right conditions, the origin of life is a rather straightforward (yet unexplained) process that happens easily. If the process were rare or difficult, one would not expect it to have happened at the first possible opportunity on Earth, but somewhat later in the planet’s history instead. Biologists now discuss whether life might have arisen several times on Earth separately. There’s every reason to think that all living things today have a common ancestry, but other, independent lines could have formed and been wiped out early. If life does form wherever it can, then presumably \( f_e = 1 \).

**Intelligence \( f_i \)**

That leaves us with only three remaining unknowns. How likely is the evolution of intelligence \( (f_i) \)? How confident can we be that extraterrestrials are able — and willing — to broadcast by radio \( (f_c) \)? And what is the average lifetime of radio-capable civilizations \( (L) \)?

These biological and sociological factors in the Drake equation are subject to greater scientific debate and uncertainty than the astronomical ones.

According to many life scientists, it is naive to suppose that evolution on another planet should necessarily result in intelligence as we know it. In his bestseller _Wonderful Life_ paleontologist Stephen Jay Gould (Harvard University) asserts, “We probably owe our own existence to ... good fortune. _Homo sapiens_ is an entity, not a tendency.” Evolution is an unpredictable, chaotic process. Gould has pointed out again and again that if we could rewind the tape of evolution on Earth and start over, it is impossible that humans would again appear on the scene.

Others counter, of course, that it is not _Homo sapiens_ we are looking for. No one expects to find men among the stars (little green ones or otherwise). Rather, the issue is whether _any_ types of organisms evolve the capability to use tools, develop a complex society, and store and manipulate information well enough to discover the principles of electronics. To optimists this seems like a difference only in degree, not in kind, from the levels of intelligence and purposeful behavior that various widely divergent species of animals have evolved independently on Earth.

But Gould notes that there is no overall pattern in evolution, no preferred direction. Our notion that the increase of biological diversity is necessarily accompanied by an increase of mental capabilities may be dead wrong. If some recently evolved animals are bigger and smarter than any earlier ones, that could just be a fluke. Human levels of planning and technology may be even more so.

To some biologists and SETI proponents, the phrase “survival of the fittest” implies that greater intelligence inevitably boosts a species’ chance to survive and spread through natural selection. But the renowned biologist Ernst Mayr (Harvard University) argues that many astronomers and physicists are much too optimistic concerning the emergence of intelligence. “Physicists still tend to think more deterministically than biologists,” wrote Mayr in the May 1996 issue of _The Planetary Report_. “They tend to say that if life has originated somewhere, it will also develop intelligence in due time. The biologist, on the other hand, is impressed by the improbability of such a development.”

Strangely enough, optimists and pessimists base their claims on the same observation — namely that technology has appeared on this planet in four billion years. Pessimists (or realists, as they would prefer to be called) like Mayr see this as evidence of the unlikeliness of intelligence as an evolutionary given. For optimists, it strengthens their belief in the existence of other civilizations.

Optimists point out that Earth has more than a billion good years ahead of it before the planet will get cooked by the expanding Sun. This is more than twice the time that has gone by since the first simple creatures crawled out of the sea onto land. If the emergence of intelligence is difficult and rare, the optimists claim, it would probably not have happened so early in the time available for it to do so. Given our early arrival in the long era expected for land life, it seems likely that entirely different intelligent creatures will emerge a few more times in the com-

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*Left: Observations of the Orion Nebula are helping astronomers close in on the value of \( f_e \), the fraction of stars with planets. At least half of the young stars seen in the Orion Nebula are surrounded by thick, dusty disks — excellent planet-forming material. Below, left: In the last three years planets have been discovered orbiting about a dozen nearby stars. Geoffrey Marcy (San Francisco State University) and R. Paul Butler (Anglo-Australian Observatory) detect the gravitational tug exerted by extrasolar planets on their parent stars. The closest analogue to a solar-system planet they have found orbits 47 Ursae Majoris. It is at least 2.4 times as massive as Jupiter and follows a nearly circular orbit around the star every 3 years.*
ing billion years. This echoes the point made from the early emergence of microorganisms on the young Earth.

Pessimists reply that we don't really know how long the Earth will remain clement — our seemingly stable climate may be the result of a long series of lucky flukes — so in fact we may have arisen late in the span of time available.

Contrary to popular belief, the fact that it has happened once tells us nothing at all about how often it happens — for the simple reason that we ourselves are the one case! Even if intelligent life is so unlikely that it appears just a single time in one remote corner of the universe, we will necessarily find ourselves right there, because we are it.

Strangely enough, both camps accept the so-called Copernican principle, which claims that humankind enjoys no preferred position in time or space. Skeptics like Mayr say it is anthropocentric to believe that humanlike intelligence has appeared over and over again in the universe. Believers like Drake are unwilling to accept our uniqueness, because this would put us on a very un-Copernican pedestal.

Evidently, $f$ is the most controversial factor in the Drake equation. Some scientists believe its value is almost certainly next to zero; others are convinced it's close to 1. There seems to be no middle ground — the question of the inevitability of intelligence is currently what most polarizes the discussion about SETI.

Even if intelligence is a likely consequence of evolution, $f$ will probably be much lower than one, as evidenced by recent insights into the stability of solar systems and planetary climates. Computer simulations by Fred Rasio and Eric Ford (Massachusetts Institute of Technology) among others show that Earth-like planets are probably unable to survive the gravitational tug-of-war in a system with two (or more) massive, Jupiter-like giants. They would be be slung out of the system or sent careening into the central star.

Conversely, systems with no giant planets at all might also be unfit for life-bearing planets. Computer simulations by George Wetherill (Carnegie Institution of Washington) indicate that Jupiter acts as the solar system's gravitational vacuum cleaner, efficiently thinning out the population of hazardous comets that venture into Earth-crossing orbits. Without a Jupiter the current impact rate of comets would be 1,000 times higher, says Wetherill, with truly catastrophic collisions (like the one 65 million years ago) happening once every 100,000 years. This would surely frustrate any slow evolutionary progress from simple life forms to higher intelligences.

Also, dynamical studies by Jacques Laskar and Philippe Robutel (Bureau des Longitudes, Paris) have shown that rocky, Earth-like planets show chaotic variations in orbital tilt that could lead to drastic climate changes. Fortunately, Earth's chaotic tendencies are damped by tidal interaction with the Moon. Without a relatively large satellite, Earth might have experienced variations in axial tilt similar to those of Mars, possibly as large as 20° to 60°. This would cause extreme variations in the patterns of the seasons.

It's anyone's guess how this would influence the evolution of life and the chances for the emergence of intelligence. Change and stress result in the emergence of versatile, adaptable species, biologists believe. Paul F. Hoffman (Harvard University) and three colleagues recently proposed that a series of extreme global ice ages between 760 and 550 million years ago, which froze every ocean surface even at the equator, were the crises that resulted in the remarkable "Precambrian explosion" of new life forms around that time. The disastrous great extinctions in Earth's later geologic record were followed by vigorous recoveries with many new species. Our own emergence as a species during an unusual run of ice ages is sometimes cited as a possible example of stress-driven evolution.

But planetary crises that are too extreme or frequent would kill off everything, or keep life beaten down to a
low level. In any case, our existence here and now seems to be the accidental result of a number of astronomical coincidences that were unimagined in 1961.

Do Aliens Broadcast? \( f_c \)

Suppose that extraterrestrial intelligences are rare but do exist. Could we expect them to communicate with us through radio signals? What fraction of civilizations are able — and willing — to broadcast in a way we can detect? In other words, what is the value of \( f_c \)? SETI advocates tend to believe it is large: sooner or later, any technological civilization will discover that radio is the most efficient way to communicate over astronomical distances, and will choose to do so.

Might there be a naive form of anthropocentrism at play here? Is it reasonable to expect that life on another planet, beginning with single-celled microorganisms, will evolve into beings who build radio telescopes? Maybe we just don’t appreciate the true diversity of biological evolution, or the scope of sciences and technologies that remain unexplored by human beings. Radio may be hopelessly primitive compared to something we have yet to discover.

Lifetimes \( L \)

With \( f_c \) and \( f_c \) completely undetermined, we’re left with the last term of the Drake equation: \( L \), the average lifetime of communicating civilizations. Here also, optimists and pessimists are far apart. Optimists claim that a stable, intelligent society could last for tens of millions of years, if not forever. This would certainly mitigate the effect of bottlenecks earlier in the Drake equation. The pessimists point out that humans invented radio technology only decades ago, and that the human race has been on the verge of destroying itself (through technological warfare and pollution) for much of that time.

One factor determining \( f_c \), the fraction of life-bearing planets on which intelligence evolves, must be how long evolution can continue without life getting wiped out. In the case of Earth, Jupiter’s immense gravitational pull snags most stray comets (like Shoemaker-Levy 9, whose impact scars are visible in this image) and captures them or flings them away before they can collide with Earth.

“Success Can’t Be Predicted”

Where does all this leave us? Can we still believe that \( N = 1 \)? Probably not. What about \( N = 0 \)? To many people that extreme is inherently unacceptable, but of course the universe isn’t obliged to live up to our hopes and expectations. Maybe there is some truth in the saying that nothing in the universe happens only once. Maybe alien civilizations are out there, and some are trying to announce themselves via radio transmissions. But their number could be very, very small.

In the preface to Is Anyone Out There? Frank Drake wrote that he wanted to "prepare thinking adults for the outcome of the present search activity — the imminent detection of signals from an extraterrestrial civilization. This discovery, which I fully expect to witness before the year 2000, will profoundly change the world." In July 1996, at the fifth international bioastronomy conference in Capri, Italy, he confessed: "Maybe I was a little bit too optimistic. Success can’t be predicted." Coccooni and Morrison already told him so in their 1959 Nature article: "The probability of success is difficult to estimate, but if we never search, the chance of success is zero.”

Meanwhile, the Drake equation still stands as the best-known icon of one of the most forward-looking endeavors of this intelligent species here on planet Earth: the search for other civilizations, for coinhabitants of the dark emptiness of the cosmos, for a wider perspective on our place in space and time and on the meaning of life. The alien formula has served this effort well by providing a rational basis for the search, by focusing our attention on the really important issues, and by defining a clearly visible goal. If only we could determine all the terms in the Drake equation, the course of action would be obvious.

We’re a long way from that goal. The first term, \( R \), has been known for decades, and we’re now coming to grips with the second, \( f_p \). That leaves us with two medium-size question marks and three big ones — and a lot of speculation. But maybe the Drake equation isn’t meant to be solved after all. Its real value may lie in those thought-provoking question marks. Uncertainty and curiosity will keep the search going for years to come. Maybe the real payoff for SETI is not to yield a yes-or-no result, but to help us discover more about ourselves.

GoyERT SCHILLING (goverts@knooware.nl) is an astronomy writer in UtrechT, the Netherlands. His recent book Tweeling aarde: De streuotocht naar leven in andere planetenstelsels (Twin Earth: The search for life in other planetary systems) was published in 1997.