



# The Drake Equation: 50 Years of Giving Direction to the Scientific Search for Life Beyond Earth

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Tucked in between two Appalachian mountain ridges in eastern West Virginia, you'll find the National Radio Astronomy Observatory's Green Bank observatory, home to one of the largest and most advanced radio telescopes on Earth. But that's not all. Green Bank is the first and oldest site of this national research center, and given that radio astronomy is a young science, this is where the history is.

For example, SETI, the search for extraterrestrial intelligence, got its start in Green Bank. Here, in 1960, Dr. Frank Drake, a young radio astronomer, pointed an 85-foot telescope at two nearby, Sun-like stars: Tau Ceti and Epsilon Eridani. Drake tuned the telescope to detect a frequency of around 1,420 MHz, the frequency at which atomic hydrogen emits. Because hydrogen is the most abundant element in the universe, Drake thought that if an extraterrestrial civilization were going to communicate with us, its astronomers might choose this familiar frequency. He was searching for a purposeful signal: a beacon.

This search, called Project Ozma, was the first of its kind and became the model for future SETI work. Project Ozma produced possibly the most significant result in SETI's history: nothing. But the first nothing is different from the nothings that follow. As Drake said himself, "For all we knew, practically every star in the sky had a civilization that's transmitting."

What Drake learned from Project Ozma's null result is that every star is **not** home to an intelligent, communicative civilization. What keeps SETI going, however, is the idea that perhaps some star system is.

2011 marks the 50<sup>th</sup> anniversary, not of the search, but of a pivotal meeting and the creation of an equation that has done much to guide us in our quest to find life in the cosmos. In 1961, Drake called a meeting of the minds in



Drake standing in front of the telescope he used to conduct the first modern search in 1960 (he called it project Ozma). Credit: NRAO/NSF/AUI.

Green Bank, bringing people like Carl Sagan and Nobel Prize-winning Melvin Calvin together to talk about SETI as a science that could—and should—be pursued. To guide the meeting, Drake came up with an equation, the Drake Equation, which laid out the variables determining how many intelligent civilizations are in the Milky Way (N):

$$N = R^* f_p n_e f_i f_c L$$

These seven factors, discussed below, not only give us a tentative answer to the question "Is anybody out there?" but also point SETI researchers in directions that could lead to a discovery. We know more about the equation's contents than we did in 1961, when the conference was held, but there is still much more to find out. Astronomy and astrobiology have been and continue to follow paths

that lead to better, more scientific, determinations of the equation's  $N$  and thus closer to a potential discovery. Along the way, we are discovering more about the universe and about our place in it.

## What does each part mean?

As you go from left to right in the Drake Equation, each term zooms closer in on the kinds of civilizations that astronomers want to find—the kinds of civilizations that we *can* find, since we must rely on picking up their transmissions with our telescopes. The terms go from galaxy-scale to individual society-scale, in neat steps that work statistical magic: When you multiply the terms (many of which are probabilities) together, you get an answer that has zeroed in on exactly what you wanted to find.

- $R^*$ , the first term, is the rate at which life-supporting stars (not too big and not too small, but just right) form;
- $f_p$  is the fraction of those life-supporting stars that has planets;
- $n_e$  is the number of those planets, per star system, that is habitable;
- $f_l$  is the fraction of the habitable planets where life develops;
- $f_i$  is the fraction of that life that develops intelligence;
- $f_c$  is the fraction of the intelligent life that uses electromagnetic communication;
- and, lastly,  $L$  is the length of time that those intelligent creatures actually send electromagnetic waves into space.

The Equation follows this path: from the kinds of stars needed to produce habitable planets, to the chances that those planets will form, to the chances that those planets will form life, to the chances that that life will be smart and not just microbial or bovine, to the chances that the intelligent life will be detectable by our telescopes, to the

amount of time that we, personally, have to detect them.

Multiplying all these numbers, some of whose values are far from certain, gives the number of communicating, intelligent civilizations that exist in the Milky Way at any given time. That's what  $N$  meant in 1961, and that's what  $N$  continues to mean today, amid advances in astronomy, astrobiology, and engineering that have changed our conception of the universe, and, thus, our estimations of  $R^*$ ,  $f_p$ ,  $n_e$ ,  $f_l$ ,  $f_i$ ,  $f_c$ , and  $L$ .

## What did Frank Drake know about the parts?

### What do we know?

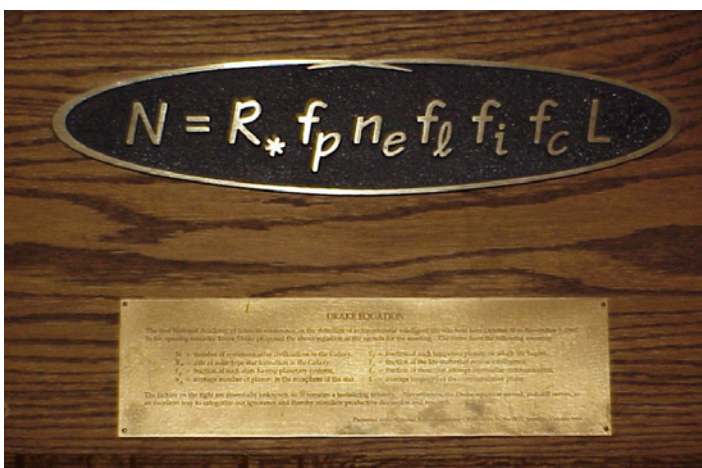
The Drake Equation looks so simple—just multiply! But calculating  $N$  isn't the hard part: The hard part is finding the numbers you need to calculate  $N$ .

Some of the quantities— $R^*$ ,  $f_p$ , and  $n_e$ —are observable with our current technology. By observing many stellar systems, astronomers can come up with reasonable numbers. For example, let's say that astronomers look at 100,000 stars and find that 40,000 have planets. If the rest of the galaxy behaves like these 100,000 stars (and, chances are, it does),  $f_p$  is 0.4, or 40%. But how would we know if a star has planets?

By watching and waiting for a planet to go in front of its star, astronomers can detect a small change in the star's brightness caused by this transit. They can also look for gravitational evidence of planets, such as changes in the star's orbit. Although such measurements were not possible in Drake's day, 506 exoplanets have been discovered since 1992. Based on the number of stars checked for planets versus the number of stars *with* planets, astronomers have determined that  $f_p$  is about 0.4. Drake, without the help of the sensitive telescopes available today, estimated  $f_p$  to be 0.5—pretty close!

$R^*$  (star formation rate), however, appears to be much lower than Drake suspected. While data in 1960 suggested that 10 new stars were born every year, the current number is more like 1 star per year. Since the first SETI meeting, we have been able to make many more observations of “star nurseries”—nebulae, where stars are born—and to gather statistics on the general population, to find stars' ages and deduce how many were forming at any given time.

Drake estimated  $n_e$ , the number of habitable planets in each system, to be 2. This estimation was based on our solar system, where one planet is definitely habitable! Mars and moons like Europa and Titan could also still harbor life, or evidence of former life. To be considered habitable, planets need orbits that don't take them too close or too far from their star; they need an atmosphere; and they need access to life-sustaining chemistry, like organic molecules and water. Currently, we are much better at detecting large, hot planets



Drake equation plaque in the NRAO Green Bank Residence Hall Lounge. Note the smudges from so many people touching the plaque. Credit: NRAO/NSF/AUI.



(ones that are like Jupiter) than planets like Earth, so no consensus on this number has been reached. It is estimated to be between 0.5 and 2. As NASA's sensitive Kepler telescope, whose mission is to find exoplanets, provides more data, we will be able to pin  $n_e$  down.

The last four terms are where the math starts to get dicier.  $f_l$ , the fraction of planets where life develops, is not something we can currently discover, since we cannot travel to the exoplanets. By looking at their chemistry, we can say whether life is possible—but not whether life actually *is*.

We can do work at home, though. Astrobiologists are trying to determine whether, given the conditions for life (conditions like those early in Earth's history), life will arise. Is life inevitable, or is it an anomaly? Drake believed that it was inevitable and set  $f_l$  to 1. Modern scientists tend to be more conservative with that estimate, so conservative that they don't like to speculate.

After we have life, how much of that life will become intelligent ( $f_i$ )? Drake said 0.01, but that was even more of a guess than  $f_l$ . Today, we can do no better. Some say that  $f_i$  is tiny: of the billions of species on Earth, we are the only one that became intelligent. Others say that all those species were leading inevitably to us, and that given the chance to develop, life will always become intelligent—meaning that  $f_i$  would be 1. Who knows?

After smart life exists, what chance does it have of using electromagnetic waves to communicate? Drake said 0.01, or 1%. There is evidence for pretty much any number on the 1-100% spectrum. Until we detect a civilization—or, really, unless we detect hundreds of civilizations—we can't know too much about this number. At that point, we won't care very much about the Drake Equation!

The same is true of  $L$ , the length of time that a typical civilization communicates: The only example we can have, until we find ETI, is ourselves, and we don't know when our communication will end. A world war could easily end us. So could a supernova. Or runaway greenhouse effect. Or an asteroid. Or, alternatively, civilization could progress for millions of years. The problem is, we'll never know until we get there. Drake said  $L$  was 10,000 years, but, again, that was just guessing, and hope.

$L$  is the term that has the most potential to change the equation's outcome. While most parameters must be between 0 and 1, and can only make  $N$  smaller,  $L$  can be anything. The lifetime of civilizations is the most important factor determining our chances of finding ETI.

Taking the current numbers (or the average of the estimates) and multiplying them, we get  $N=(1)(0.4)(1)(0.5)(0.5)(0.5)(10,000)$ —Drake's  $L$  thrown in for good measure—or  $N=500$  communicating civilizations in the galaxy.



Frank Drake explaining his equation to BBC program host Dallas Campbell in the NRAO Green Bank Residence Hall Lounge. Credit: NRAO/NSF/AUI.

## What is the value of the Drake Equation to students?

So much of the science that students learn is presented without its context. They never see the false starts, the uncertainty, the speculation, the inaccurate interpretations. Without this information, science can seem like merely a set of facts, and not the *process* that allowed scientists to draw conclusions. The importance of knowing about the nature of science—or having a conception of science as a dynamic, rigorous, logical, interpretive, not-always-procedural field—is on par with holding an encyclopedia in your brain.

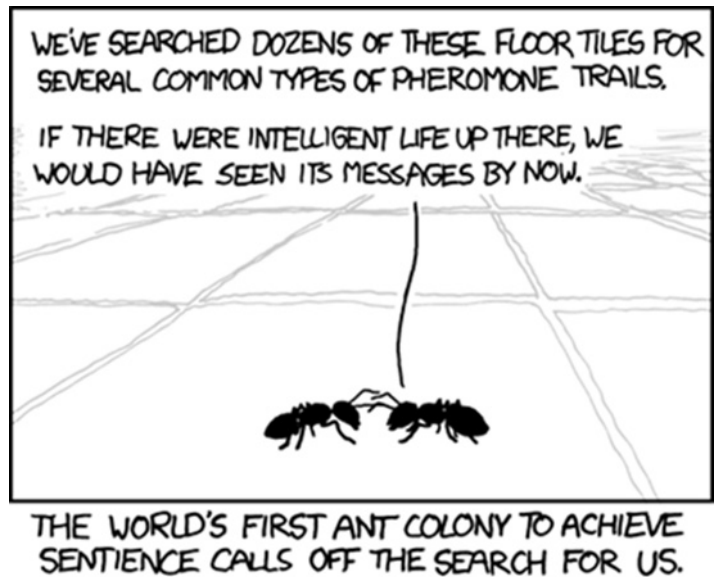
The Drake Equation, by its very existence, can teach students about the nature of science and what scientists really do, as opposed to what they have already done and put in textbooks. The Drake Equation demonstrates that science does not (yet) have all the answers, and it shows that scientists' opinions and knowledge change over time, since the values that Drake derived were often different from the ones derived today, based on new observations made possible by new technology. However, the Equation also shows that no matter how many new observations and how much fancy technology we have, we still need to speculate.

Drake speculated when he made the equation, having little concrete information about the variables, but he struck gold: The Drake Equation's terms point in the direction of modern astronomy. The information that Drake thought would be important to SETI has, it turns out, become important to astronomical research.

By breaking a huge problem (How rare or common is life in the universe?) into a set of smaller problems, Drake and the scientists who followed him were able to make sense of a question whose answer, it seemed, could only be a shrug

of the shoulders. Students, too, can learn to cut a problem up into chewable bites—a useful skill on a test, in a lab, in a term paper, in a social situation, or in a political election.

Fifty years after the Drake Equation's conception, we are much closer to being able to discover ETI. We can detect much weaker signals, we have looked at a much larger area of space, and we are able to zero in on the kinds of stars and planets that seem likely candidates. We are also, however, much closer to estimating how not-alone, or alone, we are, and thus our chances of SETI success. Sometimes, students will discover through learning about the Drake Equation, finding answers takes years and years—sometimes more than human lifetimes—and there is not always a guarantee that we will ever find answers. The long time scales and the uncertainty, however, do not mean we should abandon speculative fields of science: Instead, they are what make science exciting. As we learn more about the universe, we also create new questions. Using science to unravel its mysteries, over thousands of years of human history, unites and inspires us.



Credit: <http://xkcd.com>.

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## Resources

<http://www.seti.org/Page.aspx?pid=336>

Drake's explanation of the equation's significance and its parameters.

<http://www.pbs.org/lifebeyondearth/listening/drake.html>

A calculator that allows you to put in your estimations of the parameters.

<http://www.pbs.org/wgbh/nova/origins/drake.html>

A calculator that allows you to put in your estimations of the parameters, but also gives Drake's estimates, as well as range of scientifically valid estimates and explanations.

<http://astrobio.terc.edu/drake/>

Another calculator, but one that also calculates the number of habitable planets in the galaxy, the number of planets in the galaxy with life, and the number of planets in the galaxy with intelligent life.

<http://www.skyandtelescope.com/resources/seti/3304541.html?page=1&c=y>

A detailed analysis of the parameters and what current estimates of them mean for our chances of finding intelligent life.

The Search for Extra-terrestrial Intelligence (SETI): An Introductory Resource Guide, by Andrew Fraknoi

[http://www.astrosociety.org/education/publications/tnl/77/SETI\\_Resource\\_Guide.pdf](http://www.astrosociety.org/education/publications/tnl/77/SETI_Resource_Guide.pdf)

The Fermi Paradox

The Fermi Paradox basically asks the question: "if there are so many extraterrestrial civilizations out there, why haven't we had contact?" It is the apparent contradiction between the idea intelligent extraterrestrial life is common and has had adequate time to make contact, and the fact no contact has occurred. Here is a link to explanations of the Fermi Paradox:

<http://www.seti.org/page.aspx?pid=678>

Webb, Stephen *If the Universe is Teeming with Aliens... Where is Everybody? (50 Solutions to the Fermi Paradox)*. 2002,

Copernicus/Springer Verlag. The great physicist Enrico Fermi wondered one day why aliens were not visiting us, if they are out there. Here are some interesting answers, intelligently summarized from many sources.

# Classroom Activities

## Featured Activity:

*Is there life on other worlds?* An activity from *Life on Earth... and Elsewhere*, an Astrobiology Educators Guide from the NASA Astrobiology Institute. This activity uses the framework of the Drake Equation to have students consider the implications of each term and make their own estimates of life in the Milky Way galaxy. Included are activity procedures and worksheets, as well as a math extension activity.

[http://www.astrosociety.org/education/publications/tnl/77/UITC\\_77\\_Activity.pdf](http://www.astrosociety.org/education/publications/tnl/77/UITC_77_Activity.pdf)

## Other Activities:

*Life on Earth... and Elsewhere*, a booklet of activities on astrobiology and the search for life beyond Earth from the NASA Astrobiology Institute.

<http://nai.arc.nasa.gov/library/downloads/Astrobiology-Educator-Guide-2007.pdf>

The Drake Equation: Estimating the Number of Civilizations in the Milky Way Galaxy

<http://btc.montana.edu/ceres/html/DrakeEquation/Drake.htm>

This page contains a list of the National Science and Mathematics Education Standards that are met by learning about the Drake Equation and doing the described activities. The first lesson is about statistical extrapolation, the second is about informed estimation, and the third is about the Drake Equation (and how the first two activities fit in with it).

Activities from the SETI Institute

<http://www.seti.org/Page.aspx?pid=364>

SETI-related activities for students in grades 3–9, along with which National Standards they address.

*Messages From Space*, a GEMS teacher's guide

<http://www.lawrencehallofscience.org/gems/GEMSmessages.html>

Building on collaborative work between the SETI Institute and the Lawrence Hall of Science, *Messages from Space* takes advantage of student's fascination with extraterrestrials to catalyze study of the solar system and beyond. The activities create an exciting context for students to engage in creative learning, gaining a great deal of astronomical knowledge.

*Capturing a Whisper From Space*: poster and activities from the NASA Deep Space Network

<http://deepspace.jpl.nasa.gov/dsn/educ/poster.html>

The NASA Deep Space Network (DSN) is a series of radio telescopes used to communicate with spacecraft beyond Earth orbit. The principles the DSN telescopes use are the same ones as for the radio telescopes used in SETI. The back of the poster features classroom activities to help learners understand how a radio telescope collects and concentrates radio signals from deep space.

SETI@home

<http://setiathome.berkeley.edu>

SETI@home is a scientific experiment that uses Internet-connected computers in the Search for Extraterrestrial Intelligence (SETI). You can participate by running a free program that downloads and analyzes radio telescope data.

*Universe at Your Fingertips 2.0*, a collection of astronomy teaching resources on DVD-ROM from Project ASTRO and the Astronomical Society of the Pacific.

<http://astrosociety.org/education/astro/astropubs/universe.html>

This newly revised edition of the popular and comprehensive collection of astronomy teaching resources contains a large section on Space Exploration and SETI, including background articles, resource guides, and classroom activities.