# Astronomy Cast Episode 23:
# The Drake Equation

**Fraser Cain:** Astronomy Cast episode 23 for Monday February 12, 2007: The Drake Equation.

Welcome to Astronomy Cast, a weekly facts-based journey through the cosmos, where we help you understand not only what we know, but how we know what we know.

My name is Fraser Cain, I'm the publisher of Universe Today and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville.

Hi Pamela

**Dr. Pamela Gay:** Hey Fraser, how're you doing?

**Fraser:** I'm doing great – well, actually, I'm still in mega-school-crunch, but eight more weeks to go. Then I get to breathe again.

[laughter]

So this week we're going to talk about UFO's – well, not exactly, but we're going to talk about extra-terrestrials.

So we want to talk about how scientists think about the chances of finding other life in the universe. Our starting point is going to be the famous Drake Equation, which attempts to understand all the variables that are or could be involved in the rise of extra-terrestrial life.

Alright Pamela, pick a starting point – do you want to talk about Drake or his equation?

**Pamela:** Well, why don't we start with where Drake announced his equation?

**Fraser:** Okay, a little of both!

[laughter]

**Pamela:** Okay, so Frank Drake was an astronomer (in fact he still is an astronomer – he's at the University of California, Santa Cruz) and back in 1961, he and a colleague pulled together the first conference on the search for extra terrestrial intelligence and they did this at Greenbank radio telescope.

He put forward this idea that in trying to figure out how likely we are to find life, perhaps we should start by trying to figure out how likely life is to exist, what number of stars out in the galaxy potentially are homes for intelligent life.

He brainstormed all of the different things that you should have to factor together and came up with this really neat equation that people continue to use today in trying to figure out what probabilities we have for finding those little green men that are at the heart of every good sci-fi story.

**Fraser:** I guess the Drake equation has a real practical value, which is that if you can start to pin down some of those underlying variables, you can get a sense of how large a search you have to do in our galaxy to try and listen for signals from other worlds or maybe even be able to image some other worlds directly. If the number is really really small, then forget about it, but if the numbers are really good then maybe there's a chance within our current equipment.

**Pamela:** That's exactly right. A good way to think of it is if you need to roll a six, you know that with a six-sided die, you have a one in six chance of rolling what you need. However, if instead you have a 20-sided die, suddenly you have a 1 in 20 chance of rolling the six you need. The higher the number of sides of your dice, the harder it's going to be for you to roll that six.

If we're trying to find a planet out there and the chance is one in four stars are going to have the type of planet we're looking for, it's going to be easy to find. If it's a 1 in 10 thousand chance, we're going to have to use an awful lot of telescope time over an awful lot of telescopes and years to find those potentially civilized worlds out there.

**Fraser:** So what are some of the pieces that go into the Drake equation?

**Pamela:** The Drake equation as it was originally formulated starts off by asking, "what is the rate of star formation, and what is the lifetime of those stars?" If you factor those two things together you can get a sense of how many stars there are out there that we need to consider. The reason you need both of these things is the rate at which stars are formed in combination with the amount of time that they're around gives us a constantly updating number.

If you go into a really sad little bakery that only has one oven and can just produce one loaf of bread every three hours, then you have bread being created at a rate of every three hours. Now, if you just think, "okay, the rate of bread is one every three hours" then you might think that several days later you're going to have a gazillion loaves of bread. The truth is one loaf of bread will probably only last for 24 hours, so at most if you have one loaf of bread popping out of the oven every three hours, and they go stale every 24 hours, that little bakery is never going to have anymore than eight loaves for you to look at.

**Fraser:** So stars go stale like bread?

**Pamela:** Exactly. Our own Sun is going to basically go stale in about a billion years, and no longer be suitable for allowing life to exist on Earth. So we have to consider how often these stars form and how long are they useful.

So, when you factor these couple of different things together, you get 15 stars being formed a year, and any given star is probably only useful for about 6 billion years. That leaves you in a situation where you have about 90 billion stars at any given moment are hanging out being useful for life.

**Fraser:** Is that in the Milky Way?

**Pamela:** That's in the Milky Way.

**Fraser:** So there are actually 15 stars every day? Being formed?

**Pamela:** Every year.

**Fraser:** Every year, sorry. 15 new stars every year being formed.

**Pamela:** Yes. Roughly. We guess.

**Fraser:** That's cool. So that part of the equation is kind of nailed down/

**Pamela:** Yeah, it does have some large-scale averaging over sort of the whole life of the galaxy, so it's a smoothed out thing. There are certain places where you look and you see gazillions of stars being formed simultaneously. But if you look around on the internet, this is the generally accepted number that people are plugging in right now.

**Fraser:** Okay, and what's the next part of the equation?

**Pamela:** So the next thing we look at is what is the fraction of stars that are going to have planets? This is one of those things that we're still working to figure out, but near as we can tell, if a star has enough metallicity, enough metals, rocks, the heavier mass atoms in the area where it forms, then it's going to form with lots of heavy atoms in it, and the heavy atoms are going to be available for the planets to form as well. It looks like, in our galaxy, about 50% of the stars have the necessary amount of metals to allow planets to form.

**Fraser:** Okay, so let me see if I understand this one. Obviously we've found the big, hot Jupiters and some of the other exotic planets, so – I guess we can't directly observe those, those stars and say "aha, there's all those planets let's count them all up so we know" but there's a kind of connection between the mineral content or the metal content in the stars to the way we've been finding planets – we've been able to connect that?

**Pamela:** Yes. So, when you go outside and look up, some of the stars you see are made of almost pure Hydrogen and Helium. Others are still on the grand-scheme of things primarily Hydrogen and Helium, but they have a little bit of the heavier elements in them. That little extra bit of the heavy elements allows them to have planets around them because those same elements that were available to enrich their atmospheres were also available to form planets.

On a logarithmic scale where we set our Sun as the zero-point, we find that within roughly plus or minus 0.75 on this log scale, in the fraction of iron to hydrogen, we're able to find stars with planets.

So, that was a lot of gobble-de-gook, but the moral of the story is things that have lots of iron also have planets. There's some really neat tables of information available on Geoff Marcy's website (he's one of the big guys behind finding planets), that list the metal ratios, the iron to hydrogen ratios for all the nearby stars that have planets found around them. You can just look through and see pretty much all the stars are about the same temperature and about the same metallicity as our Sun.

Admittedly there's selection effects. They're looking for stuff that looks like the Sun, to look for planets that look like the Earth (or, actually that looks like Jupiter – we can't see the Earth yet). But other groups have gone and looked at metal-poor clusters of stars, looking for stellar transits, looking for events where planets pass in front of the star. They haven't been able to find any planets that way so far.

The more people look for planets around metal-poor stars, the more they don't find them. So, it's looking like you need to have stars with at least as much metal as the Sun (roughly) or more metal than our Sun, more metal than the Sun seems to be working just fine.

**Fraser:** Okay, so they've been able to kind of nail that number down. This is good so far.

[laughter]

**Pamela:** So far so good.

**Fraser:** I think we're going to find life just around the corner! Okay, so what's the next one?

**Pamela:** So the next one is how many planets might exist around those stars that are capable of having life. The way we multiply these numbers together is you look at the total number of stars and then you multiply that by a number between zero and one that indicates the number of those stars capable of having life. Then when we look at what's the number that can potentially support life – if it's like, every other star might have a planet that can support life, you plug in 0.5, but if you think every star might have two or three places that can support life, you plug in a two or three.

In our own solar system, you look around and you say "okay, Mercury – way too close to the Sun, too hot, can't support life as we know it, doesn't count." Mars, Venus and Earth are all three in this habitable zone that allows them to, if they have enough atmosphere (or little enough atmosphere in the case of Venus - it's greenhouse effect sorta killed it) if they have high enough gravity to hold on to its atmosphere (Mars' gravity isn't high enough to hold on to its atmosphere) all these worlds are in a habitable zone where maybe life could've existed.

So, here I look around and I figure there's probably a good chance that there could be two to three moons in any given solar system, two to three Earths, Mars', Venus', when you add all these different planets and moons that might've had life together, probably something like two or three is possible in a given solar system.

**Fraser:** So there could be two to three places in the solar system where life could evolve if that's how it works. If it has a chance to evolve, or if there's a way that it moves from planet to planet the panspermia concept.

**Pamela:** Yeah.

**Fraser:** Yeah, okay. So, so let's say then, that, and once again we're starting to get fairly, um, hypothetical right? We're not sure, we haven't ---

**Pamela:** We're *totally* hypothetical.

**Fraser:** We haven't seen any other worlds yet, we haven't seen anything else in the habitable zone, but I think that's within striking distance, I mean within the next 10-20 years, we're going to start having some amazing instruments up there.

**Pamela:** Yeah, no there's what's called the Space Interferometry Mission that's being planned, and it's estimating that of the 2 thousand stars it's planning to look at it could conceivably find planets that are only about three times greater than the mass of the Earth around 120 of those stars.

They're estimating that they'll probably find earth-massed planets – planets just in *size* like the Earth – around 6 of those 2 thousand stars, which is a small number, but it still pretty impressive to think that they can find and they can only find planets that are in special types of orbits, so that's pretty cool.

**Fraser:** So that may get answered within our lifetime. Well we're halfway through the equation, this is easy!

[laughter]

**Pamela:** Yeah, but the hard ones to guess are the ones that are coming up.

**Fraser:** Okay, hit me with them!

**Pamela:** Okay, so once you've figured out how many planets could possibly have supported life (even bacterial life), well how many of those actually bothered that possibility into a reality.

So, here in our solar system where we have three possible planets, as far as we know only one of them actually supported life and that's the one we're standing on.

**Fraser:** Right but that's why they're doing all this work into extrema files and stuff, they're starting to find life is – wherever there's water, here on Earth, there's life.

I've heard that there's an estimate there's potentially more life underground inside the Earth, in terms of bacteria in deep vents and cracks of the Earth in sort of biomass than there is on top of the Earth.

**Pamela:** Exactly. But it doesn't show a lot of intelligence.

**Fraser:** No, nonono, but you didn't say it had to be smart!

[laughter]

**Pamela:** No, I didn't

**Fraser:** You said it had to be *alive*.

**Pamela:** And, you know I really wouldn't be surprised if we found some sort of single-cell, or perhaps even – they're saying there's types of life that aren't necessarily what we're used to. Things that don't necessarily have the nucleus of the cell, the cell wall, the mitochondria. Instead there might be even simpler forms of life, and I wouldn't be surprised if we found any of these extremely simple, border-on "is this life or is this a crystal that's capable of reproducing" type of life on Mars.

**Fraser:** But even if we find life on Mars, that's where that thing I was mentioning before, the panspermia comes into play, because there could be a chance that there's some mechanism that life is getting to and from planet to planet in our own solar system, that you know, asteroids or meteors are smashing into one planet, it's kicking up debris, the debris is making its way to another planet, and you know, can deposit again. So even if we find life across our whole solar system that still doesn't rule out that life is just good at getting around inside a solar system.

**Pamela:** It doesn't, and it's quite possible if we find life on Mars, life other places, that it's just ejecta from wherever in our solar system life first formed.

But the thing is, as we talked about with Comet McNaught, we're flinging things out of our solar system periodically, so the idea of panspermia written large, allows you to actually fling bits of life all about the Universe. Now I'm not saying that happens, I'm just saying the possibility happens. I think, in my heart of hearts, that the probability that life independently crops up in multiple locations is much higher.

**Fraser:** I had read a research report where they calculated (and I don't remember the details), but essentially every planet, every solar system or every star system in a galaxy is leaving behind this trail of debris behind it, from collisions and particles are being ejected by the solar wind and all of that, and that those debris trails are kind of mixing so it's entirely possible that over certain millions or tens of millions of years, another star system may kind of pass through that debris trail. If there is a mechanism for life getting around, then it could transfer from system to system.

**Pamela:** And while the solar wind does a really good job at pushing a lot of the small stuff out of the way and preventing it from moving into the solar system, who knows if it could have any effect at all on a rogue comet from a different star system that decided it wanted to visit our star system.

**Fraser:** So even if we find life in another star system, we might still be related. But I guess that's where you can do like, genetic testing to see, you know, if they both shared DNA, then you could maybe even track back and find out when the common ancestor was and that starts to explain some things.

So I think if we find life on Mars, and we find life on Venus, at least that tells us what the origin is. If it's completely alien from the way our life works then that's important.

**Pamela:** And the problem is, since we don't really know how life starts, we don't know what its simplest form is and we can't say that this little viral packet that has like, three genes and this little viral packet that has like three genes (I don't even know if things can form that small, I'm not virologist or bacteriologist). If the smallest, simplest forms that we find, if they are almost identical, we don't know if that's because that's just how they form.

It's sort of like there's many different life forms on Earth that branched in evolution millennia ago and then ended up forming much later on, the exact same features that they didn't have in common before, because that was the most useful way to form something. So, it's without knowing how life formed, we can't say "well clearly, you'd expect things to be completely different". Sure, it seems like a good idea, makes for great sci-fi, but we can't scientifically say that it's impossible to get the most simple life forms to be virtually identical within two different environments.

**Fraser:** Okay, well you know what? I'm going to put a question mark on this one and we'll move on.

[laughter]

**Pamela:** Okay, that sounds great.

So we move from the fraction that developed life, and I'm going to say we define this simply as the fraction that allow life to exist on them for a little while, doesn't necessarily have to have started there, but the life exists. So once we have life, how much of it develops an intelligence?

When we look around our own planet, we have millions of different types of life forms, but we're the only ones that drive cars. There are other intelligent life forms on our planet, but they don't form cities the same way that we do. Many forms of whales seem to have complex language and societies and family groups, but they don't talk on cell phones. And so we have to ask what fraction do they have with intelligent life, and we have to be careful here – do we include whales? Where do we draw the line for intelligence?

**Fraser:** Does the Drake equation draw that line?

**Pamela:** It simply says what fraction develops intelligent life, and doesn't define "intelligent" for us.

We might get a clue from the next line, where it's what fraction develop technology and are willing to communicate. So there, you need to get through these three parameters: You have to have civilization, you have to have technology, and then you have to be willing to communicate. These are the people we're going to find.

If there's a society on another planet that decides "we're going to use fiber-optics for everything we do" they might develop technology, be an advanced society, and because they don't leak radio waves out of the planet, and they're not beaming radio waves off of their planet, trying to communicate, we're never going to find them.

So it's complicated here, trying to define what makes a civilization a civilization, how many civilizations that are out there are going to develop technology, and of those how many are going to try and communicate – whether it be willingly or unwillingly- I don't think we're trying to communicate with our TV signals, but we actually are trying to communicate with our TV signals just because they're out there and they're flying and they're detectable.

**Fraser:** Now what are some of the best estimates that you've heard so far? I think that's kind of a crazy question, because, you know there are so many variables in there that there could be one – we know there's at least one intelligent life form in the Universe, willing to communicate – we've already sent out our televisions so I think we're already set. And then you could have it so that they're everywhere, though that's when we move into the Fermi paradox – if they're everywhere, then where are they?

So are there some estimates?

**Pamela:** When I look around the Internet, I see everything from the most bleak "we're it" type estimates, to "there are millions of other planets out there that should be thriving with societies that we can detect". My own rath attempts to figure out what's logical got me anywhere from 100 thousand to 100 million possible societies out in the Milky Way right now. Now, given that there's roughly 45 billion stars that I think it's likely that we could look at and find planets capable of having life, you're looking for anywhere from

100 thousand to 100 million civilisations among 40 billion stars, and that's kind of hard to find.

**Fraser:** But doesn't 100 thousand make it impossible to find them – what was the big number? 100 million?

**Pamela:** 100 million.

**Fraser:** 100 million puts them in the neighbourhood.

**Pamela:** It starts to get reasonable, but it's still going to take a lot of telescope time. We've only found 170 star systems that have planets so far and we've been looking for about 12 years.

Our ability to find them is going to get better and better, but we're eventually going to run out of nearby stars to search. Once you start searching more and more distant stars, you're only going to be able to tell if they've had civilizations if those civilizations managed to form very early early on. There you run into a completely different problem that is actually not addressed in the Drake equation.

It took time for our solar system to build up metals. It took time for our stars to form and our planets to form, so the problem arises of – could it be that our society is within a few thousand years of being as young as a human race can be? In this case, as we start looking at things further and further away, we're looking further and further back in time, because it takes light time to travel, and if someone looked at the planet Earth a thousand years ago, there'd be no signs that life existed.

So as we start looking at planets that are a thousand light years away, we can only find societies that are either around stars older than ours, or that somehow managed to miraculously evolve faster than ours – and that's possible. Our planet had a rough start, we had lots of mass extinctions, collisions with asteroids, *many* bad things occurred. But those bad things also allowed the human race to eventually evolve because the dinosaurs had to get wiped out at some point.

So it's unclear if as we look further and further away, we're actually going to be able to start finding more things or if because we're looking back in time, we're doing a self-defeating act of some sort.

**Fraser:** Oh, I see, so it's like the further we look back in time, the older we see, and eventually even though there might be other civilisations near by, if everyone just gets off the starting point at the same time, no matter where we look, it's before the life had gotten civilised enough to start communicating.

**Pamela:** Right.

**Fraser:** So do you have any improvements for the Drake equation, if you had a chance to offer some feedback on it?

**Pamela:** So some of the things we need to take into consideration are, clearly, when could life have started? When did the stars that had the correct metallicity to form planets start forming? We need to take that into consideration. At what point can we expect in those stars' evolution that intelligent life could be expected to start forming? What special characteristics do solar systems need to have in order for there to be intelligent life?

There are people that speculate that in order to get a planet that is stable enough, you need to have a moon that is roughly the same proportion in mass that our moon is. Our moon prevents our planet's tilt from wobbling all over the place, and allows the north and south pole to *stay* the north and south pole, and the equator to *stay* the equator. These are useful things for life.

We also have Jupiter, which does a really good job at catching rogue comets and shredding them before they make it in to the solar system. So just having Jupiter where Jupiter exists, with the size that it has, and having a moon as large as it is around our planet, these things add up to helping allow life to exist.

I think it's easy to form planets. I think the probability that you're going to form solar systems that have the exact same combination of planets located in habitable zone that are large enough to hold an atmosphere, small enough to not gravitationally crush things, and happens to have a moon of just the right size is going to be hard. Finding that in combination with a giant gassy planet that's far away from its star, catching comets, makes it even harder. So we need to figure out how to factor in these characteristics of individual solar systems.

**Fraser:** Right, right. So you need to have a moon, you need to have a Jupiter, you need to have the right size planet – can't be too heavy, can't be too light… there's a lot of variables. I guess that's the great thing about astronomy right now. The scientists are hard at work either directly or indirectly trying to figure out a lot of those numbers.

**Pamela:** I have complete respect for the people out at the SETI Institute that are working to figure out how to tie all these pieces of information together. I have to admit I'm not exactly sure I want to find civilized alien life during my lifetime, but I respect the science that they're doing greatly. There are a lot of really smart people working on what are the best techniques for trying to find planets around other stars. And trying to define which stars do and don't have planets, both in terms of the temperatures of the stars, the sizes of the stars, and the metallicities of the stars.

**Fraser:** I wonder how much research has been driven by some of the pieces of the Drake equation. I mean, if some scientist who's quite into science fiction is saying "I'm going to try and figure out this part of the equation" I think it's probably kind of like Star-Trek, you know? It's really helped to drive certain astronomers forward on their research and their enthusiasm for the topic.

**Pamela:** One of the things that I think speaks the highest about this is the SETI Institute, out in California, is privately funded. They don't take government money. They're able to employ really good scientists, get telescope time and do all their work through donations and sponsorships.

I can't think of any other group of that prominence and notoriety – everyone's heard of SETI@Home who's interested in astronomy and extraterrestrials. They've managed to do everything they're doing on their own. NASA takes government money, obviously, and most universities are running off of NSF grants, NASA money as well as tuition. People are willing to put their money where their imagination is and trying to define where can we look for intelligent life?

**Fraser:** It's kind of like the most important scientific question out there, I think. Are we alone in the Universe? If we find that answer, either way (we're alone or there's others out there) would be one of the most important things we'd know about our state in the Universe.

**Pamela:** It's definitely a question that's a thrill to pursue. But I have to ask you this (just to turn things around): how do you see our society reacting if we actually do find signs of intelligent life?

**Fraser:** I think, because it's so far way, people will go crazy in the beginning and then it will kind of be sort of in the background. I think you can almost get used to anything, so in the beginning, for the first little while, it'll be big, big news and seep into culture in many different ways. Then I think it'll be something you're just kind of used to, like watching television. I think people will get numb to it pretty quick.

[laughter]

As amazing, as exciting, as deep and meaningful a discovery it would be, I think we would get numb to that and want something more. So, yeah, I don't think it would sort of come in on everyday, all days, all we'd be thinking about. Life would go on.

I think part of it, is it's just so impractical to talk to them and to get out and visit them, but maybe that can be solved too.

Alright, well see - this wasn't one of our hopeless episodes about a grim future!

[laughter]

**Pamela:** It was definitely filled with hope!

**Fraser:** Alright, I'm going to do my standard blurb so people can find us.

You can get more information on our website at www.astronomycast.com. You can send us any comments, questions or feedback to info@astronomycast.com.

You can join a discussion in the forums, click the "post a comment" link beside any episode on our website.

We've also got show notes and transcripts, and there's an enhanced podcast as well if you've got an iPod or portable player that can play it, you can get little pictures that go along with the episode.

You can subscribe to this podcast by pointing your podcatching software at astronomycast.com/podcast.xml Or you can sign up in iTunes, just search for Astronomy Cast in the iTunes Store and then click subscribe.

Alright, thanks Pamela! We'll talk to you next week.

**Pamela:** It's been my pleasure.

**Fraser:** Alright, bye-bye.

**Pamela:** This has been Astronomy Cast, a weekly facts-based journey through the cosmos. Show notes, transcripts and more are available on our website thanks to the kind donations of listeners like you. Check it out at www.astronomycast.com.

Music provided by Travis Searle.

*This transcript is not an exact match to the audio file. It has been edited for clarity.*