# Ask a Biologist vol 038 Topic: Life & Building E.T. Guests: Paul Davies and Ferran Garcia-Pichel

## Life & Building E.T. -

What is life and how do biologists decide if something is living or non-living? Dr. Biology visits with physicist Paul Davies and microbiologist Ferran Garcia-Pichel. They talk about life, extreme life forms (extremophiles), and the possibility of life on other planets. Listen in as they build their own E.T. and wonder if maybe, just maybe, we might all actually be E.T.

## Transcript

**Dr. Biology**: This is Ask-a-Biologist, a program about the living world, and I'm Dr. Biology. In today's show, we're going to go to extremes while talking about life - life on Earth, and the possibility of life on other planets. As a matter of fact, we're going to be talking about extremophiles and extraterrestrials. You might have heard them only with their initials: E.T. And just what E.T. looks like? Well, we're going to try to figure that out today. We're even going to build our own E.T., in the studio.

Our two guest scientists that are going to help me bring some life into this show are Professor Paul Davies, a physicist who's been thinking about and writing about science and space topics, including time travel and the possibility of life on other planets. He's also the founding director of a new institute at ASU, called Beyond. You can reach it on the web by typing in beyond.asu.edu.

Professor Davies is an author of so many books - actually, more than 20 if I'm correct. And I'm not going to list them all, but I will mention one that you'll want to check out, and that's the one called "How to Build a Time Machine." I don't know about you, but I love the title alone.

My other scientist is Ferran Garcia-Pichel, who is a return guest from an earlier show, where we talked about what you might find in a cup of dirt. Well, wait a minute. He's giving me that look. I mean a cup of soil.

**Professor Ferran Garcia-Pichel**: I see that Dr. Biology remembers well.

**Dr. Biology**: [laughs] Now, Professor Garcia-Pichel is a microbiologist, and he's been studying some very interesting organisms called extremophiles. It turns out that extremophiles are giving scientists clues about the possibility of life - not only here on Earth, but out there on other planets.

And even though one of my guests is a physicist and the other a microbiologist, both have an interest in a topic called astrobiology. In case you're not familiar with astrobiology, it combines parts of astronomy, biology, and geology. And it's focused on, primarily, looking for life or studying life - where it began, how it changed over time, and where it might exist on Earth and out there in the universe.

Welcome to the show, Professor Davies.

**Professor Paul Davies**: Hello.

**Dr. Biology**: And welcome back, Professor Garcia-Pichel.

**Professor Garcia-Pichel**: Thank you very much for inviting me.

**Dr. Biology**: Before we get started on a journey with extremophiles and E.T., let's first talk about life on Earth, because this is a really common question students ask when they come to Ask-a-Biologist, the website. They want to know what's living and what's nonliving. What would you say, Paul?

**Professor Davies**: You can make a long list of properties that we recognize in life, but we can always think of nonliving things which share some of those properties, so this makes it really tough. Now, I've got my own favorite, because I think life is really about replicating information - something is being passed on from one generation to the next. And that something we tend to think of as physical structures, but it's actually the information that is the key.

And that opens the way to what I think is probably the biggest overarching definition of life, which is that it evolves. If you have a system that replicates information and changes in some random way and then is selected for, you have the basis of Darwinian evolution. So you could say, if a system undergoes this evolution, then it's living. That is one possible definition of life.

**Dr. Biology**: OK. Ferran, how about you?

**Professor Garcia-Pichel**: Yeah. I'm of the same opinion. It's sometimes very much easier to define what is not life than what is life. And some of the definitions that you may find out there may list some of these characteristics, but you can always find something you would feel uncomfortable considering to be life that shares part of that definition.

And so, even in the case of information, for example, you still could some areas where I would feel uncomfortable defining them as life. So that's why one has to be a little practical sometimes and define life inversely, as what's worth being studied by a biologist, I guess.

**Dr. Biology**: Right. I think the idea, and what I'm getting from both of you, is you need to be flexible when you get into this definition.

**Professor Davies**: Well, if you're looking for life beyond Earth, you absolutely need to be flexible, because we could very surprised.

**Dr. Biology**: Right. Because I can see the teachers out there saying, "Well, yeah, but there are these definitions." I'm going to list the things that typically are the characteristics we define life as. One of them is being able to grow and metabolize - so, to be able to consume and use energy.

**Professor Davies**: Yeah, but tornadoes do that.

**Dr. Biology**: Right. OK. And reproduction is another one.

**Professor Davies**: Crystals do that. [laughs]

**Dr. Biology**: Crystals do that. And the last one is the power or the ability to adapt to a different kind of environment, changing environments.

**Professor Davies**: Well, a balloon will move away if you make a grasp for it, so that's an adaptive system.

**Dr. Biology**: OK. But each example you gave - tornado, crystals, balloons - each one only fulfilled one of the three criteria needed to be "living." As we combine these requirements, that's when life - or what we consider life - becomes more defined.

Now, if we were to end our show at this point, people might think they now have a really good idea of what's living and what's not living. However, there is one question that comes in to Ask-a-Biologist on a fairly frequent basis, and it has to do with viruses. The question that the students ask is, "Are viruses living or not living?" And my answer, which is the answer of Ask-a-Biologist, is yeah, sort of.

**Professor Davies**: [laughs] I think the best way is to say they're part of the life story. But of course, on their own, they can't replicate. But we should never regard organisms in isolation. They're part of an ecosystem or a biosphere. And so viruses have a place in that. In fact, the ocean is pretty much virus soup. It turns out it's teeming with viruses, most of which are completely harmless to us. As part of a life story, I think they're absolutely critical. But you can't pluck an individual virus out and keep it as a pet; it's not going to do very much.

**Dr. Biology**: Right. Exactly. So we're back to this flexibility. And we have to think of definitions and theories in a more flexible manner. And this is part of science. Science is always changing based on the information we start learning.

**Professor Davies**: I'm sure we'll have a completely different definition of life in another 500 years, when we've discovered some really exotic lifeforms - maybe here on Earth and maybe beyond Earth.

**Dr. Biology**: All right. Let's get into our world of extremophiles. Ferran, you actually study extremophiles. That's one of your areas, right?

**Professor Garcia-Pichel**: That's right. Some of the environments in which we study living organisms could be considered extreme environments. And there is a little bit always the question of everything is relative, right? So, some of the environments I study - say, for example, desert soils - may be very extreme from our point of view, in that, for example, water is very scarce. And we don't usually think of those as normal conditions.

But for the organisms that live under those conditions, those particular environments may not be very extreme, in that they may actually not like to live in what we would consider a more moderate or more mundane environment.

**Dr. Biology**: So, what is the organism that you study that is more or less an extremophile?

**Professor Garcia-Pichel**: There is a variety, for example, of cyanobacteria. That's what we like to call them. Blue-green algae they were called in the past. They are photosynthetic, just like plants. And they like to live in those environments where plants can't really make it. That's where they make a living. But for them, those environments may not be too stressful. That's what they evolved to be good at.

So, extremophilia, or the ability to be an extremeophile or liking the extreme is a matter of perspective.

**Dr. Biology**: Well, what I'm talking about extremophiles, I typically say it's those things that live in conditions that most living things can't exist. It's either too hot, it's too cold, it's too dry, it's too wet, it's too salty, it's not salty enough. All these things can create an environment that most living things on Earth can't exist.

But I say, most. There are some that do make a very good living in these extreme areas. So, let's talk some of these extremophiles and where they do live.

**Professor Davies**: the ones that attracted my attention, initially, were those that can endure scalding conditions. How hot can you get? Well the current temperature record is 122 Centigrade, which every body should know is above the normal boiling point of water.

The reason you can get these conditions is in deep oceans where the pressure prevents the water from boiling and you can have volcanic vents from which fluids spews at temperatures up to 350 centigrade. In the periphery of those vents, are not just microorganisms that can live and metabolize in those conditions, but entire ecosystems that are supported by them. Although the more complex creatures live well away from the extreme heat.

But 122 centigrade, the record just went up from 121 last week. And the question is what is the ultimate limit? Now I've been through a lab at the Marshall Space Flight Center in Huntsville, Alabama and seen microbes that were growing and metabolizing at 130 Centigrade for about half an hour, but that's unofficial.

**Dr. Biology**: Let me just quickly add that for those that don't use Celsius as a scale for telling temperature, you and I need to keep a body temperature of around 98.6 Fahrenheit. That's the equivalent of 37 degrees C. So if you compare 130 degrees C with our body temperature of 37 degrees, you can tell that's really hot.

**Professor Davies**: So, these are the really interesting ones. You can go the other way as well, to extreme cold. The problem there is that the ones that like the cold, don't do very much. They just sort of sit around. They can certainly survive in temperatures well below the normal freezing point of water.

So, the temperature range for life to survive, and in some cases to even to metabolize, is really quite huge. It probably goes from -40 Centigrade to about 130 Centigrade. Now that's life as we know it. Of course there is always the possibility of weird forms of life that could endure even more extremes of temperature.

**Dr. Biology**: We just haven't found them yet.

**Professor Davies**: Right. Well, we haven't actually looked. There have been the occasional reports here on Earth of organisms living at above the 130 figure, but these are certainly unconfirmed. The truth of the matter is it's really hard to access. These are microbes that will be living in very inaccessible places, like the deep ocean volcanic vents. And measuring the temperature and extracting living organisms from that sort of environment is a great technological challenge.

So, who knows? The other place we might find them is under the ground. You don't normally think of life extending into the Earth's crust. We think of it as a veneer on the surface of the Earth, but it turns out that if you drill down under our feet here, down to a depth of, no body knows quite how deep, but certainly kilometers, it's teeming with microbes.

The same thing in the base of the ocean, part of the ocean drilling program is to drill holes in the seabed and you find down to about a kilometer again lots of microbes. The point here is as you go deep it gets hot. If you have ever been down in a mine, you'll know it gets hotter the deeper you go. It's the internal heat of the Earth. So, the microbes that live in the rocks, deep down under our feet are thermophiles, or hyperthermophiles, the heat loving microbes.

**Dr. Biology**: Ferran, if you are deep under ground and so, I'm assuming you don't have any light, how do you get your energy? What do these extremophiles doing?

**Professor Garcia-Pichel**: Well, there is fundamentally life knows how to use two types of energy. And theoretically you could use other sources of energy but there are two that have been proven to be used by living organisms.

One is to use the energy in chemical reactions. So, to get chemical fuels, make one molecule react with another. We call this chemotrophs. They use the energy of chemical reactions.

The other one is phototrophs, the ones that use the energy of light, radiant energy. So, in this case, for example, the organisms that Paul was referring to that are living very deep within the Earth's crust most likely are basing their metabolism on the reaction of energy sources that are found naturally within the rock.

Say, for example, hydrogen that may be produced with some of the original magmatic rocks react with, say, water or CO2 in the depths of the ocean. Then they release some hydrogen that can be used, for example by a type of organisms known as methanogens, that would gain energy by the reaction of hydrogen gas with CO2 to make methane.

So, these are what we call chemolithotrophic organisms. Which of course, microbiologists like to use these long words.

**Dr. Biology**: Right. OK. Well, we'll have this on the transcript. So if anybody wants to start looking that up they can do that. All right, well, we've got these extremophiles and someone might say, OK, that's nice to know about them because they're curious creatures or curious plants and we want to know that they're here and that's all well and good.

But, with astrobiology I have a sneaking suspicion because we have the astro - in there that there is a little bit more to learning about extremophiles than just simply knowing that they are here on planet Earth.

What are we learning from these extremophiles or what is it projecting to us?

**Professor Davies**: Well, we were just discussing a very good example. When I was in high school we were told that all life on Earth depended on sunlight, ultimately. We now know that's not true, because of the alternative, chemical pathways of life.

And so, if you don't need sunlight, this opens up all sorts of possibilities in the solar system for where we might find life, where we didn't think it would exist before.

So, if we take Mars, is always a good target for life, the surface of Mars is pretty hostile. It's bathed in ultraviolet radiation, the soil is highly oxidizing. There is virtually no atmosphere. It's a freeze-dried desert, very unpleasant environment.

Beneath the surface of Mars might be a different proposition, deep enough to melt some of the permafrost so as to have liquid water. Europa is another example. It's an ice-covered moon, but beneath the ice is liquid water. It would be pitch black down there. Doesn't matter, though. Life can cope in those conditions.

So, it really has widened our horizons. When I first got interested in astrobiology, people didn't really know there was this pervasive subsurface biosphere on Earth. So, they tended to think that there was really no where else in the solar system where we might find life. We now know that that's not true.

**Dr. Biology**: Right. Because we kept looking for or thinking that you had to have a planet just like Earth to have life. And that may not be true. Quite frankly, it's probably not going to be true.

**Professor Davies**: Not in our solar system. But of course, if we go to other star systems and there's the possibility of other Earths.

**Professor Garcia-Pichel**: So, that's really the reason why astrobiologists are so interested in microbes. It's because they widen our horizons and they show us by studying how far can we go with these extremophiles. In a way they shows how many of these extra-solar worlds could hold some sort of life You know the way they guide where in the universe we are looking for life.

**Dr. Biology**:  Right. I think it is fascinating to me because we study our own planet to learn about others, rather than thinking, we have to go off to another planet to learn about them. Let's see what's here first.

**Professor Davies**:  It's cheaper to do it here.

**Professor Garcia-Pichel**:  We don't have a lot of choices.

[laughter]

**Professor Davies**:  Right. But we'd like to know, for example, are there any organisms on Earth that could survive on the surface of Mars, which is, as I explained, very hostile today. Is there anything here that could actually get by there? And it turns out that's it's not so hostile that it would kill every known life form.

There are microbes here on Earth that are very resilient to radiation and cold and so on. They might be able to eek out an existence on the Martian surface. It's really important that we know what the outer limits to life might be. We're talking all the time about life, as we know it. When we get to life, as we don't know it, then all bets are off.

**Dr. Biology**:  Right. It's actually leading me into the area that I thought would be the most fun for this show. That's where we're going to be building our own ETs. So, you get to build your own ET but you need to describe it. How is it going to exist? What kind of planet is it on? Things like: how does it communicate? Some of those fundamental things that we take for granted. I want to know what your ET is going to be able to do.

**Professor Davies**:  If we are just talking about microbes, of course, then it's a wonderland. We can imagine all sorts of different chemical gradients or physical conditions that microbes could, in principle, exploit. So that one is relatively easy.

It gets much harder if we are talking what most high school kids are concerned about, which is bug-eyed monsters or little green men or intelligent aliens who might be attempting to signal us.

**Dr. Biology**:  That's right: ET.

**Professor Davies**:  And just this morning I've been teaching a class about life in the universe and we were thinking about life on Europa. Now this is a moon that is covered in ice, as I said earlier. Probably many kilometers thick, but it has a deep ocean beneath that.

Now, we could imagine life on Europa, which has become very advanced. There could be marine creatures who over billions of years have evolved to the point of having a very rich culture. They may be advanced scientifically and so on. But they would have no idea about the structure of the universe, because they are sealed off from it by this great slab of ice over their heads.

So, they may talk about the waters above the Earth and the ice above the waters, and imagine that goes on forever. And they are completely oblivious to the fact that we have sent spacecraft to fly by their world and we're looking down from the outside.

They are looking out from the inside but they don't know we're here. And they could be way, way in advance of us, but never have thought to drill their way up through the ice above. Why would you? It's like drilling into heaven. You wouldn't attempt it. It would be a very expensive enterprise.

And so they may be there. They may be way, way ahead of us in all sorts of ways, but we don't know that they are there and they don't know that we're here.

**Dr. Biology**: And so if they're going to be in the ocean, then I'm just going to venture a guess that you are going to have them communicate through sound?

**Professor Davies**: Yes, there wouldn't be any problem with sound. Vision is a real problem. It's dark. They're living in a dark ocean. But they could have a sort of echolocation, working in water like bats have in air. Of course, if they develop technology, then we can imagine they would have all sorts of different systems for communicating electronically and so on.

There have been no fundamental impediment to doing that so long as they could get their hands on the sort of substances you need for technology, like metals and so on. But, we think that Europa has a solid core. If it's just all liquid, then it's all pretty hopeless, but if they can build stuff, then they have the chance of having very sophisticated communication technology.

But, in terms of their biology, I wouldn't expect them to have eyes. Big ears.

**Dr. Biology**: Big ears, right. And they not only would have had to discover fire, but fire under water.

**Professor Davies**: Yes, I think that's a bit of a stretch. But there would be heat coming out of possibly volcanic vents there, as well. Because Europa is tidally flexed, is the technical name. It's squashed out of shape, as it orbits around Jupiter, which has a huge gravitational field.

This causes the moon to bulge and shrink in a time varying way. That creates a lot of heat and that heat could cause geysers or hot vents of some sort to spew material up out of the solid surface that these creatures would be swimming over. So, they would know something about hot and cold, but not fire I would think.

**Dr. Biology**: Right. They might be harnessing nature better than we are. Ferran, all right, you ready? You ready to build your ET?

**Professor Garcia-Pichel**: Sure. I think in order to be our ET we need to introduce a little bit the concept of probability. So, I would like to say that the more defined your idea of the ET you want to build is, the least probable that ET would be.

So, for example, if you're a middle schooler and you're in high school and you want to think about how probable it is to have some other kid with your same birthday, for example, that would be easier and easier the larger your school is. So, if you go to a very small town school, that's very unlikely. But if you go to a very large school, probabilities are very high that you would find somebody else that has your same birthday.

So, in a way the probability to find some ET that you could come up with, you would have to look at larger and larger numbers of planets and worlds in order to find it. So, but in principle, you could extend that all the way. If you have a large enough universe, you could possibly find any kind of ET you wanted to find. You would just have to look at a large enough number of worlds or planets or settings.

Easiest ETs to find, therefore, would be microbes. They are the ones that require least specific conditions. They have a wider range of conditions in which they can survive and a wider range of chemicals that they can use for energy. And then a source of elements to make their own biomass, whatever their physical bodies are made of. You have to have a source of that.

And life as we know it, of course, is based on carbon and so, you have to have a source of carbon, at the very least. Probably some other elements, as well, in life as we know it on Earth. So you have to have a source of what we call the elements that make up life: carbon, nitrogen, phosphorus, sulfur, and so on. And so, these are restrictions that you would use in order to build your ET, but for sure, microbes would be your best bet and your easiest bet.

**Dr. Biology**: Spoken like a true microbiologist. But what if I make you have to be multi-cellular?

**Professor Garcia-Pichel**: That's no problem.

**Dr. Biology**: OK, what's it going to look like? What's it going to do? How's it going move?

**Professor Garcia-Pichel**: All right. How is it going to move? And according to my drive here, we want to get the easiest way of moving. So it's going to move probably by, I would say, excreting some of that excess mass that it's making.

**Dr. Biology**: So it's going to slough...

**Professor Garcia-Pichel**: Slough off things and move away from its own waste. That's very important.

**Dr Biology**: All right and then how's it going to communicate?

**Professor Garcia-Pichel**: It's a microbe so, therefore, microbes communicate chemically. So that's not a problem for microbes. It's very hard for us to communicate chemically. We do it sometimes with volatile substances, but microbes because the transfer of chemicals is very fast at very small scale by diffusion, they have no problem communicating by sending off chemicals.

If we would have to do that, we would have to wait for an inordinate amount of time to get a response. Wait for diffusion to take my message to you. But microbes, they are pretty happy with that. So they would communicate by chemicals.

**Dr. Biology**: All right. Well, I can see I'm going to have a hard time getting away from these microbes. While we're talking about ET, we've been talking about building ET and going to other planets-there's actually a theory that life on Earth started with incoming meteorites carrying life forms. So, the question is could we be ET on Earth?

**Professor Davies**: I've thought a lot about this, and there's a good version and a bad version of the theory you just outlined. The good version is that life may have started on Mars, because Mars was arguably a better place for life to get going. It's a smaller planet, it cooled quicker, it was ready for life sooner. But Mars gets hit from time to time by comets and asteroids with enough force to splatter rocks all around the solar system. And we know some of these Mars rocks come here to Earth because, for example, there's one not very far from where we're sitting in the meteorite collection here at ASU.

So, if Mars rocks can come here, could Mars microbes hitch a ride in those rocks and come to Earth even before there was any life on Earth? And although the evidence isn't overwhelming, I think there's a good chance that in fact life did originate on Mars-the original cradle of life was on Mars-and we are the descendents. So, in that sense we're all Martians.

Where I think this theory doesn't work well is if you suppose that meteorites came in from another star system, because there the numbers game is against you. The probability of a rock knocked off another Earth-like planet ever hitting this Earth is really very tiny. So, I think it works well between near neighbor planets within the same star system. It doesn't work well between star systems.

**Dr. Biology**: Right. That gets back to the probability that Ferran was talking about earlier, just even when you build your own ET, the more specific you get the more difficult it will be to find that kind of ET. How about you, Ferran?

**Professor Garcia-Pichel**: Well, Paul was absolutely right about this, but I would like to add that the reason why this possibility becomes more enticing is that some people think we need it. Because when we look at the record of life on Earth, some people at least are very surprised that life appeared so suddenly and so early during the evolution of the planet in terms of geology.

So, pretty much as soon as the planet cooled down to where life was possible, life was there. Or there is some evidence that that was the case. And that's why some people would like to have a little bit more time for that to have happened. And that's why the Mars idea becomes a little bit more attractive.

**Dr. Biology**: So, it was seeded, and that's why it could start up so quickly.

**Professor Garcia-Pichel**: Yes. That's pretty much it.

**Dr. Biology**: OK. Well, Paul, I have three questions I always like to ask my scientists that come on the show. Ferran has answered these.

**Professor Garcia-Pichel**: So, am I off the hook?

**Dr. Biology**: No, you're not off the hook. I have other questions for you. I never let anybody off the hook. The first one is pretty simple, but it's really important to a lot of people. They want to know, what got you started in science? Was there a particular spark? Do you remember when that happened?

**Professor Davies**: I was born a physicist. I think there is such a thing as a calling, that some people are just born to be quite naturally certain things. And I knew from the earliest age I can remember that physics was it. Of course I didn't even know what the word meant, but I can remember at the age of seven or eight being interested in the stars, in atoms, what went on inside atoms. All those sorts of things fascinated me.

And I certainly knew from the age of 12, 13, around about then, that I wanted to do physics, and in particular astrophysics. And I was more interested in the ideas so I wanted to be a theoretical astrophysicist. And that's exactly what I did.

And how did I get there? I just kept straight down the line. I knew what the goal was and I just worked towards that end. In that sense it was simple. I didn't suffer agonizing choices like so many young people seem to today.

There is so much choice now. I grew up in the 60's and in those days everybody wanted to be a physicist. You'd have to give some reason why you wouldn't want to do it. So, it seemed a very natural thing to do, and I'm really pleased I did it.

**Dr. Biology**: Well, you were born a physicist, but guess what? I'm going to take it all away from you. You can't be a scientist. I'm not going to let you be the physicist or biologist, or astrobiologist. It's all gone. What would you be and what would you do if you weren't?

**Professor Davies**: I know the answer to that question. I've often thought about this, and I've often remarked on it. I'd be an archaeologist. Now, that's a sort of science these days, but basically I'm really fascinated with what might lie in the ground and tell us about the past. And so I'm an avid reader of history books, and particularly very early history.

And I would just love to dig up something about early human history. I grew up in England and it was always my hope that I'd be digging in a field somewhere and find a crown or something like that, [laughs] cast away 1500 years ago. Wouldn't that be wonderful?

**Dr. Biology**: Ferran, when you were on "Ask a Biologist" and I asked that question I remember your answer, and it was you would be an actor. Have you thought about that any more as far as what kind of an actor you would be? Would you be a typical movie actor or are you going to be on stage? What kind of acting would you do?

**Professor Garcia-Pichel**: I would be a good actor.

**Dr. Biology**: [laughs]

**Professor Garcia-Pichel**: But, I think, yes, theater. You know, a traditional theater actor. Yes, a stage actor.

**Dr. Biology**: All right.

**Professor Garcia-Pichel**: Not movies.

**Dr. Biology**: Not movies?

**Professor Davies**: Shakespeare?

**Professor Garcia-Pichel**: Yes. Well, yes, traditional classical theater.

**Dr. Biology**: Shakespeare with an accent.

**Professor Garcia-Pichel**: Not necessarily. Well, yes. Lope de Vega, not necessarily Shakespeare.

**Professor Davies**: I'm sure Shakespeare, if he were here, would be speaking with a very strange accent.

**Dr. Biology**: Yes, he would actually. And I'm actually speaking with a strange accent depending on where in the world people are listening to this. That's true.

All right. Paul, one more question for you, and this is a little more practical. What's your advice for, I usually say a young person, but often there are people that decide to switch careers. So, someone who wants to become a scientist, someone who wants to be a physicist, what's your advice?

**Professor Davies**: My advice always to people who want to follow the physics path is first get your math straight, because this is the sticking point for so many physicists in their careers, that without the thoroughly strong grounding in mathematics it's really hard to make progress. Now, some people, of course, go into the experimental side where there's less mathematics, but there's still quite a bit. And so if you've got a really thorough foundation in mathematics you can pick up the physics later on. So, that's usually my advice.

But, the more general advice about going into science is you have to understand that doing science is about uncovering the secrets of the universe. It's not about just sort of going to a lab or something like that, from nine to five, and sort of working away soullessly at uncovering some problem and trying to piece together the evidence, and so on. It really is about a voyage of discovery.

And you should go into science, in my opinion, only if you've got that dream that you really want to know what are we doing in this universe, how does nature work; this wonderful world all around us filled with all these amazing systems, living and non-living systems, and we understand only a fraction of them. You've just got to be fascinated by wanting to know how does it all work.

**Dr. Biology**: Right. I think it's a passion. I have to say every scientist that's been in here, you hear it in their voice. And since I am in the room with you, I usually see it in their face as well.

Well, Professor Davies, I want to thank you for visiting with us today.

**Professor Davies**: My pleasure.

**Dr. Biology**: And, Professor Garcia-Pichel, thank you again for joining me on "Ask a Biologist."

**Professor Garcia-Pichel**: Always a pleasure.

**Dr. Biology**: You've been listening to "Ask a Biologist, " and my guests have been Professor Paul Davies, founding director of the Beyond Institute at ASU, and Ferran Garcia-Pichel, a professor in the School of Life Sciences, also at Arizona State University. The "Ask a Biologist" podcast is produced on the campus of Arizona State University and is recorded in the Grassroots Studio, housed in the School of Life Sciences, which is an academic unit of the College of Liberal Arts and Sciences.

And, remember, even though our program is not broadcast live, you can still send us your questions about biology using our companion website. The address is askabiologist.asu.edu. Or you can just Google the words, "ask a biologist."

I'm Dr. Biology.