Astronomy Cast Episode 209
Exotic Life

Fraser: Astronomy Cast Episode 209 for Monday November 29, 2010, Exotic Life. Welcome to Astronomy Cast, our 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, how are you doing?
Pamela: I'm doing well. How are you doing, Fraser?
Fraser: Doing great! So you're back safe and sound from TAM Australia and other trips.
Pamela: I am back, and now I'm getting ready to leave to go to the American Geophysical Union meeting where hopefully I'll get to see some of the people out in the audience, but I have to admit I'm going to be trapped inside the conference center and unable to leave, so...
Fraser: [missing audio]
Pamela: Yeah, exactly.
Fraser: And I was recently on "The Skeptic's Guide to the Universe" as a special guest when they did a live show in Vancouver, and I got to handle the "Science or Fiction." But I don't want to ruin the show for you, so give it a listen.
Pamela: Awesome.
Fraser: Now, we don't like to cover news on Astronomy Cast, but sometimes there's a news story that's so interesting and complicated and rapidly-unfolding—and it happens to cover an area that we haven't really talked much about—that we just got to talk about it. So today we thought we'd cover the discovery of arsenic-based life and exotic forms of life in general. Maybe we need to redefine our definition of life, or maybe we just got introduced into some distance cousins, or maybe it's just not that interesting at all. Nah... I think it's interesting. [missing audio] This has changed everything! No... it hasn't changed much...
Pamela: No, no not really.
Fraser: [missing audio] ...speculation up to this discovery and then all of the skepticism and counter-arguments afterwards. It's fun to go through this process. I mean... I watch... I know how it's going to unfold now. We've done so many stories on Universe Today that I know how it's going to unfold every time. So, NASA had a big meeting where they were going to discover something very, very important. And the speculation ran rampant on the internet on what that thing was going to be... and the discovery was...
Pamela: ...that it is believed by a group of researchers—with confirmation awaiting from other researchers—that there is a bacteria from a lake in California (and it never surprises me when aliens come from California) that this particular bacteria is capable of replacing phosphorus in DNA with arsenic... which is kinda cool.
Fraser: [missing audio] So, this is a bacteria, not a space alien with many tentacles. This is a single-cell bacteria. So the environment is very important, though, right? It's a California lake. Something strange about California?
Pamela: Well, it's more something strange about this particular lake. It was locked off from having fresh water coming into it a number of years ago, and so all of the nasties in

the lake have been able to get denser and denser and denser as the waters become more concentrated. So kinda think it's the Dead Sea of arsenic. It's just a very arsenic-rich lake... Mono Lake in California.

Fraser: [missing audio] ...doesn't have the combinations of life... the basic building blocks of life that we understand that you might find in a regular lake. You've got nice clean water, you've got nutrients, you've got sunlight... you've got a lake that would essentially be poisonous to most life forms.

Pamela: Yeah, that whole arsenic and lace thing... people are long-known for dying sudden deaths when "enriched" with arsenic, you might say. So they went looking specifically to see if they could find, in this arsenic-rich environment, a critter capable of making this particular substitution. This is actually something that wasn't just done on a wild whim, but rather there was a study done a number of years ago called "The Limits of Organic Life in Planetary Systems." It was a large committee put together by the National Research Council to try to figure out if we're trying to figure out if there is alien life elsewhere in the universe, where do we go looking for this potential alien life? They came out with a bunch of specific recommendations, and one of their specific recommendations was—and here I'm quoting from the paper—"to search for life that can extract essential nutrients such as phosphorus, iron, and other metals from rocks such as pyrite and apatite." Then they wanted to figure out if those key minerals could be used as key nutrients where they also said to search for organisms from environments that are limited, including limits in phosphorus and iron, such that these organisms can substitute these other elements such as arsenic for phosphorus. So, the study actually recommended finding critters that make the substitution of arsenic for phosphorus. So they were specifically looking for something based on a recommendation made by the wisest people in the field of astrobiology, we hope.

Fraser: [missing audio] ...of that paper here on Astronomy Cast because of our policy of not talking about news. But we actually got interviewed for Skepticality... it was a couple of years ago actually... so we actually went in for about an hour with Swoopy talking about this information. It really brings things around... it's quite neat because you've now got, back then, the recommendation to the scientists to go look for these environments where various pieces of the puzzle are restricted and see if life has found a way to deal with that. Now there's more implications in this original study talking about how you could replace.... could you have instead of a carbon-based life form... what other molecules will do the trick? Ammonia-based life forms and all these different exotic forms of life... silicon, etc. [missing audio] ...this is one of those things with NASA... they do a pretty good job of going forward in a very deliberate manner. If you look at their research, when they're searching for life on Mars it follows the same process. They're looking for evidence of past water. They're looking for evidence of current water. They're looking for evidence of biologically-produced compounds. They're inching towards life in a way that when the scientific evidence is found, it's very good.

Pamela: This all goes back to the idea of extraordinary things require extraordinary evidence. The search for non terrestrial-based life is one of those things that when it's finally found, that is going to be the most controversial claim ever made in science, unless some little green or grey dude comes and talks to us directly. No one really thinks that's going to be how we find life. It's going to be via a signal, it's going to be via an atmospheric signature, it's going to be via some indirect detection. So we're working on trying to figure out how do we make that indirect detection locally with bacteria that may exist on other planets. Where do we look, what do we look for, and then how do we look outside of our solar system.

Fraser: [missing audio] Can you explain in more detail exactly what this little critter is doing?

Pamela: Within our body, human beings require phosphate... one phosphorus atom and four oxygen atoms forming a molecule... for a whole lot of different stuff. Any of you who ever took high school advanced-placement biology got to memorize the ADP cycle within the body which includes phosphate as one of the major constituents of the process. One of the backbones of forming the DNA molecule, that twisted helix that defines who each of us are genetically, one of the backbones of forming that molecule is phosphate. Now the reason that people talk about making a substitution with arsenic is that if you pull out your periodic table or Google one, which is what I did, there's a really good one at www.ptable.com... a horrible name but an excellent periodic table. When you look down the columns, the reason that the periodic table has all the strange gaps that it does... the first row only has hydrogen and helium, the next row has a limited number of things... it has two things on the left and six things on the right. That pattern of the periodic table is actually built on the pattern of orbiting electrons, so in hydrogen and helium you only have two possibilities of where to stick electrons. So you have these two items. Then with each successive movement down the list you add more possibilities for these electrons. Each column in the periodic table represents how many gaps are left in the outer-most orbital, the outer-most layer that electrons can live within. So when you're looking at oxygen, when you're looking at sulfur, when you're looking at selenium, tellurium, polonium, all of these different elements that just happen to make up column 16, they all have six electrons living happily out in their outermost orbital shell and they can fit two more out there.

Fraser: [missing audio] ...eight.

Pamela: Yeah. Well, this particular orbital always goes in rings of eight. So with those six happily living electrons in that particular shell, those six electrons are just waiting to bond with something else, and just waiting for something else to come along and bond with them.

Fraser: [missing audio] ...share them or steal them from somebody, but to make that outer ring be balanced.

Pamela: Right. So when we're looking at phosphorus, in that outer-most level it has five electrons out there. If you go next down the list to arsenic, again you have five in that last orbital. So the idea is that both of them are able to form a similar molecule. With phosphate you have phosphorus and four oxygens. Then they also formed... in the mix that they fed these particular critters that they got from Mono Lake... they created a molecule that was instead arsenic and four oxygens.

Fraser: Right, so it's almost like a puzzle piece that both phosphorus and arsenic have the same puzzle piece so they can connect to oxygen in exactly the same way.

Pamela: Right. We hope... we think... Now the thing is, while chemistry is something I last took in 10th grade... having tested out of it... I have taken lots of quantum mechanics and physical chemistry which avoids a lot of the types of things that you worry about with biologicals. But what it does talk about is bonding angles... the probability that things exist... how they come together. One of the things that does change is the links of the bonds in these molecules. The exact geometry of how they form is just slightly different when you're forming it with arsenic. So it's a similar critter... a similar molecule, rather. But it's not absolutely identical. The question is... can that slightly rescaled molecule get forced to buckle itself in... twist itself just a little bit to fit in and replace the phosphate in these DNA strands.

Fraser: And the initial evidence seems to be... yes.

Pamela: Yes. Now there's been a lot of people being vocal, to say the least, about this. So the reason that you have a lot of people being vocal about this is first of all, it's highly controversial. So, you want to prove them wrong... because that's how science works. Someone says something new and you poke holes in what they said if you can. Now the other reason that they're doing this is what they were feeding the bacteria that they were working with was a salt that did contain trace amounts of phosphate. So the question is were they metabolizing using this arsenic replacement molecule, or were they simply figuring out how to metabolize just enough using these trace, trace, trace amounts of phosphate. There is life that is known to exist that metabolizes phosphate at even lower levels than what existed in this particular salt.

Fraser: Or maybe it's figured out some kind of blend. If it's a folding problem, maybe you can use as much phosphate as you can, then you have to use arsenic. So it could be something in-between.

Pamela: Right. So there's lots of possibilities. One of the things that is on the list of things that scientists are going to be doing next is figuring out how to image the DNA to actually see is the arsenic via some sort of... it's not going to be a direct image... you don't take an electron scanning microscope to look for arsenic... but they're going to be looking to most likely use radioactive isotopes of arsenic to trace is the arsenic getting used to form the DNA molecules.

Fraser: So then what are the implications? We're still going to find out whether this is true or not, and whether this is really doing this or not doing this. But as we talked about, this goes back to this study that NASA did a few years ago where they're really taking another look at the concept of what it means to be life. There are many other molecules, many other solvents that you can use to make what would appear to us in all ways to be life.

Pamela: Right. So, the question basically boils down to can life find a way, when everything else goes to pot, to still exist. Can the substitutions dreamed about in Star Trek actually be made. There's a number of different substitutions that we worry about. The one that most people have heard about is the substitution from carbon, which has four electrons in its outer-most shell, to silicon, which also has four electrons in its outer-most shell.

Fraser: And that's good because I think a lot of people say oh, is this not a carbon-based life form but an arsenic-based life form? That's not what's been discovered.

Pamela: No, this is still carbon molecules forming most of the structure of the bacterium. It's still carbon-based organic life. It's just one particular process that you have a phosphorus to arsenic substitution instead. Bodies are filled with all sorts of things and you require phosphorus... maybe...

Fraser: Maybe... or arsenic...

Pamela: But the reason that we're pretty sure that life on Earth is using carbon and oxygen and using phosphorus instead of arsenic is the cosmic abundances of all of these

things. Here on Earth, carbon is much more prevalent than silicon so it just seems natural that that was what ended up forming life. Now when it comes to phosphorus versus arsenic... again, much more prevalent here on Earth than the arsenic. But it's possible that even though cosmically you expect the same sorts of ratios that we see on the earth, it's possible that via some sort of weirdo process you end up with a planet that has a deficit in one of these particular atoms. Wouldn't it be cool if even in these environments where the atoms that we use are much rarer... what if life could still find a way to exist in these environments, those Mono Lakes of the universe?
Fraser: And what NASA identified is that there are many different places... I mean we assume carbon, water, some kind of energy source... you've got life. But, maybe it doesn't have to be carbon, maybe it could be silicon... maybe it could be some other element. In fact, as we're seeing with this, maybe you can replace some of the different elements that go into the DNA with different elements... replacing phosphorus with arsenic. But the other one that's really important is the actual medium... the solvent that the life does its work in. For us, it's water.... you hear that we're bags of mostly water. That's another one that could be completely different.
Pamela: And that's one of the ones that's even more exciting in the context of our own solar system because if we look out to Saturn's moon Titan, which is what rumor had it that this was going to be a discovery about if you read some of the rumors, on Titan, instead of having a water cycle there's a methane cycle where you have the planet rains methane, there's methane lakes on the surface. It's a combination of at that low of gravity, at that low of a temperature, methane is able to persist and have all of these different functions within the environment. You're at what's called the triple point for methane. Now recently people have been, within the past ten years, working very hard to redefine what it takes to form life. And I love that the definition I learned in elementary school is now completely replaced and this is information that has made it all the way down to the 5 year olds asking questions at events. Now we think that what it takes for life is, just as you were saying, a solvent... not necessarily water but anything that will dissolve stuff within it. You need not sunlight... that's what we learned in school... but instead you need an energy gradient. We say energy gradient because we now know that the thermal vents at the bottom of the ocean can sustain life. And we no longer say it has to be carbon... it could be something else. We're now much more open-minded in our chemistry.
Fraser: So how do these changes, as you say... the definition of life, how does that change our search for life here in the solar system? Where are the scientists starting to look?
Pamela: Well, once upon a time we were only willing to spend the money searching for life in places where we knew liquid water could exist. On the planet Mars we're still desperately searching for where are there places that in reality really salty water could exist? They're seeking brine water on Mars through a lot of theoretical models. But it means that within the solar system, on Titan where you have a methane atmosphere or methane water cycle, you have the potential for life. So we're going to go look there hopefully. We don't know what the sea of Europa might be made of, but we know there's probably liquid there and there's not enough sunlight but there's the possibility for geothermal heating. That's in fact where the ocean comes from. So that's someplace else we want to go look for life. So here we have something other than water on Titan, we

have something other than sunlight on Europa, and we've opened our eyes to the possibility that life could exist just about anywhere.
Fraser: Now would you say... I know one of the descriptions of this was that it was aliens found on Earth... there was alien life on Earth. And again, that's really just not a good description.
Pamela: No. The problem is that people like to run with things and write sensationalistic titles. We've all been guilty of it at one point or another...
Fraser: No we have not! Universe Today has a policy of never ever being sensationalist. Just the science, please...
Pamela: Ok, so I've been "punny" with my titles... I admit that. I don't think I've ever been sensationalistic, I've just been silly.... which is different. And Universe Today... ok, fine... you guys behave well.
Fraser: We don't... but anyway...
Pamela: Anyway, it's easy as a journalist when you're trying to get people to click your link rather than somebody else's link...
Fraser: But don't you people see... this is just like Star Trek! But real! Yeah, that's the angle that we take a lot.
Pamela: So NASA wrote a perfectly reasonable press release that said this will affect our search for alien life... which is true. But then didn't give either enough information to squash rumors or enough information to give away the results. So it was one of these things of... we're not going to tell you anything, we're saving it for the press release.... that allowed wild speculation to occur.
Fraser: Yeah. Again, we absolutely could've watched this unfold and... but the point here is that it's a very interesting evolutionary adaptation to a hostile environment but it is definitely not... I'm sure that we'll be able to trace the lineage to a common ancestor with regular life as we know it.
Pamela: And I have to say that some of the criticisms being leveled at this paper are completely reasonable. The concern that if the DNA molecules were actually built with an arsenic-based molecular structure they should dissolve much more readily in water than they are. That's a reasonable scientific argument. But I've seen other people just sort of stomp their foot and say that this was science by press release. Science by press release refers to times when people... and this happened with cold fusion, we've talked about this before... when people put their results out during a press conference without there being a peer-reviewed paper accepted for publication. This wasn't one of those cases. These scientists wrote a paper, they got as much confirmation as they knew how to get for their first round of work. They submitted a paper to Science. It went out for peer review. They got referees' comments back. They reacted to the referees' comments. The paper was revised. It was accepted for publication. The day the paper was published was the day of the press release, so everyone could review all of the results. They said from the very beginning that this was preliminary. We want our competitors to replicate what we've done and either prove it or show us what we did wrong. That's not science by press release. That's just science at the edge of what we understand.
Fraser: Real science. Perfectly well-done.
Pamela: Yeah.
Fraser: Yeah. Absolutely. So then does this have any implications, do you think, for the search for life in some of the other ways that we search for life? I mean we've talked

about SETI, we've talked about the terrestrial planet finder type mission where you're analyzing the atmospheres of distant planets, does this have any implications for that, do you think?

Pamela: Potentially. So right now one of the more interesting ways that we could identify not intelligent life but simply life on another planet is by looking for molecular oxygen within a certain pattern of molecules in alien atmospheres. Molecular oxygen isn't something that likes to exist by itself. It just has a tendency to do things like form carbon dioxide and carbon monoxide. So when you have that molecular oxygen signature, you probably have algae or plants or something else that we just haven't thought of. But the question is if you can have silicon-based life, if you can have arsenic-based DNA, what sorts of metabolisms do we have to think about? What sorts of chemical respiration processes do we have to think about that might lead to a different, unique signature of life within an atmosphere? This is where the astrobiologists are having a lot of fun is trying to figure out what are the different ways that life can respirate?

Fraser: And you can imagine some space mission being developed which is highly tuned to discover free oxygen in some atmosphere in some distant planet and doesn't find any oxygen in these planets but, in fact, if they had just run all the models and figured out every possible chemical outcome and then built that into the telescope, then you could say no, it doesn't have free oxygen... oh, and it doesn't have... I don't know... some kind of methane output and it doesn't have ammonia in the atmosphere. You could run through this whole checklist and imagine every possible chemical outcome and really be comprehensive about it. Or, you could say look, we found silicon oxide in the atmosphere... I'm not sure if that's one of them but... something that would have to be sustained by a biological life form. So I think this is great because it's really expanding the tool set and giving the new telescope developers more things to look for.

Pamela: And it's always good to find reaffirming data saying life really can exist anywhere. We started from the premise of life is hard... it's difficult to get life. No... difficult to get intelligence is our remaining theory. But life itself... if you've never Googled the phrase "water bear," it's this little tiny silly looks like an overly-legged gummy bear bacteria that... or I guess microbe is the correct term... you can launch these suckers on the outside of a spacecraft, orbit them around the planet for a little while, then de-orbit them through the atmosphere where they get exceedingly hot and once they're back down on Earth, they're perfectly happy to reproduce and go on being living creatures.

Fraser: It's funny because one of the most important scientific discoveries of possibly all time... the discovery of life other than on Earth... is being chipped away by the scientific research in other ways. So that by the time that you actually get there, you know... Life is found on Mars! Well, yeah, but we kinda knew it was there... we could see the methane... we've got a much wider understanding of what life is so it's not really that surprising and looks like it's related to us... Life is found on Europa! Well, you know there's water and there's vents and we were expecting that... Life is found on another planet! Well, you know we know they're in the solar system with us and particles get from one solar system to another solar system, and it looks like they're related. It's almost like it will be not surprising by the time the most important discovery of science ever is made.

Pamela: And what I love about this particular story is prior to launching spacecraft to go look at Mars up close, everyone just kind of assumed that the seasonal variations on the surface of Mars were at least partially related to plants, animals, life on Mars. We take a close-up look at Mars with a spacecraft, let out a community-wide sigh and/or expletive and kill off our thought of life anywhere in the solar system... anywhere in the universe.
Fraser: But the hope is coming back.
Pamela: The hope is coming back. Hope springs eternal... life springs eternal.
Fraser: Well, that's great! Thanks a lot, Pamela, and of course if there is any more really interesting discoveries and changes, we'll re-address the topic again in the future.
Pamela: And one more thing as we're taking off... we are ending a tax year soon here in the United States. It's very sad and exciting because it means paperwork.
Fraser: I'll just take your word for it.
Pamela: Yeah, yeah, yeah. But, if you are looking for a tax deduction, it is within my job requirement to remind you that we are tax-deductible. I would challenge everyone out there that for the year 2011, which is about to start, donate $20.11 or at least something that ends in 11 cents so that we know that the reason you're donating is you heard this plea. We can't keep paying our student unless you donate, so please donate... please help...
Fraser: Ooohhh... or buy our stuff at astrogear.org.
Pamela: That works, too.
Fraser: ...AND buy our stuff. Alright, well thanks, Pamela! We'll talk to you next week.
Pamela: Thank you Fraser. I'll talk to you later.