Kaylen (00:00):

Dr. Swingley is an associate professor in the Biological Sciences Department at NIU, where he has actually worked since 2012. He's received his Bachelor of Science in Biochemistry from Case Western Reserve University and his PhD in microbiology from Arizona State University. Dr. Swingley currently serves as an intern chair and associate professor for the Department of Biological Sciences again at Northern Illinois University. He has recently began a project looking into the possibilities of life outside of Earth. This project group is part of a team studying how photosynthesis can change a planetary environment in ways that can be detected from afar. This work links the observation of planets around the stars to tell them whether those planets can actually harbor signals that suggest life is active on that planet. Being able to link his research in tiny microbes to the study of planets many light years away is a dream come true. It's allowed him to meet so many researchers in fields way beyond his understanding.

Dr. Swingley is also involved in two different NASA research networks. This is the Virtual Planetary Laboratory and the Network for Life Detection, which he is a steering committee member and co-lead for the outreach program. These organizations have been able to broaden his horizons in terms of research and diversity. Students at NIU benefit from the research and funding opportunities that have become available through his affiliation with these groups. Today, Dr. Swingley will be talking about the interactions between life and the environment that drive evolutionary processes and environmental change.

Dr. Wesley Swingley (01:58):

All right. Well, I am going to be talking a little bit today about, as Kaylen mentioned, I kind of introduced this as a topic of thinking about life in the environment. My plans have shifted a little bit because of some recent happenings in our galaxy, and so I just wanted to give some background because I know not everybody in this group is super in depth on biology, and I thank our previous speaker for giving a lot of relevant background to some of the things that I'll be talking about today, but I'm going to talk a little bit more directly about some of these interactions that probably lead to a lot of the topics that Darren was talking about in his talk, which is the elements of life. What makes the beginning of life available?

Just a little bit of a starter, for me, I grew up in Montana, and so I grew up in a very, very small town at about 3,000 feet above sea level, and I couldn't ignore the night sky. The night sky is gorgeous there, and you can see the entire Milky Way almost every night. I miss that so much. So, I grew up loving space, but what really got me started in space research wasn't until college. As Kaylen mentioned, I have a biochemistry degree, and I didn't quite know what I wanted to do. Then, I read a book series by Kim Stanley Robinson called Red Mars, Green Mars, Blue Mars. In the book series, there's a lot of discussion about the terraforming of Mars, establishing life on Mars and establishing an atmosphere similar to that on Earth. So, that sparked a lot of my interest in what type of organisms would be critical to that process.

One of the ones, one of the areas that most people think of when we think about starting life in any environment, both on Earth and on Mars, are microorganisms, and that's because microorganisms can take hold in environments where there aren't enough nutrients available or perhaps not enough carbon or water for higher organisms such as ourselves. One of the big areas that people research this on Earth is in deserts. You might imagine that a desert like this one here in the United States or perhaps high altitude deserts like the Atacama Desert present an environment that has some features of the moon in Mars and other environments that we're interested in looking at when we think about life on other planets. That's not to say that we expect these sorts of things growing on Mars right now, but they may have in the past, and they could in the future if we develop organisms or look for organisms that can establish these communities.

These communities are typically called pioneer communities, and that's because they can move into an environment that nothing else can live in. What this person here is holding is a microbial map that's held together by a group of photosynthetic organisms. These photosynthetic organisms are not single celled like we think of when we think of microbes, but they're actually multicell filaments. They're long filamentous organisms. They were originally called algae when people first started classifying them. These algae formed these big filaments. They have a lot of slime in lake environments. They often are called pond scum in these big, slimy microbial algal communities, but in a desert, what they do is that slime and that filamentous nature holds the soil together in these soil crusts, and they can be pretty robust. These prevent erosion and other processes from damaging the desert.

They also maintain water and things like that that are useful for the organisms here and provide habitats for a huge variety of other organisms. You can kind of think of these like a forest ecosystem where the cyanobacteria are the trees that provide shelter and debris and things like that for the understory underneath. So, these communities are not just made up by these algae, but they're made up of many, many other organisms that rely on those algae for bringing in carbon, holding onto water and holding onto other nutrients.

So, these are a really cool starter organism, and these organisms that form these crosses are called cyanobacteria. Cyanobacteria are what I call our secret secret to success. Cyanobacteria are an organism that most people haven't heard of. They have been called blue-green algae as I mentioned, but most people don't think about these very much, but cyanobacteria are actually the origin of our life on our planet. That's through this little process here, and I don't expect anybody to necessarily know what this is. If you do, that's awesome, but this is the chemistry, the photochemistry of the reaction of oxygen-producing photosynthesis, oxygenic photosynthesis.

So, you can see what's happening here at the edge is O2 is coming out, and that oxygen is coming from water. So, these organisms invented this process billions of years ago that generated oxygen as a byproduct of water splitting, and they use sunlight to perform this reaction. So, this is one step in that reaction called photosystem two, and there's a photosystem one that is linked to this as well. So, this reaction was critical for the history of life on our planet. Up until that point, we had very little oxygen in the atmosphere of our planet, and this process profoundly changed things. In fact, it probably ruined life for most of the things that were around at that time. Most of the organisms around at that time including the original cyanobacteria were probably poisoned by that oxygen because oxygen is highly reactive. It provides huge, huge amounts of energy, and if you've ever had a notebook that you left out in the sun that got bleached or something like that, a part of that process is due to the oxygen in our atmosphere.

So, this process changed everything, and it provided enough energy for higher organisms and eventually down the road for multicellular organisms and us, but before this process, there was no way to generate oxygen in significant amounts in our environment. In fact, as Kaylen mentioned, this is kind of at the core of my NASA-funded research, which is looking for the limits on this reaction on Earth organisms because the chemistry here is not an Earth limitation. The chemistry of this process, the energy that's the energy on the side here needed to do this reaction of turning water into oxygen, that has real physical limits. So, this limit is true on Earth just as it is on any other planet in our solar system or our galaxy.

So, we can look at the energetics of this and see, can we set limits on this reaction on Earth that might help us understand those limits on other planets? I'm not going to talk too much about that today because it's well beyond the scope of the Artemis mission and moon and Mars discussion here, but I am going to say that this is what we end up with, right? This is what we need if we want to live anywhere else. We don't need an entire planet's worth, but we just happen to. We've gotten very lucky that we have an entire planet's worth of these green organisms here, providing the oxygen in our thin little shell of atmosphere, but as I said, I got a little sidetracked because I hadn't realized when I scheduled this talk that I would be so lucky as to have this talk right after we landed a new rover on Mars. So, this is an amazing image of the Perseverance rover landing on Mars that I assume many of you have seen or watched a few times like I have.

This Perseverance rover is significant in that it's the first lander that we've put on Mars in my lifetime that has equipment on it directly to detect life. I say my lifetime and then without saying how old I am, I'll say that the last time this happened was more than a couple years ago. So, the last lander, if you don't know, anybody who wants to throw in chat if they remember the last lander that attempted to detect life, but the last one was this one here. That isn't Mars. That isn't a guy standing on Mars. This is probably Southern California somewhere, and that's Carl Sagan. Carl Sagan is standing with a model of the Viking, one of the Viking landers. So, this is a replication of one of the two Viking landers that were shipped to Mars, and they landed within the same year in 1976.

So, 1976, 45 years ago was the last time we had equipment on Mars directly to detect life, and that's a really, really long time. There may be reasons why we haven't gone back to do the same thing, but these landers had a really cool experiment. That's this big, messy thing. I won't go over all the details of this, but this is the life detection equipment from the Viking lander. What it basically is, is a reservoir where they picked up Martian soil, again, not Californian soil, Martian soil, and they wet it, and they gave it an isotope of carbon, C-14 right here, and they basically let reactions occur. They heated it, and they wet it. They saw, does something happen to this carbon? Does this carbon get taken up by organisms? Does it get processed in any way that we can detect?

I'm here to tell you, you may be surprised to know that this was successful. They saw signs of life. Obviously, here we are, 45 years later, talking about this. So, clearly, that was not the end of the story, and in fact, this experiment was highly criticized, and both landers actually had positive detection, but there were a lot of potential concerns with the way the experiments were performed, and so I think, and I think a lot of people think that this may have poisoned the well a little bit and made it harder for scientists to argue for doing these types of experiments on Mars because of the mixed results that people saw from the Viking lander. So, it's sort of a cautionary tale that we don't want to necessarily get what we asked for because then, it presents challenges. In this case, it presented challenges that may have prevented us from going to Mars with any equipment like this for many years.

So, this Viking lander had these sort of direct incubation experiments, kind of essentially looking for Earth-like life on Mars. The Perseverance lander does not have that type of experiment. The Perseverance lander is a little more agnostic, not necessarily acknowledging that life will look like Earth life, but it's looking at life in a lens that we have on Earth. We have these expectations of what life needs, and those expectations are centered around basically six elements. These six elements, hydrogen, carbon, nitrogen, oxygen, phosphorus, and sulfur, not colored exactly what they look like, but you get the idea.

We have hydrogen being the most common element in the universe. Naturally, life uses that element in many different ways. In fact, we often think of it, if you've taken any chemistry classes, you often think of hydrogen as just the thing that's kind of stuck on everything, right? Every organic molecule has carbon and hydrogen, bunch of hydrogens, maybe some oxygens here and there, but the hydrogens are just there, but in life, hydrogen is the primary energy source. In fact, when we talk about generating energy, we're usually talking about moving hydrogens and moving electrons. We, of course, think about moving electrons when we think about energy because that's what our cellphones and things are doing when we're getting energy, but the way that organisms do it is by moving hydrogens and electrons together.

The other elements you may know more or less about some of these, we expect, of course, that carbon and oxygen are major parts of our wellbeing as well as other life on Earth. Nitrogen, you may know what nitrogen is for. Nitrogen is heavily invested in our proteins, but there's phosphorus in our DNA, sulfur in our proteins as well, and so these are all important elements of life, but of course, they're not all by themselves. They're not all alone. We know, for example, hydrogen is found as H_2, oxygen is found as O_2, nitrogen is found as N_2, but a lot of these are found in other combinations that are critical to being the elements of life on Earth.

The big ones for that on Earth are water, H_2O, right, O_2, the oxygen in our atmosphere, and also N_2 as another major component, the major component of our atmosphere. So, these three elements, I'll come back to these a couple times when we talk about this, but these are three of the critical reasons why we have life on Earth. I'll say as a bit of a spoiler later that this N_2 is actually a bit of a problem. This N_2 is not very easy to use. This oxygen is highly reactive, very energetic. This N_2 is highly stable and very, very hard to use, so we don't interact with this on Earth, but it's critical to our function and critical to the cycle of life on Earth.

So, just a quick look. I stole this picture from the web because it was a really nice visual of what makes us. We are, as you've probably heard before, probably the wrong number, but we're 60% water, and that water, of course, is these Hs and Os, which compose a huge part of our mass. So, a huge part of our mass is oxygen, and that's partly because oxygen is so much bigger than hydrogen. Oxygen weighs roughly 16 times as much as hydrogen, and so because of that, we have much more oxygen than hydrogen even though we have far more molecules of hydrogen in our body. So, those are the big ones. Nitrogen, you can see here, is a pretty big percent, 3%, but even those other ones you haven't thought about, sulfur, sulfur is 0.2%, phosphorus, 1.2% and other things, magnesium. We have iron as well, sodium, potassium. So, there's a lot of things that make us up. Not all of them are in this list of critical elements for life, and that's because a lot of organisms can swap those out. They can use other similar elements.

As you might expect, if we're made of all those things, if we at the top of the food chain are made of all those things, that must mean that most of the rest of the food chain down here is made up of similar things because we really are what we eat. Those elements come from the food that we eat. We can't get around that food. That yellow perch you maybe ate yesterday, that perch ate some sort of zooplankton, which maybe ate some phytoplankton, some algae, something like that. So, mostly, not all of course, but mostly all of these organisms have a very similar elemental balance.

So, everything needs these elements. Everything needs things to a greater or lesser extent, and a lot of what the previous talk was talking about was what these plants do because these are critical to ecosystem function, and all of these things are going on. I don't expect you to look at any of these, but this is some carbon cycling, some sulfur cycling and nitrogen cycling that these elements are not just components of our bodies. We think about this from a very consumer standpoint. We, humans, eat things. Those things did all the hard work to make that food. We just eat them to get the nutrients from them, right?

We burn carbohydrates to get our energy, and that's really all we're doing. We're burning carbohydrates. We're breathing out carbon dioxide from breaking down those carbohydrates, and that's what's happening here. This glucose is being broken down ultimately into a bunch of carbon dioxide, so that's all we're doing to make our energy, but the rest of the tree of life is doing a lot more. A lot of bacteria are taking these sulfur compounds that we don't care about, we don't use, and cycling them and generating energy or cycling these nitrogen compounds.

Here in Illinois, we often think about this cycle here because we are profoundly impacting the nitrogen cycle by pumping huge amounts of ammonia into our corn fields, and that ammonia then gets into the water column because bacteria turn it into nitrate. So, even though we put that on there, the bacteria turned it into nitrate. So, these cycles are profoundly impacted by bacteria, and they change the environment around them. Often, they change it for themselves as well, and they impact themselves and maybe provide niches for other organisms to grow while they themselves suffer.

So, consider the moon, right? The moon, we have this expectation that we're going to go there, and we're going to build this nice space station. This is from the Japanese space agency. I really like this little cartoon, but of course, we're not going to be carrying buckets and buckets of Earth soil up there. So, the expectation is that whatever we want to do there in terms of farming or any sort of sustainable growth, we have to do with what we have on hand. Just for scale, the moon is really incredibly far away. It looks so close, but it is quite far away to get to and to bring anything there. So, we have to be really strategic about what we bring.

So, what do we need to make this soil livable, and what is moon rock? Moon rock, the moon is made primarily from the same stuff as Earth, so it has a lot of the same elemental composition, but what it doesn't have is the right forms of those, and a big one is of course, water. We don't have very much water in moon rock, and that's going to be a major limitation to human habitation on the moon.

There is a lot of oxygen on the moon, but it's not in the right format, so we don't have this O2. We don't have oxygen gas because there's no atmosphere on the moon, and consequently, we also don't have nitrogen gas because there's not a lot of nitrogen on the moon. So, these things that I pointed at as being kind of important major components of the Earth ecosystem, those are all missing on the moon. So, these are things that we're going to have to think about when we get to the moon, and we'll come back to some of these in just a minute.

So, how about Mars? Of course. Mars, if we want to have habitation on Mars, it is much further away from us than the moon, and so there's no expectation that we would bring a bunch of soil to Mars, and of course, we could bring a lot of potatoes and astronaut poop as Mark did here, but we also have some of the same limitations. So, Mars also has an incredibly thin atmosphere, not ... It does have an atmosphere, and so it does have traces of oxygen and nitrogen in its atmosphere but very, very little, not very much at all.

Water, again, it doesn't have much water in its atmosphere, but it does have water. This is a great picture that came out a couple years ago of a water-filled crater. The entire north pole of Mars is water. The south pole has water, but it's also dry ice, and so Mars has water available. It has some of these things available that we might be able to use if we want to have permanent habitation there, but we're still going to run into some issues, and it also has things that we don't. This is what's called perchlorate. For any of you that study enough biology, you might know that chlorine is not a good thing. Most life doesn't jive with chlorophyll. Chlorine, sorry. I do photosynthesis stuff too much. Chlorine is not a good thing, so these perchlorates are really highly reactive, and they're very dangerous to, potentially to astronauts but also to much of the life that we might try to grow in these soils. So, there's a lot of effort out there, looking at ways to mitigate these perchlorates using plants potentially but maybe using bacterial processes as well.

I'm going to come back to that one that I mentioned, which is nitrogen, right? Nitrogen is a major problem and on Mars as well. Nitrogen is often found in gassiest form on Earth, but it really is very low in availability in the sediment, in the water column, in places like that. So, in most of our ecosystems on Earth, nitrogen is what we call the limiting nutrient or the limiting element, and that's because it's that nitrogen gas is so hard to access. Only a small number of organisms on Earth can access that nitrogen gas and bring it out of the atmosphere into something that we can use, and there's very little in the ecosystem that's available to life, and it had to have started from that nitrogen gas. So, one expectation is if we go to Mars or if we go to the moon, we might bring cylinders of nitrogen gas, right? Use the nitrogen gas itself, figure out how to use that.

We might also have this thing right here. This is urea. Urea is a solid compound, and it has a lot of nitrogens on there. It's also got some carbon that might be useful as well, but this is a solid component. Maybe it's easier to carry urea somewhere than it is nitrogen gas, but this is a major limiting element, and in fact, if you take nitrogen on Earth and you dump it in any environment, just about any environment, you increase the biological activity in that environment. This can be seen really easily in water treatment or the converse of water treatment, which is just dumping sewage or dumping waste into a water column. Whenever you do that, you get a lot of algal growth and bacterial growth because they're all taking advantage of that nitrogen that they've been waiting for their entire lives, but ultimately, the take home message from this is that we, as humans, are fragile. We are the biggest part of the problem, right?

We have very strict conditions on where we can live, but the organisms that we use have a lot more variability, and in fact, microbes, bacteria and archaea have a huge variety of environments that they can live in and can thrive in and maybe build the foundation for that ecosystem that we as humans can then step into and thrive where we can't in the first place. So, that's it. I'll thank everybody for listening. It was kind of a general talk today, so I do thank all the people that I worked with and NASA for funding me on this, but with that, I'm happy to take any questions.

Kaylen (24:56):

Yes. Thank you so much, Dr. Swingley. If anyone, again, has questions, you can unmute yourselves now. You can also submit your questions in the chat to Heidi or one of our other hosts as chat monitors, and make sure to please complete the short poll at this time. Thank you.

Heide Bjerke (25:13):

Well, I have a question, and this is Heidi Bjerke from Illinois Space Grant Consortium. I'm curious about if there are plans to try and take any bacteria in the near future or the archaea to try and send those to or create an alternative environment like Mars to test out if we can get the nitrogen and oxygen levels up.

Dr. Wesley Swingley (25:39):

I think there are a lot of people similar to Darren who are doing work at the International Space Station and looking at the growth of bacteria in some of these environments. One of the big challenges we have right now in analyzing how microbes will interact with these environments is that for the moon, we have very little material. Well, we have quite a lot but relatively very little material that we've brought back from the moon to base those experiments on, and so a lot of people use what's called the simulant. They're using a fake moon regolith, and there are a lot of people doing those sorts of experiments.

On Mars, it's a bit more of a stretch because we haven't returned anything from Mars, and so any experiments we do on Mars is based on observations from previous landers and the mineral composition based on that. Again, there are a lot of people doing these experiments on ... some of it is just the survivability of organisms in the environment, and some of them, some of the researchers are doing things like mitigation of that perchlorate on Mars, seeing if there are microbes or plants that are able to remove that, safely remove that perchlorate from the system, and then ultimately, of course, building up the organic material needed for larger organisms to grow. This is beyond my area of expertise, doing those growth experiments, but it is a very cool area.

Heide Bjerke (27:03):

Well, I'll bring up another point. I know SETI, they did a Zoom the other day, showing The Martian and had a talk with the author. I'm sure that some people might be interested like, would it be possible to use the Martian soil and just something as simple as our waste products to actually make a workable soil?

Dr. Wesley Swingley (27:29):

The problem with our waste is the bacteria that are in our waste are not necessarily the most representative for a healthy soil ecosystem, and so certainly, the one big advantage of our waste and the reason you could use it is it has a lot of the nutrients, a lot of the nitrogen, carbon, and all of that sort of stuff that organisms would need to grow, but it doesn't have a lot of the bacterial populations that plants need associated with their roots to do some of these things, and so I'm sure some people have studied some of this, but probably not the most fun experiment to do.

Heide Bjerke (28:07):

Did you want to say anything about how they're testing for the exoplanets to try and look for the possibility of life there? I know it's not necessarily in the Artemis, but if you wanted to mention that, I think it might be helpful for people too because I'm kind of excited as we find more exoplanets to see if there's anything like Earth out there.

Dr. Wesley Swingley (28:25):

Yeah, and that project, I kind of gave a very brief summary, but the people that I'm associated with, many in the Virtual Planetary Laboratory are associated with those doing observations of planets around other stars. One of the more common, more and more common ways of doing that is direct observation or observation through the planet where you have occlusion. The planet eclipses the sun. When the planet goes in front of the sun, you can actually see the atmosphere around that planet because the sun shines through it. Just like light is going through this glass to get to me, it's the same thing, and so you can detect the composition of that atmosphere.

The expectation is that at some point in the relatively near future, we will detect a planet that has some amount of oxygen in its atmosphere. So, then the question is, do we just run screaming and say we found evidence for life, or more realistically, do we look at it more carefully and say, is it even possible for that process to exist from life? So, our photosynthetic organisms are using light from our sun, which puts off a lot of visible light, a lot of high energy light. Most of the stars in our galaxy, 70% of the stars in our galaxy roughly are much, much cooler than our sun. They don't put out a lot of high energy light, so there's an expectation that there's going to be some cutoff where life cannot produce oxygen from these photosynthetic processes. So, we wouldn't expect to see oxygen around those planets. So, if we do, if we found a planet that had tons of oxygen around a very cool star, there must be some other explanation.