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Moderator: Heather Doyle
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Heather Doyle: Welcome.

Dr. Betul Kacar: Hi thanks for having me.

Heather Doyle: All right. I'll go ahead and introduce you really quickly and then would you like to take questions throughout your presentation or would you like everyone to wait until the end?

Dr. Betul Kacar: Throughout the presentation is fine. Feel free to interrupt me and ask a few questions.

Heather Doyle: Sometimes it takes just a moment for people to unmute so welcome everyone. I'm Heather Doyle from the Solar System Ambassadors Program and it's our great pleasure to host this Telecon so thank you all to everyone who's joining us. Today we're going to talk about astrobiology and we have a great honor to speak with Dr. Betul Kacar and she's an Evolutionary Biologist and an Astrobiologist. She received her Ph.D. in Biomolecular Chemistry from Emory University and she is currently with Harvard's Organismic and Evolutionary Biology Department.

Just as a final reminder please do not put us on hold because hold music might play and disrupt the talk. Also, be sure to mute your phone. If you don't know how to mute your phone just press * 6 and it will mute.

All right, take it away Dr. Kacar, thank you.

Dr. Betul Kacar: Thank you for having me. I am an Evolutionary Biologist and I also study biology at the molecular level. So, for many of you astrobiology could be a field that focuses on stars and planetary systems. And you may ask yourself what does a molecular biologist have to do with astrobiology. And today I'm hoping that you leave this talk with some answers. I am interested in understanding ancient life and I combine various fields that span evolutionary biology, synthetic biology, systems biology and through creating artificial systems in the laboratory I study past organisms.

[Slide 2] Astrobiology in case you are not familiar with the field tries to answer main questions that have to do with understanding our place in the universe. Are we alone, is there life elsewhere and how did life on earth begin? So even though astrobiology even within its name has the astro= the outer space, a lot of work that has to do with astrobiology involves our own planet. And we go to weird locations on our earth that we have no idea about. We look at microbes that live in these weird environments and in my lab, we also look at life at the DNA at the genetic scale. And my understanding is that this is also a pretty new approach within astrobiology.

So why do we care about this? [Slide 3] Hubble revealed an estimation of 100 billion galaxies in the universe. That's a big number. And there could be as many as 40 billion earth size planets that orbit in a habitable zone around a sun like ours. And [Slide 4] some of these planets may actually be earth-sized and actually could host life as well. Our goal is to understand and protect life here on earth first and also look for life elsewhere in the universe.

Dr. Betul Kacar: And here I would like to reemphasize again how much astrobiology actually focuses on understanding life here on earth and also the habitability or likelihood of life elsewhere in the universe not only to start life somewhere else but also protect life here on our planet.

Next slide 5. Just to summarize, astrobiology is the study of life, life's origin, evolution, distribution and the future in the universe. And that may include things such as your life as well as life on another planet.

And next slide [6] will have the first applied astrobiologist that's available to us. That's the Curiosity Rover. I always view this as if we were to send a geologist to Mars. A geologist would probably do what the Rover is doing with a little bit more features --and of course and with a little bit less features as well because a geologist wouldn't have lasers coming out of its eyes, shredding the rocks and analyzing the properties of these rocks in situ-- however, we do have an applied astrobiologist.

In the next slide [7] we also have a more rather famous astrobiologist for those of you Hollywood fans and he is Matt Damon who was performing experiments on Mars given that he was the only human body there and this is an astrobiology astronaut. You would think that he not only had information about how to drive a Mars Rover but also how to raise, how to plant, how to perform botanical experiments on Mars. So a very well-rounded astrobiologist in a very realistic way in fact.

So, next slide [8] I want to talk to you a little bit about myself and who am I, what do I do and how did I get involved in this field. I don't have a lot of slides and I'm hoping that we can have a conversation about astrobiology and what I do. But I have a few slides about my background.

[Slide 9] I came to the United States from Turkey originally. On the left is my grandmother who raised me and she's never been to school and so that inspired me a lot. I grew up understanding the importance of women in science and that's my first day of school in the lower left photo. I'm in the

middle kind of posing, very excited. And I came to the United States in 2003 due to an undergraduate scholarship from Harvard Youth Medical Institutes. And I spent a summer in the United States at Emory University and it changed my life completely. I really just enjoyed America and I loved science here and I loved the possibilities.

So, in 2004 I came back this time as a graduate student studying proteins. I fell in love with proteins and I've been in love with them since and I want to understand evolutionary proteins and what that could then mean in terms of understanding our planet and universe.

And the next slide kind [10] is summarizing my adventures. I did receive a post doctorate fellowship through the NASA's Astrobiology Institute and this allowed me not only to independently do my experimental system but also offered me opportunities to share my research with a lot of different people and different backgrounds including high school students, showing the middle or I visited Turkey and taught evolution in Turkey. I visited Sweden and performed experiments there as well as Japan and studied origins of life in Japan. I worked at Georgia Tech so it really was an incredible opportunity overall. And it's also exciting that there's not a single person who's not interested in the origins and evolution of life. It's such a fundamental topic so it's a pretty good field if you're also interested in talking to public about what you do.

And next slide [11] are these efforts that I have in the lab which I will talk about being recognized by the Lunar and Planetary Institute and they turned me into a cartoon character. On the left you can see this. This was the peak of my career I said I can just quit everything now. Now I made it. But they turned me into a cartoon character. And in the command tree I was talking to kids about astrobiology and how we can study origins of life in the lab and

what does an organism do, what do cells do, what does imitation actually mean and all that. So, you can download these things for high school students and use these, the documents and all the products for your teaching needs if you were interested in teaching origins of life in your high school classes.

And currently I'm Project Leader at Harvard University and I'm moving to University of Arizona as an Astrobiology Professor starting this fall.

Actually, I'm moving in two months. So, this is a new position. I think it's a first for the United States where astronomy and molecular biology fields- two different departments, are merging to create this astrobiology position because I think they understand both astronomers and molecular biologists understand that we need to communicate and we need to talk to one another if we were to understand the origins and the future of life on our planet and also find life elsewhere. So, this is a new development in my life and this is shown in this slide and Slide 12.

So now back to research and next slide - Slide 13. The goal of my research. What do I do? I am interested in understanding ancient life at the molecular level, at the DNA, at the genetic level. And I ask, okay how did life evolve? How did life get to the cellular level behavior in the past and can we resurrect life's past behavior in the laboratory? Can we reanimate the past condition of life in terms of the behavior of a cell in terms of preceding in fact, the whole genetic component? Can we resurrect ancient systems?

Next slide 14 summarizes why I am interested in this. When we look for life we look for life that resembles life we have today. And in this slide the life we have is, in this artistic way, shown on the right that's what we have right now. However, if you think about past life, past life is nothing like what we have today. In fact, if we were to travel about 3 billion years into the past you wouldn't be able to breathe. We wouldn't survive for a second. It would be

hot, acidic, a lot of meteorites but, there were microbes that managed to survive under these conditions.

So you may think that life 3 billion years ago was very different than life we have right now, however, it was life still. So when you look for life elsewhere in the universe why not we also include the life conditions of the past systems. And include that in our searches of life not only in our solar system but at the exoplanet scale and this is the motivation behind my research. Is there a question?

Jeff Nee: I have a question. Have we found fossils of microbes from 3 billion years ago and where were those found?

Dr. Betul Kacar: So on our planet yes we do have some microbial fossils that represent a bacterial organism that lived about 3 billion years ago. Although there are very few, we also have a majority of data based on isotope signals and ancient I would say biosignatures that represent the likelihood of a microbe that lived about as long as 3.8 billion years ago into the past. So we have this information.

Jeff Nee: Wow that's amazing, thank you.

Dr. Betul Kacar: Yes so we refer to them as microfossils and excuse me, please go ahead.

Woman 1: What do you mean by isotope signal?

Dr. Betul Kacar: I will briefly talk about that but basically these are chemical signatures from a sort of chemical marker that is left on the rock that indicates that some organism had a metabolism that survived under the certain chemical condition and left the certain chemical record on this rock which indicates a living

system. So, when we take a cyanobacteria or an alga or any organism, any microbe that has a certain metabolism, say a carbon fixing microbe and analyze its different isotopic value today meaning that you can imagine there are different isotopies, like, carbon or sulfur or nitrogen. You can imagine this as feeding the microbe with two different isotopes of the same element so you can feed the microbe as very heavy carbon or very light carbon. And then the microbe will generate a certain ratio of these two isotopic values, isotopes of the element and that will be the record for the certain microbe today.

Woman 1: Okay, thank you.

Dr. Betul Kacar: Yes thank you very much for the good question. Any other questions?

Woman 2: I have a question, in your picture of- Earth's past as a strange planet- it starts out big and then it's small. Is it because the earth was much larger before Theia hit the earth and created the moon?

Dr. Betul Kacar: I think this is - it's not my field so I'm not very knowledgeable about the evolution of earth's size. But based on this artistic drawing it was and I adopted that. But I'm not sure if there's a certain knowledge about that. I wouldn't be the person to know.

Woman 2: Well earth wasn't that much bigger before.

Dr. Betul Kacar: Yes probably not that much exactly.

Woman 2: I don't think they're to scale.

Dr. Betul Kacar: Yes exactly.

Woman 2: Thank you.

Dr. Betul Kacar: I will continue on the next slide [15] lies perhaps some answers to the wonderful questions that I received. One is what is a biosignature and the second one was that we have fossils that present the past and where does this information come from. So we have two main information dataset that allows us to understand the past. One of these datasets comes from biology. We study organisms today. We look at their values, their behavior such as their isotopic values or their relationship with one another such as the phylogenetic or genetic relatedness such as on the right. That's a phylogenetic tree and indicated is the *Homo sapiens*.

And this is based on DNA, right. So we understand genetics and the relatedness amongst organisms based on DNA. And this is why we know that a banana and a human being are related by 60% at the genetic level.

On the top is the rock. I would say there's more history that comes from geology that allows us to understand the past. On the right is the stromatolite formation. These are microbial mats. They present billions of years of microbes that lived on this rock billions of years ago. And there are certain locations on our planet that we find these fossils such as Australia, the United States in Montana and some in India.

So there are some regions on our planet that geologists have found these fossils, not just in the stromatolite level but different fossils that presents the organisms of the past and these could be - we're talking about billions of years scale and most will be microfossils.

In fact, on the next slide [16] Is the evolution of life's timeline. Life is thought to be 3.8 billion years old and this comes from the early record of an isotopic signal. A signal that indicates that there was an organism, a microbial

organism that survived about 3.8 billion years ago. Maybe instead of a microbe that we know today this could be a very, very simple organism that somehow managed to survive under the atmospheric conditions which was really high carbon dioxide of the past.

So we have Earth's formation and on this slide if you look to the left and then we have the heavy bombardment and we have the first organisms and important is the atmospheric oxygen. So we have the rise of atmospheric oxygen about 2.5 billion years ago and since then we have oxygen in our atmosphere and another important time will be about 0.5, between 0.5 and 0.6 that is 5 to 600,000,000 million years ago in the Cambrian explosion. And the emergency of these organisms, mollusks, worms and arthropods and then from there we are *Homo sapiens* as you will see at the end of the dark blue we've been here a lot shorter. And I like that they put fire in writing on this evolution of life time line.

So astrobiologists study different time points on this timeline. A lot of research has focused on understanding the Cambrian explosion and this time about 580 million years ago- what caused the Cambrian explosion, what kind of change in the environment triggered this? A lot of people focus on sponges and fungi and how did this bacteria to protozoa transition actually occur. A lot of research has been focused on understanding photosynthesis. What caused the rise of atmospheric oxygen. We think it is the emergence of cyanobacteria and this is exactly the research that I am doing today is understanding at the molecular level what could have caused this transition from anoxygenic environment to oxygenic environment.

And the question was what are biosignatures and that's the next slide [17]. Just by means of definition biosignatures could be any substance such as an element and isotope molecule or a phenomenon that provides scientific

evidence of past or present life. We search for biosignatures on our planet and we also look for biosignatures and especially for example on Mars we will look for carbon isotope biosignatures. These represent the oldest record of life on our planet.

On the left are some examples at the biomolecular level; carbohydrates, proteins. Proteins, nucleic acids and lipids altogether they compose a cell and their behavior dictates the metabolism, the behavior of an organism. This is true for microbes. This is true for us. Microbes and minerals -- these are of course not at the molecular level but the organism level -- can impact the environment and genetics. How are these biomolecules and microbes regulated at the DNA but also from DNA to RNA to the protein and actually at the physiological level?

So these are all regarded as biosignatures and the farther back you go in time the amount of evidence will also be scattered and very few. When you find a fossil that may present some life that's dated 3 billion years old. That's how you make a big discovery.

And next slide [18], explains our search for biosignatures elsewhere in the universe. I picked this example, I'm a bit biased. This presents the recent NASA OSIRIS-REx mission, an asteroid landing mission that will focus on identifying organics on these meteorites and then these organics will be studied. And these researchers will look for biosignatures even though this is a sample return mission.

So if a sample gets returned to earth successfully, and I think it will take place in about a year, we will be looking for biosignatures on these asteroids. Not perhaps for the aim of looking for signals of life but any condition because

given that biosignatures also can represent early environments regardless of its having this rock or asteroid hosting a life or not.

And also next slide [19] shows that they also will be looking for biosignatures I believe in March 2020 and astrobiology in fact is included as a phrase and technically I think it is one of the first missions that involves astrobiology. We will be looking for carbon isotope fractionation on Martian surfaces. And then we'll compare these values to the biosignatures and biosignature values that we measure on our planet in environments that may resemble Martian surface such as some desert areas for example the Atacama Desert in Chile.

So next slide [20] this artistic slide asks then what does my lab do? We again want to learn about ancient life. We want to learn more about past biology because we think that it could aid in search for life elsewhere in the universe. And this is a rather new field not for astrobiology but in general for the sciences because I combined a lot of different tools from a lot of different disciplines and then blended them in order to apply what I learned to the questions related to astrobiology and the origins of life.

So in next slide [21], I summarized what we do in the lab or rather the fields and the tools that we use. We use at the evolution level- phylogenetics and laboratory evolution. At the molecular level, we study the behavior of genes and proteins and what do they do and I will talk about how we connect the phylogenetics to the proteins in a minute. We engineer systems, and we engineer organisms- mostly bacteria at the genetic level meaning that we go to the chromosome of these organisms and then we make modifications in the chromosome of these organisms and we program these organisms in a way that they will behave like they did in the past.

So some of you may think- oh my is she doing Jurassic Park- and in a way yes, it would be like Jurassic Park but without any of the harm. We are not cloning dinosaurs but we are working with very harmless laboratory bacteria and modifying certain genes, not the organism. That will allow us to tie the resurrected behavior to the past. And remember I talked about biosignatures and how some of these biosignatures are caused because of proteins. And those are specifically the proteins that we target because we simply want to know what did this protein look like 3 billion years ago [and how did it behave].

Can we rewind the tape-- and I hope that we are old enough to know what a tape is because I think some of us forgot what a tape is, but can we rewind the tape 3 billion years into the past and find out what the DNA or the protein sequence of that time period looked like? And then bring them back to the future and engineer these ancient DNA inside the modern bacteria and resurrect an ancient behavior in the lab and that's exactly what we are doing.

And when we say linking it's the environment level, right? So we want to program the bacteria to understand how does this bacteria behave in an environment where there was no oxygen given that we know that 2.5 billion years ago there was no oxygen on our planet. And I call this research Revenant Genetics.

Next slide [22] is a brief analogy where I explain how the method we use could be correlated to what linguists do in order to understand ancient languages. On the left you are looking at the Turkish alphabet and this is what we use in order to speak. At least in Turkey and on the right, you are looking at the amino acids. These are nature's words. You can think of them the same way. An alphabet of a human is the same as the bacteria. Any organism will use DNA and amino acids which are forming proteins and we make sense

of these words [amino acids] in order to make sense of the behavior of the organism.

So next slide [23] then how do we travel back in time. And Hollywood used the time traveling machine in science. And the next slide [24] is perhaps boring [compared to] that but it is basically all statistics, math and inference.

So next slide [25] I have a metaphor and this is adopted [from] Steve Benner. He has a book- *Life, Universe and [the Scientific Method]*. That's the title of the book and if you're interested in these topics I highly recommend it. And here he uses this analogy where he picked the word- snow. So you can look at the pink "snow" – English, Germanic. You can look at the ancestry of this word snow. In old English, it's snaw. And then at the ancient root is a word, like, I would say snigh. So this word is the ancient version of the word snow.

And here we see that Slavic culture and Germanic and Romance and Celtic cultures all used a different version of the word snow. From here we can make various assumptions. We can assume that all these cultures lived in a place that has a lot of snow. They had to use this word to describe this environment. And one way or another they may have interacted with one another because some of them for example, Slavic and Germanic seem pretty close to one another.

And this is exactly the same thing for bacteria. And also by looking further into European [history] we can date that the split for example between the Latin and Proto-Germanic language happened about 3000 B.C.

So now let's go to the next slide and then change the words. So I will ask you to just click through the slides. As you click one more, you will see that the word Romance became bacteria and then just click and there will be about

five or six clicks and then all the words will then become amino acids. And if you keep clicking you will see that the words now will become amino acids and at the end you [will see the] reference for Steve Benner. So if you're at that slide [36] you can pause. And here what we see are different types of bacteria and instead of the word snow they have these letters that represent amino acids and altogether they're proteins.

And then we can look at the ancestry. In fact, by following statistically what the ancestor could contain in the exact position as the offspring did --for example, when we look at the proteobacteria in the red on the left you see A, C, V, G, H so we assume that if all of the offspring had an A in the first position, then the ancestor will also have an A, so on and so forth. So, this way we predict the past sequences of a variety of different genes and proteins given if the protein or DNA sequence of the current organism, the extant organism or the DNA that's available today.

So the next slide [37] here is what we do in the lab looks like. We look at all of these DNA sequences. We pick any protein that is of interest to us depending on our question and then we perform various bioinformatics methods and then we reconstruct and predict the past sequence. And then with the help of synthetic biology we bring these sequences into reality by synthesizing them and nowadays a lot of companies do this for us in a relatively affordable way. And then once we get the synthetic DNA we move forward to the genomic engineering and then clone these sequences inside modern bacteria to introduce a behavior that is different than the current behavior.

Heather Doyle: Dr. Kacar I have a question. Do you use mitochondrial DNA at all?

Dr. Betul Kacar: To my knowledge no one has used the mitochondrial DNA. This is a very good question and also a very important one because it also will allow me to say that this is a very new field. I would say maybe as old as 10 years we've been doing these ancestral sequence reconstructions heavily by not only creating these trees and analyses on the paper but also bringing them into lab and studying their properties.

So to my knowledge there has been maybe one or two proteins that represent some sort of energy pumps in the cell and I think one of these were in fact functioning inside the mitochondria but was not encoded by the mitochondrial genetic component. But other than that, very few studies actually look at eukaryotes who would have the mitochondria and try to understand behavior of mitochondria. So no one has done that and I think that would be an excellent experiment.

This is actually a very good question also because within the astrobiology field this line of research is very new. This field is new within biology and for astrobiology also it's very new. So I think there are a lot of interesting questions that could allow us to test a lot of interesting phenomenon that impacted our planet such as the endosymbiosis that would involve mitochondria that are waiting to be done. Any other questions?

Man 1: Yes, are you studying any of the historical evolution of the left-handed and right-handed molecules?

Dr. Betul Kacar: I am not studying that but again there could be, I think there are a few studies that looked at protein that could be preferably synthesizing one or the other through phylogenetics but I'm unfamiliar with any experimental work that has been done on that topic.

Dr. Betul Kacar: Any other questions.

Adrienne Provenzano: This is Adrienne Provenzano, Solar System Ambassador and I'm wondering could you tell us just a little bit about how you came to the idea or who else is coming to the idea to combine these fields and look at things differently.

Dr. Betul Kacar: Oh well okay. Actually, I do have a few more slides so I will talk about. No, I will answer your question now given that you're coming towards to the end.

Adrienne Provenzano: Okay.

Dr. Betul Kacar: So my Ph.D. focused on understanding proteins so I've been studying proteins for a while. But I was studying disease related proteins such as Parkinson's and Alzheimer's diseases. I always enjoyed being a volunteer and I believe I'm talking to a lot of volunteers today, is that correct? Yes, I've been a volunteer myself and I was mainly translating education materials into different languages especially from Eastern Europe, Middle East just basically providing some scientific knowledge to the kids who do not have access.

So during these translations I started reading about evolution heavily and I also discovered the experimental evolution as well as cytogenetics fields. It's really based on translating for papers.

Adrienne Provenzano: Great.

Dr. Betul Kacar: And then I just thought about this experiment and how cool it would be and I wrote a grant to NASA. And I got denied the first time but then I asked them, "Okay what is the problem". I asked for very honest feedback and they gave me very honest feedback. Then I corrected everything and applied again and

NASA Astrobiology Institute gave me the postdoctoral fellowship and the rest is history.

Adrienne Provenzano: And then this is a follow up, I was wondering are you working with anyone on developing any of the scientific instruments that are going to be going up on things, like the Mars 2020 or future missions?

Dr. Betul Kacar: That's an excellent question. So, this is also why I was motivated to apply to this position at the University of Arizona. And this is why I'm moving to University of Arizona because they do have exoplanet missions and also plans for other future missions and our goal is to connect these together and especially for the future exoplanet missions as well. I was briefly mentioning the goal is to take this anticodon-to-one to anticodon-more-than-one because past life is also life even though it was different. And I believe that if we can-through looking at these different sequences- find out that okay there's a different possibility than what we have today and that it existed in the past, I will consider this research successful.

Adrienne Provenzano: Great, thank you.

Dr. Betul Kacar: Thank you. So the next slide [38] I will basically end with a few slides that will touch the issue at the top level. I didn't dig in deeply here but actually I have two papers coming out, I believe within two weeks and they're both focused on resurrecting proteins that are involved in photosynthesis and what that could teach us about the transition to photosynthesis 2.5 billion years ago. But these are the motivating questions and that's what I will leave you with.

We are interested in playing the tape of life and how can we go back and how repeatable is life's evolution. We also evolve these proteins and organisms in the laboratory to see if they will evolve back to the way they are in the

present. So we are taking an ancient sequence and ancient DNA and evolving it to see if it looks like its current extant state. And resurrecting the early life biosignatures will be a major goal for my research in Arizona.

And the next slide [39] is we are also working with all of these different institutes both in the United States and in Japan and in Sweden to explore the possibility of life- Will life that we find out there in the universe look like the life we have here? Why or why not and what is the likeness of this evolution of life is repeatable out there in the universe. Does life just happen once or could it evolve again in the same way?

And in the next slide this is not a question that was posed by me. A lot of philosophers-- of course this is slide 40--and biologists such as Stephen Jay Gould himself thought about these experiments. And in this book called *Wonderful Life*, another great book he said, "I call this experiment replaying life's tape. You press the rewind button and make sure you thoroughly erase everything that actually happened. Go back to any time and place in the past then let the tape run again and see if the repetition looks at all like the original." And in this book that he wrote in 1989 in fact in the very building that I am in right now he also talked about how this experiment is impossible. That we simply cannot go back to the beginning by erasing everything. This experiment will never happen.

And in the next slide [41] I'm highlighting this because these are the exact sentences that inspired me to do this work. I agree that we will never be able to erase everything and go back to any time and repeat life. However, we can do that in the next slide [42] for bacteria and for DNA sequences that we choose one at a time. So yes, everything else in this organism may represent a modern version, right? We will only have a small amount of ancient DNA out of the many DNA sequences. But at least for one molecule at a time we can

do that. And I just published results of this work for another essential system of life that we refer to as the translation system, the information hub center of the cell.

And the next [slide 43] I put this, “Life finds a way” because what we observed by resurrecting ancient DNA and inserting them inside modern genomes is that we did not make the modern organism happy. Because we took really essential DNA of this organism that it depends on for survival and then we replaced it with, in this case a 500 million-year-old version of the same protein. And these bacteria were not happy and bacteria expresses its unhappiness by a very, very slow rate of growth, and it’s difficult to culture. After I cloned this ancient gene inside the bacterial genome, this bacteria that is now a hybrid with this ancient component, I knew that life will find a way. So the bacteria and the rest of the genetic machinery will find a way to adapt to this ancient protein and vice versa. And that’s exactly what happened.

Elsewhere in the bacteria, not the ancient gene itself- compromised [or adapted], whereas the ancient gene remained ancient. And maybe I didn’t evolve it long enough. Maybe it will happen as I continue to evolve it and that’s exactly what we are doing right now and we do see signs that after giving enough time the ancient component also starts to give in [evolve]. And these are questions that test more fundamental questions in evolution that also tie to astrobiology in terms of its connection to the repeatability of life.

So Slide 44, modern life preserved signs of ancient protobiology. So we call this protobiology, the biology before the biology. And it’s the biology that led to the biology that we know today. How were the chemicals used? How were they used and what did they do? And that’s one of the goals of the mission that I will have the pleasure of being involved with in Arizona and also

hopefully many exciting missions that we will be combining fundamental biology approaches into our exploration of the solar system and beyond.

So next slide my 45 and last one that I listed. I received a lot of funding from NASA and other support and I'm very grateful for that. John Templeton Foundation also is funding this work as well as Tokyo, Earth Life Science Institute. I have an appointment at this institute, Associate Professor, and Harvard especially Harvard Origins of Life has been investing in this work a lot and many collaborators past and present.

And the next slide [46] is where my email address is listed in case you want to send me a line. So thank you very much for having me and I'm happy to take more questions.

Heather Doyle: Well thank you so much. That was really fascinating and it's so important now as we continue to look for life on other planets, how do we find it? What does it look like? What are its signals to us that it's there? So that's really fascinating all this work that you're doing and your story is also fascinating of how you came here and how you were translating and decided to go into this work.

So my question is based on that I see you do a lot of outreach. I loved your parallel of language and the phylogenetic tree. Is there another great activity that you use to explain these things to children?

Dr. Betul Kacar: Well I'm involved with the Science Club for Girls and we together are looking at videos where we explain astrobiology in very brief and fun ways. For example, we used one of the bridges over the Charles River. We used the bridge as a timeline. Together on the bridge we explained- okay I am the great oxidation event and I happened 2.5 billion years ago and this bridge is 4

billion years and I'm just going to run across this bridge and that's how long life is. So we created a little bridge timeline to explain life evolution timeline. That was really fun.

Heather Doyle: That's great. Does anybody else have any other questions?

Man 2: Yes. Are you involved with the European ExoMars Expedition coming up later in the decade?

Dr. Betul Kacar: No, I am not currently involved with that but I'd be happy to.

Jeff Nee: Hi Dr. Kacar, Is there a documentation or write-up about that scaled timeline, the bridge timeline activity?

Dr. Betul Kacar: We have the video on YouTube I believe. I think probably you can view it. But if you send me a line I can send you some documents related to this activity for sure.

Jeff Nee: Great, thanks.

Dr. Betul Kacar: And we also, sorry, go ahead.

Jeff Nee: Oh yes I was going to say thanks. Like Heather I really appreciated your sharing a little bit of your story. I mean wish more scientists would do that for us to be honest and I just really appreciate it.

Dr. Betul Kacar: Oh thank you very much, thank you. So in terms of activities I also worked with Bart College here in New York and basically I sent them the bacteria that I cloned, so this bacteria has an ancient gene. So in one of their introductions to biology, lab course, actually throughout the whole semester they involved

this bacteria in the lab. And we didn't tell them which bacteria has the ancient gene, which one doesn't. So, they tried to figure it out and played a little game of figuring out where's the ancient bacteria. I'm happy to share if you perform any lab experiments or are a biology teacher who wants to use these bacteria in the lab I have a protocol for that and it's very affordable. I'm happy to send them out to you.

Woman 5: I have a question about your Slide 50 through 52.

Dr. Betul Kacar: Fifty? I had 46 slides. Is it the?

Woman 5: You had some extra ones. One on...

Dr. Betul Kacar: Oh extra ones, hold on.

Woman 5: Then your batch culture for I'm not sure if it's batch or synchronous culture of E. coli with modern E. coli versus hybrid which is unhappy. I presume it's the one that's later.

Dr. Betul Kacar: Yes. So if you...

Woman 5: The ancient one.

Dr. Betul Kacar: ...do you see if you go to 52 right now there are extra slides and thank you for looking into them. I put them there just in case. On the left, what you're looking at is the impact of the ancient gene on bacterial growth. So, the happy face on the left represents the modern E. coli and there's the doubling time. So our generation is about 60 years but for bacteria it's 20 to 35 minutes, depending on the bacteria. And so here is a modern E. coli with everything being modern and then once I engineered its genome with the synthetic gene

it's no longer modern, it's ancient-modern. It's a hybrid and I put the sad face because it's doubling time is about 150 doubling time and up. So instead of generating offspring every 30, 40 minutes, it's generating an offspring every 150 minutes. So that's how bad the growth was. This is a pretty remarkable increase.

Dr. Betul Kacar: So on the right, these are chemostats and one of them is pretty alone, that's the modern one. I took this picture after about a six hour growth. Technically the turbidity represents abundance and vol growth and that's why all the modern E. coli was pretty turbid. At this time point, the ancient modern one on the right was still struggling so you could see that it's not even grown yet.

Woman 5: Great, thank you.

Dr. Betul Kacar: Thank you for asking the question. I'm glad you looked into the end too.

Woman 5: Can you speak a little bit about the ribosome in Slide No. 50 which I think you might be calling 49?

Dr. Betul Kacar: So this is 50, yes. So in addition to studying proteins that impact the metabolic activity of organisms that are related to the atmosphere, I also study ribosomes. And we can imagine the ribosome as a computer or a processing center of a computer. And so you're looking at this molecule that's almost grabbing, almost eating this whole string is the ribosome itself. And the string is mRNA [messenger Ribonucleic Acid]. So mRNA here is being transcribed and there are these cone-like structures floating around. There are I believe a total of five. And these floating cone structures, are carrying this molecule highlighted in red. And those are the amino acids.

At the other end, you will see these three different molecules and these are codons. So the amino acids are being carried out into the ribosome because the codons will recognize the anti-codon and so on and so forth. And you see on the left of the ribosome there's this structure. It's a brown, green and red almost coming out of ribosome so that's the new peptide that is being synthesized and that's going to fold into a protein. And this happens really rapidly. It's happening right now actually when we are stressed this happens fast.

Usually cancer patients are shown to have this process very, very fast because usually cells have a way of controlling the error rates so- how these cones are carried to the ribosome, how fast mRNA walks through the ribosome, the binding to one another- they are all constrained. And it works really well but then a minor change can collapse the whole system.

This processing system which is again allowing DNA to be translated into the protein – DNA and RNA to protein is what we refer to as a translation system. This is the core information processing center of any cells. We have it, zebras have it, plants have it. All the living organisms have this system. Without this we cannot live. And it's a very bulky system that involves not only these cones and mRNAs but in total there are about 100 partners involved in this process. And we think that this is as old as life itself.

So we think that what you're looking at right now is a machine that's about 4 billion years old. So we think that this is very essential. So what I did is I chose one of these cones. These are the proteins and I replaced it with an ancient version. And the oldest I could use in this study was 500 million years old although I have a new paper coming out in bio and that's going to be showing that we did this also for older proteins for 2 billion, 3 billion and

even an older one. So I tried to push the constraints in the system just to understand how old can we push these things.

Or maybe I have to replace not one of them but all of them altogether. And if I'm required to replace multiple components, which ones are they and how can I know that? So, I'll be spending the next decade trying to understand these things and I look forward to it.

Woman 5: I have one last question. You say that these chromosomes translate very fast. How fast is fast?

Dr. Betul Kacar: Oh that's a very good question. So for example for E. coli there's about 10 amino acids per second.

Woman 5: Wow.

Dr. Betul Kacar: Yes, so some studies show it can be six but I would say six to 10. In my hands, I measured 10 and so that's how fast they can be. For humans, unfortunately I don't know the human rate. I know more about bacteria than I know about humans. But it's pretty fast. And there are really cool videos on YouTube if you just get a translation video, really, really fast. I think some of them are real time so you can get an idea of how fast this happens. It's really, really remarkable.

Woman 5: Thank you.

Dr. Betul Kacar: You're welcome.

Heather Doyle: I'll post some of those videos to NASA nationwide because I know where there are some good ones. I'll post some of those transition videos for you guys.

Woman 5: Thank you.

Man 4: I have a question about photosynthesis. Is cyanobacteria the oldest organism we know of that had photosynthesis? And a follow up to that would be do we have a sense of how photosynthesis got started?

Dr. Betul Kacar: Can you repeat the first question?

Man 4: Yes the first question was are cyanobacteria the oldest organisms we know of that exhibited photosynthesis?

Dr. Betul Kacar: Yes so we think that the oxygen was first produced about maybe 2.6 billion years ago, to 2.7, and that coincides with the rise of cyanobacteria as well. So we think that those in fact could be the first organisms that performed photosynthesis given that they can also perform photosynthesis under conditions such as no oxygen. And about 2.8 billion years ago we think that there was not oxygen or at least not the way we have it today in the atmosphere.

Man 4: Yes, and then do we have a sense of how photosynthesis got started, the mechanism?

Dr. Betul Kacar: Molecular mechanism?

Man 4: Yes.

Dr. Betul Kacar: Yes so that's the second question that my lab will be carrying out in addition to studying ribosomes. The second one is evolution of photosynthesis. To my knowledge it's really vague. We don't quite know the evolution of photosynthesis at the molecular level itself. But there are a lot of studies that tackle for example in cyanobacteria there are certain organelles that we think happened with the rise of oxygen, like, the carboxysome for example. They concentrate CO₂ within cyanobacteria. So, a lot of studies have focused on understanding that carboxysome as an organelle- how it evolved and how it's compartmentalized inside the cell. But in terms of the actual molecular level evolution of photosynthesis it's pretty vague and there are a lot of things unknown about that.

Man 4: Well thank you.

Woman 5: I have another question about the earliest microbial record. Does it indicate what type of metabolism it had? What was it feeding on? What was it metabolizing?

Dr. Betul Kacar: All right so that's a very good question and my understanding is that geologists and geobiologists who think about these things really hard assume that the isotopic signals or the metabolisms that cause the certain isotopic signals today are similar to the metabolisms of the past. And they have a term for this, uniformitarianism. So all life follows this somewhat uniform evolutionary trajectory and at the molecular level as well. So the metabolism that leads to this certain isotopic fractionation today, it probably existed 3 billion years ago. That's the assumption.

And so in short we don't know if that's the case because we cannot test that. We can't go back in time and study these things and this is exactly the motivation behind introducing this evolutionary phylogenetic level thinking

into these questions. Can we by creating these metabolisms that are composed of ancient components, then create these isotopic signals in the lab. And then ask ourselves are these isotopic signals any similar or different than the ones that are measured in the rock record.

So that's what my group is going towards. We are really interested in connecting the molecular level components to environments in the rock record. And it's interesting to me also because I come from a chemistry, biochemistry training. I did my postdoctoral studies on evolutionary biology. In fact, I am in the Organismic and Evolutionary Biology Department right now and I will be going for a dual position between molecular and cell Biology and Astronomy.

So as an Astrobiologist I'm very used to being transdisciplinary, interacting with scientists from different backgrounds. But then also this allows you to realize that how much scientists don't really create bridges between fields. It's not very common. So one can study evolution of a metabolism and never think about isotopes. One can study isotopes and never think about genetic evolution. So it is very fascinating to me as a young scientist to see how bridges between disciplines lack and astrobiology's amazing in that sense because it's the norm for us. When we go to an astrobiology conference it is the norm that I sit in on a talk that is about Europa and then think about extremophiles for example.

Woman 5: I'll just mention I worked in oceanography for a while and there was a lot of cross talking between disciplines in oceanography.

Dr. Betul Kacar: Oh great.

Woman 5: Probably because when you rent a ship at \$10,000 to 20,000 a day you have to have lots of scientists on board. And I worked for a food chain group that had every discipline in that research group and it was wonderful.

Dr. Betul Kacar: Oh yes that's great. That makes a lot of sense too. I guess for us if we want to understand life, to find it. First of all, we have to understand life to find it and for that we need a lot of different disciplines. I think it's not a subject for just one field of study.

Woman 5: Well good luck and have fun.

Dr. Betul Kacar: Yes, I'm really enjoying it. I'm very lucky. I sometimes wonder why – I can't believe I'm getting paid for this. It's really amazing. I feel, like, I'm doing a hobby. This is really amazing.

Woman 5: You have the right job then.

Heather Doyle: Are there any other questions? All right well Dr. Kacar it was a pleasure to have you and thank you so much for giving us your email address so that we can send any additional questions that we have or if anybody needs to email me my email's hdoyle@jpl.nasa.gov and I'm happy to help you as well.

Dr. Betul Kacar: Yes, and thank you very much. I'm also happy to send you some papers on the evolution of photosynthesis.

Heather Doyle: Sure.

Dr. Betul Kacar: There are some really established people in the field, in the astrobiology field also who did a lot of work to understand how these reaction centers, like, photosynthesis centers, how do they function today. And so, I'm happy to

send you information about that in case anybody here is interested in reading more about it.

Heather Doyle: Sure, I can attach those to the telecon where they downloaded your slides so that they can reference those if they want to check those out. So thanks again and thank you to everyone who's attending the call today. Please do share this information with your colleagues and friends with your events that you're doing. And our next telecon is actually going to be on July 11 also at noon Pacific time and it's going to be SSERVI Central. So that's the Solar System Exploration Research Virtual Institute. And we will hear from Brian Day who's the Director of Communication and Outreach there. So with that I'll say goodbye and have a great day.

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