Life in the Universe:
The Science of Astrobiology
Dr. Carl Pilcher and Daniella Scalice,
NASA Ames Research Center
Moderator: Kay Ferrari
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Coordinator: Welcome and thank you all for standing by. At this time, all participants will have an open line for the duration of today's conference. During today's conference, if you do not have a mute feature on your phone, you may use Star 6 to mute and unmute.

Today's conference is being recorded. If you have any objections, you may disconnect at this time. And you may begin.

Kay Ferrari: Thank you very much Ivy. Good afternoon everybody. This is Kay Ferrari from the Solar System Ambassador's Program and on behalf of myself and Amelia Chapman from the NASA Museum Alliance and Jeff Nee from the NASA Museum Alliance, we're delighted to invite you to our telecon this afternoon entitled Life in the Universe: The Science of Astrobiology.

Our speakers today will be Dr. Carl Pilcher and Daniella Scalice. And I'm going to do an introduction of both of them before we begin and once we begin I'll turn it over to Dr. Pilcher and he has requested that all questions be held to the end. And then he'll be happy to answer them.

So, without further delay, Dr. Carl Pilcher served as the Director of the NASA Astrobiology Institute from 2006 until his retirement in 2013. And again, as a part-time interim, Director from August 2014 to May 2016. Prior to that, he served 18 years at Nasa Headquarters in Washington D.C. in numerous capacities. He has BS and Ph.D. degrees in chemistry from the Polytechnic

Institute of Brooklyn and MIT respectively. And a Master of Public Affairs degree from the Woodrow Wilson School of Princeton Universities.

Since 2000, Daniella Scalice has been the Education Outreach and Communications Lead for the NASA Astrobiology Institute and more recently the NASA Astrobiology Program. Daniella holds a BS in Molecular Biology from UC Santa Cruz and pursued an MA in film at Humboldt State University.

Dr. Pilcher's presentation is the first PDF file under your resources entitled: Life in The Universe, The Science of Astrobiology. And without further delay, we welcome Dr. Carl Pilcher. Welcome Carl.

Dr. Carl Pilcher: Oh, thank you very much Kay. And hi to you and Daniella and to all the Ambassadors who are connected for this. So, it's really a pleasure for me to share some of astrobiology with you.

Those of you who know my background may know that I came out of the planetary science community and so there's a special place in my heart for Solar System Ambassadors. It's a wonderful program and I've always been delighted that there were so many wonderful volunteers who give their time to share solar system science, planetary science with folks who really are intrigued by it.

And I think astrobiology is yet another layer on that science because life -- as we're going to see -- is a planetary phenomenon although space processes may very well be involved in the origin of life and the evolution of life on planets. But, I think that when we think about planets, thinking about life at the same time makes a great deal of sense.

So, what I'm going to try to do in the next 45 minutes or so is to give you an overview of what astrobiology is and to talk about life as both a planetary and a cosmic phenomenon.

So, the second slide on the PDF file answers a really basic question. What is astrobiology? Well, I like to characterize it as the study of the potential of the universe to harbor life beyond earth. Now potential is a really key word in that because, of course, we tend to believe that there is life beyond earth. But, earth is the only planet that we know for sure harbors life.

So, when we talk about the potential of the universe to harbor life beyond earth -- first of all -- we're talking about habitable environments beyond earth. And we have to broaden our thinking about what might constitute habitability. And as we're going to see, what we have learned about life on earth in the last 50 years or so, by itself broadens our concept of what a habitable environment might be and then we need to broaden it yet further to take into account the possibility that life beyond earth might be very different than life on earth.

So, the questions that we address in astrobiology have really been pondered for a long time by people in many different disciplines. The third slide shows a quote from a Greek philosopher Epicurus who was one of the Greek atomists. The Greek atomist's believed that the universe was made up of an infinite number of discreet particles that they called Atoms. And of course they didn't have the modern concept of atoms.

But, it was a very modern concept to hypothesize that the universe was made up of discreet elements and that there were an infinite number of these discreet elements and this led to a conclusion that is really a strikingly modern conclusion. That there are infinite worlds both like and unlike this world of ours -- we must believe that in all worlds there are living creatures and plants and other things we see in this world. So, a remarkably modern perspective from a person who lived a very long time ago.

Now, there are other perspectives philosophers have addressed these questions. The next slide, Slide 4, shows the perspective of a Thirteenth Century theologian, St. Thomas Aquinas. St. Thomas had a different perspective on this. His quote from St. Thomas is that, "When it is said that many worlds are better than one, this sort of better does not belong to the intention of God because for the same reason it could be said that if he made two, it would be better that there were three and thus ad infinitum."

So, Thomas found the idea of an infinite number of worlds rather arbitrary and didn't think that this is the kind of universe that God would create. Well, today we are privileged to bring the tools of modern science to bear on these age old questions.

In the next slide, Slide 5, shows the three questions that astrobiology addresses today. How does life begin and evolve? Does life exist elsewhere in the universe? And, what's the future of life on Earth and beyond? To address these questions, astrobiology brings together five inter-connected areas of science.

And those are shown on Slide 6. And you are going to see here obviously some areas of science with which you are probably very familiar. Particularly having to do with the characteristics of the solar system. But, we bring that information together with other areas of science.

So, the first one on this slide is the diversity of life on modern Earth. The second is the co-evaluation of life and our planet. Life has existed on our planet for something on the order of 4 billion years and Earth -- as I'm sure most of you know -- is 4-1/2 billion years old.

So, life has existed on Earth almost since the beginning of Earth's history. And, there's a 4-billion-year long story of the co-evolution of life on our planet. And before we can intelligently consider the potential of planets beyond Earth to harbor life, it's really incumbent on us to understand that 4-billion-year history of life on earth.

But taking that information from those first two areas -- what we learn from studying life on Earth and the history of life on Earth, we can then consider the diversity of solar system environments and ask the question about potential habitability on those solar system environments. Beyond the solar system of course, we now know of thousands of planets around other stars. And so the fourth area is to extend that coalescence of knowledge beyond the solar system to planetary systems around other stars.

And finally in this particular presentation -- although I think not finally in terms of evological sequence perhaps in considering this -- perhaps initially, the question of the origin of life. Where and how are the raw ingredients for life made and how may a world transform from non-living to living? This is one of the most profound questions of our human existence. What is the origin of life? So, I'll say a few words about that toward the end of this talk.

So, let's begin with the first area. The diversity of life on modern earth. The next slide, Slide 7 -- which is entitled; The Diversity of Life on Earth -- shows on the left a diagram in the center left, that is a diagram that you would have seen in your biology class had you been taking biology more than oh about 25 years ago.

It’s the so-called five kingdom perspective on the diversity of life on earth. In this perspective, the kingdom at the bottom of this -- and this is called a tree of life -- the kingdom at the bottom of the tree of life near the root is the kingdom called Monera and these are single-celled organisms that are rather small -- only about a micron across -- and they’re relatively simple in that they don’t have a cell nucleus, they don’t have compartments within the cells, they don’t have organelles, which are small units within a cell. So, they are relatively simple cells.

The next kingdom above that are called protists and those are also single-celled organisms but much more complex. Those organisms are much larger -- typically 25 times larger than monera. They do have cell nuclei. They do have organelles like chloroplasts -- which are the photosynthetic organelle in both protists and in plants. They have many other compartments within the cells. And in this perspective, the bulk of the diversity of life was thought to be in the so-called crown kingdoms of fungi, animals and plants.

Now, this perspective on the diversity of life was derived from how organisms reproduce and what they look like. It was derived from looking at monera and protists under a microscope and looking at fungi, animals and plants -- to a large degree -- with the naked eye. And if you do that, the monera pretty much look all the same.

So, it’s kind of supported the idea that the monera were basically a uniform and maybe not that interesting kingdom of life. Protists were much more varied. Amebae, algae are all protists and so you could see more variation there. But surely, the bulk of the variation was obviously in fungi, animals and plants. I mean, just look at the diversity that you can see with your naked eye in those three crown kingdoms.

Well the diagram on the right is a modern version of the tree of life. This is a version of the tree of life that is based not on how organisms reproduce or what they look like but on the content of their genome that is on the genetic information that is contained in every organism. Guess what?

The fungi, animals and plants are three twigs on the tree of life that are toward the left --just below center -- the twig that represents all the animals is shown on the next slide, Slide 8, with a little arrow and a you are here. So that twig labeled homo represents all the animals. The twig right above it -- the caprinis -- represents all the fungi. The twig right below it labeled Zea represents all the plants.

So, this is quite a different perspective. This says that there isn't that much genetic diversity -- genetic difference -- between fungi, animals and plants.

Well, you'll see that this diagram on the right is broken up into three large areas. One is the area toward the bottom of the figure and you'll see towards the lower left of that portion of the tree of life, you'll see the word Eucarya, which is the name for those organisms. And the other two domains - the one to the upper left is all the Bacteria and the one to the upper right is all the Archaea. Now, the protists in the diagram on the left are all the rest of the eucarya domain of life.

So, all those other branches starting with giardia on the right and going all the way around to cryptomones on the left, right underneath Zea, those are all the protists. So, there is more genetic diversity among the protists than there is among all the fungi, animals and plants.

But look where the bulk of the genetic diversity of life is. It's all in the monera because the monera turn out to be those two very distinct domains of life; bacteria and archaea. And it turns out that archaea are more like eucarya. They are more like us than they are like bacteria. And this was a great, great surprise.

So, it also turns out that it has great implications for the ability of life to inhabit extreme environments. Either on this planet or potentially on other planets. The genetic diversity that you see represented there in the domains bacteria and archaea. The domains that were lumped together as monera in the earlier perspective, correspond bring with it a great deal of physiological diversity and metabolic diversity.

And it’s this physiological diversity that is the ability for life to tolerate different physiological conditions - different physical and chemical conditions as well as the metabolic diversity - the ability for life to use different fuels -- different foods -- and to breathe different substances and I’ll speak more about that in just a second. That is what enables life to inhabit areas of the earth that we thought for sure would be sterile.

So, for example, an area that we thought certainly was going to be sterile was the sea floor because after -- all and this was the thinking prior to the early 1970s -- after all everybody knows that life requires light. The sea floor is dark. Sunlight doesn’t penetrate down to the sea floor. So, you’re not going to find ecosystems on the sea floor. You might find a fish or another organism that has swum down to the sea floor and will swim back up. But you’re not going to find life inhabiting the sea floor.

Well, as I’m sure most of you know, nothing could be further from the truth. In fact, life does inhabit the sea floor just above the five kingdom picture to the upper right is a picture of tube worms at a hydrothermal vent. There are thriving ecosystems at hydrothermal vents on the sea floor.

You see at the lower right of these four pictures -- surrounding the five kingdom diagram -- you see one of the hydrothermal vents that feeds - that provides chemical energy to these ecosystems and if you take a really close look at that picture of the tube worms -- and these tube worms are typically a couple of meters long -- you will see that there are crabs feeding on the tube worms and there are shrimp swimming around as well.

So, there is really a thriving ecosystem, which is based on geochemical energy -- that geochemical energy that's coming out of the black smoke there that's shown at the lower right combined with oxygen that is dissolved in sea water that oxygen having been produced by photosynthetic organisms up near the surface. So, the sea floor is not a desert devoid of life but -- in fact -- there are ecological niches that are supporting ecosystems.

Another place that we thought would have been sterile were the centers of hot springs in places like Yellowstone National Park. And the picture to the lower left on this slide is a picture of Grand Prismatic Spring and Yellowstone National Park. You can see in the center of that spring, the water is blue -- and if I had included a close up picture of that -- you would see that it's crystal clear blue.

In Grand Prismatic Spring, it's also about 90 degrees and there are hot springs throughout Yellowstone and all over the world in which there is water very close to the boiling point of water. In some cases, acidic all the way down to a pH of 2. The acid frequently being sulfuric acid, sort of diluted battery acid but still pretty acidic.

And you see this water, you know that it's near the boiling point of water. You know that we boil water to sterilize it. The water is crystal clear. You would think for all the world, that that water would be completely sterile and in fact it's not. It's teeming with life. Much of the life being archaea. These apparently very simple cells but cells that have the ability to withstand the physiological conditions that are present in an environment like Grand Prismatic Spring.

So, let me go on to the next slide and talk about the metabolic diversity that also contributes to life being able to inhabit all of these environments. If an organism doesn't photosynthesize, it has to get its energy in another way and that other way is chemistry.

So, organisms that get their energy through chemistry do so by eating food and breathing an oxidant. So, on this chart labeled: Metabolic Diversity, Chart 9, the foods are on the left. Foods in this case are called reductants. And in this presentation, the most energy rich foods are at the top and the most energy poor foods are at the bottom. On the right, you have the oxidants. The -- in this case -- the best oxidants are at the bottom and the worst oxidants are at the top.

Now, all us animals use molecular oxygen O_2, which is shown at the lower right in red as our oxidant and we eat glucose. That's our principle fuel. We eat starch, we convert the starch largely to glucose. We can eat some other sugars but glucose is a good way of thinking about the fuel that we consume.

Now, the amount of energy that an organism gets from its metabolism from eating the particular food -- a particular fuel -- and combining it with a particular oxidant is given by the vertical distance on this diagram between the fuel and the oxidant. So, with glucose all the way toward the upper left and with molecular oxygen O_2 all the way toward the lower right, you can see that that's the largest vertical distance you can have on this diagram.

So, what that says is that we have a very high energy yielding metabolism. We get a lot of energy out of eating glucose and breathing oxygen and combining the two and we exhale carbon dioxide and water in the process. And that's one of the things that enables us to be rather large animals. And it's what enables all animals basically to grow relatively large. Certainly relative to microbes.

But there are lots of other metabolisms represented on this diagram and many, many, many more metabolisms beyond that. And it turns out that if you combine any fuel on the left with any oxidant on the right -- and the arrow connecting those two slopes down to the right -- like the arrow that's shown in the top center of the diagram -- it turns out that there is an organism generally a microbe -- some place on earth that uses that metabolism and makes a living.

So, for example, H_2 hydrogen, molecular hydrogen is shown on the diagram right next to glucose. And carbon dioxide is one of the rather poor oxidants that's shown toward the upper portion of the right-hand side of the diagram.

Well, clearly the arrow connecting hydrogen and CO_2 slopes downward to the right -- which means that energy is released in that reaction -- and there is a very common organism on earth that uses that metabolism to make a living. The product of that metabolism is methane. And the organisms that do that are called methanogens.

And many of you may know that methanogens are very common organisms. In fact, all of you are harboring methanogens in your guts. And methanogens are part of our microbiome that helps us digest our food.

So, there is a tremendous ability of microbial life to inhabit environments where there may not be any molecular oxygen. There may not be any glucose but if there's something like hydrogen on the left or hydrogen sulfide on the left or even iron shown down toward the middle of the diagram -- ferrous iron -- iron that has a two-plus charges on it. All of those can be fuels for organisms and then any of the oxidants on the right as long as they are lower in the diagram than the particular fuel can combine with that.

So, for example, nitrate, NO_3^-, down toward the lower path of the diagram on the right -- is an oxidant. For example, that many aquatic microbes will use.

So, it is this genetic diversity of life and the physiological and metabolic diversity that it conveys to life that really is what enables life to inhabit all of these environments on earth and potentially to inhabit a wide range of extreme environments elsewhere.

So, let's now talk about the co-evolution of life and the earth. The next slide shows you two pictures of ancient stromatolites. The picture at the top left is a picture - you can see the scale from the small red pocket knife that's at the bottom of the picture.

So, what you're looking at in this picture and the picture to the right are 3-1/2 billion-year-old rocks. These rocks occur in the Pilbara region of Western Australia. And these are some of the oldest rocks on earth because most rocks older than 3-1/billion years on earth have been destroyed or very strongly altered. So, it's very difficult to see ancient structures in those rocks.

You'll notice in the picture to the upper left, there are two domical structures kind of in the center of the picture that have layers' domical layers -- domes above them, -- which eventually grade into one large dome up toward the top of this particular structure. What you're looking at is you're looking at the fossilized remains of microbial communities that existed in this area three and a half billion years ago.

They're domical -- that is they're domed -- because their upper layers were photosynthesizing and they grew upward in this way to try to get to the light so that they would have the most energy available for reproduction. And you can see that they grew in layers, possibly seasonal layers -- and eventually merged into one large dome.

The picture on the right also shows a fossilized microbial community and these are called stromatolites. In this one, it is somewhat more conical. You can see that it is layered. Again, the layers are irregular. And these rock formations have been studied in great, great detail.

There was controversy initially about whether these structures were biological or not. But, there's general acceptance today in the scientific community that these are indeed the remains of fossilized microbial communities that existed on earth 3-1/2 billion years ago. Just a billion years after earth was formed.

Now, another thing that gives us confidence that this is a correct interpretation is the picture on the lower left. This is Shark Bay. Also in Western Australia but 800 kilometers away from the place in the Pilbara where these other pictures are taken.

And what you see on the picture on the lower left is a modern version of what you see immediately above it. They are roughly the same size. Those individual domes that you see in the ancient stromatolite are about a couple feet high and the ones that you see at Shark Bay are maybe a little bit taller than that but not a whole lot. So, we do see modern analogs for these ancient communities and it gives us confidence in our interpretation.

Now, life has interacted with the planet in many ways over this 3-1/2 to 4-billion-year history. And one key organism that has had an enormous impact on the planet is shown the next slide, Slide 11.

And these are cyanobacteria. These were the first oxygenic photosynthesizers on earth. That is they were the first photosynthetic organisms that generated oxygen as a byproduct. We don't know for sure when they first arose on earth. They were absolutely not the first earliest life on earth. They're really a rather complex form of photosynthesis and they're too simpler forms that most likely preceded cyano bacteria. But, cyanobacteria as the first oxygen producers had a profound effect on the planet.

If we go to the next slide. The next slide shows a very simple schematic of the history of oxygen on the planet. So, the vertical axis on the left labeled P sub O_2, P is pressure. And so this is the pressure of the molecular oxygen in units of an atmosphere and an atmosphere is the pressure on earth today.

So, one atmosphere at the top is the total pressure on earth today. And the axis along the bottom is time before the present with 4-1/2 billion years ago the formation of earth is the left and the present to the right.

Now, in this particular chart. The person who made this up just said, "Let's say that cyanobacteria came into existence 3.2 billion years ago." And you see where that green line showing the pressure of oxygen as a function of time -- you see it starts from 3.2 and goes up. But it only goes up to a thousandth to a few ten-thousandths of modern atmospheric pressure and then it stays down at that level for quite a while.

So, cyanobacteria were around why wasn’t oxygen building up in the atmosphere. Well the answer is that there were lots and lots of reductants. Lots and lots of those things that life uses as fuel in the environment.

In particular one of the reductants that some organisms use as a fuel as I mentioned earlier is iron with two-plus charges. What we call ferrous iron. And because there was a lot of ferrous iron in the oceans, one of things that happened when cyanobacteria which were also in the oceans started generating oxygen is that that ferrous iron sucked up all that oxygen and became ferric iron and precipitated and ferric iron is what we commonly call rust.

So, in other words, what those cyanobacteria did was they rusted the oceans. And only after that huge sink of oxygen -- only after most of that reduced material in the oceans had been used up -- was it possible for oxygen to build up to something approaching modern levels.

Now what’s really interesting about this is all of that rust, you may ask, well where is all that rust go? Well, the answer is that all of that rust is what we now think of as iron ore. They are the banded iron formations that occur in many parts of the world, that occur in the North Central United States that occurs in South Africa, that occur in Australia and they are the main source of iron ore for our modern civilization.

So, in a sense you could even say that cyanobacteria are responsible for the industrial revolution because without the cyanobacteria, we wouldn’t have had the iron ore that we mined and then smelted to produce the iron and steel that we needed for the industrial revolution. So, it is an interesting connection between organisms that evolved three to three and a half billion years ago and our modern society.

So, let’s go on to the diversity of solar system environments. I am going to speak about four bodies in the solar system, Mars, Europa, and Enceladus and Titan. And because I don’t have another picture of the lakes on Titan I would just call your attention particularly to the picture on the right which is a false color radar image of the surface of Titan.

Showing these rather large -- in some cases as large as the Great Lakes -- large lakes and even seas of liquid on Titan and I think all of you Solar system ambassadors know that the liquid in there is not water in this case but liquid hydrocarbons particularly, liquid methane. And we’ll come back to that point and its potential biological significance.

But just going on to Mars, this is probably the area of the talk that all of you are most familiar with. This is just this next slide, Slide 14 is just a picture of Mars that I like to include in a talk like this just to illustrate the enormous complexity of Martian geology. The enormous amount of deposition and erosion combined with many, many other processes and I think many of you are quite familiar with all of this.

One of the processes that we have known has been prevalent on Mars is the flow of liquid water across its surface. And the next slide, Slide 15 shows an image taken from the Mars Express spacecraft of the European Space Agency which shows channels -- particularly the channel that starts at the right hand edge of the slide just above the center -- and flows across towards the top of the image and all the way out on to the plain.

At the lower left center, you see an area that looks very broken up where the ground appears to have collapsed in a sense and then a channel flows out from that to the upper left. Ending on the left hand side of this slide roughly in the middle. And there are other channels showed on this slide as well.

So, that place where the ground appears very rubbly, appears to be a place where there was ground ice, which melted and it supports a topography collapsed, the ground collapsed and water flowed out from that to the lower plains area on the left. So, of course, we know that all life on Earth requires water. We'll come to the question about whether all life anywhere would require water. But since we know there is so much water on Mars, that makes it a very intriguing place to look. And as I am sure you all know for many years the Mantra for Mars exploration was follow the water.

So, we did follow the water down to the surface. We sent the Opportunity Rover landing on Mars along with a Spirit Rover in 2004 and this is just a nice picture showing the lander -- the rover having rolled off the lander and you can see the bounce marks of the lander -- which as I am sure you all know landed on air bags.

You can see the bounce marks to the upper right and the upper left. And we sent Opportunity to a particular location, Meridiani Planum and we did so because we saw from orbit that there was a signature of a mineral that normally forms in water the way it forms on Earth and iron mineral called Hematite.

And sure enough when we got there, and now we're on Slide 17. When we got there, we found that there were Hematite spherules roughly the size of blueberries and they're called blueberries and this picture shows a picture of a little depression in the rock where the blueberries collected and the Rover team named this the Blueberry Bowl -- and indeed, these are the Hematite crystals and indeed they are spherical shaped and many other aspects of how they are emplaced in the rock made it clear that they were formed in a liquid environment. They were formed when water was abundant in this area of Mars.

Now there is water in other places on Mars and this is a picture taken, the next slide, Slide 18. This is a picture taken from the Phoenix Lander. And there is an arm on the Phoenix Lander with a scoop and a camera and so the Phoenix Lander was able to take a picture of what was underneath the Lander.

Well, in this case, the Phoenix Lander landed using retro rockets rather than air bags and when you use retro rockets and land on a planet like Mars, you blow away the top few centimeters of dust. And low and behold, this up near polar latitudes -- this is at 72 degrees north -- and low and behold at polar latitudes right underneath the surface, just under a few centimeters of dust are deposits of ice.

And what's more, there can be liquid water on Mars as well. There is growing evidence for liquid water -- and I've just shown one example of this on Slide 19 -- and these are droplets of water that form on the struts of the Phoenix Lander. Now, what caused those liquid water droplets to form we believe is a salt in the Martian soil -- sodium perchlorate -- somewhat different than table salt but similar in that both table salt and sodium perchlorate absorbs water readily.

But sodium perchlorate is a much stronger absorber of water, more strongly deliquescent than table salt is. And as a result, it can absorb enough water from the atmosphere to actually create liquid droplets as you see on the struts of the lander. And there is other evidence -- particularly the recurring slope

Linnea which is didn’t include a slide here for reasons of time -- but I am sure many of you are familiar with these that show evidence that there may be near surface brines naturally occurring on Mars that is liquid salty water.

So, a more recent lander that we have sent to Mars, the Curiosity Rover is shown in Slide 20. I like to say that we sent the Curiosity Rover with a selfie stick -- that is the long arm that of course, as instruments at the end of it by which Curiosity does many of its scientific measurements. But there is also a camera. And that camera can be used then to take pictures of the Lander itself. So, this is a curiosity selfie in Slide 20. And one of the first things that Curiosity found shown in Slide 21, right near its landing site in Gale Crater were streamed bed deposits.

We sent Curiosity to Gale Crater because we thought that there was evidence of an ancient lake in Gale Crater. And there is a five-kilometer-high mountain -- Mount Sharp -- in the center of Gale Crater and we anticipated that we would see evidence of extensive aqueous alteration and see basically a history of Mars -- of the early years in Mars -- recorded in the layers on Mount Gale.

And sure enough, Curiosity did not disappoint. And shortly after its landing it found evidence that indeed there was an ancient lake with streams flowing into that lake both from the walls of the crater and from Mount Sharp in the center. And this is just an example of the stream bed deposits -- conglomerates -- of many small particles that you see in Slide 21.

Now, the main mission of the Curiosity Rover is shown in Slide 22 -- which is to examine the layers in Mount Sharp -- and the Curiosity Rover is now off to the right hand edge of this picture and up a modest distance into the foot hills. And so there is a lot more to come from the Curiosity Rover mission.

Slide 23 is just a slide that I like to include in a talk like this, just because how visually spectacular it is. This is just a small portion of the 360-degree panorama and you can see the original panorama and many, many other images on the Curiosity Mission website.

The mountain in the distance are the wall of Gale Crater -- and the sand dune that you can see -- the dark sand particles -- we're looking at the downwind face of a sand dune. Of course, we are very careful not to drive Curiosity into or try to drive over a sand dune like that.

But the terrain and the foreground shows you more of what Curiosity has been driving over. Well I can see that I'm running long, so I am going to speed up a bit.

Europa I am showing on the next slide, Slide 24 is an object with which I suspect you're all familiar, Moon of Jupiter, second of the large Galilean Satellites. Picture on the left shows more or less how it would look to the naked eye. Picture on the right is just a contrast enhanced version of that.

And you see there are different kinds of terrain. There is a model terrain to the left hand part of the image. There our Linear features and going on to the next slide, turns out that when you look at the surface carefully, the picture at the left on Slide 25 shows a close-up of the surface.

What you find out is that the surface is very broken up -- we've known since the 1970s -- in fact it was part of my Ph.D. thesis -- that this material is mostly water ice. So, what we're looking at is we're looking at frozen water ice. And you can see that the surface of Europa is covered with these ridges -- frequently doubled ridges -- and there are places where the surface appears to have been heated in such a way that part of the surface melted.

Pieces of ice floated off as icebergs. If you have trouble seeing this image in the right way, light is coming in from the right, and you can see shadows extending to the left. Some people may sometimes invert this image.

So, we think what is going on Europa is what's shown on the right in that Europa has an ice covering of perhaps a few kilometers thick and underneath that ice is a liquid water ocean 100 kilometers deep, 60 miles deep. There is as much liquid water in the ocean on Europa even though it is a small body the size of Earth's moon. There is as much liquid water on Europa as there is in all of Earth's oceans combined.

And we also have reason to believe that there are conditions in Europa's ocean that might be condusive to life, chemical conditions. So, certainly Europa is a very high priority target for astrobiological investigation. And wouldn't you like to be able to get be able to get into that ocean and find out if there is anything swimming around in there.

So, moving on to Titan, the largest Moon of Saturn. This is what Titan would look like to the naked eye. That is a photo chemical smog that is a product of sunlight acting on the methane in Titan's atmosphere. It's the kind of photo chemical smog and exactly the same color that I use to see when I was learning to observe on Mount Wilson and looking down toward JPL into that L.A. basin and that's what the L.A. basin looked like until the sun went down and the smog began to dissipate.

We have descended beneath those clouds and the smog however. And these are pictures on the next Slide, 27 taken from the Huygens Probe. And you can see on the left, a river channel network -- and we know now of course -- that the fluid flowing through that river channel network is liquid methane with some liquid ethane mixed in. But, what this river channel network also tells you, is that there was likely rain on Titan and in fact we see evidence of rain storms of liquid methane on Titan.

So the picture on the right is a picture no one ever thought would get to be taken because it's a picture of - taken by the Huygens' Probe from the surface of Titan. And the Huygens' Probe was not intended to be a lander. But it did land and successfully actually took pictures on the surface.

So, another much smaller Moon of Saturn shown on the next slide, Slide 28, is also of great interest. This is the Moon Enceladus. Enceladus is spewing material out into space in these jets that are shown in false color on the right and in - normally on the left. And we know that they contain water and salts and organics. And what it tells us is that there is also a global ocean on Enceladus. And there is even evidence of the kind of chemistry that we think may have contributed to the origin of life on Earth. So, Enceladus is another extremely interesting target for astrobiology investigation.

Moving on to Slide 29, we know -- of course today -- about thousands of planets around other stars and we know that planets are common around other stars. There are two principle means of by which we have detected planets around other stars. One is the Doppler Shift method -- which is shown on this slide -- in which an unseen planet, you can see an unseen planet illustrated in the center of this slide. In which the gravitational attraction of an unseen planet tugs its parent star around a little bit. And as a result the star ultimately moves toward a telescope on Earth -- or in Earth's orbit -- and away from it and we get alternately a blue shift of the spectral lines in that star's spectrum and a red shift as the star moves towards and away from the telescope.

And that enables us to determine that there is an unseen planet and many of those observations were done at the Keck Observatory. Another way that we have of detecting planets around other stars is the transit method. And this is a method that we can use when just by accident of the orientation of the planetary system, the planet passes in front of its parent star as observed by us here on Earth or with a telescope in orbit.

The telescope that has been in space, making these kinds of observations is the Kepler Telescope. And it has identified thousands of Planet candidates, most of which are indeed real planets. Although, confirming observations are necessary in many cases to confirm those.

And the next slide shows what the Kepler Mission is really focused on. And that is Planets in the habitable zone and particularly Earth sized planets in the habitable zone. To detect Earth sized planets in the Habitable zone - which decrease the light that you see when they pass in front of their parent star by one part in ten thousand. You really do need to be in space and in this habitable zone slide, Slide 31, the green areas are the areas of the habitable zone and that is areas -- distances from the star -- where liquid water could exist on the star’s surface.

And what we know from the Kepler Mission and from other studies as shown in Slide 32, is something on the order of 20% -- this slide shows 22 plus/minus 8 -- but you will find different numbers from different studies.

But the numbers are all similar. Something on the order of something between a 6-1/4 of all sun like stars harboring an Earth sized planet in the habitable zone. And similar numbers apply to the more common stars in the galaxy and in other galaxies. The so called M-dwarfs, which are smaller and cooler than the sun.

But again, 16%, 20%, 25% -- numbers like that -- are the fractions of those stars that harbor an Earth sized planet in the habitable zone. So, there is a tremendous potential for there to be planets with conditions that would allow liquid water to exist on the surface that's not necessarily a requirement for habitability -- Europa doesn't have liquid water on the surface -- but we think there is a habitable environment. But nonetheless, when we're studying Planets and bodies around other stars, it's a good place to start. And it seems that there are a lot of potentially habitable environments.

So, moving on to Slide 5, the Origin of Life. One thing that will be common for all habitable environments is that there will be material that is created in space that is raining down on those habitable environments. On the lower left is a meteorite, of a kind that we call carbonaceous chondrite because it has carbonaceous material.

This is one that fell in Australia in 1969 near the town of Murchison so it is called the Murchison Meteorite. And in that meteorite, we find nucleobases -- the letters of our genetic code. We find amino acids -- the components of out proteins. We find sugars -- the energy carrying molecules that we use.

And those are all molecules that were originally made in space and were falling on Earth when Earth was very young and are falling on habitable planets as those planets are forming. It turns out that ingredients for life can also be made on a planet at a hydrothermal vent. And I will just pass over this for now and answer questions about it in the interest of time.

But the chemistry of life is very difficult to get started and one of the difficulties in getting the chemistry of life started is illustrated in the next slide, Slide 35. And that is that many of the reactions that are necessary to create the biopolymers that we depend on are our DNA -- and our proteins involve extracting a molecule of water from two smaller -- from two organic molecules and joining them up.

But it is very difficult to do that when you are bathed in water in an ocean. It becomes easier; however, if you are in an environment that dries and tide pools and this one is tide pool in Portugal. Tide pools of course dry out daily and then get wetted again. So, some of the initial reactions of life might very well have occurred in a tide pool.

So, finally, just finishing up, how would we recognize alien life? Well it would be fabulous if we had Dr. McCoy in his tri-quarter and he could just tell us, yes Jim. That is definitely a life form. I have got the reading right here. Another possibility of recognizing the alien life is the supreme court test that will know it when we see it -- as shown on the right.

But, let me show you one other way that we might be able to detect alien life. Particularly in an environment that we can travel to that is an environment in this Solar System. The Biological molecules -- the molecules of life -- are very specific. We use a very specific set of amino acids in our proteins, we use a very specific set of nucleobases in our DNA, we use a very specific set of sugars as fuel. However, abiotic processes typically produce a much, much broader range of all of those kinds of molecules.

So, if we can conceptually, looking at Slide 37, if we go to another body -- Mars or any other body -- and we found indigenous organic molecules. But those molecules had a very spikey distribution that is there were only certain types of molecules and most of the other kinds of molecules that could have been present were not. If we found that kind of distribution rather than a very smooth distribution with lots and lots of different kind of molecules, we might think that there is some biology.

But the thing is that if that spikey distribution is the same as Earth's spikey distribution we might just think that well we brought along contaminants with us and we're just measuring Earth life that we brought along with us. But if as shown on Slide 38, we saw a different spikey distribution, we might say that that was evidence of alien life.

And with that, I am happy to answer questions and I do apologize, I know I think I was supposed to do this in about 45 minutes and I do apologize for running over. But I hope you enjoyed the talk and I will be happy to answer questions for whatever time we have.

Harold Kozak: Yes, Dr. Pilcher?

Dr. Pilcher: Yes?

Harold Kozak: Yes. My name is Harold Kozak, I am a NASA Ambassador but I also teach astronomy and I do a lot of astrobiology, I have two quick questions I would like to ask you.

Dr. Carl Pilcher: Sure.

Harold Kozak: One, you didn't mention to much about Venus and I have heard some talk now that they're hypothesizing that possibly when Venus first formed there could have been water and all life on Venus. I would like to know if there is any proof of that. And secondly, you mentioned about molecules in space. Now, I understand a lot of the molecules that they've found in meteorites and asteroids were the so called L-Amino Acids which basically life on the Earth utilizes. Do you think that constitutes proof that life could have come from space?

Dr. Carl Pilcher: Okay, two good questions. First there is evidence that Venus once had a great deal of water -- probably about the same amount of water that Earth had -- and that evidence is in the D to H ratio that is the deuterium to hydrogen ratio in Venuses atmosphere. It shows a much higher ratio and the way you -- than Earth -- and the way you get that higher ratio is by basically losing a lot of water. The hydrogen without the proton escapes from the atmosphere much more readily than the deuterium which is hydrogen with a proton, because a deuterium is heaver.

So, there is evidence that Venus -- for perhaps the first billion years in its history -- may have had a liquid water ocean of comparable magnitude to Earth's ocean. If so, it could have had clement conditions and the conditions could have been conditions to the origin of life. There is no evidence either way about whether life ever existed in Venuses ocean. But the fact that we think it did have an ocean for a substantial period of time after it formed, certainly opens up the possibility that one could consider the potential for life to have formed on Venus.

Coming to the L Amino Acids, there are meteorites that show relatively small excesses of L Amino Acids over the right handed L Amino Acids are left handed Amino Acids. Amino Acids for those of you who are not familiar with this, exist in mirror image forms and there are proteins that are composed entirely of the left handed versions so called L Amino Acids. There are meteorites that show a small excess of L Amino Acids over the right handed Amino Acid.

And what is speculated is that if the Amino Acids -- that were the first Amino Acids -- that were brought in in the origin of life were from space that this small excess of L Amino Acids in some meteorites might have been amplified by subsequent processes and might account for why life only uses L Amino Acids today rather than R Amino Acids.

But it's not thought to be an indication of life in space but perhaps more a possible explanation of why life on Earth today uses only L Amino Acids in its proteins.

Harold Kozak: Thank you so much.

Dr. Carl Pilcher: You're very welcome.

Man: I have a question.

Dr. Carl Pilcher: Yes?

Man: Talk to me about the significance of our big moon creating the tidal basins that you eluted to in your talk versus not having such a big moon.

Dr. Carl Pilcher: Okay, well the significance in the moon is really important for maintaining the climate habitable conditions on Earth over Earth's history. One of the things that the moon does is it stabilizes the obliquity of Earth and that is the angle between Earth's rotational access and its orbital plain. Mars -- without that big moon -- undergoes much, much larger obliquity variations. So, Mars can turn almost over on its side like Uranus -- not quite as far. And as a result, the Mar's climate goes through wild swings, you go through swings in which the poles of Mars are the warmest places on the planet when the obliquity is very high.

Earth does not go through those wild swings and so one of the effects of the moon is to stabilize Earth's climate -- and that may very well have been a very important factor over geological time in maintaining clement conditions on Earth. Tides are also obviously important. When Earth was young, the moon was much closer to Earth, the tides were commensurately much larger. And if tide pools did play a role in the origin of life, the fact that the moon was much closer and the tides were much higher, might have played a role in that too.

So, the moon could have had a lot of very interesting effects and it may be very important for planetary habitability.

Kay Ferrari: Do we have any other questions? If not, Carl that was absolutely marvelous. Thank you so much.

Man: I have got a quick question if I could?

Coordinator: Go Ahead.

Man: Dr. Pilcher, you mentioned the obliquity of Mars approaching that of Uranus?

Dr. Carl Pilcher: Well no. It goes up to 55 degrees, I didn't mean to - I was just trying to get across the concept that sometimes the pole of Mars will be pointing more to the sun than the Equator is.

Man: Okay, its axial tilt is currently 25 degrees. So are you indicating that that's changed over time?

Dr. Carl Pilcher: Yes. Yes, it does. The obliquity of all planets precesses and Mars the variation is much larger. I believe the maximum Martian obliquity is 55 degrees and I don’t quite recall what period of that variation is.

Man: Okay, thank you.

Dr. Carl Pilcher: You’re welcome.

Elena Semerdjian: Hello, this is Elena, Solar System Ambassador from Glendale, California. I was wondering if there is any science on if there is going to a change in Earth's habitable zone as the sun ages?

Dr. Carl Pilcher: Oh absolutely. Absolutely. As a star ages, as you know, it gets hotter and, as a result, the habitable zone moves further out. One of the hypotheses for why Venus lost its ocean is that when the solar system formed, the sun was cooler than it is now. 25% less luminous than it is now, and the habitable zone was closer to the sun so that both Earth and Venus were in the habitable zone. But as the sun has aged over the last five billion years or so, that the habitable zone has moved further out and Venus basically is no longer in the habitable zone.

Well as the sun continues to age, we'll reach a point at which either Earth is no longer in the habitable zone or the sun has expanded into a giant phase in which case, it will expand to the point that it would more or less incinerate the innermost planets, possibly including Earth.

So the good news, of course, is that's not going to happen for a few billion years. But it is thought that a billion years from now -- with the additional brightness of the sun -- the Earth will be hot enough that we'll probably be back to being a largely microbial world and the world will be too hot for the plants, animals, and fungi that dominate much of the surface today.

Elena Semerdjian: Thank you so much.

Dr. Carl Pilcher: You're welcome.

Kay Ferrari: Was there another question?

Man: The slide on - on Slide 8, the image of the tree of life. At that root what is the differentiation between those three branches? Is there something major that separates them?

Dr. Carl Pilcher: No, there's not. What you're looking at is a variation in genetic information. So, in a sense, there is some continuity. But what we see when we plot this genetic variation is we see this grouping of modern organisms into three distinct domains. So, there's certainly commonality between all of those domains. In fact, we couldn't construct this diagram if there weren't commonality.

There are some genes that are present in every living organism on Earth. And you have to use a gene like that in order to create a diagram like the diagram on the right. This is a gene that codes for a part of the ribosome, which is the protein factory that exists in every living cell. So, there is continuity and commonality among all of these domains of life - that is commonality among all living organisms.

But they do group into these three distinct domains that are separable from one another in that there is greater similarity within each domain than there is with the other two domains. The root you have to infer from other studies and where it shows root in the center of that diagram. We infer from other information that the last universal common ancestor -- what this diagram tells us -- because of the commonalities that are present in this diagram -- I've emphasized the diversity that's shown in this diagram -- but there's also great commonality that's represented as well.

And what it tells us is that all life had a universal common ancestor. All life has derived from, not so much an organism, but a pool of genetic information that existed in a natural system three and a half or four billion years ago, possibly even more than four billion years ago. And the genetic content of that last universal common ancestor is what's represented by that little section that's called the root.

Dr. Carl Pilcher: Did that answer your question?

Man: So, there's more detail at that root, there's not just a, you know, so there's no organism one at that point?

Dr. Carl Pilcher: It's not thought to be an organism, but rather a pool of genetic information. There -- very early on -- the first protocells were very different from modern cells and they may have been very, very leaky. They may have been a very, very rapid exchange of genetic material so life may have existed.

But it didn't exist in the sense of one generation producing another generation. It may have been much more of a hodge podge and that root really represents that genetic content of that system whatever it was and it's thought not so much to be an organism as much as a community of proto-organisms exchanging genetic information and it's the information in that total genetic pool that is the precursor to all life on Earth.

Man: Very interesting. Thank you.

Dr. Carl Pilcher: You're very welcome.

Nancy Cooper: Hi, Nancy - Solar System Ambassador from the Seattle area. And I have a question about the future microbial world of 1 billion years from now. How much water is anticipated to still be around at that time, surface-wise?

Dr. Carl Pilcher: You know, I'm not sure. I don't think Earth loses its oceans a billion years from now. So, I think the answer is probably about the same amount of water that Earth has now. Eventually, the sun will get hot enough that Earth's oceans and -- conceivably -- even much of Earth may disappear. But again, that's not going to happen until relatively late in the sun's time on the main sequence. And, of course, the sun has about another five billion years on the main sequence, so the sun doesn't start getting really hot until it starts leaving the main sequence. So that's billions of years from now.

Nancy Cooper: Thank you.

Dr. Carl Pilcher: You're welcome.

Man: I have another question. Earth's got this strong magnetic field that shields it from deadly radiation that could harm budding life -- I'm getting back to your tide pool thing.

Dr. Carl Pilcher: Yes.

Man: Venus doesn't and neither does Mars, so - and then the other issue is that -- maybe I missed something -- but if you talk about the icy moons with their deep oceans that are protected from this thick shell of ice. Well how do they start to trick without the tide pool effect? So, they don't have to worry about not having a magnetic field, but Earth and if your tide pool thing is significant or a necessary thing to get stuff started ...

Dr. Carl Pilcher: Very good questions.

Dr. Carl Pilcher: Indeed, Earth's magnetic field is very important for standing off the solar wind and protecting Earth from a lot of particle radiation -- a lot of charged particle radiation. Venus doesn't have a magnetic field. It may not have had a magnetic field since the beginning, particularly if it's been a slow rotator since the beginning. Mars apparently did have a magnetic field. Early in its history, there is evidence of magnetic stripes in the heavily cratered terrain of Mars. But Mars' magnetic field appears to have turned off very early in Mars' history, probably within the first billion years, half-billion to billion years, of Mars' history.

So, Mars might have had a magnetic field protecting the atmosphere early on and, so, if life did get started on Mars at about the same time it got started on Earth, there could have been some effects of magnetic field shielding the atmosphere and the surface.

Kay Ferrari: Okay, I hear some background noise. Thank you Carl. We have time for one more quick question for Carl and then we are going to move on to Daniella Scalice's presentation.

Man: Yes, Dr. Pilcher, just one quick question. Going back to the lakes on Titan. Do you think there's any possibility that life -- some kind of anaerobic life -- could exist in the lakes or possibly below the surface? And, if not, is it possible for NASA -- in the future -- to seed those lakes with anaerobic bacteria from the Earth itself?

Dr. Carl Pilcher: Well, I would say that the first thing that we want to do is we want to understand what could be going on in those lakes chemically and, even if there is some potential for biology. One of the questions that I am frequently asked is, is water necessary for life? And the answer is it's necessary for life on Earth, but it's not necessary for life in principle.

That is, one can envision life in some other solvent. We think that life does require a solvent. But could liquid methane be a solvent for life? You know, one can come up with reasonable arguments that said, well, you know, here's a possibility. And people have come up with hypothetical biochemistries and metabolism that could exist if there were living organisms in the lakes on Titan. Surely there is very interesting chemistry going on in the lakes on Titan and it would be very interesting to find out whether pre-biological chemistry has occurred on Titan even if life never arose on Titan.

There have been proposals for missions to land on one of the lakes and to analyze the liquid. And I certainly hope that one of those missions does manage to make it into the funded category and we actually, someday -- if not in my lifetime then in our children's lifetime or grandchildren’s lifetime -- will actually be able to get the answer to what's really going on in the lakes on Titan.

Man: Thank you.

Dr. Carl Pilcher: You’re very welcome.

Kay Ferrari: Thank you very much Carl. This was excellent. You're welcome to leave now if you have other commitments or you're welcome to stay on the line with us.

Dr. Carl Pilcher: No, I’ll stay on the line. I'm going to mute my phone. But I'll stay on the line and hear what Daniella has to say and, you know, anything else.

Kay Ferrari: Excellent. Thank you very much.

Dr. Carl Pilcher: You're very welcome.

Kay Ferrari: And, Daniella Scalice is now going to talk about the NASA Astrobiology Program and why is astrobiology so useful in education. Daniella.

Daniella Scalice: Good evening everyone, can you hear me okay?

Kay Ferrari: Yes, we can.

Daniella Scalice: Ok, great. Well, thank you Kay and thank you Carl for a fantastic presentation. I hope everybody enjoyed it as much as I did. Carl and I have been working together. When he was Director of the Astrobiology Institute, he was my boss and we've been working together for the past six or seven or eight years. So, it's wonderful now that he's retired from the Institute to keep working together. So, this has been a great pleasure for me and I hope for all of you as well.

I'm going to start in the new slide deck which is different from Carl's slides. So, hopefully you have those open in front of you. I suspect -- as educators -- you are now even more familiar with astrobiology than we were before, that my question, why is astrobiology so useful in education? Is rhetorical for you and I suspect that you have a longer list than I have here of why that's the case, but let me just call out a few things just by way of getting us started here.

So, clearly, the first bullet, astrobiology tells them an age-old question that are very deep in our DNA and builds on our natural curiosity, as you said Carl in the first few slides. Wondering about our place in the universe is not a new endeavor and astrobiology -- in my view -- is just sort of the current crack at those age-old questions. And, as you said Carl, we now have new methodologies and a suite of scientific investigations and instruments at our disposal now. So, things are different and we're coming to approach those questions differently. So, that's fun and educational. That can really get the juices flowing.

The second two bullets, again -- many of you work with students directly in programs and you work in collaborative team environments -- problem-based learning environments. The collaborative essence of astrobiology and the inherent challenges of exploration are just perfect for those kinds of learning environments.

Astrobiology, as you've surmised, takes the whole village. We need astronomers, biologists, geologists, everybody, especially philosophers and historians of science. So, there's a job for everybody in this and we - one does not do astrobiology in isolation. It just can't be done. So, that's great for learning.

And, of course, to me -- most importantly -- the last bullet here. Astrobiology literally scoffs at the notion that everything is already known. As you know, in many science learning environments, it's all sort of didactic and we're just learning facts of things that other people have done in the past and don't need rediscovering or anything like that. Astrobiology just really turns that on its head. And I think kids can really see themselves making a contribution and in that sense, it's deeply inspiring.

But this, more tongue-in-cheek, the pictures on the right why is it so useful in education? We've got a lot - we've got the whole compliment here. We've got dinosaurs, space, and slime, and, of course, the one picture that's missing there is aliens. So astrobiology has something for all kids to connect to.

Okay, I'm going to move on to the next slide. The heart of my presentation is really just to expose you and familiarize you a little bit -- with the educational materials we have as developed by our astrobiology community over the last 20 years. Alright, some have been created by NASA, some are created by trusted and vetted partners, and all these resources kind of hit somewhere in the very broad spectrum of research and topics that astrobiology covers that -- as we saw in Carl's presentation -- it's a broad spectrum of types of content and different pieces of learning. I think we have something almost for everything.

So, I want to just expose you to some of those things. To those of you working, again directly, in after school programs or in classrooms with kids and learners, we have educator guides that give you hands-on activities, curricula, lesson plans, units - there's a lot in that category.

There are some fun things, card games, and “board games”. Lots of videos kids use from -- I'm going to talk about FameLabs while we're on this slide -- but then I'll move on to talk about some other video products that have been created. There are radio shows segments on astrobiology. Podcasts that we kept our arms around and made available. Really cool web interactive from our friends at JTL and a kind of visual, visually driven things like posters, and trading cards, and graphic novels, and things like that.

So, I'm going to march on through and if, at any point, you can't hear me, please interrupt me. I have a backup phone line going on so I can switch or --

if you want to make a comment or have a quick question -- please go ahead and stop me and we'll talk about it right then and there.

So, before I move on, I just want to tell you a quick thing about FameLab. FameLab has been an initiative of the astrobiology program at NASA for the past five years. Its aim is to train early career scientists -- not only master biologists but we started off that way -- in the best practices and principles and theories of how to communicate well. And, so, it's basically all wrapped up in the guise of an international competition much like American Idol.

And, so, at all these different regional and national and international competitions, these three minute talks representing their competition have been recorded and we've put them all on that website right there, famelab.arc.NASA.gov. And, so, if there's a particular topic that you'd like to have an early career scientist talk about it's probably on that website. So, I invite you to check that out. It's turning out to be a great resource in education.

Okay, I'm going to go on and the URL up at the top of the slide is on every slide. So, on Slide 3, just, again, just to expose you to our broad category of educator guides; there has been a seminal product that was created a long time ago -- over about 15 years ago -- it was updated not that long ago, is our curriculum for middle school. It's called Life on Earth...and Elsewhere? and there are five lessons in there that can be morphed into any kind of time period that you have with learners that covers pretty much the whole spectrum of the content of astrobiology. It's really our bread and butter.

Our partners in a program called Rising StarGirls, has just created a new activity book for young learners. I think she targeted it at middle school and she is very focused on the arts. So that's why I put STEAM there, STEM with an A. Our partners at the Astronomical Society of the Pacific -- I suspect many of you know them -- have a wonderful activity guide that focuses on exoplanets.

Our partners at the Carnegie Institution for Science in Washington, DC, have done a curriculum that's more focused for the younger kids, but again, it can be extrapolated out. Exploring Ice in the Solar System. Voyages Through Time, and Astrobiology, an Integrated Approach are both ninth grade year-long curricula that are available for purchase that goes through the breadth of from soup to nuts of astrobiology and it mirrors in many ways, Carl, your talk tonight.

Okay, moving on to Slide 4. And I should say, this is not an exhaustive list. These are just some of the things I wanted to expose you to tonight. Slide 4, card games and board games; featuring just two of them here.

Astrobiobound was created by our partners at Arizona State University in the Mars Education Program there. They had a board game that they developed first, which you can see a little bit of here on the right. - No, I'm sorry, that is the Astrobiobound board game on the bottom right.

Their first board game was called Marsbound and basically, you play it. You roll dice, you have cards, and you have to develop a mission to Mars and, now in Astrobiobound a mission to Mars, Titan, or Europa and possibly Enceladus and you have to balance a budget. You have to make sure your rocket is in place. You have to have your communications bus and your antennas, you have to just basically build this thing from scratch and scientific investigation and the instruments needed to do that on your mission are just one part of it.

One of the fun things at the end of the board game is that literally dice are roll and - are rolled and sometimes your budget gets taken away. So, it's good fun and it's for kids -- middle school and high school.

The other one here is a card game called Extrem-O-Philes in the Classroom. Again, for middle and high school. Again, from our partners at ASU. That basically plays a game with - and you learn about the different Extrem-o-Philes that live in different environments here on Earth and you make a leap once you understand about them to the types of environments that they can live in on other planets and moons.

Slide 5 is our video slide. And, again, this is not an exhaustive, but just to give you an idea of what's been created and what you can be using in your program. Finding Life Beyond Earth is produced by NOVA out of WGBH in Boston. It's a full length NOVA program -- I believe its 56 minutes -- but they kind of chunked things out and there are clips available on their website as well. And they've created some lesson plans to go along and make use of those clips. So, that's a fantastic resource and a many of the astrobiologists in our community are featured in the program.

The same is true for Alien Planets Revealed, also produced by NOVA more recently and that has more to do with exoplanets; their discovery, what's going on with them now.

A very interesting and unique film that was produced out of Montana State University's Natural History Filmmaking Master’s Degree program and aired on Montana PBS a few years ago, is called The Search for the Origins of Life. And that features, again, many scientists in the astrobiology community that are, in one way or another -- and in very different ways from one another -- investigating how life originated.

It's a fantastic film. I highly recommend it. And there are some lesson plans and clips available on that website as well. And -- let me just reiterate -- everything I am talking about for the most part you can find a link to on the top of each of these slides and, of course, you can contact me and we'll talk more about them.

Another type of resource we have that was created within the last couple of years is just short clips detailing a project that's been going on and has been funded by the NASA astrobiology community down in South America. As you can see on the bottom right, up in the mountains there, the project's called Planetary Lake Lander. And basically it was the prototyping and field-testing of a robot, Aqueous, enabled robot that, one day, if all the stars can align, will find itself on Europa exploring the oceans there.

So, all kinds of wonderful videos that you could plug into your public talks, your programs for students. Any towering environment, these are great resources and there are more. This is just a few.

Slide 6. Web-based interactive, these are just some -- again -- fantastic quick, you know, you could kind of rotate if you had a bank of computers or something like that in your program. You could rotate the kids through these. They don't take very long per interaction and they cover a breadth of the research spectrum, again. Alien Safari, Extreme Planet Makeover, virtual fieldtrips. A wonderful, beautiful, historic timeline and the search for other worlds, basically chronicling from ancient times to now the quest to discover exoplanets.

A Needle in Countless Haystacks that was produced by TED, TED-ED, and most, and less quicky web-based interactive and more kind of a more in-depth exploration, but with short resources embedded in it are two -- not one -- two courses on the Coursera platform. You, yourself can sign up to take those courses and then you could have access to the embedded visual multimedia resources therein.

Slide 7. These are sort of the more visually-based things we have in our portfolio of products. We have a poster, again, of one of our bread and butter pieces produced by the NASA Astrobiology Institute shown on the bottom left there. Life, What is it? Where is it? How do we find it? There is a hands-on activity on the back of that poster with two more hands-on activities more in-depth that you can get to from the website that is given on that poster.

It's great to just hang. It's great to talk to, to speak to, it highlights Extrem-o-Philes, Titan, Europa, and Mars and, again, the link between extreme environments and Extrem-o-Philes here on Earth and habitable environments elsewhere in our solar system.

One of the coolest things I think we have in our arsenal here are the astrobiology graphic histories, aka comics or graphic novels. We at NASA have to call them graphic histories because of certain rules and regulations, but we get away with it. And they are indeed histories, they do chronicle the history of astrobiology as a science. They chronicle the history of solar system exploration. There is an issue devoted to Mars exploration, inner solar systems, outer solar systems, extremophiles, and I think exoplanets now.

So we have five of these absolutely beautiful books. They're written at a level that -- I mean I read one recently to a four-year-old and I don't think he got every bit of it -- but it was just enthralling to him. And, of course, we, as adults, fall for them as well.

We have these, we keep a repository of them. I can ship you any amount for the most part we need to rebuild our inventory on a couple of these issues -- but I can respond to requests -- for the most part, any time.

We mentioned a card game a few moments ago. It was developed because of the Extremes of Life trading cards that were developed several years prior. These are just like baseball cards except, instead of profiling baseball players, they profiled different extreme organisms. Halophiles, zenophiles, thermophiles, psychrophiles, and they just have some information on the back and you can do all kinds of things with those.

Our partners over in Europe at the -- I think I'm going to get this right, International Cartological Association designed -- and you can buy online, you can download the PDF online and print them yourself, these planetary maps for children. They are exquisite and my new go-to gift actually for young people.

So, I highly recommend checking those out. Really, really cool. There's six or seven or eight of them and our partners at NOVA when they developed the first film with a real kind of solar system focus -- they also had a poster on the solar system. We have those as well for distribution.

So, my last slide is just to show my contact information -- which I'm noticing an error and I do apologize for that -- for those of you looking at the slides. Please change my phone number to 831. It's -- I apologize for that, it's just a typo -- but email of course is a great way to contact me. You can also contact me through Kay easily and we can talk more about any of these resources and I can ship you anything that I have at any given time.

So, before I stop and say goodnight -- I want to say, on behalf of NASA, on behalf of the astrobiology program in particular, thank you so much for everything that you are doing for NASA, for solar system, for planetary science, and that hopefully now more and more for astrobiology. I've been a huge fan of the Solar System Ambassadors Program for a very long time. Kay, you're the best and all of you are doing such great work and we're so grateful.

The other thing I want to say before I close, is that Kay and I have been talking about offering more teleconferences in astrobiology. We wanted to start with an introduction, which is what we have given you tonight. But coming up, we hope to program maybe one per quarter looking at different parts of the spectrum of the content of astrobiology. So, thank you very much for having me. And I'd be happy to answer any questions now or -- I hope you'll contact me in the future -- and I can get some of these materials in your hands. Thank you.

Kay Ferrari: Thank you so much, Daniella. That was amazing. You have more things than I realized the last time we talked. You've really upped your game there. This is wonderful. Anybody have any questions for Daniella? We can take a few more minutes.

Daniella Scalice: Yes, please. Questions or comments.

Beate Czogalla: This is Beate in Georgia. Daniella, I've in the past done an experiment with kids during workshops which was about extremophiles and I think I found that on Space Place. Where you take yeast, you know -- packets of dry yeast -- and you expose them to radiation like throw them in a microwave, put them in cold water on ice and warm water, and you find out which ones are conducive to life and it's really a great, great exercise for kids to do to experience extremophiles for themselves that we have in our environment every single day. And that was a really fun little thing to do.

So I just wanted to throw that out there that, you know, there might be other things on other NASA websites -- especially something like Space Place -- that might be appropriate.

Daniella Scalice: Yes, thank you for bringing that up. I think I know which activity you're talking about and, again, it is bread and butter. It's a wonderful way to expose learners to what is a signature of life and what isn't and really look at the difference between those two things at a very deep level, but a very clear and obvious and hands-on, you know, non-subtle level.

The other thing I wanted to add, is you're right, there are so many things on other NASA websites and beyond. Carl -- you mentioned tonight -- many different missions that are exploring the solar system, exploring exoplanets. Many of those NASA missions have had in the past EPO -- education public outreach -- programs and have developed materials specifically to look at the science of that mission.

So, I encourage you to -- like for example, the Kepler mission-- they have fantastic hands-on activities that, you know, we in astrobiology didn't need to replicate because they are so good and it covers that part of our content spectrum. So, yes, please do think beyond just the at NASA Astrobiology URL here.

Kay Ferrari: Anyone else have a question?

Okay, if you have any questions, Daniella left her email address. If you have a question for Dr. Pilcher, you're welcome to send it to Daniella or to me and I'll make sure that it gets there. I want to thank you so much Carl and Daniella. This was an absolutely marvelous kick off to an astrobiology series, which I know is a very popular topic amongst our volunteers. So we're delighted to have you. We look forward to upcoming talks on astrobiology.

And -- before we sign off -- I just want to remind everyone that there are two more telecons this week. Tomorrow is the Cassini Charm telecon. This is part two of a series that they started last month. And, on Thursday, we will have the next installment of Universe of Learning with the astrophysics folks. So, thank you all for joining us tonight and thank you for your continued support and I hope you all have a good week.

Dr. Carl Pilcher: Thank you. You, too.

Daniella Scalice: Thank you so much Kay. Thanks. Goodnight everyone.

Coordinator: Thank you all for participating in today's conference. You may disconnect your line and have a great day or a great evening.

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