NWW - NASA- JPL- Ocean Worlds Telecon
Moderator: Kay Ferrari
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Kay Ferrari: Good morning and good afternoon everyone depending on where you are. Welcome today to today's Exploring Ocean Worlds: Prebiotic and Astrobiology Implications Telecon. We are pleased to have a couple of speakers with us who are working on astrobiology missions and with the astrobiology program.

Our speaker today is Dr. Morgan Cable. Morgan is a technologist in JPL's Instrument Systems Implementation and Concepts section. She is also the Assistant Project Science Systems Engineer for the Cassini mission. Morgan's research focuses on organic and biomarker detection strategies through both in situ and remote sensing techniques. She is currently working as a collaborator on the mapping image spectrometer for EUROPA or MISE, an instrument that will map Europa's surface and search for organic salts and minerals.

Daniella Scalice will be speaking a little bit later on education products in astrobiology. She is the Education and Communications Lead for the NASA Astrobiology program. She supports astrobiologists who engage in outreach, oversees curriculum development, provides content to media and educational outlets and delivers programs to educators and students all over the world.

Daniella is also the lead for the American Indian Alaskan Native Working Group for NASA's Science Mission Directorate. I'm going to turn the program over to our first speaker Morgan who will be taking questions as we go along. Welcome Morgan. We're happy to have you join us.

Dr. Morgan Cable: Thank you so much. It's a pleasure to be here. So as I go through these slides I welcome questions at any time so feel free to interrupt. We're going to be stepping through a few different topics specifically a few different ocean worlds so feel free to ask a question about that particular ocean world while we're on the topic. I hope everyone has the slides up preferably if you have the PowerPoint version. That may work a little bit better because I do have a few short animations and a couple of videos. If you are viewing by PDF, I will try to also keep tally on what slide number we're on to keep everyone on the same page. I'll just say next when you're supposed to hit a button to either advance something on the slide or move to the next one. So thank you very much.

As they mentioned my name is Morgan. I work at the NASA Jet Propulsion Lab and I'm going to take you on a brief tour through some ocean worlds. So next we're on Slide 2, now- What is an ocean world? When most people think of or picture what an ocean world might look like they may picture Kevin Costner in Waterworld or someplace where the liquid layer may be on the surface. If you hit next again you should see an image appear on the left where that is not actually the case, at least not for the ocean worlds that we are searching for in our solar system.

Aside from Earth and a little bit on Titan which I'll get into a bit later most of the ocean worlds that we're exploring actually have that liquid layer underneath a shell of ice. And that liquid may or may not be in contact with some type of rocky or silicate core and the liquid layer may be able to interact with that ice shell above it and potentially express some of the material that's present in the ocean underneath onto the surface through various mechanisms. So next on to Slide 3, let me introduce you to a few ocean worlds. If you click a couple more times you'll see Europe on your left and Ganymede and Callisto. So these are some of the Galilean moons around Jupiter that are either confirmed or we have pretty strong evidence suggesting that they have a liquid water ocean underneath variable thickness shells of ice with Europa being the most prominent so I'll talk about that later.

If you advance to Slide 4, now we're going out to the Saturn system where Titan yes everyone keeps forgetting about this but Titan in addition to all the cool stuff happening on the service has a liquid water ocean underneath a pretty thick shell of ice. And I'll talk about that a little bit later. If you click a couple more times you'll see Enceladus come up. I'll be speaking about this moon as well as Mimas, the moon that looks like the Death Star also may have a liquid water ocean. It might not be a complete global ocean in that case but Cassini has given us some tantalizing evidence of that moon as well.

Now on to Slide 5. You can see Triton the very mysterious moon of Neptune that is in fact orbiting backwards around its host planet so could be a potentially captured Kuiper built object. In this case, the liquid phase may not be liquid water but perhaps liquid nitrogen or liquid methane or some other liquid phase. We do know that there is evidence of active cryovolcanism on the surface of Triton. It's a fascinating place. I'm not going to talk anymore about it today but I really hope that we go back with some mission in the near future to Triton.

If you click one more time staying on Slide 5, you'll see Pluto which thanks to New Horizons now we have a much clearer picture of surface features and were trying to tie those to what kind of processes may be happening. This may stretch the definition a little bit of what an ocean world could be but in a way that's a good thing. We're still trying to understand and define the limits of ocean worlds, their presence in our solar system and beyond. Pluto is worthy of study in its own right.

Okay so onto Slide 6, now we're looking at an image of Saturn with a bunch of its moon starting in the rings and then extending all the way out through E-ring through Rhea and then Titan and beyond. If you click one more time a circle appears around Enceladus. Because this is what I want to speak about in a bit more detail.

If you move on to Slide 7, so Enceladus is remarkably active considering its size and the fact that we really didn’t think it was all that interesting until the discoveries of the Cassini Mission. And this is our current view of Enceladus thanks to a lot of discovery with Cassini. We know that Enceladus has an ice crust, a relatively thin one variable thickness depending on what part of the moon you’re looking at. It gets thinner near the south polar region which is the most interesting part.

We know that there is a global subsurface liquid water ocean. We’ve got a few independent lines of evidence suggesting that it is global. And we're pretty sure it’s in contact with its rocky core.

Now there are some discoveries that I'll get into in a little bit that support the evidence of hydrothermal vents at temperatures of 90 degrees C or above. That’s almost the boiling point of water happening at the south polar terrain where you have the four classic cracks in the surface that are referred to as the “Tiger Stripes”. And through these cracks we have a clue that if you click one more time onto Slide 8, you can see that along these four fractures are approximately 100 distinct collimated jets. And the contributions of these individual jets combined to form a single plume. Now we know that this plume is modulated by diurnal tidal flexing so it varies a little bit depending on where Enceladus is in its orbit around Saturn and it depends on which instrument you’re looking at whether it’s the UV instrument aboard Cassini or some of the spectrometers. It looks like it varies between say two to fourfold in terms of intensity as it orbits around Saturn.

Click one more time- now we're on to Slide 9. And we know that this plume feeds the E-ring around Saturn. And we have detected with the cosmic dust analyzer of Cassini these silicon nanograins. And this is one of our three lines of evidence that really suggests that there may be hydrothermal activity at the ocean floor of Enceladus. If you click one more time staying on Slide 9 you'll see an image coming in that's sort of a graphic generated by one of our graphic artists here at JPL putting a ring on Saturn. Click one more time and you'll see these SIO_2 particles appear in your upper right-hand side of your screen. Now these are the silica nanograins. Now they're SIO_2 silica not SIO_4 silicate. That's important. That tells us something about the pH at which these most likely formed and that gives us some of evidence that the pH of the Enceladus ocean is basic. It's about in the range of 9 to 11 but not just their oxidation phase, their size, the fact that these are 2 to 9 nanometers in diameter. The only way that these type of silica nanograins could form is if the rocky core of Enceladus is in contact with the ocean at temperatures of 90 degrees C or above. So that's where we get that really strong evidence of hydrothermal activity. And Sean Hsu, his paper down below dated 2015 is a great resource to learn more about this.

Now let's go on to Slide 10. If you click one time you'll see the plume gas features. It has been detected by various instruments, mostly the ion and neutral mass spectrometer of the Cassini Mission. Now we know that the plumes' primary composition is water. But we've also found in addition to small organic molecules like methane, ammonia, we found hydrogen recently. If you click one more time you'll see this is a table from Hunter Waites's and Chris Glein's recent 2017 paper in Science where they estimate the relative abundance of hydrogen relative to water.

And I love when Chris Glein talks about this. He says okay well let's think about this in terms of life. If hydrogen is of the easiest food for microorganisms to digest, basically that bond between those two hydrogen atoms is really easy to break. So you get energy from breaking that bond and utilizing hydrogen. Well how much energy do you get? How much is there in the plume?

Well Chris Glein did some calculations and figured out that the plume is spewing out the energetic equivalent of about 300 large pizzas an hour. So if anyone is more curious about that you can ask what estimate Chris used for his large pizza. I'm sure it varies if it's New York style versus something else but still is pretty fascinating. There's definitely a lot of energy around in that ocean, that subsurface ocean that could be available for life.

Now if you click one more time you'll see an example mass spectrum that's been obtained from the Cassini ion and neutral mass spectrometer. And you can see here in the shorter masses methane and water. But as you move over to the right approaching the limitations of that instrument we're starting to see some complex organic molecules, things that have, you know, three or four carbons bound in some complex structures. If you click one more time now we're going to instead of the plume gas to the grains. These are the ice grains that are present in the plume as well. And in these grains we also see organic molecules. Click one more time we're still on Slide 11 but you should now see on the right this is a time of flight mass spectrum from the Cassini CDA, the Cosmic Dust Analyzer. And what has been highlighted here in blue are various water ice species, in yellow are some sodium clusters which there's plenty of sodium in this ocean as well.

But I want you to pay attention to what's on the far right. Now these are masses of 90 atomic mass units and above. And Frank Postberg has nicknamed them HMOC which stands for High Mass Organic Cations. They're detecting these as positive ions.

And what’s interesting about them as they have a mass spacing of about 12 units if you notice like 91 plus 12 gives you 103. Add 12 again you get 115 and so on. And that’s the mass of a carbon atom. So this intrigued us very much because this appears to tell us that there are complex and unsaturated, that means that they don’t have a lot of hydrogen in them. Most likely there are double bonds, maybe even triple bonds in these organic molecules and they seem to extend out all the way past the range at which Cassini's mass analyzers can detect. So this is very encouraging in terms of looking for some of those key molecules that may be indicative of life or at least a habitable environment in this subsurface ocean.

So if you move on to Slide 12 of course we start looking for examples of places on earth our one example of known life in the universe and trying to see if there's some analog environments here that may be similar to what the subsurface ocean of Enceladus might be. And one of the classic places that we've discovered along the mid-Atlantic Ridge is a place called Lost City. And that’s what you’re looking at on the right-hand side here. It’s what’s called a white smoker hydrothermal system so that means that it’s not quite as hot as the black smokers and it's not quite as rich in iron but instead it’s rich in things like calcium and magnesium -- things that we believe are probably more prevalent in Enceladus’s ocean just based on its pH.

Now in these environments which are pretty much entirely cut off from sunlight- so there may be some sort of organic molecules that are generated by photosynthesis on the surface that rain down all the way to the ocean floor. But chances are most of the organizations here are not getting a lot of energy from that source. Instead their primary energy source is geothermal. It’s heat that's from the Earth’s core.

And this energy is enough to sustain if you can see here not just microorganisms like bacteria but things as large as crabs which you can see in the central image. There are tubeworms here. There are even octopi that live exclusively in these environments. So this is really encouraging that you can have these complex ecosystems forming around an environment that seems to be very similar to what may be present in the subsurface ocean of Enceladus.

So if you click one more time we're forming now on Slide 13, a better picture of what the environment of Enceladus is like underneath that shell of ice and whether or not it might be habitable. If you click one more time you should see some words in the upper left. We need to go back. Cassini has provided many revelations in terms of what it’s really like and what its possibilities are. But Cassini was never meant to be a seafaring mission. We need to go back with instruments that are specifically targeted for the modules that may tell us more about habitability or more about the potential for life to exist here.

So onto Slide 14, I just wanted to mention that of course there are many scientists and engineers who are thinking about this. And in the recent New Frontiers call I was part of a proposal team that is proposing to do exactly what I just stated, go back to Enceladus with some very sensitive and powerful instruments, the latest technology that can hopefully target these specific forms of life or evidence of life and be able to answer those questions. And so if there are more questions about this I’m happy to talk about it but I just wanted to let you all know that one chapter of Enceladus is closing but many more are opening in the future and I’m hoping that we'll get to go back in the near future. Okay so that was Enceladus. Are there any questions on Enceladus before we move on to Europa?

Adrienne Provenzano: Yes hi. This is Adrienne Provenzano, Solar System Ambassador. So you just offered to tell us a little bit more about the ELF. Could you talk about that?

Dr. Morgan Cable: Oh sure okay. If we scroll to the end of your presentation Slide 52. Can you guys all get there? It's right after this really white slide that says JPL and it sort of marks the normal end of the presentation.

Adrienne Provenzano: Okay.

Dr. Morgan Cable: Okay. So now we're on Slide 52. And what you should see is ELF as a next logical step is the title of the slide. Now ELF is a mission that fits within New Frontiers. And I'm going to talk about a couple of the instruments that we're proposing. Now we know from Cassini some of the lessons that we learned from that mission are that we absolutely need more information on what's present in the gas of the plume but also more importantly I think for life what's present in the grain. And so we have two instruments, one targeting specifically each of those pieces, those components of the plume.

Now mass spec is a very similar instrument to what is going to fly on the Europa Clipper mission. This is the mass spectrometer for planetary exploration. It's built by Hunter Waite and others at Southwest Research Institute and this would target the plume gas. Some of the features of this in particular at Enceladus are that we're focusing on an extended mass range- getting higher up. So if there are more complex organic molecules we can detect them. The mass spec also has a much better mass resolution.

Now this is important for us because for example the Cassini ion and neutral mass spectrometers while very capable at the time could not detect things that are say the same mass but made up of different elements. For example N_2, nitrogen is two nitrogen atoms 14 each so it adds up 28 but CO which is carbon and oxygen if you do the math that also is mass 28.

Now luckily for us there are slight differences in the sort of cosmic abundances of those isotopes for each of those species. So if your resolution is high enough you can actually tell the difference between N_2 and CO and other things that have the same what we call cardinal mass, that just atomic mass unit of 28. And so this mass spectrometer will have the resolution to be able to distinguish between those. And that's really important for us being able to trace for example the ultimate source of nitrogen in the Enceladus environment and things like that and it's also very sensitive.

Now the second instrument I'm going to talk about is something we call ENIJA. This this is our icy jet analyzer. And this has a lot of heritage which is great. Frank Postberg is on our team as is Sasha Kempf who is also the PI of the SUDA instruments on Europa clipper. They've built a bunch of dust detectors and can really do a good job with instruments like this. Compared to the Cassini CDA, the Cosmic Dust Analyzer on Cassini, this one has much higher resolution and also a higher mass range.

So remember those HMOC, those High Mass Organic Cations this thing will be able to detect them, not only be able to discriminate between them at higher resolutions but be more sensitive as well. So if you go on to Slide 53 we have been lucky enough to learn…

Matt Funk: Matt Funk, Solar System Ambassador. Could I ask a stupid question about…

Dr. Morgan Cable: There are no stupid questions – please go ahead.

Matt Funk: Okay. You mentioned the different isotope ratios would be useful for determining the origin of some of the atoms in the sophisticated organic molecules that the mass spec instrument is supposed to pick up. Why are we interested in knowing where the nitrogen comes from?

Dr. Morgan Cable: So one of the things that the nitrogen can tell us is how Enceladus has evolved over time whether the original nitrogen carrier was N_2 versus ammonia NH_3. It tells us whether or not Enceladus has been say exposed to a significant amount of water or hydrolysis in the past. And it can also help us inform a lot of our models which can give us constraints on composition of a whole bunch of nitrogen derived and other species that might be in the ocean. The equilibration between those species can for example determine what the pH of the ocean is or for habitability what redox pairs may be available for microorganisms to take advantage of as energy sources -- things like that. And so it is lower on our science trace matrix in terms of priority but it's important for us to understand Enceladus as a system. Does that answer your question?

Matt Funk: Absolutely. That's fascinating. Thank you.

Dr. Morgan Cable: Oh no problem. So I don't want to spend a ton of time on this because I want to make sure we have enough time to talk about a lot of the other ocean worlds but suffice to say if you're still on Slide 53 thanks to Cassini we've done a ton of modeling both of the gas which you can see a model of on the left-hand side and the grains which you can see a model of on the right-hand side. And this has helped us constrain our for example our altitude. We're planning on flying through the plume at about 50 kilometers which is low enough that we think we can scoop up enough stuff to see it but not so low that it's dangerous. We also wanted to make sure that we were above sort of the minimum altitude where the individual jets would be resolved.

If you look at the left-hand side you can see a couple of our tracks through the plume. They're labeled L2 and L3. We wanted to make sure that we didn't get so low that let's say the plume has changed or the jets that are the most powerful out of those 100 jets that are spewing stuff out of those tiger stripes we wanted to make sure that we were aiming so that we would get the bulk of the whole plume whether or not an individual jet was turned on or off. And that sort of motivated our determination to fly 50 kilometers.

And we've done a lot of the math to make sure that in terms of limits of the detection of our instruments that we can see the things that we're hoping to see based on examples that we have here on Earth of some of those communities I mentioned like the Lost City by taking numbers of okay well what do we think that the distribution of certain organic molecules would be in that system and then extrapolating it out through Enceladus.

And I have a couple of back up slides. You're free to click through they kind of step through each of our science goals for that mission. So feel free to look through that. But let's go back now...

Adrienne Provenzano:Thank you.

Dr. Morgan Cable: Of course. And if there are any other slides at the end I'm happy to stay on and answer more. But Enceladus is one of many ocean worlds and I want to make sure we get a chance to talk about a couple more. So let's go back to Slide 15. So this should say Europa beckons and it should have sort of on the right-hand side a really nice cross-section which is a very cool graphic -- I love this -- that shows our guesses about what we think Europa might look like.

Now just like Enceladus, Europa too has a global subsurface liquid water ocean. It’s ice shelf is a little bit thicker but Europa itself is larger than Enceladus and in fact it’s ocean is about three times bigger than all of Earth’s oceans combined in terms of volume. Now on this image you can see a few of the processes that we think may be happening that could potentially bring up some of that material from the subsurface ocean and express it on the surface. Europa’s surface has for example these chaos features that we're not sure exactly how they're formed which is kind of why they call them chaos because they’re just sort of crazy looking that could be formed from something like a diapir which is you can kind of think of it as it's sort of like molten ice that is able to move and flow. It’s not quite a liquid but it can still move material up and get it a lot closer to the surface.

There are other things that could happen. You could have ice fractures or veins. And of course, there is that tentative detection of plumes but there are a few papers out and I should have cited them here. But Bill Sparks is the primary author on those. So, if you just do a search for Sparks, et al, or Europa Plume in one of your literatures searching engines you should be able to find those papers to learn more about that.

Now once material gets to the surface of Europa there are a lot of things that can happen to it. I’m sure you’ve all heard all about the radiation environment of Europa. It’s pretty intense. So there may be some processing from radiation. There could also be just photolysis. There are other things that are caused by UV radiation and other wavelengths of light from our sun hitting the surface.

And then there are also things like a micrometeoroid impact, things that may garden the surface that could either change deposits or change potentially some of the biomarkers that we might look for in this really fascinating place.

So, if you hit next now we're on Slide 16. All right so we know that Europa Clipper is going to bring an arsenal of amazing instrumentation to the Jovian system. Now the Clipper mission is going to do multiple flybys of Europa while in orbit around Jupiter. And it’s going to get us much higher resolution images than we’ve ever had before. They will be bringing some spectrometers that can taste the plume if it does exist and be able to get some ideas of composition. They’ve got some mapping imaging spectrometer for Europa that will also be able to get a handle on composition.

But ultimately the best way to determine if something is habitable or potentially has life is to get down there in situ and touch it. And that’s what the proposed Europa Lander mission concept would do. And so, what you're looking at on Slide 16 is this is our current working plan. So obviously, these dates may change but the plan is to launch on SLS independent of Clipper. This would be a few years after Clipper has launched so we would arrive at the Jupiter system a few years after clipper which is great because we'll love to have some of those high resolution images pick where to land.

But the idea is that Europa Lander would launch on SLS, do an Earth gravity assist and then arrive at Jupiter sometime in the 2030. Now in terms of landing we are going to use the sky crane architecture similar to how MSL and the Mars 2020 Rovers have landed on Mars. However, there's no atmosphere at Europa or there's a very tenuous exosphere but it’s not enough to do arrow breaking or use parachutes or anything like that.

So instead of EDL, Entry Dissent and Landing which is how we normally refer to it from Mars we're going to be doing DDL, De-orbit dissent and landing because there's no atmosphere to enter so it seems like it was kind of silly to call it the same thing. So during DDL, we will have a sky crane system just like MSL did. We have tried to lengthen the tether as much as possible to minimize any exposure of the surface through the hydrazine or the products of hydrazine combustion which is the fuel that the sky crane would use. There's no other way to land like you can't use parachutes. You can't use balloons. You've got to use some type of propulsive way to land on the surface.

We will be able to land with about 100-meter accuracy to a designated landing spot on the surface. And once we've landed we will conduct a surface mission. Now if you go onto slide 17 for those of you who have the PowerPoints you should be able to click play on the video that shows the actual landing. So, we went through a lot of different landing architectures and it still may evolve assuming that this mission actually becomes real. It's still a concept.

This one we refer to as the Cricket because it's got those cute little legs. Actually, they're stabilizers that will lock in place and help us if we don't land on smooth terrain we can still maintain a nice flat, not tilted structure when we're landing. But what you're looking at here is our high gain antenna. We've got to stereo imagers that will be able to take 3-D images of the surface or stereo images of the surface. We would also have an arm that could cut down into the surface.

The science definition team for the Europa Lander released a report a few months ago -- and I highly encourage you all to read it -- talking about what sampling depths would be needed to get below that radiation processing requirement and then what potential payloads or at least what the science goals are and examples of some model payloads that might meet those science goals for this mission.

And what you're looking at now is the arm cutting into the surface and then transferring a sample to a sample transfer dock that would then move that material into the interior of the Lander for analysis by the payload. If you move onto Slide 18, now you can see an image that shows that same proposed lander architecture. Instruments will be housed within a vault to protect them from radiation and also keep them at a nice temperature.

You can see here a workspace which is in light blue. So these are the different places where the arm can reach and achieve that 10 centimeter depth that we would like. Is there anything else I want to say about this? Oh, and you can see there's stereo cameras which are mounted on the high gain antenna. One of our engineers likes to refer to the height of those stereo cameras as about toddler height for those of you who are interested in sort of trying to understand the scale of this lander in terms of size.

If you click one more time now you can see some examples of whether the lander is on through the flat surface versus slope surface or some other kind of chasm. The reason that this proposed configuration is the current version of this lander concept is because it's really robust through a bunch of different sort of topography type of the terrain because we don't really know at these lander scales, you know, at 1 meter per pixel we don't really know what the surface of Europa looks like yet. The highest resolution image we received back from Galileo -- and there was only one of them -- was 6 meters per pixel. So, we'll be really excited to see what Clipper can tell us but we may still be surprised when we land so we want to make sure that our proposed architecture is robust to as many different variations of surface topography as possible.

Now if you go onto slide 19, these are the three goals of the proposed Europa Lander mission. These were determined by science definition teams that spent many months discussing and trying to figure out exactly how you might search for life and what evidence would be convincing enough that you could say for sure whether Europa contains life or not or if it is habitable or not. So, I’m just going to walk through these briefly and let me know if you do have questions. I can answer those as well. I was part of the Project Science Team here at JPL who interfaced with the SDT. So I helped quite a bit in the writing or at least the final version of the report.

Okay so the first and primary goal of the Europa Lander concept would be to search for life. Now of course when it comes to life as Carl Sagan once said it has to be the hypothesis of last resort. You must have eliminated all other explanations for the evidence that you see and only have life be your last remaining option for you to really be sure that what you found is life. Now because of that the SDT has been targeting independent, multiple independent lines of evidence. So, some of these sub goals, for example the search for organic indicators that in and of itself also has about five target organic types that would be requested to be analyzed to determine whether or not organic indicators exist. things like amino acids for example, not just the presence of them. We know they're present in meteorites as well but relative ratios of amino acids to each other is a pretty good bio signature. The Europa Lander would also search for membrane forming molecules like fatty acids and other more complex organics.

When it comes to morphologic indicators the second part of the life goal, these can include both things at the scale of the cell but also macro scale features, things like deposits of microbial mats and things like that that you can see even with the naked eye something that maybe are context imagers could help support that life objective. For inorganic indicators, here we would be looking for minerals, things like magnesium, calcium type species and be looking for patterns that are unusual if only abiotic mechanisms are present.

And then finally and I think this is critical. I’m very glad that the SDT put this under the life goal- provenance. Now this means essentially how the sample got to where it was before you detected it. We really need to understand the history of any samples that we would collect on the surface of Europa to understand whether it was a radiation process, to understand whether it was altered by any other surface processes or things as it was delivered to the surface, how it changed from when that particular sample was originally present in the ocean. We really need to understand that very well to be able to trace back any detections to what was originally present in or what may be present still in the subsurface ocean of Europa. So that’s the life goal.

The other two goals are less important but are still very important. The habitability goal would be able to assess whether or not Europa is habitable today. So characterizing a non-ice composition is very important for this as well as determining proximity of the lander itself to liquid water. And that again sort of feeds into helping us interpret what other type of bio signatures we'll be detecting and sort of what the context is.

And then our third goal is context to support future exploration. So this is being able to tie in for example imagery and other detections of the Clipper mission at the global, regional and local scales from orbit to what we detect in the in situ on the surface in characterizing the physical properties and any dynamics processes that we can see for example that the surface of Europa is changing even on the timescales of a landed surface mission. All of this is critical not just for us understanding the measurements that Europa Lander might make but also for setting the stage as a pathfinding mission for any future follow-on missions that would land, potentially drill and access that ocean underneath the shell of ice.

Okay so let’s go onto Slide 20. This is the last slide on Europa. And this is something that Kevin Hand made. He's the chief scientist of the proposed Europa Lander mission. And he wanted to sort of put things in context in terms of when NASA last said that we were searching for life. So that would be the Viking Landers. For those of you who were alive at that time don't say if you were or not but that was back in the 1970s. We had to design the life detection experiments for Viking long before hydrothermal vents had been discovered, before any of these really complex extremophiles that we now know to thrive in an Antarctica were discovered and at least about a decade before PCR was even invented.

In terms of the technological advancements that have happened from 1976 to now of how we search for life and the extreme conditions where now we know life to be present a lot has changed which is why we think that we are capable of selecting - well headquarters will be selecting a payload that could address these questions that had been very well framed by the science definition team composed of our peers that are really knowledgeable about this. We really think that we can address this question now with a mission to Europa.

Okay so that was all I wanted to say about Europa a nd the proposed Europa Lander mission. Are there any questions about Europa? Okay well feel free to interrupt as we move...

Woman 1: I understand the radiation environment on Europa is pretty extreme. How are we going to protect the Lander from that?

Dr. Morgan Cable: That is a great question. So, it turns out actually that we worry less about the radiation affecting the Lander itself. It'll get our carrier stage the thing that we're using to transport the Lander to the surface and then communicate back to Earth. That carrier stage is actually going to get fried first and let me explain why.

At the carrier stage which will have the Lander sort of housed in it in a protective shield will be present in the Jovian system. So, it'll be exposed for a longer duration. Our surface mission for the proposed Europa Lander is probably going to be about 20 days, maybe 40 if we extend our battery, you know, if we exhaust all of our energy options. This is a battery-powered mission. We don't want to land any RTGs or any sort of radioisotope that could potentially melt and access the ocean below right? That's a big planetary protection issue.

So, we're proposing a very short mission. And so that helps in terms of the radiation dose, the cumulative dose that the Lander is not going to be that high. Now that being said it's still going to be higher than anything you would experience for example on Mars. So that's why all of the instruments that would be included in the payload with the exception of those stereo imagers, those cameras that you saw on the high beam antennas, all of the other instruments will be housed within a vault. And there's a lot of radiation shielding involved there that will help to protect the payload.

Woman 1: Thank you.

Dr. Morgan Cable: No problem.

Man 1: I have a question.

Dr. Morgan Cable: Go ahead.

Man 1: Let's see, I have a question about the point you just made all about no RTG because of the heat.

Dr. Morgan Cable: Yes.

Man 1: And you mentioned before that the landing technique was going to use a breaking rocket I think with a crane rather than…

Dr. Morgan Cable: Yes.

Man 1: ...some kind of a parachute or a cushion. Won't that also damage the surface of that place?

Dr. Morgan Cable: You're correct it will. But our engineers are very good at making sure that something has just enough fuel to do its job. But once that fuel is exhausted in that dissent stage it will break its tether. Once the Europa Lander, proposed lander has landed it will break that tether connection and then fly off and crash through on another part of the surface.

But once that impact happens it's not going to be strong enough or intense enough to penetrate very deep at all into the ice surface of Europa. So we're talking the service of Europa is around 100 Kelvin. It's essentially the hardness of granite ice at those temperatures. So there's no way that that - or that dissent stage would be able to melt its way through 100 - well depending on who you believe 10 to 100 kilometers of ice that's the hardness of granite and get to the ocean below.

Man 1: Thank you.

Dr. Morgan Cable: No problem. Any other questions? All right well like I said before and I should've included the link here.

Man 2: I have one.

Dr. Morgan Cable: If you search for the Europa Lander SDT report I highly encourage you all to read that or at least skim over it. It's a pretty big document but that has a lot of fantastic information about this. Go ahead with your question.

Man 2: Yes. I think your point was the RTG would possibly contaminat it with radioactive material rather than melting through the ice. Is that what your point was?

Dr. Morgan Cable: Actually no. At least from a planetary protection standpoint RTGs the reason that we like to use them for outer planet missions in particular is because the Sun is not very intense very far out. And so RTGs are a great way to supply energy for a long period of time. That's because it's plutonium right plutonium 213 which stays hot for a long time. And the planetary protection concern is that, that word over time since it stays hot could potentially melt down at least to some degree through part of the Europa crust. And that would happen long after our carrier stage is gone and the Europa Lander is no longer active. So, it's not something that we could control or monitor.

Man 2: I see, okay.

Dr. Morgan Cable: In terms of the radiation of RTGs that's been a technology that we've used on all the way back to Voyager. And so, we understand very well how to shield those particular energy sources so they don't cause any problems with any of our instruments. But the radiation from that RTG will be significantly less than the radiation actually present on Europa itself because it's Jupiter and its crazy magnetosphere.

Man 2: Thanks.

Dr. Morgan Cable: Yes, no worries. Any other questions? Okay so I see it's 11:47. I was going to talk a bit about some Titan lab work I've been doing but I feel like I would rather take the rest of this time to talk about some of the recent Cassini discoveries and the plan for the Grand Finale mission. What do you guys think? What would you prefer to hear about? Anyone have a preference?

Man: Titan.

Dr. Morgan Cable: Titan do you want to hear about Titan okay? Cool.

Woman: Titan.

Dr. Morgan Cable: We'll talk about Titan. Okay Slide 21, now this has a couple of animations so just as you click through a couple of times you should see different images of Titan as I talk about a little bit about. Okay so I love Titan. Titan is one of my favorite places. It is the largest moon of Saturn. It actually if you count its atmosphere it is the biggest moon in the solar system. But if you stripped that atmosphere away by clicking one now it's a little bit smaller than Ganymede. And Ganymede wins in the size category but Titan wins in the interesting category.

Just like Earth it has a thick atmosphere that's primarily made of nitrogen. And it's actually even thicker than Earth's atmosphere. And one of the things I love to describe because Titan is let's see it's a big moon but it's still less gravity than Earth and its atmosphere is thicker than Earth. So, if you were standing on the surface of Titan and you had wings and you flapped them you could fly which just blows my mind. That's wild. I would love to do that.

But anyway, so Titan has this thick atmosphere but that's not all. It also has a surface that it starts off as water ice but we think it's got this veneer of organic materials coating that water ice.   And we think that that's formed from complex reactions going on in the atmosphere that are forming these large organic molecules that are pretty much any combination of C, H, and N carbon, hydrogen and nitrogen. Any way that you can connect those three atoms together in a complex molecule, it probably exists on Titan.

And if you click again we're still on Slide 21 now you should see this great image the Cassini then took of what's called secular reflection. Now secular reflection only occurs on really, really, really smooth surfaces. Typically, only liquid surfaces can get that smooth. And you're basically just looking at a reflection of the Sun. And this was one of our first confirmations that in fact the lakes that we see in the North and South Poles are in fact made of liquid. However, Titan is much colder than Earth. And so the liquid phase on Titan is methane and ethane liquid hydrocarbon which just fascinating. And unlike anything else anywhere present in the solar system. Titan is the only other place aside from Earth to have standing liquid on its surface.

And you click one more time you'll see this is an example of what we think could even be a cryovolcano. Now I mentioned the Triton which is in orbit around Neptune has cryovolcanism. Well Titan may also. I also talked in the beginning, way back earlier on explaining that Titan just like a lot of these other ocean worlds has a liquid water ocean underneath all of the cool stuff happening on the surface. And some of these cryovolcanic features may be where some of that liquid water probably mixed with ammonia or methanol some other antifreeze type agents where some of that spills out and reaches the surface.

Now from an astrobiology point of view that gets us really excited because whenever we replicate those conditions in the lab you take like ammonia and water and freeze it and then expose it to some of the organic molecules that we think are present on Titan’s surface you get amino acids whenever those two interact which is pretty exciting from an astrobiology perspective. I’m hoping any future landed missions to Titan could potentially explore some of these putative cryovolcanic features.

No let’s go on to Slide 22. I wanted to just click through some comparisons of how Titan is similar and yet very different from Earth. Now just like Earth Titan has a hydrologic cycle however on Earth hydro refers to water on Titan that hydrologic cycle is made out of hydrocarbons- the methane and ethane. But just like we see on Earth they form clouds in the atmosphere. If you click again to Slide 23, you’ll see that the methane and ethane rain that comes from those clouds forms these rivers, channels and gullies as that liquid flows and carves features in the surface.

And if you move on to Slide 24, now you can see that the liquid pools in lakes in the north and south pole. What you’re looking at on the left here is Kraken Mare. It’s one of the largest lakes in the North Pole of Titan. If you click one more time you’ll see that it’s surface area. Click again and you’ll see that it’s comparable to what is that Lake Superior. It’s actually double, almost triple the surface area that’s present in some of our lunch lakes here on Earth. So, these are not tiny little pools. These are very large features that contain liquid hydrocarbons.

If you go one more time to Slide 25 we also see some evidence of dissolution or dissolving features. These are called karst. They’re ridges that form when a liquid phase rains down or otherwise flows through and removes materials- some materials dissolve away by that liquid phase and some other material is left behind. This is really fascinating that there are so many similarities between Earth and Titan and they’re made of such completely different things.

If you'll move on to Slide 26 you can see examples of the dunes on Titan compared to dunes on Earth. Now they may form or at least appear very similar but again on Titan these dunes are not made of sand or at least not the sand we know of these dunes are made, we think, out of organic molecules that are formed in the atmosphere, they combine and react in various ways forming haze particles and then growing in size as they accumulate more stuff falling through the atmosphere. And then they fall down on the surface. I would really love to walk around and explore what these dunes are actually made of.

Now click to Slide 27. So, this is a cartoon that my colleague Mike Malaska made to sort of show what we think a lot of the processes going on in and around Titan's surface might be. So, you can sort of start off with things that are formed in the atmosphere. They are deposited or rained down on the surface. Once they reach the surface some subsequent methane or ethane rain event could cause some things to dissolve and then be transported and deposited in these lakes. And then you have evaporation of the lakes. And something is going through that hydrocarbon cycle but some things also may be left behind as sort of evaporite layers.

And so we wanted to study some of this in the laboratory. And we wanted to focus on those lakes and those evaporites and what those might be made of as a pretty interesting place to start. Whenever you try to understand a complex world like Titan you need to take all of the individual pieces and study them individually and then figure out how they fit into the whole. And so for the laboratory we decided to take this lake/evaporite piece and try to understand that. If you click a couple more times you should see something that says okay well what happens when things evaporite from the Titan lake? That was our question we wanted to explore.

Okay so now we're on Slide 28. Now if you toggle back and forth between so if you start on Slide 28 click once more and then go back and forth between these two images what you're looking at is a superimposed Cassini VIMS this is the Visual and Infrared Mapping spectrometer VIMS superimposed with a radar image. And when you click that second time you can see that some of the features in those images have been labeled.

In blue, they are filled lakes that are filled with methane and ethane. In yellow are what we're calling evaporite deposits. We're not actually sure they're formed by evaporation but there's some sort of bathtub ring that form around some of these lakes. And then in purple are some darker deposits that we're still not sure what they're made of.

But we wanted to sort of probe what those bathtub rings are made of. Now we've done some experiments in the lab already with some organic molecules like benzene. Benzene is pretty dangerous for us but on Titan it's pretty ubiquitous. We know it's found in the atmosphere and on the surface. We also know that it's not very soluble in methane or ethane. It's sort of like oil and water is actually about the same level of solubility. And we all know oil does not dissolve in water at all right.

So that means that if a lake is saturated in benzene and then it starts to evaporate away benzene is going to be one of the first things that's left behind because it is not very soluble at all so it'll crash out of solution really quickly. Kind of like if you had a cup of coffee and you had a hot cup of coffee and you dissolve a bunch of sugar in there and then you cool it down a lot of that sugar will crash out right? It will precipitate out of the solution and sort of form white crystals at the bottom of your coffee cup. That's really what we think is happening as these lakes evaporate that the benzene is left behind like that sugar would be left behind.

So now let's click to Slide 29. I wanted to show you a little bit about how we simulate this in the lab. On the left-hand side, what you're looking at is that silver ring that large silver ring is a dewar this keeps things hot things hot or cold things called. It really keeps cold things cold when you fill it with liquid nitrogen. And that's what this dewar is filled with.

Now on the inside you can see two beakers that have a couple of wires and tubes coming in and out of them. We nested two beakers together and put a couple metal beads to confuse – there are metal beads in between them to act just like a thermal buffer because liquid nitrogen is actually too cold for what we want. Liquid nitrogen is about 76, 77 Kelvin. Titan's surface is about 90 Kelvin. So we needed to be able to heat up our little mini Titan lake which you can see is sort of orange-ish brownish. That's just because the capped on tape that we have around that beaker to hold the temperature sensor inside there.

But what you're looking at in there is a mini Titan lake that's made out of methane and ethane. And we're keeping it right at 90 Kelvin thanks to that liquid nitrogen bath. And you can see sort of the cartoon of this on the right-hand side with our temperature probe and our heater just trying to maintain that temperature as best we can.

If you click one more time you should see an image come in of this funky looking thing that's got like a whole bunch of connectors and it looks like some knobs. This is a cryostage. This is something that top for the slides open and you can put a microscope slide or some other sort of small reservoir there. And those hookups that you see on the left-hand side of this page helps us we can plumb in liquid nitrogen that'll flow around and keep it as cold as we want. You can maintain the temperature from liquid nitrogen all the way up to room temperature if you want very precisely.

And you can see that hole at the top. It's actually not a hole itself it's got a window made of quartz glass. And that's what we use to probe our sample. So we can stick this underneath a microscope or underneath a spectrometer and study the sample that's contained within that. And so that's what we use to obtain some of the images you'll see on Slide 30, if you click ahead to Slide 30.

So what we decided to do was to simulate a benzene evaporite. So we've got this benzene. We know it's present on the surface of Titan. So we just put a droplet of benzene. Now benzene is liquid at Earth temperatures but once you cool it down to Titan temperatures it freezes. And what you're looking at here is sort of the edge of a benzene droplet. The droplets sort of extend up into the left. You're just seeing sort of the lower right edge of that droplet that's frozen. And then we dumped a bunch of ethane liquid ethane on top. So we're like okay there's a rate event. Rain has happened on Titan. And then we looked to see what happened.

And we got very surprised because within about 15 minutes we saw those crystals of solid benzene break apart spontaneously at cryogenic temperatures. This is weird. Anyone who is a chemist knows that not a lot of cool stuff happens when things get really cold- reactions slow down, some of them don't ever happen cold is usually boring for chemistry. But we're finding active stuff is happening spontaneously at 90 Kelvin. This totally blew our minds.

If you click on to Slide 31, we were like okay what's going on here? That's really weird. So, we used a technique called Raman spectroscopy that basically just tells you what's there and what chemical environment it's in.

And I've labeled some of the peaks here. You can see ethane and benzene. The peaks on the left are because of ethane the peaks on the right are because of benzene.

From what we discovered was if you mixed the benzene and ethane together we saw some of the peaks shift in a weird way and we saw a new peak appear. Now this tells us that some of that ethane and benzene is in a different chemical environment than it was before. And we think that, that chemical environment means that some of that ethane is trapped within the benzene crystal structure that the benzene reorganized to accommodate some ethane which is just wild.

So if you click onto Slide 32, well that's what benzene looks like. And that's what ethane looks like. So, if you had tinker toys made out of these two blocks how would you build them together to sort of make some kind of a crystal structure that makes sense? If you move on to Slide 33, this is our best guess. We're like okay benzene is a circular molecule. It's got what we call pi electrons. And they love to pi stack and interact with hydrogen atoms or other molecules. So we figured it would be sort of like stacking two dinner plates and then squeezing an ethane in between. So we have some examples in the literature from something that happens with acetylene same size as methane but it doesn't have as many hydrogens. But it's about the same size so we figured hey maybe this is what it looks like.

If you click on to Slide 34, we thought okay well we really want to know what it actually looks like. So how do we do that? Well we can use x-ray crystallography. This is a way of you essentially fire x-rays at a crystal of your sample. And x-rays actually hit and interact with the atoms in that crystal and they will deflect and diffract and form a pattern. And from that pattern you can actually figure out where the positions of the original atoms were in the crystal structure. This is the best way to basically take a photo of atoms bound together in a crystal structure in a molecule and see exactly where they are.

So if you click on to Slide 35, this is what we found which completely blew our minds because it's way different than what we thought. If you click one more time to Slide 36 if you toggle between 35 and 36 what you can see as we've highlighted six benzene molecules that have sort of you can imagine putting a dinner plate on its side and then taking six of them and then sort of putting them kind of in a ring so they're sort of facing the next dinner plate as you go around in a circle. And then there's this hole in between those dinner plates. You can think of it as almost like a tube. And that's where the ethane molecules stick. So the benzene crystal structure totally realigns and forms these series of tubes.

If you click onto Slide 37, you can sort of see this a little bit better. I've kind of draped a white like cloth over the benzene and we can see these tubes where the ethane sits more accurately. And this is totally unforeseen. There's nothing like this elsewhere in the literature at least we had no evidence that that's would exist until we discovered it.

But we think of this is sort of the equivalent of a hydrated mineral on Titan. And that's pretty fascinating. And so we wanted to see if other molecules can do the same thing.

Okay so we were like this is wild. There's weird stuff happening on Titan. Are there other things they can do the same thing?

If you click on to Slide 38, we started to look in the literature for other molecules that we know are present on Titan or we think are present on Titan that have similar associations with each other that might do the same sort of thing at 90 Kelvin. And we looked at acetylene and ammonia as a possible example. There's some examples in the literature of these guys interacting with each other at cold temperatures but no one has done it at Titan's surface temperatures before.

So if you move on to Slide 39, we used that same Raman technique to look at acetylene by itself, ammonia by itself and then we mixed them together. Now these are both solids at Titan's surface temperature. So this was just totally crazy that two solids will react with each other and form a co-crystal just like you saw with the other ethane and benzene. If you click again still on Slide 39, you should see a couple of those new features in that red spectrum that are unique. They're not present in the other two in the either acetylene or ammonia by itself.

So if you click on to Slide 40, it looks like there are more than at least one example of co-crystals forming on Titan. But what does this mean for astrobiology? Well like I said before Titan is much colder in terms of temperature than Earth is. And we have to sort of think about things from a different chemistry perspective. For example, on Earth an ionic bond is something that is the strongest type of bond between atoms. We consider that permanent or semi-permanent on Earth. It's really tough for life to use this bond because it's very hard to break.

Well on Titan because it's so much colder it requires a lot of energy to break a covalent bond, maybe the same relative amount of energy as you would place for an ionic bond here on Earth. And you can sort of shift the energy regime a little bit. Now that means that life on Titan, if it were to exist might use what we would consider weaker bonds things like hydrogen bonding or pi bonding. That may take the place of covalent bonds in life here on Earth. And similarly, even things like Van der Waals forces places where you just have sort of a loose dipole association between molecules that may be enough for supporting some of the chemistry some of the molecular machinery that life needs. It'll be a different kind of life to be active at these low temperatures but maybe it's not impossible.

So, if you click one more time this message shows up at the bottom of the slide saying that at cryogenic temperatures weaker forces seem to become more important. So, when we think about life not as we know it but weird life, life that could exist in liquid methane or ethane or at really low temperatures we need to sort of change our way of thinking and try not to be quite as Earth centric when we approach those problems. Titan has been a great way for us to learn that.

The last slide on Titan Slide 41 shows just sort of a summary of the fact that we're discovering some really cool things on what originally we may have thought to be a kind of cold and boring place. It's not boring at all. There is active chemistry happening. There are active surface recrystallization and other weird things that are happening spontaneously. It's a very dynamic place. We want to continue to learn more about Titan in the lab but ultimately, we need more future missions, future landed or in situ missions and also orbital missions to be able to understand this fascinating moon a little bit more. Are there any questions about Titan?

Woman 2: Yes. Going back to when you were talking about the arrangement of your benzene and ethane. What strikes me is that looks an awful - I know the scale is much different but it looks an awful lot like cross section of a cilia if you look - or a cilium if you look at that. And also, I had read something about clathrates. And is this what they were talking about with clathrates?

Dr. Morgan Cable: It's very similar. So the clathrate is -- it's an excellent question by the way -- clathrates are cages. So both of these things this co-crystal I showed you and clathrates both belong to the same category which is called an inclusion compound. In inclusion compounds, you have one molecule that is called the host and one molecule that is called the guest. And so one is sort of trapped, or confined, or constrained or otherwise placed within the other molecule or organization network of molecules.

In a clathrate, typically it's for example for a water clathrate you'll have a cage that's made of water molecules that's just big enough for like a single methane or maybe an ethane molecule to be trapped inside. But that cage is closed like the door is shut. The lion is trapped in the cage. But in our co-crystal these tubes are open on either side.

And we're not sure exactly what that means in terms of processes that might happen on the surface. But one thing that we have found is that if you heat up this co-crystal it will hang onto that ethane for a lot longer than if you were to just have ethane alone and heat it up. So, it seems to be a way to keep constrain or confine ethane molecules and keep them around longer under conditions where they might not otherwise stick around.

Now one of the main mysteries of Titan is the mystery of the missing ethane. If you just look at the molecules that are in the atmosphere and the UV radiation from the Sun. UV radiation causes methane and nitrogen to break up. And the most common product of that radiation is to generate ethane.

And if you just look at the pure modeling of the atmosphere there should be enough ethane on Titan's surface to completely coat it in an ocean of ethane just like a kilometer thick or something. I can't remember exactly how thick but there should be way more ethane than we see on the surface of Titan. And we don't know where it's gone. And so maybe some of that ethane is trapped or sequestered away in co-crystals or other things like this. And that ethane is hiding underneath the surface where we can't see it.

Are there any other Titan questions?

Woman 3: I have a question about the cryovolcanos on Titan. And water underneath these surface materials. What's the evidence for that?

Dr. Morgan Cable: So you mean evidence for cryovolcanoes are evidence for the ocean?

Woman 3: Yes the oceans I guess have water underneath.

Dr. Morgan Cable: Oh so typically there are a couple of ways that we can determine whether or not a world has surface oceans. One of the best ways is to look for something called libration to see if the surface is decoupled from rotation of the core of the rest of the moon. And we have evidence for that on Titan, Enceladus, Europa pretty much all the places where we have found liquid water oceans. We've either seen evidence of this libration this decoupling or we've done gravitational measurements.

Now this is something I'm a chemist so I'm not as strong in describing. But Cassini gravity measurements they can drive by flybys. Some of these gravitational constants of these worlds and when you do that once you get down to I think it's the J3 or J5 -- and this is again not my area of expertise -- you can determine or conclude that the only way you can get that particular number for that gravitational constant is if you have a layer of liquid water.

Woman 3: Great, thank you.

Dr. Morgan Cable: Yes. And let's see Bill McKinnon I believe has some papers about this. If you do some literature searches you should be able to find some more information about gravity measurements of Cassini.

If we keep clicking through you should be able to see some cool animation showing Cassini's ring grazing orbits. If you go to Slide 43 they're in gray. It's Grand Finale orbits which were started back in April of this year and will go until our final impact orbit on September 15 of this year. Cassini is on a crash course with Saturn. We cannot alter it now. We've been squeezing between Saturn and its rings since the Grand Finale orbit started in April.

And we'll continue to do so until that final pass on September 15 when we go into the atmosphere of Saturn forever. We'll be taking measurements for as long as we can that entire time. And some of the really amazing things about this Grand Finale part of our mission aside from the fact that we never thought we could even successfully thread that needle and make it between Saturn and the rings was getting some measurements.

If you look on Slide 44 of Saturn's internal structure because we're getting closer to Saturn than we've ever been we'll be able to get the ring mass in a way we've never been able to before because we'll be able to do that measurement as we look out and decouple it from Saturn's mass. We'll be doing a lot of in situ measurements for tasting and touching some of those components of the rings in Saturn's atmosphere and taking a lot of high resolution observations.

If you click through Slide 45 and 46 you can see some of these amazing images we've had so far. The last few slides show a couple of animations Slide 47 for example and 48 of our very first plunge through the gap between

Saturn and it's rings. And I encourage you to watch those and see how we were able to successfully do that maneuver.

We tweaked the spacecraft to point our high gain antenna it's sort of our shield down to protect the spacecraft. We were worried that we would get hit by a lot of particles going through that ring plane crossing but luckily it wasn't as bad as we thought. And so in our recent passes we get about one a week we've been able to rotate the spacecraft in all sorts of different ways take a ton of measurements. And it's been a very fascinating time to be involved with Cassini.

So that's all I had to say. You guys have been a really patient audience. I know I went a bit over time but I appreciate your attention and your questions. I'm free to take any more questions you have and continue to inspire the next generation guys because NASA does some amazing stuff.

Kay Ferrari Well thank you so much Morgan. This was absolutely fascinating. We are open for a few more questions if any of you have them. If not please pull up the astrobiology education materials PDF on the telecon page. And Daniella Scalice will give us some insight as to what is available for you to use in your events. Daniella.

Daniella Scalice: Hi everyone. I won't take up too much more of your time. Thanks for having me and thanks to the whole Ambassador's program Kay and Heather in particular for hosting us in astrobiology and allowing us the opportunity to share with you through presentations like Morgan's the cutting edge stuff that's going on in astrobiology. And as Morgan said we are totally here for you as you go out and present all of this to your audiences. Just if you want to connect with us directly or through Kay please let us know how we can support you to do so.

I just have a few slides here and basically, I want to support you to find materials that you might find useful in your programs as you go out and do them. So the first slide is just kind of a fun thing-- Why is astrobiology so useful and educational? As you know and/or can imagine we're talking about these age-old questions that just permeate the human experience. So, people have very deep natural curiosity about that.

Astrobiology is very collaborative. I know we didn't talk too much about that today but the real heart of astrobiology is people working together biologists, chemists, geologists, astronomers the list goes on and on and on. So, if you are finding yourself working with students or youths in group situations than having that model can be a nice thing to work with. The inherent tennants of exploration really plug in well to the problem based learning scenario. Again, I don't know how many of you are working in a kind of deep, hands-on setting maybe this comment is a little bit more for teachers.

So finally I think as Morgan very well illustrated today we are just scoffing at this notion that everything is already known. Clearly the idea that astrobiology puts out there is that we don't know and I think as we've seen over the years children see themselves more clearly in that kind of scenario. They can actually see themselves making a contribution to astrobiology. I invite you to think about is you go out to work with this material why you find it so useful. And I'd love to hear more about it. Oh and of course the pictures here. We've got it all. I mean what's not to love? We've got dinosaurs, we've got space and we've got slime. There's nothing else the kids want to talk about right?

Okay on your second slide this is really the point of this of these slides is the URL at the top the educational materials in astrobiology. Over the years of long-term we're coming on 20 years now of investment by NASA in astrobiology. Research has become a partner investment if you will in education and outreach of projects and programs. And over those many years we have yielded great fruit in terms of products and programs that are available for you to use. Some are created by NASA others are created by our trusted partners.

So in terms of the types of things we have, we have educator guides that have hands-on activities. Sometimes they're more formalized lessons plans and units for the classroom and curriculum and so forth. We also have card games and board games. We have a lot of great videos. A shout out to our FameLab Program which we held over the past five years and a special shout out to Morgan who was a participant in the program. The URL is here famelab.arc.nasa.gov.

FameLab was basically a training program for early career scientists such as yourself Morgan to sharpen their skills in presenting to public audiences. And we have five years of astrobiologists and other types of scientists giving three minute presentations on their work. You may find some of those presentations useful in your programs. So, have a look at the FameLab Web site. And I hope you'll agree Morgan's natural ability and FameLab training were on full display today so thanks for that Morgan and good on you for making this happen.

Dr. Morgan Cable: Thank you. FameLab was an amazing opportunity. So, keep rocking it.

Daniella Scalice: We also have invested in radio shows. So, we have radio show segments and other types of podcasts. We have a lot of Web interactives that were created by our partners down at JPL. And we have all kinds of visuals posters, trading cards and even a suite of graphic novels which I encourage you to check out.

Again, everything I believe is at this URL up here. And that URL is repeated throughout my next two slides.

Just briefly educator guides we have stuff that's targeted towards middle school this Life on Earth and Elsewhere. I'm on the third slide now is our bread and butter. One of our partners is called Aomawa Shields another FameLaber who has a program called Rising Stargirls. They have an activity book that's really sort of STEAM oriented if you will STEM with arts included.

The Astronomical Society of the Pacific put together an exoplanet activity guide. There's just some really cool stuff in there Exploring Ice in the solar system that pitches down to the younger grades. Voyages Through Time and this last one here Astrobiology an Integrated Approach are both curricula for purchase for ninth grade. So probably a little bit beyond what the ambassadors do but worth checking out. There are some sort of free modules I think from Voyages Through Time you may find useful.

Next slide, Slide Number 4 we have the category and cards and board games. Two in particular I want to call out one is called AstroBioBound. This is based on a board game – these are both developed out of ASU based on a board game called MarsBound which is also very cool. And basically, it's sort of an engineering meets science let's put together a mission. And you have a budget. And you have a lot of reality around the game and there's cards that you fill in on the blanks there on the board game to the right, fantastic product.

That would be wonderful it would be perfect for an ambassador program if you have an hour or two with some kids. And I've seen this pitched up I've seen it pitched down I would say no lower than middle school. Extremophiles in the classroom is another thing that works with cards. And it’s also very focused on different environments in which we find extremophiles and how they can help us search for life elsewhere in the universe.

Next slide, Slide 5 videos lots and lots of stuff here in addition to the amazing collection of FameLab videos. PBS was aired on Montana state PBS to search for the origins of life, fantastic hour long video on different kinds of research in origins of life. Back at the top Finding Life Beyond Earth was a Nova production, Alien Planets Revealed was a Nova production. If you look those up on line you’ll find clips, you’ll find lessons plans the whole nine yards.

And one of the NASA astrobiology teams called the Planetary Lake Lander Team we produced some short clips on their adventures down in South America testing out their prototype Lake Lander that may one day find itself on one of the ocean worlds that Morgan talked about today.

Next slide, Slide 6 and there’s only one more. Web based interactive again kudos to JPL. They’ve created most of these, Alien Safari. Extreme Planet Makeover, virtual field trips, A Time for the Search for other Worlds, sort of the timeline of the exploration of and discovery of exoplanets. It’s gorgeous resources and a couple of others there. There are at least two that I know of courses MOOCs available in Coursera that have wonderful media and all kinds of resources embedded within them. Free to sign up. You might find some good material there.

And Slide 7- posters, trading cards, graphic novels other types of visuals. We have some posters that are our bread and butter. We’re happy to distribute those to you in hard copy for free. Graphic histories a.k.a. graphic novels again I think we’re up to issues - Issue 6 now. So, we’re happy - we keep an inventory of those as well at my office at NASA Ames Research Center in California, happy to distribute those for free.

We are currently out of the Extremes of Life trading cards but we're going to print more. Fantastic group in I believe Germany put together these planetary maps designed for children as a quick pic of one of those on the upper right there absolutely beautiful available for purchase. There's a link on our Web site. And we do have in stock solar system posters created by Nova as a companion to one of their films that I mentioned a moment ago. And there's again this is just the highlights, there's more on the Web site.

Last slide is just the Web site and my contact information. Again, we're here to support you as you develop and deliver your programs. So please feel free to contact me directly or through Kay. Thanks so much for your time again and for the opportunity to share the latest in astrobiology with you.

Kay Ferrari Thank you very much Daniella. Do we have any questions for Daniella?

Woman 4: Yes Daniella I have a question. I understand that you have worked with Native American communities. And I'd love to learn more of on how to connect to some in our region. I live in the Pacific Northwest in the Olympic Peninsula.

Daniella Scalice: Oh fantastic. It so happens that there is a very robust group out of the University of Washington who is working with numerous tribes in the entire Northwest Pacific area out even into Montana. So, if you want to contact me directly I'll be more than happy to tell you more about it and provide you with contacts at the University of Washington.

Woman 4: Wonderful. And is your contact information on here someplace?

Daniella Scalice: It's on the slides.

Woman 4: Here it is okay. Thank you very much.

Daniella Scalice: You bet.

Kay Ferrari I also want to add too that the two links that you provided in your presentation for educational materials and for FameLab have been added to the telecom page on the NASA Nationwide Web site.

Daniella Scalice: Oh perfect. Thanks Kay.

Kay Ferrari So people can directly get to those. And I've worked with Daniella for quite some time and I have to admit the educational materials coming out of astrobiology are just phenomenal. So please look those up. They're well worth the effort.

Daniella Scalice: All right, thanks Kay.

Kay Ferrari Any last questions for either Morgan or Daniella before we conclude?

Thank you everybody for joining us this afternoon. And I want to remind everyone that our next telecon will be Tuesday, June 13. It's entitled Walking with the Last Men on the Moon, Revisiting the Apollo 17 Landing Site With the Lunar Reconnaissance Orbiter. So, we look forward to seeing you all at that time. Thank you all for joining us. Again, thank you to our speakers Morgan and Daniella. And have a great weekend everyone. Summer is almost here. END