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Moderator: Jo Eliza Pitesky
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OPERATOR: This is Conference # 289744839R

Jo Pitesky: Okay, everyone. I have gotten a quick preview of our speaker's slides and there is going to be a lot of real great information, so we will have some people dribbling in, but I'd like to get started now. My name is Jo Pitesky. I am a member of the Cassini Flight Team here at JPL and I would like to welcome you to the last CHARM telecon that we will be having prior to the end of mission, though not our last before the end of the project. I want to encourage everybody who's joining us now, a reminder: please mute your phones.

Please, please, please, please. As a consideration to everybody else. I promise you that if you have questions, you can unmute at that time and ask our speaker. In the meantime, it’s really very important to us.

And with that, I'd like to introduce today's speaker. Chris Glein is a research scientist at Southwest Research Institute [SwRI] in San Antonio where he's a member of Cassini's Ion and Neutral Mass Spectrometer team. He received a Bachelor's in Chemistry from the University of Washington in 2006, two years after Cassini arrived at Saturn, and a Ph.D. in Geological Sciences from Arizona State University in 2012. His graduate research focused on theoretical studies of geochemical processes on the Saturnian moons Enceladus and Titan, as well as the reactivity of organic acids in hydrothermal fluids via experiments.

He did post-docs at the Geophysical Laboratory [at the Carnegie Institution of Washington] and the University of Toronto, where he gained additional expertise in high pressure temperature experimentation, and stable isotope geochemistry, respectively. He moved to SwRI in 2015. In addition to his work with Cassini, Chris is also a member of the Rosetta and Europa Clipper missions. His research interests include origins of volatile inventories on outer planetary bodies, compositions of alien oceans, and the habitability of outer planetary satellites. The latter two being fields that did not exist when he started college. Take it away, Chris.

Chris Glein: Okay. Thanks, Jo. Can everyone hear me okay?

Jo Pitesky: I can.

Chris Glein: [Slide 1] Great. Okay. And you can see my presentation, I'm assuming.

Chris Glein: Okay. Good. Right. So I'm really happy to be giving this presentation today. Thank you all for tuning in and today I’m going to tell you all about a recent discovery by the Cassini project concerning Saturn's small, but very active moon, Enceladus, and what that might mean for our understanding of whether this is an environment that could support life as we know it.

[Slide 2] The main topic of this presentation is hydrogen, and you may have seen in the news, about a month ago, we had a press conference and there were a bunch of articles written talking about hydrogen on Enceladus. And for some of you with an astronomy background, when you see the title “Hydrogen” on another planet, you might have an inclination to being puzzled, because hydrogen is the most abundant element in the universe, as shown by this table on the left-hand side, so it may not be surprising that we find hydrogen on another planet.

The right-hand image -- early image returned from the Juno mission around Jupiter. Jupiter is the largest repository of hydrogen gas, or H_2, in the Solar System. So it's common stuff to find in outer space, hydrogen is.

[Slide 3] Really what is most interesting about finding hydrogen on a planet is when you find it on these so-called ocean worlds. So Earth is the example we're most familiar with and if you look in the literature for how much hydrogen is on Earth, you can find that there's about half a part per million of H_2 gas in Earth's atmosphere, so it's not very much compared to the nitrogen and oxygen in our atmosphere.

And a major reason why you don’t find hydrogen on these solid bodies, these ocean worlds is because it's a very light gas so it's prone to escape from smaller bodies. You need huge bodies like Jupiter to hang onto the hydrogen. But there some intriguing environments on ocean worlds where hydrogen is found in great abundance.

So these, of course, are the hydrothermal vent systems that are found on the bottom of the Earth's oceans and what happens is reaction between hot water and rock produces abundant hydrogen, and recent estimates tabulate about one million metric tons of hydrogen gas being produced every year on the Earth. And it's particularly important for establishing a connection between the chemistry of a planet and the ability of a planet to support life.

[Slide 4] On the left-hand image here, I know there's a lot of lines, but these lines each correspond to different hydrothermal systems on the Earth, they names like “Rainbow” or “Lau”. And what I'm plotting here, these numbers show how much energy is available from this reaction I'm highlighting here, which is known as methanogenesis. It's using hydrogen gas to form methane. And you can see that at lower temperatures where this hydrothermal fluid, that's rich in hydrogen, mixes with seawater, abundant energy is made available. And the consequences are dramatic.

So in the late 1970s, scientists first sent submarines down near these hydrothermal vent sites and they discovered that there are teeming communities of microorganisms, and then larger ecosystems that feed on those microorganisms. So basically the foundation of these systems that are in complete darkness is chemical energy provided by the planets. So we're very excited about these types of ideas and how they might apply to other ocean worlds in the outer Solar System where we think there's abundant liquid water possibly in contact with rocks.

[Slide 5] And this is where the recent information from Enceladus is continuing to accumulate and whetting our appetites. So in 2015, there was a study from the Cassini cosmic dust analyzer [CDA] team and they reported finding silica particles. This is like small grains of beach sand that were found in outer space around the Saturn environment. And what these scientists did is they traced these particles back to Enceladus. And they found that the only way that these particles could be produced in such great abundance is if there are environments deep in Enceladus where hot fluids, that are rich in dissolved minerals like the silicon, mix with cold ocean water to form these small particles at the seafloor environment, which are eventually erupted out of Enceladus' plume.

So that's the evidence. That was the early evidence for hydrothermal environments on Enceladus. And on the right-hand side here, is a figure from a recent paper I also had in 2015, where I tried to combine the Cassini CDA data (this is the dust data) with the ion and neutral mass spectrometer measurements of CO_2 in the plume gas. You can see that there's this region where you kind of intersect both constraints that is shaded blue. That's where you get self-consistency between the two datasets, and we found that that self-consistency is achieved when the north regions, the ocean of Enceladus, has a high pH.

So this is how acidic that water is. On Earth, our seawater has a pH of about 8 and on Enceladus it looks like it's above -- about 11 to 12. So it's what we call an alkaline ocean, sort of like a solution of Windex is an alkaline solution. So putting these two pieces of evidence together we think we have evidence for hydrothermals, and then a process that produces this high pH is called serpentinization. And you're probably wondering, what the heck is that.

[Slide 6] Well, it's a geochemical process and it's called serpentinization, because when certain rocks called ultramafic rocks, so they contain these types of minerals like called olivines and pyroxenes, react with water, they make this new mineral called serpentine. And it's kind of got a bad rap because it's also one of the components in asbestos. The reason it's called serpentinization is that the mineral that's produce in these geological environments in green-colored.

And it's also California’s state rock which could be of interest to those of you on the West Coast. And it looks like it's a dominant process whenever rocks interact with water in the Solar System. So people who go to the Antarctic and collect meteorites find that when they analyze these space rocks using geochemical techniques, they find evidence of small grains of this serpentine. So it looks like it's a dominant process throughout the Solar System. And it inevitably leads to a high pH because these rocks are rich in elements like magnesium and calcium and iron.

[Slide 7] It's not too common at the surface of the Earth where humans interact, because most of these rocks that are really potent precursors of serpentinization are actually on the Earth's mantle, but there are some certain areas where these types of rocks are exposed at the seafloor. And probably the most famous example is called the Lost City Hydrothermal Vent Field. This is a vent field that was discovered about, almost 20 years ago now, in the mid-Atlantic ocean.

And it has some very unusual properties. So on this table here I'm basically showing you the physical properties, the temperature is not hot like the black smoke or hydrothermal vents, but it's sort of warm. It would be pretty warm to us, but to a microbe it's not too bad, 90 degrees Celsius. It has a pH, so this measure of the acidity, that is similar to the derived pH of the Enceladus ocean, about 9 to 11. And notice I've highlighted in bold here the hydrogen abundance.

These are some of the most hydrogen-enriched natural environments on the planet. And so the concentration here is written as "mM." This is 10 milliMolar. And so you don't really find environments on the Earth that have much more hydrogen than these Lost City vent fluids. This stuff, when people bring it to the surface, there's so much hydrogen, the fluid will be bubbling out hydrogen.

[Slide 8] And so this is basically where we were in late 2015. This is kind of the model that we were left with, is we think there are serpentinization and hydrothermal processes. If you put it together, this is the picture that emerged, where there could be some kind of high temperature zones inside of a rocky core on Enceladus shown here. The rocks might react with hot water to make hydrogen, and that hydrogen might eventually be outgassed into this plume here.

This is all, of course, very interesting to folks like myself, but notice that hydrogen is shown at the bottom here and at that time, in 2015, we had not actually found the hydrogen yet, so it was the key missing piece to this puzzle.

[Slide 9] So this leads us to October of 2015, one of the very last close flybys of Enceladus that were devoted to looking at the chemistry of the plume on Enceladus.

And a chief objective of this flyby was to form the most sensitive search yet for the presence of H_2, or hydrogen, in the plume. It was performed at a closest approach distance of less 50 kilometers from the surface. And it's just basically -- if you're not aware of what we think is happening on Enceladus, this is a nice summary from a paper in 2014, basically showing what we think: There's an ocean in contact with a rocky interior, and then this ocean is traveling through a series of plumbing and eventually erupted into outer space. So ocean water is erupting into space along with the gases dissolved in that water.

[Slide 10] And here's some of the primary data. So this is -- we were very excited when we got this data about a week after the flyby, because it's very intriguing. So the top panel shows these different masses that are instrument measures. So mass two corresponds to hydrogen or H2, mass 18 is water, mass 28 could be carbon monoxide or nitrogen gas, we don’t [know] -- they have the same mass. And mass 44 was CO_2. The top panel here, you can kind of see that as you get to zero time of closest approach, that's like right when you're in the plume, we see the largest signals detected.

And that was the old data. So we kind of had a sense of, okay, there's water in the plume, there's some CO2 and so forth. The new data, we're using this new mode called open source mode. And what open source mode does is it eliminates any sort of possibility that you could have chemistry happening inside the instrument before the molecules are being measured by the instrument.

And so that's useful because in closed source mode, there's questions of whether the hydrogen that we detect could somehow be produced inside the instrument as an artifact but in open source mode, the molecules just fly straight back into the detector where they're counted.

[Slide 11] And here's zoom in of the open source data and you could see here in red we have hydrogen counts. Some of the largest counts are about 100 to 200 counts. So we used this new mode of using the instrument and we found hydrogen in the plume. So this is very exciting of course.

Chris Glein: [Slide 15, skipped Slide 12, Slide 13, Slide 14] Then what we did is we engaged in a very detailed analysis of these data to try to understand, okay, how much hydrogen could there be in the plume. And what we had to do is we had to construct a model of how the plume erupts gases and how they are received by the spacecraft instrument. So I won't get into too many details here, other than you can see in the bottom panel, these are all the individual geysers that are providing gases to the plume.

We had to account for all of their inputs into the plume, and the top panel basically shows all the different directions at which the gases could be received by the spacecraft. So it was a difficult problem to try to understand the detailed geometry of the system.

[Slide 16] This is the results of our modeling shown here, so you could see at the top panel, this is our attempt to reproduce the water signal. So we could produce parts of it using our model, but other parts appear to be different which might indicate that the sources of water change over the course of different flybys.

And then the bottom panel is perhaps the most interesting part of this presentation. It’s the modeling of how much hydrogen is contained in the plume. So we tried two different models, one called isotropic and one called collisionless. I won't get into too many details here but we found that the isotropic is a more consist model in terms of the physical conditions of the plume. From that model, we're able to derive a best fit from the model to the data, if the plume contained about one percent hydrogen gas relative to water. That was a key number from all this analysis. There's about one percent hydrogen content of the plume of Enceladus.

[Slide 17] Okay. So then the next part. That was the data part, and then there's this whole other part of this project, where, once we convince ourselves that we understood how much hydrogen is in the plume, we decided to ask ourselves, "Well, hold on a second. Does hydrogen necessarily mean that it has to be hydrothermal or could there be other ways for a planet, or a moon, I should say, like Enceladus to acquire hydrogen?" That's what we looked into.

[Slide 18] And this table here basically summarizes [our work]. I won't go into every single argument, but we looked at a variety of possible ways that Enceladus could acquire hydrogen. So one example shown here in the second row is you could imagine that Enceladus's building blocks might have looked something like comets and if those building blocks formed at very low temperatures, less 20 degrees Kelvin, hydrogen gas could have been trapped in the building blocks of the moon.

However, when we look at the data from Enceladus, you would expect, from this type of model, that if those cold temperatures prevailed when Enceladus formed, that in addition to hydrogen gas, Enceladus should have things like Argon or Neon or CO. So these are other gases that are trapped in ice at very low temperatures, and we didn’t see those in the plume.

[Slide 19] So basically what this slide summaries is these different ways that we could imagine a moon like Enceladus making hydrogen. This is the homegrown variety for getting hydrogen when it first formed, and the second column here basically shows how we analyze the data and the different inconsistencies. So these are things that don’t add up if these were the sources of the hydrogen. You'd expect, for example, if you had homegrown hydrogen from [Radiolysis of water ice] on Enceladus's surface, water molecules would be converted to hydrogen and oxygen. We don’t see the oxygen gas, so we conclude that this is not a very viable possibility. And for all four of these possibilities we basically used that same very meticulous accounting and analysis to reject these possibilities.

[Slide 20] This will get into a little more of the chemistry. I'll just try to go through this at a very high level to help you understand what we think might be going on with making hydrogen. The fundamental idea here is that hydrogen on these types of ocean worlds is produced from water. The water has hydrogen atoms, but you need to convert hydrogen atoms to H_2 molecules, so the oxygen atom needs to be dispensed.

And the way that happens in these hydrothermal environments is the oxygen atom gets bound up to iron, and when that happens, the hydrogen is released as free hydrogen. So you can basically see [the processes] in these different equations. Let's take B, for example. The iron binds up a lot of oxygen here, so you're left with free H_2 that's produced. So we basically constructed a model where we could account for how much iron we think could be inside of Enceladus, and from that amount of iron we could use these equations, these chemical equations to calculate how much hydrogen could you get out of that.

[Slide 21] This basically summarizes the overall physical situation where you have an ocean on Enceladus but below that ocean there's a lot of rock with a lot of iron.

[Slide 22] The fundamental result is nicely understood with this particular example. So if you were to imagine that one percent out of that chunk of rock in Enceladus' core is reacting to produce the hydrogen that we see in the plume you could sustain that process for about half a billion years. So there's a lot of potential to keep making hydrogen for quite a long time. So we call that geochemistry. This appears to be a robust process. It doesn't appear to require anything particularly special.

[Slide 23] I will show you all a few comparisons to the, Earth because the Earth is something we think we understand, and it's nice to use that as a point of reference. So hydrogen is found both in Lost City and in the plume but so is methane. And when you look at the hydrogen and the methane ratio in these environments it's kind of interesting. So at Lost City the ratio is about nine and in the Enceladus plume we have larger error bars, but it's around 1 to 14 which nicely is consistent with that range of 9 that we find at Lost City. So it looks like that part of the story checks out as well.

[Slide 24] If you haven't had the chance to see this image yet I'd encourage to find it. You can find it on the NASA photo-journal website. And I think the Cassini website has it as well. This is the image that we produced for this press event with NASA, and it was produced by an artist with the LA Times. And I really like it. I think he did a great job. And I actually made a big poster for my daughter, so she really likes that, and I'm sure young children would like this as well for other families.

[Slide 25] Here's kind of an overall comparison of Enceladus to the Earth. So notice Earth really tips the scales. Here's the production rate of hydrogen on Earth, it's about 10^{12} moles per year. And Enceladus is about 1,000 times less. Perhaps it's not too surprising because Enceladus is a lot smaller than our planet, so there's not as -- the hydro-thermal activity on Enceladus is just not as widespread on a whole global basis as we find on the Earth.

[Slide 26] I have a few slides here basically explaining why we think that this is so exciting. So there's many applications of hydrogen towards astro-biology and thinking about the potential for life on Enceladus. And the key concept is that H_2 is produced from the rocks, and it links this inorganic chemistry of rocks and iron and water to the organic chemistry of complex molecules. So basically I've shown this simple schematic equation where if you have CO_2 reacting with hydrogen you can make organic molecules. So a type of organic molecules is something like a hydro-carbon, so to make a hydro-carbon you have to add hydrogen to carbon.

This [graph] shows some of our data from earlier on in the Cassini mission. At higher masses where I'm circling here, these are different organic species like benzene or butane and simple types of organic molecules. The finding of hydrogen might help us understand how these molecules are being produced inside Enceladus, whether it would be from life processes, if there's organisms out in Enceladus, or it could be geochemical processes.

[Slide 27] The finding of hydrogen is also very relevant for understanding the potential for the origin of life on Enceladus. For those of you who are familiar, one of the emerging models for how life might have originated on our planet is hydro-thermal systems looking something like Lost

City where you have simple molecules like hydrogen, CO_2 and hydrogen sulfide undergoing complex chemistry with different minerals to form more complex organic molecules. So this is very exciting for a potential connection between these early environments on Earth that could have led to the origin of life, and thinking about the possibility of life starting on Enceladus.

And actually, probably what's of greatest interest is the potential for current life on Enceladus using hydrogen as a fuel. You may have heard about the hydrogen economy. Hydrogen is a fantastic fuel.

[Slide 28] I was warned that this could be a little bit of a daunting figure, so I'm going to walk everyone through this and we're just going to go over the general ideas here. But the idea, when we have a hydrogen measurement, is we can now calculate how much energy is available if there was life present. And so, I called this, earlier on during a press conference, that we've made the first "calorie count" of an alien ocean because it's really true. We're counting how much energy there could be to support life.

[Slide 29] Let's look at how this is done. One equation -- I won't discuss any of the details other than this equation tells you how much energy is available. That is this quantity delta G and there's two parts of it. One part is theory. So we don't need to go anywhere. We can use the computer to calculate this first part. It's just based on theory. The second part of this equation though, we need measurements of CO_2, hydrogen and methane. And the great thing about Cassini is Cassini allowed us to make these measurements of these types of molecules at Enceladus.

And notice I've drawn this line here, this line at zero, so if you have zero energy that's called chemical equilibrium and that would be a state of death for any forms of life, including us.

[Slide 30] And so, from various studies of organisms on Earth, these green lines basically show how much energy is needed by life. What is the demand that life imposes on geology to continue to sustain life? We know it's about 10 to 20 in these units of affinity.

[Slide 31] Then using the Cassini data we were able to quantify how much energy is available in this Enceladus ocean plume system. That amount depends on the pH of the water which we've estimated to be between about 9 and 11. So somewhere between these two curves is where Enceladus lies.

[Slide 32] And then with the hydrogen measurement we were able to bracket it further between these two gray lines. So again we have the sweet spot of where the data are leading us. And it turns out the data are leading us to a bonanza of energy being available.

And so, to answer this question, is there enough chemical energy to support life as we know it? The answer is yes. So maybe these hydrothermal vents are actually producing a feast if there's anything around to eat it. The supply of energy is greater than the types of demands the organisms that we can study have.

[Slide 33] So the conclusion is that Enceladus is energetically habitable. There's enough energy to sustain life. And so, you might have heard of the three essential requirements that astro-biologists think about to support life. What's required to make an environment habitable? Previously Cassini has found abundant evidence for liquid water, so we can check that off our list.

We've found many of the essential elements like carbon, nitrogen and oxygen. We haven't quite found all of the needed elements, so we got kind of like a partial check-mark there. And now with this new discovery, we found that there is an abundant source of free energy in this environment that life could exploit. So if there is an Earth microbe in that ocean, it would be perfectly happy.

Of course the next natural question is whether, now that we have the sense of the environment looking like it's very promising in terms of being habitable, we want to understand could it be inhabited. And that's going to be a $1 billion question for the future.

[Slide 34] So this is a slide that basically summarizes this progression between geochemistry and ecology. I won't get into all the details other than there are very intriguing parallels between how the earliest geochemistry on planets processes hydrogen to make organic molecules, such as methane, and the biochemistry of the most primitive forms of life that we find on Earth, like [life] around these hydro-thermal systems, that process hydrogen in a very similar way to make organic molecules, and to get energy to sustain these ecosystems.

Enceladus offers us, I think, a fantastic opportunity to try to test these types of ideas of whether the drive from geochemistry, to biochemistry, to ecology, is inevitable on wet, rocky planets, or is it a very rare occurrence. We don't know the answer and I think this is an environment that can help provide critical clues to this question.

[Slide 35] You might ask, what NASA is doing now that Cassini is nearing the end and we don't have any more data flowing in from Enceladus? Well, we're interested in a lot of different things. We have the Europa Clipper that has a very similar, much more advanced payload than Cassini.

We have these mass spectrometers that are able to measure hydrogen and other different molecules that could serve as food sources. There's a variety of different proposals for the “new frontiers.” These are NASA's medium-class missions to look for evidence of life on Enceladus. And of course there is the very intriguing, but also somewhat contentious, Europa Lander that would directly search for signs of life on the surface of Europa.

So we're thinking about all of these ocean worlds and trying to understand how we can use the types of methods that we've developed from Cassini to take the next step.

[Slide 36] And so, with that I will leave you all with this conclusion slide and I would be happy to answer any questions.

Jo Pitesky: Chris, thank you. That was just wonderful. You've got a room-full of scientists and engineers sitting here at JPL who are sitting here with big grins on their faces, and it's not just because we see a giant squid poking its head out over Enceladus.

I want to open up the tele-conference for questions, who out there has something to ask us here?

(Michael Stem): I do.

Jo Pitesky: We have (Michael Stem) who is our favorite ace, who is not on console right now because we're not -- well, second favorite because (Dave Doody) is also in the room here.

(Michael Stem): Well, and our systems are down, so. Yes, I was asking Trina about the reason you said that you haven't seen the phosphorous and sulfur yet. Is that because the phosphates and the sulfates, those mostly like salts that are in the ocean, is it because it's out by the bounds of the [Mass Spectrometer]?

Chris Glein: Yes, that's a great question. So the Ion and Neutral Mass Spectrometer measures neutral volatile species, so we can't see the salts. The other instrument, the Cassini cosmic dust analyzer, could see the salts but the instrument really isn't optimized to look for sulfate and phosphate. And the reason for that is that instrument was designed to detect positively-charged species. So that's how it found the sodium plus ions in the plume particles, but it's not sensitive at all for looking at, especially trace species like phosphate.

Jo Pitesky: I have a question, and this is only half-formed because this morning I saw a presenter talking about detection of oxygen molecules in the spectra of exoplanets. And the question about what that might mean for habitability? So if might be a different issue when you're looking perhaps at a water plume, but how do you distinguish between oxygen molecule -- well, how would you distinguish a situation between oxygen molecules as signature of biological activity or as perhaps a by-product of something which is more geochemistry?

Chris Glein: That's really tough question to address, especially when you have such little data like you do from the exoplanets. Oxygen is also similarly problematic like hydrogen is because there's a lot of oxygen in the universe, so there's potentially a lot of different ways for planets to make oxygen molecules by just geochemical means. So a classic example is if you shine UV light on water, on a mixture of water vapor, oxygen gas can be produced.

I think the most sensible first strategy is to try to look for explosive mixtures. I'm always saying that somewhat jokingly, but if you find mixtures that are unhappy, they are thermo-dynamically unstable with respect to each other, that's a first sign. And then we really need to do a lot of work. So you can see by this project we presented, you have to really try to understand what the full scope of abiotic geochemistry is capable of before you start to consider biology. So this is what Carl Sagan used to say that biology is a hypothesis of last resort, and I think that's really true.

Jo Pitesky: We've received a couple of questions on the chat side and first of all from (Ocean McIntyre) who is one of our Solar System ambassadors, asking, "Is there a hypothesis as to the process that it's causing the hydrothermal vents and how long has it been occurring?"

Chris Glein: There's a hypothesis but we don't really know much about it yet. So we think -- when Enceladus' activity was first discovered it was found that we had an unsettling energy crisis where there was too much energy being released by all the heat released in the geologically active zone and these plumes. And some progress is made, they're made towards understanding how you could have energy generated, so this would be the process of tidal heating, but to get hot rock there needs to be tidal heating in this rock. And that's not something that's very well understood, yet previous modeling has suggested that the rock might be too rigid. They would not flex and generate viscous heating very efficiently.

But some recent work has suggested if the rock is mixed in with liquid water, then its properties could be much more amenable to tidal processes, and there has been some recent abstracts and conference presentation, performance and models looking into this process but this is not very well understood right now.

We think the observations are telling us that this is probably happening, but now it's up to the geo-physicists people to try to understand the details of how this could really work. And also then to address is this going to be a very transient, ephemeral process, or could it be something that's been taking place for tens or hundreds of millions of years. That's going to have tremendous applications for thinking about the temporal component of habitability, or if there could have been enough time for light to originate in Enceladus' ocean.

Jo Pitesky: Another question that has come in from (Paco FOSS Science Center) asking, "Is there any way to estimate how long these processes have been going on? And that I believe you talked about a half billion years limit about how much material I'm guessing could be, but could you expand on that some more?"

Chris Glein: Yes. The short answer is that I don't think it's possible right now. You could certainly take my calculation and run with it, and simply extrapolate the present situation into the past, and that could suggest that this process has been happening for the history of the solar system. But we should be very cautious because we don't actually -- following up on the previous question -- we don't understand the geophysics of the deep system well enough to understand if that's reasonable or completely off base to assume that the present is the key to the past for this particular system.

Jo Pitesky: I've had a couple of questions come in asking about future instrumentation and I'm just going to bundle this together. First of all from (Adriana Provisano), asks "What scientific instruments are being developed to study the hydrothermal events on Earth that may be used on Enceladus?" And then also in that same wheelhouse, from (Jonathan Ward), "What kind of instrument would be needed on a life-finder fly-by craft in order to prove that there was a biological organism present? What sort of imaging? To put it directly, how else do you prove that there is life there?"

Chris Glein: Right, all very good questions. So the type, it's hard to figure out that universal instrument to determine the presence of life versus to understand how these systems are happening in detail. People on the Earth are talking about testing mass spectrometers at hydrothermal events. So presently what people do is they collect samples from their submarines and then bring them to a laboratory which is great but that's not actually what we're going to do if we were to ever send a lander or a submarine to the bottom of Enceladus' ocean. We would to be performing the measurements in situ, so there's a lot of interest in trying to test these technologies in environments that we think we understand.

Regarding trying to find evidence of life, that's a really tough one, there's been proposals to take imagers to look for things moving like what's suggested. That's not actually a joke. People are thinking about that. And there's also various measurements that are looking for particular molecules like we find in Earth-like life, like DNA or amino acids, because there's always this tricky question of do you want to send an instrument that can perform a general survey of all the different types of organic compounds that are present? Or do you want to try to design a silver bullet to look for one very specific class of molecules?

The danger of looking just for DNA, as an example, is we don't know if life on Enceladus, that may have originated separately from life on Earth, if that form of life would use DNA. It may very well use some other type of molecule to store genetic information. So there's always a tug of war of how far do you want to go between being a generalist and being very specific. And those debates are still being made as the next generation of missions and are being designed, and it will be particularly interesting to see what NASA chooses to emphasize.

Jo Pitesky: I know that with the descriptions that have been going on about the mission concept for the Europa lander, people are really struggling with a lot of these issues as well.

Chris Glein: Yes, so you know we have to try to keep debating and do our best. At the end of the day, though, these are such complex environments. I think we're just going to be completely blown away by the complexity and how spectacular they will be.

Jo Pitesky: I had a question from (Sally Jensen) asking about the role of nitrogen in all of this?

Chris Glein: Yes, nitrogen. Well, we see, in the plume we see evidence of ammonia, and that sort of makes sense because ammonia is stable in the presence of hydrogen. So both of those molecules are what's known to chemists as reduced molecules. That makes sense but we don't really know what happens to the nitrogen from ammonia.

It's tempting to think could some of that nitrogen be incorporated into things like amino acids, or even more complex nitrogen molecules. But those are particularly difficult analytical challenges to try to detect those types of molecules. Even a simple amino acid is not easy to find because they're not terribly abundant like the simplest molecules like hydrogen ammonia and CO_2. So that's going to be a question for the next stage of exploration.

Jo Pitesky: Right. We had a question come in from (Richard Stemberg). By the way for those of you online you are welcome to ask questions yourself. Of course if you send them in by chat that's fine as well, "Do you see a future role for measuring isotopic fractionization of carbon in differentiating between biotic and abiotic forces?"

Chris Glein: Absolutely. That's one of the standard parts of our arsenal for looking at anomalies that we might attribute to the presence of life. So to explain to the rest of the general audience, many environments on the Earth were organism and make methane from CO_2. They preferentially make the lighter version of methane because it cost less energy to do that. So it's possible that we could see similar effects on Enceladus whereas if we saw some preference towards making isotopically light methane that looks like it's much different from anything we would recognize as geochemistry then that might be our first piece of evidence to suggest the presence of life.

But it's nowhere conclusive so that would be one part of the toolkit and then we want to bring multiple layers of evidence to really try to constrain does this really test for the presence of life?

Jo Pitesky: We've had a question come in from (Jack Howard) asking, "This is something you've touched on a little bit about how we would be looking for life if they're just flying by, but if we don't land on Europa or Enceladus, and some of our missions will only be fly-bys, what methodology will allow us to detect any life forms that might exist in the sub-surface oceans? That's going to be possibly, especially challenging for Europa where there is split expert opinion on whether or not we have truly seen plumes coming off or not?"

Chris Glein: Right. This is a tough problem. I think the starting point is to look at the molecules. So I'm a geo-chemist, I like to tell people that the message is in the molecules. There's a story in the molecules. The collection of molecules tells a story. I mean it's kind of like if you go to Yosemite in the United States and you look at a granite out-croft those minerals in those rocks tell a story of what's happened there. Some event happened in the past, or is happening today.

And I think it's a similar type of story at Enceladus, where the plume contains a message. It's a collection of molecules and it's going to require all of our ingenuity to try to interpret what this is telling us. So for looking for life, we want to look for what particular molecules are there, what are their abundances with respect to one another, and how does that compare to different environments on the Earth or outside of the Earth? So does the mixture of molecules look like a frozen comet that's been melted, or does it look like a hydrothermal event, or might it look like an environment where life has provided a large imprint on the chemistry. I think that's the real challenge.

Of course the difficulty is in the details to try to identify what are the key signatures that we don't think geo-chemistry can do.

Jo Pitesky: This past weekend was the JPL Ticket to Explore, when people, we had about 18,000 people coming each day to go through and take a look at what the lab has to offer. And several people were asking the Cassini folks about what we know about the composition of Enceladus' oceans, let alone Titan's. And my answer was that we can't entirely sample it. We don't really know enough about the details composition because we did not take our beach gear along with us when we flew out to Saturn. And so, what you say about the molecules containing the story rings so true for us.

Chris Glein: Yes it's kind of the bulk properties. I hope no one goes too wild there but you could make Enceladus' ocean in the kitchen in its basic properties. So it looks just like a mixture of table salt, that's sodium chloride, a little bit of sodium bicarbonate and then a little bit of sodium carbonate. So these last two things, bicarbonate is baking soda and then sodium carbonate is known as washing soda. So if you put a little bit of baking soda in an oven and cook it you can make washing soda and then you're set.

And I've made this for kids in science fairs before. We've actually, I've personally tasted this stuff and it sort of tastes like salt water. It doesn't kill you but I would encourage people here not to taste it.

Jo Pitesky: I had another question come in asking, from (Ocean McIntyre) asking, "Will any future instrumentation be looking at chirality as a key to life detection?"

Chris Glein: I think probably some of the missions that have been proposed or are currently being proposed are looking at chirality. So this is certain molecules that have bonding arrangements of different groups around carbon atoms in organic molecules, exhibit what are known as left-handed and right-handed forms. They are mirror images. And it turns out that for reasons that are not really understood, life on Earth chooses to make one particular mirror image of a certain molecule like an amino acid. And if you compare that to geochemistry, geochemistry doesn't appear to show that type of preference. So this is a particularly strong tool in our arsenal towards testing for the presence of life.

Jo Pitesky: Okay. I'd like to thank our speaker once again. That was just outstanding. It really gave a very great sense about the work we've been doing. We know how long you've been waiting to release these results. We're delighted to have you here.

And a reminder to everybody else who is listening in this will be our last CHARM until after September 15th which will mark the end of the mission but not the end of the project, and I expect that we will be resuming the CHARM tele-cons sometime after. We will see you on the other side.

Thank you as always for joining us. It's been a pleasure to have you here and have a wonderful rest of your day.

Chris Glein: Thank you.

Female: Thank you.

Male: Thanks, Chris.

END