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Moderator: Jo eliza Pitesky
April 19, 2016
1:05 p.m. CT

Operator: This is conference number 275601600R.

(Jo Piteski): Good morning or afternoon, everyone. My name is Jo Pitesky and I'm a member of the Cassini Flight Project at Jet Propulsion Laboratory. This is our spring CHARM [Cassini-Huygens Analysis and Results] telecon and we have an interesting speaker today, but before introducing him, a few reminders.

If you are in a noisy environment, we very much appreciate if you can mute your side of the phone line, so we don't hear your discussions, or your potato chips, or anything else like that, either by pressing star six or by using whatever mute capability you have on your phone.

And the other thing is that, as I said earlier, people have been asking some wonderful questions and if you think of a question during the talk, you can either give that to our speaker at the end of the talk, or if you're more comfortable, you can certainly send to me, Jo Pitesky, under the name (Karen Chan) on WebEx, under the chat feature, your question, and I ask that for you as well.

With that said, our speaker today, Jason Hofgartner, is a NASA post doctoral program fellow here at JPL. He's as associate member of Cassini's radar team and has been involved with the

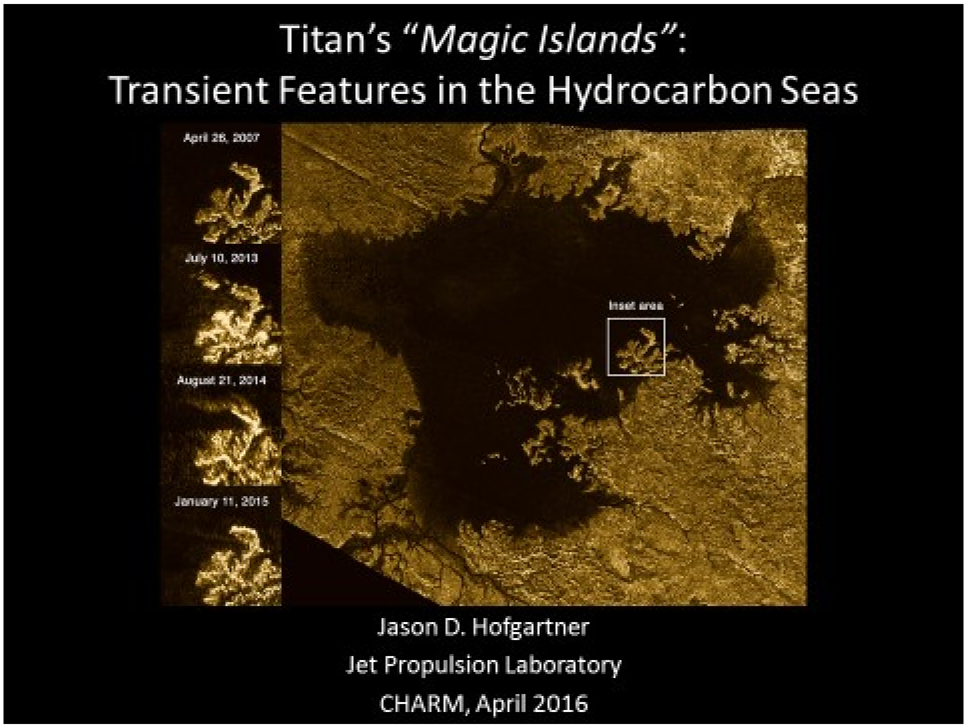
Cassini mission since early in his graduate school career at Cornell, working with Cassini's interdisciplinary scientist, Jonathan Lunine.

Jason is also a postdoc team member of the New Horizons Geology and Geophysics Investigation, for those of you who don't immediately remember, is [focused on] Pluto. Not surprisingly, Jason's research interests include planetary explorations, liquid environments in the solar system, Titan, Pluto, and Charon.

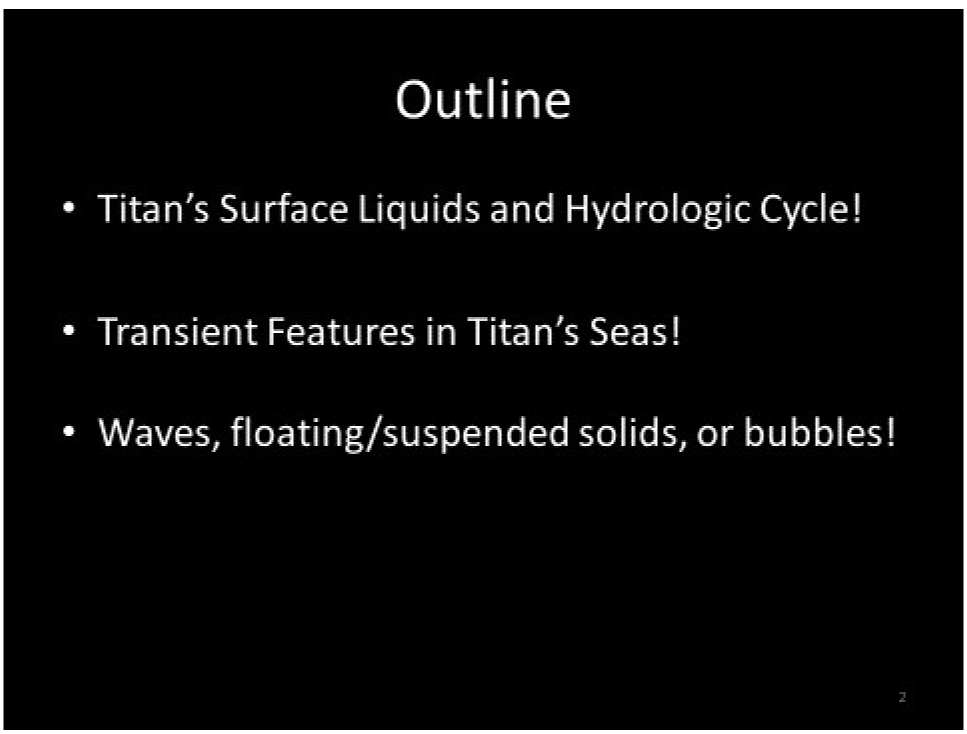
In 2014, Jason led a team of researchers in discovering and confirming the first transient features discovered in Titan seas. These enigmatic features, popularly known as Titan's “Magic Islands,” were determined to be waves, floating or suspended solids, or bubbles. Recent observations to study these features have revealed additional transient features in the seas and Jason is leading the analysis of these new observations to better understand the processes that are driving the evolution of these features.

He also, during his time at Cornell, enjoyed exploring the gorges of Ithaca and so, I wonder if he would also enjoy exploring some of the more dramatic terrain that we see in the Saturnian System.

And with that, our speaker, thank you very much.



Jason Hofgartner: OK. Thank you very much, Jo, for the nice introduction. It's a pleasure to be here today. It's always fun to talk about Titan.

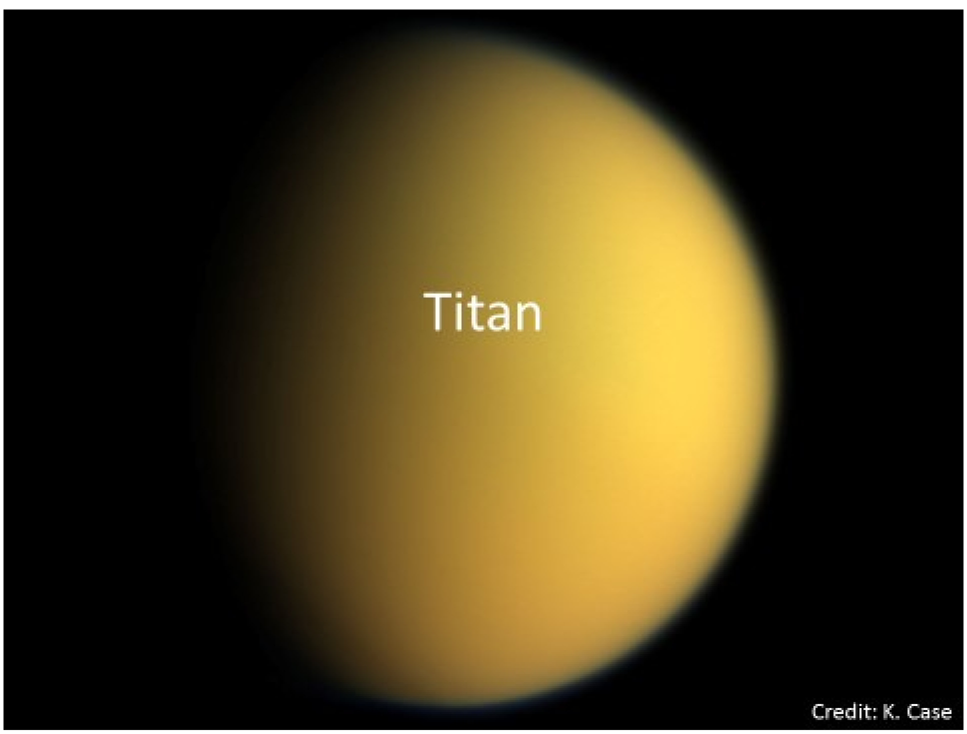


So, the outline for today's talk is on slide two here, and I'll start with an overview of basically the fact that there are surface liquids that are stable at Titan's surface, and they're participating in a hydrologic cycle, where we think we've seen that there's rain coming down. And that rain is flowing in rivers, which I think is still just an astounding fact about Titan.

Basically less than 10 years ago, that was unknown about Titan, and it's still the only place that we know of, aside from the Earth, where there are stable liquids participating in a cycle like that.

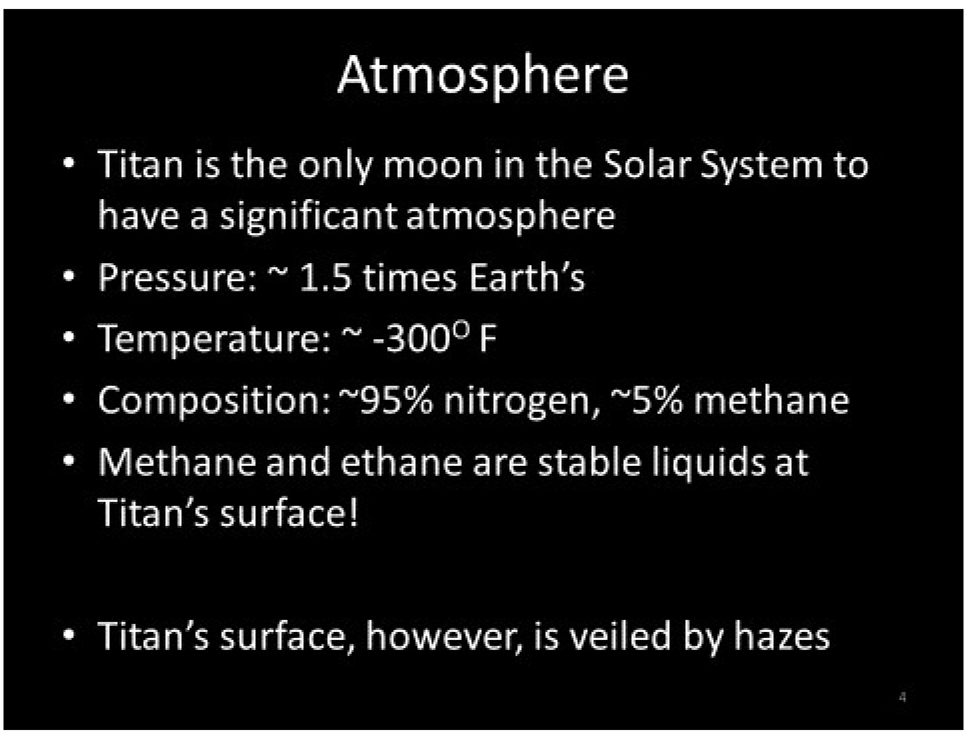
And for some of you that may be all very familiar, but hopefully for others, that will be a new introduction, or some new information. And then after that, I'll talk about these exciting features that we're seeing in some of Titan's seas, and I'll break that part of the talk up into two parts.

The first being basically just about the discovery of those features and why we know that they're transients and not something else, like an artifact in the image, or something that's fooling us. And then, I'll get into, once we've established that they're transients, what basically is causing those features. And then, as Jo mentioned, our most plausible or most likely hypotheses are that they are waves, floating or suspended solids, or bubbles.



On slide three here is a picture of Titan, basically how it appears to the naked eye. And as you can see, it's actually a very boring place in the light that you would see with your eyes. It's basically just a brown, orang-ish, golden globe. And the reason for that is because Titan has a thick atmosphere with a lot of hazes, like a smog. So, those of you in large cities, it's basically a thick smog that's much worse than any city on a bad day.

And underneath that atmosphere is an area that is larger in size than the planet Mercury, and about equal to twice the size of North and South America combined. So I love the idea of exploration and the unknown and for me, Titan is really an explorer's dream, because there is equivalent to twice the size of North and South America that has been explored in just the last 10 years. It's an incredible amount of terrain in those places, and there're just amazing things there, a lot of fun to study.



So, switching to slide four now, Titan does have an atmosphere. And even prior to Cassini, there were some interesting implications because of that atmosphere. So, it's the only moon in our solar system to have any kind of significant atmosphere. The pressure at the surface is about one and a half times the pressure that you're feeling on your skin right now. So, that's equivalent to diving down about 10 feet in water, [in terms of] the pressure on your body. That's what you would feel at the surface of Titan, so, not too dissimilar from what we're feeling, and not very uncomfortable at all.

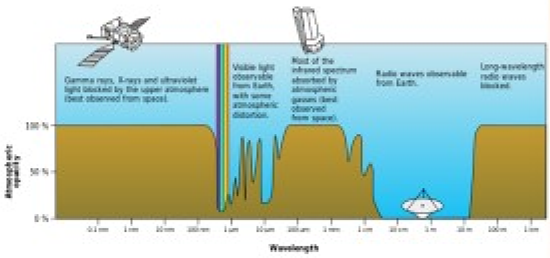
However, the temperature is very cold. It's about minus 300 degrees Fahrenheit and that's because Titan is about 10 times further from the Sun than we are. So, it would be quite uncomfortable due to the cold. The composition of the atmosphere at the surface is about 95 percent nitrogen and 5 percent methane.

Earth is 80 percent nitrogen and then the rest is oxygen and other constituents. Again, Titan is similar to the Earth in that it has a very similar atmospheric pressure, and it’s also the only atmosphere that is dominated in nitrogen just like our own.

And at these conditions, it was recognized that both methane and ethane, natural gas here on Earth, are stable liquids at Titan's surface. And so, in preparation for the Cassini mission, there was a lot of interest in being able to see the surface of Titan to look for these liquids. However, again, the surface is veiled by those thick hazes.

Cassini-Huygens Unveils Titan's Surface

- Titan's surface can be observed in infrared and microwave "atmospheric windows"



Earth's atmospheric windows

½ scale model of Cassini spacecraft

[On Slide 5] The tricks that Cassini uses to get underneath those surfaces, there are basically three [infrared, radar, and the surface probe]. Titan is that orange, golden globe in the optical, in the light that we would see with our eyes. But if you change to infrared light, then there are windows where you can see through the atmosphere. So, there are two cameras on board of Cassini that take advantage of those windows to see through the atmosphere and down to the surface.

And then, similarly, there is a large radar system. So, that's on the right-hand picture. There is, on the top there, that white radar dish, and that basically is used for the radar that takes advantage of a window in the microwave region, again, to see through the atmosphere.

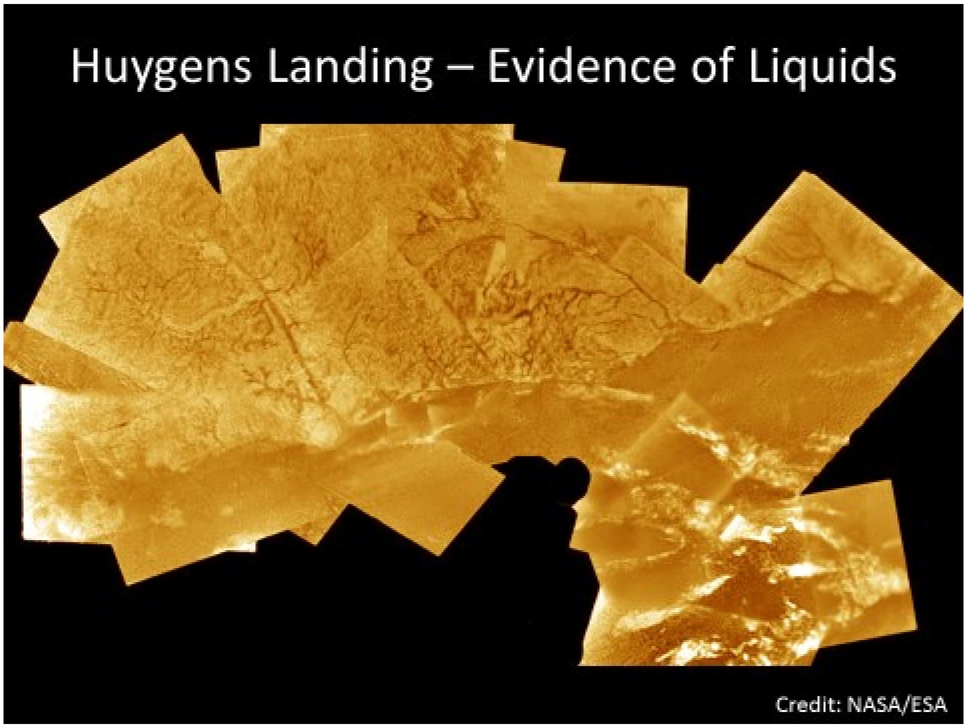
So, the left picture is basically showing different types of wavelengths of light. So, you go from X-rays to what we would see as color, to infrared, and microwaves, and radio waves. And that's for the Earth. Titan is quite similar.

On Titan, it's 100 percent through that rainbow color there. So, you wouldn't actually see the rainbow, then, there bits like that in the infrared and then, there's that large dip in the microwave and that's what Cassini uses.

I like to say that Cassini is the biggest, baddest, and most expensive spacecraft in interplanetary history where two of those adjectives are quantifiable. And a picture of it is shown on the right here, and that's actually at half-scale next to me, and I'm a five-foot-10 person for context. So, [the full scale spacecraft] is basically a bus in size, and sending this large spacecraft has turned out to be very fruitful, scientifically, because it's been able to adapt to many of the discoveries early on in the mission, and then to pursue those discoveries further, which has been a major accomplishment of the Cassini mission.

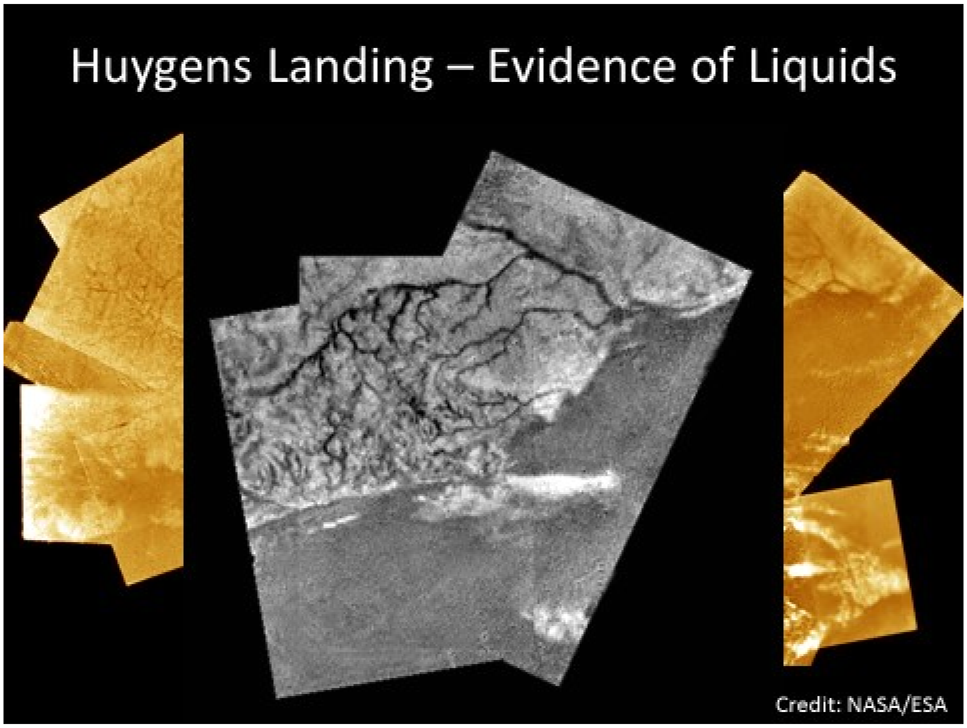
And then, one other trick that was used, of course, is to actually go under the clouds. So, sometimes, I'm always amazed that people don't realize that we've landed actually on Titan's surface and that's really an amazing accomplishment. It's the only body in the outer Solar System that we've landed on, and only one of seven, aside from the Earth, that robots have landed on.

So, the Huygens lander which was delivered by Cassini, descended underneath those thick hazes and once it got under that cloud deck, kind of like if you're landing in an airport and you're coming through the clouds, and suddenly you come out under the clouds, you see the surface.

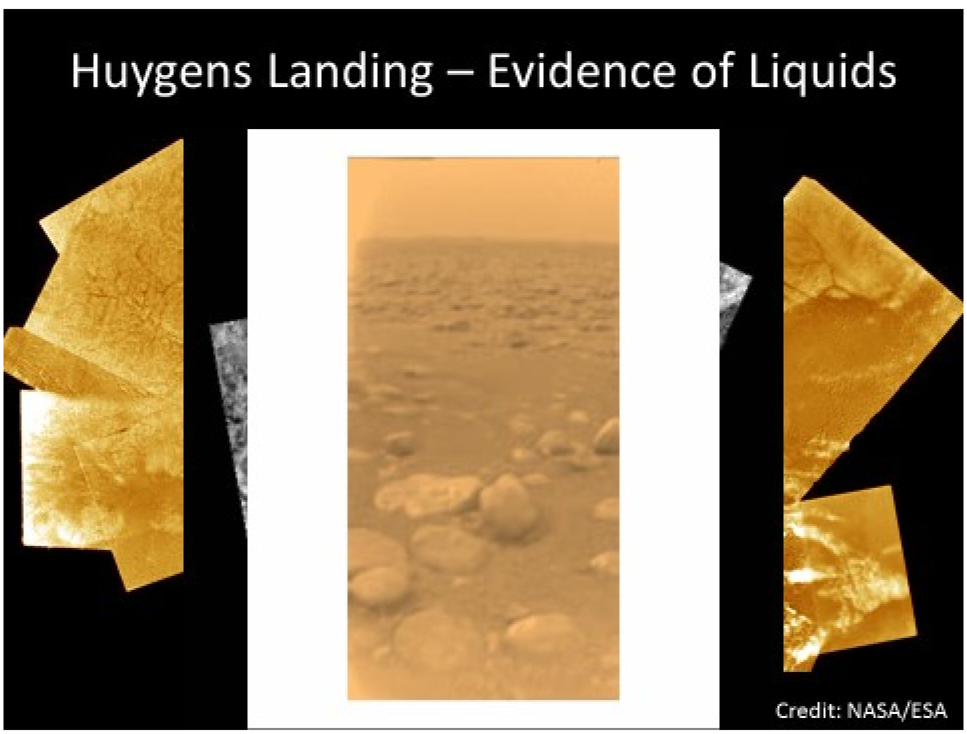


That's what Huygens [saw] and this [Slide 6] is some of the images that it took right then and there.

And what you can see, if you look closely, is that up towards the top of the picture there are several things that look like they're river channels. And in particular, there are river channels that appear to flow into bigger ones that flow into even bigger ones. So, that's the dendritic network and may indicate that's actually rain that causes those rivers.

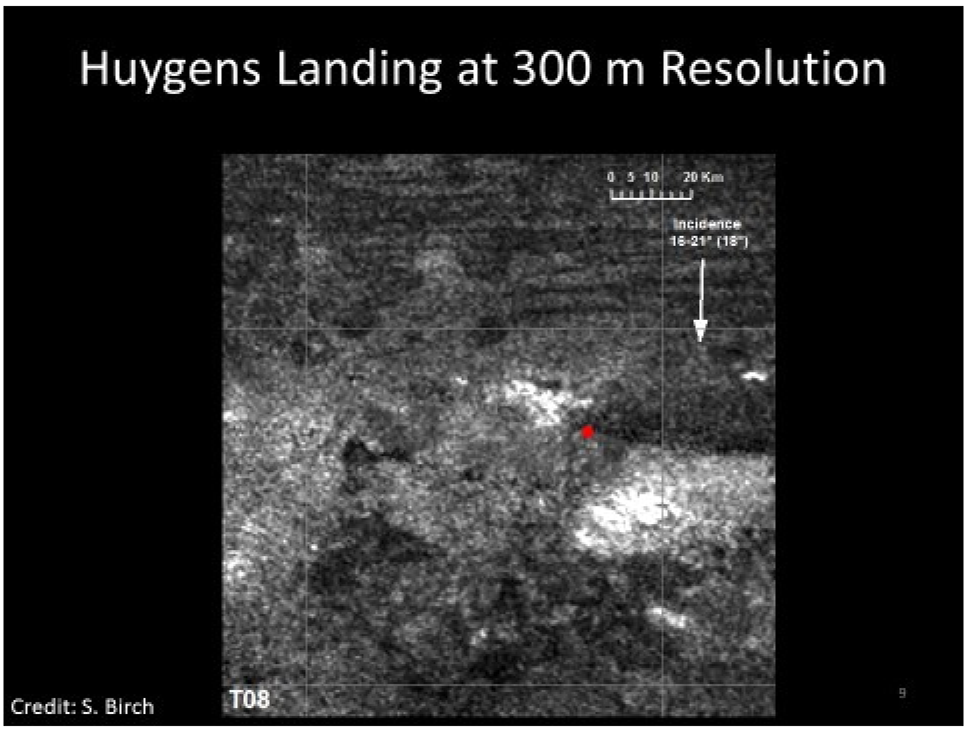


And then, as Huygens descended further, it took better imagery of those rivers [Slide 7], and then what basically is an escarpment there where the river terminates.



And then, it actually landed on the surface [Slide 8] and was on the surface returning data for about two hours and returned several pictures like this in which you can see the surface of Titan.

And an important point here is that those boulders in the front, which are probably made of water ice, they're a few centimeters across. And if you look closely, you'll notice that they're quite rounded. So, there're not very many sharp edges to them. What that indicates is that they have likely rolled or tumbled in those rivers. This was prior to ever the first discovery of liquid at Titan's surface, but it was a strong indication that they really were there.

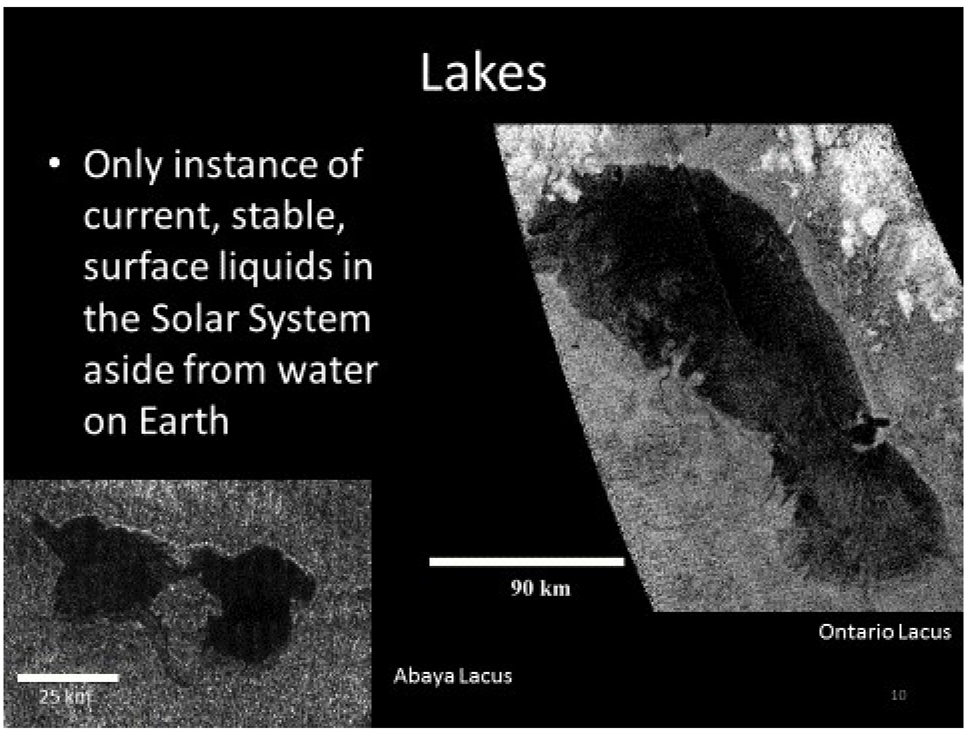


The next slide, this is slide nine now, is something I really like to show for context, because this is what that region looks like. In all other images of Titan, we have that resolution or worse. So, [this is the Huygens images of that bank where the river terminated]. The red dot is where Huygens landed.

And then, just up and left of that [red dot] you see a white, sort of triangular feature? The line of that triangle closest to the red dot, that's that line where the river is terminated and maybe you can convince yourself you see a black line through that triangle, that's that river. Although, I think, really if you're just seeing this, you probably would not have even called that a river.

And so, that's a very important point to keep in mind, that there're amazing things still hiding in the resolution of [the surface images of] Titan. Though we've explored nearly 60 percent of this incredible surface, there're actually still a lot of wonders in the resolution. And in my mind, that's one of the best reasons that, after Cassini has finished, we really need to go back to Titan because, again, just in that little triangle, there are rivers galore and amazing things in there, and it's probably true throughout the surface of Titan.

Now, in 2007, Cassini did confirm the presence of liquid at Titan's surface and I'll say again that that is still just astounding to me. because it's still the only place that we know of, aside from Earth, where that's true. And Cassini has imaged many lakes and seas.

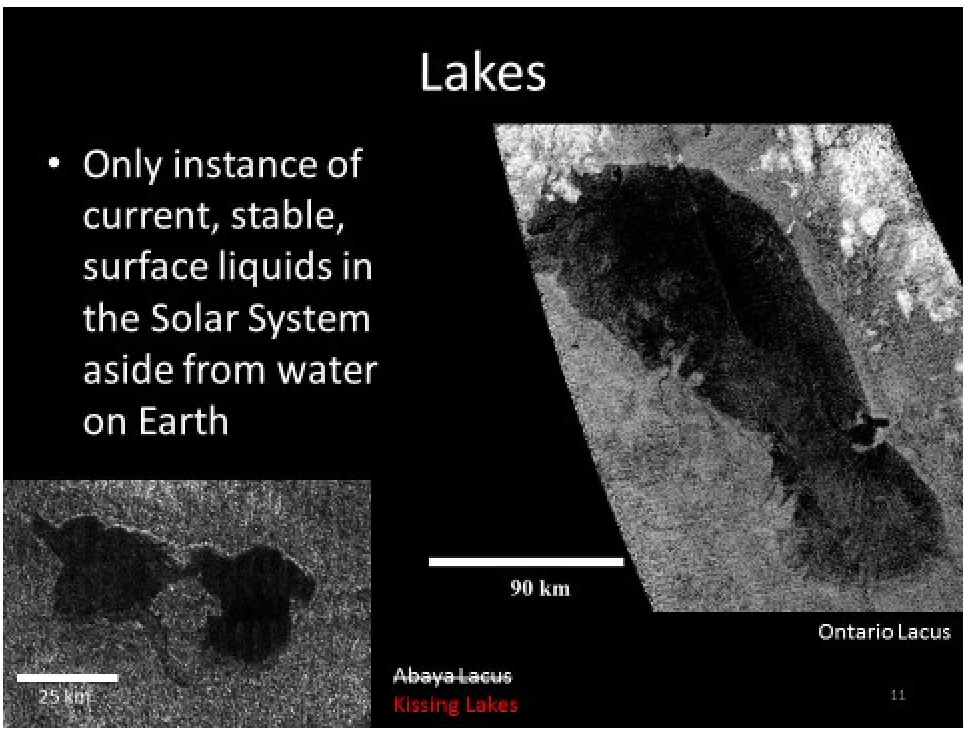


So, shown on this slide [10] are two examples of that.

The right one is what is known as “Ontario Lacus,” named after Lake Ontario on the Earth, for anyone near the Great Lakes region. I like to call it the “big foot,” because it looks very much like a right footprint. And in fact, even when I'm talking to other scientists, and I'm saying something about where on the lake I'm referring to, I'll say something like, "Near the big toe."

What you can see is that it looks a lot like the Earth. There is -- towards the left of it -- a river that looks to be flowing in, and then there's a bunch of white stuff that appears to be almost into the lake, and that's probably material that's being dumped out. Like, say, in the Mississippi Delta where there's material being dumped into the Gulf of Mexico, that's probably occurring here.

And then, on the right side is a relatively straight shoreline. And so, we don't know for sure, but one possibility is that that may be a beach. So, this is a very similar morphology to the Earth because of these liquids there.



[Slide 11] On the left are two lakes that are probably quite deep. They're known as Abaya Lacus, named after, again, lakes on the Earth. But I like to call them the “kissing lakes” just because they look like they're nice and puckered out there.

And in addition to these lakes, there have been discovered three seas in the north polar region of Titan.

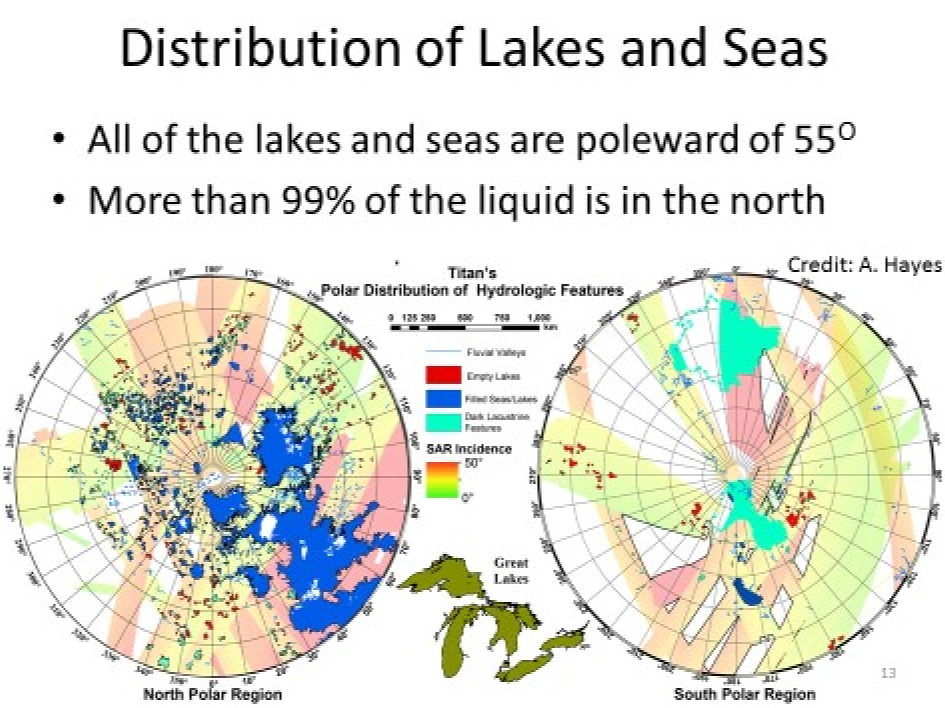
So, shown here now on slide [12], that's titled "Seas," is Ligeia Mare and I'm showing that one as the second largest sea on Titan, but I'm showing that one fully because it's going to be featured the most prominently in this talk, and it's also the one that is best studied.

Ligeia Mare is completely imaged and you can see the scale bar towards the top right. It's about equivalent in surface area to one and a half times Lake Superior on the Earth. So, if you're familiar with the Great Lakes, very large bodies of liquid water, this is a very large body of liquid hydrocarbon here.

And the reason that it appears so dark in this image is because the liquid surface is extremely flat. In fact, Cassini measurements indicate that the surface roughness, on average, is about a millimeter in changing roughness. So, for context, that's basically flatter than any natural surface on the Earth. And, that, there's a question there: "why is it so flat?"

Part of what makes that question even more prominent is the fact that we think waves on Titan [should be] very easy to make. The lower gravity, the higher atmosphere density, all these parameters [should] make it even easier to create waves on Titan as it does on Earth. So, the reason most likely why it's so flat is that there're no waves present because there's no wind present.

And then, again, when you look at this sea, what you can see is that there are morphologies that are very similar to what we're used to on the Earth. So, if you can see my mouse cursor, towards the bottom right [very bottom right corner of the sea, towards the middle of the overall image] is a large river flowing to the sea. On the bottom middle is very steep topography, looks mountainous, with lots of islands, towards the left here, maybe another beach. And then, there are bays - tidal bays, mostly likely. Very similar to the Earth.



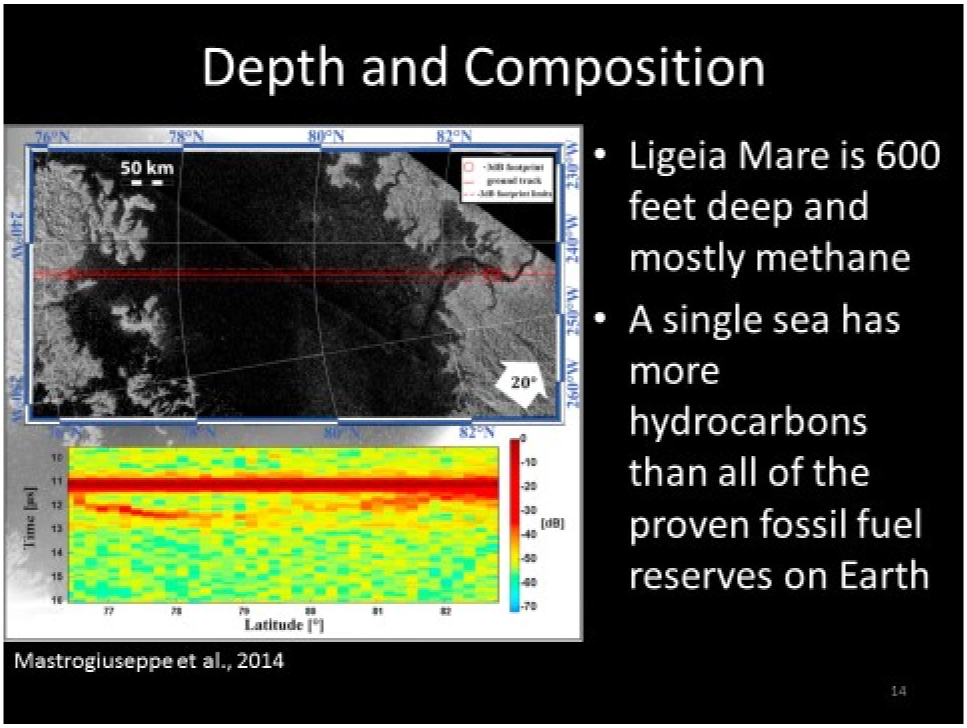
[On Slide 13] Cassini throughout its 11 years now in the Saturn system has basically mapped where all of these liquids are, and we know that they're all to the poleward of 55 degrees. So, they're either in the north or south poles. And we think the reason for that is, just like ice tends to accumulate on the Earth at the poles, the liquids are accumulating [at the poles] because it's slightly colder than it is at the equator. So, they evaporate faster at the equator. They rain out, but they tend to stick around longer at the poles.

And interestingly, more than 99 percent of the liquid now is actually currently in the north polar region. So, on the left here, that circle, that's a map of the north polar region and these things in blue are where we know there to be liquids. The Ligeia Mare is towards the top right of that left circle.

Just to the west of that is Kraken Mare, Titan's largest sea and north of that is Punga Mare. By the way, these are all named after sea monsters. And then, the other blue spots are all lakes in the north polar region.

The Great Lakes are shown here for scale. And then, on the right is the south polar region and there is Ontario Lacus, that footprint, as well as a few other little lakes present. So, more than 99 percent of the liquids are in the north.

That dichotomy is not completely understood, as to why they're all there, although one idea is that it might be kind of like ice ages here on Earth, that there's a time right now where all the liquids are in the north, and then, at other times, they're all in the south.



[On Slide 14] One of the more recent discoveries by Cassini, this is about two years old now, was a measurement of both the depth and composition of the seas. So, this was generally thought impossible by most scientists on the Cassini mission, and outside, with the Cassini spacecraft. But a young Italian named Marco Mastrogiuseppe figured out how to do this using Cassini.

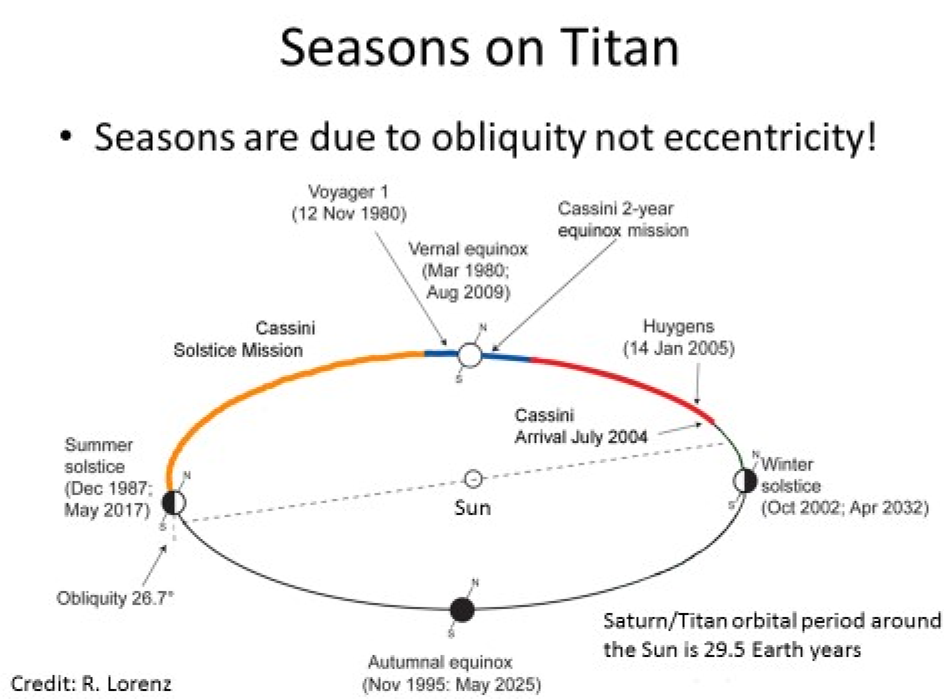
And what he did is when the radar was pointing straight down at the surface, he saw the reflection that comes back from the surface, but then, by looking a little bit later in time, there were some of the radar waves that were transmitted into the sea and then bounced off underneath and they came back.

So, if you look on the bottom left here, that red horizontal bar is basically bright reflection coming off of this very smooth surface, and then a little bit later in time are other reflections that are probably from the bottom of the sea. And because we think we know how fast the speed of light is in these methane and ethane, we can then figure out the depth.

And what was found is that Ligeia Mare is about 600 feet deep, which is very similar to about the average depths of the Great Lakes. So, the Great Lakes are nice comparisons to these seas. And in fact, because this has this depth of about 600 feet at its deepest point, or about actually 200 feet on average, we now know that within just Ligeiai Mare alone, there are actually more hydrocarbons than all of the proven fossil fuel reserves on Earth.

So, I'm not advocating that we bring those back here to the Earth, but it is an interesting factoid that really there is an incredible amount of hydrocarbons there. And similar experiments are now being done for the other two large seas.

So, that's the background to the liquid on Titan, but what we also know is that they're participating in a hydrologic cycle. So, they're cycling between the liquids and the atmosphere, we think. And part of that is related to the fact that there are seasons on Titan, which are driven by its obliquity.



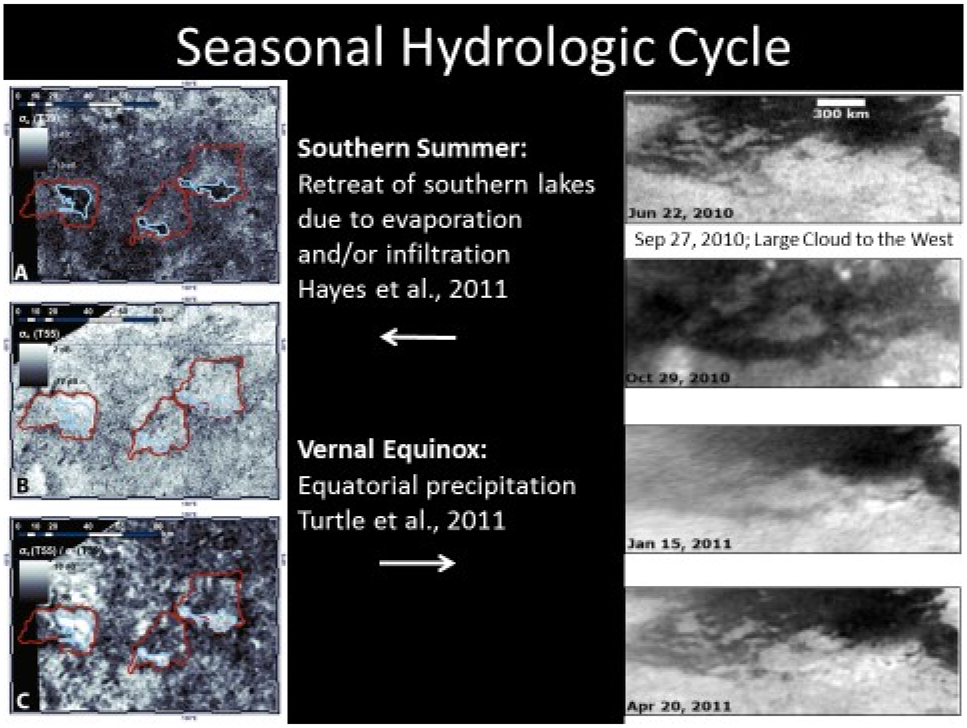
[On Slide 15] So, that's its tilt shown here at the left of this slide, and you can see that basically the north and south lines, they're not -- they're tilted relative to the orbit, by about 26.7 degrees. Earth is 23.5 degrees, so, not too dissimilar from our own, and that's what creates seasons. But on Titan and Saturn, the season is actually more like 30 years long, because that's how long it takes to go around the Sun.

And Cassini arrived shortly after the northern winter, or summer in the southern hemisphere, and has continued to the present day, probably about right here where my cursor is now [close to the left end of the yellow arc] and, of course, plans to continue its mission until May of 2017, basically right at the summer solstice in the north polar region. It has observed through northern winter, all the way to the start of summer.

This is another point I like to make. This is a really good reason why we should go back to Titan, and this plays better with people in the northeast. I recently came from upstate New York and I would explain to people that trying to understand how the seasons work, without ever seeing the summer or the fall, is pretty difficult. But I recently moved to southern California where every single day is gorgeous weather. And so, I'm learning that that's a bit more difficult to explain to folks here.

But this is my opinion as another very good reason why we definitely need to go back to Titan, because to understand really how it works, we need to see it throughout its whole seasonal cycle. And so, we need to go back and at least sample times in that sort of northern summer where all of those liquids are, and northern fall in order to really understand what's going on, if not observe it right through the whole time.

Part of the reason why I feel strongly that we should do that is because we know that these seasons do matter. So, shortly after Cassini arrived when it was summer in the southern region, it observed what we think is retreat of lakes due to either evaporation or getting absorbed into the soil.



[On Slide 16] on the left images, at the very top one there is an image of the south polar region of Titan and outlined in blue are three regions that are very dark. And because they're that dark, they're interpreted as having liquids. And then outlined in red are areas that are topographically low, so they’re basins where you might expect liquids to accumulate, and where the lakes may have been that large at past times.

And then, it was imaged subsequently a little bit later. And what you can see is that the whole surface is bright, and that can be explained due to a change in the imaging. So, that's not something that's actually changing on Titan. But when you take the ratio of those two images, that's the bottom [left] figure now, you see that within the light blue, those areas are brightened considerably more than their surroundings. And so, that's likely because there's actually a change there. And what's probably going on is that those liquids have disappeared, again, either because they have evaporated into the atmosphere, or they percolated down into the soil and have become absorbed there.

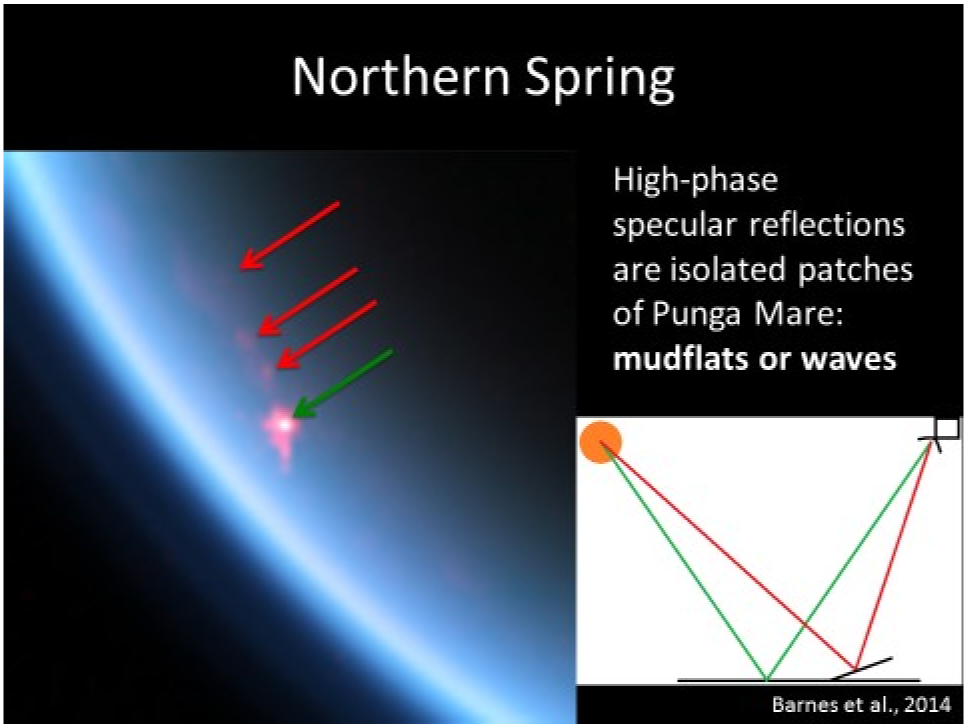
And then [on the right images], as the Sun moves north on Titan, we start to see that power that [the Sun] was bringing was powering activity in the equatorial region. So near equinox, when the Sun is basically high over the equator, [these images are] what I consider probably a very convincing rain event, probably one of the first observations ever, really, of an alien rainstorm.

So, to the top right is a base image of a large region of Titan's equatorial region. And then, just a few months after that, a large cloud was observed to the west of that. It would have just been off where these images are now [not shown in the slide]. And then, in October of that year, you can see that the surface darkened considerably.

So, if I point with my cursor, basically, compare this region right here [June 22, 2010 image] to this region right here [Oct 29, 2010 image], and what you'll see is that it's darkened considerably, and that's interpreted as the precipitation darkening the surface. And then, that surface reverts back to its initial state slowly after, again, due either to liquids evaporating, going into the soil, or flowing out into somewhere else.

After that, we were very excited for when the Sun was moving towards the northern region, because it seems to be causing activity. And again, there's 99 percent of the liquid in the north polar region. So, if we're interested in studying activity in the liquid, this is when things get exciting.

As I mentioned, the surfaces have been measured to be quite smooth. So, one idea was to start looking for waves because as summer approaches, that's when we expect the winds to pick up. That's when we might actually start to see waves.



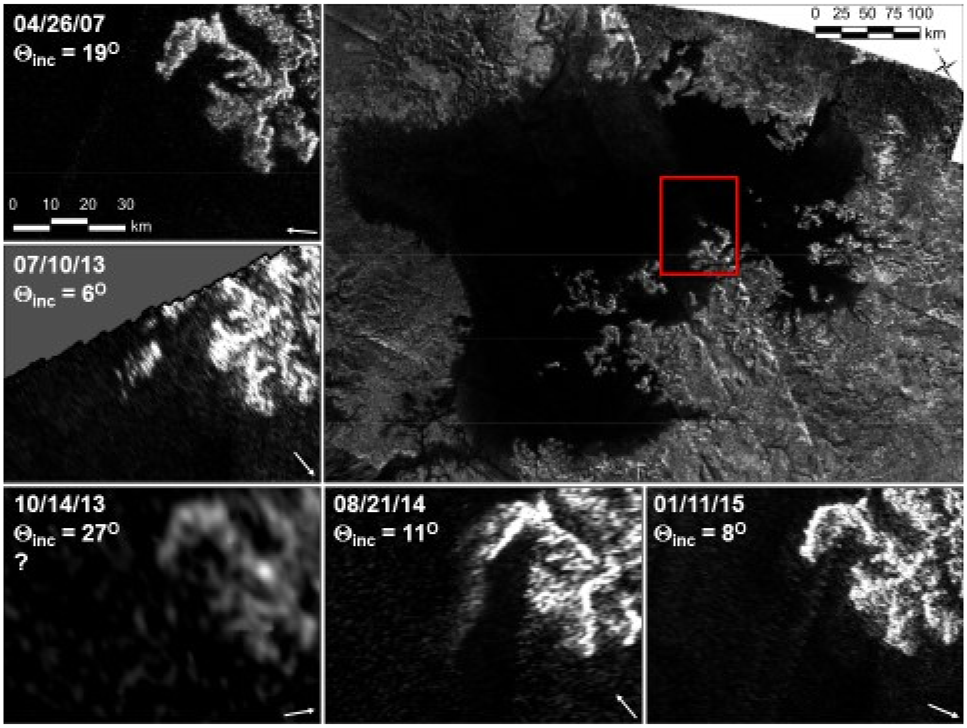
[Slide 17] So, shown on this slide here, titled "Northern Spring," is what is most likely an observation of waves on Titan as well. So, the Titan, an image of Titan, not in true color, but Titan is on the left side here. And the green area it’s pointing to is what's called the specular reflection. So, it's a reflection of the sun off of a smooth surface of a liquid. And on the bottom right is a cartoon of that where basically the green ray is coming from the sun, hitting the surface perfectly and then bouncing to the spacecraft.

The red arrows are slightly more subdued specular reflection, but they look like specular reflections as well. And so, what's going on there is that the sun's rays, again, the cartoon on the right, if you imagine that ray going down, ignore that ramp for a second and [imagine] it hits the bottom surface. When it reflects off, it's going to reflect at the same angle it came in and it should go off and miss the spacecraft.

But the fact that we're actually seeing that reflection, indicates that the surface is probably tilted there, and that's why [the spacecraft can see it at the off] angle it comes in, because the surface is tilted.

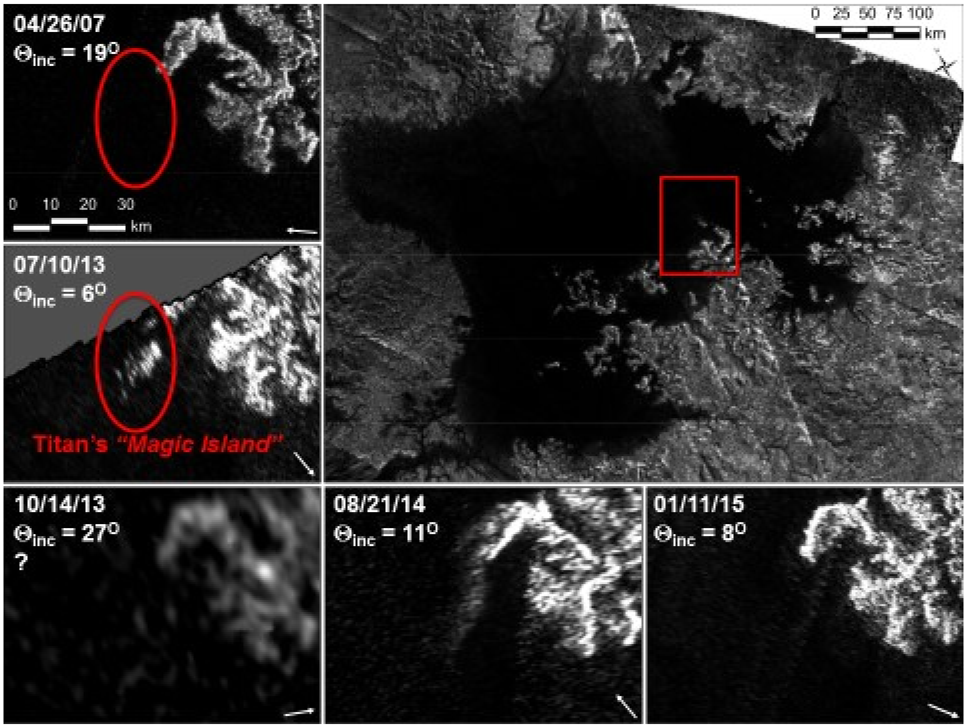
And this [tilted surface reflection] has been observed in other observations where we think there are liquids. And so, if there's a tilted surface there, it's most likely waves, although mud flats as I say at the top right can't be completely ruled out. So, this is either mud flats or waves that we think are occurring here.

[Slide 18] That sets the stage for where these radar transient features come in. And we call them Titan's "Magic Islands," and I'll say upfront that that is a misnomer term. It is something that we adopted because they look like islands but they're neither magical nor islands, okay? So "Magic Island" is just a term that we use to refer to them.



[Slide 19] And now I'm going to switch to the second of those slides where basically there's a red square over the top right. That is Ligeia Mare again just for context. And that red rectangle is rotated 90 degrees counter-clockwise, [and magnified to show] five images of that region [from the red rectangle. We've actually observed that region eight times with radar, but these five tell the whole story. So the top left is what it looks like in the beginning. There's the dark region, and that's the liquid. Then there's the lighter region, the white, that's the solid surface. And we have several images like that and they didn't show any apparent change.

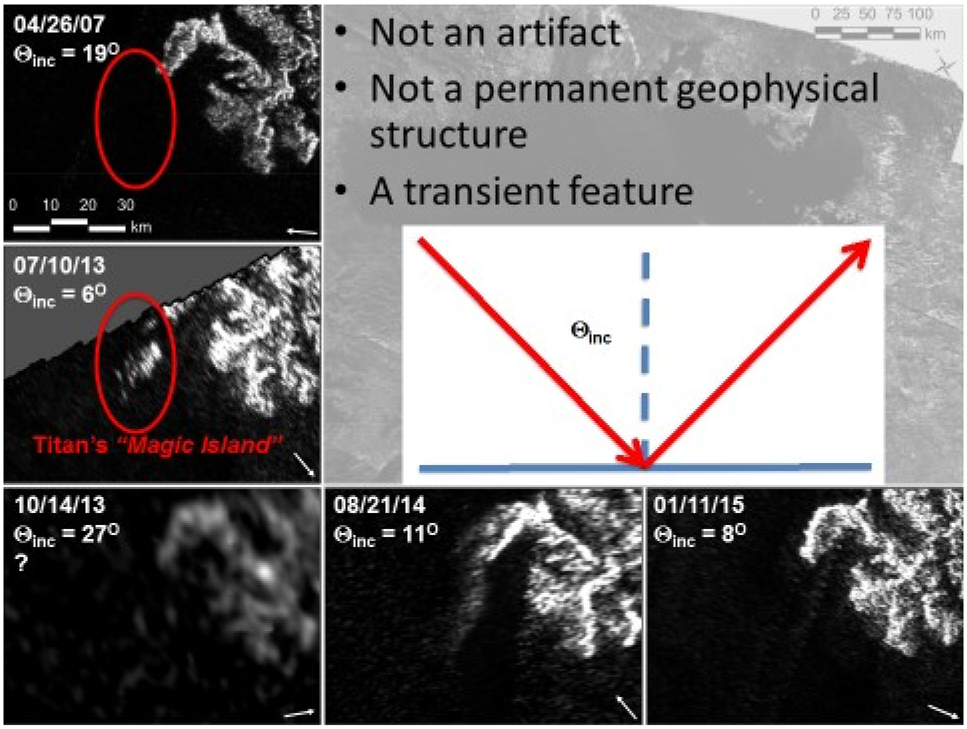
And then the second image, it's the middle left image, what you can see is that the surface there brightens considerably, and that's basically due to a change in the way that we observed it. So I put numbers at the top left of those panels and it's called "theta incidence," so that's the angle [of viewing]. And because that angle has decreased, that's why it's appeared brighter.



[On Slide 20] What's circled in the red circles now, what you can see is, in the second image, a feature that is quite bright, that's just not apparent at all in the first image. That is a real change on Titan, and that's the thing that we call Titan's "Magic Island." It's a transient feature. It's only there for a certain amount of time. It wasn't there in the previous images.

The bottom left is a lower resolution radar image of that same region, and in this case we don't observe this bright feature, this Magic Island feature. And I've put a question mark in that panel to indicate that in this case we're not sure if we are not seeing it because it's not there, or if we couldn't detect it because of the lower resolution of our observation. We're just not sure at that particular time if it was there or not. But either way in August of 2014, so the middle bottom panel now, that feature was observed again. It brightened -- it was bright there, so we see that it's there and it's basically in that exact same place although it's larger now and it's changing its size and it's actually not quite as bright.

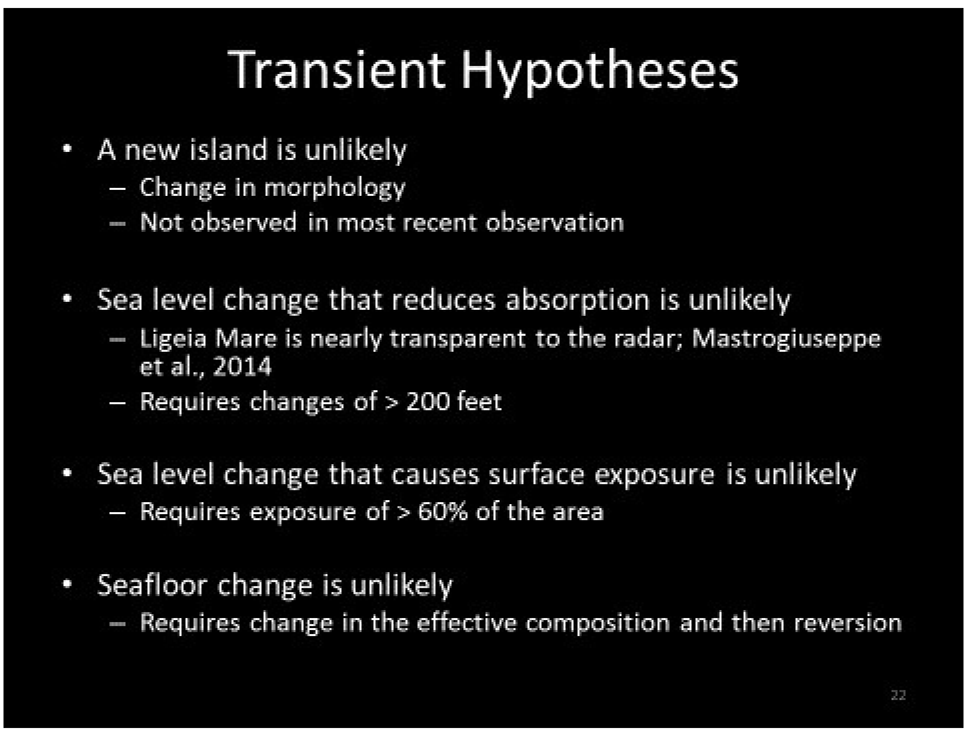
And then the most recent observation, a little over a year ago, of that area, the feature was not detected, so it's not present here at all. So this is the evolution of this feature, and that's the status of the images that we have up to the present.



So on the next slide [21], I want to discuss the fact that we know that this is not an artifact, which can happen in radar images. The way radar processing works, sometimes there can be artifacts, that aren't actually real, that will appear in the images. However, when you study those artifacts what you can learn is that when you change the geometry that you are observing the surface with, although you may have artifacts, the artifacts will not appear in the exact same place but under different geometry. So the fact that the July 10th, 2013 image and the August 21st, 2014 image have this feature in the same place indicates that it's not an artifact.

And then the second thing is that it could have been something that's always been there but it just appears much brighter if you look at it in a certain way and could have fooled us that way. And for example, that's what's going when the solid surface that you see is changing its brightness a little bit. You know, it looks like it might be changing a little bit. Those aren't real changes, those are just changes in the way we're imaging it. But what we can say is that that is not what's going on here [with the “Magic Islands”]. And the easiest way to understand that is with those numbers I put. So the July 10, 2013 is at six degrees. And the August 21st, 2014 is at 11 degrees.

And when you go to smaller angles like that what you see is that generally things brighten. However in this case our most recent observation at eight degrees is not present. So the fact that that one there is intermediate, it’s indicating that this is not what's controlling it, because if it were at that incidence angle, that number there that's controlling the appearance of this feature, it would have been present on their most recent observation. So through process of elimination, we can say that now what's left is that this must be a real transient feature.



[Slide 22] What are the possibilities for these transient features? So a new island is unlikely, and the reason for that is because of course we've seen that it's changing its size, its brightness, it's not observed in the most recent observation, so that doesn't seem likely.

Another possibility is that we know that the radar can see through the sea to some extent, because that's how we were able to measure its depth. So one possibility is that there's some amount of liquid over, say, a mountain, an undersea mountain, and the amount of liquid decreases, and so, the absorption decreases. And that makes it appear brighter. But because we actually know how it absorbs, because we were able to see, when we measured the depth, how absorption happens, then we can calculate what that [kind of a mountain] would require. And it would require that the liquid depth change by more than 200 feet, which is a very large amount. And we don't see any evidence for that kind of change anywhere else at the shoreline.

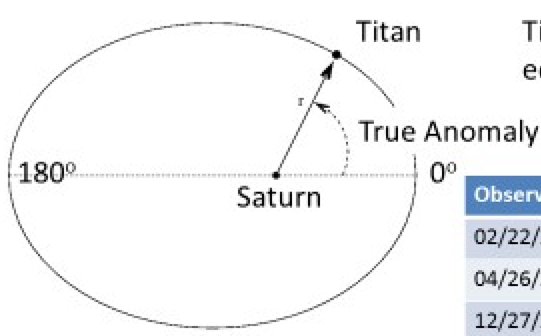
So we would expect that if the sea level were really changing by that much that we would be seeing that at other regions, and we don't. So that tells us that this hypothesis is also probably not what's going on.

A slightly less intuitive idea is that because the composition of the sea floor is not too different from the composition of the sea, when the radar is going through the sea and hits the sea floor it's not going to have a very strong reflection, most of the energy is just going to get transmitted into the actual solid sea floor. However, if you remove that sea, then when the radar comes in it's going to come in simply from the air, it's going to hit the solid sea floor. And because the composition difference there is actually much larger [than the composition difference between the liquid and the sea floor], it's going to cause much of the energy to be reflected. So this kind of thing means that if there happened to be a mountain that was just underneath the sea surface and we decreased the sea surface even by a few inches it's possible that it could cause it to suddenly brighten up. And this actually is the reason why in the images of the lakes you can see the shoreline very nicely, because the area that is actually liquid is very dark and the shoreline brightens up considerably.

And again we can calculate what this actually would require, and what it is, is that more than 60 percent of the area of that bright feature would have to be very, very near to the surface of the sea. So this is, in science, what’s often called a fine tuning problem, and we tried to avoid it because usually it means that we're not getting towards the right solution and we're trying to force the wrong solution. So this seems to be too fine tuned that just as one area has all of the surface right next to the sea level and drop it by a little bit. You don't see the changes anywhere else but you see it right there. So for that reason we consider it unlikely as well. Although, it is possible but it's not our favorite hypothesis.

Another idea is that the sea floor itself could have changed in composition. And there are ways that this could happen but the fact that in the most recent observation we didn't see this feature, again, indicates that this is unlikely, because what it would require is a change and then a change back to initial state. And that -- you can imagine that that's less natural than, say, where you have a flat surface, you have waves there, and then as soon as the wind goes away the waves are naturally going to go away. So I'm going to suggest here that that's the more likely hypothesis versus, say, a change in the sea floor.

Tides do not explain the Transient Features



Tides on Titan are due to its eccentric orbit around Saturn

Observation	True Anomaly	Transient?
02/22/2007	16	X
04/26/2007	15	X
12/27/2009	71	X
05/23/2013	68	X
07/10/2013	68	✓
10/14/2013	68	X
08/21/2014	246	✓
01/11/2015	245	X

Tides should cause consistent presence/absence with true anomaly

[Slide 23] One idea that I get a lot of great questions about is tides, so I want to give it its own slide. Tides on Titan are dominated by an eccentric orbit around Saturn. So that's different from the Earth. Tides on Earth are dominated by the fact that there is the Moon above you or in a different place relative to you.

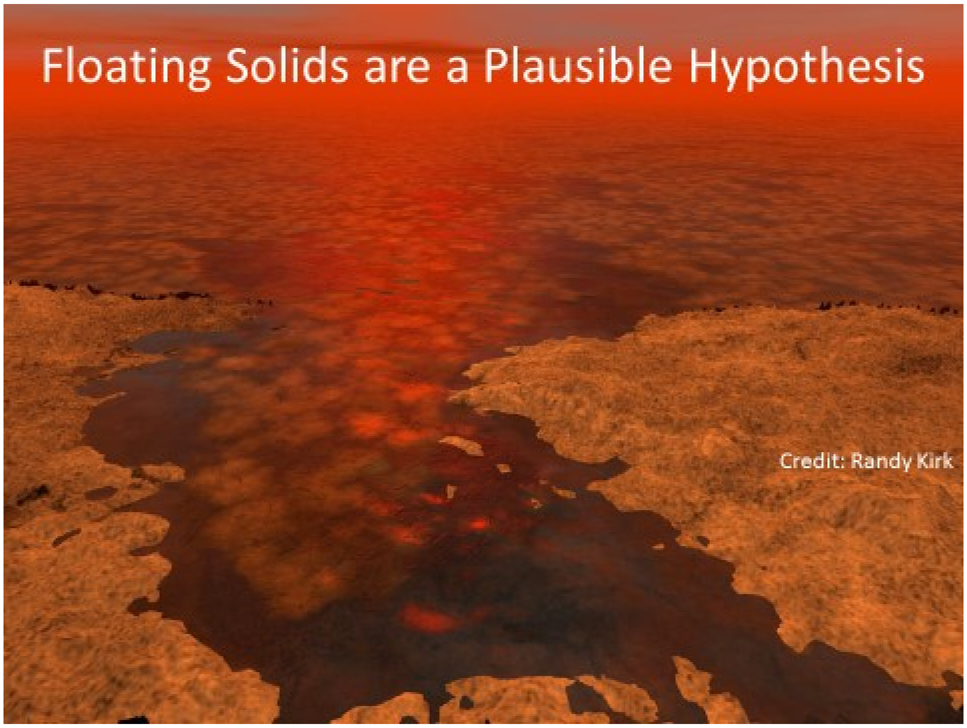
On Titan, basically Saturn is always in the same place to you, it's just that your distance from it changes. And what you would expect is that the tide, if that's what's controlling the appearance of this feature, then every time you get to basically the same location in the orbit the tide should be similar and that should control the feature. But in the table I plotted that angle of where it is in its orbit. Not plotted, but tabled it. And these four middle observations, from 2009 to 2013. What you can see is that the angle for those four observations is very similar in every case. However, the appearance of the feature is not consistent, and it appears in the July 10th observation and not the others. So if its angle [i.e. tides] were controlling, it should have caused a very consistent behavior, either all Xs or all check-marks.

And then we have another [example], the same is true for the last two observations, which, again, are basically at the same angle. And the appearance of the feature is divergent. So it's not tides that appear to be controlling the feature, at least not dominating its appearance.

[Slide 24] An idea that is plausible is bubbles. We did a lot of calculation, which I'm not going to show it here, but what we found is that if the bubbles are larger than about one-tenth the size of the wavelength, so on the order of a few tenths of an inch to an inch, or larger, than they could be consistent with the brightness that we're seeing. And what I wanted to show here is simply that this may not be too radical an idea.

So as I mentioned before, I recently moved to the Los Angeles area, and there's an amazing thing here called the La Brea Tar Pits, where a fossil fuel reservoir is essentially leaking up to the surface and creating tar pits at the surface. And what's going on is that light hydrocarbons like methane and ethane are evaporating away and forming little bubbles. And you can see pictures of them here. And this scale, this size of bubbles which are in a hydrocarbon liquid goo, just like what's probably on Titan, would be observable to the radar as long as it stretched over the 300 meters scale that we observe Titan with.

This idea has started to get more traction with other scientists, and in fact, in the labs recently, scientists have been discovering that nitrogen as well is forming bubbles in methane and ethane because it's very soluble there. So this is an area of what I think is going to be productive future research and could be what's causing these features.



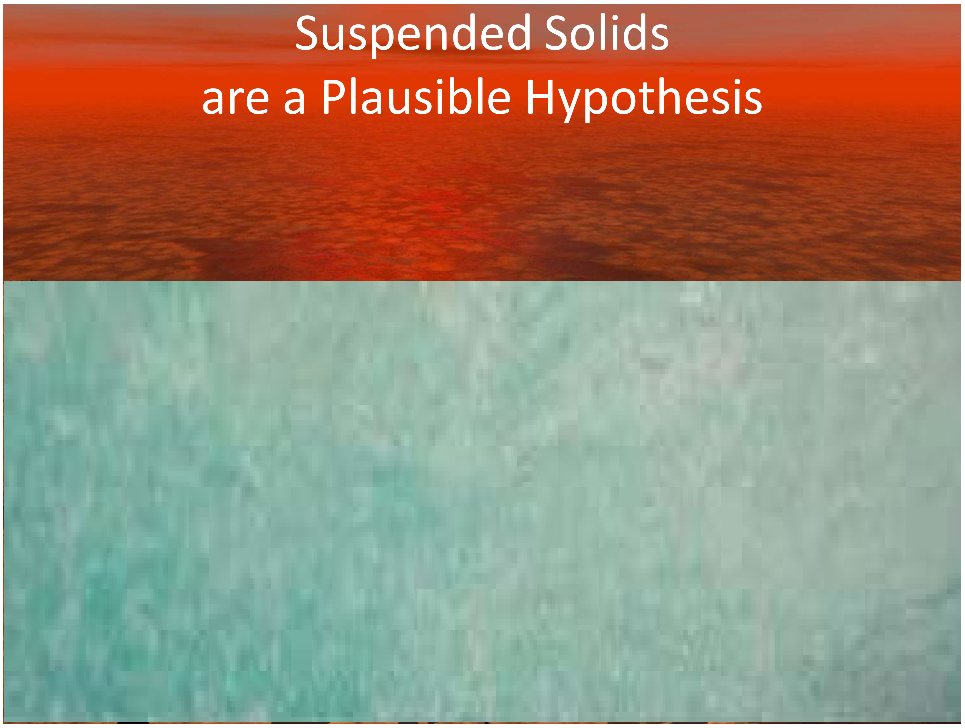
[Slide 25] Another idea is floating solids. And floating solids on Titan is another area of research where, because this is all new and the chemistry is so different, a lot of this is very new and it's only been progressing very recently. And what we can say is that there are a lot of possibilities for floating solids, and there's a lot of work going into understanding which ones might actually occur on Titan and which ones is don't. So in our work we didn't explore all those possibilities because that would have been too exhaustive, but we took a simple model where basically we said, let's let solids be represented by lands that's floating in the sea because we know how the land would scatter and we know how the seas scatters, so we mix them. And what we found is that that model is also consistent.

So that was good news and indicated that floating solids are a likely plausible hypothesis as well. And now there's more attention going into understanding what solids exactly might float in Titan’s seas, and what would be their composition, their nature, and that sort of thing.

One thing to point out is that liquid methane and ethane are less dense, by quite a bit actually, than liquid water, so there aren't many things that naturally float in them, however, generally when we form solids they'll often have what we call porosity, so air space. And that can make even a rock on the Earth, volcanic rock called pumice, will actually float on the Earth if it has enough pore space in the water. And so, that may be occurring as well.

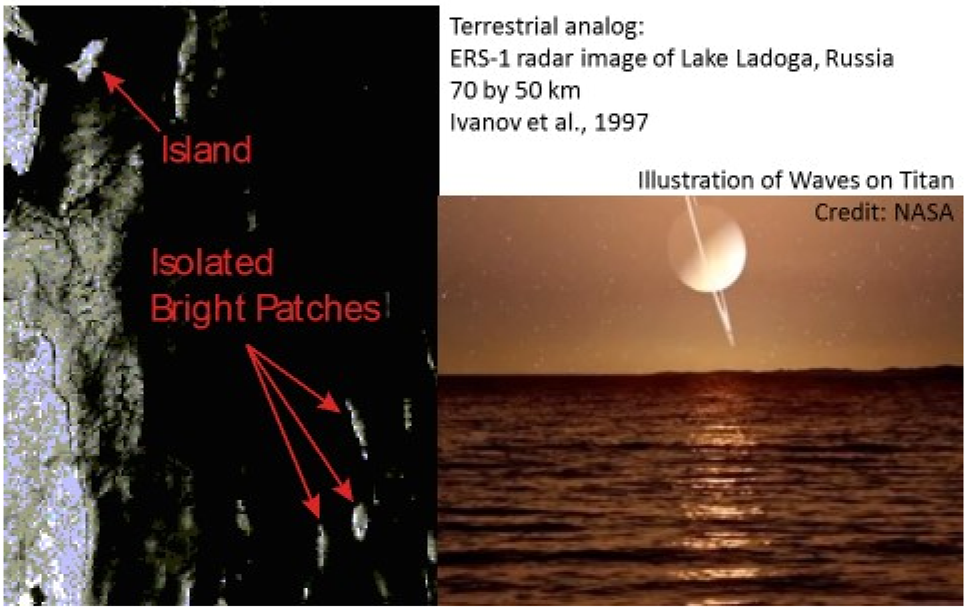
And I did want to say this picture here is not an artist illustration, and it's not a real picture either. It's real topography by another Cassini team member, Randy Kirk, and actually uses real ray tracing to get the shadows of the region. And then it's falsely colored. So the topography and the relative shadowing is correct and it's really there on Titan, but the coloring is false. And so, that's a vice nice product that Randy made.

Okay, suspended solids are another idea that would work. And the easiest way to imagine why this is, is again, remember that the radar can see through the sea essentially, and so, it's going to see through the liquid, and if there's solids just sort of in the middle of it, then that could cause [the radar] to observe these features. And this would have to be like the bubbles, about a few tenths of an inch or larger in order to be observed.



[Slide 26] So I don't have a good picture of this one, but what I imagine in my head is something kind of like if you've ever snorkeled or scuba-dived on the beach and you kicked the sand, and there's all kinds of sand around you, something kind of like that would be able to be consistent with what we're observing for this feature.

Waves are the *Preferred* Hypothesis



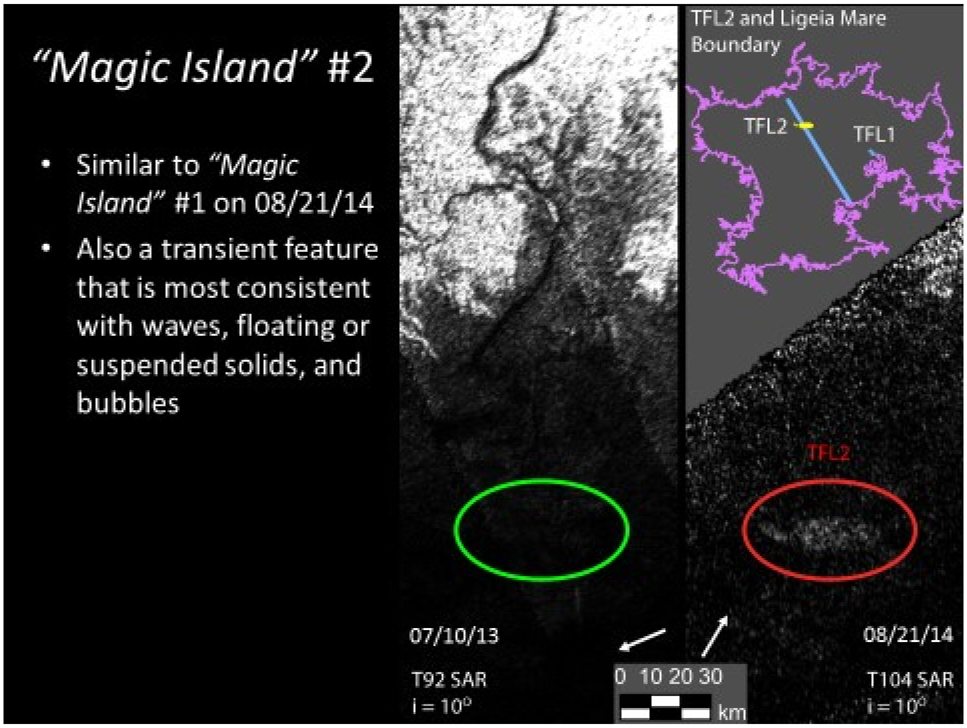
[Slide 27] And then the last one that I wanted to discuss is waves. And waves are the preferred hypothesis. So even though bubbles, and floating and suspended solids were all consistent, we can't rule them out, the same is true for waves. [Waves are] consistent, and we prefer this hypothesis. And again, we have models where we've checked that they're actually the brightness that we'd expect. As I mentioned, this is the time where we think we're starting to get towards more waves occurring in these seas, whereas before there wasn't enough wind to be driving those waves.

And one question that you may have in this case is why would it appear in just one particular spot if that were the case? And the answer is that the way the physics of waves works is that generally it's like a switch. So if your wind speed is too low there's no waves at all, and then assuming that if you cross that switch you start to make waves.

And on the Earth we know that basically when you're near that switch there's variability within the winds in different regions. And some areas might be slightly above that switch, while others are below it. And so, you can have waves that form in particular areas. And an example of that on the Earth is shown on the left image here. So this is a radar image, just like we take for Titan, of the Earth, of a lake in Russia. And most of those bright patches, especially towards the bottom right, are not real islands, they're either waves, or as the authors in this work note they could also be algae patches as well.

So that's an example -- that's a good analog on the Earth of why these might be localized bright features on Titan. And then the right is an illustration of waves on Titan. Then the reason that this is the preferred hypothesis is very simple. We didn't actually get very complicated with this, it's just that the fact that if you go to liquid areas on the Earth and ask which one of those is the most common, bubbles, floating solids, suspended solids or waves, the answer is that waves occur with the most frequency. And that's why we actually prefer this hypothesis above the others.

And one prediction of this hypothesis is that if these winds are increasing as we get closer to closer to summer in the northern region then we should start to see waves occurring in more places, because more areas are going to cross that switch where winds are high enough to create waves. And we have started to see other regions like this.



And this [Slide 28] is one of them here.

So it's called "Magic Island #2" because why not, right, if we're going to start finding lots of them we should get numeric. So here I'm only showing two of the images. The left one is from July 10th, 2013 and it's circled in green is the area where the bright feature appears. There's nothing there in this particular image. And then on the right is the -- is that feature on August 21st, 2014 where it's brightened here. And that brightening actually is very similar to the brightness of the other one at that same time. And so, the conclusions that I went through for the others apply for this one.

And the top right there is showing the location of this region [in yellow] in Ligeia Mare, also to the shoreline that's in purple, and then the other feature as well is there [in blue].

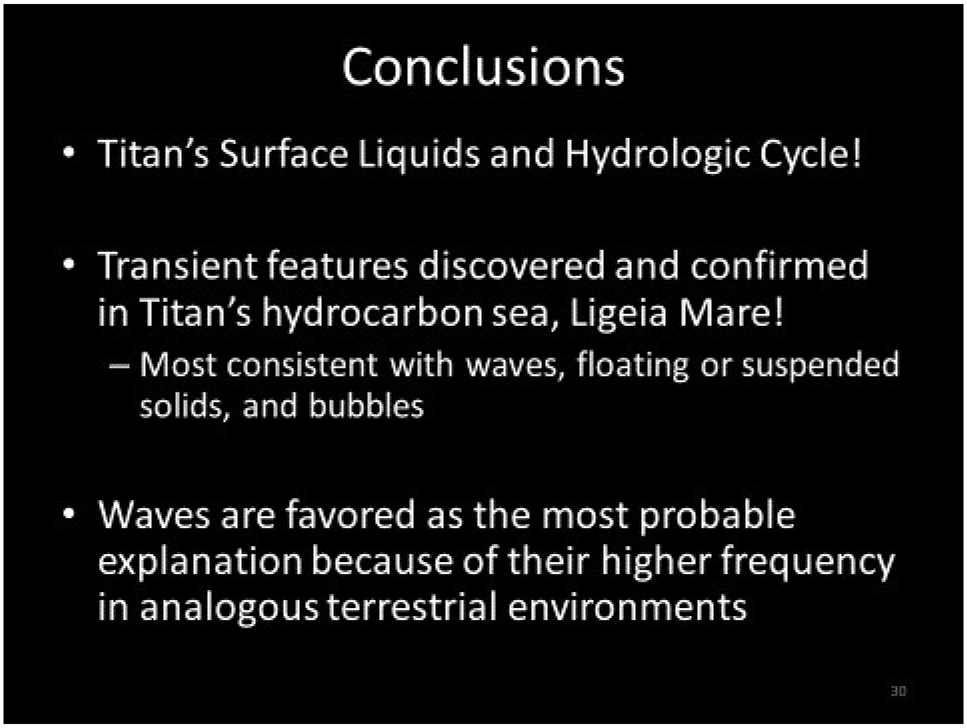
Cassini, amazingly, has done so many amazing discoveries, and it just continues going on and it has more plans for Titan. And I'm very happy to say that the final close fly-by Titan, on April 22nd, 2017, so just a little over a year from today we are going to observe this region one more time. And I'm very excited about that observation. If we don't see these Magic Islands featured again then it's not going to tell us a whole lot. But if we do see them, we've crafted this observation carefully so that it could actually tell us quite a bit.

The two things it's going to tell us are something called the “invasivity,” hopefully, of the feature, which may be able to help us distinguish between the solids and the waves. And then the other is whether it has what we call “diffuse scattering” which again will help distinguish between solids and the waves, and that one will also help for the bubbles.

Okay, is we don't see it, unfortunately it's not going to tell us too much about it. However, you know, there's certainly lots of reasons, and I've tried to give you a flavor for some of them, of why we should go back for Titan.

[Slide 28] And it's possible that we would observe whatever is going on here in our future missions. And of course there are lots of architectures that are being studied, ranging from things like the top left there, satellites that are in orbit around Titan, not just flying by it.

The aerial vehicles like the balloons and airplanes to land an asset like even boats, or rafts, or rovers, and that sort of thing. So there's a rich array of possibilities and hopefully we'll be able to get something to Titan on its way soon, and continue to study this amazing world.



[Slide 29] So to conclude, I've reviewed the fact that Titan has liquids at its surface that are stable, and that's just an amazing discovery. And that those liquids are participating in a hydrologic cycle. And then transient features have been discovered in the seas, and then subsequent observations have really confirmed that they really are transient features. And they're consistent with waves, floating or suspended solids, and bubbles, but sea level change, sea floor change, and tides are less likely. And again, we favor waves as the most likely explanation, for the simple reason that, on the Earth, that's the most common of these phenomena.

So thank you very much and if you have a question, now is the time.

(Jo Pitesky): Thank you very much, Jason. That was really wonderful.

(Kathy Lowrey): I have a couple of questions. This is Kathy Lowrey in Louisville.

Jason Hofgartner: Yes.

(Kathy Lowrey): I remember in earlier information coming about Titan, that there was speculation that there was a mixture of water, ice slush, combined with the ethane and methane. Could it be that some of the suspended solids, these floating masses could be water or ice slush.

Jason Hofgartner: Great question, (Cathy). So they're unlikely to be slushy in the sense that there is any liquid. And the reason for that -- and in the sense of the water itself being liquid, and the reason for that is that it's just far too cold for water to actually be liquid. But we think there's abundant ice, water ice at the surface of Titan, and this could be water ice particles, they absolutely could be. In that case water ice naturally is not going to float in methane and ethane. So if they're floating, the reason for that is that they probably have a considerable amount of airspace within the solids.

And, yes, as far as we know right now that's certainly a possibility. And the other is that it could actually water ice that is grounded down very small. So even smaller than those boulder I've showed where Huygens landed on the surface, and in that case that would be kind of like that suspended solids that I was mentioning. So it's kind of like the way sand [suspends] -- even though rock will sink in the water on the Earth, when you grind it down very finely as sand, it takes a lot longer to sink. And so, the water [ice] that will naturally sink in the methane and ethane, could be suspended for some amount of time in that kind of way, as well, on Titan. So, yes, those are possibilities.

(Kathy Lowrey): And the other question I had was that on your title slide there were some straight lines that looked like grooves, are those artifacts of the photography, or are those actually grooves that are on the surface? Do you know? Could they be glacial grooves?

Jason Hofgartner: Okay, great question. So can you -- can you have the title slide up now, can you describe where you are referring to a bit more for me?

(Kathy Lowrey): Okay, in the upper left hand corner there's some straight lines. And then as you come down right next where it says August 21st there's a fainter line.

Jason Hofgartner: Okay, yes, great question. So what those are, those are not real, those aren't real things on Titan. We call them “beam seams” and that's because the way Cassini’s radar images the surface of Titan, it uses five beams on every flyby. And then those beams overlap slightly, and right where they overlap sometimes you'll have that kind of effect occurring. And that’s what’s going on there, is that right at that scene this image hasn't come out quite so nicely, that's not a real thing on Titan. But good eye.

(Kathy Lowrey): Thank you.

Male: I have a question about the atmosphere.

Jason Hofgartner: Okay.

Male: On your fourth slide you say that it's about five percent of methane which was a little bit unexpected to me. And so, naturally I went to my primary source, which is always Wikipedia. And sorry about that, but I found that they said it's roughly 1.4 percent methane, instead of five. So my question really is was this an unexpectedly high percentage of atmospheric composition for methane, and tied to that, and more important, is there anything to be understood with regard to the greenhouse effects of methane, since methane is a greenhouse gas. If you've got three or four times as much as was expected, perhaps the surface temperature is also higher than was expected.

Jason Hofgartner: Yes, thanks for that question and thanks for bringing that point up. So what I'm quoting here is the composition basically of the atmosphere right at the surface. And that's about 95 percent nitrogen and five percent methane. If you go higher up into what's called the stratosphere, which is where a lot of the studies of the atmosphere are occurring, then there the composition is a little bit different, and the methane component is more like one and a half percent as you mentioned.

So both of those numbers are right. It's just that we need to clarify where exactly we're talking about. So thanks for bringing that up.

And then to your question as to whether or not this unexpected, no, this is basically about what was expected for the methane. Actually there were some models that suggested that it should be a little bit larger. So because methane is acting as this liquid that's transitioning between clouds and rain and liquids, rivers, and seas at the surface, it functions very similar to humidity on the Earth. So we didn't know exactly whether the "humidity" is near 100 percent for methane or very near to zero. When we descended, we measured it, and we found it was not near 100 percent. It was more, if I recall, it was more like 40 to 50 percent. But, really, it can range in that kind of value in "humidity," but that's what we expected for the surface.

And then it absolutely is related to global warming, because it is a greenhouse gas as you noted. And that is a very rich area on Titan of studies, that I'm not an expert on, but that I really think is great. Because, on Titan, there's actually both global warming, things that are causing warming of Titan more than it would without the atmosphere, but there's also essentially cooling processes, that are those hazes. And they're actually causing a global cooling on Titan, which has happened on the Earth as well in the past, say, from very large volcanoes.

So I think that's definitely another example of where we can learn a lot from Titan, and it can really help us understand other worlds in the Solar System and, most importantly, our own.

Male: Great, thank you.

Male: A question about the lakes, if I were standing on the shore of Ligeia Mare, what would I see? What would a hydrocarbon lake look like? Will it look like a water lake or will it have completely different features?

Jason Hofgartner: Right, a really good question. So I've never done it, so I don't know, although I'd love to. But what I think it would look like is the sea most of the time we're there would be extremely flat, and then you would probably see a long way through it actually. So it would be quite transparent.

Because liquid methane is fairly transparent at optical wavelengths and then the surrounding atmosphere would be sort of that orang-ish haze that you saw in the Huygens image. There might be a lot of dust in the atmosphere as well. And then just for fun, who knows, maybe we would see fish jumping in the sea, I don't know.

Male: But color wise, it might actually -- just like on Earth, it might just reflect the color of the atmosphere.

Jason Hofgartner: Yes.

Male: Okay. Great, thanks.

Jason Hofgartner: Yes.

Jo Pitesky: There were a couple of questions that came in by chat. First from (Jim Placksgow), isn't Titan so cold because there is little or no greenhouse effect due to the hazes blocking sunlight from reaching the surface around noon?

Jason Hofgartner: Okay, so Titan, the number one thing that's dominating Titan's temperature of course is the distance from the Sun. So that's the reason why Titan is really, really a cold place. It's 10 times further from the sun than we are.

And there are processes that are causing both global cooling and warming, but presently, the warming processes are winning. So if it wasn't for the atmosphere, then the surface would actually cool.

So the atmosphere is essential and that's part of the reason why I talked about in the beginning is that it’s essential to the fact that there are surface -- liquids at the surface because without that atmosphere, those liquids would freeze, they would be gone and actually nitrogen might actually exist as a liquid at Titan’s surface in that colder temperature. And this is an area that has received a little bit of real scientific study, as well to see if this kind of thing has ever happened on Titan.

So just to summarize again, it's very cold because of the distance from the Sun. There is global cooling and warming processes, but the warming processes are winning a little bit. It's actually a little warmer than it otherwise would be.

(Jim Placksgow): Hey, Jason, this is (Jim Placksgow). The thing is what is the temperature delta between the top of the atmosphere and the surface because it is expected that the surface should have been much warmer taking into account the distance from the Sun?

Jason Hofgartner: So I don't know exactly what the temperature of the top of the atmosphere is. There is a warming area where it is quite a bit warmer than the surface and that's basically what's causing a stratosphere. And if you look at basically just the effect of the distance from the sun, and you can do this calculation is that Titan would actually be cooler.

So it's not -- it's minus 300 Fahrenheit and 95 Kelvin, but it would -- the temperatures out there without that atmospheric warming is about 20 Kelvin, 20 degrees Celsius, that's 36 degrees Fahrenheit [cooler than it is now], where it actually would be colder without the atmosphere because of that. And then higher up, there are things that are absorbing where it's actually even warmer than either of those things.

(Jim Placksgow): And what fraction of the visible light reaches, or let's say, infrared radiation for that matter, what fraction reaches the surface? So do you have any idea?

Jason Hofgartner: So in the infrared, it really varies across the infrared. So at the very longest wavelengths that Cassini is observing the surface which is about 5 microns, it's very nearly 100%. At the lower range of the infrared which is more like 1 micron, it's probably less than 20%, so it really varies across infrared there. And then the actual visible light, it depends on the season, but it's also quite a low fraction.

(Jim Placksgow): Okay.

Jo Pitesky: We also got a question from (Tim Brant) asking about the height of the waves, and he’s from Southern California.

Jason Hofgartner: So we can't directly measure the height of these waves with the imagery that we're taking. But what we can say is that in order to be bright like we're observing, they would have to be a half an inch or larger. And what our models suggest where we have models that were developed for waves on the Earth, and then we transition them, we modify them to work on Titan, and they've never been tested on Titan, but what they predict is that these waves would be just like I said, on the order of half an inch or to an inch in size.

And the wind that it would take to get those waves is very light. So about a meter per second is what it would take. So on the Earth, that would be a very light breeze, barely noticeable and that would be enough to create these kinds of waves.

Jo Pitesky: I was also wondering when you were talking about future missions, and without having to say anything which might possibly be tipping your hand about anything you might be proposing, I am curious what would your ideal return to Titan mission look like?

Jason Hofgartner: So my ideal return mission to Titan would be something that is focused on these features. And the reason for that is because I think that's what's so unique and so relevant to understanding the Earth at Titan, which is really why I have the most fun at Titan. It's the exploring of what's new there and then also how similar it is to the Earth. And so I would focus on that although there're certainly other very wonderful things around the whole world.

Jo Pitesky: And is it something that landing in the liquid or would you something orbited?

Jason Hofgartner: Both. Yes, yes, there's definitely very good science to be done from both.

Jo Pitesky: But if you got to choose?

Jason Hofgartner: If I had to choose, I would go with a lander. But the thing to keep in mind here is that because these liquids are all at the very north polar region, if you put directly a lander -- and remember Titan has an obliquity so there's a tilt relative to the sun -- when you put the lander, if it's in the north polar region, and in the liquids, you can't communicate directly with Earth.

As Titan goes around in its 30-year cycle, you -- there's only about half of that time where if you had a lander it could communicate directly with Earth. The other time you could still land there, but you would need a satellite in between. And right now, we're actually at that time where basically if we wanted to send something to Titan, we wouldn't be able to have direct view of a lander.

So that's certainly something engineers and scientists here are very aware of, is that in order to put a lander right now, we need a satellite as well. And then 15 years from now, that would not necessarily be the case.

Jo Pitesky: Any other questions for our speaker?

Male: Yes. Can you explain why there's no wind on Titan? I mean if there's air, there should be convection as a result of temperature difference, why is there almost no wind there?

Jason Hofgartner: Right, a good question. So what we think is going on is that Titan's atmosphere is very thick, so the pressure is about 1.5 times Earth, but because there's less gravity, it basically extends quite a bit higher than the Earth and is actually about 10 times as many molecules as in the Earth's atmosphere above or as far as on the surface.

And so what that means is that there is this great big inertia in the atmosphere. So it's hard to change its temperature. So when you're blasting the Sun at an area which, remember is 10 times further than the Earth, so the Sun's energy is actually about 100 times weaker.

So even if it took the Earth 10 times further out, the Sun's energy is a hundred times weaker, the driving force for wind is that much weaker. And then also the fact that the atmosphere is thicker, there's this harder inertia to create temperature differences, all of these compound can make winds very weak.

And so we think that they occur but really only in the summer season where this can really be strong enough to create winds that are of significance.

Male: And do we have any theories as to why Titan is so special in the fact that it has an atmosphere? I mean Ganymede is way bigger and it doesn't have any noticeable atmosphere, I think, right?

Jason Hofgartner: That's right yes. Although it may have had one in the past, we don't know. That's a really great question. In my opinion, it is the most important question in Titan science, and certainly a lot of people are thinking about it, but I don't think we have the answer at this point.

One thing that Cassini was intended to do and has done a job of was to look for basically evidence of volcanoes at Titan's surface. And if there were volcanoes and then they were releasing off that methane that might explain why -- at least that would give us a hint as to what's different because of these volcanoes that are releasing methane. And Cassini has looked for these volcanoes and it has found evidence for a few, but we don't think there's enough to be creating the methane atmosphere.

And so Cassini has indicated that this probably is not likely. It doesn't seem that the methane is being delivered from outside and so the idea that I favor, although it's certainly is far from resolved yet, is that there is methane that's coming out from deeper down and it's coming out non-violently, so almost dissolving through the surface and then being released. But it is a very important question, so a very good question.

Jo Pitesky: I think there's a question in the room. (Dan), did you want to ask something?

(Dan): Okay, in the model where the Magic Islands are wind driven waves, are there any obvious topographical reasons, like maybe a breeze rolling down a river valley and that's where they happen to be?

Jason Hofgartner: So that's a really good question, and that's actually an area that I'm considering as a future area of research for this project. And the answer is because if you look at the topography, it looks like it's kind of unique in that area. It does appear to be almost like more valleys that are flooded right next to where we're seeing this feature.

And so it's possible that either the winds are being funneled by that topography, or also that the current, so if there are currents within the sea that they're being funneled. And that could explain why it's happening in this particular region. But right now, we don't have the topographic information or the models to do that. So that's a good idea for future research.

Jo Pitesky: Any other questions? Well, I'd like to thank Jason again very much for really a wonderful, highly current talk. And I'd like to thank all of you for joining us today, and I'd like to thank you especially for the great questions from you in the community. Our next telecon will be in July and August. That will be the annual anniversary extravaganza and I'll be sending out an email about that in the future. And thank you all very much again and have a great day.

Male: Thanks very much.

Jason Hofgartner: Great, thank you.

Female: Bye.

Male: Good job.

END