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Moderator: Jo eliza Pitesky
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Jo Eliza Pitesky: Good morning, everyone, and welcome to part two of the Cassini CHARM Anniversary telecon. Today, we'll be hearing from experts and scientists who worked on the Cassini talking about Saturn's largest moon Titan, all the other moons and I'm laughing because I'm very much a Titan person.

And also about the rings, which I guess is taking the number of very small things orbiting around Saturn to its logical conclusion. We're going to be starting off the first of our three talks with Dr. Zibi Turtle. Zibi is a Cassini imaging science system team associate and Cassini radar team associate, who's based at Johns Hopkins University Applied Physics Laboratory. She received her PhD in Planetary Science from the University of Arizona in 1998.

Dr. Turtle's been involved with other interplanetary imaging systems as well. She was a team associate with the Galileo Solid State Imaging instrument which targeted Jupiter. In addition to being a co-investigator for the Lunar Reconnaissance Orbiter Camera, she will be returning to

Jupiter in spirit as the principal investigator for the Europa Imaging System on NASA's Europa mission. Zibi, it's all yours.

Zibi Turtle: Thanks, Jo. It's great to be talking to everyone about Titan again, after our 11th on our -- well, I guess that's after our 11th anniversary. It's been a -- it's been a busy and exciting year. And I'm going to go over some of the highlights of the observations as well as some of those science results that have been published. Some of those are about previous observations, but newly published results.

So I'm going to go ahead and get started. I'm going to walk through what we've learned about Titan in the next -- in the last year, if my computer lets me, interesting. Okay. This is a summary of the Cassini mission and we're getting farther and farther to the right in this -- in this graph which is exciting and also a little sad as we start finding more and more last events, but like I said it's been a very exciting year for Titan Science.

And this slide shows the graphics for the flybys that have occurred over the last year. These are really fun graphics highlighting some of the primary science from each of the flyby and it's great that these get made for each.

And then in the middle I've just listed the dates of all the flybys from July 2014 through July 2015. This past January was the 10th anniversary of the Huygens landing on Titan. So, there were a lot of events associated with that and going back and thinking about all the things we've learned about Titan since we landed in early 2005.

At that point in time, we'd only had a couple of Titan flybys and we were still really trying to understand what the surface looked like and -- or not what the surface looked like but what the -- what it looks like meant.

It was still hard to interpret some of those surface features that we were seeing in the radar and the Near IR Imaging because Titan doesn't, at some scales doesn't, in some places doesn't look like what we would expect of an icy satellite because it's such a different environment and it was just spectacular as the Huygens probe images started coming back to look at a landscape that was so suddenly familiar. Looking at the images of the channel networks and we could look at this and know exactly what it is as opposed to having been puzzling over the radar images and what the cat scratches were for the previous months, so it was great to get the things back to -- and look over how much we've learned about Titan in the ensuing time.

This is a list that was released with the events for the anniversary of top 10 things that we've been learning about Titan over the past 10 years. And I included a couple of links in the presentation. Jo, are the presentations made available to everyone? I know that used to be posted somewhere.

Jo Eliza Pitesky: Yes. Unfortunately, we can't right now.

Zibi Turtle: Okay.

Jo Eliza Pitesky: However, we are going to be recording this entire thing on WebEx and so an audio and visual record of it will be available for download hopefully within the next couple of weeks.

Zibi Turtle: Okay. Great. And if you go to the JPL website for Cassini or the ESA website for Huygens, you can find the links to these movies, but there are a number of movies that were released at the anniversary and they're pretty fun to look at how all the data has been combined into those movies.

So, getting to the last year's discoveries and observations of Titan, this is an observation of Titan's high northern latitudes that we've taken on the 21st of August, so this is just over a year ago. The Titan anniversary presentation at CHARM was given last year between when we had the ISS data which revealed this cloud feature. And we have this great sequence of watching that cloud evolve and so that was presented in the CHARM telecon last year, but the VIMS data hadn't been analyzed and processed yet, so this kind of brackets that timeframe.

And in addition to that that cloud feature that we got to watch evolve over Ligeia Mare. The VIMS data show this exceedingly bright specular reflection here. And this is a reflection from the surface of Kraken Mare. Kraken Mare is kind of separated into two parts and this is just near the archipelago, right, where those are separated. So, these specular reflections are really important for understanding where the liquid distribution on Titan.

And I've got another result that I'll mention in a few slides. That's really helping us to understand the liquids on Titan, how they're distributed and how they may be behaving. Another thing that shows up in this is that you can see around Kraken Mare, there is this kind of pinkish or orange in this false color view of the VIMS data which is suggestive of evaporates.

You can see there, these similar bright materials elsewhere in high northern latitudes and that's been seen before, but it really stands out the rim of Kraken in this observation and that suggests that there's been evaporation right at the edge and that Kraken might have larger boundary in the past.

This is a very busy flyby. We had the ISS observations of the evolution of the clouds over Ligeia Mare. The VIMS and spectacular view of the high northern latitudes and there were radar observations as well. And the radar observations allowed us to look again at an area of Kraken -- sorry, this is actually Ligeia where in April 2006, we've seen the shoreline next to the seas, they're very dark here. We've seen the shoreline.

And then in July 2013, there have been a feature in the sea and this has been analyzed a lot by the radar team and it's not an artifact. It's a real feature of some sort. And we got to look at this area again, just over a year ago.

And lo and behold, it wasn't there again. These have been kind of dubbed Magic Islands by the team because they seem to kind of appear and disappear. And they're still looking at plausible explanations but those include waves on the surface because the radar is sensitive to the roughness of the surface, so if they were waves then that would roughen the surface of the sea and that might appear this way to the radar.

It's also possible that the surface is disturbed by material -- by bubbles rising from the bottom of the sea or solids that are suspended either right at the surface or just below the surface. And it's possible that there are other explanations as well.

One of the things that is harder to explain is that in some places we've seen these multiple times in basically the same place and why you'd see that, you know, if it's waves, why that would occur in the same place multiple times is a little harder to explain and then perhaps some of the other scenarios like rising bubbles if there's material outgassing at the bottom of the sea.

But it's still a bit mysterious. And so there's this observation in Ligeia, we had a similar observation again in August of last year where there's a brightening of the sea surface in Kraken Mare in this case. So there are multiple cases where we've seen this and it is suggestive, as I said potentially of waves on the surface. We do expect that wind will pick up at high northern latitudes as the summer progresses on Titan.

We are moving toward northern summer and is expected that the heating will cause more storms to occur. The same phenomenon we have on Earth in the summer and that in that case we might get rain and/or wind disturbing the surface, so it's possible we're starting to see that pickup, but we're got fortunately, some more time to continue to watch Titan and see how things continue to change.

On this same flyby again, the radar altimetry mode was used over part of Kraken Mare. This is kind of a tributary or the mouth of a river leading into Kraken Mare. And at a few places along this altimetry tracked the depth to the bottom of the river channel was measured, so in each case, it's about 30 meters deep, so that's a fair amount of liquid, but not nearly as much as seen in Ligeia which out in the sea is actually 170 meters deep.

For Kraken on this flyby, no signal was detected from the sea floor, so that suggests either that Kraken is too deep for a signal to get to the bottom and then be detected again, which should have to be more than 200 meters. That's consistent with Ligeia being 170 meters deep. Kraken is in places broader than Ligeia. And Kraken also has very steep shorelines which would be consistent with the deep-sea floor. Another possibility is that it's just that the liquid is more absorbing that there are slight differences in the liquid.

Ligeia seems to be very pure methane. It's possible that Kraken has more ethane and that might change the absorption as well. So those are some of the scenarios there that are being considered. This is that same area. There's a paper that came out last year with a new process to de-speckle, if you look. I'll go back to that radar image. You can see how speckle-y this looks in the radar return and there's a new process that Lucas et. al have developed to clean that up, it removes some of the information as cleaning data tends to do. But it does bring out some of the surface detail from that speckle-y background. So this is that same area with the channel here leading into Kraken Mare. And there are multiple views. This processing is very intensive but it has been performed for multiple areas on Titan and really brings up some of the details.

Also speaking with the lakes for a little bit longer or the seas, I should say, so here's a map that the radar team released to the North Pole a little over a year ago. And so you can see Ligeia

Mare here and Kraken. This is the area where Kraken is kind of divided by an archipelago and so that specular reflection, I spoke to in one of the early slides was coming from right about here. And here's Punga Mare, just one of the other large seas.

This is, I think, that area, that river channel that the depth was measured over in the previous slide. So, Ligeia Mare and Kraken Mare actually appear to be connected through what's now named Treves Ratim which is a word for straight. So it appears that there can actually be liquid transport between the two seas. And we know Ligeia has a fairly methane pure composition because the radar is able to see through to its bottom and 170 meters of liquid. If it is absorbing, it's not easy to see through.

The fact that they're connected brings up an interesting possibility that there might be a net transport of solutes like ethane from Ligeia into Kraken and there's been some modeling done to understand how these two bodies of liquid and the connection would behave.

And as a result of such transport, Ligeia could become fairly pure methane, but Kraken actually might be more dominated by ethane, which is interesting, especially when you start considering how the seas interact with the atmosphere because obviously, the seas are a source of the liquid that will evaporate into the atmosphere and then perhaps rain out and so trying to understand how these are such large bodies of liquid it interact with the atmosphere could have quite a significant impact on the atmosphere behavior and the seasonal weather.

Interestingly an observation this winter and I don't have the image yet, although, Christophe Sultan is going to speak about this at a conference this fall. VIMS observed again the specular point over Treves Ratim last February, so in this area.

But the specular reflection didn't come from the specular point. It was offset a little bit. And that suggests surface roughness of the liquid. And that could be surface roughness generated by wind like waves, the same way we saw potentially for the Magic Island that the radar has seen.

But it's also possible that because this is in Treves Fratum, it's actually currents, that their title currents they looked at the location of Titan in its orbit relative to Saturn which suggested that there could actually be at that time at that location is orbit tidal currents running between the two seas and that that would be enough to generate surface roughness from the turbulence of the flow back and forth between the sea.

So that's particularly interesting and I'll be anxious to see the presentation from Christophe and the presentation of the images that VIMS has. I thought it's going to be very interesting. Of course, the seas aren't the only bodies of liquid on Titan. There are also these little cookie cutter lakes that are very intriguing. They are very isolated. They have rounded, steep shorelines.

They are set very deep tens, tens, 100 meters down into the surface and unlike Kraken and Ligeia you can see how well connected they are to river channels and river networks, but the lakes don't have that. They're not necessarily near channels and they don't seem to be fed by or flow out through channels, so it's been quite a puzzle to try to understand how these could form and one hypothesis has been that they are similar to Karst terrain on earth.

On earth, water erodes carbonate and evaporate minerals by dissolution. On Titan, a new study here by Cornet et. al has looked at whether surface solid organics can dissolve in liquid hydrocarbons. We don't have a really good idea. We know that there's a lot of organic material on the surface of Titan but we don't know the composition specifically. But they have looked at the erosion rates of organics in methane and ethane and have found that it could take tens of millions of years to create a 100 meter depression if you assume a fairly rainy area.

We think the poles get a fair amount of rain. We observed that at the South Pole in late southern summer back in 2004. But we haven't seen rain yet at the North Pole, but atmospheric models suggest that the poles are rainier and under those conditions within relatively short geologic time scale depressions of the depth that have been observed could form, so that's a good indication that maybe this Karstic explanation for these lakes is going to work.

If you compare the, you know, a map of Titan, to say, Florida where there's a lot of Karstic terrain. It looks very similar. So it's good to know that the lab work is consistent with that as well and that the materials maybe behaving consistently. And, of course, as Cassini continues to make observations of Titan over the next couple of years, we'll be watching the lakes as well as the seas to look for change and just the northern hemisphere in general to look for seasonal changes in the weather pattern.

There is still, hopefully, plenty of data yet to come. Also a seasonal change going back -- this is going to the South Pole, Titan -- Cassini observed a vortex form over the high southern latitudes of Titan as we progress the form in about 2012, as northern fall was advancing. And this is a VIMS observation here, I should say. This is a VIMS observation with some pixels over the polar vortex here. This is an ISS observation of the vortex higher resolution, but it doesn't have the spectral information.

So the VIMS data have been processed so that the Titan surface is showing up in orange in the false color view and the Lin haze just show up is green and the polar vortex here in blue, stands out very well. The spectra of the polar vortex reveal hydrogen cyanide frozen as part of the composition of the cloud if you will, which means that in order for hydrogen cyanide to be frozen, Titan's atmosphere has to have cooled much more rapidly.

This is fairly soon, fairly early in Titan southern fall and the atmosphere would need to about a 100 Celsius degrees colder than the predictions that models have made for the cooling of the atmosphere, so this is a really important data point for understanding the global scale atmospheric behavior and how the seasons change it at the poles which, of course, is important because those were the reservoirs of liquid methane are most prominently distributed.

So, the graphic here illustrates the geometry that occurred during a flyby of Titan. This is a flyby in 2013. It is the paper by Bertucci et al, that just came out this year. And so during this T96 flyby in late 2013, Titan here was actually outside of Saturn's magnetic field. It was known that this was a possibility that the solar wind can at times be strong enough, but it pushes on Saturn's magnetic field and the Titan's orbit can take it outside of that. Titan, usually and almost always in Cassini's experience within the magnetic field.

But in this case, it was actually outside of the magnetosphere of Saturn. And that's really interesting. There are few planets that we can see this for. Earth, of course, is protected by the magnetic field, so our atmosphere doesn't interact with the solar wind directly. On Venus and Mars, they do. The solar wind drapes right around the planet and therefore is impinging directly on the atmospheres. It wasn't known how Titan's atmosphere because it's such complex organic chemistry would interact with the solar wind.

But as for Venus and Mars, the interaction created a shockwave right around Titan where the solar wind impinged on to the atmosphere. So, this was a very interesting and a case that everyone has been wanting to get to observe for quite a while, but in 2013, we finally got to see Titan interacting directly with the solar wind as opposed to protected by the magnetosphere.

I mentioned that one of the high priorities is understanding the seasonal changes on Titan. In particular, we've been watching for the summer storms that are supposed to pick up at high northern latitudes any day now. We keep saying this. We keep expecting this. Now, at this point in time all of the models, all the atmospheric models have predicted that clouds and rainfall should be occurring at high northern latitudes by this point in the year.

This is a list here of different events, including the dates of the Voyager 1 and 2 flybys in Titan's year. So Voyager 1 and 2 were in late March and early April. When Cassini got there, it was mid-January and now we've progressed through a Titanian year since the Voyager flybys. And at that point, we started seeing the changes in the upper atmospheric hazes, the formation of the South Polar vortex. And today, it is late May on Titan. And as I said, we've been expecting storms to occur at high northern latitudes for quite a while.

A year ago, we had a few clouds form over Ligeia and never have so few and small clouds created so much excitement about things yet to come, but since then Titan has actually have been quite sunny. So we're continuing to watch for that and one of the high priorities for future observations of Titan is to see when these storms start because that's really important for understanding the atmospheric circulation. And the hydrocarbon cycle, we expect that methane will rain out on to the surface, but we haven’t seen that happening.

And in watching changes in the lakes and the seas after a rainstorm will help constrain the hydrology, the subsurface hydrology and connections. So we're very anxious to see that and have some good opportunities coming up in the next couple of years, so hopefully everything will cooperate and we'll get to see some of that. I just wanted to put in a couple of slides showing the next few flybys. The next one is T113 at the end of this month. And each of these shows the ground track on Titan, so these are all very low latitude flybys.

It's a little while now, about a year from now, we start getting back up to high latitude, flybys where we really get to see the high northern latitudes in particular because those were illuminated well. But this is the inbound view for T113 where we get to see Shangri-La again. And actually, we haven't really seen this part of Titan very well since T12 which was back March 2006.

So now it will be very interesting again to be able to make comparisons and see if there have been any changes. We don't necessarily expect any in the dune fields, but it's a good opportunity to look for that. And I will leave it with this recent image of Titan in front of the rings and little Pandora and take any questions.

Jo Eliza Pitesky: Thanks very much, Zibi. In the room, we're all chuckling about how drought had struck not only California but also clearly Titan.

Zibi Turtle: Oh, yes.

Jo Eliza Pitesky: We are so sorry. I saw a number of questions drifting in. And I wanted to know if anybody had any questions for Dr. Turtle. Well, one of the questions I was asked was what percentage of the surface of Titan has been imaged so far by ISS? And I was guessing that we're getting up near 90% but I might way off.

Zibi Turtle: Yes. It depends a bit on the resolution that you mean. But we have seen all of the surface at some resolutions. We've seen that a little over 90%, I think at the several kilometer resolution scale. And we've seen 50%.

I'm talking about that camera right now. We've seen about 50% at the kind of one to two kilometer scale. The limiting factor for Titan is the atmosphere because there is so much atmospheric scattering, so no matter how close we get to the surface, unless we're down beneath the clouds, the way Huygen was.

We don't get to see the surface at super high resolution. VIMS can get higher resolution but has had less coverage at those resolutions because you have to be fairly close for it to be able to get the highest resolution.

The radar, which also images the surface at a scale of half a kilometer to several hundred meters, I think also has covered about 50% of Titan at this point with SAR images. It has a number of other modes as well and I think there's global coverage with the radiometry and scaterometery, but with the SAR imaging of the surface features, it's about 50% now.

Male: What will be the final percentage when the mission is completed?

Zibi Turtle: Oh, the cameras will get a little more, so we'll have global coverage at several kilometer pixel scale if not better with the cameras in the Near IR. The radar, I don't know the final number. I'm sorry. It's in the 50s I think, but I don't know the number.

Male: Okay. If I could since you mentioned the obscuring clouds, do clouds have a particular pattern that they're consistent over some spots or do the cloud patterns move across like we see on the earth.

Zibi Turtle: Yes. So I wasn't very precise in my language there. What obscures the surface for the images, so like the image at the top right now, it's not actually cloudy. This is a perfectly sunny day on Titan. The atmosphere is very hazy because of the hydrocarbon materials and the chemistry with the breakdown of methane by the UV light from the sun. So there's a lot of haze in the atmosphere and that's really obscuring the surface.

Obviously, when there are clouds, those also obscure the surface, but those are usually smaller and shorter lived, the hazes are always there. And in terms of mapping the surface, it's been great because we haven't had any clouds, so there's been nothing obscuring the surface besides this limiting factor on the resolution from the haze.

If we start picking up more clouds at northern latitudes, then that will be a different story. But we'll be able to map the clouds. In terms of predicting them, we're not doing so well, so far, because we expected that after having seen clouds in the southern hemisphere, the South Pole at late southern summer that we'd start to see clouds at the North Pole in northern summer and we haven't seen those yet.

So I don't think we understand the circulation in the cloud forming in Titan's atmosphere as well as we hoped. That being said, one never knows. This could be an anomalous year on Titan. It could be that in most years by now, there'd be tons of clouds and tons of rain at the North Pole and this is just a dry year, the same way it's a dry year in California. So we're hoping to get some more data from Titan to understand that better.

Male: Okay. Thank you.

Adrienne: Hi. This is Adrienne I'm a Solar System ambassador and I had a question about craters and was wondering if there are any lakes and craters on Titan?

Zibi Turtle: There are, in fact, craters on Titan. We haven't seen lakes in the craters. Most of the craters that we've seen actually are at lower latitudes and there're only a few tens of craters, because the surface, like earth surface is so heavily eroded the craters get eroded and buried the same way they do on earth, so if you compare a picture of the earth to a picture of the moon, right? There's has been an exactly the same cratering environment basically, but the moon is very heavily cratered in most places and, of course, Earth has impact craters but only about 150 just because of the resurfacing.

And Titan has the same situation as Earth. There's a lot of resurfacing that's erased the craters. There had been predictions that there might be ring lakes in multi-ring structures or peak-ring structures. But we haven't seen any definitive evidence of impact craters that are field with liquid.

Adrienne: Okay.

Zibi Turtle: There are some filled with dunes, though.

Adrienne: Oh, okay. So there were never any liquids there at all?

Zibi Turtle: No. I wouldn't say that. The equatorial regions on Titan, so what you can see here, actually, this is the kind of equatorial band and these dark areas are sand dune seas. But in these areas around those, we do see channels on the surface, so there's clearly have been liquid that flowed on the surface at low latitudes before.

In 2010, we even saw a big storm that appeared to rain on the surface at low latitudes. So there clearly have been liquids there before but like the deserts on earth, you get rain once in a while. You can get torrential rain falls that you get flash floods and they erode channels very quickly, but most of the time they're dry and the sand seas suggests the same things for Titan's low latitudes, but it does rain once a while but it's a predominantly arid environment.

Adrienne: Okay. And can you tell us a little bit more about the ISS survey?

Zibi Turtle: The surface mapping?

Adrienne: Yes.

Zibi Turtle: We should actually have a new map that we'll be able to release soon. We compiled the images. I think the most recent map is something like 2011, so it had been quite a while and we finally got views of the high northern latitudes a year or two ago. So we've been able to compile those all into a new map and we'll be releasing that, I hope in the month or so. So keep on the lookout for that.

There'll still be a couple of gaps in that that we'll able to fill by the end of the mission with some of the later flybys. But at this point it is pretty much 90% surface coverage at the several kilometer scale so we've got a good global map and that's really useful for comparing to the VINS map and the radar because now we can start doing really good cross correlations between the different wavelengths which tells us about the surface material so that's been very useful.

Adrienne: Right. Thank you.

Jo Eliza Pitesky: I want to thank you again – oh, I think we have time for one quick question, one last one.

Deidra: Yes. I want to ask a question. Hello?

Jo Eliza Pitesky: Okay. We have time for one more and then if people can send them we'll see if we can get answers and maybe we'll see about getting things posted on the Charm page as a follow up. So, one last question for now, please.

Deidra: Hello.

Jo Eliza Pitesky: Yes?

Deidra: Hi. This is Deidra from Ireland. Can you hear me?

Jo Eliza Pitesky: Yes.

Deidra: Yes. Hi. My question is about the clouds. Do they form in a similar way to clouds on earth, you know, coming from the liquid areas and rising up and moving and forming and dropping the rain on the moon?

Zibi Turtle: Yes. In many cases that's exactly what we've seen. The first clouds that we saw – this is back in the very first distant flyby, so July 2004, there were clouds over the South Pole and they were just little fields of cumulus convective clouds just the way I can actually see out my window right now, actually.

Deidra: Yes.

Zibi Turtle: And we did, in fact, from a larger outburst of clouds just that fall see an area of the surface that was darkened from rainfall. So, the process performing the clouds on Titan is very familiar. It's the materials that are different so, instead of water as on earth, it's methane.

Deidra: Yes. do they move differently because to me they seem to be heavier materials, I don't know but maybe they're not.

Zibi Turtle: Well, there's lower gravity, too. Titan – the main difference is altitude. Titan's atmosphere is much more extended than earth's atmosphere. So, the clouds are much higher in the atmosphere as opposed to a few kilometers up they're, you know, a few tens of kilometers up. But in general, they are very – they are very similar.

Deidra: Are you calling them similar, you know, descriptive names like (cumulus and altocumulus)

Zibi Turtle: We don't have too many examples so, we see at mid-latitudes, we've actually seen these elongated streaks but we don't see them at high enough resolution spatially or temporally really understand the dynamics in as much detail as we obviously can on earth.

Zibi Turtle: But there have been studies into the formation and the dynamics of the clouds and we're hoping that we'll get some more clouds so that we can do more observations and try to understand them better.

Deidra: Thank you.

Jo Eliza Pitesky: I'm regretfully going to have to cut off Zibi here because we do have two more wonderful speakers. If people do have questions please do send them on to – well, I'm Jo Pitesky but Karen Chan is the host for the meeting, so send those on to that screen name and I'll capture those and see what we cando. Let me just slide this over to Carly.

Zibi Turtle: Do I need to do anything to relinquish control?

Jo Eliza Pitesky: So, while Carly is getting things set up, let me tell you about her. Dr. Carly Howett is a senior research scientist at the Southwest Research Institute in Boulder, Colorado. She obtained her PhD at the University of Oxford in 2005 and since then has been working on the Cassini project.

She was recently promoted to a co-investigator on Cassini's Composite Infrared Spectrometer which we know as CIRS. She helps plan the CIRS observations of icy satellites and recently helped negotiate the observing time of the last few years of Cassini observations. She specializes in understanding the surface characteristics of Saturn's icy satellites using infrared data. Carly, it's all yours.

Carly Howett: All right. So, this is kind of a summary of the observations like Zibi presented -- the results that have come out in the last year, so not all of necessarily the observations taken the last year but kind of the analysis that's been done in the last year. And for icy satellites, this is particularly a passionate point because Cassini is gathered information which has been great if you're interested in looking at the rings from a certain vantage point or if you're interested in looking at the poles of Saturn.

If you're interested in the icy satellites, it's a bit of a downer because instead of being in that plane that the icy satellites reside in so you might get a couple of flybys every now and then, you really only get them very, very occasionally and then they're very fast flybys because they're sort of coming down past the satellite.

So, we haven't had that many observations in the last year. There's been sort of a big push to really analyze the data we had before. And we're about to really start -- we've just begun really that process of getting a lot more data as Cassini's moved down an inclination and we're back in the ring plane.

So, just to kick things off, this image I'm sure many people are familiar with I think it's one of the most spectacular ones of the icy satellites that Cassini has taken. So, you're looking at the southern pole of Enceladus and you can see these kind of glorious jets that are coming out from the southern pole.

And we're going to talk a lot about how they are made and how they are formed during this talk. It's an area of very much active research, if you pardon the pun. So, just by way of an introduction, this is the sort of ring and satellite system.

So, you can see that the majority of the dense rings are very close to Saturn when you think of it in terms of the icy satellite but rather Enceladus gives out this dust and it creates this E-ring and it's ice creates the E-ring and most of the larger icy satellites reside in this. I'm not going to focus too much on some of the smaller ones. We will touch Hyperion but there are only so many minutes so, I have to share nicely.

So, I'm going to focus on the larger ones so, Mimas, Enceladus and then Hyperion so moving out from Saturn. All right. So, with that orientation let’s dive in. So this is an image of Mimas that wasn't taken this year but it's on e of the closest ones we have. And if you look at the surface of this satellite it looks quite boring in many ways especially compared to the excitement that's going on at Titan. It's gray. It's heavily cratered. You can see there's a large crater at mid-latitudes called Herschel.

But when you look in the visible, you don't really see a whole lot going on. But when you start looking in the infrared or you start looking in the UV or in the thermal we know that there's a lot more going on in Mimas. And that was one of the big discoveries kind of early on about five years ago, we discovered that Mimas’ surface has a big thermal anomaly on it. And so, we haven't been able to get back to do any more research on that, we haven't had very good observations at high spatial resolution of Mimas. What we have done is kind of continued to look at this satellite as it moves around Saturn.

And what happens when that the orbit of Mimas isn't circular and that's very, very common, instead it kind of is slightly stretched out, elongated. And this slight deviation means that not that exactly the same point of Mimas is facing Saturn as it moves around its orbit and it will wobble slightly. And the moon does this to the earth too and it's called a libration. That's the technical term for it.

And by studying the libration you can understand what's going on in Mimas' surface. Now, if you look at this, you don't see those active geysers and things like you do on Enceladus. It doesn't look geologically active. But what gravity studies have shown is that this wobble doesn't quite make sense.

And there's two possible options to explain the way that Mimas is wobbling, one of which is the center of it, the core of it when it froze out didn't freeze as a sphere, rather it froze out in kind of an American football shape or like a rugby ball shape if you're from the other side of the pond.

And that would be pretty weird because usually these things are spinning as they cool and we all know that if you take something and spin it, it doesn't usually end up in a rugby ball. Another option is that there's still a liquid water ocean under Mimas and that's very exciting but it's A- very unlikely perhaps and B- it's difficult to imagine that because if you look at the surface there's no evidence for geologic activity and that would come in order for it to be warm enough to have a liquid ocean this is a very small target, you'd expect to see a lot fewer craters, maybe sort of signs of geology on its surface and we don't see anything like that.

So, this is going to be something that people kind of continue. This is a relatively new result and it's potentially quite an exciting one because if there is liquid water that opens up a whole new world of research for Mimas, but it's perhaps on the optimistic side.

All right. So, moving on to my favorite moon, this is Enceladus, these are just two, I think, fantastic images of the surface. So, all of Enceladus' activity we know is constrained to the southern hemisphere. There's a lot of work that is going in to understanding that. It's one of the most stable points, if something is rotating and there's a bit of Enceladus that's kind of heavier, it naturally moves to that kind of location of rotation if you like, so that naturally moves to the poles.

And so, there's evidence for sort of shell rotation so just to back up a bit, these are icy satellites, the surface is water ice and we think that in the past there would have been a liquid ocean underneath it because the face is so cold it freezes at the top but can remain liquid underneath much like lakes on the earth. And that kind of gives it a lubricant to move around, so it's possible that the whole shell can kind of move around. But we see all of the activity on Enceladus at the southern pole.

And this is only something you get to see from Cassini because in order to get this sort of resolution you're a long way from the earth and you're looking at it in very specific ways. We're looking at the southern hemisphere which is hard to see from the earth because we're kind of in the same plane. And it also shows up really well if you look at scattered light, forward scattered light, so you have to have the right geometry, basically you have the sun, your spacecraft and Enceladus in the right way in order to really see these plumes, so, it's something we only have ever really seen with a spacecraft like Cassini.

So, what I did is that these geysers, individual geysers, we call them discrete jets and so this is an idea put forward by Carolyn Poco earlier in the year and her and her team -- she's the PI of the imaging team on Cassini and her and her team looked at all of the images that ISS had taken, the camera had taken of these jets and basically they tried to figure out, okay, in this one we see, you know, a jet going here and a jet going here and a jet going here and then like kind of trying to bring that back and say, okay, where must they be located on the surface.

And when they did that, they found that there were about 100 sources and that's what's depicted in these pictures. Now, ignore the color, that's just so you can see, you know, which one is which but you can see that the jets themselves come off at all these kind of really crazy angles, some of them very low -- they're almost sort of tilted along the surface, most go straight up but some are sort of tilted either which way from that. All of them are located along the tiger stripes. These are the very warm regions we see that when we look at thermal data which is what I'm primarily interested in. They're all located along these tiger stripes.

Now, there's another way of thinking about these geysers which is has been recently put forward by Joe Spitali and that's instead of thinking of these things as discrete jets, you can think of them as almost a continuum along these tiger stripe fractures and that actually when you look at discrete jets what you're actually seeing is an optical illusion. You're seeing that the tiger stripes you can see from the top image aren't straight. They kind of wiggle around and wiggle around.

And maybe if you're looking down the line where you're actually thinking it's a discrete jet, isn't. Instead, you're just seeing kind of the effect of a bend in the tiger stripe and this on the bottom of this illustration, so this is the image I showed earlier. The brightness has been enhanced. You can kind of see that the lem is quite washed out but to really pull out the scattered dust away from the lem and when you model them as discrete jets you end up --on the right hand side, it's computer animation basically or a computer model, and you can recreate these images very well.

Now, there's definitely people in both camps, these are very new areas of research. And so, it could be that it's, you know, it's a little bit of one, it's a little bit of the other which is kind of where I think I lie, the idea that it makes sense to me that this whole area is emitting but that some regions maybe are more active than others. But a really nice movie that I want to just take a moment to show you that was around these jets and I think it really shows this kind of an optical illusion effect a little more.

So, this was a movie that JPL put out around the same time as Joe Spitali's paper came out. And it kind of just shows you how this optical illusion might work, and so, here we go. So, this is the image that we showed before and then this is that computer model that I alluded to. And you can really get a sense I think, once it starts curving around what you’re actually seeing is that sort of bend in the tiger stripe and it's causing you to think that there's an increase in the emission, but it could be more just due to the geometry of the observation.

So, of course, it's colored green just to make it easy to see. All of the emission is water so, it's very unlikely to be green. We know it's actually very good at scattering the light so we see it as a kind of increase in brightness. And I think is the end of it, it's going back to that original image.

So, this is a continuing area of research. We're hoping that other observations may be from CIRS looking at the thermal distribution and the high spatial resolutions, that's something we have been struggling to do with our data set right now or maybe with other observations, both the EV Spectrometer and VIMS such as the visual and infrared spectrometer have observations of this region as an occultation.

And what that means is that basically you look at a star move behind the target and it's a very powerful observation type because it allows you to basically get very high spatial resolution information on how the density of the atmosphere or those jets is changing. And so, by hopefully by combining all of these data sets from all these other instruments, we'll be able to build on the power that that gives you in order to kind of resolve these differences or issues or maybe it's one, maybe it's the other, maybe it's a bit of both.

Okay. Moving on, the same with Enceladus, there was a more gravity results so, we've always suspected that there must be a liquid water ocean underneath Enceladus. And when you look at the plume so, Cassini has actually flown through some of the plumes instead of tasted when you look at that results and you look at what the Cassini has seen in the plumes there is strong evidence to think that some of the water must have been in contact with a rocky core underneath.

So, we've heard for a long time that's been kind of building evidence that there's at least a liquid water -- sea underneath Enceladus' active region and Cassini has taken a lot of measurements very close to the surface of Enceladus in order to measure its gravity and those measurements are complicated to combine and the models are -- you know, to really understand what's going on in the interior just like flying by it is the changes that the spacecraft fills from the gravity are very subtle so, it's a complicated process to pull this out.

But they recently combined all these results and provided more evidence that the layering in Enceladus is such that we have an outer shell which is an icy, a cold ice shell, water ice shell and underneath that there's a regional ocean that we're showing.

We also one of the possibilities for global oceans that's not being completely ruled out but a stronger evidence to think that it's in the high -- it's an ocean at high southern latitude that's what's shown in this picture and then a low density rocky core. So, this is kinds of just adding to that dialogue about what could be going on in Enceladus' interior. And it's a hard thing to do when you're only able to flyby Titan, weren't able to land, weren't able to sort of sample it in situ. You have to kind of come up with these very clever ways of understanding what's going inside using these clever techniques.

And in this case, basically they're looking at how the spacecraft is deterred by Enceladus that when it flies by, what's the pull of Enceladus from the spacecraft. Okay. So, sort of staying with Enceladus but moving a little bit further out and I hope I'm not jumping on Matt's toes too much by showing this. This is quite complicated plot is basically looking at the effect Enceladus has on the region.

So, we talked about the plumes coming out of Enceladus and they have to go somewhere. That mass just doesn't, you know, magically disappear. And what we find is as Enceladus moves around its orbit it kind of dumps these ice particles, these dust particles into space.

And so, in figure A, this one here and the one beneath in C, that's what you're seeing, this bright spot in the middle is Enceladus. And then this is kind of the kind of bright side of it is the E-ring. So, this is the ring of Saturn that's sustained by Enceladus. And there was a lot of puzzling for a long time because this ring isn't just a nice simple ring, there's actually a lot of structure in these rings and those are known as tendrils. You can see it's kind of pulling off here and pulling off here.

And understanding what those tendrils really meant was a subject we've been looking at for some time. And some work by the ISS team has gone on to model this so, what you're looking at on the right hand side is basically a model simulation now. So, given the geometry of Enceladus, each of this particular ones have used their model to see if they could recreate these structures.

And you can see the very close similarity between this computer model, between C and D and then between A and B. And what they did was take most active geysers on Enceladus and then they looked at so where -- when in the orbit they were and then using information about the electromagnetic effects associated with the electrical charges that you can get on small grains, they can map the trajectory to these grains based on the effect that the Saturn may still have on these grains.

And these grains are very sensitive to particle size so the smaller something is, the easier it is to perturb it. And so, by doing this modeling, they showed that on the grains in the E-ring were about half a micron and to reference a micron is a millionth of a meter so these grains are very, very small. But that's a consistent size with the particles found in other Cassini observations. So, perhaps the mystery of the tendrils has somewhat been resolved, thanks to this work.

Okay. We're continuing out. This is an observation that was taken Tethys in May of this year. You can see it's a reasonably distant observation and we're just getting the sun-like crescent. So, this is giving you sort of taste of the observations that we're starting to get. Our spatial resolution is getting much better as we're getting back into the plane and we're starting to get through more targeted and close flybys of the icy satellite.

One of the ongoing questions with icy satellites science is how much the surface varies not only across individual targets but also within this sort of system so how does Mimas compare to

Tethys. And you can see this is a great example of the variation that you see on one satellite alone.

On the corner that sort of cut out and is a big crater called Odysseus. And when you look in the visible light, you can see that it really is very different, the coloration of this area is very, very different to the rest of the surface. And when you see coloration differences, that's automatically telling you that there's something different about that and that could composition, it could be phase, it could just be the way that sort of compaction and the porosity of the surface. But this is a really nice illustration that it's still a complicated world and all of the observations that are taken this year will kind of go in to understanding how that surface variation changes.

All right. Staying with Tethys this is a result that was published in a press release this year by Paul Shank and colleagues and this is still on Tethys and it's a false color image but it's been stretched a little bit. But the thing that really jumps out are these red streaks that go across the surface of Tethys and we have no idea basically what's going on here.

You see across large swaths of Tethys surface, they don't seem to be correlated with anything else. They don't seem to be particularly correlated with, say, a hemisphere on Tethys we see them kind of dotted around various hemispheres. They don't seem to be correlated with activity. We don't see an increase in the thermal emission at these regions.

They seem to be geologically young. They cut across older features that you can see in this image. They kind of cut across these crater features and they appear to be quite narrow and quite thin. They're not constrained to the equator so we don't think it was sort of a ring that might have collapsed. And we don't really have a good feeling of why this is happening and what's going on with Tethys.

So, one of the great things about having Cassini still going is you can say with new science and say hey, we're seeing this. This is kind of weird. We don't understand it. Is there any chance we can get some more time? And the Cassini project were great and they responded to this sort of begging plea earlier this year and they switched an observation so these observations are going to be taken in November. And so, that observation package is all kind of neatly tied up actually, it kind of almost had a bow around it.

But the Cassini project was so excited about this new result that they sort of undid the bow and dove in and various people gave up their observation time so that we could add in an additional two hours to have -- there was a particular time in Cassini's orbit where it's a really good opportunity to go back and have a look at this area. And so, Cassini gave us that time and we will be looking at it again in November. So, hopefully by the end of the year, we'll have more data on the ground so we'll be able to kind of understand what these mysterious streaks are actually telling us.

Okay. Cassini, as it was kind of mentioned is still doing great but some of the targeted flybys are now coming to an end. We're starting to see the beginning of the last X, the last Y and Dione was a particularly poignant one I think this year, in fact, Cassini, we had our last targeted flyby at Dione. We didn't actually have one; we had two and so, each one is given a number and we -- this is D4 and D5. So, this is the fifth one with the last targeted flyby of Dione that we'll have. They occurred in June and August of this year and these are two images that were taken.

The data is basically so new, it's beginning of August that other than some initial analysis which myself and colleagues have done, we don't have any kind of papers or results on these yet. But I think the images themselves speak volumes into the quality of the data that we're going to get down.

So, you can see on the left-hand slide, Dione is sitting on a backdrop of the rings. This was taken on June 16th and we got down to about 300 miles above the surface which is pretty darn close. You can see Dione has this kind of strange would-be terrain which is basically these bright white icey cliff and you're seeing a little bit of that on the bottom of the image.

And then as you get towards the terminator so when it moves from day and night, you can really pick out lots of the crazy topography that Dione has. Again, we think it's geologically dead. There's a chance for activity on Dione, there's been some hints and wisps but nothing concrete but there's certainly large areas that are heavily crated on Dione we can really get a sense of what a complex place or a complex surface it is in order to understand it. We don't have any pesky atmosphere so to that end, it's a little bit easier than Titan but it is a complicated world.

The other image at the right was taken actually just before the closest approach. You can see a number of bright craters. You have some bright ray craters on Dione and on Tethys we've seen that they're often correlated with an increase in the thermal inertia which means they're less porous so that material that ejects is the same composition but it's a different makeup. It's kind of more compacted than the rest of the surface.

And so, we'll be using these observations in order to understand with the same things occurring on Dione whether the nature of the impact or the effect of the impact is different on Dione. And, again, you're looking at Dione, it's a little bit hard to see with the backdrop of Saturn and then this line here is the rings and the shadow on Saturn.

So, just a completion, I saw like you can do a tour of the Saturn system without mentioning Rhea. We didn't actually have any targeted flybys. We had a lot of observations at Rhea and this was just an image that I thought was pretty, pretty, pretty. So, what you can see here is really the stark contrast of Rhea's lim against the dark night sky.

And you can see how bumpy it is. If it was a smooth surface, you'd expect to see a sort of very uniform lim but instead you're seeing kind of the edge of craters and rivets and things like that. And so, again, this just feeds into that dialogue of each of these targets being very complicated in their own right but making comparisons between them is very important.

Again, this was taken earlier in February. All of this data set is still being combined and analyzed. So, I think by the time we get to DPS which is a big conference in November, a big country science conference, there'll be a lot of neat results on this but it's a bit too early to talk at least to any length about the new results if this is geologically active so like you see on Titan, you see like you see on the Earth, all of these craters would have been somewhat eroded or at least they wouldn't be as sort of pristine as we see them on Rhea.

Okay. So, the final topic is Hyperion and this by comparison just looks absolutely bonkers. We've had some great images of Hyperion in the past. This one was taken this year. We had a sort of long campaign to look at Hyperion actually. It went on, I think, for a few days as we ended up kind of near enough to it in order to observe it. This one was taken at the end of May.

Now, Hyperion is a bit of strange one in that it rotates chaotically. And what that means is it kind of tumbles through space and most of the satellites will have the same face of their satellite facing Saturn the whole time, a bit like we only see one side of the moon as we rotate and it rotates around us. It's a very stable configuration.

And so, most satellite systems end up in that configuration. But Hyperion is kind of weird and it's weird-shaped and it's very small and so, it doesn't obey the same rules, if you like and it kind of tumbles around Saturn. We've really only been able to image one of the hemispheres whenever we go by it for various reasons, we end up looking at the same hemisphere.

And so, this is similar to the observation we saw before. You can see that it has this kind of crazy structure and there's two things that are going on here -- one is it has very, very low density. It's about half that of water which has two effects -- one is it means it's porous and has a weak surface gravity. So, what happens is when you get something that's impacting it so you have something that's going to slam in to the surface, what happens is it compresses the surface so you end up with little divots. It's a bit like dropping pennies in the sand, it kind of burrows down rather than sort of blows out.

And any material does come out instead of kind of coming back on to the surface and recoating the surface, the gravity here is so low, it just blows away. And so, you end up with this kind of a surface that has all these sort of little pockets that's almost like pennies in the sand or dust grains sort of hitting the surface. It's a very strange place. It's hard to see this, it's a black and white image but earlier observations showed that it's quite red and one of the ideas was that the red coloration was coming from one of its neighboring satellite. We don't know if that's really true but it makes it a very complicated and interesting place.

And so I think that's all I have other than saying there are some really great links, always keep an eye on the raw site, Cassini put out these images very quickly, they're not calibrated so they're difficult to do science with but to sort of see what Cassini has been seeing, there are a great resource and that's the link to that which I think it's easy if you can Google that and come up with the same answer. And it's also a really nice feature but I don't know if I'm going to be able to get to you but I kind of wanted to. Here we go, can you see this?

Carly Howett: Okay, great. So, what this is showing is basically it's a Cassini -- sorry -- Voyager and Cassini map so if I slide it all the way to the right, this is the map that was returned by the analysis of Voyager data. And if we slide it over, this is the best map that we have right now, a complete map of Mimas.

And so, you can play with this. And I mean, I'm a big fan of Enceladus but you can really see how Cassini really filled in the gap with Enceladus. This is the reason that we had no idea what the activity on Enceladus was because all of the southern hemisphere region, all the region down here was just not mapped at all by Voyager.

And you can now get a sense of just what a great job just by looking -- this is the Odysseus crater that we saw on the edge of the lim of Tethys and you can see how much more clear it is in Tethys. You can also really get a sense of how the coloration variation changes across the satellite. So, example, the blue streaks that you can see on Enceladus and then this lim-shaped feature that you see on Tethys is also correlated with a thermally anomalous region.

These wispy terrains on Dione, this is what we were alluding to before. There were various ideas about what this could be basically they're sort of geological activity, that was the big idea. When Cassini got there, it really did show that these areas are quite discrete rather than something crazy -- you're basically looking at bright, white ice cliff down the side of Dione.

And so, you can play around this. We didn't really talk about Iapetus, we haven 't had many more observations of Iapetus but Cassini really did show the stark contrast between the different hemispheres that was alluded to in Voyager data but really made very clear in Iapetus and understanding the shape has enabled us to have a much better understanding of what caused it and those results have been -- that's still a matter for discussion but it's a lot more satisfying to try and fit real observations without gaps in so it's been great.

So, that's a lot of fun and I encourage everyone to go on and have a bit a play with that. I think that came out earlier last year, but it's great. So, I think with that, if we have time, I'll go back and take questions.

Jo Eliza Pitesky: I think we have time for a couple of questions, anybody online?

Male: Could you talk a little bit about the coloration that we just saw on the previous slide?

Carly Howett: On this slide?

Male: Yes.

Carly Howett: So, like most missions don't have a full spectrum of coloration, right? So, the color cameras on Cassini are the same as that so we have discreet filters and often one of the things you can do then is you ratio them and so when we look at color, one of the things you have to think about is whether it's true color and true color means how your eye would perceive something or whether it's false color which means you kind of have these bands and you stretch them in order to pick things out.

And one of the things you can see that jumps out, let's just start with Mimas is this kind of blue lens and this really -- it's actually more UV than blue. It's a blue wing, I mean, the UV is from the same side of the spectrum. But you wouldn't get that if you just looked at it with your eyes. You wouldn't be able to see this so it's kind of exaggerated view.

And what we found is that the correlation and discoloration between the color -- between the color and what we see in this thermal data is that by combining those things, we found that the surface here is being modified. It's better able to reflect UV light but it's also more able to store heat during the day. When you look at things like where the high energy electrons bombard, it's in this blue region. It's around this area here. And so the coloration is very important as it forms like part of the surface story, notice you get coloration variations.

Like I said, there has to be something different about that surface and there're various things that could be. It could be that for some reason, the surface has been modified so it's better able to reflect light or absorb light at different wavelengths. It could be that the composition is different and so we notice a, sand and water look different and that's because the composition is different. But sand and water and ice also looks different because there's a phase change because that gives the material a different property.

I think it's a really good diagnostic tool to look at these colors and figure out what's going on. You see the same thing in Enceladus and Enceladus is a lot more blue here. And we think that because the particle size is just different. In the southern pole, the particle sizes are smaller I think which is better able to reflect blue light.

And so in itself, it can be a great diagnostic tool for figuring out, OK, this area is different to this area, why? And that's where the rest of Cassini really comes in, the other instruments because together they can kind of go ahead and start understanding and giving those answers.

Male: And the darker patch on Tethys there, is that in the direction of travel at this orbit?

Carly Howett: So this is the leading hemisphere, every time I move the pointer, so the right-hand lens is the leading hemisphere. The darker, that is the trailing hemisphere and that's the pattern you see throughout the solar system actually. You can see the same thing on Dione. It's a bit more subtle if I move this over but you can see the same thing on Rhea as well.

Male: So it's trailing.

Carly Howett: And so what is actually happening is part of it is Enceladus, is just like sending out all this stuff into the universe and its bright white ice. And so the leading hemisphere of anything outwards of Enceladus, so Thethys, Dione, Rhea, this leading hemisphere, the right-hand hemisphere is impacting that bright white ice and it's being coated by it.

So you can think of it more of a brightening of the leading hemisphere rather than the darkening of the trailing hemisphere.

Male: Excellent, thank you.

Jo Eliza Pitesky: I'm going to reluctantly leave off from icy satellites at this point. Thank you very much, Carly. If people do have questions, I will see about if we can take questions and possibly publish answers on the CHARM page in the future.

We apologize if there's some rumbling noise coming through the speakers. We are having construction here at JPL and hoping it's not going to disturb the online experience as much as it is disturbing us. So thank you very much, Carly.

And let me hand this off to Matt who is our final speaker for this day. Matt, are you online?

Matt Tiscareno: Yes.

Jo Eliza Pitesky: OK. So while you're getting set up, Dr. Matt Tiscareno who has just relocated to the SETI Institute in Northern California, studies Saturn's rings as an associate of the Cassini Imaging team.

He's an expert on the wave that propagates throughout the rings and on the regularly-shaped scalloped edges of ring gaps which he uses to infer properties of the disk and the bodies that perturb it. He led the discovery of hundreds of small moonlets embedded in the rings, seen indirectly by the propeller shaped disturbances they create in the surrounding ring material.

Drawing on the analogy between moonlets embedded in Saturn's rings, and proto-planets embedded in the disk of our early solar system, Dr. Tiscareno is currently studying in more detail the propeller-shaped structure to learn about the underlying disk-moonlet interactions and is tracking the propellers through time to study their orbital evolution.

So just as we just saw a lot of great photos from Icy satellite because this spacecraft was orbiting essentially around the equator of the planet, so we've got lots of great views. What was a great pictorial year for the icy satellites was not so much for the rings and that's going to be changing in the next couple of years as we move the spacecraft out of the equatorial plane and into high elevations.

So with that introduction, it's up to you, Matt.

Matt Tiscareno: All right. Thank you, Jo. Yes, as Jo just said, here is a profile in the ring community, we care about the inclination of the spacecraft quite a lot, so here is the inclination and here is my cursor.

So we had a really great several years of this period of high inclinations where we were looking down on the phase of the rings and we were able to get a lot of great observations. In the past year, we've been coming down off of that and wrapped up that inclined period. We're now in the equatorial region again, so Carly is happy and we are not so much, but it depends when it will swing back again.

Over here, we will start ramping up in 2016, the inclination will get higher and higher and then up here, we will have the grand finale which we'll be not only at high inclination where we have great view in geometry, but then diving down very close to the rings. We'll start to get some of these resolutions that the satellite people take for granted, where you actually fly quite close to your target which, you know, Cassini flew quite close to the rings in the orbit insertion maneuver back in 2004 and really hasn't since then, so we look at things like a kilometer per pixel as some of the best resolutions we've gotten during the main part of the mission. We're going to get down to, you know, several hundred meters per pixel which we're really excited about.

So the highlights that I'm going to discuss in this talk, I will update you on a systematic search for spiral waves that I've been doing and I'm going to put together a few people's observations and talk about some new puzzles regarding the mass of the rings. I'm going to talk a little bit about the Maxwell Ringlets project that Dick French is finishing up and then as Jo already has given a bit of an introduction on the propellers project and I'll update you on those.

So spiral density waves are a pervasive structure, especially in the outer part of the rings. They are excited by moons mostly orbiting further from Saturn than the rings, although a few of them are actually orbiting within the rings. And I should modify this slide because some of these waves are actually excited by structure within the planet, thus rotating with the planet and then exciting these structures in the ring.

These are all resonant structures. So at any location for example, let's see, this one here is where a ring particle is orbiting Saturn exactly five times every time that Mimas orbits three times. And so what that means is that whenever Mimas passes by a particular ring particle, the ring particle is at the same part of its orbit as it was the last time. And so then the pushes add up just like when you're pushing your child on the swing at the playground. If you time to push it properly, it pushes add up and the child goes higher and higher.

The same with these, Mimas' pushes add up on top of each other and so the ring particle develops a deviation from this particular orbit which then causes a wave to propagate through the ring because the ring particles are close enough together that their gravity affects each other. This is the same fundamental process that creates the spiral arms in galaxies that you see over here.

The main difference is that galaxy spirals are much more loosely wound, the spiral hasn't even gone all the way around the galaxy and only at the outer edge. Whereas the spiral arms in Saturn’s rings are very tightly wound, this, spiral arm here for example goes all the way around the planet, this is a four-arm spiral, so one, two, three, four. This one here is the same arm as this one having gone all the way around the planet and it’s only a few hundred kilometers further from Saturn's center, so these are tightly wound spirals.

And one of the interesting things about this is that although the theory for spiral density waves which was originally developed for galaxies, there's still a lot of discussion in the galaxy community as to how and even whether that theory really does describe the spiral arms of galaxies. However, that same theory has been used for Saturn's rings and it works exquisitely well and we have confirmed it in exceedingly great detail.

And in fact, what we now have the theory now down so well that we can use these waves as scientific instruments that are embedded in the rings and that each location where we see one of these waves, we can measure the parameters of that wave and then learn about the rings at that location and their properties and also the properties of whatever it is that is exciting the wave.

Here this picture here in the middle is a close-up picture, it's kind of grainy because this is from the orbit insertion, the highest resolution images that we've gotten. The exposures were low because people were worried about smear because the spacecraft is moving so fast. But this is a high-resolution picture and what we've done here and I'll be doing this a number of times in the talk is you get all the pixels that are at a single distance from Saturn, so basically you take circles in the rings and add them up.

So along here, you have all the pixels that are at a certain distance from Saturn. You add them up. And then up here, you have a radial scan that you add up. So you can see that I've kind of lined this up. So the troughs of this radial scan line up with the dark lines across the image. And what you can then do is take the different parameters of the wave. So here, the wavelength dispersion of the wave, you can see the wavelength actually changes as you go downstream, the wavelength gets smaller and smaller.

But by measuring that wavelength and how it changes, that tells you the surface density, how much material there is in the disk at that location. By looking here at where the wave begins, that tells you exactly where the resonance is. That then tells you what is the orbital speed of whatever it is that's exciting the wave, whether it's a moon or whether it's a moon inside the planet.

You also notice that the amplitude of the wave increases for awhile and then it turns around and starts decreasing again. The distance, to the point where the amplitude starts to decrease again gives you a damping parameter and that also tells you something about the viscosity of the rings at this location, how much the ring particles are rubbing against each other and dissipating energy, which again is an important property that you want to map at as many locations through the rings that you can.

And then you have the amplitude which just directly tells you the mass of the moon or the mode and the planet that is exciting the ring and then you also have a phase parameter which tells you something about where the perturbing object is with relation to where you are in the rings.

So we use this theory to analyze these waves and to learn about the disk. Here's now an image that is taken not quite so close up, but with a more stable exposure, stable camera, was able to integrate a bit longer and get really nice signal to noise, this is one of the best, highest fidelity images that we have, at least for images that cover the entire radial range of the ring. We have images like this going the entire radial range of the rings.

And so what you see as you look at this image, you see some very clear waves. This is the same wave that I showed at the beginning, actually the Mimas slide, the three-way that I showed at the beginning is a little bit higher up off the top of this slide. This is the five to three bending wave. Now there's a slightly different frequency for the in and out motion of ring particles and the up and down motion of ring particles.

So the bending wave is where Mimas is exciting the up and down motion of the ring particles. Mimas is actually on an eccentric orbit by a couple of degrees and is able to excite these vertical motions as well as in and out motion. And the bending waves it turns out propagate inward, and so you see them kind of in contrast to most of the waves that propagate outward.

So you see this clear Mimas five to three bending wave here, this is the Prometheus 12 to 11 density wave propagating outward. Then you see a bunch of other structure, looks kind of like record grooves for those of you who are old enough to remember vinyl records.

And just looking at the image, it's not really clear what all of this structure is and how we can make sense of it. But it turns out that if we take a radial scan so here is that same image that I just showed before, here, now we've taken a radial scan of that image. You can see each of these little record grooves here, here and here. Here's that jumbled structure in between the two waves. That's this structure right here.

Now, we can take another step and do what's called a wavelet analysis. What we do here is we take a spectrogram basically. We take the different frequencies. You can see for example that this wave, right here, there are lower frequencies, the wave crests are farther apart. Up here the frequencies are higher, the wave crests are closer together.

And so down here, you follow this down into the wavelet transform, you see there is power, the darker shades, are where there’s power in the frequency spectrum. You have the lower wavelength, the longer wavelength, the lower frequencies have more power here, whereas over here where you have higher frequencies, it's the higher frequencies up here that have power.

Then you can then fit model, so each of the dash lines here is a model of what a particular resonance that we can identify ought to be doing. And if you look carefully on how these dashed lines follow very closely the patterns of grey scale in this wavelet analysis, what we've done here is we are making sense of each of these little squiggles and it turns out that this jumbled record grooves here in between the two waves turns out to be several waves.

There's a PAN 46 to 45 wave. Here's a PAN 47 to 46 wave and then in between of them, then we have a Pandora 19 to 17 wave and so forth. So we can map out all of these resonances and each of these little bumps and wiggles in the ring, this is kind of mapping up the geography of the ring. This is like the craters and the valleys and the different things that you see on the surfaces of a satellite. This is how we map out the geography of the rings and understanding the structure that we see in this basically, a disk.

So moving on then, here’s another location in the rings and if you'll notice up in the top corner of each of these view graphs, I've given you a bit of an orientation here so a cross section of the rings, we have this little diamond showing where in the rings we are. So up here we're in the middle A ring here, we're still in the middle A ring.

We see some more waves and I'm not going to wade too much through the details although they're kind of details that I really like. Here this black dash line is a signature that we don't understand. Now there are some parts of the rings where just about all the structure is stuff that we don't understand, but in the outer A ring, it’s actually unusual to find structures that we don't understand and that really is a structure that we ought to be able to understand.

So this little dashed line here is a puzzle that dynamical analysis can try to figure out. And again the slopes of each of these lines give you the surface density, so we can then map out the surface density and it turns out that the A ring gives about 35 grams for every square centimeter of disk through most of the A ring, but in the outer A ring, that density tails down and gets down to only 15, so less than half of what it is in the major part of the A ring, which is weird, because this part of the A ring is actually the brightest part.

And I'm going to return to this theme later. It has long been assumed that if you see the ring look brighter, if you see the ring look like it's blocking more starlight, if you're watching a star shine through the ring, then that means that there's more stuff there. And in a number of places we're finding the opposite to actually be true. Here with these density waves, we are directly measuring the mass instead of assuming a correlation between how much brightness we see and how much stuff is there. And we actually find that although the ring is brighter over here, there's actually less stuff there.

So I'm going to return that, but we also see in this inner part of the A ring, we have one big long wave that I'm going to show you in a few slides that's given us this profile, so the whole inner A ring that then blends in the Cassini division. The outer part of the Cassini division we call the ramp because we see the surface density ramping up from only a couple grams per square centimeter down in the main part of the Cassini division ramping up here and then getting us this A ring where it's about 35.

So a little bit more about how we analyze these density waves and maybe I should go a little more quickly through this, an Iapetus wave, Iapetus is much farther from the rings. And so what we actually have is Iapetus goes around Saturn so slowly but the ring particles are whipping around really fast and the plane of the ring particle orbit is precessing around Saturn, just like you see a top, the access of a top precesses. If you spin, the top itself is spinning very fast and then you see the axis of the top, make a circular motion much more slowly. That precession motion for ring particles is here resonant with the orbit of Iapetus because Iapetus is so far from Saturn which is orbiting very slowly.

This causes a very large wave that gives us several thousands of kilometers of real estate in the ring telling us exactly what the surface density is. And I'm not going to go through this in a little bit of detail on how we measure it. I'm going to skip that.

But we have a surprising result here from the Iapetus wave. So this upper panel here is that surface density profile for about 4,000 kilometers of real estate giving us the surface density from this Iapetus wave.

And here is where it's weird. This is the optical depth profile down here, this is basically how much light is reflected if you're looking at the face of the ring or how much light is blocked if you're watching a star pass behind the rings. And there are two steps. This is the Cassini division here. This is that ramp where you see a little bit of ramping up in the A ring. We see a big step in the optical depth here and then a little bit of a doorstep here and then another big step, and then you're up in the main part of the A ring.

It turns out that the second step does have a major step in the surface density also. There is more stuff up here in the main part of the A ring and less down here. But here, when we see a big step in the optical depth, we see no step at all in the surface density. And this is really mystifying, because what this means is that you have the same amount of stuff on either side of this big step in optical depth.

For some reason the same amount of stuff blocks a whole lot more light, takes up a whole lot more space on either side of this boundary. And the simplest explanation that remains to us is that the particle properties are changing at this location. Perhaps you have the same amount of stuff in larger particles up here, you have a larger mass for each bit of surface area whereas over here, maybe it breaks up into smaller particles and you have, for the same amount of stuff, you have more surface area, so that it blocks more light. But why you would have a sharp boundary in particle properties is a mystery and we don't understand that yet.

So as I said here, and similar conclusions are now coming from other Cassini measurements that we seem to have some big changes in particle properties where previously we have assumed that these are changes in the amount of stuff that's there, but now that we're finding more methods of directly measuring the amount of stuff, directly measuring the mass, we're finding that it's about the same, so there must be these big changes in particle properties.

We're going to shift here slightly although this is getting on the theme of the last slide. I believe Phil Nicholson and Matt Hedman gave a CHARM telecom a few months ago on this whole topic, so this is just going to briefly orient you on this new project of Chrono seismology. So what this is doing is using these same spiral density waves that I was just describing to you, but a few of them, we are observing in places where there is no resonance with a moon that we know of that would raise a wave. And it turns out that many of these waves can be correlated to frequencies that come from inside the planet.

And if you have these different kinds of asymmetries in the planet that are rotating at different frequencies, they can raise waves in the ring just the same as a moon orbiting outside of the rings can do. And so Phil and Matt have been working on this and have started to use the rings basically as a detector, as a probe to help us learn more about the internal structure of Saturn.

A similar project that Dick French is leading and is just coming out in the journal is the Maxwell Ringlet. Now, we're over here in the middle of the C ring here, this is a kind of exaggerated view of what the Maxwell Ringlet looks like, this is an exaggerated simulation from Dick, and I put a little picture of Saturn in the middle.

The Maxwell Ringlet is an eccentric ringlet. It's orbiting in the middle of a gap in the C ring. And there are some eccentric ringlets, there's one called the Titan ringlet because it's precessing at the same rate the Titan is going around Saturn.

There's another one called the Huygens ringlet that has all kinds of different moves. There's a fixed lobe pattern and various other patterns that seem to be interacting with Mimas and other things. The Maxwell Ringlet seems to be a pretty pure eccentric shape precessing at the rate that you would expect given how far from Saturn it is. But what Dick and colleagues noticed is that there are some wave crests in the middle of the ring. So it's an eccentric ring, so here, it's narrower where it's closer to Saturn and it's wider where it's farther away from Saturn. So here is where it's closer to Saturn and narrower and here where it's farther from Saturn and it spreads out.

And there are these wave crests. Here at periapse where it's closest to Saturn, they look really spiky and close together. And as the ringlet moves away from Saturn, the wave crests spread apart like an accordion. And then as you move back towards the middle, towards the place where it's closest to Saturn, the wave crests actually -- here, they reverse. They become spiky gaps instead of spiky peaks.

So I don't know that all the details of that are understood, although Dick and Johan and others have done some simulations to understand this process, but one of their conclusions is that this turns out to be a two-arm spiral that is resonating with a period that is about twice Saturn's rotation period. So this turns out to be another one of these waves that fits in with Matt Hedman's Chrono seismology.

This is one of Matt Hedman's figures which Dick has modified to include the Maxwell wave. This down here is Saturn's rotation period and as you may have heard from the magnetospheric talks, Saturn's rotation period changes and is different depending on how you measure it and when you measure it and that's really weird.

But you see these different frequencies also reflected in the ring and up here you have twice the rotation period. You can have resonances with twice the rotation period and the Maxwell Ringlet is then adding to that picture.

So putting several of these themes together, we can ask how old are the rings. So there's the Iapetus, minus one to zero wave that I just showed you and there are other waves in the B and C ring including some of these chrono seismo-waves that are giving densities that don't scale with how much light the rings are reflecting, which are telling us that maybe the rings are not as dense as we expected in the places where the rings reflect more light.

At the same time, the CIRS project and I don't have a lot of details on this, but the thermal infra-red measurements of the B ring are indicating that the ring particles are fluffy in the B ring, they're lower density than we thought. Now, both of these things are challenging to what we thought about five years ago was a bit of progress that we were making. It's been a longstanding mystery how old are the rings.

There's a certain amount of dust falling into the rings all the time and yet the rings are very pristine water ice and it turned out that there are some simulations indicated that you can hide a lot of mass in the B ring and the B ring could be super massive, several times the mass of Mimas and that would make it easy to hide all of this in-falling dust and the rings could be as old as Saturn, even though they are quite pristine.

But if the rings are not so massive, then that explanation is challenged. Direct measurement of the mass through the spiral wave and this indirect measurement that the ring particles of the B ring seem to be fluffy.

Those are both challenging this conclusion that we thought was some progress. But to the rescue comes the Cassini cosmic dust analyzer which is starting to be able to measure as it measures dust in the Saturn system it's actually able to measure where the dust comes from. And a small number of the dust particles that it's measuring are actually coming outside of the Saturn system and they now have good enough statistics to separate those out and they are telling us that the interplanetary dust influx is smaller than previously thought, so we combine this with the B ring being not as massive as previously thought, we still might be able to have the B ring at 4 billion of in-falling dust.

OK, am I totally out of time, Jo? Should I just get this over with?

Jo Eliza Pitesky: Well you kind of got some time taken away from you, so another 10 minutes I think.

Matt Tiscareno: Ten minutes, all right, we can do it.

Jo Eliza Pitesky: If you can do it five minutes and give us five minutes for questions because actually you have a bunch of people in the room at least who kind of have their mouths hanging open.

Matt Tiscareno: OK, five minutes, we can do propellers. All right, propellers are moonlets that are embedded in the disk. This is a schematic of how the streamlines work. There's a movement here in the middle, the ring material around that gets disturbed and you see this propeller shaped structure.

Here are some actual pictures of the propellers and I'll skip the details. Propellers are interesting in part because they are the first time in the history of astronomy that we have tracked an object as it is orbiting, embedded in a disk. We're tracking an object's orbit while it is embedded in the disk. Everything else in the solar system that we track the orbit of, everything that we know if it's an exoplanet is orbiting in free space.

So here we have the prospect of measuring how embedded objects interact with their disk, how does the disk affects the orbit of this embedded object. And that object would have a lot of implications for how we understand protoplanetary disks, the history of our own solar system as well as disks that we see around other stars.

All right, so we see these orbits are in fact changing. We now have coming up on 10 years of data on some of these propellers and this is basically with a long-term trend subtracted off. We see it lagging behind the trend, moving ahead of the trend, lagging behind the trend, again.

So going back and forth, not a single direction of migration, but migration going back and forth. Several explanations for this has been proposed. Could it be resonances with the moons, that would predict a pure sinusoid. I think most of us are convinced that we're not seeing pure sinusoid although one researcher in particular still wants to stick with that model and there may be some situations where it's relevant.

Could it be smooth interactions with the disk? That would lead us to expect curvature in these plots. And I think we do see evidence of curvature, but we also see evidence of very sharp changes. Like here for example where you see curvature coming down here and then all of a sudden, we shoot off in this direction.

Another researcher proposed that everything here is stochastic. If it's the distance from Saturn that's moving basically randomly, you would expect these longitudes to be correlated with each other and you would see things that look like trends, but they're really just shifting temporary trends and you would never see something resolve to a long-term trend.

My favorite model is number four, that we actually do see smooth interactions with the disk that are punctuated by sudden changes. All right, and these are propellers, and so we have nicknamed them after aviation pioneers and so I'm going to give you some updates on several of these propellers and what we see them doing.

Santos-Dumont, we see taking this, what I think is a curved trajectory of over nearly five years and then it changed here and then it's taking a more smooth evolution. We have Earhart here, we didn't have very good data on it at all. And maybe I should mention briefly that what happened here in late 2012 is that we started to track these propellers a lot more often. We very intentionally said every time we can, every time there's a periapsis, if there isn't something else that needs to be happening, we want to at least check in on the proposal we already knew about.

And so we have been doing that as much as we can as you can see dramatic improvement in how often we're checking on these orbits and we can start to piece out how they're changing. And so what I think I see with Earhart is we see a curved trajectory here and then a kick and then a curved trajectory in the other direction.

Then we have Post where, again, here we have the green and the green is blown up down here, we have, I think -- it looks like a straight trajectory here and then a kick and a straight trajectory here. So here’s where we see something that is more episodic whereas with Earhart I think we saw something more gradual.

And then the granddaddy of them all is Bleriot which this is what I was showing in the first slide, the whole trend coming down this way, Bleriot then took a dramatic turn in the other direction. And it started to seem like the stochastic model was right because it was predicting that whatever time scale you're looking at, you're going to see something that looks like an oscillation on that time scale and that's just kind of what you see here, but the most recent data which I can't show because Jo said I shouldn't show anything that I haven't shown at a conference, is starting to see some curvature up here at the top end.

So I think maybe my model can be rescued, but of course this is how science works, we may have our preferred models, but we all need to be open minded and go wherever the data leads us.

So that's the end of the talk. So just in conclusion, I would like to remind people Saturn's ring system is an astrophysical disk that's accessible. It’s not light years away, it’s not billions of years in the past, we can visit it at close range. You can observe these phenomena that also operate in other kind of disks and draw parallels.

Rings also functions as detectors, they can tell us about their environment including, as I mentioned in this talk, the interior structure of Saturn. There's a lot that we understand, there's also a lot that we don't understand, and the more you get down into this data, you learn more and you just uncover more questions that you hadn't even thought to ask. So don't believe the simplicity of your models. Always be ready to be challenged and learn something new.

So thank you.

Jo Eliza Pitesky: Thank you, Matt. That was outstanding. Are there any questions online?

Well I'd like to say that it's very clear why you found your new home at SETI. And I was wondering if there are any specific avenues of investigation and collaboration that you're looking at working with people who are looking at exoplanet?

Matt Tiscareno: You know, I haven't really gotten into that. I've barely been here a month, but that doesn’t mean it's not something that we will look into.

Dave Doody: Matt, Dave Doody at JPL. It's about what you're looking forward to investigating when we are in a proximal orbit phase?

Matt Tiscareno: It's going to be totally fantastic. I think the biggest thing is -- and we're going to devote several orbits to this is directly tracking the spacecraft from earth as it swoops past the ring and we will hopefully directly measure the mass of the rings. And I can't tell you how momentous that one number is if we can do it and I think we're going to do it.

But other things that we're going to do, especially -- so the proximal orbit, there's one where we're actually diving between the ring and the planet and that's going to get us some great views of the C ring and in fact it can give us the best gravity mass measurement and we're going to be directly measuring the ring atmosphere and things like that.

But what I personally am most excited about is actually before we dive between the rings in the planet where we're diving just off the outer edge of the ring. And that's where we're going to have the closest views of the A ring which is the outer most part of the main rings. And you know, the spiral waves and the propellers, they're all in the A ring.

The A ring is heaviest in structures that we more or less understand and so really being able to get into detail is something that I have a fair idea of what's going on, we are able to better formulate our questions and look exactly where we want to look to really get some high-resolution data.

We're going to target some of the propellers I just showed you, hopefully maybe even image for central movement and see a lot more detail of how the intricate inner parts of that disturbance forms itself. We're going to get a higher resolution scan that covers the entire radial extent of the rings at -- between half and three quarters of a kilometer per pixel which is -- and now we know how to set the exposures, so we're going to get better signals and noise when we get in SOI. Lots of really great stuff.

Jo Eliza Pitesky: Any other questions online? I want to thank all of our speakers again very much. Those were three outstanding presentations. Thanks to all who are able to join us. I'm hoping that we'll be able to have a recording of this with both the visual and audio online in the next few weeks. Stay tune for that.

And then our next CHARM telecom will be on Tuesday, October 27th. I look forward to joining all of you then. Thanks very much, everyone.

Zibi Turtle: Thank you.

Matt Tiscareno: Thank you.

END