February 26, 2018 seminar.

>>Dr. Garrison: Can I get everyone's attention. I would like to introduce our speaker for today, this is Jonathan Kay from the lunar and planetary institute. A post doctoral researcher, and his interests are primarily about studying planetary body surfaces and structure change, such as analyzing and modeling icy moons of the outer solar system. Today he will talk about something interesting and also I want to remind you the lunar planetary institute is our neighbor nearby next to where the new science building is going to be. So if you are interested in the talk, definitely ask the speaker questions afterwards. And maybe a lot more you can learn and collaborate. I believe they have a summer internship program. I've been at the LPI for about six months. I started in August. I finished my PhD at the University of Illinois at chicago. So I'm new to this but if you need any one to talk to about what it's like afterwards I can give you my email address. So I'll talk about today is one of the chapters of my dissertation on

formation of the long wavelength of the lithosphere. I'll explain at some point during the talk. Before that I want to give you a little background info on the Saturnian system and what we know about it. So as you might have heard the Cassini mission just finished orbiting Saturn. This was launched in 1997. It had about a seven year flyby to orbital period to Saturn where it used various gravity assists to get there. The mission ended in 2017 with a fiery a crash into Saturn which was pretty expediting for us. And we got a lot of cool data out that have. And it's what known as a flagship mission which is the highest class that NASA launches. It cost about 2.2 billion in 1997, but this mission they started planning in the late 80s, obviously this is artist rendition. It's a joint NASA/ESA mission. They included a drone on it that landed on one of the moons. So the Saturnian system has over 62 moons that are larger than a kilometer in diameter. So much like lowering the status of Pluto. We only talk about three or four of them because we don't want people to memorize them all. So the big one that you will see is Titan, it's about 2500 kilometers in radius, that makes it bigger than our moon. It's the second biggest moon in the solar system after Ganame(PH). That's the moon of Jupiter. But some of the other once that are of great interest are Iapetus and a little about some of the notable moons of the system are Titan. We always knew that Titan had a mysterious in the late 70s we sent two spacecrafts out Voyager which currently just left the solar system, but Titan we knew was interesting because it had such a thick atmosphere. About 60 percent thicker than the earth's atmosphere. This atmosphere is made of methane and nitrogen. And we have a lot of trouble seeing into Saturn, Titan, sorry, with the visible instruments. So we have to use radar instruments and Titan has a haze because of the sort of interaction between the long hydrocarbons and the radiation from the Sun. One of the most interesting aspects it's near the triple point of methane in temperature. So water on the earth is near the triple point which means basically you can go in liquid water to solid water and to gas source water on the surface. So Titan actually has all three of these. This is an artist rendition of the probe that went through. On the right is an actual picture they got at the base. One thing you will notice there's not a lot of visibility but you see a rounded ice. I don't know how many geologic background you have. It means that it has to sort of go down a river bed where the angular fragments get broken off. So that means that these are likely (indiscernible) deposited. What we see with follow-up image, this occurred before this image did on the right. This is a visual image. One thing you will see is what is known as dendritic river valleys and that's what you get when you have that raining on a mountain that starts to erode and these feed into it. Much like the Mississippi had branches that feed into it and dump into the gulf. You see similar things on Titan. So we see some large might towns on Titan's, large relatives to a body of another part of the solar system. So once again we have this image. But most of the data we were able to get off of Titan are through this radar instrument on Cassini. So what you get are unusual looking images where you see there are some bright and dark spots. It turns out these dark spots are actually giant lakes of methane. And so they absorb all of this radiation, sorry the radar information. And so that, there's nothing for the radar to reflect off of. So we think there are largely methane and ethane. The more we know about Titan it looks like you have the ground is this methane ice. Once you get below that at a certain pressure there's likely a liquid methane ocean underneath. One of the themes in the satellites are these oceans that exist below the surface. Another one of these moons that we sort of had expectation that Titan would be interesting because we knew there was an atmosphere, but another moon we didn't expect anything was this tiny moon of Enceladus. About 250 kilometers in radius. For reference this is Great Britain. So we saw this picture early in 2004. I was an undergraduate in Massachusetts, what we are looking at is the South Pole of Enceladus. What you see is it's illuminated from behind. These are actually active jets coming out of the surface of water. So we thought it would be a boring dead piece of ice is geologically active emitting material into space. One of the ways that we age one of these satellite is look for craters. You will see in this northern part or hemisphere there are ton of craters. But as we look in the southern portion you don't see any craters. So these are what we call tiger stripes. This is where the material was getting out of the surface. One of the ways you can generate heat on these bodies is through orbital resonance so that's where -- basically these two satellites drive each other to have a more elliptical orbit so the more energy you generate and the more heat you have. This is another one of these bodies that he with think has a subsurface ocean and if you were to look at a higher resolution image of these South Pole you would see older tiger stripes occurring orientations that are different from these that are no longer active so. That's one of the ways we think that it has a success surface ocean. That basically happens that you have this shallow core underneath and then a liquid ocean and then this ice shell, so the core on this ice shell can rotate on different rates. If you have any questions I'm happy to answer as we go. So by see both the really young surface and old surface. We don't know what causes this dichotomy. Some people think it's an impact. Other people think planetary geists say it's an impact and they don't know what it is. Sort of ongoing joke in the community. But this is just a contrast of where the plume it's are and what the tiger stripes look like. A lot of interesting geology. Just another image of it and then these images on the right, are close ups of the tiger stripes. We are not sure exactly what's going on between the region. Some people think they are normal faults. I personally think that they are regions of folding that is sort of my MO. Some other interesting moons of Saturn are Mimas. Sort of a death star looking moon. That's a giant impact. You can see how it's super saturated with craters and that means every time a new crater forms it erases an old one. Then we have a Hyperion more regular, it might have been captured by Saturn. It looks more like pomace suggesting a lower velocity material. And then we have Dionne. We don't know why these cliffs forms. And then late in Cassini's orbit around Saturn we found this really weird moon Pan. And Pan is within the ring so it's probably like an object that gravitationally curves and started to accumulate material. It's kind of like two half circles with playing cards (ph) in between. And it also has weird fractures on it. So that's another one of these weird moons. So that's just six of 62. I'm going to talk about lapetus today. It has three things going for it. It doesn't have an atmosphere or any active tectonic so it's not as well loved among the Saturnian satellites. But it has alternating light and dark on each hemisphere. We think that has to do with some prophecies related to, I forgot the word. Anyway, so it's a lot bigger than Enceladus. About 7130 kilometers. It has a really bizarre equatorial ridge. The angle is hard to see. This ridge is 20 kilometers tall in places. It's taller than mount he have rest. Up to 100 kilometers wide. It's not continuous over the surface. It also has an equatorial bulge which is about 5 percent flattening and A minus C is 35 kilometers. When I say that I mean the equatorial radius is 35 kilometers larger than the polar radius, which is a lot. It's about .1 percent on the earth. So that is what I'll be talking about today but I want to give a little more background on Enceladus ridge. So what we think happened is that there was another body that was within the hill sphere of Enceladus which is it's own gravitational field so. This moon may have had its own moon. But it got so close that it was torn apart by tidal effect. If you tear apart this moon tidal, it happened slowly. Those will run out of orbital energy and slowly start to creep around the equator and bombarded the surface with small particles. If you have enough of them you can build up one of these ridges. That sort of the leading idea. One person described it as the least terrible idea I've heard that makes sense to describe this feature. Here's is just an angle view of it. So it is very rare in the solar system. We don't see anything else like that. But it's really cool feature and a lot of people are interested in it.

Just another picture of Iapetus(ph). Sometimes you look at our output and it's nice just to look at the pictures every once in a while. So this is the geologic mass. Cassini orbited Saturn for a long time. Based on the way the orbital mechanics work out you have little coverage of lapetus so we have very few high resolution images. Of those we don't have global coverage. So you can see this whole region is washed out. But to get into what I'm talking about today. I'm talking about this equatorial bulge, it has 5 percent flattening and this A minus C of about 35 kilometers.

Okay. Most of my work involves trying to estimate what are the consequences of certain heat flux on a surface. All the activity we see is driven by planet tear body is driven by this internal heat transfer. So we have a lot of heat budget on the earth interior from radioactive development. Measurement of the heat flow is easy on the earth. You can measure the present day heat flow. But if it's not on the earth it's expensive to do and you can only measure the curve.

We have curiosity on Mars, we can measure that. But there's thermal energy you can estimate is this by modeling.

There's lots of ways to deform a lithosphere. I define lithosphere as the part you would stand on up to a certain depth that behaves mechanically. So one thing I would like to look at is this folding, which is basically a contraction. You turn it into a periodic deposit.

This occurs when you have a strong layer over a weaker layer. If it's a purely elastic behavior so strain that is recoverable tells you when you reach this cohesion point you get buckling but there's a more fluid EVP where you get this folding.

So if we can constrain the thickness of this lithosphere which you can estimate from surface features it's possible to con train the thermal history of the body.

The material properties occur along that continuum we call that the (indiscernible) relationship. And you can do that using a semi-analytic model, calculations, or you can look at this process over a continuum using finite element analysis which sort of solves the matrix equation simultaneously which lets you add more detail to the calculations.

Just to give you some examples of what these folds look like on the earth of we see these layers, they are deposited horizontally and then there was a compression stress and these were warm and heat and it allows them to shorten through some sort of process.

So on a more large scale we call the features form the yield strength envelope. Where basically you have stress versus depth. And depending on where you are on this envelope is how things will form. So typically if you are within this region you get a more brittle formed, where you see folding, or if you were to bend a ruler and snap it, that would occur here. The deeper you get then more creep or viscosity driven parameters take over. And then we call this transition the conductor transition. For elastic parameters they are driven by simple equations. Us geologist know how to do some math. This is a relationship basically describes the elastic strength of ice at gas with finite and you an cohesion. Does the material have strength to begin with. And then reaching this conduct all transition there's regimes that take over which respond to boundary sliding or easy slip. And there was differential -- this is sort of the relationship that drives the deformation. And this total will describe the strain rate.

So I don't know how familiar you are with finite element analysis. But basically using sort of like CAD with physics. You can break up any domain with elements. The way I like to describe it is basically I could draw this table in finite elements space and then estimate by how much this table deflects due to the rate of this projector. Except what I like to do is simulate lithospheres over hundreds of millions ever years.

So this solves a boundary problem and breaks the domain into a series of elements. So that's how they communicate with each other and allows for application of real world (indiscernible).

So what I did for this work was simulate the deformation of this lithosphere. That's that mechanical layer. This is applicable for both long and short wavelength situations. Within the oceans and within the basin and... this can bypass some of the short coming the of the semi-analytic details because it allows you to have more resolution as well as other parameters that are difficult to get.

To do this I used Marc finite element program. You may know something else. These are kind of programs that are used in aerospace engineering.

So that's the background. So this oblate shape, typically or originally it was thought this occurred because of a spinning of a thick lithosphere. So have you ever seen a tennis ball rotate rapidly and you get that deformation where it goes out on the side. It was originally thought that if you spun a period of about 16 hours you could max the current shape. That's in contrast to the current period of about 80 days. So that means that basically as it's spinning 16 hours you shot it with some of freeze(ph Ray. You need this thick lithosphere to support it. Because that provides the strength. As soon as that tennis ball stops spinning it goes back to its shape.

We try to estimate the heat of the bodies, there's long lived radioactive isotopes and -- they put too much heat in the system versus radioactive isotopes which create a lithosphere thick enough during the spinning because there's not a ton of heat. But this model because they are short lived.

These are radioactive isotopes that provides this. So this is a plausible model. The physics work. But it's a narrow time constraint.

An alternative hypothesis is that what if there was a tectonic or begin rather than something spinning, you have a tectonic origin. So it's possible that as there's a low heat flow you have ice together but it's really porous. I mean it has a lot of holes in it.

So the density was not quite what it would be if it was perfect as you might find in Antarctica. So Sandwell and Schubert said it might cook out all of this slowly and that's what is basically would put a really large stress on the surface which would cause buckling. They found that the stresses required to do that were too large and they couldn't get it to work. But what I thought was okay, do we know that these elastic parameters are enough to drive the deformation. We don't see that purely elastic materials we see it as a more complicated elastic viscous plastic material. So I thought rather than buckling, elastic form, what if we have folding of this lithosphere to form the bulge. So we kept a lot of the same parameters. So background about my mesh generation. They were deep enough not to be influenced by this flow field. So the width of the mesh was about one-fourth the circumference. I broke it up into four hemispheres and took one and then unwrapped it. I went to a depth of

200 kilometers. My lapetus is only 700 kilometers in radius. I looked at a range of heat flows you an .1 to 5 million watts. This picture is to remind me to tell you that it was important to basically not assume that the equator with a same amount of sunlight (indiscernible) which means the equator is much warmer. That's a crucial detail for this model. I applied a range of surface temperatures from about 50 to 100 Kelvin. And I used this Cosine variation in surface. So if you image a square, the equator and slowly start moving that square up so it faces into the surface, you get about a Cosine variation in this amount of sunlight or solar flux you get.

And then all of the

temperatures are going to be dependent on the thermal model. So this Cosine variation becomes important because if you just sort of squeeze the surface you will get uniform thickening and so nothing will happen in the model. So this surface temperature creates a break. Basically the hypothesis that I was working on is that these variations in surface temperature and heat will drag variations from the heat flow to cause lifting of the surface.

So I assumed water ice properties and applied 10 percent shortening. Which shortening is coming from this velocity where all of circles can move in the X and Y direction and the arrows are where I applied the (indiscernible).

For most of my models it's about 100 million years and did a 200 million years. All of these are some of the results of the simulation. I used a more sophisticated reality.

Just to illustrate how important both temperature and conductivity are, this is a heat flow of about .75 million watts per square meter at depth. Just to look at how this conductivity broke up.

So you might being familiar how with most metals or rock conductivity is just a constant value. For ice it's actually a function of the temperature that influences how conductive the ice is going to be.

So I mostly tested around three different parameters because we don't really know exactly how porous the ice is or basically more fractured ice may have a lower velocity. And so which could decrease the conductivity.

And then just to show you how much of the range, I have you an .1 million watts per square meter to two pill watt and this is temperature as it approaches depth. You can see at 200 kilometers from my you an .1, I'm at 110 and for my 2 million-watt I'm at 300. So these can have large impacts on the temperature at depth.

Assume at ice one mechanical properties, that basically means what is the young's modulus. I looked at the range of heat flows, and I looked at 50 to 100 in 30 Kelvin increments and looked at a couple of different conductivities. My goal is to produce 35 of up lift.

So some of my most effective models were half of the normal conductivity values so that's about 325 over T. That makes the ice at depth a little warmer. Here you are looking at three outputs of this equatorial minus four radius and then time. So you can see how it grows through time. So what you will see two of my models can produce deformation of a little over 40 kilometers. And one of them is 50 to 80 produces a little over five. So suggesting that this heat with lower heat flow is pretty sensitive so it's fairly narrow range. I can do this again through our you an .75 million watts. You are looking at the equatorial, so we see a little warmer now and all three of these the total deformation coming down a little but all of them now are within this narrower range which is producing more than that 35 kilometers.

And then we can also look at what are the conductivity do to it. This is heat flow of you an .75. It seems to play a large role in the final deformation.

We can also look at what these individual heat flows do. So 60 to 90 Kelvin. 325.5. Four different heat flows here. You will notice now 2 million watts so we are starting to get too warm for that ice to support.

We need to be in some narrow window where the ice is warm enough to move relative to the pole. The ice needs warm up to move relative to the pole but not too warm that it can't support anything.

So in all of these models and

most of them we are able to produce more than we observed the amount of deformation which is good. That's always good when you are trying to write your PhD. We need a way to break that lateral homogeneity. I was able to do that through this Cosine surface profile. We found that the deformation was concentrated at the low latitudes which lifted them to the high latitudes which makes sense because in the models in the sweet spot, the ice at the equator was warmer and when it was warmer it was a little more mobile versus the ice at the pole which is stiff fer so the equator ice thickened while the ice at the pole didn't really want to move.

So caveats to some of this work. I assumed that it was differentiated. That means it separated density. So like the earth is undifferentiated. The ice would probably be a little stiff fer because it would have a lower bulk density and fraction of rock. So I don't think this would expect the conclusion to change too much. I didn't do this? Spherical geometry which didn't include the membrane effects of it. This would make the lithosphere more resistant to change. But that is mitigated by the fact that I was able to in order to solve the success models I could produce more deformation than just presently observed. So that leaves wiggle room for not having to turn the dial perfectly on it. And also leads to some potential long-term relaxation. So all of these models said that they formed within 100 million years of the formation of the body and so the solar systems like 4.4 billion years old, so that's a lot of time to sit there. So it might be shrinking in time.

Also this 100-kilometer lithosphere thickens, this mechanical layer closely correlated it spherical harmonic two to three. So the membrane stresses are just becoming clear.

So this work was able to reproduce the bulge of lapetus through folding. If you have the equator variation in surface temperature you have a heat flow between one half million watt and 1 million-watt and is a he poke planetary con subtraction. (Epoch). Even the rotational models, this rotational epoch. So all of this work was through LPI and

NASA and Hawk and Dombard. It takes a while to get this stuff done and it was worth it and a lot of fun to do.

So with that I'll take any questions that you have.

>>Dr. Garrison: Any questions?

>> (inaudible).

>>Dr. Kay: You have this orbital resonance on some bodies, primarily in Enceladus and dionne. It's more known in the Jupiter system where you have Europa and (indiscernible). And a lapetus is in terms of orbital distance from Saturn which is actually likely why this model works for formation because if you have this orbital rest resonance you have a higher heat flow over it's existence which would have cooked it out which is why you don't see it in a lot of bodies. So it needs to be a special case where it's far enough away to undergo this sort of loss and not be in (indiscernible).

>> (inaudible).

>>Dr. Kay: Sorry, do you mean -- so the that likely happened a little after the

formation of the bulge. And so it also happened pretty slowly, more like a slow crawl than like a landslide. It slowly rained down on the surface.

>> (inaudible).

>>Dr. Kay: It's possible that that could have sped up the rotation, sort of like a gravity assist. But it depending on the exact parameters for smaller body might have actually sped off at a cost of stealing some angular momentum from the bigger body. Because all of that has to be conserved.

>>Dr. Garrison: Any more questions?

>>Dr. Kay: So Titan just got selected as part of discovery class which is a smaller class mission to fly basically a drone and have it visit. It's competing against one other moon, a small body in the astroid belt. So I'm helping that Titan gets selected. We are -- we won't know that for a while so that won't probably get there until the 20 30s. Recurrently we are getting close to launching in a couple of years the Europa clipper which will fly to Europa and take a couple years hopefully of images of Europa. And then

there's some talk of maybe a smaller mission going to Enceladus. But there are not a lot, these missions are expensive and there are not a ton of opportunities to do them.

>> (inaudible).

>>Dr. Kay: So I lot of that depends on what conductivity value you use. Do you think that I should conduct (indiscernible). It's unlikely to be on Enceladus -- iopodus (ph). What do you think the heat flow is. So I think that basically it's likely the heat flow is low and the conductivity is going to be between those two parameters. So I think at about 200 kilometers that you would have somewhere around the order of 250 Kelvin, maybe shooting up to 270. I think these bodies are pretty cold. And there's likely a small liquid ocean really deep, but just the pressure as you go down you need a much, it could be much warmer.

>> (inaudible).

>>Dr. Kay: Sorry, that's just sort of the mechanical of the lithosphere. You will get liquid water but it will be (indiscernible).

>>Dr. Garrison: Other questions?

>> (inaudible).

>>Dr. Kay: So it doesn't look like there are any other places within Jupiter or Saturn to test it. We only had data from the 70s from Uranus and Neptune. So it's possible one of those have it -- systems that it's hard to disprove some of these theories because there's so much variation. So there's also talk of an ice giant mission to either one of those planets to do some follow-up work. It would be neat if there's another one but...

>> (inaudible).

>>Dr. Kay: It would -- so the finite element doesn't care what body it is. But the other target satellites would either be too small so not enough heat. Or too close to Jupiter or Saturn so it might be more likely to be in an orbital resonance which would cook out the heat more quickly. So it's all about that heat budget.

>> (inaudible).

>>Dr. Kay: It's always about sort of trying to understand how things form and why they form and what are the consequences for the ice sheets and how they swell. I think it's sort of just a general trying to improve our

knowledge, which I like.

>>Dr. Garrison: Let's thank our speaker.

(APPLAUSE).

(End of talk)