

Monday, April 9, 2018

Physics Lecture Series - Dr. Kramer

>>DR. GARRISON: Okay. Can I have everyone's attention? I want to introduce our speaker for today. This is Dr. Kramer from the Lunar and Planetary Institute which, as you know, is basically right over there. You know, we're going to be neighbors with them once we move to the new physics building next summer.

Dr. Kramer studies the composition, structure, and evolution of the moon, asteroids and other planetary bodies using data from spacecraft missions. She was a member of the science team for the moon mineralogy mapper, which is the first instrument to unambiguously detect water on the moon.

She has also been with the Lunar and Planetary Institute for 7 years now. Long time neighbor. Knows -- she's seen a lot about what's going on with this campus I guess from not too far away. So also, Lunar and Planetary Institute, I should mention, that they do have a summer internship program so if that is something you might be interested in, you might want to talk to her. Turn it over to Dr. Kramer.

>>DR. KRAMER: Okay. I hope you guys enjoy this presentation. It is my favorite subject.

Ever heard of lunar swirls? Okay. That's great because most planetary sciences haven't heard of them. If you say the moon you probably heard of them but other than that they are a pretty weird thing.

I do want to say -- I am -- I am notorious for speaking jargon and feel free to stop me

and say, I don't know what basalt is, George. You can call me George.

I am beginning with an outline of the presentation and I will do an intro to our moon and that's a capital "M" because that is our moon. Then I will give you an introduction into spectroscopy and then I will introduce space weathering, and this is different than weather. Like erosion and weather happening on earth, different on the moon. Then I will talk about how I use impact craters to look through the soil on the lunar surface and see the composition of bedrock. And then how I kind of discovered swirls again. Not really myself discovering them but saw them and appreciated them, and I will talk about some of the swirl science and some of the work I contributed to lunar swirls and conclusions.

What is the moon made of? No. It is actually made of pretty much basalt. The Maria are made up of rock-type basalt. It is the most common in the solar system. It makes up (inaudible) and all of the ocean floors. It is all over Colorado and India and all over Mars and Venus probably. On the moon it is where these dark areas are. The brighter areas we call the Highlands and they are made up almost exclusively of one mineral type which is also a common one that's in basalt and in this case, it is one mineral type and it is anorthosite and it is a bright mineral and that's why the Highlands are bright.

On this side of the moon, about 50% of that surface is dark. 50% is bright, but when you have a full moon that's a very bright future. Have you seen the far side of the moon, what that looks like? This is the far side. It would be a really bright moon if we had that facing us which geophysicists tell me it is just as likely (inaudible).

This is a bit of a diversion and I think it is cool and I am trying to propagate this

knowledge for history. I think be it was in the 16th or 17th century when Harriot and Galileo were mapping the lunar surface for the first time using a telescope, they were naming mare features. They didn't necessary thought they were water, but they called them mare. They named them for this old Proverb that stated that when the moon is waxing, the weather on earth would be pleasant. That the moon controls the weather on earth. And when the moon is waning, it would be stormy, raining and generally unpleasant.

So we have things on the waxing side like Mare Serenitatis and Mare Tranquillitatis and Fecunditatis and Nectaris. On the other side, we have Sea of Cold and Rain and Storms and Moisture and Clouds.

So we have spectroscopy and that means I am looking at these that are coming from an external light source and the light is reflecting off and shining back to the optics. So my light source is the sun.

It interacts with atoms and minerals on the surface of the grain and some of the photons will get absorbed. It is specific wavelengths depending on the composition, will get transmitted through and reflected back.

Now we have air spacecraft or observers out in space and this light is diffracted. It goes through the optics and diffracted into the component wavelengths and then we take away the spectrum of the sun because it has its own. And we get what is called a reflection spectrum and that is showing us what got absorbed and what got reflected back from the sun.

And we get these plots which shows the wavelength of light -- verses reflectance and we get these squiggly lines. And these squiggly lines are useful because the location of the

squiggly line will -- tells us how bright it is. Its shape tells us meaning. If it is flat or sloped tells us about the composition and most importantly are the absorption features which are the dips in the squiggly lines and it is more obvious in these ones.

So these four minerals here are -- five, excuse me -- are common minerals that makeup basalt. (inaudible) these are two kinds of -- that's the anorthosite mineral. And this one down here is Ilmenite and a very dark black mineral and absorbs a lot of light.

So we can use the shapes of these spectra to get out the chemistry that's going on in the surface.

Even though we have only landed in -- well, I guess technically nine locations where we have collected samples, three Russian and six American, and they are all clustered in these areas here. We actually can map the entire surface based on the squiggly lines for two elements or their oxides rather. We use the stations where the samples were taken as calibration points and then across all of the lunar surface.

And also maybe of what the (inaudible). Ilmenite is the carrier of titanium. Okay. As I said before, space weathering is more like the weathering and erosion that goes on earth's surface, which is due to wind and water and geology -- geologists tracking it all over the place.

On the moon, it is very different because there is not -- not very much water and certainly no wind, but there is a kind of wind. Anyway, what it has -- basically it comes down to two things. It is what makes the surface age. These are meteoritic bombardment and the solar wind.

So the meteorites -- here I'm talking about macro meteorites but also micro. It is a dust

grain. It gets right through and it is going to physically melt and cause a reaction to occur.

Out of it, you get things like soil. You get the breaking up of rocks and it turns into soil and blast from melting. And then you get this thing I put in quotes as "big iron." This is more of -- the line between physics and chemistry is going on with respect to macro meteorites.

These dust grains come in with all of the force they started with and they can actually -- they can actually putter, or they can cause a little bit of molting to go on and a chemical reaction to occur and all of that iron oxide that might be in that mineral reacts and the oxygen gets liberated and you get left behind with these irons. They are really tiny. But I'm calling them "big iron" here because they are bigger than 50-nanometers. That's big. And the spectral effects is by mixing. I mean the different minerals and compositions are getting mixed and the spectrum is a mixed spectrum, by darkening. And this is what is important about these larger smaller iron and they have this effect on the spectrum of taking whatever that spectrum is, the Highlands, the fresh basalt, and just darkening it across all wavelengths.

On the solar wind side, since all it can really throw is, for the most part, protons, a little bit of helium ions and photons, of course, but this is -- when these protons, which are the things that are having the most interaction, interact they can putter and cause a chemical reaction or do the agent of a chemical reaction by introducing hydrogen into the soil. But solar wind is mostly responsible for creating little iron or smaller than 50-nanometers. They can go -- these little particles have the effect on the slope of reddening it.

So there is a general darkening across all wavelengths, but what is being shown is the darkening and the reddening, so what is the slope here for the basalt is now becoming red and a

tilted slope. So what's really going on is more like there is small and big (inaudible) being created and the little irons are doing more darkening with -- they are having a shorter wavelength.

Similar to the way that we can use the spectra to identify minerals and since we know their composition, we can therefore get the chemistry of the entire lunar surface. We can use the effects they have on the spectra from weathering and create a map of the maturity of the surface. So I just talked about weathering.

Maturation is the evolution or aging of the surface material. Right? All of us as we are growing older, we are maturing, growing older. Here maturity is a measure of that maturation so here this would be like how many wrinkles are on your face or age spots or what have you?

Optical maturity is the measure of the maturity using spectroscopy. There are others that you can measure in the sample the number of ions -- as a measure of maturity, but optically using optical parameters with the darkening and the slope is optical maturity and using that that's what the moon looks like.

The bright areas are immaturity and this is -- crater is 180 million years old and they are still bright. Jackson, which is on the far side is another fresh crater.

Okay. So these craters that I just showed you, Jackson and (inaudible), they expose material and this material comes from underneath that surface. So in comes an impact crater and it goes into the ground but more importantly than digging a hole, it causes an explosion.

It goes up, out and over, so now you have fresh material overturned right onto the surface. So I actually use that fresh material that has just been overturned right on the rims of

the surface to look at the composition of the material that is exposed because that soil that's everywhere is just mixed up material over billions of years, so the composition is not -- can't really see what's going on, but I look at these fresh impacts to get at the composition of the fresh bedrock.

And I use to have animation here, but it disappeared and what it showed you is little circles appears around all of these fresh-looking impact craters.

And then there is one way I am able to actually make a map and I was able to determine that these were each different basalt units and map their relative ages and compositions. Not as they appear on the surface because on the surface they didn't look quite that divided.

And so I go about mapping the front side of the moon in this way. This isn't really my map. This is -- it is just a nice demonstration of the kind of thing that can be done. Then I went to the far side, and since I'm used to mapping basalts, I went to this and this is the largest (inaudible) and trying to map some of the mare here and I went to this place called mare -- Sea of Ingenuity.

I am a trained scientist and I have heard of lunar swirls and I didn't appreciate what a pain they are. Can you guys see them? The lunar swirls? Yes. They are like these trippy little things. That's an impact crater and that's part of an impact crater but these are different and they are not behaving according to physics as well as I can tell. What are lunar swirls you are asking?

So they are high albedo features. They usually have a sinuous shape and interweaving dark lanes. They are also associated with magnetic anomalies on the moon. Yes?

>> (inaudible).

>>DR. KRAMER: Albedo is the reflectance -- it's the brightness. Sinuous is curvy and like snake-shaped often. There are some more diffuse looking, but the moon has no global magnetic field like earth does, but it does have these discreet areas of remnant magnetism that nobody can explain why they are there, but they are. Associated with most of them, you can see kind lunar swirls. That's right.

The swirls also impart no topography. They just drape over -- whatever topography is there, if it is flat or a hill. And they look fresh. Here is the explanation of the moon and how it does not have a global magnetic field. Here is the magnetic field strength of the near side and far side of the moon and the purple areas are no magnetic field to speak of and in the other areas is an enhanced surface magnetic field. Where the squares are appearing are known lunar swirl locations.

So it is important to say that although every swirl is associated with a magnetic field, not every magnetic field has a swirl. Another weird mystery we're working on.

So I say that these swirls impart no topography. This is Reiner Gamma and the most popular because it is on the near side of the moon. You can look at it through your telescope. People have been looking at it for a while.

Here is a series of images from the Kuya, mission to the moon in the early 2000's and you can see it is flat and craters are appearing, but the (inaudible) is just lying there.

So the swirls are optically bright -- are bright and optically mature and have a high albedo and mature. These swirls try to show you the type of locations on the lunar surface you

can have. You can have mare basalt, dark area and there is a swirl, Reiner gamma. This is the Gerasimovich and I don't speak German, so I don't know if it is a hard "G." It is in the Highlands area and it is difficult to see the swirls, but you can see some here and here and then a little one right here.

And then mare Ingenii which is mare and Highlands -- and the Highlands extend up further and further towards the north and the east.

This is where they are located. This is what they look like in optical maturity. You can see it is easier to see them in Gerasimovich and in Ingenii and these parts are craters.

So there are two hypotheses for how they are formed or what they are doing there. The first is a comet impact and this is one postulating that with the swirls are actually immature and they are a recent event that occurred. It explains why they look bright and it explains why they look immature and it explains the magnetic analogy and the explanation is that the comet is impacting onto the surface of the moon and it sets up a temporary atmosphere.

There is turbulence that can create the swirly features and the pressure that is occurring, and the heat generated with the plasma and it interacts with the inner-planetary magnetic field from the sun and it imparts a magnetic field onto the surface.

The other hypothesis is a deflection of the solar wind by the existing magnetic field. In this one there is a magnetic field which I'm representing with this white thing and it is just the magnetic field and not the swirl itself just yet. I'm sorry. It's a deflection of the solar wind by the magnetic anomaly and prevents the normal maturation. So the meteorite bombardment and the solar wind is mostly protons, so it can be influenced by a magnetic field.

In this cartoon here, the basalts are flooded over it and as time goes by and if basalts mature, this area staying immature looking. In this hypothesis, the swirls are not actually fresh features. They only appear fresh because the magnetic field is deflecting solar wind. It explains their brightness and where they look immature and it explains the magnetic anomaly. This theory does have an accompanying theory of how they get there, but I will not get into because I don't care.

It also explains why they don't impart topography. And it also is the only one that explains my observations which I will go into now.

So I contributed three major results to support the hypothesis that the magnet I go field was prevent -- keeping the swirl surfaces from maturing at normal rate. Oh, and mostly importantly, I really feel strongly, and I just proved the comet impact hypothesis.

So I showed that the density of the fresh impact craters, you know, those are the ones that I use to look at what the composition is, I showed that the density of fresh impact craters on-swirl verses off-swirl. What am I writing here? What I did was to show that the density of fresh impact craters on the swirl verses off -- were much higher than those to off-swirl. I know that sounds confusing and I'm sorry. I will get into it in a minute.

I looked at the spectra of the fresh craters and compared with the mature soils on-swirl and off-swirl. Then I also looked at the hydrogen -- eight are hydroxyl OH or maybe water abundances on-swirl and off-swirl.

So Mare Ingenii. This was what I looked it and it was independent whether it occurs on a swirl or not. It was created on a threshold maturity parameter. They all needed to look like

they were more immature or fresher than the brighter swirl surface. The distribution looks pretty random, right? This is what you would expect because impact cratering is a random process.

So then when I mapped the swirls and then counted the density of the fresh impact craters that occurred within the swirl boundaries and compared with those that don't occur within the swirl boundaries, which are the dark areas or outside the mare area in general, there was four times as many impact craters on the swirls as off the swirls.

That might seem, at first, well, there must be something that's attracting the impact craters. These are large impact craters and greater than 100-meters in diameter and no magnetic field is going to affect the craters and in fact, no impact would affect a piece of dust. This is actually because where those swirls are, that magnetic field exists, and that surface is protected so these fresh craters keep looking fresher longer.

Then I compared the spectra of the craters on the swirl, these fresh craters on the swirl, and off the swirl, as well as also comparing to their mature surface, if you will. I put mature in quotes because if you are looking at the mature on the swirls, it doesn't look very mature. So all of the dark lines are fresh craters not on swirls and all of the white lines are fresh craters on swirl.

The dotted line is an ox -- this white dashed line is a mature crater on-swirl. I guess it is a coincidence or I'm not sure, but all of the off-swirl spectra are all darker than the on-swirl. These craters were selected before I ever determined what was a swirl or not a swirl, so it is not like I made this decision based on this -- I said all of these are off-swirl or on-swirl. They

divided themselves.

It is hard to tell here, but all of the spectra that are occurring on the swirl actually resemble fresh crater material and that kind of includes the soil. It does look a little mature, but nothing like a normal soil on the moon which is more like this dark one.

And also most importantly is that all of these fresh craters that are off the swirl look like they are already kind of mature in fact, but mostly they only look like they are darkening. They don't look like they are reddening.

Then I looked at the composition of these fresh craters, the iron and titanium. I will skip the iron because the titanium is where it is existing. I don't know how many geologists are in the moon, lunar geologists, but on the moon, the mineral element is the carrier of titanium. It is not a common mineral on the earth's surface, but on the moon, it is not uncommon, but it is only in the mare basalts.

If there is going to be Ilmenite, meaning high titanium, it is coming from the mare basalt. So looking at this map here, it is showing the surface titanium abundances and all of the spots you see are the fresh craters and what their composition is. So what is weird here is that of all of the fresh craters, the highest titanium abundance you can get is three and a half. But the highest that occurs on the surface is eight and that is not possible because that titanium has to come from the mare basalt, so it has to be that the higher titanium would be on the fresh craters and not on the Sawyer face because the surface is way outside; the Highlands mostly because that's what is surrounding it and it has no titanium. This is very strange.

And that's when I noticed that these areas that come up as white, coming up with these

really high abundance, absolutely correspond with the dark lanes. So I said to myself, something is tricking the titanium algorithm. What does the titanium algorithm do?

It is basically searching for a spectrum that is dark and flat. If I am seeing dark or flat, whether mature or not, I can actually ignore that part. I am looking for dark and flat. If it is dark and flat, it is a fresh ilmenite. So it has a high titanium value. Other thing that's dark and flat is little iron. Excuse me -- big iron.

So that's when I realized that this surface is not full of ilmenite. It is full of a bunch of big iron and being matured really fast and a lot of (inaudible) are being created quickly.

I should have shown you this before. This is nano-phase iron and there is a scale bar.

The third thing that I contributed was to look at the hydroxyl or water abundance on the lunar surface. The lunarology mapper was the first instrument to detect this map. It is globally, and we saw it everywhere. Completely unexpected. It would occur everywhere except right where the sun was shining, meaning that it was stay persistent at high latitudes above 60°. It would fluctuate with the lunar diurnal cycle. Meaning sun rise, as increase solar energy begins to drive off any of the water or hydroxyl at the surface. Noon, there was a maximum loss but again, in these more equator latitudes and in the afternoon, the hydroxyl water would stick again and stay on through the night, but it is (inaudible) spectroscopy so you cannot measure what is dark.

So this cycle of like moisture forming and then the sun rises, and it burns off and then the sun sets, and the moisture comes back. Does that remind you of anything?

>> (inaudible).

>>DR. KRAMER: Yeah. Well, I'm thinking of dew, right? So I'm really looking for somebody to help me market the next space mission to check this out in more detail. Mountain dew, I think this is a great idea. Here are the three solar regions, Reiner gamma on the mare and Gerasimovich on the Highlands and mare. Ingenii on both.

Just like you can make a -- the lunarology mapper was able to go out with enough -- with a good enough spectral resolution out into the region to measure this dew to the presence of any hydroxyl or water, and I say that because the instrument couldn't detect the difference between the two. The point is that it is water related.

Anyway, so we can make a map of that relative abundance and this is what happened. The swirls are perfectly outlined better than any map I have been able to see so far. You can see the swirls at Gerasimovich much better and you can also see that the ones that are out into the Highlands and Ingenii, and they do extend further, but at the time I was doing this, I was not aware of that and I cut my boundary off.

They appear dark because they have a lower hydroxyl or water abundance in their surroundings because there is not enough hydrogen making it to the surface because it is getting deflected by the magnetic field.

So in conclusion, weathering is retarded on-swirls and I got to publish that in two papers.

The swirl surface resembles spectra -- spectrally resembles fresh material, even on their mature surface. The density of immature craters that occurred on the swirls were four times that of off of the swirls. The hydroxyl is depleted on the swirl surfaces.

And this supports the solar wind deflection model and it can also -- this is explained by the solar wind protons being deflected by the magnetic and limiting weathering to micrometer, right? I showed that weathering is accelerated off the swirl because all those off-swirl fresh craters looked really dark and flat, so it looks like they actually mature quickly. Right? And then the dark lanes are not rich in titanium but rich in metallic iron.

Now, you know, the swirls provide a laboratory to study the solar wind, space weathering, and complex electromagnetic materials. (inaudible). And again, I tell you to go out with your binoculars or telescopes and look at Reiner Gamma.

And also this concept of space dew which is a solar system wide process. It is not occurring on the moon but probably asteroids and could be a viable process for which we could be extracting water or looking for reservoirs and that's it.

>>DR. GARRISON: Questions?

>> What was that relationship between the magnetic field and the swirls again? If there is also a magnetic field --

>>PROFESSOR: If there is a swirl, there is a magnetic field, but there are some that don't have swirls. There is one really big whooping glaring one in this mare region where there is two magnetic anomalies in the north and south and I have searched in detail and stretching the data as much as I could.

Most recently the ultra violet instrument -- on lunar (inaudible) orbiter has been able to see the swirls and what is interesting is that the UV is very sensitive to maturity and the swirls are kind of the only thing that keep looking immature in UV light. Like even Pico disappears.

It is another way we can hopefully -- another data set that we can hope to stretch and play with and look in these particular places where we are not seeing the swirls, and something will appear or explain why it is not happening.

>> (inaudible).

>>DR. KRAMER: Ingenii. There is a lot of reasons. It is in (inaudible) and it is the largest impact. It was about 4.2 billion years old. Never been sampled and it is actually like a number one priority, targeting location for returning samples back from the moon. If we went to Ingenii, I would go to (inaudible) and we can land on the sharp boundaries and get mature stuff and immature, with just a lander. I have an entire presentation about why we should go to Ingenii. (Laughing).

>> (inaudible).

>>DR. KRAMER: Yeah, there is three different instruments that have measured it, two of them globally. There is the Japanese mission, (inaudible). They measured it. The mare spectroscopy mission. I measured it with two different techniques and Apollo missions, two of them, and they didn't actually measure it, but it was (inaudible)

>> (inaudible).

>>DR. KRAMER: Yeah. I work in the UV visible and --

>> (inaudible).

>>DR. KRAMER: Out to about 3,000, yeah.

>> What's the concentration (inaudible)?

>>DR. KRAMER: Yeah. It is really, really complicated. Personally I, hate to get into

trying to quantify it because there is so many unknowns. The spectrometer itself there is so much noise associated with it, especially in that region, so much uncertainty, that quantifying it, in my opinion, is fruitless but people have made attempts to quantify it. I'm trying to remember, I think that most of it was coming up between the 1,000 and 8,000 PPM.

>> (inaudible).

>>DR. KRAMER: The sun. I think the sun.

>> (inaudible).

>>DR. KRAMER: Yeah, it's throwing hydro -- actually a project I'm working on is looking at how the soil is retaining that, how well it is doing at retaining it as it ages. Is it actually retaining the hydroxyl better as it ages? That says something about how it is being retained. Is it in the glossy soils or better in the fresh surfaces and that just might be like a kind of Vanderwall attraction between the surface materials and the protons.

>> (inaudible).

>>DR. KRAMER: That's actually a pretty recent paper by Mark (inaudible). He noted that on the far side, that's where the largest like spread of -- strongest magnetic field is occurring and his hypothesis is that the impact was a differentiated meteorite body and that it imparted. It just threw its core all over the surface.

>>DR. GARRISON: Any questions? All right. Thank you, Dr. Kramer. (applause).

I want to remind you guys, next week, we're going to have Steven Koontz here to talk to you about the (audio out) and spacecraft charging. See you guys.

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