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Moderator: Heather Doyle
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Heather Doyle: Thank you. Hello everyone and welcome. I'm Heather Doyle from the Solar System Ambassadors program so thanks for joining us for this telecon today. We're really excited to hear from Dr. Andrew Jordan.

And just a final reminder: please do mute your phones. If you're not sure how to do that *6 will work. If it gets a little bit noisy I might ask the operator to mute some people. You'll just have to press *6 to unmute if you found that that's happened to you when you're trying to ask a question at the end. That could be why we can't hear you.

The slides are a PDF actually this time. You can find them either on the Museum Alliance or Solar System Ambassador Web sites. If you have any issues at all just email me: hdoyle@jpl.nasa.gov and then also just don't put us on hold because sometimes there's hold music that plays.

So I'm going to turn it over to Andrea who's going to introduce Dr. Jordan now. Thanks.

Andrea Jones: Wonderful thank you so much Heather. Yes, it is my sincere pleasure today to introduce Dr. Andrew Jordan who is a member of the science team for the Cosmic Ray Telescope for the Effects of Radiation, CRaTER on NASA's Lunar Reconnaissance Orbiter Mission which is a mission orbiting the moon today and collecting all kinds of fabulous information about our nearest neighbor in space. And he is also a Co-Investigator on the NASA SSERVI Team which is Solar System Exploration Research Virtual Institute Team, the DREAM Team which is just the greatest acronym of all of the teams of course and that stands for the Dynamic Response of the Environment at Asteroids, the Moon and the Moons of Mars.

And he studies all kinds of wonderful things about space environments and how the surfaces of airless bodies in the solar system are affected by interacting with this environment. And he also happens to be a terrific speaker and has been so generous with his time in all kinds of education and public outreach activities over many, many years. He's based in New Hampshire and today he's going to talk to us about sparks on the moon. So Andrew, thank you so much for talking with us today and looking forward to it.

Andrew Jordan: Great. Thank you Andrea and good job with all the acronyms too.

Andrea Jones: Hey.

Andrew Jordan: Yes so hi everyone. I think I talked to the Museum Alliance - boy I don't know, five or so years ago. So nice to be invited back to do it again. And this talk is going to be kind of an overview of things that I find interesting, especially stuff that motivates the work that I've been doing with some other people that you see there [slide 1]: Tim Stubbs who's at Goddard and Jody Wilson, Nathan Schwadron and Harlan Spence who are all on the CRaTER Team and also on the DREAM Team and the last three of those are also here at the University of New Hampshire.

So I'll give an overview of what kind of motivates what I've been working on and then I'll show some stuff and it's a mix of things that have been published and also a little more hand-wavy stuff at the end too just so you can get a feel for how it all fits together at least in my head.

So you can go to the next slide, slide number 2 and there's just a smattering, definitely not a representative smattering of airless bodies in the solar system. There's the moon, there's Mercury which kind of looks like the moon sort of without the large maria. There's Phobos which is one of the two tiny moons of Mars. There's an asteroid, Vesta which is kind of funny looking, Iapetus which is a moon of Saturn which is really cool. That's on the upper right-hand corner. Basically, I think one hemisphere is pretty dark and the other hemisphere is really bright. And then down at the bottom there's Charon and Pluto which are kind of like a binary dwarf system but you can see - and I'm pretty sure this image is pretty close to what you would see if you looked at them. They're very different.

And the point of this is that even though all these objects are similar in that they don't have an atmosphere they all look very different and that's due to the very different histories that they've had from impacts, from how the sun as affected them, from how energetic particles from outside the solar system have affected them. And so any time the you're looking at just a picture of the surface of any one of these objects in order to interpret that picture you have to understand what's affected that surface that you've seen and it's a mixture of what the surface is made out of plus all of the things that have affected that surface.

So if you go to slide 3, and don't worry if this doesn't make a whole lot of sense. I put it up there more just to show that there's a whole lot operating on an airless body and it's not the normal things that we think of like wind and water erosion. It's more micrometeorite bombardment so tiny pieces of dust, sometimes larger ones slamming into the surface and that'll vaporize and melt material. There's contamination from landers that land on the object. There's cosmic rays, galactic cosmic rays.

There's also the solar rays but they're solar energetic particles and I'll be talking a lot about those today. The solar wind: that's just a stream of electrons and protons from the sun that goes out through the entire solar system and can be measured all the way out to Pluto and even beyond and that affects surfaces as and that can knock off atoms and break chemical bonds on the surface.

And there's all these things going on and all these processes together are call space weathering. So it's kind of like what's weathering the surface that's exposed directly to space. And all of these processes, can affect the chemistry, they can affect the physical makeup of the surface by changing the grain size and the rock sizes. And they can also even affect the nuclear characteristics, especially the galactic cosmic rays which are really energetic and can break nuclei of atoms apart.

So you go to the next slide [slide 4]. This is the circle of space weathering and it kind of traps scientists because in order to determine surface processes - or properties using remote observations whether it's just taking pictures like I showed a couple of slides ago or otherwise, we have to know how space weathering has affected the surface. But in order to know how space weathering has affected the surface we have to know what the surface is made out of and we have to know how the space weathering processes have affected the surface in order to figure out what's going on.

But in order to do that we have to use the remote observations to try to back it out. So there's a little bit of trying to pull ourselves up by the bootstraps. And if we don't know what all of the space weathering processes are then we're probably misinterpreting some of the remote observations.

The moon is a special place because we actually have samples from the moon and so we have some ground truth there and that's helped but it's also raised a lot of questions as well. So you can go to the next slide. That should be slide 5. It shows two images of the moon. The one on the left shows what we see when we look at the moon and then the one on the right shows the far side of the moon which never faces us.

And you can see they're very different. Most of the craters that you see on the far side of the moon are a lot smaller than some of the impact basins that you see on the near side and as far as I know the jury is still out as to why that is. Although you can kind of see that darkish gray area near the bottom around 5 o'clock on the right-hand image, that's the South Pole–Aitken basin and it's possibly the largest impact feature in the solar system that we know of and you can just kind of see it in this picture. By the way this image was stitched together from thousands and thousands of images taken by a camera onboard the Lunar Reconnaissance Orbiter called LROC, the LROC WAC. It also has the NAC so you can have nick NAC paddy WAC.

So let's see - next slide [6]. So mostly what you saw in that picture of the moon, not all of it but a lot of it is just from impact cratering and so this is just an image showing what happens when a meteoroid strikes the surface of the moon or any other body and it creates an ejecta blanket that shoots out from the crater and then covers all the surrounding region.

So these impacts, they create more soil, they break up rocks. They also fuse material together too because it can melt the rock and material and so that creates a glass and then that can fuse and create larger fragments. And it also really mixes stuff up. I'll talk a lot about the mixing later on.

So if you go to slide 7, this is another view of the moon but now it's rotated so the side of the moon that we see is on the right-hand side, the far side is on the left-hand side. So we're looking at the western lim of the moon and off to the left at around oh I guess that's about 8 o'clock, you see a couple of concentric circles. It's the Orientale basin and if you go to slide 8 you can see lunar orbiter pictures. So this is from the 1960s image of it dead on. It's an absolutely gorgeous picture but I'm just showing some eye candy of the different kinds of impact craters that you can get on the moon and also on other bodies as well.

Go to the next slide, slide 9, this is an image, a still, a single frame taken from a video. NASA has a program where they have a video camera, a high-speed video camera that images the moon quite frequently and looks for impact flashes. So that bright dot that you see is from an impact happening on January 4, 2008. And if you go to the next slide [10] you'll see a little popup showing the full face of the moon and where - I think it's at least 300 impacts, yes. Yes almost 350. Three hundred fifty impacts have been observed in about ten years of observing.

So meteoroid impacts are happening all the time in addition to all the other space weathering processes and there's proof of that if you go to slide 11, the image here is taken of an impact that I believe happened in 2013. This is from the LROC NAC, so the Narrow Angle Camera that takes really zoomed in pictures of the surface. And the picture on the left shows the area before the impact and the picture on the right shows the area after the impact and you can see the crater is about 30 meters across but you can see the rays, the bright rays emanating from it, spreading all the way across that image going about a kilometer away from the impact. So it's pretty neat that the longer LRO is in orbit the more of these images we can get and we can understand better how impact cratering works.

If you go to the next slide, number 12 you see a rock from Apollo 16 that was collected by the astronauts and the cube in the bottom right is 1-inch on its side just to give you a sense of scale. So this rock is maybe - I don't know, it looks like 9 or 10 inches long. And a lot of the little circular features that you see, they show up most clearly in the white splotches are tiny little craters. So usually we think of pretty big craters but there's also these little craters that are called zap pits.

If you go to the next slide, slide 13 you'll see a microscopic image of one from a piece of dust traveling really, really fast, maybe 20 or so kilometers a second that impacted a tiny grain of soil from the moon and I believe the diameter of a typical human hair is maybe ten times larger than the diameter of that crater. So that is one tiny crater. So you get weathering on very large scales plus you get weathering on these very small scales.

And on slide 14 there's an image - and I cannot remember what Apollo mission this was from but just showing you the range of impact craters that you get. Some of them are meters across in this picture and others of them are just about a small as you can see in that picture. And that little blue flare up there is just internal reflections in the camera from the sun.

Now if you go to the next slide, slide 15 all of these impacts, the big ones and then especially the little ones which really just break up the soil and then stick some of it together with glassy stuff creates a really - how do you describe it? A really jagged soil. I'll show some pictures of it later and it's really kind of clingy and sticky.

So on the left is Gene Cernan before he went on the Apollo 17 mission to the moon and on the right I believe is an image taken from pretty near the end of that mission and you can see his spacesuit does not look the same at all. It's completely dirty and there was no way that they could clean the spacesuit. The grains would actually just get embedded in the nylon that was on their suits. It had all these little barbs on it. It actually made it hard to breathe too. You go to slide 16 you see another image. There they've been working pretty hard and are really dirty. I know I go from talking about space weathering to how dirty astronaut suits are but it'll hopefully come together.

The next slide, slide 17 is taken from a little-known instrument that was brought by some of the Apollo astronauts called the Apollo Lunar Surface Close up Camera and it kind of looked like a walking cane but it had two cameras on the end of it and it would take stereoscopic images of the surface. They were only a couple of inches across and so you could look at them in three dimensions. And so this is one of those images so now you're looking at grains that are a few millimeters across and smaller and so you can see just how - I don't know exactly what the word is. I'm thinking jagged. Kind of along those lines how rough that material can be.

And then the next picture is - slide 18, is a picture of Buzz Aldrin showing his footprint and then if you go to slide 19 you can see a close up picture of that footprint where the grains are really cohesive and they're kind of sticking together. They can keep their shape. And if you go to the next slide then you'll see microscopic images of some of these grains. Some of them are spherical. Not very many of them but some of them are especially ones that are from volcanic eruptions. But in some like the one in the bottom left hand corner they're really jagged. They've been formed by being melted, by being stuck to other grains and so they get really jagged and can stick to things and that kind of bizarre shape is actually related to what I'll be talking about later.

So the next slide is the main point from all of that. It's just that impacts, meteoroid impacts create what's called regolith including soil and regolith is just a term for all that loosely consolidated material or unconsolidated material on the surface of the moon. So it includes boulders and small rocks and then the soil as well.

So now for a little bit of a change slide 22, now it's time to talk about the sun and how it affects the moon - and how it affects the Beetles. Not really. Slide 23 shows an ultraviolet image from the Solar Dynamics Observatory and I haven't shown a picture of the Lunar Reconnaissance Orbiter yet but LRO and the Solar Dynamics Observatory or SDO are actually kind of like twin spacecraft. They share the same kind of BUS. They're both boxes around a big central fuel tank and they were both made at about the same time although LRO launched first. But one's for the moon and one's for the sun.

And you can see the sun at least in this picture is a pretty active place. If you look at it right now there's I think one set of sunspots that's pretty quiet. You go to the next slide though with the Solar Dynamics Observatory in particular, solar scientists have been able to peel back the layers of what's going on underneath that surface of the sun to see how some of the large-scale flows affect the magnetic field of the sun. The sun has a really strong magnetic field and once that gets churned up really tightly it can create a lot of activity.

If you go to the next slide, slide 25, this is another image from SDO and this is kind of depicting what you would see if you had proper eye protection. This is what the sun would look like if it were a little more active than it is now. You can see a lot of sunspots which are regions where the gas is a little bit cooler than the surrounding gas and gas that's not as cool doesn't shine as brightly. So it looks black but it's still pretty bright. And the magnetic fields there are really strong.

Now if you go to slide 26, you see the exact same view of the sun but now you're looking at it in ultraviolet light and you can see all these loops, prominences where the magnetic field traps plasma around the sun. Plasma is electrons and ions.

You got to slide 27 sorry, there's an image of what can happen when those sunspots, those active regions on the sun can erupt and they can create coronal mass ejections which are these big blobs of magnetic field and plasma that shoot out into the solar system and they're huge. They can actually take up most of the inner solar system as they propagate outwards and this image is from the Solar and Heliospheric Observatory. It's a joint NASA and ESA mission that stares at the sun all the time as well.

And what it is it's actually a superposition of two images. There's an ultraviolent image of the sun in the middle but then behind that is an image from a coronagraph and a coronagraph is just a telescope that has a disk in it to block out the light of the sun but you can see the fainter outer regions. It's like a permanent solar eclipse, a permanent but artificial solar eclipse that goes on all the time inside that telescope. And so you paste the pictures together and you can see what the bright sun looks like plus the fainter outer regions, the coronal mass ejection.

So if you go to the next slide this shows another view of another coronal mass ejection. This is slide 28, back in 2000. And you can see all these little dots in the background and those are stars. I don't think there's a planet in there. Sometimes you can see planets but they're usually a lot brighter. And the white circle in the middle shows where the sun would be if that occulting disk wasn't there.

Now if you go to the next slide [29] you can see the end result of some really big coronal mass ejections or CMEs. As they plow out through the solar system they're going so fast that they create shock fronts in front of them and those shock fronts can actually accelerate electrons and especially protons to really high energies. Some of these are going almost the speed of light and so when that happens they can penetrate electronics, they can penetrate spacecraft, and that's the snow that you're seeing in this picture that was from a CME that had passed by a little while before that and it just flooded the electronics with all these energetic electrons and protons. And those are called solar energetic particles or SEPs and I'll try to remember to say solar energetic particles instead of SEPs but if I forget that's what it is.

But now we're getting a little closer to the moon. So if you go to the next slide we'll come back, slide 30 that's an image of the Lunar Reconnaissance Orbiter. It doesn't really look like that. The next slide I'll show you a picture of that. But the hood ornament of the spacecraft at least when the spacecraft is flying in that direction is the cosmic ray telescope for the effects of radiation or a CRaTER which is funny because it doesn't really have anything to do with craters. But it measures solar energetic particles during some of those big events.

If you go to the next slide [31] this is a picture of what LRO actually looks like. It's wrapped in a gray thermal blanket to protect it from the extremes of heat and cold and then I've just put orange outlines around the different instruments and you can see CRaTER all the way up at the top.

Next slide [32] is what CRaTER looks like underneath the thermal blanket in all its - it's actually aluminum. It has a certain kind of finishing on it to make it not look like aluminum.

And then slide 33 shows a cutaway. The instrument has three pairs of detectors that are labeled D1, D2 all the way down to D5 and D6. And in between those pairs of detectors are blocks of tissue-equivalent plastic and the plastic is just a dark black plastic. It's really hard but it's chemistry is similar to the chemistry of the human body so it's like most plastics it's made out of hydrogen and carbon and oxygen.

But then it also has some of the other elements in about the right percentages that the human body does and it was a plastic developed for cancer research to understand how radiation would affect cancer patients so then they developed something that would interact with radiation like the human body would. And so we're flying that on CRaTER to understand how radiation might affect the human body but we're also trying to understand how that radiation might affect the lunar surface too.

So if you go to slide 34, the plot that you see shows a couple weeks' worth of data from 2012, January of 2012 and then on the Y axis is the dose rates. So it's just how much radiation is appearing and the different colored lines on there are from the different detectors and detectors one and two, they face outer space. So they see the most radiation. Detectors three and four, they're surrounded by a lot of plastic so they're protected from a lot of radiation so they don't see as much radiation.

But those spikes that you see late in January those are solar energetic particle events. So you can see it's really quiet and all that flat line that you see is cosmic rays from outside the solar system. They're accelerated in supernova shockwaves so exploding stars can give off cosmic rays and that's kind of just a low flux background all the time. But sometimes you get these really big solar energetic particle events.

So if you go to the next slide, 35 the main point from all of that was that the sun sporadically emits energetic protons and electrons and these particles can actually penetrate the lunar soil just like they can penetrate all the way down to detectors D3 and D4 which are buried and surrounded by all that tissue-equivalent plastic. These energetic particles can actually penetrate into the lunar soil. Not very far but it's far enough for what I'm going to talk about next.

So slide 36 shows a cartoon of what can happen when these energetic particles can penetrate lunar soil. So on the left you see protons and electrons penetrating the soil and it just so happens because of the way that a proton interacts with matter versus the way that electrons interact with matter, the electrons can actually penetrate a little bit deeper than the protons. It's not entirely necessary for that to happen in order for what I'm going to talk about to occur but it's just a nice feature that that generally happens. And so that can create an electric field. So we're putting charged particles in the lunar soil and that creates an electric field.

Well when that happens the regolith doesn't really want to have an electric field in it and so that causes the charging to dissipate and so the charges for the electrons will move towards the protons and then that'll dissipate. So it's kind of like a leaky capacitor problem if you ever encountered that in physics where the capacitor doesn't keep its charge forever.

On the next slide [37] though if solar energetic particles or SEPs can charge the regolith faster than it can dissipate that charging, so it dumps a lot of protons and electrons or one or the other into the soil faster than the regolith can get rid of that extra charging then the electric field can get so strong that it can cause dielectric breakdown or sparking or arching. And that's an image of the little sparks that you see - or an image actually of a piece of plastic that has been sparked in a process similar to this. And so it's basically like little lunar lightning flashes but only in the top millimeter or so of the lunar soil.

And if you go to the next slide, slide 38 you'll see a little popup of the Combined Release and Radiation Effects Satellite or CRRES that was launched in I believe the early 90s and it was to study how energetic charged particles charge spacecraft. So this dielectric breakdown that I'm talking about is actually one of the leading causes of problems on spacecraft especially when they fly through Earth's radiation belt. Earth's magnetic field traps energetic electrons and protons that are kind of like SEPs and so when satellites fly through that they can get a lot of charging and can even get sparking or arching in their circuitry.

So the spacecraft measured that and they actually measured over 4000 sparking events. So we have a really good understanding of what the conditions are that are needed in order to get sparking and it seems like the moon actually has those conditions.

So if you go to slide 39, this is a collage of images over the lunar South Pole and the crater right in the center or almost right in the center, that's Shackleton Crater and you can see a lot of them are pretty dark and a lot of them actually are dark all the time. So if you go to the next slide, slide 40 this is zoomed in a little bit but what it is is it's a compilation of a lot of images of the South Pole of the moon and where it's really light is where there's a lot of sunlight throughout the lunar day and where it's really dark there's never any sunlight throughout the lunar day. A lunar day is about a month or a moonth.

So that's Shackleton Crater then in the middle and the sun does not shine in the Shackleton Crater so the moon's rotational axis is not titled with respect to its orbital plane around the sun whereas the Earth is so for half a year Earth's

North Pole sees a lot of sunlight while the South Pole doesn't and then for the other half of the year the South Pole sees a lot of sunlight while the North Pole doesn't. The moon doesn't have that because it doesn't have the same axial tilt that the Earth does. And so a lot of these craters near the North and the South Pole never see the sunshine in them and they are really cold. In fact, they're the coldest places measured in the solar system at this point.

You can see on the next slide, 41 on the right this is a lot of data collected by the Diviner instrument onboard LRO and Diviner measures infrared radiation from the surface of the moon. So in a sense it's taking the temperature of the moon and the temperature scale goes from purple all the way up to red and white and that goes from 40 Kelvin, so this is in Kelvin. Forty Kelvin is just 40 degrees above absolute zero and then it goes all the way up to about almost 200 Kelvin and you can see the craters that spend the most time in shadow are the coldest regions on the moon the way they're down around 40 Kelvin, especially those three large ones that in a row, kind of like Orion's Belt.

Go to the next slide [42]. So because we have soil samples from the moon through the Apollo programs their electrical properties have actually been measured and one of the things that's been measured is how conductive soil are as a function of temperature. And so that's what I've plotted here and this is the discharging timescale. So the discharging remember is how look it takes for the regolith to dissipate any charge buildup in it. So on the Y axis is the discharging timescale in units of days and then on the X axis is the temperature of the soil.

And so you can see as the soil gets colder and colder and colder, closer to zero the discharging timescale gets longer and longer and longer, up to 20 days, so multiple weeks. So basically, if you charge that soil it's going to retain that charge for a really long time.

If you go to the next slide [43], so now because we know what the charging conditions are like from the solar energetic particles that we measured with CRaTER and we also know what the conditions inside these really cold craters are like we can predict that this sparking will occur in that top millimeter or so of lunar soil. And so this is a plot of the first four or so years of data from CRaTER and on the Y axis is fluence. So that's just a measure of how many particles are hitting the instrument.

And that red line that I have drawn there is our best estimate of what the threshold is for a solar energetic particle event to cause sparking on the moon and you can see that at least two events since LRO has been in orbit have caused breakdown. And throughout the space age it translates to about an event per year. So it might've actually happened recently. So the next slide, slide 44 just sums that up. Large solar energetic particle events might cause breakdown in cold lunar soil.

So you can go to the next slide, slide 45 and this is where it starts to get a little more hand-wavy because some of this isn't published yet but I just want you to see kind of the logic of where this might go. So it's an image of the moon and at the North Pole and the South Pole I've labeled PSRs. Those are the permanently shadowed regions, so the craters where the sun doesn't shine. And in those regions, it seems like dielectric breakdown can be really important.

So breakdown or sparking can melt and it can vaporize material and that's actually just what a meteoroid impact can do. That can melt and vaporize material and it seems like in those permanently shadowed regions if breakdown is happening it can actually be as important as meteoroid impacts. So as important as the things that are making all the craters that we see.

The night side of the moon though also gets very cold down near 100 Kelvin, sometimes it's lower than that, maybe 80 Kelvin. And so on the night side of the moon it can also have the conditions needed for breakdown and you might say hey but these solar energetic particles are coming from the sun so they can only hit the day side. But it's a weird function because the particles are charged and they're traveling through the sun's magnetic field which spreads throughout the whole solar system. So they actually gyrate around the magnetic field and so they can spiral around and hit the moon on the night side instead of just on the day side and we've actually seen that with the CRaTER data.

And so it seems like sparking can happen. It still prefers the really cold locations that happen at higher latitudes. The equator tends to stay a lot warmer even during the lunar night but it seems like sparking could be important even at lower latitudes which suggests that maybe there might be sparked material in the Apollo samples. It's just it's not a form of space weathering that we've considered and it melts and vaporizes like meteoroid impacts. So it might just be masquerading as the byproducts of a meteoroid impact.

Go to the next slide [46]. This is a piece of plastic that I picked up. If you go to capturedlightning.com, I was not paid to advertise that but there's an engineer who actually sells products that are based in just what I'm talking about. He sends pieces of plastic through an electron beam and that causes sparking and so this is a piece that I actually ordered from him. And so energetic electrons are shot straight down into this piece of plastic and then when the electric field becomes too much it actually creates sparks inside the material.

And all those little channels that you see in this Lichtenberg figure are actually hollow channels and you can kind of see if you go to the next slide, slide 47, you can start to see they look like little scalloped shells, especially along the major branches and you can see where it's changed color and gotten brown. That's actually where the plastic has kind of separated to create these channels inside there. And then all this hot gas rushes out of the channels and is expelled in that top corner piece in the plastic.

So if you go to the next slide [48] this is the cartoon version of that. Here's a little grain of soil sitting on top of the regulate and let's say that it's two pieces of different minerals that are stuck together by glass and dielectric breakdown or sparking prefers to occur along those boundaries. So let's say that there's a spark, one of those channels that runs through it and the spark blows the pieces apart and now you get production of vapor caused by vaporizing some of that material. There's also some melted material that gets ejected and that can be deposited on the surrounding soil like you see in the bottom panel.

And so this might be a way to split grains, maybe even to fluff up the soil a little bit which has implications for some of the observations that we have of the lunar surface where it seems like some of these colder craters are a little more fluffy than craters that do see the sun. You can go to the next slide [49] and that's just reiterating that breakdown weathering might be important, an important process on the moon.

Now on the next slide, slide 50 and this is even getting more hand-wavy. These are just some ideas that I've had and looked into a little bit. Mercury also has craters that are permanently shadowed and they're also very cold and it's closer to the sun so it gets more solar energetic particle events. They're bigger events at Mercury so maybe it gets some sparking as well.

Some asteroids like Vesta, they're kind of like the Earth. The North Pole's in shadow for a while then the South Pole's in shadow for a while. Well when it's in shadow it gets really cold so it could possibly experience some sparking during a big solar energetic particle event. There's a lot of objects like that in the inner solar system.

As we move towards the outer solar system and you can go to slide 51 the solar energetic particles kind of drop off. There's not as many of them in the outer solar system. But there are really strong radiation belts and Jupiter has a radiation belt that's much stronger than Earth's. And actually, when Voyager 1 flew through Jupiter's radiation belt it experienced a lot of sparking inside its electronics just like spacecraft do when they fly through Earth's radiation belts.

And this image is not to scale except for Jupiter and the rings I think might be roughly to scale. But the four little satellites that you see, Metis, Adrastea, Amalthea, and Thebe and I don't remember which one is which off the top of my head. They're really, really tiny and they're the source of the rings of Jupiter, so just material that gets kicked off of them. But all four of them are pretty cold and they're orbiting right in the heart of Jupiter's radiation belts.

So they could be getting fluxes of energetic particles that are enough to cause sparking on them and they have some really weird features on them. All of them have a strange asymmetry between one hemisphere and the other, one is darker than the other and people have been scratching their heads about why that is. So maybe sparking's happening here. I'm not saying that absolutely has to be happening but it's very interesting. So hopefully someday I can look more into that.

So the last slide [52]: so it seems like breakdown weathering is a possibility on the moon and that it could be really significant, especially in the craters that don't see any sunlight but even possibly down to lower latitudes. And these conditions for breakdown weathering occur elsewhere in the solar system. We know the conditions from having measured them with spacecraft and now we can predict where it might happen in the solar system.

And I've started collaborating with some people at the Applied Physics Lab at Johns Hopkins to develop experiments to try to figure out what are some of the observational signatures in the soil of sparking as opposed to meteoroid impacts. If they're both melting and vaporizing material, is there a way to distinguish between the two of them so that we could go back to the Apollo samples and say hey this isn't actually material that's caused by an impact. It's actually caused by breakdown. So that would be pretty cool. And we're also looking into ideas for how you could detect breakdown during a really big solar energetic particle event. Although the sun is not cooperating because it's been pretty quiet recently.

So that's it on my end and I don't know if we're opening it up for questions or what are you thinking?

Heather Doyle: Yes are there any questions for Dr. Jordan? That was great. Thank you so much.

Adrienne Provensano: Yes hi. This is Adrienne Provensano Solar System Ambassador and I'm wondering do you have any information on what SEP events occurred during Apollo missions?

Andrew Jordan: So what solar energetic particle events have occurred?

Adrienne Provensano: Right, right.

Andrew Jordan: Yes there are data going back even before the Apollo mission. So we have a pretty good idea of how many SEP events there have been during the space age.

Adrienne Provensano: And then what kind of impact does your research have on returning humans to the moon and where they might want to be?

Andrew Jordan: Oh. Yes. So these sparks are really tiny. It's more like if they happen it's probably more like what you would get when it's been a cold day and you touch a doorknob and you get a little zap. It's more like that. There's not much current in them. So you don't have to worry about that. In an event like this that's big enough to cause sparking if it did you would be more worried about the SEPs directly affecting your body because that would be a really big radiation dose. And that's one of the reasons why CRaTER was developed was to understand how these SEPs affect the human body. And there was a really large SEP event that happened in between the last two Apollo missions and if it had occurred during one of the Apollo missions while the astronauts were out spacewalking it could've been pretty bad. So that's more the concern than the sparking is.

Adrienne Provensano: And that's something that's applicable to any missions anywhere.

Andrew Jordan: Yes especially in the inner solar system.

Adrienne Provensano: Right. Okay thank you.

Andrew Jordan: Yep.

Heather Doyle: Are there any other questions?

Dave Paris: I have a couple. This is Dave Paris Ambassador from New York. The picture of Cernan on the moon, the picture on the right with the dirty spacesuits the helmet is covered with some kind of hood but it doesn't show up in the left picture. Just wondering what that is.

Andrew Jordan: Yes. Oh great eye for detail. So just for flying on the rocket all they needed was the one helmet that you see on the left and you can see there's an extra blue shiny thing on the back that would protect the helmet from the headrest. And then once they got to the moon they actually put on a few more pieces to the helmet, including the gold visor that you see on the right and then that covering. And then there were actually - you don't see it on this helmet. There were other gizmos that could attach to the side and to the top so that you could have sunshades on either side, sort of like a baseball hat only on all three sides around your eyes.

Oh and if you notice too - I was staring at the picture when I put the talk together. On the left it sort of seems like Cernan has a double helmet.

Dave Paris: Yes.

Andrew Jordan: Yes and it took a little bit of digging but it turns out that while they were suiting up and getting into the spacecraft they had a protective outer helmet that didn't go all the way around their head but it was just to protect their real helmet from getting scratched. So that's what it was and you can see it in a lot of the pictures before they fly. I thought I was going a little crazy there but no it's real.

Dave Paris: Oh very good. Other question: the picture of the tiny dust particles where one is spherical.

Andrew Jordan: Yes.

Dave Paris: I'm looking for that again. And there's one in the upper right-hand corner that looks like a dumbbell.

Andrew Jordan: Yes.

Dave Paris: That looks like it probably was also…and then - yes. So the one in the upper left you said was a…but the one includes something that looks like a dumbbell. So is that just two little spheres that almost joined or any idea?

Andrew Jordan: Yes so the dumbbell features as I understand can form when material is spinning really rapidly and on Earth there are - and they're not sure exactly how they form but they're called tektites and I've actually bought one off a meteorite collector near here and they're dumbbell shaped. So they're glassy material and as they went whirling through the air it seems like it just forms a dumbbell shape. And as it's whirling it's also cooling and eventually it just becomes glass, solid glass while it's spinning.

Dave Paris: Super thank you.

Andrew Jordan: Yes. You're welcome.

Woman 1: Dr. Jordan on slide 10 could you possibly offer an explanation as to why there are so many impact candidates on that one side rather than the other? Seems like there's an awful lot right there.

Andrew Jordan: It does. And it seems like it's pretty sparse in the middle. There are two things that I can think of off the top of my head. One is it could be a function of a lunar phase. So it's easier to see impact flashes when they're in shadow than when they're on the bright side of the moon although as you can see in the picture and behind it but that's a pretty bright flash. But for some of the fainter ones it might be a lot harder to see. So that might be one reason why they tend to cluster towards one side or the other. I'm not positive about that though. And the other reason could be you tend to get more impacts in the direction that the object is traveling. That's sort of like when you're driving through snow it seems like all the snow is coming directly at you. It's not exactly the same thing but it's kind of like that. And so the west or the left side and the right side of the moon, those alternately are the sides that are plowing into material. So it could have to do with that too but I'm not going to say anything very firmly. Those are just a couple ideas.

Woman 1: Thank you.

Andrew Jordan: Yes no problem.

Man 2: Question.

Andrew Jordan: Yes?

Man 2: So what does SEP stand for again?

Andrew Jordan: Solar energetic particle.

Man 2: Thank you.

Andrew Jordan: And you might see it in the literature. It's a bunch of different ways. Sometimes you'll see SPE which is a solar proton event. Sometimes you'll see SCR which is a solar cosmic ray. That's more often in the older literature although some planetary folks still use that. I think I've even seen ESP. So we have SEP, SPE and ESP, an energetic storm particle or something like that. It kind of gets confusing. Just what everyone wanted to know, right?

Man 2: Thanks.

Andrew Jordan: No problem.

Heather Doyle: Any other last questions?

All right well thank you so much for the presentation. That was fascinating. Our next presentation will be tomorrow at noon and it's another astrobiology presentation and it's by Dr. Jackie Goordial. So we look forward to hopefully saying hi to you all tomorrow afternoon. Thanks again everybody.

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