The New Moon
Dr. Jeffrey Plescia,
Johns Hopkins University Applied Physics Laboratory
Moderator: Anita Sohus
April 12, 2016
2:00 pm CT

Coordinator: Welcome and thank you for standing by. All lines are open and interactive during today's conference.

To avoid any background noise, please utilize the mute feature on your phone or press star 6 to mute and unmute your line. Today's call is being recorded. If you have any objections, you may disconnect at this time.

It is my pleasure to introduce Ms. Amelia Chapman. Thank you ma'am, you may begin.

Amelia Chapman: Okay great, thank you so much. Welcome everybody. This is Amelia and thank you for joining us today for the Museum Alliance Professional Development Conversation - The New Moon.

As our Operator said, please make sure your phone is on mute, not just on hold.

Also, the slides for today's presentation can be found on the Museum Alliance and Solar System Ambassador site. If you have any problems, contact me at Amelia.J.Chapman@jpl.nasa.gov.

Our speaker today -- Dr. Jeffrey Plescia -- is a planetary scientist at the Johns Hopkins University Applied Physics Laboratory where he's worked since 2004. He previously worked at the U.S. Geological Survey and the Jet

Propulsion Laboratory, plus he served two temporary assignments to NASA Headquarters as the Planetary Geology and Geophysics Program Manager and as part of the Mars planning effort.

His research interests include the geology of the Moon and Mars. Recent areas of research include understanding impact mechanics and the formation of impact melt at Lunar craters.

He is currently working with the imaging experiment on the NASA Reconnaissance Orbiter.

Jeff has indicated that he's happy to take questions as we go through the talk, and so with that, I will turn it on over.

Dr. Jeffrey Plescia: Slide 1: Hi, it's nice to be here and talk about the Moon to you guys. If you have any questions, just yell until I answer as we go through.

Slide 2: So the second slide is just a view that you typically see of the Moon from the Earth. This is the view everyone has of the front side because the Moon is tidally locked; the same side always faces the Earth. And for most of history, this was our only information about the Moon.

Back in 1959, the Russians -- or the Soviet Union at that time -- sent a spacecraft called Zond, and it went around to the far side of the Moon and produced the first pictures of the backside.

And then subsequently, there were a whole series of robotic missions and the Apollo missions that got a large variety of data as well as samples. And now over the last, say, five or six years there have been a whole number of spacecraft and orbiter around the Moon from a number of different countries.

And as a result of all that, our view of what's going on on the Moon has really changed. It's a much more dynamic and interesting place than we might have thought 10 or 20 years ago.

Slide 3: The third slide is just a view of the Moon's orbit. And the interesting aspect about the Moon is that its tilt is very small; it's only about six degrees whereas the Earth is about 23-1/2 degrees.

The result of that is that in areas that the poles where you're in a deep crater they are permanently shadowed. The sun never gets above the horizon, and in many cases, even the Earth doesn't get above the horizon.

And I'll come back to this later, but the temperatures of some of those craters are 40 degrees Kelvin, and that's colder than Pluto.

Okay, the next slide, Slide 4, Nearside/Farside Sunlight -- the pictures show a mosaic of LROC pictures -- the Lunar Reconnaissance Orbiter Camera. And this shows what the moonlight looks like. But in a perspective you will never see in reality, basically what this shows is a series of little image strips taken at about noon in each place and then glued together.

So effectively, everywhere the sun is directly above the surface everywhere. And in reality, that never happens. The sun is always in one place at the part of the sky and so you see shadows and part of it as darkness. But it shows what the front side and the far side look like if you could illuminate them all at one time directly overhead.

And what you can see -- as everybody knew -- the front side has these big bases full with young -- relatively young mare lavas. And the far side is largely ancient crater terrain.

This next one, Slide 5, it says Nearside/Farside Laser, is a different kind of picture. There is a laser altimeter on the Lunar Reconnaissance Orbiter and it continuously shoots down at the surface to measure the elevation.

But it also -- since it reflects back to the light -- you get a different perspective in this picture. This is taken from - this is essentially all those little laser shots put together into a global view. I'm come back to the neat thing about this experiment in a minute.

The next slide, Slide 6, the Poles Sunlit. It gets back to this bit about because the sun is always low on the horizon at the poles; there are areas of permanent shadows that we can't see into. And this is particularly true at the South Pole -- which is the picture on the right -- and you can see all those areas are shadowed that don’t get any sunlight, and so we really couldn't see what was going on there.

But using the laser -- if you go to the next slide, Slide 7, the pole's laser, you can see everything in those permanent shadows. This doesn't look much like the last picture, but the North Pole is on the left and the South Pole is on the right. And it looks different because there are no shadows in this case. That's because we are illuminating the surface from above.

So as a result of all this data, we can now see a whole bunch of neat things that weren't able to see in the past.

Slide 8: I just wanted to illustrate the effects of lighting on what you see in this slide called Illumination Effects. These are some old Apollo pictures, and what they show is a large impact crater on the top and an area in the highlands on the bottom.

And you can see, as a result of the sun getting closer and closer to the horizon as you go from left to right, the surface gets a more exaggerated appearance. And the difference is when the sun is high -- like it is on the left -- mostly what you see are albedo features, whereas on the right -- when the sun is low -- you can see all sorts of subtle topographic features. And so using this kind of data, we can understand what's going on in terms of different materials on the Moon and topography.

Okay, next one, Slide 9, is Average Polar Temperatures. As I said, because the poles are largely permanently shadowed or large areas are shadowed for long periods of time, it gets very very cold up there. The lunar surface doesn't conduct heat very well.

And so when these two view -- of the North Pole on the left and the South Pole on the right -- the purple and sort of violet colors are very cold -- down to 40 or 50/60 degrees Kelvin. And as I said, Pluto is about 40 or 50 Kelvin so the temperatures on the Moon are like minus 400 degrees Fahrenheit. It's very very cold and it's always like that because no light gets into those areas.

You can see the orange and red areas as you get away from the pole -- get warmer because they get sunlight for various periods of time, and just like on the Earth as you go towards the equator, the average temperature goes up. And the same is true for the surface of the Moon.

The next slide, Slide 10, Polar Temperatures, the interesting thing is the graph on the right. It kind of shows what the temperatures are. But the important point here is that when you get down below about 120 or so Kelvin, a lot of stuff freezes out; water ice freezes out, methane, ammonia, CO2, O2. You get all these gases that if they got into these polar craters would effectively turn into ice and be there for a long period of time.

You can make models and think about the cratering that has occurred and how all those get transported. And one of the current ideas which we'll come back to in a few minutes is that there are big pockets of water ice in some of the permanently shadowed areas of the poles.

And it's neat from a science perspective, but if you get into the business of space exploration, if we could get out those ice deposits, we could use the water for rocket fuel by converting it to hydrogen and oxygen and then recombining it into water and use it as a rocket fuel.

The problem is the stuff is in these deep craters, it's very cold and it's dark. And so getting in there and mining this stuff would be a considerable engineering enterprise.

And we don't really understand how this stuff is distributed below the surface -- whether it's in big glacial sheets buried by some regalia, or whether it's just fine grain ice mixed in with the regalia, and that would have very different implications for how you might mine stuff on the Moon.

Okay, Landing Sites, Slide 11. There's a perception that we've sort of been everywhere on the Moon and done everything. This just shows the landing sites for both the U.S. and Soviet lander missions as well as the Apollo missions which are in blue. And then the most recent thing was the

Chinese/China lander is in the upper part of Mare Imbrium. It's the northern most orange dot. That was the lander that had a small rover that surveyed the immediate area around the landing site.

But we've only been to the front side. We've only been mostly to the Equatorial side. We did send the last surveyor down to the rim of Tycho Crater at the bottom. And like I said, the Chang’e rover went up to the northern part of Mare Imbrium.

But we haven't really been in the deep highlands. You can see most of these sites are on the Mare or next to the Mare. The only true highland site we went to was Apollo 14. So we really haven't explored the highlands of the moon which in fact make up the bulk of the moon surface.

And even - if you think about how far these guys got when they were on the surface, the next one, Slide 12, is the Apollo 11 traverse -- sort of overlaid at the same scale on a Washington Monument.

They didn't get very far; they were only there for a short time. But, I mean, they went a quarter of a million miles and they never even made it to the gift shop in that context.

Apollo 17 next slide, Slide 13, which was the last Apollo mission with a crew -- got across a much larger area. They had three EVAs, they had the rover, and so they were able to explore a huge area around the moon and collect samples from a diverse set of terrains. They landed in a valley and they were able to go across the valley to the mountains on both sides and sample those as well as sample the material on the valley floor.

I just want to show you some of what we've been able to go back in sort of history of the Apollo program that we can see in the LROC pictures. Slide 14, this is an oblique view of the Apollo 15 landing site taken from LRO. The landing site is sort of in the middle in the flat area just east of the rill which is that meandering low area on the north.

The next slide, Slide 15, also labeled Apollo 15 -- shows that we can actually see the Lem -- the bottom of the Lem). The top of the Lem took off and returned the astronauts to orbit. But you can see their footprints; you can see where the rover was parked a little bit off to the right there.

And then to the upper-left, you can see a whole cluster of little white dots and lots of footprints, and that's where they deployed all the experiments. And we can actually identify each individual experiment and figure out what it is - where it is.

And this is particularly important for the sampling sites. As they were on their EVAs, they sort of guessed where they were, they had some pictures taken from orbit and they were trying to figure out where they were in some cases. And some of that wasn't very exact. But now that we can go back and trace out the rover tracks and the footprints, we can figure out exactly where they were and exactly what they sampled and put those samples into context.

Amelia Chapman: I had a quick question for you.

Dr. Jeffrey Plescia: Yes.

Amelia Chapman: Yes, the slide with the Apollo 17 overlaid -- that's on DC I'm assuming.

Dr. Jeffrey Plescia: Yes.

Amelia Chapman: Yes. Is that available? Is that so that people can maybe use that and put it over their own cities to help put it in context for the people in their audience?

Dr. Jeffrey Plescia: Yes, all - the EVA, the dark lines, you can find those on the Web if you just type in Apollo 17 Traverse. And then you just lay it on top of your picture.

Amelia Chapman: Okay. So it's easily found.

Dr. Jeffrey Plescia: Yes. Yes, you just have to, you know, you've got to scale it correctly, but otherwise, you can find the traverses in just a line form for all the sites.

Amelia Chapman: Okay, great. Thanks.

Dr. Jeffrey Plescia: Okay, to go back to the slide called Apollo 14, Slide 16, I just want to emphasize how little things have changed since the crew was there.

On the left, there's a picture of a couple of instruments and this long flat ribbon wire that connects them. And the ribbon wire was laid flat on the ground. And we discovered when we took a picture near noon -- which is the picture on the right side -- you can see that long white line that connected to the two brighter white dots.

Turns out, that bright line seen from orbit is this little narrow wire on the surface; it's perfectly flat, the sun is directly overhead, so it reflects all the sunlight back. And in the 50 years or 40 years since the crew was there, there hasn't been much change because you can still see all the footprints and you can still see the reflection from the wires.

Slide 17: The other thing we're able to do -- like I just mentioned -- about the samples, this is the Apollo 17 Station 6 Boulder. So the crew went to the north of where they landed -- to the foot of a big mountain -- and they sampled this giant boulder. And you can see in the large image, Gene Cernan over there in the rover on the right, and this rock which is 10 or 20 meters across and 10 meters high.

The upper two pictures are pictures from above. And essentially, this boulder rolled down the hill and broke up when it stopped at the bottom of the hill, and you can see the pieces in these two pictures in the upper right.

And so we can correlate the pictures very well -- the pictures we took on the ground with the things we can see from orbit and figure out exactly where they sampled and where that rock originally came from.

Okay, the next slide, Slide 18, says Apollo S-IVB. This is a different kind of thing we did to the Moon. This was the upper stage of the Saturn V. This was the stage that put them on their way to the Moon from Earth orbit.

After they got on their way, the command module turned around and plucked at the lander out of the top of the S-IVB, and then they sent the S-IVB on its way.

What they did was to send it to the Moon to impact the Moon for the seismic experiments that were deployed on the surface of the Moon. This was similar to an earthquake, but in fact, it was an impact. But a generated a lot of energy in the Moon, and with the seismometers that are on the surface, you could determine things like the velocity and layering and whether there was a core and stuff.

And the next slide, Slide 19, called Apollo 15 S-IVB impact crater shows what the impact crater actually looks like. There's a picture on the right which just shows the general areas out in the middle of the Mare, and the pictures on the left show the crater at high sun and low sun and then a regional image. And you can see these long bright rays that extend out three or four or 500 meters from the crater.

These craters are very funny because they're shallow, they have this big lump in the middle, and it's probably because the impact of the booster was essentially the impact of a tin can. All it consisted at that point was empty fuel tanks. So when the rocket hit the surface it didn't make a crater, but because it was a funny kind of projectile, it made a funny crater.

Slide 20: The other craters we made -- Ranger 9 Impact Crater -- the first U.S. missions to the Moon were a series of spacecraft that just were aimed at the Moon, took pictures as they went towards the Moon, and eventually just crashed into the surface.

And left picture shows the floor of Alphonsus Crater where Ranger 9 impacted, and then the cluster of pictures on the right, you can see when that impact crater looks like.

These kinds of experiments are -- they weren't experiments really at the time -- but now, we can go back and look at those craters and understand some things about crater mechanics because we know how fast the spacecraft was going, we know how much it weighed, and we can determine things about the cratering.

Slide 21: The next one is called Soviet Lunar Missions. The Soviets sent a whole bunch of missions to the Moon including landers and sample returns and rovers, but the problem was they didn't really know where they were. They had a general idea, but in some cases the missions were fully conducted at night -- like this sample return at Luna 24 -- so they didn't have any pictures of the surface, or they were only on the surface for such a short period of time that they really couldn't get tracking data.

So by going back and trying to find all these things, we can understand better where these missions landed and what kind of data they collected. And in the case of the sample returns, what material was actually sampled.

In this particular case -- Luna 24 -- you can see that it's a dark blob in the upper left picture just outside the northwest rim of the crater. And in the inset in the lower left just shows the spacecraft.

The samples that returned from Luna 24 were not what they expected. They assumed they would be mature Mare material because they landed in Mare Crisium. When they got the samples back, they were all immature and no one could understand why.

And the reason we found out -- once we found the spacecraft -- was because it had sampled the ejecta from this crater which was material from depth that had been deposited across the surface. So we now we understand why those samples are like they are.

The central image shows Luna 23 -- which landed only a few kilometers away -- but it failed. It landed - they could still talk to it, but nothing would happen. And they didn't really know what the problem was.

Well it turns out -- when we found the lander -- we realized it had fallen over. You can see on the bottom a comparison between the picture and a drawing of what the vehicle might look like on its side. And we've concluded that basically, the thing came down too hard and fell over. So the transmitter was still working so they could talk to it, but nothing was going to happen because it was laying on its side.

The last one on the right is one of the Lunokhods -- one of the two rovers they sent out -- and you can follow the tracks from the lander all the way out to where the rovers are and see exactly where they went.

But we can see the details of the rover in this inset in the lower left. The thing called L is the lid; this thing had a lid that opened and closed to keep things warm at night and to collect solar power during the day. And on the right end is a laser reflector that was used to track it.

The next slide, Slide 22, Luna 20 -- this was another sample return. And only put this in there because you can, if you look at the yellow arrow, you can actually see the shadow sample canister mechanism. They drilled a core, they brought it up, and with this little arm-like device, put it into the return capsule. But you can even see the shadow of that feature now on the lunar surface.

Slide 23: Now the last mission I want to talk about is the Chang’E Rover. In the center is an orbital picture before and after the landing, and you can see the little white dot that represents the lander. If you know where to look -- and I didn't annotate it and I'm sorry -- you can actually see the rover a little bit south of the lander.

And the picture on the upper left just shows what the lander looks like from the rover, and in the lower right, what the rover looks like from the lander.

Slide 24: The next one says Ground Penetrating Radar. This is just meant to illustrate one of the experiments that was conducted on this rover.

They had a ground penetrating radar and they followed the green path that you see on the right. And the little cartoon on the left is what they found. They found layering in the subsurface, and we can interpret that material as a thin layer of regolith -- which is the red stuff -- and then the yellow stuff is the ejecta from a big crater that lies just to the west.

The orange material is the underlying Mare surface in regolith, and the blue is the underlying Mare as well. So from the short traverse, we're able to see a lot of the details of the Luna's stratigraphy.

Slide 25: Okay, now back to a little more science. The next one is called WAC Illumination Maps. And this goes back to the bit about the areas of permanent shadow on the Moon. This shows the North Pole on the left and the South Pole on the right and how long areas are in fact illuminated over the course of a year.

And you can see around the crater rims, they're illuminated, half or sometimes more than that. There are actually places near the South Pole and near the North Pole where there is almost continuous sunlight which - and this is really important if you're going to go to the Moon and you want a permanent outpost. If you go the poles, you can place the thing. So as I said, it's almost always sunlight and so you can use the sun for solar power.

But in some of the bigger craters, you can see are essentially black or very dark blue and they never get any direct sunlight. A few of them get some sunlight scattered off the rim, or in a few cases, you can actually see the Earth from the interior. But they don't get any sunlight and so it's very cold.

The next one, Slide 26, is called Diviner Thermal Anomalies. One of the weird things that we found is that the ejecta from some fresh craters can be very cold. The picture on the left is a sort of temperature map where red is hot and the blue and violet colors are cold. And you can see a little red dot in the center; that's the impact crater that's shown on the right in the visible image.

But you can see around the crater on the left is this purple area. And what that's telling us is that the surface is relatively cold by about ten degrees compared to the surrounding areas, and it's not clear why it's cold. You would expect the ejecta to have lots of blocks in it, and so you would expect that it would be warmer than the surrounding area because the blocks would retain the heat. But in a lot of cases, the stuff is cold and we really don't understand why.

The next one, Slide 27, is the Surface Block Abundance. This is just, again, this is thermal data. And what you can see, this shows the whole Moon, and you can see that most of the Moon is sort of colored in this blue color -- which indicates that there aren't many rocks in it; there's only a few percent.

You get into the Mare areas and you can see the blue gets brighter which indicates that there are more rocks, and in a couple of cases, you can see some little red dots. The prominent one on the bottom of the large figure is Tyco, but the zoom-up picture shows Copernicus.

And you can see that the inside of a lot of the craters have lots of rocks whereas the surrounding areas don't have many rocks. And from the color pattern you can see is that the highlands typically have very few large rocks on the surface, and the Mare have much more. And the reason for that is because the Mare are relatively young basalt flows, and so when you have an impact crater, you excavate the crater and throw blocks around the surface, and so they're rocks.

In the highlands, most of the highlands is made up of the ejecta from the giant basins early in history, so that stuff is already broken up. And when it gets impacted a second time, there's not as many rocks as there are in the solid Mare basalts.

Okay, so I'll talk about volatiles for a little bit. This slide, Slide 28, Sources of Lunar Polar Volatiles – we know there's stuff – volatiles - on the Moon. We saw them in the Apollo samples. But as a result of all the recent LRO data, we now understand a lot more.

Lots of places where volatiles can come from. You can have an impact from a comet, the solar wind interacts with the surface and makes water, and other kind of things can bombard the surface and just material falling in at random. So there is a lot of source from Space to add volatiles, as well as whatever came out of the room originally.

Okay, so the next one, Slide 29, is just a cartoon. Sources of migration of volatiles. When stuff is at the surface, it gets heated up by the sun. It tends to get energized and bounce around a little bit. Some of it just goes away from the Moon. Some of it hops along. And eventually, it can wind up trapped in the Polar Regions, particularly in the permanently shadowed polar craters.

So this is a sort of a schematic of how you can make water and how it can either get lost in the system or it can wind up moving across the surface.

The next slide, Slide 30, Polar Volatiles Hydrogen – this shows neutron data from orbit that indicates the amount of hydrogen in the surface, and you can see that in the Polar Regions that are illustrated in blue here, there's a whole bunch of hydrogen in the subsurface.

From the neutron data alone, we don't really know what this is. It could just be hydrogen. Or it could be water ice, or it could even be methane. From the neutron perspective, you don't care. You just know its hydrogen. But there's other data to tell us what's going on.

The next slide, Slide 31, called Polar Volatiles Water Frost - and this just shows the South Pole. Somebody have a question?

Okay. This just shows the South Polar area, and the blue shading indicates places where the ultraviolet signature suggests that there's water frost on the surface. Again, these are all areas in permanent shadow. It's very cold, and so what this would tell us is that as water molecules move across the surface, they wind up in these cold traps, and they just sit on the surface.

The next slide, Slide 32, Volatiles LCROSS - when LRO was launched on its way to the Moon, the booster was used as an experiment, similar to what was done during Apollo.

They attached a small spacecraft on top of the boosters, so after the boosters sent LRO on its way, this little spacecraft detached from the booster, and the booster was impacted into an area near the South Pole. And what it did was throw up a bunch of material that was excavated from the crater into the sunlight so that it could be looked at spectrally.

The next one, Slide 33, the squiggly lines called "LCROSS Mission" - I don't want to get into a lot of detail, but this just shows the specter of the stuff that was tossed up into the sunlight. And the key point about this was that a whole bunch of water was seen in the debris that was tossed up, both in terms of solid H2O ice as well as H2O in a vapor phase.

The other thing they saw quite a bit of was mercury. And the reason is because mercury has a – is stable at those temperatures, and it had condensed into the surface. So this tells us that a lot of the hydrogen is in the form of water and that there are big – large - amounts of water ice in the subsurface.

So this confirms the speculation that there's ice. There's also some radar data that is similarly indicative of solid ice. So we know at least locally there are big patches of ice. Whether all the hydrogen is in the form of H2O, we don't know because we haven't seen much below the surface.

Slide 34: The other neat thing about volatiles is that this just shows some data that was taken from a mission called LADEE, which orbited over the equator for close to a year. And what you can see in the plot here is that the blue is sodium and the orange is potassium that was observed by the spacecraft, and you can see there is a sort of up-and-down pattern to it.

And it turns out there are times when there's lots of sodium and potassium above the surface are also times when there's meteor showers going on. And the idea is that the micrometeor bombardment goes up, and you make lots of little craters on the surface, and you release the sodium and potassium that's in the surface material as well as whatever might be in the micrometeorite.

And so you see this periodic release of material. There's always stuff getting released, but during meteor showers it goes up considerably.

This mini-RF slide, Slide 35, is out of order. That's why I'm sort of coming back to it. This just shows the radar data that indicates that there's water ice.

Basically, the LRO spacecraft listens while a big radar antenna from the earth beams signals to the Moon.

That signal gets reflected off the Moon and collected by the spacecraft. And as the spacecraft moves in orbit, the geometry changes and, depending upon what the signals look like, is a function of that geometry. It indicates the presence of water ice in this particular place.

This is also where the L-CROSS Mission occurred in Cabeus crater. So the radar data tells us there’s water ice there. The impact tossed water ice up into the sun. And so at least in that particular location, we know there’s water ice.

Okay. This next one, Slide 36, I don’t think it will work as a PDF, so all you may see is a picture of the Moon. If you have the PowerPoint, what you’ll see is the crater coming and going, which is a new impact that was discovered. So if you go to the next slide, Slide 37, also labeled March 17th, you can see it. This is the before-and-after picture - just static - and you can see the bright impact crater that formed.

The crater is about 20 meters in diameter. The meteor that made it was about 40 kilograms. It was probably about 30 or 40 centimeters in diameter. And it hit the Moon, made a big crater and, in fact, in this case the flash was seen from the Earth.

There’s an observation program at the Marshall Space Flight Center in Alabama that monitors the Moon, and they see all kinds of little flashes. The problem is most of them are so small that it’s very hard to figure out which crater – which bright little crater - is in fact new. In this case, the flash was pretty big. We had a picture before the flash, and we got a picture after the flash, and low and behold, there was the crater.

And we’ve seen other craters form as well. This next slide, Slide 38, is from September 11, 2013. It’s the same view – the Sun is a little different, but you can see the 40-meter crater on the south side of that crater rim and the ejecta.

And so, by counting the number of craters, and measuring their diameter, and figuring out when they occurred, we can figure out what the current cratering rate on the Moon is.

And it turns out that - at least from the recent data we’ve gotten - the cratering rate appears to be higher than what was predicted from the Apollo samples and all their information. But we’ve only been there for about six years. That’s a very short time, geologically. So it may just be statistics.

We’re going to continue to collect data to see what happens; how many craters form, whether there’s any periodicity to any of this. But we can see things as small as a few meters, and if we know – if we take pictures before and after in an automated way, we can just compare them, and then we can detect very small features.

In fact, there’s lots of little sort of splotches and albedo changes that have been observed. They’re in just little secondary craters or debris thrown around. You can’t resolve a crater, but you can see the splotch. And so there’s lots of stuff being tossed around on the Moon.

Slide 39: There are also landslides. This picture shows a picture on the right, which is just the view of the surface. The picture on the left is kind of a difference picture. And you can see that those dark streaks extending down the slope, which are little landslides.

Slide 40: The next picture just has the lengths shown. So what basically this landslide on the left went down the slope of the crater more than a kilometer - the one on the right, a little under a kilometer.

But by taking pictures at different times, we can compare them and see this kind of movement. You can see the little bright tails going up. That's where the landslide started. Downhill is to the lower right.

So probably there was either – something had to trigger this landslide. It's possible there was a small impact somewhere in the area, or there was a lunar earthquake and shook the surface enough to dislodge material and have it flow downhill.

Okay. The next. Slide 41, the rest of the slides here are just kind of nice visual slides to give you an idea of things you can see on the lunar surface. This is a view of the Apollo 17 landing site. The valley on the right-hand side with the big shadow from the mountain is the valley in which they landed.

It landed at about in the middle of that where the cluster of craters is. And they drove the Rover all the way up to the hills on the left as well as to the mountain on the right.

And cutting across the valley floor, you can see a little squiggly line, and that's a wrinkle ridge. It's a thrust fall. And you can – and they went all the way there. So they covered quite a bit of ground during the three EVAs that they had.

This next slide, Slide 42, shows Giordano Bruno. This is a very young impact crater. It's about 20 kilometers in diameter. There was a suggestion in some old literature that some monks in the 16th century may, in fact, have observed the big flash on the Moon that might have been Giordano Bruno. We don't know. We don't really know how old this crater is. It's very, very young. Everything is pristine.

There aren't many craters on it, so it's very young. But whether it's only a few hundred years old, or a few thousand, or maybe a million years old, we don't know. But it's one of the biggest, freshest impact craters on the Moon.

The next slide, Slide 43, just slows the central peak of Tycho. This is a large crater. On the front side it has an enormous mountain in the middle, and this just shows what the interior of the crater looks like at low Sun.

This is Central Peak. It's the big mountain in the middle. And you can see all the lumpy stuff in the areas surrounding it. That's all impact melt that was formed when the impact occurred. It melted a lot of crustal material that ponded on the crater floor, and the central peak sticks up through the melt.

This next slide, Slide 44, also called Tycho – you can see this big boulder in the middle. That's sitting on top of the central peak. And that boulder is about the size of a baseball stadium, for scale.

So that boulder got uplifted and then in some of the other pictures we have, it can be seen to have rolled down into this little low area where it currently sits. But just to give you an idea of scale, I mean, that boulder is several hundred meters across.

Slide 45: And this last sort of oblique picture – this just shows the central peak of Tsiolkovskiy. This crater is a large complex crater is a large, complex crater on the far side, but it has – in addition to having melt somewhere underneath it, there's basalt that covers the crater floor, and so you get this big contrast between the bright central uplift and the dark basalt.

Slide 46: The last thing I want to talk about are pits on the next slide. During the course of both the Japanese mission and the current LRO mission, people began to see these little holes in the ground, which were completely unexpected.

These things are about 100 meters across and from the way the shadows occur and from the different perspectives from the orbiting pictures, you can kind of see in some cases, back underneath the edge of the hole, so there's more to the void below the surface than just the area of the hole.

It's not clear what these things are. They occur mostly on the Mare, and so one of the suggestions is that they might represent partially cleft lava tubes.

And if they are, I mean, it's interesting geologically, but one of the suggestions has been this would make a good place to put a human outpost in one of these lava tubes, because you'd be protected from radiation. You'd be protected from micrometeorites. The temperature would be stable. You'd be in the shadow, but the temperature would be whatever the average surface temperature in the area is.

The problem is getting down into this, you know, 100-meter-deep pit in the middle of the Mare. It might not be stable. But they're really interesting, and it's not entirely clear – you know, the assumption is they're just collapsed lava tubes, but there aren't very many. And their distribution appears to be kind of random.

Slide 47: And the last slide just shows the Earth viewed from LRO at the Moon over the South Pole looking back towards the Earth. You can see Africa there in the center, right, and South America to the left.

So I think I'll stop there. Any questions?

Amelia Chapman: Everyone has to get their mute button off. I had a quick question about the pits. I've never heard of that before. That's very interesting. They collapsed, though, in such perfect circles. Is the thinking that maybe there was a strike – a meteor strike – that then punched through?

Dr. Jeffrey Plescia: Not necessarily. On the Earth you get little circular holes over lava tubes as well. It just seems to be that's how they collapse. But on the Earth, you can often see them in little chains, so you're sort of sure it's a collapsed lava tube. In this case, there's just a few scattered ones, and it's not entirely clear what's going on.

Amelia Chapman: Is there any thinking of a mission to try to get down into one? Or is this –

Dr. Jeffrey Plescia: Yes, people have suggested sending something that could rappel its way down into the lava tube. It's not clear, scientifically, what you would learn. I mean if the Mare are just a stack of lava flows – if you go down this thing, what you would see is some of those individual lava flows in cross-section, but I don't know that it is as important as other things you want to do on the Moon.

Amelia Chapman: Yes. Thanks.

David Seidel: I'd say for an analogous feature, just go to Google, search on "Devil's Throat, Hawaii" for one that's almost exactly including an aerial photograph looks exactly at the same scale too.

Man: A question about LRO.

Dr. Jeffrey Plescia: Yes?

Man: Is it going to be getting any closer? Is its orbit going to be getting closer to the surface of the Moon, or is it as low as it's going to get now?

Dr. Jeffrey Plescia: It's higher than it was earlier, and it's not going to get any lower, really. When they got to the Moon, they put it into an initial elliptical orbit to check everything out.

Then they went down to a circular mapping orbit for a while. And then they put it back into an elliptical orbit because in this elliptical orbit, it requires very little fuel to maintain the orbit.

When you're down low in a circular orbit, you have to spend a lot of fuel to stay in orbit. In this circular orbit, you don't need to spend much fuel and the remaining fuel on board will last another ten years or something, because we use so little of it.

So the orbit that we're in now will evolve a little bit. The periapsis – the high point in the orbit - will come down a little bit. And it was initially put into a (pole) with the orbit going right over the pole, and it's drifted off now a few degrees, and it will continue to drift. But it's not going to get any lower.

Man: And what's the lowest point in its orbit now?

Dr. Jeffrey Plescia: About 30 or – you'd have to ask that, wouldn't you? I think it's about 50 kilometers, but I'm not sure.

Man: But nowhere as close as it was in its circular orbit.

Dr. Jeffrey Plescia: Yes.

Man: Yes, okay. Thank you.

David Seidel: Question about the landslides. That's a pretty spectacular pair of pictures there. Any idea what the slope is? Hard to tell whether it's steep or gradual.

Dr. Jeffrey Plescia: I don't know what the slope is in that particular example, but we have, you know, very detailed topography now of the Moon from a combination of the laser altimeter and you can do stereo from the images. And most of the fresh craters – and that landslide occurs in a fresh crater – the interior slopes are 20, 30, 40 degrees.

David Seidel: Thanks. Is that landslide pair that you show there, is that the only one that's been detected, or have others been seen?

Dr. Jeffrey Plescia: No, there's about almost two dozen that had been seen scattered around the Moon. And in a few cases, there's a new impact crater up near the head of the landslide, so the assumption is that the impact triggered the landslide.

In other cases, there's nothing obvious at the head, so maybe there was an impact nearby, maybe it's just a seismic event that triggered it.

David Seidel: Any possibility it has anything to do with thermal properties as day turns to night, or anything like that?

Dr. Jeffrey Plescia: It's – you can get thermal shattering of rocks, and you could have had a case where that triggered something, but you would – if the day/night cycle was triggering a landslide, I would think you would expect to see a lot more than we do.

David Seidel: Sure, yes.

Dr. Jeffrey Plescia: You might expect one somewhere every lunar day or something, and we haven't. We haven't seen that frequency.

But the thermal part, as the surface ages over time, there were a lot of boulders initially. And then over time, those boulders have gotten whittled down into fine-grained material. The original assumption was that it mostly just resulted in small impacts on the boulders, but now people think that the thermal cycling between day and night can, in effect, break up the boulders as well.

David Seidel: Thanks.

Amelia Chapman: Well, we seem to have an open line with the music on it. If that's you, please mute yourself. But do we have any other questions?

Man: I have a question.

Dr. Jeffrey Plescia: Okay.

Amelia Chapman: Go ahead.

Man: Regarding the increased number of average impacts that you're seeing, is there any concern regarding future manned lunar missions? The increased number of impacts and how that might affect those future missions.

Dr. Jeffrey Plescia: Yes. At the moment, the impact rate would appear to be higher than was previously assumed so, in theory, the risk would now appear to be higher than it was assumed to be during Apollo.

But from a standing-in-one-place and what's the likelihood there's going to be something right where you're standing over the course of a couple weeks - it's still the odds are incredibly low. But it's always possible that something could happen.

I mean, the Space Station routinely gets hit by little particles and - as well as space junk so it's conceivable. The - one of the Surveyor's spacecraft that was at the Apollo 12 site, they took off some material and brought it back, and that – those parts – has little micrometeorite craters in them. So stuff happens.

Man: Yes.

Dr. Jeffrey Plescia: Just statistics.

Man: Thank you.

Amelia Chapman: I was curious what upcoming missions are planned to try to find out more about the water and the potential use of it as fuel.

Dr. Jeffrey Plescia: The Russians have plans to send landers up into the polar areas to try to sample the volatiles that are there. Those missions are going to go into areas that do have illumination. They're not going into the permanently shadowed.

But even in the areas that receive periodic sunlight, you don't have to go very deep before you get to temperature that would be permanently freezing. So there might be stuff below the surface, even in illuminated areas, and the neutron data would suggest it's all over the place.

The U.S. has also has a mission sort of halfway between in-mind and building that will go to the South Pole to do pretty much the same thing. At the moment though, there's nothing planned that would actually go into the permanently shadowed areas and sample. There's lots of ideas, and there have been lots of studies, but that's the status at the moment.

The Chinese are also sending missions, but they're not sending them to the Pole. They're sending them – one of them's going to go to the far side, and the other one will go to the near side for a sample return.

Amelia Chapman: Right. Well do we have any other final questions?

Okay. Well, if not, I'd like to thank everybody for joining us today and invite you to join us again tomorrow, actually, at 1:00 pm Pacific Time. Then, we'll be learning about some Earth expeditions. We'll be learning about the KORUS-AQ and NAAMES Missions. So please join us again tomorrow. Thank you so much.

Dr. Jeffrey Plescia: Thank you.

David Seidel: Thanks, Jeff.

Dr. Jeffrey Plescia: You're always welcome.

Woman: Thank you.

END