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Jeff Nee: Hello everyone happy Tuesday and welcome. This is Jeff Nee from the Museum Alliance. And it is our pleasure to host this telecon today. Thank you to all of you for joining us and to anyone listening to the recording in the future. Today we'll be talking about Walking with the Last Men on the Moon. A very catchy title if I do say so.

The slides for today's presentation can be found on the Museum Alliance and Solar System Ambassador sites. There are two videos one on slide three and one on Slide 27. So be sure you have those queued up and ready to play if you only using the PDF. As always if you have any issues or questions now or in the future please email me at jnee@jpl.nasa.gov.

Our speakers today are Dr. Noah Petro and Andrea Jones of NASA's Goddard Space Flight Center. Noah is the Deputy Project Scientist for the Lunar Reconnaissance Orbiter mission. He first became interested in geology as a student at the Fox Lane High School in Bedford, New York. It was while he was a student at Bates College that he was introduced to the field of planetary geology. And following his PhD work at Brown University he came to NASA Goddard as a NASA postdoc.

Andrea Jones is the Director of International Observe the Moon Night which is coming up in October this year. And she is the LRO Educational and Public Outreach Lead along with many, many other titles. And Andrea and Noah's biography are up on the Web sites as usual and without further ado I think Noah is up first. Noah, take it away.

Dr. Noah Petro: Okay great. Thank you very much. And as Jeff mentioned if you have questions I'm happy to take them at the end. As you're taking down notes just record if there's something specific to a slide which slide that's on so that I can also pull it up and perhaps speak to something. If something very pressing comes up that just can't wait I'm also happy to take questions but happy to wait till the end.

Thanks first of all for having me. Andrea and I are sort of tag teaming this presentation. At the end of the presentation we have several slides highlighting several events coming up later this year including the eclipse which was the topic of discussion online before we got started today. And obviously that'll be a really important event for many of us.

So first of all, I'm going to be talking about some work that I've got to do over the last year and a half now really using data from the Lunar Reconnaissance Orbiter mission and reinvestigating re-exploring the Apollo 17 landing site. This year marks the 45th anniversary of the Apollo 17 mission. And so, it's timely to discuss not only the mission itself the Apollo 17 mission but also the ongoing LRO mission. This year marks the eighth anniversary of our launch which will be in about a week and a half from now it's actually less than that a week from now or so is the anniversary of our launch.

So I want to move to Slide 2 now and just talk a little bit about why we want to go back and look at a landing site with LRO data and indeed why even study the moon? You know, there's a lot of lunar surface that's yet to have been explored and so the moon is ripe for investigation. Someone might believe that well there's so much moon left to explore why look at a place we've actually already been?

Well first of all I want to make the supposition the statement that the moon is the cornerstone of understanding how planets work. And the reason that the moon is held in this lofty position is because we've been there, because we have samples, because we've visited the lunar surface six times with humans, three times with sample return robotically and the number of times with other landed missions we have the best understanding of how they moon has evolved of any of the planets apart from the Earth.

And indeed, because the moon and Earth share essentially share the same portion of space in the inner solar system the moon acts as a witness it's like a record of the processes that affects all of the planets including the Earth. The moon's surface because of its history and lack of an atmosphere, it records in a very beautiful way the processes that occur to it not only early in its history but also the ongoing processes that are changing it today.

But it's these early processes these early events four, 4-1/2 billion years ago that are recorded in the surface of the moon the record of which is not found as well preserved on the surface of the Earth that allows us to use the moon as this sort of witness place to understanding what happened early in the solar system history. And the samples from the Apollo mission specifically from the Apollo 17 mission give us that insight to what was going on not just billions of years ago but what's happened essentially today.

But with these samples from Apollo one of the most important things that we have with those samples is context. We know where those samples were located or collected from. And it's the context of those samples that we use to unravel the geologic history. We of course have meteorites from the moon but we don't know where those meteorites come from. We actually have meteorites from Mars as well. We don't know where those meteorites come from.

So we can use those Martian meteorites for example to tell us something about the history of Mars, tell us about its atmosphere, you know, the environment in which those rocks those samples were formed but not knowing where they come from on the surface of Mars or in the lunar case where those lunar meteorites come from we lose that context.

But it's the Apollo samples and especially now the Apollo samples in the context of the super high resolution LRO data that really help us better understand what those samples are telling us. I'm going to highlight a couple instances where we've done some recent reanalysis of Apollo 17 samples in the context of LRO data. And I'll get to that in a moment. But let me talk a little bit about LRO before I go forward.

So on Slide 3 just an overview of LRO. And this is the slide that has the first video which is helpfully titled A010265 LRO Instruments. But it's basically just an overview of the LRO spacecraft and the seven instruments that we have on board. As a bit of history LRO was launched again eight years ago in 2009. And its initial purpose was to serve as the name alludes to the reconnaissance mission for future human and robotic exploration.

Even though we had been to the surface with humans we really lacked the detailed maps necessary for sustaining future human exploration across the entire surface of the moon specifically the poles. We wanted to know the safest most geologically or scientifically interesting landing sites. We also wanted to know what humans might expect when they got there in the form of the radiation environment. So these seven instruments were all selected to give us basically a 3-D high resolution atlas of the lunar surface and its environment so that our future explores both human and robotic would be best prepared for not just short term but also sustained lunar exploration.

We have the seven instruments the first there listed as CRaTER which for a spacecraft that studies impact craters is a bit of a complicated name because it actually doesn't study cratering on the moon it studies the radiation environment on the moon and its environment. We have an instrument that measures the thermal properties of the surface as well as composition, an instrument that measures the presence and abundance of water ice, and frost and permanently shadowed areas as well as other surfaces of the moon.

We have a neutron detector to map the distribution of hydrogen around the lunar poles, a laser altimeter LOLA to precisely measure the lunar topography surface, its shape and actually how the shape changes over the function of a lunar orbit as there are tides on the lunar moon service it changes by a few centimeters as it goes around the Earth. We have perhaps the most well-known instrument on LRO the LROC cameras. There's actually three separate cameras on that are part of LROC to very high-resolution mappers. Cameras that image the surface roughly 50 centimeters per pixel as well as a global mapper that helps characterize the composition of the surface. And then lastly, we have a radar instrument that is probing for surface properties specifically ice deposits within the upper meter or so of the surface.

So it's these seven instruments that are on LRO that have been operated operating now for over or just about eight years that are helping change our view of the lunar surface and environment. And the data that I'll show on the course of my talk primarily are derived from the camera instrument but let me assure you that all of these instruments are really critical to the science that we are currently conducting and will be conducting in the future.

Okay so let's move on to Slide 4. Slide 4 is just a bit of a preview for some of the material that Andrea will be speaking of. But I think it's really important to highlight these two events in the body of my talk here because I'm excited for both of them. The eclipse on August 21 is going to be an amazing opportunity to talk about the moon for reasons that Andrea will get into a little bit later on.

But I'm excited to help share my excitement with the eclipse and especially the moon's central role- literally the central role the moon plays in the eclipse. And then of course later on in October International Observe the Moon Night where we'll all get to share our beautiful pictures from the eclipse and talking about the moon as well. So that's just a bit of a preview.

So one other event that comes up in December -- if we move to Slide 5 -- is the anniversary the 45th anniversary of Apollo 17, December 7 will mark the 45th anniversary of the Apollo 17 launch. And again as a bit of history, you know, Apollo 17 was not only the last of the human exploration of the moon by Apollo it was really the in my mind the climax of all of the efforts of the Mercury, Gemini and the preceding Apollo missions leading to what was really a tremendous feat of scientific engineering that led us to the moon for three days on the lunar surface. It also marks the last time that humans have ventured into deep space. And so, 45 years later we have this opportunity not just to look back but perhaps also look forward as to what may be coming in the next decades with humans in deep space.

So let's move to Slide 6. Just sort a bit of context for the near side of the moon. This is a map produced by the camera team the LROC camera team marking two spots that I'll be talking about today. At upper right in hard to read green text but outlined in an orange box is the location of the Apollo 17 landing site. And that sort of middle bottom half of the moon outline is the Tycho impact crater in one of the most brilliant observable features during a full moon that we can see with the naked eye. And it's actually these two features will come into relationship even though they are somewhat far apart from each other on the moon they are related.

Okay so Slide 7 just to summarize what Apollo 17 was able to accomplish. We're all aware that they went to the lunar surface, brought back samples but it was again this pinnacle of accomplishments. It was the last of the so-called J mission the missions that included a lunar rover which indicated that they could traverse great distances over 35 kilometers.

They brought back almost the most amount of equipment to the surface. They spent the most time outside of the lunar module and brought back 110 kilograms of lunar sample. But one of the things that's not recorded in that massive experiment at the upper right of that plot that I think is important is I think maybe the most important experiment ever sent to the moon on Apollo and that mass is not included there. And that mass represents that cumulative effects of both the Mercury, Gemini and preceding Apollo missions to get to the pinnacle of the Apollo experiments.

And if you go to Slide 8 and that's the experiment of sending the trained geologist to the lunar surface. Now I don't want to call Jack Schmitt an experiment but for those of you that know a bit of the history of Apollo, getting a scientist to the moon was not a trivial or easy feat. It took pressure from the National Science Foundation, it took pressure from the science community that the one trained field geologist who was in the Astronaut Corps should actually get a chance to go to the moon.

And so Jack Schmitt was shifted to the Apollo 17 crew becoming the 12th and final human to step on the lunar surface. He was part of the first group of scientist astronauts. He was the one geologist as part of that group. And sort of lost in the history I think is that he was critical in not just the training for prior missions but in the development of procedures, what the astronauts would do on the service, the experiments they would set up.

And so what Jack brought not just to Apollo 17 but even brings today is this experience base of being familiar with what each of the previous missions had done and what was possible to do. And I have been very fortunate and this is maybe a bit of a humble brag to get to work with Jack on re-exploring his landing site the Apollo 17 landing site. And so the work that I'll be presenting here was done in concert with him but also in working with him to help convey the story of what Apollo 17 was able to accomplish.

And it's now with the LRO data that we have that we sort of can shed new and fresh light on what he was able to do. I've presented this to him before and I know that he's not totally comfortable being called an experiment but indeed the fact that we were able to get a trained geologist to the lunar surface not just helped get great samples at the time but is now really influenced how we reevaluate the landing site. He's able to infer and see things in the LRO data that again bring fresh light to the samples and the data that the astronauts collected on Apollo 17.

Slide 9, so one of the things that I think is really important in understanding the samples that they collected and the context of the samples as collected is why they went to where they went, the valley of Taurus-Littrow. So Apollo 15 which was in 1971 was a great success. It was the first of these J missions with a rover. And because it was a success and because mission planners argued to get Apollo 17 approved for flight it was clear at the time the success of Apollo 15 that Apollo 17 should have these five objectives. And I should point out that planning for Apollo 17 started before Apollo 16. There was this sort of leapfrog of effect from Apollo. They were analyzing one mission result while planning for the next. And so Apollo 16 sort of was occurring in the midst of all of this.

But based on the results from Apollos 11 through 14 it was clear that there was a bias of samples clustered relatively close to the Apollo 15 landing site. So they wanted to get as far as feasible remaining on the near side remaining near the equator they wanted to get a sample from the crust far from the Apollo 15 landing site.

They wanted to go after what was interpreted to be at least based on the images at the time young volcanic rocks. All of the volcanic rocks that have been sampled up to that point were in the neighborhood of, 3-1/2 billion years old and older. And there was a thought that younger volcanic rocks would be available to be sampled by Apollo 17.

As sort of a secondary but important aspect was that the orbiting command module we often think of what was done on the surface but let's not forget there was a command module that was orbiting the moon at the same time. It had instruments on it- ten instruments to map the area underneath the command module. And so they wanted to have a command module that would orbit a slightly different set of the lunar surface. And so that's part of the reason why the Apollo 17 landing site was selected.

They wanted to measure while on the surface areas that had layering. And so that pointed to a volcanic surface. And finally, they wanted to deploy a long-lived surface experiment package called LSEP on the surface. That of course could have been done anywhere but they wanted to make sure that, that was part of the mission objectives for Apollo 17.

In February of 1972, so again this is before the Apollo 16 mission even flew the Apollo 17 site was selected and training began in earnest to develop the traverses, the field experiments that they would do to accomplish parts of those five objectives that I defined a moment ago. And so, between February 11 and early December the Apollo 17 mission planning began.

Images that were taken by Apollo 15 were used in the preparation for Apollo 17. So if you go to Slide 10 there's an image from Apollo 15 of the what would become the Apollo 17 landing site. In five different units geologists love to categorize rocks into different units or different types five different units within the valley were selected or identified ranging from the unit labeled one the light mantle. This was interpreted to be an avalanche deposit that blanketed a portion of the valley floor.

There was a dark darker mantling unit that was interpreted to cover a portion of the floor called the dark mantle deposit. An older more heavily cratered subfloor material labeled three there. And you can see just on visual inspection of the Apollo 15 image if you all ignore the numbers on there for a moment that there appear to be a – there's a unit that's more heavily or more saturated more heavily cratered and a more lightly cratered unit. So there was this idea that there was a subfloor more - an older unit this unit three I labeled here.

And a mountainous unit called the Sculptured Hills to the east of the landing site. And finally, the massif's these mountains that sort of bound the valley to the north and south. And so each of these five different units were identified as targets for the mission during the three traverses that the astronauts undertook.

Moving on to Slide 11, just as a point of comparison and this is an important point and we can't forget this that by Apollo 17 they were going to land in a valley not only older than the Grand Canyon but deeper than the Grand Canyon remembering that on Apollo 11 they wanted to go to the flattest, smoothest safest landing site. And so in the inner meaning a few years between Apollo 11 and 14, 17 the four years there our capabilities of landing in a really challenging environment grew by leaps and bounds.

So if you switch between Slide 11 which is a beautiful cross-section of the Grand Canyon and Slide 12 which compares the two you have this the cross-section on the top showing the 2-1/2 or 2.3 kilometers of elevation change between the top of the massif and the valley floor compared to the 1.8 kilometers of elevation change of the Grand Canyon. So again the Apollo 17 mission landed in a valley deeper than the Grand Canyon and equally spectacular I might add, harder to get to though even when driving to Northern Arizona.

Slide 13 so this starts taking a slightly more retrospective view of Apollo 17. In the immediate aftermath of the mission a preliminary science report was commissioned several months after the mission to take an immediate snapshot of what we learned. And in the immediate aftermath it was felt that we accomplished very clearly many of the goals of sampling those five units.

I have colored on the right the two goals that at the time were felt to have been most clearly accomplished that is a sampling of the light mantle and a sampling of material from the massifs. And then collecting material from the dark mantle, the subfloor and the Sculptured Hills was much less clear and more ambiguous.

At the time it was interpreted that, that light mantle that avalanche deposit was a single unit that was triggered by ejected material coming from that very distant Tycho Crater. Tycho is over 1000 kilometers away. The thought was that material was ejected from Tycho impacted on to that Southern massif and cause that landslide that was then later sampled.

The origin of that dark mantle deposit was regarded as an enigma of Apollo 17 and still somewhat curious as to what that different unit represents. The subfloor was basically all of the rocks all of the volcanic rocks that they sampled. So that was clear but it was unclear as to why there was that different appearance there.

There was one station one of the sampling stations at the Sculptured Hills to the east there and there was an expectation that they'd be able to get boulders that had rolled down the hills but at the time it was not clear that they get anything from the Sculpture Hills. And it was unclear as to why that material in the Sculptured Hills there which certainly have a different appearance. You can see lots of different knobs. It looks a little more textured or sculptured then the North and South Massifs there. And so that difference was unclear at the time.

And lastly the massifs the material the units labeled five there, boulders were sampled at the base of each of those massifs that were interpreted to have rolled down the hills there. And so material from those massifs were indeed collected.

Slide 14 now jumps to what we see today. This is actually two images that are stitched together to form this mosaic. This is the LROC's high resolution mosaic of the Apollo 17 landing site today and sort of showing them that this skill doesn't do that data service because you can zoom in quite closely to the data set to actually see some remarkable detail. And I'll show that in a moment.

Slide 15 starts labeling some features. And dead center on the image there on Slide 15 is the location of the lunar module where the Apollo 17 crew landed. And then lastly on Slide 16 shows the names of some of the craters that were visited as well as creators that were named prior to the mission. And you can see that they indeed covered the whole and essentially a good portion of the entire valley going from the foot of the South Massif, to the North Massif, and the Sculptured Hills and everything essentially in between.

And each of those stations were again not only carefully selected beforehand but also evaluated during the mission as to what would maximize the science that they would get out of it. And I really like showing these traverses when I talk about Apollo because it shows that they covered a good amount of territory but this is I still have a hard time appreciating what they were able to do. So I always like to put the exploration into some context.

Slide 17 shows the trace of the Apollo 17 EVAs [Extravehicular Activities] overlaid at the same scale with the District of Columbia with Washington DC just as an example. And that gives you a really good sense I think of what they were able to explore and the distance they were able to explore over three days. And as a DC area resident I don't think you could cover this territory in three days if you are trying to drive it yourself based on local traffic patterns.

Andrea Jones: I agree.

Dr. Noah Petro: But yes it does a really good job of putting to scale boy by the time they were doing these J missions they were covering a lot of territory. And again, that helps us as geologists get diverse samples. And again, they were able to get samples from those five different units or at least what they thought were the five units at the time.

Slide 18 is now maximizing the resolution of that narrow angle camera we have on LRO. It is showing the landing site as of a couple years ago now but we do image all of the landing sites pretty much at every opportunity we have. This is in the middle it shows the dissent stage of the lunar module. And you can see the traces of not just the rover which is parked at lower right you can see the two parallel tracks which represent the rover tracks.

You can also see these dark lanes which represent the boot prints of the astronauts that they left behind 45 years ago. To the left of the image you see some of the traces of the experiments that were left behind as part of that experiments package. And indeed, just to the north of the dissent stage there's a small smudge. And it's barely visible there but that smudge is the shadow of the American flag that was deployed during Apollo 17 and is still flying on the surface today although of course the flag is most likely heavily bleached having been in the sun for well 14 days a lunar day for 45 years but that indeed is still there.

So this sort of information especially in the immediate vicinity of the lunar module descent site where we can actually exactly trace their boot prints their rover prints tells us exactly where they were. And as you'll see in a few slides that becomes very important for reconciling some unknowns from the mission.

The next slide, slide 19 shows the same site but at different time of lunar day. The Sun is lower in the sky. And indeed, those longer shadows really help extenuate some of the surface materials not just boulders but the LEM just to the north of the lunar module descent stage, the shadow of the flag and indeed at lower right even the shadow of the rover still parked there 45 years later. A version of this has an animated either GIF showing about 20 different images of the site over the course of a lunar day. And it's really fascinating to see the shadows change. Being able to make out some of the details of the lunar module for instance that are still visible today.

Slide 20 I'm going to get into two sort of long standing questions that at least prior to our analysis were outstanding from Apollo 17. One was that light mantle deposit and its origin we talked about a moment ago as well as the history of an oft forgotten sample 70019. There are in this massive paper that Jack wrote with several of us there are a number of other sort of outstanding questions that have been answered but these are two that I'm certainly most interested in because I think they're kind of compelling and show the value of re-exploring these Apollo landing sites.

Slide 21 is a different image of the light mantle deposit than what was shown before. The prior images were showing the lunar surface at earlier times of day where shadows are more apparent. This is an image that was collected when the Sun was high in the sky. And what we see in images at different times of day tells us different things. And we like low sun angle images because it really accentuates the variability in the lunar surface however images taken closer to noon on the lunar service accentuate color differences.

Now because most of the images taken in the leading up to the Apollo 17 mission were taken during lunar morning or late in the afternoon trying to accentuate the surface morphology features we never really had really high-resolution view of the landing site at noon or at high sun. And again, not being able to see these color differences ultimately led to this interpretation that this avalanche deposit represented a single event.

Now one thing that becomes apparent in looking at this image is that there are two different brightness units. There's a darker more subdued avalanche deposit to the east- to the right and a brighter interpreted to be younger avalanche deposit to the west or to the left. And this was a surprise when we saw it because again we had always assumed for 43 years when we started this analysis that this was a single avalanche deposit representing a single event in time triggered by the Tycho ejecta impacting with the South Massif.

However, seeing these different colored units lead us to believe that maybe that was not accurate. If you go to the second slide, slide 22 here this is just a mosaic again from the LROC camera of the moon at high sun and this shows some of the color differences. And you can see those beautiful rays Tycho is at lower left emanating from the crater. And there's sort of a direct line of path from Tycho to the Apollo 17 landing site at the Taurus-Littrow valley.

Now it was assumed at the time that ejected deposit would have impacted and triggered that one event. But if we go back to the now to Slide 23 we see that there are indeed what we interpret to be these two different flows that it wasn't a single event that caused these avalanches indeed it probably wasn't even Tycho that triggered this avalanche indeed it was something else.

So if we go to Slide 24 this is now one of these majestic and I call it out of the airplane window views of the Taurus-Littrow valley. This is looking from the east to the west. And the location of the lunar module landing site is marked Challenger there. And off of the South Massif you see those now what we interpret to be the two different avalanche deposits or at least two different avalanche deposits there could be more that have come off of the South Massif there.

Now crisscrossing the valley from the south to the north you may notice that there is this wrinkle in it. That's a lo- bate scar, a tectonic feature representing basically a fault plane along the surface. And it just so happens that looks like the age of that fault corresponds to the age of at least the most recent avalanche and if not perhaps even the older one as well. And so we're now coming up with an interpretation that perhaps the mechanism to trigger those avalanches wasn't something like ejecta from Tycho but actually was moon quakes triggered by this fault at the surface that just shook the moon enough to cascade materials off the South Massif and cause these avalanche deposits.

Slide 25 shows essentially the same view but taken now at high sun angle. And again, the color difference of those avalanche deposits really stands out. I think we have a pretty strong claim or at least strong hypothesis but those avalanches were triggered by again more local events these moon quakes and not some distal event cascading in to the area.

So that was one thing. And again, this is sort of an important result because for years it was thought that the stages of samples that we have off of the South Massif age of these avalanche deposits were used to determine the age of Tycho. And it turns out that perhaps we don't have the age of Tycho at about 100 million years or thereabouts that indeed we know it's young but how young it is we don't actually know. And so I think that raises some questions about our interpretation of the age of Tycho and indeed of other recent cratering events based on that age. So that's a sort of a fun result. And again, one that throws everything up into the air but opens up questions about all of our understanding of lunar history.

Slide 26 gets into something a little bit different but also in our in interpretation of what we collected. Now they brought back as I showed before 110 kilograms of rock. But there was one sample in particular 70019 that always stood out because as I mentioned before Jack Schmitt in his preparation for Apollo 17 and his experience with Apollo worked with all of the prior missions. And he had heard from a number of the crews that they observed very small impact craters that had glassy material on the floor. This glassy impact melted material that covered floor of the crater.

And on the middle of the image there is a picture that Jack took of the creator that he recognized. And based on his experience knew he wanted to sample because he wanted to collect a piece of that melted material and record as best he could the orientation of that sample so that when that rock was brought back to the Earth any ancient magnetic field that was trapped in that rock could be oriented exactly based on the orientation of the sample as it was collected on the surface.

Because it was still glassy the thought was that it wasn't disturbed or hadn't gotten really messed up since formation. It was probably a very young crater. And so he felt that this was something that would be important to sample. And of course, in the aftermath of the Apollo 17 mission when the crew went on it's almost yearlong victory tour across the Earth the analysis of that sample and the intent of him collecting that sample was lost and no one really went back and examined that sample in any detail.

And so one of the co-authors took several of the images that he took and reoriented the sample. Now I always like to describe what the purpose of sampling these materials are. So Slide 27 is my visual clue for folks to run the second video entitled glass_bottom_Web site. That's a somewhat long video. I'm not going to suggest playing it now but after the talk I encourage people to watch that video because what that video shows is Jack explaining his collection of the sample at the time and the pictures that he was using to document the sample.

This is from a Web site called apollo17.org that is actually a really fun Web site to explore when you have a few hours because it is a wonderful re-creation the entire mission using archival footage, audio footage and images in real-time. But what it lets you do is jump in to the mission at any point and hear and see what they were doing and especially the collection of this one sample.

Slide 28 is a combination of an LROC image of the landing site as well as the reconstructed location of where that rock came from using some visual clues that were apparent in the images that Jack took on the service- boulders, creators and of course the lunar module itself. And through basic geometry we were able to reconstruct where that image must have been taken from, which crater that corresponds to and of course then it also ties to where you see boot prints. So we can immediately reconstruct exactly where Jack was 45 years ago when he took that image and where that sample comes from in space and time.

And that gives that sample a whole new life in analyzing the possibility of a magnetic field at least, a few million years ago when that crater formed. I certainly fall victim to this sometimes that in thinking that well all of Apollo's samples have been analyzed and there's nothing left to learn but that probably couldn't be further from the truth that all the samples have new life to give us especially not just through tying it to remote sensing data but of course through new analytical techniques. So this is just an example of two sort of nice little succinct science stories that came out of our reanalysis again giving fresh life to this landing site 45 years later.

Slide 29 just again some last thoughts on that is and this summarizes what I've said is that we are learning new things about the moon from LRO every day.

We're learning new things about the moon through our analysis of the samples. And putting all of this material from Apollo and the missions that preceded Apollo to today are telling us not only new things but also showing us that we have a lot left to learn about the moon. The book on the moon is far from complete. The Apollo missions left a legacy. This is an example I've shown of, really a subset of material from Apollo 17. And of course, each of the other Apollo lunar surface missions have equally compelling stories that are left to be told.

And this is my last point there is sort of a "duh" statement but I like to think that our whole solar system from Mercury to Pluto, comets, and asteroids we have an amazing and diverse solar system but it's our understanding of the moon that lets us best understand everything else that shapes all of the other objects in the solar system. I'd like to now take this moment to turn the mic over as they were to Andrea Jones who will pick up with Slide 30.

Andrea Jones: All right thanks Noah. So that was fabulous. And I really appreciate you taking the time to talk about that. And I want to just add that the experiment of bringing a geologist to the moon, I wonder how much headquarters thought they would get, 45 years of analysis of the data when they sent Jack up. So I think for all of you out there who control the funding I would recommend sending another geologist out there because it's not only what they do at the time but everything they do later which is just fabulous.

So turning things over a little bit to how to get your communities, your audiences involved. As we were talking about in the beginning the total solar eclipse is coming August 21, 2017. I'm sure all of you on the line have your calendars marked already. But I just wanted to have us all remember that as we are looking towards the Sun we are really looking at the moon blocking out the Sun. The Sun being blocked by the moon is what makes this event so exciting.

So the moon is really the central player in this entire shebang. So this is a really, really great opportunity to speak about some of the recent lunar science results that are happening. We have all lot of resources out there and I'll describe just a few of them but the most I think important eclipse story related to the moon is how the shape of the moon and as Noah was describing earlier with our LOLA instrument and other instruments that are able to measure the shape we know the shape of the moon more precisely and accurately then the shape of another object in the entire universe including the Earth because of course the Earth is largely cover by water and we don't know the shape of the seafloor as well as we do the shape of the moon.

And that roughness along the lunar limb is where sunlight will peek out and allow us to see those phenomena like Baileys Beads and the diamond ring effect and things like that. And those little points of light actually influence the shape of the moon's shadow along the ground and the topography of the Earth as well the mountains and valleys here influenced that shape as well.

So next slide please, Slide 31. On the Lunar Reconnaissance Orbiter Web site, you can find some of those recent science results. And so when people are coming to talk to about the eclipse you can talk about some of those recent results our new understanding of lunar swirls, our understanding of water on the moon in different places, the shape of the moon, the pits that we're finding, the volcanism all those things lots of them are collective here. And we will also be featuring on this Web site very soon a collection of eclipse activities that highlight the moon in particular. We'll also put them on the NASA Eclipse site and on the International Observe the Moon Night Web pages but they will be here as well.

So next slide. You're probably all familiar with this but just in case you are not of course NASA has a 2017 solar eclipse Web site. The address is here on this slide and we have lunar content on here already. And we will be featuring more as well as our activity collection here soon.

Next, so on Slide 33 I also want to make sure that if you're not already that you are aware of the eclipse gallery the solar eclipse gallery at the Scientific Visualization Studio that NASA has. And a lot of them are using data from the moon the data from LRO as well as data from our Earth orbiter so that we can put together that information. And you can learn more about, why we have eclipses? What does it look like from the moon to have an eclipse? What does it look like from the L1 sight? What does it look like in terms of the heat of the surface of the Earth as the eclipse happens? So a lot of this comes from lunar data. So I had to future that there.

Dr. Noah Petro: Can I talk for a moment about the umbra shapes one for a moment?

Andrea Jones: Sure yes.

Dr. Noah Petro: Yes. So my particular favorite are the middle little bottom middle row left three the path of totality, oblique and umbra shapes. Where Ernie Wright here at Goddard took the LRO topography data, the topography of the Earth from the shuttle radar experiment and combined them to precisely map the shadow on the surface of the Earth which had never been done before.

And in that umbra shape there's a video, a really elegant demonstration of what happens if you assume both the Earth and lunar sphere versus comparing it to the accurate topography that we have for both objects? And that does indeed shift the path of totality in some places a kilometer or so off of what was predicted assuming a spherical Earth and moon. So we now can predict with the greatest degree of accuracy with what we have of what the path will look like and indeed where those Bailey's Beads and diamond ring effects will be most visible. That's just a beautiful elegant result that is due in some part because we have this amazing mission at the moon.

Andrea Jones: Yes. And that really matters. If you're in that kilometer, you want to know where this is going to be a great show. So that was really fabulous to see.

All right and on the next slide, Slide 34 this is just my plug to let you know that after the solar eclipse on August 21 International Observe the Moon Night will be coming up on October 28 this year. And this is a fabulous opportunity to harness that energy, that enthusiasm that engagement that you are seeing probably or will continue to see over the summer around this total solar eclipse or around this partial eclipse if you're not directly on the path.

And everyone on Earth not just those people in North America will be able to see the moon on October 28 or almost everyone. And we really encourage you to get out there and continue talking about the moon. See the fabulous lunar landscape that's revealed when the Sun's light falls on to the face of the moon that we can see. And make use of our variety of resources and just keep people coming year after year after year to keep engaged in lunar science, and space science, and in observations because we don't only encourage you to look at the moon at this time but also, anything else that you can see in the sky at that time.

So Noah, next slide. On Slide 35 I think most of you have heard me talk about this or if you haven't it's great to talk to you now just to let you know International Observe the Moon Night was inspired when the Lunar

Reconnaissance Orbiter launched and we wanted to celebrate getting into orbit around the moon.

But it really has taken on this new life because people all over the country and all over the world wanted to celebrate again. And not only about the recent space science of which there is so much our understanding of our nearest neighbor in space continues to change all the time with data from LRO and other lunar spacecraft. And also, new analysis of our samples that we've already had.

But it gives you a chance to think about the moon's role in space exploration. Would we be a space faring people if it weren't for the moon? Who knows it's hard to ask but also to enjoy the cultural connections, and the artistic connections, and our language, and our poetry, and our art how all of those can feature the moon. So this is a chance to break out those books that you have in the library and talk about all of those wonderful things related to the moon beyond the science to a way to engage everyone in the community.

So next slide [36]. And then I wanted to just remind everyone that we have on our Web site observethemoonnight.org a number of resources to share more information about the moon, share our evaluation reports, our resources about engaging your own community and things like that. And I did want to let you know that we are migrating the observethemoonnight.org Web site to NASA Goddard. So soon we will have an under-construction notification on there but we have a whole lot of new things and a new look to show you soon but it's coming and it will have lots of resources here.

And I wanted to mention one other thing that we don't have necessarily resources out there but they'll be posted to the LRO Web site soon as well but this fall we are celebrating 100 days at the moon 100 lunar days at the moon with our spacecraft. And we are just really excited to think about the long-term science has been able to happen because of that long-term mission. So we'll be having lots of little features on the LRO portion of the Scientific Visualization Studio Web site and articles and things coming out.

So that'll happen October 16 is the date. And so that'll be just before International Observe the Moon Night on October 28. And so lots of resources for both of those. So thank you all. And Noah if you have any last comments?

Dr. Noah Petro: I just want to thank everybody for their time and attention. And thank you Andrea for reminding me that we are about to celebrate 100 lunar days at the moon. And that's the first time NASA or any mission has been at the moon that long. And so we're very fortunate to be in the position to have a healthy spacecraft to be able to have been operating for as long as we have because the science that we're learning the understanding that we're getting from being at the moment so long showing us a totally new moon.

And the last slide is also my contact information as well as well as my Twitter handle. So give me a follow. Every once in a while, I'll tweet about something space related not all that often.

Andrea Jones: Yes and actually of course LRO has Twitter accounts at LRO_NASA and we have Facebook accounts and things like that too. And Observe the Moonlight has hashtag Observe the Moon on Twitter. But we are also going to be launching a new Twitter account called NASA Moon which we will definitely let you know more about soon. But you can look there for eclipse content and we intend to eclipse the NASA Sun account multiple times leading up to the eclipse. So all right well thank you all again for your attention. And if you have any questions for Noah or me please let us know.

Jeff Nee: That was great. Thanks Noah, thanks Andrea. While people are un-muting I just did have a quick question for Noah since he mentioned the LRO spacecraft. How is the spacecraft doing? Is it – are there any problems at all or is it totally 100% operational?

Dr. Noah Petro: Yes. So I mean effectively it's 100% operational. Some of the instruments are in degraded states which is not a surprise for again a mission that was supposed to last one year, and then two years now here we are almost eight years later. All of the instruments are operating some again in slightly different ways and they were expected or anticipated at launch but all are still collecting valuable important science data.

The spacecraft component solar panels, and reaction wheels, and things like that are all healthy and within our normal limits. Our current fuel lifetime expected is anywhere depending on what we do with the mission from a few years up to ten years. As I always like to say the fuel gauge if there was such a thing on LRO is on empty. We have about 25 kilograms of useful fuel left. The warning light is on in your car sort of thing. But we're in this very low fuel maintenance orbit that takes us close to the South Pole far above the North Pole. So we don't have to use a lot of fuel.

And so, essentially if we eliminated all of our major burns that we could do to maintain that orbit we could let it evolve naturally where it would circulate at about 100 kilometers which would give us, ten to 13 years' worth of fuel. So the spacecraft is healthy. Everything is green as engineers like to say. And it's just up to us scientists not to break it really.

Andrea Jones: Which actually they're trying very hard to do. And the mission operations team has to work very hard to say no we don't want to flip the spacecraft 400 times a day.

Dr. Noah Petro: Yes. And we don't want to break it but we want to get - do things that might break it. So there's this nice tension between the scientists and engineers but the engineers usually win which is good because they're trying to keep it safe.

Andrea Jones: Absolutely. The scientists say this is theoretically possible and the spacecraft the operators say let's not try to push it.

Dr. Noah Petro: Let's not do that yes. So any questions?

Beate Czogalla: This is Beate in Georgia.

Jeff Nee: Oh go ahead Beate.

Beate Czogalla: I don't know somebody - I just unmuted. I don't have a question so much as a comment that I was at the LRO launch when it happened. And I have to say it was one of the most exciting days of my life. And every once in a while, I relive those moments when we thought we weren't going to launch and then there was this hole in the clouds and it went right through. And it was just the most amazing thing I had ever seen. And it's a bunch of really, really good memories. It was very exciting. And so this mission is very near and dear to my heart. So I'm so glad that we got to do this training today with you and thank you so much for giving us this update on LRO.

Andrea Jones: Oh thank you.

Ron Hobbs: Hello. This is Ron Hobbs in Seattle.

Dr. Noah Petro: Hi Ron.

Ron Hobbs: Hi. Two questions, one Noah could you talk about the article that you published and where we could find that? And I'm interested did you ever find any magnetic signature in that sample?

Dr. Noah Petro: All right well that's two excellent questions. So yes, the paper that Jack wrote with myself and a few others folks is published in Icarus. It's actually available online. If you email me at that address I can send you a PDF of it and the URL for the paper. It's still waiting a volume number because it's in what is now the third volume of a special issue of Icarus that is due to be kind of officially closed off soon. But it's…

Andrea Jones: What is a special issue Noah?

Dr. Noah Petro: So the special issue it's actually 2 years ago or so we solicited the community including the LRO team for papers for a special issue. And we got 65 or 70 submissions. It's the largest special issue that Icarus has ever had. It was really going to be one volume, and it grew to two volumes and now it's three volumes. And so this paper is in that third volume.

Andrea Jones: All is data from LRO.

Dr. Noah Petro: All featuring data from LRO. All of the seven instruments are featured in the papers. I highlighted two of the results. This is a big paper that Jack and I and others wrote. There's probably about four or five other science stories in it because Jack just wanted to one big paper basically and so we did. And it's all relevant. It's all excellent stuff.

Now the point about the magnetic study of the sample that detailed reanalysis has not happened. Basically, what we did was a proof of concept that we could orient the sample. In the immediate aftermath of the mission the sample was measured. There was a weak magnetic field but none of the reconstruction of orienting that sample was done and so one of the co-authors is going to put in a request to get the sample.

Actually, several months ago Jack was at the Johnson Space Center and went into the - one of the benefits of being a moon walker is that you can show up and say- hey I'd like to see a sample I collected and they sort of let that happen. Not just everyone can do that of course. And so he was able to go into the curation facility, see the sample, hold it again 45 years later.

And they will go through the process of requesting the sample for magnetic study. Not just anybody can get any of the samples requested. And so there's an official process that has to happen for that to occur. So we're eagerly awaiting that proposal to be selected and then the analysis to happen. So stay tuned for that.

Ron Hobbs: Yes. I'd just like to share that when I worked at the Museum of Flight I worked with Jack when he came and visited us. And that was one of the highlights of my life.

Dr. Noah Petro: Yes. He's an incredible figure -- I mean this is going to sound ridiculous -- he's down to Earth for a guy not only walked on the moon but was a senator. But, he appreciates that all of us and by all of us I mean the folks on the phone and folks here at Goddard are really trying to get the public engaged. And he sees that as being very valuable. He would love to see people going back to the moon. He'd love to see Americans going back to the moon.

Ron Hobbs: Yes, we all would.

Dr. Noah Petro: Yes.

Ron Hobbs: Thank you.

Dr. Noah Petro: My pleasure.

Adrienne Provenzano: Hi. This is Adrienne Provenzano Solar System Ambassador. And this is a great presentation. My question has to do with whether you found any specific sites for other samples because this is great the way you've combined the video imagery and the LRO observation. So has that been done for any of the other samples?

Dr. Noah Petro: Well so specifically in the paper we didn't do that level of detailed reconstruction. There's one other case and I talked about in my presentation the Sculptured Hills. And there was indeed a boulder that they sampled at what is referred to as Station 8 which is at the base of the Sculptured Hills.

And for years it was thought that well that boulder- we don't know where it's come from and it doesn't represent the Sculptured Hills. And I was able to use some different data from a recent lunar mission to show that indeed the Sculptured Hills composition where they collected the sample is similar to the sample. Basically, to connect the boulder that they sampled to that mountain and to really close loop and say yes, indeed they were able to sample Sculptured Hills. So that was a part that I wasn't able to get to in this presentation but that brings new life to that particular sample to those boulder samples that they collected on Apollo 17.

There's other examples when they were at the North Massif of two different boulders that they sampled. We were able to reconstruct the history of one of the boulders that was impossible until we had LRO data. And if you want invite me back in a month and I'll tell those stories. That's another hour-long presentation about the history of those two boulders those three boulders excuse me at Station 6, seven and eight.

The nice thing is in using that archived material that's so beautifully presented at that apollo17.org Web site which I should point out was not done by LRO. This is done by well now a person I consider to be a friend but an independent enthusiast who to put this Web site together but allows us to dive into Apollo 17, 45 years later and relive what they were doing. And then being able to tie what they were doing through a modern Web site and the data that we're collecting well that we're still collecting kind of ties together the past, the present and it lets us look at a little bit into the future as well.

Adrienne Provenzano: Well and that's sort of a follow-up question I have two. How is LRO working with any future missions right now?

Dr. Noah Petro: Well that's a really good question. So the most direct use is that there are a number of missions that have been proposed to go back and I should point out these are NASA missions that have been proposed to go back to the surface of the moon. There are a number of international missions that have been developed or are being developed to go to the surface of the moon. And then there are some missions that we have less clarity into what they're doing that have gone to the surface of the moon that in all likelihood have used LRO data.

But we're able to produce not only beautiful images of future possible landing sites but high resolution topographic maps, and slope maps and identify boulders. And so I would pause it that any future lunar mission for the next 100 years and that end date is variable but, the likelihood of needing another mission to go to the moon to map landing sites is very low. I'm part of a team that proposed to NASA for a large scale planetary mission to land on the far side of the moon, collect about a kilogram of material and bring it back to the Earth.

And basically, the backbone of that mission is that we can identify safe landing sites using LRO data. So we've got, images of potential landing sites and all of these derived topographic products and things like that, that give us confidence that we can land safely on the surface. So that's probably the best example I have of at least a direct relevant use of the data by me for planning a future mission.

Adrienne Provenzano: That's great. Thank you very much.

Dr. Noah Petro: Pleasure.

Jeff Nee: All right everyone I know we're right at the top of the hour and we're a little bit over but it's okay. Any last-minute questions for Noah and Andrea?

Woman 2: Question if you land on the backside of the moon or the far side of the moon how will you communicate with Earth? Will you use LRO?

Dr. Noah Petro: That's a great question. So LRO was not intended to be used as a far side data relay. I did a short study here at Goddard to look into the feasibility of using it. It is possible. We could. But for instance, in the mission that I was part of the proposal effort they wanted to have and I think rightly so their own dedicated relay satellite that is designed to do that.

One of the tricky things and our Mars experience sort of showed this is that we really like to be in direct communication even with the time delay to Mars but with an asset with a lander as it's happening so we know what's happening. And in case there's a something that's unplanned we can understand what happened. And so in the case of this potential future mission we would have our own dedicated relay. Now the LRO is orbiting too close to the moon even when it's on the far side to be able to communicate with anything on the far side we'd have to be essentially right over it as the landing happens. There's a little bit of logistics that would have to be worked out.

And of course, in that event we wouldn't be able to communicate between the Earth, and LRO and asset on the ground. And so what we really have to do is have a satellite that's further from the moon then LRO would be and especially we'd like it to be one of the Lagrange points far enough away where it can essentially see the Earth and the moon simultaneously. So it can communicate with us on the ground, the lander at its landing via this relay satellite. It's tricky. Of course, that then adds cost complexity but it's one of the things the NASA does really well is complex things and makes it happen.

Jeff Nee: All right well thank you everyone for joining us today. I was talking with some people here at JPL we have a day of listing their favorite moons. And people were saying, Enceladus, and Titan, Europa and whatever but my favorite moon will always be Earth's moon I think. So for everyone please remember that this talk will be recorded and archived on the Alliance site and the Ambassadors' site as well.

You're encouraged to share this presentation with your colleagues such as your education staff, your docents and whoever you think will benefit from it. Thank you again to Noah and Andrea for a great presentation. And as always if anyone has further questions about this topic either now or in the future always feel free to email us. Noah and Andrea gave their contact info. Again my name is Jeff Nee. And my email address is jnee@jpl.nasa.gov.

Our next telecon will be on Friday, June 16 about helping you plan for your eclipse events whatever they will be. And we hope to hear you there. Noah, Andrea any last words?

Andrea Jones: Well just thank you all. It was great being with you today.

Dr. Noah Petro: Likewise and happy eclipsing.

Jeff Nee: You guys as well. All right thanks everybody.

END