NWX-NASA-JPL-AUDIO-CORE (US)

Moderator: Anita Sohus
December 19, 2017
2:00 pm CT

Coordinator: Excuse me I would like to remind all participants that today's call is being recorded. If you have any objections you may disconnect at this time. Thank you. You may begin.

Kay Ferrari: Thank you very much, Brittany. Welcome everybody to the second in our series of Mars InSight telecons. This one is "Marsquakes: How Do We Detect Them and How Do We Use Them to Understand Mars?" I'm going to turn the program over to Sarah Marcotte who is going to introduce our speaker. Sarah.

Sarah Marcotte: Thanks Kay. And actually this is the third in our series of InSight telecons and they are all archived on the Museum Alliance site. So we had a mission overview in September with the PI Bruce Banerdt, we had, in November, Dr. Matt Golombek who leads our Landing Site Team talking about where InSight is going to land, and now we have Dr. Mark Panning who will be talking about marsquakes and what is the deal with marsquakes? I'm really excited for this one because I think this will be really helpful for all of us to understand how looking at marsquakes can tell us about the evolution of our rocky planets.

So Mark Panning came to us just in 2017 so he's fairly new at JPL. He's come from the University of Florida. He started as a terrestrial seismologist, but he has now gone down that dark path to become a full-time planetary scientist. So he's a member of the InSight Science Team. He does have a presentation with embedded files in it with some embedded media. We have posted both a PowerPoint version with the media in it and movies. And if you are actually using the PDF version of this presentation we do have the files listed separately on our Web sites and you can play the movie files separately if you need to. And Mark will take questions at the end of his presentation. I'll turn it over to him.

Dr. Mark Panning: Thank you very much. As Sarah said I'm on the Science Team for InSight. I've actually been involved with InSight since the mission was submitted back in 2009 or 2010, so it's been something I've been thinking about for a long time. I'm a seismologist like I said. The way I structured this, I was asked to do something about marsquakes versus earthquakes. And I kind of structured it as that. How do seismologists see quakes in general and how do we use them, kind of jumping back and forth between Earth and Mars, with a little bit of the Moon thrown in.

[Slide 2] I'm going to go now to Slide 2 in the package. This is I think the important starting point. By the way, I did want to acknowledge of course that everything here is material that comes from the whole InSight Science Team. I tried to acknowledge where the various things come from throughout, but this is obviously a large science team project and we have a lot of people working on these things.

A basic question that you should ask - and I'm sure educators, et cetera, on this line probably understand this pretty well but I think it's worthwhile presenting this from the perspective of how the general public sees things - is to ask, what are earthquakes and why do seismologists care about them? Obviously everybody knows an earthquake is when the ground shakes, and so most people tend to think of them in terms of the hazard. So I'm showing here a picture of San Francisco after the 1906 earthquake. It's a black and white picture, so maybe it's hard to see, but all of those city blocks are more or less uninhabited. It looks like the town has been leveled. Obviously that's a real issue and that's why most people care about earthquakes, but many seismologists are focused on using earthquakes to understand two basic things: number one, what are the physics of what actually happens that caused the earthquakes, and number two, using those waves, those seismic waves, that come out from an earthquake, that cause the shaking at the surface, but also go through the center of planets, in order to figure out what the inside of planets look like.

[Slide 3] So moving on to Slide 3, the critical point here is that earthquakes and marsquakes and any kind of quakes you want to talk about, they happen on faults. So faults are just cracks in the rock that have relative motion on it. The picture I'm showing here is actually a picture I always showed back in the University of Florida when I taught a class called "Earthquakes, Volcanoes and Other Hazards." I would use this to describe how faults are complicated. Fault systems are complicated. You can see in this rock that there're cracks all through it. This guy is looking at it and looking a little mystified.

If you follow individual layers you'll see that as they cross these cracks they move up or down relative to each other. There's combinations of all sorts of different motions we're seeing here. This thing that's observed here, this outcrop here, this is looking at the results of faulting that's happen over geologic time, but those motions don't happen slowly and steadily they happen in sudden slips. When that rock slips, the energy is released and that's the waves that come out from an earthquake that cause the shaking, but also cause the signals that go through the planet.

[Slide 4] If we go to Slide 4 now this includes a movie. So for those who are looking at the PowerPoint file you can just go ahead and push play for that for those who are using the PDF hopefully everybody can find this. And so when I start it you'll see that it looks at Mars, and then Mars spins around, and then it opens up. This is going to show waves propagating from the marsquake. The marsquake happens at the top there and then there's these blue and red line. The blue lines are something we call P waves, the red lines are S waves. And you'll see trailing behind the first red line, there's a bunch of red and white lines that are very close to the surface that's actually the interference pattern of S waves and P waves that we call surface waves.

I think it's fun to play this multiple times. If I were showing you an image of my screen I'd play it over and over again but for those of you who are watching, feel free to play it over and over again. Watch what these waves do. If you look on the inside there are these various thin white circles. These are layers within Mars. The center thin white circle is the Martian core. In this model the Mars core is considered entirely liquid. We actually don't know whether the Martian core is liquid, whether it's entirely liquid, or whether it has some liquid and some solid. We actually don't even know how big it is. In this picture it's chosen one particular model of Mars but that's actually one of the critical things that InSight is going to tell us: how big is the core of Mars. We actually don't know that and I'll get back to why that's important as we go through this.

The next circle going out is an internal layer within the rocky layer outside of the Martian core. This internal layer is just a change in mineralogy that happens. You'll see that the various glowing waves that propagate out bounce off of that. They bounce off the core and then they come back up to the surface. This is the critical way that we can use seismic waves to figure what's happening inside. There's also a thin white line just under the surface of Mars you can see, that's the thickness of the crust. All of these layers cause seismic waves to bounce and change direction, and so based on how long it takes seismic waves to go from the source, which is marsquake, to the receiver, which is the InSight lander, we can figure out what it had to bounce off of all of these sorts of things so that we know what the inside of Mars really looks like. So those are the waves. These are seismic waves that propagate out.

[Slide 5] If we go on to Slide 5 now, what we're landing on InSight, it's multiple instruments, but the one that I'm paying attention to the one that I'm associated with on the science team is called SEIS, S-E-I-S. And honestly I've just forgotten what that stands for. Seismic Exploration for Interior Structure I believe. We love acronyms and I don't always remember what they mean because I just say the acronym over and over again. Regardless, that's a seismometer. It's actually six different seismometers corresponding to three different directions of motion and two different types of seismometers, one that's very sensitive to lower frequencies and one that's sensitive to higher frequencies. Regardless, what these seismometers do is measure the motion of the ground.

All of us have the ability to interact to seismometers on a day to day basis. Most laptops and all smartphones have accelerometers built in. This is a particular type of seismometer. It measures the motions of your phone. It's used to tell the software of your phone when you pick it up and put it to your ear, so that it will turn off the screen so your cheek doesn't push buttons. Laptops that have spinning disk drives have them included so that they automatically shut down if you drop the laptop so that the disk isn't damaged.

I'm showing here a screenshot from a program called SeisMac which takes advantage of Macs that have the spinning drives. Actually my current Mac no longer has a spinning drive so I can't use this program anymore, but for those that have a spinning drive, it takes advantage of that existing accelerometer and converts that accelerometer information into the motion in three different directions: two horizontal axes, X and Y here, and one vertical axis, Z axis. This is just a recording from my old Mac laptop.

You'll notice that there is a lot of wiggly lines on there. If you're going along the horizontal direction that's time increasing to the right and the up and down motion, in this case, is changes in the acceleration of the laptop. So if you rapidly move it up that will give you a line on that Z component going up, if you rapidly move it, it goes down and likewise for the two horizontal directions. If you look at this picture you'll notice it's got all of the big energy is on the Z axis. This was actually me tapping out the drum solo from "Wipe Out." So if you're a really good interpreter of these records you may be able to find the rhythm of the drum solo from Wipe Out there. I can't actually see that and I'm actually pretty good at looking at these wiggles, but that's what we're looking at. When we see these wiggles it's just looking at how the ground, or your laptop, or whatever, is moving up and down or side to side as a function of time.

[Slide 6] If we move on to Slide 6, this is a more realistic seismogram that we as seismologists are more likely to see. This is actually an Earth seismogram, and it looks a lot different. There's a lot of structure to this. There are pulses of coherent energy that show up, and on here these are labeled. This is actually an earthquake record recorded at a fairly long distance away, 2300 kilometers. This is an example from 1995 but many earthquakes will look like this. I picked this one because it's pretty looking and you can see a lot of details there.

You can see two pulses showing up. First is a wave that we call a P wave. I'm going to talk more about what a P wave is, what an S wave is, and what surface waves are as we go on, but originally they were just called this because the first wave that showed up after an earthquake was the primary wave, so they called it a P wave for primary wave. The second major energy that showed up was the secondary wave. We'll go into the physics of what these waves are in following slides. Then there's a big pulse of energy that's a little more complicated looking and that's more spread out, that's actually the surface waves that are stuck to the surface. They don't go through the interior of the planet, they're stuck to the surface and propagate along like that.

Originally the first seismologists that were looking at data, once we started getting good data in the late 1800s, actually called the surface waves T waves, or tertiary. We threw that one out, but we did keep the P and S terminology.

There's an animation on this slide that pops up a little red line at the bottom and it's just a red line demonstrating the length of time that you're seeing shaking here that's showing up on the seismogram. And you can see it goes from about 250 seconds after the origin time of the earthquake to about 1000 seconds after the origin time of the earthquake.

So, if you add that up, that's about 12 minutes between the first arriving shaking and when that shaking mostly dies off at the end. So 12 minutes of shaking, which is actually very fascinating to me when I look at it because the earthquake itself happens in about a second for a magnitude 5. Big events take a little bit longer to happen, but for an actual earthquake of magnitude 5, the motion of the Earth that causes the seismic waves to propagate out lasts only about a second in this case. But because there are different kinds of waves that come out from the earthquake that go at different speeds and that take different paths through the Earth, that energy gets spread out over a much longer time window.

So the analogy I often used in class is to think if you had a race and everybody starts when the green flag goes down, if you've got a Lamborghini, it's going to get there really early. I always used the example of a Yugo, and nobody remembers the Yugo anymore, but when I was growing up that was the car we talked about as being the slow car. It was a short lived car from the 80s. Regardless, if you have one of those or an equivalent pokey car, it's going to take much longer to get to the finish line. So you're going to see the arrival time of these cars spread out even though they all started at the same green flag. So that's what we're seeing in the seismogram, and the relative timing of all of these things tells us about what's happening inside the planet.

[Slide 7] So moving on to Slide 7 there's a lingering animation in here that makes it start out blank so if you're doing this in presentation mode on the PowerPoint go ahead and click it again. This is a picture of the seismometer that we're sending to Mars. This is actually just looking at the vacuum sphere. You can't see the seismometer itself. It's inside the vacuum sphere that the engineers there are gathered around and looking at. It actually has three instruments inside that sphere that are measuring the long period motions, and they're oriented in such a way that we can get all the different directions that motion happens. That's already on the lander deck right now. The lander is about to be shipped to Vandenberg I believe. I'm not sure exactly where we are on that but it's with the lander and it's going to go. Then when we land on Mars it's going to be taken off the deck and put on the surface of Mars.

[Slide 8] Moving on to Slide 8, the point of this slide was that there are certain types of waves that show up regardless of whether the quake is happening on Earth or on Mars. I've already talked about these multiple times but now I'm starting to talk about the difference.

There are two types of waves that we called body waves. They're called that because they go through the body of the planet. They can go through the inside of the planet they're not stuck to the surface. Those two types of waves are called P waves and S waves. As I already said P waves and S waves come from primary and secondary waves, originally that's what the names mean, but seismologists often think about them as pressure waves and shear waves. That's kind of the way we remember what the letters actually mean.

P waves are kind of a push-pull sort of wave. The individual pieces of the ground are moving back and forth in the same direction that the wave is propagating, so you get parts that are squeezed together and parts that are pulled apart, so it's changing the pressure within the wave as it goes by. S waves are shear waves, so the particles actually move side to side relative to the direction that the wave is going. Because the physics of how those waves move are different, the materials they propagate through see different kinds of strength of the material. So what happens is that P waves see material that's a little stronger and so they actually move faster. The S wave, that kind of shear motion, sees the material as a little bit weaker to shear and so that wave moves a little slower. So P waves generally arrived first S waves arrive second. There's also a third kind of wave that we call surface waves. They're actually broken up into lots of different types of surface waves, but these are waves that don't go through the interior of the planet; they're stuck to the surface.

[Slide 9] If you go on to Slide 9 there's another movie here. This is showing what I'm talking about. Movies are a better way of showing what these waves are doing then trying to show a still picture. So if you start this movie, it shows the motion of a P wave. And this is why you can see it's the pressure wave. You can see that the grid lines are pushed together and then pulled apart as the wave comes through. It's really helpful if you look at the little black square on the side as you go through this, and you can see that when the first pulse comes through, it get squished together, then it gets stretched apart, and then it goes back to its original size. In general things always go back to their original shape. That's because these kind of waves are what we call elastic waves. The whole reason they move is because the Earth is elastic, which means you can put pressure on it and it will change shape, but it wants to go back to its original shape. So this is the Earth behaving as a spring, or Mars behaving as a spring, so that's a P wave.

[Slide 10] If we go on to Slide 10 we have the same kind of animation for an S wave. And you can see here that this is a side to side motion it's up and down in this version of the picture but once again the individual grid squares you can see there, even though the wave is going left to right, the grid squares go up and down. If you watched the little indicator black square on the side there, you can see that it doesn't squish together and pull apart like it did for the P wave it slides back and forth like a deck of cards. That's a shearing motion. That's why we call S waves shear waves.

[Slide 11] And finally if we go on to Slide 11 this is an example of a surface wave. This is a particular type of surface wave called a Rayleigh wave. It's actually a combination of P wave and S wave motions but it's biggest at the surface and decays as you go down. So you can see there's a lot of motion at the top, very little motion at the bottom, and if you watched the little indicator square on the side you can see it kind of changes shape, but it's in lots of different ways. It has a little bit of the squishing in and pulling apart, and it also has a little bit of the sliding side to side. That's because a Rayleigh wave is a combination of P and S motions.

It's actually a similar kind of motion as you get if you look at what something floating along on the surface of water sees when a water wave comes through, which is a type of wave we call a gravity wave. If you watch an individual, something floating on the surface, you notice it just doesn't move along with the wave. It doesn't move along with the wave unless you happen to be a surfer who is really good at it. Floating things just kind of roll back and forth across the surface and it has the same kind of motion which we call elliptical motion.

There's also another kind of surface wave called a Love wave but I don't have a picture of it but I do like to talk about Love waves because it is such a great name for a type of seismic wave.

Woman: Question here.

Dr. Mark Panning: Yes.

Woman: When you see waves on the surface, if you're in the middle of an earthquake -- I'm in California -- those are the surface waves you see, the ones that look like water waves only it's the parking lot or a floor?

Dr. Mark Panning: Yes. So most likely what you're seeing are surface waves. So the biggest motions you see locally, that are what you feel, it is possible to feel the P waves and S waves. I've only experienced a few. I lived in Northern California for a while. I did feel a few, but not that many. Often times you'll feel like a jolt and then a rumble. Often times what you're seeing there, the jolt is when the P wave comes through. It's relatively small, and then the big shaking is a combination of the S waves and surface waves. They're not as well separated if you're close to the earthquake. If you're far away there's a big difference between when the S wave comes in and when the surface waves come in, but if you're close the S waves and surface waves are pretty close to each other.

Woman: Yes you still feel that kind of bump first and then you can see the wiggly, wiggly.

Dr. Mark Panning: Yes.

Woman: Even if you're fairly close. I was in the Coalinga earthquake back in '83 and that's what happened. Now if you're living in the middle of the Central Valley which has got hundreds of feet of alluvium and all you hear is a bump that would be the P wave while somebody else is getting jiggled?

Dr. Mark Panning: Yes. In general, in any place you're going to get first the P wave, and then S wave and surface wave. Often times it's hard to tell the S wave and surface wave apart, but the ones you can see are almost always the surface waves because they have bigger motions than the P waves do.

Woman: So yes. Well where we are now all we hear - all we feel is the - a bump. And then we have to look in the news to see where it came from whereas when you're closer to an earthquake in the coastal mountains then you experience the whole thing. So that would be a P wave here in the alluvial plain correct?

Dr. Mark Panning: Possibly. I'd have to think about what you're experiencing there. You're still going to get surface waves going through there, but what you experience when you're far away, you may only feel when the relatively short period surface wave pulse comes through which is less spread out because the other stuff has got smaller amplitude and so you're not feeling it. I'd have to think about what exactly you're feeling farther way. Generally in my experience, when I was in the Bay Area, the earthquake that happened close to me I could feel that bump and then the shake, but when I was far away, all I felt was a little bit of roll. Then I could tell the difference between how far away they were. I'd have to think about what you're experiencing there in the valley.

Woman: We have a different undersurface than the Bay Area does.

Dr. Mark Panning: Yes. That will definitely change how your motion feels. So you get magnification that's happening in the basins that emphasizes some parts of the waves and not others. So I'm a little surprised that it feels a little more thump-like to you I would've expected it would have felt more rolling because basins often amplify the surface wave energy. That's why I don't exactly know how to explain your experience but there's a lot of complicated wave dynamics that can happen so I'm not sure exactly what was happening there.

Woman: Okay. Thank you very much.

Dr. Mark Panning: **[Slide 12]** So moving on to Slide 12 the question I often got asked when I was slowly converting to the dark side, as it was put in my introduction, from terrestrial seismology to planetary seismology, was "Why do planetary seismology?" What's the point of trying to go to another planet and land a seismometer there and record that data and use it? It's really a different way of doing planetary science than most planetary science out there. Most planetary missions focus on surface and orbital observations. So they tend to look at what the surface looks like and look at spectral characteristics to start determining chemistry. That's all really valuable, but it's difficult to get what's happening inside the planet, which we can't see.

Most of the information we have for planetary interiors are related to gravity measurements. We can look at the characteristics of orbits and how they change in time and how they affect planetary spacecraft, et cetera, and start looking at the gravity of the planet and the details of the gravity of the planet. That can give us things about roughly does it have a dense core or not, what's the average material it's made out of. But it turns out gravity is a really non-unique way of interpreting what the inside of a planet is. You can come up with lots of different planetary interiors that have very similar gravitational signals. We have a much more detailed picture of the interior of the Earth then we do for other planets, and that's because on the Earth we have seismology. Any time you've seen a cartoon of what the Earth looks like, all of those layers how big they are, what kind of material we've got, that really comes from seismology more than anything else.

[Slide 13] So on Slide 13 I'm just showing pictures of Earth, Mars and moon. And these are plotted on the same length scale they're not obviously on the same distance scale because Mars is not sitting in between the Earth and the Moon. That would cause very complicated tides. It's pointing out why looking at the interior of Mars is interesting for understanding what the interior of Earth looks like. Mars is in between the Moon and the Earth in terms of its size, which means that in terms of the physical process it's undergone, there is somewhat of that in-between nature.

The Earth is very active body. It has all sorts of geologic activity which has kept me employed for many years and has given us lots of interesting information about the interior. The Moon is relatively quiet. There's almost no geologic activity happening on the Moon. We have put seismometers there, and I'll talk about that in a little bit, but it's a pretty quiet body. Part of the reason why is because it's so small.

Mars is in between, which means it's had lots of activity. It doesn't have very much activity now, but it still has ongoing activity, but because it had less activity than the Earth, the surface actually maintains a lot of information over the billions of years of history, whereas Earth tends to erase things. So if we want to understand the process of terrestrial planets, Mars is kind of a unique window in which we can see lots of processes that happened, but we also preserve the initial stuff that the Earth has erased.

[Slide 14] On Slide 14, it's just showing our pictures of the interior, lots of planetary bodies that are of interest. I'm not going to talk about any of these details, but you can see here there's lots of things that have different relative sizes of the cores and all of that. All of that, that you're looking at here, is derived from gravity, but all of those things are very approximate. We know that Mars has a core that's roughly half of its radius, but our uncertainty of how big it is, is measured in hundreds of kilometers. And that makes a pretty big difference in terms of our understanding of the interior. If it's really big, that actually means that there's a lot of other things besides iron inside of it. You've got a lot of other things sulfur inside of it because, gravitationally speaking, a big, less dense core looks the same as a smaller more dense core. So if it's a small core it's more pure iron and that's telling us things about the process of how the core of Mars formed and how it differs from how the core of Earth formed.

[Slide 15] If you look to Slide 15 this is a picture of the structure of Earth. You can see here that there's pretty exact numbers put for all of the depths of the various layers here. We know how big the Earth's core is to an error of, on average, we know it to an error of less than a kilometer. At an individual location there's typography that we don't totally understand so at any individual location there's probably uncertain of a few kilometers but it's much less than the uncertainty of [Mars] and that's all because of seismology.

[Slide 16] Slide 16 is showing basically going back and showing a picture of the kinds of things I was talking about, these waves bouncing off. On the left is a picture of the different kinds of paths that seismic waves can take from a source which is at the top here to a receiver which is on the right side. All of these different paths, seismologists give them names that are a big alphabet soup: P&S, and, if you look in the small print there, there's things like PCP, and PKS, SKS, PPSS. To seismologists that tells you what path it takes, which parts of the Earth it bounces off of. That [slide] gives you, on the right, the seismograms and they have different peaks at different times, and if we look at very detailed knowledge of those times, we can figure out what material it propagated through, which controls how fast the seismic waves go, and how big the different layers are, which controls how long a path it has to take to bounce off the core, for example.

[Slide 17] Slide 17 is starting on the history of planetary seismology. I'm going to go through this pretty quick, but it's kind of a good, bad, and ugly situation. The good is the only other place that we have good seismic data from, usable seismic data from, is the Earth's Moon.

So five of the different Apollo missions placed seismometers on the surface. You can see an example of what this experiment layout looks like here. The seismometer's actually in that silver circle thing in the front. It's in that cylinder in the middle and then there's a thermal blanket put around to try to control the temperature change near the seismometer. Those landed between 1969 and 1972, and the data was recorded until 1977. It was actually turned off two months after I was born. So I've spent most of my life without any seismic data from another planet.

[Slide 18] If you go on to Slide 18, this is showing why planetary seismology is interesting. This is plotting on the same time scale what an earthquake looks like versus what a moonquake looks like. You can see the earthquake has a big pulse at the beginning and then there's basically no energy after that. This is just looking at the high frequency energy. There actually is other energy you can see out too much longer times on Earth.

Meanwhile if you look at a moonquake you can see you don’t have a sharp spike at the beginning. The energy emerges and then just rings back and forth. It’s just bouncing back and forth for an hour after an event.

This is because the Moon is fundamentally different than the Earth. The Earth, most the surface is pretty solid and it has water in it, whereas on the Moon it’s all broken up and it’s very dry. This means, on the Moon, because of that combination of it being dry and being broken up, you have energy that bounces around off of all these broken up bits of the Moon, and so you get energy that just spreads out all over the place.

We call this scattered energy and it looks very different than the Earth. We think Mars is probably going to be somewhere in-between. It's broken up at the surface. There are craters but it’s more wet than the Moon. There’s water involved and that actually reduces some of the effect of the scattering. So we expect Mars to be between these two but we won’t know till we get there. Nobody quite expected the Moon to look like it does until the data arrived.

[Slide 19] I'm listing this as “the bad” and this is not to offend anybody who had anything to do with the Viking Landers. I always have to say this when

I'm at JPL because people are still here that had to do with the Viking Landers.

This is a picture of a Viking Lander, not the one that actually landed on Mars, because Carl Sagan never made it to Mars, but there's Carl Sagan with a model of the Viking Lander. I believe that's somewhere out in the Mojave Desert. Both the Viking Landers, which launched in '76, had seismometers on them, but the seismometers were mostly put on as an afterthought. They were put on at the top of the deck. There was no move to put them on the surface like we're doing for Insight. One of them didn't uncage; there was a portion of the instrument that was locked so it wouldn't be damaged during launch and landing, and the mechanism that was supposed to release that didn't work, so there was no data from that one.

The other one did record, but just -- because of the placement and the sensitivity of the instrument, and a lot of reasons -- basically recorded the Lander rocking back and forth in the wind. It didn't record the actual motion of the surface of Mars, so it was not useful for doing what I would like to do.

[Slide 20] If you look at Slide 20, the ugly is that there are ten other seismometers that have been included in launch missions that have failed for a variety of reasons. The picture on the right is from a cartoon of what Mars 96 was supposed to look like. This was going to actually put a couple seismometers on the surface of Mars, but one of the launch stages failed and it never left Earth orbit. I believe it crashed into one of our oceans.

[Slide 21] But InSight is going to change that. It's launching on Cinco de Mayo in the upcoming year. I think the nominal time is about 4:00 in the morning. It's going to have multiple instruments on board. What I'm most interested in is SEIS which is the kind of pie plate thing off to the right in this picture. This is an older picture now. Most of them would put it on the left because that's the way we want to install it; that's a detail.

There's also this thing called HP^3 which is going to have a little drill that goes down 15 feet and measures the temperature gradient and therefore the heat flow rise. There's a radio science mission. There're also cameras -- lots of stuff. The nominal mission duration is one Martian year, which is about two Earth years. And we're going to use this data to look at what's happening inside Mars.

[Slide 22] is just showing the Lockheed Martin dramatically posed shot of the Lander in the hangar there at Lockheed Martin when they were assembling it. I just love the lighting on this picture. It's very dramatic, just to give you a scale of how big the Lander is. The arm on top of the deck is going to take the seismometer which is the kind of orangey gold thing towards the top of the center part of the Lander there. It's going to take that and put it on the surface, and then put the pie plate thing there in the middle over the top of it. That's a wind and thermal shield.

[Slide 23] This is something that I often had to address when I talk to Earth seismologists. Everything on Earth relies on networks. You probably at some point in your life had to take an Earth science course and learn about locating earthquakes. We look at the difference between P and S wave arrival times and that gives you the distance to the earthquake. And then you look at three different stations and make circles representing those distances, and where they cross, that's the epicenter of the earthquake.

I have taught classes and say “Well, you need three stations to locate an earthquake.” There are also modern methods that really take advantage of networks in these things called array seismology. And there’s a lot of really clever things you can do there. So when I talk to Earth seismologists they say, "Everything we do is networks. What are you going to do if you only have a single station on Mars? You can’t do any of the things we're doing." And I, of course, strongly disagree with that.

[Slide 24] If we go on the Slide 24 obviously having a network on Mars would be great but that requires multiple landers, multiple instruments. Costs increase very quickly. This has been proposed many times but it’s been very hard to get this to happen.

I always argue that we may be able to see much more stuff on Earth because you instead of just having one station you have hundreds and thousands of stations. But the relative difference between zero and one is infinite. In some sense, we're making a step change in our knowledge once we add in one station. So that’s a philosophical way of presenting it, but there are a lot of techniques within seismology that we can use that are based on single stations. So there’s the techniques that don’t require location information. I’m not going to talk about those today because I’ve already gone long but there’s also single station location techniques. That’s actually a lot of what I focused my time on in the early part of the mission, was just to find the single station location techniques.

[Slide 25] On Slide 25 this is a map of where we see earthquakes on Earth. You can see where those black dots are. They’re concentrated along linear features that we called the boundaries of the plates of the Earth. This is a classic picture from plate tectonics. So most earthquakes we're seeing on Earth are at the edges of these big rigid plates. They’re not spread out all over the place. They're concentrated in very particular areas.

[Slide 26] If we go on to Slide 26 Mars quakes are going to be different. There’s lots of green and red lines on here. The difference between green and red lines here are just the types of motion we're seeing here. These are all mapped faults on the surface of Mars. The red faults are places where it looks like the motion is pulling apart. The green lines looks like Mars is squishing together. They’re not showing as nice collections right along edges of plate boundaries because Mars does not have plate tectonics but there are a lot of faults that are at the surface and it’s different physics that are governing why we have Mars quakes. There is a long-term shrinking of the planet because it’s cooling and shrinking. That causes this widespread area of green lines all over the place.

As the planet shrinks it's squishing together and that causes faults. You can estimate how much energy is associated with that. There’s also an interesting thing if you look at the left of this picture there’s a lot of big mountains. That’s the Tharsis province.

The biggest one is towards the far left there which is Olympus Mons. This is a huge weight sitting on top of Mars. And it's slowly sinking down and spreading out. And that causes a lot of these red lines that are centered around that.

You can also see that there's several red lines towards the right side of the picture. We're actually, on InSight landing, towards the right side of the picture, near the equator. Regardless there are these faults all over the place, and we've done lots of modeling to show that we should see marsquakes. It will be quieter than the Earth because we don't have plate tectonics but it should be, in a sense, louder than the Moon, which only has very long-term thermal changes, which are pretty small for the Moon at this point because it's little, and tidal effects from the Earth. Once we say that we expect to see marsquakes, we can say, "Well what are the seismograms going to look like?" We have computer programs to do this.

[Slide 27] If you look at Slide 27 this is just showing an example of the calculation of these for one particular Mars model. We can use different kinds of computer programs to model different frequencies. I'm not going to go through this in detail but once we guess what Mars should look like, we can predict what the Martian seismogram should look like and look at different things we'd like to extract from those seismograms. We can predict a range of possible models and look how the seismograms differ to understand what's happening inside Mars. We also have to model what the noise on Mars is going to look like.

[Slide 28] If we look at Slide 28, most of the noise on Earth is actually driven by the oceans. There are no oceans on Mars so most of what we see is driven by pressure changes in the atmosphere and temperature changes from day to night.

On the left, the top blue line is just a noise model. There's a long period signal that's going over the course of a day. That's actually caused by temperature changes from day to night, but there’s also smaller wiggles on top of that that are caused by pressure changes. In this model, this is actually driven by an atmospheric circulation model to look at how the pressure changes and then mapping that into the seismic noise we expect to see. Then on the right, there’s the same blue line but there’s a marsquake put over the top of it. So by looking at this model we can see how we expect to see marsquakes above the noise.

[Slide 29] Twenty-nine is a little bit about single station location. It’s the only one I put on here that has equations on it. But this is work I did early on in the InSight project, and it’s basically looking at ways we can locate an event with a single station. And one way we can look at it is to look at surface waves that go around the planet more than once.

We give this a numbering scheme. If it goes a short way around it’s an R1. If it goes the long way it’s R2. If it goes all the way around that’s an R3. The relative timing of those things constrain the unknowns we have. So when the quake happened, which is t_0 on this, how far away it is which is the triangle delta, and how fast of the waves go, which is U in this particular example. I don’t expect you to memorize any of these equations, of course but it’s a relatively simple mathematical problem, and we also can talk about P and S waves that go through the center. We can use these to locate earthquakes, marsquakes rather.

[Slide 30] And once we have those locations we can use that to constrain the inside of the structure. So in Slide 30, I’m not going to explain this in too much detail, but these are models of the velocity structure of the inside of the Earth, in this case, using data that is located by the same methods we're expecting to use on Mars, and then using that to figure out what the inside of the Earth looks like. On the [left] the black line in the middle is the actual Earth structure and then the various colored lines are what we're getting with a handful of events. And then on the right is a similar approach with even smaller number of less good events. So we're trying to be realistic about the range of events we might see.

[Slide 31] So finally Slide 31 is just a summary, and the point I want to make, and what I want you to take away from this, is that if you want to know what’s going on on the inside of a planet, seismology is your way to do it. It’s the best way to know the details. So landing a seismometer is extremely valuable.

We're going to do that on Mars next year. It’s a very exciting. I’ve been building up on this for almost a decade now, so I’m really thrilled for this to happen. I can go on a long argument of why we expect to see Mars quakes but we have maps. We have estimates of how many Mars quakes we should see. So if we get them we should be able to use them even if we just see a handful of them to figure out the internal details of Mars. And if Mars is more active that we expect, we may get many, many of these events and really do some very interesting things. And with that’ll stop and I’m happy to take any questions.

Andrienne Provenzano: Yes hi. This is Adrianne Provenzano, Solar System Ambassador. And I just wondered if you could talk a little bit about how do we know that there are no plates tectonics on Mars?

Dr. Mark Panning: Well part of it is from those maps of the faults. If we were to look at faults on Earth and trying to figure out relative motions on faults on Earth, we would see that they all, for the most part, the big motions happen on the edges of plates. And so we have a concentration on the edges of plates. If you look at the fault map of Mars you can see they're spread out all over the place so that’s a first order thing that tells us about that. A dominant way we can see plate tectonics on Earth is through magnetics. If you look at oceans, you get this thing called magnetic striping. This is because the oceanic plates come up in mid ocean ridges and spread out. When they form they record the Earth's magnetic field at the time they formed and the Earth's magnetic field flips back and forth.

We don’t see anything like that on Mars. There’s a couple reasons why we wouldn’t. Right now Mars has no internal magnetic field, so of course there’d be nothing to record. But on the Earth these oceanic plates they're created at the ridges and destroyed at subduction zones and so the average age of oceanic plates is something like 100 million years compared to the age of Earth which is 4-1/2 billion years. If we look at the average age of the surface of Mars, which we can determine from looking at things like crater counts, most of the surface of Mars is billions of years old. There’s not a creation and destruction process that’s happening there.

There was a paper several years ago that argued that there may be some striping near the South Pole that people suggested maybe there was some sort of incipient plate tectonics going on there. Most people don’t believe that now because part of the reason why it looks like striping just had to do with the projection that the particular authors were using to show the magnetic anomalies. So there’s little to no evidence that plate tectonics exists or did exist on Mars.

Andrienne Provenzano: Okay thanks. And then I had another question. You were talking about moons and planets together as far as planetary seismology. So is this field approaching these different celestial bodies differently, whether it's a moon or a planet or is at all kind of the same?

Dr. Mark Panning: Well I mean the physics of wave propagation are the physics of wave propagation. It doesn't matter whether you're calling it a planet or a moon. I tend to use the phrase "planetary bodies" because then I don't have to get into a debate about whether Pluto's a planet or things like that.

Dr. Mark Panning: That's just terminology. But the waves will look different on different types of planetary bodies. I've done a lot of thinking about icy moons like Europa where you have an ice shell over a subsurface ocean. There's a lot of waves that look a lot different. When you've got that geometry, you get waves trapped in this ice shell on the top that looks different than they look on a terrestrial planet like the Earth or Mars. Once again the physics is the same but the way the seismograms look is different. Then the tools that you can use to interpret it are different. On Europa there are waves that are trapped in that ice shell and you can look at the characteristics of those waves and figure out how thick the ice shell is, which is something that we'd want to know if we were to ever land on Europa.

Andrienne Provenzano: Great. Thank you.

Chris Thompson: Hi. My name's Chris Thompson. I'm a Solar System Ambassador and I was curious, given the delay in the InSight program caused by the problem with the vacuum chamber last year, how have you used the additional time that you've had to refine the plans for the mission or really what did you do, how did you use that additional time you didn't think you were going to have?

Dr. Mark Panning: Yes so obviously the engineers got a lot more time to improve the instruments. Even beyond the fact of the vacuum leak that would have made the instrument not work, and that's why we didn't launch in 2016, there have been lots of changes to the internal mechanics to improve the quality of the instrument. So that's number one. For those of us on the science team, I'm not an engineer. I wouldn't want to use an instrument that I had built [myself], because it would break.

But we've spent a lot of time working on improving the various algorithms we're working on to try to rapidly model the data when we get it in. What we're aiming for now is to be able to, as soon as that first Mars quake is recorded, to rapidly interpret that data, turn it into a model of the internal structure of Mars, share that with the internal community, come to a conclusion and rapidly push this data out. We're working on a different time scale than a lot of planetary missions because we are planning on releasing the data that comes back, the seismic data. We're not just going to keep that within the InSight team. It will be released to the public to all seismologists via the normal channels that seismologists get their data, within weeks to months after we receive it. And so we spent a lot of time making sure that we could rapidly process and interpret that data.

Chris Thompson Thank you, got a follow on if you don't mind, a completely different subject. Don't know if you have an insight into the trajectory that's being used, but I noticed this launch is coming out of Vandenberg, assume that's probably a south launch putting it in a polar orbit. Can you help me understand why that approach has been taken as opposed to an easterly launch out of the Cape?

Dr. Mark Panning: Well this is the first planetary launch that I know of that's come out of Vandenberg instead of the Cape. The short answer is it's not as advantageous a direction but for scheduling purposes, it was easier to get the launch scheduled in the available window at Vandenberg rather than at the Cape.

Chris Thompson: Okay.

Dr. Mark Panning: The short answer is we're still able to do it because it's an overpowered rocket for what we'd need. So we can still get at Delta V

Chris Thompson: Is it an Atlas?

Dr. Mark Panning: Yes it's an Atlas. And so if you look at a picture of what InSight looks like inside the available fairing, that's just this tiny little thing and then the fairing is 90% empty space. So we're not putting up that much mass of what the rocket is capable of delivering. So we can start with a polar orbit and do a few more maneuvers and get on the appropriate trajectory to go to Mars without relying on the eastward, in-the-direction-of-rotation launch.

Chris Thompson: And you're still getting a six month trip so that's pretty quick.

Dr. Mark Panning: Yes.

Chris Thompson: Normally it's like 8-1/2.

Dr. Mark Panning: It's a standard Earth-Mars trajectory more or less, you know, which is why we can only do it every two years. The orbits only line up that way every two years.

Chris Thompson: Well thank you.

Man: A question about the image of the spacecraft there, the overhead view of the InSight. You mentioned the seismometer. Is the drill visible on the spacecraft and secondly once the drill gets on the ground how does it actually hold itself in place while it's drilling that far down?

Dr. Mark Panning: Yes so in that picture, if you're looking at Slide 22, if you look at the big metal pie plate in the middle, just to the right of that there's a black stove pipe looking thing sticking up. That's the HP^3 instrument. The drill itself is a hammer drill that's inside that stovepipe thing. That stove piping is actually just the housing for it to hold the mole initially. That's what we call the hammer. It's a mole and to have the data table routing. That's got four legs and when it's put on the surface, that's what holds it in place.

It's legs stick out to the side and that's kind of like your oil barrack on the top more or less. It's giving it the stability and then the hammer drill goes down from there. It's just connected by a cable that trails behind it.

Man: Okay thanks.

Dr. Mark Panning: Yes. Any other questions?

Kay Ferrari: Yes (Jeff) left a question before he ran out and this is with regard to Slide 7. He said, "What are the major things that make SEIS different from a regular seismometer used by the USGS?"

Dr. Mark Panning: Yes so SEIS is, in many senses, it's very comparable to a particular seismometer called an STS1. The details of that aren't that important but these are like the seismometers that are put out in what's called the Global Seismic Network which is run by a combination of USGS and a organization called Iris that's an NSF funded organization.

These are very, very sensitive instruments. On the Earth we install them in vaults underground and they're very, very sensitive. They're the most sensitive instruments you can get on the Earth. They're sensitive enough to detect the quietest motions of the Earth you ever see. That's the low noise model of the Earth so it's a very sensitive instrument.

So to put it in scale they measure motions that are comparable in scale to the size of a hydrogen atom. So they're very, very sensitive instruments. The VVV which is the one inside the sphere in the picture in Slide 7 has a sensitivity range in terms of frequency and in terms of noise. It's very similar to the STS1. So it's like the most sensitive instruments we use on Earth.

Many of the instruments we use on Earth are much less sensitive because if you want to record a big earthquake you don't need an instrument that sensitive. But we're looking at Mars which is quieter and so we want to maximize our chance of recording the data we need to record. There's also...

Kay Ferrari: I was going to say (Jeff) had another question too on Slide 4 and he was asking, "How big of a Mars quake is that animation simulating?"

Dr. Mark Panning: I honestly don't know because there's no scale bar on here so you don't know how big the motions we show are. So first order, when you're talking about seismic waves propagating over planetary distances, it's what we call a linear process. So if I make the earthquake or the marsquake twice as big the waves get twice as big. And since I'm not showing you how big the waves are in there it you can scale it however you want. So in that sense it doesn't matter what I'm showing there.

In terms of what we're actually expecting to see on Mars, the biggest events we expect to see range from mid-magnitude four, mid-fours up to maybe a magnitude five. We're not expecting to see a magnitude seven or eight or anything like we see on the Earth.

Man: Can you tell us what the purpose of the pie plate again is again on InSight that that goes over the seismometer?

Dr. Mark Panning: Yes so that's what we call the WTS or the Wind and Thermal Shield. And that's the two main purposes it has: to shield against the wind and to shield against temperature changes. So one of the problems we run into in this sort of thing is that seismometers are extremely sensitive instruments which means they're very good at measuring a lot of things that aren't what we want to measure. Because the springs within the VVV instrument are slightly magnetic it's a magnetometer. So we need to have a magnetometer on the lander to measure the magnetic fields so we can correct for that. Because wind's blowing is going to move it, there's going to be an anemometer which measures wind. Because the spring constant changes as a function of temperature, it's also a thermometer.

So we put this wind and thermal shield on there to reduce the buffeting of the wind. Mars, as you likely know, has very high velocity winds. They're not huge amounts of force associated with them because the atmosphere is not very dense. But that is a real thing we need to correct for so we cover it up so that the wind hits this wind and thermal shield which is not touching the seismometer in the middle. And also there is a thermal blanket over the instrument itself, the instruments within an evacuated sphere, and then there's another thermal blanket associated with this wind and thermal shield.

All of those levels of thermal insulation shield the instrument against large temperature changes. There is some effect of the day night cycle but it's reduced in short-term temperature variations as a little gust of wind comes by and slightly changes the temperature, that is all filtered out.

Man: And then that picture you had of the lunar seismometer, that shield around it was that same function as that thermal shield...

Dr. Mark Panning: Yeah.

Man: Great thanks.

Dr. Mark Panning: Yes.

Kay Ferrari: One more question from (Jeff).

Dr. Mark Panning: Okay.

Kay Ferrari: Have we gotten any clues about the core of Mars in terms of gravity science from the orbiting Mars spacecraft?

Dr. Mark Panning: Yes like I said we do know some things about the core of Mars from gravity, from the orbiting Mars spacecraft and from other things like looking at small changes in procession of the orbit and things like that. The biggest constraints we have, if you reconstruct the gravity signals we observe, you can get at the mass of Mars and its moment of inertia which is basically how difficult it is to spin Mars. And moment of inertia is the most useful one for understanding what’s happening with the core.

The practical example that people always think of when you think of moment of inertia this physics textbooks is you think about an ice skater. When they stick their arms out they have a big moment of inertia. It’s harder to make them spin and so they spin more slowly. As they pull their arms in their moment of inertia goes down and they can spin more rapidly. By looking at the very detailed gravity field of Mars and looking at other characteristics of the Martian orbit, we can figure out the moment of inertia of Mars. We have a pretty good estimate of that and that tells you how much of the mass has pulled in toward the middle. But it’s a very non-unique measurement.

If you can have basically the same effect of having a small dense core or having a larger less dense core. And so as soon as we know the size of Martian core from seismic data, we'll actually have a very good constraint on its density and therefore its chemistry. So how much of it is iron, how much of it is sulfur, how much might be other light elements. Right now most people think the dominant light element in the Martian core is going to be sulfur but honestly it could be other things.

Kay Ferrari: Okay well we want to be mindful of your time. It's now five after the hour.

Dr. Mark Panning: Yes if there's a few questions I can keep answering them but if people are ready to go that's also fine.

Susan Morrison: I just have a comment. I'm the lady from Fresno again, Susan Morrison a Solar System Ambassador. To clarify on the initial picture of the San Francisco earthquake most of that devastation is fire, correct?

Dr. Mark Panning: Yes absolutely. I also I love this picture. I like to show this picture because it's interesting. This picture and several others like it it looks like an aerial picture. But of course in 1906 you didn't have a lot of airplanes going around. So this is actually taken with kites which I think is fascinating.

Dr. Mark Panning: Yes it's a big series of I think of like 20 box kites tied together which give it a really stable platform. And then the camera was just hung from these kites and had a – you could open and close the shutter with a string.

Susan Morrison: Actually I had a step-grandfather who was in that earthquake so it was interesting to hear his recollections.

Man: I think in all fairness you should point out that's really the reflection of the fire that subsequently followed the earthquake not of the earthquake itself.

Dr. Mark Panning: Sure absolutely.

Man: That did much better than the wood buildings that this is showing.

Dr. Mark Panning: Yes absolutely sure this is.

Susan Morrison: Those buildings are still there. They're hollowed out. They're messed up but they’re still there because they were built of stone.

Kay Ferrari: Any other questions?

Man: Sure. Thanks for a great presentation -- appreciate it.

Dr. Mark Panning: Thanks a lot. Yes thank you very much.

Kay Ferrari: Thank you very much. It’s been great. Our next telecon is not going to be until after the first of the year and that will be live from AAS on January 11 so wishing everybody a happy holiday, another thank you again to our marvelous speaker and we’ll see you next year. Thanks everybody.

END