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Moderator: Kay Ferrari
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Coordinator: Welcome and thank you for standing by. At this time, all lines will be open and interactive for the duration of today's conference. To avoid background noise, please utilize your mute function or press star and the number six to mute or unmute your line. This call is being recorded. If you have any objections, you may disconnect at this time. I would now like to turn the call over to Ms. Kay Ferrari. Thank you. You may begin.

Kay Ferrari: Thank you very much Jennifer. Welcome everybody to our Juno telecon on March 24. We're holding this a little bit early to give you all some information and help you with your plans for a Juno arrival at Jupiter event on July 4. We're delighted to have Dr. Scott Bolton with us and Courtney O'Connor who is the EPO lead for Juno. Scott is the principal investigator of NASA's Juno mission to Jupiter and the Associate Vice President Space Science and Engineering Division of the Southwest Research Institute. His research area is planetary sciences with a focus on the giant planets and the origin of the solar system. And I'm going to turn the program over to Scott right now. Welcome Scott. Thank you for joining us.

Scott Bolton: Thank you very much. Great to be here or great to be on the line with you guys. So my understanding is all of you have the presentation or have access to it and you'll just follow along with me as I start through the slides. Is that?

Kay Ferrari: That is correct.

Scott Bolton: Okay. So I don't know. Did Courtney want to say anything before I start?

Courtney O'Connor: I just wanted to quickly introduce myself. Hi everybody. I am the public engagement lead for Juno at JPL and I'm going to let Scott take it away for the majority of the presentation but at the very end I can let you know about some of the resources that we'll have available to you all as you're hosting your own events as we get closer to Jupiter.

Scott Bolton: Okay. So then let's start on the first slide which is just the intro slide that has a big picture of the spacecraft and Jupiter behind it. And it says my name. I'll just point out a couple things. That is a - of course a simulation or an animation of Juno but it's a very realistic one. Those solar rays are quite large. We're the first solar powered mission to go out to Jupiter at that distance. I think we just passed the record not too long ago.

Those are three giant solar rays. They're - each one is about 8 1/2 meters long a piece and the whole thing spins through space kind of cart wheeling through. And so that's just sort of an intro. And the middle thing is the high gain antenna. That sends all the data back and forth and the science instruments. So I'll show some more details of that later in the presentation but I wanted to just point out to you the spacecraft is quite large. It's about 80 feet in diameter as it spins.

Okay so we'll go to the second slide or the first one of the real slides and it starts off with in the beginning. So what Juno is really about is learning about how the solar system was made and how Jupiter was formed in the first place. And so I want to go back to the early part of the solar system when how we think it first formed. And so it starts off as a cloud of gas. So before our solar system existed there was a cloud, an interstellar cloud resting in the very spot where we are now.

And we see these clouds when we look out in the galaxy. We see them floating around. They look a lot like the clouds that we see up in the sky except these are almost all hydrogen and helium. Most of the universe is hydrogen and helium. The stars are made out of hydrogen and helium and these clouds are mostly hydrogen and helium. And that's different than the rest of the charged particles that make up the universe when we think of a plasma out there.

And so if we go to the next slide you'll see a picture of these - of a typical galaxy and you see lots of stars and then there's gas and dust in between. And you can't image one of those clouds very well in that but that's what one of these galaxies looks like and there's stars out there. And these clouds are in between the stars.

And if we go to the next slide, which is the Orion Nebula, so this is a Hubble Telescope picture. This is actually one of these clouds, these interstellar clouds. They're incredibly beautiful as you can see on the left hand side. They're very colorful with the - they look like clouds that are kind of wispy through. And we see young stars forming out of these clouds. And so that's what the right hand side is. And so out of these clouds come these young stars. And so another image the next one, the pillars of creation. This is another gorgeous picture. You know, this is sort of in our galaxy you have these incredible clouds and pillars of material. And out of these things are where these new stars are born. These are the sort of origins of the solar system.

Okay so the next one is the first step. So how does it happen? What do we think really goes on out there? And so these clouds exist and they have angular momentum. They're already spinning around, rotating in some way. And they collapse on themselves. We don't completely understand the process of how - what triggers that collapse. It might be a nearby star comes by. Something happens that creates an instability in the gravity field of the cloud itself and it starts to collapse on itself. And it collapses inward and the materials in the cloud come into the center and essentially create a star. And that is a star being born.

Our Sun was born out of something like that and presumably the material and the composition of these young stars is basically equivalent to the composition of the cloud itself. So the cloud is mostly hydrogen and helium and the star is almost all hydrogen and helium. And when we look at the compositions of these things, we see they're very similar and that lends credibility to this idea.

Plus we see inside these clouds these young stars being born and eventually blowing away the material. And so most of the material from that cloud goes into the star itself. There's some leftovers, a tiny bit of the leftovers, a small percentage of the cloud itself. And those leftovers essentially form the first planet. In our case that was Jupiter. So Jupiter took the bulk of the leftovers after our star was born, more than half of the leftovers.

And if you took everything in the solar system that we have besides the sun, all the cloud - all the comets, asteroids, planets they'd all fit inside of Jupiter. So we believe Jupiter must have formed first because it used most of those leftovers and anything that massive if it had formed after other planets would have almost certainly disrupted the solar system. So there's a lot of reason to believe Jupiter must have formed first. And so it takes the bulk of the leftovers and then the leftovers of the leftovers is essentially where we come in. It's kind of a humbling concept. We're the leftovers of the leftovers. But in fact the whole rest of the solar system comes out of the leftovers after Jupiter forms.

And so the way it kind of gets set up and you'll see a little in the next slide is the history of our solar system. Well here you see on the left side here that shows an early solar system forming. This is a top down view. So you have the young star forming in the middle. That's kind of the bright part. And then you have these swirling image on the left hand side of that image is sort of maybe the first planet. And it's grabbing this dust and gas and maybe makes a gap.

And so what's really happened is that these - the cloud itself after it starts to form the first star and the leftovers if they have any momentum. So they're spinning around. They start to collapse down into a disk and these planets are formed in that disk where there's a concentration of material. And in fact all the planets in our solar system are to a large extent confined to this disc or a plane so to speak. They're all kind of lined up. We call it the ecliptic plane. Some are a little - their orbits are a little bit off of that but almost all of them are sort of, you know, in the same plane as the Sun, the Earth, Jupiter. They're all kind of lined up. There's a couple of stragglers that are kind of tilted for some dynamical reason but most of them are formed that way.

And we don't really know exactly how that happens, what happens, you know, as far as how the next planet forms. And we now know from a mission called Galileo that went to Jupiter back in 1995 -- it was launched in 1989 -- that we know that Jupiter is enriched in what cosmologists call heavy elements. So

Jupiter is almost all hydrogen and helium just like the Sun is and but it has a smidgen more of everything beyond helium. So all the, you know, a geologist would call a heavy element the metal or iron but a cosmologist considers anything heavier than helium a heavy element. And so we know Jupiter is enriched by these things but we don't really know how that happened.

And we don't understand exactly how that enrichment worked but we know that it's important because the things that Jupiter is enriched in compared to the Sun are the very things that we're made out of, both the Earth and life itself. And so something happened that allows Jupiter to get a little bit more of these heavy elements percentage-wise compared to hydrogen and we know those elements are important because we're all made out of that but we don't know exactly the process of how that happened or even the specific ratios. But we've learned quite a bit.

So let me go to the next slide which is the elements. And of course looking at - trying to understand where we came from and how we got here it's a composition gain so to speak. We're trying to look at the composition of each of the planets. We look at the composition of the Sun and we try to come up with a theory that can explain why everything has slightly different compositions. And we're all made of the same stuff but we're at slightly different ratios. So we can't look at the history of this kind of stuff by looking at the Earth because the Earth's gravity field is not large enough to have held onto the very light gases.

So we probably started with a bunch more hydrogen and helium than we have today but we're pretty close to the sun and so that hydrogen and helium gets warmed up and it escapes from us and it floats out into space. Whereas Jupiter's gravity field is very, very large and so it's believed that it's been able to hold onto its hydrogen and helium that it originally formed from. And the fact that it's still almost all hydrogen and helium and similarly in ratio to that of the Sun, that all lends credibility to that concept.

And so let me go. So of course everything is made of atoms. I'm going to step back and just talk a little bit about atoms and elements so that when I talk about heavy elements you guys can understand what I mean by that. By the way, if you have a question while I'm going through I'm okay if you just interrupt me. You might have to speak loud to get my attention but we can take some more questions at the end. But if you get some while I'm going, I'll try to deal with them.

Okay so the next slide is the periodic table of elements. So this is something out of like high school chemistry type area. So you'll see at the top you have hydrogen, the age. And on the far right hand side on the top is He. That's helium. And many of you may be familiar with this. You have all these different elements here. And some of the important ones are carbon, nitrogen and oxygen. That's number six, seven, and eight. And sulfur is 16 and various - there's lots of elements in here that are important. Those I pointed out because organics of course are very important if you're trying to understand where life came from.

And but the main thing is is that you have hydrogen and helium at the top and everything else is what a cosmologist would call a heavy element. So your - you may have a favorite element in here and you'll have to look it up and know which one it was. I can tell you that my mother's favorite is gold. So anyway we go on and so these elements the question is is how did Jupiter get more of these things? So the universe is mostly hydrogen and helium with a tiny bit of these other heavy elements and Jupiter's percentage is a little bit higher.

Okay so I'm going to go to the next step. So I - in many ways what Juno is trying to do is to understand the recipe of how you make a solar system. So here I show a soup can, Campbell’s chicken soup and a spoon and it's got lots of ingredients. So the first step in understanding a recipe is to get the ingredient list and then you start to look at, you know, how you actually put those ingredients together to make the recipe itself. So we're at the first step when it comes to Jupiter and we're trying to figure out the ingredient list itself. We understand the hydrogen and the helium and we understand that it has a higher percentage of these other elements.

Okay so the question is how do you make the solar system itself? How do you make that soup out of those elements? What happened early in the solar system to create the final soup that we call our solar system? Okay so why is Jupiter so important? Well it is the largest. I already pointed out and it probably formed first for that reason. It is also very much like the Sun in composition and the fact that we've lost our own history but we haven't lost Jupiter. So what Jupiter has got is it's sort of got these secrets held on to what was going on very early in the solar system. And there's probably no other body in the solar system that has that early history to it.

We've looked and we - and a lot of people thought comets maybe are frozen remnants from very early on and they may be. They don't quite fit any of the stuff that we're looking for. They, you know, have a different kind of water than we do. It doesn't - we turn to comets but we haven't got the answers to what really went on in the early solar system. But with Jupiter you're probably going to get that very first step and clues as to how that first step happened after the Sun formed. And I'm going to try to explain how that works and what Juno will do in order to help us understand that. And that's what this talk is mainly about.

Okay so what does Juno do to actually go in and try to understand this early part of the solar system or how Jupiter formed itself? So we have two kinds of measurements. One is the gravity science which is the essentially measuring the gravitational field of Jupiter very, very precisely in order to determine whether it's just a giant ball of gas all the way down or is there a core of heavy elements in the middle of it. We don't currently know that answer. But it's important if you want to understand the process and the timing of Jupiter's formation because if there is a core in the middle of Jupiter then indicates that materials came together in the early part of the solar system.

Rocky material that formed pieces and chunks of bodies that before Jupiter formed and then they kind of came together maybe as sticky snowballs or whatever and they kind of collected until enough mass was accumulated so that the rest of the gas and dust in the protoplanetary nebula, the leftovers so to speak, could collapse down on top around that core. On the other hand, if Jupiter does not have a core in the center and it's just basically gas and dust type material all the way down through to the center, then it may have formed much earlier. And so understanding that core whether it exists and how big it is, is a big part of getting a grasp on the theory of formed.

So the next measurement is called water abundance and we do that - what we're really after is measuring how much oxygen is in Jupiter. The oxygen is tied up in the water. And so essentially we're measuring how much water is in there. Now that's important because when scientists first figured out that Jupiter was enriched in these heavy elements, one of the leading theories was that well as the solar system formed and as a nebula expanded away from the early Sun it started to cool and ices must have formed. And oxygen is the third most abundant element in the universe. So you have hydrogen, helium and then oxygen.

And so the most abundant multi-element molecule in the universe is water, so H2O, two hydrogens, one oxygen. And so that becomes a very important fundamental thing in our universe. It's fundamental to us when we search for life and you may have heard, you know, like a lot of massive search for life or the focus on Mars is based on follow the water. And that comes from the idea that everywhere that there's liquid water on the Earth, there's a lot of life.

We see life all over the place wherever there's liquid water. It doesn't mean you need liquid water to create life but certainly on Earth that's very important to us. So if you're looking for life elsewhere, you look for liquid water. And so a lot of people that want to study life go out and look for how, you know, places where there's liquid water. There's a couple of bodies in the solar system, the moon of Jupiter called Europa, another one around Saturn called Enceladus and these have liquid water on them. So they're a very high priority for us to study.

But water is even more fundamental than that. It's some of the basics of how you move things around and it's probably the most common element out or molecule out there and it's very effective at trapping heavy elements. So when an ice crystal forms it can trap in it and/or around it other volatiles, the carbons, the nitrogen’s, the sulfur atoms. All of these things can get bunched up in water. It's very efficient at being able to create something like that.

So water as it forms in the early solar system sort of naturally can make dirty snowballs so to speak. And those dirty snowballs could fall into Jupiter and enrich it with these heavy elements. And so that was one of the ideas that if you one way to enrich Jupiter and maybe the most common theory is that it - you do it with water. And so measuring how much water is in Jupiter becomes a critical piece to kind of discriminate among theories.

There's also the fundamental question of how did we get our oceans in the first place? The Earth obviously they're very important to us and the creation of life. And so we don't really know the history of water in the early solar system, how was it distributed, how it moved around. Jupiter was very important in moving material around when it first formed and understanding how much oxygen is in it will tell us something about the distribution of water and oxygen in the very early part of the solar system. It may have been responsible for delivering the very elements that we got - that made us and created life itself.

Okay so the next slide is something called Galileo probe descent. It shows a probe on the end of a parachute. This is an artist's conception of the Galileo probe falling through the atmosphere of Jupiter. So back in 1995 this probe arrived at Jupiter. The mission was called Galileo. It had two components. One went around and orbited Jupiter and the other one dropped a probe into the atmosphere and this is an image of that. You see the front part of it is a heat shield falling off exposing the probe, falling through by this parachute.

Okay so the next slide is Galileo probe close-up and you kind of see that this looks like, you know, a submarine out of some science fiction film from the fifties or something. It's - and it very much is like that. It's evolved. It's made to go to high pressure. It's got all these little valves and things on it and little openings on the sides and those are the scientific sensors. And this thing essentially was dropped into Jupiter partly because we knew already we had hints that some of the elements were enriched compared to the Sun.

And we - scientists thought if they could measure a whole bunch of them and understand how much of each thing was in there, how much carbon versus how much nitrogen versus how much sulfur versus how much argon or krypton and xenon and all these different elements and oxygen itself that we would be able to make a lot of progress on figuring out how Jupiter was made because you'd kind of get a map or what I referred to earlier as the ingredient list, right. We wanted to get the detailed ingredient list in Jupiter so we could start to figure out the recipe.

Okay so the next slide is actually the - some of the data from the Galileo probe itself. So let me walk you through that slide on the right hand side that's sort of the data itself. So on the bottom, the horizontal axis is actually different elements. You have helium, neon, argon, krypton, xenon. Those are all noble gases. They don't react with a lot of things. And so you can - when you measure those you're looking at sort of pristine material. And then you have carbon, nitrogen, oxygen and sulfur.

Okay on the vertical scale, I start at point one and I go up to ten and that's just a ratio of these elements as compared to hydrogen and relative to the Sun, so ratio to solar. So in other words, if all of the elements that got measured came out on one, on the line that is one ratio to solar, that would mean that Jupiter had exactly the same ingredients as the Sun proportionately if everything fell on one. And so you have a little box that I've written there that's called direct gravitational capture. So what does that mean?

That means that if every - if Jupiter was made of the exact same material as the Sun, then one strong argument of how to form it would be you formed it the way the Sun did. The form - the Sun formed from a collapse of this cloud and Jupiter formed from the exact same cloud unchanged and in the same manner. So another piece of the cloud collapsed and made Jupiter. And if that was - and if Jupiter was made of the same stuff as the Sun, that's what we would expect.

Now you may get - you may form Jupiter that way and get some other answer too but if you got that exact answer that would certainly imply something like that. Okay but instead Galileo probe didn't measure that. So let me walk through the measurements briefly and tell you what's important about them. So you see helium is slightly depleted compared to Jupiter - I mean compared to the Sun, helium on Jupiter. And that was actually predicted by some theorists who had worked out the dynamics of Jupiter and said that the helium would rain down - the top part of the atmosphere would rain down into the middle part because it's a little bit heavier than the hydrogen and the neon, which is the next element that's even more depleted, would dissolve in the helium and get carried down into the middle of Jupiter.

And this was one of the best examples of a theorist getting it right. It's rare when a theorist predicts something and predicts even the right ratios and then we go get data. Because usually what happens is theorists predict something and then the data comes in and they have to change their theory. In this case, it actually matched. And so it was a very clever theory and it lent a lot of credibility and it was by - and one of the scientists that did that is a guy named Dave Stevenson. He's at Caltech. And he's on our Juno team and it was very impressive that he got that right pretty much right.

Okay so the next ones that you see are the ones that are sort of in blue. There's argon, krypton, xenon and then you have carbon, nitrogen and sulfur. And they're all basically sitting around the numbers around, you know, 2 1/2 to 3 1/2 or so. And that means they're all enriched a factor of about three or four compared to what's in the Sun relative to hydrogen. So there's just a higher percentage of those in Jupiter than there are in the Sun. Now it took about 20 or 30 minutes for this probe to drop through the atmosphere of Jupiter and make this measurement. In that 30 minutes, we saw these blue dots come out and every single theory of how the solar system was made and how Jupiter was formed was proven wrong by this data.

There wasn't a single theory that predicted this and to this day there is no theory that explains this data. It's a huge puzzle and the puzzle is that each one of these elements has a different level of volatility. In other words, they dissolve or get trapped more or less easily in water, ice, or other types of materials depending on the temperature and the pressure. So I can go into a laboratory and make a little bit of ice crystals and I can stick in krypton or xenon or carbon and they'll get trapped more or less easily. So what scientists expected was there'd be a bunch of variation in how much of this - how much each of these elements was in Jupiter. And the variability of that would give us clues as to what the process was and what the state of the early solar system was like.

When they all came out the same, it meant the volatility didn't matter and nobody had predicted that. Either Jupiter formed in such a cold environment that volatility simply didn't matter anymore or the whole enrichment happened in a way that we didn't think possible. Or maybe Jupiter didn't form where it is today. Maybe it formed further out and migrated in. And so nobody really knew the answer. And about the time that they - this measurement was made we were just starting to see other planets around other stars.

Of course we couldn’t really see them. When I say see you think of a telescope looking and seeing the planet and we have a little bit of that now. But back then what you had was some scientists had come up with a clever way of looking at the wobble of a star. And if a planet was - the size of Jupiter was going around a star the mother star would wobble a little bit and you could detect that there was something else going around it.

And what we found when they started to measure those things was that there were really huge planets like the size of Jupiter or much larger that were very, very close to their parent star, too close for theorists to explain how they could have formed there. And so the idea of planetary migration started to come into play where people thought okay maybe these giant planets are forming further out and they're moving in because they're too close to the planet to start to form there.

In other words and the reason they're too close is that if you had a giant - a really huge planet it could not form like at the distance of Mercury because the gravity field from the sun pulling on the side that was facing the star would be much stronger than the amount of gravity pulling on the planet on the other side. In other words, the planet would get pulled apart by the differential gravity field because it was so close to the star. So I have to form giant planets pretty far out or they'll get pulled apart. And so the idea was is that maybe Jupiter moved like these. Of course we don't really know if that's true.

Now one of the other measurements that I'll point out is this one that's in the red which has got hot spot meteorology. There's a line missing out of the end of that word. And that's oxygen. And the other puzzle that came out of this Galileo probe measurement was that the water was depleted. Everything else had more and the water was below what was in the Sun. And no theory could explain that because we thought water brought in this stuff. Now the consensus among scientists was that we got unlucky. The Galileo probe fell into a hot spot of Jupiter or the Sahara Desert if you will.

If you look at beautiful pictures of Jupiter there, you know, it has all these great zones and belts and there's all these little dots, white and orange and things floating around. And we went into one of these dots that seemed a bit -

a little bit warmer. When we looked at it from infrared telescope, we saw that it was warmer. And so people said oh that's a warm place. It's - the - it won't have the same composition as everything else because it's warmer than the surrounding material. Oh we just got unlucky and we went into the Sahara Desert.

The other thing that tells us about this measurement was the Galileo probe was designed to fall down to 20 bars pressure which means 20 atmospheres of - at Earth. Earth's atmosphere is one bar of pressure at sea level. So we were going down deep, right, into Jupiter's atmosphere to where we thought things would be well mixed. And each of these elements that are measured came from a well-mixed region. But the water was still increasing when the Galileo probe stopped working. And so we know we never got a well-mixed measurement of water which was consistent with well it's the Sahara Desert. The water is mixed way below. And we just got unlucky.

Now that may or may not be the right interpretation but that's generally what is thought to be true and that NASA went away and said okay. Well if we're going to learn the water abundance of Jupiter, we're going to have to go much deeper and we better not do it with one probe. We better have a whole bunch of them because we don't want to get unlucky again. And so that's a very expensive mission and because you wanted to go very deep it's very difficult and technically challenging. So nobody really knew how to do it and they kind of just waited and said well we're - we'll have to wait until we, you know, figure out how to do that. And one of the…

Woman: Dr. Bolton may I ask a question? Yes. You said it was okay to interrupt. I'm just wondering how was the data gathered? What were the scientific instruments that were used?

Scott Bolton: So there are a couple of different instruments on the Galileo probe but the main one that was looking at composition was something called a mass spectrometer. And what it does is it sucks some gas in and it has a very complicated plumbing system that separates the gases out into different based on their masses and their velocity and then charges them up, let's them, you know, strips an electron or a proton off of it. And then based on the fact that now that it's charged flies it past a little magnet so to speak or a charged plate and watches it bend. And when I watch it bend, I know how fast it's going.

So then the only thing that I need to know is how much does it weigh or what the mass is. And each of these elements has a different mass. So that's what the chemistry table of elements is basically the lightest element to the heaviest element. So the main measurement is called mass spectrometer and it's measuring how heavy are each of these atoms in this little pocket of gas that it collects as it falls through the atmosphere.

Woman: Okay. Great. Thank you very much.

Scott Bolton: There were other experiments like things looking for lightning and winds and things like that. But the - but that was people studying atmosphere dynamics and not relevant to the origin of the solar system.

Woman: Okay. Thank you.

Scott Bolton: No problem. Okay so anyway so there's - so the question is how do you explain this and how do you make this measurement? So one of the things that Juno did in order to when we came up with the mission is we figured out a way to measure how much water was in Jupiter very deep but remotely. And so that enabled us to go back and test these theories and go in and make this key water measurement from out in space without having to figure out how to make a probe that could go deep which would be much - really expensive and technically challenging. Juno is technically challenging too but the other one was almost impossible. Okay so and I'm going to - and later in this talk I'll explain how that instrument works as well.

Okay so I'm going to go to the next slide which is basically the same thing, water to oxygen and it basically shows another idea. But what I wanted to point out to this is this shows the same table of elements and shows this enrichment versus depleted. And I wanted to show that, you know, how much water is in Jupiter or how much oxygen kind of gives us a clue onto which theory might be right as to how we form Jupiter. So if there's a lot of oxygen in Jupiter, then it implies that maybe we started at pretty warm and near the distance where it is. Five AU is five astronomical units. That's where it is now.

If there's about three or four then what we call cold planetesimals, so what people are searching for is well one way to enrich everything the same is what if there were snowballs that had - that were basically just like the Sun's composition but they didn't have the hydrogen and helium in them. And those snowballs went into Jupiter. That would enrich it exactly the way we see it. Well when we look out in space we have never found a comet or any snowball that matches that. And so if those existed, they're gone now or we haven't been able to find them yet.

Now of course we haven't gone everywhere in the solar system. So we still may find something like that but no comet that we've ever come across even comes close to matching this. No asteroid, there's just nothing out there that would answer this. But that's one idea. And then if there's - if it turns out that all of Jupiter really is depleted in water, then we have to go back to the drawing board and try to figure out a theory that doesn't currently exist. So most scientists are betting on the fact that we just had this weird measurement and they're hoping that the water is there at some level and not depleted. Because if it's depleted we have to really scratch our heads and come up with a new theory.

Okay. So the next one is so the - besides the origin of Jupiter and the two measurements that I just made, Juno has a lot of other science objectives and they're divided up into four different categories. One is the origin which I've already covered and then there's the interior, the atmosphere and the magnetosphere of Jupiter. And so the interior is really about what's the interior structure like. These all link to some - in some way or another to origin as well. But I'm looking at interior structure for the sake of understanding the dynamics and how Jupiter is built itself. And one of the things is, you know, how is it rotating inside? Is it all one solid body? Is it moving around like concentric cylinders? How deep down does it go? Is there a core there?

And so we look at invisible force fields basically near Jupiter called the gravitational magnetic field and this tells us about what the inside structure is like. Also when we measure the oxygen abundance, it will have an effect on that because oxygen is the third most abundant element. And so when we're missing something that's massive like oxygen, we can't really make models of the interior because we don't really know what the molecular envelope inside of Jupiter is like unless we know how much oxygen is in it as well.

And then we have atmospheric dynamics. So we want to look at the composition. We want to know the zones and belts, you know, what makes them different colors. Why are they structured the way they are? What is the great red spot? So if those are made of something different from each other we don't really know that. We'll study the composition of that, how much water versus how much ammonia is in each of those. We'll look at temperature and cloud opacity and dynamics.

And essentially what we're going to be able to do for the first time with the atmosphere is see how deep are those zones and belts. I mean are they just at the very top of the surface and you're just looking at sort of a meteorological effect? Or do those have deep roots? And we don't really know the answer to that but Juno will address that and look for the first time.

And then finally the magnetosphere; the thing that's really new about Juno is that we're going to go into orbit over the poles of Jupiter. Galileo orbited around the equator and nothing has really gone in and looked over the poles. And so we're going to look at what's called the polar magnetosphere and that's a very important if you want to understand how the magnetosphere is structured and what's going on with it because the magnet field mines come out of the poles, comes out of the, you know, north pole and goes into the south pole. And so you have all these incredible aurora borealis like the northern lights on the Earth but they're 100 times stronger. I mean they're just much, much stronger than anything on the Earth. And so for the first time we'll go in and explore that polar magnetosphere and what's driving the incredible light show on Jupiter.

Okay so the overview of Juno is that the next slide, sorry. So we are the first solar powered mission to go out that far. We chose that because we didn't have a - most missions have gone with nuclear power sources and there wasn't any available. And so we figured out a way to do it with solar power. We have eight different science instruments on board plus a camera. The camera is a public education and outreach camera. I'll go more into each of these things. We spin. As I said we cart wheel through space. So we're spinning twice a minute. We launched back in August 5 of 2011. It takes about five years to get to Jupiter and that's coming up. That's part of the reason you're all on this line is so we arrive July 4.

And this slide might be a little bit old in the sense that it's 16 months of orbit. We basically do 33 orbits. Each one is two weeks long. But we have to take some time before we get into the right orbit. And so we go through a few months before we jump into the - these two week orbits. But eventually we get into orbits that go by - go around Jupiter every two weeks. One side of it is going very, very close to Jupiter and the other side is going out in the outermost part of the big moons near Callisto. And of course our science objective which I already kind of described.

Okay so the next one is the mission design. And so this shows you from a sideways view. Jupiter is in the center of that diagram on the left hand side. And then you have these red and yellow and green and blue colors. Those are the radiation belts of Jupiter. And the red means that you've got really high energy electrons and if you go through those they basically destroy electronic. And so we have to be very careful about those. And so the one - the white colored orbit is called number one and that's how we start. So we're kind of going sideways and you'll see the white comes in over the poles and out the south and pretty much avoids all the red zones.

But Jupiter's gravitational field is very asymmetric and it starts moving our orbit around. And so after about halfway through the mission at orbit 16, we are looking like the purple one. And you'll see it's starting to skim the yellow, a little bit of the red. And so it's starting to pick up radiation and going through dangerous hazardous regions. And then by the 31st toward the end of mission we're really going through the red zones. And so the mission is designed so that the first half gets very little radiation and the second half gets a lot more.

We had to protect ourselves from that radiation. So we are very much an armored tank going to Jupiter. In the middle of our spacecraft we had a titanium vault which is thick walls of titanium. It weighs about 200 kilos. And all the electronics are packed inside of that box. And then we have shielded cables going out to the science centers which are sitting out on the edges of the spacecraft. So we've tried to protect ourselves as best we can. This is the first spacecraft that's ever been designed to anything like that.

So we are like an armored tank. We are protecting ourselves like Superman had to do with lead in order to shield himself from kryptonite. We're using titanium which is as dense a metal as we could find that could be used in this. And that protects us from these incredibly high energy particles which would just zip right through us. And of course if there was a person on board it would - you would quickly die. But it would even kill electronics.

Okay when we go close we really get really close, 5000 kilometers above the cloud tops. So spacecraft haven't gone that close before. That's partly by design in order to get the science we want but we're also trying to dip into a little gap between these high energy radiation belts and the atmosphere itself. So Earth has radiation belts like Jupiter's. They're much more tame. Jupiter is a monster and it's the worst of all the monsters in our solar system. This is the most hazardous region there is other than going into the middle of the Sun. But the Earth has radiation belts. They're named the Van Allen radiation belts because there was a scientist named James Van Allen who first discovered them. And he basically discovered them by flying a Geiger counter on one of the first spacecraft and he saw these high radiation hits and realized that there were these belts. Jupiter's are Earth's radiation belts but on steroids.

Okay next slide is DSN-GAVRT connection. So this is one of our educational programs. We've been doing this - I've been involved with this for a long time. Our project scientist is named Steve Levin. He's also been involved in it for a long time. We've been doing this from way before we ever had a Juno. But what we basically have is a decommissioned radio antenna from NASA that they used to use for tracking that got too old and we use it for science. We basically plug it in and have a camera that faces it and control it by a computer and kids in classrooms all over the world, mostly in the U.S. but there's classrooms in other countries as well, that can actually sign online and point the antenna at Jupiter and do radio science, radio astronomy by looking at Jupiter and seeing these high energy radiation belts.

And so this diagram that you see in the lower left hand side it shows some trajectories of Juno but the main thing is its showing us that red and green spot similar to the other one. And that's a picture from the VLA, the very large array, which is a whole bunch of radio antennas that we have that can be used like an interferometer and make a map. And so that's essentially making a picture in radio and you see what Jupiter looks like. Of course the picture of Jupiter is put in there afterwards. The radio only sees the radiation belts. And you may have heard of the VLA. It became more famous from the movie Contact where those guys were out there looking for signals from extraterrestrials. But it was essentially the same place and we use it to look at Jupiter.

So the kids don't use that. The kids use a single dish but I - and so they can't make a map but they basically measure Jupiter's radiation and they learn science. And they're part of the Juno team. They will give us their data and we will share data with them. And we may - you can see there's a publication on the left hand side. I've actually published a paper with the children from Galileo and Cassini and we'll probably do that with - again with Juno as we get there and they're helping us looking at Jupiter, tracking its radiation as we approach and fly around it. And so they're monitoring it for us. So I mention that because I think it's important the educational program. So that's called GAVRT. And myself or Courtney could get you more information on that if you want.

Okay so then here's the first - the next slide is called sensing the deep atmosphere. So this is one of our experiments that I'm going to explain. It's called a microwave radiometer. And on the left hand side you see this little movie going back and forth. Here's where I don't know. Does everybody see a movie working? Anybody see a movie?

Man: Yes.

Scott Bolton: Yes? Okay. So that's rocking back and forth. That's rocking back and forth because Jupiter is tilted ten degrees. It - I should say its magnetic field is tilted ten degrees with respect to its spin axis. So the radiation belts are tied to the magnetic fields. So they wobble back and forth because the equator is spinning around but the tilt causes that wobble. So that's real. That's really happening back and forth every ten hours. Jupiter spins around in ten hours.

Okay so what we have is a - is we have an instrument on Juno that's called the microwave radiometer. It's actually six different microwave antennas all working at different frequencies that range between 1 and 50 centimeters wavelength. So the best way for me to explain what a microwave antenna is is to think about your microwave oven in your house. So you have a microwave oven and you stick a wet bowl of spaghetti in your microwave oven and you turn it on for a minute or two and it heats it up. It heats it up because microwaves are generated in that oven. They bounce around the oven, which is why you close the door. You don't want to get near it. They're not that friendly to humans.

But they go into the water molecule that's sitting in your spaghetti and they make it excited. They cause it to rotate and vibrate and that heats it up. So essentially the microwave energy that's generated by the microwaves in the oven go into the water molecule and heat up the spaghetti. If I took a bowl of cold spaghetti or I should I'm sorry. If I took a bowl of dry spaghetti and I stuck it in there I could run that for a minute or two. It really wouldn't heat up. It only heats up with water because the microwaves are this - are the right frequency to get absorbed by water.

Well the way physics works is that water molecule cannot only absorb microwaves, under the right conditions it would release a microwave and the transition and the molecule would go down and a microwave would come out. So if I had - if I did an experiment in your microwave oven in your kitchen and I stuck in a container of water and I knew exactly how much power the microwave oven was going to generate and I knew exactly how long it took for that water to boil, I could then do a calculation that would tell me how much water was in the container. So in other words if I knew the power and the time it took the - for the water to boil exactly I could tell you whether you put in one cup, one teaspoon or a half of gallon of water because it would take a different amount of power and time to boil it.

So I do that trick sort of in reverse. I look at Jupiter and I'm watching - I'm basically listening to Jupiter with these microwave antennas and Jupiter is emitting. It's glowing because it's warm. So it's called black body radiation. Jupiter is warm and while you and I would glow in the infrared, and you may have seen science experiments at high schools and things like that where you put on a pair of infrared, you know, use an infrared camera or something and you can see yourself glowing. Or you take an iron out of a fire pit and it's glowing red hot. It's glowing in the visible. We're about 100 degrees, 98. Whatever is the right temperature for humans. So we glow in the infrared.

Jupiter is colder than that. It glows in the microwave. It glows in the radio. So it's glowing and listen to that glow and I look at it and based on how much of it is glowing the - there's a microwave coming out of it because it's warm and on the way out if it hits a water molecule that microwave will get absorbed and won't come into my telescope or my antenna. And so I measure how much microwave I'm receiving and from that I can calculate how much water was in the path.

And so this chart on the left hand side, this thing that looks three dimensional with the squiggly lines on it, those show the six different frequencies. So the high - really high frequency wiggles that only go down from .1 to 1. That's a very high frequency. That's a high frequency antenna and it's - and so it - the atmosphere of Jupiter is relatively opaque to it. And so and then on the other side you have a long wiggly line that goes all the way down to 1000. There the atmosphere is much more transparent. And so I look at all of these different levels of Jupiter at the same time and I see how much water was at different depths and from that I can calculate how much water was totally in Jupiter. And that's the trick to this one experiment.

And so on the middle chart, I show this little slice of Jupiter with and you can see the red spot and a couple of the zones and belts. And then you see these little - this little blackened drawing of little different degrees of ellipses or whatever, different circles on it. That's sort of the resolution of this antenna. So when I'm at the high latitude that the resolution or that I see is quite large. But then when I go over to the equator I'm really close to Jupiter so it becomes very fine. And I'm showing you an example so that we will be able to measure from this experiment how much water and ammonia is in Jupiter at every latitude. And every - and we'll go over and make a map of Jupiter in many places.

And so it won't be subjected to a problem like falling into the Sahara Desert of Jupiter. We'll measure the Sahara Desert of Jupiter but we'll also measure everywhere else. And so we'll average that and hopefully be able to understand what the global water abundance of Jupiter - is in Jupiter. So that's how that experiment works. That's one of the more complicated experiments. Let me take a second and see does anybody have a question about that? Okay so…

Ron Schmit: Larger because the probe's farther away at that point?

Scott Bolton: Exactly. It's further away. So you can imagine taking a camera, right. I have a certain number of pixels and if I'm far away I don't get very good resolution. When I get really close I get great resolution and that's essentially what this antenna has as well. Which in reality each one of those antennas has a slightly different shape and a different kind of resolution and this drawing just represents an example. But what this trick does is it allows you to see down to 1000 bars pressure, which is incredibly deep. And so we have no idea what it's like down there. And so that's all going to be brand new. We've only see it - the very top part of this. We haven't seen to .1 really. And I show you the - where theoretically where we think ammonia and water clouds are at about one bar and ten bars pressure. So the Galileo probe went down to 20 bars pressure. So it went deep enough to what we thought was below the water cloud but it turned out not in that one spot.

Ron Schmit: So to 33 orbits that's not a whole lot of the planet map with that device.

Scott Bolton: That's correct. We don't need to - we don't expect a lot of variability across different longitudes. And so in fact this experiment will work in the very first orbit. We won't even use it probably on every orbit because after five or six orbits we will have gotten the answer. We may not - it make take us a long time to interpret the answer and understand it all. But getting more data probably won't help us.

Ron Schmit: So you don't expect such a variation if you fly over the great red spot as opposed to a white oval as opposed to just a regulator equatorial bend?

Scott Bolton: I think each of those will give you that example but I think when we fly over five or six times we will have sampled each one of those. I mean mainly those things are latitudinally dependent. In other words, you see a lot of variation in Jupiter because of the stripes are all going around sideways. And so we'll measure all of that. And the one thing that's very asymmetric in longitude is this great red spot. And so we'll go over that one or two times and we'll try to make sure we understand what the difference is there. But it would be great if you went over, you know, did this 1000 times over everything. But I don't think we have the scientific rationale to drive the mission to get that because there are no theories that would support that. If we just get the latitudinal variability we will have learned most of what we are after and we'll get the water abundance.

Man: If after a couple orbits you see great variation would that be reason to revisit that question?

Scott Bolton: No doubt it will. So we have a lot of flexibility on the mission. And if we start seeing tons of variability with this we'll just run this instrument more and we can make those choices on the fly. And we're not limited with power or anything. We could run the instrument more if we wanted. We just we don't think we do and so we're going to optimize for other science that we think needs that. But we can make that trade on the fly. So there's a lot of promise here. And a lot of this is brand new. We've never seen below the cloud tops like this. I mean there's been - there's never been an instrument like this before. It kind of just came.

You know, to be honest I thought of it in the shower one day. I don't know. It's ironic because we're looking at water but that's how the instrument was created. I just kind of thought of this idea one day and went in and talked to some colleagues and said I think I have a way of doing this. And essentially Juno was born out of that conversation.

Okay so I'm going to go to the next slide and which is atmospheric dynamics which gets to a little more of what you were just asking. So you see on the, you know, sphere of Jupiter you've got all those white ovals and white spots and you can see your point is wow maybe all of those are different. And they may be but if you went over the red spot and then went over one of those white ovals and then got to see the differences between the zones and belts, you're getting, you know, 99% of the science of Jupiter. If it turned out that every one of those little things was totally different from each other, that's a whole other game. We would just have to run this a lot more. I don't expect that to be the answer but it could be.

And part of the reason is that we're only really measuring water and ammonia with this instrument. We are getting some temperature and pressure. What creates these colors may not be the water and ammonia. It may be something else. On the left hand side I give two examples of sort of a three dimensional block of Jupiter. And so you see the zones and belts. And so the top - imagine the top part of this little box is the surface of Jupiter that you can see visibly.

And then the other part is going down deep, right, and you can see a couple hundred kilometers is about 50 bars of pressure.

So there's a couple of different possibilities. The zones and belts could go all the way down or on the lower version of this box, you see the zones and belts only go down a little bit and then underneath it's all kind of mixed together and maybe that top part is just meteorology and - or maybe this where the probe went in this hot spot goes deeper than the rest. So we don't really know the answers to any of this but this investigation will tell us about that.

Okay so the next chart is probing deep and globally. So much of what Juno is about is trying to look inside of Jupiter every way we know how. And so we do that with three different techniques. We do it by looking at the gravity field, the magnetic field and this microwave technique. So the gravity field on the left hand side of this chart you see like a big chunk, a slice out of Jupiter that goes from the top all the way to the bottom where it says ice rock core. So in the middle of Jupiter you're looking at, you know, 40 mega bars of pressure at who knows what kind of core that is. I say ice rock. What we really mean is maybe there's heavy elements down there.

At the top part, you have helium-poor molecular hydrogen right. I've got this hydrogen where the helium has been rained out. And somewhere in the middle in that part that kind of looked reddish is what we call metallic hydrogen. So there is where the hydrogen gas in Jupiter has gotten - is under so much pressure that it's basically getting squeezed. And the electrons and the protons are starting to separate and but they're still tied together in a way to make a hydrogen atom. But the elements themselves or the material itself starts to behave like a fluid and is - and like a metal. It actually conducts electricity. Hydrogen that we have on the Earth, normal hydrogen, doesn't do that.

But in Jupiter, theorists have already shown that if you can squeeze hydrogen enough it's going to become more like a metal and it's going to conduct electricity and a magnetic field. And so this is where we think the magnetic fields may be generating in side of Jupiter. So when I measure the magnetic field of Jupiter, I'm sampling the structure somewhere down into that red zone. We don't know where that red zone end is exactly. This is just some artists' and scientists' concept that may or may not be right.

But Juno when it looks at the magnetic field and sees how complex it is, we'll be able to tell how deep in Jupiter is this magnetic field forming. And that will tell us something about where this region is. The gravity field is telling me about how mass or material is distributed inside of Jupiter and it gives me information all the way down to the center. So I have one technique measuring the gravity field which is looking all the way down into the middle of Jupiter. I have a magnetic field which is telling me structure may be halfway down. And then I have this microwave technique which is you have to look to the right hand side where I've kind of peeled off, you know, the first few thousand bars. Of course, the microwave only looks to about 1000 bars but it's looking at that convective region, the meteorological layer.

And that's - those are pretty much the three ways we know how to look inside of a body like this. And so we're doing everything we can to learn about those layers. And you can see we're looking down with those microwaves down to about 600 kilometers. So we're looking pretty deep but not deep compared to the size of Jupiter. Jupiter's huge. You know, 1000 Earths fit inside of Jupiter. It's ten times the size of us. And just for context 1000 Jupiter’s fits inside our Sun. So our Sun is, you know, when I said that it used - there was only a little bit of the leftovers that went into the rest of the solar system. The Sun sucked up almost all of that cloud because 1000 Jupiter’s fit inside the Sun. So you can imagine there wasn't that many - that much left over. Okay. Of course a lot may have been blown away after the solar system formed. Okay.

Ron Schmit: Dr. Bolton is there any way that we could create metallic hydrogen on Earth? I just haven't heard of that before.

Scott Bolton: It would be - you have to create pressures like the - like a Jupiter. So it's mostly a theoretical thing. But the people that create the highest pressures are people like at Lawrence bore labs where they're trying to do fusion research. And they get a pallet of deuterium and they blast it with lasers and things trying to compress it. And they're - what they're after is triggering a fusion reaction. And they have to create an incredible pressure. They're trying to duplicate the pressure of the Sun, right. That's what triggers fusion. But on the way to that experiment, they passed the pressures of Jupiter. Of course you're looking at a tiny, tiny sample. You're not doing this in a very big room or anything.

And so while they're - while these people that are trying to study fusion are doing these experiments, mostly through the Department of Energy, there's a bunch of fundamental physicists hanging around if you will the experiment because they're going to get a data point of what hydrogen is like at very high pressure. And that's pretty much where we've learned and scientists call that the equation of state. That's how it's referred to. So the equation of state of hydrogen is what is the state of hydrogen at all temperatures and pressures? What does hydrogen behave like?

And so we only know a little bit. We're making progress because there's quite a bit of fusion research going on. But it's basically people, you know, sort of hanging out next to the fusion researchers to try to learn about how hydrogen works. So I can't create metallic - like a room of metallic hydrogen. We don't have the ability to create that kind of pressure. But you can create a tiny, tiny amount and then study how it behaves.

Man: Excuse me.

Scott Bolton: Go ahead. Is there somebody else with a question?

Man: Oh yes. So these methods that we're using to look since they only go and let us peer in so deep, are any of these going to give us any more of an idea of the core of Jupiter? Or is that an issue to be tackled by another project?

Scott Bolton: Oh no. We're going to get - we're going to do that. In fact I'm going to get to that in the very chart. So that was…yes…

So mapping Jupiter's gravity field. That's what tells me about the core. So how does that work? So basically the spacecraft flies very close past Jupiter and its trajectory or its path is pulled and pushed around by Jupiter's gravity field. So you can compare - you can think of it this way that if I had all the mass of Jupiter in a point in the center that would be sort of the theoretical. You know, all the mass would be in a single point in the center. Jupiter is infinitesimally small. I fly a spacecraft like Jupiter or like Juno past that and I can predict exactly how that path is going to go because all the mass in some point. It's all uniform. The gravity field is very uniform. I can see exactly how Jupiter or Juno would behave in its path as it flies by an object like that.

But the reality is is Jupiter is extended. It's a giant ball. It's got mass distributed inside that ball. And so I compare the path that Juno actually takes with the one that would be theoretical if all the mass was in the center and then I can say okay the path that it really took is due to the fact that there is a bunch of mass. Maybe the great red spot represents a lump of mass somewhere or maybe there's only so much in the core and the core is ten Earth masses or 15 Earth masses or whatever and the rest of it is gas. And so I can sort of tell the difference between something without a core or with a big core or a medium core. And I can also tell the difference if there are different layers in Jupiter of material that are a different density.

And so I do that by studying Jupiter's - by Juno's. I'm sorry. I do that by studying the path that the Juno spacecraft takes as it flies very close to Jupiter. And I do that by measuring something called Doppler. So Doppler was a guy that thought of this. Basically, the Doppler Shift is something that comes out of relativity and it basically says that if I'm moving very fast toward you, light that I would shine would be blue shifted. And if was moving away from you, the light that I would shine would be red shifted. And that's how we kind of determine, you know, the distance of stars and how fast they're moving away from us.

But we can use it for this - to figure out Jupiter as well because I have a radio transmitter on Juno and I know the exact frequency that that transmitter is sending its signals back to Earth with. And so I look at that frequency and I realize that it's either been red shifted or blue shifted from what it was emitted at because of Jupiter's effects on the path. It accelerated the spacecraft or slowed it down from its pure trajectory that would have been if all the mass was in the center.

And so I look at that Doppler Shift. I look at the frequency shift and then I invert that and create a model of the gravity field that is consistent with the Doppler Shift that I just measured. And I do this over and over and over again. Right every time I fly by, I fly by - I fly over a different longitude and I measure - I essentially drop a network of maps, a mapping network so to speak, of the gravity field around Jupiter and I get a lot of high order terms that are going to constrain the core that might - may or may not exist in Jupiter.

So one of the tricks, though, that I have to do is I have to equate that to what I know about the equation of state of hydrogen. And so as we learn from these fusion experiments, we may modify our interpretation of Juno data. The Juno data will be good forever. It will be - it will measure the state of Jupiter and what its gravitational field is and that data is good forever. But we may learn more about how hydrogen works and therefore how to interpret what's inside the middle of Jupiter. And we'll always be able to go back to the Juno data. We don't have to repeat the experiment. As we learn more about hydrogen, we can refine our interpretation. But we're already pretty far along that we - we'll be able to constrain the core based on the Juno data. But we'll probably learn more, you know, in ten years, 20 years whatever. We'll keep learning more. Did that get to your question?

Man: Yes.

Scott Bolton: Okay. Okay so the next chart is mapping the magnetic field. So here there's a map that or a little movie that should be playing for you that is basically showing how the different trajectories get laid down, how the different - each orbit gets laid down. So we first lay down four different orbits that are 90 degrees in longitude apart and then we do a little bit of a shift in the orbit and we lay down four that are in between those other ones. So you see the white ones first and then the yellow ones and then you do the blue ones.

And slowly we create this map. We do this for a couple of different reasons this way. One is low risk so that if something were to go wrong after four orbits, we've already got a reasonable map of Jupiter's magnetic field and the gravity field. But as the mission goes on, we keep getting better and better but we do it in a low risk fashion just in case something goes wrong with the spacecraft. Now the magnetic field is known to be highly asymmetric in both latitude and longitude. The gravity field is thought to be mostly asymmetric in latitude and that the longitudes may not be that different from each other. But that remains to be proven.

The magnetic field we already know enough about it to know that it's hugely asymmetric, just the Earth's. So we have a south Atlantic anomaly, right, where, you know, weird things happen, you know, that you read about. And that's a kink in our magnetic field. Well Jupiter has kinks in its magnetic field as well that are much larger than our south Atlantic anomaly probably. And so from looking at this, though, and the resolution that we get in longitude each time we sample basically allows us to dissect the magnetic field and learn how deep is the magnetic field getting created and what kinds of motions of this metallic hydrogen are creating this magnetic field.

And we don't really know how magnetic fields get generated very well inside planets. There's something called the Dynamo Theory which basically says I have a conducting fluid that's swirling around and inside the Earth we believe that there's a - there's molten iron flowing around that's creating our magnetic field. But we can't see in to see how that is flowing or how the magnetic field is getting created and the reason is that on the Earth there's a permanently magnetized crust that, you know, when we formed and became solid whatever the magnetic field was at that time got frozen in.

And so while the inside stuff is still moving around and generating it comes through this permanently magnetized crust and goes out into space and protects us from the solar wind and does all kinds of things our magnetic field. But when we look inside and map the magnetic field we can't map inside of this crust. So we can't see inside the middle of the Earth. We'd have to, you know, we don't have a way to see in.

Jupiter is all gas. So we're going to be able to measure. There's no permanently magnetized gas on it. We're just going to be able to see all the way down for the first time. This will be the first planet that we actually are going to measure the magnetic field to this kind of precision so that we can start to understand how the magnetic fields get generated themselves, which is very important because the magnetic fields are all through the universe. They're, you know, around the Sun has huge ones. There's pulsars. I mean all the - a lot of planets have them. Not all of them but Saturn and Uranus and Neptune all have them and Earth of course has it. And so it's - this is a fundamental experiment in addition to learning about the polar magnetosphere. Learning about how magnetic fields get generated is fundamentally important as well and will tell us about how Jupiter's is structured inside.

Okay so the next chart is exploring the polar magnetosphere. This was the fourth of the science observations or objectives that I listed. And so here you see on the lower side this beautiful picture in blue is a Hubble Telescope image of Jupiter's aurora. So on the Earth we have aurora and we have an oval. It's typically oval shaped on the top of our caps. If any of you have been lucky enough to go to Alaska in the middle of February, which and dressed warm enough to go outside, you would see an incredible light show up in the sky. And that's the aurora. And you have to go in February when it's cold because in the summer it's always daylight up there and you can't see the aurora. You've got to be seeing it at night. So you've got to go when it's cold unfortunately.

Jupiter's aurorae are similar to the Earth's. There's an oval shape but our aurora are all generated by interactions with the Sun and what's called the solar wind in our magnetic field. Basically particles, charged particles come off the Sun. They get trapped onto Earth's magnetic field lines. The flow up the magnetic field and they come down the magnetic field line and hit an atmospheric particle exciting it and making it emit light. And that's how Earth's aurora works and it's an oval. And we know that it's triggered by the Sun because as the Earth spins the oval stays fixed in - with respect to the Sun's direction. So it doesn't spin with the Earth. It basically stays fixed and with regard to whichever way the Sun is coming - the Sun particles I mean, the solar particles.

So on Jupiter it doesn't work that way. There its oval actually moves around. Part of the main oval moves around with Jupiter as it spins meaning that whatever is causing its aurora are coming from inside of Jupiter's magnetosphere. There is some stuff at the polar emission near the top that seems to be triggered by the Sun and doesn't move. And so Jupiter's a little bit of a mixture. The other thing that's amazing about Jupiter is you see these things I call Ganymede and Europa footprints and Io footprint. These are actually the satellites. The Galilean satellites of Jupiter that are going around and they are - they're tied to Jupiter through the magnetic field.

So there's a magnetic field line coming out of Jupiter that threads through the satellite and carries particles from the satellite back to Jupiter and exchanges. It's almost like an umbilical cord between the planet and its moons. And we can see the light coming from the particles coming off of these moons as they hit Jupiter's atmosphere and make these incredible aurora emissions.

So what Juno is able to do that's unique here is that we're flying over the poles and we're flying right through the regions where the particles are coming down the magnetic field lines creating these aurorae. And so for the first time we'll be able to measure the kinds of particles that are coming in, what their energies are, how they get energized and what the - what kind of currents are being generated by these things. They're all - it's like a little engine. And so the whole thing has to do with, you know, being in the right place at the right time and we have a number of instruments that go in to look at this. We have an infrared and an ultraviolet camera so that we can look at the aurora. They - they're both infrared and ultraviolet.

And then we have particle instruments that measure the charged particles at various energies. We have two kinds of instruments that do that. And then we have something that's called plasma waves. We're basically flying a radio antenna that's looking at electromagnetic waves that are moving the particles around and energizing them. And so we have a very thorough experiment to look at the magnetosphere. And it'll be the first time that any spacecraft has looked at the polar magnetosphere of Jupiter. So it's a very high priority for us.

Okay so let me go into the next one where I’m going to go a little bit more into the payload because I - some of them I've already talked about. On the left hand side, I just have a list of the science instruments, the gravity science and the magnetometer, the microwave radiometer. Those are the things that I already talked about. And they're all sitting on the sides of the spacecraft itself in between the solar arrays. Then I have something called JEDI, JADE and Waves. These are the particular instruments.

So JEDI is looking at high energy particles. JADE is looking at low energy particles. And Waves is this antenna that's looking at the electromagnetic waves that are moving around the particles and energizing them. And then I have something called UVS and JIRAM, J-I-R-A-M. UVS is the ultraviolet imager and spectrometer. And JIRAM is the infrared one. JIRAM is made in Italy. It was contributed by the Italian government and it's a copy of other experiments that have been on other spacecraft like Cassini and it looks at the infrared and it does both spectroscopy which tells me what kind of atoms might be there. But it also looks at infrared light and makes a picture of it.

And then I have something called JunoCam which is this - is a visible camera. It takes color images and it also has a methane filter because there's a lot of methane. And so we want to be able to see that. But it's mainly looking at full color images. And it's designed to be able to take great pictures of the poles of Jupiter because we've never seen what the poles look like. But it'll get great pictures everywhere. And of course we're so close to Jupiter when we fly by, only 5000 kilometers. We expect to see quite a bit and learn a lot of the - about the zones and belts from JunoCam.

JunoCam is special in the sense that it's not a full-fledged science instrument. It's actually on the payload as what's called an outreach camera. And so it's going to engage the public in a rather unique way. We have a Web site called missionjuno.com. And on that Web site people - the public can or classrooms can sign on. They can actually help choose what we'll take pictures of. They can vote on the - on what we take pictures of and whatever gets the most votes we'll go take a picture of that. So if you have your favorite white oval or and of course everybody's going to want the red spot. But there may be other things that people want.

And we'll take that picture and then when we take the picture we will deliver the raw data to the Web site so that people that want to play around with making the picture themselves, they will be able to make the first picture themselves and then post it. So it's - we're hoping that a lot of the public gets excited about that. I know that we just started that Web site and it's already getting a lot of interest. So I think we're going to engage the public in a big way with that camera. And each of you can share that with other people so that they all - they can form their own groups, whether it be schools or classrooms or just doing it themselves. Okay. So I think that's all I wanted to show here.

The magnet - I can tell you where these experiments are a little bit and that's on this other chart where you see the solar panels. The gravity science of course is the high gain antenna. The particle instruments are sitting around the bus that are looking out between the solar arrays, the same thing with the micro radiometer. There's different ones but they're all situated in between the solar arrays. There's a few experiments that are on the bottom such as the plasma wave and the infrared. They're looking down underneath and you can see that from the top picture.

And then at the very far end of one of the solar arrays, which looks a little bit different, that's called an optical bench and it has the magnetometers on it. And the reason you put them way out there is you don't want to measure the magnet field of the spacecraft. You want to measure the magnetic field of Jupiter. And so you try to put the magnetometers as far away from the spacecraft as you can and in fact there's two magnetometers. There's one way out on the end and then there's one that's partway in. And that way I can subtract one from the other and know that I've removed whatever the spacecraft contribution to the magnetic field was and only measure Jupiter's.

And co-located with those magnetometers are cameras that look at stars. They're called advanced stellar compasses but they're basically cameras. There's four cameras that are designed to look at faint stars and that's so that we can locate exactly where that magnetometer is because the solar array may deflect or move around a little bit compared to the main body of the spacecraft. And we want to make sure that we're measuring the magnetic field and we know exactly where we are. So those cameras locate the end of the solar array very, very precisely. It turns out those cameras have a lot of other use as well where they'll look for other satellites and learn about the rings and things like that. Okay.

Ron Schmit: Dr. Bolton I had a question for you.

Scott Bolton: Go ahead…

Ron Schmit: As for the spacecraft, why spinning? It would seem that would complicate things a lot.

Scott Bolton: We're spinning because we're stabilized by spinning. So there's two kinds of spacecraft. There's ones that are called pre-axis stabilized where you have to control which way you're pointing and how you're oriented very carefully because you're stabilized by the fact that there's some machine inside that's holding onto you, right, in a way…

Ron Schmit: Sure, inertia.

Scott Bolton: Or you can spin and you can become spin stabilized where so now I'm like a bicycle wheel, right. If I spin that really fast it's very hard to turn it. I mean if you turn the bike upside down I mean and you spin it, you can feel the torque from this momentum. And so when we spin twice a minute, it's very hard to disrupt us. We always know which way we're pointing. It's a very inexpensive and efficient way of maintaining control of the spacecraft itself. And because we're so big, we took advantage of that because if something this large spins just a little bit, it has a lot of angular momentum and that angular momentum is equivalent to stability. So the real answer to your question is we wanted stability.

Ron Schmit: And does that complicate the job of the sensors as they're trying to map the surface and moving around so fast?

Scott Bolton: It does. It could I should say. We designed right from the beginning all the sensors to work in this mode. And so all of them prefer to be spinning because of the way we designed it. But if I took an instrument off of something else that wasn't spinning, it wouldn't work on this spacecraft. So you have to design it upfront that way. So the particle measurements want to spin because they want to look at all space. And if I wasn't spinning, they would have to have a whole bunch of sensors or they'd have to guess about the directions that they didn't get to look in. Whereas by spinning, I've looked in two pies to radian so to speak. I can basically say I've sampled all of the space.

The microwave wants to spin because I want to look at the - that synchrotron emission. I want to look at the high - the radiation belts, which is noise to my atmosphere. So remember when I was talking about how the radiation belts emitted microwaves and we - and the GAVRT kids are going to get to look at the radiation? That radiation is also seen by my microwave radiometer but I want to look at the atmosphere and I don't - and that radiation is sort of noise to me.

So by spinning, I look at the atmosphere and then a half a second, you know, I'm spinning around twice a minute. So 30 seconds later or ten seconds later I'm looking in another direction and I can see the noise directly. So I self-calibrate. So spinning helps me calibrate the instruments as well as it allows them to see more space. And so it's actually an advantage for us the way we designed this. But you have to design it upfront that way.

Ron Schmit: Got it.

Scott Bolton: And we spin up even - to get even more stability when we fire our rocket engine at Jupiter orbit insertion. So we spin even faster to become even more stable. Okay I'm going to go to the next slide which is a video of the cruise. It kind of shows you this spin. There's sound to this. I'm not turning on my sound because it'll come through your telephone but each of you would be able to turn on the sound and listen to it yourself and it's narrated. So I should stop talking. [Play slide 28 video here.] Okay so this - a lot of these videos are available on the Web site if you want to look at them again. And - or of course you get to maybe keep this anyway.

I know I'm going to a little slow so I'm going to start to speed up. The next one is the flight path which I think was just explained by that video. But basically we went out. We had to fly by the Earth back in October 2013 and then we go out and we get enough velocity and speed to be able to reach out to Jupiter. We're basically in orbit around the Sun like a planet where one side of it is at the distance of the Earth and the other side is at the distance of Jupiter. And the whole trick is to when you arrive at Jupiter that Jupiter needs to be there and then you have to slow down so that Jupiter can grab you.

So we basically fire our rocket engines and do like a thrust and slow down enough that Jupiter grabs us. But right before it grabs us we're - we set the world's speed record for humans because we're moving faster than any other human object that's ever been made. We're cooking along at about 250,000 kilometers an hour. So it's very, very fast. But that's because Jupiter is sucking us in.

Okay next path is something from Bill Nye. So Bill made a series of videos for us and this is just one of them. [Play Slide 30 Video here.] Okay I may skip some of these videos because I'm afraid I'm going to run out of time or I already did already. So I'll go to the next one which is the Earth flyby. This just gives you some images of Jupiter or I mean of Earth as we flew by. It shows you the - what the JunoCam can really do.

The amazing thing was is we took these - we didn't - hadn't set up the Web site for the public yet but we threw these pictures out there anyway. And when we came back in the morning, we didn't even make the pictures. It came down at night. In the middle of the night, people in Europe were up making the pictures. And when we woke up all these pictures of Earth were in there and we were like wow the public really does like this stuff.

So the next one is an Earth/Moon movie. I'm going to recommend we skip that for now and you guys take a look at it yourselves. It's a little movie of the Earth and Moon that we took back in when we flew by and it's put to some music. So you can take a look at that on your own. And then the Earth flyby I just want to show another picture. I'm on one that says Earth flyby from space to ground that we flew by over South Africa at night and those are the city lights. And then you can see some astronomer - amateur astronomer took a picture of, you know, a time lapse. So you see the stars in motion. And the one that was the - is the still in the circle is Juno itself flying over the Earth back in October of 2013. That was when the government was shut down but they - and they couldn't stop us from flying by though.

And then the next one is a high Juno video. I'll skip that right now too. That's a ham radio experiment. We basically did an experiment where we sent a signal up into space basically with ham radio operators. So we created a program and you'll see it on the video if you watch it. Basically they all coordinated with us on a Web site at JPL where we sent the signal in Morse code that said, "Hi." And then we timed it so that when Jupiter - when Juno was flying by, we tried to see if we could detect that ham radio signal. And if enough of them did it, we had calculated that the signal should be strong enough that our plasma wave antenna, the radio antenna that we fly, would actually detect that signal. And we were able to see it. So it was just amazing. I think that was the first time I know of anybody doing that where we actually measured, you know, people on the Earth sending a signal up to a spacecraft flying by on its way to Jupiter.

The next chart is Jupiter orbit insertion. So maybe we should watch that because that's coming up in July. So it says JOI orbit. And so you'll see the burn of the motor.

Ron Schmit: Doctor, is it a hypergolic engine?

Scott Bolton: I'm sorry?

Ron Schmit: Is it a hypergolic engine?

Scott Bolton: A hyperbolic?

Ron Schmit: Hypergolic.

Scott Bolton: Oh no it's like hydrazine and yes.

Ron Schmit: Yes, yes okay. [Play Slide 35 Video here.]

Scott Bolton: So that burn is about 40 minutes long. And I think it ends at about 9:00 pm pacific time on July 4. Okay so the next chart is a longitude map but we already - I already showed you a movie of that. So we don't need to do that again. And here's just a couple of images of as we were building the spacecraft itself. Here we're moving that vault. We needed a crane because it was 200 kilos. But you see the crane moving the radiation vault onto the main body of the spacecraft. Those big silver balls are the propulsion tanks for the - that engine that's going to burn on July 4. And this is I think that must be at Lockheed Martin. That's who built our spacecraft.

Okay so then inside you see a couple of maps of this radiation vault. It's - there are big pieces of titanium. There's louvers on there to keep it cooler inside and there's all these electronics packed inside. That was an engineering exercise on itself just figuring out how to pack all the electronics and the cabling that had to go into it. Very high tech. Then you have the integration of the bus so that you get an idea of what it takes to build some of these. This is sort of the Juno as it's being made. We're integrating the bus with all of the electronics and the harnesses and doing a test. So Lockheed had different kinds of mechanisms to lift it up and turn it. It was quite impressive. And then we had to load it.

The next one is Juno transport out to Kennedy. [Play Slide 42 Video here.] So we had to get ready for launch and so we were loading it into the - into an Air Force jet. Ironically this was also a time when the government was closed. I'm not sure what's wrong with our Congress but we were moving it and the government was closed and they - I had to get a special exemption so that the pilot could land at Kennedy Space Center because the Air Force had closed down there except for essential things. And I had to go get a waiver because we had $1 billion spacecraft flying down there and they weren't going to let it land. So these are just sort of practical issues that you have to deal with.

And then we did some final testing and you can see a picture on the right hand side of how it gets put into the rocket itself. The top part of the rocket is there.

They called it the payload faring. And so Juno is actually designed and fit so that it can go inside of that. And it's all folded up. The solar arrays are all squeezed together there and folded like an accordion. And you see the magnetometer thing is all there and everything is kind of being stacked on top of another rocket that's going to help it get to Jupiter. And then that faring closes on it and it goes on top of the rocket and off it goes. And that's the next video. And I think this is getting near the end of the talk.

This shows you if you haven't ever seen a rocket launch, I recommend you go down to see one. They move the rocket out on railroad tracks. And there it is moving on the railroad tracks. And those towers around it are lightning towers to protect it. This shot is from cameras that are on board outside the rocket looking down at the Earth. So once that payload faring went away, that meant Juno was out in the open. Of course after that we had to open up the solar arrays. Okay so I'm going to go onto the next chart. I'm about done.

We have three passengers. I often get asked are there anybody on board. And it's just LEGO mini figures, three of them: Galileo, Juno and Jupiter. The Lego company partnered with me so that we could try to reach out to kids and help them get excited about science. And so they made these out of spacecraft aluminum and we tested them and made sure everything was clean and then installed them on the spacecraft. There's also a plaque commemorating Galileo, the scientist.

And then I've already talked about JunoCam but here's a chart that describes some of the stuff of how JunoCam's planning and voting and processing the data will work and gives you some directions on how to do that. And this is right off of our Web site. And then I think these are for Courtney to cover. Are you still with us Courtney or I did take too long?

Courtney O'Connor: I'm still here. I do want to take any questions or I'm happy to go through these slides really quick.

Scott Bolton: I'm open to either.

Courtney O'Connor: Okay. Well then I'll just quickly run through these products. For those of you who were not on at the beginning, my name is Courtney O'Connor and I'm the public engagement lead for Juno here at JPL. And I just wanted to go through some of the products that we'll have available to you for your events whether it be with museums or some smaller events in your community. More details will be coming. So if I go through this too quickly, we'll have all the links available afterwards.

So a big item is the NASA TV live broadcast that we'll have on July 4. More details coming soon including the exact timing on that. But you can expect that we'll be coming to you live from JPL with mission commentary and on camera interviews. This is broadcast out on NASA TV, Ustream and YouTube Live and it really makes for a great program. We also have some handouts that the solar system ambassadors I know that you guys submit your requests through Kay but we can provide you with lithographs, fact sheets and stickers. And a lot of these products are also available on line.

We have Jupiter teachable moments. These are products that the JPL education specialists are putting together for stem lesson plans. There's one out right now that's all about Jupiter and solar power that we posted after Juno became the furthest solar powered spacecraft. There is a Juno model that's available online. This is a do it yourself version paper model that is really fun for school kids. And we have several other products that are in the works right now, so some Juno overview videos, the crazy engineering video series which has been really popular here at JPL. So stay tuned for more information on that. Oh and then also with Jupiter being so spectacular in the night sky right now, we have several amateur astronomy videos and products that will be coming out for that.

If you go to the next slide, we're also making it so that the public can fly along with Juno. So Juno's part of our NASA 3D interactive, Eyes on the Solar System. For those of you who have used it before, it's a fantastic way for the public to fly along with the Juno spacecraft. We're going to be setting up a module so you can use that for Jupiter arrival. And there will also be some really interesting new visualizations of some of the scientifically interesting aspects that will help the public understand the science story that Scott has told so well today.

If you go onto the next slide, Juno of course we are on social media. You can follow us on Twitter, Facebook, Tumblr and YouTube and we'll be coming soon to Instagram. And then for more information on the mission, I highly recommend checking out the Juno mission Web site. There's a lot of video content there. There are interviews. There's a great Bill Nye video series. You saw one of those videos but there are I believe ten episodes in that series. And then there's also the JunoCam Web site that was mentioned earlier. And we're also on NASA.gov. So that's everything here.

Scott Bolton: Okay. I apologize that I went a little bit long. I am open to taking any questions if people have any.

Ron Schmit: I have a quick question. I guess this may be even for Courtney. With the New Horizons probe this went through the Southwest Research Institute. Can you describe for me since it's on there and people ask, how is that related to JPL and NASA? Where does that fit in the family?

Courtney O'Connor: You know, I am going to toss that one over to Scott. He can better answer that as he is over at the Research Institute.

Scott Bolton: New Horizons is another New Frontiers mission. So New Frontiers is a program at NASA that our PI led missions. It's the largest of the planetary missions that are PI led. New Horizons went I think it was about 500 million or maybe at the end it was 600 or something like that. I don't remember. But it went past Pluto and that was the first New Frontiers mission. And then the second one is Juno and then there's a third called OSIRIS-REx which is going to bring back a sample from an asteroid. So it was just a coincidence or you can say that it was Southwest Research Institute putting the missions together but basically the first two New Frontiers missions were both led by scientists that worked at Southwest Research Institute.

And so the connection is very little except that I had been - I had helped a little bit with the New Horizons. But basically Alan Stern was the PI of that. He's at Southwest Research Institute. The managing center and the spacecraft provider was Applied Physics Lab on the east coast. I believe JPL participated in helping. They certainly had to do a lot of the tracking and some of the calculations for the trajectories and things like that. But generally they were not heavily involved in New Horizons. I think they also helped with the - during the flyby itself all of the Office of Communications and how to reach the public was sort of a joint effort by JPL and other parts of NASA and the project as you probably know. But there's no direct tie other than that we're both at Southwest Research Institute.

Now from a program perspective, there is in the sense that, you know, no one mission is going to answer every question we have about how the solar system works and how the planets work. And so each mission brings a different piece of the puzzle and Pluto was a very, very distance object. It used to be called a planet. Now it's a dwarf planet. You know, I don't want to get into that whole thing but it was a piece of the puzzle in understand - in trying to understand what it was like there, how much variability is there, what kind of characteristics are Pluto. Is Pluto like that far away from the Sun? It's very important in understanding the overall solar system. And so that was our first glimpse at Pluto. It's not so easy to get there. So we flew by it but we got - we learned a great deal.

What we learned from Pluto tells us something about solar system bodies and maybe what distant objects that make up dwarves are which are basically maybe members of the Kuiper Belt which are sort of members of a comet collection. And as you heard me talk about comets a little bit and snowballs, it all kind of comes into well what is the role of ice in the early solar system. Juno is addressing sort of the very first steps and what the ice was distributed like early on. And maybe learning about Pluto and the Kuiper Belt objects helps us put that into context. So I don't - did I get to some of the things you wanted?

Ron Schmit: Not so much the mission-wise. I'm trying to figure out how the - all the organizations work together. Are they all umbrella'd by NASA and they work independently? Or, you know…

Scott Bolton: They are in a sense. I mean JPL is an official NASA center. Although it's run by Caltech, it is a NASA center. NASA has a number of centers, Goddard in Houston, right, Johnson Space Center. So APL, which is not a NASA center but is actually something more affiliated with the Navy, does space missions for NASA and is allowed to manage missions as well. They have a lot of spacecraft experience. They're all under NASA but APL is not managed by NASA. Neither is JPL directly but JPL is more under NASA than APL is. But they're all working toward fulfilling NASA's mission, the bigger mission of exploring and learning about ourselves and reaching out, right. And so there's just the different implementations. They tend to work together. They partner when it makes sense and sometimes they do stuff that's individual.

So JPL certainly supported New Horizons and it couldn't have been without certain things that JPL does uniquely. On the other hand, on Juno, APL played a role on Juno as well even though it was - the mission was managed by JPL and built by Lockheed, the spacecraft. APL provided one of the instruments and have been part of the mission and have helped me with the radiation belt analysis and things like that. So each of these centers has a different kind of expertise.

Goddard is another one. They're a big player in Juno as well. And, you know, NASA collectively taps each of these centers that have different expertise to create any given mission that they're doing. And depending on the mission and exactly what's needed, one center may play a bigger role than another. But they're all there together to do whatever is needed and each one has a unique expertise that is valuable at some level for every mission. But, you know, the concentration may be, in this case for Juno, JPL took the lead and was doing most of the work and on New Horizons APL was doing that.

Ron Schmit: Okay thank you.

Scott Bolton: Anybody else?

Man: Hi. For mapping Jupiter's gravity, the Doppler shift what is the order of magnitude for the - for that Doppler shift? I'm imagining it's really tiny. And how sensitive must our instruments be for that?

Scott Bolton: It's incredibly tiny. I don't know off the top of my head but it's a very, very tiny effect that we're looking at. So we have very, very precise systems. And the gravity experiment, the gravity science experiment on Juno is the most advanced that's ever been flown because we have both - we have two bands. We have the high gain and band that works on X band from a JPL instrument that basically works off of the high gain antenna. But then we have - Italy has provided something called the KA band which is another frequency. And we actually send the signals back and forth. I gave a kind of a high level description of it.

But what's really happening is Juno is sending a signal back to the Earth which is then received and turned around and sent back up to Juno and then Juno receives that and sends it back again. So we have something that's called up and down and we do it at two frequencies because we want to remove the noise from the charged particles that are in between Jupiter and the Earth. The solar wind is filled with that and is affecting radio stuff. And the radio signal is affected differently depending on frequency.

So we do it at two frequencies in order to be able to remove that effect. And Juno will be the first interplanetary spacecraft that does that. Cassini had a similar system also made in Italy with a very different design and it didn’t work. And so they were still able to do great gravity because but they didn't get everything to work. So Juno went with a different design but also provided by Italy and it's all working. So it'll be the first one that uses both of those frequencies and gets a very, very high precision. I can send you more information if you're interested. You could get a hold of Courtney or somebody through the Solar System Ambassadors and I can send you more details. Some of it's on our Web site though. You can look it up. I think it's something like ten to the minus nine but I'm not sure the exact number. But we measure the gravity field out to maybe 14, order 14 or so. So it's very, very precise.

Man: Great. Thank you.

Scott Bolton: Maybe that's all of them.

Kay Ferrari: Scott, Courtney. It's been a wonderful afternoon. We have just been rapt listening to you here. This is such a wonderful story and we're all looking forward to the arrival of Juno down to live for us. So I want to thank you both for giving us your time and all these materials. I want to thank all of you for joining us today. And please check the Museum Alliance and the NASA Nationwide Web sites for other upcoming telecons. Thank you everybody for joining us. Have a good evening.

Courtney O'Connor: Thank you Kay.

Scott Bolton: Thanks Kay and all. Thanks very much.

Courtney O'Connor: Thanks Scott.

Man: Thank you. That was great.

Woman: Thank you Dr. Bolton.

Scott Bolton: Thank you.

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