Heather Doyle: Welcome everybody, my name is Heather Doyle from The Solar System Ambassadors and we have an exciting topic today, very timely topic as always. The Cassini end of mission update by Dr. Trina Ray. She's been with the mission for 21 years and she's got 50 some - no 62 slides to show us so there's going to be a lot of great information.

So I'm not going to take up too much time introducing, I'm just going to turn it on over to Trina. Thank you so much for being here and take it away.

Trina Ray: So thanks so much for inviting me. When I was sitting in an executive Cassini meeting, and they said something about The Solar System Ambassadors had not gotten a talk recently about the grand finale, I said well that's a problem I can solve. So an invite went out and I'm glad you all could make it today.

So I'll let you know, I'm running a PowerPoint slide in - sort of in show mode so if you downloaded the gigantic file all the animations and everything should play. So I'll tell you when I'm going forward, and I'll try to mention what slides I'm on as I go.

So I'm forwarding on now to slide number two. I did want to at least, spend at least a few minutes just reminding everybody about the spacecraft. The Cassini orbiter is quite a large spacecraft in our family of spacecraft. It stands about 22 feet tall and the high gain antenna up at the top is four meters in diameter.

There's a nice picture there on the left, that's a real picture of the spacecraft while it was in solo thermal vac, which is a testing we do here at JPL, to test it for thermal and for vibration. And you can see people there in the lower left hand corner and around the Huygens probe, for context.

The space craft is also very heavy. It was six tons when it was fully fueled, and we had about 2,000 kilograms of fuel, and we're down to 10 plus or minus 20. So when we say we're running out of fuel, we are really running out of fuel.

We're powered by radioisotope thermoelectric generators. We had 875 watts at launch. And you know what, I need to update that. It isn't 670 currently that was from a couple years ago, it's in the high 590's now. We lose about 10 watts a year so. And we have a whopping, gigantic, huge .5 gigabyte recorder, so. Thought we would never fill that up when I first came over to the mission from voyager but of course we fill it up every couple of days.

And the Huygens probe itself you can see there in gold on the left was given to us by the European Space Agency, and we took it out there and then it had a glorious mission on Titan.

Going forward to slide number three this is just a nice graphic of the spacecraft to remind ourselves sort of what are the instruments we're dealing with, with the Cassini space craft with optical remote sensing instruments.

These are the cameras. They have visible ultraviolet, infrared. They're all collocated on the spacecraft and co-bore sighted, so they're kind of stuck to the side of the spacecraft there you have to turn the whole spacecraft to take a picture of something but once you do all cameras can see it

We also use the high gain antenna at the top to send a radio signal back to earth, but sometimes the rings are in the way of that radio signal, and so we learn about the rings of Saturn using the high gain antenna. We also take the high gain antenna and we turn it towards the body of interest, either Titan or Saturn and we blast down. And we get a return signal and we learn about the body we have blasted with the radar signal.

And then there's the instruments that are embedded - you know how many dust particles are hitting the spacecraft, what about the ions, what about the gasses.

What's the magnetic field right here where the spacecraft is? Those are called In Situ or sometimes magnetosphere and plasma science instruments and we have half a dozen of those.

Going on to the next slide which is slide four, just a reminder that it's been quite a long mission. I know we only have 17 days left, which we're reminded of all the time, there's countdown clocks everywhere. But we did launch on October 15th 1997, so we're ending the mission just one month shy of being 20 years in flight.

We had seven years to get out to Saturn, we used gravity assist of Venus twice, Earth, Jupiter, and then to get out to Saturn in a blistering fast seven years, that's a beautiful launch. It was a Titan 4-b which is the largest rocket that the U.S. was launching at the time, and it was a night launch, and it entered a cloud deck and it was, oh my gosh, just so gorgeous.

I was not there. I was back at JPL in some little crappy room, and I'm very sad that I did not get to see that launch. So that's definitely going to be a plan for the future, to see a launch. Now this movie runs on further, so you just have to hit spacebar to make it go to the next page. When you go to the Saturn system, and we're on page five now, of course you're going to study the planet itself.

You're going to study the magnificent ring structure around the planet. All of the icy satellites in particular Titan you can see there, those are to scale. Titan is about the size of the United States and Enceladus is about the size of Iowa to give some sense of it. Today we're going to be talking about what the spacecraft then has been doing for the last couple of months, which are these daring dives.

First we were just on the outside of the F ring, so if you look there where it says Janus Epimetheus there's an arrow that goes down and just to the left of that there's that faint F ring. That we - that's where our F ring grazing orbits were. And then the proximal orbits are right there in the eye of ring where it says D-ring. So it is literally just threading that gap very, very carefully.

It's been so exciting, I'm, gosh, just so excited to tell you guys about what's been happening. Okay, and then Cassini took seven years to get out there so remember Saturn orbits in about 30 years so each season lasts about seven years long. When we got there, it was in 2004 which was about the middle of northern winter. Think of it as, say, January 12th if you live in the northern hemisphere.

We had a four-year prime mission, so we were barely out of winter. So our first extended mission was to get out to Equinox, the spring Equinox, which was in 2009. Then we had a seven-year extended mission to get out to summer Solstice, and that took us out to 2017 and where the spacecraft is now, if you hit the spacebar, it zooms right across there and we are literally 17 days away from the end

Okay. I know that was blistering fast but I at least wanted to give you- oh I have the movie. I will have my computer be loud, and at least then you can hear the audio so you know where we are.

((VIDEO) https://saturn.jpl.nasa.gov/resources/7628/ Here you have the option of listening to the audio via Trina's presentation audio recording OR you can pause this audio file and watch the video in full, high quality sound and then fast forward the audio file to rejoin Trina's presentation.)

Woman 1: A lone explorer, on a mission to reveal the grandeur of Saturn, its rings and moons. After 20 years in space, NASA's Cassini spacecraft is running out of fuel. And so, to protect moons of Saturn, that could have conditions suitable for life, a spectacular end has been planned for this long-lived traveler from Earth.

Man 1: Five, four, three, two, one. And lift off of the Cassini spacecraft's million-mile trek to Saturn. We have cleared the tower.

Woman 1: In 2004, following a seven-year journey through the solar system, Cassini arrived at Saturn. The spacecraft carried a passenger. The European Huygens probe, the first human made object to land on a world in distant outer solar system. For over a decade, Cassini has shared the wonders of Saturn and its spanning of icy moons.

Taking us to astounding worlds, where methane rivers run to a methane sea. Where jets of ice and gas are blasting material into space from a liquid water ocean that might harbor the ingredients for life. And Saturn, a giant world ruled by raging storms and delicate harmonies of gravity. Now, Cassini has one last daring assignment.

Cassini's grand finale is a brand-new adventure. 22 dives through the space between Saturn and its rings, as it repeatedly braves this unexplored region, Cassini seeks new insights about the origins of the rings, and the nature of the planet's interior, closer to Saturn than ever before.

On the final orbit, Cassini will plunge into Saturn, fighting to keep its antenna pointing at Earth as it transmits its farewell. In the skies of Saturn, the journey ends as Cassini becomes part of the planet itself.

((END VIDEO))

Trina Ray: Well I just think that's a fantastic movie. I love showing it. This is one of the first times I've ever played it that I haven't teared up. So I must finally be getting used to it a little bit. Really incredible summary of what we're talking about.

Okay so headed onto the next slide, slide number eight. As mentioned in the movie why are we doing this? Well we are running out of fuel. We are just, we are literally on fumes, and we have to protect the worlds that we know are astrobiologically interesting.

If you click to the next [image], it's an animation so it brings up Enceladus. Enceladus has a global ocean, its hot ocean touching rocks, super saturated with minerals, it has hydrogen there that is the fuel for microbes. So it just is a ridiculously intriguing place for astrobiology, and we don't want to crash the space craft into Enceladus.

If you click the next one it brings up a picture of Titan, also astrobiologically interesting. It has lakes of methane, and ethane on the surface. It has a whole meteorological cycle, it just isn't a water cycle, you know. It has methane clouds, and methane rain that collect into methane rivers, and then methane seas.

So it is also just very rich in hydrocarbons, and is also very astrobiologically interesting. So we have to dispose of the spacecraft and we cannot hit one of these bodies, and so that's why we're doing what we're doing.

Now that we're coming at this from the - if you go to the next slide, Slide 9, we're coming at this from the Solstice Mission. And this is a little movie [or series of gifs that you'll need to click through] that shows the Solstice Mission in its seven years. You can see how we tried to get all of it on the system for the maps instruments, and the ORS instruments.

If you click the next [gif] of the PowerPoint, it will highlight those F Ring approximal orbits for you, so you can see them in context with the rest of the Solstice Mission. So we had to be able to get to orbits from the Solstice Mission, and that was very important.

We could've put the spacecraft in an orbit that was just orbits for 500 years and doesn't hit anything. We could've ejected it from the Saturn system, but the scientific value of these F ring approximal orbits were so high, that the science team was drooling when they saw the opportunity.

If you go to the next [gif], it's just a real close-up of those orbits. You can see in the white, those are the, what we call the ring-grazing orbits, just on the outside of the F Ring. And the blue is the approximal orbits, those are inside plunging between the planet and the rings. And then the final impact orbit, which happens on September 14th. Actually several days it happens, sort of September 11th through the 14th.

Okay so we're going to go on now and talk a little bit about the challenges of planning for this, and what we've been doing with these 21 orbits, and it's all about that gap between the planet and the rings. So if you go to Slide 10 Mind the Gap, it is all about the gap, and what are the things that we are worried about with the gap.

The next slide, Slide 11, shows sort of all the orbits in context with the planet and the rings. You can see the 22 blue orbits, and then that last impacting orbit.

If you click to the next [image], it also shows you the best picture we have of that region, and this is the picture that we use to assess the dust hazard because the rings of Saturn have - there's obviously particles in them, and those particles are getting fewer and fainter as you head towards the planet, but you don't exactly know. It's a hard picture to take.

You're sort of that close to the planet and the phase, and so everything we decided, we decided sort of from taking this picture, and blowing it out, and doing analysis on this picture.

If you advance the slide [13], there's a very nice animation of the PowerPoint that says okay at the top we have the ring plane crossing, and so you have to click the spacebar to get to the ring plane crossing, those little purple dots come in at the ring plane crossing.

If you click the spacebar again, you get the minimum altitudes. So from above, we have the rings, and from below we have Saturn. And Saturn, of course, isn't this hard body, right? Saturn is a gas giant, and so its atmosphere gets less, and less, and less but it doesn't go to nothing right in that gap. So we had to track, very carefully, both the dust coming from the rings, and the gas coming from Saturn.

If you click that one more time it’s a nice animation that takes you sort of to a view from the North Pole, and the nice thing about this is these orbits are just laid out and timed perfectly so that you can actually see them and then, of course, if you are engineers, which many of us are, it becomes an Excel graph.

So now we’re on Slide 15, if you’ve been keeping track, it’s called the Proximal Corridor and you can see there the ring plane crossings, and the minimum altitudes are right there.

Okay so what are we going to do? Well first of all, we need to understand where we really think that dust is, right? We’ve looked at the image from the G Ring, we’ve studied it, and we need to draw a line somewhere on this graph.

So we drew a line, sort of in like the 3%. There’s a 3% chance we felt that we would hit a dust particle. Typically, in the mission we have used 1% as a trigger for doing things like putting the high gain antenna in the RAM direction. This time we relaxed those a little bit because if we’d done 1%, we wouldn’t have been able to do any of these orbits. So we had to relax our risk posture even to do these orbits.

So if you click, the next slide comes in and it shows a line there, the D Ring Detection Boundary. That’s Slide 16 now, so that purple line. So four of these are flat out above where we think that we will be impacting D Ring particles. So those were going to be shielded crossings, and if you click the spacebar again, and then another time, they turn into little Captain America shields.

And we're on slide 17 now. Also, because we had never been in this location before, the project manager decided that the very first fly-by, he also wanted to be in a protective attitude. We're going somewhere we've never gone before, he wanted to be as safe as possible, and so he shielded the very first fly-by as well.

Now get to know this diagram here because we're going to come back to it in a variety of ways. So, again, you have these first five that are sort of in the middle, then you pop up into the D ring, then if you come out you pop up into the D ring again. Then you come out, then you have the last five which are down in Saturn's atmosphere, and then the very final one way on the right which is the impactor.

Okay so we've talked about the dust, let's talk about Saturn's atmosphere. We're on Slide 18 now. Saturn's atmosphere, we learned about that through occultations, both solar occultations, and stellar occultations. And so our very best guess as to what the density of Saturn's atmosphere does, as you go higher and higher, the atmosphere people went off and they refined this as best as they could.

They added additional occultations in the last three years of the mission to get as many observations as they could because Saturn's atmosphere, of course, changes over its seasons just like the Earth's atmosphere changes over its seasons.

So if you click to the next slide, we're now on Slide 19. We're going to put in a boundary for Saturn's atmosphere. The first spacebar [click] shows you the one bar atmospheric pressure. This is a measurement of pressure that is useful to atmospheric scientists. They often look at things at the one bar, or fractions of a bar, or a thousand bars.

The second [spacebar click] is where will the spacecraft be captured? Where are we confident that the spacecraft if it got below this, it would be captured? And then the last [spacebar click] is where will we lose control authority with both the thrusters, and the wheels?

And if you clicked through that, we're still on Slide 19 but it's an animation, you'll see that all of those boundaries came in, and those last five are below the control authority for the wheels. So if we were on wheels, we would lose control of the spacecraft, so we have to be on thrusters for those last five. And then you see, obviously, the one on September 15th is easily within the capture boundary of the spacecraft.

Okay going on then to Slide 20. Okay I just wanted to make sure that you saw that there were little thrusters down on thruster control on those last five. There's also thruster control on two other fly-bys, you'll see that.

We used that for the magnetometer team, we wanted to spin the spacecraft very, very quickly. As quickly as you can spin something the size of school bus with thrusters for the magnetometer, and I'll talk about that when we get to the science results.

Okay [slide 21] so you go to the scientists, and you say to them all right we have a plan. We're going to plunge the spacecraft between the planet and the rings, we're going to do this for planetary protection. If you hit the spacebar you'll see planetary protection come in there. We have to do that for spacecraft disposal.

So space again, and you get the spacecraft disposal. But what is the unique science we could do? So if you hit the spacebar again, the first one is Saturn's internal structure. Now just think about this. We have been in orbit for 13 years, and we don't know how long a day is on Saturn because how do you tell how fast a day is on a gas giant?

You can't look at the clouds because the clouds are moving relative to each other. There has to be some other way to do that. Well the way that we've traditionally done that in planetary science, is we watched the magnetic field.

The magnetic field we know is generated from the interior of the planet. The magnetic field is typically offset from the rotation axis, and as it spins around we get a little beeping sound. And so that tells us the day on Saturn. Sadly for us, the magnetic field of Saturn is very closely aligned with the rotational axis. And so that is troublesome in a couple of reasons.

One, it's very hard to get a measurement of that beep. Number two, the CIRs team tells us that, that's impossible if you have them closely aligned, the dipole will collapse upon itself, and clearly Saturn's magnetic field doesn't. But we can't get at any interior information about Saturn because we can't get close enough. We're always orbiting on the outside of those darn rings.

But now we're going to be orbiting between the planet and the rings, and so not only are we going to get gravity measurements that are going to tell us about the interior of Saturn, but we're also going to get really close magnetic field measurements that are going to tell us about this mysterious magnetic field of Saturn, that is so closely aligned to the rotational axis.

So it's a win, win. We get two key pieces of information, just by being in these orbits that tell us something about Saturn's internal structure. If you go on to the next spacebar [click], you'll see the next thing is the ring mass. Again, we've been in orbit for 13 years, and in 13 years we have done hundreds of occultations. We have put stars behind the rings of Saturn. We've put the Sun behind the rings of Saturn. We've put the Earth behind the rings of Saturn, and sent the radio signal from the spacecraft, through to the Earth.

And that thick white B Ring there, that's right in the middle of that image, we could not penetrate that and so we don't know how massive that is. And without knowing the mass of the B Ring, and therefore the mass of the rings, we don't know the age of the rings. And so this is just killings us, 13 years and we don't know these fundamental things.

But if you send a spacecraft in-between the planet and the rings, the gravity of the planet and the gravity of the rings pulls the spacecraft separately instead of together. So we'll be able to disentangle that. So, again, a total huge win if we are able to pull off these orbits.

And the third thing, if you hit the spacebar again, is the in-situ measurements. We get to actually take our iron and neutral mass spectrometer, and in those last five orbits we get to dip into Saturn's atmosphere. We get to take our particle detectors, our dust detectors, and we get to take it through that gap and really find out about the rings, the dust particles from the rings that are drifting down.

We get a great measurement of the radiation belt, and the very final orbit where we turn the spacecraft into a real-time data-taking machine, we actually turn Cassini into a Saturn probe mission in the last minutes of the mission. Just incredible. So as you can imagine, the scientists were agog about how excited they were.

Now I do have one more here if you hit the spacebar again. Of course, we're going to get some of the highest resolution observations of the rings, and the poles, and the aurora, and the atmosphere that we would ever get in the mission. And that is literally icing on the cake, right?

If you can get at these big open questions - science questions, that's the meat of it and all this high-resolution stuff is just the cherry syrup on top of the cherry on top of the whip cream on top of the icing on top of the cake.

Okay let's go on to the next slide. This is now Slide 22, so I really want to focus on these science measurements. And when we ask the scientists okay we're going to do this, how many of these passages do you need to get your science?

And if you hit the spacebar, so the radio science team, that's the team that does all that gravity, they told us they needed six. They needed to get for the higher gravity of Saturn, and then address the ring mass.

If you hit the spacebar again, that's the maps team telling us we need four. And if you hit the spacebar again, I just put in all of them. So now you can see what we're dealing with. The ion and neutral mass spectrometer needs eight, CIRs needs three, the dust - I mean it's crazy. And then the total, we needed 36 passages, and we only have 22.

So of course, we're going to have to share. It is what has to happen. We started working on this in 2014, and we got together several groups that worked on the sharing.

And if you go to slide 23, this is the ultimate product that we produced. This is all 22 orbits there. It shows you what we're doing on each orbit. Let me sort of get you oriented from the things that you already know. For example, you could see the very first - Rev-271 has HGA to RAM, but you can also see that 276 and 277 sort of in the middle - upper middle. And 281 and 282 upper right and lower left also have the HGA to RAM. Remember those are those five shielded.

You can see that the last five above them, have little red boxes that say RCS. That means we're on thruster control for the last five, 288 to 292. You can also see the two magnetometer ones, 272 and 285.

Okay so get to know this plot because we're going to revisit this plot as we go because what I wanted to do is spend 10 minutes sort of taking you through the excitement of the 22 orbits and what the team has sort of been feeling since April when we started these because it has just been incredible.

So that very first one, Rev-277, you can see there what we're doing, is we're doing cameras to Saturn, but of course we have to use the protective measures right at close approach HGA to RAM, and then again cameras to Saturn. So it's going to be one giant Saturn movie from pole to pole.

And if you click on the next slide [24] - all right. Okay I wanted to insert at least - I wanted to spend at least two minutes on the ring grazing orbits because it was so cool. So here are the ring grazing orbits that happen just before those 22.

The first slide is Slide 25, we're going to look at some moons that we saw here in the Encke, and Keeler gap. The Encke is the big gap in the middle of that blue one, and the Keeler gap is the little one to the right, almost near the right arrow.

If you go to the next slide [26], there is a picture of Pan. Incredible. I mean I don't know if you - I mean who would've thought that's what Pan was going to look like? These little ring moons that are inside of the rings, and they have structure to them. They have a little bit of dirt around them of material. They have little craters, little divots in the skirt. They have cracks that go underneath the skirt, all the way to the other side.

It's just - these moons are really incredible, and of course, if you go to the next slide [27], it wasn't five minutes after that picture came out and hit the Web, that somebody isn't sending around a little picture of pasta.

Slide 28 is a close up of Daphnis. Daphnis is in the Keeler gap there, we have a beautiful, captured beautifully the structure of how Daphnis is causing the rings of Saturn to deviate. Remember, the rings of Saturn orbit - the ones on the top orbit faster so they've - the one's on the top have already gone by Daphnis has been distorted, and now Daphnis has gone by the ones on the bottom and distorted them.

If you go onto the next slide, which is Slide 29, you can actually see -- now that we've colorized it -- a little bit of material that has been pulled off that ring and is coming to Daphnis. Just, I'll tell you, when I saw this image, I mean, I was excited about the highest resolution images of the mission, but when these things hit, it was unbelievable.

And then the next - Slide 30 is a little movie of Atlas. Actually, that didn't work on my screen. Hold on a second. A little movie of Atlas. Well, that's okay, it doesn't matter. Try to find that later. It's just a nice, you know, little sort of Atlas got closer and closer. Slide 31 is a close-up of Atlas. Here, you can see that skirt of material has almost covered Atlas. And we think that this is as large as one of these particles could be, one of these ring-moons. We don't think it could be any bigger than this or Saturn's gravity would start to pull it apart. We also had some very nice surprises.

On slide 32 -- somebody asked us if we would be seeing the Earth again in any of these orbits, and, so, we went off, we found a location. So we did take turns and take a picture of the Earth.

If you look real close there with your eyes, you might see something a little to the left of the Earth, but if you hit the space bar, you can see that I've zoomed in on it. And when this picture hit the ground we were all looking at it and somebody in meeting said, "Is that the Moon?"

And, so, of course we all went off in some huge rush because none of our software had even shown us that we would see the moon. And so, yes, within a few minutes we determined that was the Earth and the Moon. And I'll tell you, that was just - there's not a lot of science to it, but it was really quite special when this image hit the ground.

Okay. So I couldn't ignore the ring-grazing orbits because they're so cool. Okay, I did want to go back though, now we're going to step through the 22 orbits. So now we're on Slide 33. This is our very first passage. Again, just to give you context, we’re Rev 271.

Okay, so what were we worried about? Well we were worried about the dust. And when you go to the next slide, this, on the upper-left, is an audiogram from the spacecraft of a ring-grazing orbit.

So this is when we were on the outside of the rings. You can see a little white line moving across, and it's about to get to the red. And when it does, you will hear particles hitting the spacecraft, getting ionized and being picked up by our plasma radio detector.

And you can tell that we get a lot of hits on our plasma radio detector as we go through ring-plane crossings. None of them are dangerous to the spacecraft. I'll be quiet for a second so you can hear it. So, I'm going to go ahead and stop that movie.

None of those are dangerous to the spacecraft, but collectively we have to track those. And we did not know what we would see when we went on the inside. And what we saw on the inside - let me start that. Is we saw, or we heard, almost nothing. In fact, I don't even have to play that. You could just tell. You can't even see the ring-plane crossing in there.

Finally, the person, the scientist, who was showing this finally put an arrow and said, "Here’s ring-plane crossing." So, one of the most amusing things that I thought that happened in one of these meetings is - everybody is very worried about the dust. We'd go into this big meeting, it's packed.

The managers, the spacecraft manager, the navigation manager, every manager that we have. And then, there's the scientists who do this work. And the very senior scientist looks around the room and says, "There are more people in this room interested in the dust than the dust particles that hit the spacecraft." So, it was just fantastic.

Okay, the next slide, which is Slide 36, is a little movie that shows the footprints of that pole-to-pole passage that we did where we had the cameras pointed at Saturn. And you could see here, sort of, right in the middle, the spacecraft turns over so that the high gain antenna goes into that RAM direction. And then we continued on the other side.

And if you go to the next slide, which is Slide 37, that's the movie there on the left that shows you every footprint of the movie. And on the right, is a red reference dot. And one of the nice things that happened here is we had literally the world's expert.

There is no one who was more expert in Saturn's atmosphere than Andy Ingersoll from Caltech. And he was up on stage at an event we were having when these images came in. And, just play that movie again, if you can go back a slide and then just play it again, it's fantastic.

And he said things like, "I have no idea what that is. I've never seen that before. That is quite mysterious." And what a gift, that here at the end, when we're doing some of this highest-resolution of these images of these Saturn observations, that we - it’s a whole new area to explore. We didn't expect to see those little white lightning clouds like that. We didn't expect to see some of the things that we saw at the hexagon with a lot of structure in it. It's a total gift.

As you go onto the next slide [38] - we have done this twice, so I put in the June 29 one as well. Alright, so Slide 39, we've done the very first fly-by where there's no dust. We got all of our science data and all is well. So the next fly-by was the magnetometer.

This is one where the magnetometer is trying to spin very fast so that it get high signal-to-noise on all of its detectors. And you can see there how its spinning sort of like a flat disk with the high gain antenna just sort of spinning around with the magnetometer, sort of, in a dish - going around.

And that's only good enough to get its detectors on two out of its three orthogonal detectors. So we have a second magnetometer pass where we do something a little bit different. So pass two was totally successful. The magnetometer got great data, fantastic data.

But of course, they need their set of data, so we had to wait until Slide 42 now. You can see now the high gain antenna is solidly pointing at the Earth as we do an occultation. And the magnetometer is spinning around it. Now watch this occultation that comes up. The occultation -- that line that you see is that line from the high-gain antenna to the Earth.

And so you can see how the spacecraft is going to, as it sinks into the ring-plane, it's going to go all the way through the rings of Saturn. It only takes about 20 minutes. And you can get an entire occultation of the rings of Saturn in 20 minutes. Starting at the inner-ring, D, C, then through the B Ring. And then finally you can see it going through the Cassini division there, it punches right through. And then finally into the A Ring.

And usually an occultation like this would take hours and hours, but you can do it in 20 minutes on these proximal orbits. And I tell you, I went in and watched at least three times, it was so fantastic.

On the next slide, which is Slide 43, this is just an orientation slide. On the bottom is a picture of Saturn's rings as you would see with your eyes, and at the top is an optical depth profile. So the things to note are, for example, the Cassini division, where the Cassini division has very little material in it.

So, you can see it's very low there, very little material. Whereas the B Ring has a lot of material, and so the optical depth is high. The C Ring is very faint way in the left of the low material. Whereas the A Ring is, sort of, in between the two.

Okay, now, of course this is exactly the opposite of what Radio Science sees. So if you hit the spacebar, they flip it upside down. Remember the spacecraft is sending a signal through the rings to the Earth.

And so, if there's a lot of ring-stuff in the way, very little gets through. So now you can see the B Ring has a very low thing. But if there's little material, the radio science signal booms through. So you can see the Cassini division is very high. And that's exactly what Radio Science sees.

And so the next slide [44] is one of those 20 minute occultations where you can see, on those bottom, that's the X-band the Ka-band and the S-band. You can see the entire rings of Saturn just appear before your very eyes in what was the shortest, closest, fastest occultation of the mission. And it was a pure pleasure to be there when it happened.

It was very early in the morning and not only the truly hardy went -- and the radio science team has a nice tradition of printing out one of the screens and having everybody who was in the room sign it. So you can see my name there on the lower left. Radio Science Emeritus.

Okay, so if we go with the Slide 45, you can see now we've done several more passages. Those are all the radio science passages. Every one of those had a 20-minute occultation on them.

You'll notice under 274 which is the fourth smiley face, we actually don't have a smiley face, we have a, like a, flat mouth. It wasn't a complete loss. In no way was it a complete loss, but we did have a degradation of the observation with some of our European partners and the antennas they were using, so this stuff is hard.

This stuff is hard, and to imagine that every single thing would go perfectly, would be folly. So, as we headed into the next several weeks of the mission, you could see their radar rings, ISS rings, radar rings, ISS rings, and again high gain antenna to RAM.

We had some of our highest resolution images of the rings, so for right now, we're on Slide 46. Those are some of the highest resolution images of the rings. It's incredible.

If you go to the next slide, which is Slide 47, it's just a tremendous bending wave there that you can see the harmonics on it, and then on the right-hand side, you can tell that we have the resolution to see structure. Look at that thing, sort of three-quarters away across, but the straw that's on the left-side of that image is just incredible, and then another high-resolution image [on slide 48].

All right, so going on to slide 49, just again wanted to mention, we did have a problem on one of our passages, where we had a DSN outage, and we lost some data. We didn't lose the critical data, because we were doing a dual playback.

All right, so, here we are. We're about half-way through, and the magnetometer team is ready to tell us a little something. They put it out in a little press conference. They said that the magnetic field after all this, is still amazingly well-aligned with the planet's rotation axis, which is just crazy.

So, the lower limit used to be a degree, then it was a tenth of a degree, and now they're telling us that the difference between the two is much smaller than .06 degrees. And that's just mind-boggling. It's just mind-boggling, and it's quite challenging to explain as Michelle Docherty says. So, what an exciting time to be on Cassini.

Okay, going on to the next slide, which is Slide 51. Everything is hunky-dory. We've had a couple of more radio science fly-bys. We've had that other Rev-281, on the right-hand side. You could see there, we had that other noodle. We've also had some more ring observations, and we're now getting ready to do some of these cold Aurora observations.

It's not obvious, but with Saturn so big on the sky on one side, and the rings so big on the other side, it's very easy to heat the spacecraft and the instruments up to really, outside of their normal operating conditions. And so, we had to go off and really try to make one or two orbits cold, so that we could see the Aurora.

You go on to Slide 52, you'll see the little movie of the Aurora. That's Saturn, it's up above, the dark circle, up above. The sky is what's below, and you could see this is a long exposure, so those are stars drifting behind Saturn. And then that faint wispy is the Aurora.

This is one of the highest resolution Aurora pictures that we've ever gotten in a mission. Also, it's nice to see the stars as they get close to Saturn turn and deviate a little bit to the right, because they're bent by Saturn 's atmosphere.

All right, the next slide is slide 53, so we got our cold Aurora picture, smiley face there. And now we're headed into these orbits: 288 to 292, where we are going to dip our toes and head into - and not even dip our toes, we're going into Saturn's atmosphere.

We're going in on thrusters, and we are ready, and we did the first one and everybody held their breath. We had targeted to use about 10% of the thrusters, because we figured we had a factor of three uncertainty.

If it was 10%, and we got up to 30, no problem, but if we targeted 30%, and we got up to 90, that would be a challenge, because 70 is about where the spacecraft team is comfortable as a maximum. Of course, it can go higher than that, and we'll use that on the very last one.

But you go on to the next slide, slide 54. On August 13th, we successfully had our first passage into Saturn's upper, upper most atmosphere. The Ion and Neutral Mass Spectrometer, which is the instrument that's designed to suck in the atmosphere of Titan, but this time it was sucking in the atmosphere of Saturn got a direct sampling of Saturn's upper atmosphere.

It got great data. The signal to noise was fantastic, and the thrusting came in at about 30%. So, we were off by a factor or three, and we were off by a factor of three. We were ready to do a pop-up maneuver, if it had been more than that; and we were ready to do a pop-down maneuver if it had been much, much less than that and the INMS wasn't getting their data, but we heard the word yesterday, everything is fine. We're not going to do any maneuvers.

INMS is getting great data, and we're sitting at 30, 40, 50% on the duty cycle of the thrusters, and we are fantastic. All right, so that's where we are. [Slide 55] We just finished - actually yesterday, we just finished the radar data. We just got a report this morning that all data has come to the ground, so I need to put a smiley face in there.

But of course, I did the slides yesterday, when we didn't have the radar data. Some of you might have the Inside Out movie, and some of you might not, because I added that late, but Rev-289 is where we did an Inside Out movie, so if you do have that, you can go ahead and run that separately.

It's just a quick little movie that we took while we were going through the ring plane crossing and you can just see, sort of, the rings of Saturn. These are just literally pictures that we took one after the other. And right at the end, you could see as we go right through ring-plane crossing, it goes from the lit to the unlit side.

And we only have two left. Today, we only have 17 days left on the mission, and we only have two more that are optimized for the Ion and Neutral Mass Spectrometer.

And then we have a non-targeted Titan fly-by which will be the last close fly-by of the mission. That happens on September 11th. The data comes back on the evening of September 12th. And for those of us who've been Titan experts and Titan scientists for all these years, every month, the Cassini spacecraft has sent us this little burst of data that is a gift telling us something new about Titan, and that's the last time that will happen.

And for some of us, it could be the last time it happens in our entire professional career, so it's somewhat sad to be thinking about it. It's also sad to be thinking about, you know, the mission being over, and not seeing these people that we've been working with together every day for many years. That's also sad.

But I did want to tell you about the last day of the mission [Slide 56], the very last day of the mission. This is September 14th. On the very last day of the mission, we come off of a down link, and we do a very distant Titan observation. It's a meteorological campaign. We try to look at Titan six to eight times a month, and this is one of those. This is not a close Titan fly-by, this is a distant Titan.

We also do an entire observation of Saturn and its rings, not quite at this phase, but at a higher phase, so less will be lit. We watch Enceladus set behind Saturn. We are taking a little movie of that, and then we go off to do propeller observations.

And the nice thing about this, is on the last day of the mission, as the magnetometer's continuing to collect data, we get a little bit of everything, on the last day of the mission. And, of course, in the last moments of the mission, we become a Saturn probe mission, and we go from complete control of the spacecraft to complete loss of the spacecraft in one minute.

Every second of data matters, and the longer the spacecraft can stay on point and give us that Ion and Neutral Mass Spectrometer data, the happier we will be, but it's not going to be long. It will only be seconds at the end, that Cassini will be able to maintain attitude.

And so, the very last thing I have is slide [57], is a beginning of a little cartoon. This is really adorable. It appeared in Scientific American. It says, "So, Cassini, I hear you're retiring in September 2017. Congrats. How do you want to celebrate? Maybe, do lunch with me and all of my moons, or something," and if you go to the next slide [58].

"No, I'll just go barreling straight into your atmosphere, learning as much as I can before I'm crushed to death and vaporized in a spectacular whirling inferno, beneath your mysterious, stormy clouds." And then the next slide [59] is Saturn's reaction, and then the final slide [60] is, "That's awesome!" and with that, I will finish, and we have time for questions.

Heather Doyle: Wonderful, we'll give everybody a chance to unmute and ask questions here, I'll sure there are plenty.

Trina Ray: That was sort of a whirl wind.

Heather Doyle: Yes, it was. Thank you so much. Here's someone with a question, and a dog.

Tish Bresee: Hi, Trina, this is Tish at Kopernik in Vestal, New York. Two questions, please. How is it that the spacecraft is shielded in all those moments that you're talking about, shielding?

Trina Ray: Yes, what's your second question?

Tish Bresee: And who narrated that beautiful video?

Trina Ray: You know, I don't know who narrated the beautiful video, but she did a great job. Didn't she? I can probably find out. It's probably on a website somewhere.

Tish Bresee: It sounded like Carolyn Porco's words, but not her voice.

Trina Ray: Yes, no, it wasn't Carolyn, but maybe somebody who's out there can be doing a Google search, while I'm looking. So to answer your first question let me go back to a slide that shows the spacecraft quickly. Well, even the cartoon would have it so even if you go back two slides. If you see the high gain antenna there the high gain antenna almost all of the spacecraft sits behind the high gain antenna.

This was designed this way because we were going to go as close as Venus in the solar system and we needed to point the high gain antenna to the sun to protect the rest of the instruments from that. So the high gain antenna acts as a shield and everything tucks up underneath it, mostly.

The magnetometer sticks out of course and the plasma radio wave antennas stick out, but so when we talk about shielded what we mean is we're pointing a high gain antenna in the direction of danger and everybody's tucked in behind.

Tish Bresee: Oh that's cool. Thanks.

Trina Ray: Sure.

Chris Thompson: Good afternoon. This is Chris Thompson, a Solar System Ambassador. I had a question on Slide 19.

Trina Ray: Slide 19, okay. Let me zoom back to Slide 19. Okay go Chris.

Chris Thompson: On the slide, you show the tumble boundary for the reaction wheels and it's pretty much a straight line across from the early part of the mission but then in those final five orbits there's a peak in there and I'd like to understand why the change in the tumble boundary for the thrusters at that point.

Trina Ray: Okay, that's a great question. What's happening there is it depends on what is the attitude that the spacecraft is going through Saturn's atmosphere. You can imagine if we're going high gain antenna to RAM we would have a very different profile of Saturn pushing on us than if we were going sideways. So what's happening there is that we have a different attitude and so we have slightly different control authority. Great question.

Chris Thompson: Very good. Thank you very much.

Trina Ray: Oh, you're welcome. By the way, everybody always asks that so maybe I'm going to start saying what that is. Why is there that bump there, what's going on?

Julie Taylor: Hi, this is Julie Taylor. I'm just curious. Enceladus and a lot of the other icy moons out there, how do they get all that water?

Trina Ray: So most of it came from the formation of the solar system. Saturn was formed out in that part of the solar system where once you've turned on the sun, the things that were solid and could make planets and moons were metal and rock the four ices.

When astronomers talk about ices they often just mean water ice, carbon dioxide ice, methane ice and ammonia ice. And so those are solid when the sun is turned on out at the orbits of Jupiter and Saturn and so they contributed to making both the planets Jupiter and Saturn, Uranus and Neptune and the moons around them.

Christopher Hudson: I'd like to try to piggyback on that question, this is Christopher Hudson, Wisconsin. I want to ask on Enceladus. I know all the talk and the excitement with the Europa Clipper mission moving forward and I just wanted to ask your opinion on where you'd put the ranking kind of importance or feasibility on a dedicated mission to Enceladus.

Trina Ray: So of course, I think we should be doing all of them. My feeling is we should have been doing the Europa Clipper a decade ago. Cassini was conceived of in the eighties. It was built in the nineties, and the flagship for the 2000s should have been the Europa Clipper so that the flagship for this decade could have been Enceladus or Titan.

But we sort of missed that onramp, so Europa got delayed and Enceladus and Titan or Uranus and Neptune those will be next, but I think we should be going to all of them. Enceladus is just so interesting because we have so many intriguing signs.

We know there's ocean, we know there's hot, we know that we have water touching rock and getting infused with minerals, we know there's Hydrogen, which is the food for microbes. It's just, and also Enceladus is very kindly spitting it's ocean out at us so we don't have to dig down to it.

You know, I think all of those targets, and Titan, don't forget Titan. Oh my God, Titan is so incredible. All of those targets are fantastic and we should be doing all of them. And right now NASA only has half a penny of the Federal budget, in terms of the percent, so imagine what we could do with a penny.

Christopher Hudson: Yes. Thank you.

Man 3: But if you had to pick between Enceladus and Titan and you only could pick one, which one are you gonna go for?

Trina Ray: So, well, so that probably plays into my biases, I've been spending a lot of time, 13, 15 years working on Titan so of course I would rather go to Titan. But I completely understand the people who would want to go to Enceladus and both answers are right. You don't have a bad choice there. I mean if somebody's arguing to go to, you know, Mimas or something okay then they're probably wrong.

Michael Lewis: Trina. This is Michael Lewis how are you?

Trina Ray: I'm doing just fine.

Michael Lewis: Okay, great. You know, I've been with the program since the beginning also with Cassini and it's really sad that it's going to be going away.

Trina Ray: Yes, I know.

Michael Lewis: I was wondering of the angle of incidence that the spacecraft will be taking I remember when Galileo's probe went in. I was just wondering and how fast will it be going?

Trina Ray: So the spacecraft will be going about 75,000 miles per hour. The angle is determined by pointing the high gain antenna to the Earth and pointing the ion and neutral mass spectrometer into the RAM direction. So that is how we are going in sort of on our side mag boom sort of out, high gain antenna to Earth, ion and mass down.

Michael Lewis: So how long will it be traveling through the atmosphere?

Trina Ray: We will go from complete, I have total control authority, the spacecraft is in complete command the atmosphere is not affecting me at all to I have completely lost control authority in one minute.

Michael Lewis: So traveling 70,000 miles per hour in one minute it's going to travel, what, about 600…

Trina Ray: It's not going to travel very far, right? And remember Saturn is huge, so it's just right now.

Michael Lewis: A little blip, yes

Trina Ray: It's a little blip.

Michael Lewis: Thank you very much, Trina.

Trina Ray: It's a Saturn probe, but it's a Saturn probe would be upper atmosphere of Saturn.

Michael Lewis: Okay. It would view the upper atmosphere for sure. Okay. Great. Thank you.

Trina Ray: You're welcome.

Adrienne Provenzano: Hi this is Adrienne Provenzano a Solar System Ambassador.

Trina Ray: Hi, Adrienne.

Adrienne Provenzano: Great presentation. My question has to do with your connection with the mission. I'm wondering when you started on Cassini did you think you would be with the mission this much of your career and what have you gained by staying with the mission for that long?

Trina Ray: So I've been at the laboratory, the Jet Propulsion Laboratory for 28 years. My first job was the Voyager Neptune encounter. That's a pretty high bar when that's your first job.

I moved from Voyager to Galileo briefly before I joined the Cassini team. I joined an instrument team. I was on the radio science team at launch. I moved around and up on the mission so I moved over to science planning and was put in as a minion science planner on the Titan group, the Titan orbiter science team.

I started working, TA, the very first targeted Titan flyby the mission was one of the first things that I integrated with them. After a while I moved up in the ranks and became more senior in the science planning team. I actually left for a few years to do a stint as a line manager here at the lab.

And then I came back in 2014 and the gem that they offered me was a key strategic planner for the end of mission. So I have been working on this end of mission, the plans for this, for three and a half years and it is a pure pleasure to see the fruits of the all the labors of all the teams.

Often when you're the key strategic planner you don't do much of the work, all you do is lay out the schedules and make decisions about who needs to do what at what time, but it's been a huge growth opportunity. Cassini has offered me many, many growth opportunities.

I've been offered a new job on the Europa Clipper mission. I'm working for them part-time at 20% as the investigation scientist on the ice-penetrating radar instrument over there and they are still in phase B, which is the paperwork phase prior to the building phase.

I think Cassini, I didn't know. I'm not one of those people who plan out my career, like where am I going to be in five or ten years. I do interesting and interesting work is presented to me. Usually it's more critical and more difficult than the work I was doing.

I continue to move up in the ranks and it's just a pleasure. It's a pleasure to be at the laboratory. It's a pleasure to work on these missions. It's just a gift. Really, truly a gift to be a part of something that is just so incredible and so positive. I cannot speak highly enough of getting to work for NASA.

Adrienne Provenzano: Thank you. I also want to say that I really appreciate that you showed us the charts of the last orbits and the smiley faces and all that and helping us just better understand how teams have to work together and prioritize and share to make something like this come about.

Trina Ray: Oh yes, the sharing for this one. Cassini is all about sharing, because we lost a scan platform somewhere in our development phase. But yes, actually that picture, so that little picture of the chart and the smiley faces. There's one outside of the main conference room of Cassini.

I'm not going to say who put it out there and I'm not going to say who puts smiley faces on it each week, but somebody here does. And when I made a printout, they accidentally gave me four printouts, so I squirreled three more off around lab. So there's one off in the development building, there's one off in the formulation building, there's one in the lobby of this building, and smiley faces appear every week.

Adrienne Provenzano: That's great. Thank you.

Trina Ray: You're welcome.

Jerry Hilburn: Hi, this is Jerry out in California. I have a question about the mission as it relates to what we've learned about the core of Saturn. Could you tell us a little bit about what we've learned? Is it a solid, is it a liquid? I know that it's extremely hot. Please elaborate.

Trina Ray: So Jerry that is a great question and we have done now six of these flybys that have been dedicated to nothing but trying to tell us about the interior of Saturn. And this is what I can tell you. They can't figure it out. The data is so interesting, it is so intriguing, no model that they have works.

So there is still work to be done, which is just great. To think that Saturn's interior is, it is not like any of the models we currently have. And when the scientists get together, all they talk about is what they don't understand about Saturn's interior. It's probably going to take months, months to figure out what's happening inside Saturn.

I would love to tell you the answer. I would love to tell you that it was easy, oh here's what happened. The answer is that it is vastly more complicated. And by the way, to give you a sense of this, the same team that is doing this work in Cassini is doing this work on Jupiter.

It's part of the Juno mission. And they've had several flybys of Juno, and they have been able to tell you what Juno's interior is. They got their flybys, there were models, matched the models, everything was fine. But that is not what is happening with Saturn. Which by the way is fantastic.

Nothing better than scientists saying I don't know. Or that's a puzzle. Or there's more work to be done. Or isn't that interesting? I mean, eureka, that's a good moment, but you know, the I don't know moment is better.

Jerry Hilburn: Follow on question. What primary instrument were part of determining the core?

Trina Ray: So the primary instrument is called the radio science instrument. It uses the high gain antenna. It sends a signal back to the Earth. It actually sends a signal from the Earth to the high gain antenna and from the high gain antenna back, so it's actually tied to a super ultra-stable oscillator on the Earth that has really super high resolution on the frequency.

And then as the gravity of Saturn pulls at Cassini as it goes through the flyby and the gravity of the rings pulls on Cassini you get all of that in just excruciating detail by recording the data on the ground.

And then you go ahead, you model everything and you see if you can replicate what happened to the spacecraft, and you should be able to replicate everything because gravity is not a mystery, and the fact that they're having trouble, frankly is fantastic.

Jerry Hilburn: Thank you.

Roberta Parnell: Hi, this is Roberta in Bakersfield, California. What will the coverage be for the final minutes, the final day, the final moments for Cassini?

Trina Ray: Okay, so even today they just put out, if you guys go to, let me find it super quick. It was nasa.gov/cassinitelecon. Okay, so if you go to nasa.gov/ slash -- and this is all smooshed together, Cassini telecon. If you go to that website, what you'll see here is a briefing that was given to the press today.

You can actually go off and listen to the briefing if you want, it was about an hour, and there's some nice graphics here. But it also shows you everything that's happening with the NASA coverage for that day. There's going to be a NASA show that starts at like four in the morning.

Let me see if it - you might have to go one link deeper on this. Let me look here. Yes. Okay so right at the top, once you go to that there's a little blue link that says website, that takes you to the agency website and then if you go to that, it shows you sort of what is coming in the real time.

And Friday, September 15th at 9:30 Eastern is a Cassini post-mission news conference at 8:30, 7:00 to 8:30 Eastern time, so that's 4:00 to 5:30 we're going to have a live commentary on NASA TV. On Wednesday, there's going to be a press conference just before that, so that lays out everything that NASA's doing. Okay?

Roberta Parnell: Okay, great. Thank you.

Trina Ray: You're welcome. How convenient that they just had that briefing today and I can tell you about it.

Roberta Parnell: Yes.

Bob Kaplow: This is Bob Kaplow outside of Chicago. I've got a follow up to that.

Trina Ray: Hi Bob.

Bob Kaplow: The, what is this? The grand overview website has got a countdown timer on it.

Trina Ray: Yes.

Bob Kaplow: Is that the countdown to when it actually happens or is that the countdown when the signal gets to Earth or doesn't get to Earth as the case may be telling us it's happened?

Trina Ray: That's a good question. In the past, these have been countdowns to when it is actually happening at Saturn, so it's about an hour and 10 minutes different from when you will receive that data on the Earth. You know what, for the very last one I don't know which one they're doing, Bob.

I assume that for the last one since we're doing radio science down to the Earth, they might change the countdown to be of when we expect the data to be logged here at the Earth. That's just a guess though. I will - let me take a note.

So the first note was who was the speaker on the, and the second note is the countdown clock in - the question you want to know is that is it in spacecraft event time or is it in Earth received time. My guess is that it's now in Earth received time. Up to this point, they've all been in spacecraft event time.

David Seidel: Trina, I think it is because if you, the entry time is now somewhere around like about seven or eight minutes before the top of the hour.

Trina Ray: Oh, okay.

David Seidel: This is - so at eight minutes after if you put the fifteen minutes back, so sixteen days, thirteen hours, forty-five minutes, so it looks like it is Earth received time.

Trina Ray: Okay. Great.

Bob Kaplow: Thank you.

Heather Doyle: Yes and we did find out who the woman was. Stephanie Czajkowski.

Trina Ray: What was her name?

Heather Doyle: Stephanie Czajkowski, I'm hoping I'm pronouncing it right. Her last name is C-Z-A-J-K-O-W-S-K-I.

Trina Ray: Wow. I don't know her. She did a great job.

Heather Doyle: Stephanie Czajkowski. All right. Well thank you so much. This has been fascinating.

Trina Ray: Oh you're welcome.

Heather Doyle: …and we're so excited for September 15th, and it's going to be really wonderful to watch it live and just the data and the science that's going to be done for many years after will just be exciting.

Trina Ray: It really will. You know, even though the Cassini mission ends sixteen days, the program still goes on for a year, and so I believe they are intending to do several CHARM telecons over the next year with sort of like okay here's like - here's the big final power points of what each discipline and instrument has learned so I'm pretty sure they're planning on doing that and I know that the Solar System Ambassadors are big fans of the CHARM telecon.

Heather Doyle: Absolutely. We'd love that if they could continue.

Trina Ray: Yes. Okay. Thank you so much Heather.

Heather Doyle: Thank you.

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