[Snap Judgment intro]

[somber music]

**Glynn:** Today on Snap, we're proud to present a This Is Love spotlight. An out of the world story that's about two robots on Mars battling the storm together. And the people whose job it is to check on them every day, people who start to think about them, it's family. And what happened one Martian spring when the skies go dark.

The story comes to us from the podcast, This Is Love, hosted by Phoebe Judge. The show tells stories about lots of different kinds of love. Sometimes love between people, sometimes not. From the team behind, one of the first true crime podcasts out there, a show called Criminal, we proudly present Tau = 10.8. Snap judgment.

**Jennifer:** I think Mars looks a lot like Colorado. It was funny because my daughter feels like she grew up with robot siblings. I remember when she was about three years old, we went out to Colorado to visit my parents. We're driving around Garden of the Gods, and my daughter looks out the window and I heard her say, "[gasps] Wow, we're on Mars."

[laughter]

Because she grew up with the pictures. She's like, "We're on Mars." I heard her talking to herself and she said, "Well, grandma and grandpa are mama's parents, and mama works on Mars. Oh, it makes sense now."

[laughter]

This is where she goes when she's working.

[laughter]

**Phoebe:** What do you do?

**Jennifer:** I work at the Jet propulsion laboratory. I've been there 27 years.

**Phoebe:** Jennifer Herman has known she wanted to work at NASA since she was a little girl.

**Jennifer:** I was in third grade when I saw images from Voyager coming back from Saturn. It just amazed me.

**Phoebe:** NASA had launched the Voyager spacecrafts three years earlier to collect information about Jupiter, Saturn and their moons. And in November 1980, the first Voyager spacecraft finally made its way past Saturn.

**Jennifer:** My father went to the store and got a copy of Life magazine, the really big time Life magazines. It had images from Voyager on the cover, and on the inside. He was in the military, so we moved, gosh, almost every year. I would tape those images on my wall. And every time we moved to a new base, I would carefully take them down and then carefully tape them back up.

**Phoebe:** What do you remember seeing and hearing about that mission? Why were you so interested?

**Jennifer:** Oh, gosh, it's a little bit of a tangle in my mind between the Jupiter encounter and the Saturn encounter. But Carl Sagan would come on *The Tonight Show*, and that's when my parents would let me stay up late is if they heard, "Carl Sagan's going to be on Johnny Carson. You can stay up late and watch." I'm like, “Yay.”

Then they would just tell us things that we didn't know, like, "Oh, look at this red spot. Look at these clouds." When we went to Saturn, it was like, "Oh, these rings are different than we expected." Then the moons, like the moons of Jupiter, it's like, "Wow, look at IO. There are volcanoes." We didn't know there could be volcanoes this far from the sun. It was just so fascinating, all these things that we didn't know.

I think that's what amazed me the most when I was eight years old, is I figured the scientists knew everything and everything was in the books. But to think that there were things that were undiscovered, that was just so exciting to me.

**Phoebe:** Jennifer told her parents about her plans to work at NASA.

**Jennifer:** And no one in my family had gone to college, but my parents were just like, "You can do anything." Like, my dad said, "I don't know exactly what you need to do to work there, but I'm pretty sure you need to do well in math and science. So, just work hard in school, make sure you get scholarships, because college is expensive." [laughs] I found out that Caltech was the university that managed JPL. I went, “Well, maybe it would help me if I went to school there.”

**Phoebe:** JPL is NASA's Jet Propulsion Laboratory. Jennifer did get into Caltech, and she started studying physics.

**Jennifer:** But it turns out physics is really hard. [laughs] I tried, but I turned out to be better at chemistry.

**Phoebe:** When Jennifer was about to graduate, she met a group of people who worked at JPL.

**Jennifer:** I told one of them, “My dream was always to work at JPL.” But since I majored in chemistry, I guess I can't do that now. And then one in particular said, "No, that's crazy. We used to just build spacecraft that would fly by planets, but now we're going to start landing on them and studying the Martian soil and things like that. So, we actually do need people with chemistry backgrounds." And I was like, “Really?” [laughs] It was the happiest piece of news.

**Phoebe:** She applied for a job and they offered her one. She remembers driving to pick up her offer letter with her mother.

**Jennifer:** I just remember opening the envelope, and my hands were shaking and we cried in the car. My mom's like, "Wow, I'm so proud of you." [sobs] Just remembering how much it meant to me, like a dream.

**Phoebe:** She started at JPL less than a year before they successfully landed the first rover on Mars as part of the Mars Pathfinder mission. Jennifer was assigned to work on something called the Polar Lander, which was also supposed to land on Mars. She says for about a year, she spent all her time in the lab, sometimes 80 hours a week, getting the Polar Lander ready. They launched it in January of 1999, but they wouldn't know if it would get to Mars for 11 months. Finally, in December, she went to a party to watch it land.

**Jennifer:** I was with a whole group of people waiting to see it touched down, so we could be hugging and crying. [chuckles] It was funny. That's what I always told my family, like, my dream was to be on a project where we all got to hug and cry because we were so happy that it landed safely. And so, what I remember is being in the crowd listening to the telemetry for mission control. It was about to land and we lost contact.

**Phoebe:** Everyone went quiet.

**Jennifer:** People started to slowly trickle out, and it went from super crowded and excited to the sadness you feel when your team is maybe in the World Series and they lose, [laughs] and everyone's starting to leave and very glum. A co-worker of mine, the two of us, we were the most in denial, we sat at the bar, my friend. I think we were the last two people in there. The cameras left, and they turned off the feed and we just kept hoping. I think we stayed there for two hours, not ready to say goodbye.

**Phoebe:** Later she learned what had probably happened. NASA's best guess was this, that the engines meant to slow down the Polar Lander as it approached the surface of Mars had shut off too early, and it fell to the ground at 50 miles an hour.

**Jennifer:** After that happened, I told my supervisor at JPL, it's like, “I can't do flight anymore. This is too painful.”

**Phoebe:** For several years, Jennifer worked on things that were strictly on Earth. Mostly she did nuclear power research. Then a supervisor approached her and asked if she would work on solar power for two rovers that were already on Mars. Their names were Spirit and Opportunity.

**Jennifer:** I told them the whole story about the Polar Lander, "Oh no, my heart is broken. I worked on that for 80 hours a week and it crashed and I can't do flight anymore." He's like, "Oh, come on, Jennifer. The Mars rovers, they're already on the ground. [chuckles] They're not going to crash. And don't worry, it's safe. They're already there. They're already on the ground."

**Phoebe:** Jennifer agreed. Spirit and Opportunity had landed on Mars in 2004. When Jennifer joined the team in February 2005, they had already lasted more than three times what anyone expected them to. No one thought the rovers would last much longer, but they did. I'm Phoebe Judge, and This Is Love.

[somber music]

**Phoebe:** Tell me, what did these rovers look like?

**Jennifer:** Oh. Well, they have a camera mast sticking up off above the solar panel deck. The cameras almost look like eyes. And so, the solar panels are kind of flat on top, and it almost looks like the back. These wheels look like legs. So, it's very easy to see an animal in them. Like if you watch the movie, *WALL-E*. But the Mars rovers were first. [laughs]

**Keri:** A lot of people think of RC car, little remote control car size. Well, Spirit and Opportunity were about as tall as a human.

**Phoebe:** This isKeri Bean. She was in high school when the rovers landed on Mars. She remembers learning about them in a documentary at space camp. Later in college, she met a professor who studied the weather on Mars.

**Keri:** First week of college, he brought me into his office and sat me down. I got to listen into the planning meetings for Spirit and Opportunity for the day, and I had no idea what was going on. There was a bazillion acronyms, but I thought it was the coolest thing on the planet and I needed to be a part of it. And so, my very first week of college, I started working on the rovers.

**Phoebe:** How would you describe what Mars looks like?

**Keri:** Being a *Star Wars* nerd, I'd say it looks like Tatooine.

[laughter]

Sometimes there's sand dunes. Sometimes it's really rocky and really hard to drive, because there's no real good safe path or there's giant cliff faces that were driving up to or cliff edges to look over the Vista.

**Phoebe:** Do you have a favorite part of Mars?

**Keri:** Oh, goodness. I guess here's where my meteorology is showing, and I'll say it's the atmosphere. It's so different than Earth's, and yet there's a lot of similarities. Like, it actually snows on Mars. Even though the atmosphere is so different, it's so thin. It's completely made of different stuff. It still has a lot of the same aspects that apply here on Earth.

**Phoebe:** How cold does it get on Mars in winter?

**Keri:** Very cold. We're talking like minus 100 degrees Celsius. It's very cold.

**Phoebe:** And what about in the summer?

**Keri:** In the summer, humans could walk around with a little jacket on. It gets up maybe into, 70s Fahrenheit. I know I'm switching units here. That's just what I'm thinking of. But yeah, in the summer, it gets pretty warm. Walk around with a nice jacket and some oxygen. That might be important as well.

**Phoebe:** Arethere certain jobs on the rover team that are more sought after, thought to be the cool jobs?

**Keri:** I think definitely the Mars rover driver job is the most sought after.

**Phoebe:** So, rover drivers are considered like the coolest in the hierarchy.

**Vandi:** You're asking a rover driver [phoebe laughs] what is the coolest. [Vandi laughs] And I would definitely say it's a rover driver.

**Phoebe:** This is Vandi Verma. She says her twin four-year-olds don't think rover driving is particularly special.

**Vandi:** Both, me and my husband drive robots on Mars. They think everybody's parents are rover drivers. [laughs] For them, it's just like, that's how it's always been. So, when I'm leaving for work, they'll be like, "Bye, mom. Are you going drive the rover?" [laughs]

**Phoebe:** So, your husband also drives rovers?

**Vandi:** Yes, he does.

**Phoebe:** Who's the better driver in real life?

**Vandi:** [laughs]It's an interesting question. Hmm. Roads on earth are very different. [Phoebe laughs] So, what is to say?

**Phoebe:** Between Spirit and Opportunity, which rover was your favorite?

**Vandi:** The first robot I drove on Mars was Opportunity. That always has a special place in your heart. But Spirit took us on such a journey.

**Keri:** Even though technically on the engineering side, they are identical, they very much had their own personalities. Spirit landed in this just nasty lava rock field and had to work really hard for everything. She had to drive a really long way to finally start getting to some really interesting scientific spots.

Whereas Opportunity decided to make an interplanetary hole in one, land into a small crater immediately in front of some interesting rocks that confirmed that there had been liquid water there.

**Vandi:** The first images that came down, there was exposed outcrop, which is essentially like a cross section, like you might see at the Grand Canyon. And Opportunity literally landed right in front of it. So, drives, I did. I remember doing this drive with Opportunity, and it was just kilometers of sand. And then right there in the middle, you'll find encounter a meteorite. It happened to go right by it, but didn't bump into it. So, there were a lot of these situations where we always thought of Opportunity as the lucky rover.

**Phoebe:** Two years in, spirit's front wheel got stuck, so it could only drive backwards.

**Keri:** I remember thinking to myself-- I tried not to say it out loud too much, but I remember thinking back then, "Oh, Spirit's my favorite.” Opportunity--" One time my daughter heard me and she got mad. She's like, “You're not supposed to choose favorite children. You're supposed to love them all the same.” And I'm like, "No, no, no, [laughs] I love them the same. I love them the same." But I used to favor Spirit a little bit.

**Phoebe:** Part of Jennifer's job was to check how much power the rovers had. She would look at how dusty the sky was, how dusty the rover's solar panels were and predict how charged the batteries would be.

**Jennifer:** It's almost like a budget. It's kind of giving the science team a spending allowance of how much energy they're going to have for the next day's activities.

**Phoebe:** The team never let the batteries get close to empty. It would be dangerous for the rovers. The rovers needed power to run heaters. Even on the warmest summer days on Mars, temperatures can drop 170 degrees at night.

At the beginning of the mission, everyone had expected that the rover's batteries would die after 90 days on Mars or sols, because their solar panels would get too covered with dust. A sol is longer than a day on Earth. Its 24 hours, 39 minutes and 35 seconds.

**Vandi:** Mars is a very, very dusty place. The solar panels were expected to start accumulating more and more dust. And they did. The estimates were that by around sol 90, we wouldn't have enough power to be able to do anything useful.

**Phoebe:** But that's not what happened. Instead, there would be these funnels of wind on Mars, dust devils.

**Vandi:** It's an enormous whirl of wind that you can see moving across the plane. It's very interesting, because I would say it's almost like a dancer with a very whirling movement moving across.

**Phoebe:** Dust devils would sometimes clean off the solar panels, so the rovers could keep charging. Spring and summer were always the dustiest seasons. There were usually dust storms every year. But in 2007, a group of storms started to cover the entire southern hemisphere of Mars, then the entire planet. What does a dust storm on Mars look like?

**Jennifer:** Oh, gosh. I don't know if you've seen pictures of the old dust bowl days in the US.

**Phoebe:** Yeah.

**Jennifer:** The dust on Mars is very fine. And so, once it's lofted up into the air, it just stays there for a little while. It does a really good job of blocking out the sun.

**Keri:** For a solar powered rover, you can imagine not seeing the sun is pretty bad.

**Phoebe:** They measure how dusty the sky is with a number called the Tau. The lower the Tau, the clearer the sky.

**Jennifer:** Our typical Tau's were around one and a half. If it got high in the summer, it might be like a Tau of two. But we had never seen anything really high. And then in 2007, so much dust got into the atmosphere, we measured it to be, we think around a Tau of five. We didn't think we would survive anything higher than that or even that to be honest, because when you block that much of the sun, you can't generate enough energy to run the heaters, and so you'd freeze to death.

[somber music]

**Glynn:** Will the dust on Mars settle? Will the rovers ever see the sun again? When Snap Judgement returns, stay tuned.

[somber music]

Welcome back to Snap Judgment, the Tau = 10.8 episode. When last we left, a space storm had just hit, completely blocking the Mars rovers from the sun. Snap Judgment.

**Phoebe:** During the dust storm in 2007, one NASA scientist told a reporter, “The sun is 100 times fainter than normal.” He said, “We're hoping for a big break in the storm soon, but that's just a hope.” Another said, “If Mars wants to kill the rovers, it can.”

**Vandi:** It hit Opportunity much harder than it hit Spirit. I remember [chuckles] telling myself, "Oh, no, don't die, Opportunity. I love you too. [laughs] Please don't die." And so, we were so scared for it. It was very tricky. We had to pretty much turn off everything we could. After two weeks of really low energy operations, the sky started to clear.

**Phoebe:** The rovers made it through the storm. Opportunity moved on to explore a crater called Victoria. Jennifer Herman remembers talking with scientists, who told her it was unlikely that Mars would get another big dust storm for a few years. She started thinking about having a baby.

**Jennifer:** At this point, I was the lead power engineer for both rovers. And so, I felt a lot of responsibility. The rovers are so vulnerable in the winter, and they're vulnerable in the summer if there's a dust storm. Ah, but if there's not going to be a dust storm in 2009, then that's a really safe time to have a baby.

So, I told my husband there's this window of a four or five months in early 2009, which is Martian summer after a dust storm and earth winter. [laughs] Let's target those dates. And he's like, “Okay.” [laughs] So, our daughter was born in March of 2009. It was just perfect timing.

**Phoebe:** When Jennifer came back from maternity leave, she learned Spirit had gotten stuck.

**Jennifer:** They showed me pictures. The surface of Mars just looked like it always did. It just looked like the ground and there were rocks here and there. It looked completely safe.

**Phoebe:** This was in April, just after Jennifer's daughter was born. Spirit drove onto a hidden patch of soft ground, and its wheels sank into a layer of dust, spinning its wheels only made things worse. Engineers tried for eight months to get Spirit unstuck.

**Vandi:** We would get all these letters from kids who would tell us all the ways in which we could try to get it out. They'd come up with all these creative ideas, and how we could use the arm to push up against and try to wedge it out, or how we could try a different maneuver.

**Phoebe:** Martian winter was approaching.

**Keri:** During the winter, we actually had to find parking spaces to tilt the rover to point the solar panels towards the sun, and that way we could actually survive the winter.

**Phoebe:** But they couldn't tilt Spirit's solar panels toward the sun from the spot it was stuck in, and Spirit's battery was getting lower.

**Vandi:** We would just communicate in beeps, because you want to really make it succinct and just know that the rover is still alive.

**Jennifer:** By the time I came back from maternity leave, looking at the energy forecast, they had less and less energy to try to get out each day.

**Keri:** She was just stuck, and we couldn't tilt her solar panels enough. And so, one day, she just didn't get enough power to keep herself warm.

**Jennifer:** Eventually, you have to say, if it was alive and could have talked to us, it would have by now.

**Phoebe:** NASA lost contact with Spirit on March 22nd, 2010 after six years on Mars. When Spirit died, did you start thinking Opportunity might be next?

**Jennifer:** No. No. [laughs] I felt like Opportunity was a tough girl. Opportunity had survived that big dust storm, and so I almost felt like it was hard to imagine what could kill Opportunity.

**Keri:** When we would start our planning meetings for the day, it wasn't, what are we going to do with the rover for the day? It's, what are we going to do today? The rover was just a member of the team. You're constantly checking in on them, seeing how they're doing. Sometimes they throw temper tantrums and you have to come in and fix it, or sometimes things are smooth sailing, and they find a really cool thing and you feel just as proud and as accomplished if you had your own kid getting a good grade in school. So, we definitely got very attached.

**Phoebe:** They would send commands to the rover at the beginning of the Martian day.

**Jennifer:** Sometimes it'll give us a little beep, like, got it.

**Phoebe:** The rover would spend its day taking pictures or looking at rocks or driving towards a new crater.

**Jennifer:** And then before it went to sleep at night, it would call Earth back. It would go, "Hey, this is what I did today, and I'm going to go to sleep now."

**Phoebe:** Usually, on new Mars missions, for the first few months, everyone works on Mars time. And so, because Earth and Mars are spinning at different speeds, the days can be really out of sync.

**Keri:** One day you come in at 08:00 AM, the next day, you come in around 08:40 AM, the next time, 09:20 AM. It goes all the way around the clock. A lot of people describe it as constantly being jet lagged, because you're jumping essentially one time zone every day. I personally liked it. I guess that means I'm a Martian at heart. I don't know.

**Vandi:** [laughs] When we were doing Mars time operations, we'd walk out and you look at this thing and it's a small red dot in the sky, and you're like, “In a few hours, the commands I'm sending, there's a rover up there that is going to be doing things based on these instructions.” That I think really feels very unreal. You let your brain kick in and it's like, "Well, this is Mars." But you're so used to looking at it and you're so familiar with everything that it starts to feel like a place you're there.

You look at a picture that might be published somewhere off a rock, and you know exactly where it is. You know exactly where it is. I think that kind of a thing both feels very grounding, because you know these details and yet at the set time, it's a little surreal.

**Phoebe:** Like Vandi, Keri wanted to be a driver. But her degree was in meteorology, and it seemed like all the rover drivers had PhDs in computer science or robotics. NASA had landed another rover called Curiosity, and they had scientists working on an even newer, fancier one, getting it ready for launch.

**Keri:** The rover driver leads for Opportunity came up to me and said, "Hey, we're having trouble finding new rover drivers for Opportunity. No one wants to come work on the old, half broken rover. So, do you want to learn how to drive a Mars rover?" And I said, "Well, are you sure you really want me?" And they said, "Yeah."

**Phoebe:** Keri trained for about a year.

**Keri:** We're one of the few roles that can actually physically break the rover. So, we have to build that intuition of what are safe rocks to be able to drive over, what kind of terrain slip are you going to get driving over this terrain?

**Phoebe:** Finally, she got to send her first set of instructions to Opportunity. She remembers the day. It was Sol 5097.

**Keri:** I still think it was one of the coolest days. I got to move a robotic arm on the surface of another planet.

**Phoebe:** Opportunity had traveled 28 miles and broken the record for distance driven on another planet. But it was getting older. It had been on Mars for more than 14 years. One journalist wrote that, “Opportunity's team was able to recognize the signs of gray hairs, a failing memory, the desire to nap, arthritis in the robotic arm.” Summer was approaching, and several years had passed since the last big dust storm.

**Vandi:** We don't know for certainty, but we are often able to predict when there will be very large, massive dust storms.

**Jennifer:** We felt like we were due.

**Phoebe:** Jennifer Herman started worrying about storm season. She watched the weather forecasts closely. It was late May.

**Jennifer:** We had never seen a big dust storm that early. We had never seen even the little dust storms start that early. That's really early.

**Phoebe:** She tried to meet with the team's dust storm preparation lead, but he was out of town.

**Jennifer:** I was like, "Oh, I'm sure it's fine. We'll talk when you get back." There's no way we'll have a storm that early. [laughs] Famous last words.

**Phoebe:** On May 30th, a Mars orbiter spotted a dust storm forming near Opportunity. It grew fast. Within a week, the newer rover on the other side of the planet was seeing signs of it too.

**Vandi:** I was driving Curiosity, and we too were impacted by the dust storm and we could see it in our images.

**Jennifer:** There were a couple big dust storms, and I think they merged and they were coming in straight for Opportunity.

**Keri:** This was the worst one we had ever seen in the recorded history of Mars. It just completely blacked out the sky. You could not see the sun.

**Jennifer:** All we could really do is try to ride it out. Like, we did in 2007, turn everything we can off, try to use the battery as little as possible and hope the storm is going to clear up in a week or two. The problem is the storm seemed to just hang out over Opportunity. When I talked to one of the atmospheric scientists about it, he described it as a truck running over Opportunity, and then backing up and running over it again and then just sitting on it.

**Phoebe:** The storm didn't clear up. Almost two weeks went by. On June 10th, the numbers had a new record.

**Jennifer:** When Opportunity measured the Tau from the ground that day, it was 10.8. That's crazy, 10.8.

**Phoebe:** They'd never seen the sky’s dustier.

**Keri:** That was a terrifying number for me. I remember feeling sick to my stomach when I heard that was the number.

**Phoebe:** Jennifer needed to calculate how much power the rover had.

**Jennifer:** But our tools weren't working, because just the power coming off the solar array was so low because it was so dusty that I couldn't calculate it.

**Phoebe:** She remembers people asking her how it looked and if Opportunity was okay.

**Jennifer:** So, it's like, “Ah, how am I going to calculate this?

**Phoebe:** She started to improvise, doing the calculations by hand. Normally, Opportunity had around 400-watt hours of energy. In the 2007 dust storm, the lowest energy from Opportunity's solar panels had gotten was 128-watt hours. But that day, she calculated there were only 22-watt hours. That number was part of Opportunity's last message to NASA, which basically translated as, "My battery is low and it's getting dark."

**Jennifer:** I was just so proud of Opportunity, just so amazed that she was still able to call home after a horrible day like that on Mars, 22-watt hours, and then still call home and go, "Hey, Earth, this is what happened today."

**Phoebe:** The next day, they didn't hear anything.

**Keri:** We started really trying hard to send commands to the rover to hear back, but we didn't hear anything. I definitely had dreams that I could just go there and brush the dust off the solar panel myself.

**Jennifer:** NASA and JPL gave us a little more time to listen for her hoping, just to go, "Hey, this tough rover has been through a lot and survived. Let's give her the chance. Let's have the respect for what she's done."

**Keri:** As were coming up with, what are all the ways that we could wake up the rover, we became a little superstitious. Maybe the rover wanted a wake-up song.

**Jennifer:** It's a great tradition that started because of Mars time,

**Keri:** As the team would come in. of course you're on Mars time, you're kind of groggy, folks would start the day with playing a wake-up song. And so, with Spirit and Opportunity having gone on for so long, the tradition then faded out.

**Jennifer:** So, we had this big whiteboard at JPL where everybody would write down their recommendations for wake-up songs, almost like good luck, like, "Hey, Oppie, talk to us."

**Keri:** We played heavy metal. We played classical music. We played Backstreet Boys.

**Jennifer:** *Dust in the wind* by Kansas.

**Keri:** We tried everything. We don't know what kind of genre the rover likes.

[somber music]

**Glynn:** Will the rovers wake up? Will they ever communicate with earth again? Stay tuned.

Welcome back to Snap Judgment, the Tao = 10.8 episode. My name is Glynn Washington. When last we left, NASA and JPL were trying everything to reach the rovers. The clock is ticking. Snap Judgment.

**Phoebe:** It had been eight months since the last time NASA's Jet Propulsion Laboratory had heard from the rover, Opportunity.

**Jennifer:** By February 2019, if we hadn't heard from her going into winter now, then we knew weren't going to hear from her.

**Keri:** NASA came back and said, "All right, we're going to give you two more weeks. You can do whatever you want, try and do what you can. And this is going to be the final day."

**Phoebe:** To communicate with the rovers, they had to use NASA's antennas. Usually, they could only use the antennas for an hour a day for Opportunity. But they started getting messages from other NASA missions offering to give up time that they would use to talk to their own spacecraft.

**Keri:** We would just send commands all morning long through the early afternoon saying, "Should have enough sunlight now," Maybe 09:00 AM, maybe 10:00 AM, maybe 11:00 AM, 01:00 PM, let's just keep trying. We'd sit there and smash that button every eight minutes. And unfortunately, never heard anything.

**Jennifer:** When you think about it, there's three ways you can go on Mars. You could make a mistake, send a bad command or drive off a cliff or something. That's not satisfying. You don't want to be killing it because you made a mistake. Another way you could die is something breaks. Even though they were only designed to last 90 sol's, engineers don't like to be responsible for it breaking. And then the third way is Mars could decide it's your time to go. And I think a Tau 10.8 dust storm that hangs out over you for six weeks is Mars saying, "Good job, Opportunity. But you're done."

**Keri:** I think it was like a week before we officially declared the end of mission, I actually went and got a tattoo on my arm. So, I have Tau = 10.8 tattooed to my arm [chuckles] as a memorial for Opportunity. There’s no one else walking around with Tau = 10.8 on their arm.

**Phobe:** The last day they tried to wake up Opportunity, dozens of scientists that used to work with the rovers came back and gathered in the control room.

**Jennifer:** The very last time we tried to talk to it. Steve Squyres chose the song. It was important to all of us that he chose the song.

**Phoebe:** Steve Squyres had been principal scientist for the entire mission.

**Jennifer:** He picked *I'll Be Seeing You*. There wasn't a dry eye. [laughs] A beautiful song, and a nice way to say goodbye to Oppie.

[song playing]

*I'll be seeing you*

*In all the old familiar places*

*That this heart of mine embraces*

*All day through…*

**Phoebe:** Before either rover existed, Steve Squyres had spent 10 years trying to convince NASA to build them. He's talked about what it was like when they first launched them. "You pour so much of yourself into these machines, your hopes, your aspirations, your dreams, your ambitions. You work with them, and you bring them to life slowly, laboriously, and you turn them from a concept into these functioning, almost living sorts of things and you baby them. They're so important to you. Then, man, you strap it on top of a rocket, and you shoot it off into space and it's as gone as anything's ever going to be. "

**Jennifer:** I felt this emptiness, this really powerful loss when we lost contact from Opportunity. My job is to check on Opportunity's health and see how is the batteries, how's the energy, what's the projection. It's like a blend of feeling like you're feeding your pet in a way, like having power almost feels like having food. So, I checked on this robot millions of miles away. It was far away, but it was part of my daily life. And so, well, it wasn't there to check on anymore. I missed it.

**Phoebe:** On February 13th, 2019, NASA announced that the mission was over. People started sending flower arrangements. There were so many deliveries. Keri Bean says the whole operations floor was covered in flowers.

**Vandi:** It was 14 years, which is still quite incredible to think of. I don't think I ever thought of any drive as the last. Maybe it's something like, even if you know somebody who might be getting up there and they're yours. Unless it's a dire situation, you rarely ever think it's the last. I think we always hope for the next sol.

**Phoebe:** They still don't know what it was that killed Opportunity. People say it was probably the cold, maybe a broken antenna.

**Keri:** We just will never really know until we send astronauts there to take a look at her.

**Phoebe:** What did we learn about Mars that we didn't know before Spirit and Opportunity?

**Keri:** Yeah. With Spirit and Opportunity, they left a legacy of showing that Mars used to be a habitable planet. We still don't know if life actually existed there or not. But Spirit and Opportunity set the stage of, "We may not be the only life that's existed in our solar system."

**Phoebe:** Do you think that it's true that someday, maybe it's not 10 years from now, but that people will be living on Mars?

**Keri:** I sure hope so. I think it'd be really cool to expand beyond our planet. What I really hope happens is that when we finally send humans to Mars, that we make essentially a national park for the rovers, that a lot of people are like, "Oh, can't wait to bring them home." This is not their home. Mars is their home. And so, what I would love to see is a memorial park, where the rovers finally are in a nice little museum dome in their final position right there, don't move them, and actually make a walking trail of where all they explored on Mars with little plaques of like, this particular rock is where they found evidence of this. I think that would be the best way to honor the legacy of Mars exploration.

**Phoebe:** Today, Keri Bean is working on a commercial space plane. It looks like a space shuttle. Vandi Verma is working on the Mars 2020 mission, which consists of the newest rover on Mars and a Mars helicopter. Jennifer Herman is working on the new rovers too, and the Voyager spacecrafts, which are now farther into space than anything has ever gone before.

**Jennifer:** It's a childhood dream. You probably won't believe me when I tell you I actually don't cry that much. [laughs] But yeah, I can't tell you how lucky I feel to be part of the Voyager team.

**Phoebe:** Just the last question. How old is your daughter now?

**Jennifer:** Oh, she's 14 years. She just started high school.

**Phoebe:** Is she into Mars?

**Jennifer** Oh, [chuckles] yeah. It's home.

[laughter]

Her dream is to learn more about black holes, and dark matter and energy. I remember she was maybe a third or fourth grader, and she came downstairs for breakfast and she looked really tired. I'm like, "You didn't sleep well? Are you feeling, okay?" And she said, "I couldn't sleep because it just bothered me to learn that the universe is made up of all this dark matter and energy, and we know almost nothing about it. How can that be?" [laughs] And I'm like, "Well, there's unknown things that maybe you could work on." She's like, "Hmm, I should do that."

[somber music]

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