**Astronomy Cast Episode 199**

# The Voyager Program

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**Fraser:** Astronomy Cast Episode 199 for Monday September 20, 2010, The Voyager Program. Welcome to Astronomy Cast, our weekly facts-based journey through the cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hi, Pamela, how are you doing?
**Pamela:** I'm doing well, how are you doing, Fraser?
**Fraser:** Great. 199... that's really close to 200!
**Pamela:** Yes, yes it is.
**Fraser:** I know a lot of people want us to do something special for 200, but I don't know. We'll have to think of something. Either that, or you can just, you know, explain how to do gravitational mathematics. Everyone get pen and paper out...
**Pamela:** No, there are some things I like myself too much to do. Explaining tensor calculus falls into that category.
**Fraser:** Over the radio...
**Pamela:** Over the radio, yes...
**Fraser:** Alright, so launched in 1977, the twin Voyager spacecraft were sent to explore the outer planets... Jupiter, Saturn, Uranus, and Neptune. Because of a unique alignment of the planets, Voyager II was the first spacecraft to ever make a close approach to Uranus and Neptune. Let's take a look back at this amazing program and see where the spacecraft are today. And I wanted to add that "are today" because they're still going!
**Pamela:** I know... it's amazing. These missions are almost as old as we are, and they're still sending back data and we can still send them new commands. It's a two-way conversation still going on.
**Fraser:** Alright, well let's not get ahead of ourselves. Let's go back to the original concept and talk about... I guess we want to talk a bit about the missions that came before the Voyagers... the Mariners and the Pioneers.
**Pamela:** The Pioneers were two simple probes sent out to fly through the outer solar system. They were spin-stabilized, they were the most advanced things of their time. But they had limited cameras... they had limited instruments. They didn't make extremely close approaches to the planets that they went to. In the nature of the Mariner missions, where we had the early Mariners make very close approaches, sometimes even landing probes on Venus and Mercury and Mars and the inner planets. It was decided to do a pair of Mariner missions to Jupiter and Saturn. But along the way these last two Mariner missions got renamed the Voyager I and II missions.
**Fraser:** Right. There were many Mariners, as you said. There were ones that went to Venus, Mercury, Mars... some failed missions... and so they decided to rename the last two the Voyagers.
**Pamela:** Right. And these two missions took advantage of a once-in-every-175-year alignment of the outer planets. Every once in a while, you get Jupiter, Saturn, Uranus, and Neptune lined up just right so that using gravitational assists, allowing your spacecraft to be tugged toward a planet that's orbiting in the direction your mission is

going, you can add to your mission the velocity of that planet using gravitational assist. And with this once-in-every-175-year alignment, they were able to gravitationally assist their missions forward at each planet sequentially. This meant that instead of taking 30 years, the mission could be condensed down to 12 years with this added gravitational acceleration.

**Fraser:** We've talked a bit about this with some of the missions to Mars. It's that you don't just point your spacecraft at the target, fire the thrusters, and away you go and a little while later you arrive at your destination. You have to go in an elliptical orbit that is just larger than the orbit of the earth, and you sort of spiral outward from the earth. If it's quick, you make it to Mars. And if it's a much further planet, like the outer planets... like Neptune... it's quite a big spiraling journey that you have to take.

**Pamela:** Right, angular momentum is a word I shouldn't say when small children might be listening.

**Fraser:** It's rough... angular momentum is rough... is trouble.

**Pamela:** Yes. We have to deal with angular momentum, we have to deal with the energy necessary to move from one orbit to another. It's an energetic process, and when you can use something other than the chemicals you carry with you to accelerate yourself, it can make the journey a whole lot easier. Voyager I and II... when they were designed, the scientists... they took advantage of every bit of gravity they could. The thing that amazes me is that the scientists... they were clever in a lot of ways. They were told no, no, no... it's way too hard to build a spacecraft that will last more than five years. You guys are only going to Saturn and Jupiter... hold yourselves back. Congress was holding them back, reining them in. But the scientists, nonetheless, knowing they were only supposed to go to Jupiter and Saturn, they still built the spacecraft prepared, ready and launched in time to be able to make those additional journeys to the outer two planets.

**Fraser:** I can just imagine... you pass Saturn and you ask your missioner, "Hey, would you like us to go to Uranus? We could. You know, it wouldn't be that hard." Ok... let's do that!

**Pamela:** And what's amazing is that they actually could've gone on to Pluto from Neptune if they'd wanted to, but they made the decision that visiting Neptune's moon Triton was much more scientifically immediate and interesting and certain to get good results. So they varied the spacecraft's trajectory to allow a close-by approach with Triton rather than continuing on to Pluto. A similar decision was made when they were at Saturn with Titan.

**Fraser:** That's right, yeah, with Titan...

**Pamela:** So apparently moons that begin with the letter T change trajectories of Voyager missions. So in both cases they made the decision... well, we're going to forego a little bit of future science because we're not entirely sure our mission's going to keep going, but we're going to get immediate science right now, and immediate awesome results. And they did.

**Fraser:** So Voyager I was unable to have the velocity change to make it out to Uranus because it made that close fly-by of Titan and got sort of tweaked away from it on its path. So, let's talk a bit about the... let's go back to 1977 and talk about the construction and launch of these rockets.

**Pamela:** Back in 1977, back when I was a whole whopping 3 years old, these missions were launched with Voyager II taking off first because it was the second one to get to

Jupiter. Just like they sometimes do with Mars missions that are paired, the spacecraft that launches first isn't necessarily given the first number. It's the one that's gonna get there first that's given the first number. Voyager II took off, and it actually had a rather interesting heart attack-inducing take-off. Voyager was launched on a Titan rocket with a Centaur booster on top. It got a bit confused. The computers on board underwent something that I hadn't actually heard about before called robotic vertigo. It essentially...
**Fraser:** Robots shouldn't look up when they're near tall buildings, right?
**Pamela:** Exactly. It's an awesome description, and basically what it means is the computer on board was happily monitoring everything during launch, keeping track of what was going on, and then had an "oh my God what are you doing to me" moment as it was undergoing these huge accelerations, and the navigation computer had a minor heart attack and thought that it was having sensor overload issues in deep space. The computers had been programmed to do all sorts of things in case sensors went wrong, in case they started tumbling. And luckily Voyager didn't have control of its own thrusters at that moment or something really bad could have happened. The Centaur was luckily still in control of Voyager's thrusters. So Voyager sorted itself out; it successfully separated away from the Centaur booster. Everything was going fine and then it had another... I'm near the earth; I really don't know where I am, actually; I'm going to stop all communications with the planet Earth... freak out moment again. For 79 minutes it locked itself down and went into a careful series of basically ballet moves to find the sun and reorient itself. One of the things that they did when they programmed these missions was they knew that most likely if one of these missions had a freak-out moment, it would probably be while it was in the outer-most parts of our solar system. Right now... where these two missions are... it takes 12 hours for a radio signal to go from Earth out to either Voyager I or Voyager II. If a mission's having a freak-out moment, it can't have its first thing be I'm going to use up a lot of electricity and call to the planet Earth and ask for help. What they programmed it to do instead was to shut down all communications, figure out where they're pointed, reorient themselves, refind Earth, and then re-establish communications. So here they are, the poor folks on Earth, with their missions seconds of communication away from the planet, watching it undergo shutdown, reorientation, figure itself out... It finally radioed back to Earth and started operating normally. It's behaved beautifully ever since, but the first few hours of this mission, I think, caused a lot of hair loss.
**Fraser:** When you report on this stuff, we find this with Universe Today, there's a lot of this that goes on that I don't think people really realize with many of the missions, you know, shortly after launch, as it's about to... they'll go into shutdown procedures... things will malfunction... There's a lot of really interesting stories behind the scenes that go on as the scientists are wrestling with the issues that are coming up. When you look at it from the big picture, it's like... oh, a bunch of beautiful photographs and a neat story about the mission... but the day-to-day as we report on them, we report that such-and-such mission has gone into shutdown mode, this one is offline, and eventually they can't reach them anymore, so this happens a lot. This gyroscope has failed and that antenna refuses to open... yeah, there's a lot of this.
**Pamela:** And this is where we're really lucky that pretty much everything is built with redundant systems. We really rely on these redundant systems to allow these missions to carry on. Occasionally we have to figure out... ok, so we lost the main transmitter... I

believe it was Galileo that we had that problem with. And all of a sudden you have to figure out... ok, I need a new compression techniques for all these amazing images. And they reprogram all these satellites on the fly, which is about the most terrifying thing I can imagine as a programmer.
**Fraser:** Oh yeah..
**Pamela:** But they worked. They made it to Jupiter. They made it to Saturn and then they kept going.
**Fraser:** So then Voyager II launches, and then shortly after that Voyager I launches... but Voyager I beats it to Jupiter.
**Pamela:** Right. And when Voyager I got to Jupiter, it made a whole series of discoveries from seeing Jupiter's rings to being able to finally see the Great Red Spot as this spinning hurricane and turbulent bands to the lava flows on Io. This for me is kind of one of those touchstone moments. I was all of four when Voyager I got to Jupiter, and I can still remember being made to take a nap so that I could stay up and watch the data coming back and being reported on TV.
**Fraser:** I did not have that aggressive of a parent on that front, I gotta say. I was woken up to watch the space shuttle launch in 1981, but I was not ready for the real-time data coming back from the Voyagers.
**Pamela:** Oh... that's sad.
**Fraser:** But I will for my kids. When New Horizons arrives at Pluto, we are going to be right there when it happens.
**Pamela:** But your kids are going to be a bit older, so they won't require the naps at that stage.
**Fraser:** That's true, yeah. Now, this isn't the first time a spacecraft has gone to Jupiter so it's not completely momentous...
**Pamela:** No, but this was the highest resolution images that we'd had to date. New moons were being found; new belts were being found. And the fact that Io had volcanism, that was a completely new discovery. We really hadn't realized either how dangerous the radiation belt environment around the Jovian system was, or that there was volcanoes on a moon of all crazy places to find lava. Neither Pioneer 10 or 11 had seen this volcanic activity.
**Fraser:** Voyager I arrives; Voyager II comes after...
**Pamela:** Voyager II comes later. So some of the cooler stuff had already been discovered, but it did make an even closer approach. It discovered a few new rings around Jupiter and then it continued to observe the volcanic activity around Io.
**Fraser:** And Jupiter is not a safe planet to make a close fly-by on.
**Pamela:** No... no. Yeah, that would be an understatement. You have, first of all, giant gravity wells. So those are always challenging to deal with. One of the things that kinda got me was that our space shuttle orbits about 300 miles up. The Voyager missions were making approaches about 1000 times greater than that from the surface of the planet. We had Voyager II getting within about 350,000 miles of the cloud tops of Jupiter. That's a pretty good distance. And Voyager I... sorry, it did make the closer approach, not Voyager II... Voyager I came within about 217,000 miles of the cloud tops. So, that's a pretty good distance, but when you start considering the significant gravity well that you're dealing with with Jupiter... So you're maneuvering in a gravity well, you're maneuvering around a giant radiation field where you have to worry about these arcing

belts of radiation that are in part responsible for creating plasma belts and all sorts of other insane high-energy events that are amazing to look at with our orbiting observatories locally. Then you have to deal with the high gravity from these different moons. These are moons that compete with planets for a place on the mass-weighing scale of our solar system.

**Fraser:** And I know that the Voyagers really helped make the big discovery on Europa.

**Pamela:** Right. It was Voyager II that took the beautiful images of Europa that revealed all these intersecting linear features that we think come from the tidal forces basically squishing Europa like a squishy ball in a way that causes it to have liquid water and a constantly-cracking icy surface that lets some of this water ooze out and refreeze. They'd been seen in low-resolution photos of Voyager I, but it was with Voyager II with its closer high-resolution photos that we're able to have this... wow, that's weird, what is that... approach that we've been trying to sort out for all the decades since.

**Fraser:** And I know that Voyager really help conclusively understand what the Great Red Spot was.

**Pamela:** Right. The hurricane... it was finally able to see all of the eddies and the storms... we still don't know what caused it... we can recreate it in some simulations, but different people still come up with different results, but it was clearly some sort of a hurricane as seen with these missions.

**Fraser:** All of these discoveries... we just take them all as the rules as the laws these days. But you can think about it, some of these things were completely unexpected. Hey...volcanoes on Io... what's that all about? Now we're so used to them, but these are the times when these discoveries were first made. It's quite impressive. So the spacecraft... and I know they turned up a couple of more moons around Jupiter as well... and then out to Saturn.

**Pamela:** Right. So here we have Voyager I... takes off... it made its Saturn fly-by in November of 1980. Here all of a sudden we're realizing... oh my gosh... Titan has an atmosphere. This was again one of those weird... we knew it was there because of Pioneer 11, but we made the decision with Voyager I to get up close and personal and take a detailed look at this strange methane atmosphere, trying to figure out how is it that this moon is now behaving like a planet. This is where Voyager I, at this point, could have gone on to see Pluto. But the decision was made to steer it so that it looked down on the plane of the disks. This is where we get these beautiful images showing the shadow of Saturn cutting across the rings of Saturn, and then to make a close approach that allowed us to see the sunlight passing through and getting absorbed by Titan's thick atmosphere. These are just some of the most amazing images that we had up until Cassini went up and returned. We're also starting to find new rings. Voyager I took images of Saturn's F ring, bringing us new moons... new understanding.

**Fraser:** You can see, once again, that progression. Pioneer turned up a hint of an atmosphere on Titan. Voyager I was retasked to go close to Titan to really get a look at it. Then Cassini was sent with a probe designed to land on Titan, and it had the instruments to actually peer right through its atmosphere and see rivers and lakes of hydrocarbons on the surface of the moon. It's this progression... each insight gives you further questions and comes up with new mission profiles that need to then be developed and sent.

**Pamela:** And this is where you see science really as a way of telling the story... bit by bit... and it's a detective novel where first you go in and you get your first clue, and then I

realize oh, I need to take this back to the lab and use bigger instruments. Well, the lab instruments I have here aren't good enough, I need to send this out. Well, here instead of doing on the site and then in the lab and then sent out investigations, we're simply sending the lab to the planet. And we're sending progressively more complicated labs to the planet to make more and more detailed investigations.

**Fraser:** So Voyager I makes its fly past Titan and now it's on an orbit that won't let it go past Uranus and Neptune, so it's kind of done the major part of its... that's the last thing it's going to pass by. So it flies off, right?

**Pamela:** But it did go on to do one really neat thing. Back in 1990, and here I'm in high school... to me the story of Voyager is getting older and older and older. Hopefully it won't die before I do because that would be sad. So Voyager I went on in 1990 to look back on our entire solar system. It captured this fabulous series of images where it was able to make out all the planets in our solar system in this crazy strange-shaped mosaic. That was the last real set of images that we've had sent back to Earth from this particular mission.

**Fraser:** Right. And one of the most famous images on that is what Carl Sagan called "The Pale Blue Dot."

**Pamela:** Right. And he wrote this amazing essay that everyone needs to go look up where he related his thoughts about this. Here you basically have the earth just shining through a sunbeam. And what he wrote was "From this distant vantage point, the Earth might not seem of particular interest. But for us, it's different. Consider again that dot. That's here, that's home, that's us. On it, everyone you love, everyone you know, everyone you've ever heard of, every human being who ever was lived out their lives. The aggregate of our joy and suffering. Thousands of confident religions, ideologies, and economic doctrines, every hunter and voyager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every superstar, every supreme leader, every saint and sinner in the history of our species lived there, on a mote of dust, suspended in a sunbeam."

**Fraser:** That's only just a piece of it... there's actually a much longer essay. So it's highly recommended that you dig it up. Just do a search for "pale blue dot." And in fact the book, too. That was one of the most influential books for me, for space exploration and astronomy, was Pale Blue Dot by Carl Sagan. So, I highly recommend, if you haven't already, find that book and read it.

**Pamela:** And Carl Sagan's life was deeply wound up with these two missions. Both Voyager I and Voyager II carried on them these gold records that, much to the chagrin of many, have etchings of nude human forms on them. They were actually banned from putting naked pictures of people on to explain humanity because that was considered wrong. And they contain sound samples... everything from the beating of a human heart to the music of a myriad of different cultures, to people saying "hello" in all the languages of the world that they could easily get access to people saying hello in.

**Fraser:** And detailed instructions for the alien invaders to come and destroy our planet.

**Pamela:** Right. Now that is one of the arguments... that it does lay out our placement in the solar system using easy-to-follow if you have mathematical understanding definitions of where we are based on pulsars. So, yeah, it contains a lot of information, including how to find us and what we look like. But it's also a message of peace.

**Fraser:** But, theoretically, these are made of gold, right?
**Pamela:** Right.
**Fraser:** And there's not a lot happening in space, except for micrometeorites and cosmic rays, so these could last for billions of years.
**Pamela:** These are time capsules. While neither of the Voyager missions is pointed at a star, and space is mostly empty, the probability that either Voyager mission is actually going to get scooped up by an alien randomly finding it in a galaxy is fairly close to zero. But, "fairly close" and "zero" aren't the exact same thing. It could be what we did was we sent out a time capsule that we'll be the ones to find some day. Some of you may now be thinking back to the Star Trek movies...
**Fraser:** V-ger!
**Pamela:** Right... Star Trek: The Motion Picture. One of the most horrible things ever done to that series. That was actually Voyager VII, which doesn't exist. So what happened in that movie won't actually happen. The idea that we'll be the ones to find our own probe and be able to look back on ourselves... that may not be too unrealistic. And that's kind of cool to think about.
**Fraser:** So, when last we saw our heroes, Voyager I had taken this beautiful mosaic of the whole solar system. Voyager II had not made a suicidal fly-by through Titan's atmosphere and so was on target to reach Uranus.
**Pamela:** And it wasn't suicidal, it was just misdirected.
**Fraser:** Sure... a sacrificial orbit...
**Pamela:** Yes... sacrificial... we can go with that.
**Fraser:** A sacrificial trajectory... So Voyager II kept going.
**Pamela:** Right. So Voyager II went on... it did an encounter with Uranus...
**Fraser:** Now this is the first time a spacecraft has ever been... first and last time... by the time we're recording this... that a spacecraft has ever been to Uranus.
**Pamela:** And so here we are... we're discovering previously unknown moons, which is pretty cool, and it got to study this weirdo planet that's turned on its side, orbiting with a tilt of slightly more than 90 degrees, and it still looked like a pale blue dot of nothing. But hey, it got examined up close. We looked at the Uranian ring system. Uranus has one of the weirdest ring systems in the solar system because it appears to be a brand new one, in a lot of ways. It just doesn't have the same albedos, the same anything as other ring systems. But I think the coolest thing that was found while they were at Uranus... while Voyager II was at Uranus... is the moon Miranda, which basically looks like a moon that had a really, really bad day and then gravitationally pulled itself back together without asking a planetary surgeon to put on a good face.
**Fraser:** Yeah, it got a beat down for sure...
**Pamela:** Yeah.
**Fraser:** And then... so that was 1986 and I definitely... I can remember that. I was in high school and it was all in the news and in the paper and on TV. We got to see these first pictures. In fact I had a copy of this old book, I think it was from Time Life or National Geographic, called "The Universe?"... "Our Universe?" It had the spaceship on the front... I absolutely loved it. They came out with a new version a few years later once those photos were in... that they could put in the pictures from Uranus and Neptune.... the new edition. But yeah, I remember '86 was Uranus. And then three years later...

**Pamela:** Three years later, August of 1989... Neptune. So now all the planets, although we didn't know it was all the planets at the time, all the planets at that point had finally been visited by a NASA mission. Here it was made the decision that we're going to call it good after visiting Triton. So they explored this last system and decided to pass over the north pole of Triton and go on out of the disk of the galaxy. And here I think probably the coolest discovery was the Great Dark Spot on Neptune. It's since gone away, but it was there then, and that's kind of cool. We now think that this might have been actually a hole in the cloud deck of Neptune that allowed us to see down to the darker layers... we're not sure and we're waiting to see what happens as we watch Neptune pass through another orbit and pass through another set of weather seasons.
**Fraser:** And as we said right at the beginning of the show, these spacecraft are both still going, they're still functioning, and scientists can still communicate with them.
**Pamela:** And back in May, we actually as a field had a moment of "oh my God... hold your breath" because one of the two Voyager missions started sending back kind of weirdo data. It turned out that one of the bits in its memory had gone bad. They, last May, reprogrammed it to be able to send back healthy data again. So we're still undergoing this two-way communications to keep both missions going. We're periodically shutting off different instruments because they draw too much power, and the power supplies on these missions are winding down over time, but they are still going. That's pretty amazing.
**Fraser:** And there's still a little bit of science to be done out there.
**Pamela:** Right. They're still measuring all sorts of different things using their non-imaging instruments. The operational instruments that we have right now are looking at magnetic fields, are looking at low-energy charged particles... on Voyager I we still have a plasma-investigator, there's still cosmic ray detections going on, there's still plasma wave investigations going on. So science data is still getting returned.
**Fraser:** Right, I mean one of the big questions is where does the sun's influence hit the galaxy's background particles... this is the heliosphere, where the solar wind bumps up against the galaxy.
**Pamela:** So right now the missions are in what we call the heliosheath. This is where the heliopause starts to get slowed down by interactions with the interstellar media. Unfortunately, the particle counters on the missions are no longer powered up. But, they're able to figure out by looking at the responses from all the other instruments roughly where they are and they'll be able to tell when they actually leave our solar system. It looks like they're still going to be giving data when that happens.
**Fraser:** Well, I think for me the Voyagers are... in my lifetime... I know for a lot of our listeners, they were alive during the Apollo missions happened... that was before my time or I was one and two when the final Apollo missions happened, so I just don't remember them... but the Voyagers were there... the launch when I was a kid, and the big discoveries when I was a teenager, and even now, it's funny, as I lead my career writing about space and astronomy, we still have a story or two a year about the Voyagers and their latest discovery. It's been a constant companion. The writings of Carl Sagan really reinforce that. Star Trek I.... no...
**Pamela:** No... that doesn't influence anything...
**Fraser:** ...so it's great. I think for me the Voyagers were my Apollo... they were the most influential missions on me, in getting me really excited and interested in space

exploration and astronomy. A big thank you to anyone who worked on the Voyagers who's listening to this... I really appreciate everything you did.
**Pamela:** And please keep them going, and thank you NASA for upgrading the "Big Ear" so that we could keep listening to what these missions are doing.
**Fraser:** Alright, thanks a lot, Pamela. We'll talk to you next time.
**Pamela:** Sounds good... talk to you later.