Astronomy Cast Episode 49:
Mercury

Fraser Cain: Thanks to everyone who filled out the listener survey: now you're going to reap the benefits. We had thousands of comments, suggestions, feedback – we're still digging our way through it, but one thing we heard a bunch of times was people want to hear a survey of all the planets in the solar system, just take them one by one and bring you all up to speed on the latest science.

Your wish is our command, we're going to start in the middle and work our way out. So, Pamela, let's talk about Mercury.

Dr. Pamela Gay: Well, it's in the middle. It's the first rock from the Sun. it's a little world, extremely dense, lots and lots of metals, thin crust and it's not all that different from the Moon. It is, in fact, smaller than two of the Moons in the solar system. It's smaller than Titan and it's smaller than Ganymede.

For a while, back 3000 years BC, people thought it might actually be two different objects in the sky, because it only appears in the twilight in the early evening and early morning. It took people a while to figure out that it's just one object that's so close to the Sun that we never get to see it high in the sky.

Fraser: Let's start back with formation. How did Mercury form?

Pamela: Like all the planets in the solar system, it formed out of the solar nebula. It formed out of the disk of gas and dust that swirled around the Sun as the Sun was gravitationally collapsing down into the star it is today.

We're not exactly sure if it formed exactly the way it is today. There are a lot of different ideas to try and explain how you get this little tiny planet that's so amazingly dense (it's one of the densest objects in the solar system).

There are some people that think it formed a lot bigger than it is today, but something came along, and hit it and knocked part of the surface off. It re-congealed into a smaller planet, and the stuff that was knocked off either fell into the Sun or moved out into other parts of the solar system.

Fraser: So comparing it to the Earth, then, it has a core like the Earth but none of the dirt around the outside.

[laughter]

Pamela: Exactly. Basically, the core is surrounded by just a 600km thick mantle made of normal mantle stuff (like the stuff the continents are made of). On top of that is a 100-200km thick crust, this is rock, dirt and all that sort of stuff that is highly cratered by things that have hit Mercury.

It's core part, the part that is mostly metals, that's 800km thick.

Fraser: So it's just a ball of iron orbiting the Sun.

Pamela: Exactly. We think it might have formed originally with a thicker mantle, thicker crust and gotten hit by something.

A different possibility is the Sun actually blasted the crust off early on. The young Sun was an angry, flaring, high-energy, violent star. It's a phase all stars go through, just like the terrible-twos. Stars have their terrible toddler phase. It's possible during this high-energy phase, the Sun actually blasted the crust off of Mercury.

We're not sure. Both theories are kind of neat and work to explain this little, anomalous, first rock from the Sun.

Fraser: You say blasted off with the solar wind. Where would the material go?

Pamela: It would just get re-distributed throughout the solar system. All the time, Mercury's getting blasted by the Sun. the radiation and high-energy particles coming off of the Sun hit its surface and are slowly knocking particles off of Mercury.

Mercury actually has this really thin atmosphere that is formed entirely by particles that are constantly getting blasted out of the material trying to make up the crust of Mercury. So a rock sits there, it gets hit with energy from the Sun, and a couple atoms in the rock flake off, float around, form an atmosphere, and eventually get blasted out into deep space (or at least, into the inner part of the solar system, though some probably escape to deep space).

Fraser: I did an article about this recently. It's kind of a misnomer to call it an atmosphere, because with the Earth the atmosphere, we have clouds of oxygen and nitrogen particles bumping into each other. The atmosphere on Mercury doesn't actually collide in that way, it's like the particles zip past each other and only occasionally actually bump into each other.

Pamela: We know the atmosphere is there: we can see it using spectrographs, sunlight passes through it, but here atmosphere simply means there is gas near the surface of the planet. It doesn't mean the gas is there to stay: it's not. It's a transitory phenomenon. It certainly isn't an atmosphere with winds or rain or anything else that we associate with an atmosphere.

Fraser: All right, let's move down to the surface and land. What would we see?

Pamela: Mercury is this really neat looking planet. When it formed it was incredibly hot, and it's cooled over time. One of the things that happens when some things cool, is they contract. Water is anomalous: if you freeze water, it gets bigger. Pretty much everything else gets smaller when you freeze it (this is what happens with the pipes in your house).

With this planet, as its iron core contracted, it eventually shrank to the point that the entire surface cracked. It started off with this big surface, or at least a 0.01% bigger surface, that was on top of a bigger (by a very small percentage) core. The core got cooler, contracted, and the surface cracked because there wasn't as much volume of stuff supporting it any longer.

So the planet is riddled with these really cool cracks that come from the planet cooling.

Fraser: Is it fairly cratered like the Moon?

Pamela: It's cratered just like the Moon. That's one of the neat things about this world. You look at it, and it's like looking at a red version of the Moon. They're not even that different in size, just in density.

It has no way to resurface itself, so any rock, asteroid or anything that hits it, makes a crater and that crater stays there until something else comes along and hits it and re-craters the surface. So its entire surface is covered in all sorts of different craters that trace back the history of collisions that have happened throughout the entire time our solar system has been around.

Fraser: We talked in the past about extrasolar planets. If you get a planet close enough to its parent star, it can get tidally locked, where the planet is only facing one side. Mercury isn't tidally locked though, is it?

Pamela: It's sort of/kind of tidally locked. It's an object that's confused astronomers for a long time, and it's only within the past 50 years that we've started to fully understand its motion.

It's really hard to observe Mercury. If you only try and look at it when the Sun is below the horizon, it's never more than 28 degrees above the horizon. To get a sense of how low on the sky that is, try holding one arm all the way out straight in front of you, parallel with the ground. Walk up the sky with one fist at a time. When you have three fists above the horizon, on top of your fist is higher than Mercury can ever get in the sky.

There are certain times it's easier to observe Mercury than others. It just happens to work out that the times it's easiest to observe Mercury, the exact same face of Mercury is always facing us. Up until the 1960s, astronomers thought Mercury was tidally locked: the same side of Mercury always faced the Sun, and the same side of Mercury always faced toward the outer parts of the solar system.

In the 1960s, we started to use radio telescopes. With radio telescopes, we can measure how warm things are. When astronomers measured how warm the side of Mercury facing away from the Sun was, they expected to find it really cold. There's not an atmosphere to transfer heat, we thought the backside of Mercury never faced the Sun… there was nothing to warm it up. Instead we found it really hot. The only way to explain this is if the planet is rotating, or if you invoked crazy physics.

The first thing they did was they tried invoking crazy physics. It happens. But in the mid to late 1960s, we started using radar imaging. By bouncing radar light off of Mercury, we could actually watch it slowly rotate. It was realized that for every two times that Mercury goes around the Sun, it rotates three times around its axis.

So one year on Mercury is one and a half days long. This is a weird form of tidal locking that happens because Mercury's orbit isn't circular. It is in fact, the least circular orbit of any of the eight planets in the solar system.

Fraser: Don't send us mail!!

[laughter]

Pamela Okay, we're going to just not touch on the Pluto issue today. Ignoring Pluto, ignoring all the other Kuiper Belt Objects, Mercury has the most elliptical, the most oval-looking in the solar system.

As Mercury goes from being about 43 million miles away from the Sun, to about 29 million miles away from the Sun, this change in distance does some really weird pushes and pulls on Mercury. It's this change in distance that causes it to get locked into a 2:3 resonance, where for every two years, it rotates three times.

Fraser: So if it were circular, then it probably would be tidally locked, but because it has this elliptical orbit, it has this other weird thing.

Pamela: It's still called tidal locked, it's just not a 1:1 tidal locking like with the Moon, which orbits once and rotates once. Here, it orbits twice, orbits three times. It's just a different kind of tidal locking.

Fraser: I know we've sent some missions to Mercury in the past. Can we talk a bit about that?

Pamela: Trying to observe Mercury even with a spacecraft is hard. You have to fling things to the inner part of the solar system and the Sun likes to try and catch them. To date, we've only sent one mission to image Mercury that was Mariner 10. It did two high-speed flybys, taking images as it went by. In fact, it only saw one side of Mercury. So we only have images of half a planet.

The other problem with going to Mercury is it's kind of hot. Anyone who's had a computer fan stop working knows that hot electronics are non-functioning electronics. So when we send things to Mercury, we have to try and figure out how to protect them from the heat and sunlight.

So we have two big problems to solve: temperature and getting there without landing in the Sun or missing the planet. Mariner 10 did the job, got some really good images of half the planet, but we want more. Scientists always want more data (it's a problem we have).

Currently, NASA has a mission called Messenger. It just finished flying past Venus. It's on its way into Mercury. It's going to take it a few tries to settle into orbit around Mercury – it's actually going to fly past it a couple of times and use different gravitational effects to try and slow itself down.

Fraser: I guess it's very different from the spacecraft they send to mars. When they go to Mars, they can use the atmosphere to aerodynamically break their orbit. I know the mars spacecraft come through the atmosphere several times, skimming the top of the atmosphere slowing themselves down a little bit more until they're in whatever orbit they want to be in.

With Mercury, that non-atmosphere isn't going to participate, so they've got to be doing it entirely with rockets.

Pamela: They actually do it almost entirely with gravity, that's one of the cool things.

A better way to think of it is when we send things out to Jupiter and Saturn, we often use some of the inner planets to give gravity boosts. We'll send things into an orbit where they go once around the Sun and then they start to catch up on Earth. As they catch up on Earth, its gravity pulls them in and they eventually fly past Earth. As they fly past, the Earth tries to slow them down, but Earth and this object are moving in the same direction, so the amount of push we can give an object heading out toward the outer solar system, that's going in the same direction of orbit we're going in, is a lot more than the pull we give it as it goes past us.

This is called gravity-assist. It's away to speed things up by allowing the Earth's gravity to pull in the direction we're all orbiting.

If you try going around the Sun in the opposite direction, such that it comes around the Sun and is headed into a head-on collision with the Earth, the planet's gravity will still pull it toward the Earth, but as it starts to go past the Earth, because we're now moving in the other direction, we slow the object down more than we speed it up.

So you can use gravity-assist to slow things down if you try and go against the flow of orbits, or to speed things up if you go in the flow of the orbit.

Fraser: So that's what Messenger's going to do: orbit in the "wrong" direction and use that gravity to actually slow it down until it can put itself into orbit.

Pamela: Exactly, so they're gradually breaking themselves (in this case using Venus and Earth to break themselves) to get to Mercury. They're going to have to go past Mercury a couple of times before they settle into a nice orbit and then just image, image, image that entire planet.

Mercury has a lot of neat stuff it's hiding, and Mariner had image resolutions on the order of kilometres. You couldn't make out anything small. With Messenger, we'll be able to make out smaller features on the surface of the planet. One of the cool mysteries about Mercury is it might actually be hiding ice.

Fraser: Where would there be ice?

Pamela: So, with the planet Earth, we're kind of tilted. The entire planet gets to see sunlight now and then, depending which side of the planet is facing the Sun. Mercury hangs out perfectly straight. Its rotational axis is absolutely perpendicular to its orbit. This means the poles of Mercury never see sunlight at all, if you're in a crater. So the crater shadows are always, always, always in shadow.

Fraser: I see, so you have a crater on top of the planet, and as the planet is turning, that crater is like a bowl on the very top of the planet and is always in shadow. Different rim/edges of the crater would be brightened, but at the very bottom it would always be in shadow.

It could actually have ice remain in there? As you said, the whole planet itself is so hot (as we image from Earth) how could ice remain in there? It's not water sloshing around inside the crater?

Pamela: No, we think it's actual water ice. The reason we think this is when we do radar imaging of the surface, we find these areas that are extremely smooth and reflective in the exact same way we generally associate with ice. The surface temperature, while it's hot on both sides, it actually at the poles has really cold areas, areas that are significantly below zero. We've actually measured temperatures that are only 80 Kelvin in the extreme north polar regions.

Fraser: Okay, so the only reason the planet is so heated up is because it's bathed in sunlight for a good chunk of time. It's not like it's convective, where the heat moves around and warms up the whole planet, but in this case just because they're in the darkness they can stay frigid cold.

Pamela: Its complete lack of a reasonable atmosphere doesn't provide anything that holds onto the heat, so in this lack of atmosphere area, you only stay warm when there's air to trap in the temperatures.

Fraser: I wonder though, with the Moon they're talking about a similar situation. There could be ice trapped in craters at the poles of the Moon, and that would be a wonderful resource for future astronauts who land on the Moon and want to use that ice to breathe, make water and fuel and so on. What would ice tell us about Mercury?

Pamela: It actually raises more questions than it answers, because Mercury really couldn't have formed with water. it's in a part of the solar system that the Sun baked quite nicely. If you want to get the water out of something, you back it. This is part of how pottery's made: you stick it in a kiln and get all the water out of the clay. Mercury has been in that kiln, so how is there water?

The only way there could be water on Mercury is from it getting hit by comets. Something brought water in from the outer parts of the solar system. So if we find ice, it means at some point Mercury was getting hit with not just asteroids, but also with comets, and the comets left their icy remains locked on the poles. The water could just be burial ground for comets.

Fraser: What else is Messenger going to be doing while it's at Mercury?

Pamela: It's also going to be trying to understand Mercury's magnetic field.

Fraser: Mercury has a magnetic field?

Pamela: Right! It's one of those curious, "how did that happen?" kind of things. It's not a strong magnetic field. Most compasses probably wouldn't respond that strongly to its magnetic field… but it has one. That means it has a liquid iron core.

Now, when we look at Mars, it doesn't have a magnetic field. It cooled off. Mercury is a lot smaller, so this raises the question of why didn't it cool off enough that its magnetic field froze out?

Fraser: Isn't it right in front of the Sun? People have said the temperatures on Venus are hot enough to melt lead. Mercury's even closer, could the heat from the Sun be keeping it warm?

Pamela: Venus is actually hotter than Mercury. It's the greenhouse effect on Venus that's trapping all the heat inside. Mercury at its hottest is only about 700K, which is really hot, but not hot enough to explain the heat necessary to have a magnetic dynamo in the core.

Here what we actually think is happening is as the planet moves closer and further away from the Sun, this is squeezing the planet, just like Io (one of the moons of Jupiter) is getting squeezed, and this squeezing is creating the magnetic field.

That's just kind of neat. It's another characteristic that some of the rocky moons share with some of the rocky worlds.

Fraser: All right. Any other mysteries that Messenger will uncover?

Pamela: Well, there's always the "what's on the other side? " question.

Fraser: Right, I guess we have no photographs whatsoever of that other side.

Pamela: There are some tantalizing hints at fascinating structure in some of the images people have tried to take.

If you go out and use a really good telescope, and you're really careful, you can image Mercury during the day, but you're imaging through an atmosphere. When you're looking at something during the day, you can't use artificial stars to correct your telescope for atmospheric issues (you can't use adaptive optics). Folks who are expert imagers, working as hard as they can, using really good telescopes and really good telescope techniques, have put together low resolution images of Mercury.

There are hints that there is a giant crater on Mercury that has a mountain on the other side. So it's possible that something came along at some point, nailed Mercury, created a crater on one side, and the shocks went through the planet and actually affected the other side of the planet.

Fraser: Could that maybe be one of the things that knocked off some of its material?

Pamela: Since the surface was already there to get hit and form ripples and craters, whatever knocked the surface off of Mercury probably happened long beforehand.

If you hit something hard enough that the whole planet falls apart, it's going to reform as a nice, smooth ball. You get to start over from ground zero, re-cratering the planet however you will.

So this is something that came along later and threatened Mercury's life a second time. It's not good to be something that close to the Sun, where you're constantly in harm's way.

Fraser: Right, but we have other moons in the solar system, like Mimus going around Saturn, who looks like the Death Star. It has a crater on it that's so large it completely dwarfs everything on the planet. Not quite big enough to make everything have to reform, but still a pretty devastating impact.

Well, that'd be great. As soon as we start to see those pictures, I think everyone's going to be really, really impressed. I know that Messenger isn't the only mission that's probably going to be headed to Mercury. What does the future hold?

Pamela: The Europeans are also looking to launch their own mission, BepiColombo. This is a follow-up mission to Messenger that's going to go in and take additional images, be there for another year, and whatever questions Messenger opens, BepiColombo will be there to answer them (we hope).

Currently, we're looking at getting Messenger to Mercury in March 2011. it's currently leaving Venus and BepiColombo won't even be launching until Messenger's already gotten to Mercury, so they have time to change their mind and update their equipment to fill whatever needs are open.

Fraser: We talked about Mercury a couple of times in the past, in reference to relativity. It's got a pretty neat story to it, do you want to go into that?

Pamela: Mercury's orbit is this weird ellipse. It gets close, gets far away, gets close, and gets far away. This ellipse is slowly rotating. This means that if you're looking down on the solar system and you pretend the whole solar system isn't moving, as you watch, this ellipse that Mercury's rotating on, itself rotates. We see this rotation in terms of when Mercury is furthest from the Sun, and highest in our sky.

This is something people have been able to measure since before Newton. It confused us. When Newton first went through and figured out his orbits, he was left scratching his head. Once you factor in: "here's Mercury, here's what it's doing, here's the gravity from the Sun.. it's still not behaving. Here's the gravity from Jupiter… it's still not behaving. Here's the gravity from Saturn…" Once you factor in the tugs and pulls of every object that is big enough to be significant, we still can't fully explain Mercury's motion.

Mercury moves about 574 arc seconds per century in terms of how its position furthest from the Sun moves.

Fraser: Can you translate that?

Pamela: Okay, so one arc second is about the width of a piece of normal human hair held out at arm's length. So each century, we can observe Mercury's position when it's furthest from the Sun, move 574 hair strands at arms length. It's not a huge amount.

Fraser: I can see us calculating that with Hubble, today, but how could they have figured that out then?

Pamela: Ancient astronomers made some of the most amazing measurements ever. One of the most remarkable things I ever read about was how Hipparchus, back in 150 BC was going through star maps and was comparing his observations of the sky with the observations of someone named Timarchus, who worked 169 years before him.

In comparing their two maps, he realised that the North Pole was slightly different for both of them. They weren't both marking the North Pole as being exactly dead on with the star Polaris. Hipparchus was able to realise that the entire sky is slowly precessing. The point that the North Pole is located on the sky is slowly changing.

Hipparchus figured out this change is about 0.0127 degrees per year. This is a hundredth of the width of your Sun a year, and he was doing this in 150BC. That's a really amazing measurement, and it's only about 0.02 off of today's modern measurement. His measurement was 0.0127 degrees, today we know that this precession is 0.0139 degrees.

They could measure things. They had dark skies, not a lot of things to distract them – there was no YouTube, no Google… so they measured, and they thought and they went through libraries. All these things were handwritten and they were still going back and using records that were hundreds of years old. We're lucky to use things more than 10 years old, because if they're more than 10 years old, they're not in PDF on the internet.

Fraser: Okay, so we know that Mercury had a strangely changing orbit. How does that tie into relativity?

Pamela: Newton came along and looked at planets doing this and tried to calculate how much motion all these perturbations add up to. We'd observed 574 arc seconds per century, and Newton was able to come up with 531 arc seconds per century, using his calculations.

So there was this gap of about 46 arc seconds per century that we couldn't explain. People tried making up new planets. There was a theory that there was another planet inside of Mercury's orbit. We even named it – it was called Vulcan. We tried finding it. People claimed they found it, other people claimed it didn't exist.

There is no Vulcan, they were bad observations. If you look at the Sun, you're going to see spots.

Fraser: I see, so they thought that some of the Sunspots they saw were actually the planet inside. I could see you would have a difficult time finding a planet so close to the Sun. Mercury's already so hard to observe, so finding a planet that's even inside that orbit should be even harder to observe, but you could probably see it going across the face of the Sun with your telescopes.

Pamela: There's also the literal problem of if you look at the Sun, you see spots, in terms of your vision just can't cope. So you're looking at the field way too close to the Sun, and you're going to see things that are just chemical reactions in your eyes from seeing the Sun, rather than things that are actually there.

Fraser: Then after a while you won't see anything.

Pamela: Yeah, that's another bad side effect as well.

So they looked and eventually figured out there's no Vulcan. So we're left with this 46 arc seconds per century that Mercury's moving that we couldn't account for.

Finally in the 1900s, Einstein came along and worked on his theory of general relativity and special relativity. In working on these theories, he hoped, hoped, hoped that this would account for Mercury and it did within 3 arc seconds. It turns out the last 3 arc seconds is because the Sun is not a sphere, it's kind of flat and that affects things.

So from general relativity, we get a correction of 43 arc seconds per century. On top of that we get this extra correction called the Dickey-Goldberg correction that comes from the Sun not being a sphere.

When you add together Newtonian perturbations (because we have Jupiter, Saturn and everything else pulling on Mercury), a general relativity correction and then correct for the fact that the Sun is not a sphere, you can completely account for all of Mercury's motion.

Fraser: That's cool.

Pamela: Math. It works!

Fraser: Math!

All right, next time I think we'll proceed, though we might need to stick another questions show in there. We will work our way through the planets in the solar system, so Venus will be next.

This transcript is not an exact match to the audio file. It has been edited for clarity