Astronomy Cast Episode 80:
Craters

Fraser Cain: Welcome to Astronomy Cast our weekly fact-based journey through the cosmos. Pamela is in Houston, Texas.

Dr. Pamela Gay: Fraser, it's been a sad conference without you here with us.

Fraser: There you go but someone's got to hold the fort down back in Vancouver.

Pamela: Keeping Canada safe.

Fraser: Right, from space. But how's the conference been going?

Pamela: My brain is full. It's been an amazing week of all sorts of content. My background is astrophysics, it's not geophysics and I have learned more in the past week than I think I've read reading journal articles in the past several months. It's just been an amazing experience of well science concentrate.

Fraser: Can you talk the planetary lingo now?

Pamela: No. But I at least know what the people who can speak the lingo are saying most of the time.

Fraser: So you're able to translate a little better. That's good. Now the results of all your work is being posted to astronomycast.com/live

We have pictures and audio and text and video, interviews, and all kinds of stuff so if you haven't already, go to astronomycast.com/live which is where all of the coverage for this event is.

Pamela: And it's not just me. We had help from Emily Lakdawalla of the Planetary Society; Rebecca Bemrose-Fetter our producer has been doing a lot of blogging and photography. We also got a special guest correspondent.

One of my students, Scott Miller, went to see STS-123. He went to see the last night launch of the shuttle program and we have his Geeks Pilgrimage documented over on astronomycast.com/live.

Fraser: Awesome. I saw some video of the launch and I really want to see that. Have to see that launch before it stops launching. Let's get on with the show.

As you know, Pamela is attending the 39th Lunar and Planetary Sciences Conference in Houston, Texas. That means the moon and planets. When you think of the moon, you think of craters.

In fact a big theme this week at the planet is craters. Pamela has taken it as an inspiration so this week is the week we drive the show into the crater. Pamela, why don't you give us the basic explanation of how we get a crater. Although I think we can kinda guess.

Pamela: Well you start with a rock, although rocks have more words than I ever knew existed. You can have a rock that is from the moon or Mars or you can an asteroid and these can have all sorts of different names.

Most typically the ones that end up hitting planets they were calling chondrites. You get iron meteors that hit planets. When they impact they can come in at all sorts of different angles. The angle of impacts affects what direction the ejecta travels. This is the cloud of material that gets thrown out of the ground and spewed in different directions.

But you always get a round crater. That's one of the cool things that you can knock a planet and you can do it from all sorts of crazy angles and the crater is always going to be a nice happy little perfect circle.

Fraser: Why?

Pamela: It's just the way the physics works.

Fraser: Right, like the rock just gets consumed when it strikes the ground and it's always in a circle?

Pamela: There are a lot of really complicated processes that go into this. There's conservation of energy; conservation of momentum. You hit downward and material gets flung upwards as the energy is being released. It just ends up leading to this nice happy little perfectly round crater.

You can get craters that end up with multiple rings of material around them. You end up with craters that have neat layers layered through them with all sorts of different morphologies depending on where you hit.

In some cases you can actually create an instant lake if you hit someplace on the planet Earth and the crater happens to break through to the water table. This actually happened last September. In Peru there is a crater formed about 15 meters across when a fairly good-sized rocky asteroid in this case, which we didn't think those could actually reach the ground, which is a bit troubling.

But, a rocky asteroid came crashing through our atmosphere. People saw it while they were hanging out on the roof of a hotel looking up when the asteroid turned meteor turned meteorite hit the side of a riverbank. It poked through to the water table and within minutes this crater turned into a little tiny watering hole.

Fraser: Wasn't it making people sick?

Pamela: That was actually one of the stories that were in the news. Several different teams of scientists a few weeks and a few months later went down to study it. They interviewed the people involved, took pictures, documented everything.

It appears that it was a psychosomatic reaction. There was a lot of fear when this happened that it was actually a missile from a neighboring country or just some other country that for whatever reason decided to throw a missile at the middle of Peru.

This was a fairly remote area near the Bolivia border and somewhat near Lake Titicaca. There was a lot of fear and paranoia and no it was just a rock.

Fraser: Why don't you walk me through the steps nice and slow like for as a rock strikes the ground – space to crater.

Pamela: Okay. The most typical case is you have what starts as an iron asteroid. A happy little friendly object on an orbit around the sun minding its own business, but its orbit happens to intersect the orbit the Earth. It can intersect it at all different angles.

You can end up with an asteroid that hits our atmosphere head on where its path is going straight from space straight down towards the earth. That's kind of rare. Most of the time you're at some crazy angle.

Just probability says that its' more likely you're going to be somewhere between zero and 90 degrees than at 90 degrees when you hit the atmosphere. Depending on the angle that it hits the atmosphere it's going to deal with differing amounts of slowing down from the atmosphere.

Different frictional effects as it passes through the atmosphere will slow it down, heat it up, dissipate some of its energy and dissipate some of its mass through all sorts of different burning up processes. This is what you see when you look up in the sky and see this really bright streaking object. It is melting, evaporating, ionizing all these things depending on its composition.

So it's getting smaller and smaller and so you might start off with something that is several meters in size that ends up the size of a football by the time it hits the surface of the earth. Then when it hits all that energy is transferred into the ground.

You can end up with instantaneous melting. You can end up with shocks, but the basic result is you end up with this great big splash of materials that shoot straight up.

Fraser: Does the asteroid always hit? Can't they explode in the air?

Pamela: No. It doesn't. They can explode in the air, or they can vaporize in the air. The vast majority of stuff in the air that hits our atmosphere is pebble and dust grain size. Things like that aren't going to make it to the surface of the earth. It's only the larger objects and how large is required really depends on the angle that the object impacts on our atmosphere and the difference in velocity between them.

You can imagine that you have this asteroid that is on an orbit that causes it to just hit our atmosphere and is going just fast enough that it is mostly gravity sucking it in. You could also end up with an asteroid that is perhaps going around the sun in the opposite direction so it could hit the Earth's atmosphere with the exact same angle.

Because of the difference in its' orbital velocity and our orbital velocity where we have basically a head-on collision, it's screaming in at tens of kilometers per second and this huge extra velocity ends up making it a much more dangerous object.

Fraser: Okay so the rock has transferred its energy to the ground. What happens to the ground?

Pamela: It depends on how big the object is. There are some really cool models that have been done at Los Alamos National Lab where they have a super computing facility. In some of these models, there are simulated scenarios of large object hits the ocean and the splash of the ocean water is so great that a column of water goes through our atmosphere.

So we're actually if we get hit by something large enough and hopefully this would never happen because the tidal waves would be devastating and as would many other things. If you hit our oceans just right, you can splash ocean water into orbit basically. That's just really cool.

You can do the same thing if you hit land but it would be much more devastating. This is actually how we end up getting Mars rock hitting the Earth as meteors and being found as meteorites all over the planet.

At some point in Mars past it was hit by something big and chunks of Mars was sent into space on orbits that carried them to Earth where they passed through our atmosphere, survived and landed somewhere on the planet just waiting for some geophysicist or some farmer to find it.

Anyone can find a meteor. They are all over the planet. They are easiest to find in deserts and in Antarctica. But you could find one in your back yard if you're lucky.

Fraser: Now either you're on a tangent or you're avoiding my question. I think you're on a tangent.

Pamela: It's also after midnight where I am and also very late where Fraser is.

Okay, so the rock hits the planet and you can get dirt or water thrown into the air depending on where it hits. The energy as it propagates through the soil can take a chunk of the soil and actually flip it over.

You can end up with inverted layers stacked up on top the soil, dirt, or glacier around wherever the impact occurs.

Fraser: You mean like dinosaurs on top, then newer rock, then finally topsoil?

Pamela: That's exactly what happens, it's a complete flip. If there is enough energy, it can liquefy as it hits. Soil is made up of silicates, organic materials, because we have earthworms here on our planet. Organic materials form just about everywhere but they don't always have earthworms and microbes in them.

An organic material is just something that has carbon atoms and molecules. But you take this stuff and if it has silicate in it that basically melts to glass, which is cool and you can melt it and get these fascinating structures around it.

There is also all of the material that is in the meteor that has now turned meteorite and that can shatter on impact and you end up with ejecta fields that are filled with quartz crystals. You can end up with all these various blobs of shiny glass strewn all around where the central crater is located.

You also get the pieces of the meteor if it chooses to shatter, which can be chunks of metals. So you have this ejecta field around a crater rim that includes inverted materials.

In some cases depending on what you hit, if you're hitting something that's rich in metals, you might actually in the process be able to whack them hard enough or melt them just right that you end up creating magnetic fields within the materials that you've just knocked really hard

Fraser: All right, I know that if you hit a piece of iron really hard you can give it a temporary magnetic field, right? Because you are aligning all the little jiggled up iron atoms so that they're all pointing in essentially the same way and they get that magnetic field going. So a large enough rock can do that to dirt and to iron ore in the ground?

Pamela: Exactly. This is actually something that we think has happened in some cases on the moon. If you look at the lunar craters there are some amazing maps of the moon's magnetic fields from the lunar Prospector.

When you look at these maps, there is a little bit more magnetic field in one place than another and is coincident with the centers of craters where there is little upwellings of material which sometimes happens for reasons that we're still trying to figure out.

It is thought that these magnet fields are either induced through shock, like hitting it as you would hit a nail with a hammer, which is something anyone can try. Go get a real metal nail and whack it a few times with a hammer really hard and you can use it to pick up paper clips.

Either that or perhaps in some really ancient cases there was an intrinsic magnetic field around and by heating the material, you randomize the atoms in it if it is material capable of becoming a magnet.

As those heated up atoms cool they align along any magnetic field that happens to be around. This is why in different parts of the planet Earth we can actually figure out the history of the Earth's magnetic field by looking at the way the magnets are aligned, natural ferromagnetic materials.

With the moon we have these neat little lumps and bumps of magnetic fields that are coincident with craters. And that's just cool.

Fraser: Right, you get some lava that pours out of the ground or is created in an asteroid strike and it is liquid enough that all of its atoms can align while it is cooling in the magnetic field.

Then the magnetic field is cooled and they are locked in place and maintain a record of the magnetic field that was there at the time.

Pamela: In some cases if you whack something hard enough with an object that is large enough you can even do things like create the Earth's moon.

Our planet once upon a time was hit by another object and we go into this in our "How the Moon was Created" episode.

Fraser: That's like a big crater there, mighty big.

Pamela: Actually, it's more like an ejecta. So the splash of material I told you about can sometimes make it up through the atmosphere, that would be our moon.

Fraser: A really big collision.

Pamela: It's a really big collision. But in these really big collisions you don't always get moons. In fact, it looks like both Mercury and Mars have giant basins. In Mars' case one that is about half the planet – the whole hemisphere.

Both Mercury and Mars appear to have been clobbered by something of double digit percentages of their own size at some point in their past. This had huge morphological affects on the entire planet.

Fraser: Now what good have craters done for us?

Pamela: Well, they probably got rid of the dinosaurs which some would argue allowed mammals to evolve on the planet Earth and thus reign supreme and destroy the planet in new and interesting ways.

At the same time, it's a way of distributing material around the solar system and there also a tool that geophysicists can uses to measure the ages of other objects. For instance on the moon you can look around and there are lava fields on the moon. The moon actually had a much more liquid core in its past and lava was able to escape through various different types of dyke features.

There are also all sorts of very neat little underground effects of lava going underground where we could see it and creating neat geographical formations. We can date different features on the moon such as the highlands, the mare based on how many craters there are in different areas. We could also measure the depth of lava using the craters.

The way this works is you look at an area and count how many craters there are in different areas and we can also measure the depth of lava using craters. The way this works is you look at an area and count how many craters of different sizes there are within that area.

You can make a plot of number of craters versus size of craters and you'll end up with a bazillion little tiny craters and very, very few giant craters and you can fit a pretty much straight line to those relationships.

Now in an area that has a ton of craters, where you end up with the entire line shifted so that it intersects the Y-axis is really high number. That is a really old surface, one that has been around for along time getting whacked with rocks from space.

Fraser: So you just count the number and the size of craters in some region and then you consult some geophysicists chart somewhere and it tells you how old that region is. I guess you might have regions that are right at almost the beginning of the solar system while other places might just be a few million years old.

Pamela: They actually define different geological periods based on the crater number. This gives us the relative age. Trying to get at the actual age of a planet, a moon, whatever requires you to actually go out, grab a rock and do radioisotope counting. Look at what different elements have had a chance to decay in that particular rock.

We can't do that with Mars yet. But we sent Apollo astronauts to the moon and they landed in different places. By taking those rocks and looking at the radioisotopes in them and what has decayed and what is left, we're able to say this part of the moon has this age; this part another age; and use that to scale our understanding, at least with the moon, this crater rate corresponds to this date in the past. That's kinda cool.

With Mars, we're not at a point yet where we can do the radioisotope work and say we know exactly how old this part of the surface is. Although we have some fair guesses based on our understanding and on the Rovers we have sent there so far.

However, with Mars we do the same thing. We age different surfaces and also age things like stream beds, filuvial systems cut out by liquid we think and they look like deltas and we're able to say this section is older or younger than this other section based on how craters are layered on top of or not layered on top of based on these filuvial systems.

Fraser: Now we look in the sky and we see the moon just wracked by craters and yet here on Earth, I think there are meteor crater for well-known crater? Why isn't the Earth as hammered as the moon?

Pamela: It rains. We are hammered just as much as the moon. The difference is that as you look at the surface of the Earth you're not seeing any rocks that are 3.5 billion years old unless it's a rock you happen to find and pick up and test and just happened to survive.

There are a few places on the Earth where we find old rocks but it's not the whole surface of the planet. When we look at Mars; when we look at the moon, we're looking at surfaces that have rocks on their surfaces that are billions of years old and they haven't been eroded by rain or dust and the plate tectonics on both the moon & Mars are much less.

Mars has the Tharsis Bulge, it has Olympus Mons, it has all these volcanoes that are problematic. They raised a whole chunk of the surface. To understand those parts of the surface we have to do all sorts of crazy other stuff. In general the surface of both of these worlds haven't been rained on.

Already with the crater that recently formed just last September in Peru, 15-meter diameter crater is almost gone. It rains, and the rain washes soil in, flattens things back out. Anyone who has ever dug a hole in their back yard knows the hole is going to fill itself back in rather quickly.

Our planet erodes. It kinda sucks.

Fraser: So you just wonder how many enormous craters are just gone.

Pamela: There is actually thought that things like the Yucatan are crater edges. As we look more and more at satellite images we're finding more and more giant craters from their rims all over the planet.

Fraser: That's right, there's like the latest satellite missions are able to measure the contours of the Earth such precision that they are able to find these enormous craters just by the tiny little difference in the height of the rim.

It's been eroding for a hundred million years but there is still just enough of the rim remaining that they would know there was a crater there, that there was a huge collision there. Only just now they are able to discover these craters.

Pamela: The other way that we're finding it is using gravity measurements. This is one of the coolest things. I learned about this a few years ago. I thought this was really cool and I don't geek out too much about gravity.

There is the ability to measure gravity with some instruments so precisely that you can tell the difference in gravitational acceleration between someone's foot and their head using this instrumentation.

It's possible to go around with gravity detectors and if you know your distance from the center of the planet, which you can get from GPS systems, and you measure the acceleration of gravity at that altitude from the center of the planet, you can roughly figure out the amount of material that has to be between you and the center to cause that acceleration. Doing this, they go out and find things like petroleum reserves.

But working in South America, a group of geophysicists actually found a big impact basin this way because the densities versus shape of the terrain just didn't make sense for any other process. Gravity allowed them to find a hidden crater.

Fraser: They're using that technique to measure ice loss from glaciers to see how the ground such as in Canada is bouncing back after the last Ice Age. They can measure how the ground is moving back up after the Ice Age. It's pretty amazing.

Pamela: It was actually using these gravity measurements that we've recently been able to figure out that the reason that you get this weird dichotomy between the northern and southern hemispheres of Mars is because Mars got whacked by a really big object. We didn't know about what had happened for a long time because of the volcanic system that spews volcanic material all over the boundary between the highlands and the lowlands. We had to figure out how does that boundary move beneath the lava flows.

A group of geophysicists combined topographical maps that show the altitude of the terrain with gravity maps that were extremely precise. They were able to determine that if we assume that the crust of Mars has this density and the lava flows have this density, what do the boundaries between these have to look like in order to get the gravity we observe and the altitude of the land that we observe.

When they did this, they could basically peel off all the volcanoes and see what the crust looked like beneath them. They were able to find that the boundary between the highlands and the lowlands is basically a perfect ellipse around Mars. You pretty much can only get that shape if you whack Mars and you make an impact basin.

There are ways that you can work really hard with other models and twist parameters and other things and jump through lots of hoops and ignore Ockham's razor and get this to happen other ways. But the easiest way to explain those results is to say that Mars got whacked with something over 2,000 kilometers in diameter and didn't end up producing a moon in the process but instead created this dichotomy between the highlands and lowlands.

Fraser: Wow, so a couple more things. One was just to talk a bit about how the gravity and structure of what gets hit changes the nature of the crater itself.

Pamela: It's not just the gravity, it's also the surface that's getting hit. So if you impact on top of a bunch of ices and say you dig up the soil beneath the ices and spread them out on the top of the ice.

Then you can get these really neat plateau craters where over time the ice around the crater in this ejecta blanket might vaporize or sublimate away and as this ice goes straight to gas where the soil has been dug up and plopped down onto the ice it can't do that. You end up with that layer of ice basically protected by the ejecta that's on top of it and everything else around it gets lower and lower and vaporizes into the atmosphere.

You also have depending on the gravity the amount of stuff that gets flown up is going to differ. If you hit a really big heavy object with a rock, the gravity of that object is going to hold on to the material and make it not fly out quite so much.

But if you hit something much smaller you launch rocks from Mars to Earth. So the height of the crater walls is going to be a function of the density of the material you're hitting and the gravity of whatever it is that you're hitting. It all plays together.

Fraser: I know we mentioned when we were doing our tour through the solar system some of the bizarre crater formations in some of Saturn's moons.

Pamela: The death star.

Fraser: Yeah, where it almost looks like it's hitting a real spongy material and the material is just collapsing. I think there's one last really good use for craters that we haven't talked about which is when the astronauts return back to the moon one of the things that they will be looking at is the craters at the southern pole of the moon which are in some cases eternally in sunlight and in other cases eternally in shadow and may even hold water ice.

Pamela: One of the things that is amazing that I just learned this week is the difference in altitude between the base and the rim of some of these craters is like four kilometers. That's about two miles.

We talk about Denver, the mile high city. Imagine standing on the edge of something twice the altitude or more of Denver looking down. There is an amazing movie they showed us of a little tiny sad little lander craft coming in and just perching on the very edge of one of these craters.

Fraser: Nancy, one of the writers did a story about that on Universe Today. We've got the video on the site. It's kind of scary.

Pamela: The reason that we're looking to do this is when you land at the equator of the moon, in daylight you're several hundred degrees. When in darkness, you're at minus a couple hundred degrees. Pick Fahrenheit or Celsius it really doesn't matter it's really huge swings in temperature either way you go.

Once you get down into one of the craters in constant darkness the temperatures stay constant. One of the things about electronics is they don't really like to have their temperature messed with. We can engineer things that work at a couple hundred degrees and we can engineer things that work at a negative couple hundred degrees. It's hard to engineer things that can survive huge temperature swings.

If we go to one of the poles of the moon you can stick your habitats down in the shaded part and just keep people warm and stick your solar panels straight up and they will be in constant daylight. So you have constant power and thermal regulation. It's just a lot easier to function that way.

Fraser: You could have the sunlight just a few tens of meters away from your habitat and still be safe.

Pamela: One of the ways they phrased it was you can be down in a constant darkness area and just raise your hand and the simple act of raising your hand that is above your head, your hand will be in perpetual sunlight.

Fraser: I can't wait until that exploration starts happening.

Pamela: Just a few more years.

Fraser: Just a few more years. The missions are going to be launching just within the next year and it seems like it will start steamrolling from there.

Pamela: We have LCROSS and LRO are launching on the same rocket in I think October of this year. LCROSS is this really cool mission that they're going to basically plow objects into the surface of the moon making artificial craters, making our own space craft into meteorites and see what dust gets chewed up into the air. It's going to be neat work.

Fraser: All right, well I think we'll be covering that as we go for a much, much future show.

Pamela: It was a great experience and next year you need to come with us Fraser.

Fraser: Will do.

This transcript is not an exact match to the audio file. It has been edited for clarity. Transcription and editing by Cindy Leonard.