Astronomy Cast Episode 225 for Monday, March 21, 2011:

Ice in Space

Fraser: 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 am mostly over bronchitis finally.

Fraser: That's good, that's good. We took a big break, another big break, but now your voice is functioning, still a little sore, but you can get through an episode.

Pamela: And Preston, our wonderful editor, will cut out all the coughing, and none of you will have to suffer through it.

Fraser: Just me.

Pamela: Yeah, well…

Fraser: Alright, so OK, well, a huge part of the Solar System is just made of ice: the comets, rings, moons and even dwarf planets. So where did all this ice come from, and what impact (pardon the pun) has it had for life on Earth? And, you know, this has been your life for the last couple of months, right?

Pamela: It has. Back in, I guess, January, I flew out to NASA Ames and got to sit down and talk to the folks behind the new Horizons Mission, which is going to fly through the Pluto system is 2015, and this, in some ways, is one of the scariest spacecraft flight plans I've ever read because the flight plan basically states: "OK, we're going to go past Jupiter and takes lots of shiny pictures (they've done that), we're going to keep going , we're going to fly past Pluto and its moon of argued-over pronunciation "Charon," whatever you want to call it, and then we're going to keep going and there's going to be enough fuel left on board to go to one, maybe two more Kuiper Belt objects," except those objects haven't been discovered yet, so sometime between mission launch and well 2016 – 2020, we need to discover those objects. That's scary! So right now, the New Horizons team has been taking amazing images of the region of the Solar System where something with the right orbit to carry it in front of New Horizons should be located, and we just finished creating a website, "we" being me and Cory Lehan, one of our programmers, a website called "Icehunters" that takes all of these images and puts them on-line for anyone out there, this is anyone in our listening audience – your friends, your family, your kids, your grandmothers, and asks you to look through the images and help the New Horizons team discover that Kuiper Belt object that New Horizons will go to sometime after it visits Pluto.

Fraser: Right, so anybody can go and help discover where New Horizons should go next. How cool is that?

Pamela: It's really cool, in fact it's full of ice.

Fraser: It's full of ice…oh, who's the punner now?

Pamela: Yeah, yeah, yeah…

Fraser: Let's go back then, so how much of the Solar System is ice?

Pamela: Well, not a lot by mass. In fact, if you pull together all the mass in the Kuiper Belt, it's kind of a large rocky planet's worth of materials -- not a lot, and it's also scattered into what's called the Scattered Disk, and beyond the Kuiper Belt, beyond the Scattered Disk, the Oort Cloud – not really sure how much mass is tied up out there, haven't really observed it yet. It's a lot of stuff though. It's sort of like when you're cleaning your house, you don't realize how many forks you own until you realize that you have forks in every room of your house from those random snacks that have been gathered.

Fraser: Right, so we get out past the Asteroid Belt, right? And the ice starts and we've got moons that are made of ice, we've got the rings of Saturn and the rings of the other planets are made of ice, we've got the dwarf planets, the Kuiper Belt objects, the Scattered Disk, the Oort Cloud, we've got comets, short and long-period comets…

Pamela: The Centaurs inside of Jupiter's orbit…

Fraser: So why do we have this dividing line of ice? Where does that start?

Pamela: Well, the water line is midway through the Asteroid Belt, and then the freeze line is out there pretty much between Jupiter and Saturn, and these are basically the places where you go from completely blasted dry, potato-shaped asteroids to potatoes with water to things of varying mixtures of rock and ice, and then the, in general, pure ice stuff in the outer solar system, and what you're seeing is, essentially, the thermal gradient of when our Solar System formed.

Fraser: So when it formed, and not the way it is today…that's interesting.

Pamela: Yeah, and where things are located isn't purely because of where they formed. The Scattered Disk of objects -- these are things that Neptune's gravity periodically flings around, the Kuiper Belt -- these are objects that probably formed where they are located, the Oort Cloud is a mixture, well, we think a lot of the Oort Cloud is stuff that got flung out there actually, the Centaurs -- these are things that got pulled in and trapped in stable orbits, but for the most part, the Asteroid Belt formed mostly in place, the Kuiper Belt formed as much in place as anything in the outer Solar System formed in place, and these dividing lines reflect the situation in the early Solar System when things were settling into their lasting positions.

Fraser: But where did all this water come from, then? I mean, all this ice is just water, and so where did it come from and how did it distribute around throughout the entire solar system?

Pamela: Well, it's more than just water…well, water's a complicated thing. It's more than just liquid; it's ammonia, it's methane, it's anything that we call "volatiles." These are things that when exposed to enough heat, become gaseous form.

Fraser: Right, we're not just talking about water for ice -- it's everything. Right, I got that.

Pamela: And it came from the stuff our solar system formed out of. The early Solar System was this mix of molecules and atoms. You had all the iron, all of the silica, all of the stuff that we think of as heavy metals. We had all of the carbon molecules, and mixed in all of this was O2 (oxygen); mixed into all this was all kind of carbon gasses, mixed into this was the ammonia and methane, and part of this mixing process…you had different things segregated out into different places due to gravitational attraction pulling things into the center of the Solar System vs. the light pressure forcing things back out. In the inner solar system, all of that light pressure from the Sun basically said, "OK, volatiles, bye-bye, we're sending you far, far away now," and so the Earth, initially, was this molten, dry thing and we had to wait for the comets to come flying in and re-water us, I guess.

Fraser: Right, OK, so it's in that early Solar System with the light pressure and the radiation coming off of the sun, anything that wasn't made of metal and rock just couldn't sort of fight against it, and was pushed out into the outer Solar System, and even out of the whole Solar System.

Pamela: Yeah.

Fraser: And so, but then you've got that dividing line, right? You've got that dividing line in between the Asteroid Belt, so what was different there? Why did it stick around there?

Pamela: It was a combination. Well, as you increase your distance from the Sun, that pressure from the light…every time you double the distance, the light pressure spreads out over 4 times the area, so as you get further and further away, the effects get less. You also had temperature dropping, so even though the early Sun was, in some cases, hotter, it didn't fricassee things once you got far enough away. And then once you get far, far away, then you reach the point where volatiles were quite happy to sit around as nice, solid ice, and that's where you see the evolution in composition as the distance from the Sun.

Fraser: So it had nothing to do with the temperature of the sun? So it's not like the stuff was melted away, it was really about the light pressure?

Pamela: It's a combination of both. So, while things were hot enough, you had the asteroids quite simply sublimated away, volatiles on their surface. If you're cold, but not covered up, ice that is exposed to vacuum quite happily goes straight to gas. And so you had a certain amount of temperatures were high enough to sublimate away things, but at the same time, this radiation pressure is what took materials that would otherwise gravitationally get held onto and push them away, so this is where planet Earth was really hot, but was also experiencing this pressure that took everything that could have sat around as a gravitationally-held-onto atmosphere and said, “No, I’m just going to push you out of the way, I’m going to send you out to the outer solar system.”

Fraser: So then, is the amount of ice that’s in the outer solar system, is that sort of the same amount that was probably formed in the inner solar system as well, but just got blown out?

Pamela: Now you start getting into details where I have to say I’m not comfortable answering that because we’re still not quite entirely sure how solar systems formed, and so it’s unclear: How much did we lose? How much did we just rearrange? How much got sucked into Jupiter and the Sun along the way? How much became the Earth’s oceans?

Fraser: And we still don’t even know fully where the oceans came from. I mean, the comets is one of the theories, but there are other ones as well, so more research is necessary.

Pamela: Yeah, there are diverse models on how our solar system formed. There’s this one fabulous model that has Jupiter, Saturn, Uranus and Neptune starting closer in, basically as this tumbling swarm of planets that gravitationally, eventually flung each other out where you had Saturn and Jupiter in resonance for a while just radically flinging small bodies all over the Solar System, but these are models. We don’t know what’s right yet.

Fraser: Now, you mentioned there are different kinds of ice. It’s not just water ice, there’s ammonia, methane, things like that. Do those have different lines as well, or is it all about how volatile it was? Were they all collected together, or do you not see the ammonia until you’re further out?

Pamela: For the most part, the nice, happy, solid icy bodies we see -- these are the Centaurs, the Kuiper Belt objects, the Scattered Disk objects -- while they have variation in composition, we think, we’re still figuring this out. These suckers are far away and they’re faint. While they may have differences in composition (and we guess at that based on differences in albedo), they all formed in basically the same area and then got scattered around by gravitational interactions. So it's more like you take the snow bank on the side of the road that has some of it has been attacked by pollution from cars, some of it has random spilled coffee from someone falling on the ice, there's unfortunately dog pee on the snow bank, and where you grab -- or don't grab -- a handful of snow from the snow bank, there's going to be variations in composition, but in general, it's all one snow bank. And in this case, it's all one family of icy objects.

Fraser: Hmm, and is it more than about their position than their composition?

Pamela: Yeah, that's exactly how we segregate these things into different bends -- it's where they're located in the Solar System, not what are they made of like we do with other objects.

Fraser: So let's take an object that people might be familiar with that is largely comprised of ice, and take a better look at what we might find inside of it. Now, you mentioned gravel and dog pee on the snow bank, but what would Enceladus, a comet like Haley's comet, or something like that…I mean, it's not just a pure block of ice, right?

Pamela: Right, so the way we typically model comets is you take a couple of handfuls of gravel, silica, some metals, mix it all together add in dry ice, add in ammonia, add in oxygen, add in a little bit of nitrogen, add in pretty much anything you can think of that can become a frozen gas, mix it all together in a variety of slightly different ways, and that's what you get when you look at a comet and you start taking it apart. Mostly it's ice, but there are bits of rock and gravel mixed in there.

Fraser: Are things layered like the way the Earth has the different layers? If you cracked it open, would you find layers, or would you find it all just jumbled up?

Pamela: It's hard to know. We haven't had the chance to grab one of these things and take it apart. With the small objects like comets, it's generally thought that they're pretty much compositionally…when you look at non-weathering effects, the surface is going to have its own Sun-affected materials, but once you get in from the stuff that's been degraded through interactions with solar weather, it's probably a fairly consistent composition.

That's also what we think of asteroids, which are mostly rocky bodies, but as things become bigger, as you go from looking at the small potatoes to looking at things like Sirius, and once you go from looking at the smaller comets to looking at the bigger Kuiper Belt objects – things like Pluto, then you start to expect that stratification of some sort has happened, but we're still learning. We're still not entirely sure.

Fraser: Right. I guess the question is…depends on like if they're orbiting a planet.

Pamela: Like Triton orbiting Neptune…

Fraser: Right, there might be a certain amount of tidal flexing going on, so it's going to have heating up the core a bit, and maybe that allows things to differentiate a bit.

Pamela: And more than that you also have…while it formed, it also had a chance to start grabbing onto things in slightly different ways, and segregating materials out as things got bigger and bigger. You end up…planet formation is still one of those things that I'm still trying to get my head around, but one of the neat facets of forming any large object that becomes round due to having sufficient gravity, is the materials inside move around of their own accord. This is where you end up on the Earth with bands of metals that are easier to mine than if the entire composition was like a well-mixed cake batter, so through all of these complicated processes, you do end up inside of these bodies with materials moving around.

Fraser: And so what impact, then, as I joked in the beginning…what impact has this ice had on the geologic development of the Earth and life especially?

Pamela: Well, I think the most interesting one in modern history is the object that flew over the Soviet Union in the early 1900s…the Tunguska event is thought to perhaps have been a comet that chose to evaporate right prior to hitting the planet Earth, and that's kind of cool to think about.

Fraser: Yeah, I heard it was UFOs or a Black Hole.

Pamela: Yeah, I know…no.

Fraser: It was probably a little comet.

Pamela: Right, and it's though that the comet Inky, and this is a much-argued-over thing, but it's thought the comet Inky used to be much, much larger in the past, and various chunks of it have probably hit the planet Earth at various times in our past. One particular theory, not widely-accepted, but still kind of neat to think about (you're allowed to think about the not-widely-accepted, but not yet disproven theories)…it's thought that one particular chunk might have hit the Middle East and been part of the collapse of the Copper Age. Then, just in general, we have water on our planet. Pretty much all of the planetary formation models we have say that in the early parts of the Solar System, our planet should have gotten baked dry, so the water had to come from somewhere, and comets are thought to be maybe that source of water, and the same is true of the planet Mars, when we look at Mars and we see what look like riverbeds.

Fraser: Again, Mars was inside the frost line, should have had all its water blasted out, all of its ice pushed away, and yet, clearly had evidence of past water.

Pamela: And now as we start to explore the Moon and Mercury with the Lunar Reconnaissance Orbiter and the Messenger mission, we're even finding ice on the polar regions of Mercury – this little baked rock next to the Sun, and the only reason that we can even start to think of explaining that is the idea that, well, we see comets plunge into the Sun all the time using the Soho and other Sun-staring satellites…well, what if instead of plunging into the Sun, you had comets plunging into the craters and polar regions of Mercury, these places that are in constant shadow and cold enough to keep that ice? So, it looks like comets may have even brought water to Mercury.

Fraser: One thing that I find is quite interesting is what the future holds for the Solar System. You know, we've talked about how the amount of energy coming out of the Sun is heating up, that as the Sun continues to heat up, it's going to cause some trouble for life on Earth, but it's going to actually sort of push out the habitability zone of the whole solar system.

Pamela: Yeah, it's an interesting future because our Sun is going to get larger in surface area, colder in temperature, and the combination is a whole lot more…a whole bunch more thermal energy, and a surface that is much closer to the surface of the planet, and probably uncomfortably close to killing us in the future, and as we move outwards (if humanity is capable of moving outwards), we can start thinking about the necessity of finding water and finding other things that we need for life, and grabbing a hold of an asteroid and turning it into a spacecraft and going out and grabbing water from a comet. It's the stuff of science fiction, but also perhaps the stuff of a scientific future.

Fraser: And you can imagine way down the road -- billions and billions of years down the road, it could very well be that it's the outer Solar System that actually has the liquid. You could be hanging out on the beaches of Enceladus, right? Our summer home on Pluto…

Pamela: I'd much rather have rock beneath my feet, but those are futures that we can think about.

Fraser: Now, I think one of the really interesting…I mean, a lot of this research is being done right now because it has a very practical purpose, which is as we want to further explore the Solar System, we need this water, we need this ice, you know, a lot of the research that's being done, especially searching for it on the moon, has a very practical purpose.

Pamela: Right, and on the Moon, unfortunately, we're finding that, yeah, there's volatiles, yeah, there's H2O water, but a lot of it seems to be mixed into the soils, which makes it very energy-intensive to pull it out, but if we can grab one of these comets that wanders into the inner Solar System, one of these pieces of either the Kuiper Belt, or the Scattered Disk, or the Oort Cloud, all depending on what its early orbital parameters were before we captured it, if we can capture it and gently crash-land it on the Moon -- that's resources. As we start to think about how much harder it is to mine metals as we start to use up all of our easily-accessible resources, and as we start to think about the gravitational requirements of building colonies on the Moon and Mars, suddenly it starts to make sense to just go grab an asteroid, instead of mining things here on the planet Earth. So we now see comets, we now see asteroids as future resources.

Fraser: Now, in the past, we only had our own solar system to look at, but now we have hundreds of other solar systems out there to see with all of the extra-solar planets that scientists are turning up. Is this water…is this ice part of the puzzle? Will we be able to see it very well?

Pamela: We're able to see and you can't get compositions from this distance, but you can speculate. We're able to see disks of material, asteroid-like belts, Kuiper Belt-like things around other stars. In some of the more interesting cases, in young, young solar systems, we can see the empty gaps of still-forming planets and in other systems, the much larger gaps of the mature, gravitationally swept-out region. It seems to be that there's always stuff left over, and how much stuff gets left over varies from system to system. Vega has its own set of belts around it and appears to have no planets. Different solar systems are built in different ways, but one of the not-unusual features is a belt in a position that would make sense for it to be frozen objects just like our Kuiper Belt.

Fraser: Hm, and sometimes we can see it when things are colliding. It's almost like when the activity is happening.

Pamela: It's neat to be able to look around the Solar System and basically catch snapshots of solar systems in the process of growing up.

Fraser: Thanks, Pamela – oh, and so one last reminder for people: if they want to participate and help figure out where New Horizons is going to go next, what should they do?

Pamela: They should go to www.icehunters.org. And feel free to follow us on Twitter, and I'll be keeping people up-to-date, well, it's not me it's the servers will be keeping people up-to-date on all the things that are going on and being discovered.

Fraser: Cool! And if you're lucky, you will be the person that picks -- contributes to choosing the next target for New Horizons after Pluto, which would be pretty cool.

Pamela: So, hope to see you on-line.

Fraser: Well, thanks again, Pamela.

Pamela: My pleasure.