AstronomyCast Episode 247 for Monday, January 9, 2012:

The Ages of Things

Fraser: Welcome to AstronomyCast, 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: Good! And where are you this week?

Pamela: I am in Austin, Texas at the 219th meeting of the American Astronomical Society.

Fraser: That's good. So you are like buried in space news.

Pamela: I am not only buried in space news, but I'm among my people. It's a good place to be.

Fraser: [laughing] Among your people, right! With your flock – that's good!

[advertisement]

Fraser: Alright, so this going to be one of those "how we know what we know" kind of shows. How do scientists determine the ages of things? How do we know the age of everything from stone tools to the age of the Earth to the Solar System to the age of the very Universe? Alright, Pamela, so I think that was sort of the plan here, that we're going to sort of explain to people how we know what are the various measuring sticks – age measuring sticks that astronomers use and scientists use to figure out how old everything is? And I thought, well, why don't we start kind of close to home and think about, you know, when scientists discover some civilization, they discover stone tools, they find an archaeological dig -- how old is everything that was in that dig? How do they know how old that is?

Pamela: It all pretty much boils down to radioisotope dating, and looking to see what's in what sedimentary layer. One of the things that is a blessing and a curse -- and I say curse because it leads to cancer now and then and that's never a good thing -- is a variety of the atoms that get created in supernovae and through other high-energy processes aren't stable, and they're not stable on varying time scales, so some things it might be -- you set them on the table, and say you have a thousand atoms, well, you wait an hour and you have 500 atoms of what you started with, and 500 atoms is what's called a daughter material, a daughter atom, and so you can actually look to see how much, what the ratio is between these two different atoms, and based on the ratio, you can see how many half-lives have gone by. Now, if you have something that decays quickly, that's only good for time dating something in the recent past. I know as a small child, I was nerdy enough that I knew about carbon dating, and I was terrified that my teachers would use the carbon in my pencil to figure out I didn't do my homework on time because I was that kind of a nerd and lacked the level of understanding I needed.

Fraser: …or you know overestimated the abilities of your teachers.

Pamela: Exactly. Exactly, but the thing is -- carbon doesn't decay on that type of a time scale, so we can only use carbon to date things in the distant past. We can use other forms of dating for the recent past, and through all the different atoms that we have that decay on the time scales of minutes to hours to days to weeks to years to centuries, millennia, to millions of years by combining all of these different types of radioisotope decay, we're able to very carefully measure the age of different materials that contain these radioactive processes.

Fraser: And so do scientists have these overlapping methods of radioactive decay, and can they go from really, really short events all the way to the age of the Universe? I mean, are there any gaps in this?

Pamela: Well, so in general things that decay quickly are also things that we have to generate in cyclotron laboratories, so it's not like there's piles of polonium-120 lying around, so for the most part, the way we get to the things that we can radiocarbon date, and other things like that is we have to go through the archaeological record. So you look for those points where you're able to bridge from our known understanding of the past of humanity to "A-ha! I found a radioisotope that has decayed in a useful manner," and from there we just bridge our way backwards. And we do look for the times where we find in materials more than one of these radioisotopes, and just keep building our way backwards.

Fraser: And where does it sort of fall apart? I mean, does each isotope only give you so much, and then it's just not useful anymore?

Pamela: Yeah, well, it's a matter of…there's just not going to have had been enough left at the end of the period. It's the, well, you go half way to the wall, half way to the wall, half way to the wall, and never actually make it to the wall. At a certain point you have run out of atoms to decay, so you eventually get far enough back in time that the sample you're looking at has completely decayed into its daughter atoms.

Fraser: Right. And I guess you can imagine, that's kind of like you're looking at ice melting. You've got a piece of ice on a plate and it's in the living room, and you look at it and it's unmelted, and you go "well, that ice was clearly just brought out seconds ago," and then it's kind of half-melted and you know it's been within the last, you know, less than an hour, but more than a couple of minutes, but if it's just water, it could have been there for a couple of decades.

Pamela: Exactly. Well, not decades, then it evaporates.

Fraser: [laughing] I know -- it evaporated. I know, I know, I realized that as I said it. OK, great! So then, which is the tool that they would use? We're going back to my first example, right? We're going to take a look at stone tools left by Neanderthals -- what is the method that they would use to date that kind of human civilization stuff?

Pamela: So this is where we often use carbon-14. It's a naturally occurring radioactive form of carbon, and the nice thing about it is human beings tend to pick it up, plants pick it up, all of us…we're made of carbon, and so we become partly radioactive in the form of carbon-14, and so you can look at the leftover logs in fire pits, you can look at the leftover carbon in the bones and you can start to get at how old things are. carbon-14 has a radioactive half-life of 5730 years, so you can basically step back in these intervals of 1000s of years, tens of 1000s of years…in fact, we think the limit for using this is actually somewhere around 60,000 years in the past that this starts to become a not-entirely-useful way of studying the age of things in our environment.

Fraser: Right. OK, so then you've got the quantity of the carbon-14, and then it's going to… you're going to be able to measure that ratio of what you had carbon-14 and the various daughter elements that it's going to decay into, and get a sense of how old it is. OK, so we've done, then, carbon-14, and you say that, sort of, how early can we measure with that? Within a few hundred years, right? And then…

Pamela: Well, a few hundred years starts pushing it because you haven't had that much…I mean, its half life is 5730 years, so a quarter of it will have decayed in 2600 years, and so you want to get closer to the 1000 year mark than the couple-hundred year mark.

Fraser: Right, so definitely 5000 years is great, but you don't want to be measuring beyond 60,000 years.

Pamela: Yeah, that's a comfortable place to be.

Fraser: Alright, so the next age of something, I would assume, is going to be like rock formation, lava flows, things here on Earth that we're going to try and date.

Pamela: So we also look at things like the uranium to thorium dating method, which looks at uranium-234 decaying into thorium-230 and this is something where we're looking at processes that, depending on where we are in this, there's a whole network of things in this that decay. We're looking for that combination at a half-life of 80,000 years, but we can also look at uranium-235 which decays into the generally-not-talked-about-in-chemistry-class protactinium-231, which has a half-life of 34,000 years, so by looking at these different decay paths and looking at their different daughter processes, this is where we can start getting into more of the geologic record, getting back into the hundreds of thousands of years over the course of their decays.

Fraser: And, same thing if they're going to measure… I'm trying to think, soil, sediments, or ice cores -- things where you're looking at hundreds of thousands to millions of years old. So you're telling me there's little bits of uranium kind of everywhere for the measuring?

Pamela: It's actually a really good thing because it's part of what keeps our planet warm. Our planet is a lot warmer than it would be strictly from sunlight hitting it, and an atmosphere that blankets it and keeps some of the IR radiation trapped in. Our planet's internal temperature is driven by the constant decay of radioactive particles. It provides heat, and that's a good thing because heat helps to provide life, so be glad for the radioactive materials.

Fraser: Right. So then how, I mean, you keep pushing that further and further back, but I can imagine if the whole surface of the Earth is being re-surfaced (thanks to plate tectonics and such like), that there'd be no way to figure out how old the Earth itself is, and yet we know quite precisely how old the Earth is. So, how did…how on Earth did astronomers figure that one out? Geologists…we'll let the geologists have that discovery.

Pamela: We do actually look for progressively older and older rocks, and we do find rocks that are billions of years old, and this is where we start pressing ourselves backwards with things like looking at samarium and neodymium, and their decay rates, which get us back to millions of years to now a billion years, so we do have some pretty old rocks, but you're right -- we are pushing the billions of years limit. So we look at sedimentary histories; we look at the way things are capable of moving, and then we start looking at cratering histories on other worlds, and we start grabbing asteroids. Asteroids are really, at the end of the day, the final authority on the original chemistry and the age of our solar system, so we wait for asteroids to actually come to us (we call them meteorites by the time they reach the surface of the planet), and take them to labs, and this is part of why scientists are so avidly collecting meteors, and, well, we know that lots of amateur astronomers are enthusiasts. There's lots of scientists who would like to take a core sample of that big rock you have found and put on your shelf as a trophy object. That's actually a piece of data that hasn't been collected that you're keeping on your shelf.

Fraser: And so…and so the theory goes that if you're going to find a meteorite and determine how old that meteorite is, you're going to know how old the Earth is? I don't understand.

Pamela: Right. So the idea is the entire Solar System formed at once, and so the age of the Earth is the age of, well, not the Moon -- it formed later; it's a blasted-off piece. So it's sort of like its materials formed at the same time, but it was part of two other things, but all of the materials came together, maybe not in the same structure they're in now – big asteroids have broken apart into smaller asteroids, things have hit each other, creating the Earth's moon, but all of this stuff in our Solar System formed out of the same solar nebula, formed at the same time, and so if you can age a meteorite, you've aged the entire Solar System. Now, the more of these that you age at once, it's like taking more and more measurements. You're able to get a more and more precise understanding of the age, so this is where we're constantly trying to catch and collect and understand asteroids.

Fraser: And was this always assumed to be the case, or were astronomers not even really sure that all of the meteorites are the same age?

Pamela: Well, it was one of those things where you postulate it and hope it's true. And as we've measured it, it's come out to be we're able to put very good limits on the age of the Solar System using meteorites.

Fraser: Now, you hinted at for a second there that astronomers use cratering on places like the Moon, and I know on Mars and stuff… they'll use that as a totally different method for determining the age of things.

Pamela: Well, so there's two different ages that we worry about: one is when did this stuff form, and then the other is when did the surface of the stuff form. So when you look at the Earth, our surface is extremely young; in fact, there are volcanoes if you look at bits of the surface – like Etna's going…I think earlier this week it went off, and that surface is measured in days in terms of its age. Well, when we look at the Moon and we look at Mars and we look at other rocky surfaces, the only way we have since we can't readily go there all the time of getting the age of the entirety of the surface is to look at cratering histories. And this is where we actually try and get the public's help because we want to measure the ages of as much of the surface as possible so we can start understanding what was the collision history in the past, what was the bombardment history in the past, and we create projects that ask you to help us train computers to more effectively measure craters for us because -- let's face it, at the end of the day, measuring craters is fun for a while, and then you want to do other things, but we also ask you to measure craters for us.

Fraser: Right. This is a project that you're actually working on, right?

Pamela: This is…and you've been giving us server advice, so we're launching a new project called Moon Mappers with CosmoQuest, which Fraser and I have talked about a bit in some of our other hang-outs. CosmoQuest is a community where we're hoping that you'll come and learn like you do with AstronomyCast, and listen to Fraser and I, and then apply all these things that you're learning to actually doing science. And Moon Mappers is our very first science project. It's part of the Lunar Reconnaissance Orbiter mission (not the orbiter itself), and we're asking you to help us correct crater finding algorithms, to go in and tell us where does the software screw up, and fix their outputs, and to help us measure the age of various surface features on the Moon.

Fraser: So, this episode of AstronomyCast is brought to you by CosmoQuest. We're sponsoring ourselves.

Pamela: Something like that. Yeah.

Fraser: Right? But no, I mean, our goal has always been to get everybody involved in space and astronomy to some degree, and we're trying to…you know, Pamela's been working with NASA and other science agencies to get data from the spacecraft, and then bring in the general public to help in actually creating science that then gets used for real scientific research that may not even be possible to be done, and so this is one of those projects, and now we've got this umbrella organization where we can…and sort of server and hardware and software where we can actually do more and more of this. So hopefully you'll hear a bunch more of these kinds of announcements and more of these projects as we go on, and we'll recruit as many as we can to do some real science.

Pamela: And as we move forward doing this, we're going to be working to determine the ages of different features on the asteroid, Vesta -- we're working with the Dawn mission. On the surface of Mercury we're working with the Messenger mission, and in all these cases we're looking for those places that have extremely few craters – those are the young surfaces; we're looking for those places where you have crater bombarding on top of crater, crater inside of crater, these places that are extremely rich in craters -- those are the old places, and then we're looking to see, "OK, can we trace this area that's almost devoid of craters, and thus actually trace out where there was a ton of lava from an ancient volcano or a more modern volcano?" We're trying to understand what was the geologic history? How recently were there volcanoes active on the Moon? That's something I always am startled by is there was actually volcanism on the Moon. Imagine what that must have looked like to the amoebas swimming around on the planet not paying any attention. It was an amazing past, and we can better understand that past by all working together.

Fraser: But how accurate is this method of determining the cratering? I mean, I've heard astronomers say, "Well, you can see that region of the Mars is a billion years old," or "This part is very active and is about a million years old," but how can we know that this amount of craters is a billion, and that amount of craters is a million?

Pamela: Yeah. It gets tricky, especially since the cratering rate isn't constant with time. And we don't know how it varied with time, and so right now what we do is we bridge together the different periods using actually Moon rocks. So the astronauts when they went to the Moon, and the spacecraft (mostly Russian) when they went to the Moon and brought back rocks, they brought back rocks from a variety of different terrains. They brought it back from nice, young areas; they brought them back from older areas, and with each of these rocks using the radioisotope method, we were able to determine, "This area with this cratering rate is this age; this other area with this other cratering rate is this other age." Now, the problem that we run into is we've only done these sample return missions for the Moon. We want to do them for Mars. This is part of the plan for Mars MAX-C mission that's planned for the next decade. We want to do this with asteroids, and right now we're sort of making assumptions. We're saying, "OK, so we think some things happened earlier on Mars -- it's further out. Some things happened later for Mercury -- it's further in." So we're making rough corrections to what we know based on the Moon, based on theoretical models, but for the most part we're within a few hundred million years, which isn't entirely a comfortable place to be, but that's the best we can do until we bring back enough rocks to say, "OK, this type of terrain is this. Period. We're done for the entire Solar System."

Fraser: Right. I can see that part of the process is that the astronomers have…they've got pretty accurate measurements on the Moon, and they've been able to sort of correlate the cratering with the Moon rocks that they're bringing back, but then they're taking that cratering estimate and using that as a measuring stick for other parts of the Solar System, but they haven't backed it up yet with actual samples, which is, you know, hopefully going to come within the next few decades. OK, alright, so that's enough sort of stuff in our Solar System. Well, I guess there's one more object in our Solar System we should probably take a look, and that's the age of the Sun, but obviously we can grab parts of the Sun.

Pamela: No. [laughing] That would be dangerous.

Fraser: …and we're making a pretty big assumption that the Sun formed at the same time as the planets in the Solar System. So how do astronomers know this?

Pamela: Well, so at a certain point, we do assume the Sun formed at the exact same time as everything else in the Solar System, but moving beyond that, we also look at stellar evolutionary theory models, where we say, "OK, the Sun is this size, it had to go through this in the past, it took it this long to get to the stage it's at now." So that's one way of doing it, and then, where we can, we also use, well, in this case instead of radioisotope dating, we call it cosmo-chromatography, and this is where we actually use the exact same idea, but with different types of elements. For instance, strontium is one that gets used when we look at…or scandium are elements that get used when we start looking at stars and figuring out, "well, how old is that?" So there's a whole variety of isotopic combinations that can get us gigayears of age.

Fraser: Right, but we can't take, again, a piece of those distant stars, stick them in our gas chromatograph and get the age. Like, what is the method that they use to determine even just the chemical elements in the stars? How do they do that?

Pamela: So the nice thing is the Sun is actually in some ways a gas chromatograph for us. One way you can determine the composition of things here on Earth is you burn them, and you look and see what emission lines are present in the heated up materials, and you create spectra and use the spectra to get at the composition. Well, the Sun you don't exactly need to set on fire -- it's kind of already there, so when we look at the Sun, all of the atoms in our outer atmosphere, depending on the exact energies, are either emitting wavelengths of light that we can see as spectra emission lights, or much more commonly, they're sitting there absorbing out radiation and creating atomic absorption lines, and by measuring the depth of these absorption lines (do they absorb all the radiation in a given wavelength of light? Do they absorb just a little bit of light in a given wavelength?), by looking at the depth of the lines, it tells us how much light has been absorbed and a variety of other things, like what are the ratios at different temperatures? We can get at the temperature of the star, and then we can get at the surface gravity of the star, and then we can get at the abundance of materials within the star. Unfortunately, it's a three- variable problem, and you have to solve for all three variables, which can get really annoying, but when you're done you know exactly what a star is made of.

Fraser: And so by, again, measuring the ratios of those various elements, which are known to decay at very specific rates, you can determine how old that star is.

Pamela: Exactly, so here we again still use uranium, in this case, we're looking at uranium-238, which has a half-life of 4.47 billion years, and it decays into lead-206. We're also looking at rubidium, which has a 48-gigayear life. We're looking at aluminum, which has a .75-megayear half-life. So we have all these different atoms that we look at, and by looking at all these different combinations, we're able to fine tune to get a good sense of how old things are. Now the only problem with this is you have to be able to get extremely high-resolution spectra to see all these different lines, and to get high-resolution spectra you are somewhat confined to only looking at the brightest stars, and to a certain degree, only using the biggest telescopes, so it limits how far away you're able to use this method.

Fraser: OK, fine. How do astronomers know how old the Universe itself is? You know? Cause, I mean, you can't go and grab pieces of Universe stuff at the Big Bang, you know, and measure its age, so that's gotta be the final, ultimate challenge. How on Earth, do…how on Earth, how on Earth do astronomers determine just how old the Universe itself is?

Pamela: Well, for the Universe in general, because that's such a controversial number in so many ways, we need to have multiple lines of evidence. So the first thing, we say no star is allowed to be older than the Universe -- that would just be silly.

Fraser: That's fair.

Pamela: Yeah, so we just look at the oldest stars and use stellar evolutionary theory models, and we're able to figure out from the cooling of white dwarves, from how long it takes stars of different masses to become red giants, that globular clusters, which are the oldest collections of stars in the Universe are 12 billion years old, give or take. So we know the Universe is more than 12 billion years from looking at the stars, and then beyond that, we have to start looking at cosmological models and matching the predictions of those models to what we see when we examine the cosmic microwave background, and the evolution of structure in the Universe, and from the using the WMAP (the Wilkinson Microwave Anisotropy Probe), we're able to study what was the distribution of hot spots and what was their size on the cosmic microwave background radiation, and we've done entire shows on this so you should go back and listen to those.

Fraser: …one whole episode on just how old the Universe is.

Pamela: Yeah, so go back and listen to that, but it boils down to a whole lot of scary, complicated math (and geometry, more to the point), that tells us that our Universe is more than 13 billion years old. So the stars and all of the fancy calculations using the cosmic microwave background all get us to the same place -- and it's all consistent with what we see from radioisotope dating.

Fraser: And now we have that really precise, precise number. I mean, now we know it's 13.75 (plus or minus .17) billion years old.

Pamela: Yes, and they just keep adding new decimal points; the accuracy just keeps getting better.

Fraser: As successive versions of these surveys of the microwave background radiation come out with more sensitive instruments, they'll just keep adding decimal places, but we're pretty confident with the 13.7 part.

Pamela: Yeah.

Fraser: That's really cool.

Pamela: So we live in an old universe on a fairly young planet, and we're still at the beginning of the Universe, but we're at the most interesting time. And so all these techniques have ganged up to give us a consistent result, and we'll continue to work into the future, and it's just one of those neat things to see the pieces building together.

Fraser: Sounds great! Alright. Well, thanks a lot, Pamela.

Pamela: My pleasure.