AstronomyCast Episode 249 for Monday, January 23, 2012:

Schrodinger's Cat

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: I'm doing really good. Once again, for everyone listening, we are recording this episode of AstronomyCast as a live Google plus hang-out, and the big innovation that we've got this week is: 1) a commitment to a schedule, I think, which is important, so we're going to be recording AstronomyCast usually on Mondays at 12:00 noon Pacific, 3:00 p.m. Eastern and 8:00 p.m. London time, so if you want to try and catch the recording live, that's approximately the time that we're going to be doing it; although we'll, you know, depending on Pamela's…

Pamela: There'll be occasional Wednesdays when I travel.

Fraser: Yeah, your travel schedule, and we're going to try to get shows done ahead of time to catch up, so that's the plan. The other cool thing is that we've now got a page dedicated at CosmoQuest, which is the, well, we can explain that separately, but at CosmoQuest.org/hang-outs, and so what's really cool about that is that you can then go to that page, and you can, you know, just a few minutes before the show's going to start, and then when the show starts, it should just appear in that window and then you can actually watch the show. We're hoping that we can minimize the amount of: missing the show, or people wondering where it's going on, or they miss when it started, or…all of that. We're going to try to make it as regular as possible then, now that we have access to hang-outs on air. Now, Pamela, I don't think we've really gone into CosmoQuest. Did you want to take a second and explain the short version? Because I know that you can take an hour to do this, so give us the short version.

Pamela: So the short version is for a couple of years now, Fraser and I have talked about building a community where people are working on doing astronomy, learning astronomy, and basically recreating the idea of an academic learning research environment – a university, basically, but for everyday people working at home in their spare time. So we've talked about figuring out how to get telescope time, we've talked about "pie in the sky" getting our own satellite, but at the more simplistic level, CosmoQuest launched, allowing you to basically become part of the science team for the Lunar Reconnaissance Orbiter, and we are also working with the Messenger mission, the Dawn mission and the Hubble Space Telescope, and we are going to be providing you things like this show streamed live, star parties, and ways to do science that gets published and is actually really useful and needed by the scientific community.

Fraser: Yeah, it's really our belief that regular people who are interested in science who haven't necessarily gone and gotten their Astrophysics degree and their PhD can still contribute to science in meaningful ways: in identifying objects, in classifying things, and even with, you know, with small telescopes and some of the amazing amateur telescopes gathering light from variable stars, searching for supernovae…there's a ton of things that regular people can do to get involved in actual astronomical research, and so we're trying to develop tools that will bring researchers together with the public to participate in science and if things work out, well, maybe we'll be able to actually change some of the ways that science gets done -- so I think it's pretty exciting.

Pamela: …and the way science gets learned. No longer do you have to get signed up for the $1000-credit-or-more university classes. We're going to be providing you classes right here on CosmoQuest as well.

Fraser: Yeah, so again -- great big experiment, and it will take us a while to figure all the pieces out, so if you want to join us you can go to CosmoQuest.org and you can actually sign up, and you can see some of the tools. What do we have right now? We have the Moon Mappers?

Pamela: We have Moon Mappers is "live," we have Wikies in place but not yet populated with content. The goal is to get information on how to reduce NASA image data. We have lots of content. We have a blog, we have a forum, and if you have ideas for what you want to see, get on the forum and tell us what you want to see, and we'll work to make it happen.

Fraser: Yeah, but the big one, I mean with the Moon Mappers, people can actually classify objects on the Moon, and that's used by researchers. So this is some real science happening.

Pamela: And the other thing that's most important is with Moon Mappers you can fix the output of computer algorithms, so what we're trying to do is determine what is the most effective way to map the Moon: computers, humans, or some combination of both. And you can be one of those data points that helps us figure it out.

Fraser: Alright, well, let's get on with today's show, but you'll be hearing a lot more about CosmoQuest as we sort of flesh it out more.

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Fraser: Alright, so you've probably heard of "Schrodinger's cat" -- that strange thought experiment designed by Erwin Schrodinger to show how the strange predictions of Quantum Theory could impact the real world. No cats will be harmed in the making of this episode – maybe.

Pamela: [laughing] There are no cats near me. Fraser may have a cat; it's up to him to harm a cat if any cats are going to get harmed.

Fraser: Maybe, maybe, maybe…it's uncertain. It's uncertain what will happen in this "multiverse." Alright. So then, where do you want to start? Let's just start with the, sort of, the Schrodinger's cat thought experiment as initially described by Schrodinger. How do you describe it?

Pamela: So the best way to describe it is a thought experiment designed to mock a scientific concept. A lot of people really struggled with Quantum Mechanics while it was being developed, and in fact a lot of people still struggle with Quantum Mechanics.

Fraser: What do they say? Those who say they understand Quantum Mechanics don't understand Quantum Mechanics.

Pamela: Something like that. So Schrodinger came up with the thought experiment of: say you've got a cat -- a nice, big, tangible object -- you put it in a box, you can't see inside the box, you can't hear what's inside the box, cat is now in a box, you assume that it can breathe, it can eat, it can do all the catlike things it needs to stay alive under normal conditions, but then you put with the cat something that undergoes a Quantum process (in this case, radioactive decay), and all Quantum processes are described through probabilities, and one of the ideas of Quantum Mechanics is until you observe something, it's in all the probability states at once. So if you have a material, and you're not sure if it's decayed or not, well, until you look at it, it has both decayed and not decayed. And this idea that something can be in multiple states at once led Schrodinger to basically say mockingly, and this was all meant mockingly: "The cat is both dead and alive inside the box." And what's great is what started out as a way of scoffing the idea has since turned into the way we describe it.

Fraser: Well, so let's unpack that a bit then. When we say that the cat is both dead and alive, that particles decay and don't decay, what is the sort of Quantum Theory that's underpinning all of that?

Pamela: So in this case, we're talking about the probability tied to radioactive decay. We could just as easily be talking about the Quantum probabilities that a given atom will be in a specific energy level. Lots of different things are…

Fraser: Right, photons going through the slit experiment…

Pamela: Right, so lots of different things are guided by a probability, and the thing is you can't know *a priori* -- you can't know ahead of time which atom is going to behave in which way, and because it's probabilities, there's always the chance nothing's going to behave in a certain way, so imagine the radioactive isotope polonium-210; this is an isotope that periodically gets used to murder people because it has 138-day half-life, it gives off a whole lot of energy in the process of decaying. It's rather potent stuff. Now, if you happen to have, say, about 280 atoms of this on any given day, one of those atoms should decay, and after 138 days, well, half of those atoms should have decayed, but that's a probability -- it's only a probability, so it could be none of them ever decay, it could be all of them spontaneously decay, it could be that they go off in dribs and drabs where 20 decay in one day, 0 decay in the next several days – it's all defined by probabilities.

And according to Quantum Mechanics, until you observe what happened, everything has happened, and all of those different possibilities co-exist at the exact same time until the observation is made.

Fraser: So how…that's the weird part, right? I mean, you can take it back to the cat idea, and you can put the cat in a box, and you've got particles that decay and…but what is the…what is this process of, you know, "until you observe it?" How…you know, what does that mean? Until you observe it, you don't know that the thing has happened?

Pamela: So with Quantum Mechanics, stuff (atoms, cats, particles of all different types) exist in wave functions, and all of these different wave functions are said to be interacting with one another, and if you've ever been in a room with really awesome acoustics, you've walked around maybe speaking or humming to yourself trying to find that sweet spot in the room where all the echoes come back and add together to increase your voice, or walked around looking for that place where when you hum you hear no echoes coming back…well, what you're hearing is all the waves interacting with one another. Well, in Quantum Mechanics, you have all the different wave functions for all the possible things that can happen, and they're all resonating together, but you don't actually hear: Are they growing? Are they killing one another off? You can't hear the result until you listen, until you make the observation, so all the possible outcomes: the echo that builds the sound up, the lack of echo that is the dead spot in the room -- all those possibilities simultaneously co-exist in wave function, and it's through making the observation that you determine how the waves at this particular moment have collapsed down into reality.

Fraser: And when you say "making an observation," what are the kinds of things you can do to make an observation?

Pamela: Well, so with an atomic radioactive decay, you look to see which atoms are in which state, so it's literally a matter of looking to see so how much of the polonium-210 has decayed into lead-206, and so it's in that atom-counting stage that you make the observation, or alternatively, you can have a detector for alpha particles. These are the high-energy helium nuclei that get flung off in the radioactive process, so you can look for that helium nuclei flying off, and that's another way of making an observation, or for the cat -- you open the box.

Fraser: Right. OK, and so then as Schrodinger sort of originally described this experiment, what are the pieces of the puzzle that he, sort of, in his joke, I guess, the way he put it together because I know its kind of morphed into other things since then, right?

Pamela: So for Schrodinger the idea was you take a cat, a healthy, nice cat, you put it in a box that will generally preserve its life, and you put in the box with the cat something radioactive that is going to undergo a radioactive decay, and you put with it something -- a Geiger counter, some manner of detecting the radiation that is given off during that decay process in there with the cat, and you attach to that decay detector a vial of poison, and the second the detector detects a decay, it releases the poison and the poison kills the cat. So the idea is that the entire system is one convolved set of wave functions, where at any given moment, the wave functions that describe all the different possible states of all the different possible atoms are causing the cat's wave functions to be in states of dead or alive all at the same time…that it all gets entangled together until someone external observes the system and goes, "Cat is dead; therefore, detector detected nuclear decay process; therefore, something decayed." Now, the reality is the cat does observe its own death; it knows when it died (or the autopsy will determine that), but it's still one of those "Oh, that's kind of freaky!" kind of things.

Fraser: So before the observation was made (but I guess that's the point, right?)…is the cat made the observation, but I guess the way the thought experiment is going is before the experimenter opens up the box, or takes a look to see how the wave has collapsed, the cat is both alive and dead at the same time.

Pamela: Right. And this applies to lots of different systems, so you have it applying for radioactive decays, you also have this applying to the distribution of atoms in different energy states, so for instance, if you grab a neon "Open" sign, it's not always filled with neon gas, but this tube of gas that glows red, green, whatever color it is when it is that it glows when it says, "Open-Open-Open," the individual atoms in that aren't all at the exact same energy state all of the time, and there's an equation called the Boltzmann equation that looks at the temperature of the gas, looks at the density, looks at a lot of different things and says "How many of the atoms are going to be in each of the different energy states?" But it doesn't say which atom is in which state, so you have to observe the individual atoms to get at, "OK, did you fall into this probability? Did you fall into this probability?" And so there's all these different things that follow probabilities, but we can never say which atom behaves in which different way.

Fraser: But how is it different, practically, from the thought experiment? I mean, I know that if you put a cat into a box and did this experiment for real, I mean: 1) you'd get a call from PETA, but 2) you would…

Pamela: Yeah, don't do this experiment.

Fraser: You don't do this, but it also wouldn't work -- for real.

Pamela: So the for real problem is while all of the atoms do have all of these different states, the fact that you have the detector making the detection means you know whether or not something happened, and that detector is making the detection. Now, one of the interesting things there's a Quantum Mechanics paper a few years ago that basically said simply by being in existence and observing our universe, we're changing the quantum state of the Universe just by observing it, and every time we observe it, we reset the probabilities on different things, so at a certain level, we're not entirely sure where this breaks down and where it doesn't. We just know that things are dictated by probabilities and that observing things screws them up.

Fraser: And so then, what is the, I guess, what is actually going on? Like, if this was designed, this thought experiment was designed to highlight how weird Quantum Mechanics is, but what are the implications for this thought experiment in sort of Quantum Mechanics itself?

Pamela: Well, one of the interesting things is you can actually use this to look at how light changes as you pass it through a variety of different polarizers. So you can take a beam of light and pass it through a filter, and all of the light downstream from it should have a given polarization, but you can reset the probabilities through the stream as you go, and there's lots of creepiness that creeps in. The other thing is you can send atoms, or electrons, or just individual photons of light through a single slit, and as they go through the single slit, their positions where they land they move around and land in different places based on the assumption that they go through as a whole stream, and the most likely place they're going to land, due to interfering with one another, is in the center of the screen, but those interference patterns cause them to sometimes go off to the left, go off to the right, and build up this what's called a "fringe pattern," an interference pattern. Now the thing is you get the exact same pattern if you send 10,000 photons through, as if you send one photon through at a time 10,000 times, so somehow, and we're not quite sure how, the photons, the electrons, the atoms (I think this has actually been done with

Buckyballs now)…they know what their probability distribution is, and it's like they interact with all of those atoms, or molecules, or whatever that haven't gone through yet, and so the Universe is simply proving it's weird over and over and over again, and allowing us to know all these wave functions are out there waiting to interact with one another.

Fraser: There's a couple of shows that we've actually done in the past that people might find interesting. We've done a whole episode just on "entanglement," which is I think what you're talking about here, we've also done one on Quantum Mechanics, and we've also done one on "multiverses," but I think it's multiverses that there's a lot of really interesting overlap with the Schrodinger's cat experiment, and, you know, what could be a possible explanation -- a way to resolve it, right?

Pamela: Yeah, so trying to understand, "what exactly does this mean?" leads to a lot of, well, head-scratching, a lot hair-pulling as well, and occasionally, students crying over their homework assignments. One of the interpretations of this is what you're actually seeing is when something passes through a slit, it takes every possible option, and it's interacting with itself. Another way of looking at it is through all the different multiple universes that might be out there. We don't know if we're single universe or many universes. Every possibility is being realized, so in one reality, the photon goes straight through and hits in that most probable sweet spot, in another universe it goes through and goes all the way to the left, so every possibility is being realized and it's just a matter of, well, which universe are we in? And what we see just depends on the flip of the coin of which reality it is. Now this means on a macroscopic reality, if I woke up this morning and got out of bed, I could have simply did as I did and actually stand on the floor and make it out of my bed and out of my bedroom, but in another reality I might have put my feet on my dog as I got out of bed, and had the dog explode, and landed on my butt, and had to be taken away in an ambulance. Everything that could happen does happen in a universe, in this multi-universe, is another argument that quantum mechanics…

Fraser: And I guess to take it back to Schrodinger's cat, the cat in one universe is alive, and in another universe it's dead.

Pamela: And this leads to the one possible way of testing if we're in a multiverse or not, which no one should ever do, and this is the suicidal scientist experiment, where you put a scientist in a box instead of Schrodinger's cat, and there's going to be some universe where the rules of probability are such that, well, while half of those atoms should decay in a half-life, that doesn't mean any of them necessarily are going to, and there's this infinitely tiny probability that if you put someone in a box with radioactive material, none of it is going to decay as it's supposed to, it's an infinitesimally small probability, but that means there's some universe out there where you put that scientist in the box with the polonium 210 with its 138-day half life and 138 x 5 days later, still nothing has decayed, that scientist is still alive, and that means that that scientist is in the one universe that beat the odds, that did that tail-end of the probability distribution. That means in every other universe, though, that poor schmoe is dead, so don't do this experiment, but it's the only way we've come up with to test the multiverse theory.

Fraser: And so have other thought experiments been put together? I mean, you've got that one of the suicidal scientist. Are there any other thought experiments sort of in the same vein as Schrodinger's cat?

Pamela: Well, those are the main ones. At a certain point you start getting into Quantum entanglement, which we've done shows on as well, where you start looking at, "OK, these two things both were emitted in the same experiment. That means that if this one has these set of states, that one has to have that set of states in order for the properties to be preserved, let's observe them switch and see if we can prove that these suckers stay tied together," and so then we start getting to messing with the Universe, and it stops being thought experiments and it starts actually being "let's shoot photons of light down fiber-optics as far as we can to see if we can keep two different photons entangled for as long as possible."

Fraser: And we can.

Pamela: And we can.

Fraser: Well, not "we" obviously…

Pamela: Other people -- I just read the papers. It's really amazing because as much as people dislike Quantum Mechanics, and what's strange to me is we get letters all the time from people saying "Relativity is wrong."

Fraser: Relativity is wrong…yeah.

Pamela: But we don't get the same ones for Quantum Mechanics. Instead we get the "Quantum mechanics is my religion," and I'm not quite sure why people get upset about Quantum Mechanics making their stomach and their head hurt, but then embrace it as a religion; whereas, people find Relativity makes their stomach hurt and their head hurt, and therefore they reject it and come up with alternative non-mathematical theories, but for whatever reason, this weirdness, this probability distribution way of describing the Universe is readily embraced by a lot of people out there as, well, "It's just the probabilities that I had a bad day."

Fraser: Yeah, we call that "Quantum Wu" when a person takes Quantum Theory and sort of embeds it in their own alternative theories about how the Universe works.

Deepak Chopra does that a lot.

Pamela: Yeah, there are a lot of people try and use Quantum Mechanics to justify belief in a lot of things like telepathy -- and we reject that concept.

Fraser: Alright. Cool! Well, thanks a lot Pamela. That's one of those topics that we get a ton of email from people wanting us to explain it. And, I wonder why people find that…this thought experiment so fascinating.

Pamela: The idea of a cat that is both dead and live is just visually awesome, and sometimes all you need is that thought experiment that has that cool visual, like the twins that age differently from General Relativity. You just need that cool visual that goes on a t-shirt.

Fraser: And so I guess if you're a physicist and you want your theory to last into the future that everyone's going to reference, you got to figure out a way to really make it pop.

Pamela: A great thought experiment with a great cartoon sketch.

Fraser: Yeah, then you're set. That's great. Alright. Well, thanks a lot, Pamela, and we'll talk to you next week.

Pamela: Sounds good, Fraser. I'll talk to you later.