Astronomy Cast Episode 215
Monday, January 10, 2011: Light Echoes

Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the Cosmos, where we help 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 at Edwardsville. Hi Pamela! How you doing?

Pamela: I'm doing well. How are you doing Fraser?

Fraser: Doing really well! So one quick announcement, which is you've been confirmed as a guest for Dragoncon 2011. Is that right? Yes, I have applied as a guest; I have not been confirmed yet, but I'll make a big stink if it's all been (laughing)…so expect an "Astronomy Cast Live" at Dragoncon, which will be Labor Day weekend 2011.

Pamela: And we will be looking for volunteers to help us man a kick-ass booth, with all sorts of NASA stuff, so be thinking ahead.

Fraser: There you go! OK, so if you were on the fence, "should I go to Dragon*Con?" Yes, you should! We'll be there. Alright, so just as sound can echo off of distant objects, light can echo too, and the echoes of light bouncing off stellar remnants, black hole accretion disks, and clouds of gas and dust provide astronomers with another method of probing the distant Cosmos: light echoes. So then, we know what a regular echo is, you know, "echo…echo… echo…" so what is the difference between a regular echo and a light echo? What are we looking at here?

Pamela: The only difference between the two of them is in one case, you have sound waves bouncing off a distant object and taking a non-linear path to get to whoever's doing the hearing. Those two sounds: the first echo and the second echo, get heard at different times.

Fraser: So we've got a sound source like a siren or explosion or whatever…someone yelling "echo..."

Pamela: A duck quacking -- and duck quacks do echo.

Fraser: And then the sound bounces off some surface: a wall, canyon wall, a whatever, and then that sound comes back at us and we hear the source again, but now it's a reflective version. So non-linear: it went one way, bounced, and then comes back at us. Well, I guess it's bouncing and going in all directions, but we get some of it back into our ear.

Pamela: Exactly. So, in both cases it goes in all directions and it just goes in all directions from the reflective point, and in all directions from the originating point, so you can experience echoes with all sorts of crazy geometries. You can stand on all sides of that duck and get an echo.

Fraser: Right.

Pamela: But with light, it's the exact same thing. It's just the light is radiating in all directions from the source, and it could be that there's an object off in the distance, a giant super-galactic mirror, and some of that light travels to the mirror and then bounces in all directions off that mirror, and makes it to us via a different path.

Fraser: Now, we can experience the sound echoes because the speed of sound is relatively slow. I mean it's only, whatever, 1000 km/hour, so it's not very fast, but the speed of light…I guess you need these big stellar, astronomical distances before you can start to see them.

Pamela: Right. If you want to actually *see* a light echo with your eyes, you need one mammothly bright light source, which conveniently the universe does provide, but you also need the light to go a fairly long distance, and one of the other things that's kind of key is having a *pulse* of light. Having a source that's just sitting there "beam beam beam beaming," you don't end up with as neatly defined an echo as you get from a pulse.

Fraser: And I guess once again we could translate that back to sound, like if you have a horn that's just sounding non-stop, you're going to have a really hard time picking out the echo of the horn, but if you get a pulse of it, then you'll be able to hear it in the echo. So then, what are some of the events that can cause these echoes?

Pamela: Well, the most common one of all (and the type that we see all the time if you have an amateur telescope and you like to just sort of troll around for neat fuzzy things) is supernova remnants. You have a star that exploded in the distant past, it let off a huge blast of light for a short period of time by cosmological scales, and that blast of light radiated away from the now-remnant of the supernova, the neutron star, the black hole in the center, and as it radiated away, it created a show of light. And so when we look out and we see these beautiful ring-like nebulas, we're seeing, in some cases, light that hit the surrounding material and then got reflected back toward us, and in some cases, we see where the light has hit the surrounding material and caused that material to heat up and give off it's own light. So it's a mix of those two different cases, but as that show of light expands and expands and expands, it has less energy to excite that surrounding material, so what you're seeing more and more is just the reflective light from that expanding sphere.

Fraser: Wow! You could think about this cloud of gas that's just around the star -- the stellar remnant -- and I guess that was sloughed off over millions, or hundreds of thousands and millions of years, but when we look at a supernova remnant, we're just seeing this pulse of light moving through it, and so if you looked again in 1000 years, it would look different – or not at all.

Pamela: Well, what's amazing is you don't even have to wait 1000 years. The Crab Nebula, one of the favorites for amateur telescopes because it's just really pretty…this is an object that we've been able to take pretty high-resolution images of, well, since the very first astronomical glass plate cameras got developed. And you can take some of these old black and white glass plate images and compare them side to side with modern images and intermediate images from the years in between and you can see how the remnant is expanding over time, how the "glowy" stuff is overwhelming more and more stars over time, so just over a human lifetime, we can see these remnants expand when they are near enough.

Fraser: And as you said, in some cases, the material of the nebula is being heated up and then that's emitting light, and in other cases, there's actually a pulse of light from some event moving through and then we're seeing the reflection, we're seeing the echo of it. After the star dies, what could then cause some of these pulses of light?

Pamela: Well, the supernova itself – that's the pulse of light that we're seeing over time. It's just that one expanding sphere of light from that single moment when the supernova went off.

Fraser: OK, but there are stars that are in the process of dying, or having bursts and flares on its surface – we can see that…

Pamela: Right, and it's not just supernovae that we see these things from. You're right, it's all these other types of random events as well, and I think the most famous one is V838 Mon. This mysterious object that back in 2002 suddenly gave off way too much light, and then as it got looked at over the succeeding years, we saw this fuzzball of swirly material around it getting illuminated as the light from that flare event slowly propagated around the surrounding inter-stellar media.

Fraser: Yeah, and you know most people are going to be pretty aware of this picture -- it's very famous, but you know if you haven't, look it up: V838 Mon. And if you see the picture, it starts out as this little ball, and then it grows into this beautiful clouded swirl around the central star, and if you look at the picture, it really looks like it's expanding outward, but I guess all that material was already there, we're just seeing the light echo.

Pamela: And this is a really neat case that allows us to explain two different things in physics. The first one is, we're able to figure out the distance to this sucker by using the light echo because we know how fast light travels, and if we assume a roughly constant distribution of material around the central star, by watching how fast in angular size that object appears to grow on the sky, well, we know how fast it's actually growing (because that's the speed of light), and we can figure out the distance by knowing, "OK, this angular size on the sky corresponds to this actual size in reality, and in order for the triangle to have that actual distance across the sky appear to be that angular size…" I do trigonometry and I figure out of the angle, and I figure out the distance as a result. So we can figure out that this previously not cared about star, is 20,000 light years away (about 6 parsecs) just by watching how rapidly that sphere of illuminated material has grown.

Fraser: Yeah, and as we've talked about in other episodes, knowing the distance to astronomical objects is often very difficult and very important for being able to scale all the distances that astronomers look at in the universe. So that's another way for getting at distance.

Pamela: And the other neat thing about this is we know that stars give off material through a variety of different things: there's just your everyday mass loss that's going on, we know that as stars get older they can actually puff out layers of their atmospheres. It turns out in the beautiful structures we see in planetary nebulae and totally don't understand in many cases – well with V838 Mon, we see this funky structure that doesn't have any real geometry to it that's getting illuminated by this expanding outward shell of light. So we're able to see: what does an utterly generic yet utterly weird star's surrounding gaseous material look like?

Fraser: So V838 Mon is really one of the best examples we've seen of a light echo. So are astronomers…have they found other examples of this?

Pamela: As we look out all over the place, there's all sorts of random bits of light echoes that we determine. One of the neatest non-expected examples was the MACHO Project, which was looking for dark matter, kind of, in all sorts of expected but not found locations…like we were looking for stellar mass black holes, for dark stars, like neutron stars and things like that, looking for them to gravitational [missing audio] against the background. While the MACHO Project was taking image after image after image after image of areas of the sky looking for these micro-lensing events we call them, we got enough images -- I wasn't part of the we -- we, as a community, got enough images that when they were co-added together, when they were stacked in the light and one after another was added together, extremely faint structures could suddenly be seen and they kept finding these weird arcs of light, and over time they could see these weird arcs of light moving through their fields, and so they started recording these weird arcs of light and they were able to trace them back to some fairly recent supernovae…so again this supernova, but we're finding light echoes all over the place. And now as we look out as cosmological distances, we're also starting to find what had been anticipated, and this is light echoes from the extremely bright light emitted from quasars.

Fraser: And I know that you have sort of a personal stake in this discovery, right?

I do! So I work with the "Zooniverse," this is the collection of online citizen science projects: "Galaxy Zoo," "Moon Zoo," we have "Mercury Zoo" hopefully coming at the end of 2011. It's a suite of projects to get everyday people looking at images that scientists don't have enough time to just pour over. And finding light echoes isn't something you can program a computer to do because you never know what shape, what orientation, what size they're going to be. And it turns out that one of our "Zoo-ites," Hanny Van Arkel was looking through images of galaxies, classifying them as she went, and she saw what basically looked like a blue swamp thing dancing through one of the images. It was down and to the side of one of the galaxies, and she asked on the forums, "What is this thing? What is this Voorwerp?" And it turned out she'd found the first known and theoretically-expected light echo from a quasar.

Fraser: Have more been discovered since then?

Pamela: We have several potentials; they're still being followed up on. There have been blue smudges (or green smudges depending on how you map your colors) found near a series of other galaxies. It's hoped some of these will turn out to be light echoes. We're still trying to figure it out.

Fraser: So what's going on with this situation? You've got a galaxy, you've got a blue smudge nearby…what are the physics? What happened?

Pamela: In the past, the central galaxy, the nearby "disky" thing that you can see in all of the images online, the quasar in the center was actively feeding on material, so it had a brightly glowing accretion disk. The accretion disk had a magnetic field, and this magnetic field was generating jets and just like you see in some science fiction movies – Han Solo fires his laser gun and you can actually see this pulse of green light traveling through the sky – well, that's one of the problems. That wouldn't actually happen such that you can see its light actually traveling a little too fast. But with a quasar, you get this beam of light traveling through space, and when the quasar stops eating stuff, when it returns to being a quiet black hole, that pulse is left behind still traveling through space. So imagine if you will, any of the pictures you've ever seen of an active galaxy with these *giant* radio jets! Well, eventually these giant radio jets are going to come unattached at their base, and they're just going to keep traveling through space – giant radio jet attacking the nearby universe.

Fraser: Now, is that because the black hole itself has stopped feeding?

Pamela: Yeah, that's all it is. You have to have a feeding black hole, and as soon as it stops being a messy eater, those jets turn off.

Fraser: But the radio and light emitted is going to keep moving through the universe…so that's what was bouncing off some nearby rubble?

Pamela: Essentially. This is just the inter-galactic material that permeates all of space to varying degrees. Now, what's really neat about these light echoes is just like light from a flashlight, you can end up with shadows in the beam. So if you take a blob of tape and stick it to the front of your flashlight, the light that it casts on the wall or the floor or whatever you're trying to light up, will end up bright everywhere except for where that tape is, and with Hanny's Voorwerp, it looks like we're able to see the proverbial fly in front of the movie camera beam in the form of a shadow that is causing Hanny's Voorwerp to look like a dancing Kermit the frog holding his arms out in a circle where that circle inside the arms is the shadow of something that was down near the center of the quasar.

Fraser: And I know that we've had something similar even in our own Milky Way. I remember doing an article a couple of years ago about seeing light echoes from material that had been consumed by our own super-massive black hole at the heart of the Milky Way, but it hadn't been like a lot of material -- just like a Mercury-sized object had been gobbled up several decades ago or hundreds of years ago, so we could see that light echo of that material.

Pamela: And this is one of those things where you get into trouble in talking about "something happened a couple of hundred years ago, something happened a couple hundred thousand years ago…" because it's a couple hundred years before the light we're actually receiving reached our eyes.

Fraser: Right, which could be ten thousand years ago was when the light was emitted…right.

Pamela: So this ends up leaving some very hard-to-read stories and things like, "When did the black hole in the center of our galaxy eat material?"…"When did Hanny's Voorwerp form?"… because, particularly in the case of Hanny's Voorwerp, you're looking at an object 65 million light years away, and you'll read an article that says it's 65 million light years away, and the quasar likely turned off in the past 100 thousand to 300 thousand years.

Fraser: Right, plus 65 million years, right?

Pamela: So you have to remember: *add* the "plus." So our central super-massive black hole here in the Milky Way might have eaten a Mercury-sized object *yesterday*, but we won't know about that for a good long time.

Fraser: And I know we get the complaining emails, we get the nasty comments on *Universe Today* like, "Well, it didn't actually happen yesterday; it really happened 65 million years ago *plus* yesterday." We understand. We get that, but in many cases we've talked about time…it's all so complicated.

Pamela: It's all so relative.

Fraser: It's all so relative, but one of the neat things about this is you can see events happening that you wouldn't necessarily have a clear view to, right? I mean, you could see if the center of the Milky Way is all clouded with dust and gas. You're not going to be able to see that, but maybe you will be able to see light echoing off something that you do have a view to.

Pamela: Right, and this is where one of the things -- I know that there are going to be theorists cringing when I say this --

Fraser: Don't listen! Put your hands over your ears, Theorists! This is not for you!

Pamela: Now that you're not listening, Theorists…with our sun – if there's a flare on the other side of the sun, we might be able to see that light reflected off of Venus, or one of the other planets on the other side of the sun, even though we don't directly see that flare. And so this allows us a second opportunity to see events, and something that is very much not a light echo at all, but when we look at quasars and we see multiple images of the same quasar due to gravitational lensing, that gives us a chance to "Oh, I saw this flicker in the first image. I know the other two images are going to take longer to get here. Let me make sure I get the entire moving into the flicker moving out of the flicker observing run by looking at those other two images of the same object." With light echoes, you get that same sort of effect of "Oh, there is some sort of fine scale flickering in whatever it was that's triggering this expanding ring of material that we see as the outermost edge," but what we forget is that the back part of that sphere arrives to us well after the front part of the sphere and the sides of the sphere. So we get an extra chance with things like V838 Mon, and other objects like that that are expanding spheres, to see those flickerings as the material in the background moves backwards, hits the back wall of the material that's reflecting off of, and then comes towards us.

Fraser: So then, this is a tool in the tool kit for astronomers. This is a way for them to, as you said, study distance, try and find out when things happened…so what would an astronomer really want to use a light echo for?

Pamela: With things like V838 Mon, we use it to study both the detailed flickerings of that central object by looking at when the light hits us from the different parts of the shell. It also allows us to map the material surrounding the star.

Fraser: Right. I guess you could say, "Oh, looking at the five light echoes, it seems to flare out every X years."

Pamela: Right. Now, with things like Hanny's Voorwerp, we use the light echo to be able to say "OK, we now know this quasar had to have shut off within the last hundred thousand to a few hundred thousand years. And we can now study what is the environment of a "just-died" quasar, and this allows us to understand: how does the accretion disk fall apart?…how quickly does the energy dissipate?…all these detailed physics that we couldn't study before because, well, we didn't know where the dead quasars were located. This also allows us to map out, "Well, what is the general distribution of random gas in our galaxy as we look at the results from the MACHO Project, where we can see all these thin filigree light echoes traveling through just the normal inter-stellar gas?" They're just really, really good at mapping out where all the gas is located – things we didn't know we cared about, and now we know we do care about.

Fraser: And it's also quite powerful for probing supernovae, both the ones that we see happen in the sky, but also the ones that happened before we were taking good observing data.

Pamela: Right. So this gives us the chance to figure out, "OK, I see this echo, I know how fast the echo is growing, I trace it back to its source, I know when that supernovae -- that no one bothered to write down -- had to have occurred in the past. And then light echoes are also guilty of triggering their own things happening. The light echo from the quasar that caused Hanny's Voorwerp, triggered star formation. The light echoes from different supernova remnants are triggering compression of the inter-stellar media. So these light echoes, they carry force, they carry energy and we see the reflected light and we also, in some cases, see the newly-emitted light from the things they destroyed as they traveled through the universe.

Fraser: I think the astronomers studying this are lucky because they get to be in that group of people who are watching things happen in a very dynamic way. Instead of being the kind of astronomer who takes a picture of a star or a nebula or a galaxy and comes back 50 years later, takes another picture and nothing's changed -- these things unfold in days, weeks, months! I mean you look at the data, the images of V838 Mon, and it's dramatic! Just from when the Hubble space telescope took its first pictures to its most recent pictures, the changes are significant and beautiful, and I'm sure it's great to come back a year later and go, "OK, let's look at it again and see how it's different," and then study everything that's changed. It would be really exciting.

Pamela: It can be really confusing to "get" that these things exist. The poor guys with the Macha Project, when they initially saw these ribbons of light cutting across their images, they were like, "What's this? Did we make a mistake? Is this something wrong with our flat fielding?…with our filter? Did we have some sort of interference going on?"

Fraser: Some kind of artifact…yeah…

Pamela: And then you go back and you look, and this sucker has moved! Still there! Still the same thing, but in a different place, and that just leads you to question your ability to read data even more, until you can figure out, "Oh, this corresponds to a fragment of the light echo at such and such a distance."

Fraser: …one of those rare situations where it's not your mistake -- it's a tremendous discovery.

Pamela: And so light echoes can be faint and amazingly glorious like V838 Mon, they can be huge and look like Kermit the Frog like Hanny's Voorwerp, and they can just be wispy arcs of light like they found with the MACHO Project, and all of them produce their own science, and their own exciting revelations and they're within your grasp. If you go look at a supernova remnant with your telescope, and you can watch those supernova remnants change on your own -- from 1987A all the way out to observing the Crab Nebula and pulling old images off the internet. You can see those changes on your own.

Fraser: That's great! Well, thanks, Pamela.

Pamela: It's been my pleasure.