Astronomy Cast Episode 233 for Monday, October 3, 2011: Radar

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'm doing well. How are you doing?

Fraser: Good. Good. So, I don't know if people missed it, but we were on the Skeptics Guide to the Universe' 24-hour marathon, I guess, yesterday when we were recording this, and we were able to put Steven Novella to sleep.

Pamela: It's something to be proud of.

Fraser: It really is, it really is. I feel like that's going to be something I will treasure forever. Yeah, but if you missed it you should check it out. I'm sure they're going to be releasing it in some form on audio or video, or whatever, but anyway, huge congratulations to the SGU folks, and all the people who helped them out. It was an epic 24-hour show-a-thon, which we will never ever do.

Pamela: And they actually got Rebecca Watson to *enjoy* Dungeons and Dragons.

Fraser: Dungeons and Dragons – I know, I know! That was awesome.

Pamela: She is now a geek like us.

Fraser: Exactly. So Radar is one of those technologies that changed *everything*. It allows boats and aircraft to see at night and through thick fog, but it also changed astronomy and ground-imaging -- tracking asteroids with great accuracy, allowing spacecraft to peer through Venus' thick clouds and reveal secrets through the Earth's shifting sands. Alright, Pamela, Radar… now Radar is kind of just radio astronomy, right?

Pamela: Sort of, but not really…so the way to think of it is lighting something up with a flashlight and Radar are the same thing, but looking at a star and looking at a radio source are also the same thing, but in one case you're looking at reflected light. So radar's reflected light, flashlight shining on wall is reflected light, and in the other case, you're looking at a light source. So looking at a radio source with radio astronomy and looking at a star or a galaxy with an optical telescope is looking at a light source as well.

Fraser: Right, so the difference here is that when you are doing radio astronomy, you're looking at some radio source, some galaxy, some…you know, Jupiter, who knows what it is, and it is giving off radio emissions, or emissions in the radio spectrum in addition to all the other emissions it is giving off, but with radar, we are sending out an electromagnetic beam, a pulse, a blast of radio waves of microwave – whatever. It is bouncing off an object and coming back to us, and then we're studying the reflection of that to learn something.

Pamela: Exactly, so maybe you could say looking at a planet in optical light, and looking at a planet in radar is the same thing because, in both cases, you're looking at reflected light -- it's just the optical light is reflected from the Sun.

Fraser: OK, so radar is not a different, sort of, part of the electromagnetic spectrum, it is purely almost like it's a technique.

Pamela: Exactly.

Fraser: OK. Cool, cool. Um, so then can you…let's go with the history then. It's funny, you know, radar is one of those things that we use all the time. When I was a kid, we used to travel on this ferryboat. You know, I lived on a small island and I knew everybody and I knew the captain of the boat, and I used to go up to the bridge and I could watch the radar while we were going across the channel, and I could actually see other boats and land masses and stuff in the radar as the radar was being updated – really neat! So…and we use it for airplanes, and people, you know, maybe didn't realize how much it gets used for astronomy. So where did this technology come from in the first place?

Pamela: Mostly it comes from scientists being scientists and playing with the electromagnetic spectra. In the late 1800s, in the 1880s and 1890s, we started to realize that light was more than what we could see with our eyes, and scientists started realizing, "Hey, I can create radio sources, and then detect those radio sources. Hey, I can create a constant sound in radio and then reflect that off of something else and by looking for how the reflected light comes back, how long it takes to come back, I can realize there's something out there." So just as we were figuring out how to do radio broadcasts, hand in hand, we were realizing that when radio reflects off of things, well, that reflection means something there, and that's kind of cool.

Fraser: Right, OK, so I can imagine you've got this technology, you're starting to be able to detect things, but it…when did they really put it into some kind of practical use?

Pamela: Well, it…practical really started to come during WWII, and unfortunately it came a little bit slower than it should have. There's a rather frustrating story related to Pearl Harbor. America, Great Britain, New Zealand, Russia – nations all around the world -- were struggling to figure out how to use radar to detect incoming ships, to detect incoming aircraft, to basically figure out, "Holy 'expletive!' We're about to get killed!" and be able to get out aircraft, be able to get people into shelters ahead of time to help save lives, and we hadn't gotten to the stage yet of everyone in the military fully understanding the power of radar to detect things, and when you don't have fully trained leaders, bad decisions get made. So at Pearl Harbor out in Hawaii, there were a couple of privates who decided to get in a couple extra hours of training on radar, and these were radar stations that were actually supposed to be shut off, and basically their truck hadn't come to take them off to get a meal, so they turned on the equipment and started practicing, and while they were sitting there practicing, they realized that there was a larger flock of airplanes than they'd ever seen heading towards the Hawaiian Islands, and they called this in, but unfortunately, as the information made its way up the food train, the direction the aircraft were coming in from got lost and it got misinterpreted as being an expected fleet of bombers coming in vs. the reality was a huge swarm of Japanese fighter aircraft, so this clearly led to a lot of lost lives, a lot of lost boats and it was the realization of "Oh my God, we could have done so much here just by knowing how to use the technology." That really revitalized the military's investment in radar, and we started doing things like putting on aircraft beacons -- transponders that would say, "Hey, I'm friendly! Hey, I'm friendly!" and would allow radar signals to get mapped with transponder signals identifying friend from foe. Those advances…these starting to use 24-hour radar was another advance that came out of this.

Fraser: I mean, it made a huge difference in the Battle Over Britain in Europe. I mean, they set up the line of radar dishes and were able to detect the airplanes, you know, taking off from Europe and have lots of notice before they arrived in England to bomb.

Pamela: And this is where you get all the images of people seeking shelter down in the underground stations, and you get fabulous "Dr. Who" episodes of…

Fraser: Yech.

Pamela: … all the adults going down and hiding while the orphan children scavenge food from rich people's tables – I love Dr. Who…but yeah, radar saves lives.

Fraser: So, but then, I mean, that was fairly crude back in WWII, but they made a lot of improvements to the kind of thing that you can put on your ship today, turn on an airplane, and…how did it sort of make the transition to be used for astronomy?

Pamela: Well, it basically evolved one step at a time as people noticed things in their signal, noticed noise in their signal, started to realize that they could reach greater distances, so we had advances in weather radar as people started to realize, "Hey, storms show up when we're looking for airplanes, so let's figure out how to filter out the storms to see the airplanes coming…and, oh, wait! Let's do this the other way as well…"

Fraser: Filter out the airplanes to see the storms…

Pamela: Exactly, so people start playing with different wavelengths, different colors, realizing that you could see different things like precipitation just by changing the frequency of the radar beam. It was a fairly short leap to realize, "Oh, wait! If we use sufficiently long wavelengths, we can start to reflect light off of, well, planets, and accurately measure how far away is Mercury, how far away is Venus simply by sending off a pulse of radar and waiting the minutes and minutes and minutes and minutes for that light to reflect its way back to Earth."

Fraser: So what were some of the first major discoveries, the first times that radar was used for astronomy?

Pamela: It was measuring the distances to the planets. Up until we developed radar, the best we could do was…well, waiting for things like Venus to transit the Sun, Mercury to transit to Sun, and using geometry and timing arguments to get the distances as best we could, but with radar, we could remove all the error in the timing by simply very precisely measuring, "OK, it took the pulse that long," and suddenly, the errors are simply in, well, your equipment vs. in multiple locations across the planet.

Fraser: Right, and so specifically here you're taking some kind of radio emitter, you're pointing it at say Mercury, you're firing a blast of radio waves at Mercury, you're then counting how long it takes for those…for you to detect your radio waves coming back from Mercury, you know how fast the speed of light is, do the math, that tells you how far away Mercury was.

Pamela: Exactly.

Fraser: And they could actually detect the bouncing radio waves. That must have been difficult.

Pamela: Well, the difficulty comes in getting a powerful enough signal vs. in the actual technique. You need two things: you need a really powerful beam and you need a very sensitive dish, and that's just, "OK how much power can we pump into our dish to do this?" So we've been successfully able to map things with Venus since 1961, and since then we've just been able to get more powerful, more sensitive dishes and as you up both of those parameters, you're able to start seeing, both smaller things, and more distant things.

Fraser: So, smaller, more distant…can you give me more examples the kinds of things we've mapped with radar using this, you know, this technique? Like in terms of like distance and stuff, I don't want to go into some of the other aspects of astronomy, but just specifically some of the cool advances in distance and mapping.

Pamela: Well, I think by far my favorite example is the Dog Bone asteroid, Cleopatra, which we imaged using radar quite recently and as it tumbled. We were able to do real-time imaging to build a 3-dimensional model of what this little tumbling asteroid looks like, and in its ability to see things we couldn't otherwise see that radar really shines, so yeah, we've been able to do the basic things -- measure the distance to Mercury, confirm that distance, which confirmed that Mercury's orbit is affected by general relativity… that's awesome, it's always good to have more proof of general relativity, but imaging asteroids is awesome! We've been able to, for the first time, see in radar light the surface of Venus by having orbiting probes, Magellan in particular, that over and over and over did radar sampling of the surface when we were able to make out craters and volcanism…

Fraser: Yeah, this is amazing, right? I mean, before we used the radar (when I say "we," I mean "they"), you look at Venus and all Venus was was a cloud, a ball, a cloudy ball, it was just clouds, and not even just storm, just opaque clouds, and so then they sent a spacecraft like Magellan and with that the radio waves passed right through the atmosphere and then they're bouncing off the surface of Venus, and they mapped the surface of Venus to great detail and it's unbelievable – you see craters, and mountains and volcanoes (extinct volcanoes), and plains, and…I mean, if you've seen an image of Venus and it's sort of red and orange and yellow, and it's sort of bright brown-y yellow – that's the Magellan images of Venus. And they had these amazing fly-bys that you can see. They took some of these images and they turned them into videos of flying across the surface of Venus, and you could see these gorges and mountains and volcanoes and craters and stuff, and it really looks like a…like another surface of another planet instead of it being this obscure ball that you just can't see. Now, you could see the surface -- and this is all radar. I mean, without Magellan being able to peer through the atmosphere, there was nothing to see.

Pamela: And this is one of those things that we're able to do – not just by putting things in orbit around planets like Venus, which is kind of awesome, and in fact, the laser altimetry work that they're doing with MOLA and LOLA orbiting Mars and the Moon are similar -- just a different color of light. So, we very carefully mapped the surface altitude using optical light with those two planets, but with Venus, you can't shine a laser to its surface and expect the laser beam to make it back through the clouds, so we used the longer wavelength radar. But from Earth, we're able to track asteroids, to track tumbling satellites, and…I got lucky back in high school, I worked at

Haystack Observatory, and it looks like Epcot Center when you live in the town that it exists in. It's in Westford, MA where I grew up, and when you drive down one of the main streets in town you see it off on the hill as this big, Epcot Center-like, geodesic dome, but hidden inside the dome is a dish that sees both radio astronomy, but also is an active radar facility to, well, track satellites and other kind of secret activities, but while I worked there in high school they were actually able to use it to track a tumbling satellite, and while they were tracking the tumbling satellite, they were able to radio up commands -- basically, "OK, fire this thruster, fire that thruster," and regain control of the satellite. And so we're able to do some really impressive real-time imaging using radar.

Fraser: And I think that one of the most important uses of radar is actually Earth observation. I mean, there are a lot of spacecraft now that are equipped and are scanning the Earth with radar for all kinds of purposes.

Pamela: And this is for everything from looking down at the surface of the planet and probing through foliage because different densities of material reflect and are transparent to different frequencies, wavelengths of radar, and so you can train your satellites to look through the trees and see what's beneath, to track storms by being able to see where the precipitation is, to even with some Doppler radar (which is admittedly not satellite-based, but is rather ground-based radar dishes), you can actually see where tornados are located, which as someone living in Illinois is amazingly useful. We can see the paths of tornados and figure out. "OK yes or no I should hide in the basement right now," as the sirens are going of. It's so many different uses, and so from orbit we see through the trees, from the planet we're able to see through the clouds, and well, as you walk around the surface with what's called ground-penetrating radar stuff, which basically looks like a push lawnmower…as you walk around with one of those devices, you're able to see beneath the surface and track archaeological sites, to measure the various densities of ash at Pompeii, to look for things hidden beneath the surface. And its not like what you see on CSI, or Bones or any of those television cop shows – you don't actually image the dinosaur, you don't actually image the skull, but you're able to see where there's materials of various densities beneath the surface.

Fraser: So where are the limits, then, of this technique? I mean, you know, where is it not really that useful anymore?

Pamela: It starts to become less useful depending on what detail you're expecting to see. The detail you're able to see is limited by the wavelength of the light, so if I'm looking at something where I'm sending off 1-meter wavelengths of light, I can't really expect to see something smaller than 1 meter with any great amount of detail, so as we get to smaller and smaller wavelengths, they get blocked by different materials. Optical light doesn't shine through dirt, and optical light is what you need to see fine details, so as you start to get down to millimeter and centimeter radio waves, that starts to define the level of detail that you're able to see. Different wavelengths also get what's called "attenuated" – they become faint and harder to see, and so we start to run into power constraints -- where to make out fine details using the millimeter and centimeter, the amount of power you have to pump into your radar beam gets much, much higher making that harder to use as well. So we get cut off in terms of how much power we can pump into the system, how easily the light is blocked from the system, and it boils down to, "well, nearby, we can start to make out things at centimeter resolutions, but as we look across space, we're limited to meter and kilometer resolutions."

Fraser: And you're limited just by the speed of light. You're just limited to how long it will take you for your radar to get out and then to bounce right back in, but I can see…

Pamela: Well, it's a matter of limitations.

Right, but it's also the Inverse Square Law, right? The further away things are, the more power you have to pump into it to get any meaningful data back, and so for you to image the surface of Pluto, you know, if you stuck all of the, you know, all of the energy in North America into one gigantic radio-transmitter then you might have a shot at it, but it's just so far away.

Pamela: So, with radar, it's actually the Inverse Fourth Law, which makes things even harder because you have the beam gets spread out using the Inverse Square Law on the way to the object, then it has to get spread out using the Inverse Square Law on the way back from the object, and so you have to take into consideration the distance from the transmitter to the object and from the object to the receiver, which when you're dealing with a moving asteroid, a moving planet, a moving satellite – it can get complicated to figure out, but overall it's the Inverse Fourth Law, so you do need very powerful and very sensitive systems, and this is where the largest full-dish radar on the planet Earth is actually Aricebo, which is built down in a volcanic crater in Puerto Rico, dug into the dirt and lava.

Fraser: It is the backdrop of many an action-spy movie because it is such a dramatic-looking observatory.

Pamela: And so, they use primarily Aricebo, and then Goldstone, which is a more military-focused radar facility that can track things at much higher speeds. It's not like you can really turn Aricebo effectively, you have to move around your receiver at the top, but it's these two dishes that serve as the backbone for our active radar astronomy right now.

Fraser: And the time that we're actually recording this episode, it's a little after the UARS satellite crashed back to Earth, and that…you could see people wanting to track that satellite. They wanted to know because there's a 1 in 3,200 chance that it's going to hit something on Earth and a 1 in 22 trillion chance that you personally will die from this satellite, um…right? And of course, we're human beings, we have this terrible way to judge odds…we're all like, "Oh, is that going to hit me? I want to keep an eye on where that satellite is." And so people were going onto the web and searching for, you know, satellite tracking, and real-time UARS tracking, and there were a bunch of websites that were doing that, and all that data comes from these…NORAD and Goldstone, and all these really powerful tracking systems and bounce a radio, you know, signal up into space in the general direction of the satellite, and then watch for the bounce back and they're able to position where that satellite is. And so this…it's funny because, you know, because as we're recording this, a lot of people were greatly interested in radar.

Pamela: And this is where, again, we also have to point to our optical light sister technology, which is the laser ranging. Tracking the satellites is done largely with radars, but you also have places like McDonald Observatory's Lunar Laser Ranging Station, that periodically bounces lasers off of satellites, as well, to get their exact altitude. Like I was saying earlier, it's the wavelength of the light that helps you determine things more accurately, so we use the exact same concept: shine a light, wait for its return gives you the distance, and measure changes in the frequency of the light and that gives you its velocity, and combining the two and watching over time how things move, we can get the full 3-dimensional motion of an object.

Fraser: Very cool! Alright well, thank you very much, Pamela.

Pamela: It’s been my pleasure.

Fraser: Talk to you next week…

Pamela: OK. Bye-bye.