Astronomy Cast Episode 2:
In Search of Other Worlds

Fraser Cain: Last week we speculated on how Pluto's planethood would affect the definitions of extrasolar planets. That got us thinking that would be a good thing to talk about this week.

There are more than 200 extrasolar planets that have been discovered so far with new methods, techniques and observatories in the works, so those numbers should go up as we go through time. We wanted to spend this episode discussing how we detect those extrasolar planets, how we learned to detect them in the past, and what the future might hold.

So, Pamela. How do we search for planets going around other stars?

Dr. Pamela Gay: That is the key question that people have been asking since the 50s and 60s basically. As technology has improved, we've been trying to search for the elusive evidence that our solar system isn't unique. People originally started looking for the stars to actually wobble in the sky. We looked for the gravitational tugs and pushes of planets in other solar systems to cause the pinpoints of light in the sky that we like to think aren't moving to actually wobble to and fro.

For a while there were actually claims that Bernard's star probably had a planet, because people very carefully measured its position relative to other stars, and thought they saw it moving. Since then, that has panned out. Bernard's star does not have planets.

This raises the prospect of if we look for them to move up, down, left, right, north, south, east, west in the sky, what about if we instead look for motions such that the stars appear to be moving toward us or away from us. It's really, really hard to make accurate measurements of the motions of stars relative to one another's light in the sky. This is called astrometry; it's really hard.

Fraser: So if I was looking up in the sky, and carefully, carefully measuring the position of a star, I might see it making a little circle in the sky as the planet that was going around it was tugging it side to side – I guess as the planet and star were commonly orbiting their centre of gravity.

Pamela: Yeah. Stars and planets and everything in a given solar system, move around the centre of all of that mass in the solar system. If a solar system is aligned in such a way that we look at it and the planets appear to be in the plane of the sky, circling around that star, if the planets were big enough, theory says we should be able to see that star moving around in little, itty, bitty, tiny circles about the centre of that entire solar system.

The problem is planets just don't weigh that much compared to stars. The stars don't move enough that we can presently see them moving north, south, east, west, in the sky. But we have other techniques. We can very carefully measure the velocities of the stars.

Just like policemen can measure the changes in the rate of light that gets bounced off of a car moving 60mph versus a car moving 120km/h (just to mix up our units here), we can similarly measure how the light changes when it comes from a star that's moving toward us versus a star that's moving away from us.

If there's planets around a star, we call this affect the Doppler shift. We can measure the Doppler shift as the planets force the star to wobble to and fro in the sky. We can measure this accurately enough that if a star is fairly near by, and we can get enough light from it, and it has a planet that's Jupiter-sized, and not too far away from the star, we can measure those wobbles to and fro in the velocity of the star relative to our velocity.

Fraser: But the planet and the star have to be pretty well lined up in a specific way, don't they?

Pamela: Yeah

Fraser: We have to be aligned on the plane of the ecliptic between the star and the planet so the planet is kind of pushing it away from us, pulling it toward us, pushing it away from us.

Pamela: Exactly.

Fraser: If we're seeing it face-on, then we're back to the little spiral or the little circle the star should be making, but that won't really affect its velocity.

Pamela: Right, so let's imagine that solar systems are basically badly made plates. They're not entirely flat: parts of them where you have an orbit that's tilted go up and down… it's not an ideal plate, but it's mostly a flat plate.

So, you can hold that plate out at arm's length and look at the edge of it. If we have that situation, then as the objects go around, they move toward us as they come down the right side of the plate and then go up the left side of the plate. This moving closer to us and further away from us causes the star in the centre of that solar system to also move toward us and further away from us (I'm doing this with lots of hand gestures you can't see, so I'm hoping you're following this).

If we rotate that plate 90 degrees so we can see the pretty pattern on the plate, and you now imagine planets going around and around the centre of that plate, we can now see the motion of the planets, but they're always at about the same distance from us as they go around and around that central star. While the star may also be moving around and around the centre point with very tiny, tiny motions, that motion doesn't cause it to move toward us and away from us. We just don't have the abilities to measure that north/south, east/west motion in the sky with current technologies.

Luckily the Universe is fairly random. When we look at other solar systems in the galaxy around us, some of them are those edge-on plates, some are the face-on plates, and most of them lie somewhere in between. We can statistically assume that it's random orientations and then work to figure out how many solar systems we look at should have planets causing motions that are detectable. It all breaks down to statistics and being very grateful that we live in a random galaxy.

Fraser: The easiest planets to see are going to be the ones that are directly edge-on, and close.

Pamela: Yes

Fraser: The harder ones are going to be the ones that aren't edge-on or are more at an angle away from us and further away. Eventually I'm sure there's some point where it's all impossible to see or you need bigger and bigger telescopes.

Pamela: Right. So, we're building those bigger and bigger telescopes slowly.

Fraser: Okay, so we can measure the velocity of the planet as it swings back and forth from us. Why is that so accurate? Why is that easy to do while measuring the position in the sky is hard?

Pamela: Measuring the position in the sky, we have to look for changes in the angular separation between two stars. Imagine trying to see the motion of someone that is a kilometre away who decides to step sideways a millimetre. That is a bigger motion than a lot of these stars are going to have when their biggest planets yank them about their centre of mass. Measuring that type of little tiny motion on the sky, we get befuddled by things like our noisy atmosphere.

As light comes down through the atmosphere, our atmosphere distorts what we see. If you go outside with a really good telescope and look at a bright star, you can see the light from that star dance around in your field of view. It makes it really hard to measure where the centre of that star's light is.

So fine, go out into orbit and now try it. If you look at a system with a star like the Sun and a planet like Jupiter, the motion of that central star is going to be 30 times smaller than what Hubble is able to see. So we're not going to see those changes.

At the same time, when we look at radial velocity changes, here we can look at transitions in atomic lines. Atoms have electrons attached to them (unless you make them too hot and jettison all of the electrons). So your average, run-of-the-mill atom in the atmosphere of a star is going to have a bunch of electrons that, because of the high temperatures of the star, are transitioning back and forth between different energy levels. Every time they make a transition, they either absorb a photon or emit a photon.

The result is that when we look at the light from stars, we see bright lines and we see dark lines in this overall continuum of light. The positions of these lines are exact, due to the fact that an atom is an atom is an atom, and the transitions are always going to be at the same wavelengths. We know from laboratory data exactly where those atomic lines should be. Now, when a star moves, that motion causes these lines to get shifted back and forth in colour.

If an object is coming toward us, we see all those lines get a little bit bluer. If an object is moving away from us, we see all these lines get a little bit redder. Sound does the same thing: when we hear a fire truck coming toward us, you hear the pitch get much higher. When it gets past you and starts going away from you, you hear the pitch get lower. The lower pitches are the same concept as light getting redder: it's all waves. These very fine transitions in atoms we can measure very precisely kilometres per second changes in the velocity of a star, looking at these little fine lines that don't get distorted by the atmosphere affecting two different stars differently.

Because we can measure them so finely, it's technologically easier than looking for motion on the sky of the actual star. We're just looking for velocity – position and velocity are slightly different. It's easier to measure velocity than position.

Fraser: Right. Now, most of the planets that have been discovered so far using Hubble and even ground-based telescopes have been discovered using this technique, right?

Pamela: Right. The majority of these planets were found using Doppler measurements of the radial velocities – the velocity of the star toward and way from us in the sky. This work was initially done ground-based using the McDonald Observatory 107 inch telescope (they didn't do it first, but they did do it), Keck Observatory… a number of the big observatories have got on board doing this. These guys looked at stars that were near enough that the light from the stars appeared to be very bright, because they were going to take that light from the star and spread it out across metres so you can see all the fine gradiations in the spectrum of the star.

We've all seen (at one point or another) rainbows cast on walls by prisms or a glass of water at a weird angle next to a window. Imagine that rainbow of light you saw on your wall spread out across metres and metres so you can see all the fine gradiations in colour from the Sun. We do that same thing with light from other stars.

It's easy to see a rainbow on your wall from the Sun, because the Sun is really bright (even when you spread its light out on the wall it's still fairly bright). Imagine spreading out the light from a flashlight: that's harder to see, the light is fainter. As you start getting to stars, you pretty much can only do this with a lot of the brightest stars in the sky because you're spreading that light out over so much space that you run out of light pretty quick to spread out.

So we look at the brightest stars, spread their light out with a spectroscope, and look for these little tiny atomic transition lines and measure their radial velocities. We look at bright, near-by stars.

Fraser: So if I had this rainbow on my wall, and flipped between the two positions of the star, would I see the lines moving back and forth?

Pamela: Exactly.

Fraser: Okay. I think that gives a good understanding for how most of the planets are found. I know there are some other techniques as well. There's a way we measure the dimming of a star as a planet moves in front of it, right?

Pamela: That's called a planetary transit. The idea is that when a planet (which doesn't emit light on its own), passes in front of a star, it's going to block out some of the light from the star behind it. Planets in general are tiny compared to stars, so they don't block out a lot of light, but we have abilities to measure the light coming from stars very, very accurately. If you can measure the dimming and brightening of a star as a planet first passes in front of it, and then passes out from in front of it repeatedly, and start to see this cycle of the star's light dimming and re-brightening to its original magnitude, you can say, "Hah, there must be something here." Based on the amount of dimming that's seen, you can say, "this is a planet" or, "this is just a really small star that is pretending to be a planet." With the biggest planets and the smallest stars, we start to get a fuzzy line. With small planets, compared to small stars, it's fairly easy to say we have found a planet this way. We have seen a star get dim, brighten back up to where it was, and we know something is there causing this eclipsing behaviour.

Again, though, this only works for when we're looking at solar systems edge-on. The planet has to pass in front of the star in our line of sight. If you go back to holding that plate at arm's length again, put a speck of dirt in the centre of the plate and how many different angles can you hold the plate at, such that the edge of the plate blocks the speck of dirt? Those are the only angles we can see these transits.

Fraser: I guess the benefit is the two methods are complementary. You can find it with one and confirm it with the other.

Pamela: That's what people are doing. It speeds up the amount of time spent discovering planets. You can get two different people on two different instruments: one finds it, the other confirms it. With science it's always good to be able to confirm your discoveries in more than one way.

Fraser: There's a third way that's turned up a couple of planets, and that's pretty fascinating, the gravitational micro-lensing technique.

Pamela: This is one of these neat things that comes out of Einstein thinking way too hard about gravity. Our Sun sends off light in all directions, so I can be anywhere 360 degrees around east/west, go up/down, anywhere I want in the solar system and I still see light from the Sun. The amount of light I see is just the light that came from the surface of the Sun and headed in my direction. There's other light headed in all other directions and I don’t get to see that from where I am, unless I use something to bend that light my direction.

Gravity doesn't just affect you, me and things that we drop on our feet. It also affects light. If I have a really high-mass object like another star, and I put it between me and the light from the background star, the gravity from that object that's closer to me will bend the light from an object behind it, such that light that would normally shoot off in some other direction, now gets bent to come to my field of view, so that I can now see that light that was destined for somebody else.

This causes objects to appear to suddenly brighten. As the object passes in front of the object in the back, light that we weren't normally going to see suddenly gets to us. We get an increase in the amount of light here on Earth.

Fraser: So we'll see a star we were already looking at, brighten up?

Pamela: Exactly.

Fraser: Right. And what we were seeing behind it is something we might not even have been able to see, but it's actually the light from a more distant star that's being focussed like a telescope.

Pamela: Yes. Gravity acts like a lens, magnifying the light that reaches us. It's just bending light that wasn't supposed to reach us, to reach us in a new way. Now, the gravity of that foreground object, depending on the alignment, can cause an object to magnify in a lot of different ways. You can get a ring of light from a background object, you can get a cross where the object gets replicated in all different ways – it's a geometry problem.

The neat thing about this geometry problem is it's also affected by the shape of the object in the foreground. If you have a star with a planet next to it pass in front of a background object, the mass of that planet will also work to magnify the light, to redirect that light from the background object toward us here on Earth, allowing us to see this weird mass distribution of star + planet in the foreground as it changes the light of the background object.

Fraser: Right, and I guess we see the brightening, and that's kind of the alert that there's a transit going on, and then the astronomers can measure the shape of how that brightening goes over time, as the closer star moves in front of the more distant star, and you'll be able to say, "oh, okay, there's a planet affecting the lensing of the more distant star"

Pamela: This isn't necessarily a really fast process. Objects in the foreground may pass very slowly in front of objects in the background. When this happens, the teams that are looking for these events can go, "ooo, here's one starting – let's get everyone watching to see what happens as this foreground star goes in front of this background star (or foreground object passes in front of background star)".

It's while we're watching these slow events unfold, with eyes around the planet, that we start to see these planets show up and not all the eyes that are turned looking at these micro-lensing events are necessarily professional astronomers with PhDs sitting at multi-metre telescopes. One of the planetary transits was actually observed by a group of our southern hemisphere friends who were working on their amateur astronomy facilities, helping teams of professional observers keep round-the-clock coverage of these micro-lensing events.

This is the type of work that anyone with a telescope can get involved in. there's an excellent website, transitsearch.org that works to explain how transits work. They get amateurs involved as well, and some of the gravitational lensing teams, such as MACHO are looking for amateurs to also work with them.

Fraser: I guess the ideal though, is you can take your big telescope, point it in the sky at a star, look at it and go, "there's some planets!" You can see them brightly next to the star. Why isn't that happening, and what's that going to take?

Pamela: We just don't have the technology. That's first of all something you just can't do from the planet, because we have this atmosphere that just blurs everything to bits. We're working to find ways to overcome that. The Very Large Telescope (which is a topic for another day) has found some really good ways to do it. In general, what you want to do is get above the atmosphere.

There are some different missions that are looking to send telescopes into space to specifically look for planetary transits and to look directly for planets next to stars. Sometime in the next couple of months the European Space Agency is going to be launching a mission, COROT that is going to be looking at a bunch of different patches in the sky and looking to see if there's any variations in what they see in the light from stars that are due to planets. They're specifically looking at astro-seismology, and looking for star-quakes that send ripples across the surface of stars (we see this in our own Sun). While they're making all these careful stellar-earthquake measurements (or stellar star-quake measurements) they're also going to be looking to see if planets affect things. It's still not quite a direct detection method.

The direct detection method is going to come later, when we start launching new technologies that we're still starting to develop, such as giant coronagraphs. The idea here is, you take an image of a section of the sky, and use special optics to reduce the light that comes from the central star by, say a factor of a billion, then look for faint planets that would otherwise get lost in the light from the star.

Fraser: Right, if you had a firefly next to a searchlight, 20km away, even if you've got a telescope good enough to be able to see the firefly, it'll get washed out by the searchlight. If you can block out the searchlight you might stand a chance to see the firefly.

Pamela: This is something that we all do at a certain level when we're driving into the Sun. You're driving along, facing west at sunset, you hold your fist up in front of your steering wheel and your eyes, drive with your other hand and use your fist to block out the light of the Sun so you can see the cars around you. That is, perhaps, the crudest coronagraph you could have. By building much more complicated optics, you can effectively block out the light from a star and look for faint things around it.

That's one way – the other way to do it is when light comes toward us, it's waves. Waves can either cancel one another out, or build one another up. We've probably all seen this in water where two waves of different velocities combine and you suddenly get a bigger wave for a moment.

It's possible to collect the light from stars with multiple different mirrors, and then combine that light with slight delays in timing, such that the light waves for the star cancel one another out, whereas the light waves for the planet don't. This is called a nulling interferometer. It's something that's still under development, and it's another way to be able to see faint things around a bright object, just by using the special properties of light to bring out faint things we might not otherwise get to see.

Fraser: So you would use the nulling interferometer to silence the waves from the star, but that might still leave waves from other objects around it visible in the telescope.

Pamela: Exactly. The nulling part, the cancelling out of the light waves only affects the central star in a field, whereas the light waves from the planets which aren't in the very centre of the field, are still allowed to combine in such a way that we can see these faint planets.

Fraser: Great, once again Pamela thank you very much for explaining this in depth. That gives a really good background on the search for extrasolar planets. We're just getting started. In the next few years and decades, there's going to be hundreds and thousands of planets discovered. I hope within a few years we'll start seeing pictures of other planets. It's an exciting time.

Pamela: There's plans to launch a terrestrial planet finder (if NASA doesn't cancel its budget), by 2020, that will be able to see these things.

Fraser: NASA if you're listening, don't cancel that project. Thank you.

This transcript is not an exact match to the audio file. It has been edited for clarity.