Astronomy Cast Episode 3:
Hot Jupiters and Pulsar Planets

Fraser Cain: Last week we talked about the various ways that astronomers have been finding extrasolar planets using the different kinds of techniques. This week we wanted to talk about the actual kinds of planets that have been discovered. Back in the day, astronomers were expecting that the kinds of solar systems they would be finding would be very similar to the solar systems that we live in, and that hasn't been the case.

Dr. Pamela Gay: It's actually one of these things where, strange as it may sound, our modern solar system formation model dates all the way back to 1755 and Immauel Kant, who came up with the nebular hypothesis. Up until fairly recently (with modifications over time), everyone said to form a solar system, take a giant cloud of gas and disturb it somehow (say, a nearby supernova goes off and nudges it), it begins to collapse, it begins to spin, you end up with a flattened dust disk in which planets form. The dust disk is warmest near the star, and that's where the rocky planets form because all the gases are getting evaporated out there. Once you get past a certain distance, there's what's called a frost line. Past that line you're able to get the gaseous planets.

So we had this very distinct theory-based, using tests of our own solar system, model for what we thought solar systems should look like: you have a star, rocky planets on the inside, gaseous planets on the outside and we keep all the chunks of ice in the outer most parts of the solar system.

Then we started finding planets around other stars, and they don't match our models, necessarily. We've been working to modify that model to account for the hot Jupiters that are being found near stars, to account for the fact that there's planets around pulsars.

Fraser: What kinds of planets have been turned up so far?

Pamela: The very first planet around another star was actually found in 1992 around a pulsar, by Alexander Wolszczan. He's a radio astronomer at Penn State University. He was measuring the timings of pulses coming from a very fast spinning neutron star. He found that the pulses weren't in perfect rhythm with one another. Sometimes they seemed to arrive a little bit too early, and sometimes they seemed to arrive a little bit too late. This implied that something was causing the pulsar's distance from us to very slightly change so the pulsar was sometimes a little bit further away and those pulses had to travel further to get to us (and were thus slowed down), or sometimes the pulsar was a little bit closer.

The only way to explain this kind of tiny motion in the pulsar was to say there had to be a planet there that was yanking the pulsar around. Since then we've continued to find planets around pulsars. In fact, fairly recently a miniature system was again found by Alex Wolszczan in which there are four different planets that seem to form a half-size solar system model, where you have planets that are scaled down with spacings proportional to Mercury, Venus and Earth, and then there's another planet out in the outer edges of this pulsar solar system. So we're still finding these.

Fraser: When they say planet, they must be using the term pretty loosely.

Pamela: These are little tiny chunks. We can't say if they specifically meet all of the criteria set down by the IAU. We don't know if there's even smaller chunks of stuff in the orbits they're in. These little tiny, highly rocky things weren't formed out of the original gas and dust that the star that eventually compressed down to the neutron star formed out of. Rather, we think they formed out of the gas and dust that was expelled by the supernova that formed the pulsar.

Basically, you start out with a giant star. The giant star hits a critical point in its lifespan. It can no longer generate its own energy, so it explodes as a supernova. When it explodes as a supernova, it spews the outer layers of the star out all around. It appears that some of this gas and dust that is spewed out from the supernova coalesces into pulsar planets.

After the atmosphere has been spewed off, the core of that star collapses down and forms a neutron star, a star that is so dense that the protons and electrons can no longer stay separate, and coalesce into neutrons. So you have this highly compact object that is spinning super fast, and around it the remnants of the former star form new worlds.

Not exactly like you find in our solar system.

Fraser: No, but then a few years later people started to turn up what we might consider to be "real" planets.

Pamela: Exactly. In 1995 a Swiss team led by Michael Mayor and Diedler Queloz of Geneva announced that they'd found a rapidly orbiting planet going around the bright nearby star 51 Pegasus. This wasn't like anything anyone ever expected to find. It was a planet similar to Jupiter in mass, but with an orbit that was smaller than Mercury's. This was not something anyone had expected to ever find. Suddenly all of our solar system formations had to account for how to get planets to basically be on top of their stars when they're gaseous planets.

Fraser: Right, astronomers were expecting it was going to be rocks and rocky planets like Earth and then gaseous planets, and then ice planets, all nice and calm, but no.

Pamela: Everything lined up politely, ordered by type distance from the sun, and no. The Universe doesn't like to do what we expect.

Fraser: So if we were in 51 Pegasus what would be seeing? What would this planet look like?

Pamela: We'd be really hot, and probably melt – or at least evaporate. The sun would just completely fill the sky. Our Sun is huge, but it's far away, so it appears to be about the size of a quarter held out at arm's length. If instead, we were so much closer, it would just fill the entire sky most of the time.

For 51 Peg the planet is just 0.05 AU away from its central star. This makes the star (which is a lot like our Sun) fill basically 70 degrees of the sky. Imagine the Sun stretching almost from zenith to the horizon; it's pretty spectacular to imagine.

Fraser: Do astronomers think this kind of situation is common, or is this just what they were able to find?

Pamela: We're still trying to find out exact statistics. Currently the observational techniques that have been used the longest and the most are sensitive to hot Jupiters. They're sensitive to giant planets very close to normal stars. That's primarily what we're choosing to look at, and that's what our technique is most able to find. There's selection effects.

We're starting to use new techniques to find planets around other types of stars and to find other sizes of planets, and we're getting more and more technology that is able to find smaller and smaller planets. Exact proportions, we're not sure, but it will come in time.

Fraser: So in the beginning what we saw were lots and lots of gigantic planets really close to their home-star. Now as the techniques are getting better, we're finding smaller planets, more distant and more what we would consider to be "normal" orbits.

Pamela: We're finally starting to find rocky planets. That's perhaps the most comforting thing of all. We'd been finding hot gassy planets for a long time, and now we're finally starting to turn out icy planets, we're starting to turn out rocky planets, there was a system found that had three planets, again still in fairly close orbits.

Our orbital period takes us 365 days to go around the Sun. These planets have orbits of just nine days, 32 days, 197 days. They're much closer into their sun, but they have masses that are only 10-18 times the mass of the Earth. These are things we can start to think about. We are finding rocky planets, and this is just a really nice thing to know… these things do exist, we just need to start looking for them and develop the technology to find them consistently.

We're also starting to find things that we're not quite sure how to account for. There was recently a planet found that was about the density of cork. This is not something any planet formation model can account for, and it's not alone: there's two of them so far that have been found. To get the density of cork, you have to be really hot – hotter than being close to a star can account for. Somehow these planets seem to be generating their own heat, which is something a planet is not supposed to do in large amounts.

Fraser: So when they say the density of cork, they're saying it would be say, the mass of Jupiter but much larger, so it would have that mass spread over a larger area? I remember looking at old books, like my old astronomy books when I was a kid, and they always had pictures of Saturn floating in water?

Is Saturn the consistency of cork?

Pamela: No – that's the confusing part. Yes, Saturn is less dense than water – it will float, it's a giant gas ball. But there's a difference between cork and just being less dense than water. These planets are, in the case of Hat P1 (an ever-so non-imaginatively named planet), this world is 1.38 times the radius of Jupiter, so it's one and a third times wider than Jupiter is, but it's only half the mass. That's a pretty dramatic difference in how much mass you have crammed into how large an area. This is an extremely low density world.

To put some numbers on that, Saturn's density is 70% the density of water, and Jupiter's density is about 30% greater than water. This world is just 25% the density of water. That shows you it's a lot less dense than Saturn.

Fraser: What seem to be the limits for a terrestrial world like earth?

Pamela: We're still trying to figure that out. Getting down to the lower masses around normal stars (not around pulsars) is something that we're still trying to figure out how to do. The smallest planets currently being found are being found through microlensing events, where the planet passes in front of a background star and its gravitational pull affects the light from that background object.

So we're starting to find things that are several Earth-masses in size, but we haven't quite made it all the way down to an Earth-mass yet. What we are finding is actually asteroid belts around other stars. We can't find Earths, but we can at least find asteroids, and that's another pretty cool thing.

Fraser: how would we be able to see an asteroid belt? The individual asteroids are a lot smaller than a planet like Earth.

Pamela: It's all about heat. Dust, gas, rocks… they all (when they get heated up by a star) radiate heat. We can see that heat as infrared light. When you get a large dust belt, a large asteroid belt around a star, it gets heated up by the star and then the Spitzer Space Telescope can discover it.

The Spitzer Space Telescope has been systematically finding asteroid belts and even icy belts reminiscent of the Kuiper Belt around distant stars. All you're doing is looking for reflected light coming off of a large belt of objects. What's neat is some of these look very similar to our own belt. They appear around stars similar in age to our own Sun, and they have very defined edges.

For instance, the star HD69830, it's a Sun-like star, it has an asteroid belt that is, admittedly about 25 times more massive than our own asteroid belt, but this asteroid belt is extremely well-defined, which tells us there's probably a planet near it that is able to herd or shepherd the asteroids into staying in a nice, coherent, well-defined belt, just like the moons of Saturn are able to shepherd the rings into coherent rings.

Fraser: I guess that would be when they always have the science fiction shows where people are going through an asteroid belt, manoeuvring around all these asteroids. That wouldn't really happen here in our solar system, but they'd be getting closer to that in a place like that with that many asteroids kicking around.

Pamela: Exactly.

Fraser: So the difference between a planet and a star is a planet is just an amount of mass. Especially with Jupiter, if you kept piling mass on Jupiter, it would eventually ignite as a star. How large can these planets get?

Pamela: This is where we start getting into great debates among astronomers. Coming up with a qualitative way to define what is a planet, and what is a star, requires us to start looking at things like are we going to look at energy generation mechanisms. Jupiter is actually generating more energy than it receives from the Sun. If you look at Jupiter, and you measure all the light that you get back at the planet Earth, and then try and account for all that light comes from, you first say, "Jupiter's a gas ball, it reflects light from the Sun, we know how much sunlight is hitting it, we know its size, we know we should be getting a certain numerical amount of light reflected back at us," and we get more.

To account for where that more comes from, we think about things like it's a giant ball of gas that's slowly condensing. It's getting smaller over time, and as this happens, as it gravitationally contracts, the gas that is getting squished smaller and smaller together is actually radiating away heat.

So gravitational contraction can produce heat. What else can we have an energy generation mechanism? If you make Jupiter bigger, the deuterium (the hydrogen in it that has a special added neutron), will actually start fusing, and we'll get deuterium energy production. That's a very short-lived phenomenon. If we want to get actual hydrogen burning like we have in the Sun, you have to make it even bigger to get enough pressure in the centre of the planet to get the hydrogen to burn and fuse.

At what stage do you start calling something a planet, and start calling something a brown dwarf star? These are things that are still being debated. In the end it's probably going to come down to at what stage do stars begin to generate their own energy, and do we count it with when they're just burning deuterium or do we wait and only count them when they start burning hydrogen in their cores.

Fraser: But as always it's not a specific line you can draw, it's a grey area that starts even with Jupiter all the way up to something becoming a brown dwarf.

Pamela: Yeah, it's a complicated question and as everything with Pluto recently demonstrated, trying to come down with a concrete definition is something that gets everyone hot around the collar. Everyone wants to say, "my object is a ___" and if your object is on the boundary and you have a particular opinion it becomes a very emotional battle. You want everything to be logical, but astronomers are still humans and we want to have our own personal, "this is a planet, this is a star" and it's hard to say, "well, this object is on the boundary".

Fraser: There was an object recently that was discovered on the boundary.

Pamela: That's right. A planet was recently found around the brown dwarf CHXR73. This maybe a planet object is just 12 times the size of Jupiter, and it doesn't look like it was formed with the brown dwarf star. So this raises the question of if something isn't formed alongside the star that it orbits, is it a planet? If these two objects each formed out of their own disks of gas and dust and ended up getting gravitationally bound together later, are they still a star and its attached world? We don't know.

Currently, the Spitzer Space Telescope is going to take a look and see if it can find a disk of dust around the little 12 Jupiter-mass object, and see if perhaps it is quantitatively its own separate star-like, very tiny thing, that might have its own planets forming around it. It's right on the boundary where we need to have a definition and we just don't have one right now.

Fraser: One thing that's been a bit of a controversy is, I know there's been a discovery recently of something researchers were calling "planimos" which are, I guess, solitary planets not actually going around a star, but actually having their own little mini solar system, completely floating through space.

Pamela: These are very confusing objects. They get more confusing the more of them we find. Sometimes when you're looking around you find these things that are clearly not big enough to be stars. They're not orbiting anything, so where did they come from?

If you have multiple stars forming together, you get a lot of weird gravitational interactions going on. It's been shown, initially by Victor Zebehay, when you get multiple objects gravitationally interacting, you can have a three-body problem where one of the objects gets radically flung out of the system. So it's possible that when you have multiple stars forming, and planets forming around these multiple stars, that some of the planets can get ejected from the system and end up roaming the galaxy completely on their own.

This seemed like a perfectly reasonable model until recently when astronomers discovered a double system of these planimos, these planetary-mass objects. This was worked on by Ray Jayawardhana. Using ESA's 3.5m New Technology telescope at La Silla in Chile, he found a pair of these double planetary mass objects floating freely through space. They were bound together gravitationally, but only barely.

It seems hard to imagine how these barely bound together planets could have survived a violent flinging from the parent system they might have been born in. So now we're trying to figure out how to form loosely bound binary planimos that are freely floating through the galaxy… and we're not quite sure. But that's what makes astronomy interesting.

Fraser: But if you've got a star and you've got a disk of material around it, and in that disk various objects are able to come together… I guess the question is couldn't you have a smaller cloud of gas and dust come together and just not have enough mass to turn into a star, but it could turn into something.

Pamela: And that's the other argument. Can you collapse down a small disk and have it collapse down to the density of a planet? Models are still working to try and figure that out, and the answer could be yes, and we just need to find one of these things in the process of forming. That's the neat thing about the Spitzer telescope. It can answer these questions as it looks through the nearby galaxy and looks at areas where stars and planets around them are forming.

Spitzer recently looked at the Orion cloud complex and found nearly 23 hundred planetary disks around stars. These are all places where planets could be forming. Now all we need to do is find a disk that isn't exactly forming a star, but just might be forming planets instead (and only planets).

Fraser: Awesome. I hope we turn up some more of these planets in the next couple of years. I think the point is we're in what I call the golden age of astronomy. We're just getting started, there are so many cool telescopes, there are so many new space telescopes, and a lot of new techniques that are being developed.

Hopefully, five or ten years down the road, this conversation will be completely different. Hopefully we'll have found a lot more planets that are more like our planet and maybe even we'll have an idea if there's life.

Pamela: We're just getting started. We've found over 200 planets, and I'm sure there's thousands and tens of thousands of them out there to be found yet. We are just now starting to have a firm, statistical understanding of what's going on, and you need to have the clear observations before you can build clean models, but that's happening today.

We're finding things, we're going to be able to start defining the models, new technologies are being built, being used. Direct detections of planets are going to be happening in the next months, not just the next years. It's a great time to be.

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