# Exoplanets: Crash Course Astronomy #27

Crash Course: Astronomy
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(PBS Digital Studios Intro)

Phil: When you look up at the night sky, and if you happen to live far from city lights, you can see thousands of stars. It seems like the sky is crammed shoulder to shoulder with them, and you're only seeing the tiniest fraction of stars there are. Billions more exist that are two faint to see with just your eyes.

As you ponder this incredible number, a natural thought arises. Are there planets circling those stars, too? And are any of them like Earth? People just like you and me have wondered about this for thousands of years, and right now, today, we can answer that question, and the answer is yes.

(Intro)

Our sun is orbited by a lovely array of planets, and they're wildly diverse, big, small, airless, rocky, gaseous, hot, cold, and more. That makes you think that maybe forming planets is easy. With so many varieties to choose from, even if making planets is hard, there are so many stars in the sky that it's hard to believe our sun is the only one that's been able to pull this trick off.

Astronomers have fretted over this for a long time, but trying to find such planet is hard. The biggest problem is any such planets would be faint, far away, and sitting right on top of their parent star. Being able to see one in a telescope would be like trying to spot a firefly sitting next to a searchlight.

So if you can't spot a planet like that directly, maybe you can spot it indirectly. Imagine two kids, one big and one small, facing each other. They clasp hands and start to spin around. As they do, the little kid, who weighs less, will make a big circle, and the bigger kid will make a small circle.

The same would be true of a star and planet. As the planet orbits the star, it makes a big circle or ellipse, but the planet has gravity, too, and it tugs on the star. That means the star will make a small circle, what's called reflexive motion. For a long time, astronomers looked really hard for this motion in nearby stars, but it turns out that indirect effect is also too small to see. There were a few false alarms, but no real planets.

Then, in 1992, everything changed. Astronomers Alexander Wolszczan and Dale Frail made a shocking announcement. They found not just one planet, but tow orbiting a pulsar, the dead remnant of a star that had exploded.

This was really bizarre. When a star explodes, it's a catastrophic event that should destabilize any orbiting planets. It's the last place anyone would have thought to find them. However, followup work quickly confirmed that the planets did indeed exist, and in fact a third one was found a few years later.

The first true alien planets had been found. Officially we call them exoplanets. Which you have to admit is pretty cool. While this was an incredible discovery, it was still a little unsatisfying. For one thing pulsar's are really weird and for another, it looked like those planets may have formed around the pulsar after the supernova explosion, from the material left over from the catastrophe.

That's nothing at all like our own solar system, and that still left the question open. Are there exoplanets orbiting sun-like stars. We didn't have to wait long to find out. In 1995, Swiss astronomers Michel Mayor and Didier Queloz made a big announcement. They had found a planet orbiting the star 51 Peg, a star very much like the sun, just 50 light-years away.

How did they do it? Well, remember those two kids holding hands and circling each other? Even thought the wiggling back and forth of the star is too small to measure, that doesn't mean the effect is undetectable. As the host star of the exoplanet makes its little circle, sometimes it's headed towards us and sometimes away. That means that its light will undergo a Doppler shift, and that can be detected.

It's not a big shift, it takes some pretty fancy equipment to see it, but it's measurable. That's how Mayor and Queloz found their planet. And the planet they found, called 51 Peg B is weird. For one thing, the orbital period turns out to be just a little over 4.23 days. That's right, I said days. That means the planet is seriously close to its parent star, just 8 million kilometers out. Compare that to Mercury which on average is 55 million kilometers from the sun. Not only that, but the amount of Doppler shift in the star is related to the mass of the planet. A more massive planet pulls harder on the star, making it move more quickly. They found the planet was at least half the mass of Jupiter, and probably more.

That was a problem. According to planetary formation models, that wasn't possible. You can't form a planet that big that close to a star. Well it turns out the models are probably right, the planet didn't form that close. It probably formed farther out, just like Jupiter did, and like Jupiter it then moved, migrated inward toward the star as it interacted with the disk of planet-forming material around the star.

In our solar system, Jupiter didn't get very far in its inward motion. It's thought that interactions with Saturn put the breaks on that and pulled Jupiter out to where it is now. Apparently 51 Peg B didn't have its own version of Saturn pulling on it. Its inward spiral continued until it ran out of disk material to interact with, which was very close indeed to the star. We call planets like that "hot Jupiters"

Once 51 Peg B was found, other teams began looking for short-period planets, and within a few years, several more had been found, many of the hot Jupiters just like 51 Peg B. Now mind you, at first there was a lot of doubt and skepticism in the community about these exoplanet discoveries. A lot of other phenomena could masquerade as planets like star spots, pulsating stars, or background stars messing up the measurements. Scientists discussed these possibilities vociferously, as well they should.

Science is all about not fooling ourselves. A good scientist wants other scientists to try and poke holes in their ideas, it's disappointing to be wrong, but if we're wrong, we wanna know. That all changed in 1999. A planet called HD 209458b had been discovered on a very short orbit around its star, taking just 3.5 days. As luck would have it, from Earth we see the planet's orbit edge-on.

That means once per orbit it passes directly in front of its star. This event is called a transit, and when the planet transits the star, it blocks a little bit of the star's light and that means that we can detect a dip in the star's brightness. And sure enough, that dip was found. HD 209458b was the first independent confirmation of and exoplanet, and pretty much everyone was jumping on the bandwagon after that.

The beauty of transiting exoplanets is that the amount of starlight blocked tells you how big the planet is; a big planet blocks more light. If we know the planet's mass from the star's Doppler shift, we can use the planet's size to calculate its density. This is important: a gas giant like Jupiter has low density, and a rocky metallic planet like Earth has a very high density. Without even being able to see the planet directly, we can already start to determine what it's like physically.

In 2009, NASA launched a space-based telescope named Kepler, designed specifically to stare at 150,000 starts to detect that telltale dip in light indicating exoplanet transits. And oh my, did it work. By

early 2015, Kepler found its 1,000th confirmed exoplanet, and there are 500 more confirmed from ground-based telescopes. That's more that 1500 planets! And we have well over 3,000 more candidates from Kepler awaiting confirmation.

All these planets have been found using indirect methods. What about actually seeing them, getting photographs of them? That's hard, because planets are so faint. But it's not impossible.

In 2004, the first picture of an exoplanet was released: 2M1207b, a planet with five times the mass of Jupiter. It orbits a brown dwarf, a peculiar kind of low mass star that we'll learn more about in a future episode. It's a young system, which makes it easier to see: the planet is still glowing hot from its formation, and it appears a lot brighter using a telescope that can see in the infrared.

About a dozen other planets have been seen this way, too. My favorite is the planet orbiting the star Beta Pictoris. It has seven times the mass or Jupiter, and orbits the star in about 20 years--and we've actually seen it move! Images taken a few years apart actually show the planet in different position around the star, confirming its orbital motion. That is incredible.

Taking photos of these planets is still a daunting task, which is why so few have been seen. But we're getting better at this, and as new technology comes along, we'll get more pictures of exoplanets and learn even more about them.

The sheer variety of exoplanets is staggering. Hot Jupiters are the easiest to find, because they're massive and fast, making their signal easier to detect. But as the techniques have improved, planets of lower mass have been seen. The smallest exoplanet found is smaller than Mercury, and not much bigger than Earth's moon. We've seen planets bigger than Earth, but smaller than Neptune called "Super Earths."

About 500 multiple planet systems have been found too, including one with seven planets. We've found them around every kind of star, too. Exoplanets have been detected around stars like the Sun as well as tiny, cool red dwarfs; hot, massive blue stars; and even red giants, stars nearing the ends of their lives.

One exoplanet system announced in 2015 is incredibly old. The host star is 11 billion years old! When our solar system was just beginning to form, these planets were already over six billion years old - older than our solar system is now. We've ever seen planets orbiting binary stars, making Star Wars seem a lot closer to home than being in a galaxy far, far away.

We've seen so many exoplanets now that we can extrapolate a bit and get some numbers. The results are staggering. In our galaxy alone, there may be hundreds of billions of planets. In fact, planets may outnumber stars in the sky.

Now, if we've seen planets as big as Jupiter, and as small as Mercury, then we must have seen planets around the same size as Earth, right? Yes. Yes, we have. We've actually found hundreds of them so far. It looks like making planets the same size as ours is pretty easy for stars to do.

But Earth-sized is one thing, Earth-like is another. How many of these planets might actually be habitable? That is, at the right distance from their star to have Earth-like conditions, where liquid water could exist on their surface? We're not sure. But, from what we've seen so far, it looks like the galaxy may have more than 10 billion Earth-like planets. Ten. Billion. And maybe a lot more than that.

Now, I want to be careful here: we don't know what kind of atmospheres these planets will have or what they're composed of. Do the planets have magnetic fields strong enough to prevent solar wind from eroding away their atmosphere? Do they even have an atmosphere, let alone liquid water? We don't know. But still, there are a lot of planets out there.

There could very well be a twin of Earth orbiting a star not too far away. And over the whole galaxy? We could be part of a very large family. After all this time, we finally have an answer to one of the biggest questions we've ever asked in astronomy: the sky is filled with planets.

Today you learned that planets orbiting other stars exist and can be detected with a variety of methods. Nearly 2,000 have been found so far. The most successful method is using transits, where a planet physically passes in front of its parent star, producing a measurable dip in the star's light. Another way is to measure the Doppler shift in a star's light due to reflexive motion as the planet orbits. Exoplanets appear to orbit nearly every kind of star, and we've even found planets that are the same size as Earth. We think there may be many billions of Earth-like planets in our galaxy.

CrashCourse Astronomy is produced in association with PBS Digital Studios. Head over to their YouTube channel to catch even more awesome videos. This episode was written by me, Phil Plait. The script was edited by Blake de Pastino, and our consultant is Dr. Michelle Thaller. It was directed by Nicholas Jenkins, edited by Nicole Sweeney, the sound designer is Michael Aranda, and the graphics team is Thought Café.