Brown Dwarfs: Crash Course Astronomy #28

Crash Course: Astronomy
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https://nerdfighteria.info/v/4zKVx29_A1w

(PBS Digital Intro)

Phil: The sky we now know is full of stars and planets. Stars are massive enough to fuse hydrogen into helium in their cores, generating energy. The heat created by that process tries to expand them, but they're gravity balances that outward force, creating an equilibrium. Planets, even gas giants like Jupiter, are far too small to generate fusion. The stuff inside them resists being squeezed, so their gravity is balanced by simple gas pressure. Jupiter is only about 1% the mass needed to have fusion going on in its core, and that's a pretty big gap between a big planet and a small star. It's natural to ask: what would happen if we dumped more mass onto Jupiter? Eventually, it would become a star, the pressure in its core would get high enough to initiate hydrogen fusion, but what if we stopped just short of that? What if we have an object far more massive than a planet, but not quite massive enough to become a true star? What sort of thing would we have then? What indeed?

(Intro)

By the late 1950s, astronomers were starting to get a pretty good handle on how stars worked. The mathematical equations that govern the physical processes of fusing hydrogen into helium were being worked out and applied to what we know from observing the stars themselves. In the 1960s, the idea that you could have a star with a minimum mass was becoming clear. If it had less than about 0.075 times the sun's mass, roughly 75 times the mass of Jupiter, it simply lacked the oomph needed to squeeze hydrogen together hard enough to generate fusion. What would such an object look like?

Well, it might form like a star, collapsing from a gas cloud just like the sun did 4.6 billion years ago, but instead of turning on and becoming a star, it would simply sit there, cooling. It might start off pretty hot, due to the physical forces that made it, but it couldn't sustain that heat. Like a charcoal ember, it would radiate its heat away. After a few billion years, it would be cold, black, and for all intents and purposes, dead.

As people started working out what such an object would be like, they tried to come up with a name for them. These things were black and small, but the name "black dwarf" was already being used for another type of object. Some people called them sub-stellar objects, but that wasn't terribly catchy.

Really low mass stars are read, and these new objects would be so cool that they'd emit light in the infrared, and almost nothing at all in the visible. So they're somewhere between red and black. Jill Tarter, then a young astronomer working in the field, but who later made a name for herself looking for aliens, and oh boy, we'll get to that later, dubbed them "brown dwarfs". She didn't mean it literally, stars can't be brown, but the name stuck. Work proceeded in figuring out what brown dwarfs were like, and a lot of progress was made despite there not being any actual examples of them found.

But the hunt was on. Now, as I talked about in episode 26, astronomers classify stars by their temperature. The hottest are O-stars, then B-stars, which are slightly cooler, down through A, F, G, K, and with the coolest stars being M.

But then, in 1988, astronomers found a star that was so cool, it was distinct from even the M class stars. It was the first of a new cooler class of stars, so it was given the letter L. Why L? Because there wasn't any other astronomical object that used that letter, so why not?

Many more such L-Stars were found, but still, these weren't true brown dwarfs. These stars were massive enough to initiate fusion in their cores. Worse yet, when brown dwarfs are first born, they're very hot. They can mimic higher mass L-stars for a while, looking just like them, making it hard to distinguish between the two. But then a way out was found. A low-mass brown dwarf, it was determined, would have lithium in it, whereas normal stars wouldn't.

Lithium is an element, the next one in the periodic table after hydrogen and helium. It can be fused much like hydrogen can, and regular stars would quickly use up their supply of lithium when they were still young. Brown dwarfs, lighter than about 65 times the mass of Jupiter, wouldn't fuse lithium at all. Very careful observations of an object would be able to detect lithium if it were there.

That would provide a test to distinguish brown dwarfs from regular stars. The lithium test isn't perfect, but it does work under a lot of circumstances. Astronomers began using it to look for actual real brown dwarfs, and so they found one. In 1995, a group of astronomers was observing the Pleiades, a nearby cluster of stars that's visible to the naked eye. They were trying to find the faintest stars they could in that cluster to get a complete sample of its membership. The advantage of this is that the distance to the cluster was pretty well-known, so a faint star in it must be very low-mass.

They found an oddball object, which they named Teide 1. It was very red and cool, and best of all, lithium was found in its spectrum. The best models of stellar mass showed that it had about 50 times the mass of Jupiter, or .05 times the mass of the Sun. It was clearly sub-stellar. Huzzah! The very first true brown dwarf had been found.

At just about the same time, astronomers found that another nearby star called Gliese 229 had an extremely faint companion. Spectra showed that it was even weirder than Teide 1. It also had lithium, and so was clearly a brown dwarf, but it's spectrum showed it had methane in its atmosphere. Methane is a delicate molecule, and would break down even in the mild heat of Teide 1's atmosphere. This new object, called Gliese 229b was even cooler than Teide 1.

It was looking like we needed yet another letter to classify stars, and so T Dwarfs became a thing. On a personal note, when I worked on Hubble Space Telescope, Gliese 229b was one of our camera's first targets after it was installed on Hubble in 1997. I was lucky enough to work on the spectrum we took of it, and it was freaky. It emitted almost no light in the visible part of the spectrum, and rocketed up in the infrared. I'd seen a lot of stellar spectra before, but nothing like this. Remember, Gliese 229b had only been discovered two years before. I became so intrigued by it, I wound up studying low-mass stars and brown dwarfs for several years after.

Well, it didn't take long before more brown dwarfs were found. In 2009, NASA launched the wide-field infrared survey explorer, or WISE, an orbiting observatory designed to scan the entire sky looking at infrared light.

It found hundreds of brown dwarfs, and now, at least 2,000 are known, with more found all the time. Some are so cool that they form yet another classification, Y Dwarfs. So now we have O, B, A, F, G, K, M, L, T, and Y. You're on your own for an acronym here.

So if brown dwarfs aren't brown, what color are they? Some are so cool, they don't emit visible light at all, so they'd be black. You can be right over one and you wouldn't see it. But some are still warm, and so give off some visible light, feeble as it might be. What color would they look? Funny thing. They might be magenta. You'd think they'd be really red because of their temperature, but it's a bit more complicated than that.

Remember, they have molecules in their atmospheres that absorb specific colors of light. In some brown dwarfs, there are molecules like methane and even water, well, steam, at those temperatures, that are pretty picky about what colors they absorb. Some of these molecules block more red light than blue, so that messes with their colors, making them look magenta.

WISE takes pictures in the infrared, which our eyes can't see. To make pictures, astronomers map each infrared color to one our eyes can see, so an image using the shortest wavelength infrared detector is displayed as blue, the medium wavelength one green, and the longest one red. Brown dwarfs put out a lot of light in the intermediate wavelength WISE sees, so weirdly, they appear green in WISE pictures. That does make them easy to spot in those images, even when thousands of other stars are visible, too.

The physical nature of brown dwarfs is just as weird as you'd expect. For one thing, they have a very unusual characteristic. As they get more massive, they don't get any bigger. Usually, if you dump mass onto an object, it gets bigger. Take two lumps of clay and smush 'em together and you get one more massive, slightly larger lump. Same with planets and stars. But brown dwarfs are different. At their cores, the density is very high and the physics is a bit different than what you'd expect. The details are complex, but the end result is that when you add more mass to them, they actually get denser, not bigger.

This effect becomes important right around the mass of Jupiter, which means that a brown dwarf twice as massive as our biggest planet won't actually be a whole lot bigger. So what's the difference between a small brown dwarf and a really big planet? Well, not much. Nature isn't as picky as we are about having narrowly defined borders between classes of objects.

Some people say a planet forms from a disc of material around a star, growing larger as it accretes stuff, while a brown dwarf collapses directly from a cloud of gas and dust. But then you could have two objects the same mass and which look exactly the same yet one would be a planet and one a brown dwarf, depending on how they formed. That strikes me as inconvenient. Astronomers are still debating this, and it gets worse.

For example, as I said before, brown dwarfs over 65 times Jupiter's mass fuse lithium. It turns out that ones more massive than about 13 times Jupiter can also fuse deuterium, an atom that's very similar to hydrogen, except it has a proton and a neutron in its nucleus.

But neither of these fuses actual hydrogen, so they're not considered true stars. That's still a little arbitrary, so again, I don't make too much of a fuss about it. I think it's best not to think of them as planets or stars, but something with characteristics of both. For example, the way their atmospheres behave depends a lot on how hot they are. In some, iron is vaporized, a gas. In others, they're just cool enough that iron condenses out of the atmosphere, which means it literally rains molten iron.

One more thing. The nearest star to the sun is a red dwarf called Proxima Centauri, which orbits the binary star, Alpha Centauri. It's about 4.2 light years away. In 2013, astronomers announced the discovery of a binary pair of brown dwarfs called Luhman 16. They're only 6.5 light years away, and became the third closest known star system to Earth.

You gotta wonder, could there be an even fainter, cooler brown dwarf closer to us? We know there's none in our solar system, even out in the Oort Cloud. It would have been seen by now by one of several different sky surveys. But a light-year or two out? Maybe.

Is Proxima Centauri really the closest star or will we find one even closer? It seems unlikely, but no more unlikely than the existence of brown dwarfs themselves. Maybe sometime soon, we'll have to rewrite astronomy textbooks... again.

Today you learned that brown dwarfs are objects intermediate in mass between giant planets and small stars. They were only recently discovered, but thousands are now known. More massive ones can fuse deuterium, and even lithium, but not hydrogen distinguishing them from normal stars. Sort of.

Crash Course Astronomy is produced in association with PBS Digital Studios. Head on over to their YouTube channel and see 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.