Binary and Multiple Stars: Crash Course Astronomy #34

Crash Course: Astronomy
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We have one star in the solar system. The sun. Sure, it has a lot of planets, moons, asteroids, comets it schleps with it as it moves through space, but no other star is part of our family. The sun is alone.

Based on that, you might naturally think that, like the sun, stars are single too. They sure look that way by eye. But when you point a telescope at the sky, you find that this is not the case. A lot of stars travel the universe with companions. And sometimes more than one.

[Intro]

With so many stars in the sky, some appear close together just by coincidence, even though in space they are actually very far apart. We call these optical double stars. By the 18th century, astronomers were starting to recognize that many stars that appeared close together really were physically orbiting each other. We call these binary stars to distinguish them from the coincidentally close together, double stars. Although the numbers are a little bit uncertain, something like a third to half of all stars in the sky are part of a binary, or multiple, star system.

One such binary system is visible to the naked eye and has been know for thousands of years. You may have seen it yourself. The star marking the kink in the handle of the Big Dipper is actually two stars, one called Mizar and the fainter one called Alcor. They're close enough together that you need decent eyesight to separate them. And they were actually used as an eye test in ancient times.

Binary stars, almost certainly, form together, near each other in the gas cloud that was their originally stellar nursery. Instead of a single clump collapsing and forming a star, like our sun, there are two such dense clumps and they both collect material until they become true stars.

There are lots of kinds of binary stars. If the two stars can be seen separately using a telescope, they're called a visual binary. This is kind of a fluid classification. As telescopes get better, stars that are closer together can be resolved.

These kinds of stars are fairly common. The brightest star in the night sky, Sirius, is a visual binary. It's a luminous blue star, about twice the mass of the sun, orbited by a much small, fainter, white dwarf.

It's funny too. As I mentioned in an earlier episode, white dwarfs can be very hot and energetic and emit light at much higher energy than normal stars. When you observe Sirius with an X-ray telescope, the white dwarf is by far the brighter of the two.

Visual binaries are important, because, if you observe them long enough, you might be able to see their orbital motion. If we can measure their distance from Earth, then the actual size and shape of their orbits can be determined, and in turn, using the math of physics and gravity, this can be used to find the masses of the stars.

In fact, the only way we know to get accurate measurements of stellar masses, is when they're in binaries. And once we know the masses of the stars, as we saw in Episode 26, we can learn everything else about them. How big they are, how brightly they shine, and even how long they live. It's no exaggeration to say, that observing binary stars opened up the new scientific field of astrophysics, applying physics to astronomy. And that led to us understanding everything we do about the universe today. Not Bad!

Not all binaries are visual binaries though. Some stars orbit so closely together, that we can't split them, even with our biggest telescopes. So how do we know they're binaries? Spectroscopy!

As the two stars orbit each other, over time, one will appear to be heading toward us, while the other circles away, and vice versa as they switch sides. While we may not see that motion directly, if we take spectra of their light, breaking it up into individual narrow colors, we can see the Doppler shift in their spectra.

On their merry-go-round path, one under goes a red shift as it moves away, and the other has a blue shift as it moves toward us. These kinds of stars are called spectroscopic binaries.

Remember Mizar and Alcor, the Big Dipper eye test stars? I said they were a binary system, but I lied. Well, I understated. In even a small telescope, you can see that Mizar is a visual binary, but turns out that both of those two stars making up Mizar are actually spectroscopic binaries too. Mizar is a binary binary star. Even better, Alcor is a spectroscopic binary too. Since Mizar and Alcor orbit each other, it turns out they make up a sextuple star system, six stars all gravitationally bound to one another.

Obviously stars can be in bigger groups than binaries. There are triple star systems, quadruple, and more. Polaris, the North Star, is actually a pentuple star system, composed of five stars. It's possible that multiple stars are born in lots of systems.

However, it's pretty hard to get a stable system like that. If the orbits aren't just right, some of the stars tend to get ejected from the system. The ones we see today are the ones that coincidentally got things just right. Even then, they may not be stable in the long run. Was the Sun born is such a system?

We don't really know. It's certainly possible and one way to find out would be to find stars that have a very similar elemental composition as the Sun. But the Sun was born billions of years ago, plenty of time for any stars born with it to wander off. Even at relatively slow speeds, 4.5 billion years is a long time. And for all we know, they could be 50,000 light years away, and completely invisible to us. If there are long lost sibling to the Sun out there, they may remain lost.

Just like planets orbiting the Sun, binary star orbits can be short or very long. Some stars separated by tens or hundreds of billions of kilometers can take centuries to orbit each other, while some are so close they may only take days.

One binary star, the most bizarre I know of, is called 4U 1820-30, and it's composed of a neutron star and a white dwarf. Their gravity is so strong, and they're so close together, that they orbit each other in 685 seconds, 11.4 minutes; roughly the length of this episode.

Like exoplanets, binary star orbits are tipped every which way to our line of sight from Earth. But for some of them, we see their orbits edge on, or very nearly so. For these binaries, we see each of these stars pass in front of each other, blocking it from our view. We call these eclipsing binaries.

Eclipsing binaries are interesting, because as one star blocks another, the total light we see from the system dips, just like in a solar eclipse when the moon blocks the Sun. Over the course of one orbit, we see two such dips, as the first star blocks the second, and then half an orbit later when the second passes over the first.

If the two stars are similar, say both like the Sun, then the two dips look very similar. But if one star is much brighter than the other, then the two dips look very different. The brighter star dominates the total light we see. So, when the fainter star goes behind the

brighter star, the light hardly drops at all. But when that fainter star blocks the brighter one, we see a bigger dip in the light.

By carefully examining the sizes and shapes of the dips this way, a lot of interesting information can be gleaned from the system, including the sizes, masses, rotation rates, temperatures of the stars, the sizes and shape of the orbit, and even distance to the system.

Some stars, like humans, enjoy cuddling. They get so close together they become contact binaries; literally, two stars touching each other. These are very strange objects. The stars can be stretched out into tear-drop shapes, due to the mutual tidal effects. If they get very close together, they merge into a double-lobed, stellar peanut shape, like two stars cocooned in shared material. This can make things really weird for them.

Imagine two stars born at the same time, perhaps a few million kilometers apart, tightly orbiting each other. One has, say, five times the mass of the Sun, so it's a hot blue star. And the other one just has one-half, so it's a red dwarf.

The red dwarf doesn't do much. It just slowly fuses hydrogen into helium, glowing feebly. The bigger star, though, goes through its nuclear fuel rapidly and becomes a red giant. It blows off a wind of matter and loses mass. Since the stars' gravity depends on their masses, as the big star loses mass, the orbits get a little wonky, becoming more elliptical. But when the massive star swells, it gets so big, the two become a contact binary.

A lot of the material leaving the higher mass star gets dumped on the red dwarf, which starts to grow. Eventually, the big star loses most of its mass and becomes a white dwarf, while what used to be the lower mass star has grown, and now might be more massive than the other star. It's a bit like Robin Hood; taking from the rich and giving to the poor. If he gets too enthusiastic about it, then the poor become rich and the rich become poor.

When we look at that binary system, we see a white dwarf star that is clearly more evolved than a high mass one; the opposite of what we expect. This is called the Algol paradox, after the contact binary star Algol in Perseus, which shows this effect.

Mass transfer between two stars can yield even more dramatic results. Imagine this same system a couple of billion years later. The high mass star has lost its outer layers and is a dense white dwarf. The other star eventually runs out of hydrogen fuel and swells into a red giant. This material then flows onto the white dwarf.

White dwarfs have cruelly strong gravity. If the hydrogen flowing onto its surface piles up enough, the gravity can squeeze it so hard, it fuses into helium. If the flow rate is just right, it piles up on the white dwarf and then fuses in a single, colossal flash, erupting in a huge, explosive flare. Some of these explosions can be incredibly violent, tens of thousands of times brighter than the Sun.

When this happens, a previously invisible star can suddenly flare into visibility in the sky. These have been seen historically and called stellar novae, for new star. I love the irony. These stars actually have to be old, near the ends of their lives to go nova, but the name stuck.

The explosion can blow out the stream of matter falling from the other star, but when things settle down, after a few weeks or months, the matter stream can fall back on the white dwarf and the whole cycle repeats. These are called recurrent novae. If the matter stream is slower, the material can fuse steadily, never piling up, so it never explodes. However, the mass of the white dwarf still increases.

If it reaches a mass of around 1.4 times that of the Sun, it gets compressed by its own gravity so much, that its temperature soars upwards. It gets so hot, that carbon fusion initiates. And that is a big problem.

In a normal star, it would just expand, due to all the extra energy being generated. But a white dwarf can't. It's ruled by electron degeneracy pressure. The extra energy just goes into fusing more carbon. And what you get is a runaway, thermonuclear event. All the carbon, everywhere inside the white dwarf, fuses all at once. All of it!

Basically, a solar mass of carbon will instantly fuse, releasing all that energy all at once. It's like setting fire to a dynamite factory. The star explodes. You get a supernova, and it's a completely different process than when a high mass star explodes. But, coincidentally, it releases about the same amount of energy. The star tears itself to vapor and gets so bright, it can be seen, literally, most of the way across the universe.

Ooh, this makes them very, very important indeed, as you'll see in a future episode.

Today, you learned that double stars are stars that appear to be near each other in the sky. But if they're gravitationally bound together, we call them binary stars. Many stars are part of binary, or multiple, system.s If they're close enough together, they'll actually touch, merging into one peanut-shaped star.

In some close binaries, matter can flow from one star to another, changing the way it ages. If one star is a white dwarf, this can cause periodic explosions, and possibly even lead to blowing up the entire star.

Crash Course 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 Blade 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 Cafe.