Stars: Crash Course Astronomy #26

Crash Course: Astronomy
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Twinkle, twinkle little star. Oh. I know who you are.

(Intro)

=====Introduction=====

At first glance, stars pretty much all look alike. Twinkly dots, scattered across the sky. But as I talked about in episode 2, when you look more closely you see differences. The most obvious is that some look bright and some faint. As I said then, sometimes that's due to them being at different distances, but it's also true that stars emit different amounts of light too.

If you look through binoculars or take pictures of them, you'll see they're all different colors too. Some appear white, some red, orange, blue and for a long time the reason for this was a mystery.

(0:50) In the waning years of the 19th Century, astrophotography was becoming an important scientific tool. Being able to hook a camera up to a telescope and take long exposures meant being able to see fainter objects, revealing previously hidden details. It also meant that spectroscopy became a force, say it with me now, FOR SCIENCE!

=====Spectra and Classification=====

(1:08) A spectrum is the result when you divide the incoming light from an object into individual colors or wavelengths. This reveals a vast amount of physical data about the object, but in the late 1800s, we were only just starting to figure that out. Interpreting stellar spectra was a tough problem. The spectrum we measure from a star is a combination of two different kinds of spectra. Stars are hot dense balls of gas, so they give off a continuous spectrum; that is they emit light at all wavelengths. However stars also have atmospheres, thinner layers of gas above the denser inner layers. These gases absorb light at specific wavelengths from the light below depending on the elements in them. The result is that the continuous spectrum of a star has gaps in it, darker bands where different elements absorb different colors.

(1:51) At first, stars were classified by the strengths of their hydrogen lines. The strongest were called 'A' stars, the next strongest 'B', then 'C', and so on. But in 1901 a new system was introduced by spectroscopist Annie Jump Cannon, who dropped or merged a few of the old classifications and then rearranged them into one that classified stars by the strengths and appearances of many different absorption lines in their spectra. A few years later, physicist Max Planck solved a thorny problem in physics, showing how objects like stars give off light of different colors based on their temperature. Hotter stars put out more light at the blue end of the spectrum, while cooler ones peaked in the red. Around this same time, Bengali physicist Meghnad Saha solved another tough problem: how atoms give off light at different temperatures. Two decades later, the brilliant astronomer Cecelia Payne-Gaposchkin put all these pieces together. She showed that the spectra of stars depended on the temperature and elements in their atmospheres. This unlocked the secrets of the stars, allowing astronomers to understand not just their composition, but also many other physical traits.

(2:51) For example: at the time it was thought that stars had roughly the same composition as the Earth but Payne-Goposchkin showed that stars were overwhelmingly composed of hydrogen, with helium as the second most abundant element. The classification scheme proposed by Cannon and decoded by Payne-Gaposchkin is still used today and arranges stars by their temperature, assigning each a letter. Because they were rearranged from a older system the letters aren't alphabetical, so the hottest are 'O' type stars, slightly cooler are 'B' followed by 'A', 'F', 'G', 'K' and 'M'. It's a little weird but many people use the mnemonic "OH BE A FINE GUY KISS ME" or "OH BE A FINE GIRL KISS ME" to remember it, which was dreamed up by Annie Jump Cannon herself.

(3:33) Each letter grouping is divided into 10 subgroups, again according to temperature. We've also discovered even cooler stars in the past few decades and these are assigned the letters 'L', 'T' and 'Y'.
The Sun has a surface temperature of about 5500° Celsius, and is a G2 star. A slightly hotter star would be a G1 and a slightly cooler star a G3. Sirius, the brightest star in the night sky is much hotter than the sun and is classified as an A0. Betelgeuse, which is red and cool, is an M2.

=====Star Colors and Luminosity=====

Stars come in almost every color of the rainbow. Hot stars are blue, cool star red. In between there are orange and even some yellow stars BUT there are no green stars. Look as much as you want and you won't find any. It's because of the was our eyes see color. A star can put out lots of green light but if it does it'll also emit red, blue and orange and our eyes mix those together to form other colors. A star can actually emit more green light than any other color but we'll wind up seeing in as white. How do I know? Because if you look at the Sun's spectrum, it actually peaks in the green. Isn't that weird? The Sun puts out more green light than any other color but our eyes see all the mixed colors together as white.

(4:43) Wait. What? White? You may be thinking the Sun is actually yellow. Not really. The light from the Sun is white but some of the shorter wavelengths like purple and blue and some green get scattered away by molecules of nitrogen in our air. Those appear to be coming from every direction but the Sun, which is why the sky looks blue. The Sun doesn't emit much purple so the sky doesn't look purple and the green doesn't scatter as well as blue. That gives the Sun a yellowish tint to our eyes and looking at the Sun is painful anyway, so it's hard to accurately gauge what color it appears. That's also why sunsets look orange or red. You're looking through more air on the horizon to see the Sun so all the bluer light is scattered away.

(5:21) So we can use spectra to determine a lot about a star but if you combine that with knowing a star's distance, things get amazing. You can measure how bright the star appears to be in your telescope and by using the distance you can calculate how much energy it's actually giving off, what astronomers call it's Luminosity. An intrinsically faint light looks bright if it's nearby, but so does a very luminous light far away. By knowing the distance you can correct for that and figure out how luminous the objects actually are. This was, no exaggeration, THE key to understanding stars. A lot of a stars physical characteristics are related. It's luminosity depends on its size and temperature. If two stars are the same size but one is hotter, the hotter one will be more luminous. If two stars are the same temperature but one is bigger, the bigger one will be more luminous. Knowing the temperature and distance means knowing the stars themselves. Still, it's a LOT of data. A century ago, spectra were taken of hundreds of thousands of stars. How do you even start looking at all that?

=====Trends and the single most important graph=====

(6:21) The best way to understand a large group of objects is to look for trends. Is there a relationship between color and distance? How about temperature and size? You compare and contrast them in as many ways as possible and see what pops up. I'll spare you the work. A century ago astronomers Ejnar Hertzsprung and Henry Norris Russell made a graph in which they plotted a star's luminosity vs it's temperature. When they did, they got a surprise. A VERY strong trend. This is called an HR diagram, after Hertzsprung and Russell.

It's not an exaggeration to call it the single most important graph in all of astronomy. In this graph, really bright stars are near the top, fainter ones near the bottom. Hot, blue stars are on the left and cool, red stars on the right. The groups are pretty obvious. There's that thick line running diagonally down the middle, the clump to the upper right and the smaller clump to the lower left. This took a long time to fully understand but now we know this diagram is showing us how stars live their lives. Most stars fall into that thick line and that's why astronomers call it the main sequence. The term is a little misleading, it's not really a sequence per se, but as usual in astronomy it's an old term and we got stuck with it.

The reason the main sequence is a broad long line has to do with how stars make energy. Like the Sun, stars generate energy by fusing hydrogen into helium in their cores. A star that fuses hydrogen faster will be hotter because it's making more energy. The rate of fusion depends on the pressure in a star's core. More massive stars can squeeze their cores harder so they fuse faster and get hotter than low mass stars. It's pretty much that simple. And that explains the main sequence. Stars spend most of their lives fusing hydrogen into helium which is why the main sequence has most of the stars on it. Those are the ones merrily going about their starry business of making energy. Massive stars are hotter and more luminous so they fall on the upper left of the main sequence. Stars with lower mass are cooler and redder so they fall a little lower to the right and so on. The Sun is there too, more or less in the middle. What about the other groups?

(8:21) Well the stars on the lower left are hot, blue/white but very faint. That means they must be small and we call them white dwarfs. They're the result of a star like the sun eventually running out of hydrogen fuel. We'll get back to them in a future episode. The stars on the upper right are luminous but cool. They must therefore by huge. These are red giants, also part of the dying process of stars like the Sun. Above them are red super giants, massive stars beginning their death stage. You can see some stars that are also that luminous but at the upper left. Those are blue super giants. They're more rare but they too are the end stage for some stars and again we'll get them soon enough in a future episode but I'll just say here that it.....doesn't end well for them.

=====A Brighter note and Conclusions=====

(9:03) But on a brighter note we literally owe our existence to them, and this implies something very nifty about the HR diagram. Stars can change position on it. Not only that, but massive stars vs low mass stars age differently and go to different parts of the HR diagram as they die. In many ways the diagram allows us to tell at a glance, just what a star's doing with itself. This difference between the way low mass stars like the Sun and higher mass stars age is actually critical to understanding a lot more about what we see in the sky, so much so that they'll be handled separately in later episodes. I'm sorry to tease so much about what's to come but this aspect of stars, finally understanding them physically, was a MAJOR step in astronomy, leading to understanding so much more. And don't you worry, we'll get to all that.

=====Today you learned.....=====

Today you learned that stars can be categorized using their spectra. Together with their distance, this provides a wealth of information about them, including their luminosity, size and temperature.
The HR diagram plots stars luminosity vs temperature and most stars fall along the main sequence, where they live most of their lives.

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