# Astronomy Cast Episode 217 for Monday January 24, 2011
## Stellar Classification

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Fraser: Welcome to Astronomy Cast where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, I'm the publisher of Universe Today, and with me as always, is Dr. Pamela Gay, a professor at Southern Illinois University – Edwardsville.

Fraser: Hi, Pamela. How are you doing?

Pamela: I'm doing well! How are you doing, Fraser?

Fraser: I'm doing great! I've got nothing else to say. You have anything interesting to say?

Pamela: Um, life is good?

Fraser: OK, well on that note…

Pamela: There's a shuttle launch coming?

Fraser: That's true. So on that note, let's continue with the show then. Chit-chat over! Chit-chat done! Have you ever heard an astronomer utter these words: "Oh, be a fine girl and kiss me?" Now, they're not being romantic, they're just trying to remember the different ways to organize stars, as detailed nicely on the Hertzsprung-Russell diagram. So let's figure out what all this means, and what differentiates a type O star from a type G star. Well, I know this is the show that everybody's been waiting for [laughing]… but sometimes we'll talk about the really cool, crazy stuff and sometimes we'll go back to the fundamentals to stop your eyes from glazing over as you flip through the pages of an astronomy book and you see this big picture of all these stars, and you're like "whatever, whatever that is…I'm moving on." No! Stop! Time to understand it. That is the Hertzsprung-Russell diagram and it is a way of organizing different stellar stages? Classifications?

Pamela: Everything about stars: their fuel, their evolutionary stage, their temperature, how bright they are…it all gets trapped in this one diagram.

Fraser: And normally, you know, I think we try to let people imagine with their minds, but in this case, if you actually did want to go and Google up yourself a Hertzsprung-Russell diagram, that might be helpful as we continue into this conversation, but even, you know, not -- I think there's enough here for everybody. Even those of you on a forest walk can envision stars collected into this graph. Alright, so what are we talking about here, and why does this even matter?

Pamela: Well, the reason it matters is for scientists, we need graphs. We *require* graphs. And in this one particular case, if you make a graph that are at the same distance and put on one axis how bright they appear, and put on the other axis what temperature they are, what color they are (it's the same thing), you start ending up with these really nice lines along which the stars naturally clump up, and those lines have physical meaning. There's this beautiful, curvy "S" (well, it's mostly like an "S" that you stretched and stretched and stretched until it was almost a straight line), and that "S" that starts in the upper left-hand corner (it's kind of rotated 45 degrees) and ends in the lower right-hand corner -- that's what we call the main sequence of stars, and it's along that line that all stars that are burning hydrogen in their core, exist, as well as all other stars that are in their first stage of burning nuclear fuels.

Fraser: OK, so imagine that graph, the left-hand I guess, the vertical axis is mass?

Pamela: Vertical axis, well, so mass actually doesn't play into the diagram that much. If you look along the diagonals you can get there, but the vertical axis, the Y-axis, is how bright the star appears.

Fraser: So the vertical axis is brightness, and the horizontal axis is color.

Pamela: Yes, and we have blue on the left and red on the right, which is hot on the left and cool on the right.

Fraser: Right, so in the very upper left-hand corner of the graph you're going to get a star that is very bright and very blue, and in the bottom right-hand corner, you're going to get a star that is not so bright and red.

Pamela: Exactly.

Fraser: And, as you say, you get this line that goes from the upper left-hand corner, quite smoothly moving down towards the lower right-hand corner, although as you say, it's a bit of an "S."

Pamela: And this curve, one of the things that makes it so important, is how much of this letter "S" we get to see is a function of how old the stellar population we're looking at happens to be. So if you look at a very young group of stars, an open cluster, a group of stars that is still in the process of forming, you'll get all the stars in the upper left-hand corner, and it's still in the process of forming you're probably going to be missing some of the stars down in the lower right. But if you look at an extremely old population of stars, something like a globular cluster, those really hot, really bright, really massive stars in the upper left-hand corner, they're going to be dead, they're going to have evolved off this letter "S," this main sequence, to a different part of the diagram. So we can actually use this diagram for a cluster of stars to figure out exactly how old that cluster of stars happens to be.

Fraser: You look at how many of the stars have evolved off the main sequence.

Pamela: Exactly – "what's the "turning point?" is how we talk about it.

Fraser: So where's this coming from? I mean, someone had to have made some kind of realization at some point. I'm guessing their names are somehow involved in the name of the diagram itself.

Pamela: It might just have been, well, I can't pronounce this poor guy's first name: Ejnar Hertzsprung, and then of course, Russell is Norris Russell. So, these two – Henry Norris Russell – these two astronomers, at the same time, working between 1911 and 1913, came up with the refinements for this diagram. But what's interesting is the history behind that "Oh be a fine girl kiss me…"

Fraser: That's a puzzler! I mean, what does "O" or "G" have to do with the actual colors?

Pamela: And the thing that bothered me when I first saw this diagram is why aren't they in order? And this all goes back to our understanding of spectral classifications. People started taking spectral images of stars – this is where you take the starlight and you shine it through a slit, a prism, and "grism," [sic] and you get many different combinations of things, and as a result, you end up with the light spread out into very fine-grained rainbow, where you can see where light gets absorbed out by the atmosphere of the star and where there's extra light due to emission lines in the atmosphere of the star. And we didn't actually understand that when people started taking stellar spectra. We didn't understand what role temperature played when we started taking stellar spectra, and so these were just a really neat way of getting additional information. These neat lines on the rainbows of these stars and the first people to try and figure out how to sort out what these spectra meant were two of Pickering's women at Harvard. So on one hand you had Antonia

Maury, who was Henry Draper, the famous Henry Draper of the Draper catalog's, niece. And she came up with this really complicated system that looked at the widths of the lines, what the lines were, and it had some basis in physical reality, but we didn't understand that at the time. Then there was Wilhelmina Fleming, who looked at the lines and took a very straightforward approach. She knew what the Hydrogen Balmer series was, she knew what the lines were in the stars, and she classified the stars, such that "A" stars had the most Hydrogen Balmer lines, and as you worked your way down the alphabet, the Balmer lines slowly disappeared.

Fraser: So, this is where you get like, A, B, C…

Pamela: Exactly, except we got rid of some of the classifications: C went away, D went away…

Fraser: Because they just weren't distinct enough from the others?

Pamela: Well, and it turned out that once we understood that the prominence of these different lines has to do with the temperature of the gas, they just weren't needed. And so, it was realized "O" stars were, "Oh dear, these were the hottest," so they got bumped over to the right-hand side of the graph. And we realized that A stars -- they're still pretty hot, but they're a little cooler than the O stars, and the B stars were somewhere in between. So, as we started to pick out what are all the different lines? What are all the different spectral lines that correspond to different temperatures in these stellar spectra? What do they mean? We're able to pick it apart and figure out "Oh, if you look at these very particular to hot star lines, you get "O" stars, and "G" if you start looking at how the hydrogen lines have started to get weaker, you get "G" stars. So we built up this entire classification system based on temperature using the original letters that were ascribed to literally thousands of classified spectra that were classified before we had a good physical meaning for the system.

Fraser: But because people were so comfortable with using those letters to describe the stars, they kept them, even though now they're just not in order anymore.

Pamela: Exactly, and what's kind of neat about this story is the woman who sat down and tried to figure out the argument on how to classify spectra -- the disagreement between Antonia Maury's system, and Wilhelmina Fleming's system – when she looked at it and came up with the physical interpretations, she initially kind of more than annoyed Antonia Maury who left Harvard for a while, but as she examined it, she realized that Antonia's usage of the thickness of the lines actually had physical meaning. When you start making plots that have, not just temperature along one axis, but then you make it 2-dimensional, you add that second axis, you add that luminosity in, she found that the stars that had different thicknesses of lines, these are the dwarf stars, the super giant stars, the sub-dwarfs, these different thicknesses of lines clumped up as well, and had physical meaning as well. Now we know the thickness of the line is, at least in part, due to how strong gravity is at the surface of the star.

Fraser: So, why don't we maybe take a walk down the main sequence anyway, and see where some distinct classifications of stars because, even though it is fairly smooth, they do kind of clump up a bit.

Pamela: Right. So we have pretty much through the middle of this diagram, the central curvy bit of the "S" if you can imagine the top part of the "S" and the bottom part of the "S" and then you have the two parts in the middle. Those two parts in the middle are the dwarf stars and our own Sun counts as one of these dwarf stars. These are stars that are burning hydrogen in their center. These are stars that usually have additional layers that aren't completely involved in radioactive processes yet, and they're nice, happy, generic stars that aren't' going to explode in violent ways. Those are the giant stars that aren't the red giants, they're not the super giants, these are just the physically giant stars that exist in the upper left-hand corner. They very quickly become super giants and blue giants as they very quickly dive off the main sequence before exploding as supernovas. And then in the bottom part of this diagram, that bottom part of the "S," we have the red dwarfs. These are the stars that, in some cases, are involving their entire atmosphere in nuclear burning. They are completely convective and they're going to burn their entire store of hydrogen over time, and then very gently cool off into tiny, tiny white dwarfs, and that's that main "S" part of the curve.

Fraser: And sorry, just what the letters, the blue stars associate with what? The "O" and the "B"?

Pamela: Exactly.

Fraser: And then in the middle part, it's the A, F and the G?

Pamela: A and F are thought of as being white. The human eye doesn't really perceive stars as green at any point. It's just the way…stars give off light in all colors, and when we look at a star that might be giving off the majority of its light in the green, it's giving off light in all colors as well and our eyes are perceiving it as white. So we have A and F stars are perceived as white by the human eye, and then as we cool off and get into the G and K stars, these are yellow-orange stars, and then it just slowly tapers off into the deep reds as we start to get into the M's. And some classification systems will add an L in after that.

Fraser: And so when you hear about an M dwarf, that is a star, like a red dwarf star that's in that M classification.

Pamela: And Barnard's star is perhaps one of the most famous red dwarfs out there, other than, of course, the spacecraft…

Fraser: [laughing] Right, the TV show…yeah…and again, if you look at the diagram, there is that main sequence we have been talking about and then there are stuff that's off the main sequence that we've talked about. So what's going on here?

Pamela: So, the easiest part of this to explain is if you jump down below that letter "S", running parallel to the straight part of this diagram, spanning from just around the letter B and then cooling all the way off is this diagonal line of very, very faint stars. These are stars the brightness of the red dwarfs, or even fainter, and these little tiny stars that start off at high temperatures and then cool off are all white dwarf stars. So the death stage of stars like our sun, stars a little bit bigger than our sun, and everything smaller then our sun is a white dwarf, and white dwarfs are the degenerate matter, the stellar fragment that is no longer undergoing any nuclear reaction that we think structurally, in some cases, might actually resemble diamonds. These are crystalline carbons with electrons and what's called an electron-degenerate gas.

Fraser: And so, they do follow their own cluster, but it is away from the rest of the stars because, as you said, they're no longer actively burning; they're really just cooling down from what they used to be and I guess the situation is that we only really see them up until the white level because there aren't many stars, you know, there aren't many cooler stars that have had a chance to die yet.

Pamela: Yeah, this is one of those things that people don't really think about. In some cases, our understanding of stellar evolution is more advanced than what the universe allows us to look at. The universe has only been around for 13.7 billion years, and it takes white dwarfs a long time to, first of all, get formed. You have to wait for the not low mass, but lower than giant giant mass stars to finish their entire life cycle and then you have to wait for these things to cool off to see what is the end stage of their existence. We believe they just cool off like a barbecue briquette, basically. So we're only able to see some parts of this pattern, and they're faint so that makes them even harder to see, and as they cool off they give off even less light, but they do place a constraint on the age of the universe. If we see a white dwarf that had to have had longer than the age of the universe to cool off to get where it is on the H-R diagram, we know there is something wrong with our understanding of the universe, but so far that's never happened, so we're doing OK.

Fraser: And then, so that's one of the off-the-main-sequence, but there's another one too.

Pamela: There are multiple other ones, so the other big one is the red giant branch. This is where pretty much all the big boys go to die. That's kind of the depressing way to look at it, but as stars evolve off the main sequence and proceed to start doing other things, such as burning a shell of hydrogen around their core, they'll evolve into this diagonal line that comes off of the center of the letter "S." And at this stage they're bloated up, they're much cooler and they're now undergoing a different form of burning.

Fraser: Right, and so they're bright, according to the graph, but cool. So they're more toward that red color, but they're also then brighter, so they're…as you said, it's almost like a cross. They're going the other direction from the main sequence.

Pamela: So if you imagine just the main sequence and the giant stars we now have a backwards letter "Y" in our diagram. Now, coming off of that giant branch we have, in some cases, in older systems with just the right combinations, we have a small branch, a horizontal branch extending straight left-right through the H-R diagram, and this is where you end up with stars that have undergone a helium flash in their core. These are stars that are now burning helium with a shell of hydrogen around them, and depending on exactly what they are in the process of doing, they could either be evolving towards the left, or they could be evolving towards the right, which is one of the things that makes studying stellar evolution particularly confusing at times, because you're looking at a star and without additional data, you're not quite sure which way it's moving in its evolution.  What's neat is this horizontal branch cuts through what's called the "region of instability," which is a region that cuts along a mostly-vertical line through the entire H-R diagram, and stars all along this instability strip pulsate, so on the horizontal branch, stars in this unstable region, these are your **RV Tauri** stars, these are your pulsating variables.  If you move up the strip there's another horizontal branch as well, these are the super giant stars.  This is where the largest stars are burning shell after shell after shell of material, and in here you also start to find your Cepheid branch stars.

Fraser:  And so this is where you get your, as you said, when a really giant star first forms, it's briefly on the main sequence and then puffs up, gets very bright, and can either remain hot or can be cooler, but is completely steps away from all the main sequence brightness color connection.

Pamela:  Right.

Fraser:  And they don't last long.

Pamela:  No, not at all!  And what's neat is across this entire diagram, if you're able to get the mass of the star and you're able to plot its point on the diagram, you can get all sorts of information -- from what it's burning in its core, to where it's been in its life, to what's likely to happen to it in the future.  Using this diagram, we are able to use populations of stars to understand the lives of individual stars.  When we use the H-R diagram, we'll say, "OK, let's look at that globular cluster -- all the stars are about the same distance, they're all made of about the same stuff," and so the only things that makes these stars different from one another is their mass. Now we can look at multiple globular clusters to figure how does the H-R diagram differ?  How does stellar evolution differ as a function of mass for systems that have slightly different amounts of metals, and slightly different amounts of iron and other metals (every element other than hydrogen and helium, we consider metal), but putting together the pictures of all these systems at different ages, all these systems at different “metallicities,” we can start to say very specifically a star like our sun will have this specific future, and that’s kind of neat to learn all from a graph.

Fraser: It’s interesting to me how you can show an astronomer a star and they’ll know what the color is by analyzing the light, and then they can look at what the apparent brightness is and then they can know roughly how far away the star is because they know how bright, based on this graph, a star like that should be, or they can know what stage of evolution it’s in. They can guess at its mass because they have this great relationship on this graph. It’s amazing what an astronomer can figure out, and I can see how what’s really fascinating is what are the nuances? How is it different? As you said, you look at one globular cluster, and the stars have all taken some strange shared direction down the H-R diagram, well, it’s different from a different cluster, so there’s these similarities and these differences, and that I’m sure tells these astronomers tons!

Pamela: It’s strange to think that one graph, one lousy graph that we torture students with by making them make them, by showing them plots of the nearest stars – this one graph holds so many keys to our understanding of the universe. We use it for everything.

Fraser: Now, is this the only way that astronomers will express this kind of thing? Are there other graphs like this that people might encounter?

Pamela: When it comes to trying to understand stars, we make pretty much consistently graphs of color or temperature or spectral type, which are three different ways of saying the same type of information vs. the -- in an ideal situation -- the absolute magnitude or total luminosity of the stars. And when we don’t have that information, if we’re looking at stars that are all the same distance, we’ll just make a plot vs. how bright they appear to be. That’s pretty much what we do.  We call it different names at times.  We call it color magnitude diagrams or H-R diagrams, but it's really the same thing.

Fraser:  And I guess neutron stars, black holes, they don't show up on these.

Pamela:  No, not so much -- neutron stars you could figure out where to put them, but they're just cooling off as well, and they're generally not known for being observed by how bright they appear. We like to look at how brightly they pulse instead.  It's just a different way of starting to consider things.

Fraser:  What about objects that are…before they're forming as stars?  You know like T-Tauri objects, things like that?

Pamela:  So objects -- proto-stars -- as they're in the process of forming, these objects start off slightly cooler and slightly brighter in some cases, and so they drop on to the main sequence.

Fraser:  …as opposed to branching off, that's interesting.  Alright, well I think that's good!  Hopefully, now, everyone when they see an H-R diagram will know what they're looking at, and not just flip the page immediately.

Pamela:  It's a graph, but it's a good graph.

Fraser:  It's key, so…well, thanks a lot!

Pamela:  Thank you.  Talk to you later.