Episode 22:
Variable Stars

Fraser Cain: Astronomy Cast episode 22 for Monday February 5, 2007: Variable Stars.

Welcome to Astronomy Cast, your weekly facts-based journey through the cosmos 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 we've also got Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville.

Hi Pamela,

Dr. Pamela Gay: Hey Fraser how are you doing?

Fraser: Good, are you recovered from the black hole questions?

Pamela: I'm getting there, my brain is only slightly relativistically bent

[laughter]

Fraser: At this point I think more will be coming in, so like I said I think we'll be doing this about once a month probably.

Things are a little different this time, assuming we got everything done. This is our first enhanced podcast, so we now have show notes that go along with the podcast with background links to almost everything we could think of that we mentioned in the show.

We've got a full transcript of the show so you can all follow along or just read if you don't have anyway of listening to the show, and I think it's a great language to use as well it's great because you can read while you hear us talking so if English isn't your first language this is a way to boost it up.

Pamela: Thanks again for all your donations; these resources wouldn't be possible without that assistance since we're now able to hire someone to help us out. If you like the show and especially if you like the additional material, consider a donation. Here's the cool thing: the donations can be used as a write-off if you pay taxes in the United States.

Fraser: So just click on the donate link on our website and follow the instructions there. Thanks again.

Okay, so, this week we're going to cover the surprising variability of stars. People think that, uh, - the surprise, the big surprise…

[laughter]

Um, I'm trying to juice it up, but it is interesting! So, alright.

[more laughter]

People think that the stars just change in brightness when they explode, but there's lots of other ways that stars can change. And Pamela, this is a topic near and dear to your heart, isn't it/

Pamela: My very first astronomical love was a little variable star called AH Leo, and I'm still plugging away to try and make sense out of that little star. I've been working on hundreds of other variables since then and basically traveling all over the universe with my telescope trying to sort things out based on the inconsistencies of stars' behaviour.

Fraser: So you're actually doing active work in variable stars right now, aren't you?

Pamela: Oh yes, that's my little sub field that I'm particularly interested in. I work on trying to make sense out of the variable stars that don't do what your textbooks say they should be doing.

There's some stars out there that, when you look at them, they change in brightness from day to day, which we actually do expect for some stars. How they change from day to day doesn't behave in any way that makes sense following the normal textbook rules for these stars.

Fraser: Alright, so let's start with the textbook then. What are the different kinds of variable stars out there?

Pamela: Well in general, variable stars come in dozens of types, but these can be broken down into three different categories.

There are stars that, when you look at them appear to be a single star that varies in brightness from night to night or sometimes week to week because it's actually not one star that you're looking at, but two stars. As the dimmer of the two stars passes in front of the brighter of the two stars, it blocks out some of its light, and you see the two star that appears as one star system fade down and then as that fainter star gets out of the way the entire system gets brighter again. In fact, the bright star Algol is one of these binary systems that appears to get fainter and brighter over weeks at a time based on this binary event.

Fraser: How can a star get dimmer when another star is going in front of it? Wouldn't that be just as bright? If you put a light in front of another light, you've still got a light.

Pamela: Stars come in different brightnesses. It's the combined light of the total system that appears to get fainter. Think of it this way: if I am shining a ginormous spotlight at your house, and decide to park my Jeep in front of that giant spotlight and turn on its headlights, my Jeep is still producing light, but it's headlights are no where near as bright as that spotlight's light, and my Jeep is physically blocking the light from the spotlight from getting toward your house and sending fainter light at your house. So the total light getting there is fainter.

Fraser: I guess there's a point just before the two lights line up where you do have the two of them added together, right? So you're seeing both and then one goes in front of the other and then you have only one.

Pamela: In fact with binaries, we see what's called a double eclipse pattern, where most of the time the two stars aren't lined up with each other and you see the light from the two stars combined, sort of like the case of my headlights and the spotlight both beaming on your house at the same time. But whenever my jeep goes behind the spotlight (for whatever reason it decides to go back there), then only the light from the spotlight is hitting your house and so it's a little bit less light. You may not notice it without doing all sorts of fancy calculations and measurements but there is still less light hitting your house. You only see the significant difference when the much fainter object goes in front of the much brighter object and blocks out (or eclipses to be scientific) some of the brighter light's light.

Fraser: Now I guess obviously the two stars need to be lined up perfectly, sort of we need to be right up looking at that plate right on the side where we're seeing the two stars go around. There must be lots of situations where the stars aren't lined up so we just have no way of seeing them.

Pamela: Exactly. There are just as many systems that are orbiting one another as binaries that never eclipse onanother as there are systems that eclipse each other with a perfect alignment along the equator. It's one of those neat things about the Universe having lots of random alignments of stars. This distribution allows some systems to be lined up perfectly for us to see eclipses, some systems to be lined up perfectly for us to be able to watch those stars go round and around each other (if we're using high enough magnification, and the high enough quality adaptive optics through our atmosphere). Most systems lie somewhere in between, where perhaps only the edges of the two stars pass in front of each other, or perhaps it's just a glancing eclipse. There's lots of different things that the different geometries allow to happen.

Fraser: Will our telescopes – like, can Hubble pick out the two individual stars before one goes in front of the other, or are they just too close?

Pamela: It depends on the systems that we're looking at. In some cases you can actually look at the binary systems with telescopes like Hubble and see the two stars side by side, and then moving in front of one another and then side by side again. In general we actually have to detangle what's going on using all sorts of mathematical modeling, where we're sort of guessing at what is the alignment based on the shape of how the stars get fainter and brighter.

For instance, if you have a really equal set of stars passing in front one another, the amount of time that the star that's going in front blocks out the light of the star behind it completely is very very short. It spends a large amount of time starting to cover it, starting to cover it, covering it some more, covering it some more, then it completely covers it for a brief moment, then it comes back out. So you see this continual faintening, this continual dimming of the star in the back and you see this continuous brightening of the star in the back. You don't have a lot of "the star is eclipsed" time.

Whereas if there's a huge difference in the size of the two stars, you might have a little tiny star pass in front where you see "wow it got dim fast" and then the little star passes in front, passes in front, passes in front and it stays at a constant fainter amount of light for a period of time. Then that little star pulls itself back out from in front of the bigger star and you see it re-brighten rapidly.

So we can actually get at the differences in size between two stars based on how the light varies over time.

Fraser: Okay, so that's the one way. What's another way that stars can vary?

Pamela: There it wasn't the actual stars that were varying in brightness, it was this weird geometry effect. There are stars that intrinsically vary in brightness. In general, stars are well-balanced between pressure from all of the photons being produced in the center pushing outwards on the atmosphere of the star, and the gravitational pull on the atmosphere of the star trying to collapse the star downwards. Everything is balanced perfectly so the stars are neither expanding nor contracting.

But sometimes as stars are going through life and slowly changing in temperature and slowly changing in energy generation mechanism, they'll become unbalanced. Most of the time they become unbalanced and then pull themselves together. Sometimes they become unbalanced and stay unbalanced. This is the case for instance in the stars that I like to study the most, RR Lyrae stars.

In some of these stars, they begin to collapse down and as the star collapses down it heats up. As it heats up, some of that heat can actually go into changing the structure of the atoms. It can ionize them and send electrons flying off in new directions. As the star collapses down, it's both heating up and changing the structure of the atoms. Eventually as it contracts down it reaches a point where it goes "Oh, I'm too hot" and it can't stand being that hot anymore, so it expands back outwards, cooling off.

As it expands back outwards, that energy that had gone into ionizing some of the atoms gets put into giving an extra kick on the expansion of the star. This kick is sort of like pushing a little kid on the swing right after they've started to come down from their highest point. If you push them at just the right moment, their next swing will be even higher. In this case, that extra push causes the star to expand out past the point where it might have found a new equilibrium. It expands and expands and expands and goes "Oh, I'm too big" and then collapses back down.

This process can repeat over and over and over seemingly exactly the same way (in well-behaved stars) for over 100 years.

Fraser: How much of a change in size will it go between the two times?

Pamela: Instead of change of size, let's think in terms of change in luminosity. We can see these stars change about ten times in the amount of light that's coming off of them. That's sort of like going from a Christmas tree light bulb to the 100 watt lightbulb in your table lamp.

They're changing vast amounts in the amount that's coming off of them during this process. It's hard to directly measure how the radius of one of these stars is changing, because they're kind of far way.

But we can very accurately measure how they're changing in luminosity and we can see in terms of the same science that policemen use to measure how fast your car is going, that we use to measure how fast galaxies are receding, we can also use that to measure the velocities of the surfaces of the stars. It's by looking at the inward velocity and the outward velocity that we know how the stars are moving, as they're getting brighter and dimmer.

Fraser: How fast do they move?

Pamela: The surface of the star can actually be moving as fast as 40km a second.

Fraser: Does it take like a week for it to get from its small point to it's biggest point –

Pamela: Ohhh –

Fraser: Or does it take less than a second to go from this tiny star to engulf –

Pamela: No

Fraser: I guess what I'm saying, tiny star to engulfing the orbit of the Earth, right?

[laughter]

Pamela: So, a star that is several times the Sun's radius will actually expand and contract in just 6 hours. It will go from its largest point to its smallest point and all the way back out to it's largest point in just 6 hours.

These aren't little tiny variations. We don't have exact numbers in general just because they're too far away to go out and measure them with a tape measure, but these are huge variations and they're occurring over very short periods of time. It's hard to imagine anything on Earth that big being able to change its structure that fast, but we see it when we look at the stars.

Fraser: That would just be astounding to see up close I can't even imagine what it would be like to see that. So are there any other kinds of stars that change like that?

Pamela: There are lots of different intrinsic variables. We have the RR Lyraes, my own pet favourite star. There are Cepheids, which we talked about when we talked about the distance scale.

Cepheid variables are big and it takes them on the order of tens of days to change in brightness from faintest to brightest and back down to faintest again. These stars are bright enough that we can see them in other galaxies and use them to measure distances between all sorts of different places to get nearby galaxies calibrated with the supernova distance scale.

Fraser: So what's going on in those stars?

Pamela: It's the exact same process, but because these stars start off with a different mass and a different chemical composition, they end up being much more luminous than the RR Lyrae stars when they finally get around to being pulsating variables.

If you do a plot of all the stars that we know about, that is a plot of temperature vs. how much light the stars give off, there is this stripe that goes through this diagram and any star that ends up within this stripe will be unstable. It's just something that occurs with the chemical properties in the atoms and atmosphere of these stars that leads them to have different instabilities.

So, you end up with these giant Cepheids. You end up with the sun-mass RR Lyrae stars. You also end up with (admittedly for different physical reasons), white dwarf stars that vary in brightness. In their case, they're so dense that they jiggle on the seconds-scale. You end up with a star the size of the Moon with the mass of the Sun that is varying in brightness on the order of seconds.

Fraser: Is it also varying in size as well?

Pamela: Yes, but on a much smaller scale.

Fraser: So it's almost like a dimmer switch is being turned on and off or up and down and up and down.

Pamela: Exactly.

Fraser: Wow. Was that all the stars that will change intrinsically in brightness? Can't certain parts of stars change in brightness?

Pamela: There are other reasons that different things are seen as variable. For instance T Tauri stars, they're stars that are in the process of becoming full-blown adults. They're still in their infancy, they still haven't worked everything out, and they're still in the process of starting up.

On their surface, they'll get giant sunspots (in this case star spots). As the star rotates and these star spots go in and out of view, we see the stars brightness changing. Because their solar systems are still getting sorted out, there are clouds of gas and dust that can also get in the way, causing them to appear to vary in brightness.

All of these things add up together to make these young, still forming T Tauri stars appear to be variable.

There are also elderly stars, Mira variables that are in the process of poofing away their atmospheres, as they get ready to become planetary nebula. They're also unstable for a lot of reasons that we're still trying to figure out that are probably tied in to their elderly age.

So you can see stars as unstable in brightness just as they're forming, just as they're dying and whenever they pass through this instability strip in a diagram of temperature vs. luminosity.

Fraser: Are there features that can actually happen on the stars themselves? You said a big sunspot group. I remember working on a story, it must have been a couple of years ago, where there are some stars that experience like, flares on the surface that would wipe out life on Earth if we had them on the sun.

[laughter]

Pamela: There was work done by a woman named Suzanne Hawley and several others that were studying flare stars. These are stars whose surfaces are so active that we can see their coronal activity, the same type of activity that appears as pretty flares on the edge of our sun and at most causes really pretty northern lights here on the planet Earth. We can see their flares as very noticeable changes in the brightness of these stars that appear to come and go, again just a few seconds at a time, a few minutes at a time. So these flares are very spectacular.

As I was also saying, star spots – if you look at the luminosity of a star with high enough precision, you can actually see changes in the total light coming off of a star that are caused by… one day it has seven or eight giant star spots, another day it has 30 giant star spots. These changes by the star spots we can measure here on Earth.

Fraser: We can measure, you call them star spots, but they're the same as sunspots but obviously they're not on the sun

Pamela: Exactly

Fraser: We can measure those on other stars from here on Earth?

Pamela: Yes. We just have to be precise enough in our measuring. All things are possible if your measurements are good enough.

Fraser: Or your equipment is good enough.

[laughter]

Pamela: There was a really neat paper I read a few years ago where they were working to try and figure out how to take the measurements they were taking of star spots and the measurements themselves didn't allow them to just look at the surface of the star and say "ah, there's four star spots in this pattern on the surface of this star". By combining a bunch of different measurements, they were able to figure out where the star spots would appear.

To test their system, they created artificial data sets where they did such crazy things as put smiley faces on the surface of their theoretical stars using star spots, and they were able to reproduce these crazy, man-made patterns on their crazy man-made stars using their software.

They can use that same software to figure out what, not quite so humorous but much more scientifically interesting, things real stars are doing.

Fraser: Now, what's a nova? Isn't that a brightening of a star?

Pamela: Some stars vary much more violently than others. When we talk about nova and supernova, we're talking about stars that are explosively varying in brightness. In the case of supernova you have a star, that varies once and only once as it explodes itself into a new state of being.

Fraser: Isnt' that like the end of some variations and then you get one last different variation?

[laughter]

Pamela: Well with the supernova - yes. Depending on what type of star it is, if it's a white dwarf that is sucking matter off of a nearby binary star, it can happen quite dramatically and quite suddenly. But when you're dealing with things like the type II supernova, where you have a giant star at the end of its life, you might see an unstable behaviour. Sort of like what we're seeing with Eta Carina right now. Eta Carina, as we've learned, can blow any day, and we see it varying in brightness.

Now, nova are this intermediate case, where you have, often, a white dwarf and a companion star and the white dwarf is sucking material off of that companion star. That material builds up in a disk around the white dwarf and slowly falls onto the white dwarf itself.

In the case of what we call classical nova, we see one of these stars flare violently, brightly into existence, where we might not ever have noticed there was another star before. This happens roughly 40-60 times in our Galaxy each year. We may not see all of them, but that's roughly how often it happens.

These stars we generally don't see repeat their behaviour. This isn't to say that they don't repeat their behaviour – it could be that 400 years from now, one of these white dwarfs will have sucked enough matter off of its companion that we'll see it flare up again, but it doesn't do this on human life scales.

A different type of nova that's not quite so violent is called a dwarf nova. These stars can flare up sometimes as frequently as every 100 days or so. Again, they're sucking matter off their companion star and the matter that they've sucked off gets compressed and squished and compressed and squished until thermonuclear reactions go on, just like the types of reactions that you get going on in the centre of our Sun.

These reactions can go on on the surface of a white dwarf or even in the accretion disk (that disk of material that surrounds the white dwarf) and when these reactions go off, we see that object suddenly flaring up in brightness. Then it will fade away, suck more material, suck more material and pressure build up, temperature builds up and it repeats the explosion.

What's neat is because these things are periodic in their explosive behaviour, we can learn about the physics of how white dwarfs gravitationally strip material off of nearby companions and what conditions are necessary to cause nuclear reactions to happen somewhere outside of the centre of stars.

Fraser: Now, what if, let's say, something crashed into a star? Comets go into the Sun all the time, what about if something larger like a planet went into a star. Would we see that as a nova?

Pamela: That's really not enough matter. If you took the Earth, you'd have to compact it down really, really tiny over a very small volume to get nuclear reactions, so you need several planets worth of material to go "squish" on the surface of a white dwarf to get one of these novas. So if you fed a steady diet of planets to a white dwarf, yes, you would get a nova activity.

Fraser: Now, what about V838 –

Pamela: Mon

Fraser: Mon. That's a star that I know has sort of been brightening and dimming and flared up recently. One theory that I'd heard is that its outer envelope or atmosphere had gobbled up a bunch of planets and we saw those as flares.

Pamela: People are still trying to figure out what exactly happened with V838 Mon. Before the nova event, or the brightening event, or whatever the event turns out to have been, there was a fairly normal everyday star hanging out in that direction. Unfortunately along the same line of sight there's a second star. Depending on what paper you read that second star is either part of the V838 Mon system or it's just along the line of sight, so there's this confusion factor.

Some of the papers are saying that this plain jane, everyday normal star consumed some of its planets and this caused abnormal behaviour and the star flared up, brightened radically, and it's the light from that brightening radically travelling away from the star and lighting up surrounding material that's causing this really spectacular nebula around the original star.

We're still sorting out what happens. I think that it's going to take finding other objects like V838 Mon to really get a clear cut understanding of what happened. I think just like our initial understanding of supernova 1987a required a lot of Rube Goldberg-like theories, our current understanding of V838 Mon has some Rube Goldberg-nature behind it. It could be true, but I'm going to hold off making my final "this is what V838 Mon is" proclamation until the research gets a little bit more sound and there's a better consensus of what happened.

Fraser: And I guess that this is what you're saying – that some of the stuff that most interests you is the stuff that could rewrite textbooks.

Pamela: Exactly. Astronomy is one of these really neat fields where, every semester as I'm flipping through my textbook, I can look at one new thing and go "oh, yeah, not right anymore. We figured this out last week." Everyday some new object does something that we've never seen before.

Fraser: It's kind of similar with what I do. I have lots of articles that I write, where it always kind of ends up that "this discovery has forced astronomers to go back and think again about their theories" because it doesn't match predictions.

Pamela: The place that I'm most comfortable is where I can say "here is what we see, and we see these ten different related situations that seem to build on one another, and based on these ten different things (or if we're really lucky these hundred or these thousand related things) behaving in related ways, we have this understanding. V838 Mon is a single case, and that is what makes it so cool, because it's so unique. But trying to understand something on a single, admittedly spectacular, data set… it's hard. Imagine trying to understand the development of a human being based on one really good medical work-up done during a three week period surrounding a heart attack

Fraser: Right, or a pregnancy.

Pamela: Exactly.

Fraser: Okay, well I think that's great Pamela. Hopefully that covers the variable star topic in depth for people. If not, ask us questions and we'll answer them!

Alright, well I'm going to do my standard blurb: You can get more information about the show from our website at www.astronomycast.com.

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Thanks a lot Pamela, we'll talk to you next week!

Pamela: It's been my pleasure, Fraser.

Fraser: Bye-bye.

Pamela: This has been Astronomy Cast, a weekly facts-based journey through the cosmos. Show notes, transcripts and more are available on our website thanks to the kind donations of listeners like you. Check it out at www.astronomycast.com.

Music provided by Travis Searle.

This transcript is not an exact match to the audio file. It has been edited for clarity.