Astronomy Cast Episode 283 for Monday, December 3, 2012:
Stellar Motion

Fraser: Welcome to Astronomy Cast, our 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 with me is Dr. Pamela Gay, a professor at Southern Illinois University – Edwardsville. Hi, Pamela. How are you doing?

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

Fraser: Good. So this is the last episode that we're recording before we embark upon our "Not the End of the World" cruise, and hang out in real life and record some shows with our fans and friends on a boat in the Caribbean watching the world not burn.

Pamela: This is a good way to spend the Holidays.

Fraser: Yeah. This is going to be fun.

Pamela: We get to climb around on Mayan wreckage because, really, weather does bad things to ruins...and yeah, it's going to be awesome.

Fraser: Yeah, and we'll see how this works and see if we can organize some other events in future years, so this is going to be a great experiment. And we'll meet a lot of really cool people, so that's going to be great, but it's going to be a little spotty for the next couple of weeks while we're away from our regular internet, so…sorry.

Pamela: We'll be back!

Fraser: We'll be back…yep. Now, as always, we are recording this episode as a live Google plus hang-out, so if you ever want to watch us record the episode live, we tend to record -- we try to record on Mondays at noon Pacific, so you can...if you want to be able to watch us, just come to Google plus, or on YouTube and watch us live at those times, so yeah. Alright, let's get rolling.

[advertisement]

Fraser: So our universe appears timeless and unchanging, the stars taking their nightly path across the sky, but over long periods of time you realize that our local region, and even the entire Milky Way is in constant motion. The constellations we see today could be very different millions or even thousands of years ago. Today we'll discuss stellar motion, how astronomers detect it, and how it's useful, so this is great. There was a book... I'm trying to remember, I don't even remember what the book was, but it was showing this example of what the Big Dipper looks like today, and what it probably looked like... like a 100,000 years ago, you know, when early humans were walking around and it was actually quite different -- unrecognizably different.

Pamela: Yeah, 100,000 ago our planet was aligned somewhat differently, and there are stars that are moving at rates such that they'll have gone from one constellation to an entirely different constellation in that period of time. The sky will still be recognizable insofar as most of the bright stars will still be there, or will have already gotten there, but there will be noticeable changes. Things like Eta Carinae has gotten hugely brighter in the intervening years.

Fraser: But just... these stars are drifting around in the Milky Way. All the stars -- the Sun is drifting around, our nearby stars are drifting around, and the configuration...

Pamela: I wouldn't say drifting. They're moving with purpose due to gravity.

Fraser: [laughing] They're gravitational, they're following their gravitational trajectories around, but it's just, you know, and what we see is these familiar constellations is not the way it has always been, and is not the way it will always be. So what's going on? What happened?

Pamela: Orbits. It's one of these things that is remarkably simple to explain, and then really hard and confusing to observe. We have the Sun is orbiting around the Milky Way, we have other stars are orbiting around the Milky Way, we all have slightly different orbits, some more circular, some less circular, some faster, some slower, and we perceive objects that are closer to us as moving faster through the field of view than things that are further away, and so this adds up to seeing stars like Bernard's star, which is about six light years away – it's moving ten arc seconds or so a year. That's noticeable and completely observable. Other stars are slowly drifting, and it was such that, well, in the 1800s, we were able to look and see noticeable changes in how Ptolemy's stellar catalog appeared compared to how the actual sky appeared.

Fraser: And so did the ancient astronomers have any idea that these kinds of motions were happening?

Pamela: Well, they picked up on things like the changing of the North Pole star over the course of 1000s of years, so I guess "ancient" depends on who you look to being considered ancient, but we have known for 1000s of...well, 1000-ish years that our North Pole is slowly changing, and we've known for hundreds of years about stars actually moving across the sky. It wasn't until we started being able to use telescopes and binoculars, however, that we were able to start measuring the proper motions of a lot of these stars.

Fraser: Right, so I guess the really important thing to understand is when you look at the constellations, you're not actually seeing a group of stars in the sky moving together as a team; you're seeing stars that happen to line up from our perspective...

Pamela: Right.

Fraser: ...but in fact, these stars could be 100 light years away, or if it's a really bright star, it could be 1000s of light years away, and you just don't know it.

Pamela: We won't see those motions.

Fraser: Yeah, yeah, no but you might see, well, the close stars might be moving, and they might be moving one direction, and the next star a little further back might be moving another direction. Within a few 1000 years you're going to get these motions, and the constellation's going to tear itself apart over the 1000s of years. So what kinds of measurements are required...like how do astronomers actually determine what is this motion of the stars?

Pamela: Well, we can actually measure these in scientific instruments two different types of motion. One motion is simply the motion across the sky, so we refer to that as "proper motion." This is the motion you see between different stars; it's how if you take a picture of the North Star every couple of years, you'll be able to see it slowly trekking across the sky. The other type of motion that we have is "radial motion," so this is motion perpendicular to the plane of the sky, so we can't actually see that. It's like if you have an airplane coming toward you, all you see is this really bright light that appears to be getting brighter in the sky. Well, with the stars the same thing, except for the whole getting brighter part, but we can look at these stars using spectroscopy and measure how their lines appear to be shifted, and that shifting is largely caused by their forward or backward motion, so red-shifting or blue-shifting, depending on direction.

Fraser: Right, they're taking into account the Doppler effect to get a sense of its motion.

Pamela: So when we measure the radial motion, and we measure the proper motion, well, that gives us motion in two different directions, vectoral math comes into play, and we can figure out, relative to our own solar system, the actual motion of other stars throughout the galaxy.

Now, the issue with this is that's relative to us, and we're moving too, so a lot more math is required to start sorting out actual motions relative to the center of mass of the galaxy, but it's straightforward to measure, it's just complicated to correct everything.

Fraser: And so, when you say it's straightforward to measure, what is the actual technique that's used to actually make these measurements?

Pamela: Well, it's two different techniques: one is called astrometry, and this is the act of very precisely measuring where things are located on the sky, the other is just taking spectra and measuring the Doppler shift. Now, it does get somewhat more complicated because to get at the actual motion, in terms of velocity more than just direction, you also have to start taking into account, well, how far away is that object? Because if you see something move across the sky and it's very far away and it moves this far, well, that sucker's speeding. Well, if you see it move that same distance and it's close to you, it could be going very slowly, so we have to figure out how to measure the distance to objects. Well, the primary way of measuring distance is you see when you go between one side of the Sun and the other, between one eye and the other, if you want to hold your thumb out and line it up with some distant object, if you go from only having your left eye open to only having your right eye open, your thumb will appear to move across the background. Well, if you move our planet half-way across the Sun, the nearby stars will appear to move relative to distant stars, or more importantly, relative to distant galaxies that we don't see the motion of at all, so when we're trying to measure the proper motion of stars, and we're trying to get at their distance, we now have this double issue of Earth moving creating parallax, star moving screwing up parallax, so you have to take multiple years of measurements to be able to correct out these stars' motion across the sky to get only its distance using parallax, and this only works for the nearest stars. When you start getting further, you have to start using other techniques, the error bars go up...it's a complicated process, but it can be done for some stars.

Fraser: What is the range into the Milky Way that astronomers can actually use this technique to detect their motion? Proper motion?

Pamela: You know, that's a question I don't actually know the answer to.

Fraser: You know...is it based on the astrometry? It's based on how well you can use this technique, the parallax method, to actually get at the distance of a star.

Pamela: So in terms of being able to measure their vectorial velocities, that's a different issue from just being able to measure proper motions. In order to measure proper motions, the sucker has to be going fast enough, so there are stars we can measure the distances to them, but we can perceive proper motions in them, and there are stars we have trouble measuring the distances to, and we do see proper motions.

Fraser: Right, I see, yeah.

Pamela: So it's the issue of how fast is it moving across the background stars relative to our motion, and so if you have two stars that are moving in opposite directions, or a star that's moving in the opposite direction relative to us, that may have a faster perceived motion than something that's pretty much co-orbiting with us. It's complicated to try and say something like, "Well, we can only measure out to this distance," when there's so many different factors involved.

Fraser: Now, I know that stars form often in large groups, right, I mean, the stars are forming in these great nebulae, and then the stars themselves are coalescing out of this cloud of gas and dust, and then starting to actually turn into real stars, and then they start to drift away.

Pamela: Right, the breaking of open clusters.

Fraser: Right. And you always talk about these examples where you look at, say, the Orion nebula, and that's a really nascent nebula, and then you look at something else that's maybe a little older, and then you look at things like the...

Pamela: Hades cluster...

Fraser: Yeah, the Hades cluster, and that's sort of a little further along, or the Pleiades...

Pamela: [missing audio]

Fraser: And eventually we lose sight of these clusters entirely, so I'm assuming that one of the key uses of this stellar motion is to try and figure out how these stars came together, or how they came apart.

Pamela: Right, so when we look at clusters like the Hades cluster, this is one where we can actually look at the proper motions and see the stars appearing to radiate away from that old central core that they belonged to, and one of the ways that astronomers have worked to determine membership in the Hades cluster is they look at the motions of the stars in that region of space. There's foreground stars that aren't part of the cluster, there's background stars that aren't part of the cluster, there's probably interloping stars that weren't part of the cluster, and over time as we watch the stars in this region of the sky, we can track their motion and those that are members of Hades, we can sort of follow their motion back toward the central point where the cluster used to be, well, more clustered.

Fraser: Now, can we do that with our own cluster, the one that the Sun formed within?

Pamela: No, we just can't. Our own star is billions of years old. The cluster that it was part of has long since completely shredded itself. One of the things you have to keep in mind is we've gone around our own galaxy tens of times, and with each of these orbits around the galaxy, the cluster gets more and more strung out, and eventually breaks apart into so many pieces that you can't identify what belonged where in the far past.

Fraser: What are the forces that are actually tearing them apart?

Pamela: It's just differential rotation, so it's more matter...you can't think of it as a force actively shredding it, so much as passive -- some of the stars can't keep up. The stars that are closer in to the center of the Milky Way, they're orbiting faster, the stars that are farther out are orbiting slower, and over time these differences in distance in the differences in orbital velocity that are associated with them just stretch and stretch and stretch until you can't tell what belonged where once upon a time. You also end up with disruptions where one of the clusters...the light just happened to pass by a really big other star and will get its path changed and all of this adds up.

Fraser: Right, and you get these gravity waves, right, that move...these pressure waves that move through the Milky Way's spiral arms, right?

Pamela: Gravity waves are something we don't have to worry about with this.

Fraser: Like the spiral density waves that are moving through the Milky Way and they're pulling and pushing these clusters apart, and that's not helping.

Pamela: No, so basically you end up with pile-ups of mass that depending on where they are will pull the stars in different directions, and so all of it adds up to gravity is the great factor. It's not doing any ripping and tearing, but the side effect is disruption over long periods of time.

Fraser: But do you think there might be some advancement in the future where maybe astronomers can somehow combine, I don't know, looking at the chemical signatures of stars that we see out in the Milky Way, and then maybe try to compute some kind of motion back to our neighborhood, or to some common shared location to try and figure out our brothers and sisters?

Pamela: I think there's probably just a little too much chaos involved, too many different factors that can't be reproduced, but there are scientists who are actively doing high-resolution spectroscopy to measure the finest differences in composition between different stars, trying to say, "These are the stars that might have been born at the same time we are; these are the stars that are the most similar to our own sun," and you can make guesses that there's the possibility that these our are siblings, but we can't actually know which stars are our siblings or not.

Fraser: Right, and so ideally you'd be able to put both pieces of evidence together. You'd say we see these stars, they look very similar, and we see from their motion that we can trace them back to a common origin; therefore, they're most likely related to us, but with one piece of information or the other, it's really hard to make that calculation.

Pamela: Exactly.

Fraser: So there's some situations, some environments, or some occurrences that happened here in the Milky Way that I think are interesting. They'll set these stars on extreme motions, and so you often see these situations where astronomers have discovered the fastest moving star, or you know, a star that's leaving the Milky Way. So what's going on here?

Pamela: So we have three basic situations that end up creating high moving stars. In one case, you have supernovae explosions in systems that were binary, and one of those poor stars gets ejected and it flies away, or you can end up with an asymmetric supernova, in which case supernova boom goes one way, star goes the other way, end up with an escapee. You can also have three-body motions, and we see this in globular clusters, we think, where three stars end up coming together. Through a variety of motions one of them gets flung out, and so you end up with a system flying away there as well.

Fraser: Right, right, but I mean, what's just amazing to me is the velocities that are involved. You can end up with these situations where stars are kicked out of the Milky Way at significant portions like, you know...

Pamela: 1000s of km per second.

Fraser: 1000s of km per second, yeah, 100s of 1000s of km per second -- it's crazy! I mean, again, how are astronomers discovering these? Because you'd think it's like a needle in a haystack -- you're looking at, whatever, hundreds of millions of stars and you kind of go, "Oh! That one's moving very fast!"

Pamela: Well, it's a matter of a lot of these are very faint, but you look at two images and then you get annoyed because one of the suckers moved, and a lot of the science we do nowadays takes two different images, you subtract them and you look for the differences between these two subtracted images. Things like high-motion stars just pop out when you're looking at image subtraction, so this is one of the ways we do it is two images over time, and well, they're often looking for supernovae and turning up high-velocity stars, in other cases, they're looking for them, so looking in the vicinities of supernovae, looking for the original stars involved in the disaster. Globular clusters...it's more a matter of finding them via the math, trying to figure out what causes globular clusters to maintain their structure for billions of years, and looking at three-body interactions and the flinging of stars into more eccentric orbits. That appears to be one of the ways that globular clusters maintain their shape.

Fraser: And I think there's another environment where we see a lot of stellar motion, and that's circling a supermassive black hole at the core of the Milky Way.

Pamela: Right, and in this case we can use what's called drizzle imaging. You take a whole bunch of images...

Fraser: Drizzle imaging? I've never heard that term before.

Pamela: [laughing] It's just a method of aligning everything up. You take a lot of fast images to try to, well, in this case trying to compensate for atmospheric blur, and then you stack them centroided on the brightest points, so you assume that all the points are kind of dancing in concert in your image, line them up, and you're able to see extraordinarily faint things that otherwise the seeing of the atmosphere would have blurred into oblivion. So using this type of imaging...this is also a process they use for enhancing resolution in [missing audio] space telescope images. It's a really neat process.

Fraser: Magnifying enhanced.

Pamela: Enhanced. No magnification, just enhancement, so using this technique we've been able to actually see, and this was work done by Andrea Ghez out at UCLA to see stars orbiting the supermassive black hole in the center of the Milky Way. Now, what gets me is you've actually left out one of the most interesting stellar motions that an amateur can observe.

Fraser: Can I just mention that that video of the stars orbiting the supermassive black hole, the video of that you can find animations and videos of...is one of the most dramatic, when you realize what it is you're looking at, it's one of the most dramatic videos I've ever seen in astronomy because you're seeing stars whipping around the black hole at the center of the Milky Way. It's unbelievable that they're orbiting these elliptical orbits like comets going around this black hole, and you're seeing it happen in like ten years. This is not taking a long time; you're seeing stars make these orbits in ten years. Amazing! So if you have a second...and maybe we'll put it in the show notes, but by all means, search up these videos to see these motions, so go ahead. Sorry. The most interesting...more interesting than that – proceed.

Pamela: So I said that could be observed by amateurs. You kind of need like tech to start observing the stars at the center of the galaxy, but with double stars that are actually variable stars, some of these have periods of tens of years, and you can actually watch binary stars orbit one another over time, and this is another form of gravity moving things. But here you have the combined motion of two stars that are orbiting one another on the sky, then that pair of stars as they rotate are going around the center of the Milky way, so now you have a really complicated motion, but most of the time the motion we see is dominated by just that orbital velocity.

Fraser: And there's another situation as well, which in fact, our good friend Peter Lake actually helped demonstrate recently, which is you get the situation of this gravitational micro-lensing, where you've got stars moving, one star...well, I'm going to let you explain it. You're the astronomer, not me.

Pamela: Well, I don't think Peter was actually micro-lensing. He looked at a transit.

Fraser: Yeah, he looked at a transit.

Pamela: So which was awesome, but completely different. Micro-lensing is the case where we don't actually see what's moving at all; it's black to us, but if you get a small star passing in front of something in the background, its gravity can work to lens the background object's light in causing the sudden brightening. In a few cases, we've actually been able to find planets this way because first the star passing in front of the background object lenses, and then the planet of the foreground star passing in front of the background object lenses, so you end up with this double spike, that's quite interesting to look at.

Fraser: Well, normally we go 25 minutes, half an hour, sometimes we run a little long, but I actually think we covered this one top to bottom, front to back. We covered all the stellar motion that a person can see. I have one question: if you're taking astronomy in a university, when would you typically take this, learn all this stuff?

Pamela: Well, it's the basics of proper motion because it's gravity, so it tends to be week three of the course. Astronomy 101 in many ways is how you kill somebody with astronomy, so week one starts out all nice and friendly, usually a little bit about the scientific method, Galileo and Kepler, Ptolemy...

Fraser: Learn the planets: My Very Excellent Mother Just Served Us Nachos...

Pamela: Right, and then you suddenly jump into electromagnetism, learn everything about the electromagnetic spectrum, and this order can get reversed. Then here is Kepler's laws, here is how everything moves in the sky, so yeah, within the first three or four weeks, you end up getting clobbered with electromagnetism, radiative transfer, gravitation, Kepler's Laws of Motion, learning how to use orbits to calculate this, that, and the other thing using eclipsing binaries – it is death!

Fraser: You're not selling this, Pamela. You're not selling this. This is...

Pamela: So there's a different between taking Astro. 101 and learning astronomy. I recommend learning astronomy. There's lots of other venues -- like us!

Fraser: Right, right, but if you want to be an astronomer, you're going to have to punch your way through Astronomy 101, suffer your way through 101, yeah...rite of passage. Well, fantastic, Pamela! Thank you very much, and we'll see you in person in like four days, so this is great!

Pamela: Yeah. See you Friday!

Fraser: Alright. Bye-bye.