Astronomy Cast Episode 211 for Monday, December 13, 2010: Celestial Navigation

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, and a month from December 13th – fictional date – I'm going to be at the AAS meeting in Seattle, WA, and we will be doing an event called "Astrozone," so you can goolge "Astrozone" and come out and take a look at us and see what we have to show you, if you're interested.

Fraser: Now, what's funny about this show is that both you and I will be taking cruises -- separate cruises, you're going with your husband, I'm going with my family -- half a hemisphere apart. You'll be in Europe and I'll be in Miami, but you know, navigation at sea…I thought it would be a good opportunity to talk about celestial navigation.

Pamela: All I have to say is I'm really glad we have GPS.

Fraser: You know, I picked up a sailboat and I've been kind of going through all the learning, and there's whole, huge sections about how to do celestial navigation. I'm like, "Why bother? Just get a GPS." I've got 3 GPSs.

Pamela: Well, the problem is your batteries…
Fraser: Yeah, what if it runs out? OK, so before there was GPS,

navigators had to rely on the sun and the stars to find their way around the earth. It's easier than it sounds if you've got the right instruments: clear skies, a really accurate clock and good books. So, let's examine the history of celestial navigation, learn about the different methods, and we'll give you some practical ways to go out and do this for yourself. Alright, so before we go into the actual navigation, I think it's important to just talk about the geometry of the Earth and the stars and why this all works.

Pamela: Right, so we conveniently live on a rotating planet, and just like if you stand in one place on a floor with a tile ceiling, or on top of a tile floor -- depending on whether you like to look up or look down -- if you spin in one place, you'll see that the object straight above you and straight beneath you stays perfectly stationary. You can do this in an office chair. It sometimes works better if you have someone else spin you, but not too fast because that's a bad thing, but as you rotate, you'll see all the other objects around you go on nice perfectly circular paths around you. Now, if for some reason, while you're in your office chair that your companion is rotating for you, you lean back so that now you're not looking straight up or straight down, but rather as you rotate, (and like you literally have to tilt the chair – don't try this at home you will die) if you try tilting the entire thing, you can actually get it so that as you rotate, the point that you're rotating about appears to be kind of off straight overhead, so you end up with "straight overhead" as this path where "straight overhead" stays at a constant angle. Now, that sounds confusing, but…

Fraser: No, I think I understand, but I'll take a shot at it, too. Now, you take your chair, your office chair that you're spinning around on and you put some kind of ramp underneath, so that the wheels of the chair are what's on a slope, and so then the chair is still turning, but the point being that now your axis of rotation is pointed at a different spot on the ceiling, so it's not just like you lean back on your chair while you're turning because that's just going to widen your circle. You're still going to have the same axis of rotation. What's important and what mimics what we have with the Earth is that you've got to have that angle away from straight up and down.

Pamela: And, if you measure the angle between straight overhead and that point that you're rotating about -- because you tilted your chair in a precarious and dangerous way (please don't become an organ donor) -- because of that tilt, you're going to see that that straight overhead point, as it rotates past, always maintains the same angle off of that non-moving point that you're rotating about.

Fraser: And now imagine that those flecks on the ceiling that you're looking at are really stars.

Pamela: And so where I live, which isn't too far off of 30 (I'm going to use 30 just because it's a nice round number)…where I'm located, 30 degrees north of the equator (give or take a lot because I like round numbers) if I go outside at night, what I see is about 30 degrees above the southern horizon. I can look over and there's Polaris, just hanging out fairly low in the sky, not very bright…this is one of those things that really screws people up. I think at least once a year I have someone go outside, look straight south at a planet and go, "Wow, look how bright the North Star is!" No, that's Venus.

Fraser: Yeah, that's only if you're standing on the North Pole. So, once again, I think this is great because this is something even kids can do. If you know where the North Star is, go out some night with your protractor, and line it up perfectly, so you can measure the angle between the ground and up an imaginary line that goes up to Polaris, and that will tell you your latitude on the Earth.

Pamela: And it can be a whole lot simpler than using a protractor. One of the neat things about being human being is that we're built to scale. So if I hold my fist out at arm's length, the width of my hand at arm's length is going to be 10 degrees. Now, little kids can have littler hands, but they're also going to have much shorter arms; and conveniently, a little kid's fist held out at arm's length is going to be 10 degrees, and a giant basketball player with giant hands and really long arms -- still 10 degrees. So one of the things you can do is just go out and "walk" your fists up the sky and prove, "Wow! OK, I'm 30 degrees north of the equator, and I see the North Pole Star 30 degrees above the horizon."

Fraser: And I live near the 49th parallel; so for me, Polaris is 49 degrees above the horizon, and if you kept going north from where I live you would end up at the North Pole, and there it would be 90 degrees or directly overhead.

Pamela: And what's nice about this is as long as you're on one of the nice Atlantic trading routes, which is where all of the celestial navigation originally played such a strong role, Polaris just hangs out there being a nice let-me-tell-you-how-far-north-or-south-you-are kind of object. Now, the problem is as you start to get down toward the equatorial regions, well the Southern Hemisphere doesn't exactly offer such a nice, polite star that is within a degree of the actual axis of rotation. So, instead what you have to do look at, well here's a grouping of stars and within roughly the center of this grouping of stars is where the south celestial pole is located.

Fraser: Right. It's not like we're not thinking about you folks in the Southern Hemisphere. You just have a much harder job ahead of you. There's the "Southern clump!" [laughing]

Pamela: [laughing] Right. So it's a bit of a challenge. Now, if you happen to be exactly on the equator, you don't really have anything to look at because the North Pole is buried in the haze in one direction, the South Pole is buried in the haze in the other direction; but conveniently, you can watch stars rise straight in the east, pass straight overhead and set straight in the west, and sort of go, "Oh, OK -- I'm straight under the equator." And as you get off a few degrees one way or the other you can look to see what is the path of the stars across the sky. It's kind of annoying, but you can do it.

Fraser: So, then with celestial navigation, what was the historical way then that travelers used to use this geometry of the Earth and the stars to find their way?

Pamela: Well, the most simplistic way of doing it was simple dead reckoning. You figure out OK, there's the North Star, or there is the "drinking gourd." There's actually a whole bunch of American slave songs that describe how to go north by following the constellations, and a whole lot of different constellations are made up to help reckoning direction based on the time of year. So, as you move from one culture to another throughout the globe, you find different constellations, and they're like, "OK, look for this constellation – that's North. Look for this constellation and that's South." Remember the time of year, and people would go "OK, I roughly know how fast I'm going. I know roughly what direction I'm going in," and they dead reckoned. And this is the same thing you might do if you shut off all the lights in your house. You start off heading in a straight line down the hallway. You know it's six steps to the bathroom, turn a sharp right, beware of the toilet, so you take one step to the left to step around it -- you're dead reckoning. Now, it's one thing to do it in your house with the lights shut off trying not to wake up the dog or something, but it's something else to be doing it at sea when the winds might be a bit higher, the tide's a bit slower than you anticipated. So this wasn't exactly the most accurate way to get from one point to another, but it's the starting point that people had.

Fraser: Right, and so once again, for sailors, they use a terminology called "knots" and that's a speed. And so you can know what speed you've been maintaining hour after hour after hour. You just add it up; you say, "I went seven knots in the last hour, and then I went 7 knots the hour before that, and so then you add it all up, and if you know that you've been keeping the North Star in a certain position in the sky, then you've been following a straight heading, and you've moved whatever a hundred knots in the last day.

Pamela: And if you think about it, Peter Pan is all about celestial navigation – the second star to the right…

Fraser: There we go! But this really breaks down because it stops you from going in circles, which is great, but there were a lot of mistakes… you don't really know where you are on the Earth.

Pamela: Right, and this is where one of the problems we run into is, well the Earth is rotating, which means you have to know "when" you are to know "where" you are, and so you're kind of good at noon. Figure out when is the sun at the highest point in the sky, measure how high it is above the horizon -- that gives you north and south. You know what time it is, so you sort of get there -- kind of, sort of, not great… With stars you look to figure out the rising and setting times, and figure out where you are north and south, and you can kind of figure out where you are, but again it's all "kind of sort of," so this is where the best way we ended up coming up with was actually initially what's called an "intercept method" and this is where you figure out, "OK, where would I have to be on the planet to see the moon straight overhead? Well, I don't see the moon straight over head, I see it X degrees above the horizon," so draw a circle marking everywhere on the planet where you would see the moon that many degrees above the horizon. OK, rinse, repeat and do the same thing for the sun. You now have two circles and those two circles only have two possible solutions, two places where they overlap, and usually they're separated by a few thousand miles, so you can figure out where you are by knowing within a thousand miles of where you are on the planet.

Fraser: But you need to have a sight line to both the moon and the sun.

Pamela: Right, so this doesn't exactly work during new moon, it doesn't exactly work during full moon, and it only works for part of the day the rest of the time.

Fraser: If there's a delay, you're going to get some inaccuracies because you check your moon sighting, and then you check your sun sighting 12 hours after.

Pamela: Right, and so that just leads to all kinds of hurt, but you really want to have both at the same time, so you're kind of stuck for a large chunk of the month -- well, at least a few days of the month -- so that wasn't the most accurate way of doing things, and this also is the problem of: you take your measurements, you go to your map, you draw lots of circles and you figure out where you were when you took your measurements. It doesn't tell you where you are now, it tells you where you were.

Fraser: Right, and that's not always so helpful, especially if you're getting close to shore, there's rocks, reefs…

Pamela: Right, so the next good method they came up with was what's called the Lunar Distance -- and none of these are actually good enough to tell you with reefs. All of these are going to tell you within 10 miles, 20 miles, 30 miles where you're located. Most of them are actually 30 miles or more, which when you're aiming for shore, that will get you to land unless it's a really tiny island, but it's not going to get you around that big coral reef – for that you'd need a map. So the next big improvement we came up with (and I was not alive when this happened) is a method that only works when the sun is down, and that's Lunar Distances, and here you measure how far the sun is located from a key star or multiple key stars. And our moon is moving at a pretty good clip against the background stars. It moves about 12 degrees per day, and if you can make a very accurate distance determination of where the moon is relative to hopefully more than one really bright star, you can figure out, within about 30 miles, where you are on the planet.

Fraser: Because your view of the triangle -- the angle of your view of the moon to that star -- will change where you are on the Earth because the moon is much closer than those stars are.

Pamela: Well, that's not the big thing. The big thing is you get the time from the measured angle between the lunar distance and the star, so you get the time from that distance and then you measure "Well, how high is the star above the horizon? How high is the moon above the horizon?"

Fraser: I see, I see, so in other words, when the moon makes that close approach to the star, it means that it's a certain time with a high degree of accuracy. Throw out your clock. There's your new clock.

Pamela: Yes, so you get your time and your position relative to the stars, based on the separation of the two objects, and then you get the "where" based on how high they are above the horizon.

Fraser: I'm not sure if we really explained this well, I mean, the fact is that if the earth didn't rotate, if it just hung in space against the background stars, to find any place on Earth, all you would have to do is measure your angle to the North Star, or one star, and then measure your angle to another star, and then that would tell you your position on Earth – just like that -- through triangulation, but because the Earth is rotating, it's those stars you're looking at to the west and the east that are just constantly changing, and that's the real challenge that they're looking to overcome. So, you've got like a new kind of clock, which is great!

Pamela: Yeah, so just to try to put it into a little more context, what you know is, "OK, so the moon and the star at a given time, according to a clock in Greenwich (this is how they did it – everything is measured off of Greenwich, England) at a given time relative to Greenwich, England have a given separation." Well, no matter where you are on the planet, you're going to see the same separation with the instruments they had. Now, what varies is how high in the horizon those objects are. If those objects were straight overhead in Greenwich at midnight, and you happen to be off the coast of California, you're not going to see them, but if you see a time that corresponds to noon in Greenwich, but they're straight overhead for you, you know that you're 180 degrees around the planet from Greenwich. So you figure out what time do those two objects have that location, and where must the planet be rotated in order to see it, and that tells you where you are east-west, based on where the planet has to be to see a given alignment.

Fraser: And that is some wicked math.

Pamela: And this again gets you to the problem of "Oh, crud! First I have to measure the angle" – and the math is actually even worse than that because you have to correct for the atmosphere bending the light, so you have to correct for this atmospheric bending, and so first you go, you make your measurements, you then take into account atmospheric – the fancy word is "refraction" – you then do all of your calculations, and that tells you where you were when you made the calculations, and now you're somewhere else.

Fraser: Right. So, if you're coming up on that reef – not super helpful.

Pamela: Yeah, if you only know where you are within 30 miles, it doesn't help you anyways with the reef, but if you're finding a really tiny island, then you might care.

Fraser: So, what was the next real improvement then?

Pamela: We needed a watch. It's just that simple.

Fraser: This is the problem, right? You had these clocks—these gigantic pendulum grandfather clock kind of contraptions. And you take one of those to sea… it's not going to work because the rolling ocean is just going to mess up the clock, and within hours, days, minutes – it's not going to be able to tell time. You need something really, really stable and really accurate and this just did not exist in anything you could transport with you.

Pamela: We just didn't have the materials yet. We were still trying to figure out what are the different properties of the metals, how do we bond different metals to one another. Metallurgical science was in existence, but it wasn't a detailed science yet, when they start worrying about this. So, in 1714, Great Britain put forward the "longitude prize." It was established through the Longitude Act, and it was the British government's way of saying, "Look guys, we really need to solve this problem. We're kind of an empire at sea. Somebody, please go figure out how to measure longitude." Different people took different methods of doing this, and actually the Lunar Distance method got 3000 pounds for making contributions that improved things. So Tobias Mayer got 3000 pounds from this prize for being able to figure out where you are within like 30 nautical miles – not great, but good, sort of, kind of… but the real trick came with John Harrison working to figure out chronometers, and this required new forms of steel to be made. It required figuring out how to build metals that didn't require temperature corrections, and that's one of the things that we take for granted. When you build a thermostat in house, it's actually, well you probably don't build it you just go buy it at Home Depot.

Fraser: I built mine.

Pamela: OK, fine. You can make these in a Physics lab class. You just get metal that on one side expands when it gets heated, and on the other side perhaps contracts – they just have different thermal properties that cause the little piece of metal inside your thermostat to change shape as the temperature in your house changes. It's really amazing how much metals built with the correct properties will deform with even one or two degrees of temperature variation. Now, if you're building a watch, you don't want any thermal distortions going on with all the delicate gears and springs and everything else. So, we had to figure out how to make metals that, well, corrected themselves as needed as the temperatures varied, especially out at sea.

Fraser: Now, there's actually a great show, I think it was called "Longitude," that was done a few years ago, and they went into the whole history of the prize. It was a mini-series that documented it, and it was just fantastic.

Pamela: There's a book as well. It's by the same author that did <u>Gallileo's Daughter</u>, Dava Sobel. I can't recommend the books enough.

Fraser: I really liked the mini-series, too. So, I know he came up with a few solutions. He made these great big clocks trying to come up with a way to create a great big grandfather clock that could still withstand the rolling gait of the sea; but in the end, his final strategy was a pocket watch. It's a big pocket watch, but it's still a very pocket watch-y looking contraption, and it was a very accurate clock that you could carry around, and by carrying it around, you no longer need to worry about what's happening with the ocean. It's small and stable.

Pamela: What was quite amazing is that he tried his darnedest to get the prize money that was offered. It was basically a fortune by the standards of the time. It was 20,000 pounds if you could be accurate to within 30 nautical miles going back and forth and do it repetitively. Now, he showed that his instruments were only losing a handful of seconds on an entire trans-Atlantic journey, and managed to sail all the way to the Caribbean and then sail all the way back and the British Parliament said, "Oh, it was just dumb luck. It was a fluke. You have to replicate it." So, they gave him some money – token money, no big deal -- but really not enough, and so he, after much frustration, replicated the experiment and came out even better on the second try and the British Parliament said, "No, it's still just luck," and Harrison actually having to end up going to King George and get the King involved. Now, can you imagine? You're a watchmaker, and you get so frustrated trying to collect the money that you *know* you earned building a watch, and no one really wants to help you and you have to go to the King and ask the King to intercede with Parliament, and Parliament still said "no."

Fraser: And I know that with this device…Captain Cook considered it his most prized possession.

Pamela: Yes. James Cook had the very first one. He used it on his second and third voyages. He used the Lunar Distance model the first time. So he knew how to use the Lunar Distance method, which was then the best, and still swore by the chronometer, and King George III basically took one of them himself and kept it in the palace and found that it was accurate, that within a third of a second per day, and Parliament still said "no." There was a lot of strange politics involved with this.

Fraser: Did he end up winning the prize?

Pamela: No one ever got the prize. They did end up eventually giving him the money, but not the prize. This is one of the frustrating things when you're a scientist is there's a lot of time it's not the money you're out for, it's the name recognition. If you look at a lot of the [missing audio] prizes, the money that you have to invest to win the prize is much, much greater than what you win, but it's being that person who won the prize – that's where it is, and he died three years after they said, "No, but here we'll give you some money anyway." So he basically spent his entire adult life chasing a prize that bull-headed Parliament refused to give him.

Fraser: And so this methodology is essentially what is the modern celestial navigation. It's the same system: you go out at night, you take your protractor…

Pamela: And it's really a Sextant. You can build one of these with [missing audio]…

Fraser: You take your Sextant, you have a way to determine the angle, you point one part at the horizon, another part up at a star that you know what star it is, you mark down the time and the angle, and then you do another reading at another star, and then maybe if you want, another at another star, and then you look it all up in a table.

Pamela: Right. You figure out what time does that star have that angle above the horizon, and what's often done, actually, is you figure out where the celestial meridian is, where is that line that goes from the north celestial pole down to the northern horizon and the southern horizon, and you look to figure out what time do stars cross the meridian. So rise times and meridian crossings are some of the most important times, and all of these times are tabulated. The U. S. Naval Observatory, in some ways, has a lot of the best catalogs because they're necessary for navigation.

Fraser: And this is, I guess, where we wanted to turn this into "part-tutorial" anyway. We're going to put a lot of these links in the show notes. There are both the books that you can look up the numbers, but also calculators on-line that you can just put in some of the data, and it will pop back out your location.

Pamela: And you can build very simple tools for the Lunar Distance method, or more accurate time plus angle. You need a Cross-staff and a Sextant. You can build both with paper, a protractor, straw, string and a meter stick, and you can watch the sky change.

Fraser: And you could use this method -- there are still sailors now who don't use GPS. They still will use the celestial navigation method to circumnavigate the Earth because it doesn't matter if it gets wet -- it still all just works fine. It doesn't need batteries. It's not as easy and simple a way, but you can definitely make your whole way around the Earth using just the celestial navigation.

Pamela: So, it's all geometry in the end, and a few fairly simple tools, and it's amazing what we've solved in the past 300 years.

Fraser: I've almost gotten interested enough to go and learn it… No, no, I'm still going to use my GPS.

Pamela: It's still good…

Fraser: It's still good… it's very cool. Thanks a lot, Pamela.

Pamela: It's my pleasure.