Astronomy Cast Episode 170
Coordinate Systems

Fraser: 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. Hello Pamela.
Pamela: Hey Fraser, how's it going?
Fraser: Good. So I've got to admit, this is a show for me today. This is my show...now the rest of you can listen in if you want, but this is sort of designed to help me get over a bit of a mental block that I've got, so yeah... so this is going to be one of those weeks where we tackle something you're mentally avoiding, and by "you" I mean "me." You all know those astronomical terms like alt-azimuth, right ascension, declination, arc seconds, arc minutes... of course not, your mind has blocked them out. But today we're going to explain them so you don't need to avoid them anymore. Soon you'll be ready to find anything in the cosmos. I will readily admit that if you give me the alt-azimuth numbers or the right ascension and declination and say go find that thing with your telescope, I will just give you a blank stare. If you say, "Show me how big something is in arc minutes," I would just kind of draw a circle and show you and kind of hope I was right. So, yeah, I... I know the moon is half a degree across, I've used that in enough articles now that I know that, but honestly.... so I just have this mental block and I just pass right past it. So today, we go with my mental block and maybe everybody else's as well so--coordinate systems, so Pamela what are the different coordinate systems that astronomers use to find something in the sky?
Pamela: There's basically three different coordinate systems that we use most. The first is the one that you learn when you're learning how to use an amateur telescope and that is the "altitude-azimuth" or "alt-az" system which just tells you where something is relative to the horizon. Then there's the equatorial system. This is the system that is used on almost all star charts. But sometimes when you start looking at the galaxy and start looking at the universe as a whole you want to go out and start using galactic coordinate systems instead. So those are the three primary ones in use. But if you start dealing with historic documents, you pull in a fourth coordinate system which is the ecliptic coordinate system.
Fraser: Right, and that's still used in astrology... but you know...
Pamela: Yeah. The rest of us, we just noted it for historical reasons.
Fraser: Right. Ok, well let's just start at the beginning then. So, I get a new telescope, I'm going to learn the altitude-azimuth method. How does this work? What is this based on?
Pamela: Well, quite simply, the altitude is how many degrees above the horizon is something located, and you're hoping it's a lot of degrees above the horizon because if you're down near the horizon you get lost in the atmospheric muck.
Fraser: Ok, so horizon to directly overhead...
Pamela: Which is the zenith point....
Fraser: Which is the zenith point--how many degrees is that?
Pamela: That's 90 degrees.
Fraser: 90 degrees, so there would be like 90 lines from the horizon up to the zenith point. Ok, and are they equally spaced? So...

Pamela: Everything's equally spaced, and the way we actually look at it isn't lines it's how many fists above the horizon is something.
Fraser: This is fist held at arm's length.
Pamela: Fist held at arm's length is about ten degrees. So you can fit nine fists, if you do it carefully and accurately, between the horizon and straight overhead.
Fraser: Right.
Pamela: And this works for little people and big people because the bigger your hand is, the longer your arm should be. So that big hand ends up far away from your eye and it still looks like it spans ten degrees. And a little hand is usually attached to a little arm putting it closer to the eye, making it still cover up ten degrees.
Fraser: Ok, and so then how will that be sort of described... so if I'm going to see the altitude measured, to go look for it, will it say like it's ten degrees above the horizon? How will they mark it?
Pamela: Right, so that's actually--most times when you're looking up coordinates, unless you're looking up.... yeah I can't think of a time that you're looking something up that they say "alt-az," but when you're setting your telescope up you start to worry about these things so the north pole, for instance, the north pole is zero degrees azimuth, and then where that north pole star is located, assuming you're in the northern hemisphere, is going to depend on what your latitude is. So if you're at zero degrees, if you're right on the equator, then the north pole is zero degrees above the horizon. If you're 30 degrees north of the equator, then the pole is 30 degrees above the horizon. So it has an altitude of 30 degrees.
Fraser: Right. Ok, and if you're standing on the north pole...
Pamela: If you're standing on the north pole, it's straight overhead so you're 90 degrees north of the equator, and in turn the north pole star is 90 degrees above your horizon.
Fraser: Ok, alright, and then you started to jump to the next part of it which is the azimuth.
Pamela: Right, and so the azimuth, that tells you where in the sky something is located around the clock dial, essentially. So if north is noon, and as you work your way off that angle, you can say you're going 30 degrees east, and so when you go 30 degrees east you basically follow in a clockwise direction around the horizon. You can say that something is 40 degrees west and go in an anticlockwise direction around the horizon.
Fraser: Ok, I got that. So if you tell me to go to look 90 degrees east, I will sort of stare at the north pole, at the north star, and then I will turn to the right 90 degrees.
Pamela: And you'll end up looking dead east at that point.
Fraser: I'll be looking dead east and that's the direction I'm going to be looking at. Ok, so then to sort of put that all together then, are there minuses, plusses, how would you put it all together into numbers so I could kind of break it apart? So if you gave me a altitude-azimuth coordinate, what would it look like?
Pamela: It would be something like 45 degrees altitude, 30 degrees east.
Fraser: And is it always going to be 30 degrees east, or would it just say 30 or...
Pamela: It will give you an east or west direction.
Fraser: So if it's west, then I'm turning left from looking at the north star.
Pamela: Yes.

Fraser: Ok, alright, so I think I've got that. Now what if... I guess you can't see below the horizon so it's always going to be... things are always going to be from the horizon and up.
Pamela: Yes.
Fraser: And so I'm going to use my fists or sometimes use fingers, I know Tammy, one of the writers on Universe Today, she goes, "use this many fingers up, so one fist and two more fingers."
Pamela: Right. So your three middle fingers are about four degrees, the tip of your little finger is about one degree, and this allows you to find your way around the sky fairly well.
Fraser: Right. And if you're going to have to turn 45, just go half-way between north and east, and if your going to have to turn... right, so I think I've got that.
Pamela: So the only time you'll actually see alt-az written down is when it's associated with a time. So you might see, if you go outside at 10 PM tonight there'll be an iridium flare 40 degrees above the horizon at an azimuth of 25 west.
Fraser: Now, what is the advantage, why do they use this one compared to other systems?
Pamela: Because it's the simplest way to build a telescope. That's really all there is to it. In order to use the other types of coordinate systems, you have to take into account the tilt of the pole, and so you have to put a wedge on your telescope, you have to essentially take into account the fact that our planet's rotated in figuring out where things are located in the sky. So alt-az has problems insofar as, well the sky is moving. But given a specific time and a specific place on the planet and a telescope that doesn't have a wedge, you're stuck in an alt-az coordinate system.
Fraser: Right. So that would be like a big Dobsonian, or something... so will the telescope actually have the degree.... have that built somehow onto the mount?
Pamela: Right. That's the problem is the mount itself, unless you have a wedge, will only tell you your altitude above the horizon and your azimuth, assuming you bothered to line it up with north.
Fraser: Right.
Pamela: So your telescope leaves you kinda stuck.
Fraser: Right. But if you, you know, you can get pretty close, right? Your telescope, your mount is going to show you what your altitude is, it's going to show you what your facing is, assuming as you said that you start, that you line up north with north, and then you can turn your telescope around and it will sort of tell you what your facing is, and then as well up and down, what your altitude is.
Pamela: Right. Now, the only problem is that when you look up coordinates, in general, they're always given in something else. So, your telescope is giving you alt-az coordinates, and then you need software or something to translate to more universal coordinates that don't care what time it is, that don't care where on the planet you are, and this is where we start to get to the equatorial coordinate system.
Fraser: Hit me! I'm ready!
Pamela: So, the equatorial coordinate system is defined by essentially taking key points on the planet Earth and extending them out to the sky. So, we take the planet's equator and we expand it out and turn it into the celestial equator. We take the north pole of the planet and spit it out into the sky and make it the north pole of the celestial sphere. Here,

instead of having latitude and longitude, we have what we call declination and right ascension. And declination, well that's our north-south way of measuring things. So the equator is again zero, the north pole is 90 degrees, south pole is minus 90 degrees. And then the right ascension is designed to confuse. Basically, they sat back and they said, "Ok we need to define a zero point on the sky, somehow." But the sky is moving. So how do we determine what zero is? And what they came up with is the zero point is the point on the sky that is exactly lined up between the earth and the sun on the vernal equinox. So, if you want to find zero, you wait until the vernal equinox, draw a line through the sun and notice that you can't see because the sun's in the way. So then you wait six months and on the autumnal equinox you wait and you see what is exactly overhead at midnight. And the actual definition says "at midnight at Greenwich England on the 0th meridian line" as well.
Fraser: And is that the same spot every year?
Pamela: And this is where precession comes in.
Fraser: Ahh...
Pamela: So, it's not actually the same point every year. The north pole of the planet Earth is constantly changing.
Fraser: Right, it's wobbling.
Pamela: Right. It's both precessing and it's also going through a process called nutation... it's wobbling. And so the exact zero point of the RA system changes every single year. So when you look up coordinates in a book, the book will always tell you, well these are the coordinates for 1950, these are the coordinates for the year 2000. Pretty soon we're going to need to come up with a new set of coordinates because as it turns out, in just a 50 year period, an object can move about 7/10 of a degree which, in the grand scheme of things, doesn't seem like that much, but when you're trying to point a telescope, that's a huge amount. That's enough that you can start worrying about, well am I picking up a planet, am I picking up its binary companion, am I picking up the correct galaxy in a cluster? So, again computers get in the way, save us from having to do the calculations, take coordinates that we look up that are 1950 coordinates, 2000 coordinates and translate them into whatever year the observations are being made.
Fraser: So then if I'm standing on the equator, my directly overhead then is going to be half-way between the north and south pole, right?
Pamela: So directly overhead you have zero degrees declination.
Fraser: Right. OK. And if I'm standing on the north pole I have 90, and if I'm standing on the south pole I have minus 90?
Pamela: Directly overhead.
Fraser: Right. Ok, alright. And then you mentioned that it's at the point where the autumnal equinox or the vernal... so whereabouts is that in the sky?
Pamela: So, it actually coordinates quite nicely for being the first point in the constellation Ares. So if you find the constellation Ares, its westernmost point is going to be the 0th point, and then as the sky rotates, as you move east across the constellation, you get to higher and higher right ascensions.
Fraser: Right, and I'm thinking of Ares right now. It's like... I think of it as three stars. There's like two long ones separated and then a little one that jigs down.
Pamela: So you know your constellations you just don't know where they're located.

Fraser: Right... right. Well, like I know where they are sort of in relation... I go out and go there's, you know... it's, it's March, or sorry, it's um you know April, May, you know... there's--I don't know--Andromeda, right... you know, it's winter and there's, there's Orion, but...
Pamela: So, it's basically a V with a tail on it is the way I think of it.
Fraser: Yeah, right. So, you can, so it's sort of the beginning, the westernmost side of that constellation is the 0th point. And then, so then which way, right? So if I'm looking at Ares, which way is positive and which way is negative? Or is it just one number?
Pamela: Well, it never goes negative, it goes from 0 to 24, it's actually measured in hours with right ascension.
Fraser: Ah, well that makes sense.
Pamela: So, if you go outside on the fall equinox and you look straight up at midnight, what you should be seeing is the first point of Ares. And then as you watch the clock change, and as you watch the sky rotate, one hour later, one hour of RA will be straight overhead, two hours later, two hours of RA will be straight overhead. So as the sky rotates, you see increasing hours of right ascension pass overhead.
Fraser: Right, ok I see, so it really takes into account the rotation of the earth which makes the stars seem to move.
Pamela: Yes.
Fraser: Right, ok, and so that's how I can... because that point in Ares is always moving in the sky, I just find that point in Ares and then I can just measure off of that one way or the other.
Pamela: Yes.
Fraser: And then I can go up and down, following from the north pole to the south pole, following the celestial coordinate. Ok, that almost makes sense. So then how will numbers in declination and right ascension be expressed?
Pamela: They're always expressed as, well ok, Sloan Digital Sky Survey changed how they're always expressed. Up until Sloan came along, it was always right ascension in hours. So you'd see something that was 16 hours 32 minutes 24 seconds. And then declination was typically done in degrees minutes seconds but sometimes decimals cropped in because people got tired of converting between hours, minutes, seconds, and Excel likes to use decimal degrees instead. So declination would typically be something between 0 and 90 or 0 and negative 90 degrees minutes seconds.
Fraser: Ok, alright, so then I'd know if it was 16, then I'd know that I would turn 16 hours worth of motion from the point of Ares to the left until I saw it, is that right? No, to the..
Pamela: To the east.
Fraser: To the east, so I'd turn right, so I... so if it's, you know, it it's one hour, then I'd turn 1/24 of the sky and look to the east.
Pamela: Right, and if it's 16, you look between your feet, basically...
Fraser: Depending on where you are.
Pamela: Depending on where you are. If you're looking at a circumpolar object, you could be looking down from the north pole for instance.
Fraser: Right. Ok, alright. So that gives us sort of our second system. And now let's add the third system on.

Pamela: Well, this is the galactic coordinate system, this is where we start using our galaxy to define its own, well our galaxy has an equator, our galaxy has a north pole, our galaxy has a south pole, so let's use those to define the coordinate system. Now, the tricky bit on the galactic coordinate system is, well, we can't get to 0,0. That's, if you think of the way a nice friendly coordinate system would be, the very center of the galaxy would be the center of the galactic coordinate system. But, on the sky, that would lead to a lot of confusion, because then you have to do all sorts of corrections for the earth's position and it just gets ugly very quickly. So the way we actually define the coordinate system is here we are, planet Earth, except then we imagine we're actually at the sun, because the earth moves around the sun...
Fraser: Here we are Sun, center of the universe...
Pamela: Right. And then we draw a line from the sun to the center of the galaxy. And that line that we've just drawn, that line defines where our 0 degrees galactic east-westish type coordinate systems are. So we have a circle going around the plane of the galaxy pointing from the sun straight through the center out the other side of the galaxy gives us 0.
Fraser: Right.
Pamela: Now if you go 90 degrees in a clockwise direction that gets you to 270 degrees. If you instead go 90 degrees in a counterclockwise direction, that gives you 90 degrees, and these are your galactic longitudes.
Fraser: And so then how would we measure an object? Right...once again, using the galactic coordinate system, I want to find Orion nebula, how would I do that?
Pamela: So, you need another coordinate as well, you need to know the latitude, and this is how many degrees up from this plane of the galaxy an object's located, so if you look out you might say that you're looking 27 degrees longitude, but then you also need the latitude which tells you how far out of the plane an object is. That will again go, if you're pointing towards the north galactic pole it will go from zero to 90 degrees, if you're looking down through the galaxy towards the south galactic pole or past the south galactic pole as the case may be, that gets you to minus 90 degrees.
Fraser: But isn't that kind of the same as the declination right ascension just different center points?
Pamela: It's exactly the same but has different center points. We're going from using the plane of the planets, as defining where the equator is. Actually we use the equator of the planet earth, not the orbital plane, but they're close.
Fraser: But we don't have... you know when I think of the galactic coordinate system I imagine, you know, the way that in Star Trek they would navigate around the galaxy. But there isn't really anything that works that way, there's nothing where you say, you know it's in this direction and it's 42 light years away.
Pamela: No. Because when you're just trying to find something on the sky, that's not useful.
Fraser: Because this is all just... from our perspective the entire sky is just a sphere that we look at and find points on that sphere. We don't care how far things away are. That kind of navigation is irrelevant. So, to think of an analogy, can you imagine if ground-based navigation worked the same way? So from my perspective here in Vancouver, right, Calgary and New York City are very close to each other. And London is just... London is also very close.

Pamela: But we actually do exactly the same thing in some ways, because we ignore up and down relative to the surface of the planet, so when I tell you where something on the planet is located, I give you a latitude and longitude position, but that means that an ocean liner, which is on the surface of the ocean, an airplane, which is above the surface of the ocean, and a submarine all have the exact same latitude and longitude position.
Fraser: Right. But they could be several kilometers apart.
Pamela: So, here what we're dealing with is that when we look out on the sky, that's a single skin that we're essentially looking at, but as we look at things superimposed on that skin you might end up with the random lucky alignment where you have Saturn, some star, and some distant galaxy all roughly superimposed in the same field of view on your telescope.
Fraser: Right. Even though they're obviously very far apart. Ok, and there isn't any universal coordinate system which accounts for the distances of things and lets you navigate your starship to them?
Pamela: Well, this is where we bring in to account things like red shift. So, when I'm building visualizations to fly through the universe I include latitude and longitude position on the sky or the RA and dec position on the sky, but then I give the red shift information as well, correcting it, as needed, for motions inside of clusters, and stuff. And it's that red shift that gives me that third dimension.
Fraser: Right. And that tells you how far away things are because how fast they are moving away from us. That's cool.
Pamela: Exactly.
Fraser: Ok, now there's sort of one last piece of the puzzle here which is the degrees, arc minutes, arc seconds and fractions thereof, and often, I know things will be like measured... you'll see a photo from the Hubble Space Telescope and they'll say that this planet measures one arc second across, or something like that, right?
Pamela: Right.
Fraser: So, then what are they talking about?
Pamela: Well, that's the perceived size on the sky. And we use time because... well it used to be the easiest way to measure position was you built a very stable building and you built a cross-hair, and then you looked at the cross-hair, and time is fairly easy to measure, and so you measured the time at which something crossed the cross-hair on one side and the time that the other edge of it crossed the cross-hair. That could tell you, for instance, how big the Pleiades were as they passed through your cross-hairs. What it boils down to is one hour is the size... it's 15 degrees across. It's the size of something that takes one hour to pass straight overhead. One minute is 1/60 of that, it's something that would take 60 seconds to pass overhead.
Fraser: Right, so just for some comparison, right, so let's say we have the moon, and I know that the moon is 1/2 a degree across, so how long then does... I'm doing some math in my head here, how long does the moon take...
Pamela: Well, this is where things get kinda tricky because we have 2 different... we have arc seconds in time and then we also have in degrees. So, RA is a measure of time. Declination is in degrees, just to confuse you...
Fraser: Is there a translation?
Pamela: Well if you take the entire sky, there's 360 degrees all the way around the sky, there's 24 hours all the way around the sky, so there's 15 degrees is equal to one hour.

Fraser: One arc hour.
Pamela: Yes.
Fraser: And then we can start dividing it up by then.
Pamela: Yes, so if I have one minute of RA that's going to be how something crosses the sky. Now if I say it's ten degrees across, that's my fist held at arm's length. If I say it's one degree across, that's my pinky held out at arm's length. And if I say one arc second, on the degrees system, that's I yank a piece of hair out of my head and hold it out at arm's length and the width of that piece of hair is one arc second.
Fraser: Right. And we have a difficult time seeing one arc second. How small of an object can the human eye perceive?
Pamela: That depends on the human eye.
Fraser: You know...
Pamela: The real problem is more of our atmosphere. The atmosphere is typically only good to 1 to 3 arc seconds, depending on where you are on the planet, and the human eye can usually get down to 1 or 2 arc seconds fairly well. But below that you start to run into confusion between the sky and what the eye is capable of.
Fraser: And so when we get, like, Jupiter... I'm not sure if you know how big it is offhand...
Pamela: No, I have to admit I don't...
Fraser: But, you know, we can't resolve Jupiter as a sphere or as a circle with the naked eye.
Pamela: Actually, some people can...
Fraser: Those people are liars. I kid...
Pamela: So, when Mars was at its closest approach a few years ago, it was 3 arc seconds across, and that starts to be at the point where if you have really good eyes and really perfect skies, you can look up and say, "Oh, that thing isn't behaving the way other things are behaving... that's a disc.
Fraser: You get that a bit with Venus, I find.
Pamela: Yeah, and with Jupiter, the whole system with the planets and everything, you're starting to get to the point where people with really good eyes can start to separate the moons away from the surface of Jupiter. So, looking out at the different planets, Jupiter can be 30, 40 arc seconds across... that is a clear, apparent disc. Saturn's 15-20 arc seconds across ignoring the rings. That again is something you can see as a disc.
Fraser: But is it just that the glare makes it hard to see it, or something?
Pamela: Well, the human eye isn't really good at telling area is what we're actually running into. And this is where you get to the "Twinkle Twinkle Little Star" nursery rhyme being how you differentiate between stars and planets. Stars are point sources, they have a single beam of light coming at us and the atmosphere tends to make that jumble around a lot more than a disc of a planet. So, with normal skies, planets don't twinkle, stars do. Now if you have really, really bad skies, then everything's twinkling. But in general that nursery rhyme helps you differentiate the stars from the planets.
Fraser: That is cool. Well, I think we uh... I think I now finally understand it. And for about the next hour or so, I think I'll be able to keep it in my head and then it'll be gone... that's alright. But thank you very much Pamela, I do appreciate that. You know a lot of the shows you know I sometimes know more than I perhaps lead off, but this episode--all new to me. So that's great.

Pamela: Cool.
Fraser: Alright well thanks a lot!
Pamela: Bye bye.