Astronomy Cast Episode 182

Astrometry

Fraser: Astronomy Cast Episode 182 for Monday March 22, 2010, Astrometry. 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're you doing?
Pamela: I'm doing well. How are you doing, Fraser?
Fraser: Good. One little piece of news... which is that we've had a couple of radio stations ask if they can run Astronomy Cast on the air and want our permission, and... YES! So if you run a radio station, if you know a radio station and you want to use Astronomy Cast, feel free... be our guest. Free... don't pay ever! Yes, that would be fine with us... would be great if you want to do that... college radio, NPR, or here in Canada on the CBC... CBC--call me! And ABC in Australia... anything. For free... go ahead... play it all you like. Use our content for any purpose whatsoever. Just so that's all clear. But yeah, if you want to email us and want us to do a little promo for you, no problem. That'd be cool. Alright, so let's move on with the show. So, astronomers have been cataloging star positions for thousands of years from the first calculations made by Hipparchus to the more recent star catalogs made by the spacecraft named after him. This is astrometry... another way to find our place in the universe. Alright Pamela, well I guess we need to go right back to the earliest age, and I guess at some point, humans realized that there was some kind of rhyme or reason to the position of the stars... that they weren't going anywhere, that there's a way to map this. And I think the name that comes to mind is Hipparchus, so how did this all come about?
Pamela: Well, it's impossible to know exactly when people realized that... well, wow, you see the Plow every night, you see whatever your favorite constellation is year after year after year... always appearing in the same season. Star maps though, those started being made originally by the ancient Babylonians. That's where we start getting squirrelly names like Zubenelgenubi for different stars and Betelgeuse which leads to many arguments over *betelgice,* *beetlejuice,* whatever...
Fraser: Right, but we have to thank the Babylonians for that name... wow...
Pamela: Yeah, so those names all came down from the ancient Babylonians. But in terms of things we can get our hands on and study easily, well we can't necessarily get our hands on the work by Hipparchus... not in all cases... but his work, his original star maps from basically 150 B.C., his original work throughout his life, it was used as the base information for the Almagest by Ptolemy, which is perhaps one of the most famous early astronomy books.
Fraser: So, who was Hipparchus?
Pamela: He was a mathematician, he was a geometrist. He was working in the Mediterranean... he was at Rhodes for some of his measurements, he was in Egypt for others. He was a Greek. And as he traveled and as he measured, he worked with others to try to figure out... if I'm seeing this, what are you seeing when you are. It was in putting all these pieces together that Hipparchus was able to make some really amazing

discoveries. He was one of the early scientists who based his discoveries not on philosophy, not on shadows on cave walls, but on looking. So he noticed things like... the moon has an obvious change in size over time. When he watched it through what's called the diopter, he was able to tell that sometimes it was a little bit bigger, sometimes it was a little bit smaller, and this was an interesting discovery back in the days when we thought all orbits were perfect circles.
Fraser: Right, right, I mean the moon changes like 15% from its most distant point to its closest point. It actually changes in brightness, there are some full moons that are a lot brighter than others. And they were able to calculate this.
Pamela: And noticing all this, he sat down and tried to run the math assuming epicycles to try to figure out what's going on based on the changes in size that he was able to observe.
Fraser: So, epicycles... this is where the moon is orbiting the earth in a perfect circle but then it's on a little....
Pamela: ...tiny circle on top of the perfect circle. So you can imagine it like a bicycle wheel that the moon is attached to the outside of the bicycle wheel and the bicycle wheel is rolling itself around the moon's perfectly circular orbit. So you end up with the moon essentially doing loop-the-loops around the earth but never crossing over the same point on the loop-the-loop... so just like a bicycle you don't end up with the rim doing weird things as it rolls across the ground... you always end up with constant movement forward of the tire. The moon constantly moves forward.
Fraser: Right, so he was able to use... by looking at the moon from different places on the earth, working out its distance.
Pamela: And he also used eclipses as a specific way to make sure he got the timing right. So, by having him in one place watching the eclipse and noting... I see the sun blocked out 100% and having somebody else somewhere else looking at the eclipse saying.... I see it blocked out this percent and figuring out what angular shift that must imply. So if you hold your thumb up and you block out a distant object and you blink from one eye to the next, you'll see your thumb bounce left and right. Well, if you're at two different points on the earth's surface, and you look at the moon against the sun, and you see the moon bounce left and right, well you can use geometry to figure out where the moon has to be located.
Fraser: That's amazing. Amazing they can work out that stuff so long ago.
Pamela: And they were able to do it fairly accurately. Now when the eclipse that they were looking at occurred, the sun wasn't high in the sky so it wasn't a perfect measurement, but it was good enough to get a lower limit on far away the moon should be.
Fraser: And how big the earth is, and how far away the sun might be... I mean they were pretty close on all that stuff. It's quite amazing. When you think about the ancient Greeks, and how they thought... they knew a lot... they didn't think the world was flat...they knew roughly how big the earth was... it's quite amazing, so anyway, right, but I guess Hipparchus and what we're doing is most famously named for working out the star positions.
Pamela: Right. He basically sat and created a map of the sky that very carefully tracked what did the stars look like where he was living. Exactly why he did this... it's thought that it might have been encouraged by an observation of a supernova that made him just

want to note down where everything is so that if something else new cropped up he would be able to know it was new. And so using what was called an armillary sphere, a way to very carefully measure the separations on the sky, he wrote down the positions for at least 850 stars. It's unknown quite what coordinate system he used, but his 850 stars-- these formed the foundation for Ptolemy's work about 300 years later. that basically charted a lot more stars and again formed the foundations for our modern way of looking up at the stars.
Fraser: And just to kind of get into the nitty-gritty here, you talk about using an armillary sphere... what did that look like? How was this tool used to calculate star positions?
Pamela: Well, it was a small device... you might call it a spherical astrolabe. It basically allowed you to mark out where the horizons were, and you had lots of different rings that you could rotate to start figuring out what the angles were. Now I have to admit, to me it looks like a very complicated strange device and I'm not entirely sure how you use it to make measurements, but I think it was a good way of lining things up, and, you know, if this is here and this is here and you can measure the angle off of set known positions, you can start to figure out where things go in the sky. So I don't think he was actually using it, holding it up in front of his eye and making measurements but was rather using it to make calculations. I know where these things are, I've measured this relative to these, therefore this has to be in this location.
Fraser: Right, and so Ptolemy used sort of similar methods, but of course with Ptolemy he had everything orbiting around the earth.
Pamela: Which is a bit problematic and then, epicycles...
Fraser: Yeah, epicycles. Let's make this more complicated.... But, he produced an even more accurate map... So then what was the next improvement on this process?
Pamela: So, you had Hipparchus working about 150 BC, Ptolemy working about 300 years later, and then while the Europeans were busy with their Crusades, you had the Arabs working very carefully to produce new catalogs. I'm going to destroy this pronunciation... I'm going to apologize as I so often do on this show... There was someone by the name of Abd al-Rahman al-Sufi who worked on a catalog of about 10,000 entries of the sun's position over the years. And, he was very carefully also noticing when eclipses occurred and it was off of a lot of his work that future work was able to say... ok, we now know how things are changing. We now know how the sun's position on the sky is changing over time. So, then there was another astronomer, Ulugh Beg, who compiled a catalog of star positions. This time instead of the 800, it was 1019 stars. And this new star, it was probably consistent to less-than-your-pinky's-width across the sky. He was making fairly precise measurements.
Fraser: Right, and it's interesting.... A lot of the star names that we use today are Arab names. A lot of the modern names that we use... I mean you talked about some Babylonian ones and some other backgrounds... but a lot of them are Arab names. And if you look at big lists of all the named stars, most of them have Arab names. It's quite interesting. So then kind of now we get into the modern age where maybe Ptolemy was wrong... maybe not everything does revolve around the earth, right?
Pamela: Well, and here's the thing... with the early debates on who is orbiting what, it was easy to say on both sides... well, you're wrong because you're not fitting the data, or oh, no I'm right... it's the data that has the errors. If you don't have extremely precise

instruments, you can always blame the data. And it was Tycho Brahe who took the first really amazing set of data where his positions were the most precise ever made. If you hold your thumb up on the sky, it's 2 degrees across... depending on your thumb... some thumbs are fatter than others. And each of those degrees can be divided up into 60 minutes, each of those minutes can be divided up into 60 seconds, so you're looking at several hundred seconds spanning across your thumb. Now his measurements were accurate to within 15 to 35 seconds of arc across the sky. Using his data, you could no longer argue with whether your math was right or wrong... either it was right or it was wrong. It had to match the data. That was the source that was the most reliable.

Fraser: And then this star data would then be used, right? So you could then say Saturn was this far away from that star on this date. And that would be the way that you could then start to detect these elliptical orbits, not circular orbits... right?

Pamela: Right. And so you could very precisely say... relative to the sun, relative to the earth, exactly where everything was located in the sky over time. And this is where poor Kepler was left struggling. He was a mathematician. He was very good at what he did, and he was looking for circular orbits... he was looking for perfect circles. He tried inscribing them in crazy geometries, he tried doing all sorts of crazy stuff before finally realizing the data said... and you can't argue with good data... the data said planets are moving in ellipses.

Fraser: It's really interesting, because it's like these star maps are so important for every other piece of astronomy. Without these star maps we would have no way to know the truth about the way the universe functions.... about the fact that the sun is the center of the solar system, and it's this background information... somebody had to build this background map that you could then chart everything against. If you didn't have that map, no other kind of astronomy was going to be possible without it. So, they're the unsung heroes...

Pamela: And what's amazing is just how they did these things... so Brahe basically had a room where he had a device that could slide up and down, but only in one coordinate... it's what is called a mural quadrant. And he waited for the earth to rotate... and as the earth rotated it carried things in and out of his field of view, allowing him to very precisely, knowing that his object was secure, see this is definitely separated from this by this amount... this is definitely separated from this other thing by this amount... And, this gave him one part of the sky, though... there was still so much more of the sky waiting to be discovered. So since then, we've been working to try and pull together the entire sky into one coherent catalog. And this is where it starts to get tricky. You have things getting carried over Poland where Brahe's working, you have things pulled over Arizona where later-people started working, you had people working in South Africa... working in Australia... all using very precise instruments... instruments that said, relative to where I'm located, this object has this angle in the sky and passed as high overhead as it could at this time... this next one passed over a few minutes later... you need time, you need position. And now I have one very accurate stripe, another very accurate stripe, and then you have to figure out how to align the stripes of sky you very carefully matched.

Fraser: Right, and so they were building... a series of astronomers came, one after another, building more and more detailed star maps, filling in these holes in the sky. But I think the big question that they had to answer was how far away are these stars... I mean we can make a very accurate sphere around the earth and position all the stars on it, but a

truer understanding of our place in the universe is to create a true 3-D map where you know the accurate distance to each one of these stars... so how did that happen?
Pamela: We had hints of how to do it as early back as Hipparchus. We knew that using parallax--if you shift yourself from the left to the right... north on the planet to south on the planet... you can see nearby objects shift... like the moon. It was thought if some of the stars are closer than some of the other stars, won't you see them shift left to right?
Fraser: Oh, like over the course of a year, so when you're on one side of the earth's orbit around the sun you're looking at the sun from one point of view, and then you wait six months, you're on the other side of the earth's orbit and you'd see the star from another point of view. And the close stars should be wiggling back and forth against the background stars.
Pamela: And people started trying to make these measurements as early as the 1500s when we finally started getting good telescopes with good fields of view. But none of those early instruments were quite good enough. James Bradley made the first really solid attempt in 1729, and unfortunately what he was able to instead discover was light suffers aberration by our atmosphere, the planet is wobbling a little bit, it has nutation in its axis, and so he very carefully cataloged 3222 stars and didn't find parallax. But, when Frederick Vessel was working in the 1800s, he built on Bradley's work. As he made his very careful--with even better optics--measurements, he was finally able to measure the stellar parallax of star 61 Cygni that we now know has a parallax of .3 arc seconds. So, an arc second--just to give you an even clearer idea of what it is--take a piece of hair, yank it out of your head, hold it at taut at arm's length, and the width of the piece of hair... that's one arc second on the sky.
Fraser: So it's a third of a piece of hair held at arm's length and he was able to measure that distance in movement, through the wiggly, jiggly atmosphere...
Pamela: And he had to wait for the earth to move six months to measure that shift compared to other nearby stars that were more distant.
Fraser: And this was a big parallax, right?
Pamela: This was a huge parallax, and it's not an easy set of measurements to make, and they made it. Now what we talk about is milliarcseconds. The Tycho catalog looked at parallaxes of 20 to 30 milliarc seconds. So here you're starting to look at 2/100, 3/100 of an arc second of a shift. It's complicated work, but we're able to do it. This is giving us a 3-dimensional understanding of nearby objects.
Fraser: So I guess the story comes around... there's the Hipparchus satellite, launched about 20 years ago.
Pamela: And the Hipparchus mission built on that Tycho catalog. It looked at 2 1/2 million stars and published in 2000, it was again able to make these milliarcsecond measurements of parallax. It did 2 things... it didn't just measure the parallax, it also measured the radial motion of the star. So it started to be able to give us distinct... these things aren't just shifting due to the earth's motion, but they're actually moving across the sky due to their own orbital motion. That starts to give you a full picture of... well, this thing is orbiting this way, and this other thing is orbiting this other way... and now do we not only know how far away things are, but we know how fast they're moving across the sky. Now it's goal was actually not to do just the 20 or 30 milliarcseconds, but it actually got down to an arcsecond or less, depending on the star. So it starts to give us a pretty good understanding of exactly where things are in our nearby universe.

Fraser: And so when we see these current maps, these 3-dimensional maps of our surroundings... a lot of the work is done by the Hipparchus spacecraft. It's amazing to think about that Hipparchus detected all of this motion, that all of the stars that we see in the sky today... it's just temporary. All the constellations that we see today... the stars are buzzing around... right and left, up and down. Over thousands of years, the constellations will look quite mangled and eventually lose their current shape.
Pamela: And this actually makes setting the zero points on any particular chart rather difficult. You can't say this particular star is a zero point. In fact even naming the stars gets difficult, because if you look at some of the names of the stars, they're named Orion number, number, number, number... but that star has moved and is no longer in the constellation Orion. So when we're creating maps, you have to have some solid reference frame... turn right at the boulder. That's how we do things when you drive in New Hampshire. But you can't turn right at the red giant when that red giant is Mira and it's whipping itself through the galaxy. We actually have to tie all of our coordinate systems to the most distant objects because, yeah, they are moving, but they're so fare away that we can't perceive any of that motion. So we tie all of our coordinate systems to quasars, active galaxies off in the most distance regions of the universe... because they don't move, as near as we can tell.
Fraser: Yeah, in a time frame that astronomers are going to be concerned about. So, in the end, the final mapping tool are these quasars, and so if astronomers want to judge whether things are moving, everything is done against this background of these quasars.
Pamela: And what's awesome about these quasars, is they actually solve a lot of problems. They don't just allow us to tie together all the optical data, because luckily there's quasars in the entire sky and you can see them from satellites. So, if someone in Australia is mapping in the optical this small region of the sky, as long as it has quasars in it... we can tie in their small catalog with all the rest of the catalogs. But you start to get into trouble when you start to look at radio sources. How do I know that this radio sblop on my map corresponds to this optical clear, pretty, shiny galaxy unless I know for certain the two coordinate systems are the same? And again, quasars are nice and polite and occasionally radio-loud... so what we do is we also look for the quasars that give off radio emissions and we use them to ground our radio catalogs to our optical catalogs. We work our way through the entire electromagnetic spectrum this way... looking for things far away, non-moving and shiny, and we make those our zero points.
Fraser: That's really cool. Well, thanks Hipparchus... and thanks Pamela. We'll talk to you next week.
Pamela: Sounds good Fraser, I'll talk to you later.