Astronomy Cast Episode 189
Johannes Kepler and His Laws

Fraser: Astronomy Cast Episode 189 for Monday May 10, 2010, Johannes Kepler and His Laws. 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... just a little bit too hot here.
Fraser: Right, well you need to turn off all your fans to keep your place nice and quiet so we don't bother the listeners... just another sacrifice that we make!
Pamela: I am sitting in a sauna for the sake of better audio!
Fraser: Perfect! I'm sure they're very grateful. Alright, Nicolas Copernicus changed our understanding of the universe when he rearranged the solar system to put the sun at the center with the earth becoming just another one of the planets orbiting. But the movement of the planets didn't really match the theory, not until Johannes Kepler came along with his ellipses... and everything finally worked out. So, we're going to do another of our two-parters... this week we're going to talk about Johannes Kepler and the three immutable laws of planetary motion. Then next week, we'll talk about the mission Kepler, which is about one of the coolest missions that is up in space right now, and could very well discover earth-sized worlds orbiting other stars. It's guaranteed to...
Pamela: We hope, we hope... nothing's guaranteed...
Fraser: We hope... So, that'll be next week. This week we'll talk about the man, next week we'll talk about the mission named after the man. People have been enjoying that... Alright, so let's talk about Kepler and I guess we should go back and retell some history... We started out with Ptolemy... placing the earth at the center of the universe but keeping really good records of the bizarre motions of the planets going around the sky. He would, to account for these bizarre backward motions, he would put circles within circles, but in the end, he came up with some pretty solid math to back it up. Copernicus came along and said let's try instead putting the earth as just another planet and putting the sun at the center. The problem with that is that the math didn't work out. The planets didn't follow nice circular orbits around the sun. So where does the story go from here?
Pamela: Well, this is one of those things of... they were trying to be data-driven... they were trying to work off of records, and when Kepler came along... he was, first of all, someone who wasn't going to make his own observations. So he's relying on other people's data and he's trying...
Fraser: That's for the little people...
Pamela: Well, no, it was actually more complicated than that... Kepler... he didn't have an easy life. He was born a month premature back when being a premie wasn't the type of thing that we had NICU units to take care of... he also had smallpox as a child. The combination of being sick, of being premature, it's hard to tell exactly what was the primary cause but he didn't have good vision. Without good vision it's kind of hard to look up and make good, accurate observations of the night sky. You really have to have good eyes to do that, and he didn't have that. So here you have this person who was

deeply inspired by a comet as a kid, was mathematically driven, was said to be mathematically brilliant and all records point to that being true, but he just didn't have it in him as an individual to be the record keeper. And that's fine... the world needs theorists.

Fraser: Right, and this was a time just before the telescope was really doing a lot of work and you had people like Tycho Brahe who were making these really detailed observations.

Pamela: But Brahe was keeping them all to himself, was the problem.

Fraser: Right, but with the unaided eye... they weren't using a telescope, they had a sighting tube that they would get lined up with the star to record the position, record the planets' positions, and all that. But you really needed your good eyeballs to get an accurate fix on the position of everything.

Pamela: Right, and just to be able to make out the fainter and fainter objects, and to differentiate between the different objects when things got crowded... yeah, you had to have good vision and you had to be careful. Kepler had the careful going for him, but he didn't have the good vision. So, here he was working very hard to come up with good theories and he's working very hard to have everything be mathematically centered. While he's working on all of his cosmologies, he's working as a schoolteacher... I love this... he wasn't a professor, he was a schoolteacher. While he's working on all of his theories he's also working as a schoolteacher, and he eventually sent his work out to several people... Tycho Brahe being one of them. He sought their opinions for his theories of how things might be aligned... this was when he was still working on geometric models where he said take a polygon, inscribe a circle within it, circumscribe a sphere outside of it, one of these spheres... this might be how we get at the surfaces that the planets orbit on. But he was working from imperfect data... when you're working with imperfect data you can come up with theories that fit beautifully to your imperfect data, but are wrong. So when he sent his work out to, among other people, Brahe, he got back comments. The comments he got back from Brahe were very challenging and they forced him to look his things over and Brahe called into question how accurate were Copernicus' records and Kepler was working on Copernicus' data--how accurate was that? Eventually Kepler ended up going out and visiting Brahe in Poland and working with Brahe's numbers. This was actually very difficult because first of all, he had to get there... that's not too big a deal even back then... but once he got there he had to convince Brahe and Brahe's assistants to let him have direct access to the numbers. Once he had that direct access, he wasn't allowed to copy any of the numbers for his own work, so he had to sit there and work directly from Brahe's notes. He worked hard to try to improve his work. He went back home and continued to work on the mathematics that he'd started on and he was trying very hard to just make sense of Mars... just one lousy planet... He kept up this dialogue with Brahe until eventually Brahe invited him to come work for him in Poland. This wasn't a pretty process... the initial going back to Poland was precipitated by Brahe and Kepler getting into a massive fight and Kepler leaving, and they had to make things up and eventually work out job description and living arrangements and salary and all these sorts of things. Once it was sorted out, then Brahe finally got to share all of his data with Kepler who finally got to turn all this data into an honest real workable theory of our solar system.

Fraser: Right, and I don't know if we mentioned it, but Kepler was from Germany, right?

Pamela: He was from Austria, actually. Well, he lived in many different nations. This is one of those things that we just don't think about... these are people that moved all over the place. He was born in the German state of Baden-Wurttemberg, and he was of royal descendency, actually. His grandfather had been Lord Mayor of the town of Weil der Stadt. He ended up living in Poland at one point, he ended up living in Austria at one point, so he lived in many different places. When he went to go work with Brahe, he had been teaching at a school in Graz, Austria. So he was of German descent, teaching at a school in Graz, going to see Brahe in Poland. So, he was all over Europe. But, he was staying in Protestant Europe.
Fraser: Right. And then unfortunately Brahe died.
Pamela: Yes. And that added more complications because, at that point, Kepler was finally getting ready to start publishing his theories and he had to publish them based on Brahe's work, but to publish them based on Brahe's work he had to have permission from the descendents of Brahe to use the results of Brahe, and it ended up being a mess and finally Kepler was able to publish everything, but he had to publish everything using his own money to do it, which was a bit problematic when you're a poor mathematician relying on royalty to occasionally pay you.
Fraser: And so what was he working on... when you say he began to publish, what was the part of what he was saying?
Pamela: Well, he had two major publications that turned out to be true. The first one was he was working on trying to describe how planets actually do orbit. This work culminated in a book called Astronomia nova... A New Astronomy, which is strangely the name of so many books over history... you just keep naming things "New Astronomy."
Fraser: New Astronomy... yeah... a new kind of science...
Pamela: Yeah, we're not real creative types. But in Astronomia nova, he included his first two laws of planetary motion. The first law is that every planet moves in an ellipse, which surprisingly no one had tried mathematically before. This is one of those things that baffled Kepler. Everyone knew Aristotle had said things should orbit in circles, and Kepler had figured that they knew the circles didn't quite work... they'd come up with these epicycles, they'd come up with these deferents... that's where first of all they put the planets on circles that roll around on the orbits, and then they off-center the circles with the deferents. It's a very complicated system, and it still didn't quite work. Kepler figured someone along the lines must have said a circle is just a special part of an ellipse and tried that, but it turned out no one had. So, he was the first person to figure out... oh, that works.
Fraser: And we can get an ellipse from slicing a cone, right?
Pamela: Right. Any cone... take it and slice it at a diagonal and you get an ellipse. Another way to get it is to take two tacks and put them into a tack board and attach a pen with a string to those two different... we call them foci but in this case they're physically tacks on a tack board... As you move your pen around, at the extreme of that point in the string it's going to trace out an ellipse where when you're along the line that the two tacks are on, that's where you end up getting stuck closest to one of the tacks. When you're at the midway point between the two tacks, there you're able to get the furthest away from the two tacks. It ends up shaping out the entire ellipse.
Fraser: Right, so if you want to do an experiment, want to show the kids how ellipses are formed... give this a shot. So, either make a cone and go at it with a band saw, or take two

tacks, put them into a piece of wood or a board on the wall and then grab a pen and draw out... always keep the string tight... and let the tacks define how far the string can go in different directions and you'll trace out an ellipse. This is the shape that the planets are following. But I guess in the solar system we're not looking at tacks, we're looking at...
Pamela: The sun and... the other foci, actually, doesn't physically exist. So one of those two tacks, one of those two foci, that's the location of the sun. The other foci is just a mathematically-existing place. Just to add one more thing... if you're working with little kids and you want to explain conic sections, get yourself an ice cream cone, wrap a string around it at a crazy diagonal, and then eat around the edge to reveal where the string is. Then you can use flour or the top of an uneaten ice cream canister and carve out the shapes. First the round for the complete cone, then the crazy ellipse from where you've eaten down to your string.
Fraser: Right. That sounds good. I'm going to go do that experiment right now. But, right, he tried a bunch of different shapes, right? He followed some of the bizarre movements and tried some of the other different shapes as well, but in the end it was the ellipse... it was this slice of a cone that perfectly matched the motions that the planets followed.
Pamela: Right. And in the exact same "A New Astronomy" publication, Astronomia nova, he also published his second law of planetary motion, that a line joining a planet and the sun sweeps out equal areas during equal intervals of time. What this means is that when a planet is particularly close to the sun, it's going to chug along on its orbit much, much faster. When it's further away from the sun, it's going to move much slower. So if you look at the skinny, not-quite-a-triangle swept out in a couple of days of motion when a planet is far, far away from the sun, the area of that not-quite-a-triangle is equal to the area of a much stouter segment of the circle that's swept out when the planet is much closer.
Fraser: Right, right... so you could imagine, actually... hold a stopwatch, watch how far the planet goes... stop the stopwatch for a set amount of time... be it minutes, seconds, hours, and then fill in that shaded area that the planet has made. That number should be the same amount of area every time.
Pamela: And you can actually do this if you have fairly good planetarium software. Set up your screen so that the sun sits at the center, then turn on the planets and make sure you get a couple of them up on the screen. Step through it a week at a time and print out... kill a lot of trees... print out for each one-week interval. Then you can use tracing paper to combine all of these images into one. Or if you're particularly computer-savvy, just screen capture and layer these images together and use photo-shop and transparency or something, and make an aggregate image. You can see how it moves so much faster when it's close and so much slower when it's further away.
Fraser: Right, right. And that's like that thing with comets, right? When we see comets, they're following these very elongated elliptical orbits around the sun, and that tail shows up as they get very close. And if you see these cool animations, it looks like the comet whips around the sun and then it slows down as it's heading away.
Pamela: With Halley's comet this is particularly amazing to think about... it has an orbit of over 70 years but it's only in the inner part of the solar system where we can see it readily for less than a year at a time.

Fraser: So, we've got two laws of planetary motion... planets follow ellipses, and area that the planet fills in of the ellipse of its orbit is the same amount when you look at the time.
Pamela: Right.
Fraser: But I know he's got three laws.
Pamela: Right. So both of those he was able to publish in 1609 and this was, remarkably enough, the same year that Galileo first turned the telescope up towards the sky. One of the things that Kepler doesn't get enough attention for is the work he did with optics, the work he did trying to understand how light gets refracted by our atmosphere, trying to understand why is the moon red during an eclipse. Optics and reflections... it was something that deeply intrigued him and so as soon as he could he got his hands on a telescope and he started trying to understand how is it that lenses work... what are the images that project into the eye. Kepler's the one who actually figured out that when you look at a tree in your yard, that image that you see... well, your brain has flipped it right side up. Your eye actually has all of the images upside down on the retina where it's getting detected because the lens in your eye flips images. But then your brain flips them back. Kepler's the one who figured that out before we had any understanding of what a brain really even is... he attributed it to the soul, but it was along the right lines and it's still a pretty cool achievement.
Fraser: So when did the third law come along?
Pamela: The third law came along in 1619 after he had gone off and worked with lenses and telescopes and everything else. The third law says that the square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of the orbit.
Fraser: It just rolls off the tongue... yeah...
Pamela: It just rolls off the tongue. This is where he finally moved beyond just looking at the orbit of Mars and he started looking at the rest of the solar system, putting all of the pieces together. One of the biggest works of his life was the Rudolphine Tables. These were published in 1623 finally, again held up by debates with the Brahe family. In them, he tabulated predictions for all the different planets. They weren't entirely accurate... there were some early detractors of Kepler who looked at these tables and said he didn't get the transits of Mercury and Venus absolutely correct, but once he modified the tables with new data, once he corrected so that everything was perfect, all of his theories worked. We were finally able to get a mathematical scale size for our solar system. We could figure out what our distance was from the sun, relatively. Then, using ratios, we could figure out how far everything else was from the sun as well for the very first time.
Fraser: Now as I recall, he was an astronomer... but he was also an astrologer.
Pamela: Yes.
Fraser: And his day job was often doing horoscopes for people.
Pamela: Yes. He actually... when he was in seminary... he didn't go to university to become a mathematician, he initially planned on becoming a minister. The times he lived in were very different from ours theologically, scientifically, and in every other way. Physics and astronomy weren't tightly related yet, and so he spent his days in university studying mathematics, studying religion... he was a devout Lutheran, which got him in a lot of trouble... but he also cast horoscopes for all of his classmates and became renowned for accurately casting horoscopes. In many of this publications, in early drafts and in some publications even in final drafts, he attributed a lot of what he saw to planets and

the sun have souls, to looking for the astrological concepts that could be better understood through his mathematical understanding of the planets. He was trying very hard to pull all of these different realms together. He felt that you could study the intelligent design of the universe through physics... that God communicated through physics and that astrology was part of that, where it was how our lives were being influenced. It's a very metaphysical way of looking at things which today I think would get you promptly laughed out of an institution and accused of woo-woo science. But in his time, it was acceptable and he actually through the years would do things like go to courts that were Catholic and say no I'm Lutheran, and he was able to keep everything somehow lined up and centralized in a way that allowed him to do excellent mathematics, allowed him to do amazing astronomy, and still maintain this belief in astrology and this very strong Lutheran faith.
Fraser: So, he produced the Rudolphine tables, and that completed the third law of Kepler's Laws of Planetary Motion. So what happened then?
Pamela: Well, that was pretty much his culminating work. At that point when they came out in 1623, he wasn't exactly a young man. He was born in 1571; he was in his fifties. He was a teacher at that point. He was having trouble with the Reformation, with the rise or re-rise of the Catholic Church. His poor mother, as a result of one of his pieces that was very much an allegorical text... he wrote a piece called Somnium... the Dream... It lead to his mother, after his death, being brought up on witch trials. And as this ended up getting circulated, it caused problems because people couldn't separate the allegory from the real science. He ended up having to rewrite it with more footnotes than were in the original text, trying to explain what was allegory, what was scientific content. He unfortunately ended up spending a lot of his later years just improving and improving and improving on what he was doing and also trying to figure out how to communicate it that didn't get his mom brought up on a witch trial. And that's troubling...
Fraser: Right. And so when did he die?
Pamela: He ended up dying in 1630. He lived from Dec. 27, 1571 to Nov. 15, 1630. It was a good long life considering the time that he lived in. He accomplished a lot of work and published a number of books. What's interesting is his work was never as loudly embraced as others of his peers, and it's only been in the recent 1900s that people have been working to collect everything together. I think he may have... the problem that he had... some of the works he did--completely awesome. Some of the works he did--a little woo. And that caused different communities to give his work some distance.
Fraser: Right. And what was his... I mean how was he perceived by some of his contemporaries? Galileo was working around the same time...
Pamela: Galileo actually pretty much ignored, much to Kepler's dismay, his New Astronomy. Kepler published a treatise praising the Dialogues written by Galileo. Then when he finished his New Astronomy, sent a copy off to Galileo and Galileo never really said anything. So that must have been frustrating, and he had the same problem with other people reading his work, and they'd correspond with him, but he just didn't get the public acknowledgement that he might have wanted.
Fraser: Hmm.... that's too bad. It's the same story that we hear time and time again... they do amazing work that resonates through astronomy, and they're just not recognized in their time.

Pamela: And his work wasn't immediately accepted... it was complicated... it was pure math... and it changed everything. It wasn't observational like what Galileo did, so Galileo and Descartes completely ignored him. No one else really said very much.
Fraser: Yeah, I really think that the four people that all kind of came together... you've got Copernicus with sort of like a big, bold... let's just try this... you know, let's just put the sun in the middle and see what happens, but things didn't really work out. Then you had Brahe making the really detailed observations but not really having any place to put it. You had Galileo making these observations and seeing things out there, but not necessarily having... he was backing up things Copernicus was saying, but not really having the detailed observations to really explain things. Then you had Kepler who really brought in the math. Those four are really at the heart of that whole renaissance time that changed everything.
Pamela: And what ended up happening is that after Kepler's death, one of his other works... An Epitome of Copernican Astronomy... it was embraced and passed around. So it was after his death that his work was finally acknowledged and people finally started reading it and shipping it off to other people to read and embracing the idea of elliptical orbits.
Fraser: And even today... it still gets used; it still gets taught... still do the math... so it still comes into play.
Pamela: And Newton was able to take and finally put something other than the soul as the basis behind what makes planets orbit. And I think helped as well... having something other than the sun's soul being the motivating force.
Fraser: So, I think we can wrap it up here. But next week, we're going to talk about the Kepler mission, which I guess doesn't have a lot to do with Kepler, but...
Pamela: Planets...
Fraser: Planets... it's seeking planets, which is pretty amazing, so... it's one of the most exciting missions out there... so, we'll talk to you next week, Pamela.
Pamela: Sounds good, Fraser. I'll talk to you later.