Astronomy Cast Episode 184
History of Astronomy, Part 2 - The Greeks

Fraser: Astronomy Cast Episode 184 for Monday April 5, 2010, History of Astronomy, Part 2 - The Greeks. 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: Very well. Well, we survived the first episode of history of astronomy... gave us both a headache. And I think today... even more headaches! So, with the earliest astronomers out of the way, we can now move on to one of the most productive eras in astronomy--the ancient Greeks. Even though they didn't have telescopes, the Greeks worked out the size and shape of the earth, the distance to the moon and the sun, and even had some accurate ideas about our place in the universe. Alright, well Pamela, where were we when we last left our heroes... and by heroes I mean astronomers, of course.
Pamela: Well, I think we left off just as Alexander the Great was getting ready to conquer the Mediterranean. We'd seen the Chinese create star maps, we'd seen India with constellations, we'd watched the Arab cultures in Mesopotamia develop mathematical ways of predicting planets...
Fraser: Stonehenge, pyramids, ancient Babylonians, Sumerians... oh the Sumerians... so, right... where do you want to start?
Pamela: Well, why don't we start with Pythagoras in 500 BCE. It wasn't until about 320 BCE that Alexander took over, but Pythagoras was the first big-name Greek that we're all tortured by in mathematics class.
Fraser: Uh, A squared plus B squared equals C squared?
Pamela: Something like that...
Fraser: Right... I mean Pythagoras--King of Trigonometry, right?
Pamela: Exactly. And also someone who observed the planets very closely, and he was the first person to realize... oh, shoot, that bright object that is up in the evening and that bright object that's up right before the sun rises... that's the same object! It's actually new knowledge... well, relatively speaking over the course of all humanity. It isn't something that we've known for a long time. It's only in 500 BCE that Venus was realized to be one object, and not two different objects in the sky.
Fraser: That's right, and so there are many ancient cultures that had two different names for Venus. There was that Morning Star and that Evening Star. They named them differently, and they had different aspects, and they were different gods... and they needed different offerings, and all that.
Pamela: Right. And it's easy to see it that way because it sets or rises always right next to the sun so you don't have that connectedness of getting to see its position change across the entire course of the night.
Fraser: What about Mercury? Did they have the same opinion about Mercury?
Pamela: You know, I actually haven't seen anything on that, so I don't know.
Fraser: Neither have I. If anyone knows, let us know.

Pamela: And we can thank Pythagoras for Venus, so that's a start.
Fraser: So, Pythagoras worked out that Venus was the same object.
Pamela: Yes. And then we start getting into the great thinkers. So, Plato was the first to come around. The Babylonians had worked out mathematical ways of figuring out what planet will be in the sky when... but that's not the same thing as having a geometric model that describes the reality of the solar system. It was Plato who, around 400 BCE, said... you know, we need to come up with the math, the geometry, a model to describe our solar system instead of just tables of numbers. So, he was the first person who basically encouraged a field of what would eventually become cosmology.
Fraser: And he didn't do a lot of the work, so who are the people who actually ended up coming up with these calculations?
Pamela: Well, it was Eudoxus of... this is such a strange name to our modern ears... but Snydus... it was Eudoxus of Cnidus who came up with a model of planets where the planets sat on different circles, different spheres, that rotated inside one another... with different spheres rolling at different rates to describe the planetary motions.
Fraser: Right, so this is still that concept that the earth is the center of the universe and the planets and the sun and the moon and the stars are all on crystalline spheres that rotate around the earth... like some kind of--I don't know--music box.
Pamela: And this is actually a pretty good idea from people who didn't have the concept of gravity, didn't have pretty much any of the basic physics that we use today. But it had one problem with it... if you have one sphere resting on the surface of another sphere, and you start rotating it, what happens to the sphere it's resting on?
Fraser: I'm guessing there would be friction between the spheres? They would all kind of heat up and lock up?
Pamela: Well, and they'd start rotating each other so there's this problem where if Jupiter's rotating at one speed and Saturn's rotating at another, why don't the two spheres eventually end up rotating together? And it was Aristotle in the 300s BCE who took Eudoxus' model and said... oh, we need "un-rolling" spheres. So, Aristotle basically put in an extra set of spheres that if you roll one one way and you roll the other the other way, and somehow this takes into account all the motions so that you're able to absorb forces from one sphere to another. It's still a complicated model, and I'm not sure how it works in reality unless you have different sets of wheels between the two things that roll at different rates allowing free motion. It's still clunky, it still doesn't really work so well, but at least he was thinking through friction.
Fraser: Right, right... I can see them constructing glass spheres... you know, blowing glass spheres and then putting them inside each other and going... well, this isn't working....why can the ones in the universe work so nicely?
Pamela: And Aristotle was really big on thought experiments... and you can just see him there... working through this and talking through this with other people in the university and realizing that we need to fix this! And then talking through it some more... It was Aristotle who really put the philosophy into it, making astronomy very much a thought experiment as well as observations where he introduced the concept of things being perfect spheres, where he introduced that it must be Earth-centered for philosophical reasons. So he really spread that world view... that way of thinking... as well as... oh, friction--we need to take care of this with un-rolling spheres.
Fraser: Right, ok... and who was next? Who do you think was important next?

Pamela: Well, we're now starting to get into the Hellenistic Greek where we're starting to look at a time period where people were working in the Library of Alexandria, where there was great thinking going on and experiments going on all around the Mediterranean. It was Autolycus who pointed out more problems in Eudoxus' model. Here what he was critiquing was with everything moving on perfect spheres and rotating at constant rates... how is it that you end up with planets that appear to slow down relative to the stars? How is it that you actually get all the different variations in planetary motion across the sky? He noted that Eudoxus' model couldn't make accurate predictions. It also didn't explain the changes in brightness that we see with Venus and some of the other planets.
Fraser: Right, and we see that situation... it's something that you can... if you watch the planets every night, you can really see this... that some of the planets--especially like Mars and Venus--they'll move... well, Mars as one of the outer planets, it'll move very quickly from one night to the next night. Then it will slow down from night to night... and then it will stop, and then it will go backwards... right... and then it will stop. Then it will go forwards again compared to the background stars. And, I mean, that concept.... what on Earth is the crystal sphere doing? Because I mean it's not like it's even stopping in the same position... it's almost like it moves down a little bit in the sky, then it moves up a little bit in the sky... So you can imagine trying to hold a crystal sphere in your hand and trying to make that motion from what you would see from inside. It would be quite troubling... because, you know, friction alone... what's causing that change? And I could see the change of brightness, right? I mean you get Venus... Venus' changes in brightness are enormous... Venus can be a star not much brighter than any other star, and then other times Venus is blazing in the sky! It's the most bright thing out there apart from the moon.
Pamela: Yeah, it gets mistaken as a UFO on a regular basis as it hovers over city skylines brighter than anything else... and sometimes the only apparent star in the sky in twilight. Other times... it has phases. If you look at it through a small telescope, you can see a crescent Venus, and that crescent doesn't give off a whole lot of light... making Venus a fairly faint star in the twilight hours.
Fraser: Right, so thanks Autolycus... just jabbing holes in the model...
Pamela: So, problems were raised, and people went off and continued to work on these problems, and for awhile other people worked on other problems. This was the period where people actually started making measurements. They started really looking for tangible geometric solutions for things... so this brings us a number of years later in 240 BCE where we actually started to figure out how big the planet Earth is, and that's pretty amazing when you think about the fact that to the people making these measurements the entire mapped surface of the earth was the Greek empire... they knew bits and pieces of Europe, and they knew bits and pieces of Africa and a little bit out to India, and that was it. They knew very little of the planet, but they were able to figure out the size of the entire planet.
Fraser: So what was the experiment... what was method that they used?
Pamela: This is the episode with too many bad-to-pronounce names...
Fraser: You're not allowed to apologize in advance.... just take a few shots at it and then you'll get it... and we'll just edit it out...

Pamela: Alright.... Eratosthenes... he was able to realize that on the summer solstice at the local noon in the city of Swenet the sun was straight overhead... and because the sun was straight overhead, sunlight would shine straight down a well. But where he lived, the sun didn't do that on the solstice. Rather, it shone at a slight angle, so that if you stuck a stick straight into the ground you were able to see that there was a shadow. Using trigonometry, he was able to figure out that the sun was about seven degrees away from straight overhead.
Fraser: Right, so with the well, that place was right on the equator... pretty much...
Pamela: Not on the equator... it was the summer solstice so it was on the Tropic of Cancer... it was north of the equator.
Fraser: Right... ok, ok... right. But it would have a moment when the sun was directly overhead. I mean... here where I live in Canada we'll never see that, right? But some of our listeners may have... I don't know what it's like to have the sun directly overhead.
Pamela: Hot...
Fraser: It's always down towards the horizon.
Pamela: And luckily for him, what they were experiencing was... you had sun straight overhead in one place, you had a shadow in another place, and you can actually figure out... if you take a sphere and start stabbing sticks through it... you can figure out what the sun angle has to be to get that seven degree difference from straight overhead... and doing trigonometry he figured out... well, this is one fiftieth of a circle, if I know the distance between me and that city, and he could figure out the distance between him and that city based on how long it took a camel to get back and forth between the two of them.
Fraser: Very accurate measurement...
Pamela: Very accurate measurement... so he estimated the distance between the cities to be about 5000 stadia, which turns out to be about 500 miles, about 800 kilometers. So based on this estimation, he calculated the circumference of the planet. And it turned out that he got it right within one percent of the actual size, including all of his estimates once he factored everything in. That's a pretty amazing measurement.
Fraser: Do you think that those kinds of discoveries were well understood by the researchers of the day? I wonder how much of that information made it into the Library of Alexandria, and how much of it was disseminated around... did the various mathematicians accept that number?
Pamela: I think that the dissemination was really the hard part.
Fraser: Yeah, or was it like no, the world is flat and over there are dragons...
Pamela: Right... and the Greeks didn't generally accept that the world was flat. It's hard to have a flat planet with things orbiting on spheres around it. But, somewhere the fact that the earth was that big just didn't fully get internalized. Imagine how it would force you to change your world view from "we dominate the entire planet" to "no, we dominate a very small section of a very large planet." And yeah, there's a lot of dragons out there... if that's how you label what you don't know on a map.
Fraser: So, he was calculating the circumference of the earth, but I know sort of around the same time there was Aristarchus who was doing even cooler calculations.
Pamela: Well, I can't say one is cooler than the other...
Fraser: I just did...
Pamela: Ok, fine... well I'm allowed to say I'm not sure I agree with you.

Fraser: Be agnostic about the calculations... I'm telling you these calculations--much cooler!
Pamela: Yeah, but they don't change world view the same way. So, we have Aristarchus... whose name is pronounceable... we have Aristarchus who was off measuring things again. And what he noticed was the moon when it was at half phase, when you only saw one fourth of the sphere, or half the side that's visible illuminated, from his measurements when there was this particular lunar phase, he tried to measure the angle between the sun-earth-moon and he ended up with 87 degrees. So using the assumption that the angle between the earth-moon-sun... so go from the earth to the moon to the sun... and that angle... that the angle symbol lives on the surface of the moon, that angle had to be 90 degrees to get it so you see a quarter of the moon illuminated. And then he worked to measure... well what's the angle if you go from earth to moon to sun and put the angle sign on the surface of the planet earth... that angle he measured as 87 degrees. And then based on basic trigonometry, he started calculating distances... started calculating ratios, and he couldn't get the exact distance... but based on his ratios he was able to figure out--very incorrectly, but nonetheless interestingly--the sun was 18-20 times further away from the earth to the moon. This is wrong, but it shows that people were trying to make measurements using the scientific method, using experiment, using observations, instead of building things strictly out of philosophy. And that's pretty impressive. Now, once he had this ratio of the distances, he then went out and looked at a lunar eclipse and he measured all the parameters of the lunar eclipse to try to get to the exact sizes. How big is the moon compared to the earth? How big is the sun compared to the moon? Again, his results weren't so good, but...
Fraser: Right, I was trying to do the calculation... started with the distance to the moon and distance to the sun... it's actually about 390...
Pamela: Yeah, so he was off by more than a factor of ten... which even in astronomy where we aim for order of magnitude isn't that great, but I really appreciate that he was trying to make measurements. Once of the things that mucked up his measurements is that our atmosphere moves things around... and it's also just really hard to make these measurements. How do you exactly line up your tools on the center of the moon, on the center of the sun to accurately measure the angle between the two of them? It's a challenge... and he tried.... and his math was right, it was just his measurements were wrong.
Fraser: Right. But he had a good method...
Pamela: Yeah. And that goes a long ways... not always the right way, but it goes a long ways.
Fraser: Right...no, no.. I think this goes back again to the conversation we had in the last episode where... I don't know... you have this idea of these people... they were human beings... they had the same kinds of brain power, the same kinds of ways of seeing the world in many ways... they just didn't have as sophisticated tools... they didn't have as many giants to stand on their shoulders... to know what had come before. But, they were really trying and they were using some pretty great methods, and I think that's... you know, we don't give them enough credit, in many cases.
Pamela: And the fact that their names have been passes down for a couple thousand years goes a long way to saying that these are people throughout all of history whose names keep coming up as the great thinkers, so every few generations we have that

genius that changes our world view and it's just neat looking back and saying this person changed our world view. Even if they weren't right, they changed how we do things. Newton didn't have it completely right either, but Einstein built on what he did.
Fraser: Oh, we'll get to Newton...
Pamela: Just not today...
Fraser: Yeah, so who's next, then?
Pamela: Well, so here we get to someone who I have to admit... this one broke me for awhile. If you're ever looking up astronomy stuff in the history of astronomy, you'll find records to Ptolemy in the 240s BCE who figured out the leap day... and then Ptolemy who in 150 AD figured out epicycles and wrote the Almagest. And this completely broke me. It turns out there's more than one Ptolemy out there, and in fact there is a whole Ptolemaic dynasty...
Fraser: Oh, so he didn't live for like 250... 300 years...
Pamela: Right... exactly... there was Ptolemy III who was part of the Ptolemaic dynasty. Actually Cleopatra... the famous Cleopatra with Marc Antony and Julius Caesar--she was part of this Ptolemaic dynasty. So it was Ptolemy III in about 238 BCE figured out that we need to add an extra day to the year every four years. The year is actually 365 and a quarter days. He figured out how to fix the calendars. This wasn't actually implemented until Julius Caesar, but he's the one who figured it out. And this again is one of those really hard to sort out things because you need generations of data.
Fraser: Right.... and that's all he's got.
Pamela: That's all he's got, but it's still cool.
Fraser: No, absolutely....
Pamela: We need a calendar....
Fraser: Yeah... ok... next?
Pamela: So next is probably people trying to cure the problem with the spheres within spheres issue of our model of our solar system. So last we left it we had sets of rotating spheres, all symmetric within one another, Earth at the exact center... and it didn't work.
Fraser: Right... you just sweep under the rug reality.
Pamela: Right.
Fraser: You know... reality doesn't match your model, but, you know, clearly reality is wrong, the model is right.
Pamela: Exactly. That is a very philosophical way of looking at things.
Fraser: Right. It's very Plato, right.... with these sort of pure forms of things. So, someone took another crack at well... like could we figure out a new model that matches reality better...
Pamela: So we had Apollonius of Perga who said ok, well, what we have isn't working so let's move things around and add more circles. So, first he said, well the circles don't all have to be symmetric off the center. You can have one sphere center offset from another sphere center. This is deferents. And then the other thing he said is well, maybe the speed differences are because we have also have epicycles. We have circles on circles. So you can basically imagine the moon attached to a bicycle wheel that's rolling around the orbit of the moon. That's the epicycle. Then you move the moon's entire orbit slightly off-center from the earth, and that's the deferant. And he started figuring out these epicycles and deferants for everything in the sky, trying desperately to match reality

with mathematics, using a geometrical model instead of just the friendly, happening tables that the Babylonians and Sumerians worked from.

Fraser: But I mean the thing with these methods is that they did work... they got results. Now, with our modern understanding of the planets moving on elliptical pathways around the sun, that forms the shape. But back then, it's a circle, but you move it a little off of the... you know, so it's not orbiting the exact center... that helps give you times when it speeds up and slows down from your point of view, and then you put it on, as you said, this little bicycle wheel, this epicycle rolling around this orbit, and that gives the bizarre movement, and you just change the size of this epicycle. They got pretty close.

Pamela: They got pretty close, and it's really hard to get very accurate when you don't have precise star maps, when you don't have an accurate way of even measuring time... we're talking back before there were clocks, back before there were watches. So, without accurate timekeeping, and without accurate star maps... yeah, the planet's a little bit off, but who can say how much off it is... So, they did pretty good, but no, it wasn't perfect. But perfect would require perfect maps and that would require a couple thousand more years.... or at least a thousand more years.

Fraser: Right. Right. But there were some pretty good maps....

Pamela: There were some pretty good maps, and actually the better maps came after poor Apollonius, who tried as hard as he could, but it was Hipparchus who around 130 BCE got frustrated and started making maps. Exactly the reason that he started making star maps is up for debate, but one reason that's given is pretty cool. It's said that he saw a nova in the sky and he wanted to have accurate maps so if people in the future saw novae, they'd be able to know for certain that yes, that is a star that wasn't there yesterday... instead of being something that wasn't noticed yesterday. So, Hipparchus started making maps, and he also got frustrated that the Greek models weren't as accurate as the Babylonian mathematical predictions. So he started making other careful observations and he started pulling together observations that were written down from around the world or at least around the empire. In looking at these historic records, he was able to figure out precession, he was able to figure out the north pole isn't always pointed at Polaris. Sometimes it's pointed at other stars like Thuban. These are really cool steps forward. And I just love the fact that he got annoyed, and so he did really good science. I think that's just great.

Fraser: Yeah, fixing a problem. Yeah, and we talk a lot more about Hipparchus in our Astrometry episode, which we just did, so we don't need to cover that again too much. So, I guess now we're getting into the period of the Romans.

Pamela: Right. So, the Roman empire technically started in 31 BCE and lasted until 476 AD. And once we start getting into the Roman empire, we start renaming things, always good to give things your own language and then force your own language on others... and this is where we start getting things like... yay! We finally have a calendar that works! Julius Caesar put the leap day into action in 45 BCE. And in 150 AD, we have Ptolemy who again works very hard to refine epicycles, to refine all the models to try to make them work as well as he can. Along the way he documents the work of what comes before him and I think this is one of the things that's most important of what Ptolemy did. He didn't just write down his discoveries.... he reviewed the course of everything that had come before him. He documented Hipparchus' understanding of precession, he built on Hipparchus' star catalogs, he drew in results from the Babylonians... everything he did, built on other people. He didn't start from scratch. He didn't start from first principles, he started from what do we already know... And that really starts the modern age of astronomy in a lot of ways.

Fraser: Right... except that unfortunately....

Pamela: He was wrong.

Fraser: He was completely wrong... yeah, but I think that he is the most important ancient astronomer. Before the renaissance, he's the big name. He did the most accurate, the most precise, the most important work... just wrong.... Earth at the center of the universe, everything rotating around it, spheres within spheres, very accurately done...

Pamela: Spheres on spheres, accurately done...

Fraser: Spheres on spheres, very incorrect, but really good. So Ptolemy's work really stood the test of time. It remained as the understanding of our place in the universe until the modern era.

Pamela: Right, it went through the Holy Roman Empire, it survived the rest of the Roman empire before that, and it was only when Kepler and Galileo started beating on it with data and new ideas that it finally collapsed... but that's for another episode.

Fraser: That's the next show...

Pamela: It is the next episode. So we leave in 150 AD, and we'll actually pick up about a factor of 10 later in time...

Fraser: Right, right... after the dark ages, so... Alright, well we'll talk to you next week, Pamela.

Pamela: Ok, talk to you later.