Astronomy Cast Episode 266 for Monday, May 21, 2012: Archimedes

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Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the Cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain; I'm the publisher of *Universe Today*, and with me is Dr. Pamela Gay, a professor at Southern Illinois University – Edwardsville. Hi, Pamela. How are you doing?

Pamela: I'm doing well. How are you doing?

Fraser: I'm doing very well. We're fresh off of our most recent virtual star party, which was a lot of fun. We had a lot of the great summer constellation objects starting to show up now, and I think if people haven't had a chance, we connect up a whole bunch of telescopes every Sunday night as soon as it gets dark on the west coast, so in the summer time that's around nine, in the winter time…

Pamela: West coast of North America...

Fraser: The west coast of North America -- yeah…the west coast of Australia? No. The west coast of North America because we've got some great telescopes on the west coast, so around 9:00 pm Pacific or so, we start going in the summertime. In the wintertime, it's more like 5:00 pm Pacific, and then we just run the telescopes for a couple of hours, we take requests, whatever you want to see, and then Pamela or Phil stop by and we explain the science and it's a really good time. So if you want to…we're trying to use this new media, this new technology in interesting ways, and we've been really well aware that the big problem with Astronomy Cast is it's just audio, and so if we can actually…why not incorporate the video? And so we "live stream" telescopes right onto the internet, we take requests, it's awesome.

Pamela: And if you want to find out about when the virtual star parties are going to happen, and all the other video things that Fraser and I are putting out there on the internet, go to CosmoQuest.org, sign up for an account, and sign up to get our newsletter, and every Sunday (Monday if you're in the pacific rim), you'll end up getting a newsletter that lists all the times and all the different things that we're up to. So for instance, the newsletter that went out last night talked about how myself, and "Noisy Astronomy" Nicole Gallucci are both going to be at the Amazing Meeting, and we hope to meet up with you.

Fraser: Aw, I'm going to miss the Amazing Meeting this year. That sounds great.

[advertisement]

Fraser: So it's time to look deep into history to the birthplace of modern mathematics: Ancient Greece. And one of the most famous mathematicians of the time was Archimedes. We use many of his mathematical theories and inventions to this day, while others, not so much -- they're steeped in legend and mystery.

Fraser: So Pamela, do you have a whole section when you're teaching people where you go through some of the Archimedes principles?

Pamela: It's more a matter of they keep randomly cropping up depending on what I'm teaching. So when I'm teaching freshman physics, he crops up all through different things we're trying to understand. So when we start talking about basic machines, he came up with the simple Archimedes Screw, which was used to raise water, and you can also use it to raise "stuff." Then he comes up when people start grouching about having to use Calculus because he really is the father of the ideas behind Calculus, even if he's not the one who developed Calculus. Then when we're talking about the initial measurements of distance to the Moon…he didn't do that, but he wrote about what was done by Aristarchus, so he just keeps cropping up as this 300-years-before-Jesus guy, who was doing amazing modern mathematics.

Fraser: Yeah, and also, for people who want to build death rays, he comes up.

Pamela: Well, yes, there's that too. That's actually one of the more awesome things that he may or may not have done.

Fraser: Yeah, I think the “Mythbusters” have taken a real crack at trying to figure out if he had done it, but we’ll get to that in a little bit. So then, who was Archimedes, and when did he live?

Pamela: So he lived about 300 years B.C. (287 B.C. is given as his birth year, roughly), died roughly 212 B.C., actually lived to be an old man by the standards of the time. He lived to be a bout 75, which didn’t usually happen back then, and one of the sadnesses is he didn’t actually die of old age; he died by annoying a soldier, basically. There are a couple of different stories about his death. It’s generally agreed that he died when the city of Syracuse was captured during the Second Punic War, and that the general that captured the city, Marcus Claudius Marcellus, had ordered that he was not to be harmed. He was seen as a scientific, mathematical resource that was to be protected, sort of like a lot of the German rocket scientists in World War II were protected, but depending on whose story you read, the soldier who came across him either found him doing mathematics in the sand (this was in the days before whiteboard -- you used what you had, in this case, sand was the moral equivalent of a whiteboard), according to one story he was working figures in the sand, and the soldier said, “Come with me,” and was going to take him to the general, and he said, “No, no, no! I need to finish the calculation I’m doing,” and the soldier killed him. According to the other story, the mathematical instruments he had with him were seen as valuable, or dangerous, and he was killed for the mathematical instruments he had. In either case, the general, Marcellus, was rather annoyed at the soldier because he was a valuable protected resource that was killed essentially for no reason. A little old doddering man who basically mouthed off to a soldier.

Fraser: You can just imagine…I don’t know…that would be like an episode of the Big Bang Theory.

Pamela: [laughing] I can just see Sheldon doing this!

Fraser: He was just like a quintessential…clearly, a quintessential math geek: “No, no, I need to finish my calculation.” When a soldier upon threat of death was telling him to come along, most people will come along, but no, Archimedes had to finish his calculation. Clearly, he had some ideas that he had to get out of his head. OK, so that was how he lived and he died, but there had to be some interesting stuff in the middle. So where did he get started? I know what the big problem with a lot of these scientists from antiquity is that there's just so little information on them.

Pamela: Yeah. So we don't know a lot about him. Luckily, he was written about a bit by Plutarch. He did a lot of his own writing, and so while we don't know the day-to-day details -- we don't know if he had kids, we don't know if he was even married, we don't know any of those -- we do know a lot about who he corresponded with, based on his writings. So it's imagined that he might have studied in Alexandria, Egypt because of correspondence he had with Conon of Samos, and Eratosthenes of Cyrene. So the fact that he was corresponding with these people as friends, leads people to think, well, perhaps he studied with them in Alexandria. It's a guess. We do know that he spent significant portions of his life in Syracuse, on the island of Sicily, and that he was one of the most renowned, both mathematicians and builder of random things, and I think it's the building of random things and the solving of random problems that relied on both experiment and mathematics that he gets remembered for. Lots of people have seen the various cartoons of a naked Archimedes springing out of the bath with a king's crown (it's a cartoon -- the king's crown was not in the bath with him) because he was given the task of determining if a crown the King had made was pure gold or not, and the way to do this (short of melting the crown) was a bit problematic, but he is supposedly the person who, while in the bath thinking, realized as he moved, and the water level moved, that water is, for the most part, an uncompressible fluid, and so if you take something, and it submerges completely in the water, the amount of water displaced is going to give you the volume of the object, and based on the volume and the weight of the object, you can measure its density. If you can measure its density, you can figure out if it's made of pure gold or not because pure metals…each pure metal has a different density, and sure enough, it turned out the crown was polluted with silver, so his "Eureka" moment, where he is said to have sprung out of the bath naked screaming "Eureka!" – no one knows if that's true or not, but we now torture all good first-year physics students with repeating Archimedes' experiment.

Fraser: You like give them a crown, put them in the bath, and tell them to determine if it's pure gold or not?

Pamela: It's usually not a crown, it's usually a series of small cylinders of pure metals, and a graduated cylinder, and you say, "Here are these metals, figure out what they are. Here's a Periodic Table -- you're on your own."

And they have to use Archimedes' Principle to measure the density of these different objects, and then determine what are they.

Fraser: And so just to sort of explain to people who perhaps have never done this, you would take these cylinders of metal, you would put them in the water, and you would be able to determine how much water they displace based on their density.

Pamela: Yes. Well, you also have to weigh them. So they displace a given volume. Now, the other thing that comes out of this is he also figured out the Buoyancy Principle, so you figure out the density of something that's able to completely submerge by measuring its mass and then measuring how much water is displaced. This gets you the density. Now the other thing you can do is he figured out that the mass of the water displaced by a boat (or something else that's floating), is equal to the mass that is doing the floating bit, and so this is the Buoyancy Principle. So if you have a giant steel ship, the reason it's able to float is because it's displacing a given amount of water, and the water's pushing on it, and it's pushing on the water, and it all works out with the buoyancy force.

Pamela: Right. The overall density of the ship, when you include all the air that's inside, is still going to be lower than the density of water, so it's more buoyant than the water and it floats up on top.

Fraser: And water weighs a remarkable 62 pounds per cubic foot, so that means you take a area that is the size of your standard floor tile and cube it, so you have a three-dimensional square that would fit on that standard floor tile and that small volume of water weighs about half as much as your standard teenage girl [laughing]. And so you have a vast amount of weight in water, and you don't have to displace a lot of water to float a human, or even to float a ship.

Fraser: And, not to go to Mythbusters too often, but didn't they even make a ship out of concrete?

Pamela: Yeah, they did. That was kind of awesome!

Fraser: Or stone? They did a ship out of stone? Yeah, anyway, the point being…

Pamela: They made one out of cement.

Fraser: Out of cement, yeah, but the point being that you can…and that's how you can do it with steel, right? As long as the overall density of what it is that you're working with is lower than the density of the water, the whole thing is going to float, as long as the water doesn't get in. As soon as the water gets in, then it's going to sink.

Pamela: And building cement canoes is kind of a standard thing to ask civil engineers to do because it's fun to torture them, plus cement's fun to play with.

Fraser: That's cool. Right, so I think, you know, if there's anything to take away, it's this whole concept of Archimedes' Principle, and really, if you've gone and taken any math, any science, any physics, you will have run up against this and you will have done the calculations to determine the amount of…the density of various objects. And this is used all the time, even in astronomy. Astronomers have calculated the density of planets, of stars…

Pamela: Or more to the point, we are much…we use the Buoyancy Principle, which he came up with, for those stratospheric balloons that people are using to send "Camilla the Chicken" up to outer space, and to send all sorts of scientific payloads up to that boundary between the atmosphere and space. Balloons are held up by the Buoyancy Principle because the inside of the balloon is made of a lower-density material than the outside of the balloon, or the air surrounding the balloon, so they're able to float up. Sometimes it's something as simple as having a hotter gas, and the hotter gases have a lower density, so it's able to be supported by the buoyant force. Sometimes it's a matter of using hydrogen or helium as the gas inside the balloon. So different balloons work in different ways -- all of them are supported by the buoyancy force, all of them are able to carry payloads up, whether it be a human being taking photos, or a camera set-up that's traveling to the boundary between the atmosphere and space.

Fraser: Now, he was sort of most famously known for the Archimedes Principle, but he was able to…we've mentioned this, he liked to play in almost every area, so he also worked on a lot of engineering-type tasks as well, and I think one of the most famous things from there is the Archimedes Screw.

Pamela: Right, so this is…if you've never been to a science museum, this is your excuse for going because most science museums will actually have a hands-on demo where you can turn a screw and it raises fluid up. It's just this neat system where it turns out that when you run an inclined plane that's shaped like a screw through fluid, the fluid will get carried up the inclined plane. It's just one of those awesome, "Wow! How did he figure it out?" I have no clue how he figured it out; it was just one of those "moment of genius" things that he did. He's also famous for figuring out levers, which seems like a really lame thing, but he was the person who figured out that if you want to lift a heavier object, you just need a longer lever arm. and that's the whole concept of with a long enough lever arm you could lift the planet Earth.

Fraser: Which is true, but you'd need some place to put the lever.

Pamela: Right, and then you also have to figure out, well, what force is it that you're trying to displace? But yeah, it's entirely true -- you could do it (with a bunch of caveats).

Fraser: If you've never seen an Archimedes Screw, this is an idea…you've got a cylinder, and inside the cylinder you've got a screw (like a great big screw bit), and then a handle on the top, and as you turn this screw in the water, the water just moves up the cylinder and pours out the top, and this is the way they were able to pull water out of wells, and out of rivers and stuff from a lower level to a higher level -- just an amazing technology! You can imagine: it saved you from having to drop buckets down, it was the thing you could hook up animals to and be able to turn it and water just poured out the top like clockwork.

Pamela: Well, and unlike buckets, it's a continuous flow of fluid, so one of the more useful ways of using it was just to raise river water up a hill. So you can imagine: you have the nice incline, and then you have oxen at the top that are, through a set of gears, turning your screw with you, and they're able to irrigate your fields.

Fraser: Yeah, that would have been a huge…you can see why the general would have wanted him kept alive with those kinds of ideas coming out of him. Now, I think the other thing Archimedes was really famous for was a lot of his work with circles, and spheres, and the underlying math involved.

Pamela: He was an insane mathematician. There is a process that is called either the Method of Exhaustion or Brute Force, which is a way of solving math problems by basically doing a bazillion little tiny calculations. When you're first learning Calculus, one of the first things that they teach you is the area underneath a curve can be solved for by treating it as a bunch of little, tiny rectangles, and adding all those little tiny rectangles together. Archimedes is the person to blame for that.

Fraser: I remember that!

Pamela: [laughing] And so he used this Brute Force summation technique to get at the areas under curves to start to figure out the volumes of rotated curves, rotated volumes. He set out to figure out all sorts of volumes that nowadays we happily solve using Calculus, and because he did his Brute Force mechanisms, he was able to come up with fairly accurate values of Pie. I mean…you can't come up with a completely accurate unless you have infinite time value, but he came out with a fairly precise value of Pie. And the thing he did that he was actually most proud of, (and the fact that he did it without Calculus – kudos!) he was able to figure out that the volume and surface area of a sphere inscribed within a cylinder is 2/3 of that of the cylinder. So this means that if you take a sphere, and you put it in a cylinder, where the diameter of the cylinder is the same as the diameter of the sphere, and the height of the cylinder is the same as the height of the sphere, then the area (including the caps of the cylinder) is going to be larger than that of the sphere, such that the sphere is 2/3. And it works for both area and volume, which is just one of those neat little parallels that someone working in ancient Greece could totally get behind. So when he died, it was at his request…there was a statue of the sphere within the cylinder as part of his burial.

Fraser: That would be a very difficult statue to build.

Pamela: Yeah, I was actually really hoping, as I was researching this show, that I could find a picture of it, but it turns out that his tomb has been lost and it was one of those moments of "Huh! That's bizarre" because they thought they had found it in the 1960s, and then they misplaced it, and the fact that it got misplaced in modern times is something that highly disturbs me, but if you've ever gotten the chance to wander through Greece or Italy, you're wandering around and everywhere you look there's bits of ancient stuff, and you can sort of imagine someone needs to build a building, and they have to get rid of the ancient stuff, and so I fear that overpopulation is slowly going to remove records of lots of really awesome old stuff.

Fraser: So let's talk about a couple of his inventions, and ideas that maybe weren't quite so based in reality, and maybe it was a little more myth and legend that could perhaps have been busted recently.

Pamela: Well, I think you're getting at the idea that you could use mirrors to set flame to ships. One of the great weapons of mass destruction of Ancient Greece that Archimedes was given credit for was using mirrors to set fire to ships. The idea was you get a bunch of soldiers along the shore, they all have parabolic mirrors, they point their parabolic mirrors at the ship, and the ship combusts. And there have been a couple of different tests on this. The first test that was done on this was done in 1973, it was a Greek scientist Ioannis Sakkas (sorry I'm mispronouncing that), and it took place outside of Athens, so they had the Sun at the same altitude that you'd have it at, they used 70 mirrors -- they were fairly large mirrors, they were 1.5 by 1 meter in size, so more than my arm span wide probably and twice, yeah, they were big…so 1.5 by 1 meter, 1 meter is 36 inches or so, so these were hard to hold, hard to manufacture, but they did everything they could to make them authentic. These were copper-coated, and they pointed all of these large mirrors at a plywood mock-up, and the plywood mock-up very quickly, at a distance of 160 feet, caught on fire. So using these large mirrors, a fairly small distance (160 feet, 50 meters, about half a football field), they were able to set the boat on fire. Now, Mythbusters came along and tried to replicate this, but they opted to use much smaller mirrors, and then they put the ship at a greater distance, and they found that, after about ten minutes, they were able to get everything focused together, everything not moving, perfect weather conditions, they were able to get smoldering and a little bit of flames. So when you make it a slightly more realistic idea, it appears that maybe it doesn't work so well, and then when they repeated this again on Mythbusters a second time, with an even more realistic greater distance to the boat, they couldn't even with 500 school children be able to get things on fire. So it appears that Archimedes might have been able to set things on fire if they were like almost on top of the harbor, and the mirrors were really big, and the weather was perfect. And the other caveat was it had to be happening near dawn/early morning because of where the Sun was relative to the harbor. Mythbusters considers it busted, has guessed that likely what was actually happening is they were blinding people on the boat, shining mirrors into their face. And flaming arrows are a whole lot easier to use to set fire to boats, so you can imagine someone getting blinded by a mirror, and then all of a sudden their boat sets on fire, so you blame the mirror when really it was a flaming arrow.

Fraser: But I think actually shooting, or using the mirrors to blind people that should be pretty effective when you think about it because you couldn't get a sense of where the troops are on the land, where to land, so if you just set up some people, maybe some non-combatants with these mirrors to blind people, that might be a fairly effective way to keep people…at least add a little more confusion to the invasion.

Pamela: And if you think about it, if they were attacking at dawn, they were attacking with the idea of having the Sun behind them to blind the people they're attacking, so it's the exact same strategy on both sides. One side is using the mirror to blind people, and the other side is just using direct sunlight to blind people.

Fraser: Now, the other thing he created was the "claw." Have you heard about this: The Archimedes Claw?

Pamela: No. That one I don't know about.

Fraser: It was like a crane that could be used to kind of grab a ship and pull it out of the water as it was attacking, so you know…and people have, again, tried to test that out and see. There was a show, it was like "Super Weapons: The Ancient World," or something like that, and they tested out building an Archimedes Claw and they thought, "Eh, maybe. Maybe it might work," but it would have to…again, it would have to be really close, you'd have to have this gigantic boom arm that would reach out, and you would grapple with the ship.

Pamela: And couldn't you just sail out of reach of something like that? It wouldn't really be all that stealthy.

Fraser: Well, it's not as stealthy as…the point is, as these people are about to land, are about to invade, you mess up their ship, but it just it doesn't sound like it would have been the best way to go about it. Now, one of the things that we've always gone with was we try to match up the scientist and their associated mission. So has there been a mission for Archimedes?

Pamela: You know, the ESA website's left me confused on this point. There is in the late '80s, and up until 1992, a bunch of references even in books to the ESA (European Space Agency) Archimedes Satellite Network, which was a network of satellites that had highly-elliptical orbits that were going to be used to do telecommunications in Europe, and these are extremely useful because while they're going over the northern polar regions and sending signals to Scandinavia and other northern extremes that are kind of hard to get signals from geo-stationary satellites to. They're moving at near geo-stationary rates, and then they zip out and they move quickly on their far-out elliptical parts, and then very slowly swing by again, so this is a technique that's been used by the Russians, and used by others, but then I could never figure out if they launched the sucker. There are no references to it past 1992 that I was able to find, so I think this is a mission that didn't make it into existence. What was fun, though, is that I found references to the trials that were the "Eureka" mission, so there was clearly some humor involved. There's lots of books talking about this model, there's some journal articles…can't figure out if it was launched or not.

Fraser: Hm. Well, I know when the Europeans launched their Galileo constellation...

Pamela: Yeah.

Fraser: Right? Was it the Galileo? Anyway…

Pamela: There is communications going on in Europe.

Fraser: No, no, but there's a GPS system that's being developed by Europeans.

Pamela: So this is one of the mysteries.

Fraser: Yeah, yeah -- one of the mysteries. OK. Now, was there anything else we want to talk about Archimedes while we're sort of flubbing the show?

Pamela: He is the father of Brute Force mathematics that we torture high school students with, and that is just kind of awesome. He left behind a series of books, and what's kind of amazing is because so much has been lost in the 2300 years since he worked, we don't even know if we lost more than we kept. So just imagine if the libraries in Alexandria had never been burned. Imagine if more texts had made it into the future. I think the only thing that we've left out so far is one of the perfect spirals is the Archimedes Spiral. This is a spiral that is formed when you have something that is rotating at a constant rate and moving away from the circle at a constant rate, and in polar coordinates, which is a way to define mathematics when things are moving around an axis in a symmetric way. It's a nice, clean equation, where the distance that you're at is equal to A+B(theta), where A is a constant that defines how wide it ends up being, and B tells how quickly it's rotating. So he defined a spiral, and that's kind of cool.

Fraser: And I know he also left a bunch of mysteries, too. He came up with a whole bunch of mysteries like…what were they? He wrote a bunch of, I guess, a bunch of books on the measure of the circles, on spirals, on the sphere in the cylinder, on floating bodies…so this is where a lot of these books that came to us today. And then he left a bunch of problems as well. In one, he tried to count the number of grains of sand that would fit inside the Universe, trying to count the number of cows in a herd…so he left a bunch of really interesting work, and I guess this was…I wonder how much of his stuff might have been burned in the library of Alexandria and how much of it remained.

Pamela: Yeah, it's hard to tell. All we know is we've lost a lot of volumes, and…imagine if he'd lived after we knew about Calculus. He was already trying to do all sorts of problems that require summations, that require set theory, that require a whole lot of complex ways of dealing with large numbers, and he came so close to discovering Calculus, and he just stopped at summation.

Fraser: I always wonder about that. You know, there's so many times when there are these calculations, these discoveries, or people are really close to even things like understanding how the human circulatory system works, or the germ theory, or…

Pamela: Atomic theory, which is his grains of sand idea…

Fraser: Yeah, or in this case, you can imagine that he'd gotten that close to Calculus, well what would happen if they were doing Calculus 2000 years ago? Would that have changed anything? So I always wonder if some of these, just these discoveries that almost…they didn't require any specific time. You know, some of the modern stuff, you needed the materials and the equipment, and the scientific discoveries to even make these further discoveries, but there's a lot of stuff that's just a… you know, evolution -- you just had to realize the way the world worked and then you could have made that discovery at any time.

Pamela: I think you needed a fossil record to get to evolution, so that required a little bit of geology.

Fraser: No! But it wasn't…I mean there could have been geologists 2000 years ago, right?

Pamela: That's true.

Fraser: They could have been digging through the rock layers and finding all of these dinosaurs, in fact they might have been while they were building the pyramids! Who knows? So I'm wondering if some of these discoveries were made multiple times and it never stuck until…almost like the modern invention of the way the communication and the way the scientific method is maintained and communicated, and the way the research is done that now none of these discoveries are going to be lost, but a long time ago people were making these discoveries and then they were getting lost.

Pamela: Yeah, and it's terrifying to think how much knowledge was lost between the burning of Alexandria and the Dark Ages, when knowledge was suppressed. It was the Arabic nations that really cherished science and knowledge, and we basically have the Muslim Middle East to thank for the fact that Algebra survived, and so many other records that would have been lost had they not protected them.

Fraser: Yeah. Alright, well, thanks once again, Pamela, and we will see you next week.

Pamela: See you later, Fraser.