Astronomy Cast Episode 265 for Monday, May 14, 2012
Arthur Eddington

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?

Fraser: Doing good. Now last week we asked nicely for donations and a bunch of you responded and that was fantastic, and I think we're going to make this a two-parter, where we ask you for donations again. So if Astronomy Cast is important to you, and you want to help contribute to the show, we've got sort of editing people, transcript people, education outreach, and we really need your help. So you can go to Astrosphere.org and there's a place to donate there, and also, actually you can actually donate from within Youtube as well, right?

Pamela: Yeah, there's a link on Youtube, and you can just go to Astronomycast.com and there's a donations link there. We've done everything we can to make it easy for you to donate, so donate via Paypal either via the Astronomy Cast website, the Youtube website, or the Astrosphere New Media website. Fraser and I do this for the love of…well, actually, it's more because you love it, and we're trying to respond to your love, but we do have Preston, who we torture with our audio goofs, we have Joe, who's helping to keep everything running, we have Nancy, who writes our show notes, we have Rome, who does all of our transcripts, and we want to feed our staff.

Fraser: Yeah, and the reality is that, you know, we try to just focus on creating the shows themselves. I mean, you know, Pamela's so busy, so we have all this help, and that helps get all the other stuff that makes the shows really valuable, and that way we can just focus our efforts on doing the recordings of the shows themselves, so it means a lot.

Pamela: So thank you in advance.

Fraser: Thank you very much.

Pamela: Donations tax deductible in the United States where law allows.

Fraser: Yeah! Use it as a tax write-off. Alright, so let's get rolling.

[advertisement]

Fraser: So we can thank Arthur Eddington for much of our current understanding of stars. He provided some of the breakthrough concepts that explain what is really going on in there deep in the hottest places in the Universe, and sadly, the spacecraft with his name wasn't so successful. This episode is going to be great. He's a fantastic scientist (one of my favorites), and yet we're breaking our trend, which is that we do these two-part episodes.

Pamela: Well, we're only sort of…

Fraser: I know. I know, but normally we do scientist, and the spacecraft that was named after them, and in this case we are going to do scientist and the spacecraft that was named after him, but…

Pamela: The spacecraft doesn't warrant its own show, it's kind of a footnote. It's a failed… NASA sometimes breaks its own rules, and ESA unfortunately, doesn't have this rule, and the rule is: you give the spacecraft a really dumb name until it launches. So for instance, you had GLAST, which I don't even remember what GLAST stood for other than gamma-ray large something something telescope…

Fraser: Array survey telescope, or something…yeah.

Pamela: Right, so GLAST was a really cool acronym. GLAST launched; they renamed GLAST Fermi. Fermi is a great name, commemorates a great scientist. We've worked really hard to limit the scientists we discuss, based on they've historically changed the world enough that they have a mission named after them. Well, one of the things that unfortunately happens is that occasionally names get removed from the list of spacecraft because they've been used, and then their mission never launched. And this wasn't the scientist's fault, so were going to commemorate and celebrate Eddington for being a cranky guy, whose mission didn't get launched -- and it's not his fault.

Fraser: It's not his fault. We'll provide a little more information about that by the end of the show, but why don't we go back around and then talk about Arthur Eddington. So who was Arthur Eddington?

Pamela: He was a British scientist at the turn of the last century. He had an interesting upbringing. His father died when he was quite young, and he ended up pretty much being raised by his mother and sister, and self-educated at home for a while, eventually ended up going to school, getting scholarships to go to college, studied the sciences, eventually got scholarships, studied physics, went on and got his PhD. And throughout all of his upbringing, he was raised with a Quaker pacifist upbringing, and the reason I bring this up is because, as a Quaker, he, on one hand, was a conscientious objector to World War I, and escaped serving in any of the different ways they had scientists serving in WWI in Great Britain, but at the same time, as a pacifist, he is known for his academic arguments with folks, so there's this wonderful juxtapositioning, and conscientious objector to WWI, which I'm totally fine with, but also being the guy who got into these huge debates in the literature over how stars are supported or not, depending on who he was arguing with.

Fraser: And so he was one of those people that just couldn't let an argument go, right?

Pamela: I… he couldn't. I know. I've worked with the type.

Fraser: I might be the type.

Pamela: Science is filled with them. There's different debates that you know won't end until the dude dies, and unfortunately, with Eddington, he was the dude that we had to wait die.

Fraser: So he had a cranky, cantankerous personality, he would argue to the death about the things that he believed in, but at the same time, didn't want to pick up a gun. I can dig that. I'm totally fine with that. So then, what was his background?

Pamela: [laughing] He was a scientist who had a very, very strong mathematical background, and not all astronomers are strong mathematicians, some are very good observationalists, some are very good with computer science – I tend to be on those two sides, but he was amazing with both the mathematics, and he could also do observations when he needed to. So he really started to make a name for himself in how he looked at stars and the ability of stars to support themselves because he went from looking at…there's sepheid pulsating variable stars, and the fact that they're pulsating was kind of a new and novel idea when Eddington was doing his work at the beginning of the 1900s. And he was trying to figure out how do you get giant luminous stars that vary in brightness, and the idea of them being binary stars was something that kept coming up over and over and over again, but when he looked at, well, how big would the orbit have to be to make everything make sense, he realized that the stars had to be bigger than the orbit of the binary, and you can't end up with a star causing an eclipsing binary if it's orbiting inside the star that's being…it just didn't work. So he came with the notion: "Well, maybe stars are supported in a way we hadn't thought about before," and it's kind of hard to imagine, but when he was working in the early 1900s, we hadn't figured out how stars worked yet. People were still considering, well, are they supported via heat? Is it simply that ideal gas law, and they're hot due to some sort of chemical burning? And so everything was using the ideal gas law, and that was kind of the right track, but the notion that light pressure, radiation pressure played a role wasn't there. The idea that it wasn't chemical burning, it was nuclear burning that was going on was an idea that didn't even exist.

Fraser: Hmm. So before Eddington even had a deep think about it, they actually thought there was some kind of chemical reaction going on inside stars?

Pamela: People actually did calculations on the basis of, well, what if stars were made of coal? How long would they last? In other similar chemical ideas…

Fraser: It wouldn't.

Pamela: Yeah, it was basically along those lines of: Let's imagine that stars are composed of the most efficient fuels known at that time. And different people did all sorts of different calculations, and you couldn't get stars that lasted nearly long enough to even match....

Fraser: Big ball of gasoline...

Pamela: Yeah, and they couldn't match the geological records. Stars were all far too young, and it was very confusing. And the whole idea now of pulsating stars – couldn't make any sense out of that one. And so Eddington came along and he added in the idea of radiation pressure, and without having a physical explanation for the radiation pressure, he started devising from first principles ways of looking at how the different forces have to balance one another to have gravity crushing in and radiation pushing outward to balance the star, and he got equations that worked. He could model stars, he could explain the relationships between mass and luminosity, and he had no physical explanation for it. It was this beautiful work, sort of along the lines of what Kepler did in planetary orbits many centuries earlier, where there was a problem, there was observation, and he matched the observation, and then it took others to come along and explain the physics.

Fraser: Right, so he knew…he could come up with an idea that matched what he was seeing, but they still had no idea what would be causing such a thing.

Pamela: Yeah.

Fraser: But, I mean, this concept of radiation pressure… I mean, there was a lot of work being done on quantum physics on Relativity all that time, so a lot of that must have started to inform his thinking.

Pamela: It was informing his thinking, and what's really interesting is a lot of what he did initially started out with him and Russell (of the H-R diagram) basically debating how these giant stars supported themselves, trying to explain the velocity seen in the spectral lines. And it was out of his conversations with Russell that he was able to develop his theories, and Russell would say, "but did you think of…?" and Eddington would absorb these ideas until his theories really started to be able to match what was being observed, and what was kind of awesome is as Eddington thought through the quantum mechanics, and thought through how light and matter interact with one another, he started to take into account things like, "Well, maybe part of what's able to drive these pulsating variable stars is changing opacities in the outside of the star," and so even while they still didn't fully understand nuclear fission and fusion, he was able to start thinking through things like "well maybe if you change the opacity in the outside of the star so suddenly the light can't push through the outer atmosphere, you'll be able to build up energy, and this will drive the pulsation be changing the opacity." So Eddington was actually one of the first people to figure out: how do you make stars pulsate? He was one of the first people to develop working models for the atmospheres of stars, and he was actually the one that Chandra Sekhar worked with while he was doing his early research and that's where the ironies start to crop in.

Fraser: Right, and so you can imagine this understanding, right, that light is pushing out from the interior of the star, and it's hitting this, I guess, this opaque layer and that's almost billowing it out like a balloon, and then the opacity is changing, and it's almost like it's releasing that…that light is now able to escape, and it changes…it would even change the size and shape of the star dramatically in a very short period of time, and then it would build back up again, right?

Pamela: And so what actually ends up happening is you have these large stars, and as they expand out, they cool, and they eventually get large enough and cool enough that the helium atoms (or whichever atoms are responsible in a given star) de-ionize. So they reach out and they grab all of their electrons, and when they grab all of their electrons, they suddenly become more opaque. So this changes the opacity of the star, and the way it works is when it gets too big, it becomes more transparent, it's able to collapse down; when it collapses back down, it heats up, it ionizes, traps the energy again until that gives it a kick, and part of the kick that it gets is that moment when the helium ionizes, there's extra energy released in that process, or it's the interplay between when things are ionized and when things aren't ionized that's causing this extra kick.

Fraser: I've got an analogy. You know, if you've ever taken a hair dryer and you put a ping pong ball on top of it, you turn on the hair dryer, and the ping pong ball kind of floats up in front of it, and then you turn off the hair dryer and the ping pong ball falls down, and then you turn it back on it floats back up. But the point being, you find that balance between the thrust of the air from the dryer, and gravity pulling it back down, and you turn that source of thrust off, and then -- boom! the ping pong ball will drop again.

Pamela: This is a lot more like one of those little bobbing birds that you can get at science museums.

Fraser: Yeah, yeah – "it's drinking the water!"

Pamela: It's drinking the water, and eventually gets enough stuff in it that it changes, empties, bobs forward, and it's much more similar to that bobbing bird in all reality.

Fraser: So let's get back to Eddington here because I think we're going to get too off course here with the science. So he had come up with this idea…how was this idea received by the scientific community?

Pamela: Over time, it was gradually accepted. Initially, it was problematic because he put forward an idea that there was really no physics to support. There was just a lot of light pressure supporting stars, and nothing supporting the light pressure, but over time, as he was able to incorporate in people's arguments, as he was able to say, "well, what about this," as he was able to reproduce the mass-luminosity relationships that were seen, and as people figured out fusion and fission in stars as all of these things came together throughout all of the development of astrophysics – because this was the time when astronomy started to split so that we had people that were doing just plain observational astronomy, which is awesome, but were also delving into the astrophysics and explaining the "hows" and "whats" that were driving the things that were observed, as all of the astrophysics developed, his theories gained detail, gained prominence, and are now part of how we understand how stars work.

Fraser: And so he was working on this, and I guess, this is where he gained his reputation for being a bit of a crank, or not a crank in the sort of scientific way, but crank-y. He was a debater, right? He had a fairly famous relationship with Chandra Sekhar.

Pamela: Well, and Jeans as well, and it was Jeans that…here's the funny part, we have Jeans, who's another big pillar of astro-physics at the time, he was one of the ones who helped define how gas clouds collapse to form stars. The Jeans in stability and so many other wonderful things, and gas laws, and Jeans was just like "No, you do not have a physical basis for what you're saying," and so the two of them had this fabulous debate going on in the literature that boiled down to Eddington saying, "But it works!" and Jeans saying "But you don't have a basis!"

Fraser: "That's a fantastic theory, but we all know that coal can't generate that amount of light pressure," right?

Pamela: Yeah, it wasn't quite that, but yeah, it was along those lines. And so it started with you have Eddington vs. Jeans going back and forth, and then poor Chandra, poor Chandra was a student. He was brilliant – probably one of the most brilliant scientists of his age, and it's a pity that Einstein so overshadowed him in the public because Chandra Sekhar really could have been an amazing role model as well. Chandra on the way to England to go to graduate school, pretty much sorted out that when stars begin to run out of nuclear fuel (this is working later on after people have begun to understand the nuclear processes inside of stars), when they run out of fuel to generate the light pressure to support the outer parts of the star, the star collapses. When the star collapses, you end up with everything under vast amounts of pressure, and as he ran through the math, he realized that there's a certain point where what's left (that white dwarf star that's created when a Sun-type star collapses), the electrons in the star are packed so closely together they no longer act like a normal gas. They in fact become what's called an degenerate electron gas, a relativistically degenerate gas. Suddenly the Pauli exclusion principle no longer applies in the same way, all the things you learned in first year chemistry go out the window, math becomes both much harder to understand and much easier to do, and he realized all of this on the boat, and then he realized while he's on his way to graduate school that at a certain mass, that degenerate electron gas is no longer able to support itself anymore, and in fact, something needs to happen. And this led to the ideas of a neutron stars, this led to the ideas of black holes, all of these things derived out of this notion that when gas is put under a certain pressure, it just sort of goes, "No," and something has to radically change.

Fraser: But without that…light pressure is really the key, right, it's that light pressure's the thing that's holding the whole thing together. If you get it to the right state, then you're going to lose that light pressure, and then the whole thing is going to collapse inward. So Chandra Sekhar comes, you know, fresh off the boat, with a head full of really challenging ideas…

Pamela: And Eddington says, "No."

Fraser: …and he says "no," which is kind of weird because he had just recently been delivering a whole bunch of really challenging ideas to a scientific community that said "no."

Pamela: So this is one of those things that I look at, and it's one of these moments of a scientist being a human being, where poor Chandra, he spent night after night after night talking about his theories with this advisor, with this colleague, and goes to present at a conference, gets to the conference, sees when he gets to the conference that Eddington is speaking on the same topic he is -- the topic of what happens to stars when they no longer have light pressure supporting them, and Eddington basically gets up (the man Chandra's been discussing all off his ideas with), Eddington basically gets there and stands up and does what half the cranks in my inbox do, and says, "Who can believe this theory? It makes no sense! What is it that star's just going to collapse down until gravity prevents light from flying away?"

Fraser: "Like there's some kind of dark matter?"

Pamela: "Dark stars…"

Fraser: "I don't like it!"

Fraser: His scientific argument is very compelling, yeah.

Pamela: So Eddington basically makes the argument of "Black holes make my stomach unhappy, therefore, they can't exist," which isn't valid. And so it's this matter of Jeans and Eddington had this debate where Jeans was going, "You don't have a physical underlying theory, Dude," and Eddington continued on until it worked and everyone respected him. Then Chandra comes along and says, "I have a theory based on physics," and Eddington goes, "It doesn't make sense. Who can believe in those objects existing?"

Fraser: Now, I know that Eddington was a big fan of Einstein, too, right?

Pamela: Yes, and that was one of the interesting things that also came out of him being a Quaker in some ways is during WWI, when he looked around the community, he made the choice to try and keep science going, to keep the international community moving forward, even in these times of war, and it's wonderful to look at the various people who have done this during both WWI and WWII, and during WWI, he was one of the people that looked around and saw this theory being developed by a young German, and called attention to it, and because he was such a superb mathematician, he had the ability to really get a lot of insight out of what Relativity had to offer, and so over the next actually decades, Eddington was one of the people working very hard to popularize Relativity, and to make it something that people who didn't have his mathematical abilities were actually able to comprehend, and Eddington actually worked really hard to…not just communicate it, but also prove it and led an expedition to take photos of the 1919 eclipse of the Sun to see if he could measure how the light from the stars got bent as it passed near the Sun to see if the bending reflected strictly Newtonian gravity, or both Newtonian gravity and the predictions of general Relativity.

Fraser: And so…and what was the result of the experiment? I know he…there was a great TV show. Did you see that? There was like a movie. It was called "Eddington and Einstein," or "Einstein and Eddington," and it sort of details the whole story and their letters back and forth, and the work that Eddington did that really helped validate Einstein's discoveries.

Pamela: And the funny part is that Eddington's observations weren't that great. There was actually a second team that made observations that seemed to rule out Relativity, but they had mechanical issues with their telescope, so Eddington just sort of ignored what they did, and read a lot into his poor observations, and the world was more than willing to accept Relativity based on this bad set of data that mostly kind of sort of mostly showed that Relativity worked. But since then there's lots and lots and lots of evidence taken with better telescopes, and we fully trust Relativity. It's just funny that the world accepted it based on kind of bad data.

Fraser: But would you say that Eddington's vote of confidence for the theory really helped propel Einstein as the science "rock star" that he became later on?

Pamela: [laughing] Well, I think the rock star had more to do with the fact that Einstein did have such a unique haircut and personality.

Fraser: Oh, OK. Right, but the point being that his ideas were deeply challenging to the established status quo, and yet to have such a prominent scientist in England being able to provide that level of, you know, commitment to stand behind it meant a lot to help Einstein's career path and helped him with his future, where he ended up in the United States, as well.

Pamela: No, that's entirely true, and in a way Eddington helped popularize Einstein and also helped motivate Chandra to be an amazing researcher through, basically, making it impossible for Chandra to advance his career goals in England, and making it such that everyone knew about the work of this young German scientist, and so that young German scientist, Einstein, was able to get jobs in America, escape Germany, and have a fabulous career, and Chandra realized, I'm never going to have a career in England, got himself out of Dodge, went to Chicago, and built an amazing career there. So two completely different ways of motivating someone to switch universities, and Eddington was responsible in many ways for both of their different careers.

Fraser: So as some of the other thinking, like fusion, the ideas of fusion power in the star, you know, how did that inform his thinking? Where did those…?

Pamela: Well, so that all started to come in piecemeal. So he was developing his theories based in a lot of cases, just on dimensional analysis, so any of you who have taken a Physics class and had your teacher yell at you, "Did you check your units?" Eddington actually started with the units, he started figuring out "OK, so how do I balance this that and the other forces together to get everything balanced to balance the star?" and he identified the empty pieces, and then the rest of the scientific community luckily advanced and helped fill in those empty pieces, so it all came together. It was an awesome time, and it's hard to tell without dedicating the year to researching this how all the pieces came together specifically.

Fraser: He had a lot of pretty interesting philosophical ideas as well; I mean, he was not only a very skilled researcher, and really pushed the concept the solar physics idea ahead, but he actually had a lot of fairly interesting philosophical...you know, he was idealist. He had…a lot of his arguments came from that as well. 'How did he hold that' kind of played into his concepts, you know, his cosmology and his ideas on physics and astronomy, and things like that?

Pamela: I think, in a way, it led him down a very strange path in the end of his career, where he started trying to build, like so many scientists in the time did, a "theory of everything," but for him his theory of everything was actually numerology.

Fraser: You know, in researching this show as well it was interesting to me that it's almost like when you begin your research into your theory of everything, that's when you're about to die

Pamela: That's when your career ends.

Fraser: That's when your career ends, and that's sort of the thing that will end everyone's lives, you know. Like Einstein was doing the same thing, and so you look at…and researcher after researcher: "And then, nearing the end of his years, he investigated the possibility of a theory of everything…"

Pamela: And now we mock him for what he looked at.

Fraser: And now we mock him for what he looked at, yeah, although there's a certain amount of mockery even reserved for Einstein.

Pamela: Einstein was determined that quantum was a bad thing.

Fraser: So, all I'm suggesting…if there are any researchers out there considering working on a theory of everything, be careful because it just might kill you. It's the cursed theory! That's just my theory.

Pamela: It's just really strange, the path that Eddington's career took toward the end because he was working really hard to try and figure out numbers and how they factor together, where he assumed that the numbers associated with electrons and protons had to be written into the firmament of the Universe, and if there was something special in the 1 over…at the time it was originally thought to be 136 of the fine-structure constant, and then when it was realized that it was closer to 1 over 137, he was like, "Oh, no, no, no! This all totally makes sense now."

Fraser: "That makes sense!"

Pamela: And it's just kind of sad to watch. I don't know.

Fraser: Alright, well, I think…so I guess we're going to wrap up, so where did he die?

Pamela: In England.

Fraser: Yeah.

Pamela: Yeah. He lived a good life. He passed away toward the end of WWII, so he lived during that amazing time in England where the country saw all manner of horror, all manner of political change, all manner of social change. He passed away in 1948, having started his career at the beginning of WWI, really, as a professor, and it was an amazing time to be alive, especially where he was alive. And he really helped define our field, and almost, almost got to define the name of a mission, but they didn't launch it.

Fraser: Right, and so what happened with the mission? What was the mission supposed to do?

Pamela: It was supposed to search for Earth-like planets.

Fraser: [groan] That would have been awesome!

Pamela: Yeah, it would have. It would have. It's a mission that's canceled. It was going to be very similar to the Kepler mission, it was going to observe about 200,000 stars, look for changes in light due to the transits, it just never got built, so…

Fraser: And they made that terrible mistake of naming it before they launched it, and so now the Eddington name is…lost forever??

Pamela: Yeah.

Fraser: Really? Like, really?

Pamela: I don't know if it's forever. I don't know what the superstition about sharing names is, but right now ESA lists Eddington as canceled.

Fraser: Right, somebody should…well, I still think there's going to be a need to build a mission of almost that exact profile, especially when you look at the success that Kepler's been having in discovering planets, you know, to build another spacecraft right on the heels of that and discover Earth-size planets. I think it would be awesome…so I think that's great! Have you ever heard of the Eddington number for cycling?

Pamela: Yes! Yes!

Fraser: Because that's big in the cycling community. It's the number of consecutive days that you've done a ride of a distance. In other words, say you have an Eddington number of five. It means for the last five days, you've ridden five miles, and then six is the last days for six miles, and so if you get to seventy, then you've had seventy consecutive days, you've done seventy days…seventy-mile rides for seventy days.

Pamela: And it has to be consecutive?

Fraser: Well, it might not be consecutive, but it's the number of days that you've cycled for more than a certain distance, so the point being that the higher that number gets, the more difficult it is because it's the number of…because to get seventy miles, to continuously hit seventy miles is brutal. He was a real avid cycler though, right?

Pamela: What's interesting is there's a related number we use to determine which professors are leading researchers, and which aren't, and that's what's called the h-index, and it's how many papers have you had that have been cited by more than "x" people.

Fraser: Oh, right, and so the bigger that number is the more meaningful it gets. It's almost like it's an exponential, or logarithmic progression. That's really cool. Alright, well, thank you very much, Pamela. That was great!

Pamela: It was my pleasure, Fraser.

Fraser: And we will see you next week.