Astronomy Cast Episode 106:

The Search for the Theory of Everything

Fraser Cain: Hey Pamela, are you ready for the Theory of Everything?

Dr. Pamela Gay: I think the correct title for this show is: AstronomyCast: the Episode where Fraser breaks Pamela's brain!

Fraser: I've been looking forward to this show. We're going to need another co-host by the end of this show, so if there are any Astrophysicists out there, I intend to shatter Pamela today, so resumes gratefully accepted.

Pamela: And I'd just like to add the disclaimer Observational Astronomist not String Theorist.

Fraser: [Laughter] Right so at the earliest moments of the Universe there were no separate Forces. Energy or Matter was all just the same stuff and then the different Forces froze out differentiating into Electromagnetism – the Strong Force and the Weak Force.

Today we're going to look at the problem that has puzzled Physicists for generations. Is there a single equation that explains all the Forces that we see in the Universe and is there some way to put Gravity into it? Pamela, in preparation for this show, you promised to solve the problem and then win a Nobel Prize for the show. So how did that go?

Pamela: Um, yeah let's not talk about that one.

Fraser: I'm thinking you'll just come up with it as we go. [Laughter] You'll go: "Oh, I know! Here's how it works." Then we'll sorta spend the rest of the show working on that [Laughter]. Then we'll send in the application for the Nobel Prize and Sweden here we come.

Pamela: I think I can probably give a half reasonable layman's explanation of what's going on, but let's leave it at that.

Fraser: Alright. So I guess the part that's interesting is we've spent the last three shows talking about Gravity, Electromagnetism and the Strong and Weak Nuclear Forces. How do these Forces come together and how did Physicists work this out?

Pamela: It started as so many things start, with misdirection. Looking at all the Forces and looking at the history of Physics, people went well; originally Electricity and Magnetism were considered two completely different things. Then Maxwell came along and unified them. What if we can just continue this trend and just keep putting things together?

So as we develop this Four-Force theory of the Universe, which seems to work, it was Einstein perhaps who first gave the most stubborn attempt at unifying the Forces. What he noticed was the Weak Nuclear Force and the Strong Nuclear Force that had one set of mathematical descriptions.

Gravity and Electromagnetism have their own mathematical formulism. But when you look at the form for Gravity and when you look at the form the Electric Force, they mathematically have the exact same set up.

A constant times two qualities of the particles being looked at, in this case either their Masses or their Charges over their separation squared. He figured that since they must have the same mathematical formulism according to experimentation, then perhaps there is a way to unify these two Forces.

Fraser: Okay, hold on before you go any further. He understood that both Gravity and Electromagnetism decrease their strength by the inverse square of the distance, right? So, the further you get the weaker they become at exactly the same rate and that they both have a Constant. So they just look like they're the same thing. I could see how anyone could look at that and just think they've got to be just two versions of the same Force.

Pamela: As a Physics Prof I'm guilty of teaching the equation for Electric Force and going "look, it's identical to Gravity" and no it's not. [Laughter] What we've learned since then unfortunately is Gravity separated itself off first and Electromagnetism sort of separated itself off last. You really can't get from one to the other without getting through the Strong and the Weak Force, so he couldn't get there.

Fraser: Right. So how far did he get?

Pamela: He didn't get anywhere. He just tried.

Fraser: But didn't he like end his life working on this?

Pamela: All because you end your life working on a problem doesn't mean you're working on it in a way that leads to anything useful. It's a kind of sad state. In the early parts of Einstein's career, he made amazing breakthroughs. But at the end of his career as well as being an amazing mentor to the field and creating lots of quotes that go on posters nowadays, he was spending his time trying to unite two Forces that just refused to be united.

It was a noble effort and it didn't work. The problem that we have is Physics is controlled by sub-atomic particles and he was looking for a more geometric way, a non-particle way to bring these forces together.

It's only as we've started to extend our understanding of Particle Physics, as we've started to discover things like anti-Matter, as we've started to think about things that still aren't testable like Super-Symmetry and String Theory, that we've even found mathematical ways to make it conceivable that we can bring these Forces together.

Fraser: Okay, so it's almost like there was a whole bunch of additional information that has only since recently been seen with the Big Particle Accelerators and some of the other theories that have shown that the problem is a lot more complicated than Einstein might have thought that it was.

Pamela: That's exactly the problem.

Fraser: Right. How then did Physicists understand that Electromagnetism could be collected together with the Weak and Strong Forces then?

Pamela: The first thing that they had to do was look at the particles that mediate the Forces. Look at the Bosons. In this case it's the 4 Electromagnetism – the Photon that carries the Electromagnetic Force and the W & Z Bosons that carry the Weak Nuclear Force.

As you crank up the energy in a system, as you turn up the temperature and the density, the Photons and the W & Z Bosons start to have similar energies. As the Photons have the same Energy as the W & Z Bosons, they start to act in the exact same way. At these higher energies - exact same way is probably too strong a way – but they start to act in ways that you can't differentiate.

Fraser: Okay, whoa! [Laughter] Now as I remember you teaching me, Energy and Matter are interchangeable.

Pamela: Yes.

Fraser: So Photons, which move at the speed of light, can be turned into Matter and anti-Matter at the same time.

Pamela: Yes.

Fraser: So what you're saying is that if you increase the Energies of the Matter of the System, you get to the point where the Photons and the Bosons kind of have the same amount of Energy. If you converted the Photons to Bosons, you'd get the same amount. Is that right?

Pamela: I wouldn't say you're converting anything. You're dealing with…

Fraser: I'm not saying that you're converting but you're saying you have an equivalent amount.

Pamela: Yeah. The Photons are a type of Bosons. So you have the Photons carrying the Electromagnetic Force and you have the W & Z Bosons - because we named them stupid, you have the W's and the Z's – are carrying around the Weak Nuclear Force. As you crank up the Energy of the entire system, the Photons Energy goes up too.

Eventually the Photons are carrying as much Energy as the W and the Z Bosons. Once you get to these super high energies, these super high densities in temperatures you start to not be able to tell the difference between the Electromagnetic Force and the Weak Nuclear Force. At this point the two Forces start acting as a unified Electro-Weak Force.

Fraser: Right. This is the Electro-Weak Force. So where did the Electro-Weak Force actually show up in the Universe?

Pamela: They first started to separate somewhere a little bit before 10 to the minus 10 seconds after the Big Bang so we're still like way beginning of the Universe. But, we're going to go even earlier than this.

Fraser: So fractions after the beginning of the Universe – the Big Bang – Bang and then you just have the Electro-Weak Force and then moments after that it separates into Electromagnetism and the Weak Force.

Pamela: Yes. The separation starts to occur when the Universe had cooled off. I love this idea. The Universe has cooled off to ten to the 27 Kelvin.

Fraser: It's merely a one followed by [Laughter] 27 zeroes Kelvin.

Pamela: And the Energy at that point is a hundred giga Electron Volts.

Fraser: Right. I think the center of the Sun is like 15 million Kelvins.

Pamela: It's a big High Energy….

Fraser: Yeah, it's pretty High Energy Physics. Now we've taken the two Forces, mushed them together, and then where does the Strong Force come into this?

Pamela: The Strong Force, we haven't actually been able to experimentally say can probably been combined in with the Electro-Weak. But we think it can. This is where we're still kinda working on things. We know there was an Electro-Weak Force, a time when Electromagnetism and Weak were combined.

We think using what we call Grand Unified Theories that there is an earlier time at a little bit before 10 to the negative thirty-fifth of a second after the Big Bang or so, when the Universe was a mere 10 to the 27 Kelvin, that the Strong Force and the Electro-Weak Force were able to combine using similar mechanisms to how the Weak Nuclear Force and the Electromagnetic Force were able to combine.

You crank the Energy up, all the Bosons start acting the exact same way and when all the Bosons are acting the same way then all the Forces act the same way – we think.

Fraser: If I understand there have been many predictions made by this Theory and so far a lot of these Particles have been detected in the Particle Accelerators that have been used so far, right?

Pamela: This is where things start to get tricky. We have direct evidence of W & Z Bosons. They've been discovered. The Gluons that carry the Strong Nuclear Force are a little bit trickier. We think we have evidence of them. We say we have evidence of them, but it's not like we've tracked one in a bottle and carried it around.

The problem with Gluons is they only exist inside Nuclei. And to get at a Gluon you have to break something into lots of little tiny bits and thus you've broken apart the thing that the Gluon lives inside.

So we see what looks like the Energy of a Gluon falling apart, but it's a little bit harder to understand how to combine the Physics when we can't take a Gluon and study it.

Fraser: This is going to be one of the objectives I guess of the Large Hadron Collider, right? Crank the Energies up to another level where you might be seeing Gluons all day long.

Pamela: You're still breaking apart the things they live within. You're still breaking up what we call Hadrons – the Particles that are inside Nuclei. As long as those things are broken up the Gluons are unstable, they're just falling apart.

What the Large Hadron Collider is going to do is find us another one in the missing Bosons. This is the Higgs Boson. One of the things that is also kinda broken with our current understanding is we don't know where Mass comes from. One of the really troubling things that we have to deal with is why is it that when Electromagnetism and the Weak Force split we ended up with the Photon which has no Mass and we ended up with the W & Z Bosons that have Mass and why is it that the Gluons have so much Mass or Energy however you want to look at it?

This is one of those things that really confuse us. We think that it is the Higgs Boson that brings Mass to things. The more we can learn about the Higgs Boson the more we can understand how it is able to do all the crazy things it does.

Fraser: The hope is that the Large Hadron Collider will have enough Energy to be able to actually be able to start generating these Higgs Boson Particles so that Scientists will be able to detect them and work the accurate numbers for the Higgs Boson into their calculations.

Pamela: It's a goal.

Fraser: Yeah. All right so this is the Standard Model, right? We're kinda up to the Standard Model here...

Pamela: Yeah.

Fraser: …of Physics where the E^m becomes the Electro-Weak and then the Electro-Weak merges in with the Strong Nuclear Force…I think you said earlier in the show then the first Force to hive? 14:29 off was Gravity. I'm assuming then that if we just crank the Energy levels even higher the Gluons start to act like Gravitons?

Pamela: Well and here's where we just don't know. We have a Particle Physics understanding of how Electromagnetism works. We have a Particle Physics understanding of how the Electro-Weak Force works and of how the Strong Force works by itself.

We're still working on the Grand Unified Theory that gets us all the way to uniting these Forces together. But we don't have a Particle Physics understanding of Gravity. When we look at Gravity if you follow Einstein's way of visualizing it, it is a change in the Geometry of Space.

Now we're trying to switch over to a Quantum Mechanics view of everything where Force is carried by Particles; where nothing is smooth and where you're dealing with probabilities and Gravity just doesn't fit within that way of looking at things.

As we have been trying to unify the Forces, we have to first find a Quantum Mechanics view of how Gravity works – Quantum Gravity. We don't have that. In order to try and get there people have been going lots of different directions and as near as we can tell the best way to get there from here is perhaps through String Theory.

Fraser: I'm going to put a line in the sand right now and say up until now we have lots and lots and plenty of evidence. We're going to move into pure speculation [Laughter] land.

It kills us to do it because we love facts-based observational Astronomy but we know that a lot of you are really interested in this subject. We're going to move forward into the purely theoretical – the land where there is no evidence there is only theories. [Laughter] So proceed.

Pamela: Well, okay but first let's start a little bit more grounded in what we actually know. We have to …….

Fraser: I drew a line!

Pamela: I know.

Fraser: We have a line in the sand here. Okay, I'll let you go back as long as we can go back into crazy land again when we're done. [Laughter]

Pamela: So we have to start with the Standard Model of Particle Physics and we have to show that it is broken. When we look at all the stuff that's out there, all the stuff that's making you, me, tables, chairs, all that sort of stuff we find there are six happy little Quarks.

The up and down Quarks conveniently make the Protons and Neutrons which are stable. They line up in our happy little first-generation part of this chart conveniently with the Electron and the Electron Neutrino all stable themselves.

Then we end up with a second generation – two more Quarks two more of what we call Leptons. Electrons and Electron Neutrinos are Leptons. So we have this generation that includes a Muon and then we have a third generation – 2 more Quarks. Another Lepton - the Tau Particle and the Tau Neutrino to go with it. Everything nicely lined up like little soldiers.

Also matching these we have our 4 Bosons. We have the Photon, the Gluon, and the W & Z Bosons. Everything lines up symmetrically. There's no reason for this. This actually led one Nobel Laureate to say who ordered the Tau Particle when it was finally discovered? Symmetries without reason are confusing but we're about to make it worse.

In trying to understand how it is that you can combine the Quarks to build Hadrons and how everything has Mass, we realized we couldn't get there from here easily. The Higgs Boson introduced a lot of challenges. The way to get around those mathematical challenges was to then introduce a new Particle to match every Particle we already knew.

Fraser: Wait, hold on a second we haven't even discovered the Higgs Boson yet but Physicists are predicting the Higgs Boson but they already know what their problem is with the Higgs Boson?

Pamela: [Laughter] Yes. We've had this happen before. This was actually a problem that was dealt with in the 19th Century with the Electron. We couldn't explain the Mass of the Electron. There's just too much stuff stuck into too small an area.

The way we were finally able to explain the creation of Electrons was through anti-Matter. Because we have Electrons and Positrons the anti-Matter version of the Electron, it's possible to figure out mathematically how this stuff, all the Charge, all the Mass into basically a point in Space to create an Electron.

Fraser: So we've got the Matter and we've got the anti-Matter and they come together and produce a tremendous amount of Energy or we go the other way, we turn Energy into Matter and anti-Matter. I don't understand what that has to do with the Higgs.

Pamela: We basically took and said okay we have all these normal Matter Particles and now we're going to double the number of Particles by creating anti-Matter and it fixed all the math.

Then we had the Higgs Boson and we couldn't figure out how to make it interact politely with all the things that had Mass. We were kind of confused by things like Photons don't have Mass and Gluons have a high amount of Energy which is like having Mass.

This made no sense. The way around it seemed to be to create yet another entire family of Particles.

Fraser: So just to make the Higgs work, you then have to predict a whole pile of additional Particles on top of that. So, it's almost like they all come together.

You get the Higgs and then you get some other Particle that makes it work and the only way you can have that Particle that makes it work is have a whole bunch more particles.

Pamela: Yes. We're okay with this.

Fraser: [Laughter] Okay with this, all right.

Pamela: [Laughter] This is actually something that sort of kind of maybe makes predictions that are provable. The Super Symmetric Partners – the Spartners have sort of kind of predicted Masses and the lightest of them is something that we like to blame Dark Matter on sometimes.

It's possible the lightest of these Super Symmetric Particles might be something Large Hadron Collider could get at.

Fraser: So would there then be an equivalent – you went through all the Particles in all their happy shapes and all lined up like they're little soldiers – there would be Symmetric Particles for all of those?

Pamela: Yes!

Fraser: Right and including the as of yet undiscovered Higgs.

Pamela: Probably.

Fraser: But like what does this have to do with Gravity?

Pamela: Now we're trying to figure out how to mathematically describe all of this. In the process of trying to describe all of these Particles, Scientists struck on the idea of what if Particles are nothing more than Strings that are oscillating in different ways and the way they oscillate defines the different characteristics of the different Particles.

This is where the math gets scary. It's out of trying to come up with the math that describes all of these different Particles that as you start to try and figure out how to build a Proton out of Quarks? How do you build Neutrons? How do you build what we call Hadrons?

Protons and Neutrons are Hadrons. In the process of trying to figure this out, they ended up with this weirdo Particle that had a set of characteristics including no Mass that wasn't generally useful unless it just happened to be the Graviton. It actually sorta fell out of the math that you could build using String Theory a Particle that led to Gravity.

Fraser: Oh, okay let me have another shot at this. In creating that whole collection, that Super Symmetrical set of Particles you got one Particle in that that could work for Gravity.

Pamela: Once you start to try and figure out how to build Neutrons and Protons out of Strings.

Fraser: I see so it's like if you can use this method where the math seems to work that allows you to build Protons and Neutrons out of these Particles, one of the happy side effects is that it also helps to explain Gravity.

Pamela: Right. There are lots of other things that are falling out of these theories. We start to end up with weird characteristics like the Proton, the thing that basically Atoms need in order to act like happy Atoms. Protons decay eventually so there's this possibility that in like ten to the 44 years or some obnoxiously large number like that Protons will start decaying in the way that like Uranium breaks down into other different things.

Except in this case the Protons are breaking down into Energy. This sort of causes things like those Black Holes and White Dwarfs and Lone Solid Planets without Stars that are the only things left after the Energy Death of the Universe. They start evaporating.

Fraser: Yeah, I know we talked about that a bit in one of our shows. The Large Hadron Collider for starters should be able to, if we're lucky, detect some of those heavier particles and maybe put some parameters on the Super Symmetry.

On that whole other collection of Particles that mirrors the Higgs Boson. So, find the Higgs Boson and then find the Symmetrical Particle for it and maybe keep going up the chain. Is that right?

Pamela: Yeah, that's unfortunately the fate we have and none of the things that we know about currently will help us really understand is this String Theory or is this just a really ugly Particle Universe where these are all just stand-alone little Particles.

Fraser: I think that without you actually going into the math of String Theory, I hope that gives people the understanding of where String Theory comes from. It's a way to mathematically solve the introduction of these Super Symmetrical Particles.

One of the happy outcomes of that is that it might predict how Gravity works with the rest of the Particles. So is there sort of a whole other line of thinking?

Pamela: Right now, String Theory is the direction everyone is going in. There are people who are thinking Super Symmetry doesn't require Strings. We don't really have any other alternatives. There's a bunch of different flavors of String Theory but it really all boils down to strings.

There are a lot of people – myself included – that are just kind of hoping that maybe some young genius will come along a new way of visualizing the Universe that might open our eyes to some sort of creative idea.

We've been working on String Theory since about 1970. There hasn't been a major breakthrough the way Einstein said "let's look at everything in terms of Geometry." We need that young genius to think out of the box and think creatively to bring all the pieces together.

Fraser: As I understand String Theory is going to be almost impossible to observe observationally.

Pamela: Right. There are a few predictions like Cosmic Strings fall out of some of the theories and the Cosmic Strings and String Theory – the use of the word String its different strings in these two cases.

In the case of Cosmic Strings you end up with basically this high, high density line through Space where it's basically a line where the dimensions don't line up right. Sort of like when you get ice cracking as it freezes in a lake.

In this case as the Universe solidified out and ended up with these faults in its structure. It's possible that these things exist and we might someday detect one. There were a couple papers a few years ago of possible detections but none of them ever panned out.

Fraser: Right as I recall these are where you might get the first moments after the Big Bang magnified in the structure of the Universe as the Universe went through its inflation and expanded any little changes, permutations would just get blown up, really magnified into the Universe, right? You can see it.

Pamela: Right. There are people who have predicted that if you build a telescope that has a thousand square kilometer surface area that works in the Radio, maybe you can detect other features in the Sky. But, that's a telescope we don't exactly have the resources to build.

Fraser: Yet. [Laughter]

Pamela: Okay, so if we go and grab an Asteroid, tear it apart and turn it into a Radio telescope...right now we're not there. So right now we have no way to tell all of these different proofs apart. It's frustrating.

Fraser: So, in other words there are apart from Super Symmetry there are no really serious attempts to unify Gravity and the other Forces.

Pamela: This is the direction we're going in right now – for better or worse.

Fraser: That's why billions have been spent to build the Large Hadron Collider and hopefully within the next couple of years, new Particles will freeze out of the energies and we'll be able to see them.

Pamela: And what's cool about that Large Hadron Collider is it could always turn up something we never predicted forcing us to rethink everything but giving us an experimental starting point. And that's just cool.

Fraser: You know, I don’t think you were able to come up with something brand new that would win this show the Nobel Prize.

Pamela: No, I’m much happier with telescopes than I am with math.

Fraser: Well then we’re going to get the Nobel Prize with something having to do with telescopes. [Laughter] We’ll go to Sweden eventually. Thanks Pamela and thank you for wrapping your head around this. I really hope that this was able to give people some access to what the direction of the cutting edge of the Physics is going in.

It’s not easy to understand. I don’t understand it. You barely understand it and you’re in it. [Laughter] I really look forward to everything that comes out of Large Hadron Collider and the Physicists working there. I can’t wait.

Pamela: And I know we’re going to get letters on this one. If you want to know more go read Brian Green’s book, “An Elegant Universe.” If you are a String Theorist, we’re sorry.

This transcript is not an exact match to the audio file. It has been edited for clarity.
Transcription and editing by Cindy Leonard.