Jon Spooner:	00:02	Hello and welcome to Live from The Space Shed, a podcast all about space and science hosted by me, Jon Spooner and me
Mini Jon:	00:12	You mean me
Jon Spooner:	00:12	Sorry. Yeah, I mean you.
Mini Jon:	00:13	Mini Jon!
Jon Spooner:	00:16	Mini Jon! Long story short, a few years ago, I accidentally set up my own space agency based out of the shed at the bottom of my garden. Turns out if you go around telling people you're the Director of Human Space Flight Operations for the Unlimited Space Agency, wearing an orange space suit, more people than you might think want to play along and now the British astronaut, Tim Peake is our patron and he took me with him to space.
Mini Jon:	00:36	He took *me* with him to space!
Jon Spooner:	00:39	Yeah. Yeah. Alright. He took *you* with him to space. So Mini Jon became UNSA's first astronaut.
Mini Jon:	00:47	Woohoo!
Jon Spooner:	00:47	Since then we've been touring in UNSA's mobile headquarters, The Space Shed, to festivals like Latitude and Blue Dot telling stories, talking to some super cool space and science people, and we've recorded our chats so you can find out about their amazing work as well.
Mini Jon:	01:04	Jon?
Jon Spooner:	01:08	Yes, Mini Jon?
Mini Jon:	01:10	What is your favourite particle?
Jon Spooner:	01:10	My favourite particle? You've been having a sneak listen to this week's interview with particle physicist Professor Jon Butterworth, haven't you?
Mini Jon:	01:20	Maaaaaybeeeee...
Jon Spooner:	01:20	So this week's guest in Live from The Space Shed is Professor Jon Butterworth, who works on the Large Hadron Collider's ATLAS experiment at CERN.

Mini Jon:	01:30	The what, what and what?
Jon Spooner:	01:30	's alright MJ. I didn't know what any of those things were either. Luckily Jon, Professor Jon who visited us at Latitude Festival describes them and his work brilliantly.
Mini Jon:	01:40	Cool!
Jon Spooner:	01:40	I know. It's almost like he's a Professor of physics or something.
Mini Jon:	01:44	Let's go!
Jon Spooner:	01:45	OK, let's go. Enjoy this episode of Live from The Space Shed.
Jon Spooner:	02:03	Wahey! Wow, even I didn't know if we were going to take off there [laughs] Hey. Hey. Welcome. My name's Jon, Jon Spooner. I am the Director of Human Space Flight Operations here at the Unlimited Space Agency. Welcome to unsafe HQ, The Space Shed. Give it up for The Space Shed. [Cheers] Wooooo. Yeh. Hey, I'll tell you what, a mid-afternoon audience is much more vocal than a 12 o'clock audience, I tell you. Hey. Hey. Later today at six o'clock we got some DJs playing. We've got our Science in the House DJs, real particle physicists doing a set here later at six o'clock. Tomorrow we've got some very cool people joining us. We've got astrophysicists. We've got Abbie hotsy. She is the lead engineer on the Mars, ExoMars rover projects. She is sending a vehicle to another planet. She's going to be here talking to us, and I'm going to tell a story about How I Hacked My Way Into Space, that's all tomorrow. But this afternoon, one of my favourite things about my job is I get to meet some very cool people. Uh, very clever people and we're joined by one this afternoon. He is a particle physicist. Um, has worked extensively on the Large Hadron Collider over at CERN. Would you like to meet him? [Audience cheers] Loving this afternoon's audience! Please give it up, a big Latitude welcome to Professor Jon Butterworth!
Audience:	03:22	[Cheers]
Jon Spooner:	03:26	Jon, welcome. Thanks very much for joining us in the Shed this afternoon.
Jon Butterworth:	03:32	What a build up.
Jon Spooner:	03:35	There's a little prize for anyone that guesses the, we did a version of the tune...

Audience:	03:42	Star Man
Jon Spooner:	03:42	Star Man! Yeah, yeah, you get a, you get a prize. It's not actually all that appropriate is it, because you're not an astrophysicist.
Jon Butterworth:	03:49	David Bowie is always appropriate.
Jon Spooner:	03:51	I agree with you. Jon. Thanks so much for coming in today.
Jon Butterworth:	03:54	It's a pleasure.
Jon Spooner:	03:54	You are actually a particle physicist.
Jon Butterworth:	03:56	I am actually that thing, yes.
Jon Spooner:	03:58	Yeah, and you're a Professor of physics at UCO. You've worked, as I was saying, extensively on the ATLAS experiment at the Large Hadron Collider in CERN.
Jon Butterworth:	04:05	That's right.
Jon Spooner:	04:06	You basically understand everything there is to understand about the universe.
Jon Butterworth:	04:10	As well as anyone else, yes.
Jon Spooner:	04:12	You see this, I love this. This is always the answer from the scientists. Yeah, we kind of...
Jon Butterworth:	04:16	Um...
Jon Spooner:	04:19	And you're here. I mean it all sounds very impressive.
Jon Butterworth:	04:22	Well it is.
Jon Spooner:	04:23	It is. Well, that's good to know. Um, but I don't know. I mean, what is, what is particle physics?
Jon Butterworth:	04:29	Particle physics is, is the, it's a kind of quest to understand what the smallest constituents and most fundamental laws of nature are. So, if you take a piece of material and you say take a piece of grass or a piece of this fence, you cut it in half and you cut it in half and you keep doing that. We know at some point you'll get to molecules and then you'll get to atoms and then you'll break the atoms up into electrons and protons and you'll, you'll break them up. The question that particle physics is trying to answer is, does that process stop, are there smallest things or

can you just keep going forever? And if it does stop, what are the smallest things and how do they interact with each other and how did they make up the universe that we see around us.

Jon Spooner: [05:13] They sound like amazing questions to be trying to answer. What is the answer?

Jon Butterworth: [05:20] The answer at the moment, and you should bear in mind that science is always provisional. So it's a, it's the answer that we have, which is consistent with our mathematical knowledge and with all the experiments we've been able to do, of which the best is of course the Large Hadron Collider, and the answer at the moment is something we call the Standard Model of particle physics. It's one of those incredibly sexy names we have for things like the Big Bang, or you know...

Jon Spooner: [05:45] This sounds a bit boring, the Standard Model.

Jon Butterworth: [05:47] It's, it's like, um, when I grew up in Manchester and the Standard Indian was a name, a lot of the Indians we're called the Standard Indian, and I used to wonder why they chose that name, and I think it's because it sets the standard, it's a really high standard and it's kind of the thing you have to reach in order to call yourself an Indian restaurant. And I think we're kind of like that with the Standard Model. It's a proper model that describes what the fundamental constituents are, which is electrons, which you may have, you may know, you may have heard of electrons, they carry electric current. Um, and then there are corks, which you might not have heard of, but corks are inside the atomic nucleus. So they make up protons and neutrons, which are what make up all the elements in the periodic table, and that, they are the most important bits, really of the standard model.

Jon Spooner: [06:36] OK. So the Standard Model isn't as boring as it sounds. It's a really, really cool model.

Jon Butterworth: [06:40] Yes.

Jon Spooner: [06:41] I think you should call it that.

Jon Butterworth: [06:41] In fact, it's more of a theory than a model actually as well. It's not even really, it's not only a model, it's not really fair.

Jon Spooner: [06:47] This really gets us into it, doesn't it? Yeah. You say all of this and then it's always a qualification. Oh look, my desks moving. That's a spoiler for later. If anyone's coming back to see the show tomorrow. Pretend you didn't see that. Um, so you got the Standard Model. That's all very cool. It sounds brilliant. But why? I mean this is something, how long have you been a particle physicist?

Jon Butterworth:	07:07	Um, I guess... I'll trying to... That's a really hard question. 25 years I guess, about then I did my PhD. Yeah.
Jon Spooner:	07:14	25 years. OK. So why have you been, why have you been a part- 25 years of your life dedicated to this, for why?
Jon Butterworth:	07:20	I did do some other stuff, it is a, it is a thing worth dedicating your career too, I think. And um, it's really the, the, like any job, it has its day-to-day challenges. It has things where you have too many meetings or you have bits of kit that don't work properly or you spent too long- so all those stuff go with it. But they're in many jobs. But underlying it, is this idea that we're doing all this, this stuff, this amazing, these amazing experiments. I'm, I'm not a theorist, so I'm much more impressed by our experiments than by the Standard Model theory, I have to say. But the bits of kit we get to build and play with and the, the ideas that we're testing and extending, it's so, um, you have to pinch yourself every now and then. You have a boring day at the office and then you come back and go, yeah, but yeah, but this is why we're doing it and look what we've done, what we're doing, and over 25 years it adds up to quite a lot. Um, I think it's really important that human beings look around ourselves and don't just see like the beautiful trees and the sunshine and the other people, but also try and understand how it works. And I think there are, the front series of human knowledge are really important. Particle physics isn't the only one, space is another, um, understanding how biological life works is another, uh, particle physics isn't gonna help you much with that. But understanding what the fundamental laws of nature are and what the fundamental bits and pieces that we're made of are, is a really exciting and important frontier of knowledge that I like working at.
Jon Spooner:	08:46	I think it's a super cool job. I love particle-
Jon Butterworth:	08:49	It's not as cool as being a space man, I have to say. But there you go.
Jon Spooner:	08:51	Well, yeah. Yeah. It has its moments. I'll be honest. Um, but the thing that I loved about, a few years ago, I really got into my quantum physics, love quantum physics. But it was the moment where I understood and realised, someone explained to me that basically we are all just atoms, all fundamentally, profoundly

connected to each other physically and everything else in the universe, and the atoms that are me now, they weren't the atoms that were me three months ago.

Jon Butterworth: 09:15 Yeah. We've shifted around and-

Jon Spooner: 09:17 That makes me feel really cool about being in the universe.

Jon Butterworth: 09:20 You know where some of them come from, so my wedding band here, right? This is made of um, gold and platinum. Gold and platinum are really hard to make cause they're really heavy nuclear elements. The nuclei are really heavy. So the Big Bang you get hydrogen and helium made and a bit of lithium. I then when stars burn, they'll make carbon and oxygen and stuff. But you can't get anything heavier than iron, made an a star until it explodes. Then you got a supernova and when it's burning so fast, you can make really heavy elements. Even that isn't enough now, it's probably gold and platinum. Most of the gold and platinum around on the earth was made when two stars blew up. Um, and then turned into neutrons stars, super dense stars and then collided with each other. And it's something that violent it takes to make really, really heavy nuclei. So this wedding band was probably made in a neutron star collision about 5 billion years ago. If that doesn't blow your mind, I don't know what it does.

Jon Spooner: 10:16 I didn't know that, I've got a platinum one. I didn't know that, that's so cool! Five billion years old. Does that increase the value of it even more?

Jon Butterworth: 10:25 If you could point out which star it came from, it might do, you know, you can have your little certificate on it.

Jon Spooner: 10:30 I'm going to try. I'm going try. Um, so these experiments, so you're not theoretic- you're not just imagining stuff, you're actually doing experiments to find out for sure how these ideas work. One of the biggest, coolest experiments that you were working on, as I said, was the ATLAS experiment at the Large Hadron Collider in CERN. Now, let's just work on the basis that maybe, some people don't know what ATLAS, or the LHC, or even CERN is. What are those things?

Jon Butterworth: 10:54 Right. Okay. So, CERN is the Centre European Research Nuclear, which is, uh, is the European Centre for Nuclear Research. You can probably tell that it's a bilingual lab, in fact the UK is about 20% of it and you don't have to speak French to work there as you can tell from my accident. Um, or the way I pronounced the lab's name I guess. Um, but it's, it was founded in the fifties. It's a, we all pay, everyone who's a taxpayer, anyway, um, so not our own banks, but everyone else pretty much will pay about a pound, two pounds a year, into it and has been doing for a long time then, um, that has enabled us to do this cutting edge research there. I've, most European countries are members of it and also the US and Japan and Russia and China, they all collaborate there as well. So that's the enterprise, that it is.

Jon Spooner: 11:48 It's like the International Space Station, this massive international collaboration where the Large Hadron Collider lives.

Jon Butterworth: 11:55 Yeah. So the Large Hadron Collider is this big, uh, it's a 27 kilometers of magnets in a tunnel under Geneva. Actually most of it's under France, so it's under the French Swiss border. The main lab is in, is in Switzerland, in Geneva. But the, um, the rest of it is, um, is mostly in the, under the Jura mountains in France. It's about, um, 80 meters underground, most of the time.

Jon Spooner: 12:19 Most of the time?

Jon Butterworth: 12:22 Well, it varies in depth.

Jon Spooner: 12:23 Oh I see, it doesn't move [laughs].

Jon Butterworth: 12:26 God, that would be cool. It's, um, yeah, it goes under the mountain. So sometimes it's deeper. Some of it is deeper, but in that tunnel, we have the, uh, we're steering and accelerating the two highest energy beams of particles we've ever had, which are protons, which is essentially, um, the, the nucleus of a hydrogen atom, going in opposite directions and at four places on that ring, we bring them into a head on collision with each other and we smash them to pieces. It's a subtle way of trying to work out what's going on inside them basically. And, so that's CERN and the Large Hadron Collider.

Jon Spooner: 13:00 Excellent answers already.

Jon Butterworth: 13:00 And then ATLAS is basically one of the digital cameras, if you like, that we built to surround those collisions in order to record what actually happens when these protons collide. And that's what I help build. I was a part of the UK effort to build big chunks of that.

Jon Spooner:	13:14	Who thinks that's a really cool job? [Laughs] That's excellent. Your pound a year is doing good work. Um, let's not, no, I was going to get into thanking-
Jon Butterworth:	13:25	I would like to thank all you taxpayers for funding it, because I'm very privileged to work on it, I have to say.
Jon Spooner:	13:29	We shouldn't bring up Brexit, right. Let's not do Brexit now-
Jon Butterworth:	13:32	I didn't mention that-
Jon Spooner:	13:33	No, no, no, no, no-
Jon Butterworth:	13:34	Actually, I did peripheral- you didn't, I'm sorry.
Jon Spooner:	13:36	No, no, no, it's all good. It's all good. It's all good. And a few years ago, so this is a very cool experiment, and a few years ago there was, I've got it written down here, there was something, uh, called the Higgs Boson or something. There was a big fuss, I remember in the news there was some people talking and going on and on about the Higgs Boson. What's that?
Jon Butterworth:	13:53	So the Higgs Boson is a kind of, it's the, you know, when you build an arch, an archway, and you have a keystone in the top and if you don't put the keystone in right, the whole thing falls over. The Higgs Boson is, is sort of the keystone of the Standard Model. So the Standard Model describes electrons and quarks and things.
Jon Spooner:	14:13	The universe
Jon Butterworth:	14:13	The building blocks of the, yeah, basically, yes. Sorry, I don't know why I put it, I don't know why I put it-
Jon Spooner:	14:18	You're the Professor, sorry, sorry.
Jon Butterworth:	14:19	No you're right, you're right. And all, it lines those particles to actually be infinitely small. So this question about can I keep dividing things up forever? The answer is no, because you reach electrons and quarks and they're actually infinitely smaller and they're indivisible. Now that is a very weird concept that you have in an infinitely small particle. It's even weirder when you have a, um, the idea that this infinitely small particle actually has mass. It has substance, and they do, and that was not only conceptually weird, it turns out that's mathematically very difficult to achieve. Very difficult to write down a theory that will allow you to predict stuff and predict the way these

particles make up the universe and give them mass and have them infinitely small. And the only way we worked out to do this was actually, two Belgium physicists called François Brout and um, Englert, François Englert and Robert Brout, sorry, and um, Peter Higgs in Edinburgh, and they worked out a mathematically consistent way of allowing this to happen, that you can have infinitely small particles with mass. Even before we actually knew about quarks, they were way ahead of the game. It's 1961 or something. There's like, I don't know. So before I was born, we'd been wondering whether there's a Higgs around, right. And no one really took it very seriously at the time because we didn't know the rest of the Standard Model anyway, but as the rest of the Standard Model fell into place, partly because of some theoret- good theoretical work and mainly because the experiments were going well this is the way it is, this is what happens, it became more and more obvious that we really needed this Higgs Boson and there's nothing else like it in nature. It's a unique object. We call it a scale of Boson, which is to do with how much spinning, whether it spins or not, in fact it doesn't spin at all, that's why it's a scaler, that's what scaling means, and all the others do. So, it's a really unique thing.

Jon Spooner:	16:04	Non spinning-
Jon Butterworth:	16:04	Non spinning particle. Yeah, basically. And it's weird because it's there, even in empty space. So if you remove all the energy you can from a bit of space, you'll remove all the electrons, you'll move all the electromagnetic fields or the photons, you move all the matter and all the quarks, but they'll be Higgs Boson still there, there will be a Higgs field still there. If you want to remove the Higgs, you have to put energy in. So the lowest energy bit of the universe has Higgs, the Higgs there, and it's by sticking to that Higgs, that all the other things get mass. So it's a kind of, and it's only with by that that all the other predictions of the Standard Model only makes sense if this Higgs Boson actually works, is there. So we were quite tense. We quite keen to find it or show, it would in some ways be more fun to prove it wasn't there because that would have meant the theorists would have to go back to the drawing board, but...
Jon Spooner:	16:51	This is one of my favourite things about the job that you do, that you like to fail because the point of which you, you've got an idea and the point at which you develop an experiment and it doesn't come out the way that you expected. You learn something new from doing that.

Jon Butterworth:	17:03	I think it's an Isaac Asimov quote that I really like that he says, that the most exciting words in science are not Eureka but, that's weird. [Laughter]
Jon Spooner:	17:12	There's one of my favourite quotes is, it's an Einstein quote, but he describes his teleportation, back to the quantum stuff, there's a, the idea of a quantum entanglement where objects change state at the same time, with no, no time in between, across any distance in the universe, and no one can explain it. His description of it was, well, it's spooky action at a distance.
Jon Butterworth:	17:32	That's right, he hated it, but it's-
Jon Spooner:	17:33	It's just how it works.
Jon Butterworth:	17:36	It happens, yeah. He spent his whole later career trying to prove it didn't, but it did.
Jon Spooner:	17:39	So basically you made an experiment with lots of other people
Jon Butterworth:	17:43	Yeah, about 6,000 and other people on the, probably a lot more than that actually, but the papers were signed by 3000 people each. Yes.
Jon Spooner:	17:50	That's cool. And so you all got to share this thing that you may discover that proves that the Standard Model of physics is correct and this is now a fact.
Jon Butterworth:	17:58	It is, yes.
Jon Spooner:	18:00	The weird thing is a fact.
Jon Butterworth:	18:02	Yeah.
Jon Spooner:	18:02	That's cool. That's what the Hadron Collider has been doing. We have discovered the Higgs Boson. It's due for an upgrade quite soon?
Jon Butterworth:	18:09	Indeed.
Jon Spooner:	18:09	This is a better name. I like this name. It's the...
Jon Butterworth:	18:12	What, the High Luminosity upgrade?
Jon Spooner:	18:14	The High Luminosity upgrade. Hands up, who wants a High Luminosity upgrade? That sounds like something. Yeah, loads of

us. That sounds like something you should be able to get painted on your face here. What is it?

Jon Butterworth: [18:27]

What does it do? So to find out new stuff with the new Collider, it typically needs to push the boundaries in one of two ways. So, one way is that you have higher energy particles than you've ever had before and what that gets you, is you can create heavier new particles because =MC2, so more energy means more mass and therefore you can create new stuff. The other one, we've kind of pushed the Large Hadron Collider as far as it will go now in energy, it's not going to go any higher energy without a radical, well probably a new tunnel actually, that's another story, but the other way you can do it is, is, um, by collecting more data, just building up the statistics. And that's the luminosity. So the luminosity is essentially the brightness of the beams, it's how many protons are you colliding per second. We're stepping that up and we're turning up the power basically in that way. What that does for you is like, because it's, it's because it's quantum mechanics, it's all statistical, OK. So, my favourite analogy of it is if you're rolling the dice, so say you have a dice and you want to check whether the dice is fair or not, OK. So you roll the dice six times and you might expect that you would have one, two, three, four, five and six would all come at once, but actually, you know probably that's not gonna happen, you don't really learn anything by rolling the dice six times. But if you roll it 6 million times, you better get about a million of each, otherwise someone's being silly with the dice and the dice isn't fair. And that's the kind of situation we're in, in that we want to know this is particle really the Higgs, is the Standard Model really predicting its behaviour, is it really doing what it wants, and with the data we have at the moment we can say, well probably to within about 20%, but if we roll it, if we turn up the luminosity, which means rolling the dice many, many more times, we're colliding many, many more protons, then we can see whether that's true to maybe 1% or maybe 1.1% depending on what it is we're measuring and if it's not true then we've found something new again. Then we, then we've broken the Standard Model again and we maybe get a clue to some of the questions the Standard Model doesn't answer.

Jon Spooner: [20:18]

But you say, you say that the Standard Model is, it's a fact and it describes the universe as best as we can right now, but what does it mean if you, how does the universe or understanding of it change if-?

Jon Butterworth: [20:31]

Well, the Standard Model is, I mean it's the fact in the sense that it gives you really excellent predictions for all the things we've mentioned so far, pretty much, OK, and that, that's not gonna change. Even if we find the Standard Model is not the whole story, then those predictions won't change because we know they're right. We've verified them with experiments. But you always try to extend the theory, so with Newton and for instance, Newton's laws, they basically work by, because Einstein in a sense proved Newton was wrong, but he didn't invalidate. We still learn Newton's laws of skill because they're good enough for most things in everyday life. It's only when you're going close to the speed of light that you need to worry about special relativity for instance. Um, but Einstein did build a bigger theory that contained Newton's laws as well. So they're still there and still right, but there's more there because Einstein got a better theory. What we're looking for is the same situation with the Standard Model, the Standard Model will still be there in the way that Newton's laws are still there, but we want a bigger theory because there's some things that the Standard Model doesn't explain that which we can talk about if you like, but they're dark energy, dark matter, the missing anti-matter in the universe, where gravity fits in. There's all kinds of stuff on our shopping list that the Standard Model doesn't really help. So, if we saw a deviation at the Large Hadron Collider, we'd hope it was a kind of loose end we could tug at to answer some of those questions.

Jon Spooner: 21:45 Let's talk about, a little bit about dark energy. I'm going to, um, open up and I'm going to get to ask, in fact, first things first, quick show of hands before you arrived here, show of hands, who knew what the LHC and the ATLAS experiment were? Show of hands, who didn't? And keep your hands up if you now do. [Background laughter] Yeah, you've done really well. You've, that's great. Look at that. That's a, that's education in action right there. And dark energy and dark matter, two different things, dark energy, dark matter. My understanding is that that's just all the other stuff that we don't understand in the universe.

Jon Butterworth: 22:19 That's pretty much it. Yes. And they, I guess the question you'd ask is why did we think there is other stuff there?

Jon Spooner: 22:26 Yeah

Jon Butterworth: 22:26 Dark energy is a little flaky. I mean dark energy is really a, they've named it dark energy sort of in tribute to dark matter, and I'll talk about dark matter in a minute, cause it's, I take it more seriously.

Jon Spooner: 22:37 They're playing at 8:00 PM on the 6 Music stage tonight. Yeah.

Jon Butterworth:	22:41	They, um, they [laughs] dark energy is really just a way of, uh, you could just say the universe is increasing its rate of expansion. That's a bit of a surprise. We don't know why. So we'll call it dark energy. OK. So leave that aside, right. Let's let the astronomers sort that one out at some point. Dark matter is, is to me, much more serious of an issue actually, because it's quite easy to see the evidence for it, for why we think there's something there. So if you look at the, the rotate, the way galaxy, we see galaxies, we see they're spinning, and we can see that they're spinning because we measure the light from the stars and we can see the Doppler shift. So we see it red shifted or blue shifted, then from that we can measure the velocity that with the speed with which to turn in.
Jon Spooner:	23:23	It's so matter of fact, isn't it? Yeah, we can see the galaxies and we know exactly how fast they're spinning.
Jon Butterworth:	23:28	Yep
Jon Spooner:	23:28	That's fine. Yeah. Sorry, carry on.
Jon Butterworth:	23:30	No, it's pretty cool. Only, only because of quantum mechanics and cool telescopes, but yes. So we did that and then we can also estimate how much matter there is in the galaxies, basically because we can see it burning and we can see the infra- all different wave lengths, we can see the infrared from the gases. We can see the stars burning and therefore we know how much gravitational force there is holding these galaxies together. And if you put those sums together, knowing what we do about the mass and what we do about gravity, then they shouldn't be working. They should be flying apart. They're spinning too fast. OK. So it's like you imagine a, um, a roundabout, it's just spinning so fast that the metal can't hold it together. It will fly to pieces. That's pretty much what the galaxy should be doing because there isn't enough mass to produce enough gravity to hold them together.
Jon Spooner:	24:11	So it should be, it should look like a really bad day at the playground and a massive use-
Jon Butterworth:	24:16	... everywhere. Going all over the place.
Jon Spooner:	24:18	But it isn't, everyone's having a lovely time.
Jon Butterworth:	24:19	That's right. And so you've got two ways out of that. One, either you fundamentally misunderstood something about gravity, which is general relativity, which is possible. Or two, there's a

lot more matter in these galaxies than we can see and we call that matter, that missing matter, that matter, and it's not something that's in the Standard Model.

Jon Spooner: 24:37 And is that something that the LHC will help us to find?

Jon Butterworth: 24:42 We really hope so. To be honest, there are some kinds of dark matter the LHC will never be able to see. There are other kinds that we might even produce in the lab and say, look, we got some dark matter, here it is, kinda thing. So, so and there are also really cool experiments underground in, in mines hiding away from the radiation, from the atmosphere, looking for dark matter, bumping into their detectors as well. So there's, there's a lot of ways you can approach looking for dark matter. And there are theories trying to change general relativity to try and explain the, the, try and change gravity so that we don't need dark matter as well. But I think most people that, Einstein was really clever, you know, it's, it's really quite hard to change federal general relativity in any way that makes any sense. So, I think the consensus is probably dark matter is there, although there is still people saying, well what if, what if gravity's wrong?

Jon Spooner: 25:33 And the High Luminosity upgrade is, when's that gonna happen? When do we find out?

Jon Butterworth: 25:37 To be honest, sneakily, we're sort of doing it now. So were running at the moment with higher luminosity we had last year, and we're, we're getting there gradually, but at the end of this year we'll have, we'll shut down for a couple of years, where we go and refurbish parts of the detector, but mainly the, the accelerator. So the, the first stage of the High Luminosity upgrade will be, what does that, 2021 and then we have another stage of it after that where we replace some big chunks of the detector. So, it's going to be over the next decade or so, it's going to, it's not a quick game particle physics, I'm afraid, but it's, we're getting there.

Jon Spooner: 26:08 No, but in 10 years, what you're saying is, is that we really could know a huge amount more about the universe and what that extra matter in it is.

Jon Butterworth: 26:16 Yeah. I mean, to be honest, with the Higgs, I could've given you a more precise date, I'd say by then we'll know whether or not there's a Higgs right. Dark matter, it's much more open ended. We're kind of off, we've had a, all my career, right, until 2012 when we found the Higgs, we've had a very clear theoretical map of what we should be looking for as experimentalists. Now we have no map, so we, we've got unanswered questions but

		we don't have a recipe for go, for how to go and answer them. We're really exploring in the dark. Shining, the LHC is shining a light in places we've never looked before and we don't know whether they're going to be empty or whether they're going to have the most exciting new thing in there that we've ever seen.
Jon Spooner:	26:51	This is cool. So 10 years. There's some of our audience members here. I'm just wanting some of the younger people that are here or some of the older people who want to career change, but you might be in a perfect position. Another show of hands, who's interested in maybe helping to find out what dark matter is? Ok, we've got some, yeah. I don't want to dampen your spirits, but you might- [laughter] There's some, there's some guys here. How would, how would, do you mind? How old are you? 10, so 20 that would be perfect to be involved in these sorts of-
Jon Butterworth:	27:21	Could be, could be your PhD thesis.
Jon Spooner:	27:24	How would you go about, from the age of 10 to now, in 10 years time maybe being part of that?
Jon Butterworth:	27:31	Whoa. Um, you, well first of all go to cool events like this and listen to people like him. So you're doing that right. Um, basically stay curious at school and, and don't just do physics. Learn all, when you get a chance to learn new things, learn them because you never know what bit of information is going to be useful, and also by staying curious, you just keep your brain fit and it works really well. And then obviously if you want to do physics, then when you start choosing your options at secondary school, choose maths and physics and chemistry probably as well. And, and, and then go through university doing that as well. That's what I did. And, um, and it kind of works in the end and oh, but you know, don't, stay curious about everything, don't, I would advise you not to lock on too closely when you're 10, because things change. And even when I was at university I wasn't sure I wanted to go and be a particle physicist as a job. I did it because I was, it was so exciting and I wanted to, but I didn't, you know, I, I've thought about doing other things on the way, but yeah, it's all possible. There are lots of possibilities and this is a great one.
Jon Spooner:	28:33	That's clear advice. Do you think he might do it?
Audience:	28:35	[in background] Yes
Jon Spooner:	28:35	Yes. He's going to find some dark matter! [laughs]

Jon Butterworth:	28:39	It would be brilliant. Well, if you do, then look me up wherever I am in some geriatric place at UCL, in my office, and come and show me first.
Jon Spooner:	28:47	I was going to say as well, make sure you get Jon's number before you leave so that in a few years time you can write to him and say, oh, do you remember that time at Latitude, and I said I was going to find some dark matter? I'm that guy. Maybe you could be his supervisor on his PhD.
Jon Butterworth:	29:01	That would be ace.
Jon Spooner:	29:02	Just planting seeds. Um, brilliant. So I, that's a beautiful, excellent, clear explanation for me of what the LHC is, where it's going, what it wants to do. Like, so you've got lots of experience doing lots of things. My take on it is that you basically understand everything there is to know about the universe. [laughs] That's, that's the position I'm taking. At which point-
Jon Butterworth:	29:25	If you stick to physics. I'll, I might give you a run for your money.
Jon Spooner:	29:27	Ok. You can, you can, you can take the physics slant on any of the questions that we might now get. Does anyone here, given all of that amazing stuff, have a question that they, it's not every day you get to meet and have your questions answered from someone that works that closely with this sort of experiment at this level. So there is, yes, the, oh wait, hang on a minute, we've got, um, some loudhailers here. We're going to put one against your mouth. Go on Flora.
Audience:	29:51	[in background] Why does the universe keep expanding? Does it have anything to do with dark matter?
Jon Spooner:	29:56	Such a good question! Why does the universe keep expanding? I like the fact that you, you just know that that's happening, for anyone else that didn't know that the universe is expanding. Uh, why does it do that? And does it have anything to do with dark matter Jon?
Jon Butterworth:	30:08	Right, so, it's expanding, this is what we think, and bear in mind, this is theory, so there's evidence for it, but it's not guaranteed to be right. During my career, our ideas about this has changed quite a lot, because of evidence. So, but we do, what we're pretty sure of is that there was a Big Bang and it all kicked off and why it kicked off is something that we do still argue and discuss about. There are some physical models about how suddenly a big wad of energy was dumped in space and

expanded. But once this is expanding, there are the, um, what you would think is going on then is that dark matter, which you mentioned, and normal matter actually, will just be pulling it down. They'll be attracting each other and trying to slow it down. So, you can imagine it expanding and then gradually slowing down as gravity kind of puts the brakes on. Now we know as of about 15 years ago, um, that that's not actually what's happening. The, the universe is actually speeding up. So dark matter and normal matter are slowing it down, but this thing that we mentioned called dark energy, is what we call the fact that we've observed that it's speeding up. Now we don't actually know why. We don't know what's doing that, but we know something is. So...

Jon Spooner:	31:19	Did that answer your question?
Audience:	31:22	A bit
Jon Spooner:	31:22	A bit. Yes. And again, I'm going to guess you're maybe six years old? [audience member answers] You are. What a great guess. Um, again, you can get together with this guy down in the front and together you can work out whether or not any of those things are affecting it. Uh, you'll create some dark matter and together you're going to answer all the questions about the universe. That's my vision for you. Don't let me down [laughs]. Yes! Brilliant. Yes. Phil. We've got an excited person here.
Audience:	31:50	How quickly do particles go around the Large Hadron Collider?
Jon Spooner:	31:55	How quickly do particles go around the Large Hadron Collider.
Jon Butterworth:	31:58	Good question, and I always struggle with the answer because it's 99.9999999 and I always forget how many 9's percent the speed of light. So practically, it's the speed of light. It's slightly below. The reason- but that was true of the colliders that were running when I was your age. When, yeah, when I was your age. So one of the frustrating things about being a speed freak in physics is you can't go faster than the speed of light. So what, what we, what happens is as you accelerate a particle, as you put more energy in to make it go faster. It goes faster and faster, but up to a point it sort of stops going fast and it um, it stops going faster and faster and it kind of approaches the speed of light and can never go past it. It still has more energy though and that's what we're doing. So we have higher energy, really, really high energy beams, but they don't go any faster than the speed of light. So the speed of light is the answer, really.

Jon Spooner:	32:52	The speed of light thing is annoying.
Jon Butterworth:	32:55	Irritating, yes.
Jon Spooner:	32:55	Yeah. Why? Why is it so annoying? Why can't you go at the speed of light?
Jon Butterworth:	32:59	Well it's Einstein again, really.
Jon Spooner:	33:03	He's annoying.
Jon Butterworth:	33:03	He is annoying. The the, the way that the universe seems to be set up, is anything that has mass can't go faster than light and anything that has no mass must go at the speed of light, can't go slower or faster.
Jon Spooner:	33:14	That's just the way it is.
Jon Butterworth:	33:15	That's the way the equations of motion actually seem to work, so.
Jon Spooner:	33:18	Ok. Yeah. That's your question really clearly answered, isn't it? Basically the speed of light, which is fast! Yes. Young man on the front here.
Audience:	33:29	What's your favourite particle?
Jon Spooner:	33:31	Oh, I like it. What's your favourite particle, Jon?
Jon Butterworth:	33:34	I have to give, for consistency, I'll have to give the answer I gave on The Infinite Monkey Cage, which is the proton because it's strong and stable [laughter], which would be a refreshing break at the moment. But I like the proton because it is actually, this is a serious point other than the political gag, which is well past its sell by date [laughter], the, the, um-
Jon Spooner:	33:53	Thanks for-
Jon Butterworth:	33:56	No it's my gag, it's alright [laughter]. But it's unusual because it's like, an electron is one of the infinitely small particles in the Standard Model and that's pretty cool. Neutrinos too. But, but the Proton is made of quarks so it's not a fundamental particle, but yet it seems to last forever. Its lifetime is much longer than the age of the universe, and I find that kind of fascinating. And, what I did a lot of my PhD on was actually the strong, what we call the strong nuclear force, which is what holds the quarks

		together inside the proton. And so I like it for all those reasons, it's great.
Jon Spooner:	34:29	What's your-
Jon Butterworth:	34:29	Also it cures cancer. But there we are.
Jon Spooner:	34:31	Oh just slip that in [laughs]. Um, let's not get into that because that is a whole other conversation.
Jon Butterworth:	34:38	It is, yeah.
Jon Spooner:	34:38	But that's one of the really exciting things as well. There's another speaker that, uh, we were, Susie, she who couldn't join us this weekend sadly, but that's the work she's doing, right. She's using protons that work towards curing cancer.
Jon Butterworth:	34:49	Absolutely, they're building a, in Manchester in the Christie opposite my office in the UCL building, two big proton therapy centres to do that. Just that.
Jon Spooner:	34:56	Which would be a cool thing, right. Um, what's your favourite particle? [audience member answers] Same. The Proton. Mines, do you want to know what, mine's the Neutrino. Uh, I like it.
Jon Butterworth:	35:04	That's pretty good, yeah. But which one though? There are three and they keep mixing up. Which one's your favourite?
Jon Spooner:	35:09	Tau.
Jon Butterworth:	35:09	The Tau. Good choice.
Jon Spooner:	35:11	Yeah. Well, someone described them to me once, I don't know if this is still true, but Neutrinos are cool because they're the, the smallest amount of reality ever imagined by human being.
Jon Butterworth:	35:20	Yeah. I think that's-
Jon Spooner:	35:20	I thought that was really beautifully poetic. Uh. One person nodding. I'll get on, right so any more questions? Yes. Let's have, uh, this woman here in the green top.
Audience:	35:33	This isn't really my question, it's a question that I get asked a lot, because I'm a physics teacher, all the time by my kids and I can't answer it. They always ask me, do you think there are any other Big Bangs that have taken place at all-

Jon Spooner:	[35:44]	Oh good one. Are there other universes?
Jon Butterworth:	[35:47]	Are there other Big Bangs? Um, the first point would be to say that no one really knows, right. As a physicist you have to say that we don't really know, um, the, personally, and this is a personal take, it seems at the moment probably quite likely that the, there are. So, in my career, the, what we think of about the Big Bang has changed a lot over the, while I've been a physicist. So, we used to think there was a Big Bang for reasons unknown, and then there was a period of inflation where there's some fields, some quantum field that boosts the whole expansion of the universe and then that stops and then things carry on as normal, and we understand everything post-inflation quite well, but we don't understand inflation very well. This is all in the first 10 to the minus, 20th of a second or something of the universe. What we think now is that, it's not that we don't think of it that way, we think of there being a period of inflation and then the Big Bang. So the Big Bang is now the end of inflation, when all this rapidly expanding quantum field dumps into normal matter and bang, you get everything, the universe starts off. In that model, it's quite plausible that inflation is going on across the whole load of space time dimensions, all the time and every now and then it just goes bang in different places and there could be a lot of them going on. So, this is only a theory, it's only a guess, but to me that seems like the most natural theory and is consistent with our observations. But honestly, we can't observe all these other universes, all we can do is observe evidence that inflation actually happens, and we do have pretty good evidence for that and it seems mathematically most plausible that that's probably what's going on. But it's a guess. It's not a, it's not science, it's speculative theoretical physics, but, but it's got some evidence behind it.
Jon Spooner:	[37:26]	I would take from that, that the answer is yes. So when they ask you, what year, what year are they? Your students?
Audience:	[37:33]	Secondary.
Jon Spooner:	[37:33]	Secondary students. But yeah, you can sp- go yeah, actually I was at Latitude last weekend. Oh well done miss. And I found out that there are many other universes, which is great. Anyone else got us a question for Jon? Yes. Oh, hang on. We have to wait for the loudhailer, you're very close but-
Audience:	[37:49]	You talk about having a torch looking in dark places as it were. How do you know what you're looking for? Is there ever a feeling that actually, probably, you looked and missed it?

Jon Spooner: 38:01 How do you know what,-

Jon Butterworth: 38:03 What we're looking for is to, it's a really good question. Uh, we lose a lot of sleep over it actually because we can't possibly record, even on something like the Large Hadron Collider, we can't possibly record all the data from every single collision. So, we have to make some pre-selections, and your nightmare is always that you've gone to all this trouble of, of making these collisions and then you've by mistake thrown the interesting ones away. So we go to enormous lengths to try and, um, not do that, and to dream up possible weird ways we could be losing them or that new things could be appearing that we haven't thought of. We on theory, I mean I've drawn the distinction between theorists and experimentalists, but to be honest, mostly we work as a team and they're suggesting ways, weird things we might have missed and we're building detectors to see them. Um, the other way, so that's one way, the other way is, um, that we do know because we found the Higgs, we have a very precise theory of what should happen. So we can go and test what should happen in ways that we've never observed before. So that's the kind of the negative of it, in that you say, well, we know what should happen, so if it doesn't happen, that's something new as well. So you can do both. You look for really weird things that you might have missed and it's very hard to be definitive in that, and we do keep cooking up new, new things that we should go look for in our data and doing data mining on these samples we do have, and redesigning the filters to see if we can pick up things we might have missed. But the other thing is go and measure what the theory says should happen in some very challenging places in the dark. And if it doesn't, if what we see doesn't agree with the theory, that's also a clue that something new is going on. So there's kind of two approaches. I mostly, personally work on the latter one of those where I make precise measurements of things that we have of new processes of Higgs production and, and back to Boson. Things that we haven't ever seen before, but the theory makes a prediction for, um, so that's, that's what I do but lots of people do the other thing too.

Jon Spooner: 39:53 Sounds like a mix of hard work and imagination.

Jon Butterworth: 39:58 It is actually, it's a very good way of describing what we do, I think.

Jon Spooner: 40:01 I'm wondering as well, because that's, it's all you physicists and scientists, you lot, doing that work. I want, do you ever work with, you talk about making up weird ideas, which feels a lot like what my job is as an artist and all the artists that are here at this

		festival. But is there, do you ever collaborate with artists to come? I would suggest they'd come up with some really weird ideas.
Jon Butterworth:	40:23	Um, we do, the artists are often interested in what we do and those in our program at CERN, we have a, we have a Gormley statue in our lobby for this because he was interested in that. I say a statue, it looks more like a piece of wire wool but it's there anyway. And um, I'm not convinced, personally I've never found that actually very helpful in doing new science. I find it helpful in appreciating and understanding what we do know and assimilating it. So then probably it does indirectly help the new stuff. But I don't, I don't know. Some physicists may do, I'm not sure. What I do find, I used to be very scathing about philosophy actually. About it not, not being very useful and going round in circles, but the work that I just described that I'm working on now and the particular approach we've taken is something that, which I'm working on now with two PhD students and two post-docs, is something that we come to a meeting on the philosophy of science, which is, I never would have thought that would have happened. So people do it in different ways. I find that important but not, not really for stimulating the ideas more for simulating the ideas I would say.
Jon Spooner:	41:26	Sounds like a challenge to me. I'm going to buy you a cider when we've closed up the shed and give you some ideas.
Jon Butterworth:	41:33	A cider definitely helps. You've never asked me- [laughter]
Jon Spooner:	41:36	Cooking up the ideas in the pub. Look it's, tell you what we'll take one more question because, I'll just say as well, Jon, you're not going to run away when we close the shed are you?
Jon Butterworth:	41:43	No, no.
Jon Spooner:	41:43	So if you don't-
Jon Butterworth:	41:45	I'll sign books, if you want as well.
Jon Spooner:	41:46	I was gonna, I was getting there, I was getting there, I was getting there. If you don't get an opportunity to ask a question from Jon right here, right now, and you want to, he's not gonna run away. So come and badger him for a bit, before we go off for a cider, and after you've bought his book, a signed copy of his-
Jon Butterworth:	42:00	It's not compulsory, I'll still answer questions anyway.

Jon Spooner:	42:04	[Laughs] But that would be the best way to- go on tell us what the book is.
Jon Butterworth:	42:07	The book is, it's my description of, of what I do in my, in my job. So, a lot of it is what we've just been discussing. What really was a privilege in it, is that I got hooked up with an illustrator and it turns out I think of this, of physics, as shining the torch thing, I think of it really as a map of exploring the kind of invisible universe, the subatomic world. And this guy drew these maps from my head and that, and so it's a kind of tour through this map of particle physics and finishing with the, on the east coast where we're exploring lands that we don't even know if they're there or not.
Jon Spooner:	42:38	That's cool. That sounds like you were working with an artist to come up with new ways of describing.
Jon Butterworth:	42:42	I was giving him the ideas [laughter]
Jon Spooner:	42:43	So, the book sounds great. Like I say, Jon isn't going to be running away. At six o'clock this evening, we're going to be opening the shed. Dr Rob Appleby who's... who was there. Um, but he's-
Jon Butterworth:	42:54	He's gone to get ready.
Jon Spooner:	42:54	He's going to be spinning some tunes, so come back for that. We've got more scientists with us tomorrow. I'll be telling the story of How I Hacked My Way Into Space. Thank you very much for coming out. Would you please give a massive Latitude round of applause to Professor Jon Butterworth [claps and cheers].
Jon Butterworth:	43:09	Thank you.
Mini Jon:	43:16	I like Jon.
Jon Spooner:	43:16	Yeah. I like him too, MJ.
Mini Jon:	43:19	Can we go to CERN?
Jon Spooner:	43:19	Can we go to CERN? I'd love to go to CERN. I mean, we'd probably have to be invited though.
Mini Jon:	43:28	Jon could invite us!
Jon Spooner:	43:28	Jon could invite us. What a great idea. Maybe he'll listen to this, hear that you'd like to go to CERN and maybe get a commission

		with their Arts Programme and we can make something super cool with them and get paid for it as well!
Mini Jon:	43:40	That would be cool
Jon Spooner:	43:42	It would be cool, MJ. Let's see what happens. Thanks for listening to this episode of Live from The Space Shed. Next time I'm chatting with space engineer, Abbie Hutty, she's the lead structures engineer on the European Space Agency's, ExoMars rover due to launch TO MARS in 2020.
Mini Jon:	44:03	We had some problems for this one, didn't we?
Jon Spooner:	44:03	Yeah. Yeah. There were some technical issues with the Space Shed that day, yes. But I think we dealt with them like true astronauts.
Mini Jon:	44:12	Work the problem!
Jon Spooner:	44:12	Exactly, MJ. Work the problem. Subscribe to Live from The Space Shed on Apple Podcasts, Spotify, Google Play or wherever you get your podcasts, to find out just how shambolic we can be. You can follow us on Twitter and on Instagram at @untheatre that's <u-n-theatre>. You can find full details and social links at our website thespaceshed.com
Jon Spooner:	44:35	Live from The Space Shed is an Unlimited Theatre production with Season 1 brought to you in association with the Science & Technologies Facilities Council, the Cockcroft Institute, The Space and Arts Council England. With special thanks to Dr Rob Appleby of Manchester University. Our theme music is 'Go!' by Public Service Broadcasting used with their extremely kind permission. Our sound engineer and editor is Andy Wood with additional sound design by Elena Pena. The show is produced by Jon Spooner and Alice Massey, with support from our friends at Storythings. Live from The Space Shed is an Unlimited Theatre production on behalf of the Unlimited Space Agency. See you for more Live from The Space Shed soon!