>> Welcome to the podcast series of Raising the Bar Sydney. Raising the Bar, in 2019 saw 21 University of Sydney academics take their research out of the lectures theatre and into bars across Sydney all on one night. In this podcast, you'll hear Geraint Lewis's talk, Waiting For The End of Time. Enjoy the talk.

[ Applause ]

>> Okay, thank you, everyone. Yes, my name is Geraint Lewis, and I'm a cosmologist at the University of Sydney. And my job is to study the evolution of the universe. So, what I want to know is, why does our universe look the way it does? And we know that by looking back over the history of our universe, the 14 billion years since the Big Bang today, and that tells us the forces that shape the universe around us. But, what I want to do tonight is takes on a bit of a journey. Not a journey through space, but a journey through time. What I want to do is ask the question, "Well, what's going to happen to our universe tomorrow?" And by tomorrow, I just don't mean, our tomorrow. I mean, all of the tomorrow's of the universe, what's going to happen over the next few billion, trillion, out into uncountable number of years? What's in store for us? So, every journey begins with a single step. And we're actually going to have to take a step backwards, to get to where we are before we can head off into the future. So, how do scientists understand the evolution of the universe? What has happened? So, over the last 100 years or so, we've come to realise a lot of important things about our universe. Firstly, our universe hasn't been around forever. Our universe was born in an event, roughly 14 billion years ago called the Big Bang. At that time, to quote a famous TV show, the universe was in a hot, dense state. Exceedingly dense, exceedingly hot, and exceedingly featureless. The universe was expanding. And as it expanded, it cooled. And in that cooling, matter had starts to fall together. So, gravity was doing its thing and pulling bits of matter together to form the regions that would become the galaxies, the stars and galaxies that we see today. For the first, possibly 15 million years, first 100 million years, the universe was dark. After the fires of the Big Bang, there were no stars or anything. There was just gas that was hanging around. And so, there was no light in the universe. But after this roughly 100 million years, gravity was able to pull gas together, the first stars were born and the universe lit up. Roughly, 10 billion years ago, big groups of matter started coming together. Lots of stars living in individual places, and the galaxies were born. And one of those was our own Milky Way Galaxy, which grew over time by eating smaller galaxies around us to become the object that we have today. So, our sun is one of roughly two to 300 billion stars living together in what's known as the Milky Way Galaxy. And spread throughout the observable universe, we know that there are probably between a few hundred billion and a trillion galaxies that we have observed. That's in the region of the universe, we can see. Beyond that, we think there's effectively an infinite amount of universe that continues on forever. So, our universe has grown over time. Stars were born, stars have evolved, stars have died. And we find ourselves here on the earth, 14 billion years after the start. And we can use our laws of science, our laws of physics to start to ask the question, well,

what's going to happen out into the future? So, the timescales that we're going to have to deal with are astronomical timescales, right? So, to the universe, minutes, hours, days, centuries, they don't mean anything. So, we're going to have to take steps, initially, small steps of order billions of years. And then out over trillions of years, and then much further into the universe. Now, we're going to be guided by the laws of physics as we understand them. But as we go out into the far distant universe, we will encounter conditions that we haven't seen in the universe before. And we might find that our laws of physics aren't the complete story. So, things become a little bit more hand wavy, a little bit more uncertain, and I'll try and let you know when we get there. But for the next few billion years, we think we know quite clearly what's going to happen. So, what's the next exciting event for our universe? Well, for us, we have our Milky Way Galaxy, and roughly 2 billion – sorry, 2 million light years away, is the Andromeda Galaxy. And Andromeda is a similar galaxy to our own. It has slightly more stars, maybe 400 billion stars, and it's sitting there at 2 million light years. What we know is that that Andromeda galaxy and the Milky Way approach each other at roughly half a million kilometres per hour. So, if you do the math quickly in your head. That means that in roughly 3 billion years, these two galaxies are going to collide. Up until that point, our sun is happily going to circle the centre of the Milky Way, taking 250 million years for each orbit. But as these two big galaxies get close, then lots of interesting things are going to happen. Now, one of the defining things about the Milky Way Galaxy is there's a big group of stars in the middle, which we can see on the sky, the centre of the galaxy, and in the constellation of Sagittarius, and then there's a big disc of stars, which we call the Milky Way. That's the thing that stretches across the sky. When Andromeda and the Milky Way get close, their gravities are very, very strong and they start to walk and ripple those beautiful spiral discs, the things that define these galaxies. And they will collide. So, these galaxies will hit each other at thousands of kilometres per second. Now, one of the interesting things is that stars themselves are actually very small compared to the distances between stars. So, when galaxies collide, all of the stars tend to rush past each other. So, the chances of a star hitting another star, they're really, really small. Even though there are hundreds of billions of them. But the Milky Way and Andromeda also contain lots of gas, lots of gas clouds. And gas clouds, when they collide, they don't go through each other, they shock and they collapse. And so, in this collision, the Milky Way is going to produce lots of hot blue, young stars. That's what you get when you make gas clouds collapse. So, if we're around in 3 billion years' time, the night sky is going to light up like the best Christmas tree you've ever seen. As well as all these young stars, some of this gas in the collisions gets funnelled down into the centre of Andromeda and over the Milky Way. And in the centre of those galaxies, we know that there are black holes, these ultra-dense objects. Inside the Milky Way, we know that the black hole has a mass of millions of times the mass of our sun. That gas folds in and swirls around it. As it swirls around, it travels close to the speed of light, it gets hotter and hotter and hotter. It starts to glow and the centres of the galaxies will light up brighter than all of those stars that were created. So, it's going to be an exciting time. The collision will occur, the galaxies will move apart, gravity will draw them back together, they will continue to collide and continue to collide. And eventually, the collision settles down, okay? And what's left inside of the two beautiful spiral galaxies we started with is one big amorphous blob of roughly a trillion stars, which has got the horrendous name of Milkomeda, all right? Now, those hot blue stars that were created, right? They're the James Deans of stars, they live fast and they die young, all right? Now, if you don't know who James Dean is, right? They were the Amy Winehouse of stars, all right? And if you don't know who Amy Winehouse is, I have run out and cultural references. But they live for roughly 10 million years or so, bang, they're gone. That gas that was swirling around in the middle of the Milky Way, that gets swallowed by the black hole eventually. The black holes go back to being quiet. So, the galaxy settles down. And you've just got this big blob of stars. There's a chance that our sun could be ejected in the collision. It could be thrown into intergalactic space. But I'll probably it's going to end up inside this big blob of stars. But on these timescales, stretching out now over 5, 6 billion years, a lot of things are going to happen to our sun. Our sun was born roughly 5 billion years ago and stars have a lifetime. They have fuel in their cores, nuclear fuel. The sun is burning hydrogen into helium every second, and it gets lighter by 11 million tonnes per second. And that change in mass becomes energy, which becomes the sunlight that rains down on the earth. But, there's only a certain amount of fuel there. And in roughly 3 to 4 billion years, the sun is going to run out of nuclear fuel. Now, that means the sun is going to be entering its middle age to late age [inaudible] everybody when we get to that stage, you become a bit cantankerous, right? So, the sun actually undergoes a change in size and it starts to swell and grow. It grows to what's known as a red giant star. So, it will get larger and larger and larger. It will swallow the planet Mercury. It'll continue to increase in size. It will swallow Venus. It will increase in size, it will swallow the Earth. And it will probably get large enough to get out to the orbit of Mars, before finally blowing off its outer regions and essentially ending its life as a star. As you can imagine, that's also the end of life on Earth. So, if we don't get off this planet in the next 3 billion years, then, you know, effectively, we're doomed because this place has gotten our future. Now, I know 3 billion years sounds like a long time, but humans are very good at waiting till the last minute until they do something, right? So, I've given you a warning, okay? So, that's all well and good. We still got this large blob of stars, the sun has died by then. But we've got all the stars there. What's the next thing that's going to happen for the universe? Well, we're going to jump out now to basically around 100 billion years. What we know, as I mentioned, is that the universe is expanding, right? We've got lots of measurements that have shown this. But at the end of the 1990s, what we discovered is that this expansion is accelerating. Now, initially, we thought the expansion of the universe should be slowing down. All the matter in the universe pulls in the expansion, slows it down. But, what we discovered is actually, right now the expansion is speeding up. And what we've discovered is that to make this happen, you need other stuff in the universe, other than the matter that's out there. And what we know is that we must have this dark energy that's called, because we're not very good at naming things, which produces this cosmic acceleration. What that means is that every single second, every object in the universe is moving away from us faster and faster and faster. And if we look out over this timescale of roughly 100 billion years, then what you find is that by that point, everything is moving away from us so fast, that effectively lose sight of all of the external galaxies out there. So, if you're an astronomer, a deep sky astronomer who studies objects like other galaxies, we live in a time now where we can do that. In the future of the universe, things will have moved away so fast that the night sky outside of our blob of stars goes completely black. And any civilisation that basically, you know, rises during that time in the distant future will look out in the universe and they will see nothing. They will just say, "Well, clearly we're alone, right? This group of stars is it, and there's nothing else out there in the universe." Now, I should point out astronomy doesn't normally end with happy stories, right? So, if you're waiting for the, and everybody lived happily ever after. Bad news, right? So, we now need to take our next step. So, we're now going to step out to a trillion years into the future. So, we're getting a long way into the future of the universe. But, we think that the universe has got an infinite future ahead of it. So, we've barely started. On this kind of timescale, then the nature of our actual galaxy itself starts to change. Why? Well, as I mentioned, stars have finite lifetime. Stars are born, stars live and stars die. And every time a star goes through this cycle, stars explode, the gas gets recycled and some of it brought back together to get the next generation of stars. And that's very good for us because the elements from which we're made; the carbon and the oxygen, they were forged in the hearts of stars before being basically blasted out into space and recycled into material which formed our sun. So, this material continuously recycles and elements a carbon, oxygen, iron, et cetera, they start to build up in the universe. And those elements get more and more numerous. But, this affects the rate that stars get born. The efficiency of star formation starts to decrease. And by about a trillion years into the future, there will no longer be gas clouds from which we can create new stars.

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>> So, the time of stellar birth will come to an end, all right? We will be left with stars, but no new stars will be born. The only thing that can happen then is stars can age. Now, stars like our Sun have a lifetime of around 10 billion years. So, on the scale of a trillion years, they're gone in a flash. And what happens is, we're left with little stars, little red dwarf stars that they call them, a mass around a 10th the mass of the sun. And they burn their nuclear fuel really, really slowly. And they can last for trillions of years. So, they will sit there burning very slowly. All of the stars like the sun will be gone. And all we will have left are these faint red stars, trillions of them, but faint red stars. Now, they live for a long time, but they don't live forever. And on a timescale of now out to around 100 trillion years, even these small little dwarf stars start to exhaust their nuclear fuel. So, they don't explode in a, you know, in a nice

colourful fashion. These stars basically just go out. So, they basically run out of fuel and then they stop burning and they just start cooling down. And they will come a day, 120 trillion years from now when the last star in all of this darkness eventually goes out, and the universe will be plunged into blackness, okay? As you can imagine, prospects for life at this sort of timescale are not looking that good. But maybe that's it, right? Maybe we've reached the future. Maybe that's it. We've got all these dead stars, trillions of them living together. And that's it for the universe, right? It's an infinite time ahead. Maybe this is all it's going to do. But, the laws of physics tells us that things will not stay just in this simple way. Now, we're going to need to take a really big step, right? We're at 100 trillion years. And we now have to take a step out to a number of years that doesn't actually have a name. So, we're now going to step out to around 10 to the power of 40 years. So, that's one, followed by 40 zeros. Why on this immense time scale? Well, we know from the fact that we have matter in the universe that our laws of physics are slightly distorted. During the Big Bang, the birth of the universe, we should have created equal amounts of matter and antimatter. And as the universe cooled down, these should have annihilated to leave no matter whatsoever. But, we're here, right? There is clearly matter in the universe. And to achieve that, you need to sort of twist the laws of physics slightly. Now, one consequence of this twist that allows us to be here is that the stuff that we are made of ultimately is not stable. So, if you remember your high school physics, right? You've got your picture of the atom, you've got your electrons whizzing around the outside. In the nucleus, you've got protons and neutrons stuck together. And a neutron on its own will just decay in about 15 minutes. It will turn into something else. But a proton looks stable. Looks like it should be around forever. Except we've had to add that twist to the laws of physics. And that twist tells us that on these timescales of around 10 to the 40 years, protons are no longer stable. And what that means is that after this time period, protons themselves start to basically decay into smaller things, into electrons and light. What that means is that basically matter melts, okay? Anything that's solid matter will basically just melt away. It'll turn into these smaller particles and just zip off into the darkness. So, on this timescale, immense timescale, I said 10 to the 4o years, then all of these dead star hearts that are out there will melt away into the blackness. And the universe will just be filled with the simplest of particles, the electrons and particles of light, the photons. So, maybe this is it, all right? Maybe this is the end point of the universe. No, because there's this one actor that's still playing a game here. We're going to have to take another big step. So, we're going to have to go from 10 to the 40 years, just a little one, out of 10 to the 100 years, okay? Again, we don't have names for these. But, as I mentioned, when the Milky Way and Andromeda collided, there were black holes at the centres of those galaxies. And we also produce a lot of black holes when big stars die. And black holes being held together by the immense force of gravity means that their matter, which is locked away in their core, basically can resist this melting of matter. So, you might think that once we've got past this matter melting stage, we have these particles whizzing around, and they'll just be black holes in the darkness. Except, we have to look for the ghost of Stephen Hawking. Now, Stephen Hawking who died a couple of years ago, of course, was a physicist, who spent his life studying the universe and black holes. And when he was a young researcher, what he discovered is that black holes aren't truly black. And what he meant by that is that, if you could go near the dangerous edge of a black hole. It has an edge called the event horizon. It's not a physical edge, you can't tap on it. But it's that edge – if you get too close, then you're caught by the gravity of the black hole, and you're destined to be at the centre, there's nothing else you can do about it. But if you examine that edge, which we call the event horizon in detail, and you consider the strange world of quantum mechanics where things pop in and out of existence, what you find is that at the surface of the black hole, quantum mechanics makes these little particles popping out of existence. And some of them fall in and some of them escape. And, if you do the calculations, and I won't recreate the calculations here, what you find is that the ones that fall in basically rob the black hole of some mass, all right? So, every little particle that drops in, the mass of the black hole gets slightly smaller. And that's compensated by the energy that's carried away by the particles that escape. So, what that means is that black holes are very slowly converting their mass in their centre into radiation at their event horizon. Which means that they're evaporating very, very slowly, okay? It's a very, very inefficient process. Now, this stuff called Hawking radiation. It's a theoretical idea. We haven't actually found a way of, you know, getting a black hole in the laboratory testing it and seeing if it's there. But, you know, a lot of people think that yep, this black hole radiation, it's something that should exist in the universe. Now, for most of the life of the universe, you don't care, right? Because black holes, right? Even if they are leaking a few bits of radiation every so often. There's stars around and everything. So, you can ignore them. But when we get out to roughly 100 – where are we? 10 to the 100 years. I forgot my time scales there. 10 to the 100 years, then what you find is that on those immense scales, then even the most massive black holes, which have a mass of more than a billion times the mass of the sun, they will started radiating so much energy over this period, that their mass would have shrunk down and shrunk down and shrunk down. And eventually, what you find is that the mass basically shrinks away to zero. Now, the way this evaporation works is that it becomes more active, the smaller the black hole gets. And so, as you black hole is big, it leaks on a little bit of radiation. But as it gets smaller and smaller and smaller, it leaks more and more and more, and you've got this runaway feedback effect more or less. It's smaller, smaller, it radiates more and more. And the black hole will disappear in a pop of X-rays, gamma rays, you know, optical light. So, the universe will spend this huge amount of time in complete darkness and every so often, they'll be a [inaudible] as the black hole disappears into the darkness. And then another, and then another, and then another. Now, the time between each of these will be an immense amount of time. But, eventually, even the black holes themselves will melt away into the darkness. So, 10 to the 100 years. So, we've reached a point now, where there are no stars, there is no matter in the way we understand matter. All we have is the sea of radiation, and we have this sea of little particles bouncing around. The universe is still expanding, okay? Expansion is still going on. So, all the stuff in the universe is getting colder and colder and colder. All the radiation is going to longer and longer wavelengths. And all of the little electrons which are buzzing around, they're getting slower and slower and slower, and the distances between them are getting larger and larger and larger. Till eventually, you might have only one electron per observable universe. So, we've reached a point which physicists happily call the heat death of the universe. And what this means is that there is no energy available to do anything. The universe is featureless, there is no energy. Everything is just sitting there continuously getting colder and colder and colder. Now, for some physicists, you say, right, that's it. That's the future of the universe. But we really can't end on a down note, can we, right? So, is there any light at the end of this tunnel? The answer is, a definite maybe, okay? So, what could it be? Well, as I mentioned, what we discovered at the end of the 1990s was that the universe is accelerating, there must be this stuff out there called dark energy, which is causing the universe to accelerate. Now, in our future universe, this dark energy stuff will still be there, it will be completely dominant, and it will be throughout the universe, and it will be still causing the expansion of the universe to accelerate. Now, we don't really understand what dark energy is, but we think it's one of these things we call a quantum field, right? It's stuff that pervades the universe and obeys the laws of quantum mechanics. And we know that it's got a certain amount of energy per cubic metre, right? So, there's every metre of space, there's some dark energy. What we know from quantum mechanics is that energies are quantized. They come in specific levels, right? Energy here, energy here, nothing in between. And in the right circumstances, you can get something to transition from one energy state to another energy state. And this is what we see when electrons jump around the atoms, they jump in between energy states. So, we can ask the question, can dark energy jump between energy states? Can it go from having this energy it has now, to drop down to have a lower energy in the future? And again, this is now hand-waving physics, which is always the best kind of physics, right? You can sit down and you can scribble down some numbers and you can work out the probability of how long you'd have to wait for dark energy to jump from one energy level down to another energy level. And, ballpark number, roughly 10 to the power of 10 to the power of 50 years, okay? So, that's 10 to the power of 1 followed by 50 zeros. Which is a number, much bigger than we want to care about. Then there's a chance that dark energy will undergo one of these transitions from a higher energy level to a lower energy level. What could that do? Well, that burst of energy, that release of energy could kick start a new Big Bang, right? Now, the way that this works, it's not that you get a brand new Big Bang in this universe. This transition of energy basically causes the birth of a new universe somewhere out there. And again, this is a much bigger talk than the Raising the Bar talk that's here. But, the eventual transition that we have in our universe might give birth to a universe, which has very similar conditions to our own, okay? And in that universe, after billions of years, it too could form stars, planets and eventually life. So, on these events and timescales, while that might be the end of our universe, it might be, you know, the beginnings of another universe. Before we wrap up, though, we have to just take a little look backwards and ask the question about where did our universe come from? And that has many that think that maybe our universe was born from the transition of dark energy in a previous universe that already lived out this 10 to the 10 to the 50 years, before its dark energy transitioned and formed a new universe. So, the happiest thing I can possibly say is that maybe our universe, while it has not necessarily the brightest future ahead of it, is that we just might be part of this continuous sequence of universes that have existed infinitely far into the past, and hopefully will exist infinitely far into the future. And I'll finish there. So, thank you.

[ Applause ]

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