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#333: Whatever happened to the ozone hole? Lessons in timely action to avert global disaster

VOICEOVER
This is Up Close, the research talk show from the University of Melbourne, Australia.

SHANE HUNTINGTON
I'm Dr Shane Huntington. Thanks for joining us. While the sun's energy keeps us warm, enables our food to grow and has the potential to power our future, it's easy to forget that it also produces dangerous forms of radiation. Prolonged exposure to ultraviolet radiation can be deadly and, despite our attempts to limit the dose of UV, it's difficult to completely avoid, especially given its important role in producing vitamin D in our bodies. For the most part, we're protected from radiation by out planet's combination of magnetic fields and atmospheric gases. But we can't take these for granted. The atmospheric layer of ozone, one of Earth's important filters of UV, was at serious risk only a few decades ago when certain industrial emissions were found to be thinning the ozone and creating a hole through which dangerous amounts of UV could pass. But, unlike to our current call for action against climate change, the world responded in earnest to the ozone hole problem in the 1980s. Some 30 years later, how is the ozone layer travelling? Have we, in fact, succeeded in repairing that perilous hole over the South Pole? To answer these questions and discuss the geopolitical parallels to tackling climate change globally, we are joined by two atmospheric scientists. David Karoly is Professor of Atmospheric Science in the School of Earth Sciences and the Australian Research Council's Centre of Excellence for Climate System Science, and Robin Schofield is a lecturer for Climate System Science and Researcher in the Atmospheric and Oceanic Sciences Group. Our guests today are both from the University of Melbourne. Welcome to Up Close, David and Robin.

DAVID KAROLY
I'm glad to be here.

ROBIN SCHOFIELD
Thanks very much, Shane.

SHANE HUNTINGTON
Robin, let's start with some basic chemistry about ozone. First of all, what is ozone? How is it created? Where do we find it predominantly in the atmosphere?

ROBIN SCHOFIELD
Ozone is three oxygen atoms joined together. It's a bent molecule. Because it's bent, it's very effective at absorbing ultraviolet radiation. When it does that, it splits apart again. We find it in the stratosphere largely because it needs this UV radiation environment to actually form. Oxygen that we breathe makes up 21 per cent of our atmosphere. The UV environment will split and oxygen molecule apart. So that's two oxygen atoms. They split them apart and form radicals. Those radicals will then join with another oxygen molecule and create that three oxygen atom bent molecule.

SHANE HUNTINGTON
Why does that make this a molecule that can absorb UV? So what is meant by the term bent? How do we absorb the UV with that molecule?

ROBIN SCHOFIELD
So oxygen itself is a linear molecule. When you have two atoms in a molecule, they can only vibrate in a straight line. If we can imagine a triangle when we have the oxygen atoms at each point of that triangle, that's our bent molecule. That means that every vibration the atoms stretch and compact. That's really effective at absorbing radiation.

SHANE HUNTINGTON
Now, there's been talk of the destruction of the ozone layer over many years now. Most famously the chlorofluorocarbons or CFCs that most commonly people would remember in certain spray cans but also a major industrial pollutant. What is it about these chemicals that makes them so effective at damaging ozone or removing the ozone from our atmosphere?

ROBIN SCHOFIELD
These chemicals are highly unreactive in a low radiation environment, which is why they've had a wide uptake in use in refrigerants, in air-conditioning units. They're non-flammable. But when they get up to the stratosphere, you've got a high radiation environment, all that UV radiation that the ozone is filtering, is very effective at splitting off the chlorine and the bromine contained within these molecules. Those atoms also form radicals. They are very effective at then creating a catalytic ozone destruction cycle. Like a catalytic converter in your car, it can be reused over, and over and over again to perform the same reaction. That's generally how all the catalytic ozone loss cycles work.

SHANE HUNTINGTON
So presumably then, if it's used in that way, we don't need a lot of it to be quite destructive. Is that right?

ROBIN SCHOFIELD

You don't need very much at all. With chlorine you'll find that it won't stay in that radical form very long. Bromine's quite different. It remains in its radical form largely.

SHANE HUNTINGTON
You mentioned coolants and so forth and the fact that these chemicals are non-reactive at the Earth's surface where the radiation levels are low. David, are they the primary reasons why we started using these things? Was there any sort of foresight about the potential for this damage or did we just not understand the atmospheric chemistry enough at that point?

DAVID KAROLY
The background to this was that these chlorofluorocarbons were used as propellants in spray cans because they weren't reactive. They were used in refrigerators and in air conditioning units, again, because they weren't reactive. No-one anticipated at that stage that they might have chemical impacts, would breakdown in the upper atmosphere and would then have adverse chemical impacts on anything, let alone the ozone layer. The first discoveries of the potential adverse impacts was when the original measurements of the dispersal of these chlorofluorocarbons - their main use was originally in the Northern Hemisphere. They were measured in the Southern Hemisphere in ocean regions away from any, I guess, potential sources like in Australia or South America. That was measurements in the 1960s. They were then measured in the upper atmosphere in some balloon measurements and by satellite data rather later. It was only in the 1970s that the first potential impacts of these ozone-depleting chemicals in the stratosphere was identified, whereas they'd already been used for more than, well, 10 or 20 years by then.

SHANE HUNTINGTON
Robin, obviously the build-up of ozone in the atmosphere happens in a certain way. How is that layer actually replenished over time?

ROBIN SCHOFIELD
Well, the highest UV levels are found in the tropics. So that's the highest production region for ozone. Then the stratospheric circulation distributes that across the globe, and so it moves it from the tropics towards the poles.

SHANE HUNTINGTON
Presumably though - and we've discussed this to some degree in our previous interview with you - but these atmospheric layers are quite confined to some degree, aren't they? I mean, the ozone stays in a very specific range predominantly. Is that right?

ROBIN SCHOFIELD
Yes, it does. That is a stratosphere. A strato means layered. It's through that region where the temperature increases. That means you get rather horizontal transport than vertical transport. So the troposphere, which goes from the surface up to around 10, 11 kilometres around where the planes fly and above that is in a stratospheric layer which runs from actually 10 to 50 kilometres. But if we brought all

of the ozone down to the surface it would only be three millimetres thick.

SHANE HUNTINGTON
Right.

DAVID KAROLY
It's also interesting to think about why is it that the ozone is formed at around 10 to 15 kilometres because you need both UV radiation and you need oxygen. The oxygen gets split apart by the high energy radiation. There's lots more oxygen at the surface because the density of the atmosphere increases as you come down to the surface. The interesting dilemma is why, if you've got more of the oxygen at the surface, isn't there more ozone formed at the surface? The answer is, in fact, oxygen is so efficient at absorbing this high-energy, ultraviolent radiation that it all gets absorbed as soon as there's enough oxygen. The peak then in the formation of ozone is at around 15 to 20 kilometres where there's enough UV radiation and enough oxygen. As you go lower down, all the UV radiation's been absorbed. It's all disappeared. You can't form ozone by these direct reactions. Now, there is another process which causes a second slight peak in ozone. That's when ozone is formed through what's called photochemical smog, through air pollution close to the surface where, again, a different range of chemical reactions as well as sunlight are required to produce ozone near the surface. We sometimes hear that called "bad ozone" because that ozone is highly reactive, causes eye problems, causes the acrid sensations that you get around smog or urban air pollution. We can also describe sometimes the ozone layer when it's 15 kilometres above the surface and the stratosphere is described as good ozone. It's the same ozone. It's just good because it's well above the surface.

SHANE HUNTINGTON
Now, David, I've got to ask you, when you say there's no UV getting to the surface that can do that. I mean, obviously those of us with fair skin would contest that view quite strongly.

DAVID KAROLY
Yes.

SHANE HUNTINGTON
Is it at such a low level that it's just not capable at that point or what's the real sort of story there?

DAVID KAROLY
Okay, sunlight and ultraviolet radiation span a wide range of wavelengths. The energy in the sunlight is directly related to the wavelength. The shorter the wavelength, the higher is the energy of the radiation. We need very high energy radiation, as Robin has talked about before, to split the oxygen molecule, O2, into two oxygen atoms or radicals. That requires a certain wavelength because the shorter wavelengths have even higher energy. They can split up. But once all that really short wavelength energy, what's called UVC wavelengths, all of that gets

absorbed by the splitting of the oxygen molecules. We then get UVB and UVA, slightly longer wavelengths, slightly lower energies but unfortunately UVB radiation is the radiation that's most impactful in terms of skin cancer and other harmful effects because some of that does reach the surface of the earth. The amount of UVB radiation that reaches the surface of the earth is dependent upon the amount of ozone because ozone will absorb UVB radiation but only partly. Most of it's absorbed as the UV layer is thick enough.

SHANE HUNTINGTON
I'm Shane Huntington and you're listening to Up Close. We're asking whatever happened to the ozone hole. We're joined today by Professor David Karoly and Dr Robin Schofield. David, the Montreal Protocol, which was the global agreement to limit and eventually stop production of ozone-depleting chemicals, came into effect in 1987. This seems remarkably quick compared to the efforts to limit greenhouse gas emissions, for example. What do you think are the main drivers for that speed and the agreement itself?

DAVID KAROLY
The main driver for the introduction of this Montreal Protocol was, in fact, this recognition that human production of these ozone-depleting chemicals, the chlorofluorocarbons and also chemicals that contain bromine that were used in fire extinguishers, that they could have a major impact on the ozone layer. There were extensive negotiations over the 1980s amongst international groups and international governments as well that there should be this agreement, much the same way as the ongoing discussions that are taking place around the world about controlling greenhouse gas emissions. There was repeated international negotiating sessions on reducing the production of ozone-depleting chemicals. What happened just before the 1987 ozone discussions was the first observations of an unexpected very, very rapid depletion of ozone over Antarctica. It was first discovered in 1985 by some British scientists. Essentially what was found was that there was an almost complete destruction of ozone in the layer over the Antarctic continent so that the ozone layer was less than 50 per cent of the normal amount. It was reduced to half its normal amount. It happened in springtime. At the time, the mechanism or the process for this incredibly rapid September destruction of ozone over Antarctica was not well understood. However, that was a major incentive in 1987 because it was perceived that the most likely cause was to do with these human increases of ozone-depleting chemicals.

SHANE HUNTINGTON
There must have been a number of very large companies with significant vested interests in (a) keeping things going as they were or potentially (b) in completely changing it and starting up new industries. Did that have an impact on the Montreal Protocol because we were certainly seeing that sort of impact in limiting our response to climate change at the moment.

DAVID KAROLY
You're absolutely right, Shane. There was lots of back stories about the politics and

the negotiation. Obviously the negotiation is taking place amongst major international governments. The Australian government was a key player in trying to control the emissions, production and use of these ozone-depleting chemicals. But within Europe there were desires to not restrict the use of ozone-depleting chemicals because the companies that were using these chemicals recognised that the patent rights for these ozone-depleting chemicals were expiring and they would be able to use them and produce them without having to pay as much in terms of licence fees. The original inventors of these ozone-depleting chemicals - and they're used in refrigerators, air conditioners, propellants and things like that - most of those patents were held by US companies. DuPont and other companies were major players in this. They recognised that their patent rights were running out and that perhaps if they could introduce new, more environmentally beneficial chemicals that didn't impact the ozone layer, in addition these chemicals had new patents and would essentially provide them with more licence income. So there was a commercial battle as well as an international battle between US government, US companies, European companies and many of the European national governments. In the end, what was decided was an agreement to staged reduction in production. Initially it only applied to the developed countries. The developing countries were allowed a much longer timeline so that by the year 2000 there would be complete stoppage of production of these ozone-depleting chemicals by developed countries but that they would then be phased out over a longer period in the developing countries.

SHANE HUNTINGTON
Robin, let's talk about that distribution around the globe. Obviously the majority of these chemicals at the time were released in the Northern Hemisphere. Yet somehow us poor folks down in the Southern Hemisphere ended up with the greatest level of depletion, as David mentioned, over Antarctica. How does that redistribution occur?

ROBIN SCHOFIELD
There is a redistribution across the hemispheres. It's very slow and it takes up to a year if something's just well mixed. Then once it's in the tropical stratosphere, you get redistribution across the globe moving towards the poles. That process, from the tropics to the poles and the stratosphere takes about six years. But every year in springtime we see these large depletions of ozone over the Antarctic. We really need three ingredients, a very stable, cold stratosphere over the winter and you get a circulation pattern setting up a large vortex. That vortex will cut the communication from the mid latitudes into the polar region off. You create a contained vessel. Because it's so cold you'll get what's called Polar Stratospheric Clouds forming. These clouds provide a surface made of nitric acid and of ice. That removes nitrogen and water from the stratosphere. So you've got this vessel, cold conditions. You've got a reaction surface and you're removing what is essentially locking up the chlorine most of the time. So you've got these effective means of releasing chlorine into this radical form. Then the other thing you need, and why it happens in springtime, is when the polar night ends and you get the sunlight returning.

SHANE HUNTINGTON

Can you clarify for us why the ozone depletion region, this ozone hole, primarily is occurring over Antarctica and over the Southern Pole and we don't see the same thing over the Arctic?

ROBIN SCHOFIELD
Well, Antarctica has a large land mass which - and I talked about the circulation and the wind setting up and you're requiring a really stable vortex. While that vortices will form in the Northern Hemisphere you don't have that land mass there. You get a lot more instability and a type of wave breaking. So you don't get an enclosed, nice vortex. It'll split and move around. When a vortex in the Northern Hemisphere does set up it can create an ozone hole. That happened in 2011 but we get that stable environment happening in the Antarctic every year.

SHANE HUNTINGTON
Every year, yeah.

DAVID KAROLY
Let me just add a little bit to that. One of the other reasons that there are differences between the Northern Hemisphere and the Southern Hemisphere is that, in fact, in middle latitudes, the sort of region where we have the strongest winds. In the Southern Hemisphere, it's predominantly ocean. We don't have has much of the sorts of large-scale waves. That means the transport of ozone from the tropics to high latitudes is not quite as strong in the Southern Hemisphere. In particular, it doesn't transport heat as well from the tropics into the Antarctic regions. So the temperature over the polar regions in Antarctica is generally colder than it is in the Northern Hemisphere because the effective transport, not only of ozone but of heat into higher latitudes - the polar regions - is more efficient in the Northern Hemisphere. So the Northern Hemisphere has typically more ozone over the pole and it has warmer temperatures. That means there's less chance of these Polar Stratospheric Cloud forms. So, as Robin said, when associated with year to year variability, you get a very stable vortex with stronger winds around Antarctica yet it only has happened infrequently, about once every five years or so you'll get a stable vortex. That then traps the colder air over the Arctic region. You get the same isolation and Polar Stratospheric Clouds can form and then the ozone depletion can occur. But typically it lasts a much shorter time period even in the springtime in the Northern Hemisphere. So, yes, occasionally you can get short-lived ozone holes of the Arctic but not very often.

SHANE HUNTINGTON
When we talk about this hole, I'm not sure people have a good mindset of just how big this thing is. What is the size, I mean, relative to a land mass like Australia or North America? How big is this hole over Antarctica?

DAVID KAROLY
So the area of the hole is more than 10 million square kilometres. It's larger than the United States. It's larger than Australia. It's enormous. When you see videos - and we're going to try to link to an animation that shows this ozone hole forming. In

terms of the thickness though, there is still ozone that remains higher up in the stratosphere and below the main depletion region because the main depletion region, as Robin described, is contained within some layers, the stratosphere limits mixing in the vertical. So it's really a layer between about 15 and 20 kilometres for which the ozone is essentially completely destroyed every September and October. Because this vertical motion can't take place, that layer can't get replenished, it's all gone in that layer. It's almost like a notch completely removed.

SHANE HUNTINGTON
Now, David we've been in the Montreal Protocol now for about 27 years. We're starting to see, I understand, a bit of a recovery of the ozone layer. So, first of all, what sort of recovery are we seeing? Secondly, why is it so slow? Twenty-seven years seems an awful long time.

DAVID KAROLY
Those are really good questions, Shane. Let me talk about the second one first of all. The ozone-depleting chemicals that we've talked about, the chlorofluorocarbons, the halons and other chemicals, have very, very long lifetimes. Even in the stratosphere where they are being destroyed, they still survive for a very, very long time. So typically 100 years or longer would be the destruction half-life of any of the chemicals that we're talking about. While the Montreal Protocol has limited production of most of these long-lived chemicals, they still exist in the stratosphere. It takes a very long time for them to be removed. So the 27 year since the Montreal Protocol, first of all, the Montreal Protocol still allowed some emissions. There was only a peak in these ozone-depleting chemicals in terms of their concentrations in the stratosphere about 10 years ago. It's then taken, because of the year to year natural variability in the amount of ozone that's being produced and how quickly it's being transported, to be able to have the scientists, who were typically quite conservative, to have enough data and enough confidence to say that the ozone layer itself, across the whole globe, is starting to recover. We needed enough data for a long enough period to say, yes, the expectations that the ozone layer would recover as the ozone-depleting chemicals were reducing, that we can actually see that now, but only when we look across the whole globe. If we look at Antarctica and the amount of ozone in the ozone hole, it's got such large variations from one year to the next that we haven't yet been able to say definitively that the Antarctic ozone hole has started to recover. There's lots of, I guess, preliminary evidence but not sufficient for the conservative scientists to say, yes, we're very confident that the ozone layer over Antarctica has started to recover.

SHANE HUNTINGTON
You're listening to Up Close. I'm Shane Huntington. My guests are atmospheric scientists, Dr Robin Schofield and Professor David Karoly. We're talking today about the global campaign to repair the ozone layer. Now, David, when we think about this overall picture of what we've done, what's happened and the timing involved, this must be a fundamental wakeup call for people who are suggesting the possibilities of geoengineering as a response to climate change. Is that right to look at this as a, in a sense, a form of geoengineering where we've tinkered with just one parameter and

we're seeing this massive onslaught of responses as a result?

DAVID KAROLY
Absolutely. Our understanding of the climate system and the atmosphere wasn't good enough, first of all, to understand what would happen when we introduced chlorofluorocarbons and, secondly, be able to predict the surprises because the formation of the Antarctic ozone hole was a scientific surprise. No-one had anticipated it. The really good news is that, because of concerted global action through the Montreal Protocol and its amendments, scientists recognised it, governments responded, stopped the production and use of these chlorofluorocarbons and we're now seeing the recovery. However, when we start to look at what is being suggested through geoengineering, other human interventions on the climate and atmospheric system to perhaps try to combat global climate change. The uncertainties are so great, in terms of what might be the unanticipated adverse impacts that we really need to be cautious about what geoengineering might do. In fact, one of the suggested type of geoengineering is to inject particles into the stratosphere. This is because particles are routinely injected into the stratosphere with major volcanic eruptions. They reflect sunlight. That reflection of sunlight leads to a slight cooling of the lower atmosphere by a couple of tenths of a degree for a period of one to three years after the major volcanic eruptions. You often hear about some of the really big volcanos like Krakatoa leading to the year without a summer. The most recent major volcanic eruption was Mount Pinatubo. It lead to a cooling of about two-tenths of a degree globally. The other that it did was lead to major ozone destruction globally because these extra particles in the stratosphere, they're injected by the volcanos, act in the same as the Polar Stratospheric Clouds. It's a catalytic surface that can accelerate the release of those ozone-depleting chemicals into their active form, as Robin talked about already. That then can load to accelerated ozone destruction facilitated through this catalytic converter reaction on the services on the particles that are released by the volcanic eruptions injecting them into the stratosphere.

SHANE HUNTINGTON
Robin, when do you think we can expect a full recovery of the ozone layer and is that even possible?

ROBIN SCHOFIELD
Well, we'd expect, and it is just an estimate, the return of the equivalent effect of stratospheric chlorine, this is converting all those bromine-containing chemicals into the chlorine because bromine is about 60 times more effective at destroying ozone, then chlorine. So when we put them all on the same scale, we can expect those to return to 1980 levels and middle latitudes by 2050. But we have to wait 25 more years - so 2075 - for a return over Antarctica.

SHANE HUNTINGTON
David, in terms of the biosphere down in Antarctica, it is quite complicated. It's quite rich. Are we seeing the effects of the reduction in the ozone layer or in the ozone hole, as it were, on that biosphere at this point in time?

DAVID KAROLY
There are a number of studies that have tried to identify the increase in UV radiation in springtime over Antarctica and also over the high latitudes of South America because some of the largest population areas in the region that's affected by the ozone hole are, in fact, over the high latitudes of South America. Now, they haven't found any identified human impacts in the high altitudes of South America or even on the expeditioners that go down and live in Antarctica as research scientists. But there have been studies that have found impact from this increase in UV radiation on krill, which is one of the major components of the food change in the high latitudes around Antarctica, important food for many of the fish but also in particular for whales in high latitudes. There has been an identified change. This is because UV radiation affects DNA. That's why it causes skin cancer. It's been identified in DNA impacts in the krill.

SHANE HUNTINGTON
Robin, you've talked somewhat about the temperature requirements for many of these reactions to occur. We're in the scenario at the moment where our globe is changing the overall average temperature so we have global warning. Is this likely to help or hinder the recovery of the ozone layer?

ROBIN SCHOFIELD
So while we increase carbon dioxide, nitrous oxide and methane increase the temperature at the surface and we term it global warming, it is actually going to be cooling the stratosphere. Colder reactions slow down ozone loss cycles. This means that we will expect an increase in ozone actually if everything kept equal. The changes in the stratosphere are going on due to increases in these greenhouse gases will actually occur at a time when we're seeing a recovery of the ozone hole. And so both of these will have an effect.

SHANE HUNTINGTON
So we've just got to make sure, I suppose, David, that no-one uses that as an argument for not doing anything.

DAVID KAROLY
That's correct. So one of the things that Robin perhaps didn't mention is that, in fact, because all these combination of the reductions in ozone-depleting chemicals leading to the recovery of the ozone layer and the changes in the temperature and, in fact, even this overturning circulation that mixes the ozone from the tropics into higher latitudes, we're actually expecting a super recovery because the atmosphere will be different because of the changes in circulation and the stratosphere, because of the colder temperatures in the stratosphere. When we get back to these 1980 or even 1960 levels of chlorofluorocarbons we're expecting about 10 to 20 per cent more ozone in the ozone layer, which is good in many ways because it reduces the likely impact of this high intensity UV radiation, UVB radiation on skin cancer. Actually it will also have impacts on UV radiation producing vitamin D in our skins. So it's something that we need to be aware of all the time, that a small amount of UV radiation is good but it's a very small amount. Too much is really bad.

SHANE HUNTINGTON
David, just to finish, the Montreal Protocol, you could argue, has been quite an amazing success in terms of the globe coming together to take action against what is a very, very serious threat. Are there lessons to be learnt from this that we can now put into play with regards to climate change because, in a sense, we've almost been going for the same period on that argument and we haven't made a huge amount of progress? So what can we draw out of the Montreal Protocol that will actually get us moving again in the right direction for climate change?

DAVID KAROLY
The Montreal Protocol, as you've mentioned, as been a very successful environmental agreement. It was used by many countries and by many governments as a model for the establishment for an international agreement on greenhouse gases, on the gases that are important for global warming. One of the difficulties, however, was that in practice, controlling ozone-depleting chemicals because their manufacture was limited to a smaller number of gases used primarily for a smaller number of uses, refrigerants, air conditioners, fire extinguishers. The important sources of greenhouse gases, carbon dioxide, methane and nitrous oxide, spans a much, much wider range of uses in human activities, from energy uses, building, agriculture, construction, an enormous range. Controlling greenhouse gases has ended up being a much more politically-charged process. The Montreal Protocol was really a top-down government imposed agreement that involved all countries. That has been, and is continuing to prove, to be much harder for an agreement on climate change. There is, however, one important aspect of the Montreal Protocol that is often overlooked. As Robin mentioned, there are a range of these ozone-depleting chemicals, have very long lifetimes but they are also greenhouse gases that impact the climate system by absorbing infrared radiation. Because of their long lifetimes they are very effective greenhouse gases, much more effective molecule per molecule than carbon dioxide. Now, the total masses or volumes of these gases is quite small. But, in fact, the Montreal Protocol has had five times greater impact on reducing global warming due to the reductions in chlorofluorocarbons than has the Kyoto Protocol through its reductions on greenhouse gases over what they would have been if there hadn't been either of these agreements. So, in that sense, not only has the Montreal Protocol been good for improving the ozone layer. It's also been good for slowing down global warming.

SHANE HUNTINGTON
Robin and David, thank you very much for being our guests on Up Close today.

ROBIN SCHOFIELD
Thanks very much, Shane.

DAVID KAROLY
Thank you for having me, Shane.

SHANE HUNTINGTON
Dr Robin Schofield and Professor David Karoly are atmospheric scientists in the

School of Earth Sciences at the University of Melbourne. If you'd like more information or a transcript of this episode, head to the Up Close website where you will also find the links mentioned in this episode. Up Close is a production of the University of Melbourne, Australia. This episode was recorded on 15 December 2014. Producers were Kelvin Param, Eric van Bemmel and Dr Daryl Holland. Audio engineering by Gavin Nebauer. Up Close is created by Eric van Bemmel and Kelvin Param. I'm Dr Shane Huntington. Until next time, goodbye.

VOICEOVER
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