Presenter: Dr Eric Thrane - *2016*

Title: The detection of gravitational waves - (17:00)

Time	***Dialogue***
00:13 00:43	Hello. I am Eric Thrane and I am an astrophysicist and a lecturer in the school of physics and astronomy at Monash University. I divide my time between teaching first year physics classes here at Monash and the rest of my time I use gravity to try to unlock some of the secrets of the universe. An in this talk I am going to tell you about something very exciting that happened last year that our team at Monash played an important role in and that's the discovery of gravitational waves from the merger of two black holes. The story began 100 years ago with everyone's favourite physicist Albert Einstein. Einstein is known for a number of important contributions to our understanding of physics but perhaps his boldest idea was proposing the theory of General Relativity which tells us how gravity works.
01:20 01:52	General relativity tells us that you can visualise gravity as warped space-time. So imagine that you have a stretchy sheet of fabric and this stretchy sheet represents space-time. When you put a massive body on this sheet which you can think of as a bowling ball or a cricket ball but which might represent a massive object like a star or a planet, it causes the fabric to sag and this sagging represents the gravitational field due to that massive body. So if you then imagine that you take some smaller round object, maybe a marble and you roll it on this curved space-time, this warped fabric, it can travel an interesting path. It can form a circle orbiting another bigger ball and this is analogous to the motion of the moon around the earth for example. So the moon in this case is like the marble and the earth is like the heavier bowling ball and the moon is just travelling on this curved space-time.
02:35 03:02	And this picture has been tremendously successful at explaining all of the gravitational phenomena in the universe from the motion of the moon around the earth to the planets around the sun to the expansion of the universe following the big bang. But there are some interesting features about this picture of gravity and you can kind of get to it intuitively if you just think about it. Imagine taking a very very heavy ball and putting on this fabric sheet so it starts to sag a lot and you start packing mass on it making this ball heavier and heavier you might wonder if you keep doing this is there some breaking point where the fabric of space – time just snaps and tears? And indeed you would be correct if you thought this. A tear in the fabric of space-time is called a Black hole and we believe that black holes are all throughout the universe and our own Milky Way galaxy.
03:39 04:14	They're created we believe from the collapse of massive stars. Once a start has burned off all of its nuclear fuel it can no longer counteract the extreme crushing force of gravity and so it contracts and it contracts until there is nothing left to prevent it from contracting into the smallest possible object in the universe. And when it makes this final compression where it can't be compressed any longer it's what we call a black hole. Black holes are extreme objects. The gravitational field around a black hole is so strong that not even light can escape from it and this makes them excellent laboratories for understanding Einstein's theory of general relativity and the extreme universe. Just to give you an idea though of how extreme black holes are, if you wanted to make a black hole out of the earth, you would have to take the entire planet, all of the oceans and land and the planets core and crush it into an object roughly the size of a pea

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04:48 05:21	So these are really tremendous, amazing objects and yet I want something a little bit more exciting. You see my original training as an undergraduate was in particle colliders and so black holes are extreme but I see them and I say can't we smash them together like in a particle collider and see what comes out? This is just my intuition that I have developed and so indeed you can ask this question. What if you take the most extreme object in the universe, the black hole and you take two of them and you smash them together? What do you expect to happen? And the answer is the second remarkable prediction of general relativity that we are going to talk about today. Gravitational waves. Ripples in the fabric of space-time. These ripples are created if you go back to our image of stretchy fabric when two objects smash into each other or alternatively you could image just dropping a bowling ball on a stretchy sheet of fabric.
05:50 06:21	They emanate outward from the cosmic cataclysm that caused them. They carry with them energy and momentum and they travel at the speed of light, sometimes for hundreds of millions or even billions of years before they reach earth where we hope to be able to detect them. If a gravitational wave was passing through the stage right now and it was caused by two black holes just on the other side of this screen to make the gravitation wave as loud as possible. You would see me stretched. First the stretching of space-time would make me taller and thinner and the next moment I would be made wide and shorter and then it would alternate back and forth. Taller, wider, taller, wider. This is the characteristic stretching of a gravitational wave.
06:46 07:21	And yet typically you don't experience this in our day to day lives and in fact even dedicated gravitational wave detectors only detect the very loudest gravitational wave signals in the universe. So why is that? Well it turn out that the force of gravity is very weak and the amplitude of these gravitational waves is therefore accordingly small. The typical gravitational wave amplitude that we have looked for is measured in terms of how much things get stretched and this is one part in 10^{21}. This is almost an unfathomably small number. This means if you want to detect gravitational waves you will need to build a facility capable of measuring a change in length of one thousandth of the size of an atomic nucleus measured over lengths of kilometres.
07:42 08:15	While Einstein published this idea, described this idea of gravitational waves almost 100 years ago, for decades scientists thought this was purely academic. No one would ever be able to detect such a thing and yet last year, on September 14th, 2015, the LIGO collaboration which stands for Laser Interferometer Gravitational wave Observatory, which we are a part of here at Monash did this impossible sounding feat. So how did we do it? Behind me is a cartoon showing you the basic idea. This is a cartoon of the LIGO detector and the key ingredient in this detector is light. We start with a laser beam and we split it in half. We send half of the laser beam down one arm which is four kilometres long and we send the other down a second four kilometre arm. At the end of each arm is a mirror and the light bounces off this mirror and returns back to the vertex where it was split.
08:51 09:18	We time how long it takes for the light to go down this arm and how long it takes for the light to go down that arm and we compare the travel time of each beam of light. If a gravitational wave passes through the detector it momentarily lengthens one arm while shortening the other arm and causing us to observe a difference in the travel time of light between the two arms. The next moment this switches making the other arm longer and the other arm shorter. Alternatingly back and forth and this is the signature of a gravitational wave and how we detected gravitational waves. Based on the way that we saw space-time wiggle we can make inferences about what object must have created it and after many weeks studying the way in which LIGO wiggled we were able to reconstruct what must have created this gravitational wave.

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09:44 10:17	And here is a video of a reconstruction showing what we believe happened. 1.3 Billion years ago, two black holes, each more than 30 times more massive than our own sun were orbiting each other in the final seconds of their life as separate black holes. You can see them as these two black spheres and you note beneath them that the coloured surface. This represents the stretched space-time in the vicinity of these black holes. At the very bottom of the movie you can see a rippling wave and this is showing how gravitational waves are emanating out from these two black holes as they orbit around each other. Here we are now approaching T=zero the moment when the two black holes cease to be separate and they merge forming a single black hole. Finally the gravitational waves from the black holes rippling emanate outward travelling to us a billion years later to be observed in the LIGO detectors causing one arm to be momentarily one thousands of an atomic nucleus longer than the other arm allowing us to reconstruct this scene.
10:57 11:32	It's hard to convey just how energetic of an event this gravitational wave emission was but I will try. Imagine taking the entire sun that gives us warmth and light and instead of having it slowly burning away its nuclear fuel over billions of years , imaging that in less than a second I took the sun and converted it into pure radiation. Pure energy. The resulting explosion would only be one third of the energy that was released when these two black holes merged. So this was truly a tremendously violent cosmic event. While you can visualise gravitational waves it is also possible to hear them and this is because the frequencies that LIGO uses in order to measure gravitational waves correspond very well to the frequencies that our own ears hear. So it is not only possible to watch a recreation of what must have happened with the merging black holes but we can also hear what a gravitational wave signal sounds like.
12:08 12:41	And I'm going to play a sound for you now which is going to be two massive stars merging and it going to start off as a low pitch sound and as the two stars orbit each other their frequency will get higher. Their tome will get higher and they finally merge and create a black hole. (Plays tone at 12:26 to 12:30). I like to think it sounds like a child's slide whistle perhaps showing the softer side of black holes. On the one hand their collisions are very dramatic releases of energy but they have a very silly sound associated with them. This is the team of researchers at Monash University who were involved with LIGO during the detection of gravitational waves. At the time we had three full time faculty members, two post-doctoral researchers and a handful of students all working on gravitational wave astronomy, and Monash contributed in a number of important ways to the discovery of gravitational waves.
13:09 13:37	Our team includes the leader of one of LIGO's data analysis groups and in its capacity Monash helped lead a project to infer, based on the detection of the nearby black hole merger, what can we infer about the most distant black holes in the entire universe? And from that study we learned that by the time LIGO reaches its full sensitivity, it's full capability we may be able to hear gravitational waves from the very edges of the universe. We were also involved in vetting the detection of gravitational waves and to do this we inserted, on purpose fake gravitational wave signals into the detector by physically shaking the mirrors, not by hand but by using computers we shook the mirrors in ways that simulated a passing gravitational wave.
13:57 14:28	And by checking what came out of the detector looked like what we thought we were putting into it we were able to gain confidence that the event we observed in September of last year was a true black hole merger. This also put us in an exciting place in the detection of gravitational waves because on the very night hat gravitational waves swept through the detector researchers around the world were asking if this was a test and we were very lucky to be among the first people in the world to know that this wasn't a test and we were working on the testing system and we could check that this had not been a test. Finally Monash is working to make the LIGO detector more sensitive than ever before and a leader in this project is one of our honour students Chris Whittle.

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12:28 15:20	You can see him on the slide third from the left and take a look at him now in his civilian clothes because I'm going to advance the slide and show you a picture of Chris at the LIGO Stanford Observatory in the United States of America. Here Chris is in a clean suit and that is because he is working with other researchers inside the instrument, the LIGO detector. And it is very important because this instrument is one of the most exquisitely sensitive devices ever developed by mankind, to be very careful not to introduce any contamination into the detector. And it's my hope that Chris and his colleagues at the LIGO detector will give us back a new LIGO interferometer when it comes on line again in eth coming months and it is more sensitive than ever before allowing us to see further out into the universe and detect more gravitational waves.
15:46 13:48 16:45	While the past year working on the detection of gravitational waves has been extremely exciting and while it been an honour to be part of the team that vindicated Einstein's Theory of General Relativity for me this opening of a new window on the universe is just the beginning. What makes me most excited talking to students in class, what makes me most excited working with researchers is the possibility of using LIGO and using gravitational wave astronomy to find things, to find sources of gravitational waves that we don't even know about. That no one has previously predicted and that might teach us things about the Universe that we can't even imagine. This is what makes me passionate about gravitational wave astronomy and this is what makes me passionate about working at Monash. Thank-you.