GRAVITATIONAL WAVES - Curated Transcript of BBC In Our Time podcast
https://www.bbc.co.uk/programmes/b007h8gv
Last on Thu 17 May 2007 21:30 BBC Radio 4 FM

This transcript was created by downloading the podcast from the BBC website and passing it to Assembly AI V2 (https://www.assemblyai.com/) and then manually editing the resulting raw transcript to assign voices, to correct spelling, and to introduce occasional time stamps. Edits have also been made to better communicate the factual content of the podcast, rather than capturing all the details of the audio record. Such edits are indicated in the transcript.

Comments and corrections are welcome, and sincere apologies are made for any substantial inaccuracies in the following transcript.

(Credits from the BBC Website)

In Our Time is hosted by Melvyn Bragg. Melvyn's guests on this podcast are:

Jim Al-Khalili, Professor of Physics at the University of Surrey;

Carolin Crawford, Royal Society Research Fellow at the Institute of Astronomy, Cambridge;

Sheila Rowan, Professor in Experimental Physics in the Department of Physics and Astronomy at the University of Glasgow
----

Curated Transcript:

[Melvyn Bragg] Hello. The rather unpoetically named Star SN 2006gy is roughly 150 times the size of our sun. On Monday of last week, it went supernova, creating the biggest stellar explosion ever recorded. But among the vast swathes of dust, gas and visible matter ejected into space, perhaps the most significant consequences were invisible, emanating out from the star, like the ripples from a pebble thrown into a pond. These are called gravitational waves. They're run through the fabric of spacetime itself and, having been predicted by Einstein nearly 100 years ago, we may be on the verge of proving they exist. But what are gravitational waves? Why are scientists trying to measure them? And if they succeed, what would a gravitational picture of the universe look like? With me to discuss gravitational waves are Jim Al-Khalili, Professor of Physics at the University of Surrey, Carolin Crawford, Royal Society Research Fellow at the Institute of Astronomy, Cambridge, and Sheila Rowan, Professor in Experimental Physics in the Department of Physics and Astronomy at the University of Glasgow.

[2:28]

[Melvyn Bragg] Jim Al-Khalili, Gravitational Waves were first predicted by Einstein's theory of General Relativity, published in 1916, following up on his paper on Special Relativity, published in 1905. Can you just tell us how those two papers affected the then going notion of gravity?

[2:46]
[Jim Al-Khalili] Yes, well, in Einstein's Special Theory of Relativity, that's the E=MC^2 ("E equals M C squared") theory. So that's the one that came out first in which the notion of space and time ... were changed [from] the idea that space is absolute, it's the stage on which everything happens and that time is [the idea that] there's a cosmic clock ticking by at a constant rate everywhere. That's the Newtonian view of our universe that was overthrown in Einstein's Special Theory of Relativity. But it took ten more years before he could incorporate the idea of gravity into his theory of relativity. Now, gravity is also something that Newton had something to say about. But Newton's view of gravity was of this sort of magical, invisible force that pulls all objects together. So [this force is] the reason we stick to the Earth, the reason the Earth goes round the sun and so on. And Newton's picture of gravity is as a force that acts instantaneously between objects. What Einstein did in his General Theory of Relativity was to explain gravity not as a force, but as something that happens to space and time themselves, sort of [a] "curvature of space and time". Now, these are words, and we can say them, and a lot of people have heard the notion of curvature of space and time, but it's a really, really complicated concept to try and imagine: Space is three dimensions; we know we live in three dimensions of space. Time, Einstein tells us, is the fourth dimension and so you have a four dimensional space time, which we can't imagine because our brains are only three dimensional. And then you think, well, four dimensional spacetime gravity causes it to bend, to curve, and you can't have a picture of something that bends and curves after all, we just haven't got the facilities to think in these higher dimensions. So it's a very abstract mathematical idea, but it's also a very beautiful and simple theory. Einstein's general theory of relativity is one of the most accurate and beautiful mathematical theories ever devised.

[Melvyn Bragg] Is there a sense in which he "refined Newton" or "erased Newton"?...

[Jim Al-Khalili] Well, in terms of the picture he gave us of gravity, it was very different. In terms of the predictions as to how strong the gravitational force is between any two objects, it was refining Newton. So, for instance, when NASA send rockets to the moon and out into the solar system, they don't need to worry about Einstein's refining of Newton's law of gravity.

[Melvyn Bragg] They go because of Newton.

[Jim Al-Khalili] They go because of Newton, and Newton is perfectly fine for all intents and purposes. Where Newton's theory breaks down is when gravity gets very, very strong, and that's where these new predictions, like gravitational waves, start to come into play.

[5:40]
[Melvyn Bragg] Right... So you think that's enough to say about the change in the idea of gravity before we move on towards these gravitational waves?

[Jim Al-Khalili] Well, we can come back to clarifying things...

[Melvyn Bragg] OK, Carolin Crawford, how did these ideas then cause him to predict gravitational waves?

[Carolin Crawford] Well, you have a mass in space, and that warps, as Jim says, it warps the space and time around it, and the force of gravity is due to this curvature. That's fine if you've got a mass still in space. You've got this fixed distortion of the space around it. But if that mass begins to move, the gravitational field around it has got to change, that means the spacetime, the shape of spacetime, has to adapt and evolve to take into account this new gravitational field, to take into account the motion of this mass. And so when a mass moves...

[Melvyn Bragg] We're talking about a huge object in space - any huge object or cluster of objects?

[Carolin Crawford] Well, I mean, just pick a a huge object in space, just a nice mass in space. If that [object] moves, it is going to set up a disturbance in spacetime. And so what these waves are they're almost like a signal that carries out the information to the rest of the universe that the gravitational field around this object has changed. ...They propagate outwards from the motion of this mass at the speed of light. The thing that's very difficult to get your head around is the idea that these are not ... like "waves" as we're used to them. We think of waves like light waves [or] radio waves that travel through space, across the universe. The difference is that gravitational waves are actually distortions of the spacetime itself. So they actually travel through and distort the space and time. So it's quite a strange concept.

[Melvyn Bragg] It is. Can you say it again in another form of words so we can absorb it a second time?

[Carolin Crawford] Okay, I'll try. One analogy is to other theories we have for example, how light and radio waves are produced. [It is known that these waves are produced by "electric charges in motion". This result is explained by]... Maxwell's theories of electricity and magnetism. It is a beautiful mathematical solution that predicts the existence of these [light and radio waves as a consequence of having electric charges in motion]. Now, [gravitational waves is a similar thing...In a similar way to Maxwell's theories, Einstein's theory of General Relativity predicts that ...a mass in motion...will set up these ripples in spacetime, propagating out.] So ... this is a very simple glossing over what's happening. It's not just the mass has to be in motion it also has to be accelerating [and] that means there has to be a change in either the rate of motion or the direction of motion [of that mass]. And this has all got to happen in an "asymmetric fashion". So we're now kind of layering up lots of different criteria to produce gravitational waves.

[Melvyn Bragg] What kind of things give off these gravitational waves and why?

[Carolin Crawford] Well, the kind of things that give off these gravitational waves, as I say, [have] got to be something in motion, something where that motion is changing. And [they have] got to be heavy in [an] asymmetric fashion. So if you just have a mass spinning or a spinning disk, that's not enough [because] it's still symmetric. A cylindrically symmetric [or] spherically symmetric [moving mass] is still going to not give off any gravitational waves. Even a mass just moving through space and time isn't going to give off gravitational waves. However, if you have a kind of situation, [where] something is shaped like a bone or a dumbbell, if it spins along its vertical axis, you've got a symmetric situation that's not going to give off gravitational waves, but [if] it tumbles end over end, you've got a different kind of motion. And that's the kind of motion that sets up gravitational waves. So [to] go back to space, we get gravitational waves from motions on Earth, but they are insignificantly tiny. ... The amount of radiation you get goes up as very strongly as the mass and the speed that you're traveling at so to get any kind of significant gravitational wave, ... you have to go to these astrophysical phenomena. You need an enormous mass traveling at a speed that's nearly relativistic and it's got to be doing this in an asymmetric fashion. So we get black holes and supernova and binary stars ... giving [out] gravitational waves.

[Melvyn Bragg] Can I just go to Sheila for a moment? ... Einstein predicted ... gravitational waves in his theory, but what was the first piece of evidence that gravital gravitational waves might actually exist?

[10:09]
[Sheila Rowan] Well, we do, in fact, have strong indirect evidence that they exist and that came again from an astrophysical observation. And in ...1974, I think, there was a pair of scientists, Hulse and Taylor, who were looking at pulsars - a particular kind of astrophysical source where we have something called a neutron star, which is a particular kind of star, which is in some ways like a giant atomic nucleus that's made up of the same kind of particles, neutrons, that you find in the middle of atoms, but on a huge scale.... And a neutron star, under some circumstances, can spin. If you've got a spinning neutron star, it can beam radiation that comes out of its ends. And it's a bit like a beacon, a bit like a lighthouse. As it spins, that radiation can be beamed towards us on Earth and we see pulses of radiation. And so they were looking at pulsars and they found ...a particular pulsar that's in what we call a binary system - and this means that there were two stars orbiting round one another, orbiting round a common center. And one of these was a pulsar. And over a long period of time, over months and years, what they did really was from the measurements they were making, they were able to watch the evolution of the orbit. In other words, they were measuring how long it took these two stars to orbit round one another. And they did that over a long period of time and they could see that the stars were getting closer and closer together - they were losing energy. And General Relativity allows us to predict how fast that orbit should be decaying and what the change in the orbit should look like and that prediction of general relativity includes the fact that this binary system should be radiating away energy in the form of gravitational waves. And when they compared the observations they were making with the predictions of general relativity, they agreed beautifully. And that agreement comes about in part because energy is being lost due to gravitational waves.

[Melvyn Bragg] But we still haven't direct evidence... But ... to bring the discussion down to this studio...what would happen if a gravitational wave were passing through this room right now?

[Sheila Rowan] I would hope that they are - we believe that they are. And, as Carolin said, they distort spacetime. What does that mean to us? Well, if we look down, ... at a coffee cup sitting on the desk here, the top of the coffee cup is round. If a gravitational wave comes from above us, goes through the studio and passes through our coffee cup, what it'll do to the shape of the coffee cup is it'll change the shape. So if the top starts as a circle, as a gravitational wave passes through, that circle will become distorted into a rugby-ball shape. And then as the gravitational wave cycles through, it'll go back to being a circle, and then it'll become a rugby-ball shape in the other direction. And cyclically, that circle will be squished, stretched and compressed. And as we sit here, we're all being stretched and compressed, just slightly, as gravitational waves pass through us...it's changing the shape of object.

[Melvyn Bragg] Jim, do you want to come in for a moment?

[Jim Al-Khalili] Yeah. The thing is, there are these two predictions of how we would detect ... gravitational waves. The clincher would be, as Sheila says, to actually detect distortion - stretching and squeezing of spacetime. Now, again, we say "spacetime", which is pedantically correct, but effectively what we're talking about...

[Melvyn Bragg] I can't be the only person who's spinning around, trying to sort of see what spacetime is...

[14:09]
[Jim Al-Khalili] And so, with apologies to fellow scientists who like to use the term "spacetime", I will just use the word "space". Space gets squeezed and stretched. As Sheila explained, if a gravity wave passes through any region of space in one direction, lengths contracts and get shorter, and in the other direction, at right angles to it, they will get longer - so it's like a distortion of space itself.

[Melvyn Bragg] ...Carolin Crawford, before we look at the existence of gravitational waves, ... could you explain, as an astronomer, why the proof of their existence would be a significant breakthrough?

[Carolin Crawford] Well, the foremost reason, of course, is that this is a prediction from Einstein's theory of General Relativity that is yet to be verified. And so, at the simplest fundamental level, it's verifying the whole theory of General Relativity and our understanding of it and the kind of objects Sheila described, two neutron stars going around each other. Imagine you could receive the signal from two black holes going around each other: They're traveling at enormous speeds in a huge gravitational field [and by] looking at how they react to each other, the gravitational [wave] signal coming off, from there, you [would] get these really acute tests of our theories of General Relativity. But astronomically speaking, you can take it further than that. I mean, gravity is everywhere in the universe. Everything we see is ...controlled by gravity. But astronomers have to rely on looking at the light that's emitted by objects whose motions are controlled by gravity. Imagine we could detect gravitational waves, we would be actually observing the gravity first-hand instead of inferring what's happening second-hand from the light of these objects being controlled by gravity. We [would] start to get signals from gravity itself and that is quite a shift in how we might view and observe the universe.

[Melvyn Bragg] So we're getting signals from the 95% of the universe that we can't see? ...You did a grimace there. I've got it wrong, haven't I?

...

[Carolin Crawford] Well, ... of course, again, we only see the light from a tiny fraction of the whole universe, as you say, right? This is huge fraction, which is invisible, yet still produces gravity. And, yes, so we're going to get gravitational signals from both dark matter and from light that's emitting. So the key thing is we're going to be able to observe the behavior of gravity. The other thing that's really nice is that we're used to light. Light gets stopped by matter, it gets scattered by matter as it travels across space. The light waves get modified, they get changed. Gravitational waves pass through matter completely unscathed. I mean, as Sheila said, they're going right through us now, right through the Earth now. That means that if we've got some circumstance ... you mentioned a supernova. This happens when a star at the end of its life, a giant star, after a few million years, it can no longer hold itself up against gravity, and it dies in this spectacular explosion, throws off the outer layers of the star, the central core of the star implodes to form a neutron star [or] a black hole. But you can imagine, all of this is really sheathed from our view, is obscured from our view, from the light, but the gravitational wave signals that mark the birth of this neutron star, a black hole, will be able to be directly detected.

[Melvyn Bragg] Sheila, can I bring you in again? You explained very eloquently the indirect evidence and the pulsars and so on. What ... will the direct evidence, if it is arrived at (which we'll come to later in the program - how people are trying to arrive at it as we speak), what will that bring?

[18:01]
[Sheila Rowan] The direct evidence means that we'll see directly the effect of the squishing of spacetime on objects here on Earth. And it'll let us look back, as Carolin said, to understand about the sources - direct viewing of sources in a gravitational picture. And so it will bring ... us information about things like black holes [which], in particular, are a very interesting source. [Black holes are formed when some stars collapse after going supernova.] [After a period of some controversy,] people now really believe that [black holes] exist, but they're still very exotic objects and difficult to view, because, by definition, a black hole is something that's got so much gravitational pull that nothing can escape from it. So we can't get information about the black hole itself. Now, we can do observations, using the techniques we [presently] have, of stuff round about the black hole, so we can see light from X-rays, from gas [that is] [around] a black hole, but we can't probe the black hole itself. But the gravitational [wave] picture may let us see really what the black hole itself is doing. If we've got two black holes ... in a binary system ... orbiting round one another [and] losing energy [so] that they come in and coalesce. At the edge of the black hole (the ... boundary of spacetime beyond which nothing can escape), when those two black holes coalesce, there's disturbances of that boundary, gravitational disturbances, and they should cause direct gravitational signals that we could detect here on earth and see ... the edges of a black hole in a real gravitational picture.

[Melvyn Bragg] Jim?

[19:52]

[Jim Al-Khalili] I think it's also important to stress... just how difficult it would be. Einstein published his General Theory of Relativity in early 1916, and it was only a few months later, in the same year, that he published a paper where he predicted that gravitational waves should exist. This was a prediction purely from the mathematics of the equations of his theory. (In fact, he got the answer wrong, apparently by a factor of two and the English astronomer Arthur Eddington had to point it out to him. Eddington was also an expert on General Relativity. In fact, I think he was once asked by a colleague [wheterh] it [was] true that he was one of only three people who actually understood general relativity. And he went quiet, and the colleague said, oh, don't be modest. He said, "no, I'm trying to think who the third person might be".) But since that time, 1916, and to now, we're only now designing experiments to detect gravitational waves. As we mentioned before, a gravitational wave would would cause space lengths to shrink (contract) by a very, very small amount. A typical gravitational wave. Bearing in mind that universe is so big and these objects, like coalescing, black holes, and supernovae, are so far away, the gravitational waves that reach us typically will be so weak that a meter length of space would change in length by about a millionth of the diameter of an atomic nucleus. So we're down into ... the random Brownian motion - vibrations of atoms within a...solid object will completely swamp the effects that gravitational waves will have on that object. So it's incredibly difficult to actually pick up these weak signals.

[Melvyn Bragg] How do they compare then, with other kinds of waves, like electromagnetic waves?

[Jim Al-Khalili] Electromagnetic [waves] are many, many trillions of times more powerful than a gravitational wave. To give another example, [in the, already mentioned,] indirect detection of gravitational waves through the Hulse-Taylor binary system of neutron stars, it was the energy given off by the gravitational waves rather than the waves themselves that were picked up. [Speaking of the energy of gravitational waves,] ... the Earth going around the sun [will] ... give out gravitational waves because, again, it's a disturbance of mass in space. ...The power [(energy per second)] given off by the Earth-Sun system is equivalent to something like half a dozen light bulbs. So half a dozen 60-Watt light bulbs. ...Imagine how massive and how violent these [events would] have to be ...[so many light years away from Earth] if they were to give off gravitaional waves that we could [detect here].

[Melvyn Bragg] Carolin?

[22:31]
[Carolin Crawford] The other thing, of course, is that, ...as Jim describes, ... these very violent cataclysms [that would]...produce detectable gravitational waves, ...[would also] have to happen relatively near to us. ..Of course, this is space [and] by "relatively [near]", I mean within so many thousands or millions of light years. A lot of the uncertainty about gravitational waves is not only what sources produce them, but how frequently these occurrences happen. We've talked about neutron stars or binary black holes, coalescing orbiting around each other. How often do they merge together? Is it like one a century within our galaxy? One every ten years? There are big uncertainties like that, let alone all the other really challenging difficulties of detection.

[Melvyn Bragg] Could gravitational waves shed any new light, new light, on the origin of the universe?

[23:27]
[Carolin Crawford] Oh, that's very interesting. Going back to the origin of the universe, there is an idea that after the Big Bang, there was this period of exponential growth within the universe called "inflation". And there are ideas that there should be a background, a diffuse background everywhere, of gravitational waves produced within this inflationary period. And this should have produced some distortions back then that could be visible on ... what's called the ... "last scattering surface". This is a cosmic microwave background. And it is hoped that some future experiments like "Planck" will actually start to pick up some of these signals from this very early universe.

[Melvyn Bragg] Can I come to you, Sheila? You were on a program we did a couple of years ago on the "graviton", which, as I understand, is the particle of gravity. How does the graviton relate to gravitational waves?

[24:11]
[Sheila Rowan] The idea that there should be a particle associated with gravitational waves is an extrapolation from what we know about other kinds of forces like the electromagnetic force. There are four fundamental forces, of which gravity is one. [For] the other forces, ... we have good models [that support the fact that] there's a particle which helps transmit the force associated with the force. So that's true for the electromagnetic waves - there should be particles associated with them, virtual particles. People believe then, gravity is a force. It's likely there should be a particle associated with it. That's how it can be transmitted. The difference is that for the other forces, we can apply quantum mechanics to them. We have a tool for dealing with these forces that involves being able to apply them over small scales ... using a specific mathematical techniques.... Gravity, described beautifully by General Relativity, is different. We can't apply the same tools to it as we can to the other forces. So whilst we feel there should be a particle associated with gravity being transmitted and gravitational waves being transmitted, we don't [yet] have the tools .. to describe that. That particle would be the "graviton". So despite the fact it has a name, we don't have a good model for how that would fit into the theme.

[Melvyn Bragg] And we can't be certain that it exists?

[Sheila Rowan] We can't, I think.

[Melvyn Bragg] A lot of this is bending the imagination ... we're talking very seriously about things that might not exist, relating to things that we can't find yet, the gravitational waves.

[Sheila Rowan] I think we should distinguish between the graviton and gravitational waves. The graviton is, I think, a step too far for this particular discussion .... Gravitational waves, on the other hand, I think we have such a good theory that predicts them, such good indirect evidence that they exist. There's no other way to explain the observations that have been made that we really do have confidence that the gravitational waves are there for us to see. It's just that it's a very, very hard experimental task to do... It it's a great challenge.

[Melvyn Bragg] Jim Al-Khalili, is this part of the bigger problem in physics, trying to reconcile general relativity to quantum physics?

[Jim Al-Khalili] In a sense, it is. I mean, gravitational waves are yet another way of saying Einstein's General Theory of Relativity is correct. And ever since he published his first paper, there have been experimental tests of General Relativity, and they've all come through with flying colors. Gravitational waves, along with one or two other predictions of General Relativity are still waiting to be nailed. But we don't have any doubt that they will sooner or later. But in terms of reconciling all the theories of physics together and all the forces of nature together, the graviton certainly is a prediction of that. But as Sheila says, that's something for the future. But we are still testing General Relativity to see whether in fact it is 100% correct. It may need modifying if we're ever going to merge it in with the other theories that describe the other forces, such as the theories of quantum physics.

[Melvyn Bragg] Sheila?

[27:42]
[Sheila Rowan] Indeed, gravitational waves, although we've talked about them being a prediction of General Relativity, in fact, it's really Special Relativity that tells us there's got to be something like gravitational waves. And that what Special Relativity tells us, is that you can't transmit information faster than the speed of light. And that's any kind of information, you can't send a signal to your friend on the other side of the universe in any way with that information traveling faster than the speed of light. And that's true for gravitational information. So if a star somewhere on the far side of the universe explodes and there's a big change in its mass distribution, we can't know about that instantaneously. It's got to take time for that information to get to us. In other words, there's got to be propagating traveling gravitational information - gravitational waves. And so even without General Relativity, some form of gravitational radiation has to exist to ...[satisfy Special Relativity].

[Jim Al-Khalili] There's a nice example of that. We talk about that the light from the sun takes eight minutes to reach the Earth. So if the sun were to suddenly cease to exist, it would take us eight minutes to realize it before the sky goes dark. It'll also take eight minutes for the Earth to realize that there's no longer any gravitational pull and that it can just float away off into space. So the effects of gravity from the sun, we believe, and the light coming from the sun travel both at the same speed.

[Melvyn Bragg] OK, let's devote the rest of the program to the attempt to detect these gravitational waves, which, apart from anything else, from what I've read for this program, involves the most extraordinary...feats of technology, which I hope you'll talk about in some detail. But let's just give it a context, we've talked about gravity, we've talked about gravitational waves. Carolin Crawford, what are the problems you face in trying to detect ... what is basically a ripple in the fabric of spacetime, which is, as Jim pointed out kindly at the beginning, we can't imagine?

[Carolin Crawford] Well, the problem is, and again, as Jim said, over a meter's length, this distortion is going to be this tiny fraction, somewhere like a millionth, the size of an atomic nucleus. And that is just such a tiny signal you're looking for. And that is really the main challenge, because, as you say, there's Brownian motion. There's all kinds of other noise that can set up vibrations... that can mask this signal. In terms of how we detect them, the kind of method now that is used, there are a couple of observatories in the States where you have an L shape, and what you're looking for is for one branch of the L to be stretched at the same time as the other branch is squeezed.

[Melvyn Bragg] Can I just [ask you to] hold on a second? ...[I'd just like listeners to have an idea why it's so difficult to detect the tiny ripples and disturbances resulting from gravitational waves....Could you say a few words about that?]

[31:00]
[Sheila Rowan] Maybe I can say a few words about that? Gravity is a very weak force. It doesn't seem like that ... to us, because it's what holds us on the Earth. But in fact, it's very weak, so these gravitational effects we're looking for are very, very weak. I think if we can go back, actually, to your introduction at the very beginning, your analogy of throwing a stone into a pond and seeing the ripples come out... [This isn't a bad analogy...] and if we imagine our universe, in fact, is like a big flat piece of rubber on which we put a mass - we plonk the sun. That rubber then curves so that if we brought along another object and tried to set it on the rubber sheet, it would roll down that curve towards the towards the first object, down that curve on the rubber sheet. That curve on the rubber sheet we think of as being "gravity", and it sits there as a static force. Then if that star in the middle, or sun, or another star, wobbles a bit, it changes its position, its mass moves, it sends out ripples across the rubber sheet. Those are the gravitational waves we're trying to detect. And the trouble is, those ripples are tiny. So if we look at two points on the rubber sheet, they will be stretched and compressed. We said that was the effect of the gravitational waves, but it's a tiny, tiny amount. And what we do, as Carolin mentioned, is we literally, on Earth, plonk down two masses. And they are masses. They're pieces of glass, they're mirrors. They're a reasonable size, about 6 kg or so. So it's kind of two chunks of glass. And we try and measure very accurately their positions and measure the changes in their positions as a gravitational wave passes through them. And, as as Jim [...mentioned...] the change in their position is...absolutely tiny. The mirrors...are pieces of glass with coatings on the front to make mirrors. The changes in the positions of those mirrors, as you said, is much, much smaller than the size of an atomic nucleus. Tiny, tiny effects. So as they sit there, you can imagine we put them in the ground, we try and measure their position. We need a very accurate ruler to do that as the first thing. And the ruler that we use is actually the wavelength of light. We take light from a laser. Waves of light from a laser come along, we put in what's called a beam splitter, which splits that light into two, and those waves of light go out, bounce off our mirrors, come back again, and add up. And ... how they add up... can either add up to give us a bright spot, which we would literally see, or a dark spot. And whether it's bright or dark depends on how far the light waves have traveled when they hit these mirrors and came back again. So, the brightness of the spot that we see is giving us information about how far the light has traveled and what the positions of these mirrors are.

[Melvyn Bragg] Would you like to take that up, Carolin?...

[Carolin Crawford] Yeah. Well, again, go back to this L shape. As Sheila says, you have these lasers traveling along each stretch of the L, and you're looking for exactly the signal that it's changed in one. It's stretched in one side of the L, and it's squeezed in the other side of the L. And you get this by measuring to this fantastic accuracy the path that the light has traveled in each branch of the L.

[Melvyn Bragg] ...Jim Al-Khalili, is there a history to these kinds of experiments? Can you give us some context here?

[Jim Al-Khalili] It's very interesting that this idea actually goes back to the second half of the 19th century to one of the most famous experiments in physics. In fact, it was the experiment that got Einstein interested as a young boy in notions of space and time. From the very start, the idea that light waves interfere and cause these patterns and fringes was was known long before the English physicist Thomas Young showed this back in the first few years of the 19th century. But two American physicists, round about the 1870s, called Michelson and Morley developed an experiment where they were looking for a medium in space called the ether that most scientists at the time believed was the medium that carried light waves. So, in the same way that we need air to carry sound waves (and... if there's a vacuum, sound doesn't carry [so you will be unable to hear anything in space]) - physicists in the 19th century believed there had to be something that carried light waves. And Michelson and Morley designed this experiment using this device, which we now call an interferometer, where two light beams travel in two directions at right angles, covering two different paths that can be very carefully controlled, bounce off mirrors, come back, and recombine and interfere. And the way that interference pattern changes tells us how far each separate light beam has traveled there and back. So any changes in that path length, if you can control everything else, tells you whether the path has changed.

[Melvyn Bragg] And it's developed now to the latest one, Sheila Rowan, a plan for a new experimental setup called the Laser Interferometer Space Antenna. What is that going to do that one hasn't been able to achieve before now?

[36:32]
[Sheila Rowan] Right. Well, there are two classes of these experiments experiments done on the ground and experiments done in space. And before we get to "LISA" the Laser Interfront, or Space Antenna, that's the space version of these experiments. I think I should probably just say a little bit about the ground experiments, which explains partly why we're going to put one in space. The experiments on the ground, as you just heard, measure the positions of mirrors...very accurately. But you can imagine if we just took our mirror and sat it on the ground, tried to detect its motion due to gravitational waves, we'd be completely swamped by the fact the ground's moving. A truck drives past, shakes the ground, the mirrors move far more than any gravitational wave would make them move. So we carefully suspend them as mirrors, that turns out to be a noise source that we can relatively easily get around just by hanging the mirrors as pendulums. And that pendulum acts as a mechanical filter to get rid of seismic noise so that we can get around. There's also the thermal noise of these mirrors shaking. The individual atoms and molecules have some temperature [and] that temperature causes them to shake slightly. So that's a noise source that is harder to get around. And there are various noise sources like that which we work very hard on reducing to the point where we have built detectors on the ground that can measure these tiny, tiny, tiny displacements that are just about the level we would expect to see gravitational waves at certain frequencies - between about, at the moment, ... 50 Hz or so up to a Kilohertz or so. ...These mirrors would be shaking, say, between 50 and a

couple of thousand times a second due to gravitational waves. That's what we're trying to see. And there are certain sources, some of the astrophysical sources we talked about that should produce signals at those frequencies. The supernova, for instance, ... the coalescence, the coming together of these binary stars, we hope to be able to see those on the ground. But at very low frequencies, so sources that produce very slow gravitational changes, we won't be able to see [effects] on the ground. And for that, we need to put a detector in space, because there's a particular noise source on the ground just called "gravity gradient noise". People slowly walking past these mirrors exert a straight gravitational pull on them... and that's bigger than any gravity wave effect on the ground. But that only happens slowly. You only walk slowly past the mirror. You don't run past the mirror a thousand times a second. So for those low frequency sources to get away from that noise source, we have to put a detector in space.

[Melvyn Bragg] Do you want to come in and give the listeners, ...some idea of the size of these. Carolin?

[39:18]
[Carolin Crawford] ... The idea [of LISA] is that you have three spacecraft that are the corners of an equilateral triangle... [In] the ground experiments that are currently running, the length of the L shape is about 4 kilometers. The advantage of putting them in space is that these three spacecraft at each side of this triangle, they're all going to be 5 million km apart. So you have the amount of signal that you detect goes up over the longer the distance you measure it over. And so that increases the sensitivity as well as increasing the range of the frequencies that we can detect these waves from, as Sheila said.

[Melvyn Bragg] Can you just give us some idea of the precision involved, the technology involved? Because from what I've read about it just seems again, almost as mind boggling as the theories, really.

[Jim Al-Khalili] It's remarkable that we've known that gravitational waves should be out there and the technology is advancing all the time. But even these experiments, they've taken so many years to design and build, I mean, LISA won't be ready for another ten years or ... so, maybe earlier.

[Carolin Crawford] Well, it depends whether it's funded it's not even certain yet. It's up for competition against other space missions... It's being funded by the American and the European space agencies...The Europeans have given some money to it, but the Americans have still decide in a few months time whether they're going to fund it.

[Melvyn Bragg] There is a body of opinion that so much money ... may not be best spent detecting things that may not actually exist.

[Sheila Rowan] As I say, I think we're pretty sure that gravitational waves do exist. There isn't a great controversy over that anymore. They're hard to detect, but I think there's no real genuine controversy anymore over whether a form of gravitational radiation exists. We do believe they exist...There's no direct detection yet, but there's very strong indirect evidence. And all our theories tell us that some form of gravitational radiation has to exist or it's going to cause us great problems with our current theories of how we believe the universe behaves....If [an experiment] tells us that general relativity is wrong, that's going to be an enormous revolution in physics. So if we can show that general relativity is wrong, then that's going to be huge.

[Jim Al-Khalili] That's the crucial point, because one could also argue that if we are so sure that gravitational waves exist, why should we spending so many hundreds of millions of pounds to design experiment that's just going to confirm what we already know. And the point is that we are trying to test general relativity and push it to the limits and see if it really is correct and needs modifying. So, along with all these new theories to try and unify the forces of nature, some of them are expensive, some of them worthwhile, they're part of our inheritance.

[Sheila Rowan] And gravity is the least understood force of all the forces. It's the most significant force that governs the behavior of our universe and yet the least understood in some ways. [As an example] just over the last ... five to ten years, [we have discovered] the significance of "dark matter" and "dark energy", the fact that our universe is expanding much faster than we can possibly understand. Gravity somehow has got to play a role in that, and we really don't understand how. So experiments to understand gravity better and General Relativity better are hugely significant for how we understand our universe.

[Melvyn Bragg] Well, thank you very much for letting me accompany you through the last 44 minutes. I've enjoyed it and I think I've understood a bit of it. I hope I'll remember enough of it next week, but thank you very much to Jim Al-Khalili, Carolin Crawford and Sheila Rowan.
