

NARRATOR: For millennia, we've looked out into the darkness to read the messages written on the night sky. Since Galileo first turned a telescope to the heavens, astronomers have probed the planets, the stars, the distant galaxies. But there are some mysteries so deep, the answers cannot be found with traditional tools. For those, it takes something entirely different... a revolutionary new kind of observatory. It's not a telescope. It's something far more radical... built to detect a whisper of a signal that's never been directly measured. Known as LIGO, it is 20 years in planning, a dozen more in construction, and it all comes down to this moment, the moment LIGO begins searching the cosmos on the hunt for a whole new kind of cosmic messenger.

WEISS: Let's begin.

NARRATOR: Professor Ray Weiss has been dreaming about this moment for decades. Weiss and his colleagues had long been convinced there was another way to study the universe beyond traditional telescopes.

WEISS: When you start looking with other ways of looking at the universe, this thing that looks so pristine and pretty at night and so placid and puts you into a good mood about coming to peace with the world, if you really look a little harder you'll find out there's all chaos going on out there.

NARRATOR: Chaos--from the fiery collision of neutron stars, to the eruption of a supernova. Weiss believes these cataclysmic events leave behind clues about the fundamental nature of matter and energy, even the origins of time and space. These clues are what LIGO measures. They're called gravitational waves, and they're not anything like the gravity you thought you knew. It was Newton and his apple that first defined gravity, the force that pulls the fruit down, the force that pulls the earth into orbit around the sun and holds it there. But Albert Einstein redefined all that in his famous General Theory of Relativity. Gravity, he said, isn't the attraction of objects like stars and planets. It's a distortion of space and time, what Einstein called "space-time."

WEINSTEIN: What general relativity tells us is that space is not a simple flat arena in which matter and energy plays around but itself can be dynamic. It can change its shape, it can curve.

NARRATOR: According to Einstein, space-time is like a fabric and what we call gravity is the warping of this fabric by a massive object like a star. A planet orbits a star when it's caught in this warped space like a ball spinning around a roulette wheel.

GONZALEZ: So it's not that there's a force between them. It's that this space where they live is creating these holes and they're falling into each other's holes.

NARRATOR: It's an astonishing idea, and it led Einstein to a prediction that when a massive object collides with another or changes speed or direction, it produces waves in the fabric of space-time--gravity waves. Like ripples on a pond, these waves travel outward from their source, carrying information about the events that cause them. Racing at the speed of light, they are the ultimate cosmic messengers, Einstein's messengers.

WEISS: The gravity waves just permeate, they go right through everything. The universe is totally transparent to gravity waves. Now, think of such a thing. What that means is that if you get a gravity wave, it hasn't been messed around with, and you get what exactly happened at the source.

NARRATOR: As scientists tried to simulate these waves, they found that up close, they're violent events, they can be immensely powerful. A passing wave causes objects in its path to stretch and compress, stretch and compress.

WEISS: If you're in a place where the gravitational waves are very strong, like near a black hole, they could tear you up. They could stretch you to pieces in one direction, squish you the other way. You would be very upset by a strong gravitational wave.

NARRATOR: But by the time they reach us, they are nowhere near as strong.

THORNE: Just as a wave on the surface of pond you get weaker and weaker the farther they propagate, so do gravitational waves, which is why they're so weak by the time they reach the Earth.

NARRATOR: Just how weak are they? After traveling across the universe, the average ripple would stretch a yardstick by only a tiny fraction of the width of an atom.

WEISS: It's a number that is so small, Einstein saw that number in the 1916 paper, and he said, "Ohh! This is just too small to deal with. Nobody will ever measure such a thing."

NARRATOR: The prospect was so daunting, it took more than 40 years before a scientist decided to try. His name was Joseph Weber. Weber developed the first real experiment to detect gravity waves, a vibrating cylinder. A clever idea, and although Weber's detector wasn't sensitive enough to measure gravity waves, the excitement surrounding the experiment motivated many.

NARRATOR: Rai Weiss, a young professor at the time, thought he had a better way.

NARRATOR: The key to Rai's idea lies in the way a gravity wave distorts the fabric of space.

WEISS: This is what happens to space itself. It stretches in one direction, and it compresses the other. It collapses up and down, and it stretches sideways. Here is a gravity wave at a certain frequency. The frequency is once a second or something like that. That's what it does.

NARRATOR: To measure this stretching and squeezing, Rai turned to a device called an interferometer. A laser beam is split and sent down a pair of long perpendicular tubes, each precisely the same length. The two beams bounce off mirrors and recombine back at the base. The light waves come back lined up in such a way they cancel each other out.

WEISS: And you add them together, you get nothing, you get a zero, a big fat zero. No light gets detected at the photodetector.

NARRATOR: But when a gravity wave comes along, it distorts space and changes the distance between the mirrors. One arm becomes a little longer, the other a little shorter. An instant later, they switch. This back and forth stretching and squeezing happens over and over until the wave has passed. As the distances change, so does the alignment between the peaks and valleys of the two returning light waves, and the light waves no longer cancel each other out when added together in the recombined beam. Now some light does reach the detector with an intensity that varies as the distance between the mirrors varies. Measure that intensity, and you're measuring gravity waves.

WEISS: The light takes a longer time in here than it did in this arm. Now it takes a shorter time, and these things don't cancel so beautifully anymore. And that is, in fact, the whole idea.

NARRATOR: By 1990, labs had begun to spring up across the world, with the goal of finding ways to measure tiny gravitational waves with an interferometer.

MAVALVALA: I guess that's looking better.

MCGUIRE: It's a big challenge. In some sense it is a high-risk experiment. Oh, but the payoff is enormous and that's the thing that keeps you really motivated.

NARRATOR: Now, at twin labs in the heart of Louisiana, and in the high desert of Washington State, dedicated teams of scientists and engineers are undertaking one of the great technological challenges of the new century.

GONZALEZ: We are measuring distances that are almost unthinkable small. These small effects are coming from these big masses far away, from black holes, from neutron stars, and then we are going see things happening in the universe by measuring these small things.

NARRATOR: It's called LIGO, short for Laser Interferometer Gravitational-Wave Observatory. Each LIGO Lab is a real-world version of the interferometer Weiss envisioned, made up of two arms extending 4 kilometers in length. The size is key because the tiny stretching and squeezing effect increases in proportion to the length of the interferometer. The longer you make it, the more the mirrors move and the easier the signal is to detect. Also key is state-of-the-art optical and laser technology: mirrors polished to a precision never before attempted; high-powered lasers, among the most stable in the world. LIGO is the work of hundreds of scientists, engineers, and students, the LIGO Scientific Collaboration based at the labs and at dozens of universities around the world. Their goal, to measure the movement of mirrors down to a thousandth the diameter of a proton.

WEINSTEIN: And that's something no one has ever done before. It's something that requires pushing the limits of technology in every sense, and what usually limits you when you are trying to measure something better than ever before is noise.

[Siren]

[Whistle blows]

NARRATOR: What physicists call noise is a host of vibrations and other disturbances that can shake the mirrors and mess up the data. Welcome to the modern world. LIGO scientists have always known that to detect a gravity wave from space they'd have to isolate this signal from the noise on earth. The challenge is like trying to make out a tune from across a busy city. You need to know what you're listening for, and you have to separate it from all the surrounding noises. That's not so easy. The LIGO labs were built in quiet rural areas, but their instruments are incredibly sensitive. If a tree falls in the forest, they hear it. LIGO's Louisiana site is surrounded by logging, but that's just the beginning. Even waves thousands of miles away can affect LIGO's instruments. Then there are the earthquakes, windstorms, volcanoes. The whole planet is shaking and vibrating.

MAVALVALA: Everything else on our planet wants to move the mirror more than the gravitational wave does. So the big challenge is how do you keep a mirror so still against all of these other external forces that are trying to push on it so that it will only move when the gravitational wave comes by?

NARRATOR: The answer begins with one of the largest vacuums ever made. A laser beam can travel down LIGO's long arms without the distorting effects of air and remain stable as it bounces back and forth between mirrors. The mirrors themselves are cushioned with the suspension system that cuts

outside noise by a factor of 10 billion. Springs and weights absorb movement from the ground. Vibrations are further reduced by fine wires that suspend the mirrors. If any remaining vibrations get through, a series of tiny magnets nudges the mirrors just enough to exactly counter them. The ultimate goal is to approach the very limits of measurement, down to a scale so small that quantum laws turn the straight lines of a ruler into a tangle of fuzzy impressions. Even with noise reduced to the lowest possible level, LIGO must still be able to tell when an incoming signal really is a gravity wave. That's one reason two identical labs were built, separated by 1,900 miles. If both labs pick up the same signal, chances are it's not noise from Earth, but a gravitational wave from space.

NARRATOR: Once detected, these waves could be electronically converted to sounds, sounds you can hear. Take neutron stars in the act of merging.

WEISS: They make this wonderful chirp. It's a cosmic chirp.

GONZALEZ: It would sound something like ooooooowarp!!!

WEISS: it goes mmmump, like that. Mmmump.

[Whistles]

THORNE: And that combination of the observations that we make together with numerical simulations, I expect, will revolutionize our understanding of general relativity and its consequences.

NARRATOR: If the team can track down these titanic explosions, they can go after the biggest explosion of them all. LIGO holds this amazing potential, to go back to the beginning, to the first moments of space and time, the Big Bang.

WEISS: It takes you all the way back to the instant of creation. Now, imagine such a concept. Now nobody is guaranteeing us that we will see something from that, but gravity waves are the only way you will get information from that epoch. That alone is a justification for doing everything you can to try to detect them.

NARRATOR: The hope is, this new science will take physics even beyond Einstein's great theory and one day yield discoveries about space and time as fundamental as the discovery of the atom.

MCGUIRE: Most of what we know about the universe comes from electromagnetic radiation. LIGO as a project is important because it's going to potentially open up a new window on the universe.

NARRATOR: As the search for gravity waves begins, LIGO is inspiring kids and adults alike. Stargazers like these are actually becoming part of the action.

KID: Oh, cool!

NARRATOR: Because the LIGO team needs such vast computing power, it's turning to homes with computers all across the country, tying them together in a vast network. Anyone who wants to help can join the search for gravitational waves through a project called Einstein@Home.

Boy: Gravity waves are rumbles in space that they're searching for. They look for them a lot.

NARRATOR: From these ranks may well come the next generation of gravitational wave explorers.

BLACK: I hope I never stop stepping back and looking at the big picture and saying, “Instead of trying to get this one piece of electronics to work, I’m trying to detect gravity waves.” And that is something that, when you stop and you think about that, there is a moment of wonder there. You say to yourself, “What on Earth am I doing here? This is incredible.”

THORNE: I think that’s what characterizes many scientists. They are people who never lost their childlike wonder about the universe, and they’re still driven by that child-like wonder.

[Siren]

NARRATOR: LIGO is now attempting to filter out the noise and pick up the symphony of space-time...

[Horns honking]

NARRATOR: To make out the tune in the cacophony, the melody that echoes across the universe.

WEINSTEIN: And we’re now on the verge of being able to listen to the music being played on the fabric of the universe, to what you might call Einstein’s Symphony. That’s what LIGO and its sister projects are all about.

[Playing classical music]

NARRATOR: History has shown that great discoveries in science usually occur when revolutionary instruments provide new means to explore the universe. LIGO gives us a fresh set of eyes—an entirely new way to uncover the universe’s deepest mysteries. Today, LIGO stands on the brink of discovery. A dream for decades, it’s now a reality, a new branch of science just being born, an observatory unlike any other ready to hear the music of the cosmos echoing from the most distant reaches of space and time.

You got it. You got to do your end.

Yea I’m trying. I’m trying. I can’t see mine

Ok, Ok.

No, no, no. It’s right here on my tweezer.

That’s short.

Ok.

Just lift like that. Because, you see, if I have messed up somehow--

Oh, yea. Ok. I see what you mean. So you’ve made a--

If I had made a ground, that could have done you a job, Ok?

Ok.

Ok. You wouldn’t do that, would you?

Of course I could. Oh, yea. It’s easy.