Universitat de València

Lectio of Professor Dr. Barry Clark Barish delivered at the investiture ceremony as Doctor ‘Honoris Causa’ by the University of Valencia.

València, 31 May 2022

Let me begin by thanking Maria Vicenta Mestre Escriva, Rector and the University of Valencia for this honor. I also want to give special thanks to my friend and colleague, Professor Juan Fuster, for his support on my behalf.

INTRODUCING MYSELF

I will begin today, by telling you a little about myself. I was born in Omaha, Nebraska in the United States. My parents were working class people and neither went to college, but they always encouraged me to get an education. We moved to California when I was 10 years old and lived near Hollywood, where story-telling and the movies was the center of cultural life. Not surprisingly, at the age of about 13 or so, I wanted to be a fiction writer. It was only in high school when I had algebra, calculus and some science that I decided to study technical fields. For me, that meant engineering and I went to the University of California, Berkeley.

It was in Berkeley that I took physics, quickly grew to love it, and have pursued it as my career from that time till today. I also met my wife in Berkeley, so that was a transformative time for me. After receiving me PhD I came to Caltech as a postdoctoral scholar and have been there ever since as a professor. My role models were Enrico Fermi, the great Italian physicist, as a student and that inspired me to go into nuclear and particle physics. At Caltech, I had the good fortune to have Richard Feynman as a friend and colleague for many years, and he also had a large influence on my career.

As for me career, I have been a particle physicist, doing experiments on the major accelerators in the world, and have even designed accelerators. But, the physics for which I received the Nobel Prize was for the discovery of 'gravitational waves' which I will talk about today, hopefully at a level that will give you a sense of what we discovered and why it is important. So, let me begin.

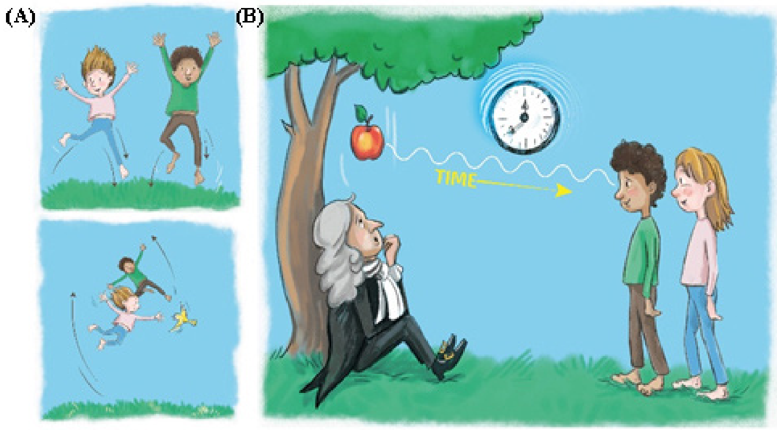
Imagine you could choose a new set of eyes that would help you see things you have never been able to see before. Maybe you would choose X-ray vision, like in the movies, or maybe you would prefer to zoom into tiny things and see the wonders of the microscopic world. Science has recently gained a new set of eyes—a new way to look into the mysteries of the universe—using gravitational waves, which are waves produced by gravity itself. In the next few minutes, I will take you on a journey that begins with an explanation of gravity—from the classical perspective of Isaac Newton to the modern and more complex view of Albert Einstein. Then, I will explain how movements of massive objects create gravitational waves, which are ripples in space and time, and how they can be used to explain mysteries of the universe, and even help us to understand the origins of our own planet Earth.

GRAVITY—FROM NEWTON TO EINSTEIN

Let's begin our journey in 1687 when the great English mathematician and physicist Sir Isaac Newton published his famous book, The Principia, in which he presented his unified theory of gravity – the first "universal" theory in science. It explained gravity, whether for the apple falling from the tree, the moon traversing around the earth, the earth around the sun, the tides, or everywhere involving gravity. Newton's theory stated that the gravitational force between two objects is proportional to the product of their masses and inversely proportional to the square of how far apart they are. This may sound complicated, but it means that the more mass objects have, and the closer they are to each other, the stronger the gravitational force they have on each other. Newton's theory is the most successful theory of physics, ever. Yet, it turns out that Newton's wonderful theory has a few limitations.

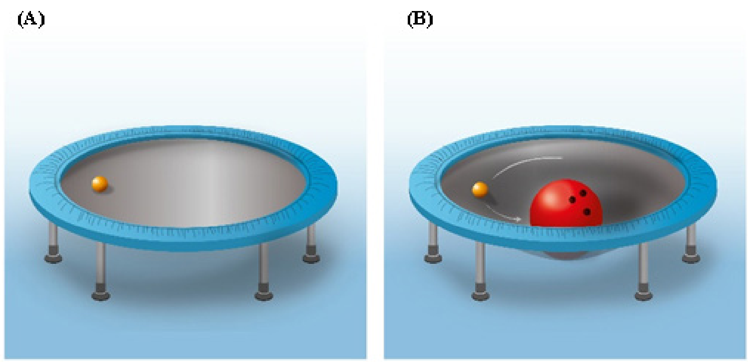
Have you ever wondered why, when an apple falls from a tree, it falls down and not up? Why, when you jump, you come back down to Earth rather than flying upwards? Newton's theory does not answer this simple question. It only tells us the amount of gravitational force the two objects exert on each other, like the force between the apple and the Earth or between you and the Earth. Newton's theory does not consider the direction of the force, either toward each other or away from each other. Even more basic, it does explain what causes the gravitational force in the first palace.

The second difficulty with Newton's theory is a little harder to grasp. Imagine that the Sun suddenly disappeared. If it disappeared right now, it would take about eight minutes before we could see that it was no longer there, because it takes eight minutes for light to reach us from the Sun. This is true for everything that happens in the universe—it takes time for the information to travel from an event to an observer. When an apple falls from a tree, it takes some time (even if only a tiny fraction of a second) for the observer to know what actually happened. Newton's theory does not take this time interval into account so, according to his theory, the observer sees the apple falling at exactly the same moment that it actually falls. We know that this is not possible; therefore, we conclude that something is missing in Newton's theory.



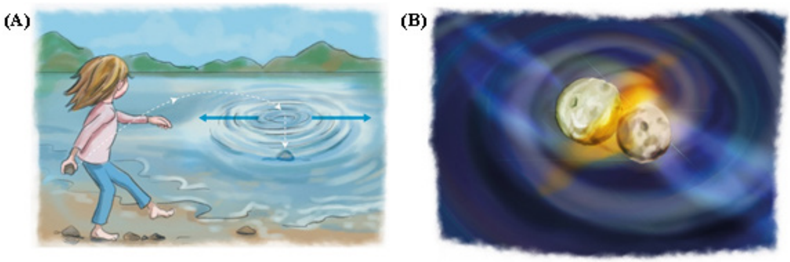
How can we solve these problems with Newton's theory? More than 200 years after Newton, the beloved physicist Albert Einstein produced a solution. In 1915, Einstein published a new theory of gravity called the Theory of General Relativity. Einstein's theory has a completely different way of describing gravity, that enable us to understand what Newton's theory was unable to explain. This does not mean that Newton's theory was wrong—it just means that it was incomplete, and that the newer theory helps us understand things in a deeper way. Einstein's theory says that, around any massive object, space and time are distorted or curved, and this creates a pull toward that object.

Imagine placing a marble on a flat surface, a stretched membrane or trampoline. The marble will stay where it was placed. However, if you put a large bowling ball at the center of the trampoline, it will the curve the surface such that the marble will fall towards the center of the trampoline. The presence of the heavy bowling ball distorted the space occupied by the trampoline in a way that made the marble move towards the bowling ball, as if attracted by it. That is basically what happens in Einstein's theory of general relativity. The presence of any mass distorts the space around it in a way that creates an attraction between masses. This picture of gravity answers the question that Newton could not answer: why (and how) does gravity create an attractive force, and why do you fall toward the Earth when you jump up? The second problem, which relates to time, was also solved by Einstein because his theory takes the speed of light into account.



WHAT ARE GRAVITATIONAL WAVES?

One of the predictions of Einstein's theory of general relativity is that gravity should have waves—gravitational waves. A simple way to think about gravitational waves is to imagine yourself by a still pond…then you throw a rock into the pond. The rock makes a splash and drops to the bottom of the pond. Although the rock is now resting at the bottom of the pond, you can still see the effect it had on the surface of the water, where ripples (or waves) move from the point where the rock entered outward (Figure 3A). This is also the way to visualize what happens with gravitational waves. What makes a gravitational wave is not a rock falling into a pond, but rather the motion or collision of massive objects in space.



CHALLENGES AND SUCCESSES OF DETECTING GRAVITATIONAL WAVES

After Einstein's theory predicted the existence of gravitational waves, experimental physicists started trying to detect them. I myself have dedicated more than 20 years of my life developing methods to detect gravitational waves—and I am still doing so. It turns out that, when it comes to gravitational waves, we have both a big misfortune and a big fortune. The misfortune is that we cannot currently make gravitational waves in our laboratories, because they are just too weak for us to detect with the techniques we have available. This is a misfortune because good experiments are ones where we understand everything involved, and that is accomplished in a laboratory.

On the other hand, we were blessed with a great fortune that nature, itself, creates gravitational waves that are much stronger than any we could possibly make in our laboratory. This means that some astronomical events that create gravitational waves—two of which I will mention—can potentially be detected with our present, state-of-the-art detectors. Though these events must be the most violent and energetic astronomical events in the universe for us to detect them, they still occur frequently enough to study. The most violent events in the universe are explosions and collisions of extremely dense and heavy objects.

When it comes to violent collisions in space, the most energetic are collisions of massive compact objects such as black holes and neutron stars. Black holes are the most massive objects known in the universe, and they have such powerful gravitational attraction that they “swallow” anything that comes near them, even stars. Nothing can escape from inside black holes, not even light—hence their name. Neutron stars are the remains of stars that have burned up their fuel and collapsed. They are extremely dense and consist mainly of neutral subatomic particle called neutrons.

In 2015, the first gravitational waves were discovered by my two colleagues, Rainer Weiss, Kip Thorne and myself. We won the Nobel Prize in Physics, just two years later, in 2017. Usually, it takes at least 20 years before scientists receive a Nobel Prize for their work, but the discovery of gravitational waves was of special importance. Since those first observations of gravitational waves from the collision of two black holes, we detected collisions between two neutron stars.

HOW WE DETECT GRAVITATIONAL WAVES

When we detect gravitational waves, we actually measure the distortions (ripples) that they create in space and time. When these distortions arrive at our detectors, they are incredibly small—much smaller even than the size of a single proton. To measure such small signals, our detectors must have greater accuracy than 1/1000 the size of a proton! As you can imagine, this is extremely hard to achieve, and it requires the use of a very special technique called interferometry. I will not describe it here in detail, but interferometry uses the interactions between laser beams to spot very small contractions and expansions of space. To make such sensitive measurements, we need to isolate our equipment so nothing can disturb our measurements—even a tiny movement could swamp the signal we are looking for. One source of disturbance is the movement of Earth itself, which shakes as it revolves on its axis (this shaking is too mild to be felt by humans, but it is detectable by sensitive instruments). This means that we need to float our measuring instrument, so that it does not pick up the Earth's movements.

It has been extremely challenging to build instruments for measuring gravitational waves. The instrument we use is called LIGO, which stands for Laser Interferometer Gravitational-Wave Observatory. LIGO is a few kilometers long. Building and operating it cost more than 1 billion dollars. Much of my work still involves developing the technologies that enable us to achieve greater sensitivity in the detection of gravitational waves, without unwanted movements ruining our measurements. Many people ask me if it is frustrating to work on the same problem for more than 20 years. My answer is absolutely not! I have had a great deal of fun solving problems along the way, and it is a great privilege to do something that no one has ever done before.

GRAVITATIONAL WAVES: A NEW WINDOW ON THE UNIVERSE

What is the importance of gravitational waves in understanding the universe? First, gravitational waves help us verify whether Einstein's theory of general relativity is indeed correct, or maybe, like for Newton, there is a theory needed beyond Einstein's.

Second, gravitational waves can help us view the universe in a totally new way and we are just beginning with the observations of LIGO. This is a little like for Galileo Galilei, 400 years ago, who looked at the sky for the first time with a telescope and discovered that Jupiter had four moons. We can use gravitational waves to look at the universe in a completely different way with a "gravitational telescope". Hopefully, what we will learn will be as rich as what has been learned using telescopes since Galileo's time.

FINAL COMMENTS

I have been fortunate to have had a rich and rewarding career, a wonderful wife and family, and many happy times. Being an American scientist honored here in Spain, validates the fact that 'science has no border.' We speak the same language of science whether we are in California, Spain or Russia. I only hope that we can do the same between the countries of the world.

Thank you.

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