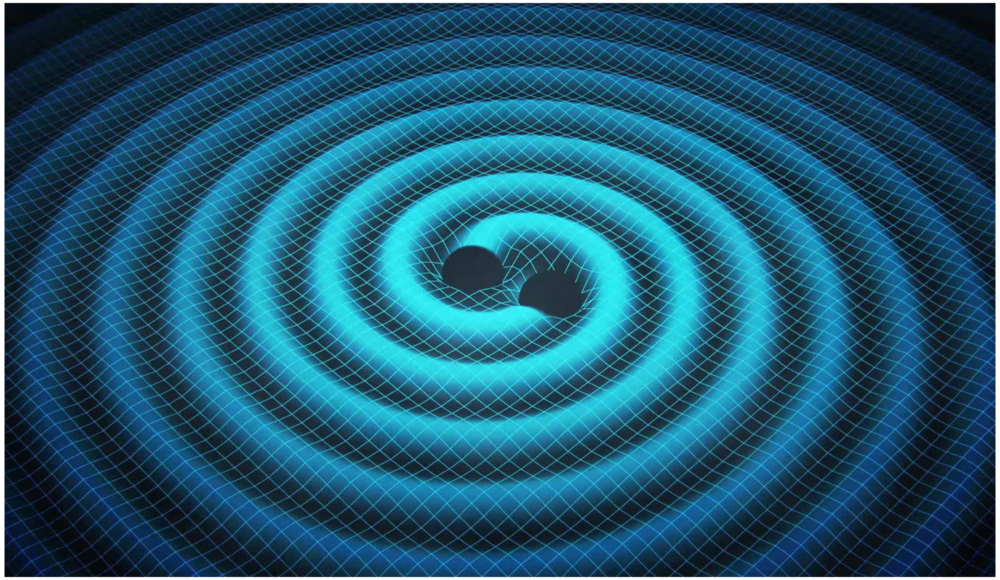
Ripples in the fabric of the Universe

The detection of gravitational waves directly for the first time opens a new window



Merging black holes distort the fabric of space-time and emit gravitational waves.
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ASTROPHYSICAL SERIES

Jonathan Freundlich

Hundred years after the publication of Albert Einstein's general relativity theory, gravitational waves have been detected directly for the first time. The observed ripples in the fabric of space-time come from the merger of two black holes and open a new window on the Universe.

What is gravity?

Our attraction towards the Earth, which makes us stick to the ground instead of flying away, the movements of planets around the Sun or of the Moon around the Earth all have a common origin. While classical mechanics describes it as an invisible, gravitational force, Albert Einstein's general relativity theory explains it as a property of space-time itself.

According to general relativity, space and time are intimately related in a space-time fabric which is not fixed once and for all and actually depends on its matter and energy content. A massive object such as our Sun bends this flexible fabric similarly as a heavy ball would curb a stretched piece of cloth. If you throw a marble on the **curbed** cloth, it would fall towards the ball or circle around it. Precisely what would be expected from the gravitational force. In fact, general relativity considers gravity as a deformation of the space-time fabric: the Earth distorts space and time in such a way that we are attracted towards our planet.

General relativity gave a framework to understand the structure of the Universe, predicted the existence of black holes, and also had a very practical application: without taking into account the bending of space-time around the Earth, the GPS systems you may sometimes use to locate yourself wouldn't work!

Gravitational waves

If space-time can be distorted by massive objects such as stars or black holes, some **distortions** could also propagate across space and time like ripples or waves at the surface of a water pond. When you throw a stone in a pond, it first

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distorts the water surface locally but then creates ripples that propagate outwards. If space-time is flexible enough to bend, it could also be able to ripple, hence gravitational waves. While the ripples in the water pond depend on the size and weight of the stone you throw, gravitational waves depend on the masses of the objects generating them.

Only the most massive objects and the most violent events are capable of generating gravitational waves that could actually be measured: collisions of neutron stars or black holes, **supernovae** explosions, or maybe the very first moments after the Big Bang.

The LIGO experiment: a new window on the Universe

When a gravitational wave passes, our local space is successively stretched and compressed, but differently in each direction. The LIGO experiment involves two detectors at different places in the United States, each of them comprising two 4-kilometer long perpendicular arms whose relative length is very very precisely measured by a laser beam.

The experiment is sensitive to a tiny fraction of the size of an atom nucleus! If a gravitational wave comes past, the relative length of the two arms changes. And this is what has just been observed: a space-time distortion whose pattern corresponds exactly to what we would expect from the merger of two black holes. This is a spectacular confirmation of Albert Einstein's general relativity!

The LIGO measurement was not only the first direct detection of a gravitational wave, but also the first "observation" of a black hole merger. It opens a brand new field of astrophysics: while we usually mostly observe distant astronomical objects and events from the light they emit, gravitational waves will enable us to "hear" the space-time distortions they create.

(Jonathan Freundlich is a postdoctoral research assistant at the Paris Observatory, working on star formation and galaxy evolution. He can be reached at jonathan.freundlich@obspm.fr)

THE PROFOUND DISCOVERY

- **The bending of space-time around our Sun has been observed as early as 1919, a few years after the publication of the theory. Light indeed follows the curvature of space-time, which results in slight variations in the observed positions of stars whose light passes very close to the Sun: the real position of these stars has not changed, but it appears so because their light has been bent.**
- **The first evidence for the existence of gravitational waves was indirect. When two very dense neutron stars orbit closely around each other, their rotation speed increases because of the emission of gravitational waves. This effect has been measured since the 1970s and corresponds exactly with the predictions of general relativity.**
- **LIGO stands for "Laser Interferometer Gravitational-wave Observatory". Within the detector, a laser beam is split between the two arms and then recombined, forming an interference pattern that is highly sensitive to the relative length of the arms.**
- **The signal observed by LIGO is very weak and should not be confused with vibrations originating from a passing truck: the two detectors have to be properly isolated, and the measure confirmed by both. An additional LIGO detector should be built in India soon (LIGO-India), which would make the detections even more reliable.**