The instruments to detect gravitational waves

A global network of interferometers

To localize the source of a gravitational wave in space, it is necessary to have multiple interferometers in a network.
Besides the two LIGO detectors in the USA and Virgo in Italy, the network of interferometers also includes the KAGRA detector in Japan and the GEO600 detector in Germany. This latter detector is less sensitive, but has made important contributions to the development of new technologies. In India, the IndIGO detector, a twin of LIGO, is in the construction phase.
At least three detectors are necessary to triangulate the position of a source. A precise location makes it possible to alert other instruments, such as Earth- and space-based telescopes, and to provide indications on how to orientate these instruments in order to observe other possible electromagnetic emissions. In this way, a new type of astronomy has been created, so-called *multi-messenger astronomy.*

The interferometers

Detecting gravitational waves is a complex task, because gravitational interaction is by far the weakest of the four forces in nature. To study gravitational waves, physicists have designed special detectors, which have required cutting-edge technological solutions.These detectors are laser interferometers, which are composed of two orthogonal arms of kilometric length (4 km for LIGO, 3 km for Virgo), along which laser beams are propagated. These beams are then reflected by mirrors in order to lengthen their path and finally recombined to produce an interference pattern.
When a gravitational wave crosses the interferometer, it produces a variation in the length of the arms: one stretches while the other shrinks. These length variations, which are much smaller than the diameter of an atomic nucleus (less than one billionth of a meter), produce a dephasing of laser light that is observed by the detector.
One of the two experiments to have detected gravitational waves is Virgo, a Michelson laser interferometer built to search for gravitational waves. Virgo is located in Cascina, Pisa, on the plane of the Arno valley, and is hosted by the European Gravitational Observatory (EGO), which was founded in the year 2000 by the Istituto Nazionale di Fisica Nucleare (INFN) and the Centre National de la Recherche Scientifique francese (CNRS). One of the high-technology mirrors of the Virgo gravitational-wave interferometer.

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One of the high technology mirrors of the gravitational waves interferometer Virgo.

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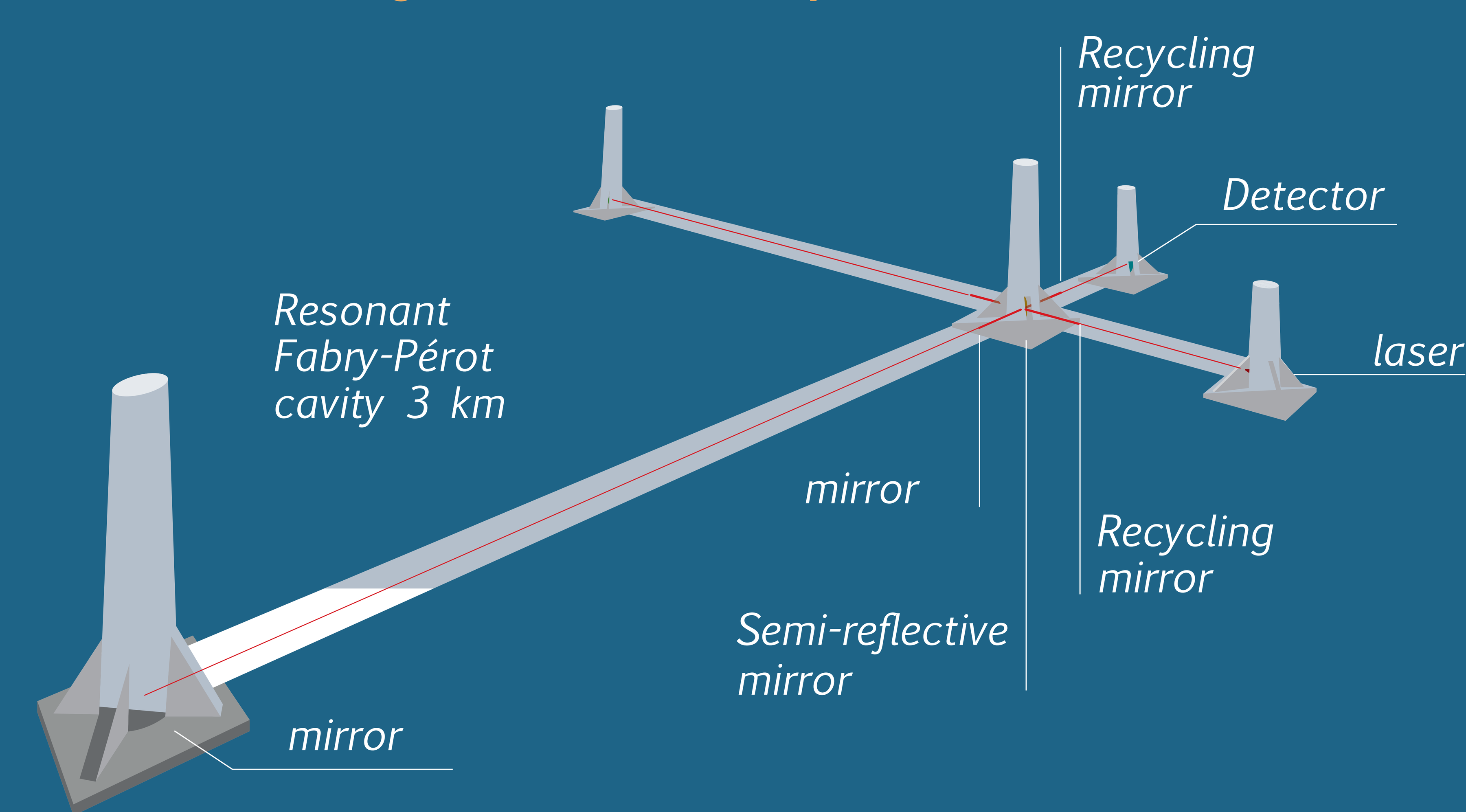
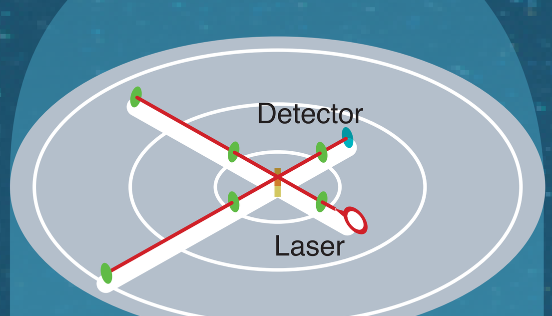
Inside one of the two Virgo arms.
Each arm is 3 km long. Within the tube, laser light circulates and a very high vacuum is created, slightly less than interstellar vacuum, in order to reduce the effects of light dispersion that air molecules could cause destroying the measurement.

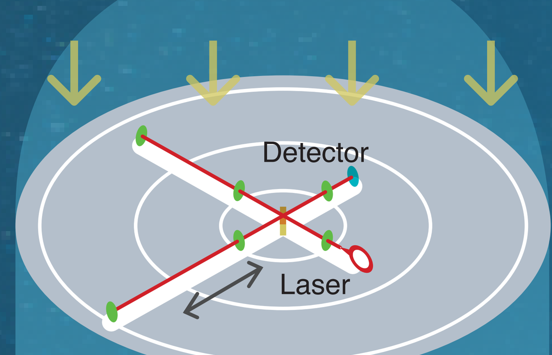
Virgo interferometer component schematics.



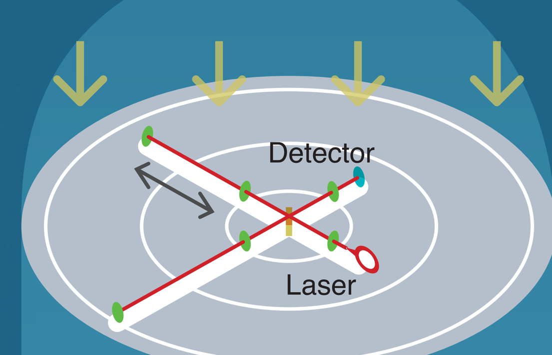
How an interferometer works



The two beams, coming from the arms, are recombined (in phase opposition), so that no signal of light is formed in the detector.



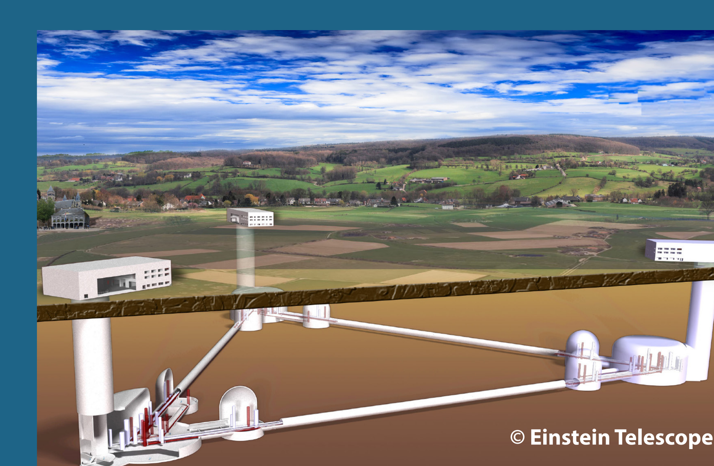
A gravitational wave crosses the interferometer producing an infinitesimal variation of the arms.



The variation induces a dephasing of the two light beams that is observed by the detector. The signal measured by the detector is correlated to the amplitude of the gravitational wave.

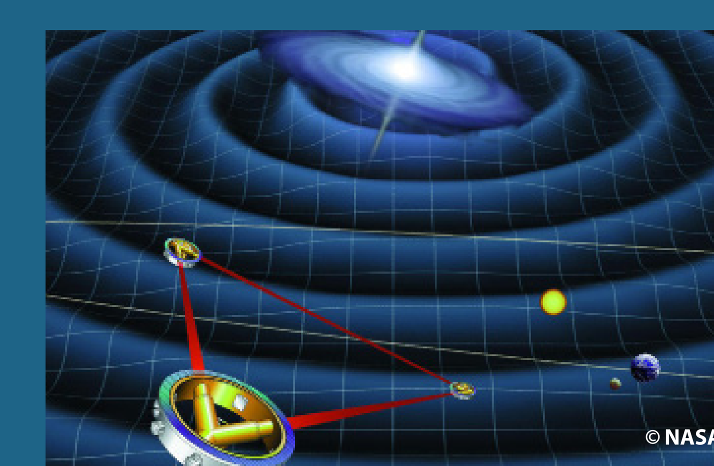
The future: ET and LISA

Around the year 2030, gravitational-wave detectors that are more sensitive than those of the present day, will be in operation. We will thus be in a position to both listen far deeper into the Universe and to widen the catalogue of possibly observable gravitational wave sources. The Einstein Telescope (ET), a European project, and Cosmic Explorer, an American project, will be in Earth-based operation and are the natural evolutions of Virgo and LIGO.
LISA, the first interferometer to detect gravitational waves in space, with arms formed by spacecraft that will be 2.5 million kilometres apart and in heliocentric orbit, will perform different and complementary measurements with respect to ground-based detectors. The network will be capable of efficiently covering all of the the possible gravitational-wave spectrum.



© Einstein Telescope

A possible artistic representation of the third-generation interferometer, Einstein Telescope. The three tunnels in which light propagates are underground, in order to reduce the effects of seismic noise. The mirrors are cooled to a temperature of a few Kelvin, in order to reduce thermal noise.



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An artistic representation of the LISA space detector. Three laser interferometers continuously measure the distances between three pairs of test-masses, which float freely inside three satellites. The system orbits around the Sun at the same distance as the Earth.

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