Advanced Virgo

Towards Gravitational Wave Astronomy

Gravitational waves: a new way to explore the Universe

Gravitational waves (GW) are tiny ripples in the fabric of space-time that are produced by violent events in the universe, such as the collision of black holes and supernova explosions.

GW are emitted by accelerating masses, in much the same way as electromagnetic waves are produced by accelerating charges – such as electrons (the current) in a radio antenna.

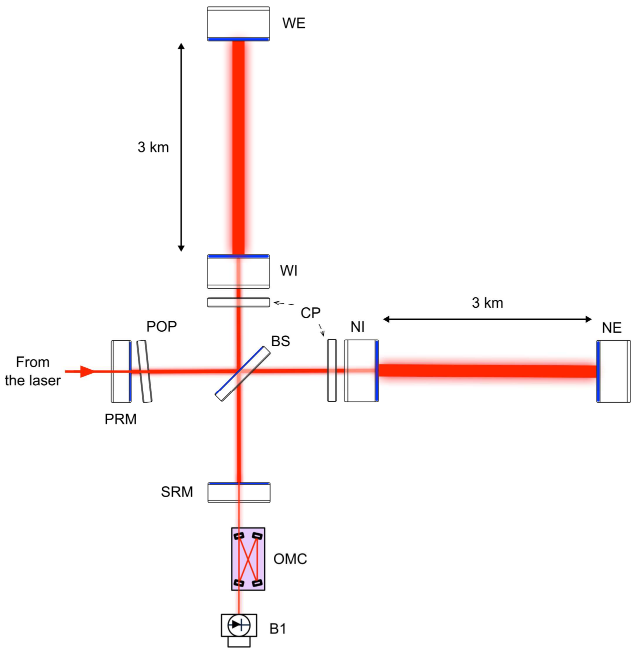
Predicted by Albert Einstein in 1916 as a consequence of his General Theory of Relativity, the direct detection of GW will open a new astronomy, allowing totally new insights into the universe.

With GW we might probe parts of the universe hidden by cosmic dusts, or give a completely different perspective to astronomical events that are both visible and invisible in the electromagnetic spectrum.

Aerial view of the Advanced Virgo site in the vicinity of Cascina, near Pisa, in Italy. The upgraded interferometer will use the same Virgo infrastructure, at EGO (European Gravitational Observatory), consisting of two 3 km long arms and several buildings in the central area and at both arm ends.

What is Advanced Virgo?

Advanced Virgo will be a second generation GW detector and will be developed by upgrading the original Virgo interferometer. With a sensitivity 10 times better than that of first generation detectors, Advanced Virgo will be able to explore a Universe region with a radius of several hundred million light years, collecting tens of events per year of observation.



Working principle

GW, being perturbations of the structure of space-time, produce minuscule changes in the relative distances of free masses. The Advanced Virgo interferometer will monitor such distances by shooting laser beams in two perpendicular directions and studying the interference pattern after beam reflection on mirror test masses suspended at a distance of 3 km.

Advanced Virgo represents the evolution of the first generation interferometers (Virgo, LIGO, GEO600) and is expected to be operative around 2015, together with the two Advanced LIGO interferometers (aLIGO), which are undergoing a similar sensitivity enhancement.

Sensitivity will be improved by increasing the laser power, using larger beam spots, using larger and better quality mirrors suspended with tiny fused silica wires, adding a signal recycling cavity and increasing the finesse of the 3 km long Fabry-Perot cavities.

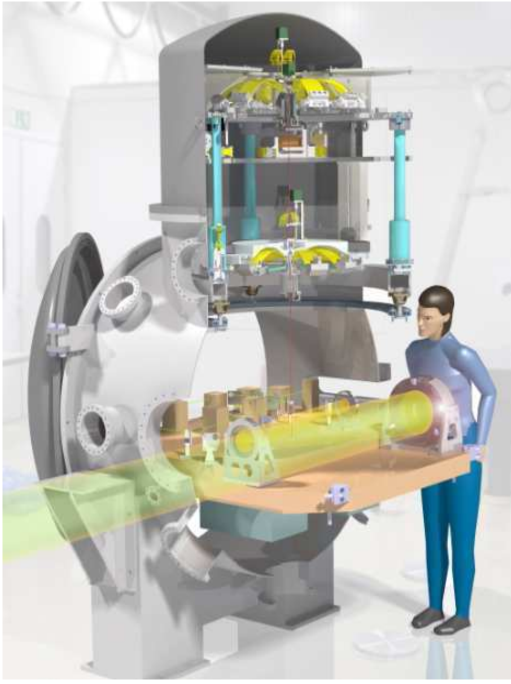
***Virgo** was built by the Centre National de la Recherche Scientifique (CNRS, France) and by the Istituto Nazionale di Fisica Nucleare (INFN, Italy). The National Institute for Subatomic Physics (Nikhef, the Netherlands) will also contribute to the building of Advanced Virgo, which will also be supported by the Hungarian Academy of Sciences and the Polish National Science Centre.*

Techniques and Challenges

Attaining the goal sensitivity will imply pushing several components and techniques beyond present limits.
The test masses will be heavy mirrors (42 kg) made of ultra pure fused silica, suspended with thin fused silica wires, characterised by low absorption and low mechanical losses; these will also be illuminated on their periphery by auxiliary infrared lasers, to keep their temperature uniform and to preserve the shape of their surface. Improved coating techniques will be used to further reduce optical and mechanical losses.
A fibre amplifier is being developed to realise a laser providing 200 W; the high power allows to reduce shot noise (photon number statistical fluctuations).
Pushing the noise limit below 10 Hz will require improving the performances of the mirror anti-seismic suspensions.
Finally “quantum non-demolition” methods will be attempted to enhance sensitivity in frequency ranges where interesting GW sources are expected.

Ultra-High-Vacuum

Inside view of the North arm. The pipe on the left hand side is the 3 km long, 1.2 m diameter, vacuum pipe for the free propagation of the laser beam. The inner residual gas pressure is less than a millionth of a millionth of an atmosphere. The Virgo vacuum system, about 6,000 m^3, is, by far, the largest ultra-high-vacuum system in Europe.



Optical Benches

The new suspended injection and detection optical benches will provide seismic isolation and in-vacuum location for the delicate optical elements of the system, such as the photodiodes devoted to the detection of the output signal of the interferometer.
The minimal stray-light scattered off the almost perfect optical surfaces will be absorbed by a sophisticated system of baffles made of special absorbing materials, such as DLC (Diamond Like Carbon).

World wide Collaboration and the Future

Second generation detector activity will begin in 2016, after several months of commissioning. As with first generation Virgo and LIGO, time coincidences among several detectors will disentangle genuine signals from those produced by local noise and help to localise the source in the sky by measuring GW arrival time difference. Virgo/LIGO quasi-real-time data exchange will enable complete and coherent data analysis, enhancing its effectiveness. Coincidences with neutrino and gamma ray detectors will help in understanding the nature of the originating astrophysical phenomena, starting “multi-messenger astronomy”.
Second generation detector production will likely continue up to the 2020-2030 decade, awaiting the start of the Einstein Telescope (ET), the 10-km arm underground cryogenic detector, the conceptual design of which has been recently completed. Meanwhile, two new interferometers will come into operation: Indigo, the third LIGO interferometer, translated to India; and KAGRA, the 3-km arm Japanese underground interferometer, designed to accept, at a later stage, cryogenic test masses.
The combination of Advanced Virgo/LIGO, Indigo, KAGRA and ET may make it possible to follow the GW train emitted by an inspiralling binary star during the hours before coalescence. This will constitute an unprecedented laboratory to study matter in strong gravity, probing General Relativity to extreme limits.

The Virgo Collaboration *(https://wwwcascina.virgo.infn.it/) is a scientific collaboration constituted by several French CNRS laboratories (APC-Paris, Artemis/IPR-Nice, ESPCI-Paris, LAL-Orsay, LAPP-Annecy, LKB-Paris, LMA-Lyon), several Italian INFN laboratories (Firenze/Urbino, Napoli, Padova/Trento, Perugia, Pisa, Roma La Sapienza, Roma Tor Vergata), Nikhef (Amsterdam), Radboud University (Nijmegen), Wigner RCP-RMKI (Budapest) and Polgraw (Warszawa).*

The European Gravitational Observatory *-* ***EGO*** *(http://www.ego-gw.it/) is a CNRS-INFN consortium created to host Virgo, keep it working, manage the site and, in general, promote theoretical and experimental research in the field of gravitational physics in Europe.*