

Gravitational Waves

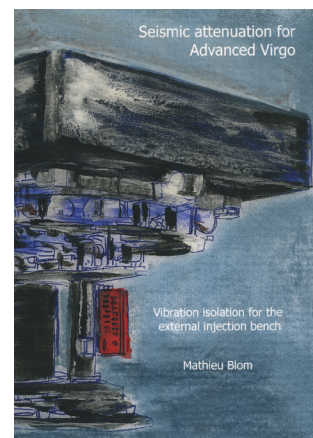
listening to a chirp in the universe

MultiSAS systems have been assembled and tested at Nikhef, and were subsequently installed at the Virgo site and pre-commissioned. All ground vibrations are attenuated by at least a million times.



FOM projectruimte
Chris Van Den Broeck

Chris Van Den Broeck received a FOM 'projectruimte' grant for his proposal *"The discovery of gravitational waves with Advanced Virgo and LIGO"*: "Systems that include a black hole, have exceedingly complex gravitational-wave signal waveforms. I will develop a method that will boost detection efficiency by searching with the most advanced waveform models, that will deliver fast information to astronomers and will enable the full scientific exploitation of the signals."



Matheus Ronaldus Blom
9 December 2015



Management
prof.dr. J.F.J. van den Brand

Albert Einstein predicted the existence of gravitational waves in 1916, the year after the final formulation of the field equations of general relativity. He showed that the linearised weak-field equations had wave solutions: transverse waves of spatial strain that travel at the speed of light, generated by time variations of the mass quadrupole moment of the source. In 1974 Hulse and Taylor discovered the binary pulsar system PSR B1913+16, and the observed energy loss was in agreement with predictions from the quadrupole formula. Subsequent analysis led to the recognition that direct observations of the amplitude and phase of gravitational waves (GW) would enable studies of additional relativistic systems. This will provide new tests of general relativity, especially in the dynamic strong-field regime. Nikhef participates in the Advanced Virgo project and together with LIGO, this LIGO Virgo Consortium (LVC) pursues the first direct detection gravitational waves by developing a worldwide network of second generation laser interferometric GW detectors. These instruments will have ten times enhanced sensitivity with respect to initial LIGO and Virgo instruments, and thus a 1000 times larger accessible volume of the universe. The detectors are undergoing a commissioning phase in 2015 with first LVC data taking with both Advanced LIGO interferometers scheduled to start in September 2016. Joint data taking with Advanced Virgo is planned for the second half of 2016.

Instrumentation for Advanced Virgo

Advanced Virgo is a major upgrade, with the goal of increasing the sensitivity by about one order of magnitude with respect to initial Virgo in the whole detection band. Nikhef contributes to Advanced Virgo by providing cryogenic vacuum links in the interferometer arms. Vacuum pressures below 10^{-9} mbar are required to suppress frequency noise introduced by scattering the laser beam from fluctuating residual gas atoms in the interferometer arms. Four cryogenic systems to achieve such ultra-high vacuum pressures have been designed at Nikhef. These so-called cryolinks were installed and commissioned in 2015, and are now fully operational in Advanced Virgo. Also the linear alignment system that is used for the angular alignment of Virgo's core optical components, has been upgraded. Sensing can now be accomplished at

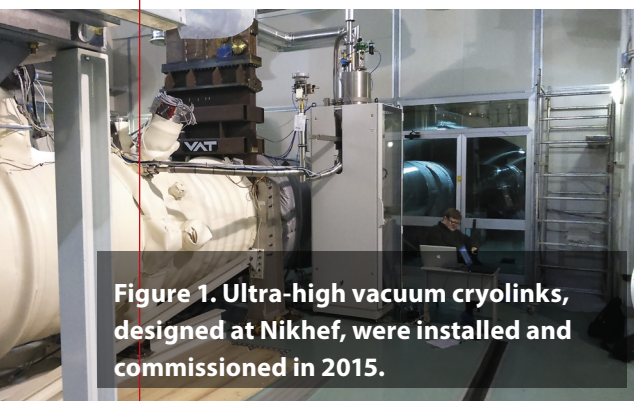


Figure 1. Ultra-high vacuum cryolinks, designed at Nikhef, were installed and commissioned in 2015.

DC and can accommodate modulation frequencies as high as 131 MHz. Demodulation is carried out with digital techniques. Also novel vacuum compatible low power galvoscanners have been installed. These scanners are needed for the automatic beam centering on the RF quadrant photodiodes used for differential wavefront sensing.

Nikhef leads the Suspended Benches project subsystem, and has improved the external benches for the injection and detection optical tables, as well as for the optical tables at the end of the interferometer arms. All ground vibrations are attenuated by at least a million times. In this manner Virgo's sensing elements are now under

stable conditions. This ensures that the seismic motion of the angular alignment sensors (and related pick-off telescopes) placed on the suspended benches will not couple to the output of the detector through scattered light. All five so-called MultiSAS have been assembled and tested at Nikhef, and were subsequently installed at the Virgo site and pre-commissioned; full commissioning is foreseen before summer 2016.

In addition, Nikhef has responsibility for the input mode cleaner (IMC). The IMC is a high finesse triangular cavity with 145 m length which is used to clean the injected laser beam from unwanted optical modes. Moreover, the IMC is part of Virgo's elaborate frequency stabilization scheme. Fig. 2 shows the dihedron that is installed on the new injection bench. Finally, Nikhef is responsible for the development and commissioning of three new phase cameras. These instruments can provide accurate images of the spatial distribution of amplitude and phase of the various circulating laser fields (both the carrier and sidebands are imaged). These instruments are of paramount importance for the active compensation of the aberrations of the transmissive optics of the interferometer, which otherwise could compromise the detector stability and would limit the usable optical power. Installation of the first unit took place in 2015, while the remaining systems will be installed in early 2016.

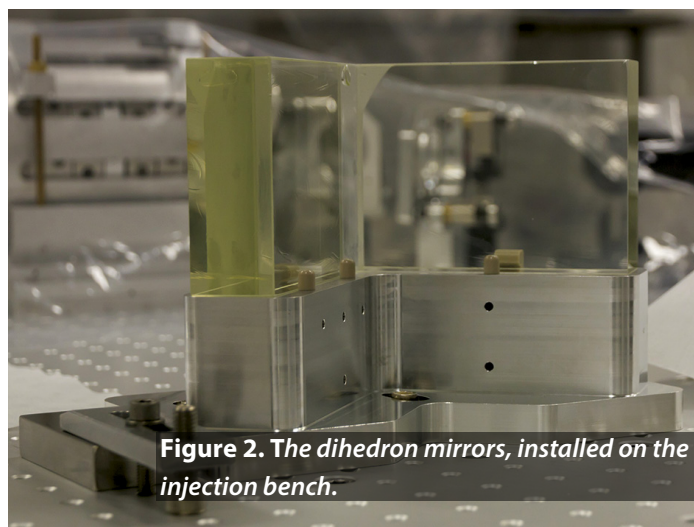


Figure 2. The dihedron mirrors, installed on the injection bench.

The three km long north pipe of Virgo.



Data analysis

Nikhef has made leading contributions to the LIGO–Virgo analysis effort, and at present Chris van den Broeck is Data Analysis Coordinator for the Virgo Collaboration. Software has been developed that allows extracting fundamental physics information from the signal of merging compact binaries. This includes individual component masses and spins, the sky location and orientation of the binary, and the distance to the source. Coalescence of compact binaries that are composed of neutron stars (NS) and black holes (BH), is considered one of the most probable sources for the first direct detection of GW events. The so-called TIGER (Test Infrastructure for GEneral Relativity) pipeline has been developed, to test the genuinely strong-field dynamics of general relativity in a model-independent way up to seventh order in a post-Newtonian expansion of the GW phase.

Significant effort has been devoted to characterise the equation of state (EOS) of neutron stars by using future data from NS–NS coalescences. Note that the NS EOS represents one of the most unknown observables in astrophysics. In addition, the Nikhef Virgo group has developed a dedicated data analysis pipeline called Polynomial Search. This pipeline is used in the search for continuous gravitational waves from fast-spinning neutron stars in binary systems.

Einstein Telescope

Einstein Telescope (see Fig. 3) is a new infrastructure project that will bring Europe to the forefront of the most promising new development in our quest to fully understand the origin and evolution of the universe, the emergence of the field of Gravitational Wave Astronomy. Gravitation is the least understood fundamental force of nature. Challenges include discovery and exploitation of various sources of gravitational waves, experimental constraints on the corresponding quantum (graviton) and the development of an observation-based field of research on quantum gravity. We propose that Einstein Telescope is realized in the Netherlands and will be an underground international facility containing cryogenic interferometers with 10 km arms. We have submitted proposals to both KNAW (Royal Netherlands Academy of Arts and Sciences) and NWO (Netherlands Science Organization) and propose a phased approach where Phase I will allow qualification of sites in the Netherlands. After successful site selection, next phases will involve construction, followed by exploitation.

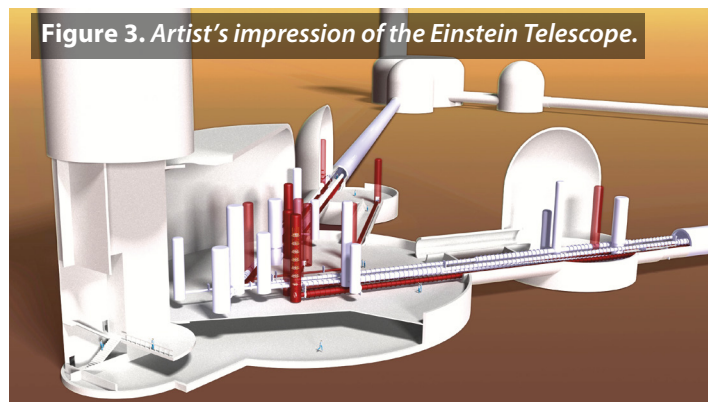


Figure 3. Artist's impression of the Einstein Telescope.

