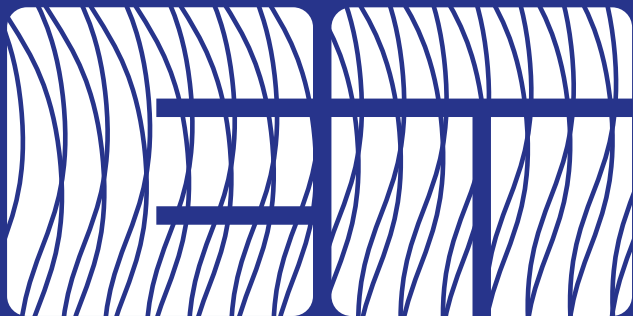




**EINSTEIN
TELESCOPE**

**TECHNOLOGIES
OF TOMORROW**

**Engage.
Innovate.
Explore.**

Einstein Telescope A FUTURE GRAVITATIONAL-WAVE OBSERVATORY

The Einstein Telescope (ET) is a proposed third-generation gravitational-wave (GW) observatory, poised to revolutionise our comprehension of the universe and to put the fundamentals of gravity to the test. Designed as an advanced underground facility, ET aims to enhance and expand upon the successes of second-generation laser-interferometric detectors such as Advanced Virgo and Advanced LIGO. To achieve its goals ET requires intense developments which are currently being carried out by a large international collaboration.

ET underground facility. 3D visualisation
(Marco Kraan / Nikhef)

A 3D architectural rendering of the Einstein Telescope (ET) underground facility. The image shows a vast, dimly lit underground cavern with a series of large, cylindrical vacuum tubes arranged in a triangular pattern. The tubes are supported by a complex network of steel beams and scaffolding. Several small figures of people are visible on walkways and platforms, providing a sense of scale to the massive structure. The overall atmosphere is one of a futuristic, high-tech scientific environment.

HOW IT WORKS

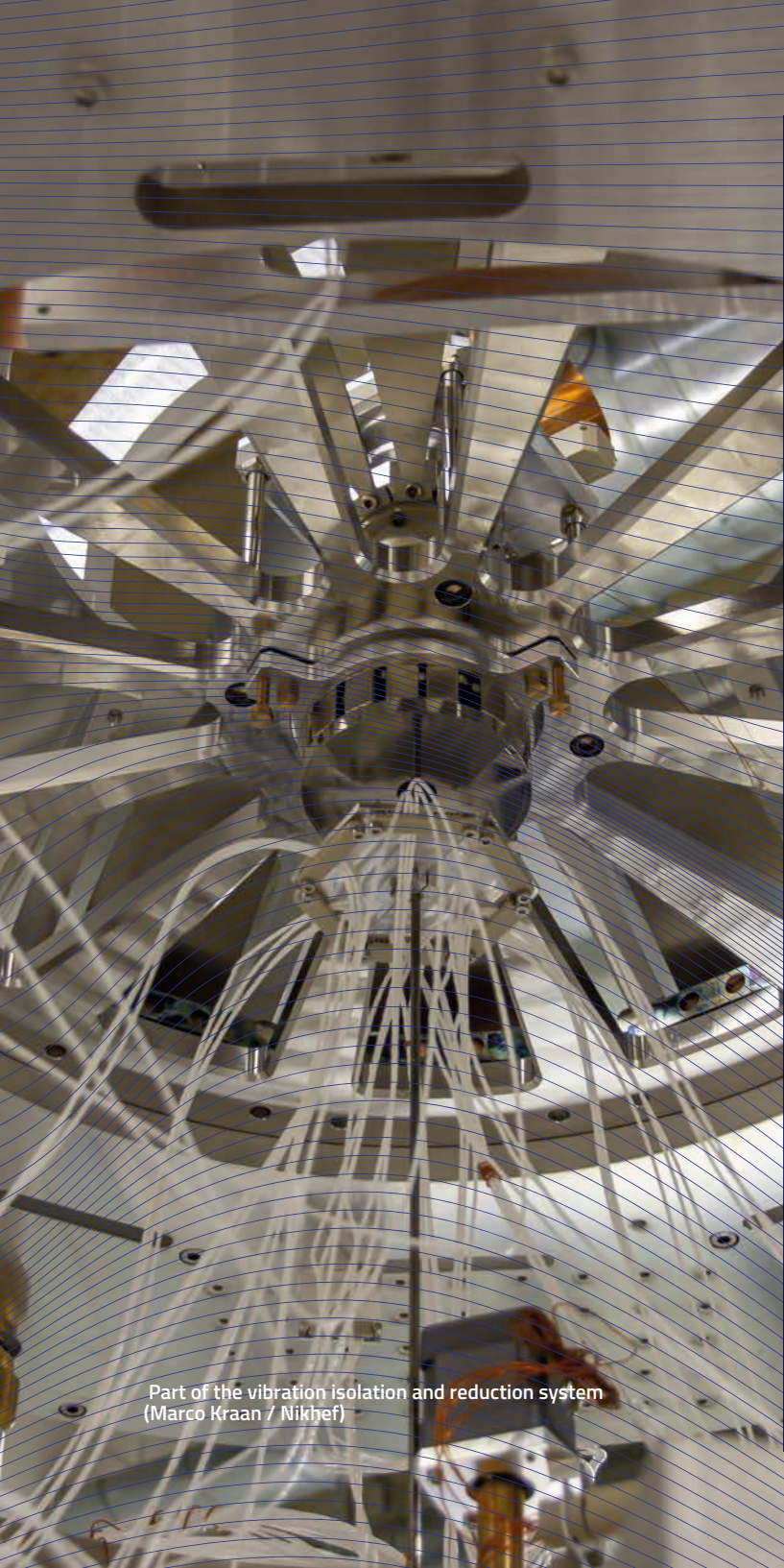
The operating principle of ET, like that of Virgo, LIGO and KAGRA, is based on interferometry. Laser beams travel through long vacuum tubes in different directions, running back and forth until they recombine and generate an interference pattern on an output screen. This method allows ET to measure with unprecedented accuracy the infinitesimal variations in the distances travelled by light inside the vacuum pipes as gravitational waves pass by (less than a billionth of a billionth of a metre). Consequently, it will detect ripples in spacetime caused by accelerating massive objects, such as merging black holes millions or even billions of light-years from Earth. This will allow us to better understand our universe and, ultimately, to shed light on its very origins.

ET underground facility. 3D visualisation
(Marco Kraan / Nikhef)

SCIENCE & INDUSTRY

Industry involvement is of paramount importance to the success of this ambitious project. It plays an essential role in driving technological advancement beyond the current state of the art, while providing the timely expertise needed to optimise production processes and reduce costs. Outlined next are the key technologies currently being developed for ET.

One of the tunnels of the Virgo gravitational wave detector
(Cyril FRESILLON/Virgo/CNRS)



SENSORS AND PRECISION MECHANICS

Everything in the external environment can disrupt the detection of GW signals. To isolate the experiment as much as possible, a massive ultra-high vacuum system will be required, as well as seismic motion attenuators for core optics, mode cleaners, benches, and mirrors.

Additionally, inertial sensors will measure earthly vibrations so they can be digitally excluded from readouts. To ensure high sensitivity, the photosensitive diodes that capture the laser interference signal will operate in cryogenic vacuum conditions.

Part of the vibration isolation and reduction system
(Marco Kraan / Nikhef)

OPTICS & OPTICAL METROLOGY

ET will rely on the precise measurement of relative length differences in kilometre-scale arms of a laser interferometer. Key optical components include super-polished mirrors with optimised coatings, an ultra-stable laser producing monochromatic beams, and additional systems for instrument control and stabilisation. Detection of the GW hinges on minute 'flickers' in the photodetector output, so ET requires low round-trip losses of below 50 ppm to achieve several hundred kW of laser power, minimal wave-front distortions, and low amplitude and phase noise with stable pointing accuracy. Improving the quality of mirror coatings to reduce optical losses is an area where industry expertise in advanced materials and precision manufacturing is crucial.

Virgo scientist working on one of the mirrors of the detector
(Maurizio Perciballi)



LASERS

The laser source for ET requires extreme precision at a wavelength of approximately 2090 nm. Commercially available lasers need to be improved to achieve the linewidths and stabilities sufficient for ET. The implementation of novel quantum technologies, such as squeezed light sources, could be enhanced through collaboration with the photonics industry.

VACUUM SYSTEM

ET will be a massive UHV vacuum system (about 10^{-10} mbar pressure) featuring around 130 km of 1-metre diameter pipes, ensuring undisturbed laser beams between mirrors suspended to dampen vibrations and housed in 10-20 metre high, 3-5 metre diameter towers. Industries specialising in vacuum technology, such as those involved in accelerator or space applications, could provide innovative solutions for more robust and efficient vacuum systems.

The North tunnel of the Virgo detector
(Enrico Sacchetti)

ADVANCED CONTROL ALGORITHMS

ET requires advanced control systems to manage its thousands of signals and maintain the interferometers at optimal performance. Current interferometers are limited by control-generated noise at low frequencies. New algorithms, including AI methods, are crucial to overcoming this limitation.

CIVIL ENGINEERING, SIMULATION, AND MODELLING

ET is planned to be an underground facility that will require advanced tunnelling techniques and very stable foundations to support the heavy and complex equipment with extreme precision. Advancements in numerical modelling software and virtual/augmented reality, which have revolutionised the computation and visualisation of processes like ground motions, as well as the growth of Building Information Modelling (BIM) in civil engineering, represent some of the technological advancements that ET will have to fully exploit, drawing upon the expertise of capable and innovative industrial partners.

Part of the vibration isolation and reduction system
(Marco Kraan / Nikhef)

The image shows a large, multi-tiered, cylindrical cryogenic cooling system, likely for the ET project. It is situated in a cleanroom environment with a curved, ribbed ceiling and bright, rectangular light fixtures. The system consists of several stacked cylindrical sections, with various pipes, valves, and gauges visible. A person is visible on a platform near the top of the structure, providing a sense of scale. The overall atmosphere is industrial and high-tech.

VIBRATION-FREE CRYOGENIC COOLING

ET will feature core optics operating at a temperature of 10 K (-263°C). The 200 kg mirrors are suspended by very thin wires. After the initial cooldown, the operating temperature of the mirrors must be maintained solely through radiation and conduction via very low-stiffness thermal straps (heat links) to ensure that the detector's performance is not affected by vibrations from the cryogenic plant. In this scenario, companies involved in cryogenics and advanced cooling technologies could help develop ultralow noise cryocoolers and active vibration isolators compatible with the UHV low-temperature environment.

DATA HANDLING AND PROCESSING

The vast amounts of data generated by ET will require sophisticated data processing and storage solutions. Collaboration with tech companies specialising in big data, cloud computing, and AI could lead to more efficient data management and analysis tools.

ETpathfinder, an R&D infrastructure for testing and prototyping innovative concepts and enabling technologies for ET (Maastricht University)

A EUROPEAN PROJECT

The Einstein Telescope is a multifaceted European initiative, bringing together multiple countries and institutions. Each participating body focuses on a different dimension of the project, such as science, management and diplomacy. The scientific collaboration alone comprises 2,000 members across 307 institutions in 31 countries, predominantly in Europe. Since 2021, ET has been included in the ESFRI Roadmap, the European Strategy Forum on Research Infrastructures' document that identifies the priority projects for Europe. The project receives support from the European Union through two Horizon Europe projects: the Einstein Telescope Preparatory Phase project (2022–2026), which prepared many key building blocks for approval, construction and operation; and the ET-COMPASS project (2027–2028), which focuses on further developing organisational and management aspects required to move from the preparatory to the operational phase, with key activities of this transition coordinated by the Einstein Telescope Organisation (ETO).



OPPORTUNITIES FOR INDUSTRY

The construction of the Einstein Telescope is expected to begin before the end of this decade, with an investment estimated in the ESFRI proposal at more than €1.7 billion.

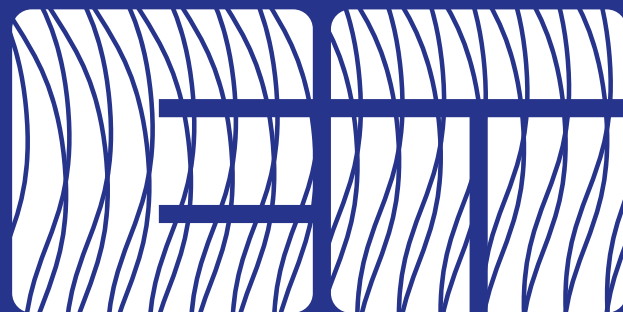
Building a world-leading, frontier research infrastructure in Europe requires substantial investment. It also demands extensive R&D effort with close collaboration between the scientific community and industry. This makes the Einstein Telescope a unique opportunity for European enterprises.

Numerous collaboration opportunities are already available, and further opportunities will arise in the coming years. For ongoing opportunities, please visit the information channels of the candidate host consortia:

- EMR candidate site:
einsteintelelescope-emr.eu
- Lausitz candidate site:
einsteintelelescope-lausitz.de
- Sardinia candidate site:
einstein-telescope.it

To stay up to date about the Einstein Telescope in general and future opportunities, visit: **einsteintelelescope.eu**

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More about the Einstein Telescope
and industry involvement:

Website: einsteintelelescope.eu

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