# The Einstein Telescope ET

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## 1. Introduction

The detection of gravitational waves (GW) with interferometric detectors is expected to take place within at most one year after the second generation of GW detectors, advanced LIGO[1] and advanced Virgo,[2] come close to their design sensitivity. While the sensitivity of these second generation detectors will be good enough to observe signals with a high Signal-to-Noise ratio at rates of a few per year at best, routine GW astronomy, which is the goal for the following generation, requires more sensitive instruments. In a European-wide effort a conceptual design study (http://www.etgw.eu/) for such a third generation GW observatory has been started in Summer 2008. The goal for the Einstein Telescope (ET) is an improvement in sensitivity by a factor of 10, with respect to the advanced detectors, and the possibility to access the 1-10 Hz frequency range, still inaccessible for the 2nd generation.

## 2. Science with ET

The Einstein Telescope will provide a wealth of new scientific information:[3]

**Astrophysics** Measure in great detail the physical parameters of compact stars [i.e., neutron stars (NS) and black holes (BH)] in a binary system,[4,5] constrain the equation-of-state of NS and solve the enigma of gamma ray bursts (GRB).[3,6]

**General Relativity** Test general relativity by comparing observations of massive binary star systems with numerical relativity (NR) predictions and constrain alternative theories of gravity (such as the Brans–Dicke theory) through the observation of NS–BH coalescences.[3]

**Cosmology** Measure cosmological parameters from standard sirens of gravity[7,8] and probe the primordial Universe through the measurement of the GW stochastic background.[3]

**Astroparticle physics** Measure or constrain the neutrino[9] and graviton masses through the detection of the GW emitted in a supernova.

## 3. Noise reduction

The improvement of the sensitivity beyond the advanced detectors by a factor of ten, challenges the Design Team with widening the limits of current technologies and finding ways of avoiding current limitations with new techniques.

**Site requirements** One key parameter for enhancing the sensitivity is increasing the arm length. 30 km of overall arm (tunnel) length is foreseen for the Einstein Telescope. In order to cut down seismic influences, especially via direct Newtonian coupling of surrounding masses to the mirrors, the so called Gravity Gradient Noise,[10,11] the baseline design foresees an underground location at a depth of about 100 m. Seismic studies assessing the seismic background are currently being made at various locations in Europe. The overall infrastructure will be designed for a lifetime of about five decades.

**Seismic isolation** The currently envisioned isolation of the interferometer mirrors from ground motion can be done with a hybrid active/passive system suspending long cascaded pendula from an actively isolated platform mounted as an inverted pendulum, in the style of the Virgo Superattenuator (SA). Measurements have shown that a Virgo SA would provide enough isolation down to a frequency of about 3 Hz for ET in an underground location with moderate seismic noise.[12,13]

**Thermal noise issues** Strategies developed for reducing thermal noise in the advanced GW detectors will be extended to suit the needs of ET. Thermal noise rises toward low frequencies and hence plays the most important role there. In ET thermal noise will be reduced by cooling the mirrors and suspensions to cryogenic temperatures and thereby reducing the thermal excitation. By choosing the right mirror material a high mechanical quality factor can be achieved, which confines most of the thermally excited motion to frequencies around the mechanical resonances of the system, cutting down the off-resonance contributions in the detection band. Increasing the beam diameter on the mirrors can reduce thermal noise by averaging over fluctuations within the beam width. Silicon or Sapphire are candidate materials for cryogenic temperatures whereas fused silica is currently regarded the best available material for optics at room temperature.

**Quantum noise** In order to cut down shot noise in the high frequency range of ET light power levels in the interferometer arms of about 3 MW will need to be achieved with powerful lasers and recycling techniques. This high power will require optics with extraordinary low absorption in the coatings and the substrates. Whether the candidate materials for cryogenic operation, Sapphire and Silicon, can achieve low enough absorption levels still needs to be determined. Counteracting radiation pressure noise will require heavy mirrors with masses of several hundred kg. Squeezing the vacuum noise incident to the output port by up to 15 dB in conjunction with extremely low optical losses in the signal path can achieve a further reduction of shot noise and radiation pressure noise. Several concepts involving filter cavities to optimize the usage of squeezing or further reduce quantum noises have been investigated together with quantum-non-demolition techniques, which e.g. rather measure the speed than the position of the test masses in a Sagnac topology.[14,15]

**Xylophone interferometers** The contradicting requirements of high light power in the interferometer arms and simultaneously extremely low heat input to the test masses for cryogenic operation can be resolved by distributing the measurement task onto two separate interferometers one operating at high frequencies and the other at low ones. In this so called Xylophone arrangement the low frequency interferometer will operate at cryogenic temperatures where thermal noise is well suppressed and the high power interferometer with low shot noise at high frequencies will operate at room temperature.[16]

## 4. ET Timing

Now, in May 2010, the ET project has finished the first two years of a three year conceptual design study phase, which eventually will be followed by a more detailed technical design phase. Construction may start around 2018, after GW have been detected with the 2nd generation of GW detectors. Following this path the Einstein Telescope could produce first scientific data around 2025.

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