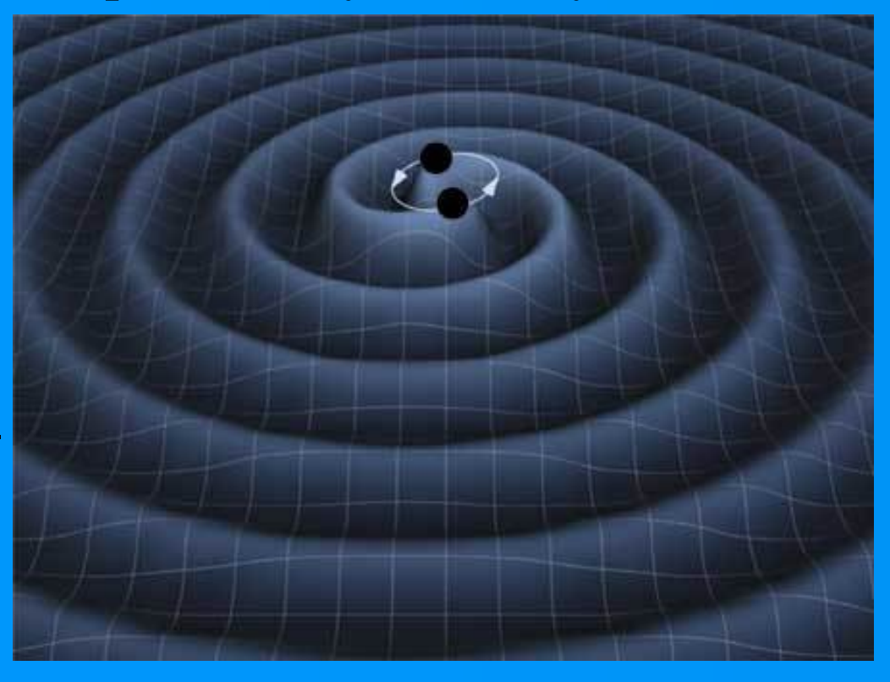
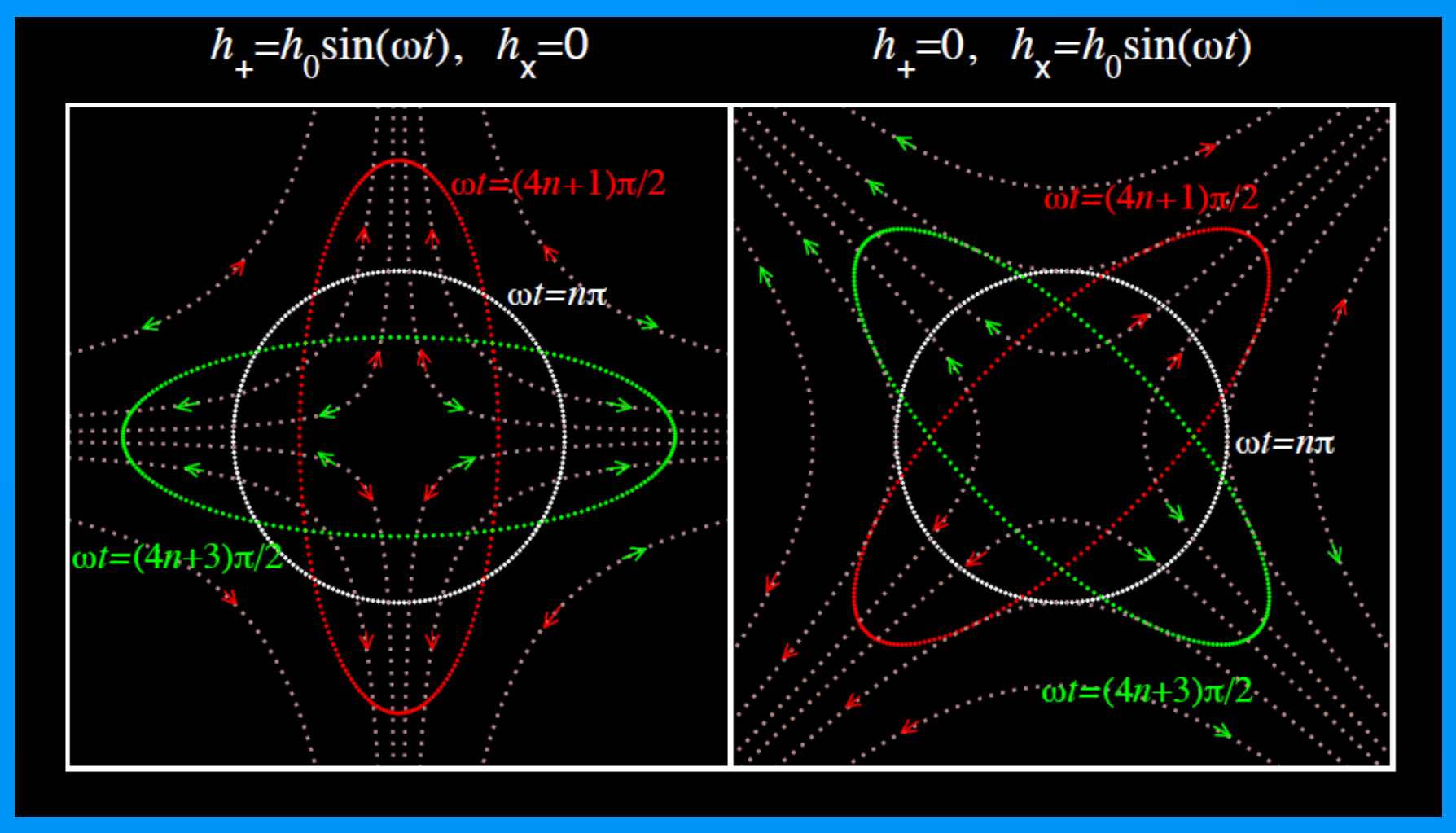
The Einstein gravitational wave Telescope (ET)

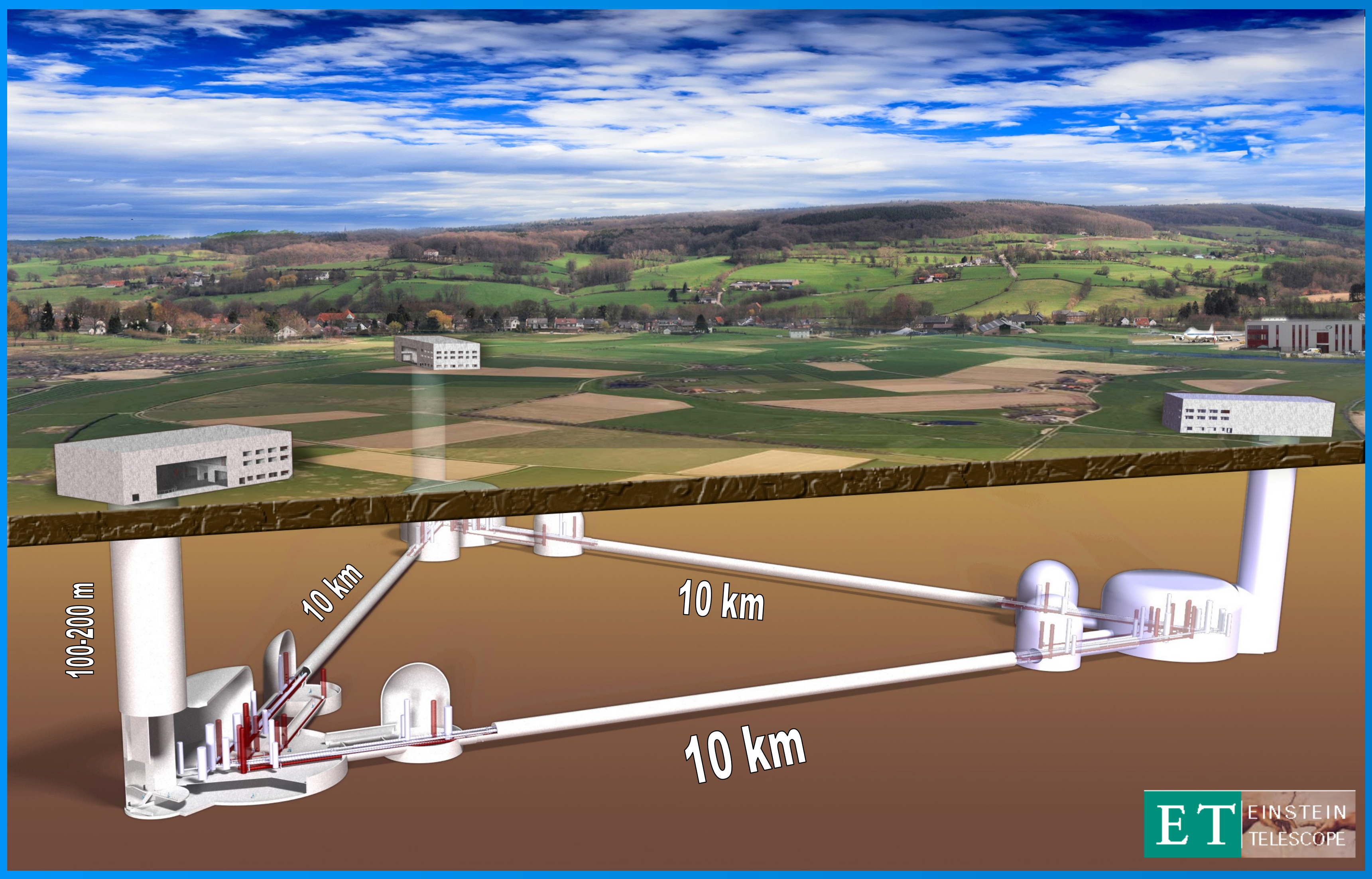
The Gravitational Waves



The Gravitational Waves (GW) are predicted by the theory of General Relativity of Einstein. GW are emitted by stellar masses under acceleration and they are propagating, as a ripple in the space-time, at light speed.

According to the General Relativity the GW have two polarizations (so-called "+" and "×") and the effect of the passage of a GW is the strain of the spacetime , modulating the reciprocal distance of a mass distribution, as schematized in figure





The long search of the GW

Since the '60 physicists are attempting to detect the GW signal. The initial detectors, ideated by Joe Weber, were based on a metallic cylinder ("bar") , resonating at the GW passage. In 1993, R.A. Hulse and J.M. Taylor won the Nobel Prize having measured that the energy loss of the binary system PSR19163+16 of coalescing neutron stars. is compatible with the energy emitted through GW, in the General Relativity prediction. In the last decades a new kind of GW detectors has bee developed, based on giant interferometers. TAMA in Japan, a "300 m" arm detector, LIGO in US, composed by two "4-km "arm detectors, GEO600 , in Germany, a British-German collaboration, composed by a 600 m arm Michelson interferometer and the Virgo detector, a "3-km" arm interferometer, realized close to Pise (Italy) by INFN (Italy) and CNRS (France), now supported also by Dutch, Polish and Hungarian research groups. These detectors demonstrated the validity of the working principle, reaching their design sensitivity to GW. Now, these machines are under upgrade, toward the second generation (so-called "Advanced Detectors"), that promise in few years the detection of the GW signal emitted by a binary system of compact stars.

ET—the (design) study of the third generation

In 2008, the European Commission funded a design study, within the 7th Framework Programme, of a 3rd generation observatory. Eight institutions, five European countries, leaders in the experimental GW search, joined their competences to design a unique European Research Infrastructure that can give to Europe a leading position in the new era of the gravitational wave precision astronomy, opened by the 3rd generation of GW observatories. In addition to the scientists belonging to the eight beneficiaries, many more joined the ET science team, coming from different institutions and different countries like Hungary, Poland, Spain, Russia, Japan and US, giving to the project a pan-European character and a worldwide visibility. The whole ET science team counts, now, more than 220 scientists. For three years the ET science team developed the initial ET science case, designed the infrastructures of the observatory, identified the crucial technologies and the needed R&D. The pre-release of the design document has been released the 20th of June., with a great event at the European Gravitational Observatory (EGO) site.

Participant	Country
EGO	Italy France
INFN	Italy
MPG	Germany
CNRS	France
University of Birmingham	UK
University of Glasgow	UK
Nikhef	NL
Cardiff University	UK

ET—the Science targets

An observatory with the capability of ET will produce tremendous scientific payoffs. ET will make it possible to observe a greater variety of phenomena and provide a new tool for expanding our knowledge of fundamental physics, cosmology and relativistic astrophysics. ET's key science objectives are:

Fundamental Physics and Gravity

- *Is the nature of gravitational radiation as predicted by Einstein's theory?*
  ET will allow a test of the wave generation formula beyond the quadrupole approximation and check whether there are only two polarizations as predicted by Einstein's theory or six as in scalar tensor theories. It could accurately measure the GW propagation speed by coincident observation of GW and EM radiation from BNS coalescences at z~2 and constrain the graviton mass.
- *Are black hole spacetimes uniquely given by the Kerr geometry?*
  By measuring different quasi-normal modes, ET will test if the spacetime geometry of a BH is uniquely described by its mass and spin. Additionally, ET can measure the multipole moments of a source from the radiation emitted as a stellar-mass BH spirals into an intermediate-mass BH and confirm if the different moments depend only on the massive BH's mass and spin
- *What is the physics of gravitational collapse?*
  ET can study supernovae and explore if they leave behind a massive object that is trapped inside an event horizon or lead to a naked singularity, or some other exotic object. ET could well reveal a new class of objects and phenomena, for instance *silent supernovae* and other gravitationally unstable transients.
- *What is the equation of state of matter at supra-nuclear densities as might be found in NS cores?*
  The equation of state (EoS) of NSs affects the late-time evolution of BNS and NSBH systems. By matching the observed radiation from the coalescence of such sources to theoretical predictions ET will deduce the EoS of NS cores.

Cosmology

- *What are the true luminosity distances of cosmological sources?*
  BBH and BNS binaries are an astronomer's ideal *standard candles* or, more appropriately, *sirens* Gravitational wave observations alone can determine both the apparent and absolute luminosity of a source. With ET these standard sirens can be used to calibrate the cosmic distance ladder.
- *What is the EoS of dark energy and how does it vary with redshift?*
  ET could observe thousands of coalescing BNS and NSBH systems in coincidence with optical or gamma-ray observations and hence measure both the luminosity distance and redshift. ET will, therefore, facilitate precision measurement of the dark energy EoS and its variation with redshift.
- *How did the black holes at galactic nuclei form and evolve?*
  ET can verify if seeds of galaxy formation were intermediate BHs of hundreds to thousands of solar masses and map their merger history up to redshifts of z~5-15 depending on the total mass and mass ratio of progenitor binaries.
- *What were the physical conditions in the primeval Universe and what phase transitions occurred in its early history?*
  Stochastic GW backgrounds could be produced by quantum processes in the primordial Universe or during phase transitions in its early history. ET will be sensitive to background densities $\rho_{GW} \geq 10^{-12} \rho_c$, where ρ_c is the critical density of the Universe.

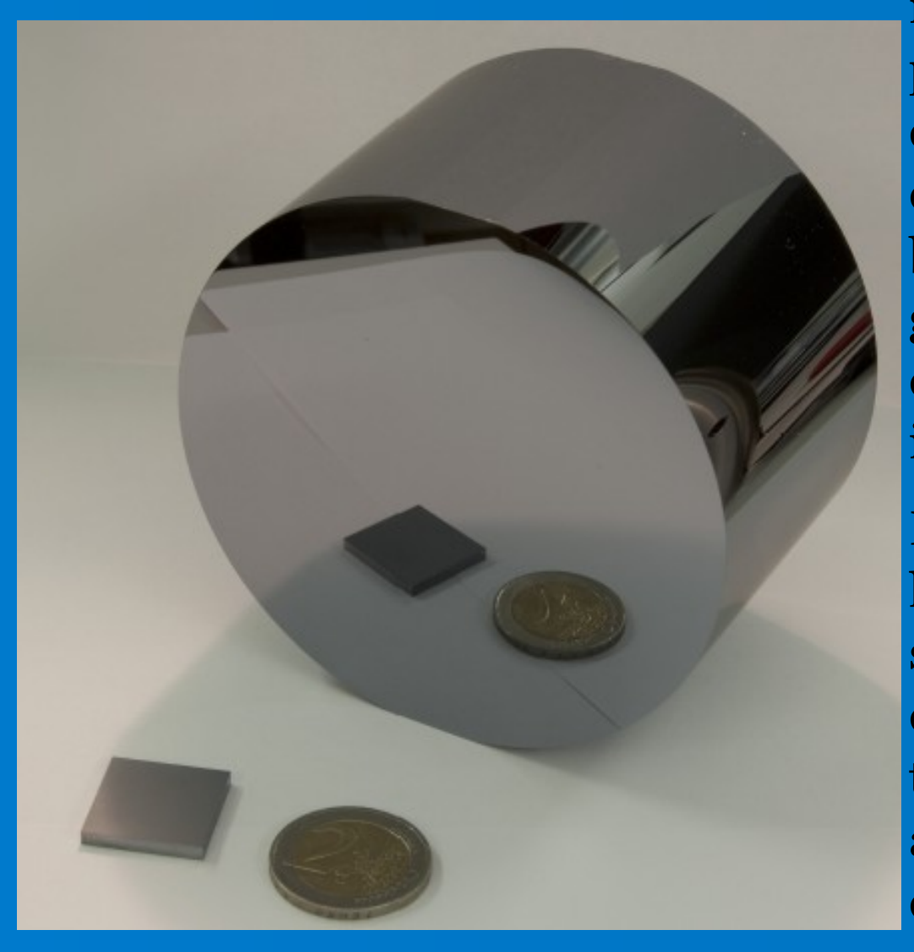
Astrophysics and Multimessenger Astronomy

- *What is the mass function of BHs and NSs and their redshift distribution?*
  ET will measure masses and spins of millions of NSs and BHs in binary systems and will thereby obtain a census of these objects as a function of redshift. This will be a very valuable tool for understanding a host of questions in astronomy related to redshift evolution of compact objects.
- *What are the progenitors of gamma-ray bursts?*
  Gamma-ray bursts (GRBs) are the most luminous electromagnetic sources in the Universe. While advanced detectors might provide some clues as to their origin, ET will provide a large statistical sample of events that could be used to understand GRB progenitors and to test their astrophysical models.
- *How do compact binaries form and evolve?*
  The process by which main sequence binary stars evolve into compact binaries (that is, BNS and BBH) could be understood by ET's observation of millions of coalescing binaries with different masses, mass ratios and spins and mapping the observed population to astrophysical models.
- *What is the physical mechanism behind supernovae and how asymmetric is the gravitational collapse that ensues?*
  Supernovae are complex processes whose modelling requires many different inputs, including relativistic magneto-hydrodynamics, general relativity and nuclear and particle physics. ET's observation of supernovae in coincidence with the detection of neutrinos could provide the data necessary to constrain models and help understand the process by which stars collapse to form NSs and BHs.
- *What is the nature of the NS crust and its interaction with the core?*
  ET should detect NS ellipticities that are few × 10^{-10} or larger depending on their spin frequency. This can be used to deduce the property of NS crusts. ET might also detect GWs that are expected to be emitted when pulsars glitch and magnetars flare and thereby help understand crust-core interaction that is believed to transfer angular momentum from the core to crust.

ET—Technology development

The realization of a 3rd generation GW observatory requires the development of new technologies and an intense R&D plan for the next decade. In fact each detector, composed by two interferometers, will be extremely demanding for the performances of the optical and mechanical components.

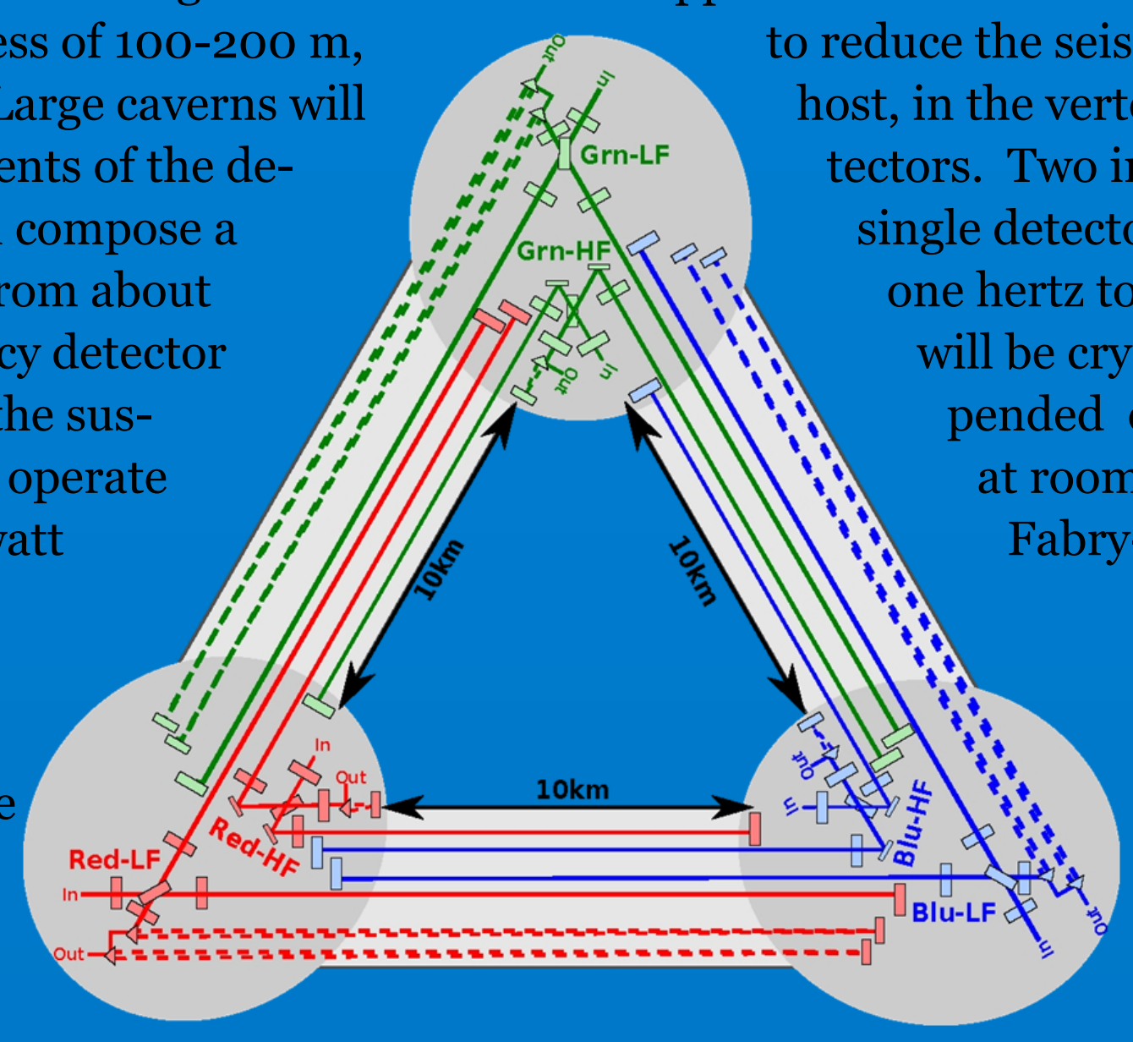
New high power continuous wave lasers, operating at 1064 nm and having about one kW of power are requested for the high frequency interferometer. Low absorption optics, low scattering polishing and coatings of the mirrors are mandatory. Low noise, 1550nm lasers are requested for the low frequency interferometer. Cryogenic temperature compliant optics are needed; new chemical bonding technology need to be developed. Seismic filters and other precision mechanics component must be developed. Low vibration noise cryogenic plants must be designed and realized.



High performances, low noise control systems are requested. New investigation and analysis algorithms must be developed. The latest evolutions in computing (GPUs, parallel computing, GRID, …) will be adopted to explore the whole potential of the ET observatory

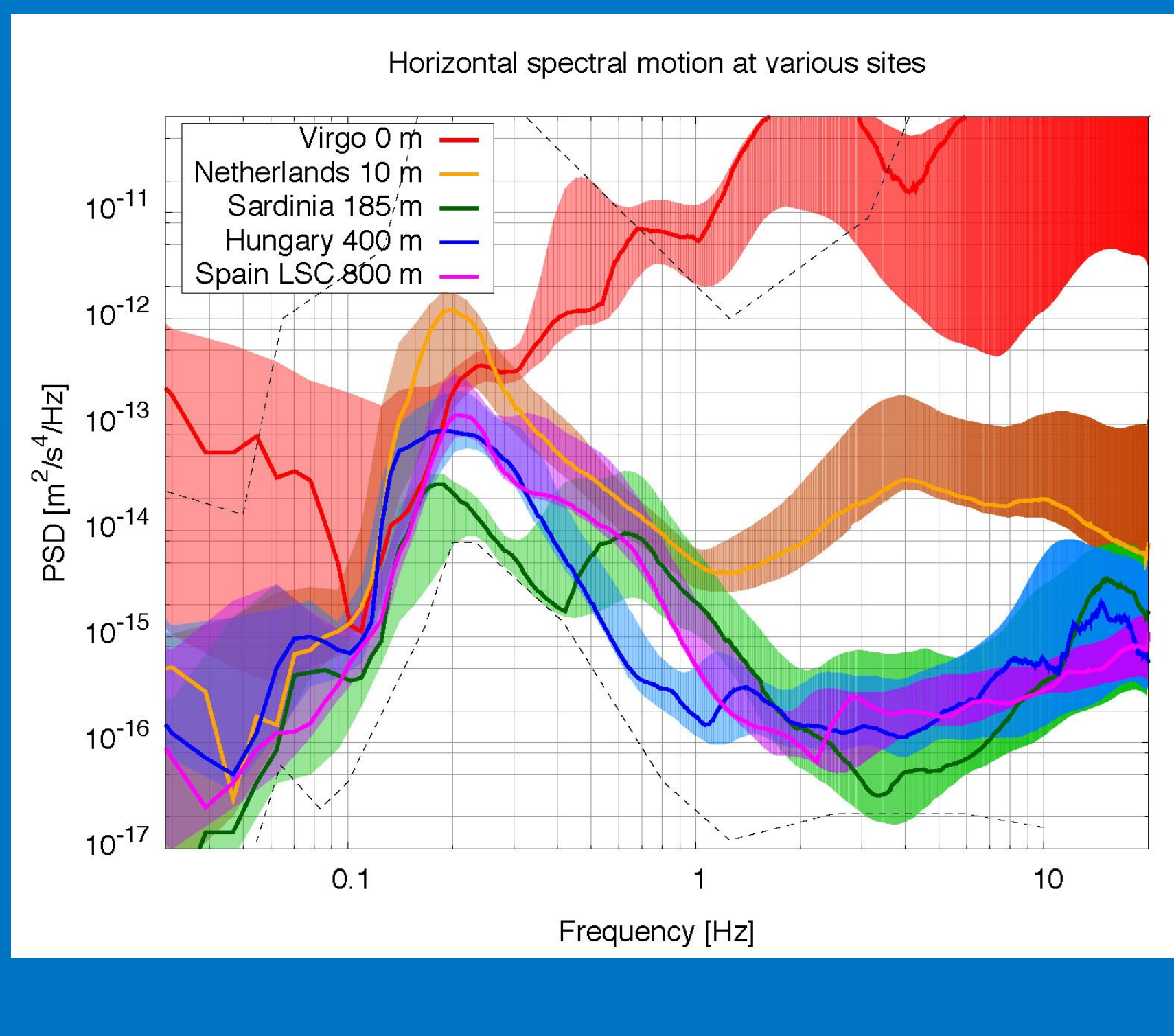
ET—The infrastructure

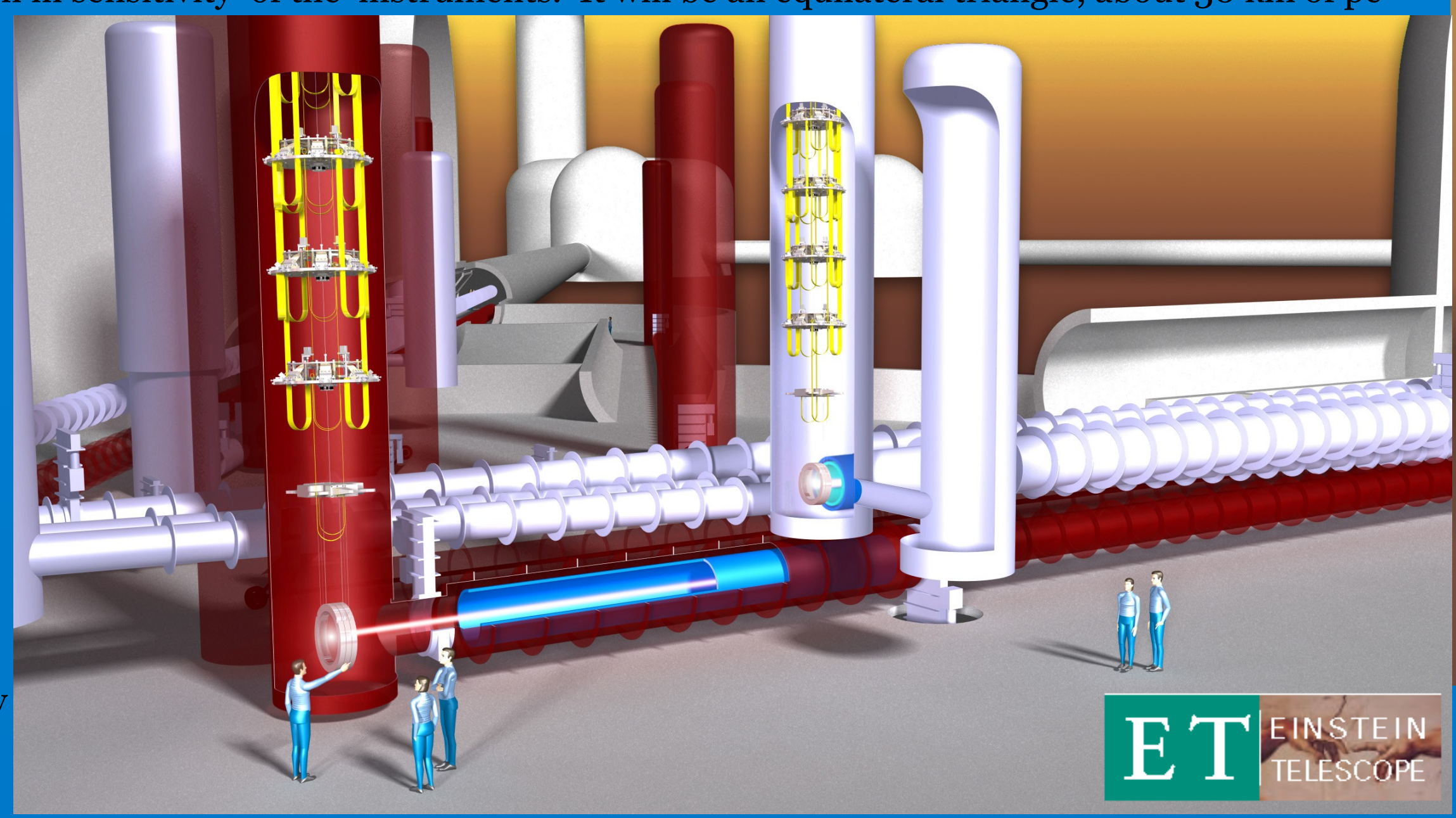
The ET observatory will be a research infrastructure that will last for decades, hosting up to three gravitational wave detectors and allowing the implementation, over several years, of the needed upgrades when the technological evolutions of the apparatuses will allow a further gain in sensitivity of the instruments. It will be an equilateral triangle, about 30 km of perimeter, realized at a deepness of 100-200 m, to reduce the seismic and environmental disturbances . Large caverns will host, in the vertex, the optical and mechanical components of the detectors. Two interferometers (xylophone design) will compose a single detector spanning the whole frequency range from about one hertz to ten kHz of frequency. The low frequency detector will be cryogenic and adopting new materials for the suspended optics; the high frequency detector will operate at room temperature and will implement Mwatt Fabry-Perot cavities.

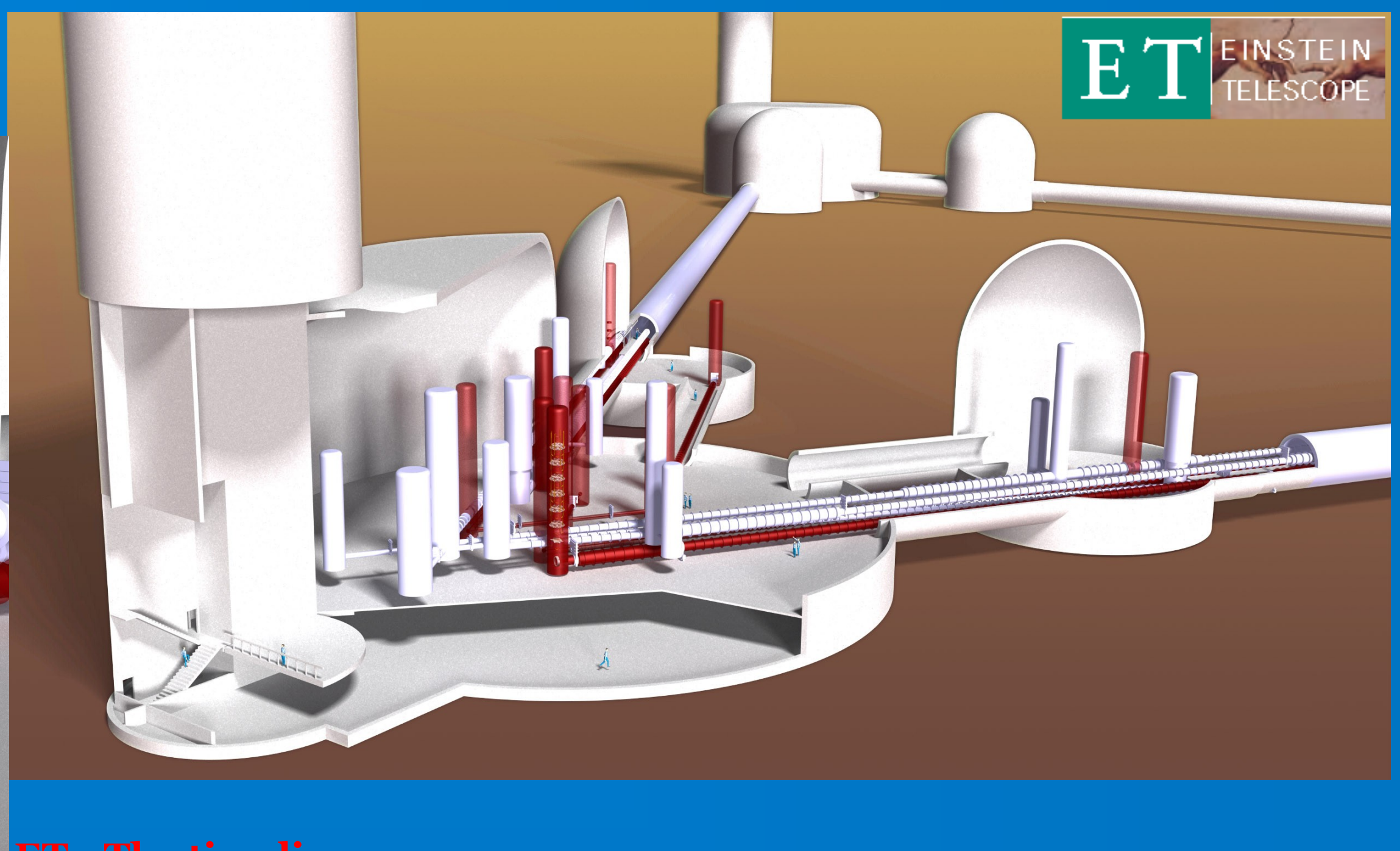


ET—The site

The seismic properties of the site hosting the ET observatory are of crucial importance to improve the sensitivity of the detectors at low frequency. For this reason eleven underground sites have been investigated in Europe to verify the feasibility of this infrastructure in Europe. Three of them (in Hungary, Italy and Spain) shown an excellent seismic noise characteristics, compliant with the ET requirements. Further investigations are needed to improve our knowledge of the site properties and to define the actual site.







ET—The timeline

The realization of the ET observatory is a fundamental brick of the evolution of the GW search scenario. The worldwide GW scientific community, through its coordination international committee (GWIC) defined the roadmap of the detectors development in the World. ET (in Europe) and few other similar companions (in the rest of the World), will be the final targets of this evolution.

In the ET design study document a more detailed plan for the ET observatory is reported, covering the operations for the present and the next decade.