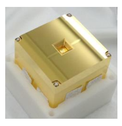
Detectors of Gravitational Waves and Quantum Gravity Effects

Virgo, LISA, Einstein Telescope, GRAFIQO

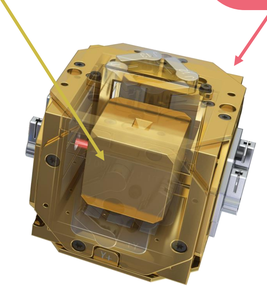
10 anni di TIFPA

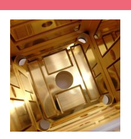
Achieving femto g / Hz$^{1/2}$

Free-falling 2 kg **test mass** of a gold-platinum alloy
- *F=ma* → The more massive the TM, the lower the acceleration
- Dense → Most forces scale with the surface
- Very low magnetic susceptibility

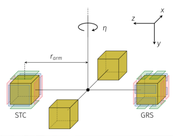


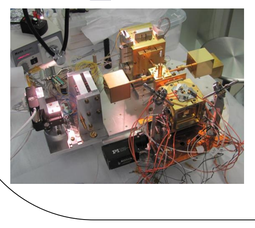
Electrode housing
- nN-level electrostatic actuation
- nm-level capacitive position sensing
- Large gaps (~ mm) to limit electric and disturbances and residual gas damping ($F \sim 1/d^n$)
- High thermal conductivity
- Faraday shield

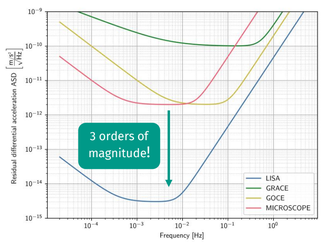




Low residual gas pressure around the TM





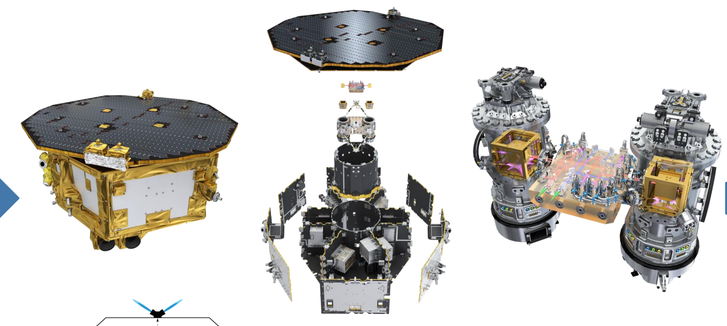


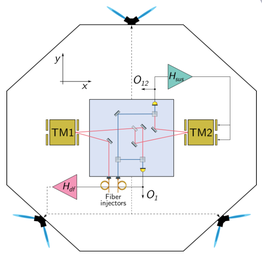
The design of the **Gravitational Reference System** (GRS) for LISA has been driven by torsion pendulum experiments

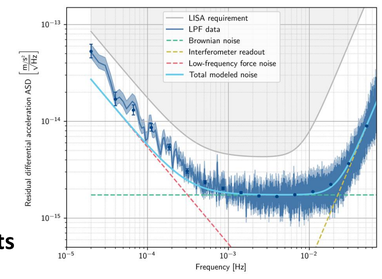
LISA Pathfinder – The Quietest Lab in the Universe

A space mission to test the LISA technology: a LISA arm shrunk down to 38 cm.

The only way to measure stray forces at the level for LISA it going far away from the Earth's gravitational gradients.







Better than LISA requirements at all frequencies!

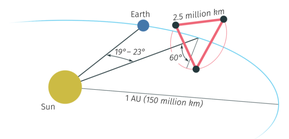
LISA

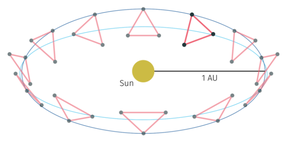
Constellation of 3 satellites to generate a **giant interferometer**.

GWs induce a **tidal acceleration** on the TMs, detected as a Doppler shift in the received laser beam.

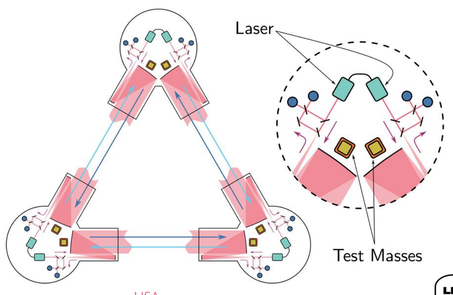
Local forces accelerate the TMs: their effect is indistinguishable from GWs.

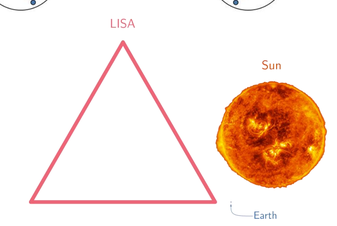
LISA has been **adopted** by ESA in January 2024 and will be launched in 2035!





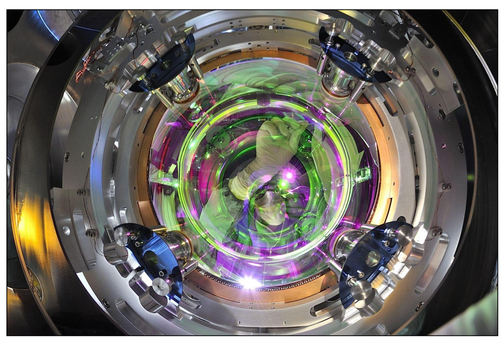
Full heritage of LISA Pathfinder GRS





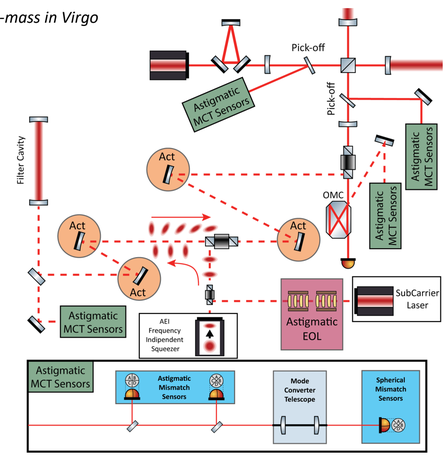
VIRGO

Coordinated Observing Runs with LIGO and KAGRA



Commissioning activities involving Trento's group:
- Squeezed light injection
- Mode matching for squeezing
  - Sensing
  - Correction
- Interferometer sensing and control
- Simulations for debugging and design

Test-mass in Virgo



Virgo optical layout: Actuators (Act) and Mode Converter Telescopes (MCT) for the next Virgo upgrade

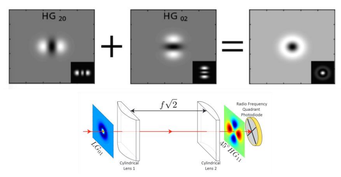
Actuators and Mode Converter Telescopes MCT are designed and developed by the Trento group

Laboratory of Interferometry and Quantum Optics @Trento

New laboratory infrastructure from 2023:
temperature stability, clean laminar flow, suspended optical tables

Laboratory of Interferometry and Quantum Optics (credits Federico Nardelli)

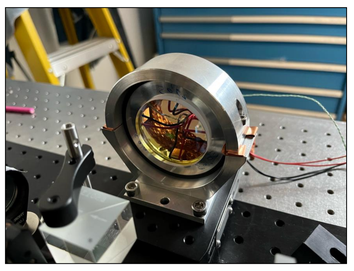
Several ongoing projects aimed to improve sensitivity of current and future GW detectors using LASER sources both at 1064 nm and 1550 nm wavelengths



Laguerre-Gauss modes are converted in Hermite-Gauss modes with a Mode Converter Telescope (MCT) and sensed with a heterodyne technique

The presence of higher-order modes in laser beams is exploited to sense the level of losses due to the optical mismatch

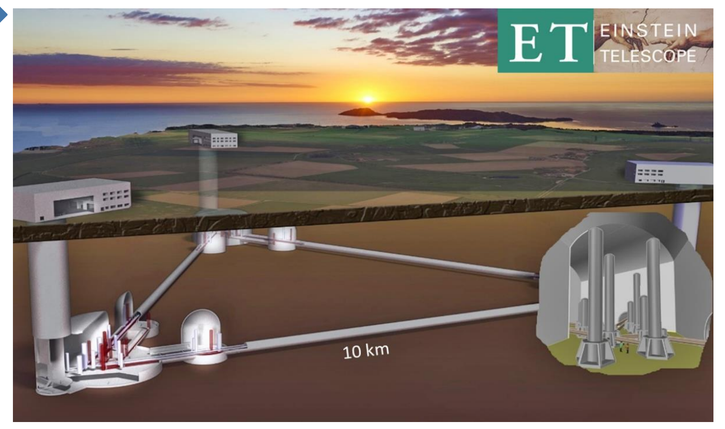
The light wavefront is reshaped by a deformable mirror: an external ring with a different coefficient of thermal expansion squeezes the mirror to change its radius of curvature



Deformable Mirror

Einstein telescope –

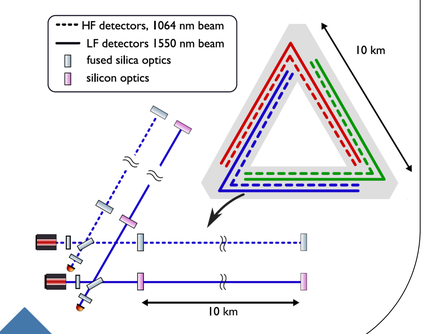
Major European Infrastructure for GW Research



ET is a laser interferometer with arms 10 Km long, located underground at depths between 100 and 300 meters

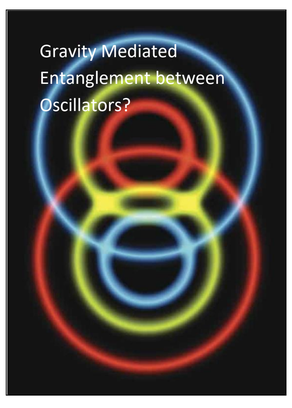
Selection of site(s) and of the topology of the ET observatory are still in progress.

The group in Trento is actively involved on the development of all the future long baseline interferometers of the ET observatory:
- Optical design
- Sensing of the optical losses
- Quantum noise reduction
- Squeezed light sources
- Test masses development

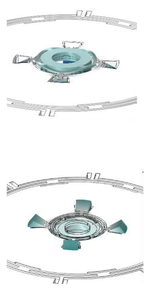


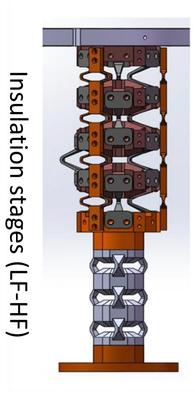
GRAvitational Force In Quantum Optomechanics (GRAFIQO)

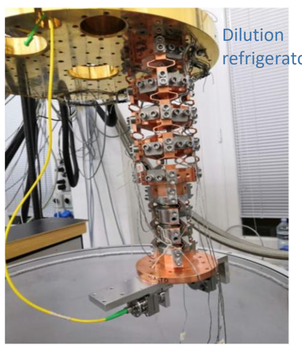
Probing the quantum nature of gravity with state-of-the-art optomechanical experiments: detecting the gravitational pull of a mass in superposition would be direct evidence of the quantum nature of gravity (Feynman - 1957)



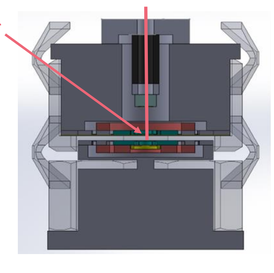
Hollow Cylindrical masses

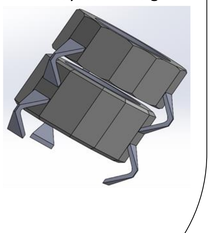






Nd:YAG laser



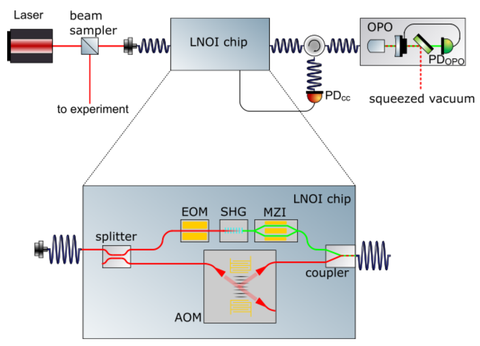


Microfabricated silicon harmonic oscillators (mass of 10 mg) positioned at sub-mm distance, under high vacuum (<10^{-7} mbar), and at ultra-cryogenic temperatures (45 mK), seismically isolated, with a noise floor down to 10^{-37}m^2/Hz in the acoustic band.

READ-OUT by exploiting strong dispersive coupling of a high-finesse optical cavity to a nanomembrane

Advanced technologies for GW detection

Quantum and **thermal** noises are key limiting sources for current and future generation of gravitational wave detectors.



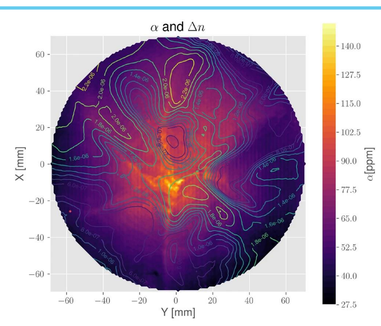
Integrated squeezed vacuum source for measurements beyond the quantum limit

Realization of an integrated squeezed vacuum source capable of providing high-purity squeezed vacuum states. The key features of this device are its compactness and the possibility of implementing it as an independent addition to any already existing experiment.

Integrated squeezed vacuum source key components:
1. Lithium Niobate On Insulator (LNOI) chip
2. Fibered Optical Parametric Oscillator (OPO)

Development of crystalline test masses

There is a correlation between the distribution of the absorption coefficient and the birefringence in large-size crystalline substrates such as sapphire. We can say that the compositional absorption inhomogeneities are an important factor for increased internal stress and, thus, the birefringence structures that were observed.



Trento Institute for Fundamental Physics and Applications