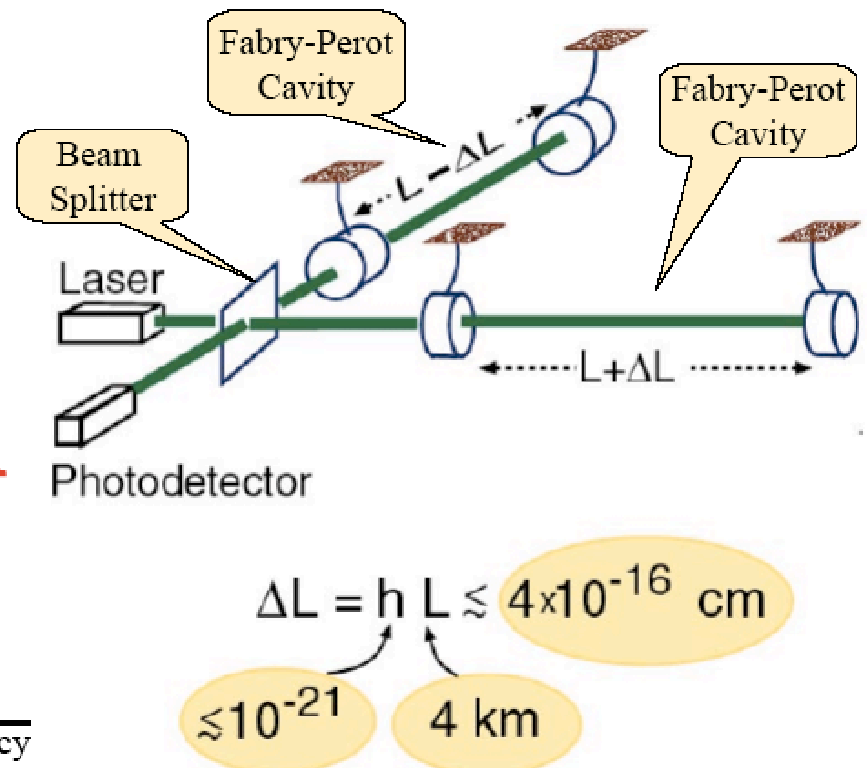
Detection with interferometers

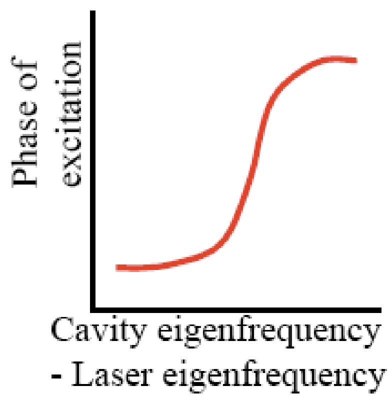
Most promising technique use laser interferometry of the Michelson type. Light from a powerful laser is split into 2 long orthogonal paths and reflected against mirrors attached to test weights at the end of the arms. The 2 returning light beams are made interfere with each other creating interference fringes which would be stationary if the test bodies are at rest and their distance=const

A GW would cause a shift in the interference pattern. Cavities are resonant Fabry-Perot: light is allowed to travel many times through mirrors increasing the number of photons in the beams allowing a higher resolution

Accuracy of 10^{-18} m can be achieved

- **Schematic description of detector:**





Noise

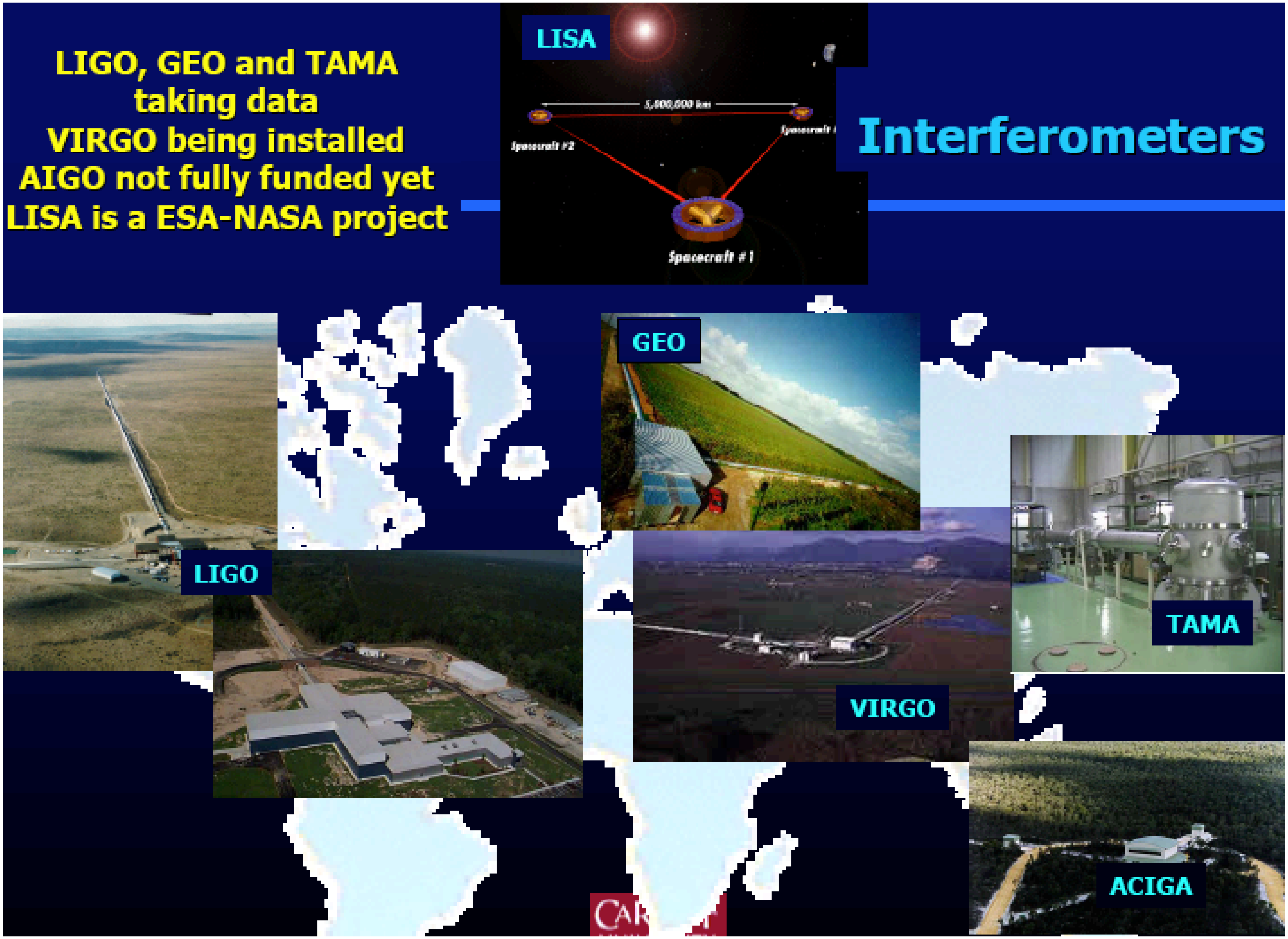
- Environment: seismic at low frequencies
- Thermal noise from test weights and mirrors at intermediate frequencies
- Shot noise from the laser system at high frequencies: the determination of location of interference fringes necessitates many photons. When the number of photons decreases, stochastic effects smear the measurement

- Ground based interferometrs are designed to achieve strain sensitivity of about 10^{-21} over a wide band (10-5000 Hz); a 1000m arm length necessitates a displacement sensitivity of 10^{-18} m rms
- To eliminate environmental noise => space based interferometer such as LISA - laser interferometer antenna

Working principle

Arranged in Michelson configuration to have differential sensitivity to displacements along its orthogonal arms.The laser light is split by a beam splitter and directed along the orthogonal arms which are defined by input and output test mass optics. The light passes through the input test masses, reflects off the interferometer end test masses, travels back and recombines at the beam splitter to interfere at a photodetector. Small differential length changes in the arms caused by a gw passage produce a relative phase shift in the arm light which is seen as a change in intensity at the output photodetector. To reduce shot noise a laser with high power must be used, stabilized in intensity (to limit noise on test masses from time varying radiation pressure) and frequency (to limit wavelength fluctuations that appear as length measurement errors). Test masses are suspended from seismic attenuators to attenuate ground noise in the detection band. The interferometer is placed in vacuum to avoid air density fluctuations and acoustic noise. An ultimate limit to the performance of ground-based detectors is imposed by gravity gradient noise caused by Earth motion and time varying atmospheric conditions from which the test masses cannot be shielded.

World Interferometers



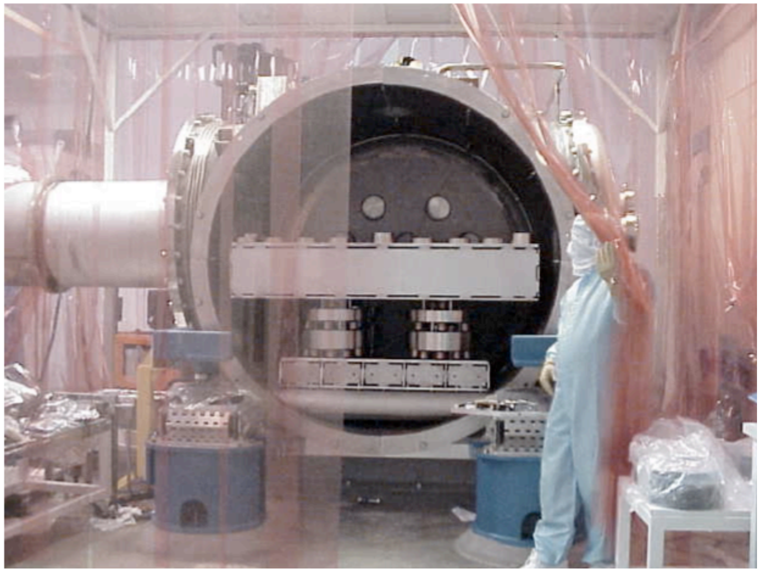
LIGO

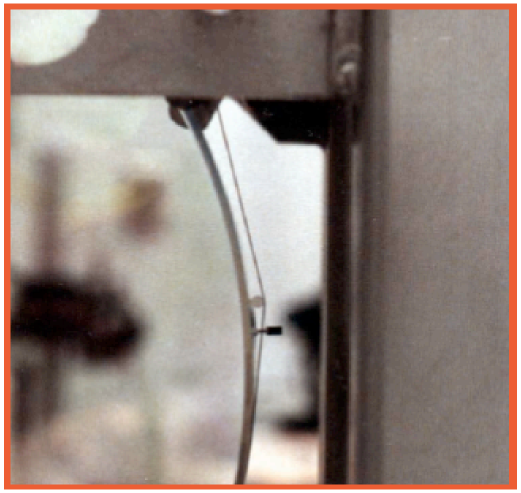
2 facilities with 4 km arms in Hanford, WA and Livingston, LA

The detector

Seismic Isolation

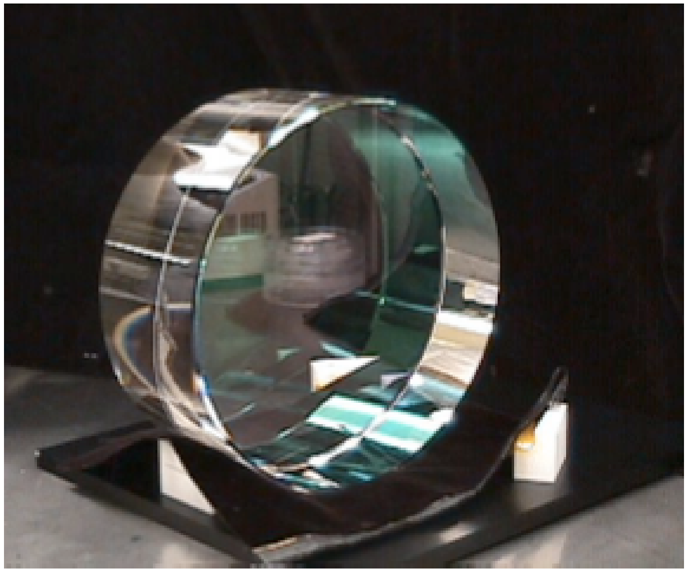
Test-Mass Mirror and its Suspension





Monitor motions of 40 kg saphire mirrors to:

- $\sim 10^{-17}$ cm ~ 1/10,000 diameter of atomic nucleus
- $\sim 10^{-13}$ of the wavelength of light



Virgo

- Location: near Pisa (Italy);
- Arm length: 3km;
- Frequency range: ~ 5 Hz – 10 kHz;
- Sensitivity:

  $\tilde{h} \sim 3 \cdot 10^{-21}$ Hz$^{-1/2}$ @ 10 Hz;

  $\tilde{h} \sim 3 \cdot 10^{-23}$ Hz$^{-1/2}$ @ 200 Hz.

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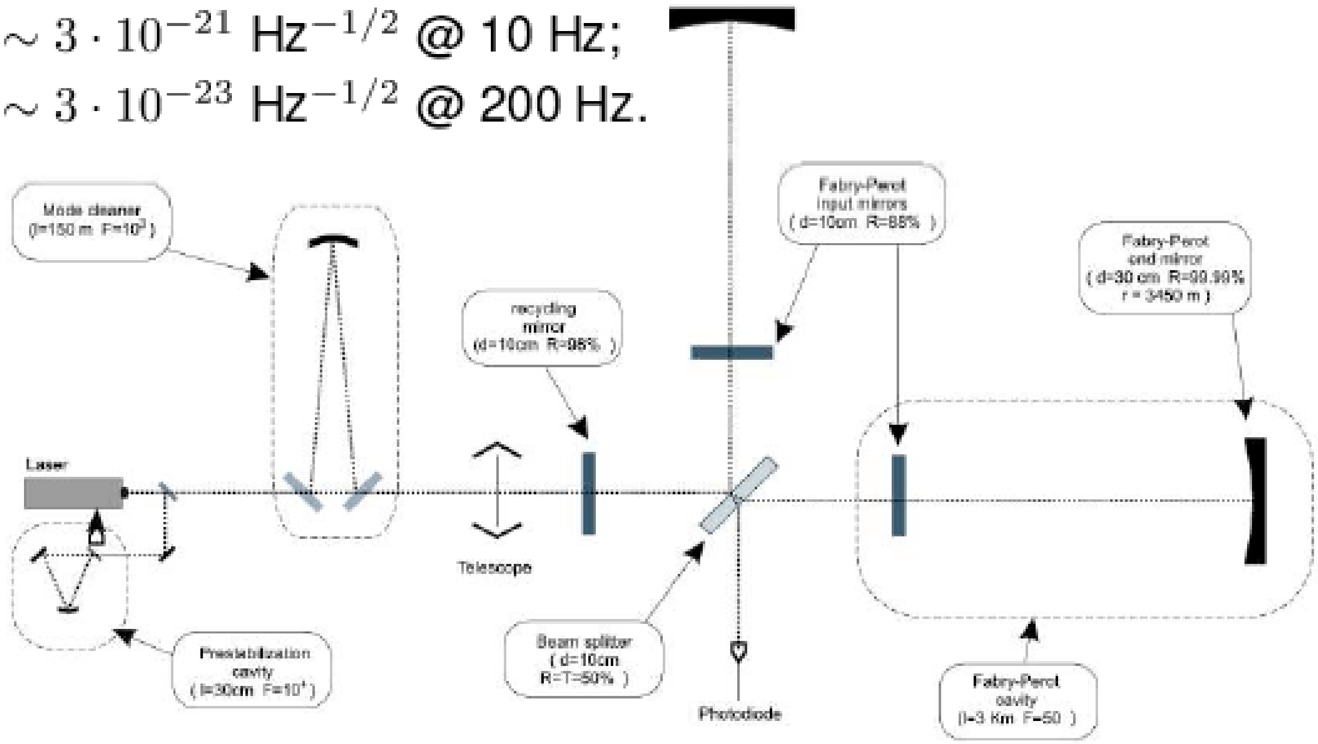


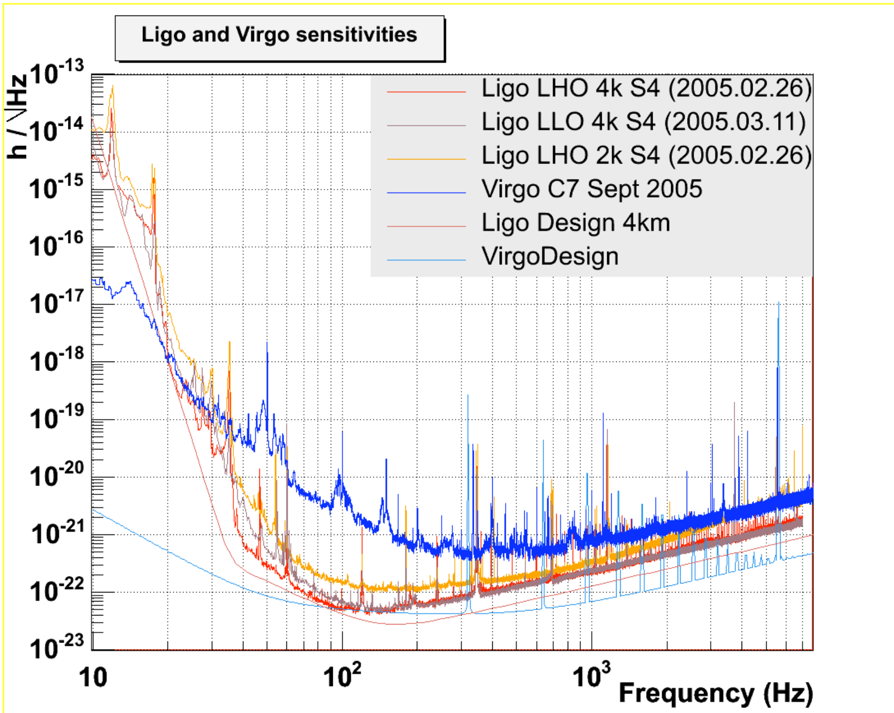
Schematic design of the VIRGO interferometer, with the 3 km long Fabry-Perot cavities and the recycling cavity.

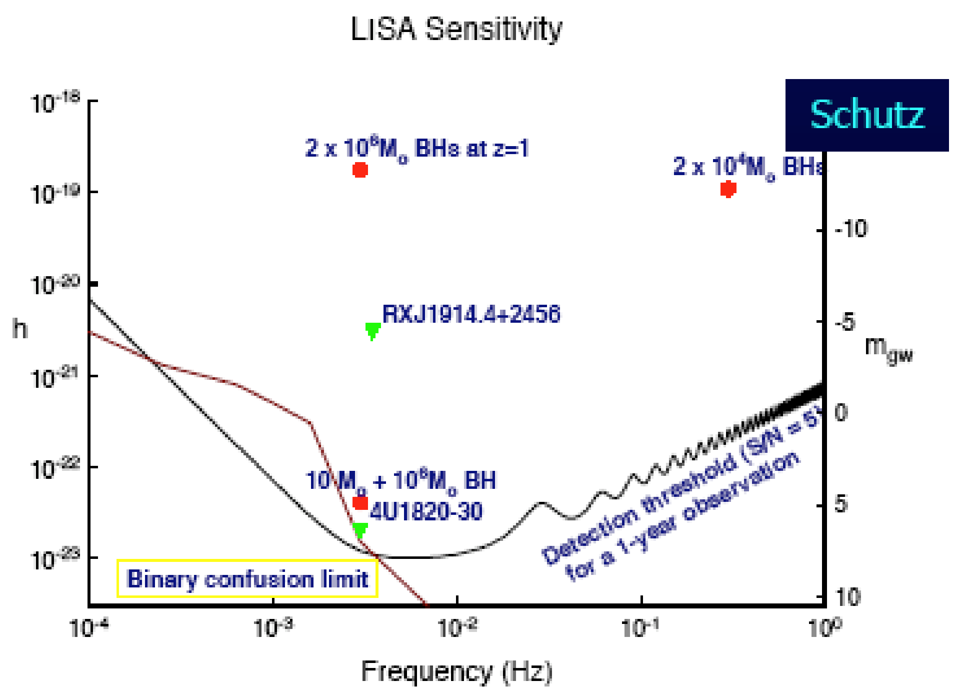
Spaced-based interferometers

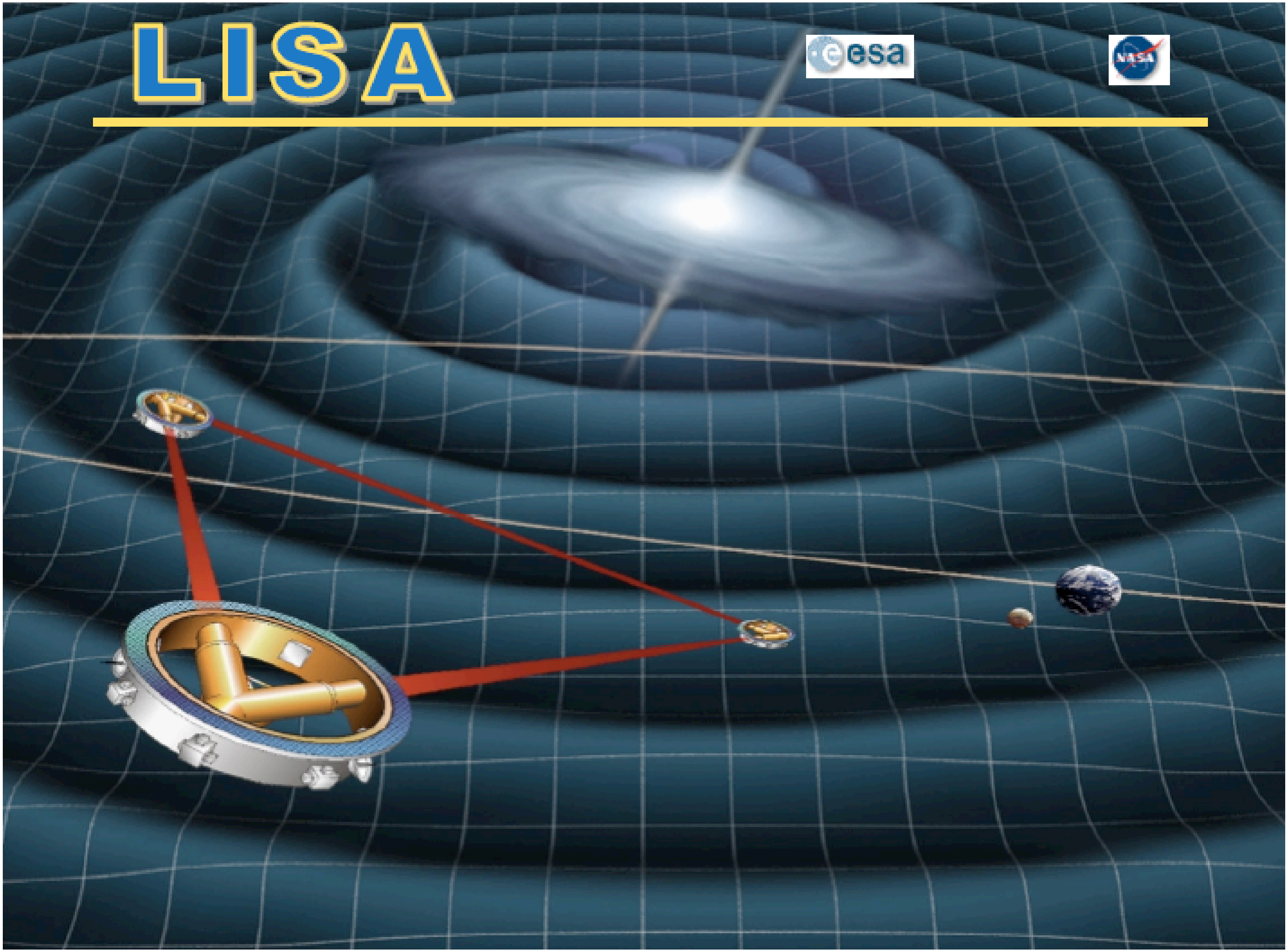
Advantage: absence of seismic noise and stable thermal environment, presence of vacuum. Long arms are possible: a length of 10^9 m allows sensing at a frequency of 1 mHz and yields strain sensitivity of 10^{-21} with a displacement sensitivity of only 10^{-12} m. Because the transmitted beam spreads through diffraction over long distances there is insufficient power to reflect the beam back to its starting point. Thus a transponding scheme is used in which an onboard laser at a far spacecraft is phase locked to the incoming beam and sends its light back to the initial spacecraft.

Two test masses are contained in the spacecrafts.A drag-free control system guarantees that the distance between the masses is constant at level of 4e-11 m accuracy. Active discharging of test masses (due to CRs) can be achieved with UV light.

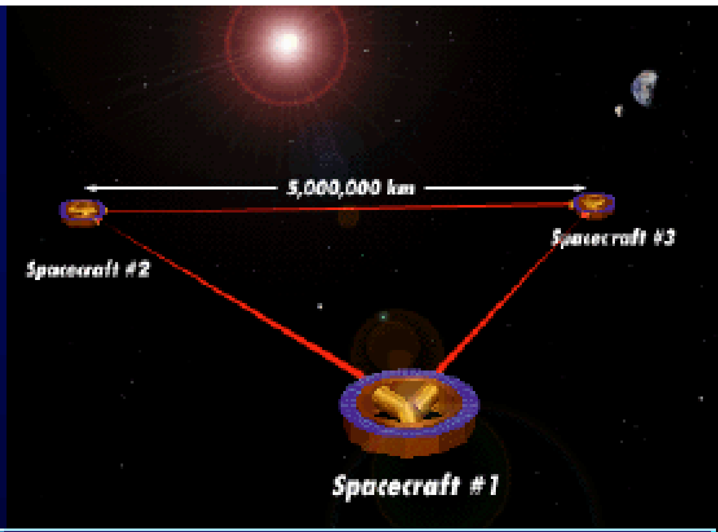
Interferometers sensitivities

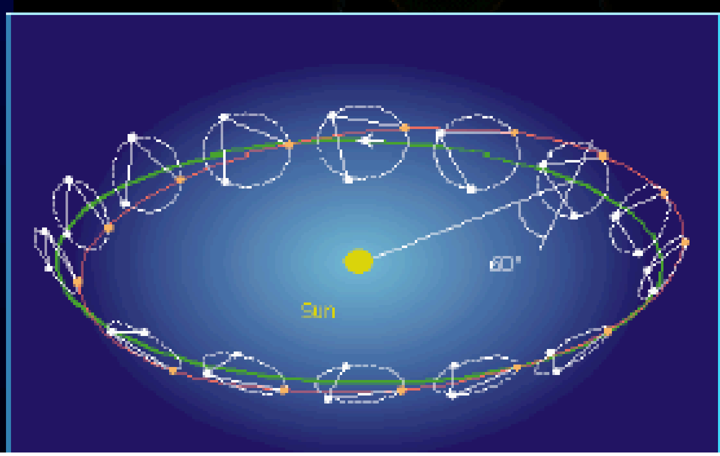





LISA
esa
NASA

LISA concept





- ESA-NASA collaboration
  - **<u>Intended for launch in 2011</u>**
- 3 space craft, 5 million km apart, in heliocentric orbit
- Test masses are passive mirrors shielded from solar radiation
- Crafts orbit out of the ecliptic always retaining their formation
- Sensitivity limited by:
  - long-term control
  - GW b/g by Galactic sources
  - shot noise ...

Session OG3, LCGT LISA and other talk