LISA: The space-based gravitational wave observatory

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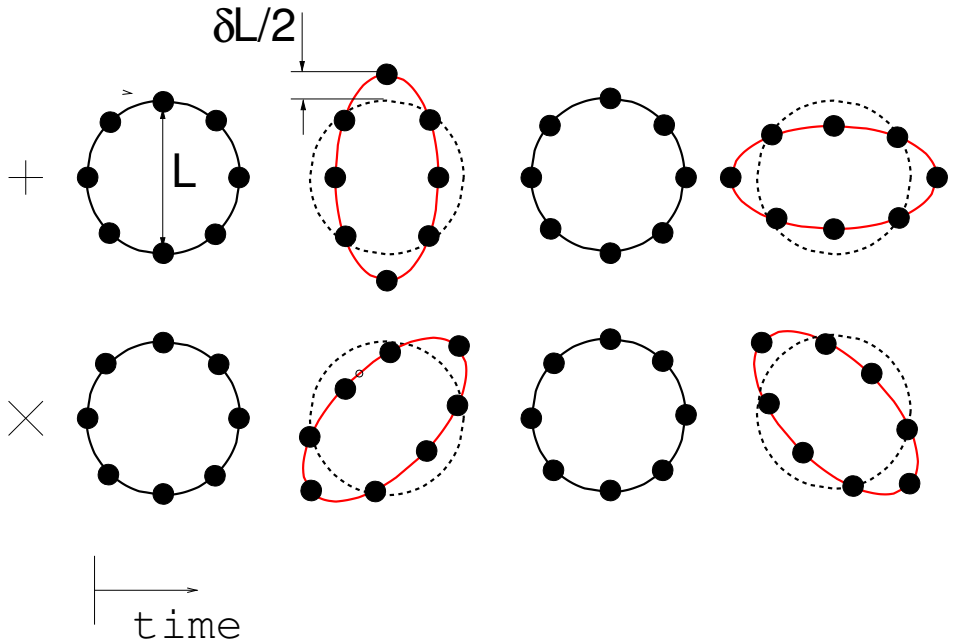
Gravitational waves

GWs: ripples of the space-time geometry caused by assymetric movements of a mass distribution (vibrations of the spacetime fabric)

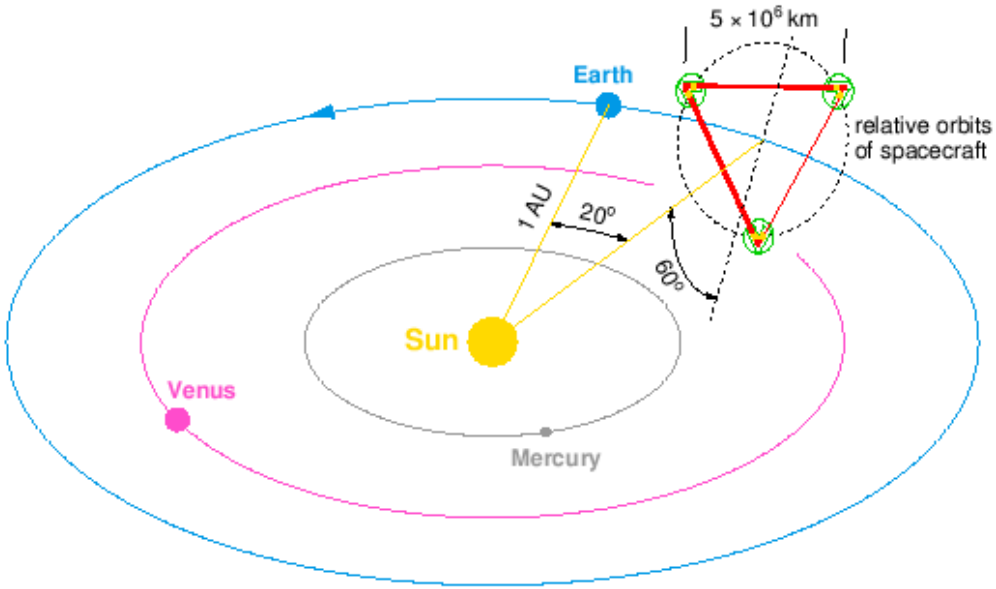
- travel at the speed of light
- 2 polarization modes ('+' and 'x')
- transverse to the direction of propagation

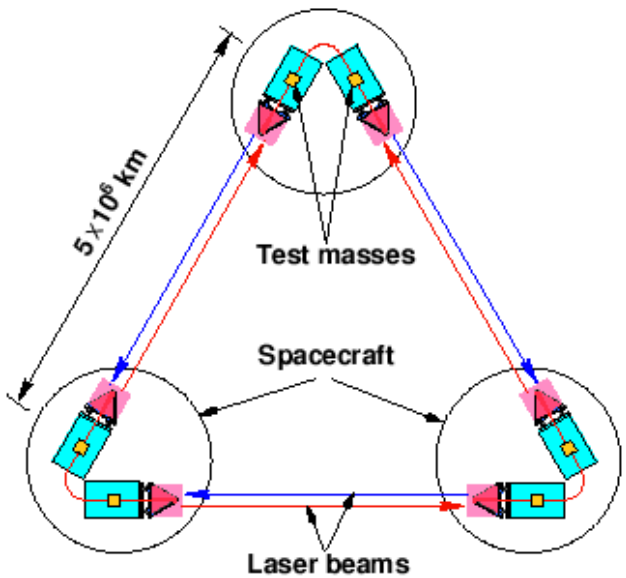


$$\text{Strain}: h = \frac{\delta\ell}{\ell} = \frac{2G}{c^4}\frac{\ddot{Q}}{r} \sim 10^{-21}$$

GW detection: LISA mission

- 3 SC in heliocentric orbit at 45 Mkm behind the Earth
- Equilateral triangle of 5×10^6 km side
- 2 proof masses (PMs) in *free fall* in each SC
- Giant *Michelson* interferometer measures changes in light travel time between the proof masses

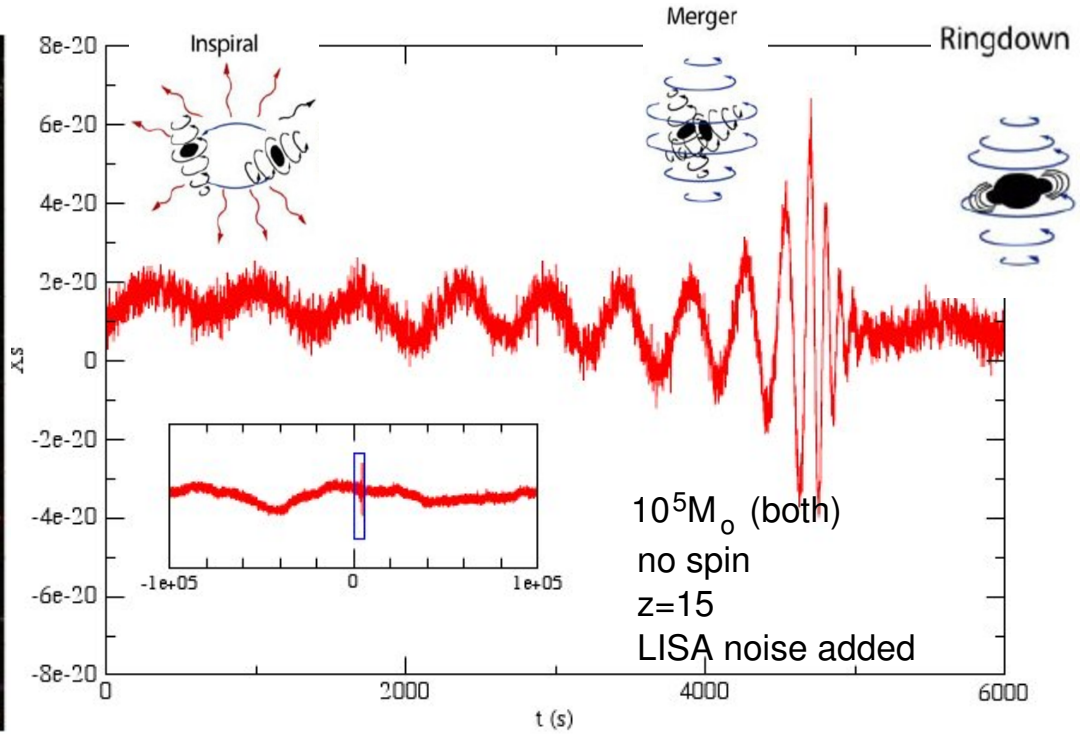




Scientific objectives: GW sources

Massive Black Holes: $10^4 M_\odot$ to $10^7 M_\odot$

- Formation, growth and merger $\rightarrow$ history of galaxies formation
- SMBH mergers: $\sim$1 year^{-1}; MBH to form SMBH: $\sim$100 year^{-1}
- System properties (mass, spin, orientation, distance)

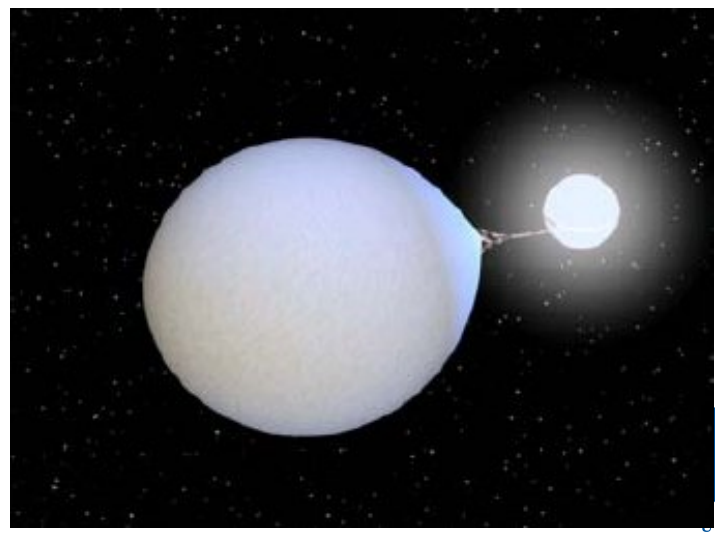


EMRIs: $10M_\odot$ BH and $10^6 M_\odot$ SMBH

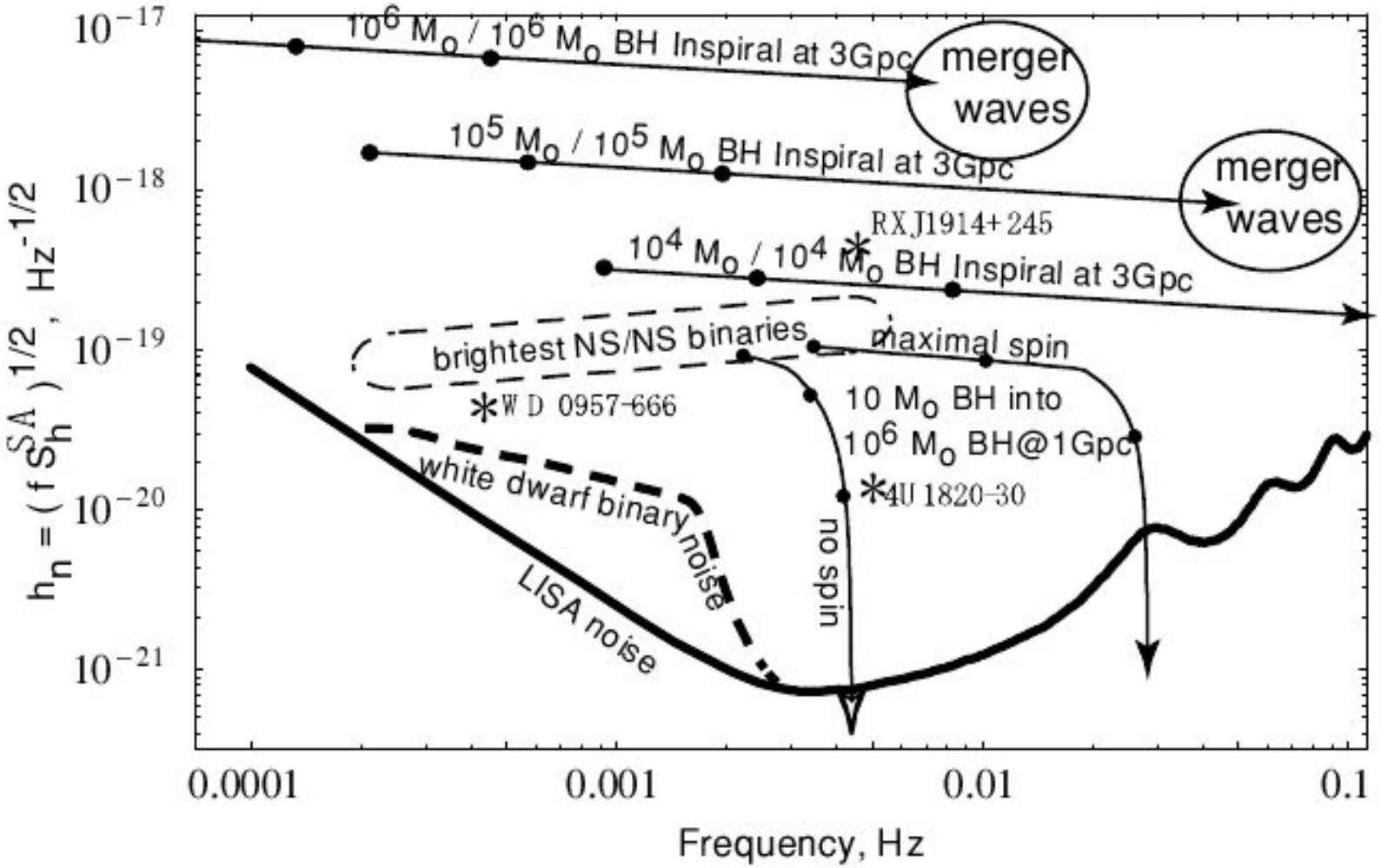
- GR testbed: precision probes of Kerr metric
- All parameters measured from GW signal

Galactic binaries

- 9 known galactic binaries in the LISA band [verification binaries]
- Mass, distance, orbits
- History of stars in our galaxy
- Too many! ($\sim 10^5$): WDB noise



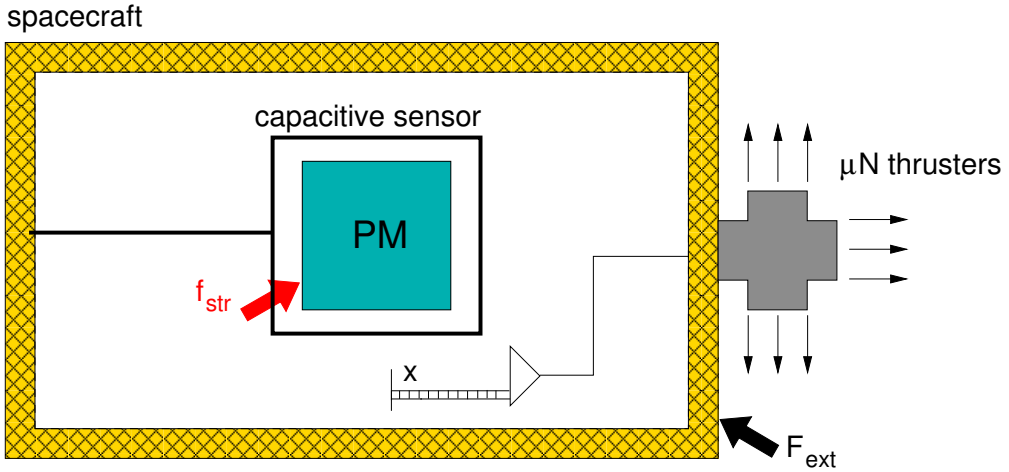
LISA sensitvity



Gravitational Reference Sensor: free-fall

First thing to do is to have the proof masses in free-fall
$\rightarrow$ only subjected to inertial forces

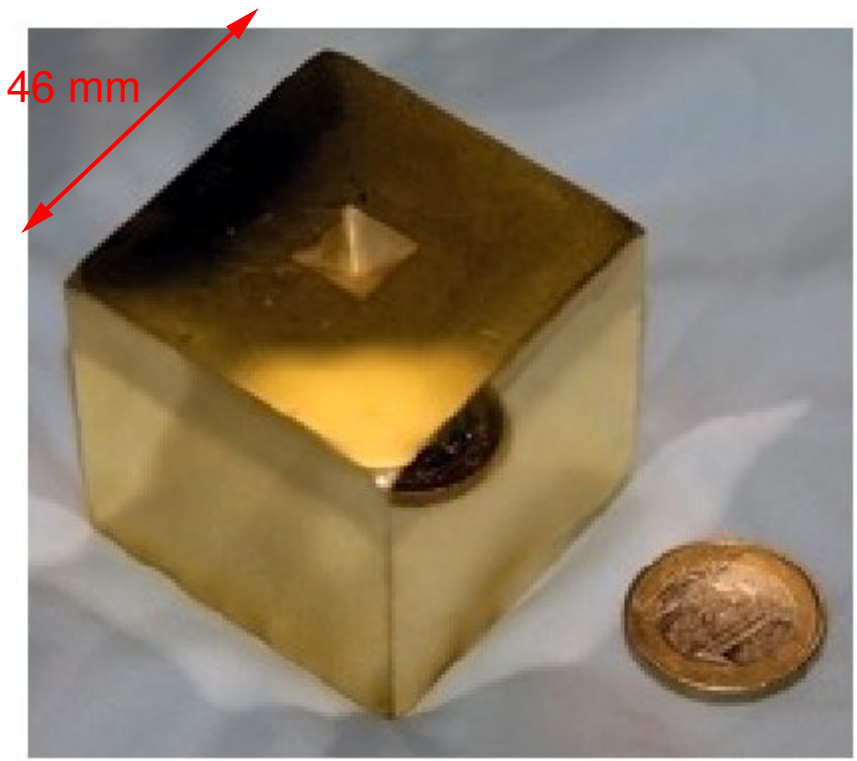
$$S_{a,\mathrm{LISA}}^{1/2}(f) \lesssim 3\times10^{-15}\left[1+\left(\frac{f}{8\,\mathrm{mHz}}\right)^2\right]\frac{\mathrm{m}}{\mathrm{s}^2}\frac{1}{\mathrm{Hz}^{1/2}}, \quad 0.1\,\mathrm{mHz} \leq f \leq 1\,\mathrm{Hz}$$

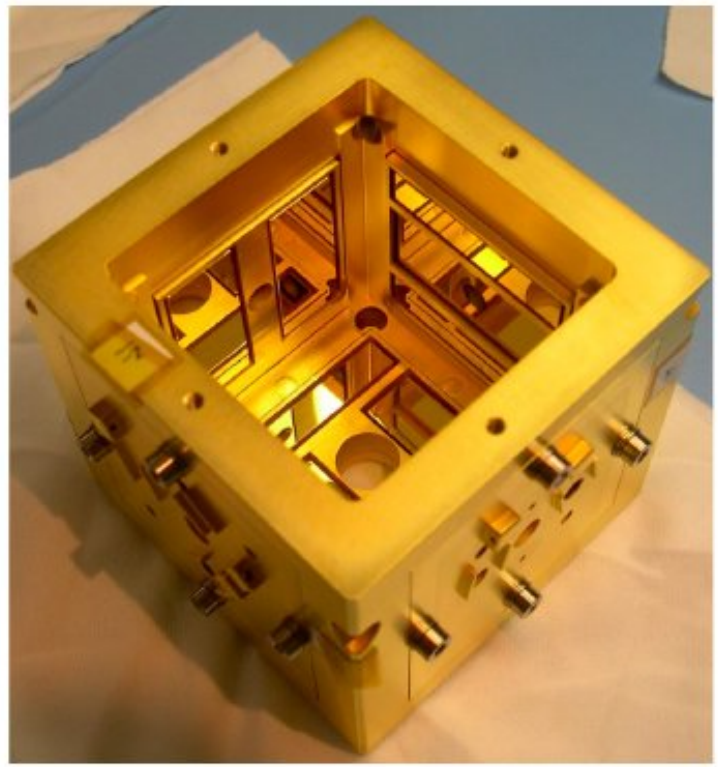


- f_{str} minimized by design (T, B, μg)
- F_{ext} shielded by the SC
- capactive sensor + DFACS + μN thrusters keep the SC centered to the PM

- Has to be tested in space
- To be tested by LISA Pathfinder (LPF) in 2014

Proof mass and Electrode Housing (LPF)

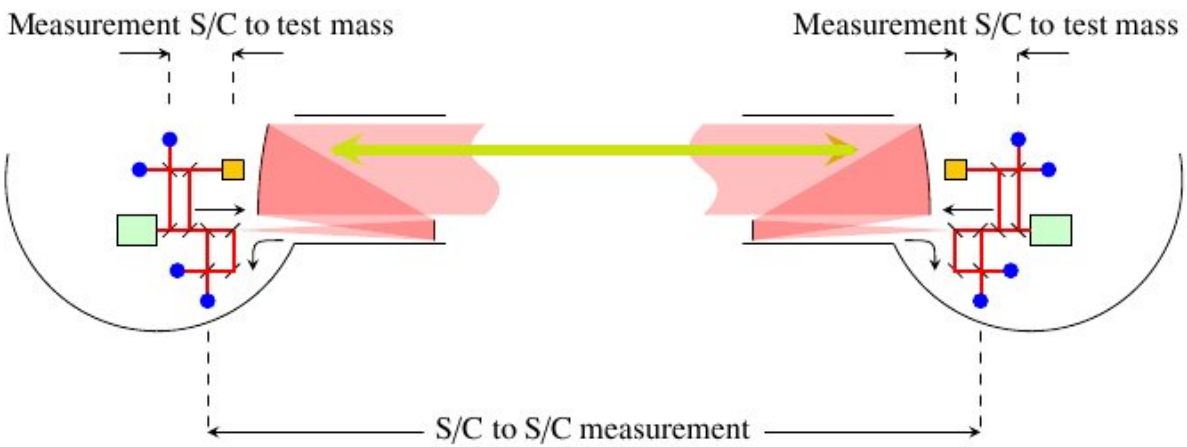


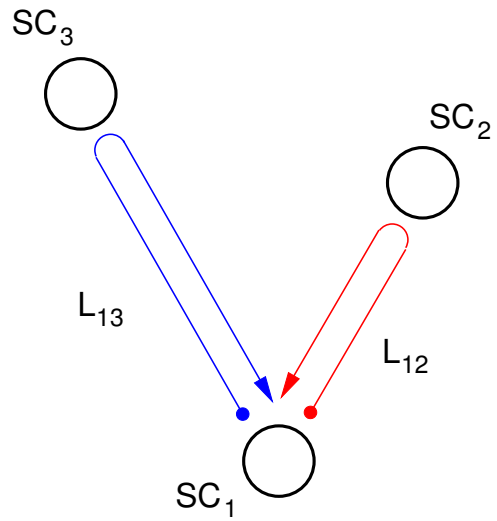


Interferometry

Once we have the PMs in free-fall we have to measure the distance between them at the pico-meter level to detect GW

- PM interferometer: PM-SC distance
- Science interferometer: SC-SC distance (Time-delay interferometry: synthesize a Michelson interferometer by a linear combination of time-shifted signals)

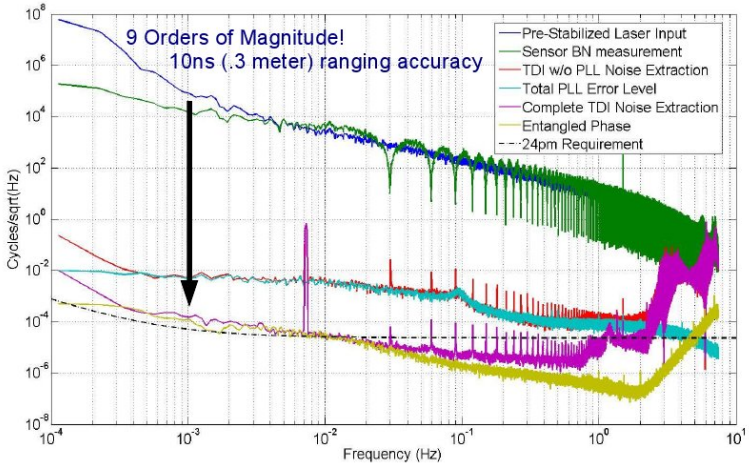




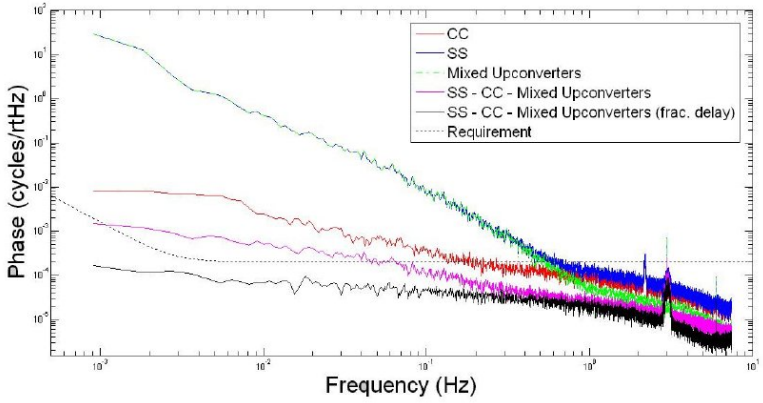
$$S_x^{1/2}(f) \leq 18 \times 10^{-12} \left[1 + \left(\frac{2.8\,\mathrm{mHz}}{f}\right)^4\right]^{1/2} \frac{\mathrm{m}}{\mathrm{Hz}^{1/2}}$$

LISA research at UF

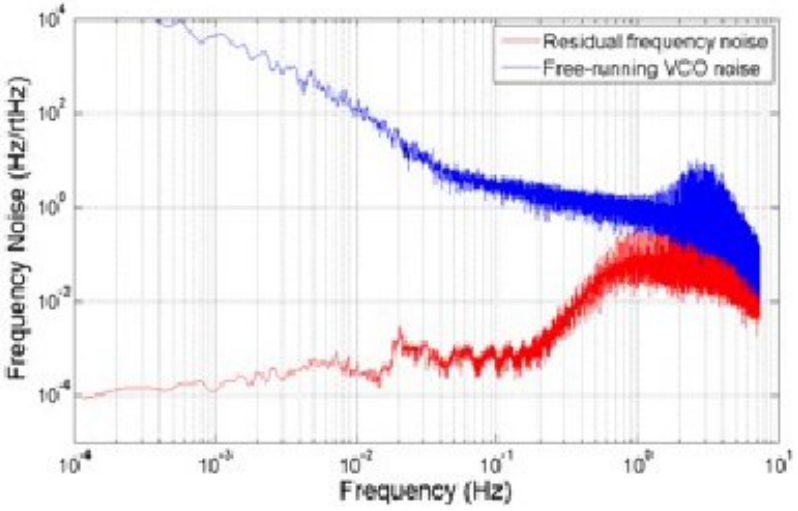
TDI: experimental proof of concept



Ranging: Up/Down-Converters, EOMs, PRN ranging



Arm-locking



- Frequency laser stabilization (see Darsa Donelan talk)
- Telescope investigations (see Dan Korytov talk)

LISA status

joint LISA (2B$) NASA/ESA mission no longer exists

ESA (2015)

NGO: New Gravitational (Wave) Observatory

- descoped mission
  - shorter arms
  - only 2 arms
  - orbit closer to Earth
  - power/mass reduction
- ESA decision by Summer next year
- LISA Pathfinder to be launched 2014

1BEuro

if ESA goes ahead

NASA (2025)

SGO: Space Gravitational (Wave) Observatory

Different configurations under investigation

- power/mass reduction
- shorter arms
- only 2 arms
- different orbits
- etc.

320M$–2B$

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