Enhancing the astrophysical reach of LIGO with squeezed light

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For the LIGO Scientific Collaboration

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Beating quantum noise with squeezed light

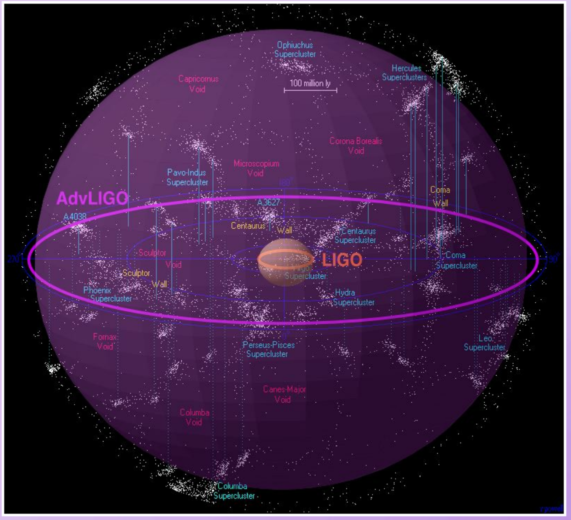
✓ The quantum nature of light limits our ability to detect gravitational waves

✓ Quantum noise can be reduced by using non classical (squeezed) states of light

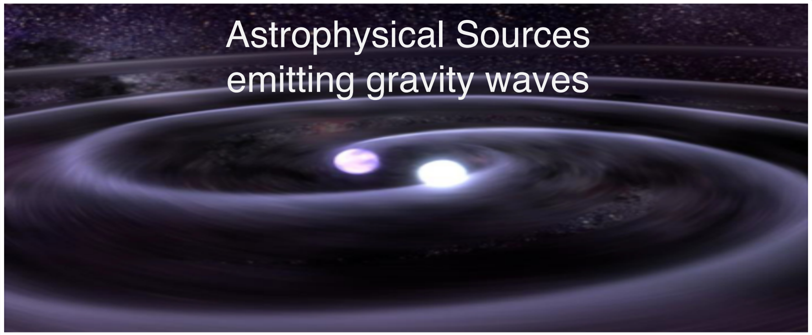
✓ We injected squeezed light in the most sensitive gravitational wave detector in the world…and we made it even better!

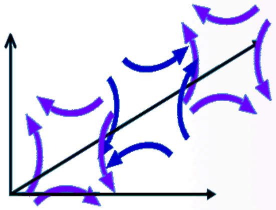
✓ This result gives us confidence that we can use squeezed light to improve the next generation of LIGO detectors, Advanced LIGO

✓ New opportunity for extending the Advanced LIGO astrophysical reach and observe the gravitational wave Universe with unprecedented sensitivity

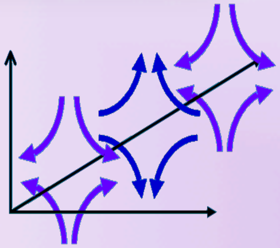


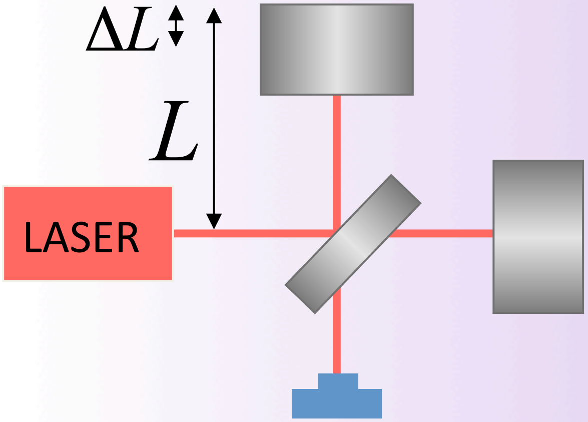
How we detect gravitational waves


Astrophysical Sources
emitting gravity waves



Gravitational waves: ripples in the space-time propagating at the speed of light





Michelson Interferometer

Differential displacement
of the mirrors

$$h = \frac{\Delta L}{L} \sim \frac{10^{-18}[m]}{4000[m]}$$

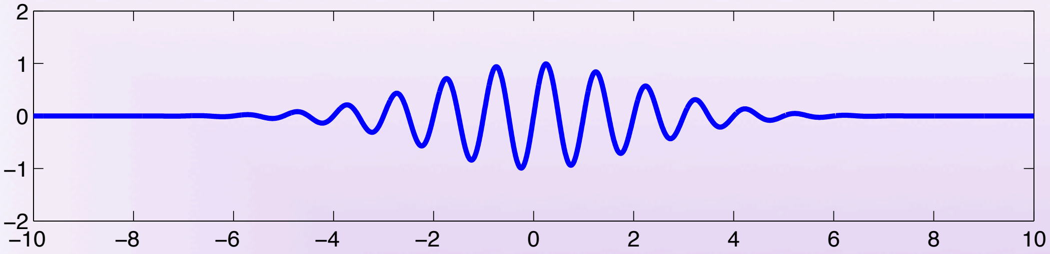
Amplitude of the
gravitational wave

Interferometer
arm length

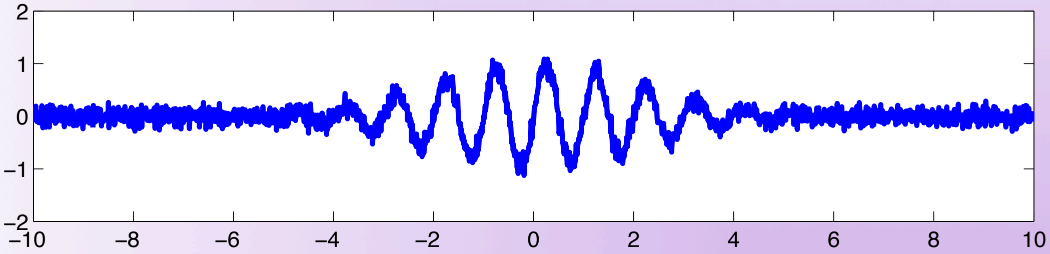
How “noise” affects our measurement

- ✧ External disturbances (“noise”) will mask the displacement induced by the wave…

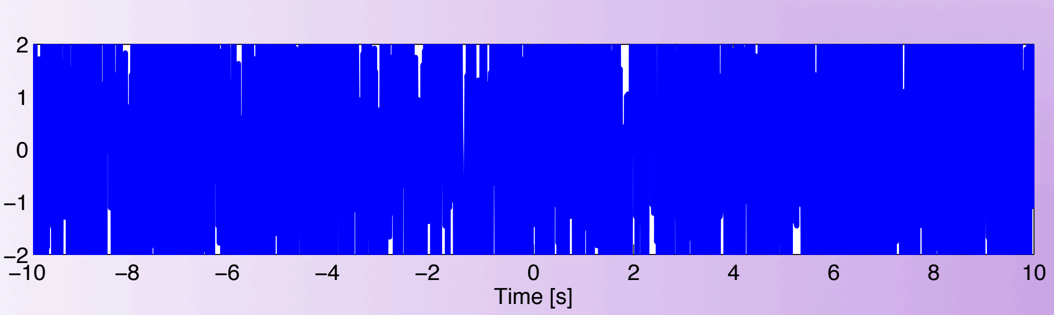
Noise free signal



A little bit of noise

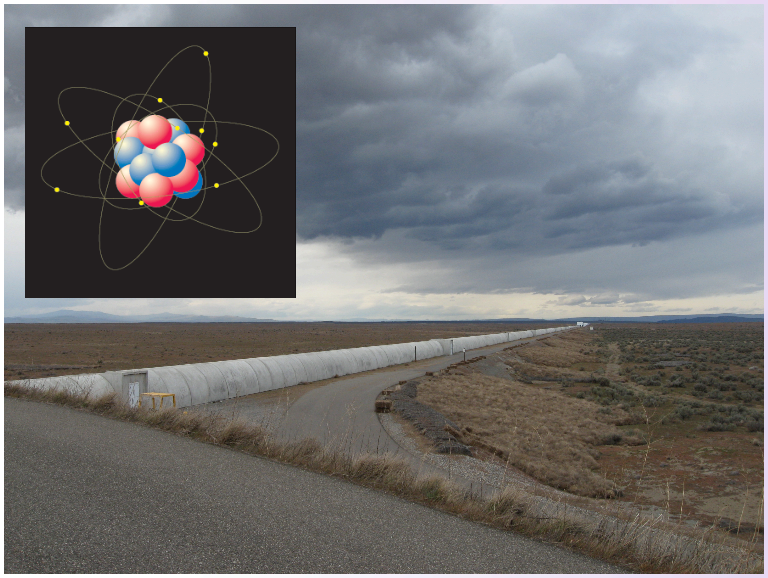


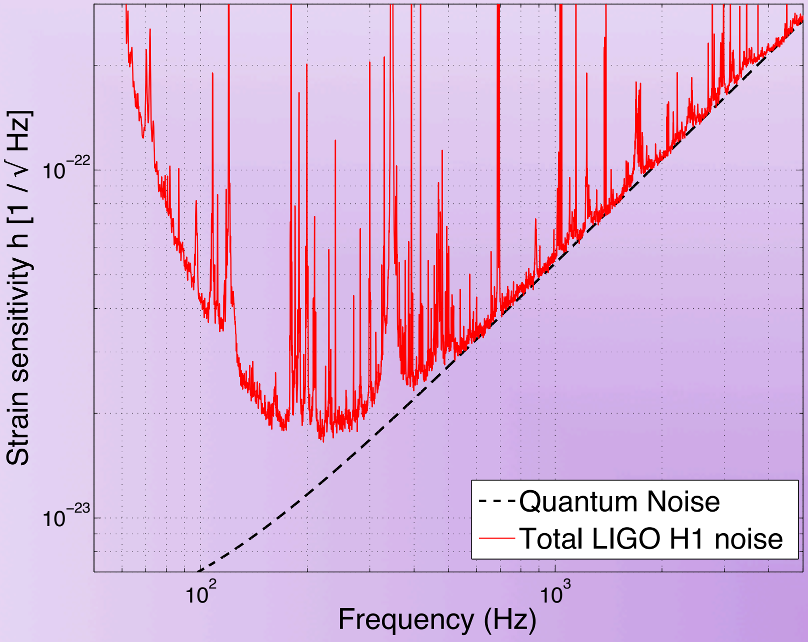
Signal buried by the noise



Even “noise” caused by the quantum nature of light limits our measurement!

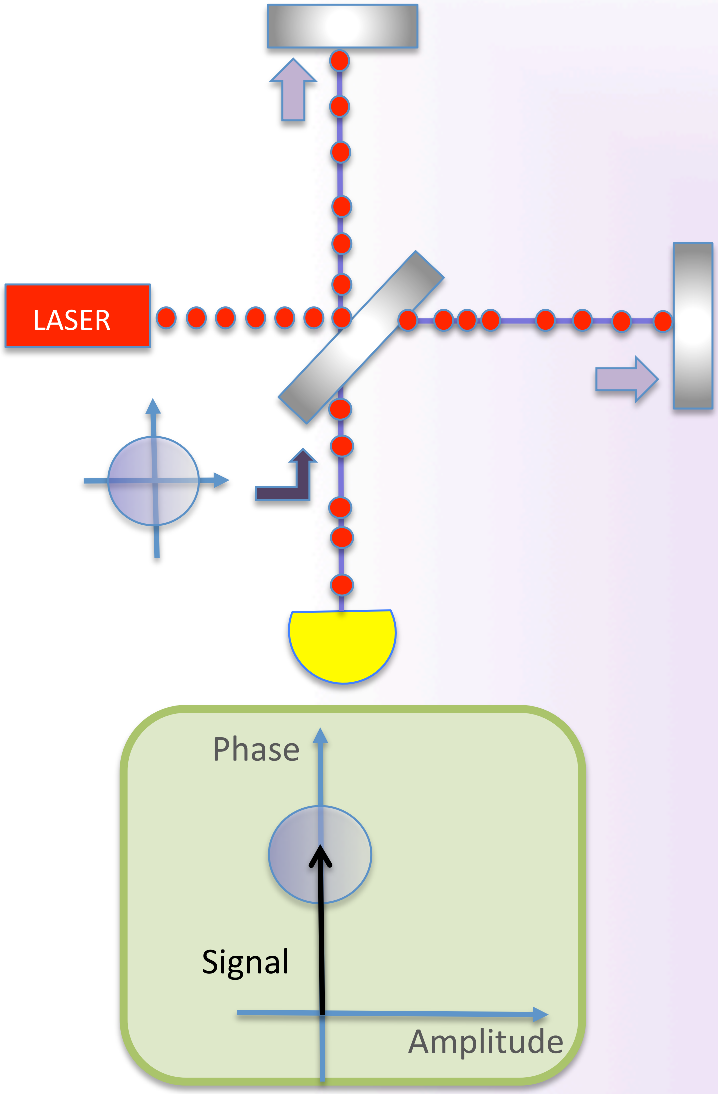
We want to measure displacements 1000 times smaller than the radius of a proton, over 4 kilometers…
…anything you can think of is a noise source!





Amplitude Spectral Density of LIGO noise

Quantum noise: fluctuations of the vacuum



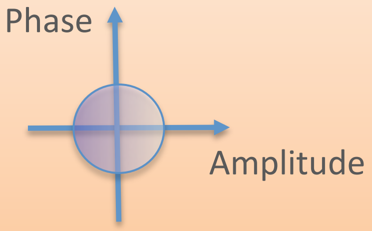
Heisenberg Uncertainty Principle

$$\Delta p \Delta x \geq \frac{\hbar}{2}$$

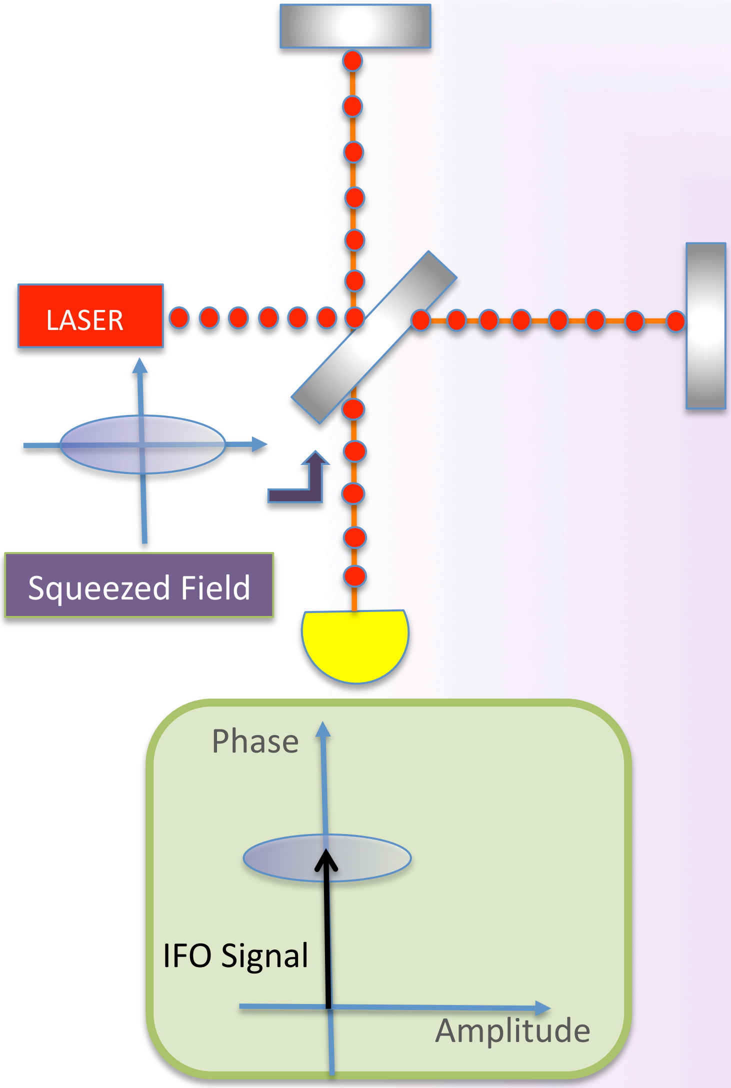
the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa

Same principle applies for the amplitude and phase of the electromagnetic field..

…and even for the amplitude and phase of the vacuum!



Vacuum Getting Squeezed



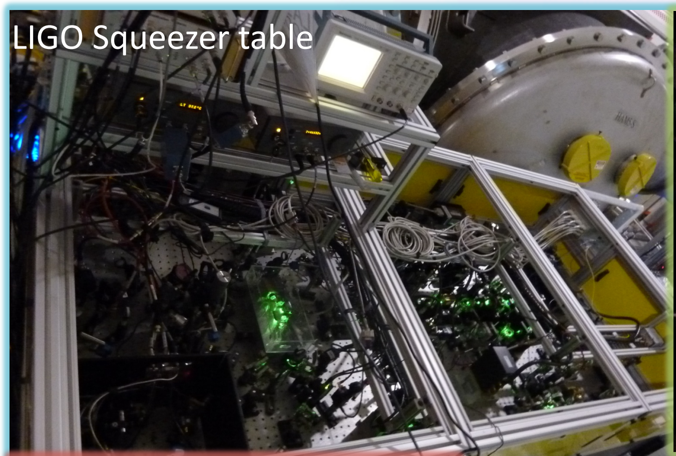
- Reduce quantum noise by injecting squeezed vacuum: less uncertainty in one of the two quadratures (amplitude or phase)
- **Heisenberg Uncertainty Principle**: if the noise gets smaller in one quadrature, it gets bigger in the other
- You can squeeze the vacuum so as to reduce the noise in the quadrature you care about

IN THEORY…

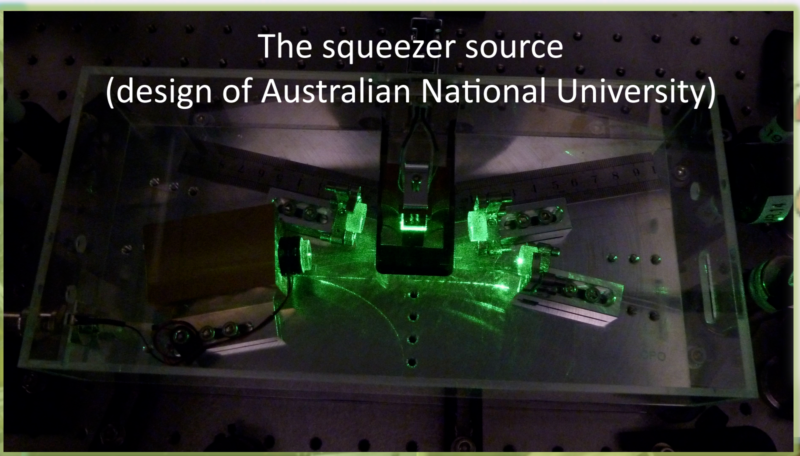
C. M. Caves, Phys. Rev. Lett. 45, 75 (1980).
C. M. Caves, Quantum-mechanical noise in an interferometer. Phys. Rev. D 23, p. 1693 (1981).

“In theory, theory and practice are the same. In practice, they are not.” - A. Einstein

World wide effort and many years of development to make squeezing compatible with gravitational wave detectors

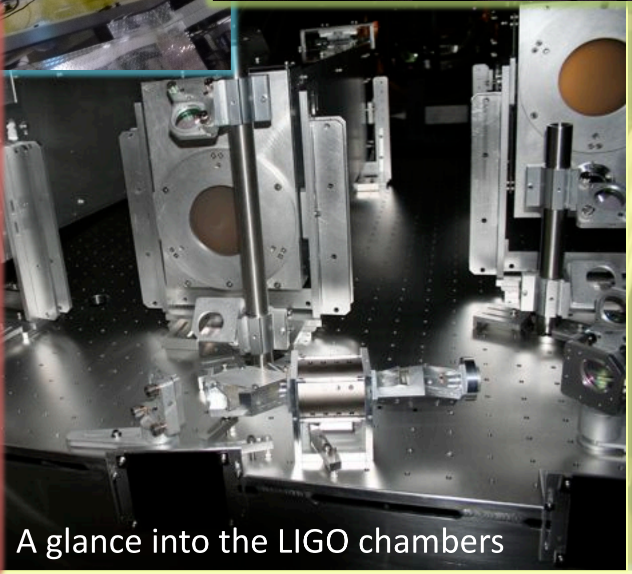


LIGO Squeezer table

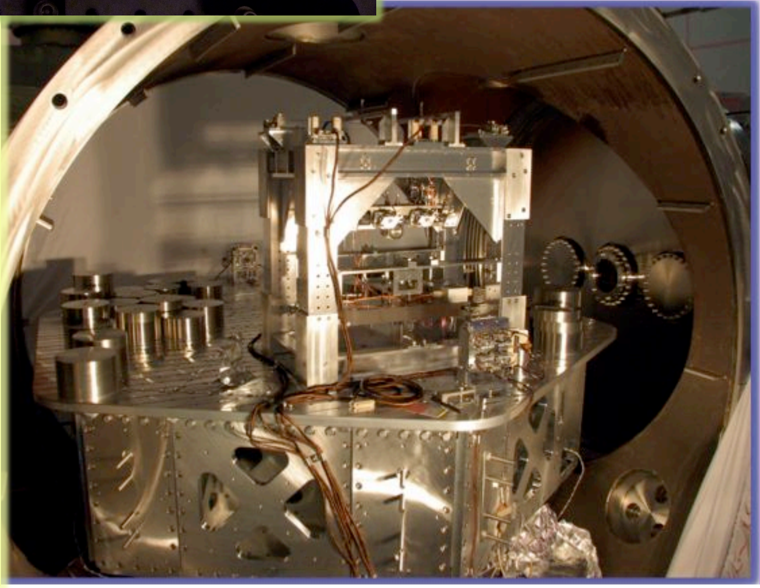


The squeezer source
(design of Australian National University)

Installation of the squeezer table

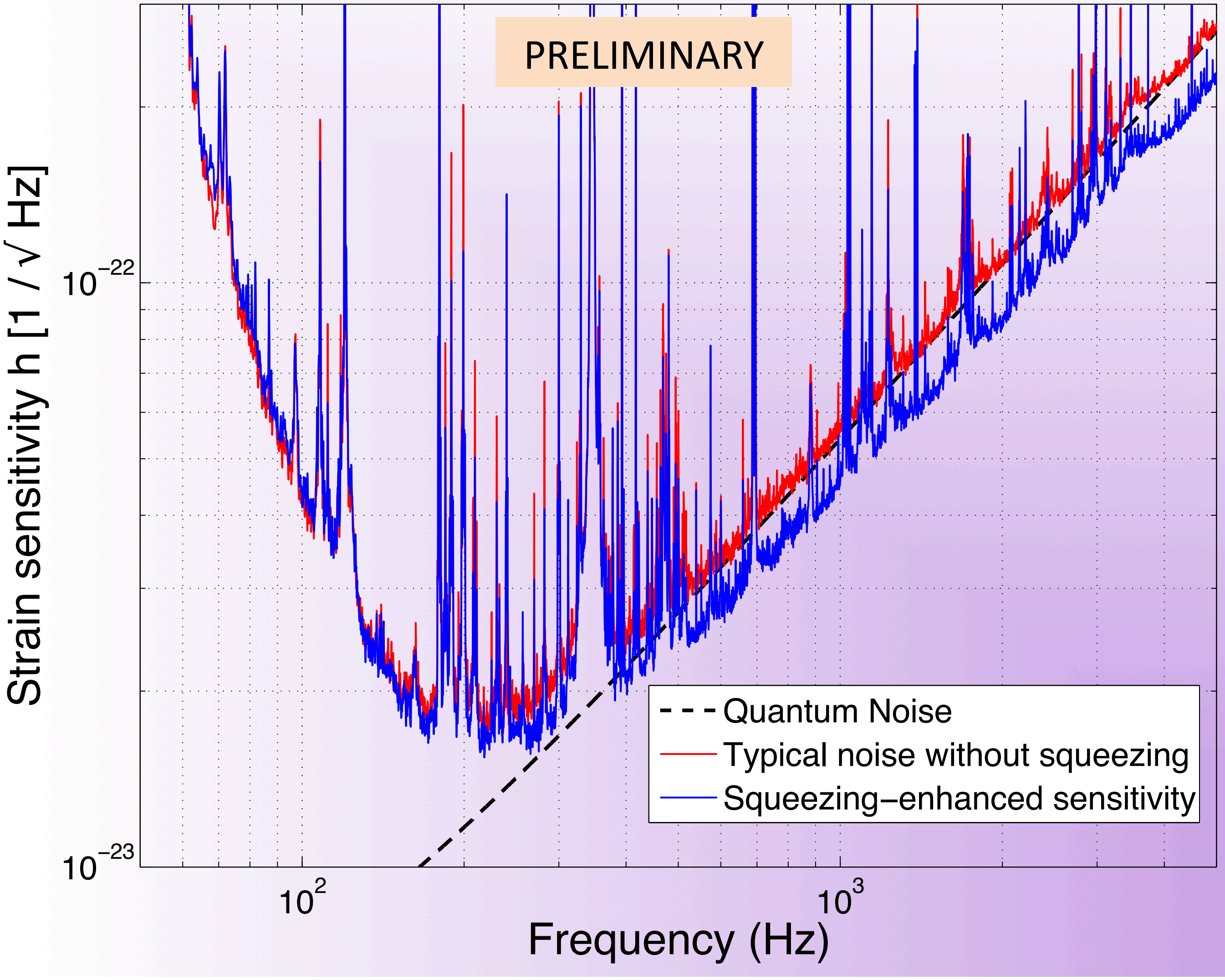


A glance into the LIGO chambers



IN PRACTICE: Quantum noise reduction in the 4-km LIGO H1 Interferometer

$$h = \frac{\Delta L}{L}$$



LIGO H1 Squeezing Experiment

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