Reducing Quantum and Thermal Noises in GW detectors

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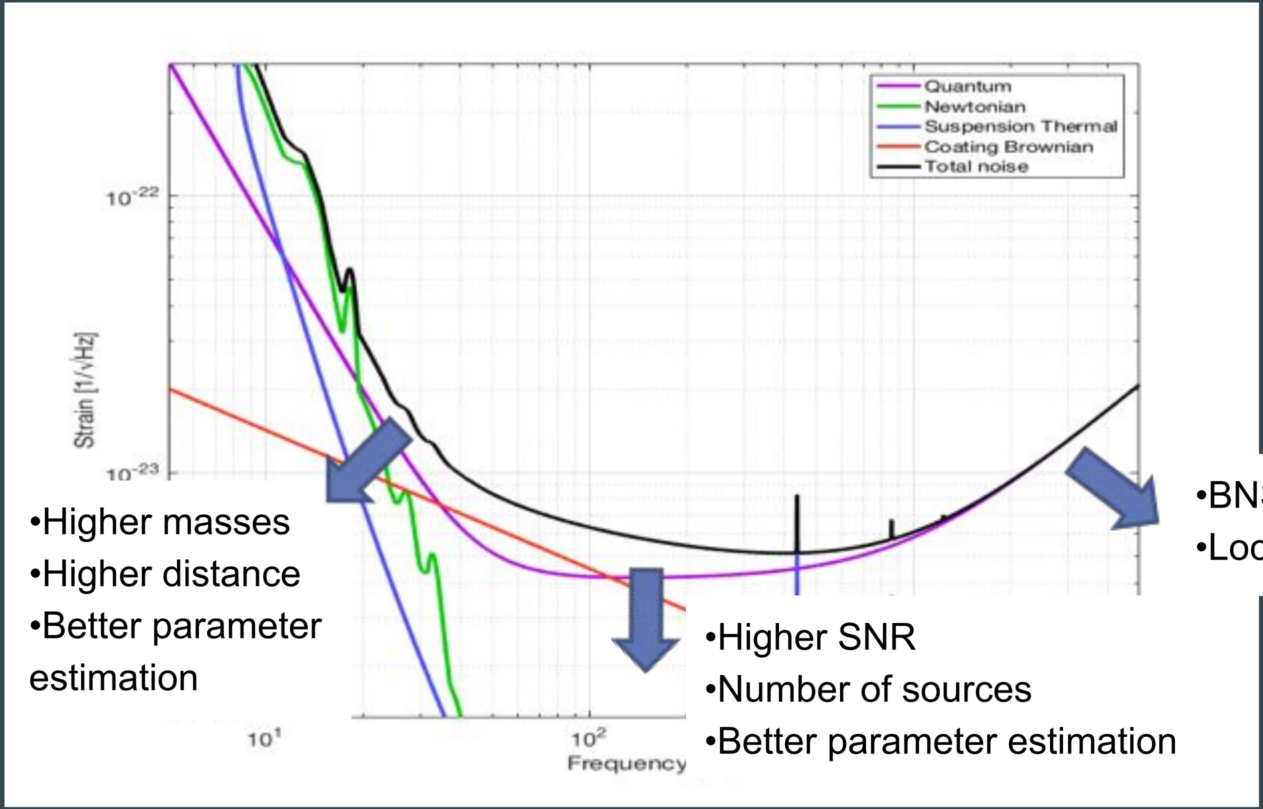
in behalf of the Virgo groups

Improving sensitivity

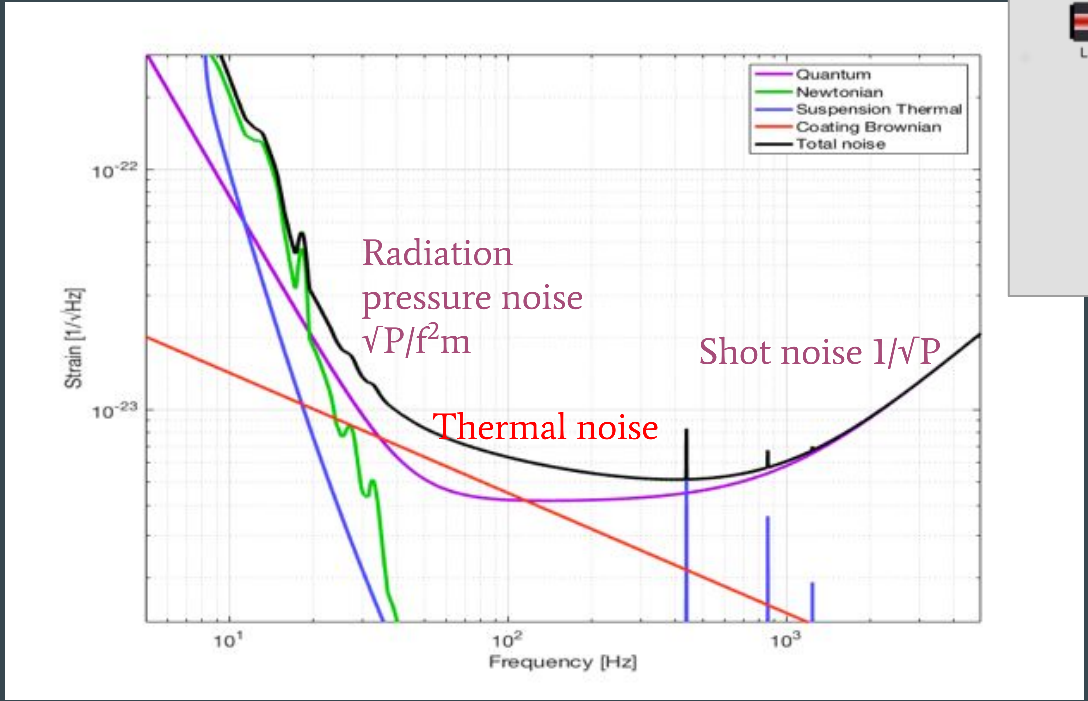


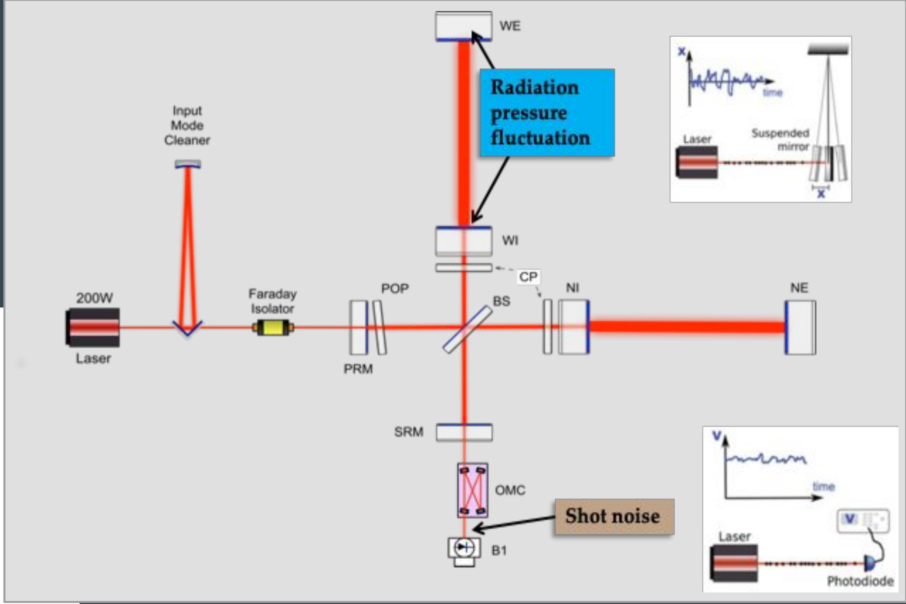
- Higher masses
- Higher distance
- Better parameter estimation

- Higher SNR
- Number of sources
- Better parameter estimation

- BNS merger physics
- Localization

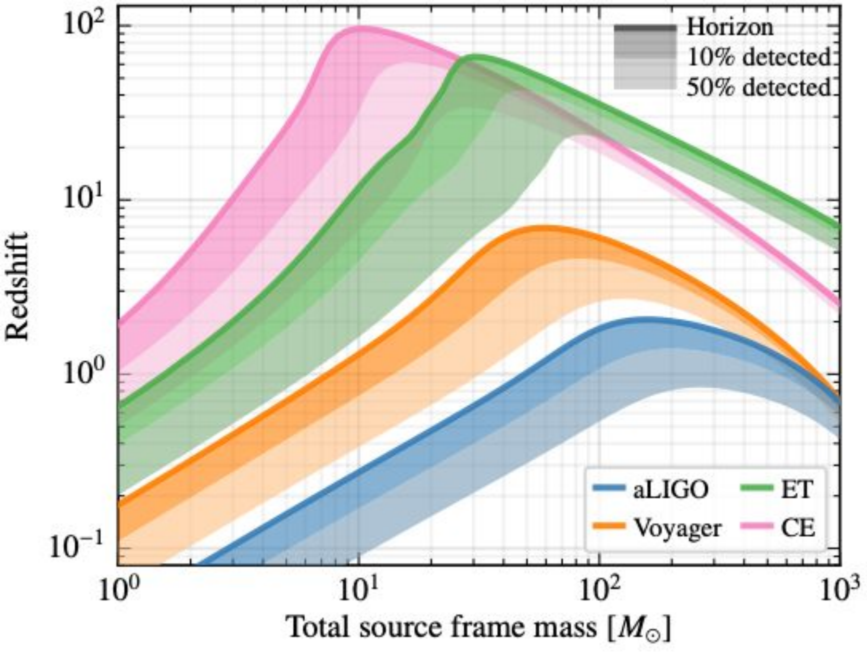
Limiting noise

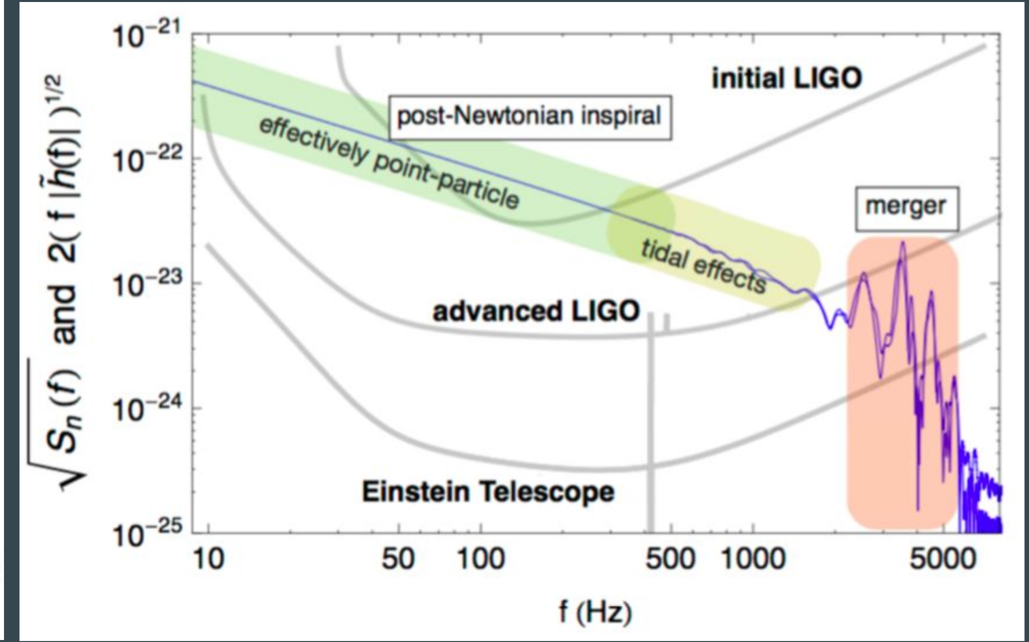




Advanced Virgo design sensitivity

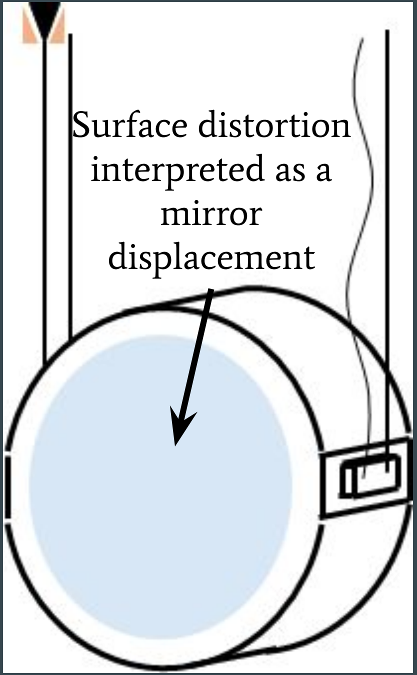
Also needed for next generation : Einstein Telescope





One solution against thermal noise

Fluctuation-dissipation theorem : Callen & Welton, Phys. Rev. 83 p34 (1951)



➡ **Mechanical motion thermally excited**

$$S_x(f) = \frac{k_B T}{\pi^2 f^2} \times \Re(Z^{-1})$$

$Z = \frac{F}{v}$: Mechanical impedance

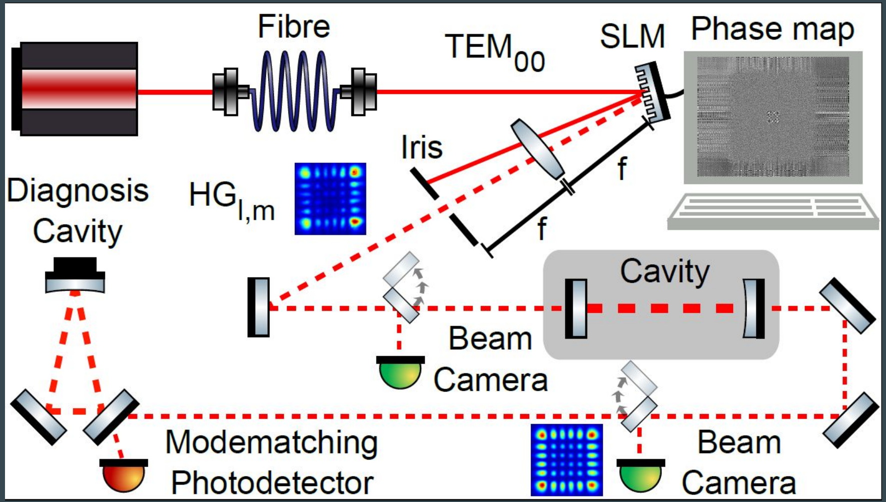
Apparent displacement

Depends on :

- The mechanical quality factor
- <u>The optical incident mode</u>

One solution against thermal noise

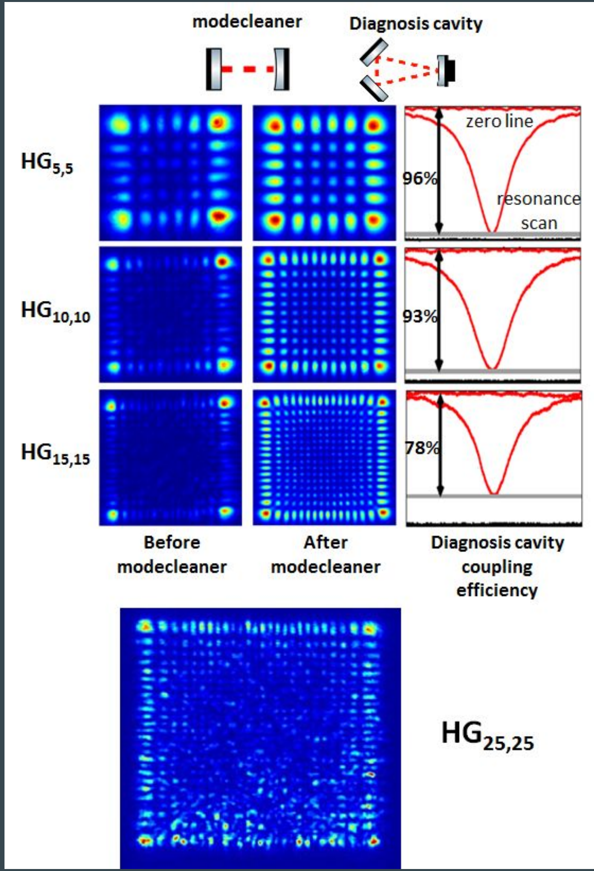
➡ Hermite-Gauss high order modes



Increase the power of the HG modes :

- High power SLM
- Conversion efficiency

@ ARTEMIS



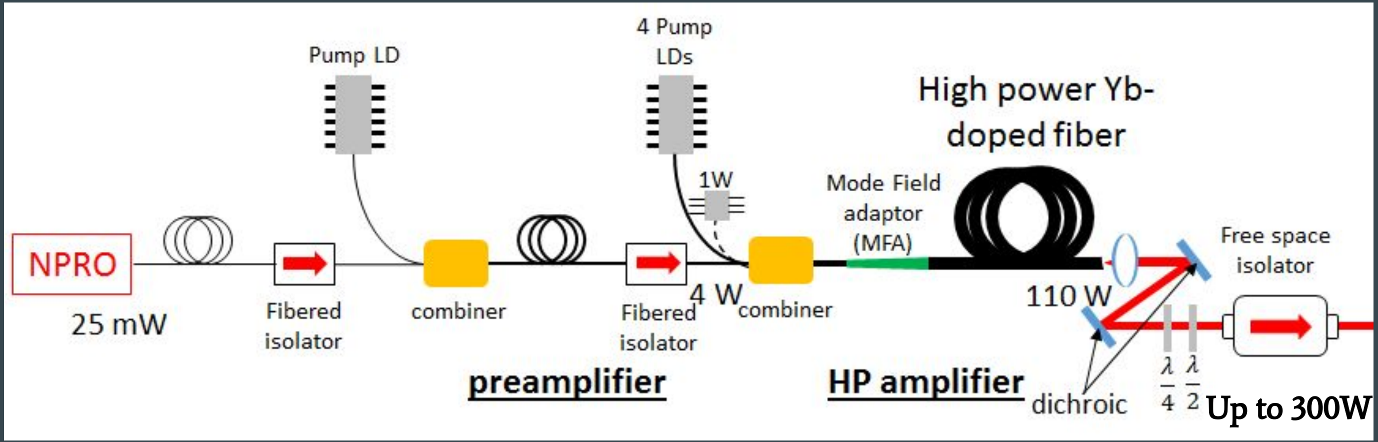
Reducing Quantum noise

- Increase power at input of the interferometer
  - Will reduce noise in the high frequency band (shot noise)
  - Important drawback : reduce sensitivity in the low frequency band, radiation pressure noise
  - Also possibility to have parametric instabilities (see later)
  - Impact on thermal noise

- Play with quantum nature of light and vacuum
  - Squeezing techniques with dependance in frequency
  - Need measurements and development of squeezing techniques

Increasing power

➡ Towards fiber technology



ALPHANOV R&D

ALS industrialization

ARTEMIS & LP2N Test & Metrology

➡

- AdV+ Phase 1 : 70 W
- AdV+ Phase 2 : 130 W
- Einstein Telescope : 500 W

Standard squeezing

2 variables in relationship with Heisenberg principle

→ Phase and amplitude

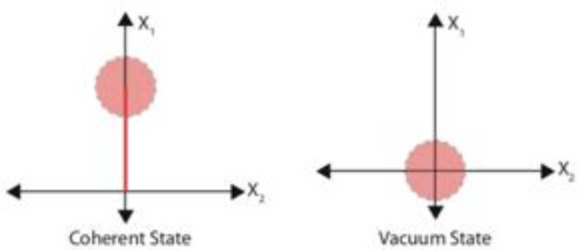
One can play with the shape of the coherent/vacuum state : from circle to ellipse - to be done to low frequency

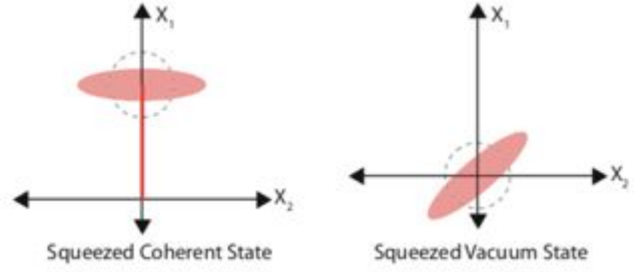
→ But then degrade the other part

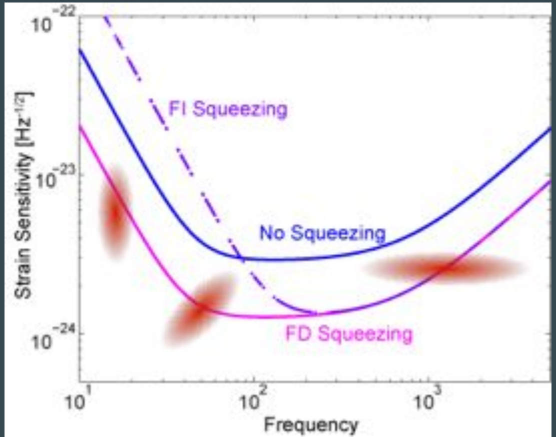
Use the frequency dependance of the noise and rotate the ellipse

→ Need new optical cavity to allow this

Squeezing very sensitive to all optical losses



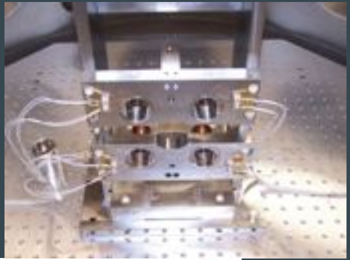


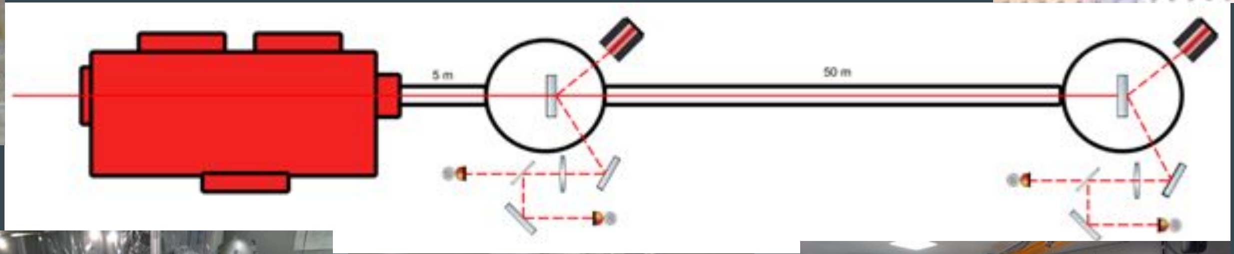


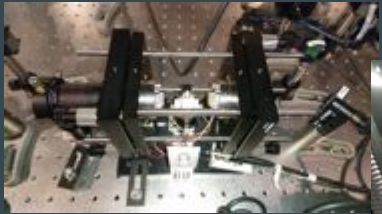
Exsqueez / QFilter

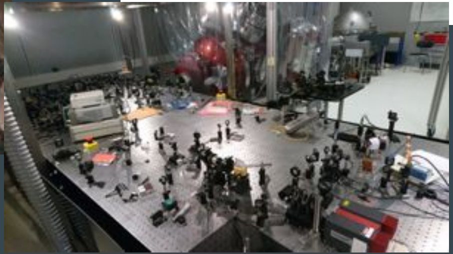
ANR projects - prepare squeezing under vacuum for Advanced Virgo - 50m filtering cavity - system installed at IJCLab
Collaboration between LKB, IJCLab, IP2I and LAPP

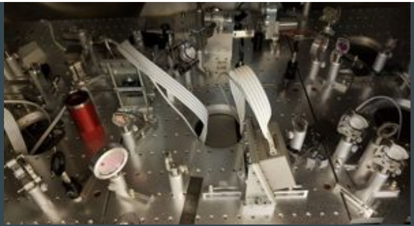
Evolution : adding a third mirror to improve filtering on squeezing











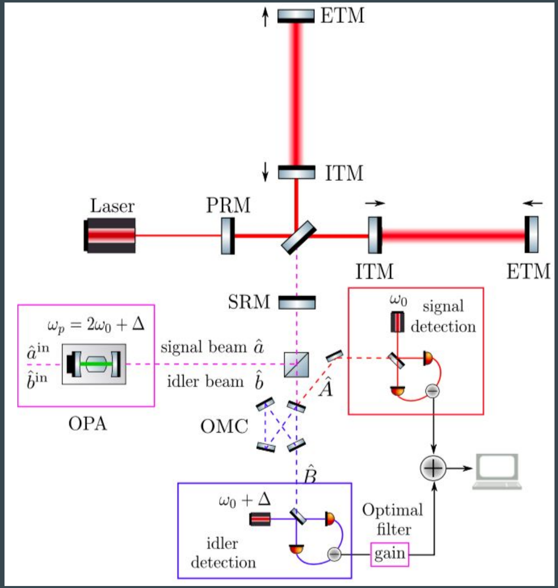
Other possibility:
EPR frequency dependant squeezing

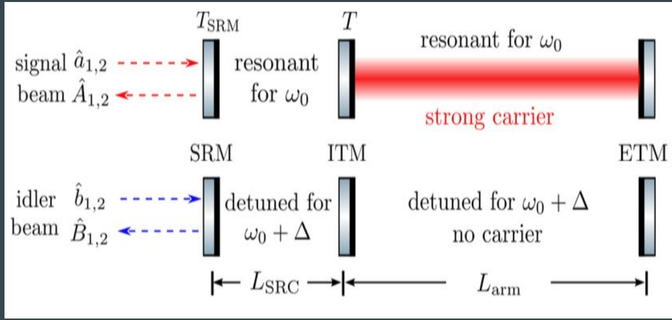
Present frequency dependent squeezing request a new low-losses optical cavity

Proposal and studies since 3 years to see if can use the interferometer itself as filtering cavity using EPR effect present in the squeezing production:

- Less components
- Less expensive
- Flexible
- Remove the control of a cavity
- But reduce injected squeezing and bring new losses

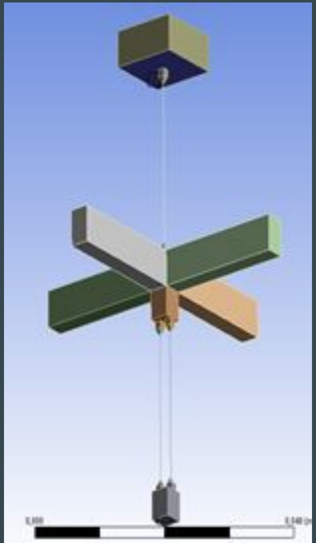
Some studies done at APC with INFN





A table-top experiment (ARTEMIS)

Optomechanical effects at the quantum level (radiation pressure, ponderomotive squeezing…)



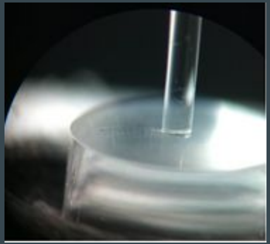
Low noise, low frequency (3 Hz) oscillator

High temperature plasma fiber pulling :

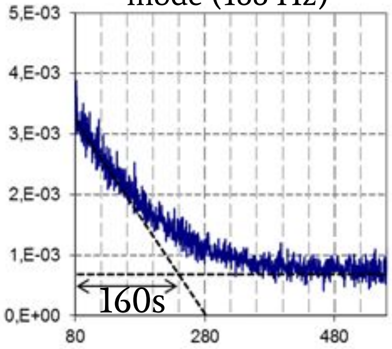
- 10 to 25 µm
- breaking limit > 3.9 GPa

Fiber to mirror soft silicate bonding :

- Thickness 2µm
- Breaking stress >1.4 MPa

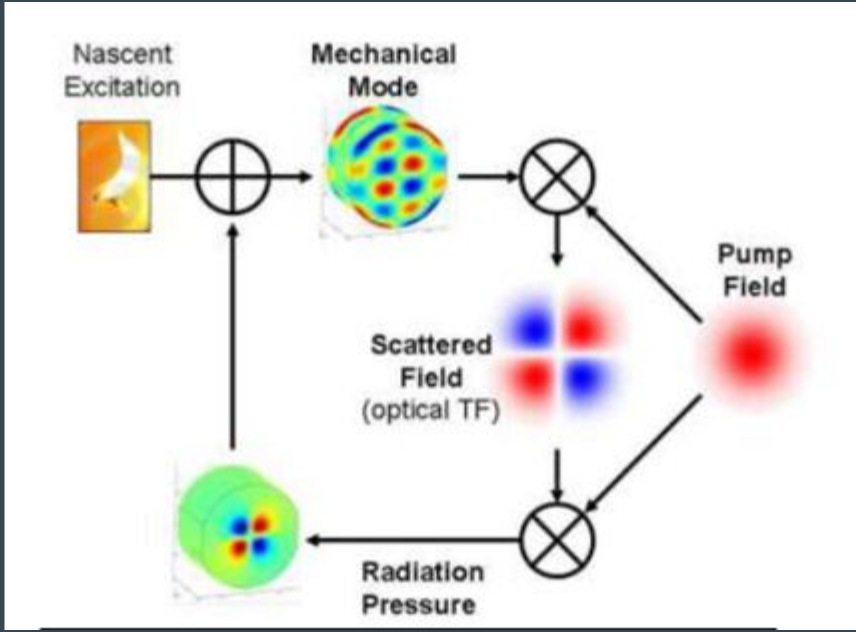


Quality factor measured on a the ring down of a violin mode (188 Hz)



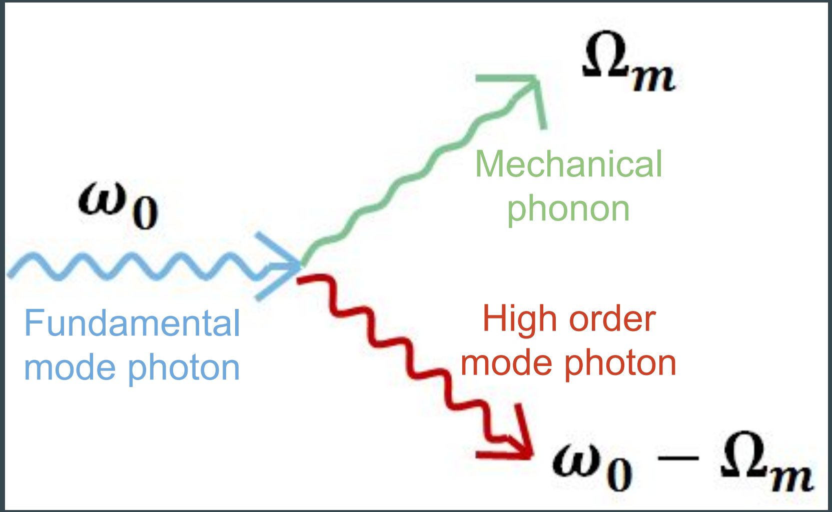
$Q = 5 \times 10^5$

Parametric instabilities



Evans et al, Phys. Lett. A, 374(4), 665-671 (2010)

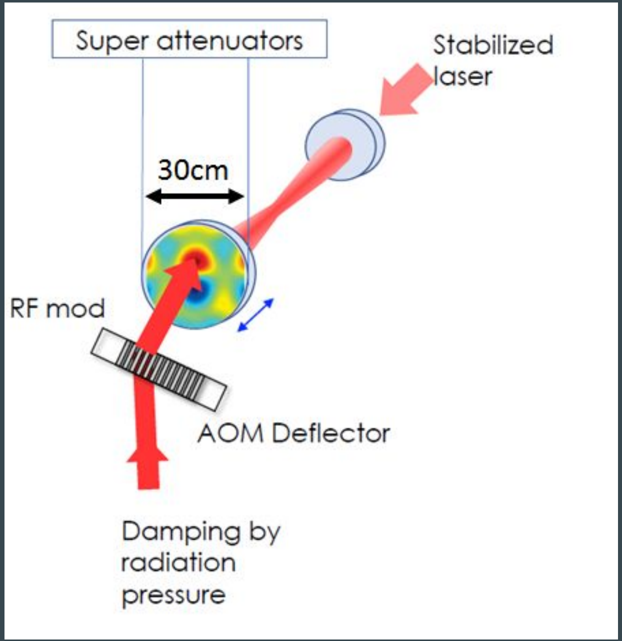
inelastic scattering



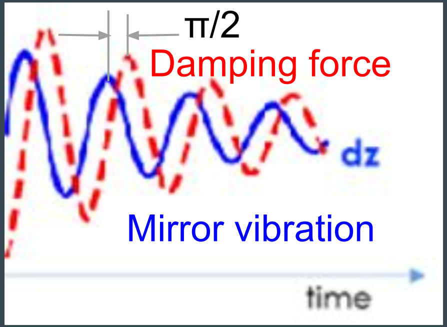
➡ **Parametric amplification : loss of contrast + ITF instability (unlock)**

Parametric instabilities : mitigation

⇨ Damping force applied on the mirror by radiation pressure



- Laser power ~1-10W
- Scan range ~30 cm



Conclusions

- Gain of one order of magnitude in sensitivity is expected for the next generation of gravitational wave interferometers
  - Lot of new physics accessible
  - Next generation will be at the same time as LISA mission - multibands GW studies will then be possible !

- French groups from Virgo (IN2P3, INP, INSIS) are participating to this effort with studies done on the main physical noises

- Needs of support on theses R&D to define the best option(s) to reach the design sensitivity