Laboratoire Kastler Brossel

Thermal and quantum noises in interferometric measurements

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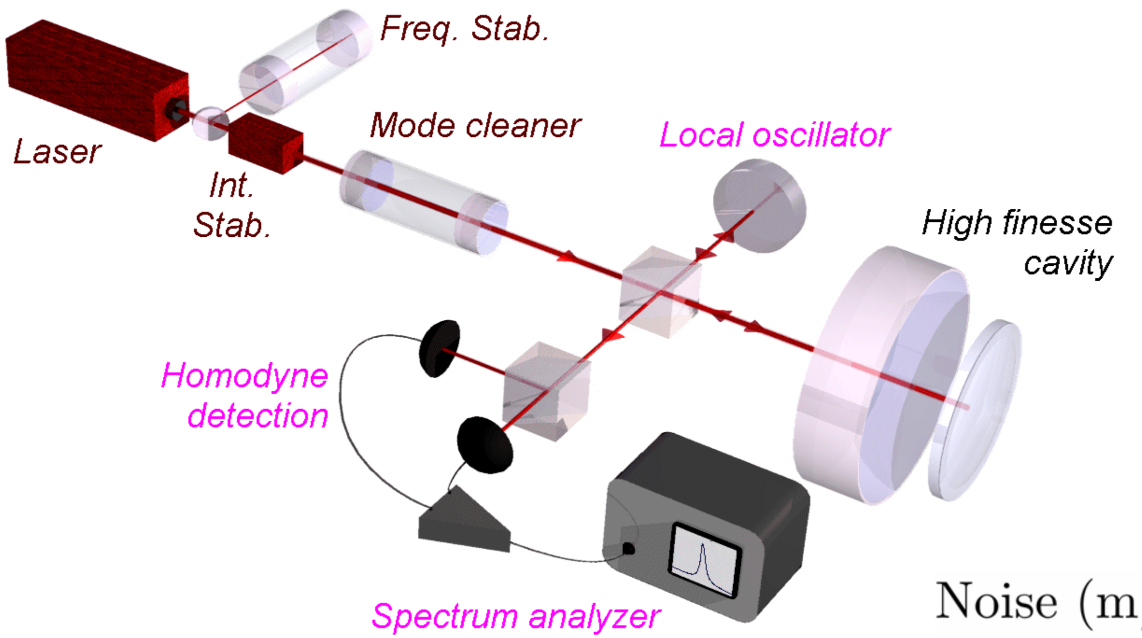
Noises reduction in interferometric measurements

- Exhaustive study of the thermal noise with a high finesse cavity
- Observation of radiation pressure effect
  back-action noise cancellation
- Sensitivity improvement by cavity detuning
  (self cooling effect, observation of the cavity instability)

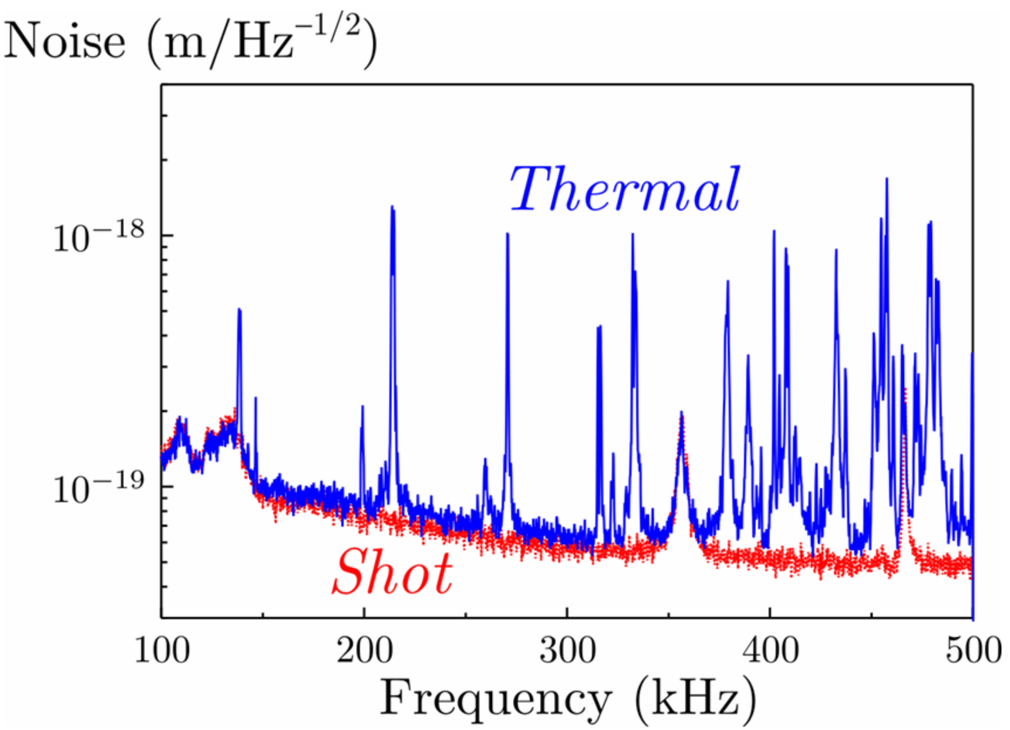
Very sensitive optomechanical sensor



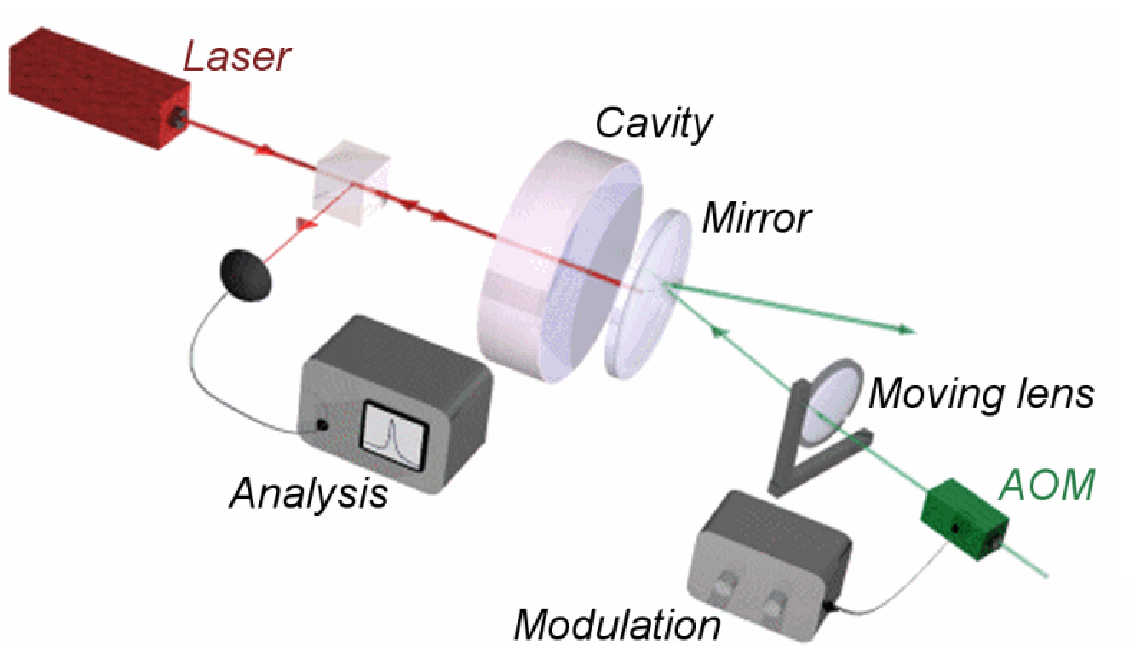
- Highly stable laser source
- High finesse cavity (30 000)

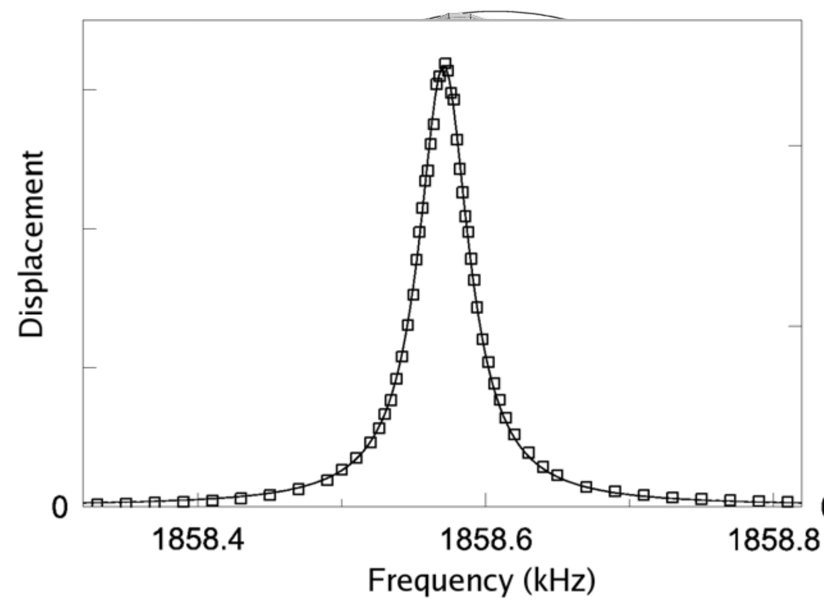
Quantum limited sensitivity:

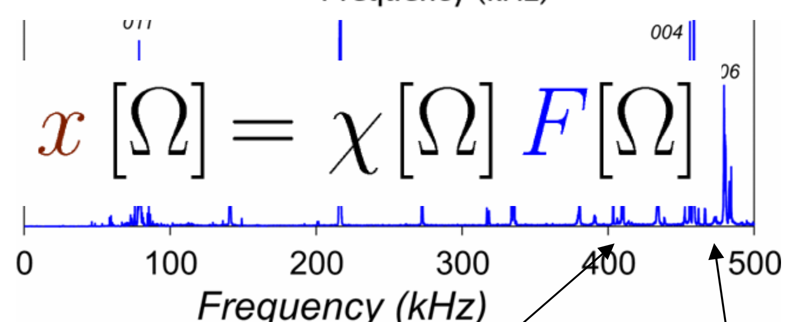
$$\delta x_{min} = 5 \times 10^{-20}\, m/\sqrt{Hz}$$



Characterization of internal modes







$$x[\Omega] = \chi[\Omega]\, F[\Omega]$$

Optical excitation by an intensity-modulated beam

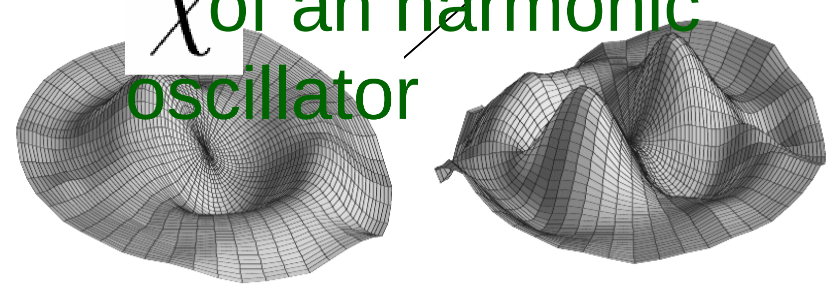
Spatial scan over the mirror surface

↓

Frequency, Q, effective mass

Spatial structure of the modes

χ of an harmonic oscillator

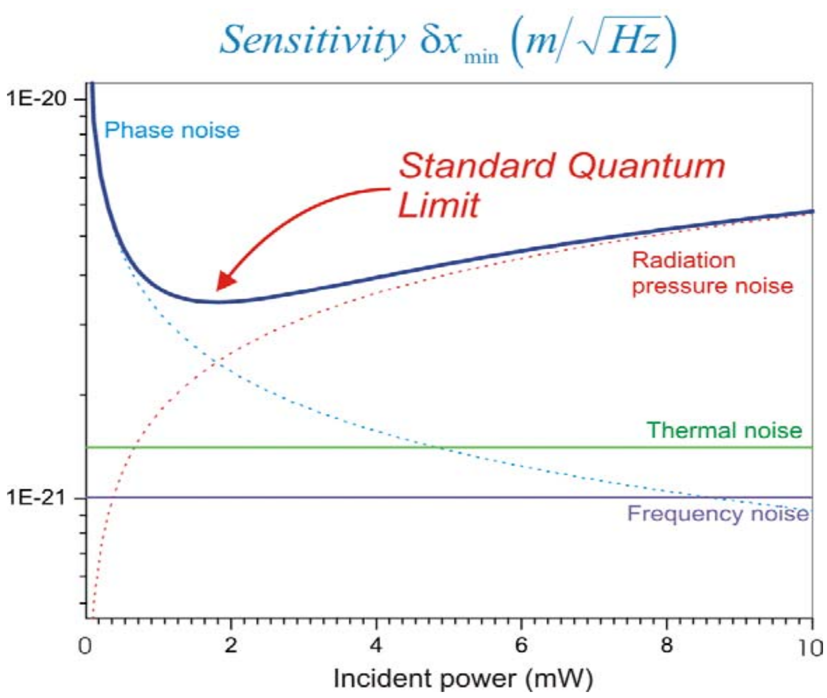


Quantum effects of the radiation pressure

Observation of the Standard Quantum Limit

Test of quantum noise reduction schemes

Squeezed light, quantum locking…



Main experimental improvements:

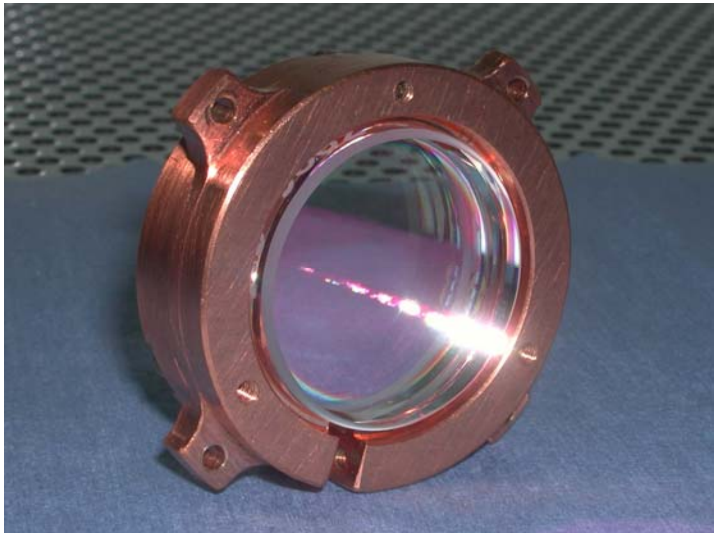
- Better mechanical response

  M≈10mg Q>10^6

- Better sensitivity

- Low temperature operation

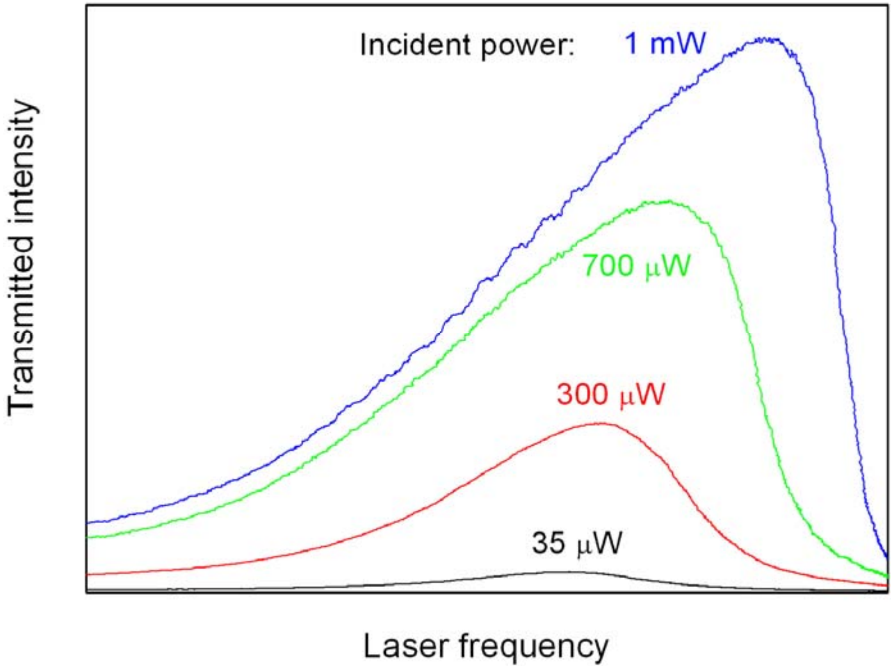
Current status of the experiment



New cavity with a finesse 230 000

Intracavity intensity increased by a factor of 10

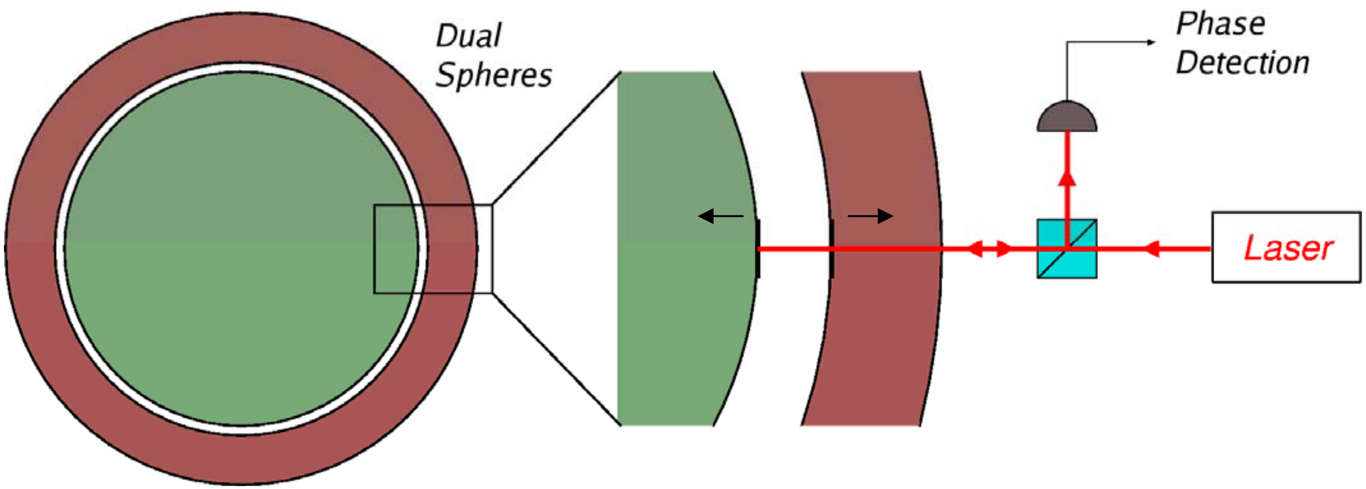
Improvement of the laser frequency locking



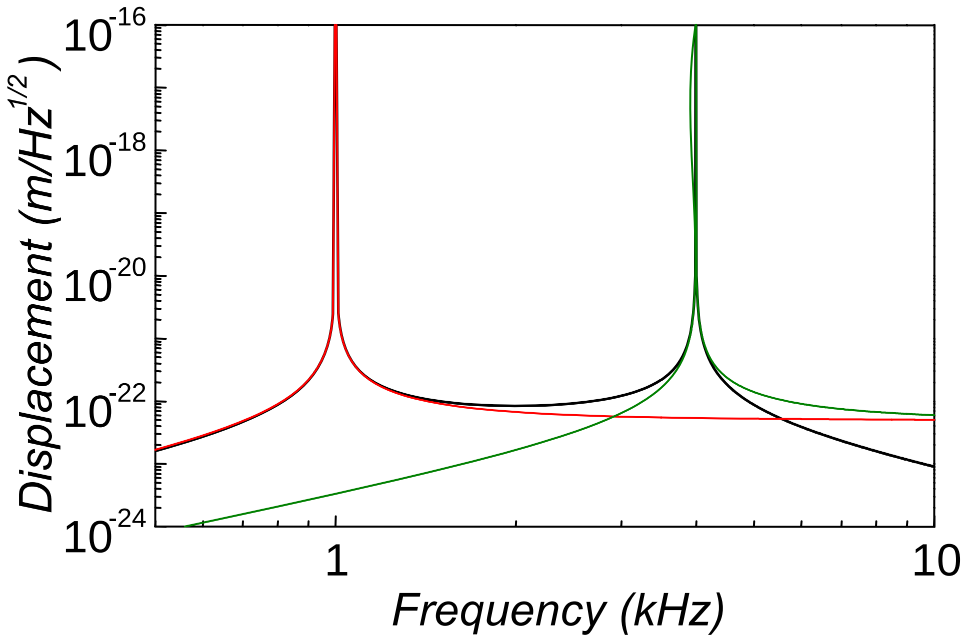
Cryogenic setup (4K)

Back action noise evading

First appears in the context of dual resonant detectors

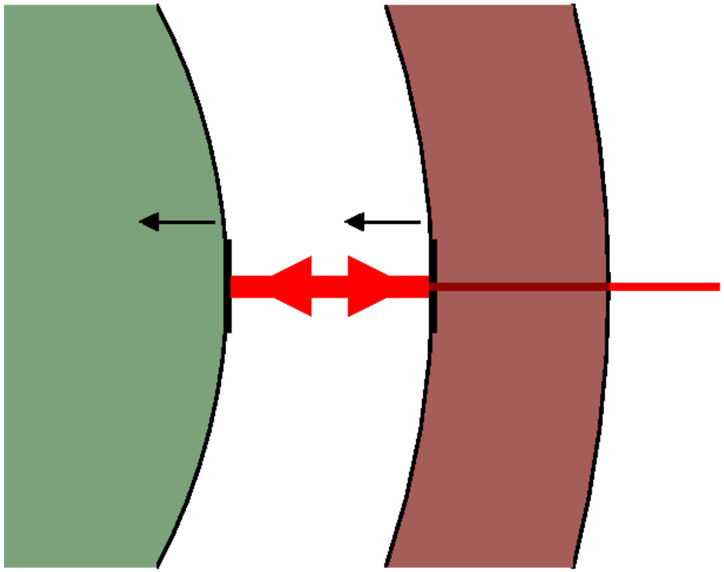


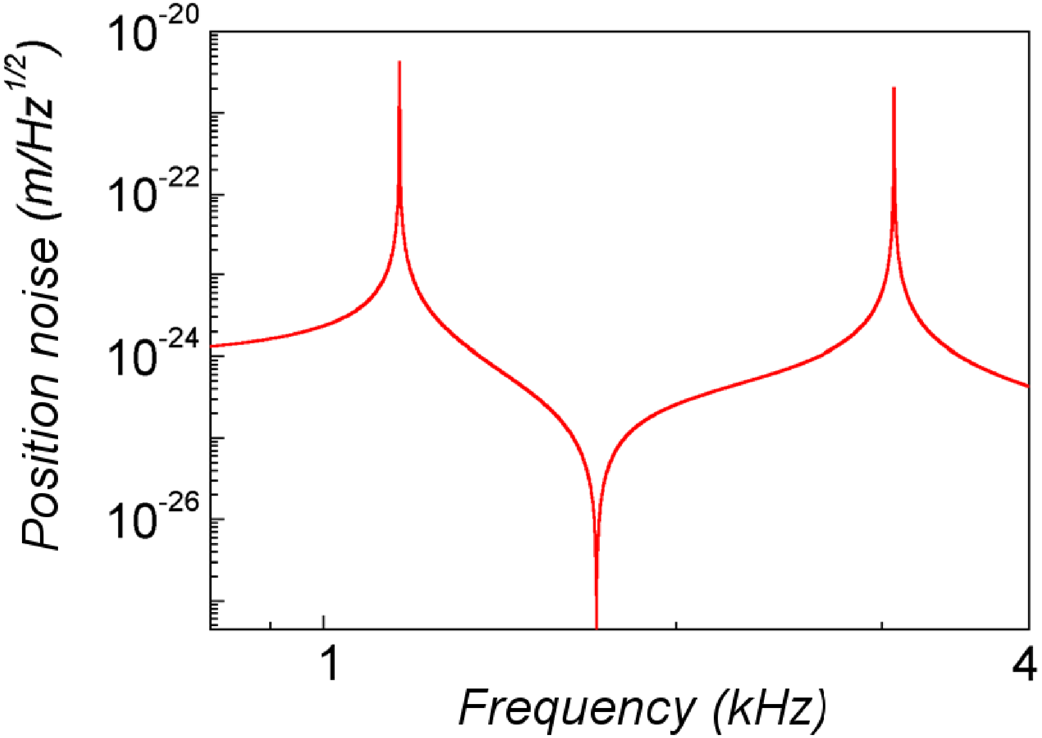
Between fundamental resonances,
the responses of the spheres to
the gravitationnal wave are opposite



Back action noise evading

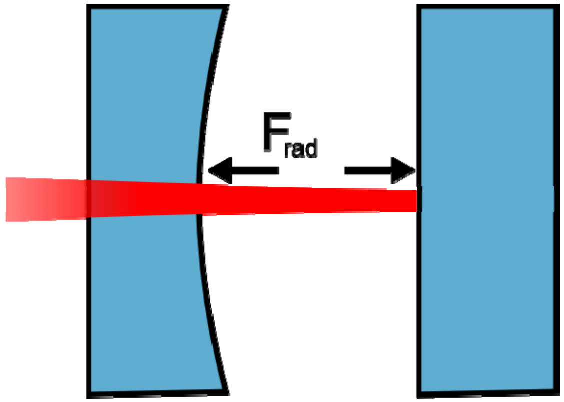
Between resonances, the responses to the radiation pressure are in phase → Back action noise cancellation





Large improvement of the sensitivity

Radiation pressure noise cancellation

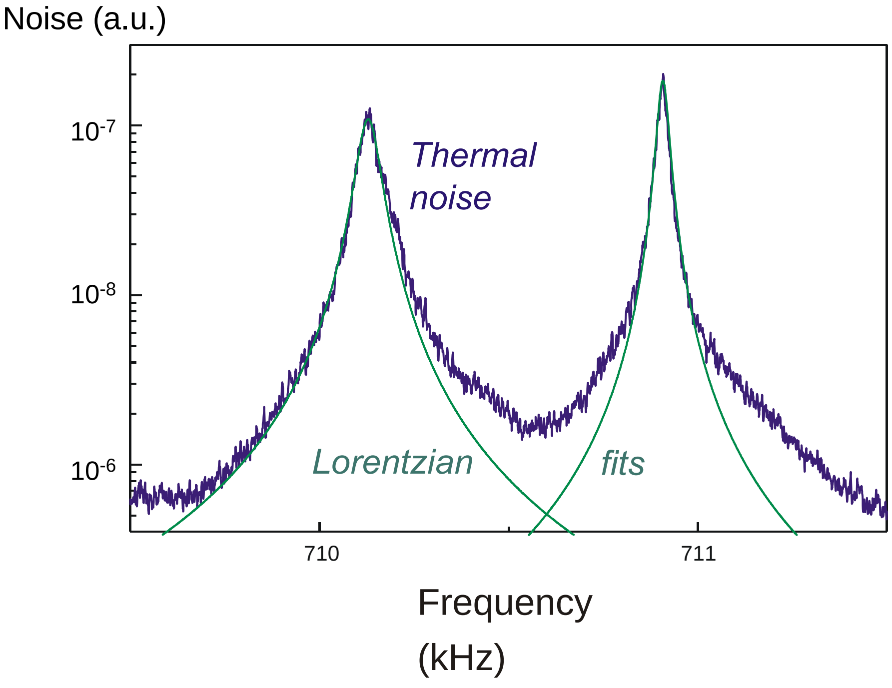


Similar effect in Fabry Perot cavity with two merely identical mirrors

Thermal noise of both mirror are uncorrelated

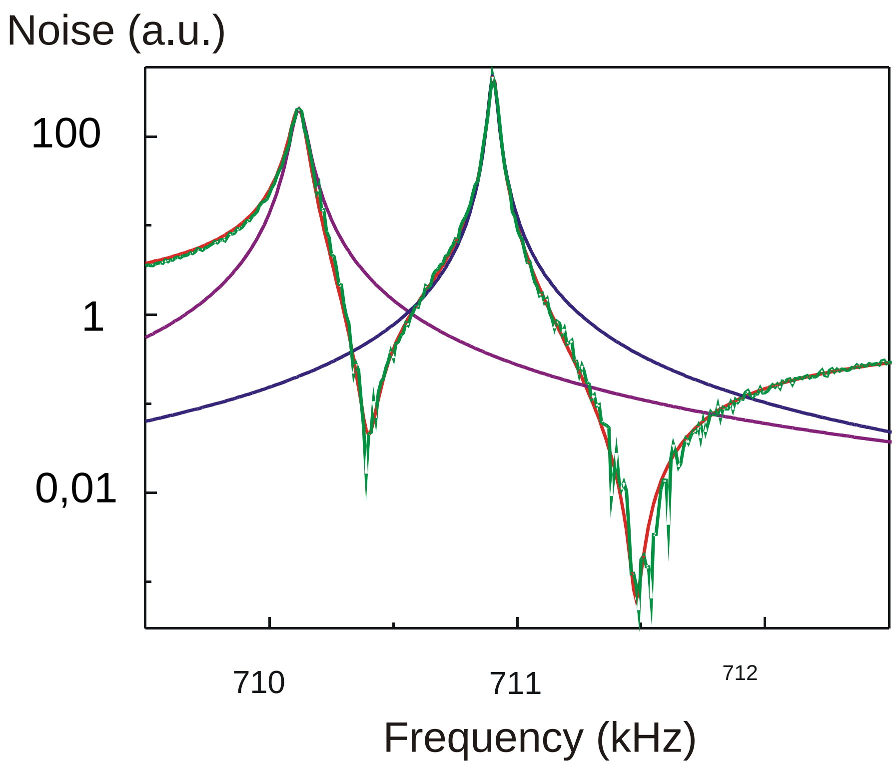
↓

Contributions of each mirror are added



Cancellation of radiation pressure effect

A second cross-polarized laser beam is injected into the cavity



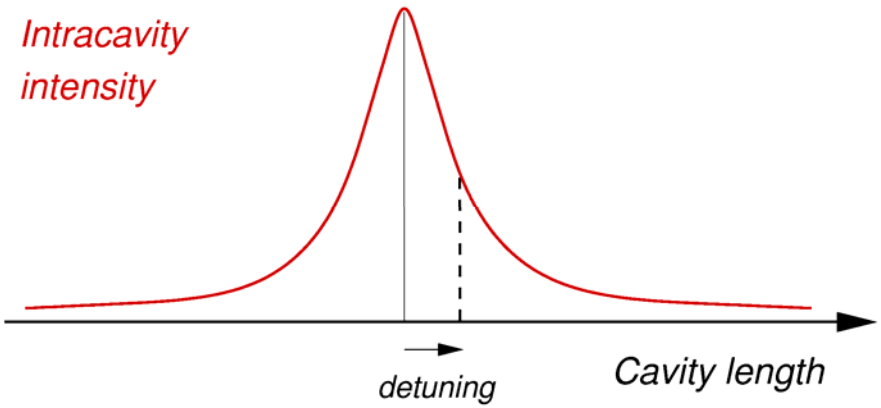
Frequency scan of a classical excitation

Presence of two dips

- Peak-Peak cancellation
- Peak-Baseline cancellation

Noise reduction by a factor of 200

Change of mirror dynamics by cavity detuning



$$F_{\mathrm{rad}}[\Omega] \propto x[\Omega] + x_{\mathrm{sig}}[\Omega]$$

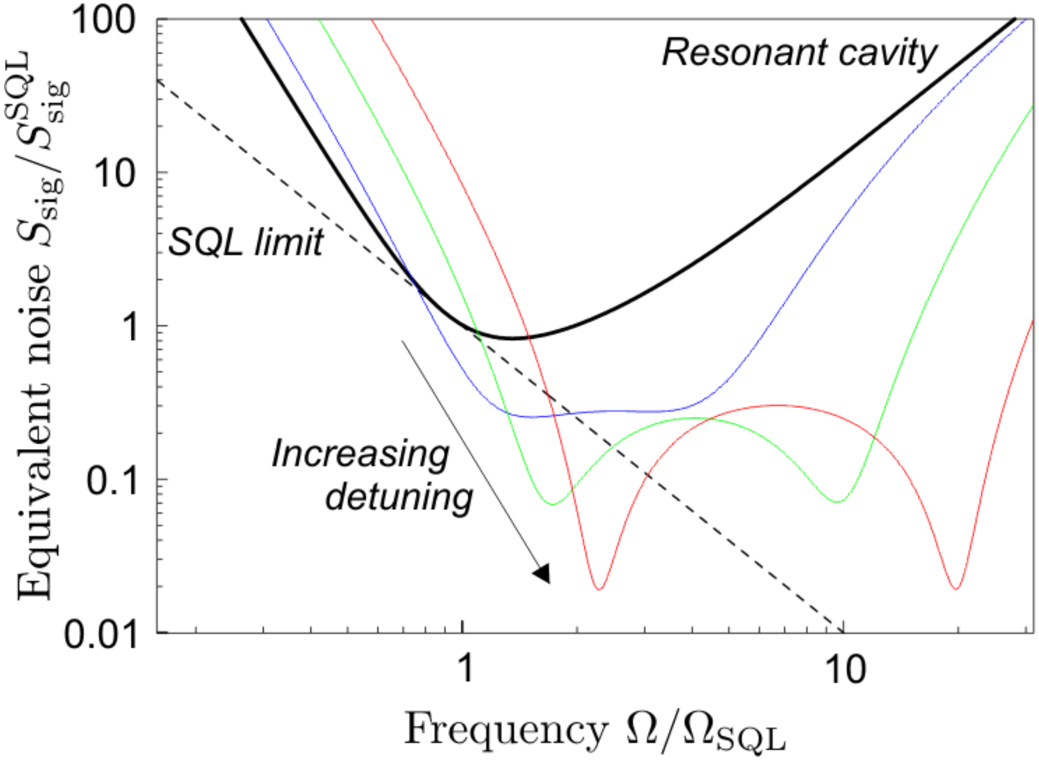
$$x[\Omega] = \chi[\Omega]\, F_{\mathrm{rad}}[\Omega]$$

Internal radiation pressure sensitive to the cavity length

Two effects:

- Amplification of the signal
- modification of the mirror dynamics

Sensitivity improvement in GW detector



Similar effect in a gravitational interferometer with a detuned signal-recycling cavity

Test with our experiment

Self-cooling effect

Effect on the thermal noise

Taking into account the cavity bandwidth, the internal radiation pressure force is dephased

↓

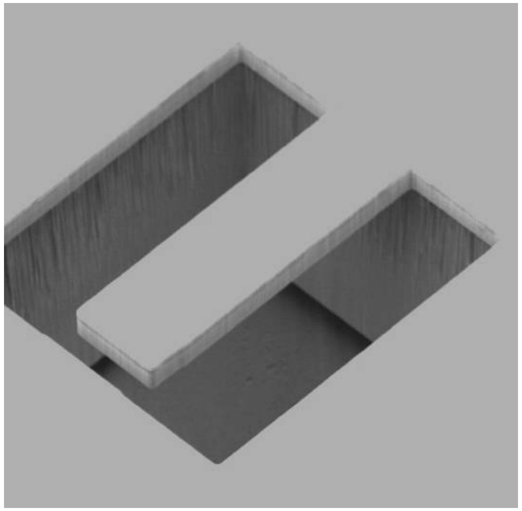
The viscous force modifies the damping rate of the mirror: $\Gamma \longrightarrow \Gamma_{\text{eff}}$

↓

Modification of temperature by a factor $\Gamma/\Gamma_{\text{eff}}$

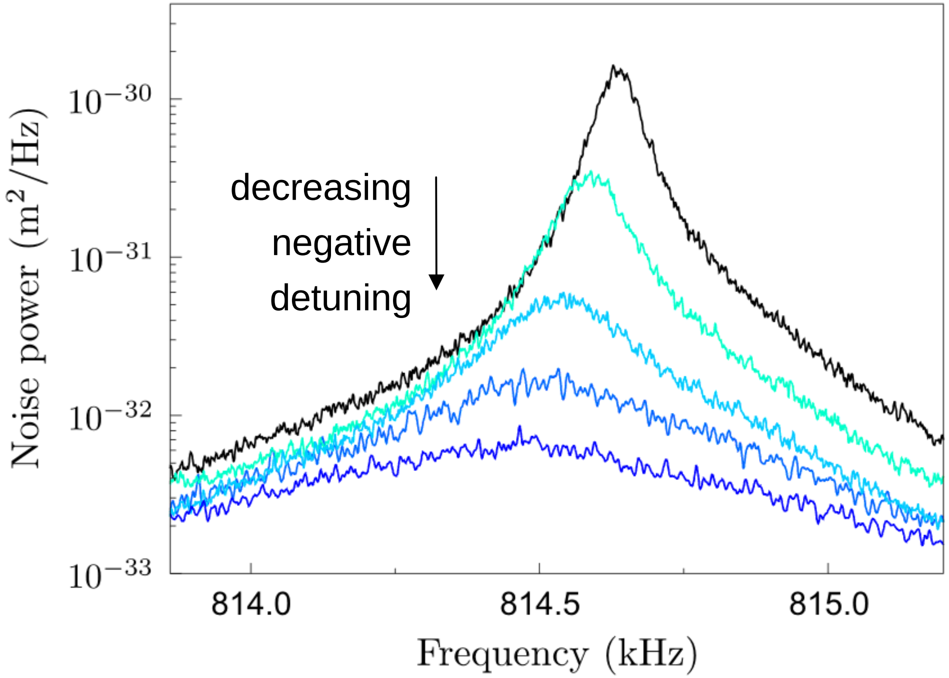
Thermal noise reduction by self cooling effect

Experiment with a mirror coated on a micro mechanical system (MEMS)



$1\ \text{mm} \times 400\,\mu\text{m} \times 60\,\mu\text{m}$

$M \simeq 100\,\mu\text{g}$

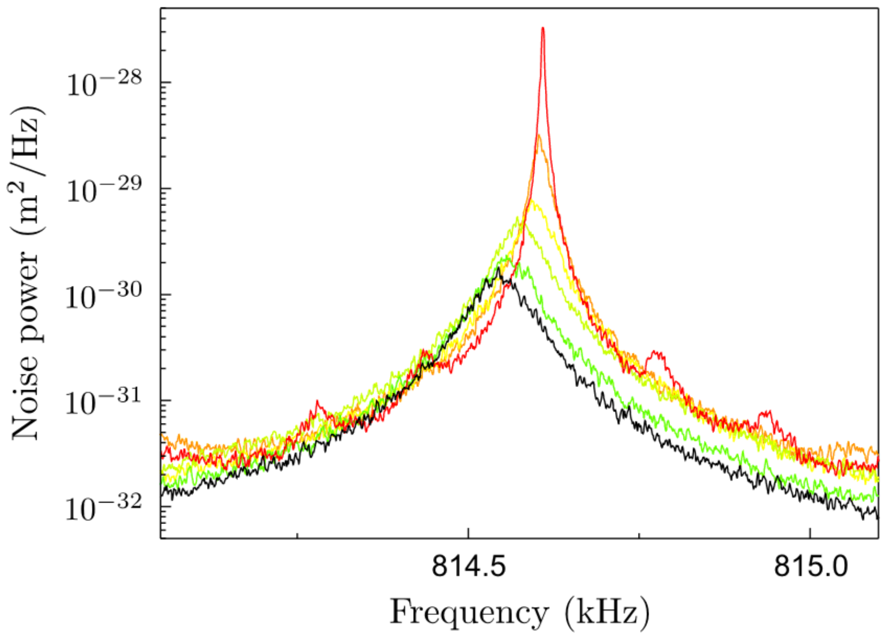


Reduction of the effective temperature

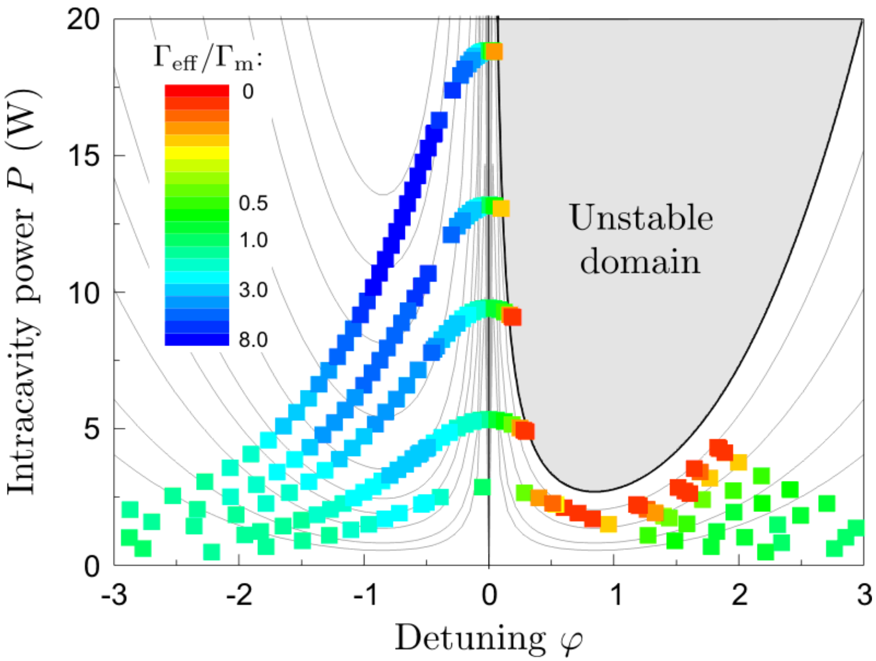
Cooling of the mode down to 10 K

Observation of the cavity instability

Thermal noise :



Airy Peaks in φ – *P plan* :



Heating up to 2000 K

First experimental demonstration of a radiation pressure instability

in a open optical cavity

Conclusion

What's done :

- Exhaustive study of thermal noise
- Observation of radiation pressure cancellation
- Demonstration of self cooling effect and observation of instability

Next steps :

- Experimental observation and tests of quantum noise
- Comprehensive study of quantum noise, search for innovative quantum optics methods