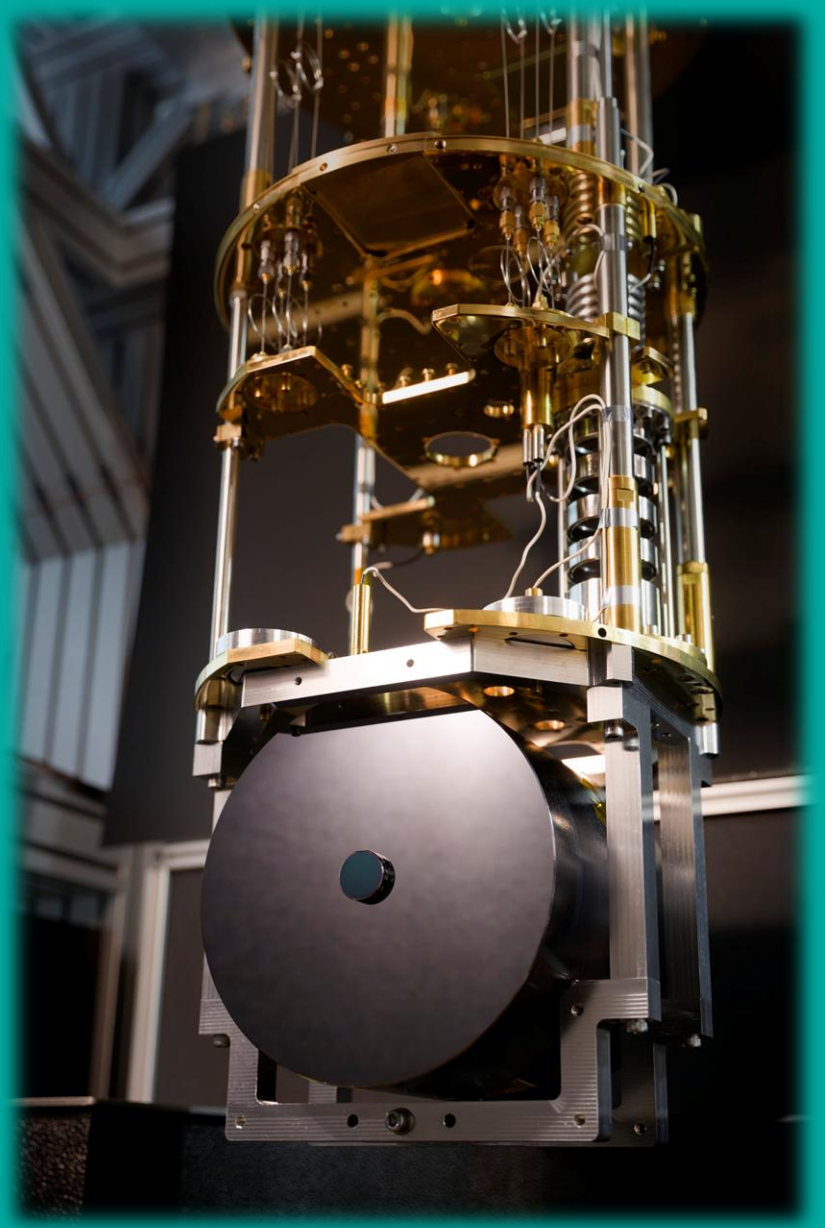
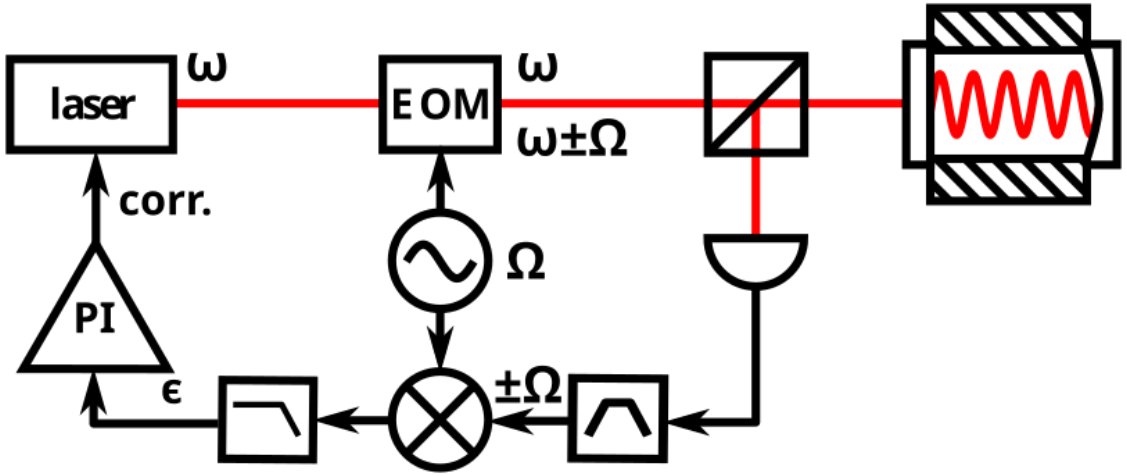
Cryogenic silicon Fabry-Perot cavities at FEMTO-ST

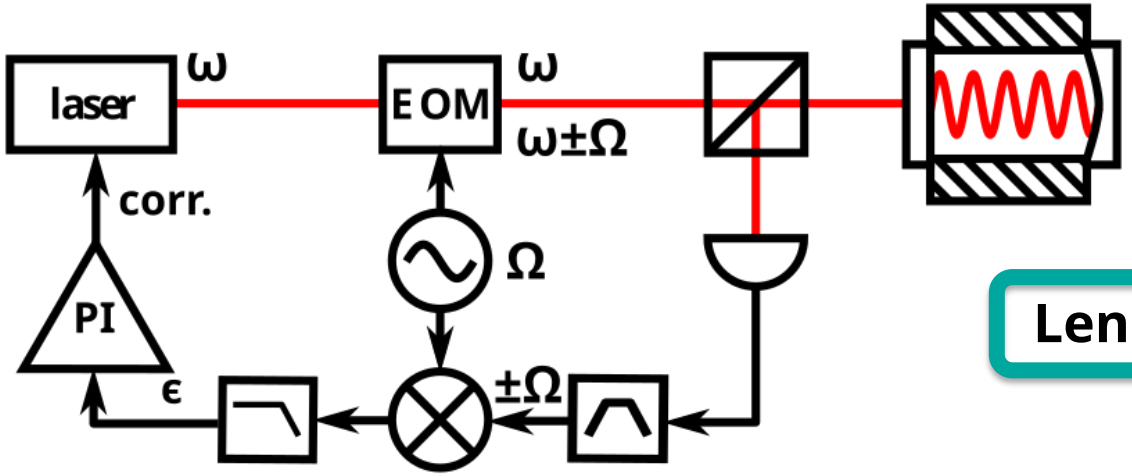
Pierre Roset, Yara Hariri, Rémi Meyer, Jacques Millo<3, Clément Lacroûte, Yann Kersalé and Jonathan Gillot



INTRODUCTION AND MOTIVATION



INTRODUCTION AND MOTIVATION



Reduce all the noise

Length fluctuation (thermal)

Doppler effect

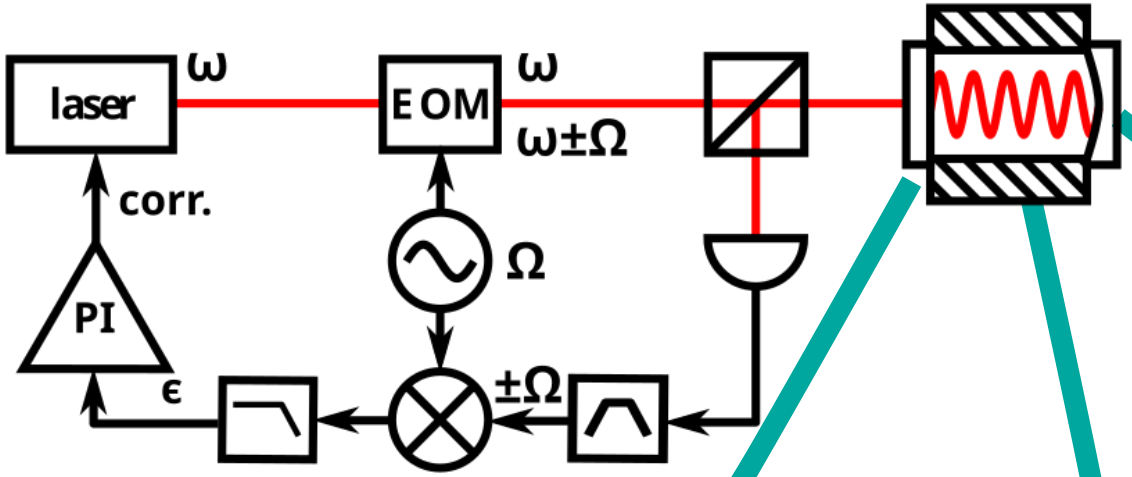
Residual amplitude modulation

Vibration

Optical power fluctuation

●●●

INTRODUCTION AND MOTIVATION



Reduce thermal noise

Change mirror coating

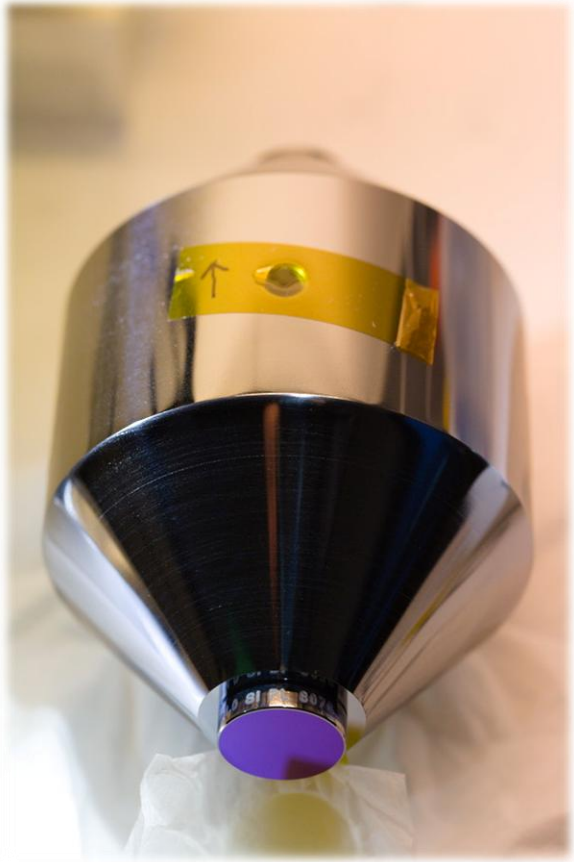
Increase cavity length

Reduce temperature

FEMTO-ST
Silicon cavities

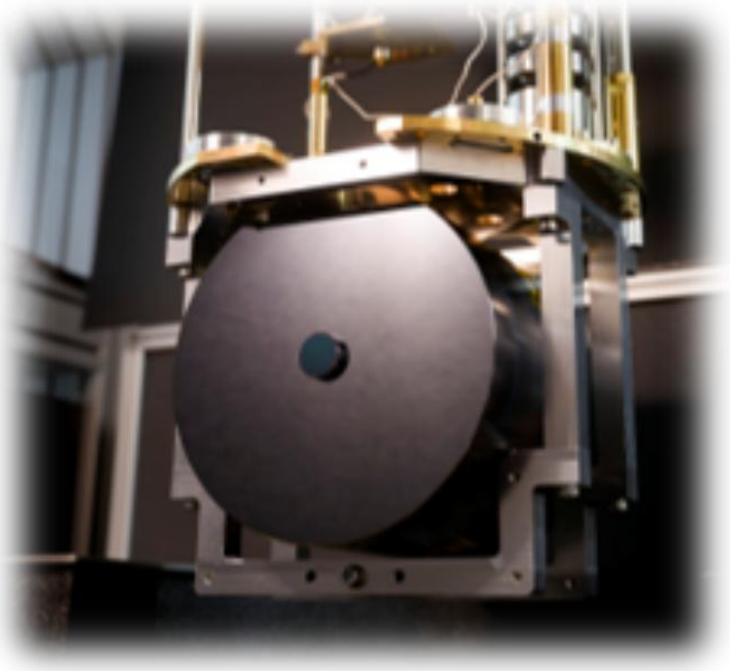
CAVITY CHARACTERISTICS

Length	14 cm
Finesse	350000
Temperature	17 K (zero-crossing)
Coating	SiO_2/Ta_2O_5
Thermal noise	$\sigma_y = 3 \times 10^{-17}$



17 K cavity

CAVITY CHARACTERISTICS

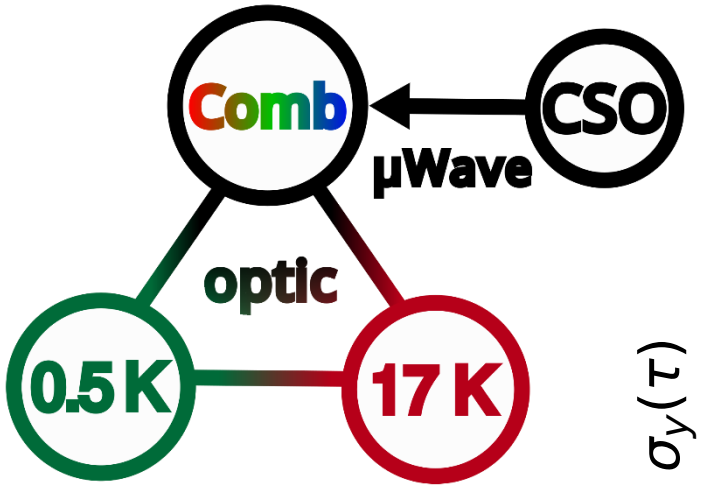


500mK cavity

Length	18 cm
Finesse	450000
Temperature	0.5 K
Coating	$Al_{0.92}Ga_{0.08}As/GaAs$
Mode splitting	261 kHz
Thermal noise	$\sigma_y = 1.3 \times 10^{-18}$

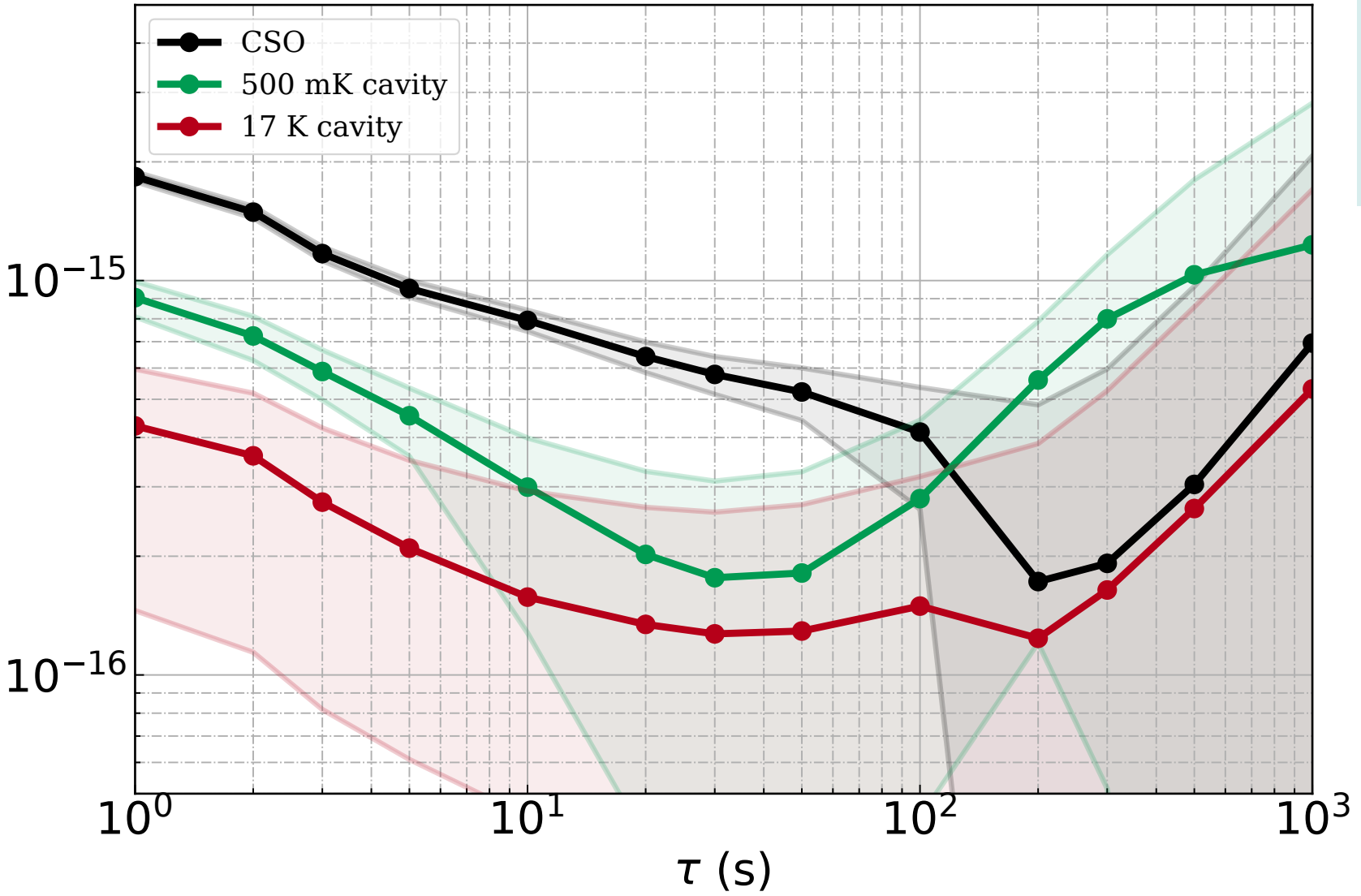
Current Stability of the cavities

3 Cornered hat method



Not at thermal noise level

Limitation need to be investigated



17 K silicon cavity

17 K cavity

Mirror replacement

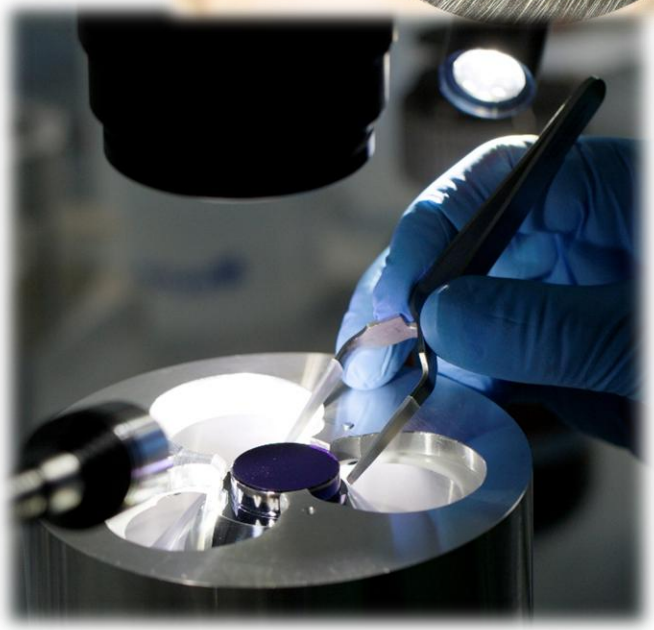
Thanks to First-TF (HiFi coatings project)

Defect on the old mirrors and the spacer due to (bad) manufacturing process. Finesse: 75000

New mirror contacted at PTB (thank to T. Legero).

New Finesse: 350000





17 K cavity

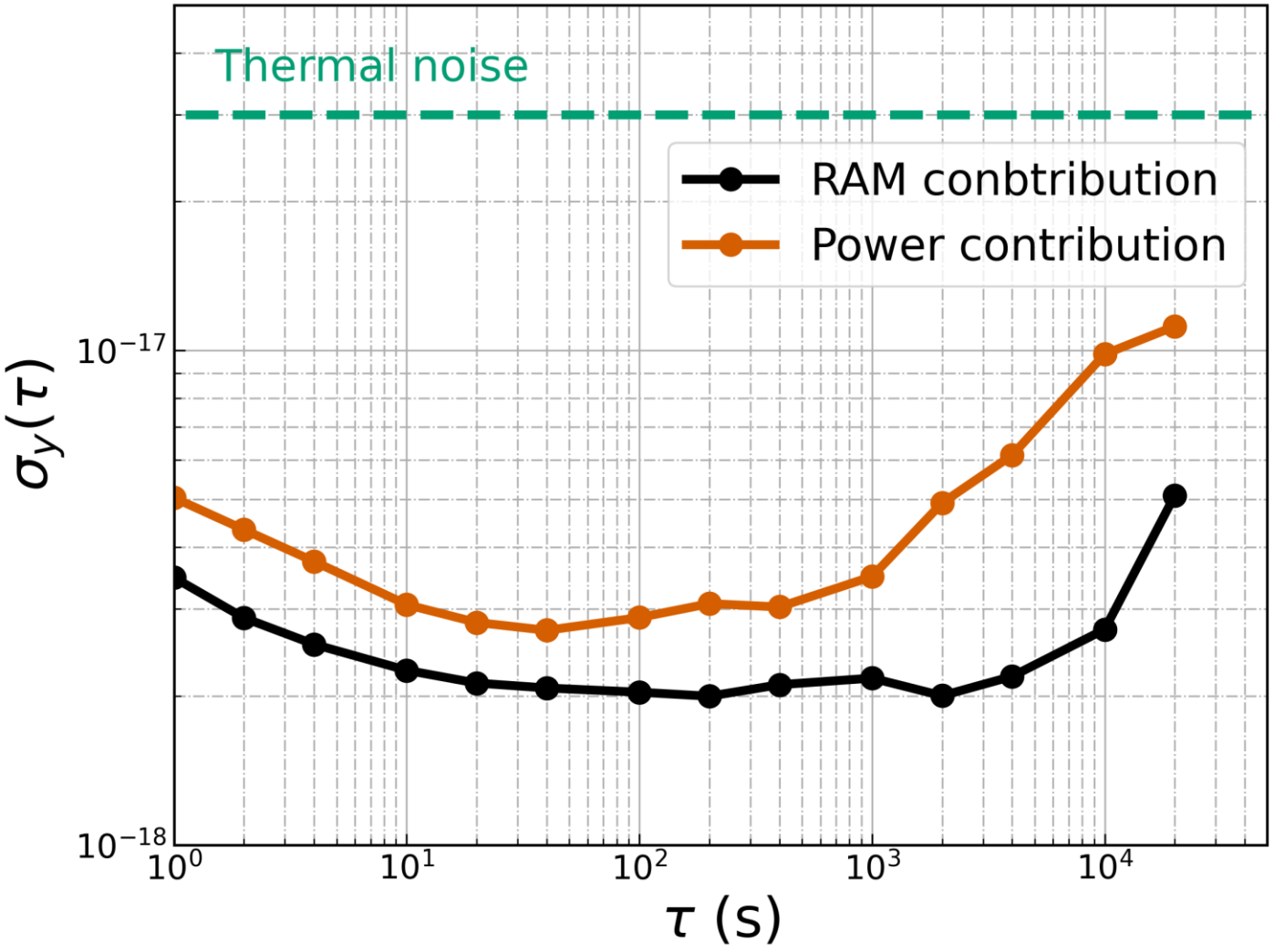
Power and Residual Amplitude Modulation (RAM) contribution

Power lock from [1]

RAM lock from [2]

Relative sensitivity of the cavity to power fluctuation: 8.76×10^{-14} W^{-1}

RAM and power fluctuation almost an order of magnitude lower than thermal noise



[1] F. Tricot *et al.*, 10.1063/1.5046852.

[2] Jonathan Gillot *et al.*, 10.1364/OE.465597

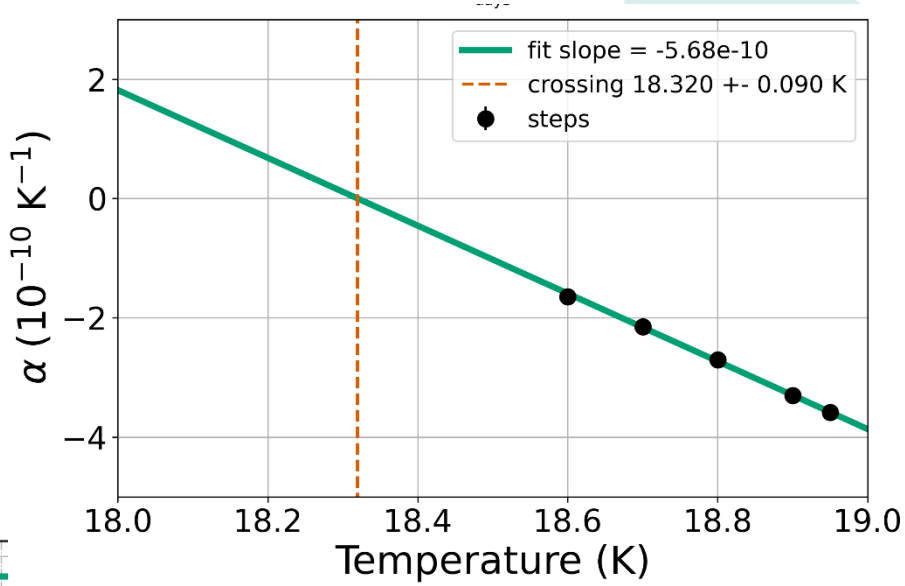
17 K cavity

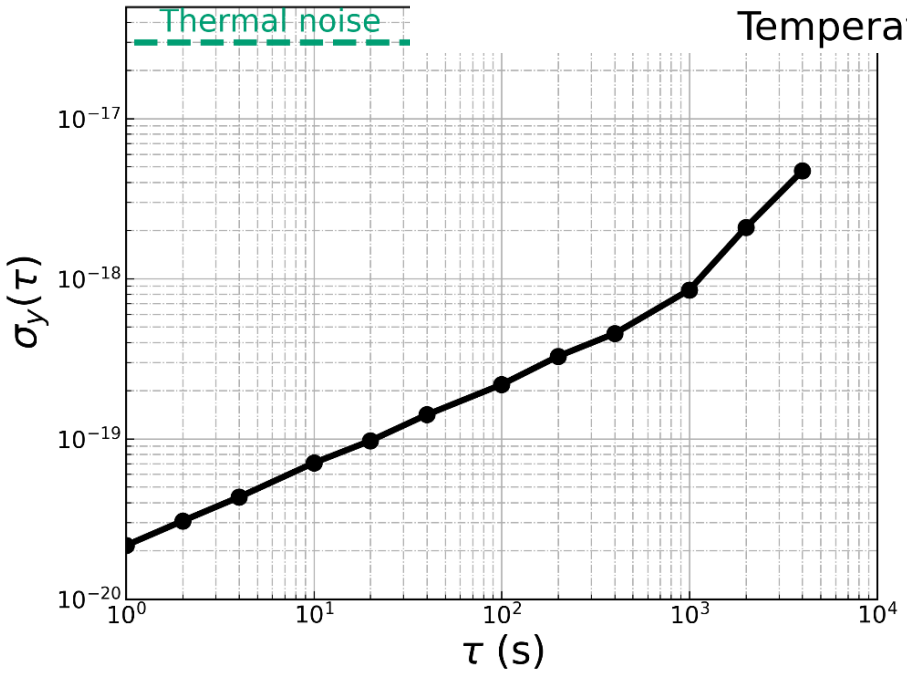
CTE and temperature control

CTE measurement need to be done with the new mirror.

First estimation of the new lock temperature for the zero-crossing 18.32 K (instead of 18)

Point on the other side of the zero-crossing needed to confirm (very long measurement $\tau \simeq 1$ day)

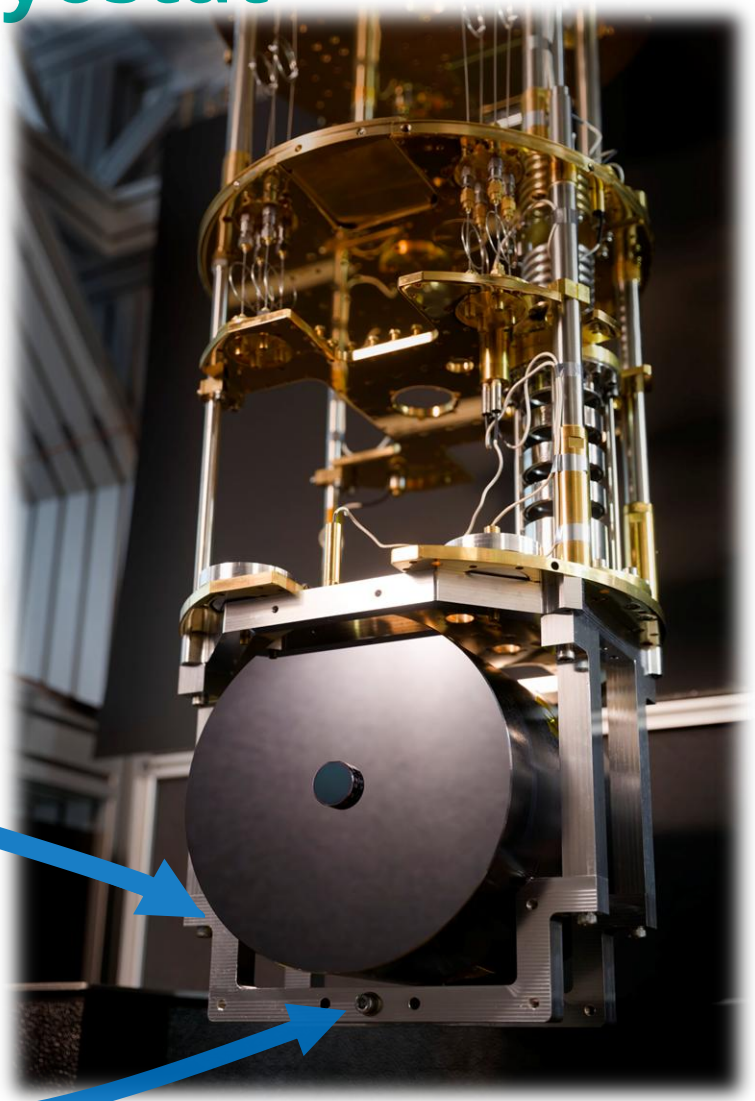




Cavity inside a dilution cryostat

The Dilution cryostat

Commercial **BlueFors** dilution cryostat *BF-LD250*

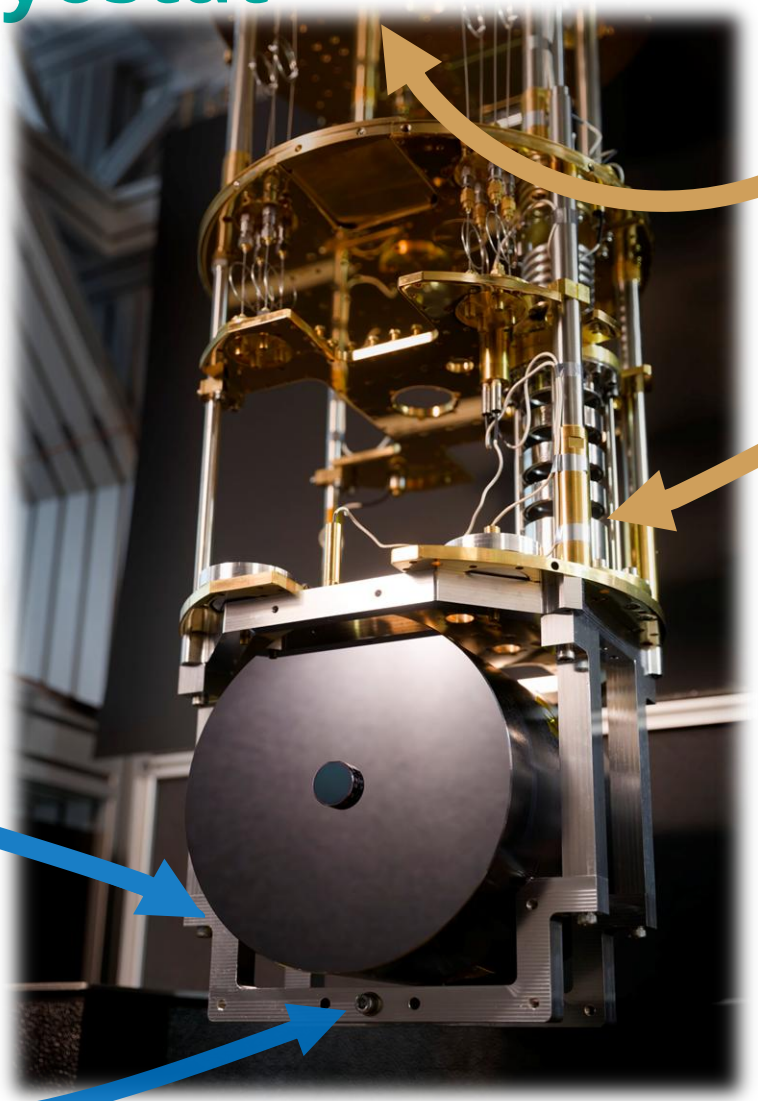


3 ball bearings support the cavity

Cavity frame

The Dilution cryostat

Commercial **BlueFors** dilution cryostat *BF-LD250*



Pulse tube cold head
T ≃ 4 K

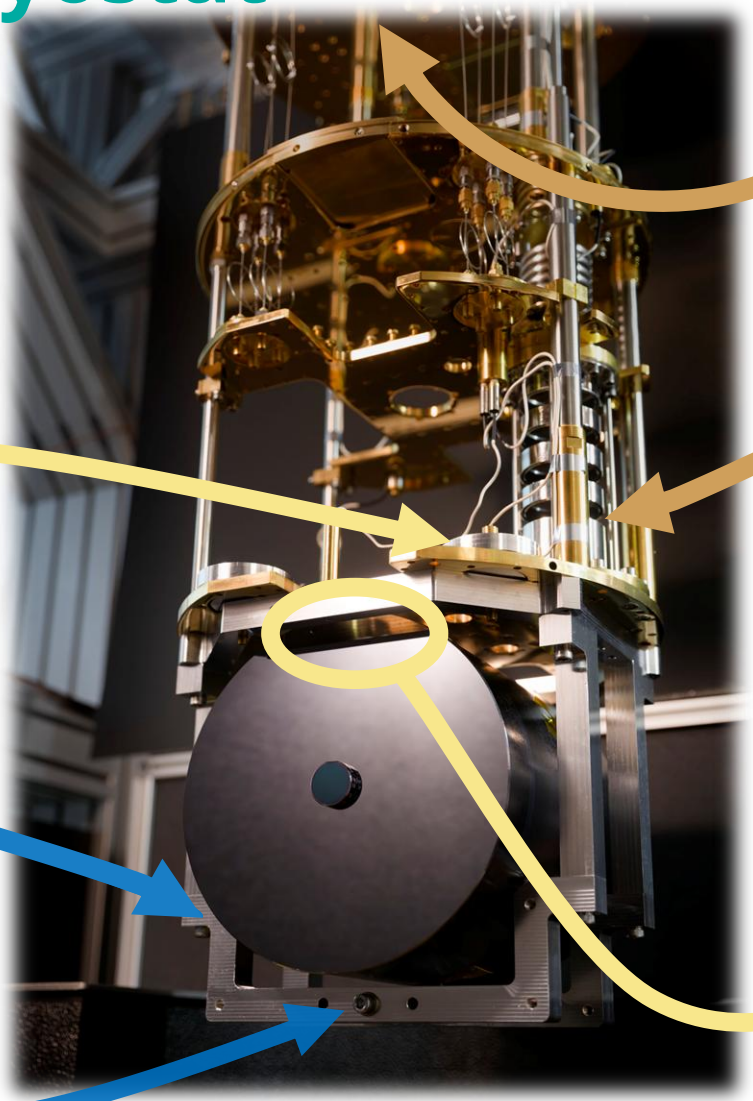
^{3}He/^{4}He mixing chamber

3 ball bearings support the cavity

Cavity frame

The Dilution cryostat

Commercial **BlueFors** dilution cryostat *BF-LD250*



Pulse tube cold head
T ≃ 4 K

^{3}He/^{4}He mixing chamber

Coldest point **T = 53 mK**
Locking probe and heater

3 ball bearings support the cavity

Cavity frame

RuO_2 probe glued to the cavity **T = 500 mK**



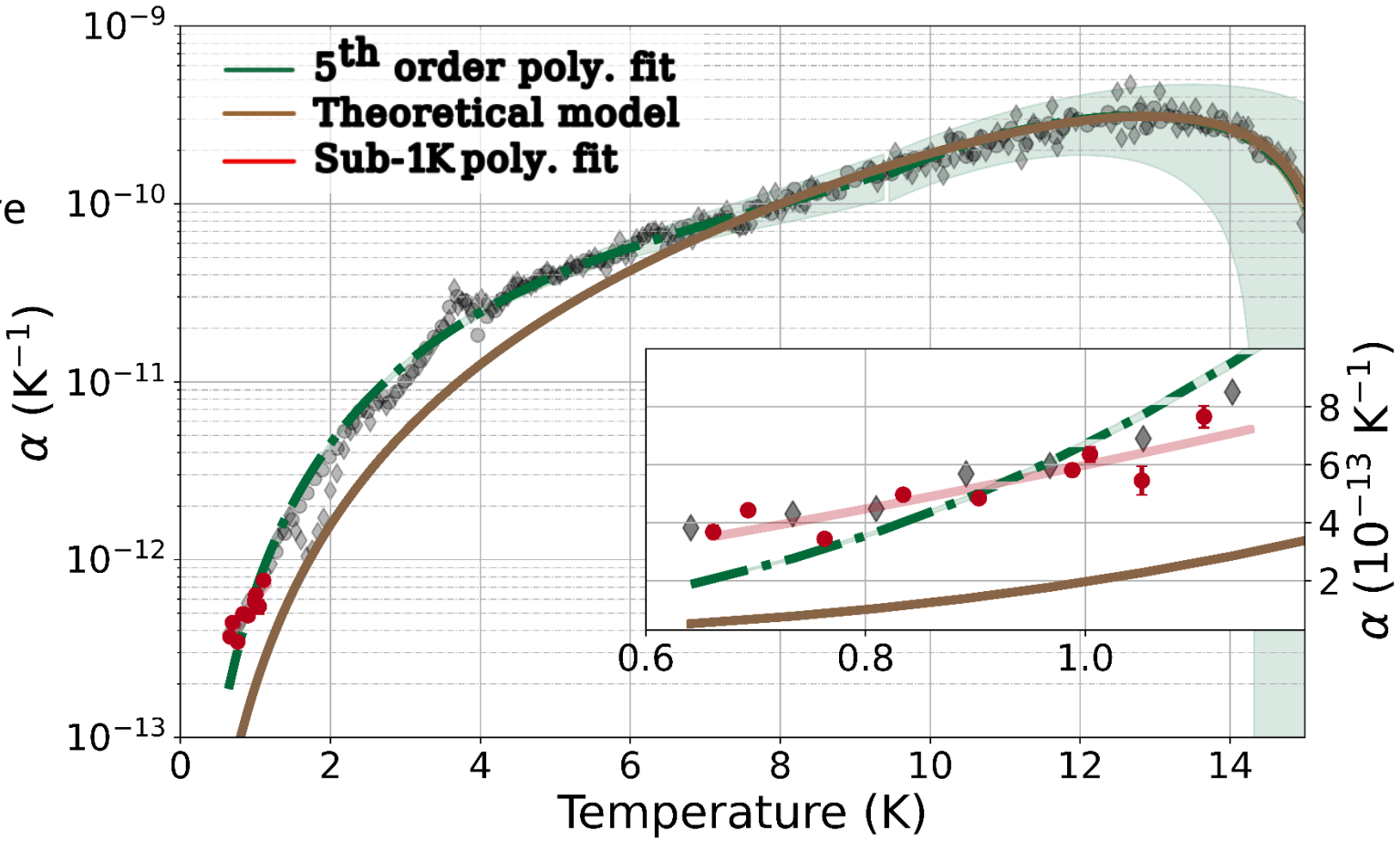
Thermal expansion

Lowest measurement of the CTE of Si

Equation of CTE at sub-1K temperature

$$\alpha_{\mathrm{sub-1K}}(\mathrm{T}) = 4.0(16) \times 10^{-13}\mathrm{T} + 2.0(17) \times 10^{-13}\mathrm{T}^2$$

$$\alpha_{\mathrm{sub-1K}}(550\ \mathrm{mK}) \approx 3.3 \times 10^{-13}\ \mathrm{K}^{-1}$$



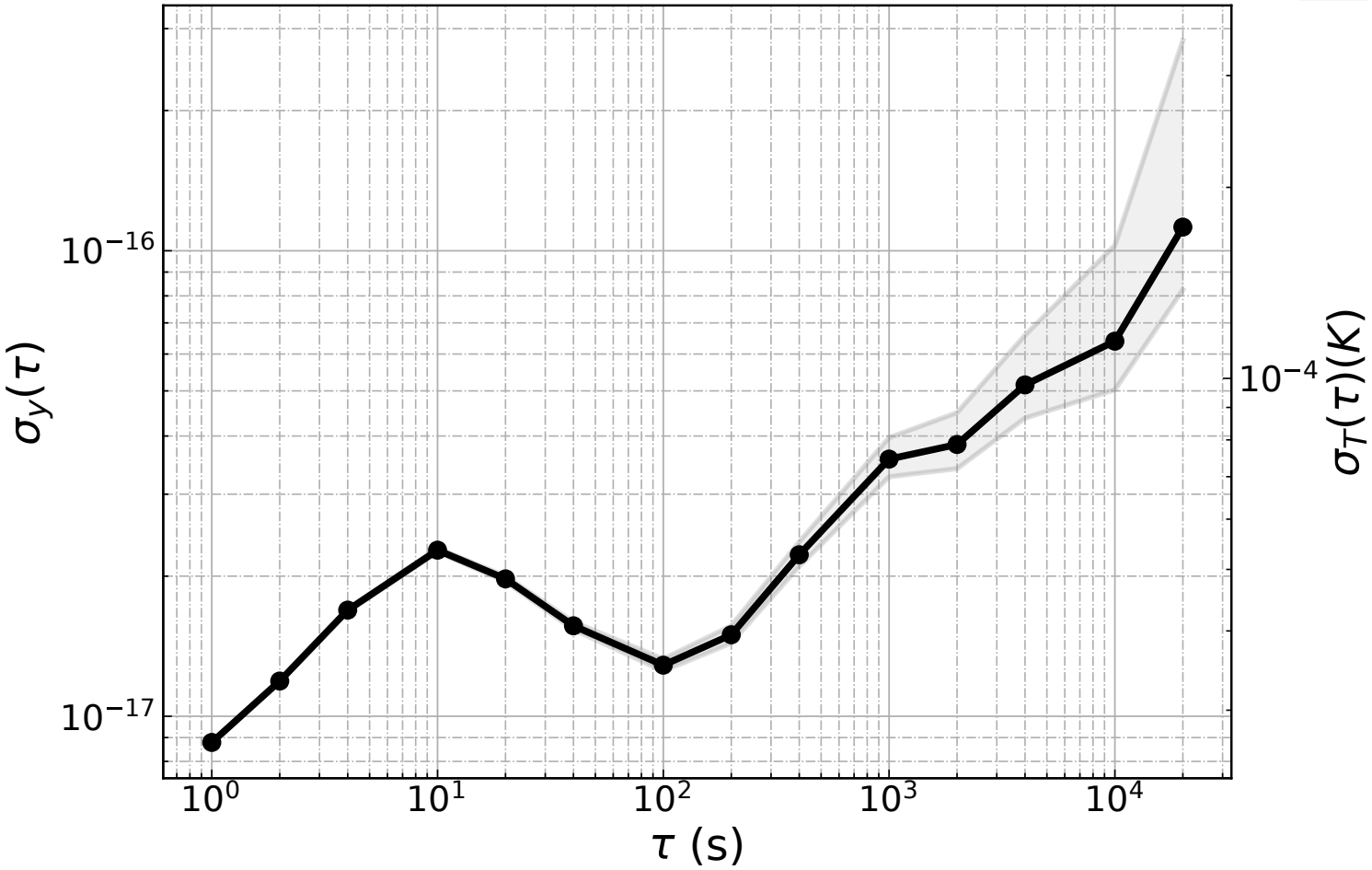
* Pierre Roset *et al*, Optics Letters, 10.1364/OL.607376

Temperature contribution

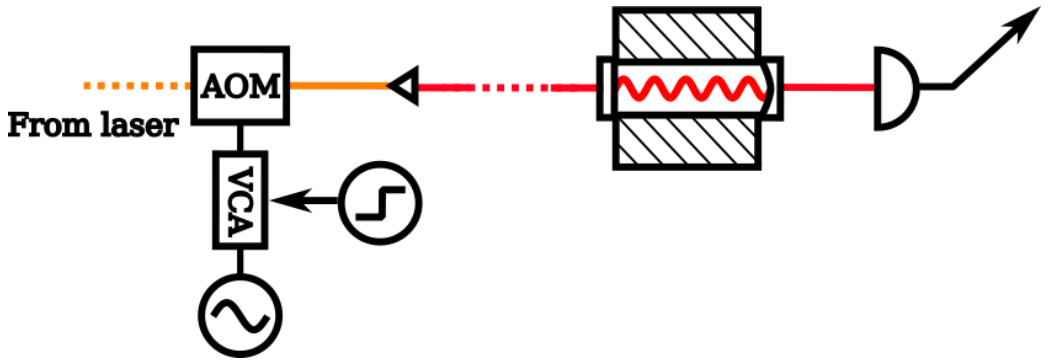
$$\alpha_{\mathrm{sub-1K}}(550\ \mathrm{mK}) \approx 3.3 \times 10^{-13}\ \mathrm{K}^{-1}$$

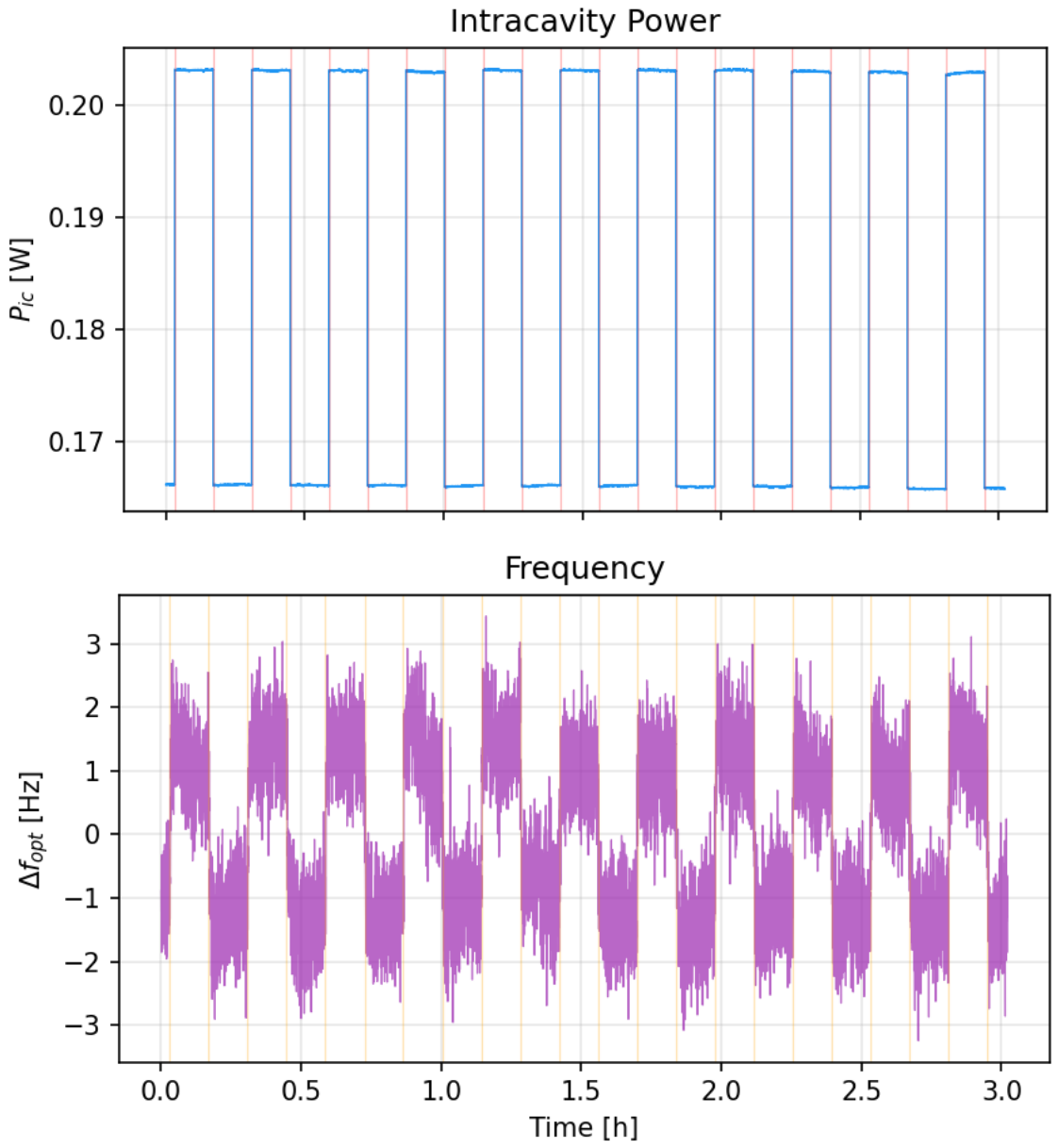
No contribution of the temperature now

The lack of thermal filtering in the system will not allow to reach the thermal noise floor



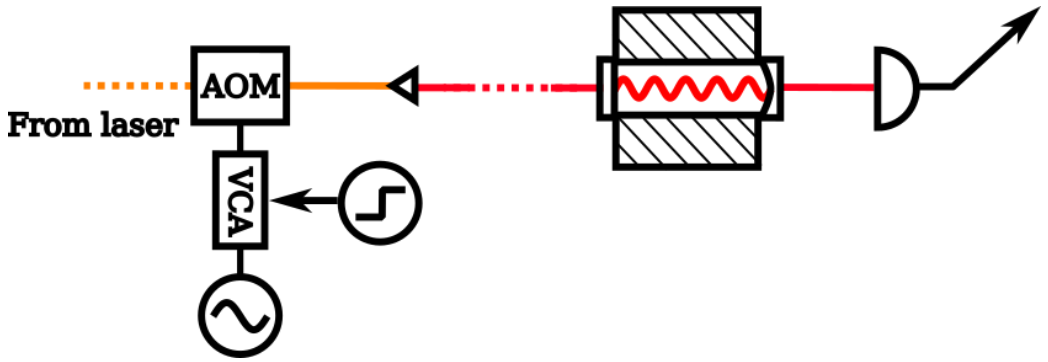
Optical power fluctuation

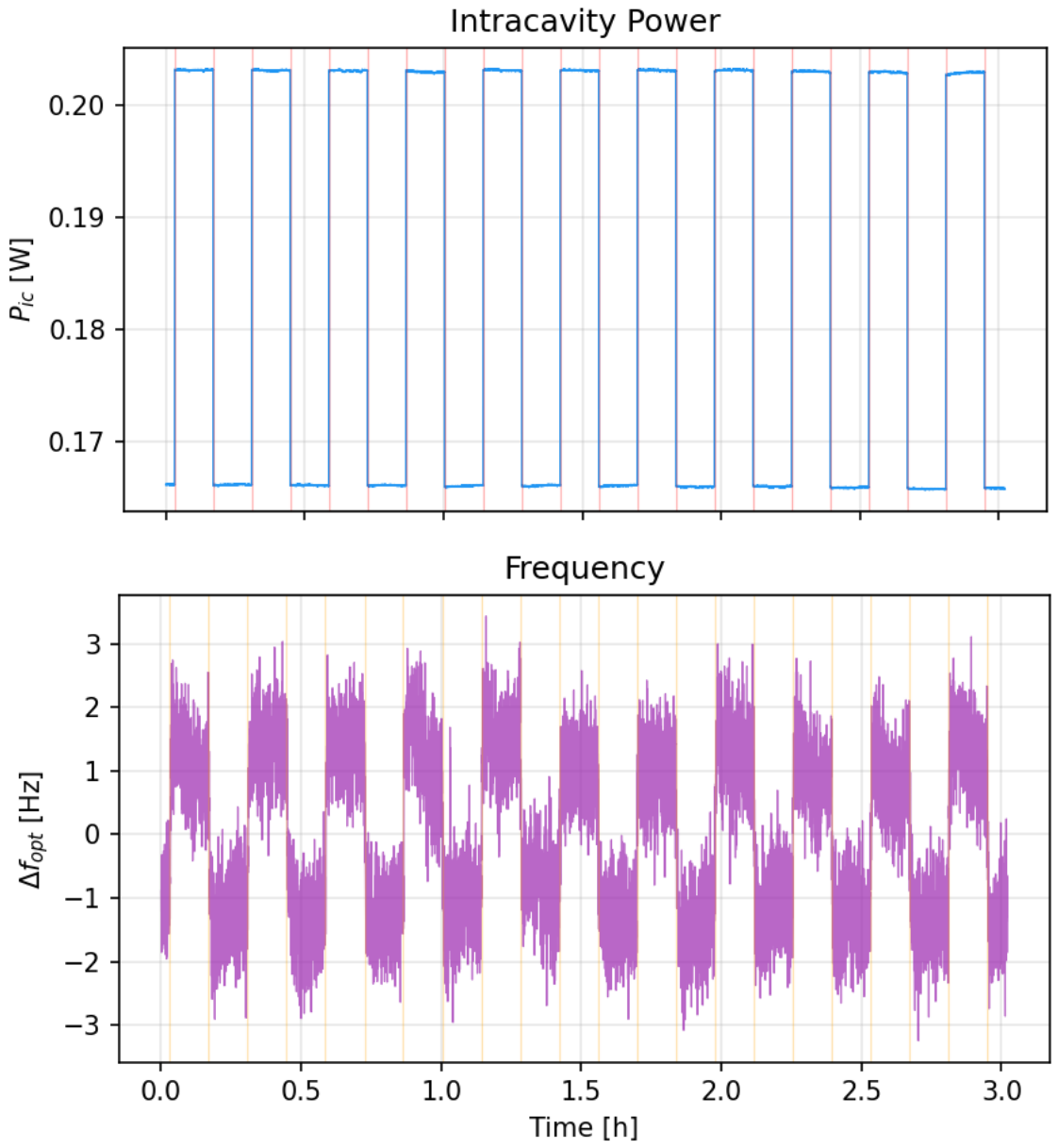




* Yu, Jialiang et al., 10.1103/PhysRevX.13.041002

Optical power fluctuation





amorphous	Crystalline 500 mk	Crystalline *
8.76×10^{-14} W^{-1}	$\mathbf{3.35 \times 10^{-13}\ W^{-1}}$	1×10^{-12} W^{-1}

* Yu, Jialiang et al., 10.1103/PhysRevX.13.041002

Optical power contribution

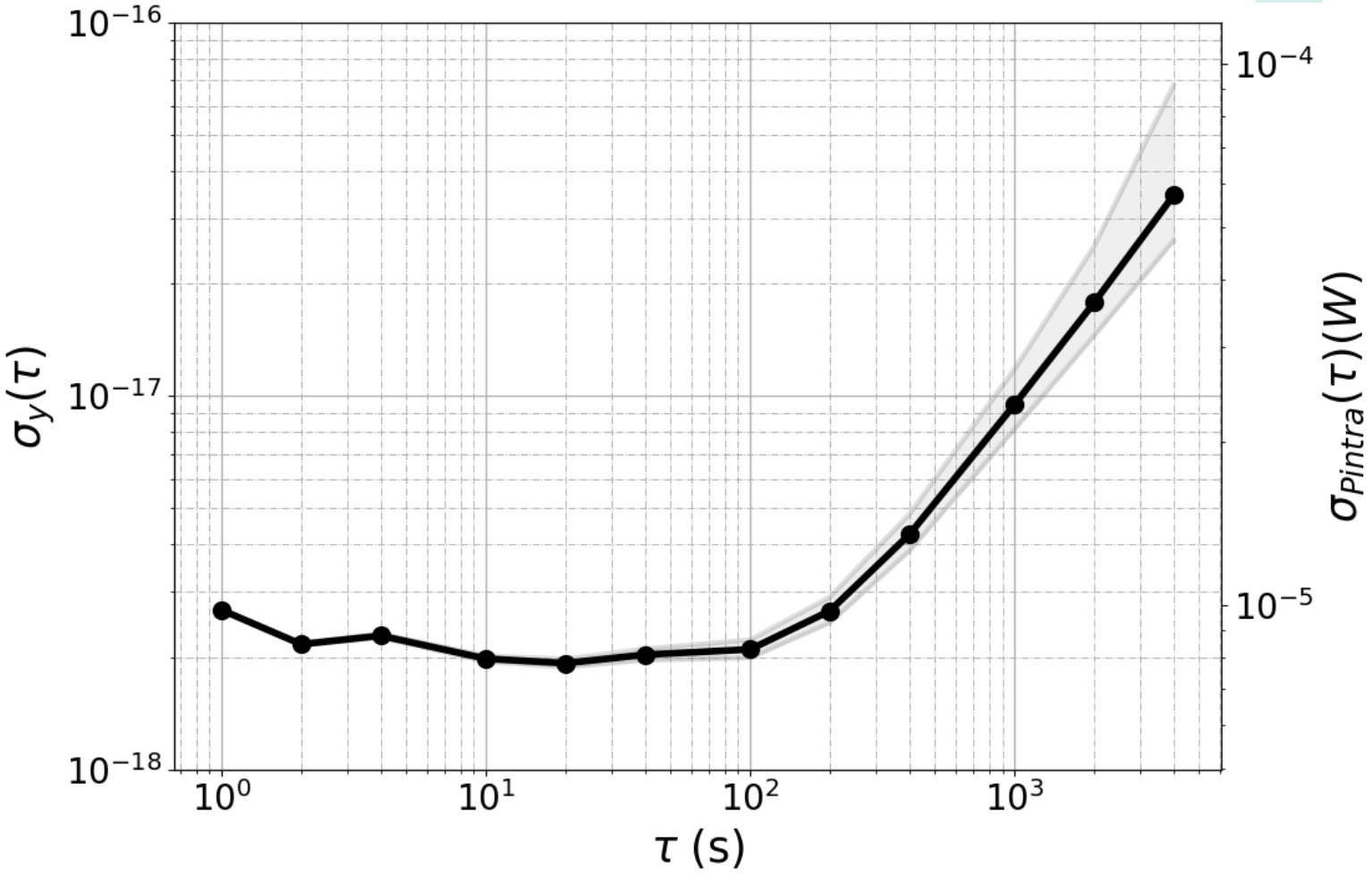
Power lock performance :

$$\sigma_{P\text{intra}} < 10^{-5}\ \text{W}$$

Cavity sensitivity:

$$65\ \text{Hz}\ \text{W}^{-1}$$

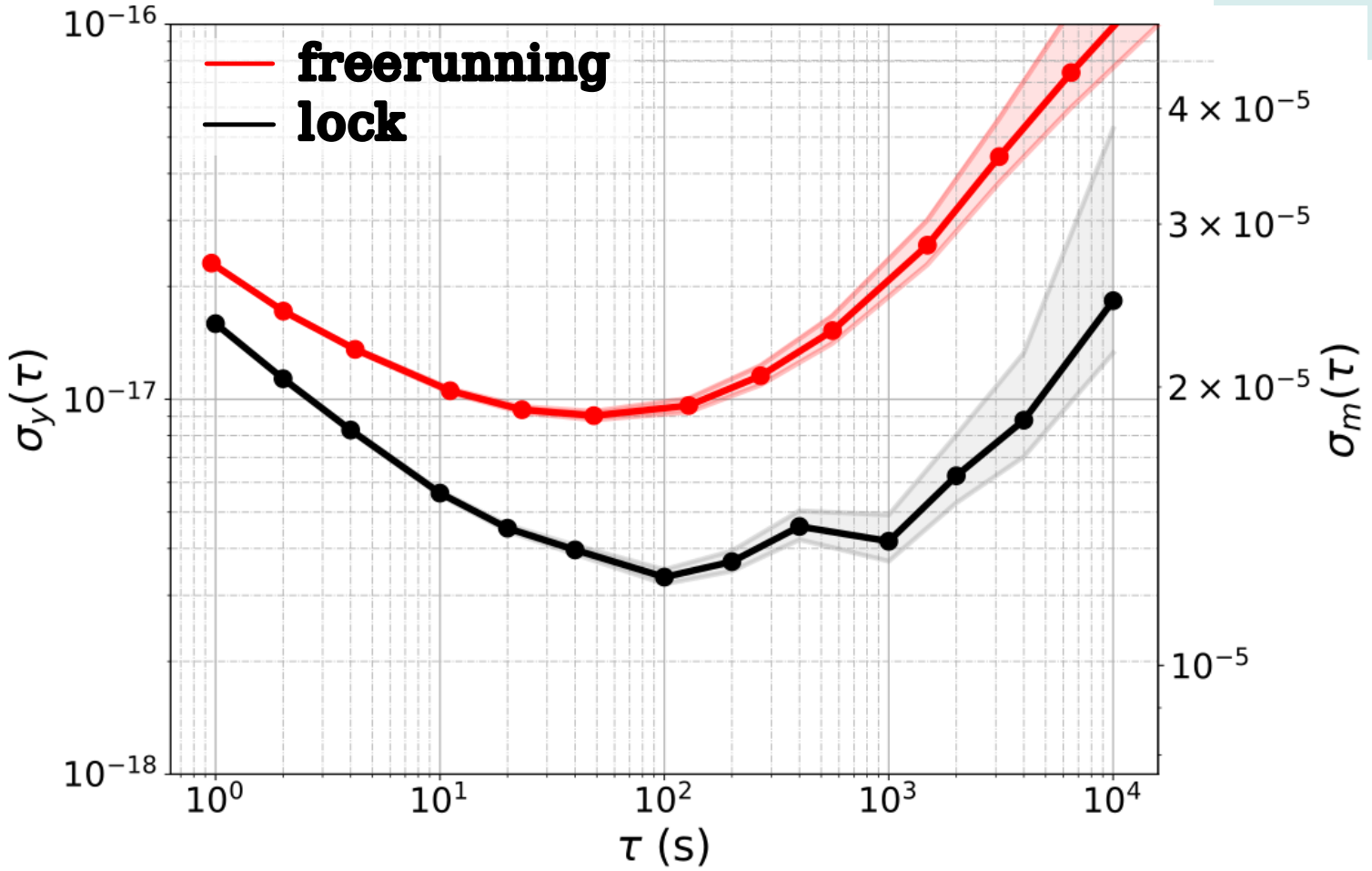
Power contribution in the low 10^{-18}



RAM

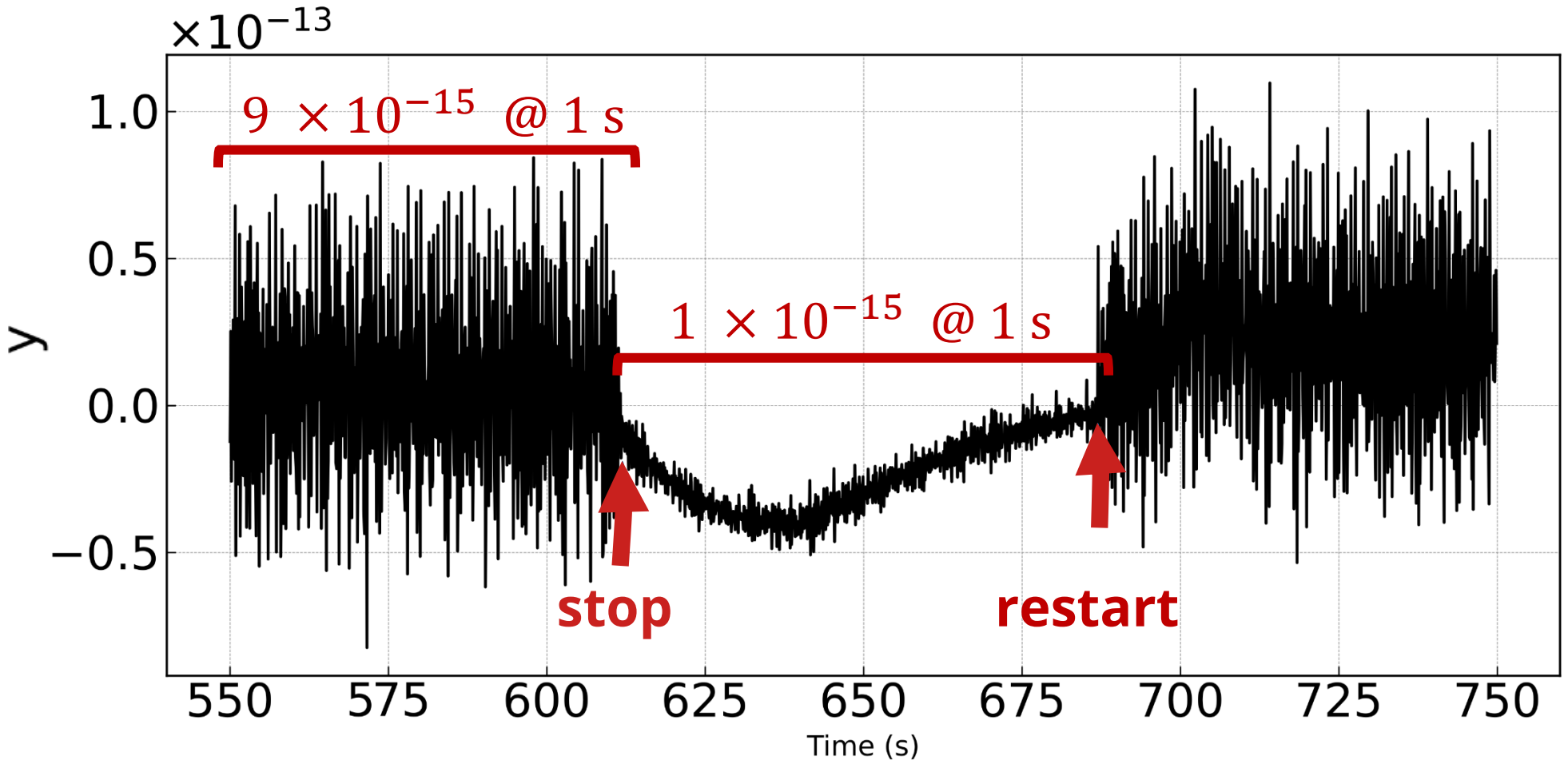
Very low free running RAM level with temperature stabilization only

Lower mid and long term with DC lock of the EOM

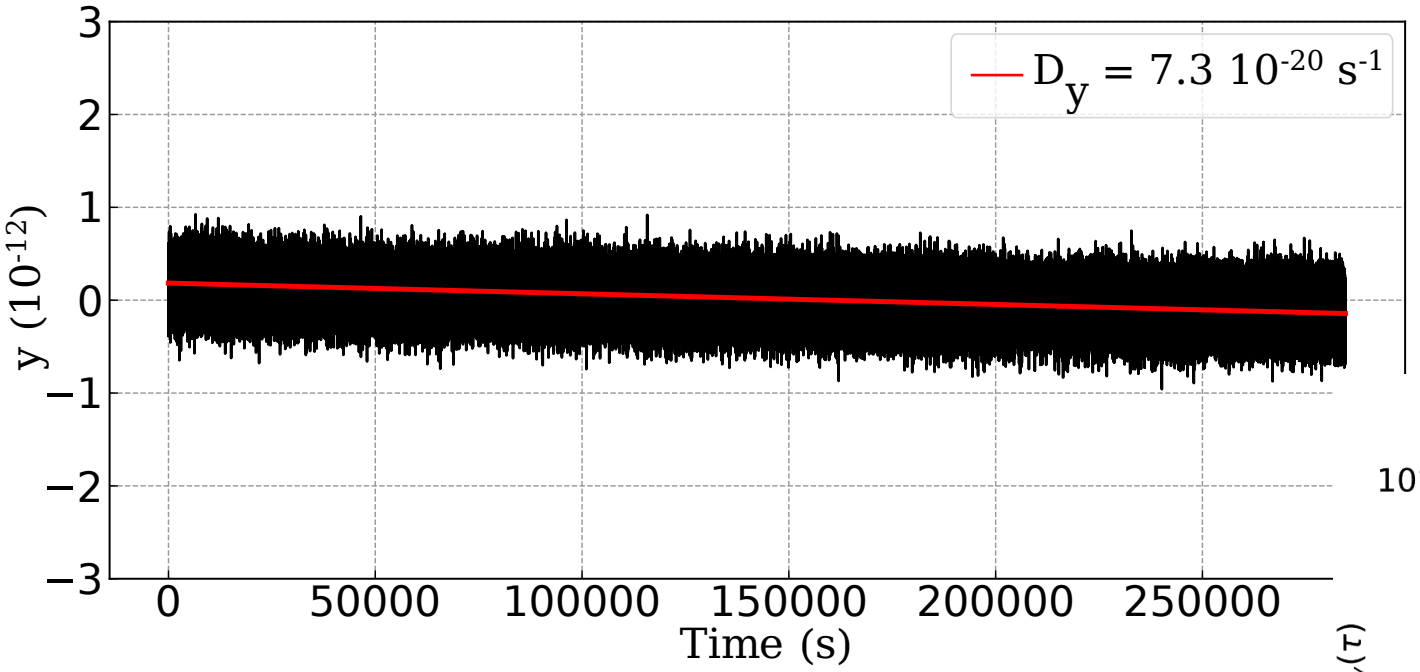


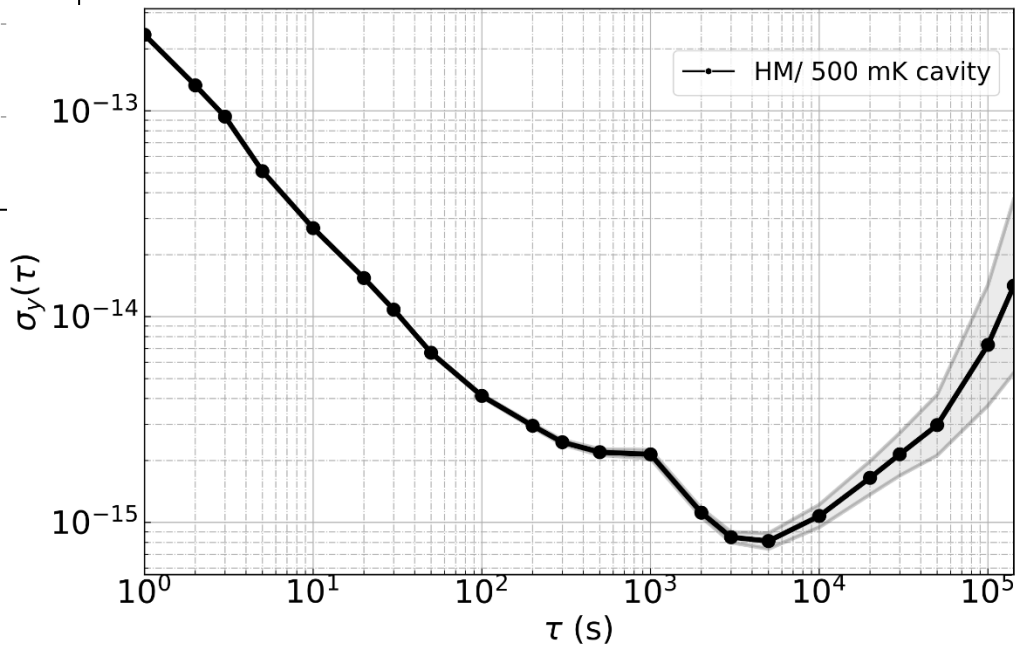
Jonathan Gillot *et al.*, 10.1364/OE.465597

Acceleration sensitivity



Drift measurement with hydrogen maser





Very low drift for cavities

Current state of the art *: $D_y = 5\ 10^{-20} s^{-1}$

* Yu, Jialiang et al., 10.1103/PhysRevX.13.041002

Conclusions & perspectives

CONCLUSIONS & PERSPECTIVES

sub 10^{-15} fractional frequency stability for the two cavities

17 K cavity maybe limited by the measurement or vibration
500 mK cavity limited by vibration.

Investigate on feed forward techniques

CONCLUSIONS & PERSPECTIVES

sub 10^{-15} fractional frequency stability for the two cavities

17 K cavity maybe limited by the measurement or vibration
500 mK cavity limited by vibration.

Investigate on feed forward techniques

Coldest ultra-stable silicon Fabry-Perot cavity at 550 mK in operation

Next step

Investigation on crystalline coating and related noise

With the CAVI-TWIN project (FIRST-TF)