Dissipation in a Tantala film from 10K to 150K from thermal noise measurements

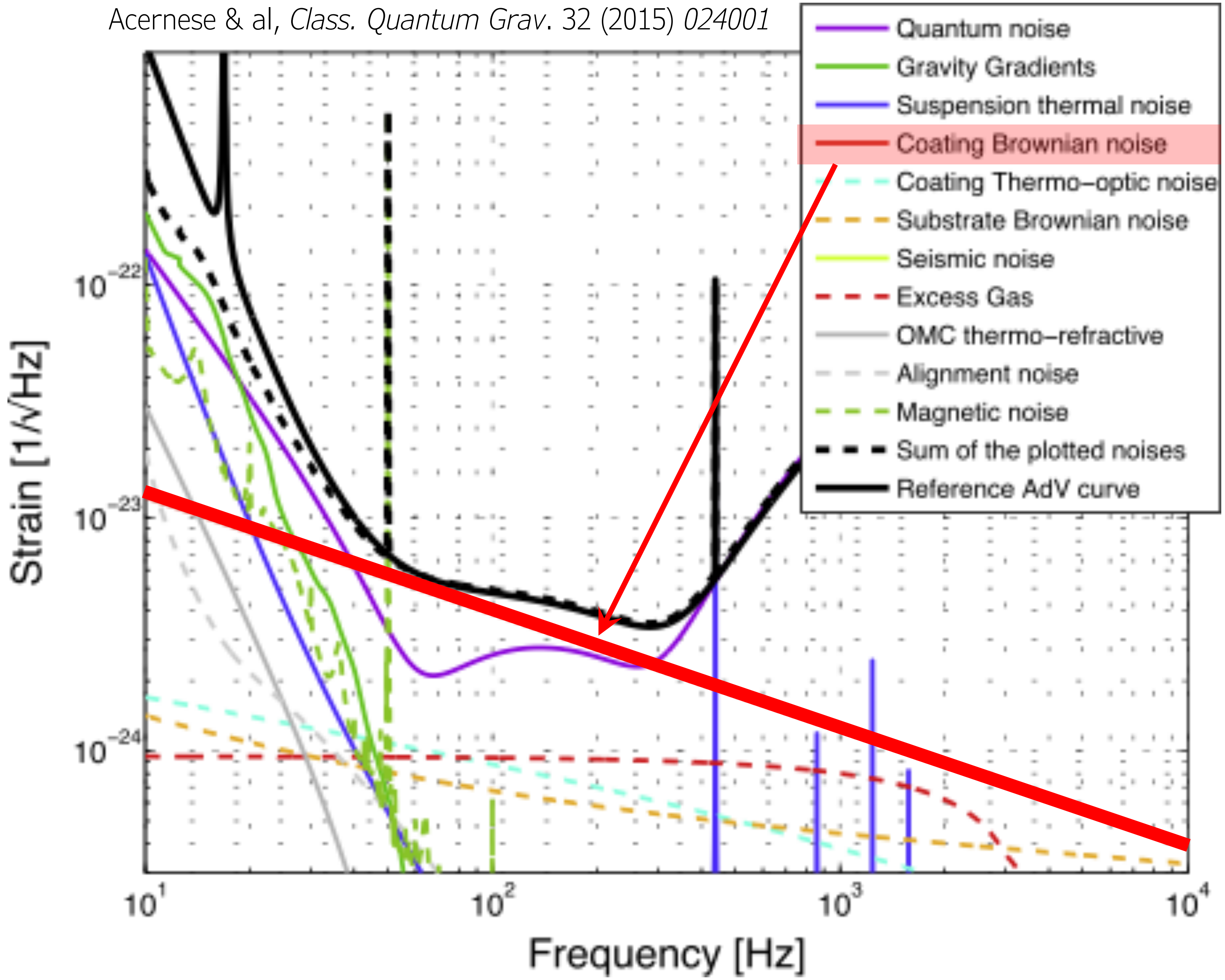
R. Pedurand[1,2], G. Hansali[1], V. Dolique[1,2], A. Fontana[2], L. Merini[1], D. Hofman[1], B. Sassolas[1], C. Michel[1], L. Pinard[1], J. Teillon[1], M. Granata[1], J. Degallaix[1], G. Cagnoli[1,3], L. Bellon[2]

[1]LMA [2]LPENSL [3]ILM

Funding agencies

Hosting institutions

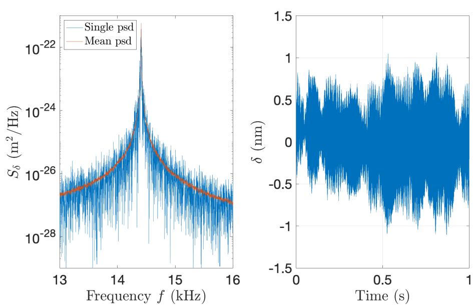
Acernese & al, *Class. Quantum Grav*. 32 (2015) *024001*



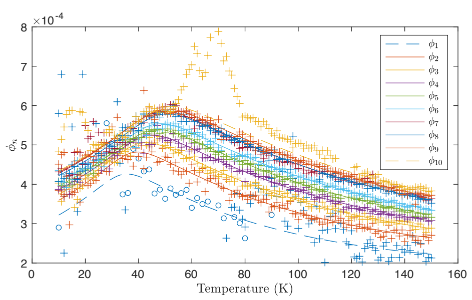
PSD: $S_{xx} \propto \frac{k_b T}{f} \frac{(1-\sigma^2)}{Y} \frac{d}{w^2} \Phi(\omega)$

- Sample: Tantala coated cantilever

- Cryogenic differential interferometer

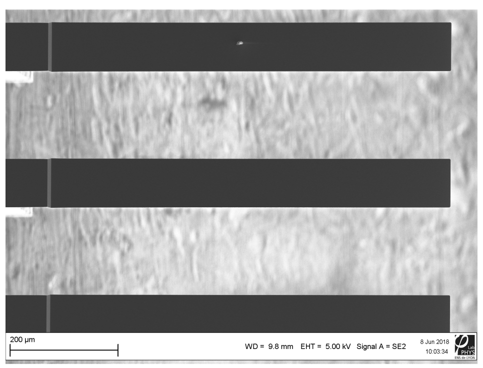


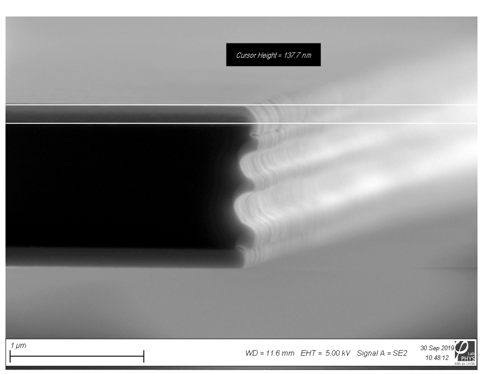
- Thermal noise measurement

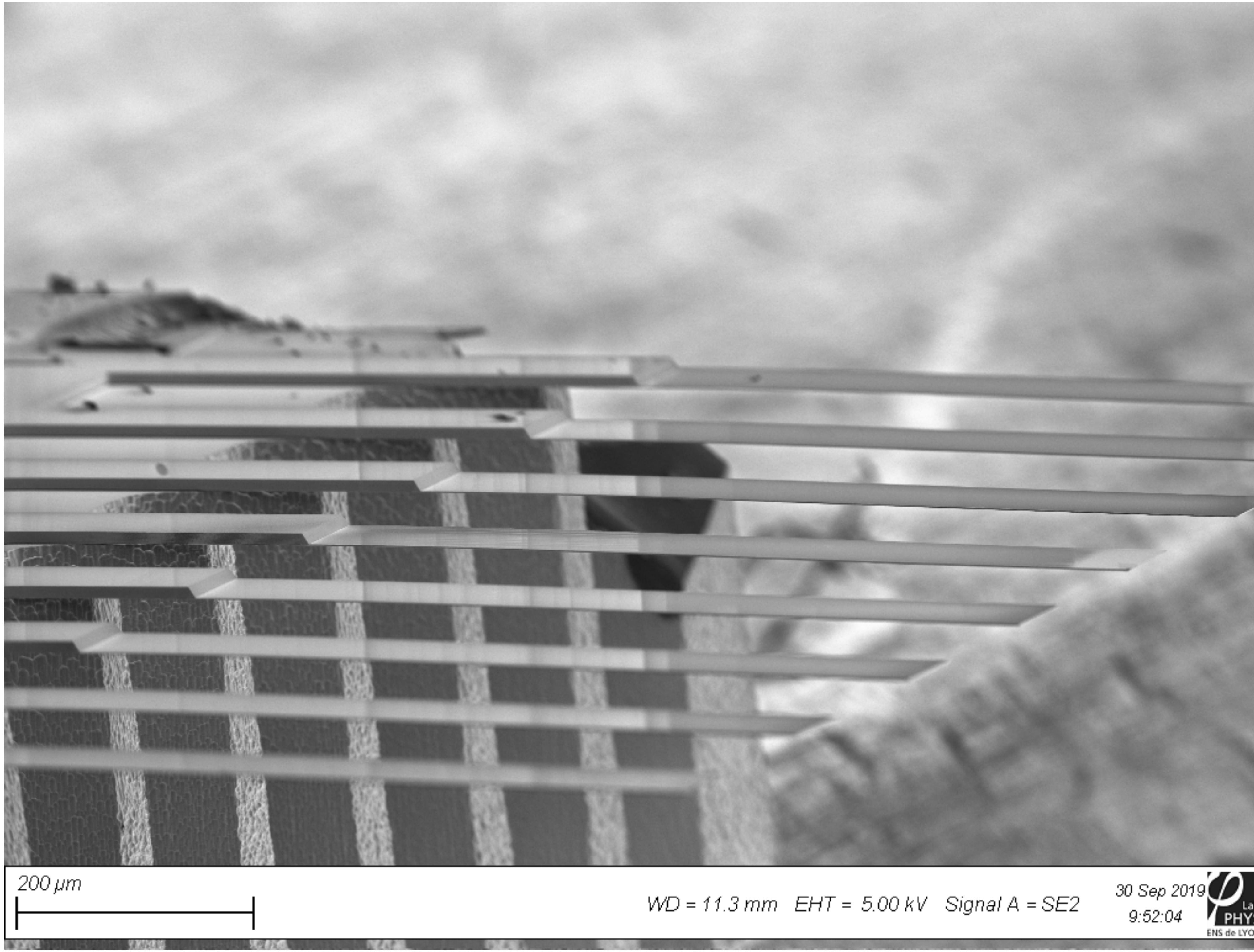


- Measurement of internal damping

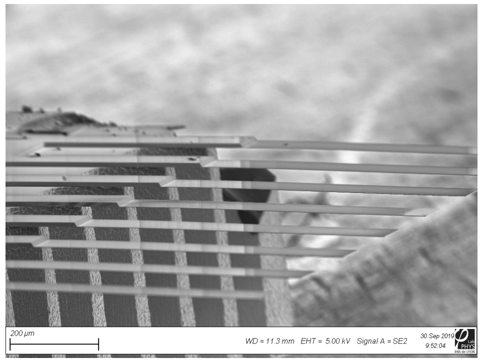
Sample : Si cantilever, Ta_2O_5 coating, annealed

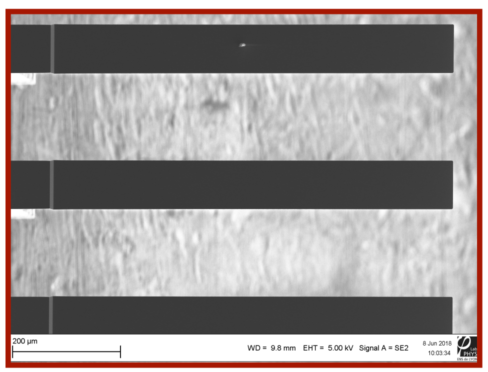


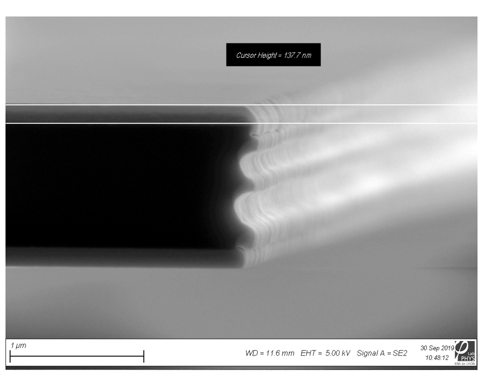


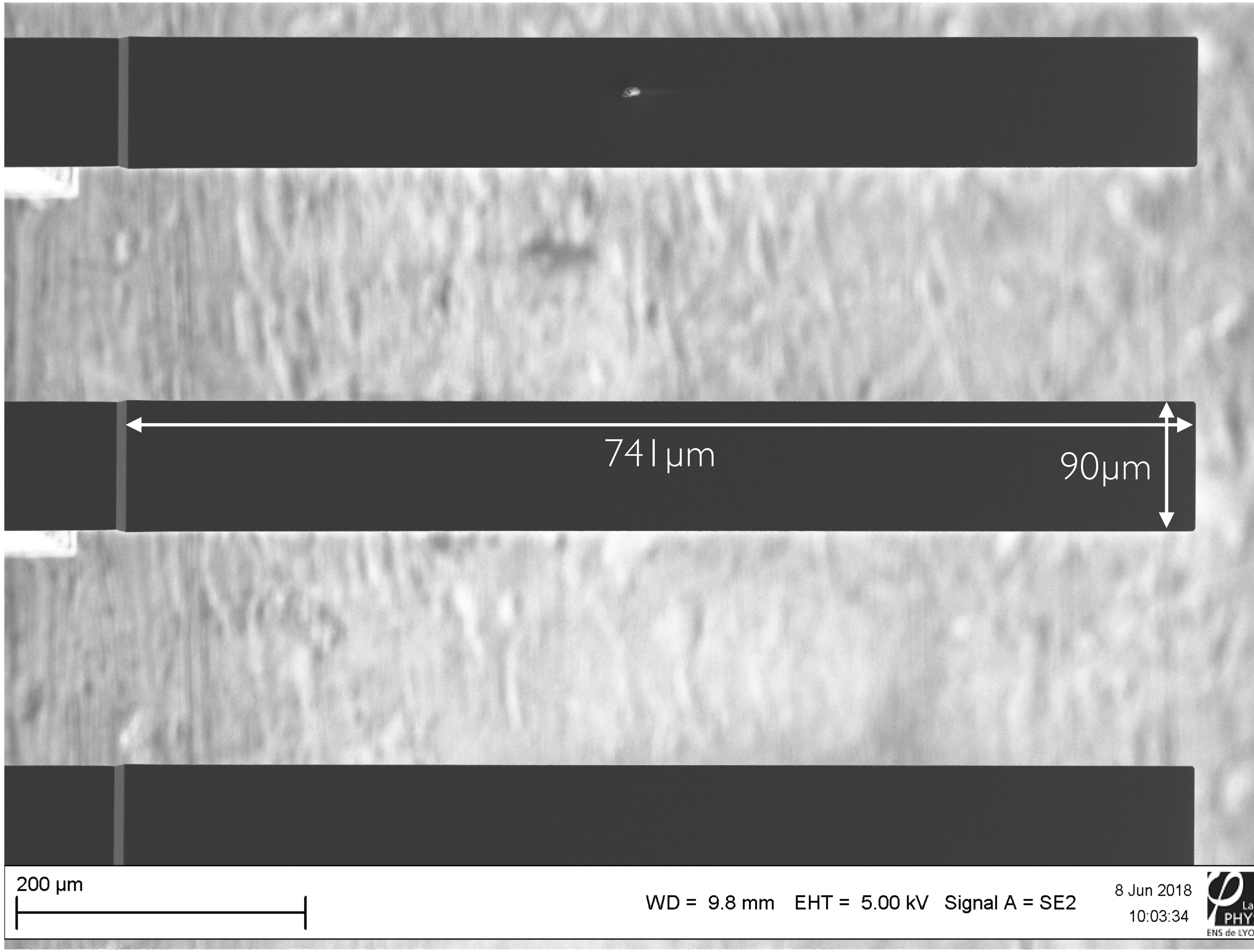


Sample : Si cantilever, Ta_2O_5 coating, annealed

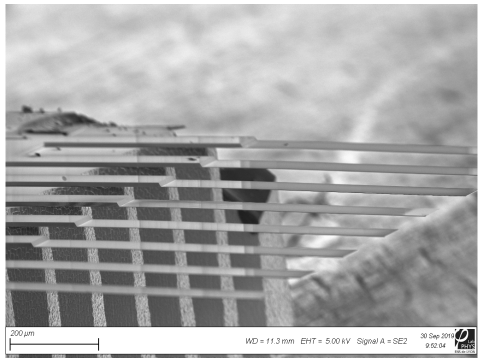


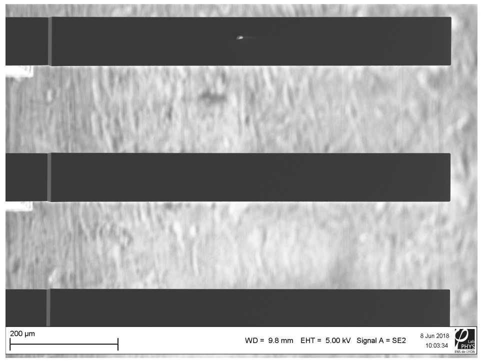


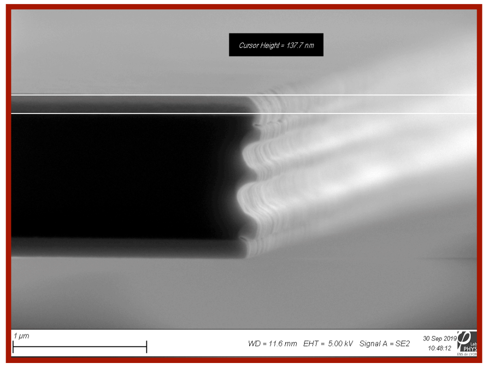


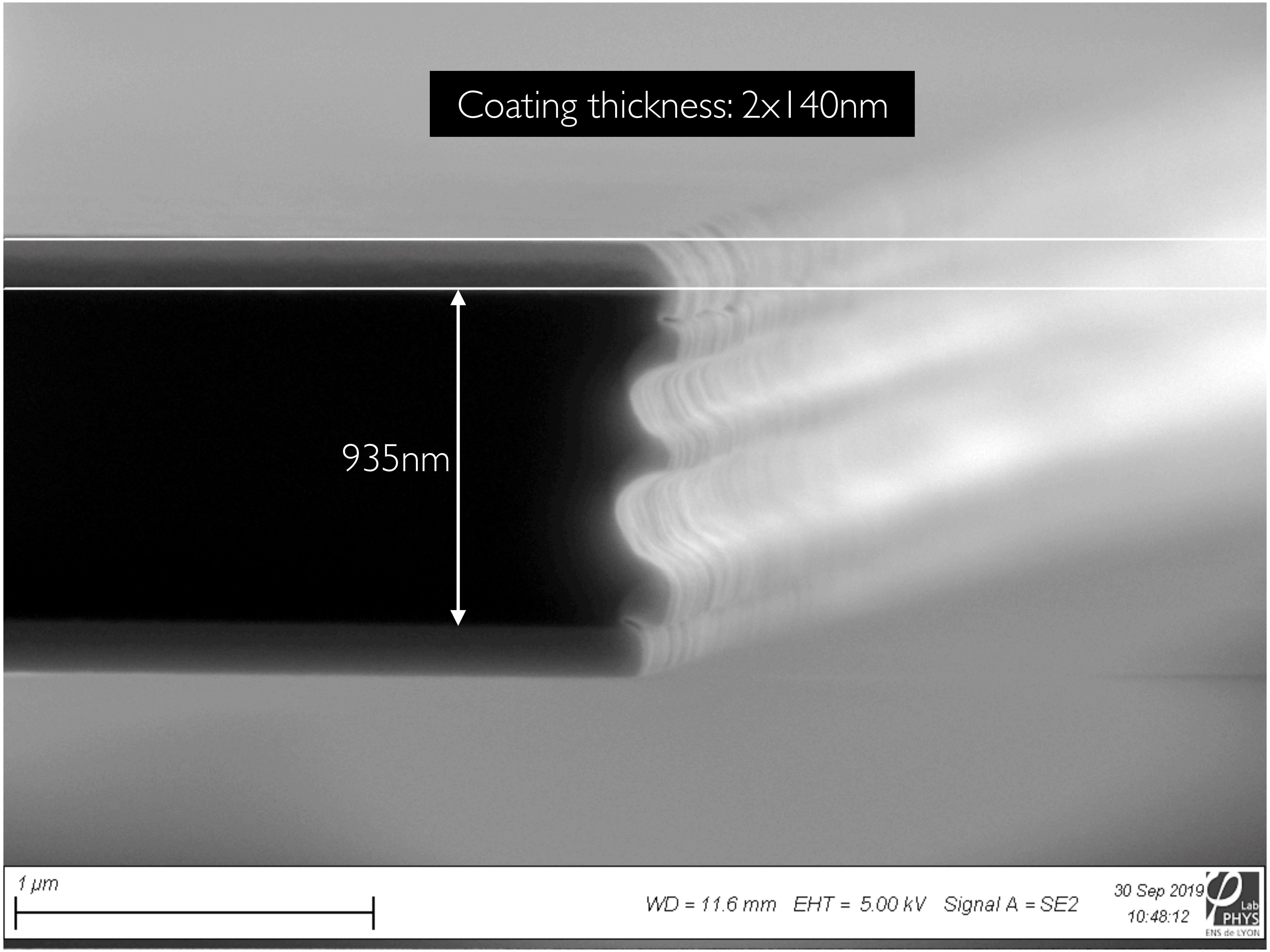


Sample : Si cantilever, Ta_2O_5 coating, annealed

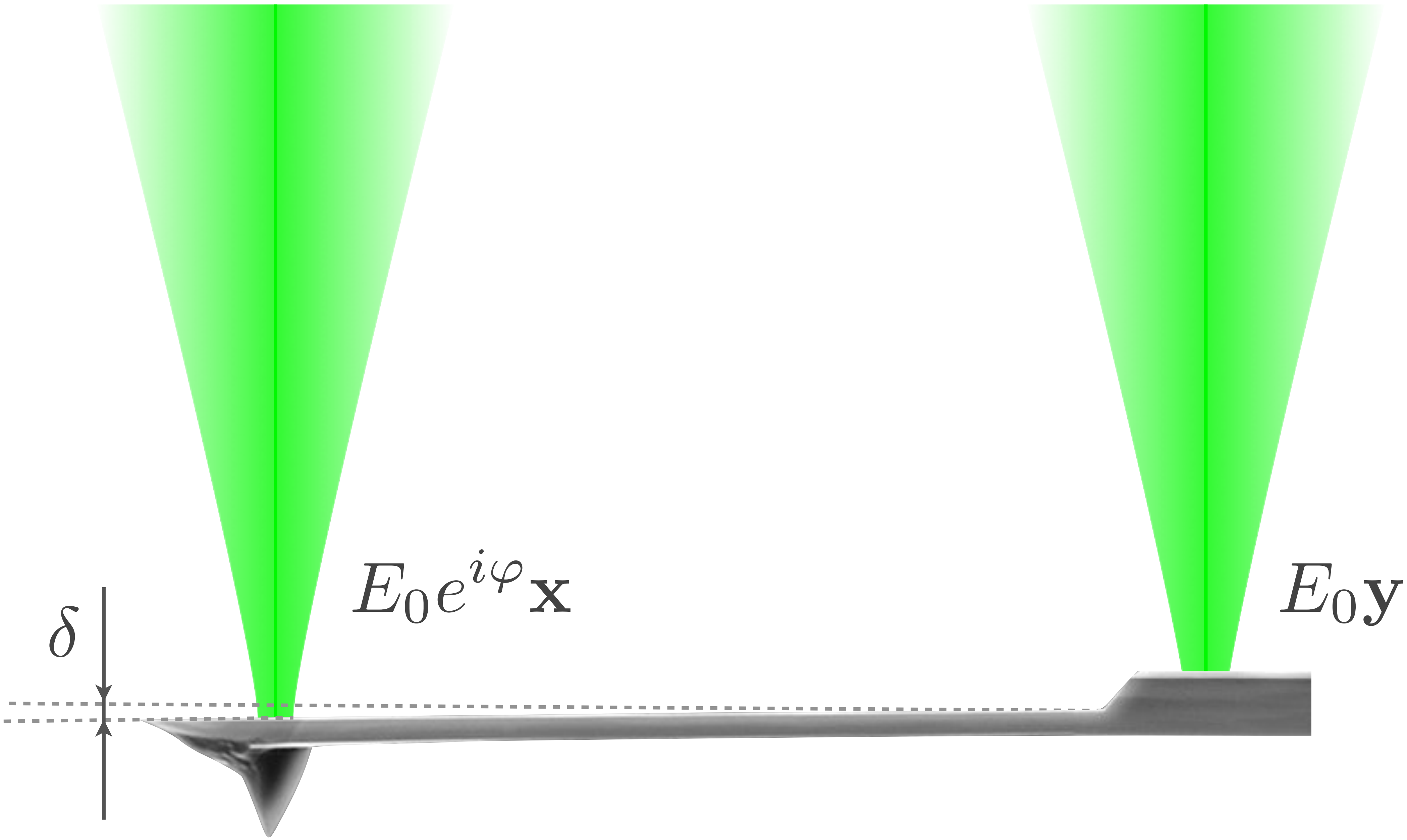








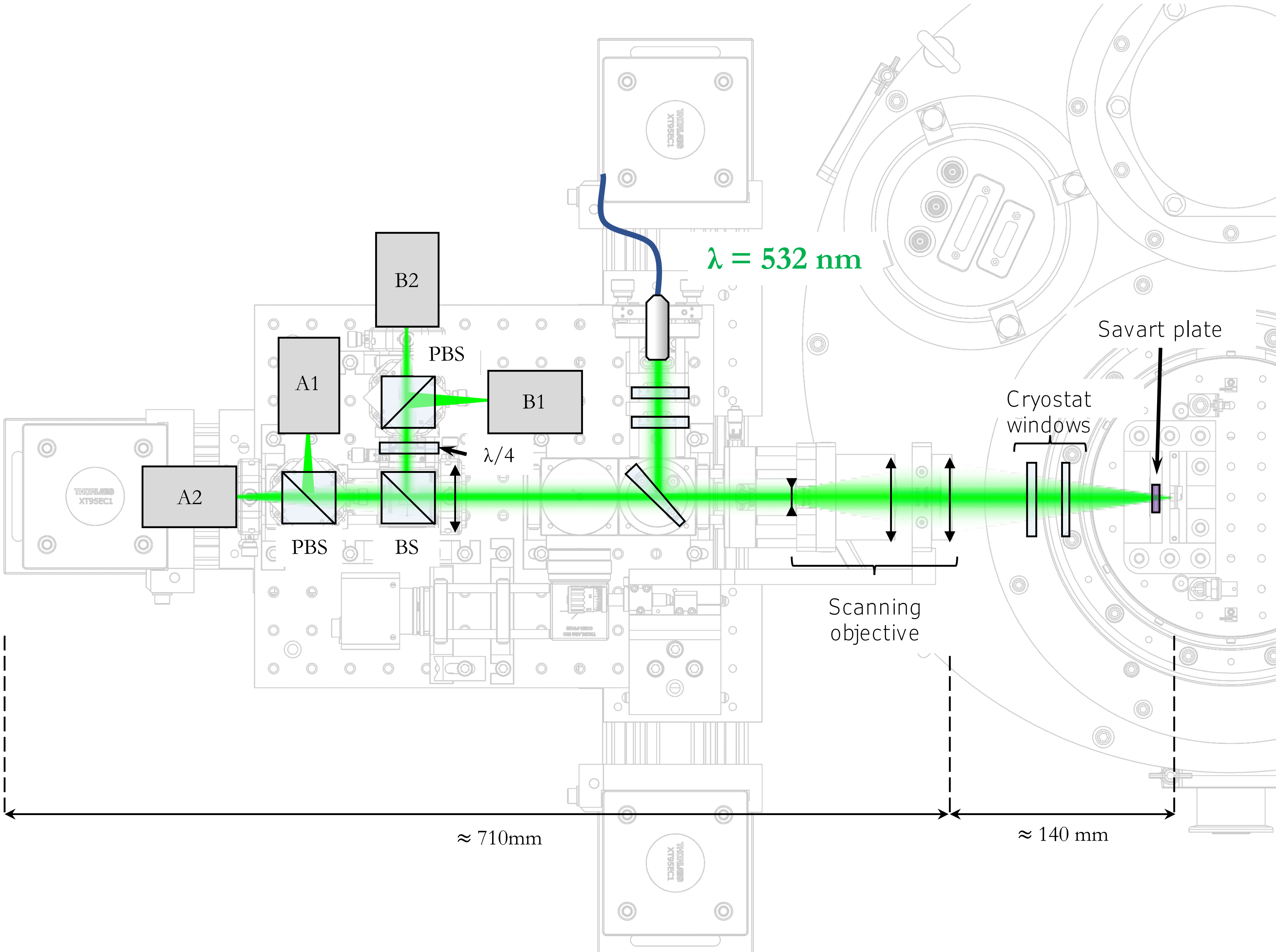
Quadrature Phase Differential Interferometer



$$\varphi = \frac{2\pi}{\lambda} 2\delta$$

C. Schonenberger and S. F. Alvarado, *Review of Scientific Instruments* **60**, 3131–3134, 1989.

Quadrature Phase Differential Interferometer

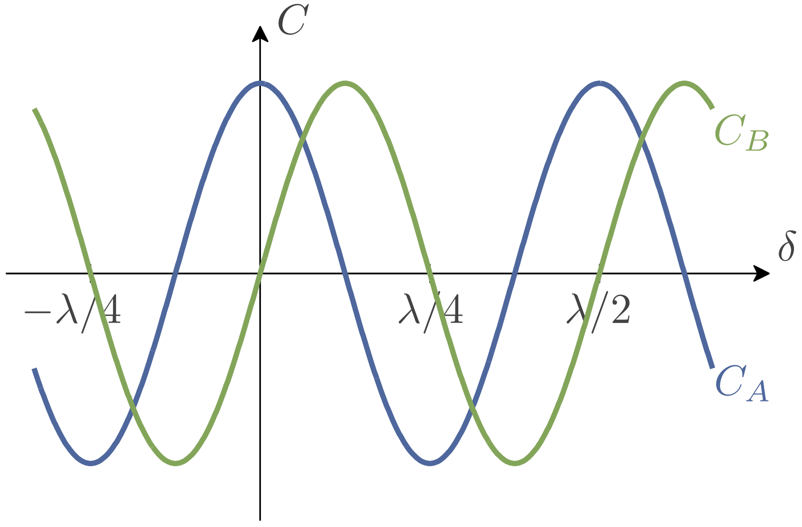


Photodiodes A

$$C_A = \cos(\varphi)$$

Photodiodes B

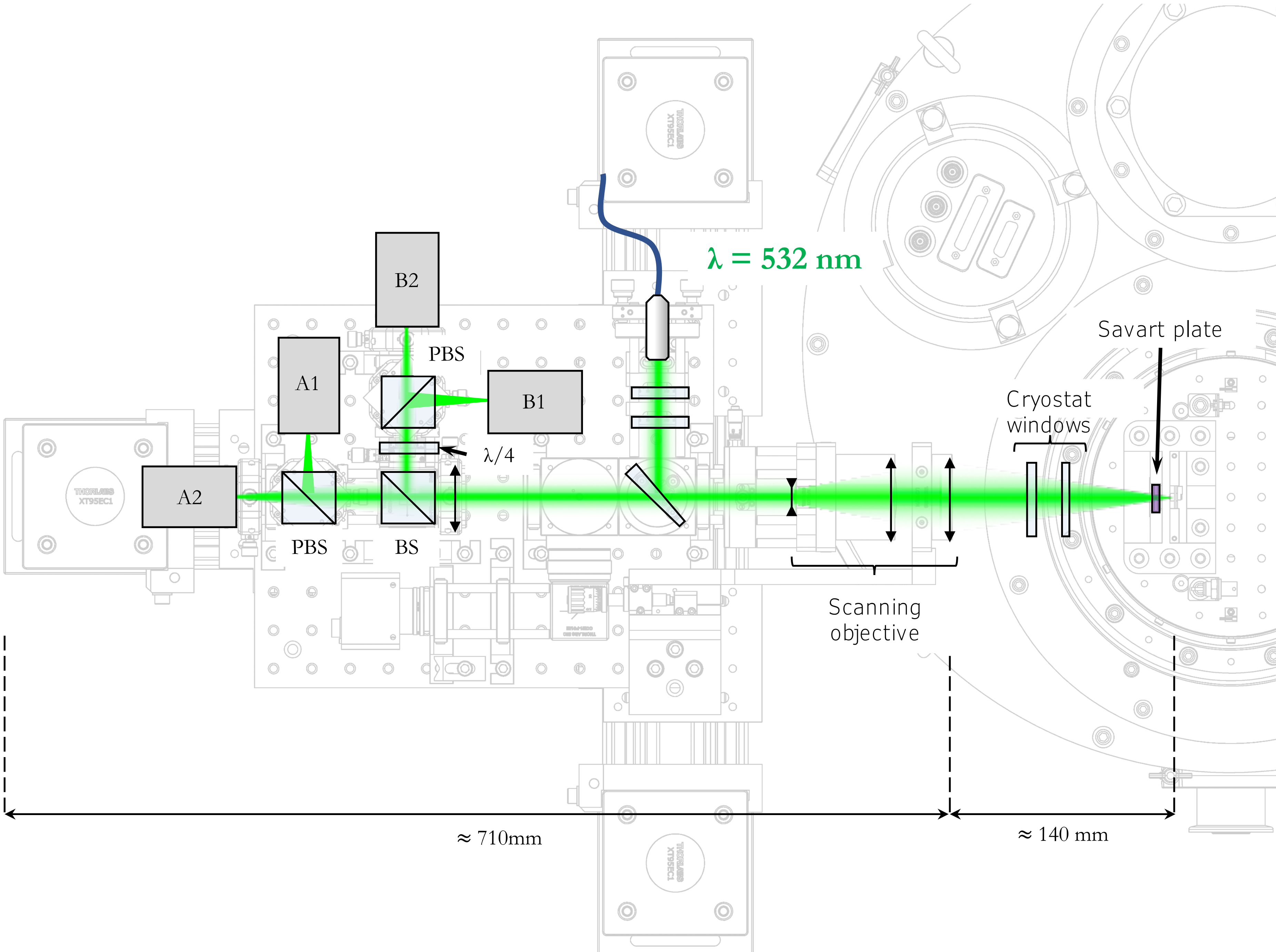
$$C_B = \sin(\varphi)$$



$$\varphi = \frac{2\pi}{\lambda} 2\delta$$

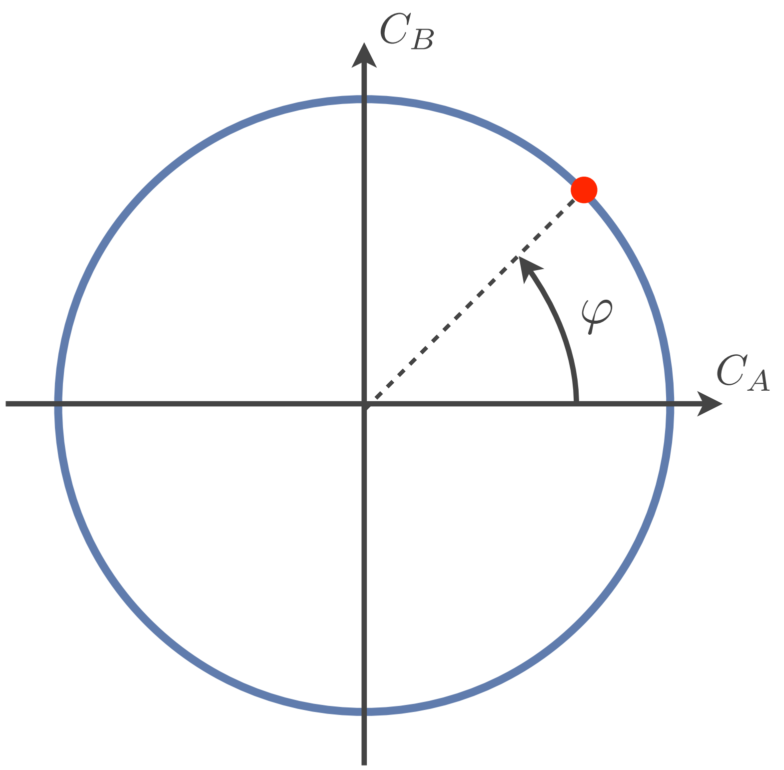
P. Paolino, F. Aguilar, L. Bellon, *Review of Scientific Instruments* **84**, 095001, 2013.

Quadrature Phase Differential Interferometer



Photodiodes A & B

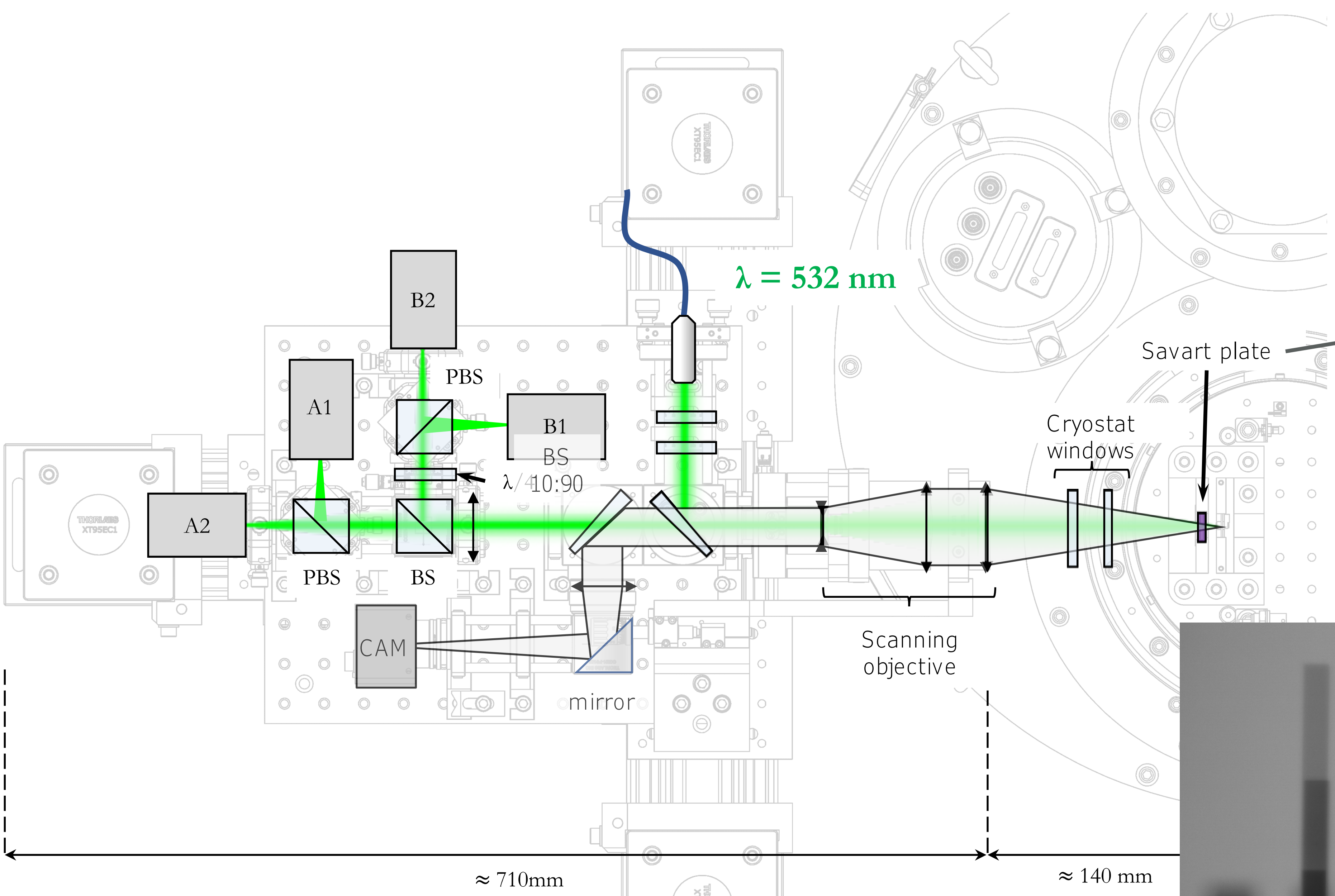
$$C^\star = C_A + iC_B$$
$$= e^{i\varphi}$$

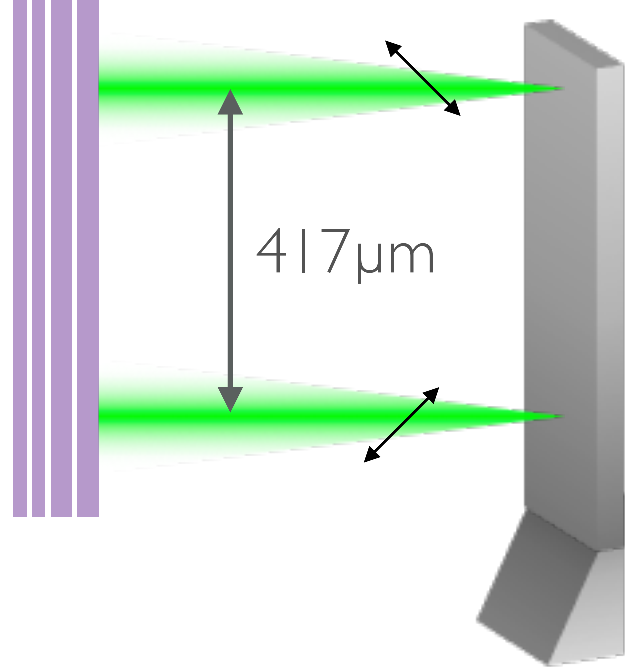


$$\varphi = \frac{2\pi}{\lambda} 2\delta$$

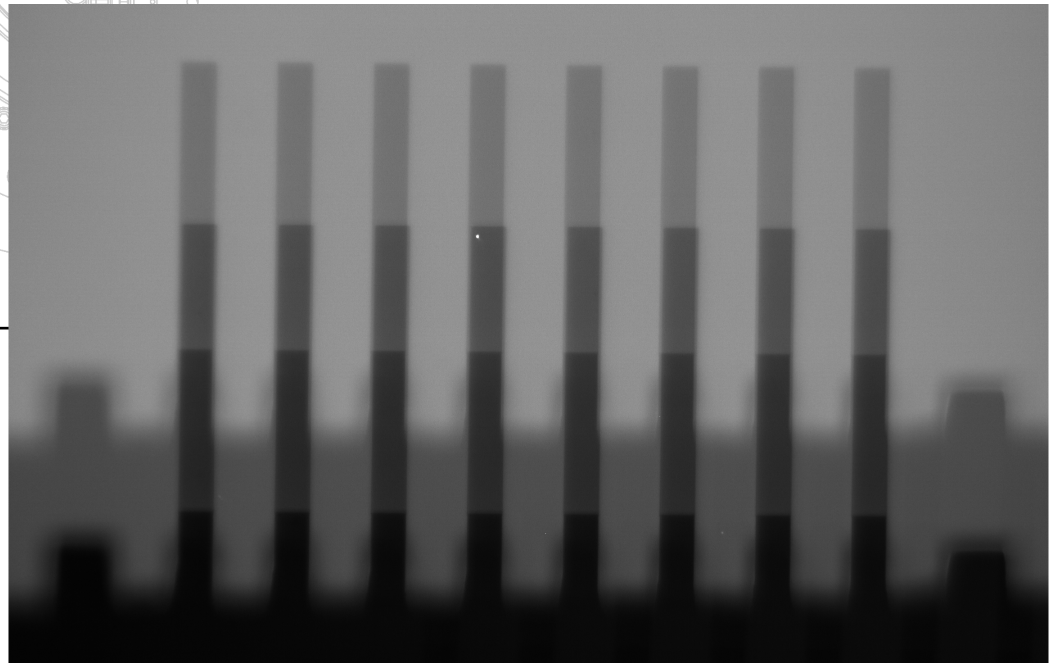
P. Paolino, F. Aguilar, L. Bellon, *Review of Scientific Instruments* **84**, 095001, 2013.

Quadrature Phase Differential Interferometer

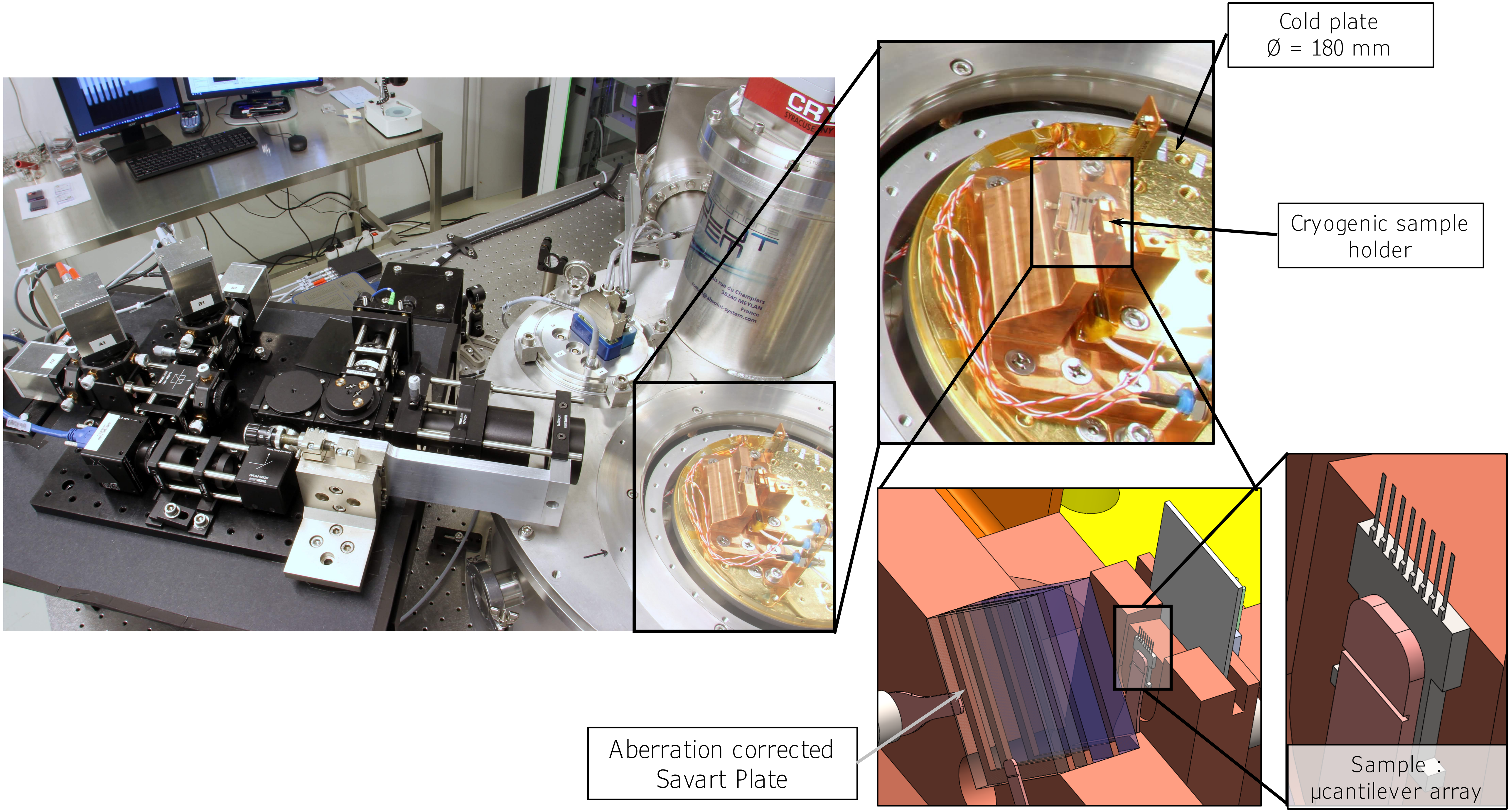




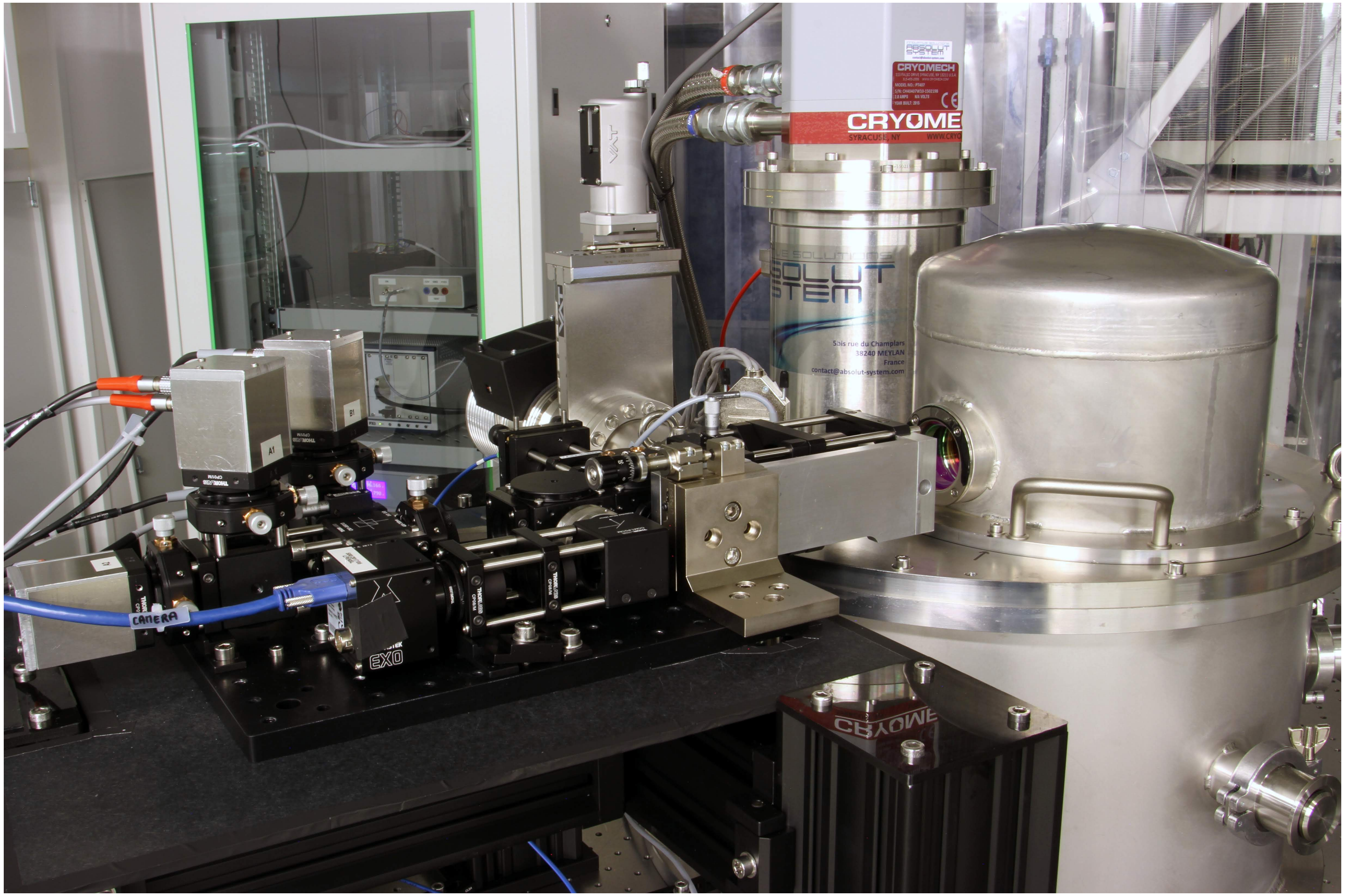
Spots size: 3µm



Cryo-QPDI


Cold plate
Ø = 180 mm
Cryogenic sample holder
Aberration corrected Savart Plate
Sample : µcantilever array

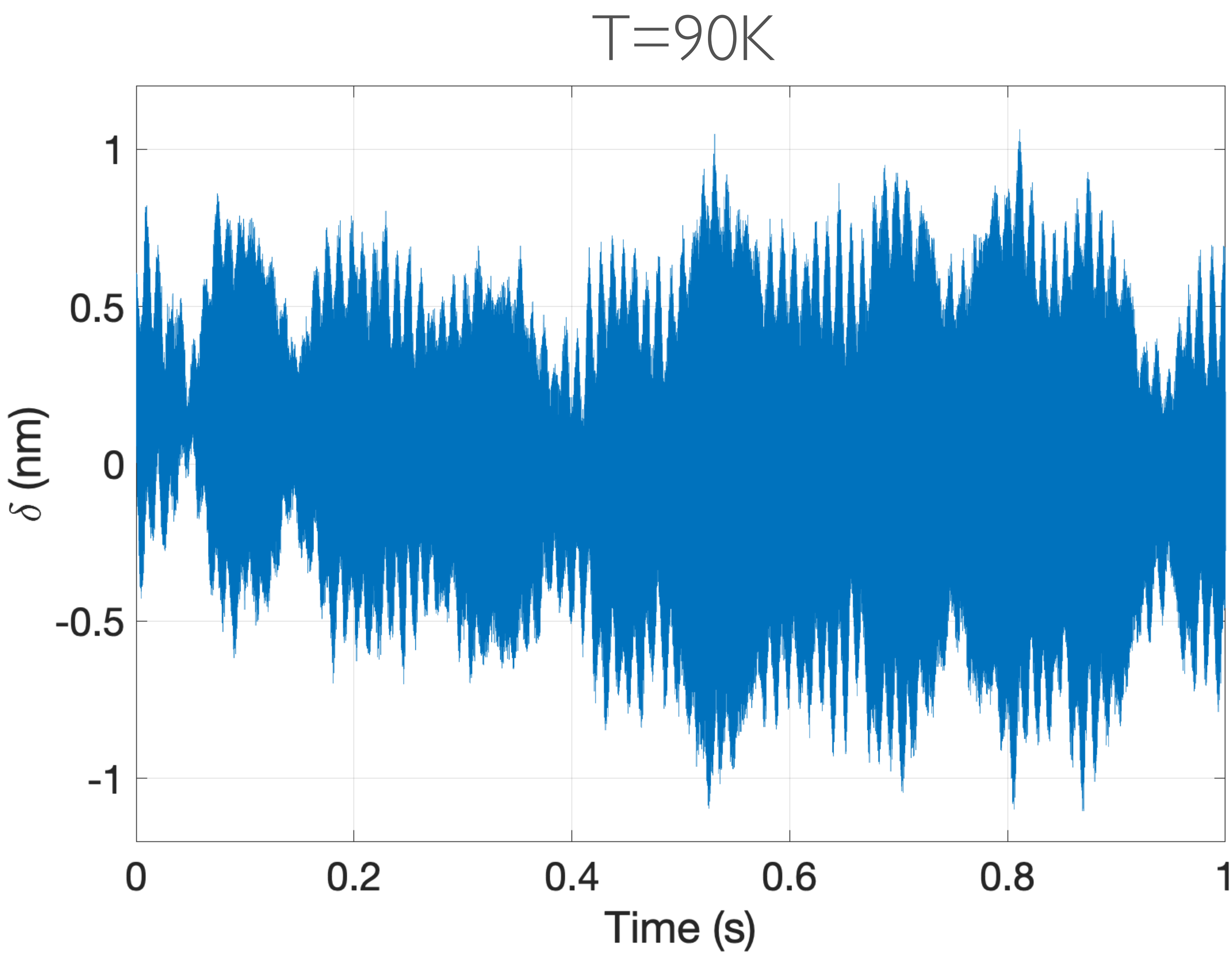
Pulse tube Cryostat



Minimum temperature
6K

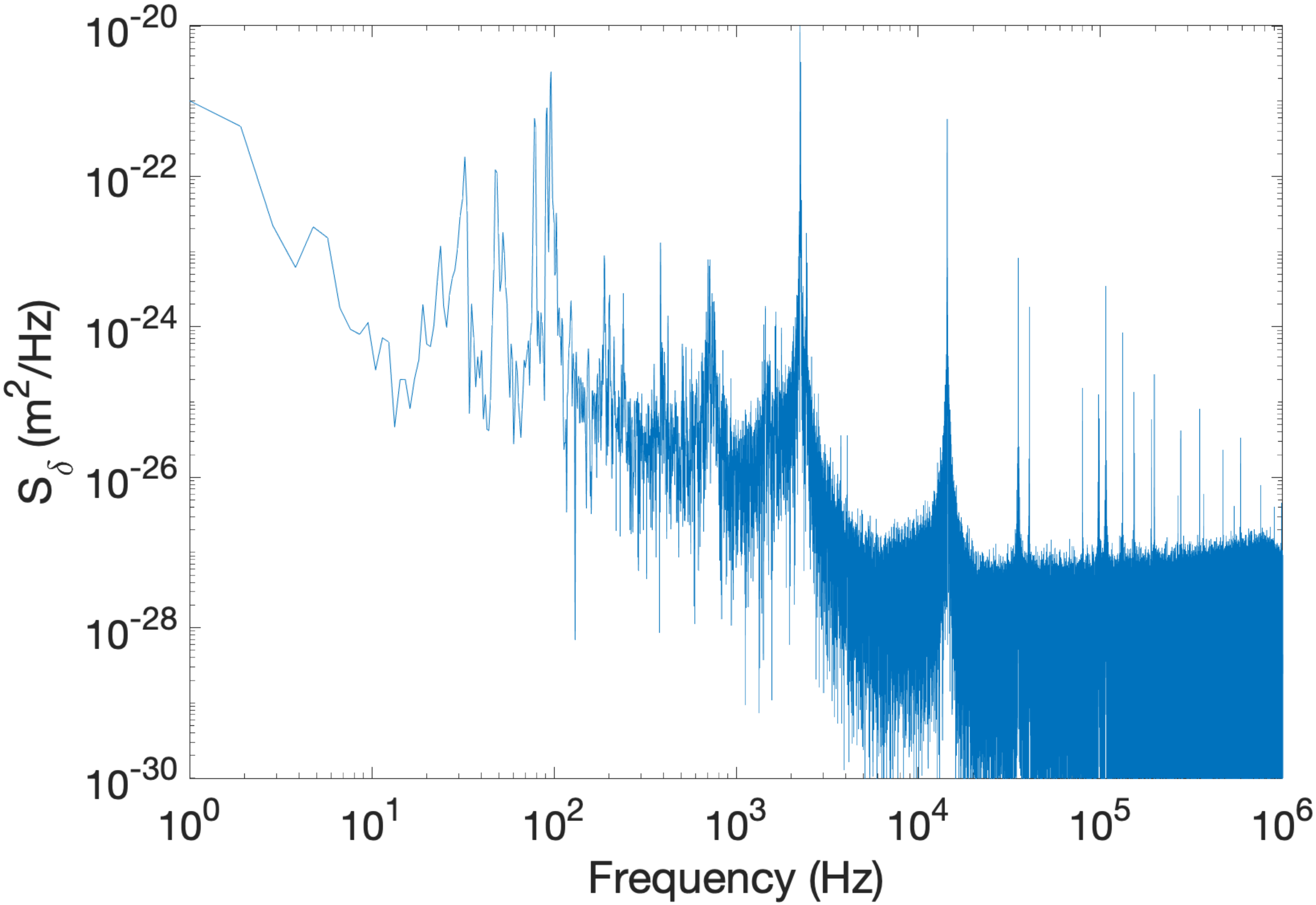
Heating rate (strong inertia)
1K/7min

Vacuum
10^{-8}mbar


T=90K
1
0.5
0
-0.5
-1
δ (nm)
0
0.2
0.4
0.6
0.8
1
Time (s)

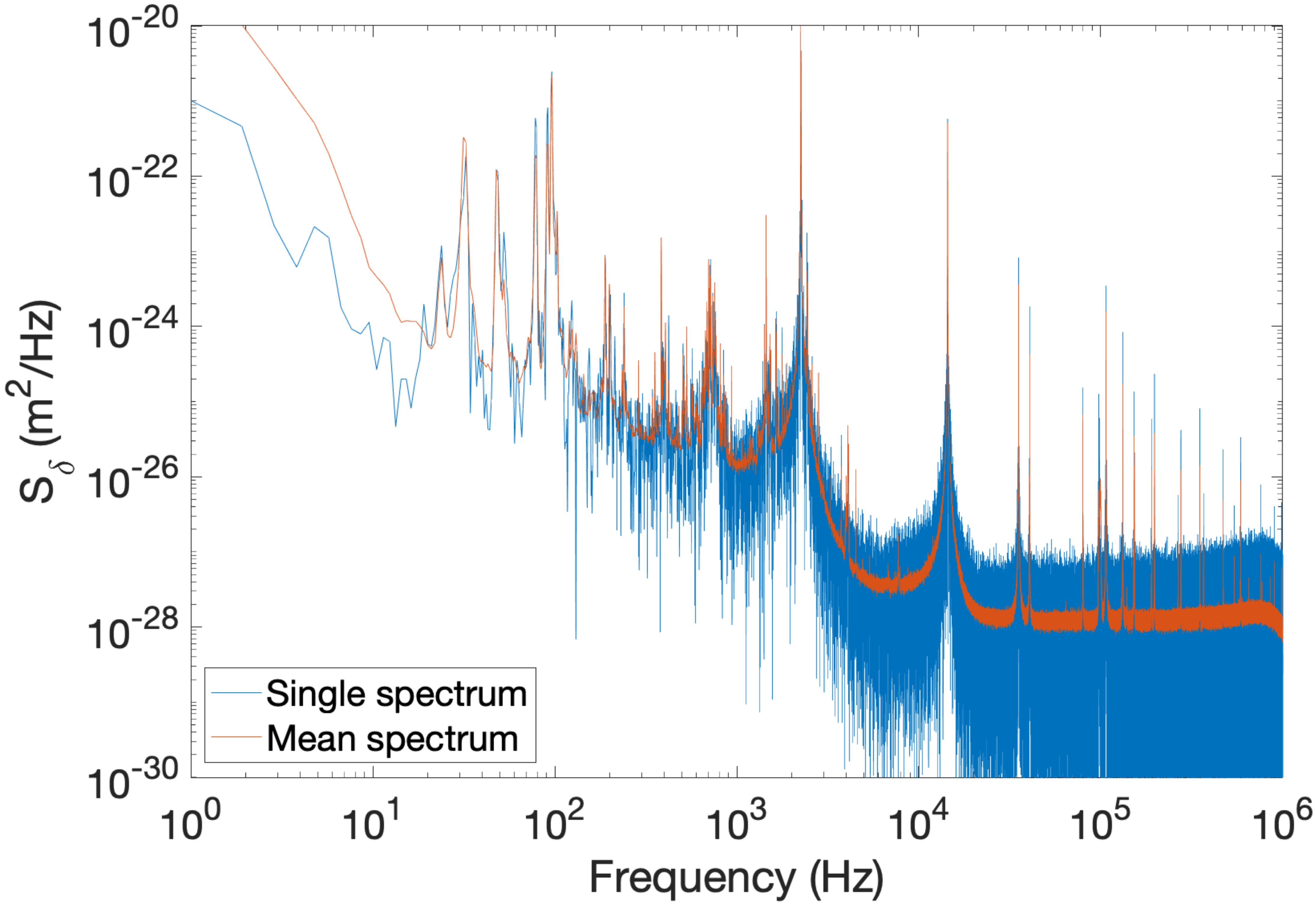
Thermal noise measurement

T=90K



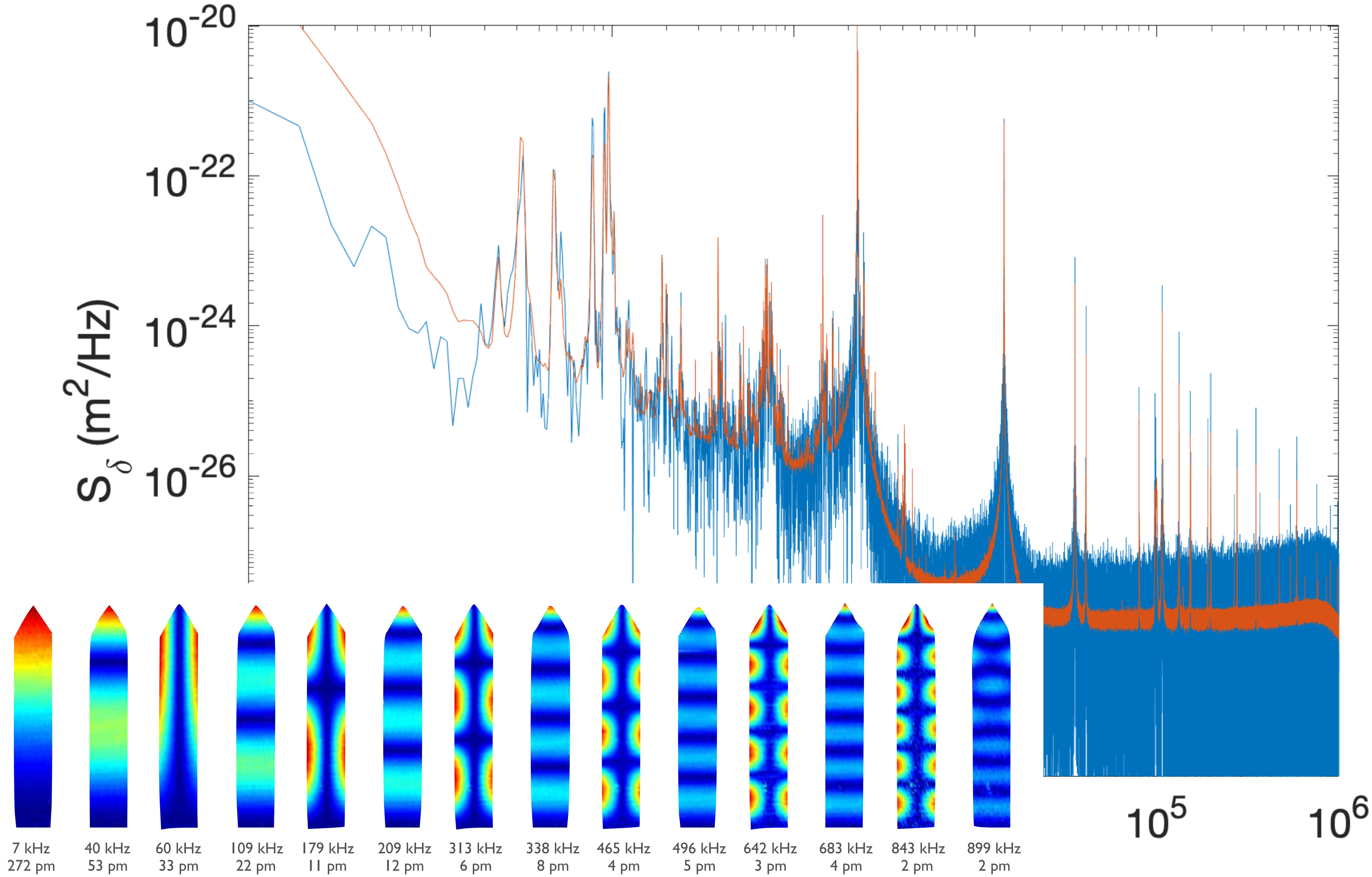
Thermal noise measurement

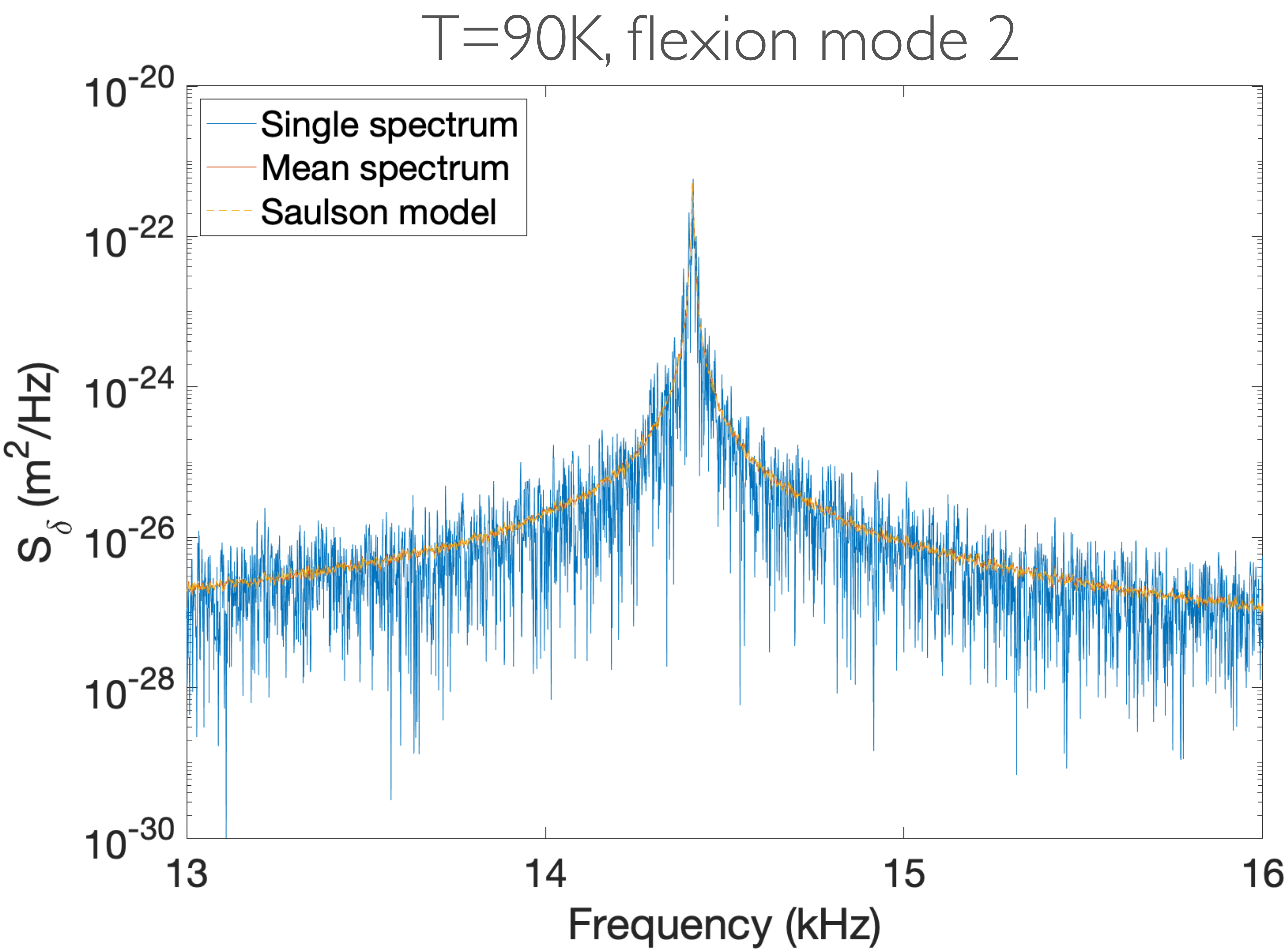
T=90K



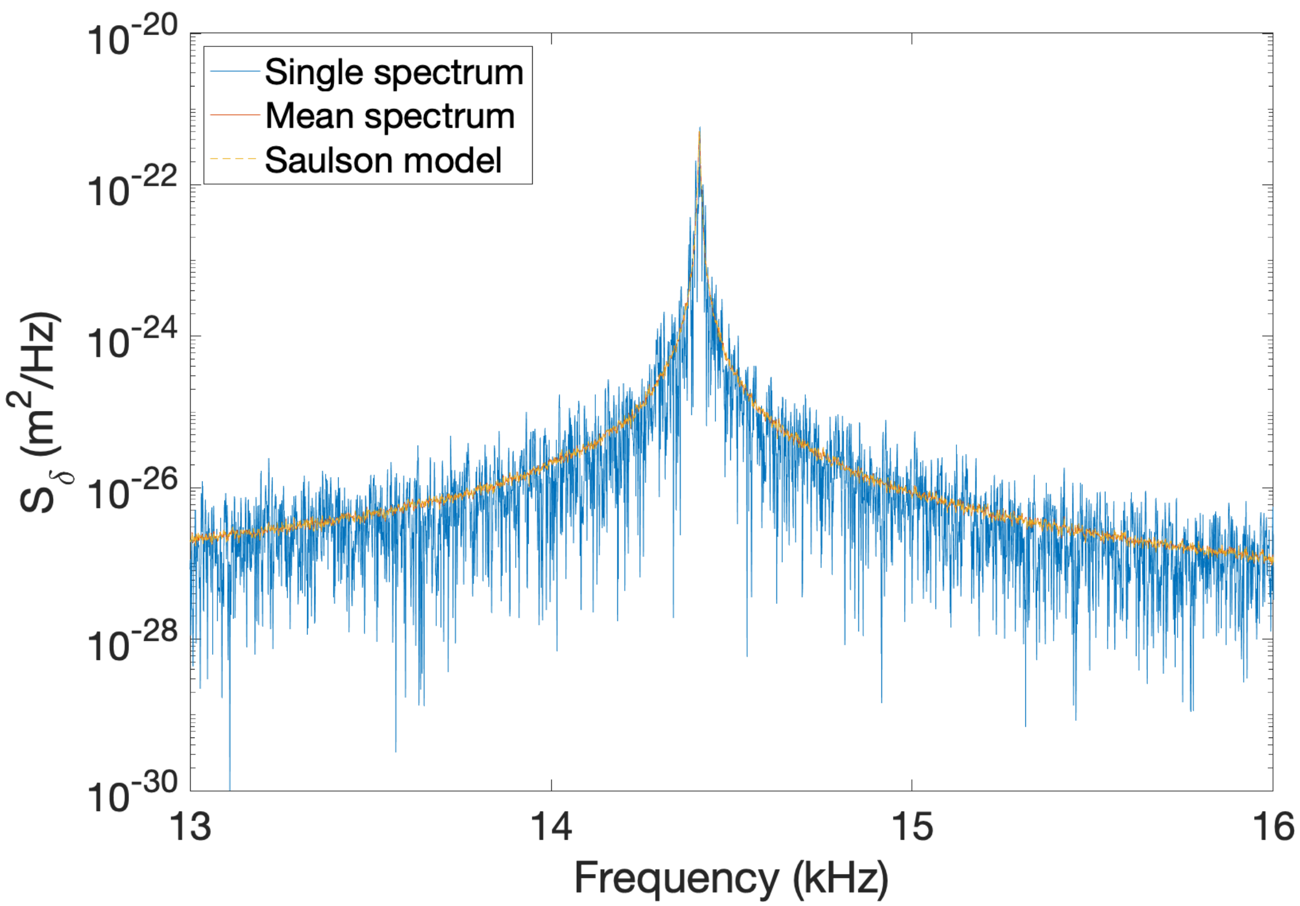
Thermal noise measurement

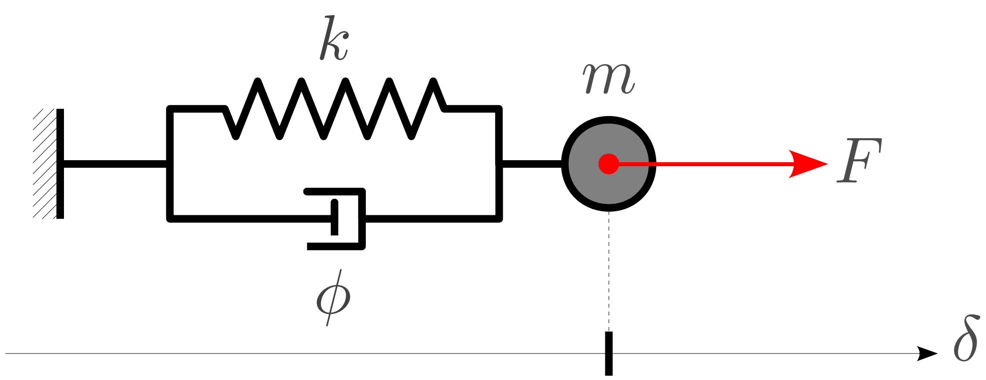
T=90K




T=90K, flexion mode 2
Single spectrum
Mean spectrum
Saulson model
10^{-20}
10^{-22}
10^{-24}
10^{-26}
10^{-28}
10^{-30}
S_δ (m^2/Hz)
13
14
15
16
Frequency (kHz)

T=90K, flexion mode 2





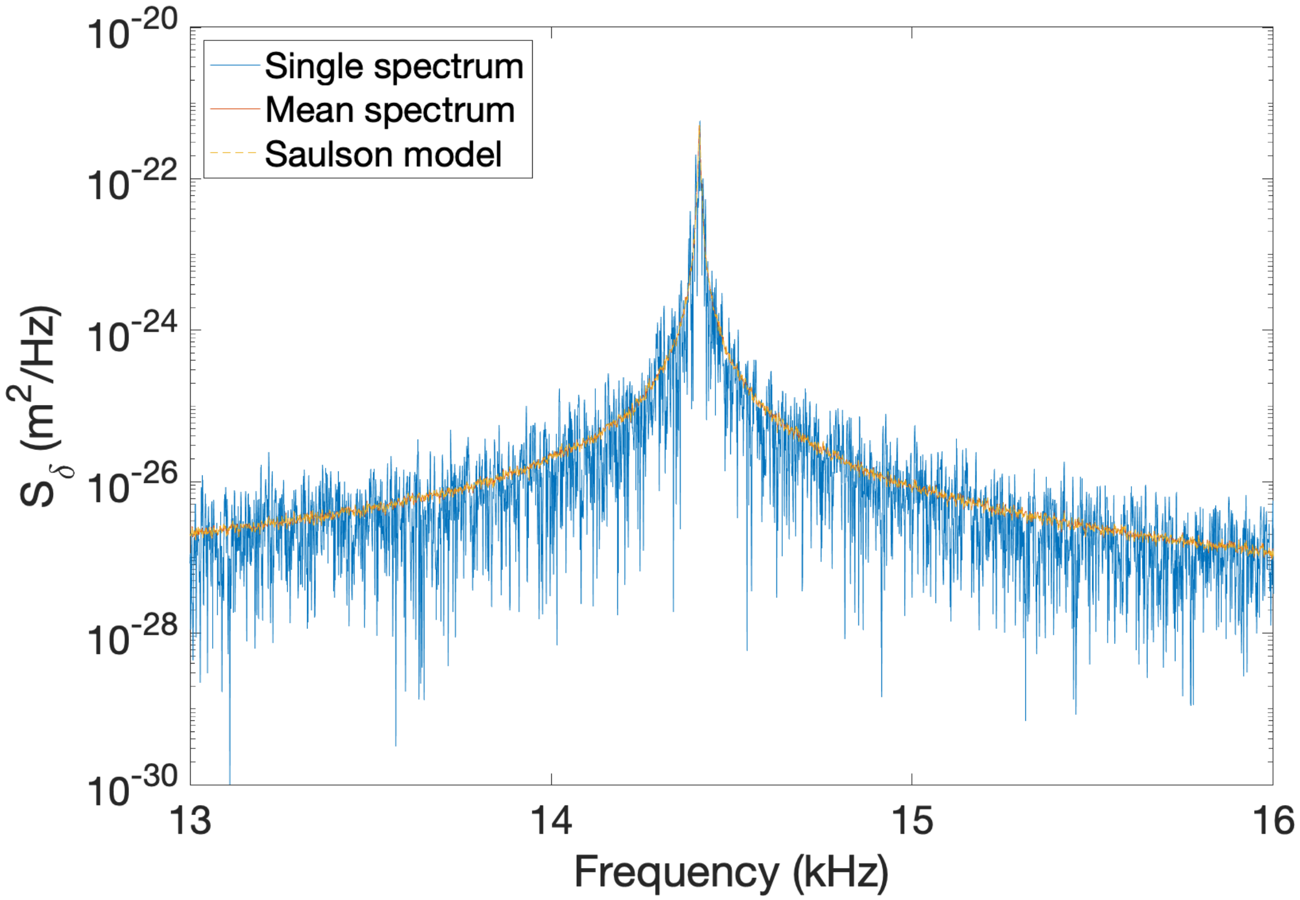
Saulson model

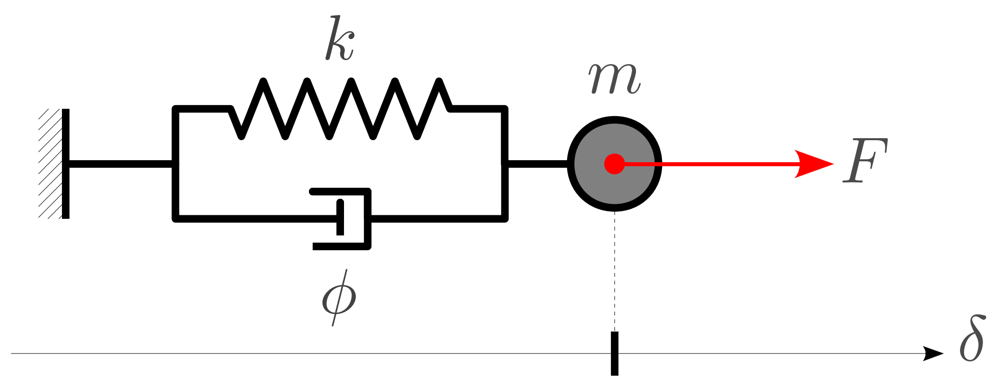
$$F(\omega) = \left[k(1+i\phi) - m\omega^2\right]\delta(\omega)$$

Fluctuation-Dissipation Theorem

$$S_\delta(\omega) = \frac{2k_BT}{\pi\omega k}\frac{\phi}{(1-\omega^2/\omega_0^2)^2+\phi^2} = -\frac{2k_BT}{\pi\omega}\mathrm{Im}\left[\frac{\delta(\omega)}{F(\omega)}\right]$$

T=90K, flexion mode 2





Saulson model

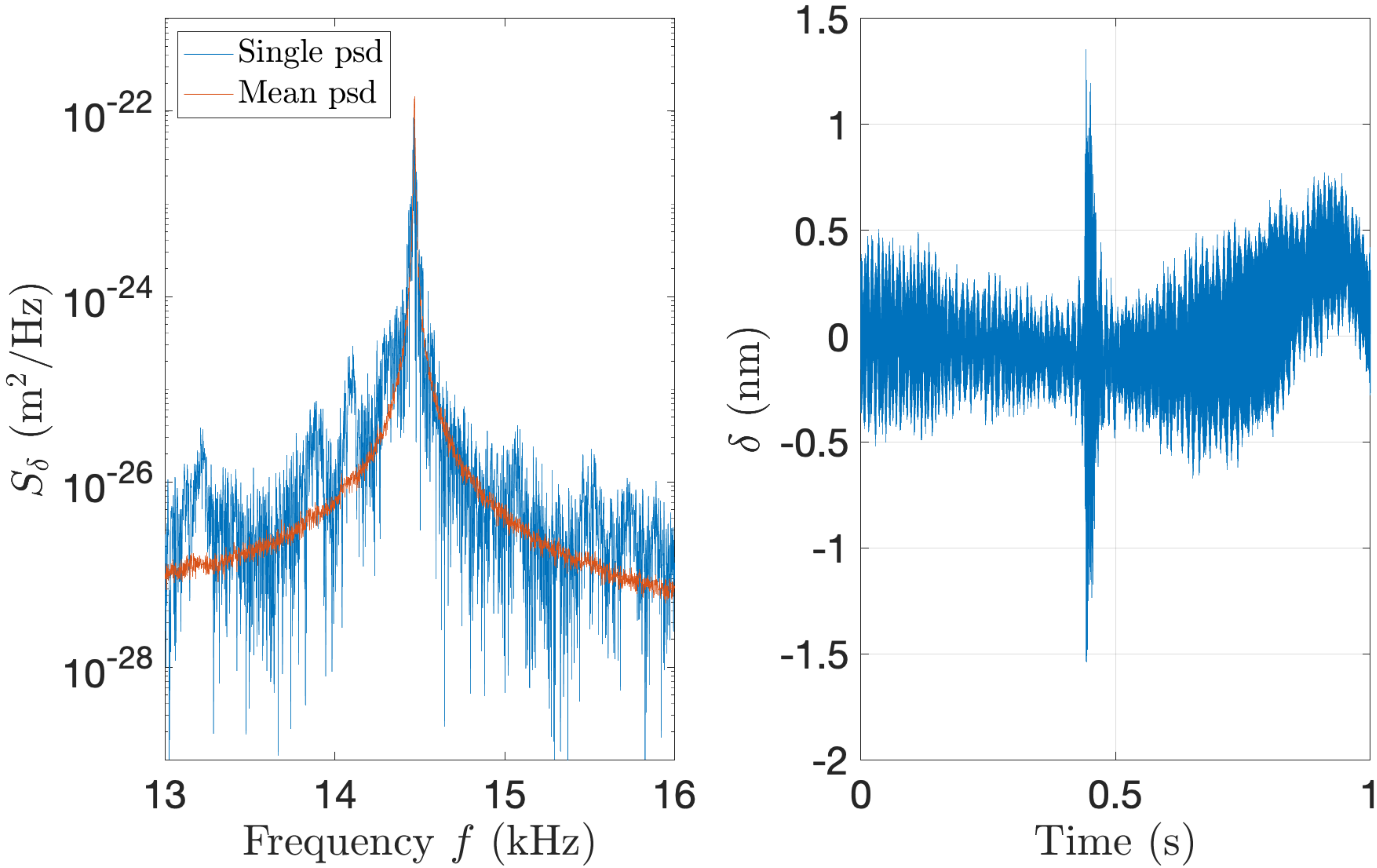
$$F(\omega) = \left[k(1+i\phi) - m\omega^2\right]\delta(\omega)$$

Fluctuation-Dissipation Theorem

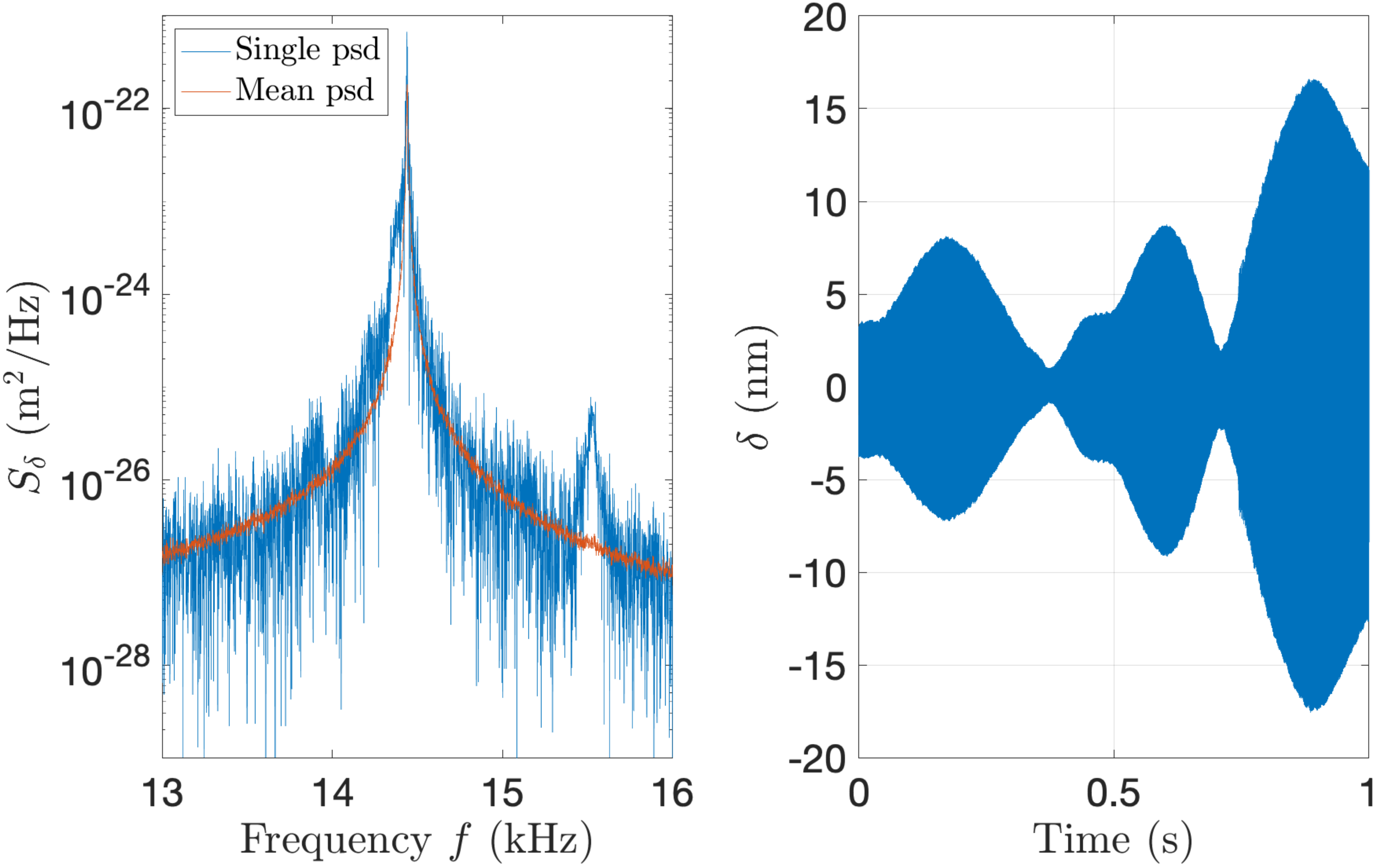
Fit

$$S_\delta(\omega) = \frac{2k_BT}{\pi\omega k}\frac{\phi}{(1-\omega^2/\omega_0^2)^2+\phi^2} \longrightarrow \phi, \omega_0, k \ (\text{thus } m)$$

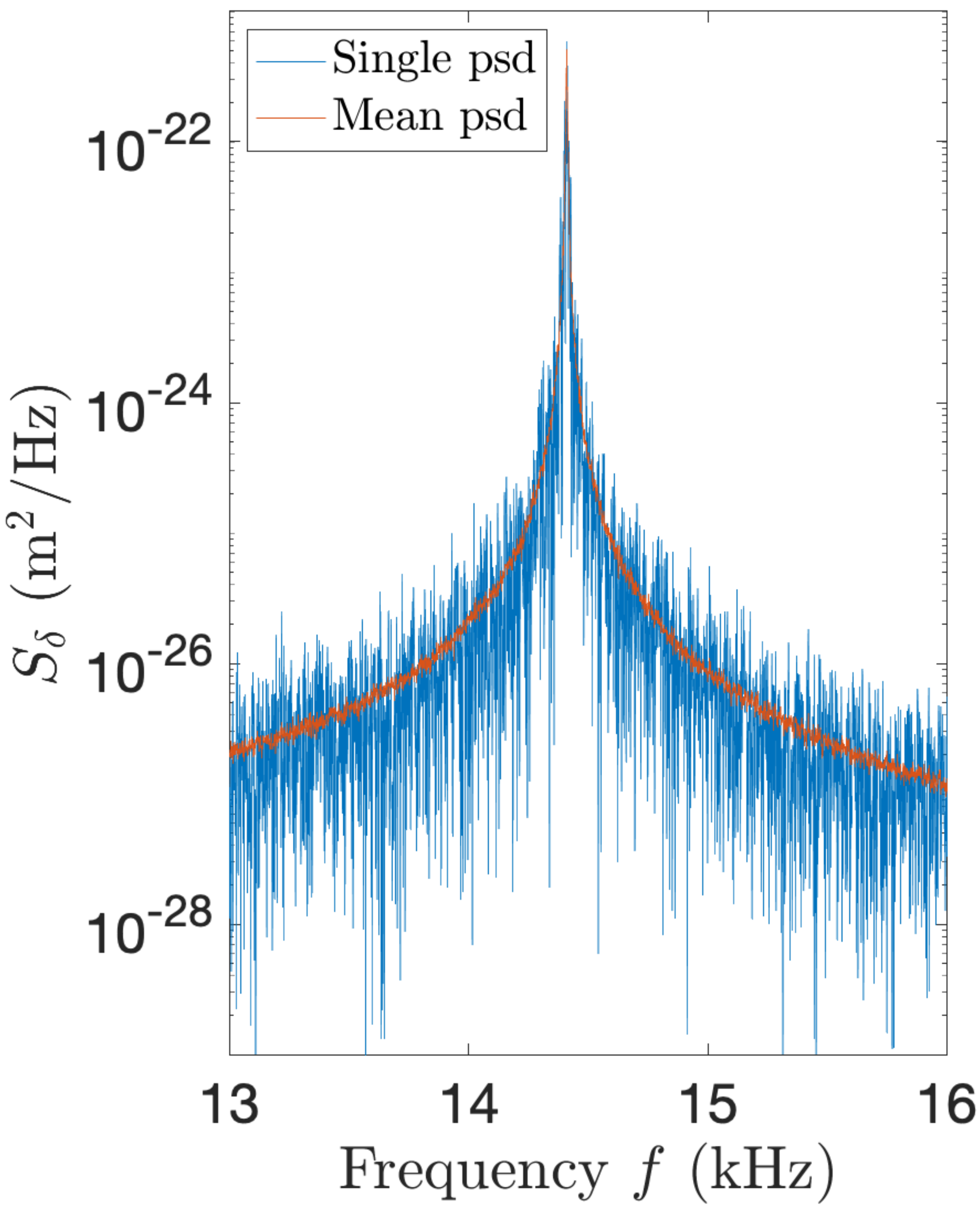
T=34K, flexion mode 2

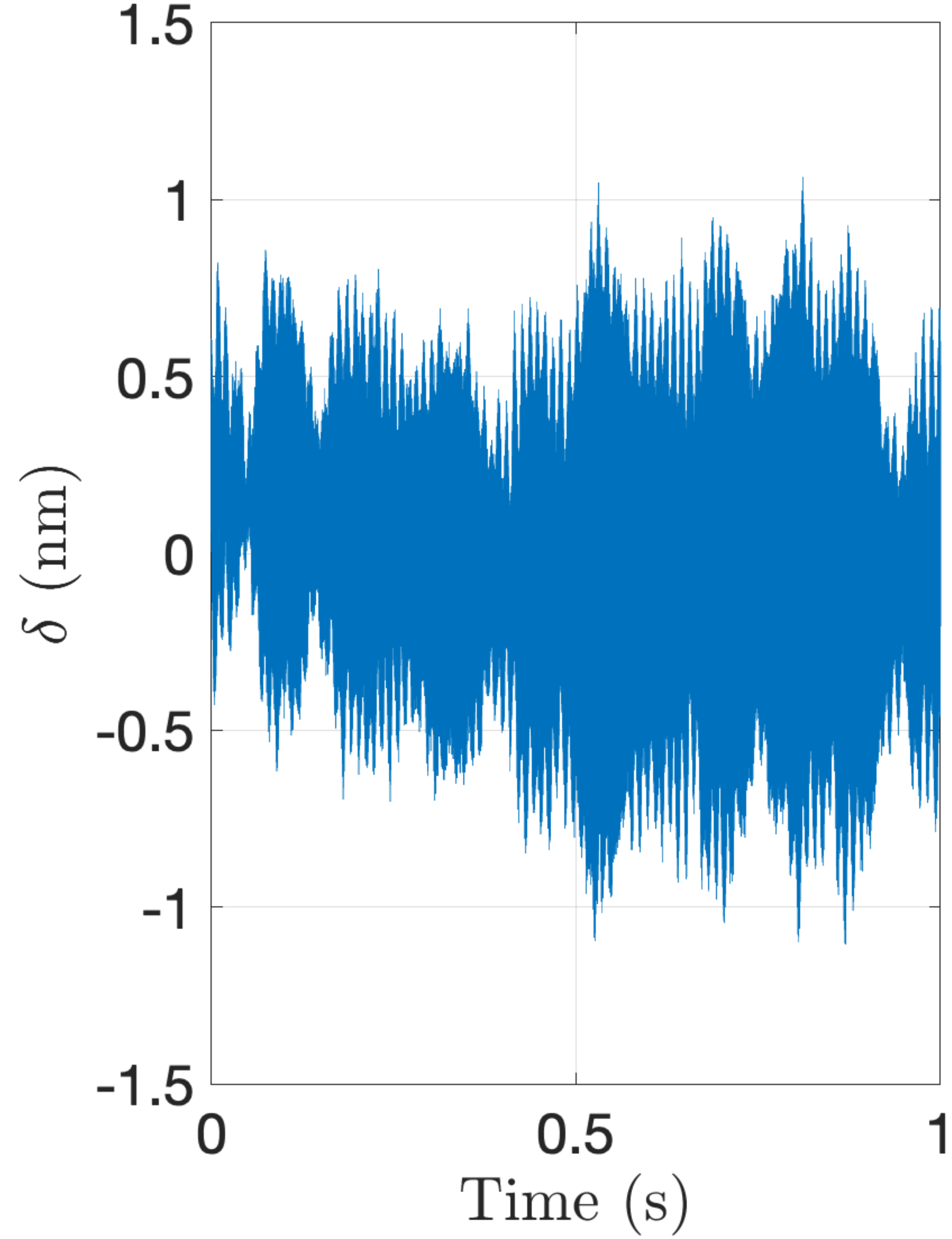


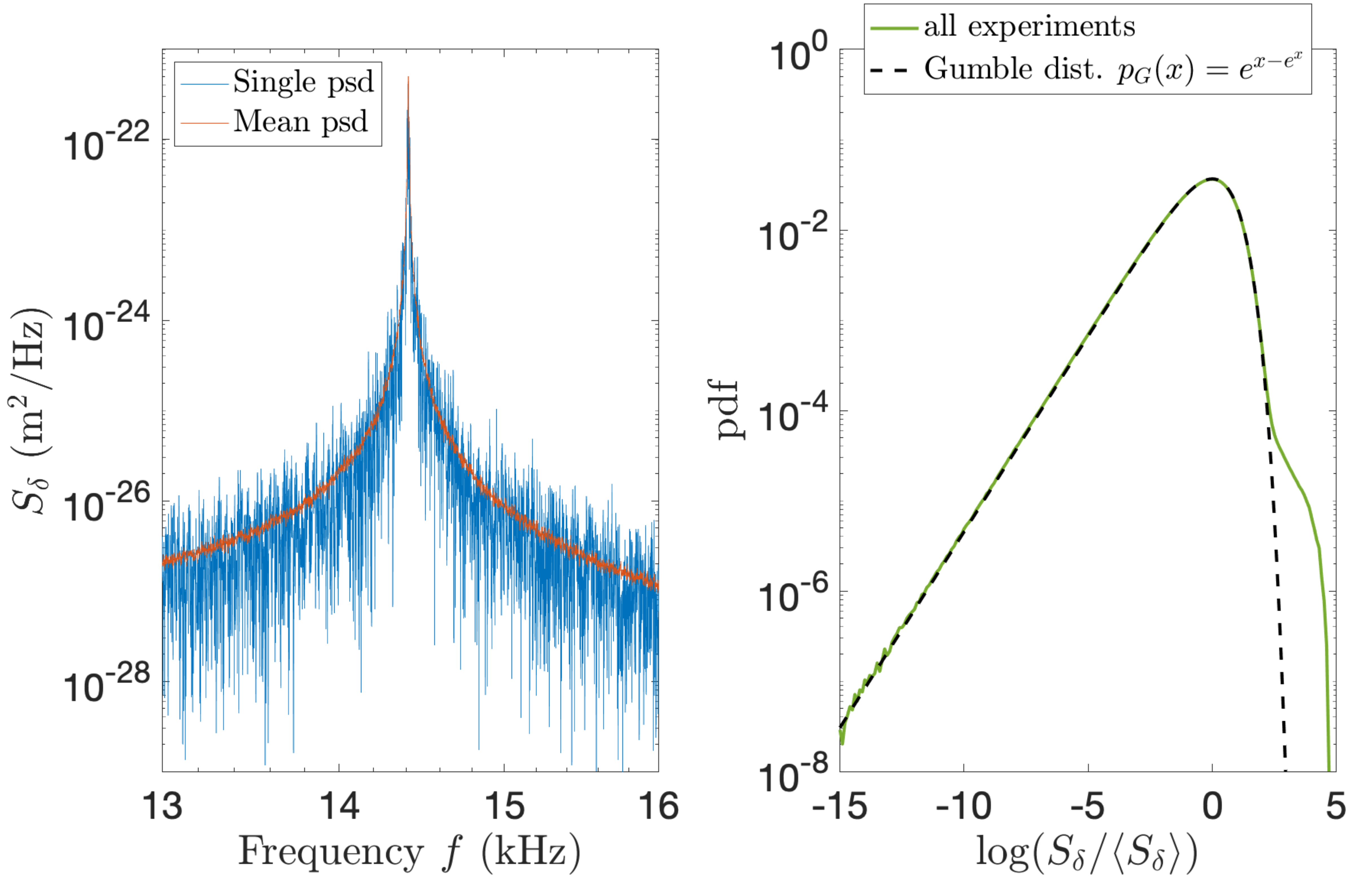
T=49K, flexion mode 2



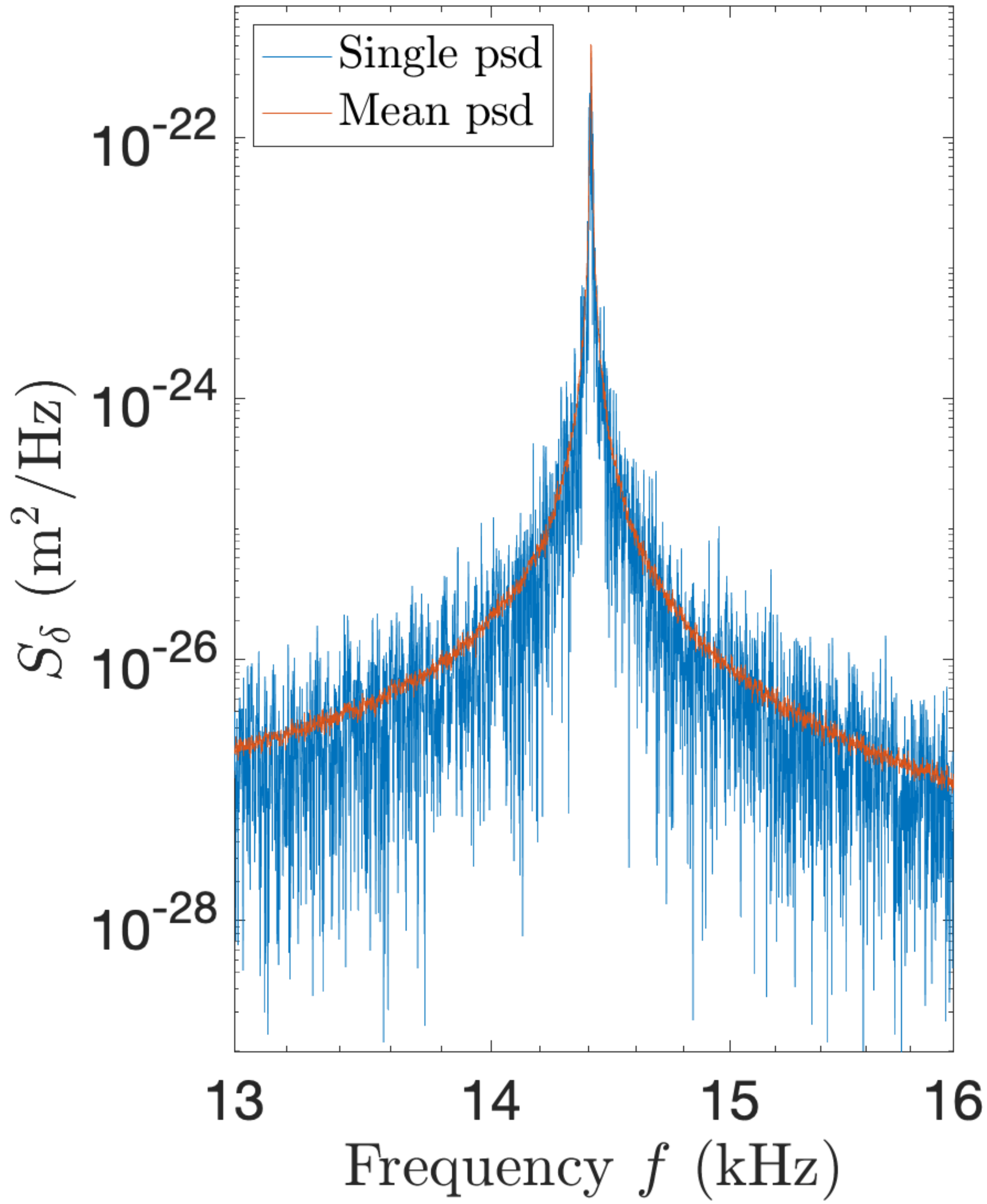
T=90K, flexion mode 2

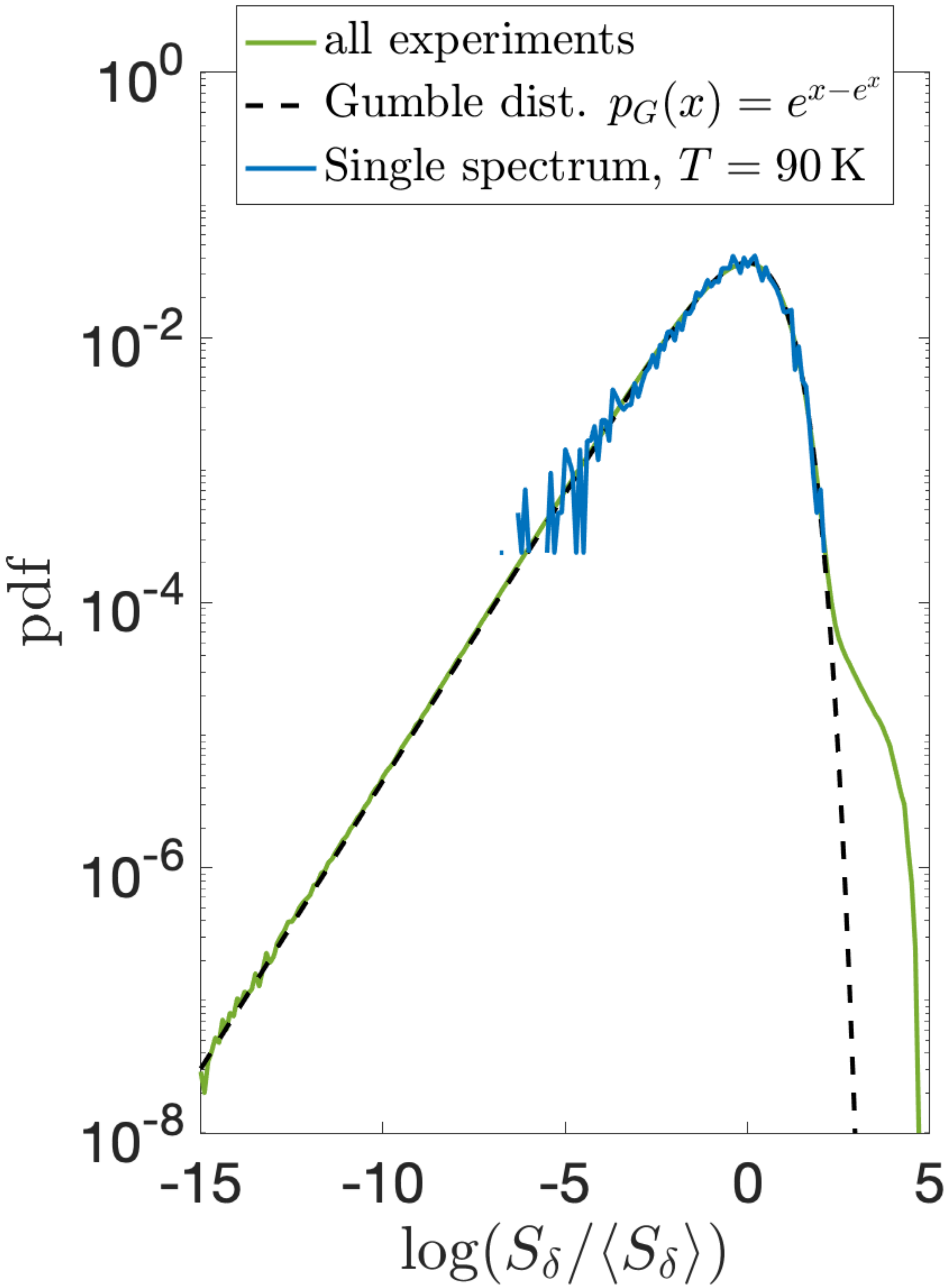




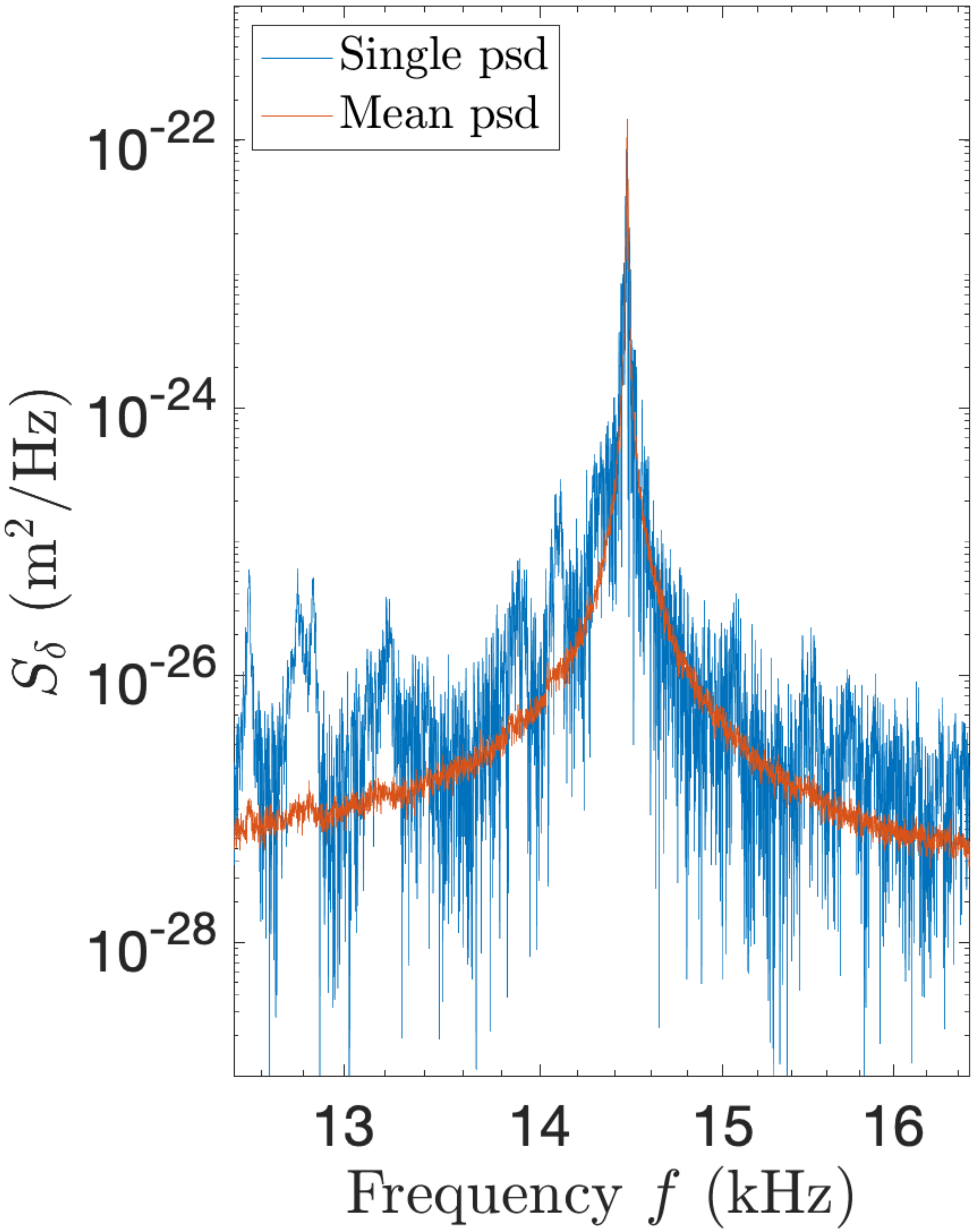

Single psd
Mean psd
10^{-22}
10^{-24}
10^{-26}
10^{-28}
S_δ (m^2/Hz)
13
14
15
16
Frequency f (kHz)
all experiments
Gumble dist. $p_G(x) = e^{x-e^x}$
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
pdf
-15
-10
-5
0
5
$\log(S_\delta/\langle S_\delta\rangle)$

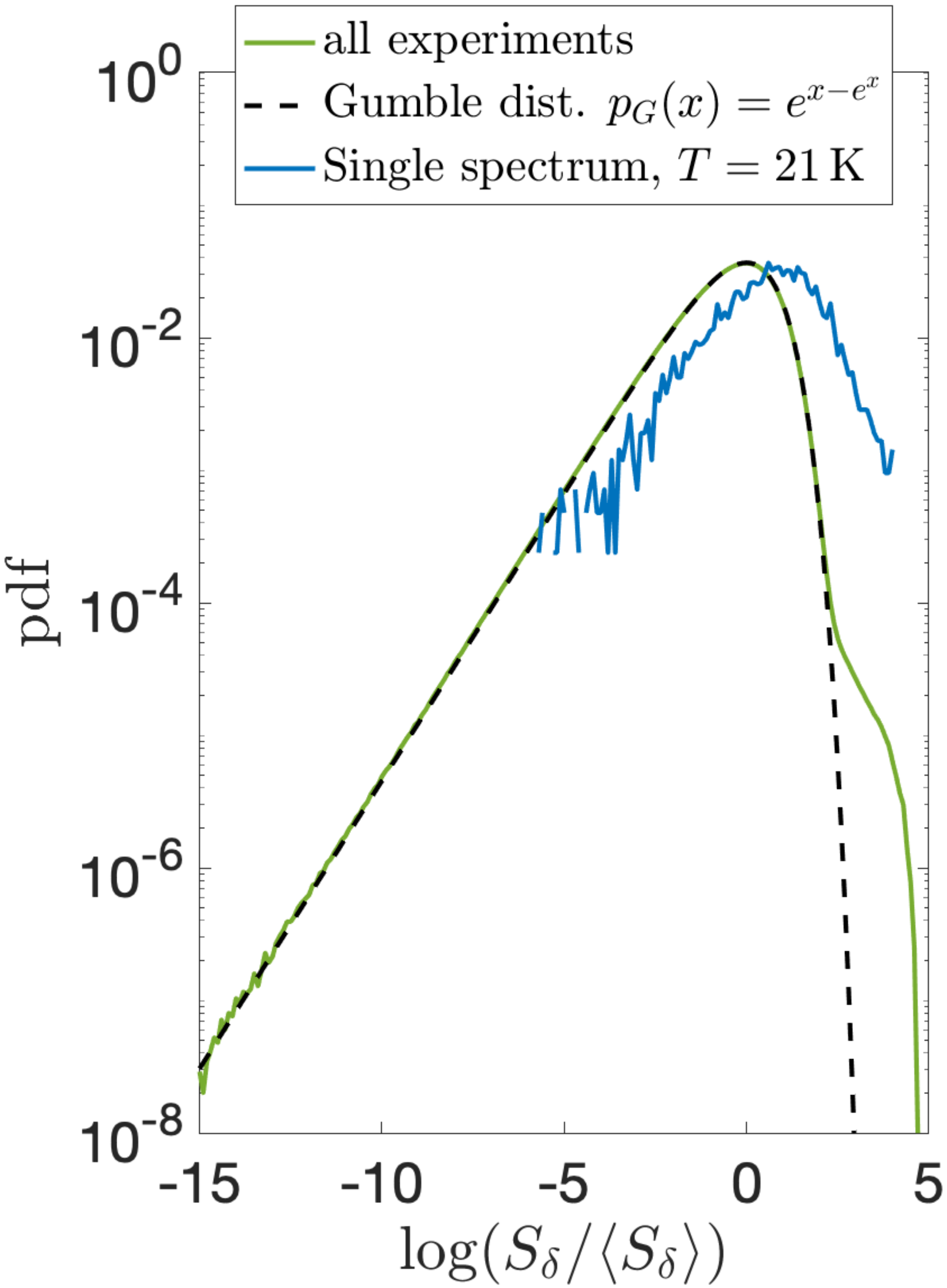
Thermal noise measurement



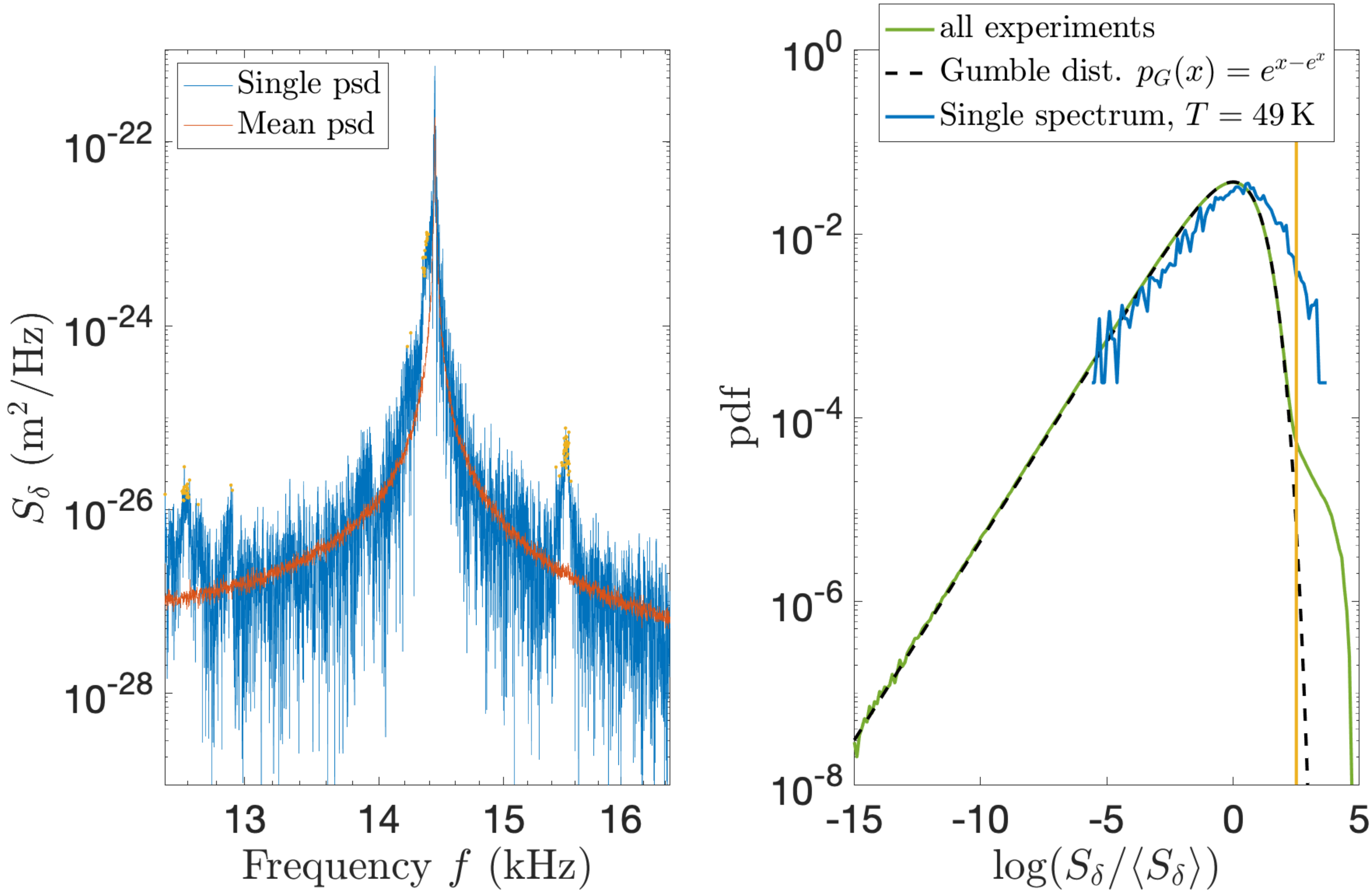


Thermal noise measurement

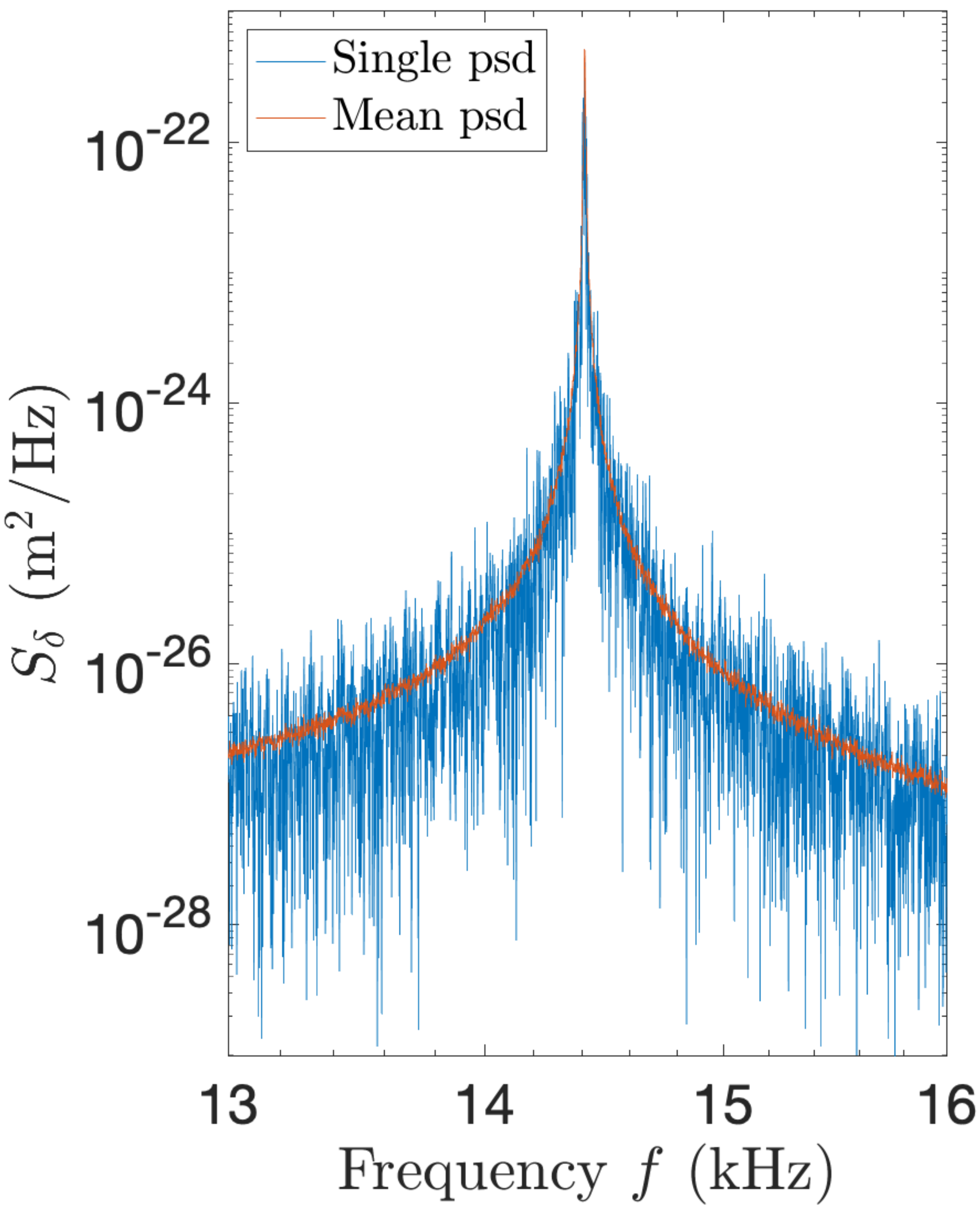


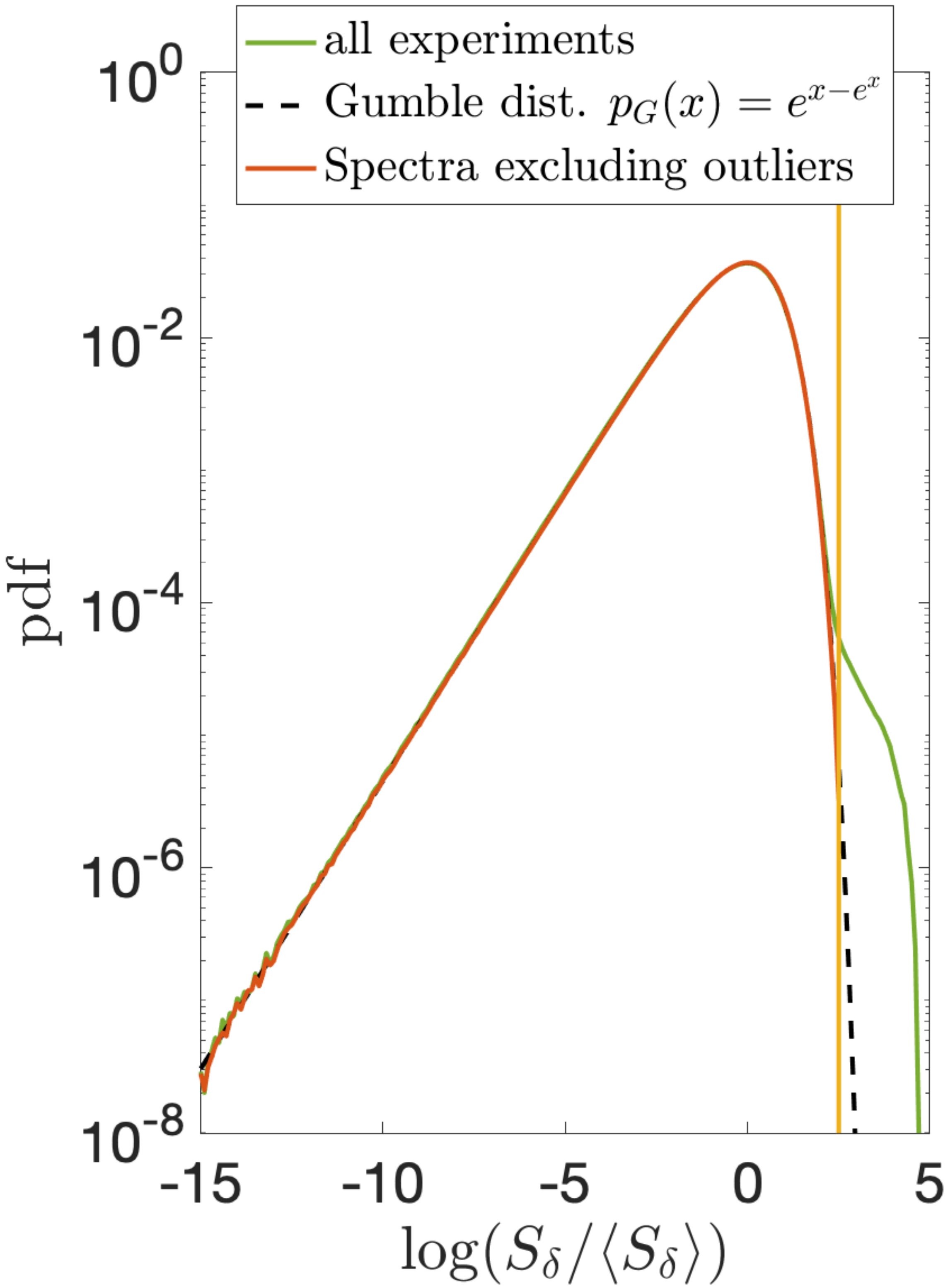


Thermal noise measurement

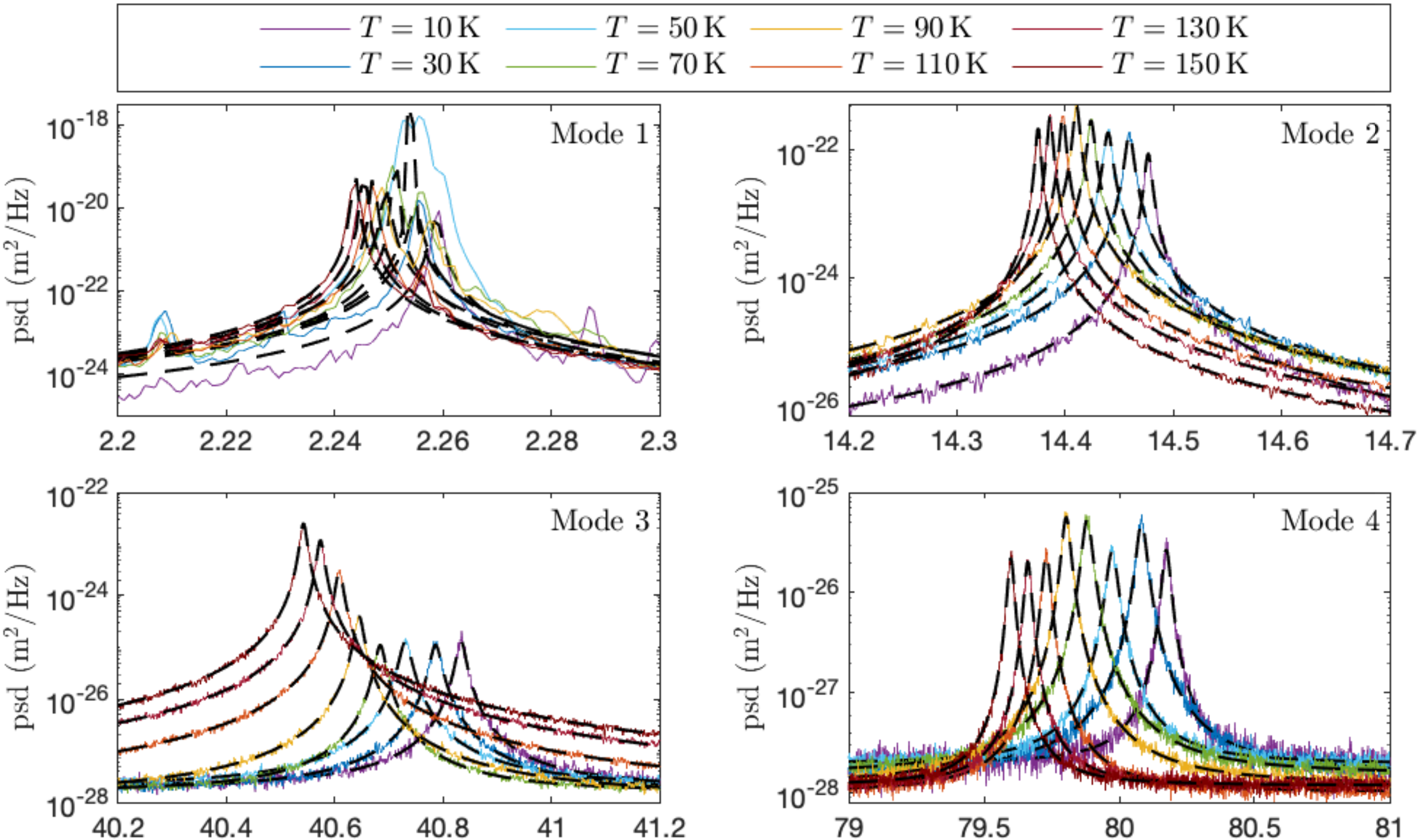


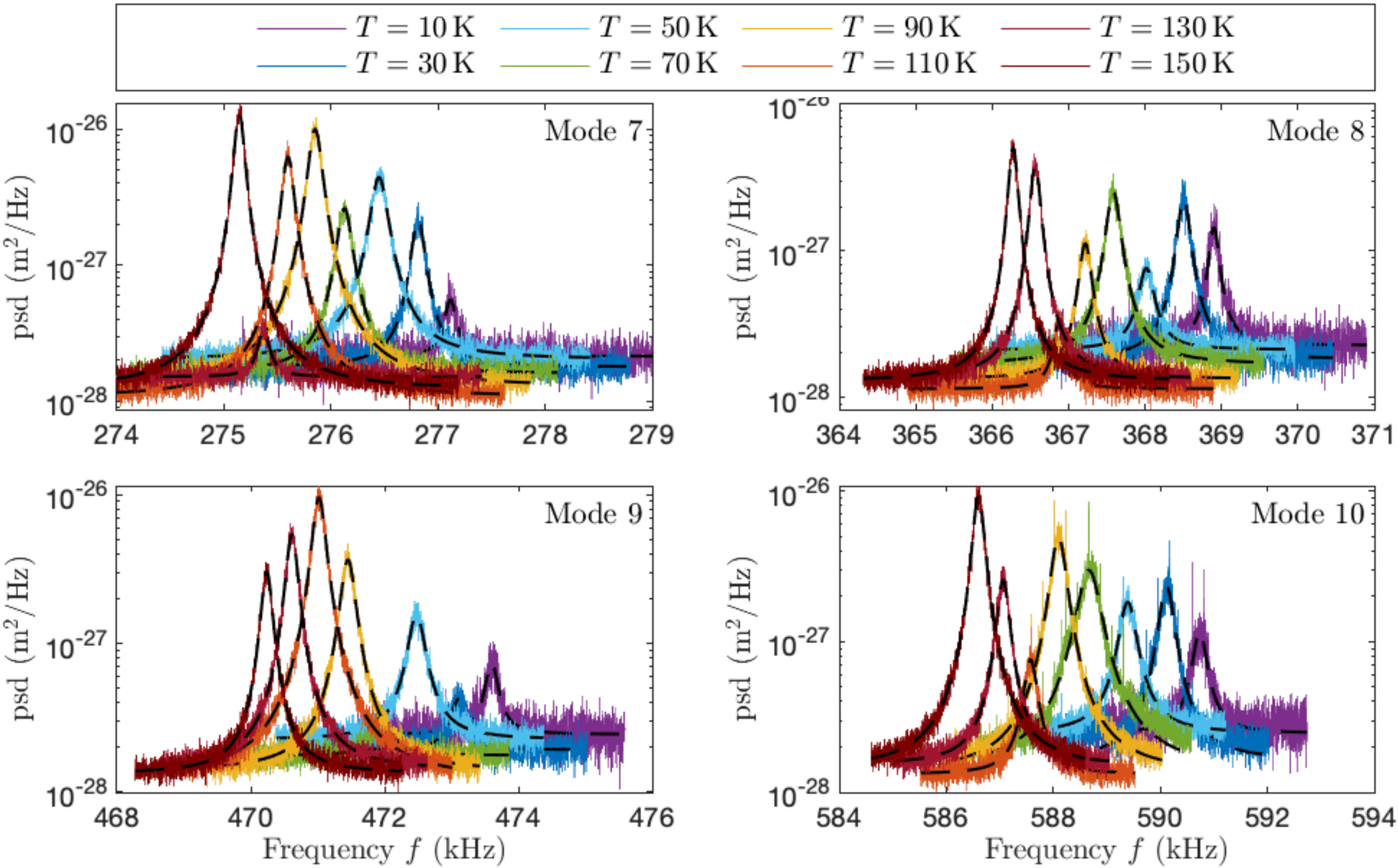
Thermal noise measurement





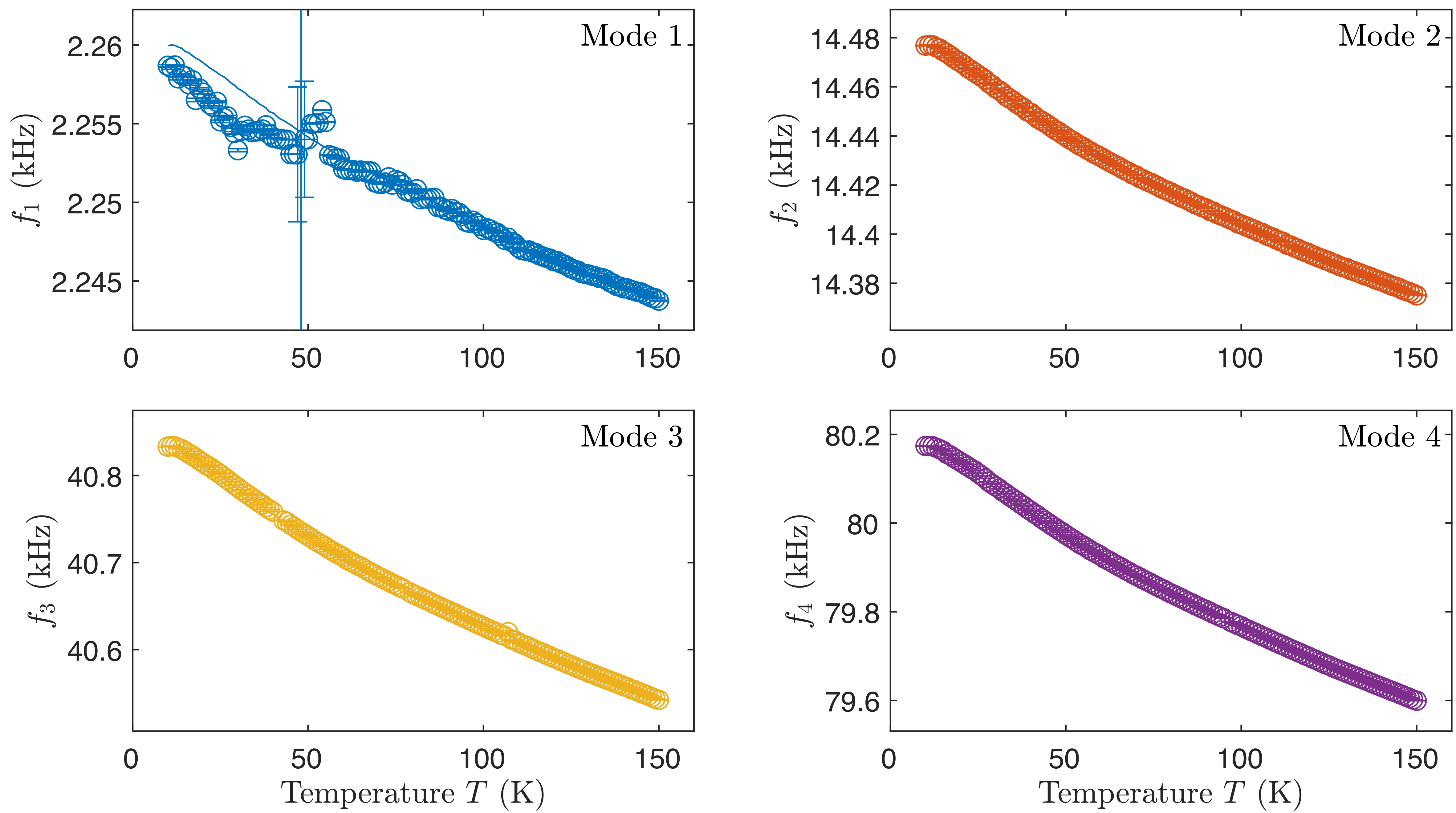
Fits of resonances





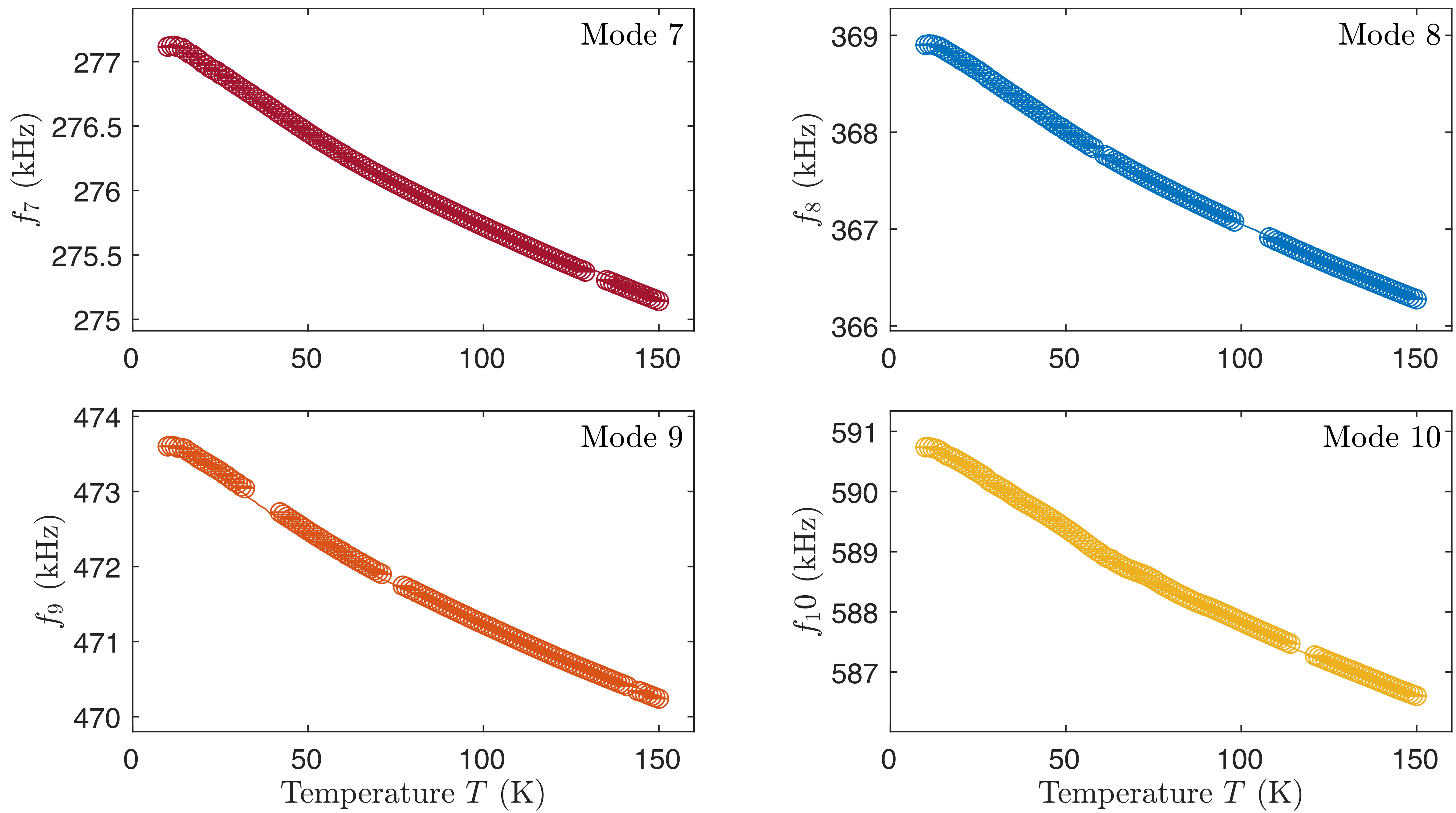
T = 10 K
T = 30 K
T = 50 K
T = 70 K
T = 90 K
T = 110 K
T = 130 K
T = 150 K
Mode 7
Mode 8
Mode 9
Mode 10
psd (m²/Hz)
Frequency f (kHz)

Resonance frequency f_n



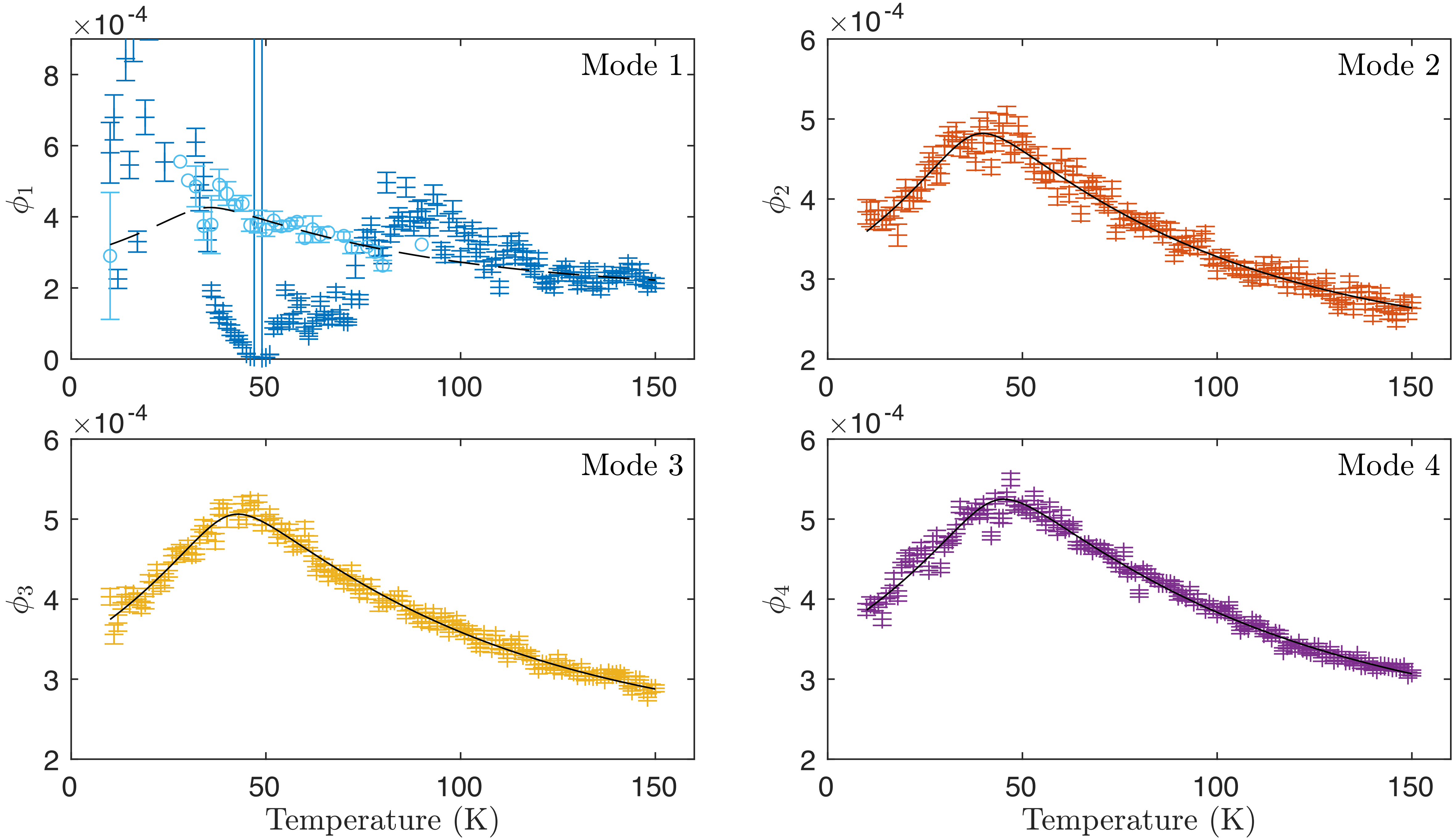
→ Young's modulus dependency on temperature

Resonance frequency f_n

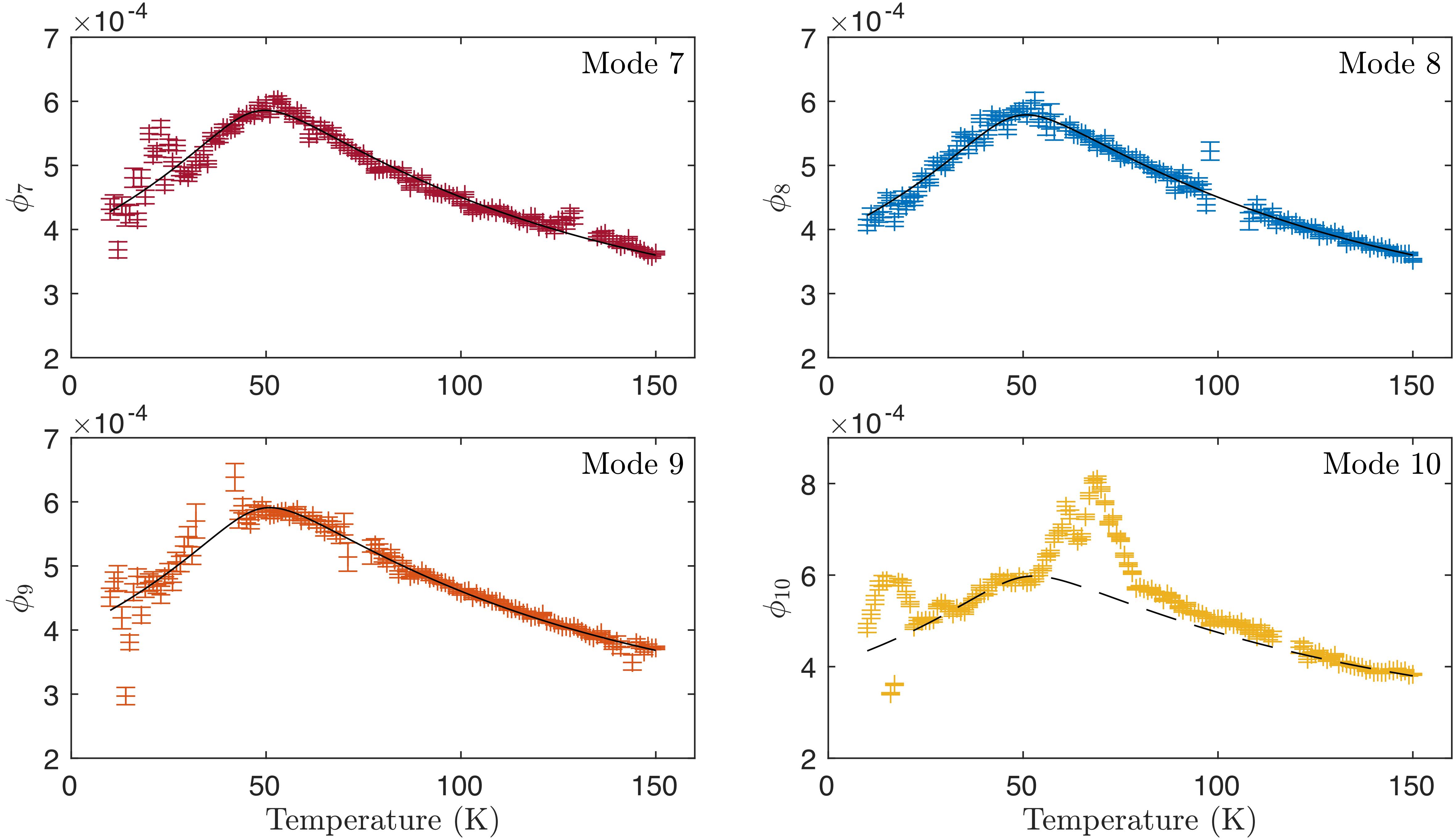


→ Young's modulus dependency on temperature

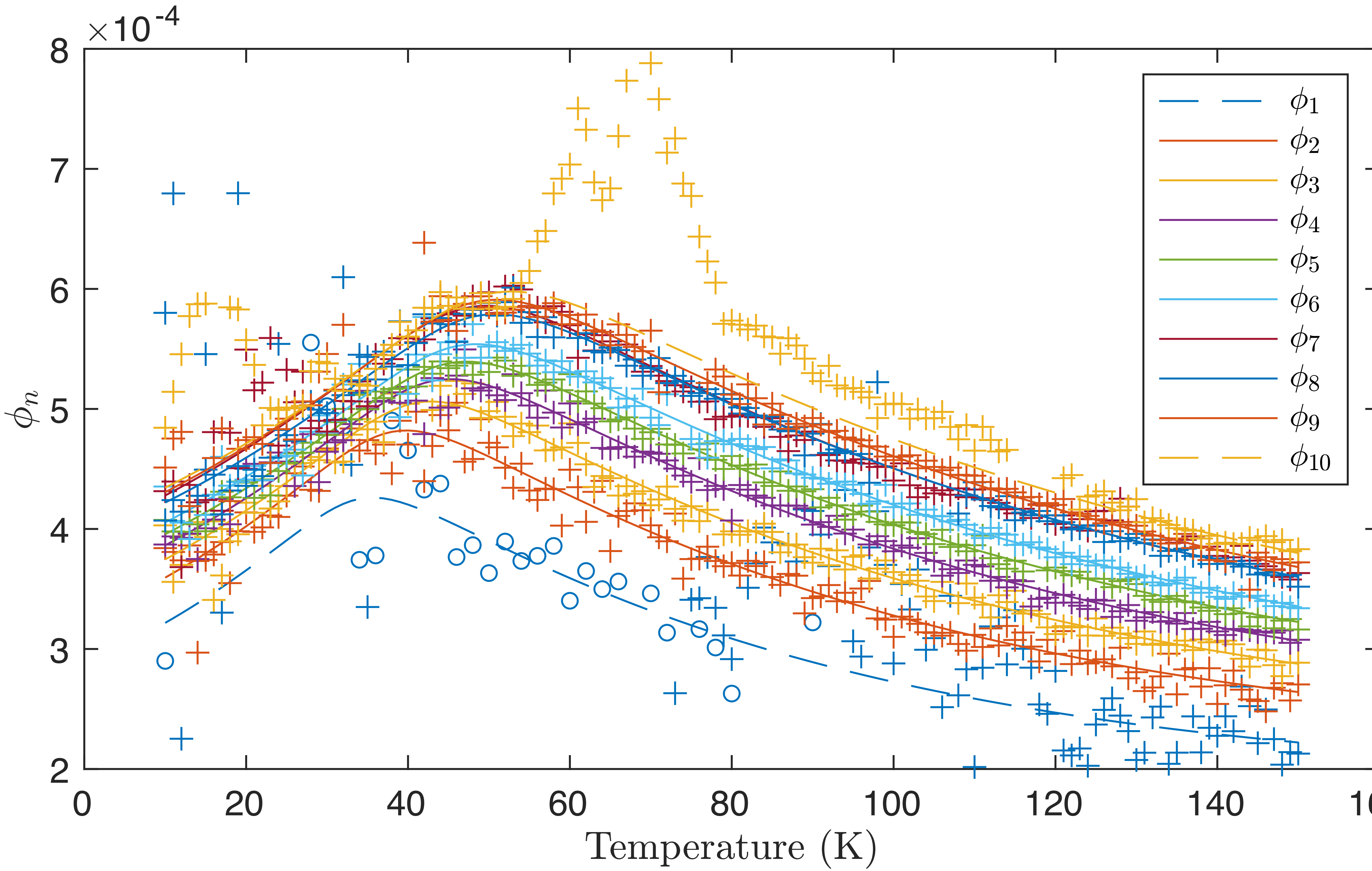
Internal damping ϕ



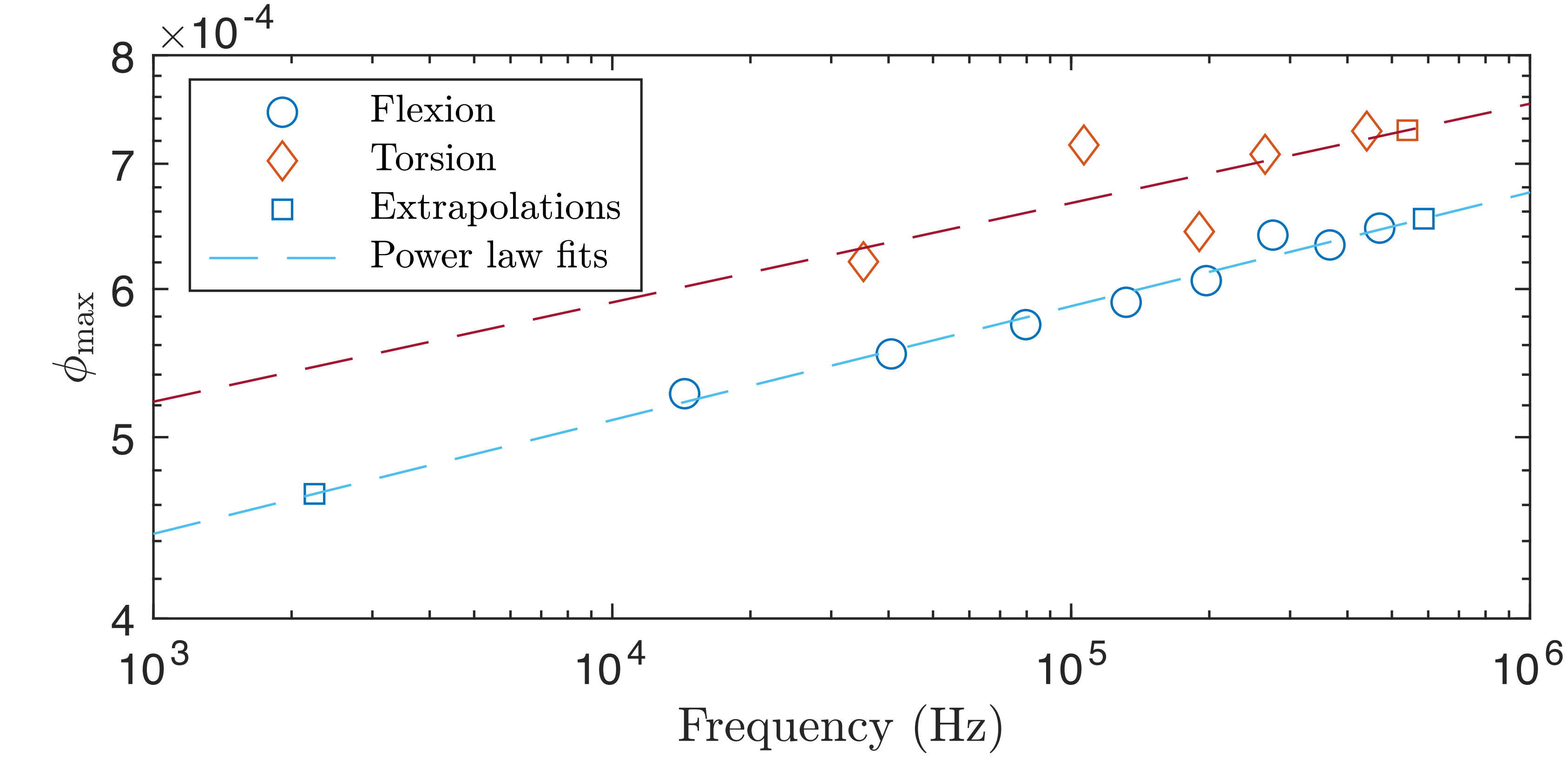
Internal damping ϕ

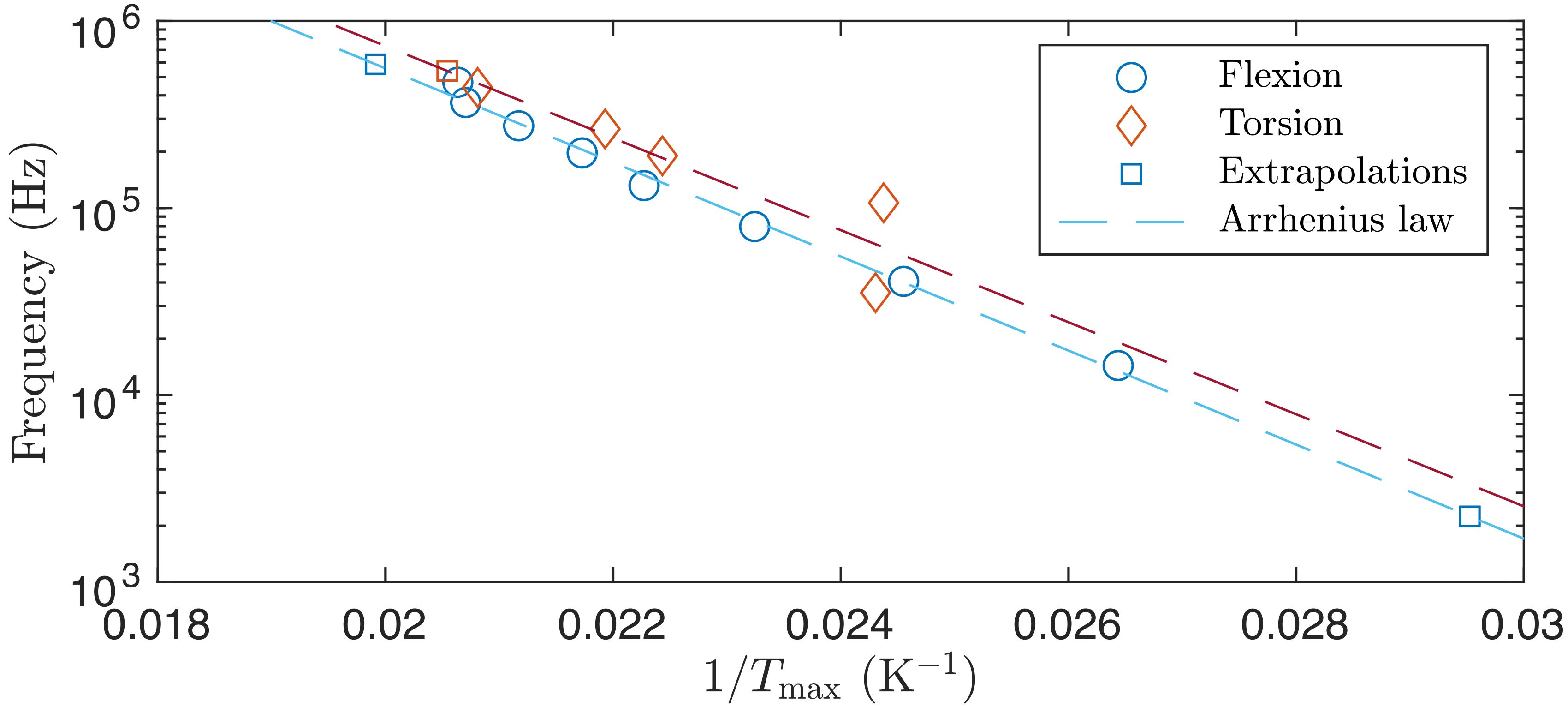


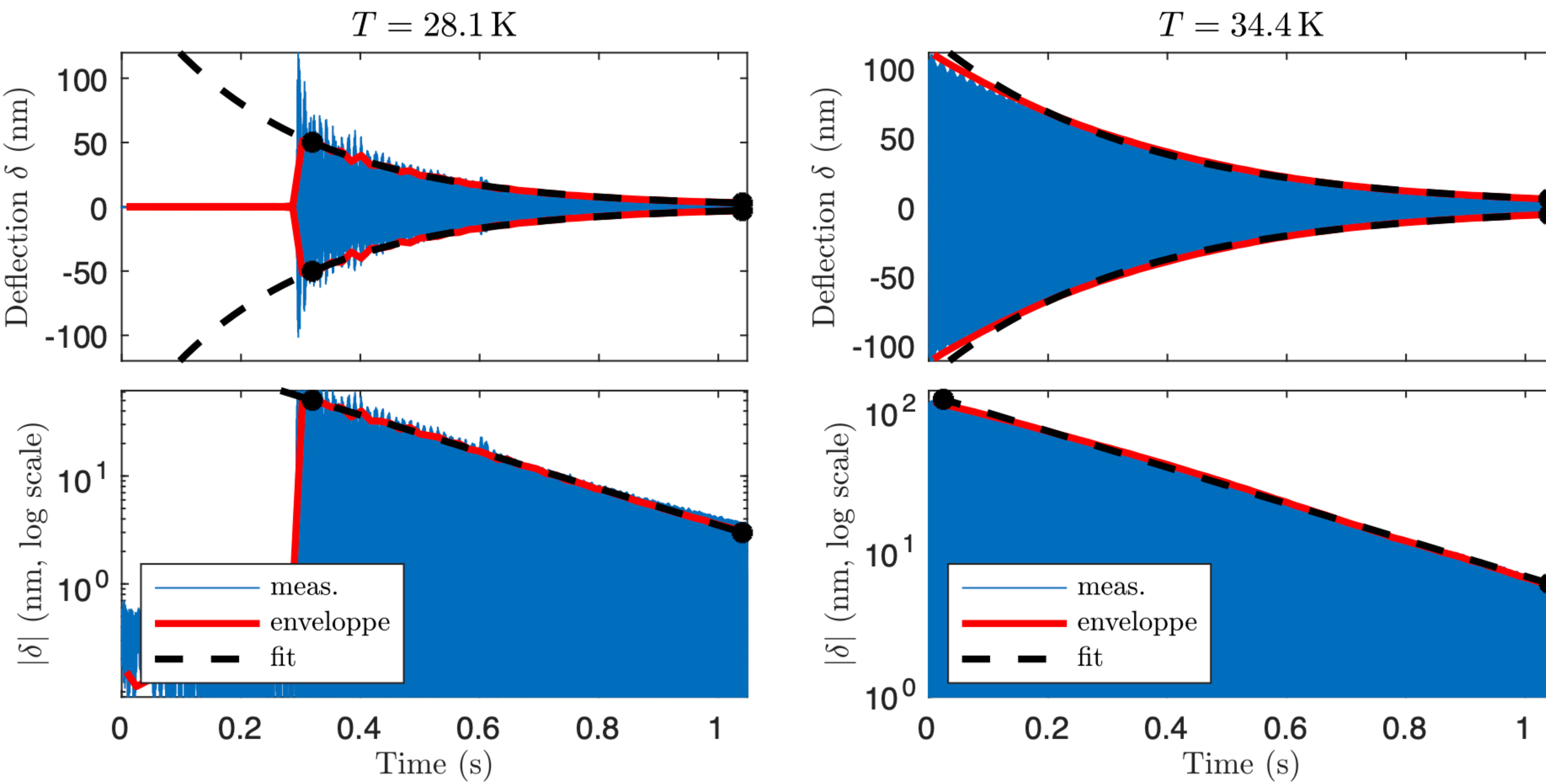
Internal damping ϕ



Internal damping ϕ

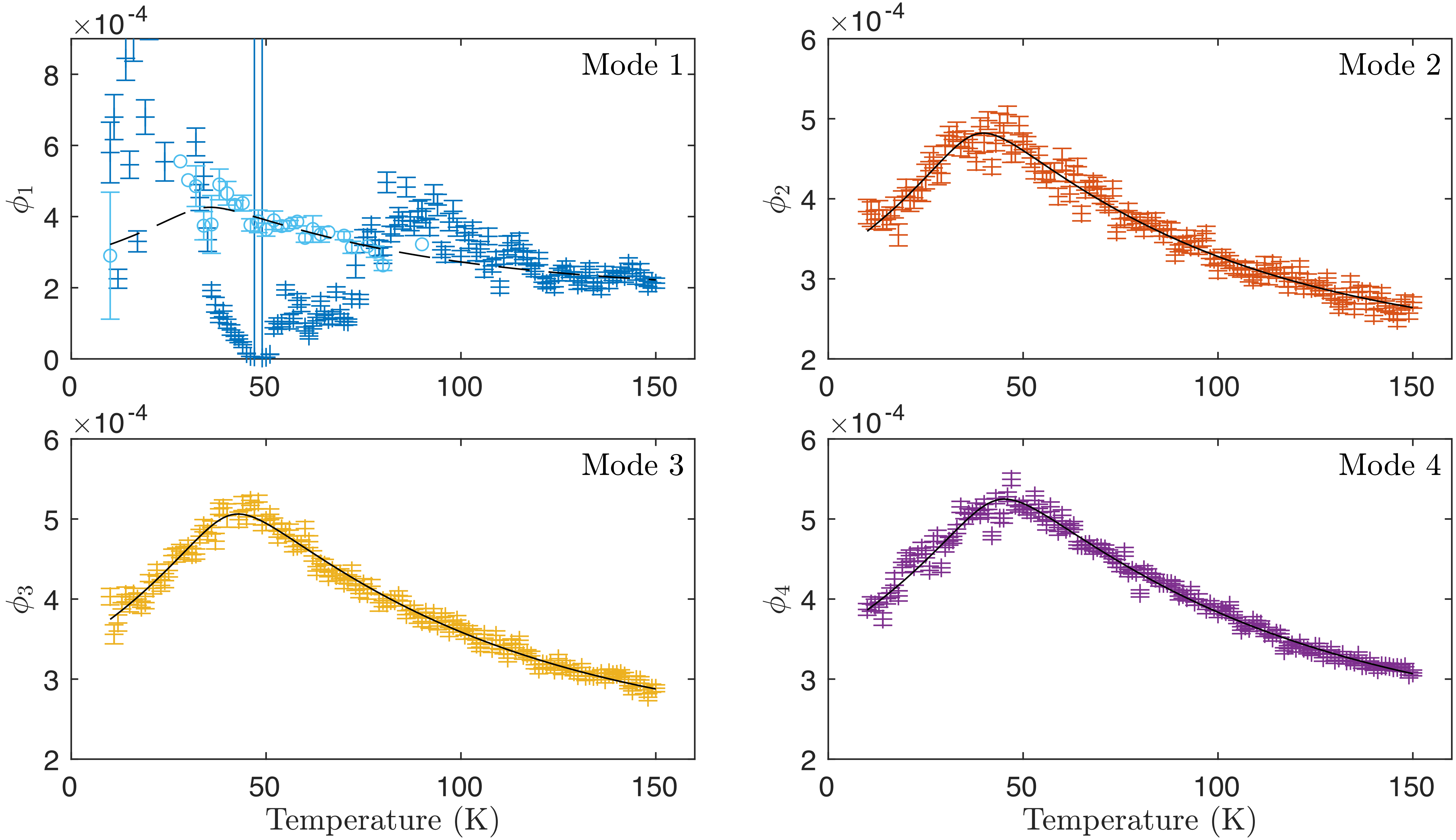




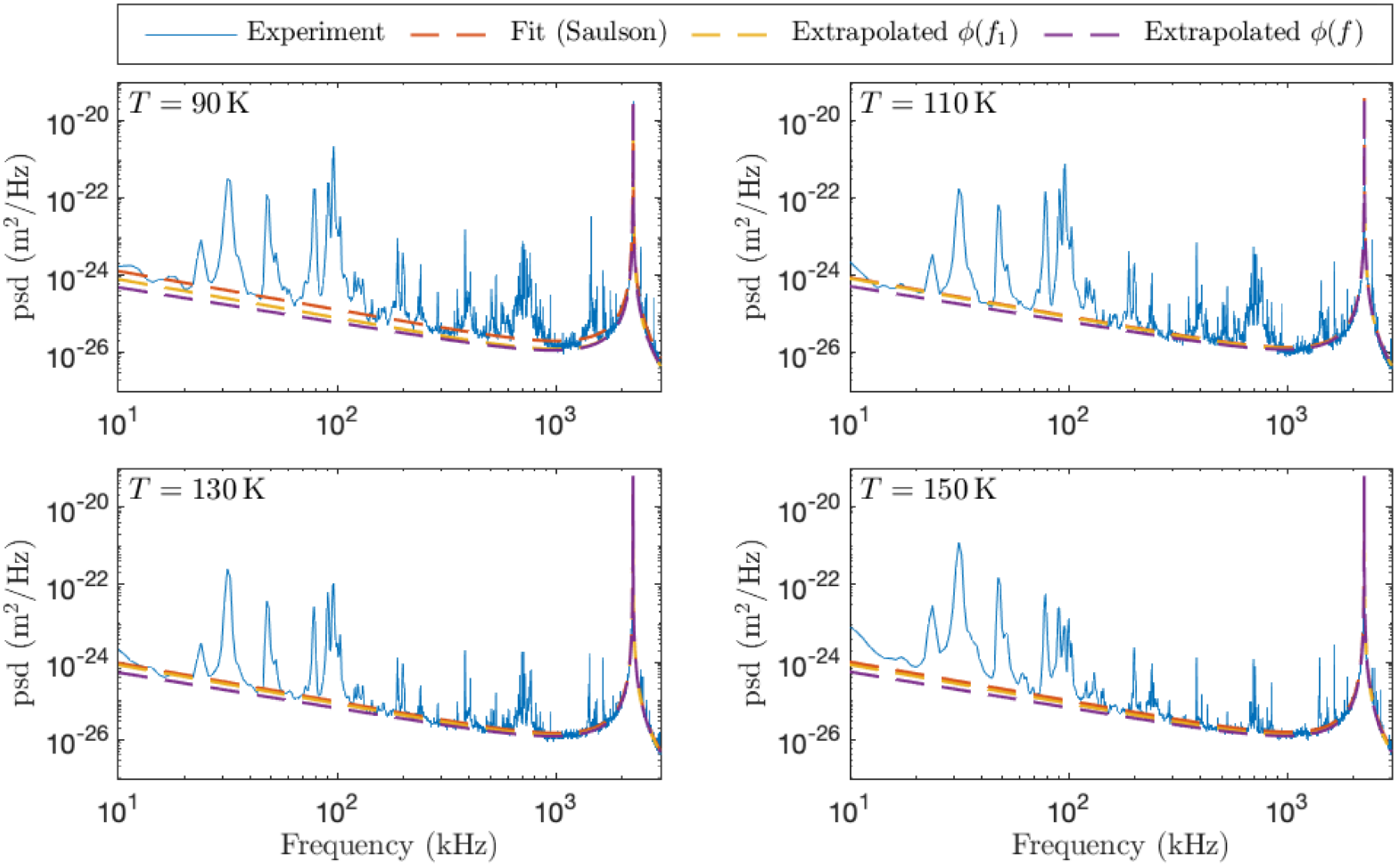


$T = 28.1\,\mathrm{K}$
$T = 34.4\,\mathrm{K}$
Deflection δ (nm)
100
50
0
-50
-100
$|\delta|$ (nm, log scale)
10^2
10^1
10^0
meas.
enveloppe
fit
0
0.2
0.4
0.6
0.8
1
Time (s)

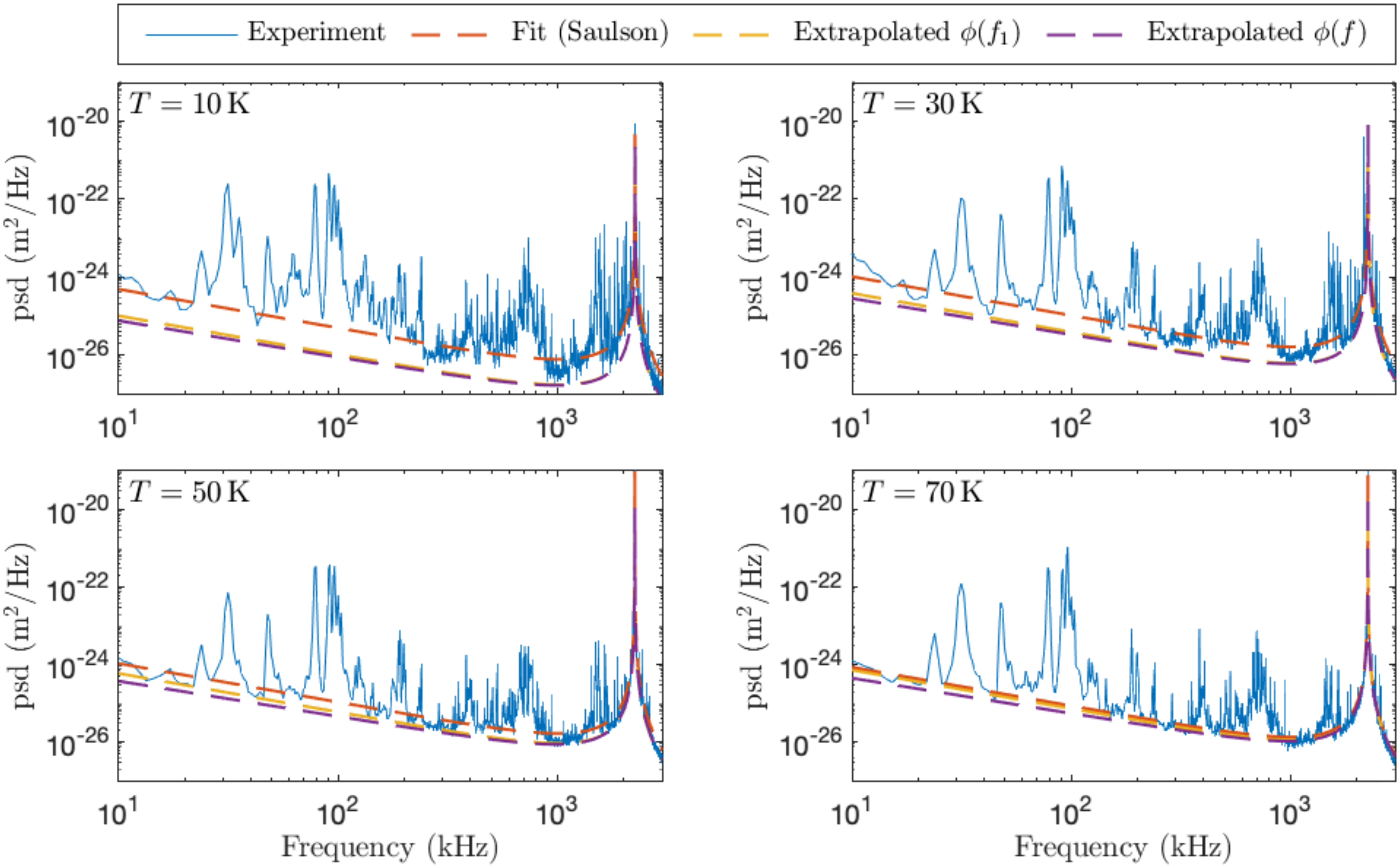
Internal damping ϕ



Low frequency behavior

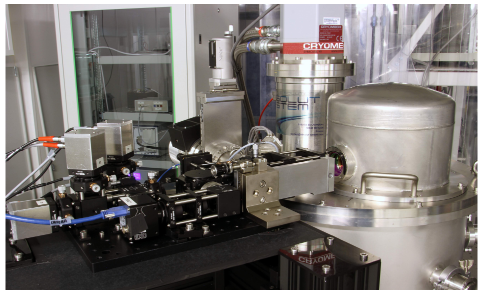


Low frequency behavior

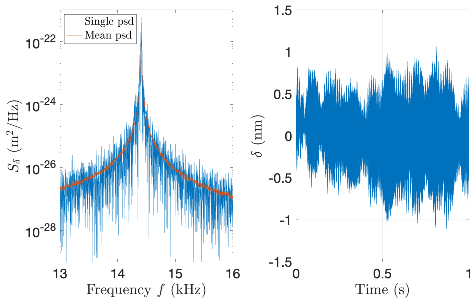


Conclusion

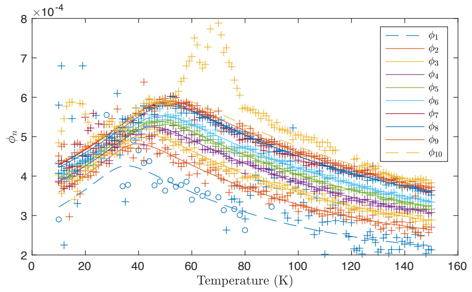
- Sample: Tantala coated cantilever



- Cryogenic differential interferometer



- Thermal noise measurement



- Measurement of internal damping

Internal damping of Ta_2O_5, more to come !