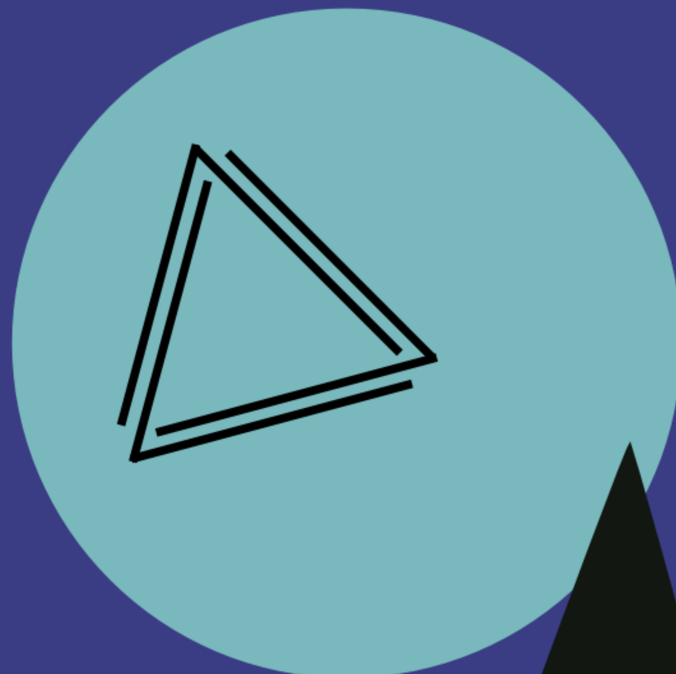
Thermo-refractive noise for E.T.



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3rd Einstein Telescope Annual Workshop

November 2010

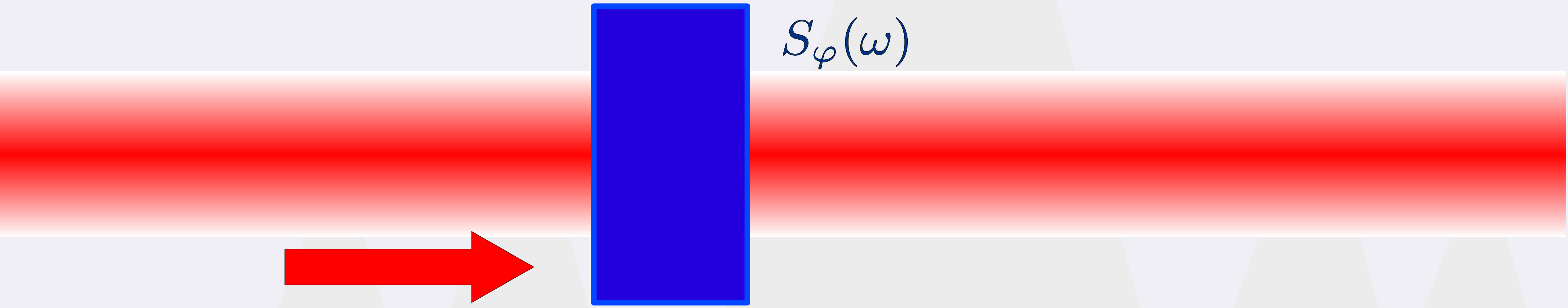
The thermorefractive noise

Quick history:

- First derived by Braginsky[1]
- Then confirmed (and extended) by Levin[2]

Origin:

- Random fluctuations of temperature in the substrate
- Induced phase fluctuations for the **transmitted** beam



[1] *Physics Letters A* 324 (2004) 345–360
[2] *Phys. Rev. D* 80 (2009) 062004

Parameters and formula

How the PSD phase noise looks like ?

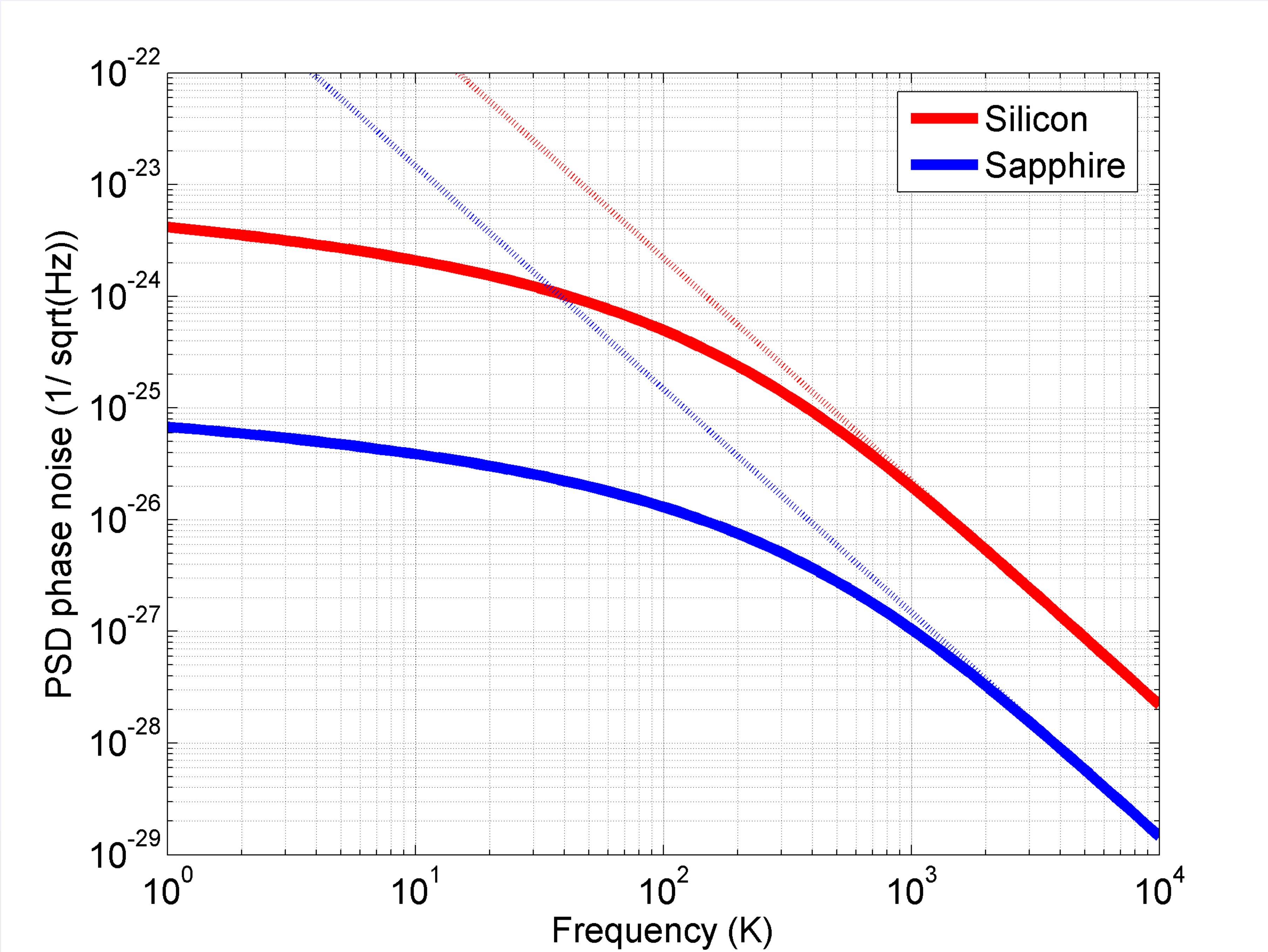
$$S_\varphi(\omega) = \frac{4\beta^2 k^2 l k_B T^2 \kappa}{\pi\left((C\rho)^2 r_0^4 \omega^2\right)}$$

(adiabatic approximation)

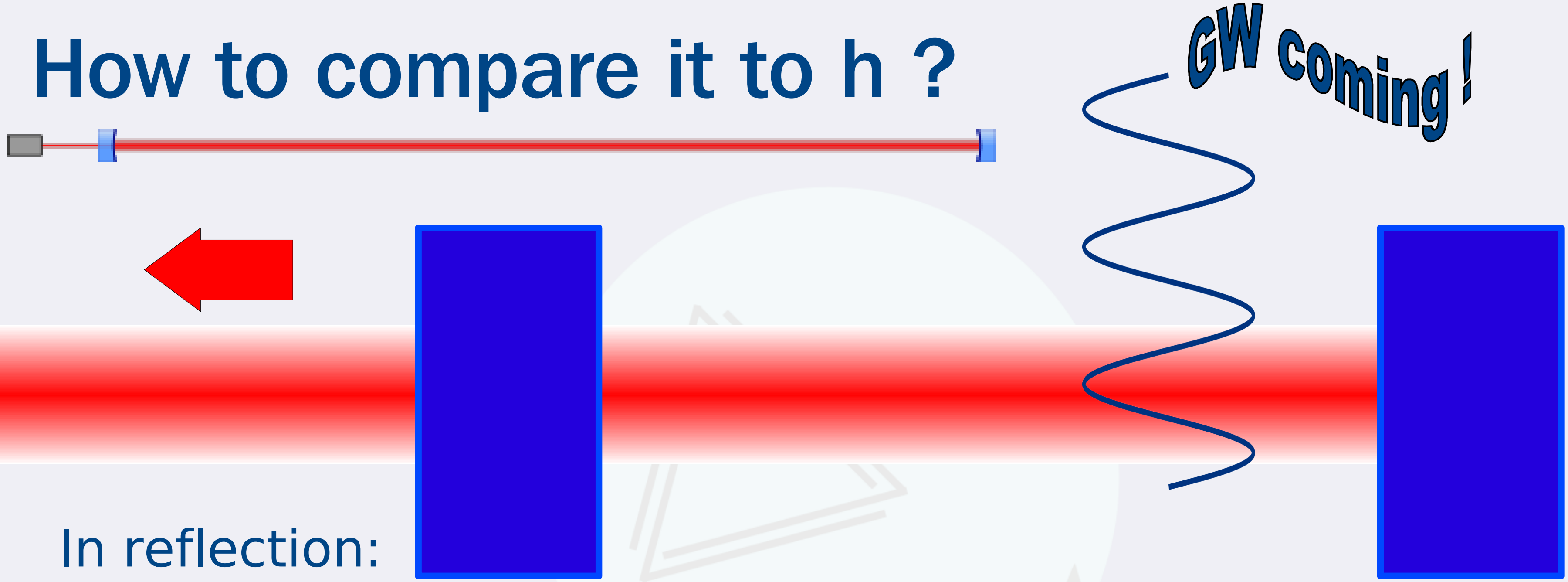
with:

			material dependent ?
β		thermo-optic coefficient	✓
k	$= 2\pi/\lambda$	the wave number	
κ		the thermal conductivity	✓
l		the length of the substrate	
T		the temperature	
C		the specific heat	✓
ρ		the density	✓
r_0		the beam radius	
ω		the angular frequency	

Silicon vs sapphire at 10 K



How to compare it to h ?



In reflection:

$$\sqrt{S_{\varphi}(\omega)}$$ amplitude thermo refractive phase noise

$$+$$

$$\phi_h(\omega)$$ phase change due to GW signal

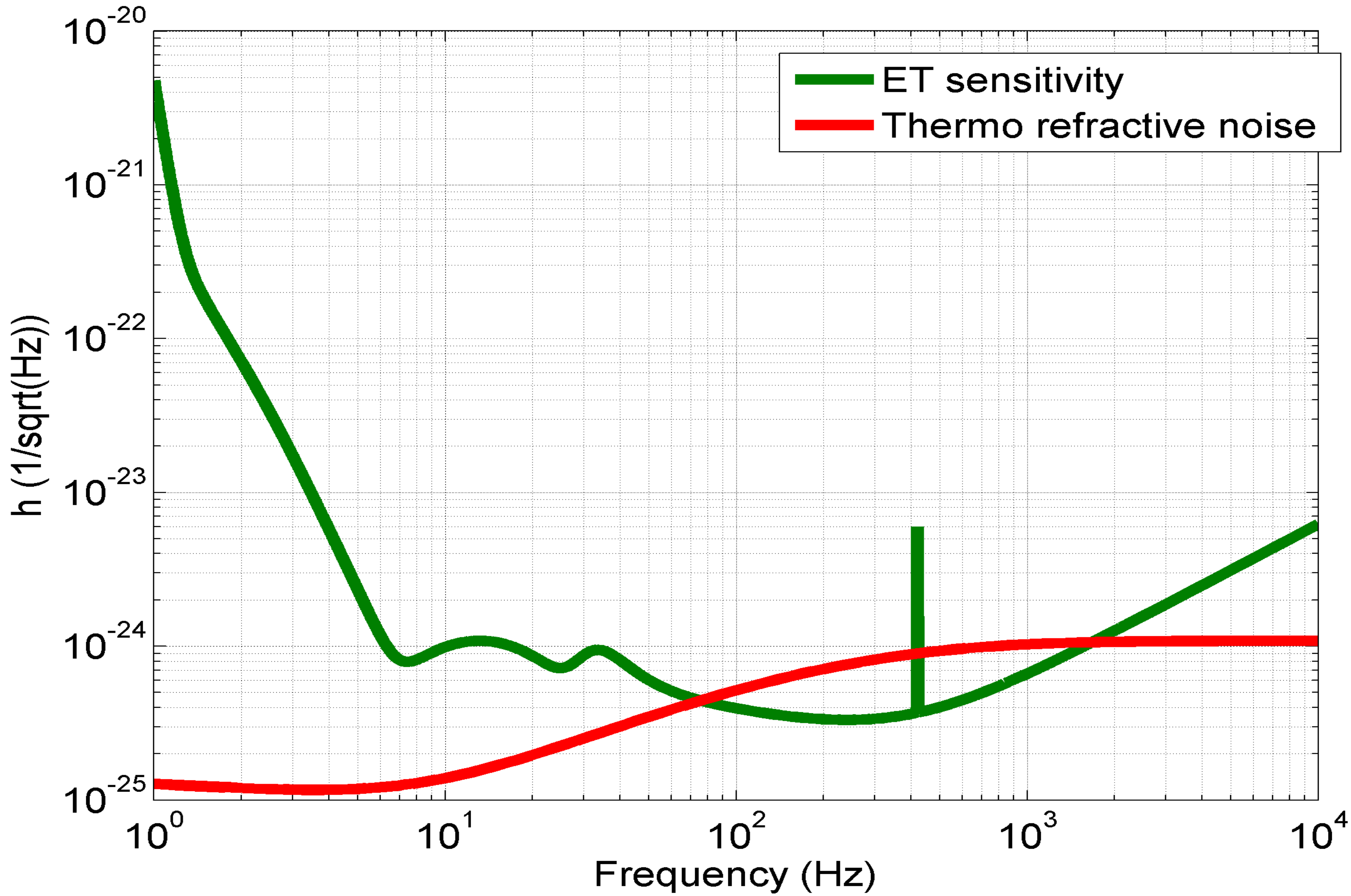
$$\phi_h(f) = \frac{4\pi}{\lambda}\frac{2F}{\pi}\frac{1}{\sqrt{1+(f/f_c)^2)}}hL$$

To be able to measure the GW signal, we must have:

$$\phi_h(\omega) \gg \sqrt{S_{\varphi}(\omega)}$$

Related to h

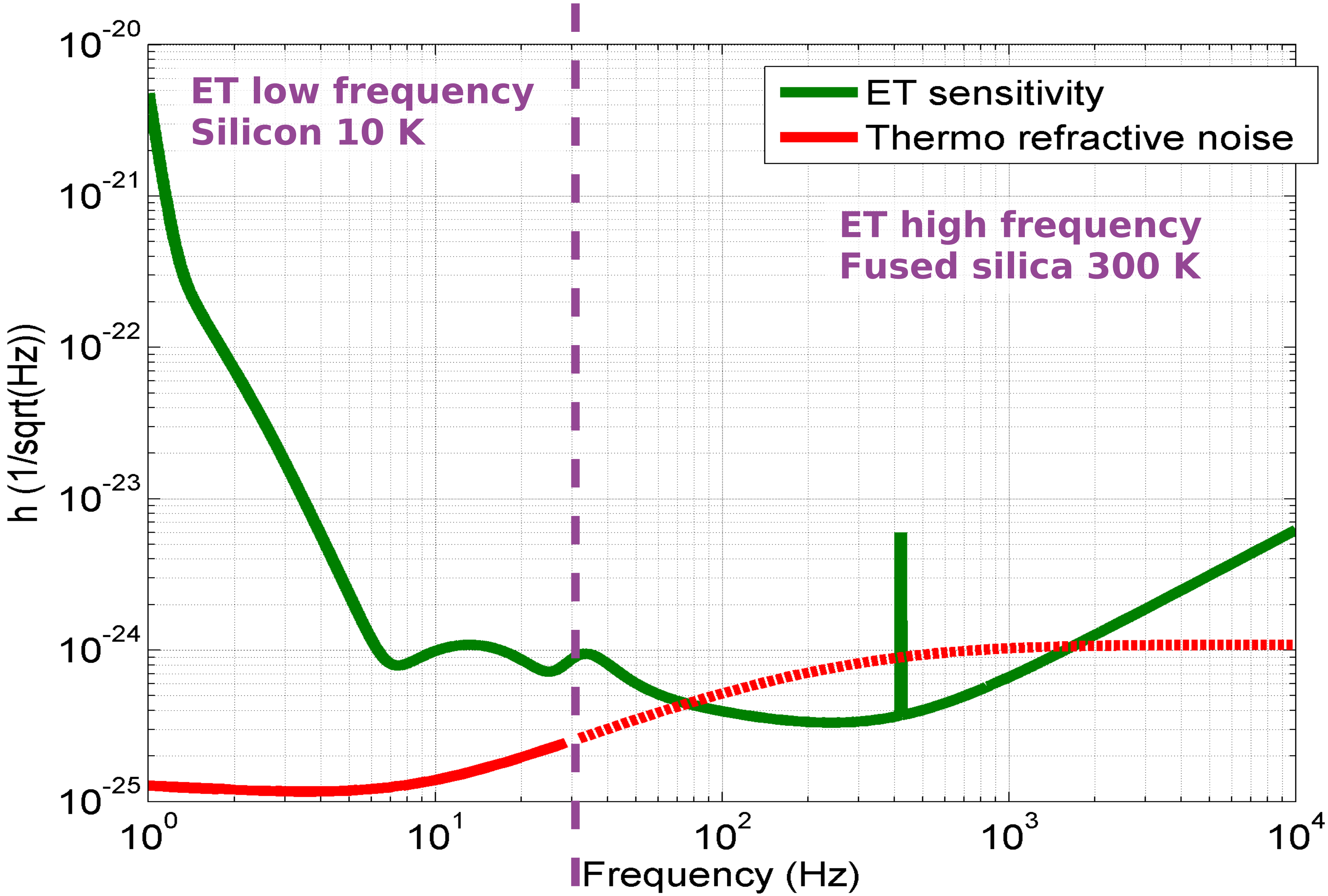
For silicon mirrors at 10K[1]



[1] Class. Quantum Grav. (2010) 27 015003

Related to h

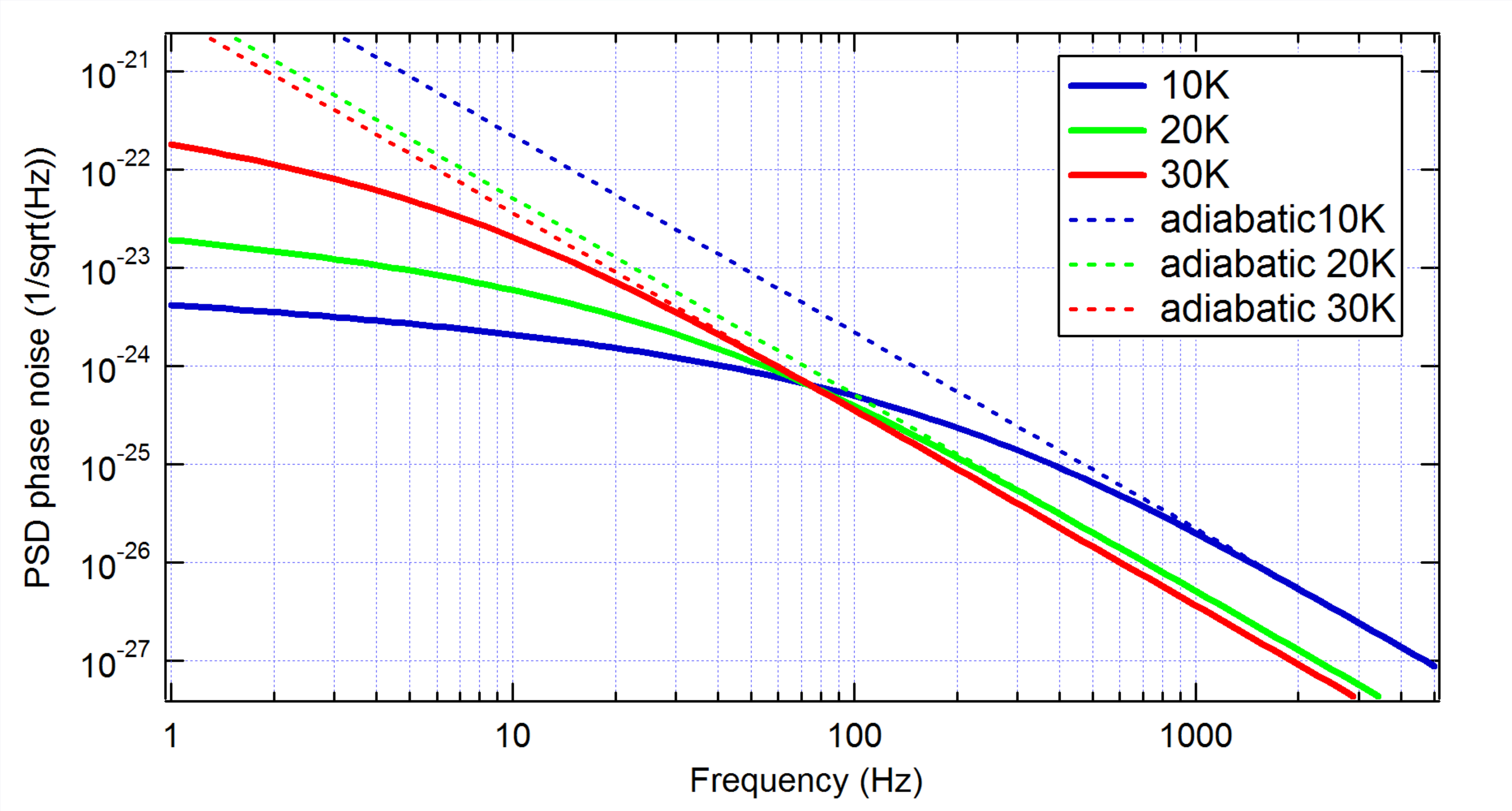
Wait! we have a xylophone[1]...



[1] *Class. Quantum Grav.* (2010) 27 015003

Changing the temperature

For silicon mirrors



$\beta(10\text{K}) = 1 \times 10^{-6}$ $\beta(20\text{K}) = 2 \times 10^{-6}$ $\beta(30\text{K}) = 5.8 \times 10^{-6}$

The thermo-optic coefficient (also known as dn/dT)

One of the least known parameter! because:

- it is for cryogenic temperature (10K)
- it is extremely small
- it is wavelength dependent

For sapphire, use an upper limit:

$$\beta = 9 \times 10^{-8}\ [1/\mathrm{K}]$$

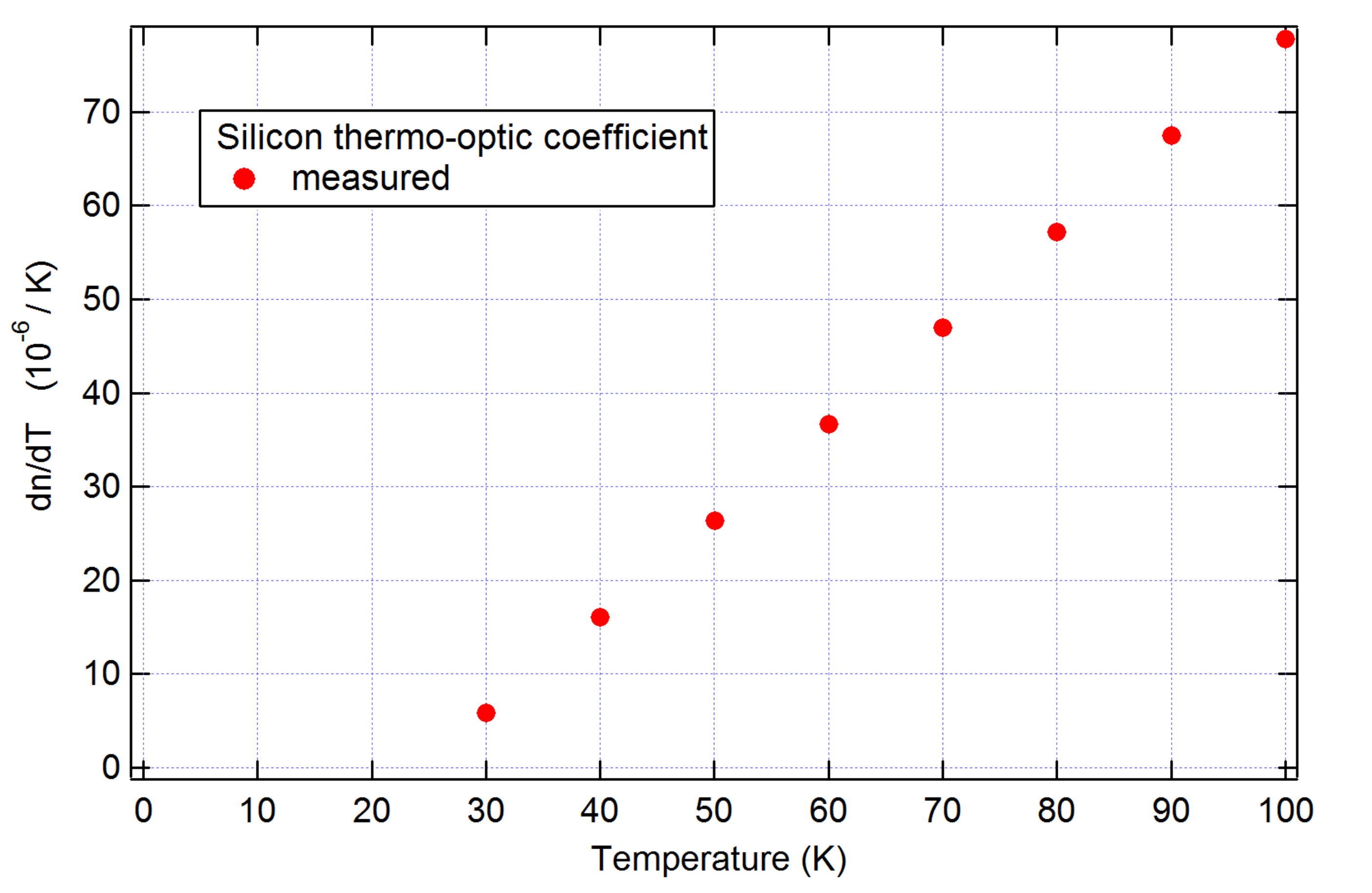
measured for sapphire LCGT research[1]

[1] *Class. Quantum Grav.* (2002) 19 2045

Silicon thermo-optic coefficient

Coefficient value critical since the noise may be close to be limiting.

Measured up to 30K[1]

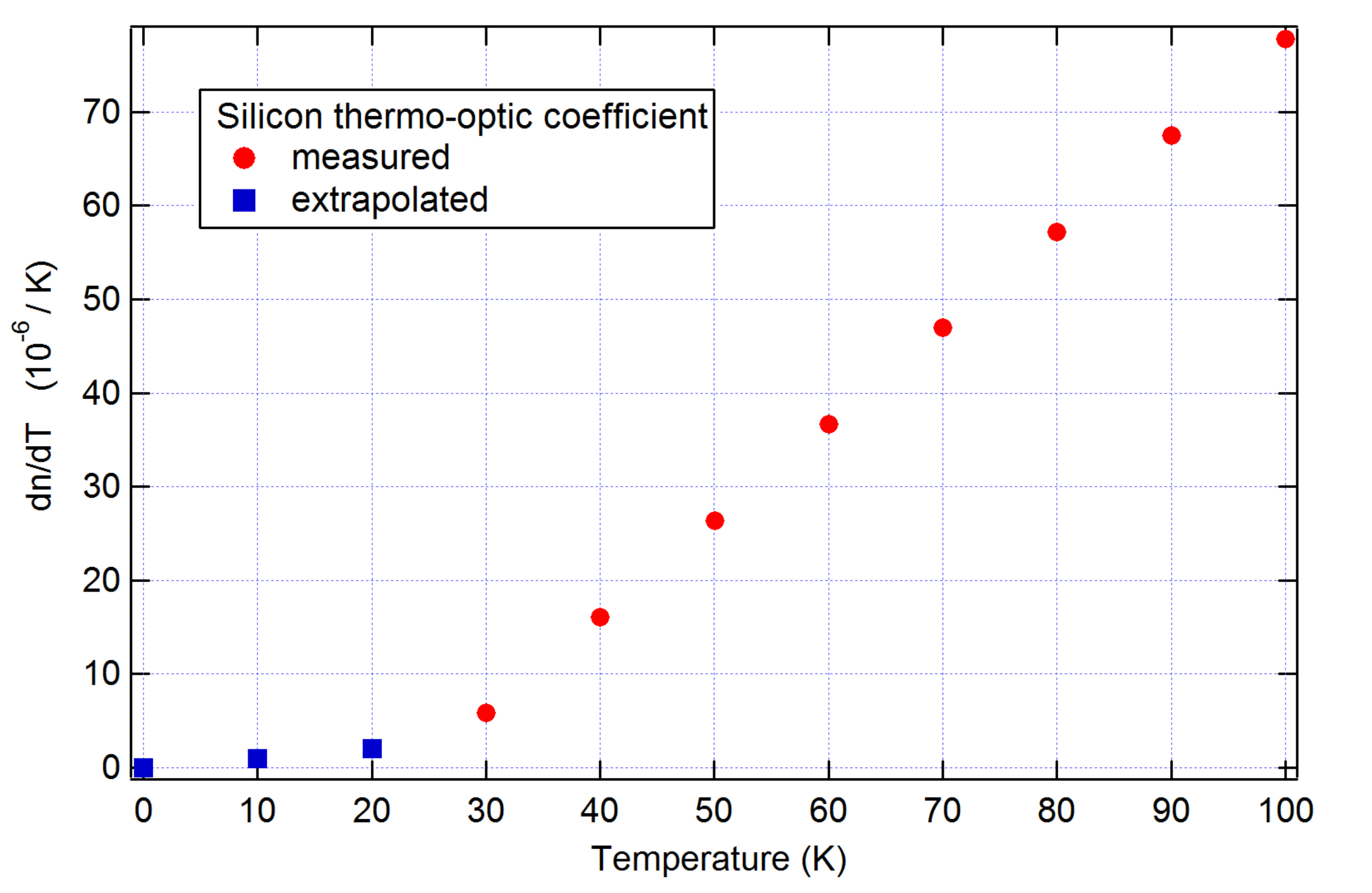


[1] Proc. SPIE (2006) Vol. 6273, 62732J

Silicon thermo-optic coefficient

Coefficient value critical since the noise may be close to be limiting.

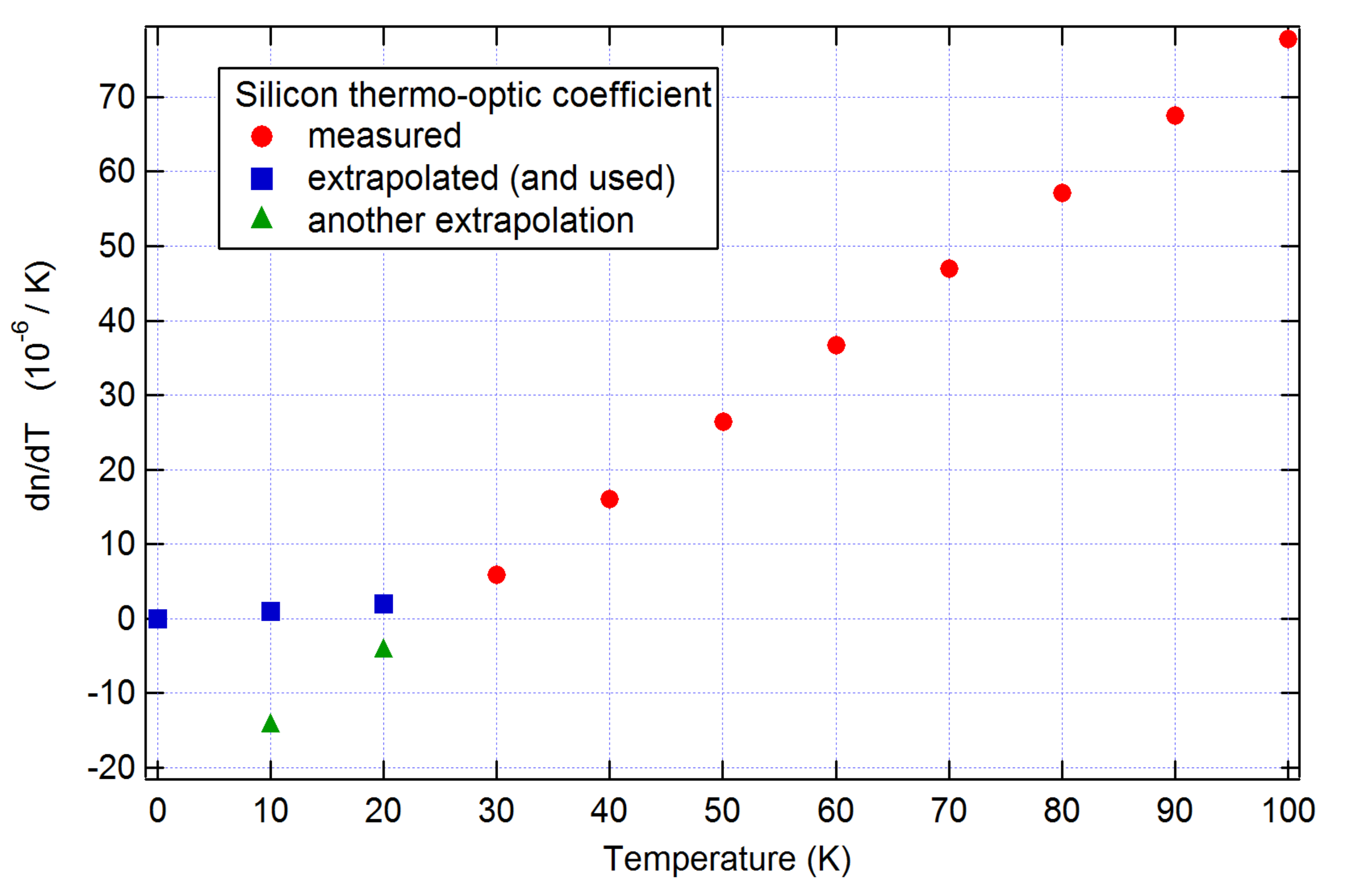
A possible extrapolation



Silicon thermo-optic coefficient

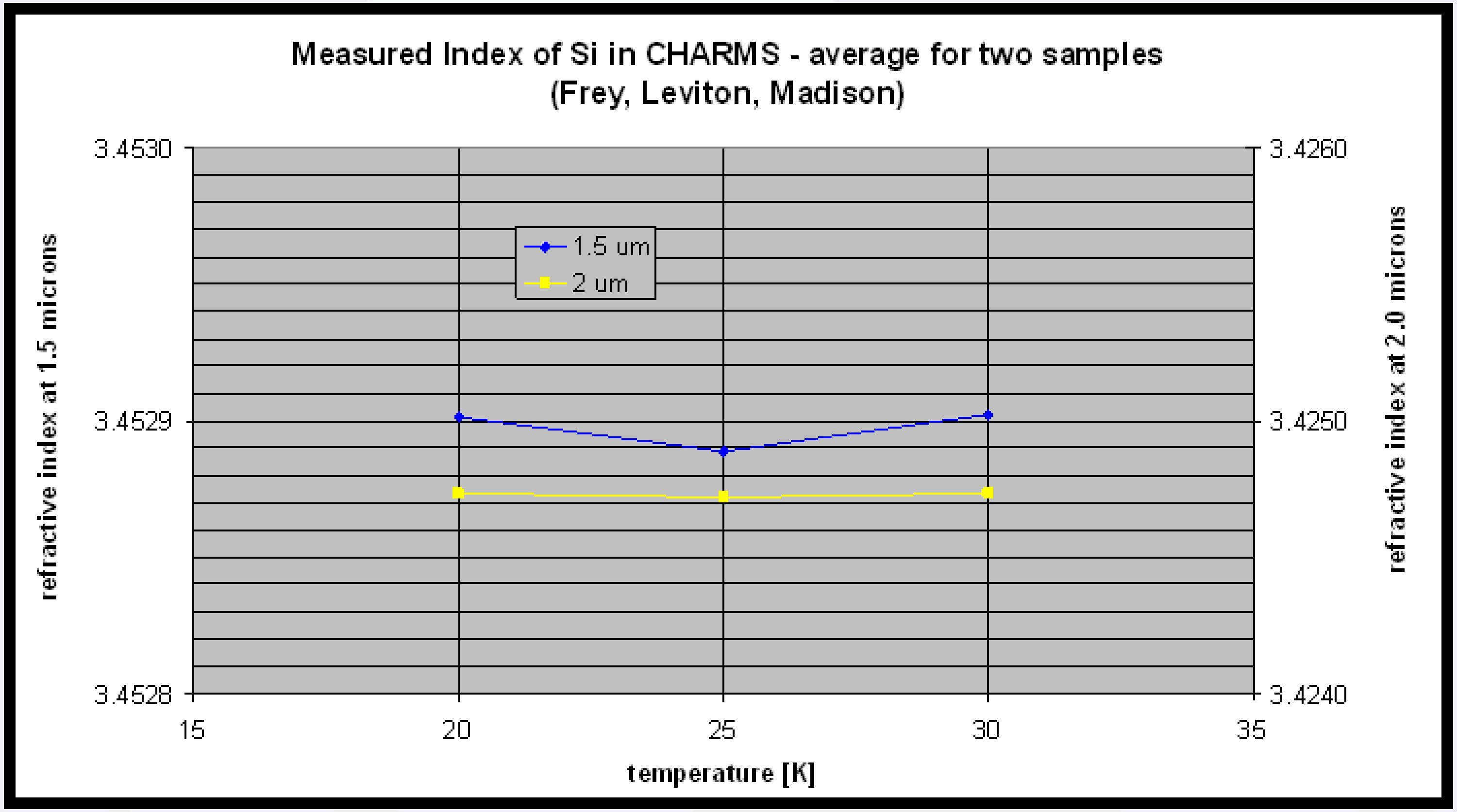
Coefficient value critical since the noise may be close to be limiting.

Another extrapolation:



Silicon thermo-optic coefficient

Raw data from the authors of the publication[1]:

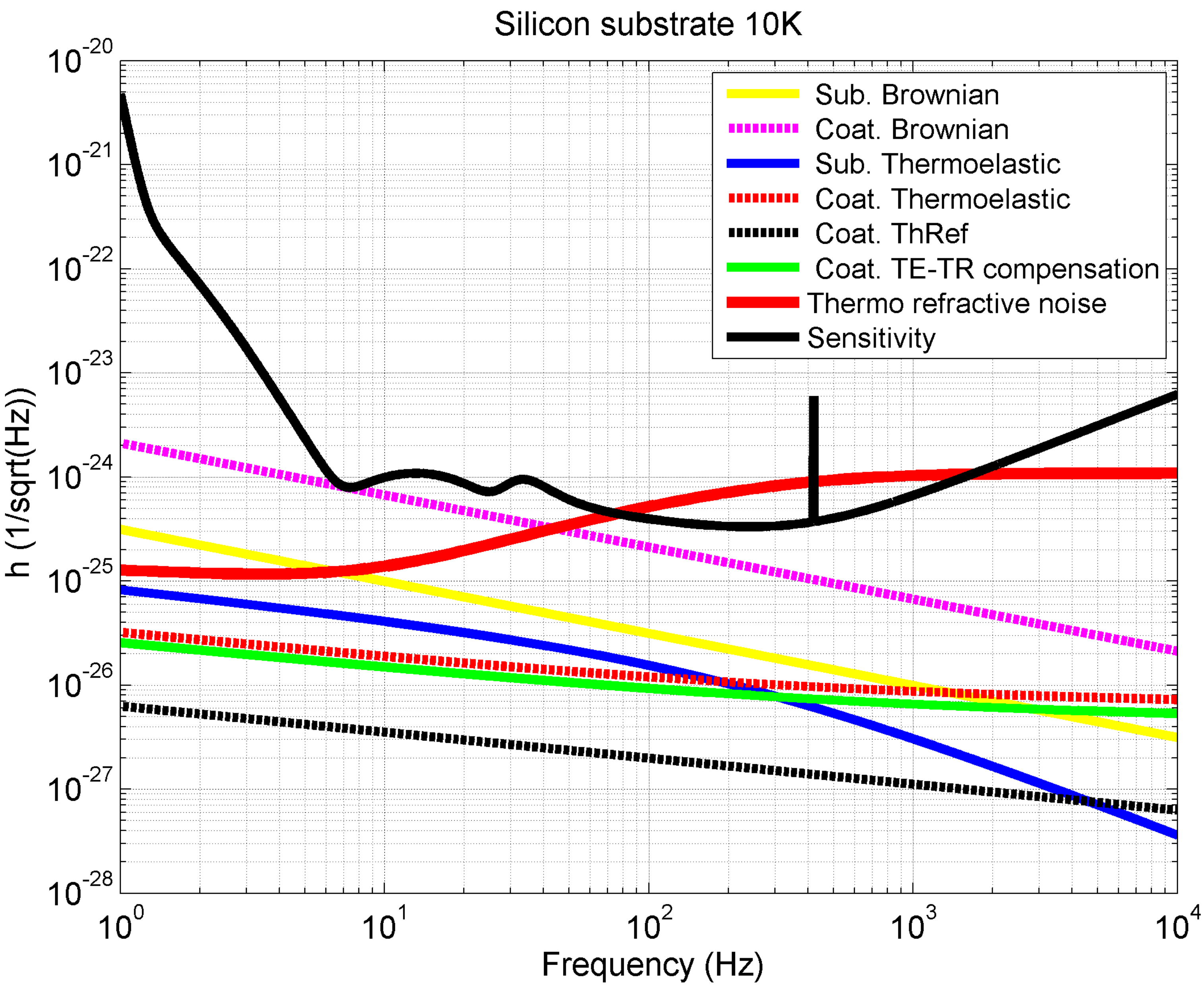


Accuracy of measurement: 0.0001

- Sweet spot around 25 K (dn/dT = 0)
- dn/dT higher than expected at 10 K

[1] Proc. SPIE (2006) Vol. 6273, 62732J

Other thermal noise



Plot with ET-B/C parameters
Coating loss angle:

$$\phi_{SiO_2} = 5 \times 10^{-4}$$

$$\phi_{Ta_2O_5} = 3.8 \times 10^{-4}$$

Conclusion

- A new addition to ET thermal noise inventory: the transmissive thermo-refractive noise

- Noise to be monitored and will fluctuate in the coming years

- Also concerns the beam splitter