Squeezing for GW Interferometers

and

Servo Enhanced Cooling in a Optomechanical System

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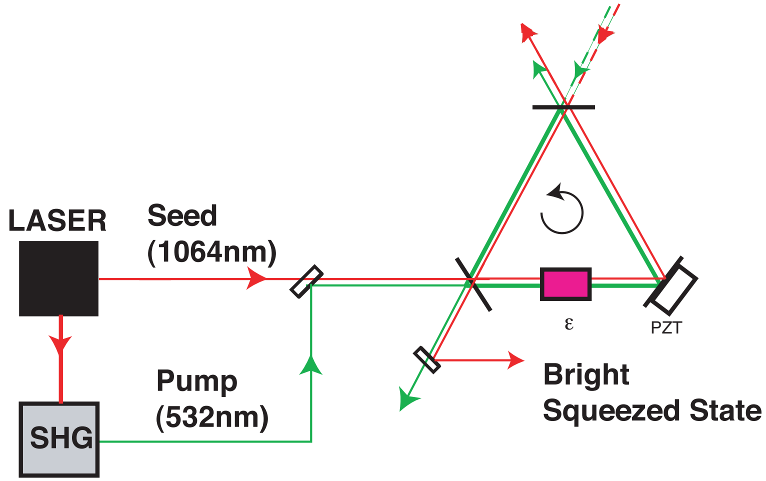
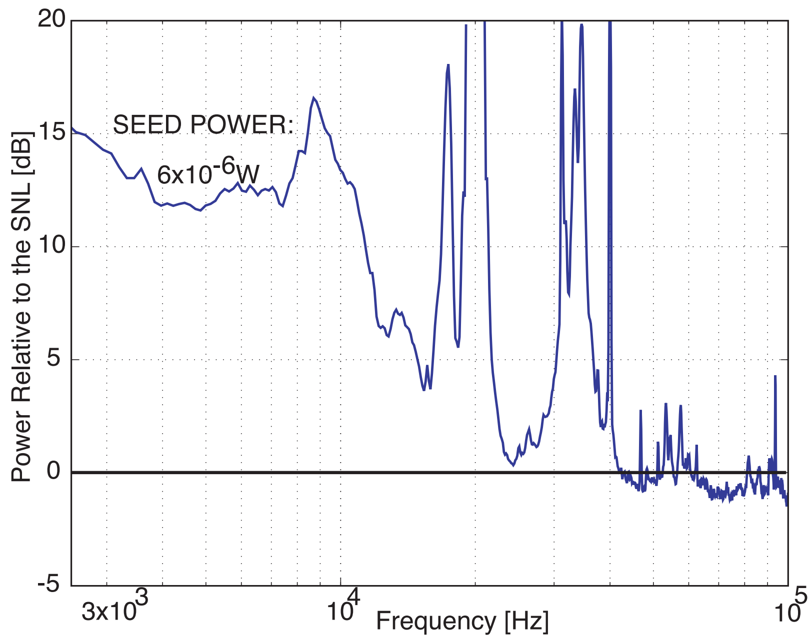
Producing LF Squeezing

- Use **P**arametric **A**mplification
- Noise sources that can mask squeezing
  - Pump intensity and phase noise
  - Seed intensity and phase noise
  - Cavity length fluctuations
- These noise sources **do not couple** to the squeezed state when, operated below threshold and vacuum seeded.





McKenzie, Grosse, Bowen, Whitcomb, Gray, McClelland and Lam, **PRL** (2004)

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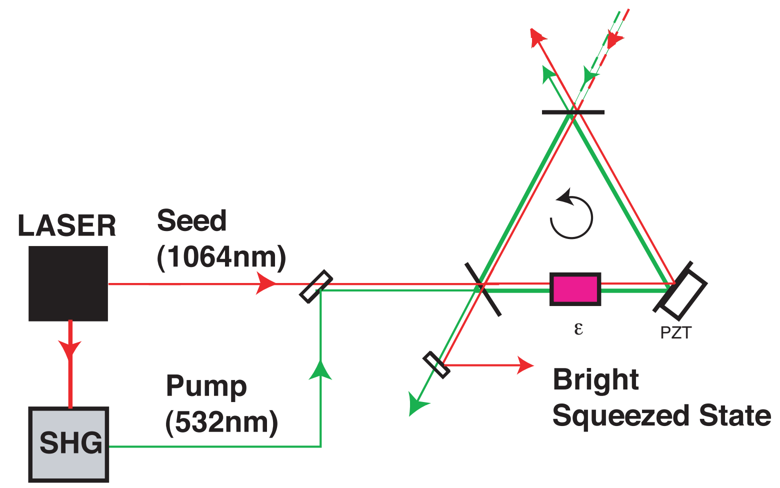

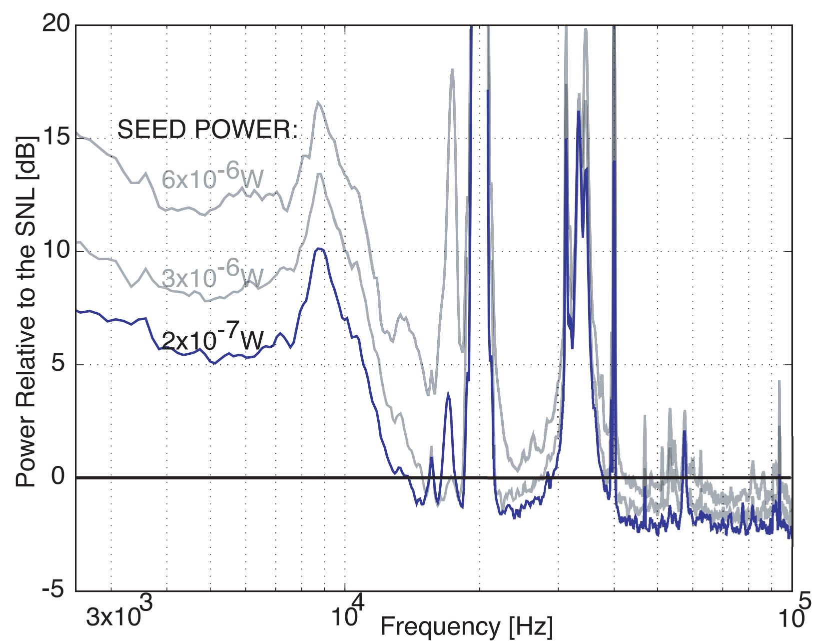

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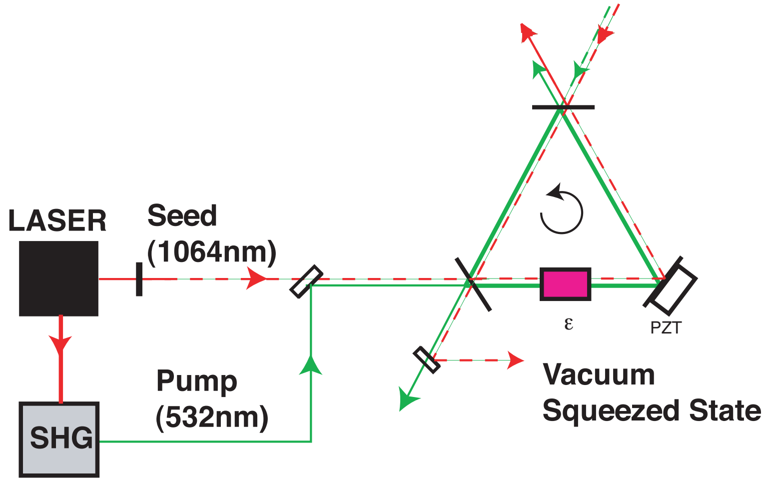

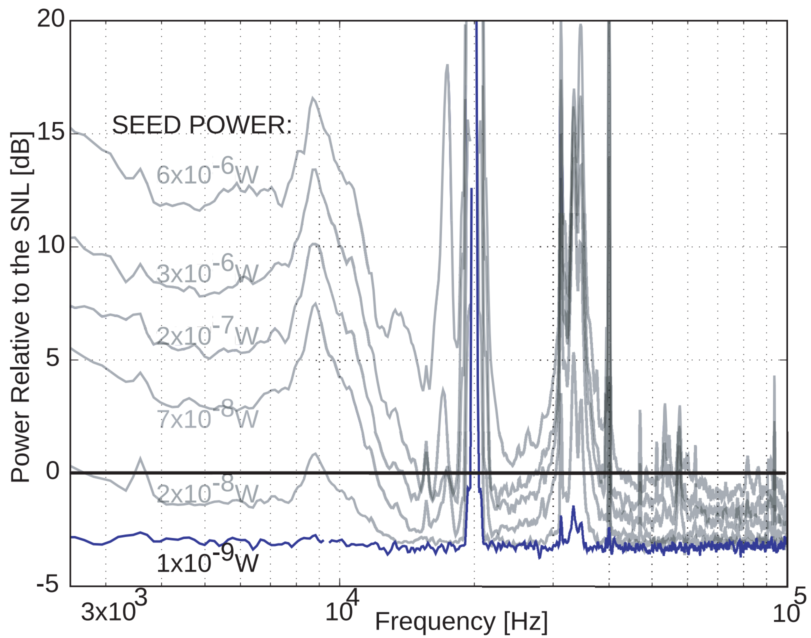

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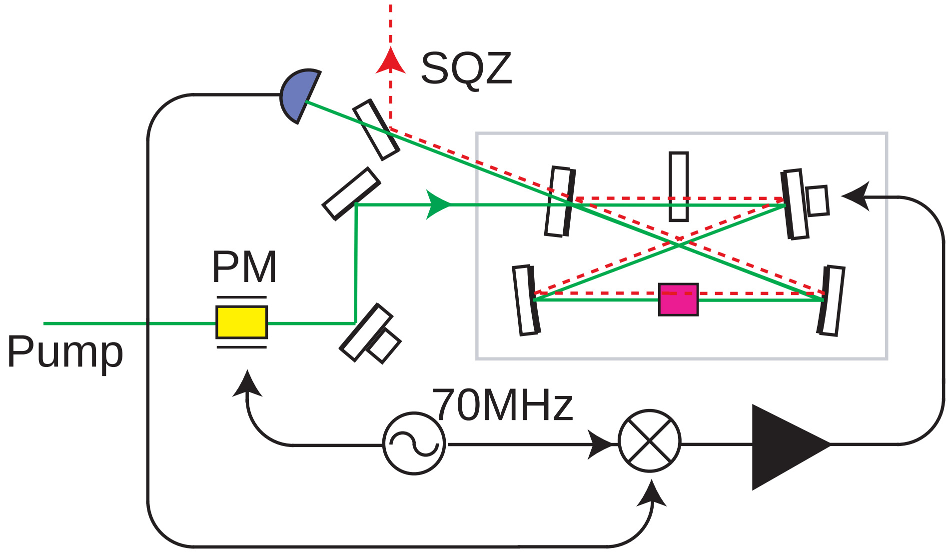
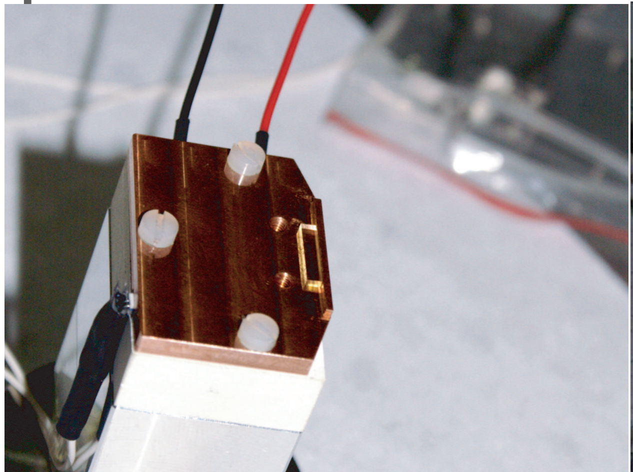
Key Technologies

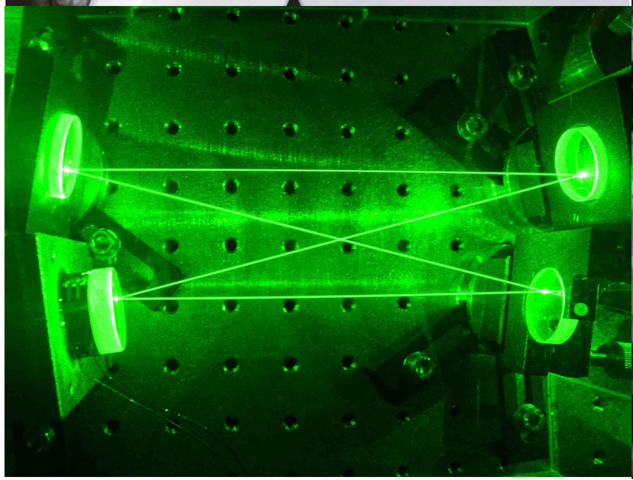
- Doubly Resonant
  - $\longrightarrow$ Use pump for cavity length control
  - $\longrightarrow$ Large effective pump power
  - $\longrightarrow$ Extra d.o.f. The relative resonance condition of 532nm & 1064nm

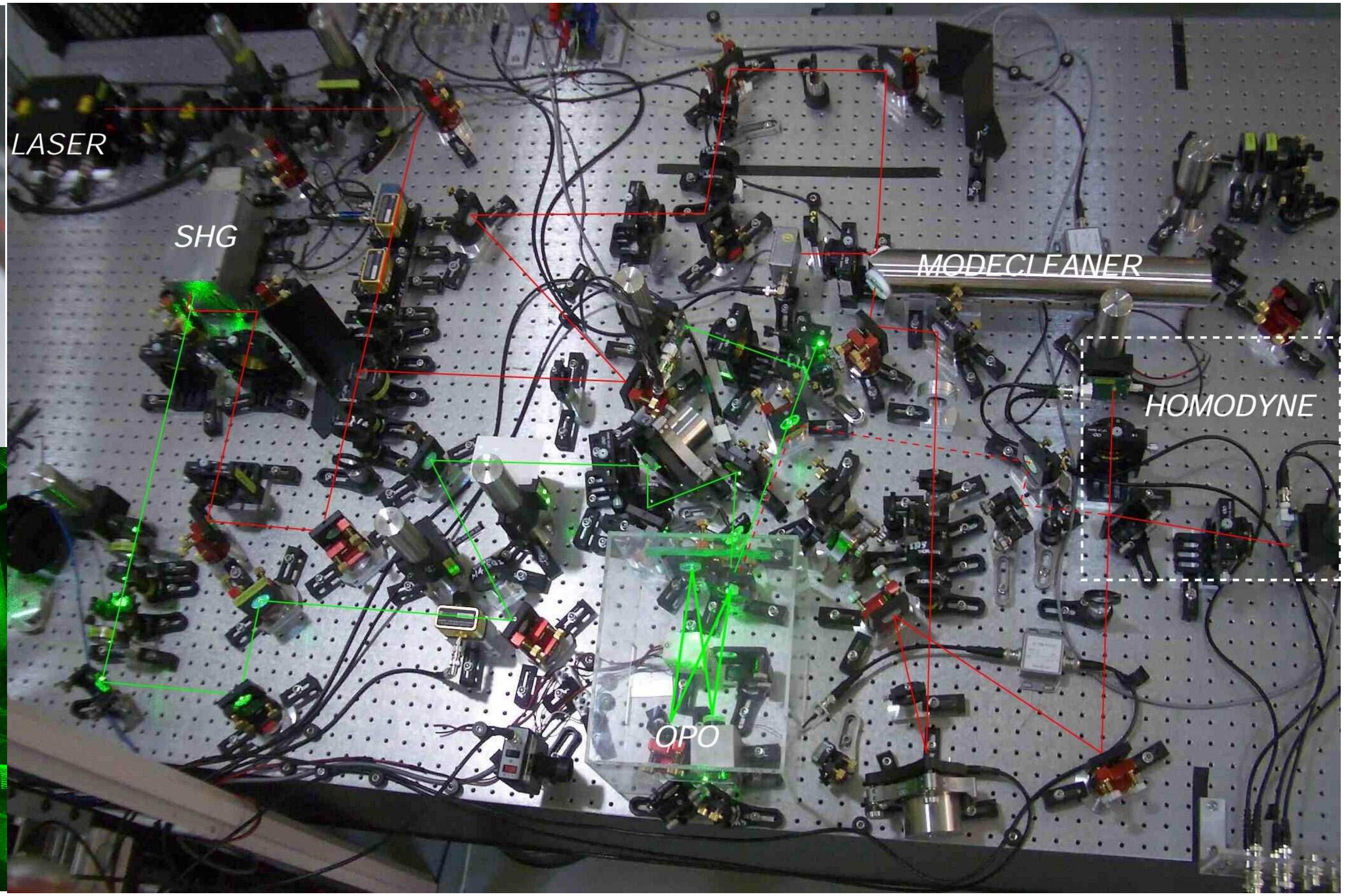


- Traveling-Wave cavity
  - $\longrightarrow$ Isolation from backscatter
- Crystal: Periodically poled potassium titanyl phosphate (PPKTP)
  - $\longrightarrow$ High nonlinearity, phase matched at 37^{o}C
  - $\longrightarrow$ No sign of grey tracking.

Photos

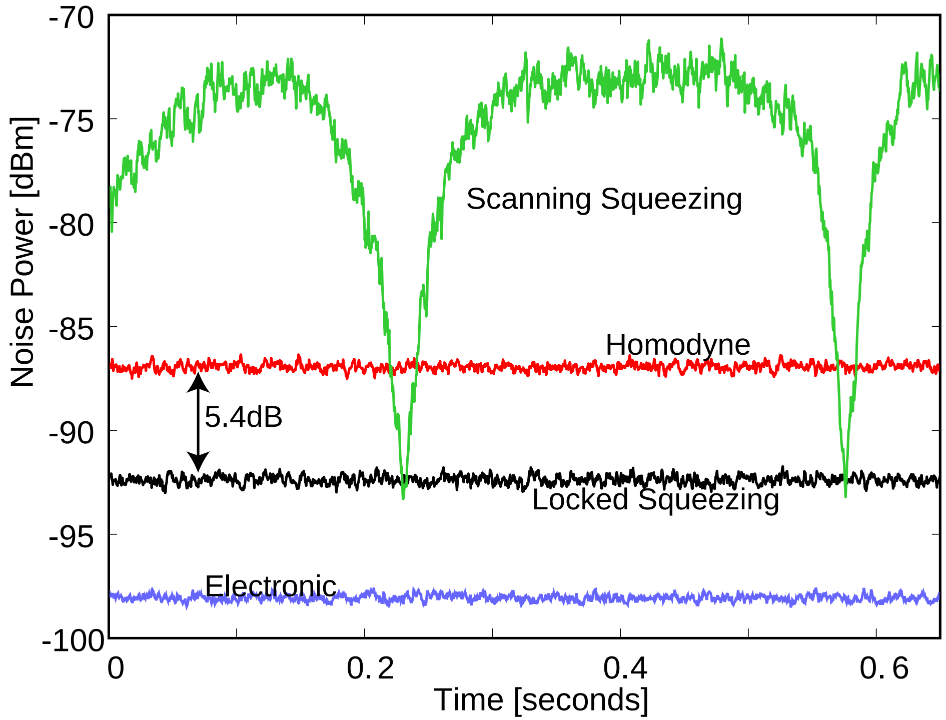






Quadrature Scan

- Measured squeezing = 5.4dB
  - Subtract electronic noise = 6.5 dB
- Total Det efficiency = 83%
  - OPO Escape = 94%
  - photodetector = 93%
  - LO interference = 96%
  - Optics = 99%
- inferred squeezing out of OPO = 8.2dB



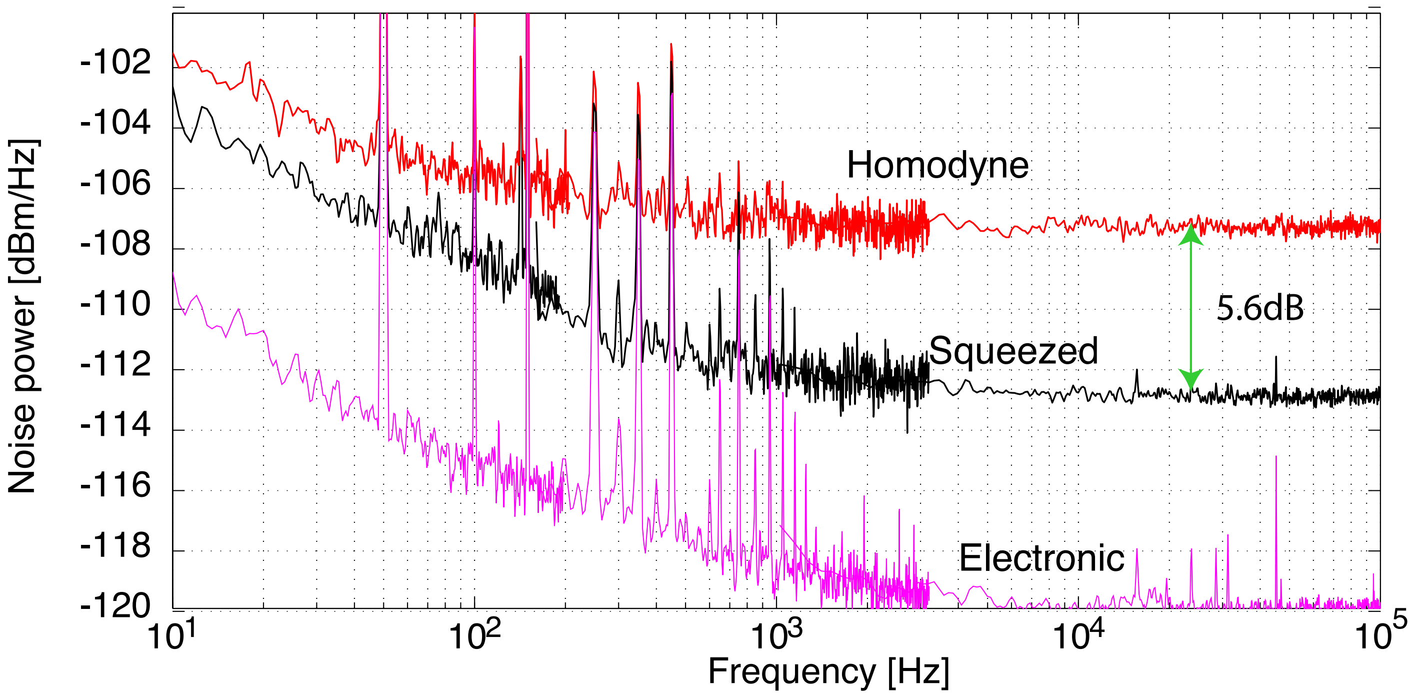
Measured at 100 kHz

Squeezed Vacuum Spectrum

- Locked using quantum noise locking[1]
- Homodyne detector not SNL below few hundred Hz

  $\longrightarrow$ Due to scattered light, beam jitter?

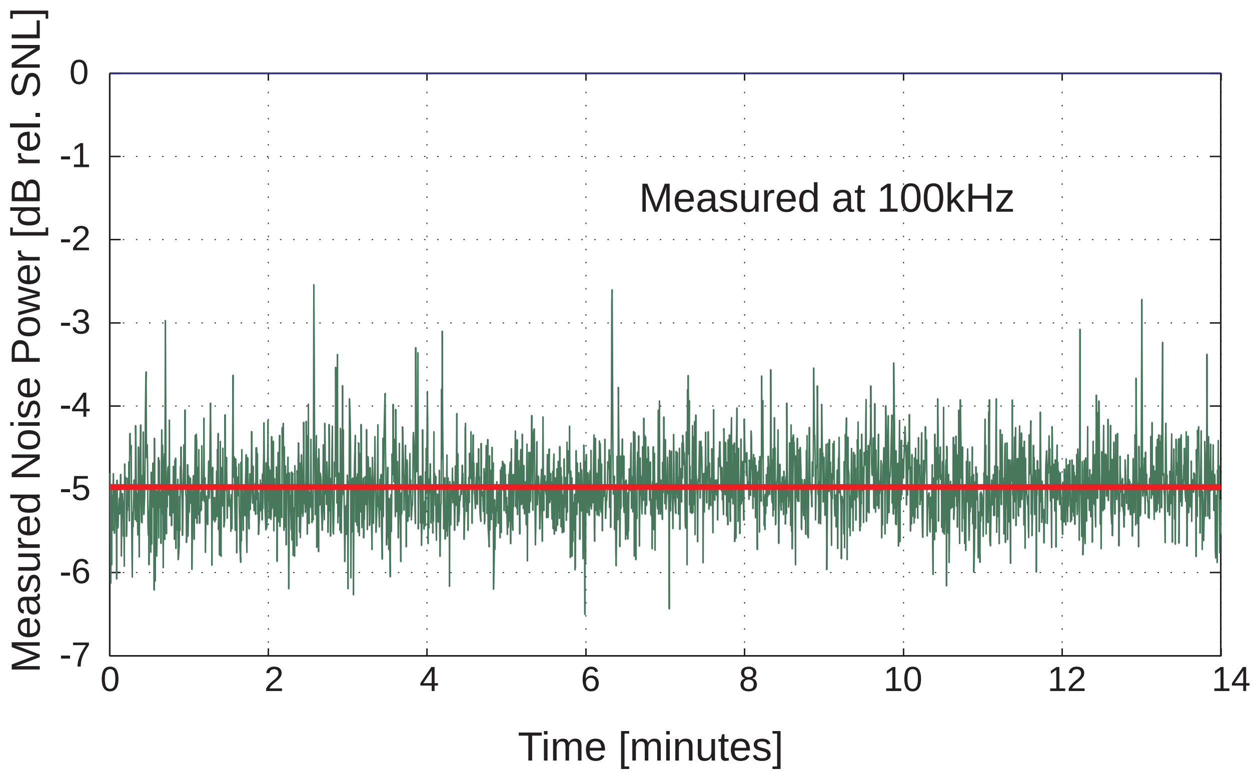
  $\longrightarrow$ Limits measurement of squeezing



[1] McKenzie, Mikhailov, Goda, Lam, Grosse, Gray, Mavalvala and McClelland **JOB** (2005)

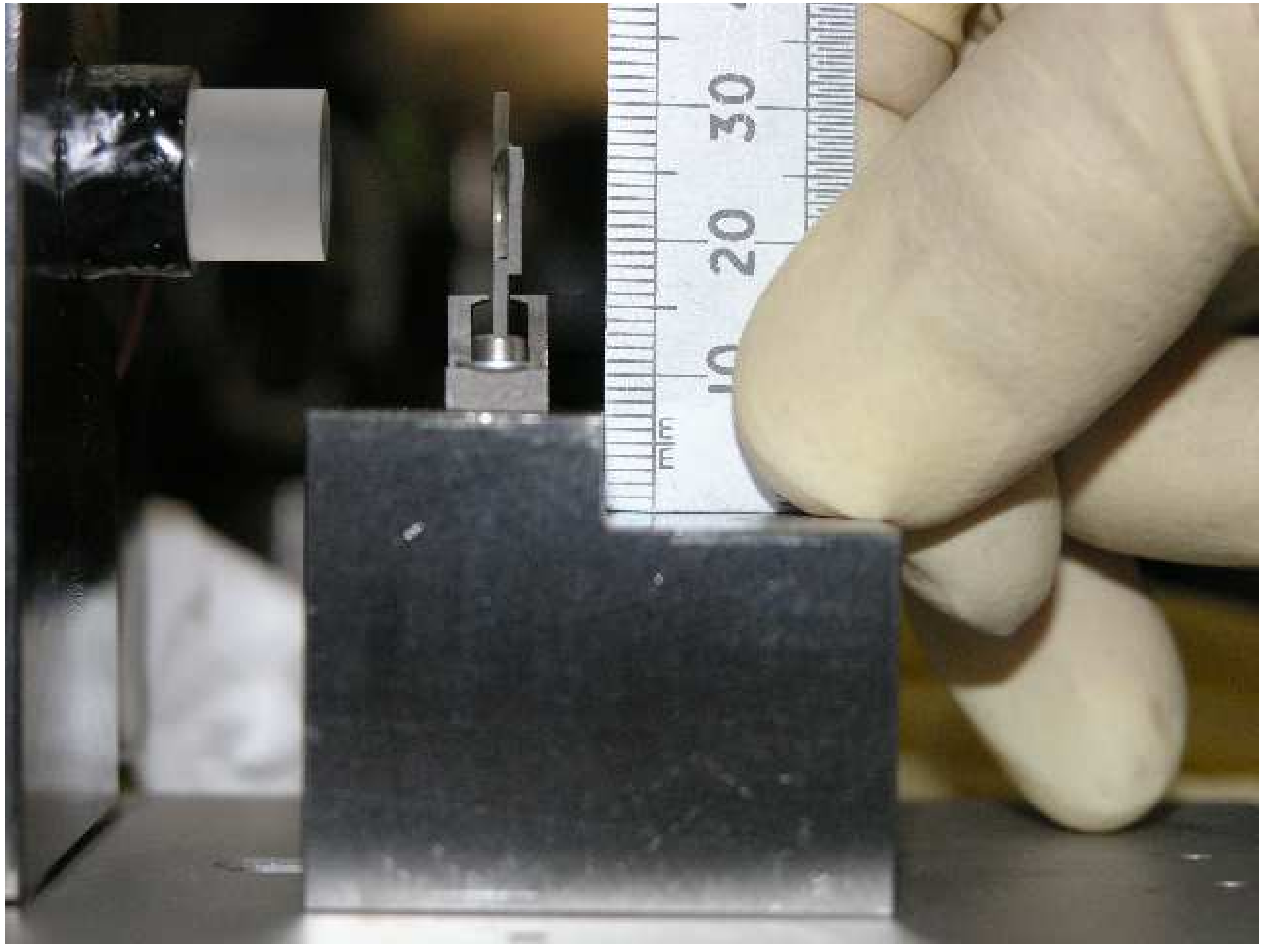
Lock stability

- Good stability
- Limited by range of actuators/temperature stability of Lab



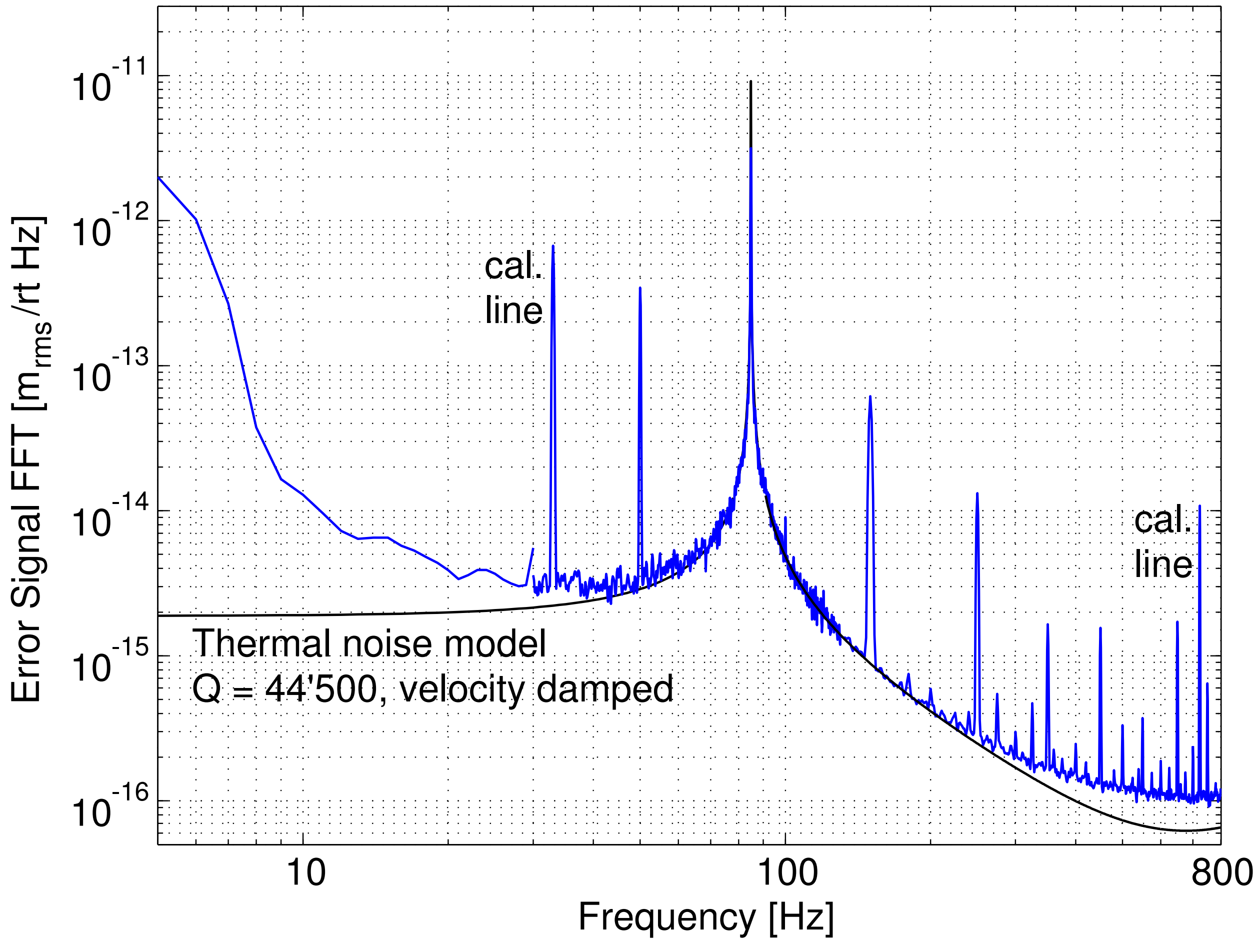
Suspension TN measurement

Small mirror mounted on soft niobium flexure



Thermal Noise Measurement

- Fits velocity damped model
- Measurement with small detuning



Servo enhanced cooling of a flexure

- A detuned cavity gives rise to an optical spring, k_0
- Servo interaction with the cavity response modifies the optical spring[1,2]

The magnitude of the optical spring becomes

$$k_g = \frac{k_0}{\sqrt{1 + 2G_0 \cos(\psi) + G_0^2}}$$

ψ = loop phase, G_0 = loop magnitude. The phase is rotated to

$$\theta_{\rm opt} = \tan^{-1}\left(\frac{G_0 \sin(\psi)}{1 + G_0 \cos(\psi)}\right)$$

This allows optical cooling well inside the cavity linewidth

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[1] Mullavey, ANU honors thesis (2006), [2] Schediwy *et al*, LSC Tech Review (2006)

Servo enhanced cooling of a flexure

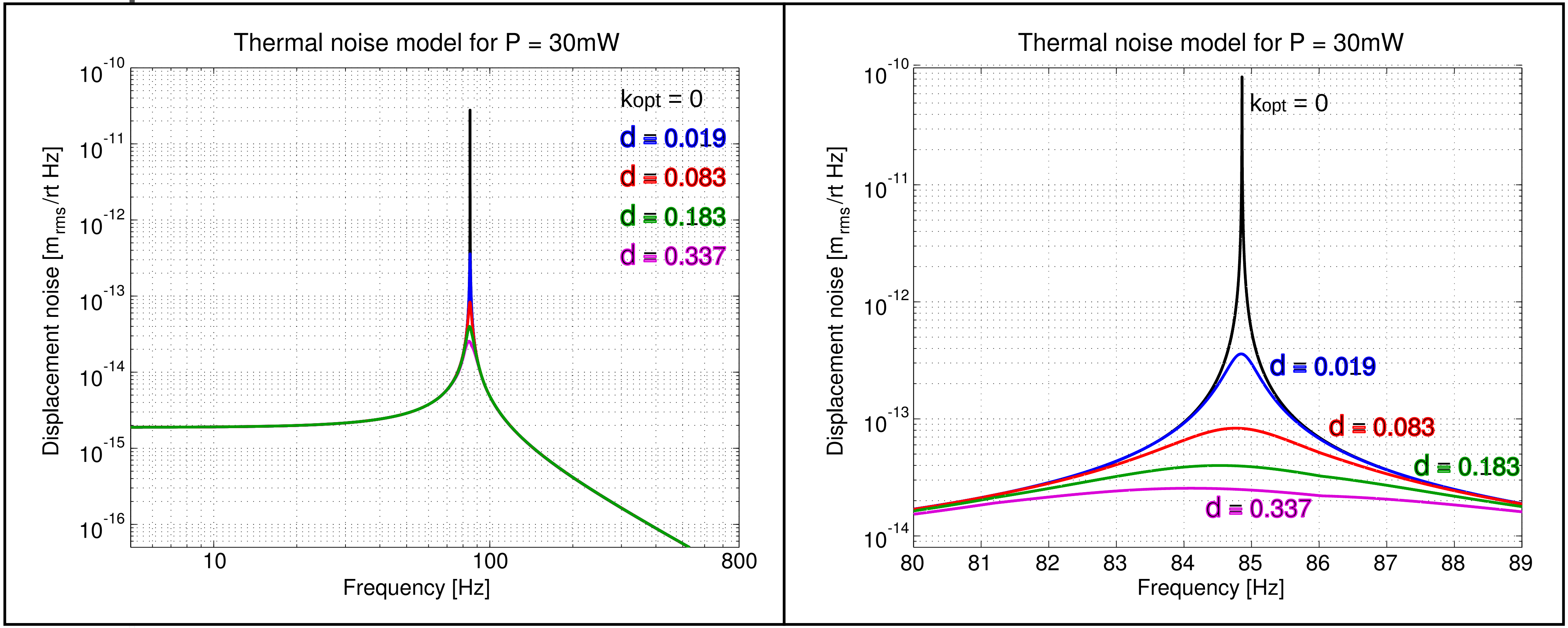
The optical spring modifies the flexure thermal noise spectrum;

$$\hat{x}_{th}^2 = \frac{4\, k_B\, T \phi\, \omega_0^2}{m\, \omega\, \left[\left(\omega^2 - \omega_0^2 - k_g \cos(\theta_{\rm opt})/m\right)^2 + \left(\phi\, \omega_0^2 + k_g \sin(\theta_{\rm opt})/m\right)^2 \right]}$$

T - temperature, ϕ - loss angle m - mass, ω_0 - resonance freq.

- Spring can be stiffened/weakened $\propto \cos\theta_{opt}$
- Spring can be damped/anti-damped $\propto \sin\theta_{opt}$

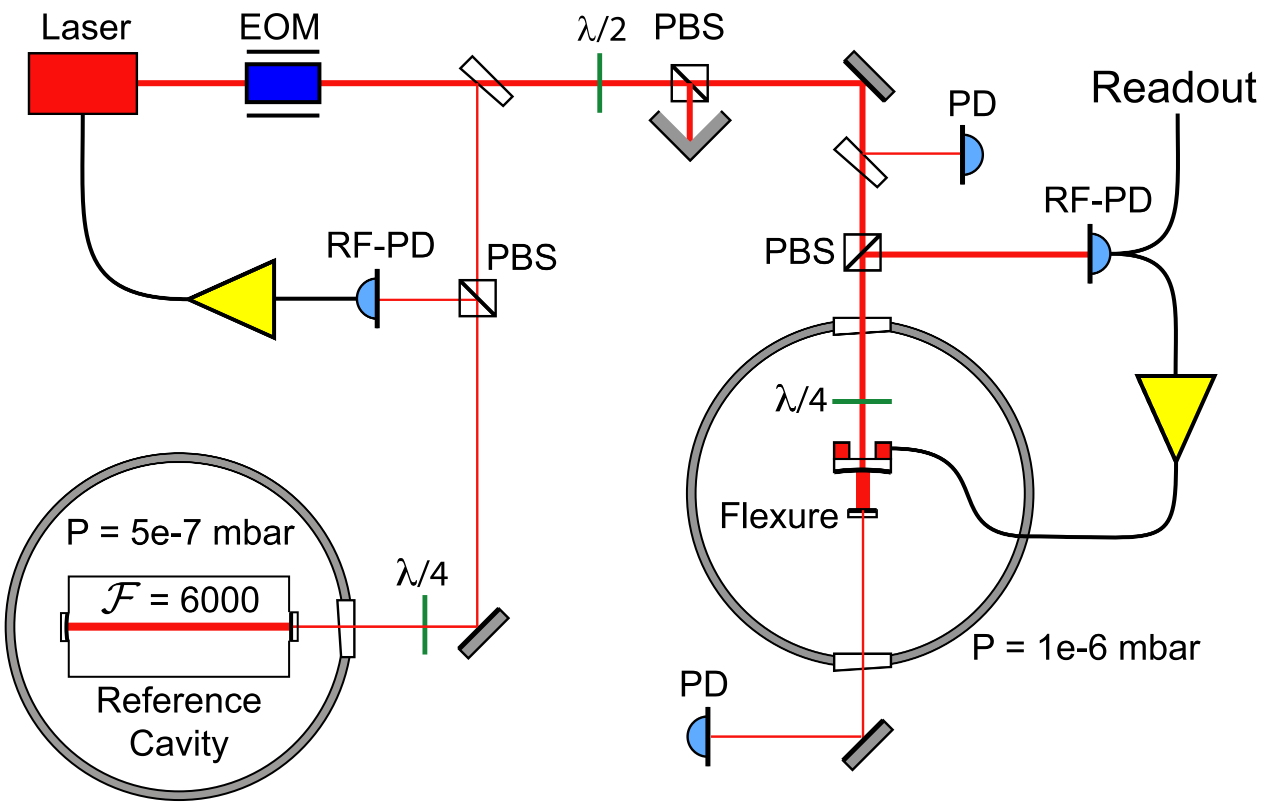
Theory



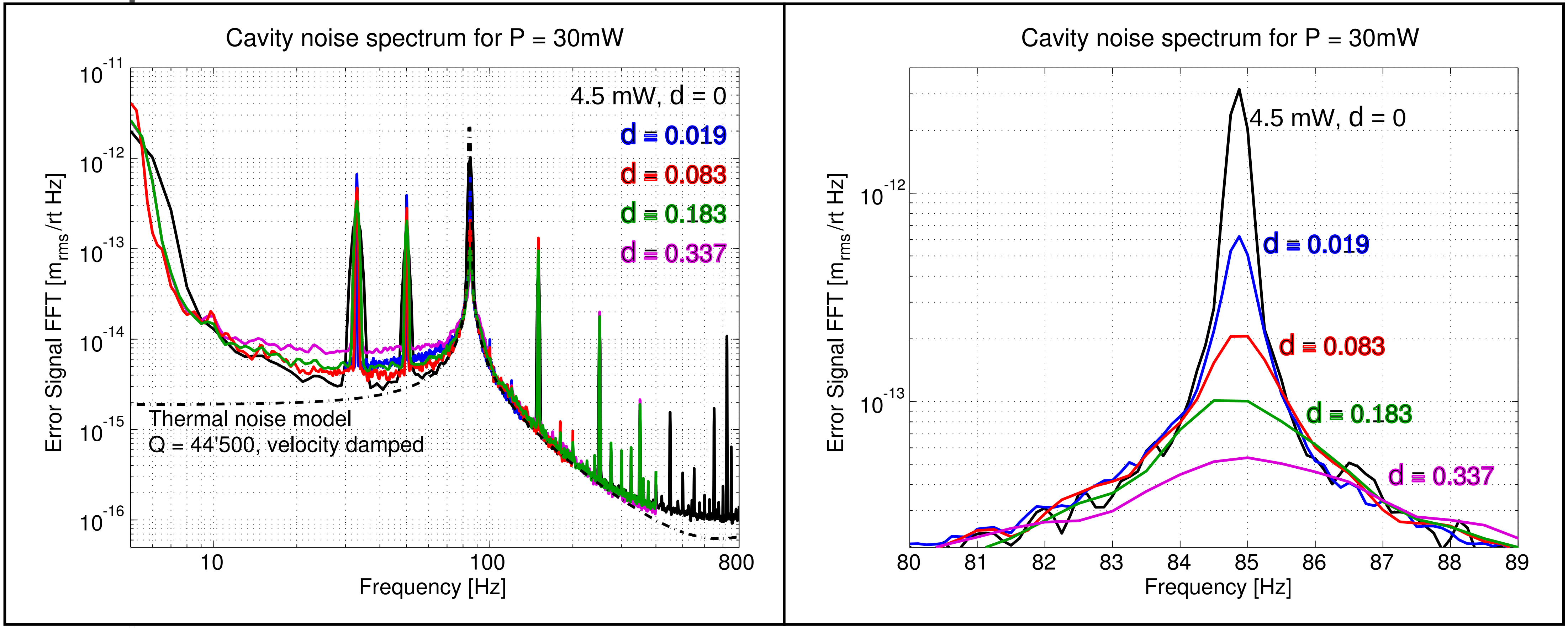
Here d is detuning. $d = 1 \rightleftharpoons$ Half-width at half max.

Experimental setup

- Frequency stabilization via a monolithic reference cavity
- Test cavity controlled using PDH, $300\,Hz$ bandwidth
- Variable input power $(0 - 200\,mW)$, cavity detuning $(\delta = 0 - 0.5)$



Data



Effective temperature is 82mK

Summary

- Nice squeezer design
- Stable low frequency squeezing
- Measurement of suspension thermal noise
- Servo enhanced cooling of thermal noise to 82mK