Suppression of LIGO Mirror Vibrational Mode Q's

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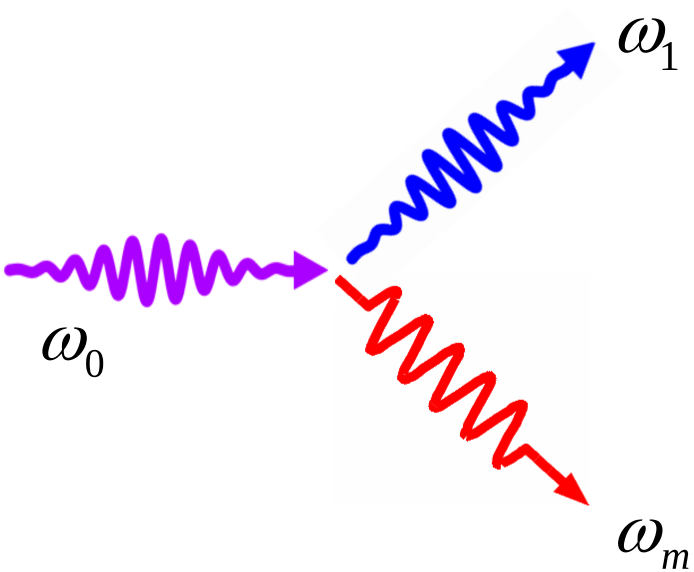
Mentor: Eric Black

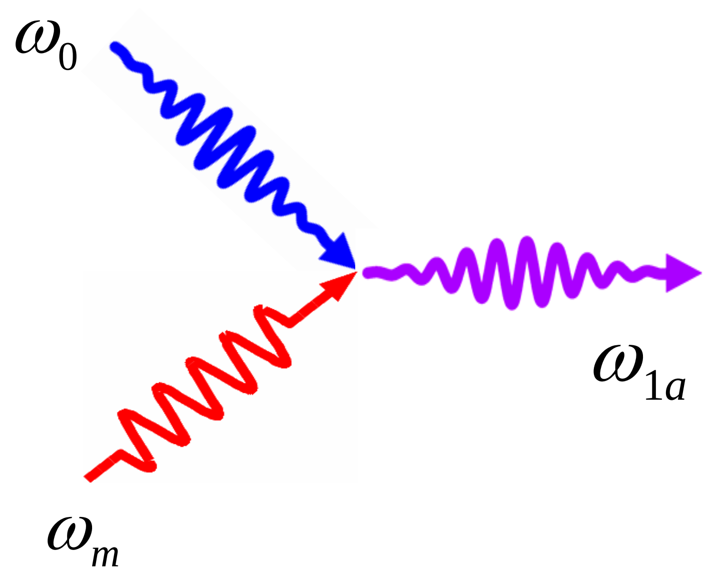
Acousto-Optic Coupling

Stokes process



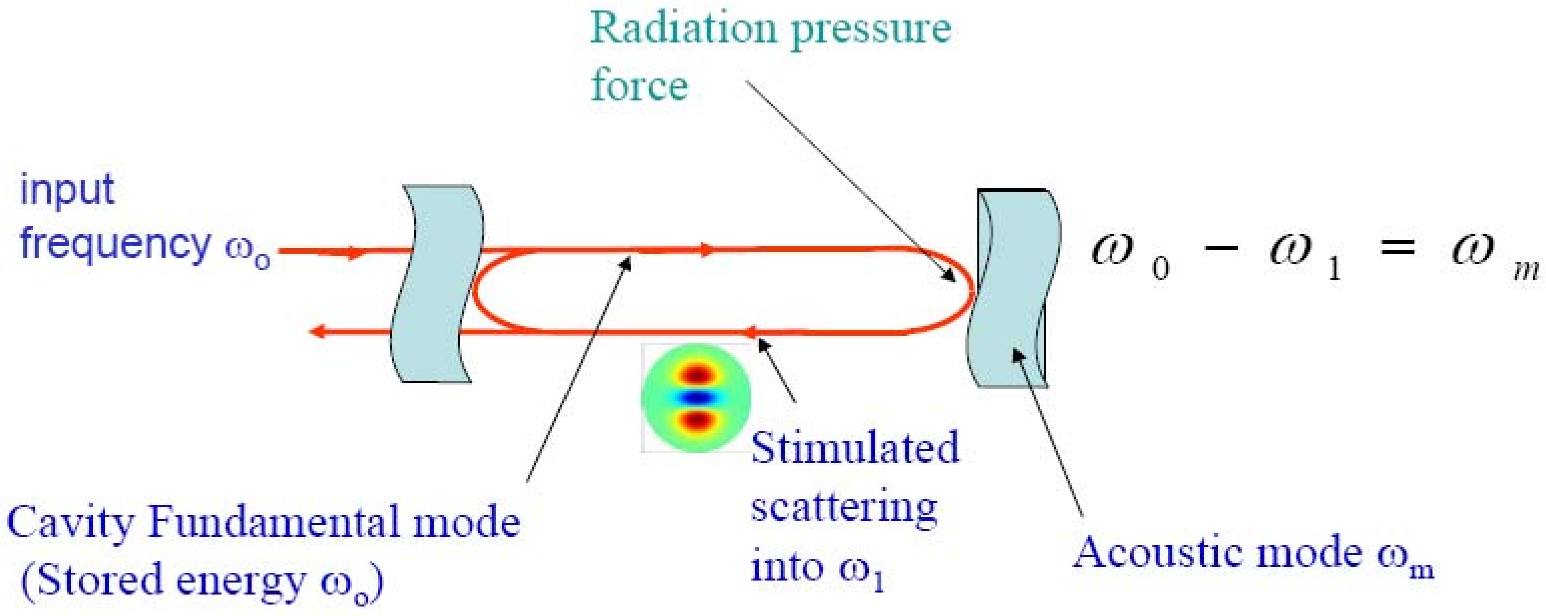
$$\omega_1 = \omega_0 - \omega_m$$

Anti-Stokes process



$$\omega_{1a} = \omega_0 + \omega_m$$

Parametric Instability



Ju, et al. G050325-00

Condition for Instability

Mechanical Q

$$R \approx \frac{2PQ_m}{McL\omega_m^2}\left(\frac{Q_1\Lambda_1}{1+\Delta\omega_1^2/\delta_1^2}-\frac{Q_{1a}\Lambda_{1a}}{1+\Delta\omega_{1a}^2/\delta_{1a}^2}\right)>1$$

Stokes Mode

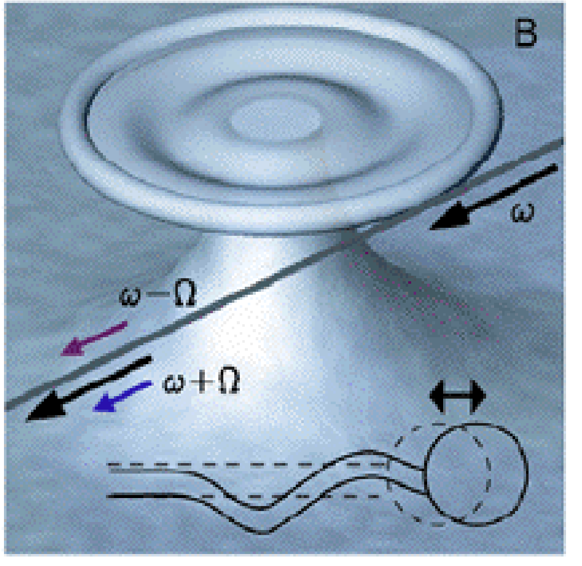
Anti-Stokes mode

Ju, et al. G050325-00 who got it from
Braginsky, et al. Phys. Lett. A 305, 111 (2002)

Concern for AdvLIGO

- Likelihood of instability rises with circulating power
  - 830 kW for AdvLIGO compared to 10-50 kW
- Effect already observed in micro-cavities by Vahala group
  - Phys. Rev. Lett. 95, 033901 (2005)
- Later in suspended mirror cavity at MIT
  - LIGO-P050045-00-R (Oct. 27, 2005)

Toroid micro-cavity

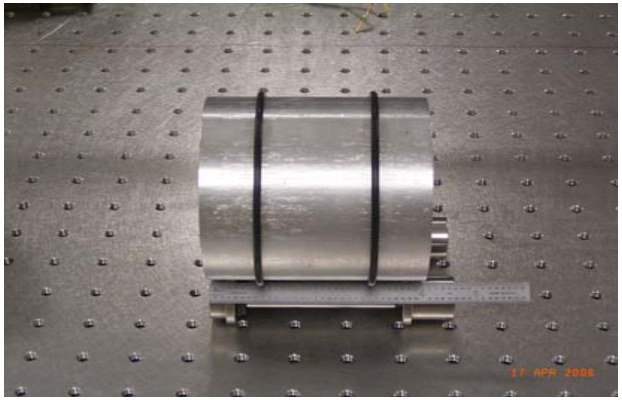


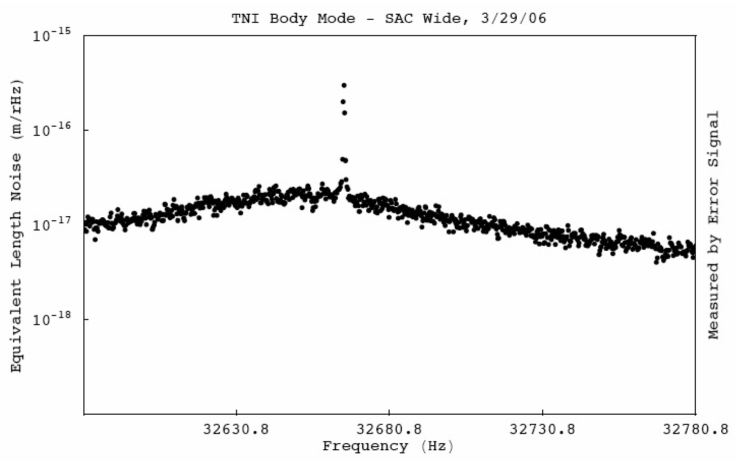
Possible Solution

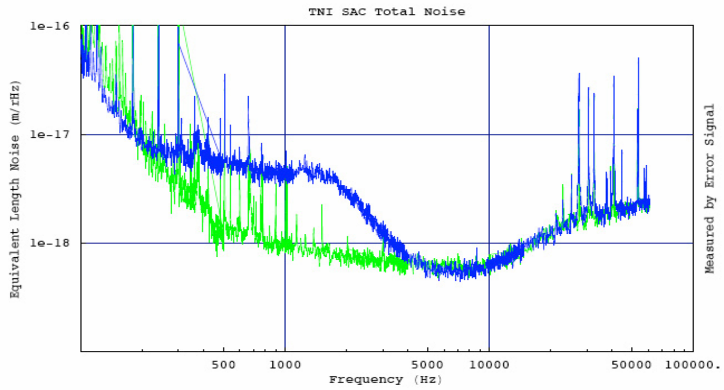
- Instability gain R also proportional to mirror acoustic mode Q's
  - Attempt to lower Q's without affecting thermal noise
  - Can be accomplished by placing ring dampers around mirror

Previous work

- Two types of rings have been studied in the TNI previously
- buna rubber, 1/8” thick
- Very effective at crushing Q’s
- Raised noise floor at low frequencies (ring modes)



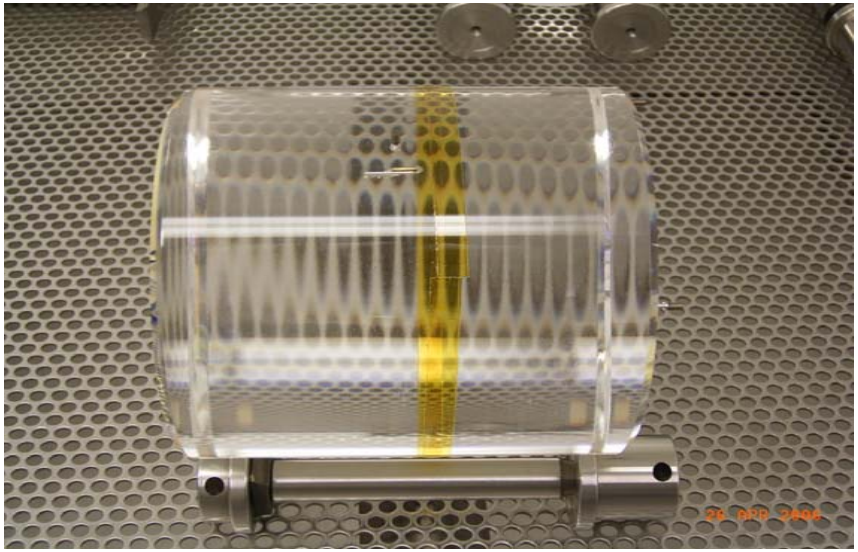




Previous Work

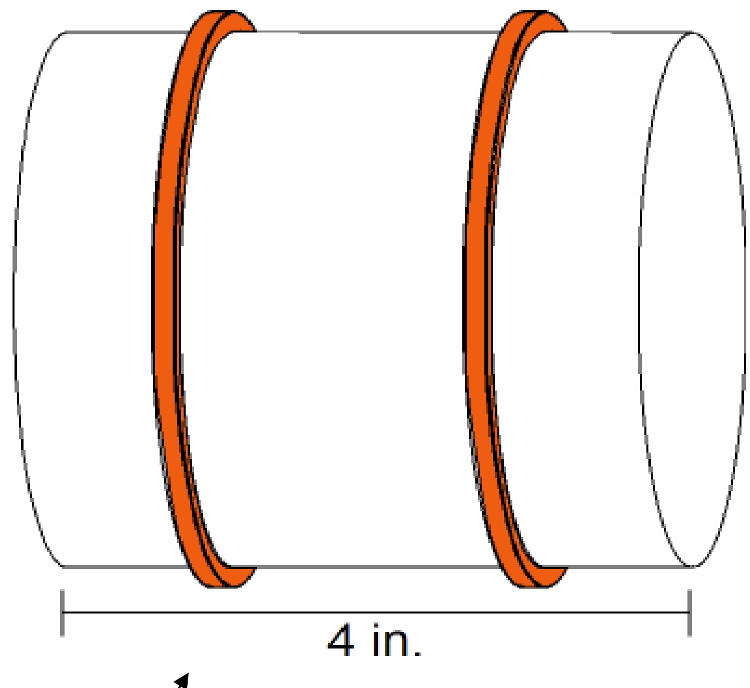
- Kapton tape
- Noise floor unaffected
- Also had insignificant affect on Q's

- Need something in between these two extremes



Copper Ring Dampers

- Placed on south cavity output mirror of Thermal Noise Interferometer (TNI)
- Rings fastened with screw
- Will measure how dampers affect mechanical Q's
- Ringbands have rectangular cross-section



3x5 mm copper ringbands

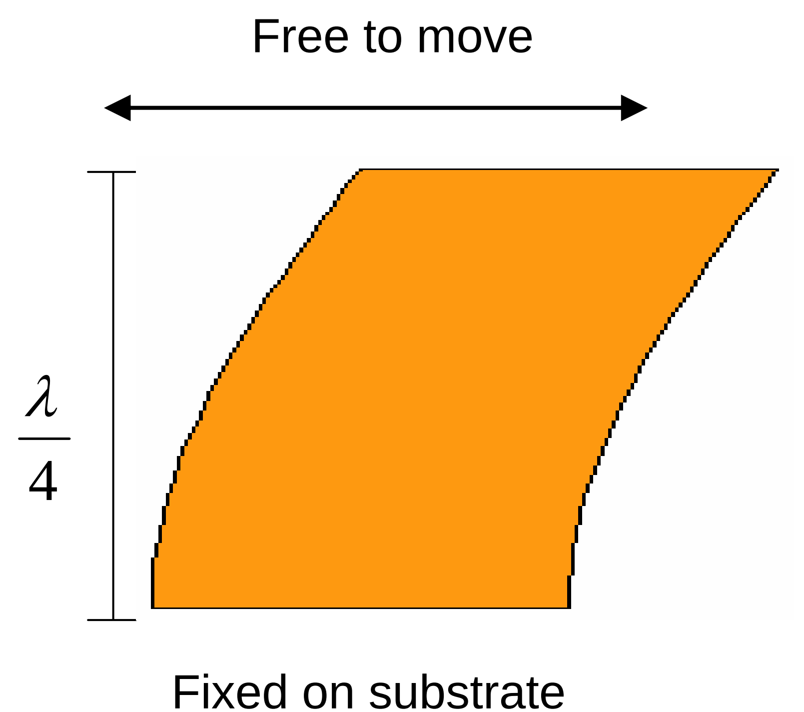
Ring Design

Shear wave equation (transverse waves)

$$\frac{\partial^2 y}{\partial x^2} = \frac{\rho}{G}\frac{\partial^2 y}{\partial t^2}$$

→ wave speed $v = \sqrt{\frac{G}{\rho}}$

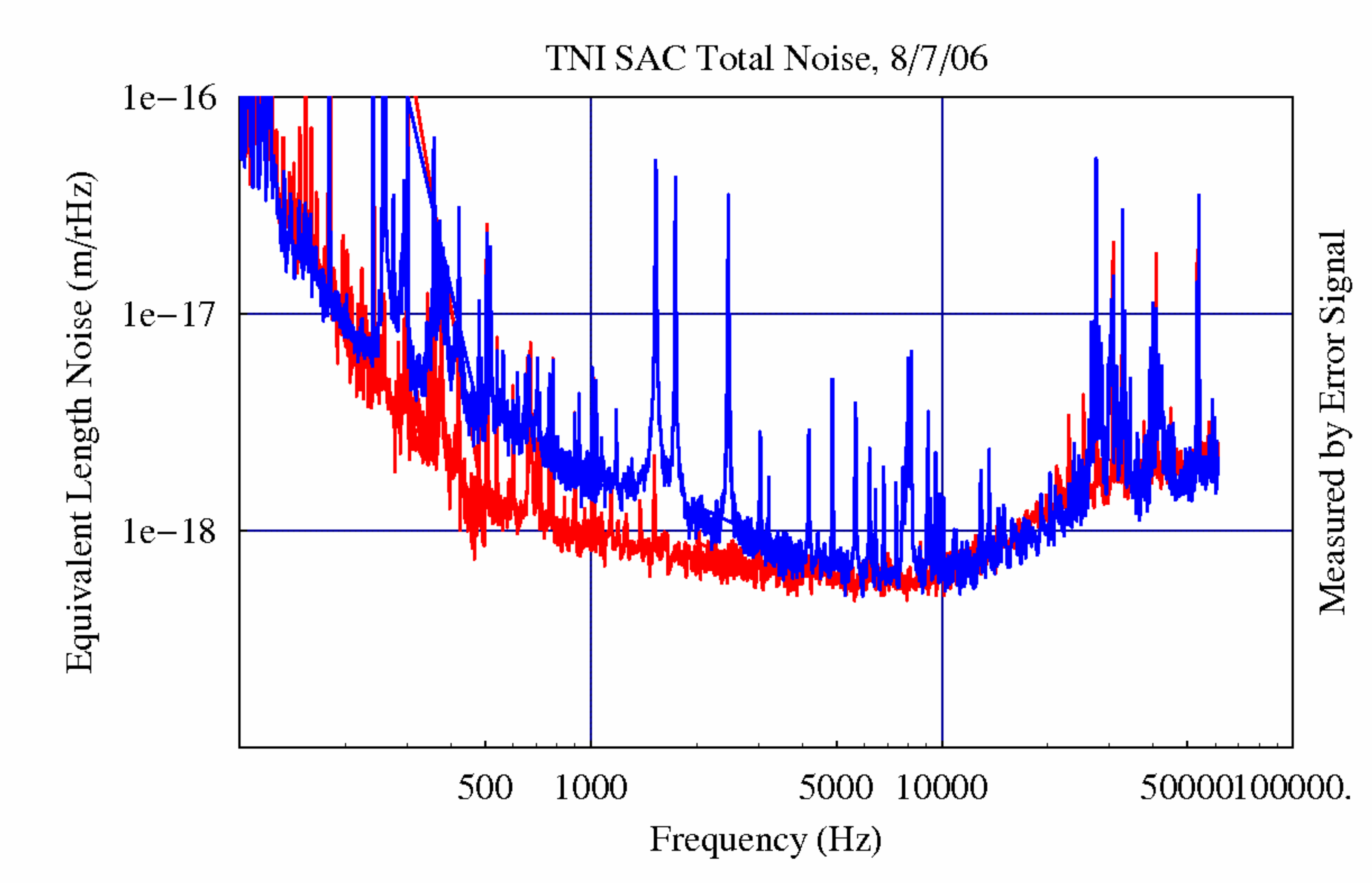
$$f_n = \frac{2n-1}{4d}\sqrt{\frac{G}{\rho}}$$



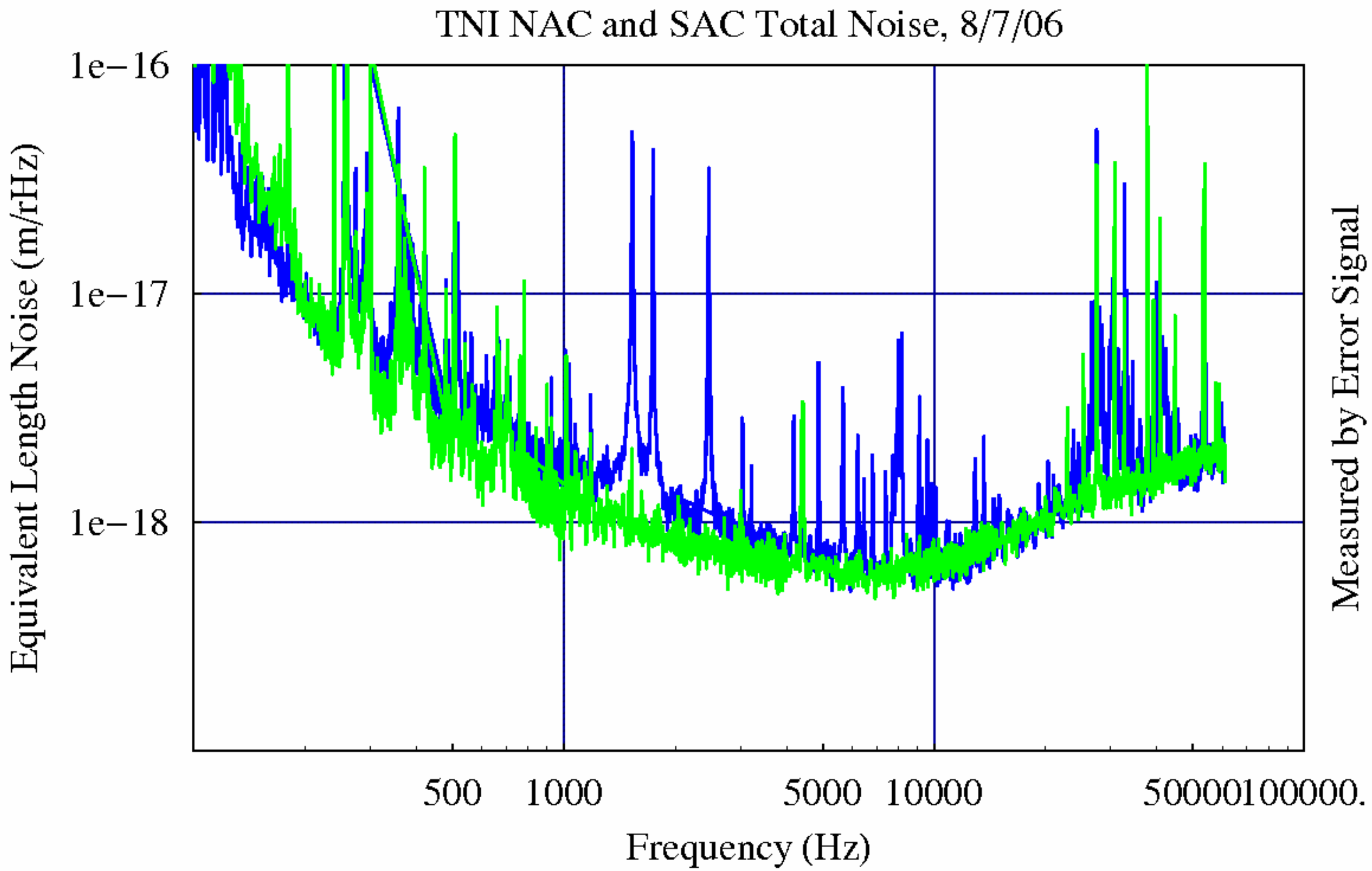
Predicts fundamental f = 145 kHz for 4 mm copper ring

- Well out of thermal noise region

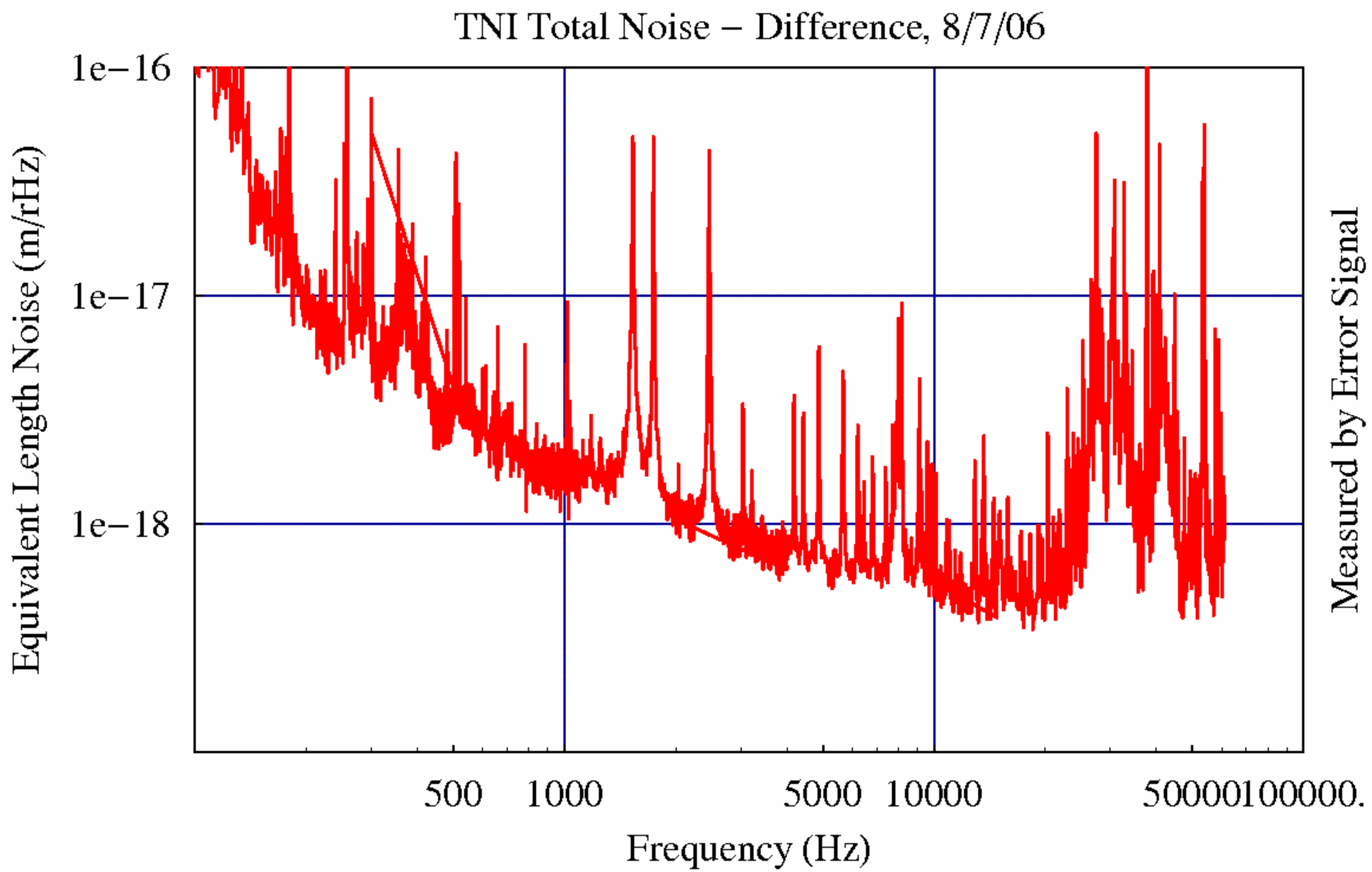
SAC Total Noise



SAC vs. NAC


TNI NAC and SAC Total Noise, 8/7/06
1e−16
1e−17
1e−18
Equivalent Length Noise (m/rHz)
Measured by Error Signal
500
1000
5000
10000
50000100000.
Frequency (Hz)

Differential data



Possibilities

- Mass that rings add to mirror is not negligible
  - SAC mirror response recalibrated, did change slightly from previous calibration
- Ring dampers have raised SAC’s noise floor

Conclusion

- Copper ring dampers are doing their job
  - Unable to excite mirror acoustic modes
  - Seems that Q's are reduced so much that we're unable to measure quantitatively
  - Notch filter not needed for SAC lock at high power
- More still desired
  - Rings have introduced their own modes into displacement noise
  - Need to find out why these modes are there and eliminate them

Future Work

- Place solid rings around mirrors, instead of ones fastened with screw
- Determine what causes low frequency peaks
- Evaluate effectiveness at preventing parametric instabilities

Acknowledgments

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LIGO

SURF