Thermal Noise Interferometer Update and Status

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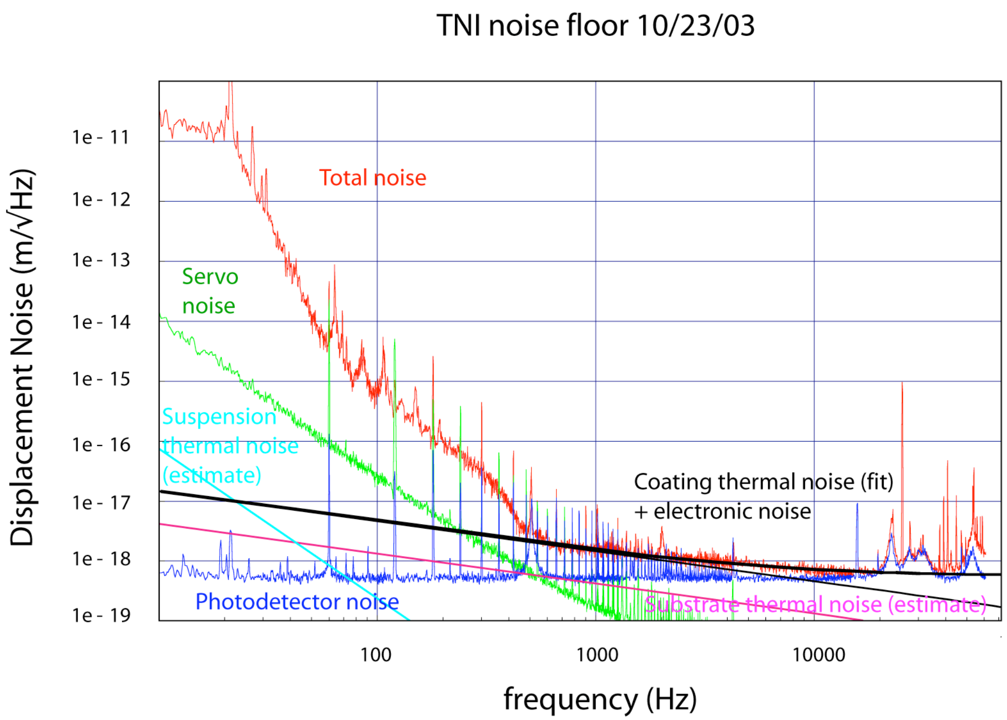
TNI Goals

- Direct measurement of broadband thermal noise at lowest reasonable levels
  - If there are any unanticipated noise sources, we want to see them in a test-bed interferometer, not in advanced LIGO.
- Model validation in extremely low-displacement-noise regime.
  - Do we uncover any unexpected losses (with known noise mechanisms) at very low displacement-noise levels?
- Measurement of required thermal noise parameters for AdLIGO materials
  - Core Optics: "Braginsky-noise" models need, for Sapphire
    - Thermal-expansion coefficient α
    - Thermal conductivity κ
  - Coatings: Structural-damping thermal noise models, for Silica-Tantala and others, need
    - Mechanical loss angle ϕ
    - Loss angle is possibly anisotriopic. Ringdown measurements get value for strains parallel to coating-substrate interface, direct TN measurement gets value for perpendicular strains
  - Coatings: Braginsky-noise models require, for Silica-Tantala and others
    - Thermal-expansion coefficient α
    - Thermal conductivity κ

Broadband Thermal Noise Measurements

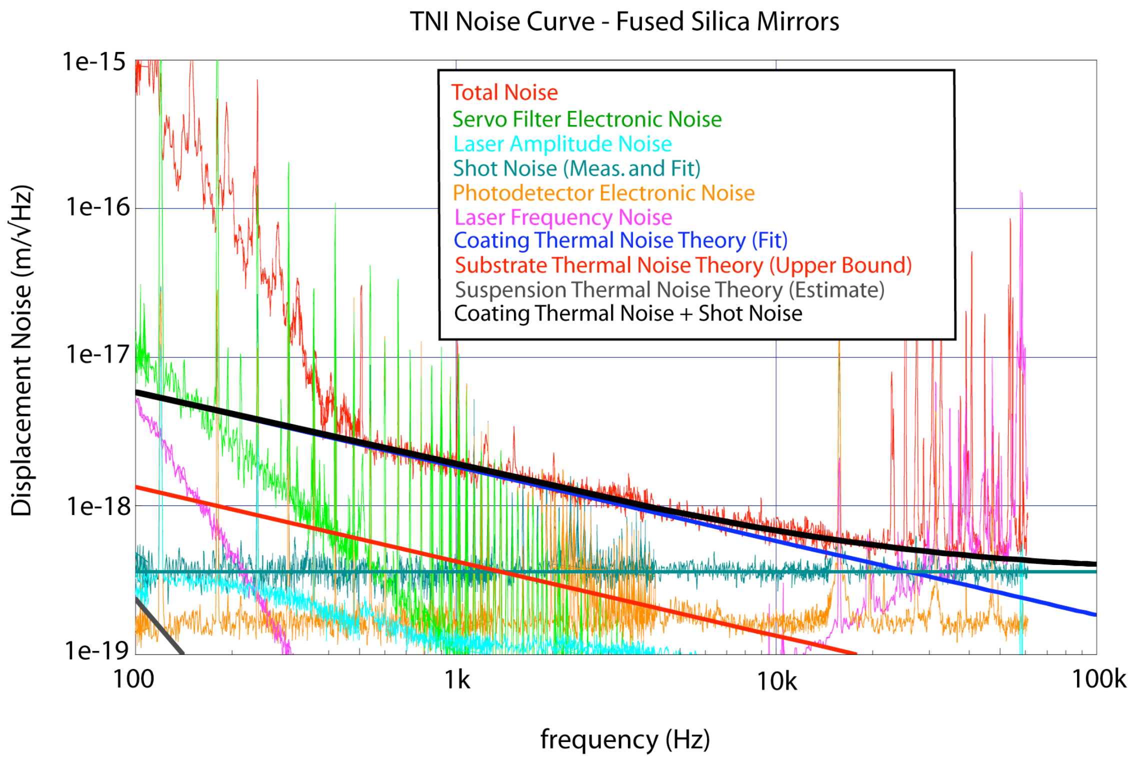
- Gonzalez and Saulson
  - Gonzalez and Saulson, J. Accoust. Soc. Am. 96, 207-212 (1994)
  - Verified fluctuation-dissipation theorem in torsional pendulum
- 40-meter
  - A. Abramovici, et al., Phys. Lett. A 218, 157-163 (1996)
  - Claim made of observation of broadband thermal noise in compound (i.e. glued-together) optics. No analysis given.
- Yamamoto
  - Yamamoto, et al., Phys. Lett. A 280, 289-296 (2001); Class. Quant. Grav. 19, 1689-1696 (2002)
  - Verification of fluctuation-dissipation theorem, effect of inhomogeneous losses in a leaf-spring
- Numata
  - Numata, et al., Phys. Rev. Lett. 91 (26), 260602 (2003)
  - Verification of fluctuation-dissipation theorem in mirrors
  - Selection of spot sizes, materials designed to make thermal noise relatively large, easy to measure
  - BK7, Calcium-Fluoride substrates not suitable for AdLIGO
  - Measured coating thermal noise in Silica-Tantala coatings on fused-silica substrates, which are candidate materials for AdLIGO

Last Sensitivity Curve: 10/23/03



- Coating thermal noise observed in Silica-Tantala coatings on fused-silica substrates
  - Loss angle required to fit noise floor: 1.2e-4
  - Observed noise somewhat lower than predicted from ringdown measurements: Harry *et al.,* Class. Quantum Grav. 19 (5) pp. 897-917 (2002), Penn *et al*., Class. Quantum Grav. 20 pp. 2917-2915 (2003)
- Noise level is 3x lower than previous Silica-Tantala coating noise measurement.
  - Numata, *et al*., PRL 91 (26), 260602 (Dec. 31, 2003)
- Electronic noise limits sensitivity at lowest levels
- What are the levels of additional noise sources?

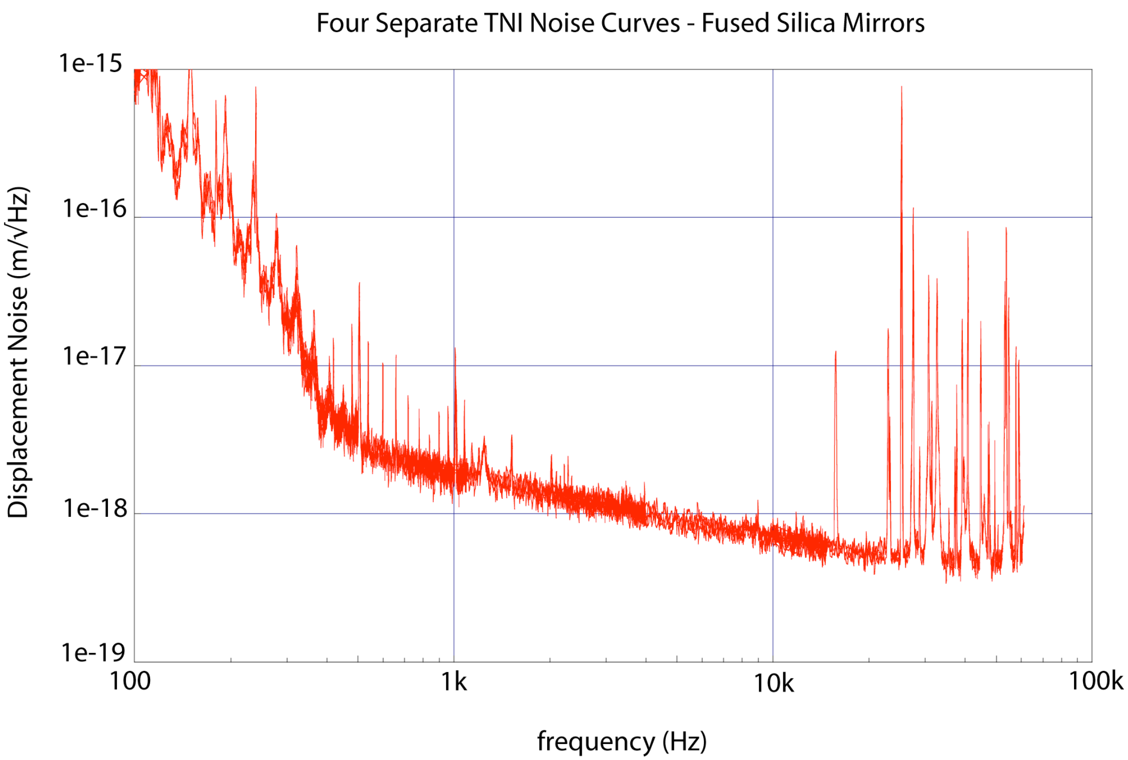
Improved Sensitivity with Fused Silica Mirrors



- Photodetector electronic noise reduced by factor of 4
- Additional noise sources quantified
- Shot Noise now dominates at high frequencies
- Broadband thermal noise measured at 10x better than previous BK7 measurement
- Noise level remains at ~3x lower level than previous measurement in same materials
- Silica-Tantala (isotropic) coating loss angle:

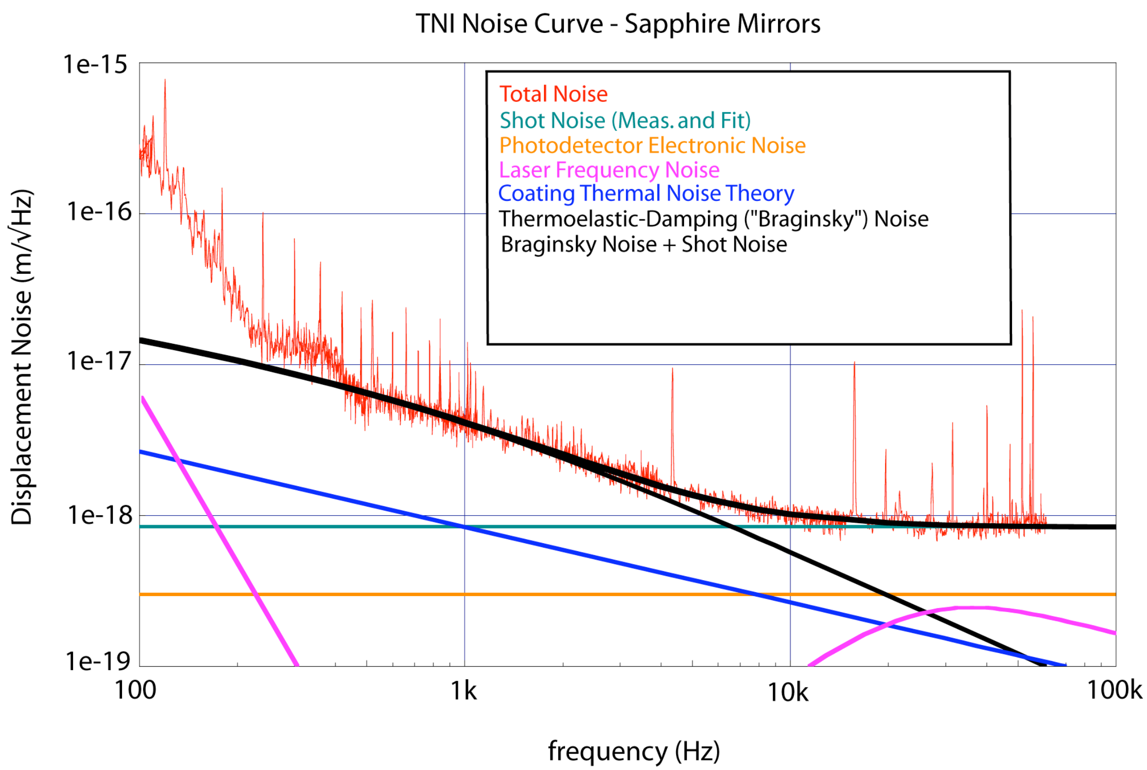
ϕ=1.2-1.8e-4

Measurement Uncertainty and Reproducibility



- Calibration uncertainty <10%
- Shot-to-shot variation in phi <5%
- Change in noise level after removal and reinstallation of mirrors (realignment) = 25%
- Change in phi = 50%
- Uncertainty in phi is determined by alignment, not measurement or calibration uncertainties.
- Does coating thermal noise vary over the face of the optic? Would it matter for the large spot sizes that will be used in AdLIGO?

Sapphire



- Fused-silica substrates removed, sapphire installed
- Noise curve obtained
- Parameters
  - $\alpha = 2.7\text{e-}6\ K^{-1}$
  - $\kappa = 44$ W/mK
- Numerical error in existing theory initially gave unexpected parameters
  - Cerdonio, et al., Phys. Rev. D 63 (8), 082003 (2001)
- Braginsky model validated in Sapphire
- Thermoelastic-damping noise measured at 10x lower level than previous Calcium-Fluoride measurement
  - Numata, *et al.*, PRL 91 (26), 260602 (Dec. 31, 2003)
- Is this the only set of parameters that will fit the data?

Conclusions

- The TNI is fulfilling its mission to measure broadband thermal noise at the lowest levels ever observed.
- The TNI is beginning to contribute to the AdLIGO effort by measuring thermal noise *and extracting relevant parameters* in candidate materials for optics and coatings.
- Existing thermoelastic-damping-noise theory (non-adiabatic-limit) must be corrected to yield correct noise floor with accepted Sapphire parameters.