Estimating thermo-optic noise from AdLIGO coatings

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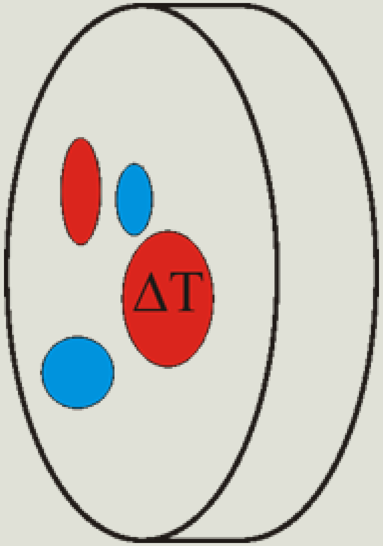
Thermo-optic noise

- Equilibrium temperature fluctuations in the test mass surface cause fluctuations in physical parameters of the coating
  - Thermal expansion coefficient, $\alpha \Rightarrow$ Thermoelastic noise.
  - Thermorefractive coeff. $\beta = dn/dT \Rightarrow$ Thermorefractive noise.

Thermo-optic noise

= (coherent) sum of thermoelastic and thermorefractive contributions.



Thermorefractive contribution somewhat higher than thermoelastic contribution but same order of magnitude.

$$S_T(\omega) = \frac{\sqrt{2} k_B T^2}{\pi r_0^2 \sqrt{\omega \kappa \rho C}}$$

$$S_{x,TE}(\omega) = \frac{\sqrt{2} k_B T^2}{\pi r_0^2 \sqrt{\omega \kappa \rho C}} \times \left(2 \alpha_{eff} d\right)^2$$

$$S_{x,TR}(\omega) = \frac{\sqrt{2} k_B T^2}{\pi r_0^2 \sqrt{\omega \kappa \rho C}} \times \left(2 \beta_{eff} d\right)^2$$

$$\alpha_{eff} = \left(1 + \nu_{bulk}\right) \left[\frac{\alpha_1 d_1}{d_1 + d_2} \frac{E_1 \left(1 - 2\nu_{bulk}\right)}{E_{bulk}\left(1 - 2\nu_1\right)} + \frac{\alpha_2 d_2}{d_1 + d_2} \frac{E_2 \left(1 - 2\nu_{bulk}\right)}{E_{bulk}\left(1 - 2\nu_2\right)} - \alpha_{bulk} \right]$$

$$\beta_{eff} = \frac{n_1 n_2 \left(\beta_1 + \beta_2\right)}{8\left(n_1^2 - n_2^2\right)} \frac{\lambda}{d}$$

Formulas shown are from Braginsky and Vyatchanin (2003).

Independent thermoelastic noise calculation using a different approach due to Fejer et al. (2004) is used in Bench 5.0 .

How to estimate thermo-optic noise

- Use formulas (From Braginsky and Vyatchanin or Fejer et al.)
  - Need α and β for both the high index and low index coating materials *in their amorphous-film state*.
  - The $\beta_{T\alpha_2O_5}$ for ion beam coatings never measured. Measurement of $\beta_{T\alpha_2O_5}$ for LIGO style coatings necessary.
  - One measurement exists for electron beam deposited coating. Rather high: $\beta_{T\alpha_2O_5}$ = 1.21x10^{-4} (Inci).
- May be possible to measure the noise directly in the TNI.

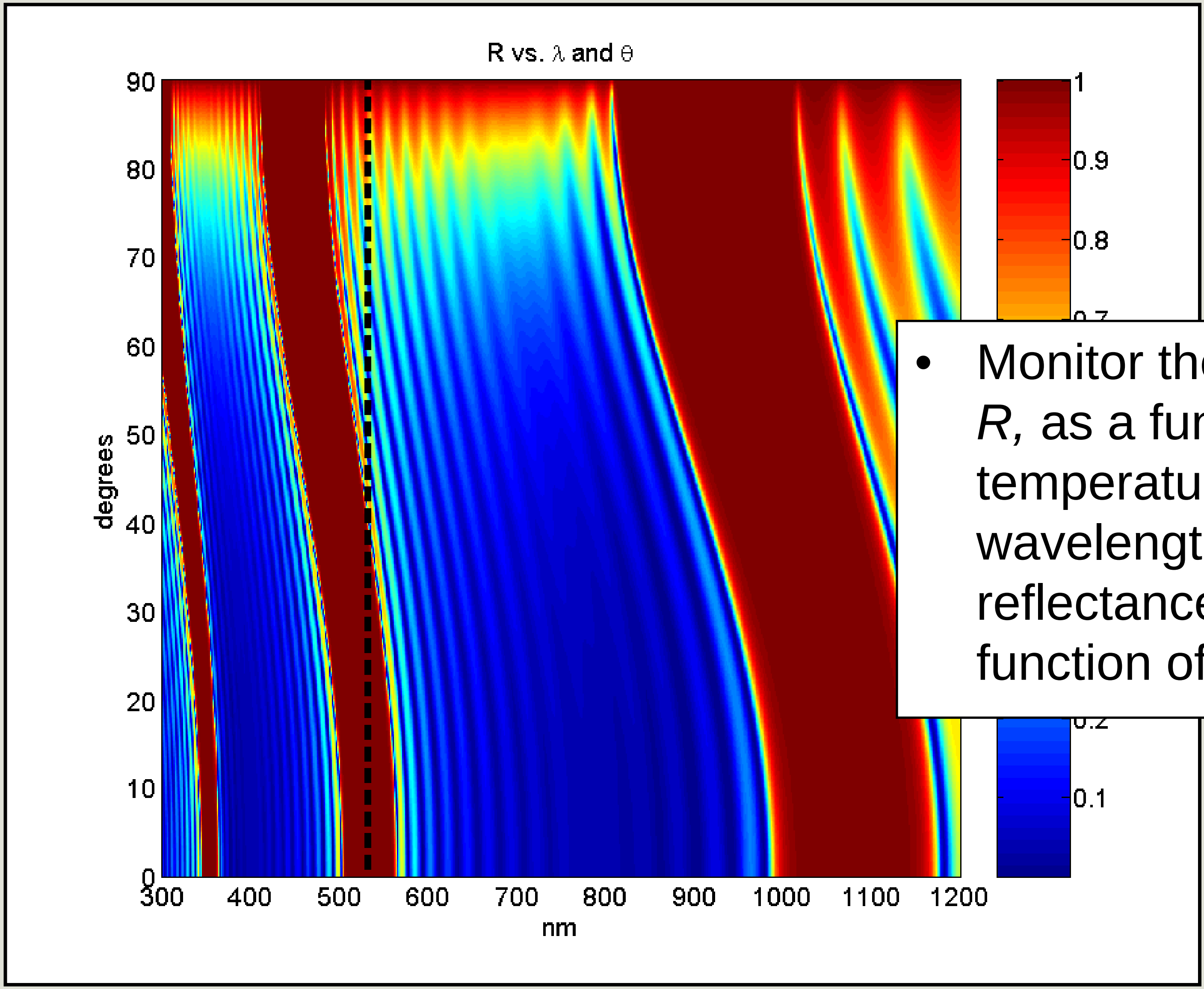
How to measure $\beta_{T\alpha_2 O_5}$ with resolution of several 10^{-6} K^{-1} over ΔT~100 K near room temperature.

- Brewster angle change of a single tantala layer:
  - Need DC sensitivity to $\Delta\theta_B \sim 10^{-4}$ rad. –> *“Somewhat hard”* due to laser beam pointing stability, air motion etc.

- Ellipsometry:
  - Need DC sensitivity to changes of R_p / R_s on the order of about 10^{-4} . –> *“Fairly doable”*.

- $\mathrm{d}R/\mathrm{d}T$ for a 30-layer coating for a λ on the “reflectivity cliff”:
  - Need DC sensitive to $\Delta R \sim 1\%$. –> *“Easy”*.

Measuring dn/dT for Ta_2O_5 coating layers



- Monitor the reflectance, *R*, as a function of temperature at a wavelength where the reflectance is a strong function of n_{Ta2O5}.

The setup

<u>Obtain</u>:

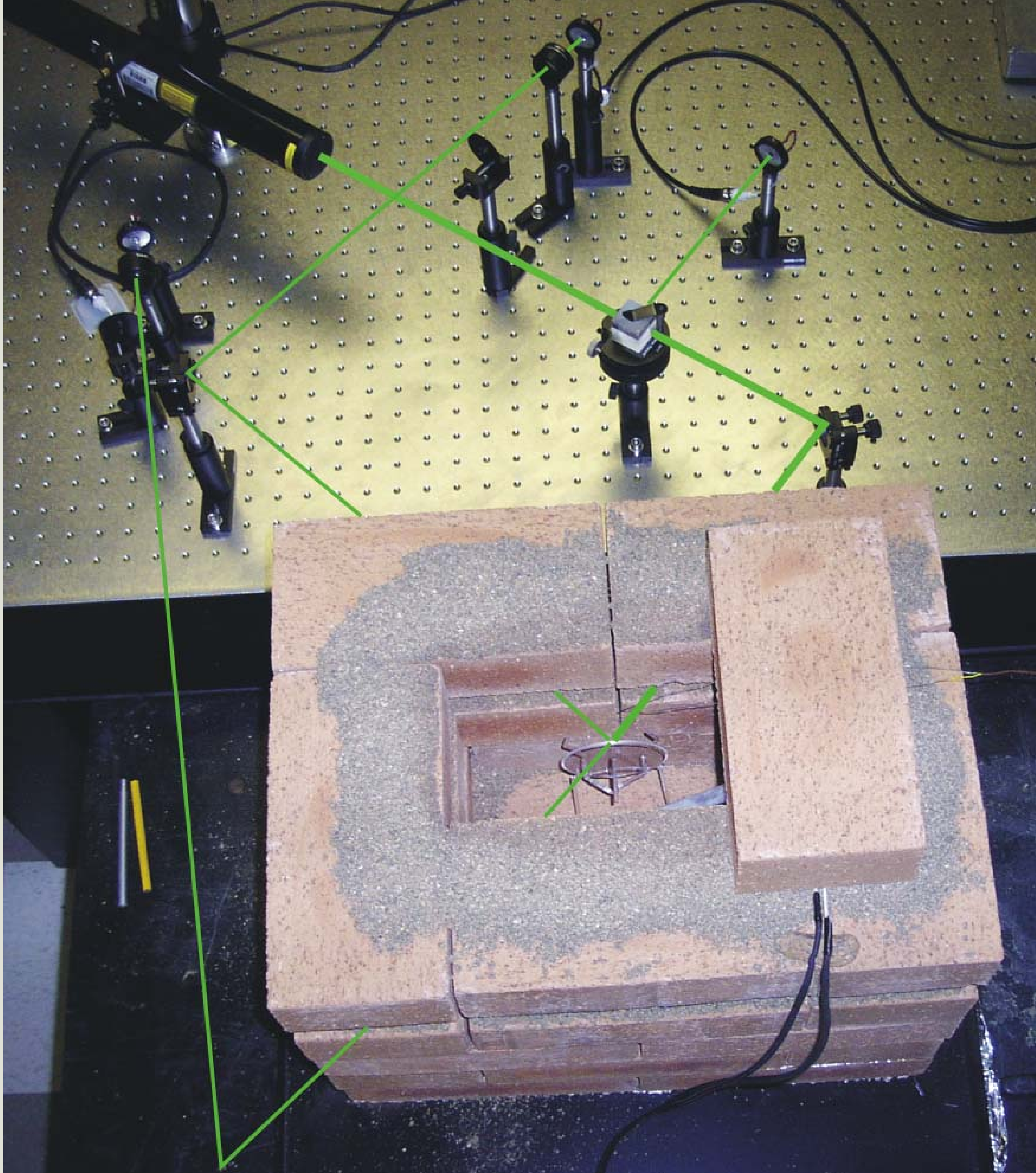
(P_{trans} / P_{input})

and

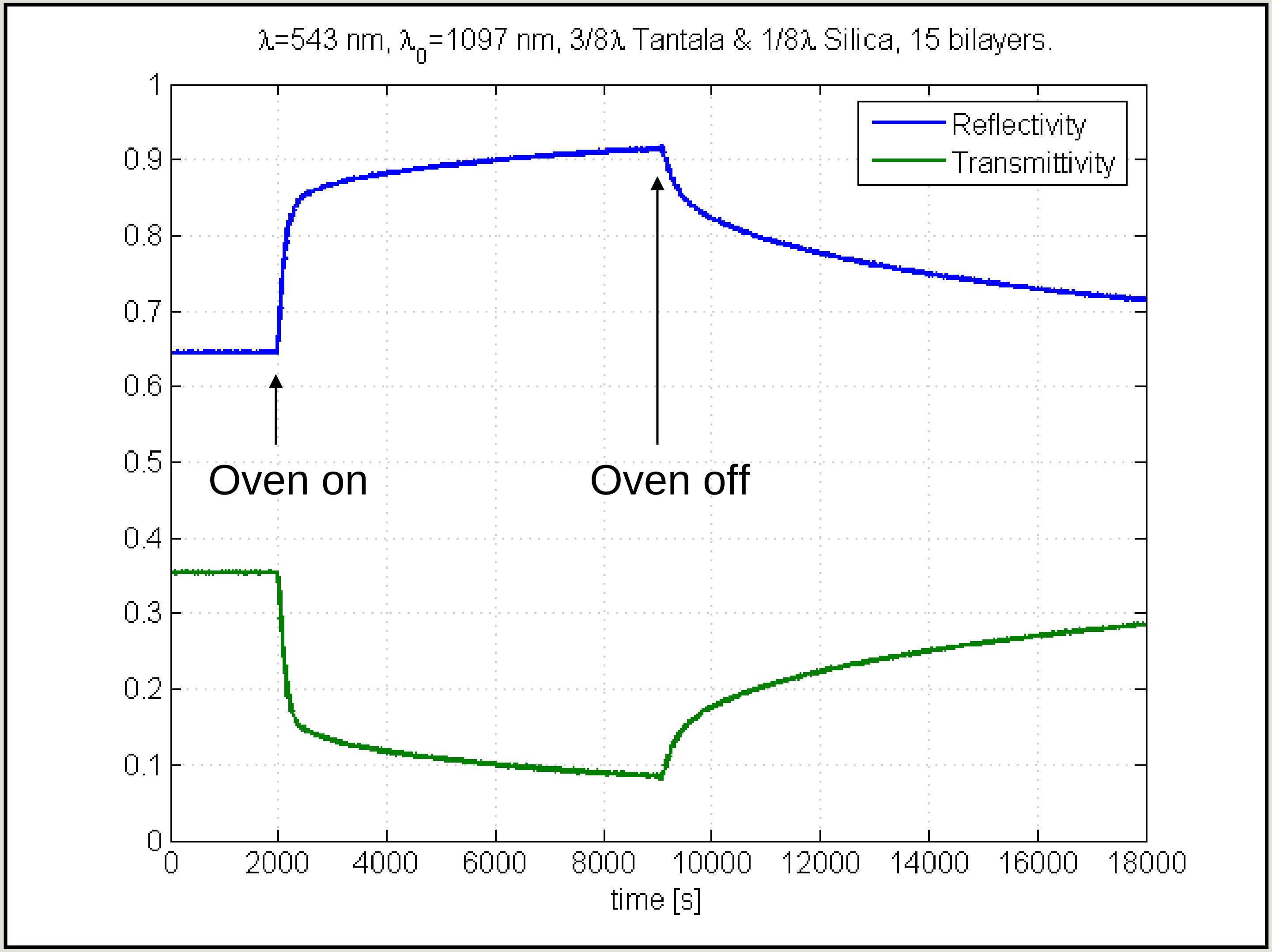
(P_{refl} / P_{input})

versus

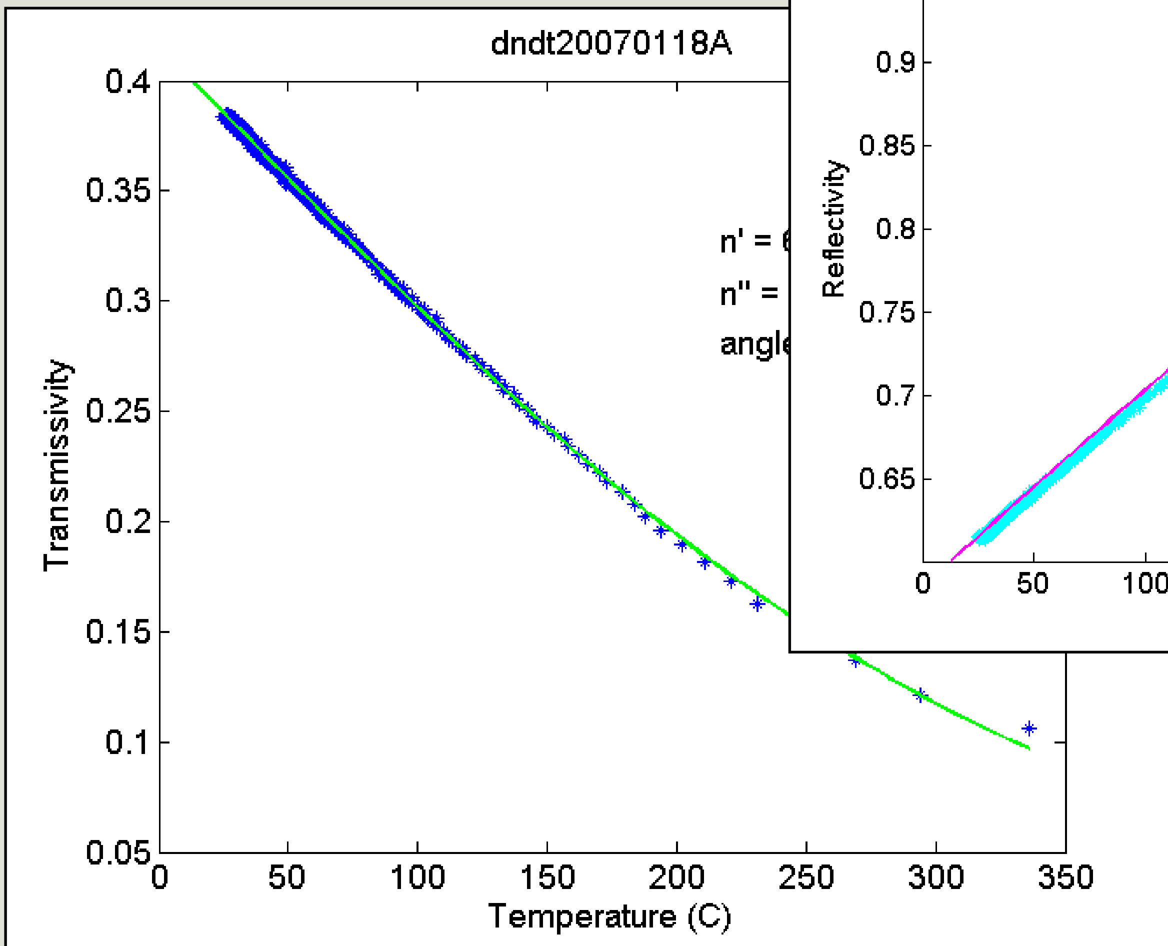
T_{sample}

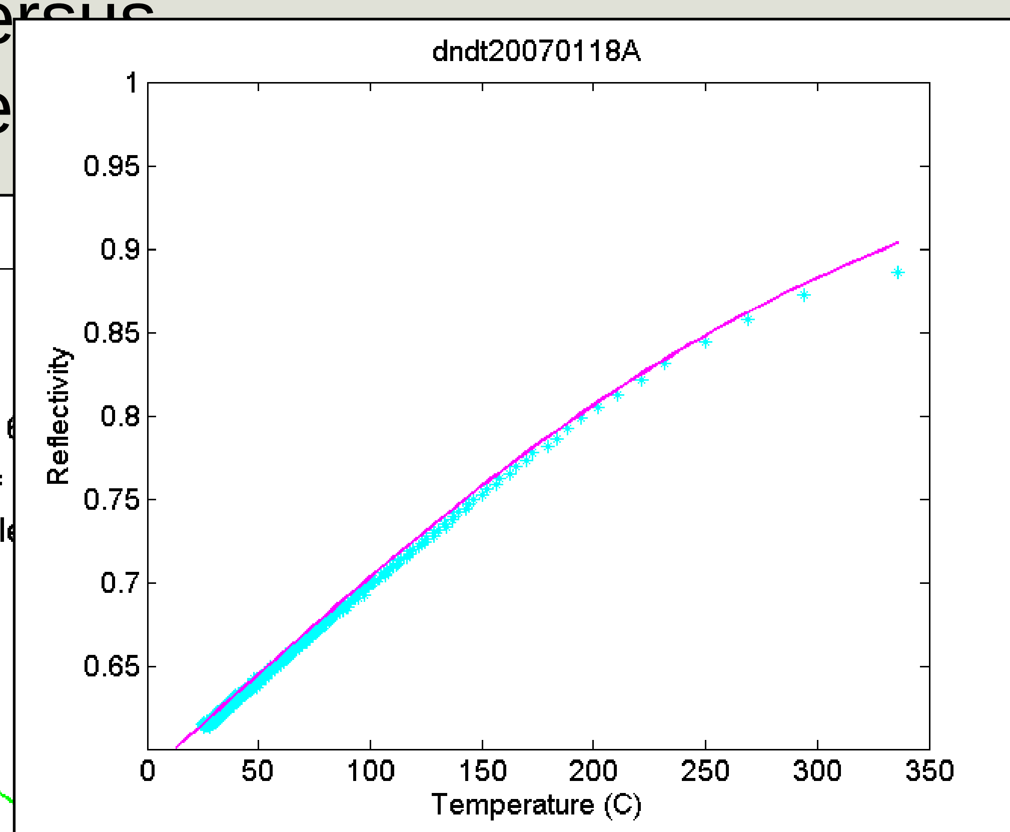


Typical raw data

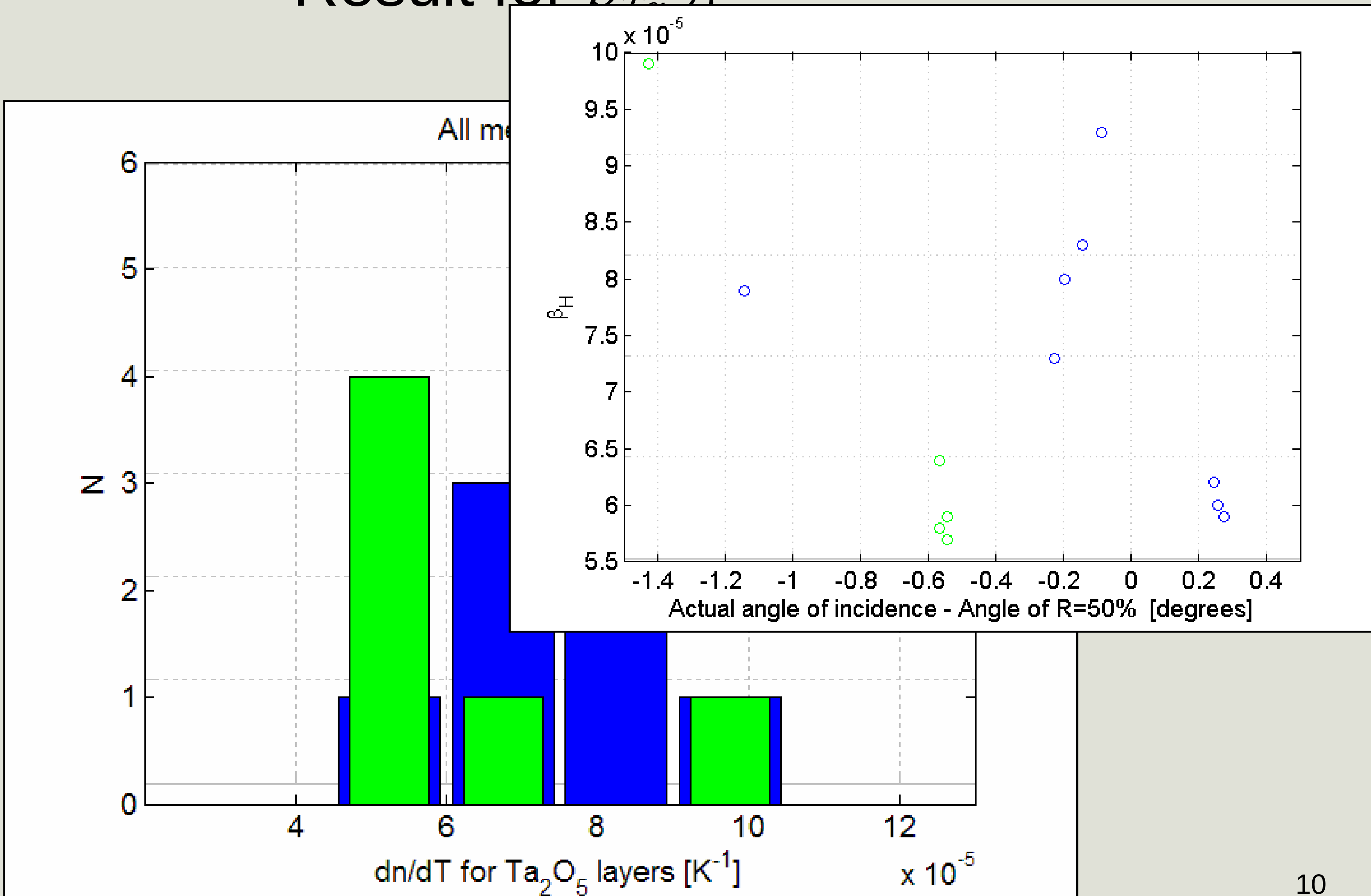


Reflectivity and Transmissivity versus Temperature



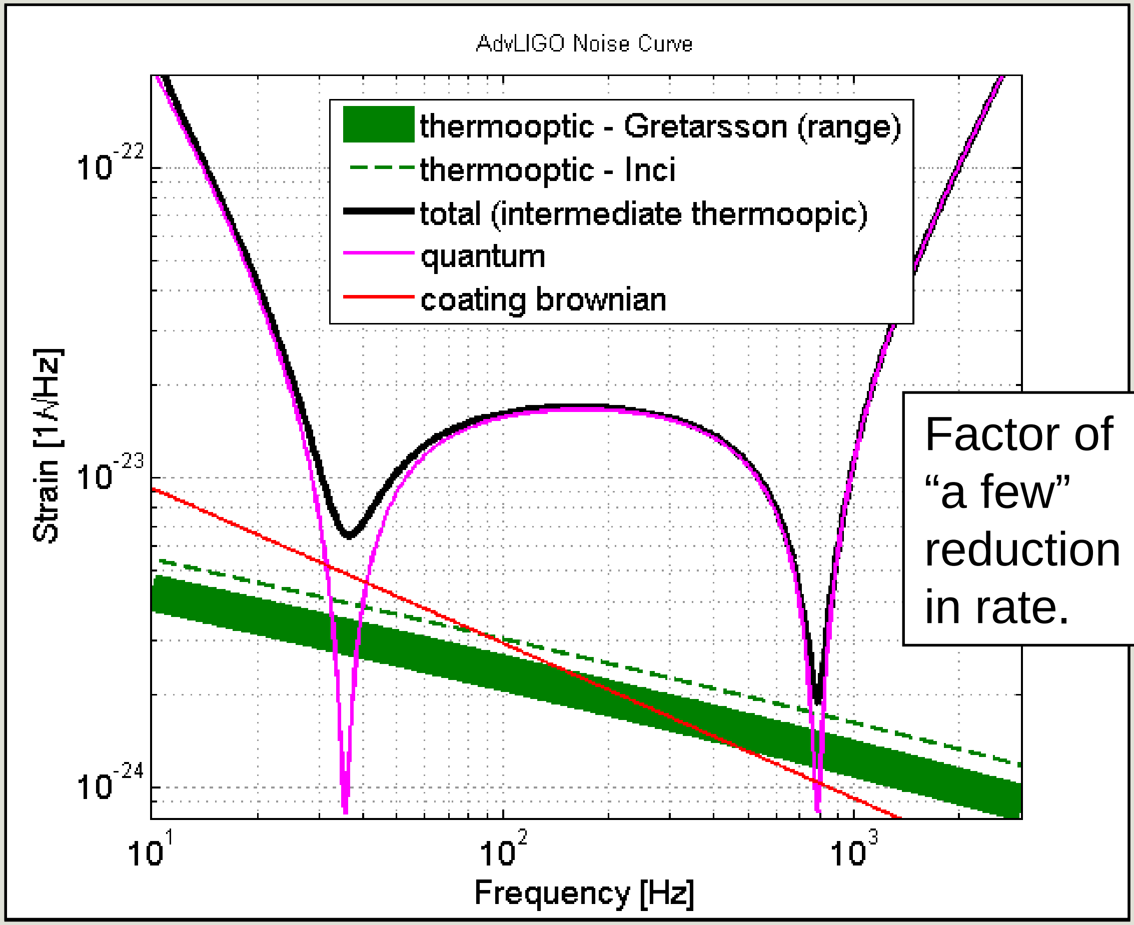


Result for $\beta_{Ta_2O_5}$



Thermo-optic noise from AdLIGO coatings

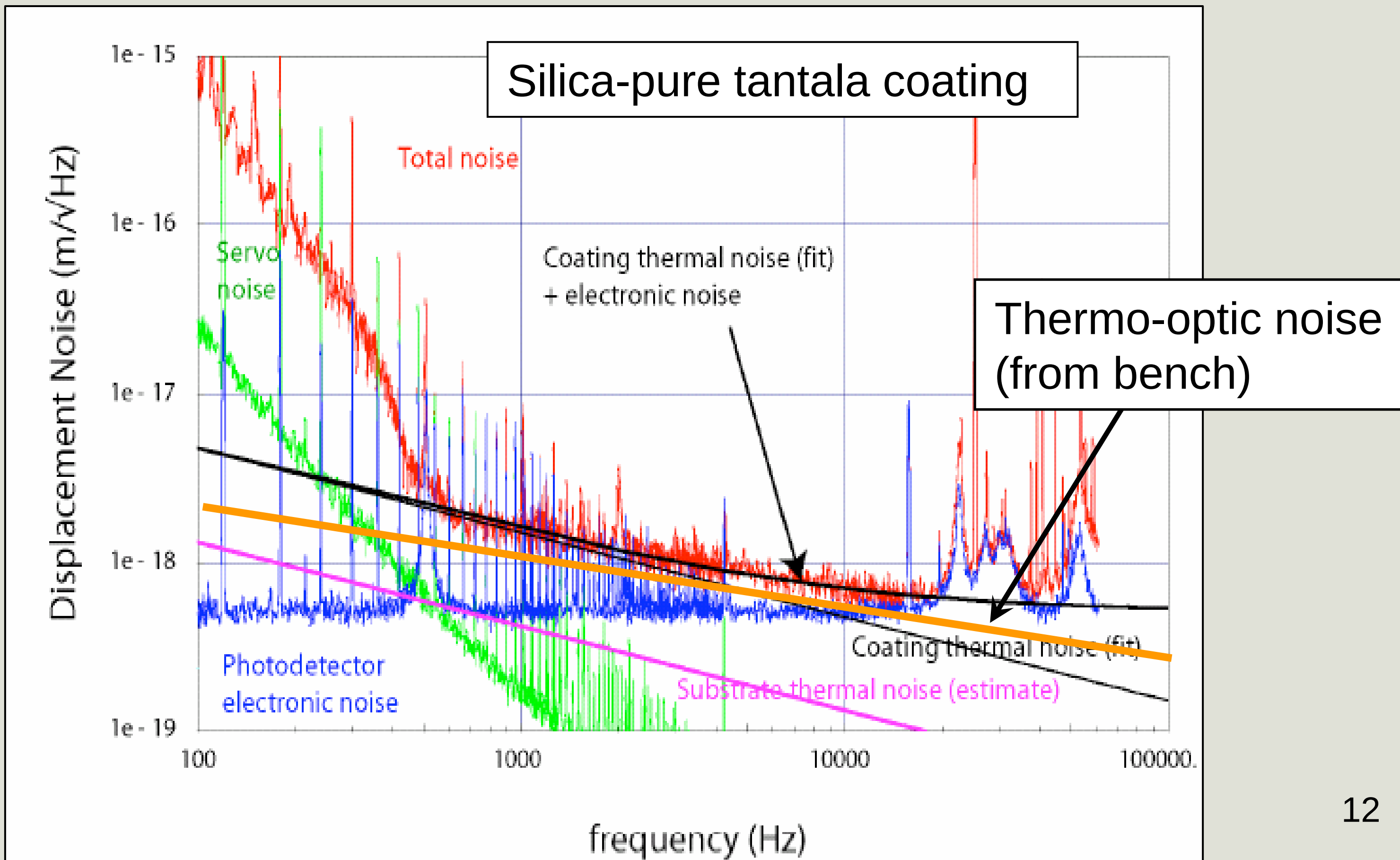
- A clearly “visible” noise source for AdLIGO in the broadband mode.
- The limiting noise source for AdLIGO in the narrowband mode.



Factor of “a few” reduction in rate.

The TNI is in the ballpark

- With $\beta_{Ta_2O_5}$ = 7.5 x10^{-5}, the TNI is *very close* to seeing thermo-optic noise.
  - TNI calibration under review (quoted noise floor probably too low by ~25%)
  - My measurements to date are at λ=543 nm. TNI interrogates at 1064 nm.



Next

- Measure $\lambda/8$ Ta_2O_5, $3\lambda/8$ SiO_2 coating with current (green) laser for comparison with current results.
- Change to 1064 nm laser.
- Measure some of the existing $\lambda/4$ coatings on thin samples:
  - Start with pure tantala / silica coating for comparison with previous results.
  - Get to Titania-doped tantala / silica as quickly as possible.