# TCS Noise Coupling

Phil Willems, Caltech

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# How We Have Estimated TCS Noise Coupling Before Now

- Assume TCS actuator power fluctuates at audio frequency.
- Thermal diffusion length is $l \approx \sqrt{\frac{k}{\pi f \rho C_V}}$
- This is about 50 microns at 100 Hz so the temperature fluctuation is restricted to a thin surface layer.
- This thin layer thermally expands and contracts.
- To the extent the IFO beam overlaps with this thermally expanding layer, we see noise. Regions far from heating are immune.

# Why This Is Incomplete

- The heat fluctuation is localized, true, but-
- Its thermal expansion produces a stress that propagates throughout the optic.
- This stress propagation is at the speed of sound, i.e. instantaneous relative to the LIGO bandwidth.
- The position of the mirror surface relative to the mirror center of mass (which does not move) thereby changes.

# An Extreme Example

"Popsicle stick" mirror:

-long and thin compared to probe beam

-makes the calculation of bending effects easy

-for a bimetallic strip,

$$\frac{1}{R}=\frac{6Y_1Y_2(t_1+t_2)t_1t_2\Delta\varepsilon}{Y_1^2t_1^4+4Y_1Yt_1^3t_2+6Y_1Yt_1^2t_2^2+4Y_1Yt_1t_2^3+Y_2^2t_2^4}$$

-where the *misfit strain* is

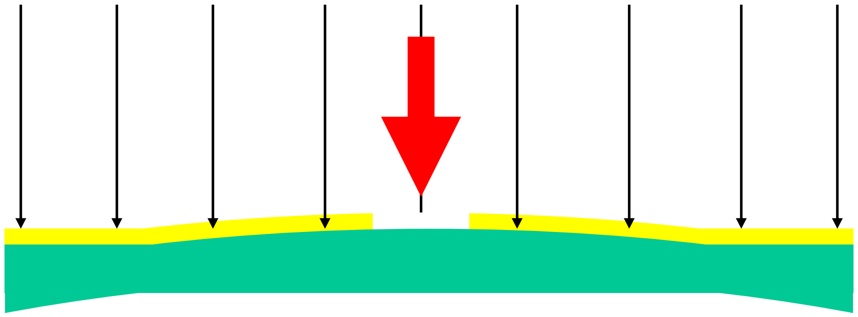
$$\Delta\varepsilon=(\alpha_1-\alpha_2)\Delta T$$

$$\Delta\varepsilon=\alpha\Delta T$$

-for us this simplifies to

$$\frac{1}{R}\approx\frac{6t_1\alpha\Delta T}{t_2^2}$$

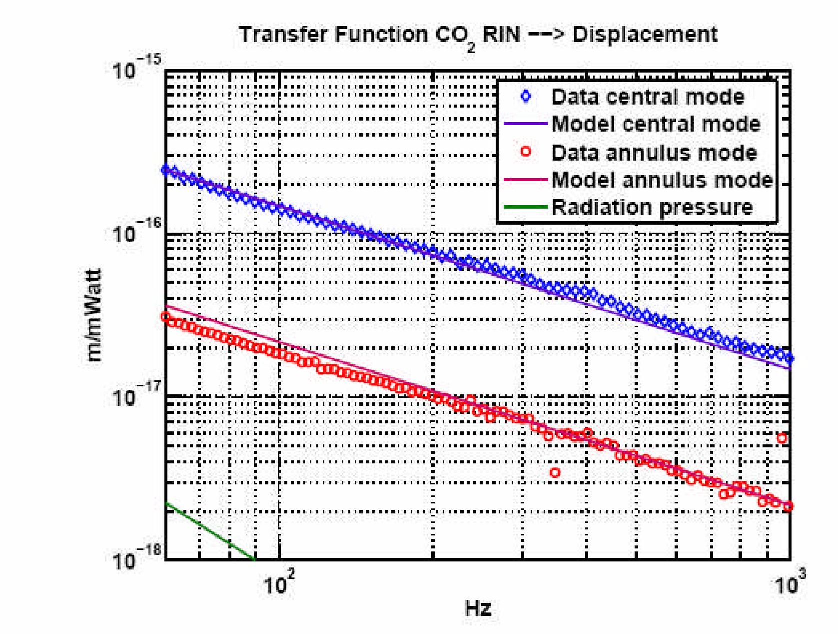
-this moves the mirror face relative to the mirror center of mass, which does not move



Notice that the bending is seen by the probe beam even though the TCS heating be elsewhere.

# What about real LIGO mirrors?

- I haven't figured out how to fully model this yet- thin layers are not friendly to FEM models
- But Stefan has a simplified calculation that shows very good agreement to our observed noise coupling…



# So what, Phil?

- Roughly speaking, this noise coupling to test mass displacement doesn't change much regardless of where the thermal compensation hits the mirror.
- Advanced LIGO has tight noise specs.
- This mechanism likely means only ring heaters may act on test masses- no hope for $CO_2$ lasers.
- For compensation plates, $CO_2$ lasers are still an option but this noise must be considered.
- Other thermally compensated optics?