The Study of Evanescent-Wave Heat Transfer in a Parallel Plane Geometry

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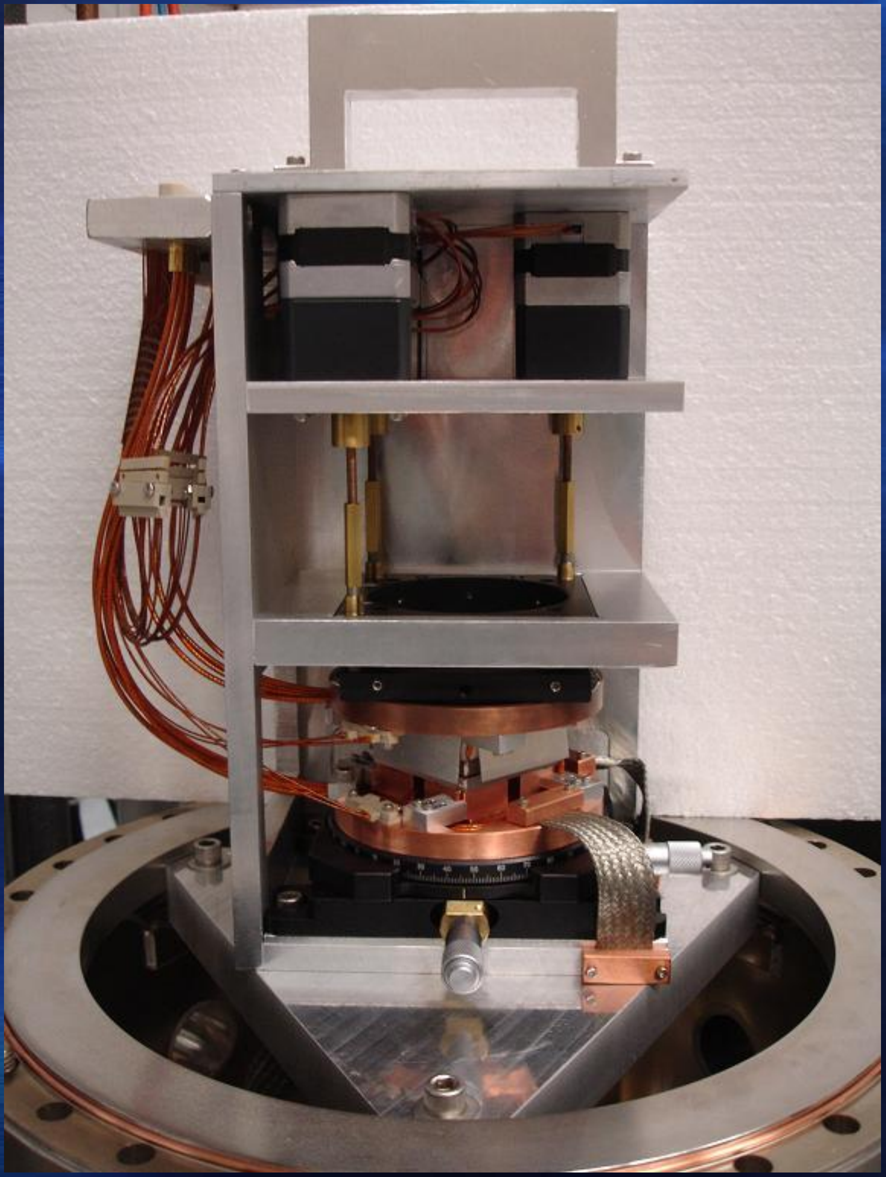
Outline

- Theory
- Experimental setup
- Results
- Application in LIGO
- Current standing

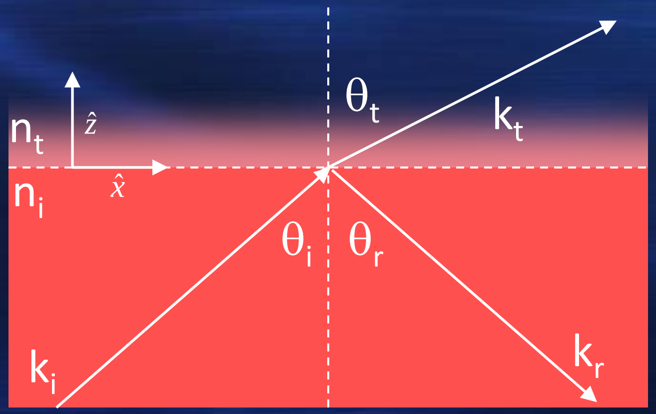


What is Evanescent-Wave Heat Transfer?

- Exponentially decaying EM field outside a material medium
  - Produced by total internal reflection inside a medium.
- For a propagating wave in the transmitted medium
  - k_{tx} and k_{tz} can be found by using Snell's Law.
  - In the case of total internal reflection ($\sin\theta_i > n_t/n_i$)
- Thus resulting in,

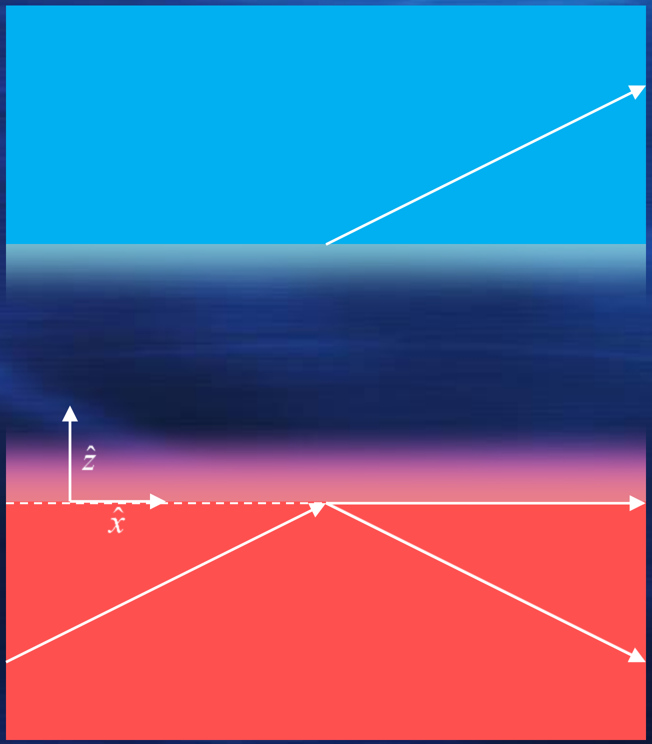
$$\vec{E}_t = \vec{E}_{t0} e^{ik_t x \frac{n_i}{n_t} \sin\theta_i} e^{-k_t z \sqrt{\frac{n_i^2}{n_t^2} \sin^2\theta_i - 1}} e^{-i\omega t}$$

  - E_{tz} is exponentially decaying



What is it Good For?

- If another medium is brought near the interface, then some of the energy emitted in the z direction can propagate into the new material.
- This condition known as frustrated total internal reflection (photon tunneling).

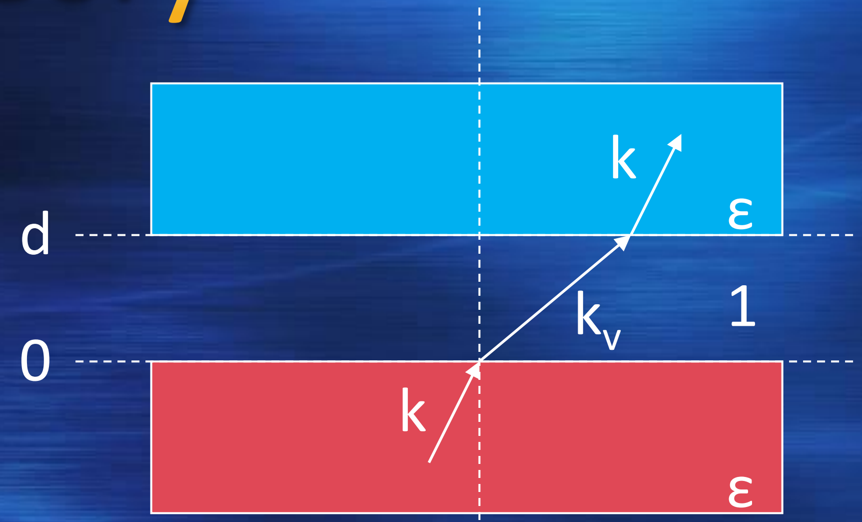


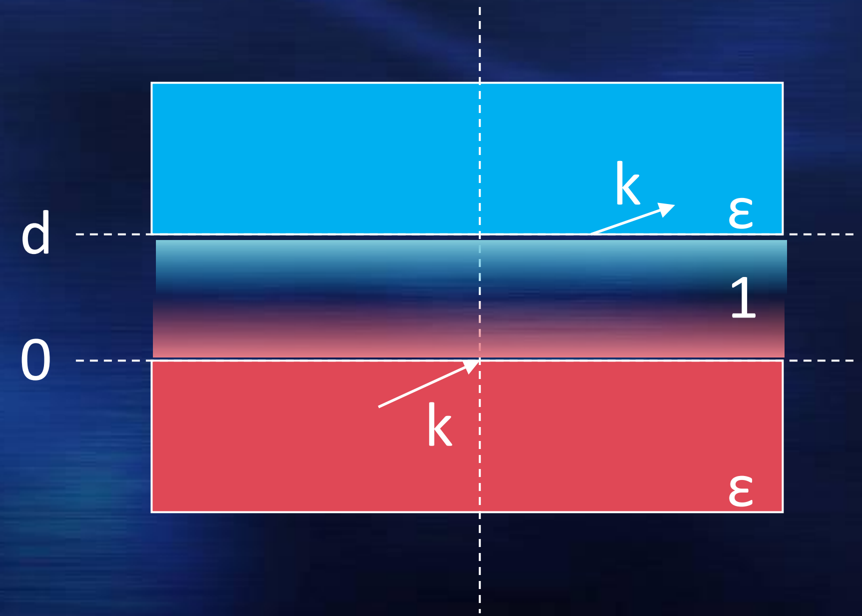
Theory

- Heat transfer coefficient $\mathcal{W}$ is the sum of two parts $\mathcal{W}_{sin}$ and $\mathcal{W}_{exp}$

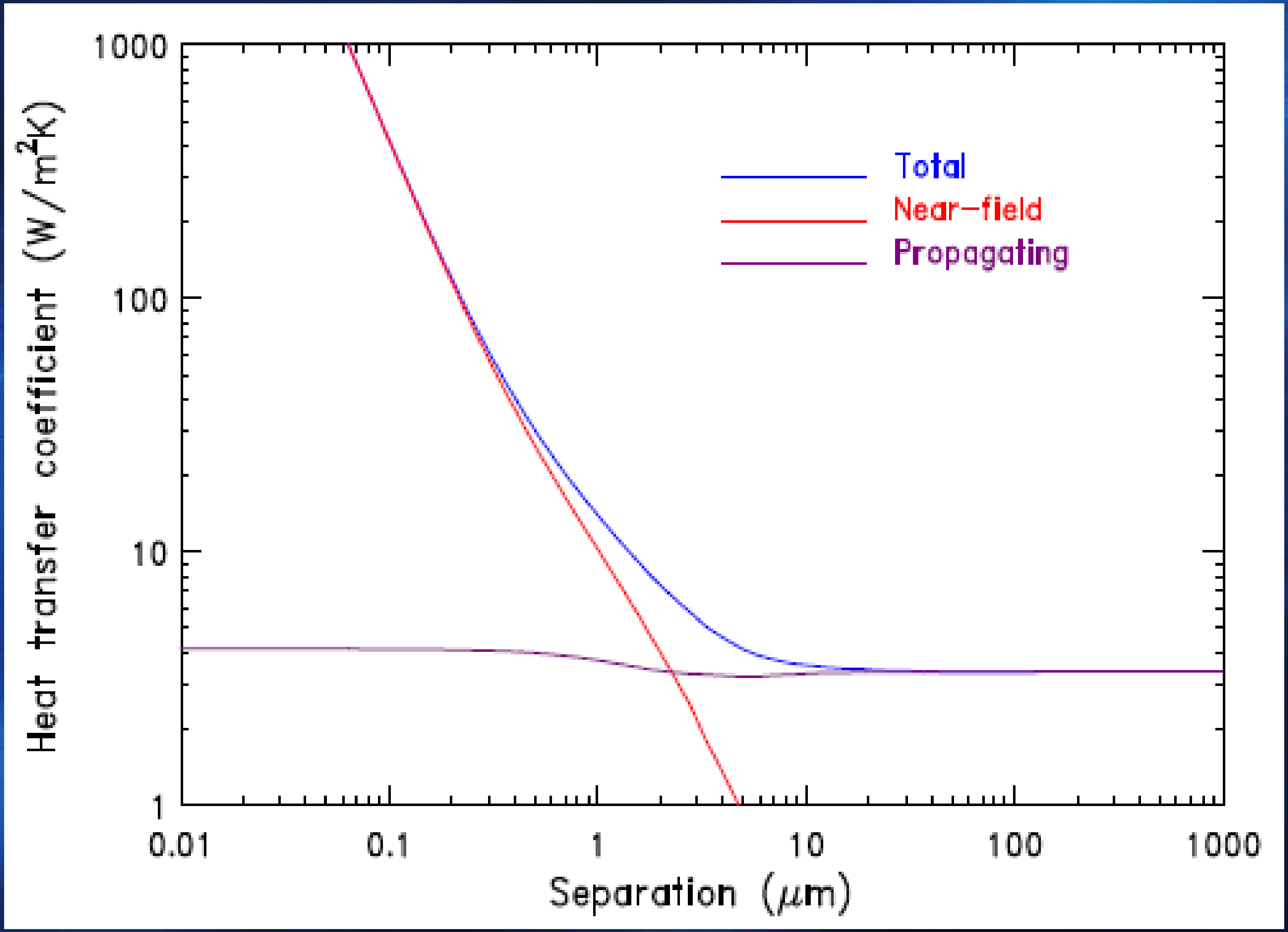
- $\mathcal{W}_{sin}$ is for propagating fields (far-field)

- $\mathcal{W}_{exp}$ is for the near-field





Theory



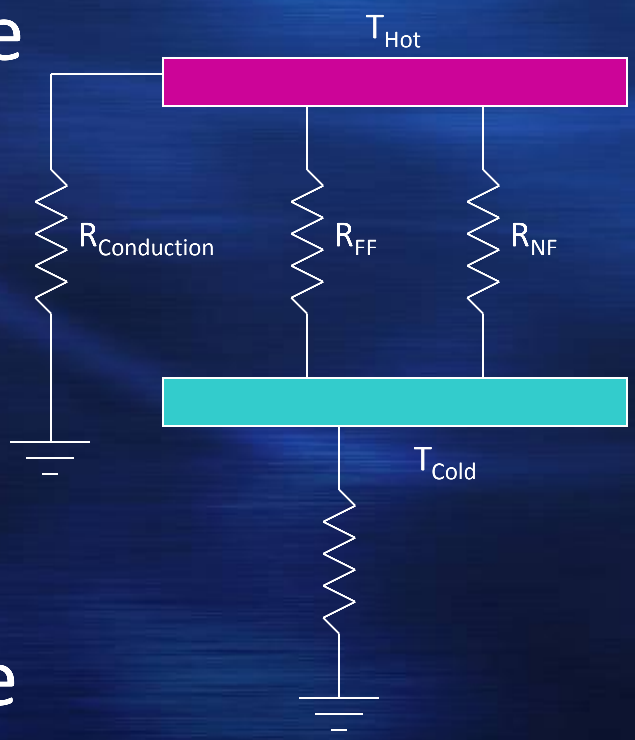
1000
100
10
1
0.01
0.1
1
10
100
1000
Separation (μm)
Heat transfer coefficient (W/m2K)
Total
Near-field
Propagating

Heat Transfer Measurements

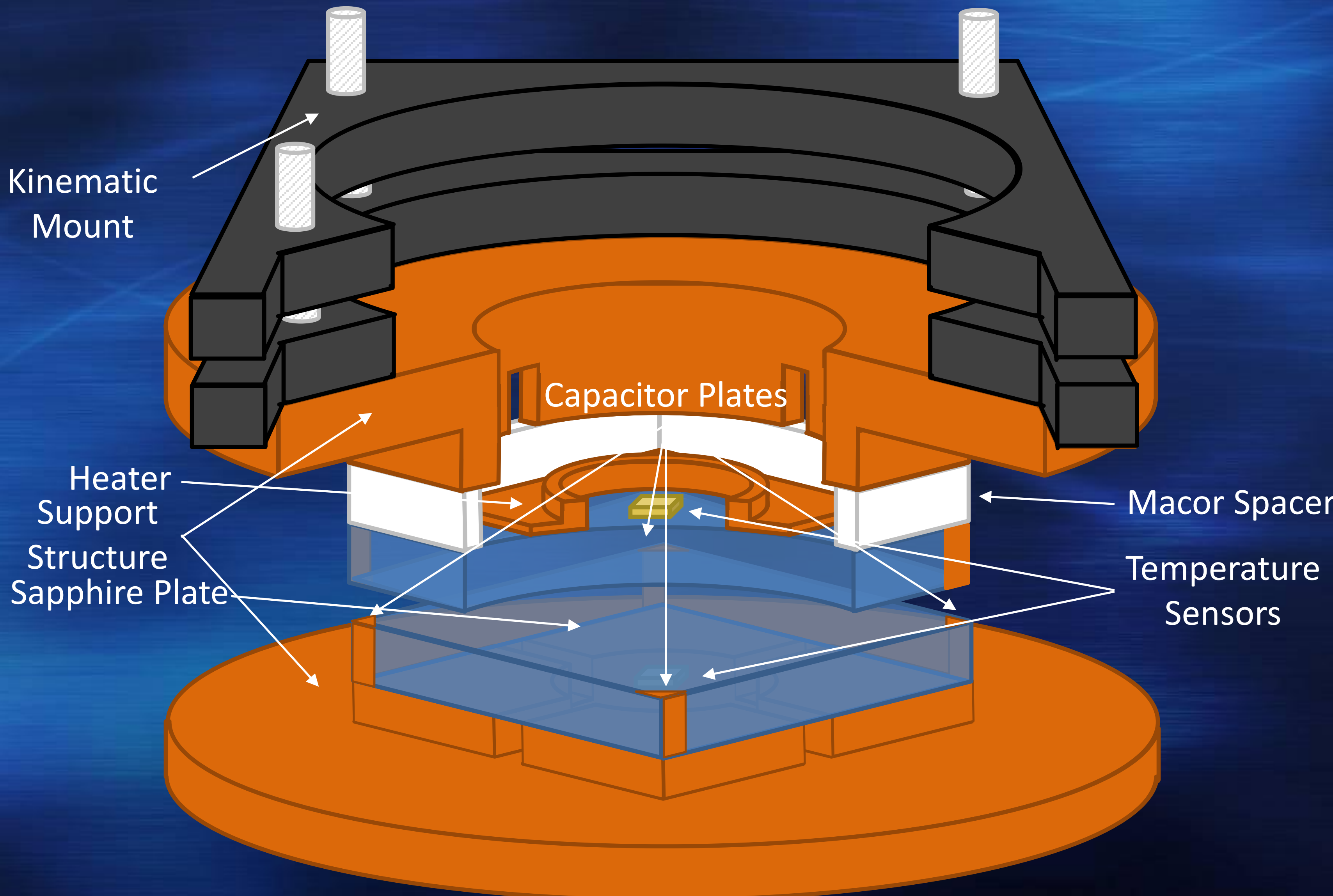
To measure the heat transfer we take the ratio of power going to the heater to the area times the difference in temperature of the two plates

$$w = \frac{P}{A \cdot \Delta T}$$

By moving the two plates closer together we should see an increase of the power going to the heater



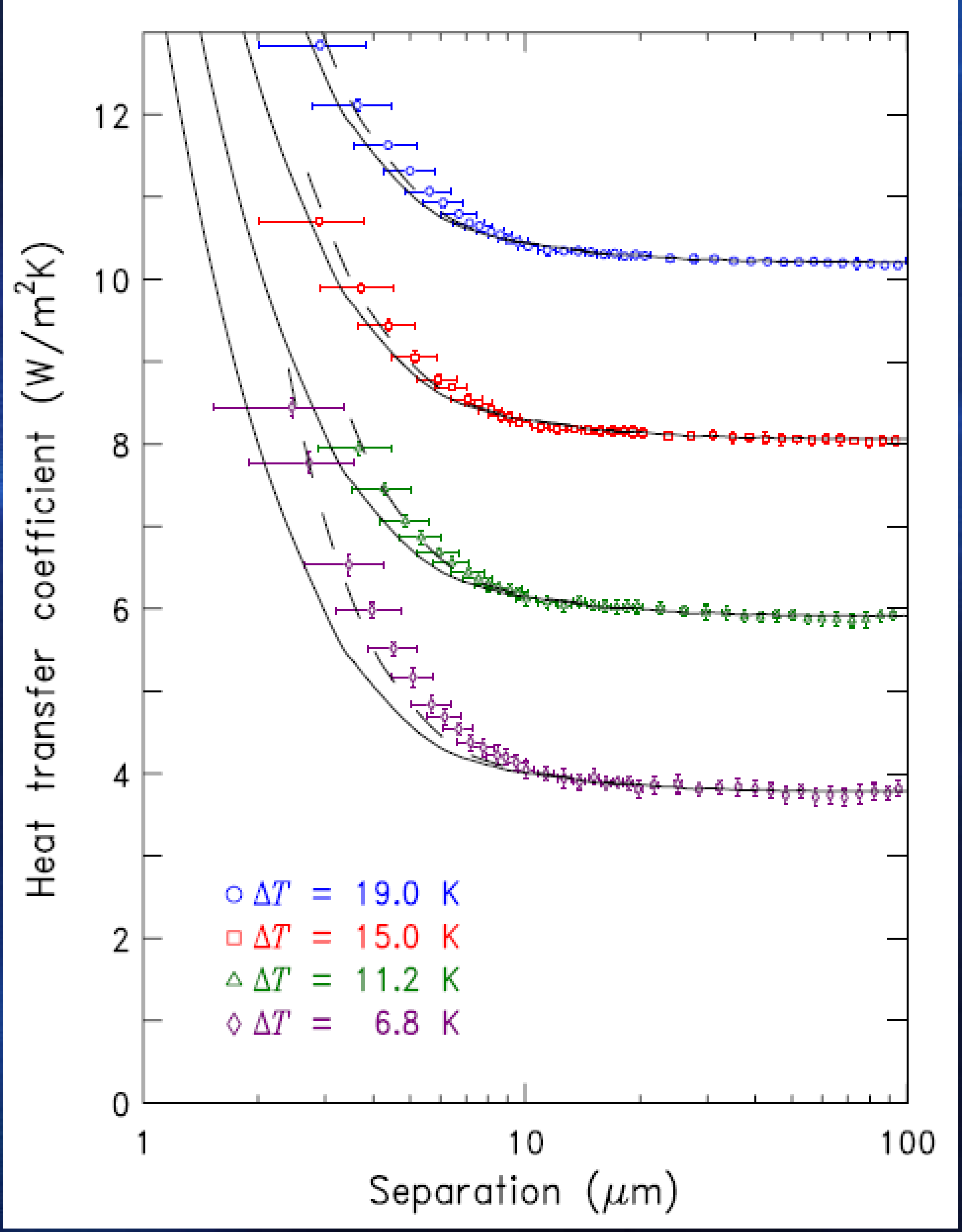
Experiment



Kinematic Mount
Capacitor Plates
Heater
Support Structure
Sapphire Plate
Macor Spacer
Temperature Sensors

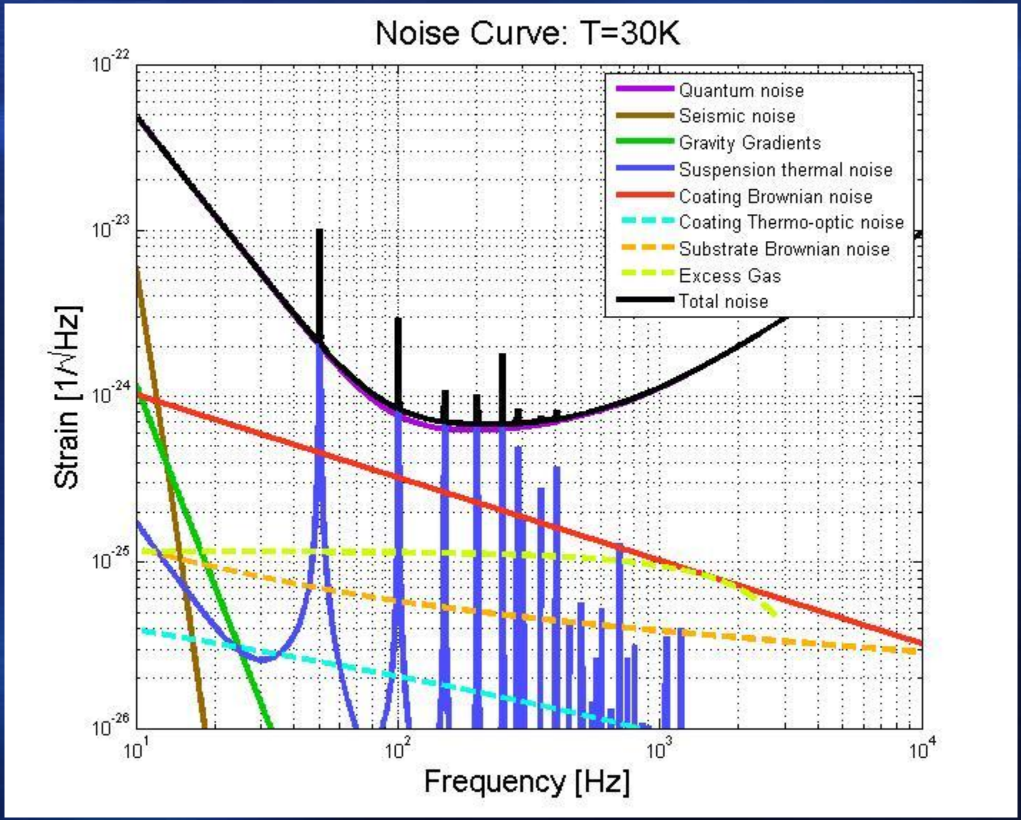
Results

- Four data runs at four different temperature differences (offset by 2 W/m^2K from each other)
- Model prediction is in solid black
- Correction for bend in sapphire plate is in dashed black



Cooling LIGO

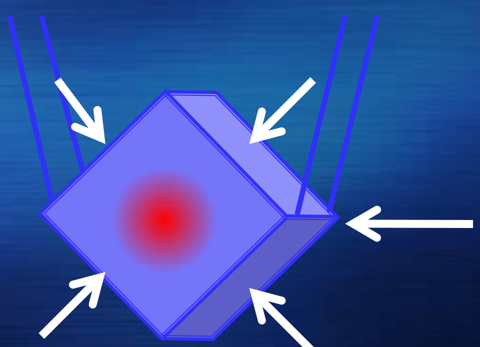
- Future versions of LIGO may be cryogenic
  - To reduce thermal noise
  - A need arises to remove absorbed laser power from the test masses ~3W
- Methods of Heat Transfer
  - Convection <<1μW
  - Conduction ~60mW
  - Radiation ~700mW (far field)

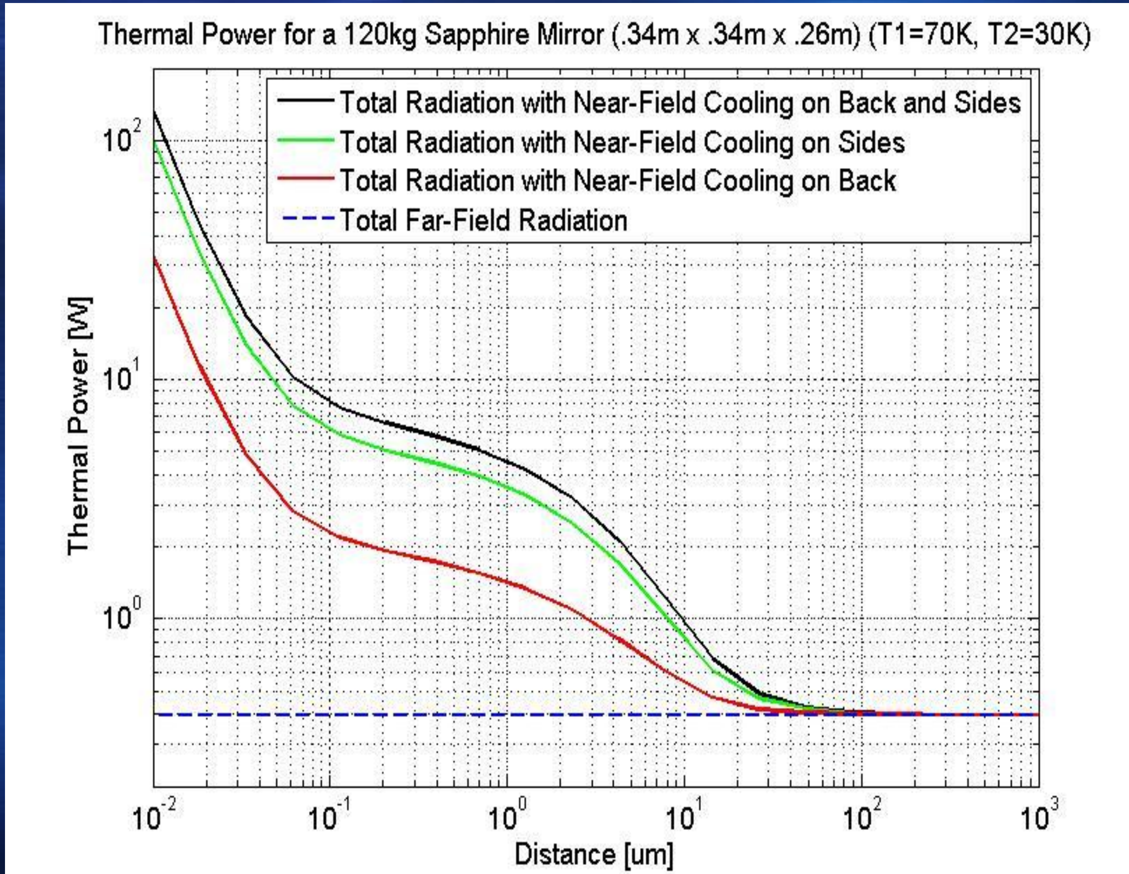


Pushing towards the ET sensitivity using ‘conventional’ technology, Stefan Hild et al, 2008
Gravitational Wave Interferometer Noise Calculator (GWINC) , Sam Finn et al, 1999

Evanescent waves and LIGO

- Implementing near field cooling
  - Back
    - Only have to deal with one surface
    - Have to deal with noise coupling due to electrostatics and Casimir force
  - Sides
    - Have to deal with multiple surfaces
    - Noise coupling has minimal impact
  - Back and Sides

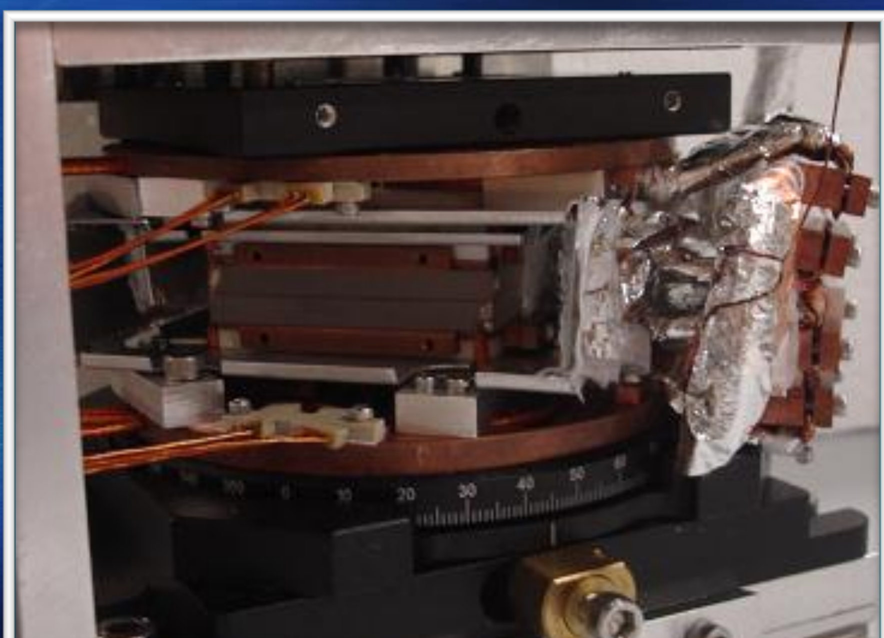


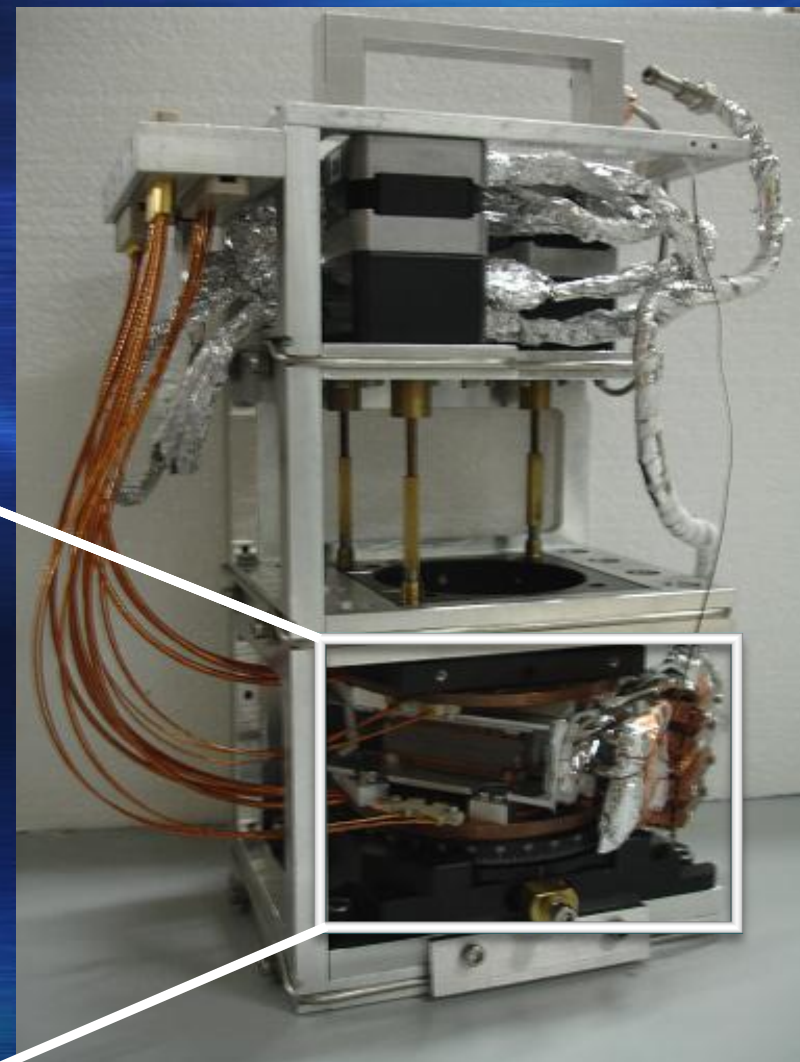


Conduction through the fibers: 4.4×10^{-6} W/K (<< far field radiation)

Modifications

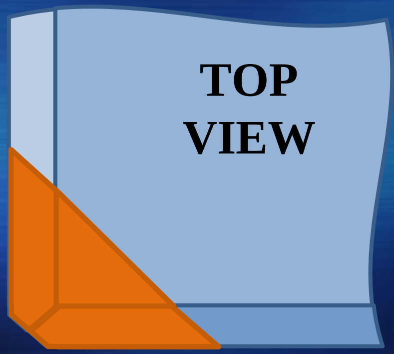
- Modified to work in cryogenic conditions
- Thicker Sapphire plates
- Both sapphire plates will be thermally controlled

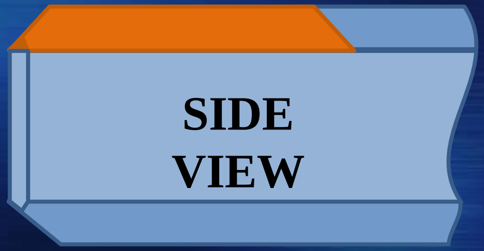


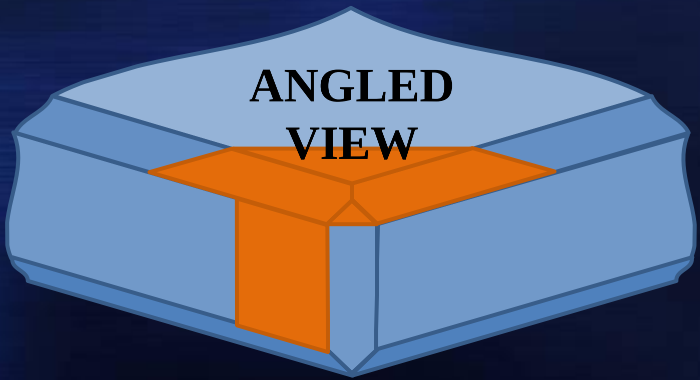


Capacitance Measurements

- The new sapphire plates have a bigger bevel.
- This adds a stray capacitance to the total which causes our distance measurements to be less accurate
- A work in progress







Capacitance Measurements

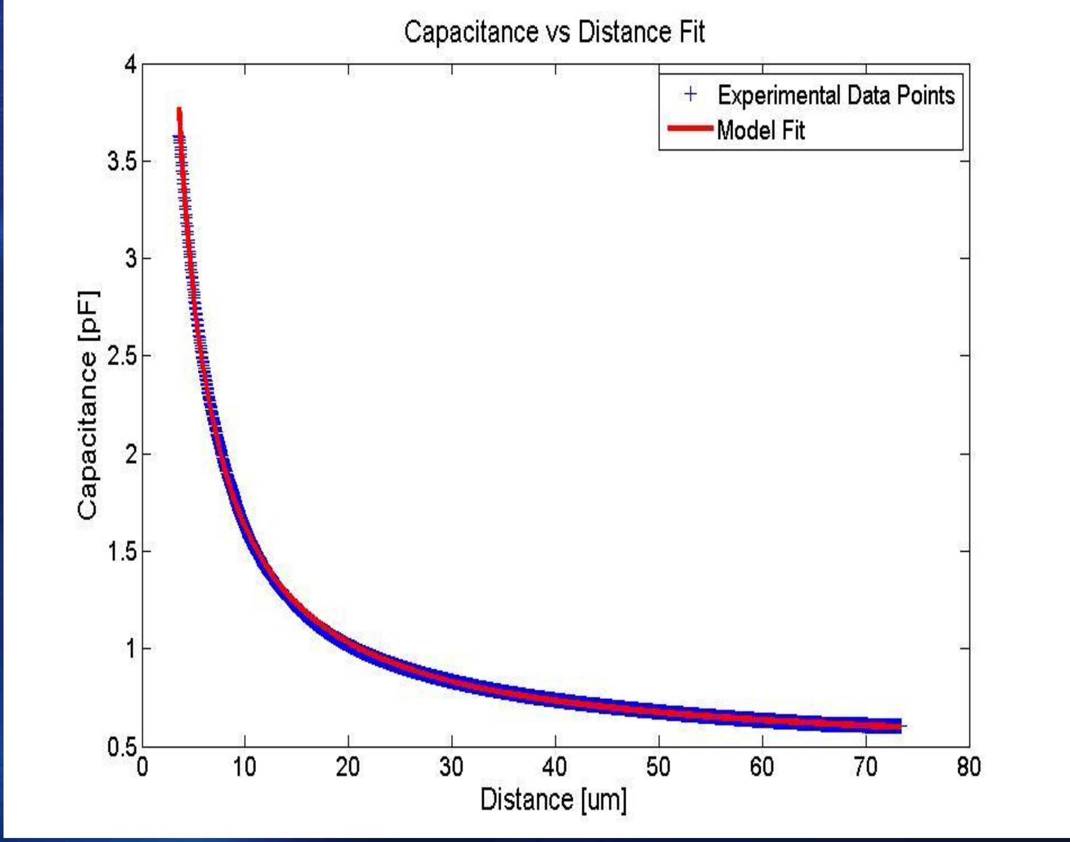
- Originally we fit to the equation

$$C = \frac{\gamma}{d + d_0} + \delta$$

  - Where γ, δ, and d_0 are fitted values.

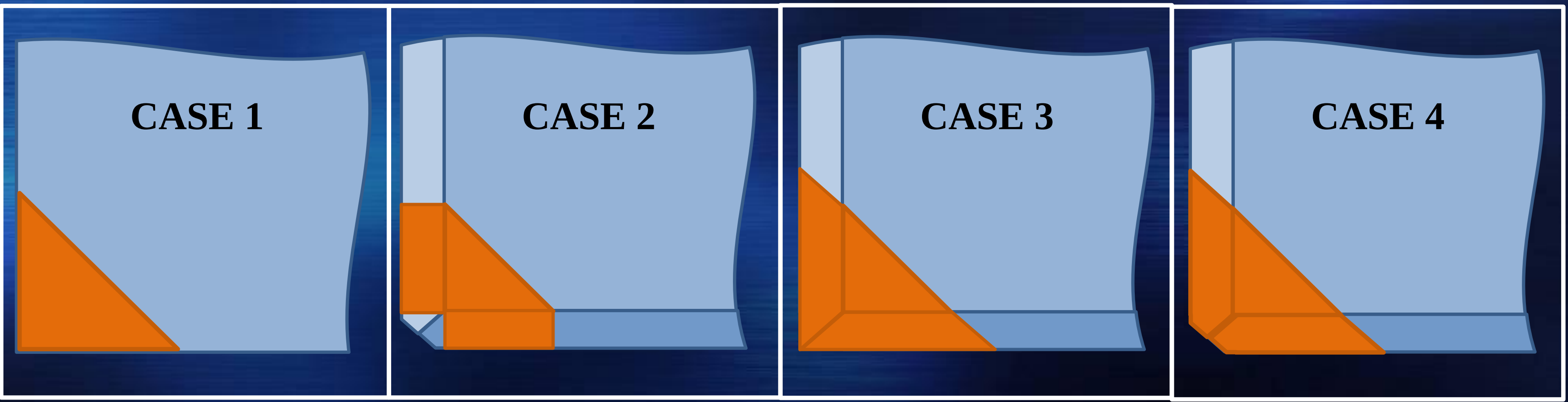
- Once these values were determined we could easily find d(C).

$$d(C) = \frac{\gamma}{C - \delta} - d_0$$



Capacitance Measurements

- Depending on which case we use and if we approximate we can get different values for the fits
- These fits can be about 5 μm off from one another



Cleaning

- With thicker sapphire plates
  - Less bend
  - Dirt becomes a bigger problem
- Even in the UF LIGO clean room there is still dust from wipes and sticky sediment from unknown origin (likely from the clean solutions).
- We are working on a method for cleaning to clean the sapphire plates.
  - Drag wipe with acetone
  - Drag wipe with methanol
  - Coat with first contact (but not on capacitor plates)

Conclusion

- Measured evanescent-wave heat transfer across a small gap and it agrees with theory
- Can potentially be used to take excess heat from mirrors in LIGO
- Working on important issue to ensure proper measurements