A Calibrated Blackbody Source for Testing Next-Generation Wavefront Actuators

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LIGO SURF PRESENTATION

19 AUGUST 2022

LIGO-T2200206-v5

Overview

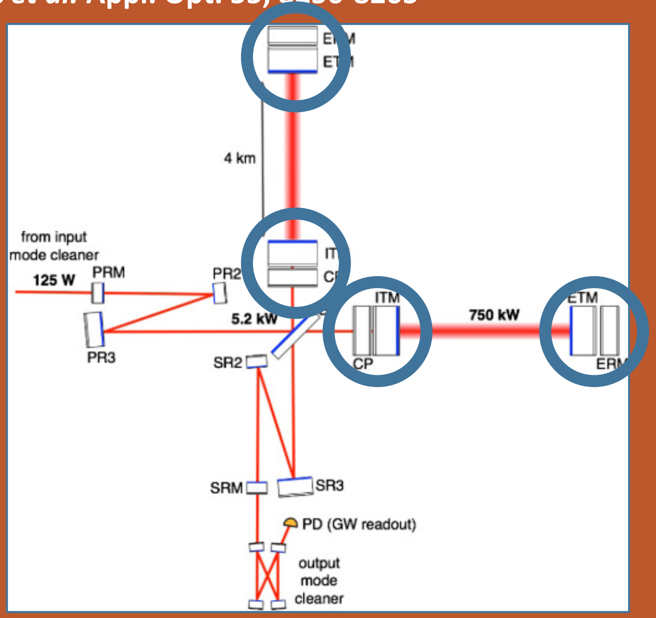
1. Project Objectives
2. Background (TCS and Adaptive Optics)
3. Project design and lab setup
4. Theoretical Predictions and Experimental Data
5. Validation

Project Objectives

Theoretical incident irradiance profile == experimental results

- Design and measure a calibrated blackbody source
- Fit our calibration with data and theoretical calculations (end-to-end validation)
- Long-term goal
  1. Eliminate loss-inducing optical aberrations in test masses
  2. Increase resonating laser power and reduce quantum noise floor of aLIGO

Brooks *et al.* Appl. Opt. 55, 8256-8265 (2016)



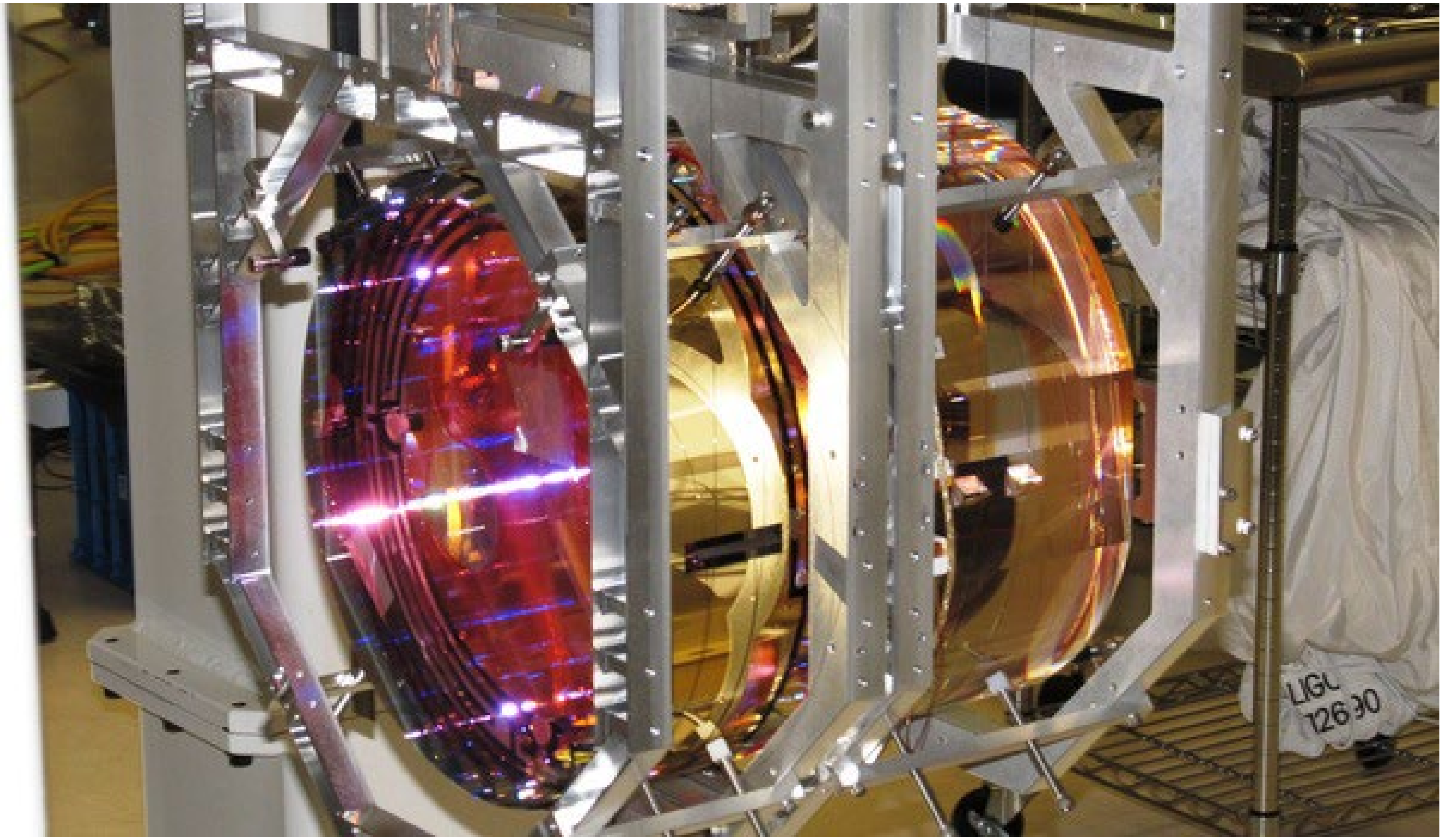
Main issues:

-Static curvature errors

-Thermally-induced spatial distortions

-Point defects within act as sources of optical error

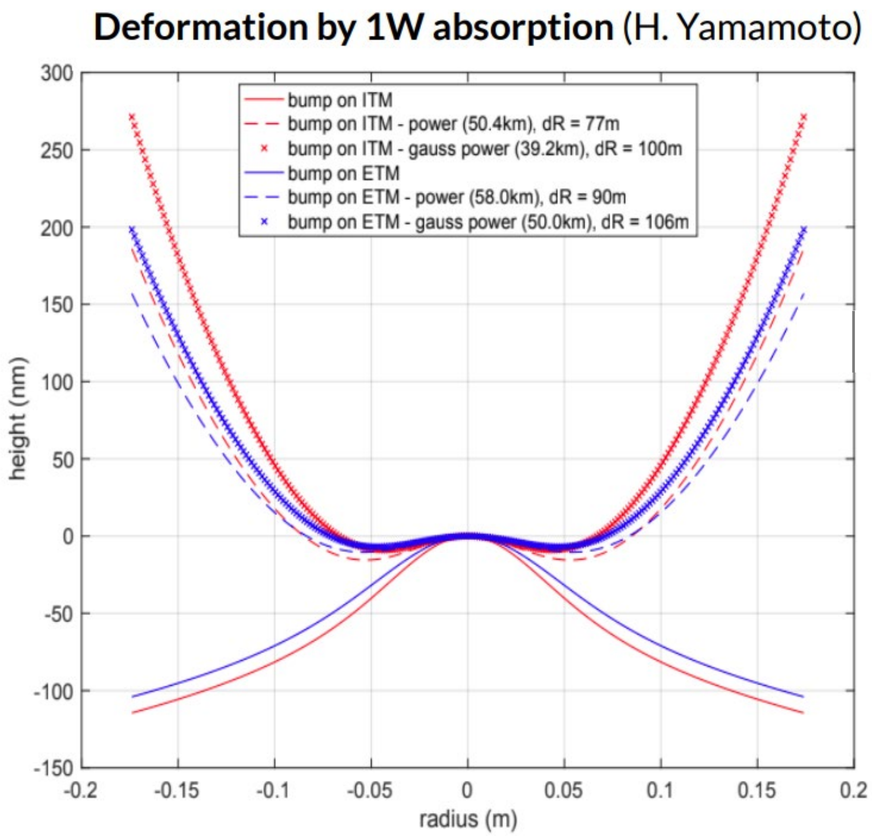
Test Masses



https://www.ligo.caltech.edu/news/ligo20170216

Current Ring Heaters

- Fix radius of curvature in center of TM
- Overcompensate further out from center
- More power = more surface deformation closer to the center
- Want to flatten where the ideal gaussian mode hits



Residual deformation after RH correction

Richardson LIGO-G2200399

Adaptive Optics and Wavefront Distortions

Improve the test masses by reducing effects of wavefront distortions

Laser has one mode; an ideal gaussian beam

↓

Hits point defects in TM

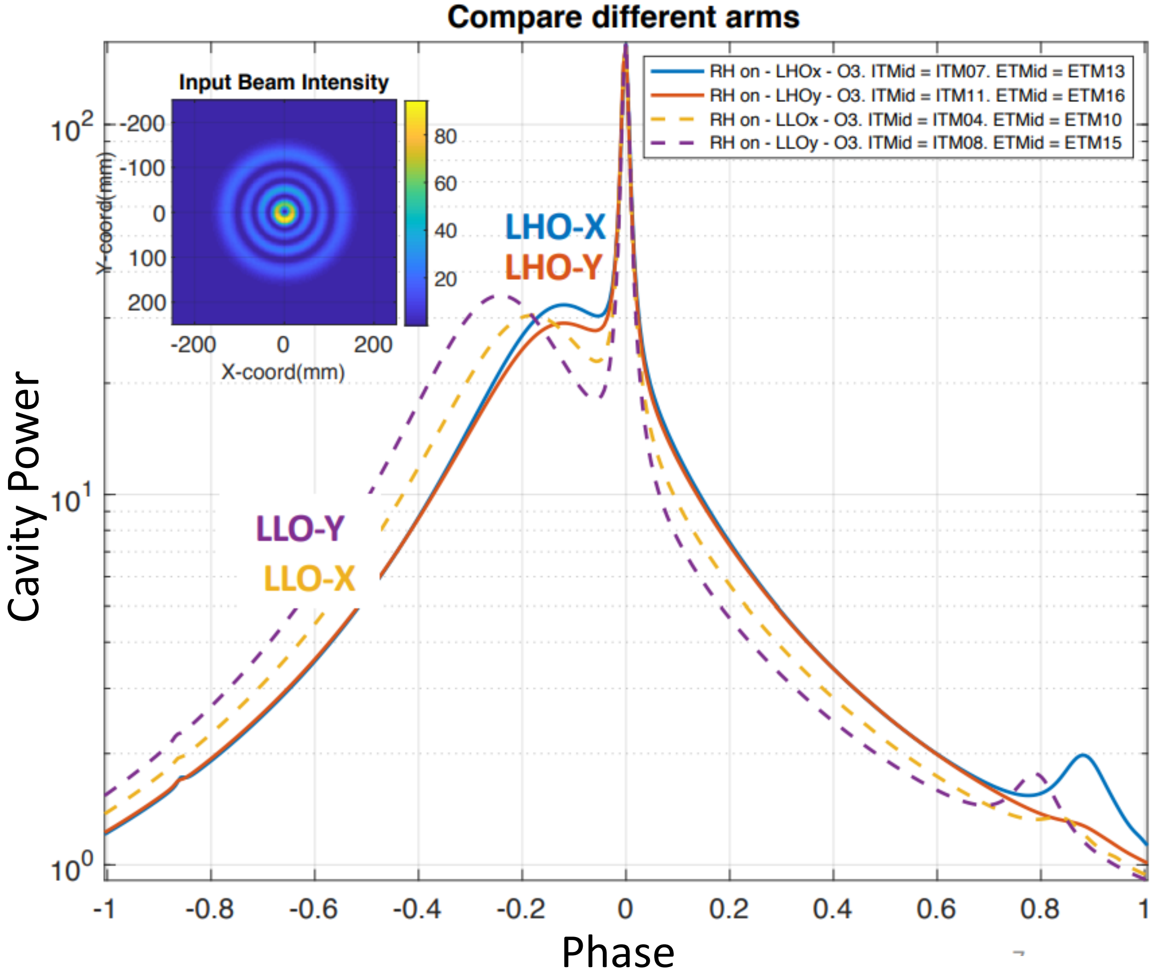
↓

Parts of laser light scatter and enter higher order modes (HOMs)

Wavefront Distortions

- Closer a HOM is to 0-0 mode, the greater the loss
- Eventually, will have a HOM with resonance within the aLIGO arms
- LHO 7th order very close to 0-0 resonance

What does this mean for power loss?

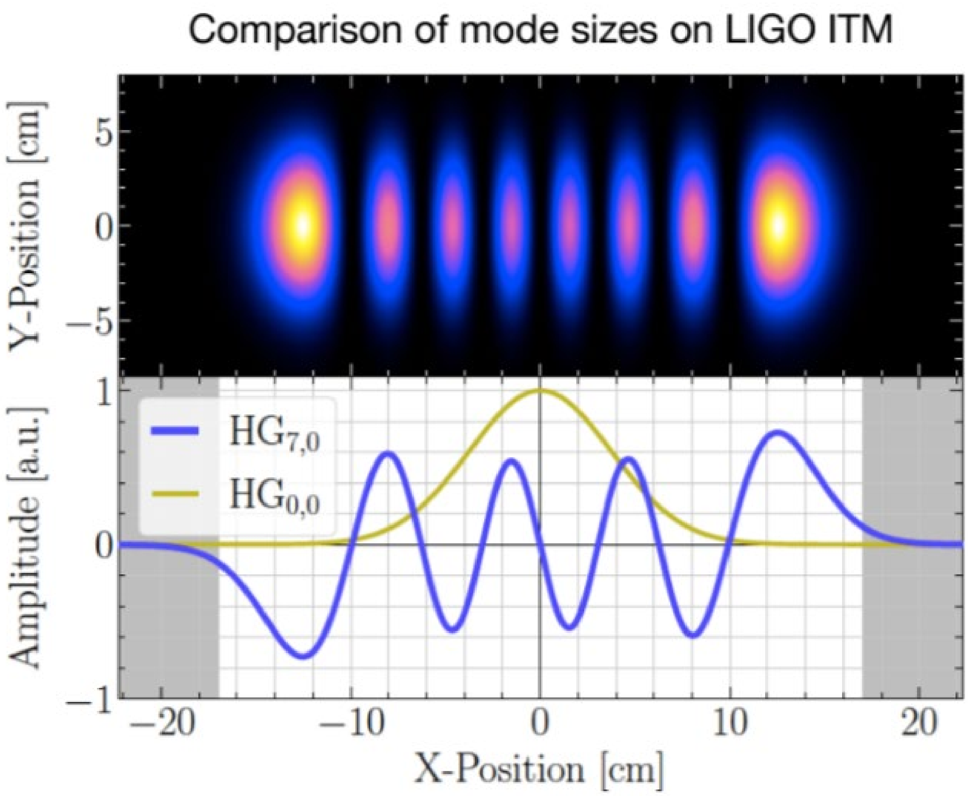


Brooks, Vajente, Yamamoto G2000874-v3, 2020

Power Loss with the Seventh Order Mode

$$Loss_{00,mn} = L_o * \mathbf{Gain_{mn}}$$

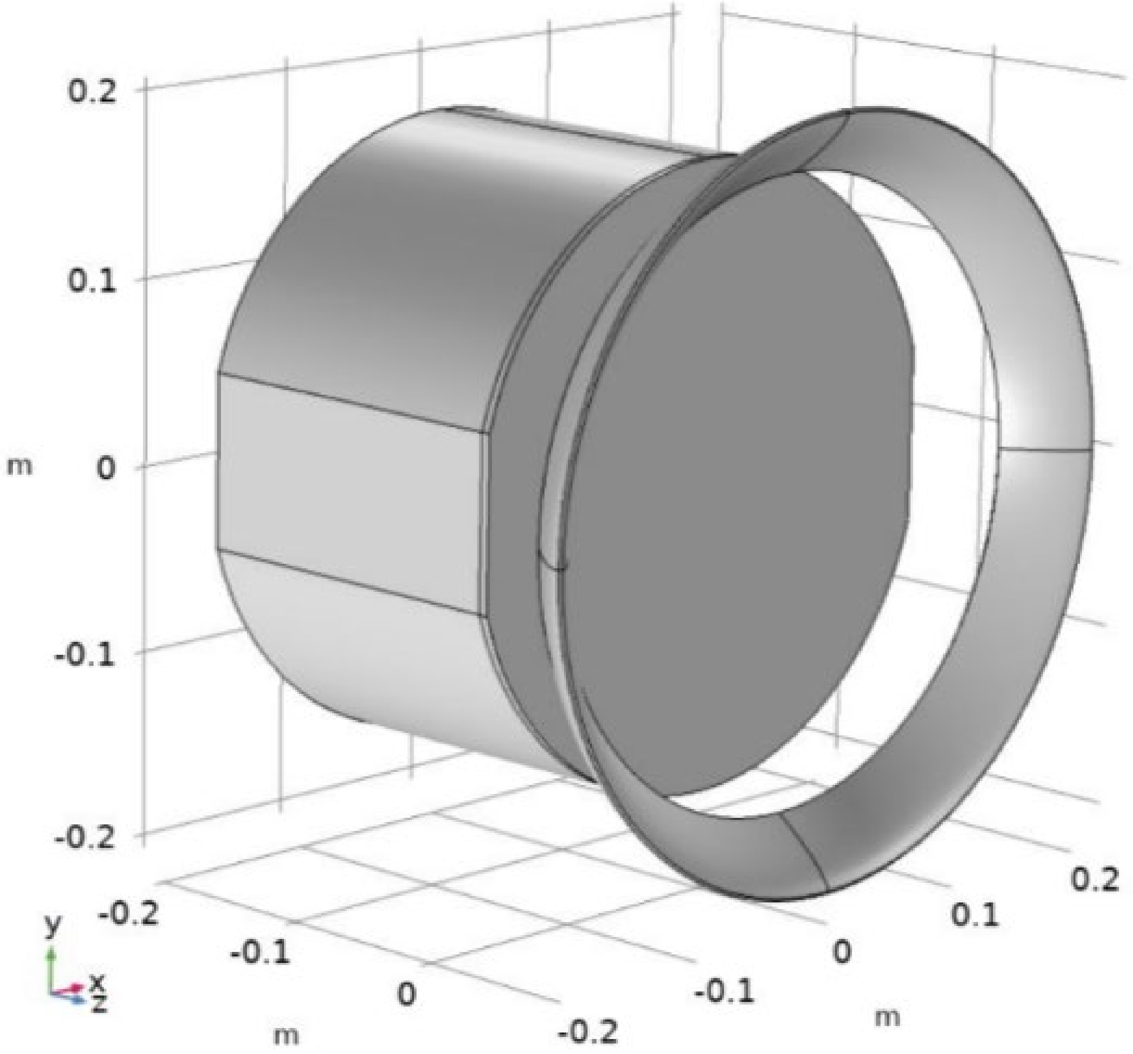
- Single Bounce Scattering
- Degeneracy between 7th order mode and 0-0 mode
- 7th OM uses power that should be going towards 0-0 mode
- Cannot change point defects, must change the optical gain



Richardson *et al*. LIGO-G2101549

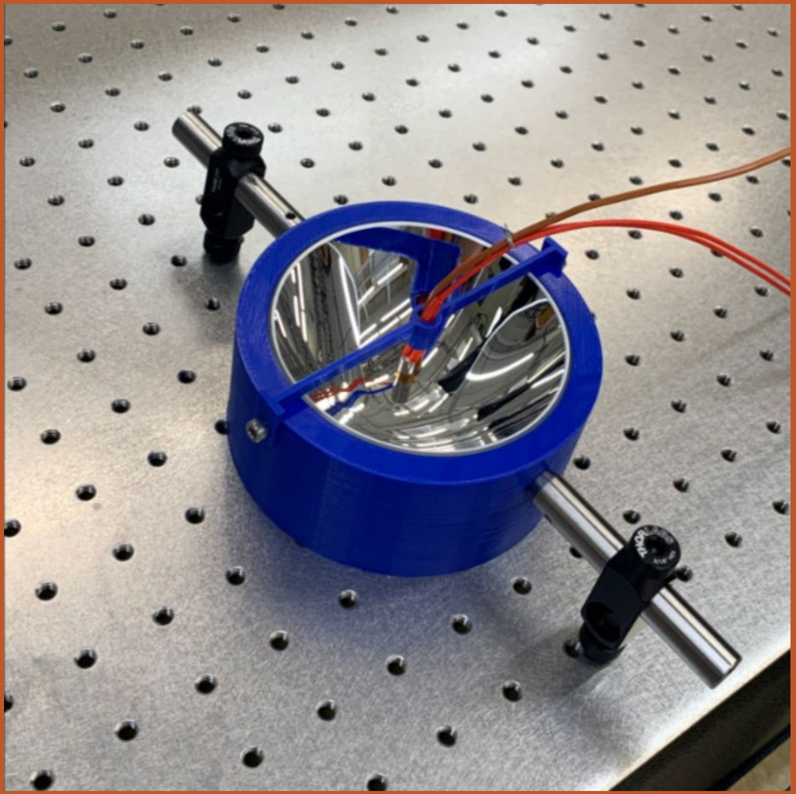
Next Generation Ring heater actuators

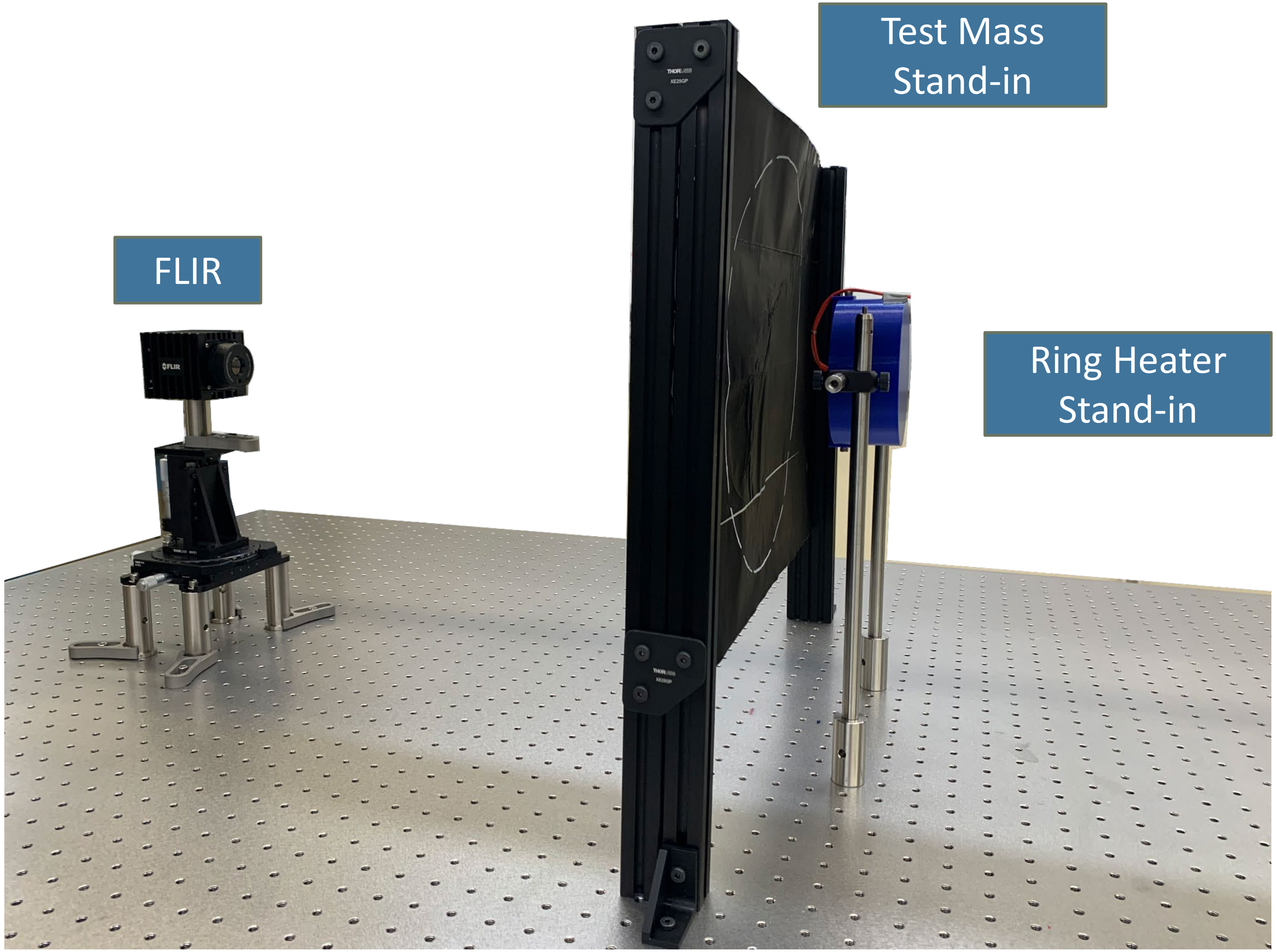
- Will address 7th OM
- 0-0 mode has smaller profile, so it will not be affected
- Need to know: transfer of power, confirmation of observations



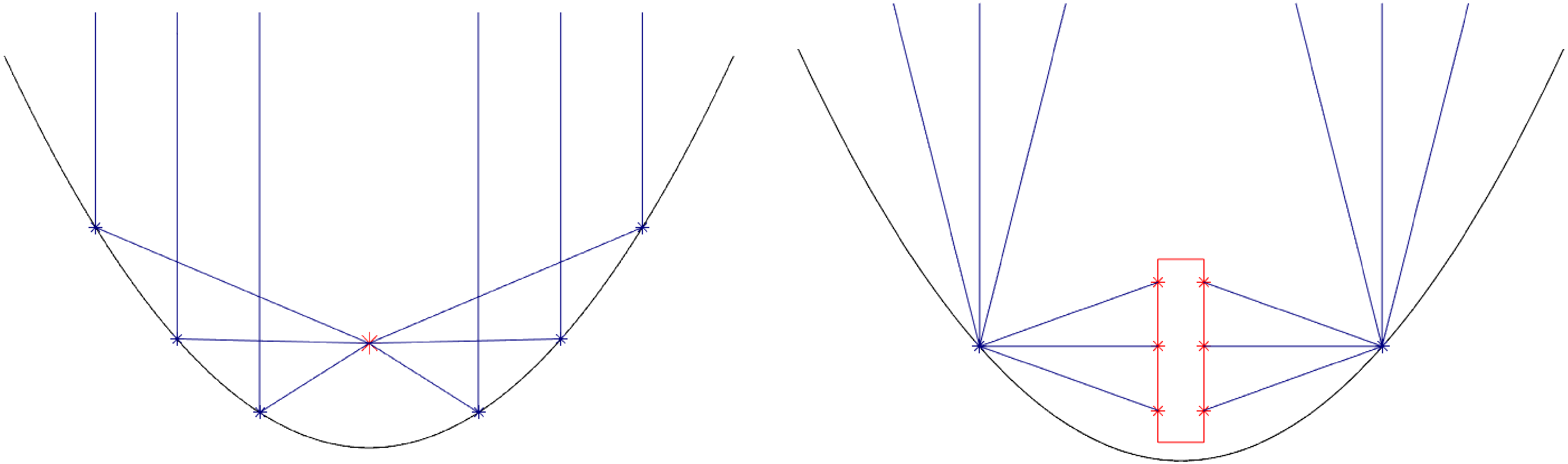
Richardson *et al.* LIGO-G2101549

The Setup





Collimated vs. Reality



Neatly Collimated
All rays from a point source

Scattered
Rays not from a point source

Initial Calculations

UNKNOWNS: emissivity, temperature profile

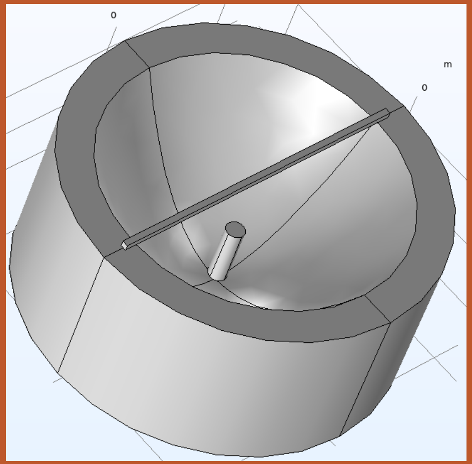
Emissivity ε = 0.57

$$P_{diss} = \varepsilon * A * \sigma_{SB} * (T^4 - T_o^4) = 0.192 \text{ W}$$

T = heater temp (388.15 K) T_o = atmosphere temp (300.15 K)

A = emitting surface area (4.05e-4 m) σ_{SB} = 5.67e-8 W/m^{2}K^4

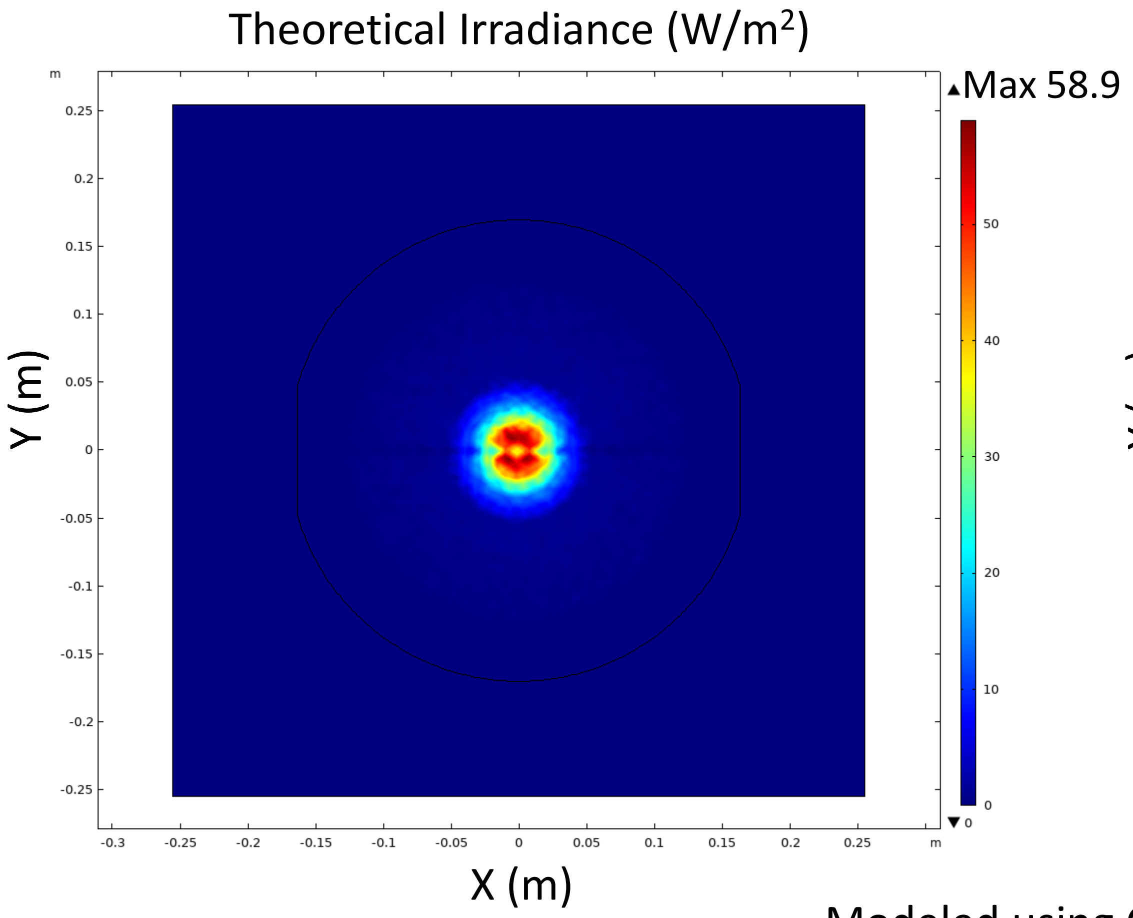
Heater when viewed with FLIR

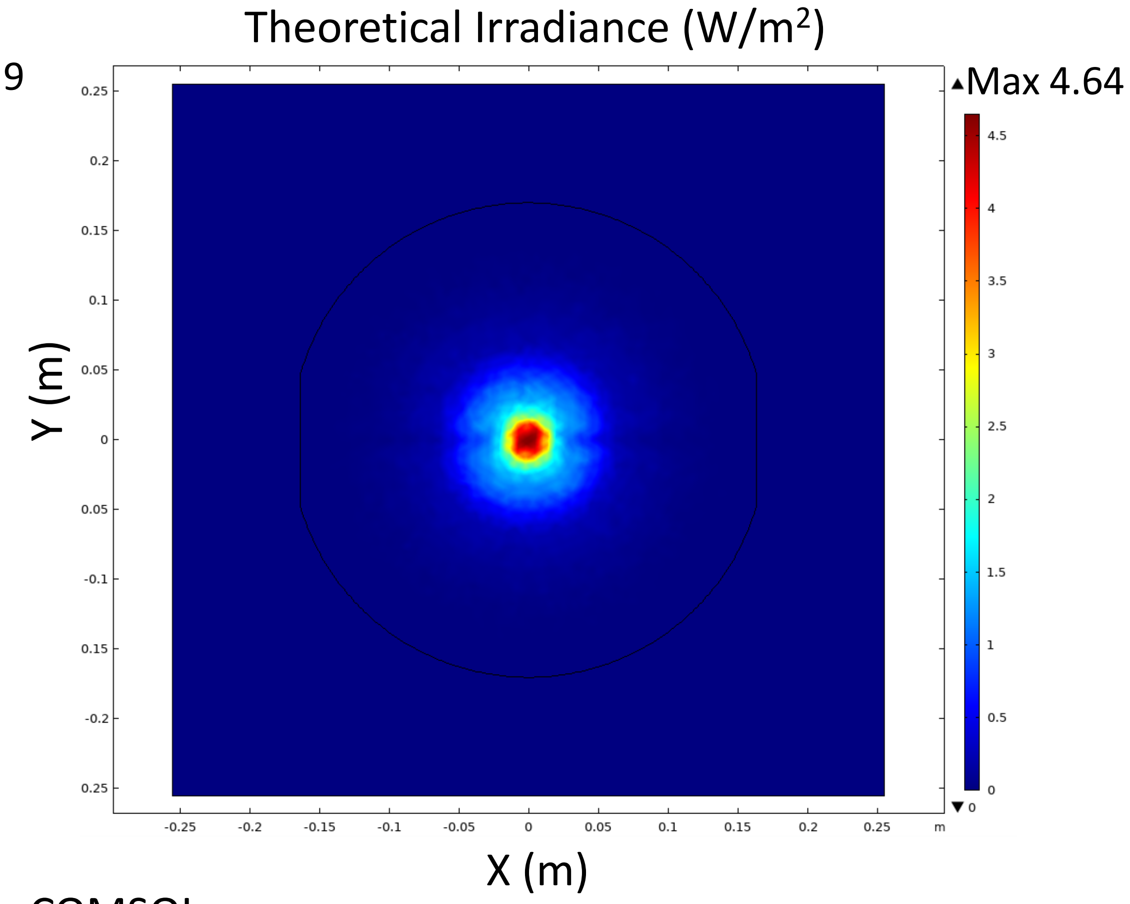


Comsol CAD Geometry

Point Source

Cartridge Heater





Modeled using COMSOL

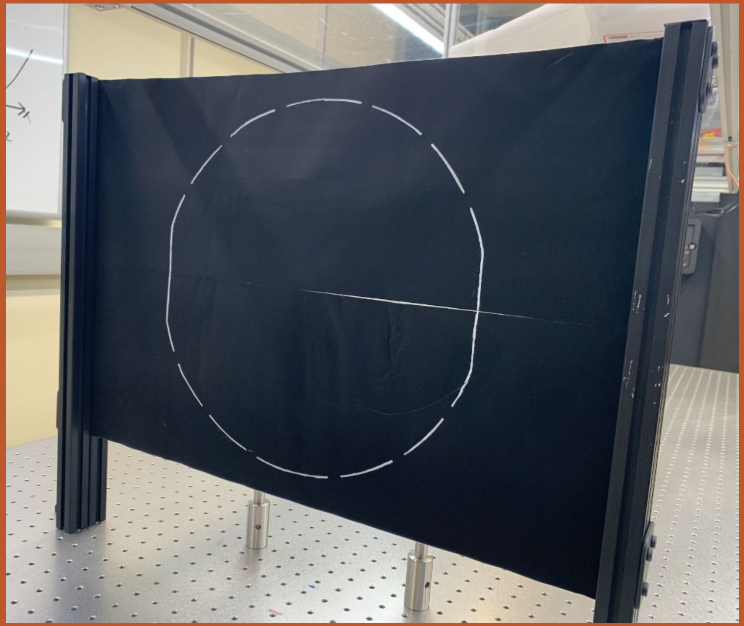
Power Absorbed Calculations

Max irradiance E_e on screen (from Comsol) = 4.64 W/m^2

Emissivity ε = 0.99

$$T = \left(\frac{E_e}{\varepsilon * \sigma_{SB}} + T_o^4\right)^{1/4} = 301.32 \text{ K} = 28.3 \text{ C}$$

Does this match our real data?



IR absorptive screen

Validation

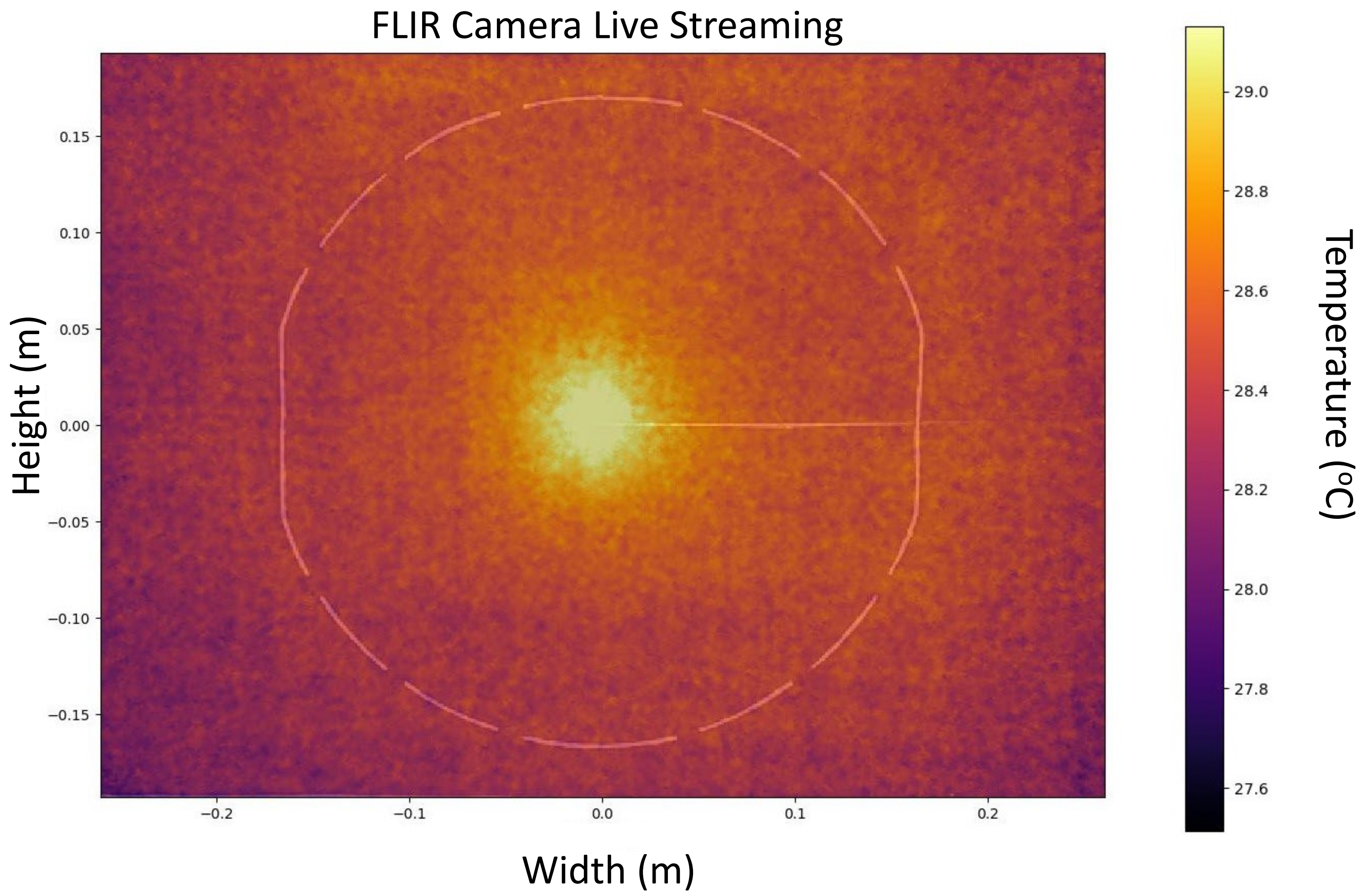
Running at 1.12 W of input power

Max temperature = 29 ^{o}C

Matches temperature of other side!

Clear center hot spot, but no ring shape

Measured Irradiance

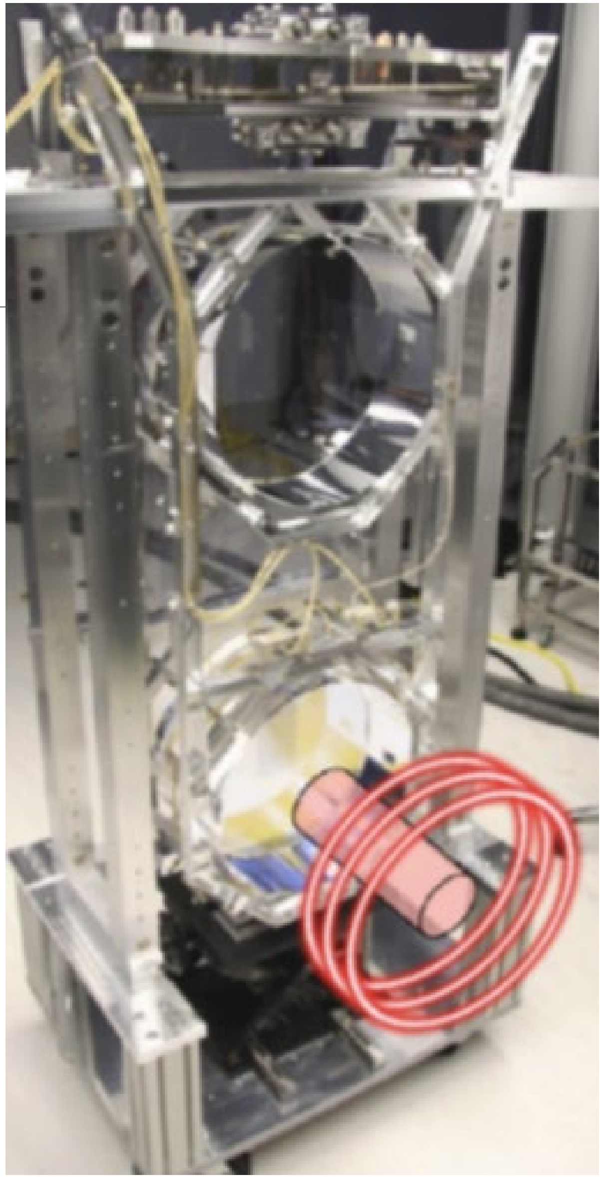


Future Applications

- Testing RH prototypes and spatially complex patterns as soon as parts are fabricated

- Will be able to target single bounce scattering directly

- By 04, will hopefully reduce the effect of point absorbers and move the arm power closer to the design power



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Acknowledgements

Thank you to my mentor Ryan Andersen and my PI Dr. Jon Richardson for all your assistance and support through this project.

I would also like to acknowledge UC Riverside, LIGO laboratory, the Caltech SURF program, and the NSF for creating this wonderful opportunity.