Mitigating Laser Damage in LIGO Optics

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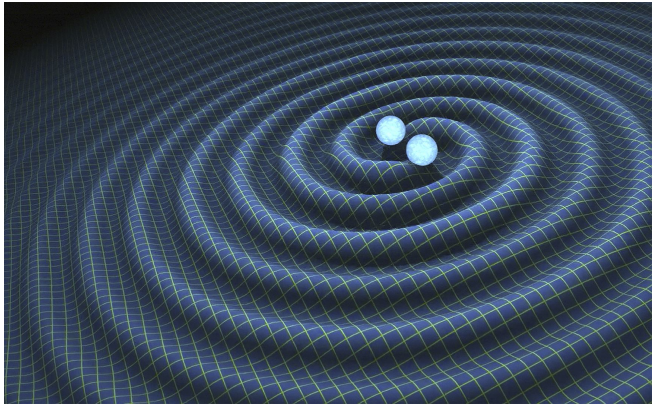
Mechanical Engineering ‘22

Laser Interferometer Gravitational-Wave Observatory

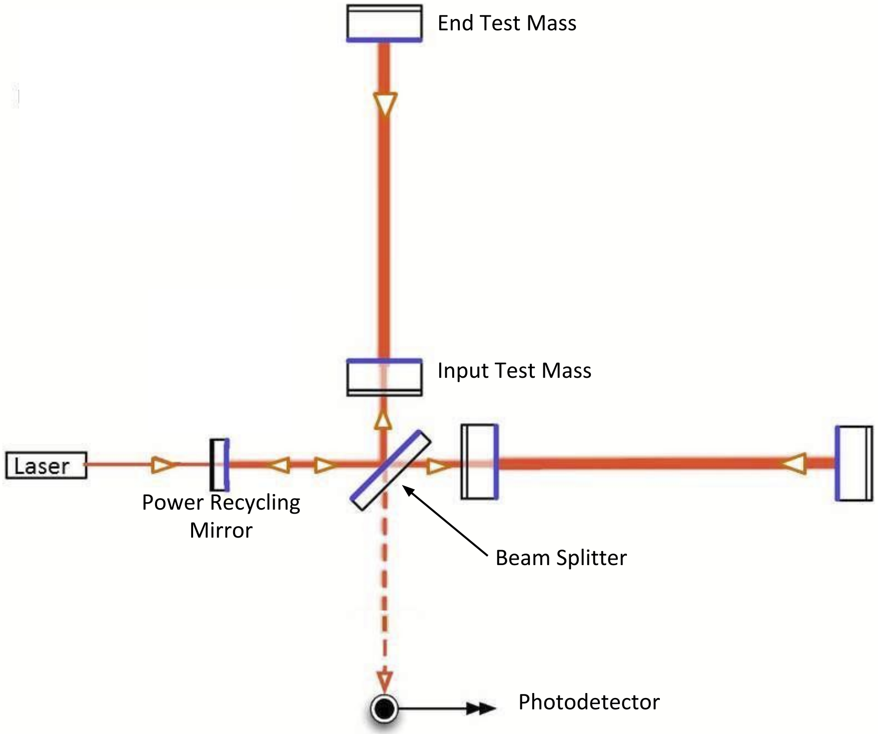
https://www.ligo.caltech.edu/



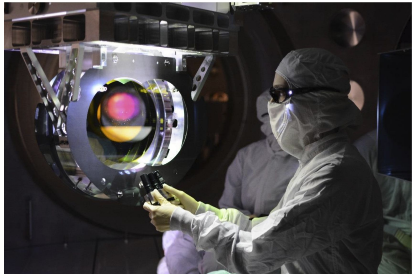
https://www.nasa.gov/feature/goddard/2016/nsf-s-ligo-has-detected-gravitational-waves/

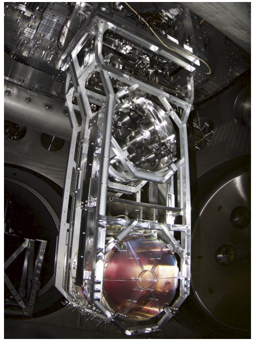
LIGO Optics and Laser Intensity Levels

https://www.ligo.caltech.edu/news/ligo20191001



https://www.ligo.caltech.edu/page/ligos-ifo





Optic	Estimated Intensity [W/mm²]
Beam Splitter	0.3445
ETM	33.98
ITM	46.84
PRM	199.9

Stray Light Control - Absorbing Materials

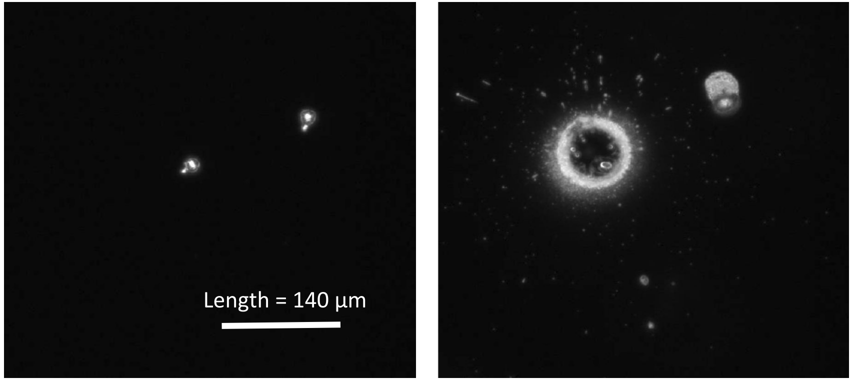
- Beam dumps and baffles absorb scattered infrared light
- Black glass used in critical areas
  - Very low reflectivity compared to other materials
  - Extremely fragile and difficult to install
  - Overheats at high power
- Different materials used at higher power
- Search for better materials and coatings ongoing

https://www.ligo.caltech.edu/news/ligo20191104

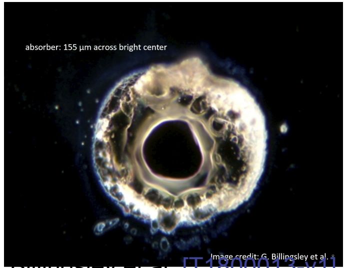
DLC coated SSTL baffle installation

Contamination and Laser Damage

Particle pre and post irradiation at 400 W/mm²



Gushwa et al. [P1400205-v8]



Billingsley et al. [T1800013-v1]

- Dust particles melt into optic coatings at 92 W/mm² [Billingsley et al., G1400209-v2]
  - Test masses, power recycling mirror, and mode cleaner regularly reach higher intensities
  - Multiple defects found on these optics
- Larger particles (10 µm) and higher power more likely to yield bigger pits
- Low level contaminants can still cause damage in optic coatings
- Increasing cleanliness procedures can only reduce contamination by so much

Laser Damage Facility (Testing Set-Up)

- In vacuum and in air testing capabilities
- Testing intensities ranging from 50 mW/mm^2 to 1 $kW/W/mm^2$
- Equipped with XY translation stages for raster scans
- Damage captured with Nikon Scanning Darkfield microscope
- Higher power laser needed for contamination tests (and more resistant filters, beam dumps, etc.)

Ananyeva et al. [G1800420-v1]

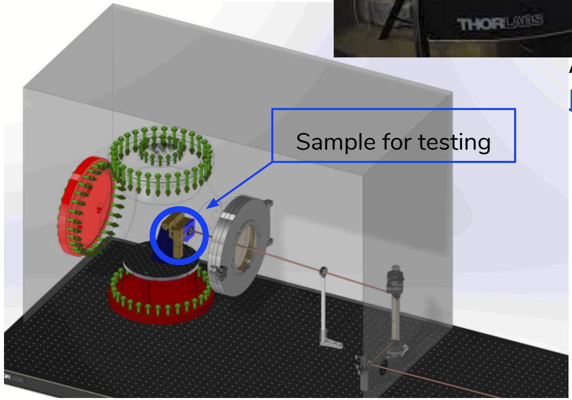


Image of the setup at Caltech and modelled in Solidworks

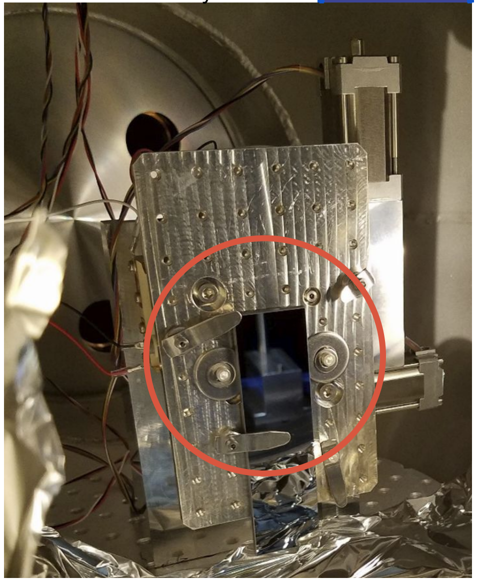
Evaluating Different Absorbing Materials

- Studying five different materials for upgrading stray light absorbing optics [Ananyeva et al., G1800420-v1]
- Irradiated with CW 1064 nm
- Each sample irradiated at 10 points (5 min per point) at increasing power levels
  - Power increased until damage occured
- Samples were cleaned prior to irradiation

Material	Cost	Reflectivity	Backscatter
Black glass	$$	4%	2×10^{-4}
Diamond-like Carbon Coated SSTL	$$	6%	2×10^{-4}
Silicon	$$$$	10%	8×10^{-5}
Sintered Silicon Carbide	$$$	Diffuse	High

Ananyeva et al. [T1800001-v2]

Ananyeva et al. [E1700388-v3]



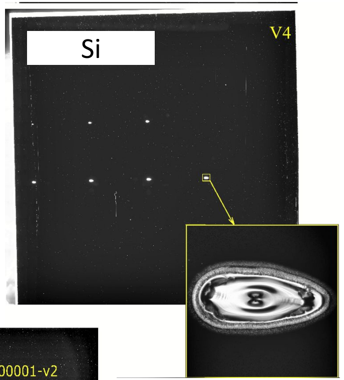
Silicon sample installed in vacuum chamber

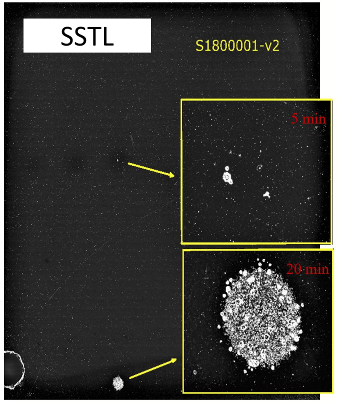
Damage Thresholds and Analysis

Material	Damage Threshold [W/mm²]	Total Power [W]
Black glass	0.3	2.86
Diamond-like Carbon Coated SSTL	5.04	31.8
Silicon	371.13	16
Sintered Silicon Carbide	736.97	37.05

Ananyeva et al. [T1800001-v2]

- SiC can sustain high temperatures but is more reflective than black glass
  - A good option for areas with high power
  - Alternatively, sintered SiC is inexpensive but cannot be polished
- DLC SSTL should be used at low power areas
  - Has low reflectivity at small incident angles

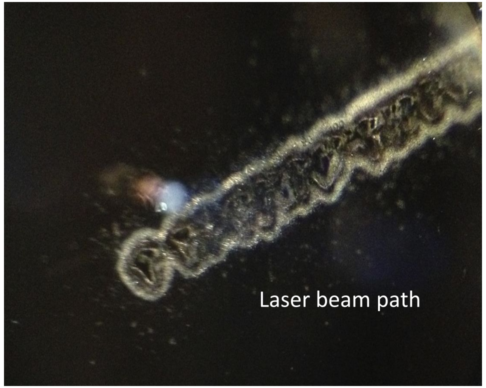




Ananyeva et al. [E1700388-v3]

Research on Contamination and Laser Damage Ongoing

- Currently preparing for contamination experiments
  - How clean should LIGO optics be?
  - Utilizing similar set up as the absorbing material experiment
- Updating laser damage facility and additional components for high power testing (100 W)
- Modelling new laser set up on Zemax
  - Running simulations to model damage with Comsol



Billingsley et al. [G1400209-v2]

Conclusion

Thank you for listening!