OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

A New Facility for Testing GW Thermal Compensation Systems at Full Scale

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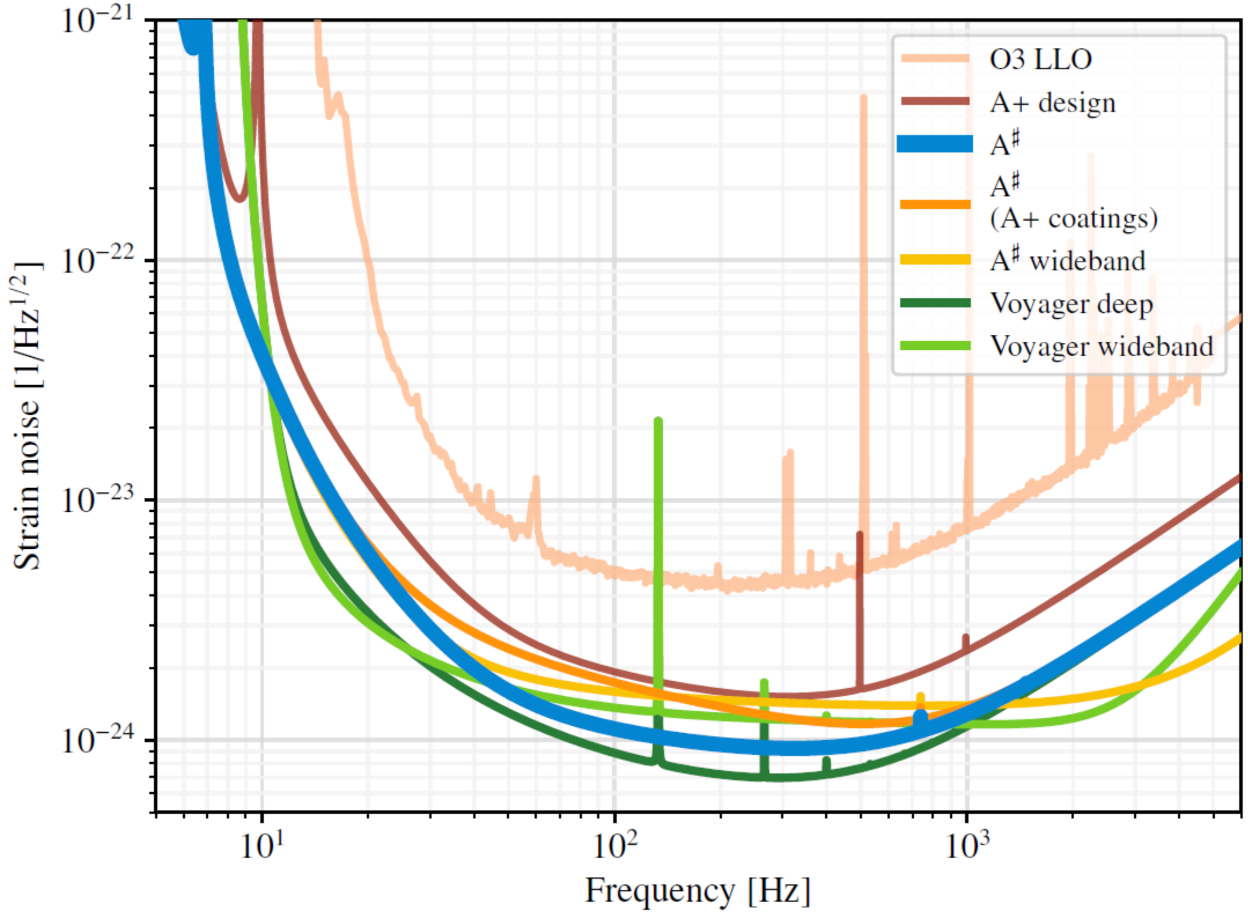
Talk Outline

- Quick introduction to TCS
- Why do we need a Full Scale TCS test facility
- Design of new TCS facility
- Initial test plans for TCS facility
- Current status and timelines

Planned Future Sensitivity of LIGO Detectors



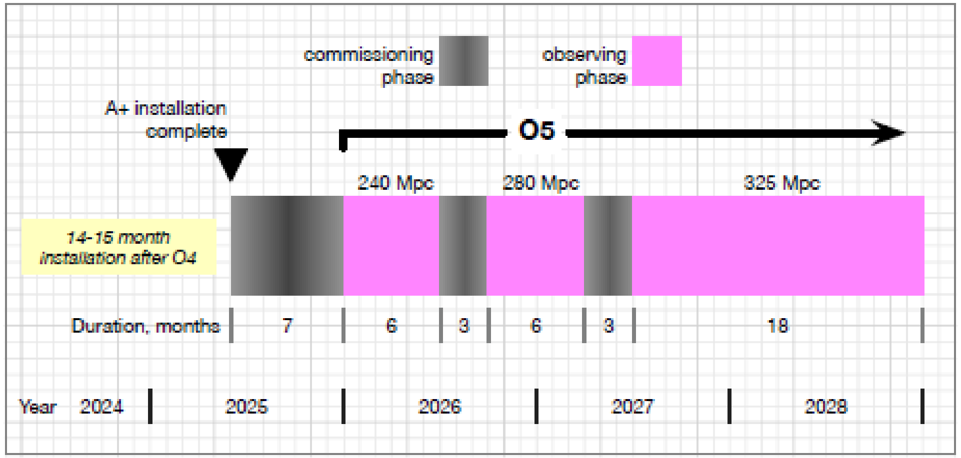


Figure 3: Proposed O5 timeline, with O5 ending at the end of 2028.

- Figures from the Post O5 Committee Report LIGO – T2200287-v2

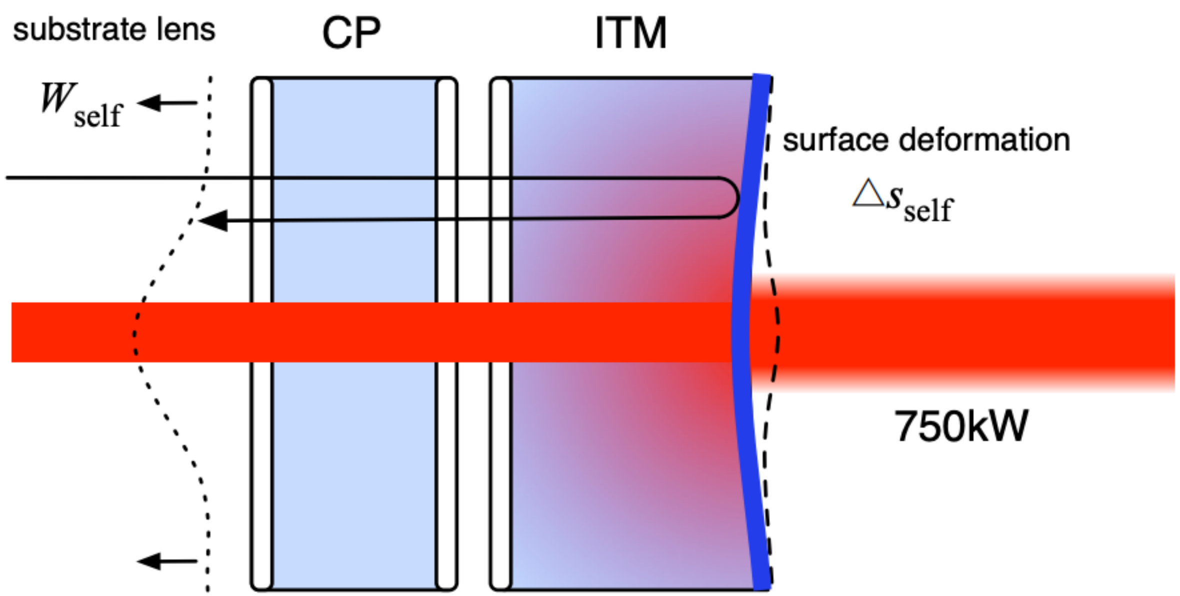
A look at the allowable losses

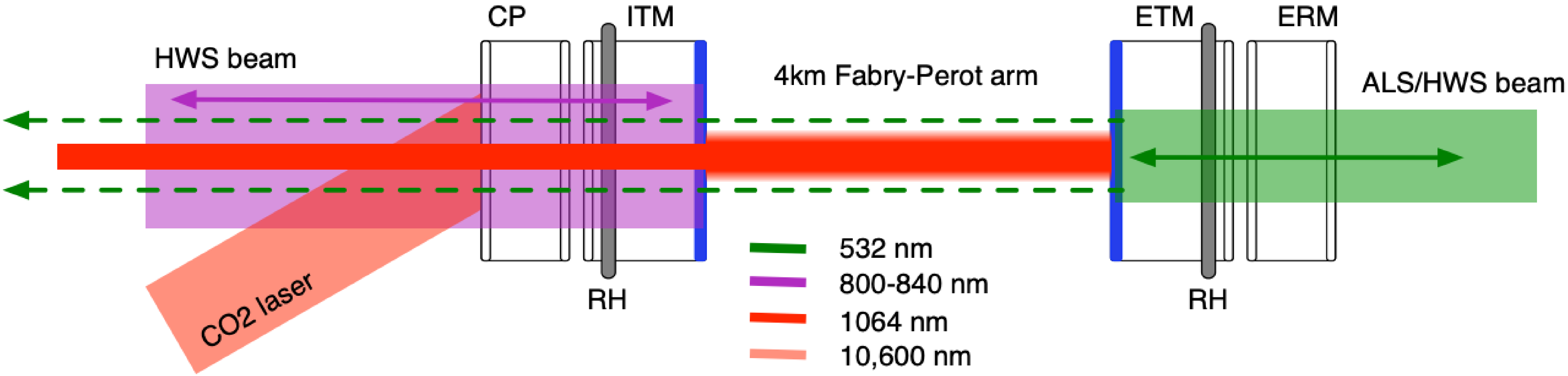
	Parameter	Units	A+	A$^\sharp$	Voyager
	Arm power	kW	750	1500	4000
	Source squeezing level	dB	12	18	18
	Roundtrip FC loss	ppm	40	30	10
	Roundtrip arm loss	ppm	75	75	20
	SEC loss	ppm	3000	500	500
Squeezer and Injection loss	OPO	%	2	1	1
	$4 \times$ Faraday pass	%	2	2	2
	FC pickoff	%	1	1	1
	Total injection loss	%	5	4	4
Readout loss	$1 \times$ Faraday pass	%	0.5	0.5	0.5
	Output steering	%	1.5	1	1
	OMC and PDs	%	2.5	2	2
	Total readout loss	%	4.5	3.5	3.5
Dephasing	Squeezer RMS phase	mrad	30	10	10
	FC RMS length	pm	0.7	0.7	0.7
	SEC RMS length	pm	10	10	10
Mode mismatch	SQZ/FC	%	0.5	0.25	0.25
	SQZ/IFO	%	1	0.5	0.5
	IFO/OMC	%	2	0.5	0.5
	Arm cavities/SEC	%	2	2	2
Observed squeezing	at 1 kHz	dB	6.8	9.8	9.1

Table from the LSC Post O5 Committee Report

LIGO TCS

High optical power in the arm cavities and recycling cavities get absorbed in the HR coatings of the ITMs ~1ppm and substrates. This causes surface deformations and substrate thermal lens.

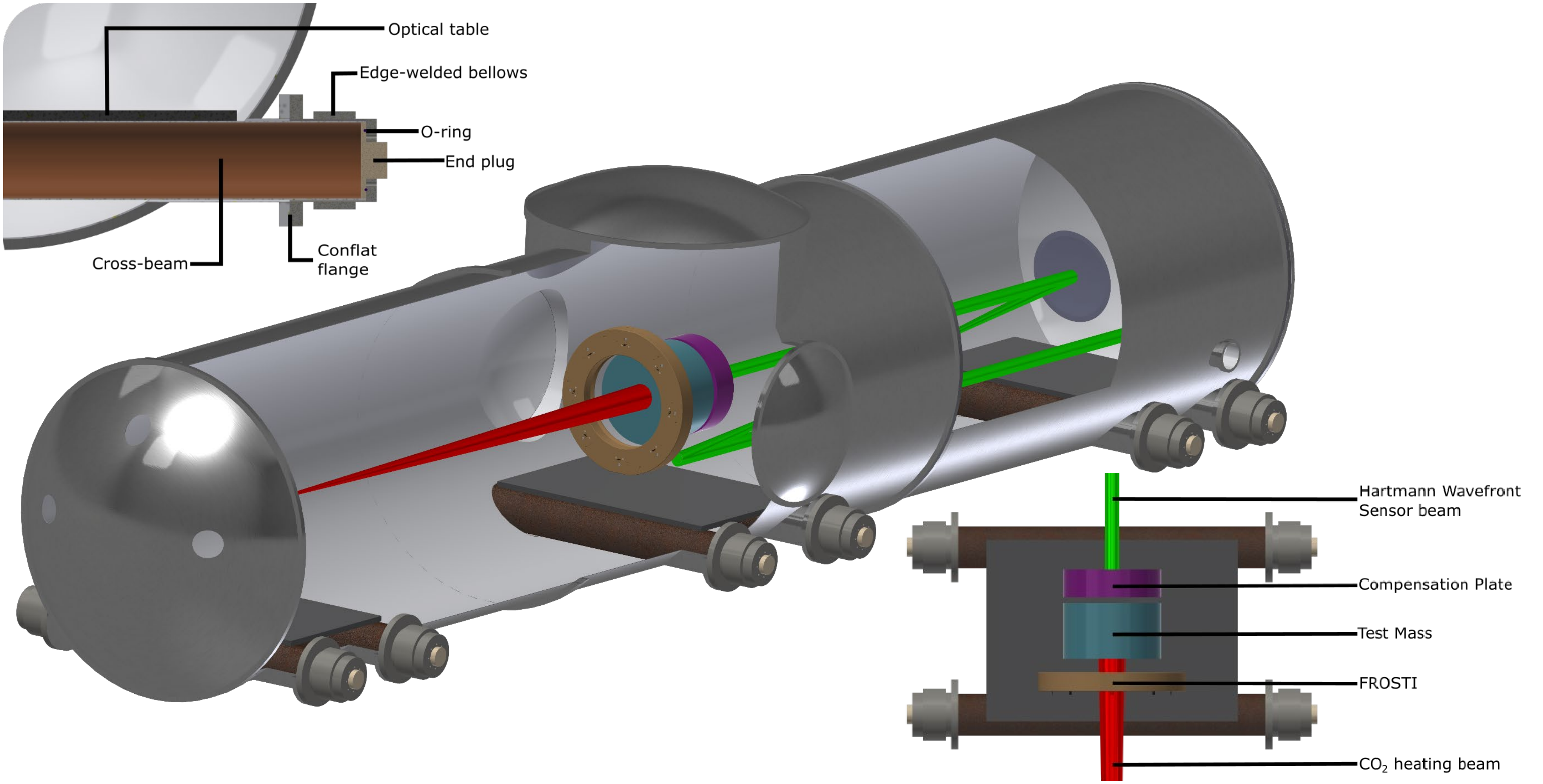




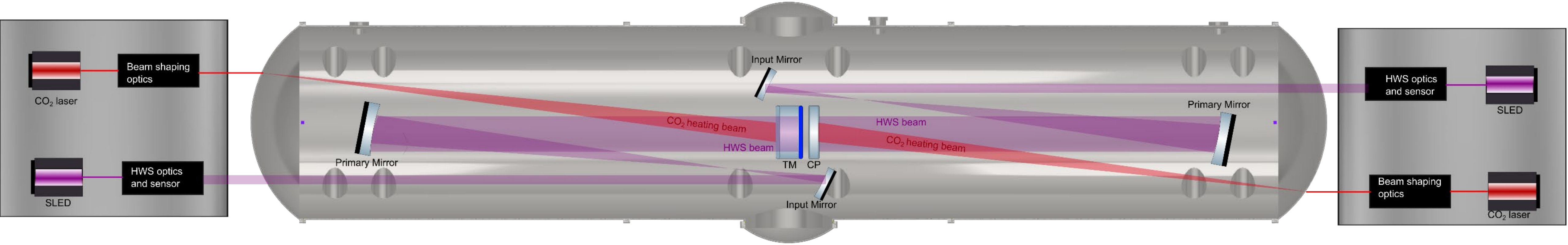
A New Test Facility

- The time constants of TCS are long (10s minutes to hours)
- The only place you can test this at full scale is at the GW sites (Virgo has a smaller test facility). - Commissioning time is really precious - $65 k per day
- Need a test facility that has a full size test mass and beams. LIGO Laboratory is loaning an old test mass.
- Has to have similar thermal boundary conditions
- Currently, no interferometry plans, simulate arm cavity beams with CO2 laser.
- Expandable tank to study beamsplitter thermal compensation at a later date.
- ARC LIEF Grant Recently Awarded with Chief Investigators Ottaway (UA), Brown (UA), Veitch(UA), Eicholz (ANU), Slagmolen (ANU), Blair (UWA) and Partner Investigators Mansell (Syracuse), Richardson (UCR) and Brooks (CIT)

The proposed design of the new facility



Facility Showing Sensing and Heating Beams

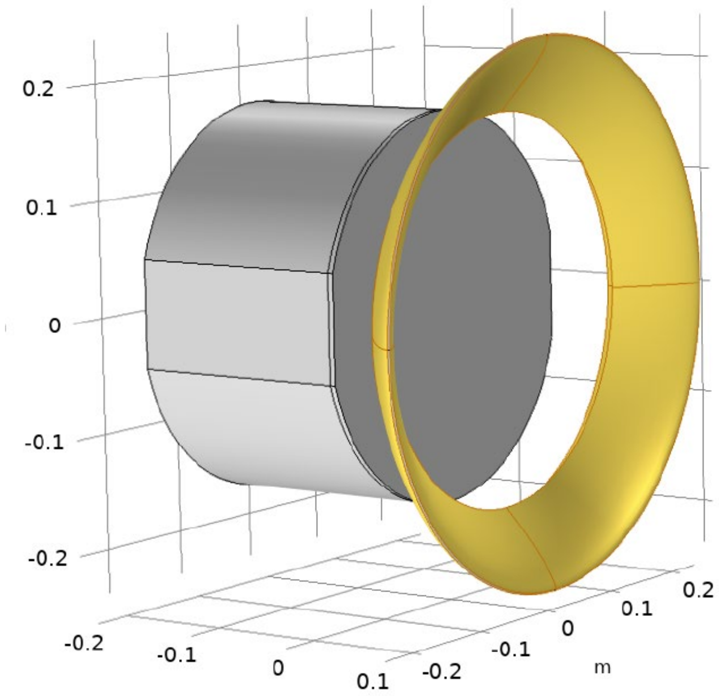


- Need to test larger HWS probe
  - Aim to probe the whole aperture
  - Need large slightly off-axis reflectors
- Two heating beams for CO2 compensation and simulate cavity mode heating
  - CO2 compensation beam needs to be off-axis and work around the Hartman Reflectors

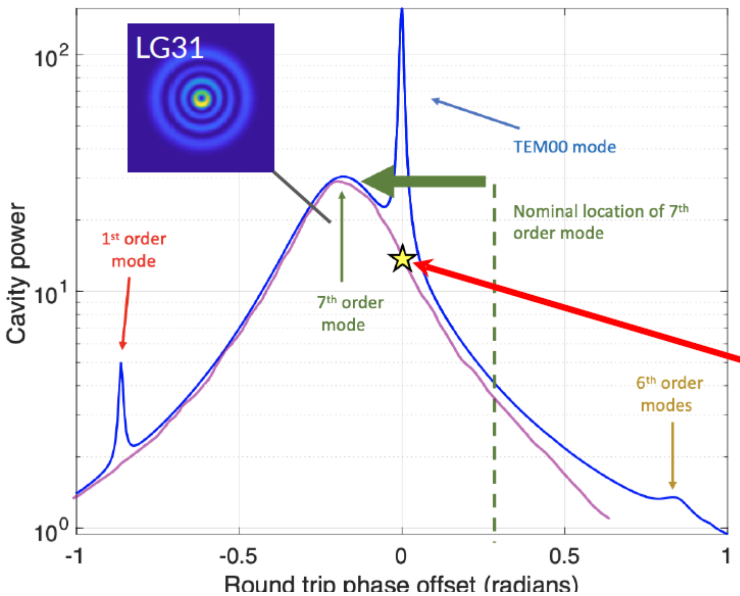
What tests/research are planned for the facility in short/medium term ?

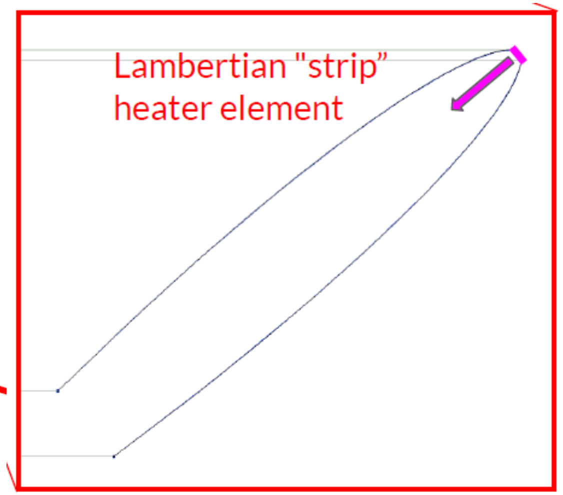
Testing New Front Heater Designs

- Collaboration with Jon Richardson and Huy Tuong Cao at University of California Riverside
- Front surface heating tailor the front surface to fix near 7th Order Mode Degeneracy
- Test at Full Scale and New CO_2 patterns to compensate
- Images from LIGO-G2200399
- Next Generation Front Surface Correction later in the project



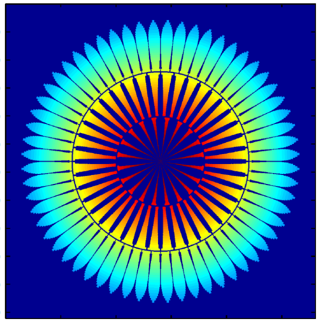
Simulated arm cavity scan (A. Brooks, G2101232)





Tighter Coupling between CO_2 Laser Compensation Mask Design and Hartmann Sensor Data

- Mask were tried to compensate point absorbers but insufficient commissioning time allowed
- Create a better loop between the as built system and masks



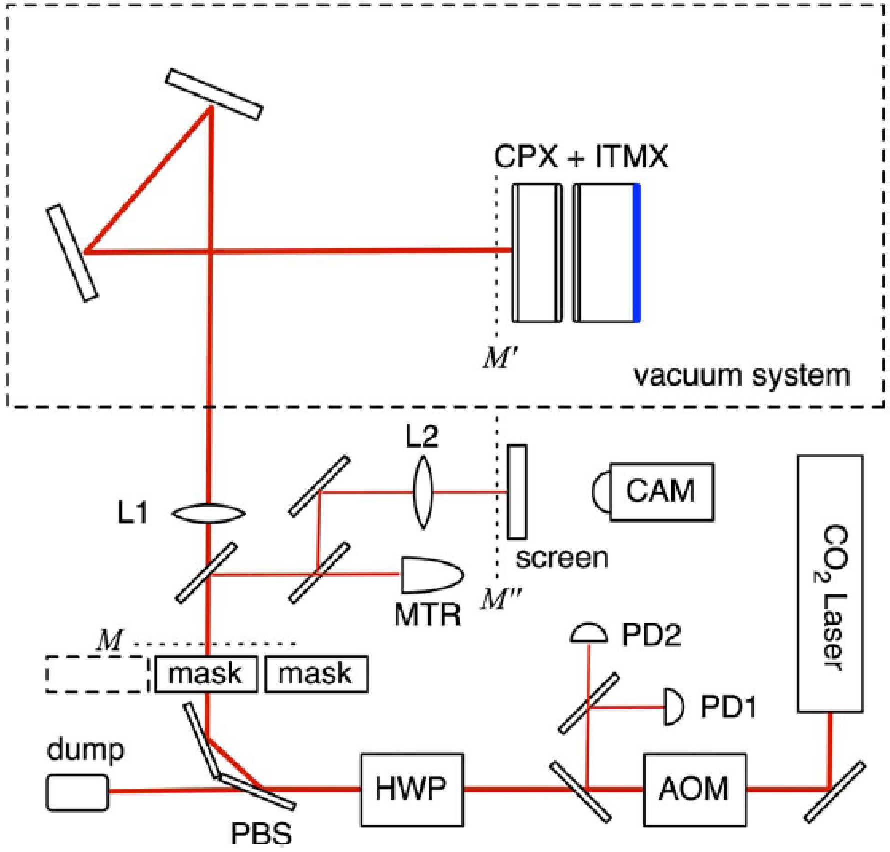


Fig. 11. Schematic layout of CO_2 laser projector.

LIGO-T1100570-v5

8256 Vol. 55, No. 29 / October 10 2016 / *Applied Optics* **Research Article**

applied optics

Overview of Advanced LIGO adaptive optics

Aidan F. Brooks,[1,*] Benjamin Abbott,[1] Muzammil A. Arain,[2] Giacomo Ciani,[2] Ayodele Cole,[1] Greg Grabeel,[3] Eric Gustafson,[1] Chris Guido,[4] Matthew Heintze,[4] Alastair Heptonstall,[1] Mindy Jacobson,[1] Won Kim,[5] Eleanor King,[5] Alexander Lynch,[1] Stephen O'Connor,[1] David Ottaway,[5] Ken Mailand,[1] Guido Mueller,[2] Jesper Munch,[5] Virginio Sannibale,[1] Zhenhua Shao,[1] Michael Smith,[1] Peter Veitch,[5] Thomas Vo,[3] Cheryl Vorvick,[3] and Phil Willems[1]

Real Time Spatially Variable Masks and New Lasers

- 3.5 um lasers Fibre lasers have been demonstrated to 15 W
- Opens the door to real time spatially variable heat patterns
- Can use deformable mirrors or LCD modulators with Mach Zender Interferometers
- Alternative is an Array of Fibre Lasers

February 1, 2014 / Vol. 39, No. 3 / OPTICS LETTERS 493

Mid-infrared fiber lasers at and beyond 3.5 μm using dual-wavelength pumping

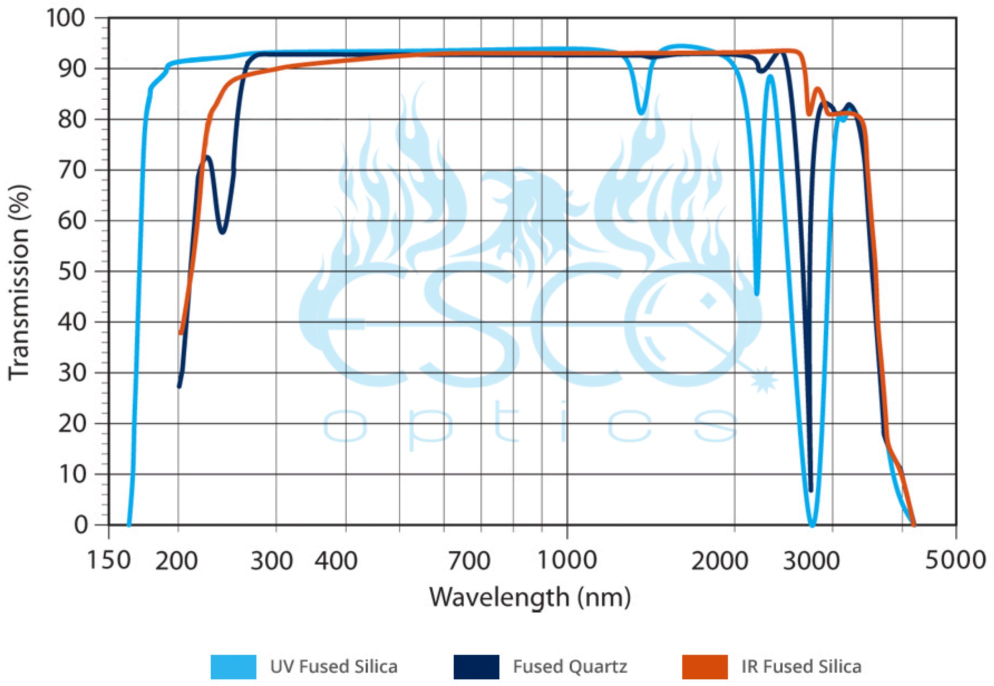
Ori Henderson-Sapir,* Jesper Munch, and David J. Ottaway

Letter Vol. 47, No. 2 / 15 January 2022 / Optics Letters 289

Optics Letters

15 W monolithic fiber laser at 3.55 μm

Maxime Lemieux-Tanguay,* Vincent Fortin, Tommy Boilard, Pascal Paradis, Frédéric Maes, Lauris Talbot, Réal Vallée, and Martin Bernier



Current Status and Looking Forward

- Vacuum Conceptual Design Complete with three vendors supplying quotes – Anticipate order placed in weeks with supply near end of year
- Now we turn our attention to:
  - Optical Design
  - Mechanical Design for test mass, compensation, ring heater support

- We are building a general facility that we hope will serve the GW communities needs for years to come
- Want to collaborate to test and verifies the communities ideas for next generation

Any Questions ?

Point Absorbers Have Really Thrown a Spanner in the Works

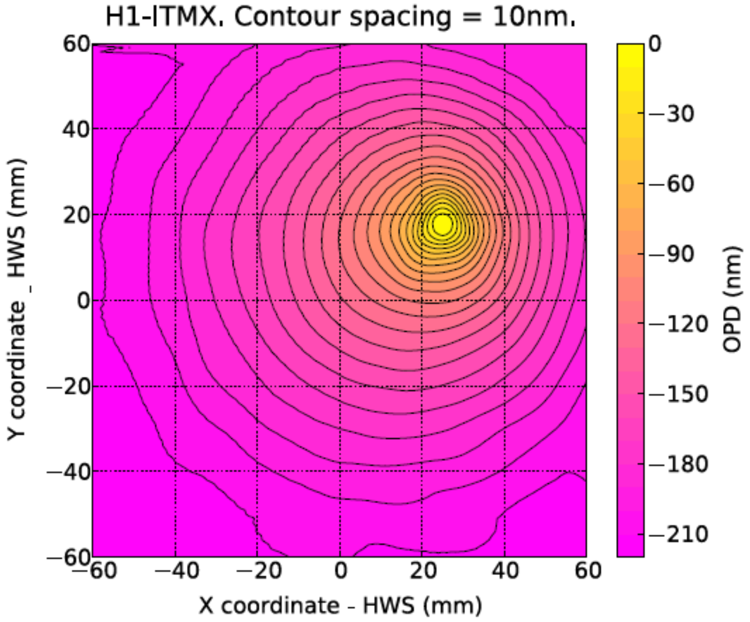


Fig. 2. Hartmann sensor measurement of optical path distortion (thermo-refractive plus thermo-elastic) from a single point absorber on H1-ITMX. Cold reference taken at GPS time: 1180229513 s, and hot measurement taken 3322 s later at GPS time: 1180232835 s. This measurement corresponds to approximately 27 ± 2.5 mW power absorbed in the point.

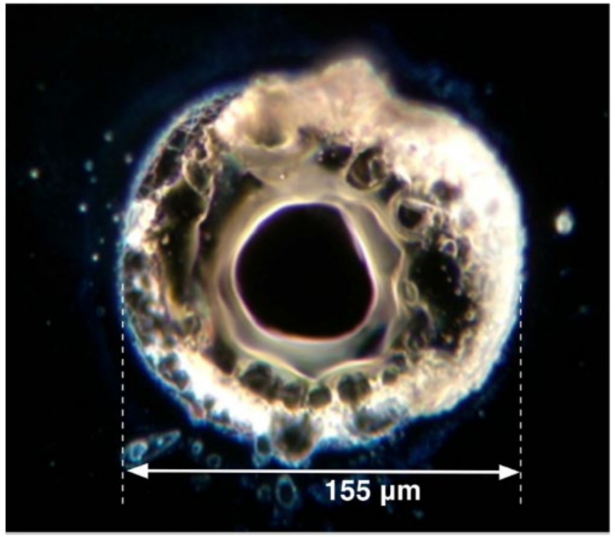


Fig. 3. Dark-field microscope image of point absorber measured on an Advanced LIGO optic (corresponding to the thermal lens measurement shown in Fig. 2). Also shown in Buikema *et al.* [1].

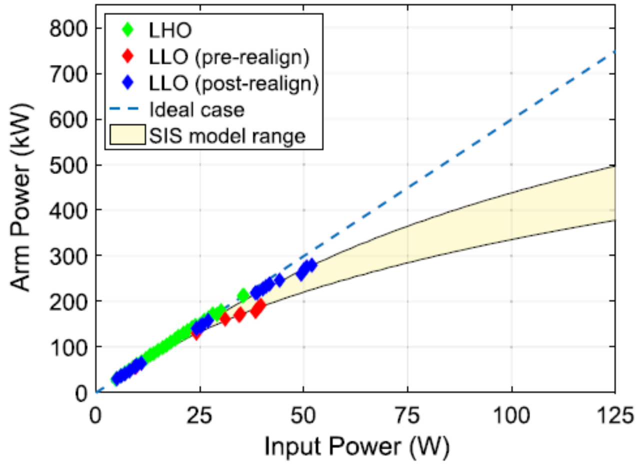


Fig. 7. Arm power versus input laser power. The dashed line shows the case of constant optical gain. The data points show the measurements from the LIGO sites. The yellow range shows predictions from the SIS model assuming uniform absorption and a variety of point absorbers on the optic consistent. As the effect of the point absorber is decreased, the uniform absorption becomes the limiting factor preventing ideal buildup of arm power.

Research Article Vol. 60, No. 13 / 1 May 2021 / *Applied Optics* **4047**

applied optics

Point absorbers in Advanced LIGO

AIDAN F. BROOKS *et al.* *,†

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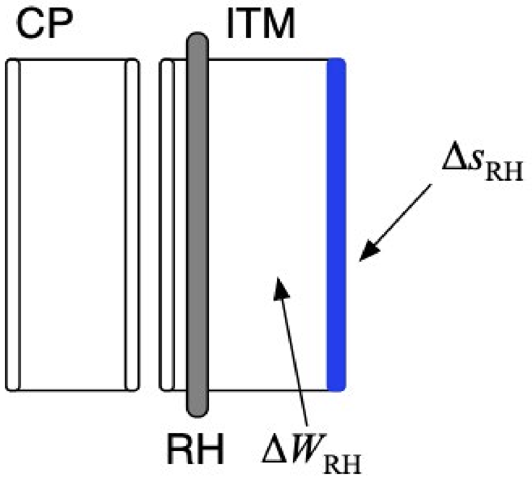
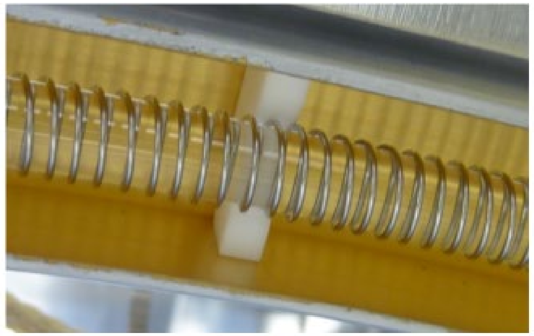
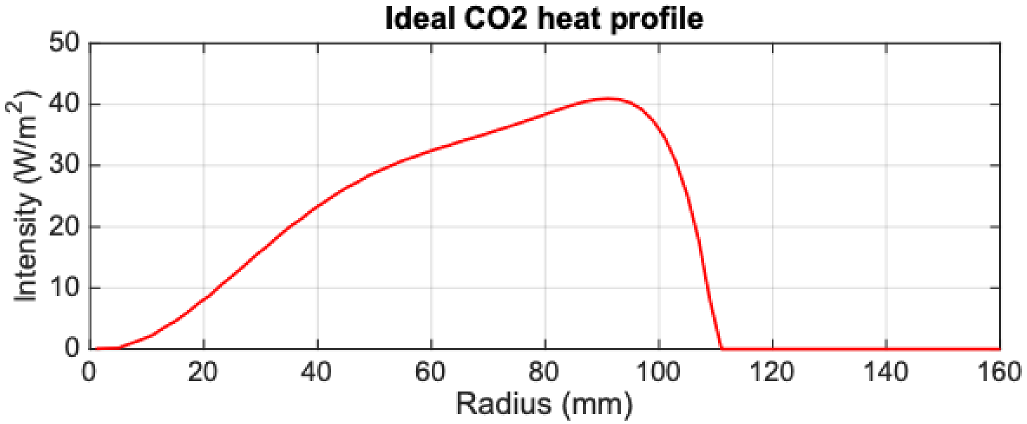
TCS at full optical power

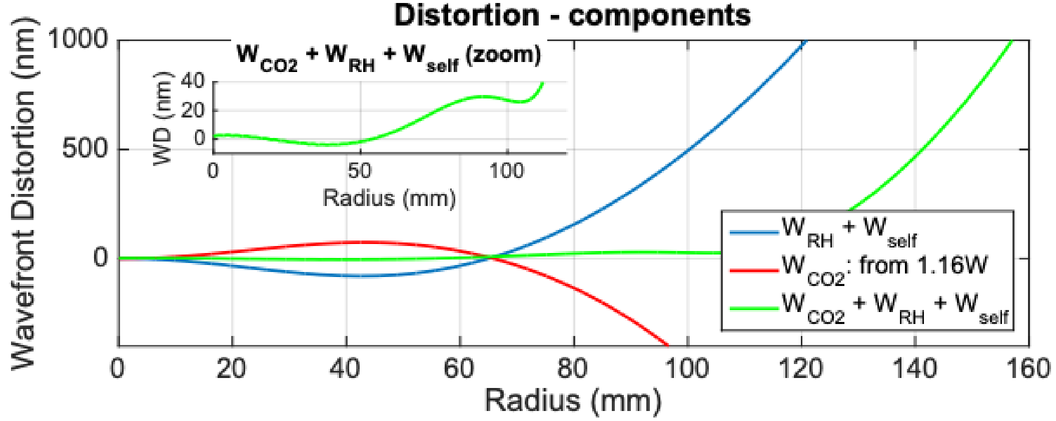
Ring heater: Heats the optic, thermoelastic deformation curves the HR surface in the opposite direction compared to coating absorption. Also induces a thermal lens which is opposite to coating absorption substrate lens.

CO2: Shaped CO2 beam which induces a thermal lens in the CP which reduces OPD left over from RH and coating absorption.









A Quick Review of the Interferometer