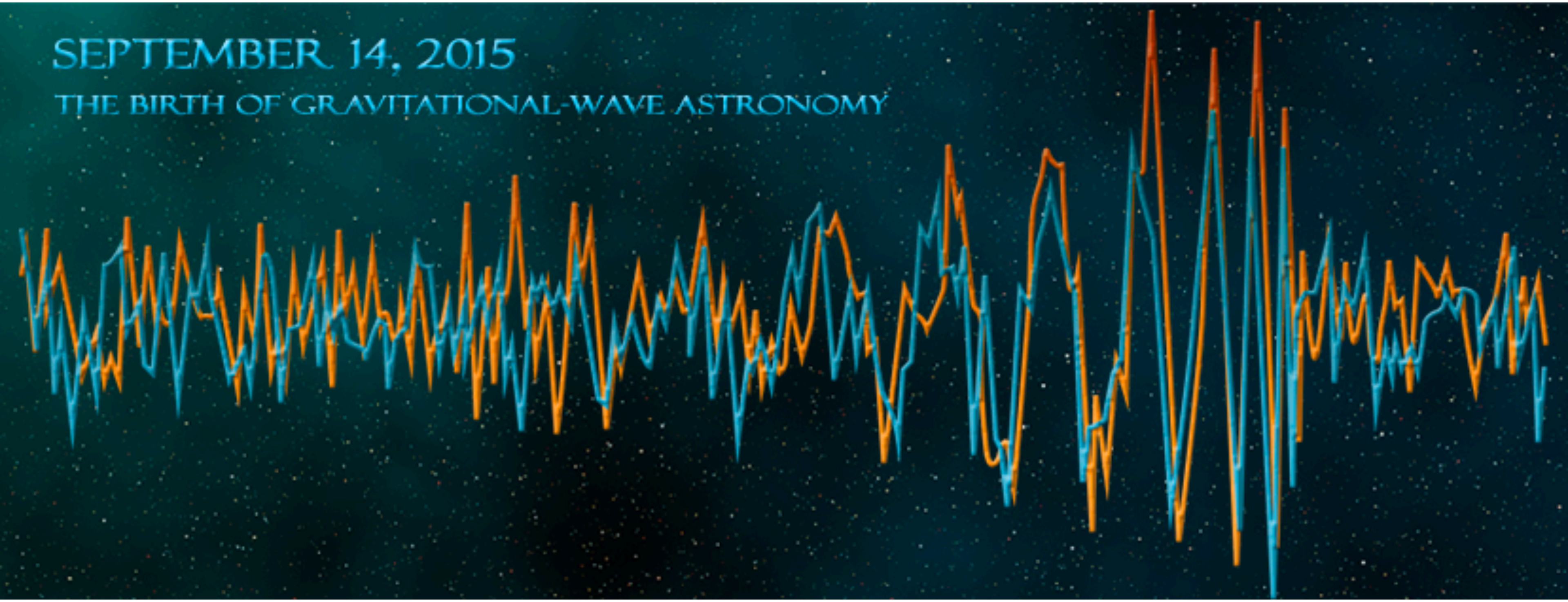
# Characterization of Advanced LIGO Core Optics

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ASPE Topical Meeting
Precision Engineering and Optics
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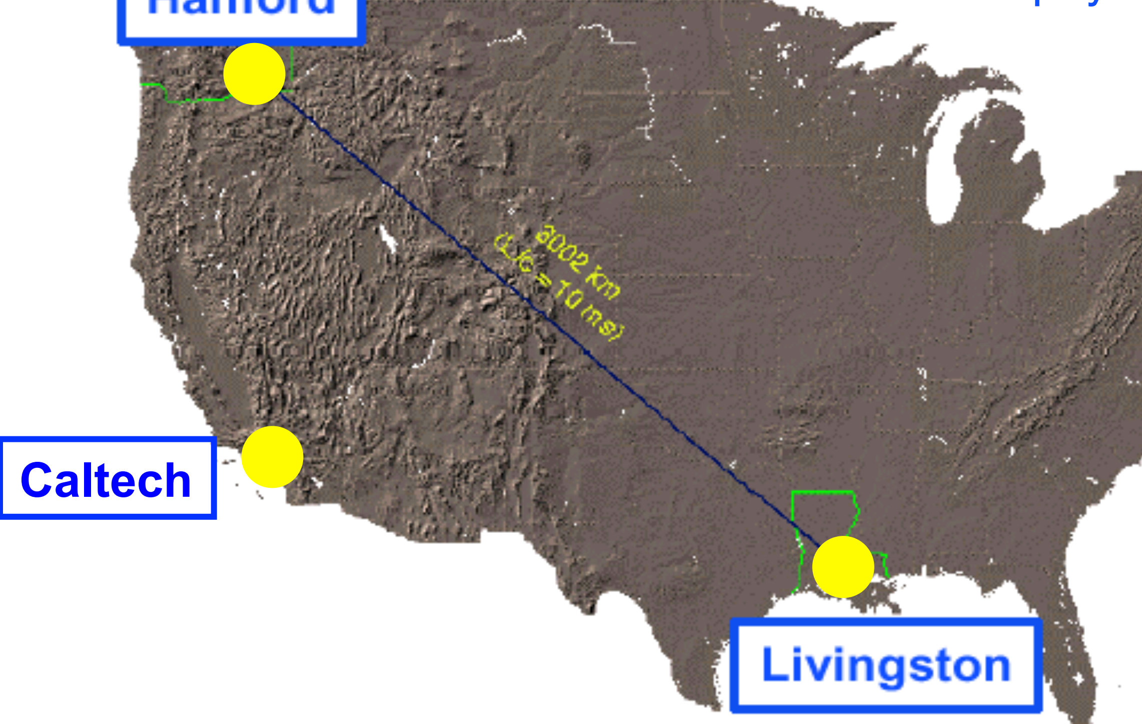
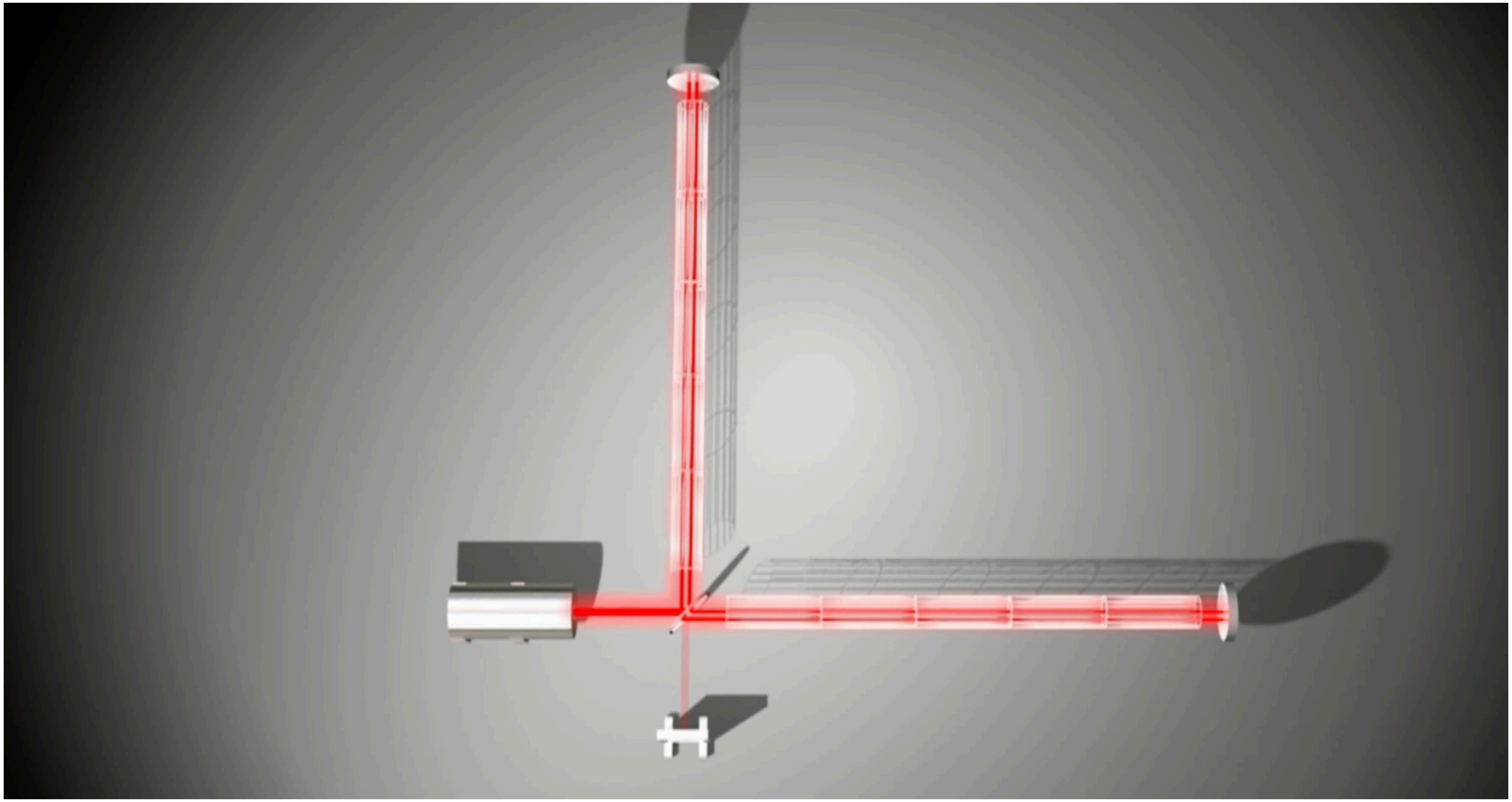
# LIGO Laboratory: two Observatories and Caltech, MIT campuses

- Mission: to develop gravitational-wave detectors, and to operate them as astrophysical observatories
- Jointly managed by Caltech and MIT
- Requires instrument science at the frontiers of physics fundamental limits



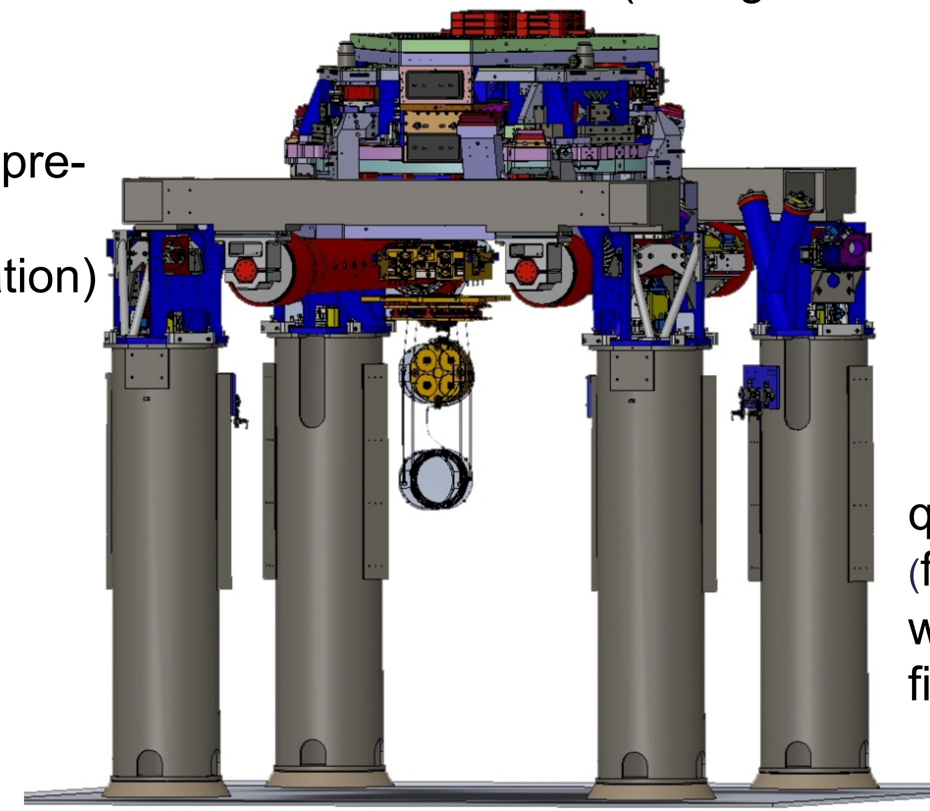

# The basic LIGO layout



# A close approximation of floating

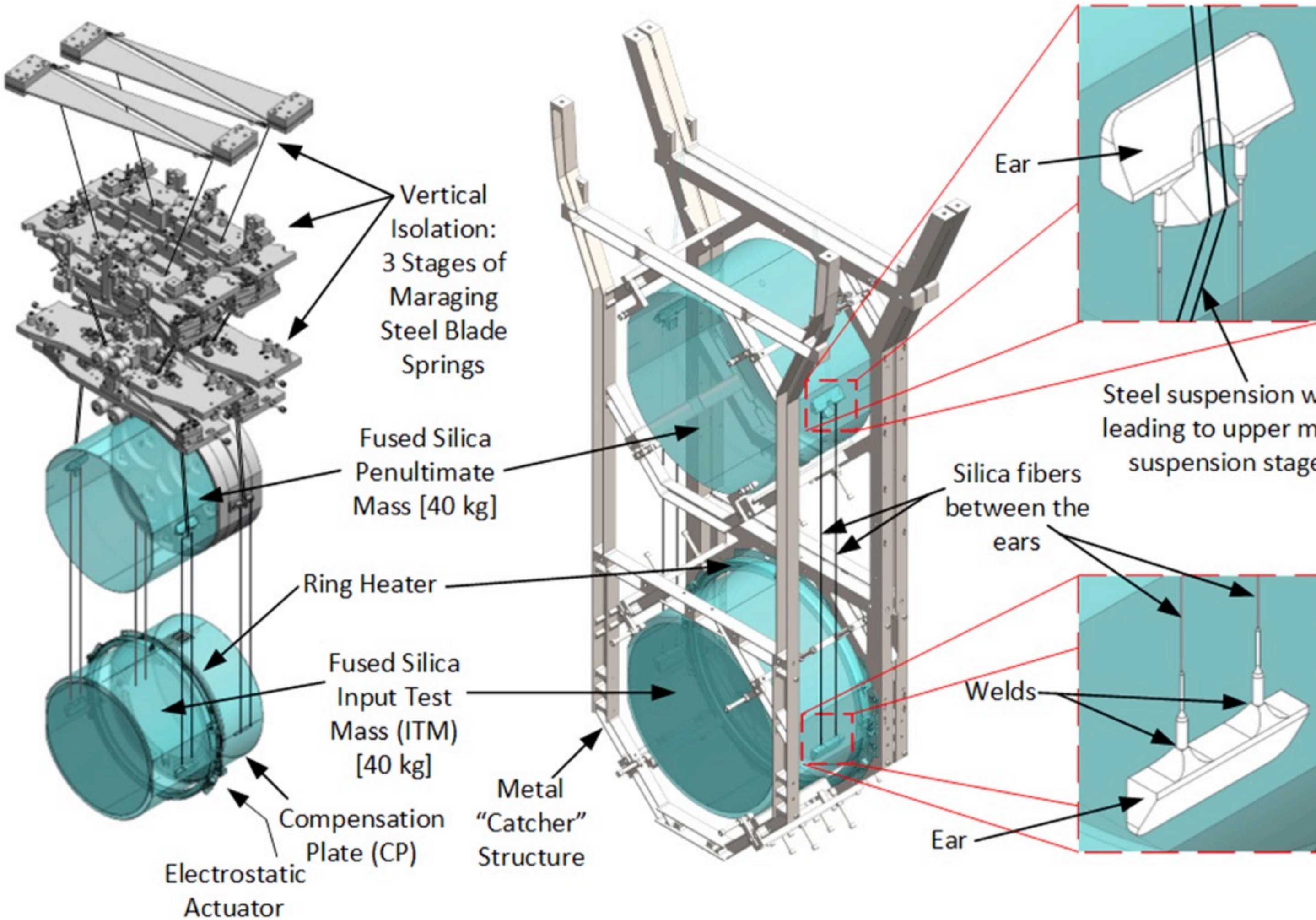
active isolation platform
(2 stages of isolation)

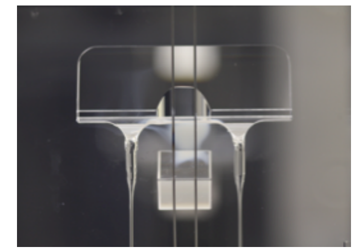
hydraulic external pre-isolator (HEPI)
(one stage of isolation)

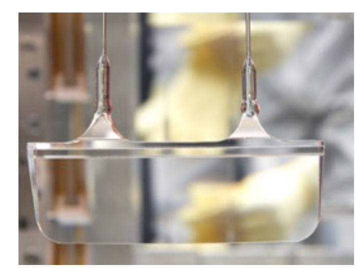


quadruple pendulum
(four stages of isolation)
with monolithic silica
final stage

# Advanced LIGO Suspensions



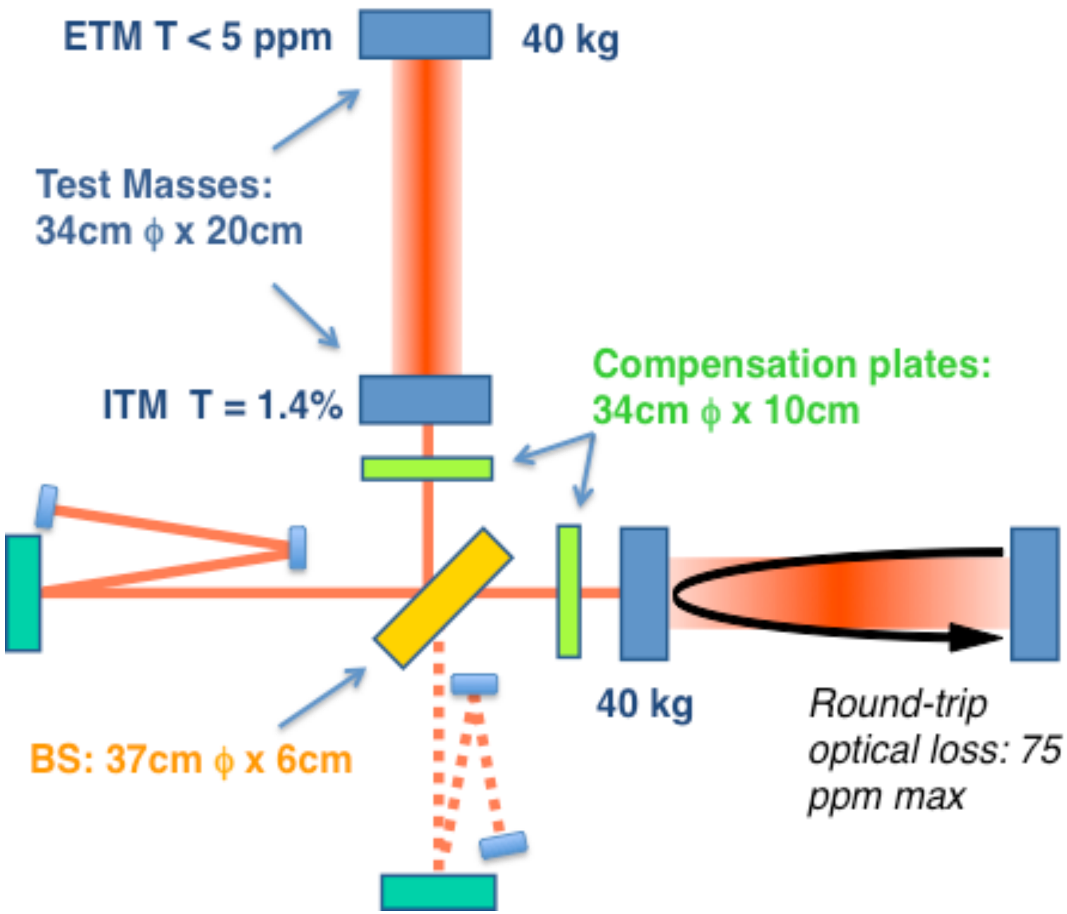





# 340 mm ∅, 200 mm thick
# 40 Kg Fused Silica

# Core Optics

And Much More

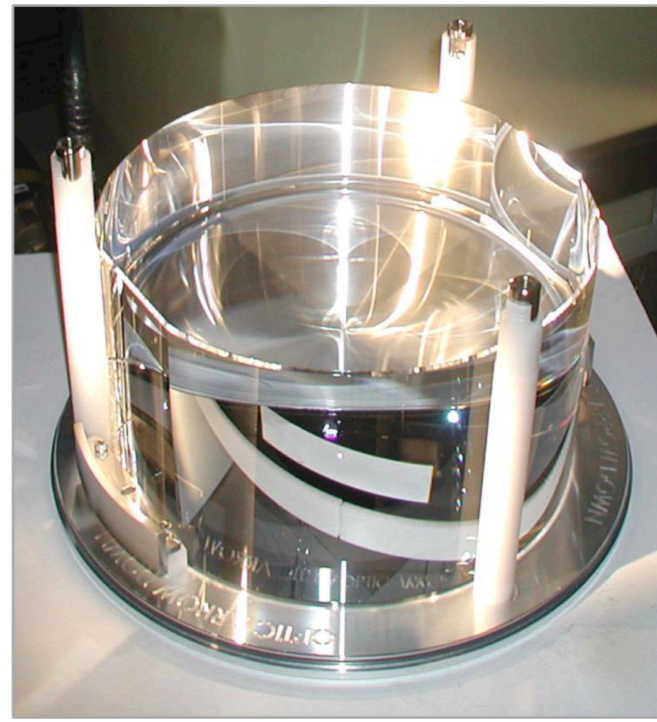


# Arm Cavity Loss details: Results are within budget

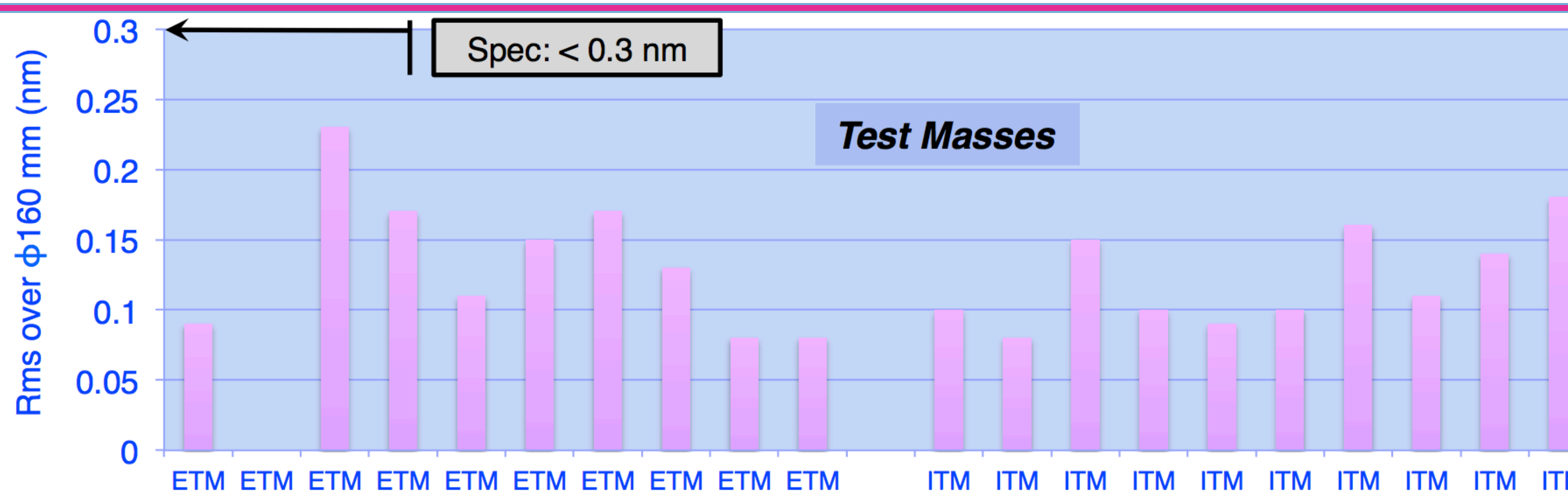
| **Round Trip Cavity loss 2 surfaces (ppm)** | **Design Budget (ppm)** | **Actuals (modeled)** **based on average of completed pieces in 2013** **(ppm)** |
|---|---|---|
| Microroughness scatter (>1/mm) | 8 | 4.4; 2.2 Per mirror |
| Defects (Polish, Coating, Contamination) | 26 | 20; 10 per mirror<br>includes polish and coating |
| Coating Absorption | 1 | 0.6; 0.3 per mirror |
| **Surface Figure Error & Diffraction** | 24 | 16.2 |
| ETM Transmission | 5 | 4.2 |
| Total ( required < 75 ppm) | 64 | 45.4 |

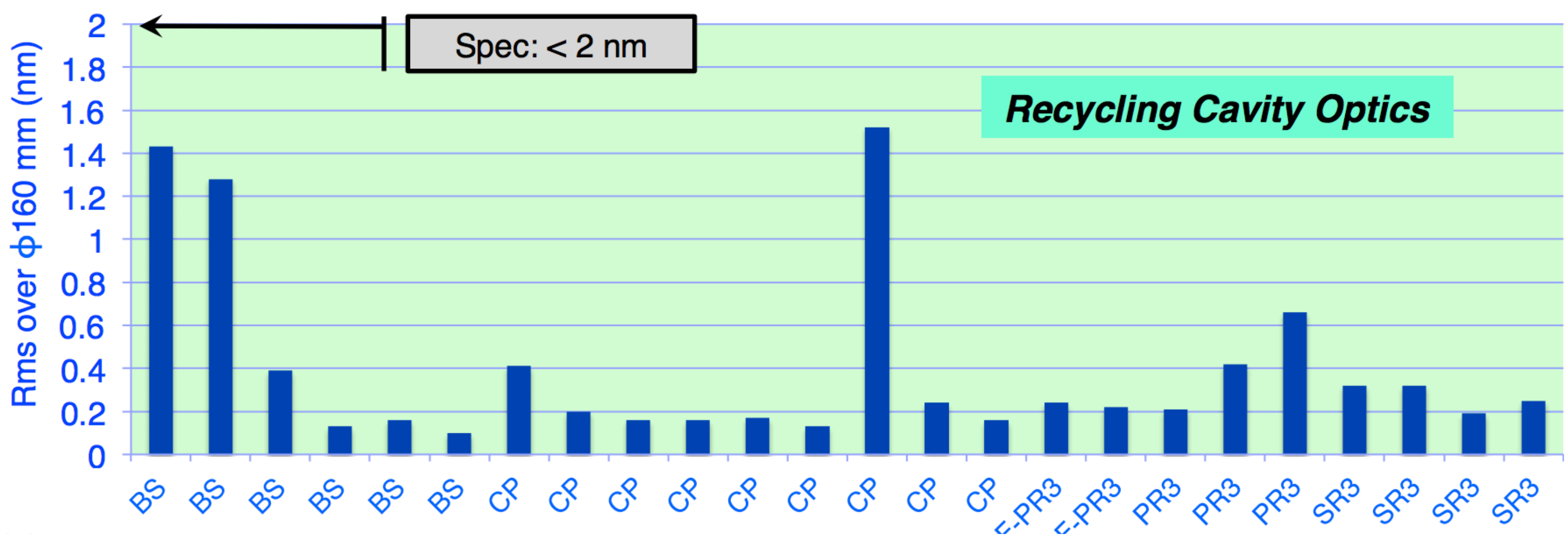
# Design approach

- Fused silica substrates
  - » Low OH Fused silica used for in-cavity optics:
    - – Beam Splitter
    - – Compensation Plate
    - – Input Test Mass
- Two step polish:
  - » Superpolish: ~1 Å microroughness, within 100nm of figure
  - » Ion Beam Figuring: Corrects figure, maintains microroughness
- Ion Beam sputtered coating
  - » Test Masses coated at LMA – Lyon France
  - » Recycling Cavity optics coated at CSIRO – Lindfield Australia



# Figure, as polished
# Tilt, Power and Astigmatism removed

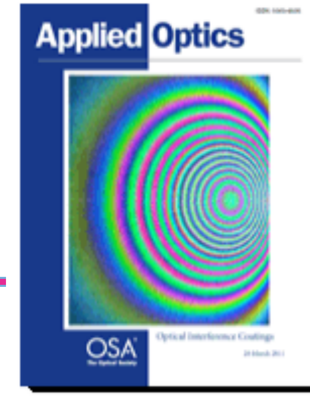


# LIGO Figure measurement: Fizeau Interferometer

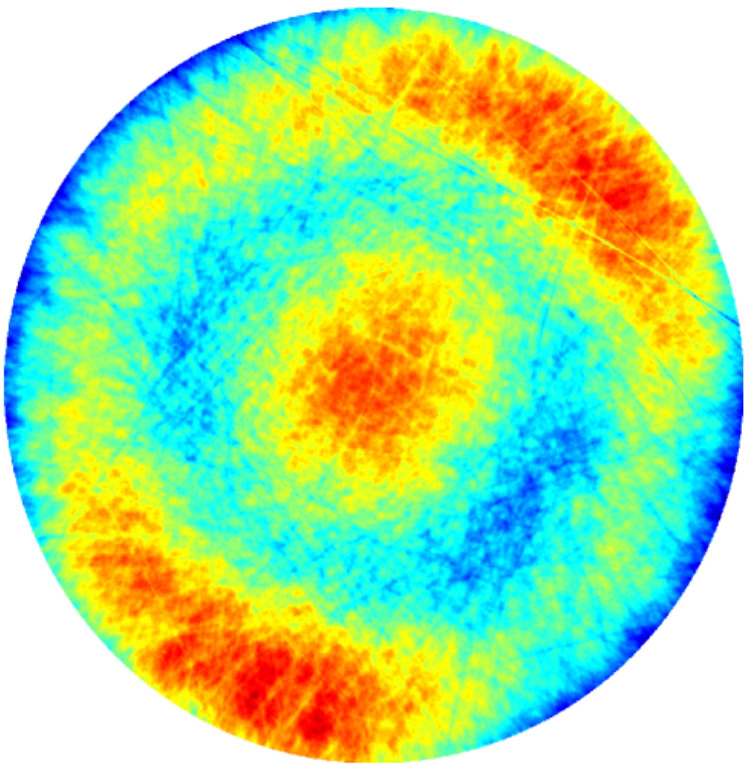
- Zygo interferometer installed at Caltech, 1064 nm
- 4 magnifications; 1X, 2X, 10X, 20X
- The instrument and environment are quite stable, showing a uniform noise floor of 0.1 to 0.15 nm rms.
  - » Polishing requirement is 0.3 nm rms
  - » Vendor reports some surfaces at 0.08 nm rms
- Good agreement with Polishing vendor measurements

# Before and after coating measured on different instruments

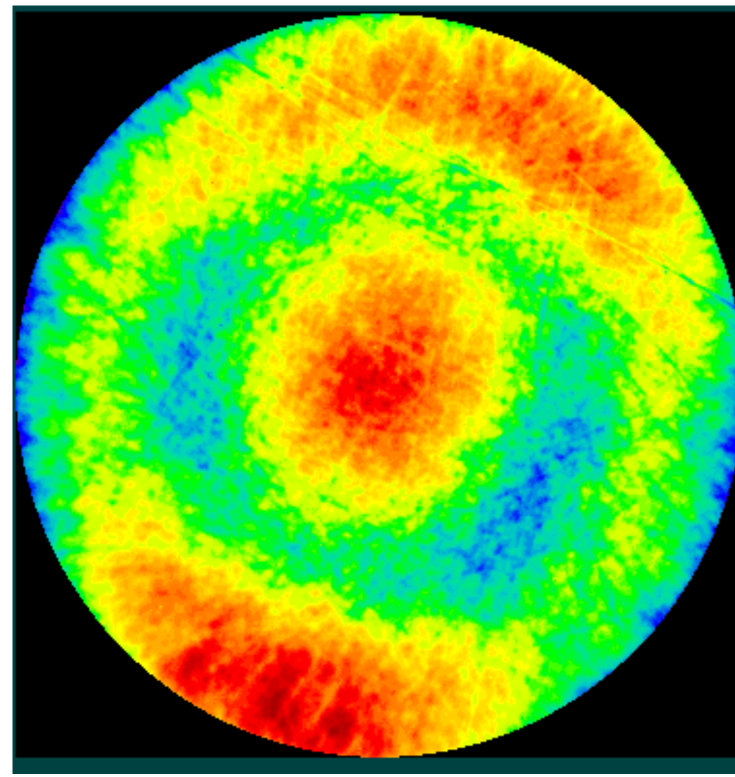



300 mm diameter, <u>same color scale</u>, Power subtracted (Δ 3.5nm)

Uncoated (Zygo EPO)
11.4 nm PV 1.7 nm rms

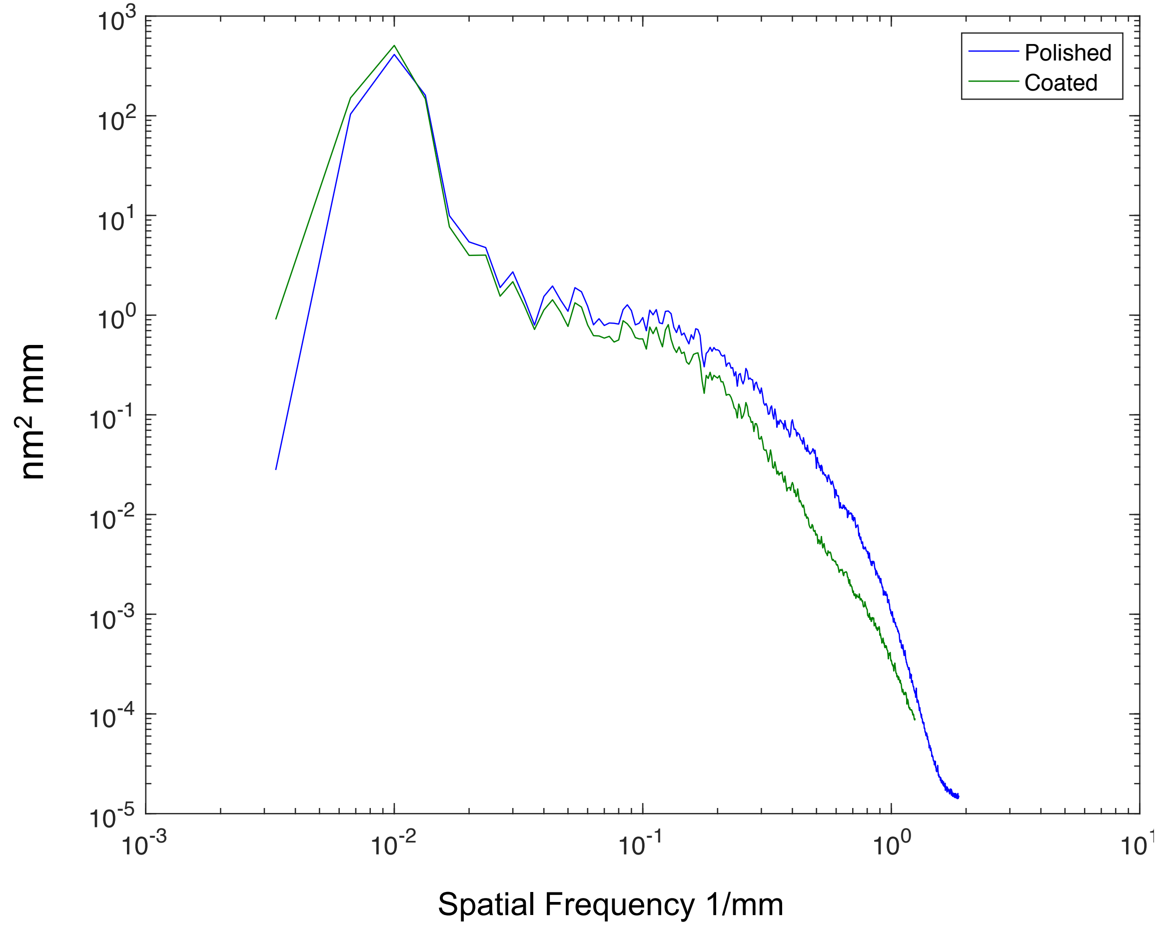


Coated at CSIRO (LIGO)
9.8 nm PV 1.6 nm rms



Mark Gross, Svetlana Dligatch, and Anatoli Chtanov, "Optimization of coating uniformity in an ion beam sputtering system using a modified planetary rotation method," Appl. Opt. 50, C316-C320 (2011)

# Before and after coating measured on different instruments

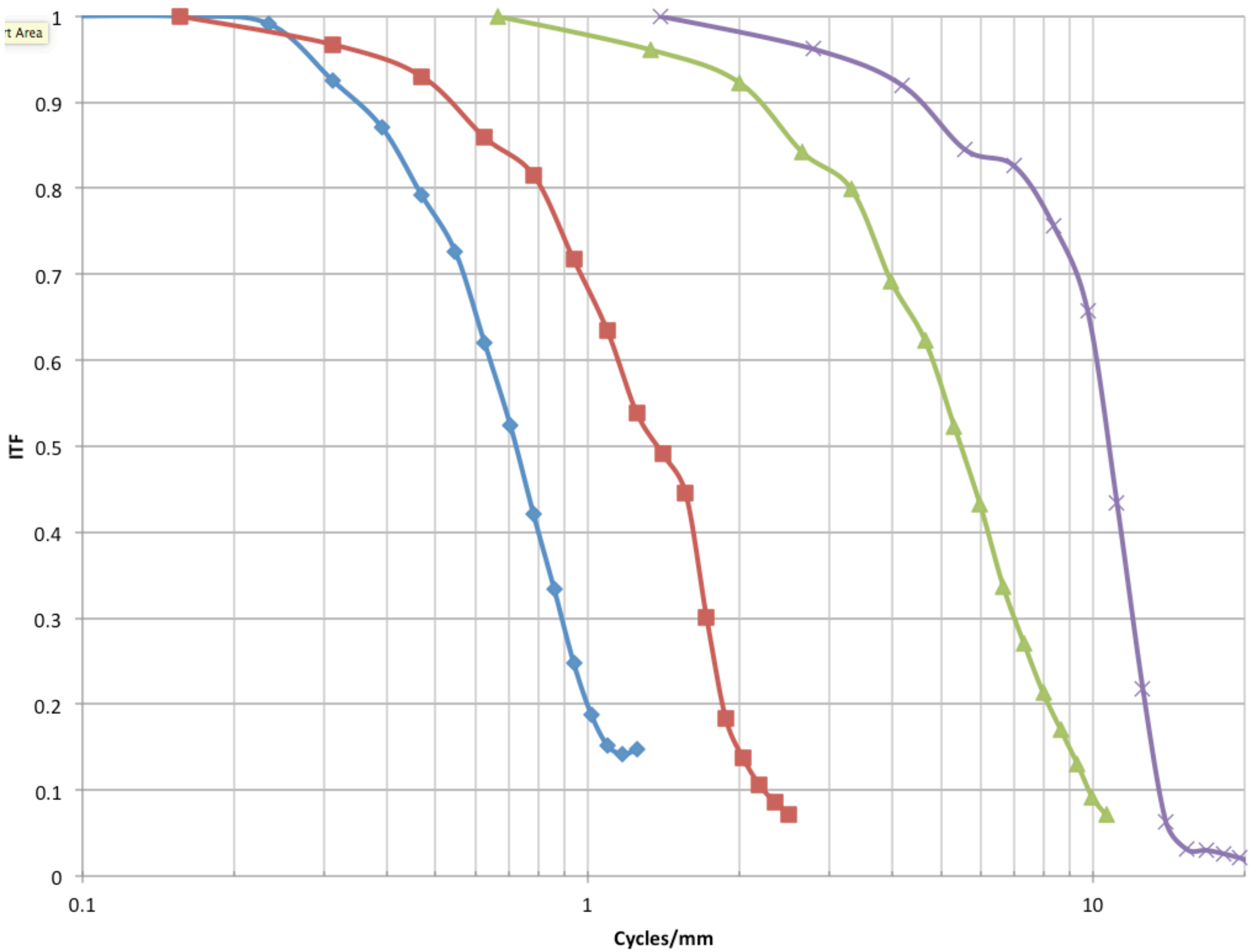



Zygo instrument
λ = 632 nm
Res = 267 μm

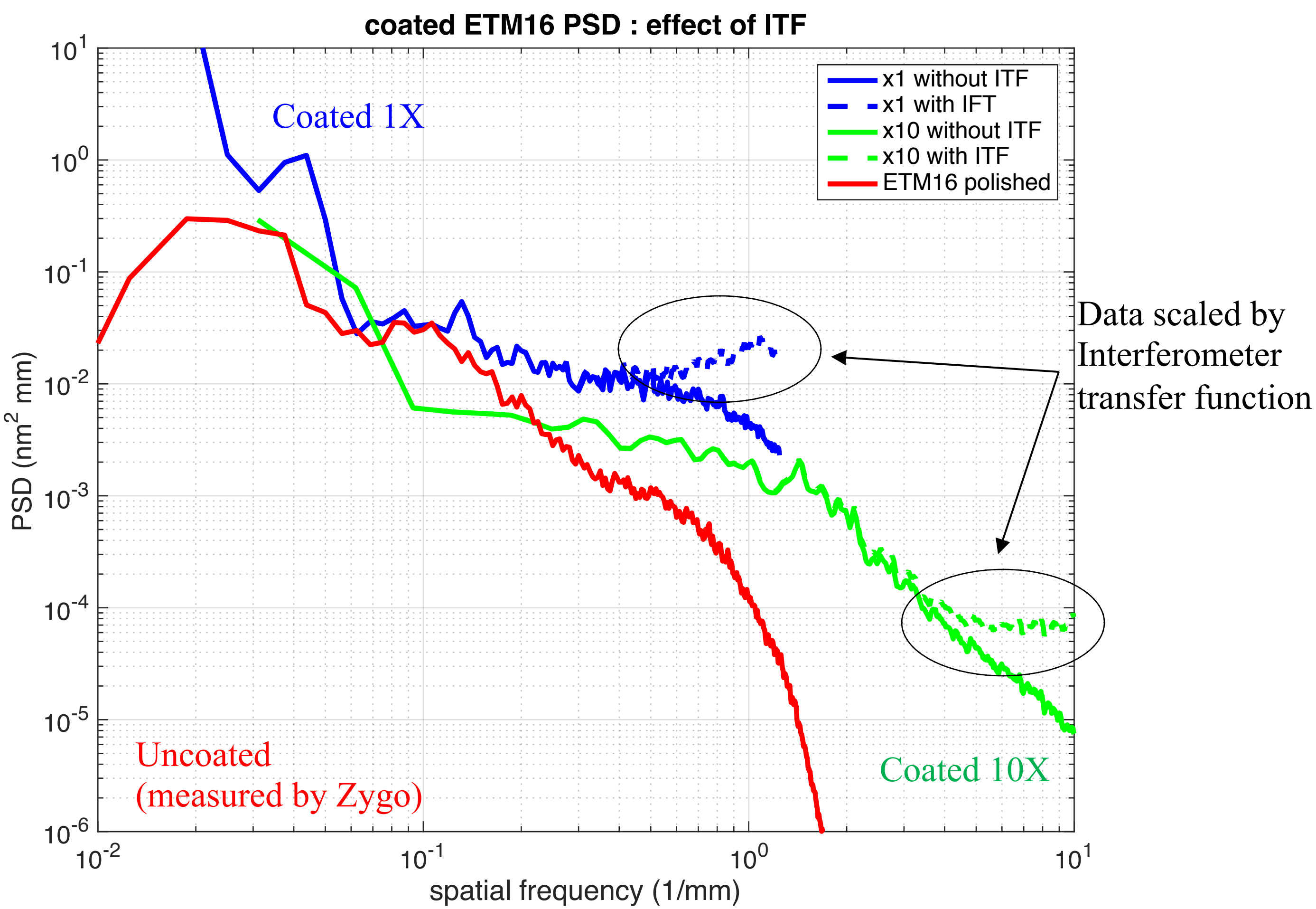
LIGO instrument
λ = 1064 nm
Res = 400 μm

# Instrument transfer function

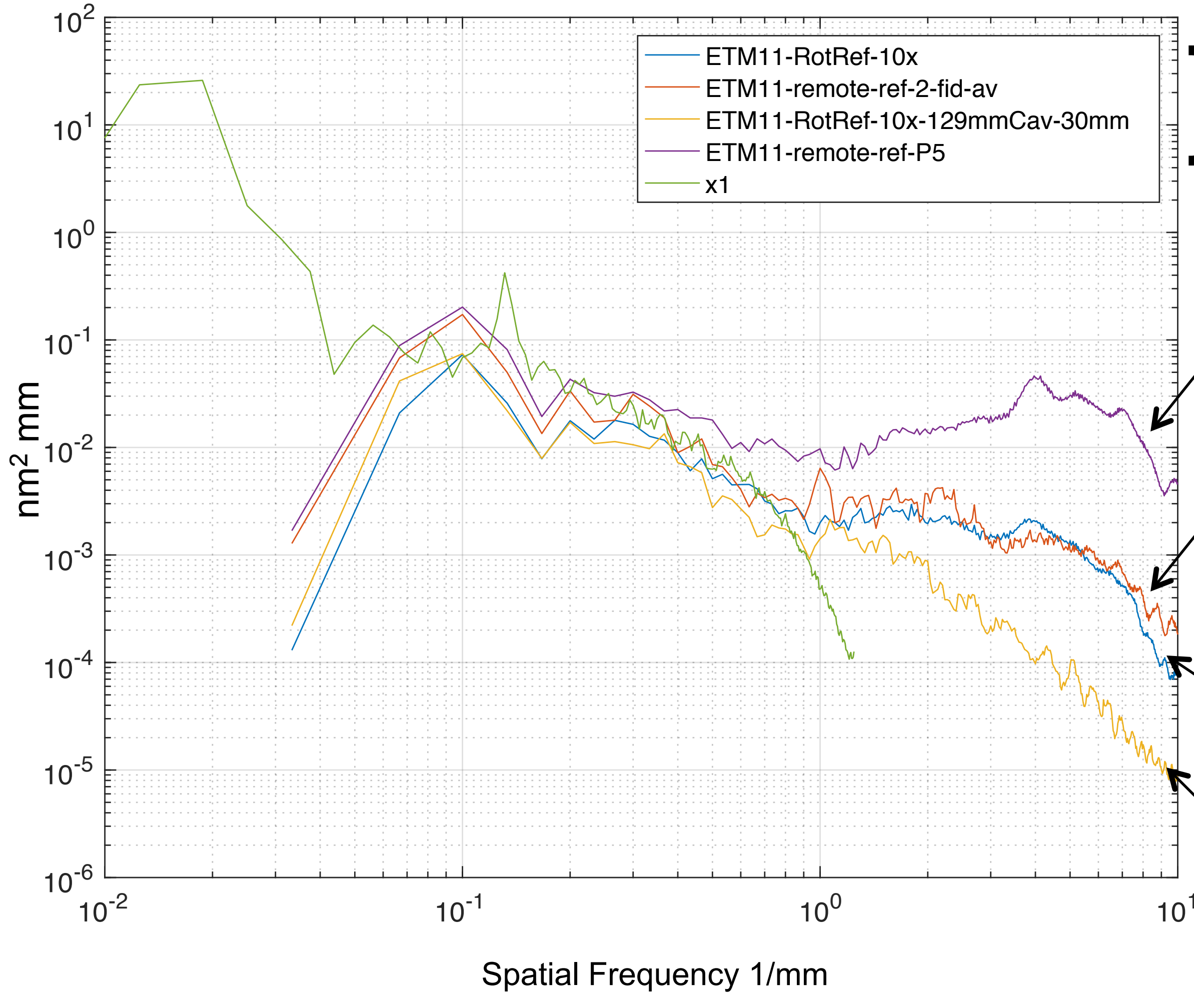
Provided by Zygo Middlefield



# Instrument transfer function Correction?



# Compare 1x data to 10x using different methods




} 30 mm aperture

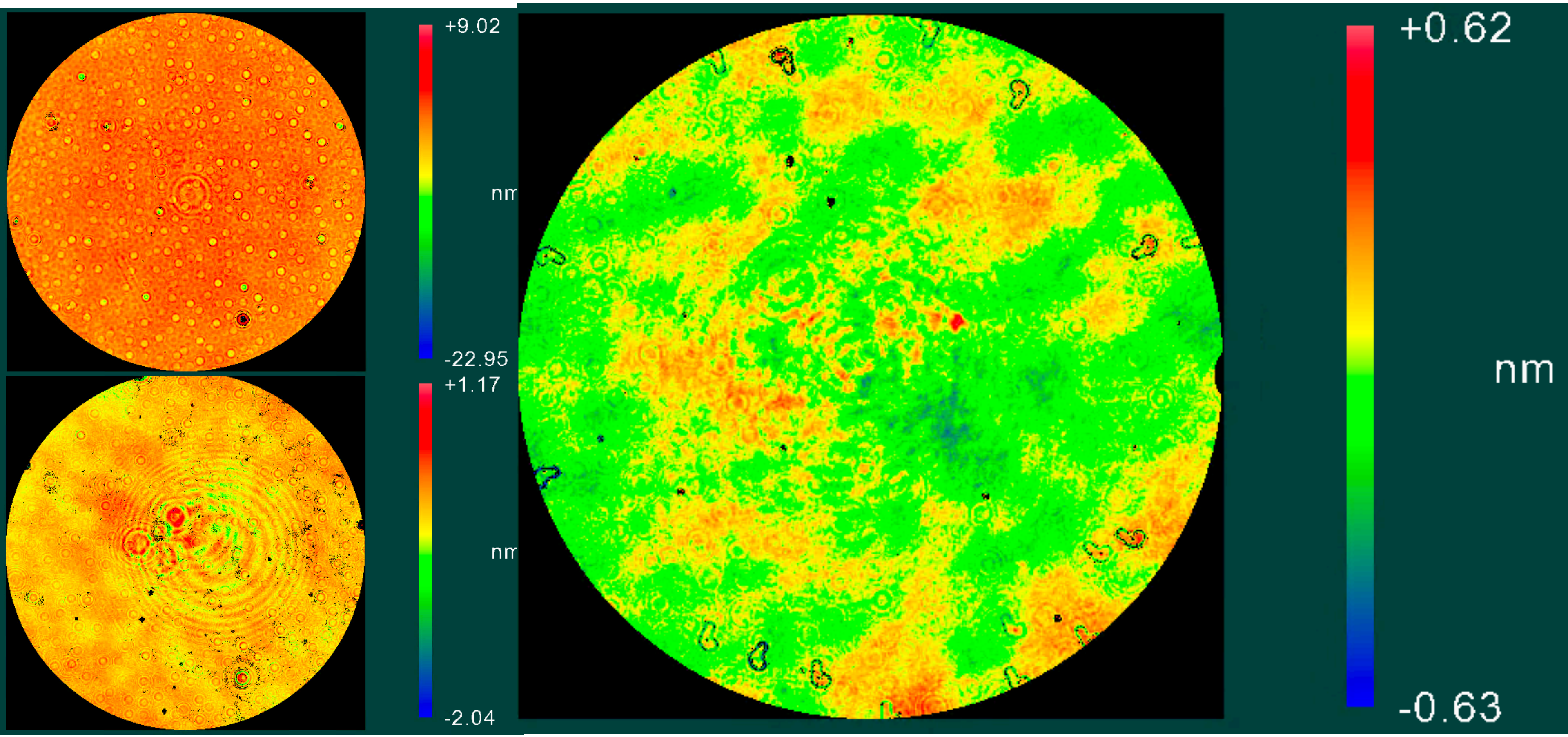
1 center set minus average of 10 random sets used as reference

2 center sets. Each minus average of 10 random sets (used as reference.) Average using fiducials

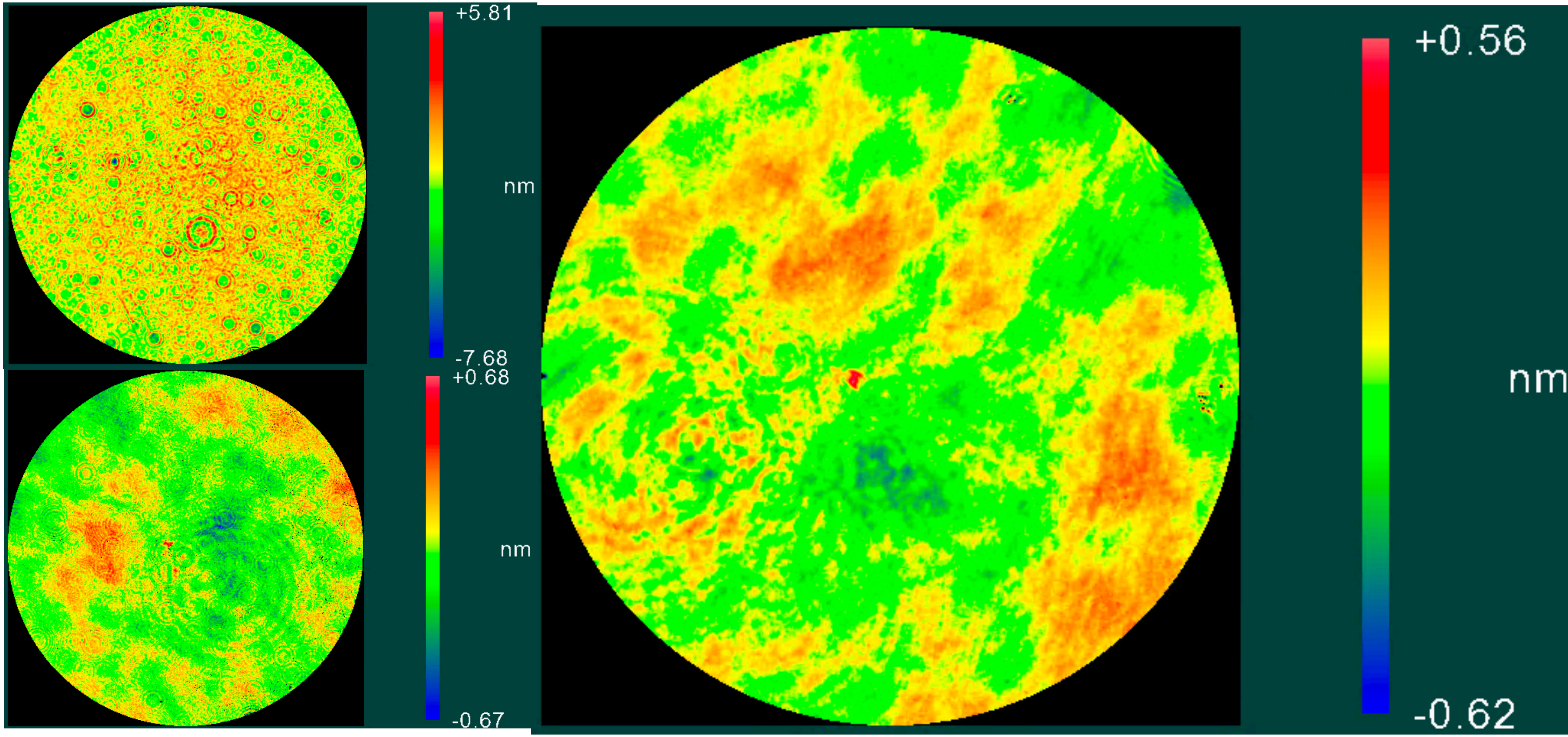
Same method as 1X 80 mm cavity
C. Evans and R. Kestner, "Test optics error removal," Appl. Opt. 35, 1015-1021 (1996).

Same method as 1X, but 130 mm cavity

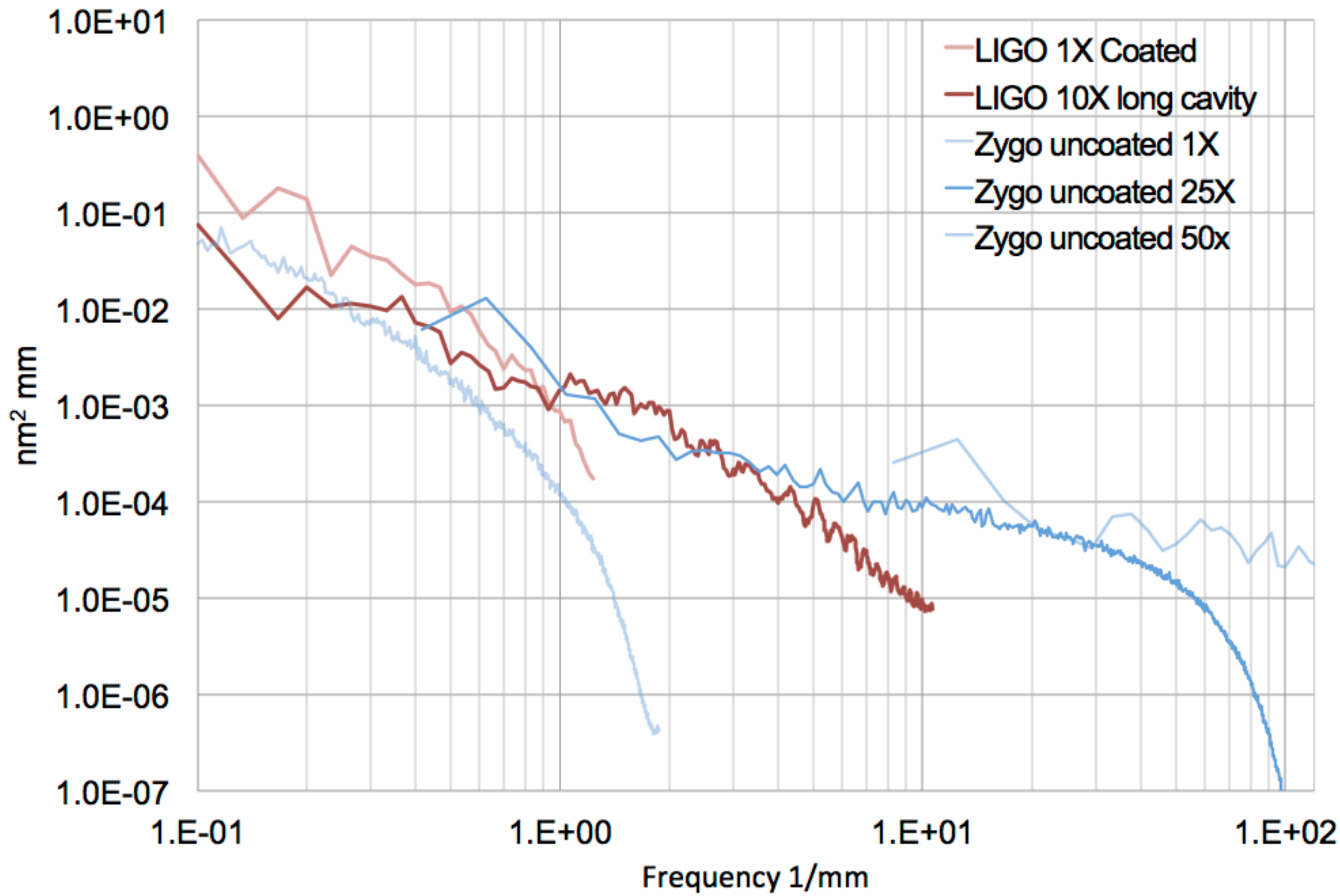
# 10X taken with a cavity length of 80 mm



# 10X taken with a cavity length of 130 mm



# PSDs of ETM11 Compare Coated and Uncoated



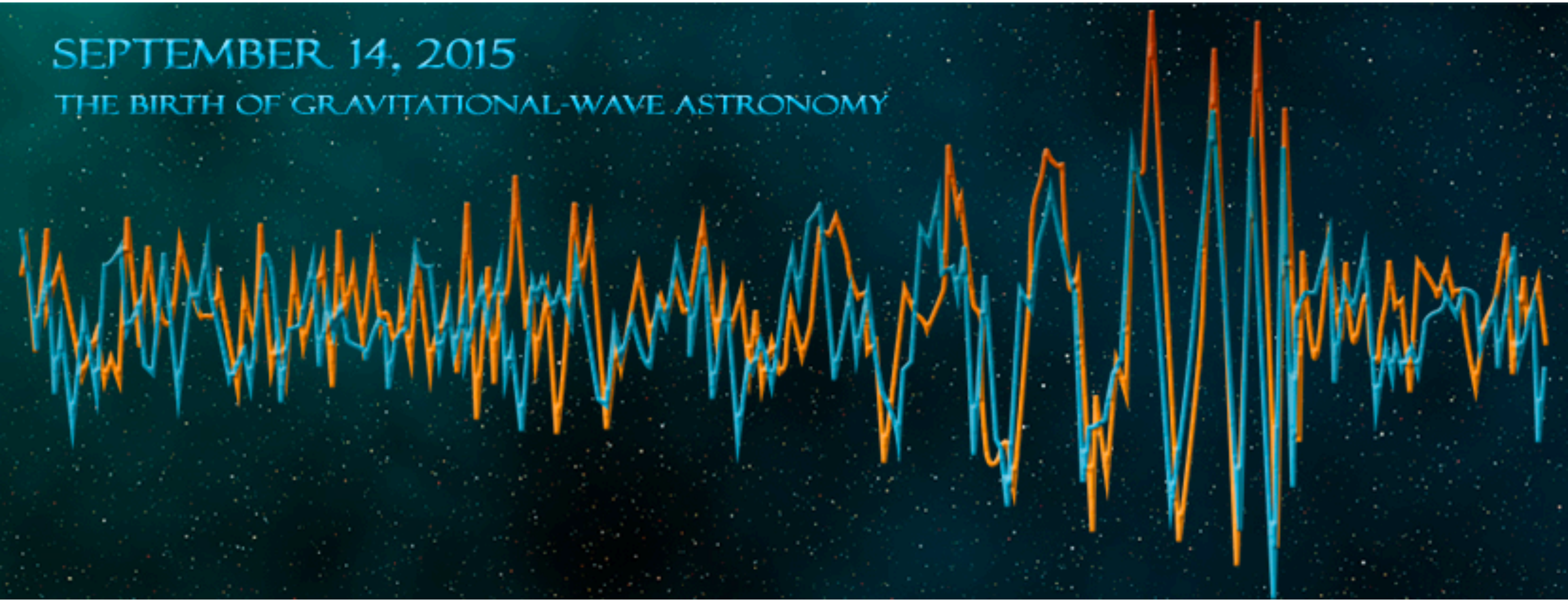
# LIGO Scientific Collaboration

LIGO

LSC

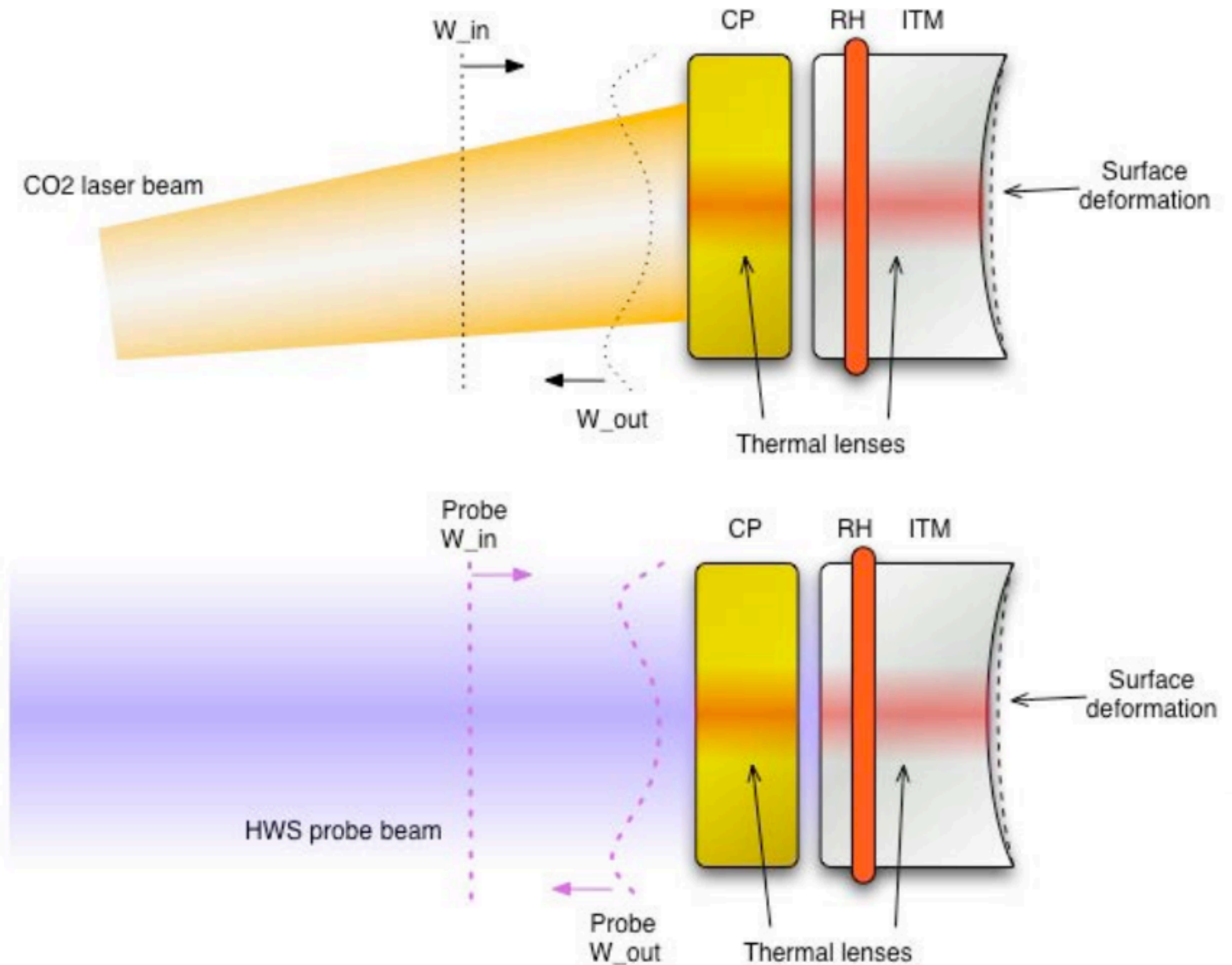
Trinity University
University of Maryland
Andrews University
Washington State University
California State University Fullerton
The University of Alabama in Huntsville
Whitman College
Sonoma State University
indigo
Montclair State University
University of Glasgow
Australian National University
American University
University of the West of Scotland UWS
Texas Tech University
清華大學 Tsinghua University
R·I·T
University of Strathclyde
Michigan
Max Planck Institute for Gravitational Physics
Albert Einstein Institute
The University of Western Australia
CITA ICAT
Università degli Studi del Sannio
NASA Goddard Space Flight Center
ICTP SAIFR
University of Cambridge
ACU
The University of Chicago
Montana State University
The University of Mississippi
The University of Adelaide Australia
Southern University Agricultural & Mechanical College
Columbia University in the City of New York
Caltech
University of Minnesota
University of Birmingham
The University of Melbourne
UIB Universitat de les Illes Balears
University of Washington
GEO 600
UTRGV
University of Wisconsin Milwaukee
Northwestern
Syracuse University
Cardiff University Prifysgol Caerdydd
Monash University
INPE
UF University of Florida
Georgia Institute of Technology
Korean Gravitational-Wave Group
LSU Louisiana State University
ACIGA
University of Southampton
Charles Sturt University
Embry-Riddle Aeronautical University
Leibniz Universität Hannover
PennState
Science & Technology Facilities Council
Rutherford Appleton Laboratory

# Thank you

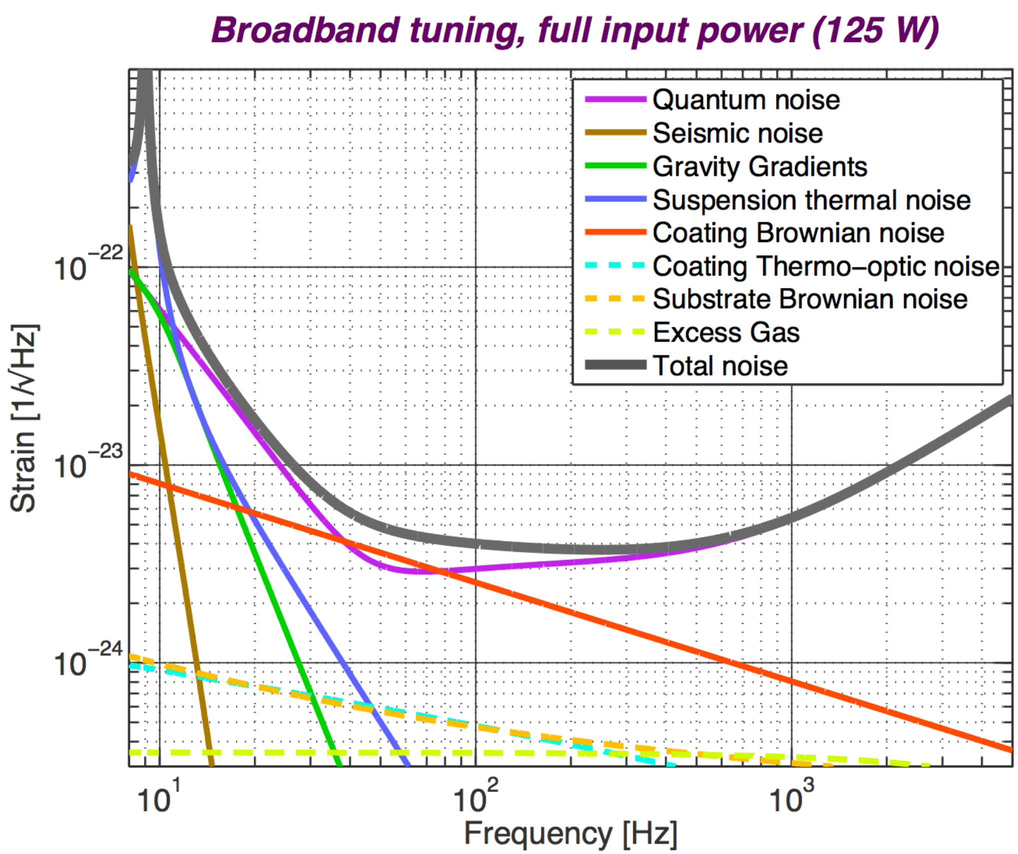



See also
losc.ligo.org dcc.ligo.org

# Compensation plate and ITM



# Noise summary




Limiting noise sources at 40 Hz:

- Quantum noise
  - Shot Noise
  - Radiation Pressure
- Coating Brownian noise