Summary of Stray Light Mitigation Strategies at 2G interferometers

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GWADW2021 Gravitational Wave Advanced Detector Workshop

Online 2021

Outline

- IFT layout and stray light
- Baffles/baffles
- Long arms baffling
- Suspended vs non-suspended
- Baffles in Core Optics
- CryoBaffles
- R&D on materials
- Large angle stray Light in benches*
- Towards acting monitoring

- Final notes on future

Collecting highlights from more than a decade of SLC work at Virgo.

See talk by Beatrice D'Angelo on Dust in Optics
See talk by Michal Was on Bench Optics

See talk by Alena Ananyeva @ LIGO

* Not including work on suspended benches

Layout

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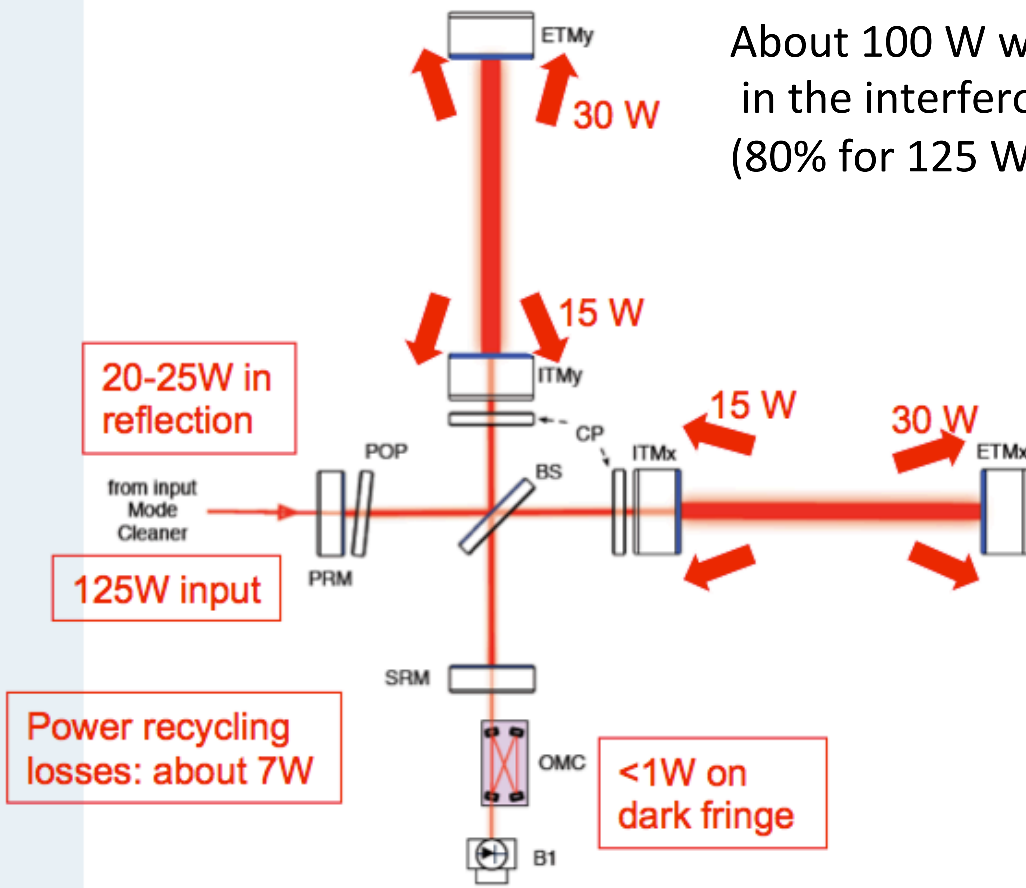
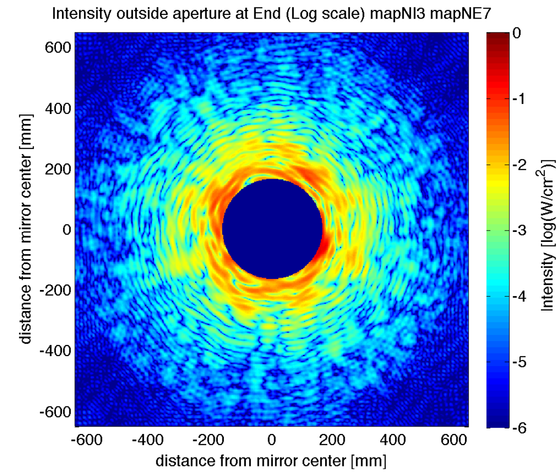
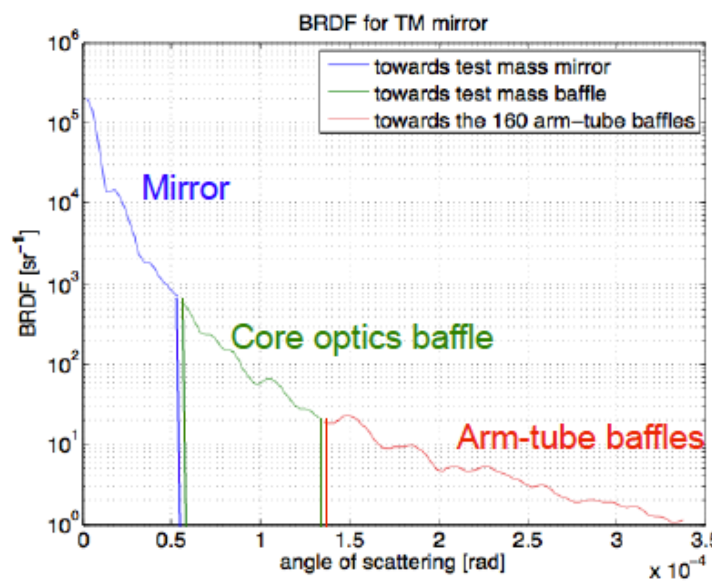


About 100 W would be diffused light in the interferometer (80% for 125 W input)





Most of the light at small angles close to the mirrors
→ Dictated by the mirror maps/defects
Larger angles going to core-optics/cryo stations
Scattered light in long tube much smaller but can kill the GW signal if not mitigated.

A re-coupling of 10^{24} W/W enough to destroy the expected GW signal

baffles/baffles

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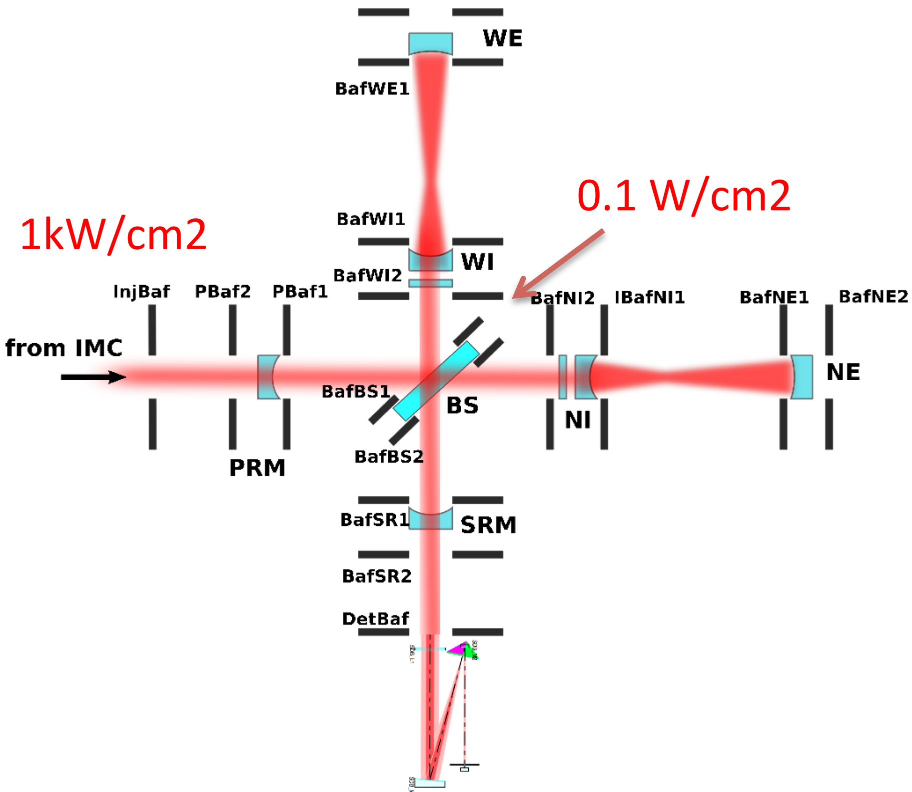
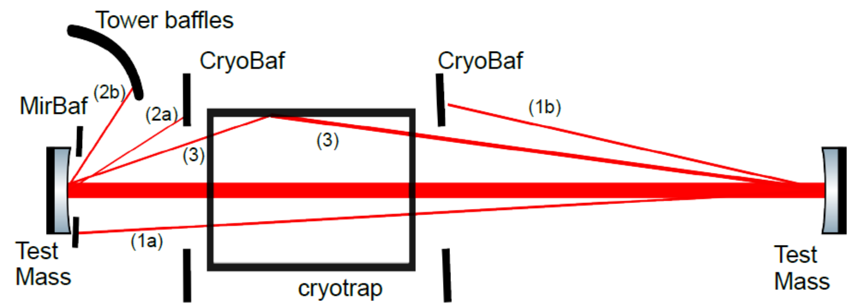
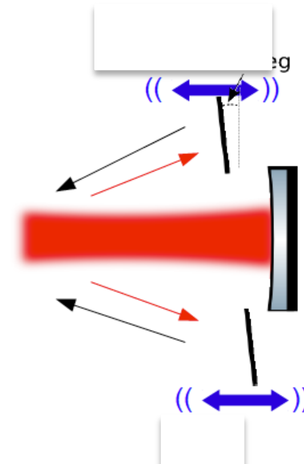




$$\Delta\phi = 4\pi/\lambda \;\; x(f)\; \mathrm{Power}^{1/2}{}_{\mathrm{recoupled}}$$



Need to put baffles almost everywhere

→ Important to understand the intensity of the light to determine potential damage
Different materials in different places

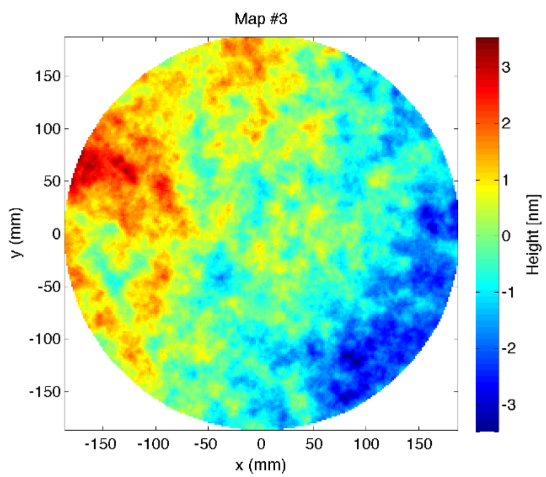
→ Important to understand baffle vibrations

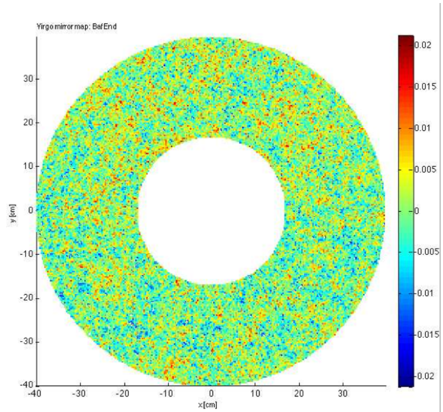
Re-coupled photons propagates vibrations
Inducing a phase fluctuation faking GWs

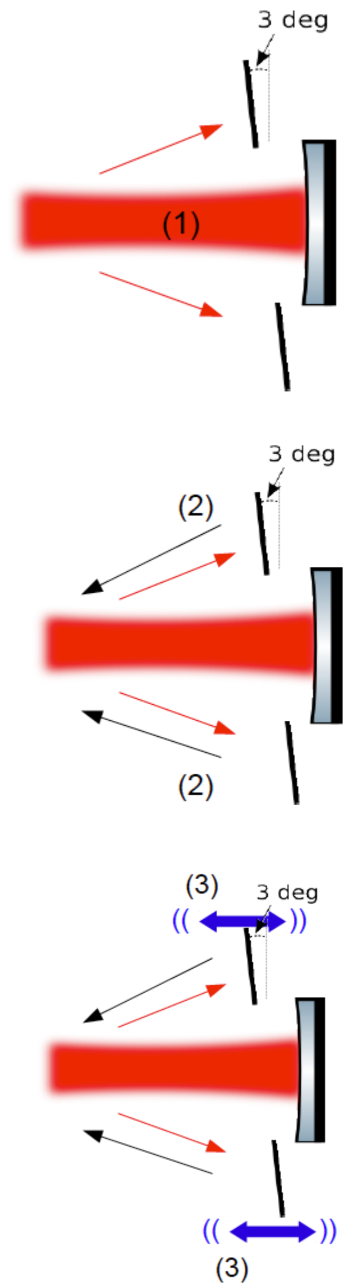
Computing SLC noise

1. Use FFT simulation to understand light illuminating baffle
   - Needs mirror maps
2. Use FFT to understand how much couples back to ITF
   - Baffle as intra cavity source with effective map
3. Using Optickle to compute the Transfer function from baffle displacement to dark Fringe → tricks on how to model ITF

→ Given a baffle displacement translate into h(f) sensitivity
→ Validate with data (injection tests)







$$\tilde{x}_{baf}(\omega) = \frac{\lambda}{4\pi}\sqrt{PSD\left[\sin\left(\frac{4\pi}{\lambda}x_{baf}(t)\right)\right]} \qquad h_{noise}(\omega) = \frac{TF_{B1/baf}}{TF_{B1/DARM}}\frac{1}{L_{arm}}\, c_{xx}\, \tilde{x}_{baf}(\omega)$$

Baffles in long arms

PHYSICAL REVIEW D VOLUME 56, NUMBER 10 15 NOVEMBER 1997

Scattered light noise in gravitational wave interferometric detectors: A statistical approach

Jean-Yves Vinet
Laboratoire d'Optique Appliquée, Ecole polytechnique-Ecole Nationale Supérieure de Techniques Avancées, 91120 Palaiseau, France

Violette Brisson
Laboratoire de l'Accélérateur Linéaire, Bat. 208, Université Paris-Sud, 91405 Orsay, France

0556-2821/97/56(10)/6085(11)/$10.00 56 6085

PHYSICAL REVIEW D VOLUME 54, NUMBER 2 15 JULY 1996

Scattered light noise in gravitational wave interferometric detectors: Coherent effects

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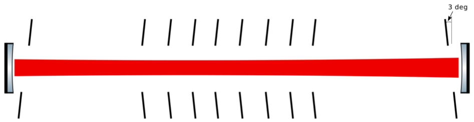
0556-2821/96/54(2)/1276(11)/$10.00 54 1276

[1] Vinet, Brisson, Braccini, Ferrante, Pinard, Bondu, Tournie, "Scattered light noise in gravitational wave interferometric detectors: a statistical approach", Physical Review D (1997)

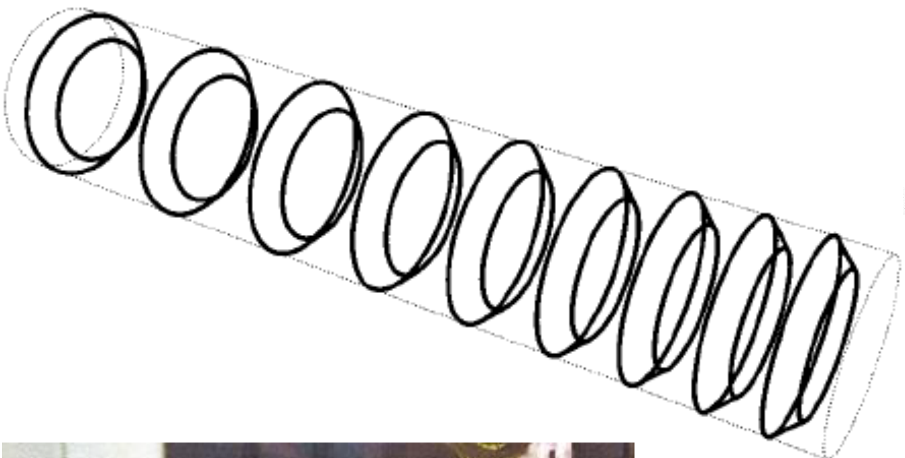
[2] Vinet, Brisson, Braccini, "Scattered light noise in gravitational wave interferometric detectors: Coherent effects", Physical Review D (1996)

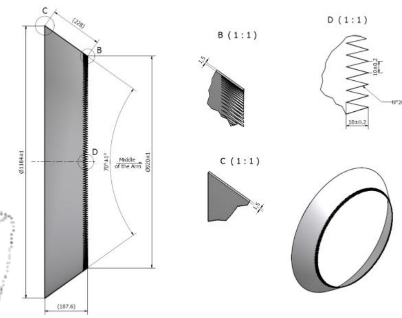
- → Demonstrate the need for chain of baffles in main arms
- → Following work by K.S. Thorne in 1989

- → As a result 160 baffles in each main arm
- → R&D on edge shape led to the serrate solution



Baffles in long arms





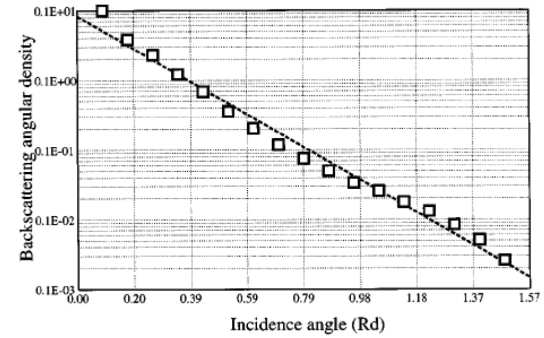
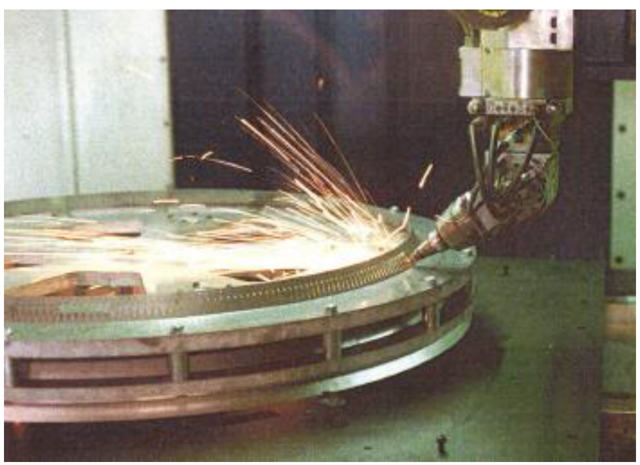
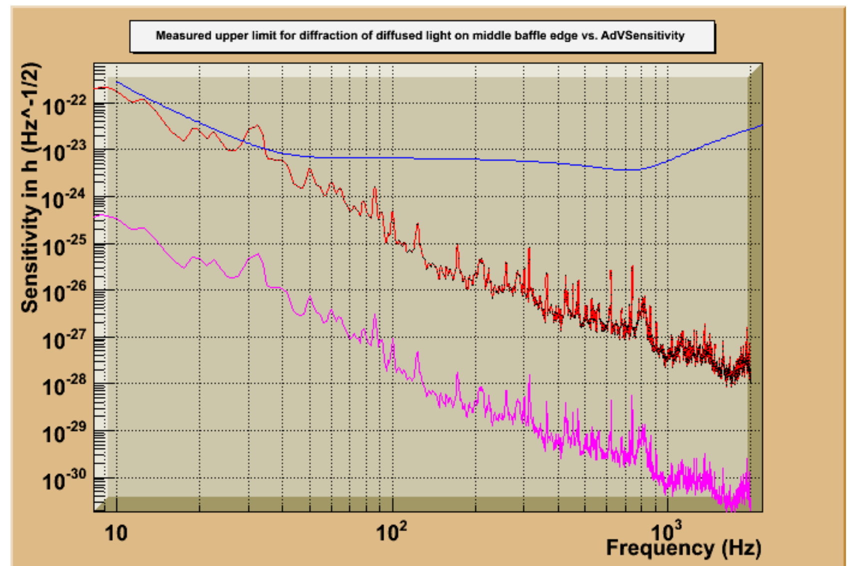


FIG. 4. BRDF of stainless steel for backscattering. Dashed line: exponential fit.





Calculations indicate that serrate shapes
reduce drastically the reflectivity and diffraction effects

VIR-0172A-08

→ Early on injection studies indicated the noise is below the required sensitivity

Suspended/non-suspended

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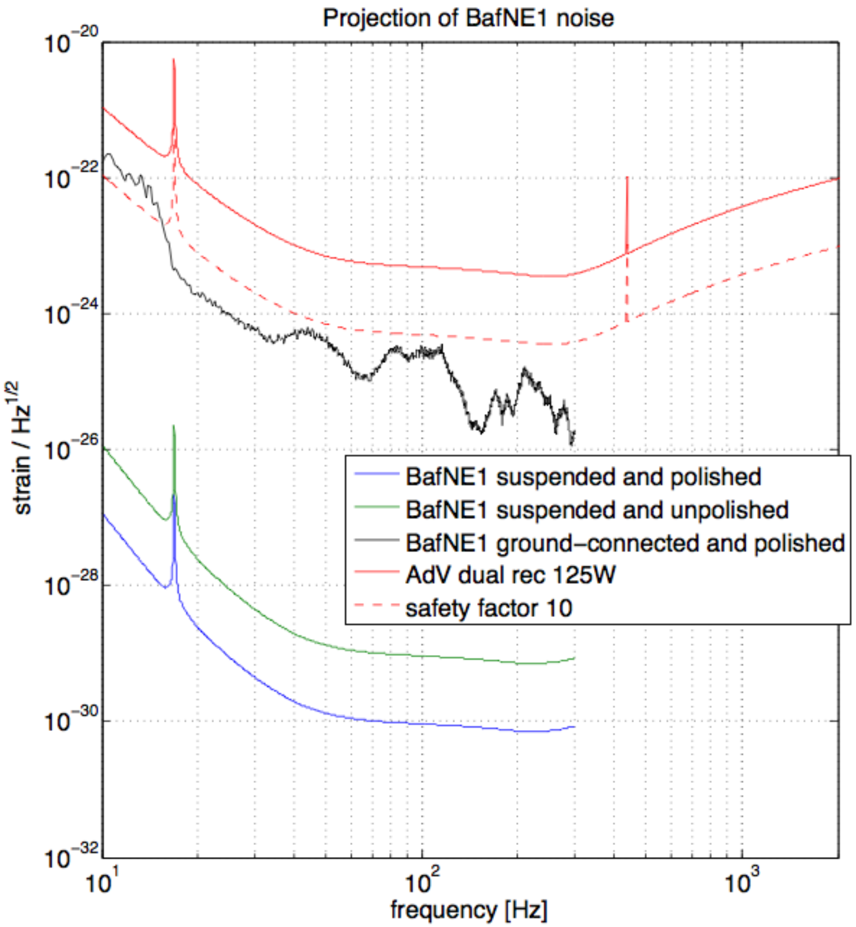
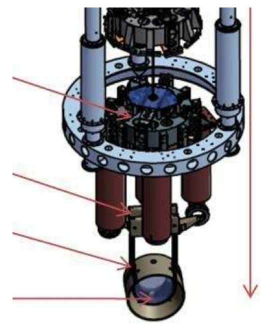
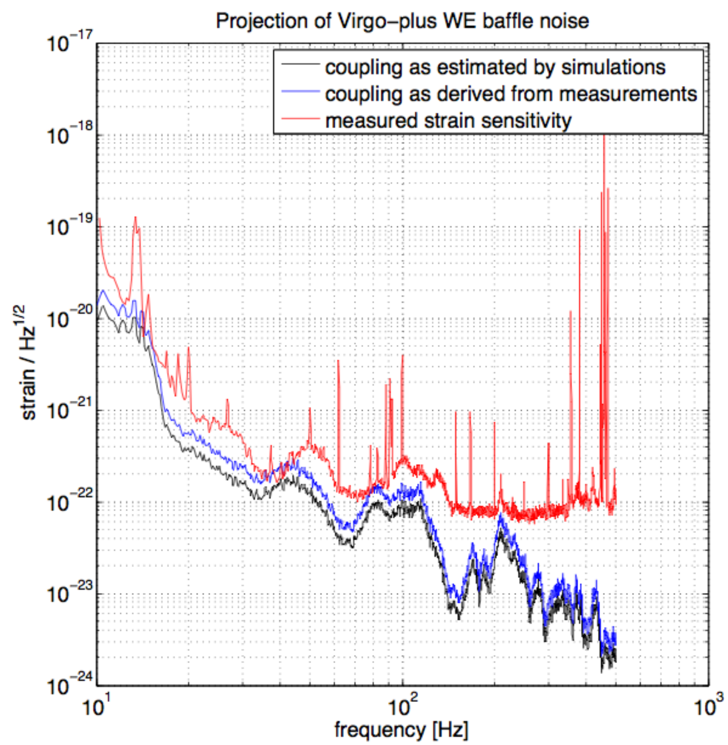




$$x_{Baf}(f) \sim 10^4 \times h_{strain}(f)\ L_{cav}$$



Given all the approximations one needs to be 1/10 of designed sensitivity (at least)

→ Here it is clear you need to suspend the baffles in the core optics

VIR-0406A-12
VIR-0127A-13
VIR-04824A-14
VIR-0009A-16

Notes on Materials

Intense R&D on materials for the baffles by the time of the preparation for Virgo

CNRS
Centre National de la Recherche Scientifique

INFN
Istituto Nazionale di Fisica Nucleare

AdV SLC:
Characterization of Silicon Carbide for constructing baffles and beam dumps in AdV

AdV SLC:
Characterization of Diamond-Like Carbon for coating baffles and beam dumps in AdV

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Istituto Nazionale di Fisica Nucleare

AdV SLC: Characterization of AR coatings on stainless-steel for construction of baffles and beam dumps in AdV

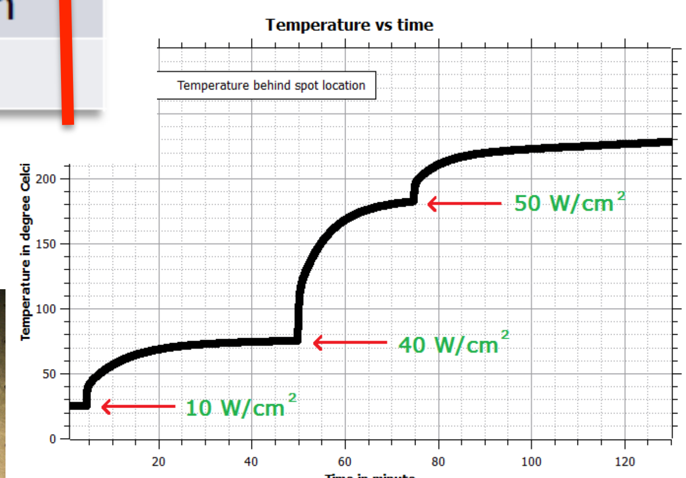
VIR-0482A-14

V.Bavigadda*[1], G.Pillant[1], A.Magazzu[1], and A.Chiummo[1]
[1]*EGO - European Gravitational Observatory*

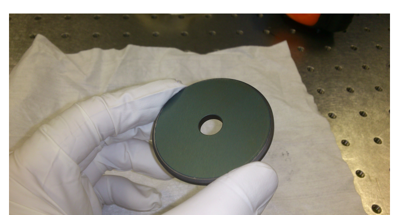
Date: December 10, 2014

Material	LIDT	TIS
SiC + AR	30kW/cm2	~20-50ppm
DLC + AR	500W/cm2	~500-1000ppm
AR-on-steel	>50W/cm2	~300-500ppm
Abs. Glass + AR	~1W/cm2	~100ppm

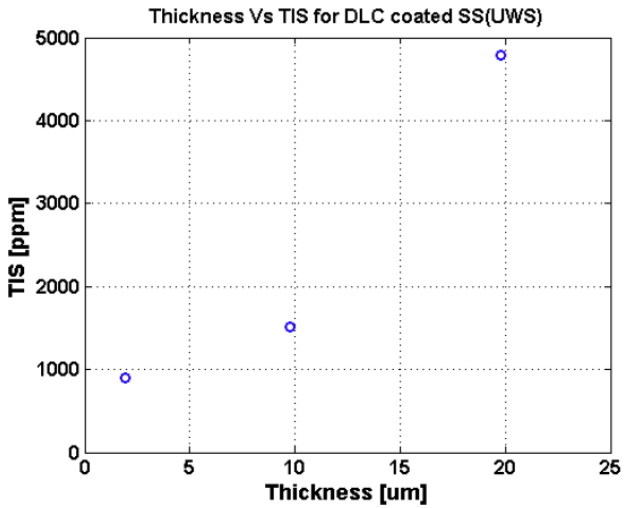
cost



Other important considerations:
- Temperature dependence
- Scalability with surface dimension
- Reproducibility
- Cost (no much SiC+AR used)

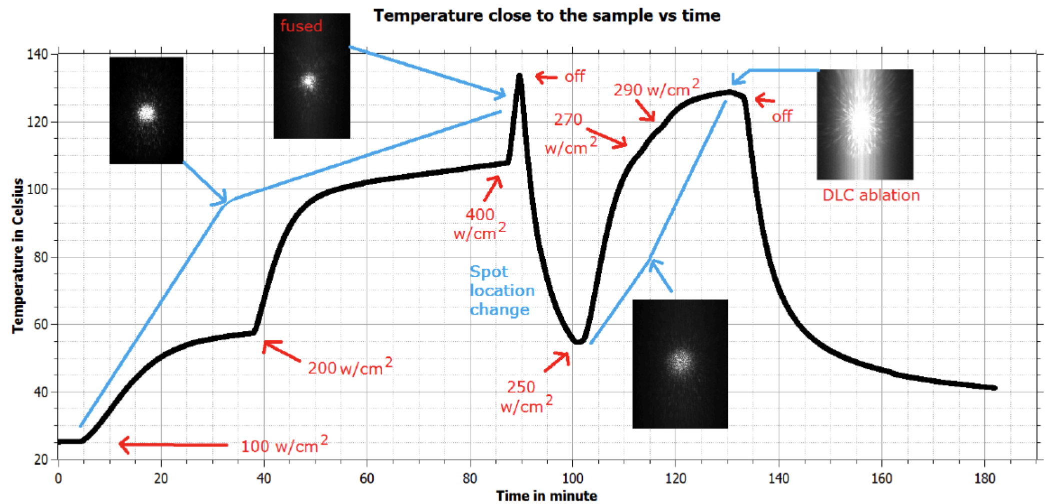


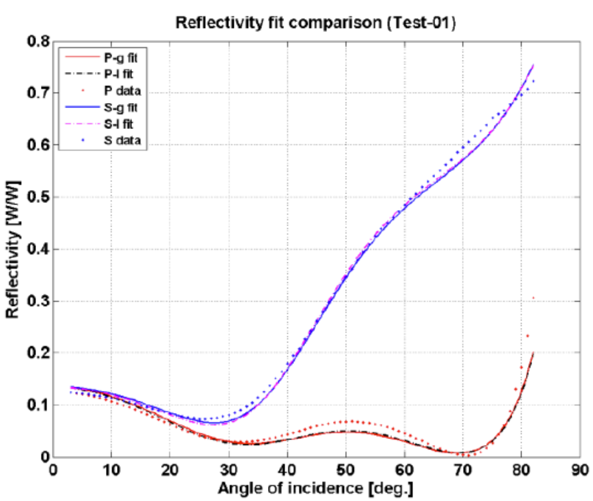
Notes on materials (cont.)



Intensive R&D on Diamond-like Carbon (DLC) indicated It can be used in places with large exposure

→ INJ baffle and part of the baffles in the cryotraps



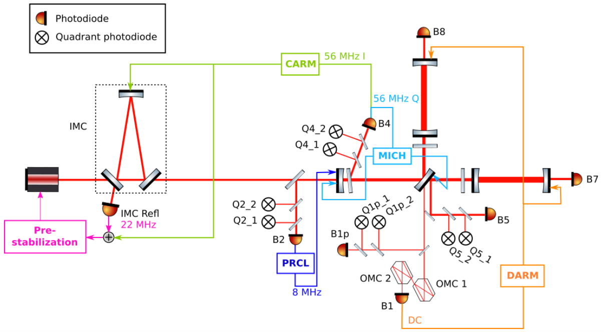


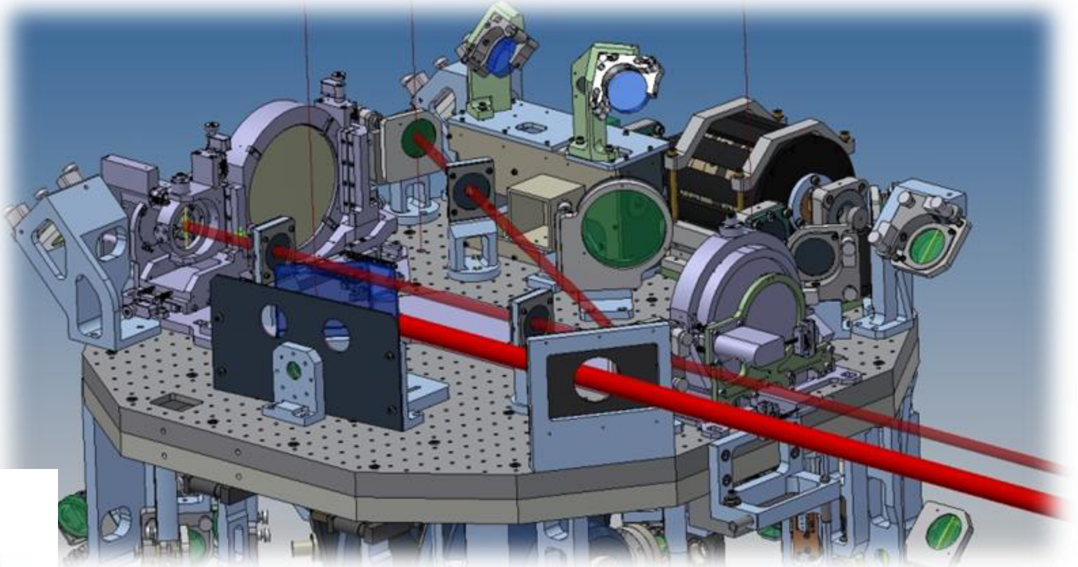
DLC showed large TIS largely dependent on thickness

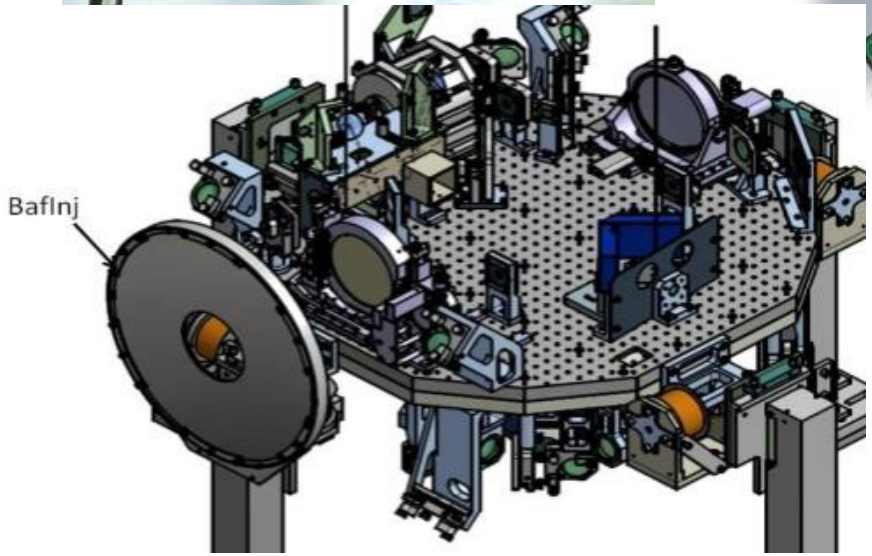
Some issues with DLC+AR coating reproducibility

→ Massive presence of Stainless-Steel (SS) + AR coating

IMC

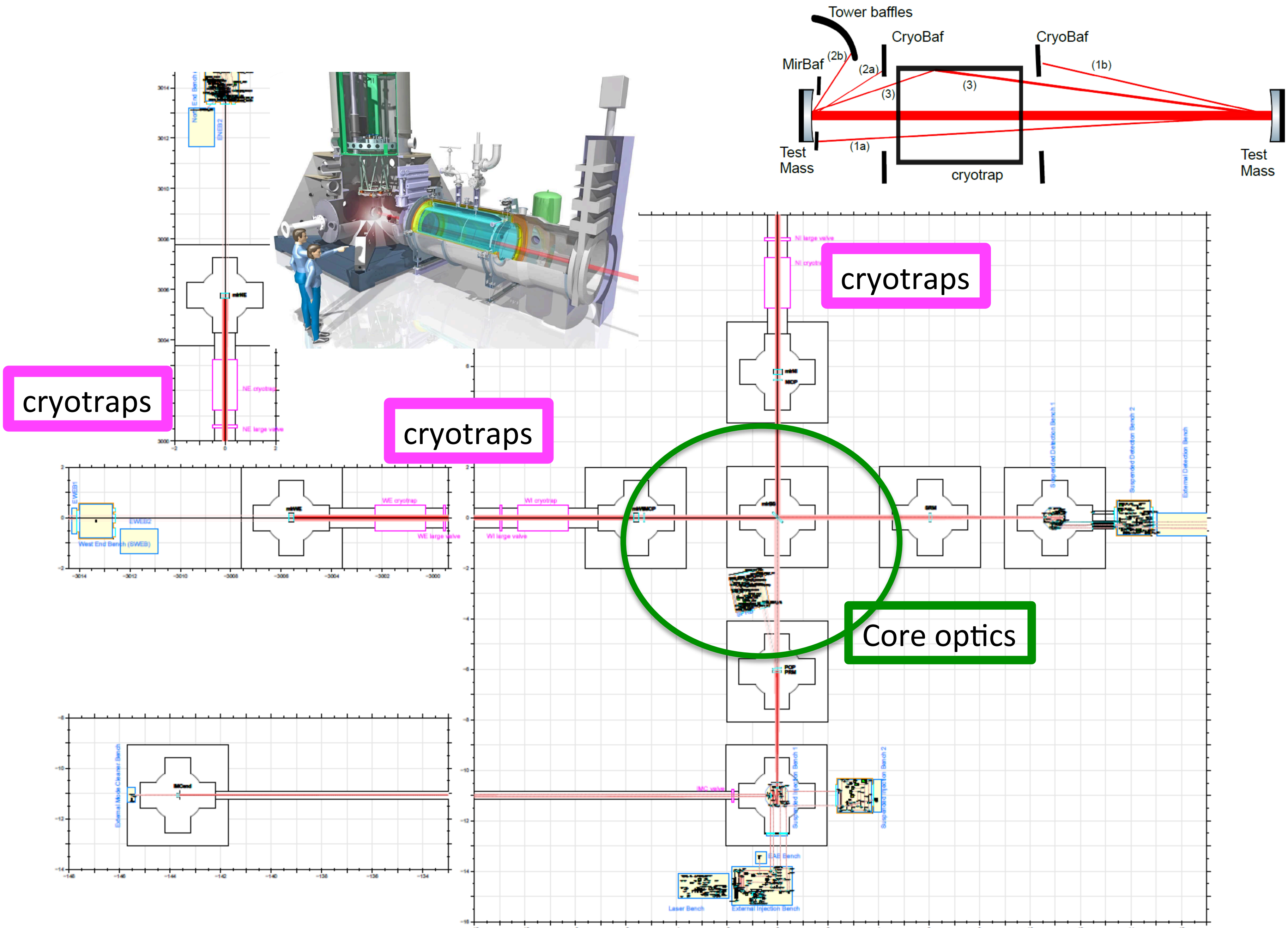




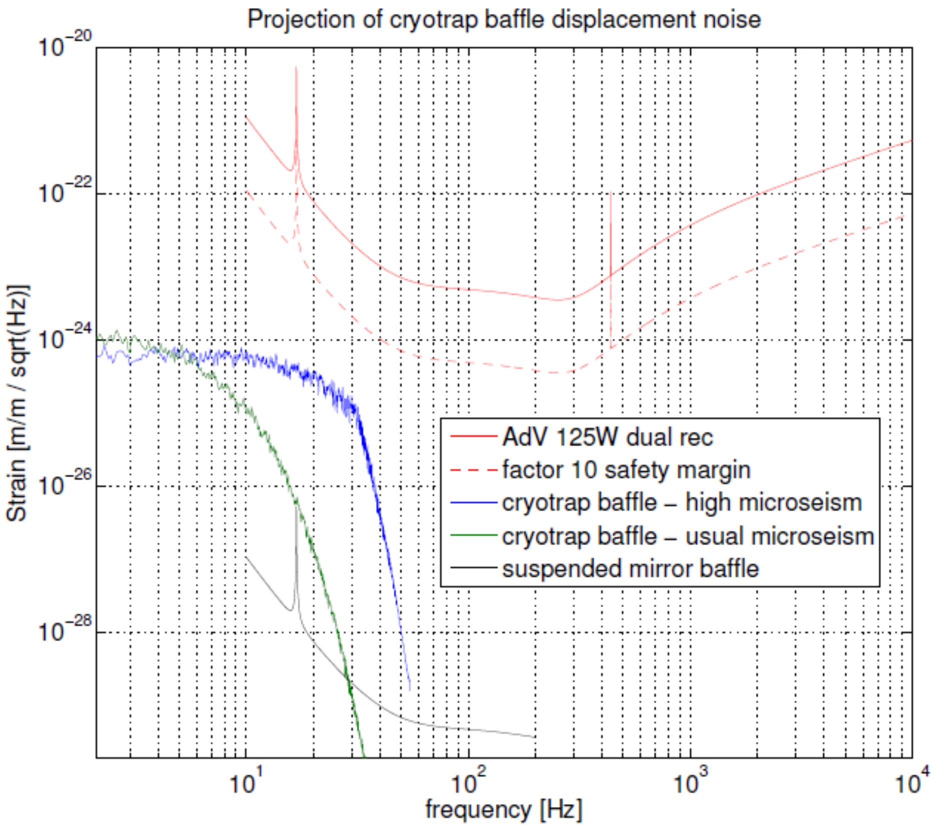


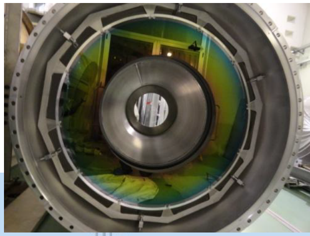
INJBaffle made out of DLC + AR-coating given the intensity of the light (up to 1kW /cm2)

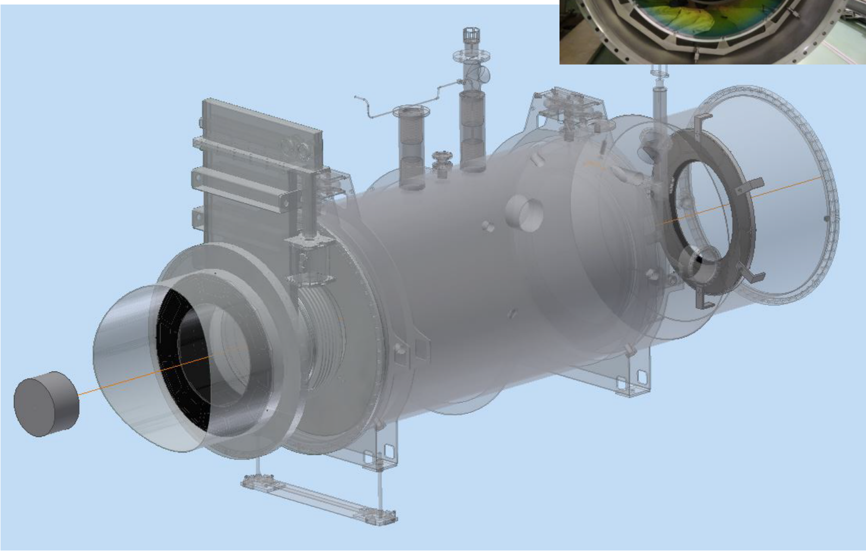
IMC end mirror baffle made out of SS


Tower baffles
CryoBaf
CryoBaf
MirBaf
(2b)
(2a)
(3)
(3)
(1b)
(1a)
Test Mass
cryotrap
Test Mass
cryotraps
cryotraps
cryotraps
Core optics

Cryotraps





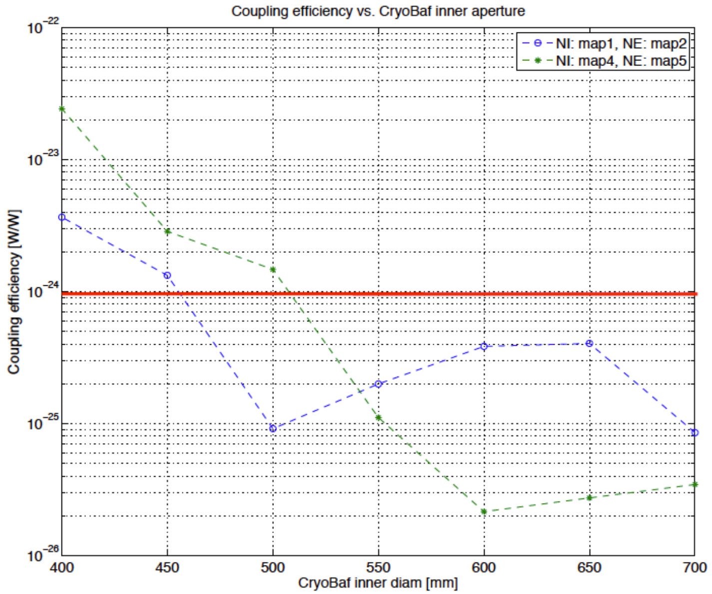


Requires slightly different treatment since this refers to wide angles (FFT is not so valid)

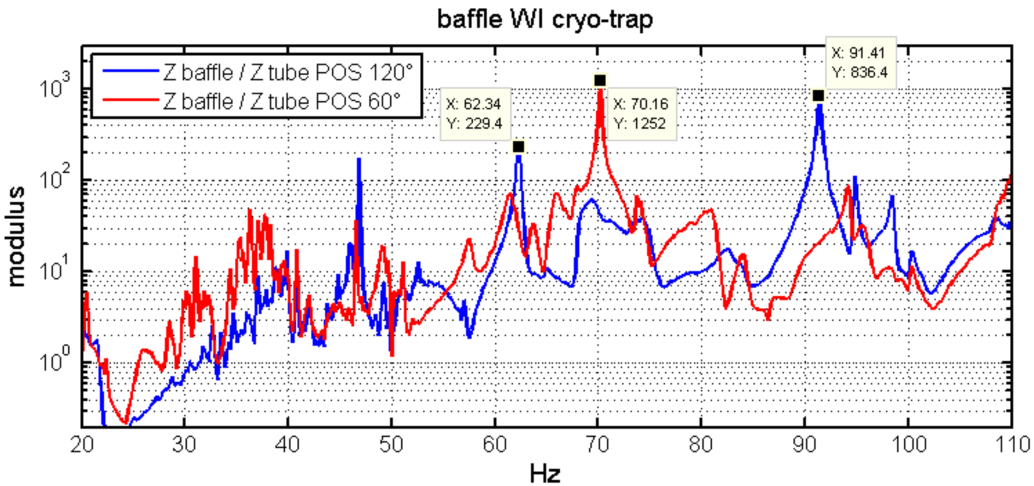
Aperture dictated by the coupling < 10^{-24} W/W

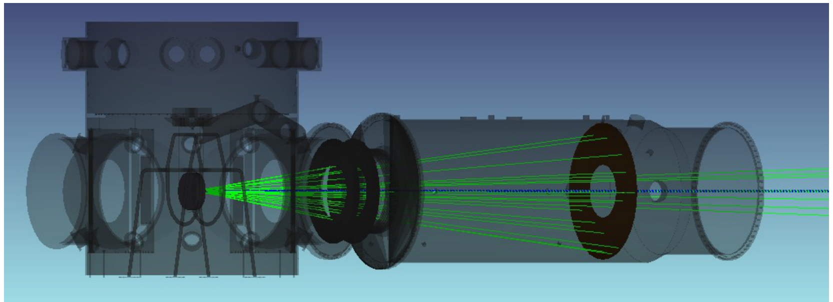
→ Being reviewed now for AdV+ phase II (end mirrors)

Special campaign to understand the vibration modes of the baffle and how this would affect the ITF

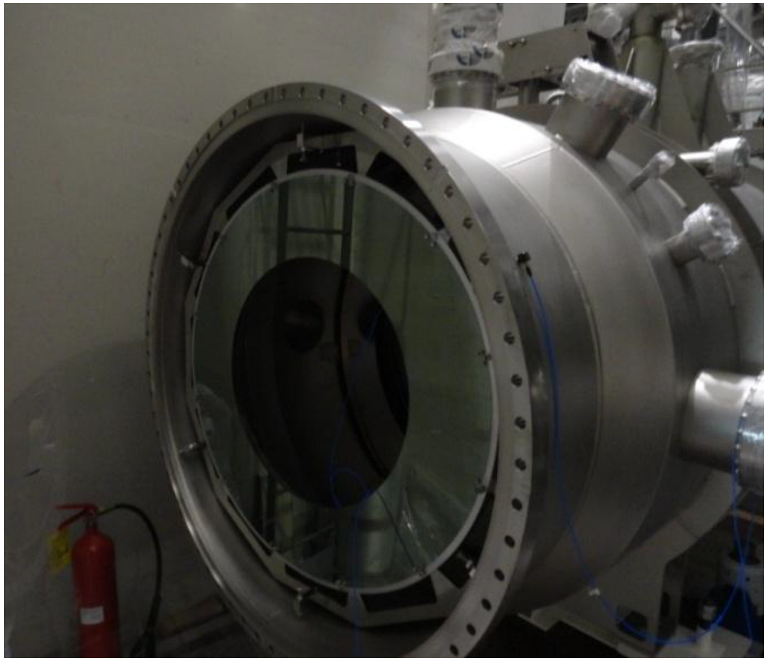


Cryo Baffle Vibrations

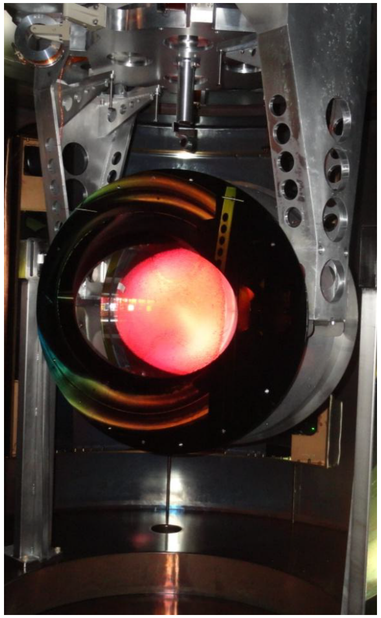


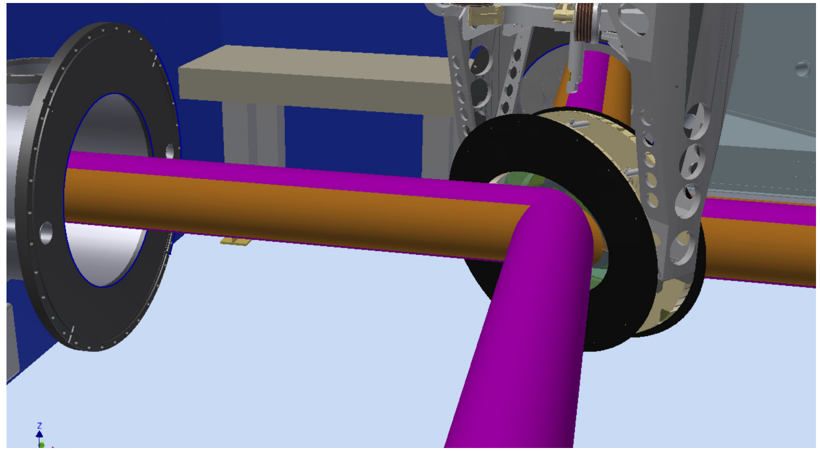


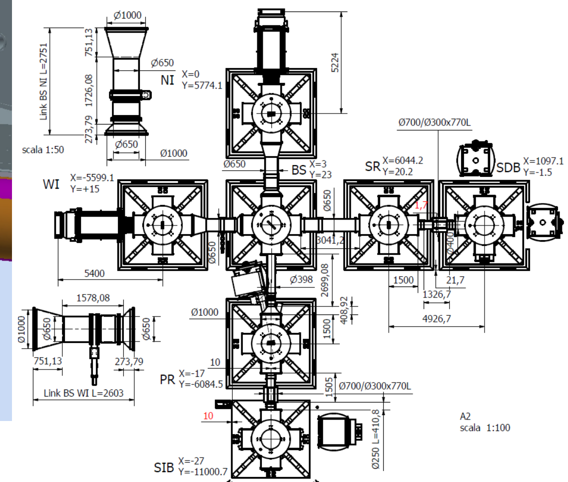
Using shakers and accelerometers to understand the eigenmodes

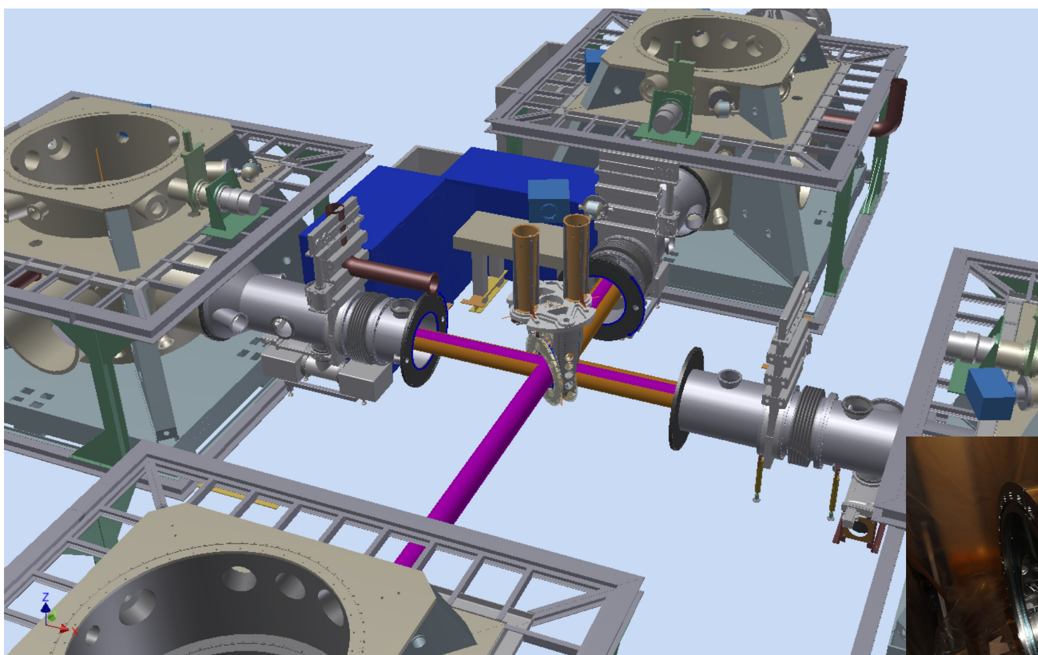


Central Optics Baffles





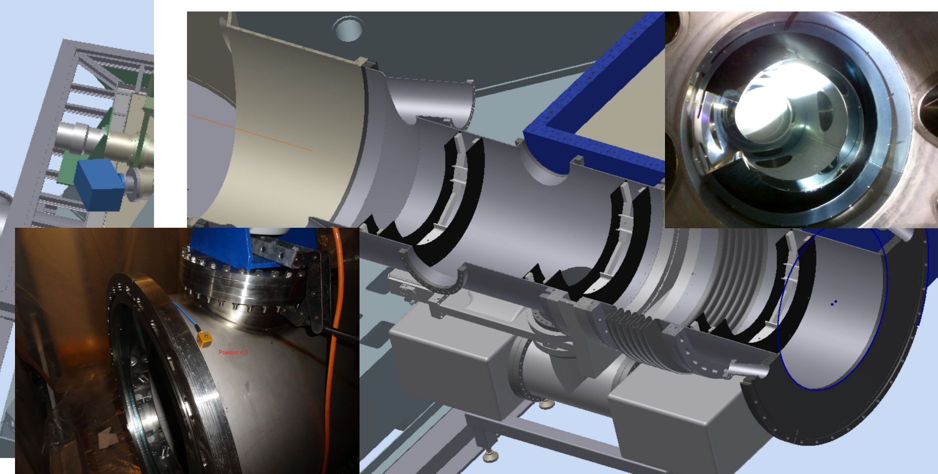




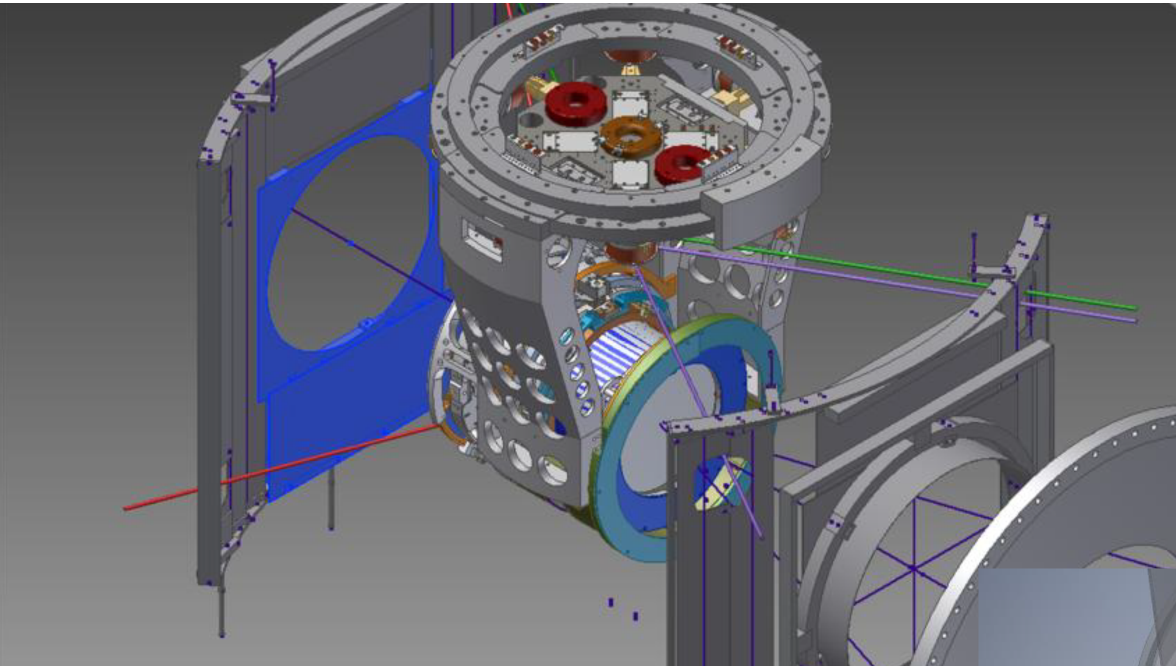
Combination of SS+AR , DCL+AR

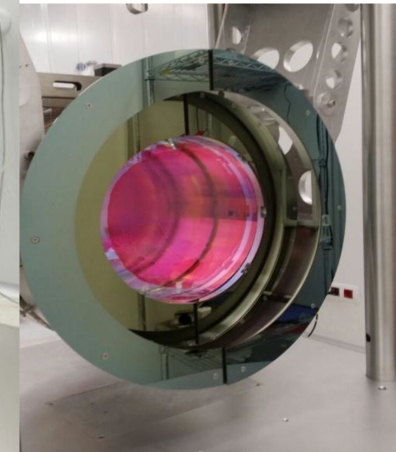
Full study of vibrations to facilitate

Noise hunting (VIR-0147A-16)



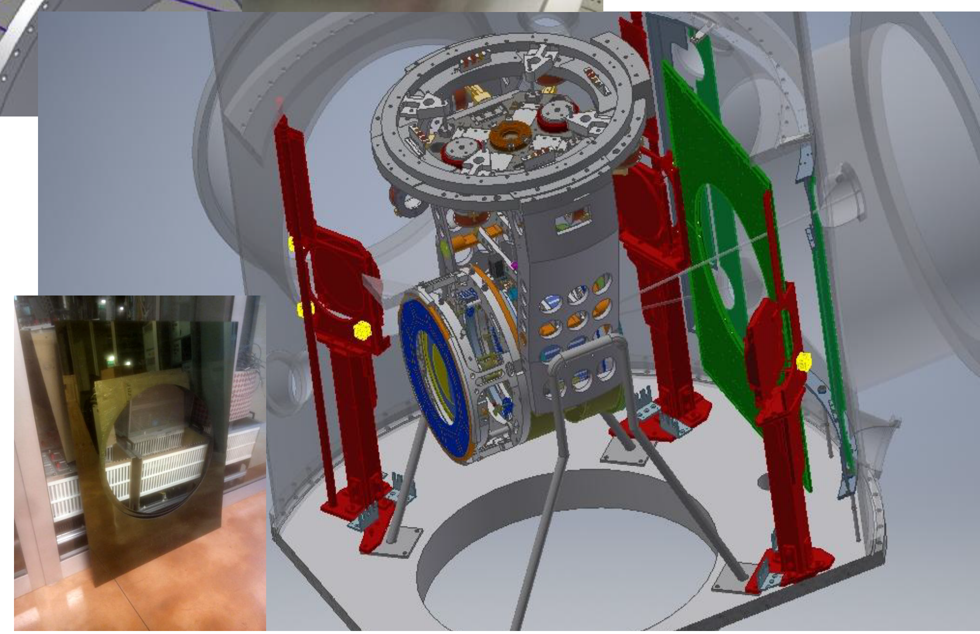
Payload and tower baffles



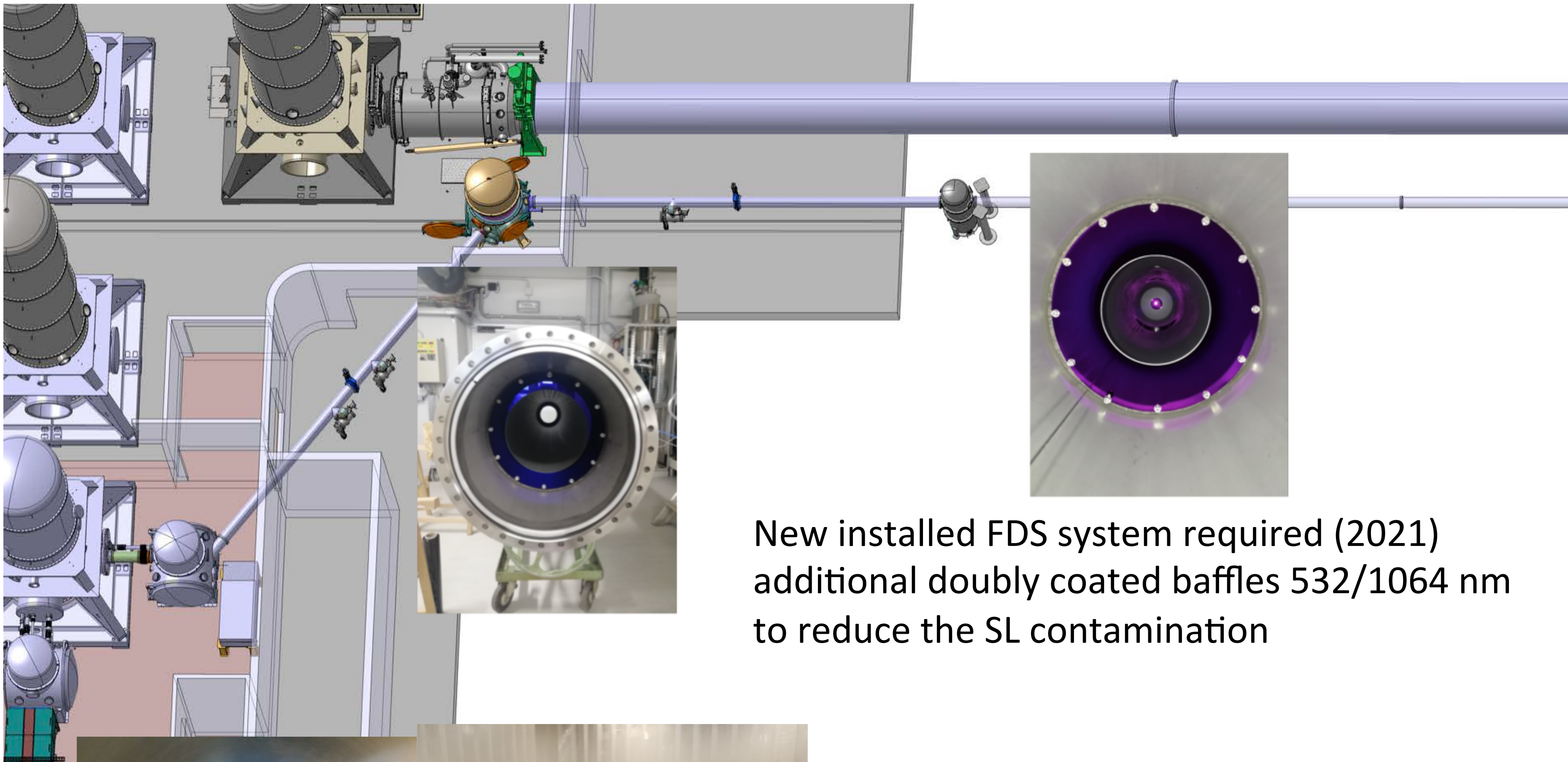


The intensity in the baffles in the arms is very small → SS + AR massively used.

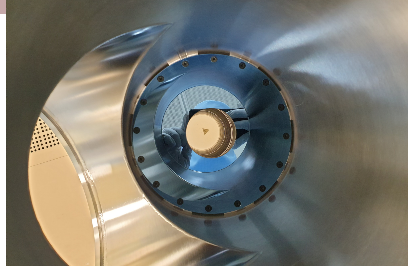
The towers walls needed to be blacked to suppress scattering from the mirrors at large angles → original (fragile) glass-AR Replaced gradually by SS-AR



Frequency Dependent Squeezing

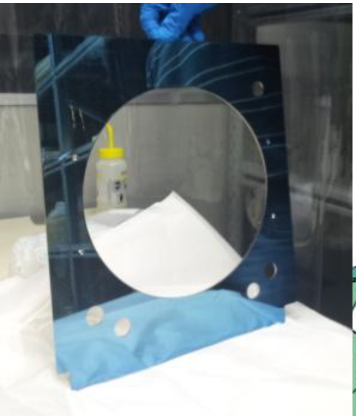


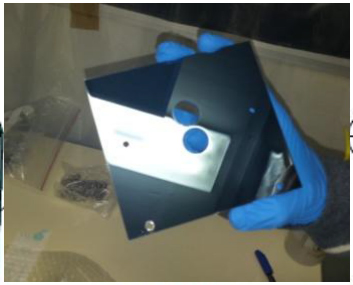
New installed FDS system required (2021) additional doubly coated baffles 532/1064 nm to reduce the SL contamination

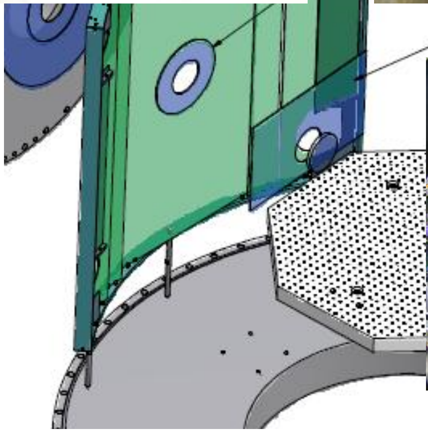


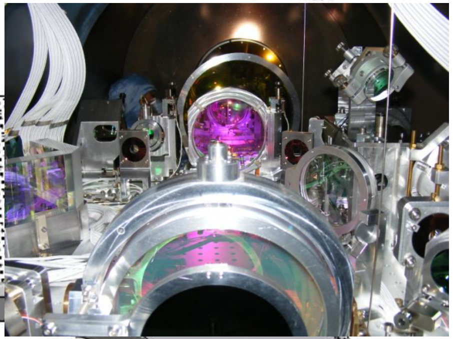
See talk by Eleonora Polini

SL in benches (DET tower)





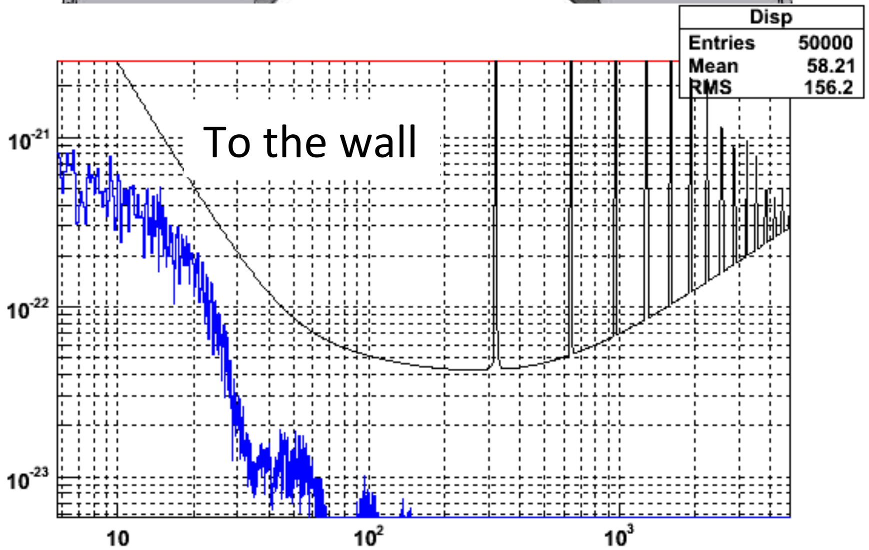


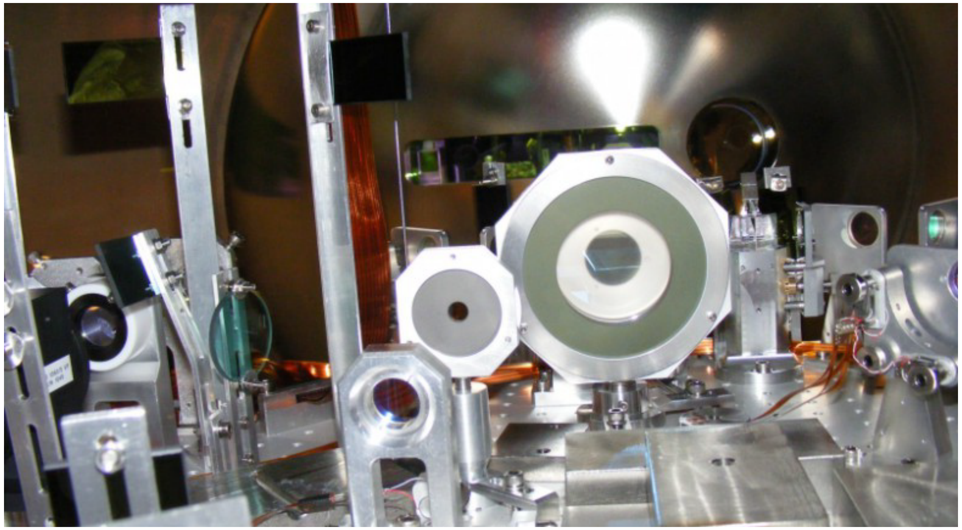


$$h(t) = G \cdot \sin(2 \cdot \frac{2\pi}{\lambda} \cdot x(t))$$

Studies to place baffles at the tower walls
Instead of suspending them

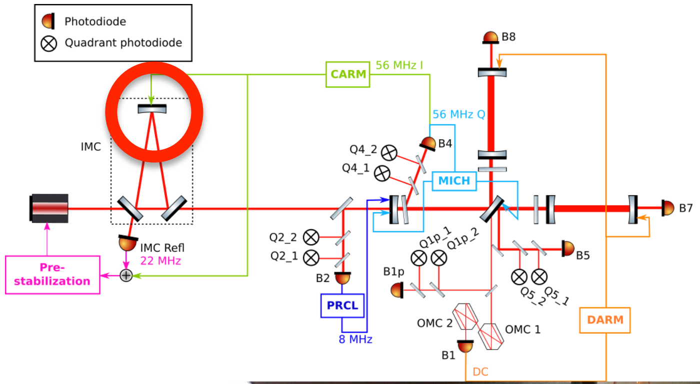
→ The solution must be at the bench to suppress SL and ghost beams with baffles/diaphragms



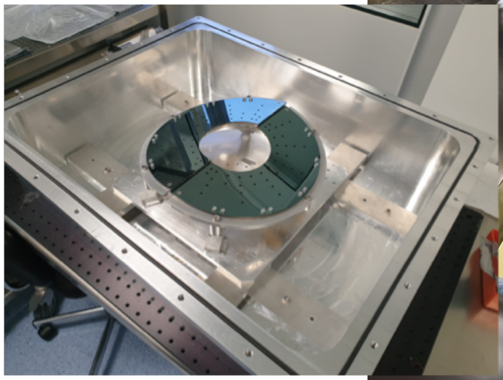


Towards active SLC monitoring

- AdV+ is bringing a new concept for active monitoring of the stray light in the main cavities
  - Evolution of mirror maps
  - Alignment and HOMs detection
  - Correlation with glitches
  - Validation of SLC simulations



- A demonstrator of the technology in the form of an instrumented baffle in the Input Mode Cleaner is now in place in AdV+
  - In commissioning @ EGO
  - To be integral part of O4 operations
  - A step towards instrumenting main mirrors in long arms in O5



See Ll. Mir talk on the subject

Notes for the future

- In preparation for 3G projects

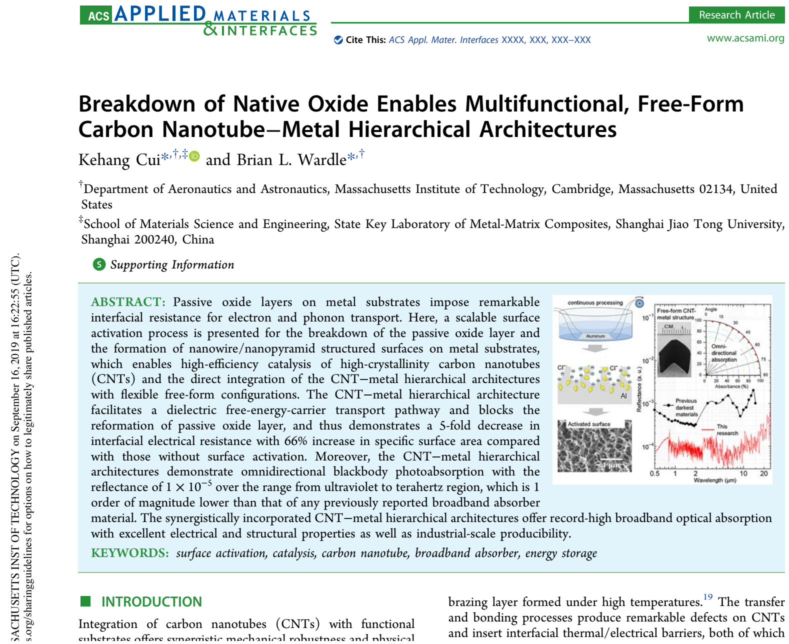
- R&D on new materials with larger absorption and higher damage thresholds

  → we wavelengths for ET-LH will require a new R&D campaign and certification

- Better simulation tools to propagate the SL effects into GW sensitivity (including also benches)

- A richer network of displacement monitors embedded in the baffle systems (in the original Virgo plan and excluded due to funding/timing) should be a reality for ET

- An active monitoring approach to control SL inside cavities using instrumented baffles in strategic locations (suspended mirrors, cryotraps, etc.…)


ACS APPLIED MATERIALS & INTERFACES — Research Article
Cite This: ACS Appl. Mater. Interfaces XXXX, XXX, XXX−XXX — www.acsami.org

Breakdown of Native Oxide Enables Multifunctional, Free-Form Carbon Nanotube−Metal Hierarchical Architectures

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Supporting Information

ABSTRACT: Passive oxide layers on metal substrates impose remarkable interfacial resistance for electron and phonon transport. Here, a scalable surface activation process is presented for the breakdown of the passive oxide layer and the formation of nanowire/nanopyramid structured surfaces on metal substrates, which enables high-efficiency catalysis of high-crystallinity carbon nanotubes (CNTs) and the direct integration of the CNT−metal hierarchical architectures with flexible free-form configurations. The CNT−metal hierarchical architecture facilitates a dielectric free-energy-carrier transport pathway and blocks the reformation of passive oxide layer, and thus demonstrates a 5-fold decrease in interfacial electrical resistance with 66% increase in specific surface area compared with those without surface activation. Moreover, the CNT−metal hierarchical architectures demonstrate omnidirectional blackbody photoabsorption with the reflectance of 1×10^{-5} over the range from ultraviolet to terahertz region, which is 1 order of magnitude lower than that of any previously reported broadband absorber material. The synergistically incorporated CNT−metal hierarchical architectures offer record-high broadband optical absorption with excellent electrical and structural properties as well as industrial-scale producibility.

KEYWORDS: surface activation, catalysis, carbon nanotube, broadband absorber, energy storage

INTRODUCTION

Integration of carbon nanotubes (CNTs) with functional substrates offers synergistic mechanical robustness and physical

brazing layer formed under high temperatures.[19] The transfer and bonding processes produce remarkable defects on CNTs and insert interfacial thermal/electrical barriers, both of which