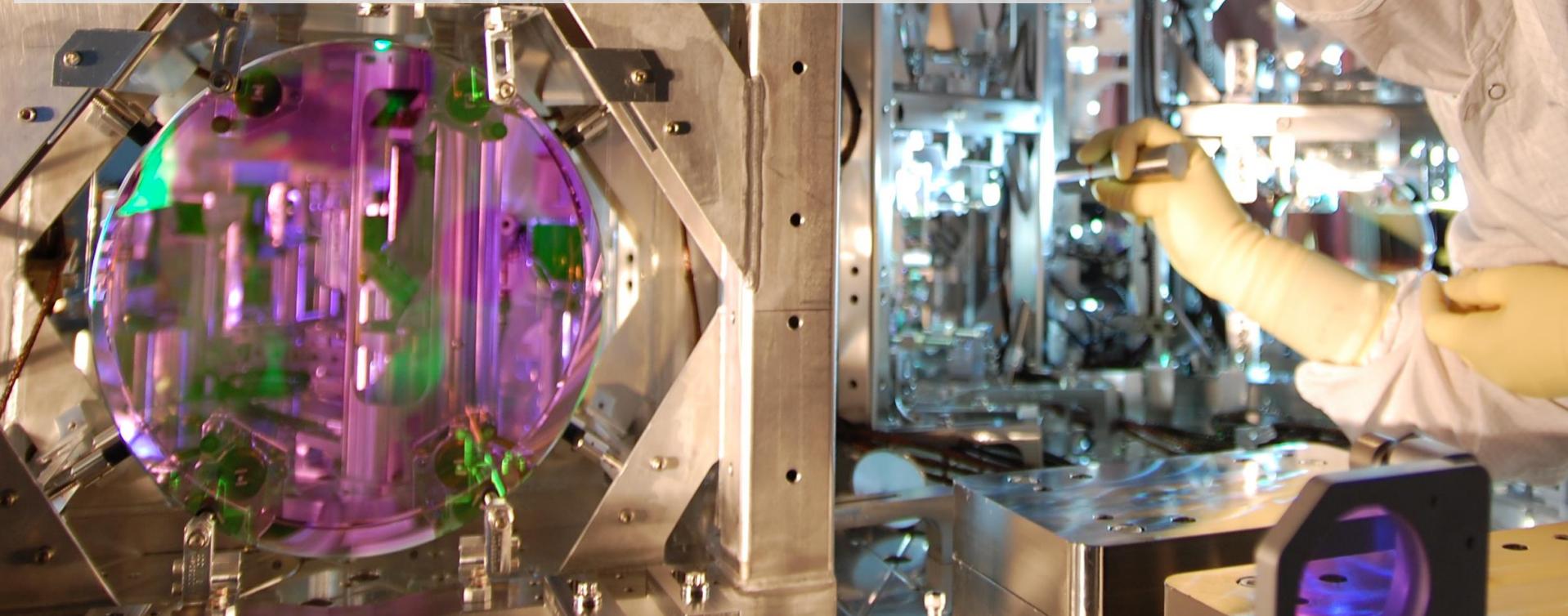




11
102
1004

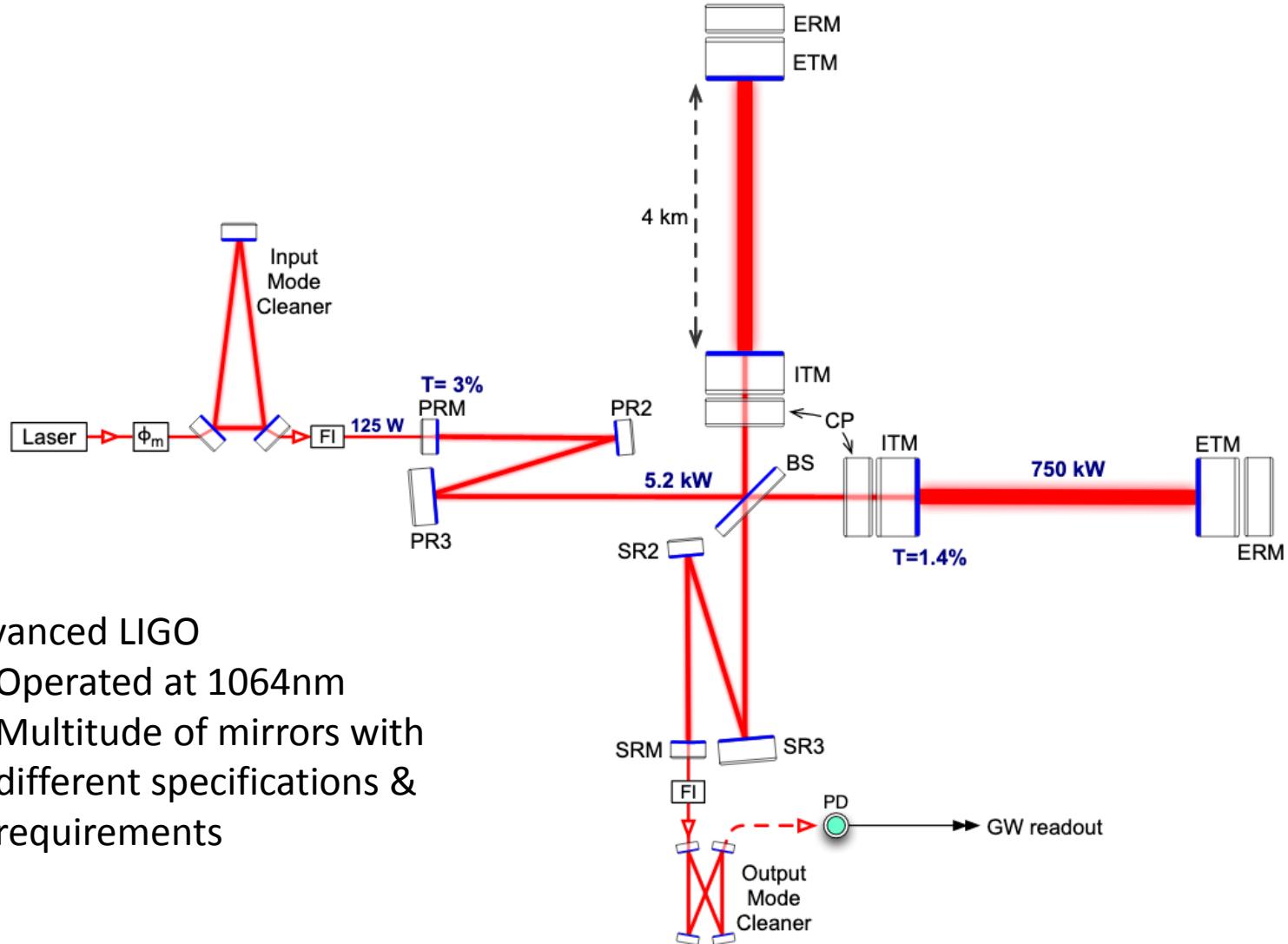
Mirrors: bulk-materials, coatings, thermal noise, cryogenics





Mirrors in GW detectors

1 1
1 0 2
1 0 0 4



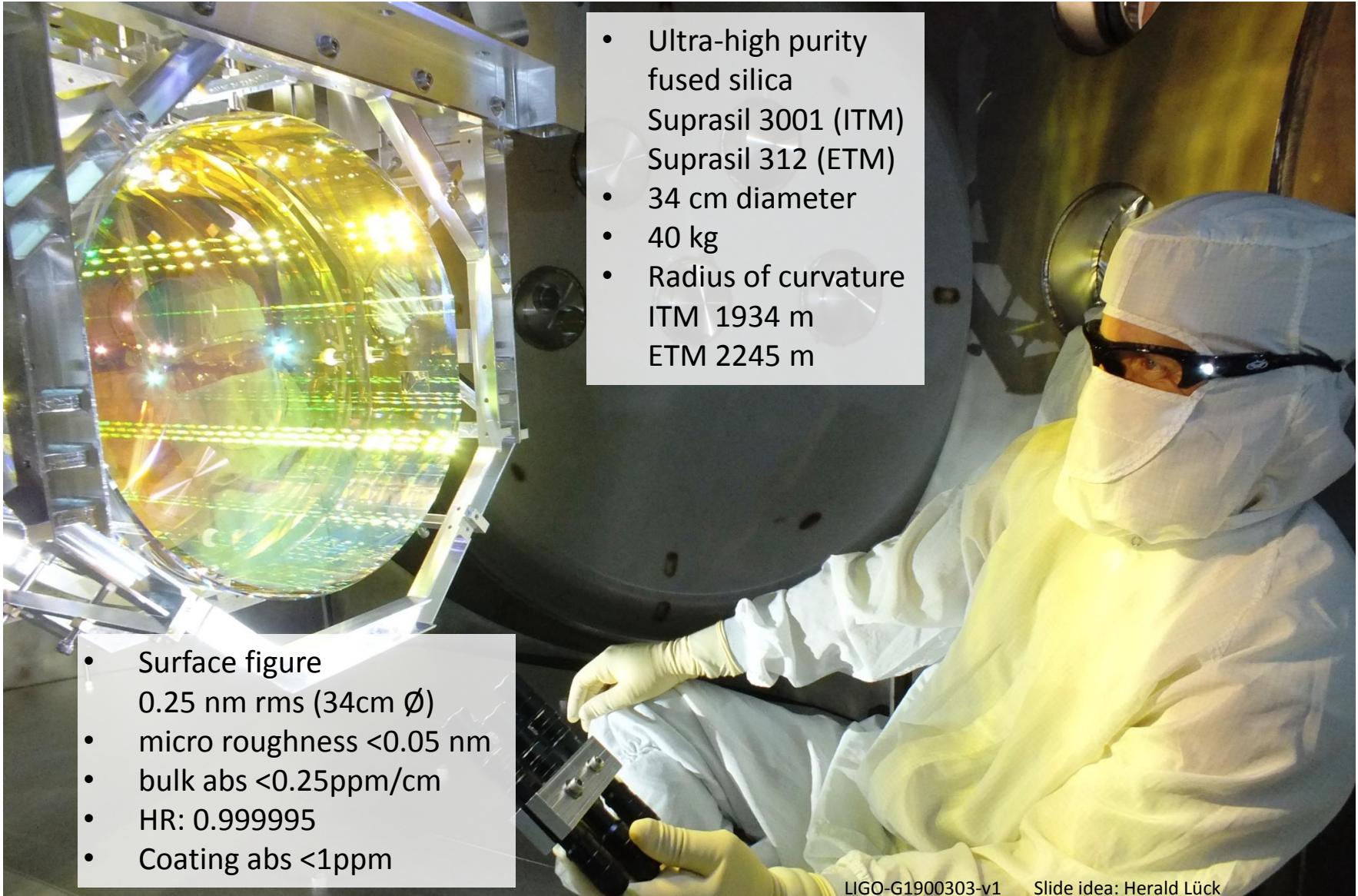
Advanced LIGO

- Operated at 1064nm
- Multitude of mirrors with different specifications & requirements



Advanced LIGO optics

1 1
1 0 2
1 0 0 4

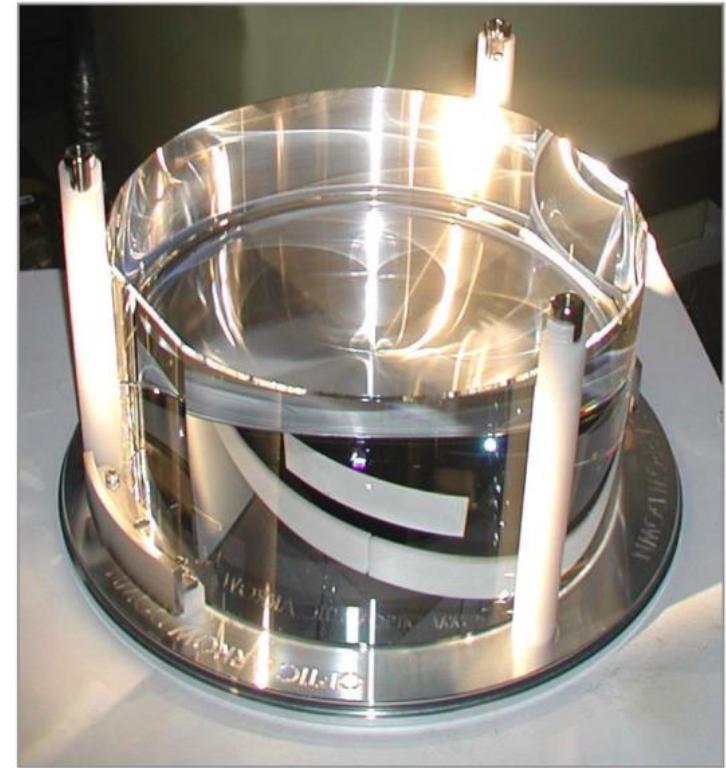




Advanced LIGO optics

1
10
100
1000
2
4

- 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





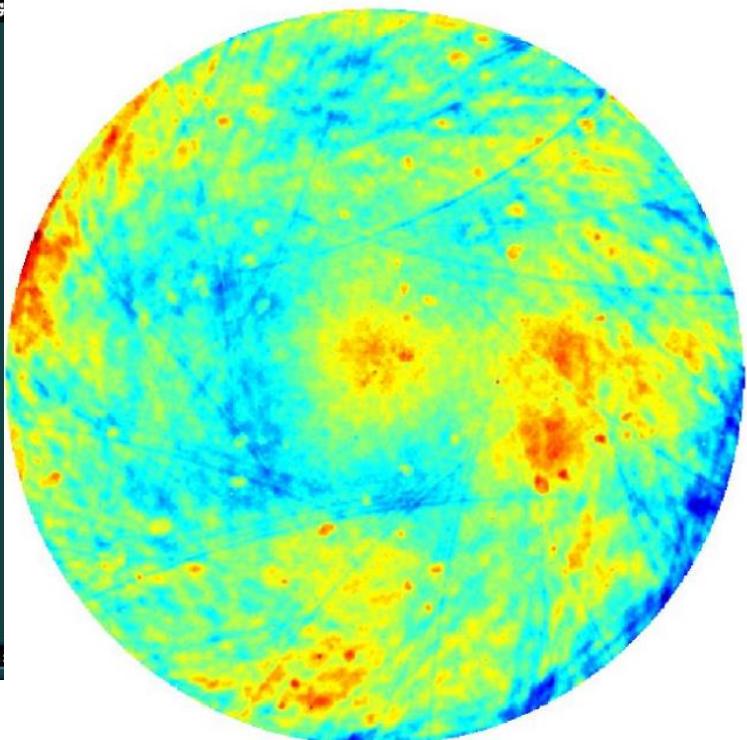
Coating uniformity



- Planetary drive IBS coating machine
- Optimized motion -> better uniformity

First generation

ETM 08 R1 ø160 Z1-6 Removed

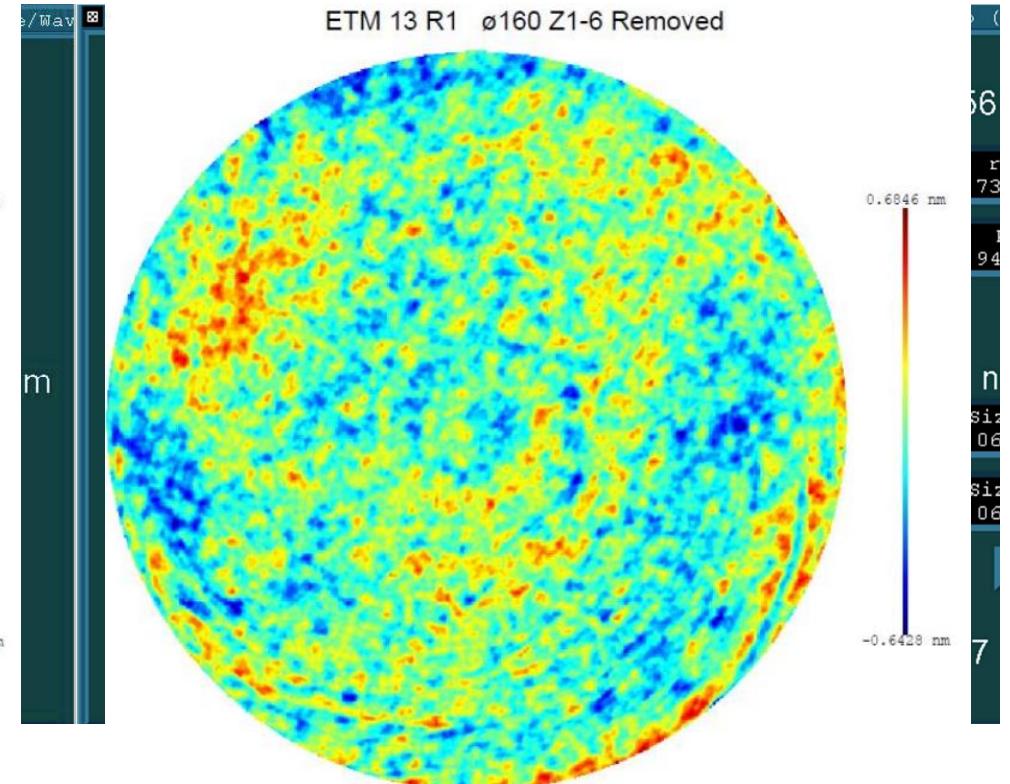


LIGO-C1103233

LIGO-C1000486

After optimization

ETM 13 R1 ø160 Z1-6 Removed



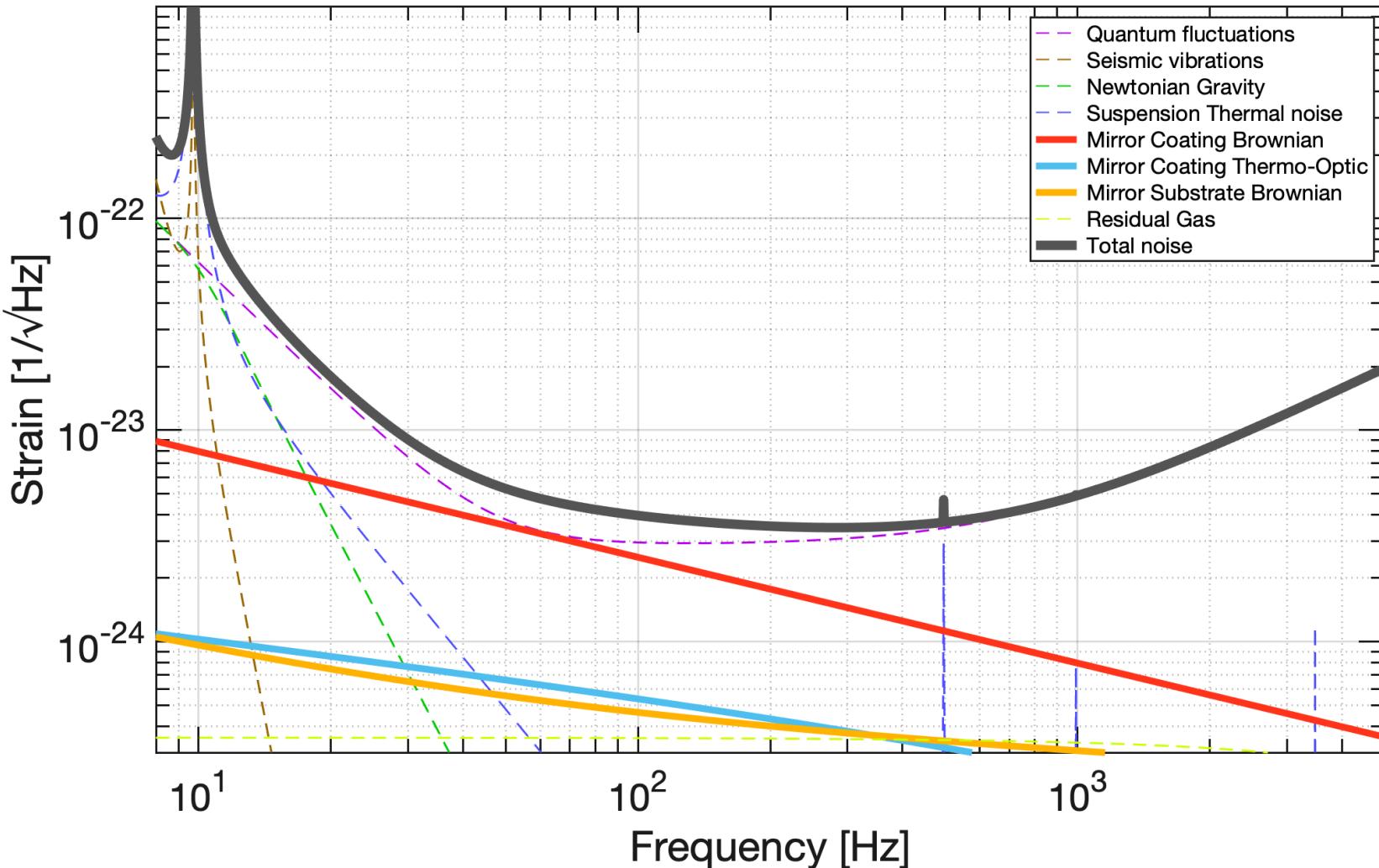
LIGO-C1103238

LIGO-C1106293



Thermal noise limitation

1
10
100
1000
4





Reducing coating thermal noise



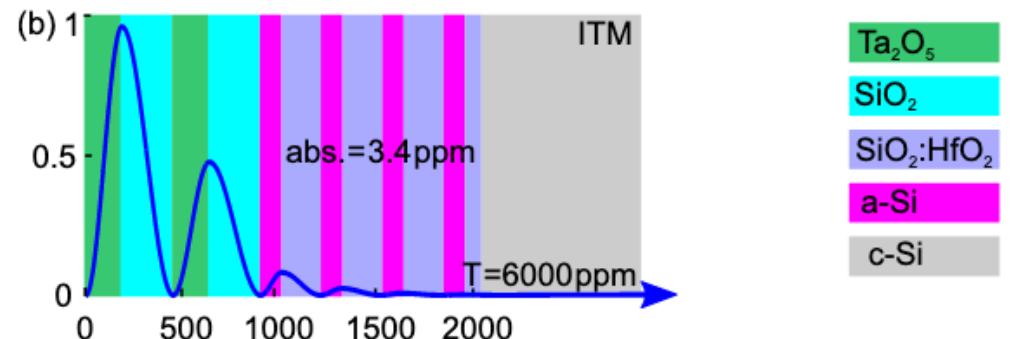
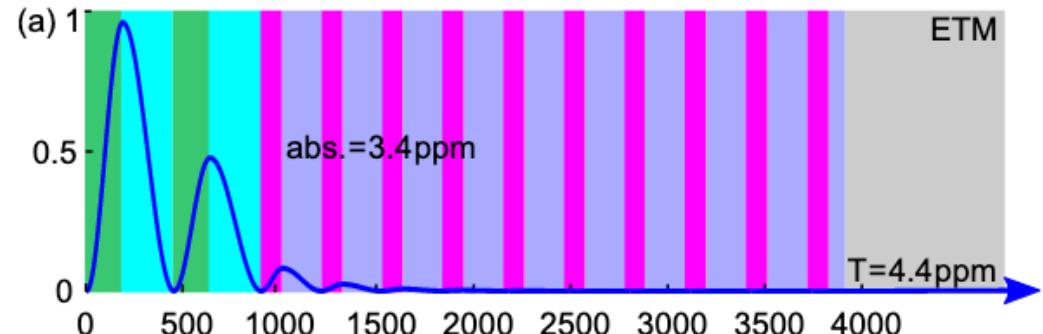
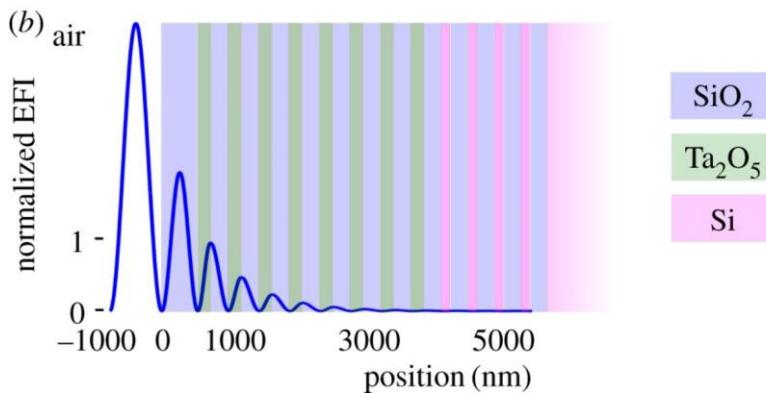
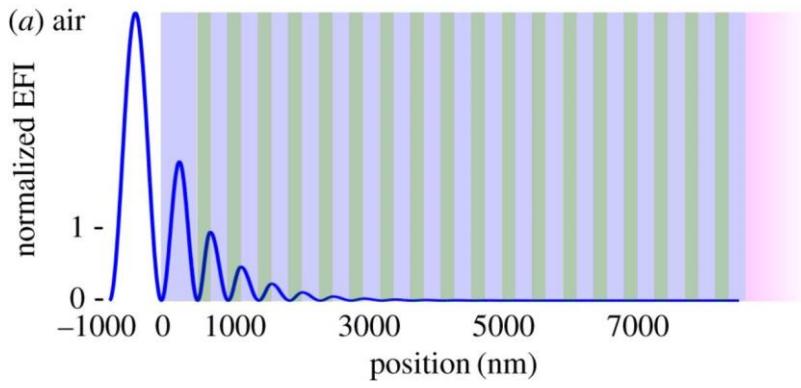
$$S_{\text{Coating}}(f) = \frac{4k_B \mathbf{T}}{\pi^2 f} \frac{(1 + \sigma_S)(1 - 2\sigma_S)}{E_S} \frac{\mathbf{d}}{\mathbf{w}} \boldsymbol{\phi}_{\mathbf{C}}$$

- Increase beam size on mirrors
- Reduce/Optimize coating thickness
- Reduce mechanical loss
- Reduce temperature of mirrors

S. Reid and I. W. Martin. "Development of Mirror Coatings for Gravitational Wave Detectors".
In: Coatings 6.4 (2016).

Optimize thickness

- Multi-material coatings
 - Use of high index materials





Reducing coating thermal noise



$$S_{\text{Coating}}(f) = \frac{4k_B \mathbf{T}}{\pi^2 f} \frac{(1 + \sigma_S)(1 - 2\sigma_S)}{E_S} \frac{\mathbf{d}}{\mathbf{w}} \boldsymbol{\phi}_{\mathbf{C}}$$

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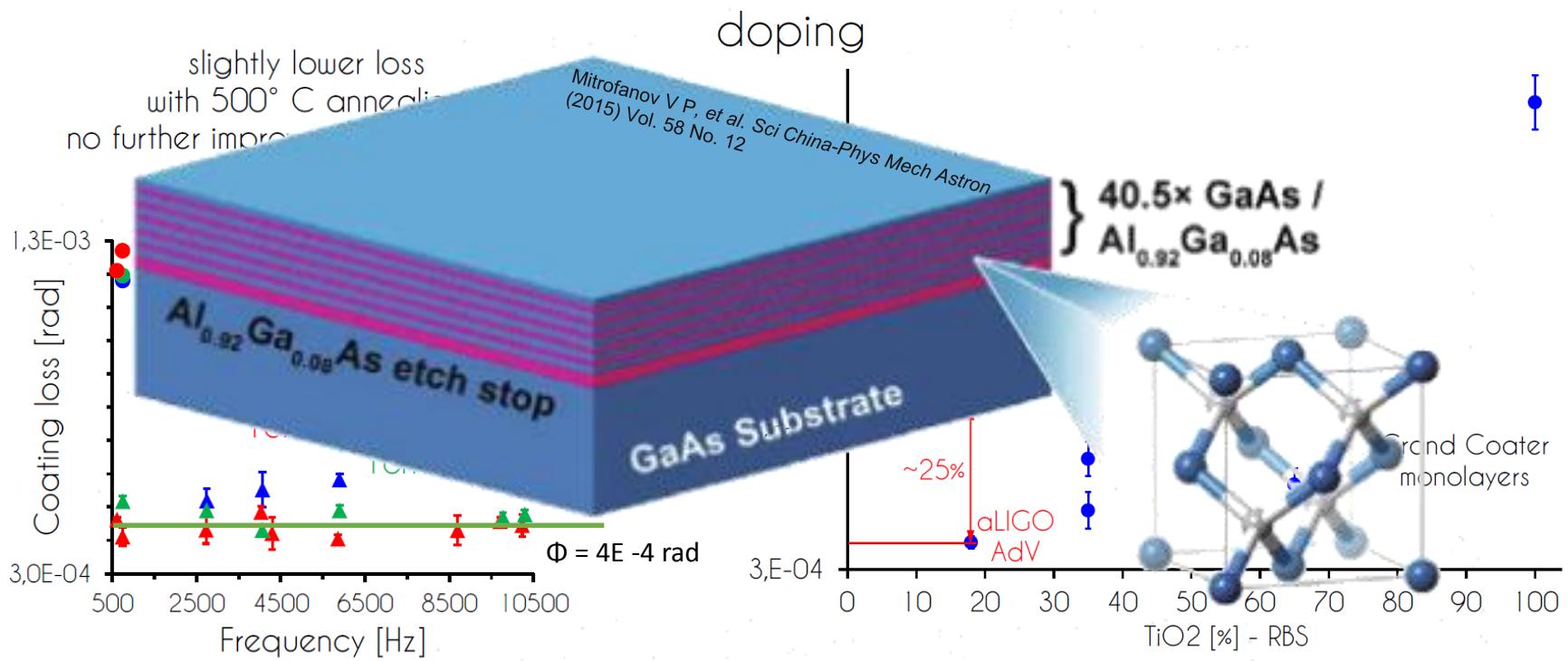
S. Reid and I. W. Martin. "Development of Mirror Coatings for Gravitational Wave Detectors".
In: Coatings 6.4 (2016).



Low mechanical loss

100
1000
10000
100000

- Annealing after deposition
- Doping with different materials
- Crystalline coatings





Reducing coating thermal noise



$$S_{\text{Coating}}(f) = \frac{4k_B \mathbf{T}}{\pi^2 f} \frac{(1 + \sigma_S)(1 - 2\sigma_S)}{E_S} \frac{\mathbf{d}}{\mathbf{w}} \boldsymbol{\phi}_{\mathbf{C}}$$

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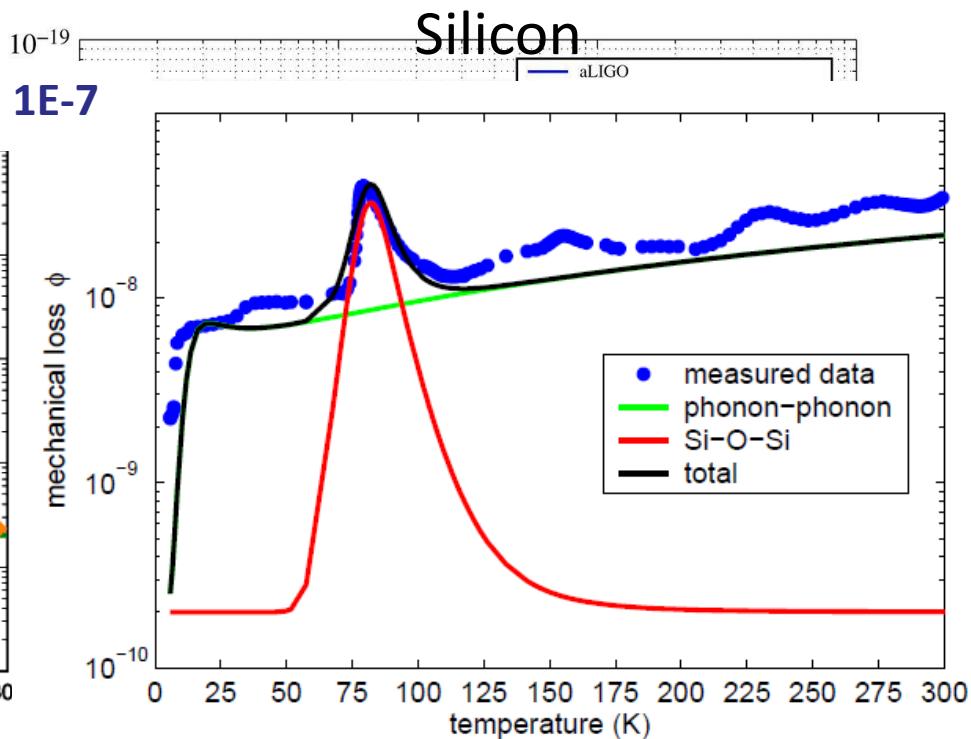
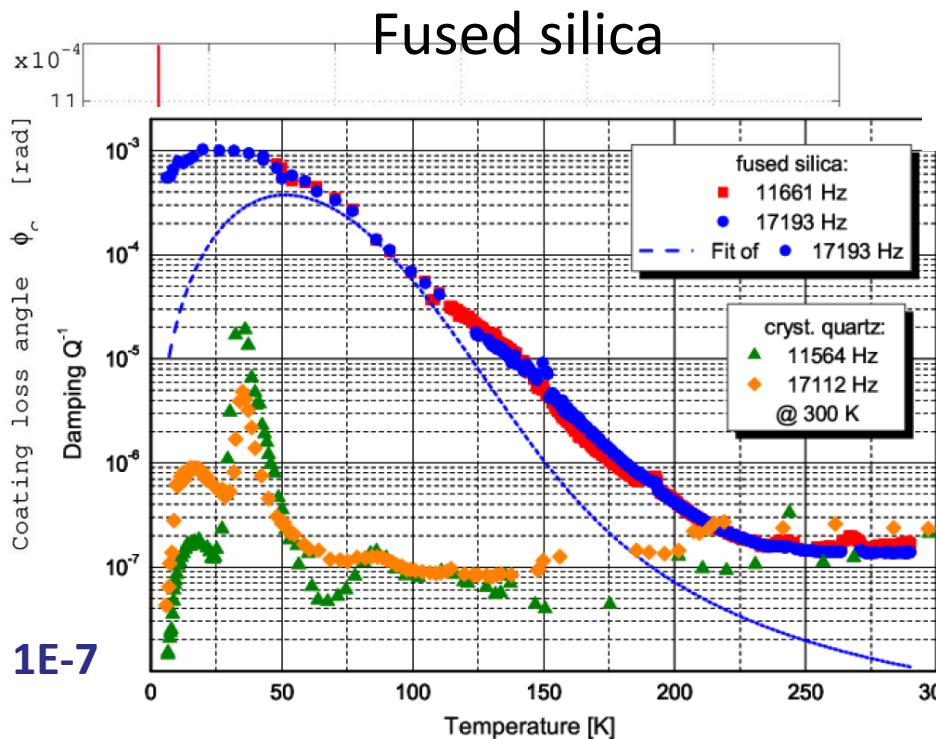
S. Reid and I. W. Martin. "Development of Mirror Coatings for Gravitational Wave Detectors".
In: Coatings 6.4 (2016).



Low temperature

1
10
100
1000
4

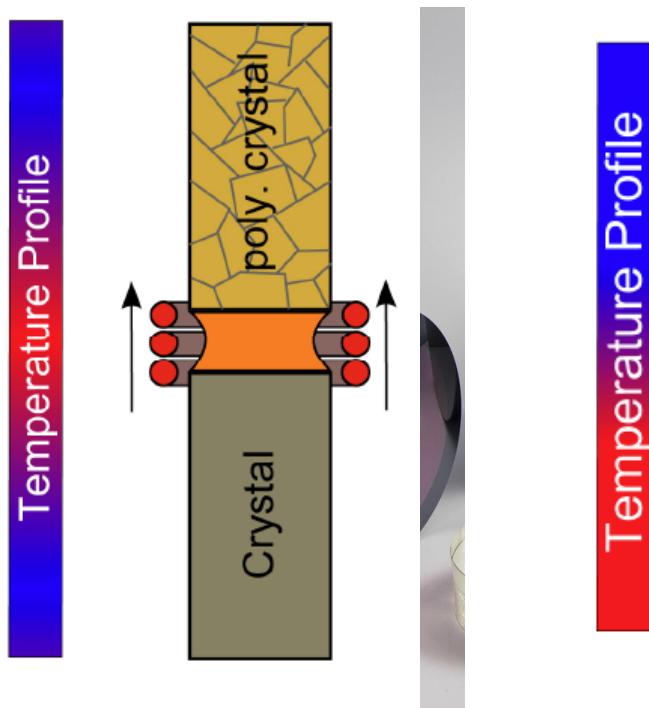
- Seems straight forward at first
- BUT: Mechanical loss temperature dependent



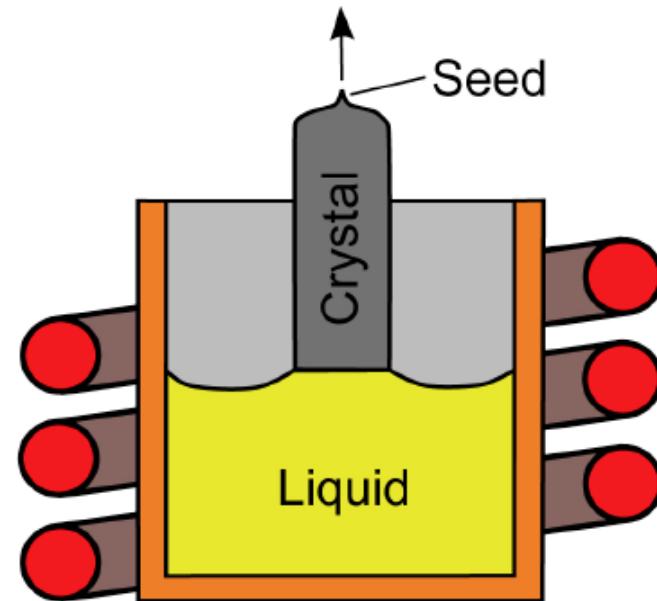
Si mirror substrates

1
10
100
1000
4

- Size > 45 cm of optics still a (technical) challenge
- Float zone silicon is of higher purity



Float zone silicon
Max 20cm dia.
Low absorption



Magnetically stabilised Czochralski
Max 45cm dia.
Absorption too high?

Nawrodt et al.

https://tds.ego-gw.it/?call_file=ET-0002A-13.pdf



Challenges towards ET



- Need high purity silicon substrates in the required size of about 45-50cm for ET-LF
 - Low absorption for ITMs?
- How can we reach the required surface quality
 - Current polishing/figuring methods sufficient?
- How do we cool down the mirrors?
 - Ribbons, fibers, rods?
- Need better mirror coatings with low mechanical loss and low optical absorption
 - Multi-material, crystalline, resonant waveguides?



Thank you for your
attention!