Couches Minces Optiques
– CMO –

Massimo GRANATA

on behalf of

Laboratoire des Matériaux Avancés (LMA), IP2I Lyon

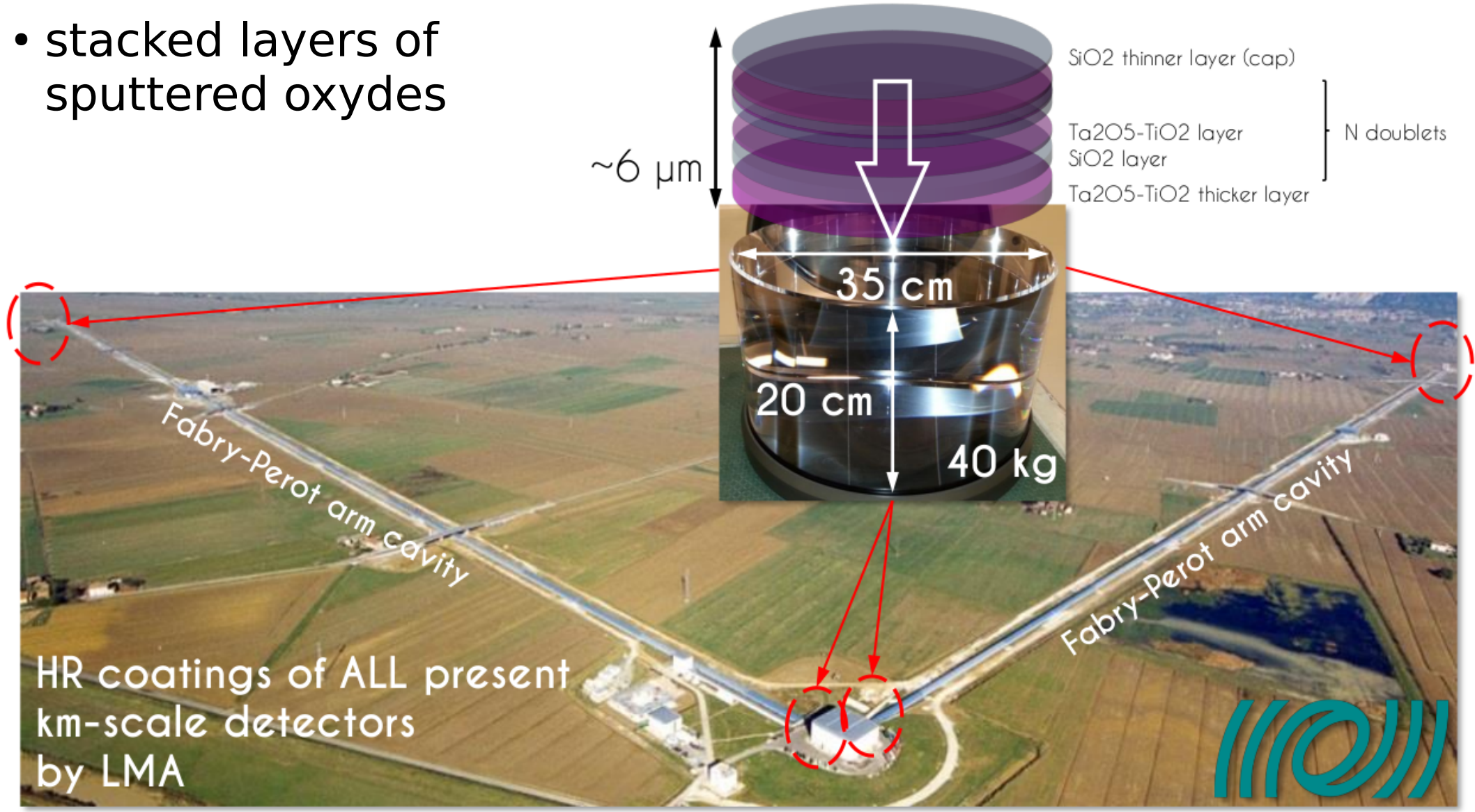
Journées R&T IN2P3 – Octobre 2021

ID card

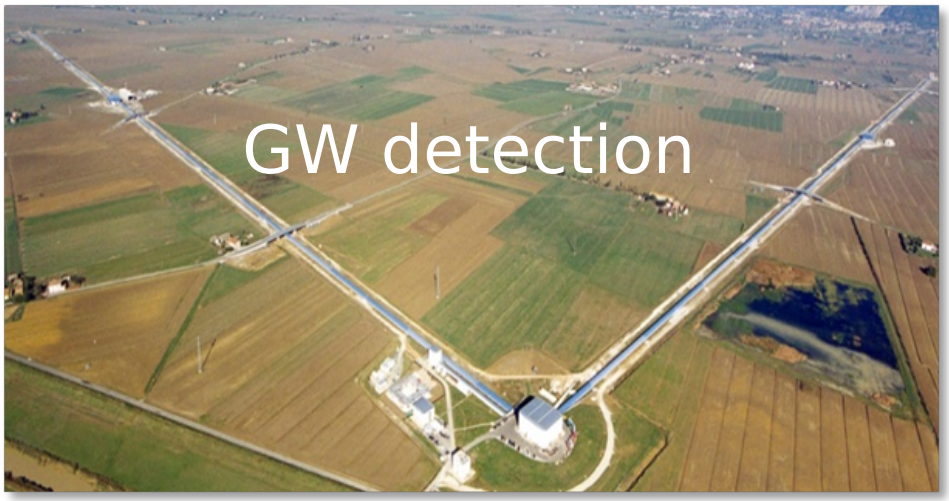
- IN2P3 R&T project (‘Master Projet’ before 2020)
- objective: development of low-loss HR coatings
- 24 months – Jan. 2021 to Dec.2022
- IN2P3 contribution: 87.5 kEU
  + 22.5 kEU from ANR ViSIONs
  + 6 kEU from European Gravitational-Wave Observatory
- 5.2 FTE – all LMA
- asset: from TRL 2 to 6

Bragg reflectors of GW interferometers

- stacked layers of sputtered oxydes



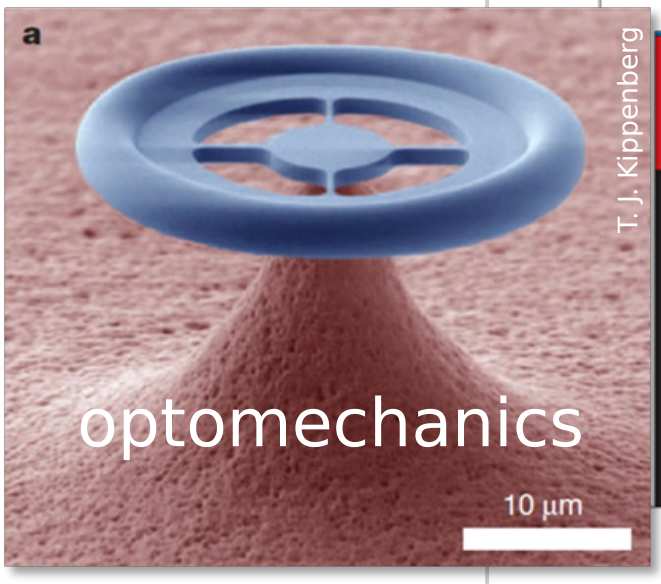
Motivation

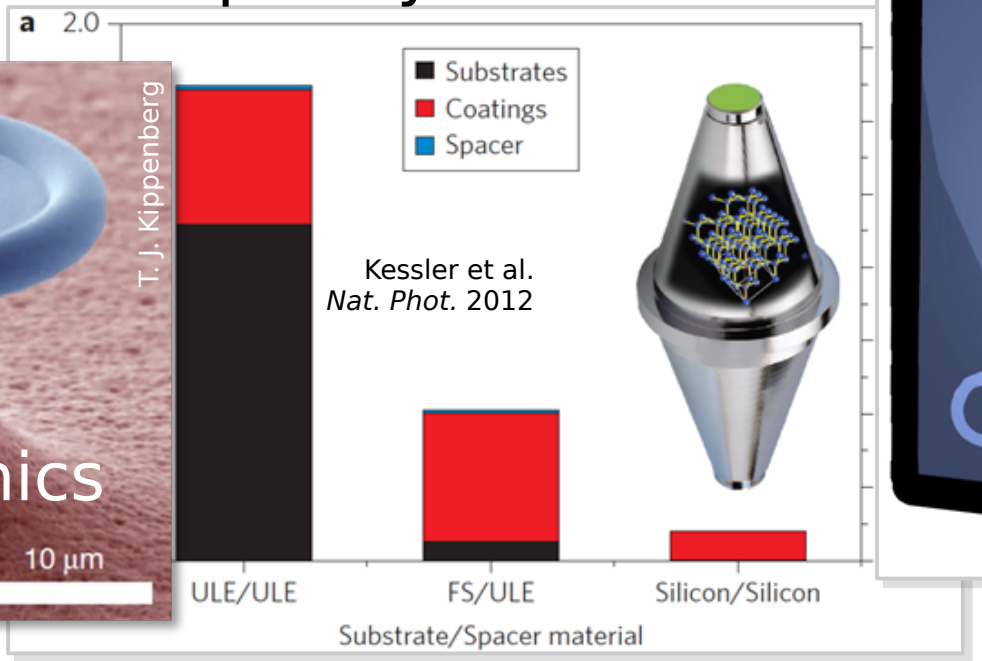


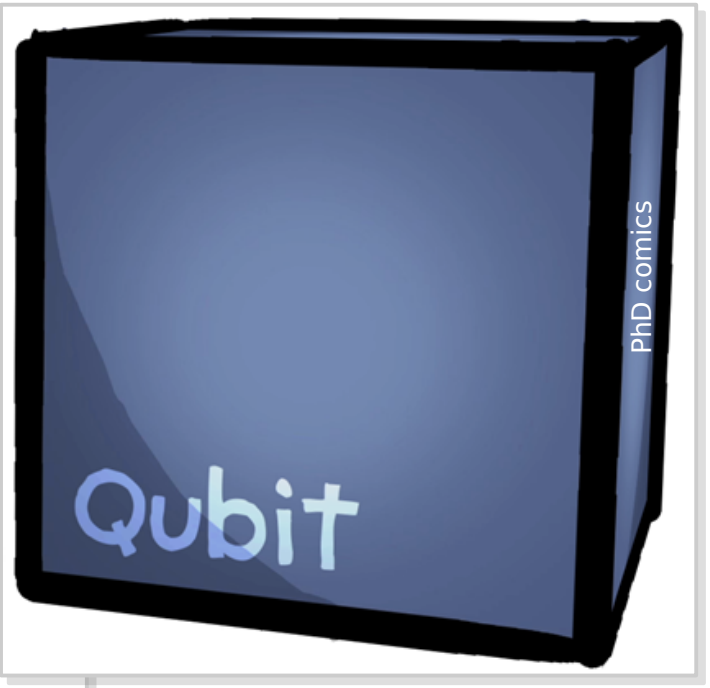
→ low optical loss
absorption, scattering
→ low mechanical loss
thermal noise

also beneficial to:

frequency standards







Key parameters

for Fabry-Perot cavities:

coating thickness

coating internal friction

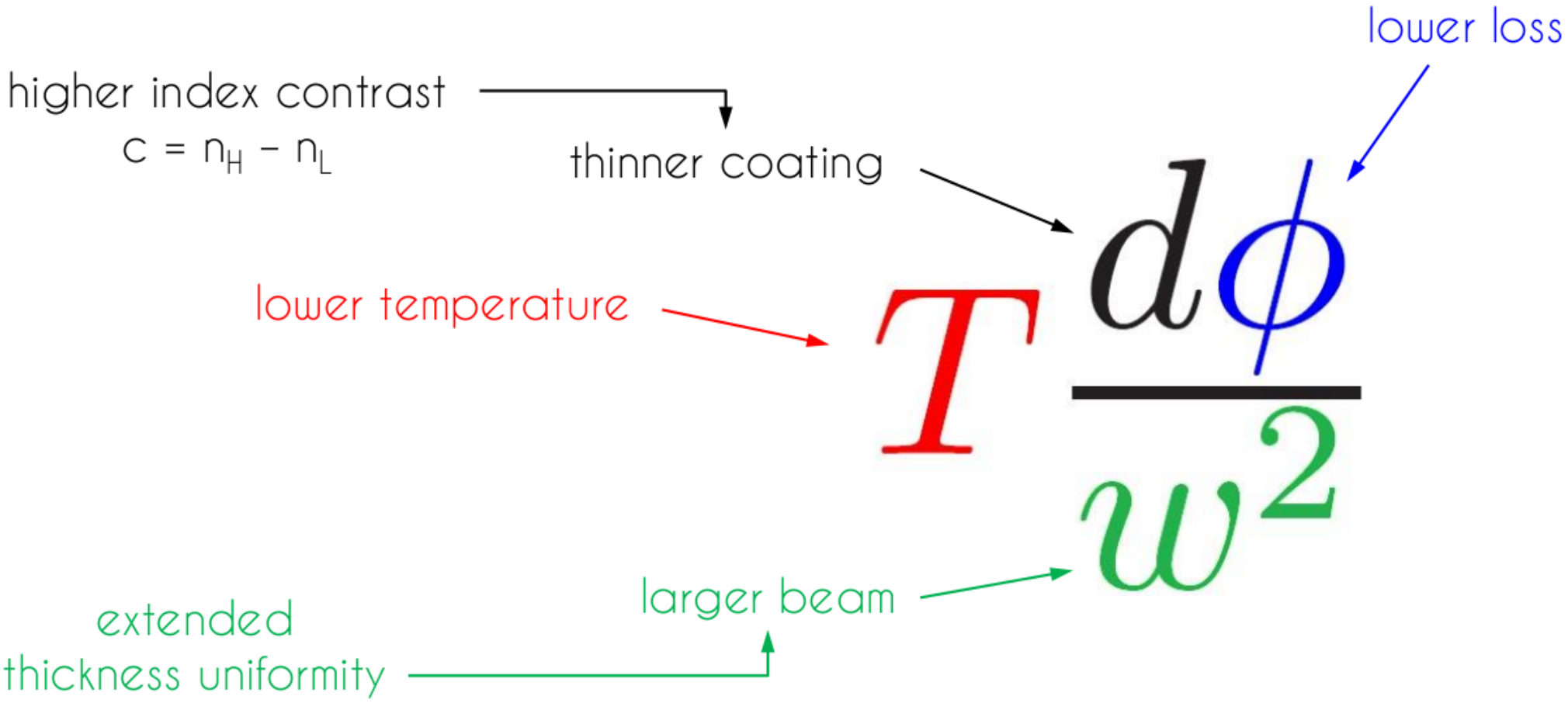
temperature

$$S_{CTN} \propto T \frac{d\phi}{w^2}$$

beam size

Harry et al, Class. Quantum Grav. 19 (2002)

Key parameters



Overview

- ‘recipe’ = material + growth parameters + treatments

  requirements [see doi.org/10.1364/AO.377293 for details]

refractive index	$n < 1.45$ or $n > 2.09$
optical absorption	$\alpha < 1$ part per million (ppm)
scattered light	$\alpha_s < 10$ ppm
mechanical loss	$\varphi_c < 1e\text{-}4$ rad

  options:

  → materials

  oxides, SiNx, SiC, fluorides

  → growth technique & settings

  IBS, growth rate

  → treatments

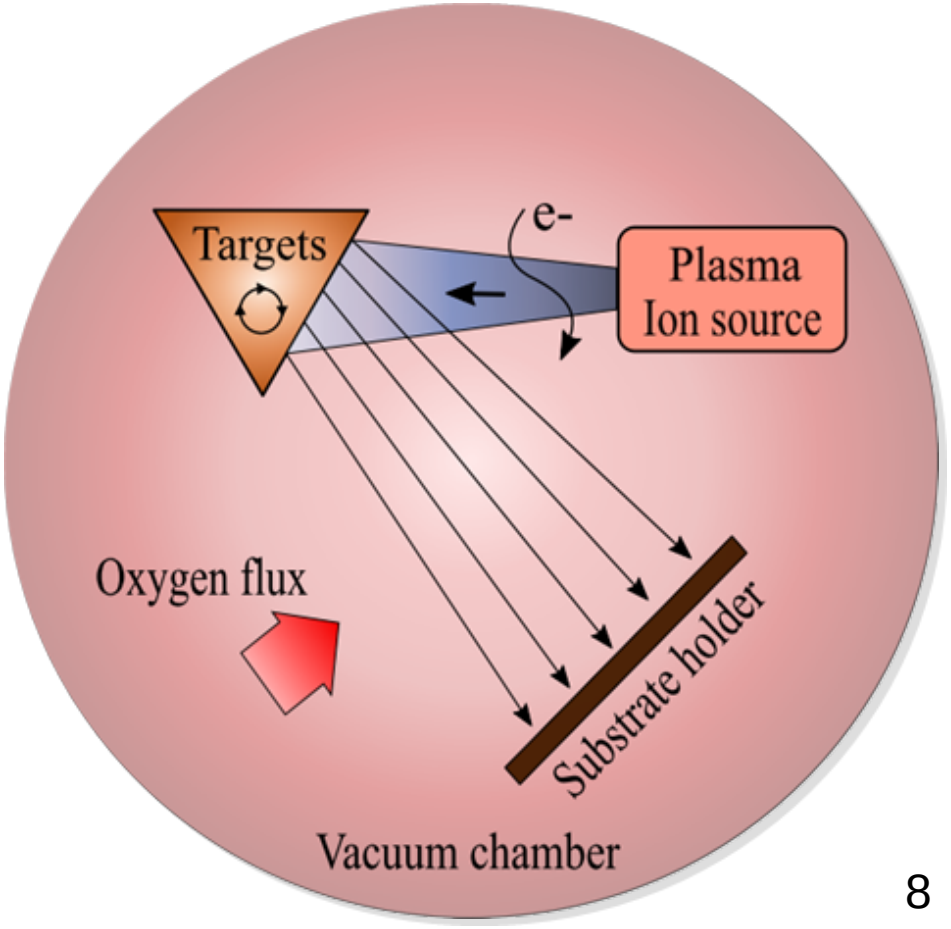
  post-deposition annealing

Ion-beam sputtering (IBS)

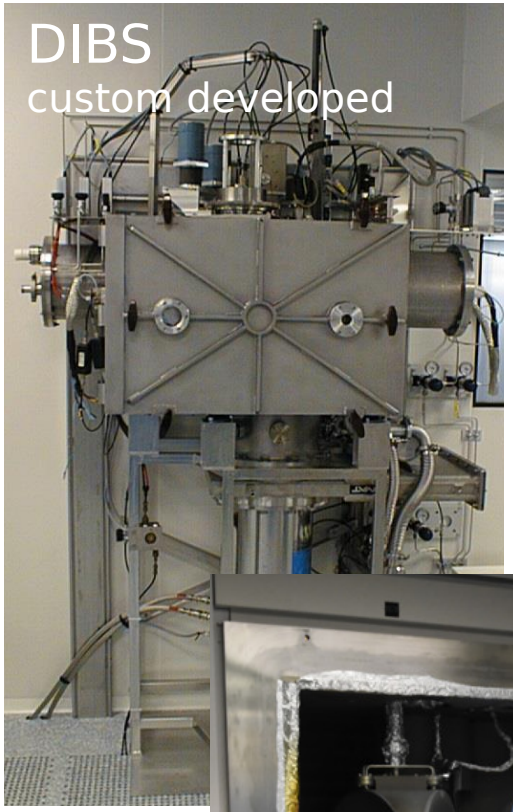
✔ lowest optical loss

- deposition parameters
  - ion energy & current
  - growth rate
  - partial pressures

  → optimal set of values



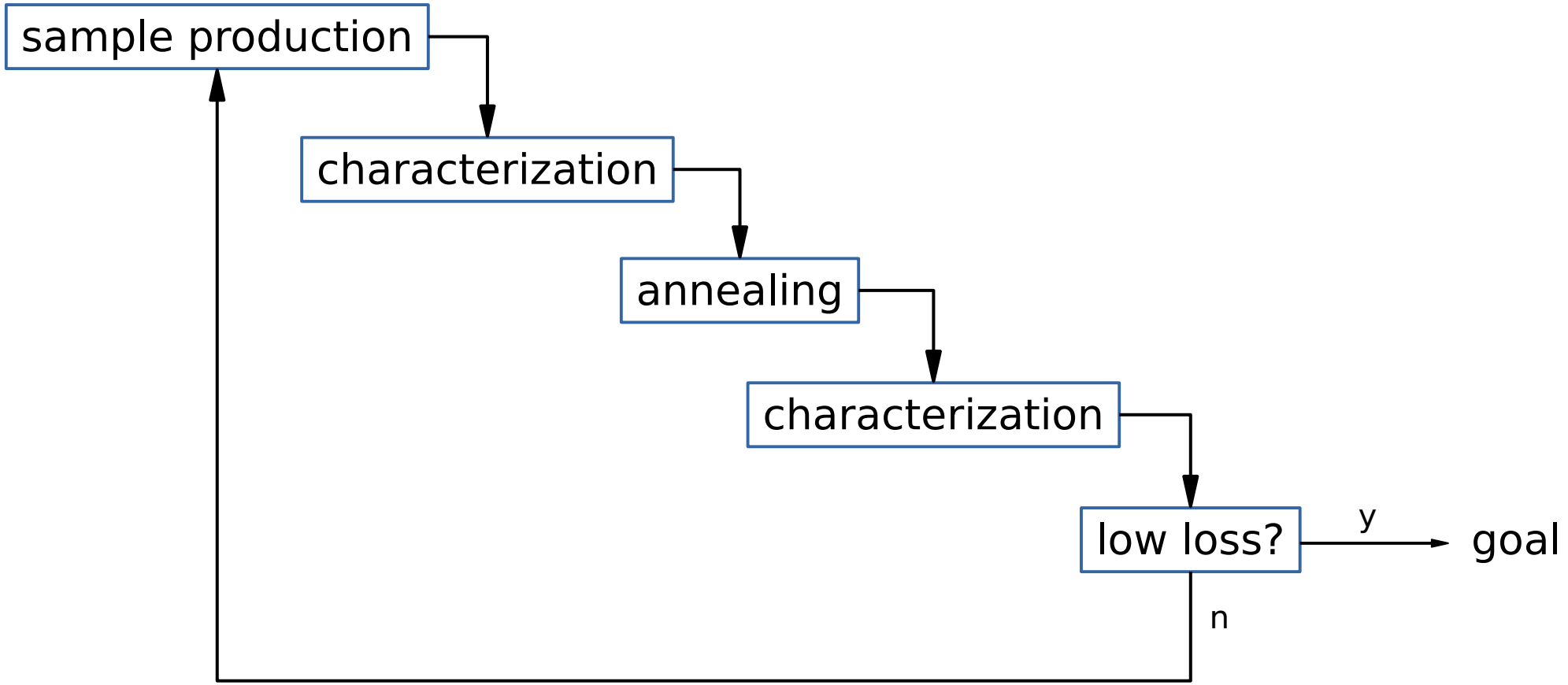
IBS facilities @ LMA



photos: C. Fresillon (photothèque CNRS) / E. Le Roux / LMA

Method

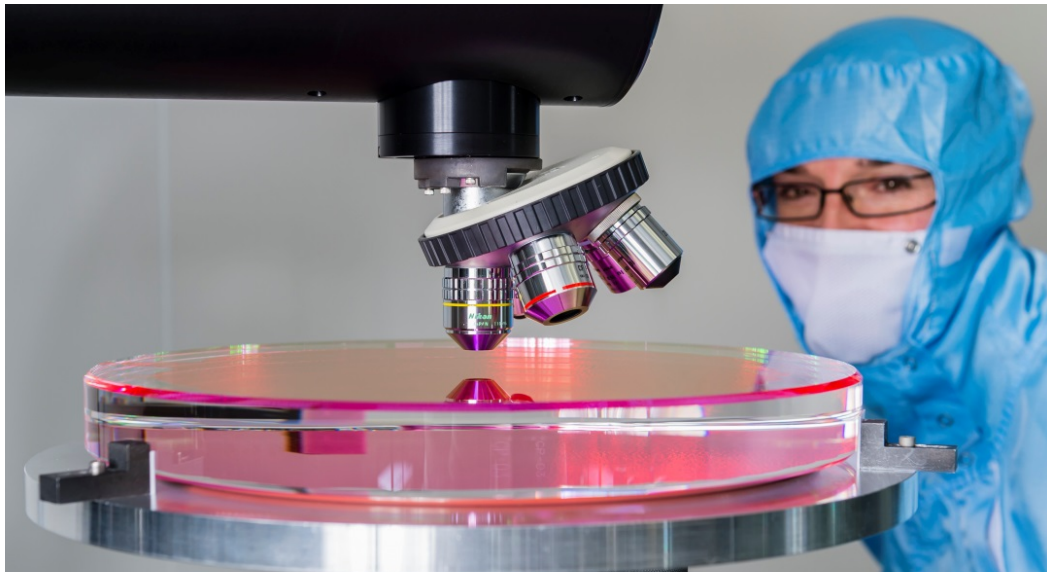
- optimization by trial & error

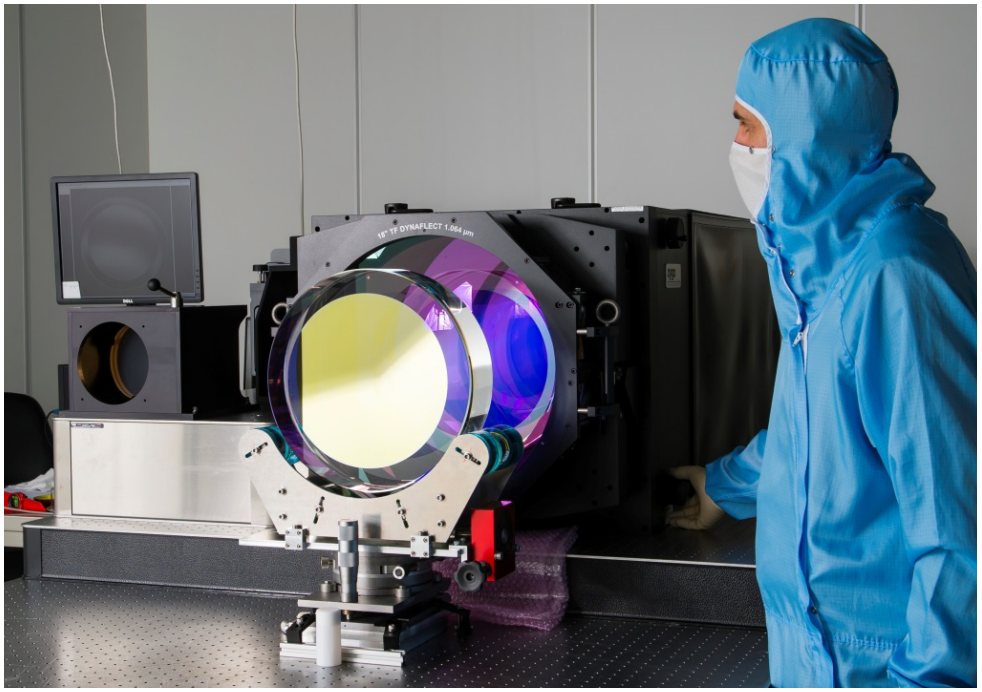


Tools

- scattering
- surface defects
- wavefront
- absorption [ambient/cryogenic temp.]
- spectro-photometry

photos: C. Fresillon (photothèque CNRS)

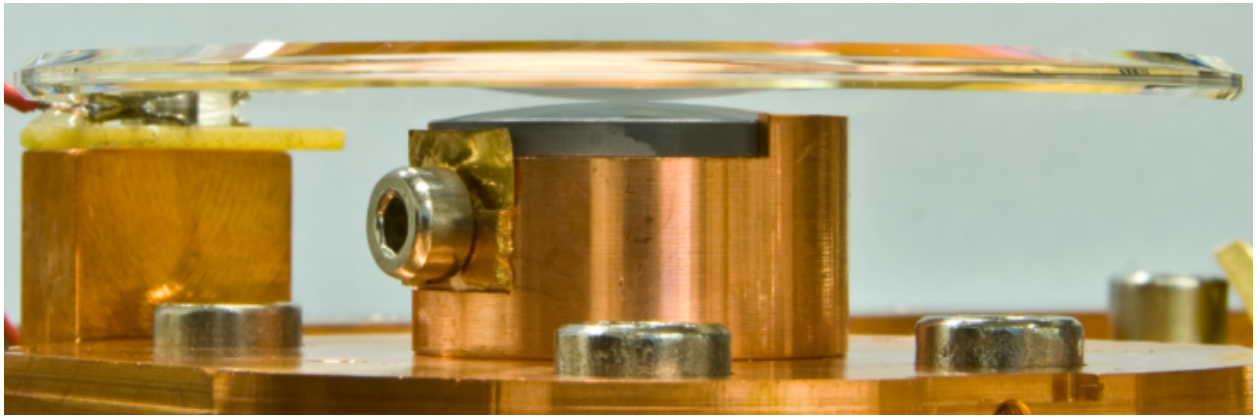




Tools

Gentle Nodal Suspension (GeNS) system

- mechanical loss angle φ_C [ambient/cryogenic temp.]
- dilution factors
- Young modulus
- Poisson ratio



Granata et al, Class. Quantum Grav. 37 (2020)
Cesarini et al, Rev. Sci. Instrum. 80 (2009)

✔ reliable Q measurements

→ models of substrates & coatings

→ systematic errors (edge effect, temperature) removed

→ new protocols & standards developed

2 papers in preparation

developed at LMA,

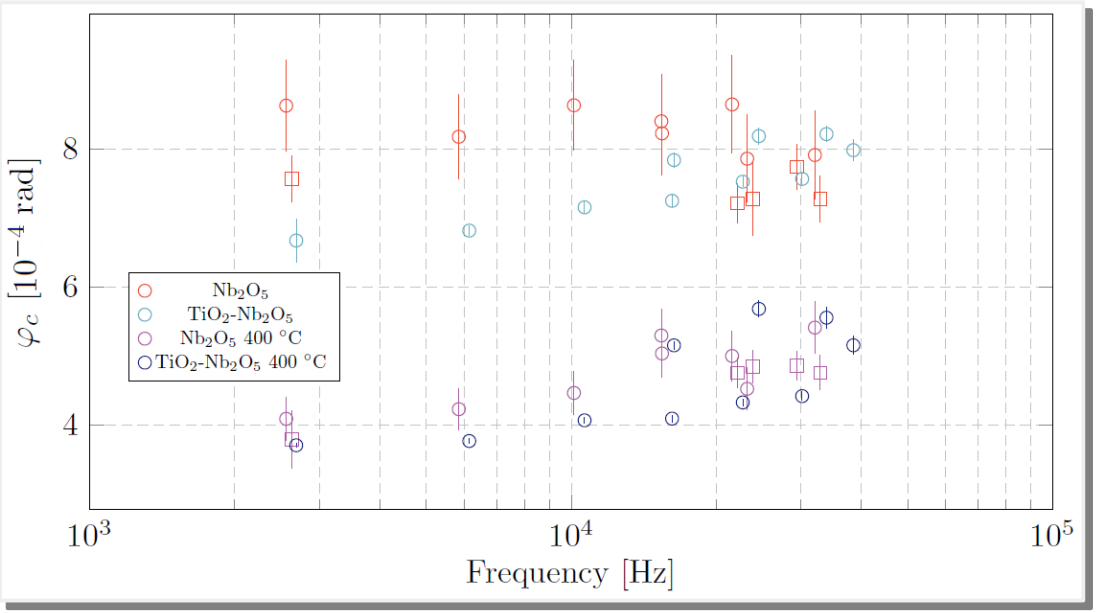
adopted by Virgo & LIGO Collaborations as reference solution

Oxides [Master Projet]

- Nb2O5 / TiO2-Nb2O5
  - ✔ higher n
  - ✔ low α, αs
  - ✘ φc still too high

  results published this year

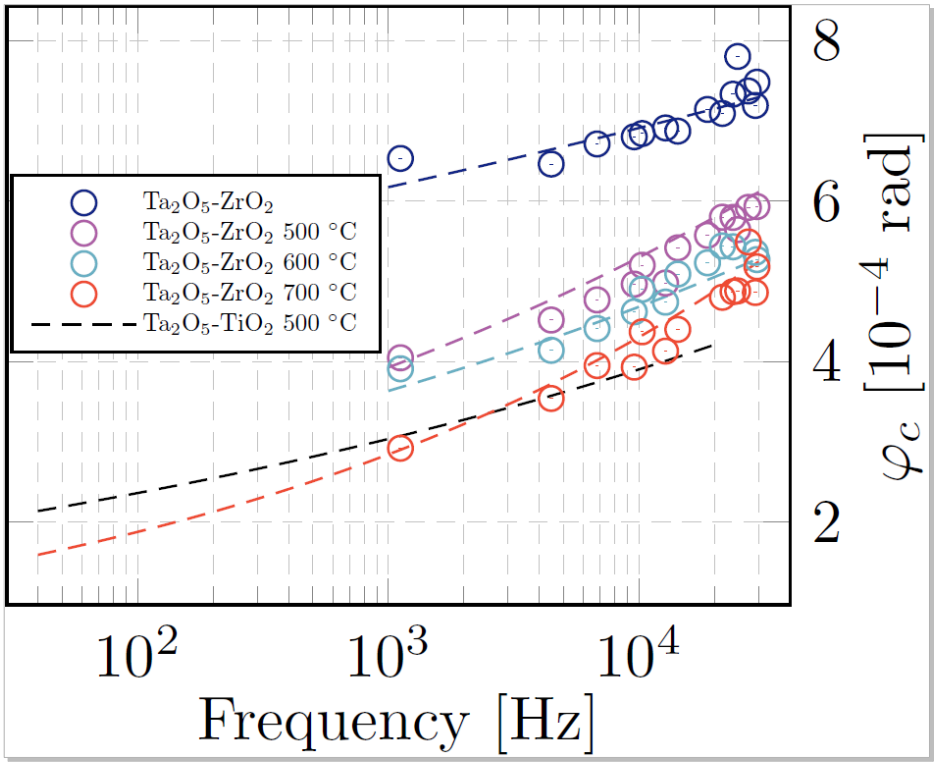
  doi.org/10.1103/PhysRevD.103.072001



- Ta2O5-ZrO2
  - ✔ tested in the Grand Coater
    same machines used for LIGO/Virgo mirrors
  - ✔ ~25% lower φc
    than in high-index layers of LIGO/Virgo mirrors
  - ✔ HR stack tested
    - ✔ α ≈ 0.5 ppm
    - ✘ αs ≈ 45 ppm
    - ✔ cracking issue solved
    - ✔ amorphous @ Tann = 800 °C
    - ✘ defects when annealed

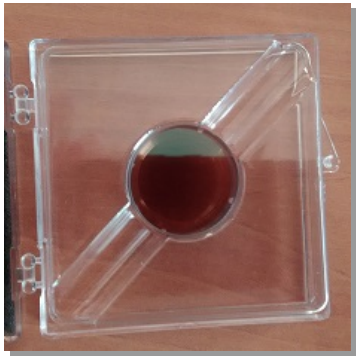
  results published this year

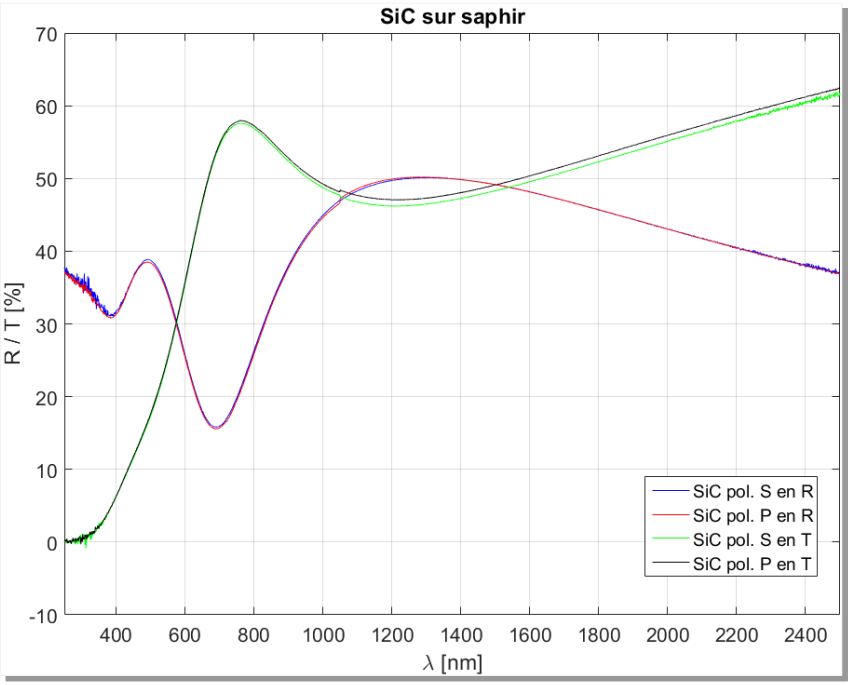
  doi.org/10.1103/PhysRevD.103.072001



SiC [Master Projet]

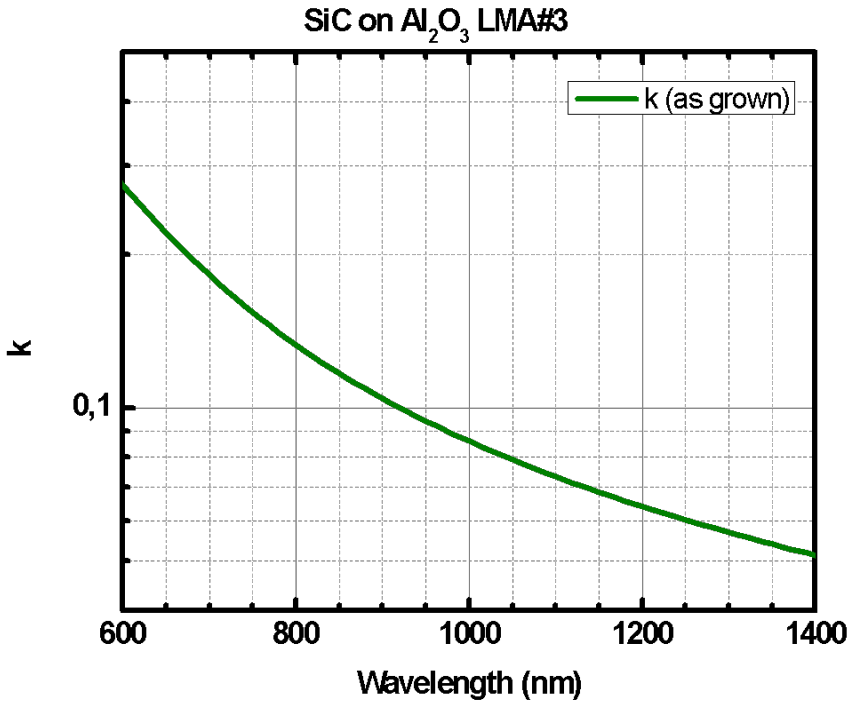
- ✔ very high n
- ✘ very high α, α_s
- ✘ high φ_c

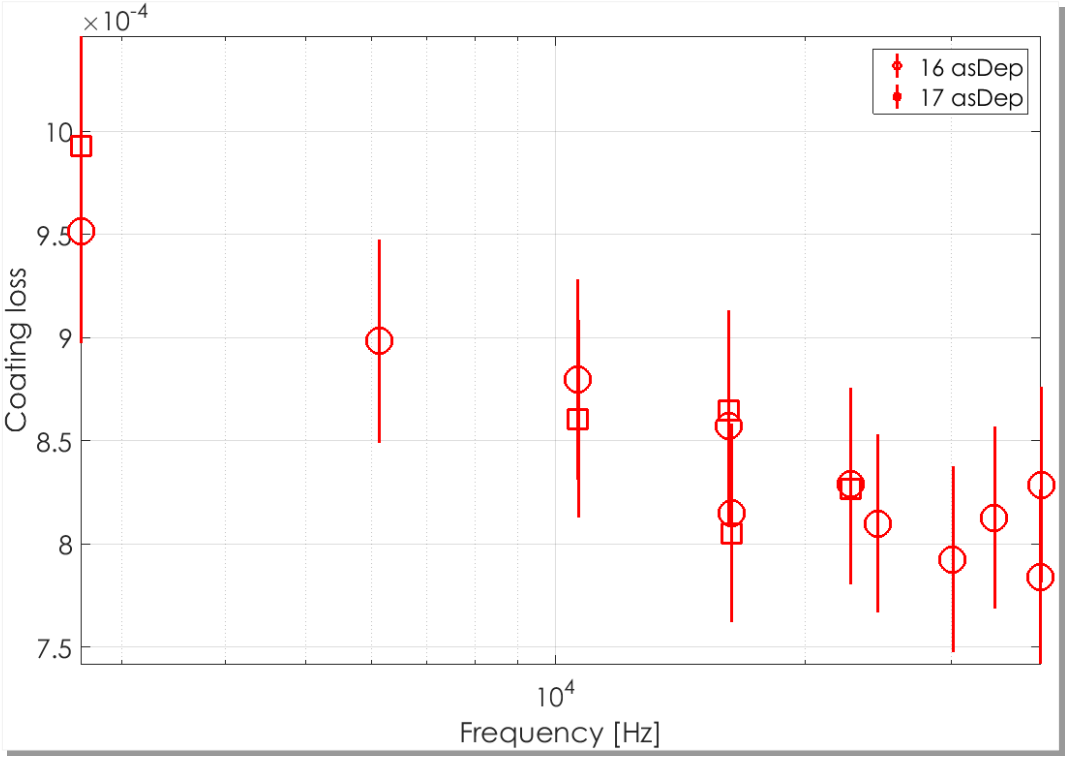




- contribution from Virgo Coating R&D Collaboration

- paper in preparation



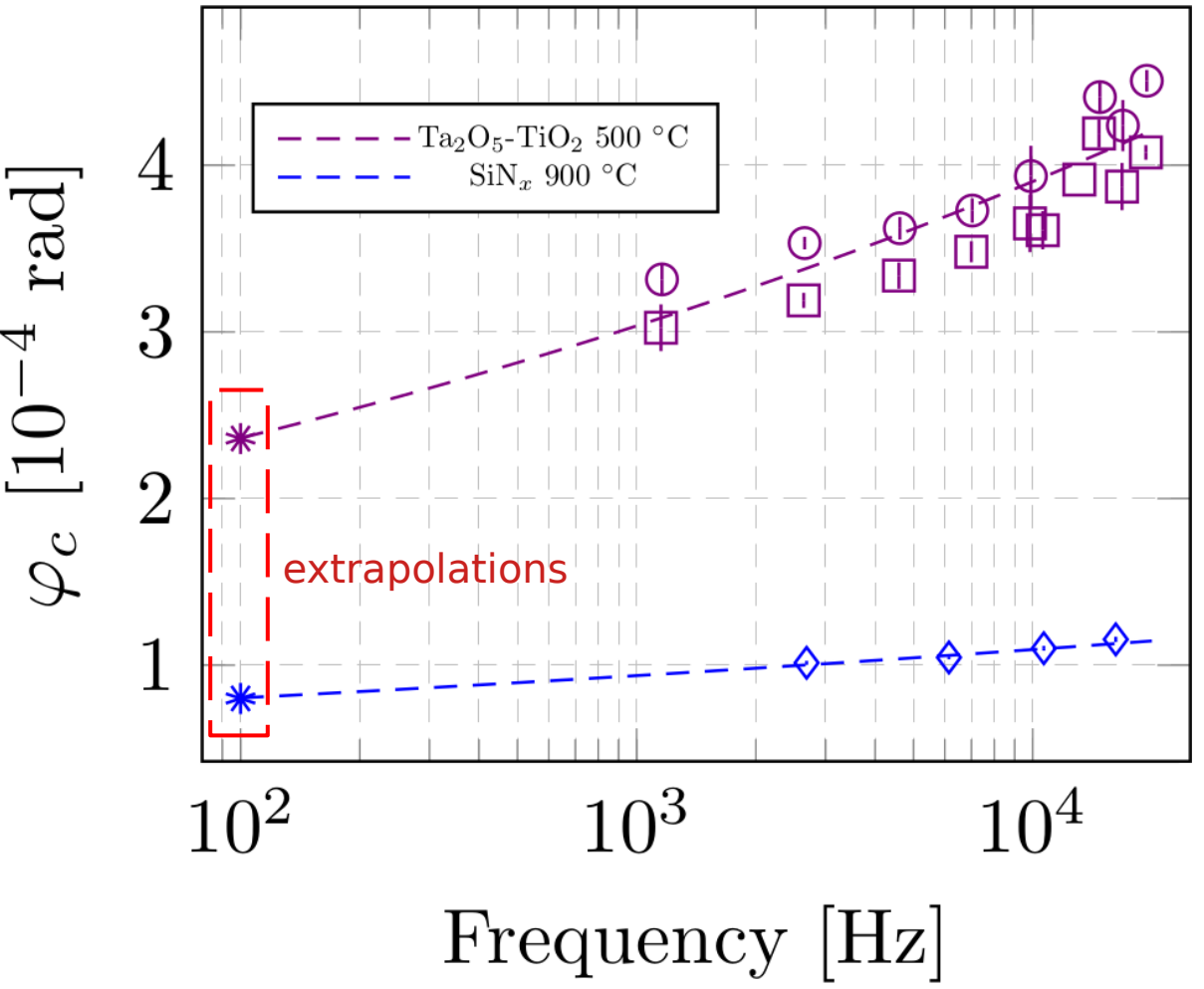


SiNx

- ✔ high n
- ✔ 3 times lower φ_c
- ✘ α, α_s still too high

- ✔ HR stack tested
  - ✘ $\alpha = 44 \pm 2$ ppm
  - ✘ $\alpha_s = 60 \pm 15$ ppm
  - ✔ amorphous
    @ $T_{ann} = 1000$ °C
  - ✘ defects when annealed

- work still ongoing
- paper(s) in preparation



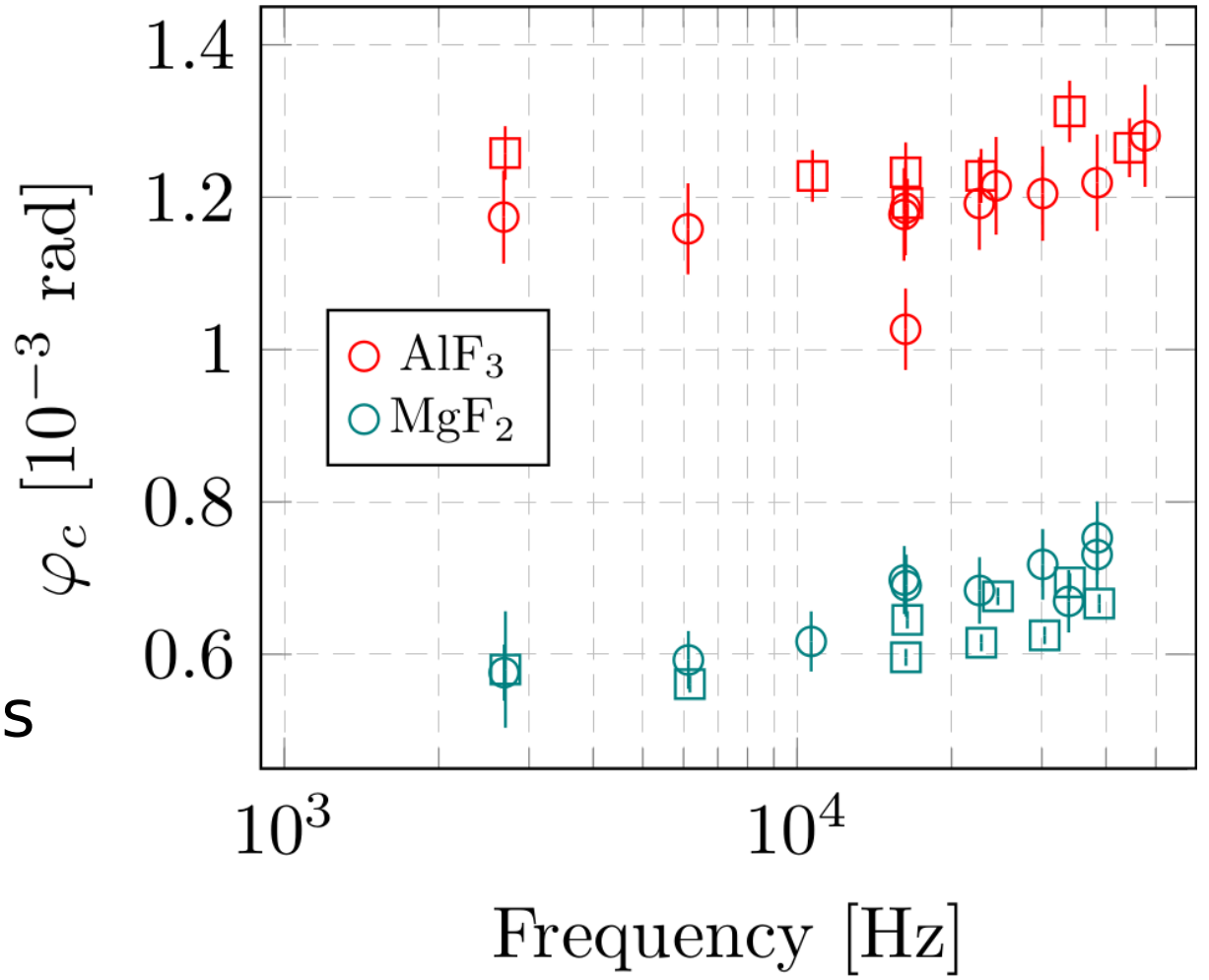
Fluorides

- ✔ low n
- ✘ high α, α_s

- ✔ annealing tested
  - ✘ α, α_s still too high

- 2 papers in preparation

- cryogenic measurements starting soon

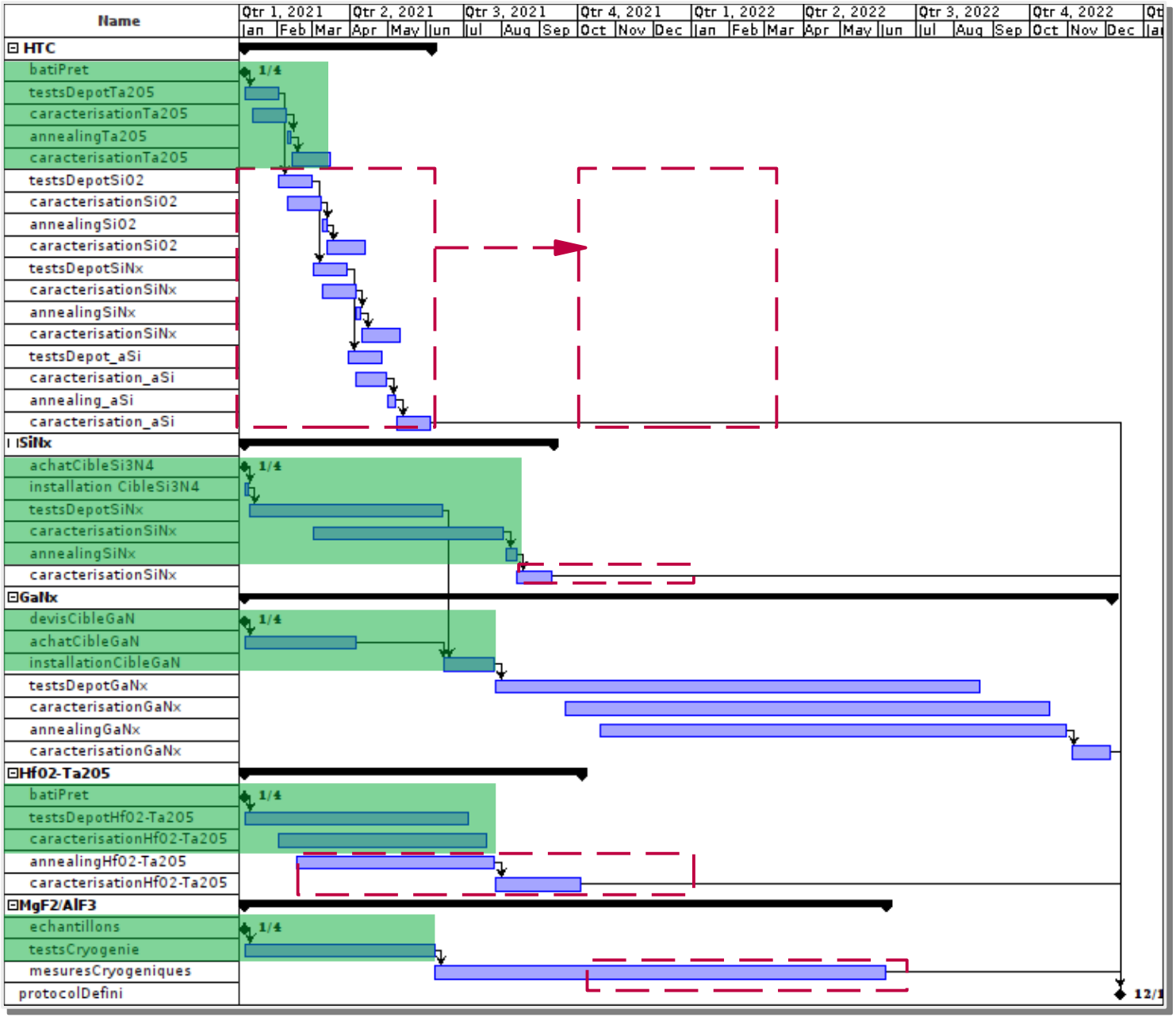


Working plan

- Ta2O5 / SiO2 / aSi
  - ✔ ~~growth rate~~
  - → substrate heating
- SiNx
  - ✔ ~~bombardment~~
  - → substrate heating
- GaNx
  - → growth rate / bombardment / substr. heating / annealing
- HfO2-Ta2O5
  - → growth rate / annealing
- MgF2 / AlF3
  - ✔ ~~annealing~~
  - → cryogenic characterization

Schedule

- optimal ‘recipe’ = material + growth parameters + treatments
- 1” samples



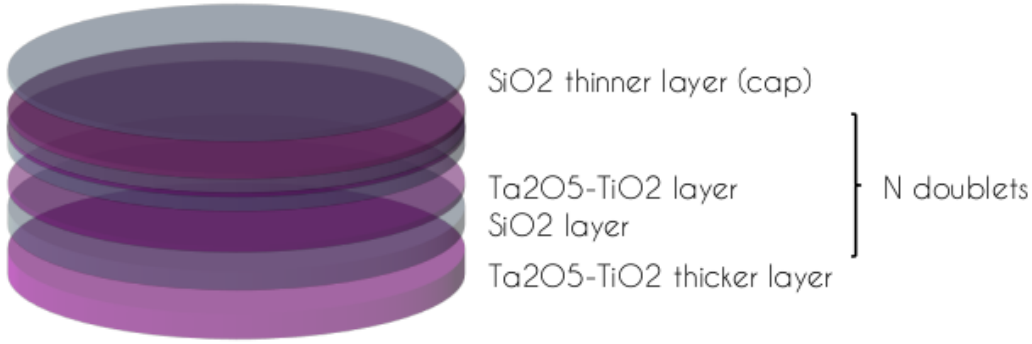
Summary

- many options tested
  none fully viable yet
- work ongoing, mostly on time
- 90% of 2021 funds spent, last orders to be issued soon
- 6 papers to be published soon
  more to come in the near future

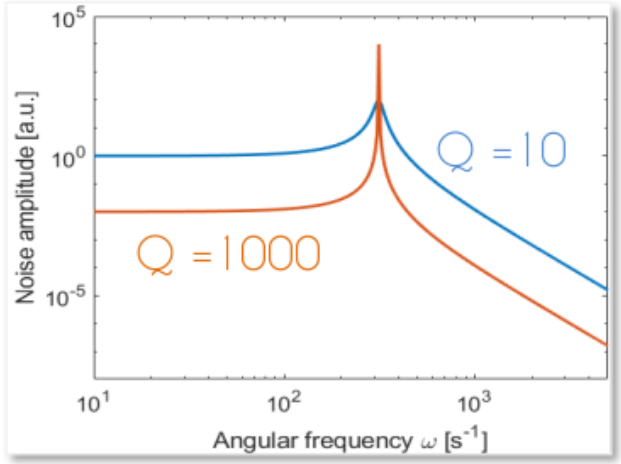
Thank you for listening

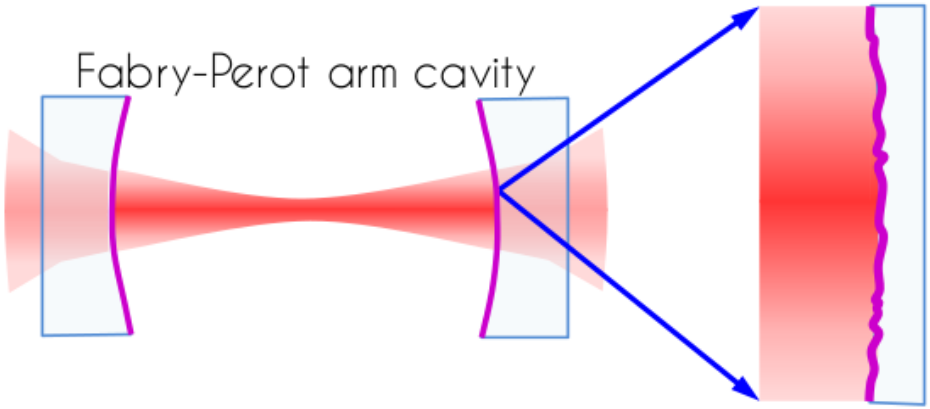
Bragg reflectors of GW interferometers

outstanding optical properties
but source of
thermal noise (TN)



- feature of dissipative systems at thermal equilibrium
- energy leakage to off-resonance spectrum
- intensity proportional to system internal friction
  loss angle $\Phi = 1/Q$

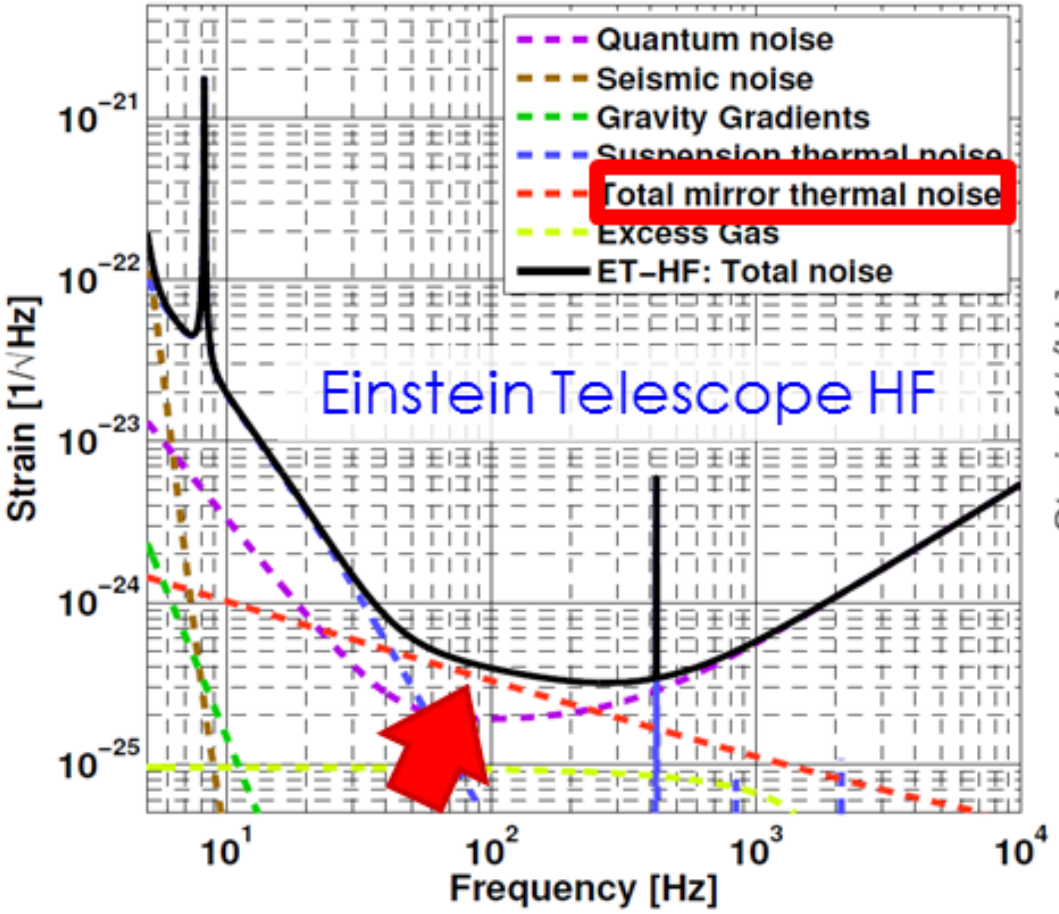


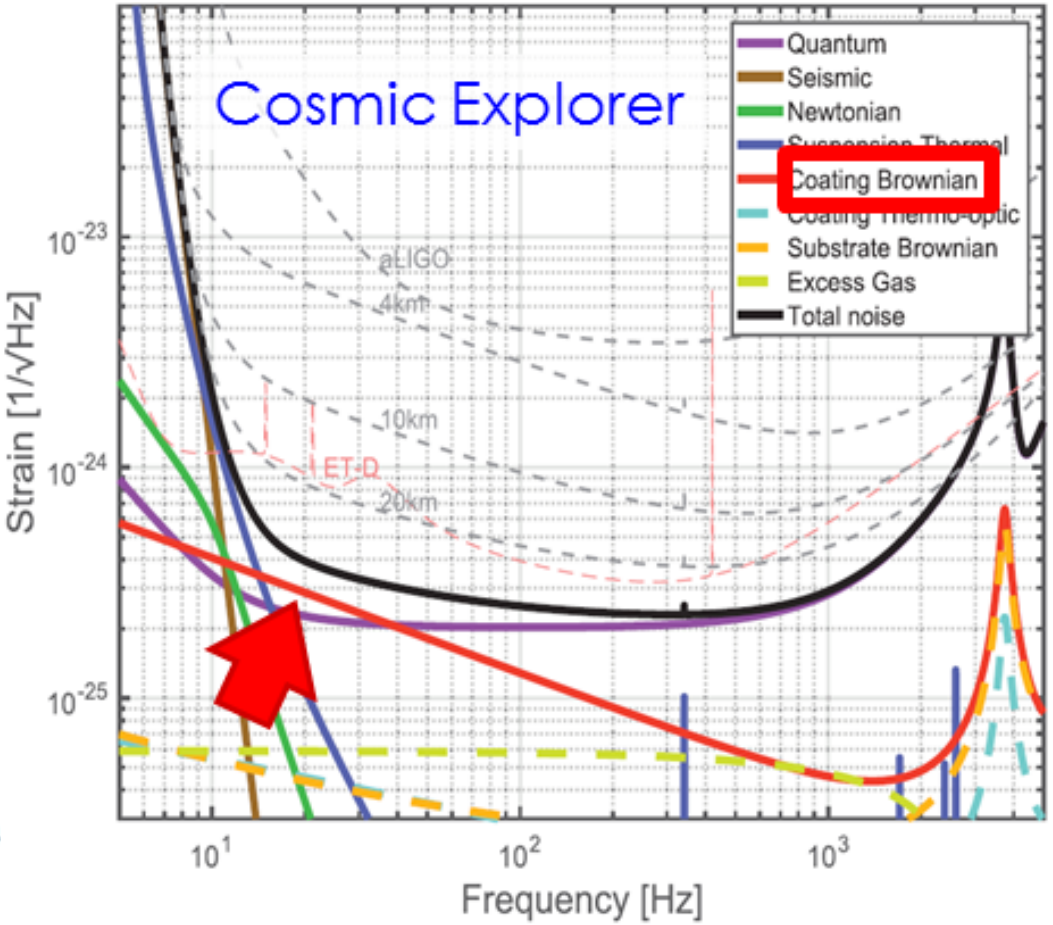


surface fluctuations

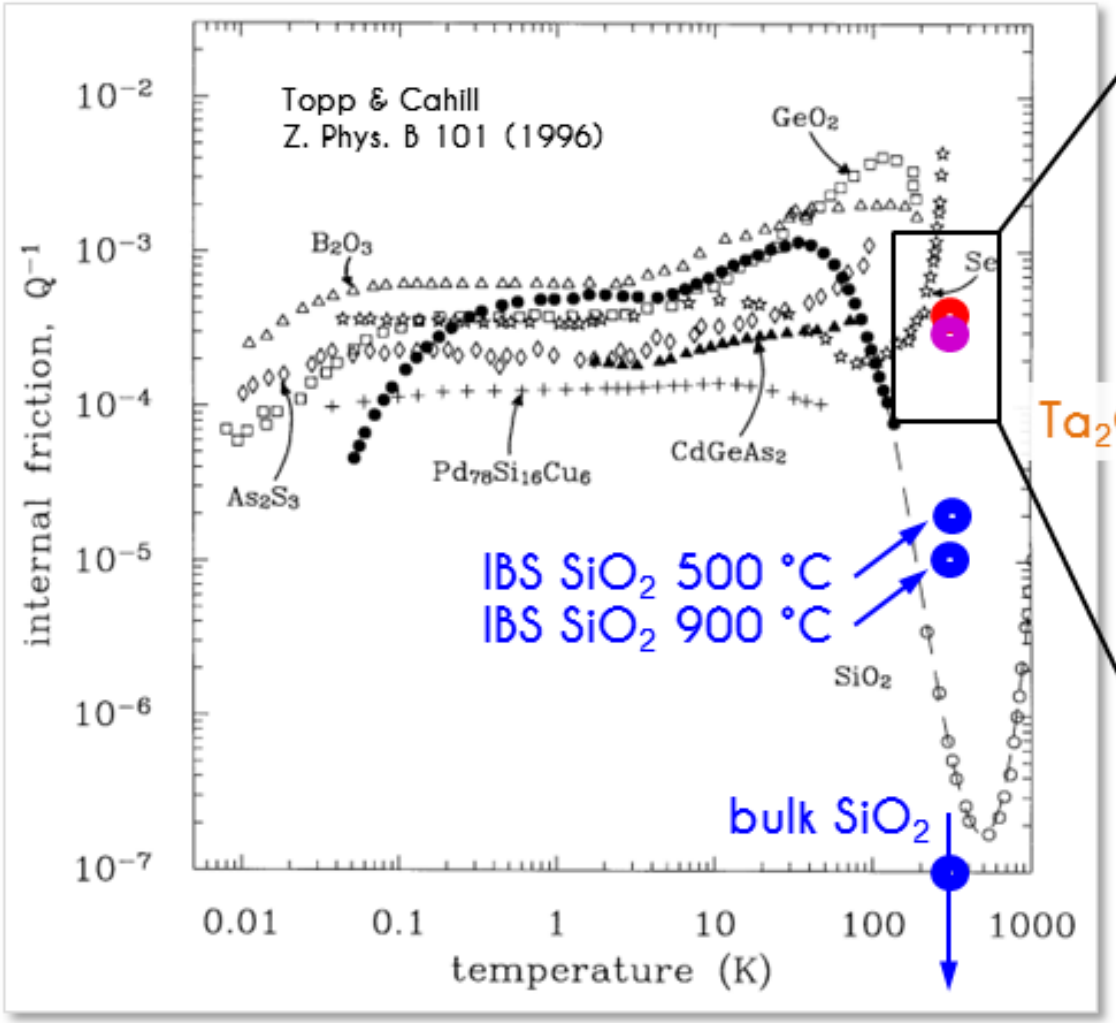
→ phase noise

Future gravitational-wave interferometers





amorphous solids



IBS coatings