R&D activity on low-losses coatings @ LMA

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KAGRA International Workshop – 20.12.2020

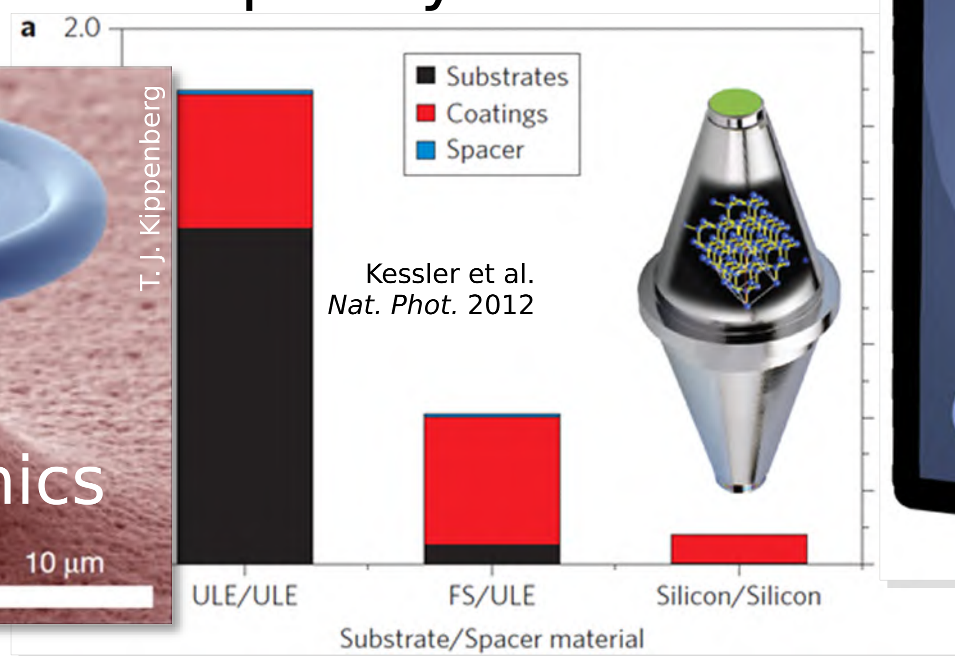
Motivation

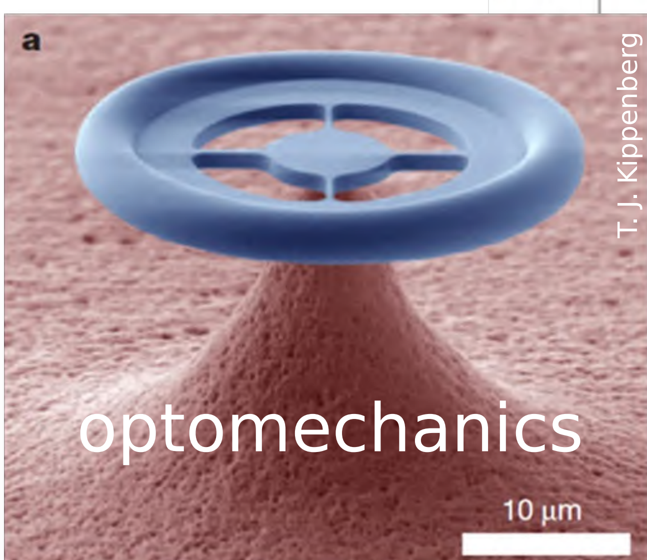
→ low mechanical loss
thermal noise

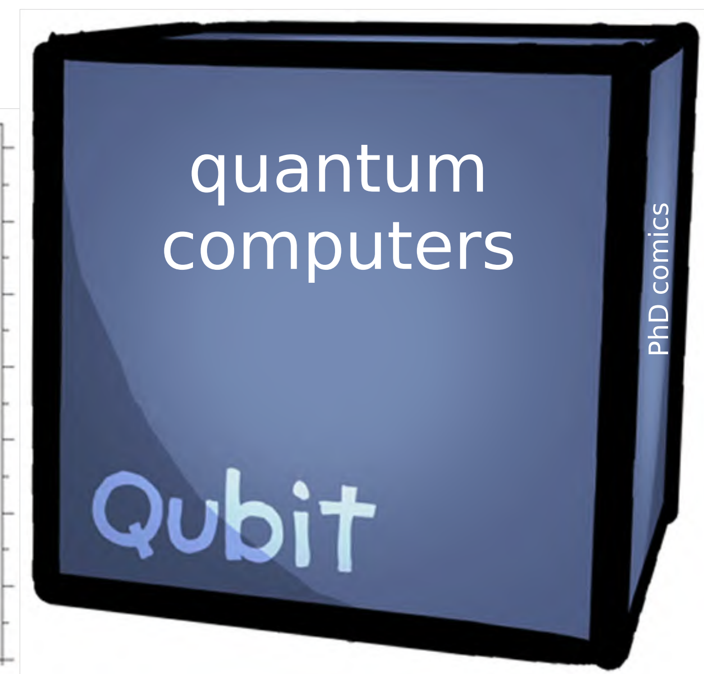
→ low optical loss
absorption, scattering

also beneficial to:

frequency standards

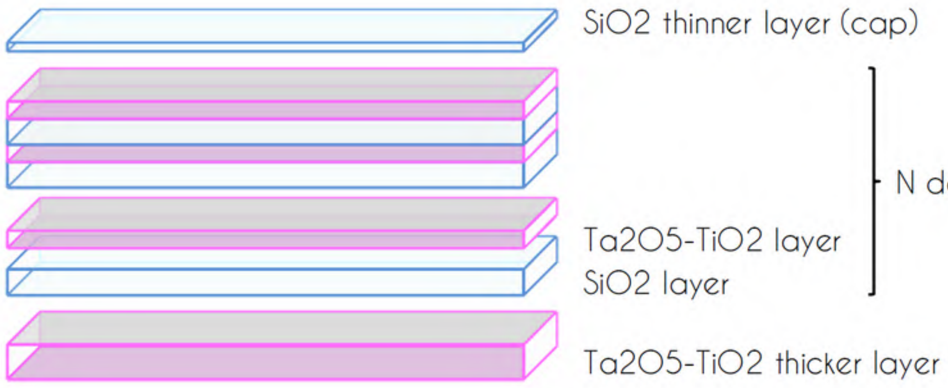






I. new materials

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



Multilayers coating

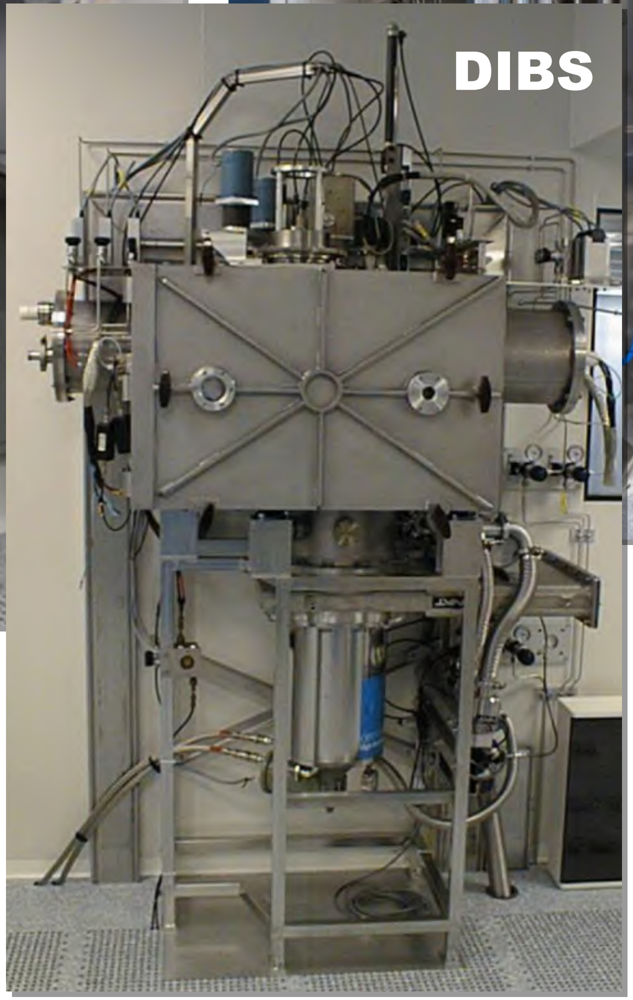
refractive index	$n < 1.45$ or $n > 2.09$
mechanical loss	$\varphi_c < 1e\text{-}4$ rad
optical absorption	$\alpha < 1$ part per million (ppm)
scattered light	$\alpha_s < 10$ ppm

growth technique = ion-beam sputtering (IBS)

→ lowest optical loss on large diameter ✔

'recipe' = material + growth parameters + treatments

IBS coaters @ LMA



Gentle Nodal Suspension (GeNS) system

Characterization of:

- ✔ coating mechanical loss
- ✔ coating dilution factors
- ✔ coating Young modulus & Poisson ratio

→ doi.org/10.1088/1361-6382/ab77e9

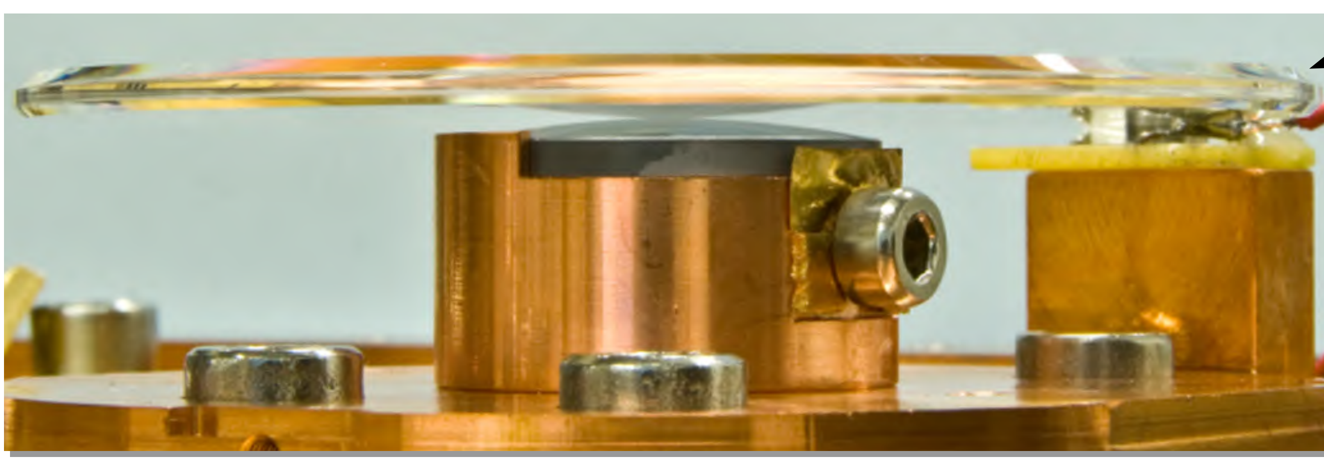
✔ reliable measurements

→ models of substrates [doi.org/10.1016/j.physleta.2017.05.065] & coatings

→ systematic errors (edge effect) removed

→ new protocols & standards developed

2 papers in preparation



coated wafer

Ta2O5 – high-index layers of KAGRA coatings

- 3 machines used → different growth parameters

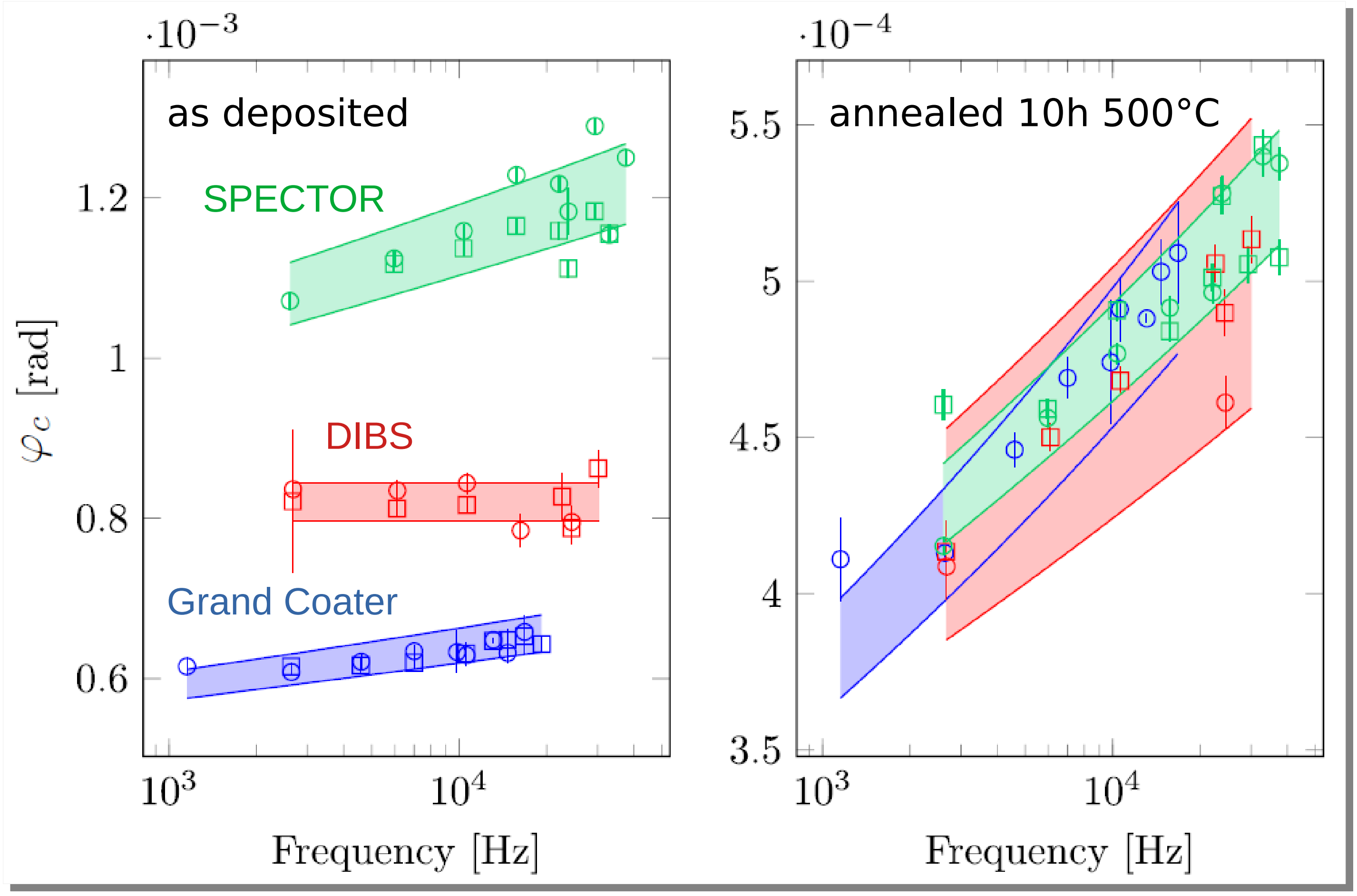
✘ high φ_c

✔ high n

✔ low α

✔ low α_s

- impact of growth parameters assessed
- annealing erases growth history



- results published [doi.org/10.1088/1361-6382/ab77e9]

SiO_2 – low-index layers of KAGRA coatings

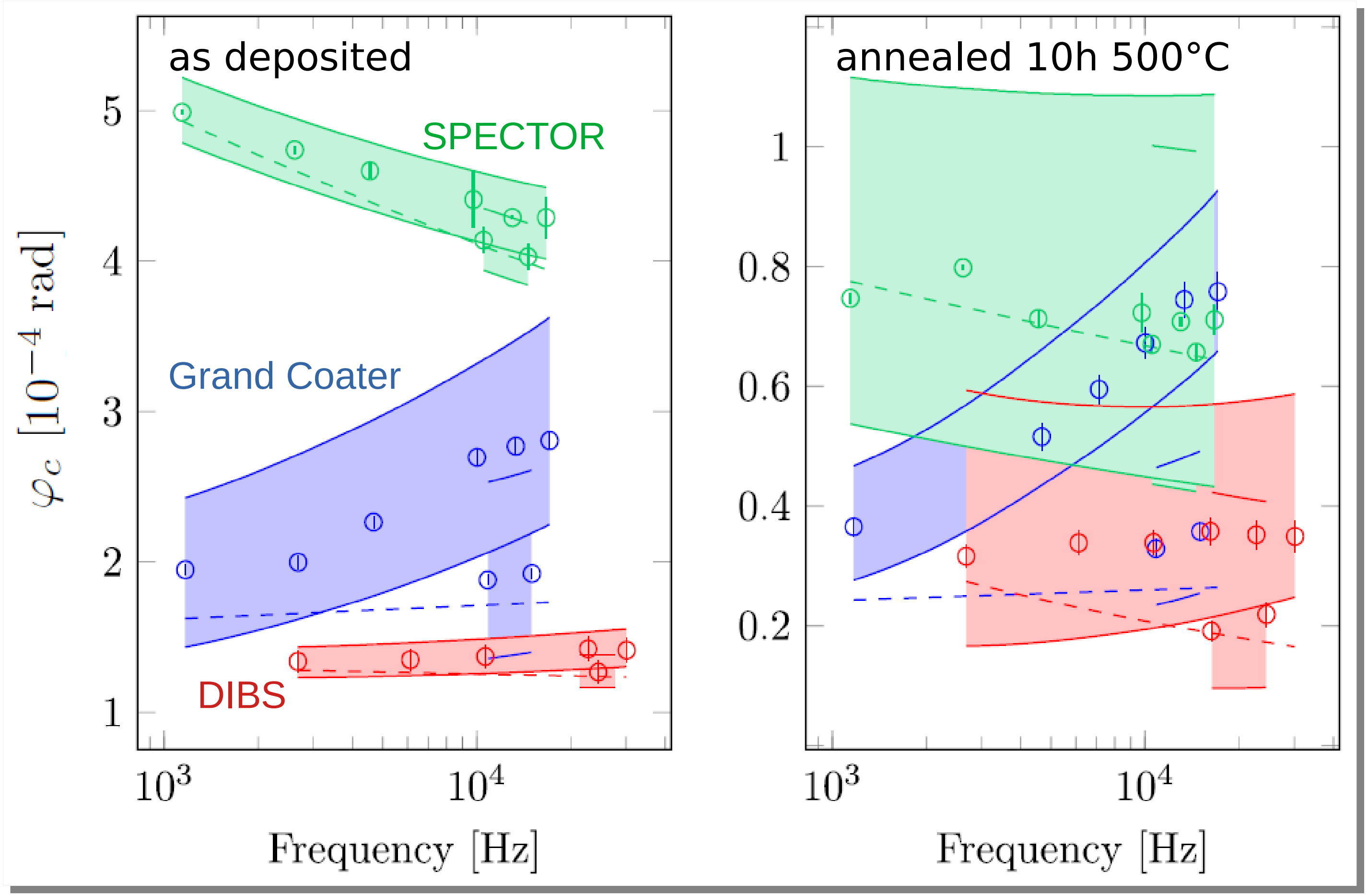
- 3 machines used → different growth parameters

✔ lowest φ_c

✔ low n

✔ low α

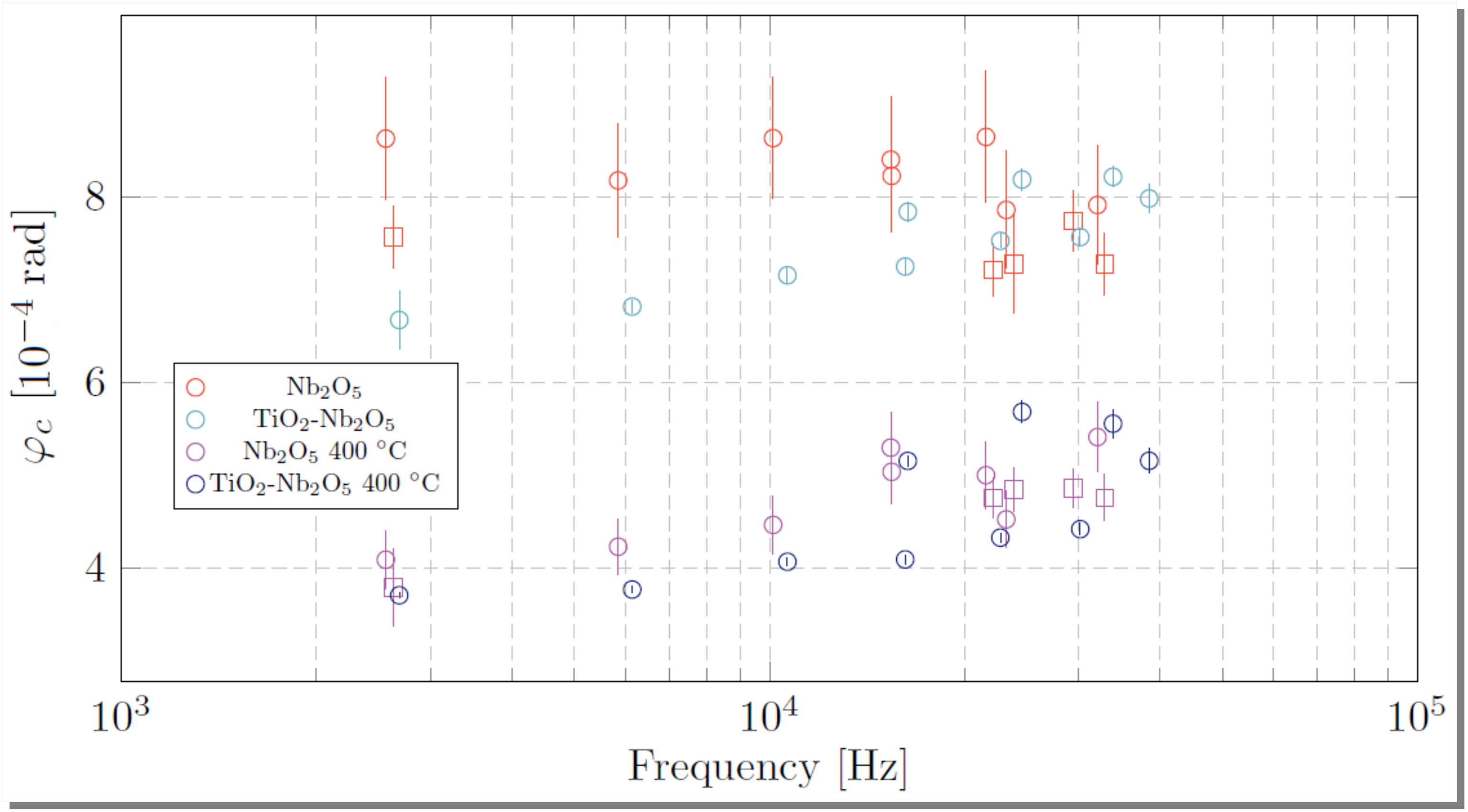
✔ low α_s



- growth parameters are critical

- results published [doi.org/10.1088/1361-6382/ab77e9]

Nb2O5 / TiO2-Nb2O5



✔ higher n

✔ low α, $α_s$

✘ $φ_c$ still too high

✘ bubble-like defects

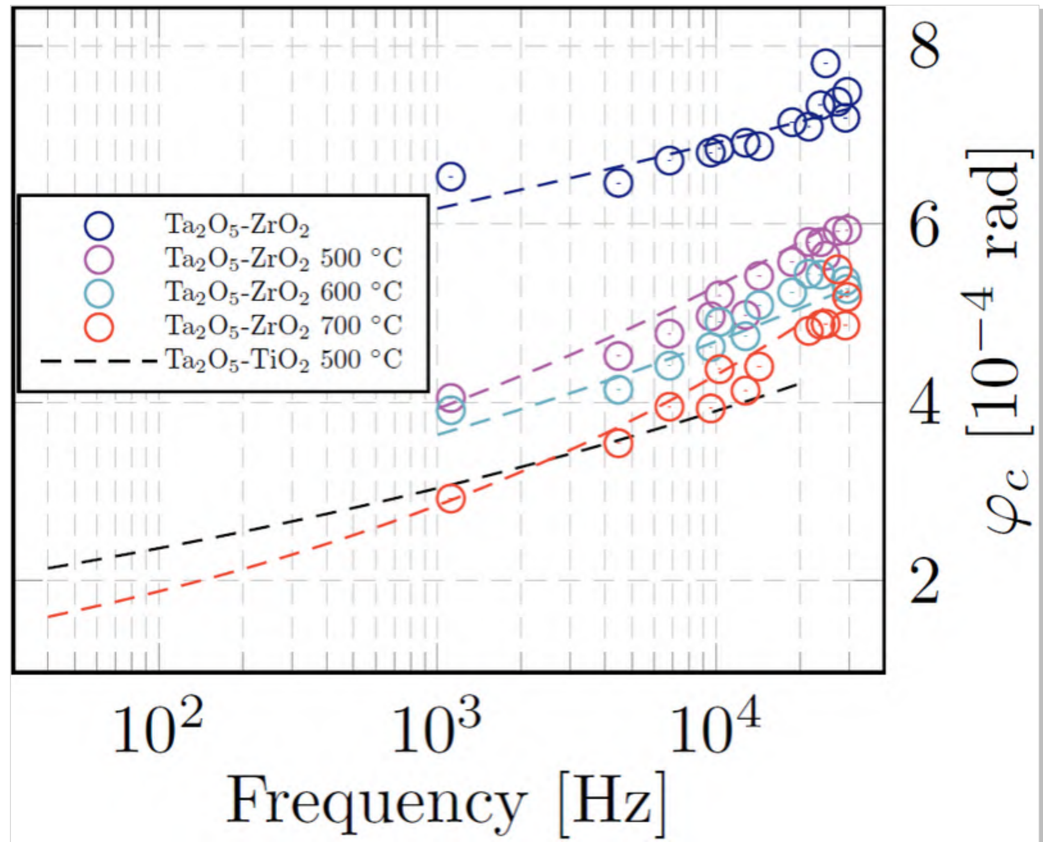
- preliminary results published [doi.org/10.1364/AO.377293]

- new LMA-MIT paper completed – under P&P/DRS review
P2000496/VIR-1022A-20

Ta2O5-ZrO2

✔ tested in the Grand Coater
same machine than
KAGRA coatings

✔ ~25% lower φ_c
than Ta2O5-TiO2 coating
→ AdV+

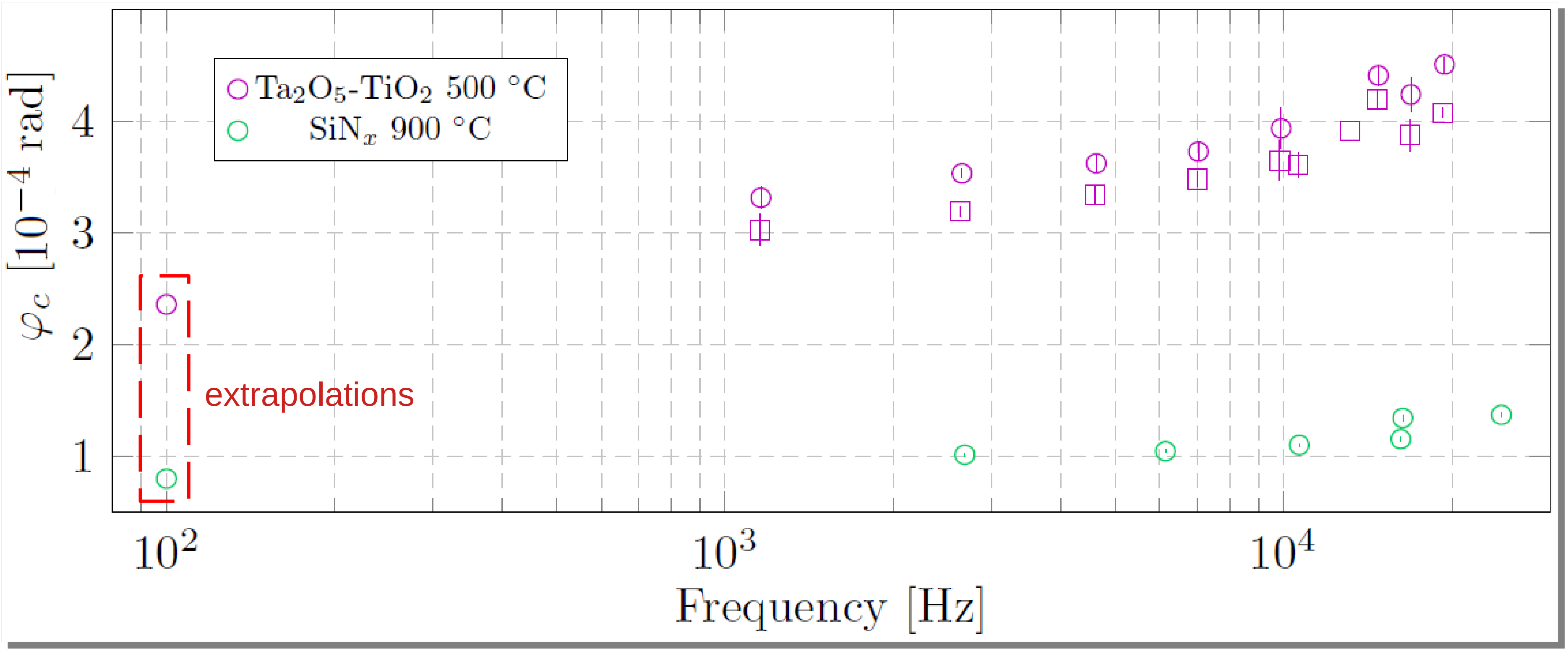


LIGO / Virgo HR stack tested
✔ $\alpha \approx 0.5$ ppm
✘ $\alpha_s \approx 45$ ppm
cracking issue solved
still amorphous @ T_{ann} = 800 °C but bubble-like defects

- preliminary results published [doi.org/10.1364/AO.377293]
- new collaborative LVC paper ongoing

P2000510/VIR-1040A-20

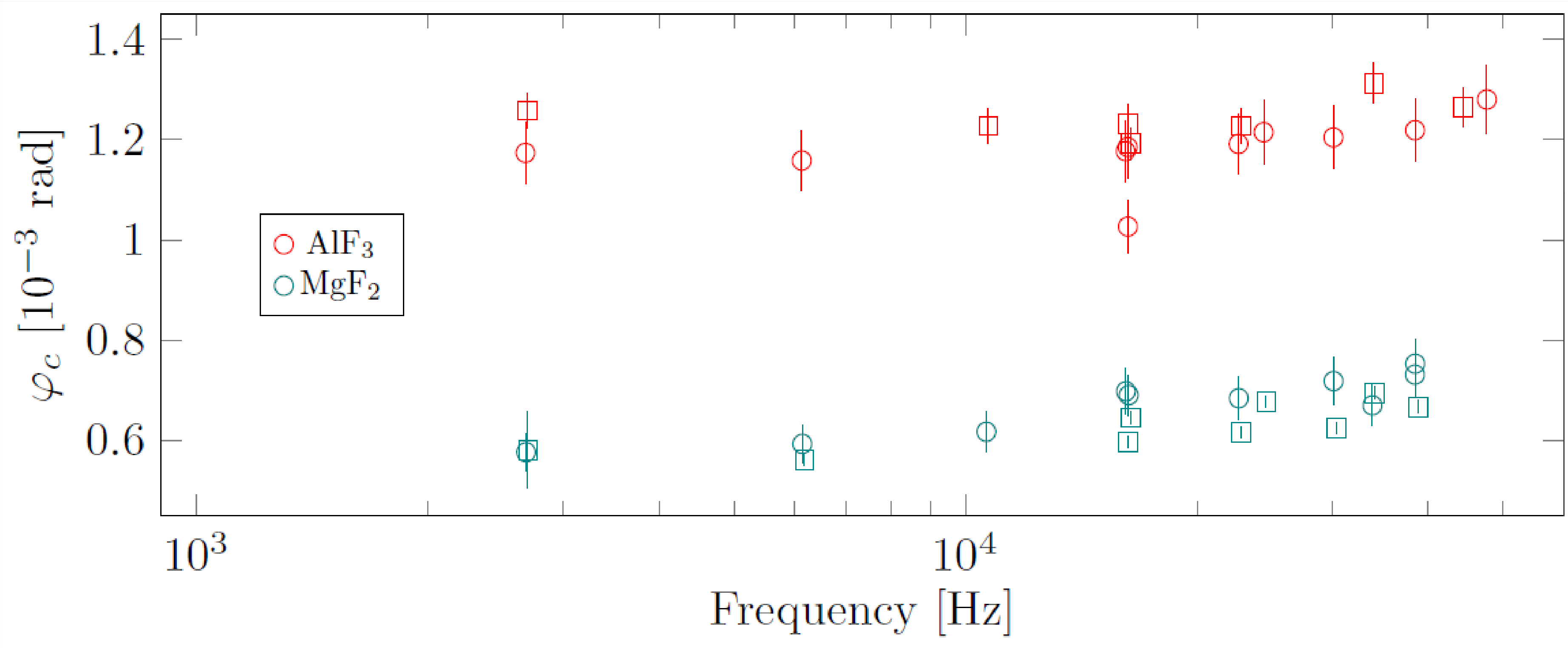
SiNx



✔ x3 lower φ_c than Ta2O5-TiO2 coating → AdV+, ET

- HR stack tested
  - ✘ $\alpha = 2 \times 10^2$ ppm before annealing
  - ✘ $\alpha_s = 12$ ppm before annealing
  - still amorphous @ $T_{ann} = 900$ °C but bubble-like defects
- preliminary results published [doi.org/10.1364/AO.377293]

Fluorides



✔ lower n

✘ high φ_c before annealing

✘ high α before annealing

- preliminary results published [doi.org/10.1364/AO.377293]
- effect of annealing: 2 papers in preparation
- cryogenic characterization starting soon

Summary

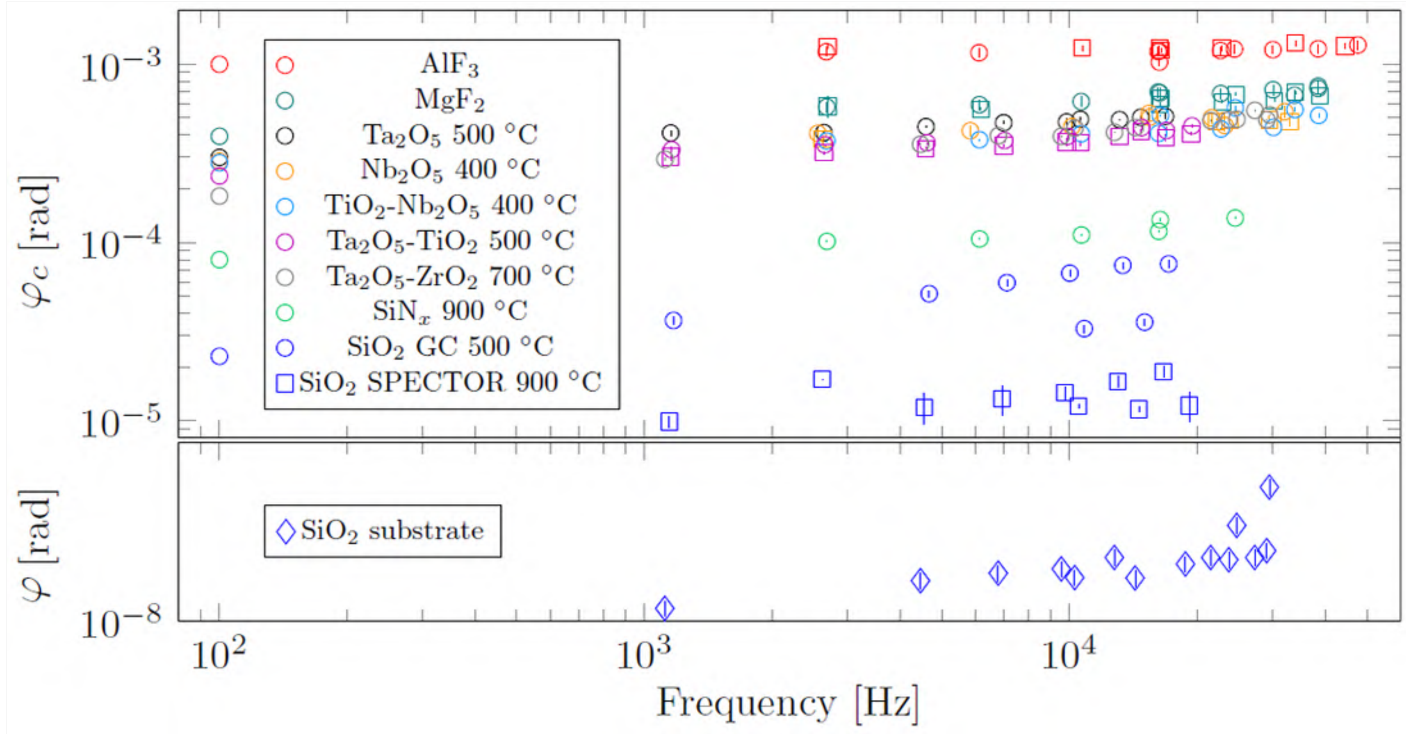
✔ many options tested

✘ none viable yet

- improvements still possible

  → SiNx

  → Ta2O5-ZrO2



doi.org/10.1364/AO.377293

for more details (selected papers):

- substrate models: doi.org/10.1016/j.physleta.2017.05.065
- optical & structural properties: doi.org/10.1103/PhysRevMaterials.2.053607
  doi.org/10.1088/2515-7639/ab206e
  doi.org/10.1116/1.5122661
  doi.org/10.1038/s41598-020-58380-1
- coatings of aLIGO, AdV, KAGRA: doi.org/10.1088/1361-6382/ab77e9
- coating r&d review: doi.org/10.1364/AO.377293

6 new papers in preparation

Action plan – quick overview

- materials

  Ta_2O_5-ZrO_2, HfO_2-Ta_2O_5, aSi, SiN_x, MgF_2, AlF_3

- growth parameters

  rate, substrate heating

- post-deposition treatments

  annealing

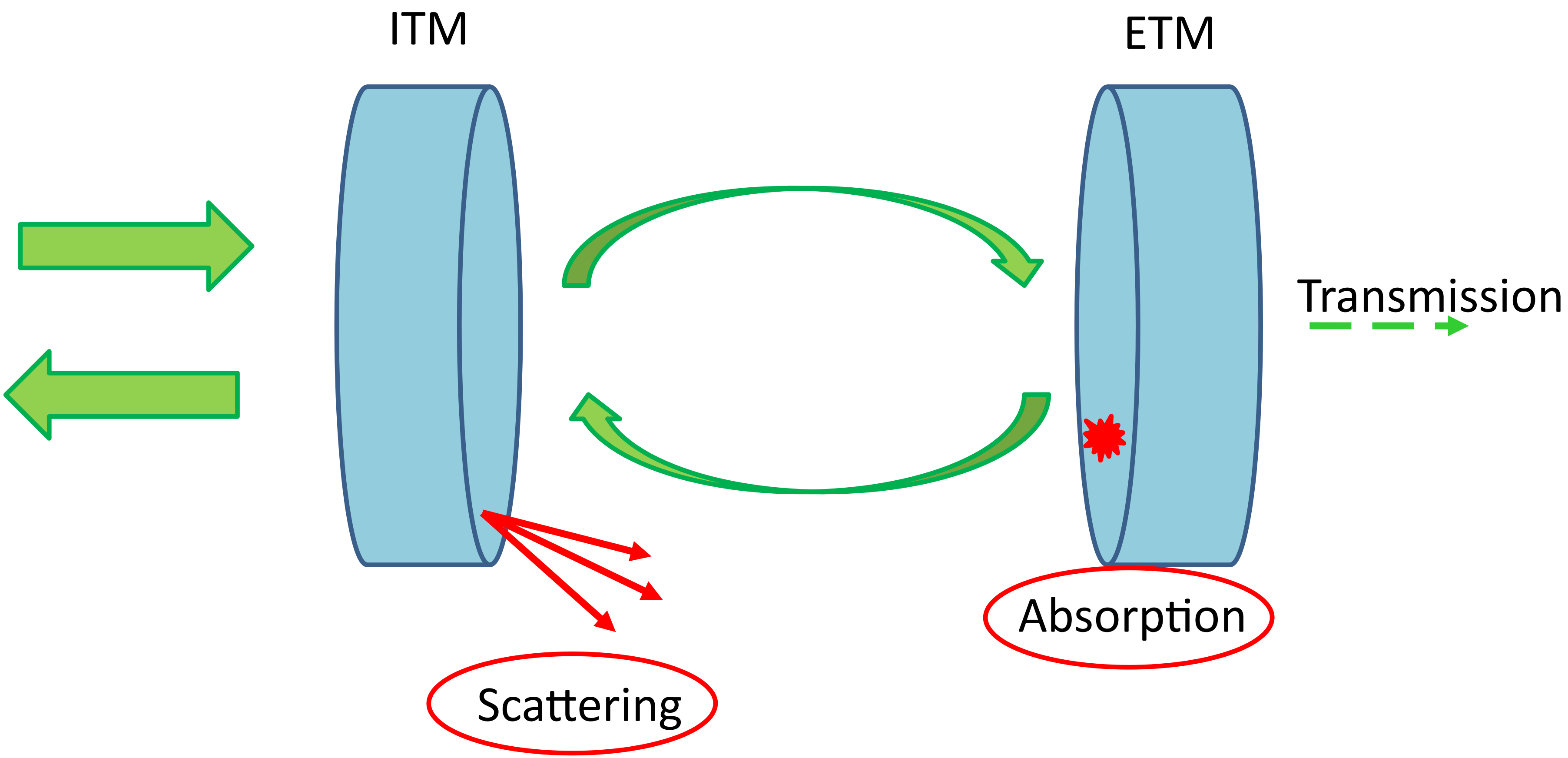
- cryogenic characterization

  SiN_x, MgF_2, AlF_3

II. reduction of optical losses

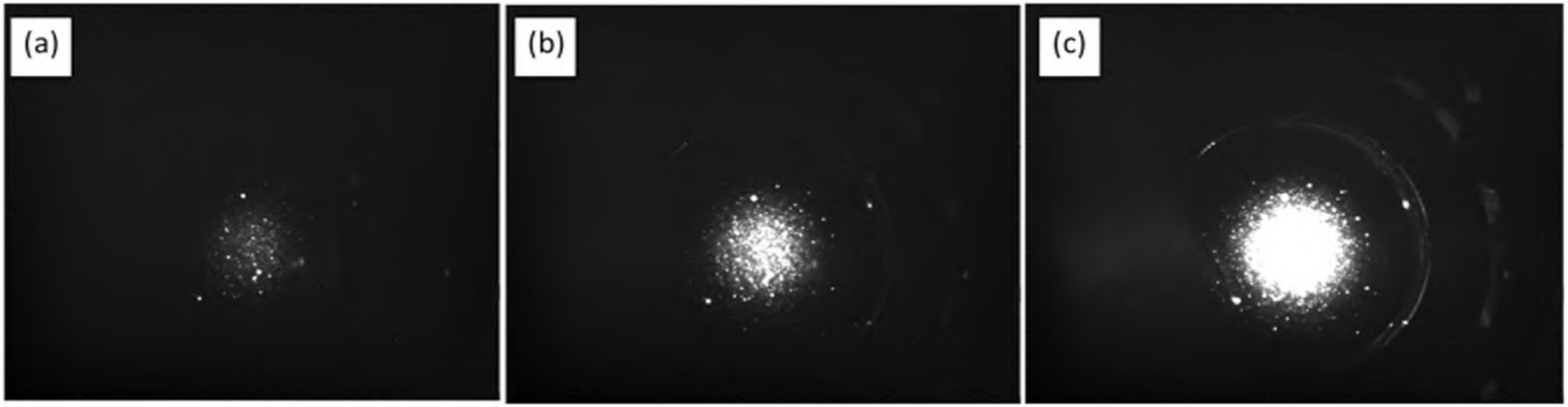
The optical losses

- example of the arm cavities, the most critical place



Optical scattering

- point defects in the coating structure
- responsible for extra scattering loss ?

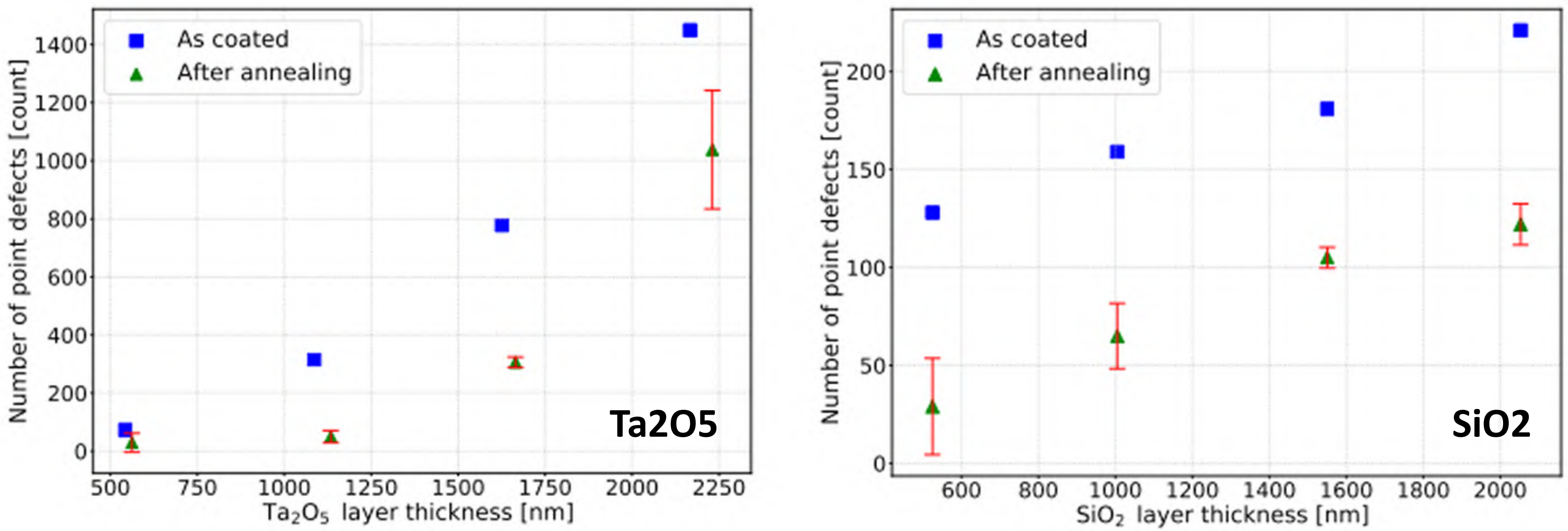


Exemple on the Advanced Virgo mirrors (EM). While increasing the circulating power, we can notice more and more point defect

- A PhD thesis has started since 2019:
  - new detection procedure at LMA
  - investigation on the origin of the defect
  - mitigation strategy

Optical scattering

- study carried on monolayers of Ta_2O_5 and SiO_2



S. Sayah et al.,submitted to Applied Optics (2020) [arXiv:1911.02638]

- more defects in Ta_2O_5 compared to SiO_2
- different defect sizes in the 2 materials
- post deposition annealing cure the defects (also observed by LIGO G2000374-v2).

Absorbing point

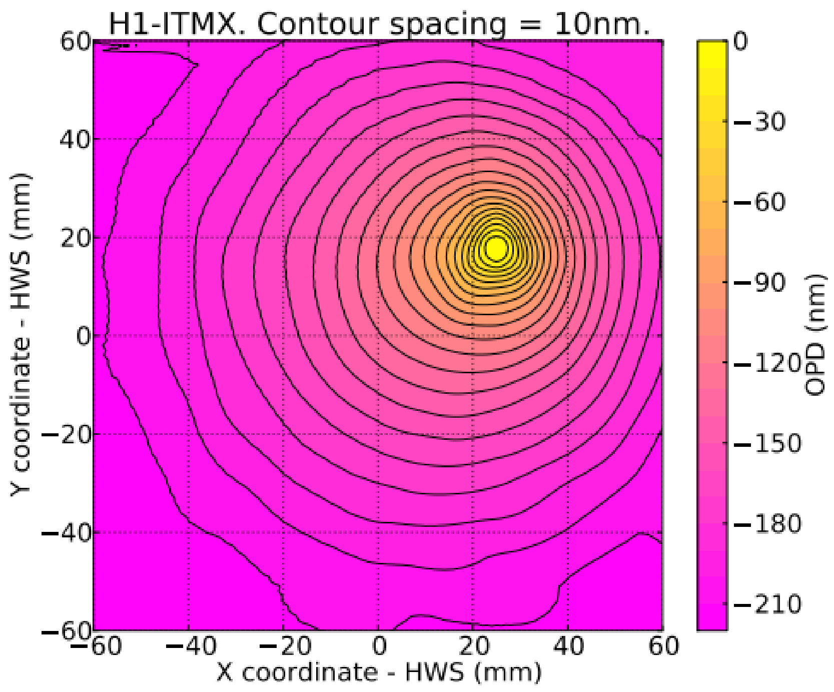


FIG. 2. Hartmann sensor measurement of optical path distortion (thermo-refractive plus thermo-elastic) from a single point absorber on H1-ITMX. Cold reference taken at GPS time: 1 180 229 513 s, hot measurement taken 3322 s later at GPS time: 1 180 232 835 s. This measurement corresponds to approximately 29 mW power absorbed in the point.

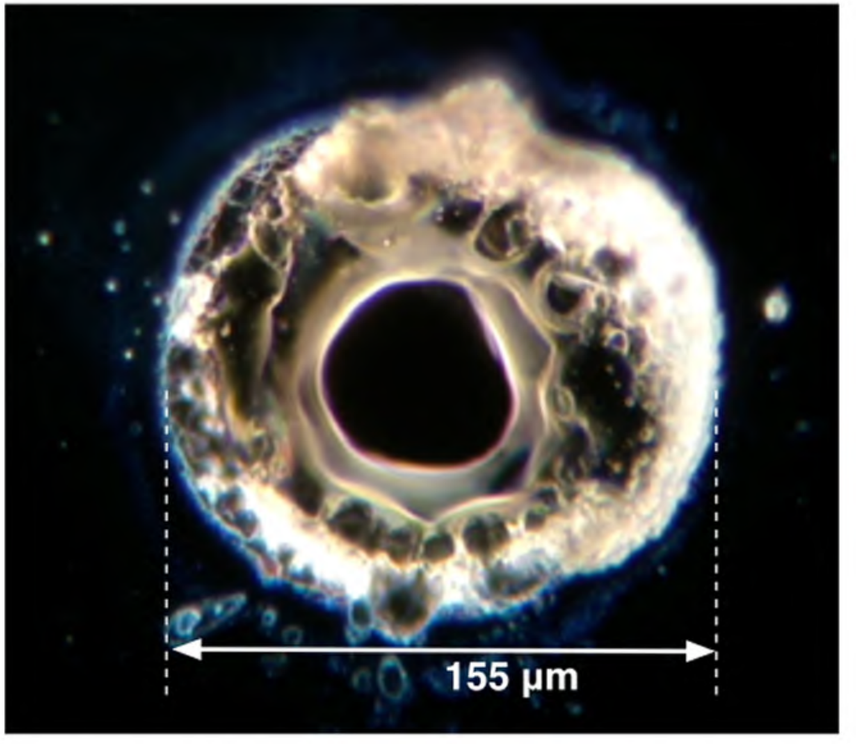


FIG. 3. Dark field microscope image of point absorber measured on an Advanced LIGO optic (corresponding to the thermal lens measurement shown in Figure 2). Also shown in Buikema et. al. [1].

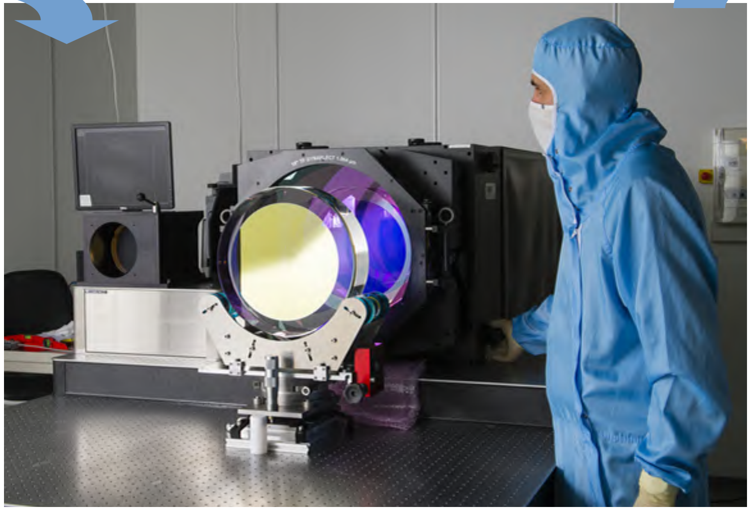
Brooks et al. P1900287-v2

- ~50% of the tests masses have point absorbers (G1901108-v4)
- likely aluminium contamination
- research in collaboration with LIGO

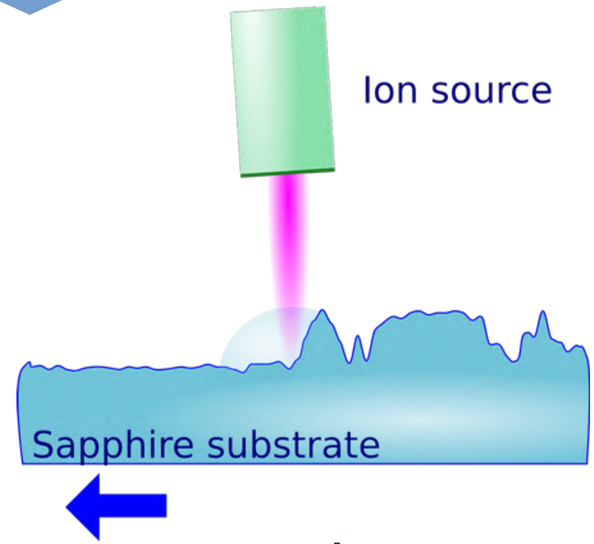
Ion Beam Figuring (IBF) demonstration

- with Polygon Physics, provider of ion beam sources
- IBF demonstration on sapphire (∅100 mm)
- can process other materials later
- Principle:

Substrate



Surface measurement

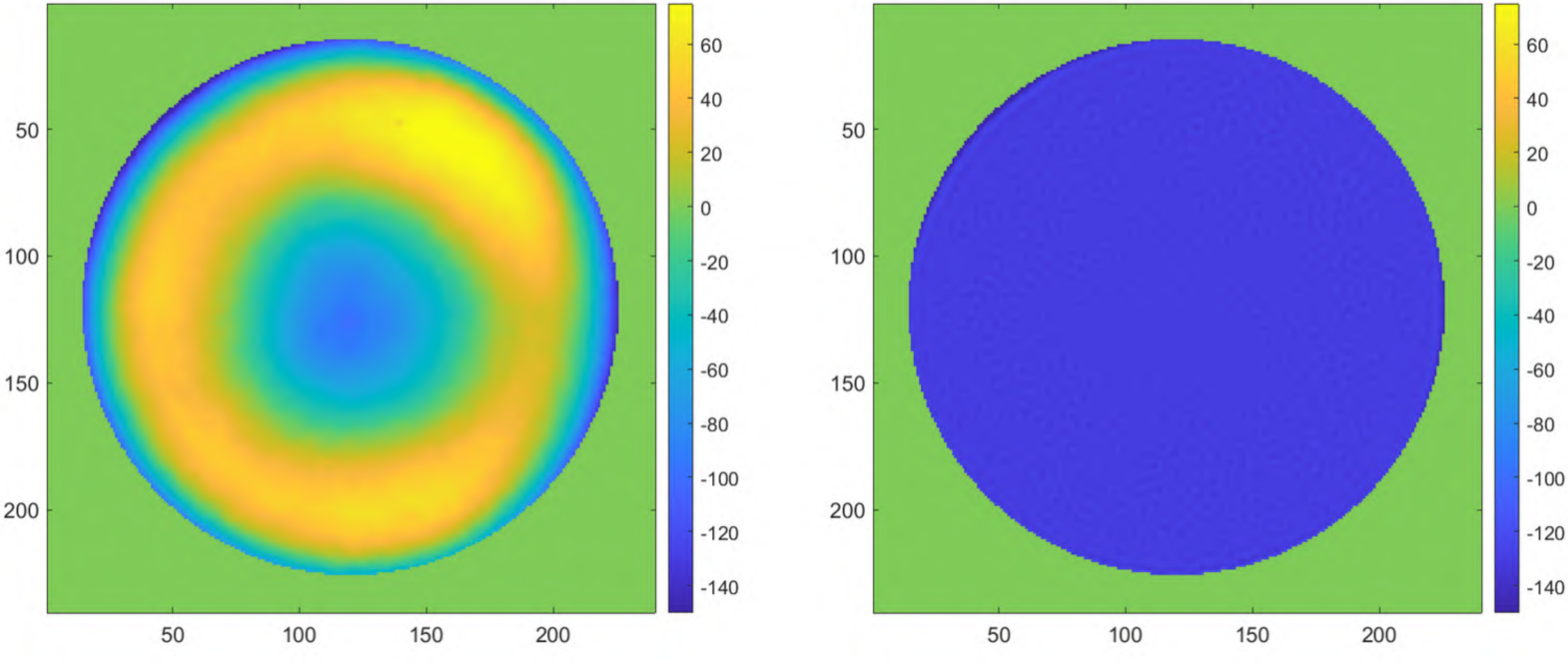


Remove bumps

Ion Beam Figuring (IBF) demonstration

- dedicated algorithm already done
- correction done in the central diameter of 80 mm

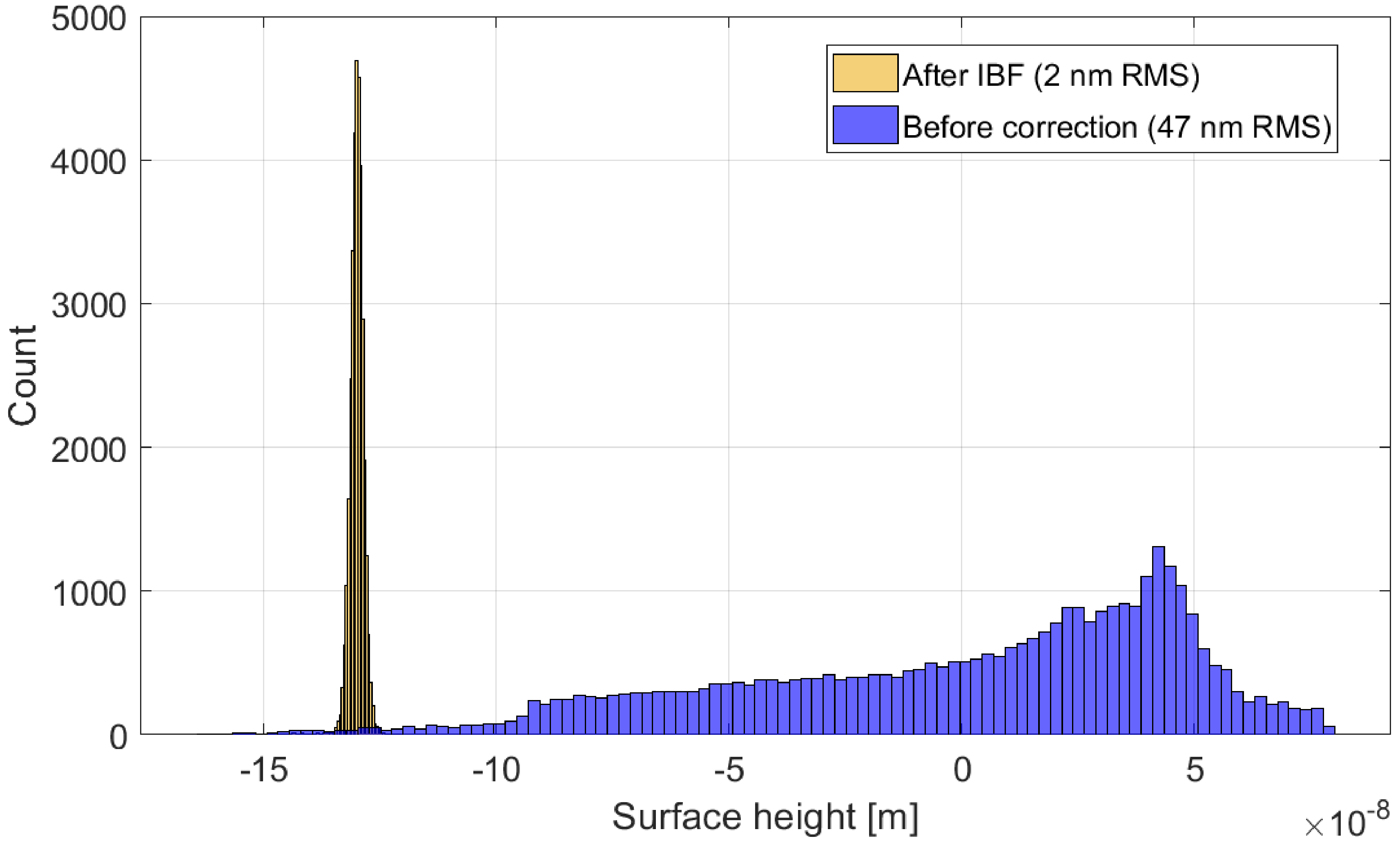
Vertical scale in nm



Before *After*

Ion Beam Figuring (IBF) demonstration

- dedicated algorithm already done
- correction done in the central diameter of 80 mm

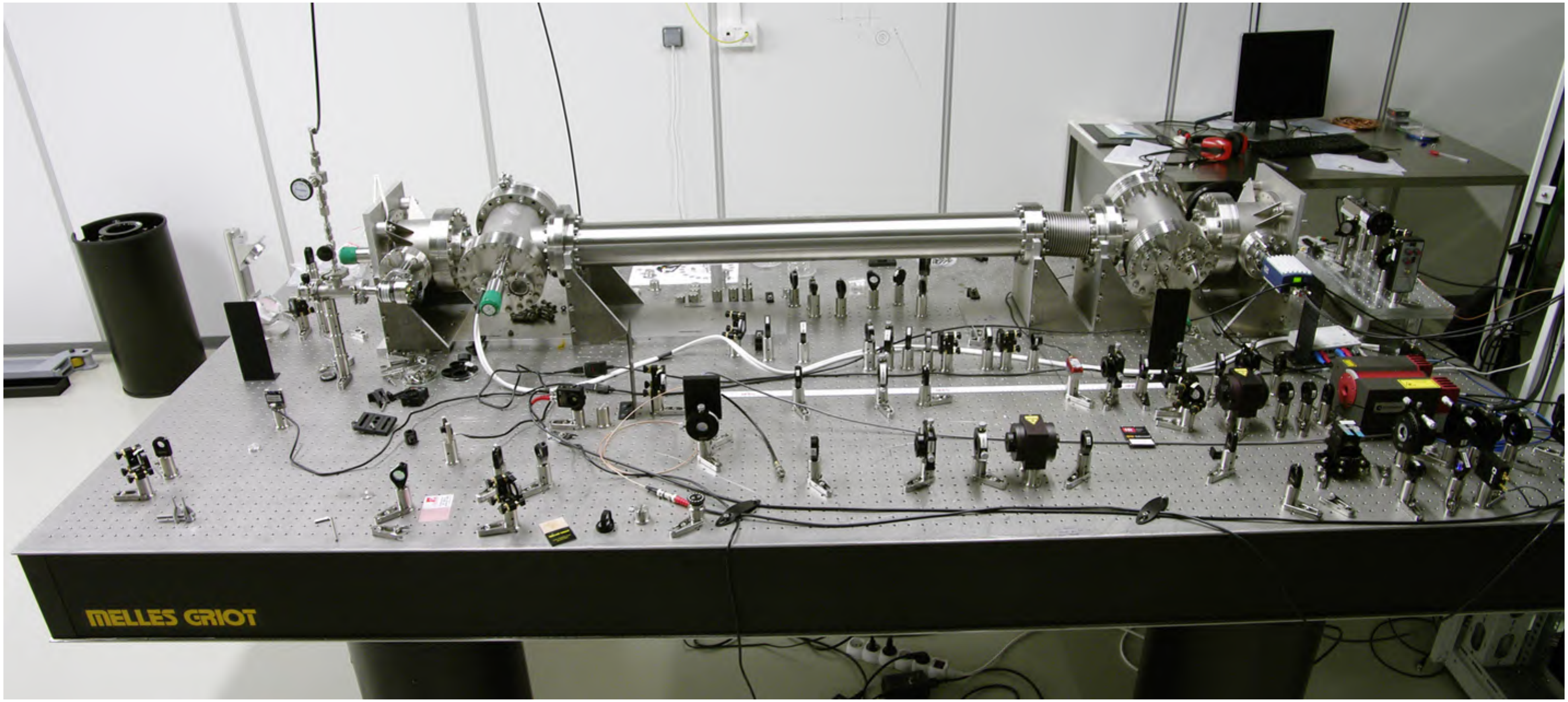


Ion Beam Figuring (IBF) demonstration

- refurbished one old coating chamber
- waiting for the ion source, first result mid 2021

Total optical loss measurement

- high finesse 1.6 m long Fabry-Perot cavity
- finesse measurement by ring-down
- measurement of scattering and absorption losses at the same time



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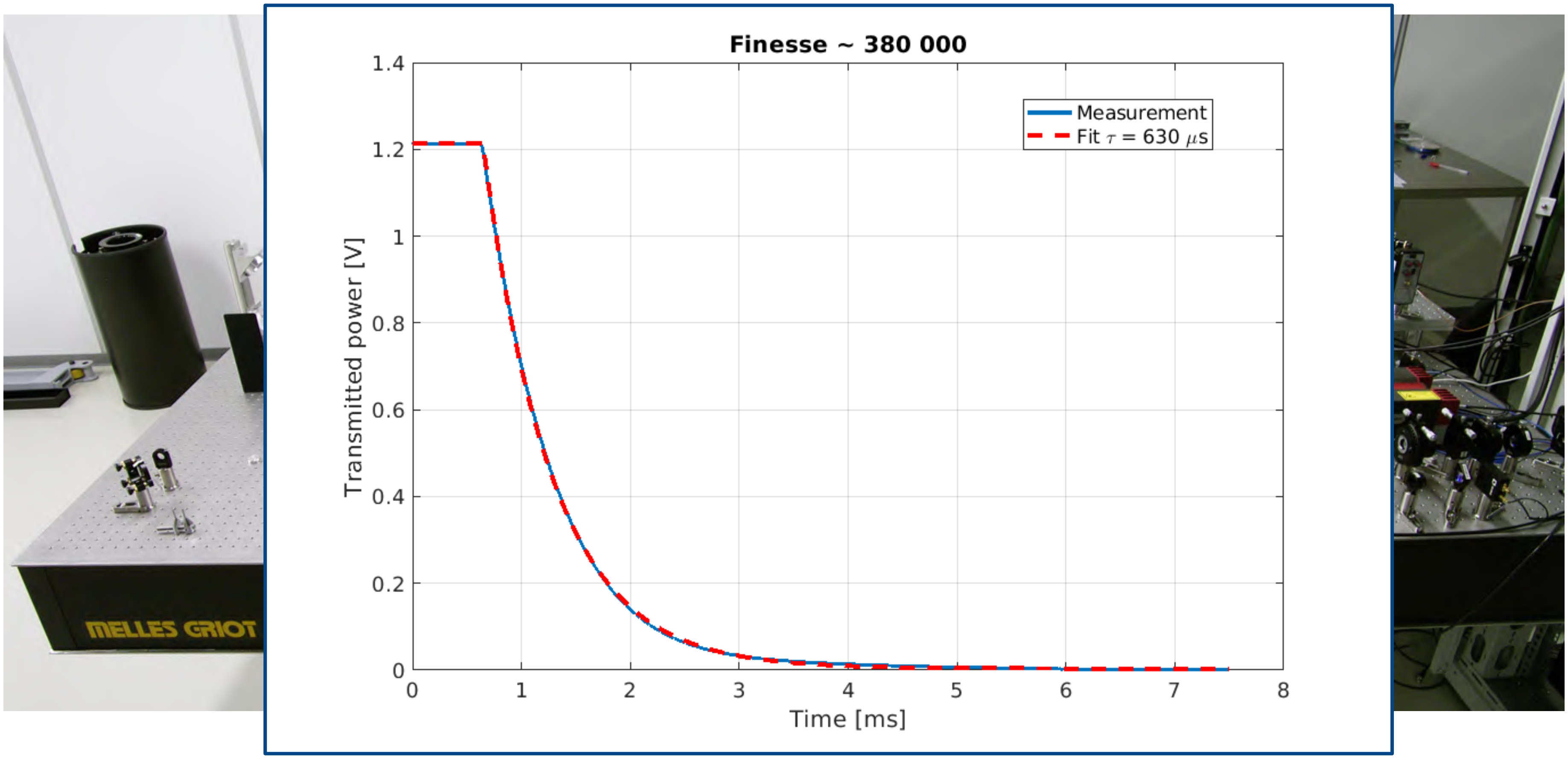
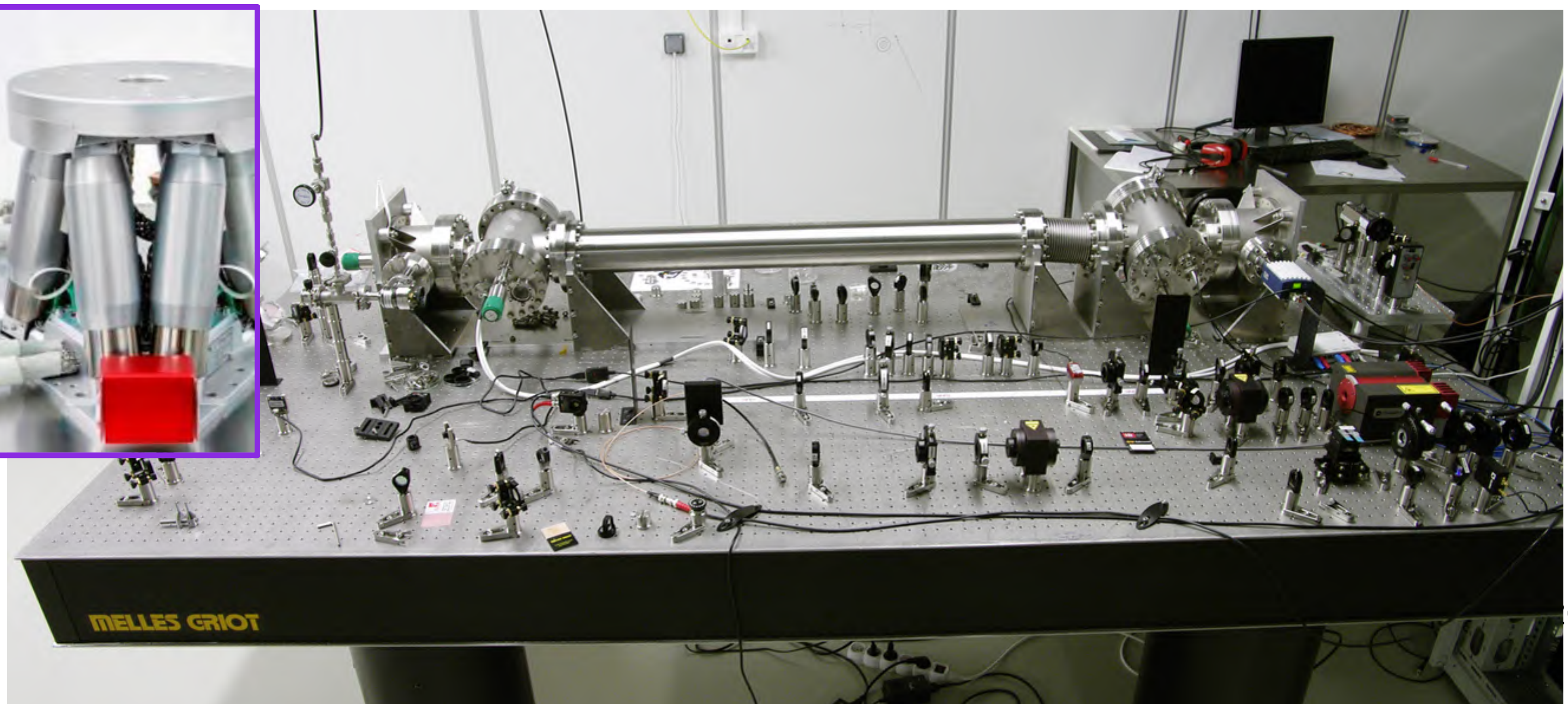


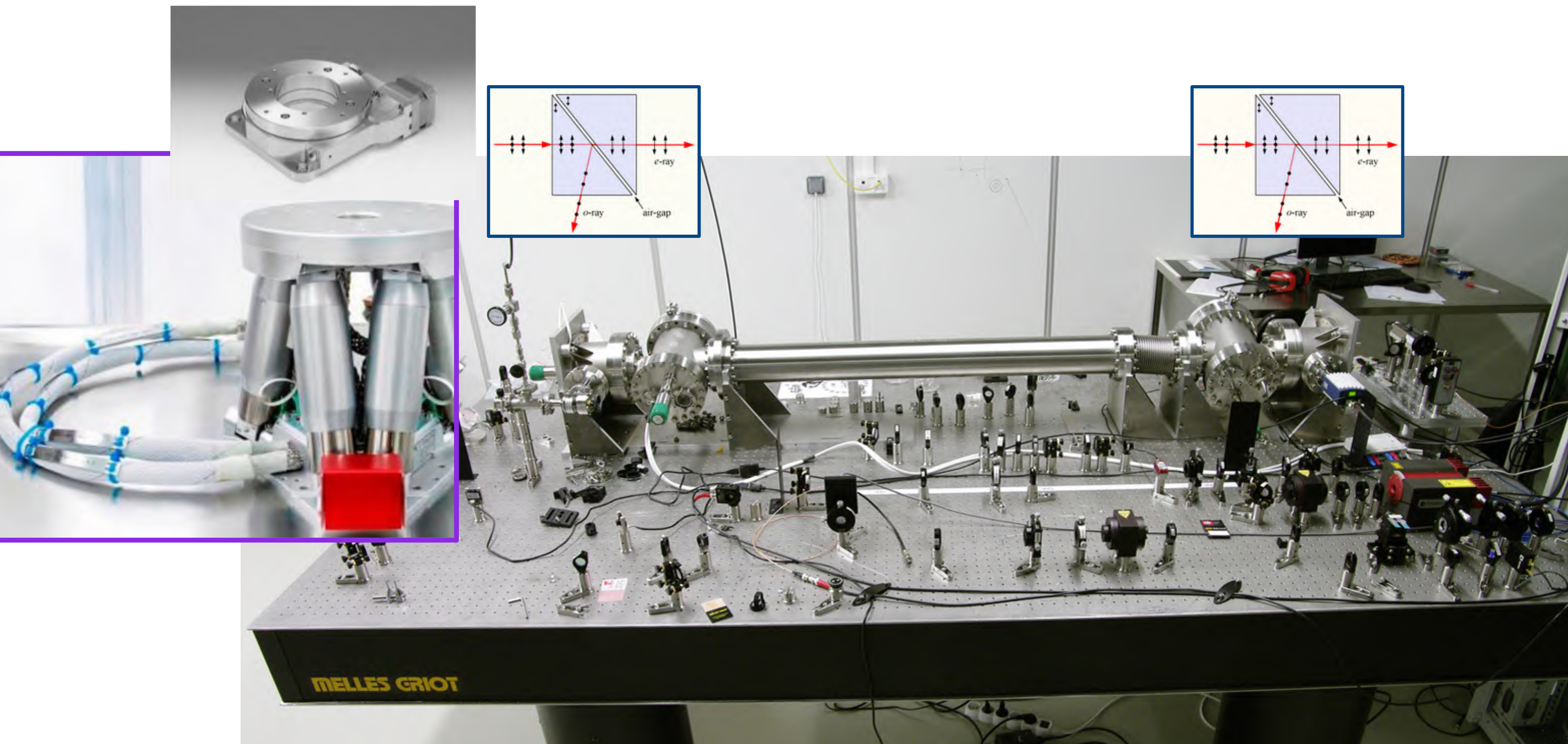
Total optical loss measurement (part of OSAG)

- large upgrade of this experiment
- mirrors mounted on hexapodes for transverse scan of the mirror
- fine tuning of cavity length
- scattering loss correlated by surface and scattering measurement
- test on sapphire mirrors



Total optical loss measurement (with iLM)

- in one year add polariser and analyser before/after the cavity
- mirrors mounted on rotational mount
- birefringence measurement of small substrates and mirrors



Conclusion

- Intensive coating R&D at LMA and within Virgo collaboration
- short term goal: room temperature ‘+’ upgrade of LIGO/Virgo
- soon, explore the cryogenic performances of new materials
- Complementary development on sapphire substrates at iLM and LMA