APPEC Technology Forum 2017

3-4 May 2017 *Hanover*

Amorphous coatings for 3rd generation Gravitational Waves detectors

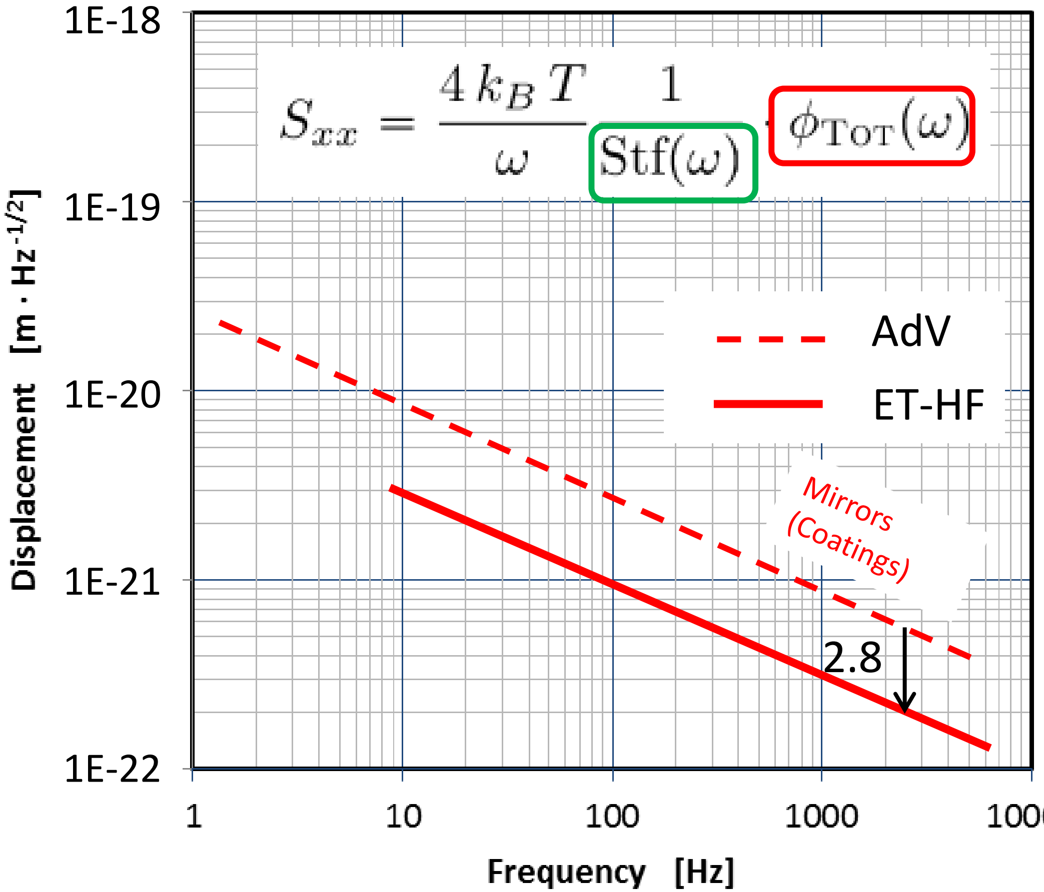
G. Cagnoli

for the

Laboratoire des Matériaux Avancés

LMA LABORATOIRE MATÉRIAUX AVANCÉS

ET-HF coating noise budget



Coating thermal noise is dominant around 100 Hz where the detectors are more sensitive

Coating ThNs reduction comes from:

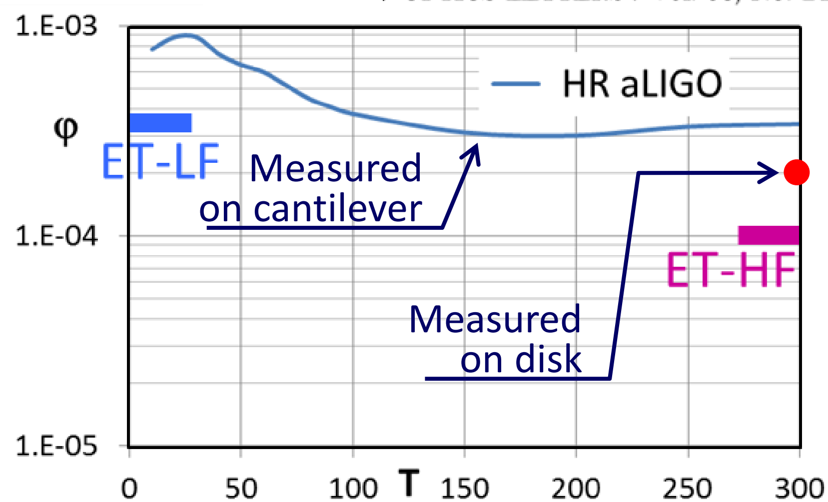
Beam Size

Loss angle

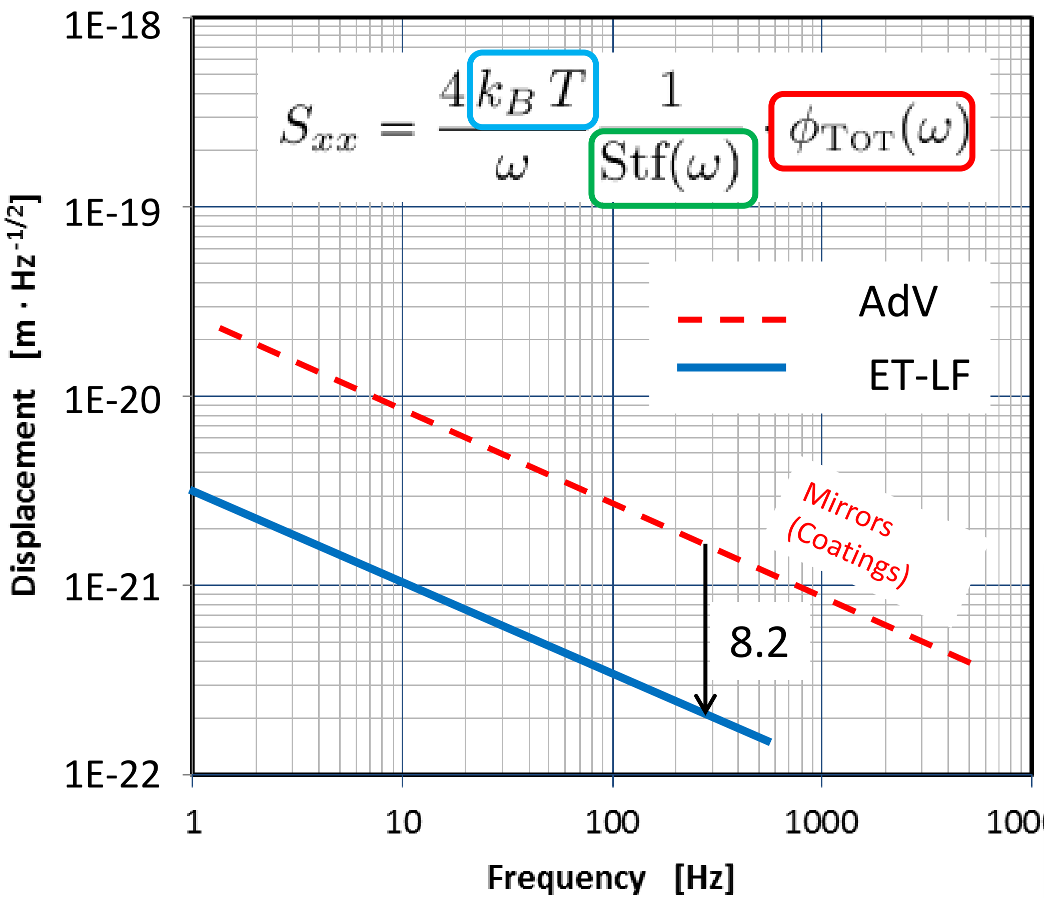
ET-HF **N**oise **R**eduction **F**actor:

NRF = 2.8 = 1.7 · $\sqrt{2.7}$

Granata & al, OPTICS LETTERS / Vol. 38, No. 24



ET-LF coating noise budget



Coating thermal noise is dominant around 100 Hz where the detectors are more sensitive

Coating ThNs reduction comes from:

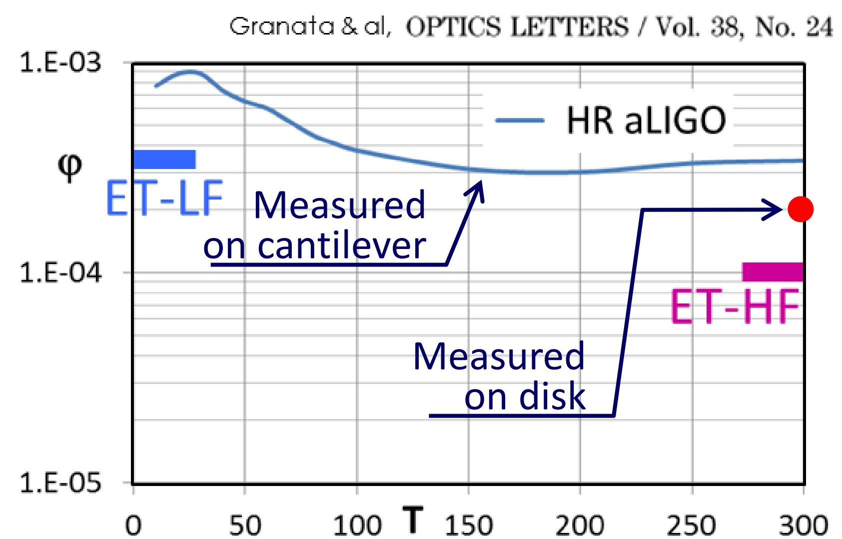
Temperature

Beam Size

Loss angle

ET-LF **N**oise **R**eduction **F**actor:

NRF = 8.2 = $\sqrt{30}$ · 1.7 · $\sqrt{0.8}$

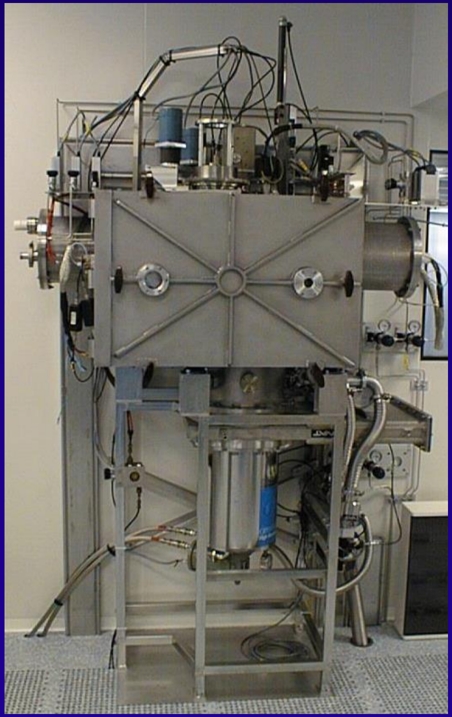


LMA
http://lma.in2p3.fr/

- 20 people
- Optical coatings
  - ♦ Design
  - ♦ Realisation
  - ♦ Metrology

- Scientific axes
  - ♦ Gravitational Waves
  - ♦ Astronomical Instrumentation
  - ♦ Fundamental Physics

ion-beam sputtering facilities



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

metrology – optics

- scattering
- surface defects
- wavefront
- absorption [ambient/cryogenic]

photos: C. Fresillon – photothèque CNRS

metrology – mechanics

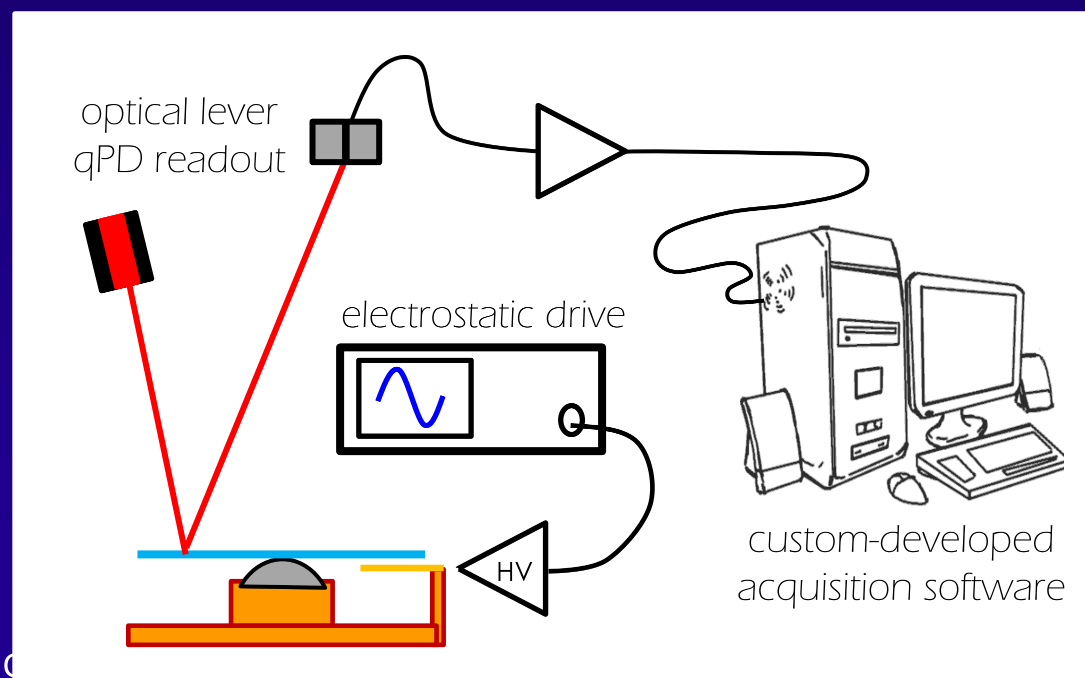
Gentle Nodal Suspension (GeNS)

- clamp-free
- high repeatability

Cesarini & al, Rev. Sci. Instrum. 80 (2009)
Cesarini & al, Class. Quantum Grav. 27 (2010)

non-destructive analysis:

- dilution factor
- mechanical loss
- Young's modulus
- Poisson's ratio



Not just thermal noise

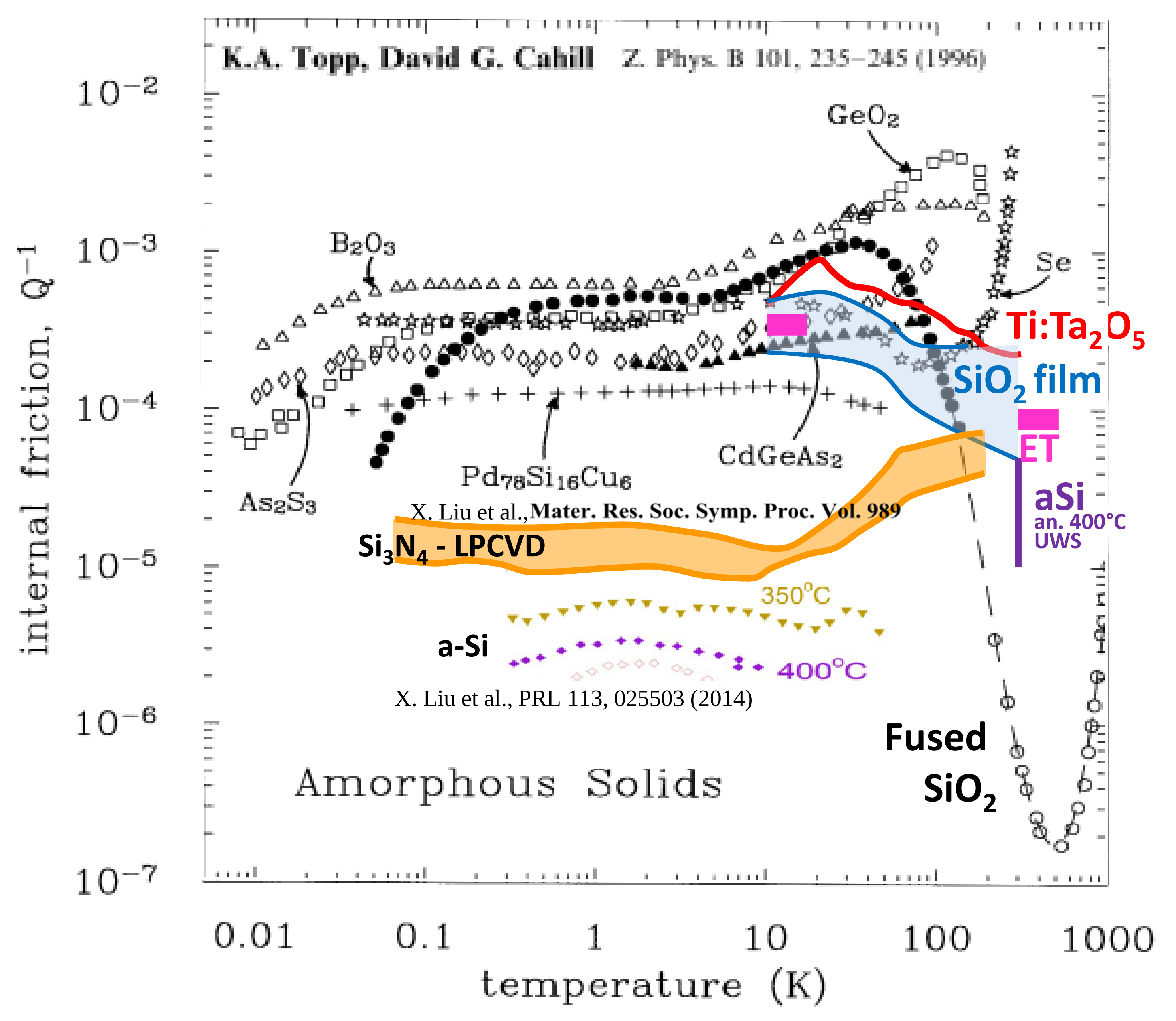
- Cavity round trip losses
  - 80ppm in Advanced Detectors
- Scattering
  - Low frequency noise in GWD
- Transmission
  - Highly symmetrical cavities
  - Perfect 50% beam splitters
  - Low reflectivity AR coatings
  - Dichroic mirrors for non-linear optics
  - Controlled phase relation

Critical parameters

L. Pinard et al., Applied Optics 56 (4) 2017 C11

- State of the art
  - ♦ Thickness uniformity = 0.05% on 20 cm
  - ♦ Absorption = 0.27 ± 0.07 ppm
  - ♦ Scattering (Ø160 mm) = 4.9 ± 1.5 ppm
  - ♦ Mechanical losses ETM = (2.2 ± 0.2) 10^{-4}
  - ♦ Precision of optical response (ITM) = 0.014%
  - ♦ AR reflectivity < 50 ppm
  - ♦ Roughness (Ø160 mm) = 0.36 nm RMS (ETM)

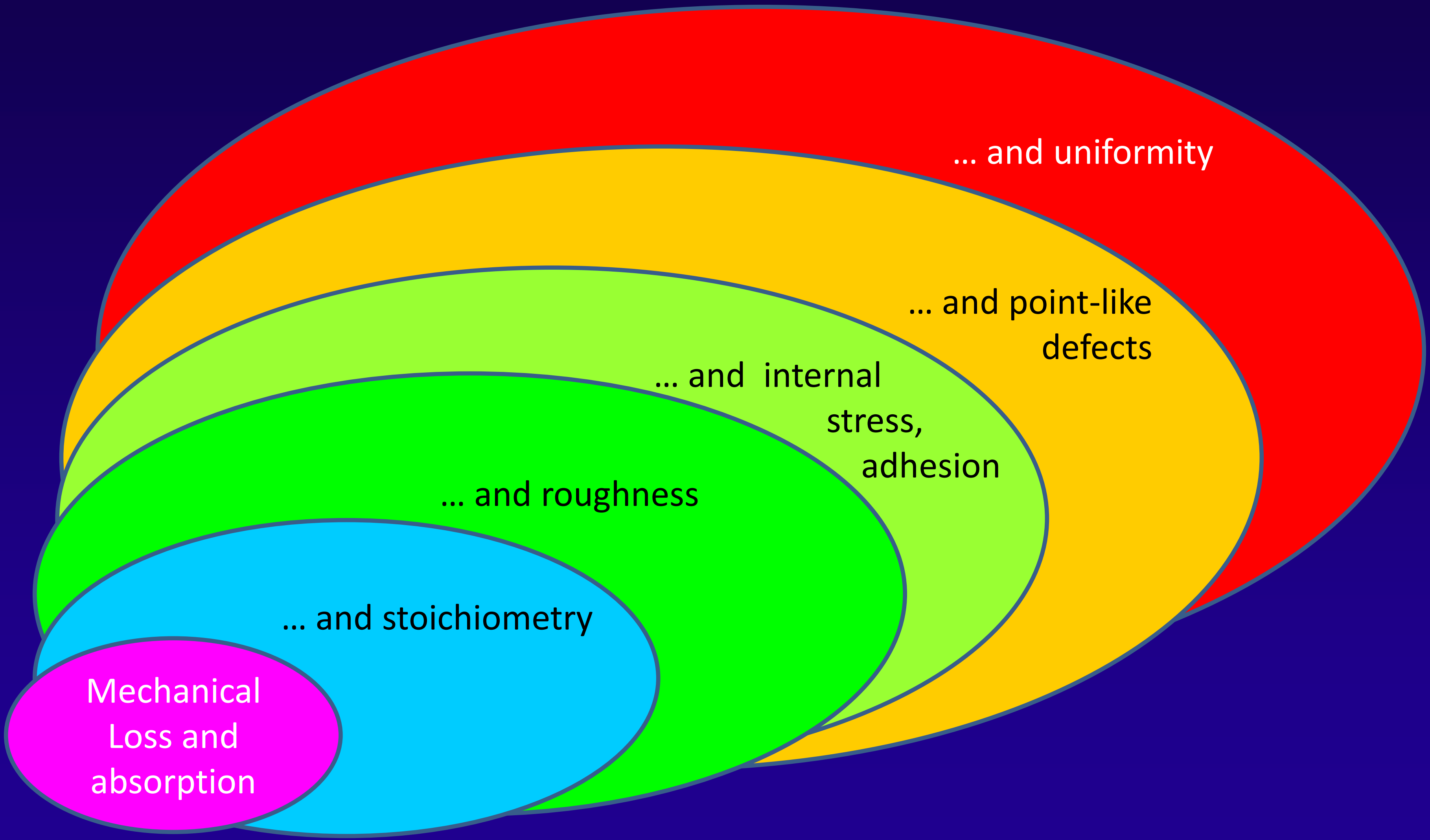
Mechanical losses of amorphous materials



Key factors for the IBS technology

- Chemical composition of the target
- Ion gun parameters
  - Sputtering
  - Assistance
- Deposition gases
- Substrate temperature
- Deposition rate
- Annealing temperature
- Annealing atmosphere

Coating development: from the material to the mirror



Coating development: technological challenges

- Deposition
  - ♦ 600 mm diameter optics (+ BS)
  - ♦ 300 kg optics
  - ♦ Cleaning
  - ♦ High temperature
  - ♦ Stoichiometry control
  - ♦ Thickness control
  - ♦ Uniformity
  - ♦ Point defect reduction
  - ♦ Control of stress
- Metrology
  - ♦ Wavefront distortion
  - ♦ Thickness uniformity
  - ♦ Absorption
  - ♦ Total scattering
  - ♦ Point defect analysis
  - ♦ Spectrophotometry on large optics
  - ♦ Elastic constants
  - ♦ Mechanical loss angle
  - ♦ Stress

The coating research at LMA

- Materials

Pragmatic

- ♦ Selection and Optimization
- ♦ Advanced detectors upgrade
- ♦ 3rd generation

Fundamental Physics

- ♦ Relaxations in amorphous materials

Collaborations

- ♦ ReGGAE: local, origin of relaxations
- ♦ AdV+: Virgo+Jena U+PTB
- ♦ GAST: FR, D, UK, IT, crystalline coatings on sapphire

- Coaters and metrology

Ongoing

- ♦ Uniformity
- ♦ In-situ optical metrology for real time thickness control
- ♦ Spectrophotometric bench for large optics
- ♦ Thermal noise direct measurements

Planned

- ♦ High T deposition
- ♦ Point like defects

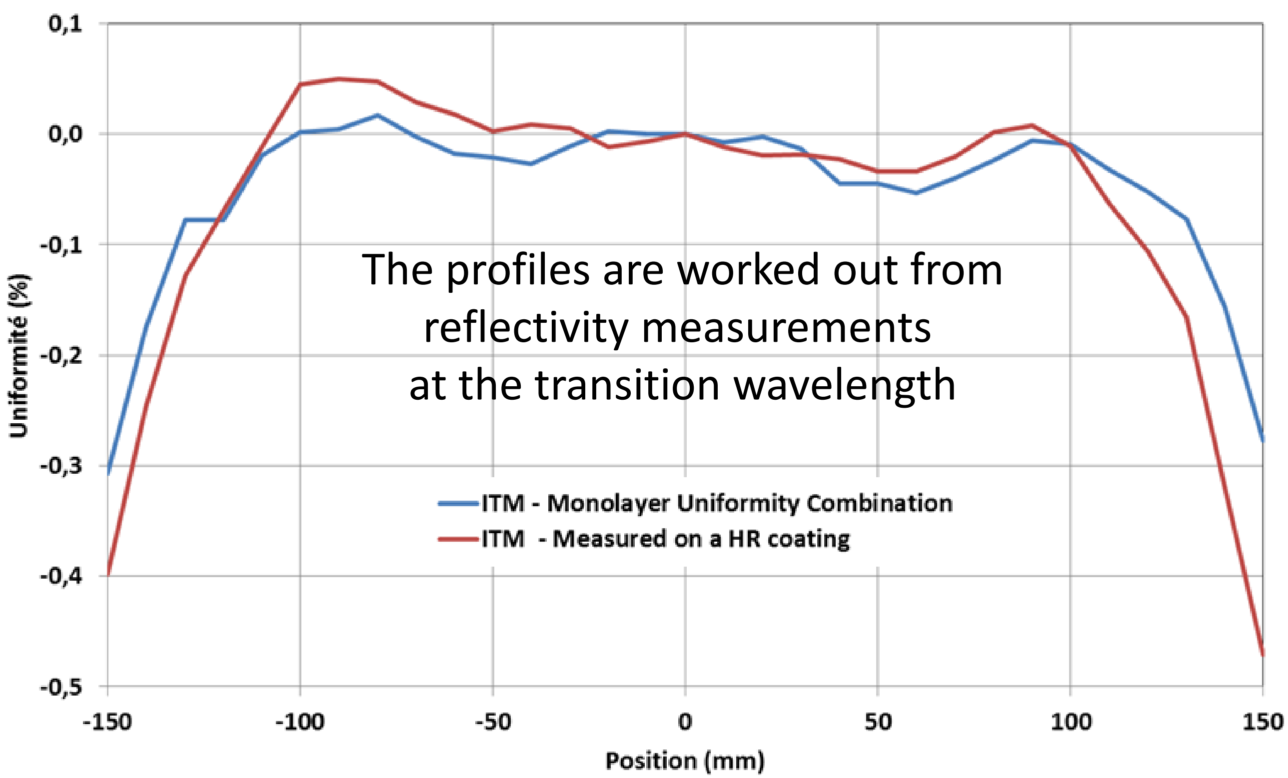
Some results on Material research

- Full acoustical spectroscopy measurements (GeNS)
- Correlation between mechanical losses and Raman spectra in silica (ReGGAE-ILM)
- Full characterization of standard materials
- New evaluation of the mixing ratio effect on losses in TiO2/Ta2O5

Latest results on wavefront control

1) The superposition of monolayers profiles gives the profile of the multilayer

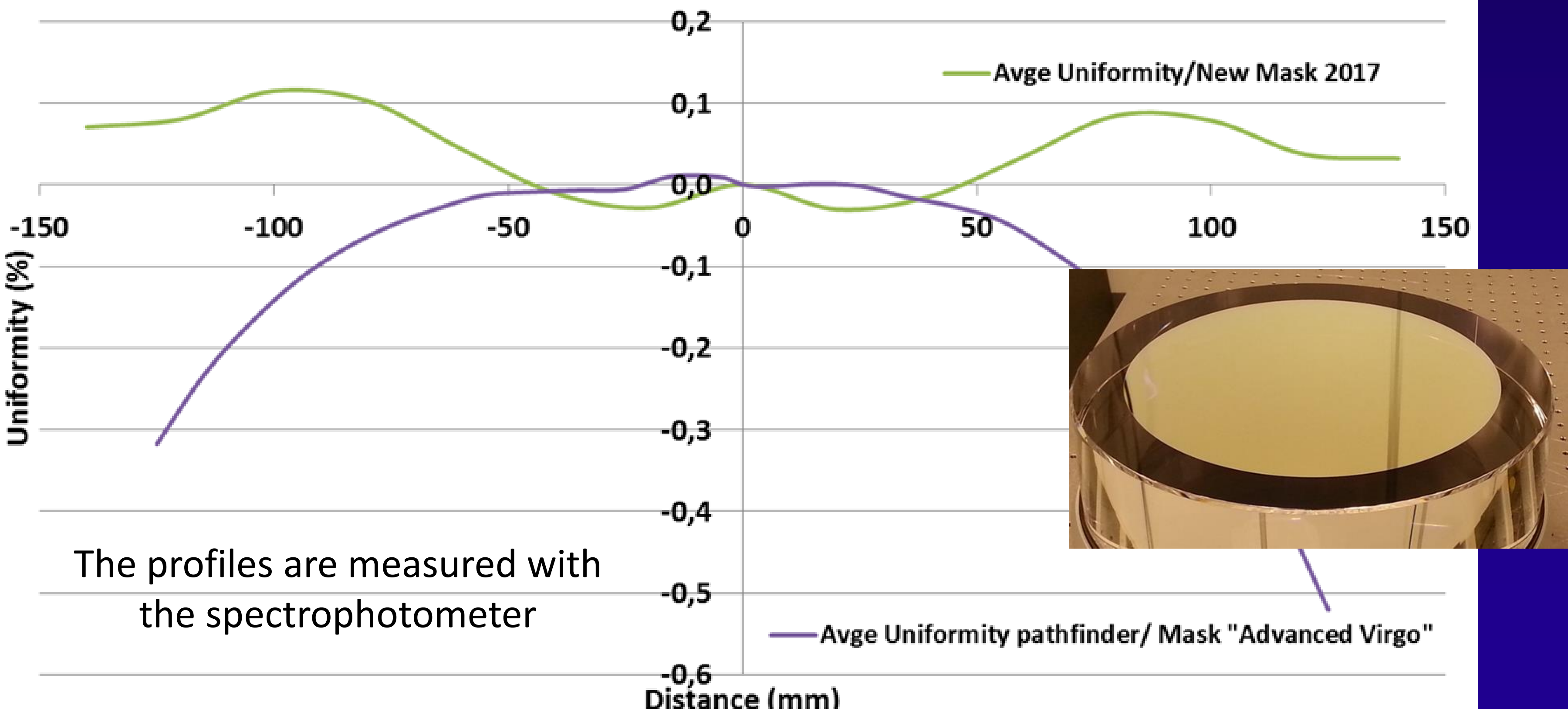
Comparison of the ITM Uniformity profiles between the one measured on the Multilayer coating and the one calculated with the H and L monolayer experimental uniformity profiles



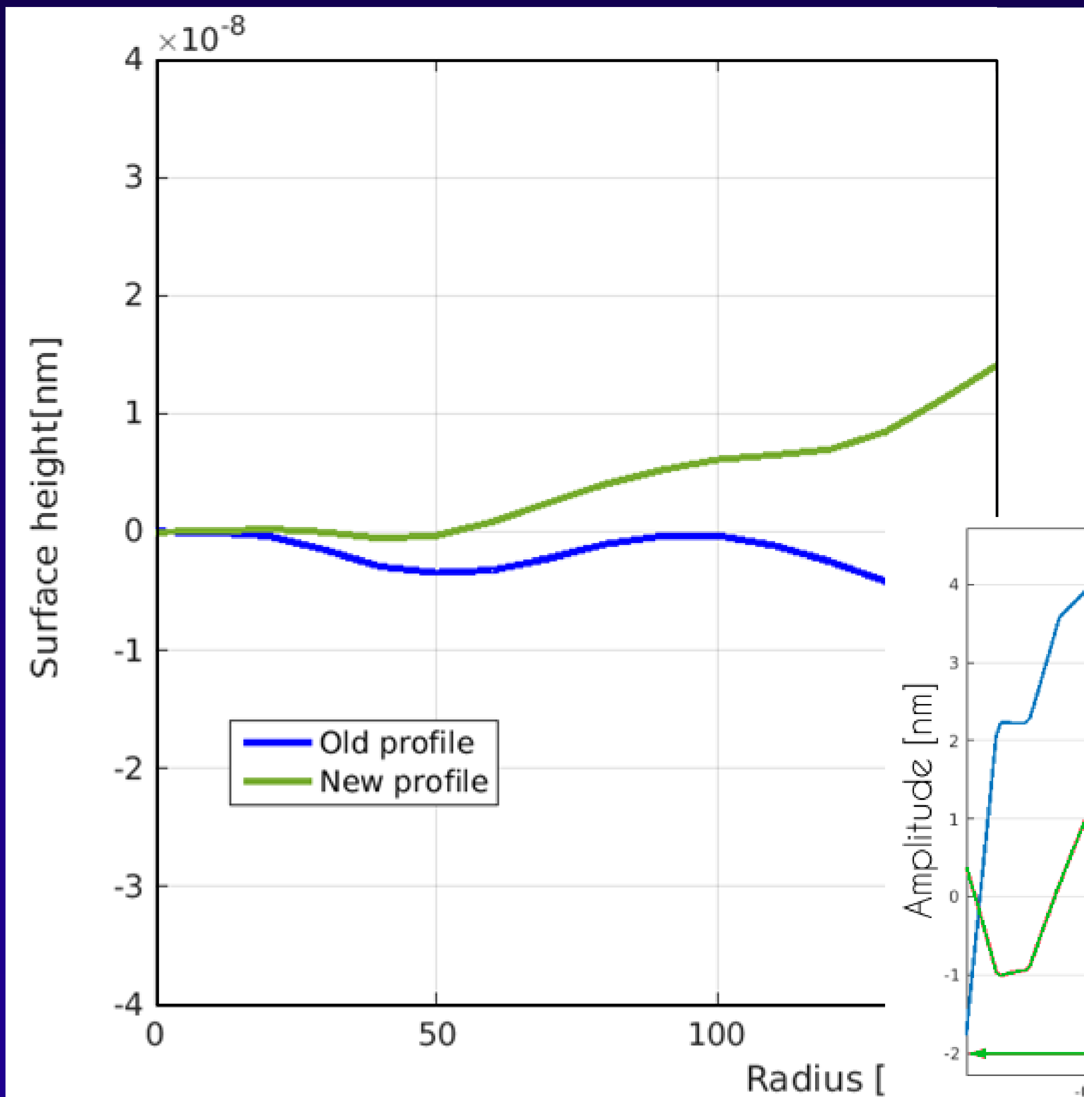
Latest results on wavefront control

2) The uniformity has been improved at large diameters (planetary motion)

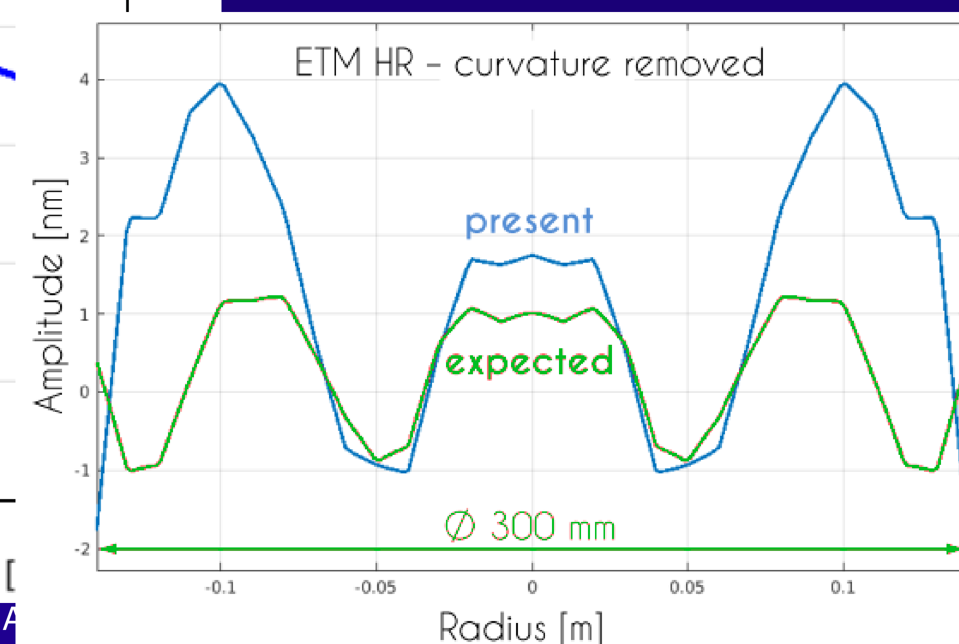
Broad band HR coating (520-870 nm) for a Fabry-Perot Etalon 3.5µm total thickness.
Thickness ratio between High and Low index layer similar to the Advanced Virgo IM
Goal : no curvature generated by the coating uniformity



Prediction on a HR coating



- New profile, uniformity measured on monolayers
- Exemple for an ETM style (T = 4 ppm) profile



Conclusions

- Technological aspects of coating development are important as much as the material research
- Availability of coaters and people is essential
- Attention: metrology could be a limit
- An extended research plan has been put in place by LMA and its collaborators for amorphous materials
- Amorphous materials could fulfill the specifications for the 3rd generation of GW detectors