



# High quality mirror coatings

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LMA Director

<http://lma.in2p3.fr/Lmagb.htm>

## LMA

- ◆ Research Platform of IP2I/Lyon - CNRS/IN2P3
- ◆ Located on the campus of University Claude Bernard Lyon 1
- ◆ Infrastructure realized for the needs of Virgo
- ◆ Coating activity since #1970

## Expertise

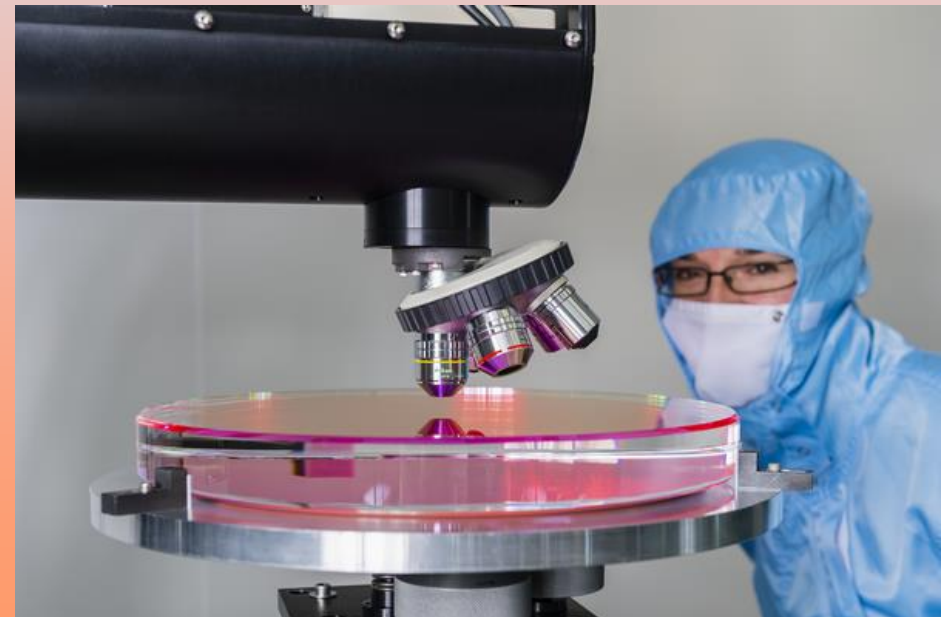
- ◆ Coatings (low losses)
- ◆ Coatings on large optics
- ◆ Materials
- ◆ Optical/Mechanical metrology

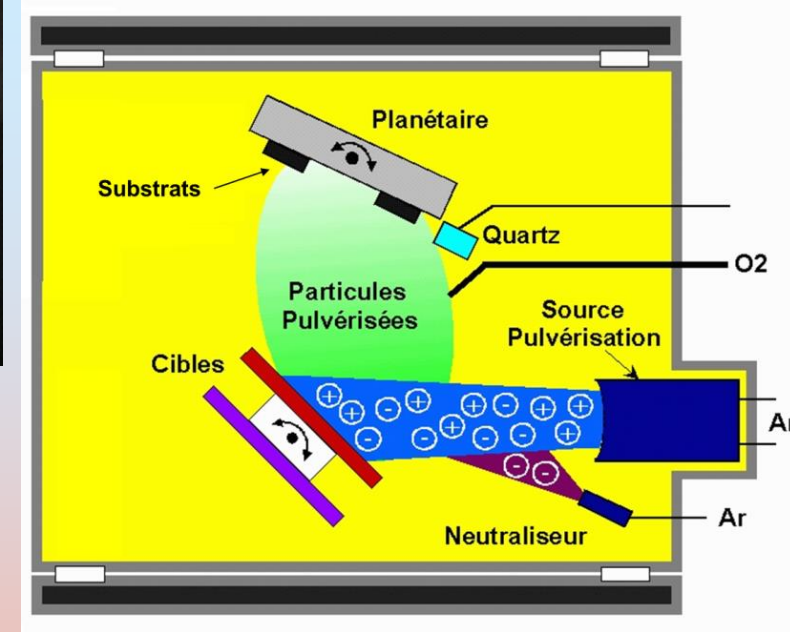
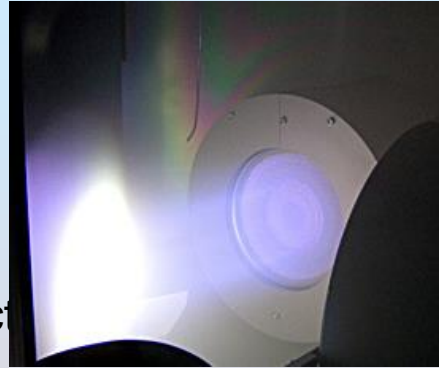
## Mission

- ◆ Produce research and services in the field of coatings and optics for:
  - scientific applications
  - large research infrastructures
  - industry

## Manpower

- ◆ 13 people: 1 Researcher, 8 Engineers, 2 Technicians, 2 PhD, 1 CDD IR





- Clean rooms
  - 500 m<sup>2</sup> clean rooms
  - 100 m<sup>2</sup> in class ISO3
- Large IBS coating chamber
  - developed for the Virgo project
  - 2,4x2,4x2,2 m<sup>3</sup>
  - probably the largest IBS coating chamber in the world
  - possible to coat 1 m diameter optics



✓ For Advanced Virgo :

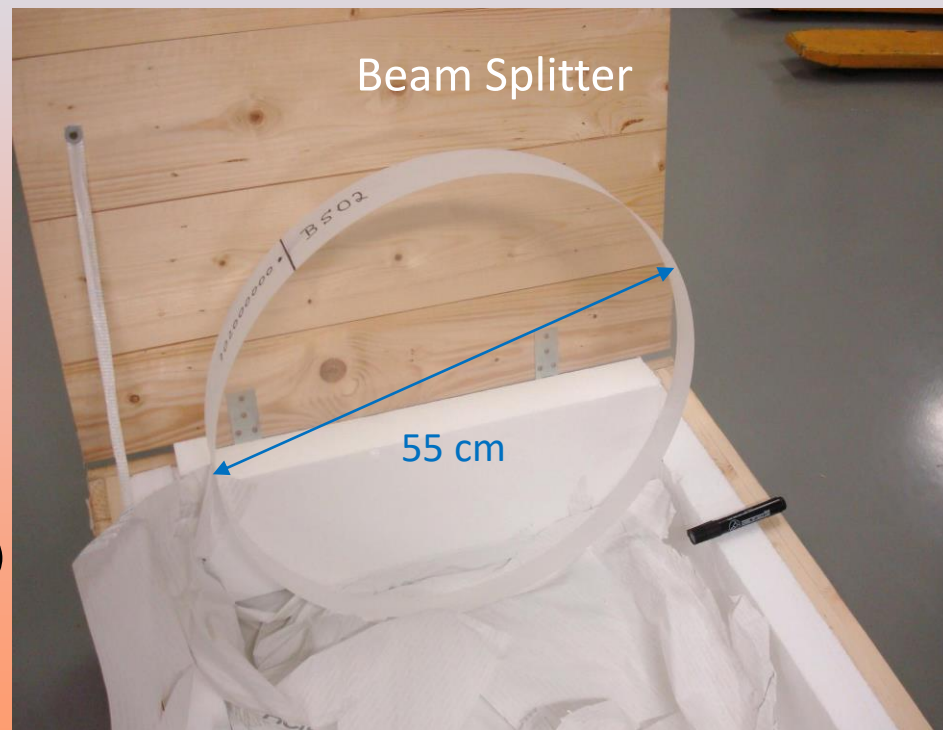
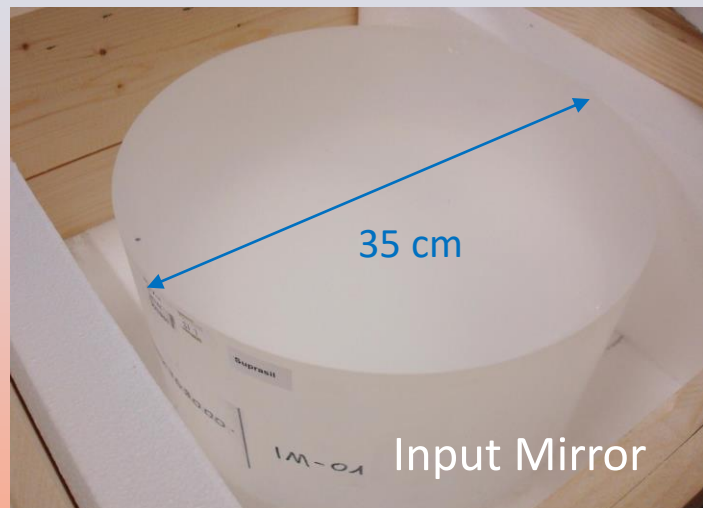
Total Round Trip Losses = **75 ppm**



25 ppm : Abs+Scatt+T

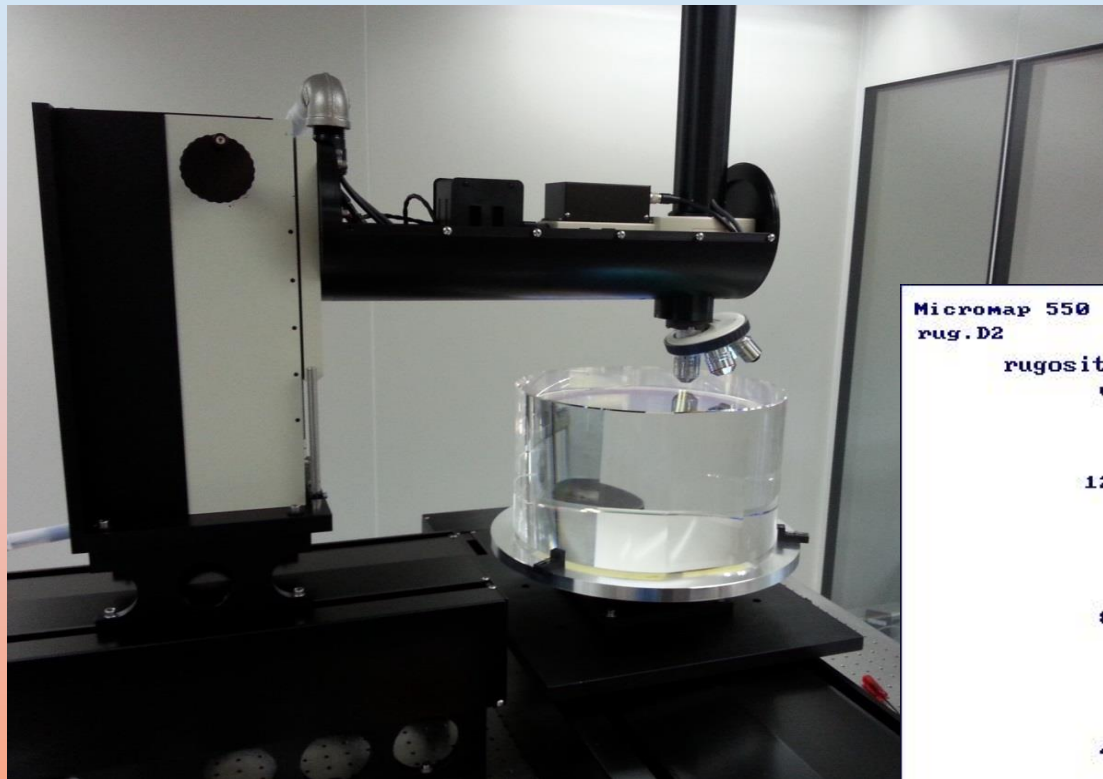


**50 ppm : Flatness imperfections**  
Specifications very severe

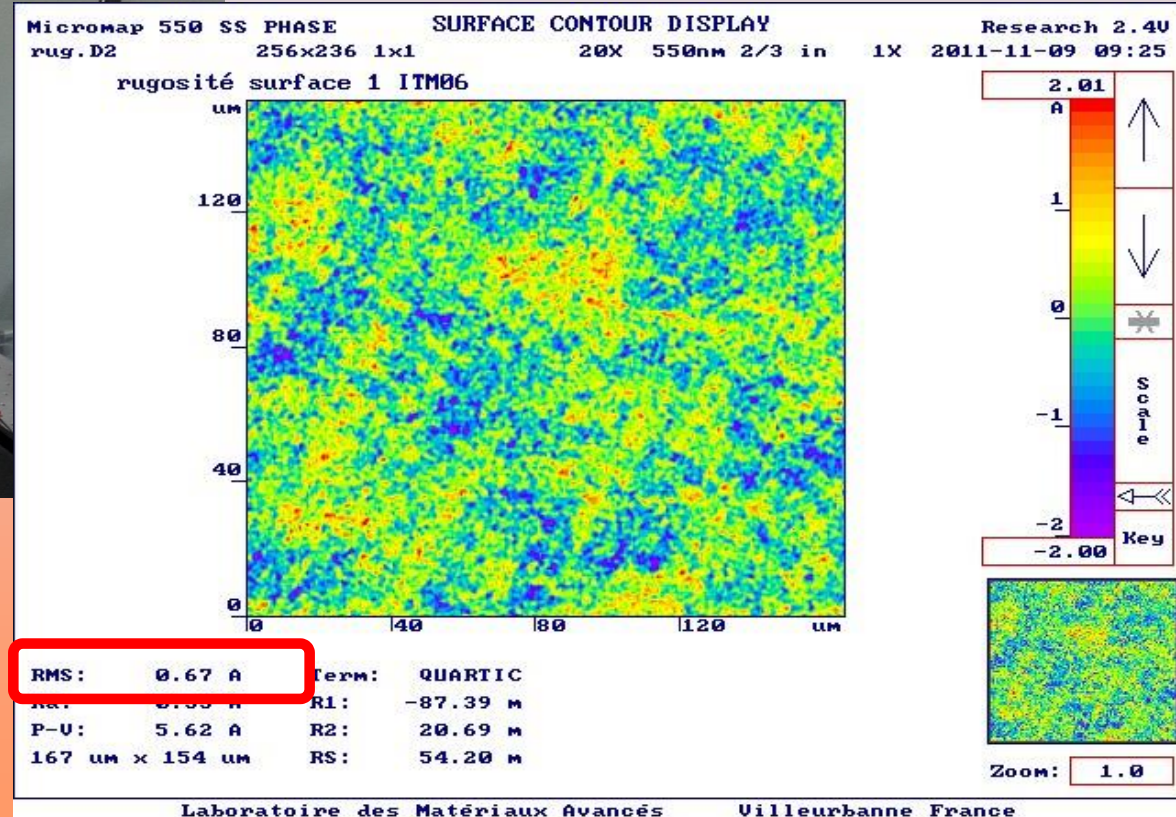


- ✓ Low absorption fused silica (Suprasil 3002)  
0.25 ppm/cm @1064nm (LMA measurement)
- ✓ Diameter = 35 cm
- ✓ Thickness = 20 cm, Weight = 40 kg
- ✓ Blank cost 130 k€ (without polishing)

- ✓ Polishing : Specifications on the number of surface defects and microroughness ( $<1 \text{ \AA RMS}$ ) very severe to guarantee a low scattering level



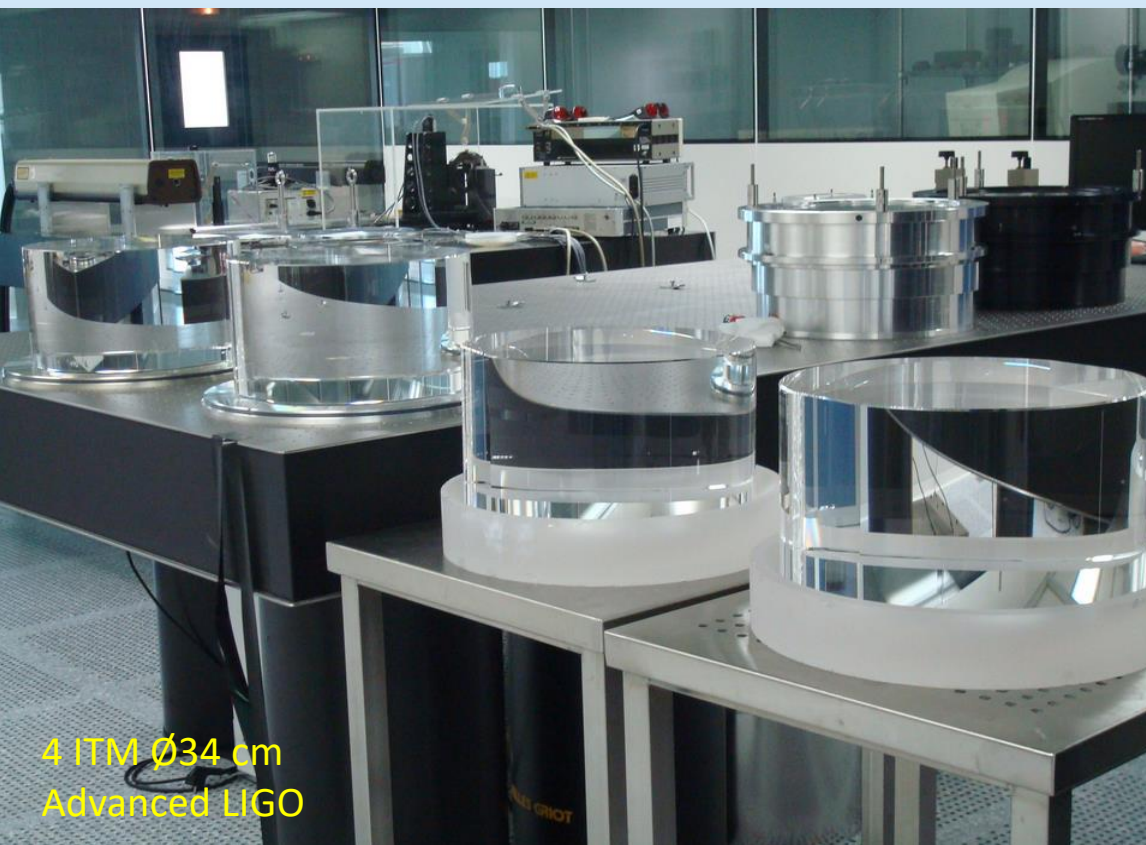
**0.67 +/- 0.1 Angströms RMS**





## GW interferometer mirrors : the substrate

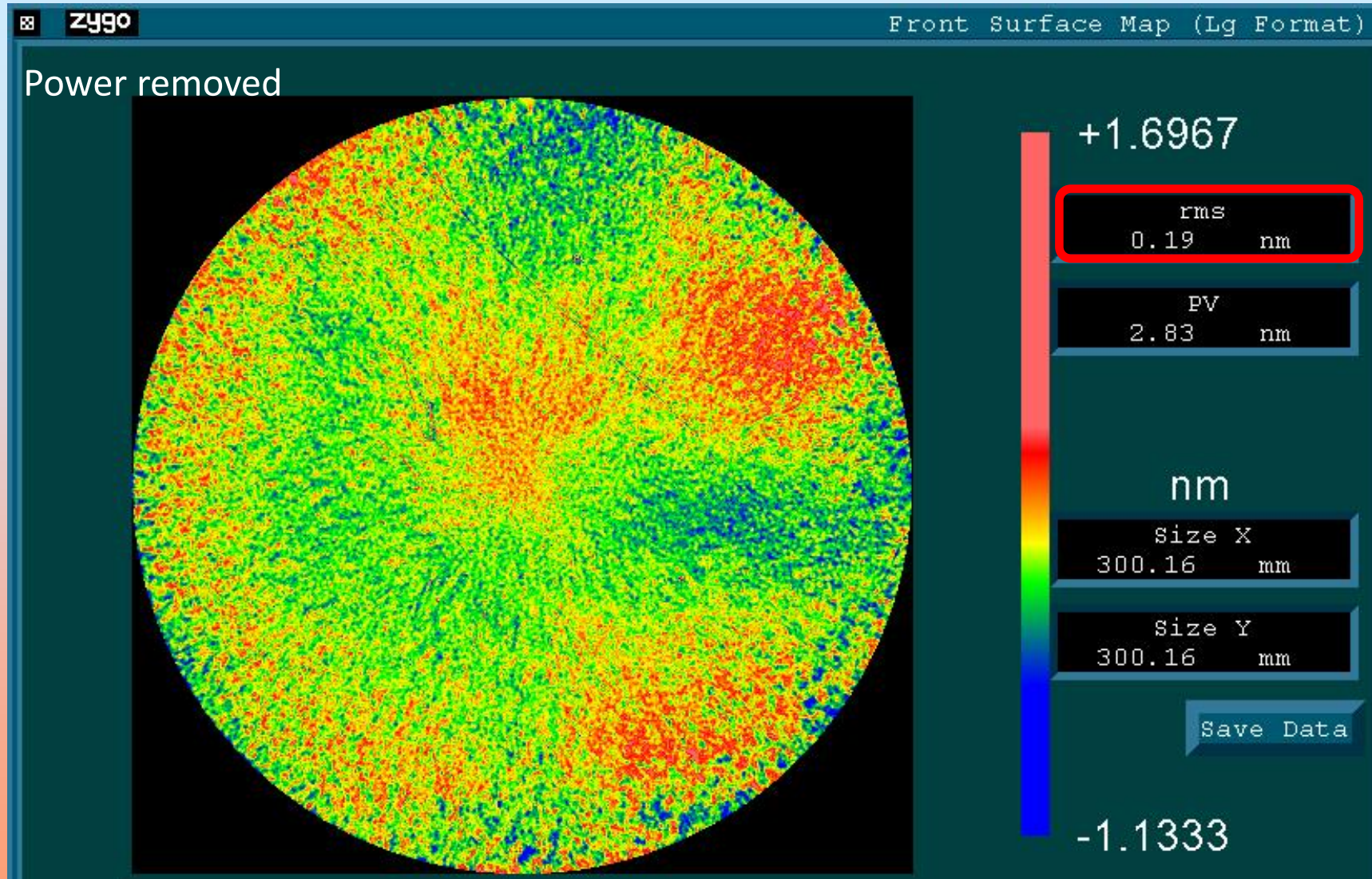
- ✓ Polishing : RMS Flatness needed : **< 0.5 nm RMS** sur  $\text{Ø}15/16$  cm (never obtained before) – Ion Beam Figuring polishing (ZYGO corp.)



4 ITM  $\text{Ø}34$  cm  
Advanced LIGO



IM  $\text{Ø}35$  cm  
Advanced Virgo



**Advanced Virgo IM substrate : 0.19 nm RMS - 2.8 nm PV (30 cm diam.)**



## GW interferometer IBS mirrors Coatings

- ✓ Coating Performances very challenging compared to the 1<sup>st</sup> mirror generation:
  - Low avge absorption : **< 0.5 ppm at 1064 nm**
  - Low avge scattering : **< 10 ppm at 1064 nm**
  - Very low ITM AR coating reflectivity : **Goal <50 ppm**
  - Coating uniformity : **< 0.5 nm RMS Ø15/16 cm (All Zernike terms < 0.5 nm)**



- ✓ Combination of  $\text{Ti:Ta}_2\text{O}_5$  and optimized design (no quarter-wave layers) improved the absorption level of the HR coating made by Ion Beam Sputtering (R&D work started with LIGO in 2006)
  - ✓ 0.5-0.6 ppm on the Virgo+ mirrors (2009)
  - ✓ For the 10 ITMs : **0.22 +/- 0.03 ppm** (average +/-  $\sigma$ )
  - ✓ For the 10 ETMs : **0.27 +/- 0.07 ppm** (LMA measurements)
  - ✓ Same results for the Advanced Virgo cavity mirrors
- ✓ Average level confirmed with measurements made at Caltech on a complete different bench, also with in-situ measurements

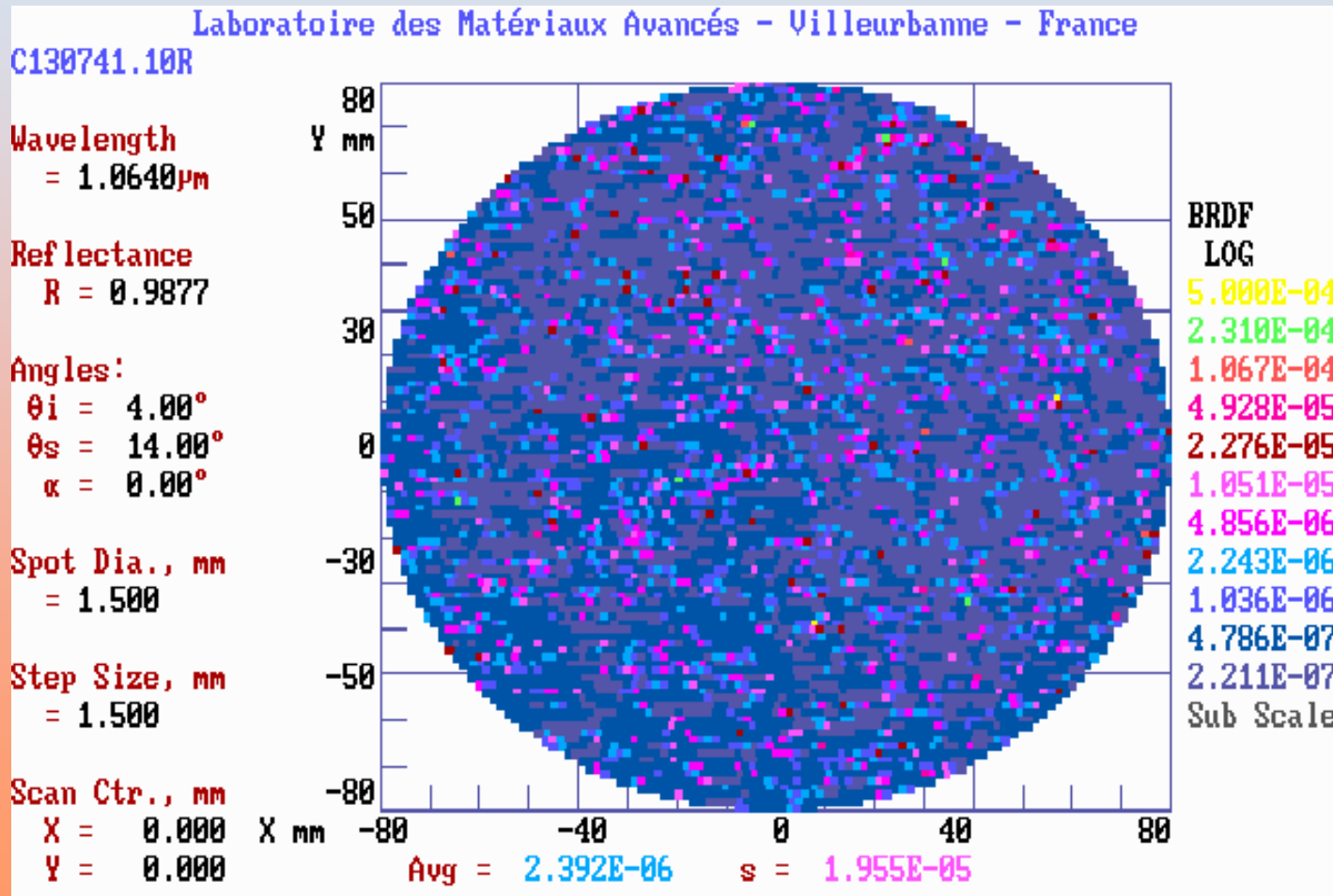
- ✓ To improve the scattering after coating :
  - New wet cleaning machine, Better efficiency on very small particles



- Improvement of the surface control before closing the coating chamber door (visual observation in the dark with a high power halogen lamp, use of ionized dry air gun)

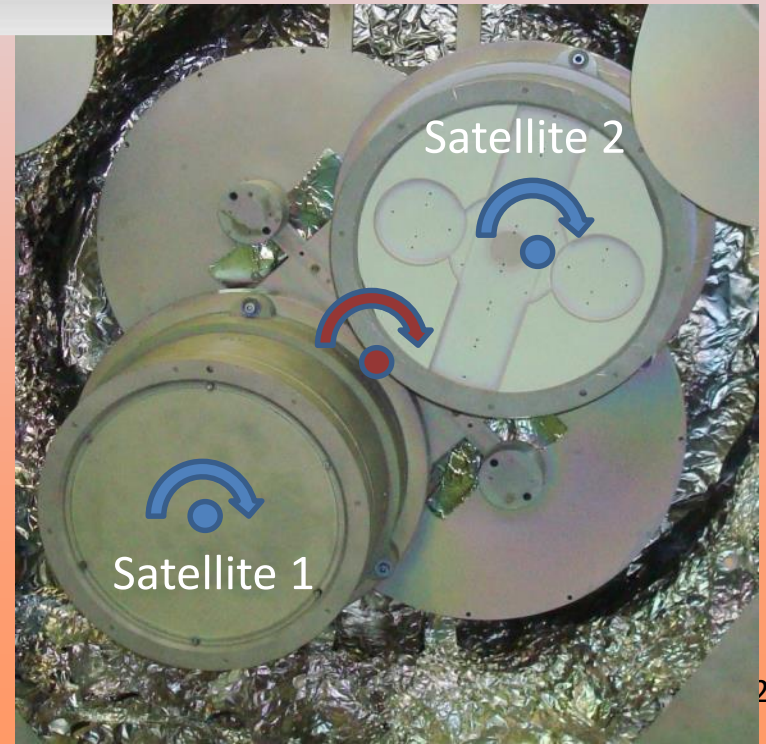
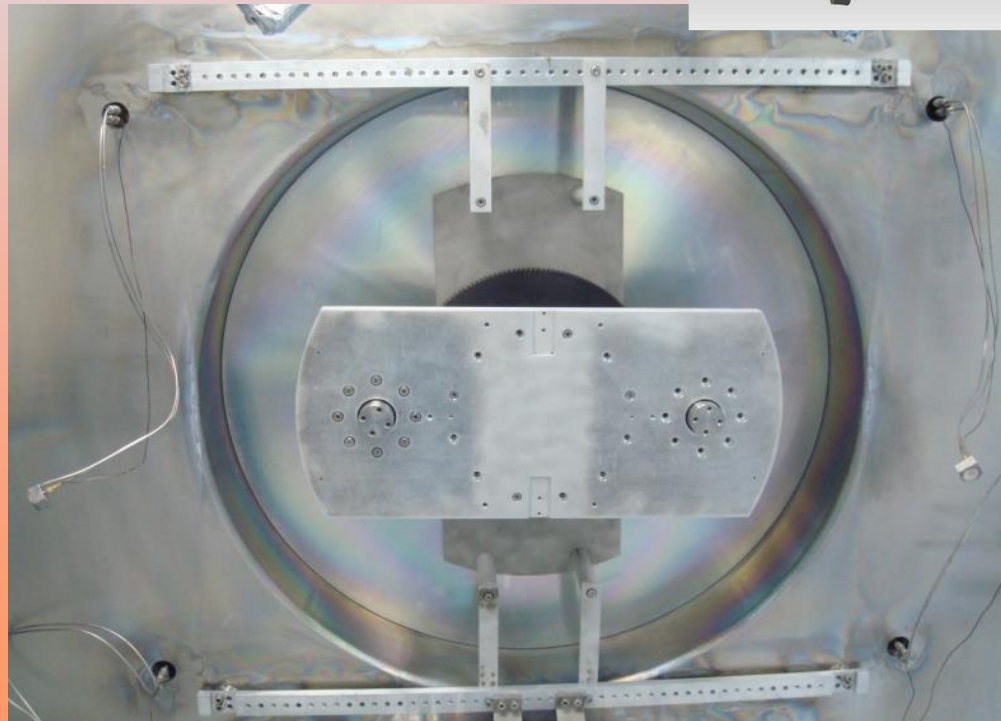
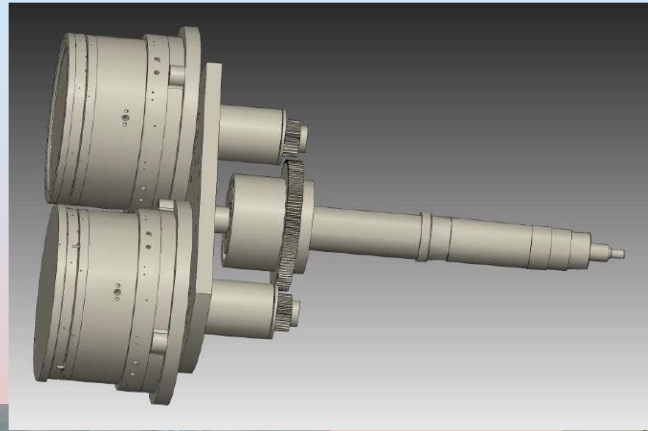
✓ Average scattering level on Ø160 mm achieved :

- On 10 ITMs : **3.7 +/- 1.2 ppm**
- On 10 ETMs : **4.9 +/- 1.5 ppm**
- Best result : **2.3 ppm**

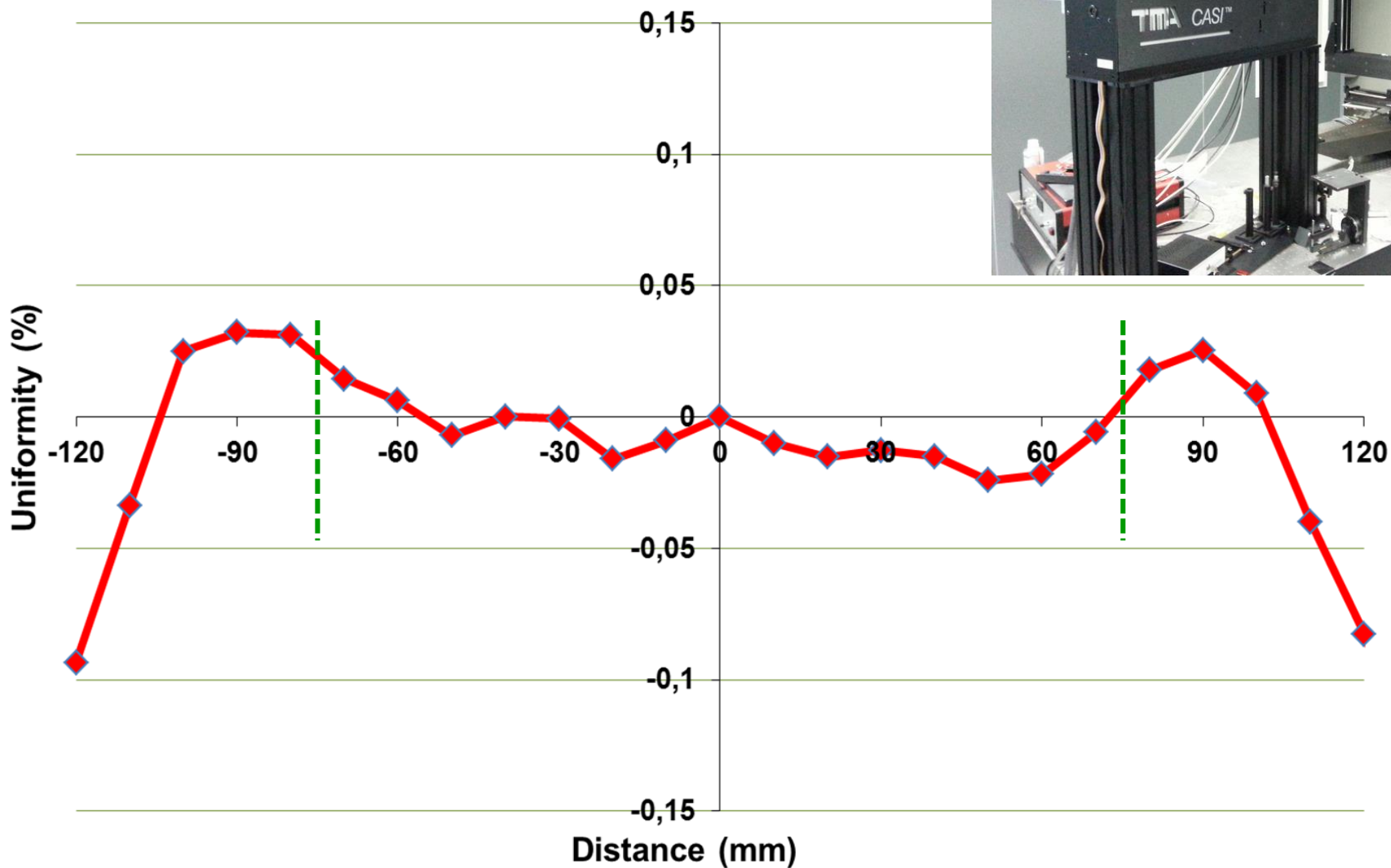
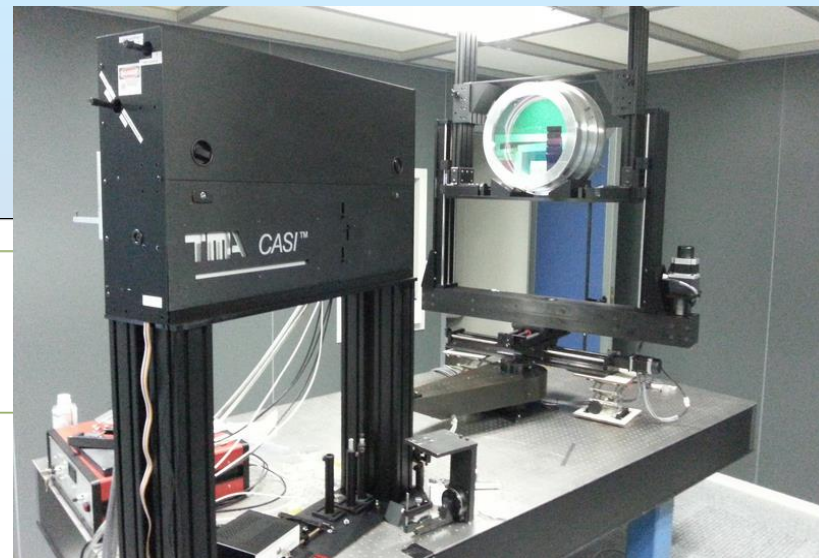


# HR Coating Uniformity

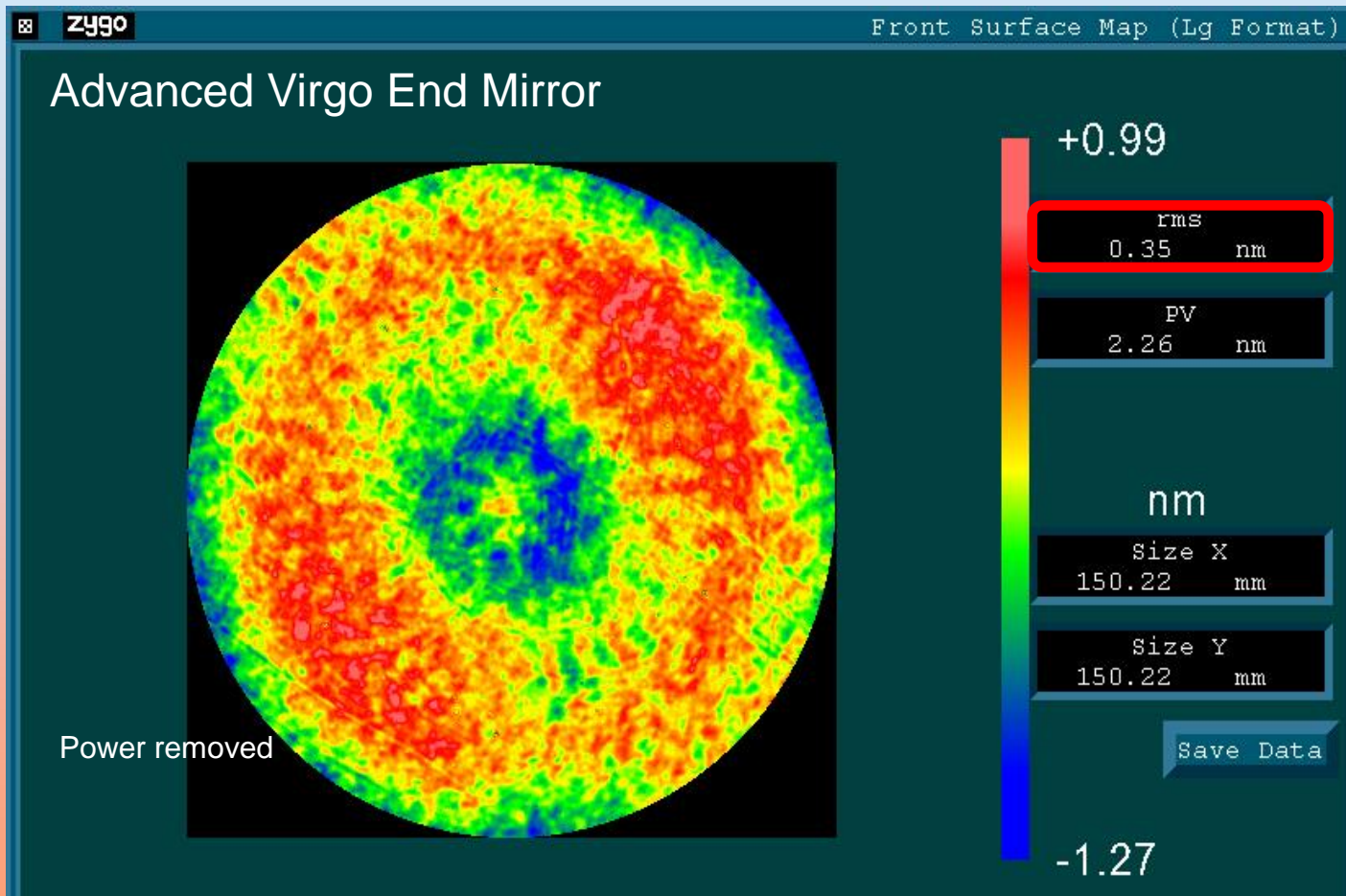
- ✓ Home made NEW planetary system developed and installed in the coating chamber



Average uniformity profile on a HR coating  
**# 0.05% on Ø20 cm (3 nm PV for EM)**



- ✓ Planetary system with masking for each High/Low index layer (mask shape optimization with several iterations)



**Final Result**



3 Michelson type operating interferometers with 3 or 4 km arms in Italy near Pisa (LMA part of the collaboration Virgo) and in the US

1 new detector in Japan (mirror in Sapphire)

LMA has coated the mirrors of all these interferometers (world leadership)



LIGO Handford



LIGO Livingston

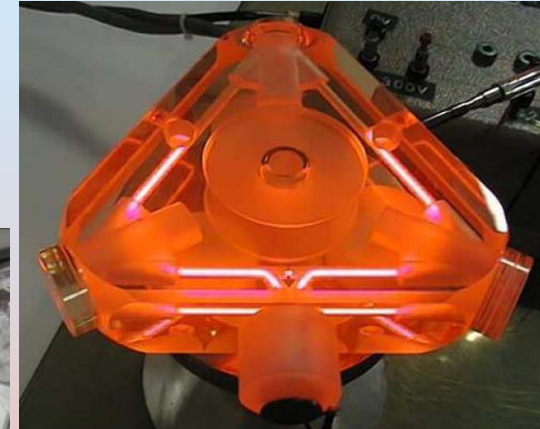
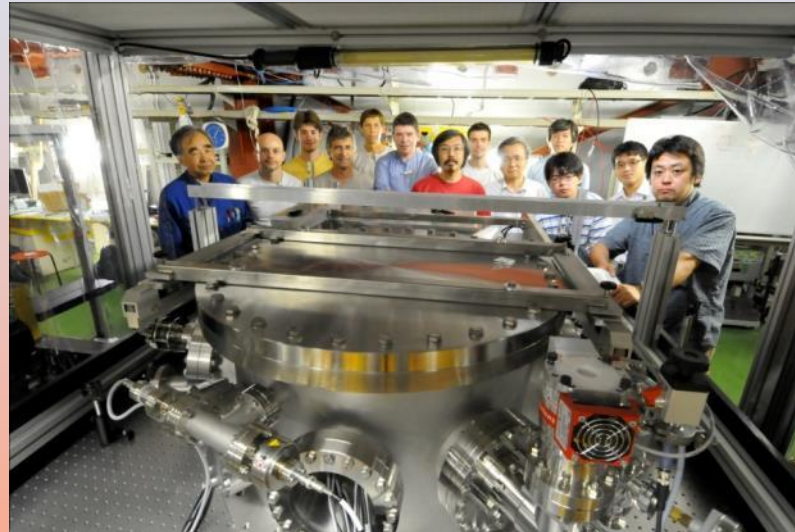
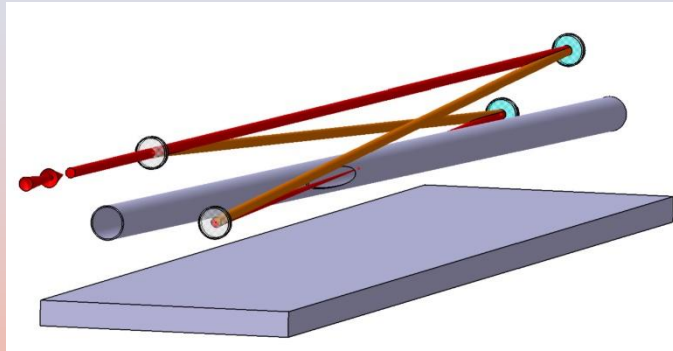


Virgo

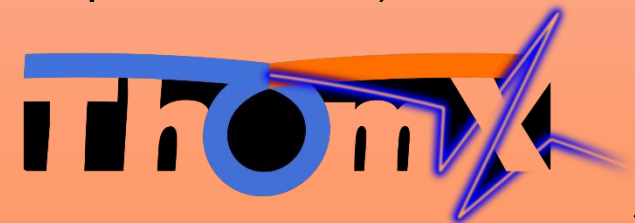
# LMA IBS coatings in various experiments that need low loss coatings

- Gyrolasers 633 nm : Collaboration with private companies (SAFRAN, Thales) 1990/2000
- Scientific projects :
  - KEK and IJCLAB (formerly LAL) (Compton effect 1031 nm) : ANR MightyLaser – non planar 4 mirrors cavity

Collaboration MightyLaser - KEK



- ThomX mirrors : micropolished substrates (ULE, Suprasil, saphir, 1031 nm)





# LMA IBS coatings in various experiments that need low loss coatings

- Scientific projects :
  - BMV (Biréfringence Magnétique du vide): LNCMI (Toulouse) C. Rizzo  
Long collaboration started in 2008, ANR project, 1064 nm



# LMA IBS coatings in various experiments that need low loss coatings

- **Scientific projects :**

- BMV (Biréfringence Magnétique du vide): LNCMI (Toulouse) C. Rizzo

Référence	Référence substrat	Diffusion moyenne Ø12 mm	Diffusion au centre (Ø2 mm)
C16053/11	N°25	12 ppm	7 ppm
C16053/12	N°26	2,5 ppm	<b>1,1 ppm</b>
C16053/13	N°34	3,5 ppm	<b>1,2 ppm</b>
C16053/14	N°30	2,8 ppm	2,8 ppm
C16053/15	N°29	5 ppm	2,7 ppm
C16053/16	N°24	5,5 ppm	<b>2 ppm</b>

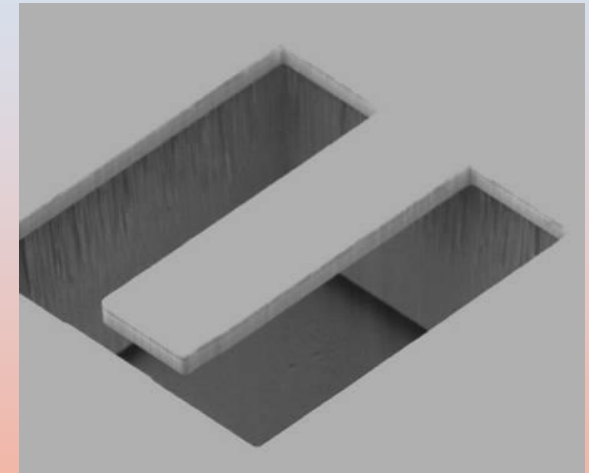
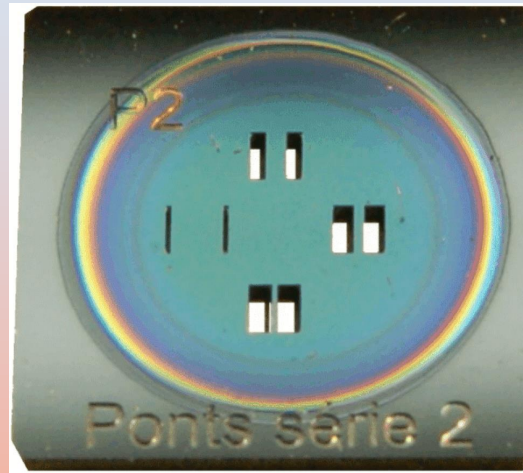
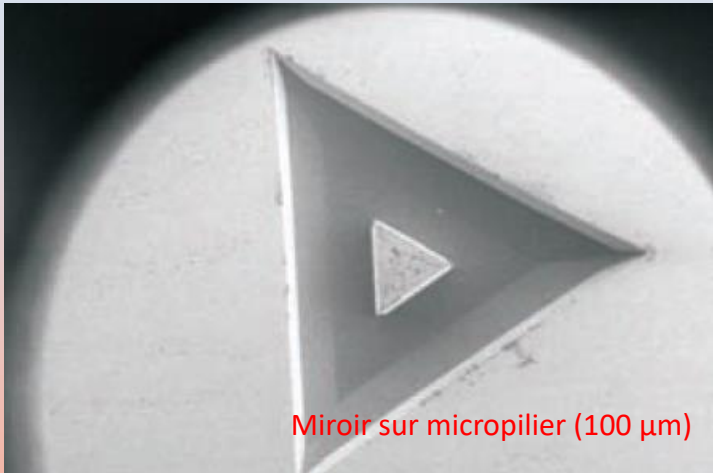
- Transmission measured at 1064 nm : **2 ppm**
- Absorption at 1064 nm HR coating : **0,25-0,3 ppm**

$$F = \pi / (T + P) = \pi / (2 \text{ ppm} + 1,35 \text{ ppm}) = 940 \ 000$$

- Experimental cavity finesse measured : #600 000

# LMA IBS coatings in various experiments that need low loss coatings

- Scientific projects :
  - Coating on micro-nano optomechanical resonators in the quantum regime (optical cavity at 1064 nm at 100 mK), finesse 200 000



# LMA Thank You for your Attention

