The VIRGO large mirrors : a challenge for low loss coatings

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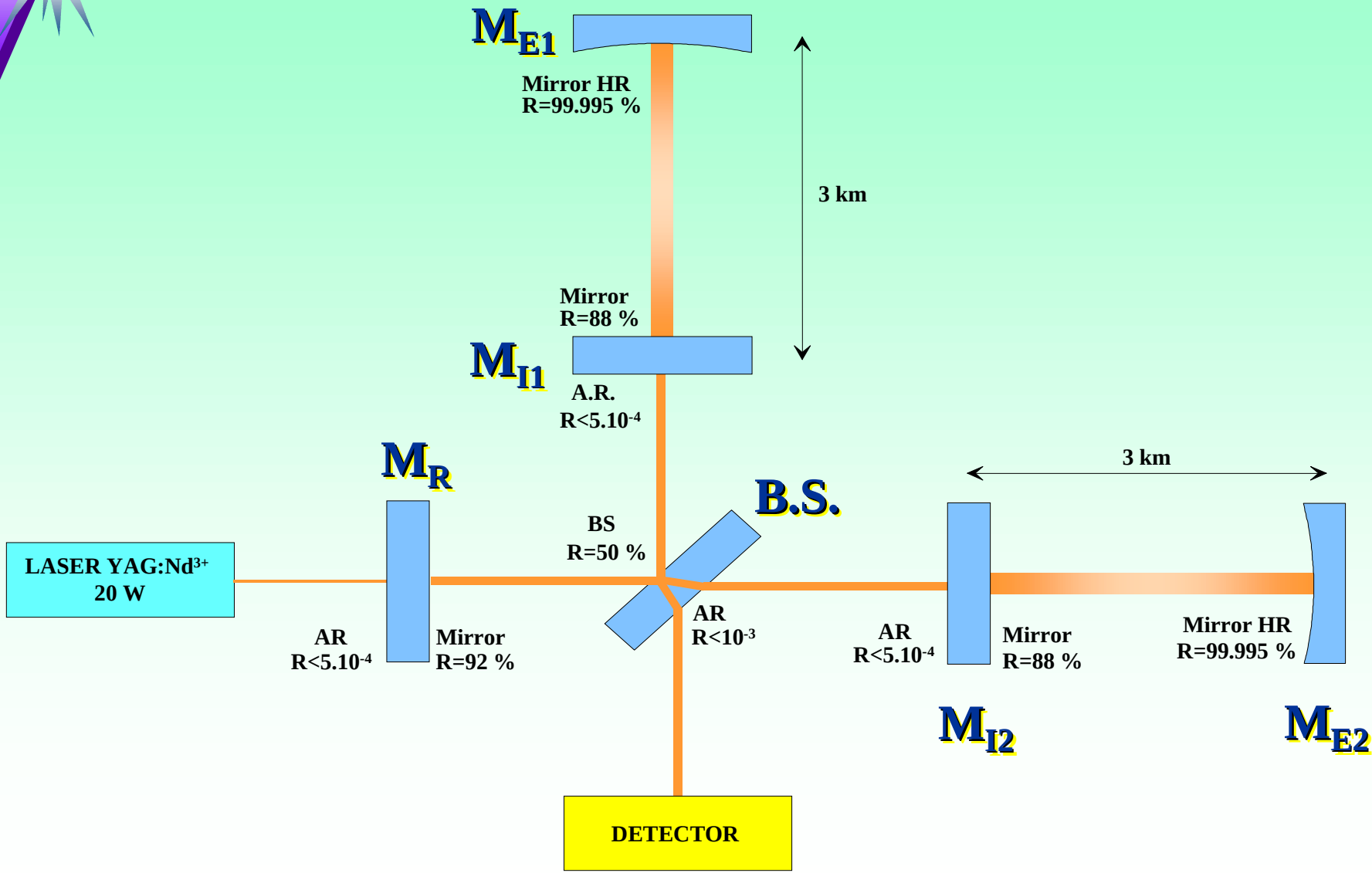
http://lyoinfo.in2p3.fr/sma/Smagb.htm

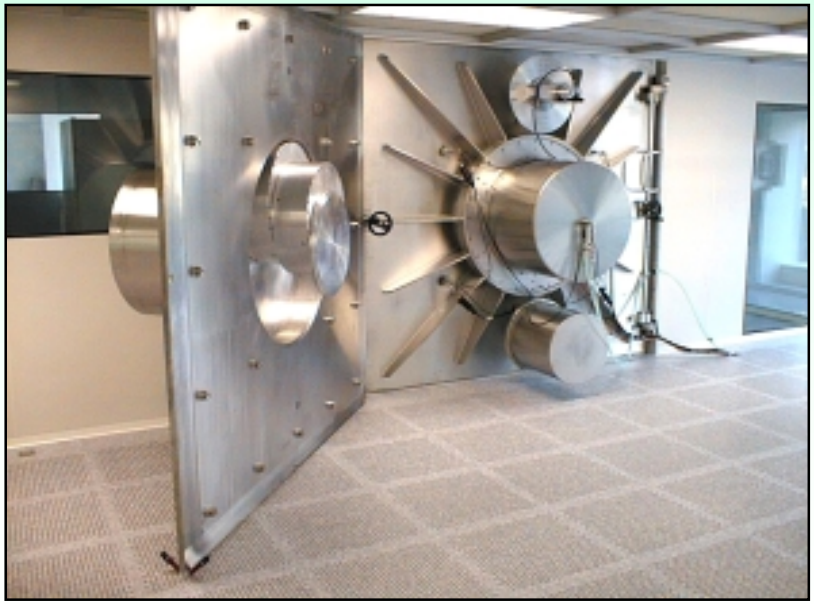
LIGO-G030490-00-Z

The VIRGO interferometer



The VIRGO large coater

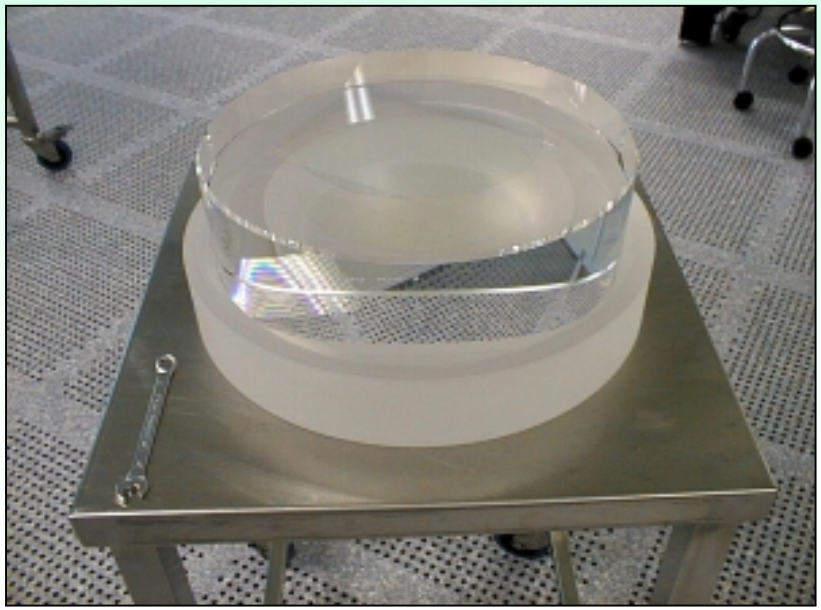
- Dimension: 2.2x2.4x2.4 m^3
- Base Pressure: 2.10^{-8} mbar in 3 hours
  Clean vacuum (cryo pumps, primary dry pumping)
- Ion Beam Sputtering technology
- Environment: Class 1 Clean Room

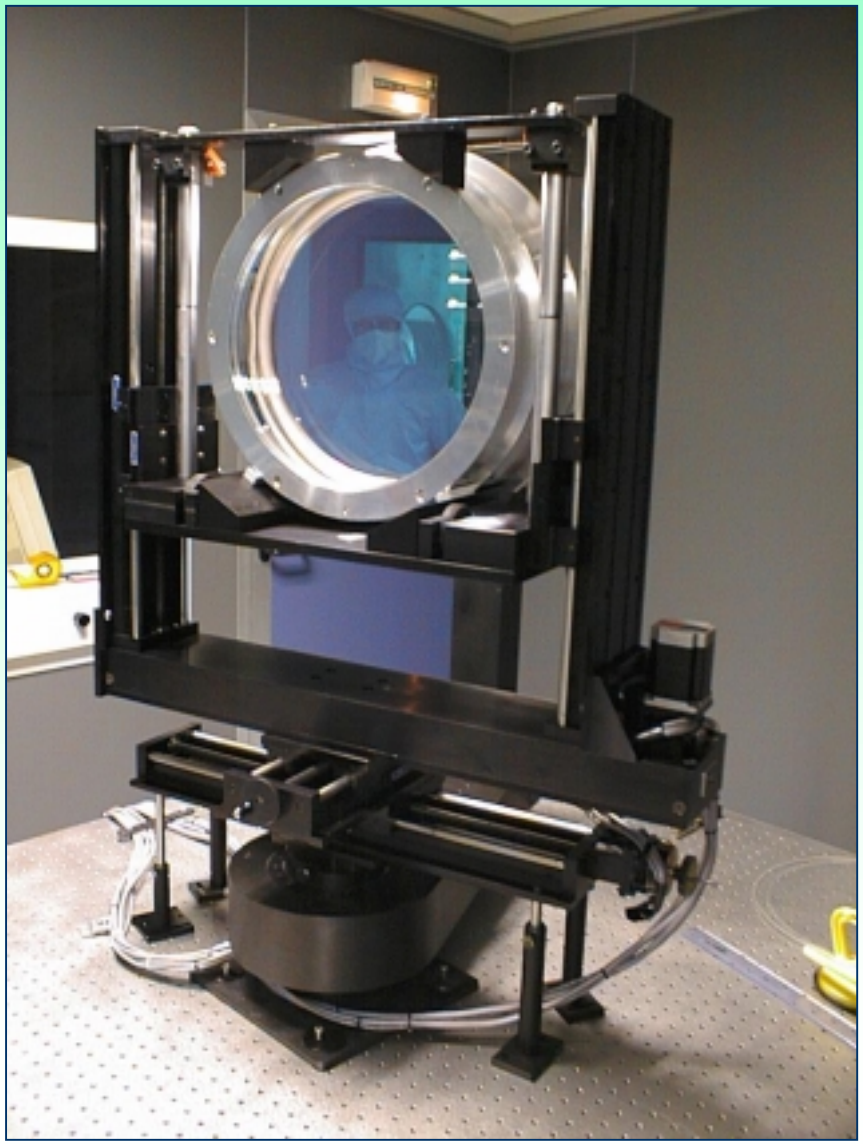


First VIRGO End Mirror (December 2001)

- Bulk diameter : 350 mm
- Coating diameter : 330 mm
- Bulk Thickness : 96 mm
- Weight : 20 kg

6 components ready in June 2002 (Planning OK), installation in progress





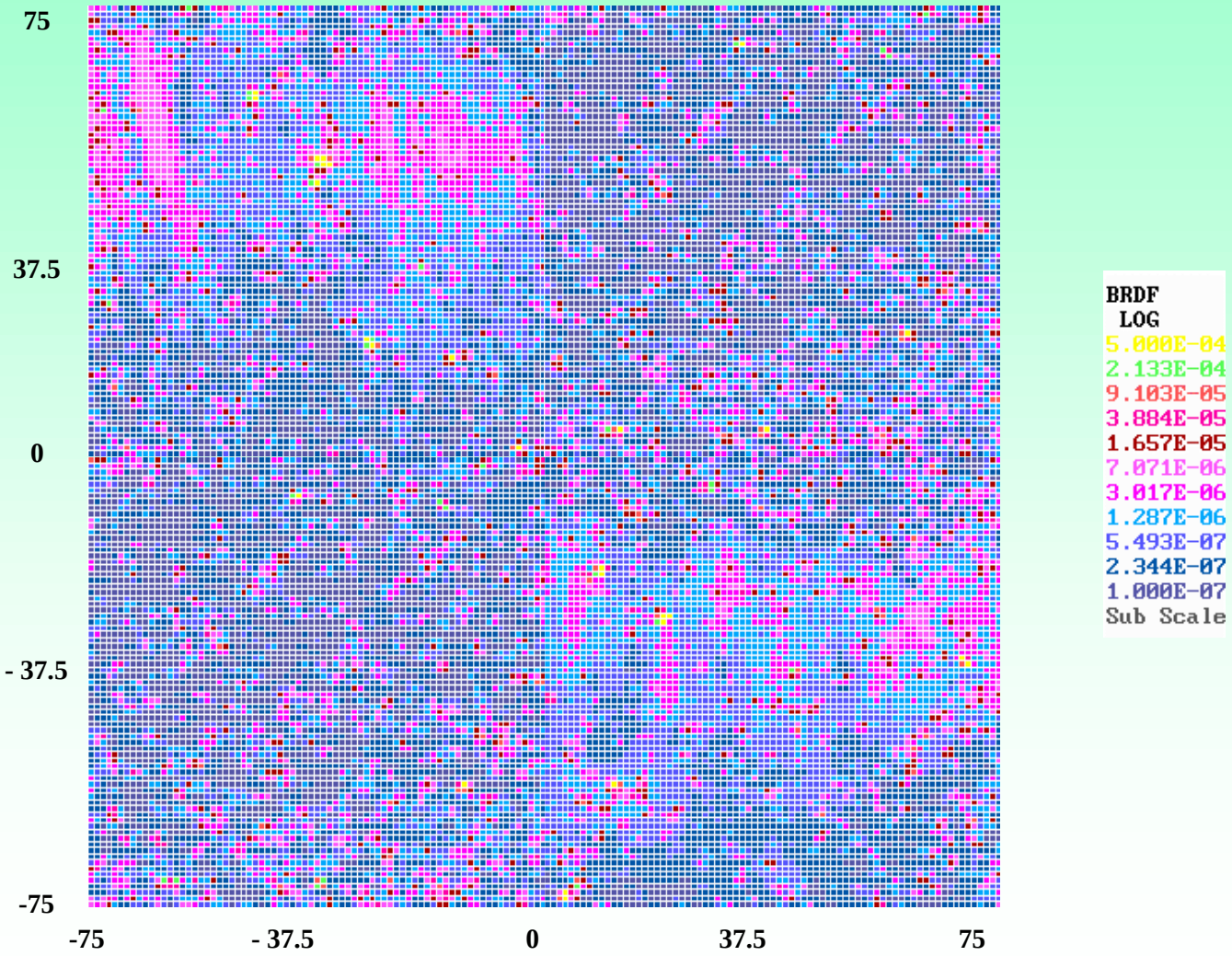
VEM04 End Mirror

Optical Performances
Ø350 mm, Thk. 96mm

SIDE B measurements	VIRGO specifications	SMA-VIRGO mesurements
average scattering	< 5 ppm	4 ppm 150×150 mm^2
average transmission	10 < T < 50 ppm	42,9 +/- 0,2 ppm Ø50 mm
average absorption	< 5 ppm	0,63 +/- 0,07 ppm Ø150 mm
wavefront flatness	< 8 nm RMS Ø150 mm	3,8 nm RMS Ø150 mm
shape	concave 3450 +/- 100 m Ø150 mm	concave 3580 +/- 17 m Ø150 mm

VEM04 End Mirror

Scattering mapping on 150x150 mm²



4 ppm
150×150 mm²

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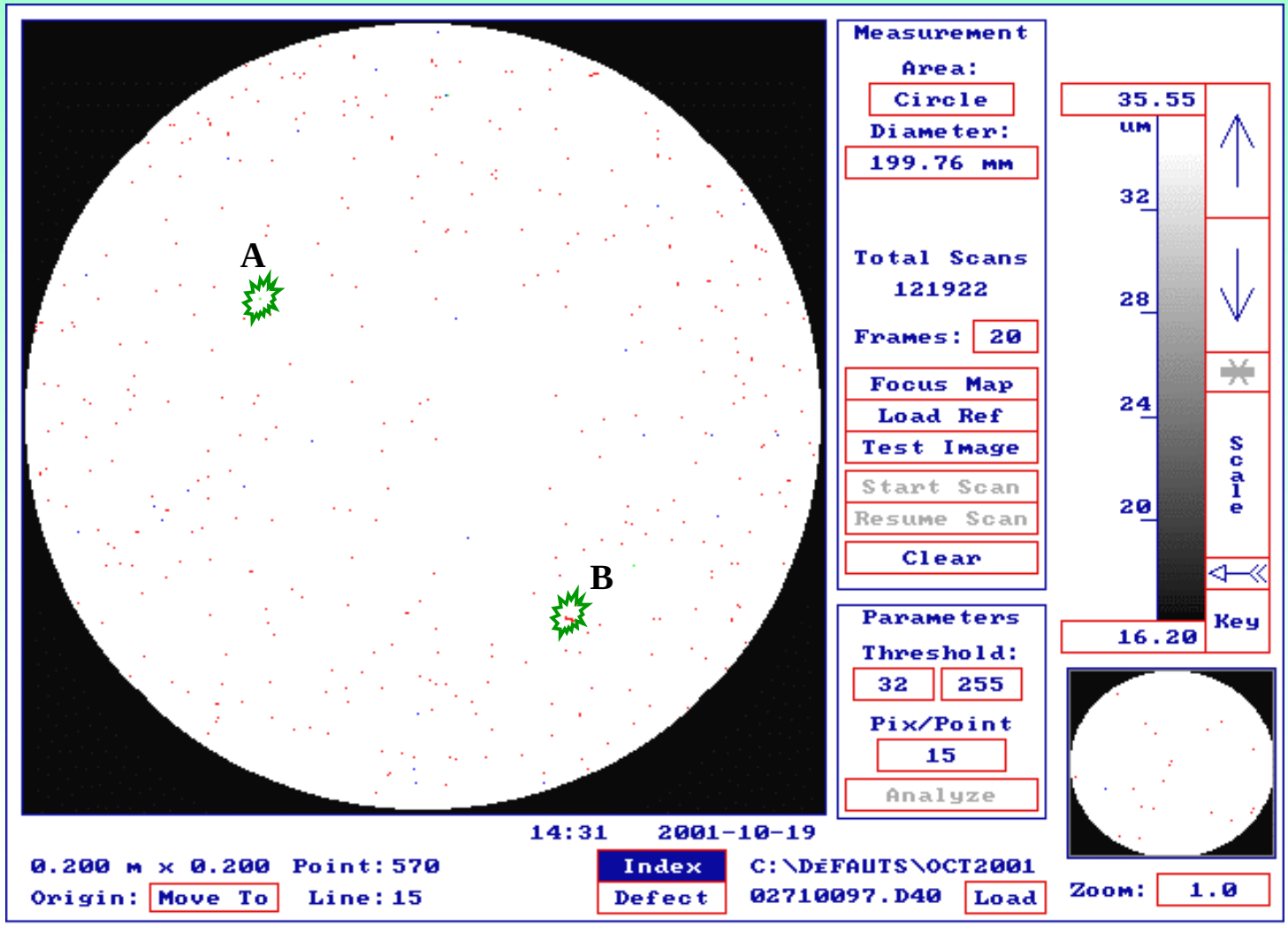
VEM04 End Mirror

Defects detection



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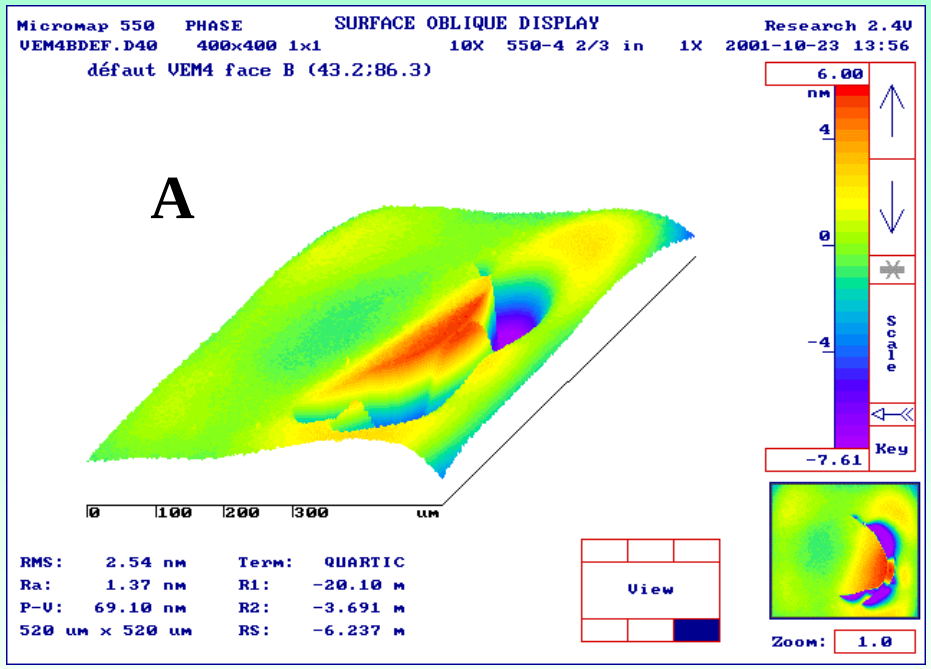
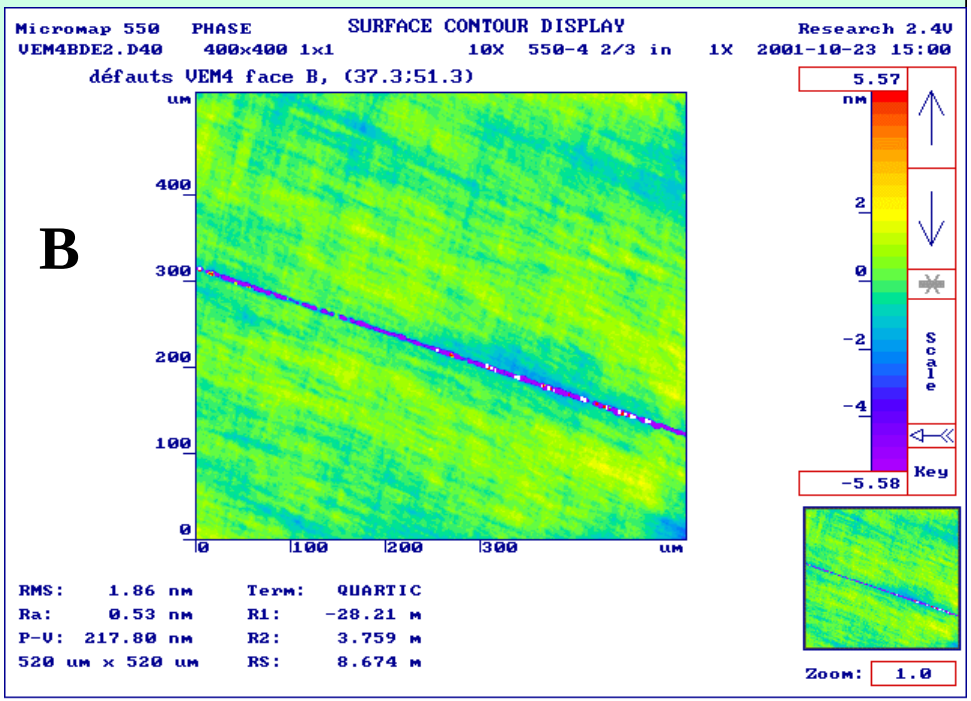
VEM04 END MIRROR

Defects detection





VIM01 Input Mirror

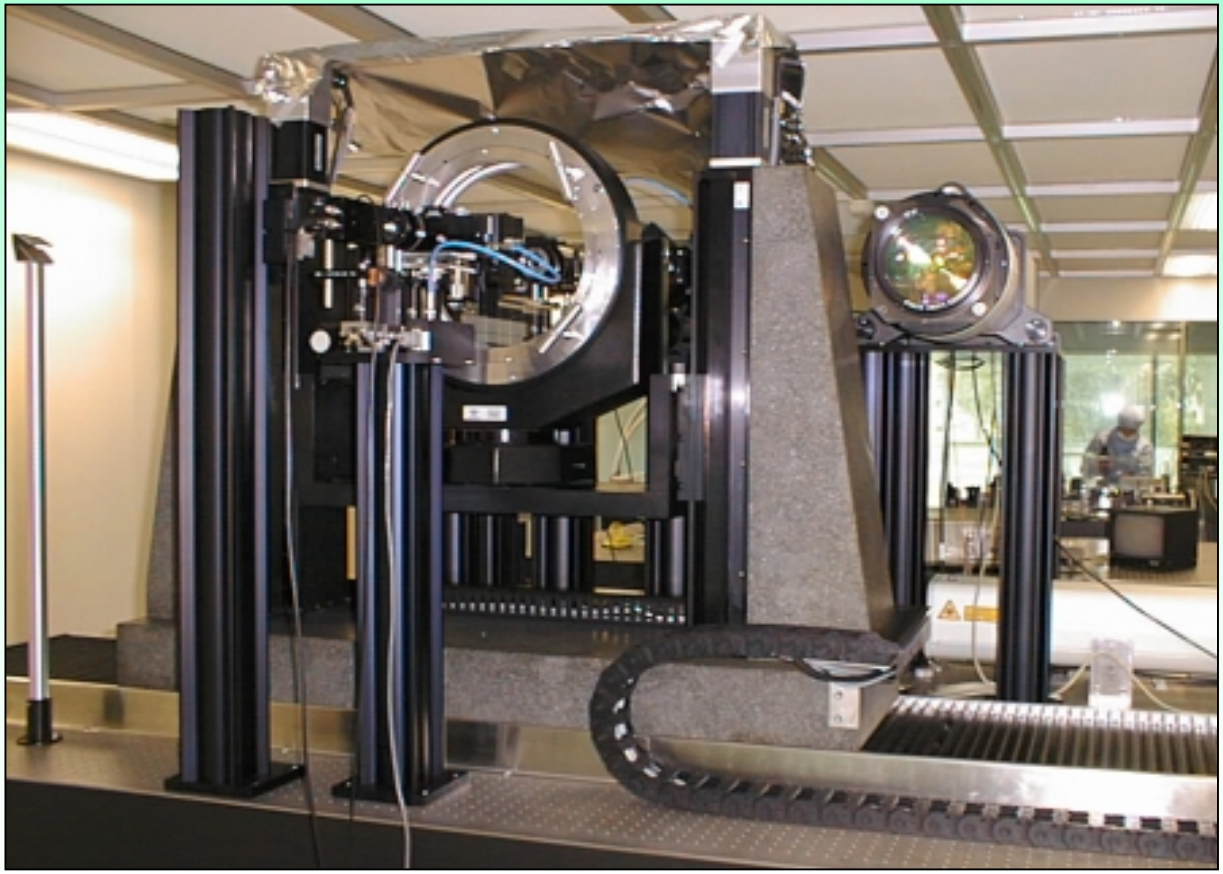
Optical Performances
Ø350 mm, Thk. 96mm

measurements	VIRGO specifications	SMA-VIRGO mesurements
average scattering (HR)	< 5 ppm	7 ppm Ø100 mm 5 ppm Ø60 mm
average scattering (AR)	< 5 ppm	0,9 ppm Ø100 mm
transmission difference between VIM01 and VIM02	ΔT < 0.12 %	ΔT = 0,14 +/- 0,03 % Ø100 mm
average absorption (HR)	< 5 ppm	1,2 +/- 0.1 ppm Ø150 mm
wavefront flatness (HR)	< 8 nm RMS Ø60 mm	2,6 nm RMS Ø60 mm
transmitted wavefront	-	2,5 nm RMS Ø60 mm
reflexion (AR)	R < 500 ppm	132 +/- 2 ppm Ø100 mm

VIM01 Input Mirror

Surface/Bulk Absorption measurement

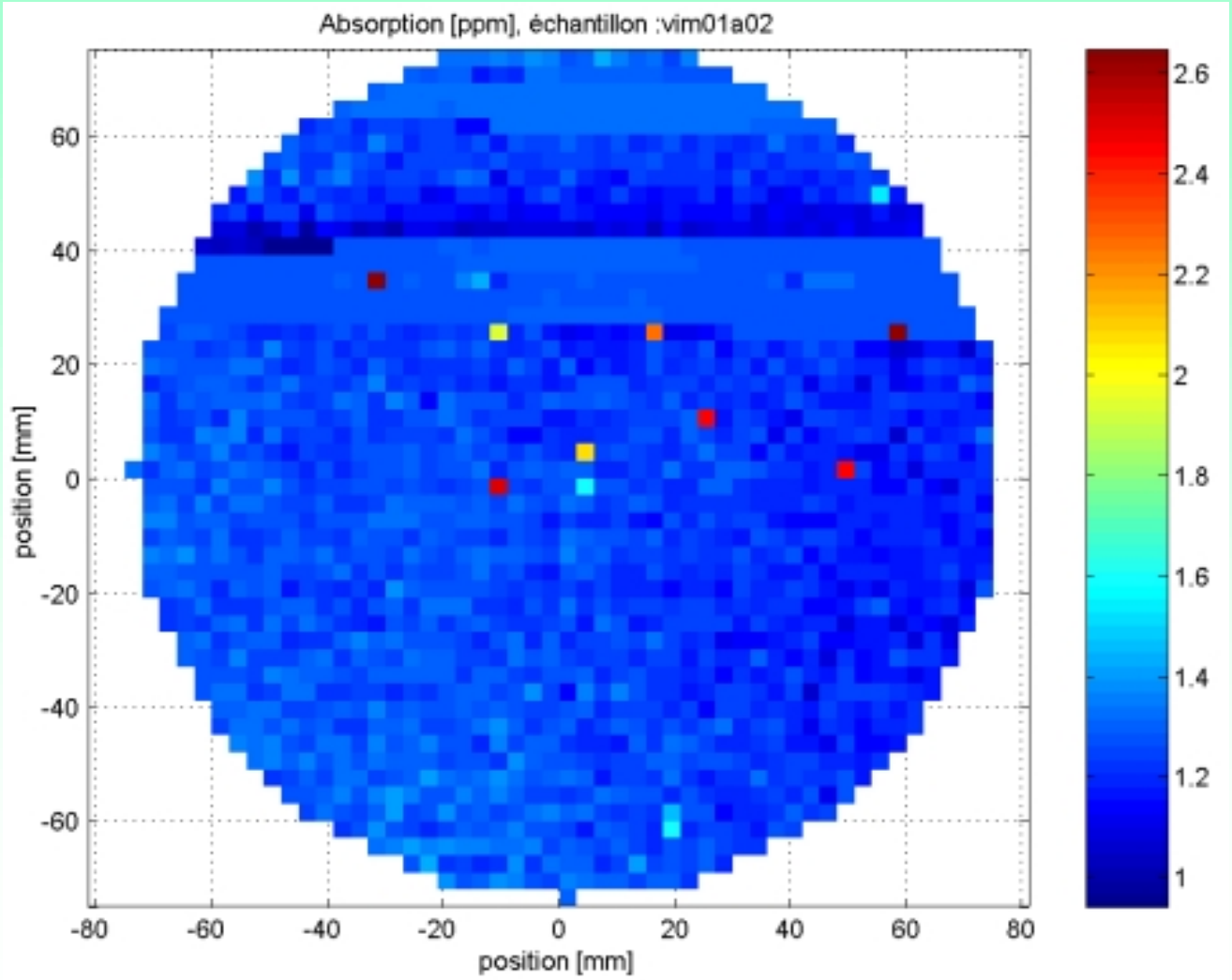
- Photothermal Deflection Developed with ESPCI
- Mappings up to Ø400 mm
- Sensitivity
  - 20 ppb surface
  - 30 ppb/cm bulk



VIM01 Input Mirror

Surface Absorption measurement

1,2 +/- 0,1 ppm
Ø150 mm



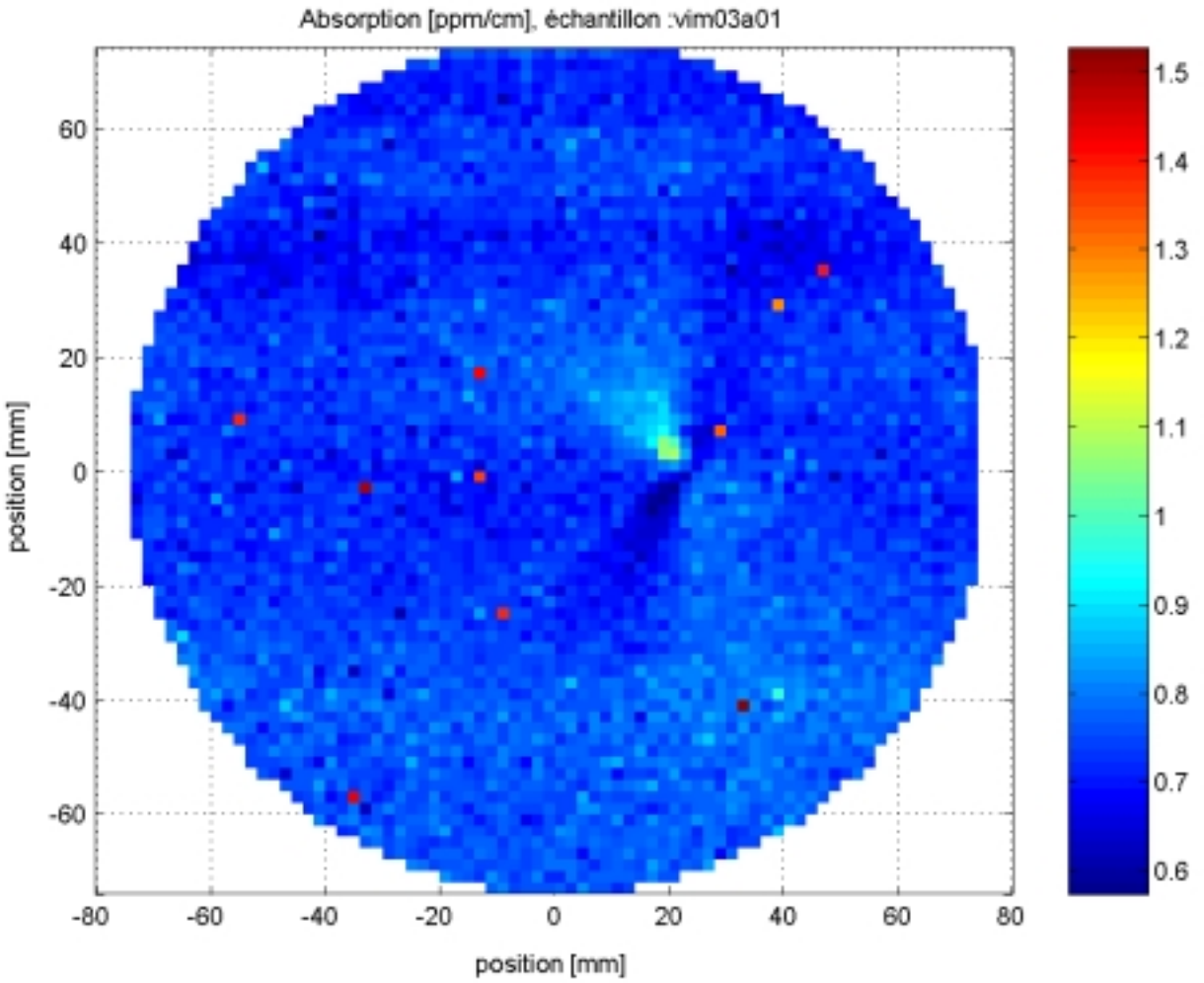
VIM01 Input Mirror

Bulk Absorption measurement

0,74 +/- 0,05 ppm/cm
Ø150 mm

Virgo requirement :
< 1 ppm/cm
for transmissive component

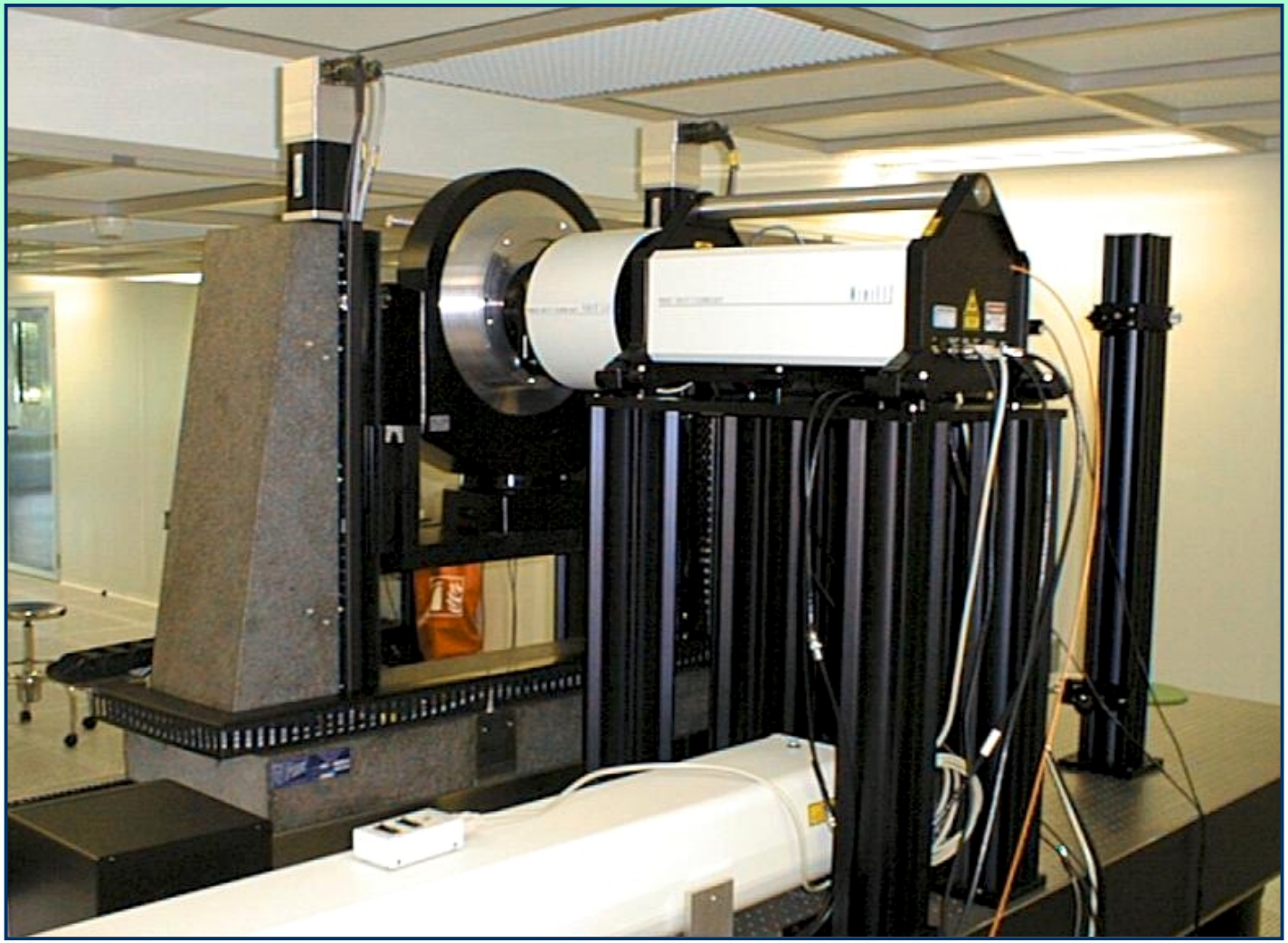
Suprasil 311/312 SV
(low -OH)



Large wavefront measurement

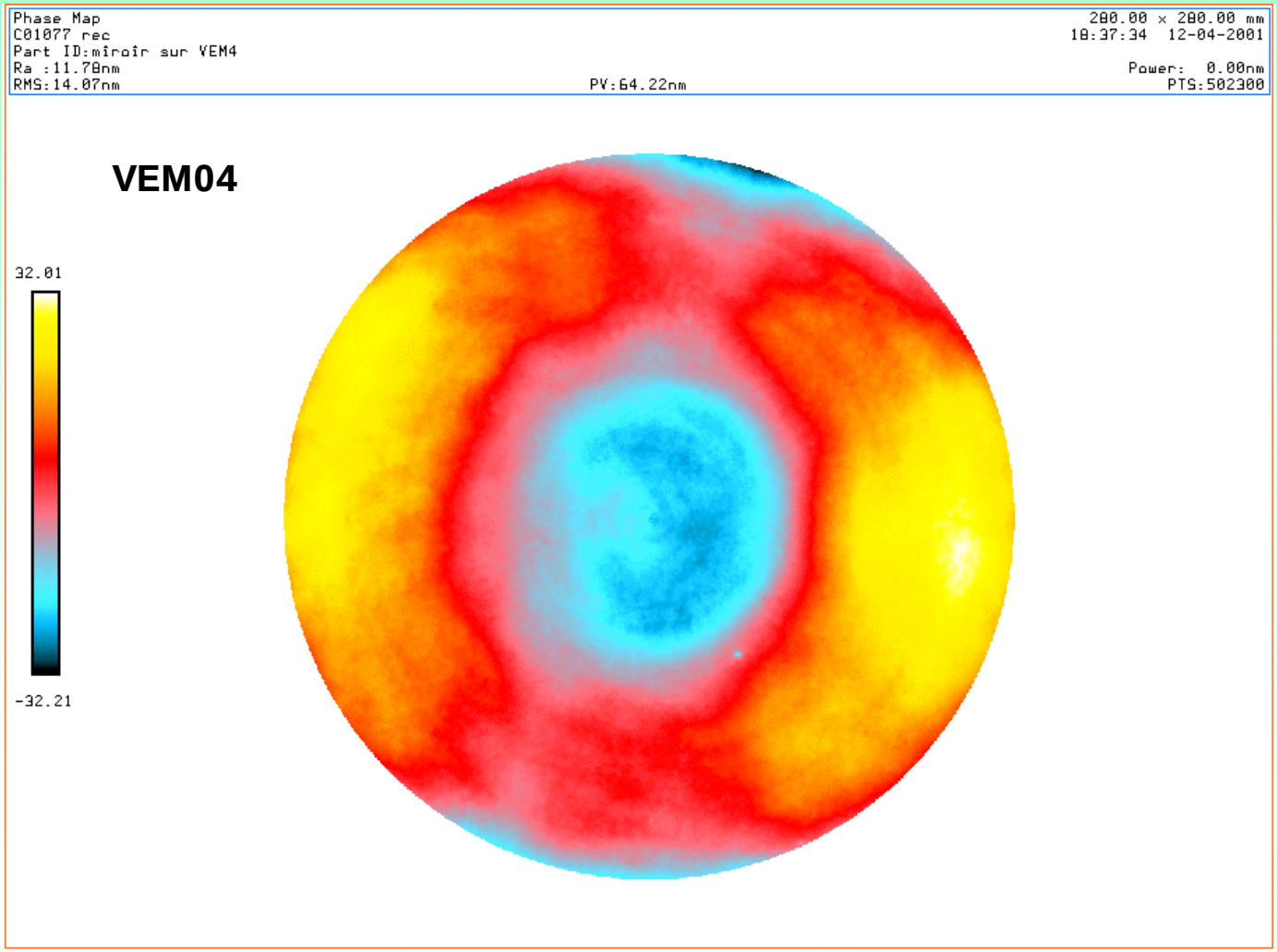
Stitching interferometry

Wavefront measurement up to Ø400 mm



Large wavefront measurement

Stitching interferometry
Wavefront on Ø280 mm

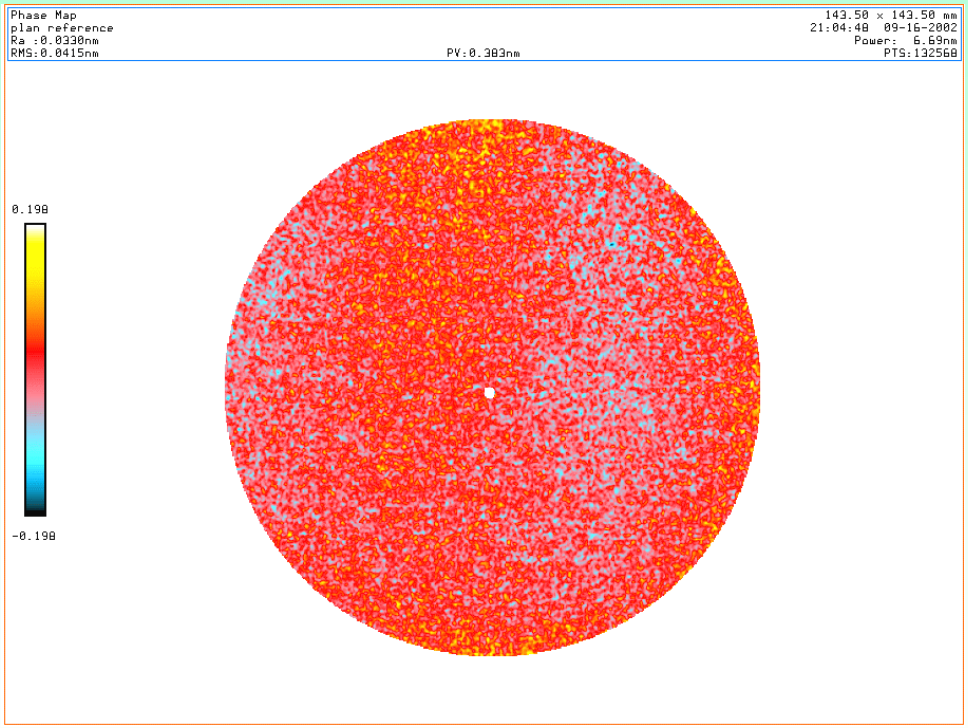


Large wavefront measurement

Stitching interferometry

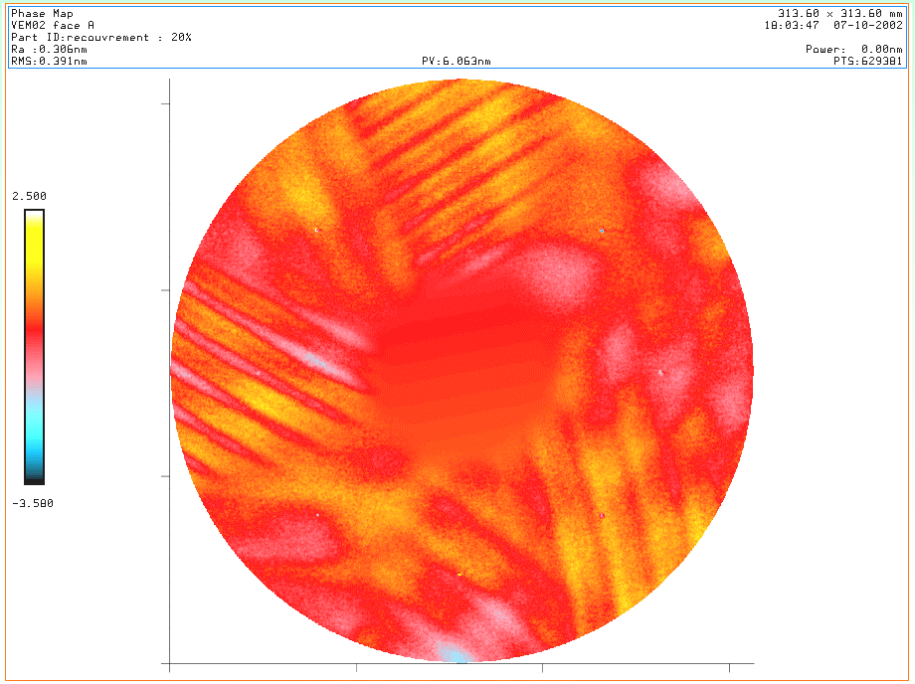
Standard Reproducibility (Ø150 mm)

0,04 nm RMS



Stitching Reproducibility (Ø350 mm)

0,4 nm RMS



Mirror Coating R&D

- Difficult to improve
  - scattering (point defects, roughness)

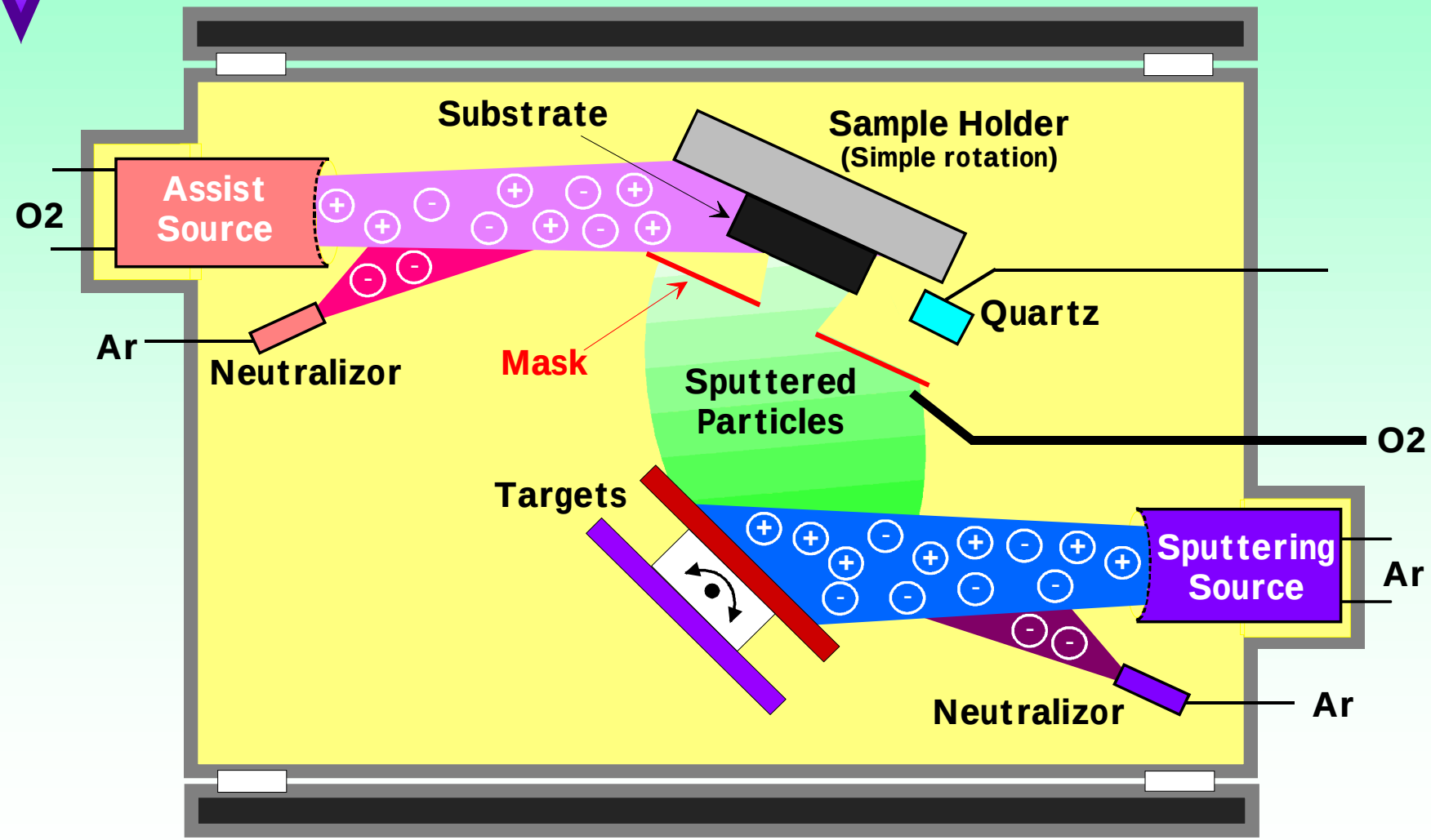
    keep the scattering level in the ITF

- Improving the mirrors **surface flatness**
  - coating thickness uniformity
  - corrective coating : flat, special shapes

- Improving the **material properties**
  - ↘ absorption
  - ↘ mechanical loss ϕ

Mirror Coating R&D

Coating uniformity



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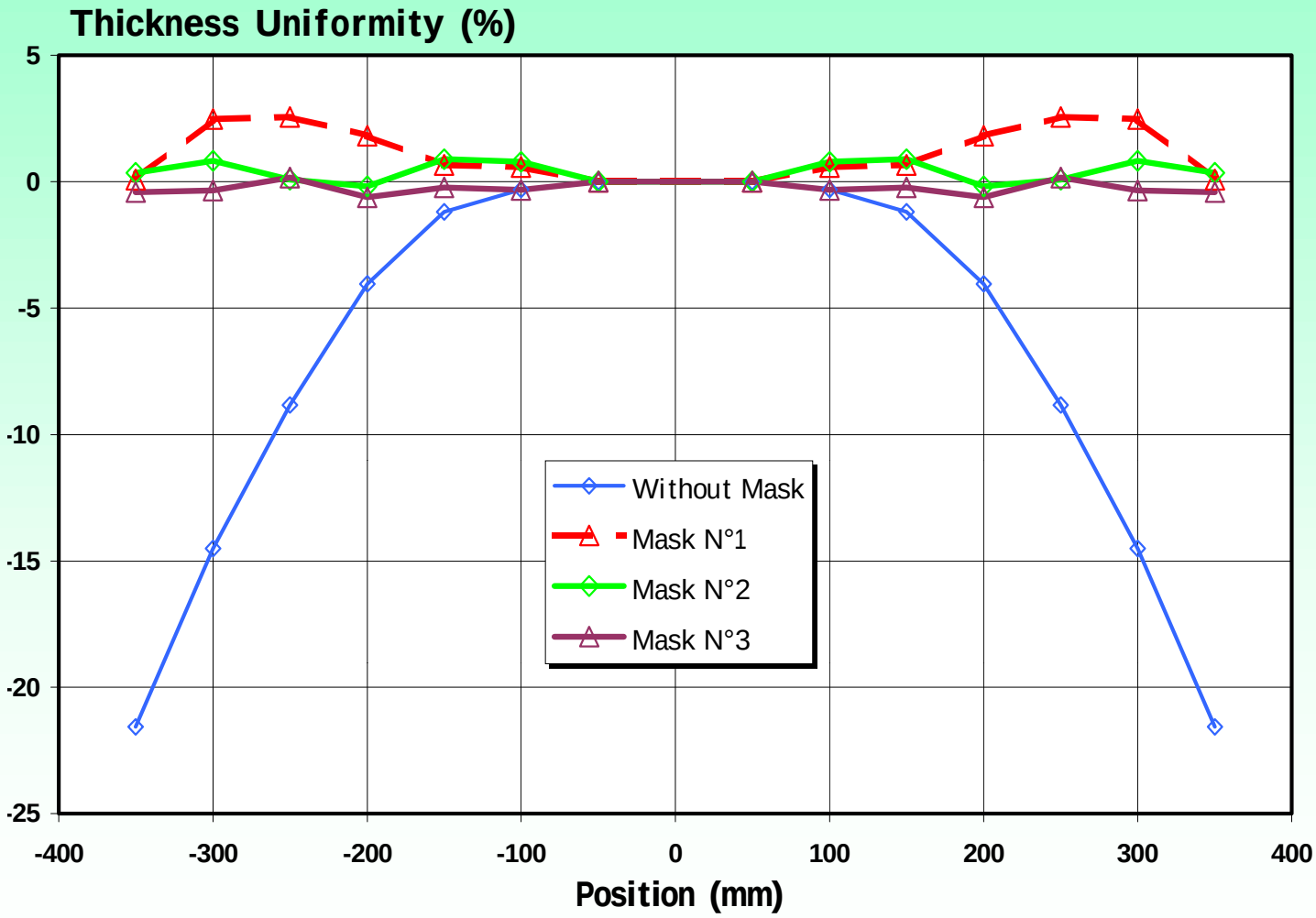
Mirror Coating R&D

Monolayer thickness uniformity

6.10^{-3} on Ø350 mm without masking

3.10^{-3} on Ø700 mm with masking

Useful for mirror matching

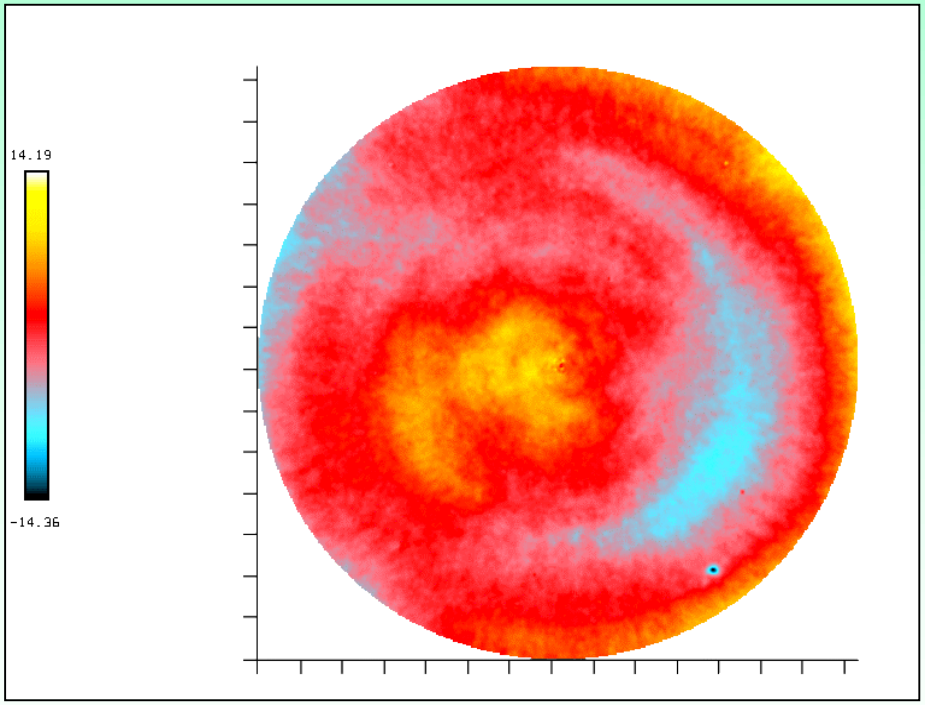


Mirror Coating R&D

Coating uniformity

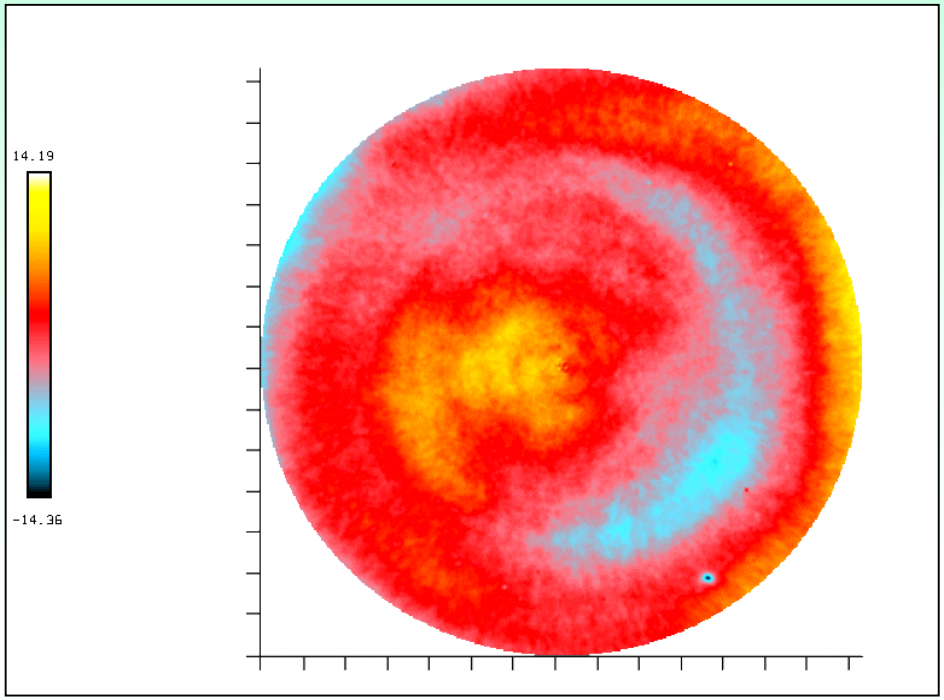
Before coating

3,38 nm RMS - 25,5 nm PV



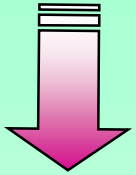
After coating

3,37 nm RMS - 25,2 nm PV



Mirror Coating R&D

High uniformity coating



The coating reproduces the substrate

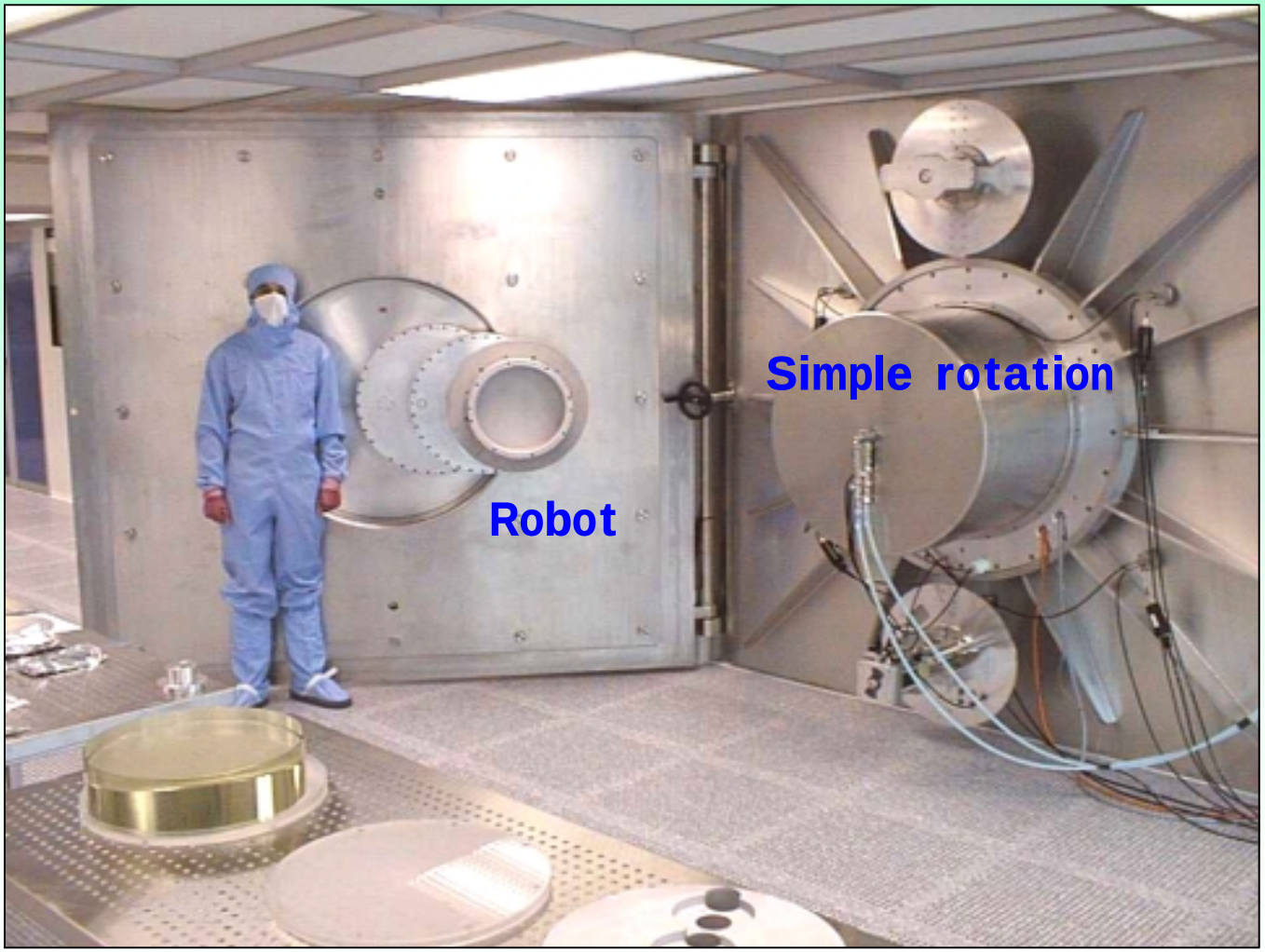
Flatness Limitation = Substrate

Substrate Correction before coating

- **Flatness (# 1nm RMS), control interferometer sensitivity**
- **Special shape (“Mexican Hat”)**
- **Small curvature correction eventually**

Mirror Coating R&D

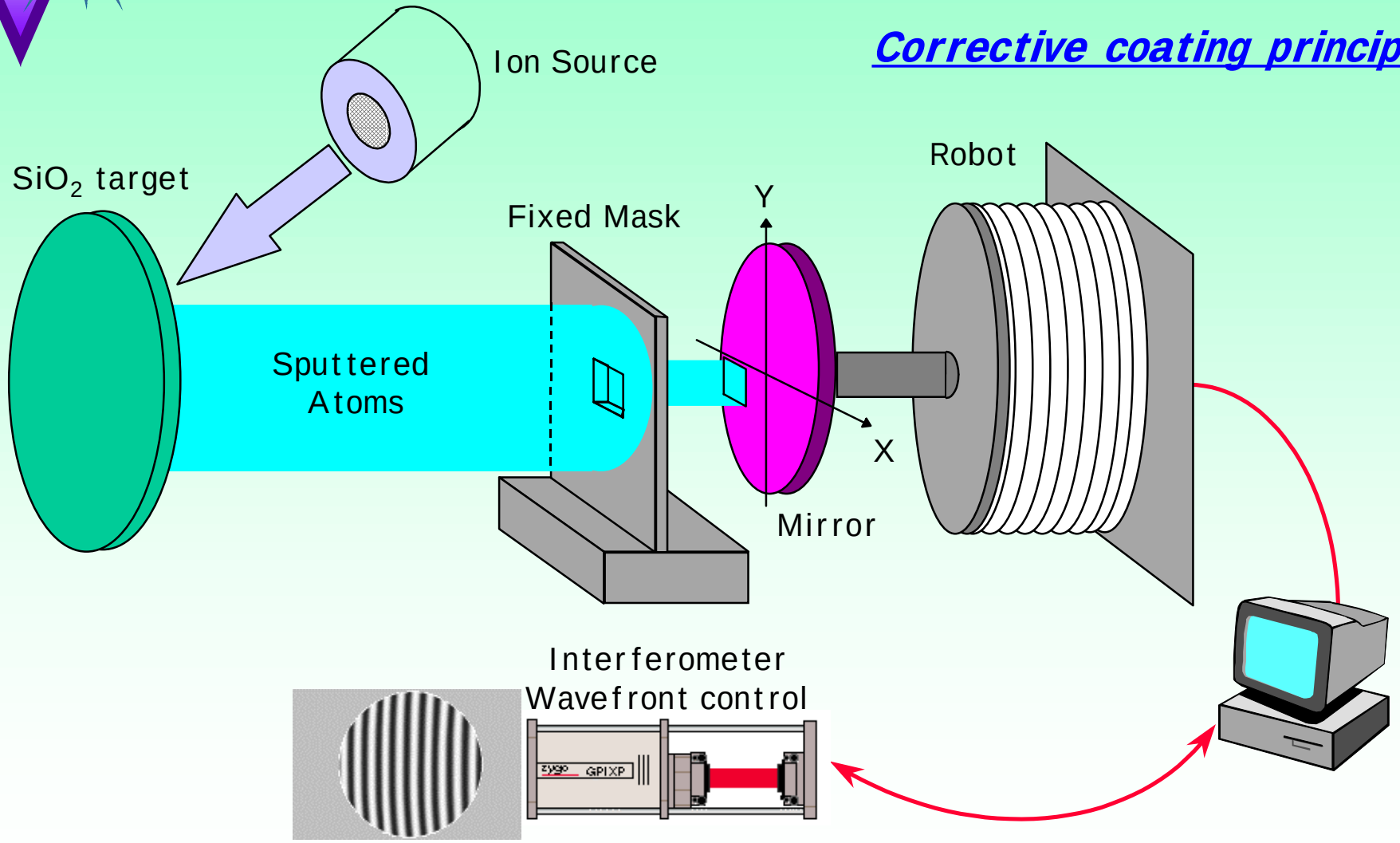
Wavefront Correction



Mirror Coating R&D

Wavefront Correction

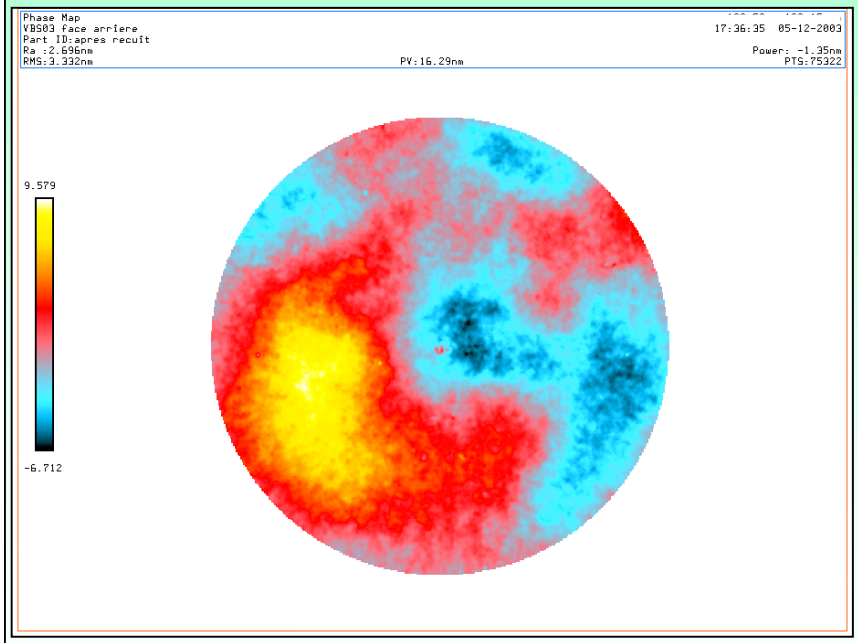
Corrective coating principle



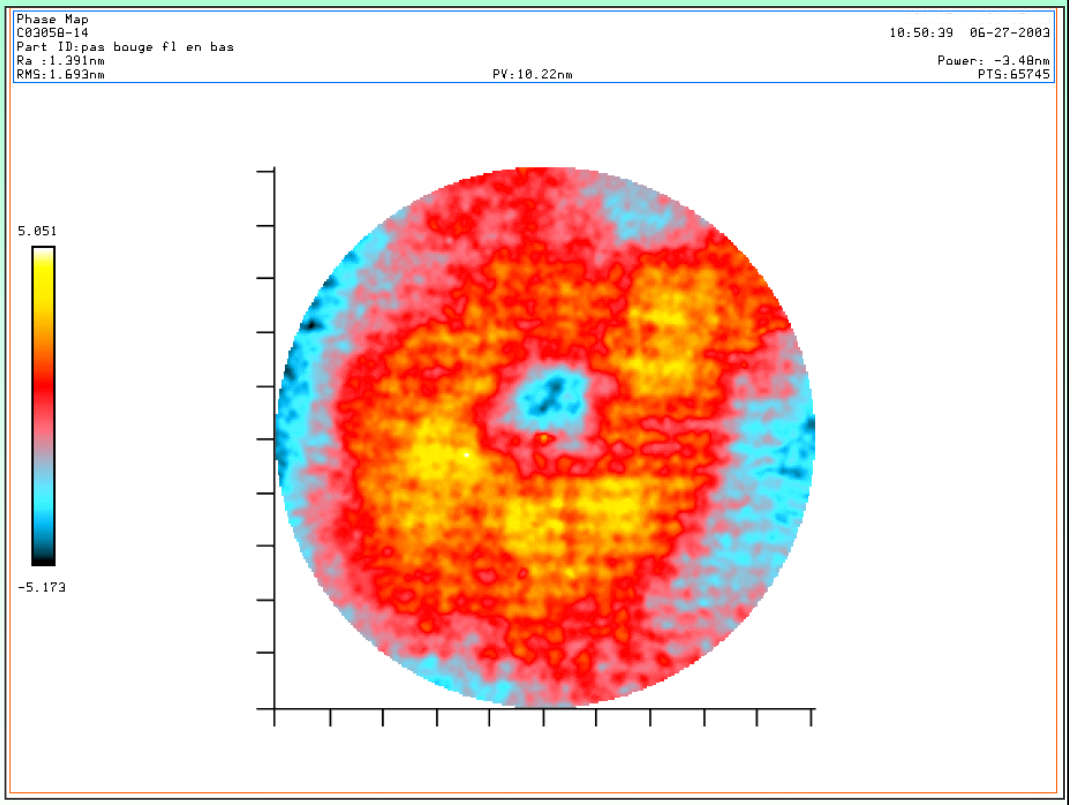
Mirror Coating R&D

Substrate Wavefront Correction

Substrate ∅156 mm VIRGO type, FIRST try (“Flat”)



Before correction (∅110 mm)
3.3 nm R.M.S.
16 nm P.V.



After correction (∅110 mm)
1.7 nm R.M.S.
10 nm P.V.

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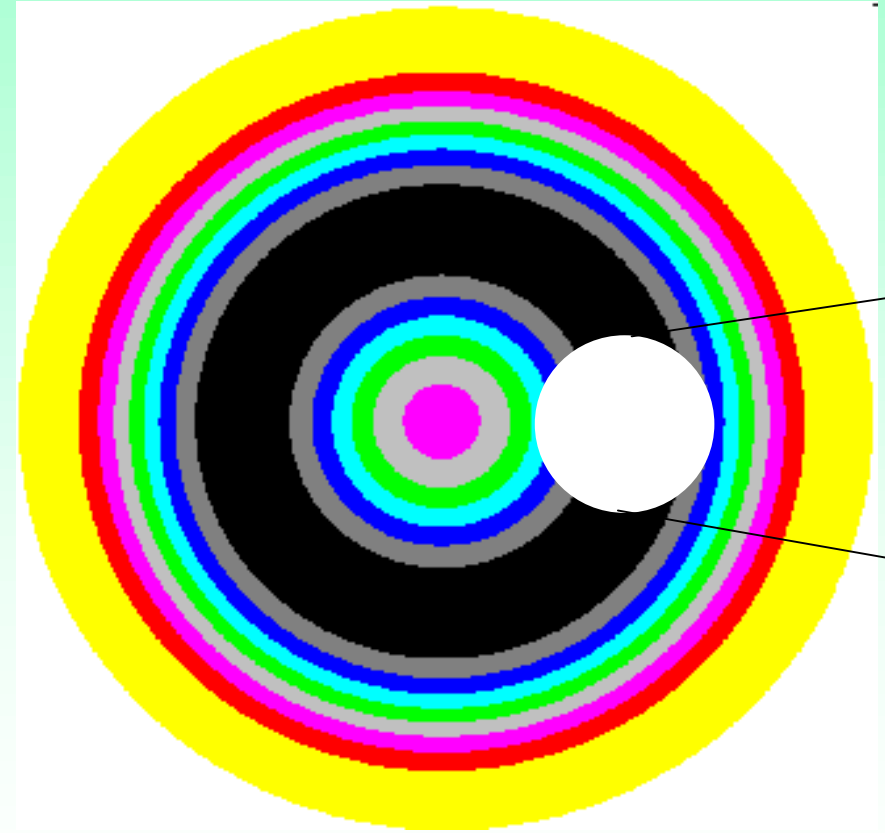
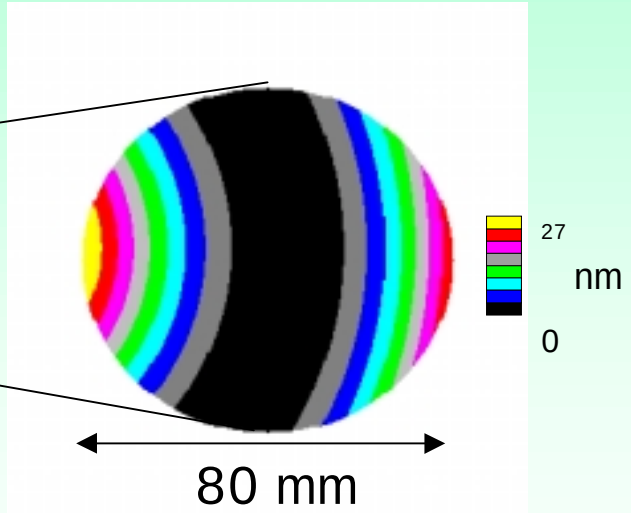
Mirror Coating R&D

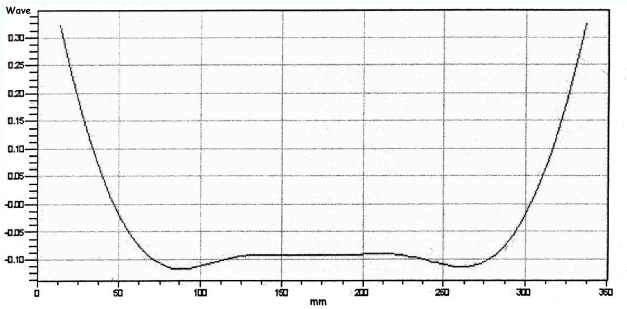
"Mexican Hat" Wavefront

Top view of a Mexican hat



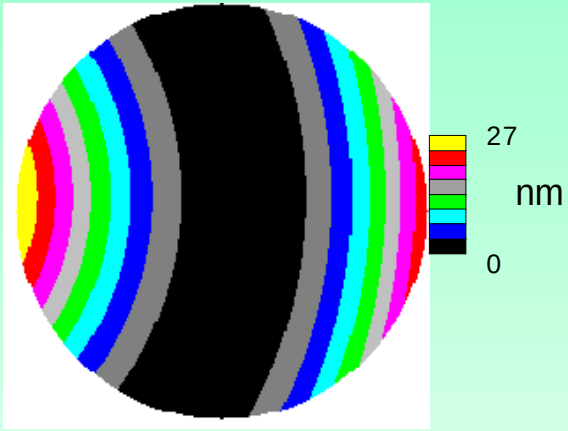
Studied area of Mexican hat



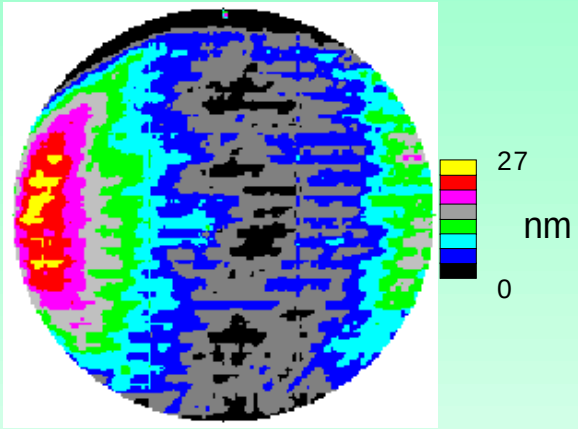


Mirror Coating R&D

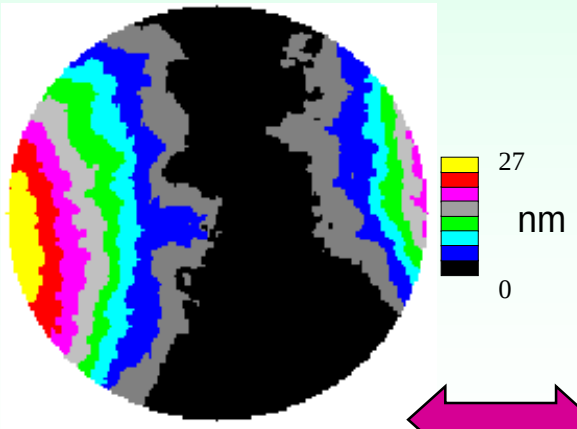
"Mexican Hat" Wavefront



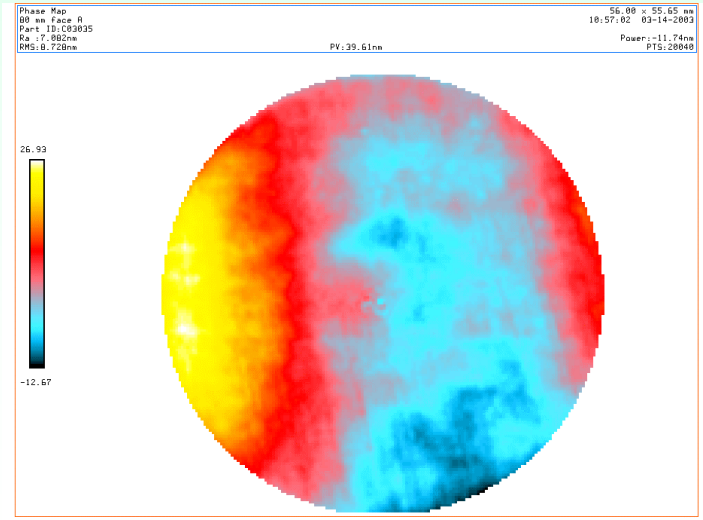
Theoretical mexican hat



Corrective coating simulation



Experimental mexican hat



L. PINARD

Mirror Coating R&D

Material properties

Goal : ↘ absorption and ↘ mechanical loss ϕ

Absorption (< 0,1 ppm)

- Difficult to improve more the target material purity
- Coater cleanliness
- Improvement of the substrate surface quality in term of pollution

  Diffusion in the coatings

  R&D program necessary with bulk material manufacturer

Mirror Coating R&D

Material properties

mechanical loss ϕ

- Use of new materials (ternary alloys, doped materials)
- Improve the mechanical properties (Young modulus)
- Stable links
- Stress decrease
- Compromise with optical properties (n, k)
- Study in progress (IN2P3 contract, R&D EGO (?)

  Advanced LIGO (?))

Mirror Coating R&D

Material properties

mechanical loss ϕ

- Ta_2O_5 doped with proprietary dopant, first try

- Thin 3' sample(mirror) tested (Greg Harry, MIT)

$\phi_{\text{undoped}} = 2.8\ 10^{-4}$ ⇒ $\phi_{\text{doped}} = 1.8\ 10^{-4}$

Improvement : 36%

- Goal : ϕ = 3-5 10^{-5}