High Reflectivity Mirrors Technology

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OVERVIEW

- Introduction – LMA Presentation
  - Cavity mirrors Realizations
- Substrates Choice and substrates preparation
- IBS deposition technique
- High reflectivity multilayers
- Optical Performances
  - Optical Metrology
  - Preserving performances vs time

Introduction – LMA Presentation

Laboratoire des Matériaux Avancés in Lyon

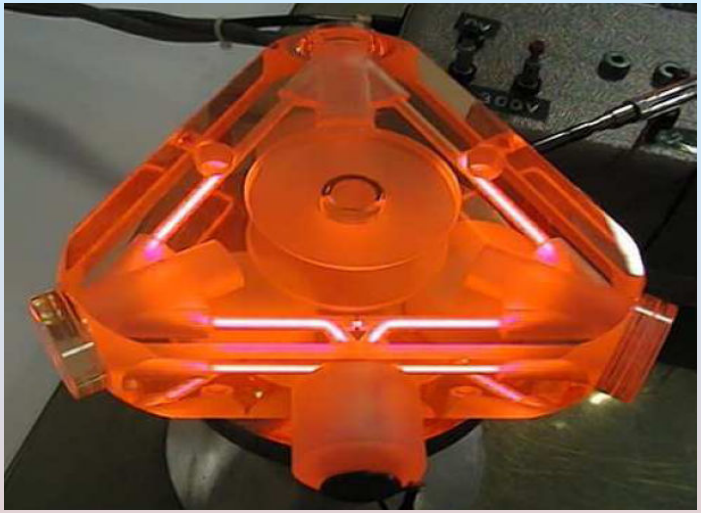
UPS from IN2P3/CNRS (Unité Propre de Service) since 2004 (before IPNL)
Group of 12 engineers, 2 Physicists
Specialized in the study, the realization and the characterization of thin films realized by various deposition processes (CVD, PVD).

150 m^2 clean room class 1 :
Deposition systems, metrology

Cleanliness Importance

Low loss coatings
On small and large
Components for cavities
(Mirrors, AR, dichroic...)

Introduction - Realizations



- Gyrolaser mirrors : Sagem (since 1990)

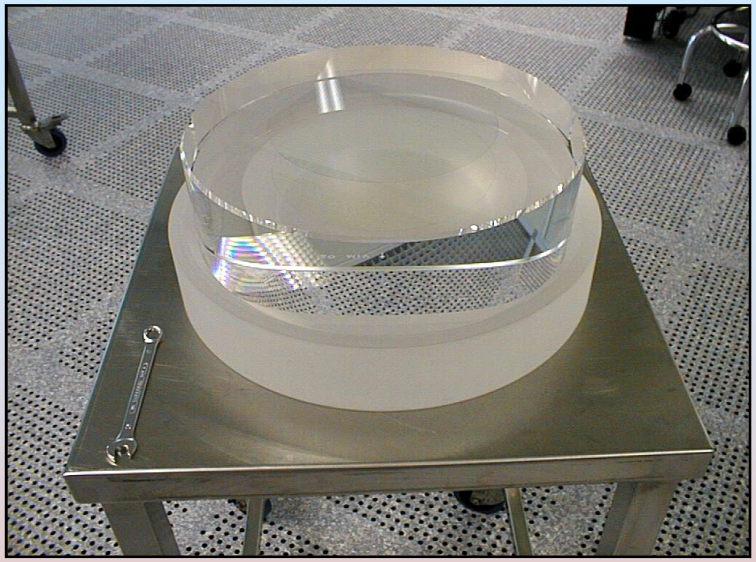
- Mirrors on Sapphire substrates : finesse 100 000 at 300°K and 4°K
  University of Western Australia (1996)

- Cavity mirrors for Hera DESY (finesse 30 000) : 2001 (V. Brisson)

- Mirrors for the BMV ((Magnetic Birefringence of Vacuum) cavity: C. Rizzo (2007)
  Finesse > 500 000

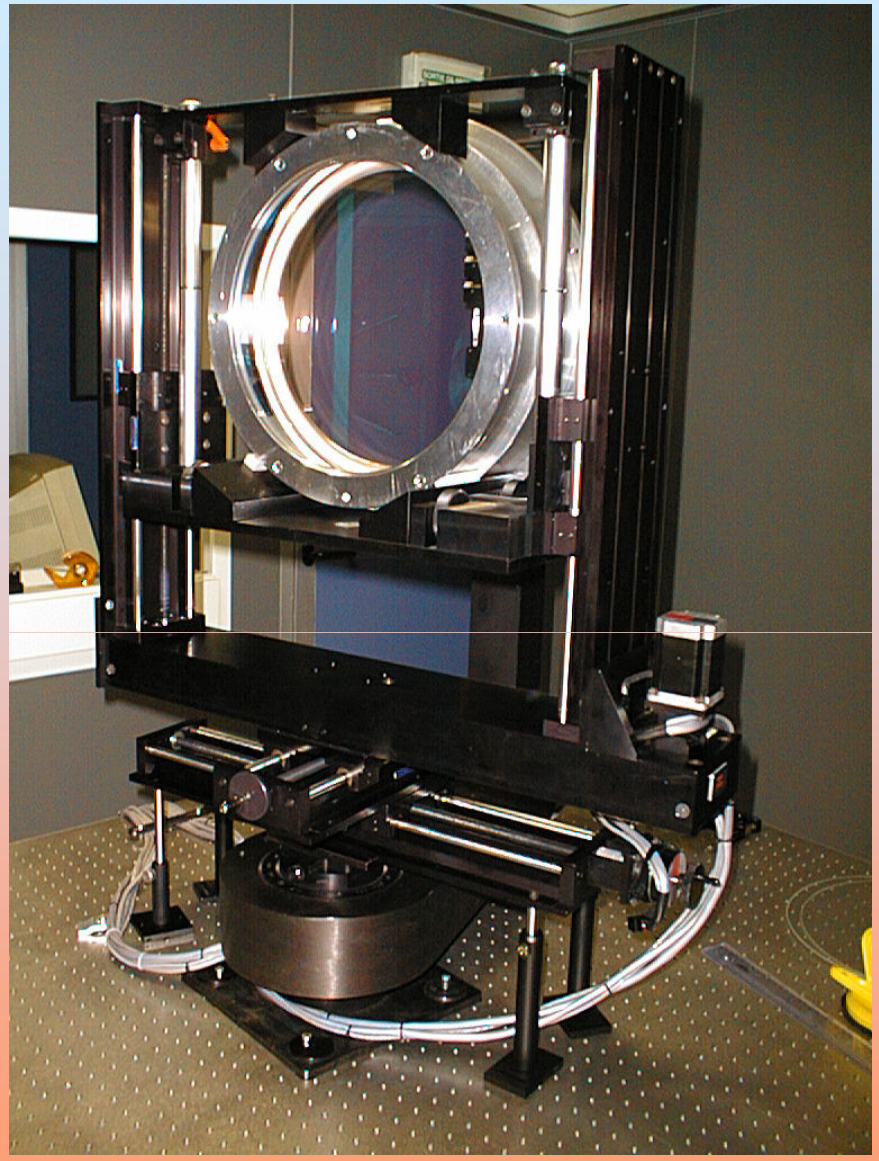
- Project MIGHTYLASER (F. Zomer) : Finesse 30 000 and 300 000

Introduction - Realizations



- Diameter = 350 mm,
- Thickness = 96 mm, Weight = 20 kg

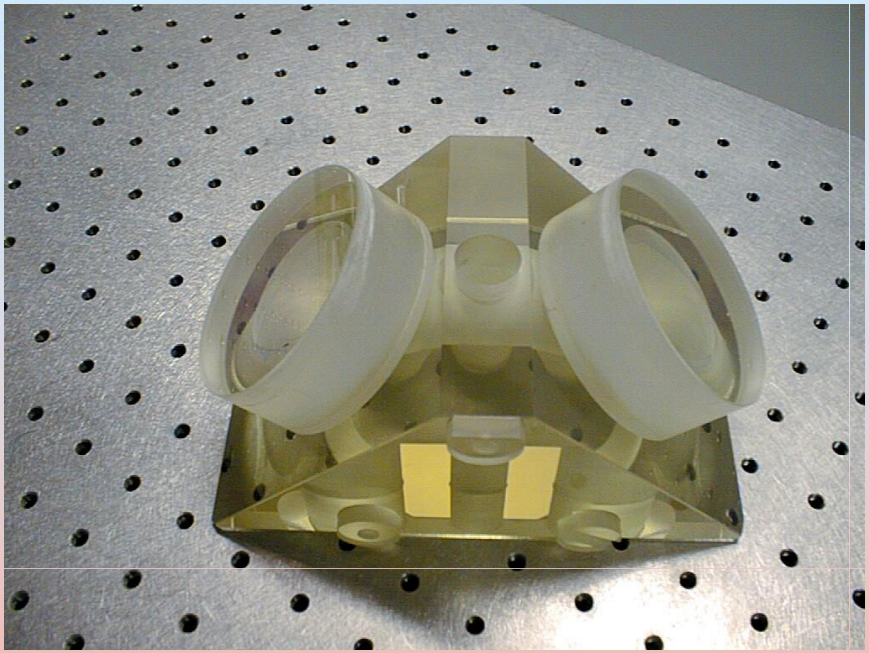
SIDE B measurements	VIRGO specifications	LMA mesurements
average scattering	< 5 ppm	4 ppm 150×150 mm^2
average transmission	10 < T < 50 ppm	42,9 +/- 0,2 ppm ∅150 mm
average absorption	< 5 ppm	0,63 +/- 0,07 ppm ∅150 mm
wavefront flatness	< 8 nm RMS ∅150 mm	3,8 nm RMS ∅150 mm



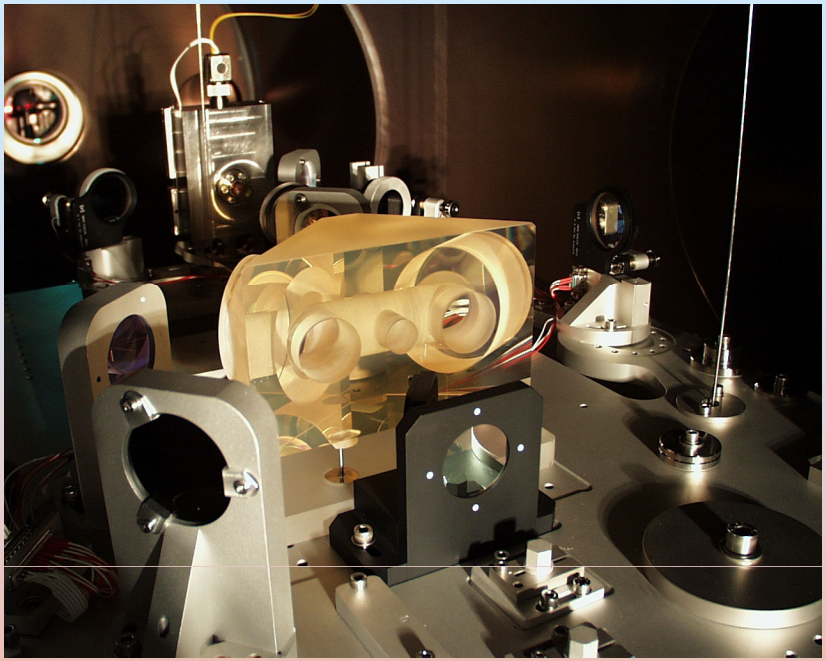
VIRGO

Introduction - Realizations

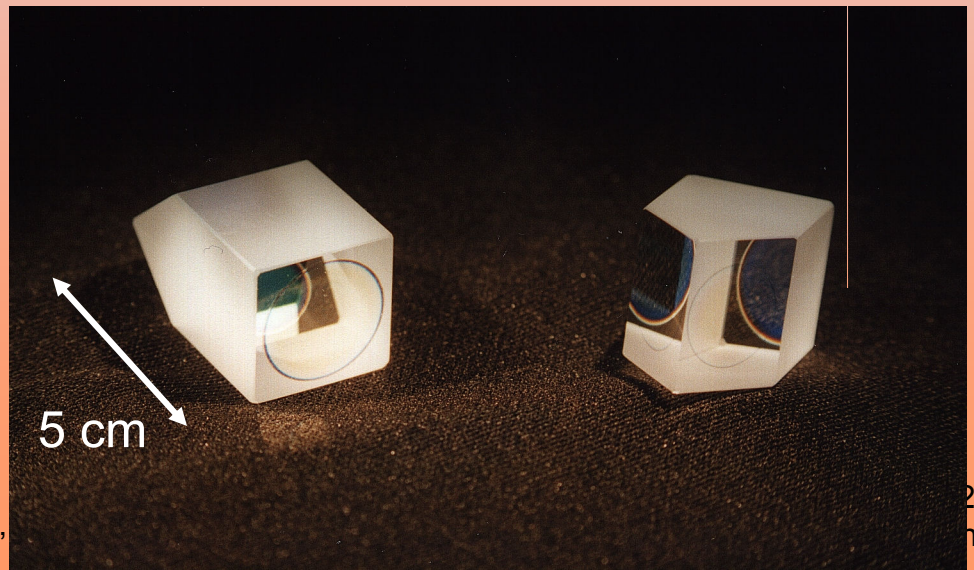
VIRGO Mode Cleaner

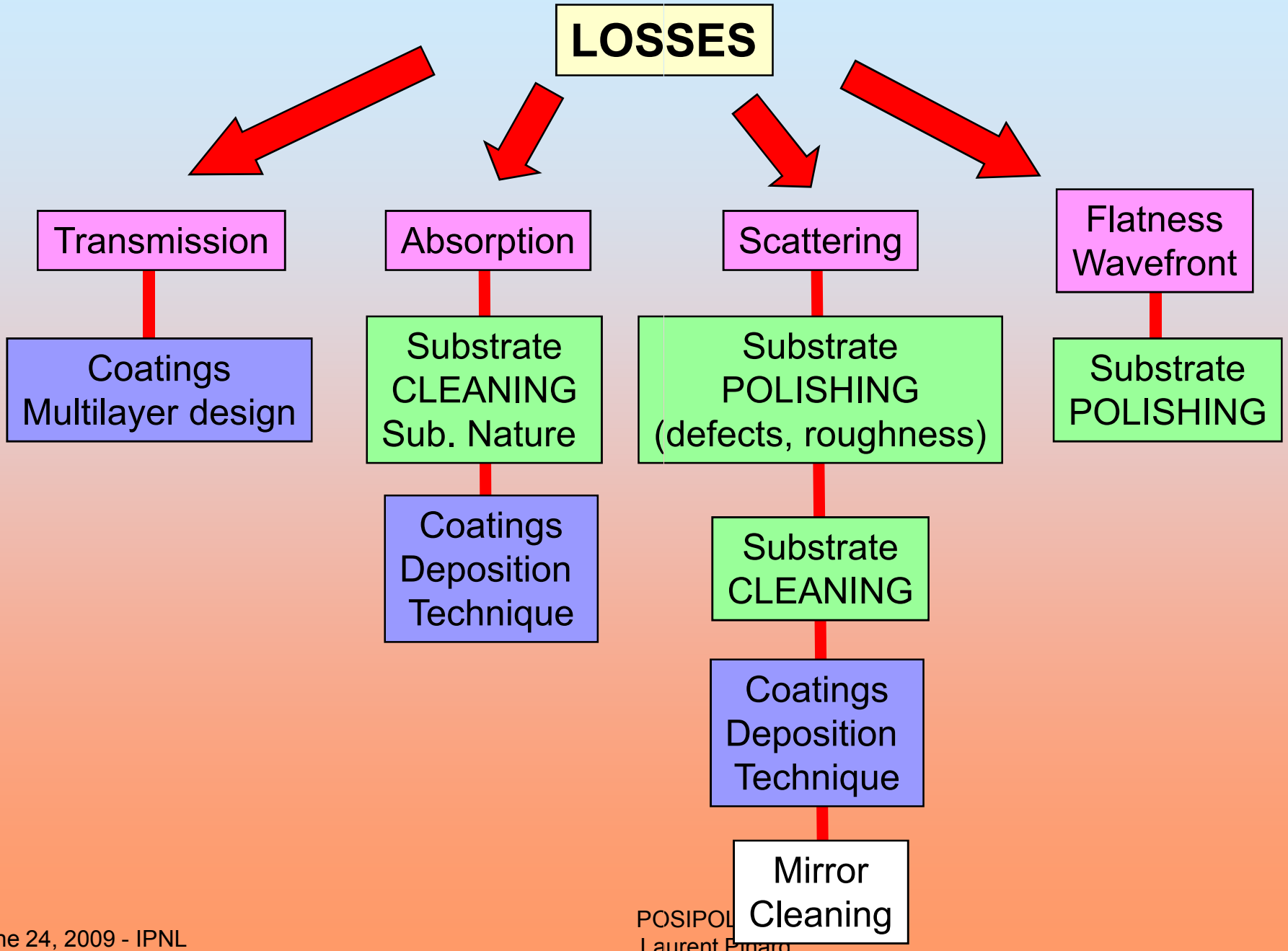


After optical contact



On the optical bench




LOSSES
Transmission
Coatings Multilayer design
Absorption
Substrate CLEANING Sub. Nature
Coatings Deposition Technique
Scattering
Substrate POLISHING (defects, roughness)
Substrate CLEANING
Coatings Deposition Technique
Mirror Cleaning
Flatness Wavefront
Substrate POLISHING

Substrate Choice and Substrate Preparation

Polishing / Scattering

Scattering Sources

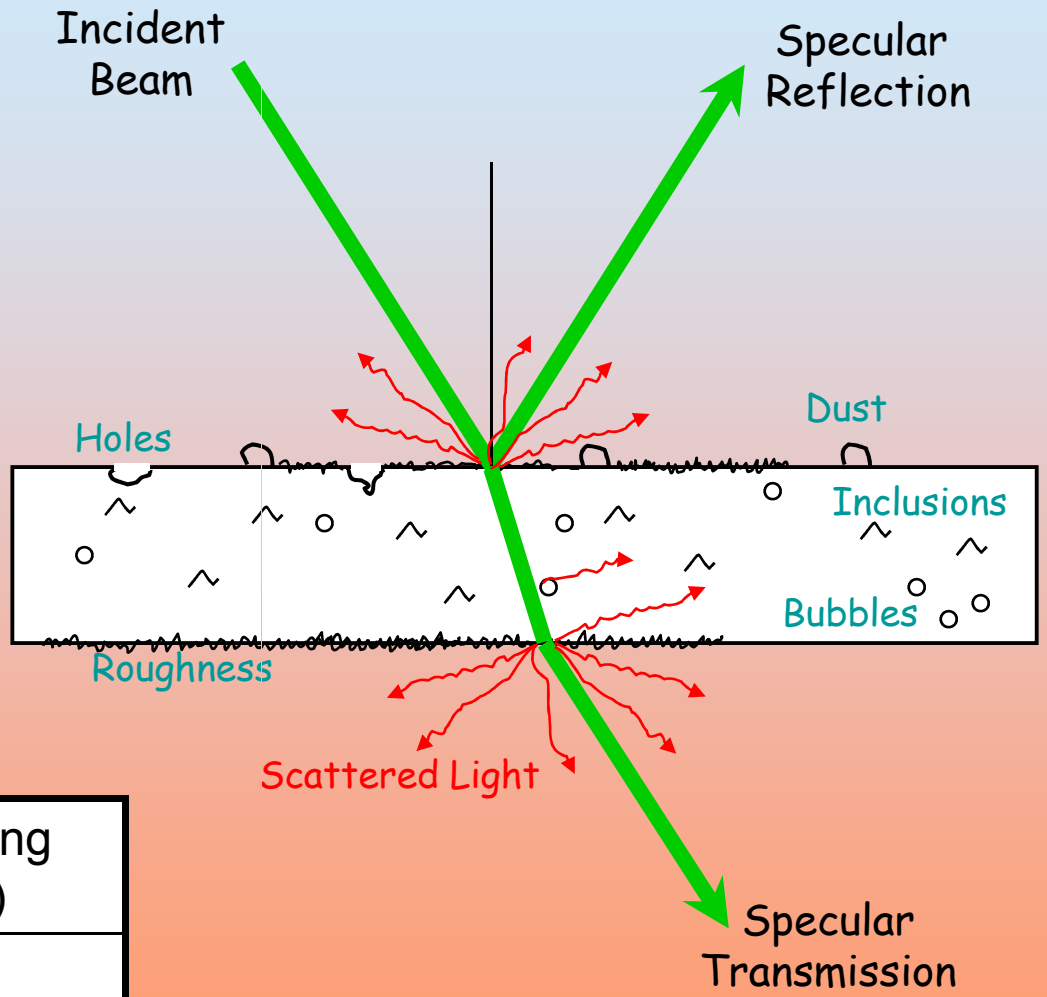
Surface

- Roughness
- Scratches
- Holes
- **Particles (Dust)**

Clean Environment

Volume

- Inclusions
- Bubbles

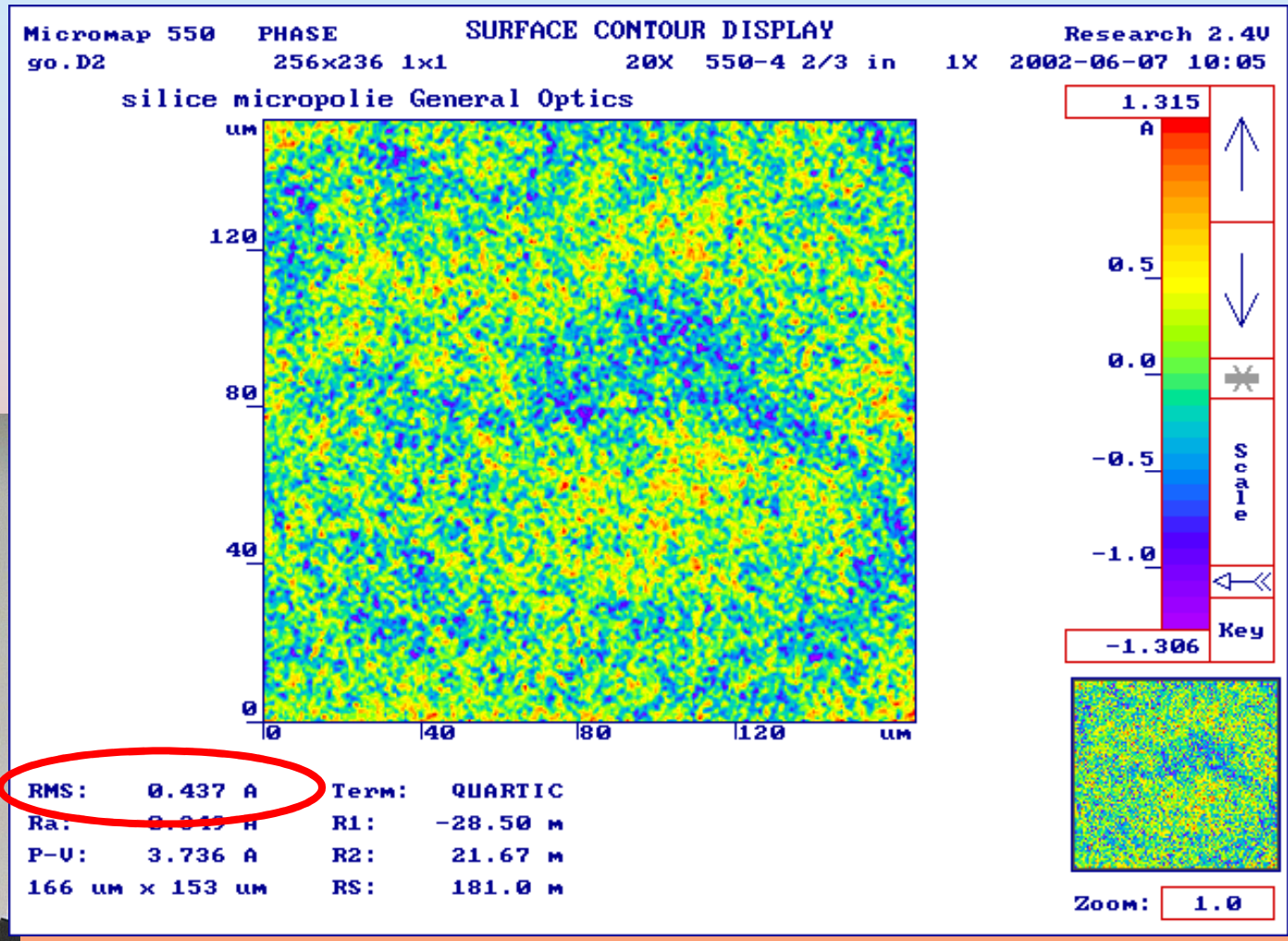


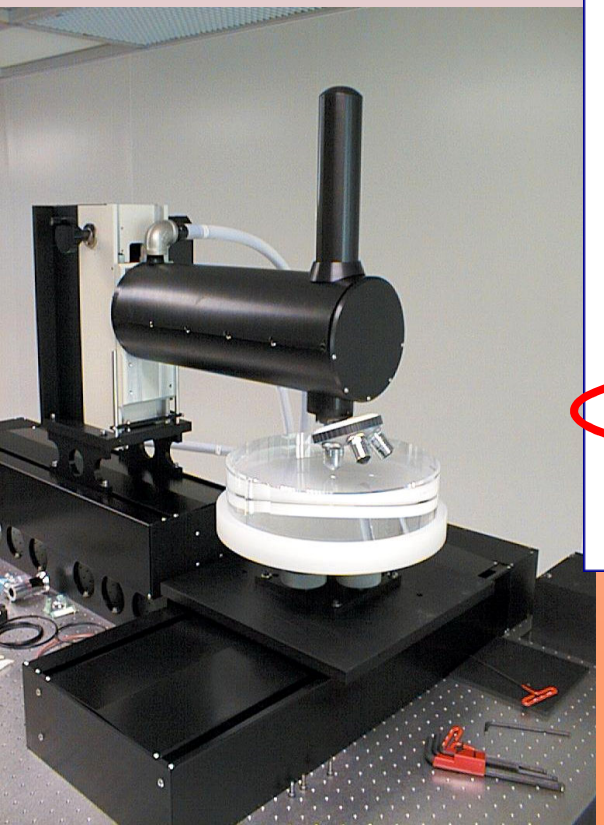
Roughness (Å)	Scattering (ppm)
1	# 1
10	#130

Substrate Choice and Substrate Preparation

American, Australian, French companies

Roughness Micropolished Substrate



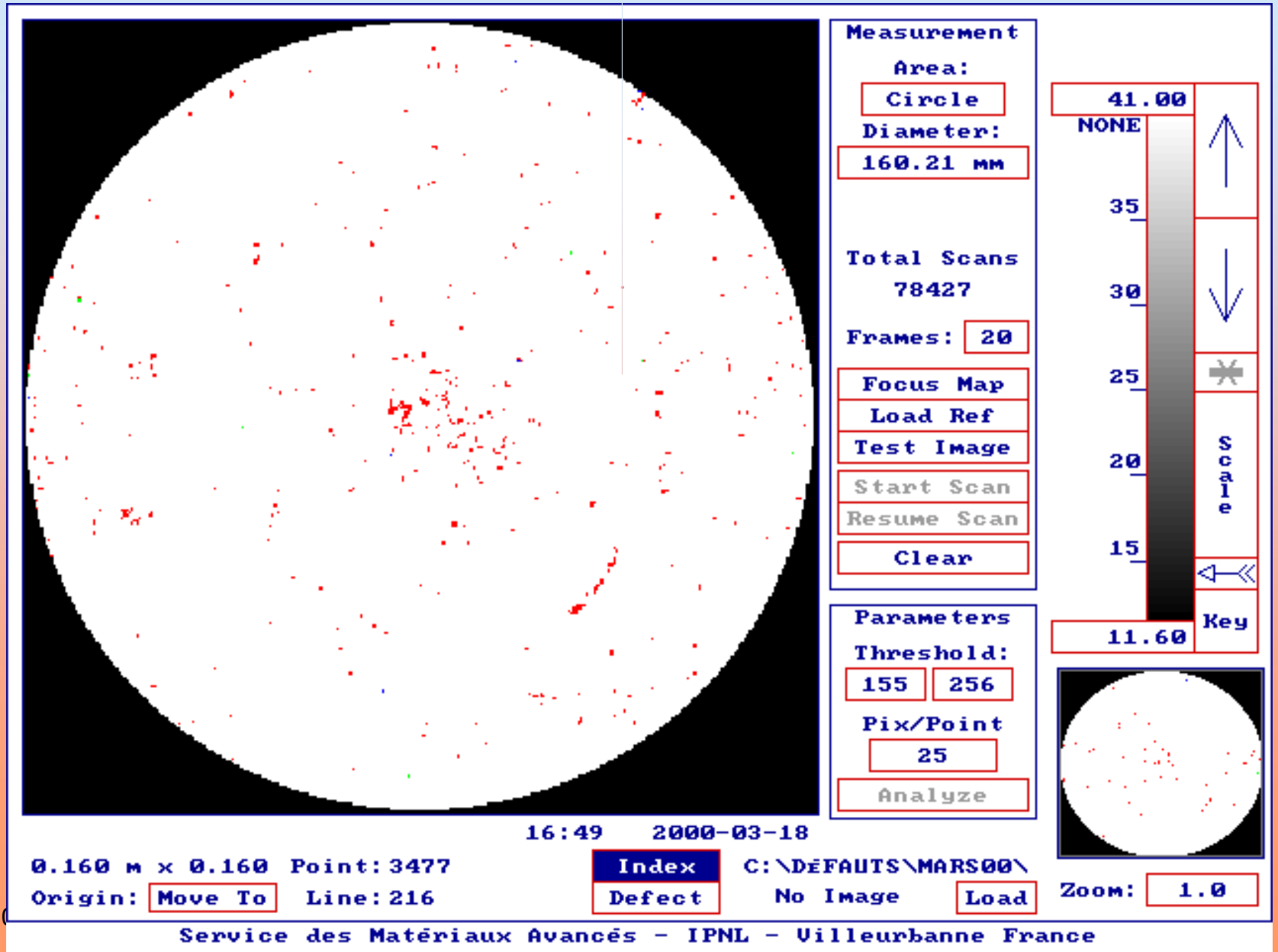


Optical Profilometer MICROMAP (proto unique in Europe)

Substrate Choice and Substrate Preparation

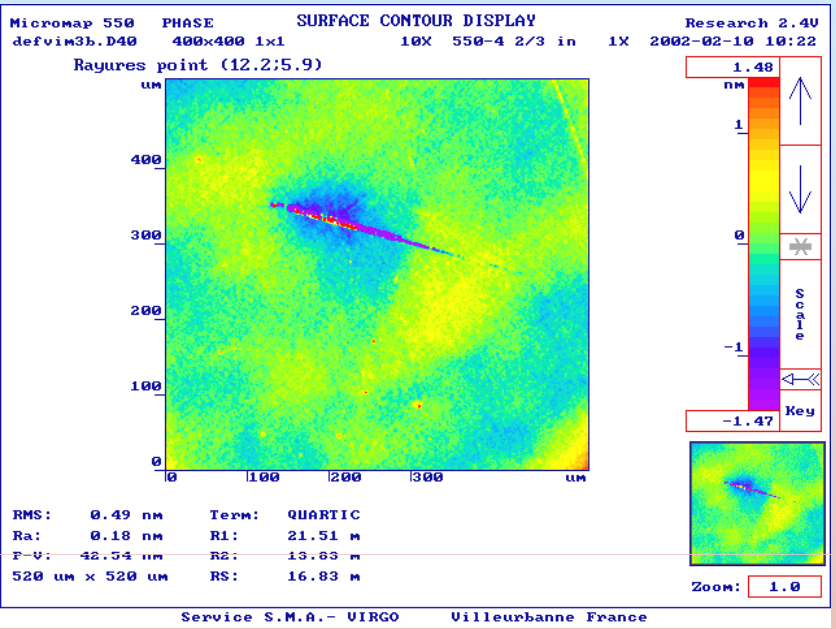
Defects Detection

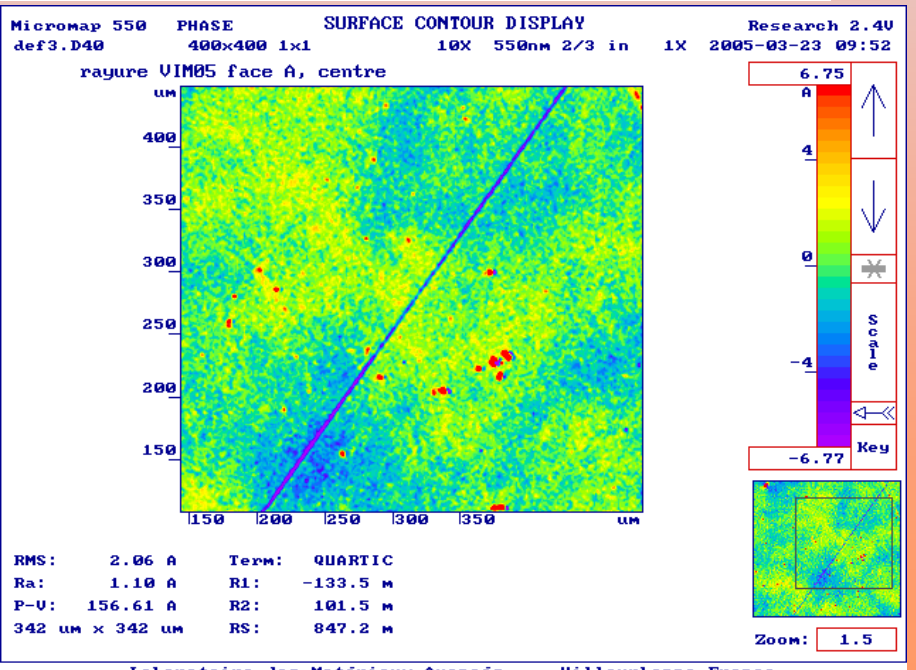
Scan on ∅300 mm max, measured area 500*500 µm^2 , threshold 0,3 µm

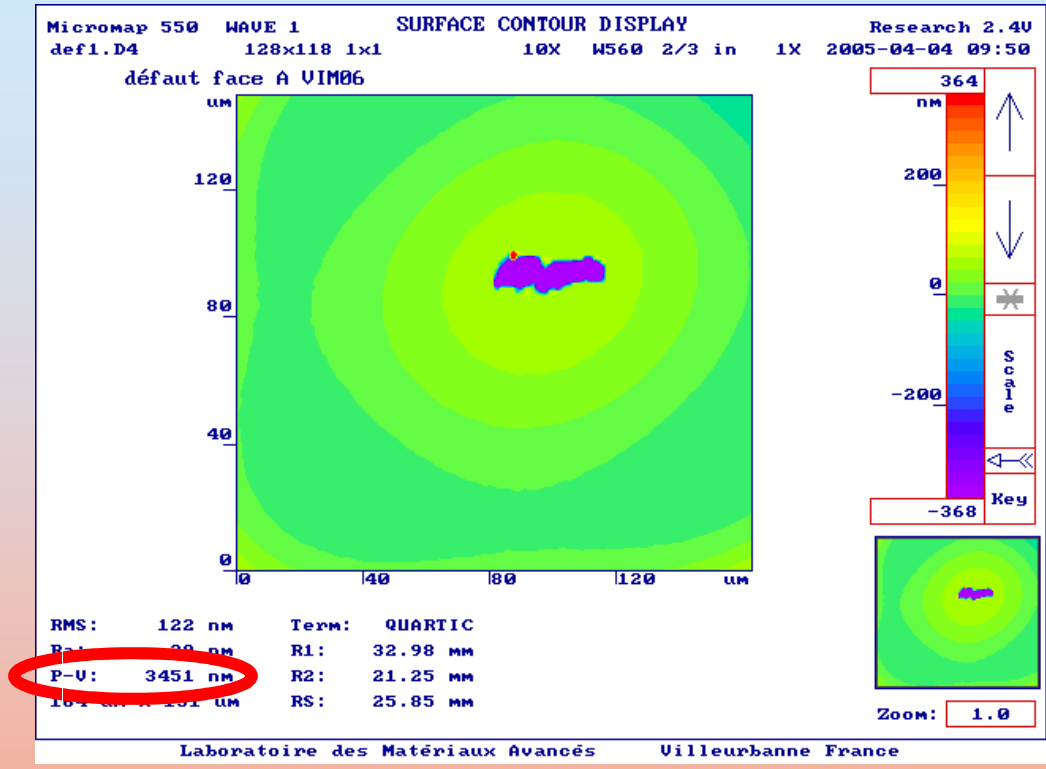


Substrate Choice and Substrate Preparation

Defects Detection





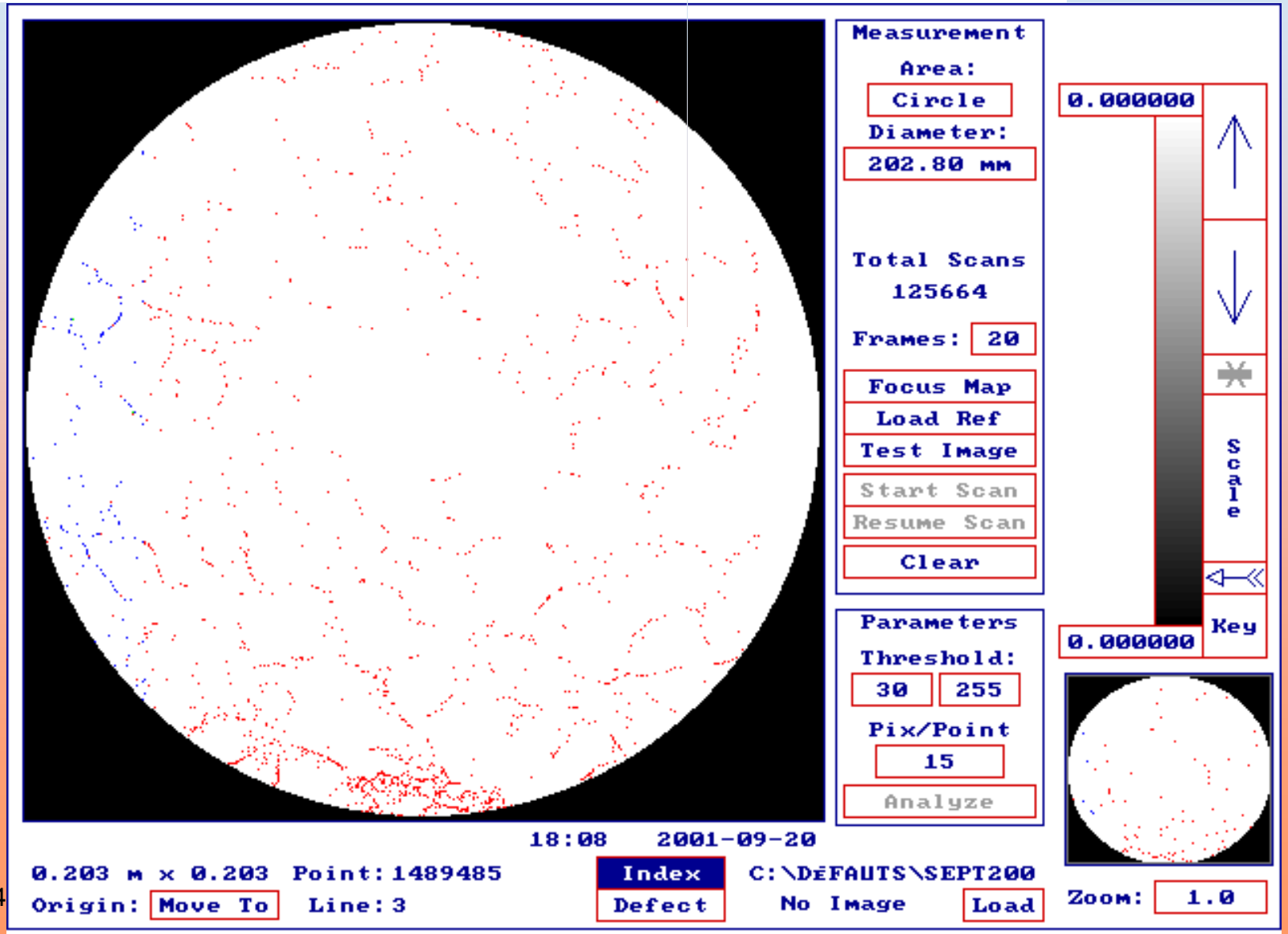


Scratches/ Holes

Substrate Choice and Substrate Preparation

Defects Detection - CLEANING

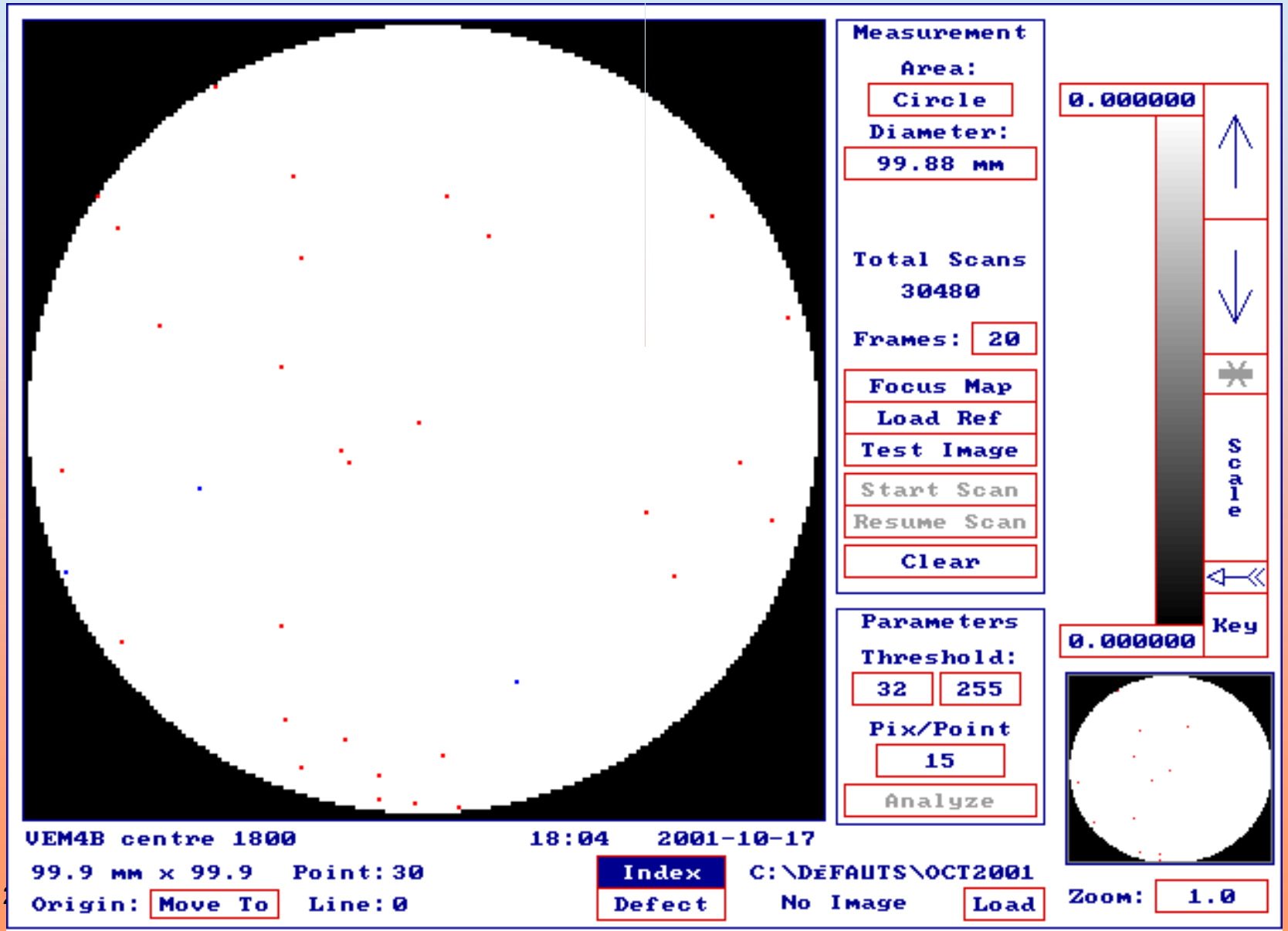
Bad Cleaning : > 10^6 defects on Ø 200 mm (drying)



Substrate Choice and Substrate Preparation

Defects Detection - CLEANING

Good Cleaning: 30 defects on Ø 100 mm



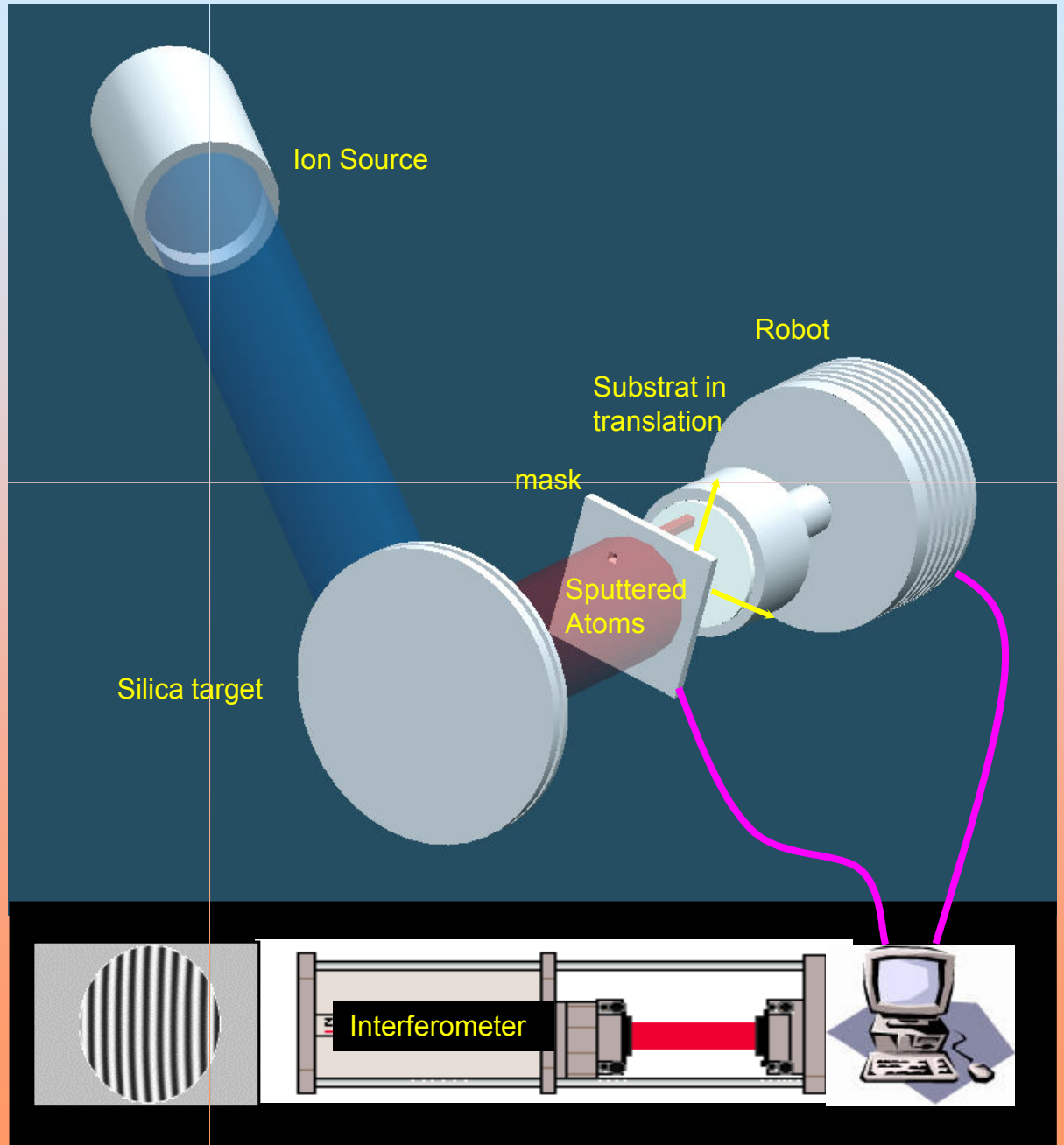
Substrate Choice and Substrate Preparation

Flatness – Wavefront improvement

Corrective Coating

Add silica to fill the holes

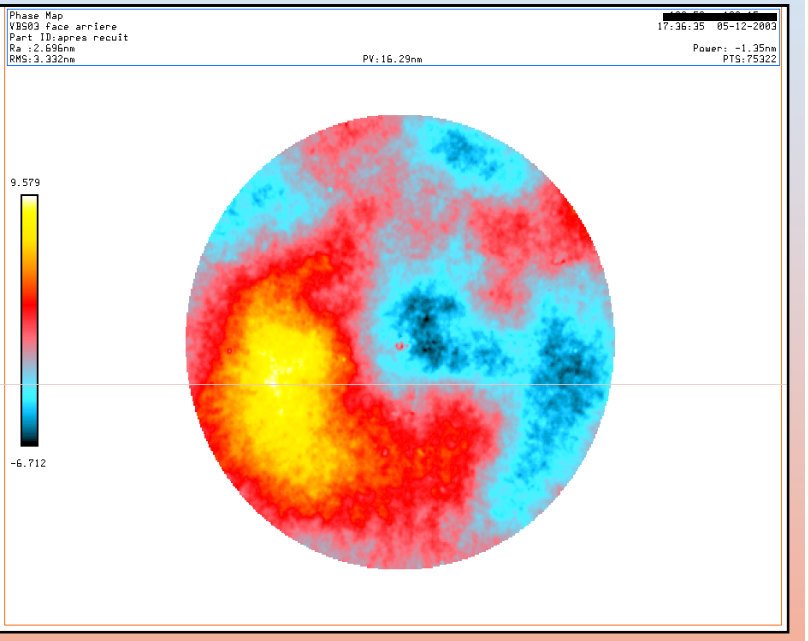
- Flat Surface (< 1 nm RMS)
  Advanced Virgo



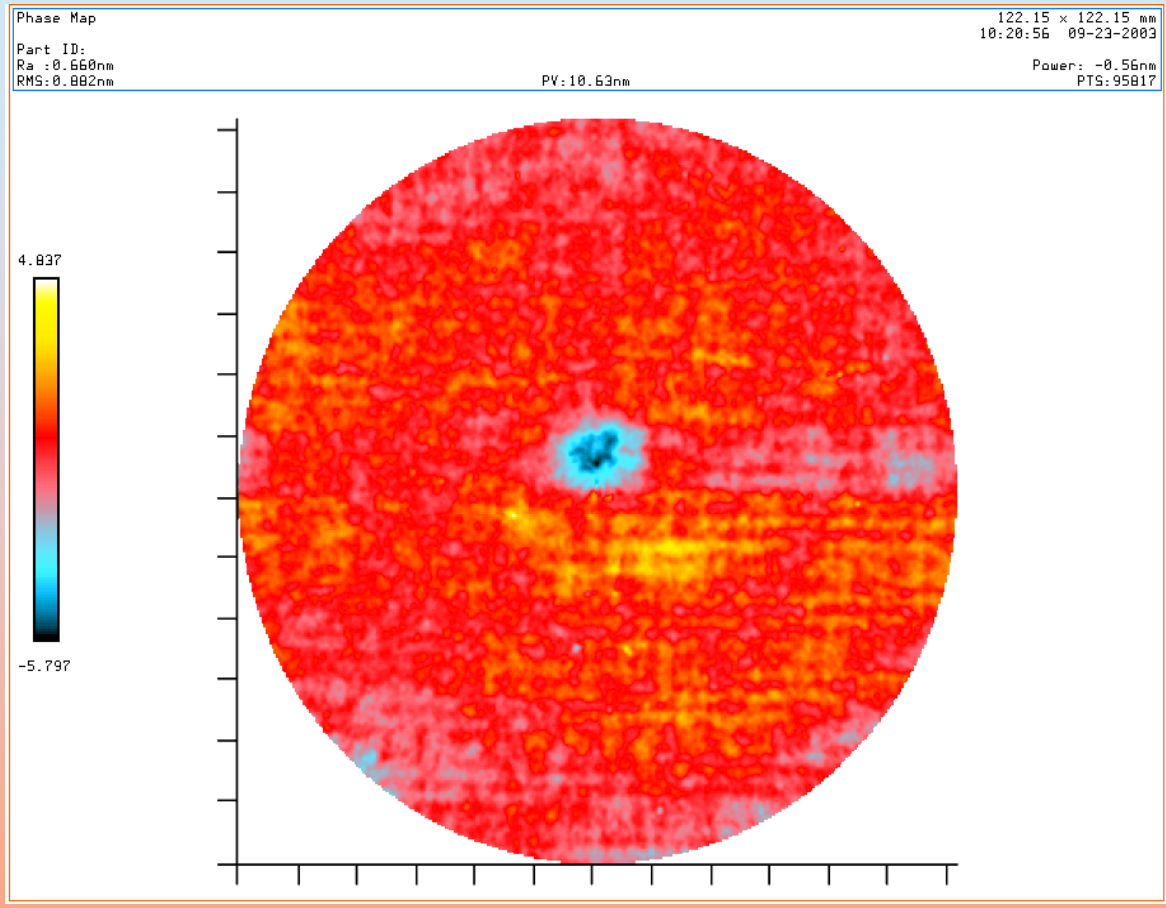
Substrate Choice and Substrate Preparation

Flatness – Wavefront improvement

Substrate ∅156 mm VIRGO type



Before correction (∅120 mm)
3.3 nm R.M.S.
16 nm P.V.



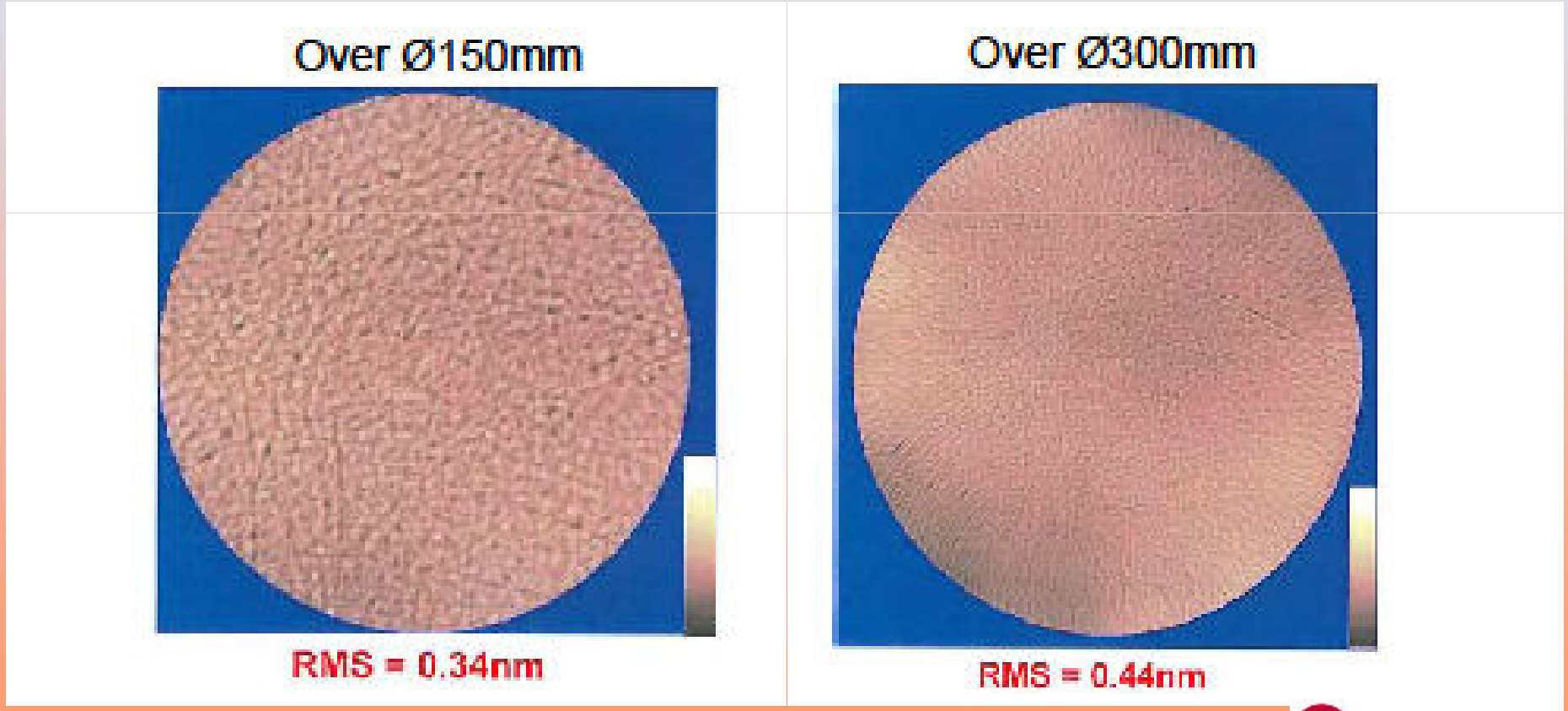
After correction (∅120 mm)
0.98 nm R.M.S.
10 nm P.V.
Microroughness preserved (0,5 Å RMS)

Substrate Choice and Substrate Preparation

Flatness – Wavefront improvement

Ion Beam Polishing : remove « bumps» with an ion beam

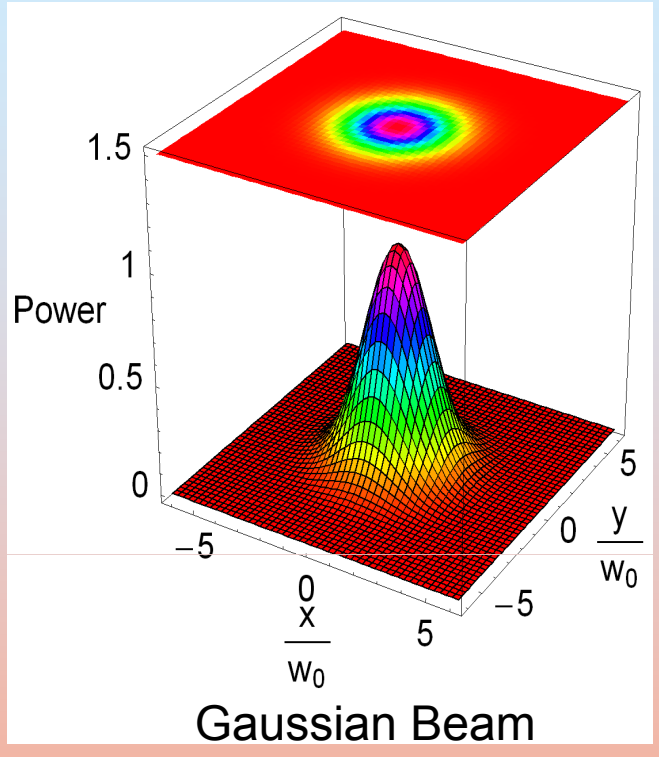
Very good flatness on large area (US company)
Microroughness higher (1,6 Å RMS)



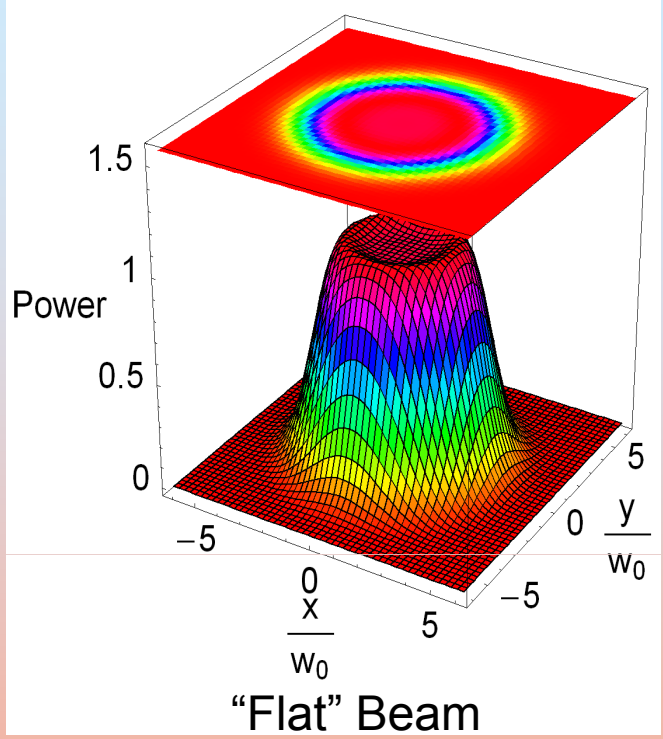
L3 communications
Integrated Optical Systems
Tinsley

Substrate Choice and Substrate Preparation

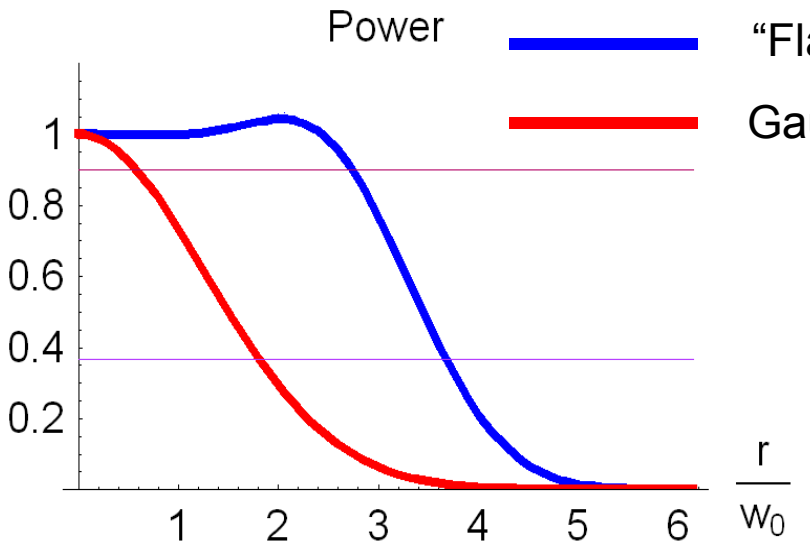
Shape realization : « Mexican hat »

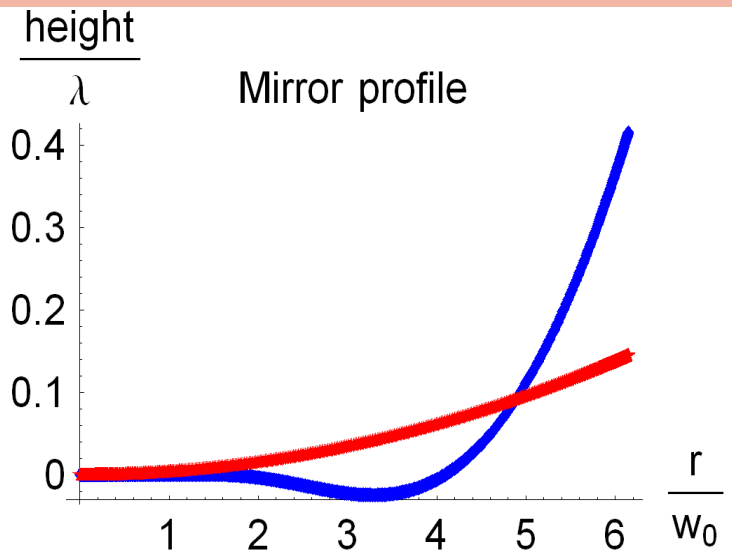


Gaussian Beam



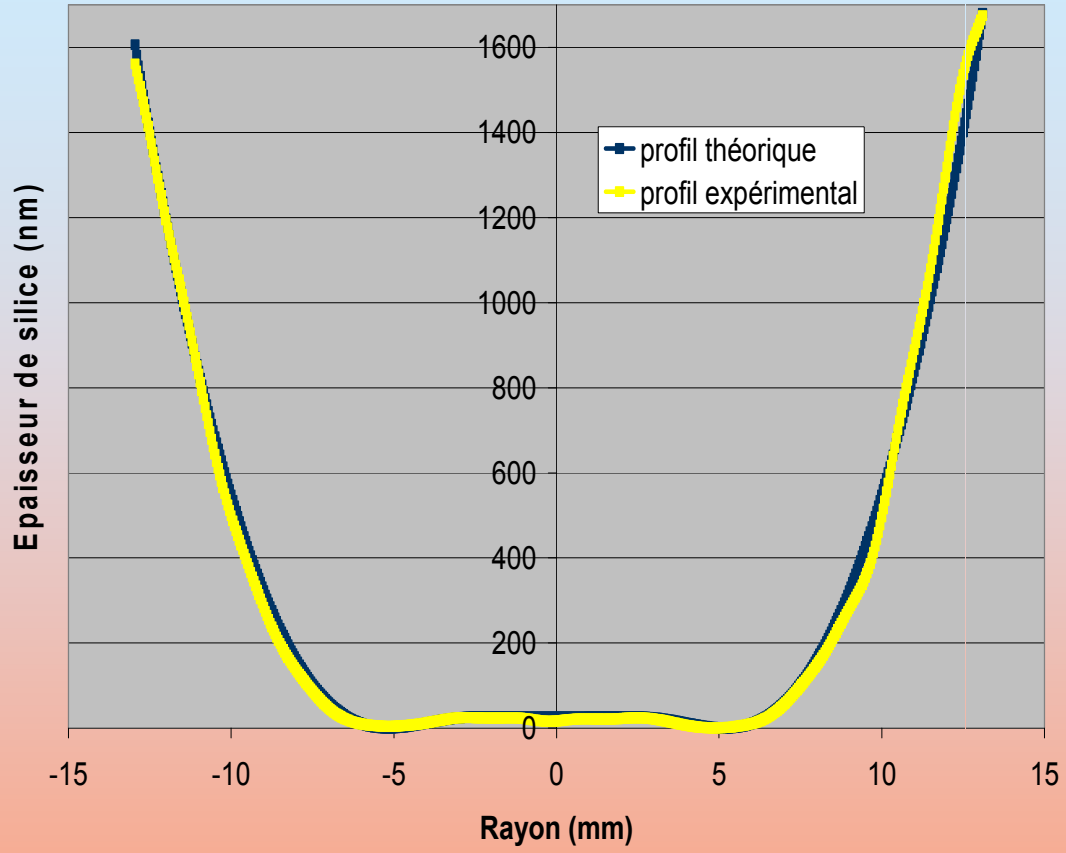
"Flat" Beam

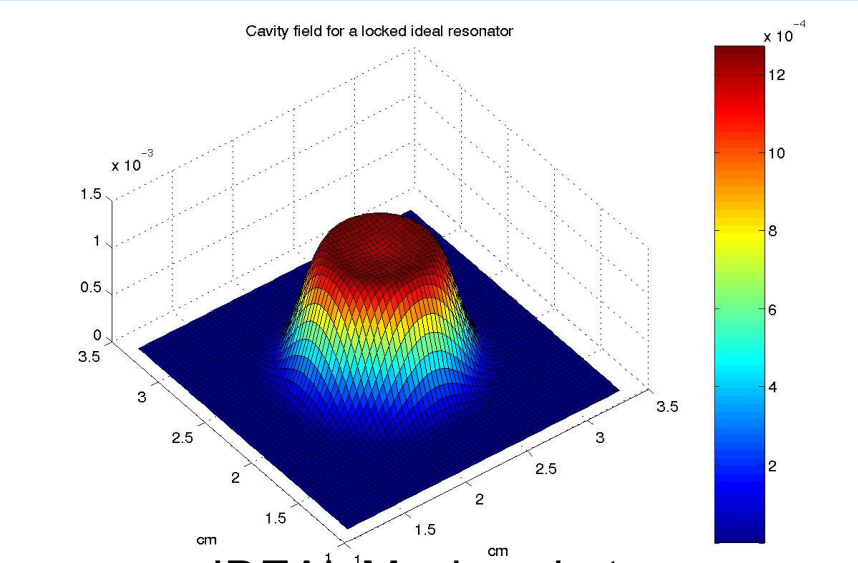




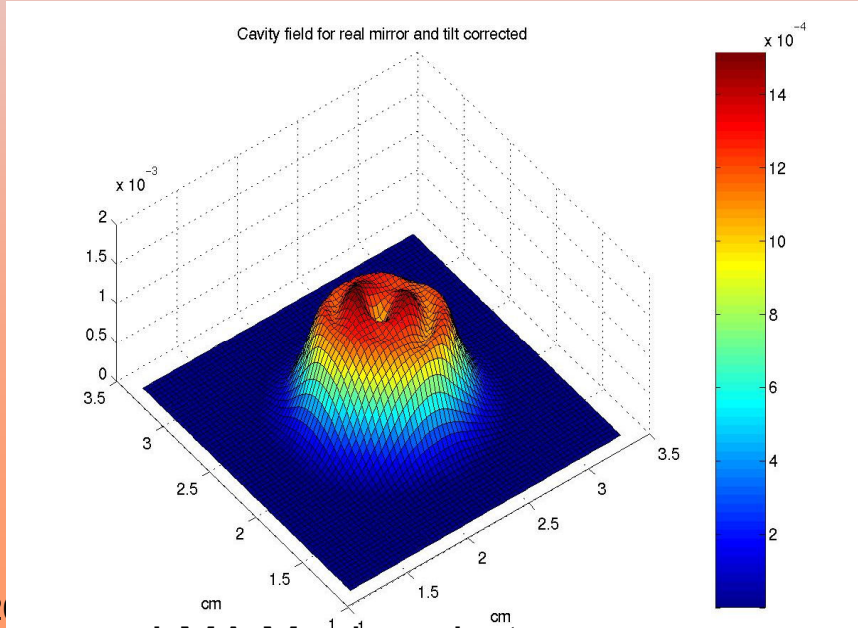
Substrate Choice and Substrate Preparation

Shape realization : « Mexican hat »





IDEAL Mexican hat



LMA Mexican hat

Error compared to the theoretical profil :

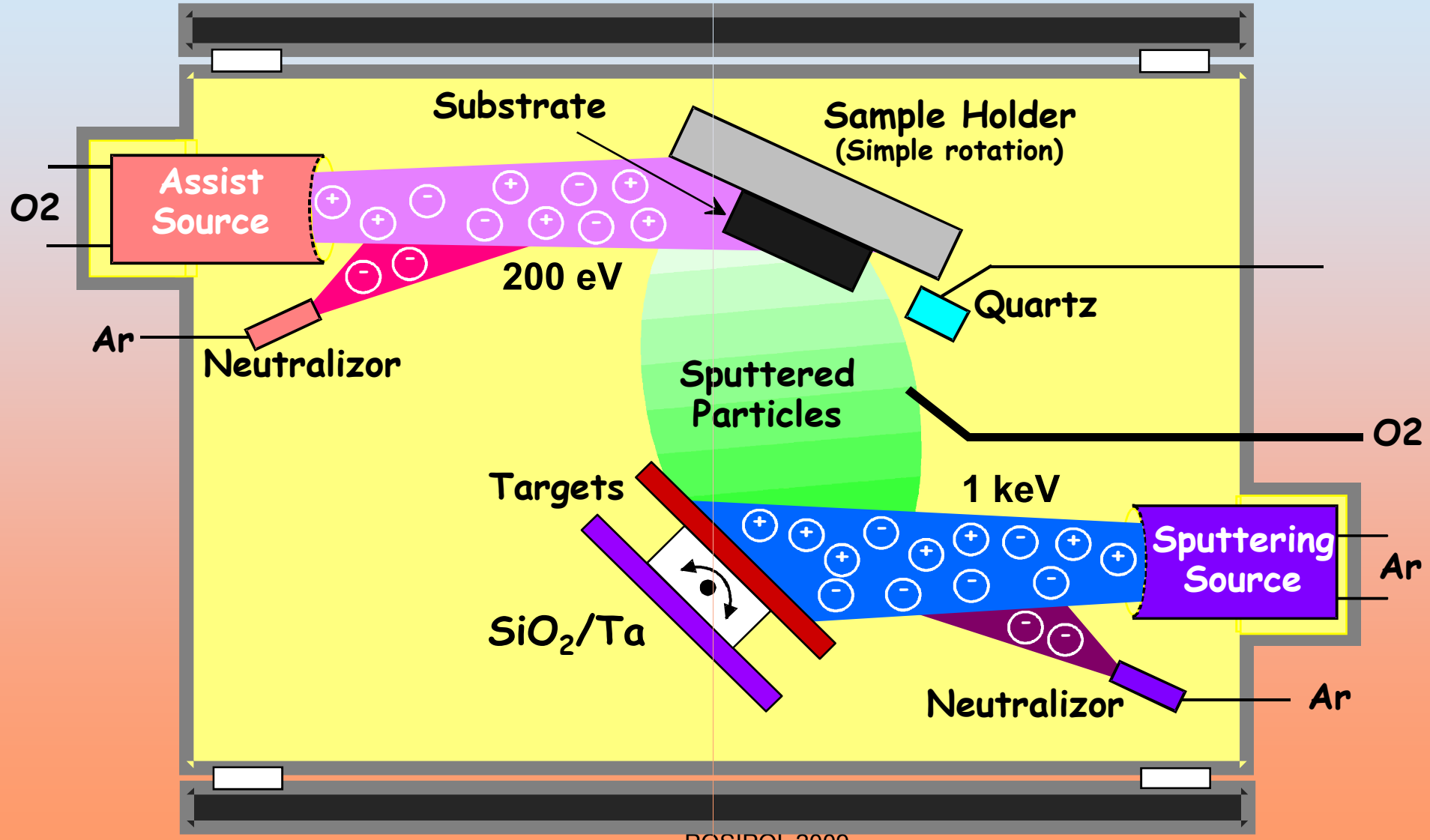
10 nm in central area (Ø < 14 mm)

100 nm on the edges (14 mm < Ø < 26 mm)

50 mm Mirrors for Caltech (USA)

Ion Beam Sputtering - IBS

Deposition technique used all over the world to realize low-loss coatings



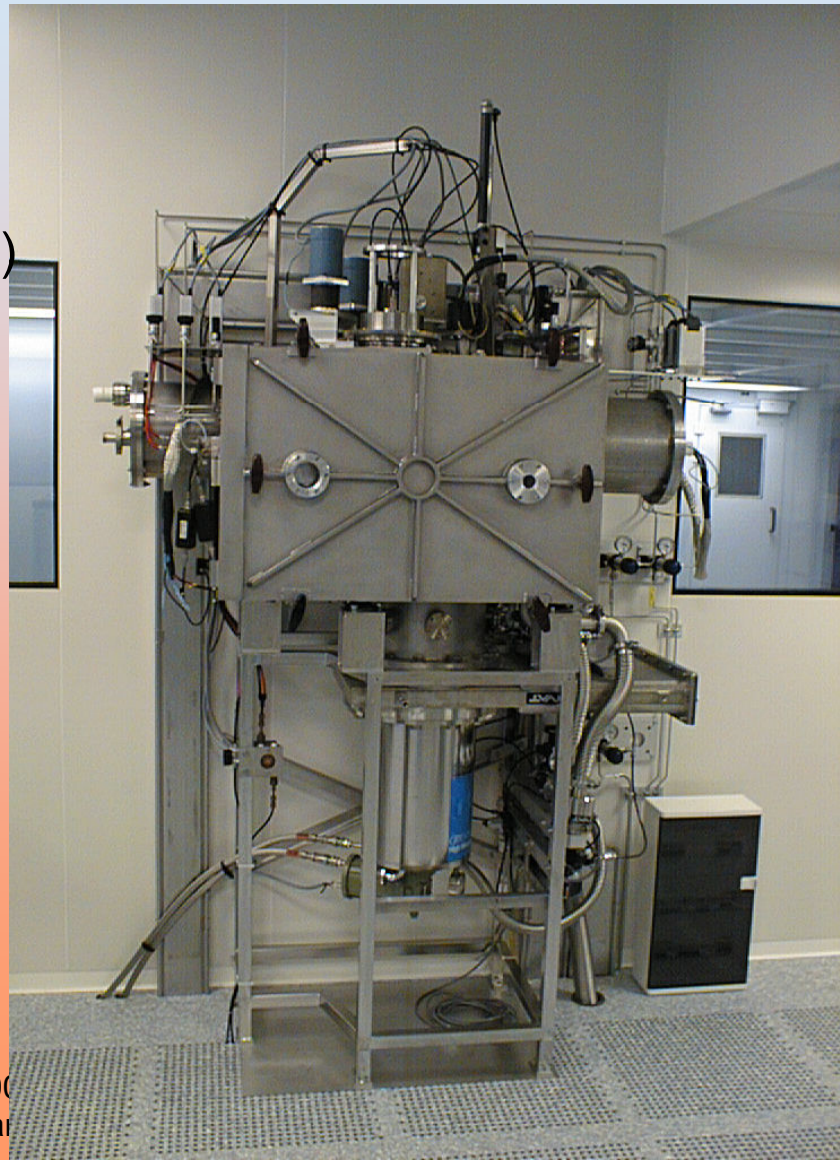
Ion Beam Sputtering - IBS

- IBS coater at LMA : 0.6*0.6*0.8 m^3 : 1st IBS coater in France (1986)
- Installed in a class 1 clean room
- «Clean» pumping : (no H_20, oil…)

  Cryopumps/ Dry pumps
- Ultra pure targets (> 99,999 %)
- Drawback : deposition speed very low (< 1Å/s)

  for Ar atomic %age low

  Otherwise Absorption increase
- Component diameter up to 80 mm



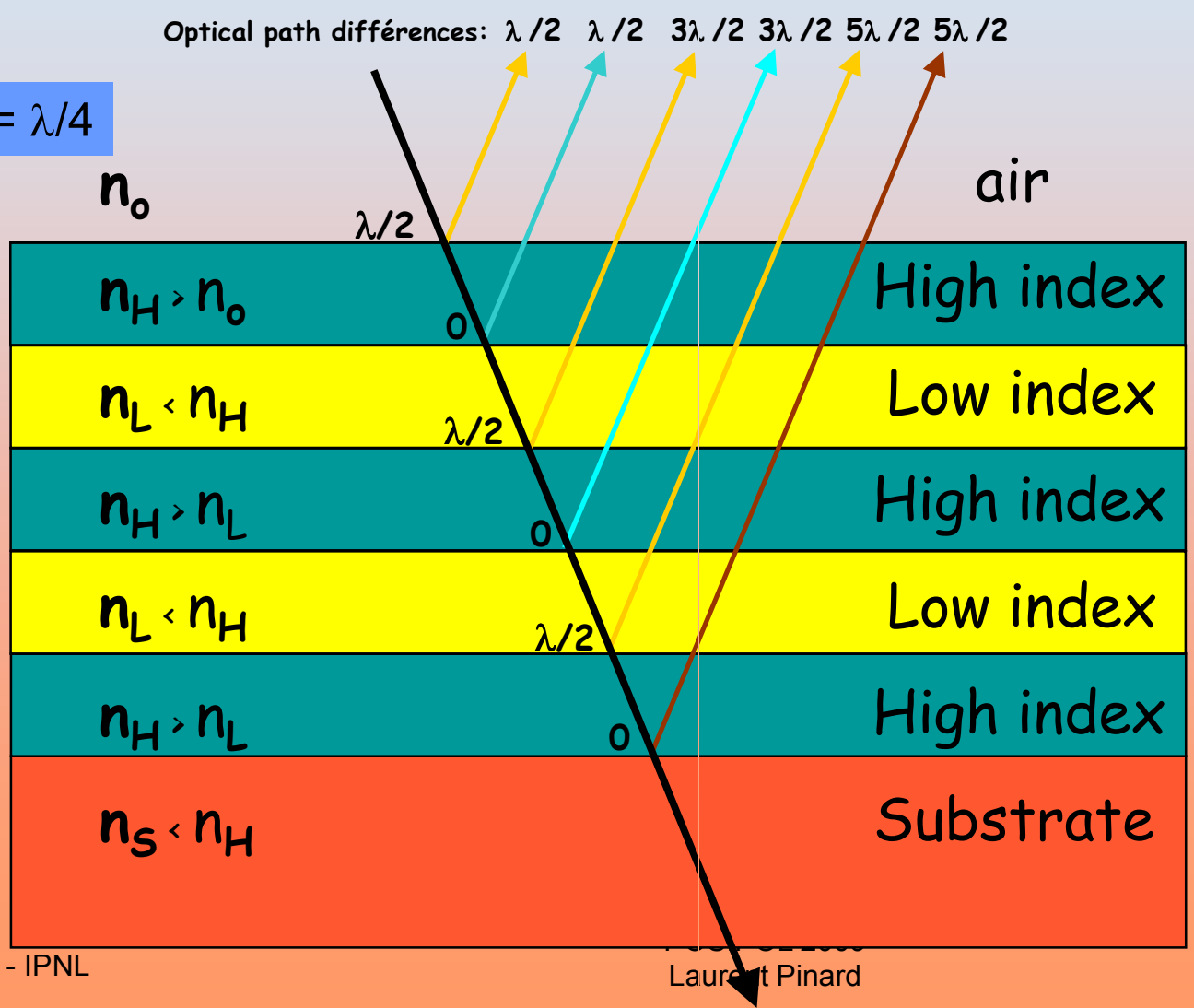
Ion Beam Sputtering - IBS

"VIRGO" Coater : 2.2*2.2*2.4 m^3 – Unique in Europe
Coating capacity ∅1m , thickness uniformity #6.10^{-3}

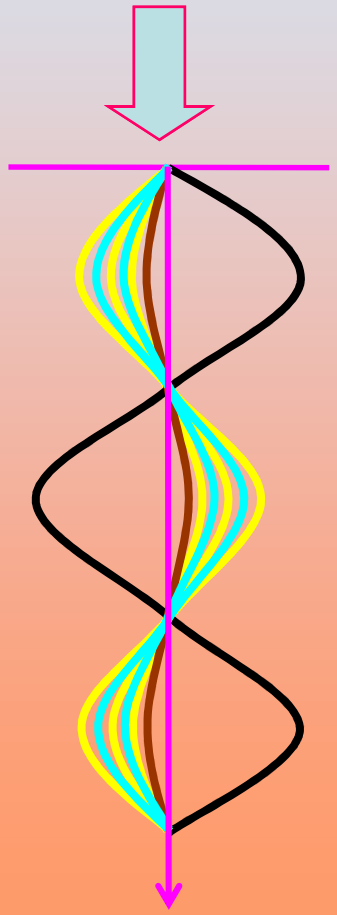
Mirror : multidielectric coating

- Mirror : multilayer of dielectric thin films (oxides)
- The optical properties of the multilayers depends on the interferences between the different layers and on the layer nature

Opt Thk = λ/4



Constructive interferences



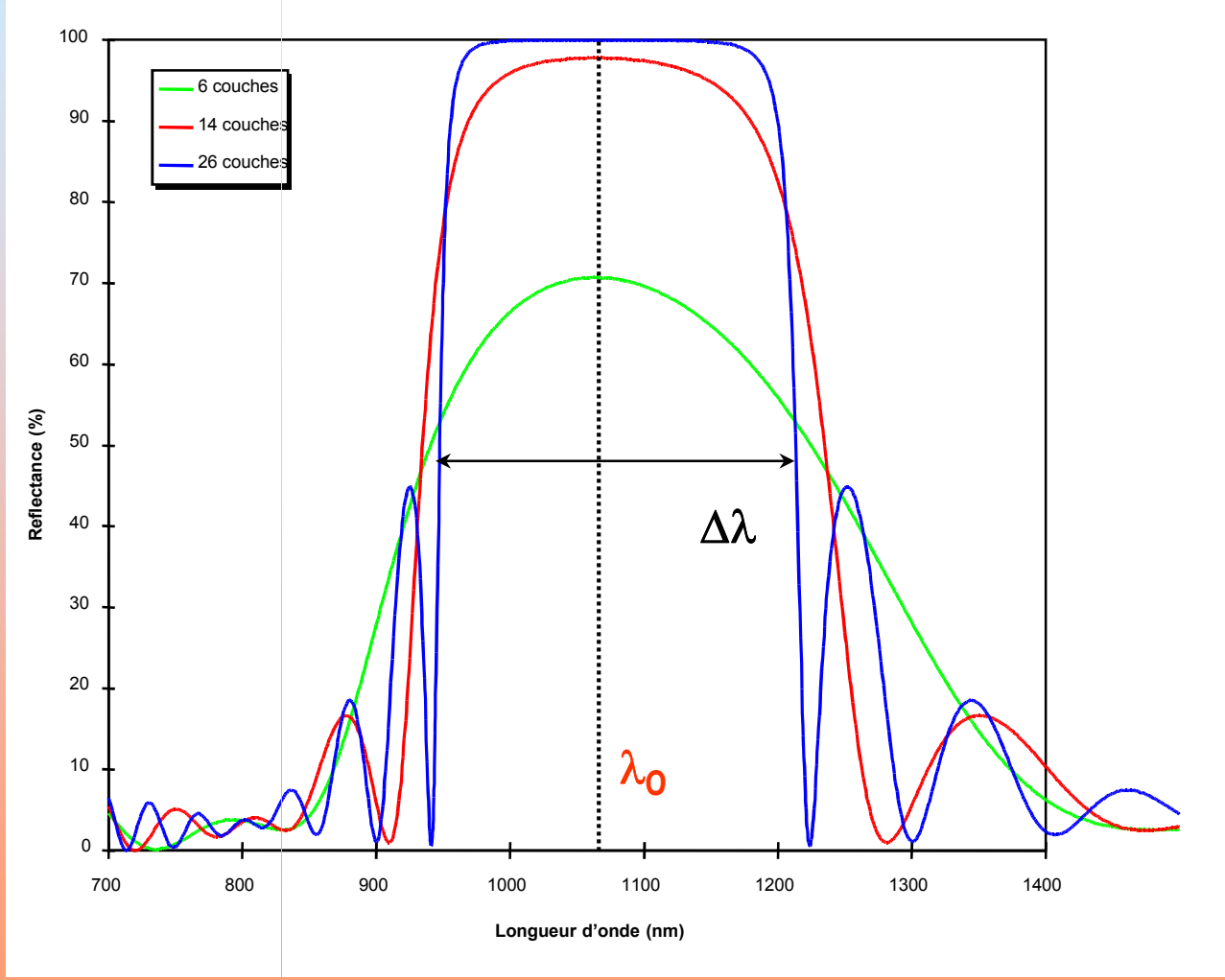
Mirror : multidielectric coating

Multilayer of quarter wave dielectric coatings of high (H-Ta_2O_5) and low (L-SiO_2) refraction index : **$(HL)^x$ HLL**

R > 99.9% - limited by the optical losses (T, A, S)

$$R = \frac{\left(1-(n_H/n_B)^{2x}.n_H^2/n_S\right)^2}{\left(1+(n_H/n_B)^{2x}.n_H^2/n_S\right)^2}$$

$$\Delta\lambda = \pi \,.\, \lambda_0 \,.\, \arcsin\frac{n_H - n_B}{n_H + n_B}$$



- <u>Advantages :</u>

- High reflectivity (**> 99.9 %**)
- Low absorption loss (Visible, IR : << 10 ppm)

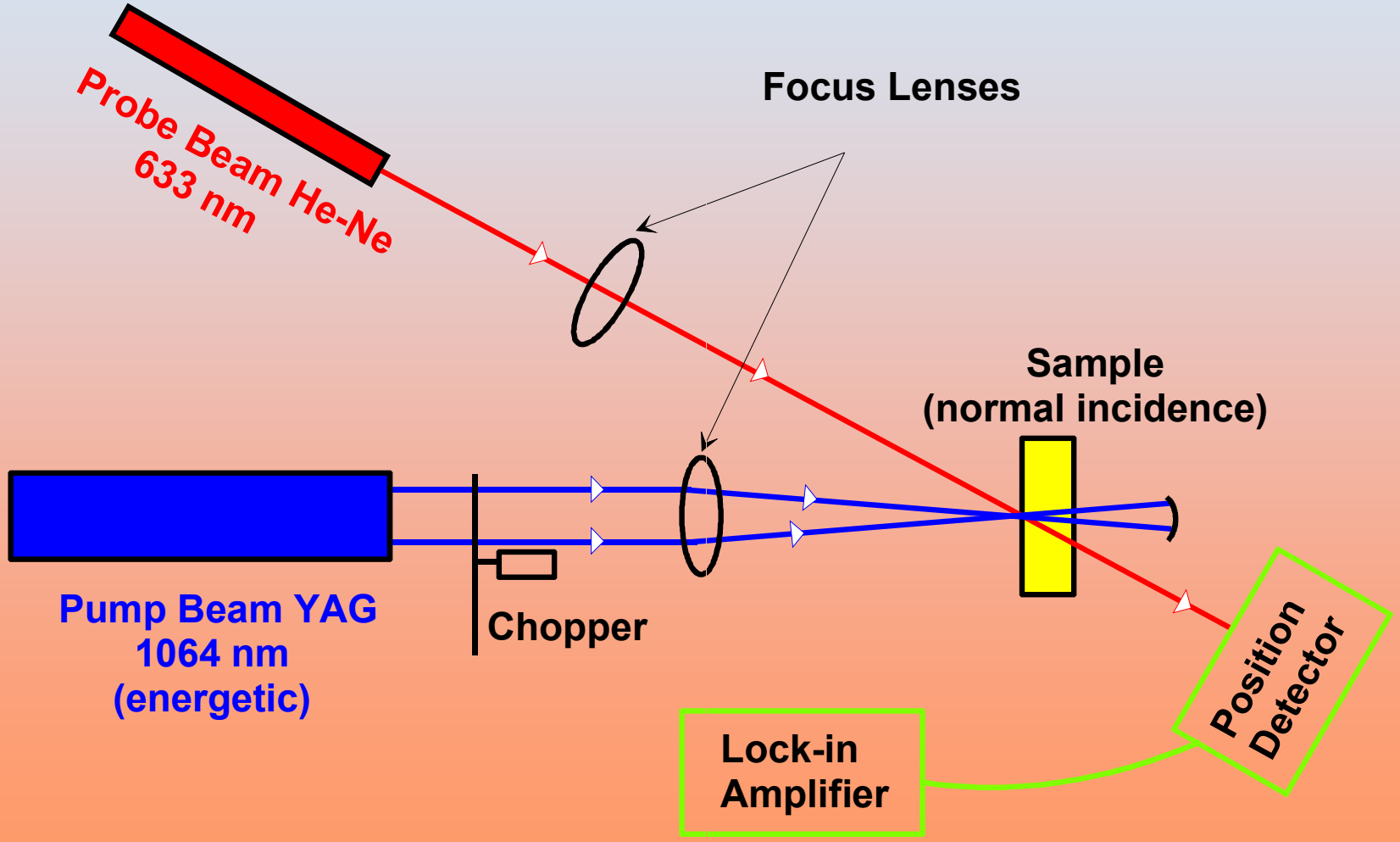
- <u>Drawbacks</u> :

- Multilayer $(HL)^x$ HLL (> 30 layers, deposition time long)
- High reflectivity on a narrow band (**Δλ = 250 nm** - depend on the refraction index contrast)

Mirrors Optical Performances

- Transmission : possible to have **T< 1 ppm** and to measure it

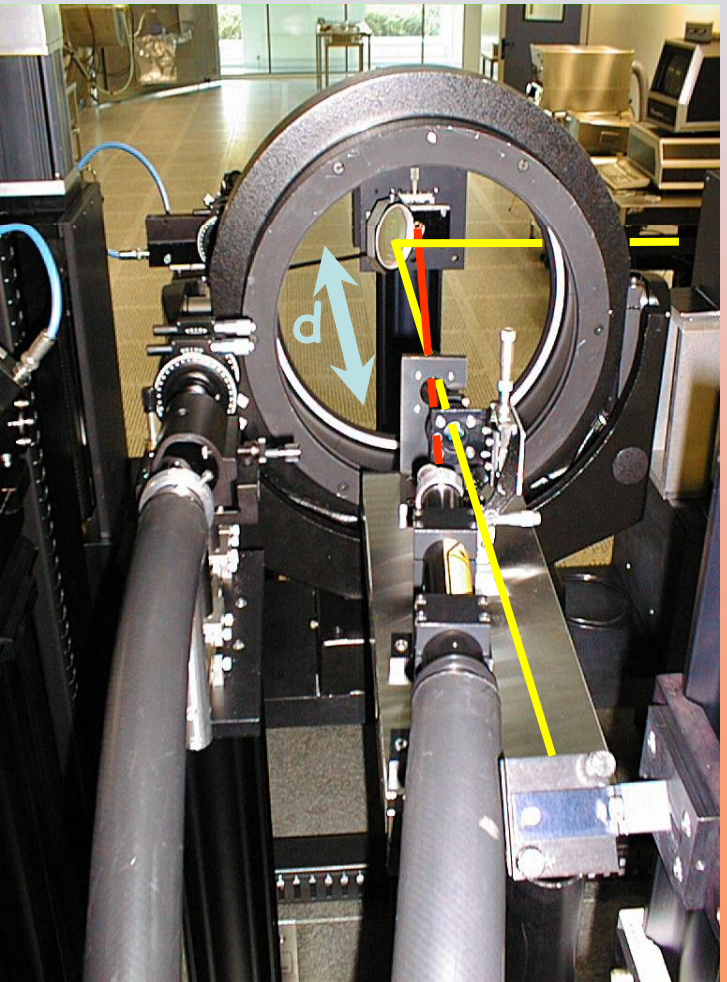
- Absorption (@ 1064 nm) : **0,3 ppm** (@633 nm #3 ppm)
  Problem = measuring absorption levels so low : « mirage effect » (photothermy)

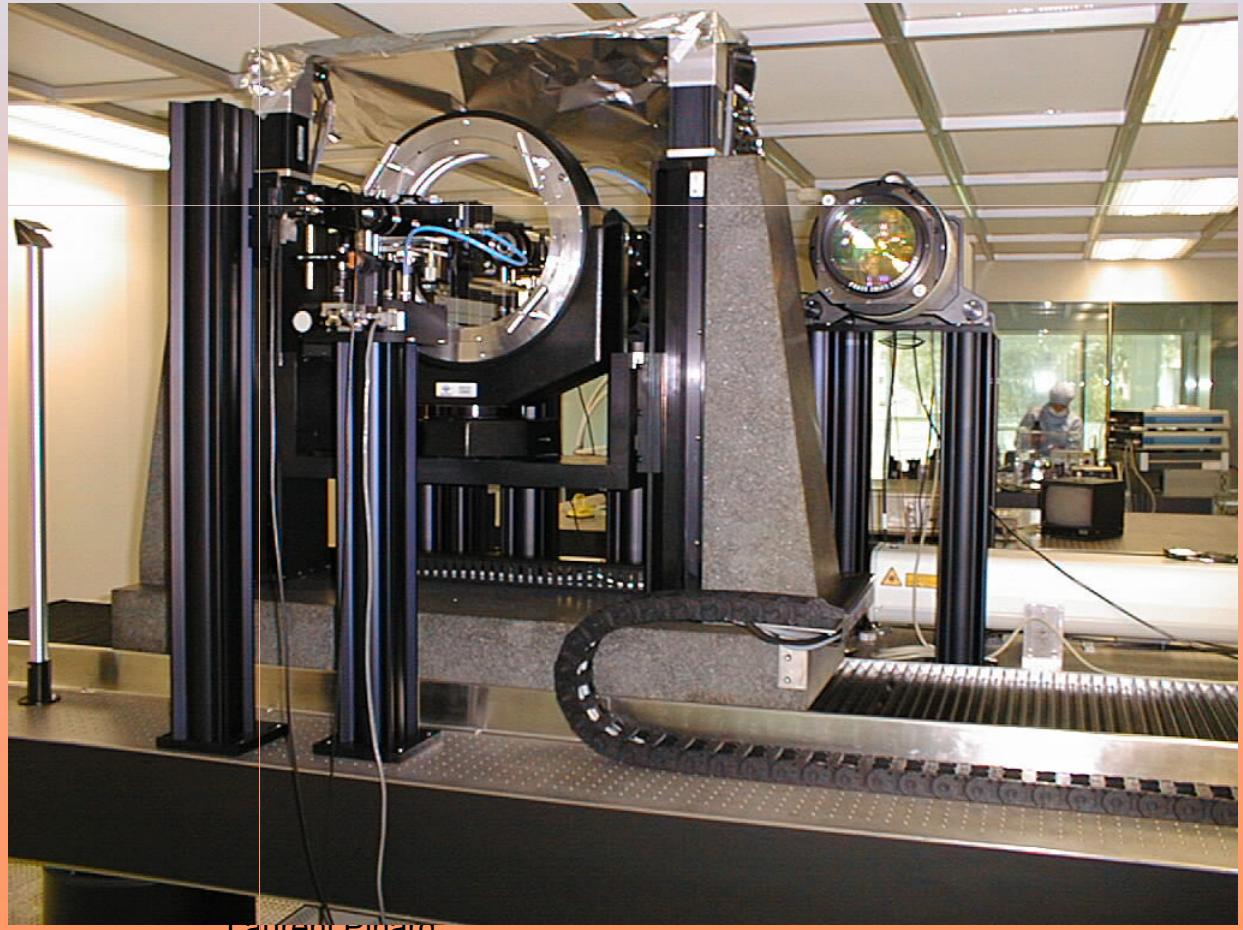


Mirrors Optical Performances

Absorption Bench

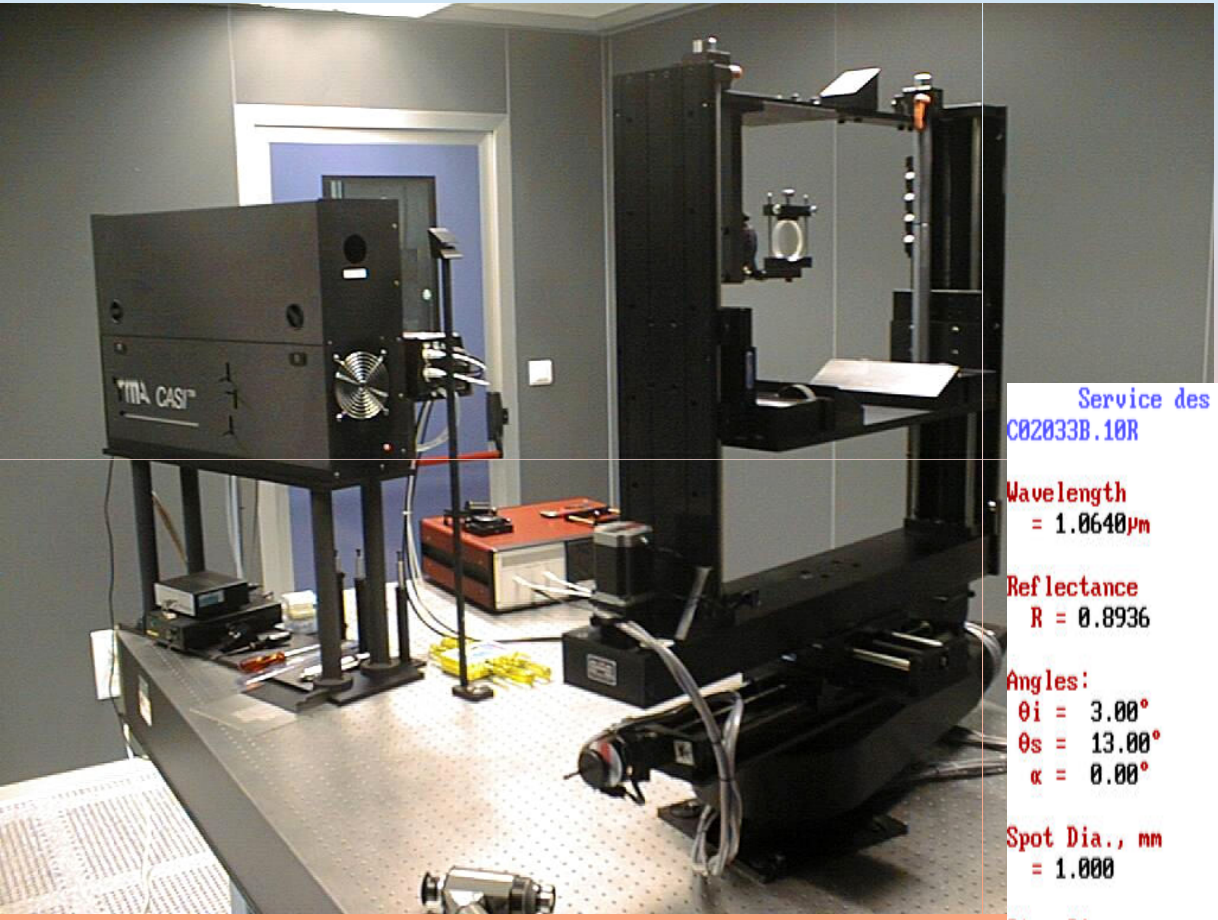
- Relative Measurement (reference sample)
- Sensitivity (@ 1064 nm) :
  - surface absorption : 0,02 ppm
  - bulk absorption : 0,1 ppm/cm



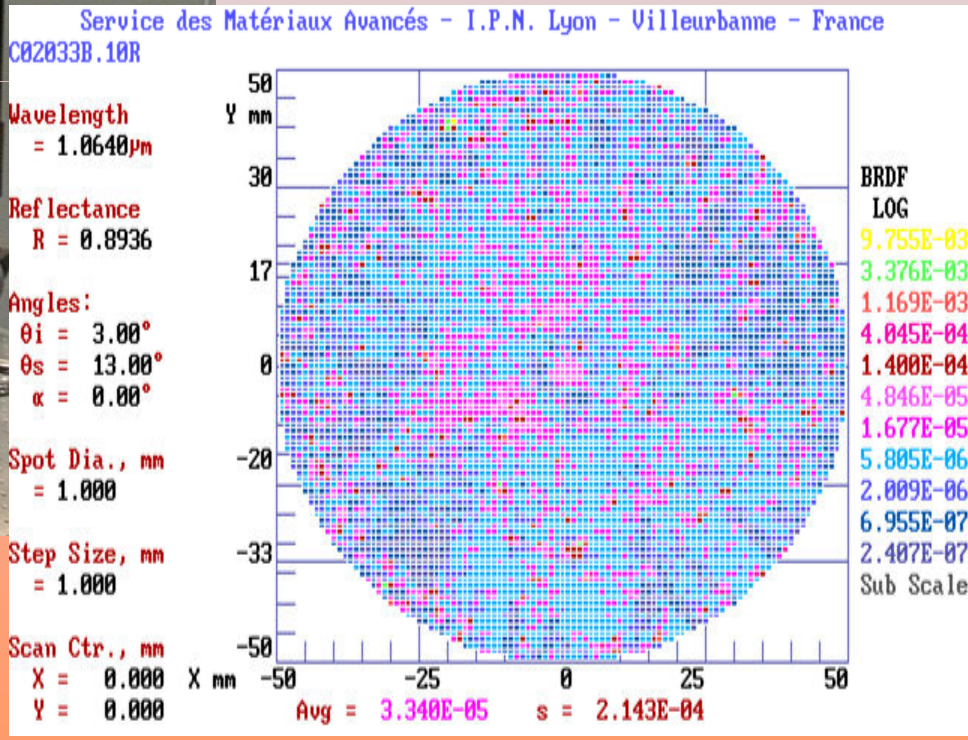


Mirrors Optical Performances

❖ Scattering : **# 5 ppm** on optical components (small or large dimensions)



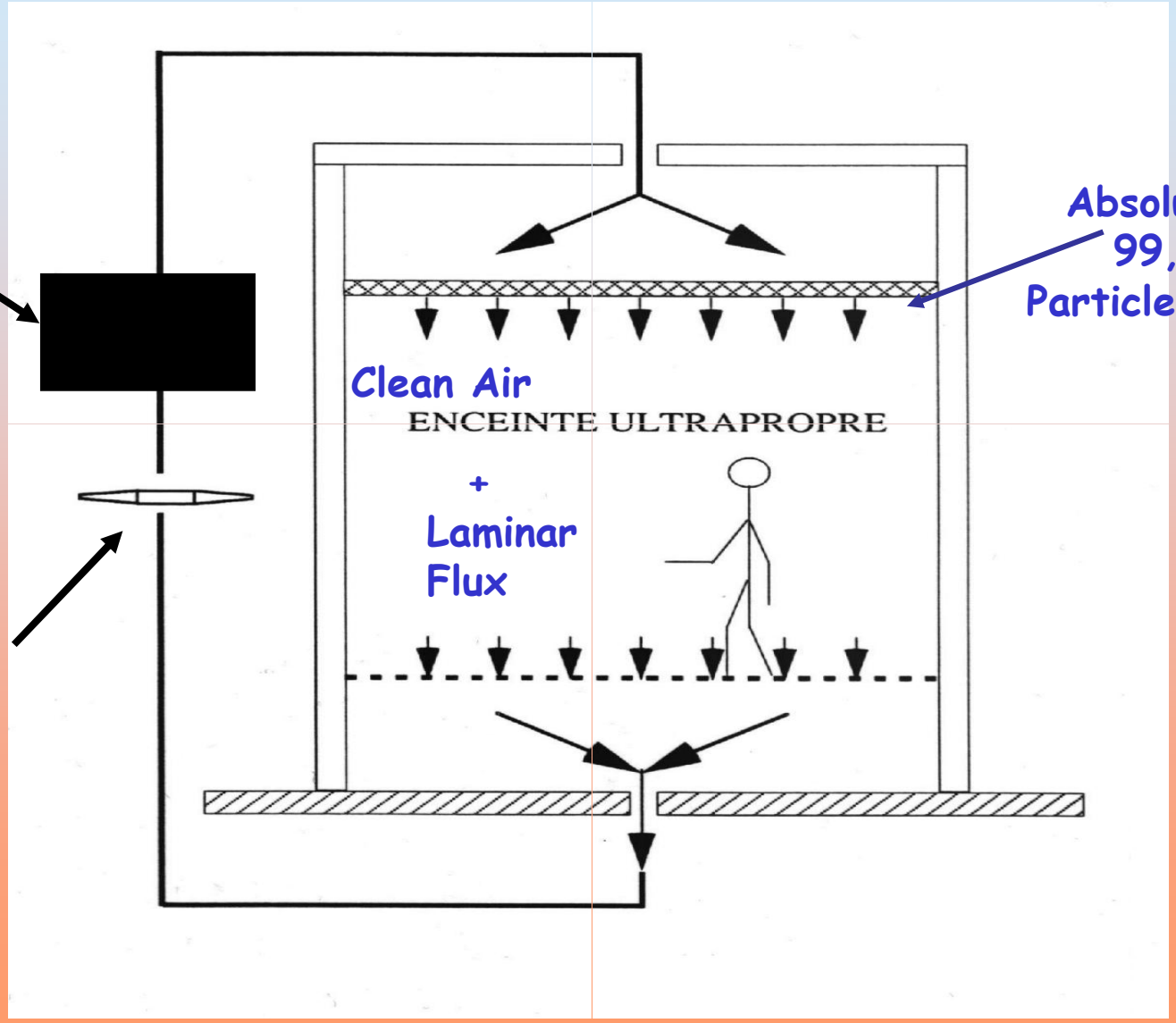
Maps on ∅ 400 mm
SNR # 10^{-9}
Scattering level < 1ppm



Mirrors Optical Performances

Scattering-Cleanliness

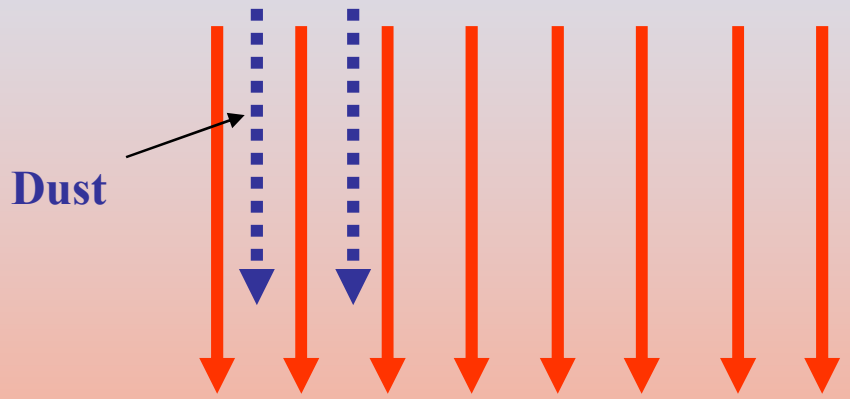
All the mirror production steps in clean room



Mirrors Optical Performances

Scattering-Cleanliness

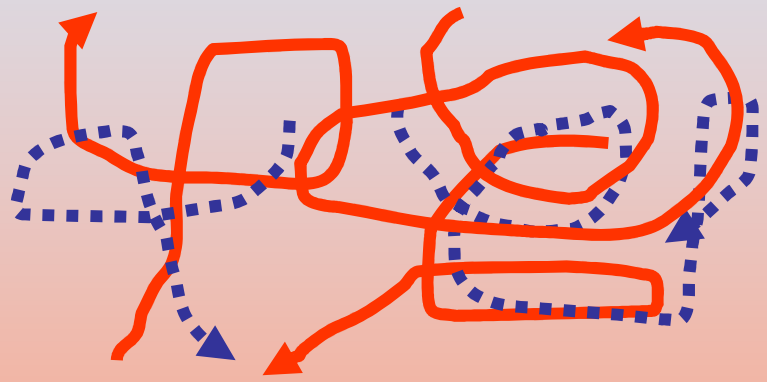
Laminar Flux



Particles carried away by the recycled flux

Low probability to contaminate the sample

Turbulent Flux

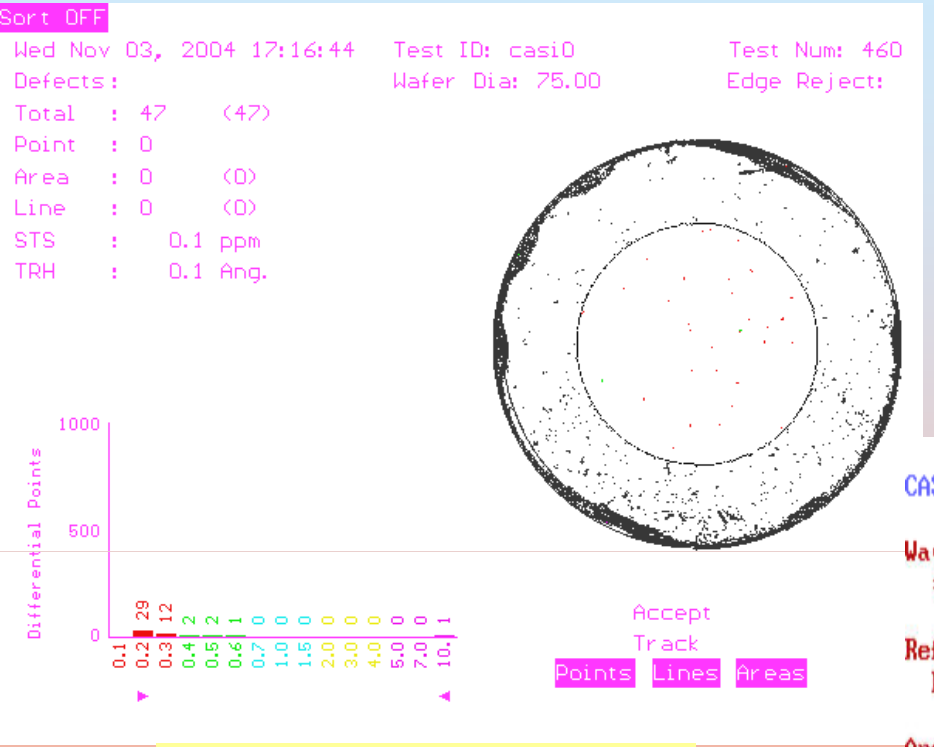


High Probability to contaminate the sample

Mirrors Optical Performances

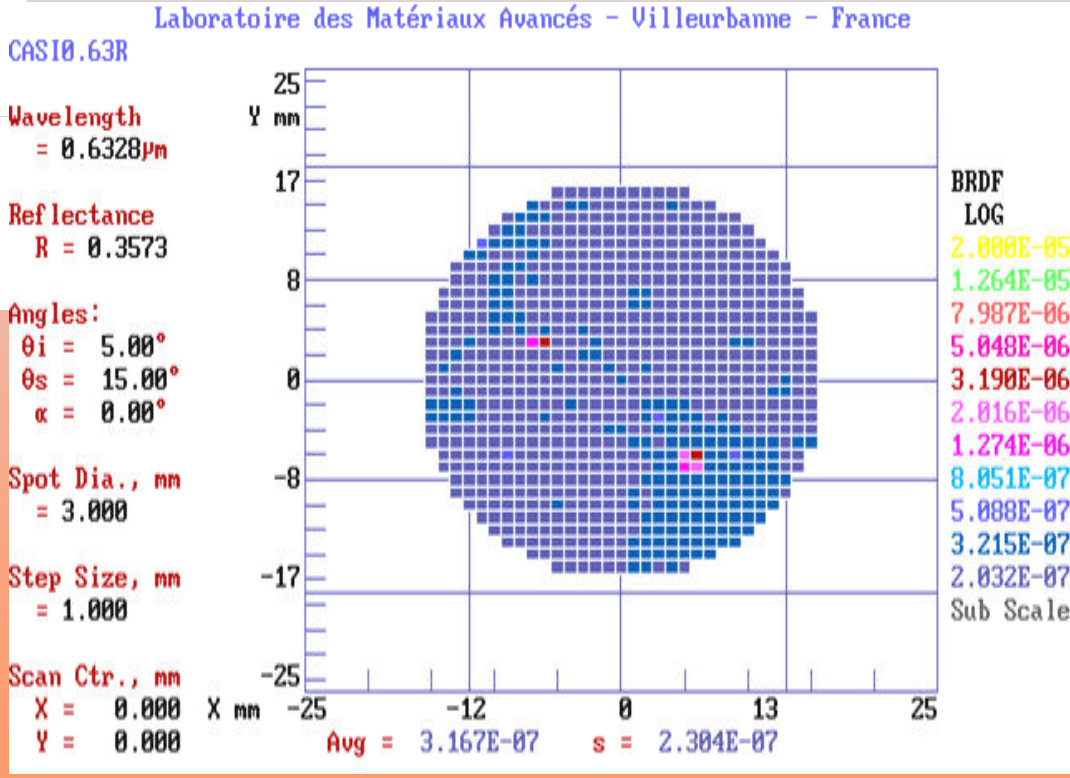
Scattering-Cleanliness

Particles counting



47 particles (< 0,3 µm)

Scattering maps @ 633 nm

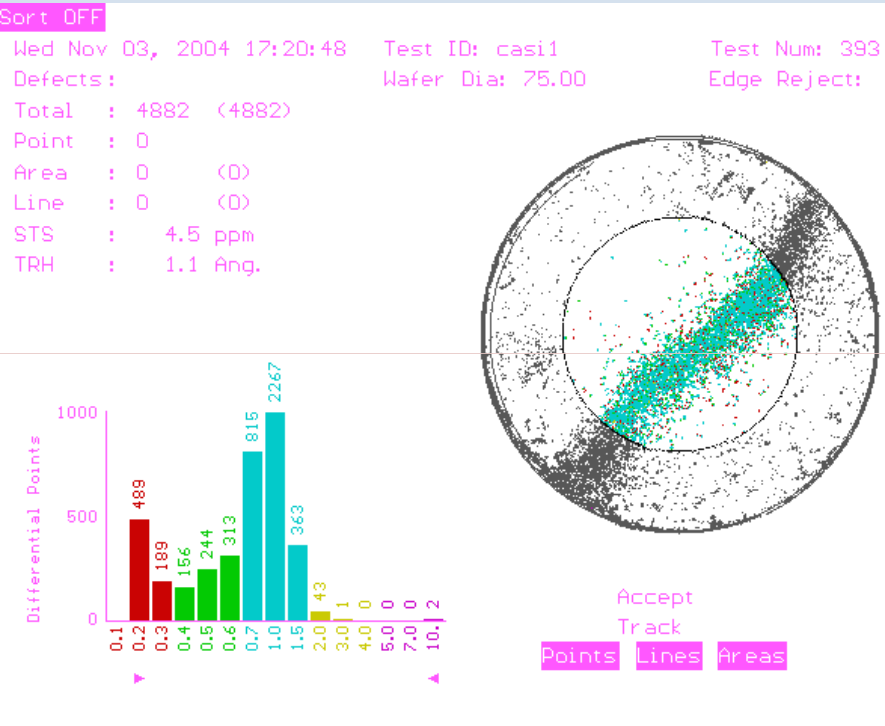


Average scattering 0.3 ppm

Mirrors Optical Performances

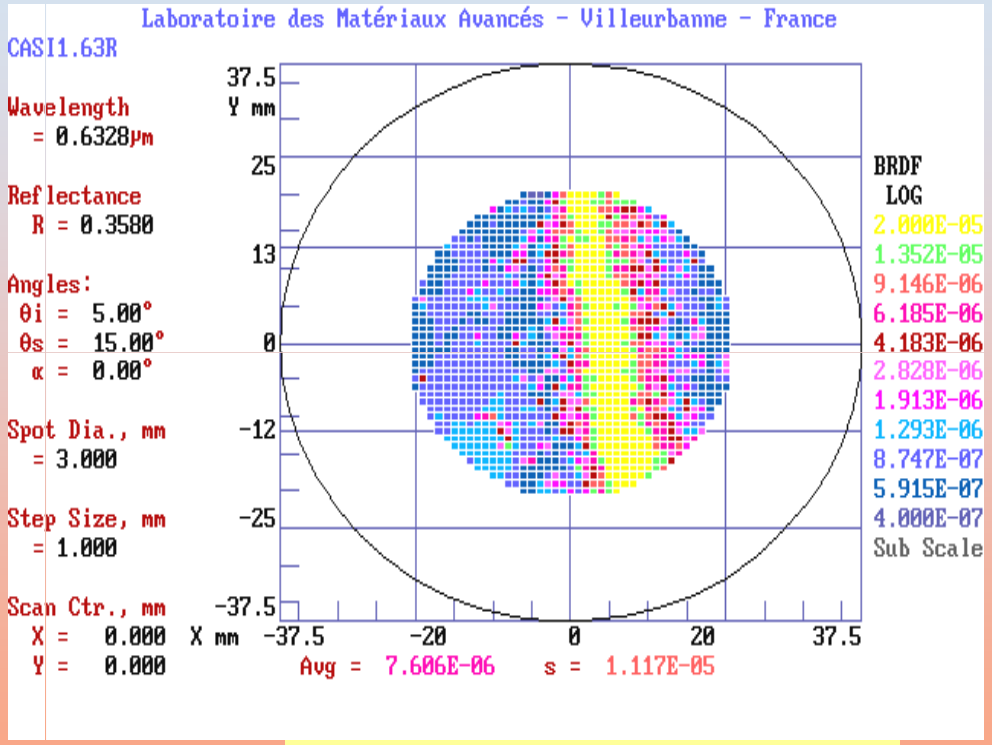
Scattering-Cleanliness

Particles counting



3000 particles of 1 µm

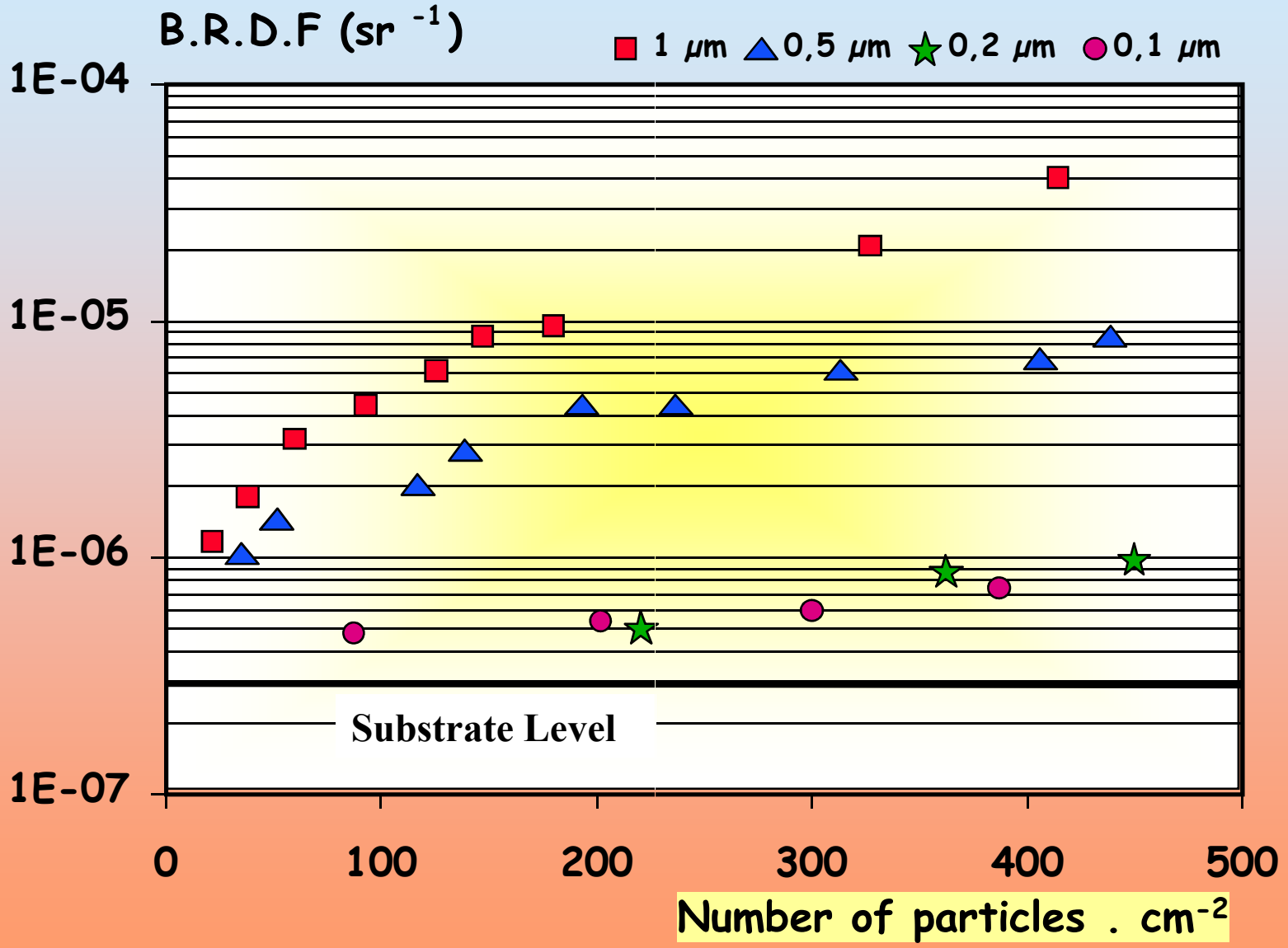
Scattering maps @ 633 nm



Average scattering 7 ppm
(multiplied par **23**)

Mirrors Optical Performances

Scattering-Cleanliness

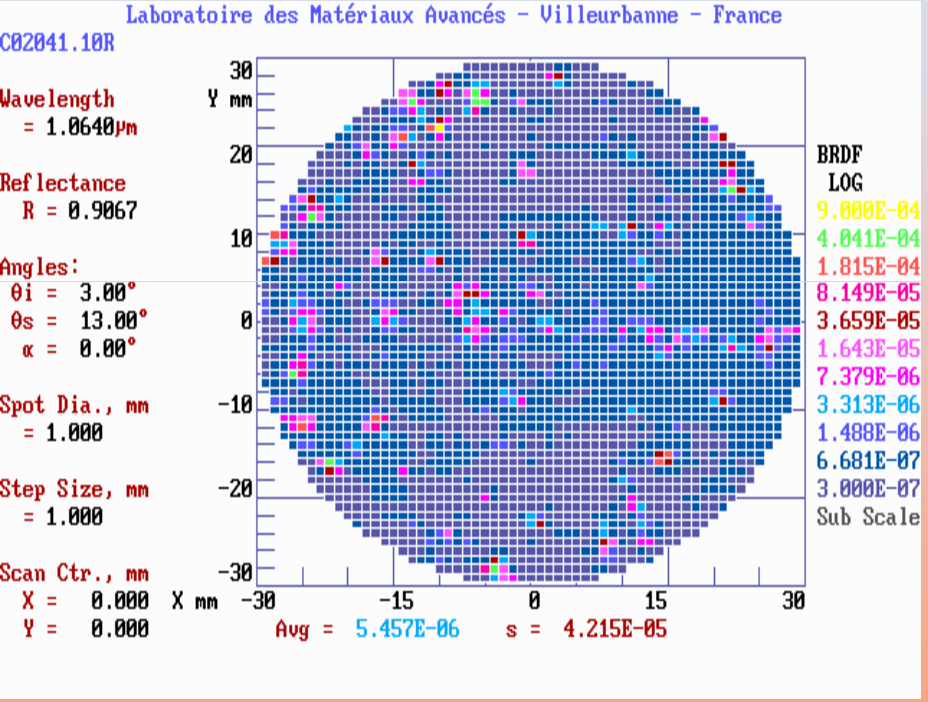


Mirrors Optical Performances

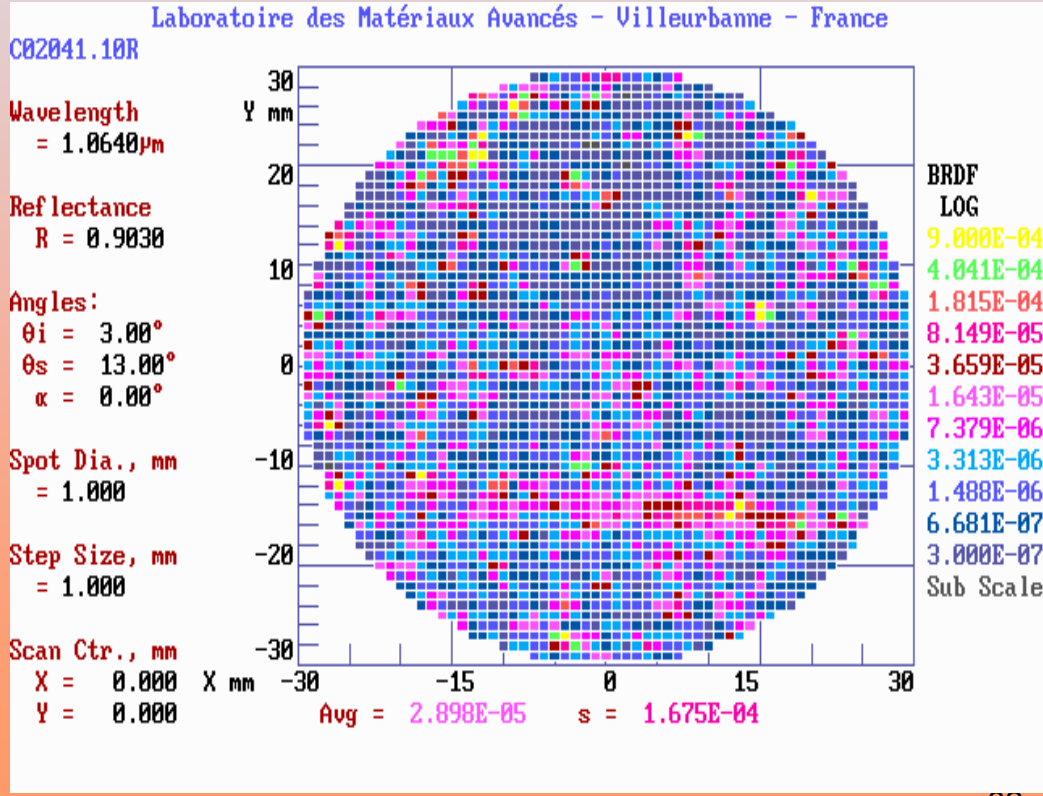
Scattering-Cleanliness

Main problem for mirrors users : keep the loss level low

- manipulate in clean conditions (clean room)
- never touch the surface
- clean vacuum in cavities (no turbulences)



Virgo mirror
Average Scattering 4 ppm



After use
Average Scattering 25 ppm

Mirrors Optical Performances

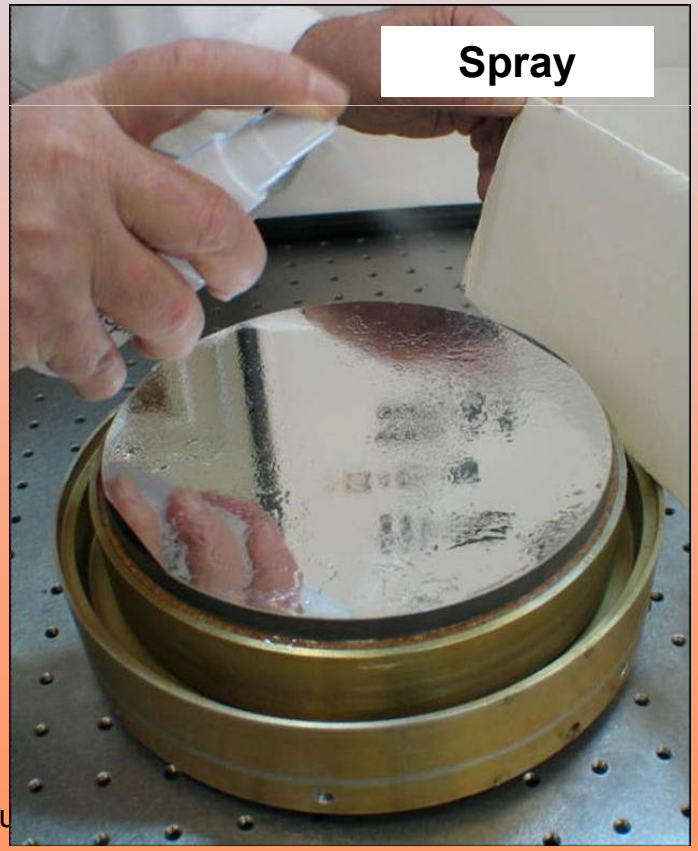
Scattering-Cleanliness

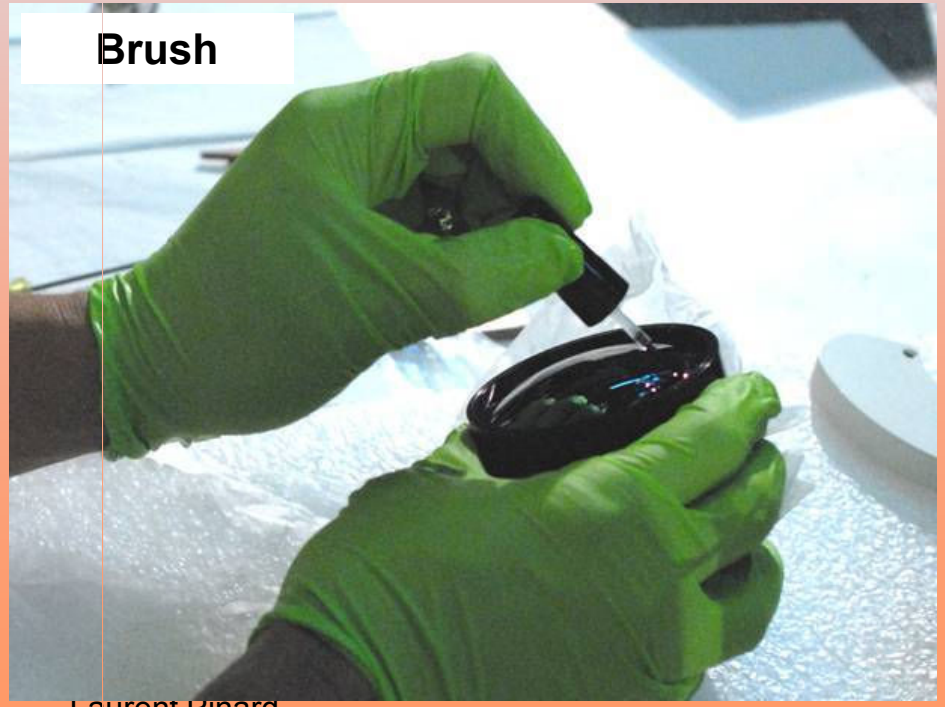
- Polluted Mirror : in general reversible
  Cleaning (wet) possible if mirror dismountable (not possible in Virgo)

- Other solution for the cleaning : removable polymer film « First Contact »
  (http://www.photoniccleaning.com/)

Mirrors Optical Performances

- Liquid, dry in ¼ hour
- Can be put by spray or with **a brush**
- 2 important properties
  - Protect optical surfaces (during mounting,…)
  - **Can clean optical surfaces**



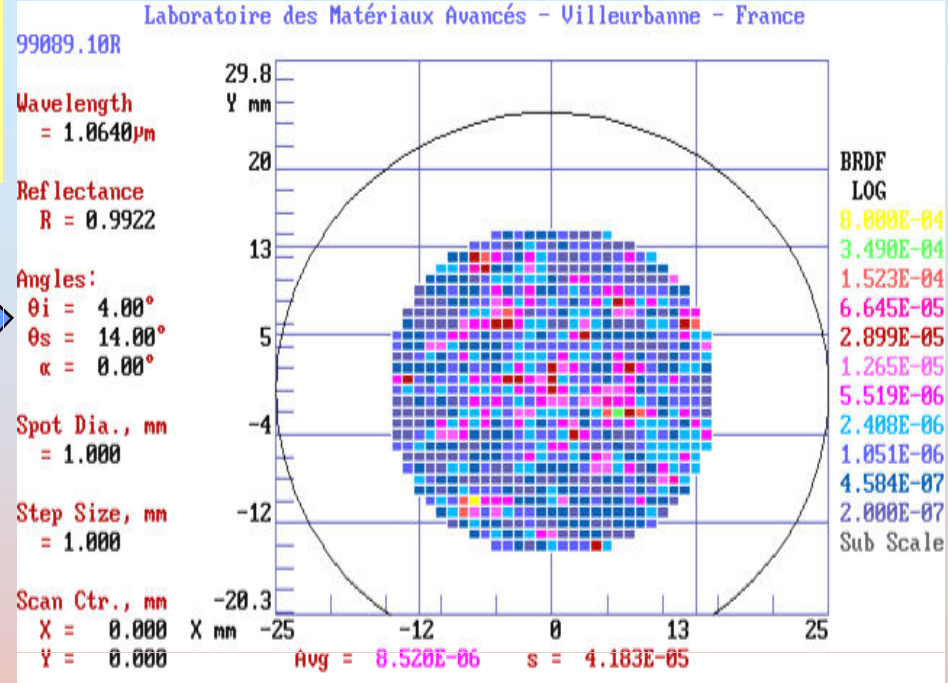


Mirrors Optical Performances

50 mm Mirror after classical cleaning

Scattering : 6 ppm

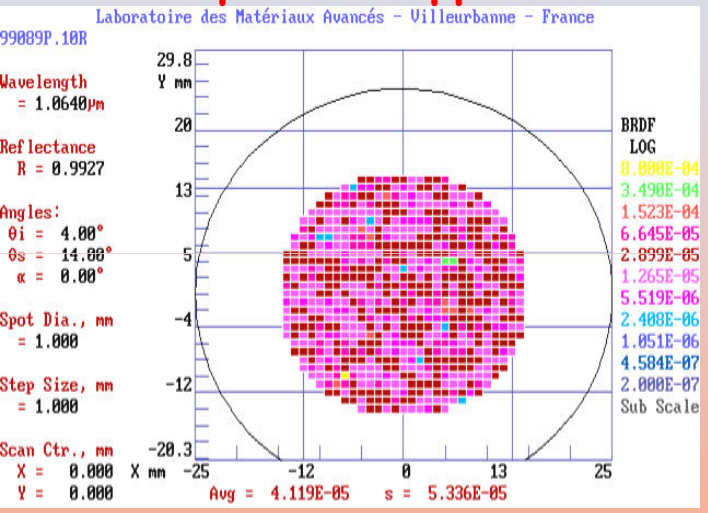
Absorption : 1.91 ppm



50 mm Mirror polluted

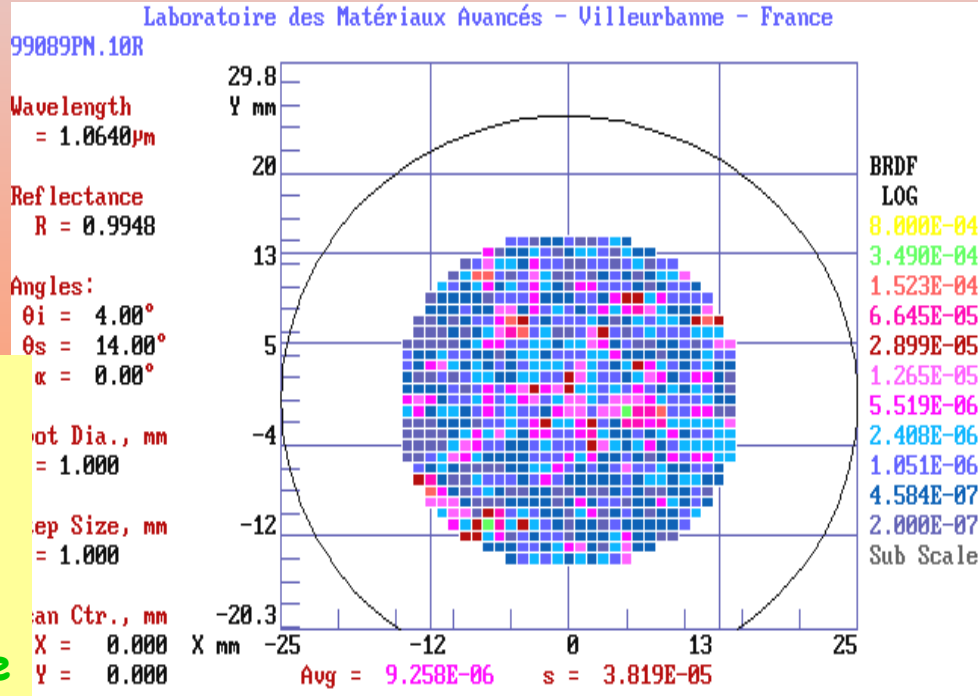
Scattering : 25 ppm

Absorption : 5 ppm



Particles

Polymer



50 mm Mirror, after putting and removing the film 'First Contact'

Scattering : 6-6.5 ppm

Absorption : 1.73 ppm

The film has cleaned and did not let absorbing waste on the surface