Projet ANR- 09-NANO-008-AXOC

AXOC: Advanced X-ray Optics Components coupled high accuracy mechanics for X-ray nano-focusing

01/12/2009- 31/05/2013

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Journées Nationales Nanosciences et Nanotechnologies 2012

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AXOC: project goals

Development of a state-of-the-art scanning hard X-ray nanoprobe including:

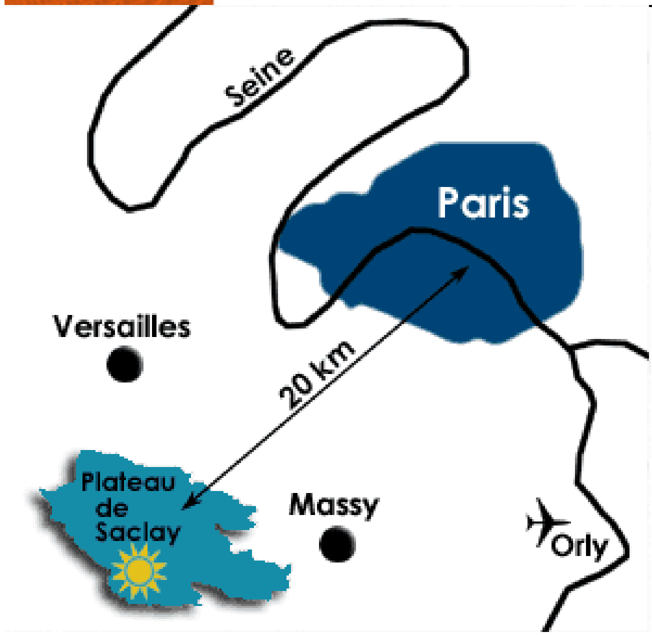
- nano-focusing Kirckpatrick-Baez mirror-system
  - mirror fabrication
  - mechanics
- a high precision sample stage

Development of optical and at wavelength metrology techniques adapted to the characterization of very high optical quality mirrors

adapted to the Nanoscopium beamline of Synchrotron Soleil

Nanoscopium: Scanning hard X-ray imaging beamline at Synchrotron Soleil (St Aubin)

155 long nanoprobe beamline, aiming down to 30 nm spatial resolution



Exploitation of beam coherence for focusing and contrast formation

Diffraction limited focusing

Multimodal and multi-technique imaging
Chemical and structural information

Responsible: A. Somogyi

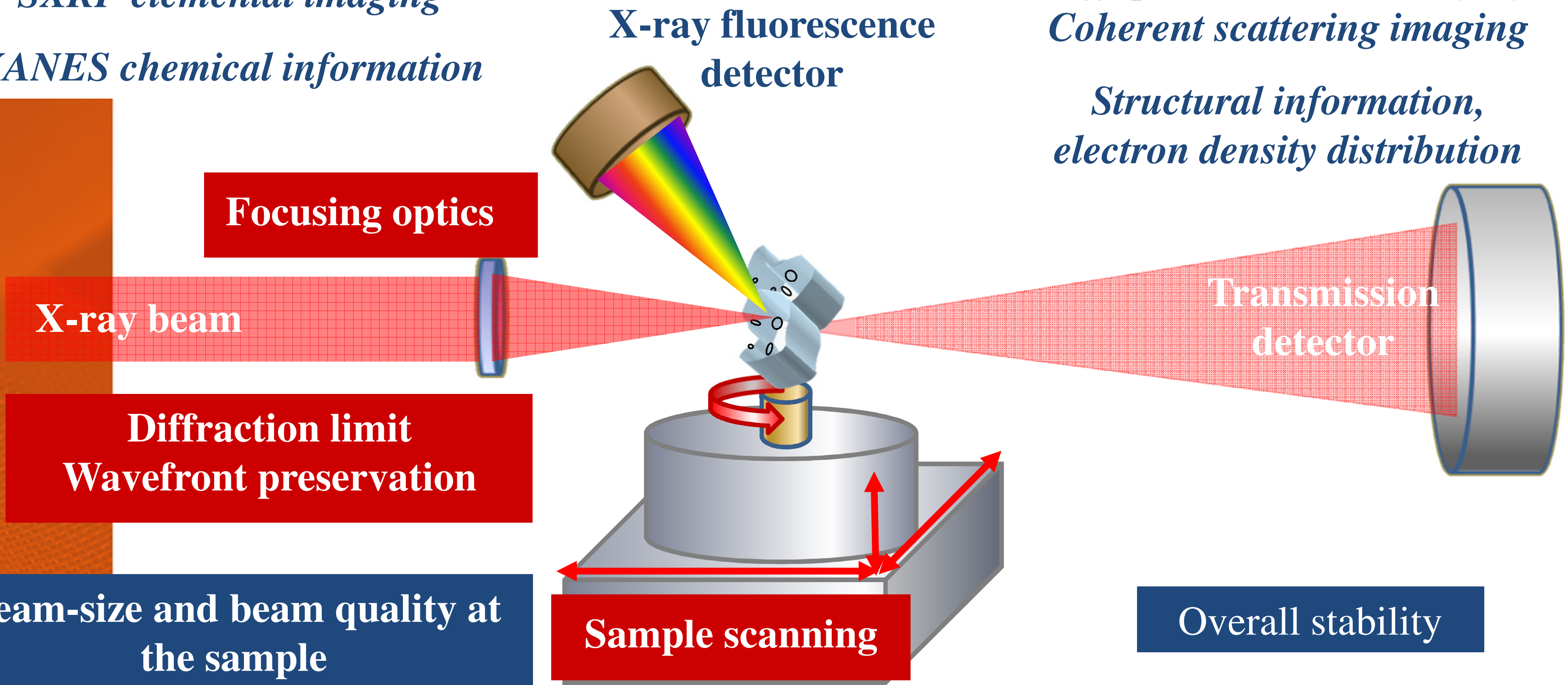
Scanning hard X-ray nano-imaging

SXRF elemental imaging

XANES chemical information

Diff. phase contrast imaging
Coherent scattering imaging

Structural information, electron density distribution



Diffraction limit
Wavefront preservation

Beam-size and beam quality at the sample

Overall stability

Sample stage: Precision XYZΘ
~5-10 nm resolution (encoder, feedback)

AXOC-project

Resolution, performance

Deliverables of the AXOC project

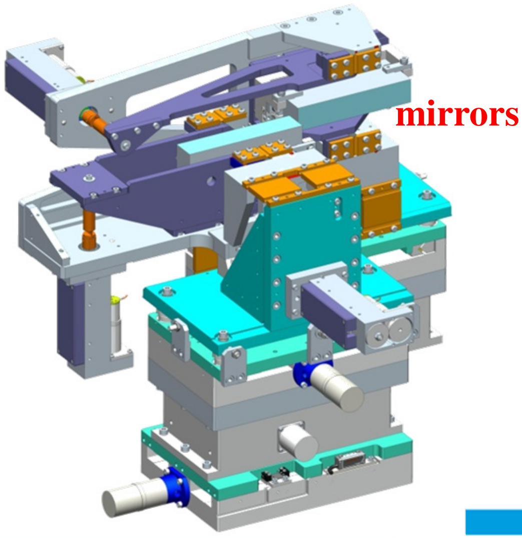
Focusing optics: Kirkpatrick-Baez mirror system

Diffraction-limited focusing and coherence based applications: high optical mirror quality, Mirror conception (Task1, Soleil)

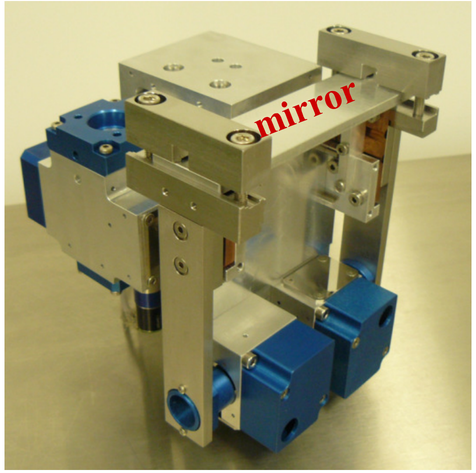
Two alternative principles

Monolithic, elliptically shaped Si mirrors, deterministic polishing (Task3, SESO)

Bent Si mirrors, lateral shape optimisation, deterministic polishing (Task3, SESO)



High stability, high precision mirror positioning (Task2, ISP)



Adaptation of the existing bending system (ISP) constructed by FEASO RTRA Project (2007)

Deliverables of the AXOC project

Development of adapted mirror metrology tools (Task5)

Surface correction of flat SiO_2 mirrors by det. deposition: high quality metrology standard for intercomparison (Task4, LMA)

Vertical translation stage with nanometer precision precision and mm travel range

(Task2, ISP)

Task1: Mirror conception

The conception of 3 mirror-pairs has been finished

Total reflection KB mirror systems for Nanoscopium with Elliptical mirror shape: by two alternative principles

- **Monolithic, elliptically shaped Si mirrors**
- **Flat Si mirrors, lateral shape optimisation, elliptical shape by bending**

Surface finishing by deterministic polishing (SESO, Task3)

- **Flat SiO_2 mirrors**: for high quality metrology standard

Surface correction by deterministic deposition (LMA, Task4)

Example: Flat Si mirrors, lateral shape optimisation, elliptical shape by bending

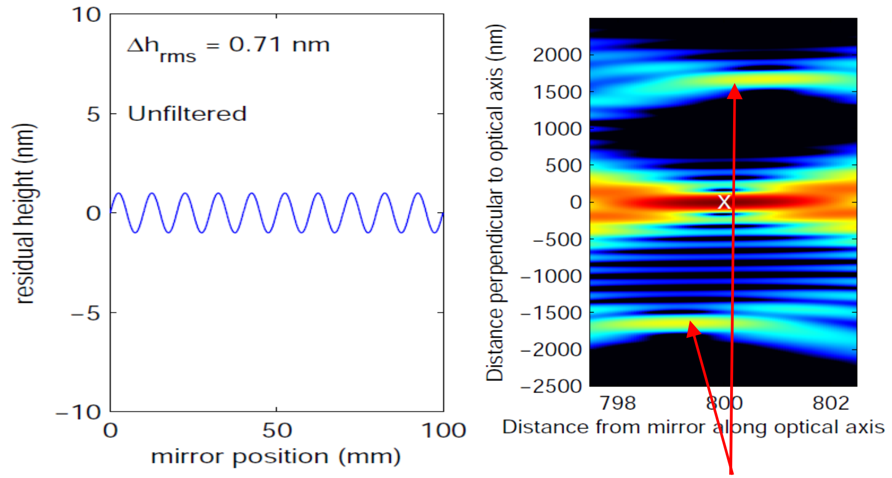
Working startegy :

- **High precision bending mechanical system (ISP)**
- **Two high optical quality flat mirrors with lateral shape optimization for the required working conditions (Thalès-SESO, SOLEIL)**

Required characteristics by wave-optical calculations (SOLEIL)

Figure errors must be below 0.75 nm-rms to achieve more than 0.8 Strehl ratio over 5-20 keV energy range.

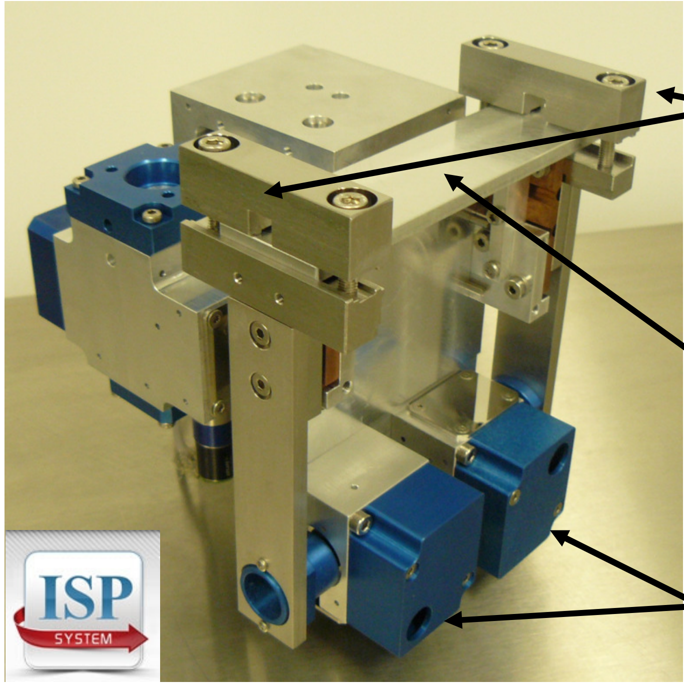
The amplitude of periodic errors, particularly with spatial period above a few mm, must be minimised.

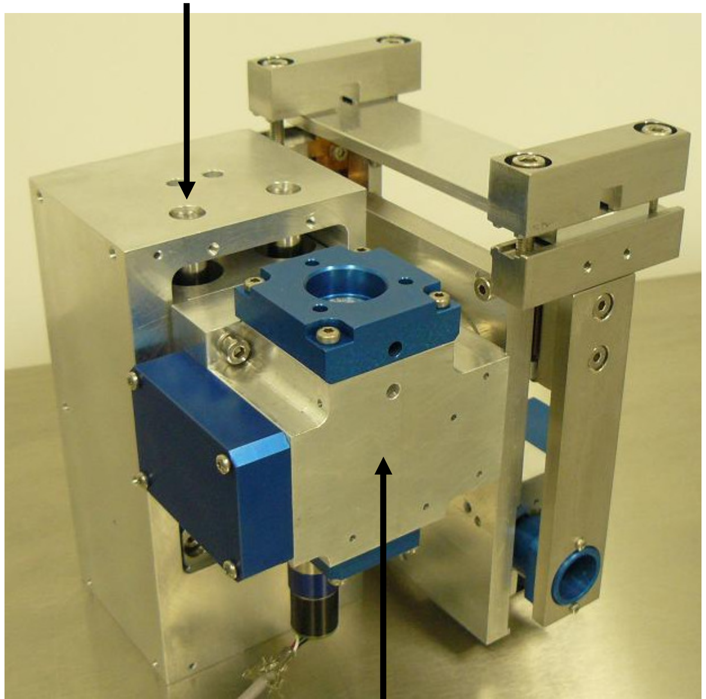


10 mm spatial period P-V = 1 nm → 10% I_{max} side-lobes

FEASO RTRA Project (2007)

Thematics: « Instrumentation à ses limites » & « Lumière extrême »





2 actuators bending mechanical system
Large range of elliptical profiles achievable
Dynamic Range : R = 800 m → R = 20 m
Sag up to 40 µm over 80 mm useful length

Historical

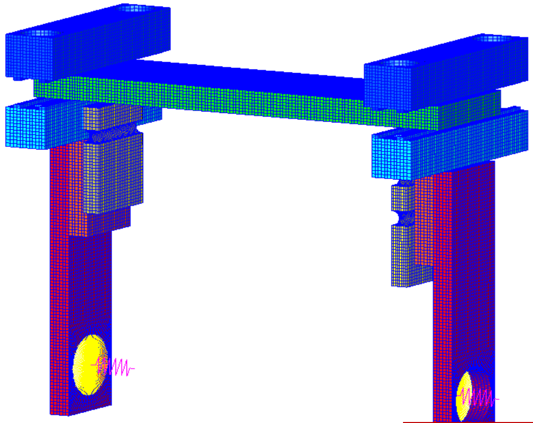
Finite Element Analysis Model (IDEAS) :

Bender ReDesign

Solid elements : 4 mm mesh

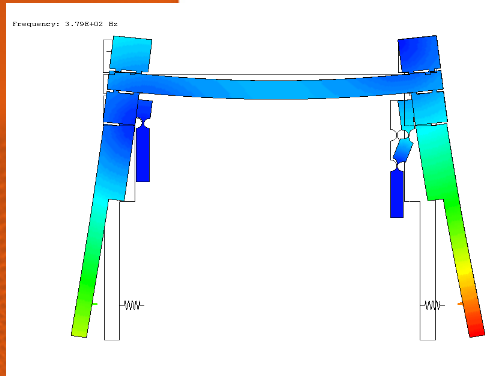
Mirror surface : 1 mm mesh

(allows to retrieve the local slopes with 1 mm spatial resolution)



166 465 nodes
141 104 elements

In test



Modal analysis shows a first vibration mode at 379 Hz

Mirror width profile optimisation

Elastic Beam Theory approximation

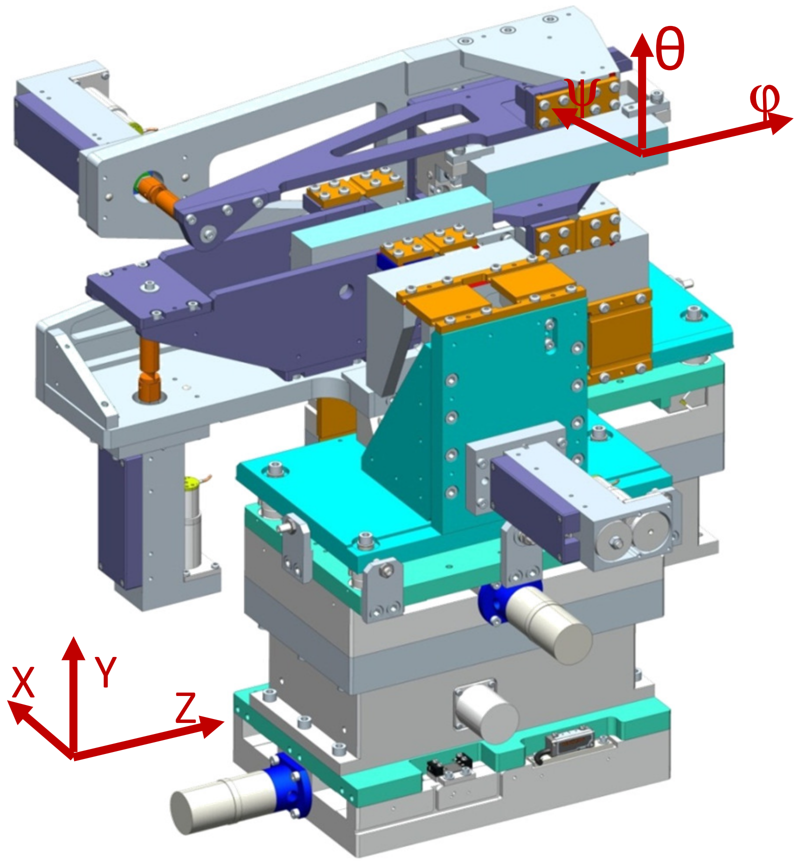
<u>FEA Influence Functions and Interaction Matrix based Optimisation</u>

Lateral profiling and surface finishing in progress (SESO)

Task2: Construction of positioning systems (mechanics, motion control)

High precision, high stability positioning system for monolithic, elliptically shaped Si mirrors

Technical specifications, tolerances, stability criteria (Soleil): based on wavefront propagation calculations



Demanded mirror motions :

M1 mirror
3 motorised translation: X1, Y, Z1
2 motorised rotations: θ1 and ϕ1
1 rotation manuelle : ψ1

M2 mirror:

2 translations motorisées : X2, Y2
1 rotation motorisée : θ2
2 rotations manuelles : ϕ2 et ψ2

2 independent, closely embeded mechanics

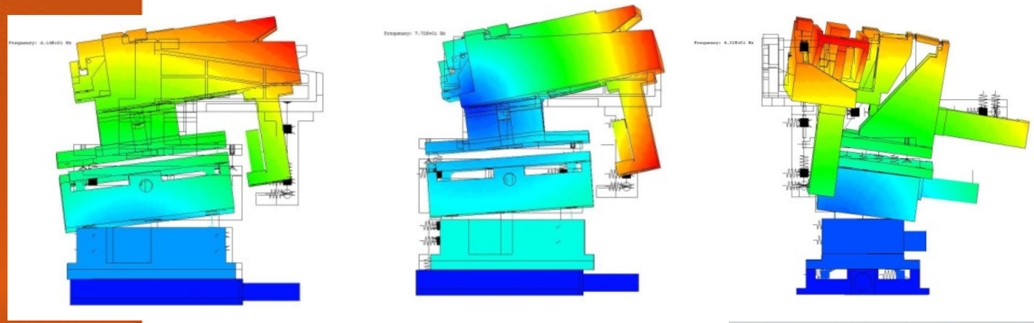
Critical motions for mirror performance		Range	Resolution	Precision
θ2, θ2	Pitch	-0.1°-0.2°	0.15 µrad	0.5 µrad
φ1	Roll, perpendicularity	+/- 100µrad	5µrad	10µrad

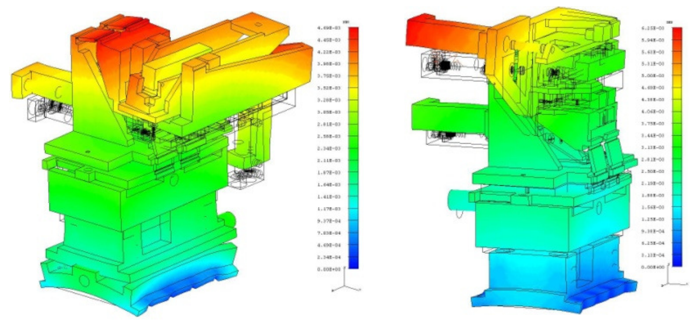
HJ11

Working strategy :

Finite element calculations and dimensioning, calculalation of the first eigen-frequences (≥40Hz)

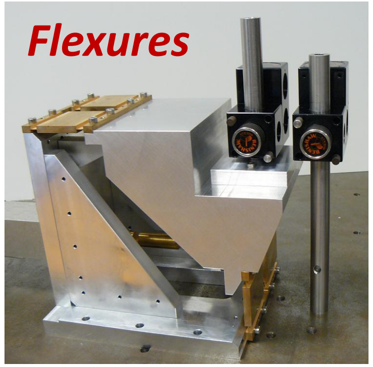
Thermo-mechanical analysis of the ensemble



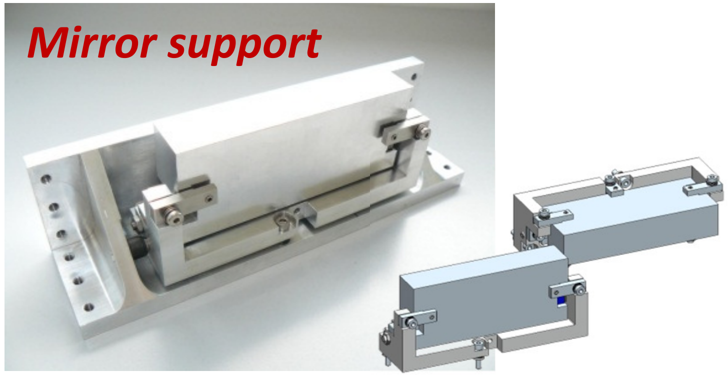


Prototypes

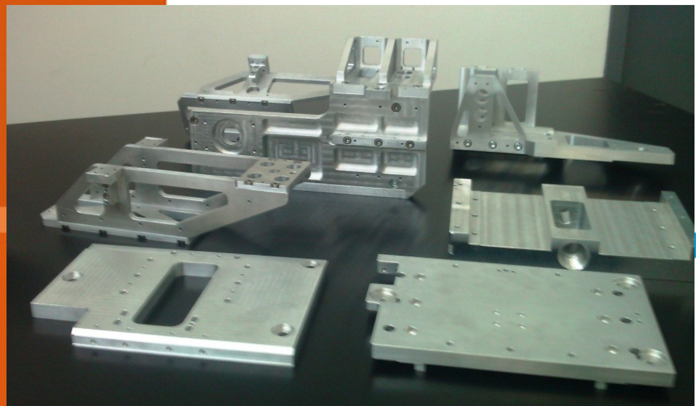
Validation of the dimensioning of the critical elements



Pitch: 0.15 µrad resolution
0.5 µrad precision



distortion-free mirror fixation



Fabrication of the components of the validated final design

Assembling tests: 2012 Nov-Dec
Delivery to Soleil 2013 Febr

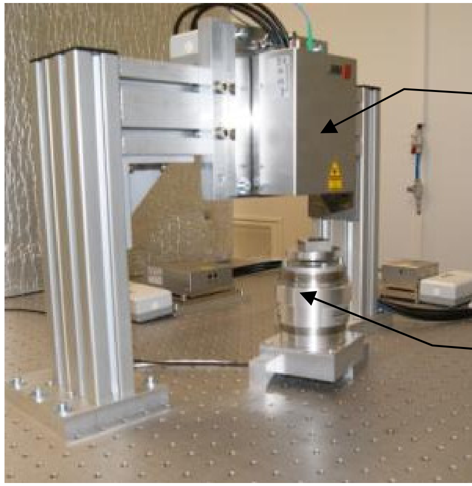
Diapositive 14

HJ11 modifier le bandeau à gauche pour différencier des présentation officielle ANR?
HACCOUN Julien; 25/07/2012

Vertical sample positioning stage

Technical specifications, tolerances, stability criteria (Soleil)

Travel range: 1-2 mm
Resolution: 5 nm
Scanning modes:
•Continuous fast (1 mm/s) « fly scan »
•Precision step scan, with ~5 nm resolution



3 axis interferometer

prototype

Working principle:
• **high precision translation stage (linear motor, flexure based guidance) with load compensation mechanism**
•**dedicated electronics for motion control**

Challenges:

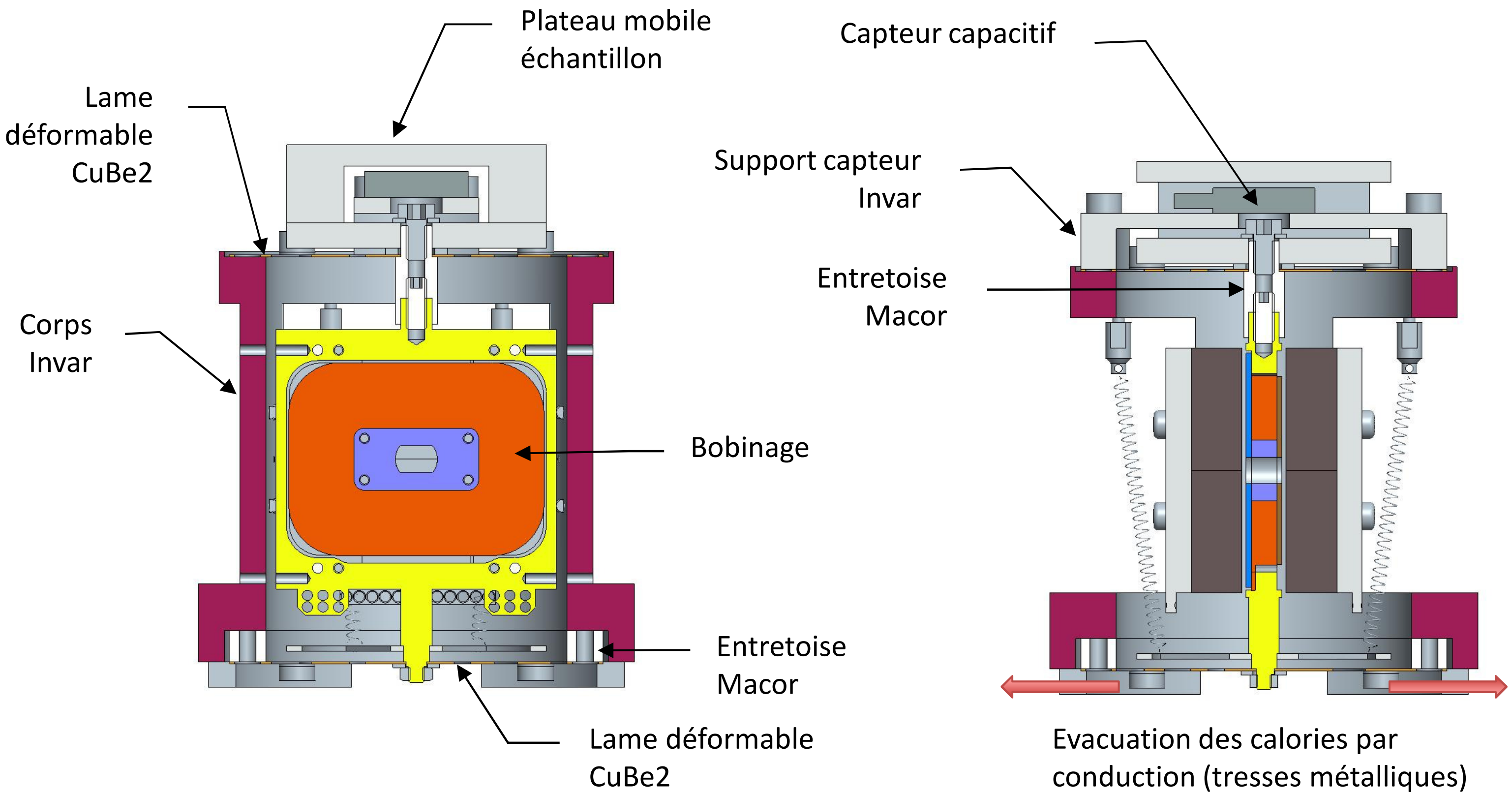
- **Obtaining electronic noise levels compatible with 5 nm resolution & mm travel range**
- **« Flyscan » mode**

HJ7

Sample positioning

→ **Optimization: minimizing the heat transfer to the sample**

Take into account and correct for the differential dilatation in the closed loop feedback



Dépôt de brevet (ISP):

→ Actionneur linéaire sans contact à guidage flexible et application à une table de déplacement

Diapositive 16

HJ7 modifier le bandeau à gauche pour différencier des présentation officielle ANR?
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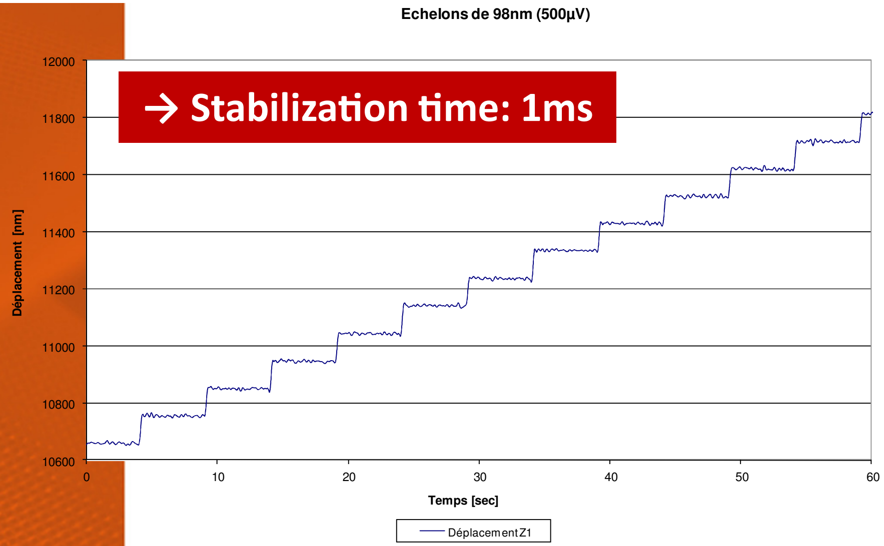
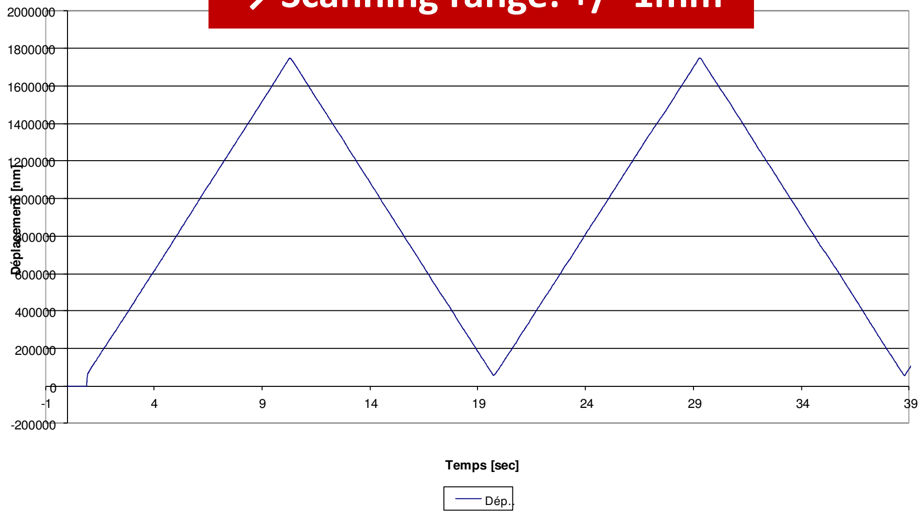
HJ8

Sample positioning

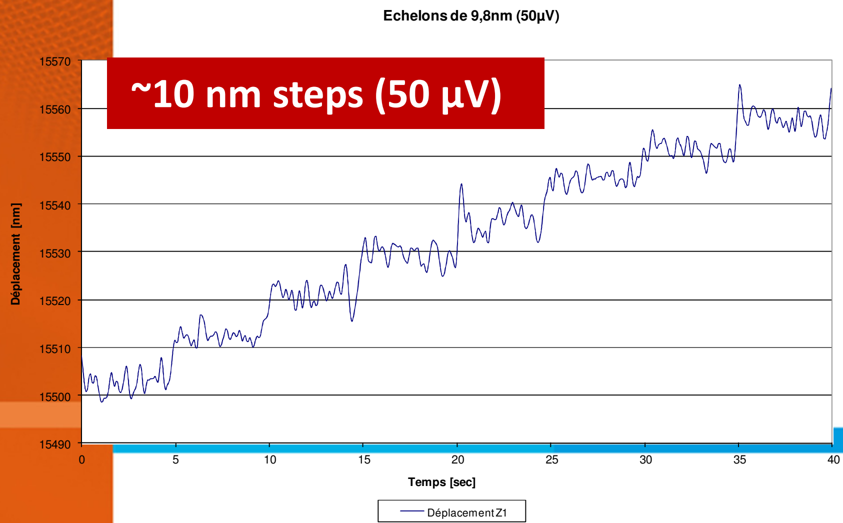
→ *Validation of the electronic control and the closed loop feedback*



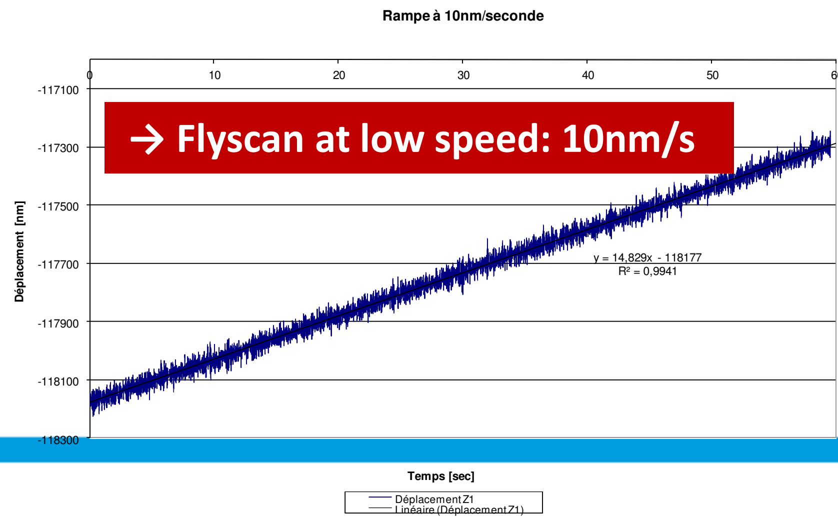
→ Stabilization time: 1ms



→ Scanning range: +/- 1mm



~10 nm steps (50 µV)



→ Flyscan at low speed: 10nm/s

→ Resolution <1nm with 24 bits control electronics

Diapositive 17

HJ8 modifier le bandeau à gauche pour différencier des présentation officielle ANR?
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Task 3: Mirror fabrication by deterministic ion-beam polishing (IBP)

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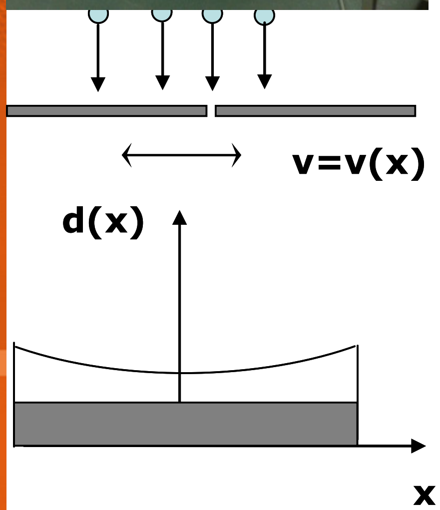
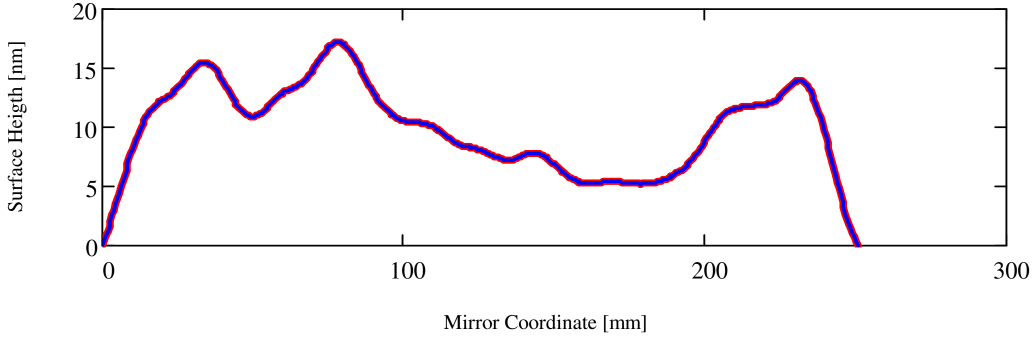
SESO : Experimental facility (mirror lengths < 1.5 m): thin film coating & IBP



Residual height R(x)



Aim: correction of the artifacts of standard polishing

Local correction of less 1 nm in height can be reliably applied

IBP Steps

1. **Measure height profile P(x)**
2. **Ellipse equation (goal), E(x)**
3. **Evaluation of residual height R(x)**
   → R(L)=R(0)=0
4. **Calculation v(x)**

Mirror fabrication by IBP (SESO)

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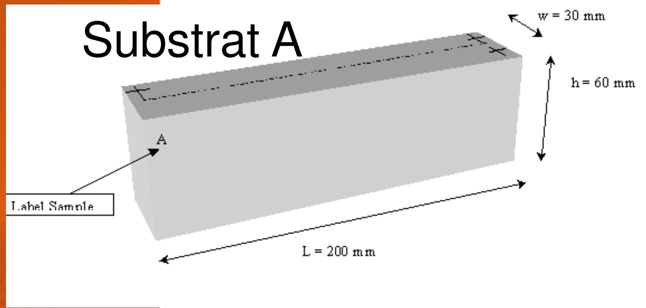
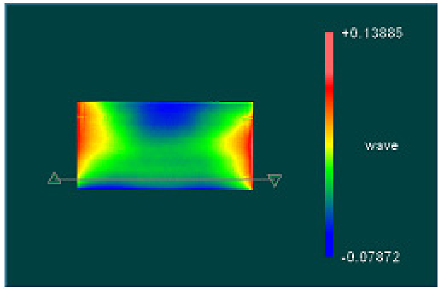
Results: surface finishing is in progress

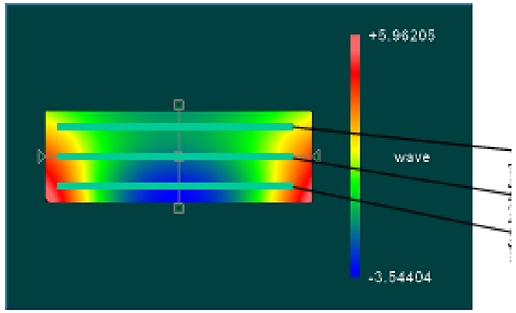
Si substrates for monolithic elliptically shaped mirrors



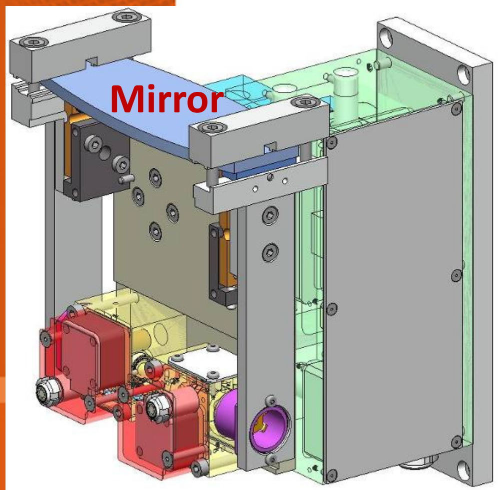
Nano-MRX (before IBP)

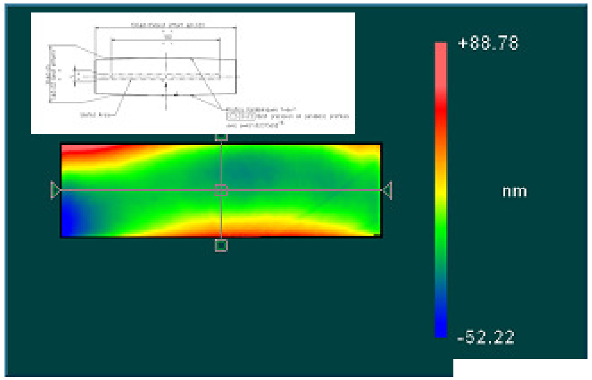


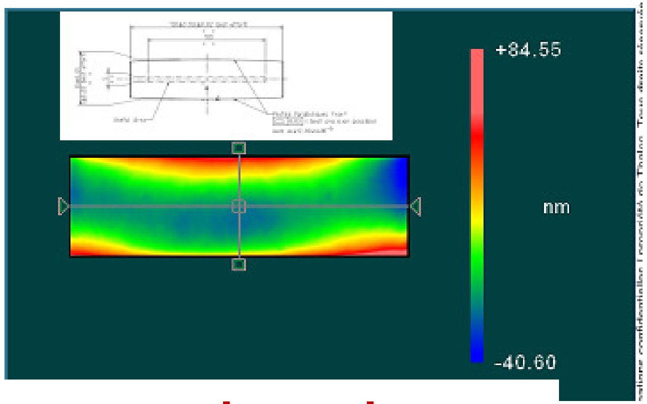
Nano-MRX(after IBP)



Si substrates for flat, torpedo shaped mirrors







Before torpedo cutting

CNC Cutting of TORPEDO shapes (in progress) (+/- 30 µm accuracy)

Task 4: Surface finishing by deterministic deposition

Working strategy

Definition of mirror characteristics (SOLEIL)

↓

Polishing of SiO_2 substrates & visible metrology & fiducial markers for comparative metrology and det. deposition (SESO)

↓

Comparative métrologie before det. deposition (SESO, SOLEIL, LMA)

↓

Deterministic deposition (LMA)

↓ ↑

Comparative métrologie after det. Deposition (SESO, SOLEIL, LMA)

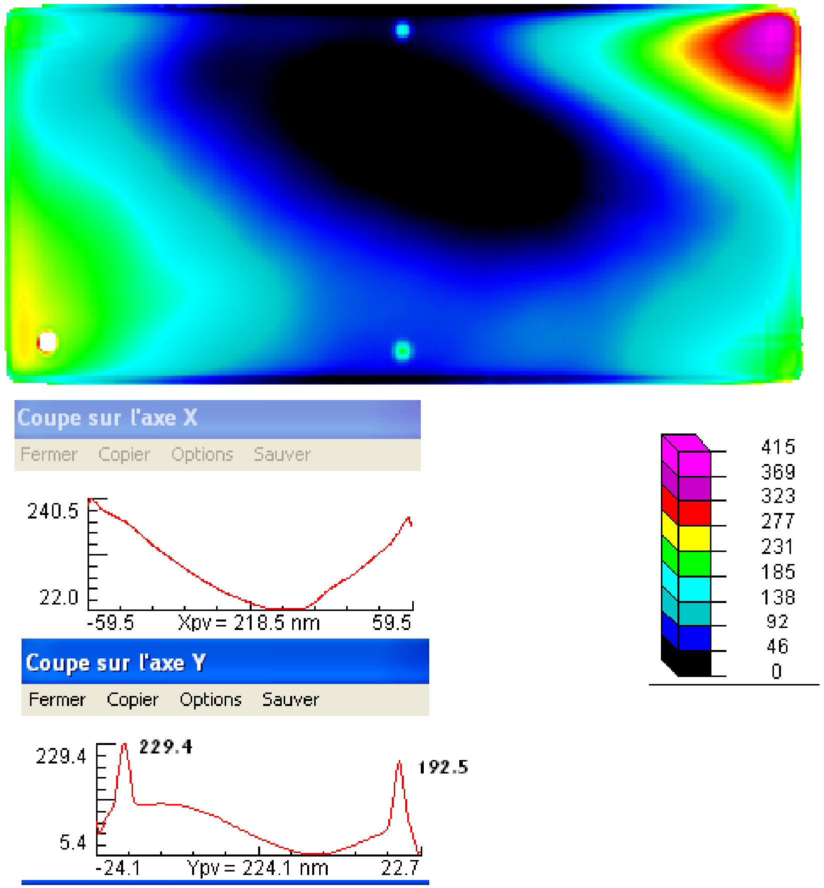
↓

Validation

Starting SiO_2 substrates (polished by SESO)

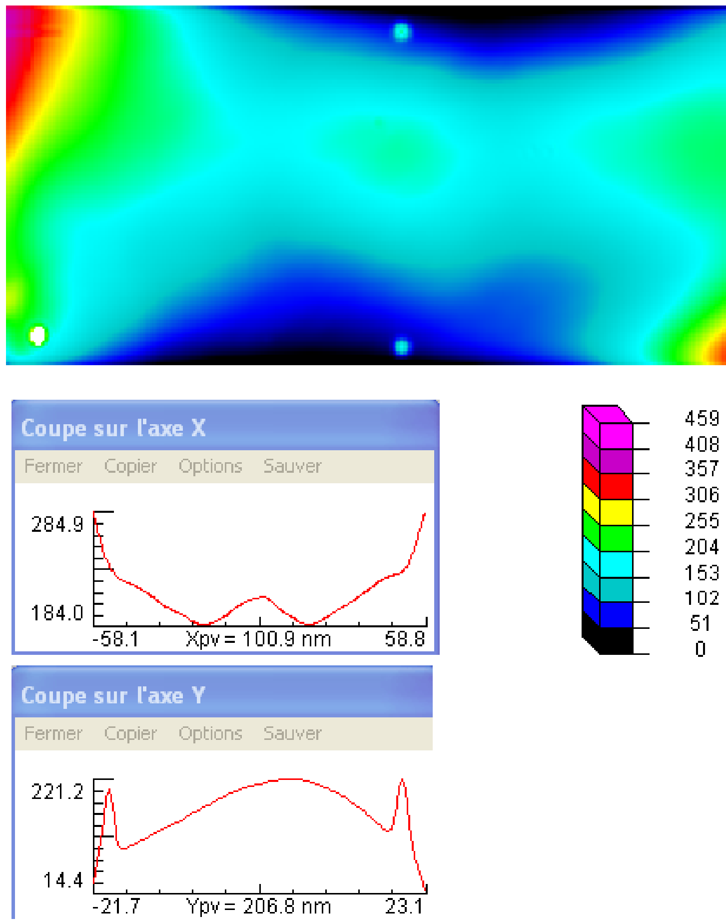
Substrat A

Shape error P to V: 218 nm



Substrat B

Shape error P to V: 76 nm

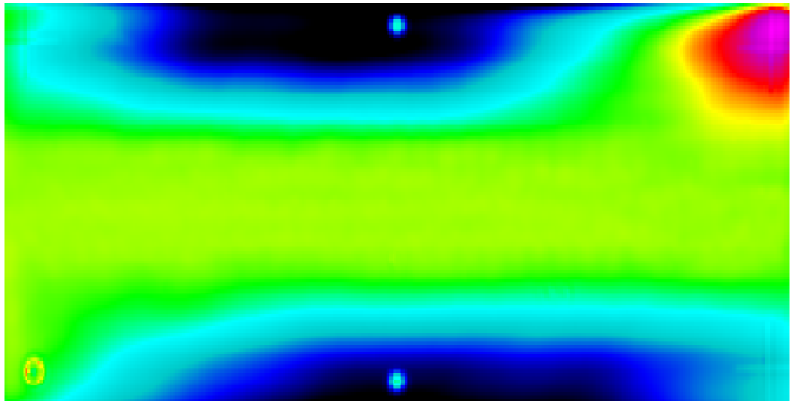


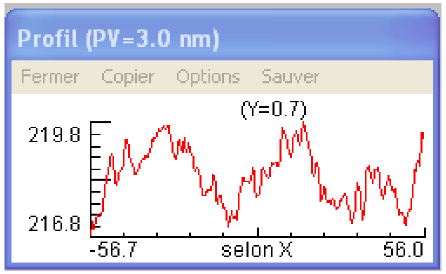
Results:

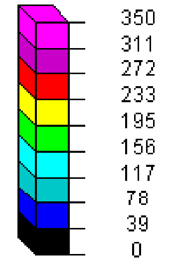
After surface correction (LMA)

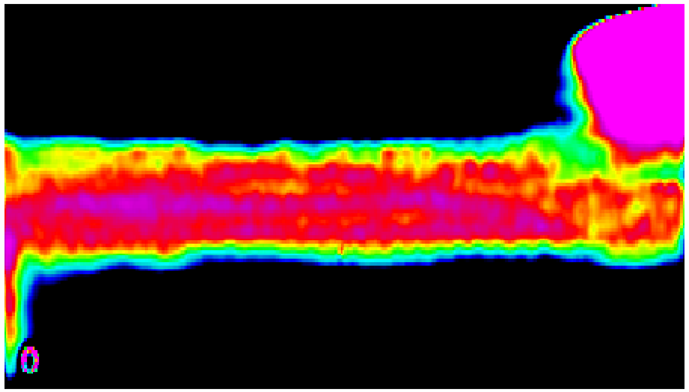
Substrat A

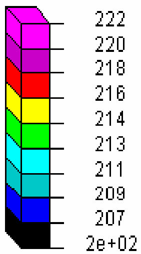
Shape error P to V: 3 nm





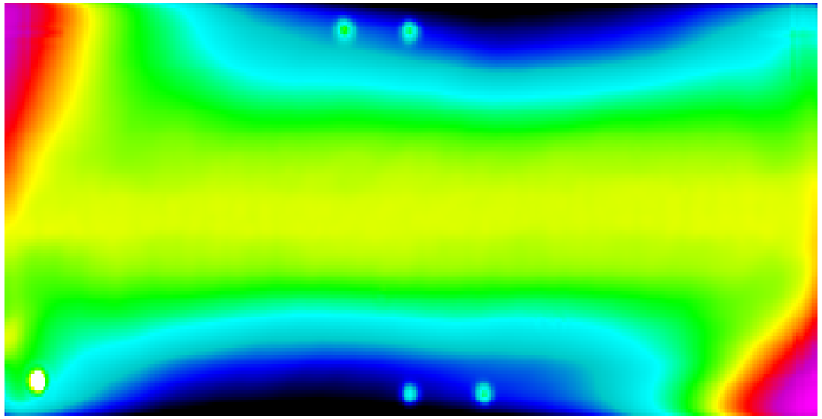


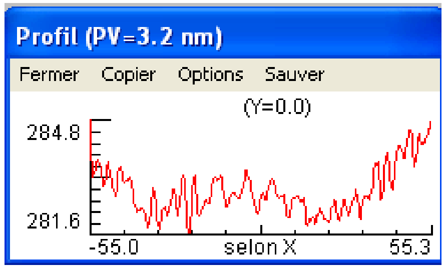


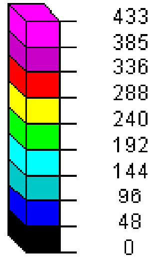


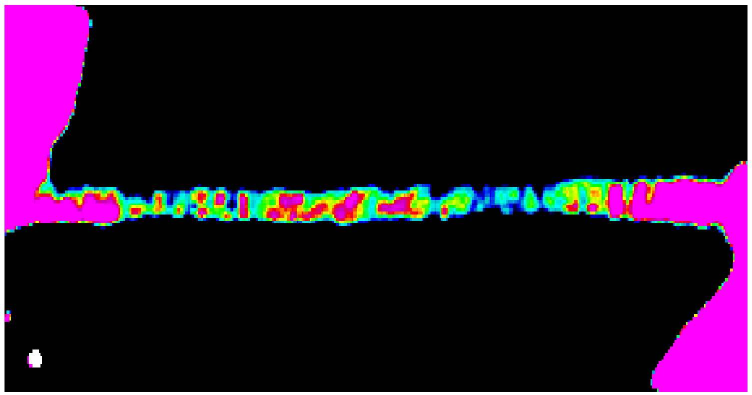
Substrat B

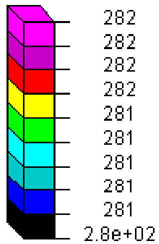
Shape error P to V: 3,2 nm







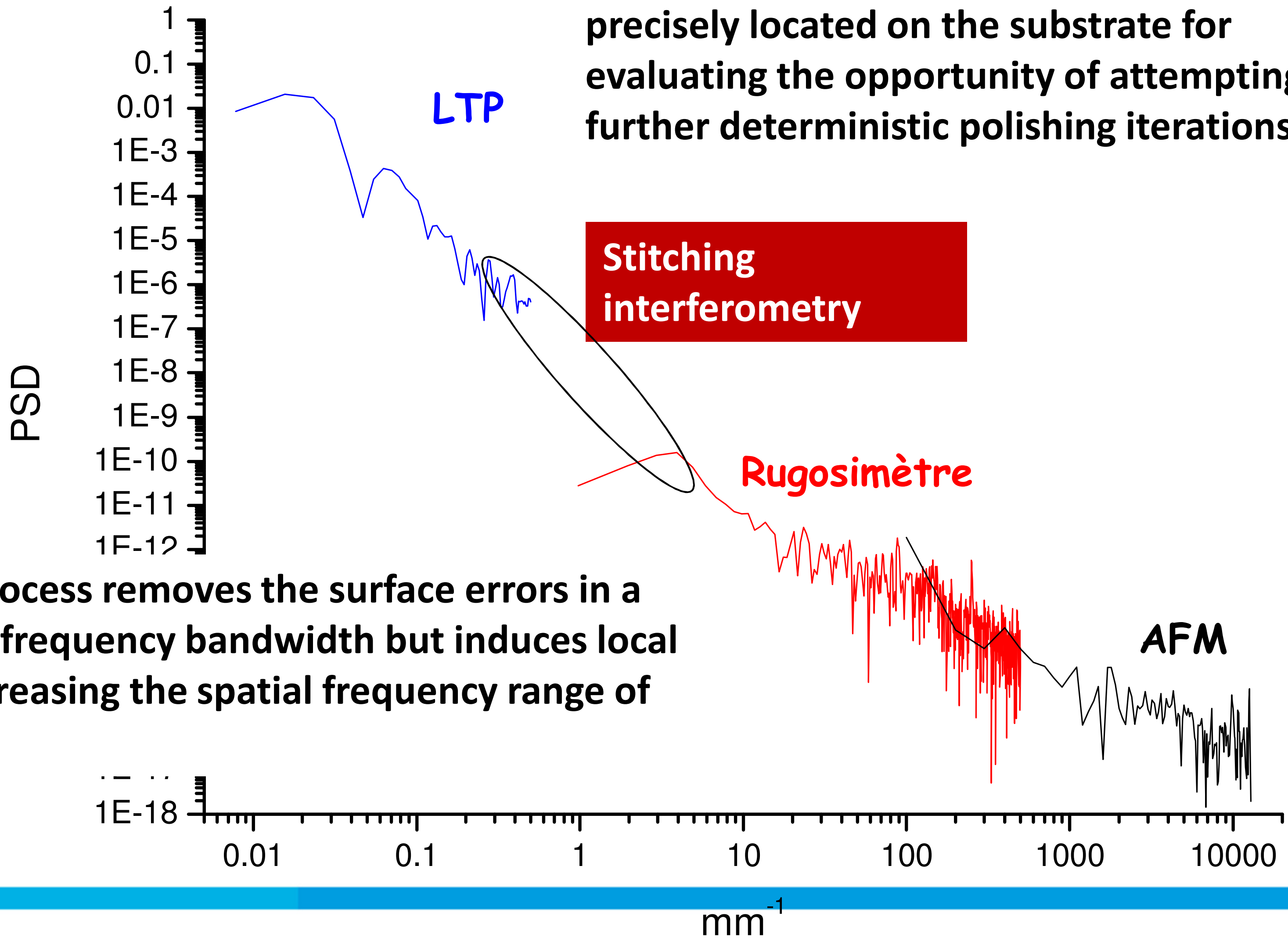




Task 5: Mirror metrology developments

Aim: to develop optical metrology adapted to nanofocusing optics

The spatial frequency range from 0.5 to 20 1/mm was missing. The defects must be precisely located on the substrate for evaluating the opportunity of attempting a further deterministic polishing iterations.



Re-polishing process removes the surface errors in a desired spatial frequency bandwidth but induces local side effects increasing the spatial frequency range of defects.

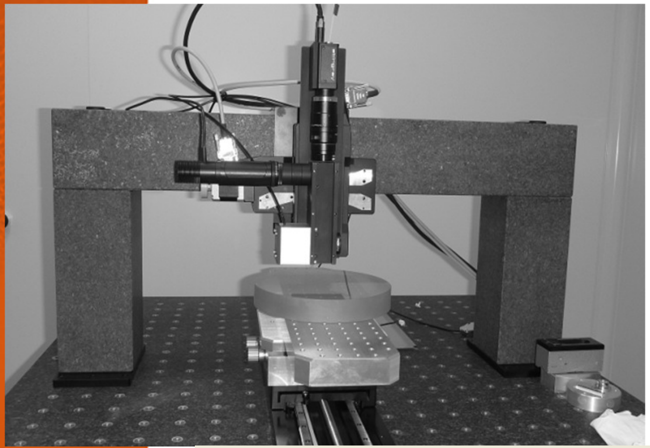
Available instruments, methods in the framework of AXOC

Stitching interferometry, under development at Soleil

Aim: to link a process of local surface modification to surface shape measurements.
Needed: sub-nanometer height accuracy and a lateral resolution below 1 mm.

Goal : ±0.1 nm height accuracy; field of view up to 20 mm and, below 100 µm spatial resolution.

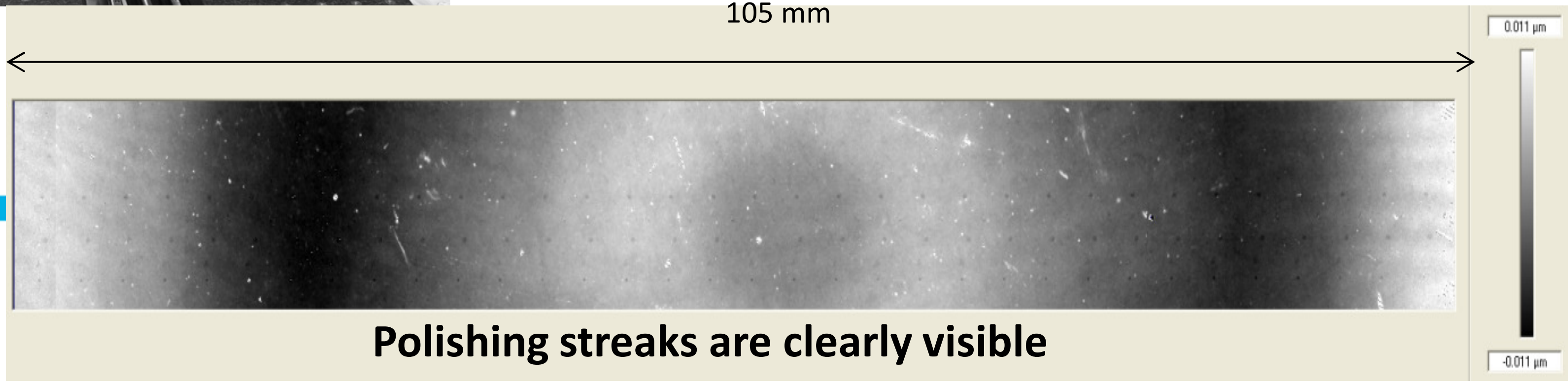
2nd prototype



Results

Without any filtering, the short term repeatability is <0.8 nm PV.

First stitching topography of a plane mirror stitching 20 individual images on 105 mm length.
Measurement step is 5 mm.
The slope error: 0.9 µrad rms (by LTP).



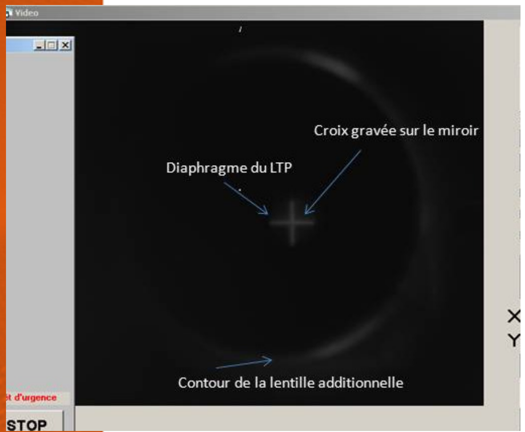
Polishing streaks are clearly visible

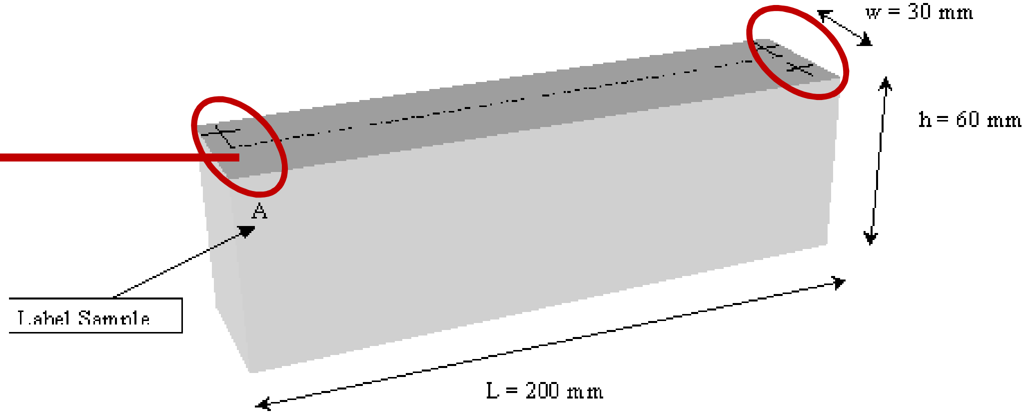
Muriel Thomasset, et al., **A new Phase-shift Microscope Designed for High Accuracy Stitching Interferometry,** Submitted for publication

F. Polack et al., **Determination and compensation of the “reference surface” from redundant sets of surface measurements,** Submitted for publication

Intercomparison metrology SOLEIL-SESO-LMA: for each mirror

Fiducial markers:





Sensibility of mirror positioning: 20µm, repeatibility: < 50 µm

Intercomparison metrology SOLEIL-SESO: results

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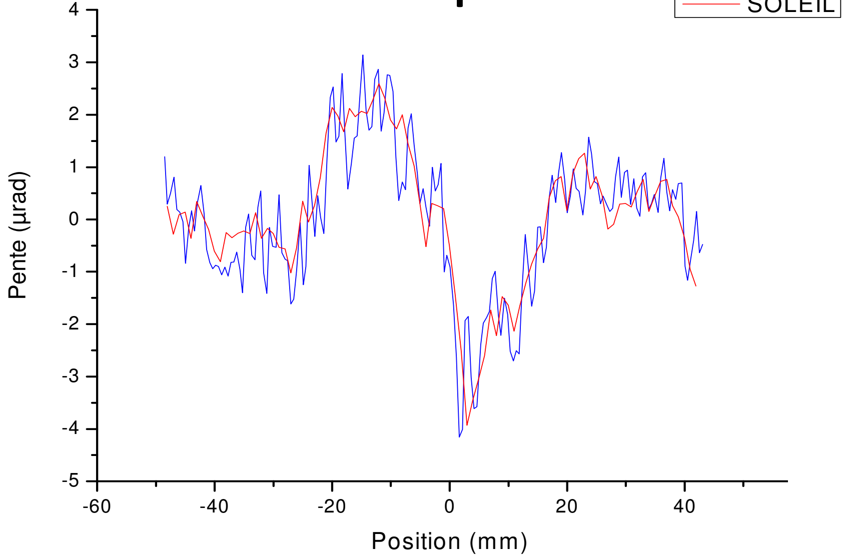
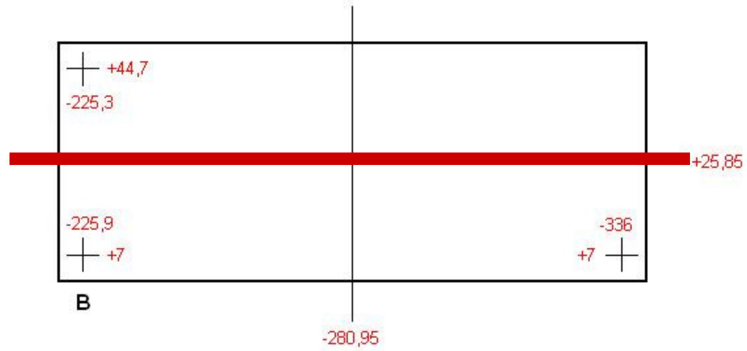
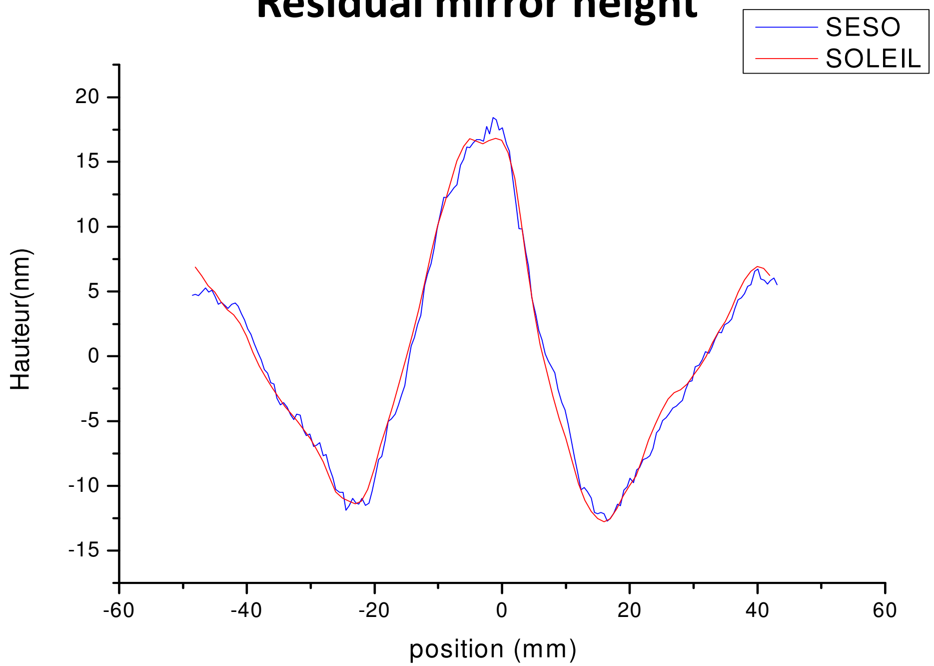
Mirror slope





Residual mirror height



Residual variation of the mirror slope and height after subtraction of the best sphere

SiO_2 substrate