

## Centre Spatial de Liège

- **Infrared holographic interferometry for metrology of space payloads**
- **NDI by optical-laser techniques for aeronautical composites**

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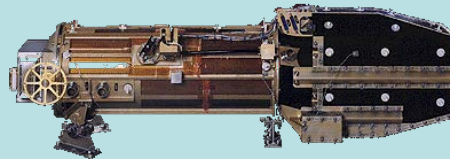
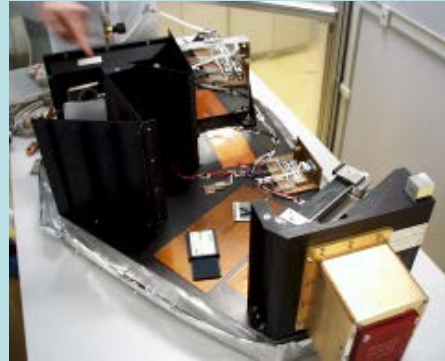
4031 Angleur (Liège) - BELGIUM

## Optics for Space

Simulated space environment testing  
Large chambers with optical benches



Development of optical  
Space instrumentation



Development of  
Advanced Technologies

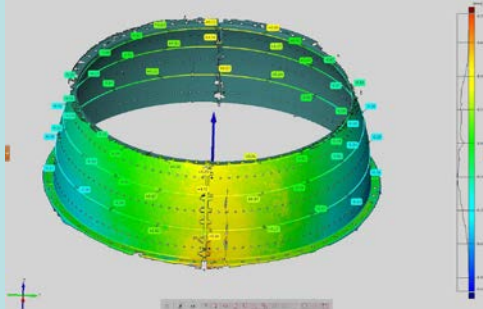
- Vacuum-Cryogeny
- Quality insurance
- Thermal Design
- Signal Processing
- Spaceborne Electronics
- Smart sensors
- Surface processing
- Optical Design
- Optical Metrology
- Non Destructive Testing



## Research in laser and optical metrology and NDT for aerospace

### Dimensional measurement

- Fringe projection
- Digital Image Correlation



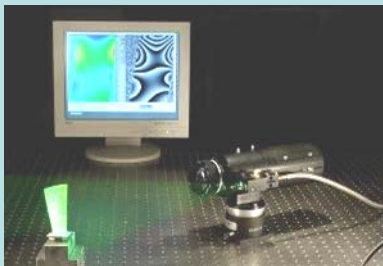
### Thermography

- Pulsed + Lock-in
- Vibrothermography (ULg)

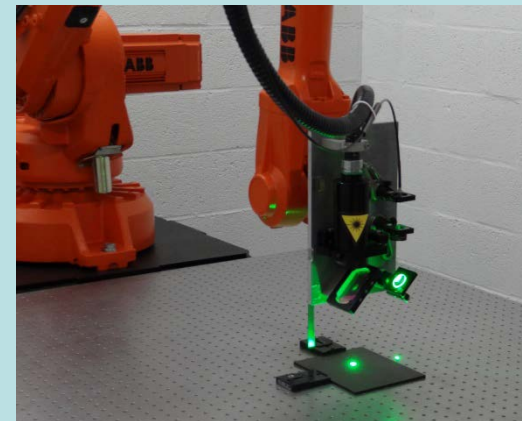


### Full-Field Deformation measurement

- Holography
- Speckle interferometry
- Shearography



### Laser Ultrasonics

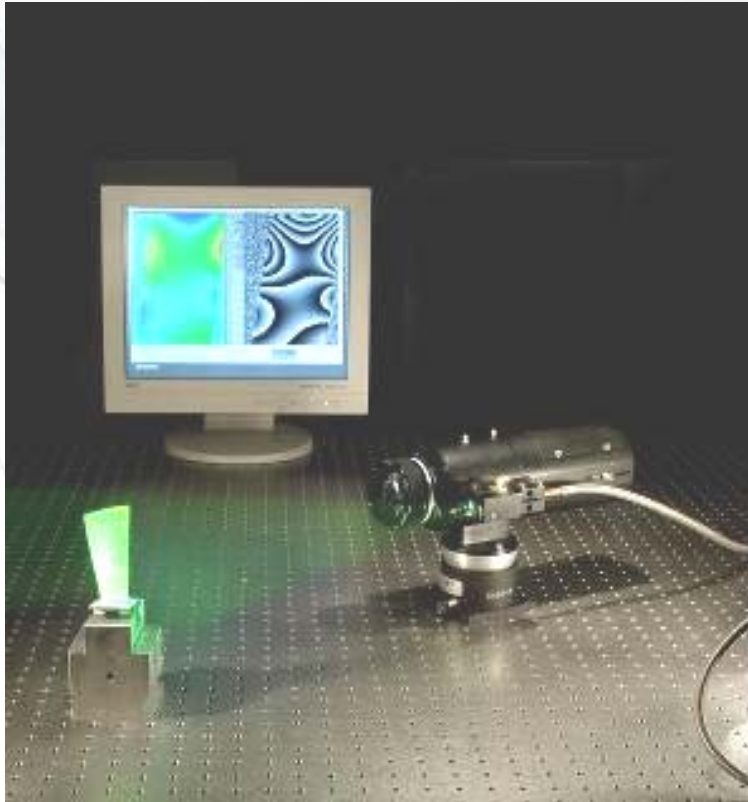




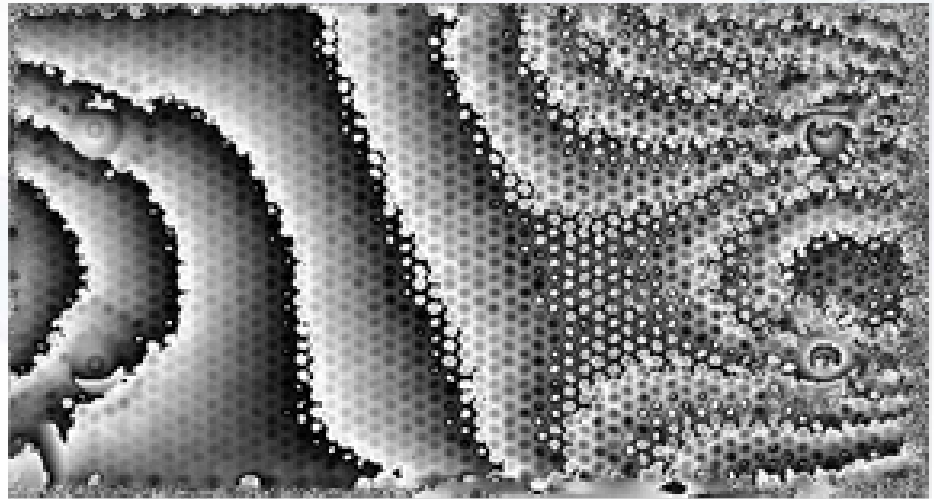
## **Infrared holographic interferometry for metrology of space payloads**

# Holographic camera

- Analog hologram recording
- Photorefractive crystals ( $\text{Bi}_{12}\text{SiO}_{20}$ )
- In-situ recording + Fully erasable + Reusable

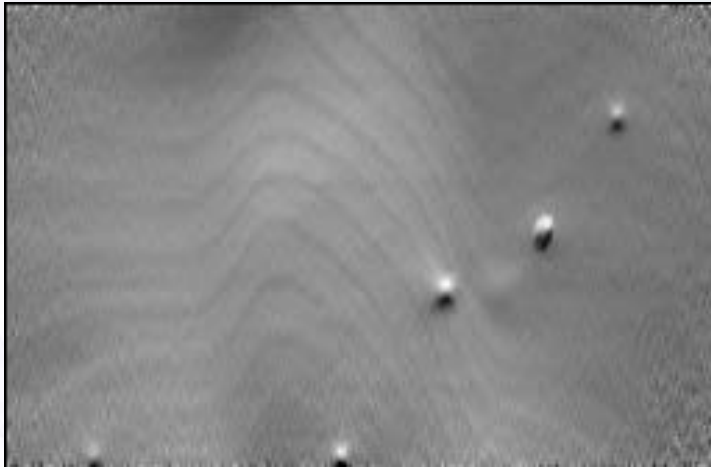


- Green Laser (532 nm)
- Displacement range : 15 nm - 25  $\mu\text{m}$
- Very high resolution

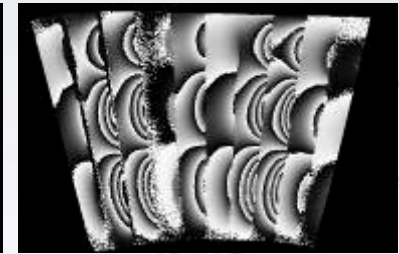
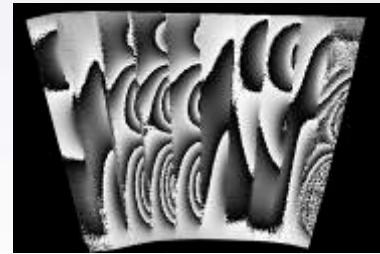


- Applications

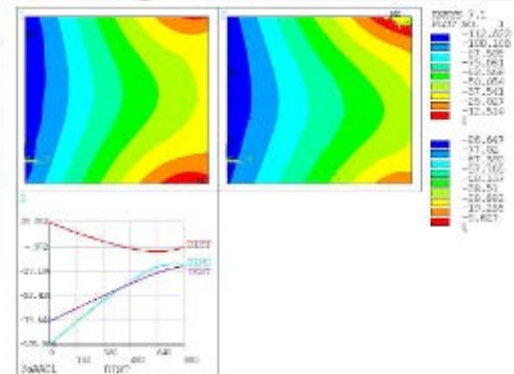
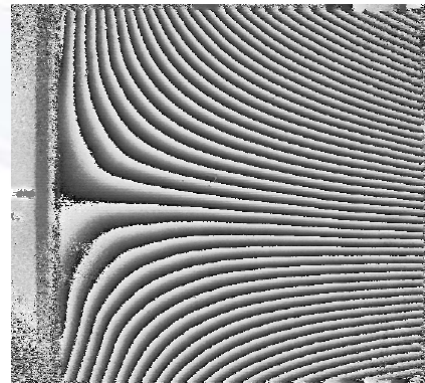
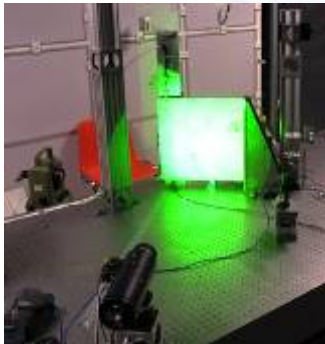
**Defect Detection in composites (CFRP)**



**Vibration Mode Shapes**



**Metrology – FEM comparison**





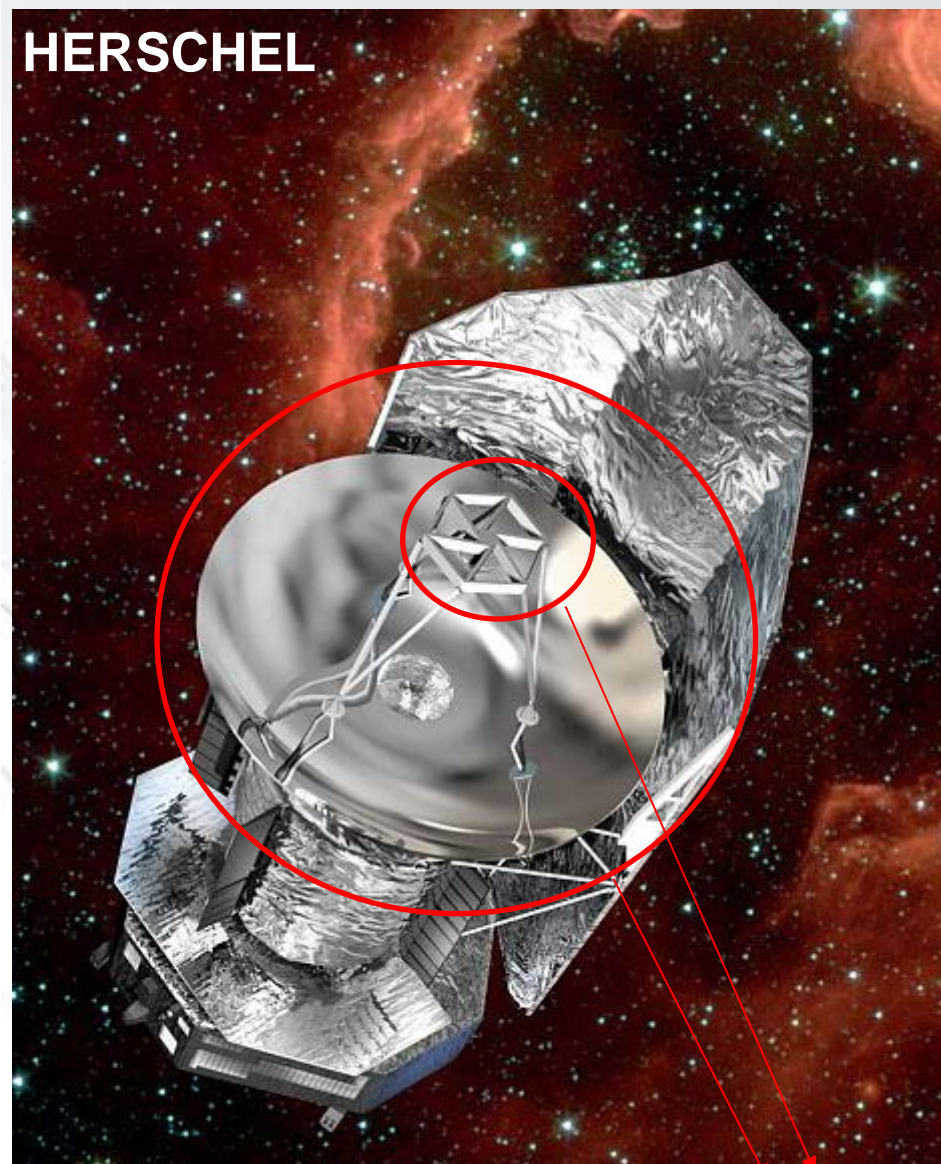
# Metrology on composite structures

- Thermo-mechanical assessment of composite space materials/structures

### Space instrument structure in test bench



# Test of large optics

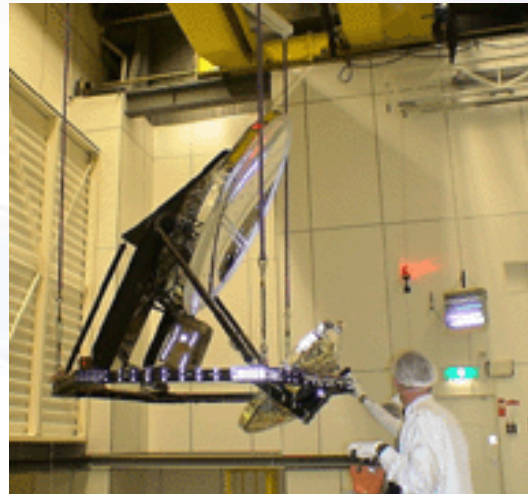


**Aspheric reflectors**



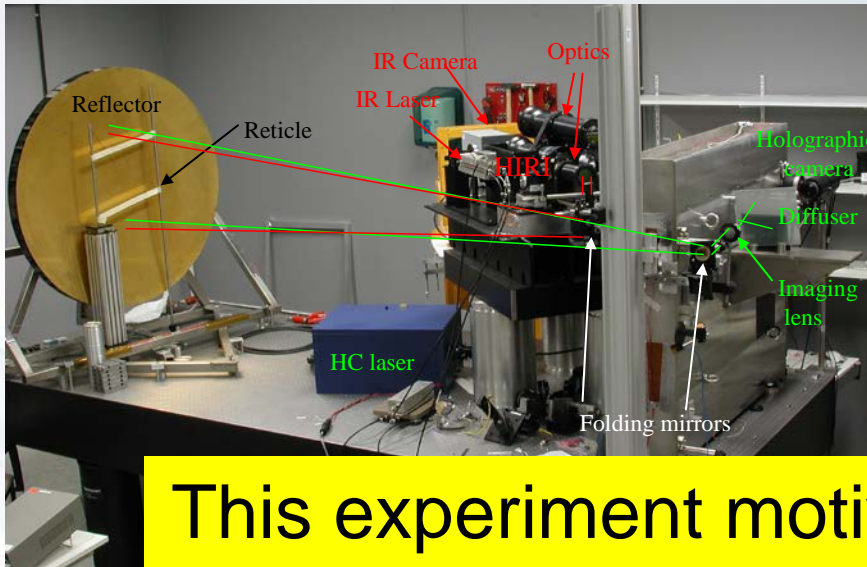
# Test of large optics

- ESA and other space agencies need:
  - Full-field **deformations** of reflectors in vacuum-thermal testing
  - Large reflectors: up to 4 m diameter
  - Range of deformations: 1  $\mu\text{m}$  – 250  $\mu\text{m}$
  - **Reflectors cannot be equipped with cooperative targets nor sprayed with scattering powder !**

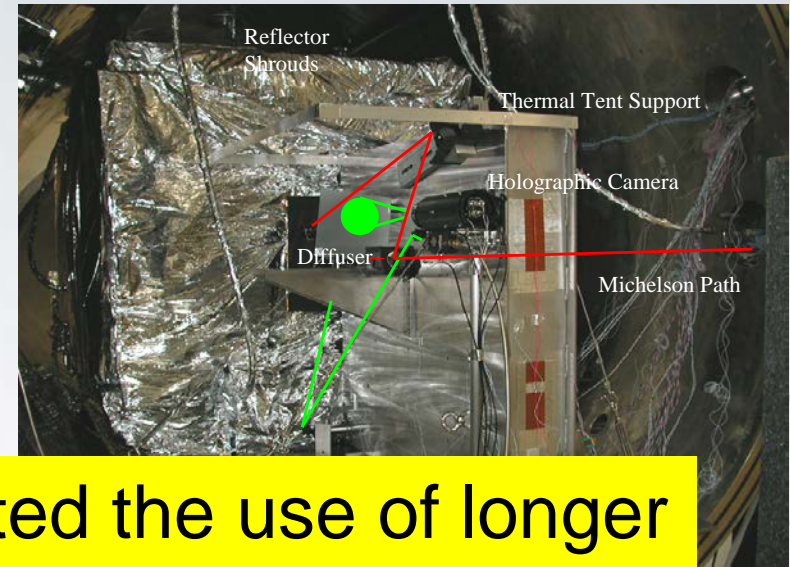


# Test of large optics

## Development of holographic setup in lab



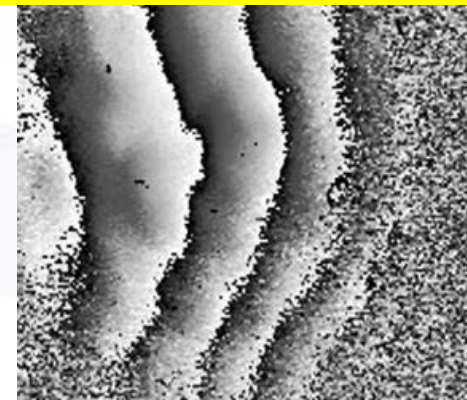
## Setup in CSL vacuum chamber



This experiment motivated the use of longer wavelengths applied to holography



**Good results of Deformation (mechanical load)**



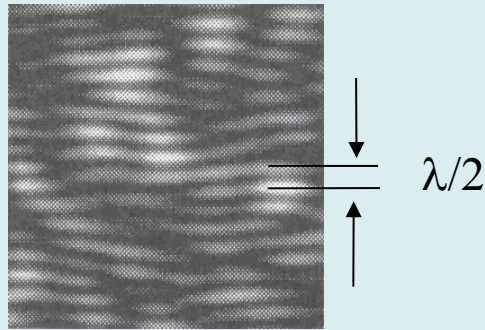
**Poor results (thermal load)**

**Instability of Setup (vibrations,...)**



# Infrared Holography

**Zoom of local interference pattern  
(hologram-specklegram)**

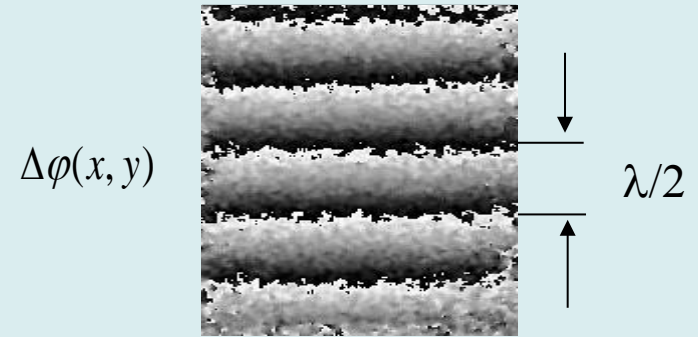


**Pattern must be stable during recording  
(depends on frame rate)**

Set-up stability criterion :  $< \lambda/10$

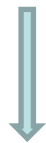
Visible lasers : stability better than **50 nm**

**Phase map / displacement field**



**Measurement range  $\iff$  Number of fringes**

Visible lasers : range = **50 nm – 10  $\mu\text{m}$**



stability can be only **1  $\mu\text{m}$**

**CO<sub>2</sub> laser  
 $\lambda=10 \mu\text{m}$   
(LWIR range)**



range = **1  $\mu\text{m}$  – 200  $\mu\text{m}$**

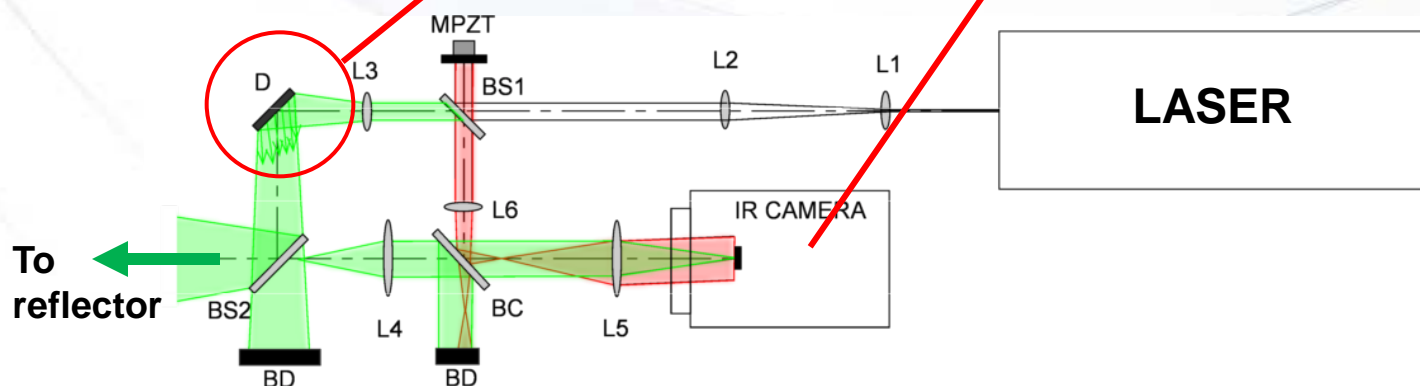
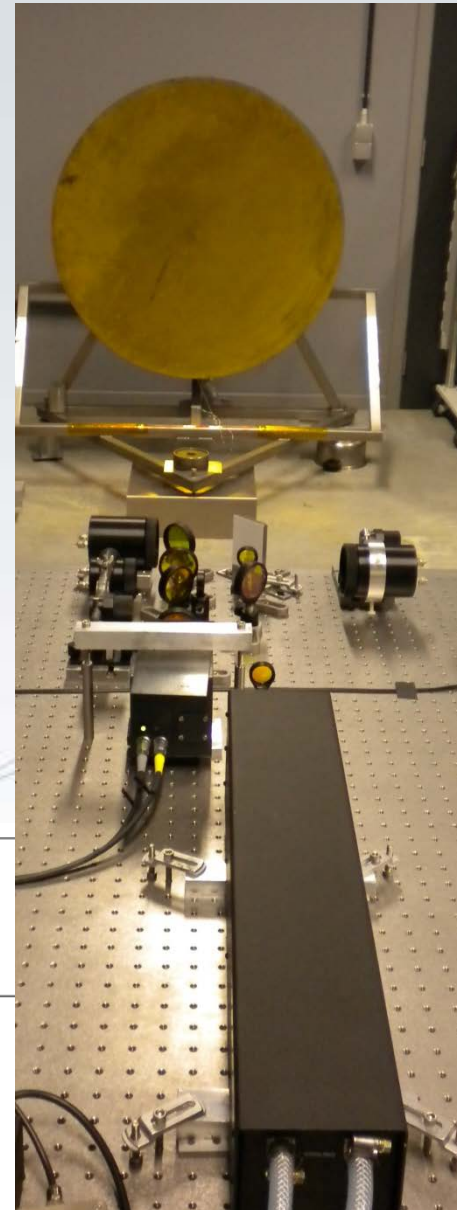
- HOLODIR instrument implemented in laboratory to measure its performances
- Observation of a parabolic reflector
  - Diameter : 1.1 m
  - F# : 1.4



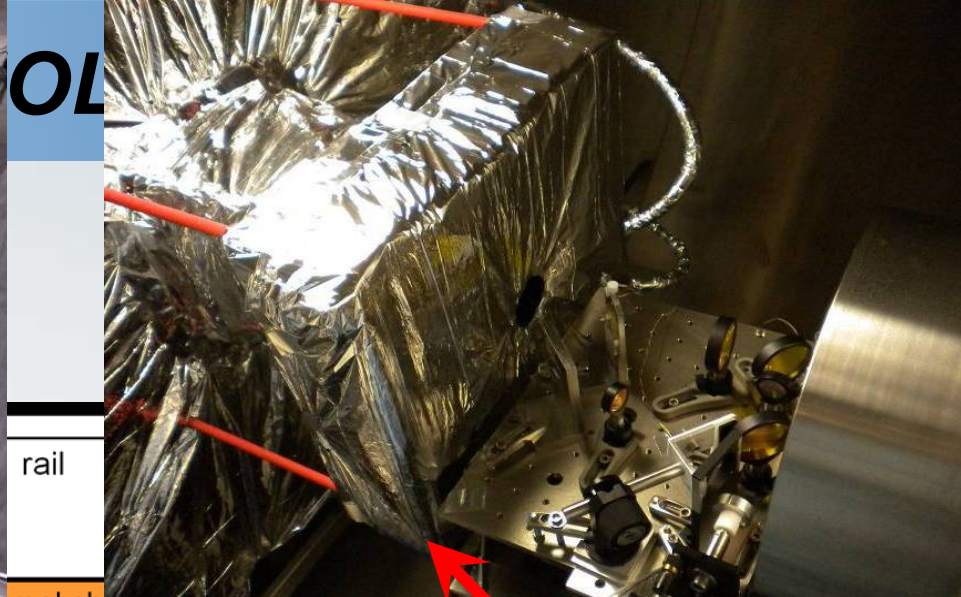
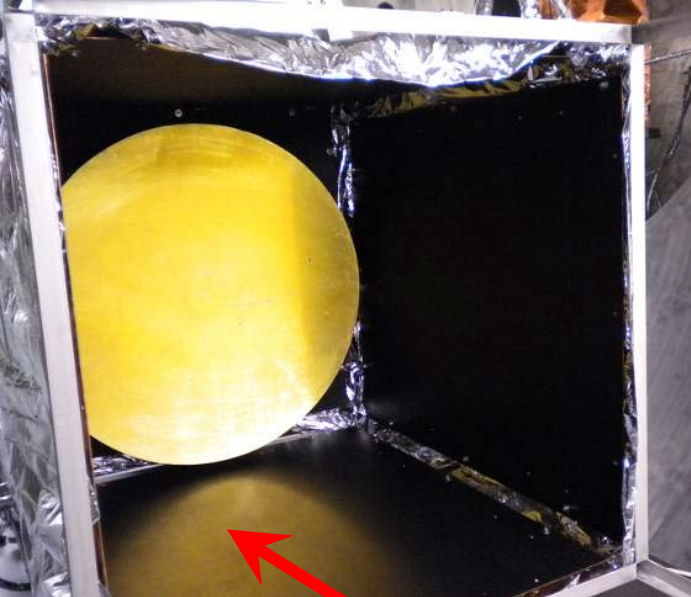
Diffuser



Uncooled  $\mu$ -bolometer  
 640x480 pixels  
 Pixel Pitch : 25  $\mu\text{m}$   
 Frame rate 60 Hz  
 16 bits

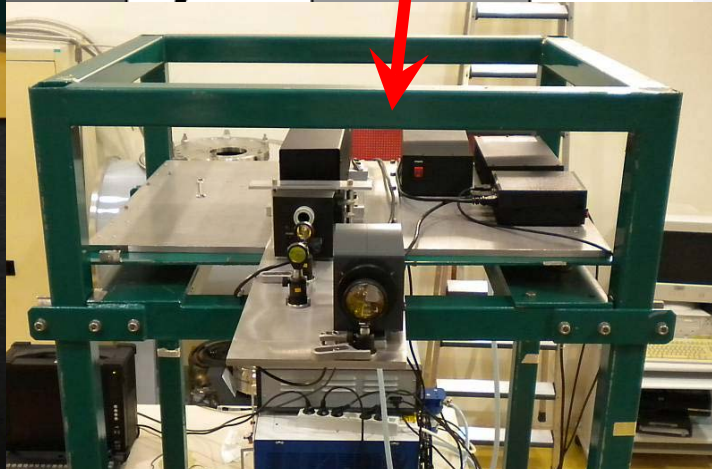
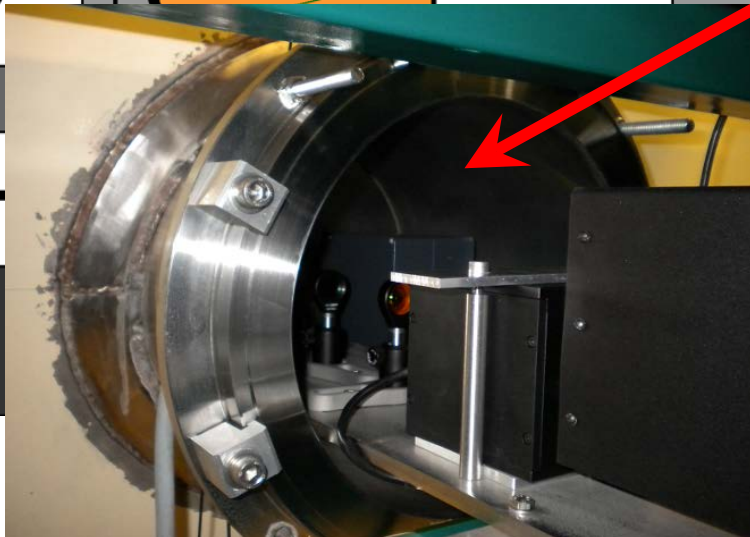
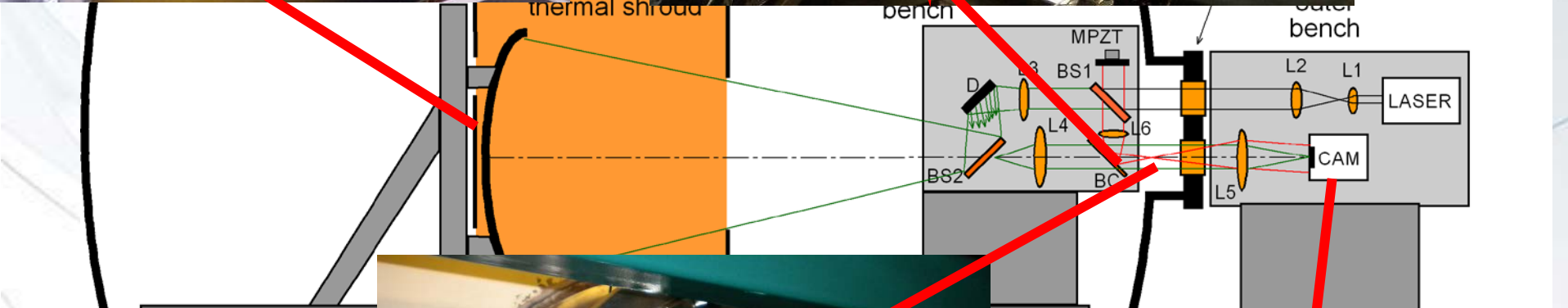




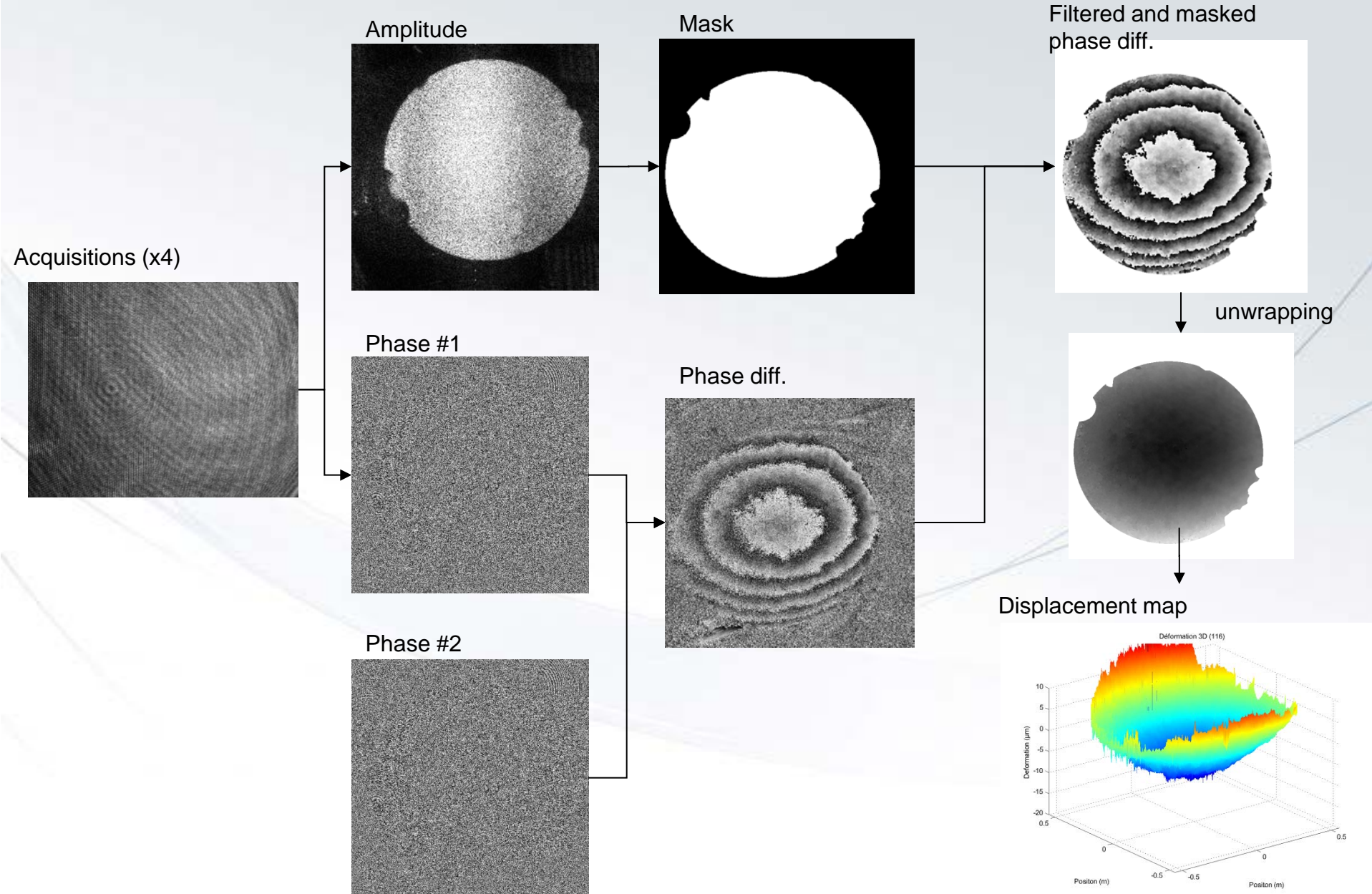


OL

rail



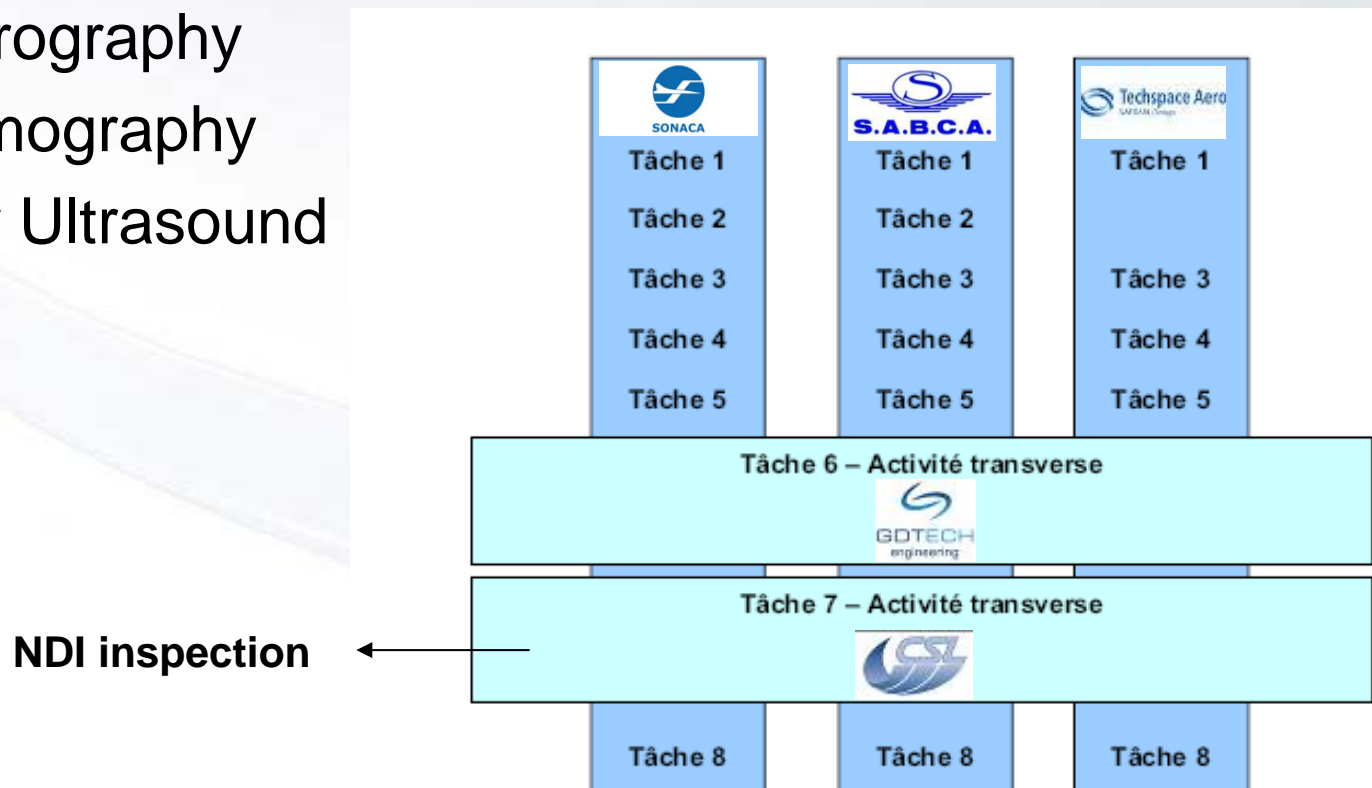
# HOLODIR project





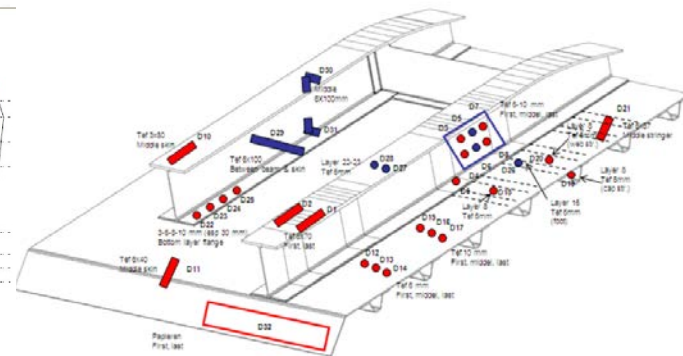
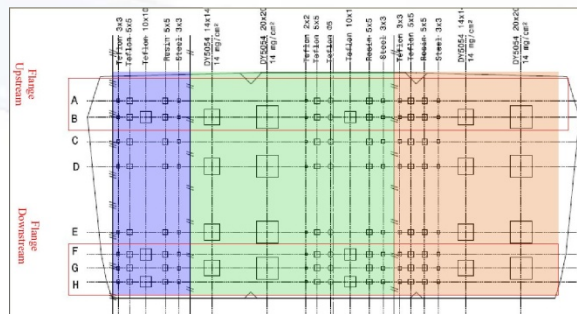
## **Nondestructive inspection by optical-laser techniques for aeronautical composites**

- Purposes
  - Study non-contact NDI techniques
  - Complex shaped composites structures
- Techniques considered
  - Shearography
  - Thermography
  - Laser Ultrasound

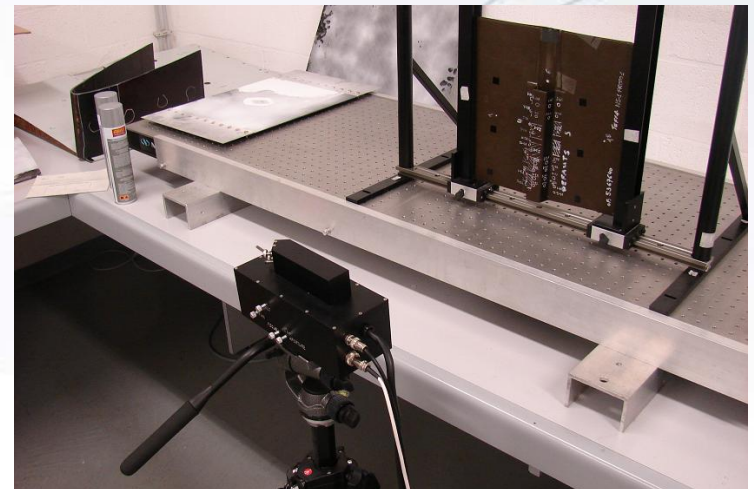
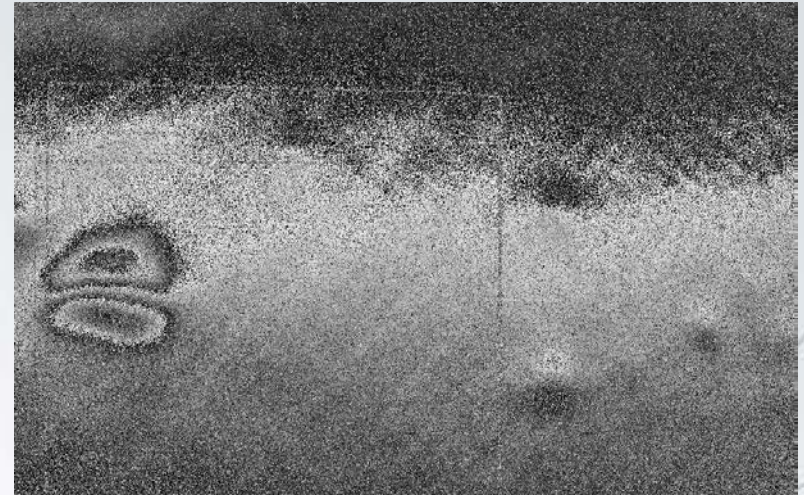
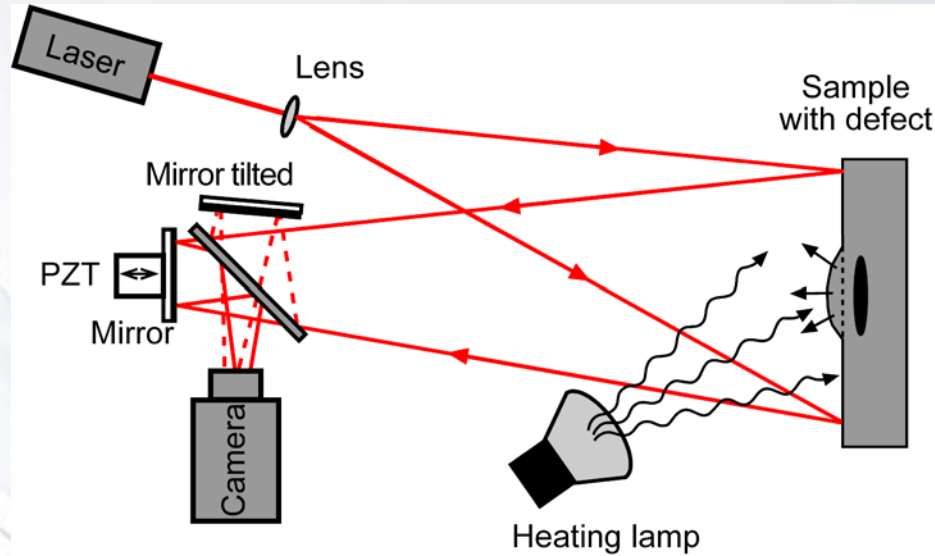




## Monolithic samples Calibrated defects (teflon inserts, flashbreaker,...)

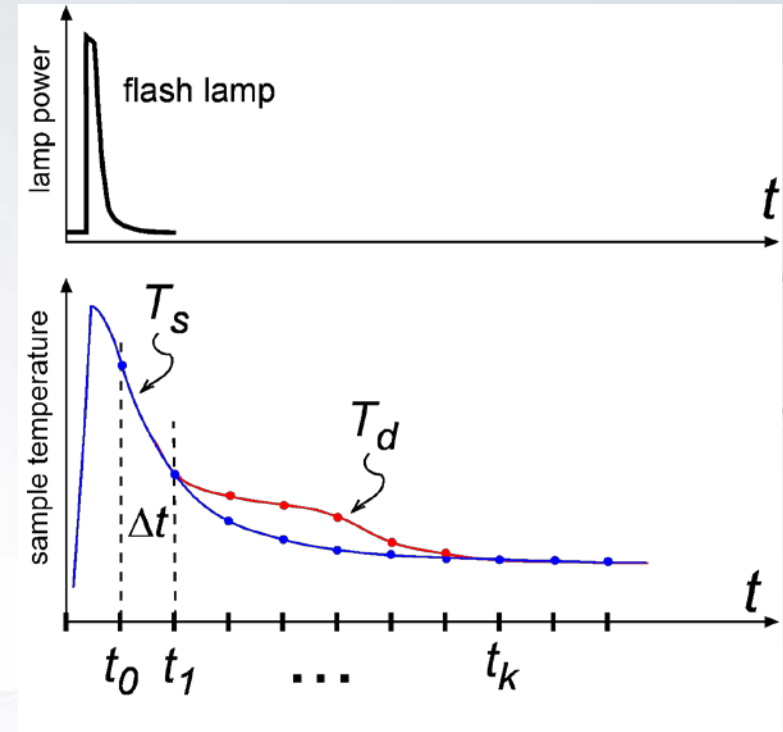
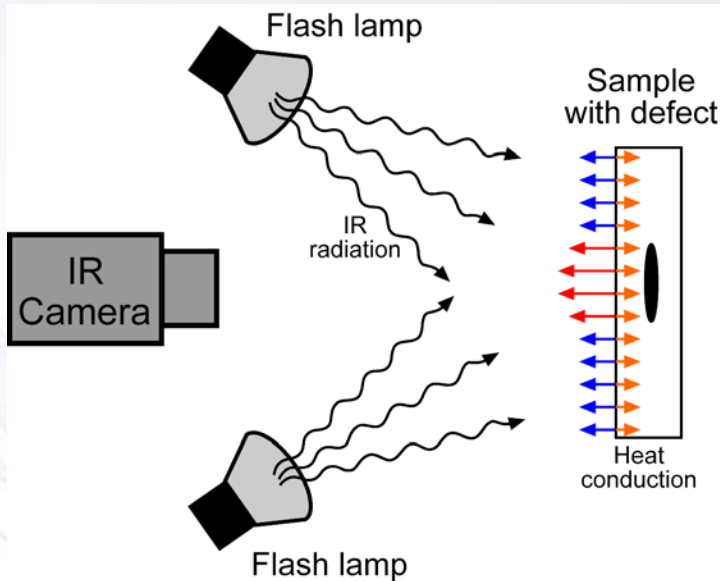


- Shearography with heating



# Techniques used

- Thermography : Optical Pulse Thermography (OPT)



Surface observation of thermal wave and its effect on internal defect

$$t \approx \frac{z^2}{\alpha}$$

The observation time  $t$  is related to the defect depth  
( $\alpha$  : thermal diffusion coefficient)



- Thermography : OPT
  - Pulse Phase Thermography (PPT)

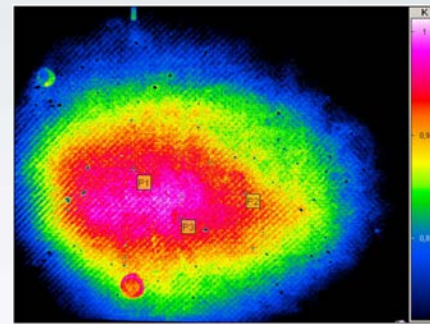
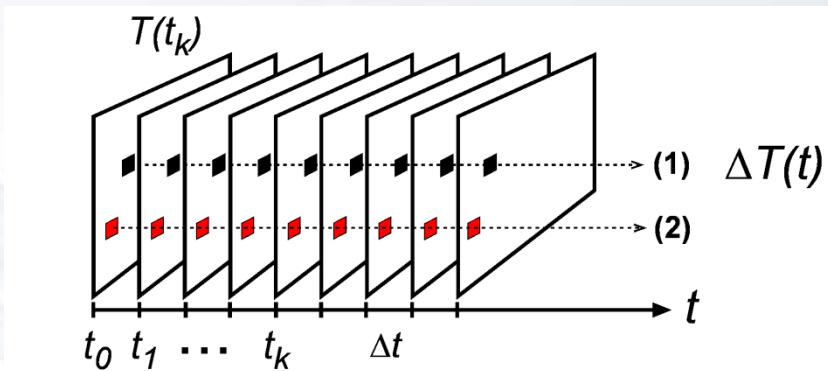


Figure 19: Amplitude image of the PPT analysis

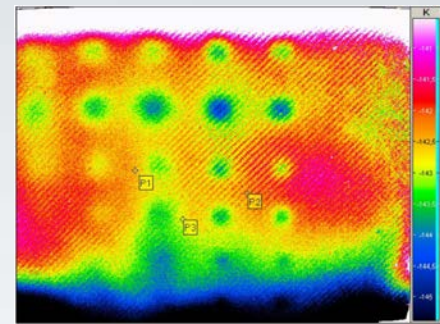
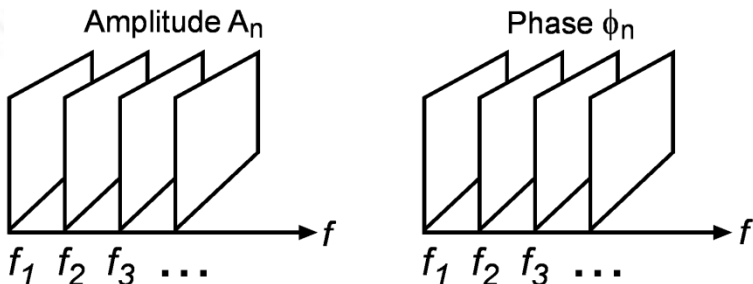


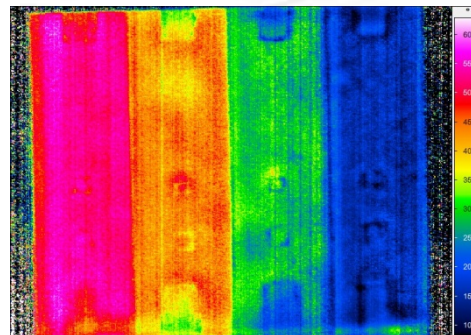
Figure 18: Phase image of the PPT analysis

Fourier Transform

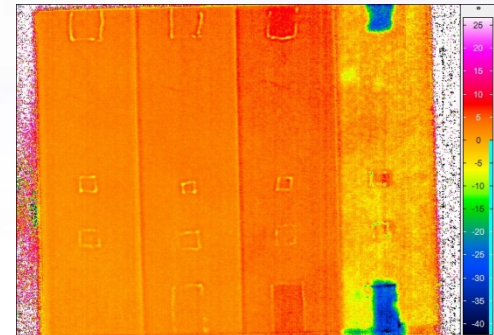


$$f_n = \frac{n}{N \Delta t}$$

$f$  low ( $n$  small)  
 $t$  high  
 $z$  deep



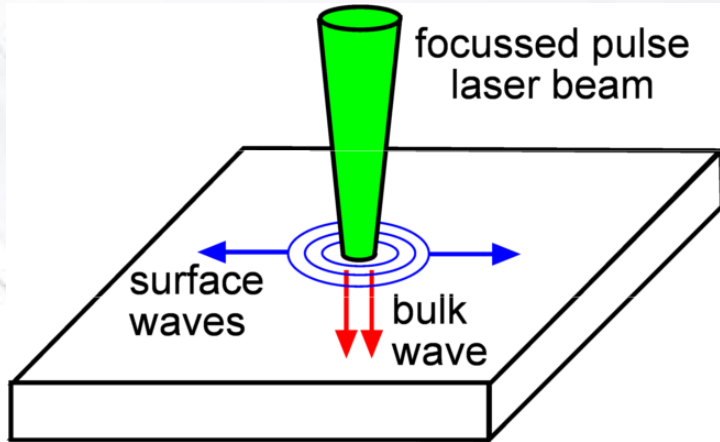
$f=0,0125$  Hz



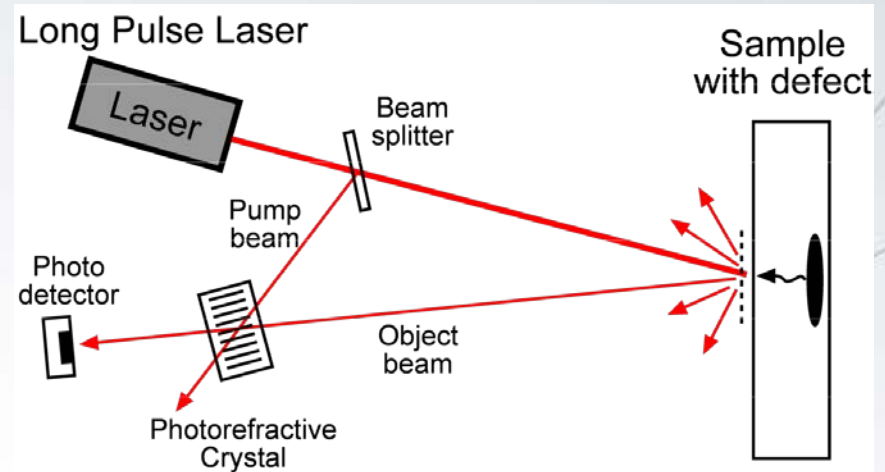
$f=0,25$  Hz

- Laser Ultrasounds

## Generation of ultrasound by laser Thermoelastic effect



## Detection of ultrasound by laser Interferometric probe (with laser) and Two-Wave Mixing



- ✓ No couplant – No water
- ✓ Signal independent of geometry
- ✓ Economically interesting for curved parts (see. EADS-Lockheed Martin publications)

- Examples of existing systems

LUIS (Tecnocampus Nantes)



LUIS (Sacramento, 1996)



Lockheed Martin (2000)



LUCIE (Tecnocampus Nantes, 2011)



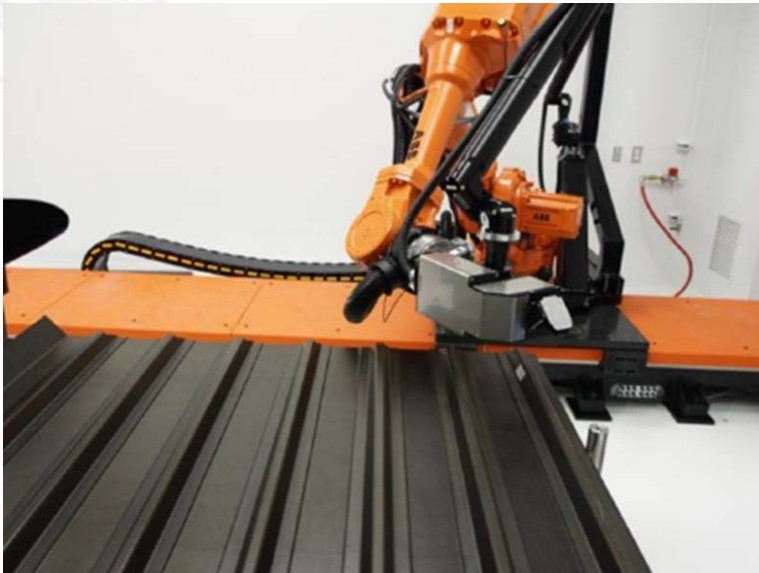


- Equipements used

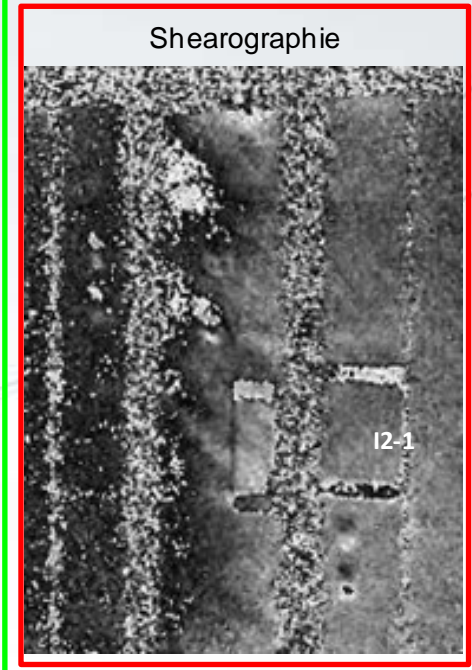
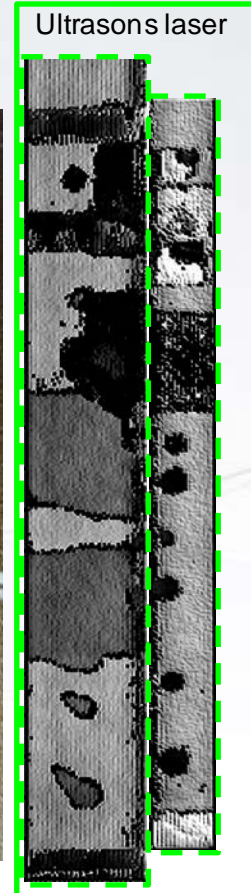
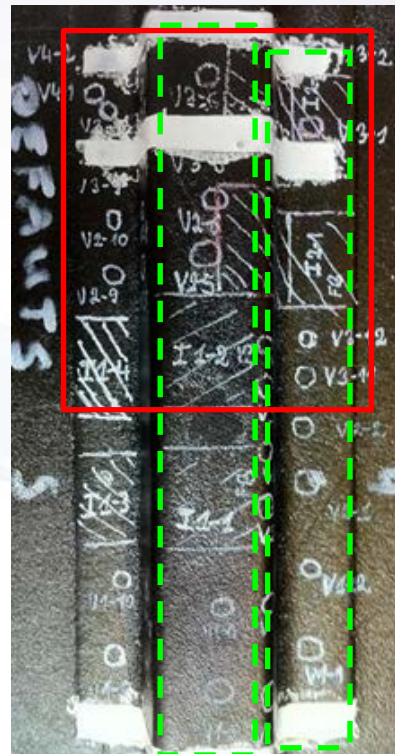
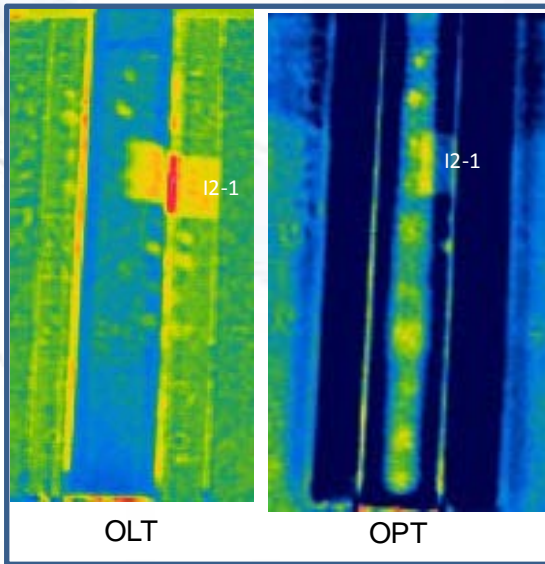
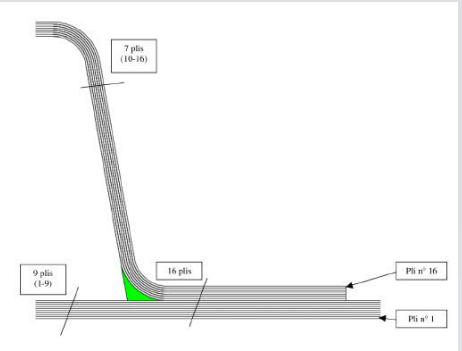
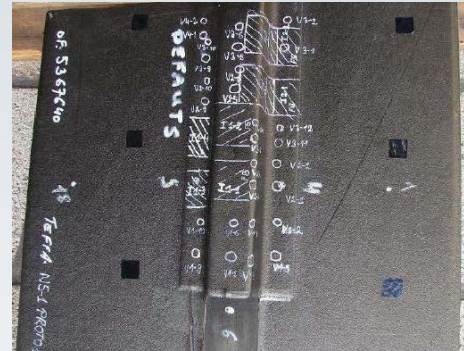


## CTA Montreal

- Generation : pulsed CO<sub>2</sub> laser (10.6 μm)
- Detection : pulsed YAG laser (1064 nm)
- Probe TWM
- repetition rate : 100 Hz
- Laser Spot : 2 mm
- Scanning step : 0,5 mm
- manufacturer TECNAR

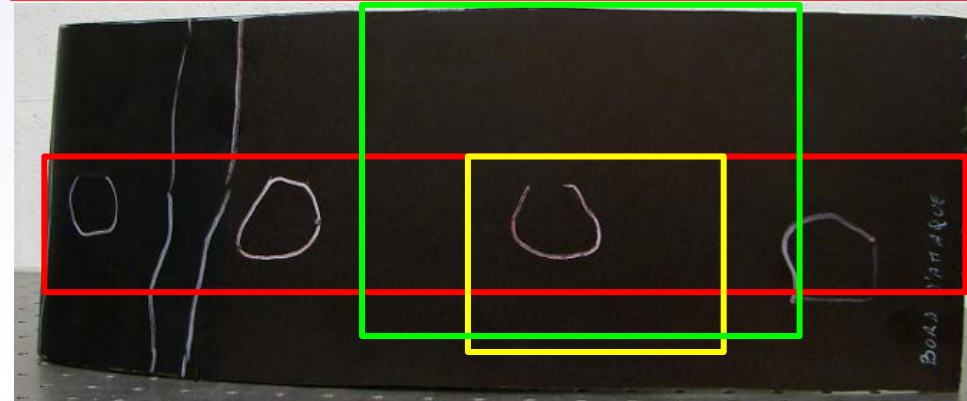
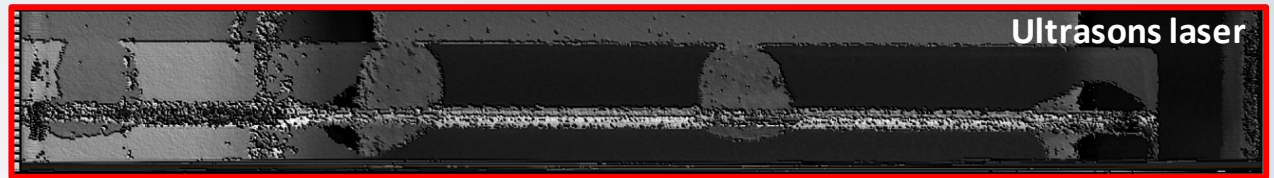


- Sample 1: Comparison

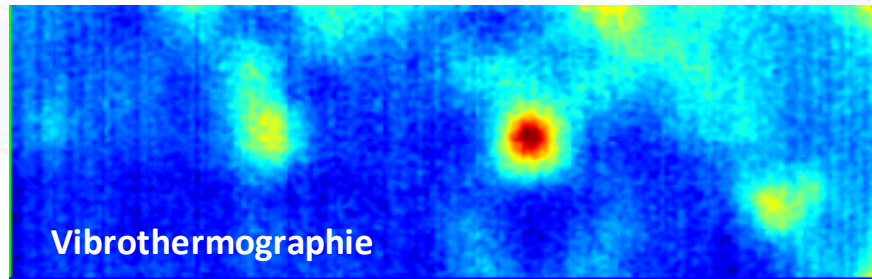
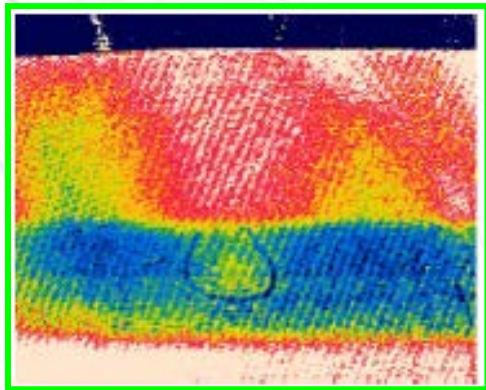




- Sample 2 : Comparison



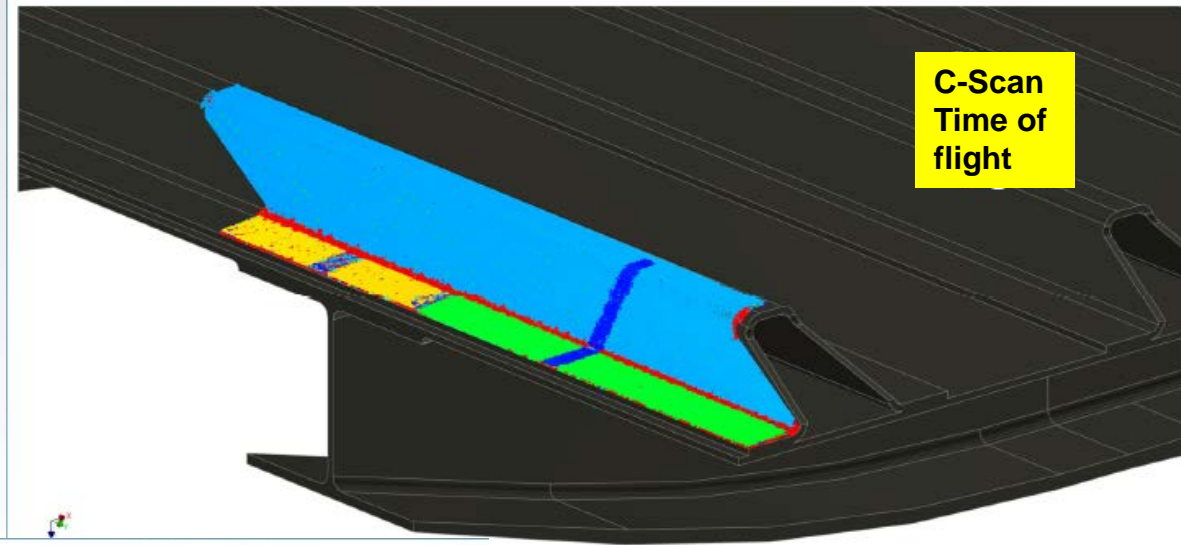
Optical pulse thermography



Vibrothermographie



- Sample 4 : Laser Ultrasound

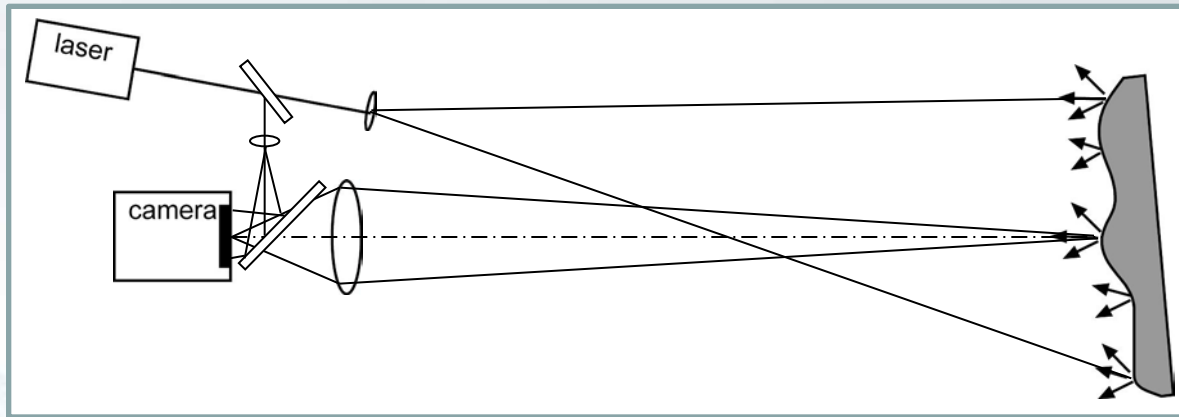


# Comparison

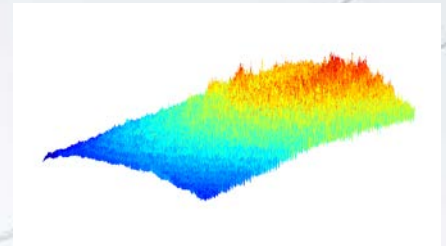
	Thermography	Shearography	Laser UT
Depth	1,5 mm	> 1,5 mm	>>> 1,5 mm
Dimensions	3-4 mm	3-4 mm	2 mm
Interpretation	+	-	++
Measurement	Qualitative	Qualitative	Quantitative
Depth assessment	-	--	++
Set-up	+	+	- (scanning)
Cost	\$\$	\$	\$\$\$\$

**NDT techniques must be envisaged in complementarity**

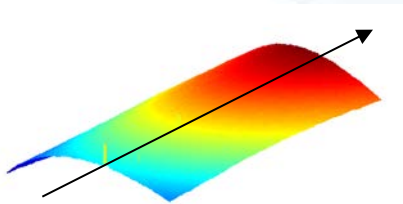
## Infrared holography



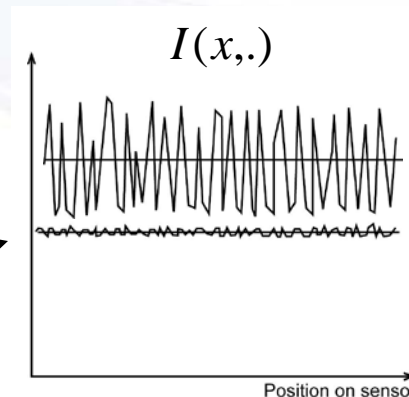
$$I(x, y) = I_{\text{thermal}}(x, y) + I_{\text{average}}(x, y) + C(x, y) \cos[\psi(x, y)]$$



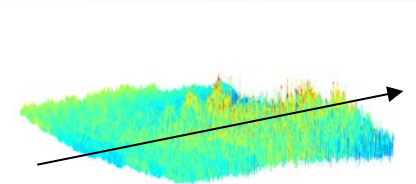
Laser OFF



Thermal background

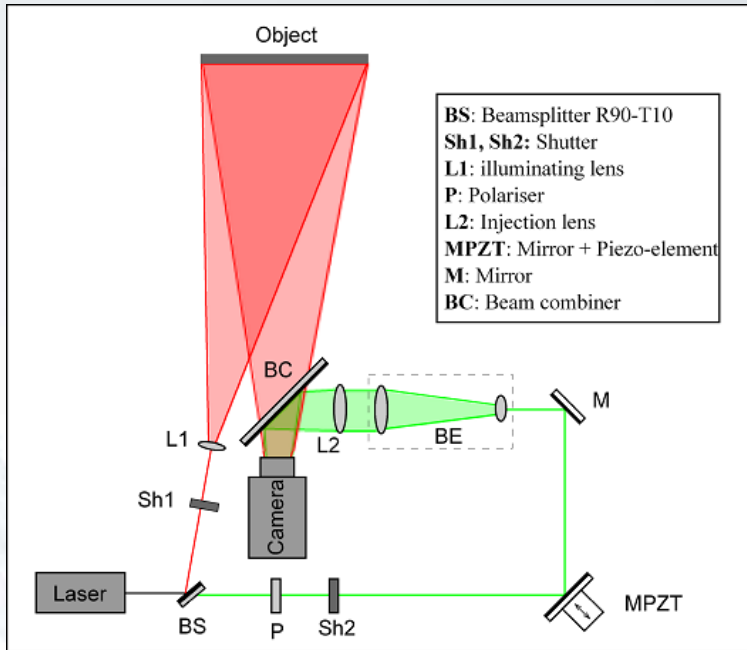


Laser ON

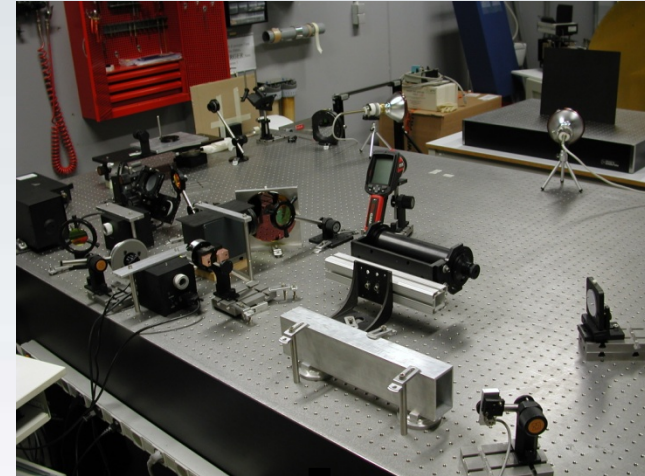


Hologram/Specklegram

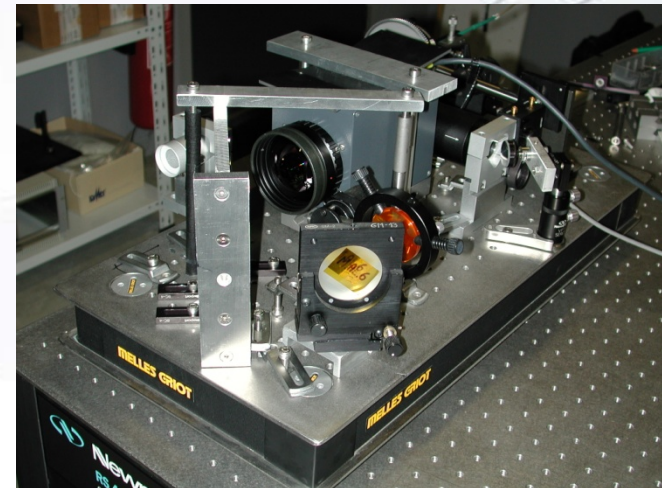




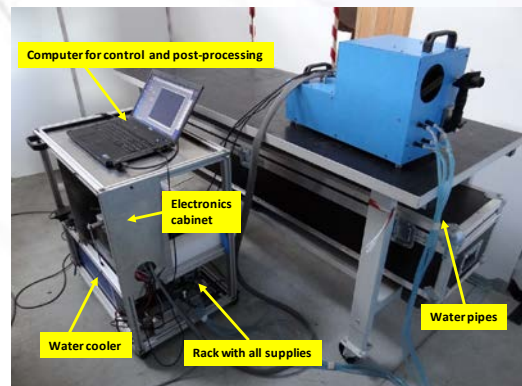
Laboratory set-up



Laboratory compact prototype

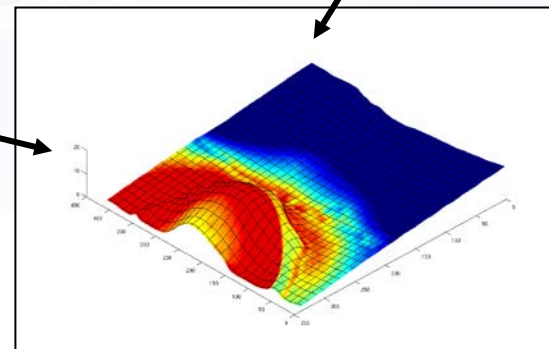
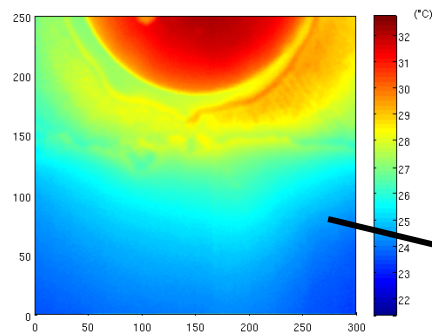
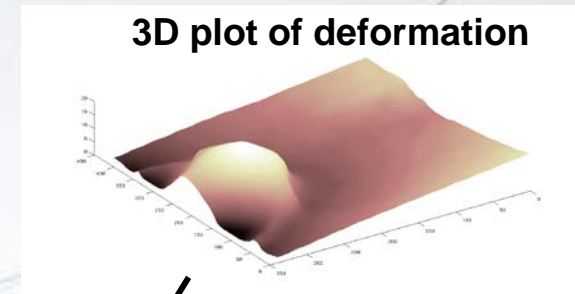
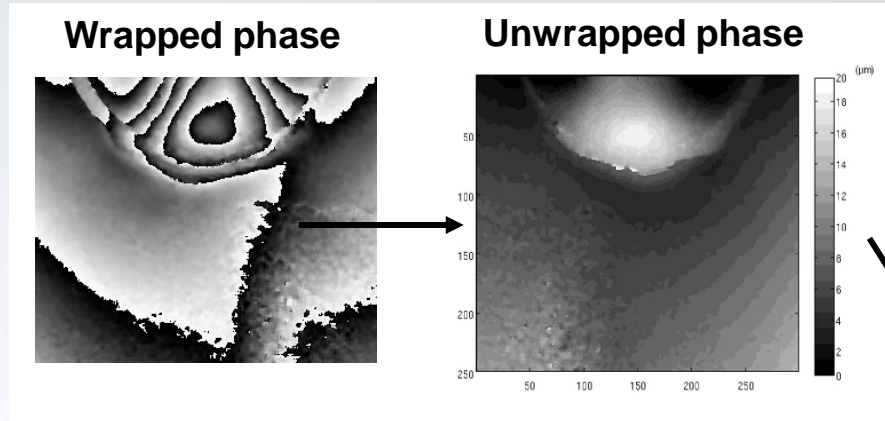
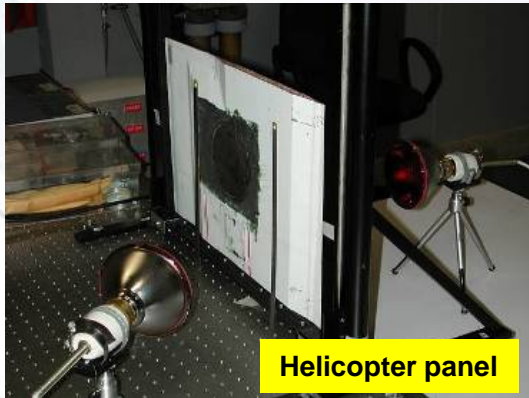


Transportable field prototype

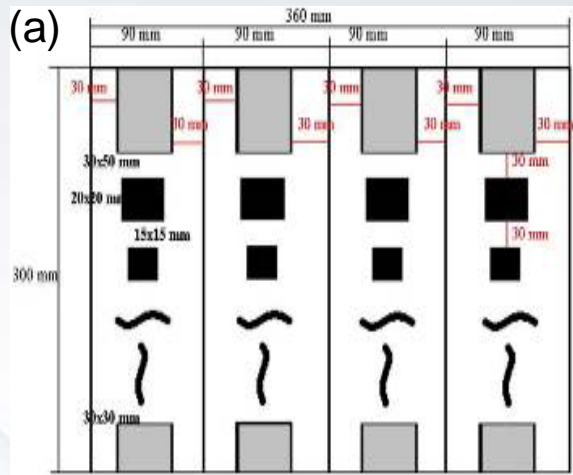


# FANTOM project

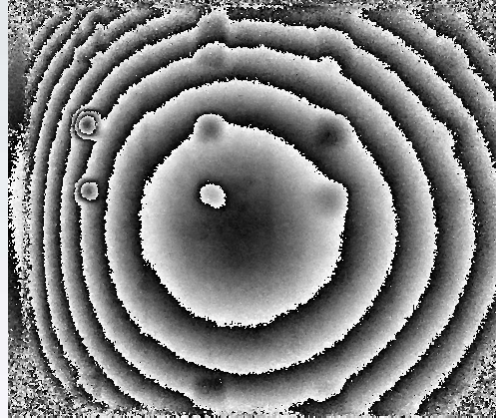
- Decoupling temperature and deformation



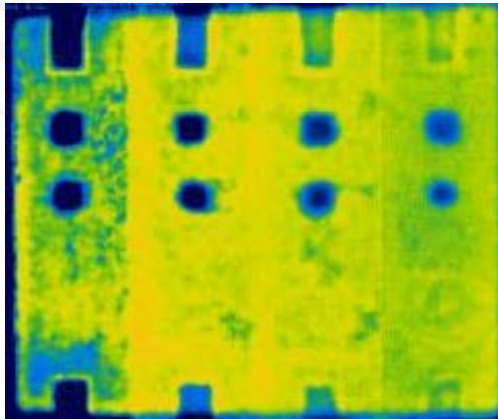
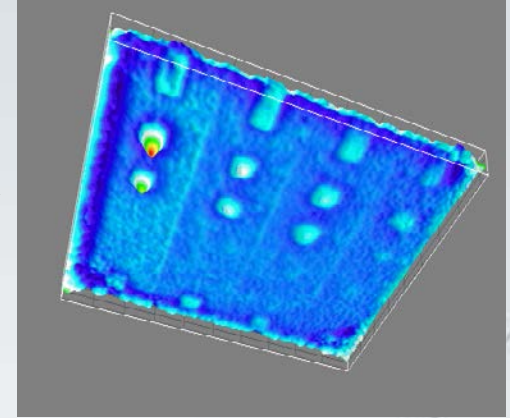
# FANTOM project



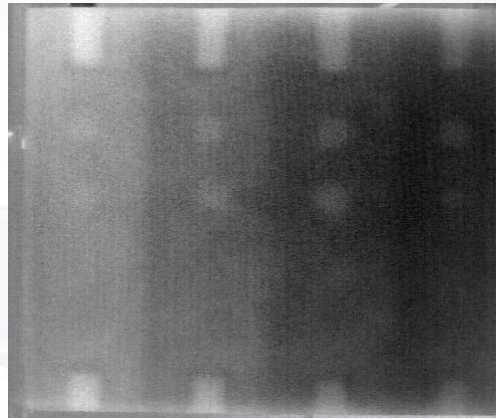
(b) FANTOM interferogram



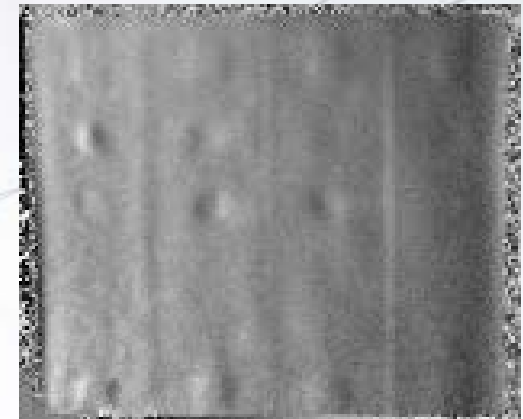
(c) FANTOM deformation



(d) OLT phase thermogram



(e) FANTOM thermogram



(f) SHEARO deformation

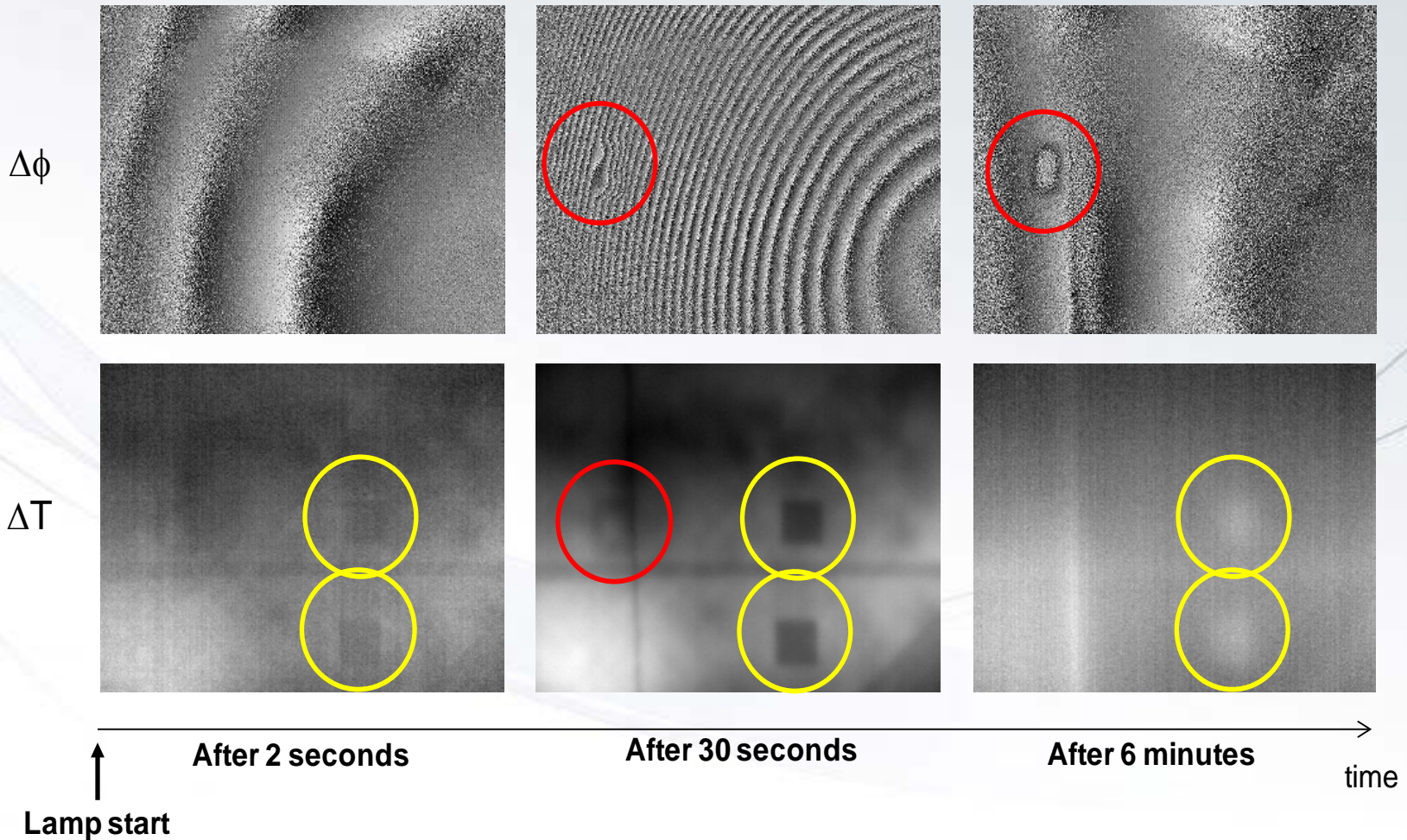


# FANTOM project

- Industrial tests : Airbus (D41, Toulouse)



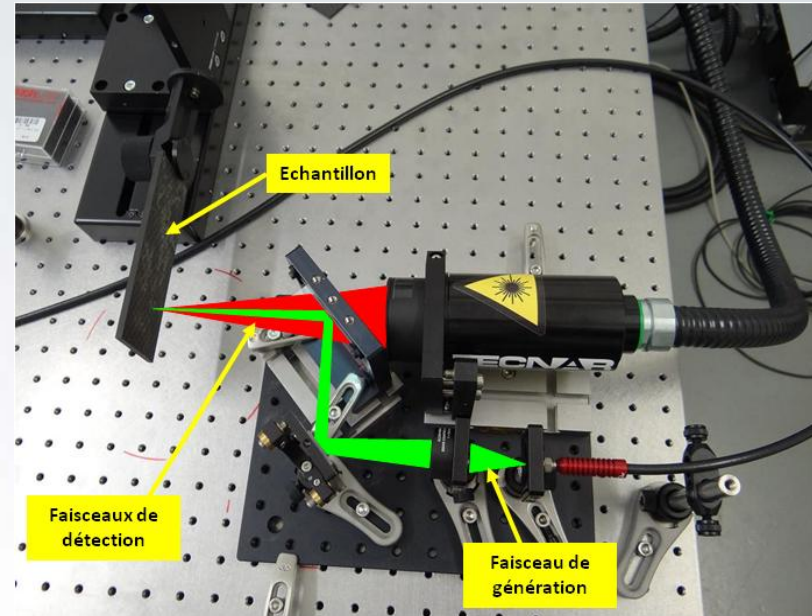
- Industrial tests : delamination on composite





# Current developments

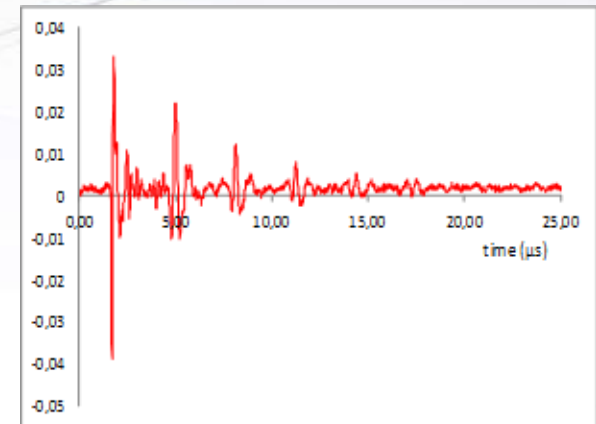
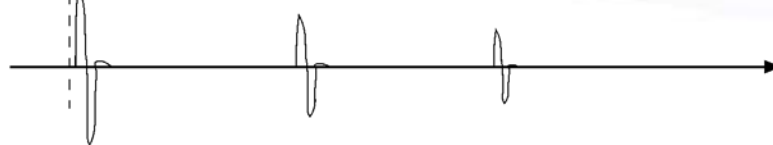
- Robotized full fibered laser ultrasound system
  - Generation (532 nm)
  - Detection (1064 nm)
  - 30 Hz rep. rate



Laser pulses

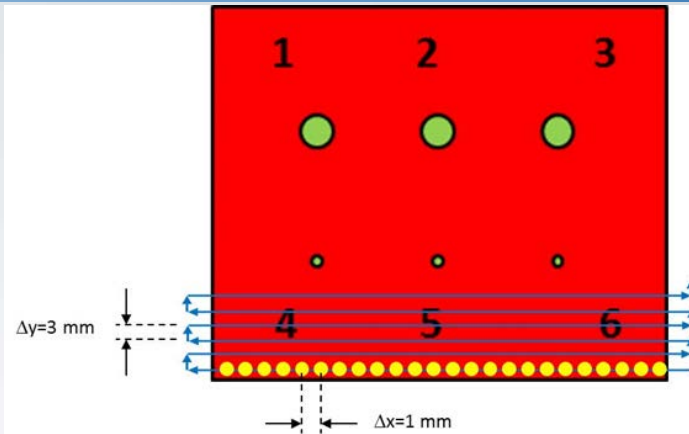


A-Scan

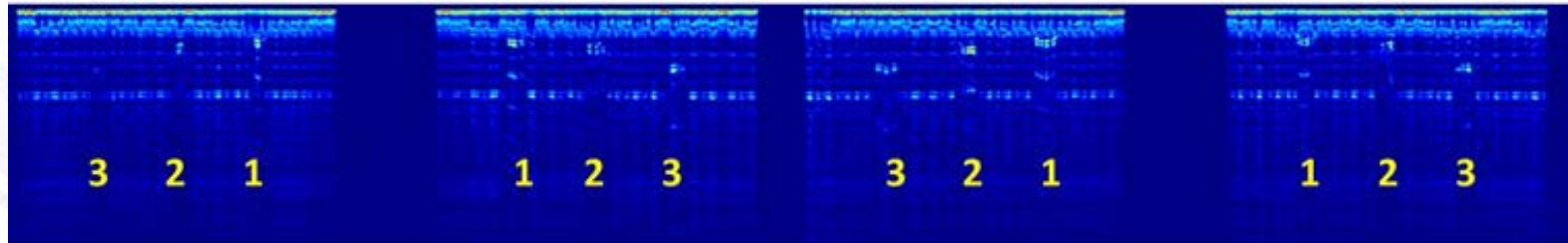




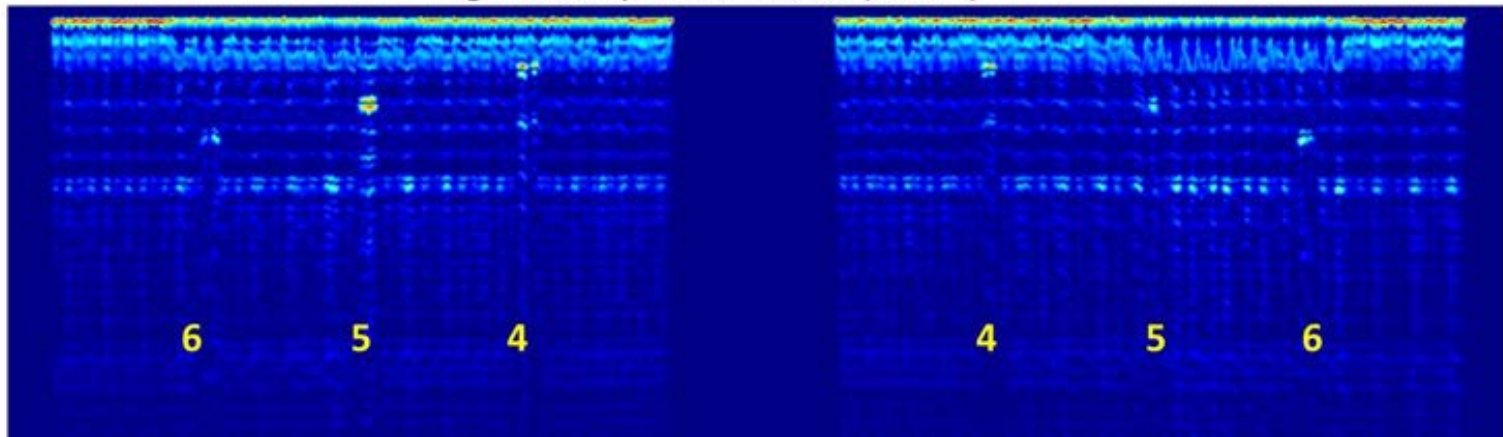
# Current developments



Lignes des grands défauts (12 mm)



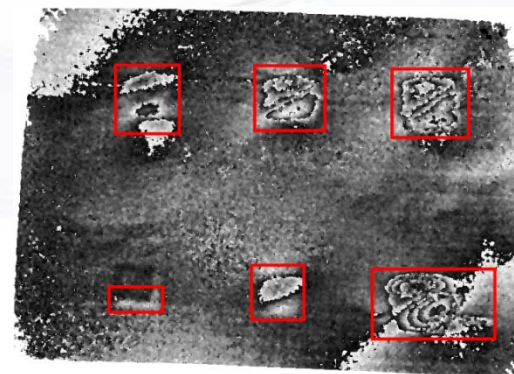
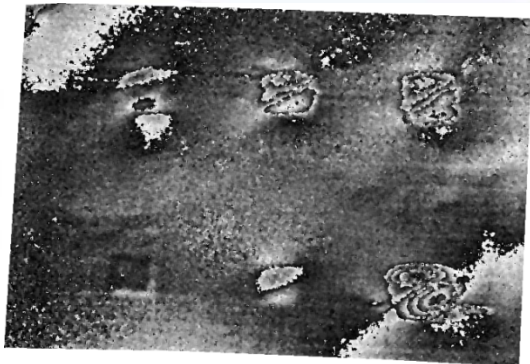
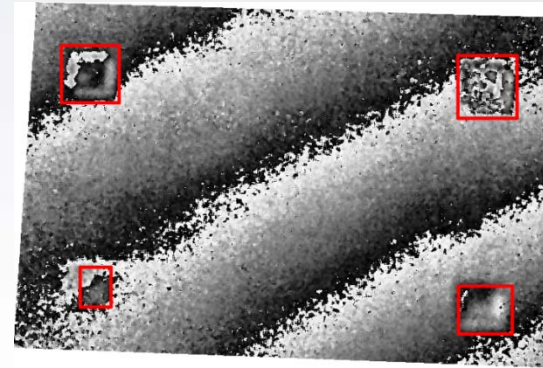
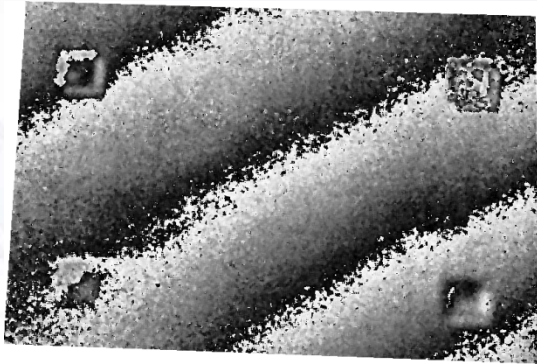
Lignes des petits défauts (6 mm)



- Data fusion between
  - Thermography
  - Shearography
  - Laser ultrasound
  - Shape measurement or CAD
- Modelling for helping interpretation of NDI
  - Finite Element Analysis
  - Reverse Engineering on defect
- New post-processings for shearography

# Current developments

- Shearography : automated detection

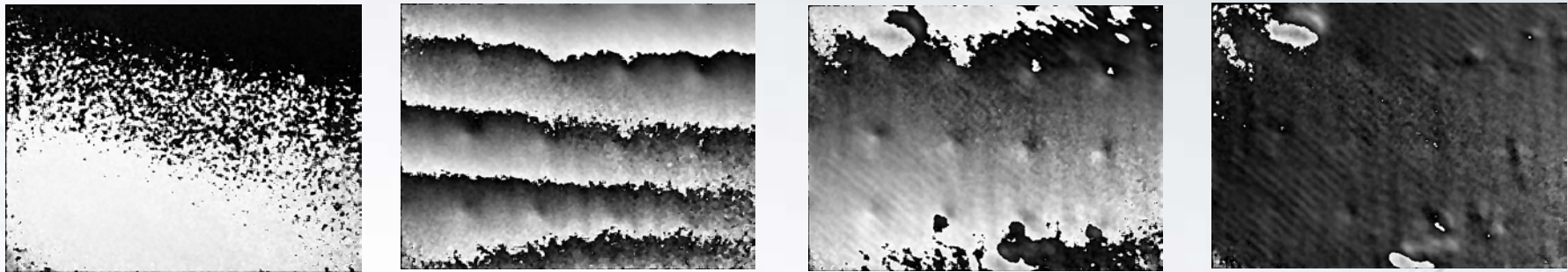




- Shearography : Principal Components Analysis

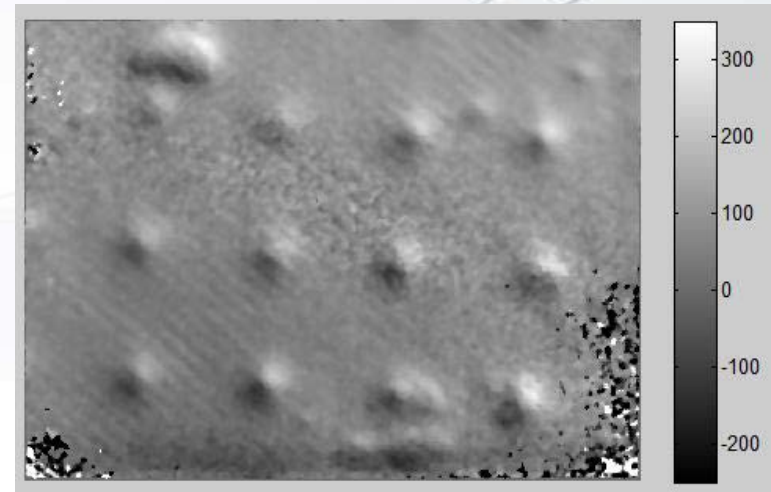
Temporal sequence shows various defects at different instants

Heat wave travelling through the sample



PCA provides

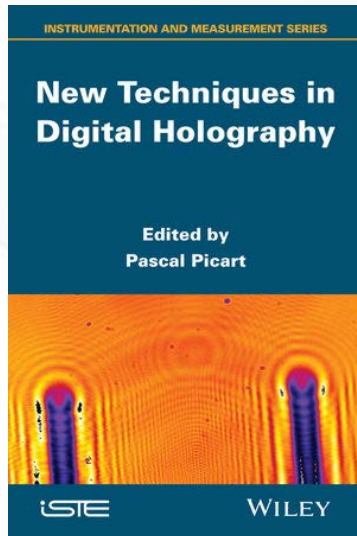
- A few eigenvectors showing different variability of signal in space and time
- Low order eigenfunctions show all defects



***Thanks for your attention !***

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Chapter VI. Infrared digital holography