Showcase on high speed imaging and application to experimental mechanics

Tuesday 23 November 2010 National Physical Laboratory, Teddington, UK

Ecole Nationale Supérieure d'Arts et Métiers

Examples of the use of ultra high speed cameras for full-field strain measurements in high strain rate testing

Professor Fabrice PIERRON

Arts et Métiers ParisTech
Châlons-en-Champagne, France

Introduction

- **High speed imaging**
  - Single CMOS sensor
  - Frame rate < 10 kHz for 1 Mpixel
  - Good quality images, affordable
- **Ultra high speed imaging**
  - 1 MHz range for 1 Mpixel
  - Limitation on speed: data transfer
  - Two strategies
    - Multi-sensors
    - On-chip memory
  - Expensive
  - Metrological issues

Objectives

- Present three case studies with three different cameras
  - IMACON 200 (multisensor), DRS (similar cameras at showcase, eg Specialized Imaging)
  - CORDIN 550-62 (multi-sensor)
  - SHIMADZU HPV-1
- Evaluate metrological performances
- Show examples of quantitative full-field measurement
  - Digital image correlation
  - Grid method

ARTS ET MÉTIERS ParisTech

LMPF Laboratoire de Mécanique et Procédés de Fabrication

Ecole Nationale Supérieure d'Arts et Métiers

CASE STUDY 1

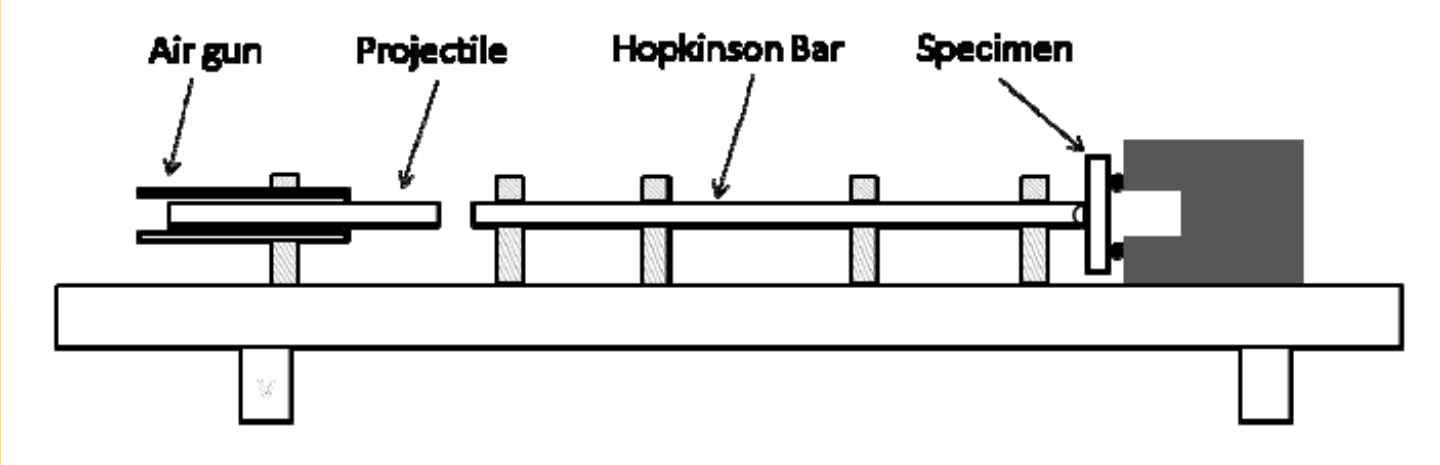
Three-point bending on an aluminium bar

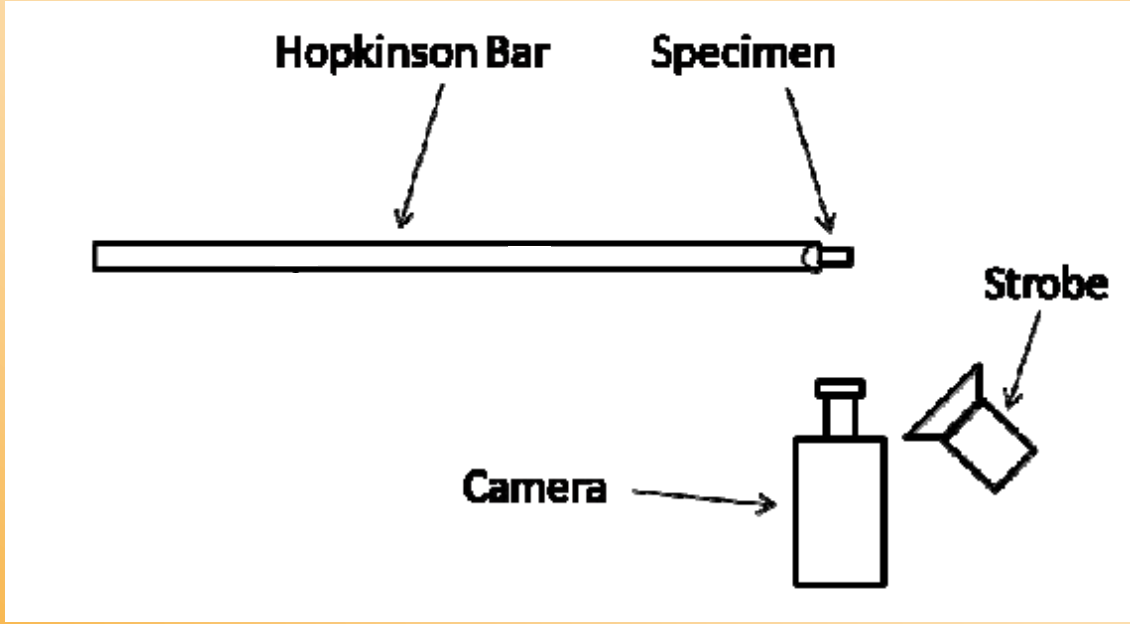
IMACON 200 camera

Prof. Michael A. SUTTON
Dr Vikrant TIWARI

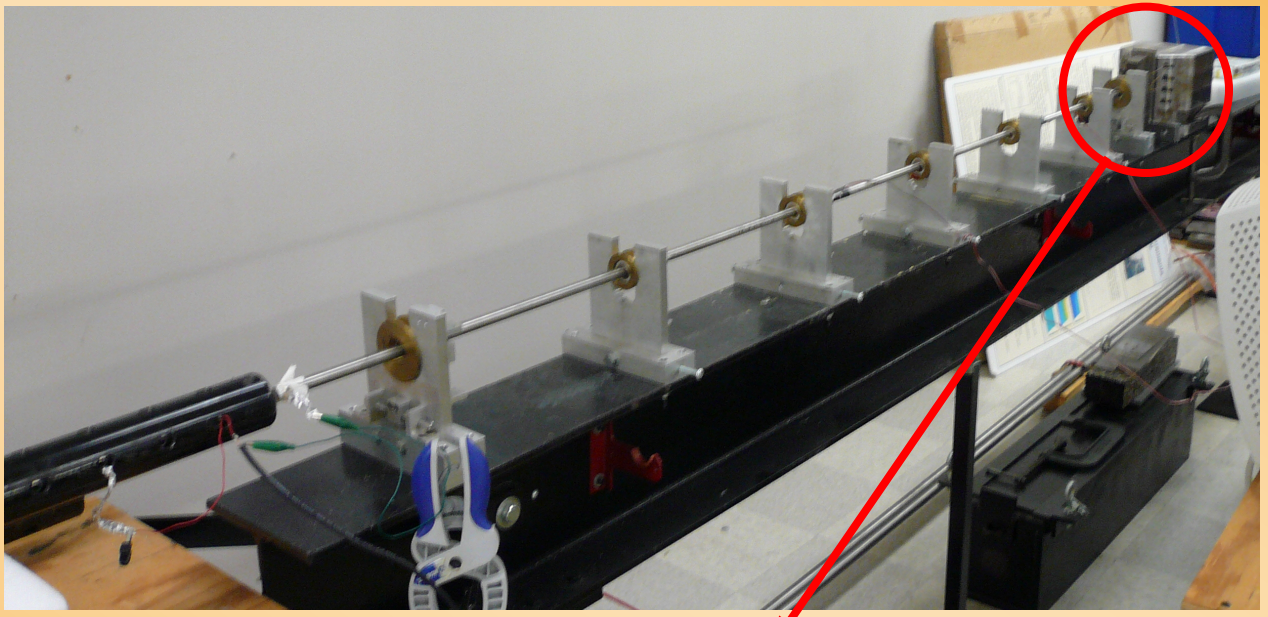
UNIVERSITY OF SOUTH CAROLINA

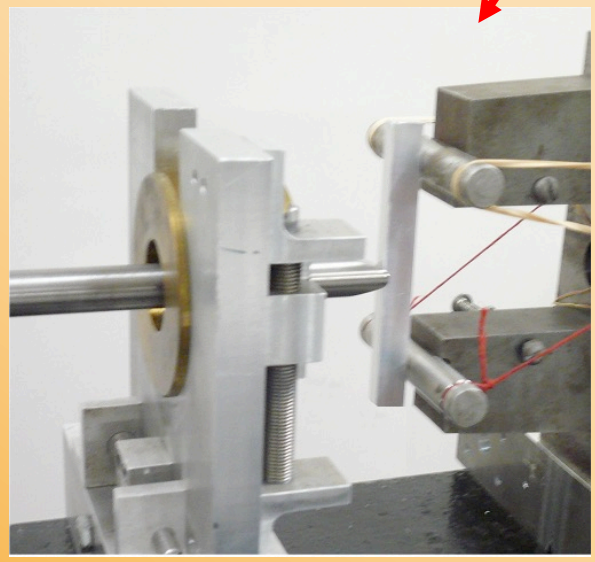
Test set-up


Air gun
Projectile
Hopkinson Bar
Specimen


Hopkinson Bar
Specimen
Strobe
Camera

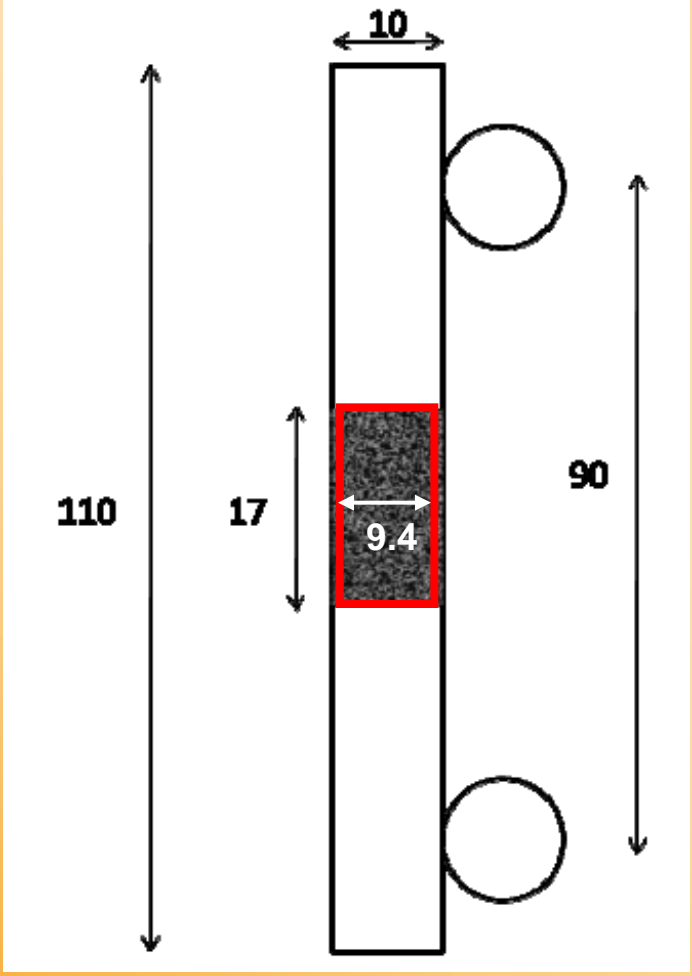
Test set-up

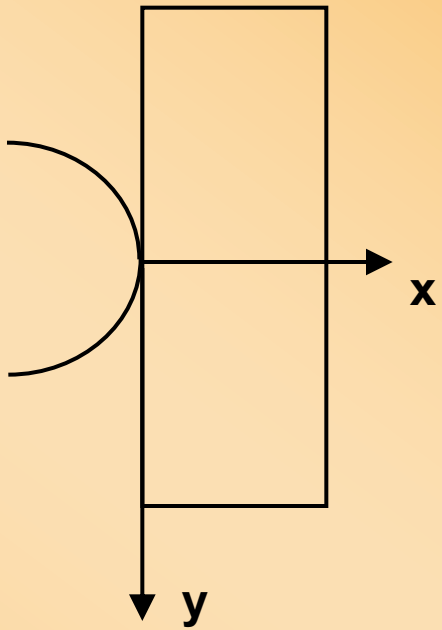




Test set-up

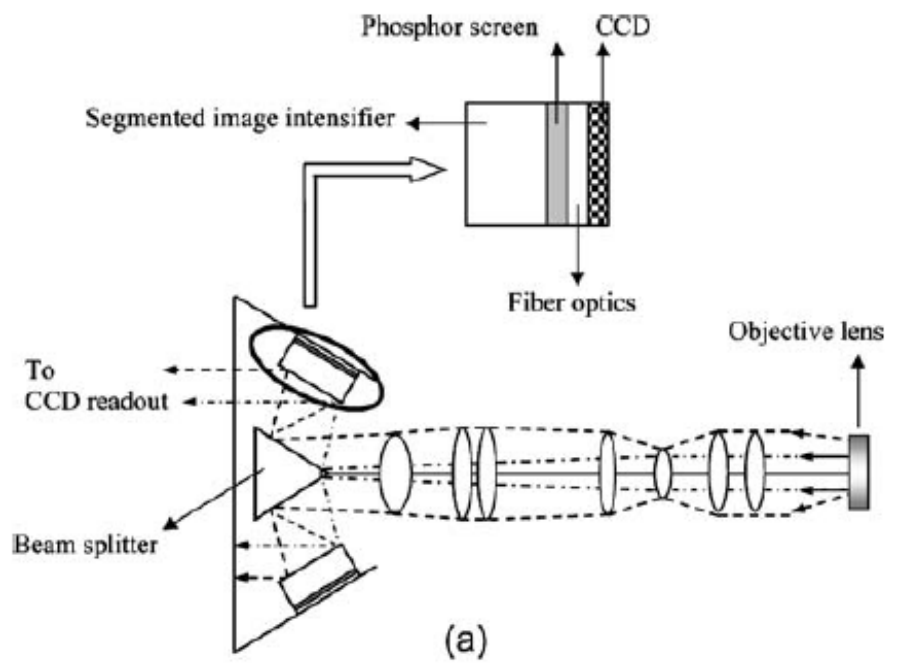
- Test specimen: aluminium (dimensions in mm)





IMACON 200

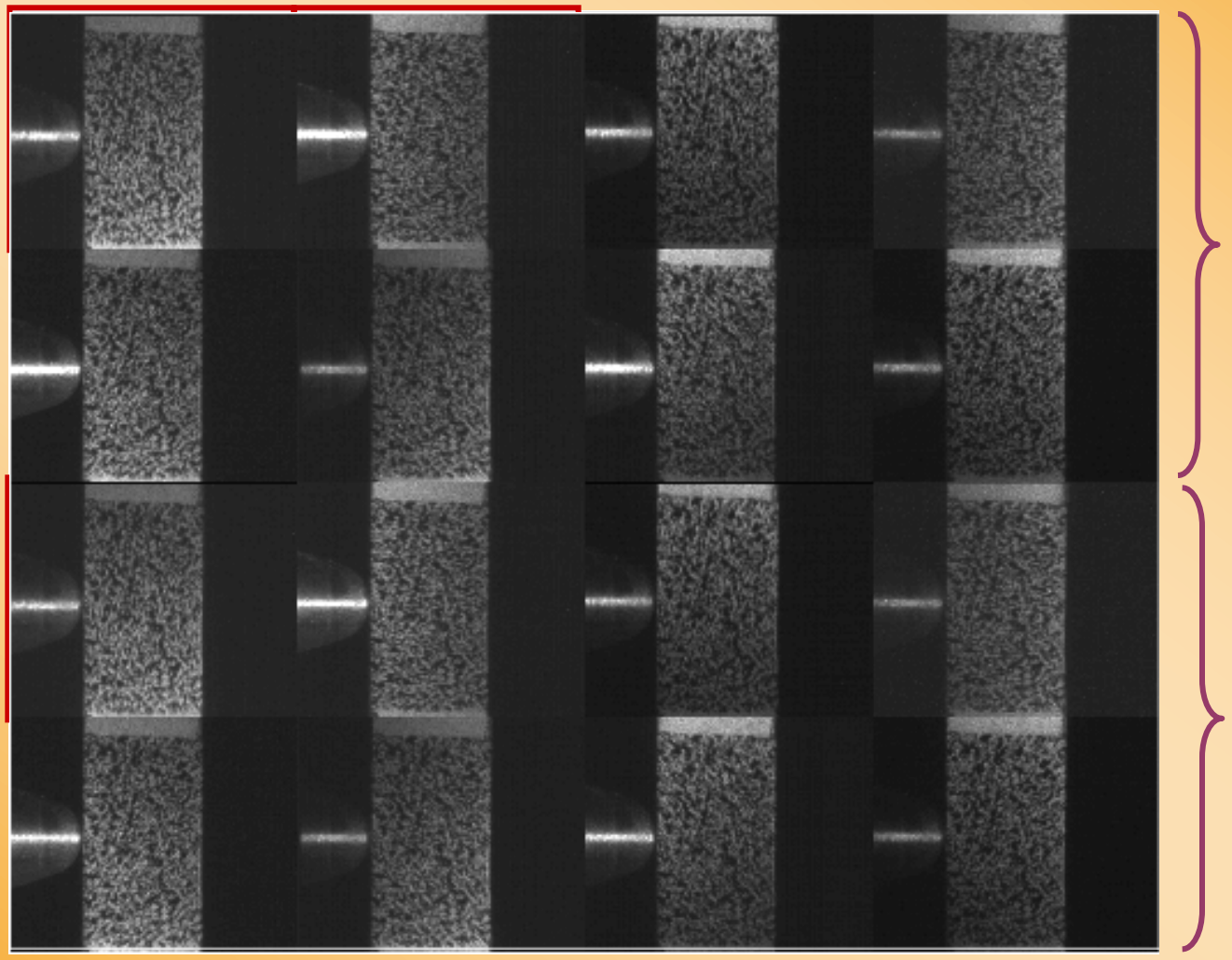
- **Camera technology**
  - 8 CCD sensors, static beam splitting
  - Light amplifiers (phosphor screens)
  - Frame rate: up to 200 MHz, 1k x 1k pixels, 16 images



Tiwari V, Sutton MA, McNeill SR (2007) Assessment of high speed imaging systems for 2D and 3D deformation measurements: methodology development and validation. Exp Mech. 47(4):561–579

IMACON 200

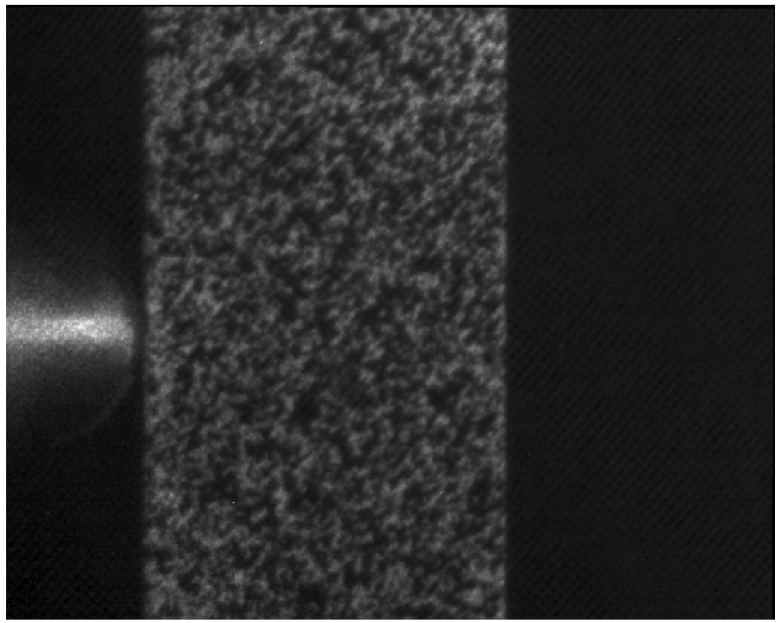
- **Still images**



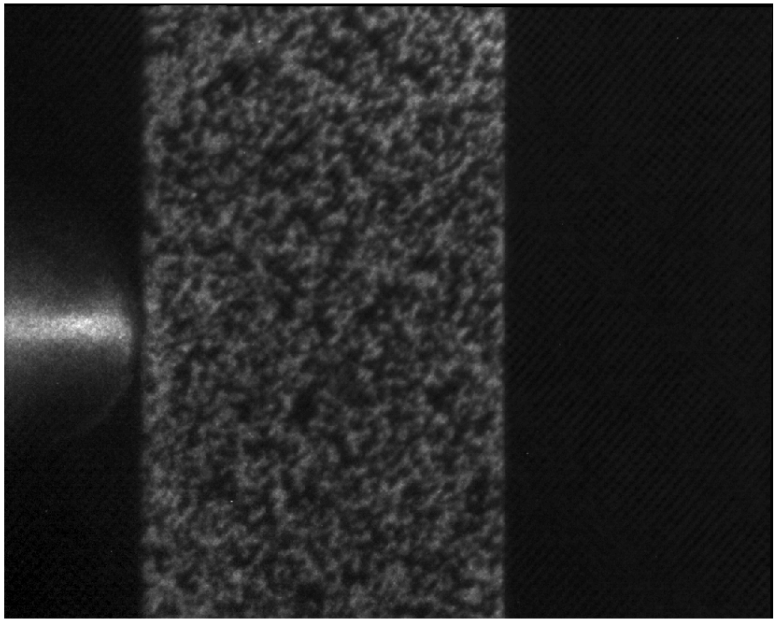
IMACON 200

- **Still images**
  - **Flat field correction**
  - **Correlate images from a set of still images (reference)**

Still image number 8



Still image number 16

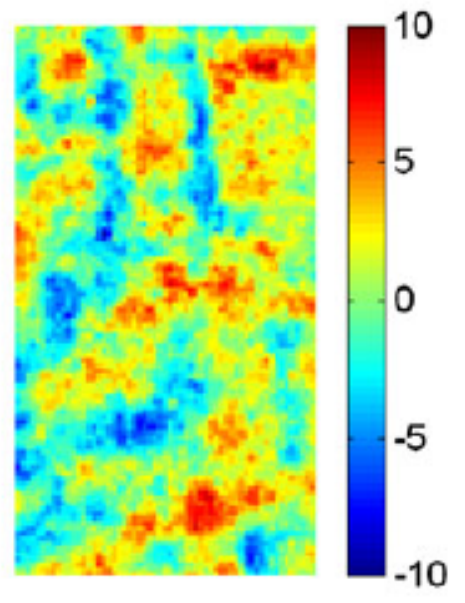


Performances

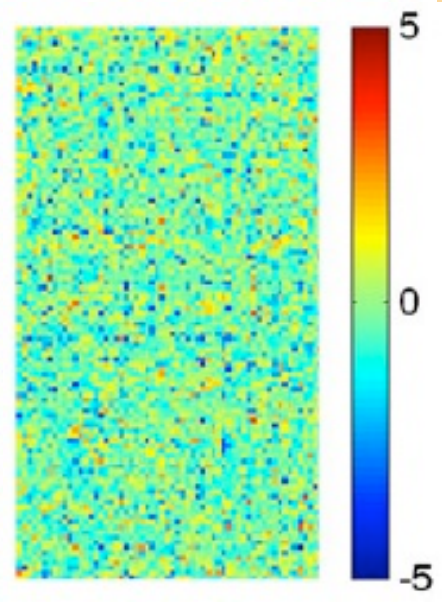
- Resolution in displacement
  - 2 sets of still images at 100000 fps
  - 31 pixels subset, shift of 5
  - Resolution (standard deviation of obtained displacements)
    - Without smoothing: ~ 0.18 pixels
    - Diffuse approximation, radius of 24 pts : ~ 0.1 pixels (<0.01 pixel for standard cameras)
- Resolution in strain
  - Without smoothing: ~ 1.2%
  - With smoothing: ~ 0.1%

Performances

- **Noise**
  - Two still images, grey level difference (% of dynamic range)
  - Same number of pixels
  - Spatially correlated noise: light amplifiers



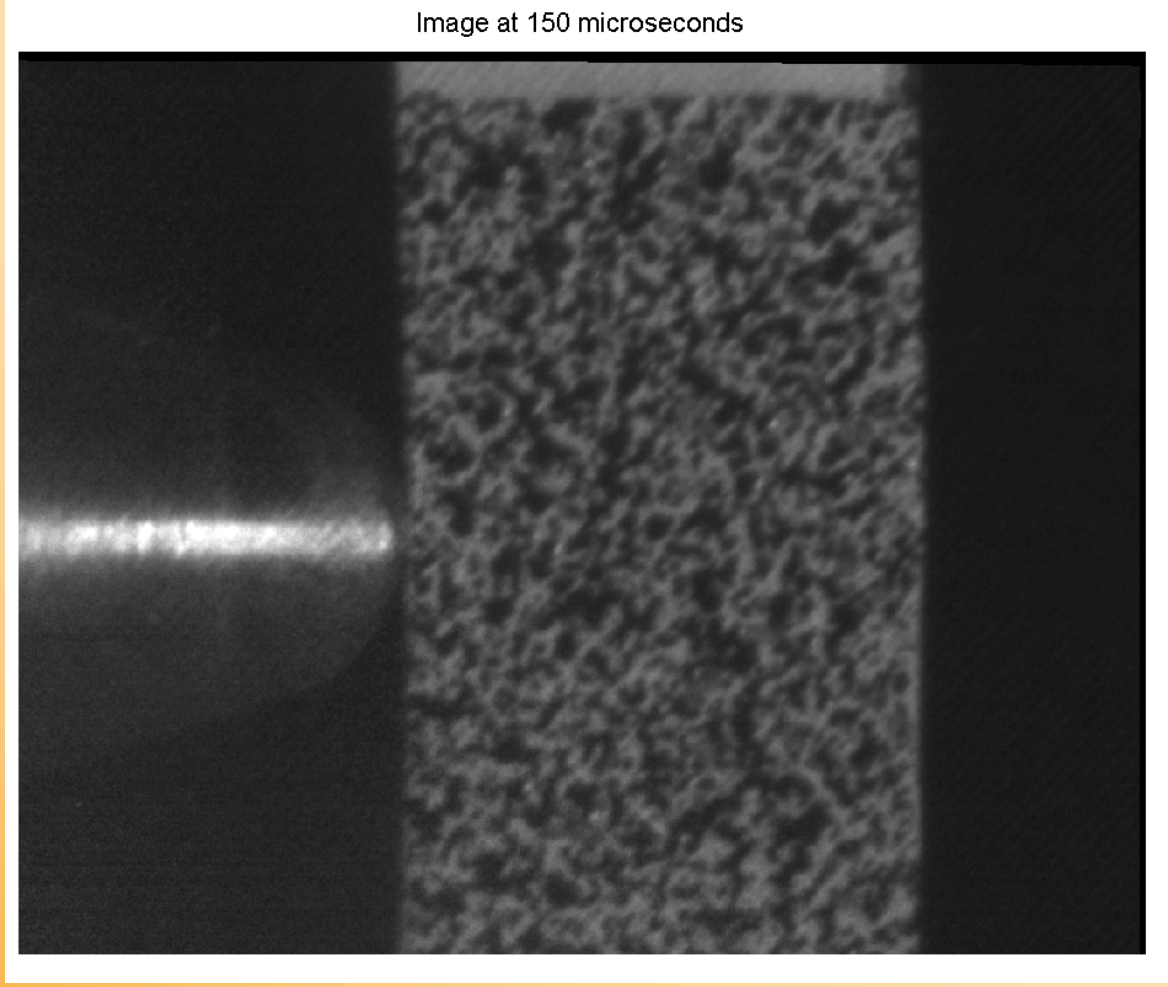
IMACON 200



Photron SA5

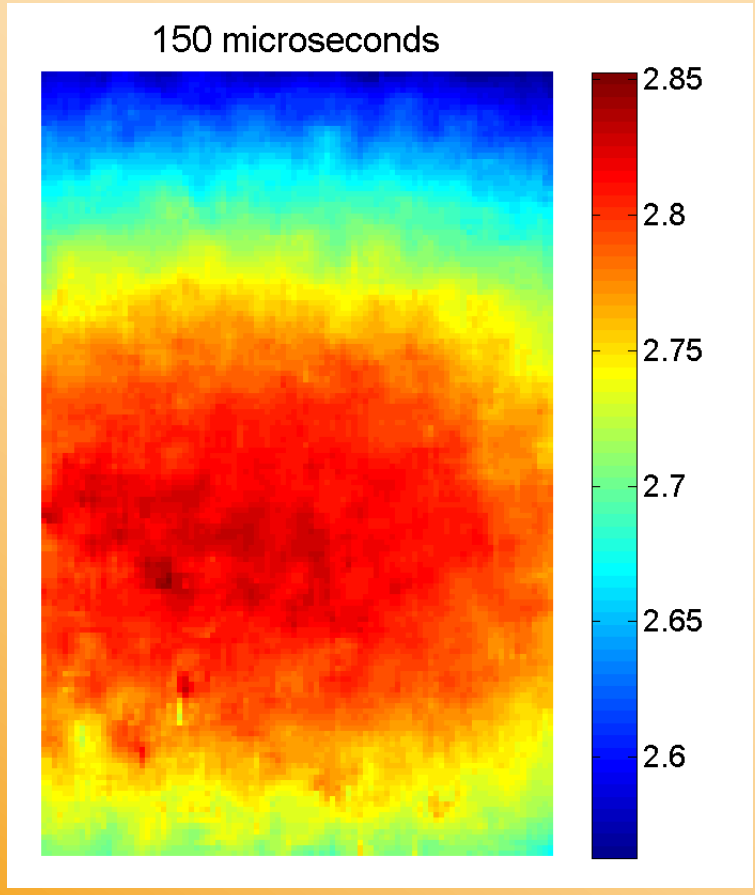
Zoom in

- **Grey level images**

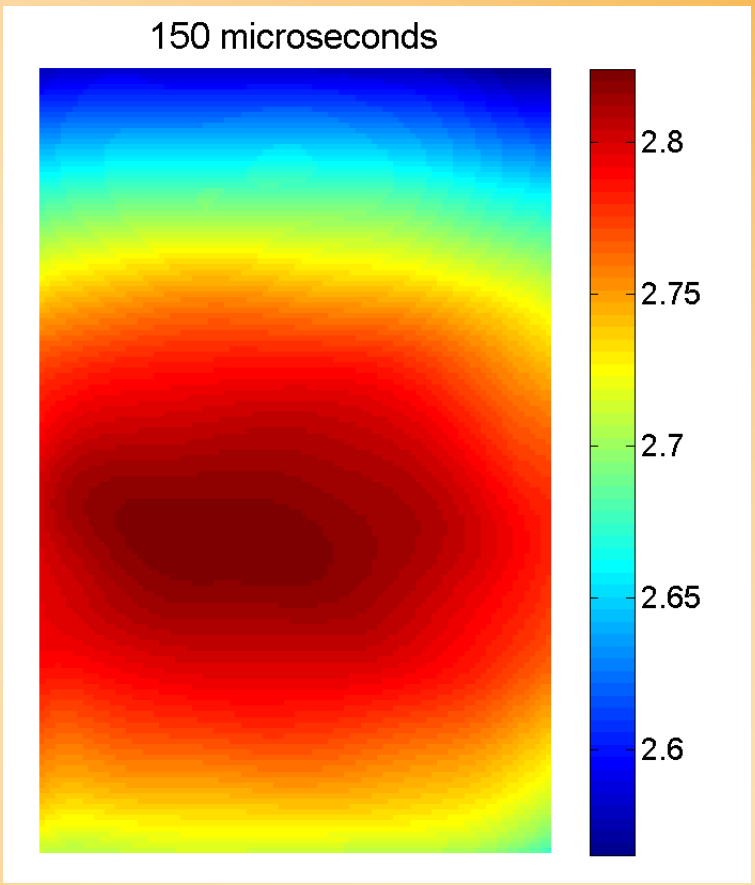


- Displacement map: u_x in mm

Raw



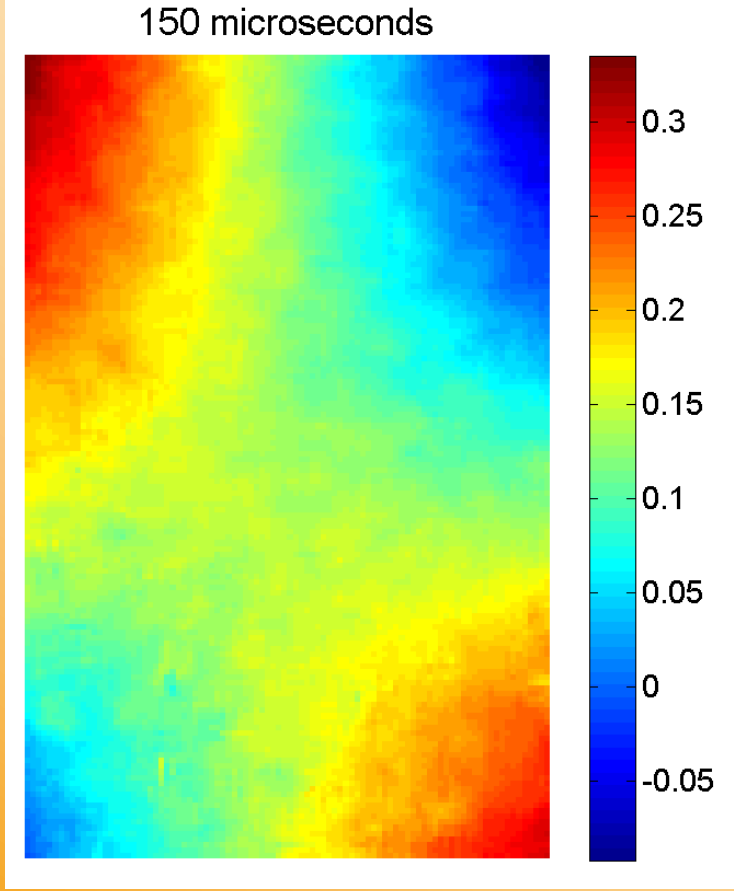
DA Smoothed (R=24)



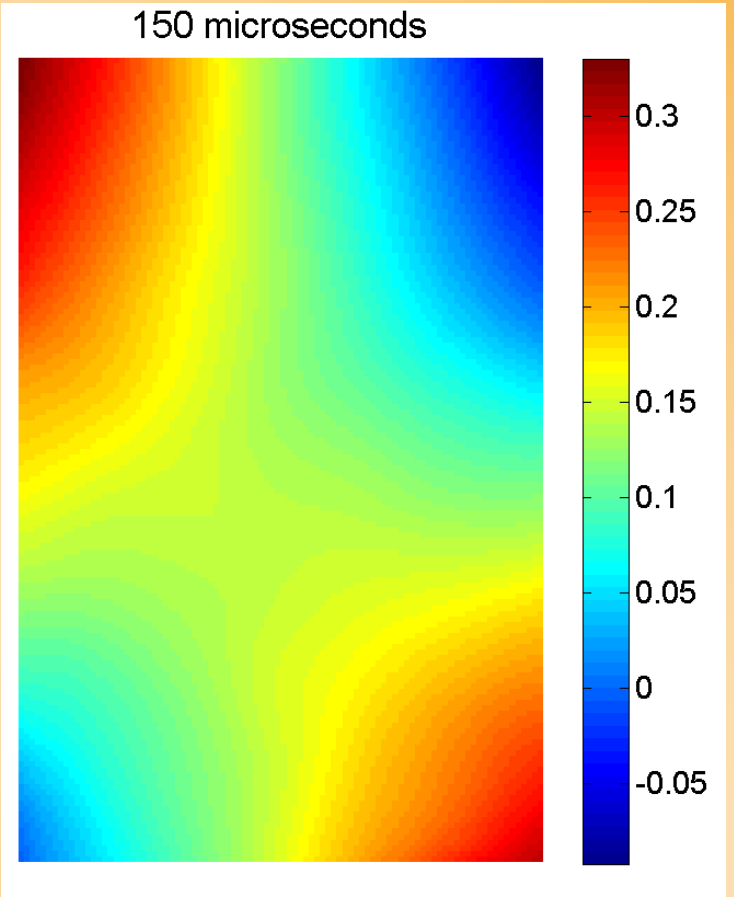
Results

- Displacement map: u_y in mm

Raw



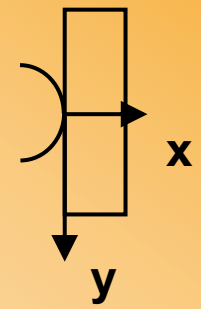
DA Smoothed (R=24)

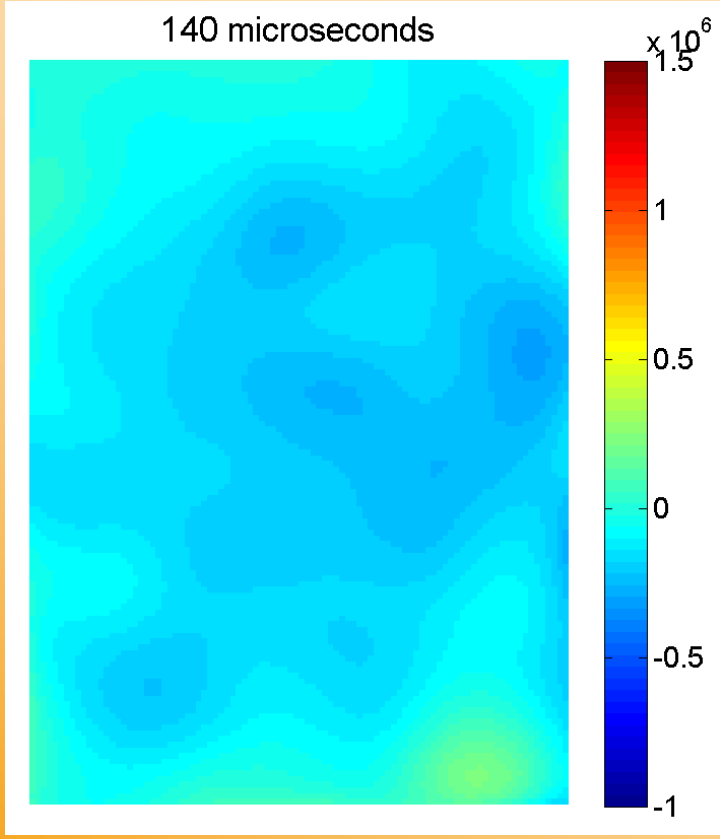


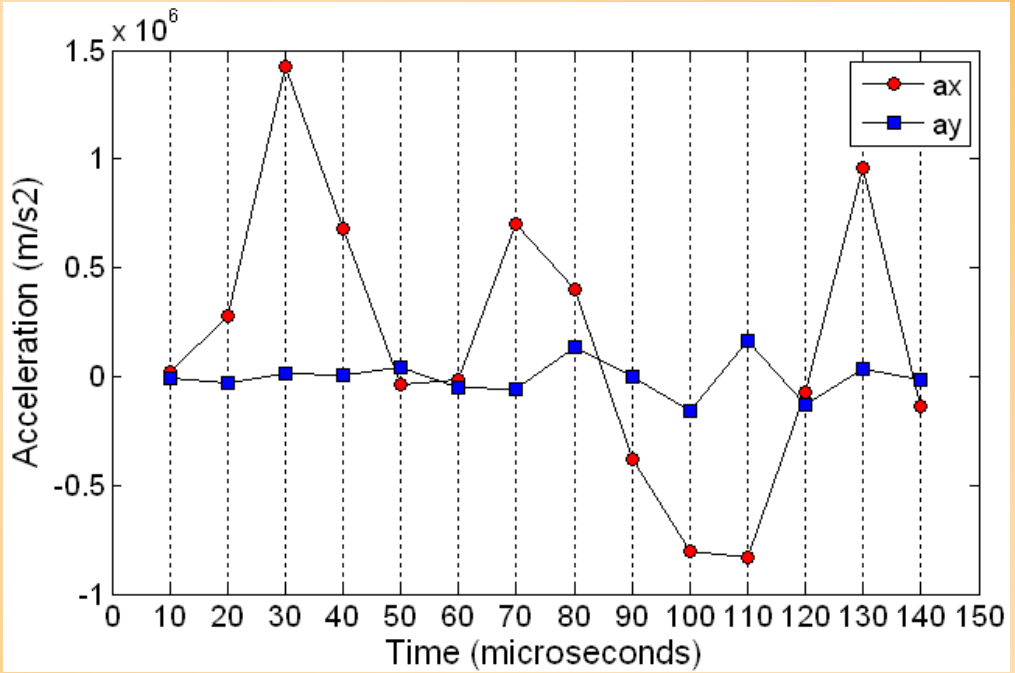
Results

- Acceleration map: a_x in $m.s^{-2}$

$$a_\alpha(t) = \frac{u_\alpha(t+\Delta t) + u_\alpha(t-\Delta t) - 2u_\alpha(t)}{\Delta t^2}$$







Average acceleration

Results

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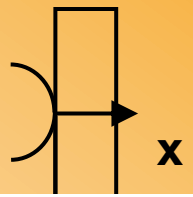
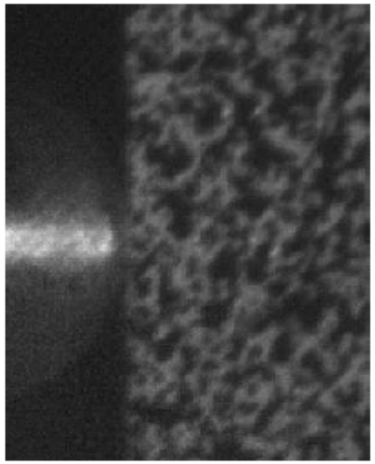
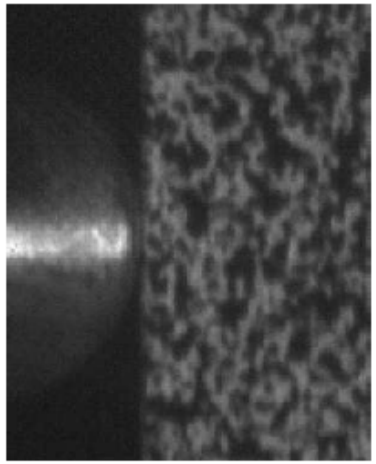
Acceleration and speed

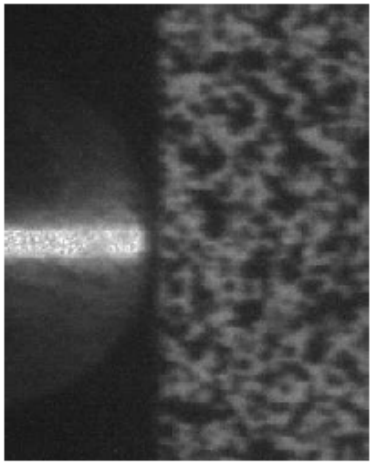




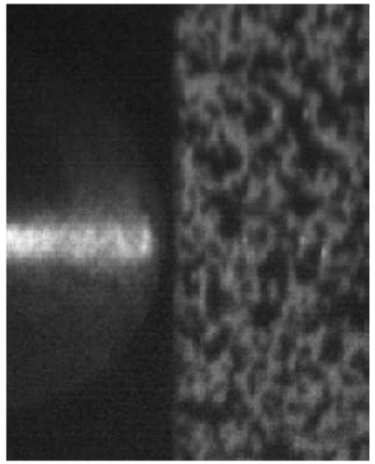
(A) 70 μs



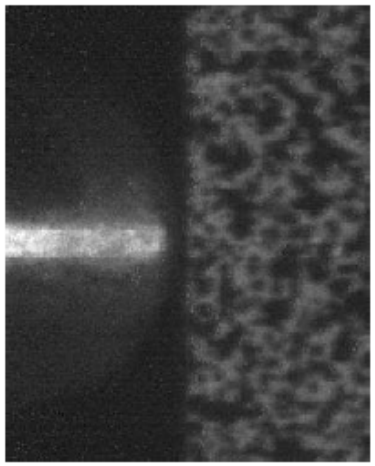
(B) 80 μs



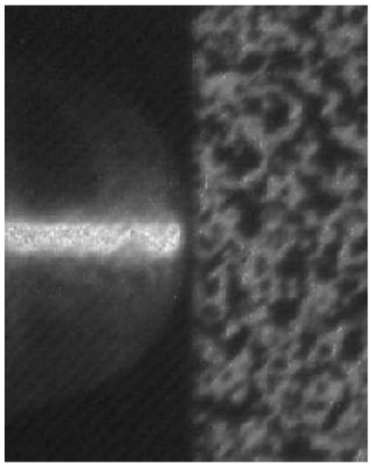
(C) 90 μs



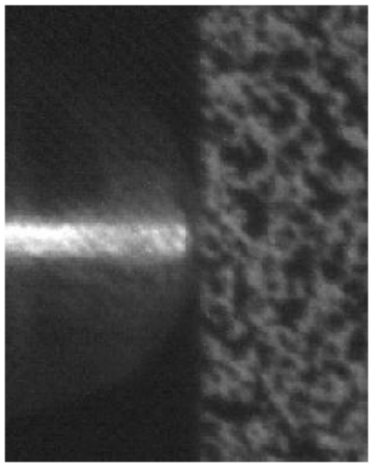
(D) 100 μs



(E) 110 μs



(F) 120 μs



(G) 130 μs

Results

- **Complete analysis and results**
  - **Reconstruction of impact force from shear strains**
  - **Calculation of inertial force**
  - **Consistent with deformation**

Pierron F., Sutton M., Tiwari V.,
Ultra high speed DIC and Virtual Fields Method analysis of a three point bending impact test on an aluminium bar,
***Experimental Mechanics*, 2010. Available online.**

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CASE STUDY 2

Tensile test on a composite specimen

Cordin 550-62 camera

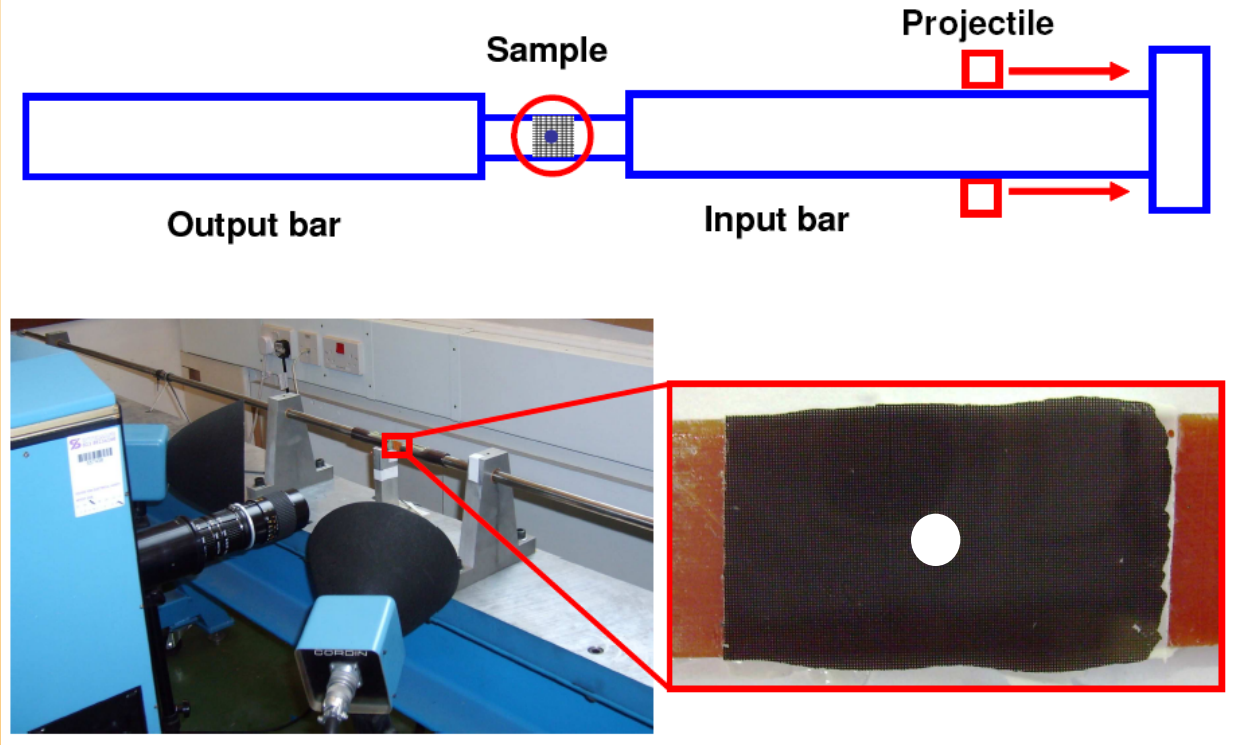
Dr Raphaël MOULART

ARTS ET MÉTIERS ParisTech Châlons-en-Champagne

Prof. Michael R. WISNOM
Dr Stephen R. Hallett

University of BRISTOL

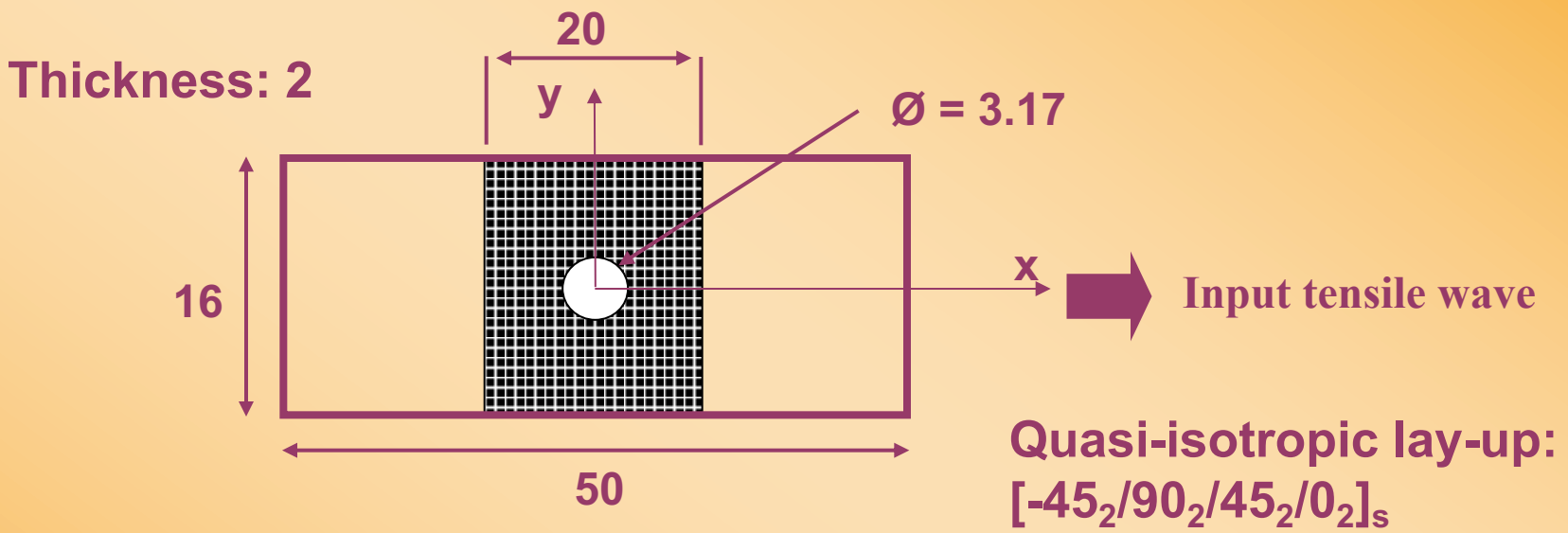
Test set-up


Projectile
Sample
Output bar
Input bar


End-caps are screwed onto the bars
The sample is glued to end-caps

Test set-up

- Test specimen: glass-epoxy composite, with and without hole

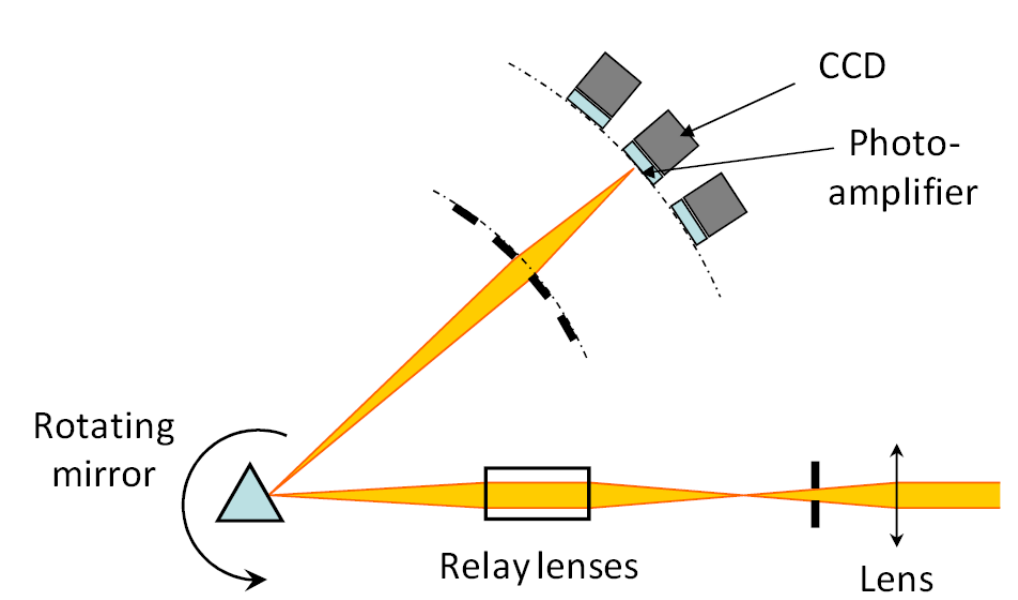


Quasi-isotropic lay-up: $[-45_2/90_2/45_2/0_2]_s$

- Cross-line grid: 200 μm pitch
  - Transferred onto specimen
  - Displacements obtained by spatial phase shifting
  - 9 pixels per period

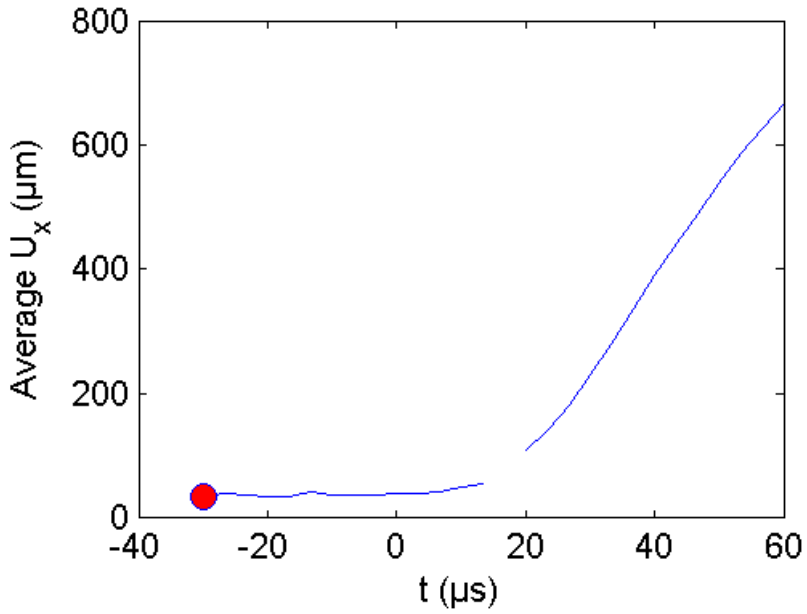
CORDIN 550-62

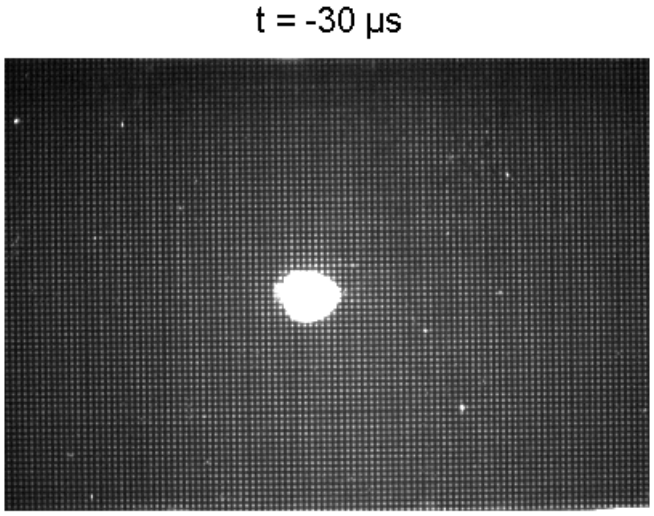
- Ultra high speed camera: Cordin 550-62



- Time resolution: 3.3 μs (300.000 fps) – light issues
  - Maximum frame rate: 4 Mfps!
- Spatial resolution: 1 Mpixel

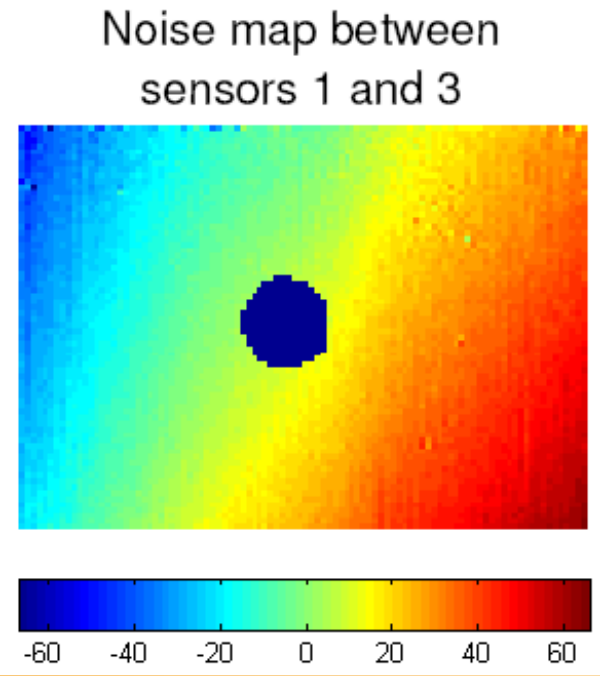
- Grey level images



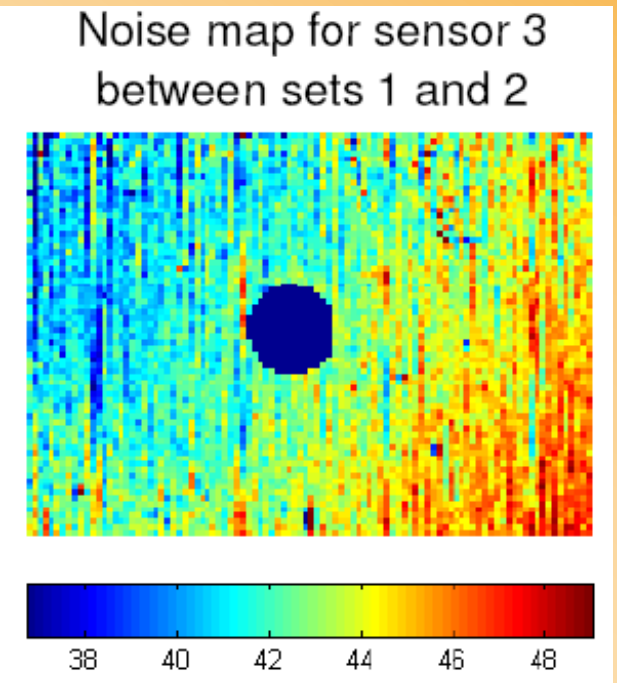


CORDIN 550-62

- Problem of bias caused by sensor positions

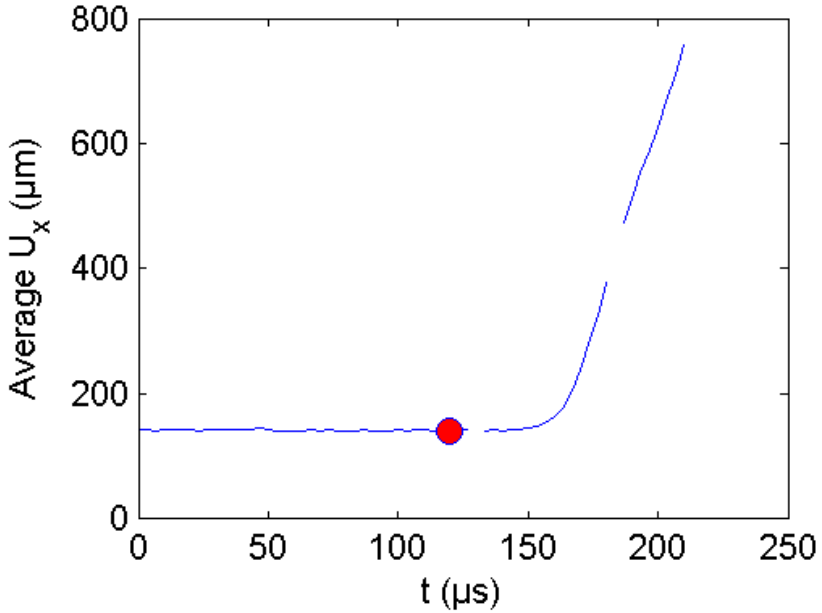


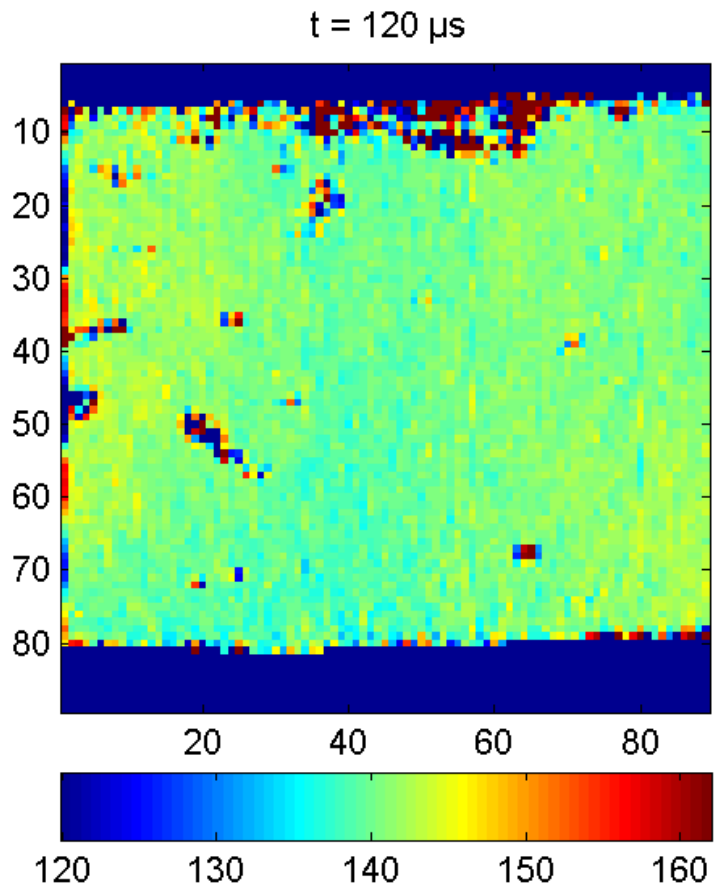
Ux in μm



- Need for a first set of 62 still images
- Phase maps obtained sensor by sensor
- Final resolution: 5 μm (2.5% of grid pitch)
- Standard CCD camera: 0.5% of the grid pitch

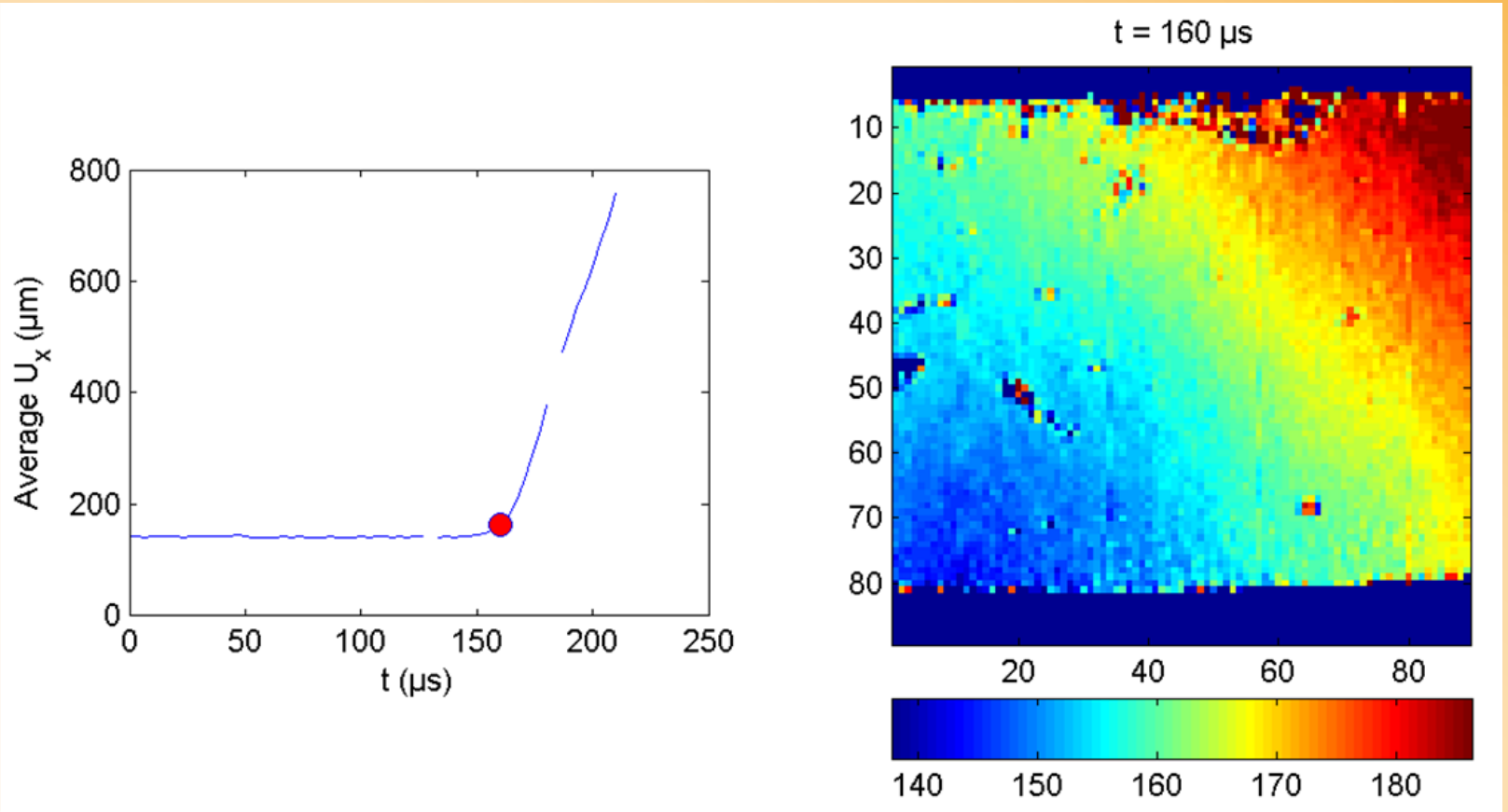
- **Problem of image acquisition**





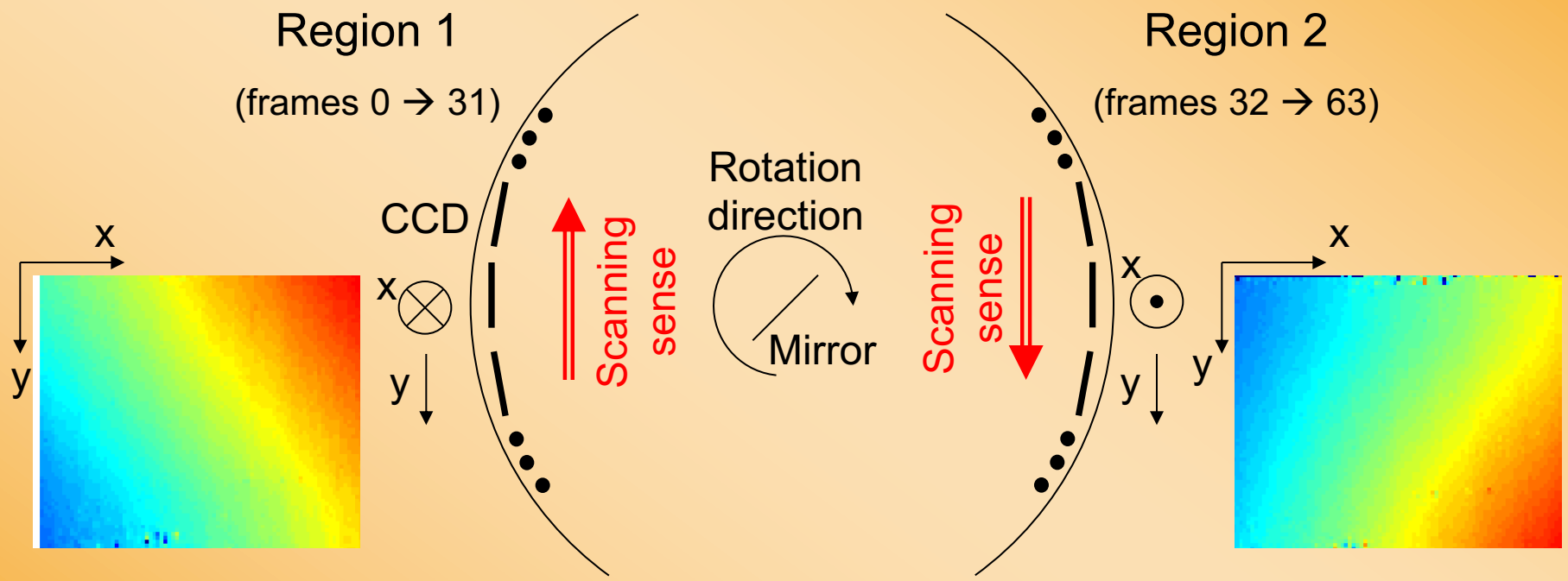
Ux in µm

- **Problem of image acquisition**

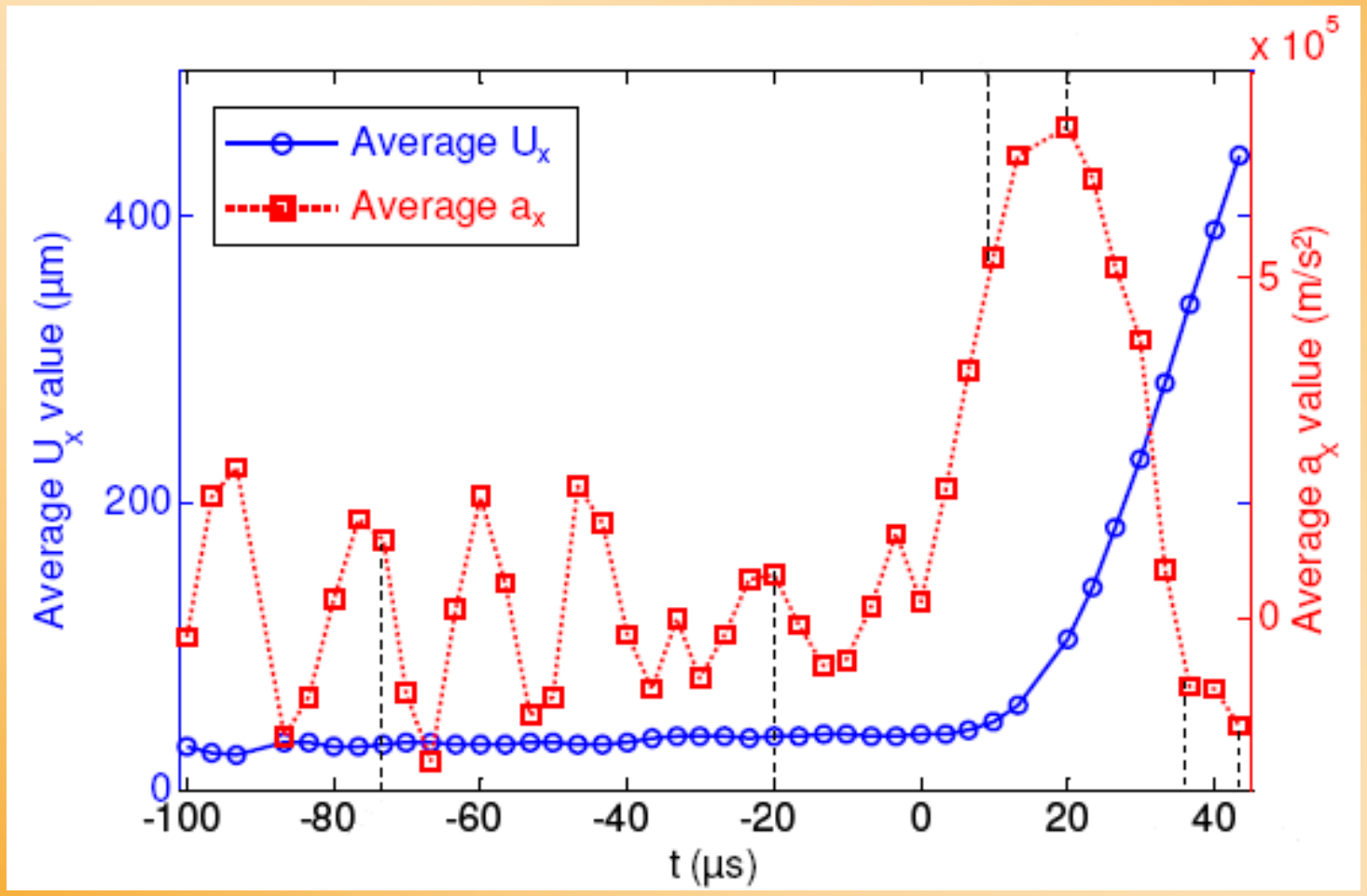


Ux in µm

- **Problem of image acquisition**

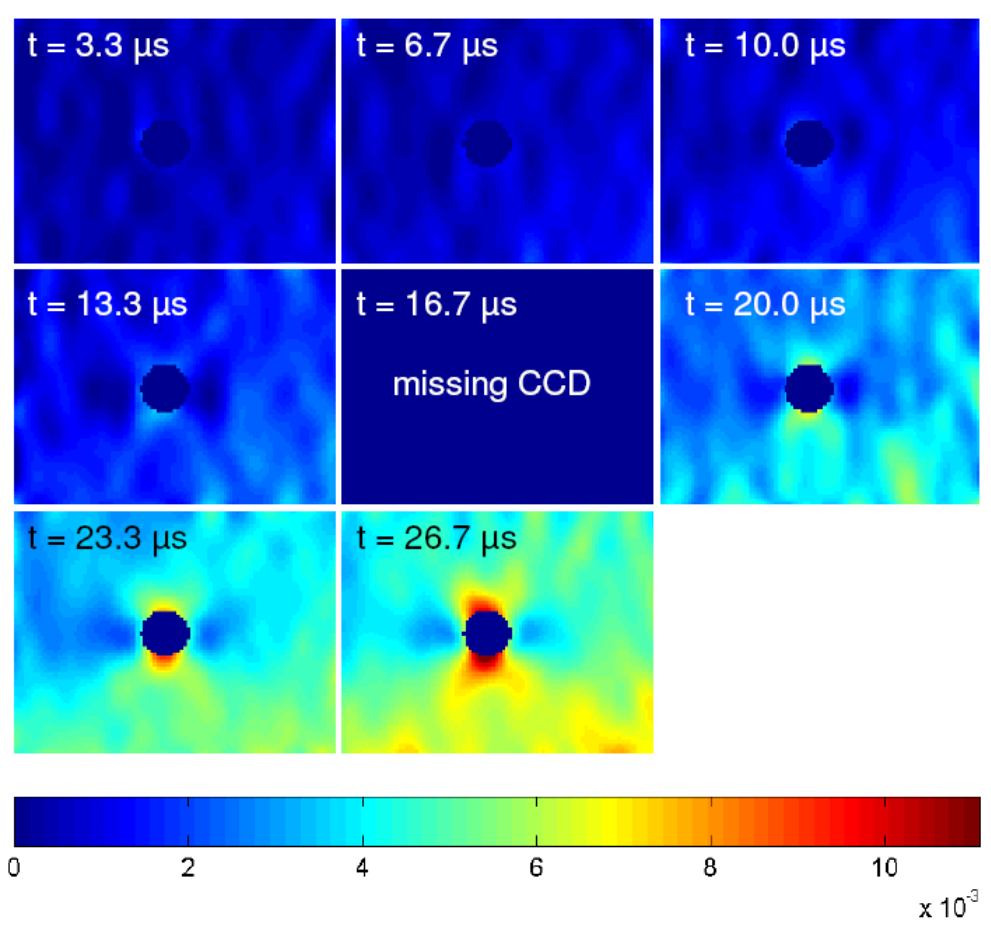


- Vibration from the rotating mirror?



CORDIN 550-62

- **Strain maps: spatial differentiation**
  - **Local smoothing (diffuse approximation)**
  - **Resolution: 10^{-3}**



Results

Stiffness identification

Virtual Fields Method (www.camfit.fr)

$$-\int_V \sigma : \varepsilon^* dV + \int_{\partial V} T.u^* dS = \int_V \rho a.u^* dV$$

Stiffness (to be identified)
Strains (measured)

Acceleration (measured)

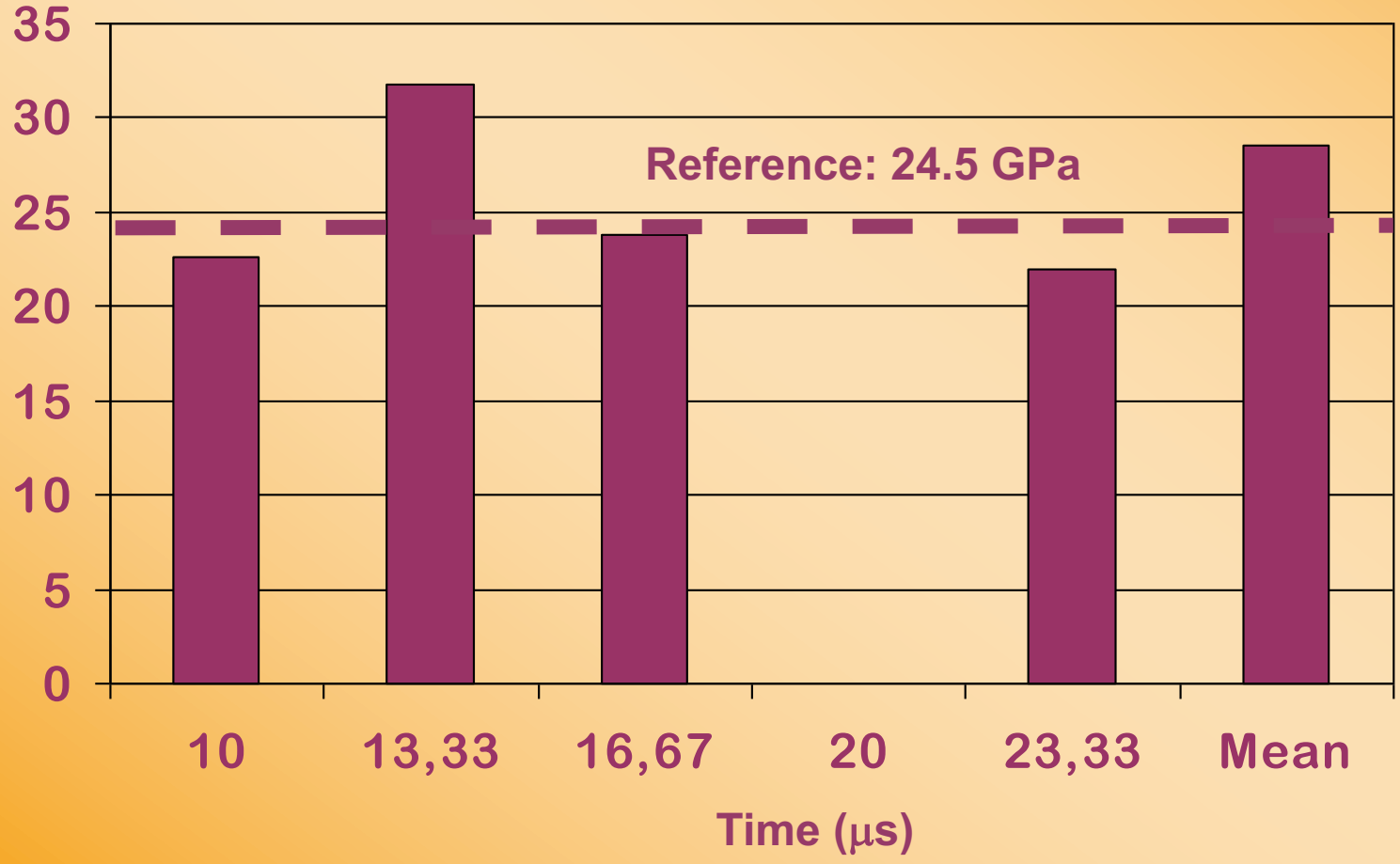
Possible to identify stiffness without load measurement
Inertia effects: distributed volume load cell

Moulart R., Pierron F., Hallett S., Wisnom M.R.
Full-field strain measurement and identification of mechanical properties at high strain rate
Experimental Mechanics, accepted, 2010.

Results

- Specimen without a hole

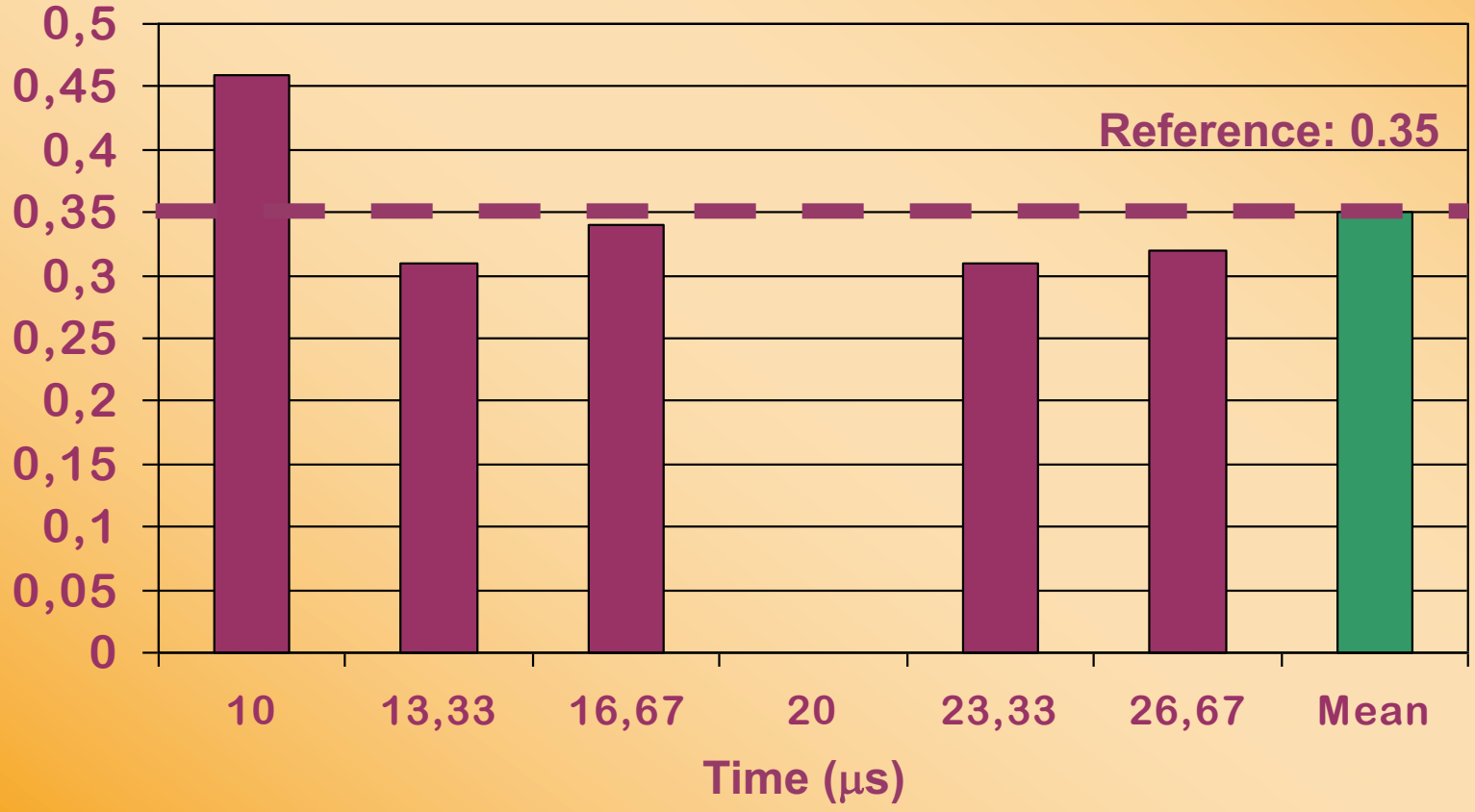
Young's modulus (GPa)



Results

- Specimen without a hole

Poisson's ratio



CASE STUDY 3

Spalling test on concrete

SHIMADZU HPV-1 camera

Dr Pascal FORQUIN

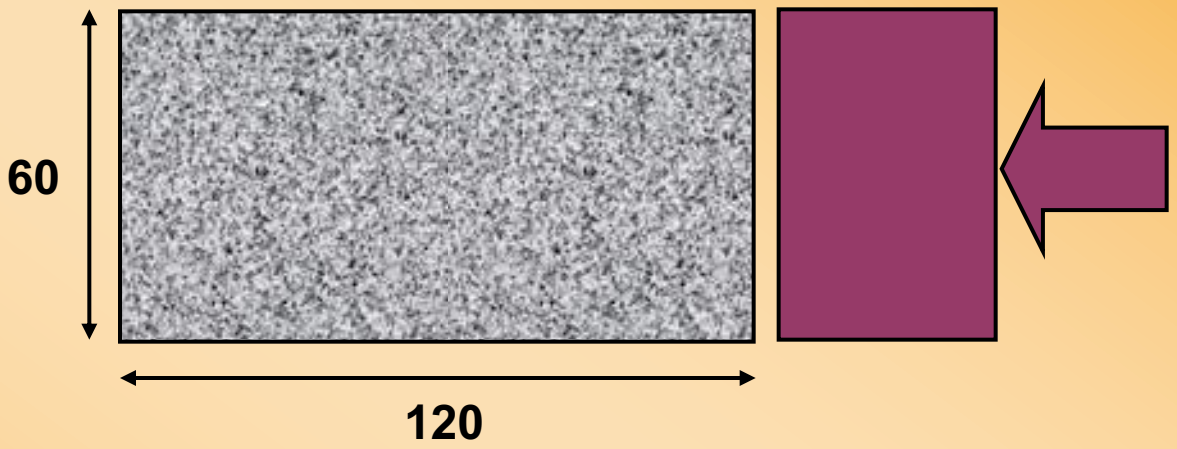
paul verlaine université - metz

Test set-up

Test set-up

- **Test specimen: concrete (dimensions in mm)**

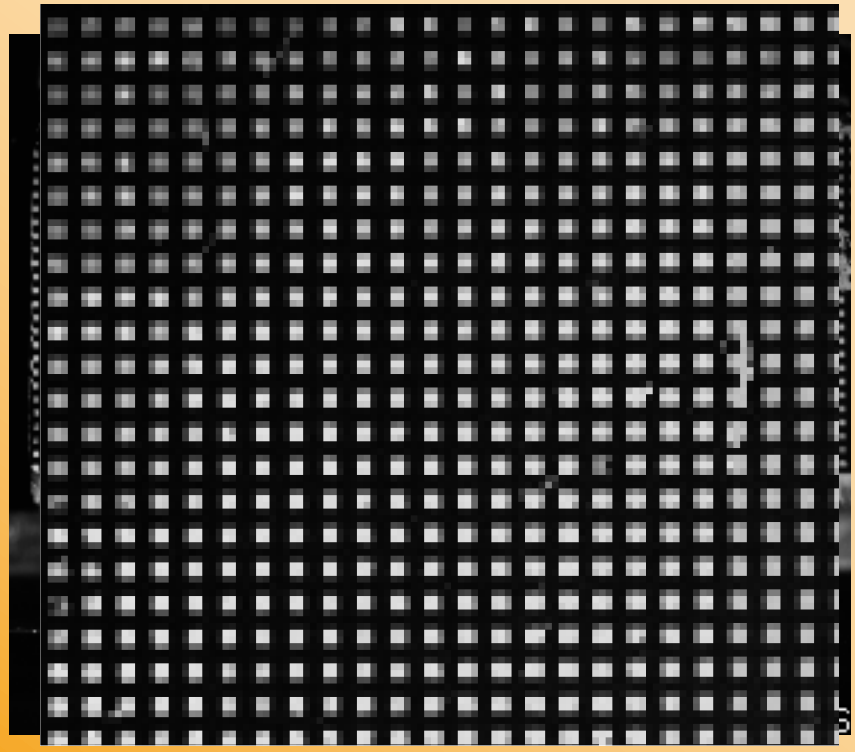
Thickness: 20



- **Shimadzu HPV-1 camera**
  - Single sensor with on-board memory
    - 312 x 260 pixels
    - 102 images
    - Up to 1 MHz

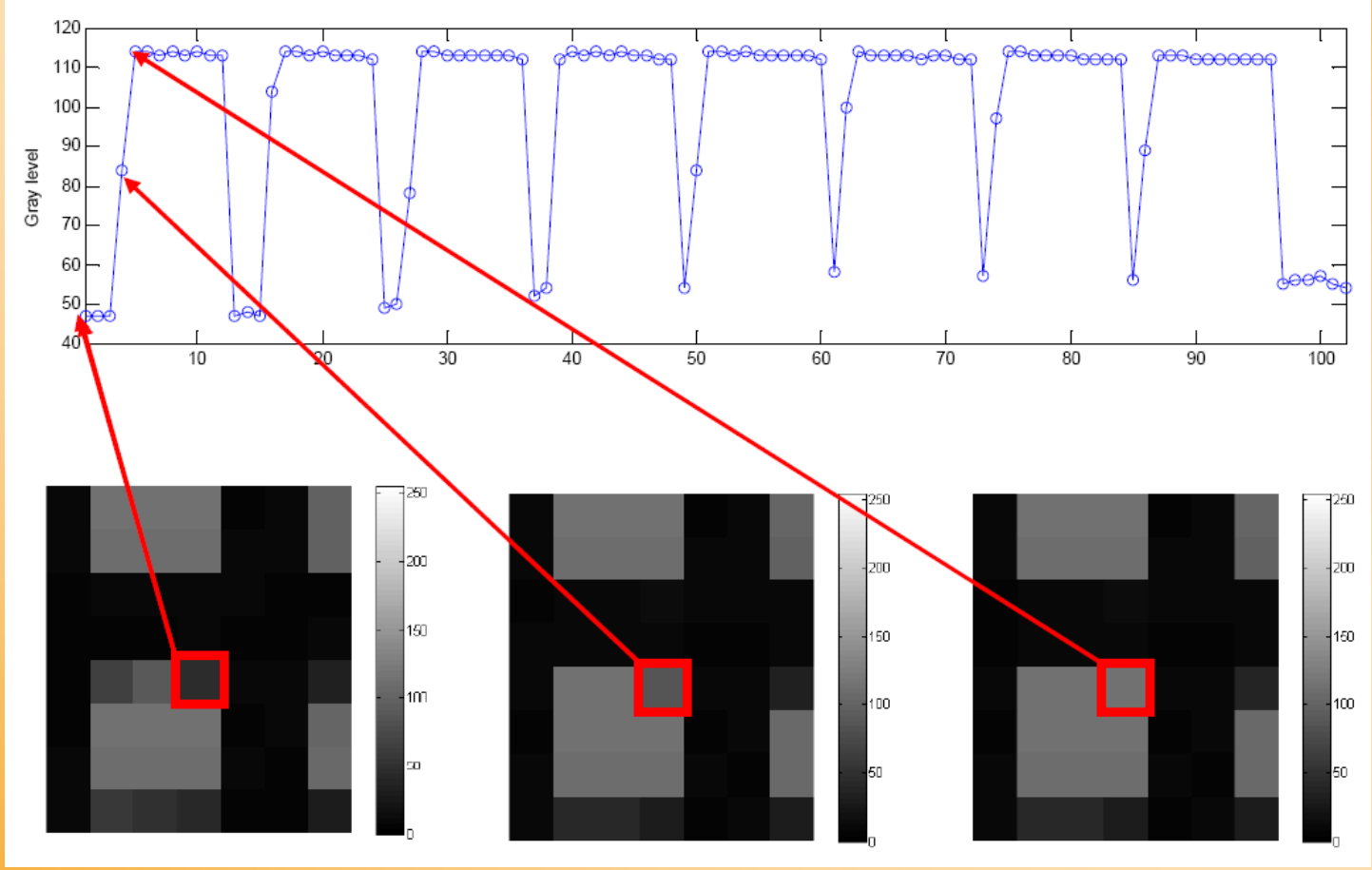
SHIMADZU HPV-1

- **Measurements**
  - Problem of fill factor
    - 14% in the 312 pixels direction
    - 76% in the 260 pixels direction



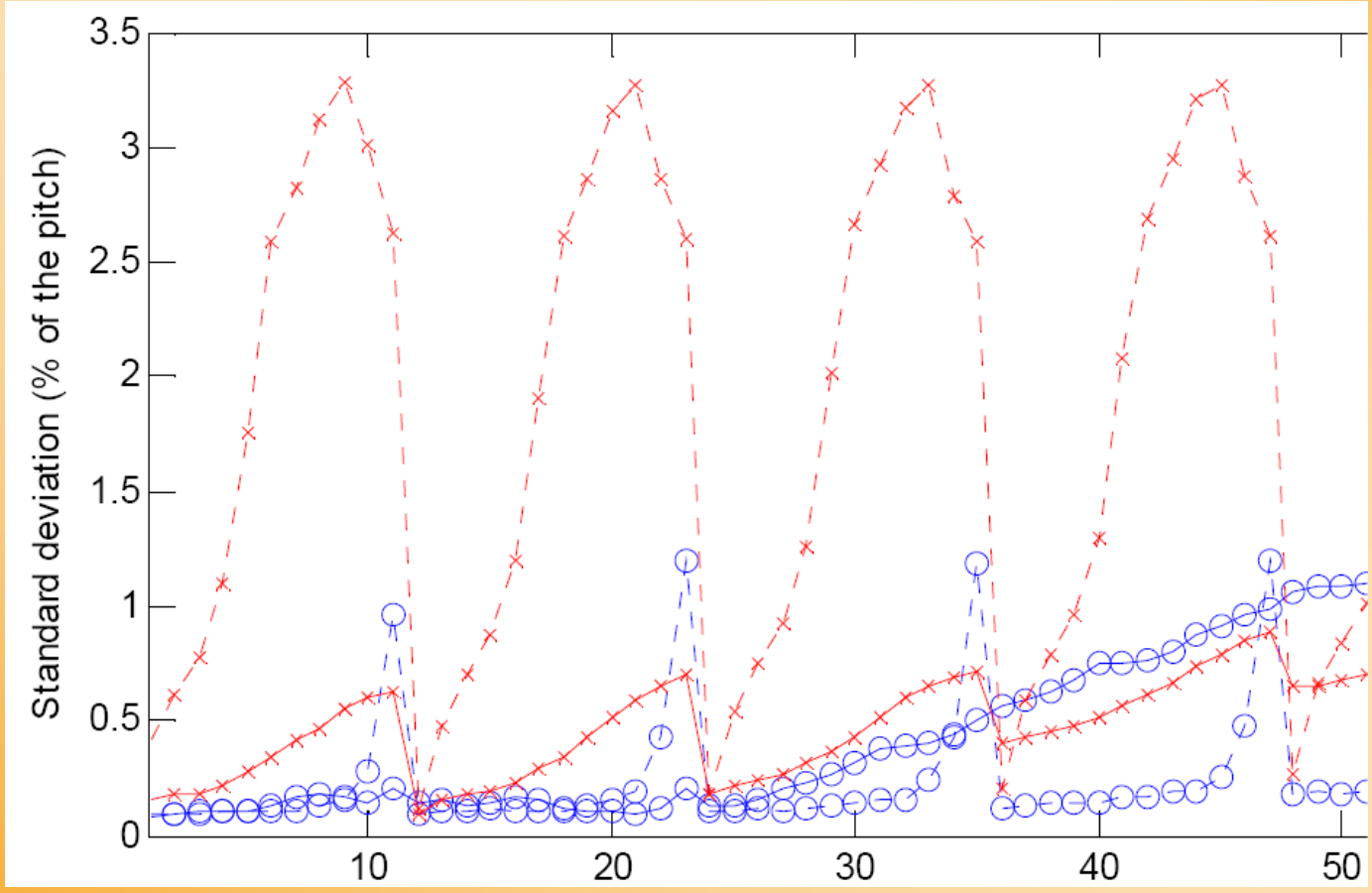
Measurements

Problem of pixel intensity variation



Resolution

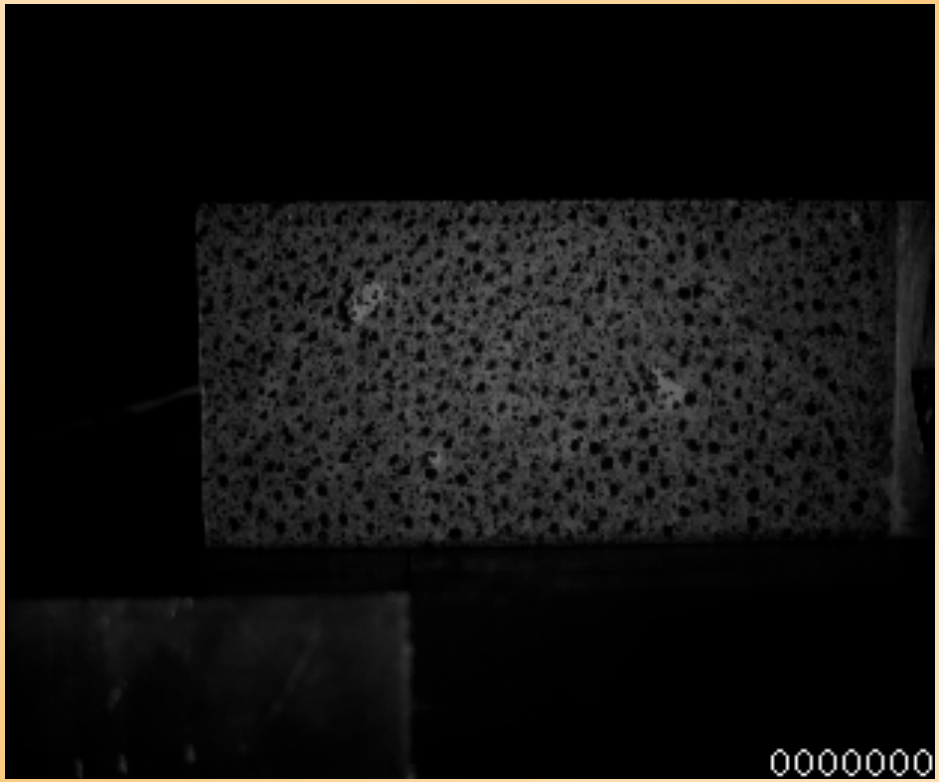
- Two static grids: 2mm pitch (4 pixels, blue) et 3mm (5 pixels, red): performance similar to Cordin camera



Results

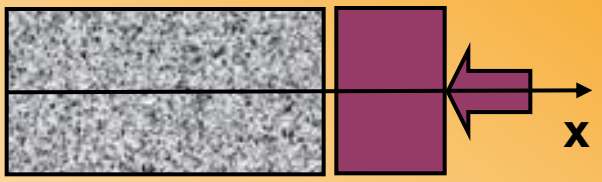
- **VIC 2D correlation software**
  - Active area: 228 x 115
  - Correlation subset: 21 x 21, step: 5
  - Final data set size: 43 x 19 pixels (110 mm x 48 mm)

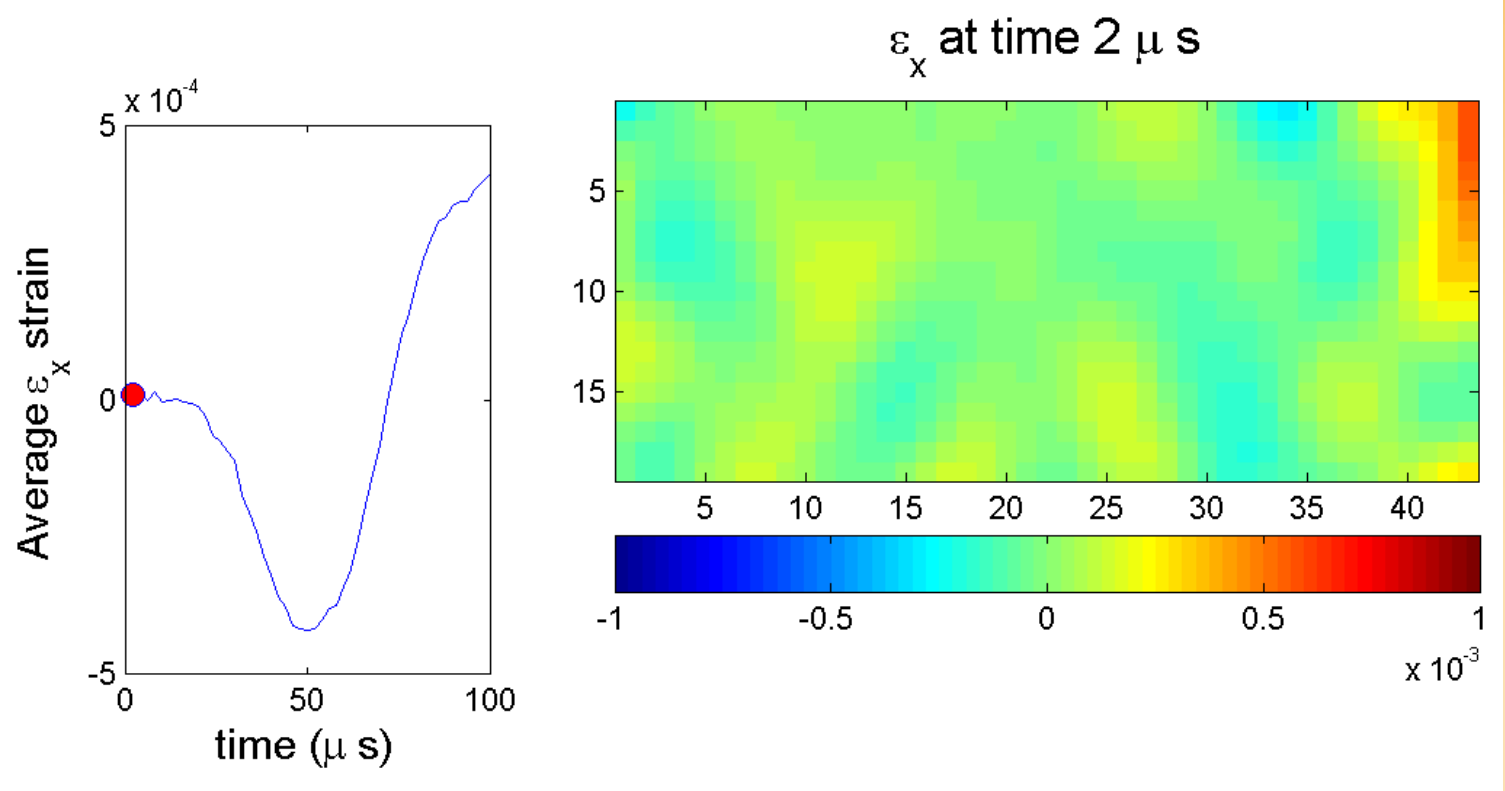
Interframe time: 2 ms
until image 84, then 8 ms



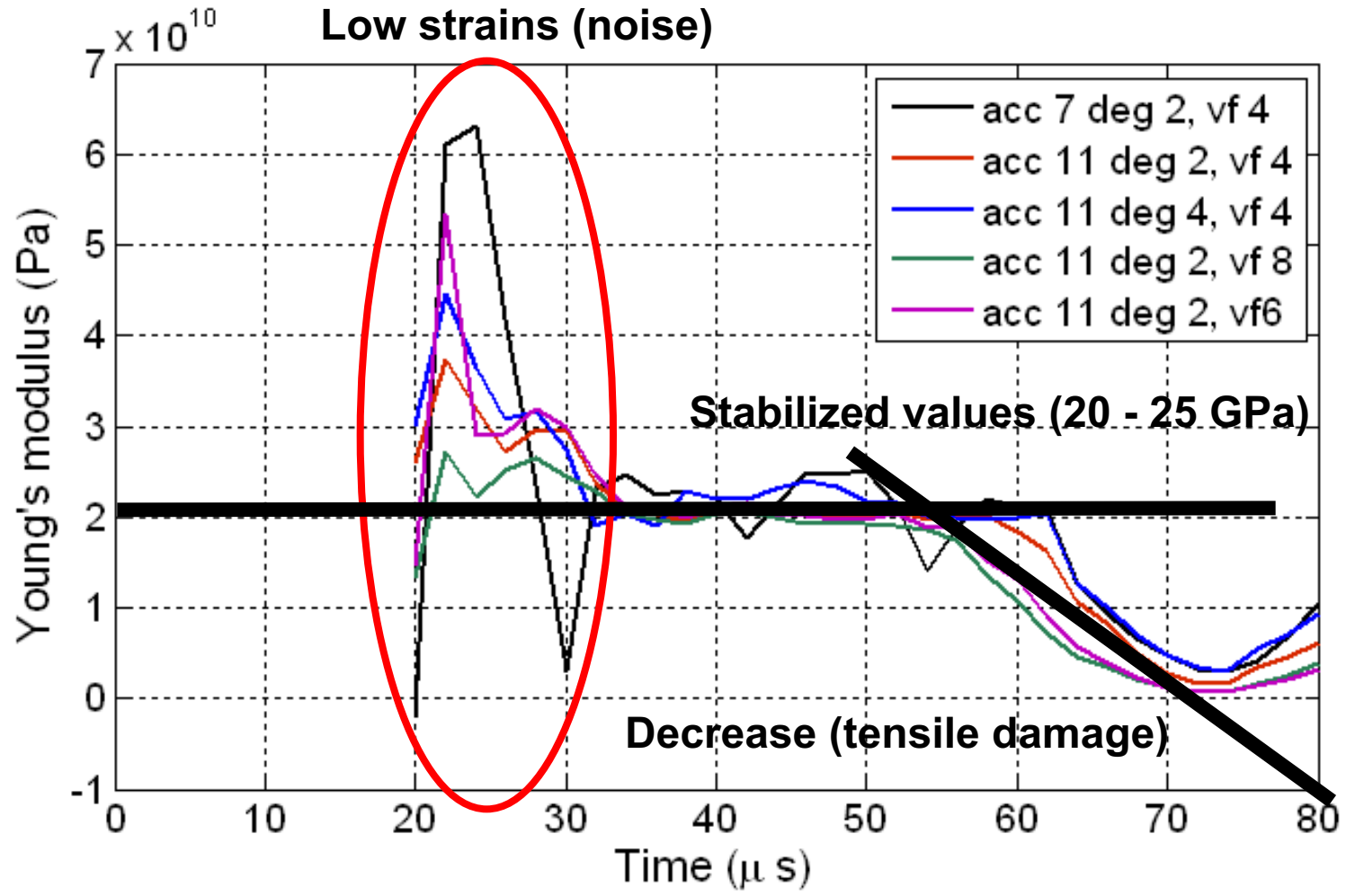
Results

- **Eps x Strain**
  - Up to crack initiation only





Young's modulus identification



CONCLUSION

- **UHS cameras**
  - Great pieces of kit
- **Full-field measurements in HSR testing**
  - Great potential
  - Use of inertial forces for identification (VFM)
  - Design of novel tests
- **Key issue: quality of UHS cameras**
  - Requires improvement
  - Technology adapted to measurements (not just images)
  - Need for collaborations with camera manufacturers