Use of CIVA to develop in a (very) short time a NDT procedure to resolve a bonding crisis related to the mirrors of the Extremely Large Telescope

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Agenda

01
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02
Bonding Crisis

03
Inspection of back face pads

04
Inspection of lateral face pads

05
Conclusions

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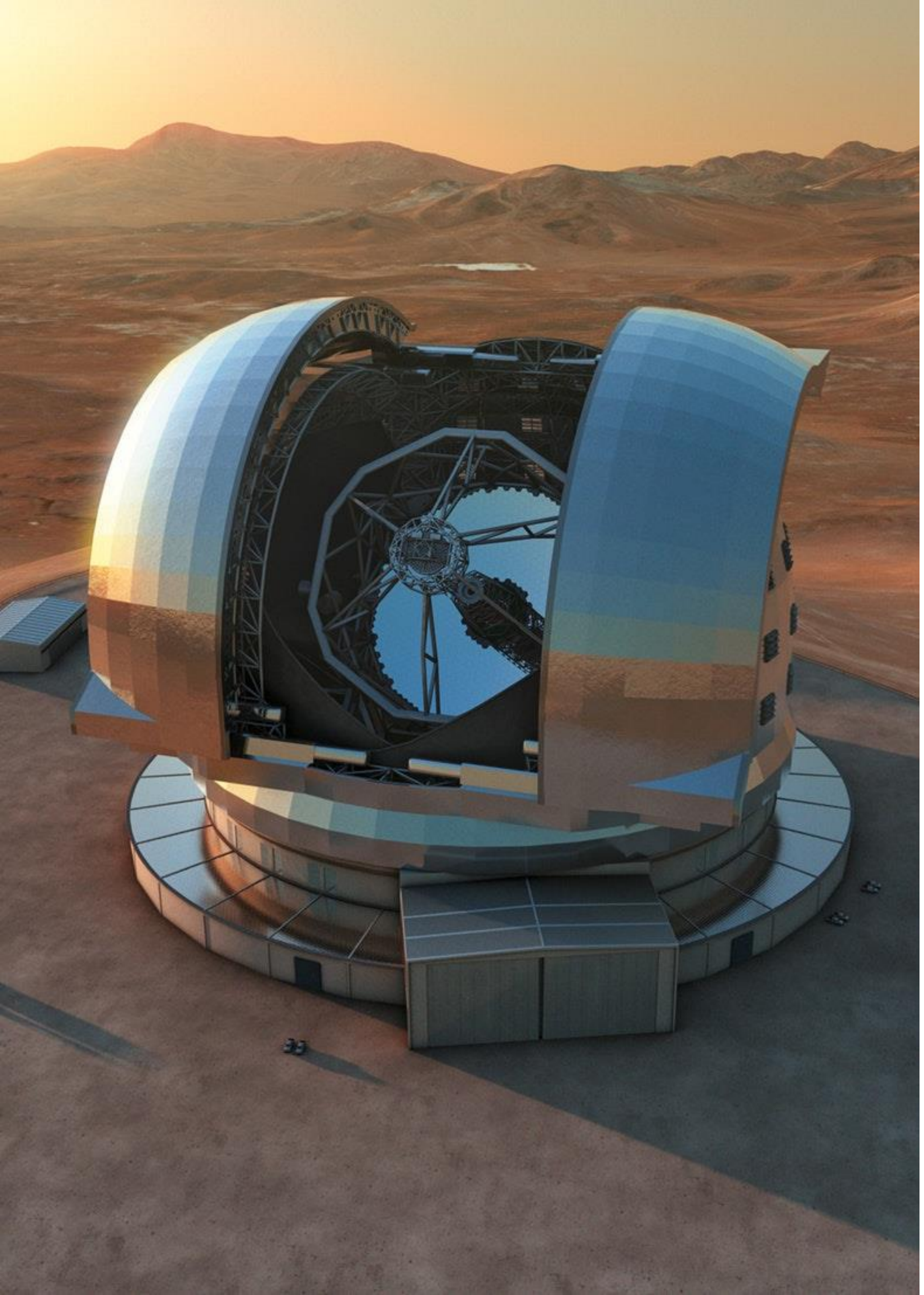


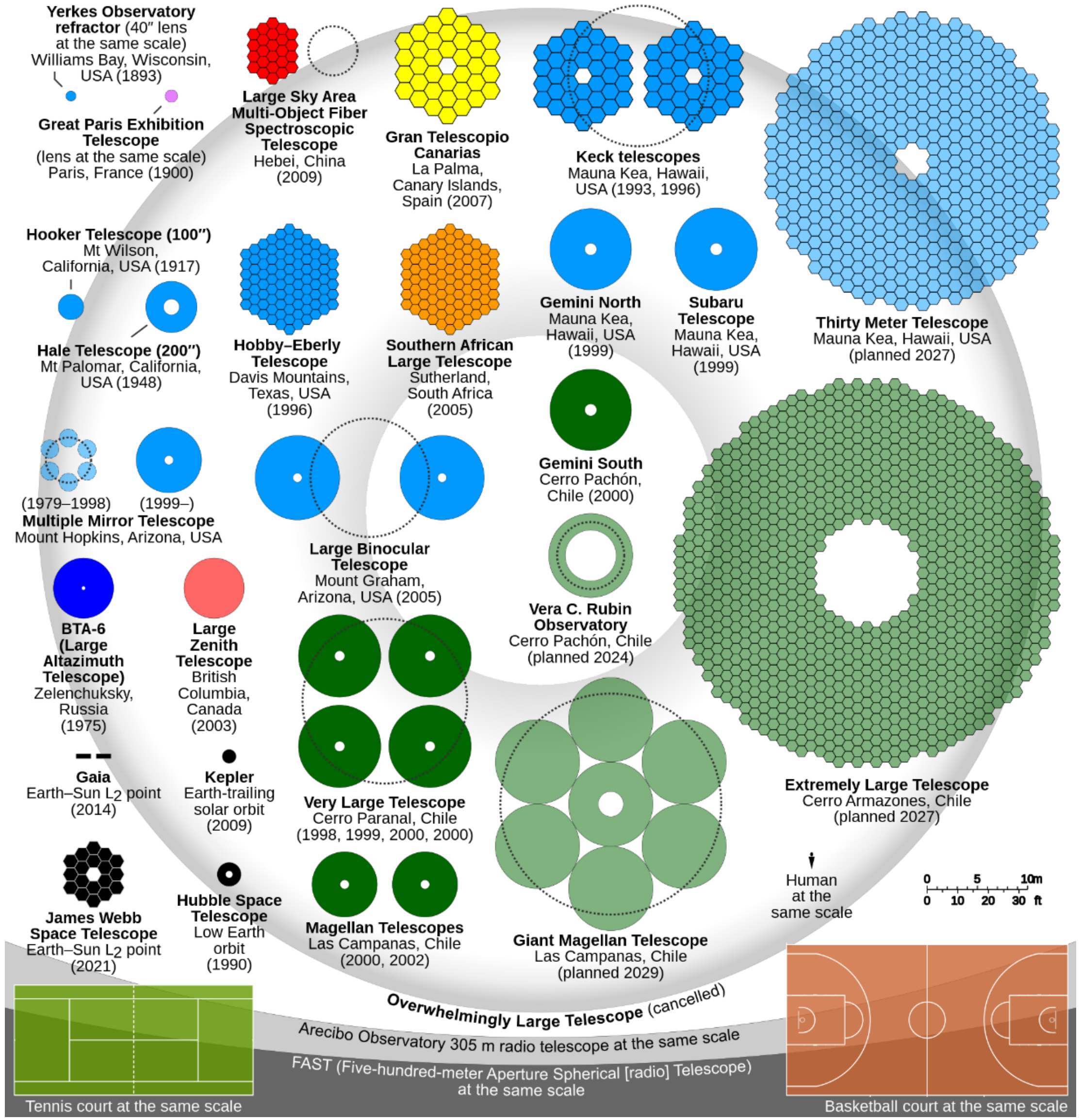
Chapter 1

The Extremely Large Telescope

Why build larger (aperture) telescopes?

- Resolving power $\theta \sim 1{,}22\,\dfrac{\lambda}{D}$
- Light gathering power $\sim A \propto D^2$
- Imaging speed for point sources $\propto D^4$

How the nebula NGC 3603 could be seen by three different telescopes: Hubble Space Telescope, Very Large Telescope, Extremely Large Telescope.



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The Extremely Large Telescope (ELT)

- ESO Master of Works:
  - European Southern Observatory
  - 16 Member States
- Budget: 1.3 billion euros
- First light: 2028
- Site: Cerro Armazones (Atacama, Chile)
  - 3046 m above sea level
  - 23 km from the VLT at bird's eye view

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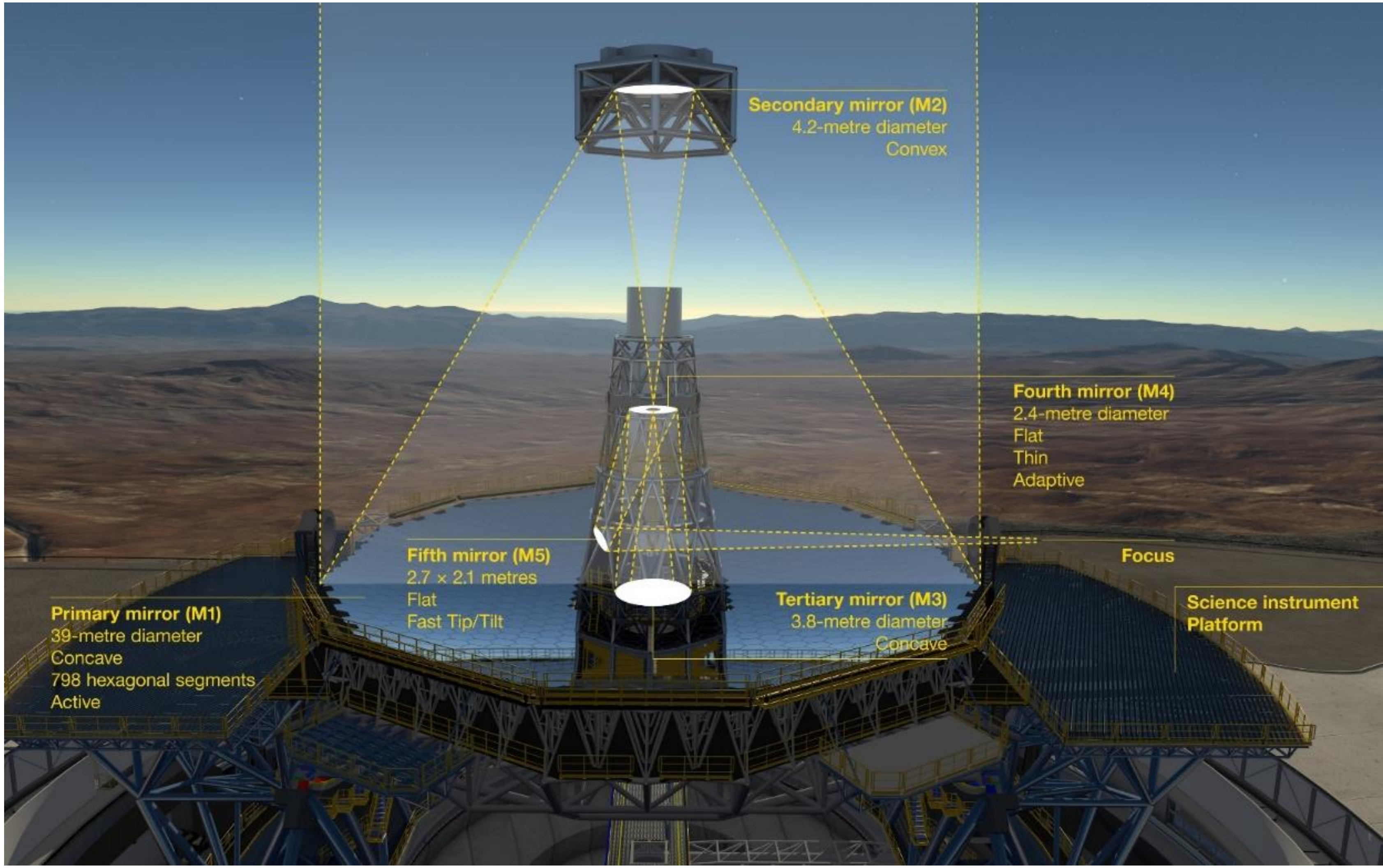
A few figures

- M1: Diameter 39m
  - 798 Segments of 1.44m
  - Largest primary mirror in the world
  - Equivalent to ~20 VLT
- M2 and M3 class 4m
  - M2 is the largest convex mirror ever made
- M4: Diameter 2.4m
  - Largest adaptive mirror ever made
- M5: SiC plane of 2.8 x 2.2m.



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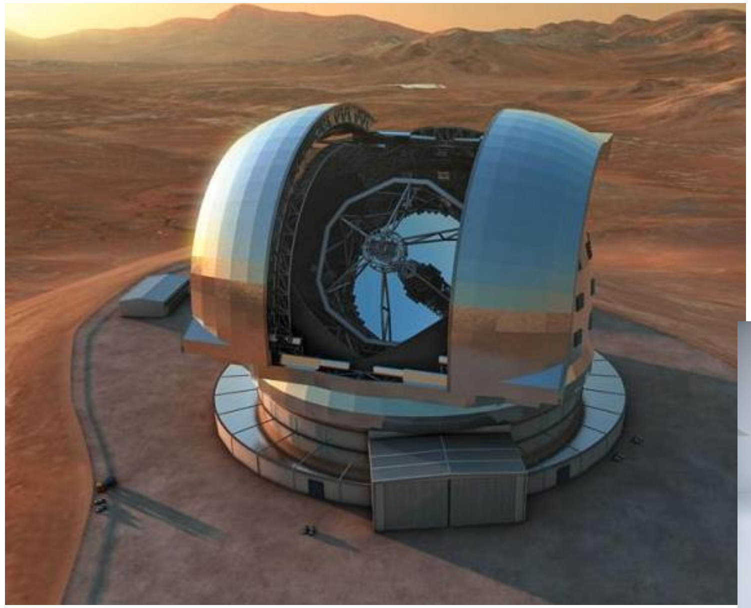
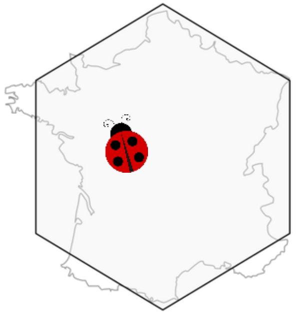
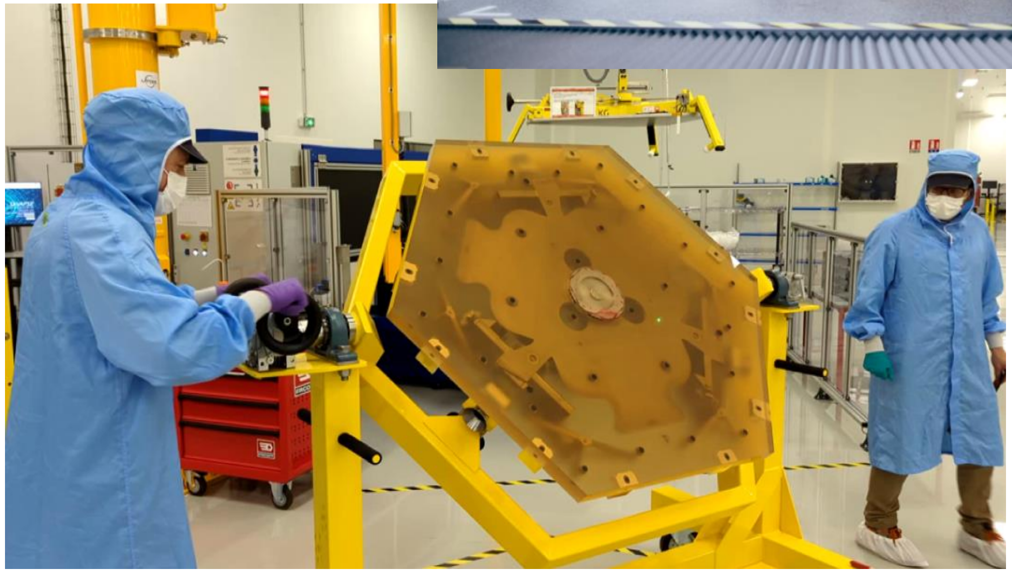
The ELT M1 mirrors

- **931 (798 + 133) segments**:
  - 6 sectors 133 segments + 1 spare sector
- 133 different forms:
  - Irregular hexagons 1.44 m tip to tip
  - All off-axis aspherical (max 300 µm PtV)
  - Bending radius 71270 3 mm
  - All different contour (10 mm)
  - Mechanical references machined at 50 microns
- Surface shape error:
  - Specified to the edge
  - < 25 nm RMS (including curvature)
  - < 7.5 nm RMS (excluding BF)
  - < 2 nm RMS roughness
- 51 interface pads (**69 glue joints**)
  - More than 64 000 joints on M1
  - 30 years life (seismic, thermal)







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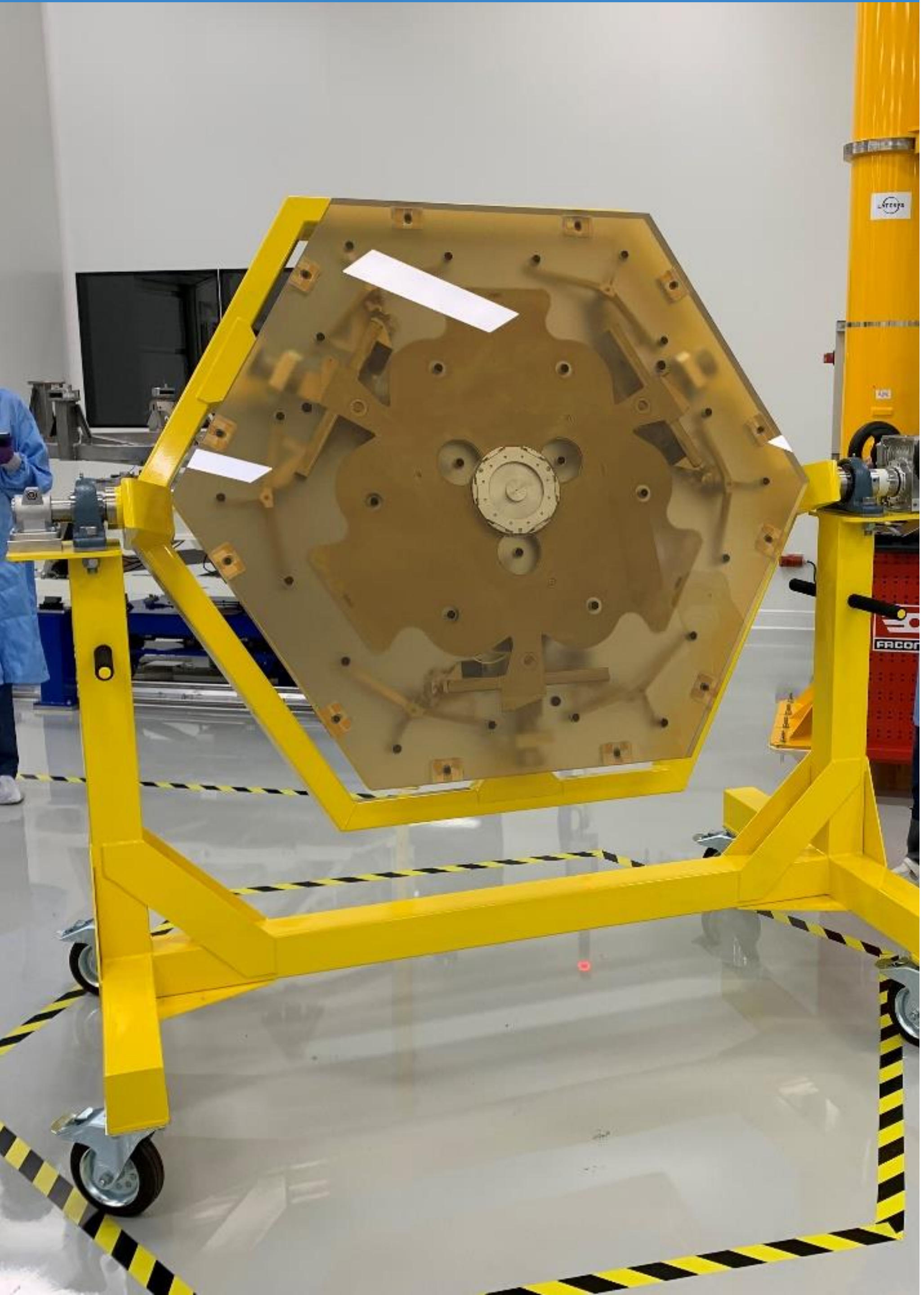

Chapter 2

The Bonding crisis

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Identification of the crisis

- **Cavities (“voids”) in the glue joints between the pads and the segment are detected**
  - Critical impact on bonding in extreme conditions (temperature excursion, seismic)
- **Highlight in Fall 2021**
  - Few month before first delivery to ESO
- **Difficult detection**
  - Destructive detection
  - Detection only in case of repair
  - Low number of occurrences (4% of glue joints)
- **Complex process**
  - Several potential sources of air bubbles
- **Process on the critical path of production**








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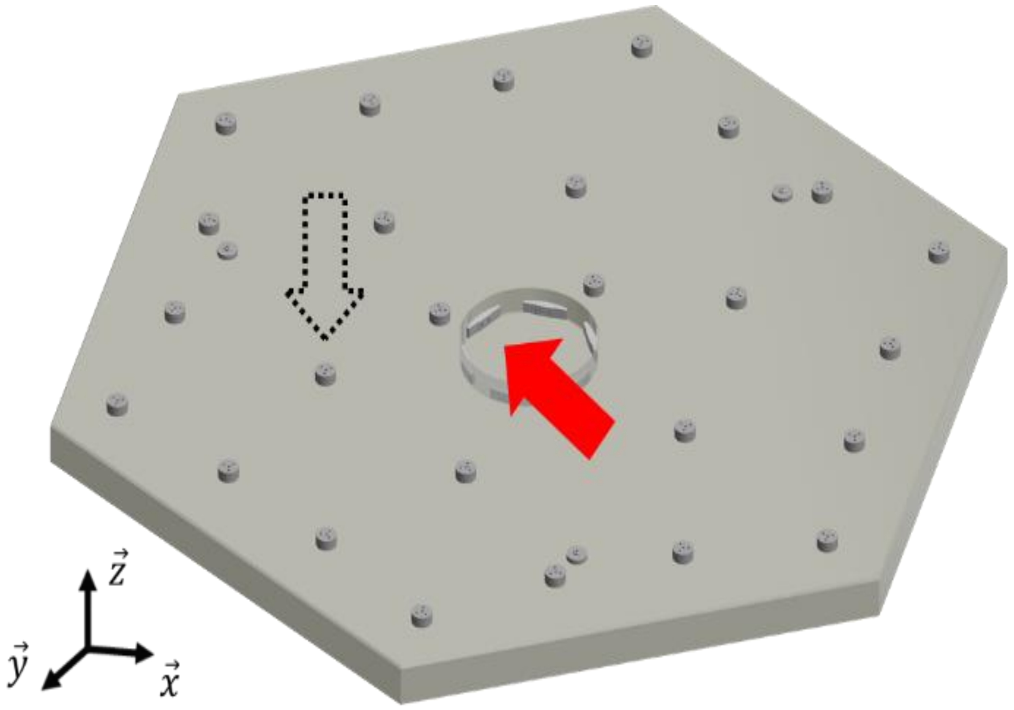
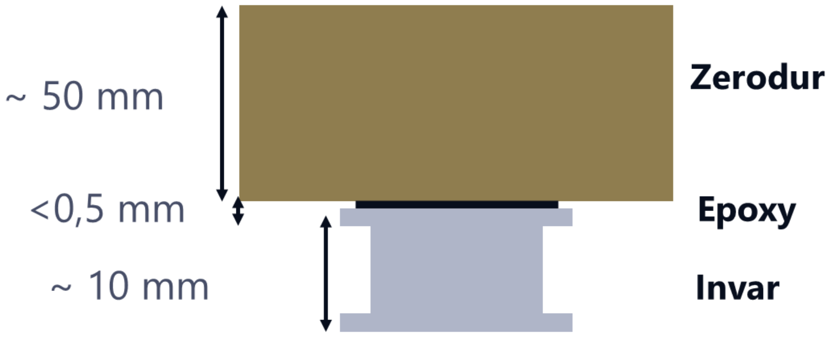
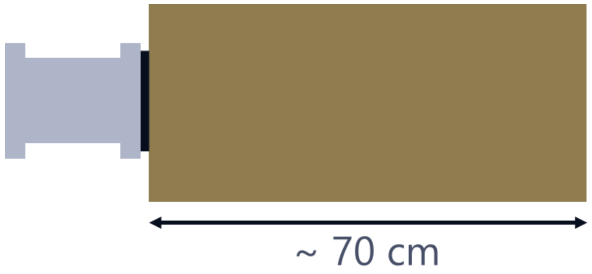
Request for NDT solution

- **Must be :**
  - operational in the few following months
  - compatible with the production line
    - Rapid
    - Ligth
  - realized by bonding operators, not trained to NDT
    - Analysis on a simple image







- **Solution based on phased-array imaging**

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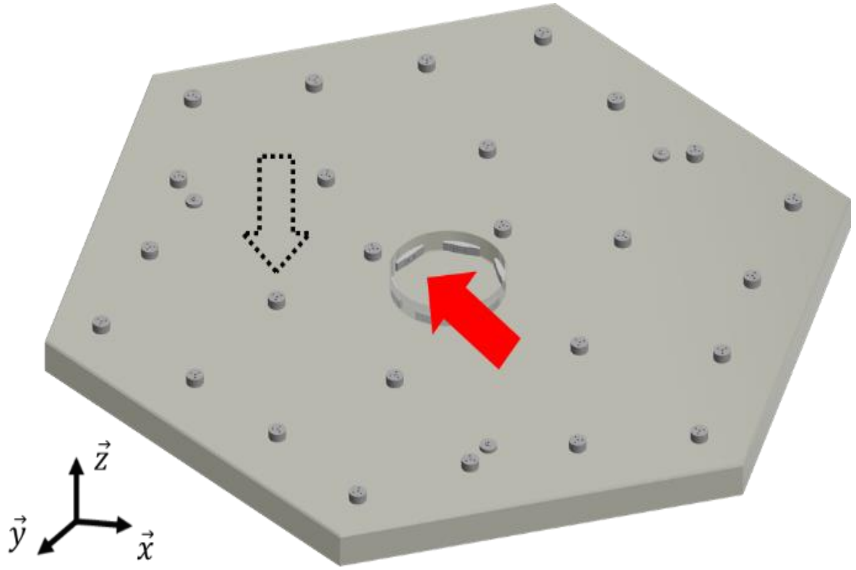
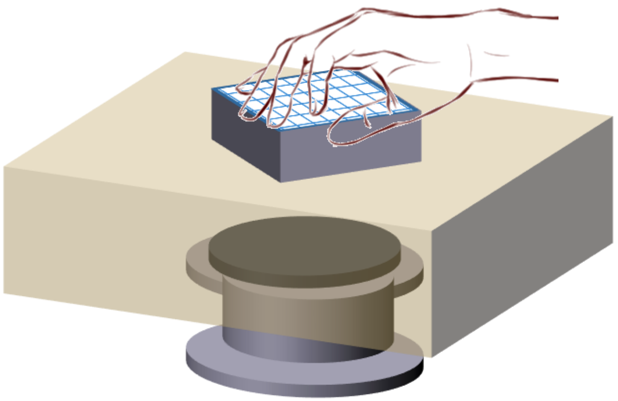
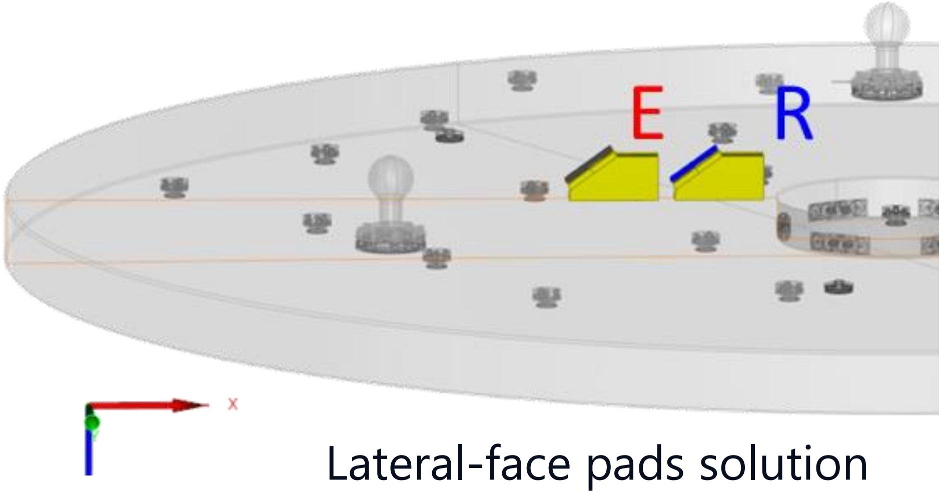
Solution

- **Phased-array UT imaging with R-Theta portable encodeur**





Back-face pads solution



Lateral-face pads solution

- **Request for Extende to validate the proposed approach and to size the control using CIVA**

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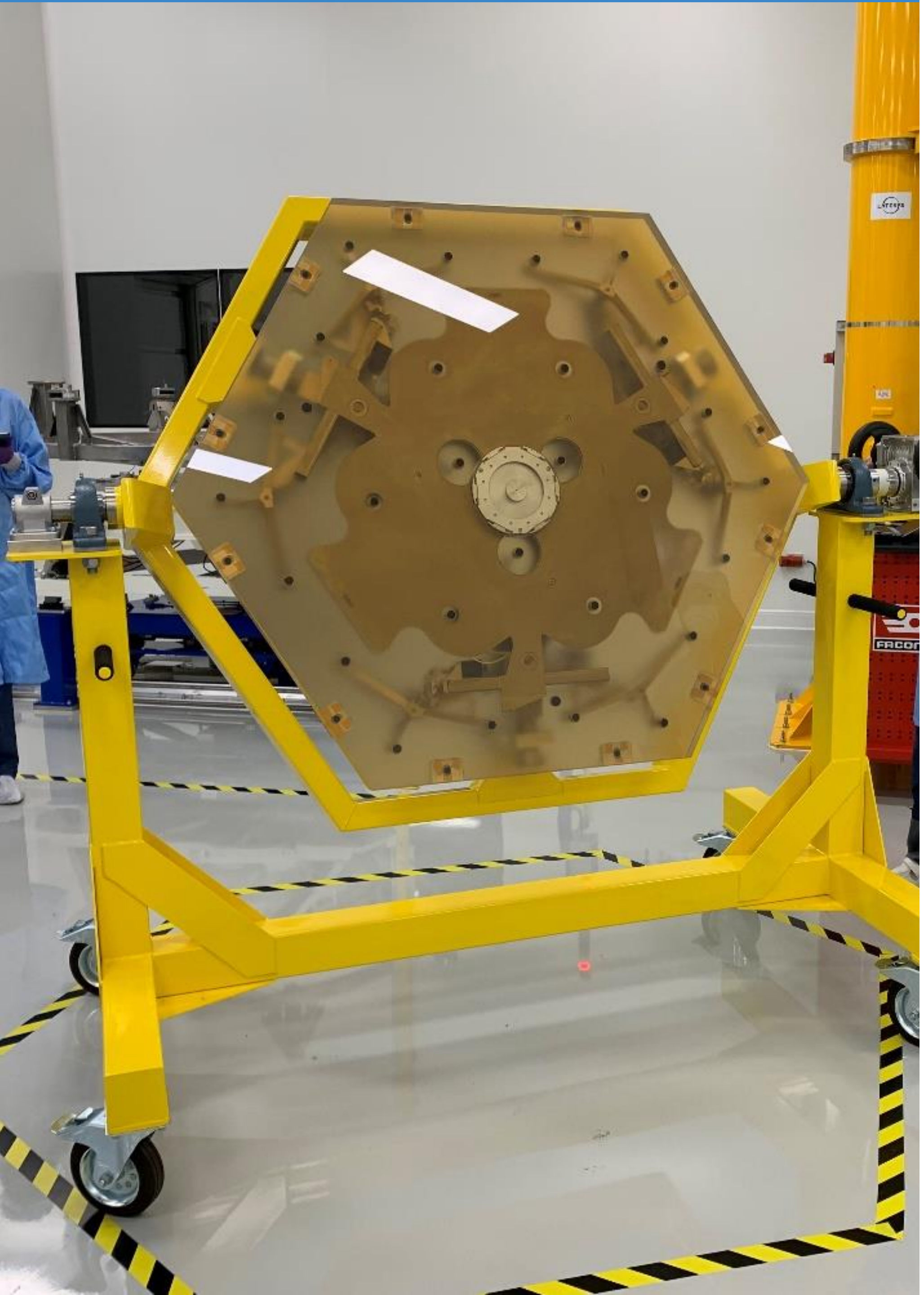


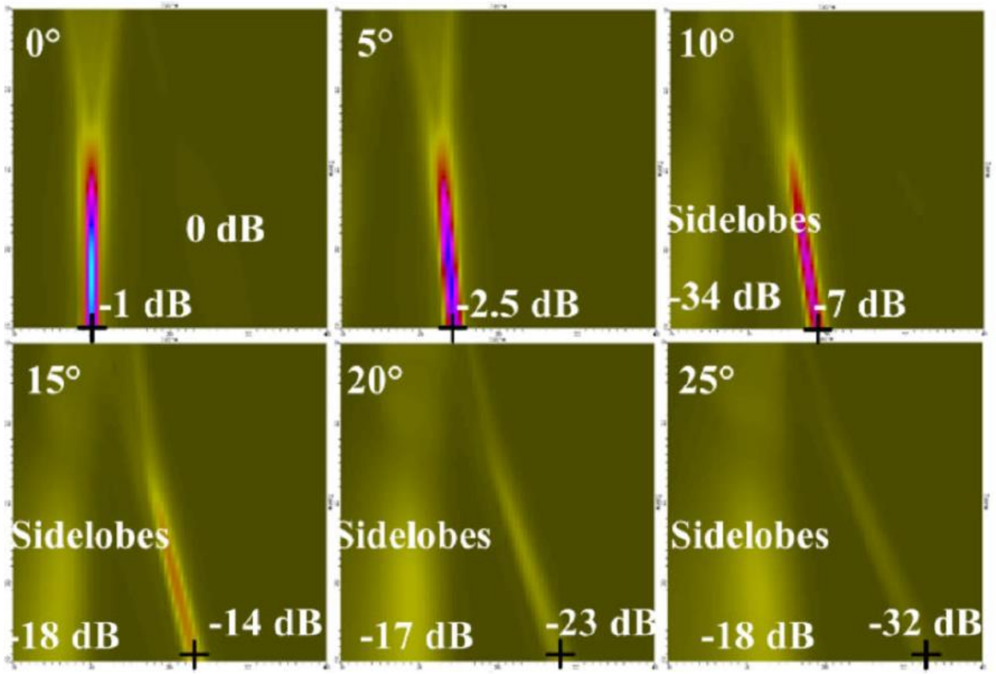
Chapter 3

Ultrasonic imaging of the back face pads

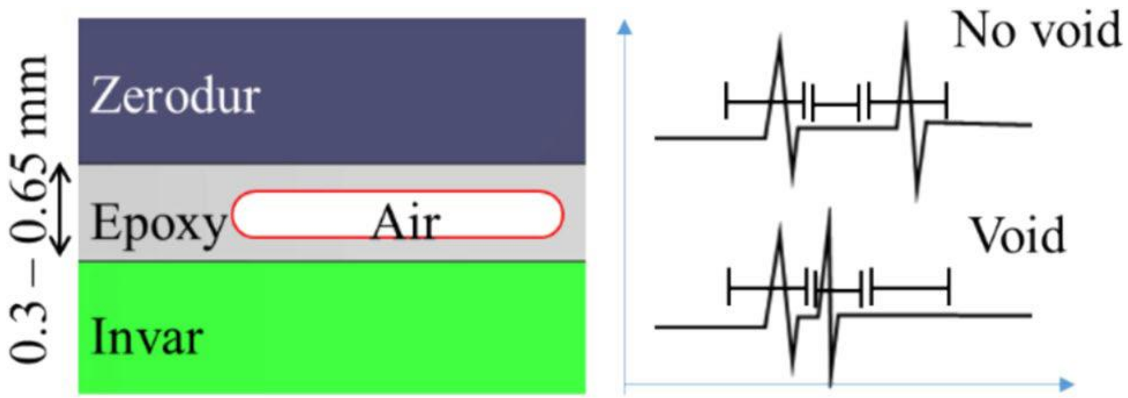
- Check an identify probe
- Find the optimal imaging mode

Validation of a phased-array proposed on catalogue

- **Probe :**
  - 11x11 square matrix
  - 17 MHz
  - Elementary size : 0,9x0,9 mm^2
- **Simulation of beam deviation**



- **Simulation of echo detection**
  - 17 MHz is enough to separate echoes from different interfaces



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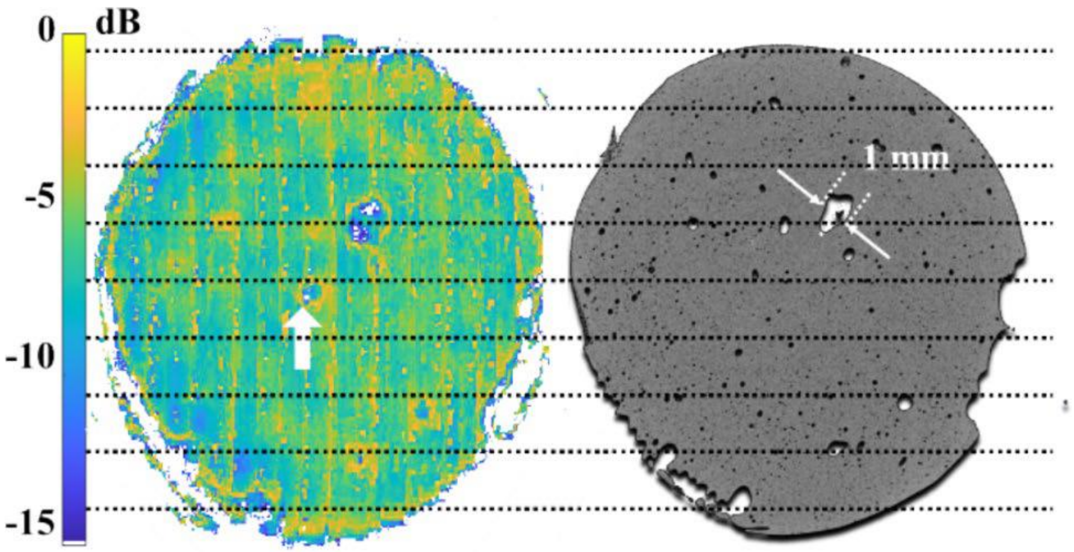
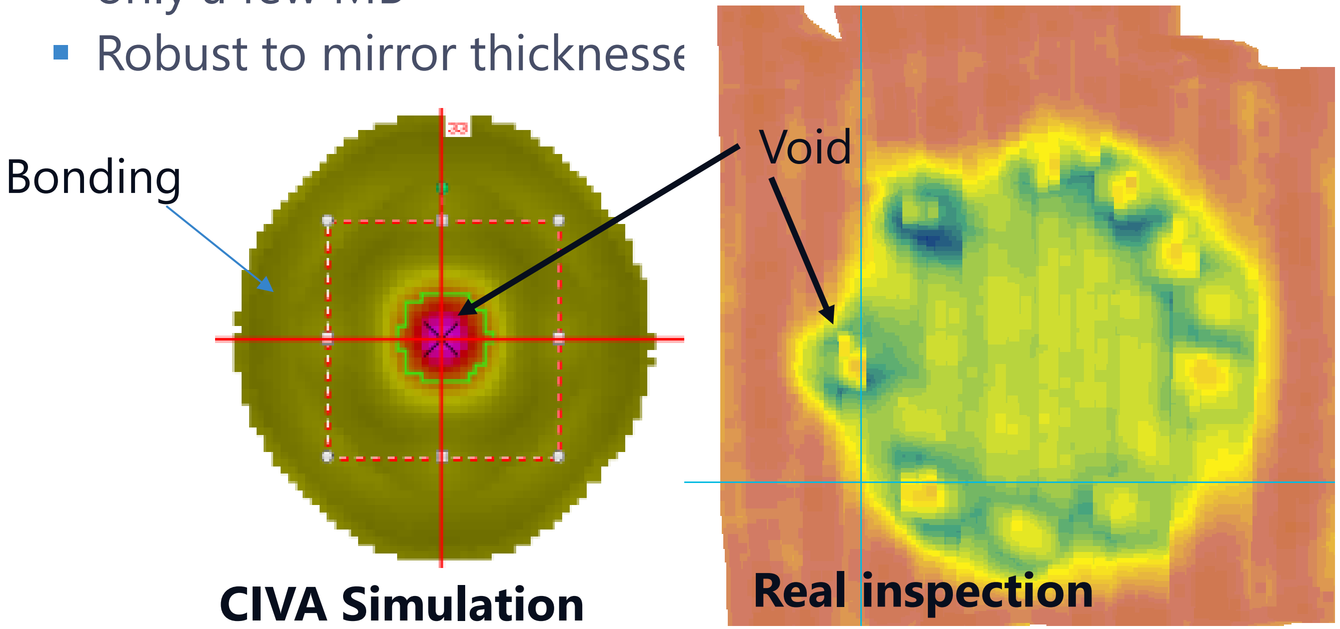
Imaging mode

- **TFM imaging in the volume of the bonding**
  - 3D imaging because of mirror thicknesses variation
  - Required around 2Go per bonding

- **Sector scan + encodeur**
  - only a few MB
  - Robust to mirror thicknesse



Comparison between an ultrasonic inspection (left, dB scale) and an image obtained from computed X-ray tomography of a representative bonding of the back face of the M1 mirror of ELT.



CIVA Simulation **Real inspection**

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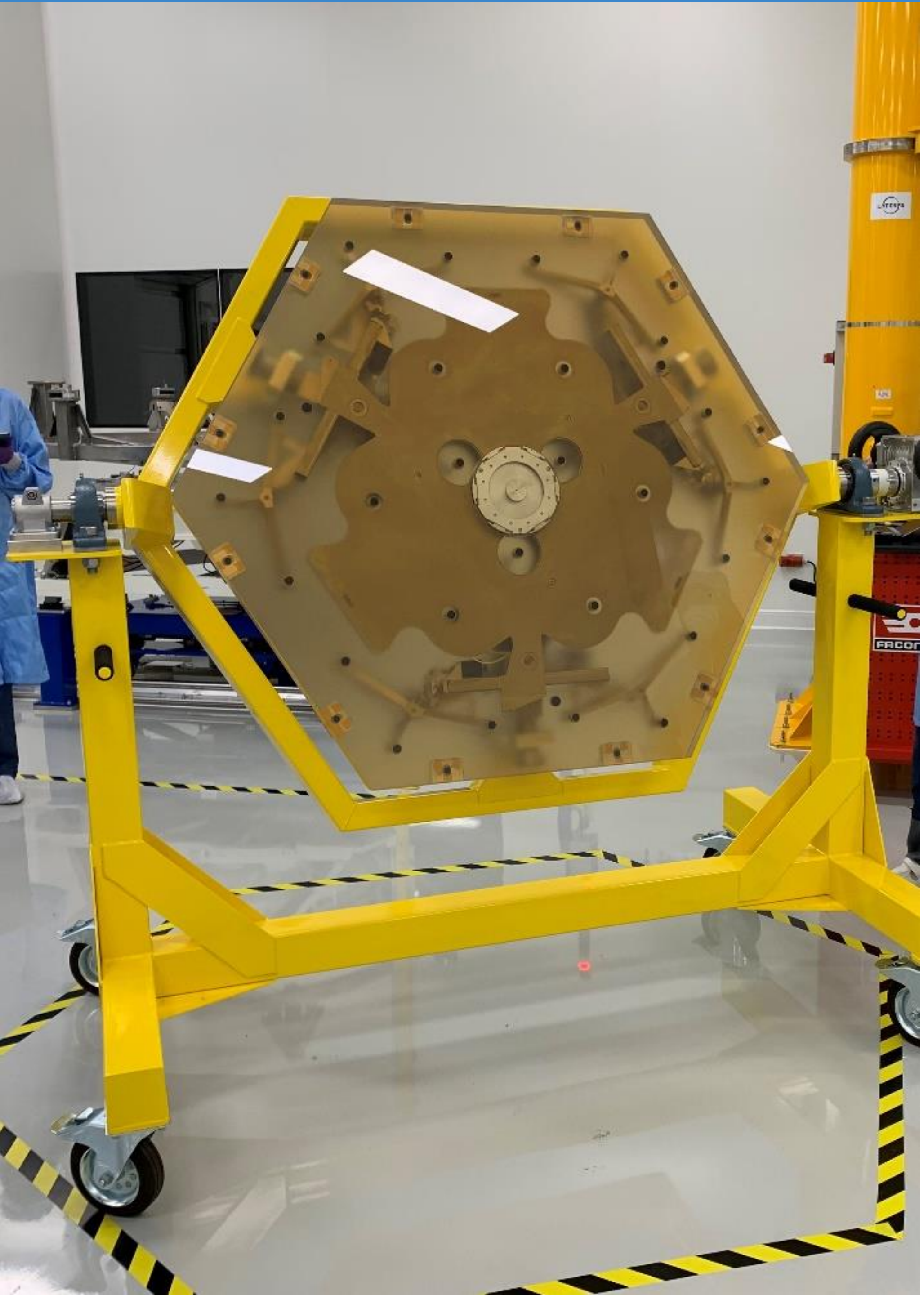


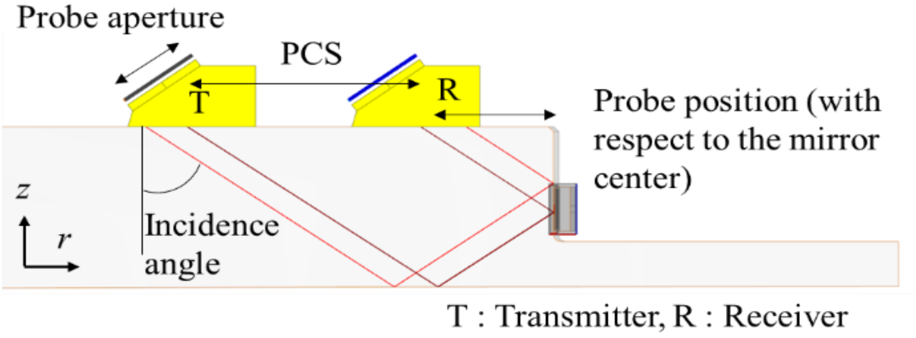
Chapter 4

TFM imaging of the edge bonding using a tandem configuration

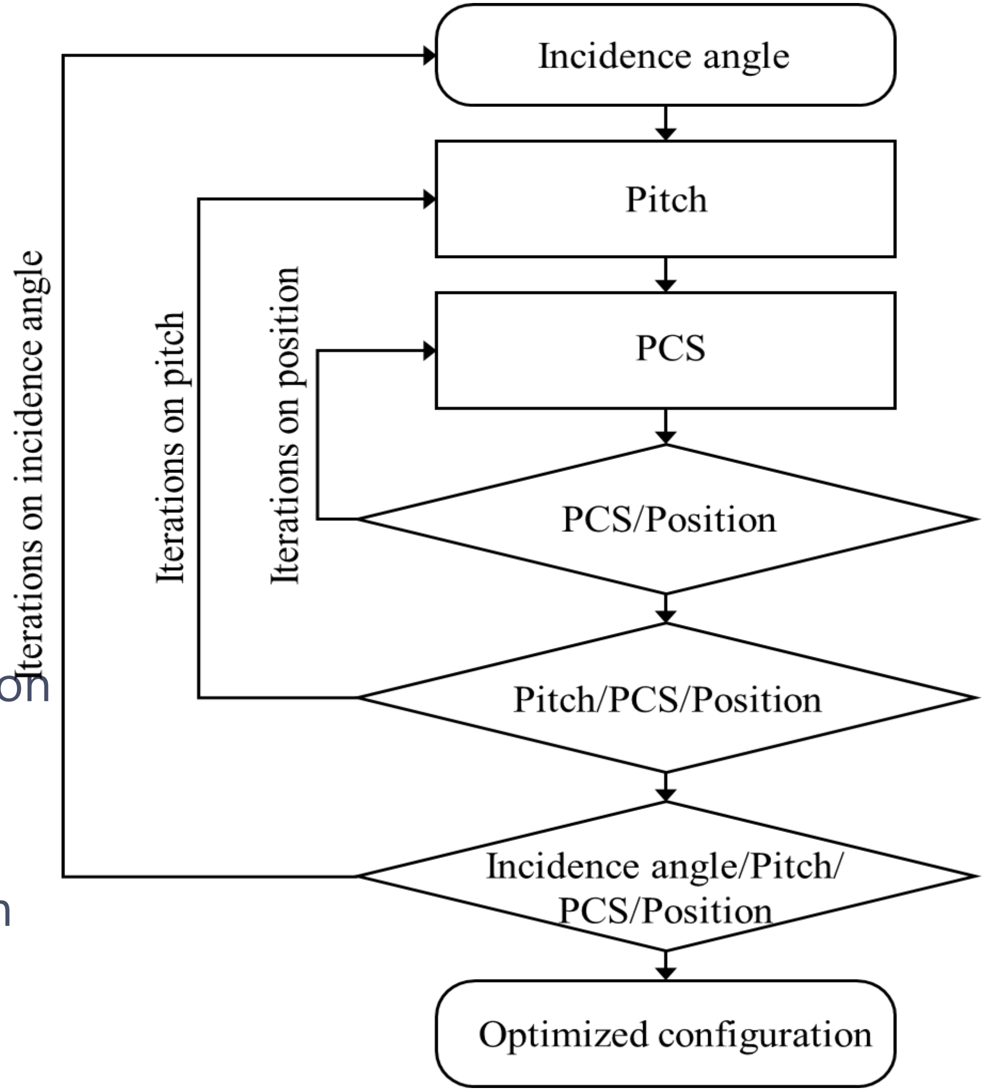
- Check the faisability
- If yes : Optimise the control, size the probes

CIVA Sizing of the control

- **Ultrasound simulations (Parametric simulations):**
  - Frequency
  - Incidence angle, Pitch, PCS, Position…



  - Elévation, probe passive focusing for emission and reception
  - Imaging strategy
- **Control simulation**
  - Taking into account the convex shape of the mirror, system footprint on the mirror, calibration,…



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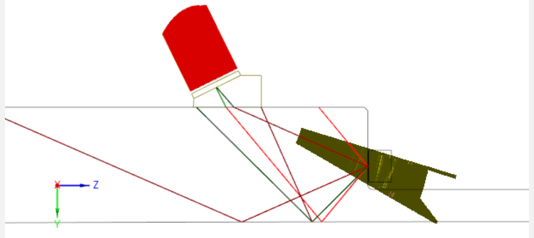
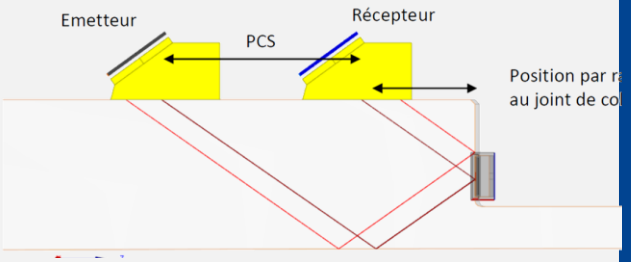
Illustrations (2D simulations)

Configuration





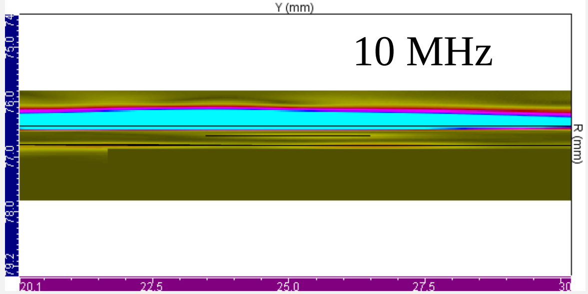
One probe : non homogeneous amplitude & uncontrolled areas

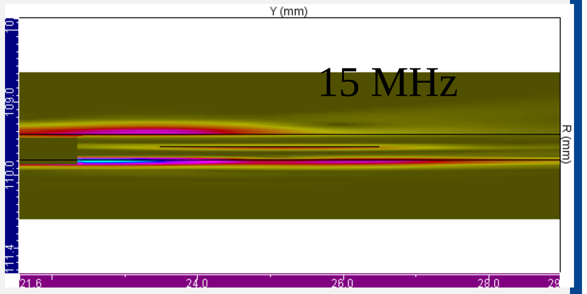
Tandem : OK

Frequency

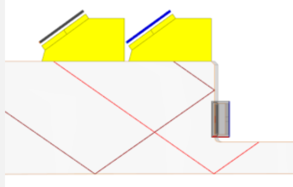
. Simulations from 10 to 17 MHz.

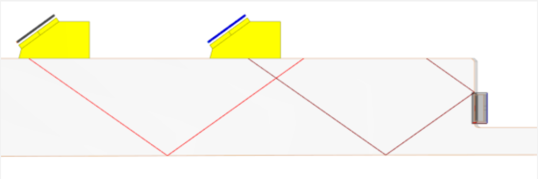
. 15MHz allows a good resolution of the interface echoes





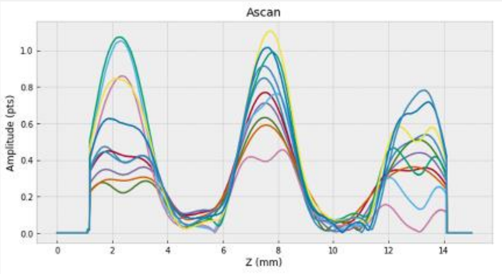
Probe aperture & PCS





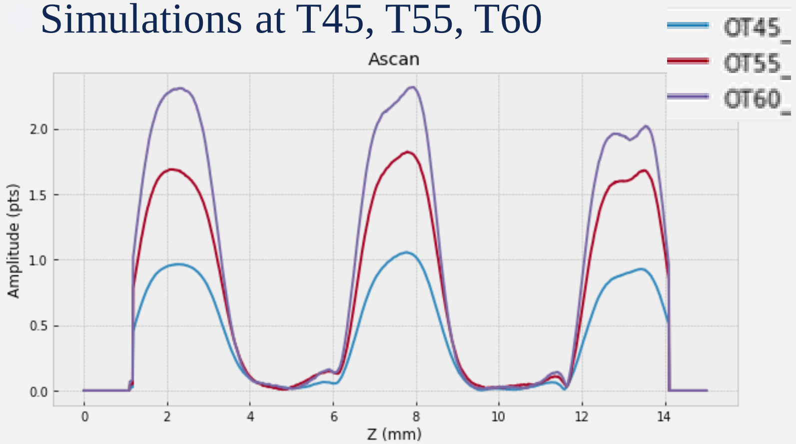
Parametric study :

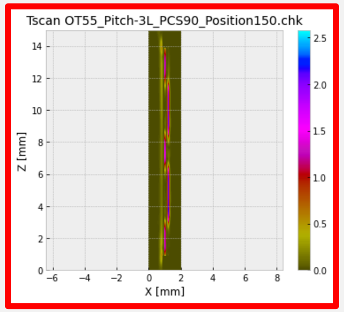
- À pitch fixé, simulation sur PCS et position
- Boucle sur le pitch



Refraction angle

Simulations at T45, T55, T60





T 55 : Good and constant amplitude of signal from voids

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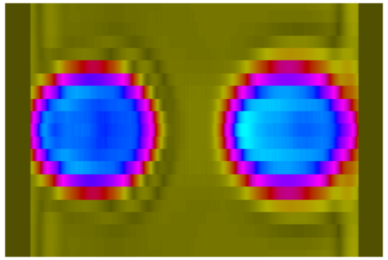
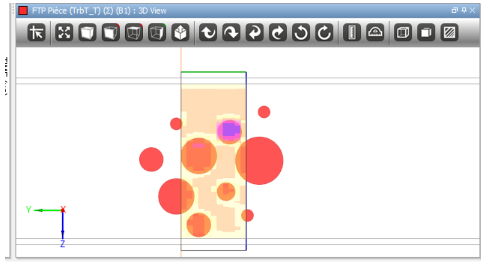
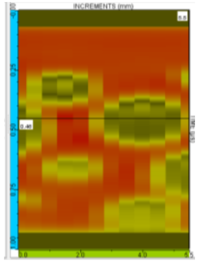
Illustrations (3D simulations)

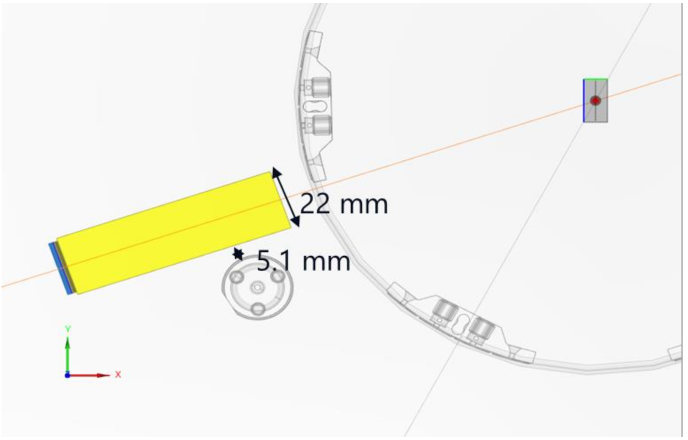
- **Simulations of the detection**

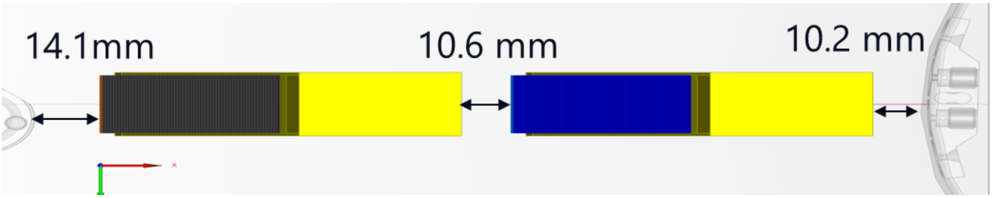






- **Simulation of the control : check of the equipment on the CAD**





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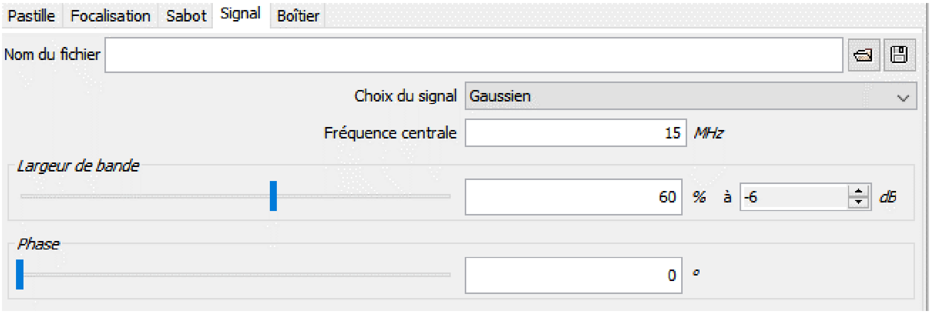
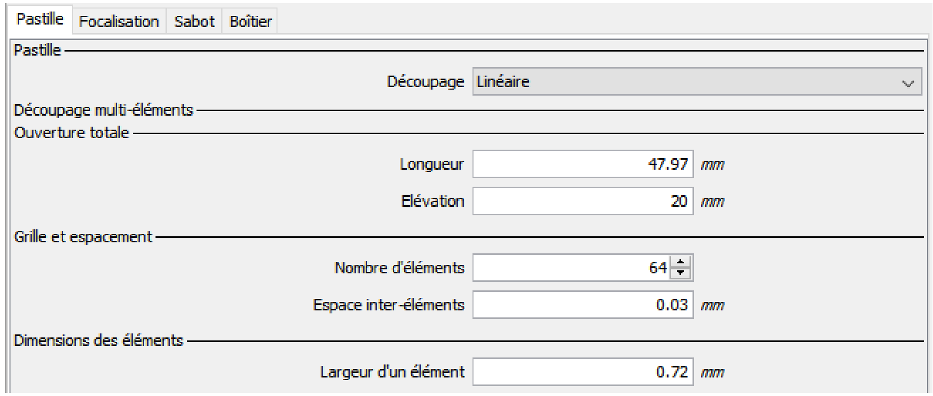
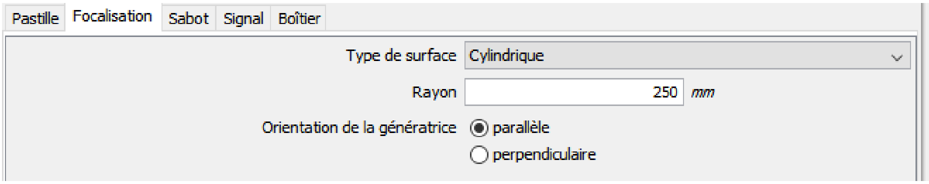
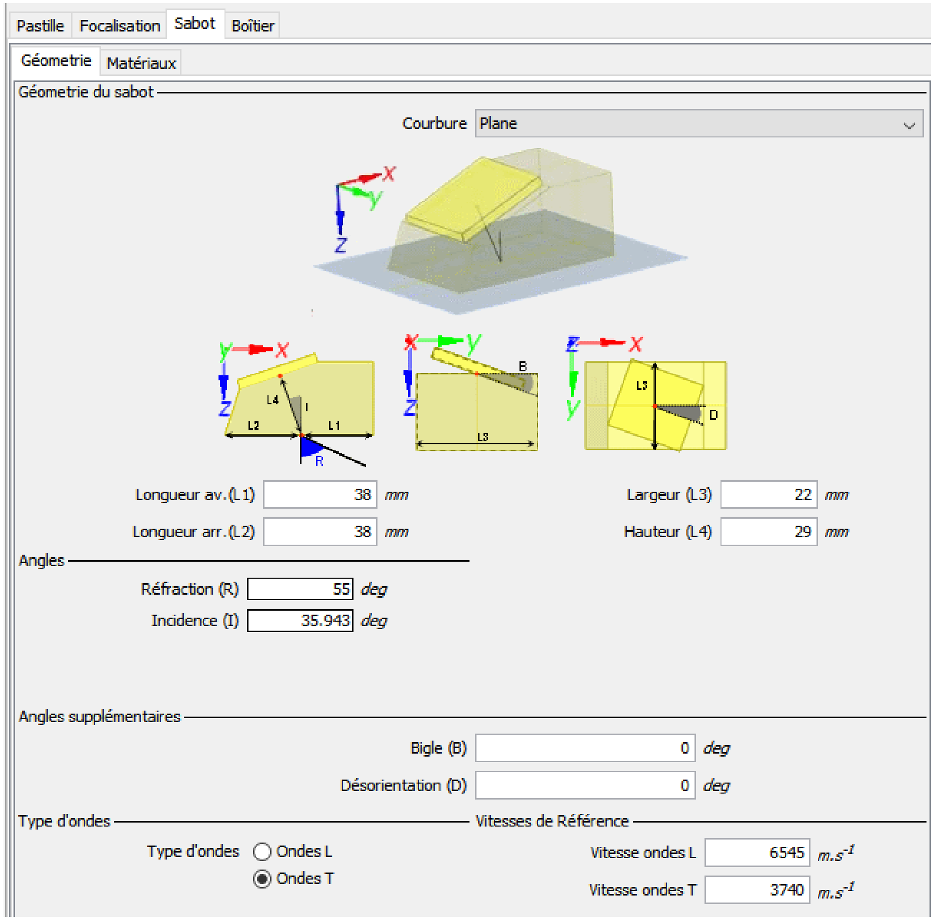
Probes sizing

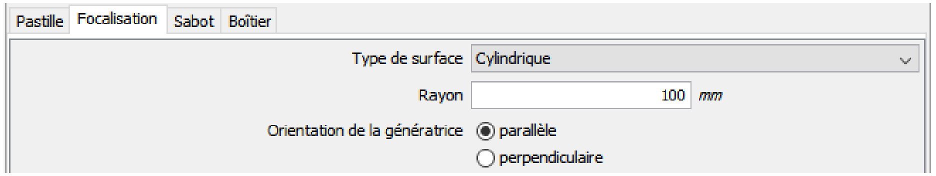
▪ Specifications for the probes











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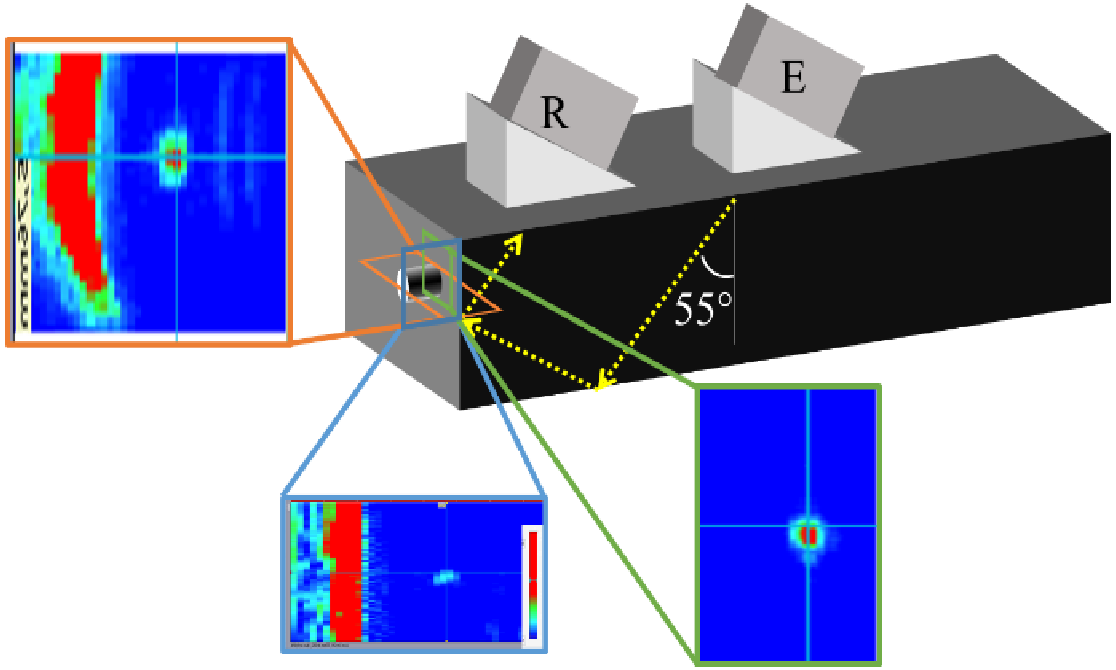
Implementation

- **First test on a flat bottom hole (1 mm diameter)**



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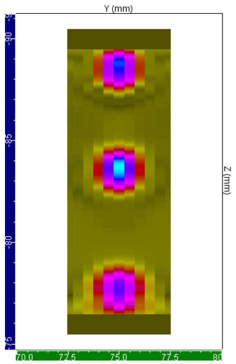
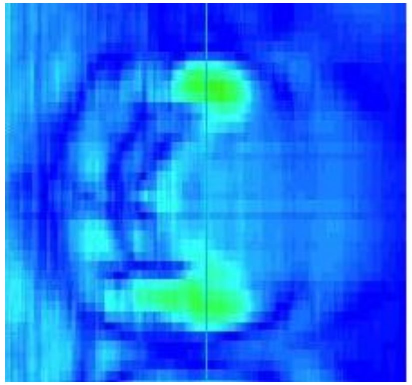
Implementation

- **Inspection of lateral-face bondings**





Right : Simulation of the detection of 3 voids of 2mm diameter in the bonding.

Left : Experimental detection of the detection of 2 voids.

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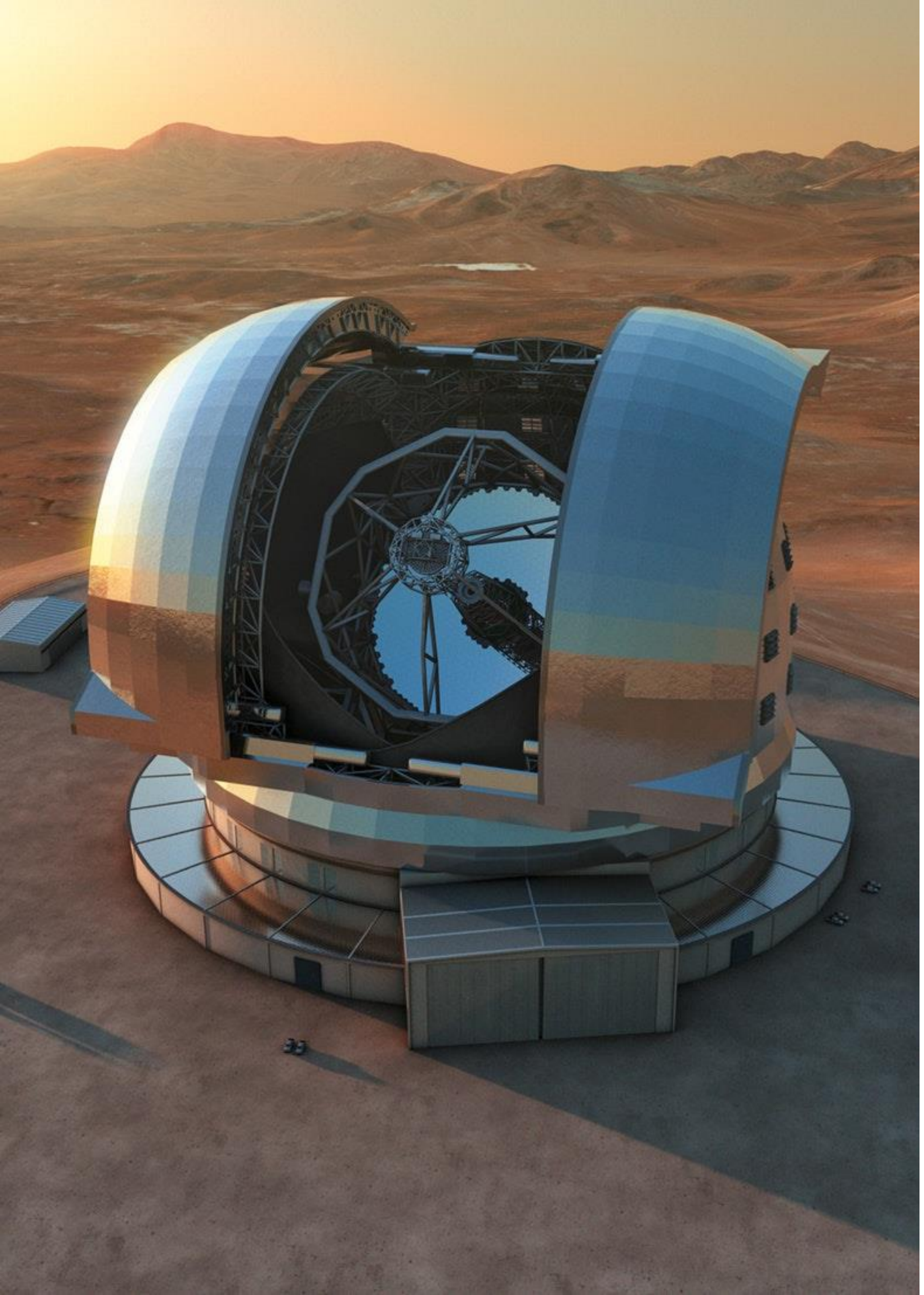


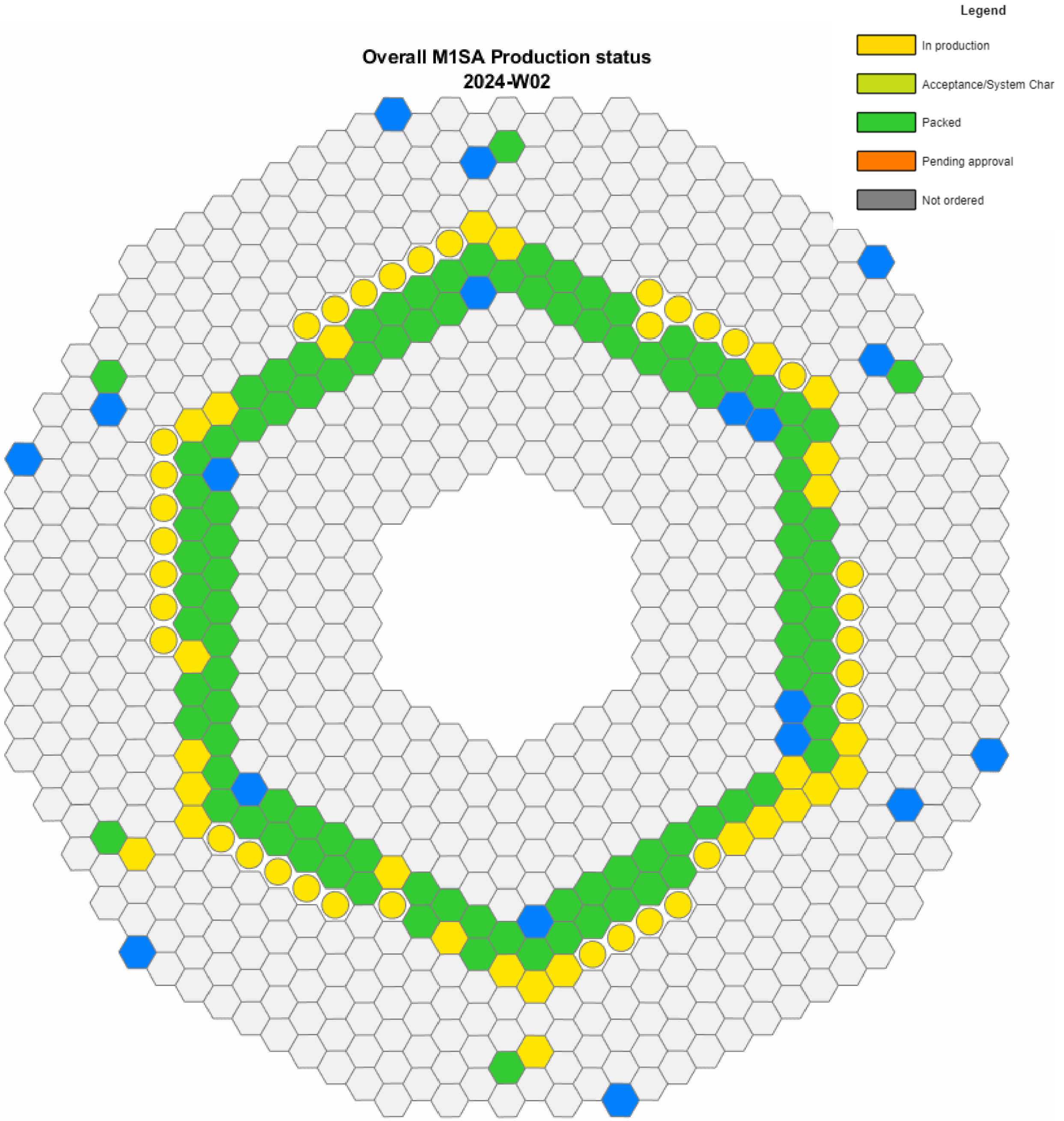
Chapter 5

Conclusions

Conclusions

- Civa software, with the expertise of Extende, allowed to validate and size NDT procedures for bonding inspection, using L0 and T55 waves
  - The use of simulation has enabled us to get it right first time, thereby reducing development costs and timescales.
  - Simulations are in good agreement with experiments

- Mirrors have been delivered on time



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