Une petite histoire autour de la simulation du CND par ondes guidées

une collaboration POEMS-CEA

OUTLINE

1. Overview of guided wave modeling
    - 1.1. Context/Motivation
    - 1.2. Waveguide and Modal formalism

2. Chronology 2006/2024
    - 2.1. CIVA evolution
    - 2.2. Elastic waveguide
    - 2.3. Half Space Matching (HSM)

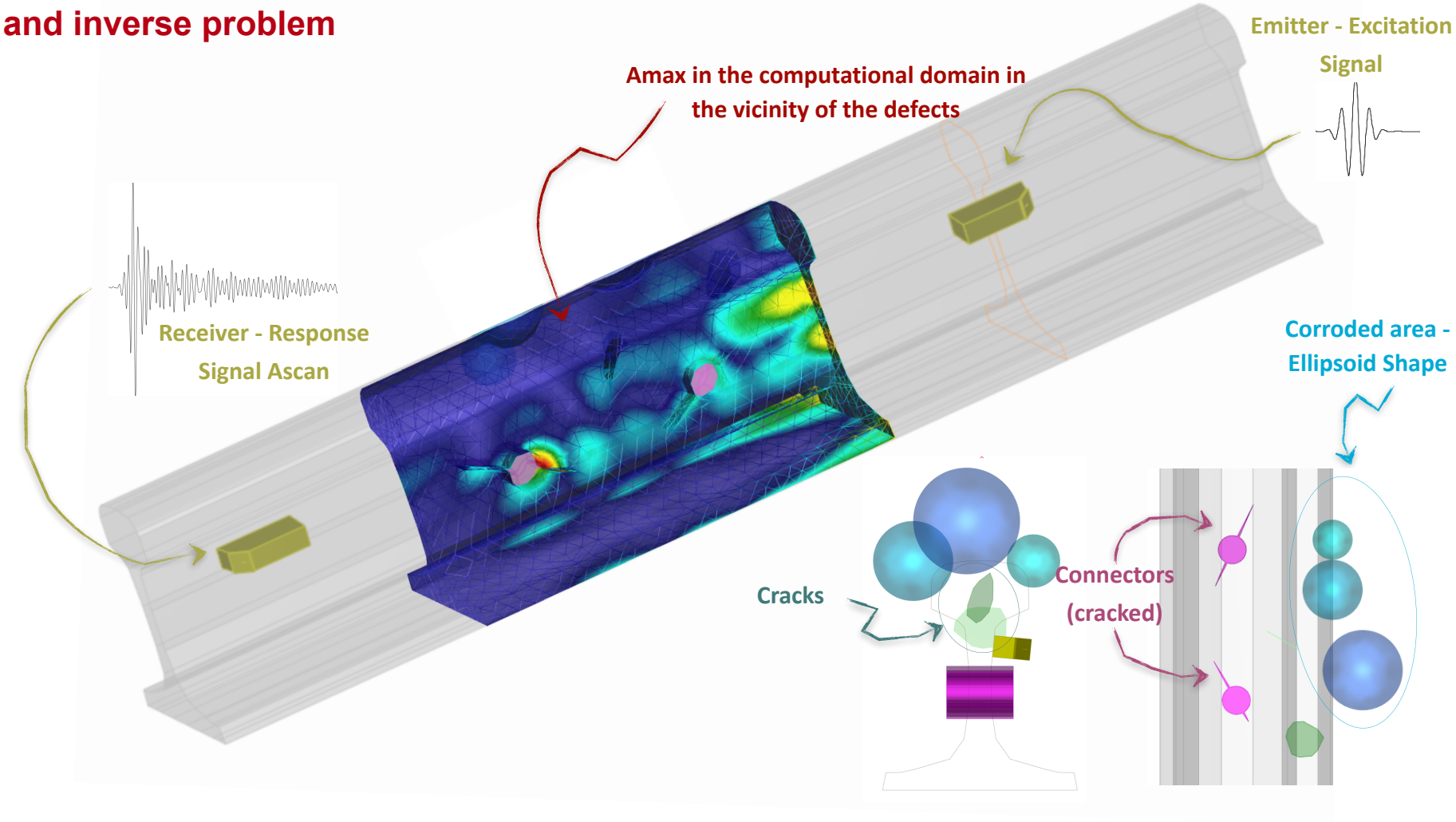
3. Demo

SIMULATION OF NON DESTRUCTIVE INSPECTION BY GUIDED WAVES

Context and motivations

Simulate guided waves propagation in a domain containing several localized defects (cracks, corrosion, cavities)

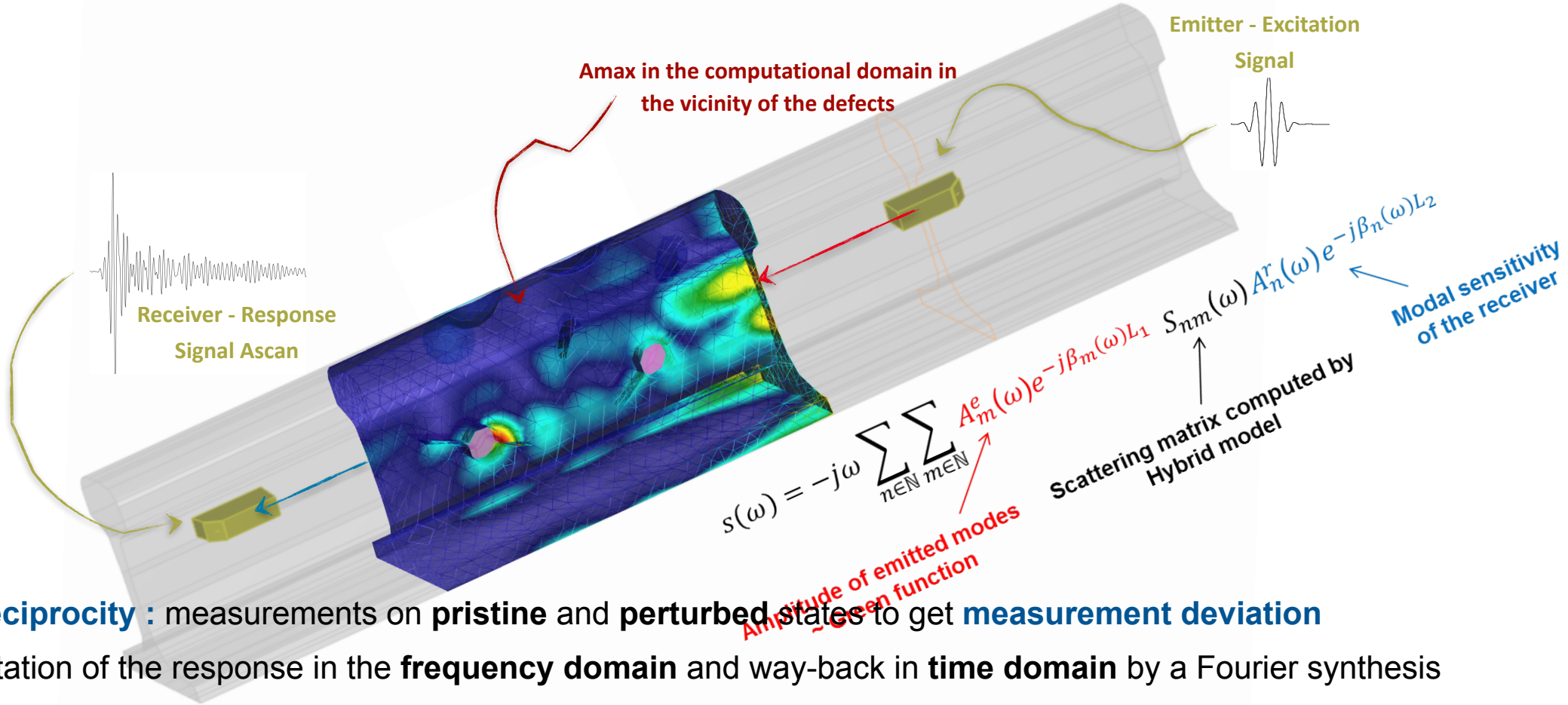
⇛ **direct and inverse problem**



WAVEGUIDE AND MODAL FORMALISM

Modal Formalism

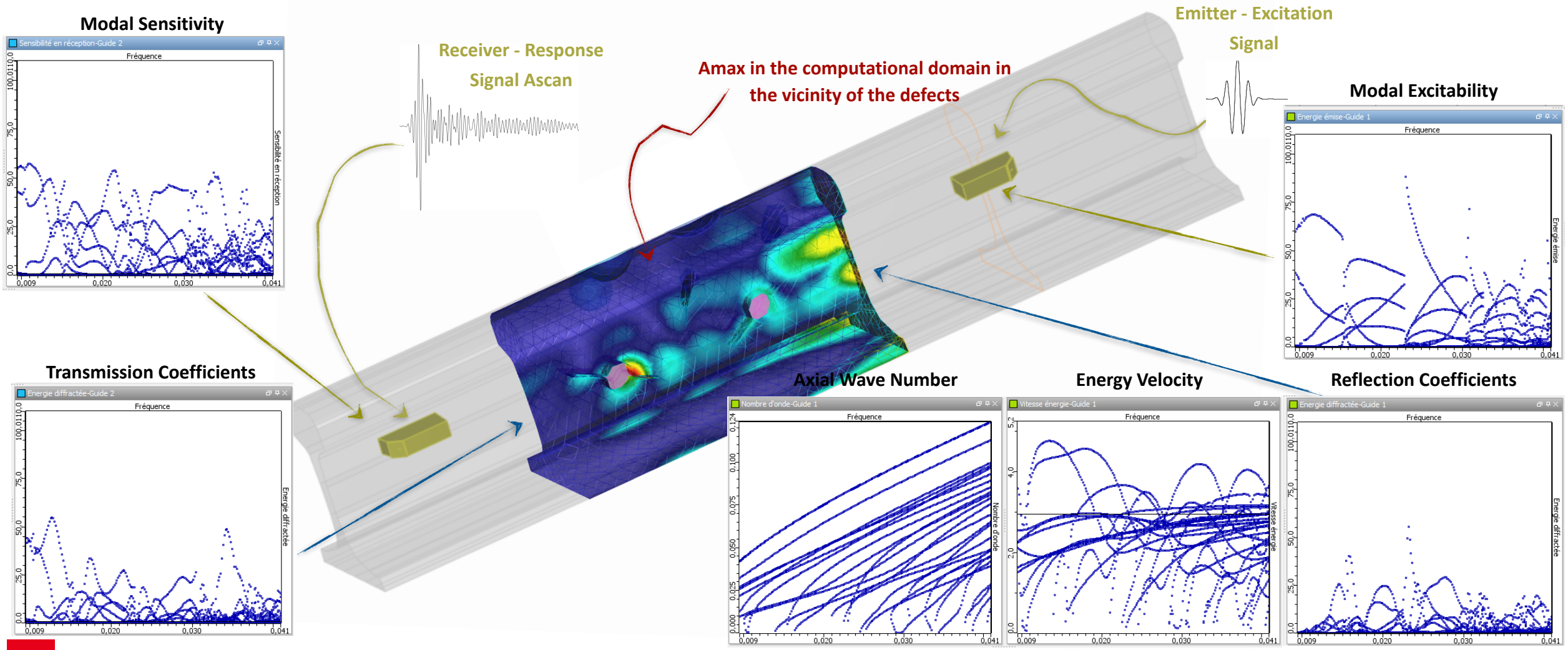
- The elastodynamic field is represented by a **superposition of modes** at a given frequency ω



- **Auld reciprocity :** measurements on **pristine** and **perturbed** states to get **measurement deviation**
- Computation of the response in the **frequency domain** and way-back in **time domain** by a Fourier synthesis

WAVEGUIDE AND MODAL FORMALISM

Dispersion curves for the representation of all modal quantities over a frequency range



3 MODULES TO UNDERSTAND AND SIMULATE THE PHYSIC OF GUIDED WAVES

Modes Computation

- Determination of the modes propagating in the structure in the frequency domain
- Modal characteristics (phase/energy velocity, wave number, attenuation…) represented in the form of dispersion curves

Field Computation

- Determination of the elastodynamic field radiated by a source in different sections of the structure
- Modal Excitability of the source (dispersion curves)

Inspection Simulation

- Determination of the time signal received by the receiver
- Modal conversions related to the perturbations/defects of the structure (energy dispersion curves)

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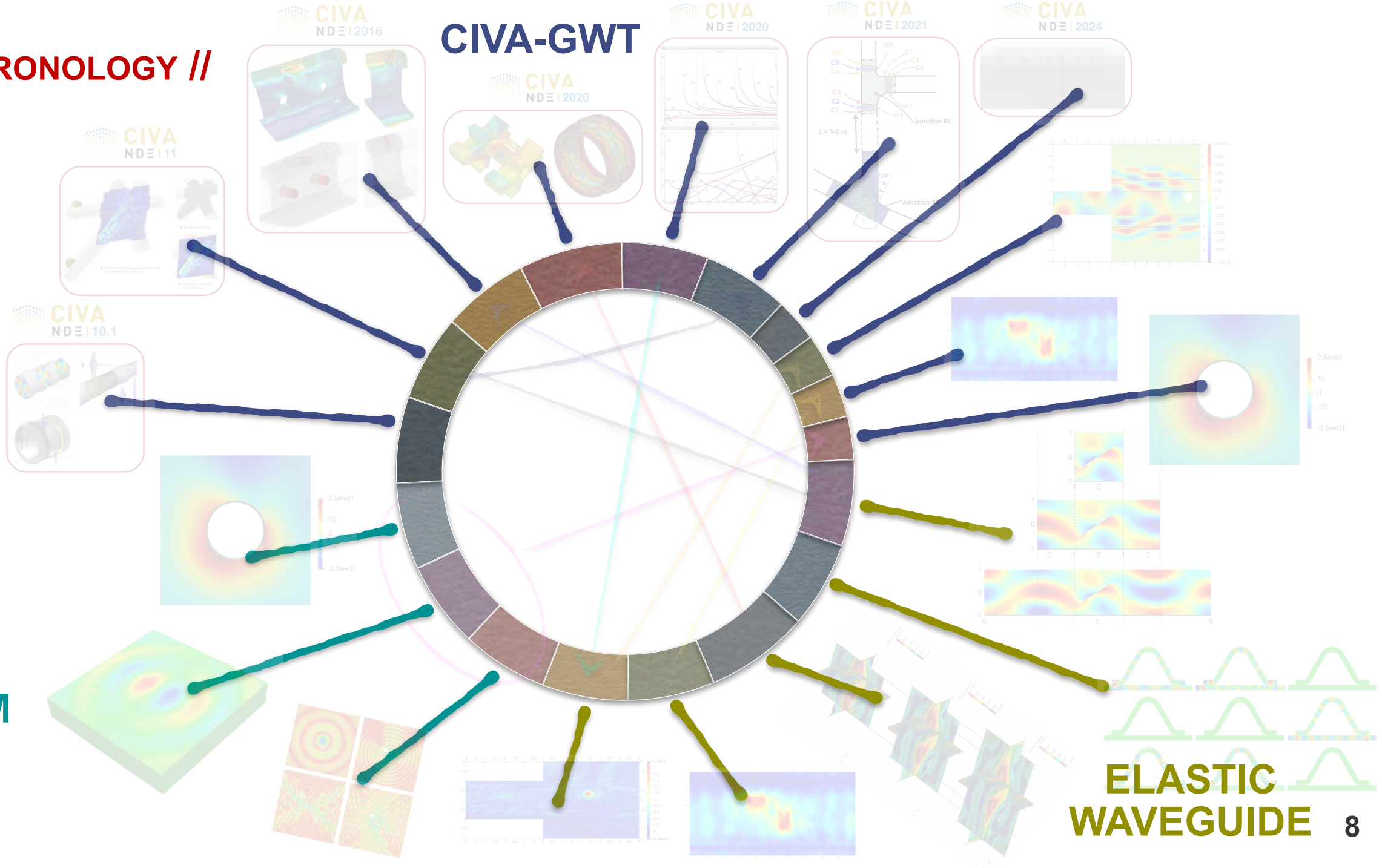
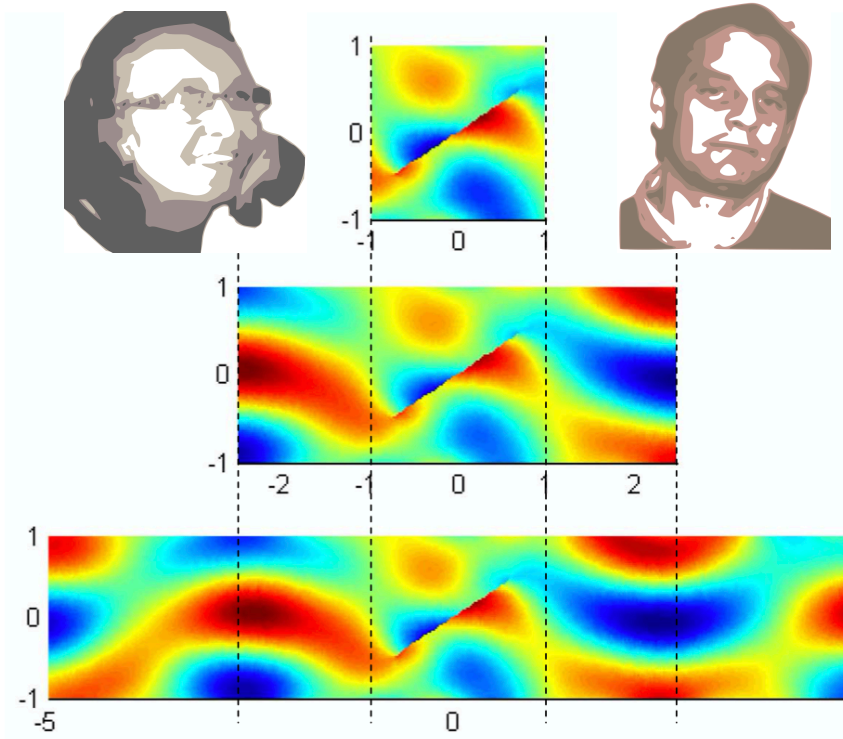
CHRONOLOGY //


CIVA-GWT
CIVA N·D·E | 2016
CIVA N·D·E | 2020
CIVA N·D·E | 2020
CIVA N·D·E | 2021
CIVA N·D·E | 2024
CIVA N·D·E | 11
CIVA N·D·E | 10.1
HSM
ELASTIC WAVEGUIDE

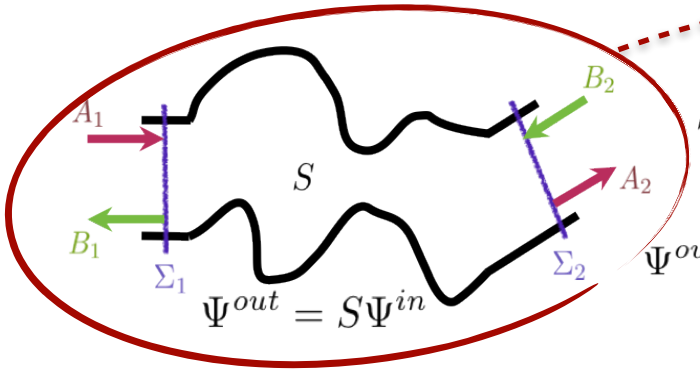
SCATTERING IN ELASTIC WAVEGUIDE : PART 1



Transparent Boundary Conditions (TBC) in elastic waveguide

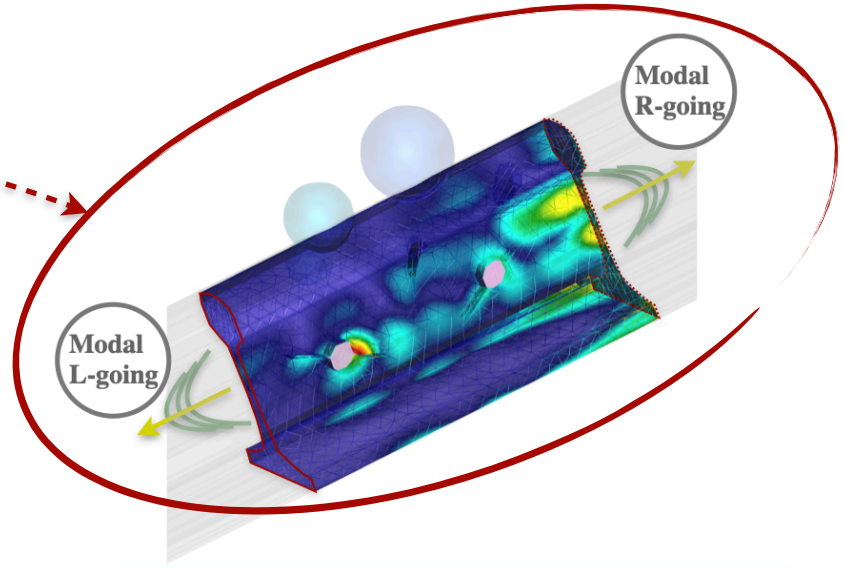
V. Baronian, A-S. Bonnet-Ben Dhia and E. Lunéville, **TBC for the harmonic diffraction problem in an elastic waveguide** (2010)

- **Coupling FE/Modal representations**, **XY formalism ⇛ YtoX operator** (generalization of DtN map), arbitrary localized perturbation
- **Code : MELINA**
- **Exact Condition** (No spurious reflection) - **Non local** TBC (lost of sparsity)
- **Orthotropic** medium (orthogonality « Fraser »)
- Gives the **scattering matrix** : Modes conversions and sensitivity toward the defect are known



$$S = \begin{pmatrix} R_{11} & T_{12} \\ T_{21} & R_{22} \end{pmatrix}$$

$$\Psi^{out} = \begin{pmatrix} B_1 \\ A_2 \end{pmatrix} \quad \Psi^{in} = \begin{pmatrix} A_1 \\ B_2 \end{pmatrix}$$



A. Maurel, V. Pagneux, **Lamb wave propagation in inhomogeneous elastic waveguide** (2002)

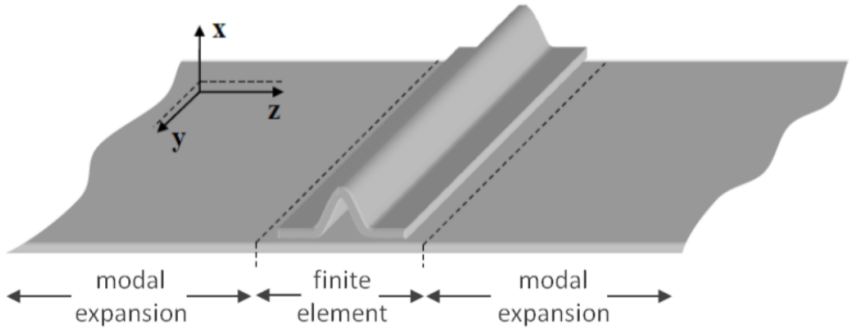
V. Pagneux, A. Maurel, **Scattering matrix properties with evanescent modes for waveguides in fluids and solids** (2004)

SCATTERING IN ELASTIC WAVEGUIDE : PART 2

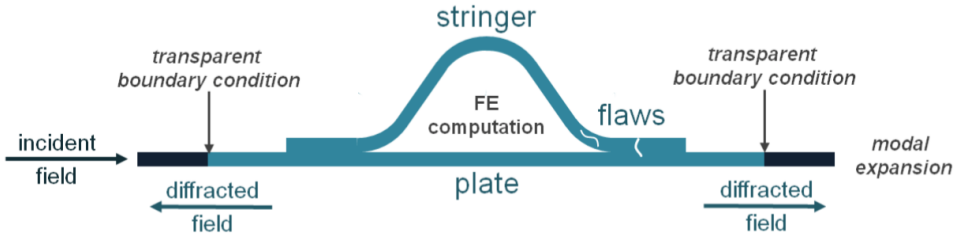
TBC for 2D elastic waveguide with obliquely incident wave (L. Taupin - 2008/2011)

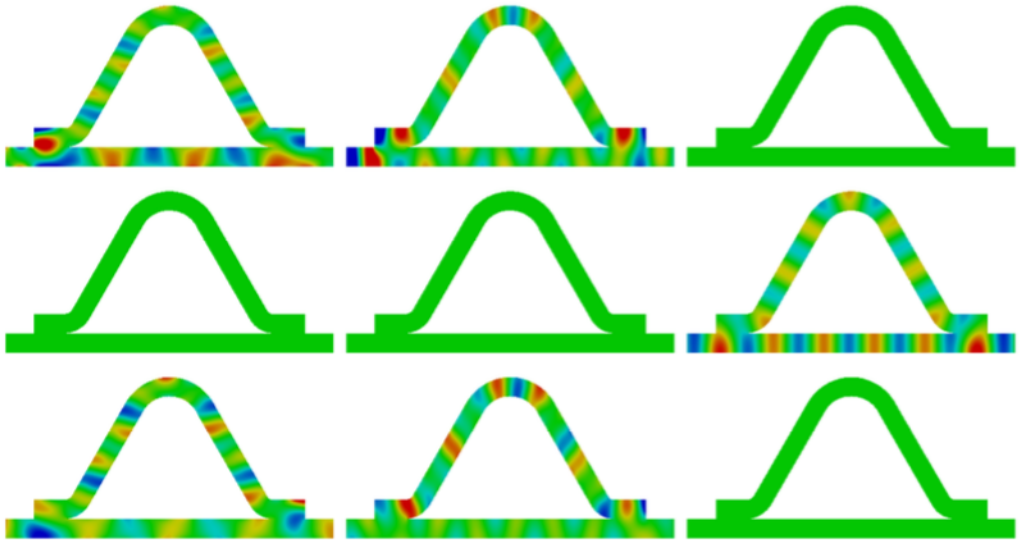
L. Taupin, A. Lhémery, V. Baronian, A-S. Bonnet-Ben Dhia, **Scattering of obliquely incident guided waves by a stiffener bonded to a plate** (2011)

- **Coupling FE/Modal representations**, **XY formalism ⇛ YtoX operator**
- **Code : MELINA ⇛ XLIFE++**
- **Linear flaw** (translational invariance)
- **Anisotropic** medium (lost of orthogonality « Fraser »)

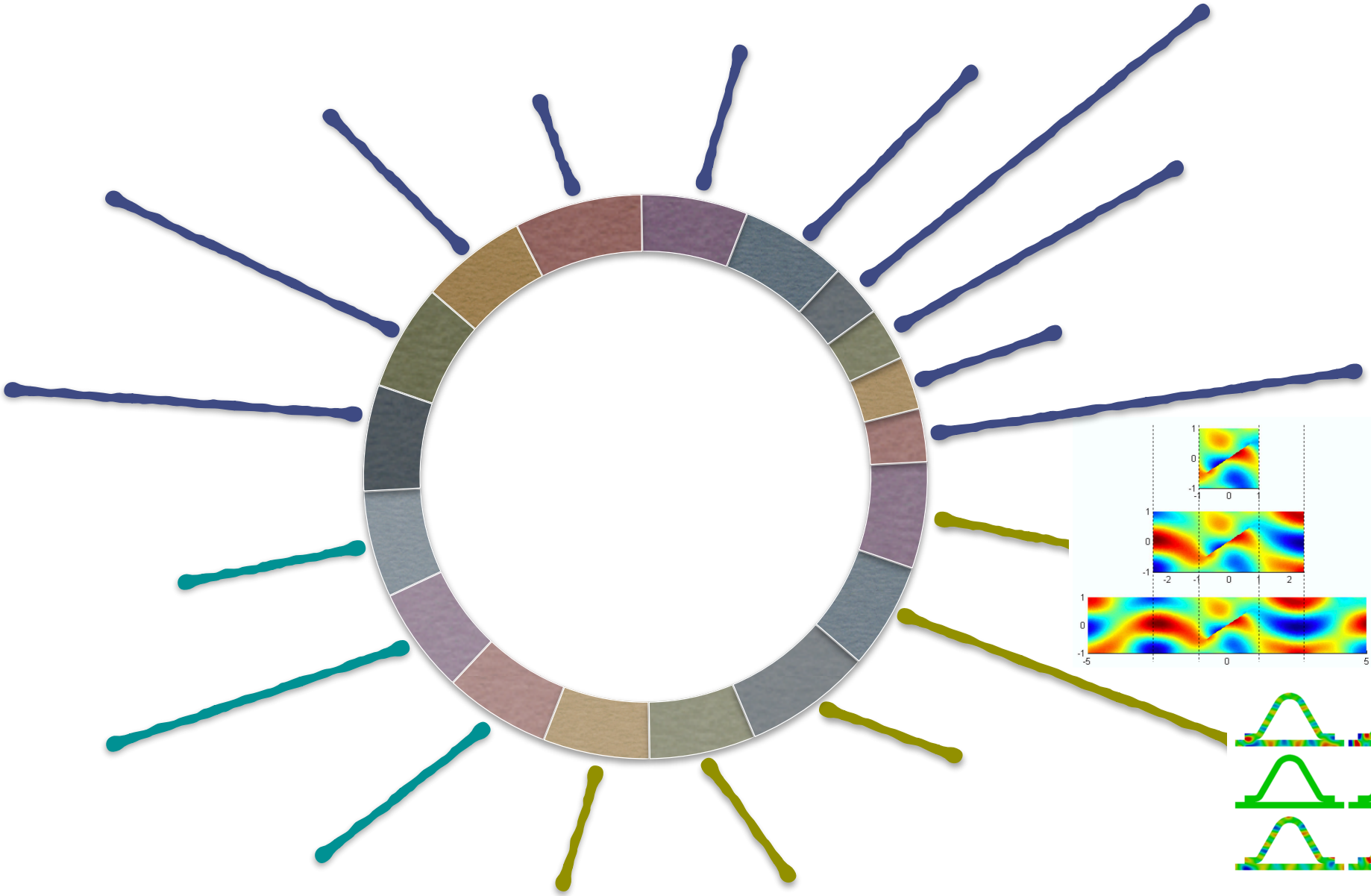


XLiFE++





CHRONOLOGY //



CHRONOLOGY OF CIVA : THE BEGINNING (2012)

CIVA N·D·E | 10.1

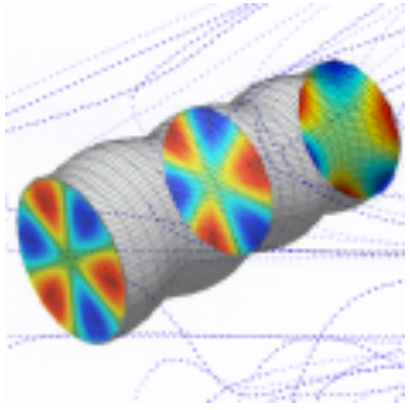
Development of 3 modules (Modes/Beam/Inspection) to simulate propagation in elastic waveguide

K. Jezzine, **Approche modale pour la simulation globale de contrôles non destructifs par ondes guidées** (2006)

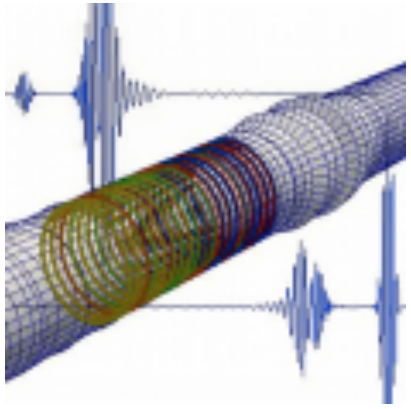
- **Geometry : 2D cartesian and axisymmetric**
- **Flaws : vertical crack only**
- **Numerical methods : SAFE** (modes/beam computation), **Modes Matching** (modes interaction) and **Modal synthesis** (time domain)
- **Isotropic material**
- **Contribution : K. Jezzine (2006)**

$$s(w) = -j\omega \sum_{n\in\mathbb{N}} \sum_{m\in\mathbb{N}} A_m^e(\omega)\, e^{-j\beta_m(\omega)L_1}\, S_{nm}(\omega)\, A_n^r(\omega)\, e^{-j\beta_n(\omega)L_2}$$

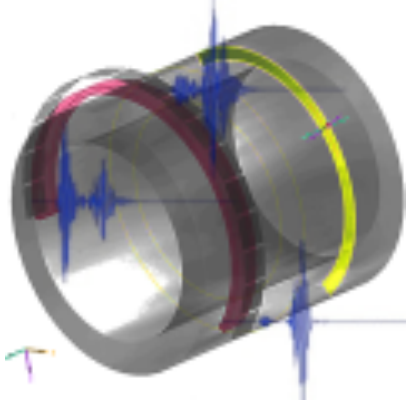
MODES COMPUTATION



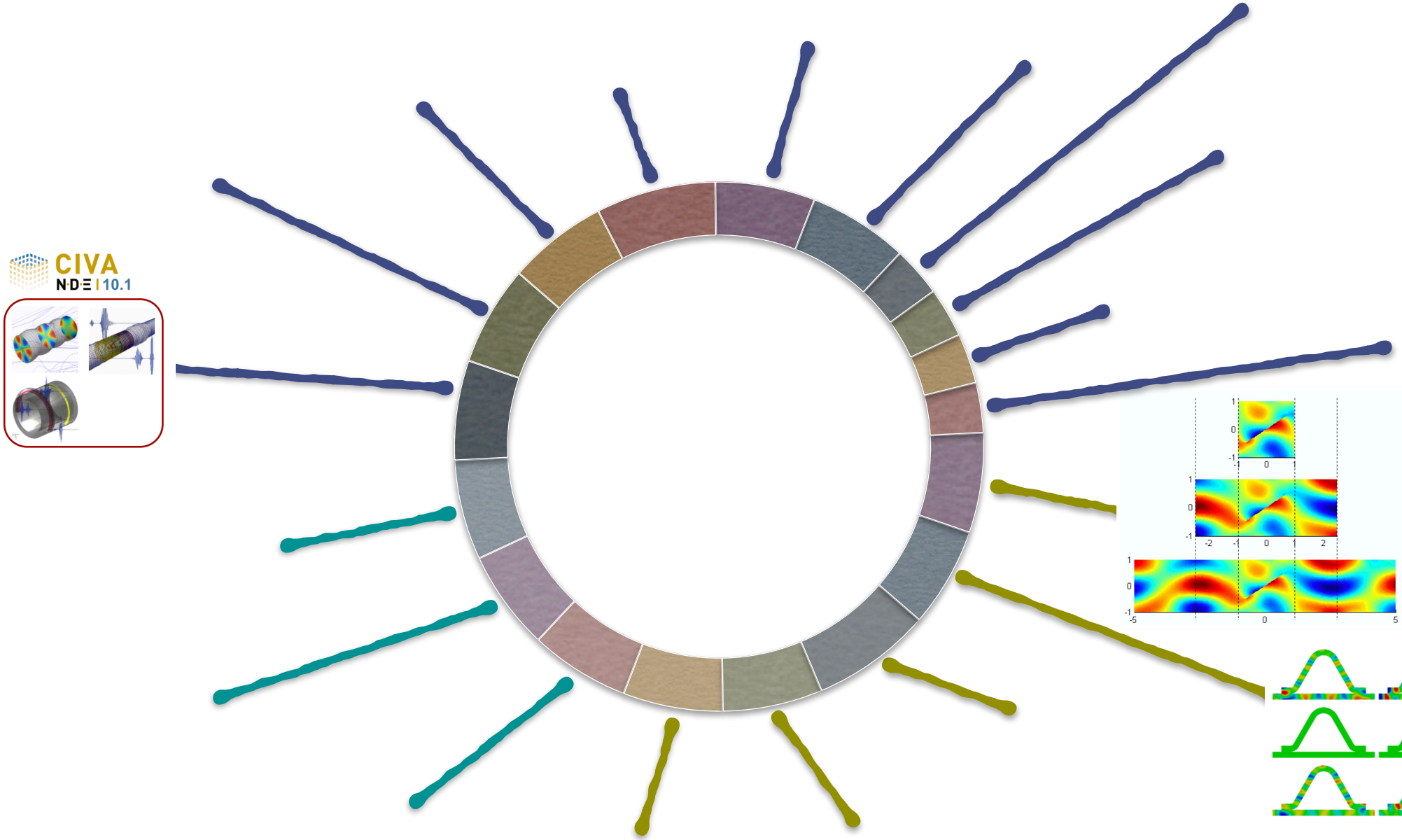
BEAM COMPUTATION



INSPECTION SIMULATION



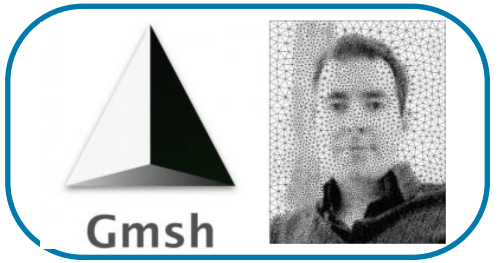
CHRONOLOGY //



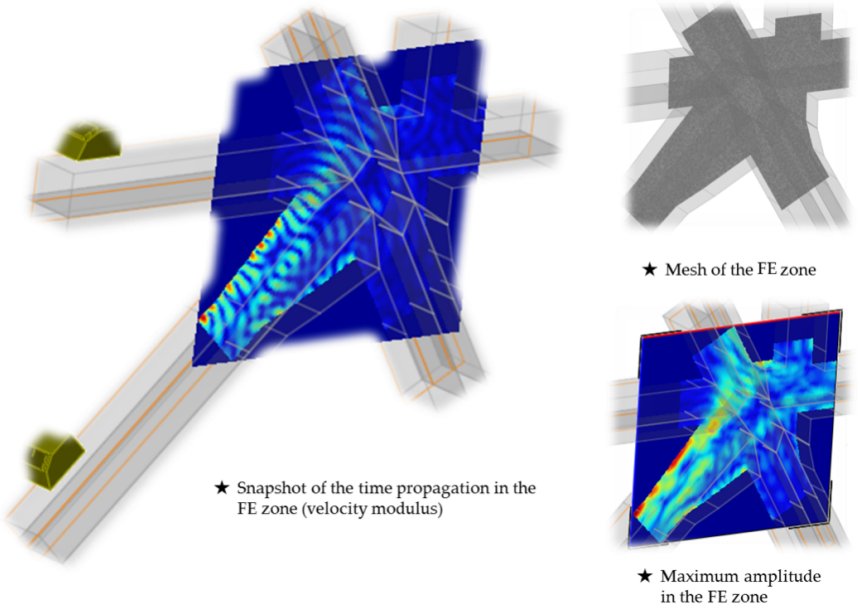
CHRONOLOGY OF CIVA : YTOX PART 1 (2014 : +5 YEARS…)

1st implementation of YtoX method / automatic 2D meshing

C. Geuzaine, J-F. Remacle, **Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post- processing facilities** (2009)



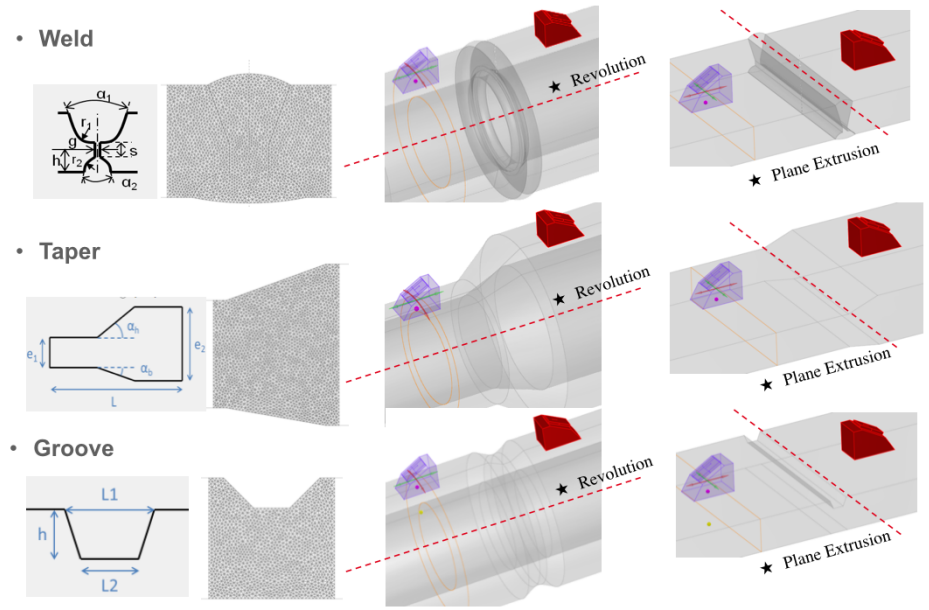
- **Geometry : 2D cartesian and axisymmetric specimens for modes interaction**
- **Flaws : arbitrary perturbations**
- **Numerical methods : 2D Hybrid FE/Modal coupling** (modes interaction)
- **Isotropic material**
- **Contribution : K. Jezzine (2006) - V. Baronian (2009) - GMSH (2D mesh)**



★ Snapshot of the time propagation in the FE zone (velocity modulus)

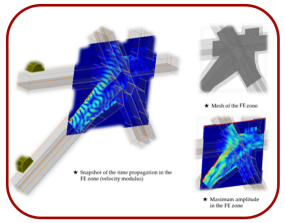
★ Mesh of the FE zone

★ Maximum amplitude in the FE zone

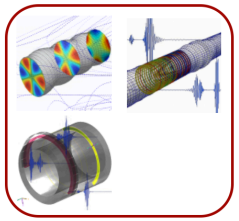


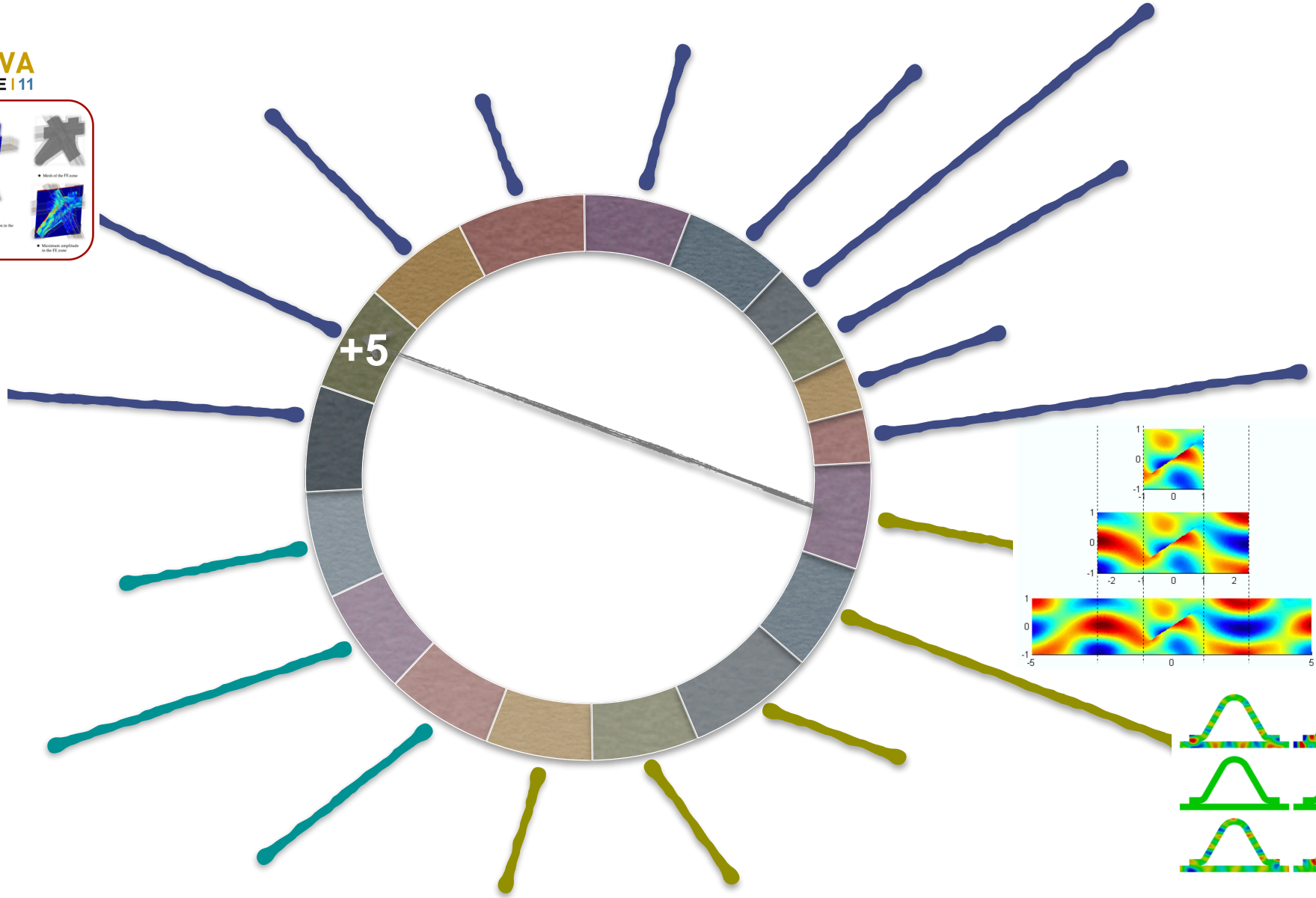
CHRONOLOGY //

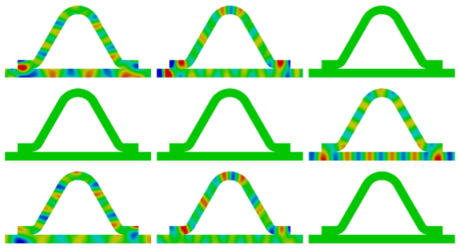
CIVA NDE | 11



CIVA NDE | 10.1







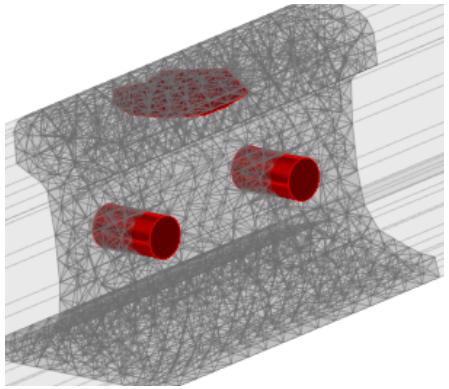
CHRONOLOGY OF CIVA : Y2X PART 2 (2016 : +2 YEARS…)

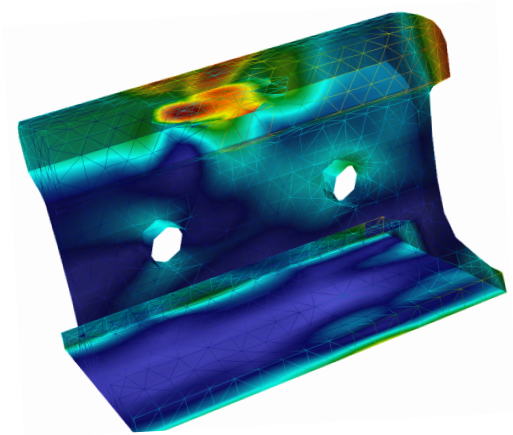
CIVA N·D·E | 2016

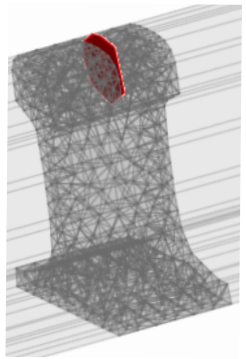
2nd implementation of YtoX method / automatic 3D meshing

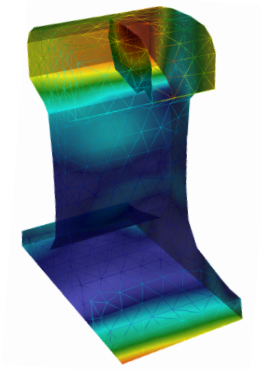
C. Geuzaine, J-F. Remacle, **Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post- processing facilities** (2009)

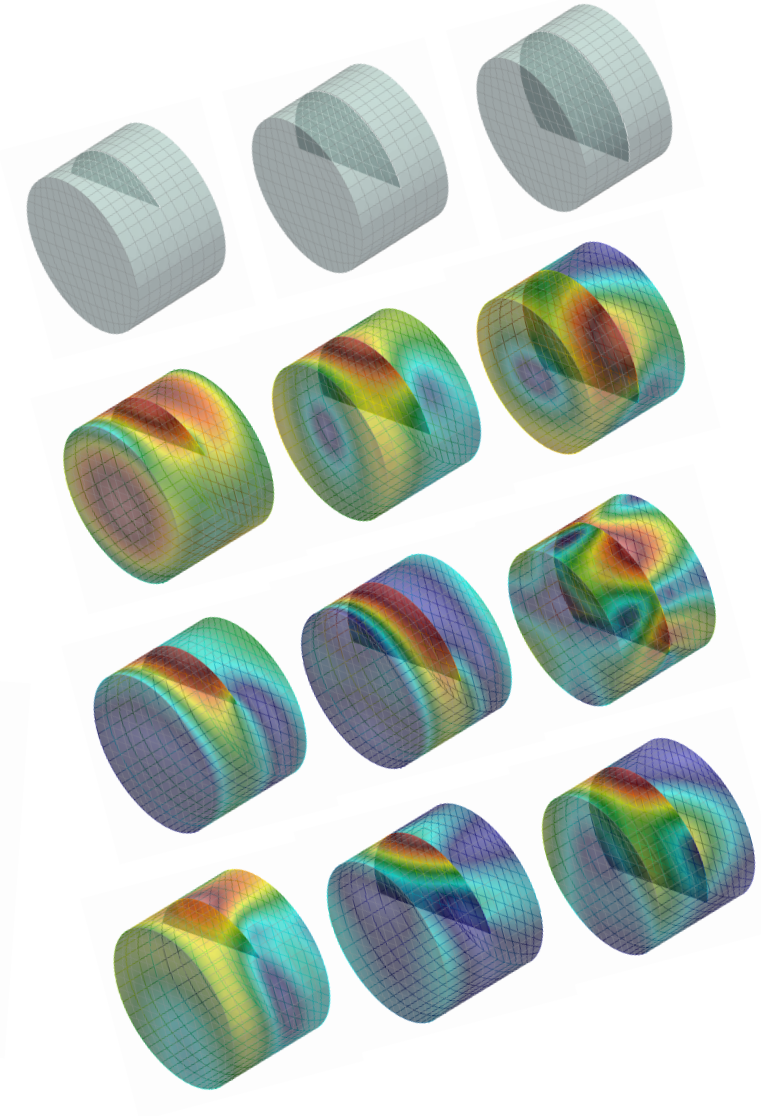
- **Geometry : 3D cylinder of arbitrary cross section for modes interaction**
- **Flaws : arbitrary perturbations** (complex surface crack, cavities)
- **Numerical methods : 3D Hybrid FE/Modal coupling** (modes interaction)
- **Isotropic material**
- **Contribution : K. Jezzine (2006) - V. Baronian (2009) - GMSH (3D mesh)**



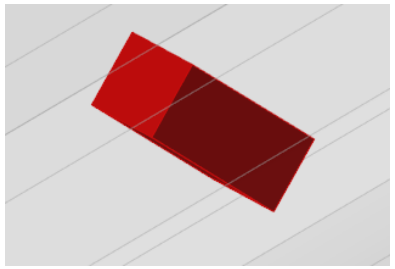




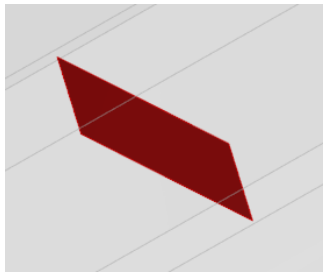




FEATURED FLAWS

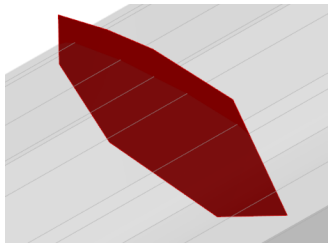


Rectangular block



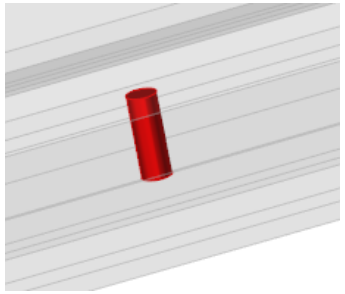
Rectangular crack

Semi elliptical crack



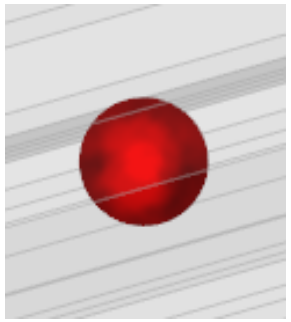
CAD-contoured crack

Multi-faceted defect

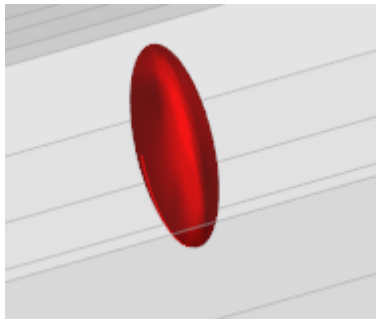


Flat bottom hole

Hemispherical bottom hole



Spherical

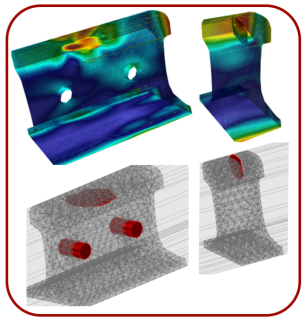


Ellipsoidal

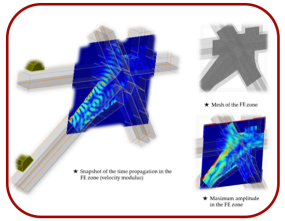
Branched defect

CHRONOLOGY //

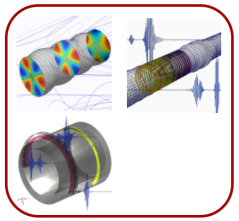
CIVA N·D·E | 2016

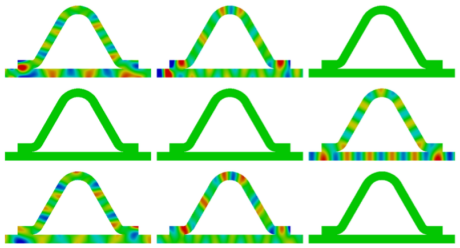


CIVA N·D·E | 11



CIVA N·D·E | 10.1



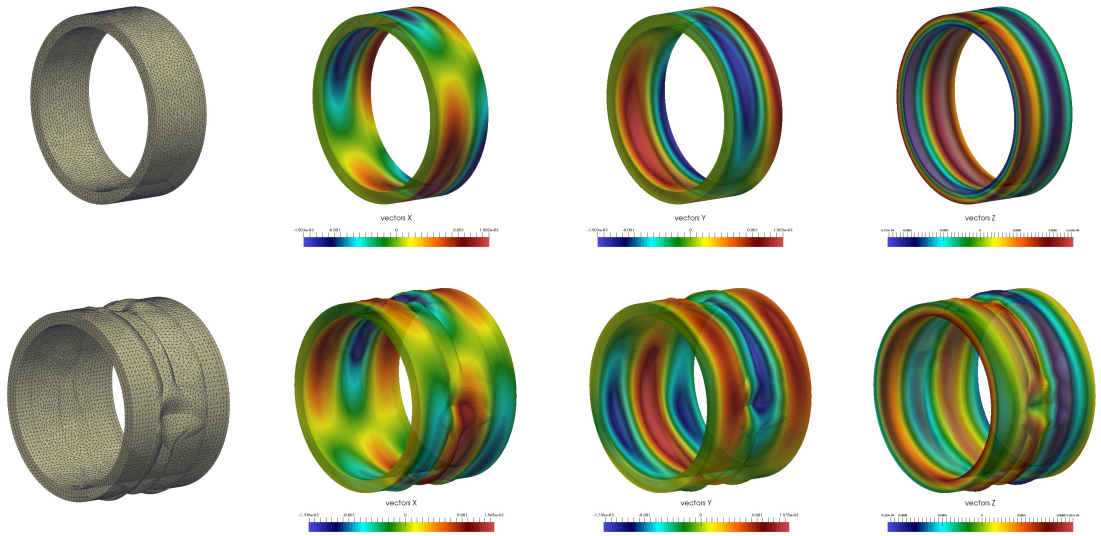


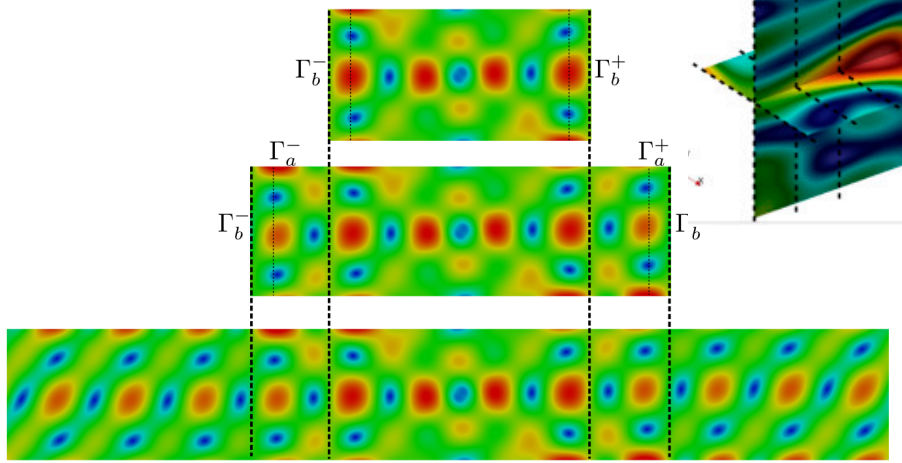
SCATTERING IN ELASTIC WAVEGUIDE : PART 3

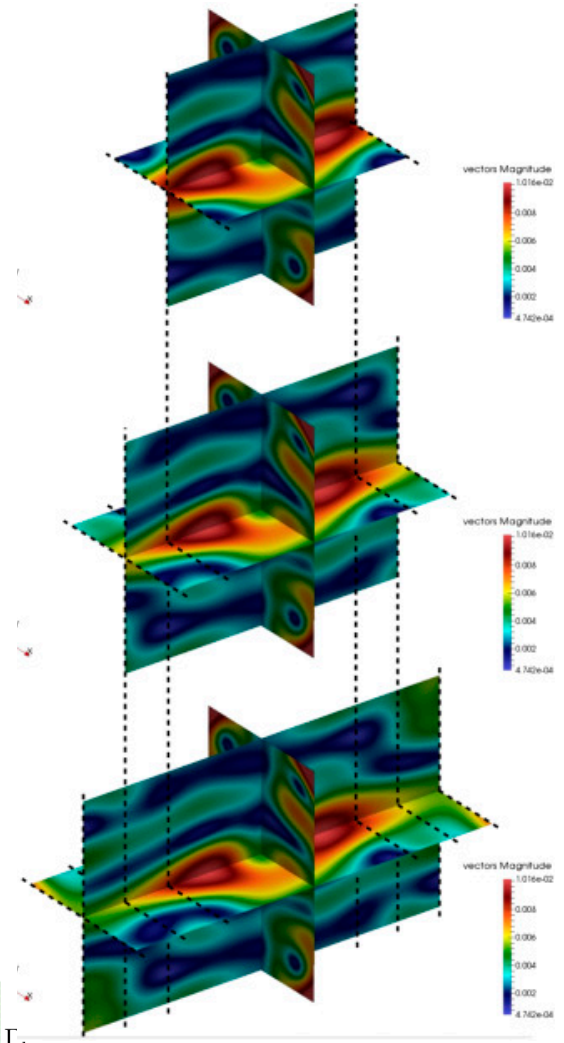
New TBC in elastic waveguide (A. Tonnoir - 2011/2015)

V. Baronian, A-S. Bonnet-Ben Dhia, S. Fliss and A. Tonnoir, **Iterative methods for scattering problems in unbounded anisotropic waveguides** (2016)

- **Coupling FE/Modal representations**, **XY formalism**, **Overlap ⇛ YtoR operator & OtoR operator** (modal « Outgoing » transmission condition)
- **Iterative solver GMRES**, reduction of memory cost
- **Code : Antoine, Prototype CEA**
- **Anisotropic** medium

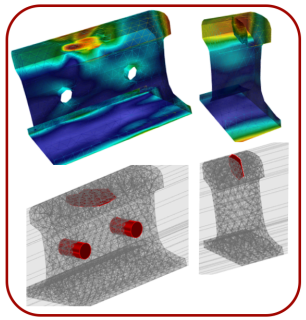




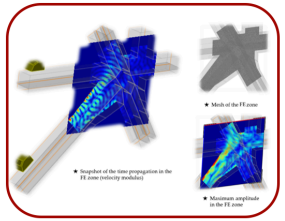


CHRONOLOGY //

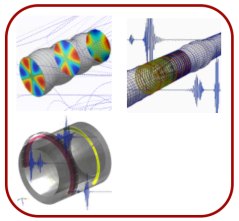
CIVA N·D·E | 2016

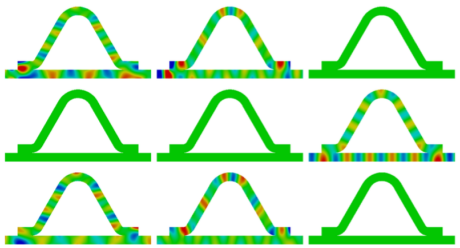


CIVA N·D·E | 11



CIVA N·D·E | 10.1



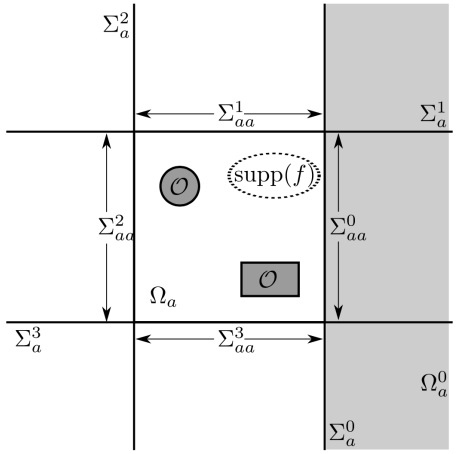


HALF SPACE MATCHING (HSM) METHOD : PART 1

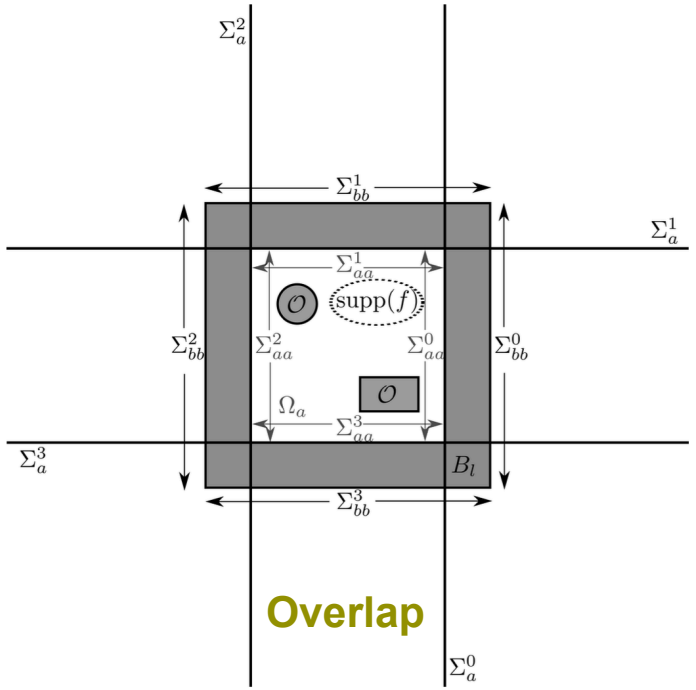
Transparent boundary conditions for 2D acoustic/elastic media (A. Tonnoir - 2011/2015)

A-S. Bonnet-Ben Dhia, S. Fliss and A. Tonnoir, **The Halfspace Matching Method : a new method to solve scattering problem in infinite media** (2018)

- **Geometry : 2D acoustic/elastic (no modes)**
- **Multi-domain formulation**, **Compatibility relations**, **integral operators**
- **Iterative solver GMRES**, reduction of memory cost
- **Code : Antoine**
- **Anisotropic** medium



No Overlap



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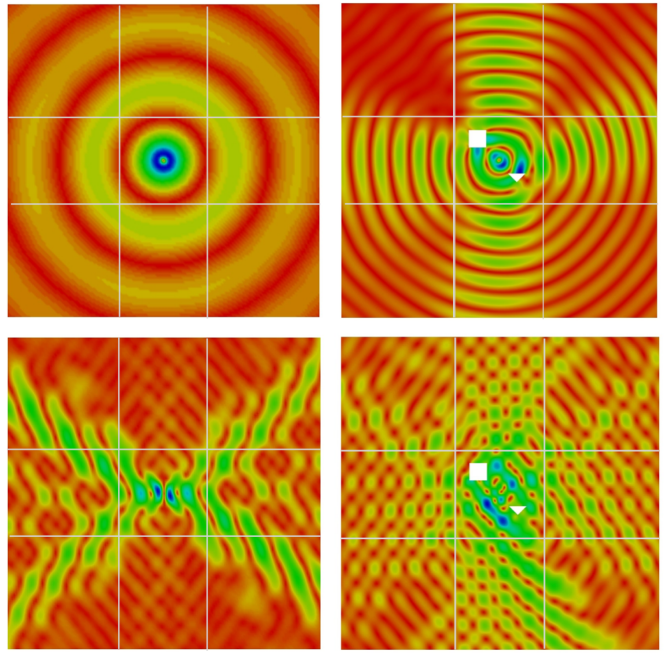
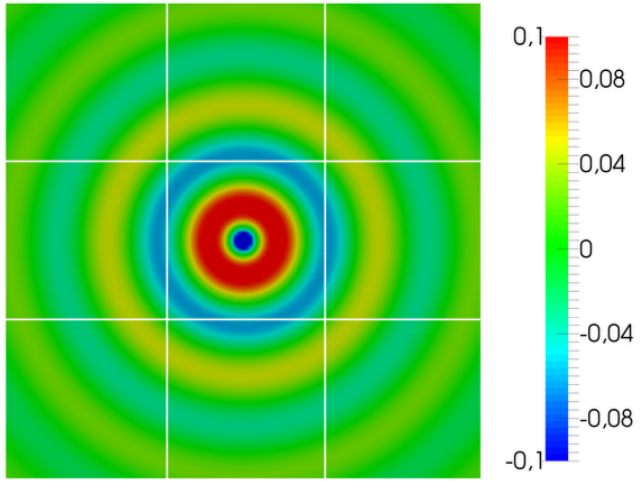
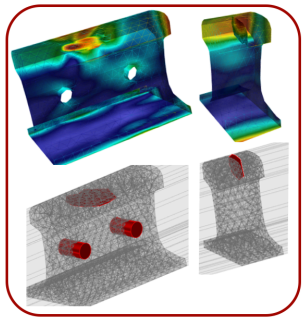


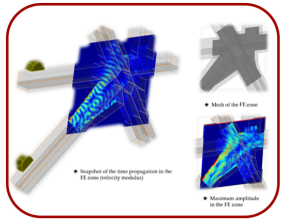


CHRONOLOGY //

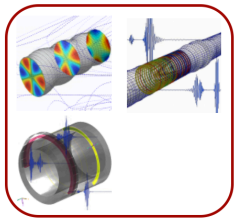
CIVA N·D·E | 2016

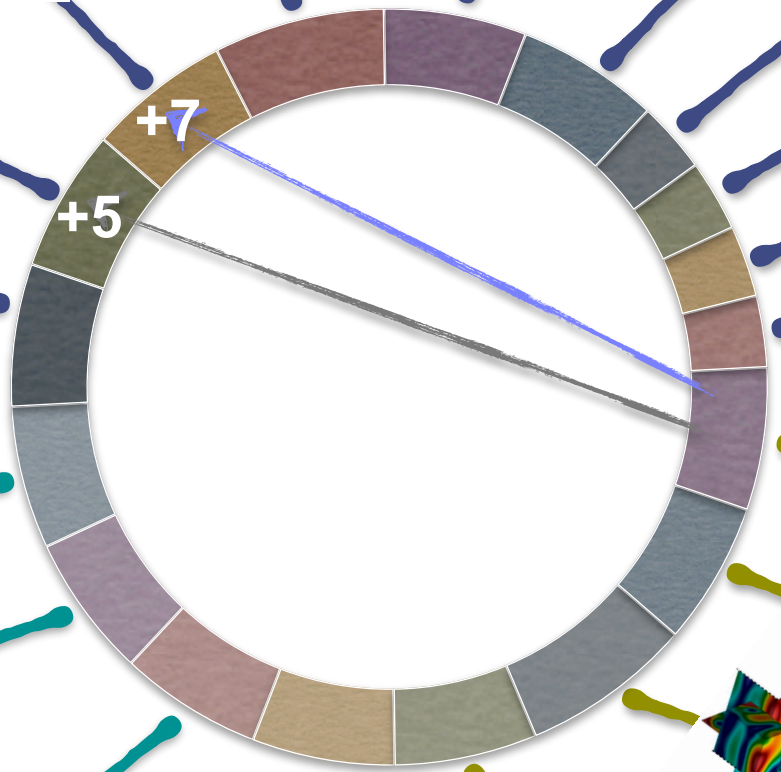


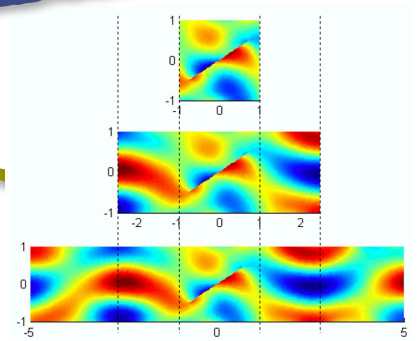
CIVA N·D·E | 11

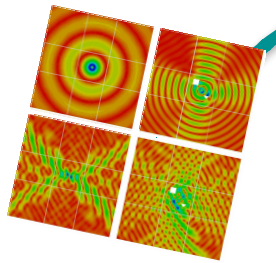


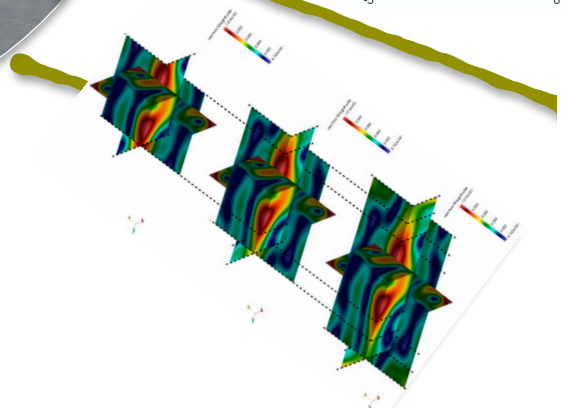
CIVA N·D·E | 10.1

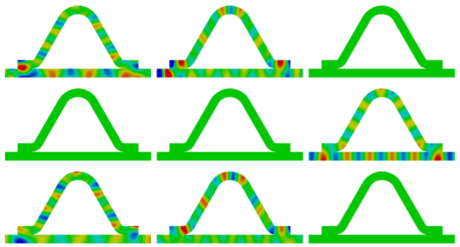










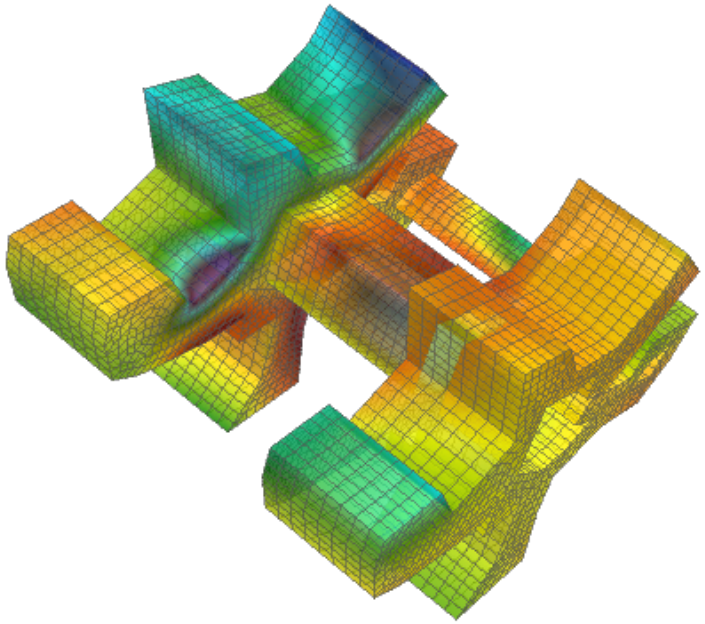


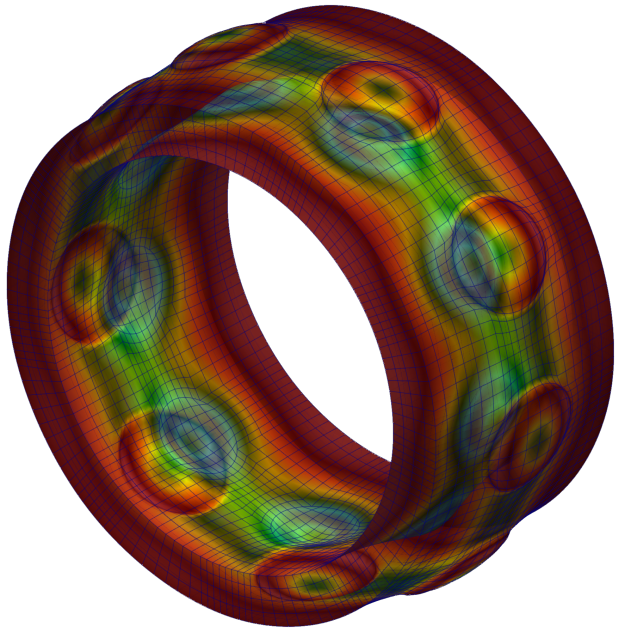
CHRONOLOGY OF CIVA : OTOR & ITERATIVE SOLVER (2020)

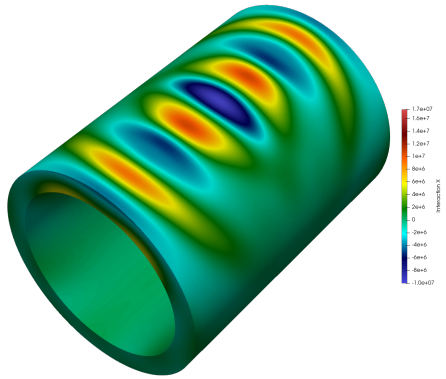
CIVA N·D·E | 2020

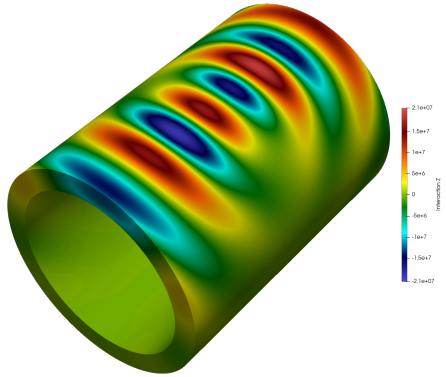
Implementation of OtoR operator

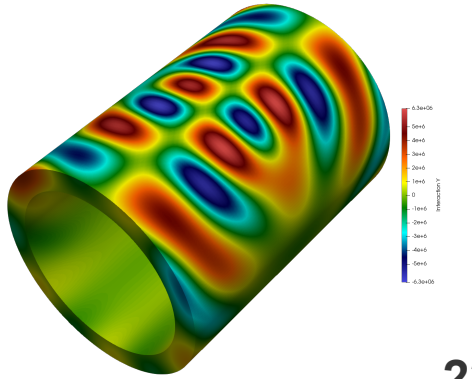
- **Geometry : 3D elastic waveguide**
- **Flaws/Sources : arbitrary perturbations, complex sources (EMAT, multi-arrays)**
- **Overlap ⇛ YtoR operator & OtoR operator** (modal « Outgoing » transmission condition)
- **Iterative solver GMRES**, reduction of memory cost
- **Anisotropic material**





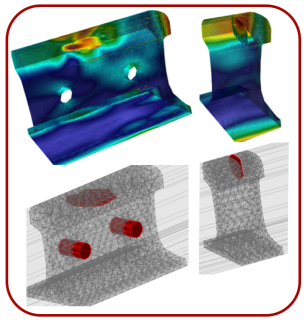




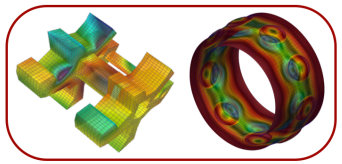


CHRONOLOGY //

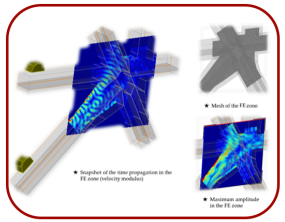
CIVA N·D·E | 2016



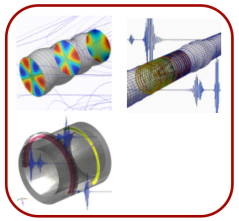
CIVA N·D·E | 2020

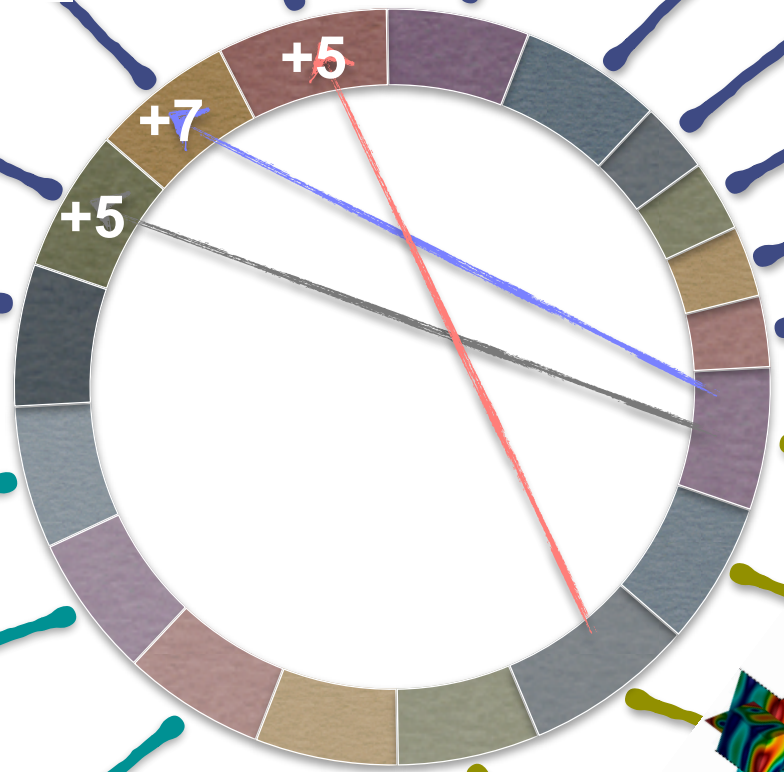


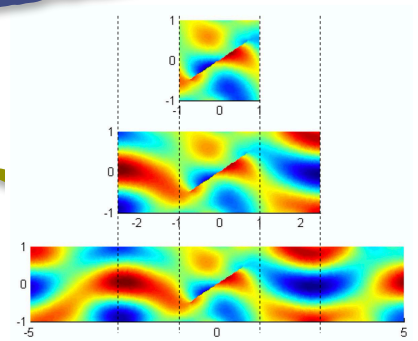
CIVA N·D·E | 11

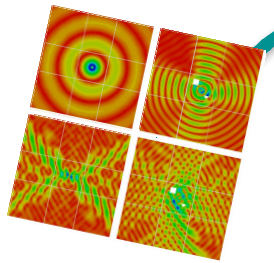


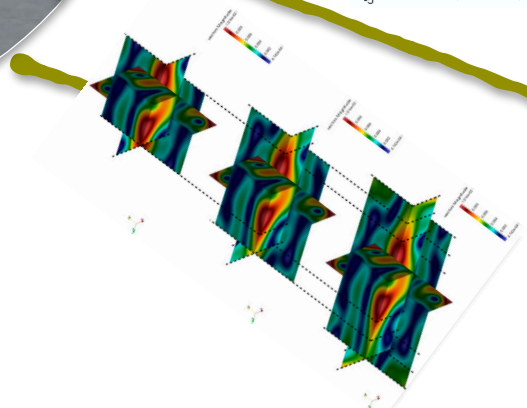
CIVA N·D·E | 10.1

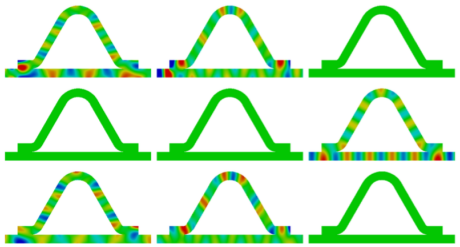










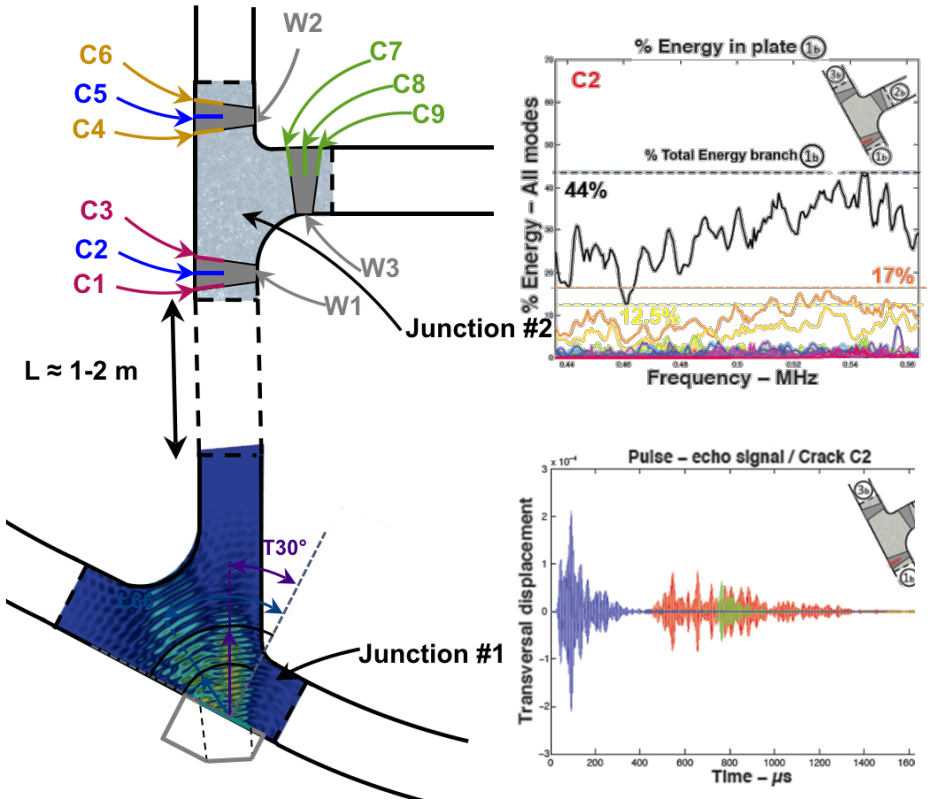


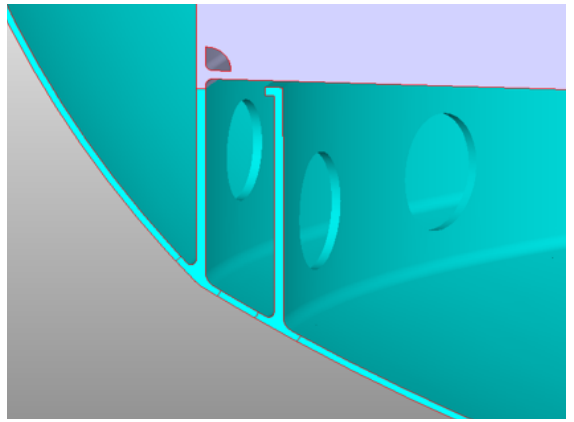
CHRONOLOGY OF CIVA : MULTI-BOX

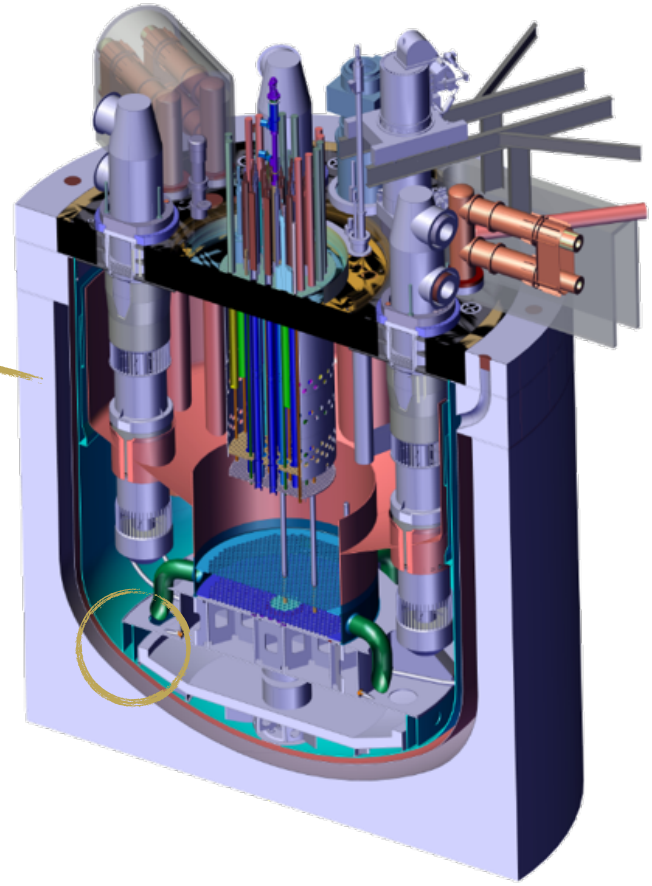
CIVA N·D·E | 2021

Implementation of the multi-box architecture to combine several FE/Modal box computation

- **Geometry : 3D elastic waveguide**
- **Flaws/Sources : arbitrary perturbations,**

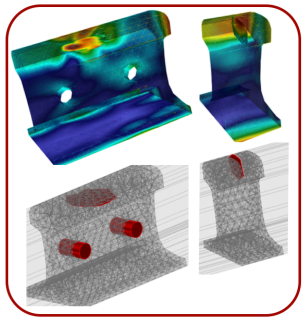




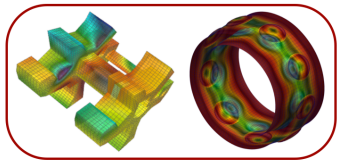


CHRONOLOGY //

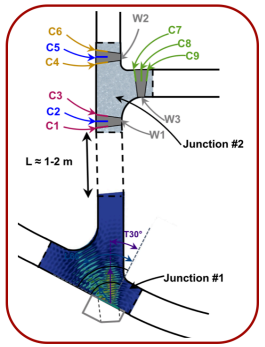
CIVA N·D·E | 2016



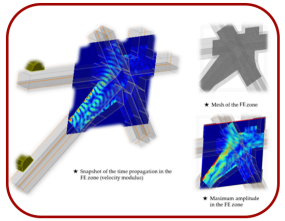
CIVA N·D·E | 2020



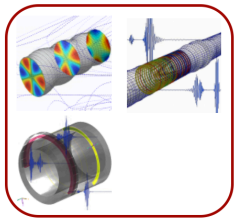
CIVA N·D·E | 2021

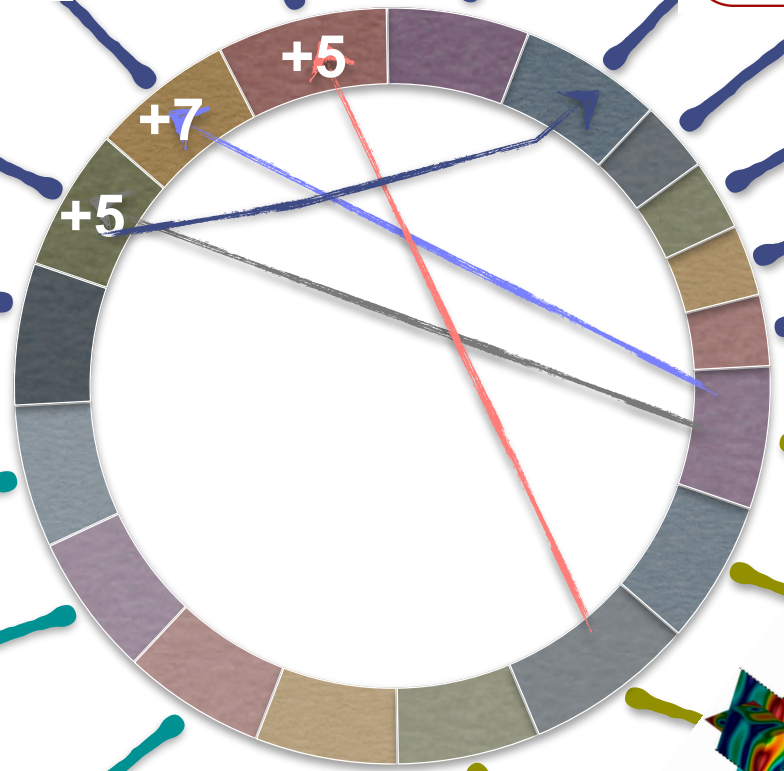


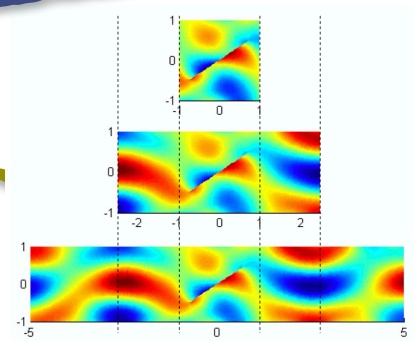
CIVA N·D·E | 11

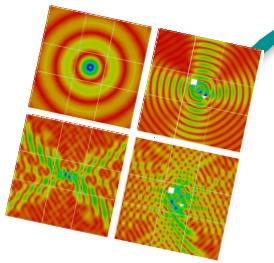


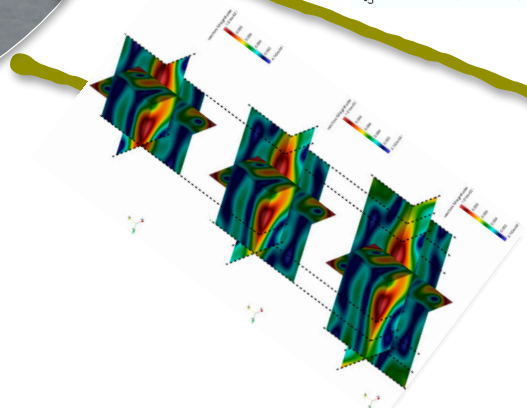
CIVA N·D·E | 10.1

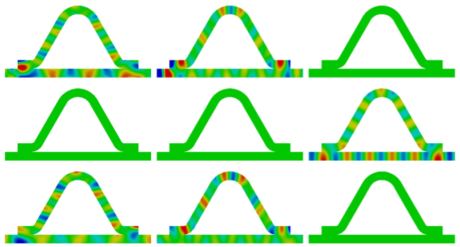










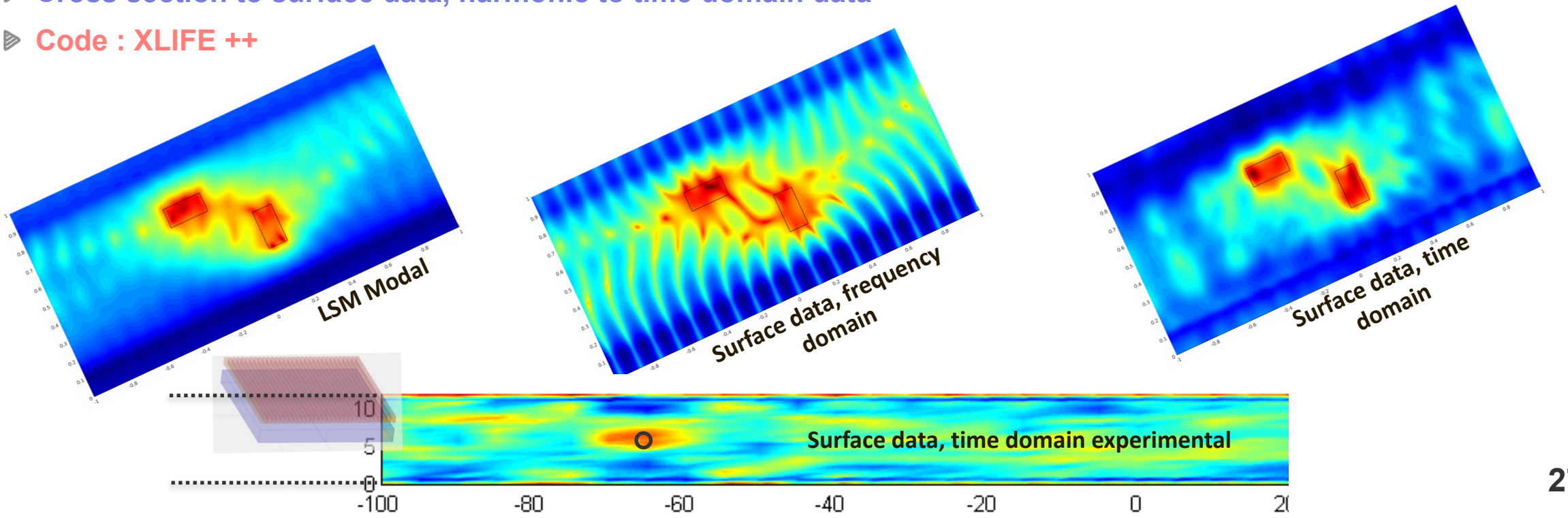


DEFECT IMAGING IN ELASTIC WAVEGUIDE : PART 1

Linear Sampling method for imaging defect in elastic waveguide (A. Recoquillay - 2015/2018)

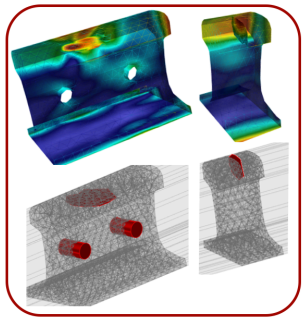
L. Bourgeois, B. Chapuis, A. Recoquillay, V. Baronian, **Linear Sampling Method applied to Non Destructive Testing of an elastic waveguide : theory, numerics and experiments** (2018)

- **Geometry : 2D/3D elastic waveguide**
- **Flaws : cracks and surface/core defect type**
- **YX formalism ⇛ YtoX operator** to get the scattering matrix coefficients (direct problem)
- **Cross section to surface data, harmonic to time domain data**
- **Code : XLIFE ++**

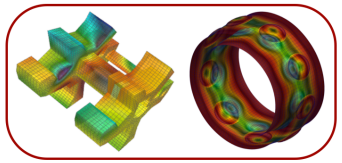


CHRONOLOGY //

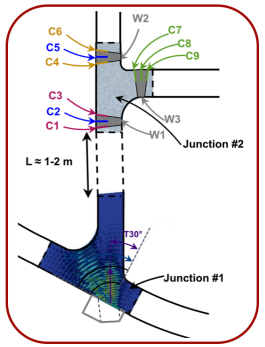
CIVA N·D·E | 2016



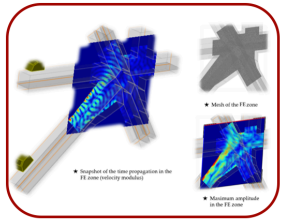
CIVA N·D·E | 2020



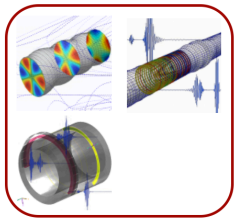
CIVA N·D·E | 2021

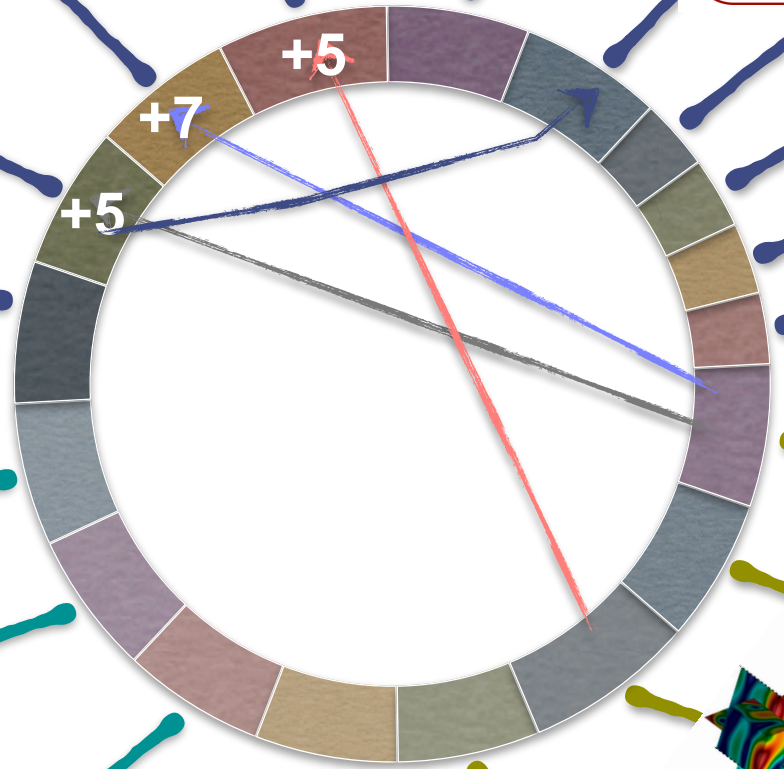


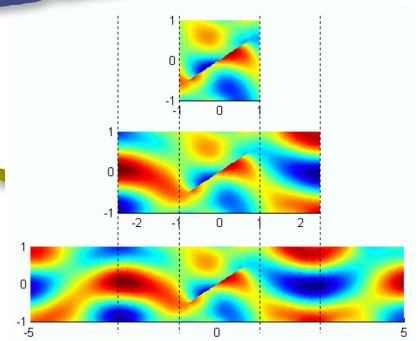
CIVA N·D·E | 11

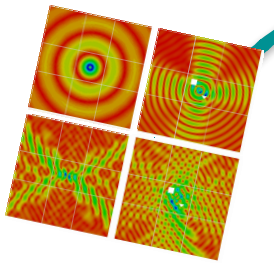


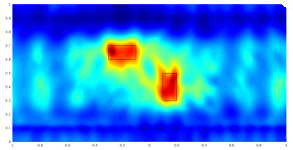
CIVA N·D·E | 10.1

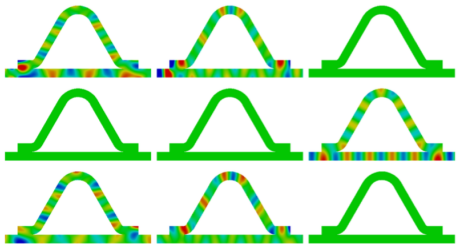








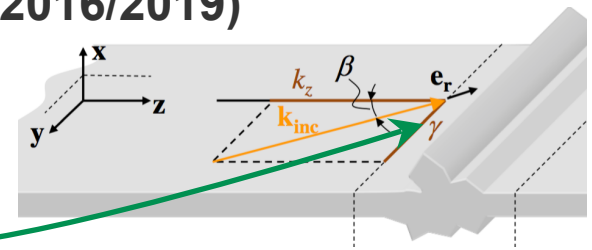




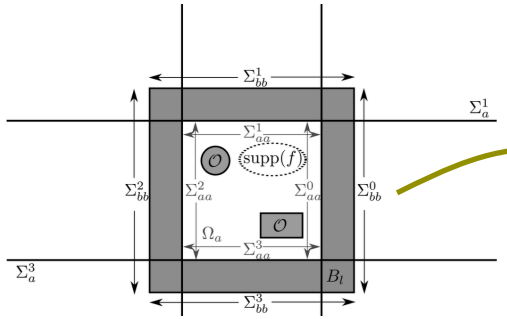
HALF SPACE MATCHING (HSM) METHOD : PART 2

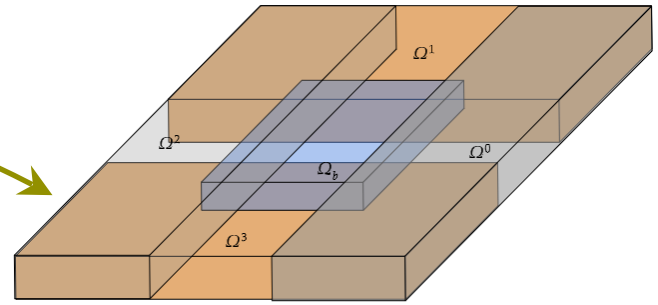
Transparent boundary conditions for 3D elastic plate (Y. Tjandrawidjaja - 2016/2019)

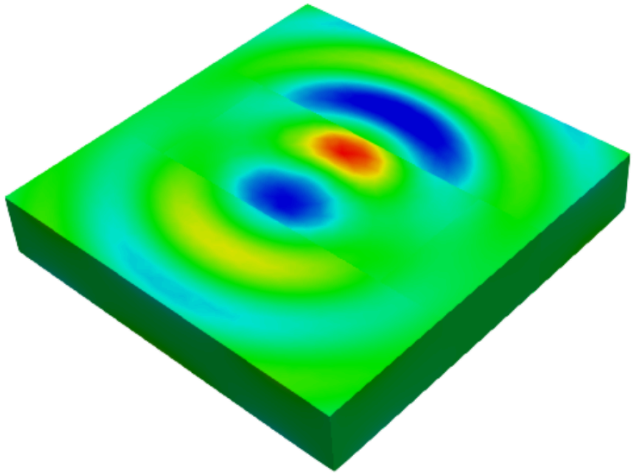
Y. Tjandrawidjaja, **Some contributions to the analysis of the Half-Space Matching Method for scattering problems and extension to 3D elastic plates** (2019)

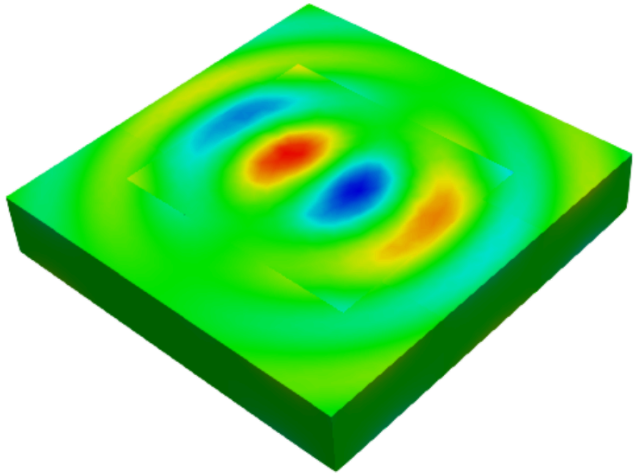


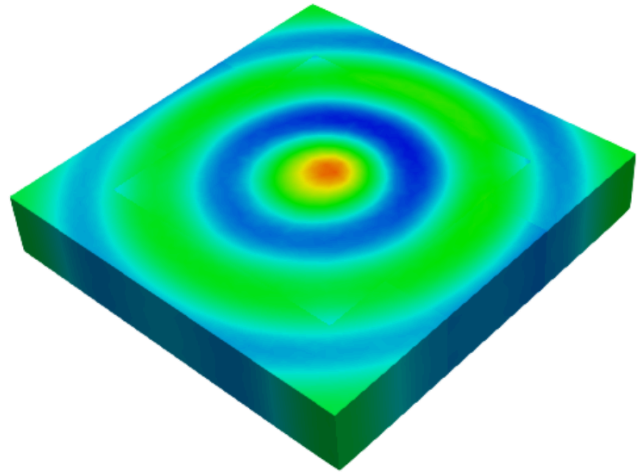
- **Geometry : 3D elastic plate (modes are back : ξ modes)**
- **Multi-domain & Multi-trace formulations**, **Compatibility relations, integral operators,** Fourier transform, **ξ modes (bi-orthonality)**
- **Direct solver**, high memory cost
- **Code : XLIFE++**
- **Anisotropic** medium





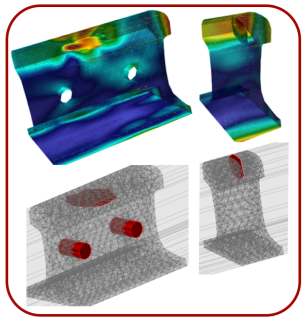




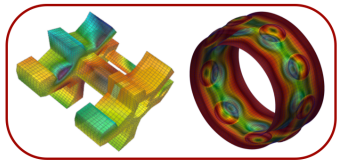


CHRONOLOGY //

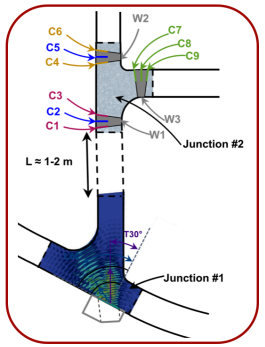
CIVA N·D·E | 2016



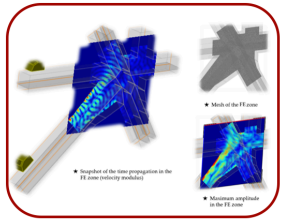
CIVA N·D·E | 2020



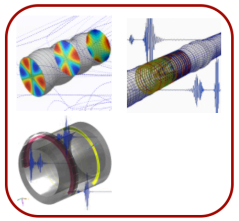
CIVA N·D·E | 2021

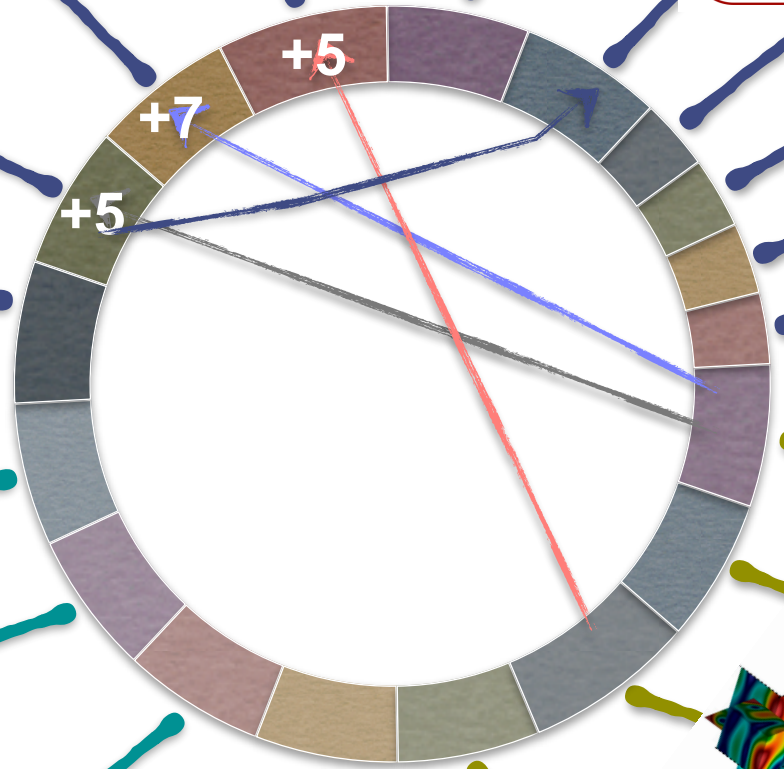


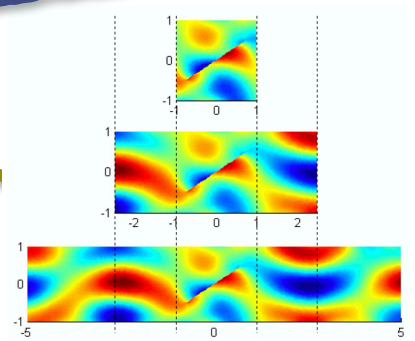
CIVA N·D·E | 11

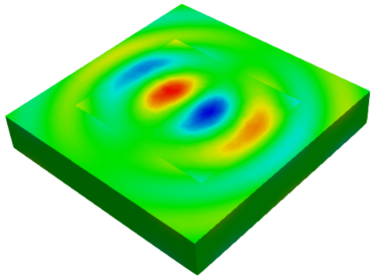


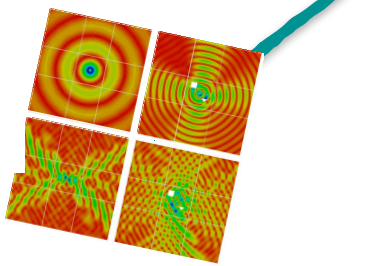
CIVA N·D·E | 10.1

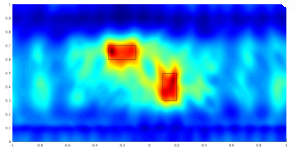


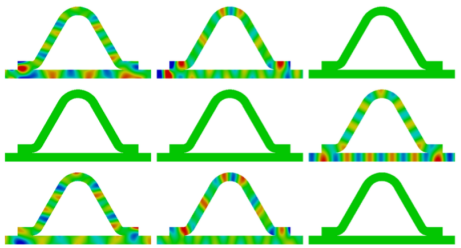










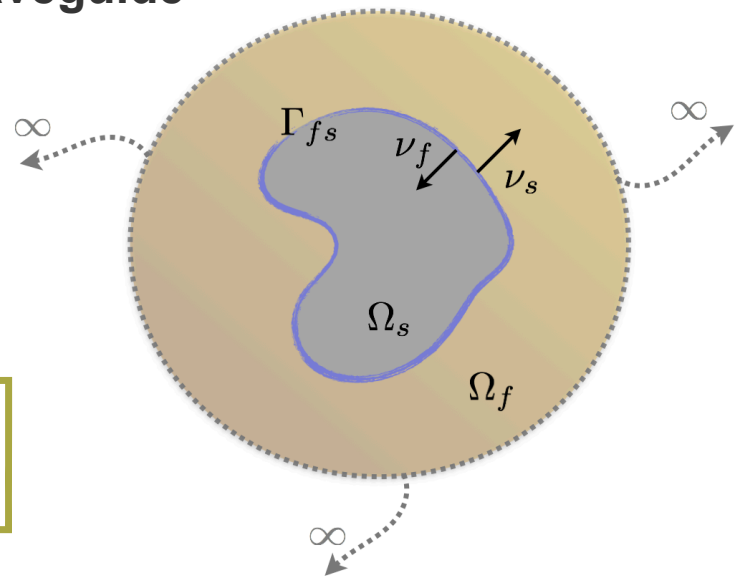


CHRONOLOGY OF CIVA : MODES IN SUBMERGED WAVEGUIDE (2020)

CIVA N·D·E | 2020

Implementation of a mixed formulation for coupled Fluid/Structure waveguide

- **Geometry : 2D cartesian and axisymmetric specimens**
- **Numerical methods : SAFE-PML method**
- **Isotropic material**



Equation in fluid medium

$$\Delta\Phi + \frac{\omega^2}{c_f^2}\Phi = 0 \quad \text{dans} \quad \Omega_f,$$

$$p = -\rho_f \frac{\partial \Phi}{\partial t} = -\imath\omega\rho_f\Phi \quad \text{et} \quad \mathbf{v} = \imath\omega\mathbf{u}.$$

Equation in solid medium

$$-\operatorname{div}\sigma(\mathbf{u}) - \omega^2\rho_s\,\mathbf{u} = 0 \quad \text{dans} \quad \Omega_s = S \times \mathbb{R},$$

Continuity relation

$$\begin{cases} \sigma(\mathbf{u})\cdot\nu_s = -p\,\nu_s & \text{sur} \quad \Gamma_{fs}, \\ \mathbf{v}\cdot\nu_s = \nabla\Phi\cdot\nu_s & \text{sur} \quad \Gamma_{fs}, \end{cases}$$

Mixed Variational formulation

$$\begin{cases} \displaystyle\int_{\Omega_s} \boldsymbol{\sigma}(\mathbf{u}) : \varepsilon(\tilde{\mathbf{u}}) - \int_{\Omega_s} \rho_s\,\omega^2\,\mathbf{u}\,\tilde{\mathbf{u}} - \int_{\Gamma_{fs}} \imath\omega\,\rho_f(\tilde{\mathbf{u}}\cdot\nu_s)\Phi &= 0 \\ \displaystyle\int_{\Omega_f} \rho_f\nabla\Phi\,\nabla\tilde{\Phi} - \int_{\Omega_f} \rho_f\frac{\omega^2}{c_f^2}\Phi\,\tilde{\Phi} - \int_{\Gamma_{fs}} \imath\omega\rho_f(\mathbf{u}\cdot\nu_f)\tilde{\Phi} &= 0 \end{cases}$$

Modes expression

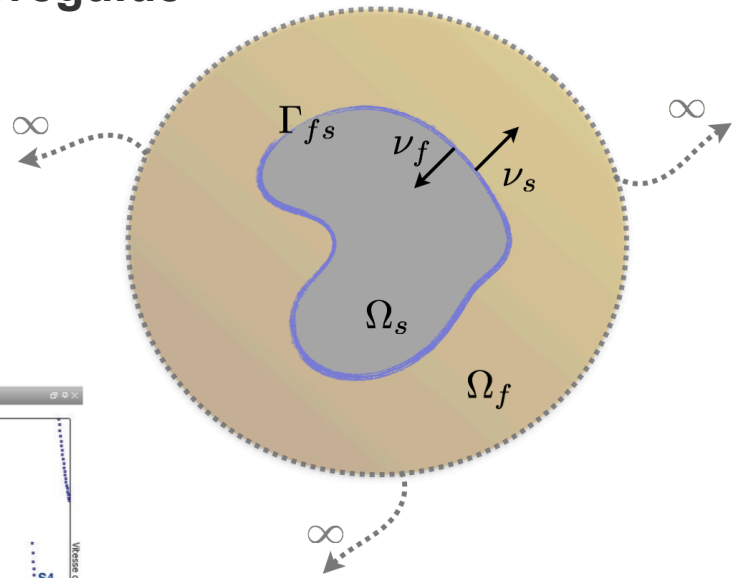
$$\begin{pmatrix} \mathbf{u}(\mathbf{x}_s, z) \\ \Phi(\mathbf{x}_s, z) \end{pmatrix} = \begin{pmatrix} \boldsymbol{u}(\mathbf{x}_s) \\ \Phi(\mathbf{x}_s) \end{pmatrix} e^{-\imath\beta z},$$

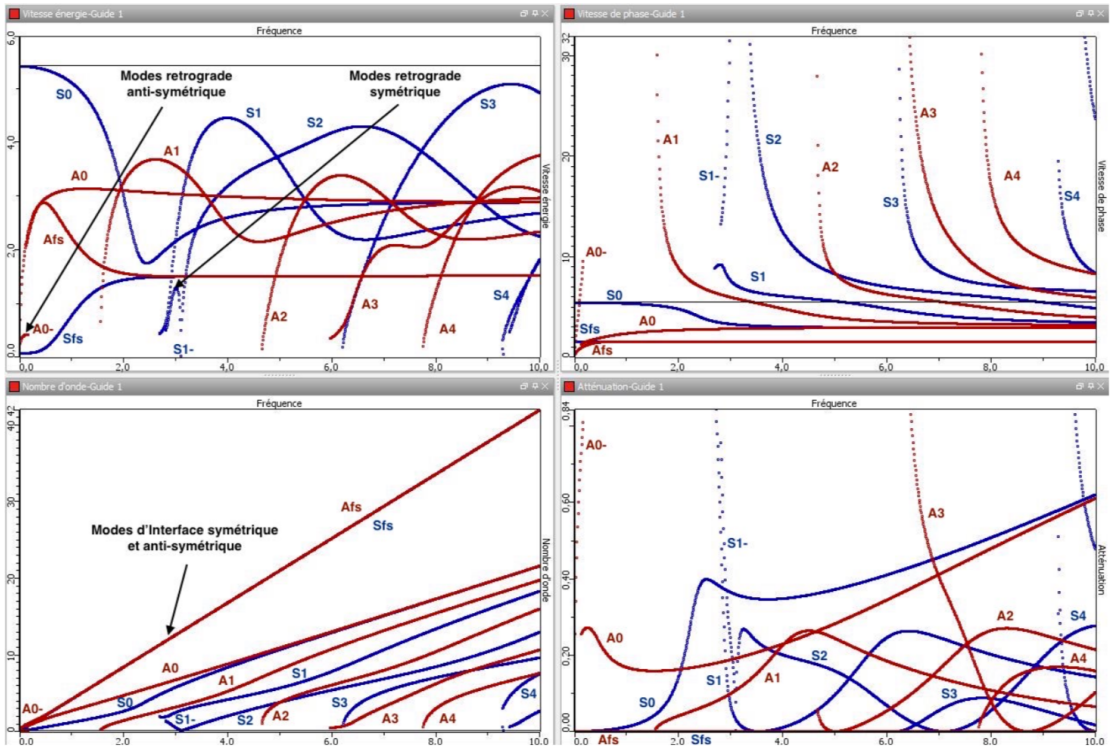
CHRONOLOGY OF CIVA : MODES IN SUBMERGED WAVEGUIDE (2020)

CIVA N·D·E | 2020

Implementation of a mixed formulation for coupled Fluid/Structure waveguide

- **Geometry : 2D cartesian and axisymmetric specimens**
- **Numerical methods : SAFE-PML method**
- **Isotropic material**
- **Difficulty : wrong approximation Scholte and Q-Scholte modes with PML**





CHRONOLOGY OF CIVA : BOUNDED FLUID/STRUCTURE WAVEGUIDE (2021/2024)

- D2 = TDF ext
- D3 = FPS int
- D4 = FPS ext
- Ldg = lame de gaz

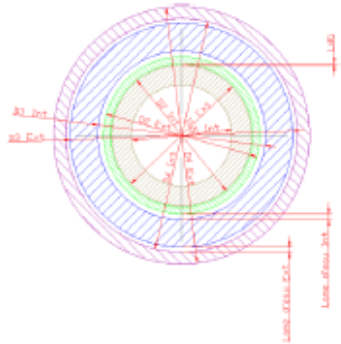
Section C-C = ***TDFi Partie basse – PFM***

Section D-D = ***TDFi Partie basse***

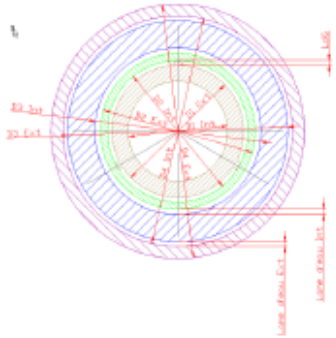
SectionF-F = ***TDFi Partie Haute***

Section G-G = ***TDFi Partie Supérieure***

SECTION C - C (Plan de flux moyen)



SECTION D - D



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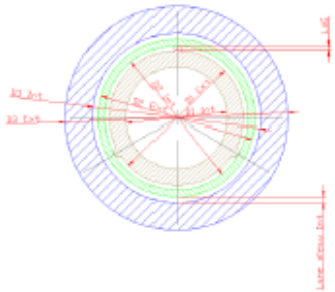

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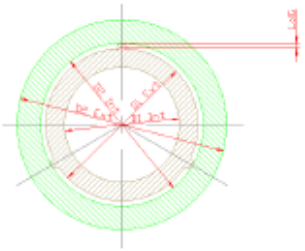
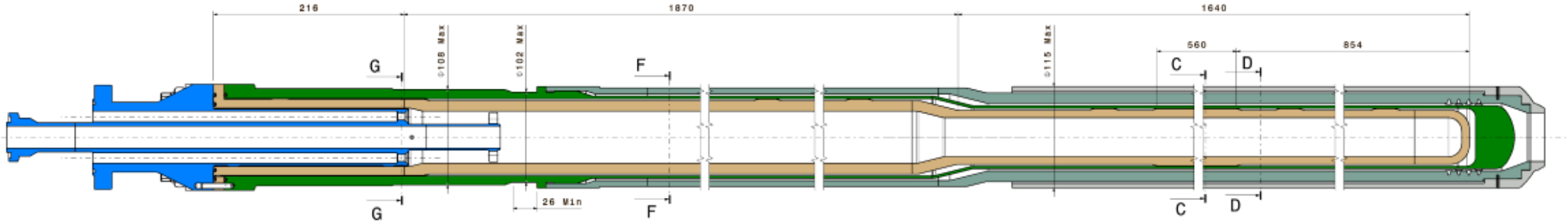




CHRONOLOGY OF CIVA : BOUNDED FLUID/STRUCTURE WAVEGUIDE (2021/2024)

Implementation of YtoX method for coupled F/S waveguide

CIVA N·D·E | 2024

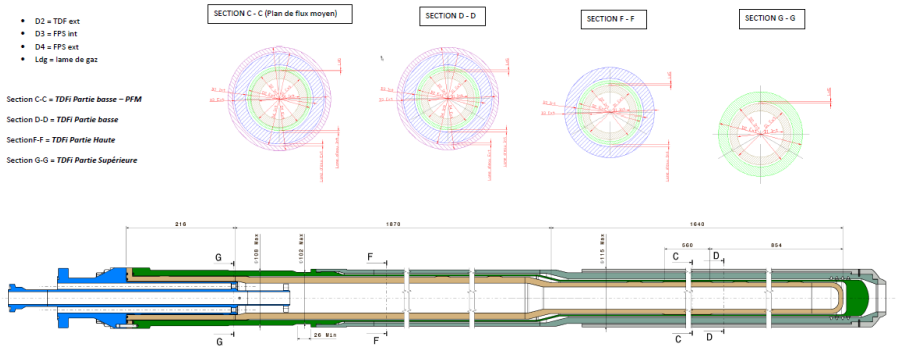
- **Geometry : 2D cartesian and axisymmetric specimens for modes interaction**
- **Flaws : arbitrary perturbations/interface irregularity**
- **Extension of XY formalism (**valid for **elastic** and **acoustic** waveguide**)**

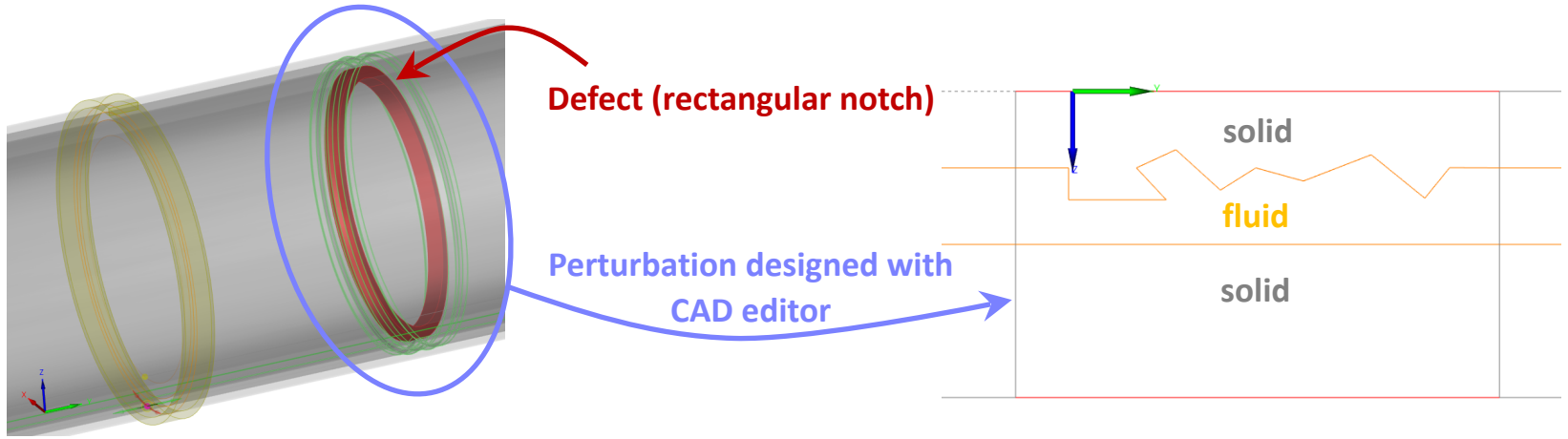
V. Pagneux, A. Maurel, **Scattering matrix properties with evanescent modes for waveguides in fluids and solids** (2004)

…to coupled F/S with bounded cross section

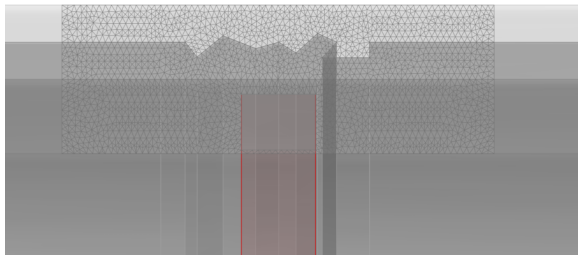
- **Fraser's bi-orthogonality still valid :**

$$\left(X_{sf}, Y_{sf}\right) = \left(X_s, Y_s\right) + \left(X_f, Y_f\right)$$



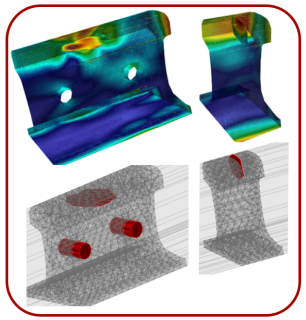


Mesh of the computational domain

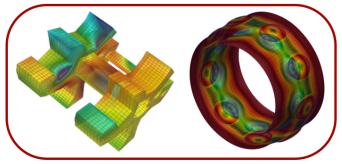


CHRONOLOGY //

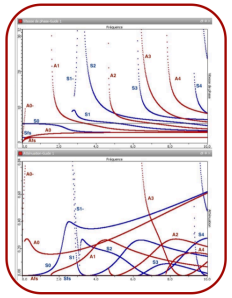
CIVA N·D·E | 2016



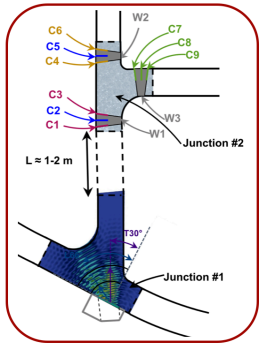
CIVA N·D·E | 2020



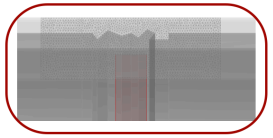
CIVA N·D·E | 2020



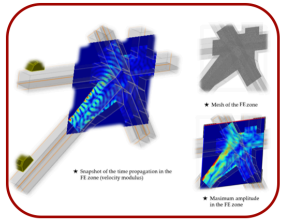
CIVA N·D·E | 2021



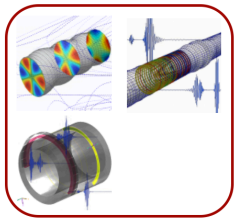
CIVA N·D·E | 2024

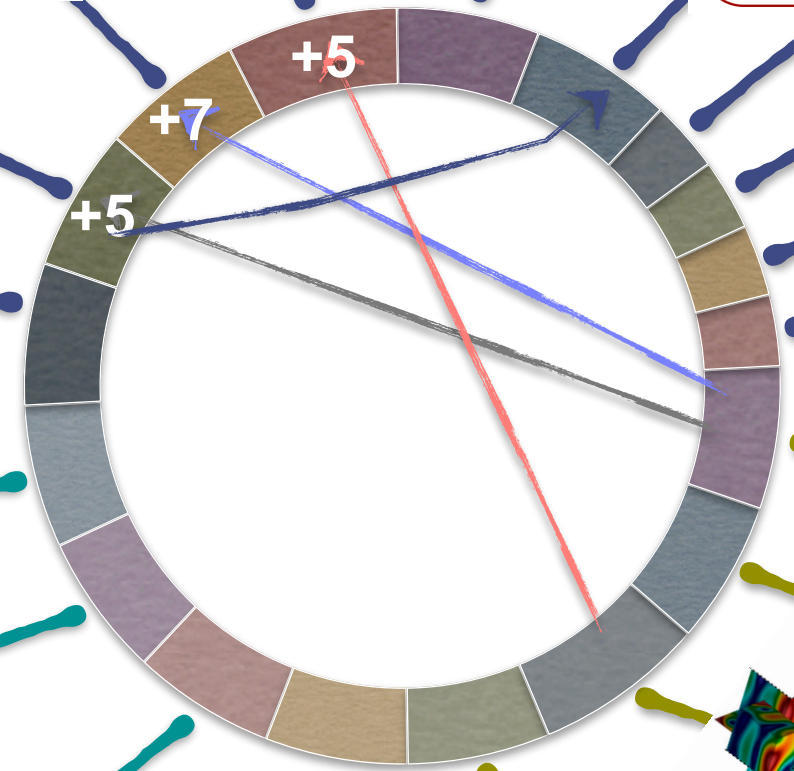


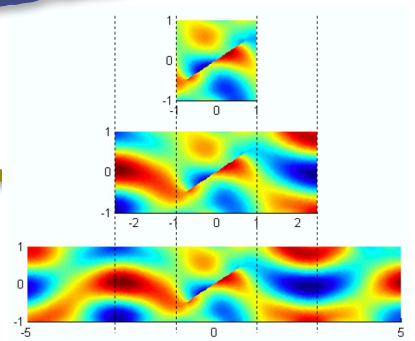
CIVA N·D·E | 11

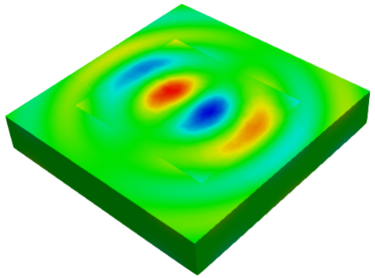


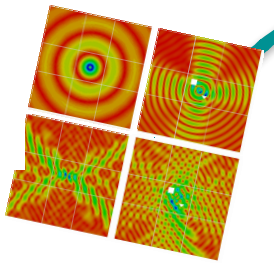
CIVA N·D·E | 10.1

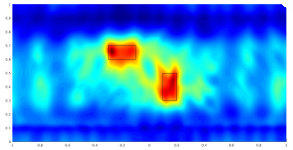


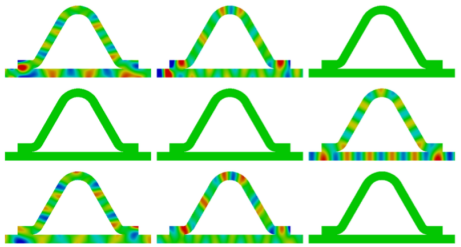










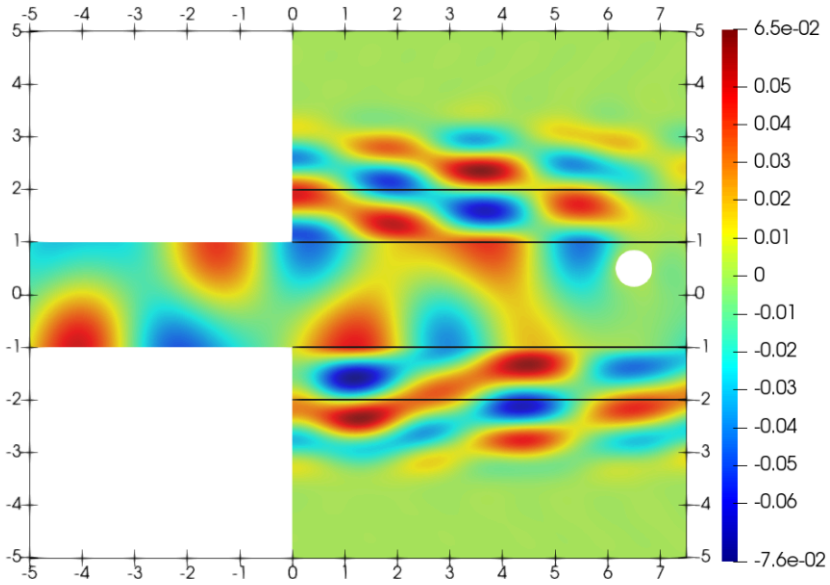


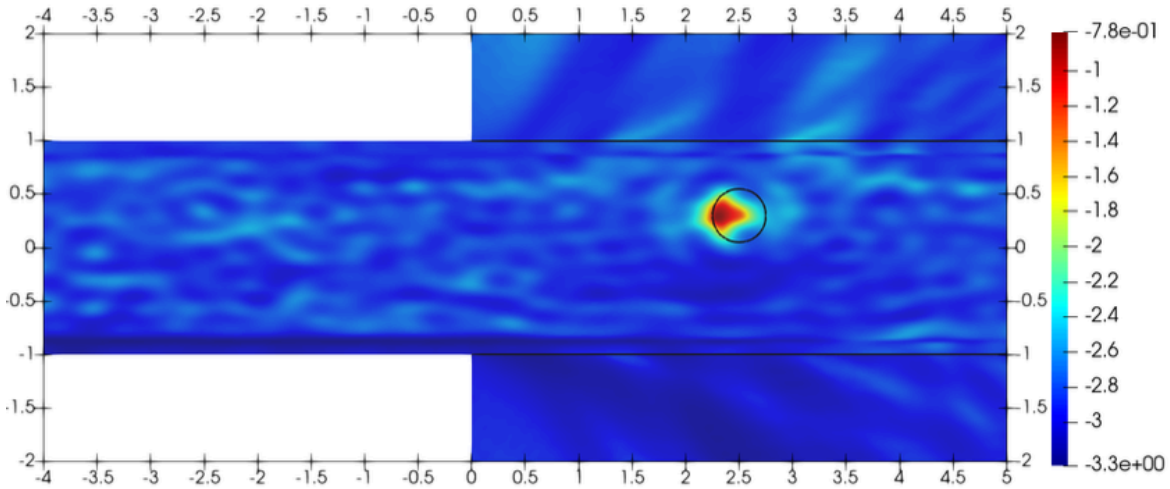
DEFECT IMAGING IN ELASTIC WAVEGUIDE : PART 2

Linear Sampling method for imaging partially submerged elastic waveguide (J-F. Fritsch - 2019/2023)

J. F. Fritsch, **Propagation des ondes dans les guides partiellement enfouis : résolution du problème direct et imagerie par méthode de type échantillonnage** (2023)

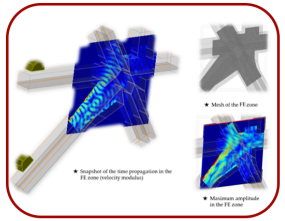
- **Geometry : 2D/3D elastic waveguide**
- **Flaws : surface/core defect type in solid part**
- **XY formalism for submerged waveguide ⇛ YtoX operator with PML,** direct and inverse scattering problem
- **Cross section to surface data, harmonic data**
- **Code : XLIFE ++**



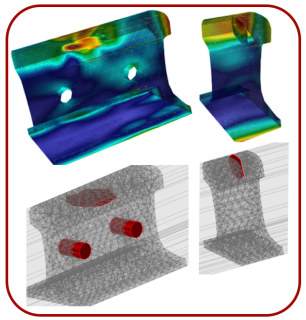


CHRONOLOGY //

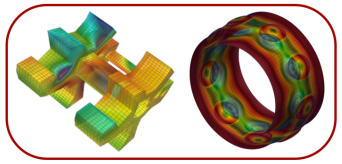
CIVA N·D·E | 11



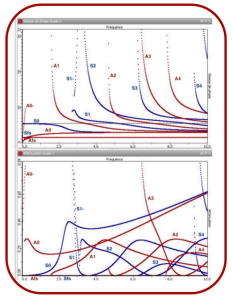
CIVA N·D·E | 2016



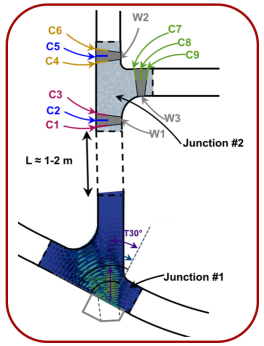
CIVA N·D·E | 2020



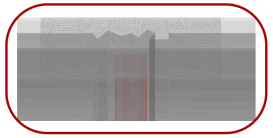
CIVA N·D·E | 2020



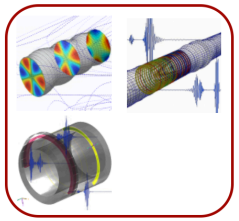
CIVA N·D·E | 2021

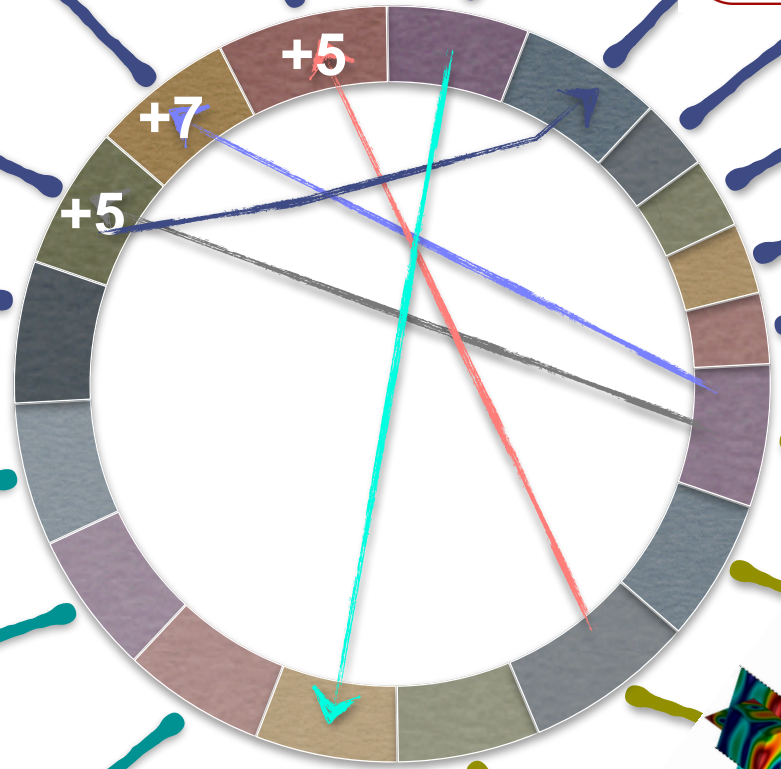


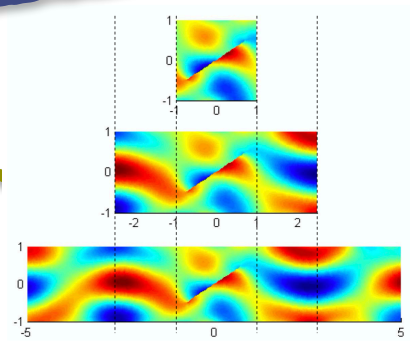
CIVA N·D·E | 2024

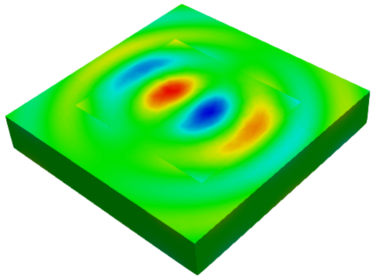


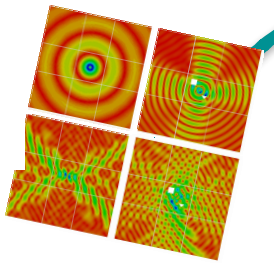
CIVA N·D·E | 10.1

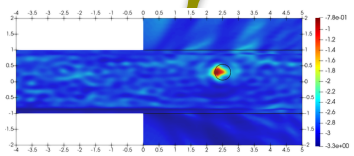


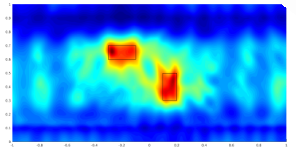


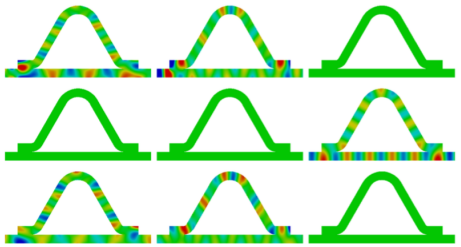






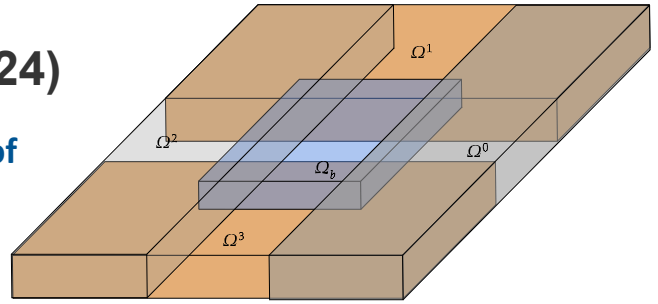






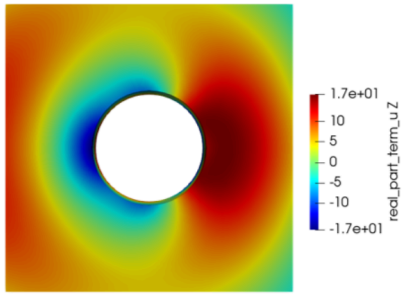
HALF SPACE MATCHING (HSM) METHOD : PART 3

Transparent boundary conditions for 3D elastic plate (A. Allouko 2020/2024)

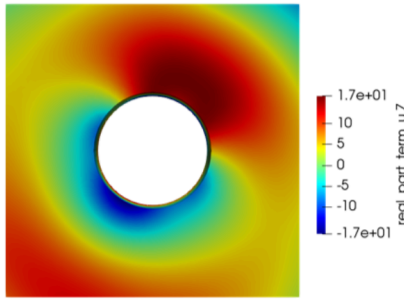


A. Allouko, **Hybrid modal - finite elements modeling for ultrasonic testing of an elastic plate. Treatment of oscillating integrals of the HSM method** (2024)

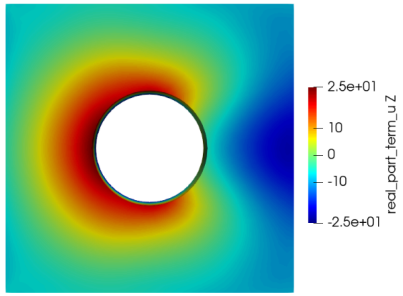
- **Geometry : 3D elastic plate (modes are back : ξ modes)**
- **Multi-domain & Multi-trace formulations**, **Compatibility relations, integral operators, ξ modes**, Fourier transform
- **Direct solver**, high memory cost
- **Code : XLIFE++**
- **Anisotropic** medium



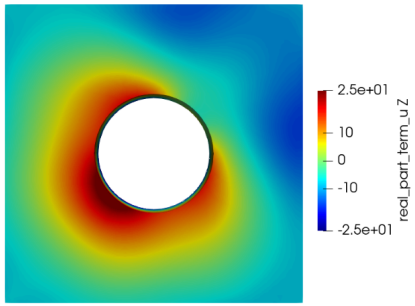
(a) $\theta = 0°$



(b) $\theta = 40°$



(a) $\theta = 0°$



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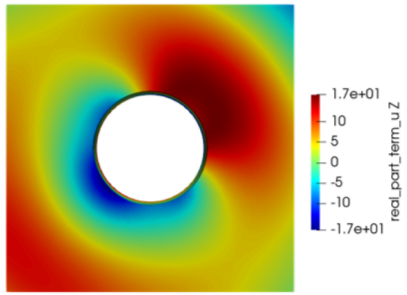
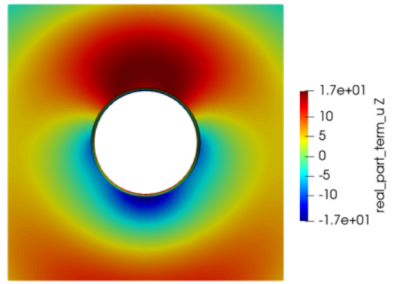
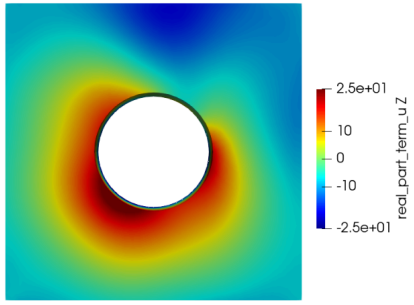


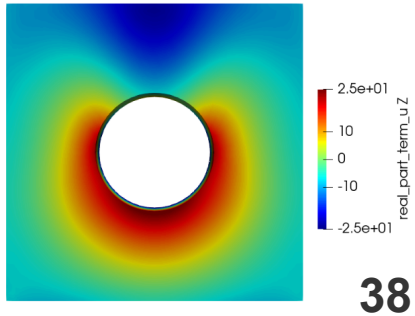
(b) $\theta = 60°$



(c) $\theta = 90°$



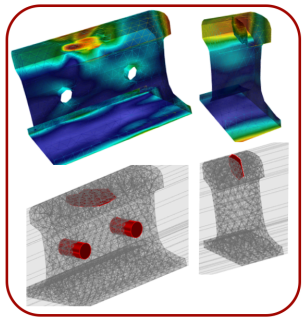
(b) $\theta = 60°$



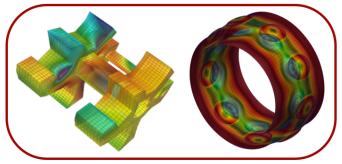
(c) $\theta = 90°$

CHRONOLOGY //

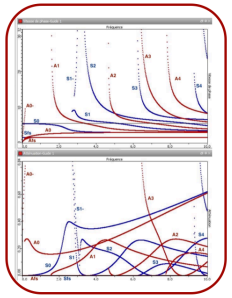
CIVA N·D·E | 2016



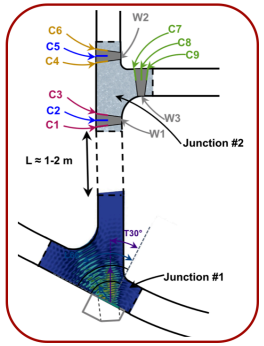
CIVA N·D·E | 2020



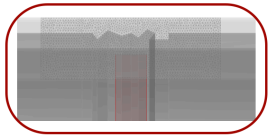
CIVA N·D·E | 2020



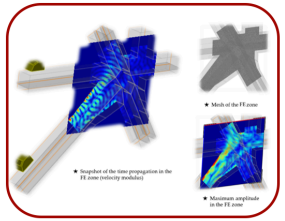
CIVA N·D·E | 2021



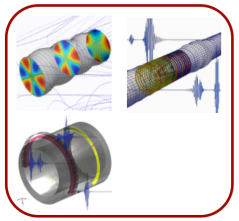
CIVA N·D·E | 2024

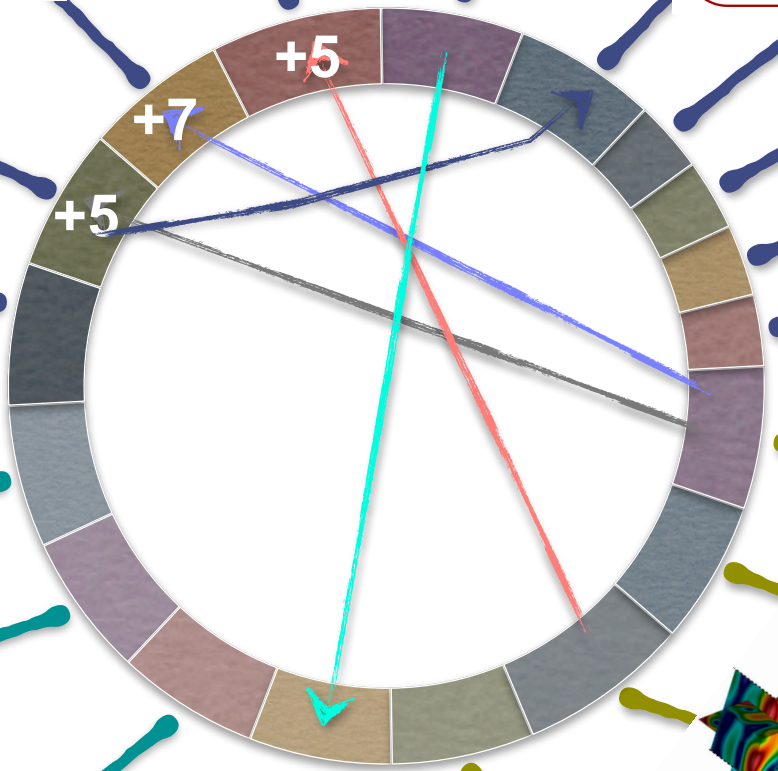


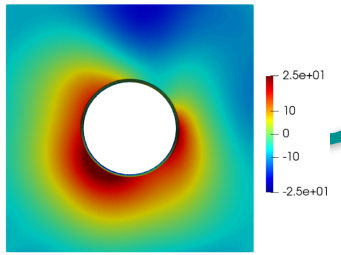
CIVA N·D·E | 11

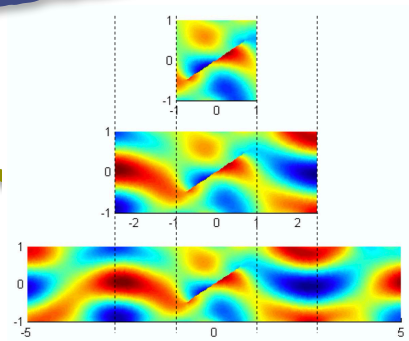


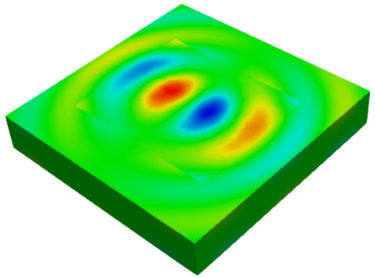
CIVA N·D·E | 10.1

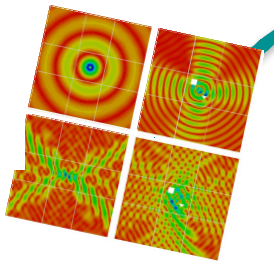


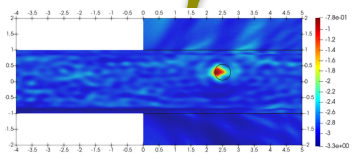


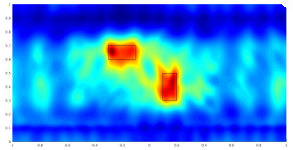


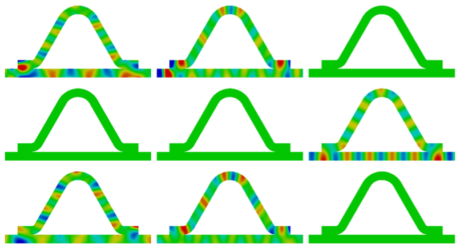






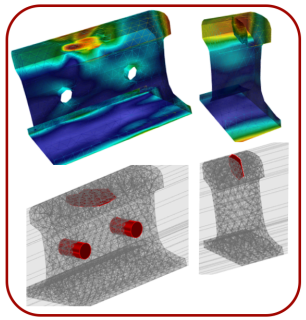




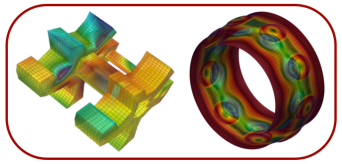


CHRONOLOGY //

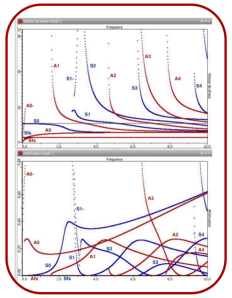
CIVA N·D·E | 2016



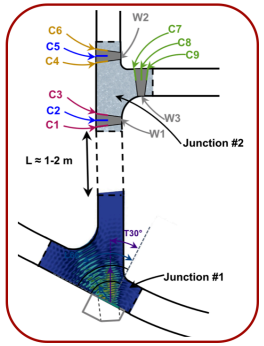
CIVA N·D·E | 2020



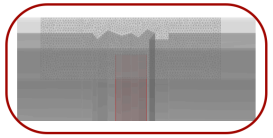
CIVA N·D·E | 2020



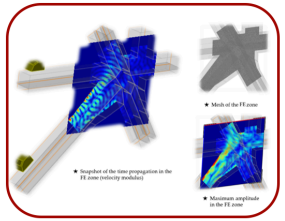
CIVA N·D·E | 2021



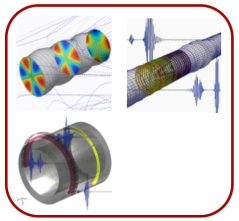
CIVA N·D·E | 2024

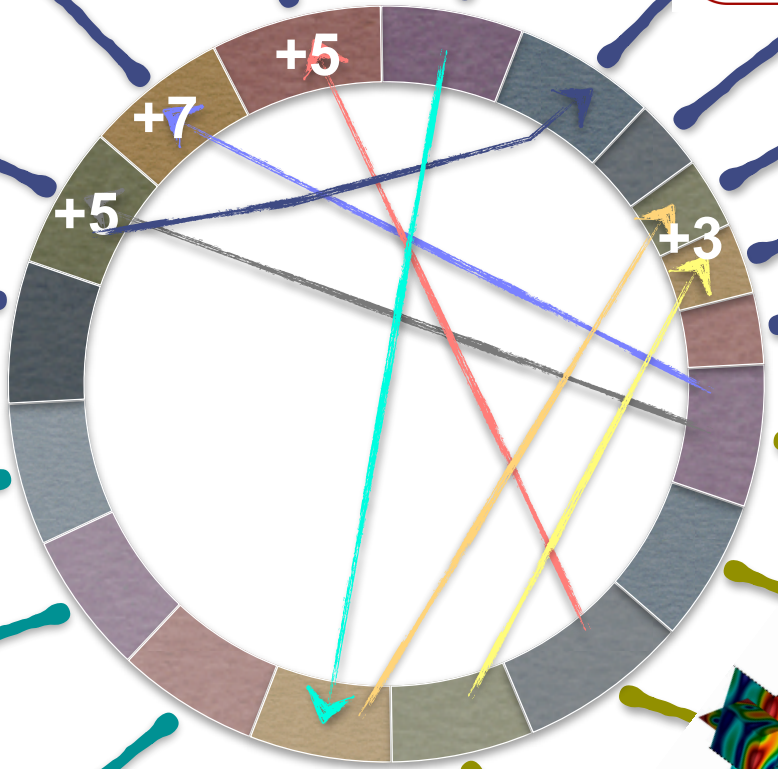


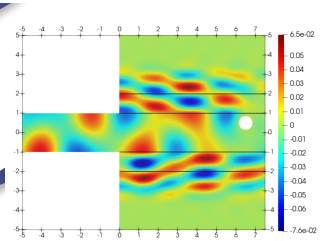
CIVA N·D·E | 11

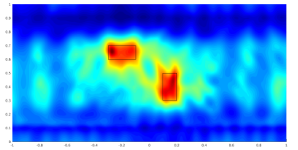


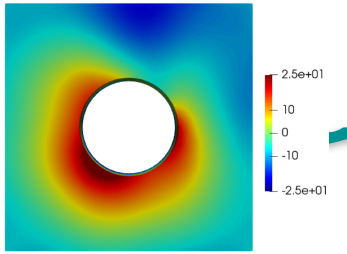
CIVA N·D·E | 10.1

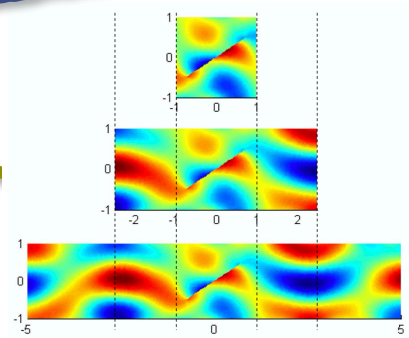


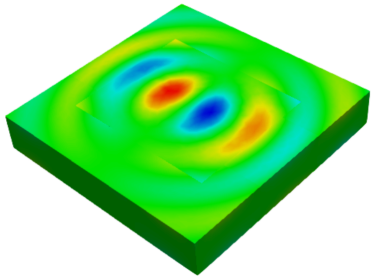


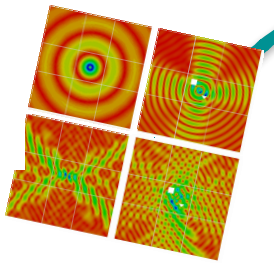


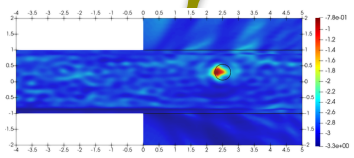


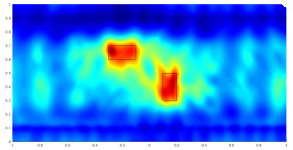


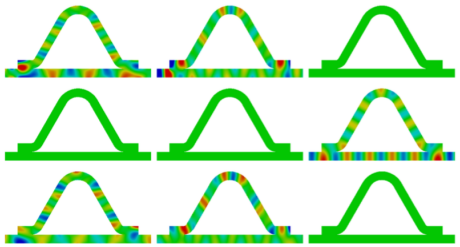






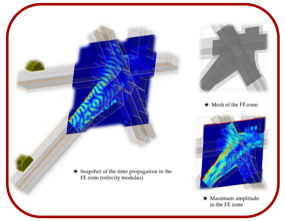




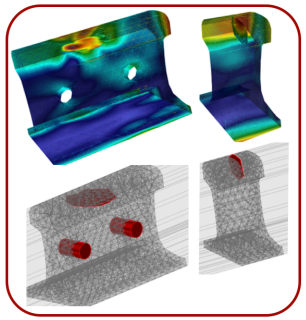


CHRONOLOGY //

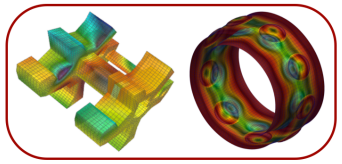
CIVA N·D·E | 11



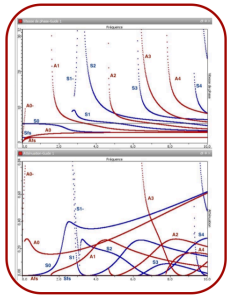
CIVA N·D·E | 2016



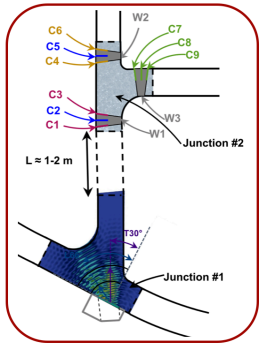
CIVA N·D·E | 2020



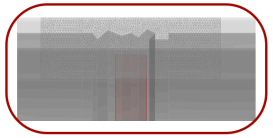
CIVA N·D·E | 2020



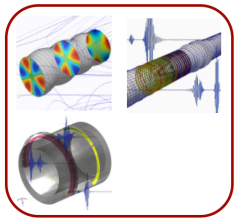
CIVA N·D·E | 2021

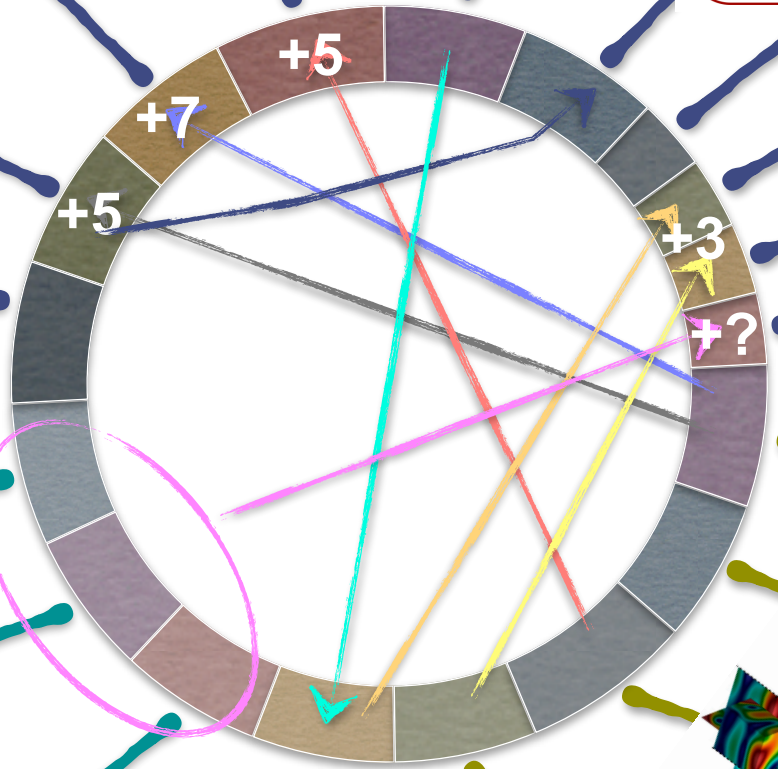


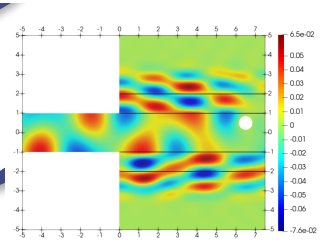
CIVA N·D·E | 2024

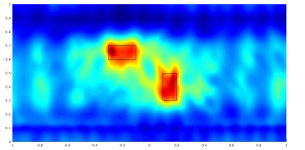


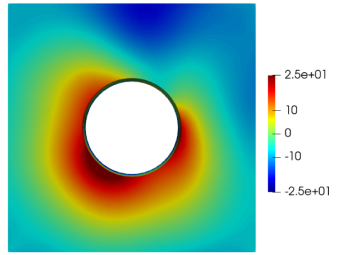
CIVA N·D·E | 10.1

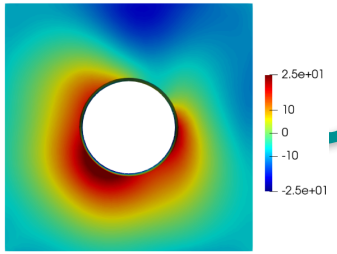


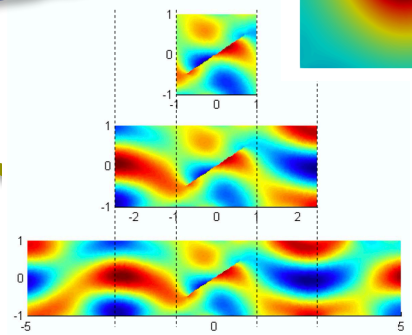


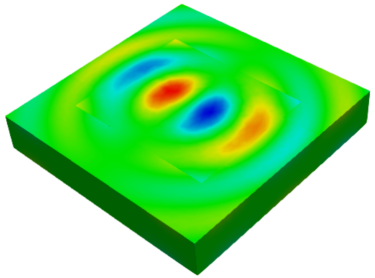


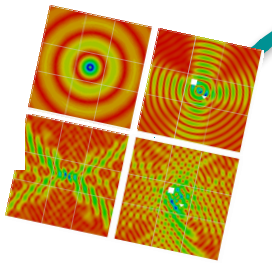


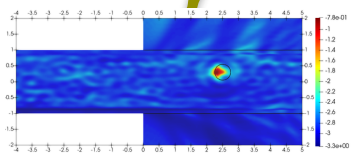


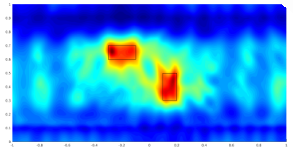


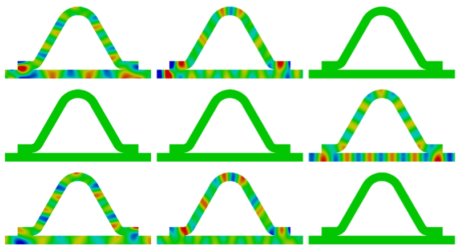












OUTLINE

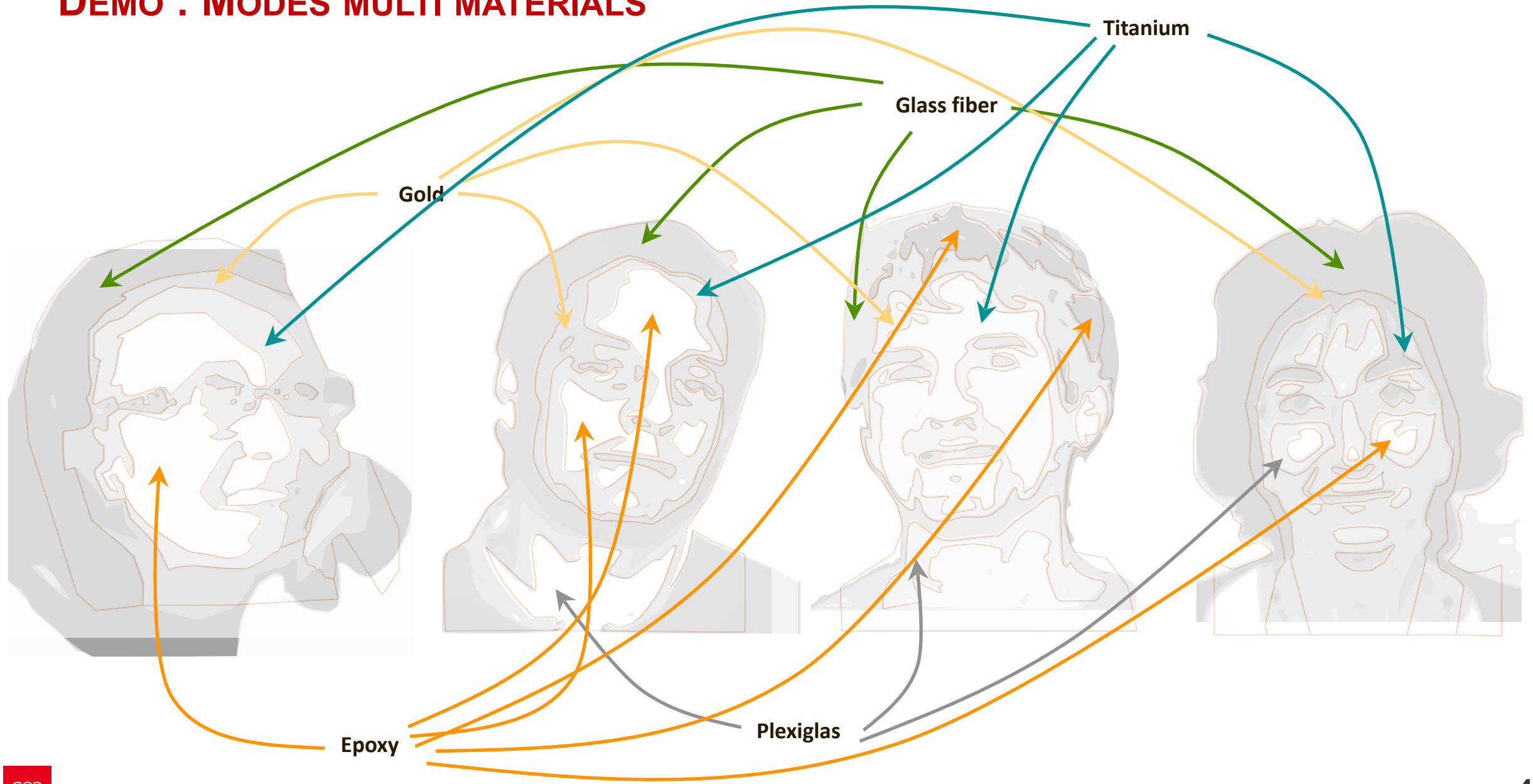
1. Overview of guided wave modeling
    - 1.1. Context/Motivation
    - 1.2. Waveguide and Modal formalism

2. Chronology 2006/2024
    - 2.1. CIVA evolution
    - 2.2. Elastic waveguide
    - 2.3. Half Space Matching (HSM)

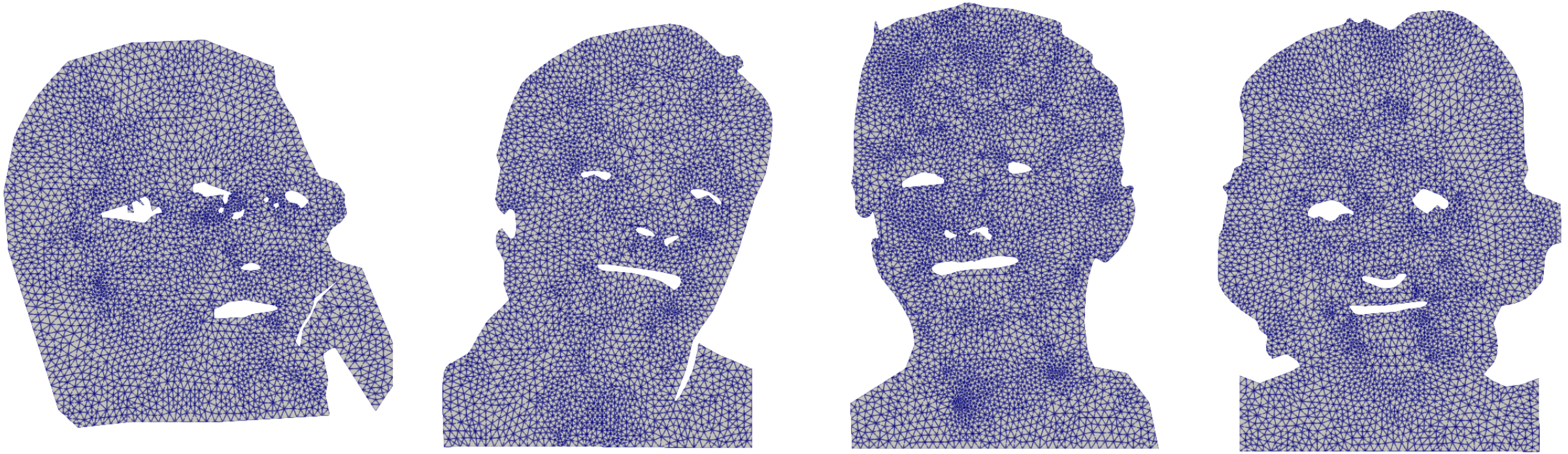
3. Demo

DEMO : MODES

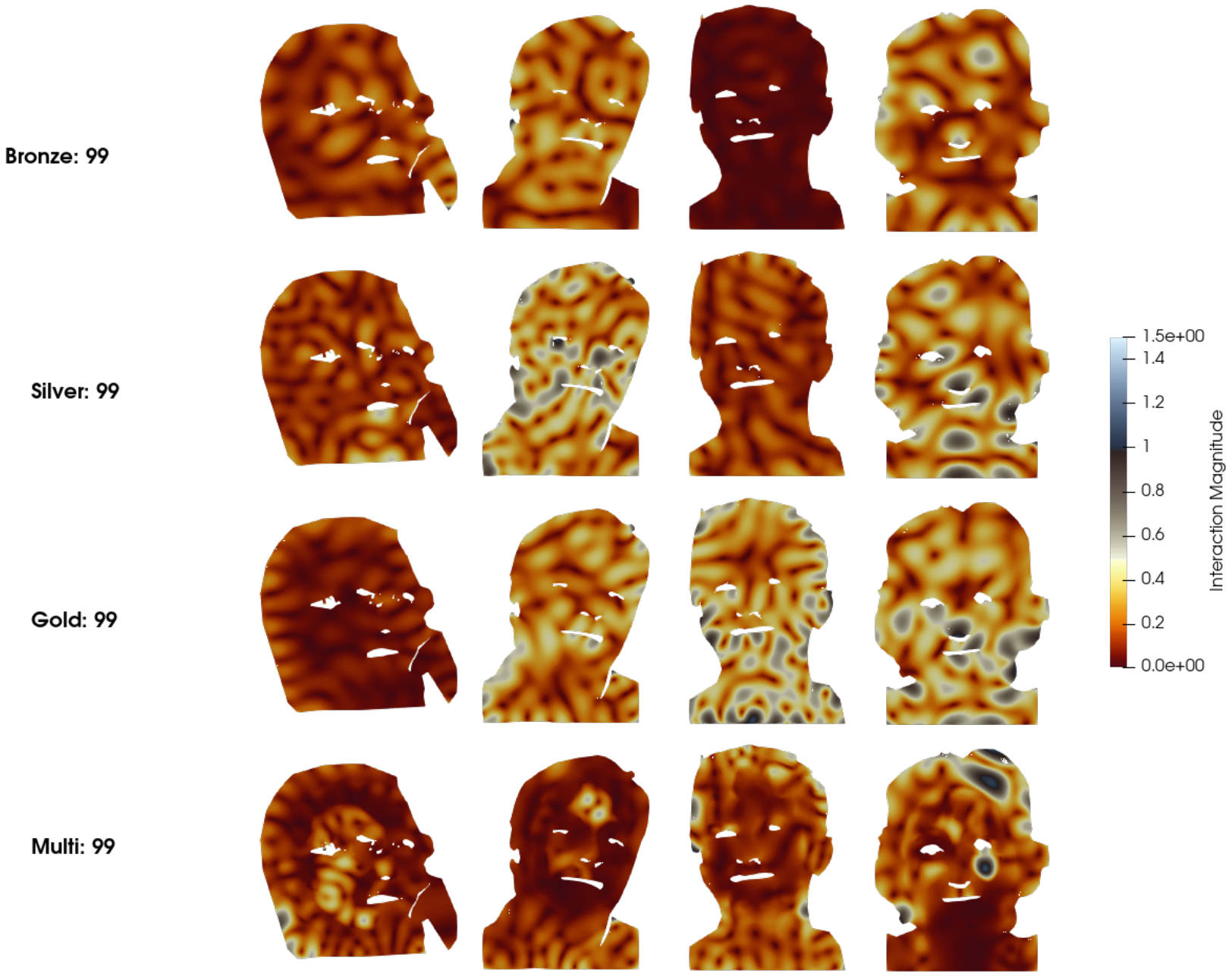
DEMO : MODES MULTI MATERIALS



DEMO : MODES



DEMO : JO MODES



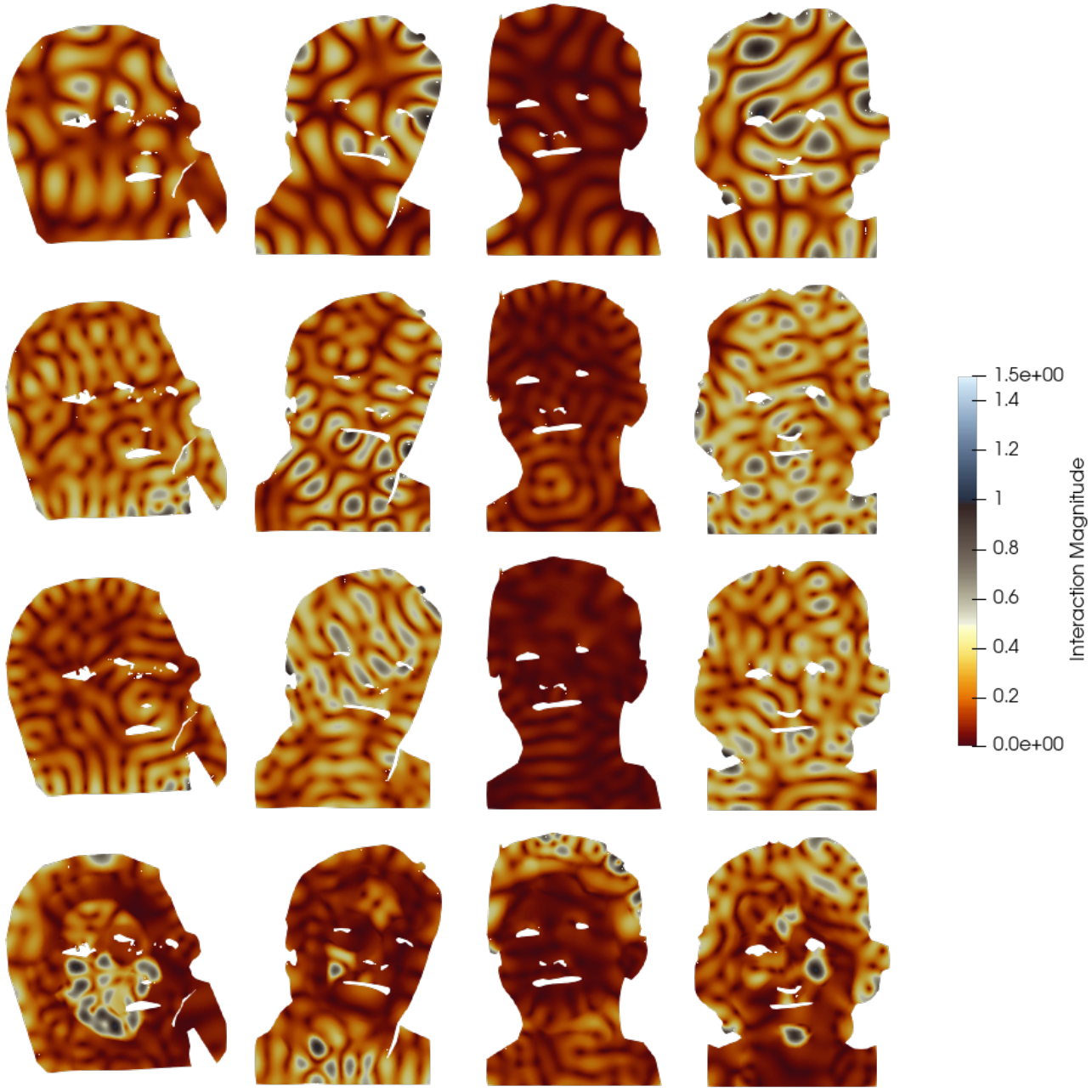
DEMO : JO MODES

Bronze: 200

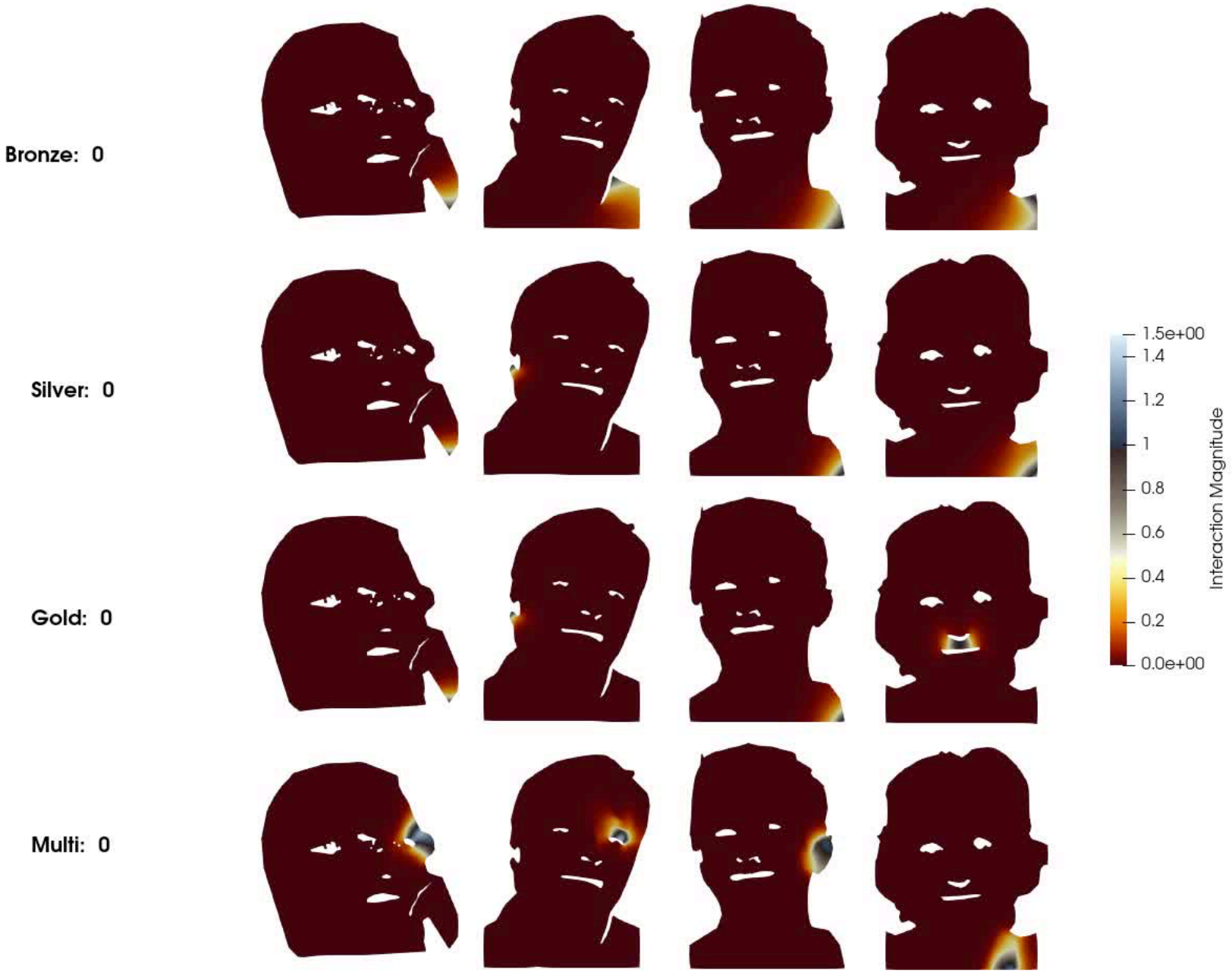
Silver: 200

Gold: 200

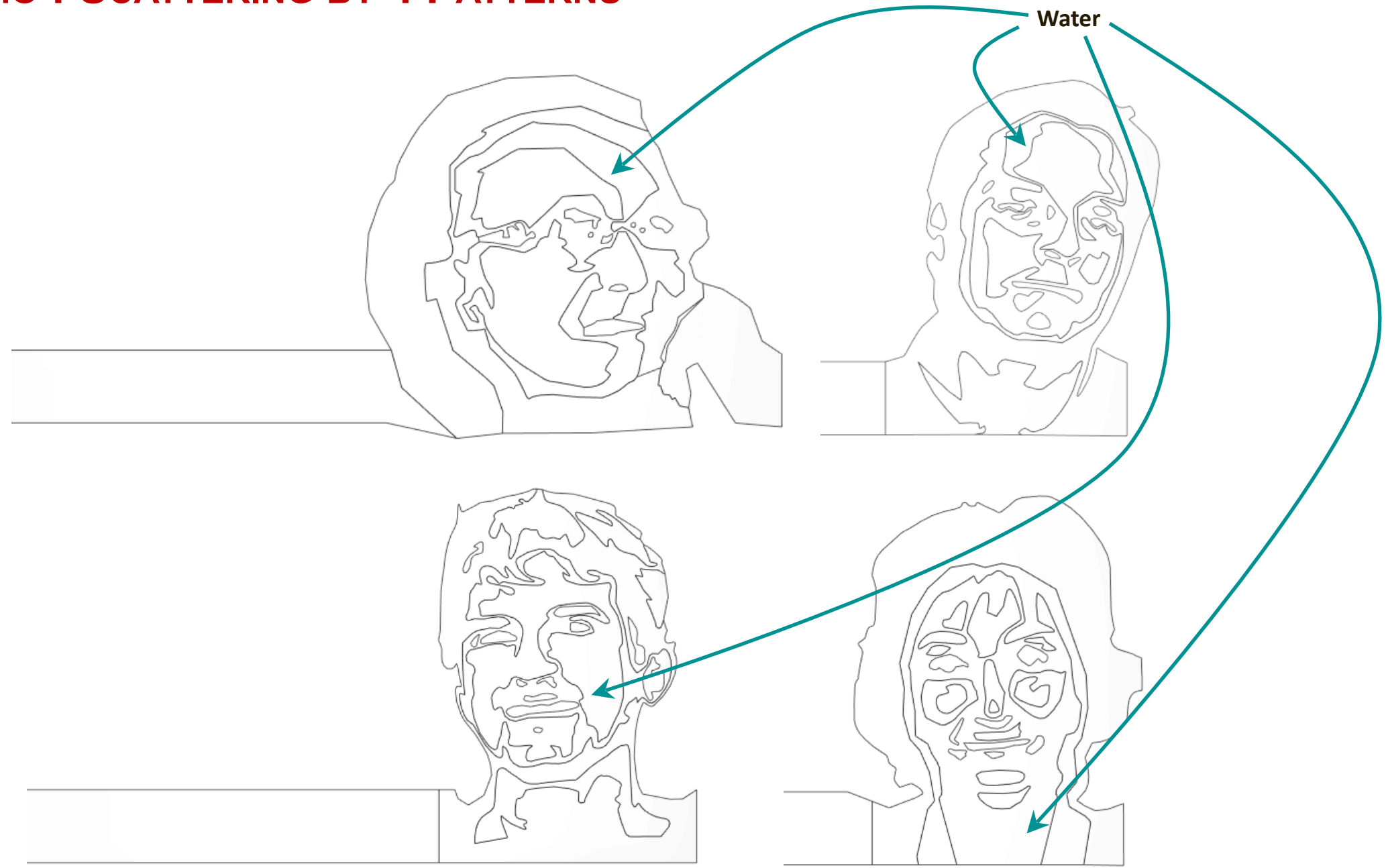
Multi: 200



DEMO : JO MODES



DEMO : SCATTERING BY 4 PATTERNS



DEMO : SCATTERING BY POETS' PATTERNS

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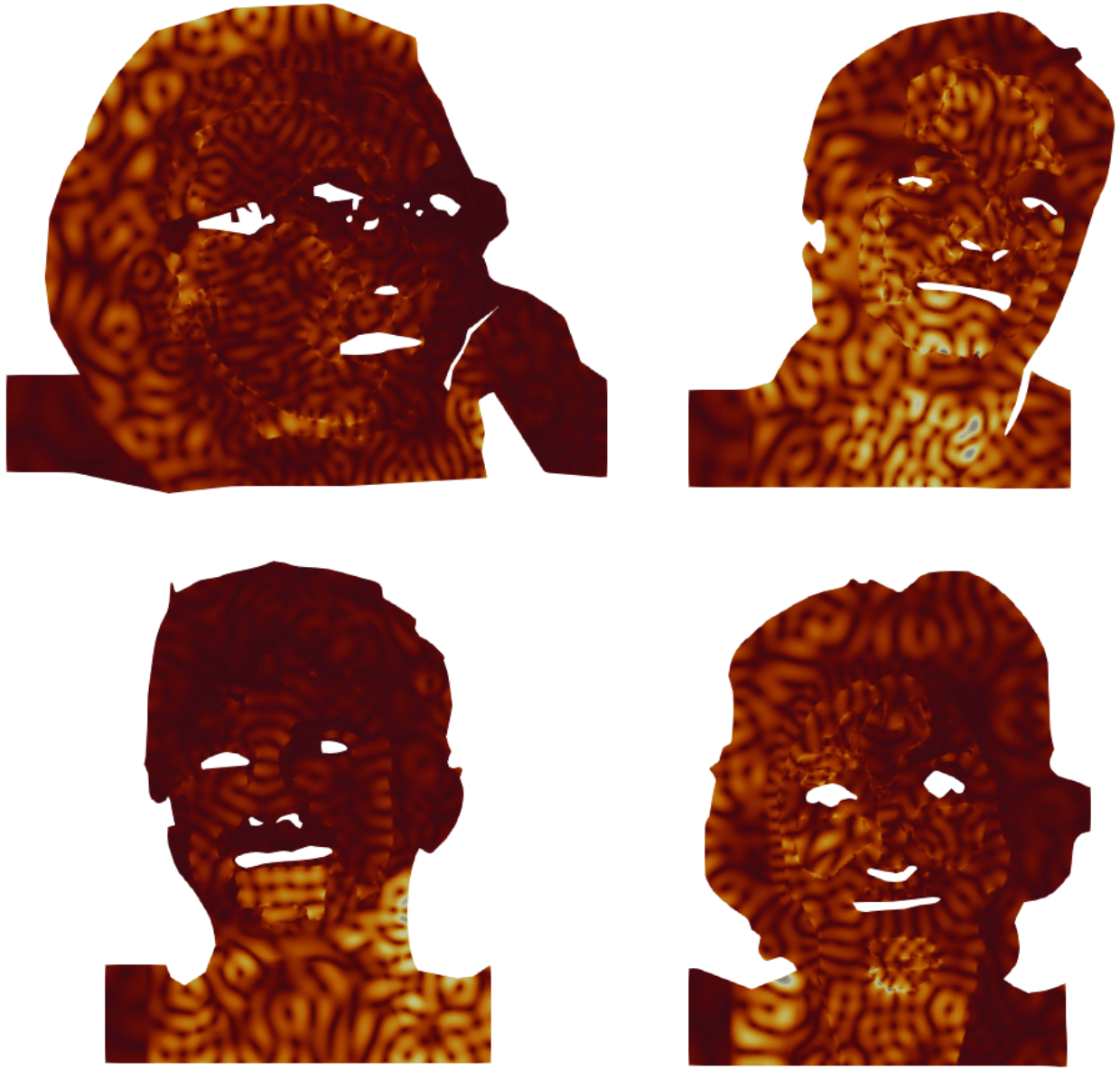
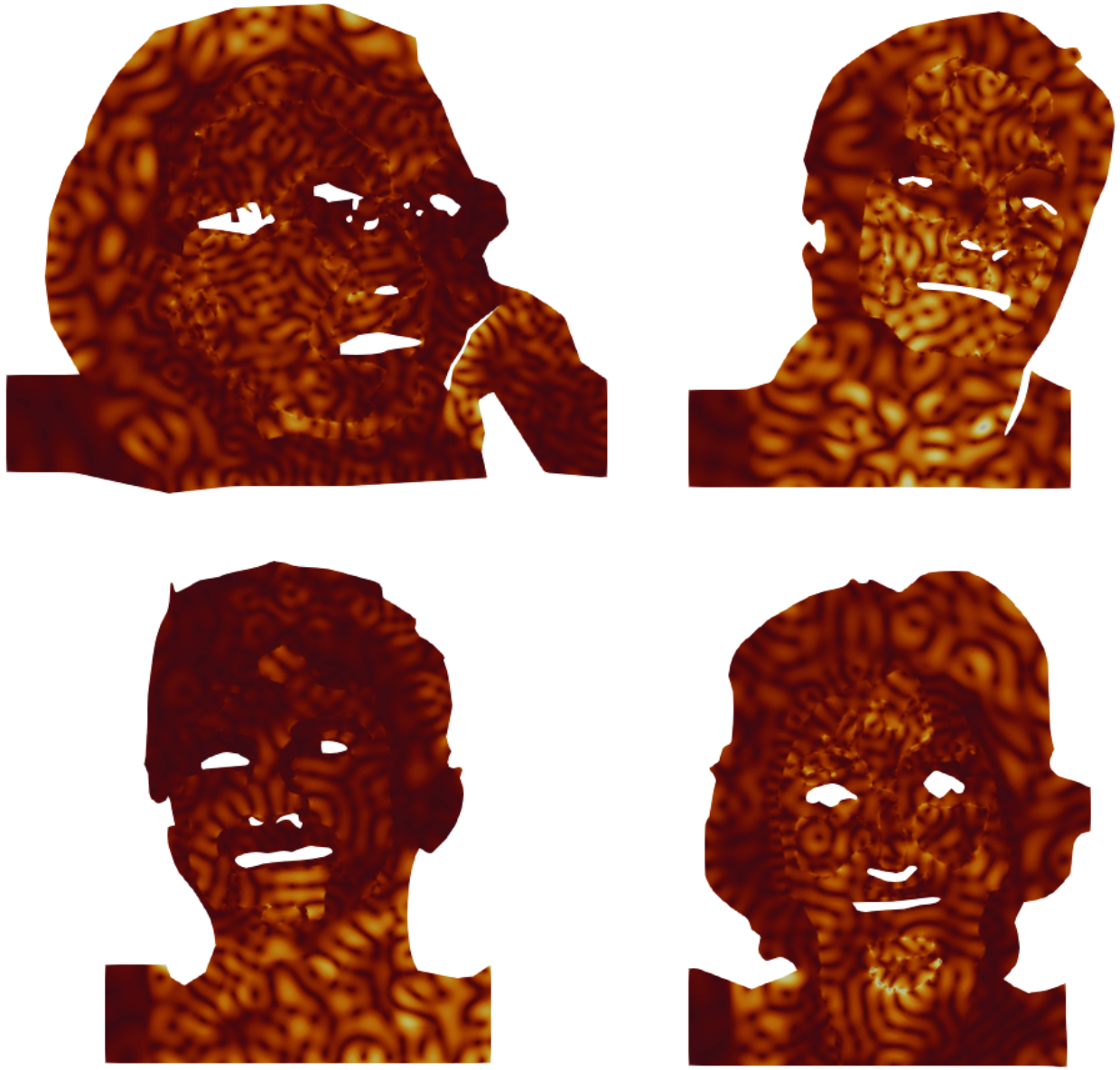
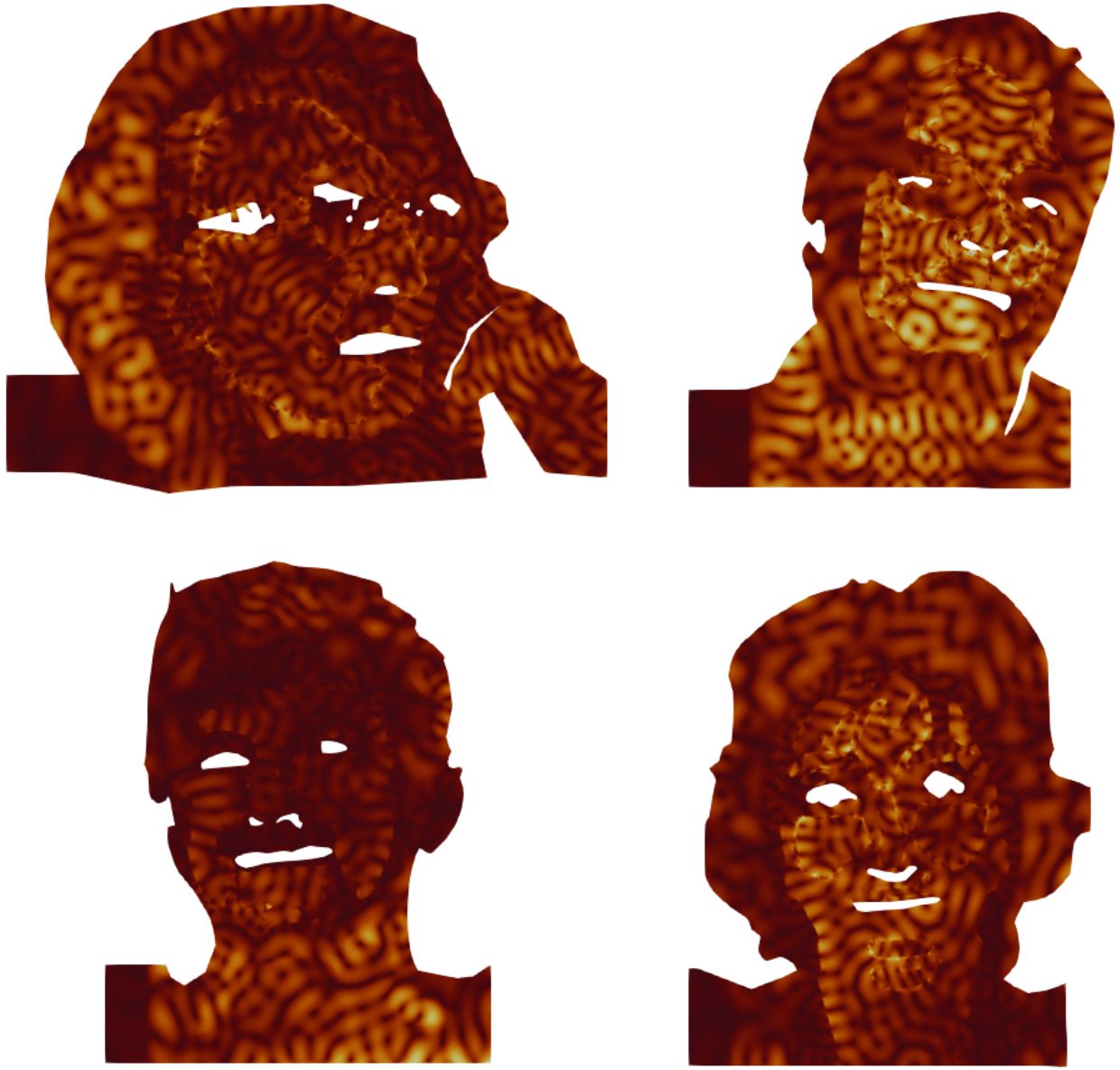


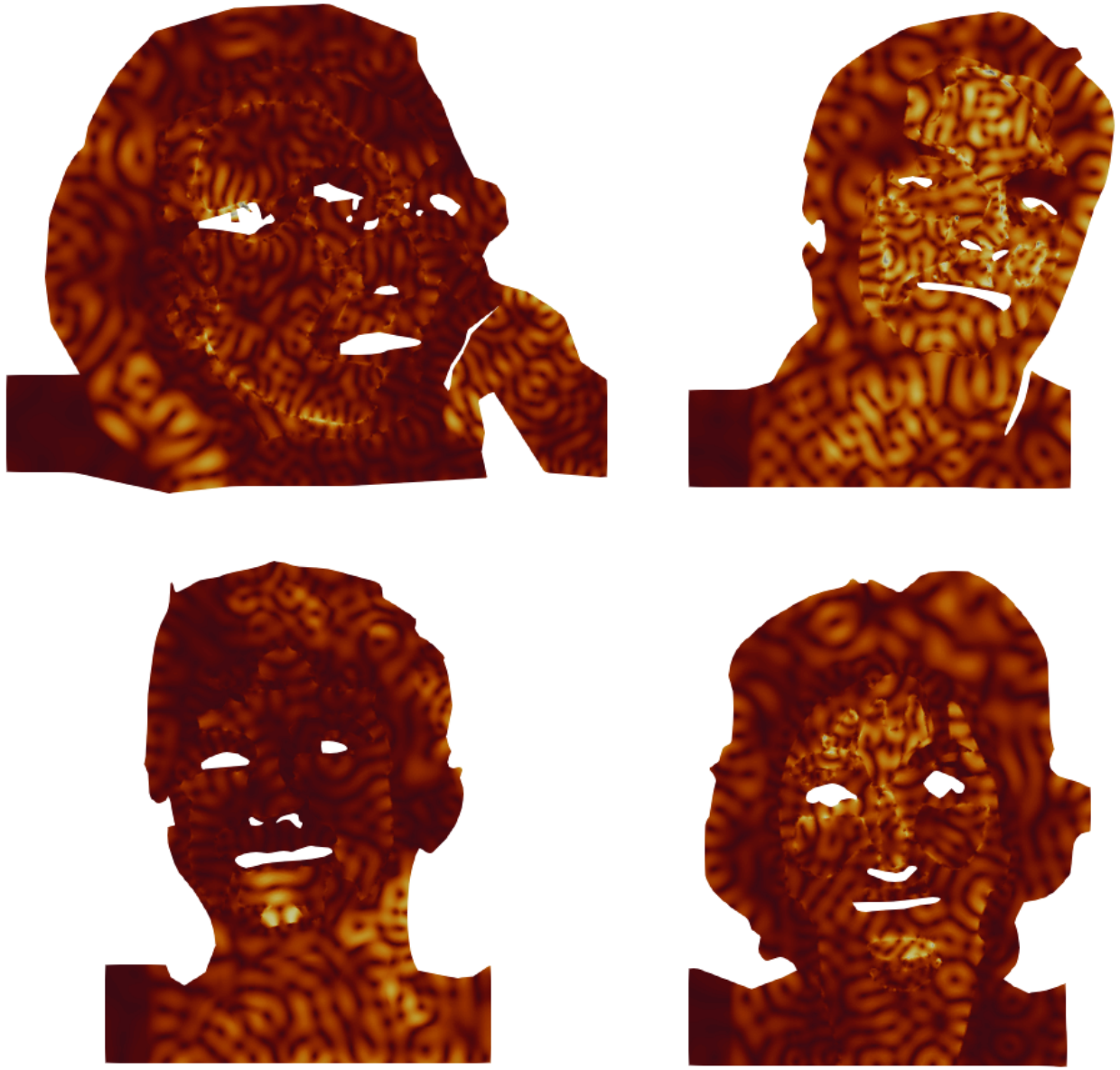
DEMO : SCATTERING BY POETS' PATTERNS



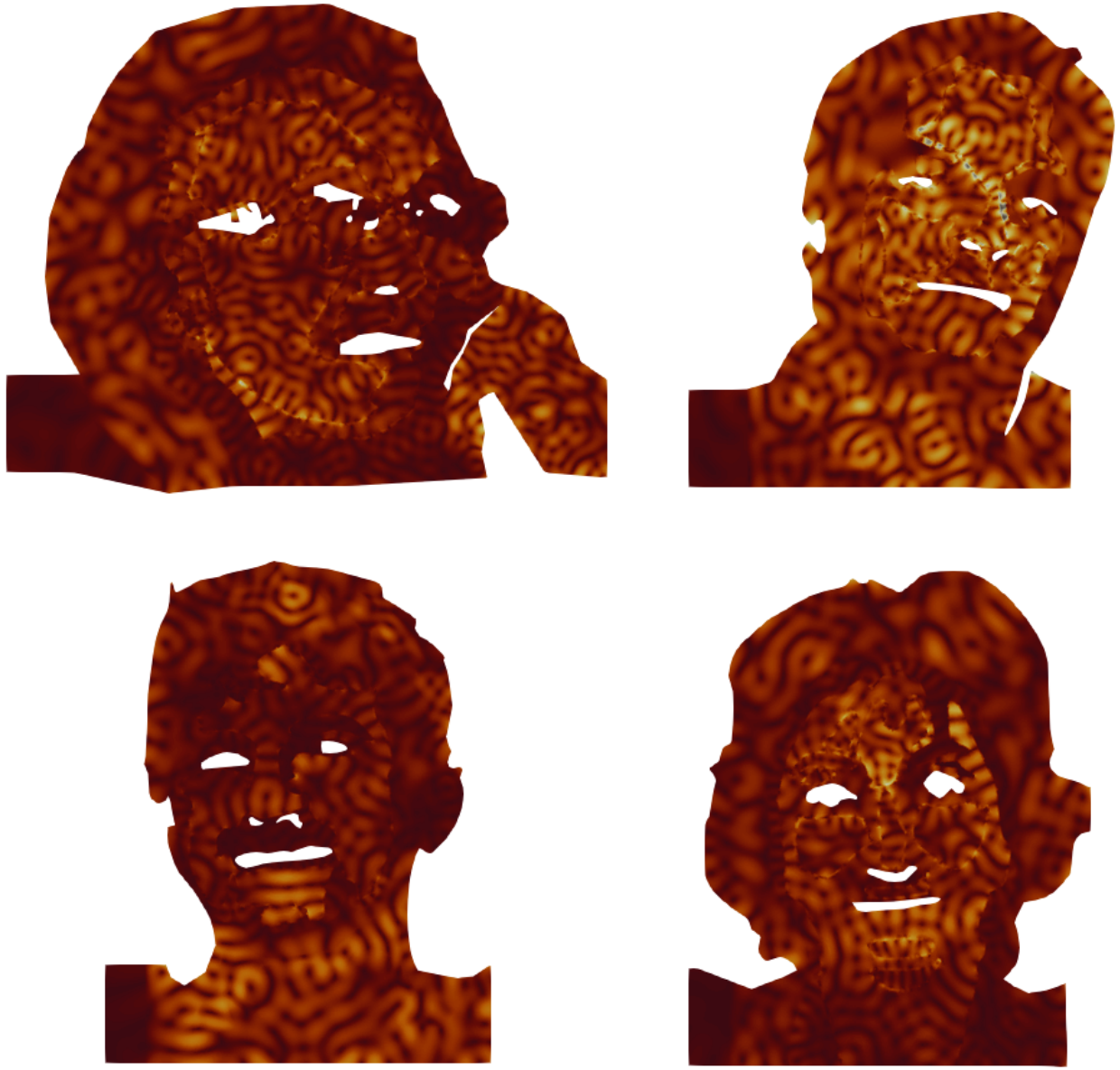
DEMO : SCATTERING BY POETS' PATTERNS



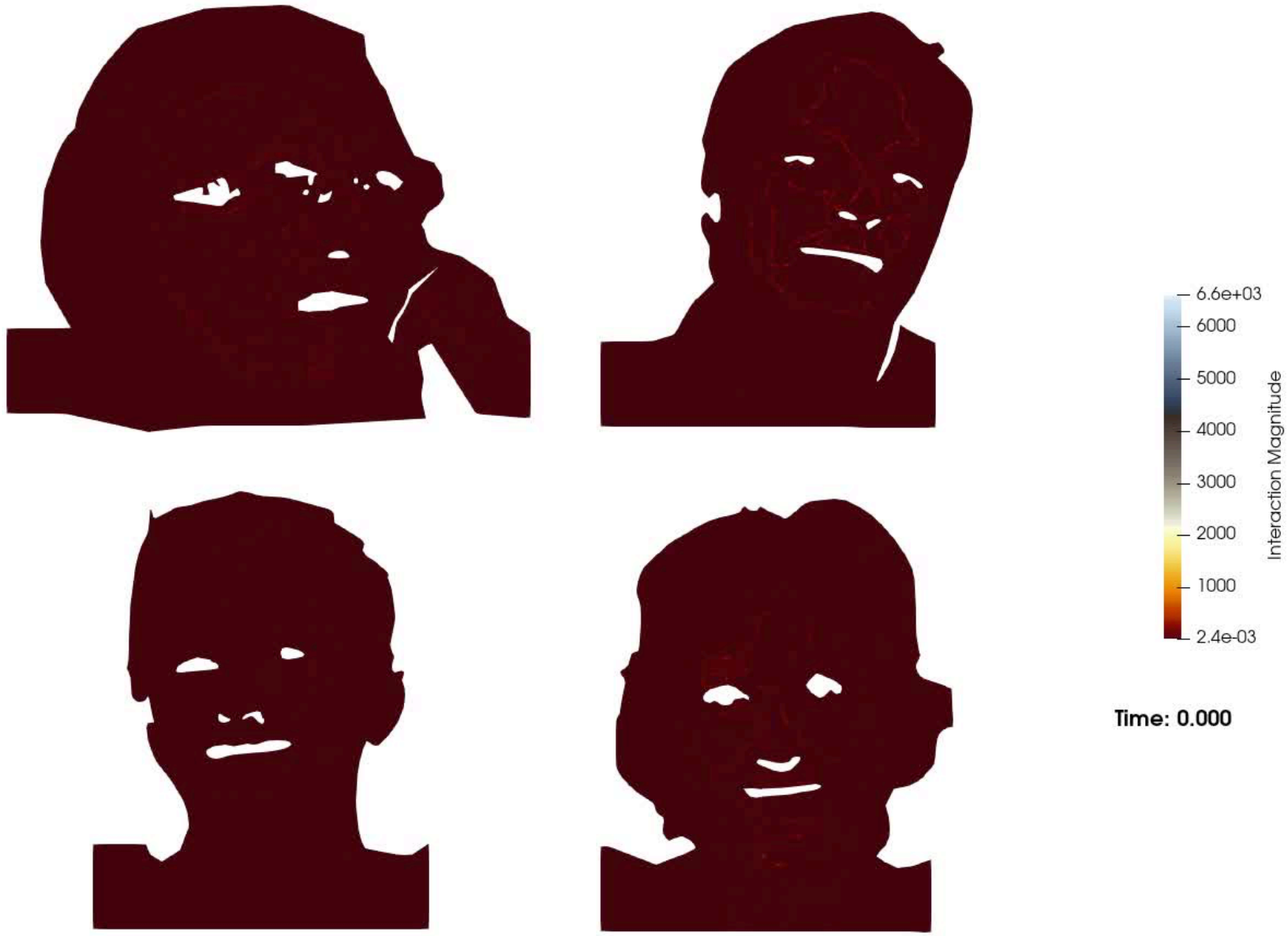
DEMO : SCATTERING BY POETS' PATTERNS



DEMO : SCATTERING BY POETS' PATTERNS



DEMO : SCATTERING BY POETS' PATTERNS



DEMO : SCATTERING BY POETS' PATTERNS + CRACKS

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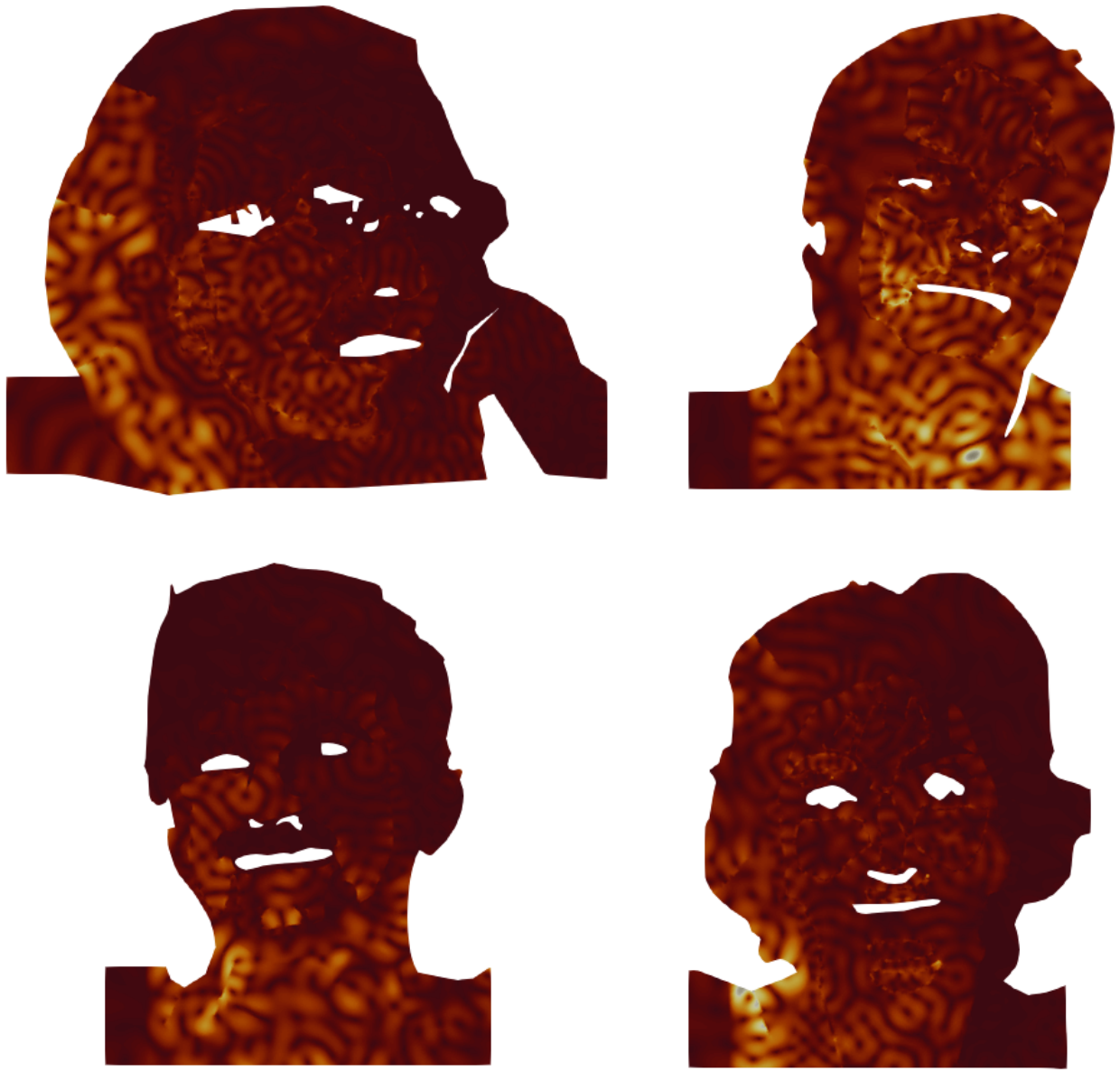

DEMO : SCATTERING BY POETS' PATTERNS + CRACKS

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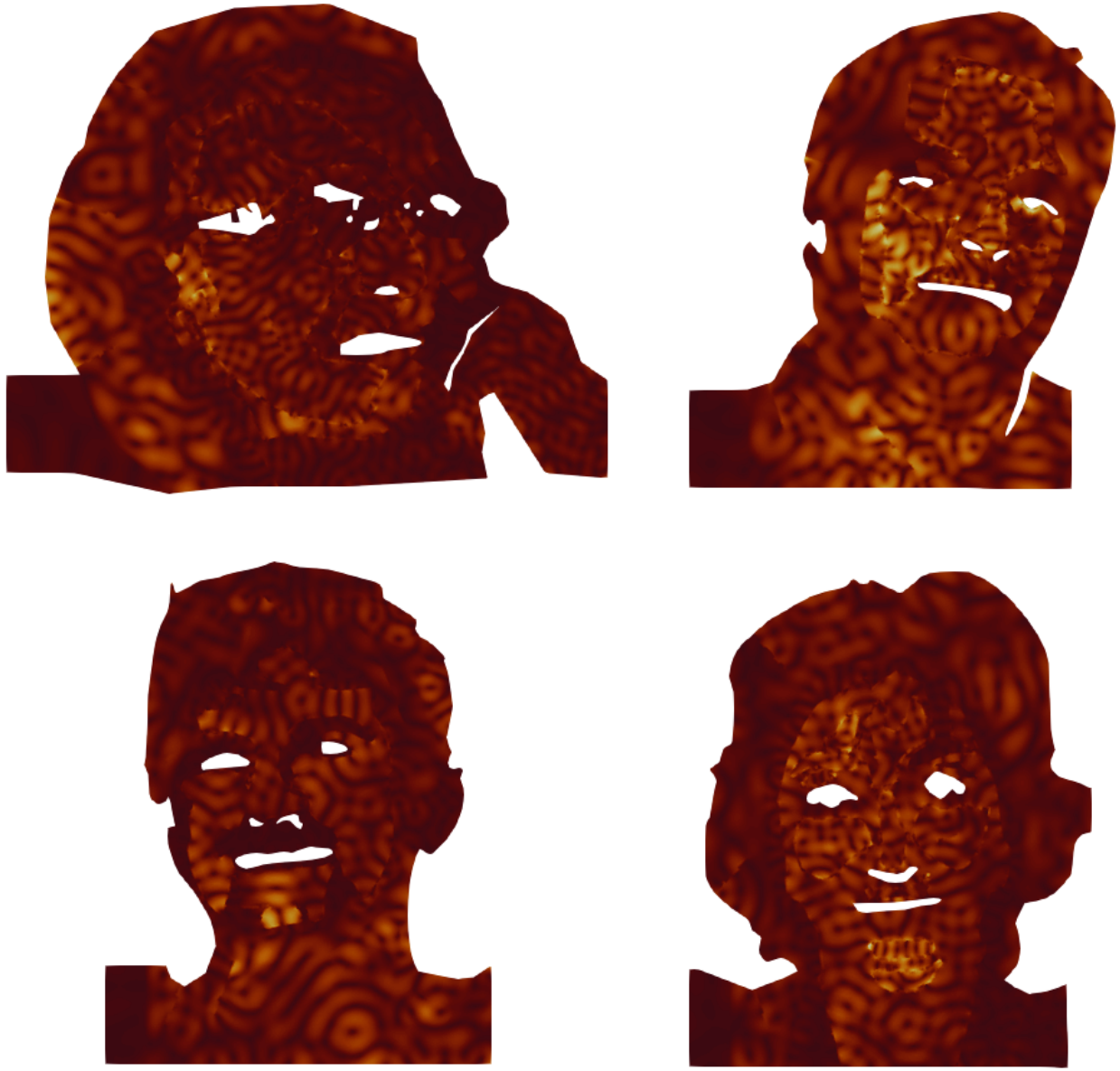
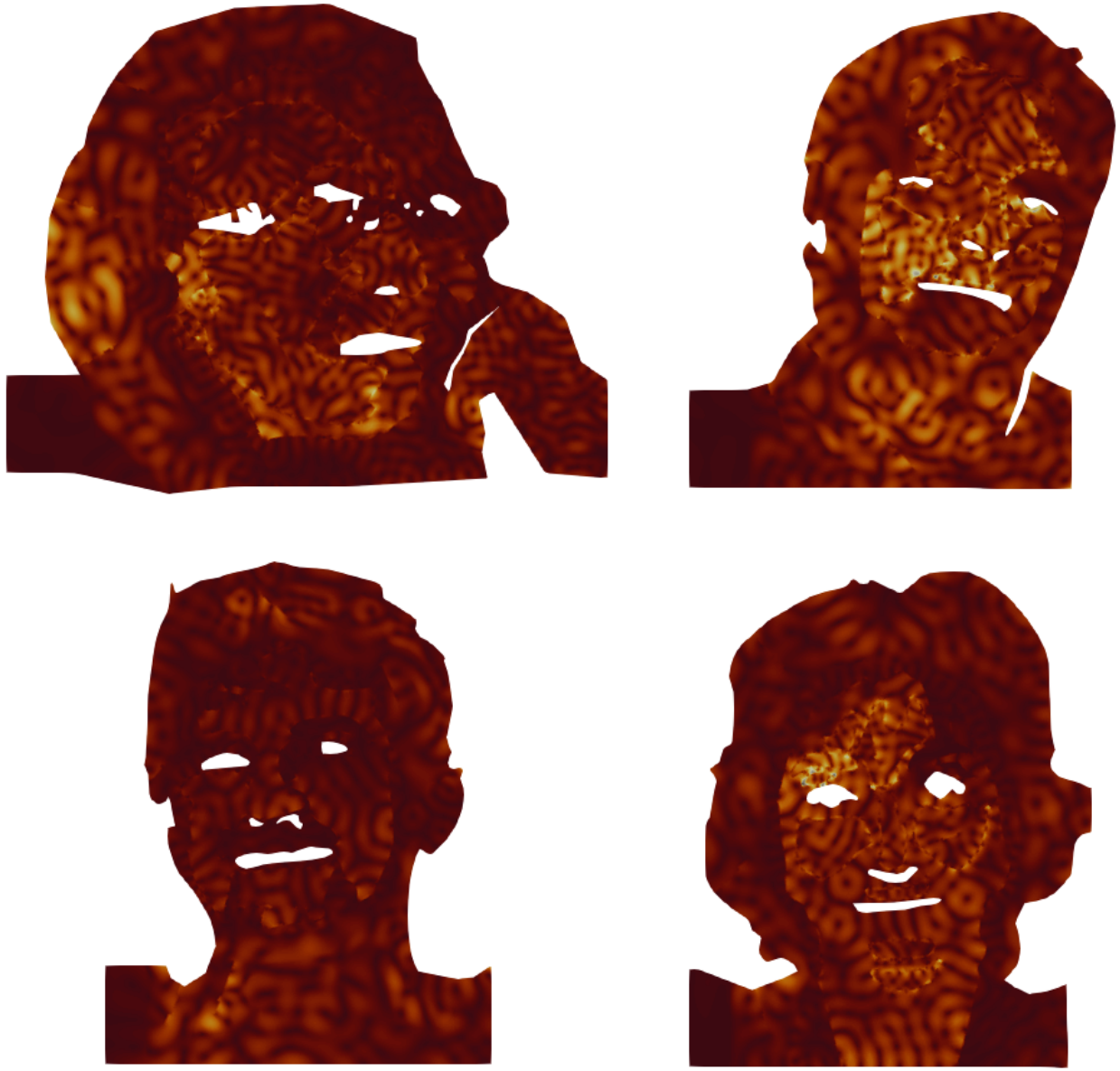
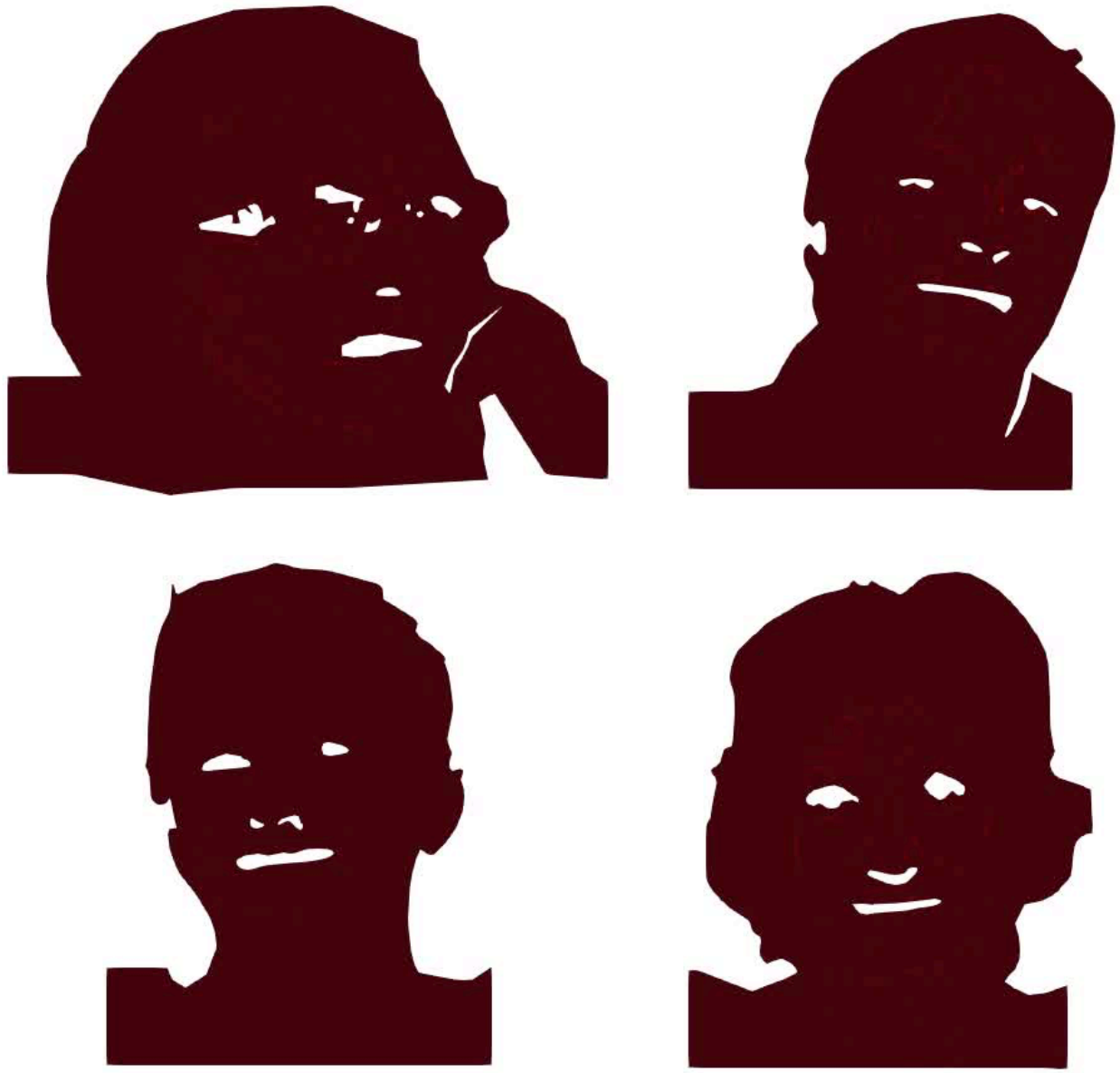


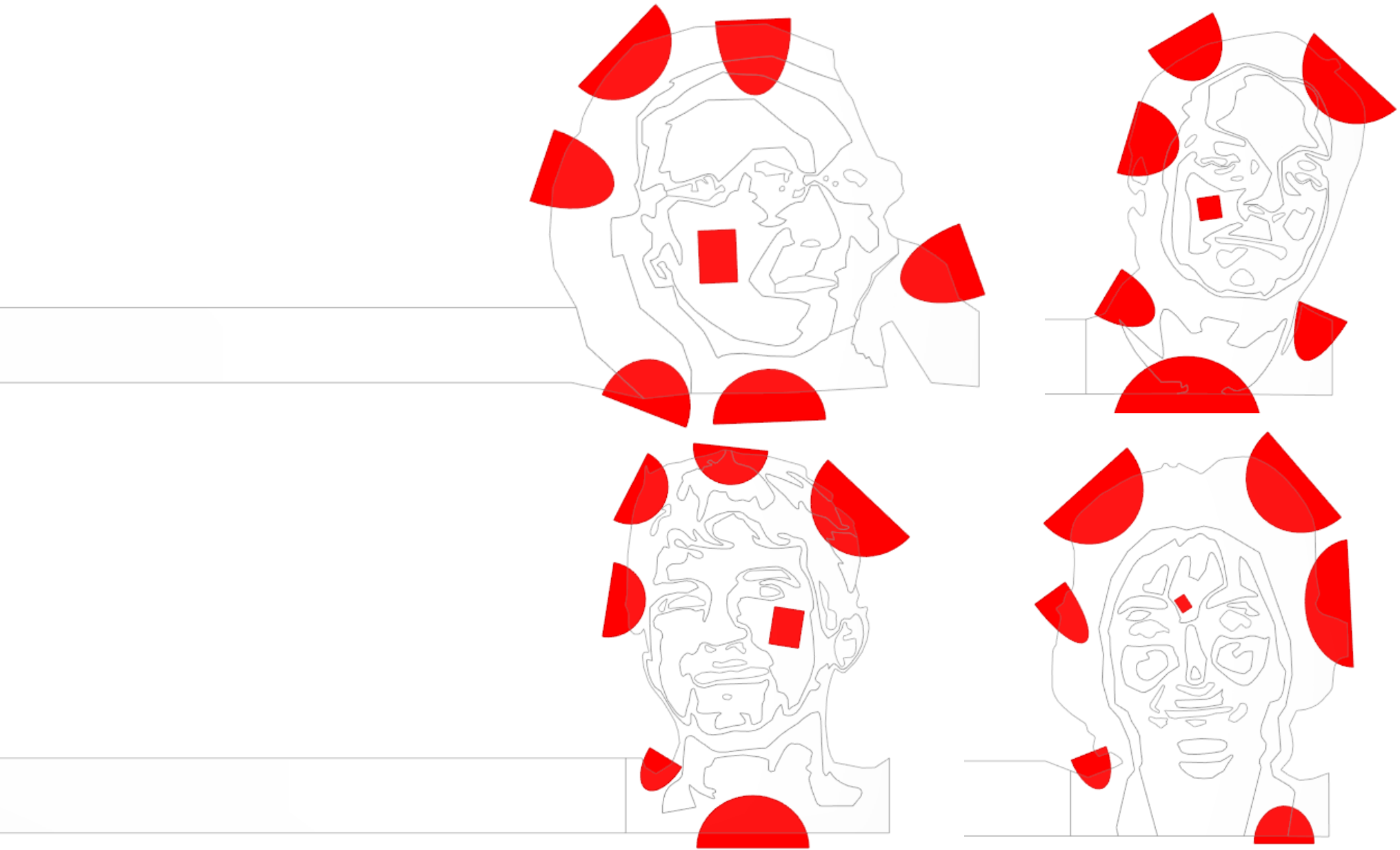
DEMO : SCATTERING BY POETS' PATTERNS + CRACKS



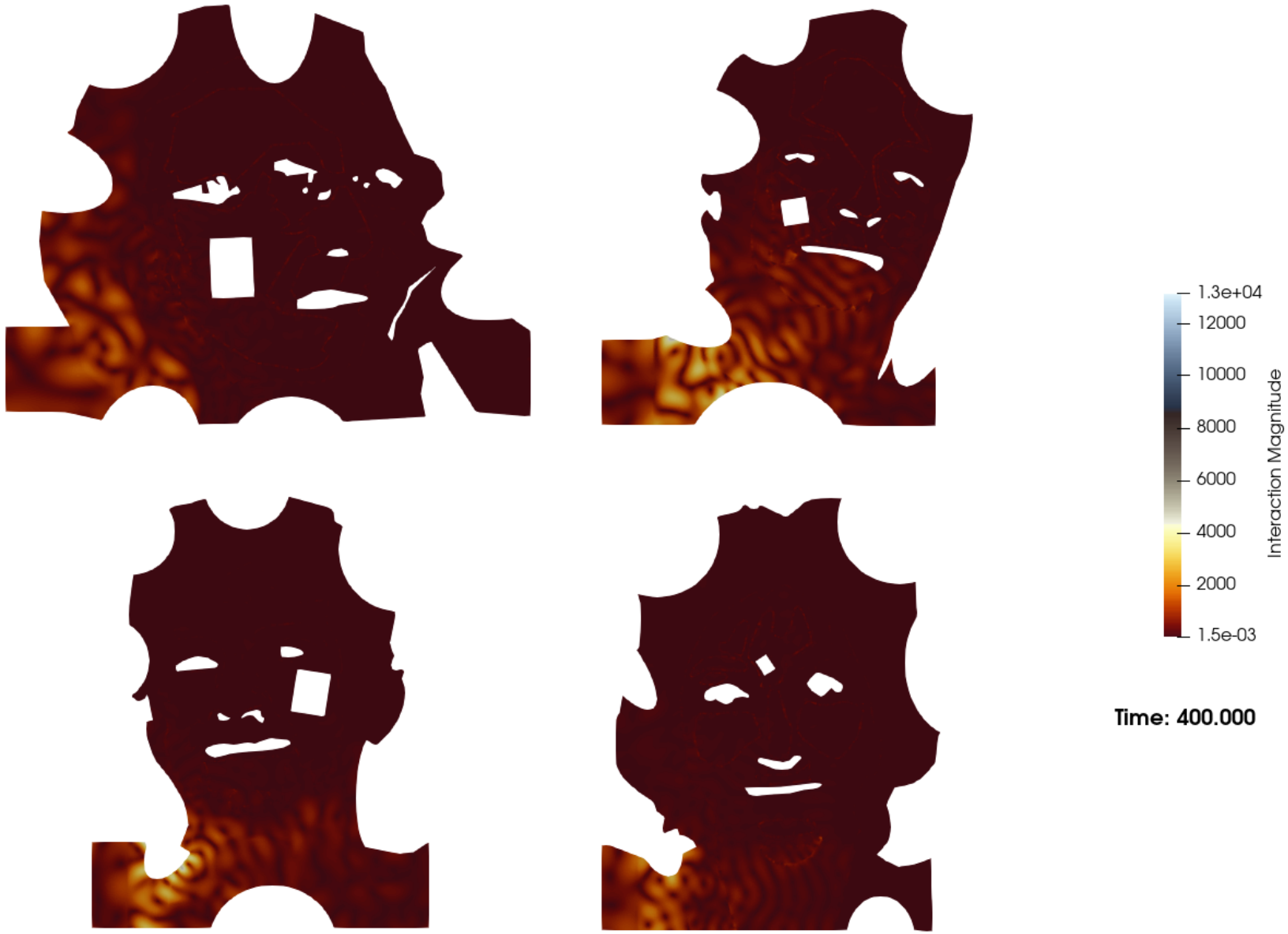
DEMO : SCATTERING BY POETS' PATTERNS + CRACKS



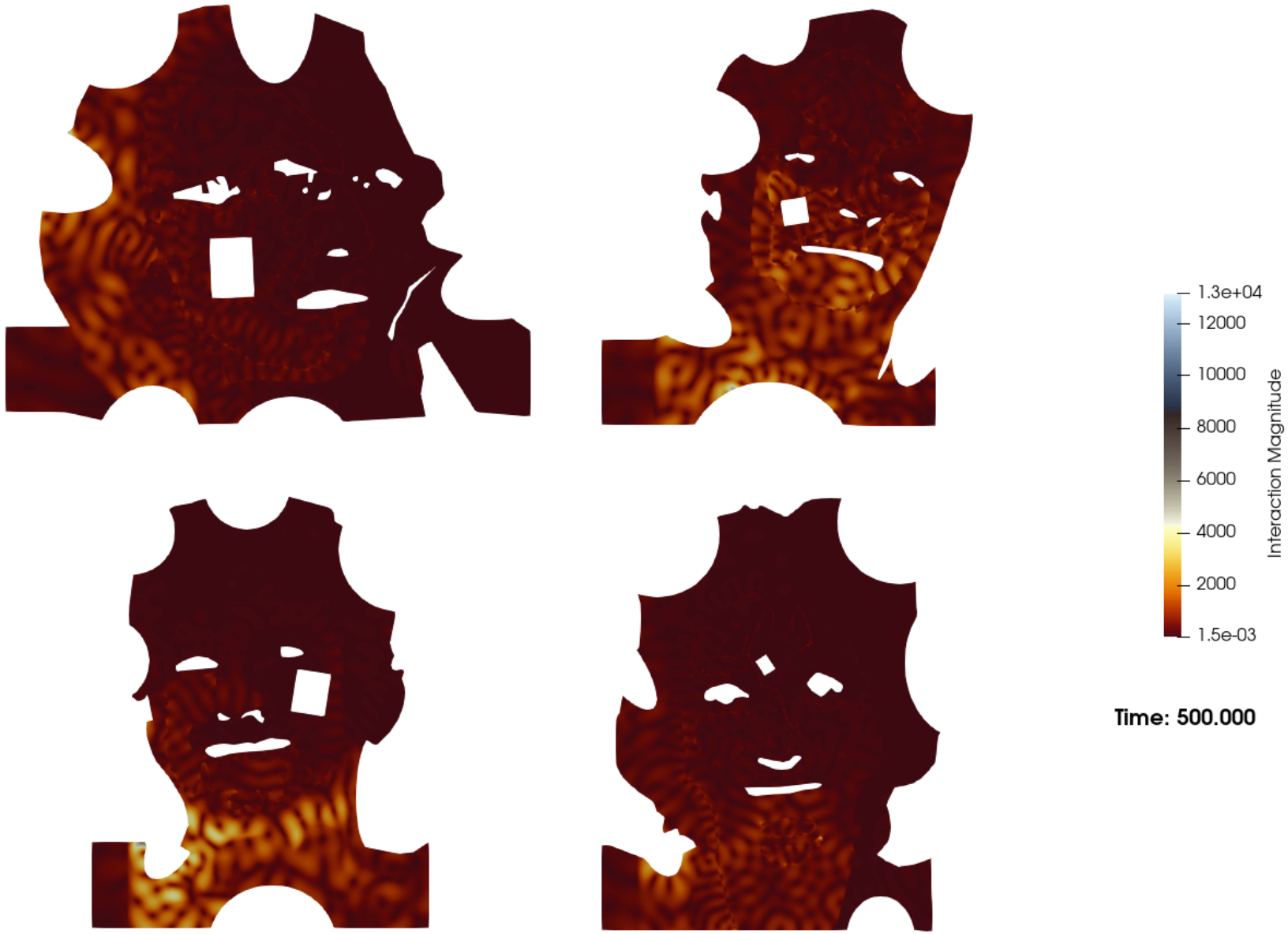
DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



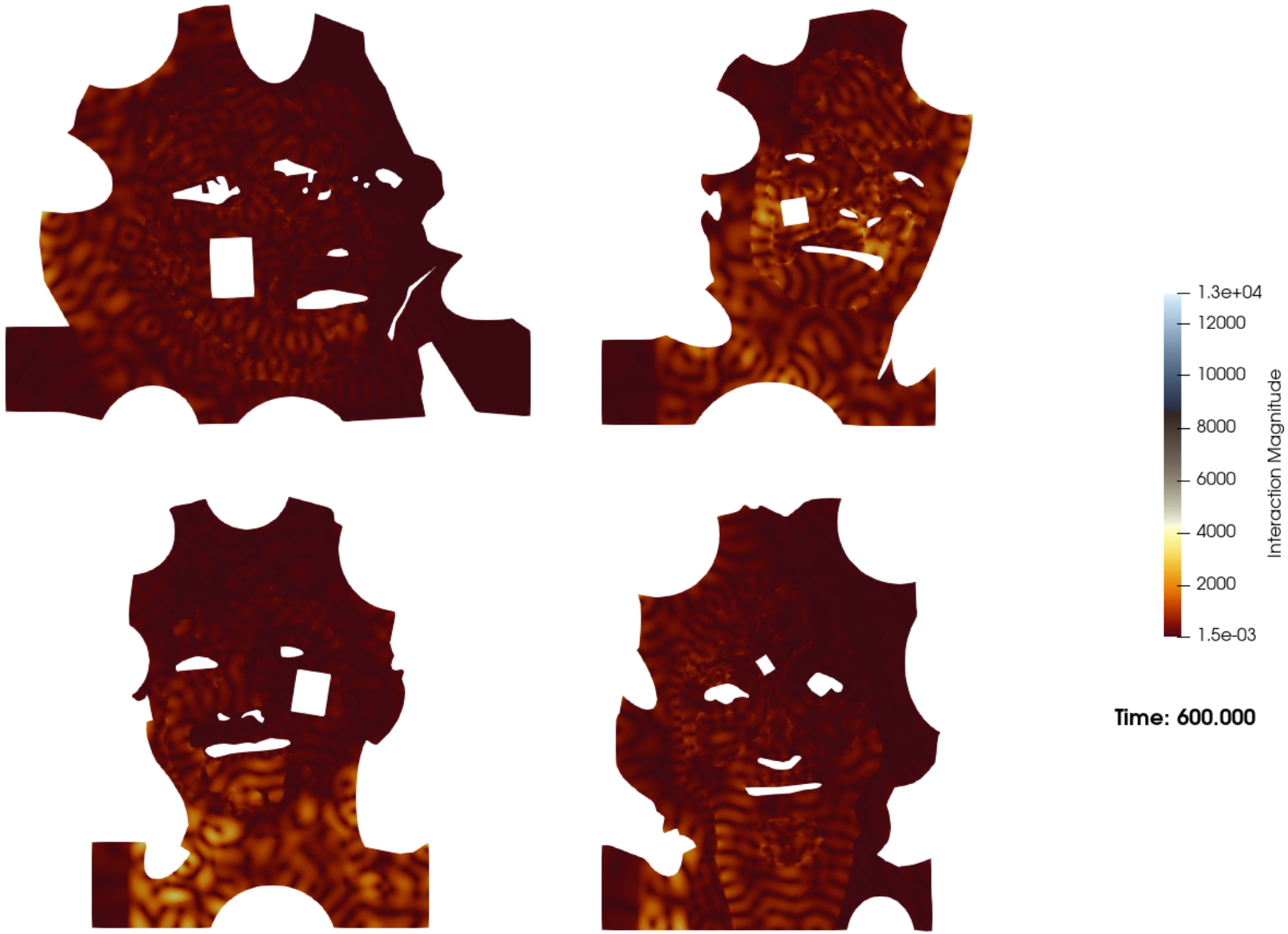
DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)

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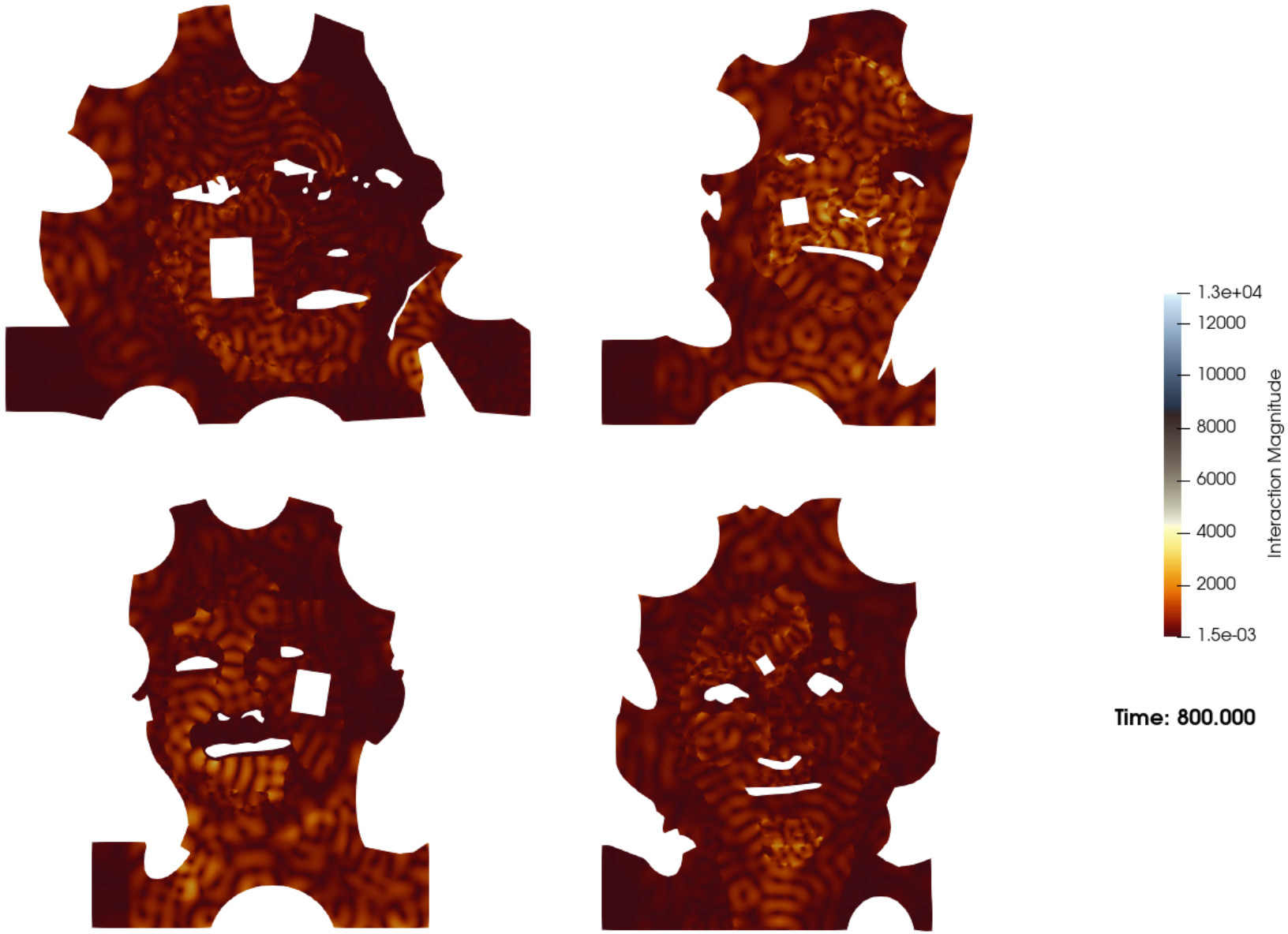
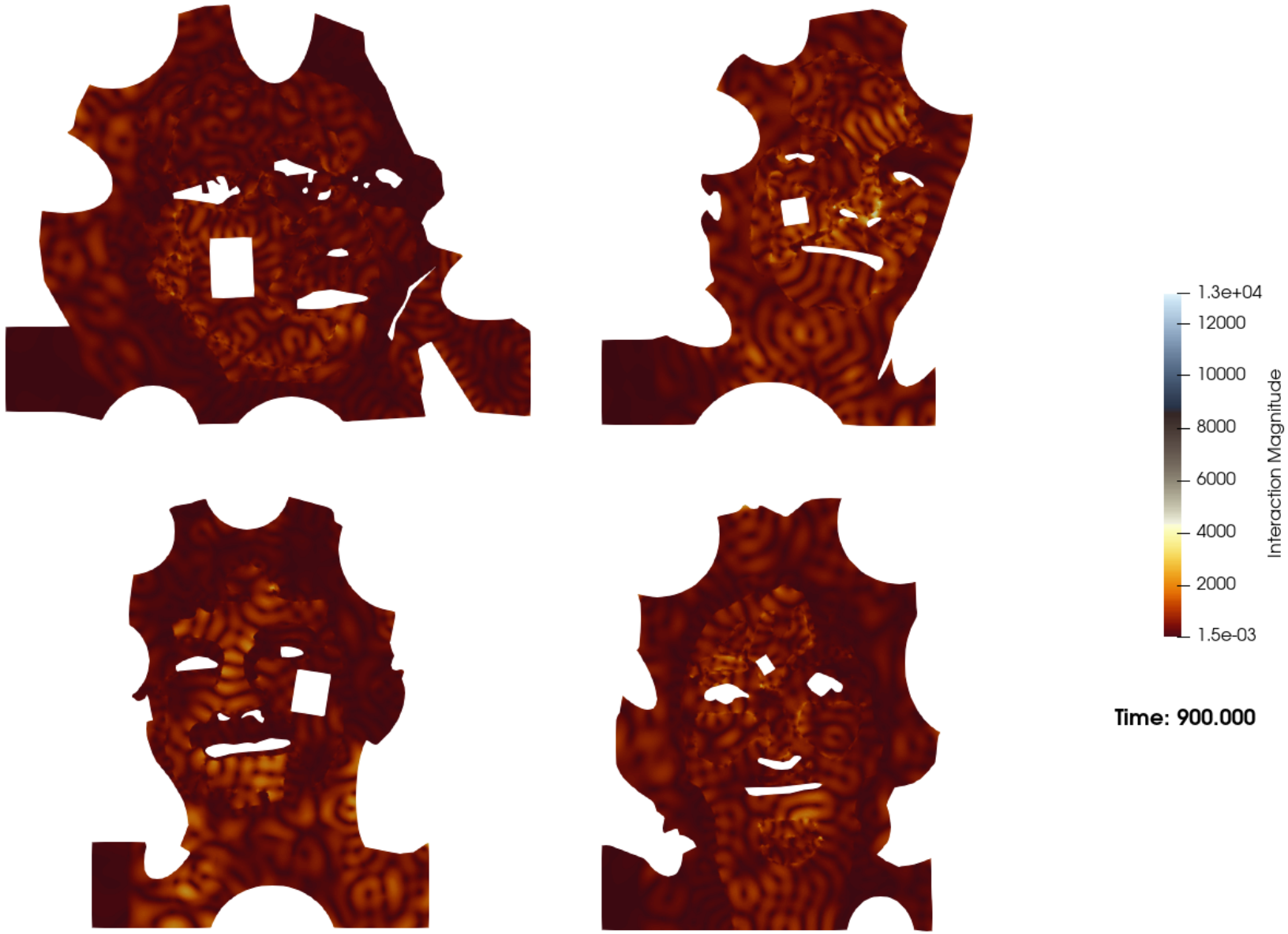
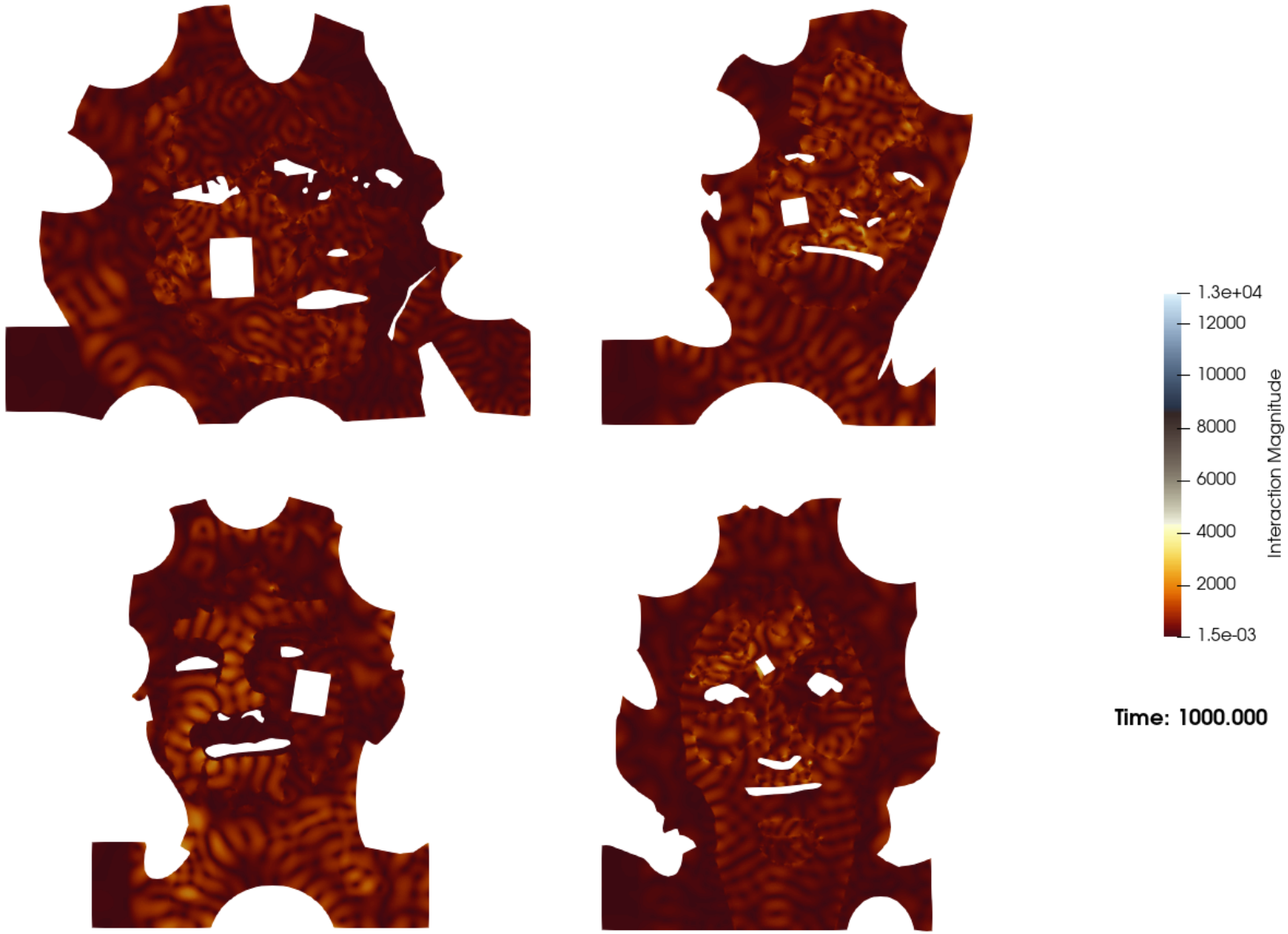


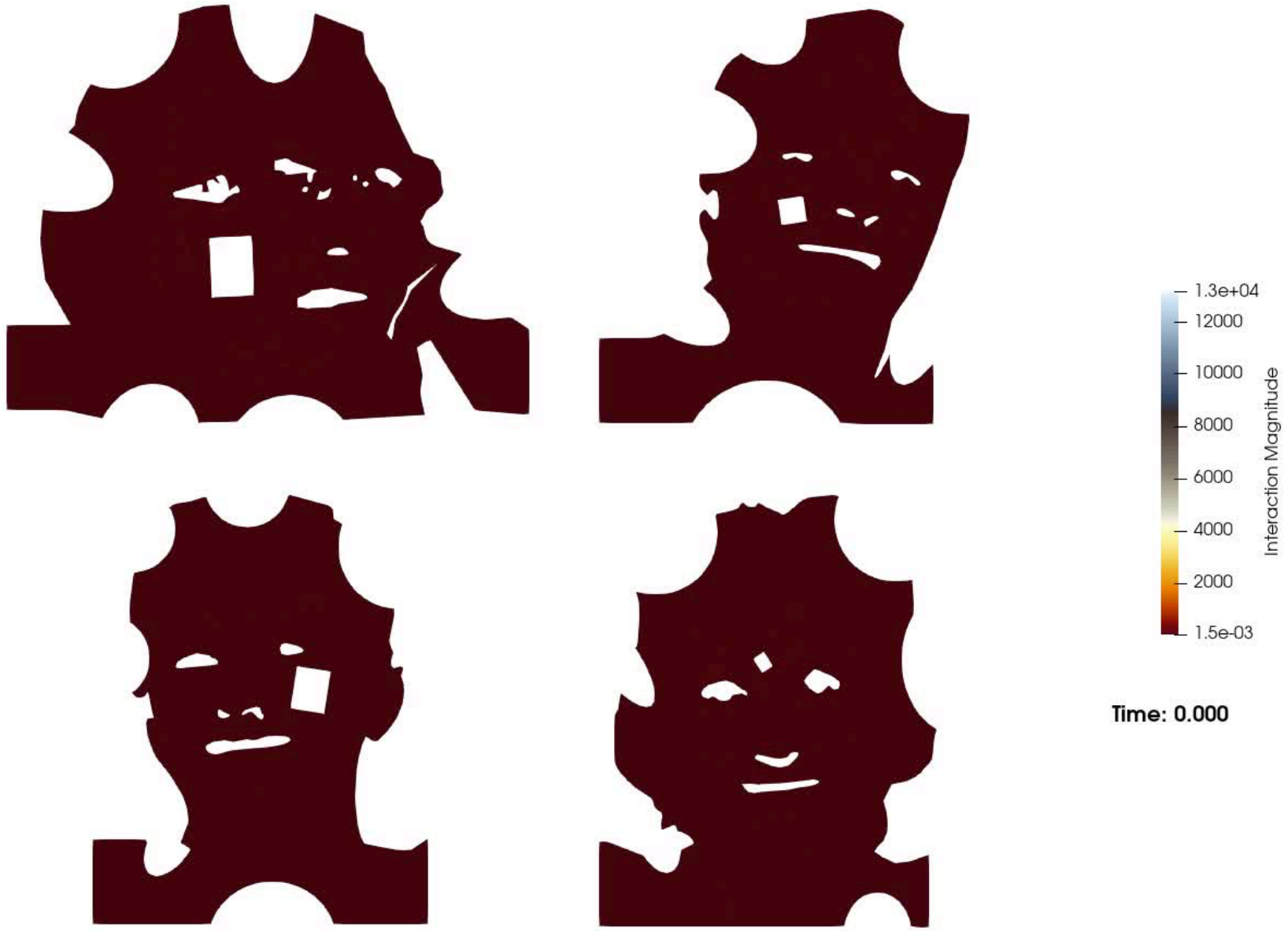
DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



DEMO : SCATTERING BY POETS' PATTERNS + HOLE(MIAM)



Bronze: 99

Silver: 99

Gold: 99

Multi: 99

THANKS FOR ALL & HAPPY BIRTHDAY

POUR ANNE-SOPHIE

AMOND ALLOUKO

OBJECTIF :

J'aimerais te remercier pour ce que tu as fait pour moi. T'honorer pour ces années et tes contributions pour la recherche française.

D’OÙ JE FAIS CES SLIDES

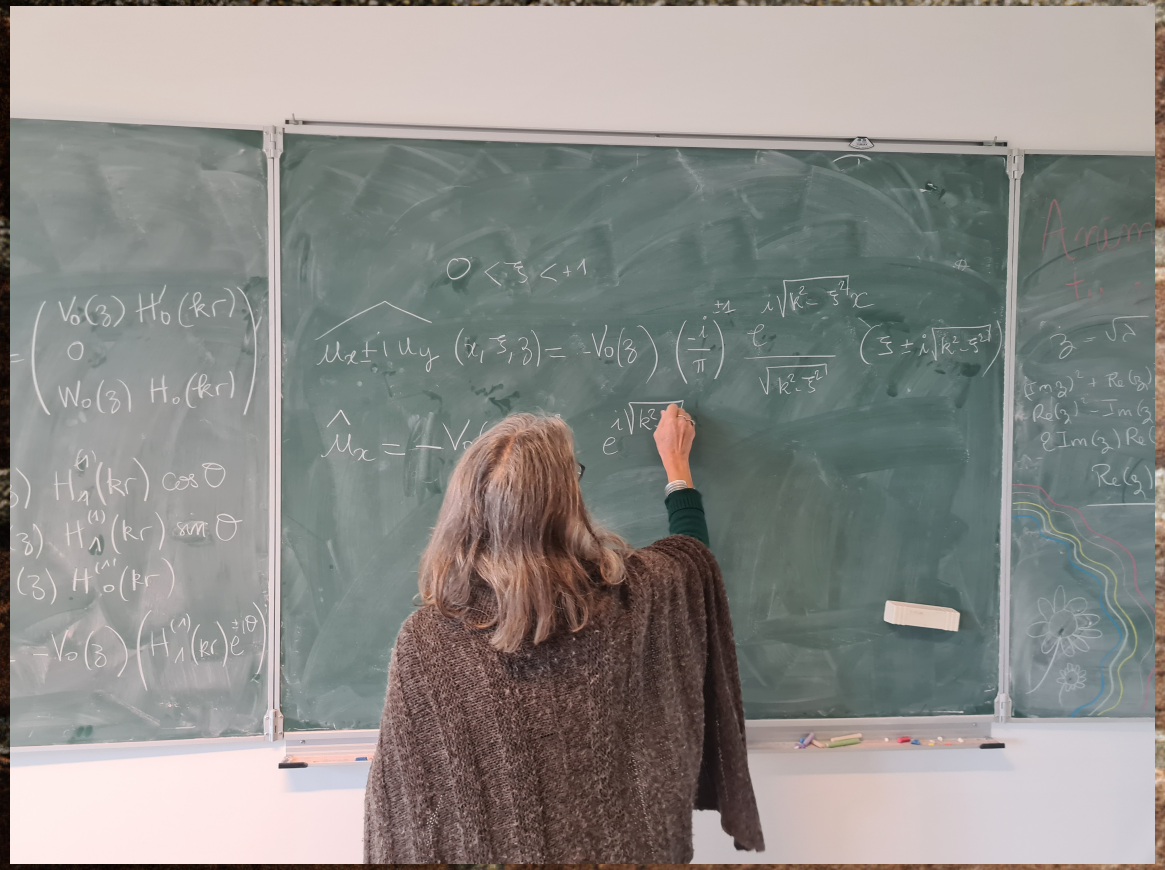
On a rien vu, ok ?☺

Abidjan, Côte d’Ivoire

CE QUE JE RETIENS DE TOI :

- GENTILLESSE, ATTENTIONNÉE, MATERNELLE
- RIGOUREUSE, MÊME DANS LES PETITES CHOSES
- POUR L'ÉNERGIE : ALORS LÀ, TU SAIS EN TRANSMETTRE ☺
- TRÈS PÉDAGOGUE, J'AI ÉNORMÉMENT APPRIS DE TOI

J'ADORAIS TE VOIR PARTIR DANS DES DÉVELOPPEMENTS



Pour à la fin, te demander de résumer .

Toujours patiente pour réexpliquer.

EN RÉSUMÉ, MERCI POUR TOUT. MA FIERTÉ A ÉTÉ DE TE RENDRE FIER

Je retourne pour une seconde bière, amusez vous !