

Numerical simulation of thermoplastic compression moulding complex shapes.

[Arthur Levy, arthur.levy@univ-nantes.fr](mailto:arthur.levy@univ-nantes.fr)

Laboratoire de Thermique et Energie de Nantes



Nantes



main campus



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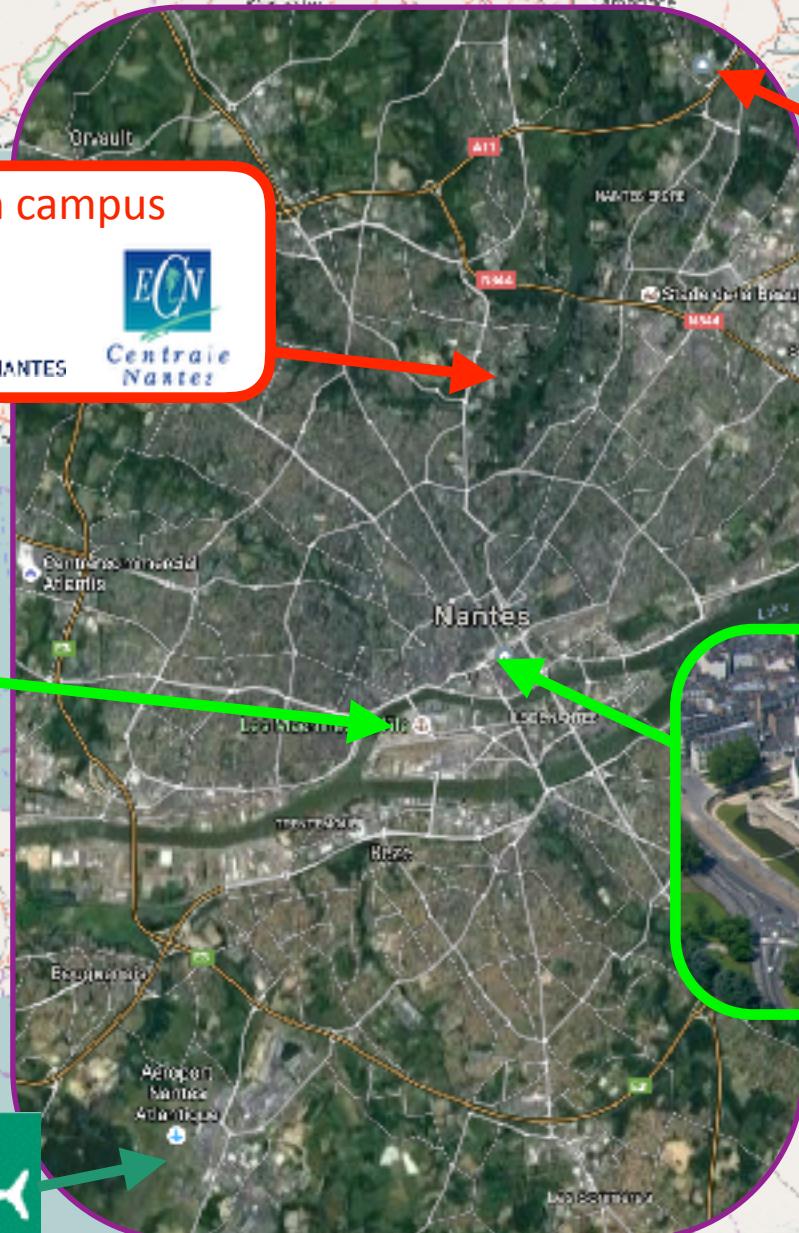


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Nantes

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A Composite hub in France

Industries



Academics



Institutes



Laboratoire de Thermique et Energie de Nantes (LTEN)



Composite team



Didier Delaunay



Jean-Luc Bailleul



Vincent Sobotka



Nicolas Boyard



Steven Le Corre

Numerical simulation of thermoplastic compression moulding complex shapes.



Arthur Levy,



Vincent Sobotka,



Steven Le Corre,



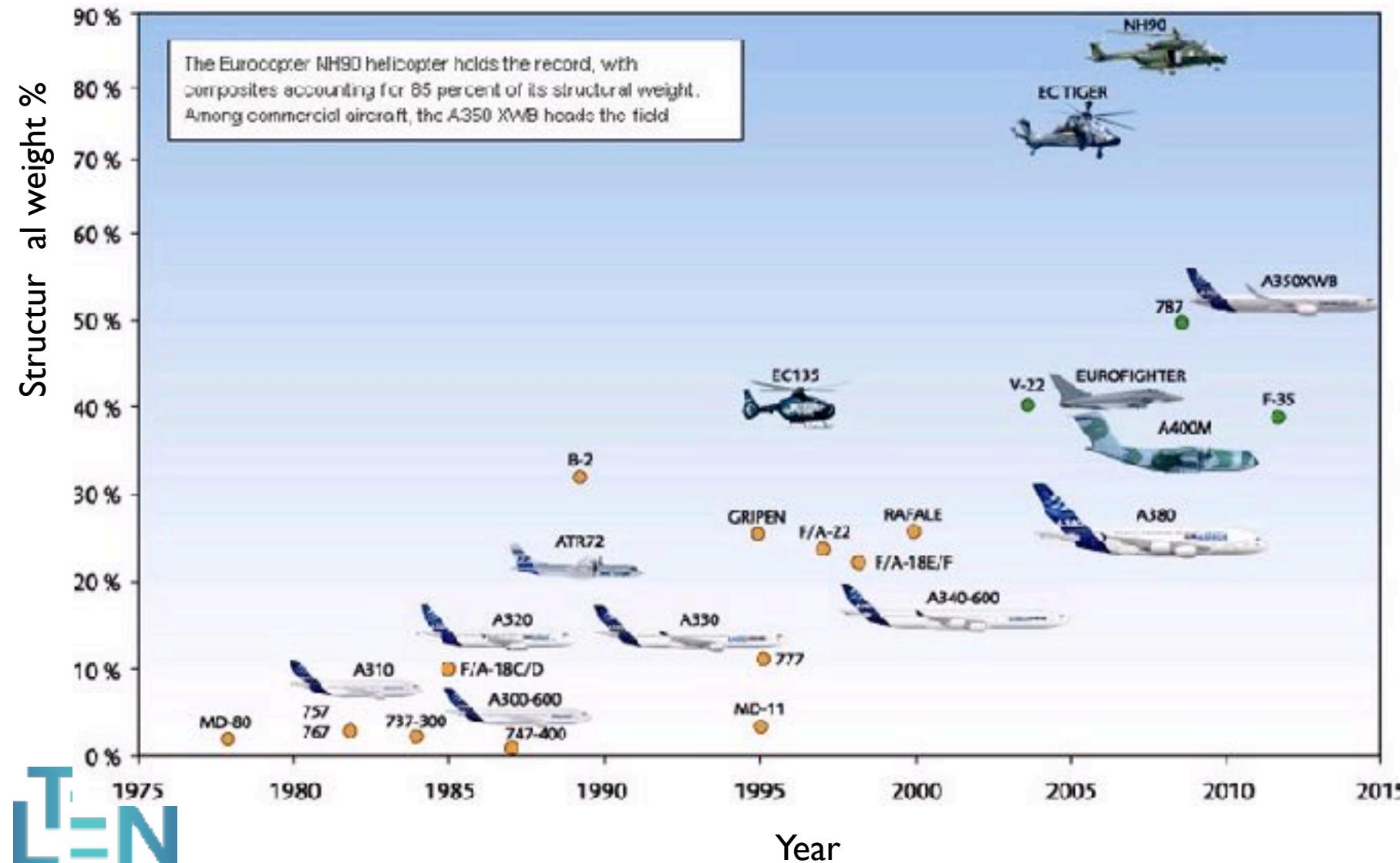
Maxime Villière



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Composite use in aeronautical industry



Today's challenges

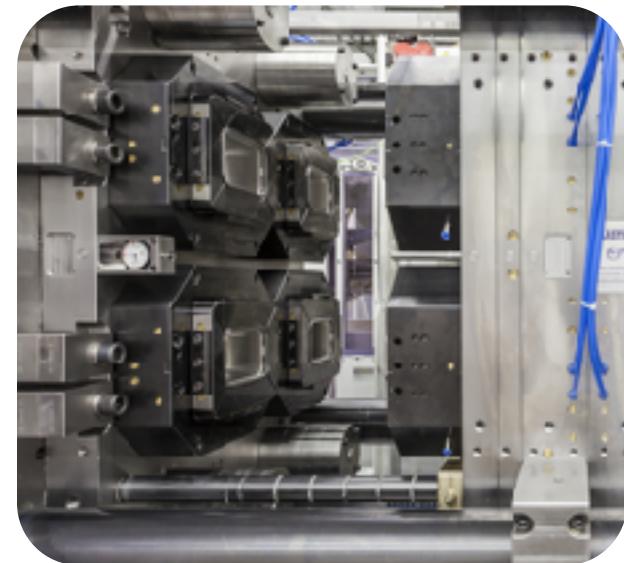
Increase part complexity and dimensions



Ultra-thick laminate Airbus

- Intricate parts
- Thick parts

Reduce manufacturing cost



Plastic Omnium

- Fast and efficient cycles
- Out-of-autoclave



Compression moulding of thermoplastic composites

Thermoplastic compression moulding

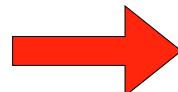
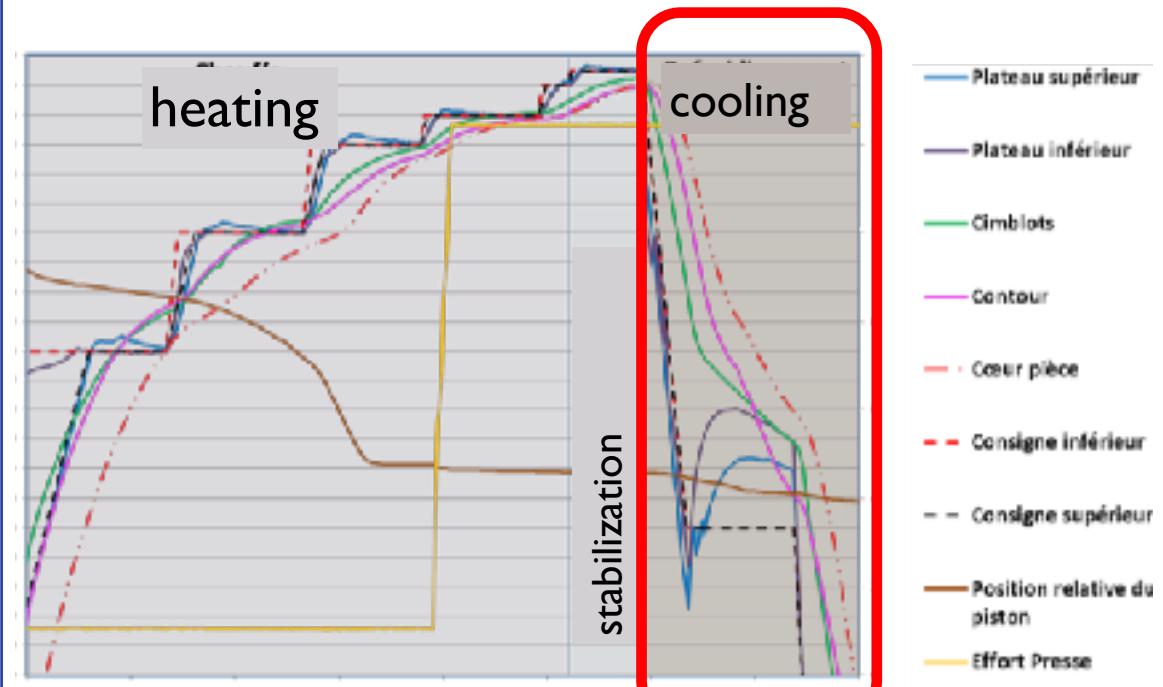
Procedure



Pinette Press

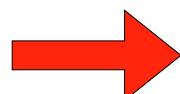
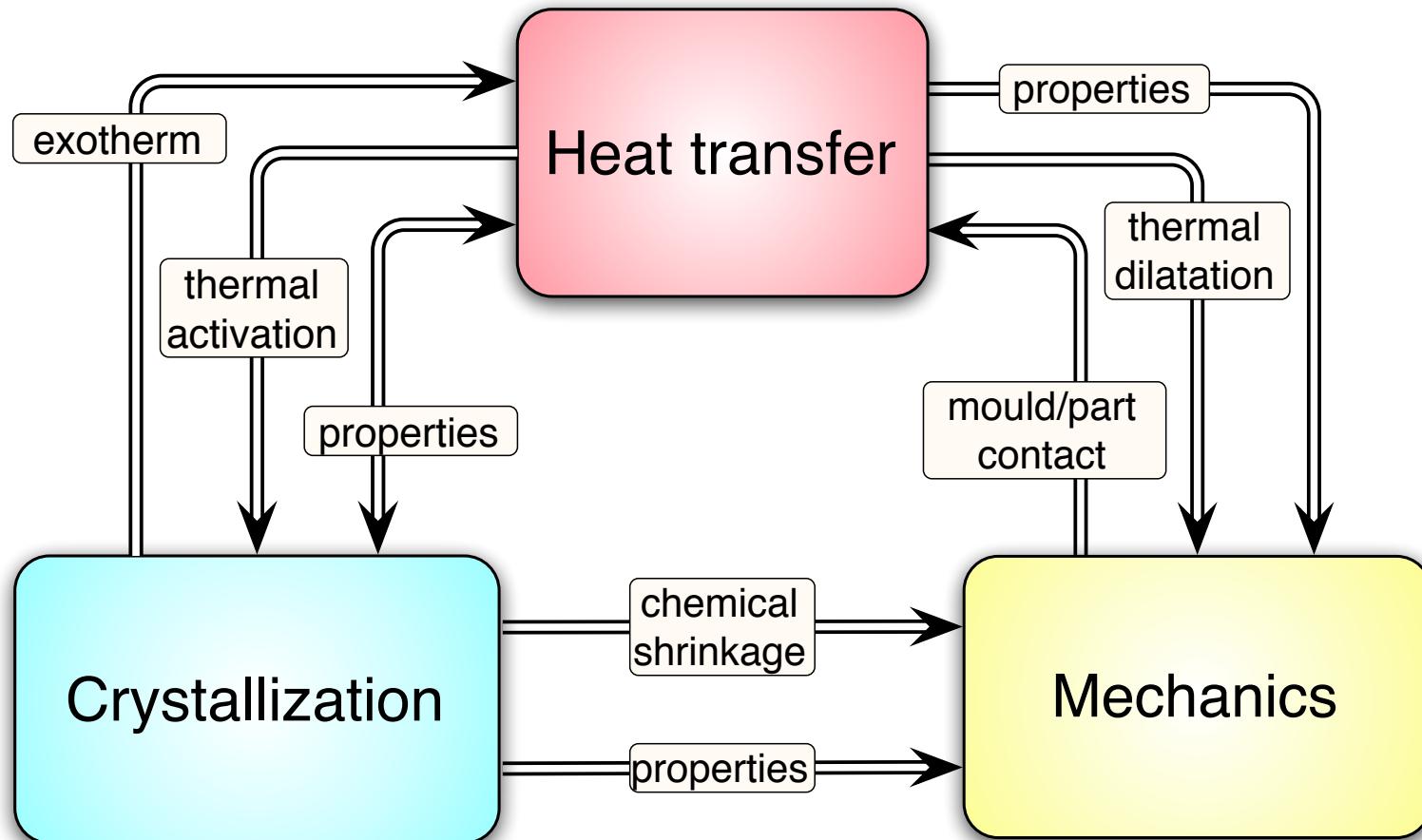
Thick part

Complex temperature cycle



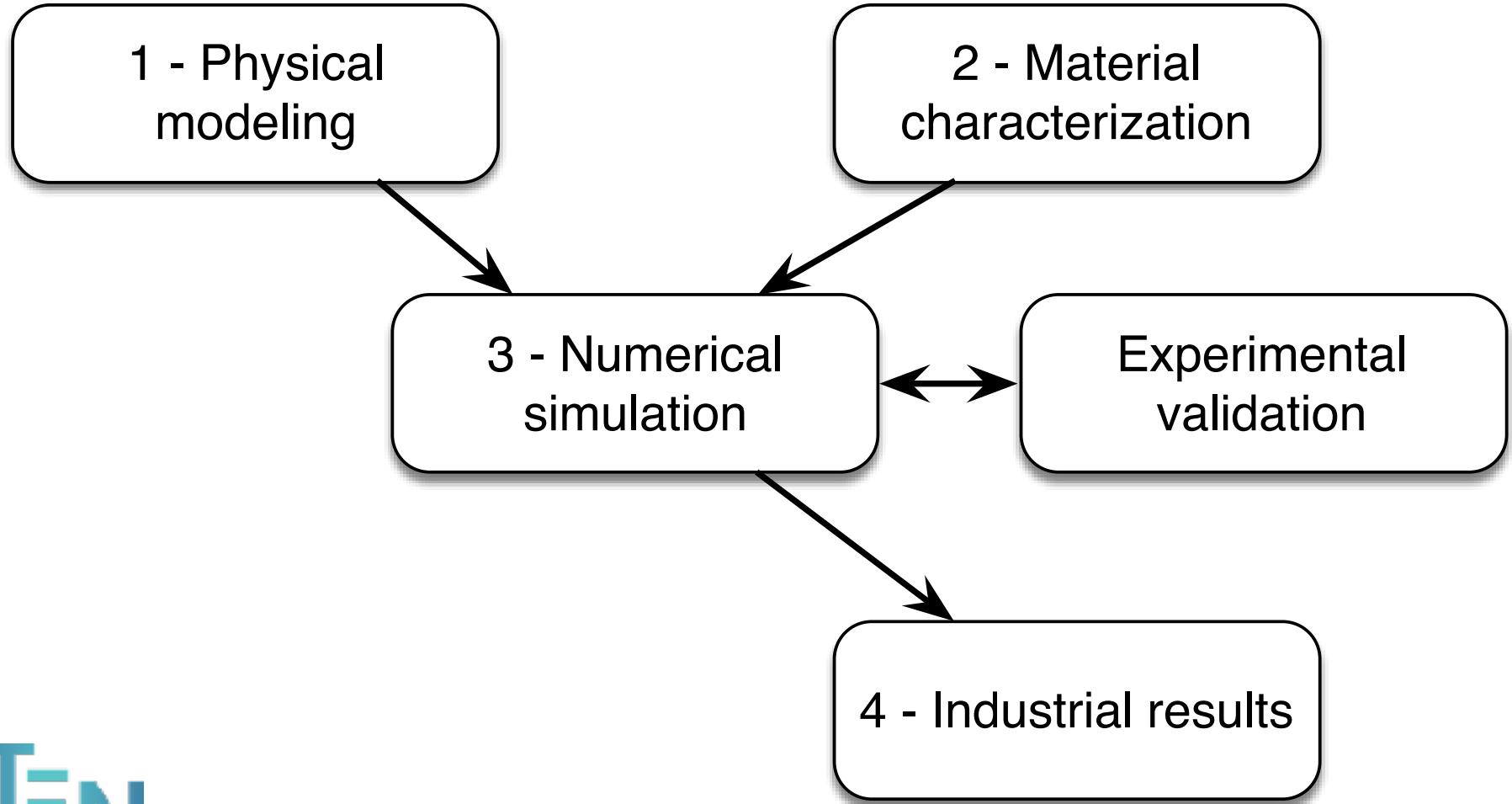
Study of the cooling phase

Motivation

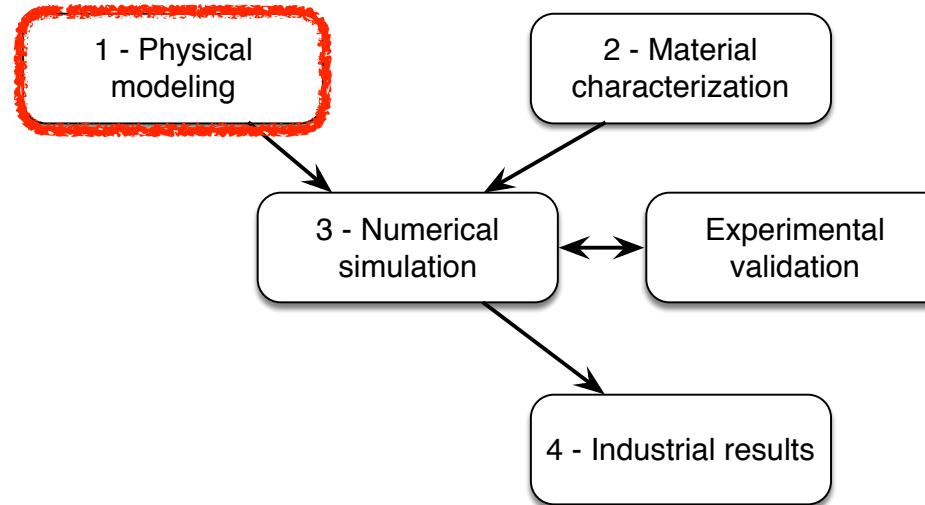


**Prediction of heat transfer and crystallization.
Understand / control / optimize the process**

Outline

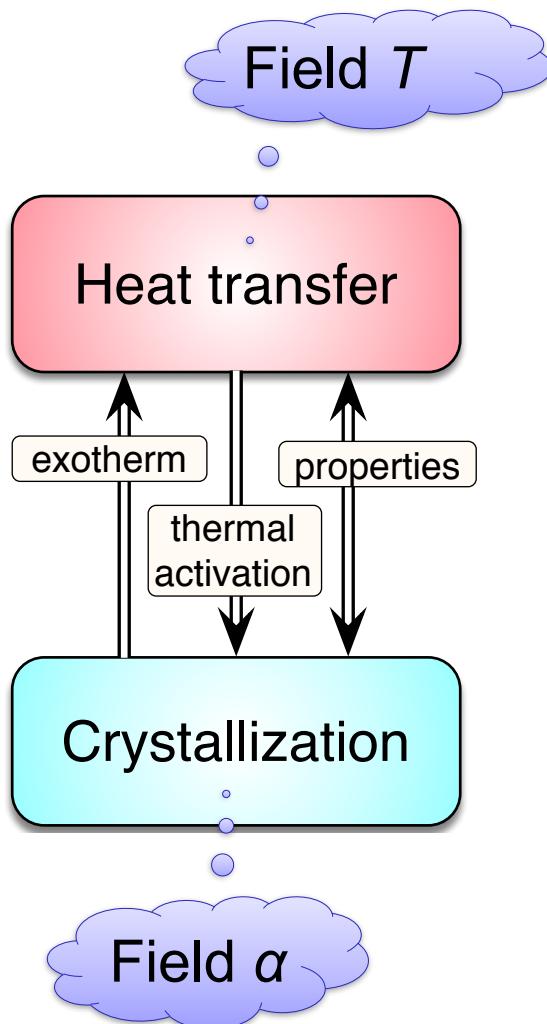


Modelling

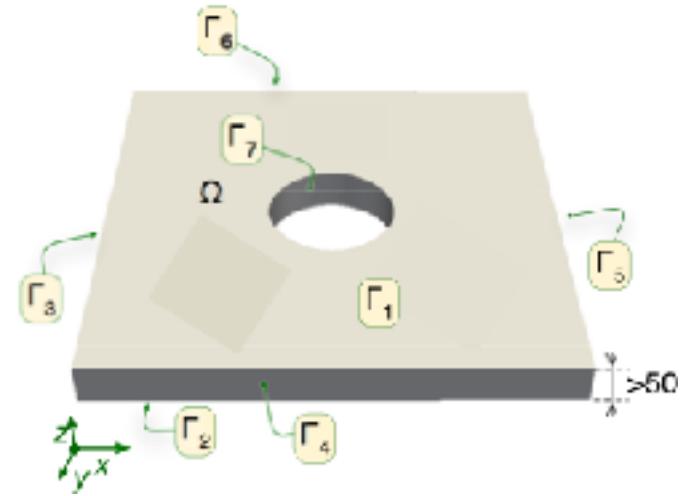


Framework

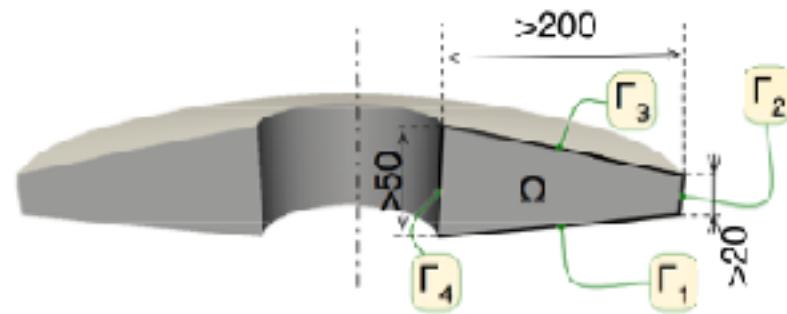
Physics involved



Thick geometries



3D industrial intricate domain
(idealized here for confidentiality reasons)



Simplified 2D geometry

Heat transfer

Homogeneous transverse isotropic material

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\bar{\lambda} \nabla T) + \rho_m \phi_m L \frac{\partial \alpha}{\partial t}$$

Inertia

density

Specific heat

diffusion

Thermal conductivity

$$\bar{\lambda} = \begin{bmatrix} \lambda_{plan} & 0 & 0 \\ 0 & \lambda_{plan} & 0 \\ 0 & 0 & \lambda_z \end{bmatrix}$$

exotherm

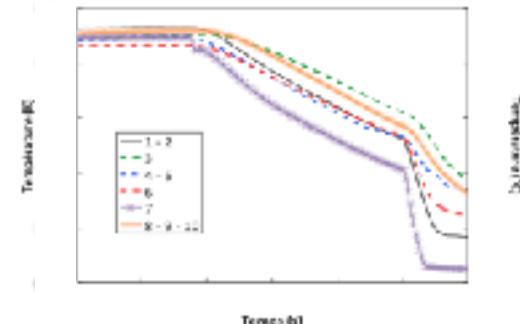
Cristallization heat

Initial condition

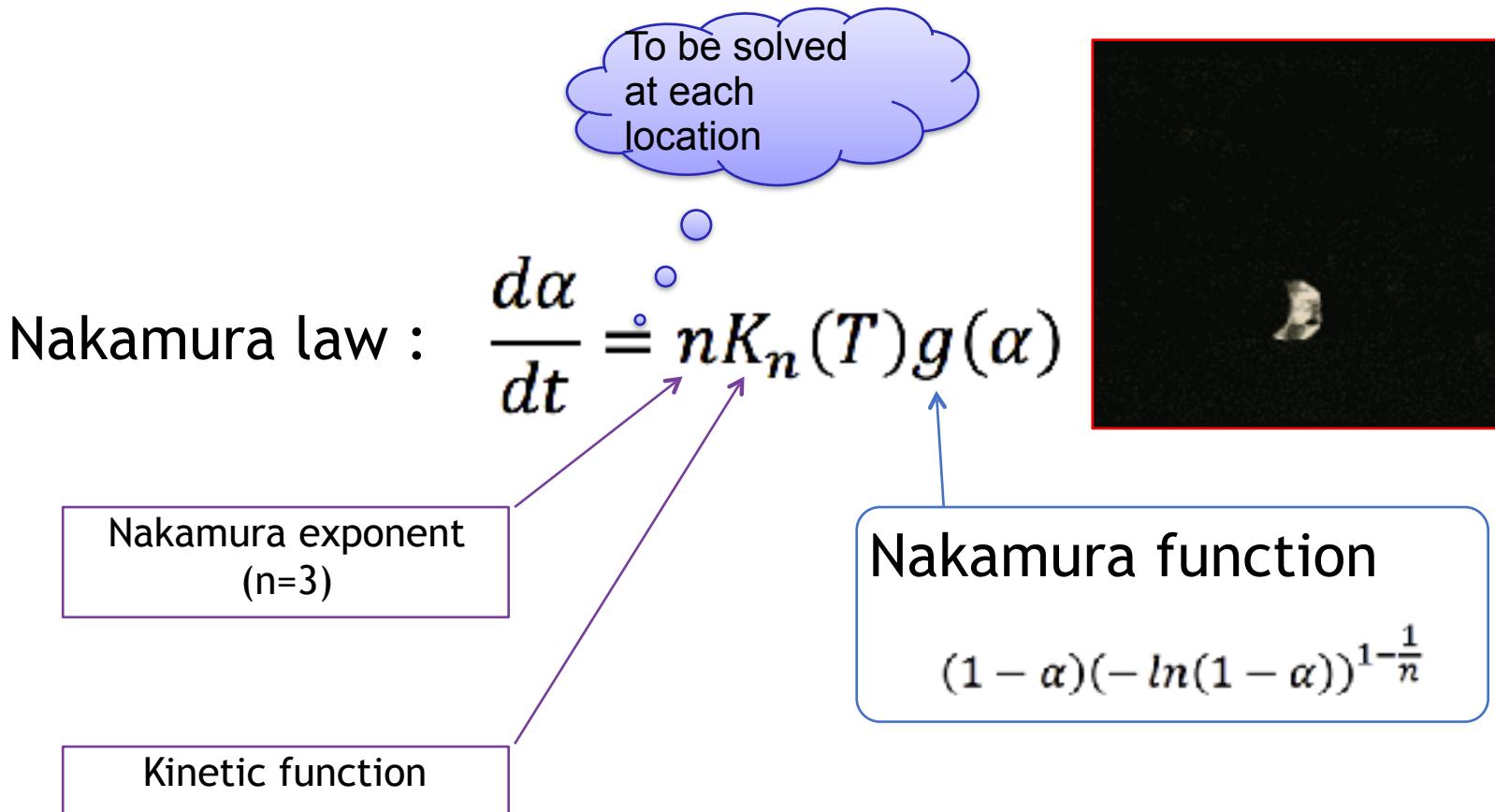
isotherm / molten

Boundary conditions

Real cycle
measured
experimentally



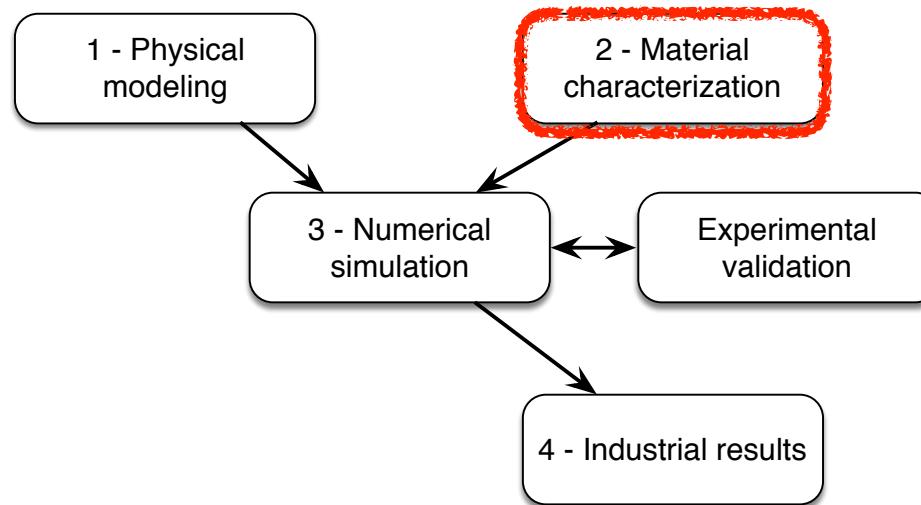
Crystallization kinetics



- Initial condition : molten ($\alpha(t=0)=0$)

[Nakamura et al. 72, Tardif et al. 14, Quinlan 11]

Characterization



Crystallization kinetics

$$\frac{d\alpha}{dt} = nK_n(T)g(\alpha)$$

Avrami index

Kinetic function

Published example : PEEK

ature

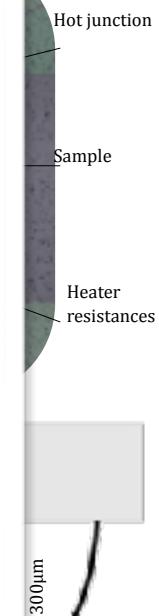
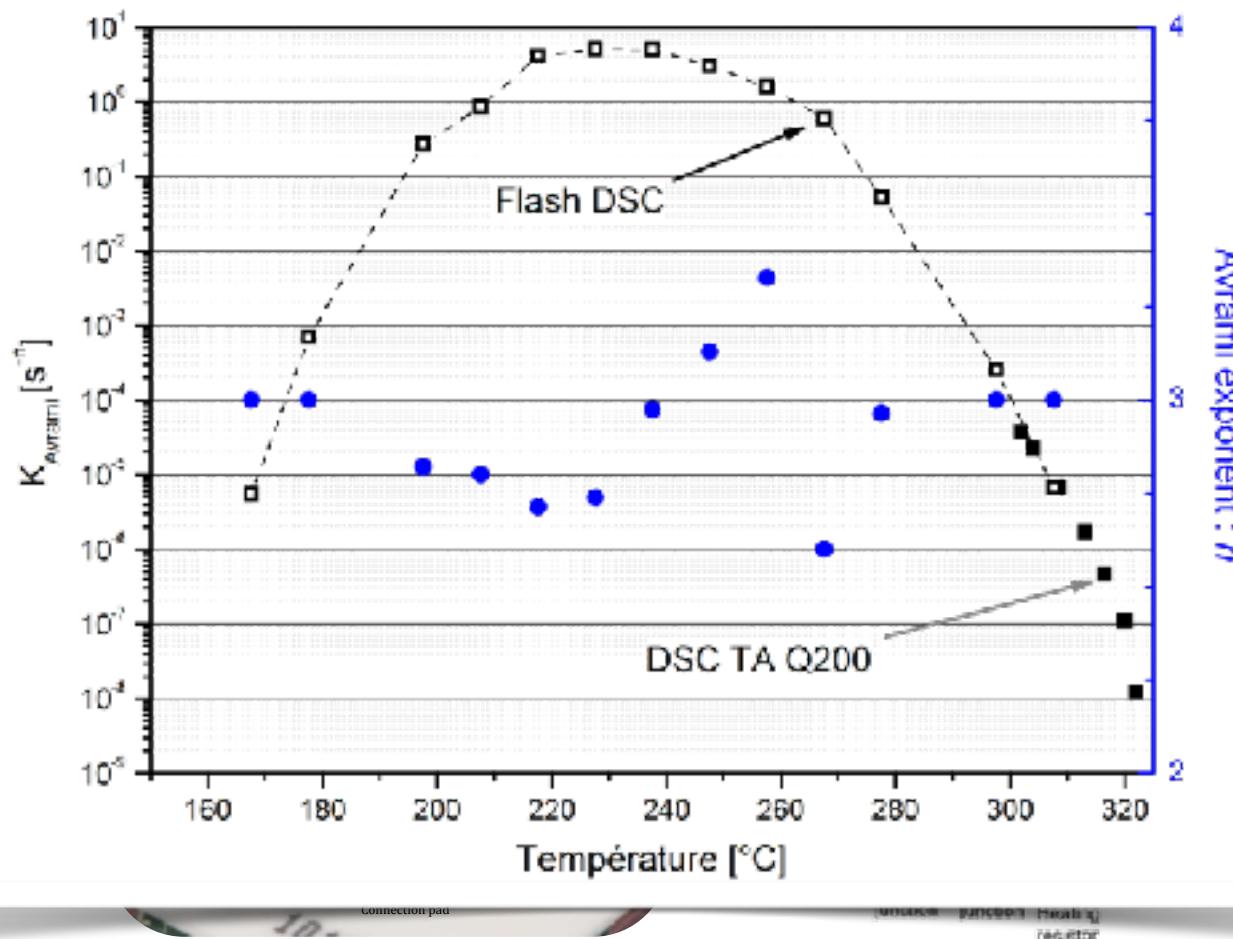
[Tardif et al. 14]

Working zone
150 x 150 μm^2

Flash D

Membrane
1.6mm x 1.6mm x

[V. Mathot 11, Pignon

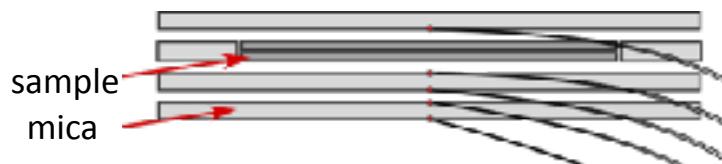
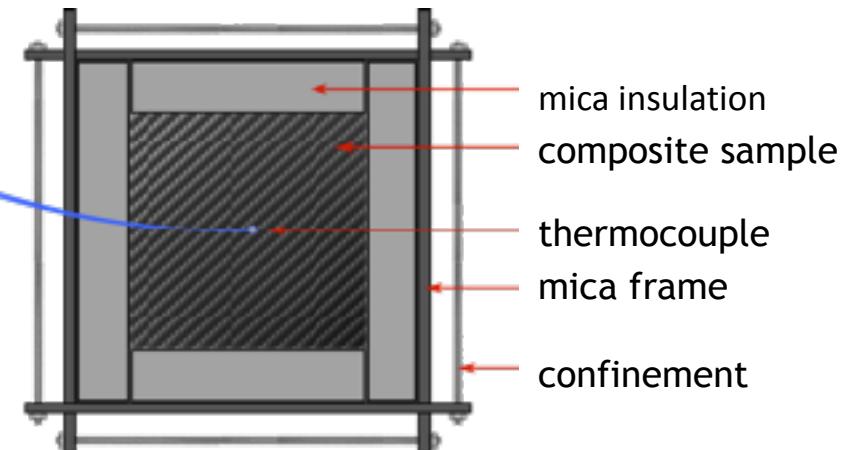


Thermal characterization

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) + \rho_m \phi_m L \frac{\partial \alpha}{\partial t}$$

Challenge: up to molten state

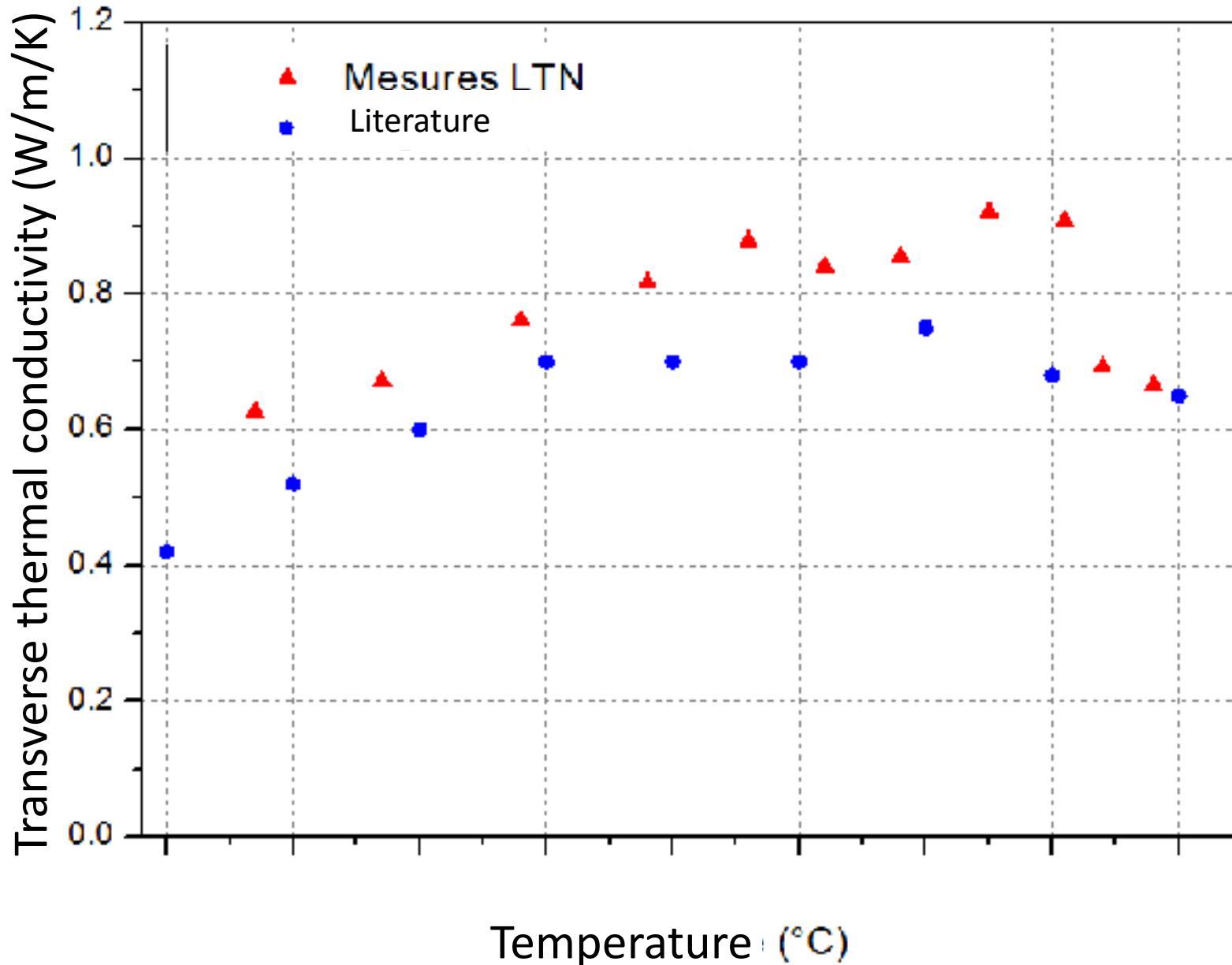
Guarded hot plate



Home made setup SLALOM

goal : enhancing in-plane heat transfer

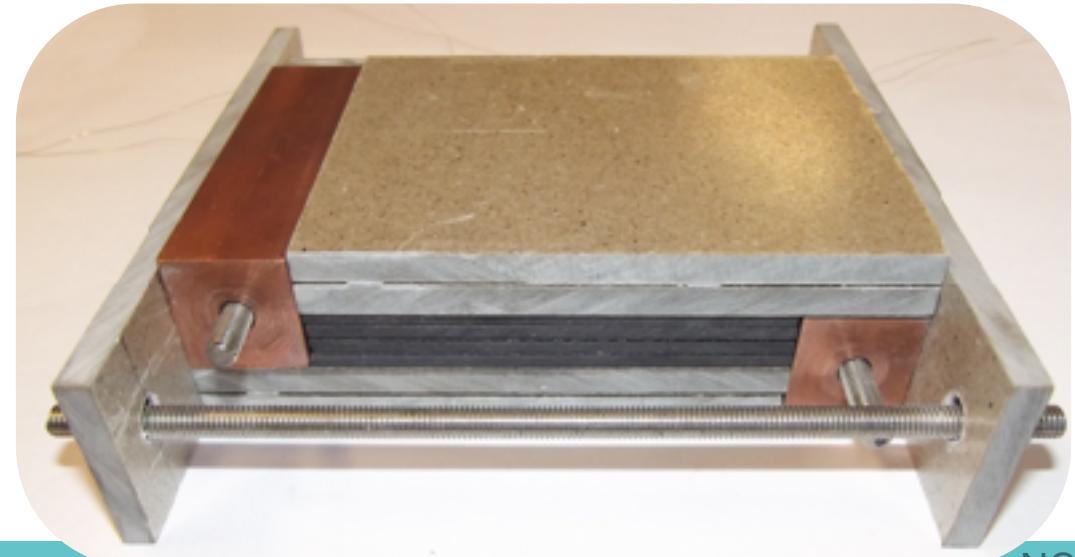
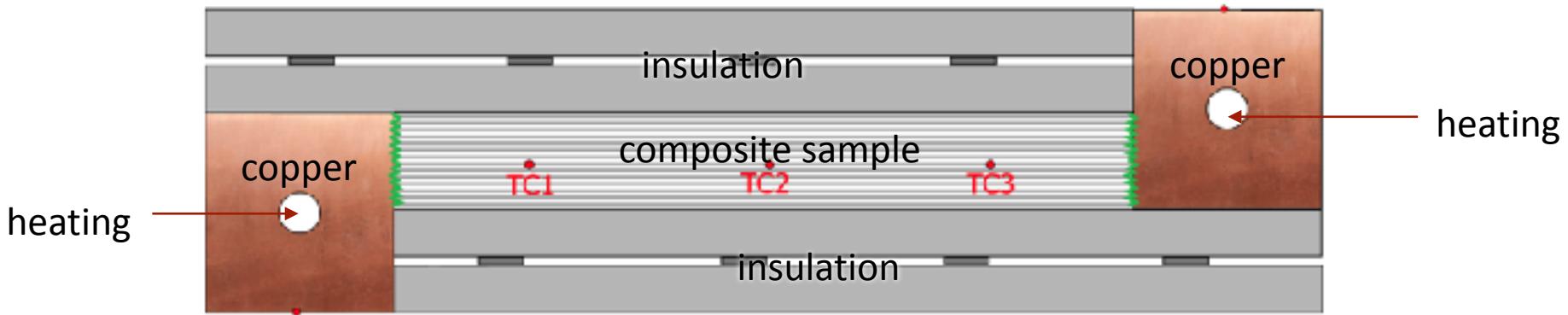
Modified guarded hot plate



SLALOM device

context : inverse method

large in-plane temperature gradients



Inverse method

Numerical simulation



Parameter set

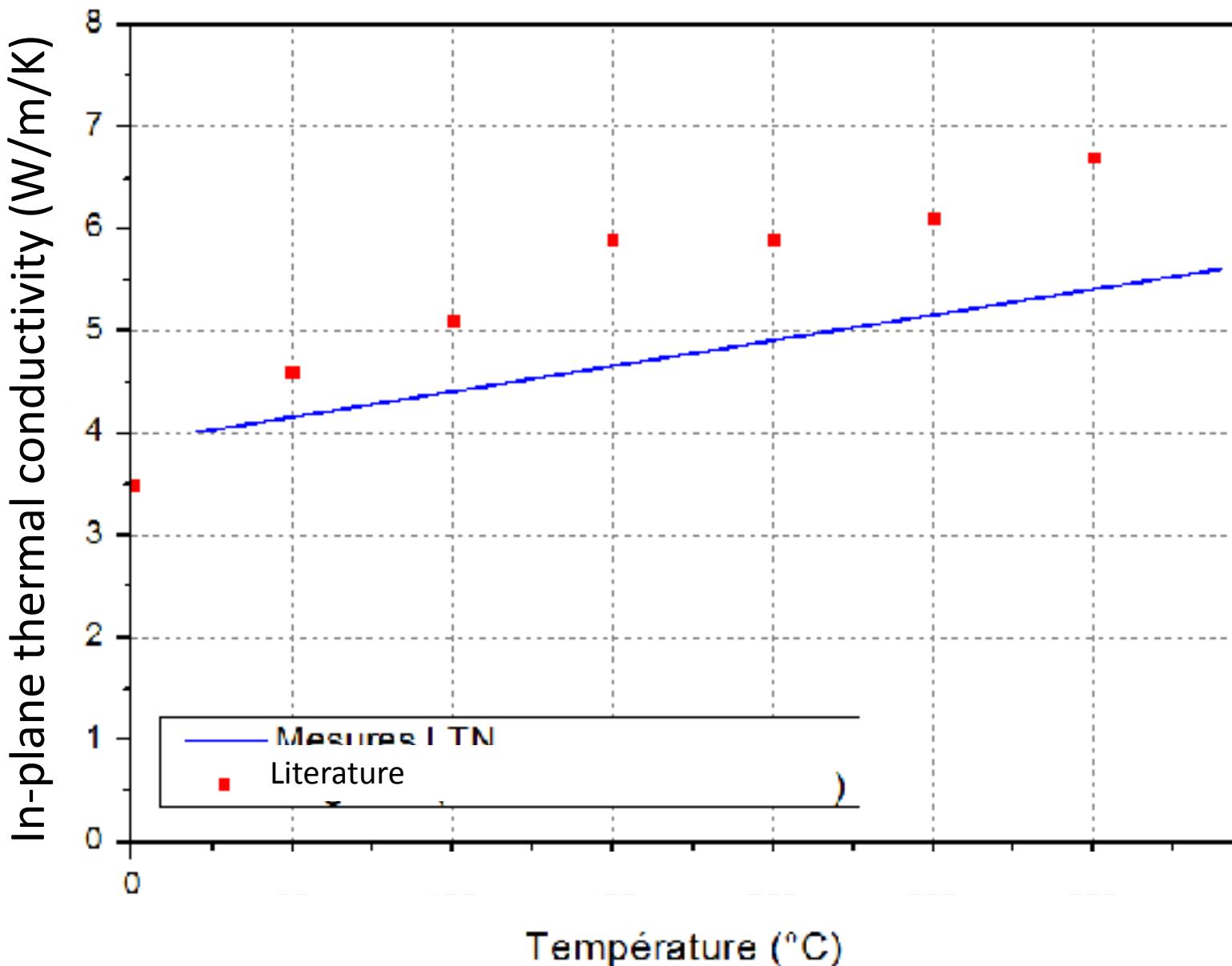
$$\begin{aligned} \lambda_{plan} &= a+bT \\ TCR \end{aligned}$$

Error estimation

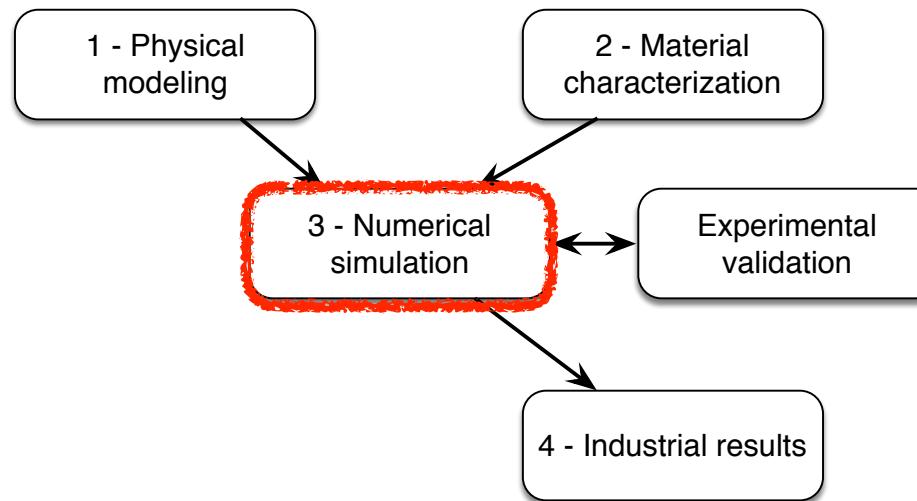
$$\sum_{TC} \sum_{times} (T_{num} - T_{exp})^2$$

Minimization

Results

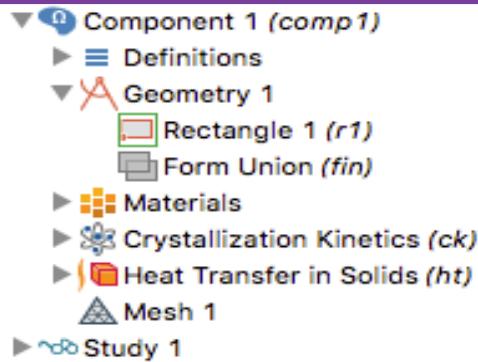
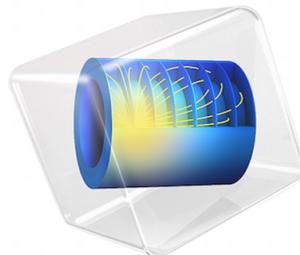


Simulation



Small parts

Comsol Module



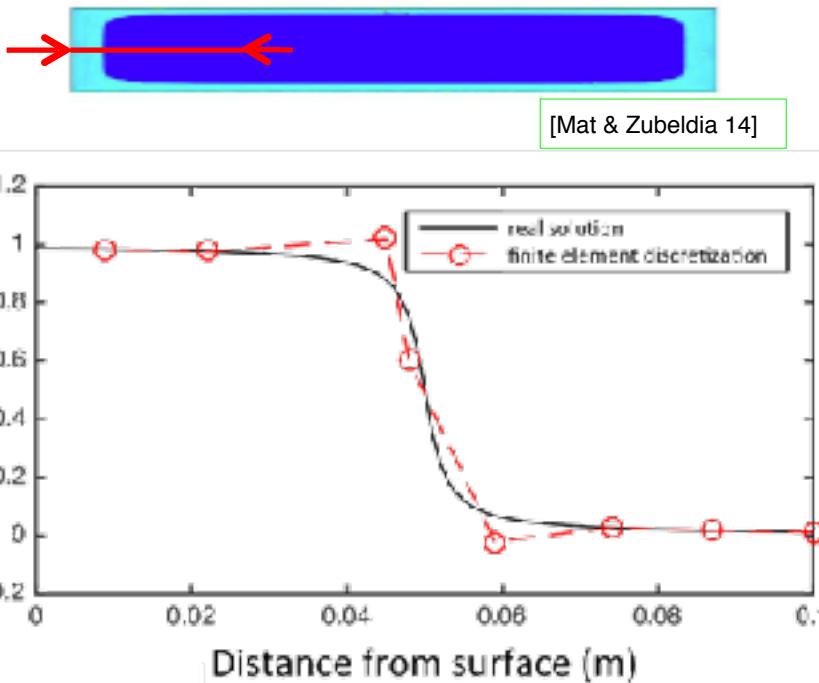
Available for free



[https://
github.com/arthurlevy/ComsolPhysics](https://github.com/arthurlevy/ComsolPhysics)

Thick part difficulties

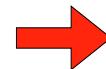
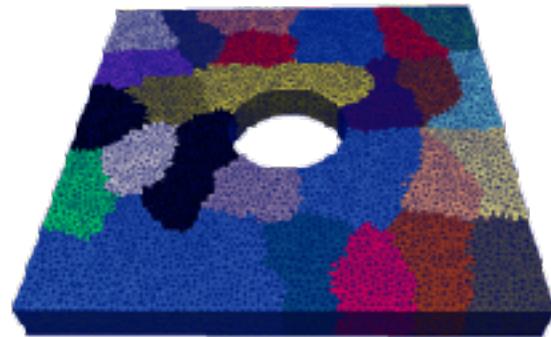
Crystallization front



Automatic remeshing

Parallel computation

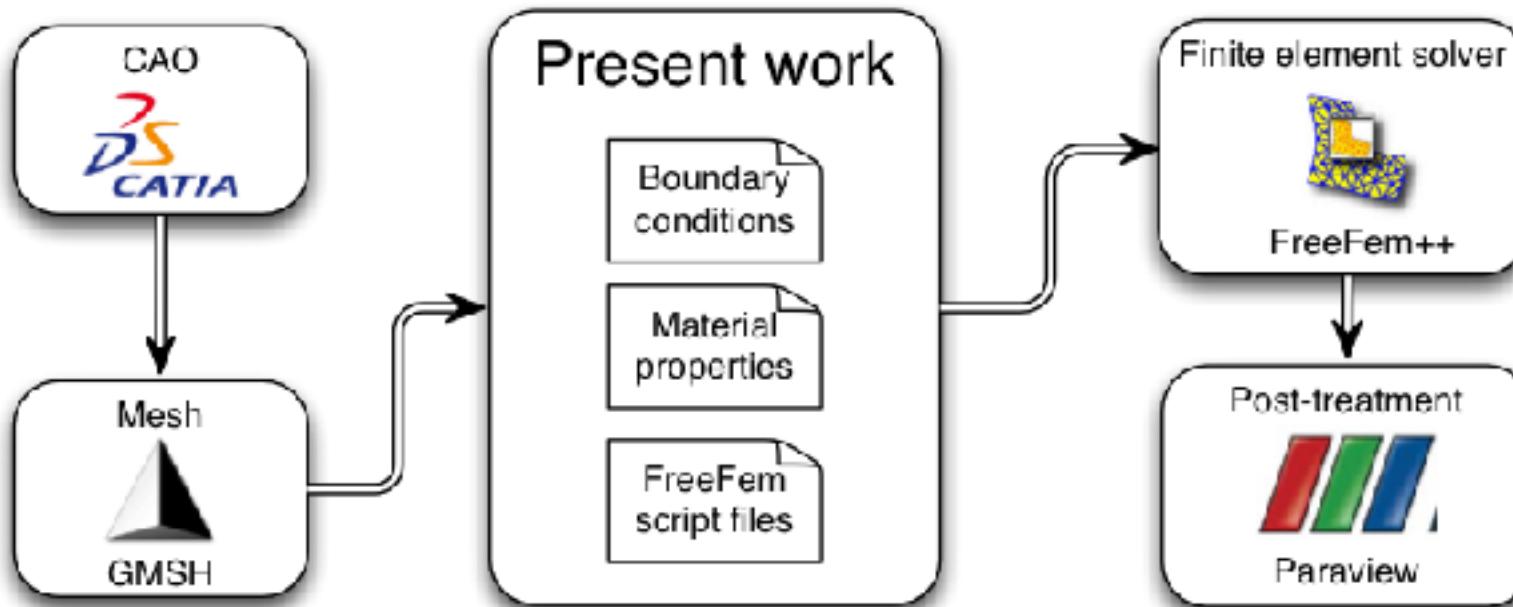
- Partitioning (METIS)
- Parallel
 - assembly
 - solving (MUMPS)



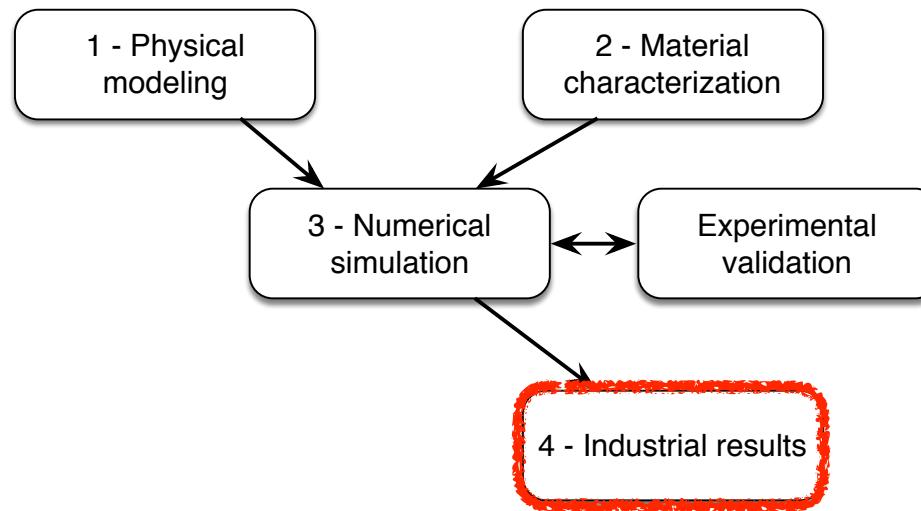
Up to 4 million dofs

Implementation Framework

- Standard P1 finite elements
- Strong coupling using mixed field (T,a)
- Nonlinear solving
- Implicit time integration w/ adaptative time stepping

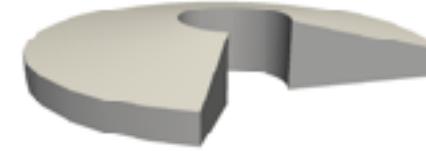


Application



Presented studies

- 3D demonstrator
- 2D parametric study



Application

-

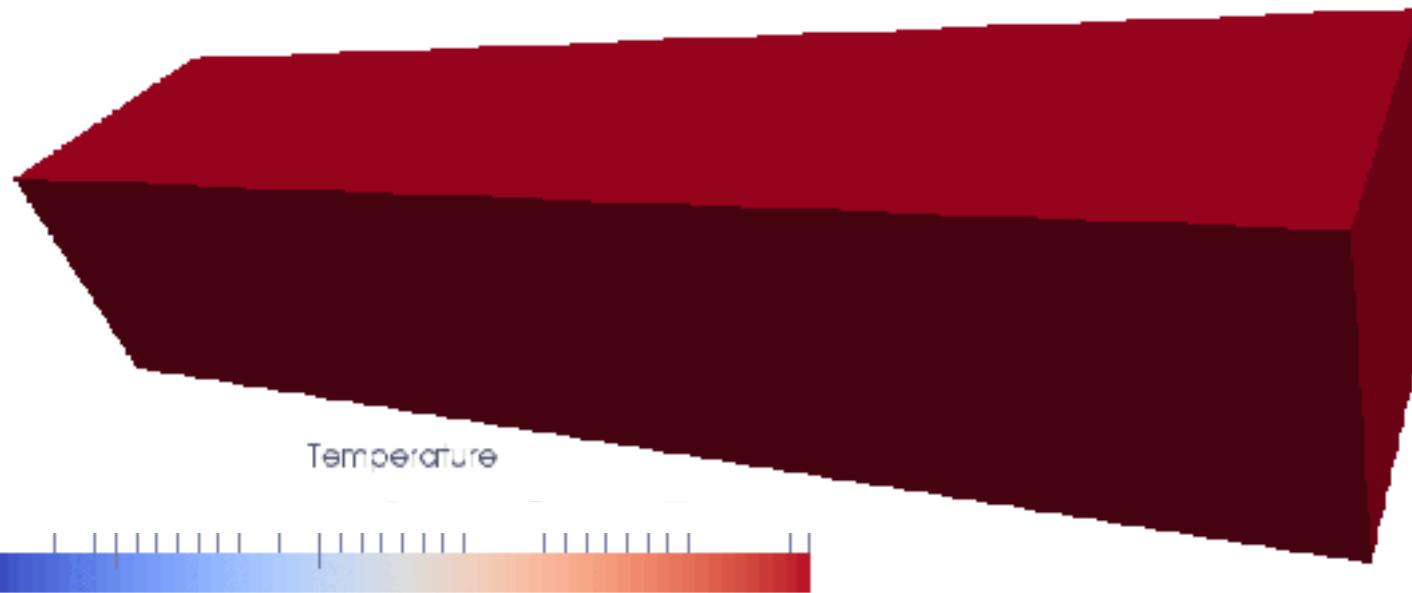
3D demonstrator



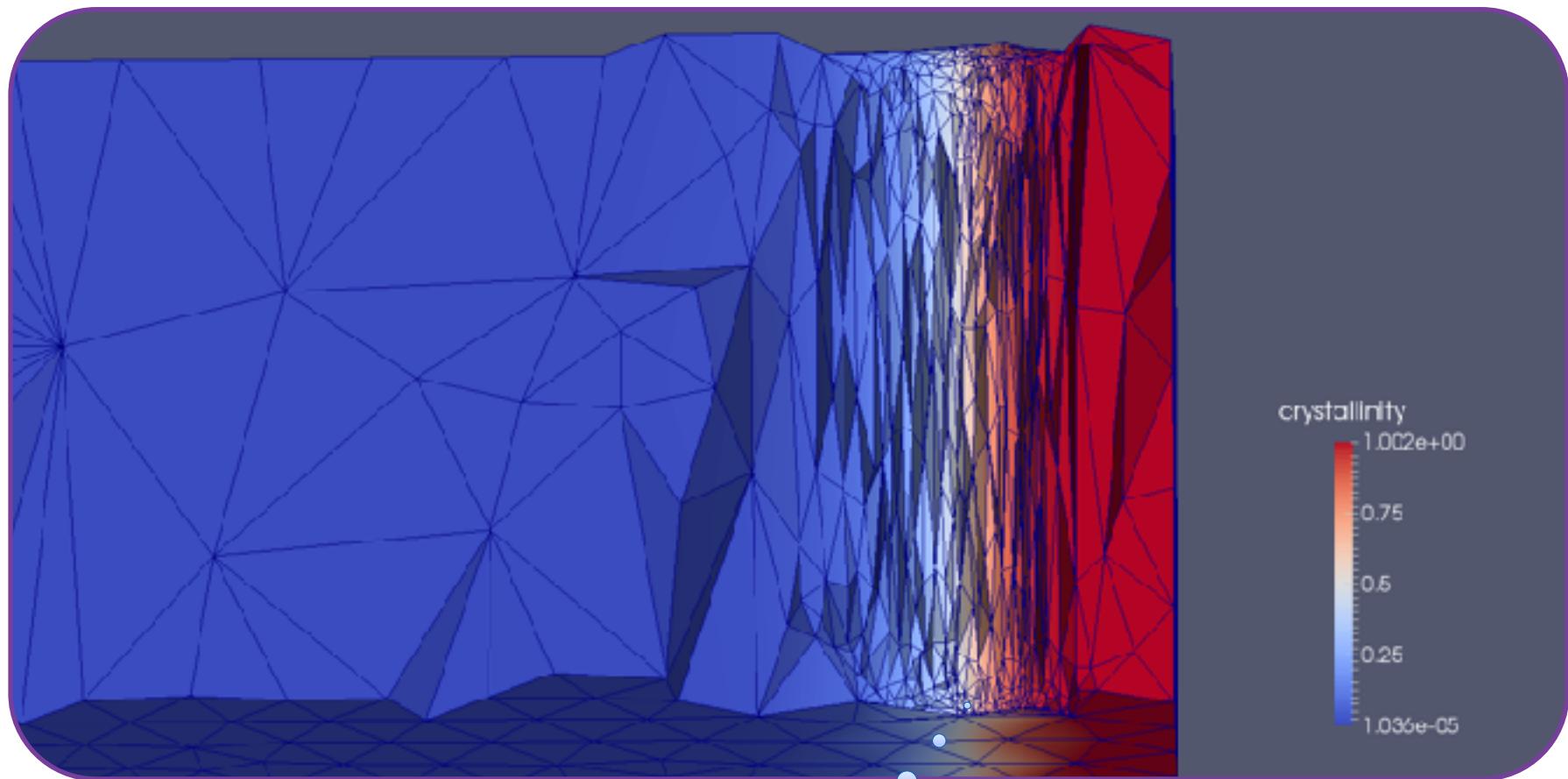
Temperatures

Industrial geometry not shown here.

Test case : Thermal shock on a block.



Crystallization



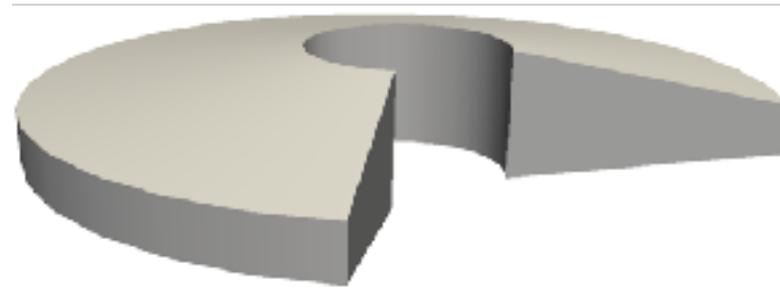
Automatic
remeshing



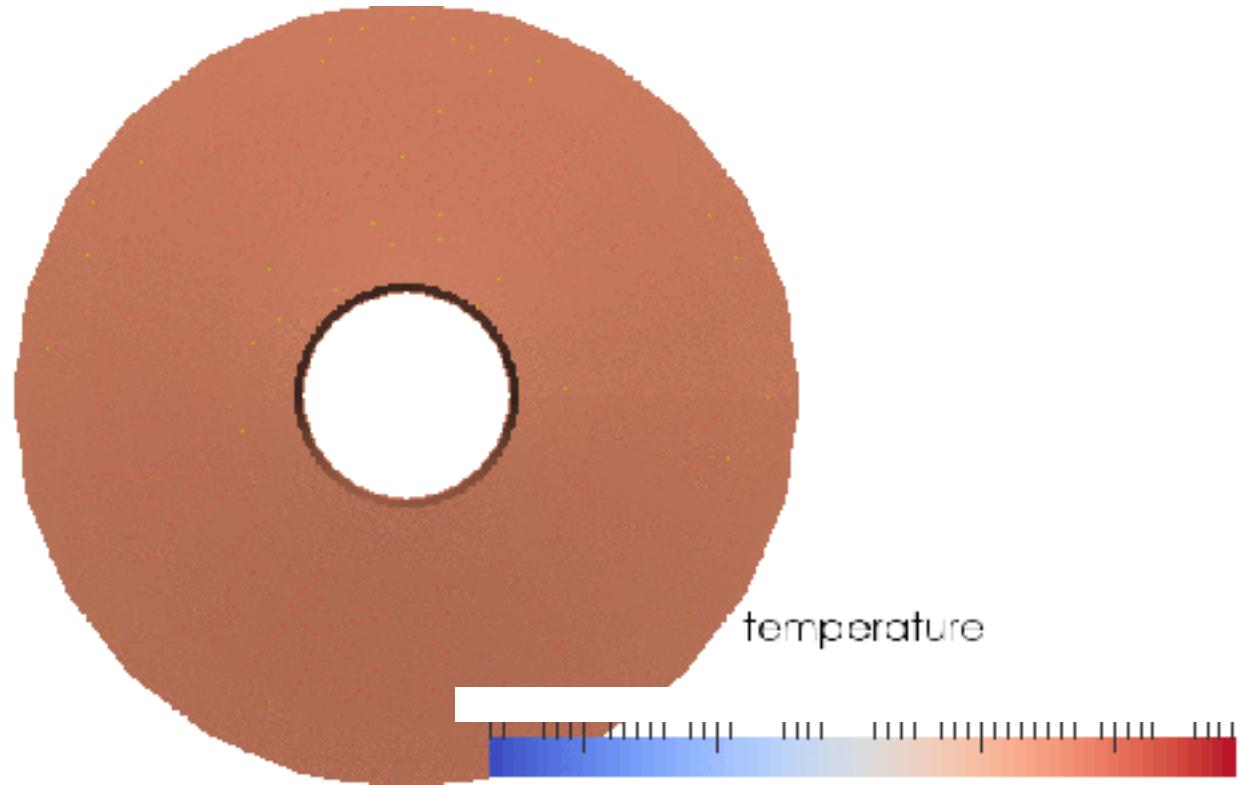
Application

-

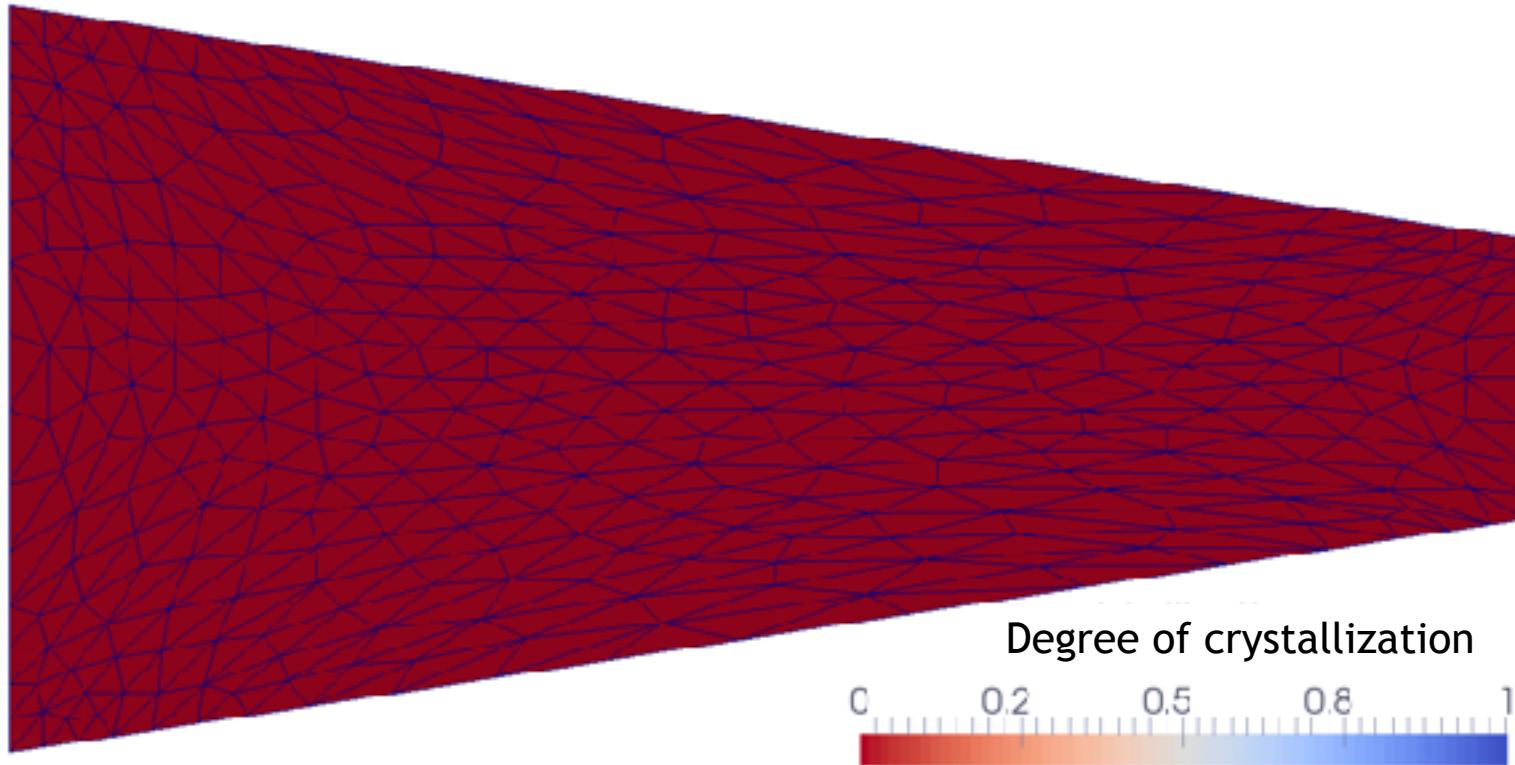
2D study



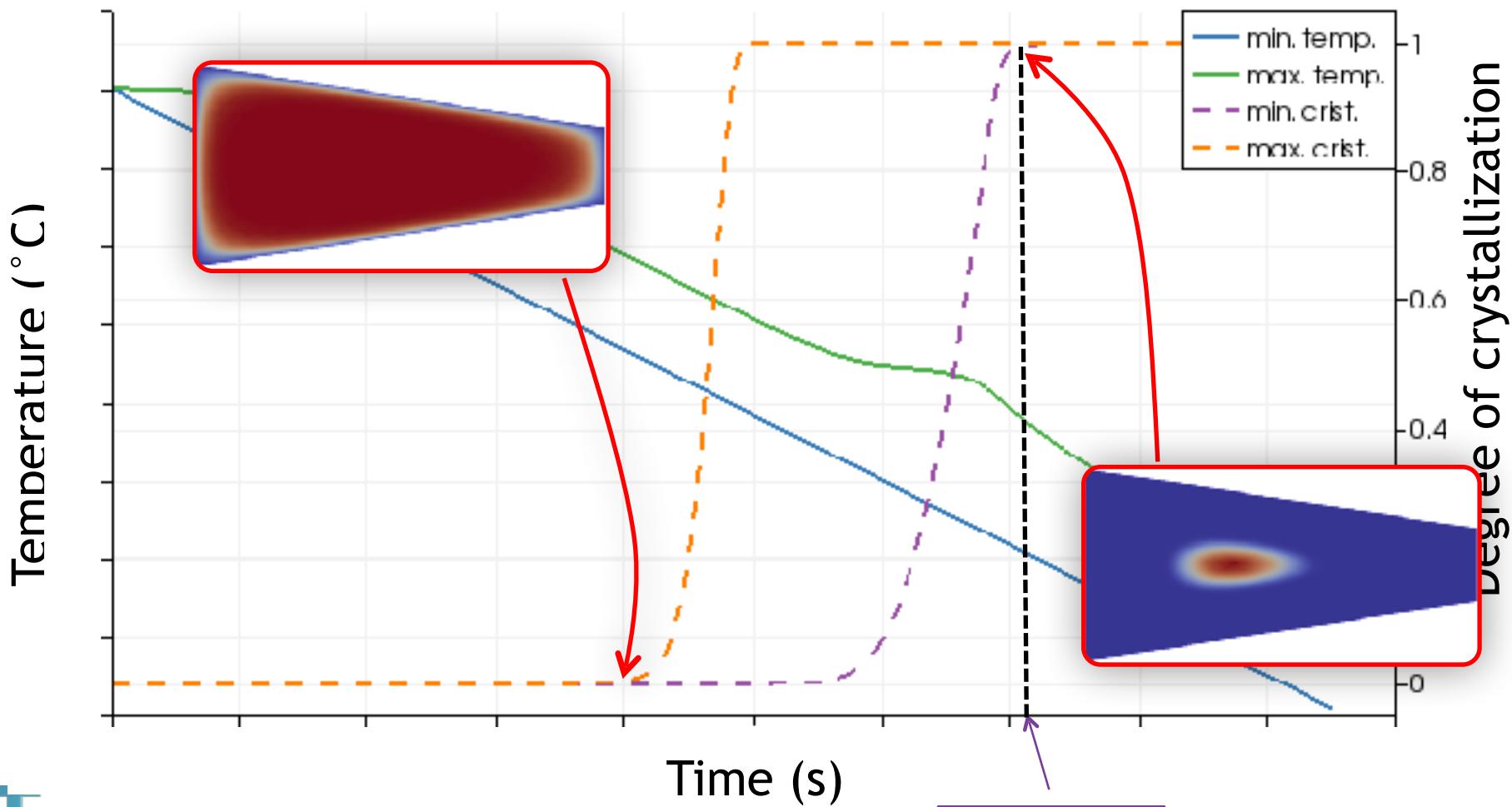
Temperature



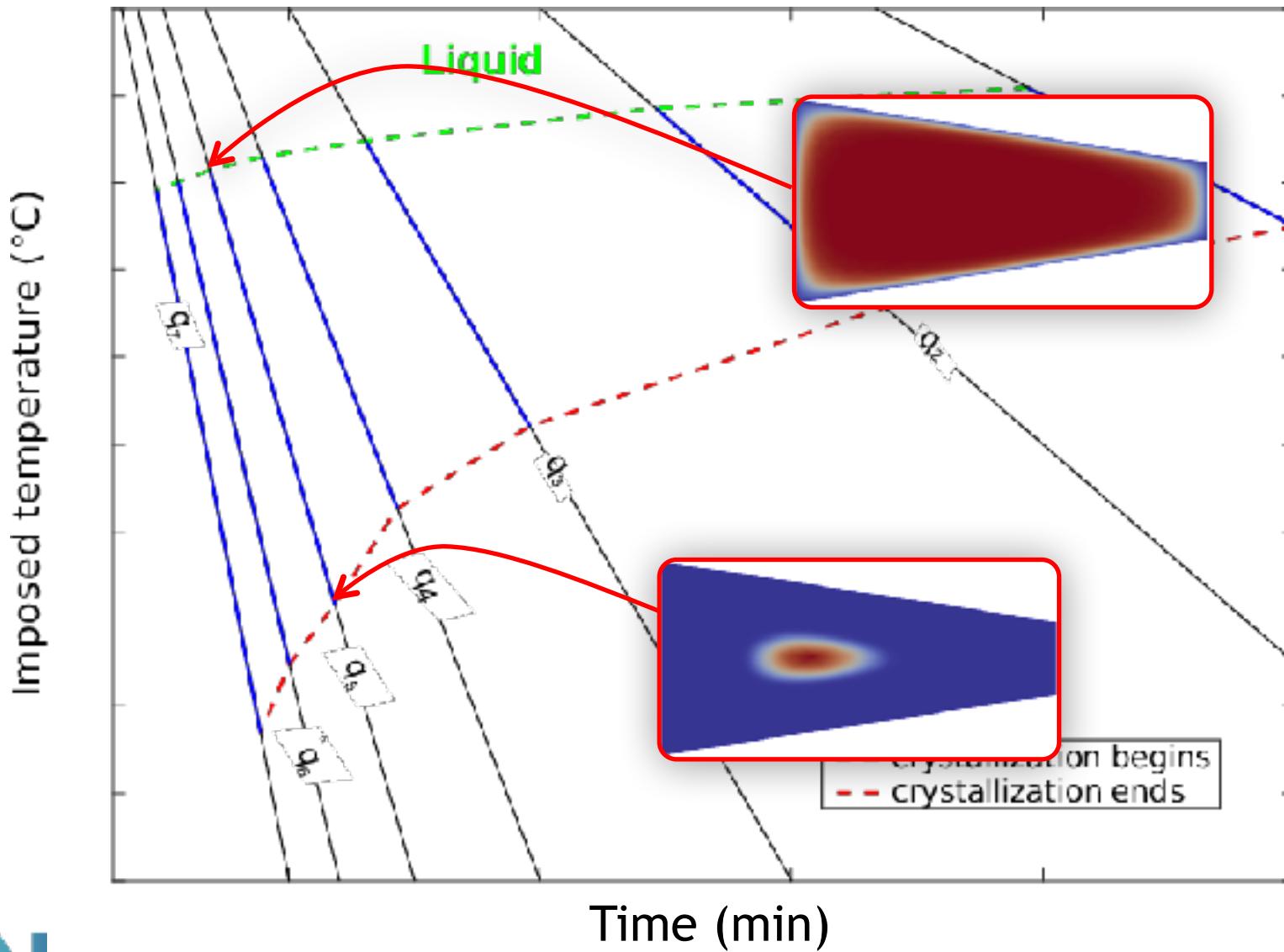
Crystallization



Extrema in the domain



Continuous cooling diagram



→ Slow cooling = solidification at higher temperature.

Conclusions

Multiphysical modelling of composite processing

Specific material characterization techniques

Simulation tool 2D+3D

Better understanding of the process
Parametric study, design chart

Acknowledgements

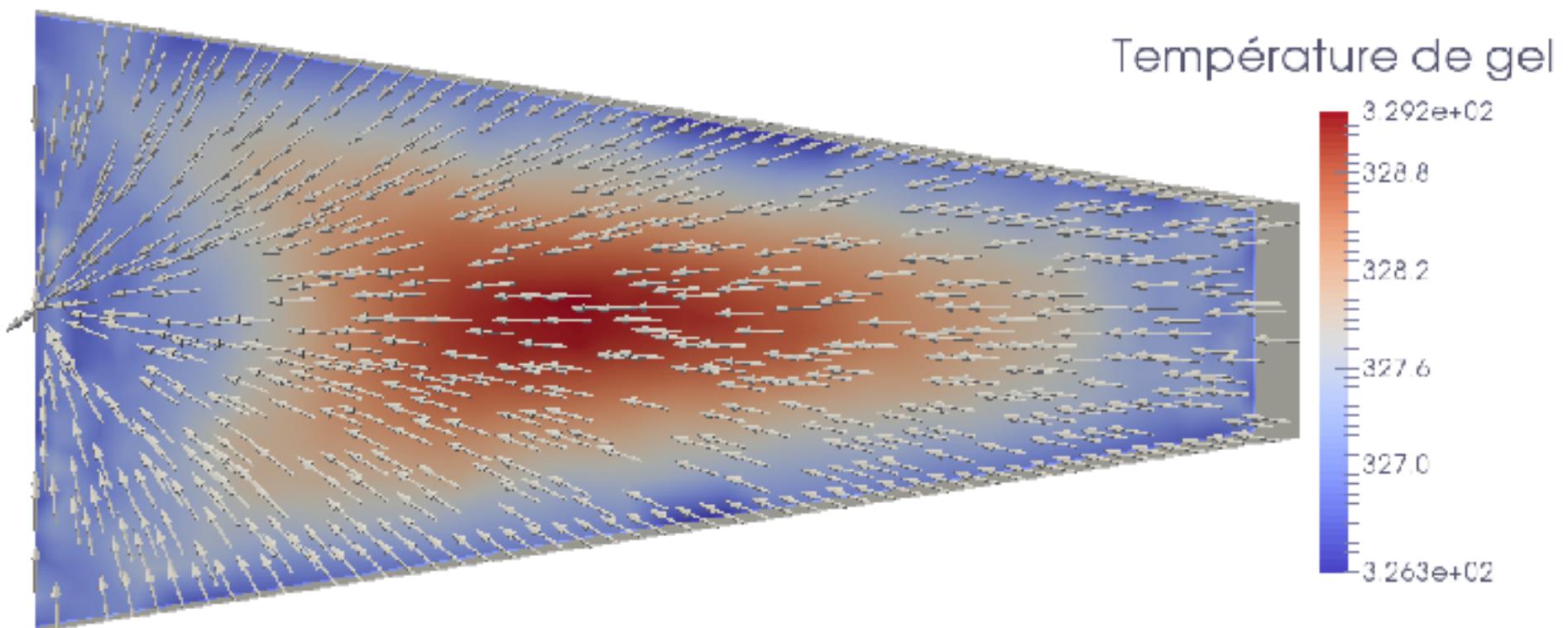
- Airbus Helicopters (Hélène Sibois) and DGA for financial support
- Nathalie Robert (LTN) for parallel installation on cluster
- University of Bristol for my ongoing visiting scholarship

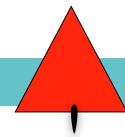
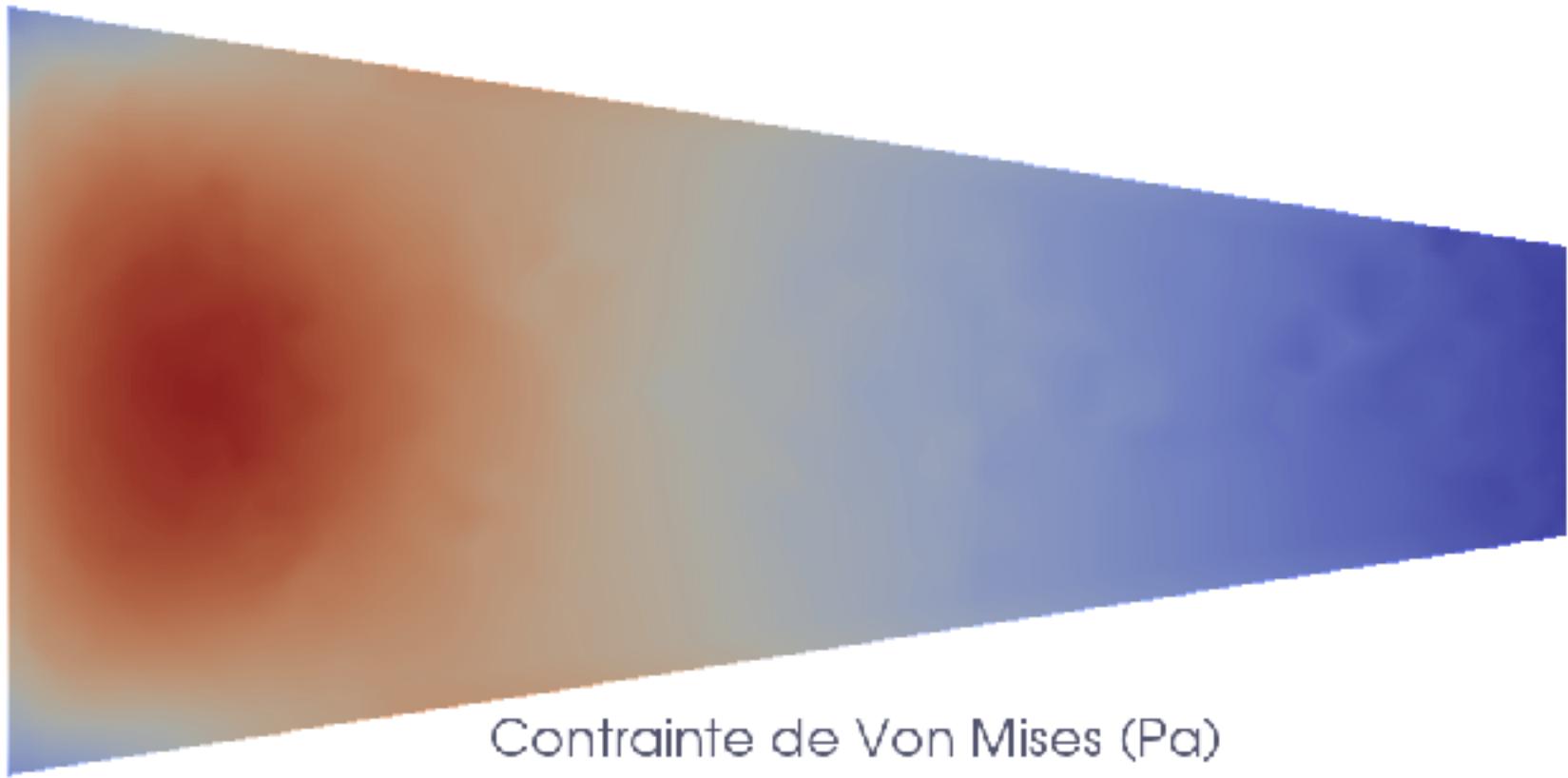
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Laboratoire de Thermique et Energie de Nantes

Backup slides





Standard numerical methods

Discretization

Spatial :

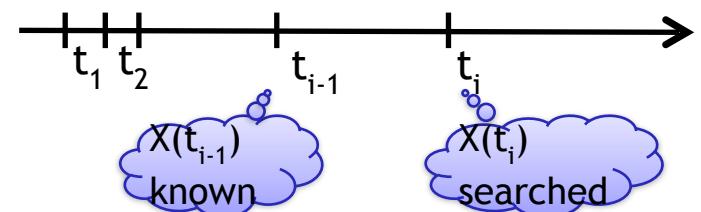
Finite elements
PI approximation

Unknown:

$$\{X\} = \langle T_1, T_2, \dots, T_n, \alpha_1, \alpha_2, \dots, \alpha_n \rangle^T$$

Temporal :

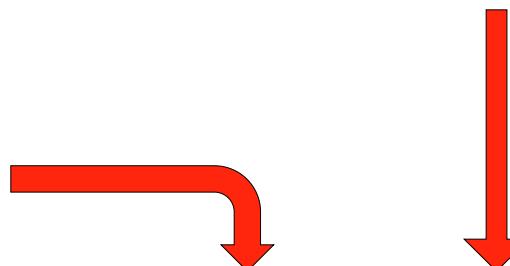
Iterative scheme



Euler implicite (sta

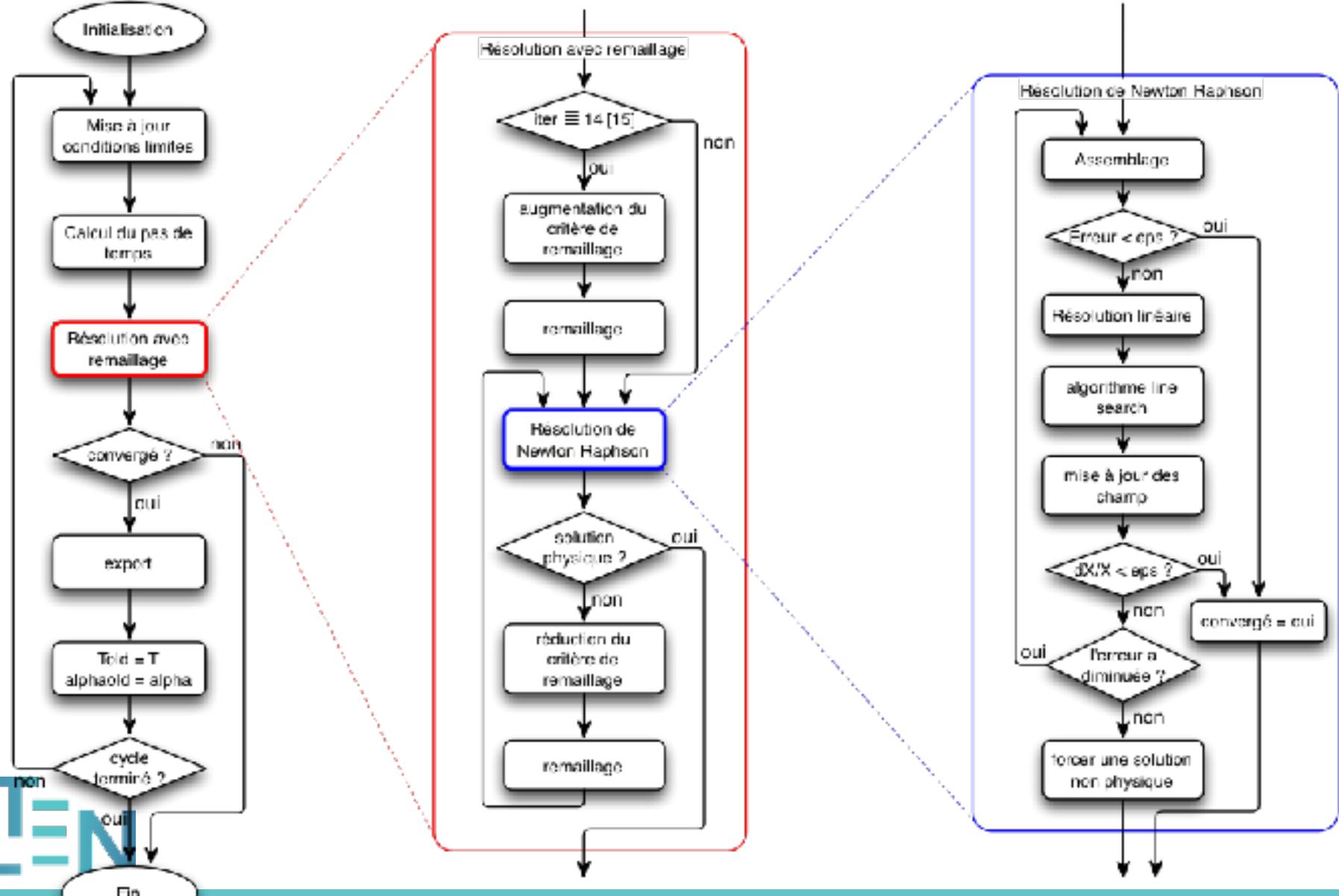
Thermo-kinetics
model

Weak form

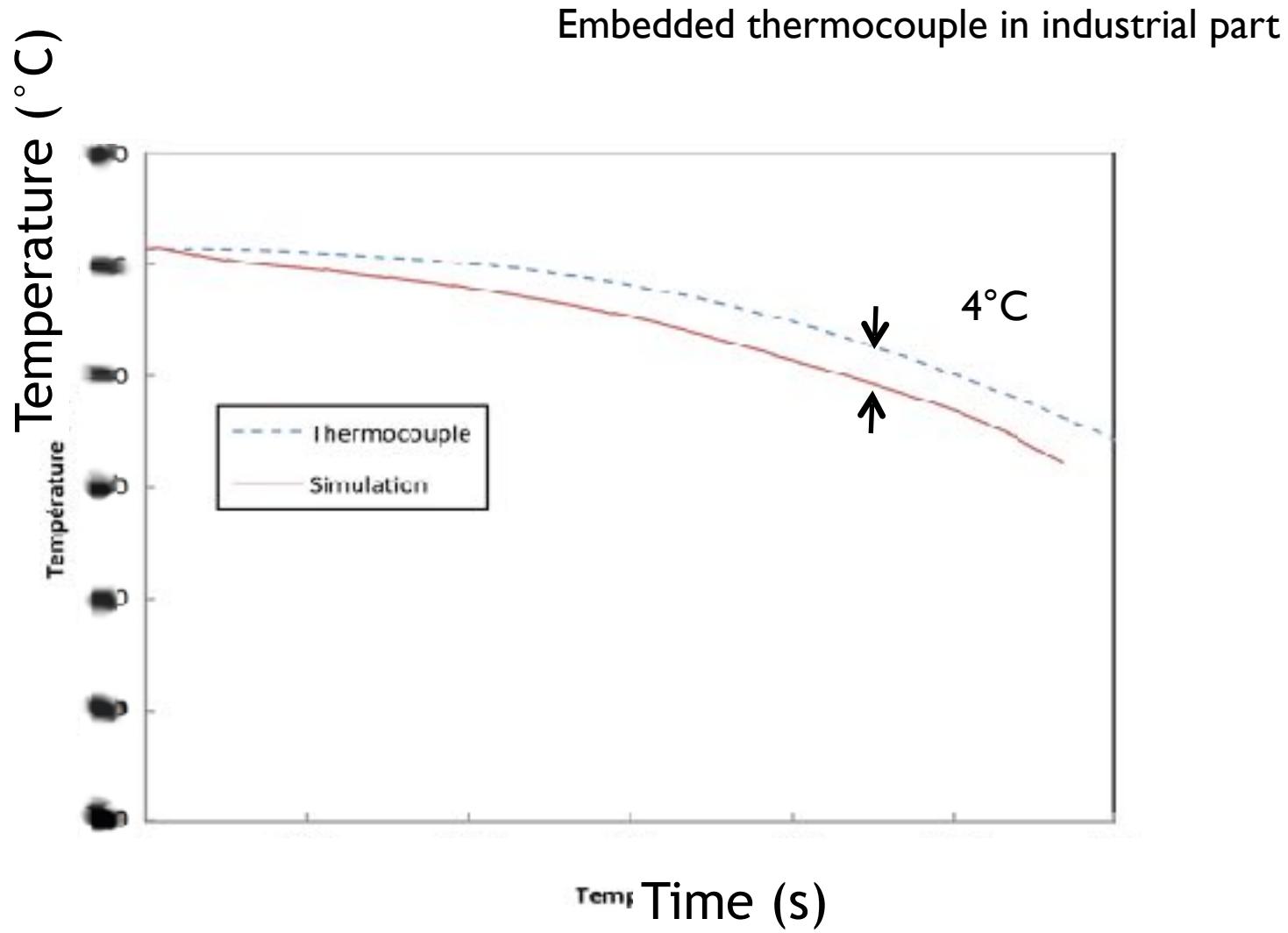


$$R(\{X_i\}) = \{0\}$$

Algorithm



Experimental validation



Mould temperature management