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## Multiphysics Modelling and Optimization of Magnetocaloric Devices

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# Multiphysics modelling of magnetocaloric device and experimental results

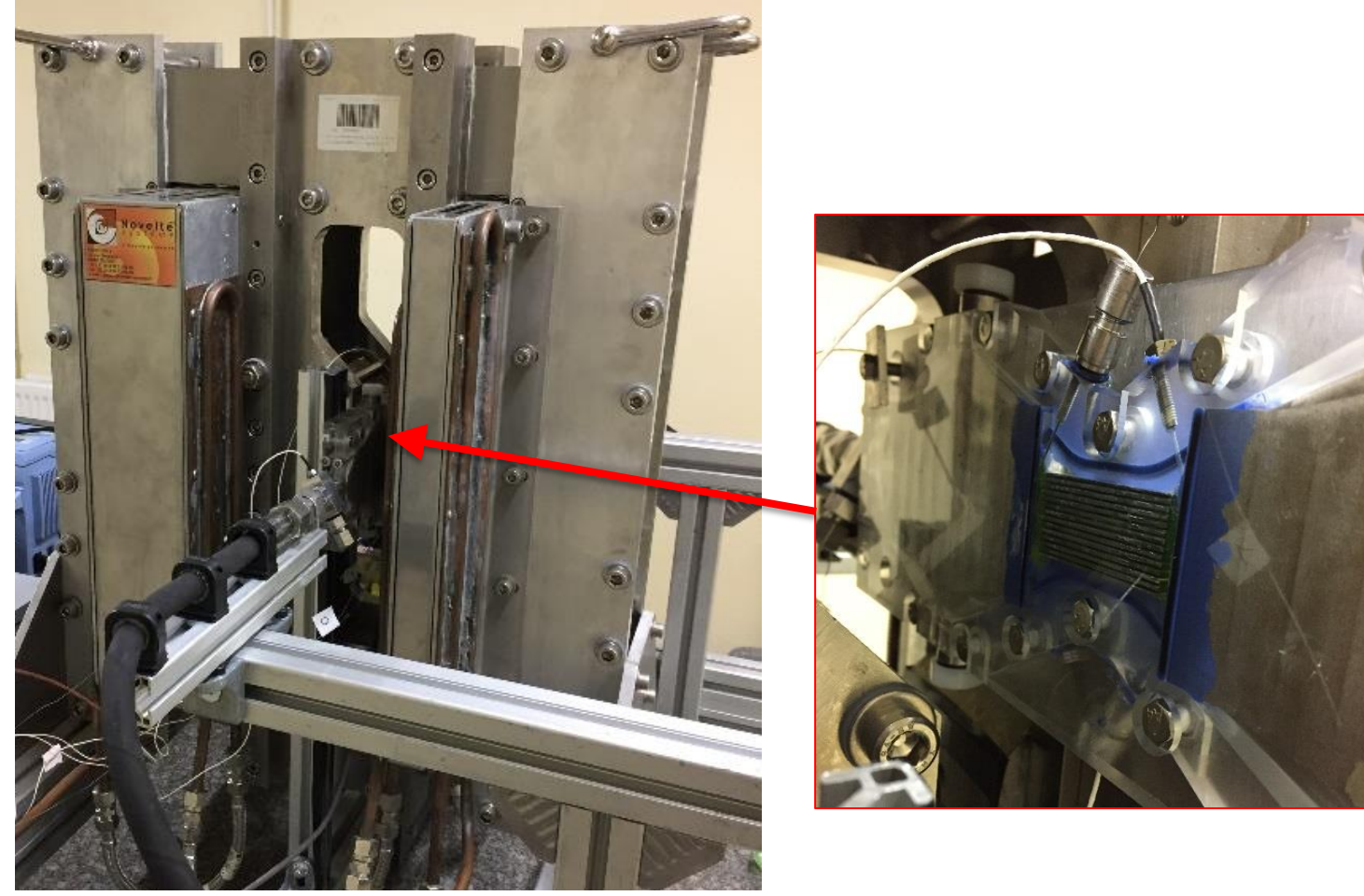
A. Ismail, A. Plait, T. Li, M. Perrin, T. Laroche Lambert, S. Giurgea, Y. Bailly, J.C. Roy, T. Barrière

## Context and objectives

### AMR cycle analysis

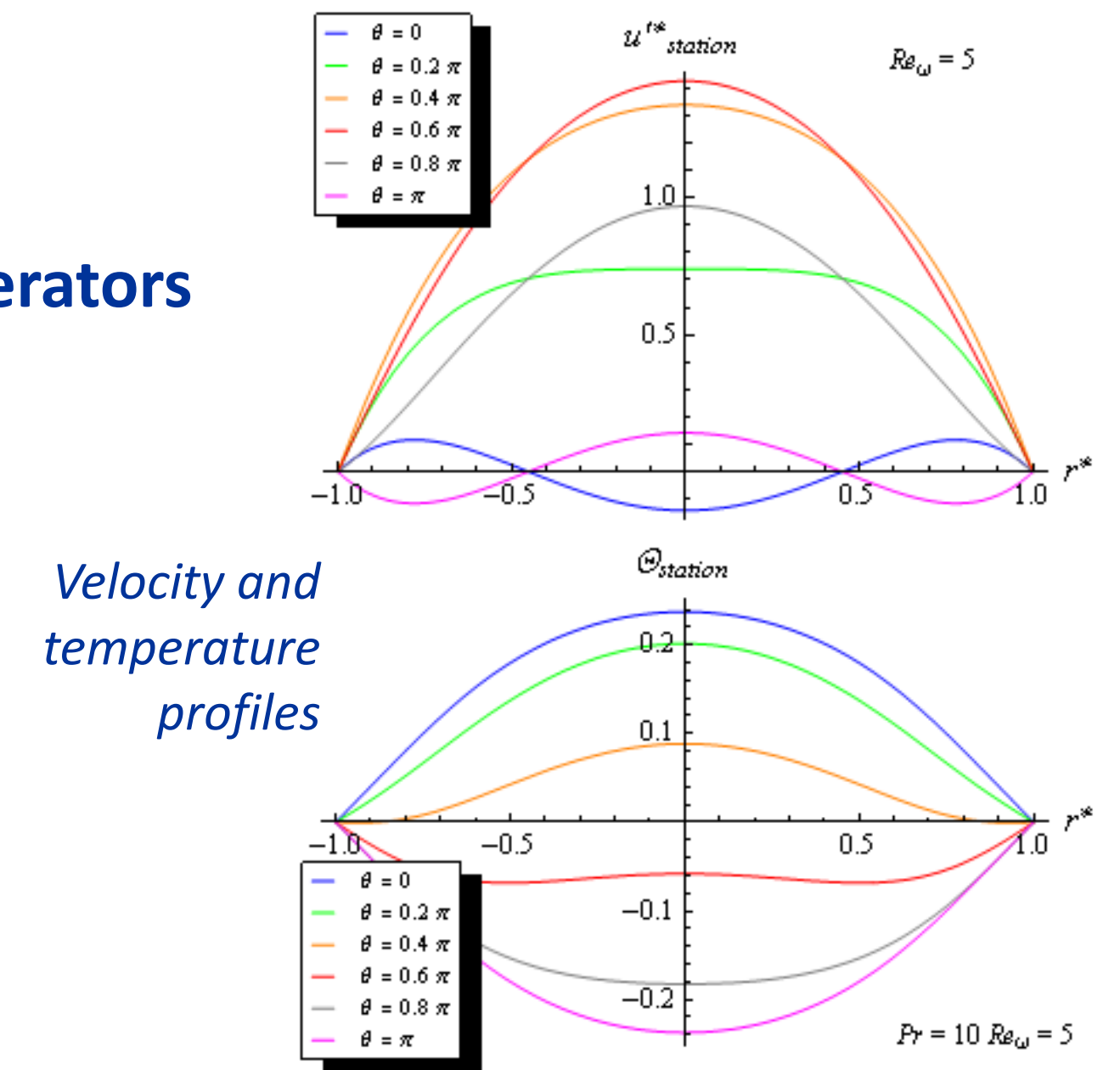
- Designing, implementing, optimizing devices for cheaper heating and refrigeration devices based on the magnetocaloric effect

FEMTO-ST magnetocaloric device



### Physical study of magnetocaloric regenerators

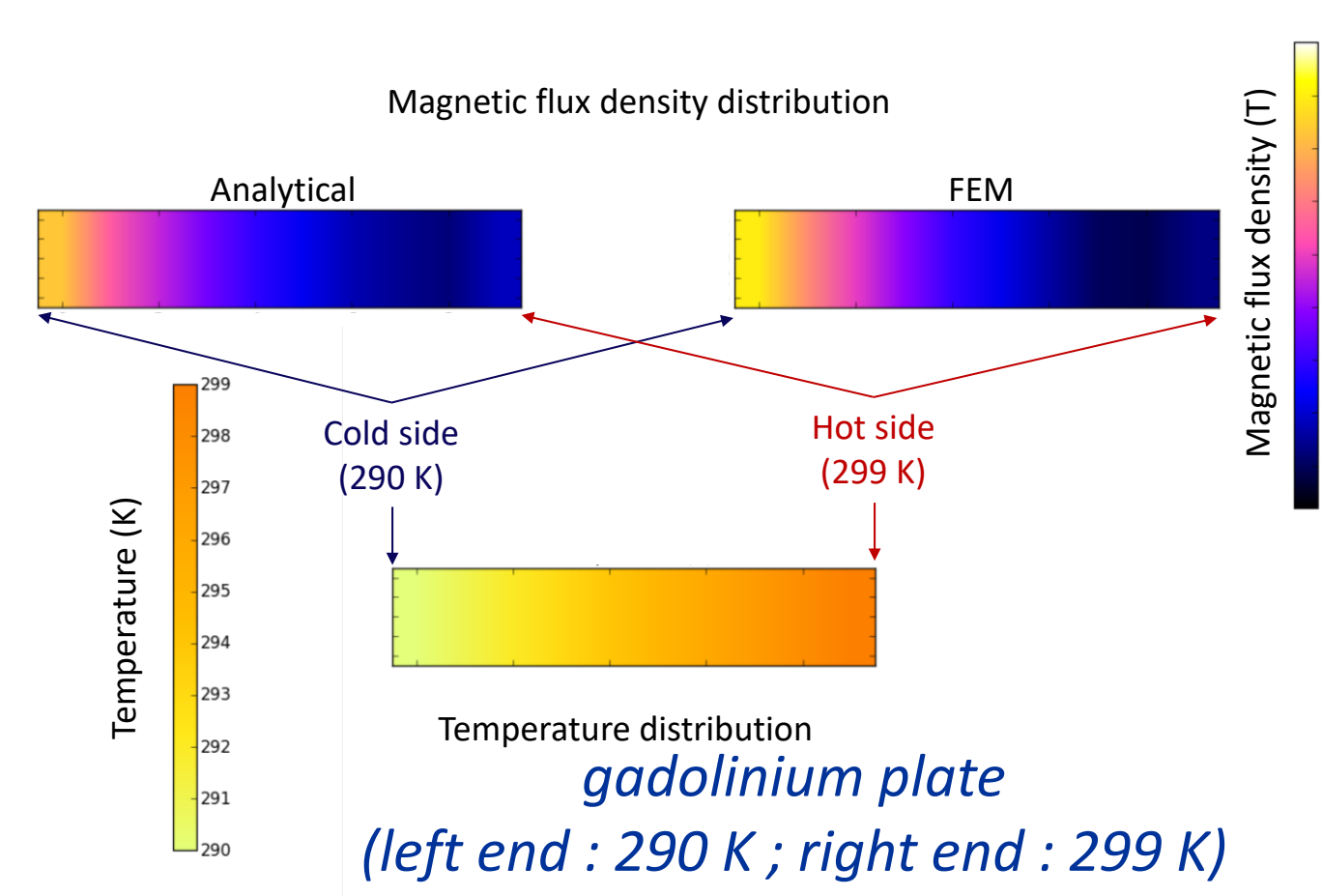
- Modelling all phenomena that occur in magnetocaloric regenerator with alternating flow of coolant between parallel plates during AMR cycles



## Multiphysics modelling

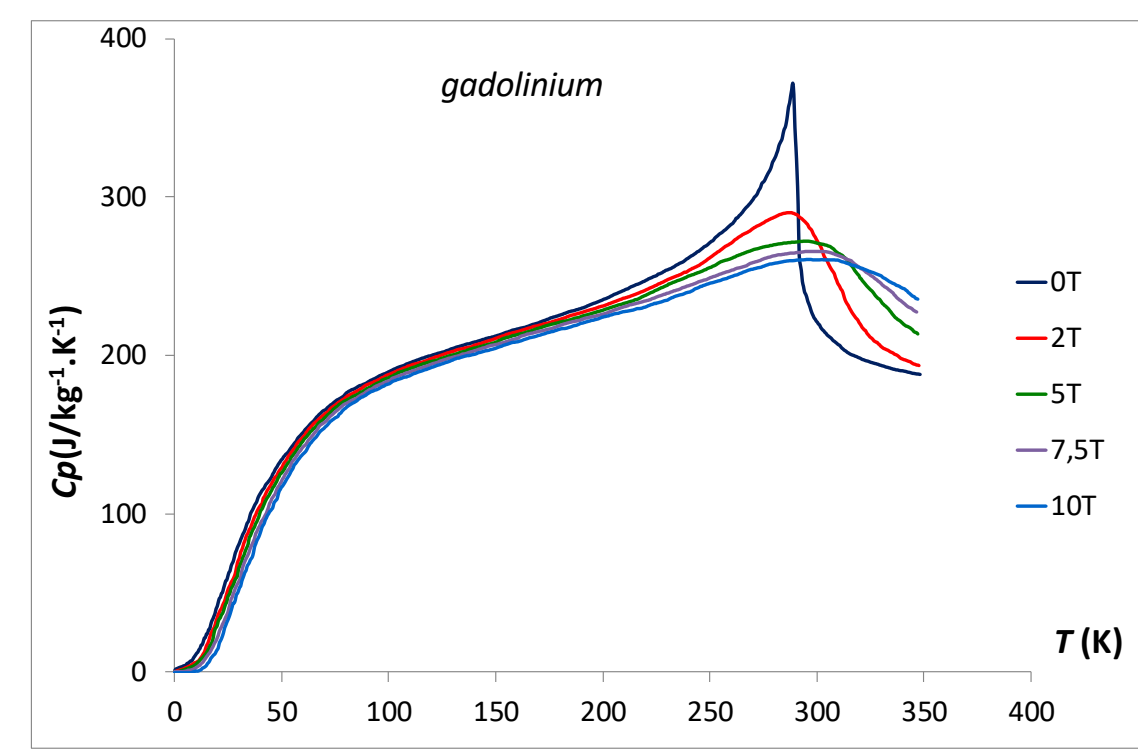
### Magnetostatic model

- 2D modeling of the internal magnetic field and magnetic flux density distribution in magnetocaloric material
- Magn. Equiv. Circuit (reluctance network)
- $B_{int}$  and  $H_{int}$  for every node
- calculation time = FEM calculation time/300



### Magnetocaloric model

- 2D modeling of thermodynamic of ferromagnetic transient, with magnetization distribution and magnetocaloric power density generate
- magnetization  $M(H_{int}, T)$  behavior
- magnetocaloric power density  $\dot{q}$



$$\dot{q} = -\mu_0 T \left( \frac{\partial M}{\partial T} \right)_{H_{int}} \frac{dH_{int}}{dt}$$

### Thermo-fluidic model

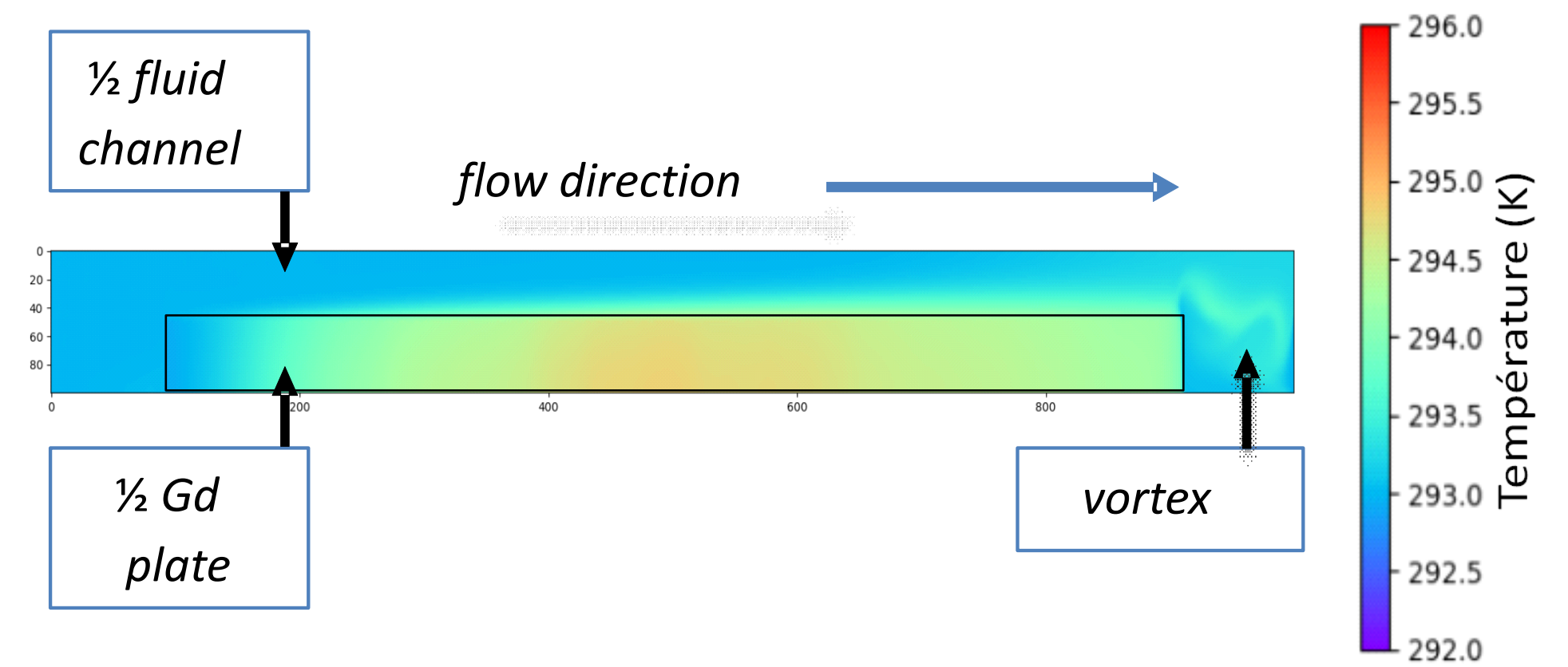
- 2D modeling of heat transfers of magnetocaloric material (parallel plates) with oscillating flow
- heat capacity (interpolate experimental data)
- solid temperature  $\frac{\partial T_s}{\partial t} = \frac{\lambda_s}{\rho_s c_s} \left( \frac{\partial^2 T_s}{\partial x^2} + \frac{\partial^2 T_s}{\partial r^2} \right)$
- fluid temperature  $\frac{\partial T_f}{\partial t} + u \frac{\partial T_f}{\partial x} = \frac{\nu}{Pr} \left( \frac{\partial^2 T_f}{\partial x^2} + \frac{\partial^2 T_f}{\partial r^2} \right)$

### CFD model (Fluent®) :

- 2D and 3D modeling of heat transfers of magnetocaloric material (parallel plates) with oscillating flow
- numerical reference for magnetocaloric numerical simulations in Python code
- material : gadolinium
- geometry : parallel-plate
- symmetry simplification : 1/2 plate and 1/2 canal
- frequency : any value
- method : temperature jump / source term
- $C_p$  : constant /  $T$  &  $B$  dependent
- demagnetizing field : with / without
- sinusoidal flow / trapezoidal flow

#### Objectives:

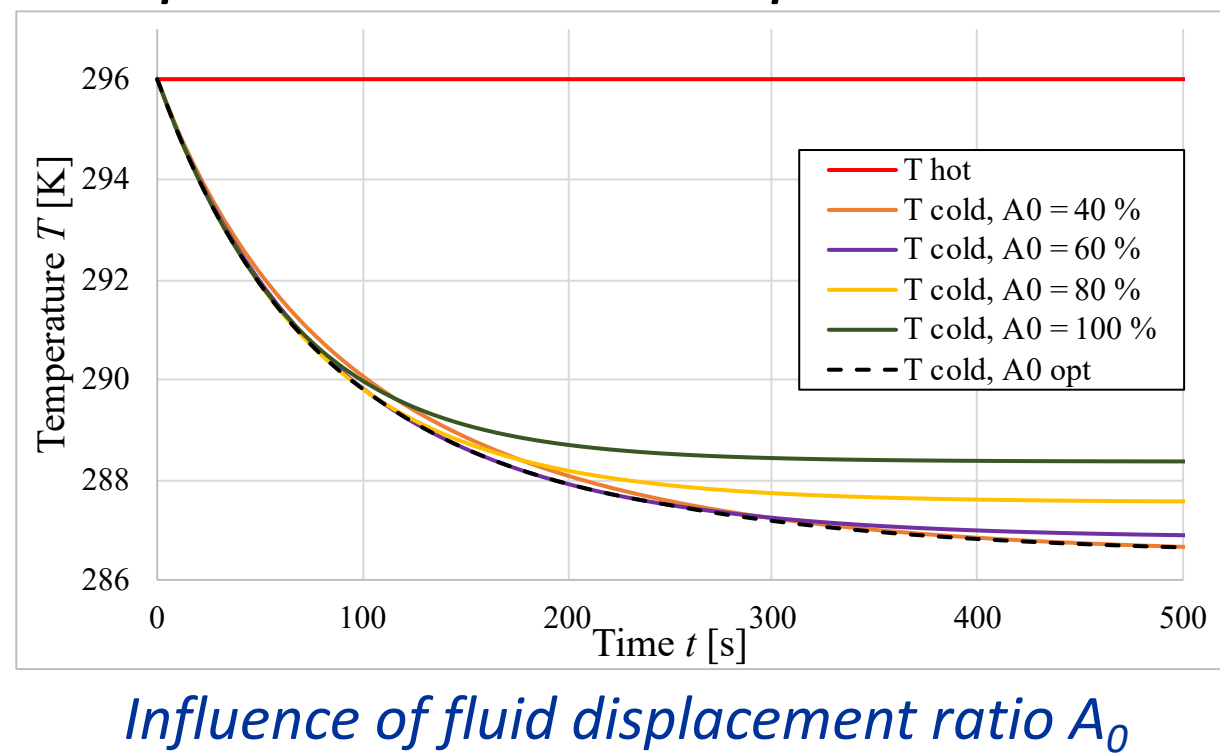
- annular effect
- effect of plate micro-structure on AMR efficiency
- simulation of multi-Curie regenerator for optimization of the AMR efficiency



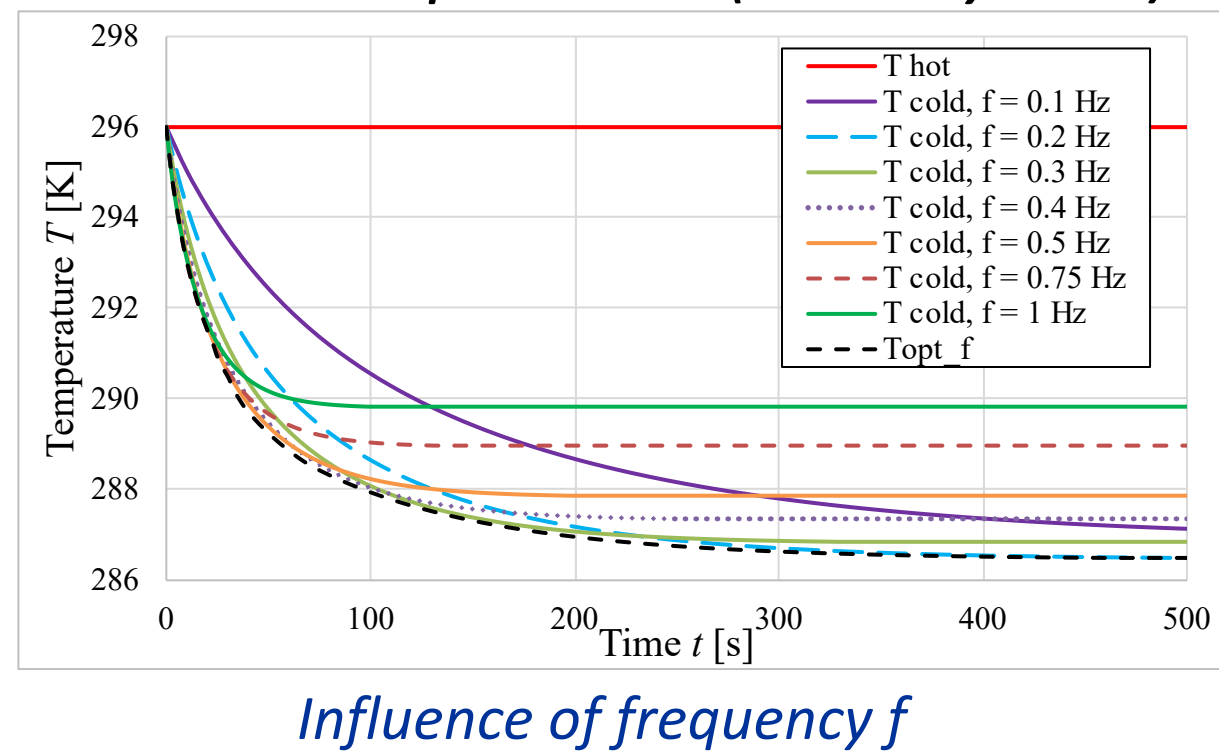
## Results, comparison and optimization

### Simulation results

- Imposed hot side temperature 296 K ; free cold side temperature (code Python)

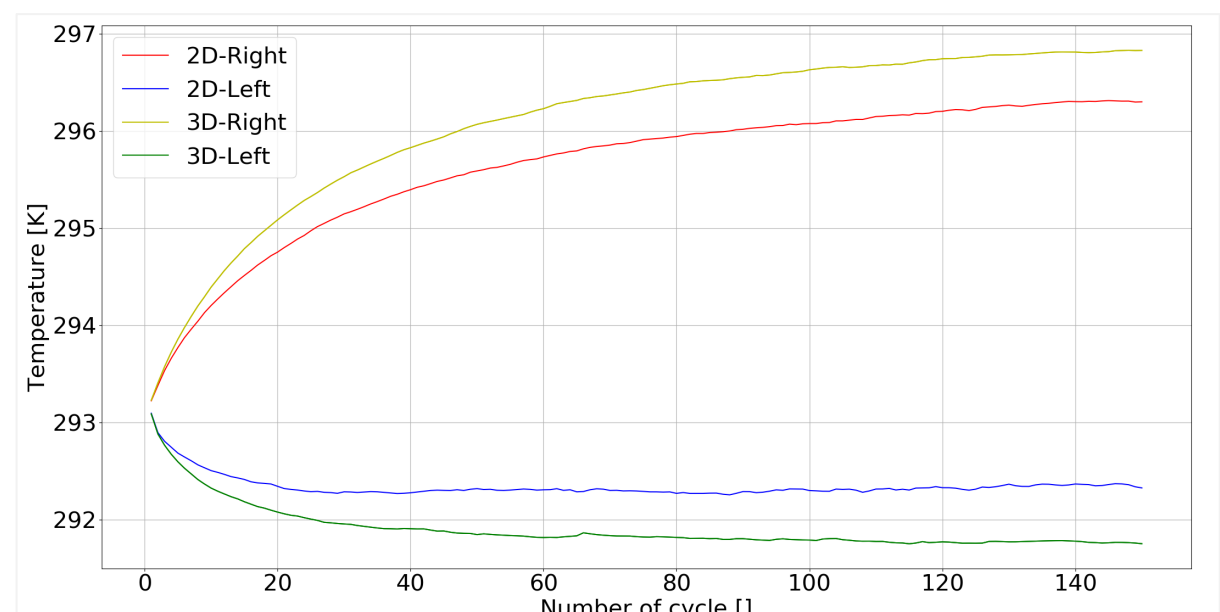


Influence of fluid displacement ratio  $A_0$

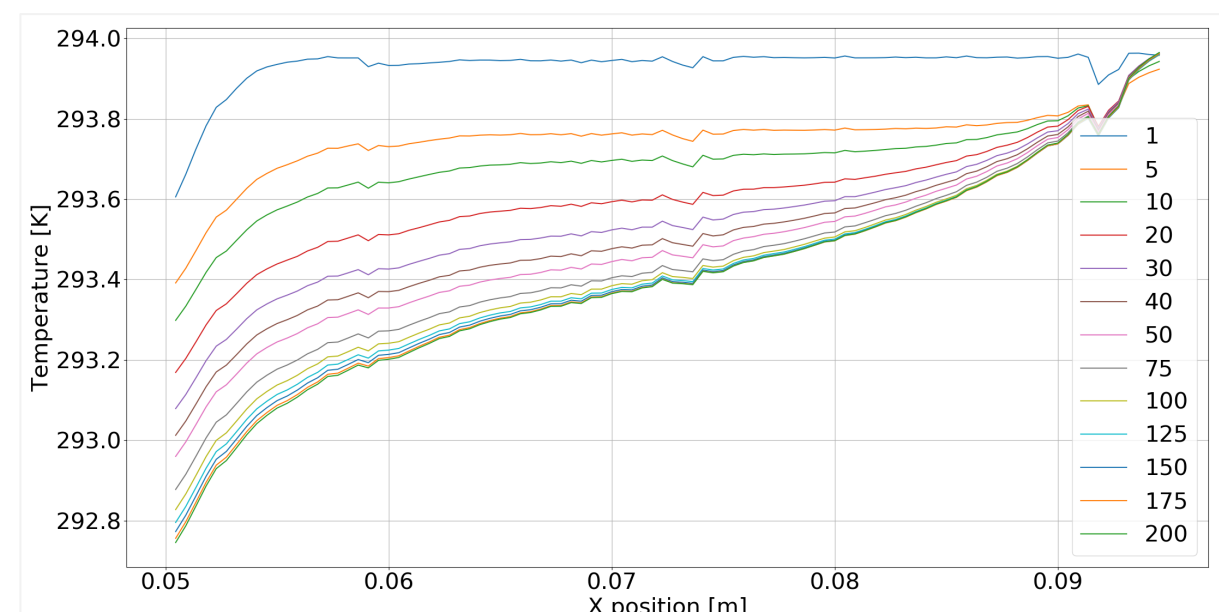


Influence of frequency  $f$

- Adiabatic case (Fluent)



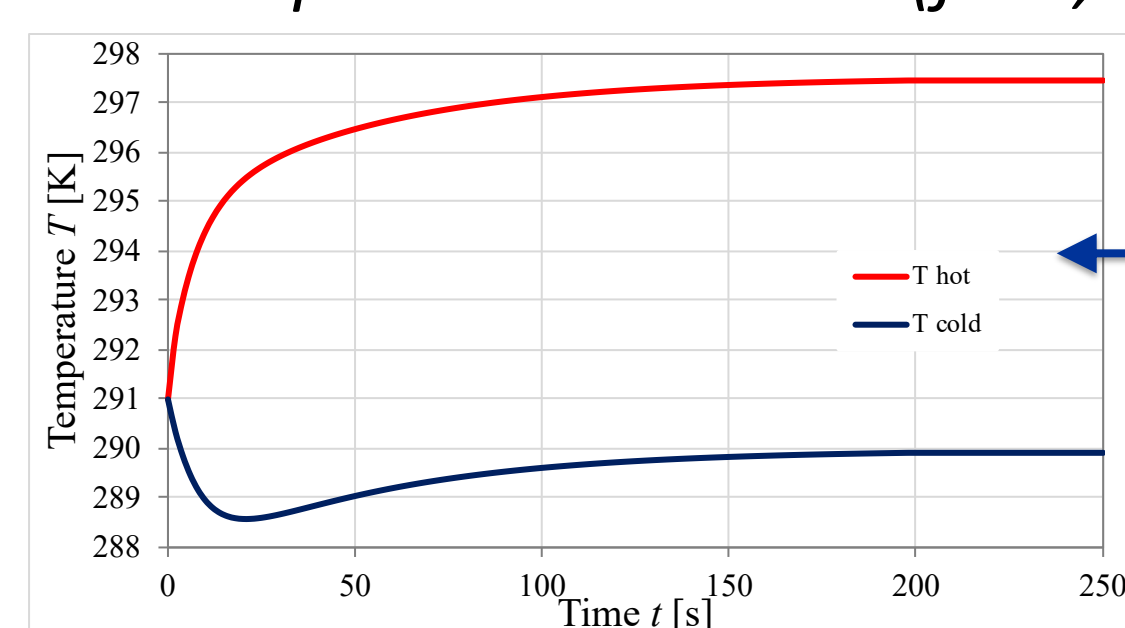
Gadolinium plate temperatures for 2D and 3D simulation (adiabatic case)



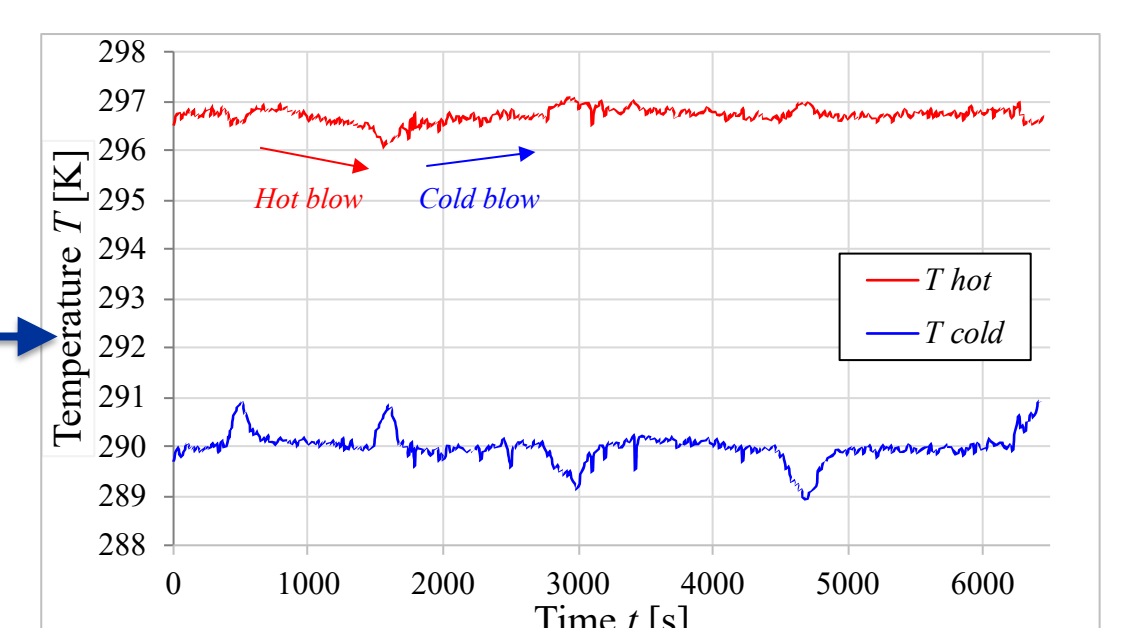
Axial temperature profile evolution over AMR cycles (adiabatic case)

### Experimental results

- Temperature evolution ( $f = 0,5$  Hz,  $A_0 = 56\%$ ) in adiabatic conditions

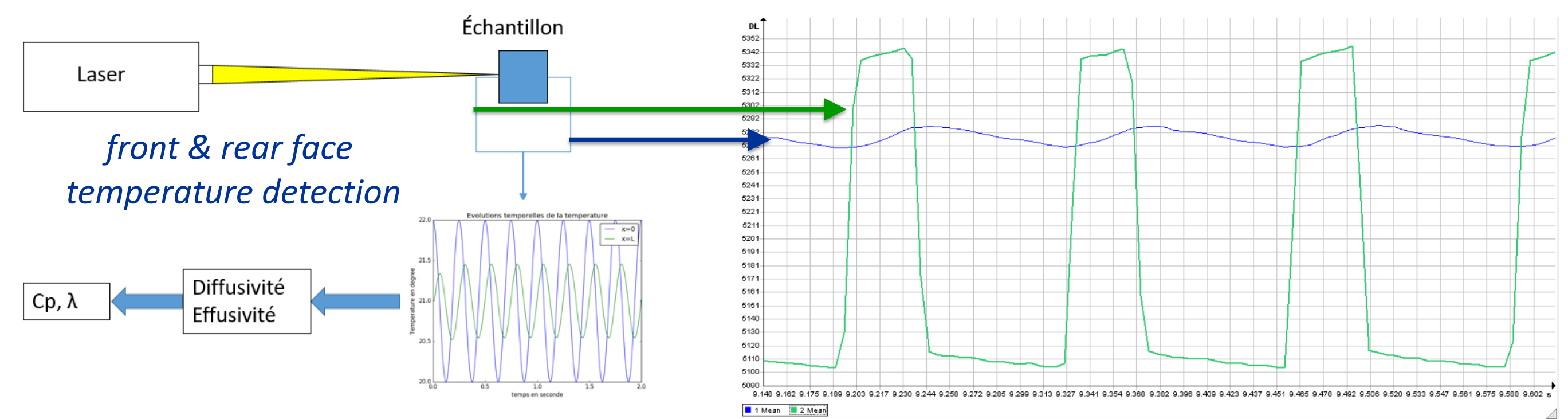


Gadolinium regenerator temperature (multiphysics simulation → 7,6 K)



Temperature results at steady (experimental bench → 6,9 K)

- Thermo-flash calorimetry of magnetocaloric materials in magnetic field



## Conclusions and prospects

### Key points

- very fast time calculation of multiphysics modelling compared to FEM codes
- high physical reliability of regenerator behavior in AMR cycles
- avoiding heat transfer, friction or porosity coefficients
- optimization of frequency and fluid displacement ratio for accelerated refrigeration
- good fit between multiphysics modelling and experimental results

### Further modelling and experiments

- extended calculations and experiments to high frequency → annular effect
- multi-Curie temperature regenerators → higher MC power density
- $\mu$ -PIV investigation of alternating flow in magnetocaloric regenerators
- high precision measurement of  $C_p(H,T)$  and  $\lambda(H,T)$  of magnetocaloric materials
- CompoMag Project for new optimized magnetocaloric composite regenerators

### Contacts

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