Recent developments in *Code_Saturne* for the simulation of lightning direct effects

ONERA DMPH & DSNA

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retour sur innovation

Introduction

- **Aircrafts are struck by lightning more than once per year. Lightning direct effects may cause fuselage puncture, mechanical breakdowns, sparking and ignition of fire in fuel tank area**

- **Lightning threat is taken into account in the design of aircraft with conception rules and certification processes**

- **Experiments in laboratory do not give enough information for the optimization of the material / structure against lightning direct effects (ok / not ok).**

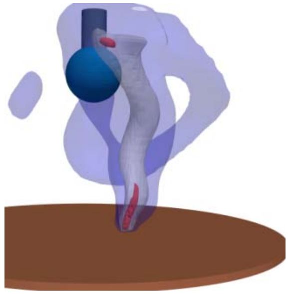
- **Simulations give qualitative understanding of the mechnanisms involved in the damaging of the structure**

- **Code_Saturne is used to simulate:**
  - **The dynamic of lightning arc column, the interaction with airflow**
  - **The interaction of lightning arc with material**
  - **The heating and damaning of the structure due to lightning current**

Emirates A380 at Heathrow

ONERA GRIFON

Code_Saturne



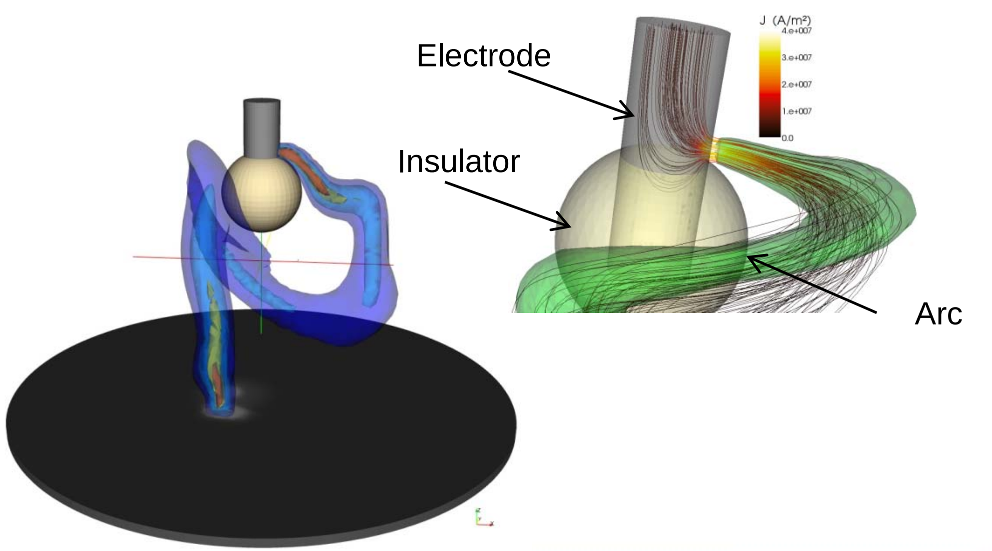
- Diffusion in heterogeneous media
- Radiative transfers
- Coupling with external code with CWIPI

Diffusion in heterogeneous media

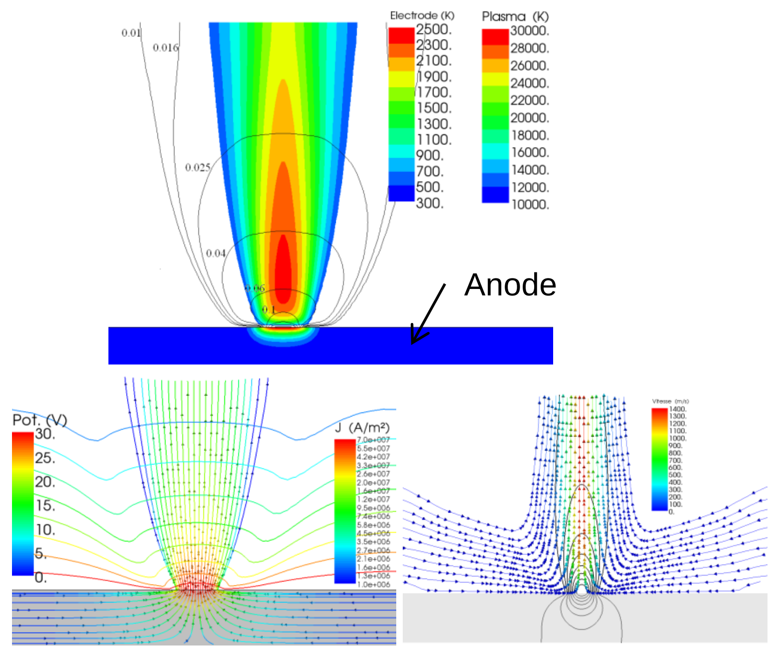
MOTIVATIONS

- The electrodes are included in the computation domain because of EM coupling
- Computation domain may contain:
  - Arc zone (fluid, conductive or not)
  - Electrode zone (solid, very conductive)
  - Dielectrics (solid, not conductive)
- The computation domain is heterogenous

Example of the jet diverting electrode



Example of the jet of plasma



Diffusion in heterogeneous media

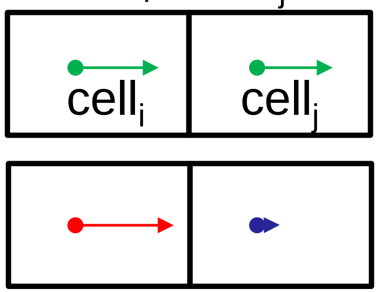
- **Heterogeneous media requires harmonic mean (iviscf=1)**
- **Standard reconstruction method in CS are not suited**
- ➢ **Reconstruction based on flux**

Flux $\mathbf{F} = \lambda\, \mathbf{G} = \lambda\, \mathbf{grad}(U)$

$\lambda_i << \lambda_j$

Flux

Grad



Conservative flux **F**

Discontinuous Gradient **G**

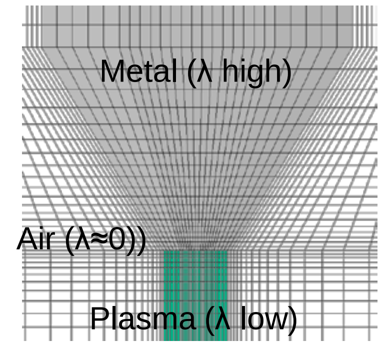
<u>Flux based least square minimization</u>

$f_i \approx (1/2\lambda_i)\ \Sigma(\lambda_i \mathbf{G}_i \cdot \mathbf{d}_{ij} - \lambda_{ij} \mathbf{G}_{ij} \cdot \mathbf{d}_{ij})$ with $\mathbf{G}_{ij} = (U_i - U_j)\cdot \mathbf{d}_{ij} / d^2_{ij}$

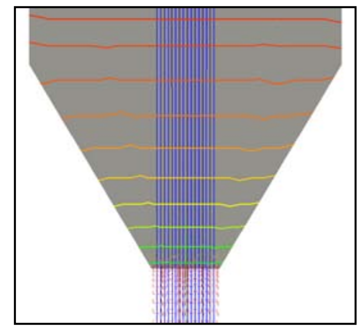
$\mathbf{S}_{ij} \approx (\lambda_j / (\lambda_i + \lambda_j))\ [U_j - U_i]\ \mathbf{d}_{ij} / d_{ij}^2$

Example: electrode and plasma column

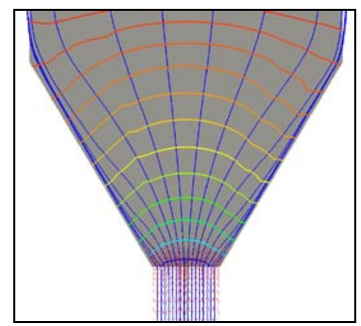
Mesh and geometry



Without reconstruction

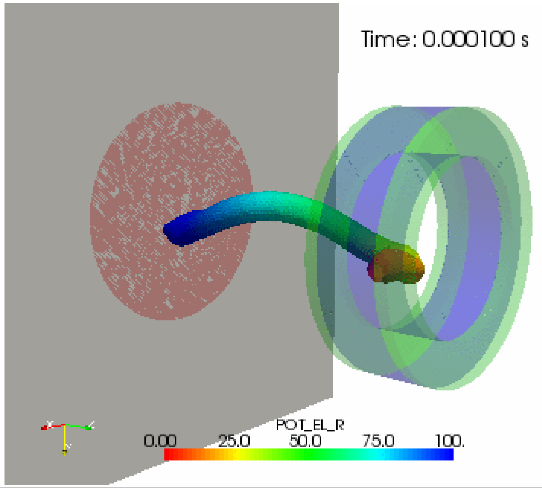


With reconstruction

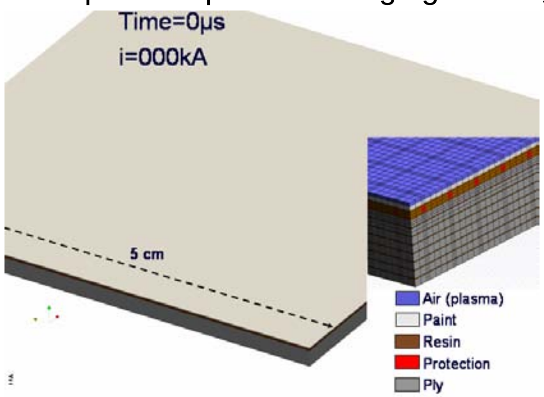


Diffusion in heterogeneous media: examples

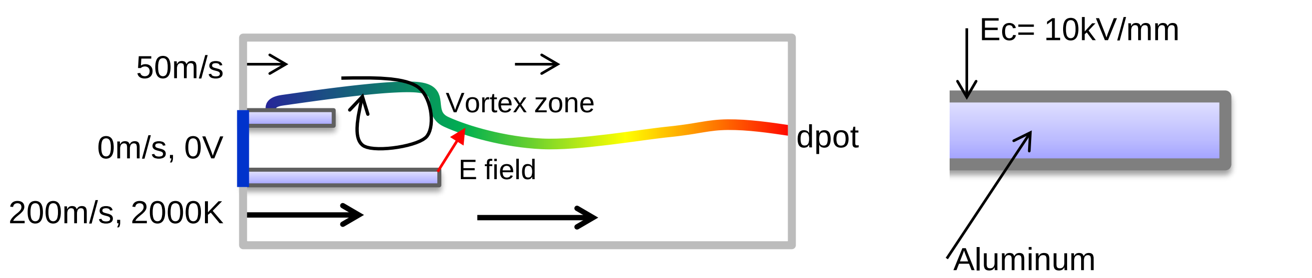
Example: hollow electrode

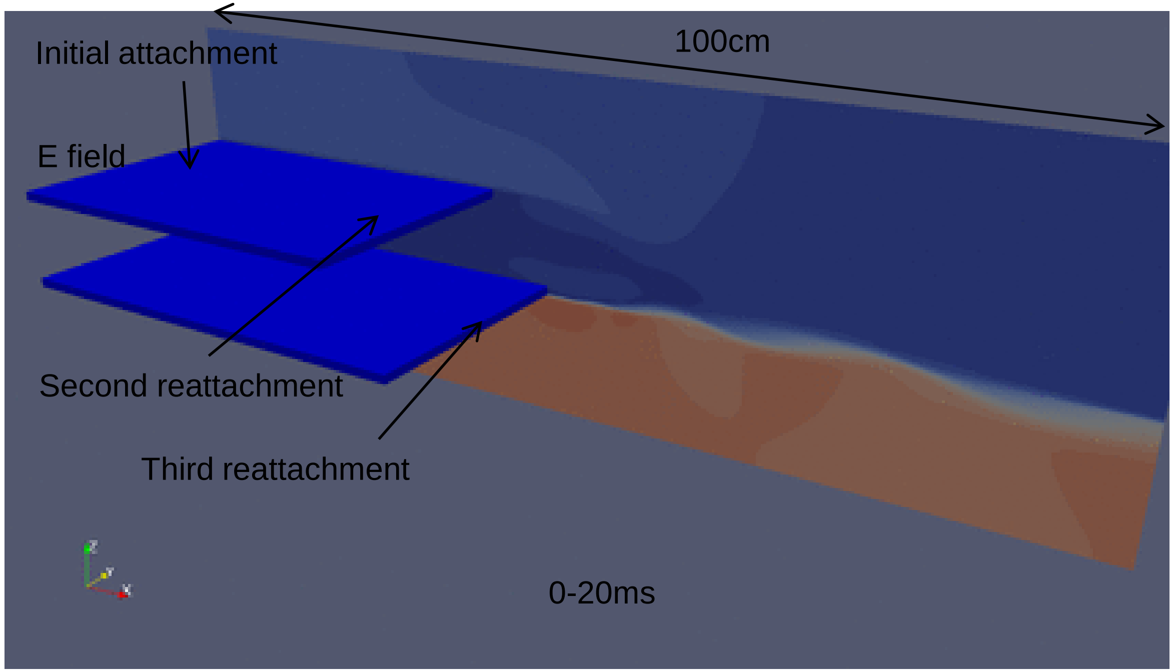


Example: composite damaging du to lightning strike



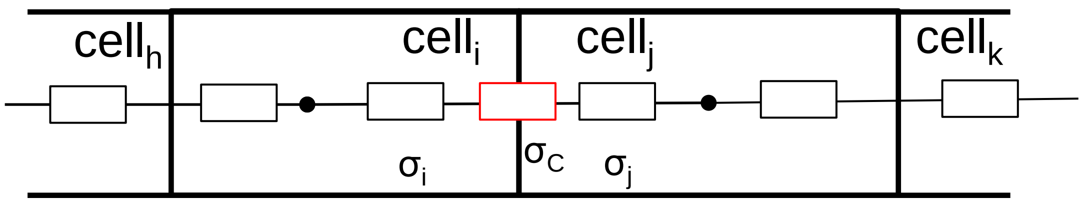
Example: reattachment in complex airflow around an engine





Diffusion in heterogeneous media: contact resistance

- **Contact resistance = Additional diffusion coefficient on specific faces**
- **Thin physical thickness (1 to 10µm)**



Example for electric diffusion div(σ**grad**(U))

- Total diffusion coefficient for solving step

σ_C : contact electric conductivity

$\sigma_{ij} = 2\ _i\ \sigma_j/(\sigma_i + \sigma_j)$! harmonic mean, pond=0.5

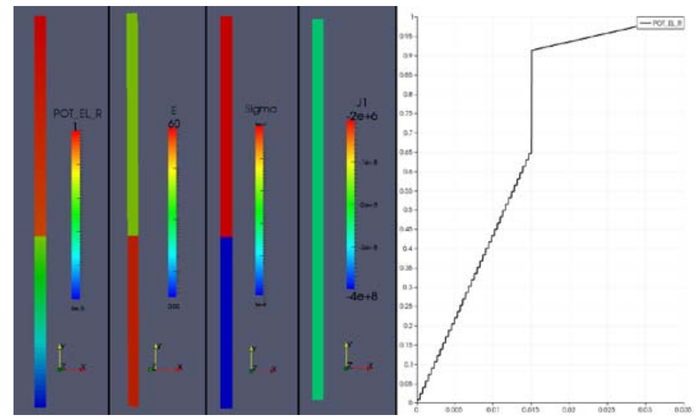
$\sigma_{TOT} = \sigma_{ij}\ \sigma_C/(\sigma_{ij} + \sigma_C)$! in vscfa(ifac)

- The gradient dues to σ_C doesn't exist in the cell, only in the face

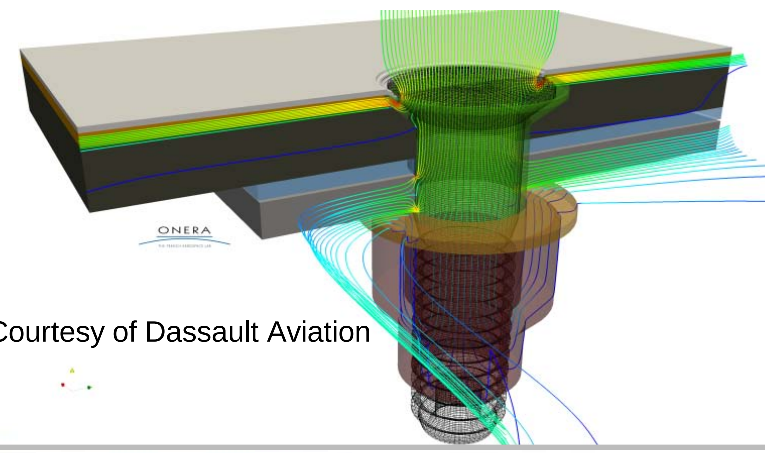
- Gradient on internal faces due to contact not for taken into account in reconstruction step

$\mathbf{G}_{ij} = (\sigma_{ij} / \sigma_{TOT})\ (U_i - U_j)\cdot\mathbf{d}_{ij} / d^2_{ij}$

Example: Electric conduction in a Ti-Al contact ,Rc=100mΩ



Example: Electric conduction in an aeronautic fastenner



Courtesy of Dassault Aviation

- Diffusion in heterogeneous media
- Radiative transfers
- Coupling with external code with CWIPI

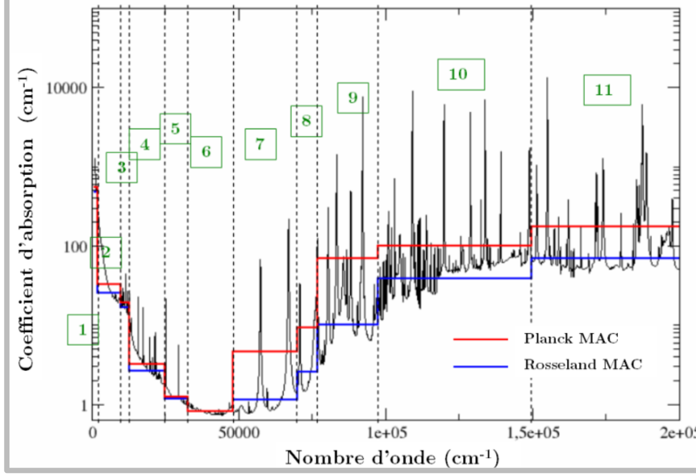
Radiative transfers: spectral bands and SP3 method

- The default model is dedicated to gray media, i.e. a single absorption coefficient for all the spectrum (from IR to UV)
- The absorption coefficient of thermal plasma highly depends on the wavelengh, temperature and pressure
- Development of subroutines that read and interpolate a data bank of abosrption coefficient for a given number of spectral bands
- Adapation of the code to perform calculation on all the bands for the two methods already developped in CS (DOM and P1)
- Development of SP3 method

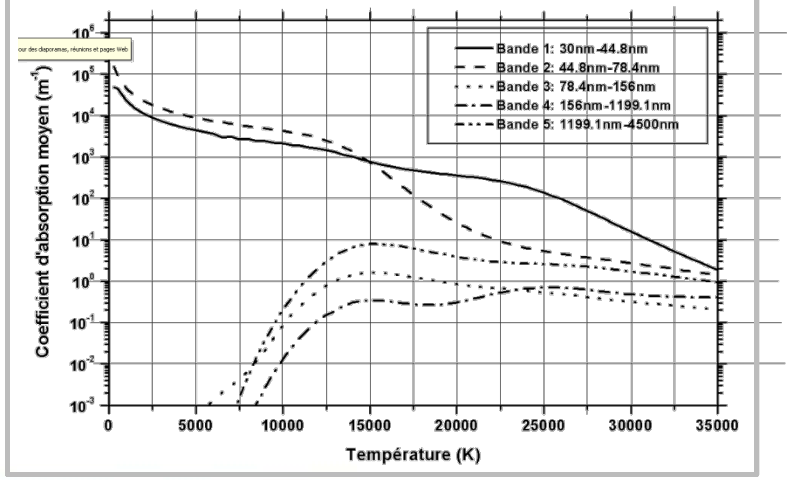
$$\vec{\nabla} \cdot \left(\frac{\mu_i}{\kappa} \vec{\nabla} \psi_i \right) = \kappa \left(\psi_i - 4\pi L^0 \right) \qquad i = 1, 2$$

Air plasma, 25kK, 100bar, 11 spectral bands

Black:

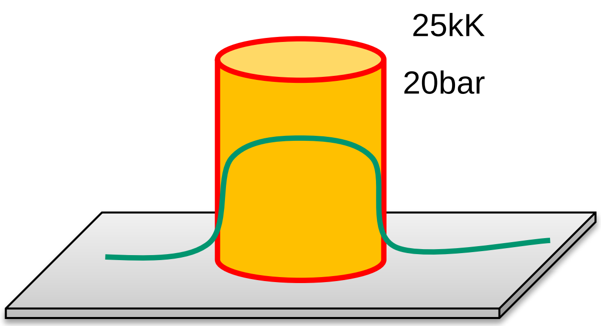


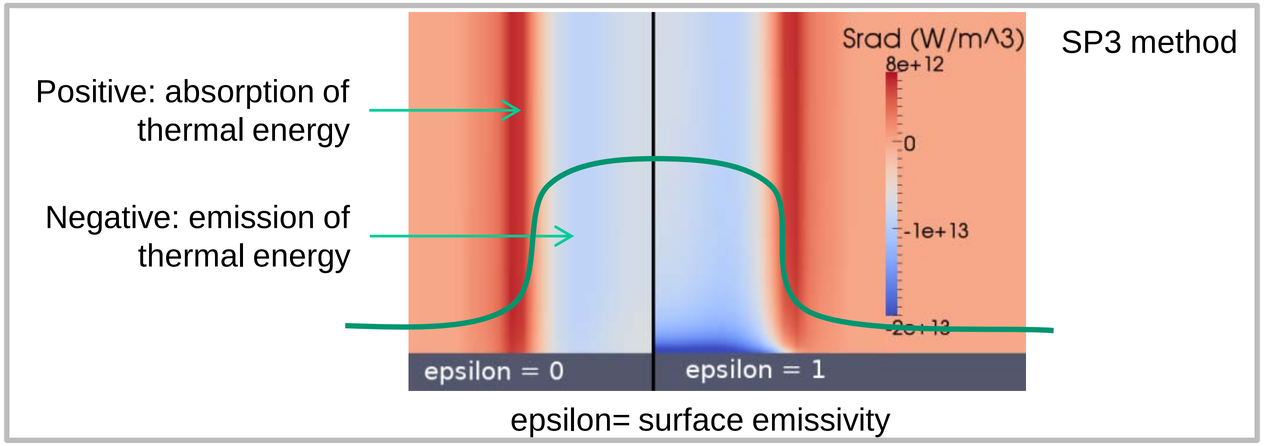
Argon, 1bar, 5 spectral bands



Radiative transfers: example

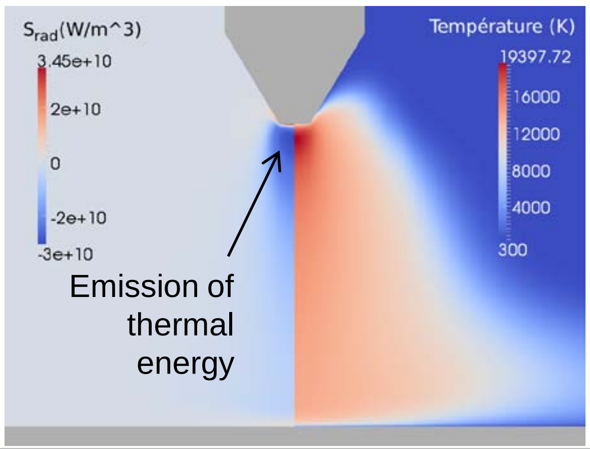
- **Example of RT in a plasma cylinder on a planar electrod**



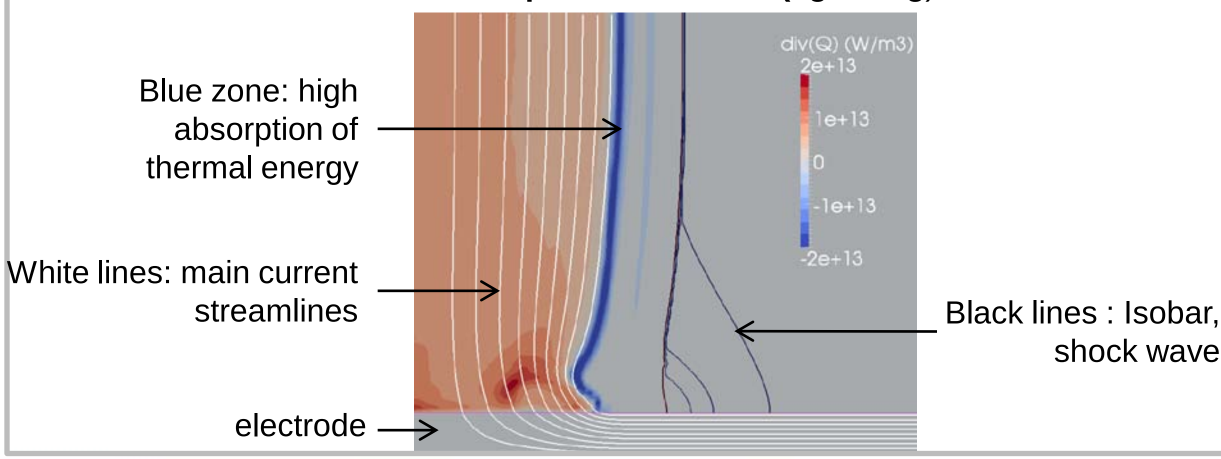


- **Example of RT in electric arcs**

200A DC arc in air (welding like application)



200kA pulsed arc in air (lightning)



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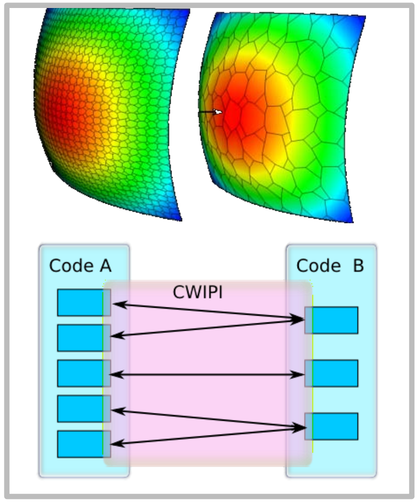
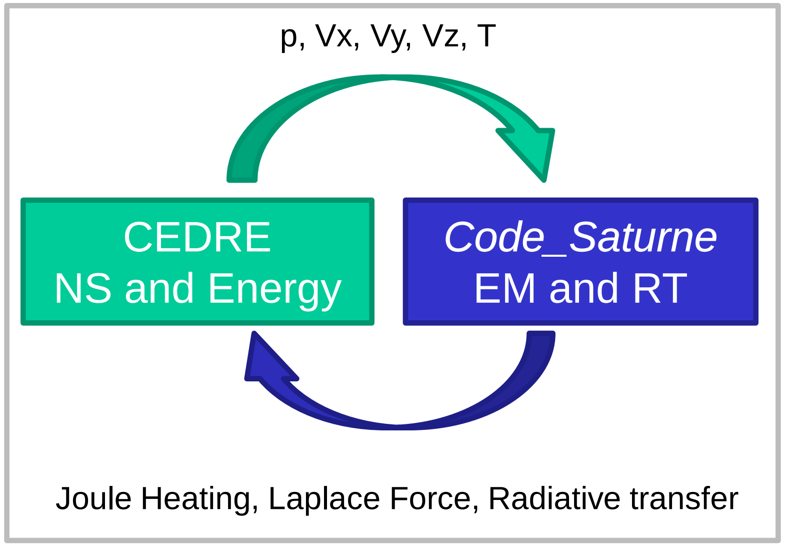
Coupling with external code with CWIPI

- **CWIPI: Coupling With Parallele Interface (LGPL), based on BFT and FVM**
- **2D, 3D coupling, different geometries, mesh, time step**
- **Coupling with CEDRE for compressible flow**

  (CEDRE: Onera's unstrucured diphasic code for combustion and aerodynamic)
- **CEDRE-CS coupling for long arc interacting with airflow (wing, engine, antenna, open rotor, deicing …)**





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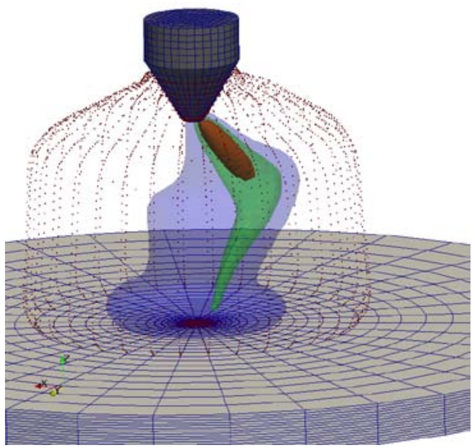

200kA pulsed arc in air (lightning)