SERPENT workshop
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Dynamically linked Serpent/OpenFOAM in transient mode

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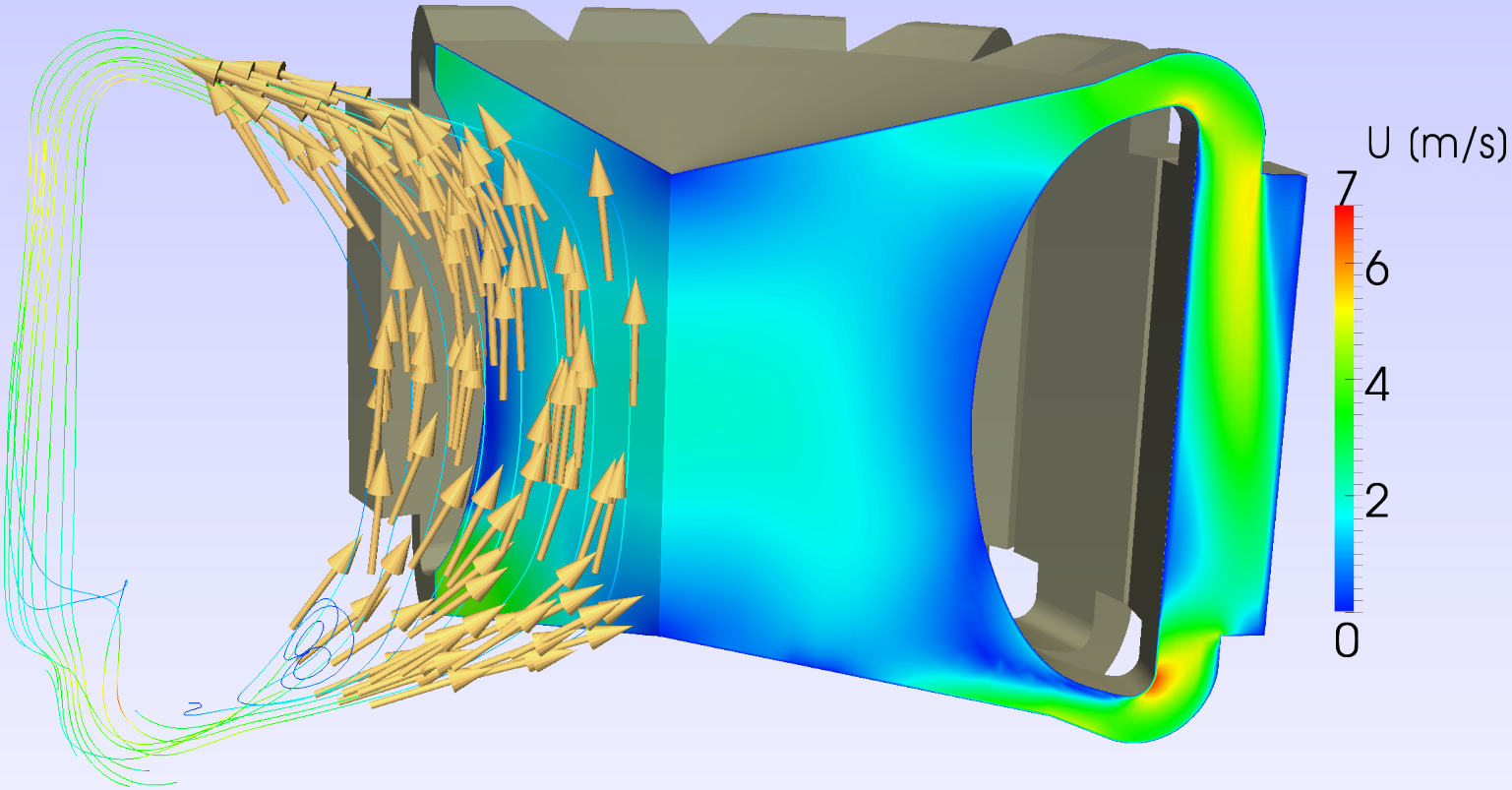
Super prompt-critical transient simulations in the MSFR

...coupling CFD and neutron transport



Very low speed of sound due to He bubbles in the salt (0.1% - 1% vol.)

Effective prompt lifetime in the MSFR $\sim 1\mu s$

Delay between power deposition and thermal expansion feedbacks

- Short background:
  Serpent/OpenFOAM coupling in steady state mode
- Serpent/OpenFOAM in transient mode:
  Preliminary validation case (Godiva super prompt-critical burst)

Steady-state Serpent/OpenFOAM coupling

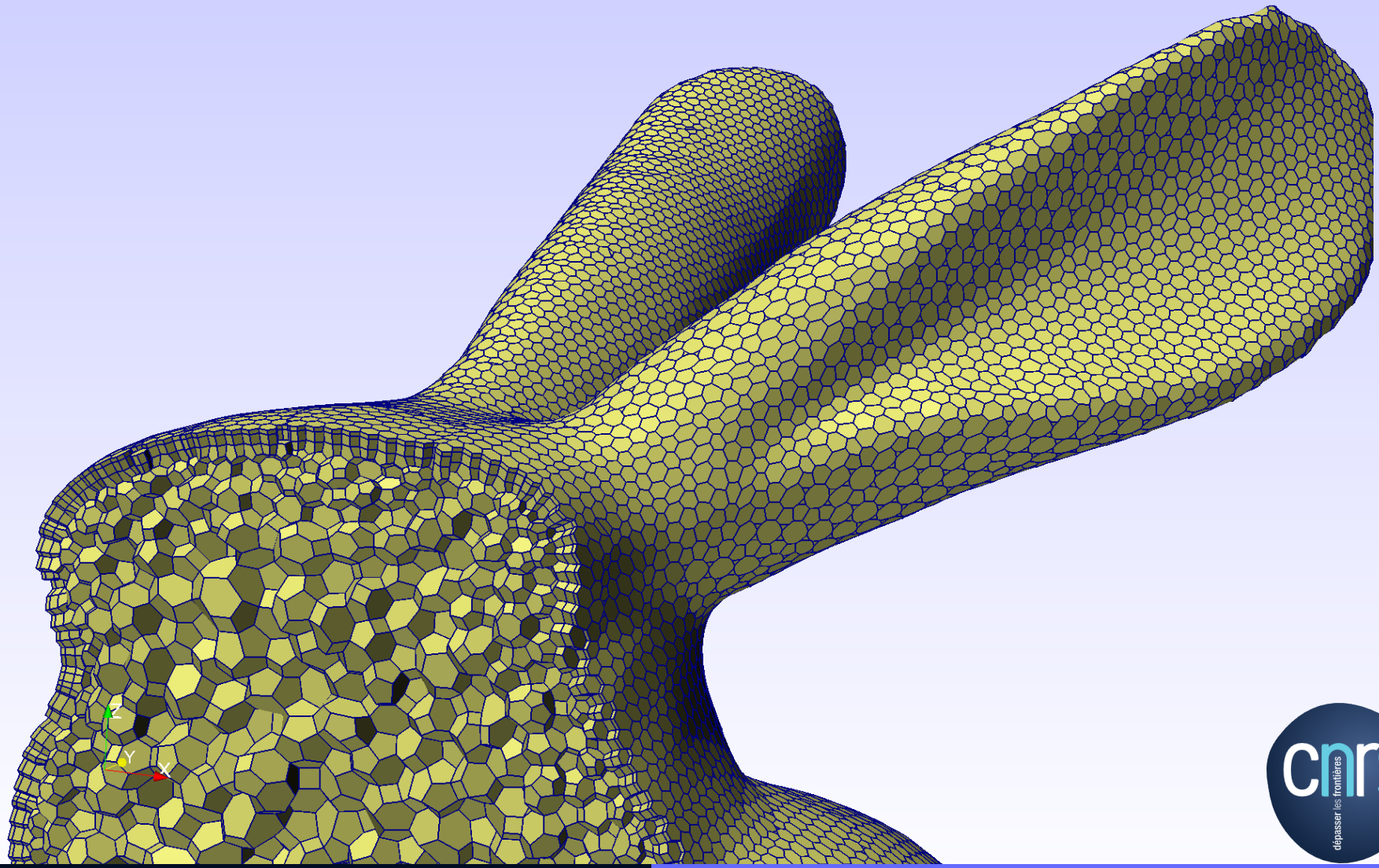
Short background (from last Serpent meeting)

OpenFOAM libraries dynamically linked to Serpent-2

- Serpent takes care of the **hard job**: transporting neutrons
- Serpent "asks" material properties at (X,Y,Z) (e.g., fuel density)
- Serpent "tells" quantities to score at (X,Y,Z) (e.g., fuel density)
- The other physics are solved with standard FV methods
- Coupling is performed at runtime (i.e. every *n* cycles)
  Code-to-code coupling & complex I/O files can be avoided
- The mesh can be deformed at each iteration
- With delta tracking, we just need to know the cell index of (X,Y,Z)
- Fast octree-based mesh search are available in OpenFOAM

Critical Stanford bunny

Short background (from last Serpent meeting)



Hot Stanford bunny
Short background (from last Serpent meeting)

Simple multiphysics coupling test case:

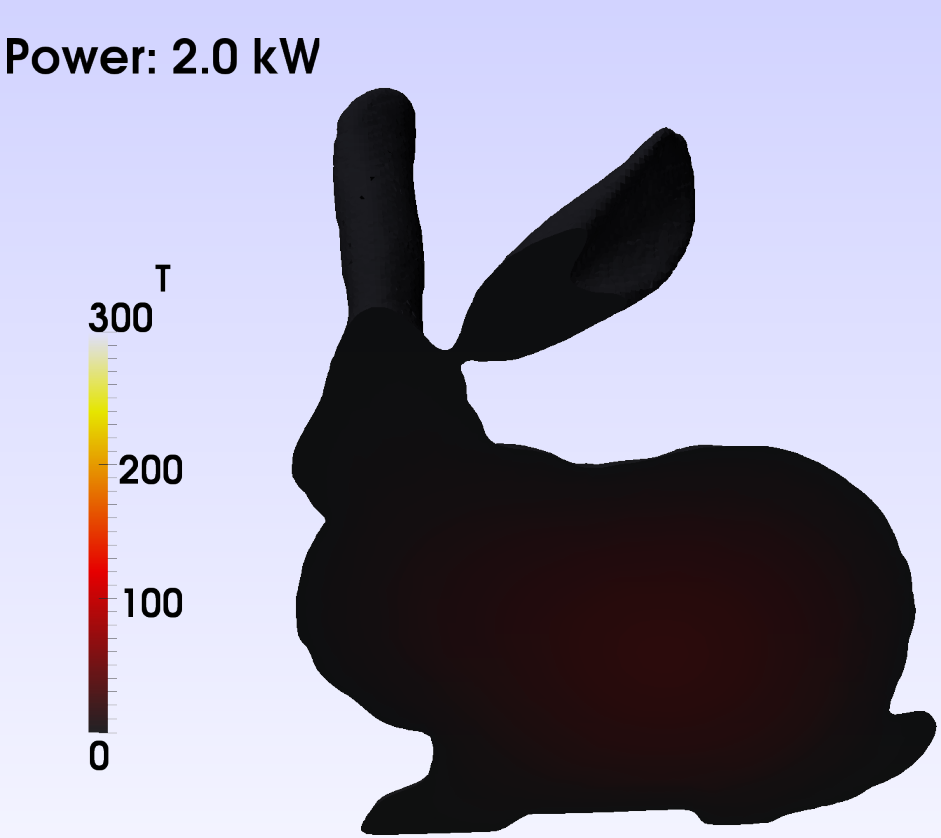
- Neutron transport
- Heat diffusion
- Solid mechanics (simple linear-elastic behavior)
- Moving-mesh & material density update

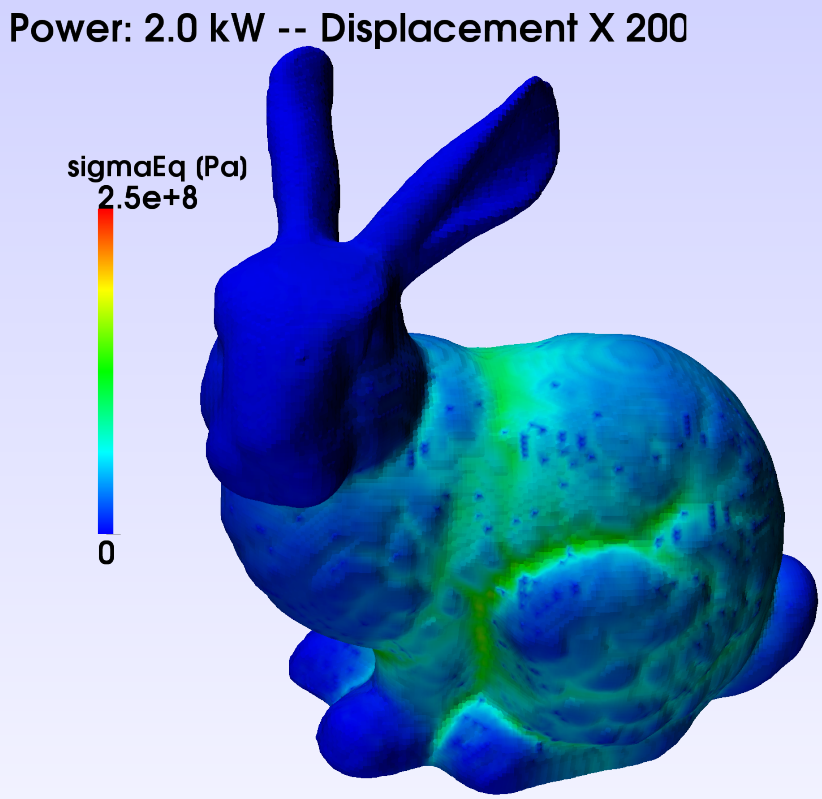
  (mass conservation is ensured for each displaced cell)

BCs: zero temperature at boundary, no displacement at the center of the bottom base

Hot Stanford bunny

Short background (from last Serpent meeting)





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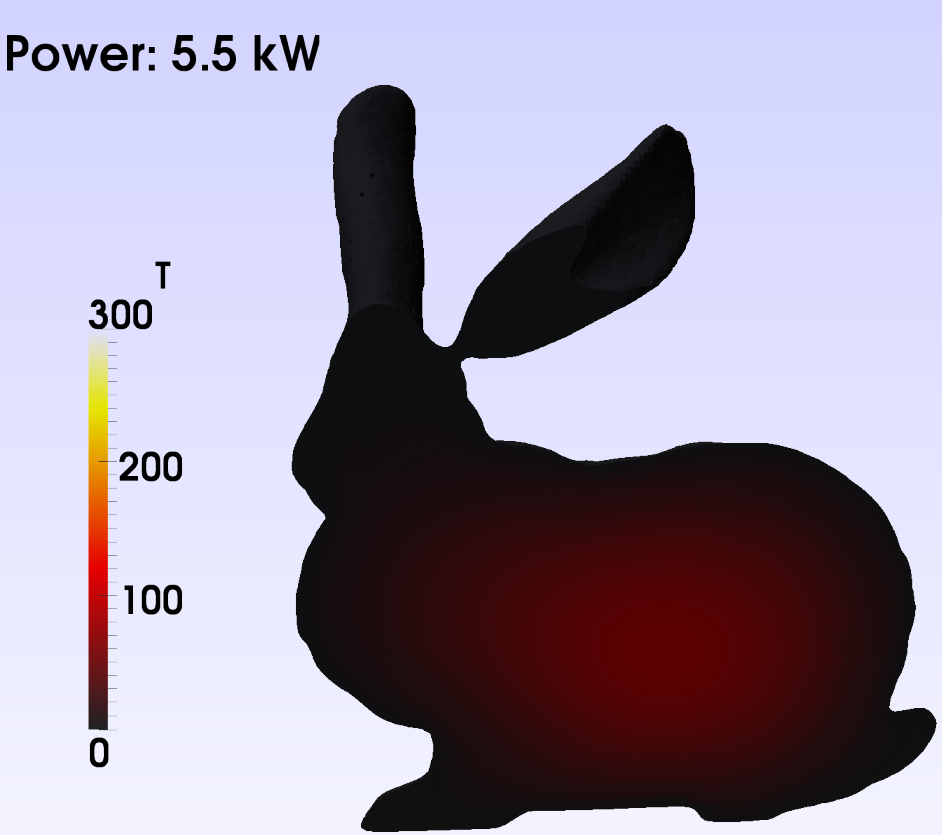
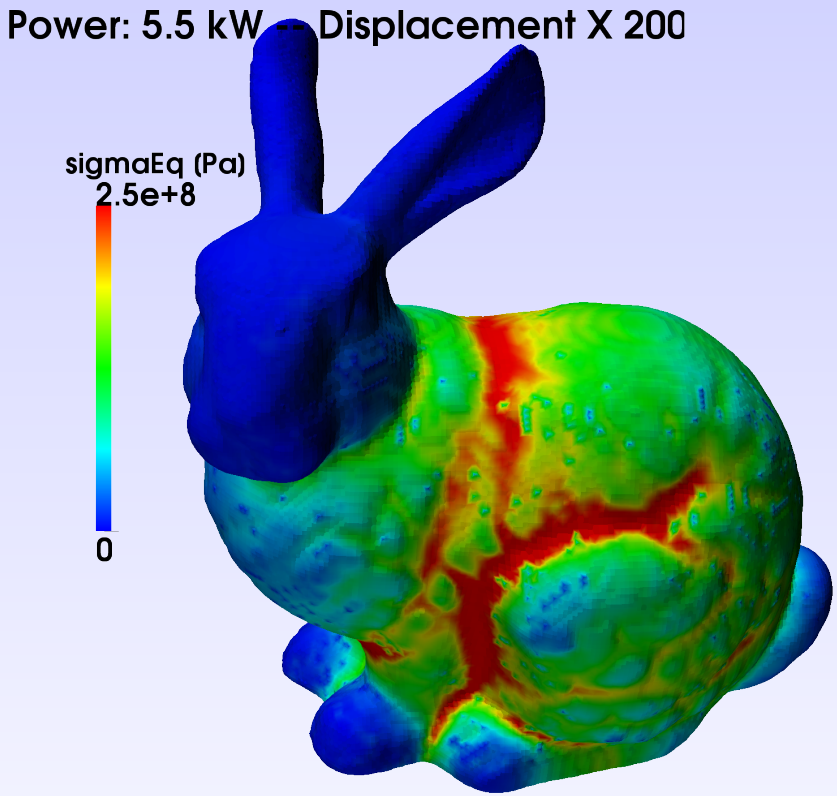
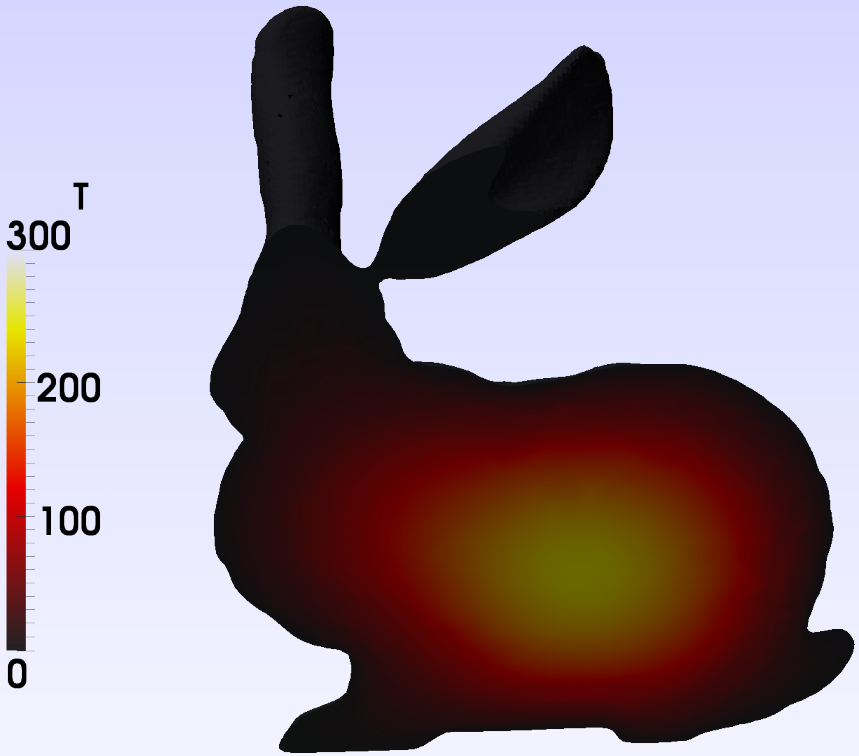




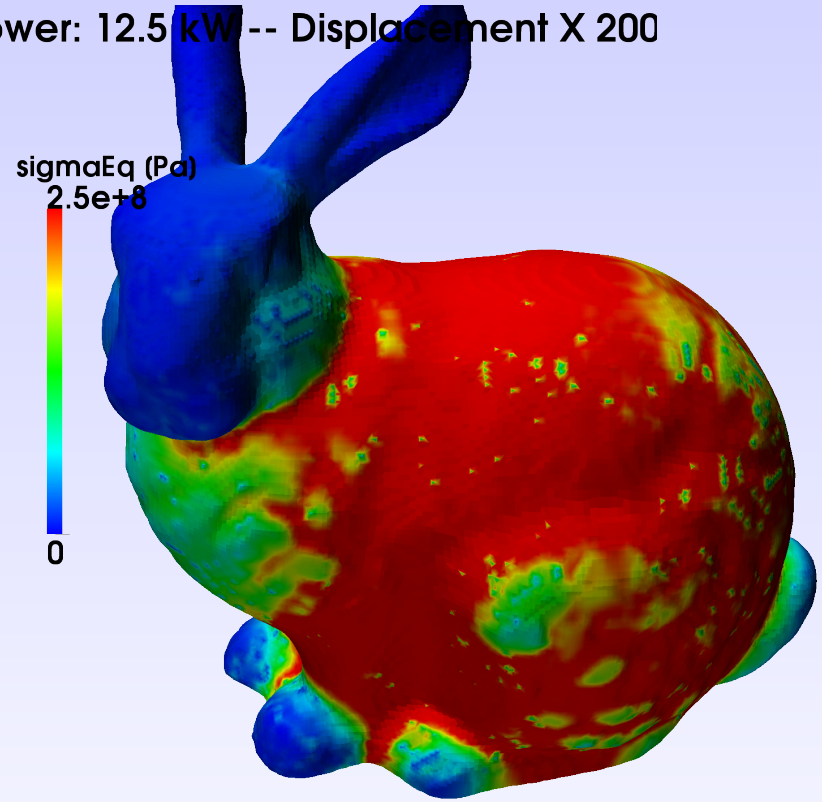
Hot Stanford bunny

Short background (from last Serpent meeting)

Power: 12.5 kW



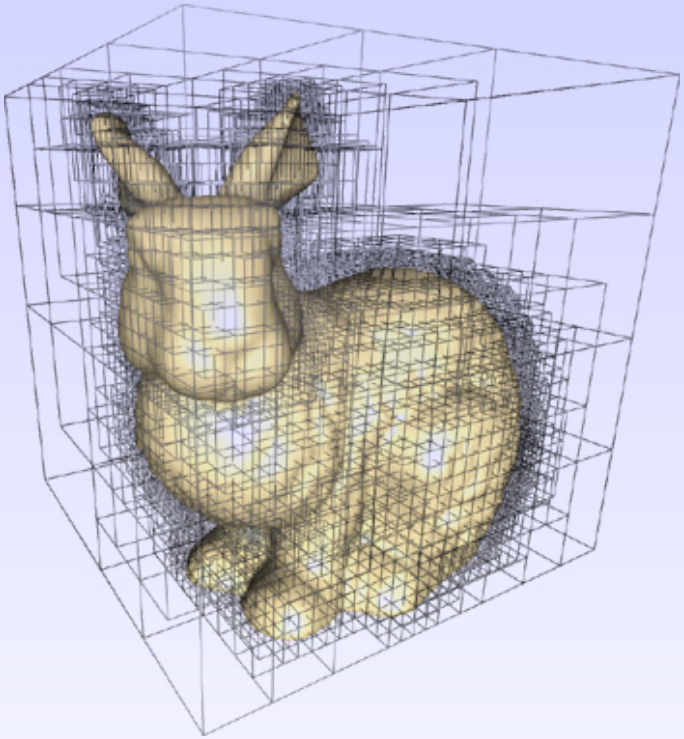
Power: 12.5 kW -- Displacement X 200



Octree-based mesh search and Delta Tracking

Short background (from last Serpent meeting)

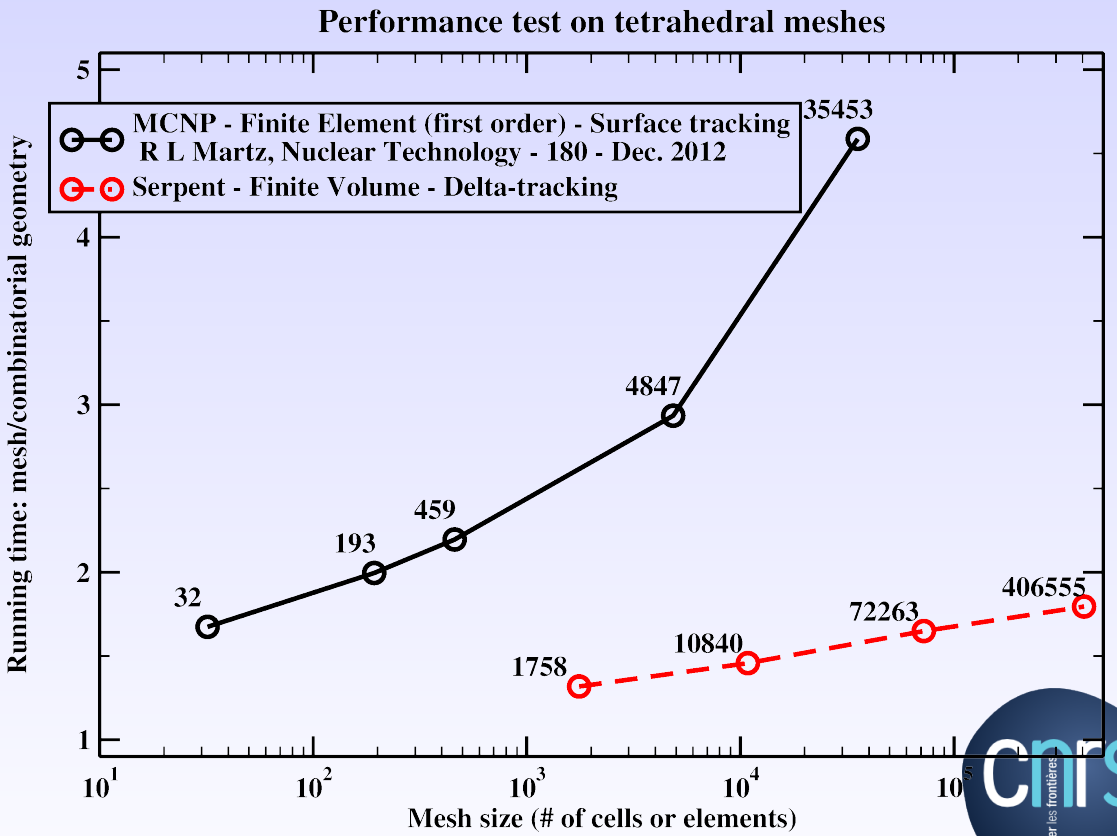
Octree-based mesh search algorithms available in OF



Picture from:

http : //http.developer.nvidia.com/

Performances: Godiva test case



Latest developments LPSC/CNRS Grenoble

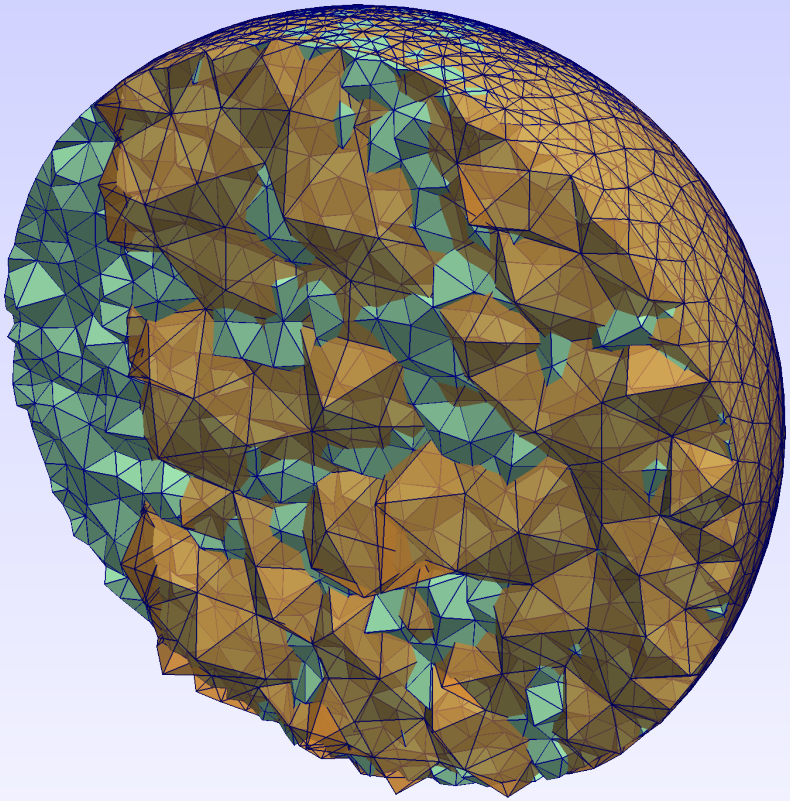
Preliminary results

Extending the idea to transient mode

Our goal: analysis of super prompt-critical transient in the MSFR

Preliminary validation: Godiva super prompt-critical burst

Two-meshes approach



- One mesh for CFD (solid mechanics, here)
  - Solving equations (Finite Volume)
- One mesh for neutron transport
  - Scoring energy deposition
  - Reading material properties for DT
- Mesh-to-mesh mapping at runtime
- Mesh deformation at each time step
- Explicit time coupling
- Possible adaptive time stepping

Latest developments LPSC/CNRS Grenoble

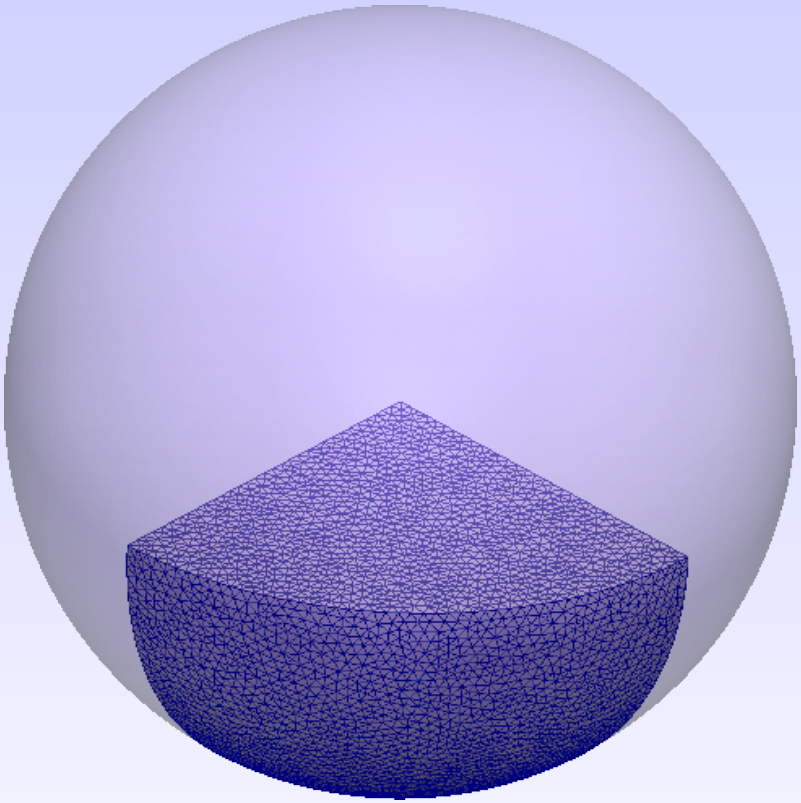
Godiva super prompt-critical burst

Godiva: spherical assembly $\sim$ 50 kg of metallic U

- Experimental results from LA-2029 (1960, public release 1995?)
- Effective prompt lifetime = few ns
- Rapid power excursion
- Thermal expansion feedbacks (no Doppler)
- In fast transients (T$\sim$10μs) speed of sound (few km/s) is relatively small: thermal-expansion is not in equilibrium with temperature fields

Modelling conditions "close" to MSFR super prompt-critical transient.

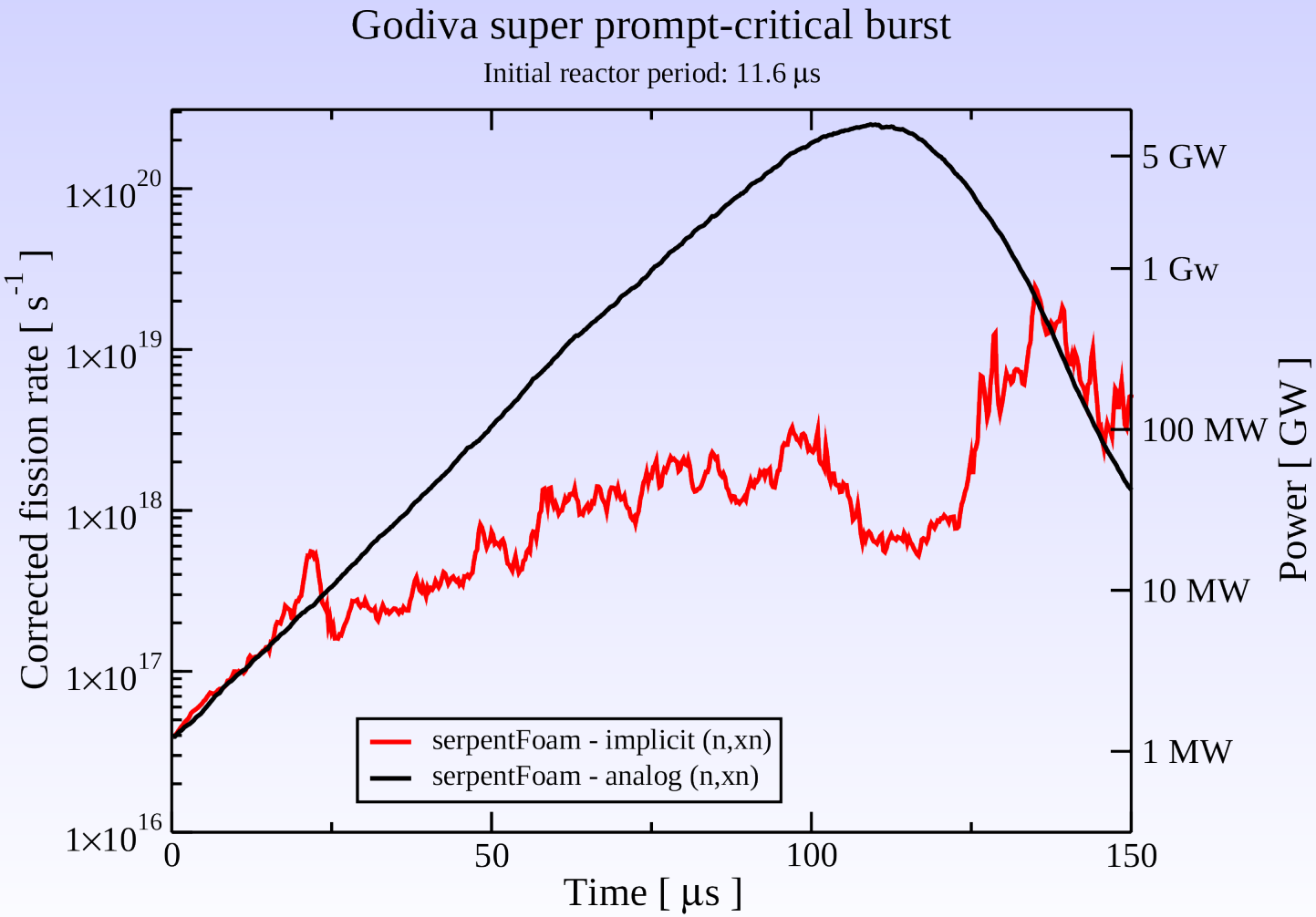
Simplified geometry



- Geometry: 1/8 of solid sphere
  - ≪bouncing of the upper section≫ not modelled
- Symmetry conditions in the 3 planes
- Void boundary condition
  - Room-return neutrons play important role in the $\sim$ *ms* time scales
- No delayed neutron precursors

Godiva super prompt-critical burst

Divergenge of weight distribution due to implicit (n,xn)

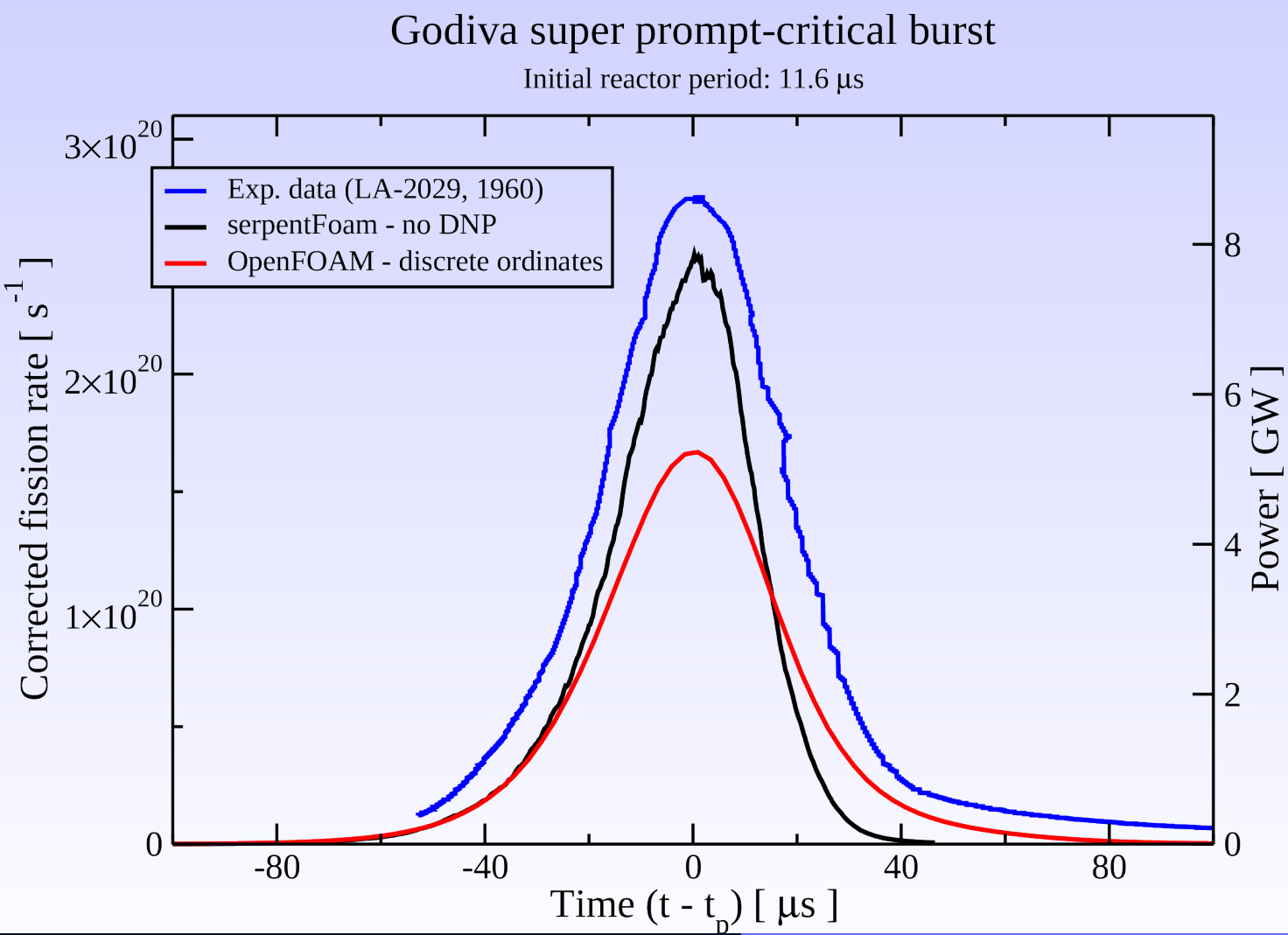


Godiva super prompt-critical burst

Validation against Italy vs. Germany credit spread of 3-years government bond

Godiva super prompt-critical burst

Validation against Los Alamos experimental data



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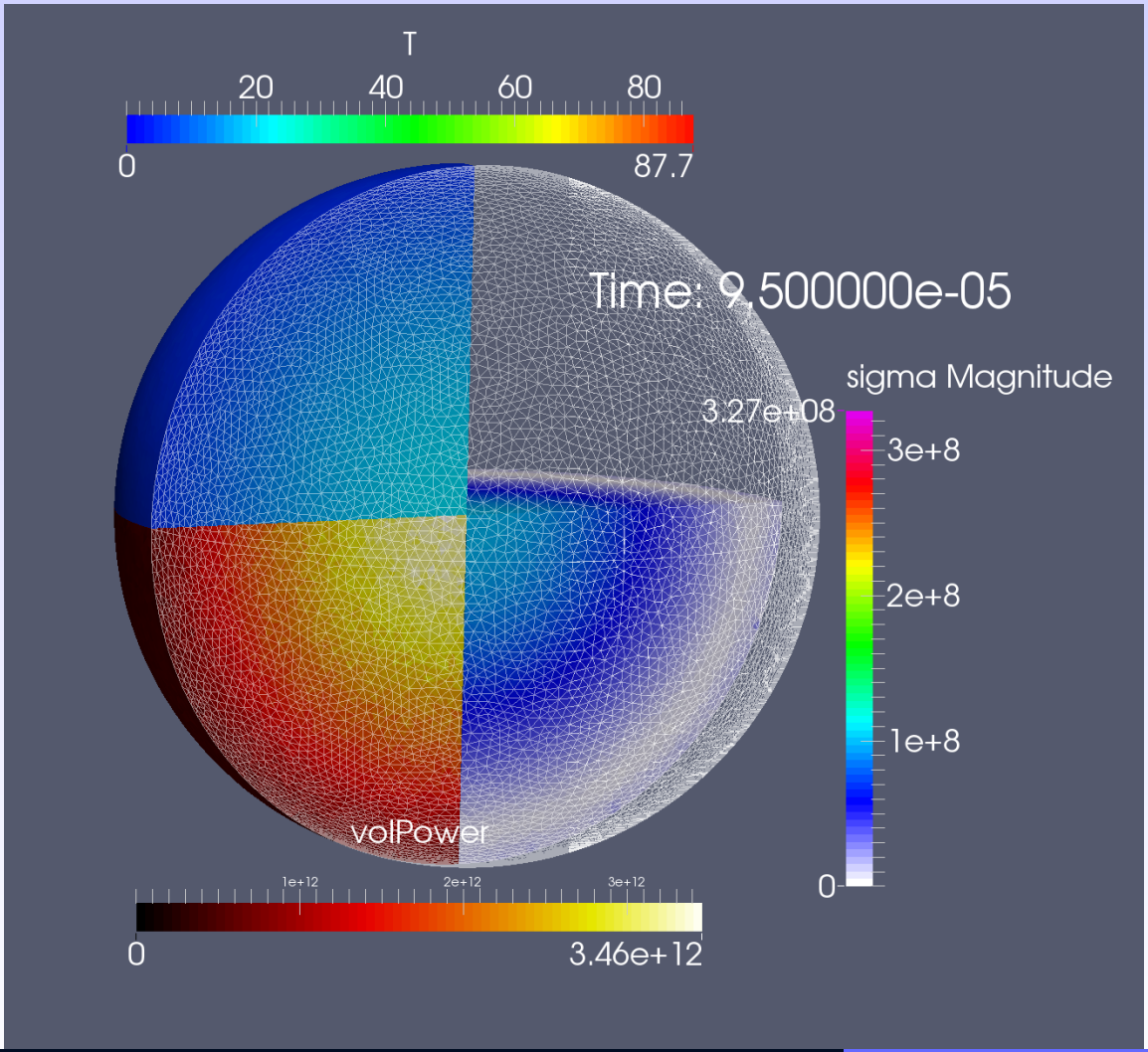

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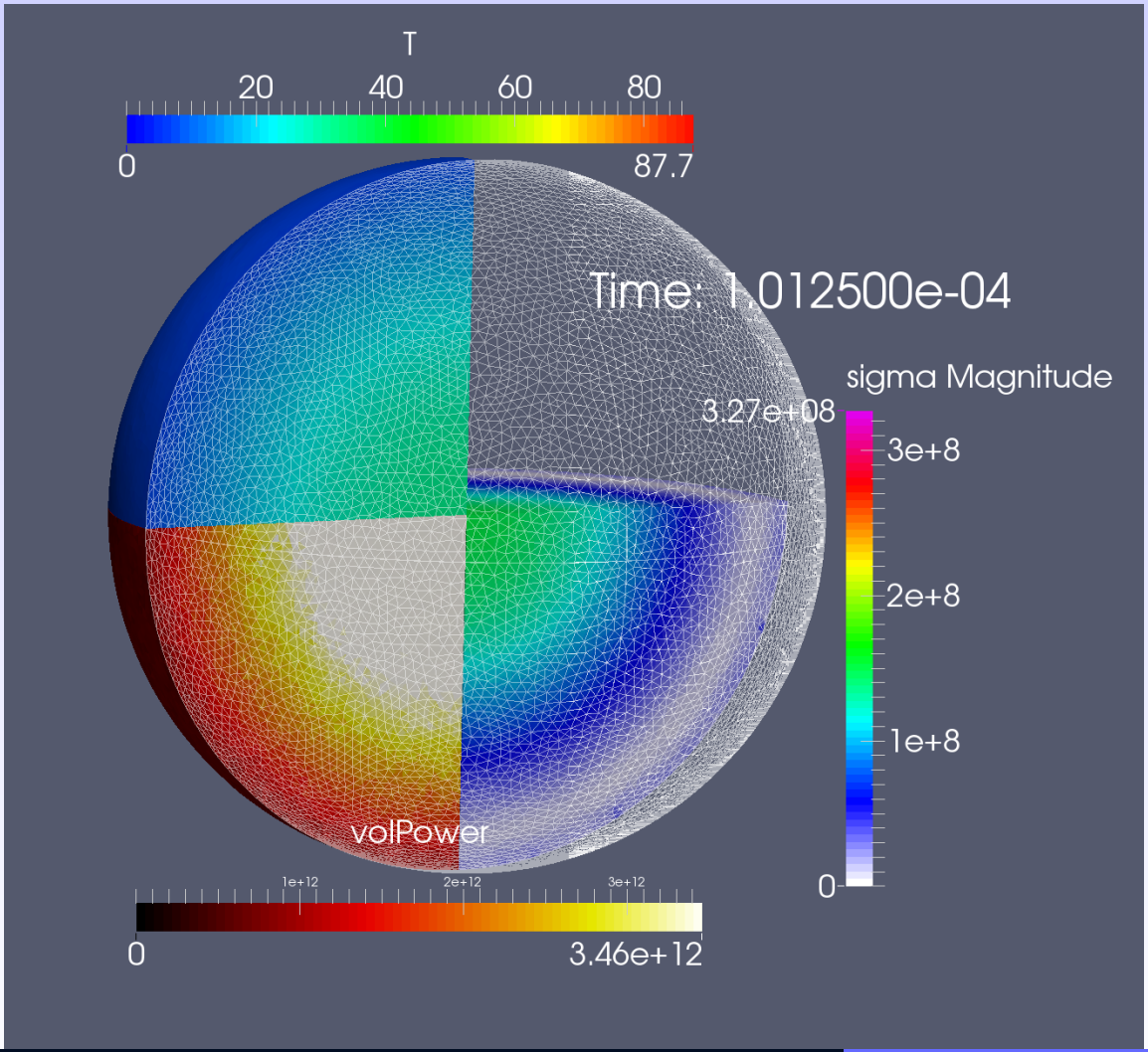

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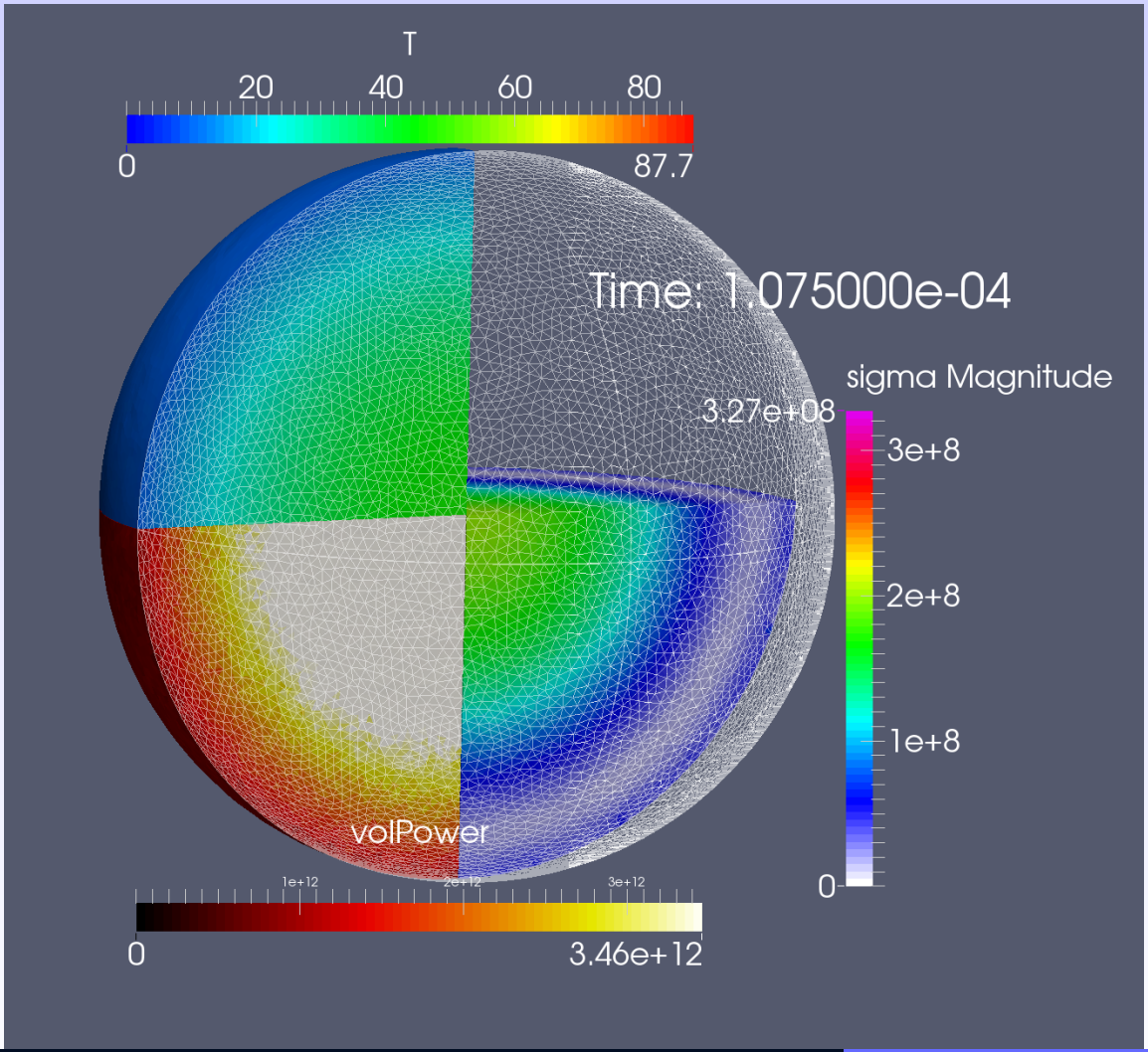

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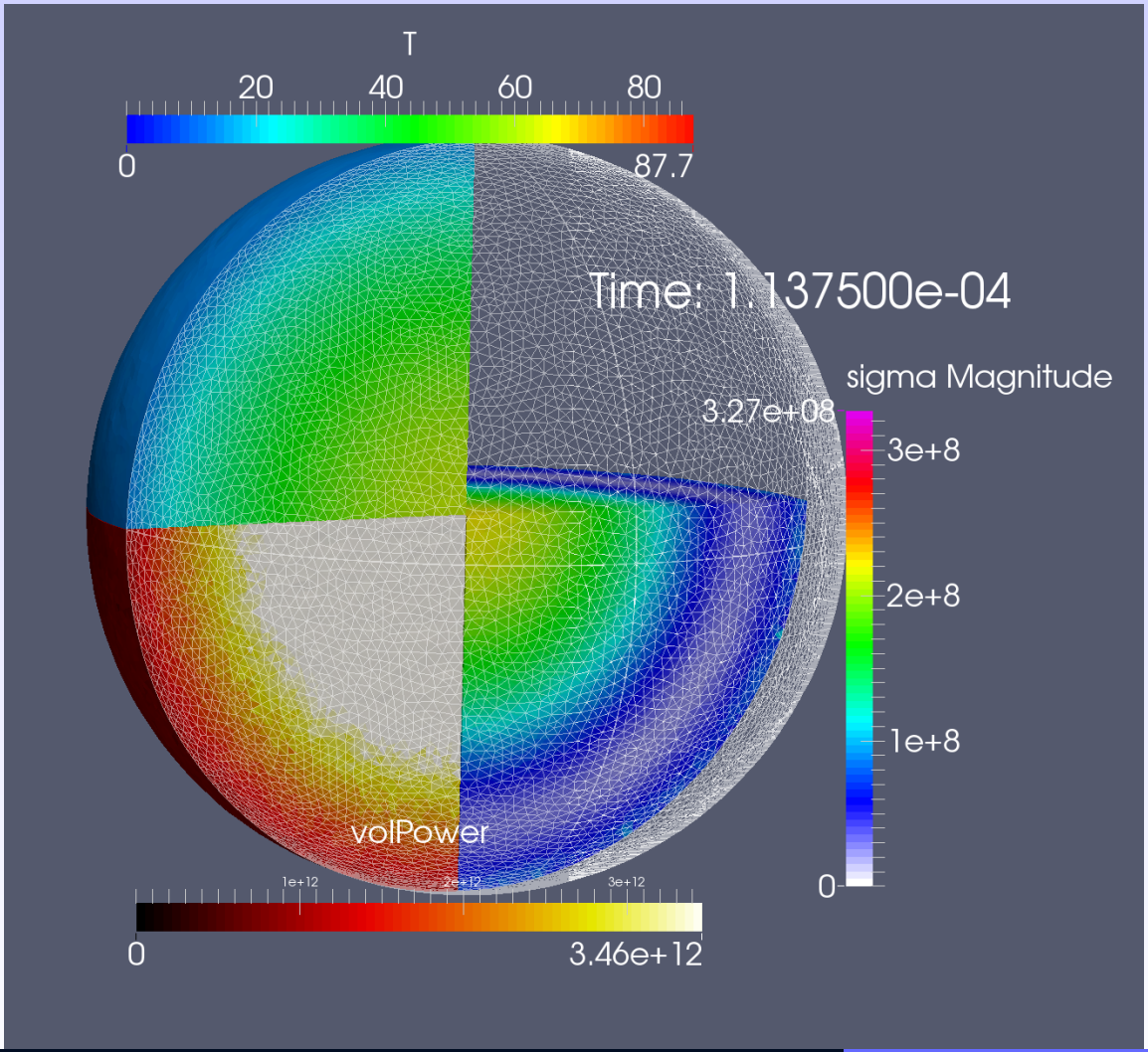

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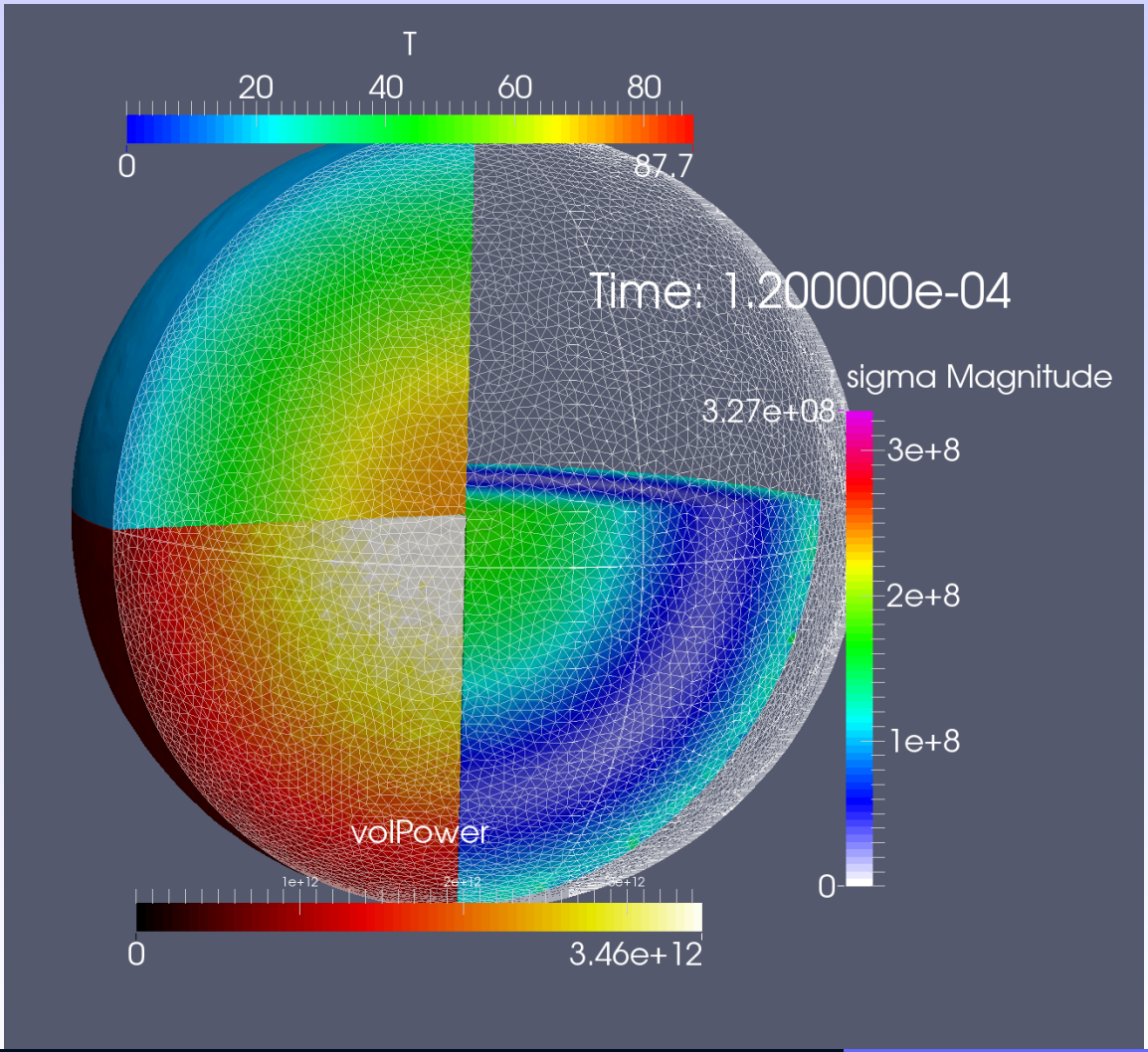

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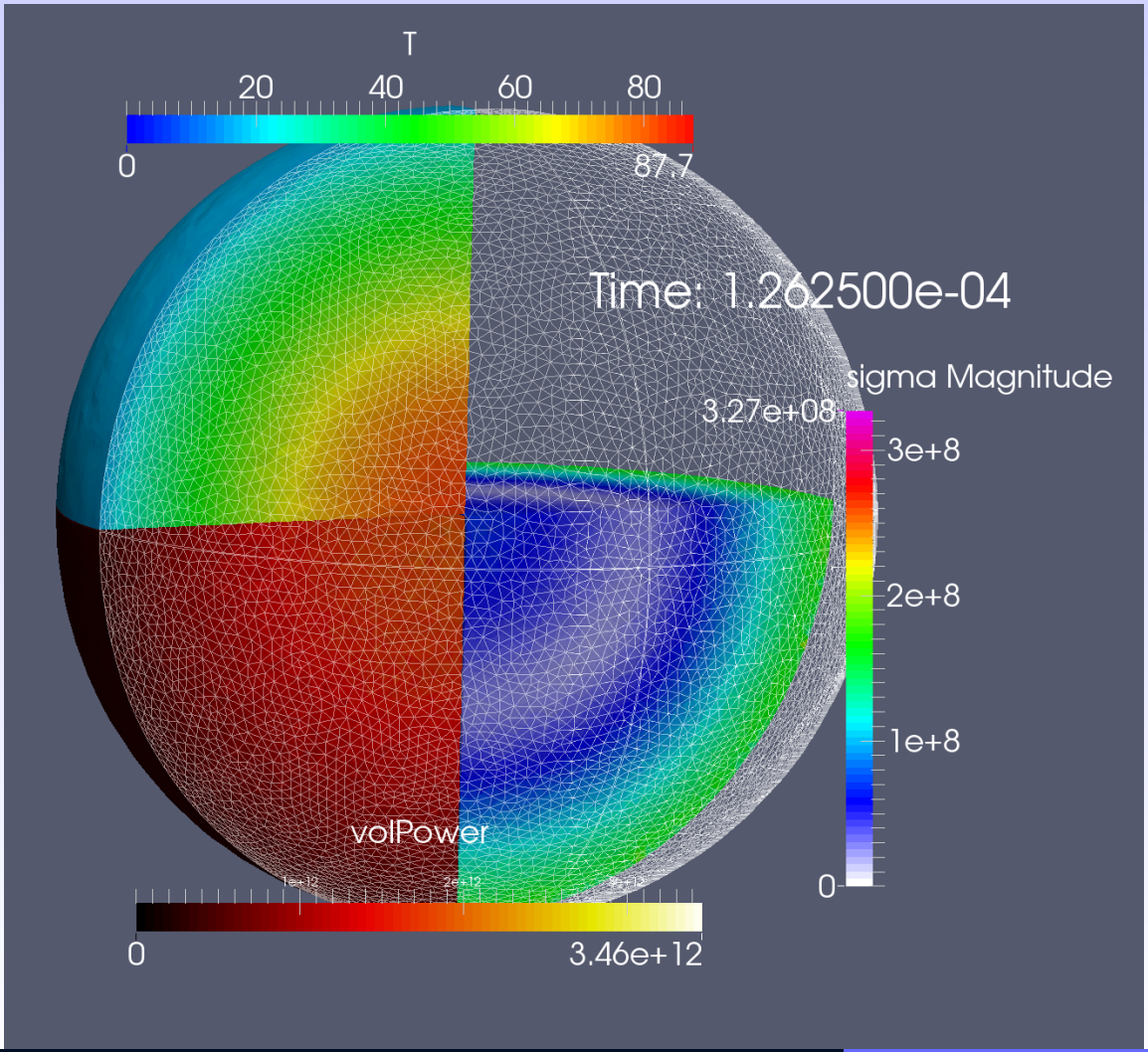

Godiva super prompt-critical burst

OpenFOAM discrete ordinates simulation very expensive (CPU)

(from: Fiorina, C., Aufiero, M., Pelloni, S. and Mikityuk, K: *ICONE22-30395, 2014*)

Serpent/OpenFOAM Monte Carlo simulation less expensive (CPU)
but higher memory requirement (allocating particle structures)

CPU time is almost independent of the time step and the mesh size

Next steps

- Coupling neutron transport with density-based CFD compressible solvers for MSFR transients
- Implicit treatment of delayed neutron precursors

THANK YOU FOR THE ATTENTION

QUESTIONS? SUGGESTIONS? NEW IDEAS?