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Lid-driven cavity highly turbulent flow subjected to high magnetic field

Luca Marioni, François Bay, Elie Hachem

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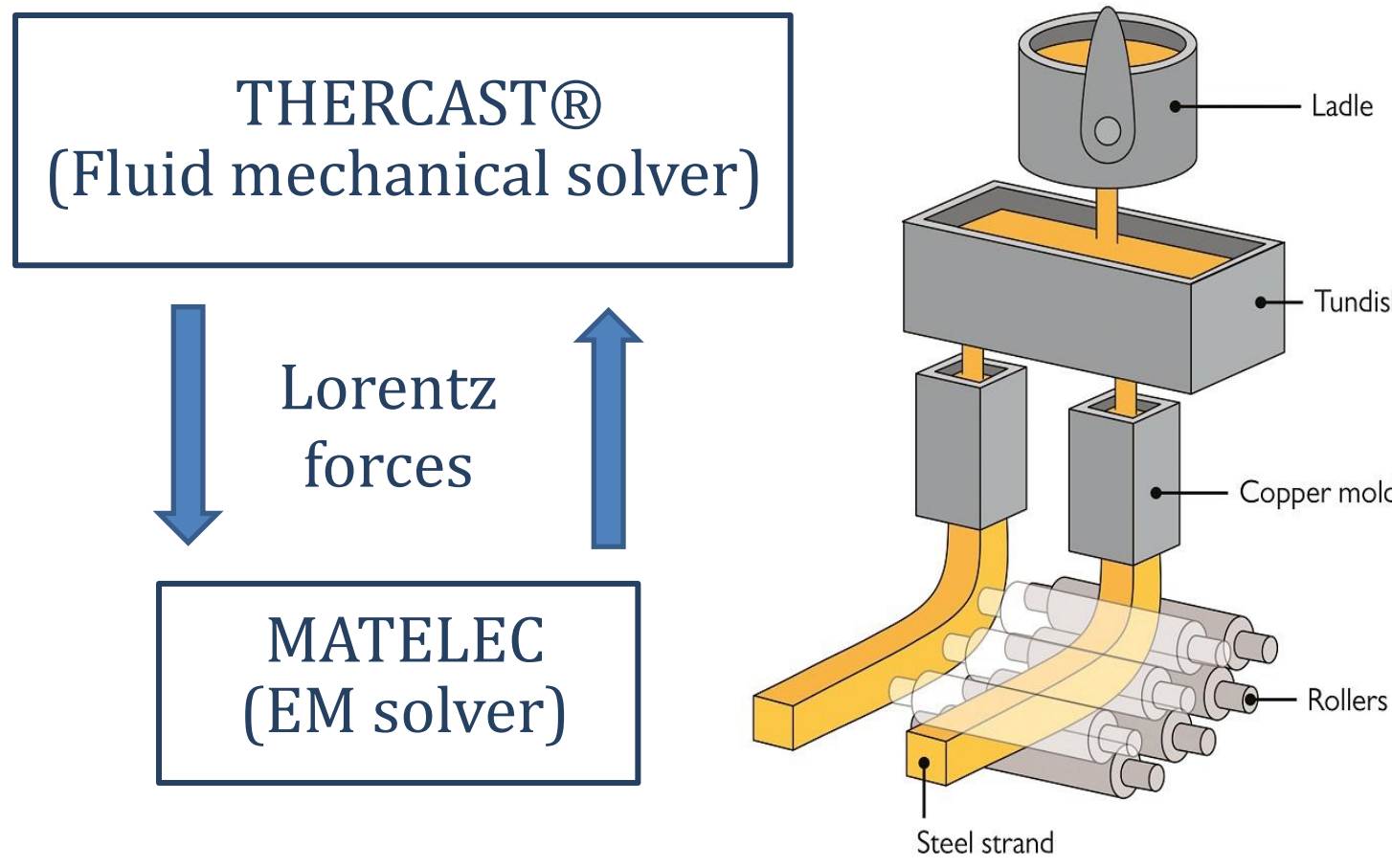
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Lid-driven cavity highly turbulent flow subjected to high magnetic field

Determination of critical time-step for explicit MHD schemes

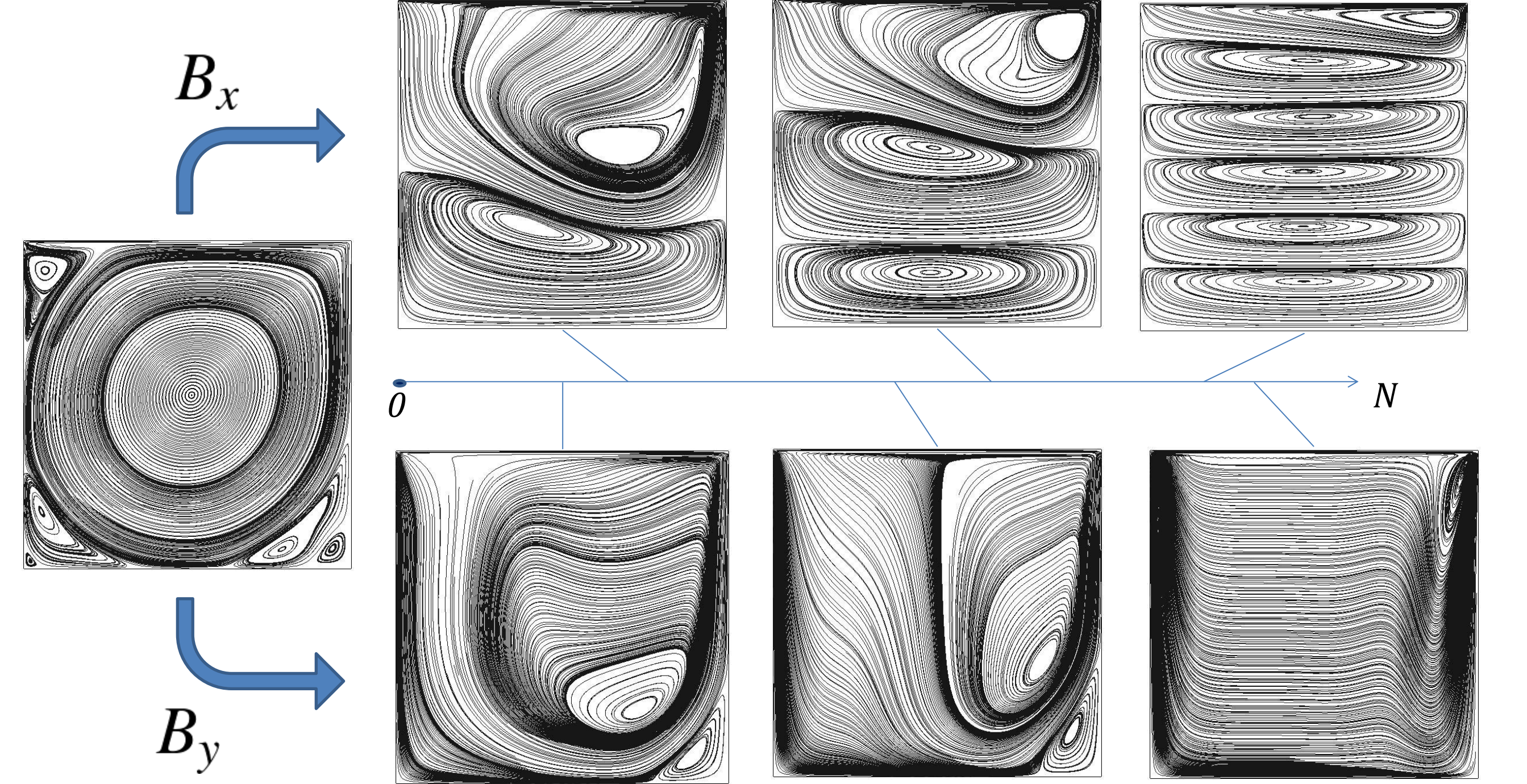
Control of fluid flow in CC:

- Electromagnetic **braking** and **stirring** in **continuous casting** process of steel
- Coupled simulation in commercial software:



A representative study case:

- Problem:
 - Highly **turbulent flow**
- Solution:
 - Impose a constant magnetic field to control and **brake the flow**
- Numerical procedure:
 - Lid-driven cavity benchmark^[1]
 - Relate the **Stuart number** (N) to the target braking level



Computational model:

Electromagnetic Field:

$$\Delta\phi = \partial_z(u_x B_y - u_y B_x) \equiv 0$$

Lorentz Forces:

$$f_L = \sigma(u \times B) \times B$$

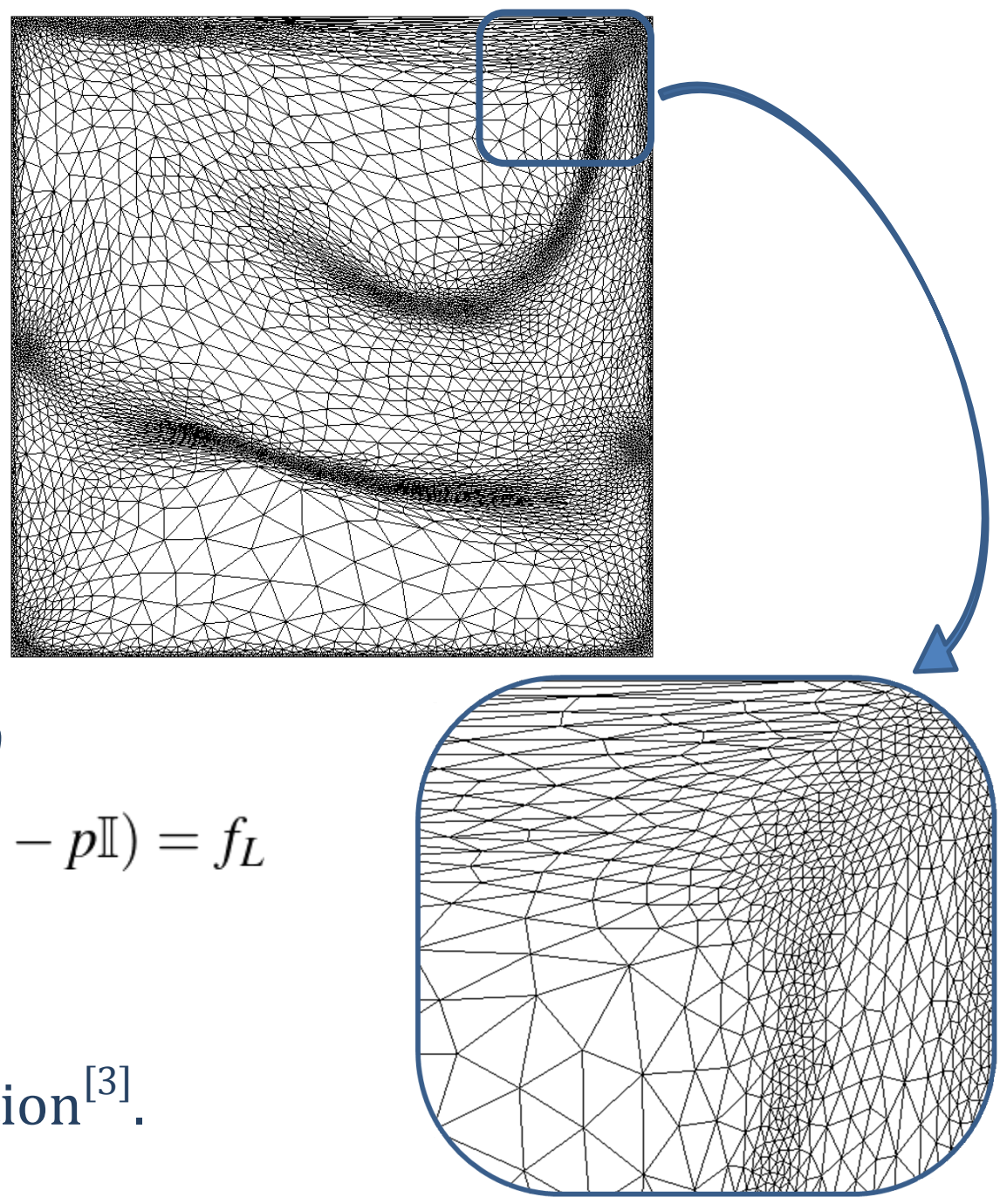
Navier-Stokes:

(multiscale stabilized FE^[2])

$$\rho(\partial_t u + u \cdot \nabla u) - \nabla \cdot (2\mu \varepsilon(u) - p\mathbb{I}) = f_L$$

$$\nabla \cdot u = 0$$

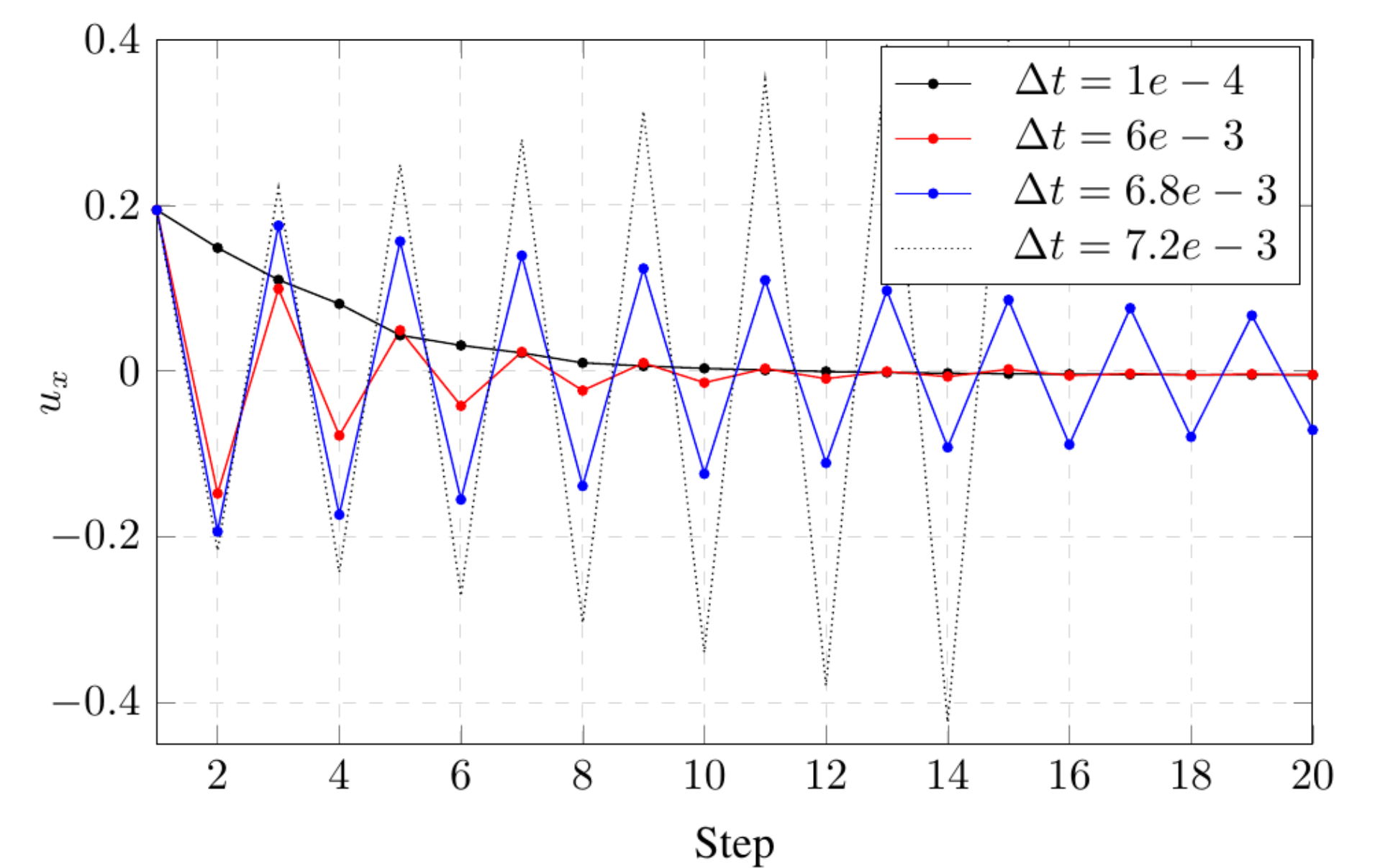
Anisotropic mesh adaptation^[3].



Numerical instabilities:

- The Lorentz force is tracked **explicitly**.
- The excessive size of the time-step leads to completely brake the flow normally to B and to accelerate it in the opposite direction, i.e. $u^n \cdot f_L^n < 0$.
- The CFL condition is not capable anymore to guarantee **numerical convergence**.

$$\Delta t_{CFL} < C \frac{h}{u}$$

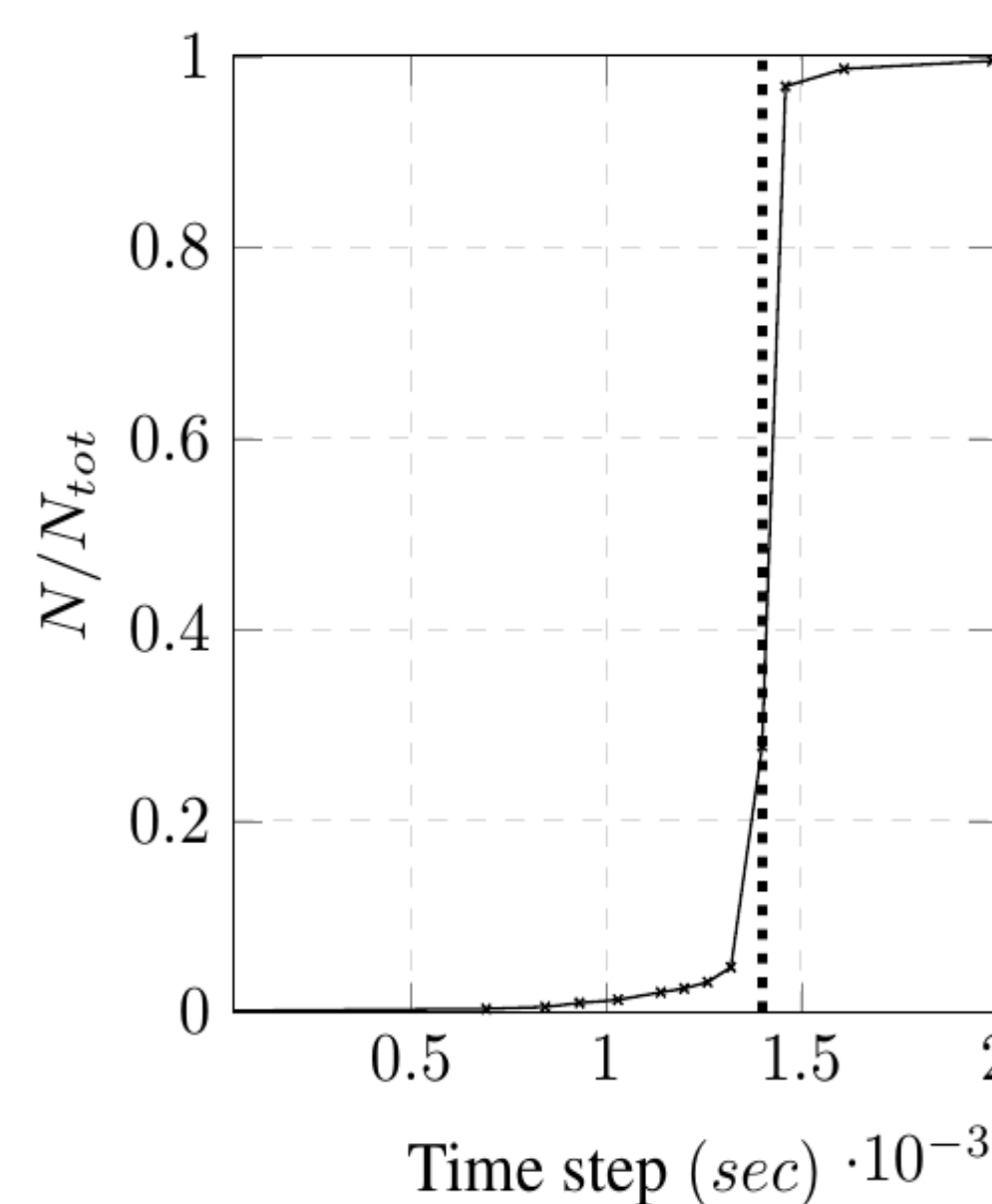
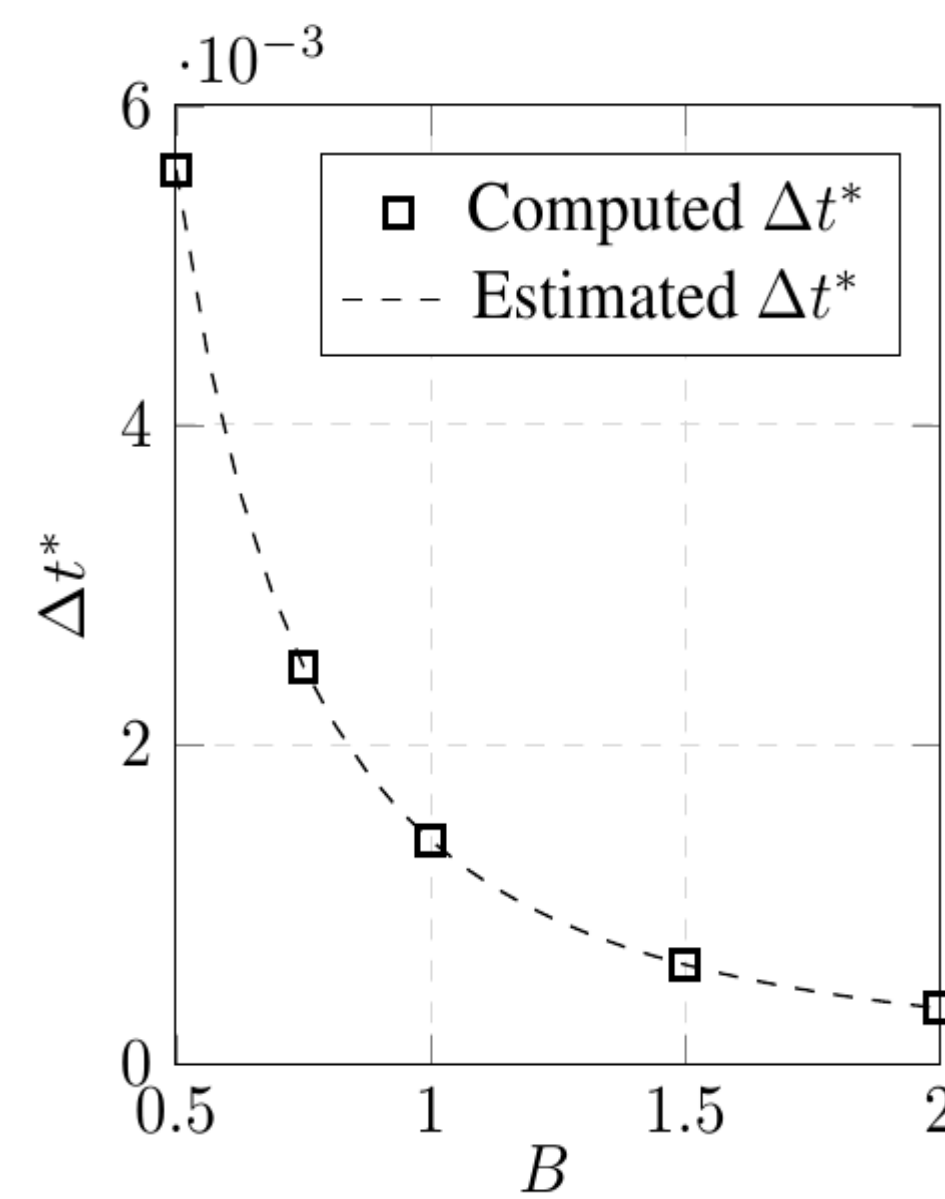
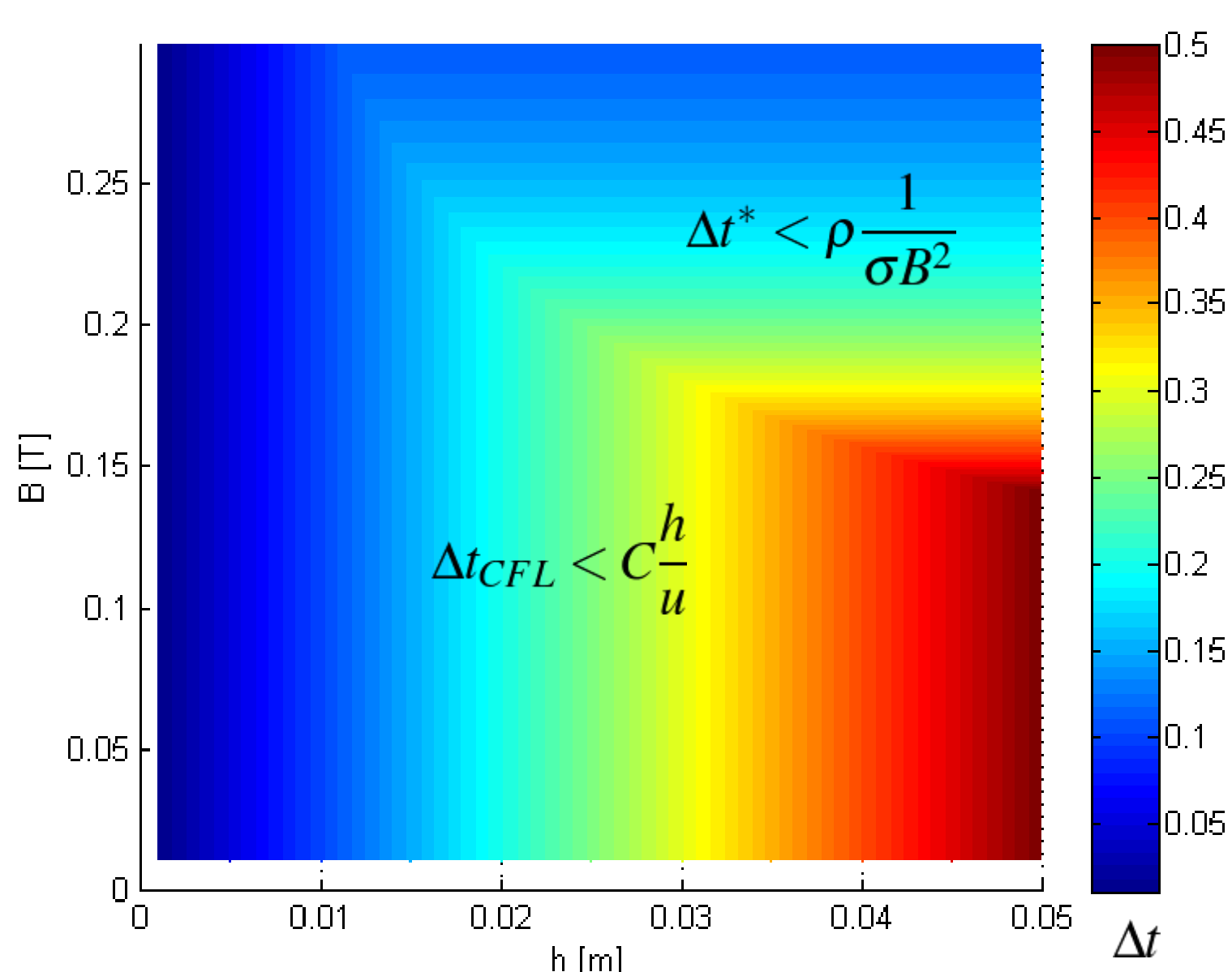
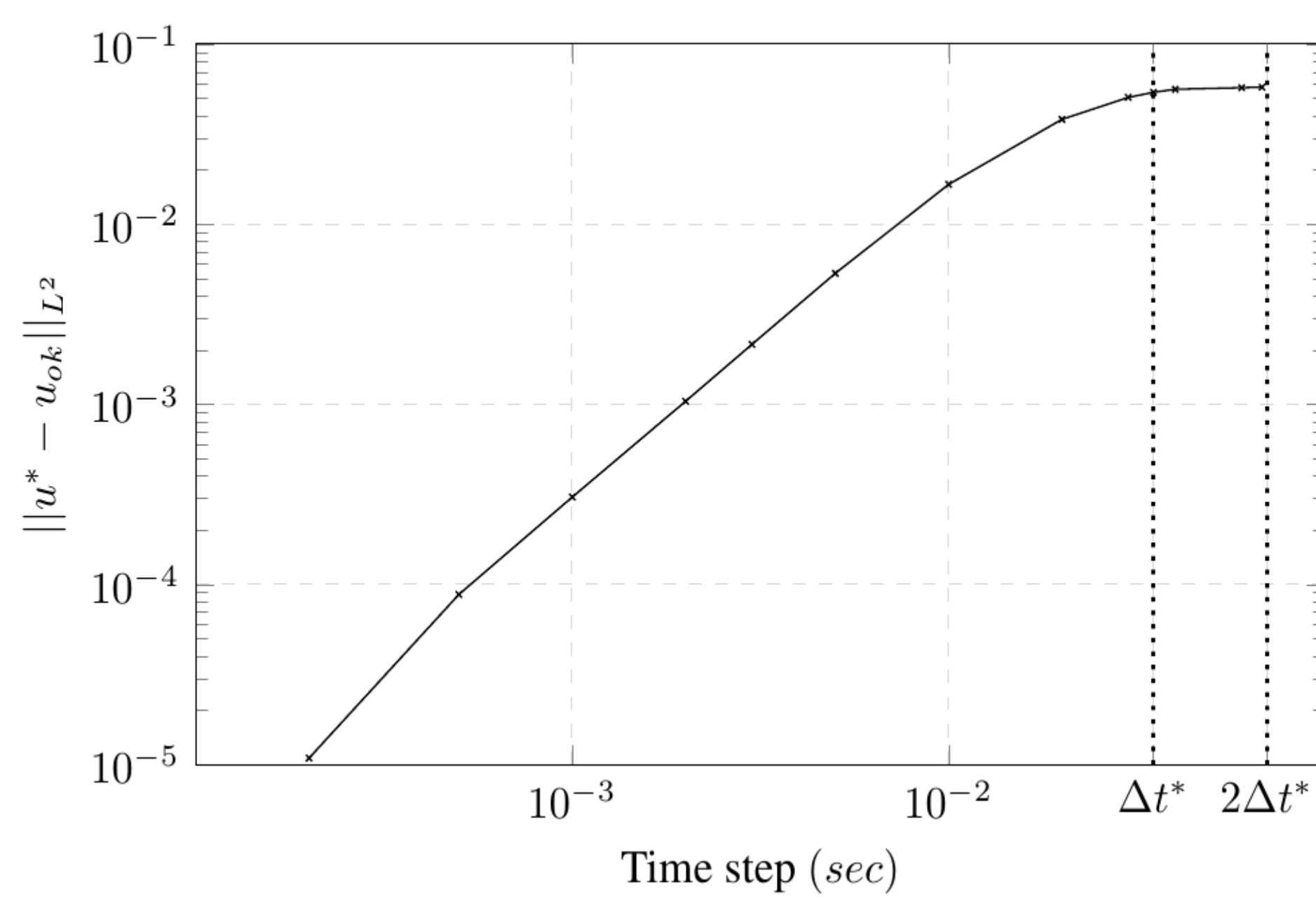


Determination of the critical time-step:

➤ Solution:

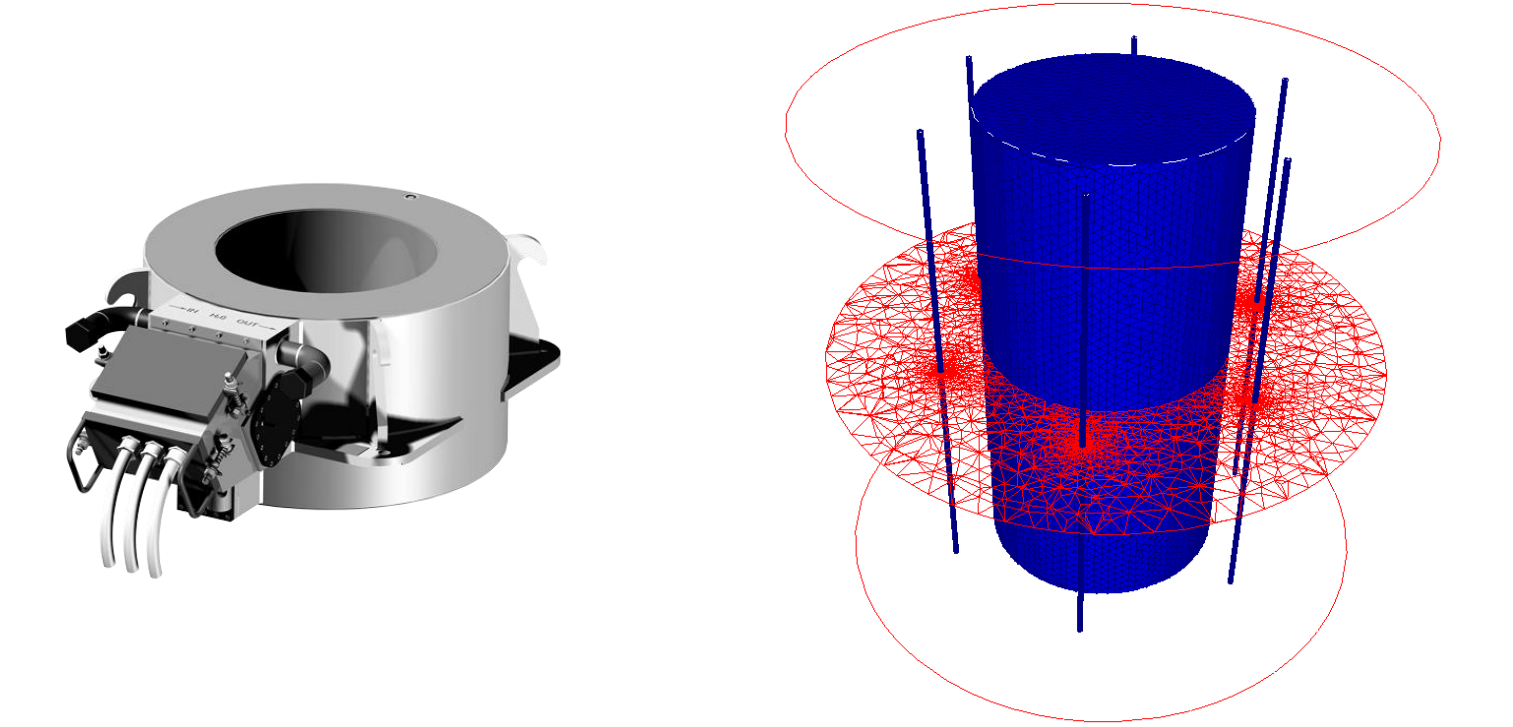
- Computation of the **limit time-step** as the time-step which leads to a complete dissipation of the kinetic energy within one time increment when the magnetic field is normal to the velocity.

$$\Delta t^* < \rho \frac{1}{\sigma B^2}$$



Conclusions & Perspectives:

- The flow is highly affected by the magnetic field and its direction.
- In some configurations, the CFL condition is not enough to guarantee the **numerical convergence**.
- A new **time-step threshold** which guarantees convergence in **explicit schemes** is proposed.
- An **implicit** modelling of the Lorentz force has to be included in the multiscale stabilized finite-elements solver.
- The braking effect will be taken into account in the complete simulation of **electromagnetic stirring**.



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References:

- [1] U. Ghia, K. N. Ghia, and C. Shin. High-resolution for incompressible flow using the Navier-Stokes equations and a multigrid method. *Journal of computational physics*, 48(3):387–411, 1982.
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