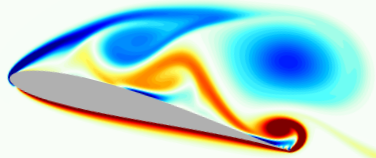
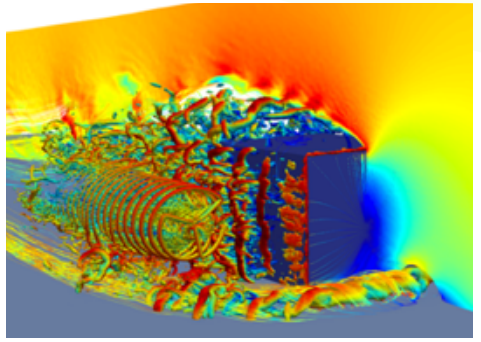
# Accurate numerical prediction of vortical flows with AMR

- Turbulent flows are 3D, unsteady and include vortical structures with a wide range of scales.
- Lagrangian methods (e.g. vpm) are very well suited to simulate turbulence (DNS or LES)
  - in many flows of interest, vorticity is confined in a small region



  - Lagrangian methods only require computational elements where the vorticity is => very efficient.
  - they lead to low (or no) dispersion and diffusion error
  - boundary conditions are tricky (complex geometries).



- **Can we approach the quality of Lagrangian methods using an Eulerian solver with AMR ?**

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# Vortex ring collision

- **Fully periodic box with size :** $L_x \times L_y \times L_z = 8\pi \times 8\pi \times 4\pi$
- **Initial condition :** $\omega_\theta(r) = \frac{\Gamma}{\pi\sigma^2} \exp\left(-s^2/\sigma^2\right) \quad s^2 = z^2 + \left(r - R'(\theta)\right)^2 \quad \frac{R'(\theta)}{R_0} = 1 + \epsilon$

$$\frac{\sigma}{h} = 23.3 \qquad \frac{\sigma}{R} = 0.35 \qquad Re = \frac{\Gamma}{\nu} = 10000$$

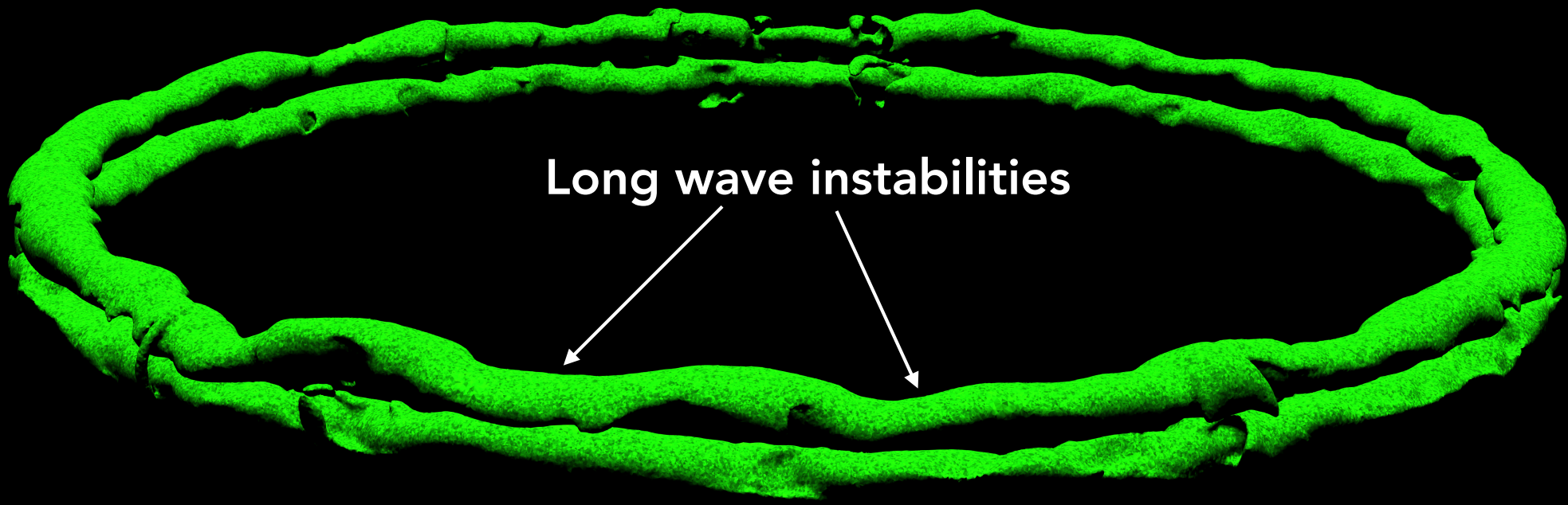
$$Re_{h,\omega} = \frac{\omega_{max} h^2}{\nu} = 5.8$$

$\nabla^2 \boldsymbol{u} = -\nabla \times \boldsymbol{\omega}$ **3 Poisson equations to solve at t=0**

$$CFL = 0.3$$

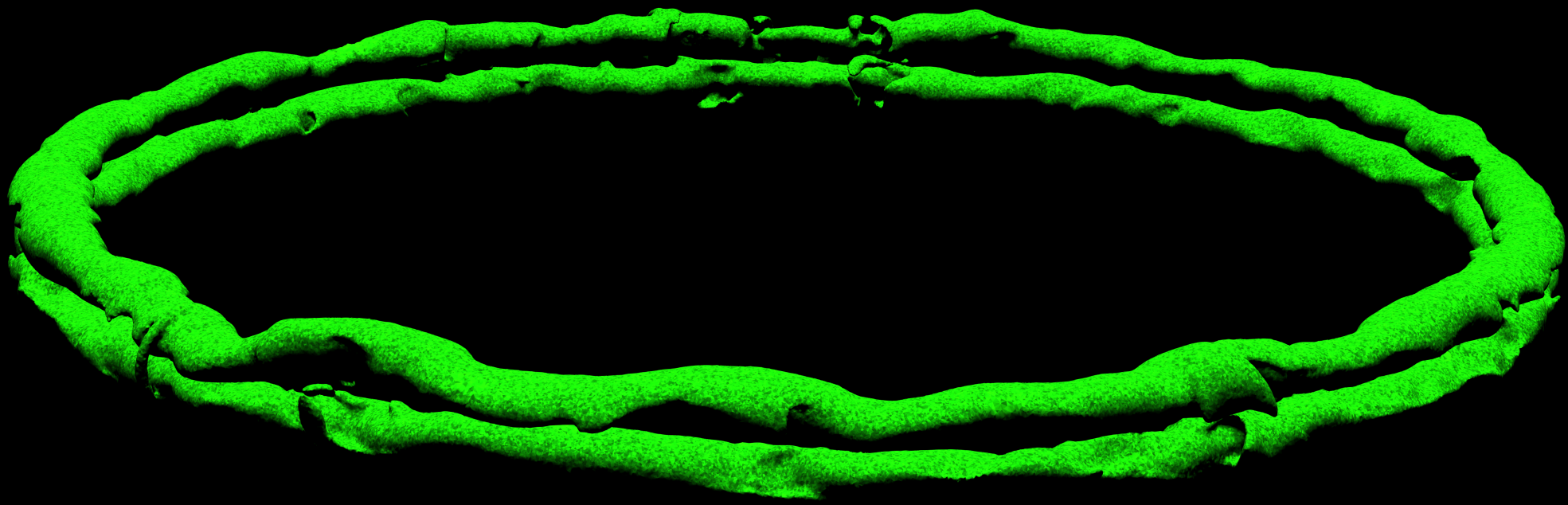
- **Uniform resolution :** $N_x \times N_y \times N_z = 1675 \times 1675 \times 837 = 2.3 \times 10^9$
- **Transitional flow with topological change !**

The initial analytical rings,
come close to each other due to their self-induced velocity

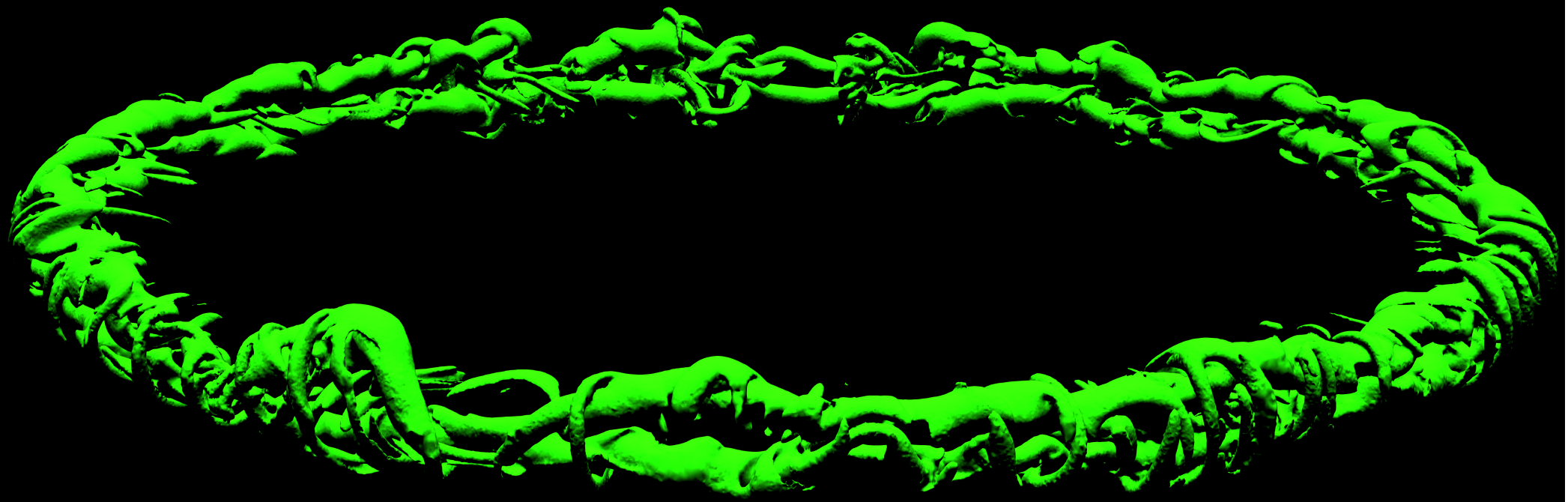


Rings approach each other under both mutual and self-induction

Instabilities growth in time



Secondary vortical structures are formed

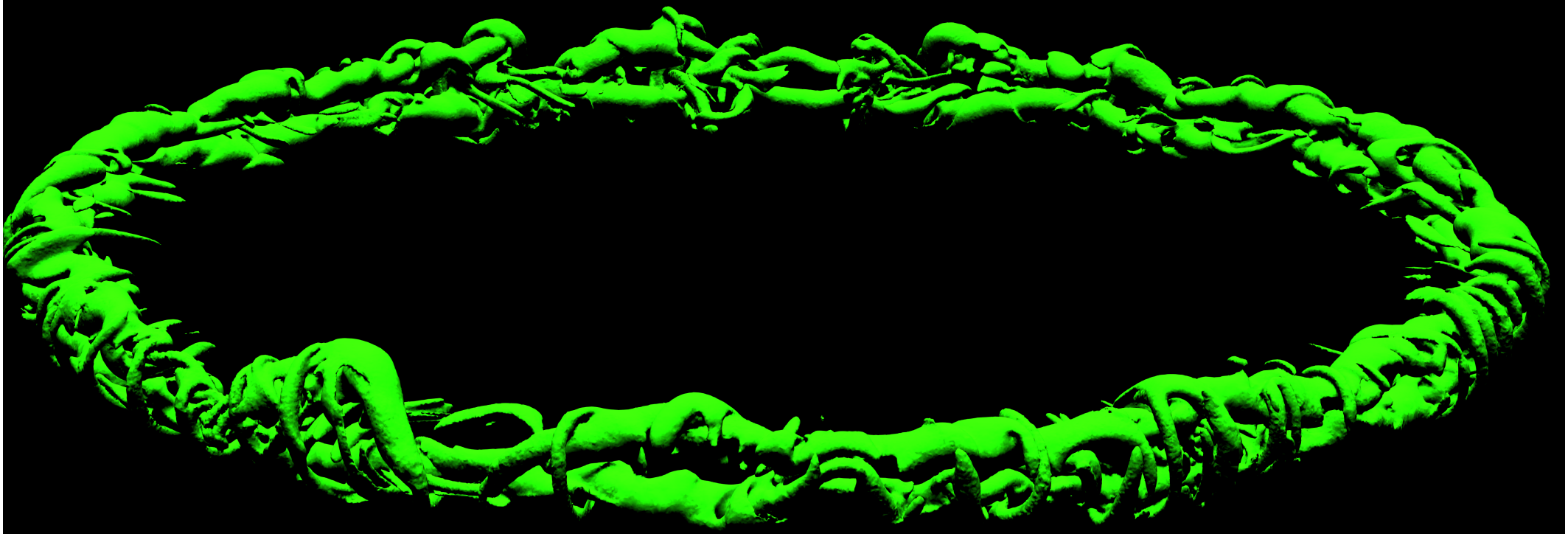


Vortex tubes « touch » and generate small scales

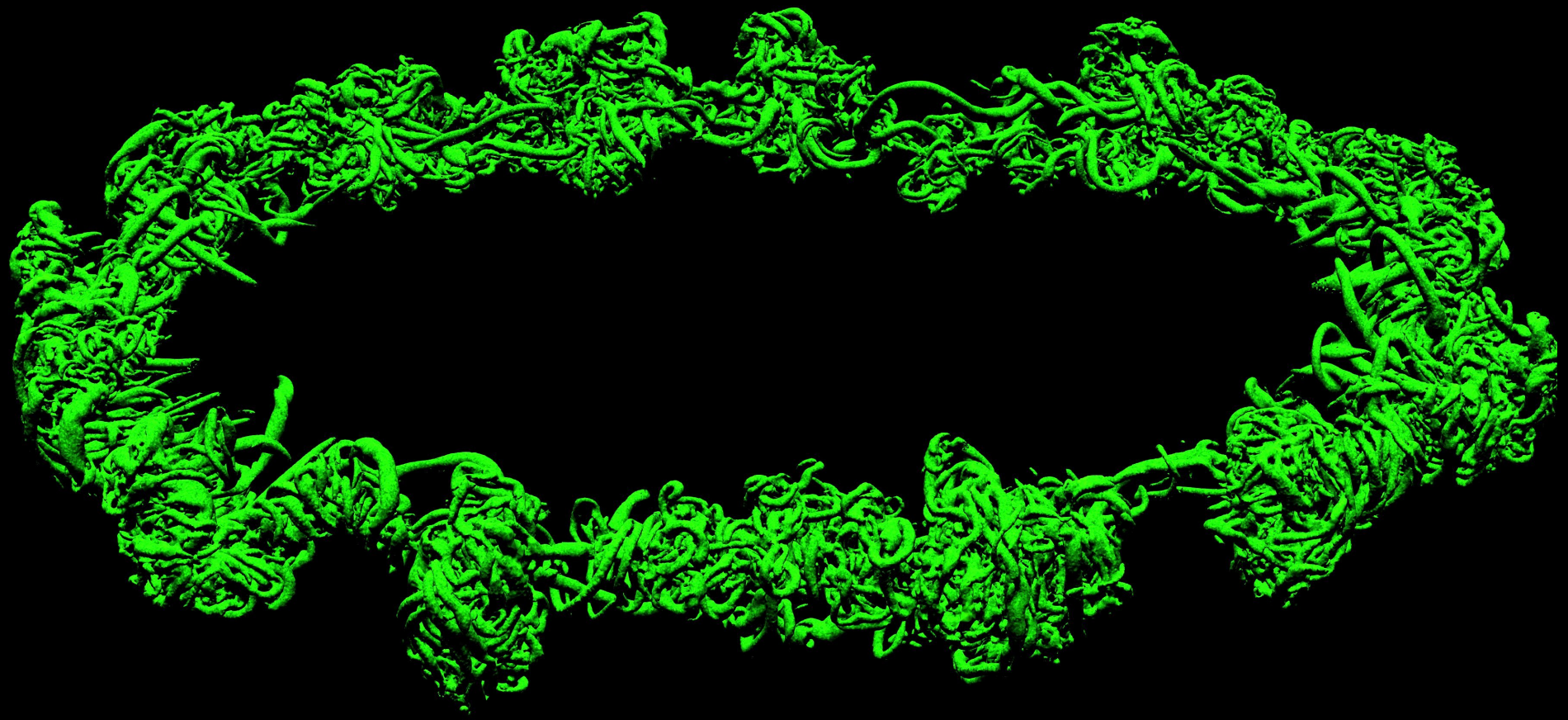
Large vorticity gradients are present in the zone of interaction.

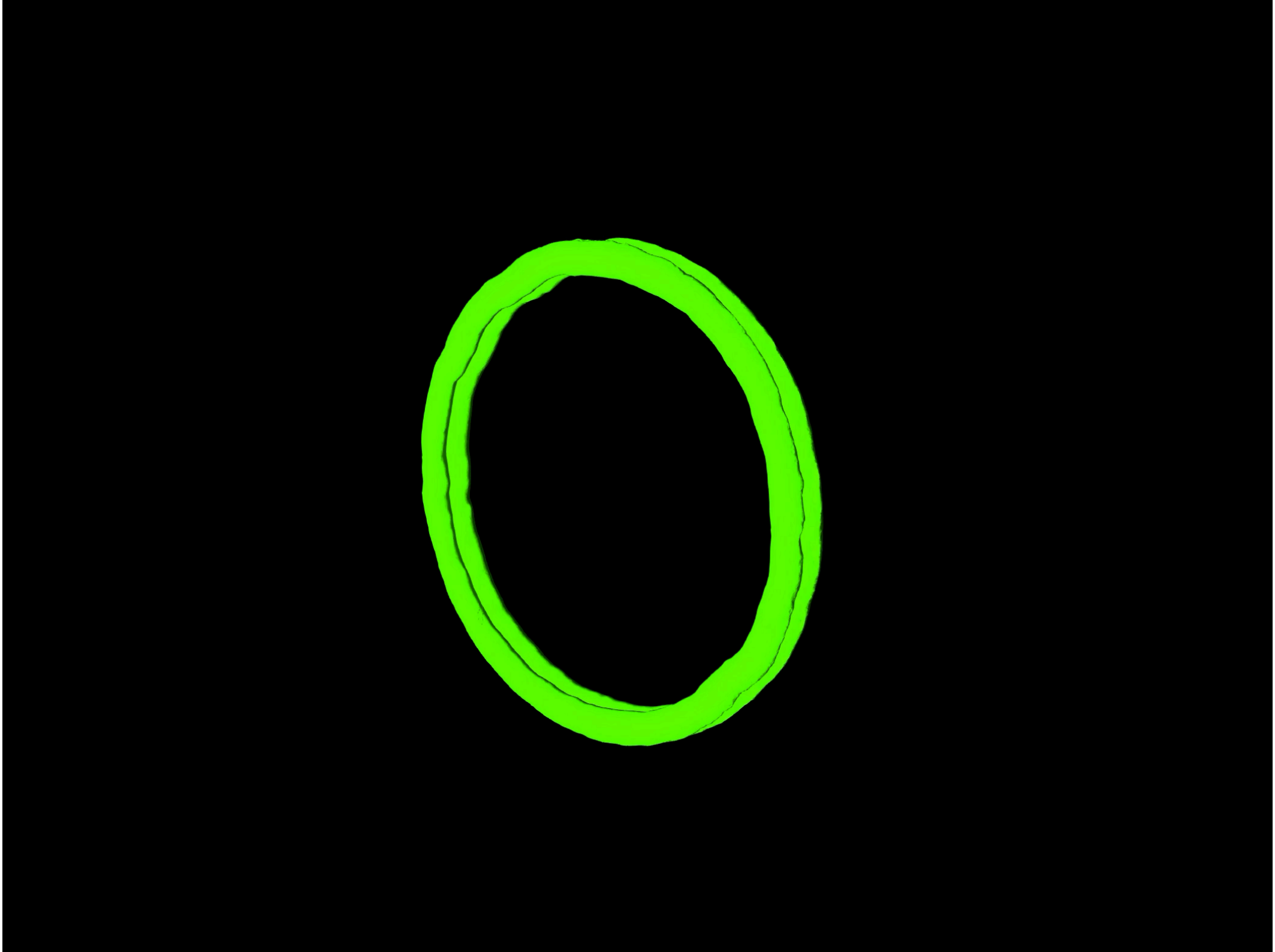
These gradients enable the viscous term in

$$\frac{\partial \omega}{\partial t} + \boldsymbol{u} \cdot \nabla \omega = \omega \cdot \nabla \boldsymbol{u} + \nu \nabla^2 \omega$$



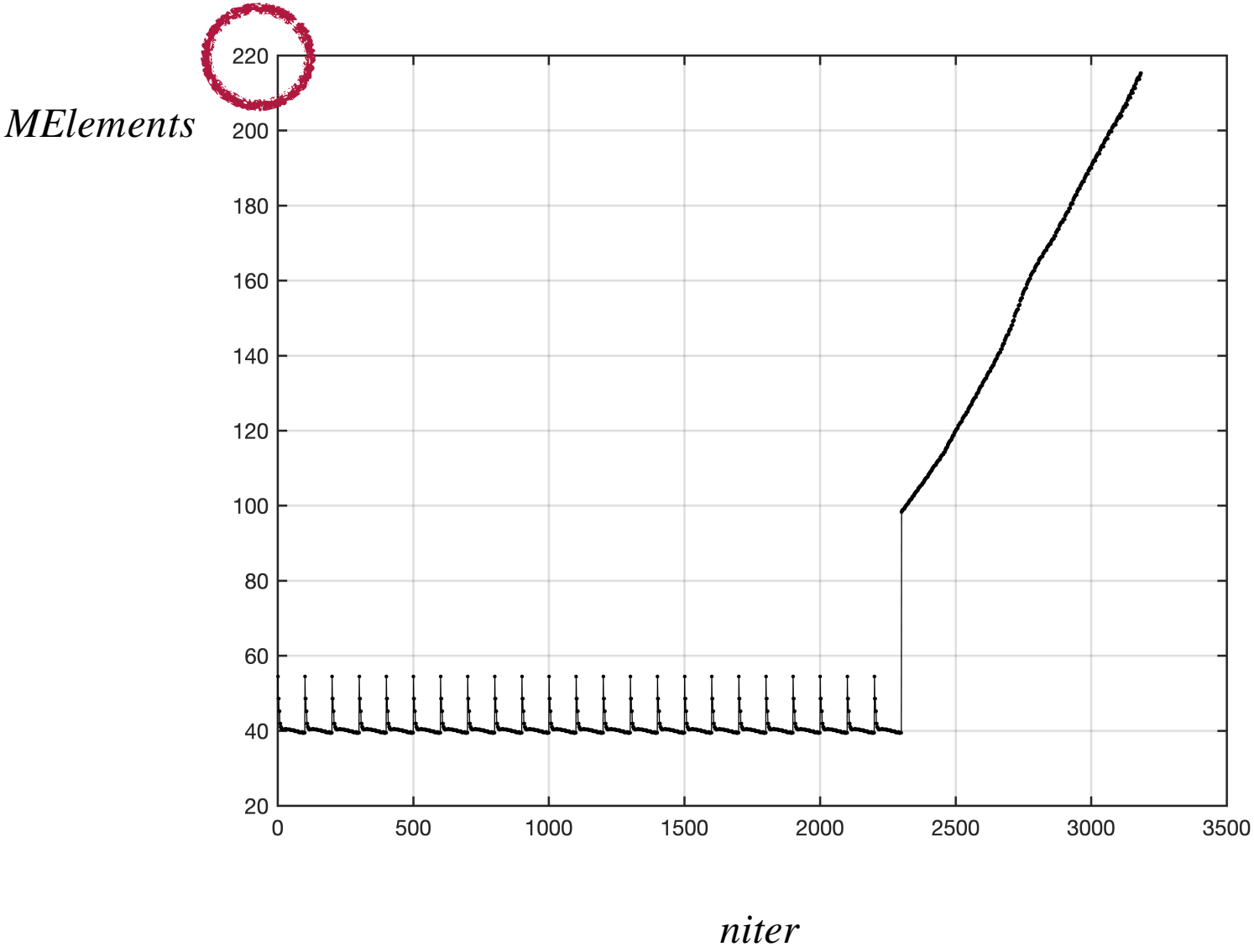
Small scales dissipates energy and dynamics dies

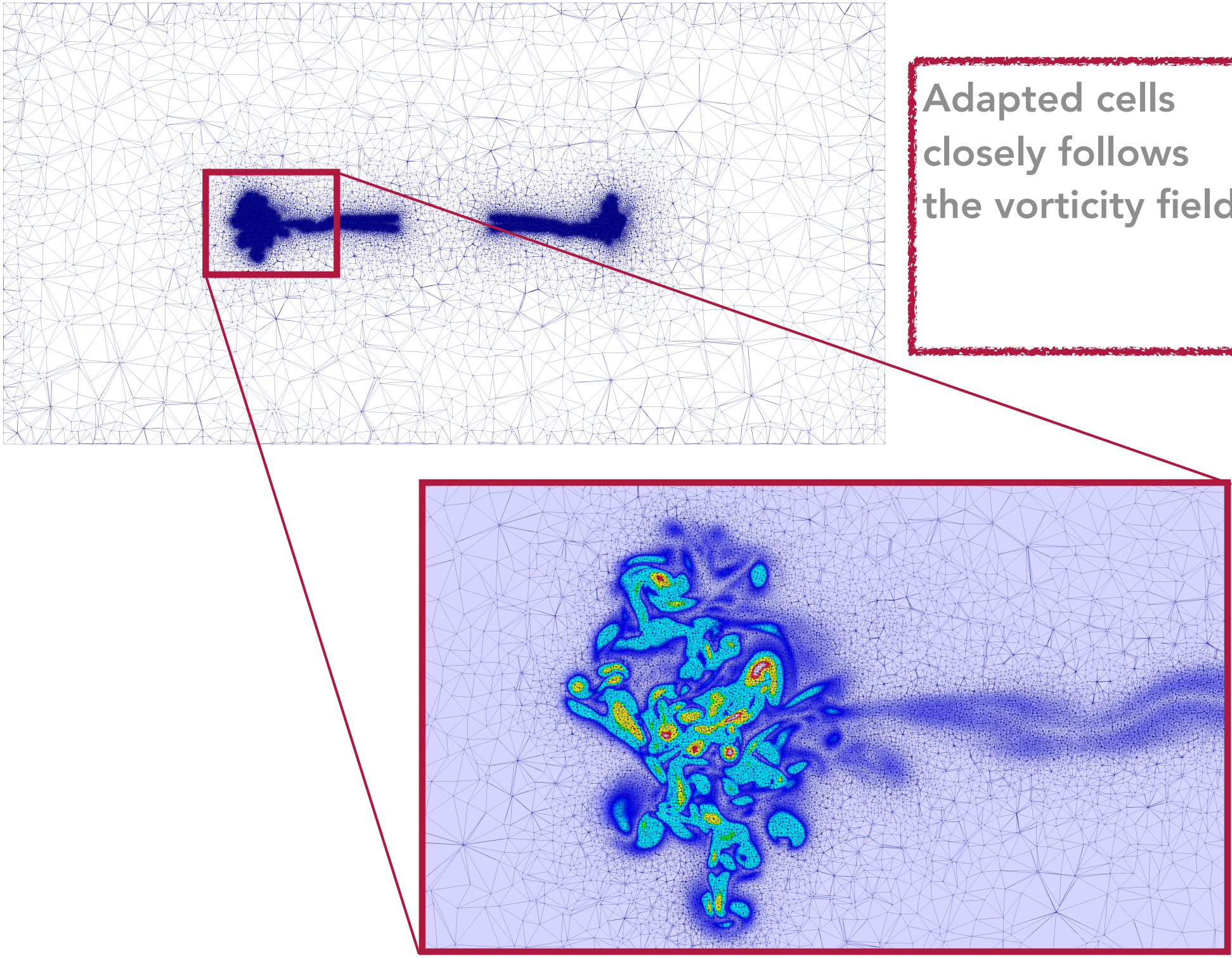




# Mesh adaptation

$$\frac{\omega_{treshold}}{\omega_{max}} = 0.038 \qquad \frac{h_{background}}{R} = 1.5 \qquad \frac{\sigma}{h} = 23.3$$





Adapted cells closely follows the vorticity field

# Conclusions & perspectives

- Using AMR for compact vortical flows has proven to be efficient & accurate with vorticity based refinement criterion.
- Further improvements :
  - unbounded BC’s
    - Biot Savart with FMM
    - James Lackner
  - evaluate physical diagnostics
  - automatic remeshing frequency

# Conclusions & perspectives: ring in ground effect