Flux Rope Emergence Simulations With Different MHD Codes

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SEVENTH FRAMEWORK PROGRAMME

SWIFF Benchmarks

- Transition to turbulent reconnection (2D)
- Longcope-Strauss problem (2D)
- Magnetopause challenge (2D)
- **CME initiation challenge (3D)**

SWIFF Numerical Codes

- **FlipMHD** – viscous resistive MHD code (Brackbill, 1991)
- **MPI-AMRVAC** – MPI implementation of the Versatile Advection Code with adaptive Mesh Refinement (Keppens et al 2012)
- Stagger
- UNIPI two-fluid code
- ASI hybrid PIC code
- iPIC3D

Flux Rope Emergence Setup

Semi-circular rope (Fan & Gibson 2004)

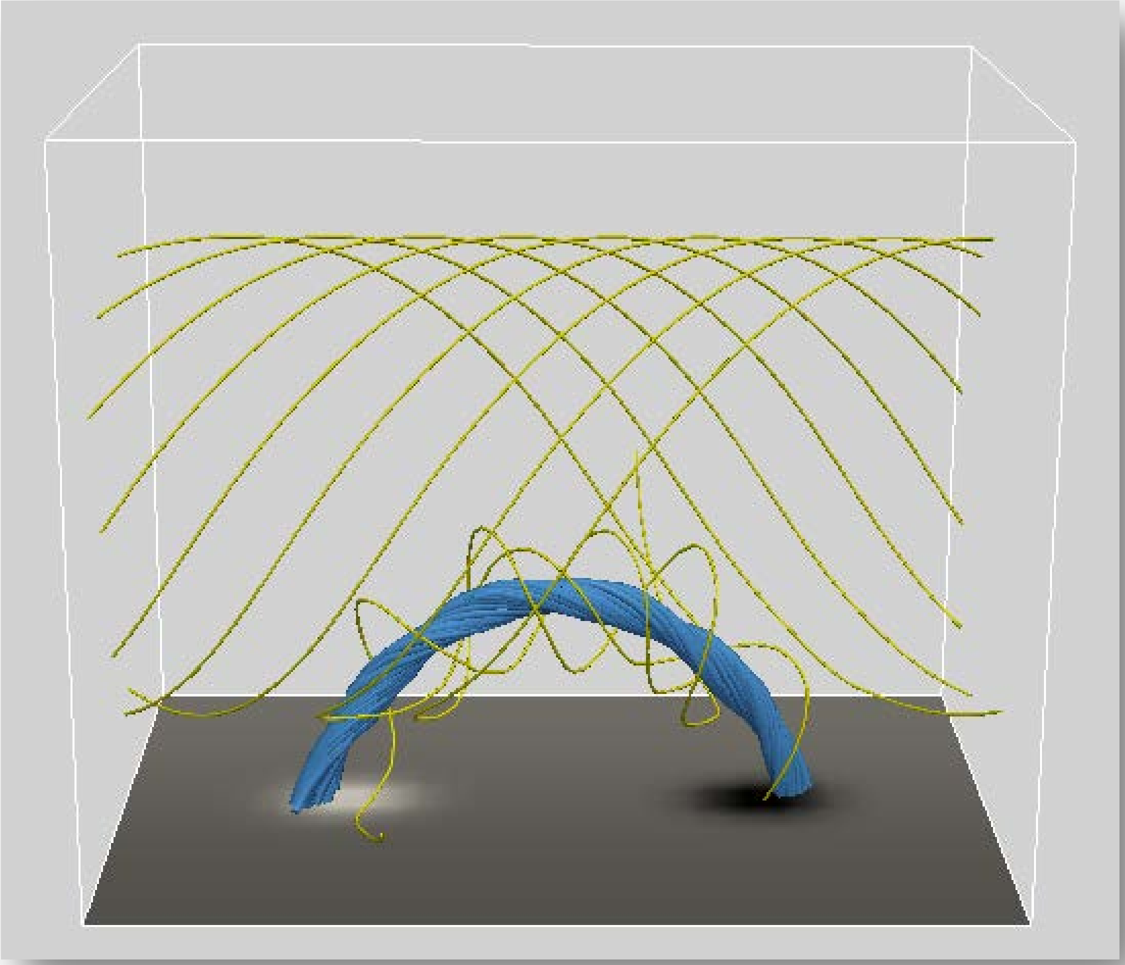
$$\boldsymbol{B} = \boldsymbol{\nabla} \times \left[\frac{A(r,\theta)}{r\sin\theta}\hat{\varphi}\right] + B_{\varphi}(r,\theta)\hat{\varphi},$$
$$A(r,\theta) = \frac{1}{2}qa^2B_t\exp\left[-\frac{\overline{\omega}^2(r,\theta)}{a^2}\right],$$
$$B_{\varphi}(r,\theta) = \frac{aB_t}{r\sin\theta}\exp\left[-\frac{\overline{\omega}^2(r,\theta)}{a^2}\right].$$

Embedded to the background sheared arcade (Aschwanden 2004)

$$B_x = B_{x0}\sin(kx)\exp(-lz),$$
$$B_y = B_{y0}\sin(kx)\exp(-lz),$$
$$B_z = B_{z0}\cos(kx)\,(-lz),$$
$$B_{x0} = \frac{l}{k}B_0, B_{y0} = \frac{\alpha}{k}B_0, k^2 - l^2 - \alpha^2 = 0.$$

Setup Parameters

$B_0 = p_0 = \rho_0 = 1,$
$u_0 = 0,$
$B_t = 9B_0,$
$R = 0.375,$
$q = -1,$
$a = 0.1,$
$L_x = 1.5, L_y = 1, L_z = 1.25,$
$n_x = 30, n_y = 20, n_z = 25.$



Boundary conditions:

X – open

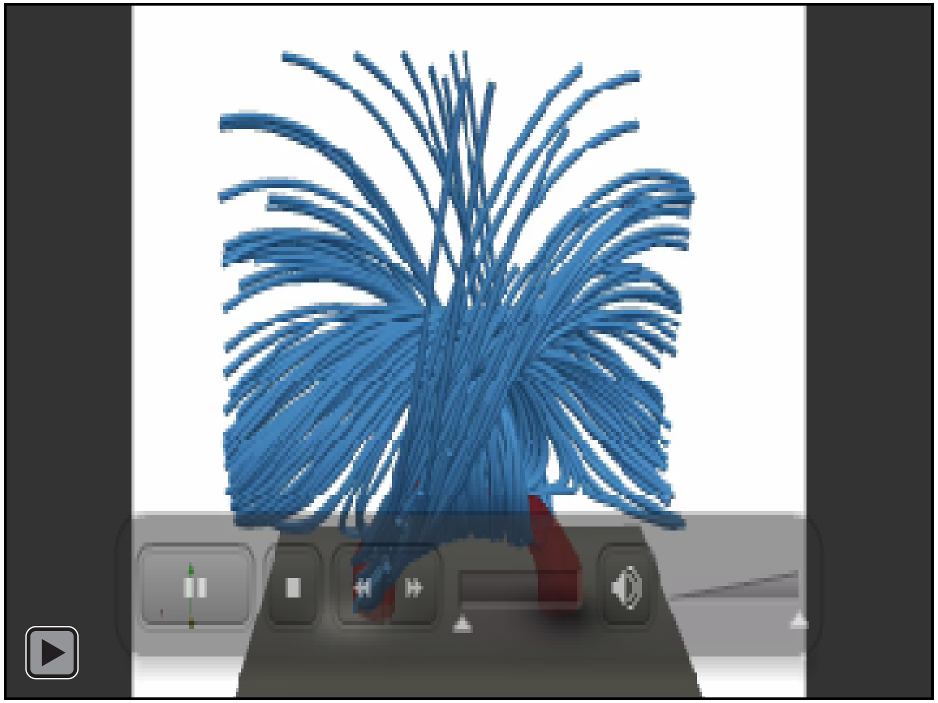
Y – periodic

Top – open

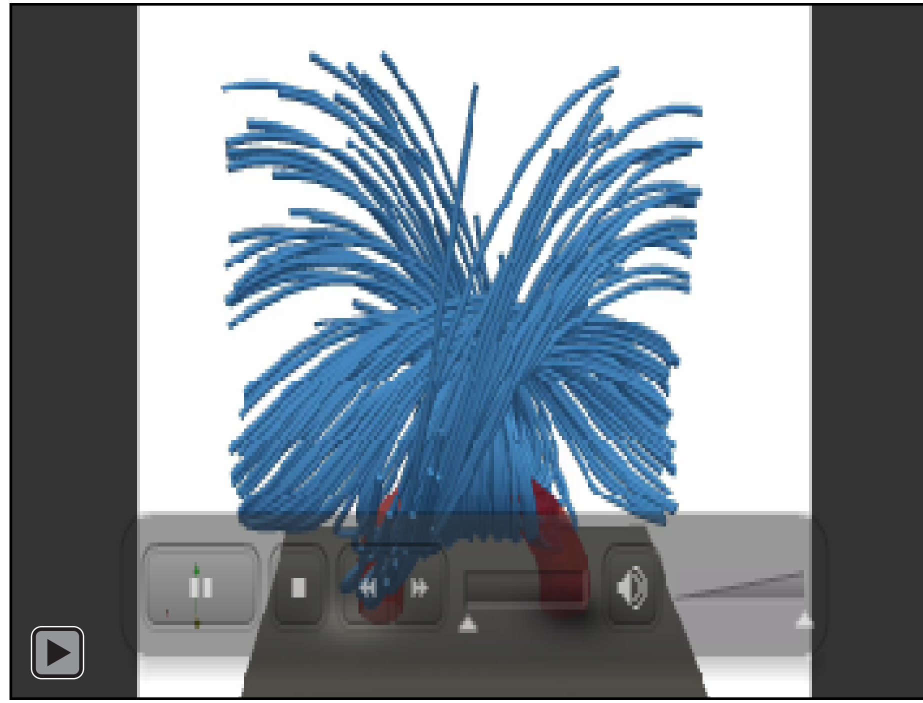
Bottom – constant B_z

Results: FlipMHD

Viscous



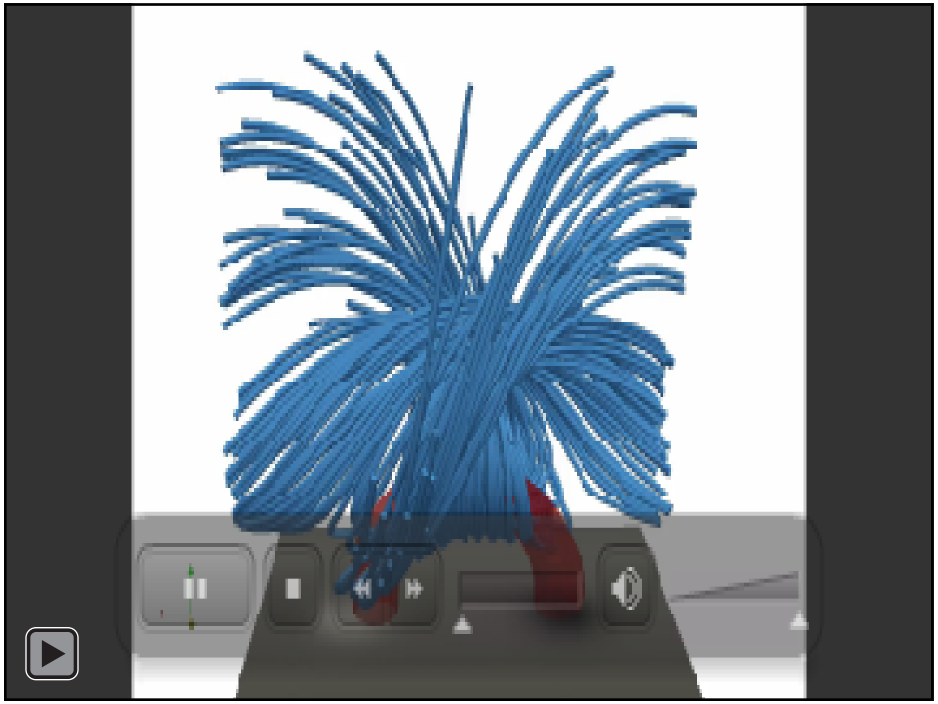
No viscosity



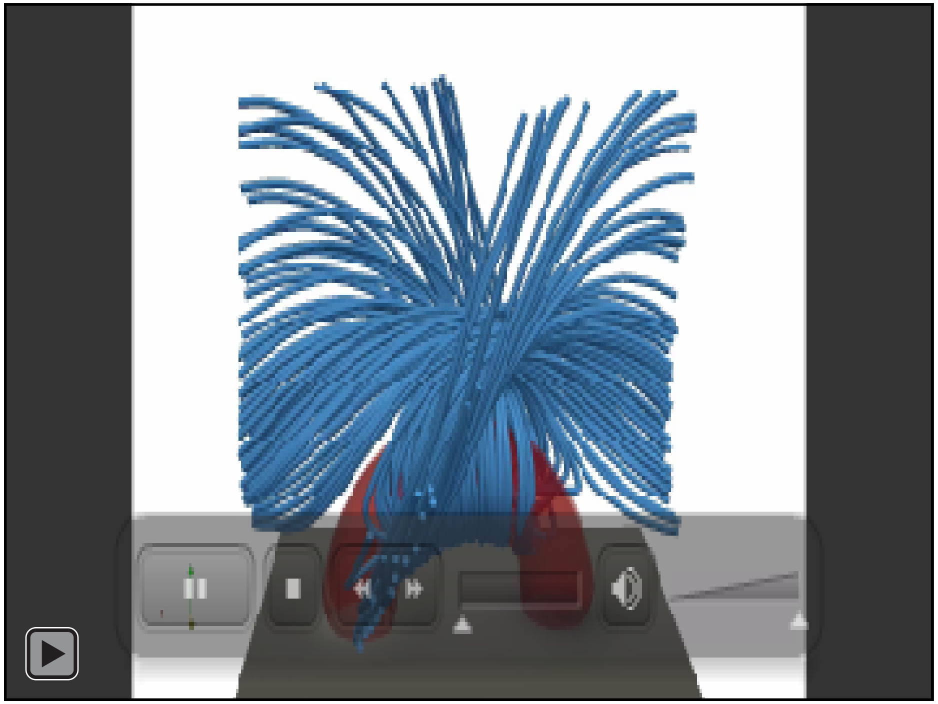
Blue represent magnetic field lines; red contour is at constant density 0.8; The grayscale on the bottom is B_z. Note the destruction of density “tube” in the second case!

FlipMHD vs MPI-AMRVAC

FlipMHD (no viscosity)

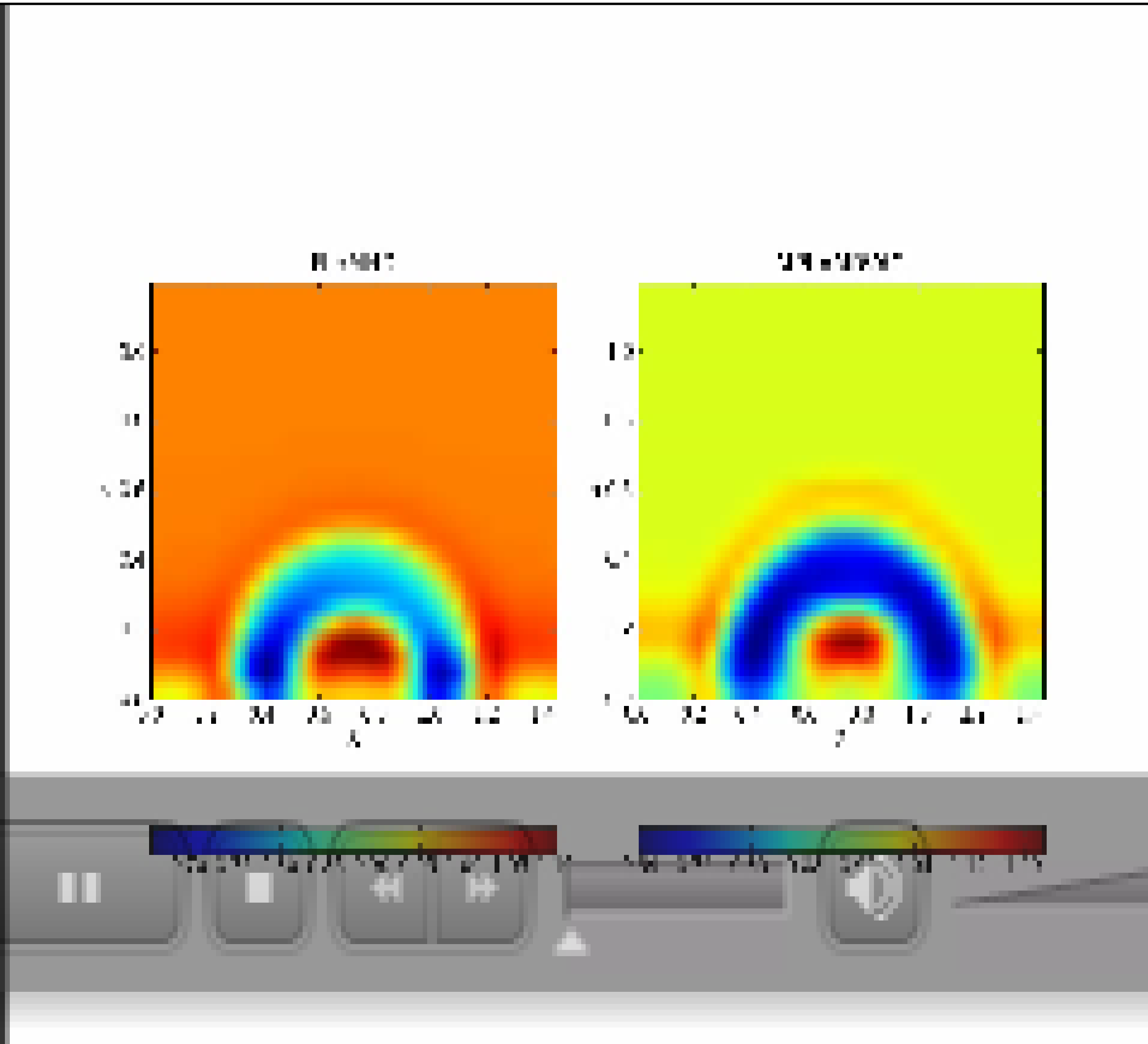


MPI-AMRVAC

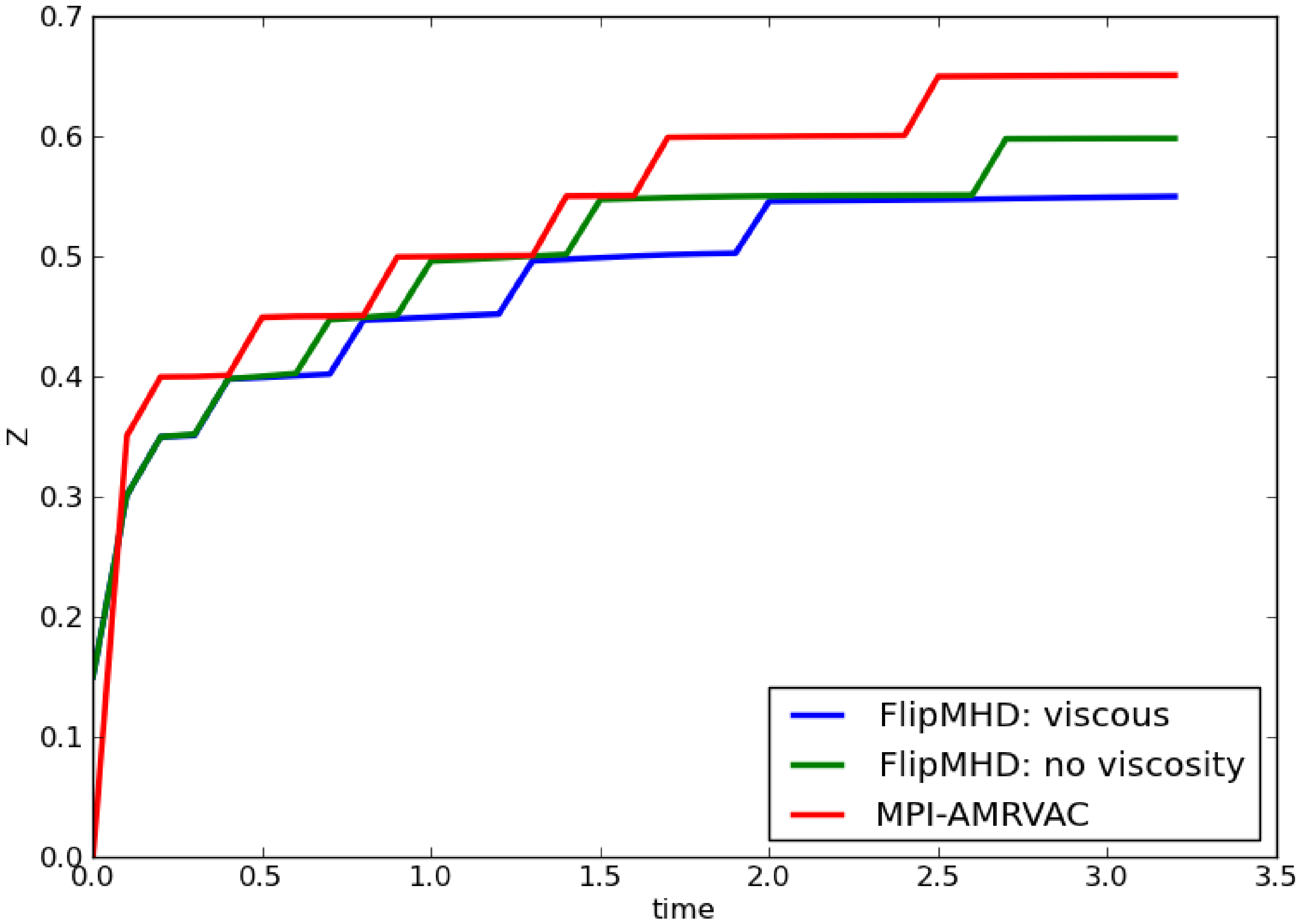


Blue represent magnetic field lines; red contour is at constant density 0.8; The grayscale on the bottom is B_z. In both cases, the tube is destroyed. The behavior of field lines is very similar.

Density Variation in XZ Plane



Results: rise of the rope



Conclusions

The initial configuration leads to immediate emergence of the flux rope, and is handy for comparison of numerical codes

The overall behavior is qualitatively the same in FlipMHD and MPI-AMRVAC simulations

Rise and rotation of the flux rope is slower in viscous simulations

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SWIFF is a European Commission funded Framework Programme 7 project.

The goals of SWIFF are:

- Zero-in on the physics of all aspects of space weather and design mathematical models that can address them.
- Develop specific computational models that are especially suited to handling the great complexity of space weather events where the range of time evolutions and of spatial variations are so much more challenging than in regular meteorological models.
- Develop the software needed to implement such computational models on the modern supercomputers available now in Europe.

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