Rosseland Centre for Solar Physics

First results from global MHD simulations of Solar convective zone

Andrius Popovas, Å. Nordlund, M. Szydlarski

Hinode-15 / Iris-12, Prague 2022

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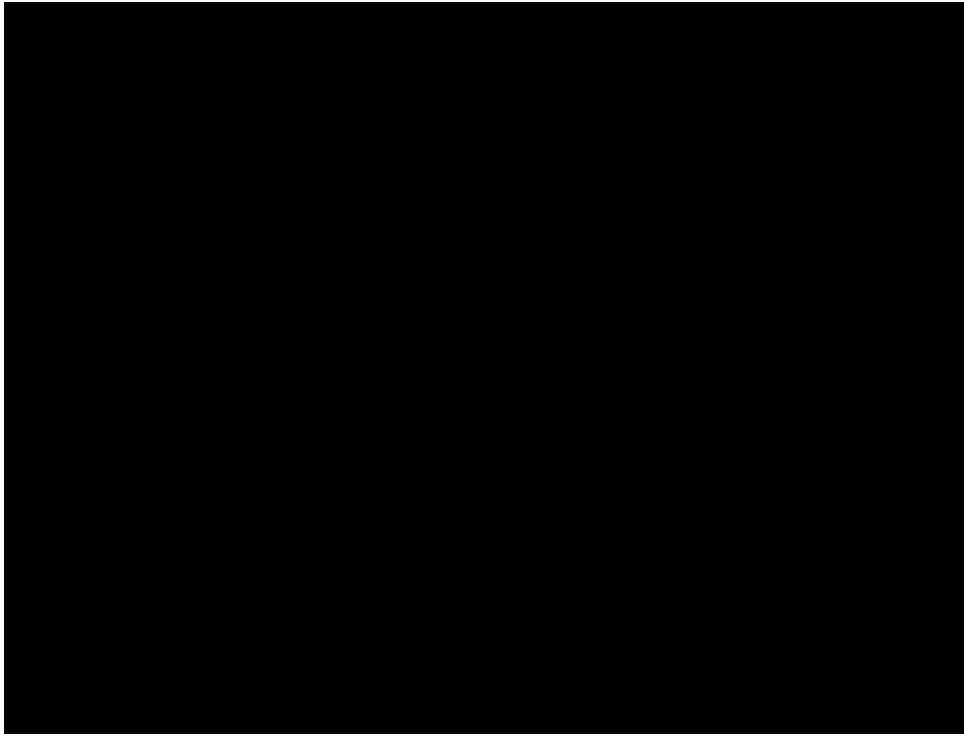

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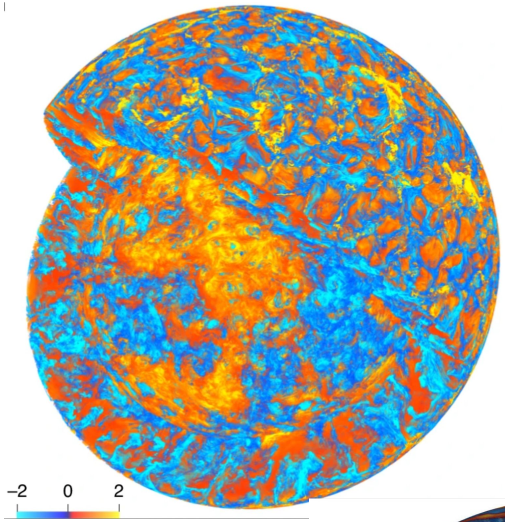
Other works

- ➢ Hotta & Kusano (Nature Astronomy, 2021)
- ➢ Hotta et al. (AJ, 2022)
- ➢ Guerrero et al. (Submitted to ApJ, 2022)
- ➢ Käpylä (A&A, 2021)
- ➢ etc.



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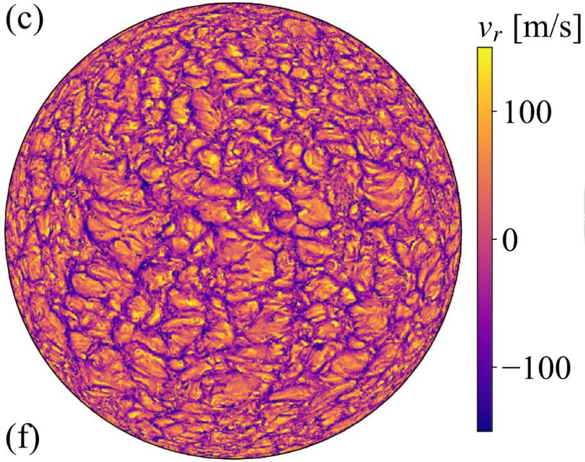

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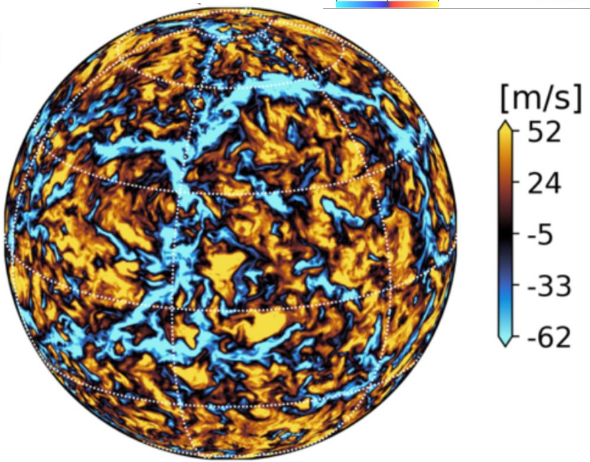
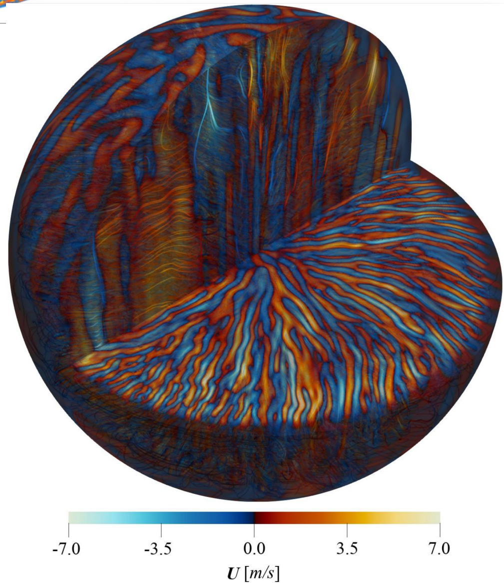




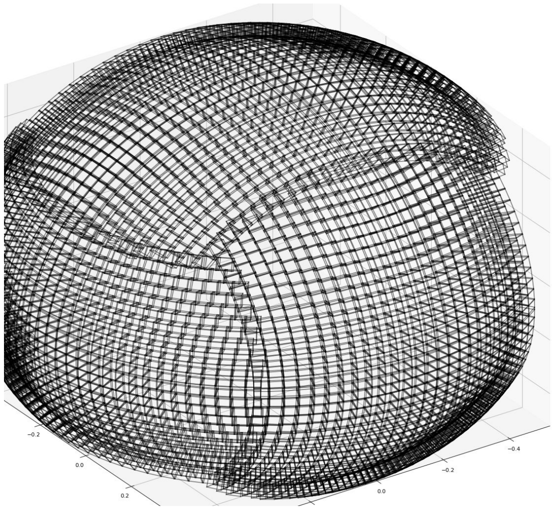
The **DISPATCH** framework

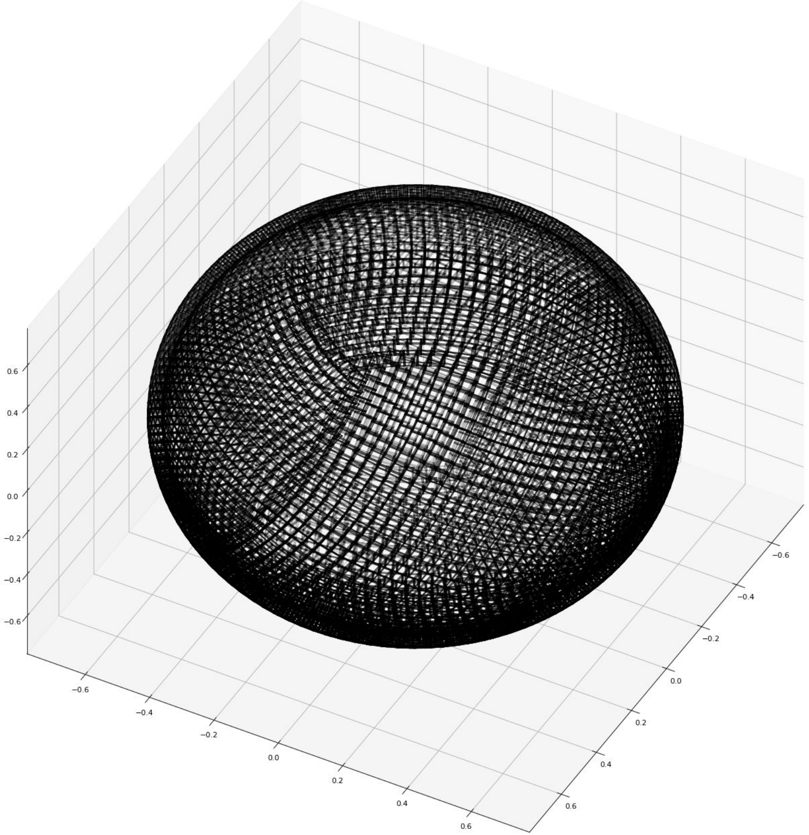
- *Local timesteps*
  - local Courant conditions ➪ great cost savings
- *Solver agnostic*
  - We are using a new entropy-based HLLD Riemann solver (Popovas et al., in prep.)
- *Local MPI* communications
  - gives theoretically unlimited scaling
- *Curvilinear meshes*
  - We are using a Volleyball mesh decomposition
- Can use *Static & Adaptive Mesh Refinement*

Nordlund, Ramsey, Popovas & Küffmeier, MNRAS 477, 624 (2018)

The ‘volleyball’ domain decomposition

- Locally Cartesian, globally - spherical, avoids singularity at the poles





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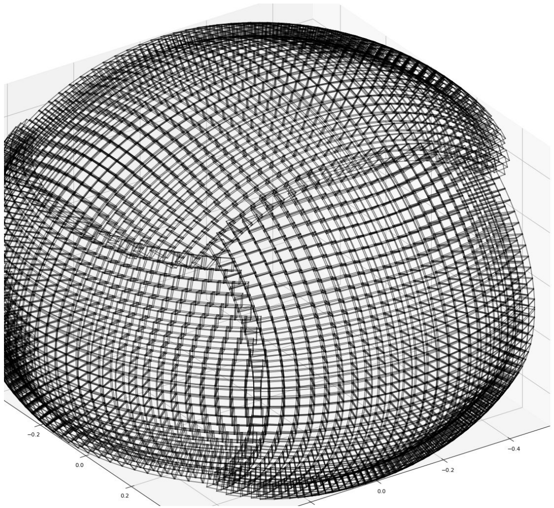
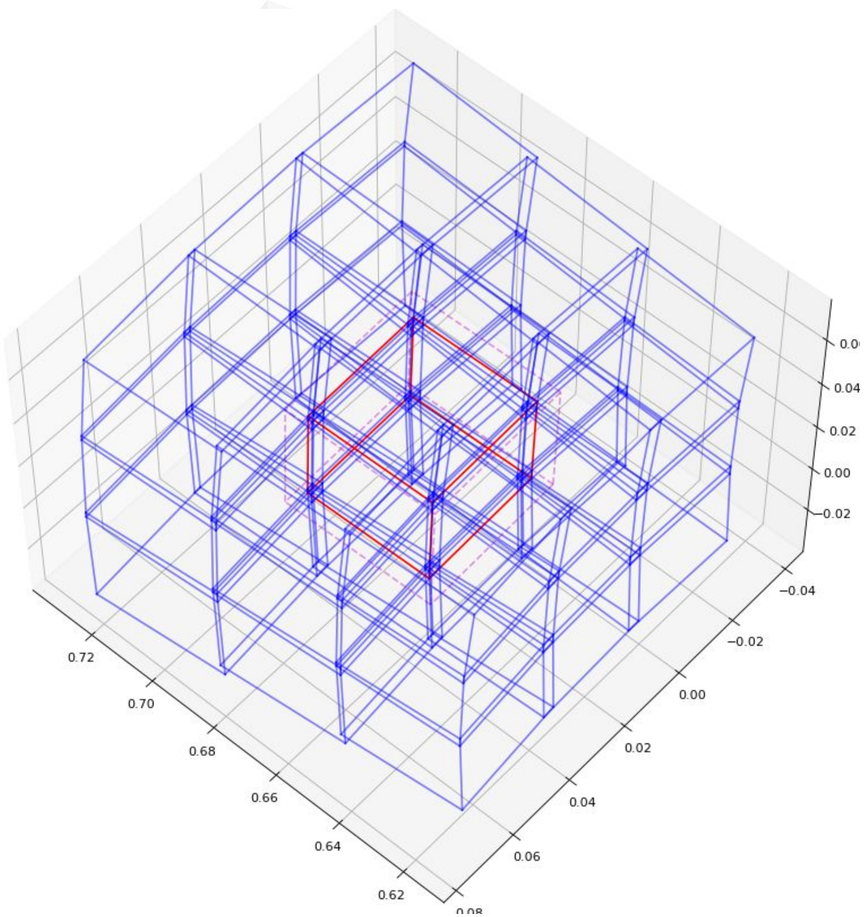
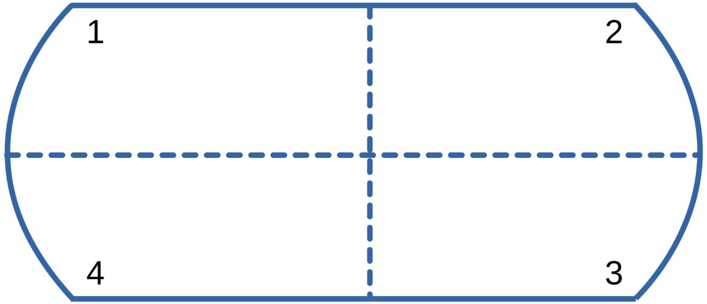
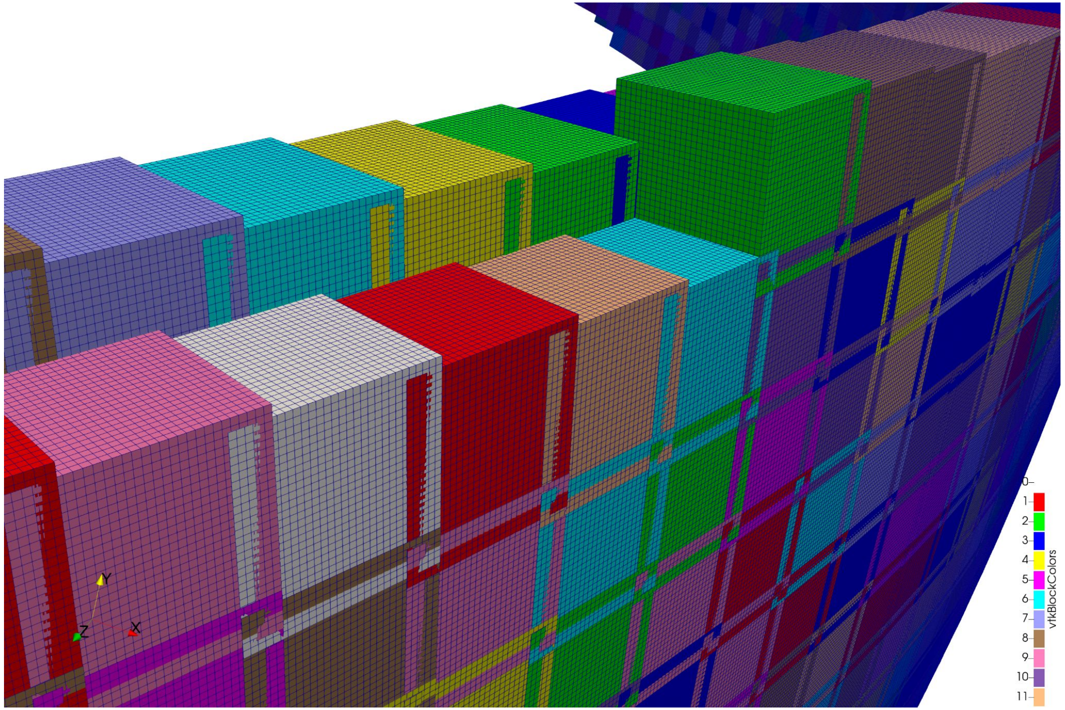




The ‘volleyball’ domain decomposition

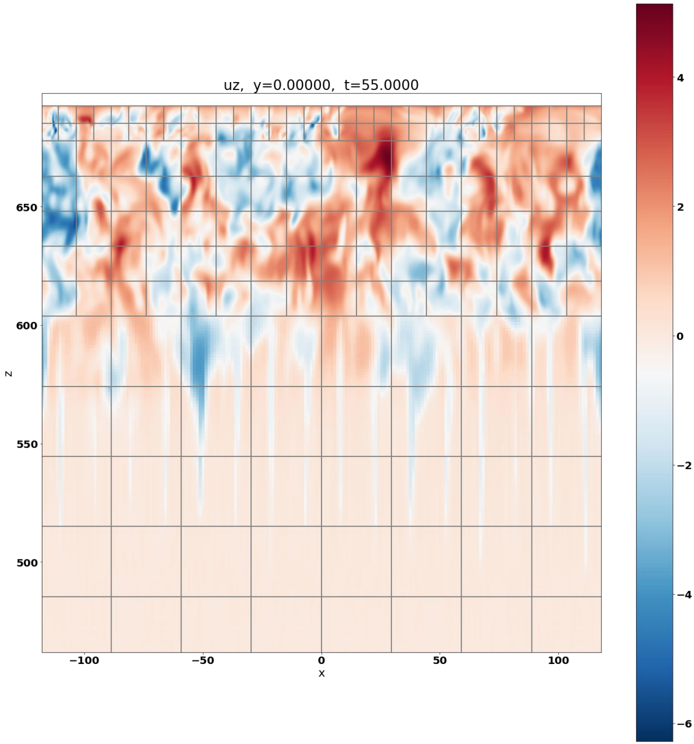
- ➢ *Patches overlap with a slight angle*
  - *Large angles at seams*
- ➢ *Simple MPI decomposition with good initial load balancing*





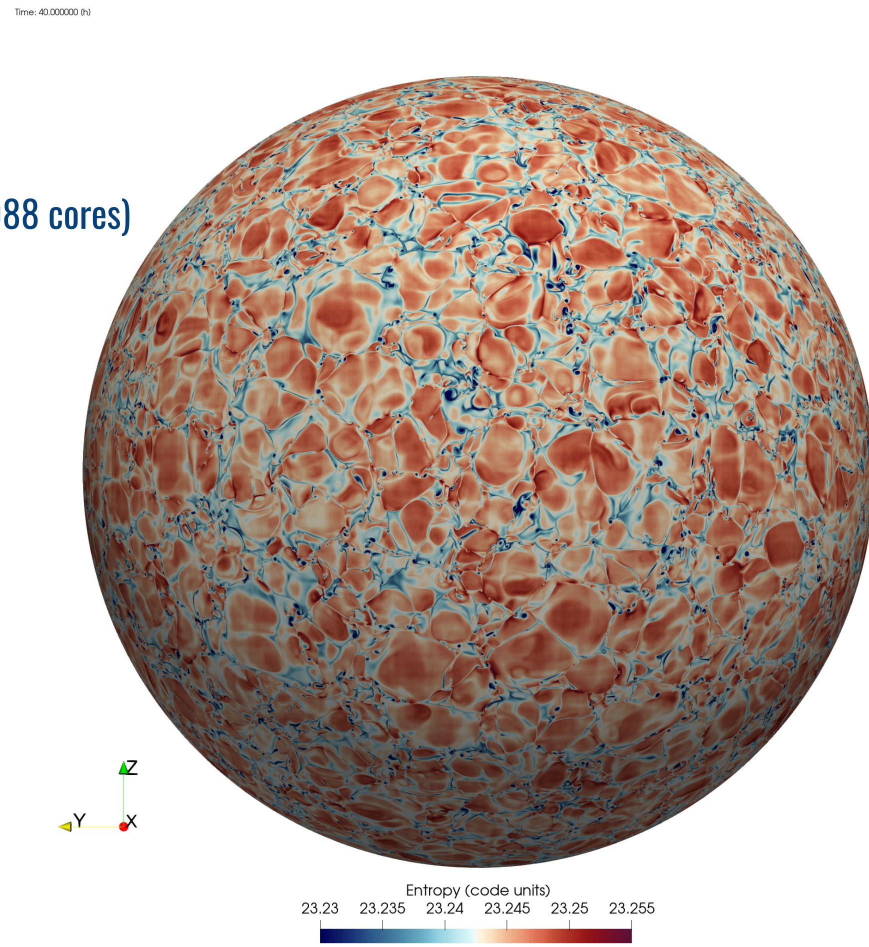
Experimental setup

- JCD model-S (Christensen-Dalsgaard et al., 1996) as initial HSE
  - Modified with tabular EOS
- Tabular EOS (Tomida & Hori, private comm., 2016)
- Entropy-based HLLD Riemann solver (Popovas et al., in prep.)
- Newton cooling
- Coriolis force
- Radially dependent gravity
- Trial run 0.655-0.995 $R_\odot$
- *Static mesh refinement*
- 200k patches (~1.5M after final refinement), 24^3 cells per patch
- 0.5Mm resolution (<100 km after final refinement) at 0.995 $R_\odot$

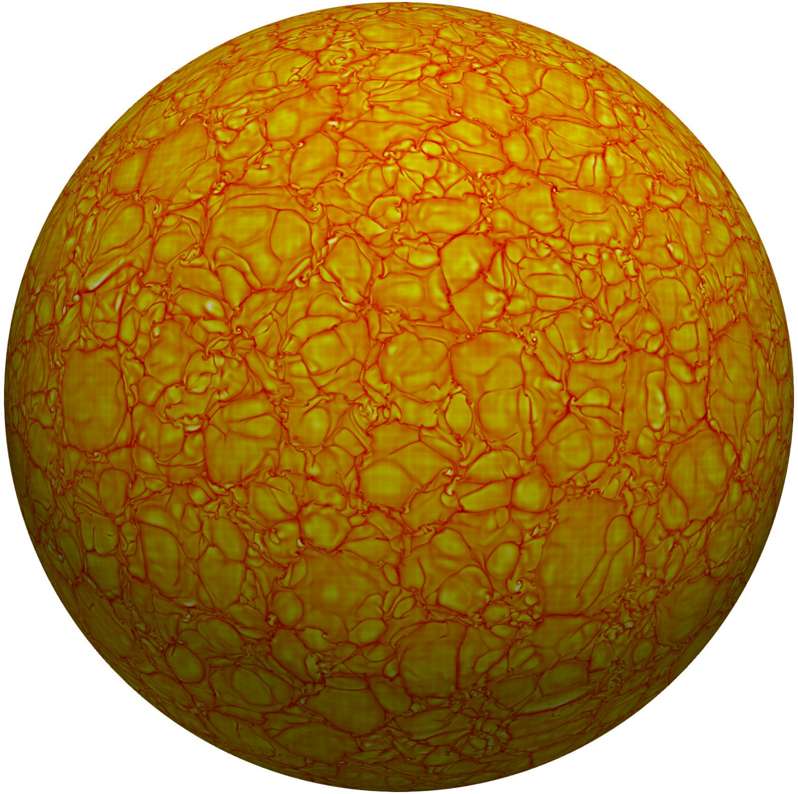


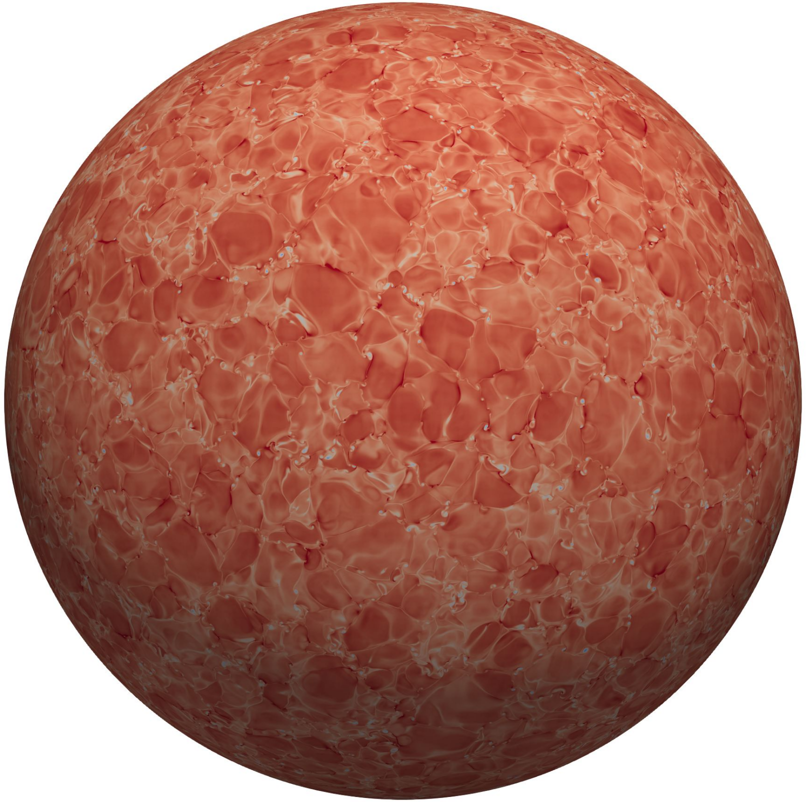
Production runs

- Running on Lumi and Betzy machines
  - 200k patches
  - Production relaxation on 196 nodes (25088 cores)
  - 2x realtime Sun
- 3 levels of refinement (70 km resolution)
  - 4.5M patches
  - 4TB snapshots
  - Optimally 910 nodes (116480 cores)



Initial results





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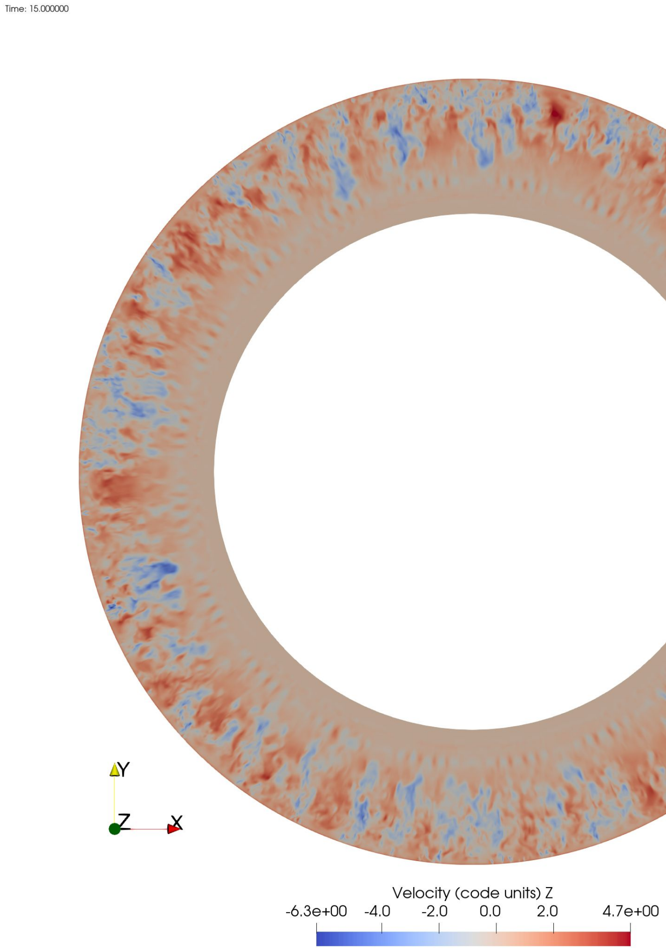
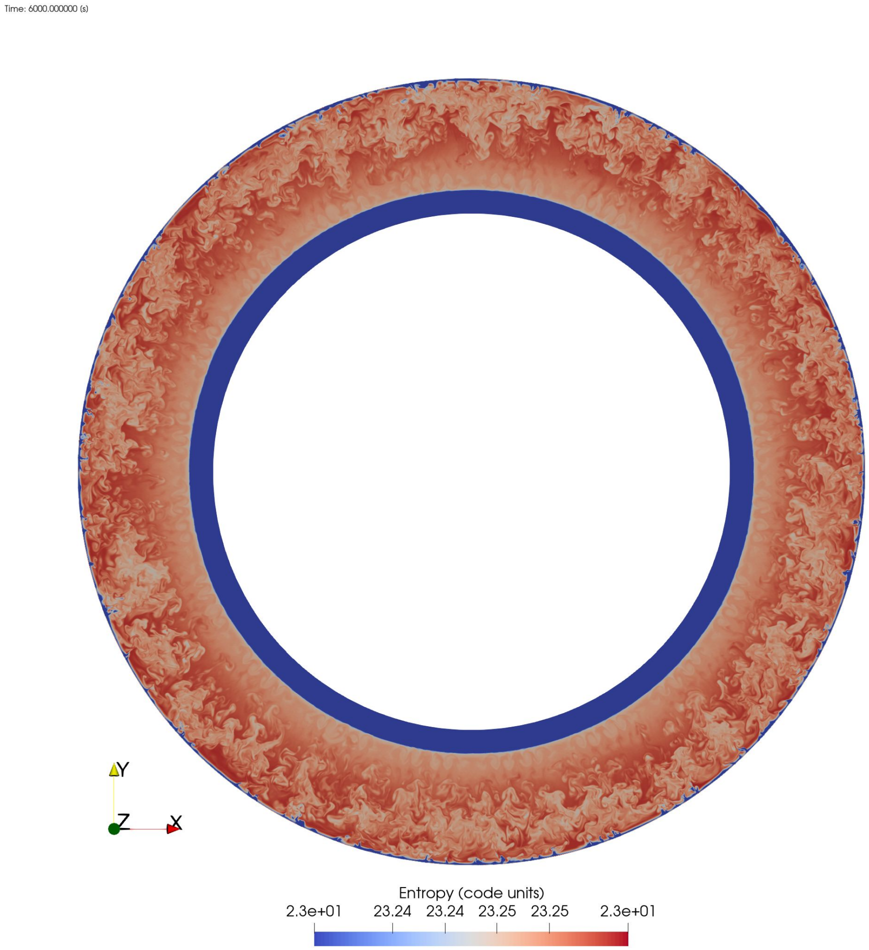
Initial results





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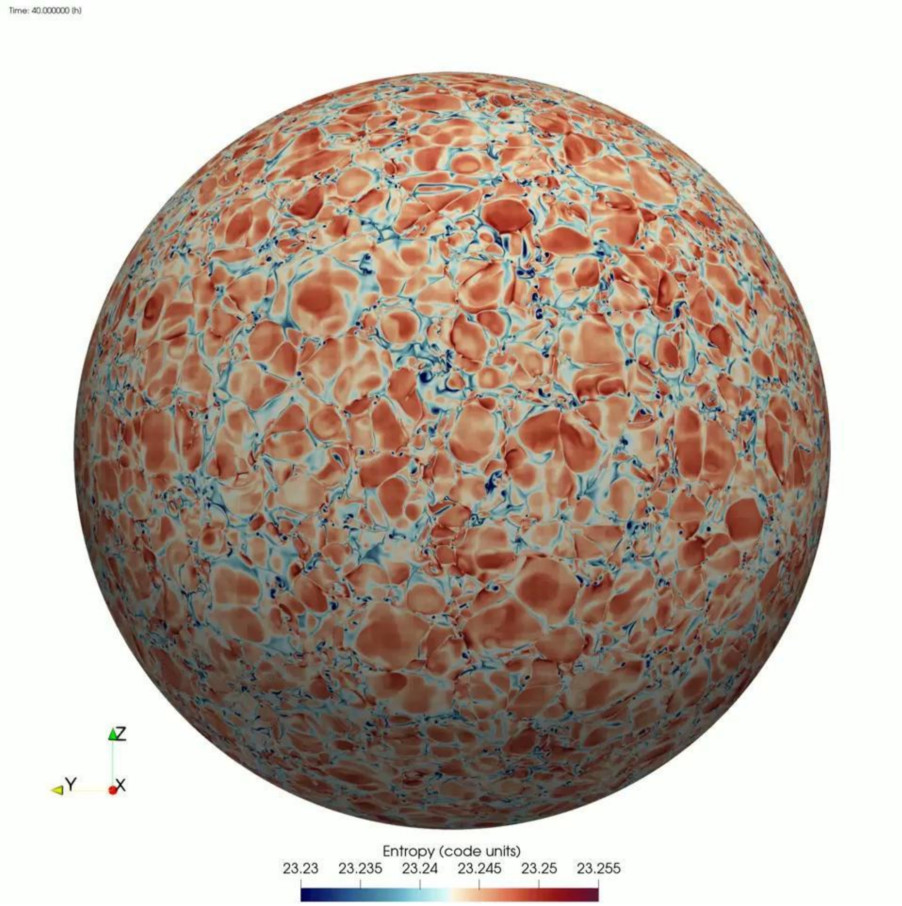
Initial results



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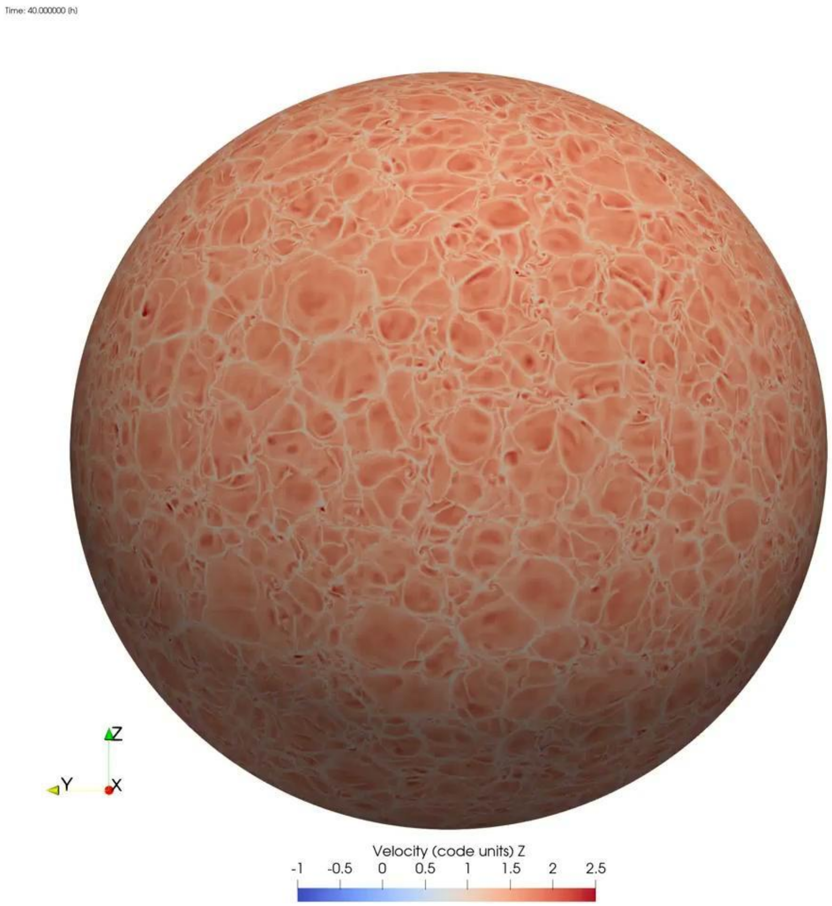
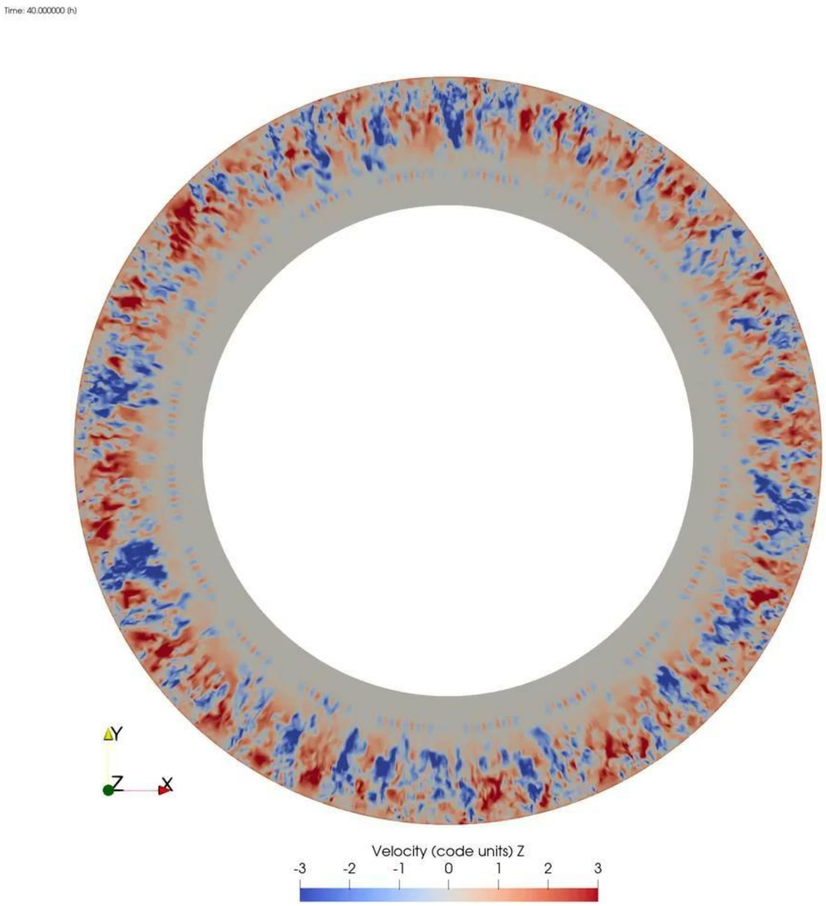
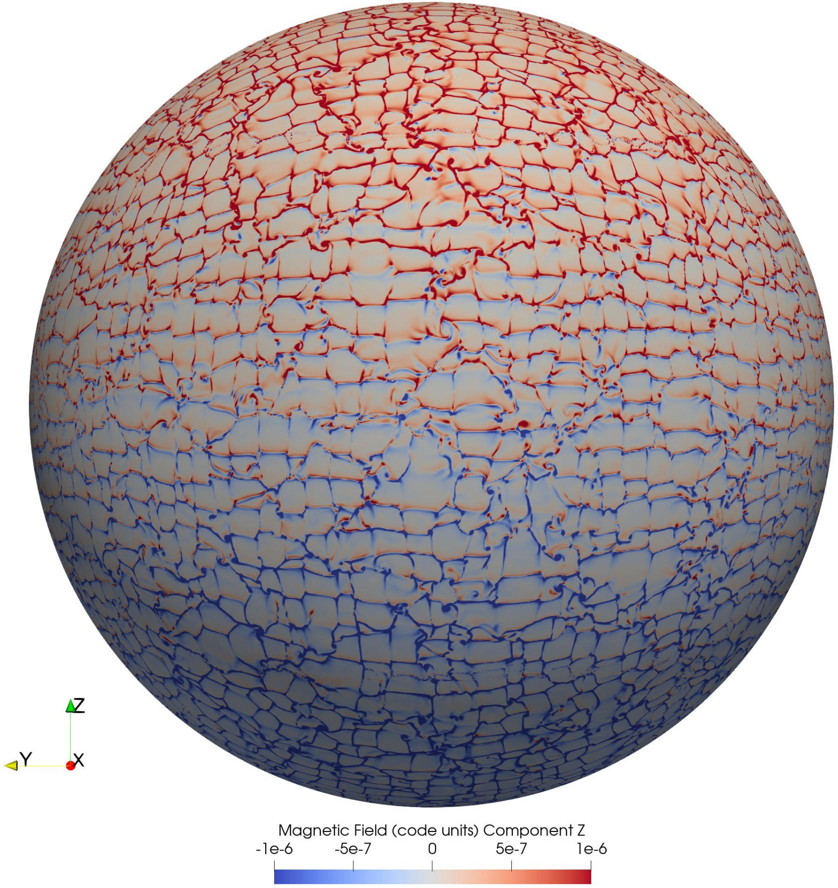
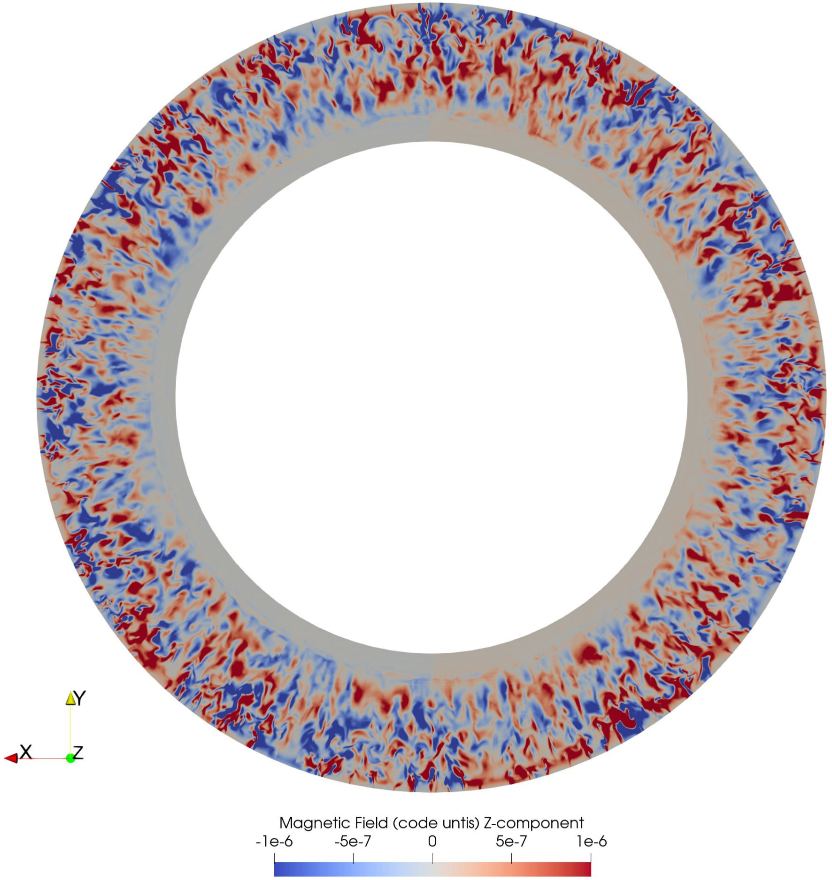




Initial results





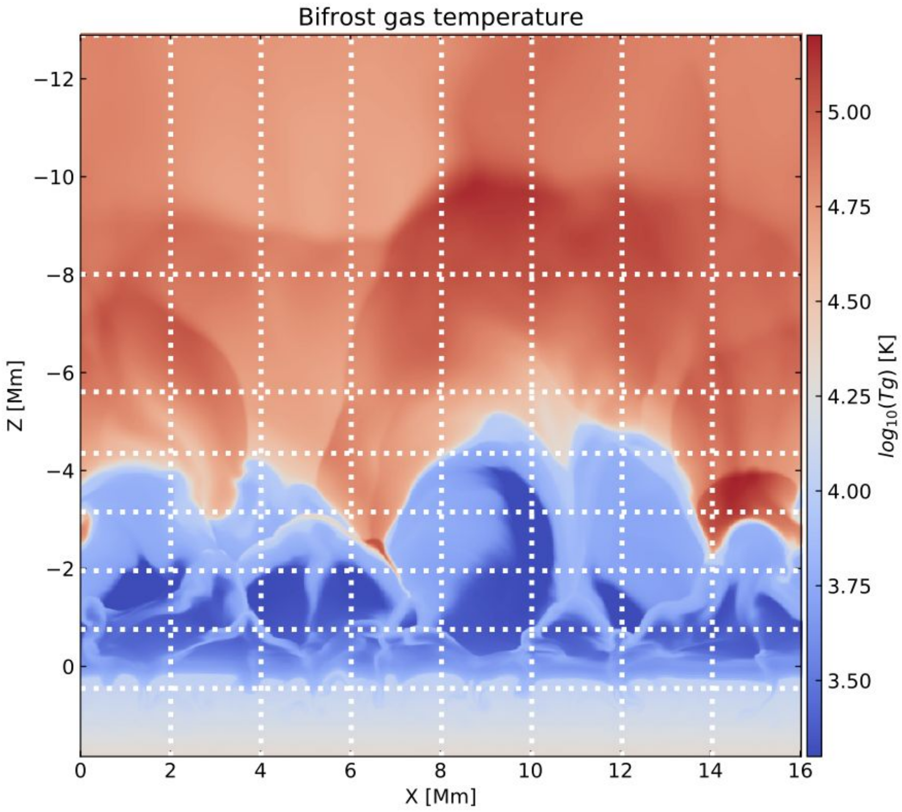
Next steps

- Build up analysis and visualization tools
- Build the simulation inwards and outwards
  - Add core
  - Add photosphere
- Additional physics

Potential scientific output

- Local and global dynamo studies
- Active regions and flux emergence
- Helioseismology
- You name it - we have an entire Sun to play with!
- *Snapshots will be made public*

Local timesteps



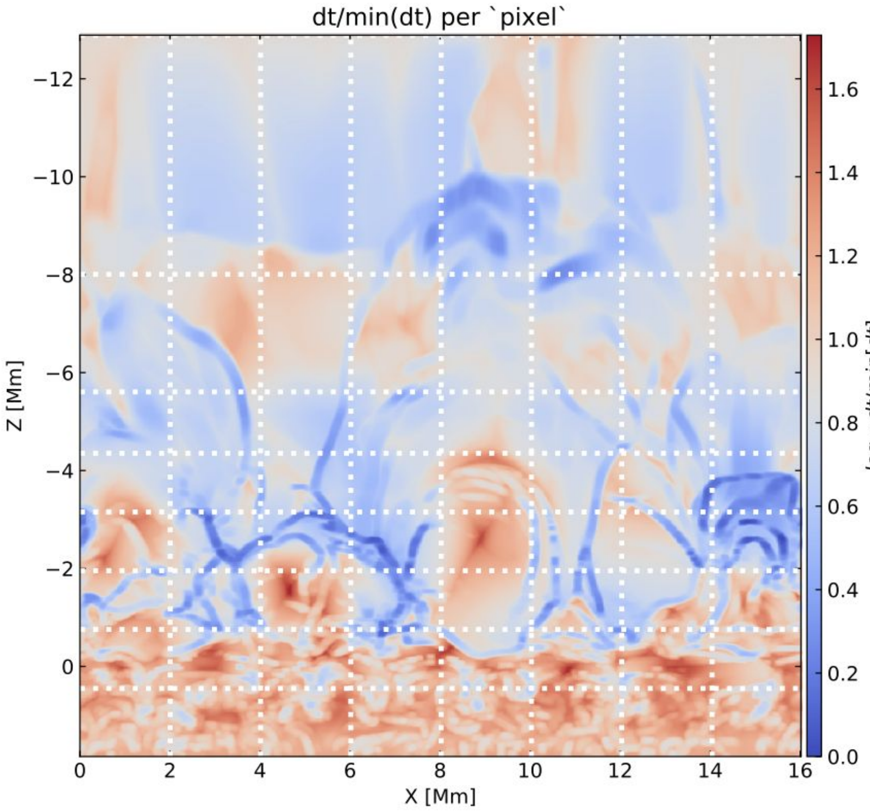
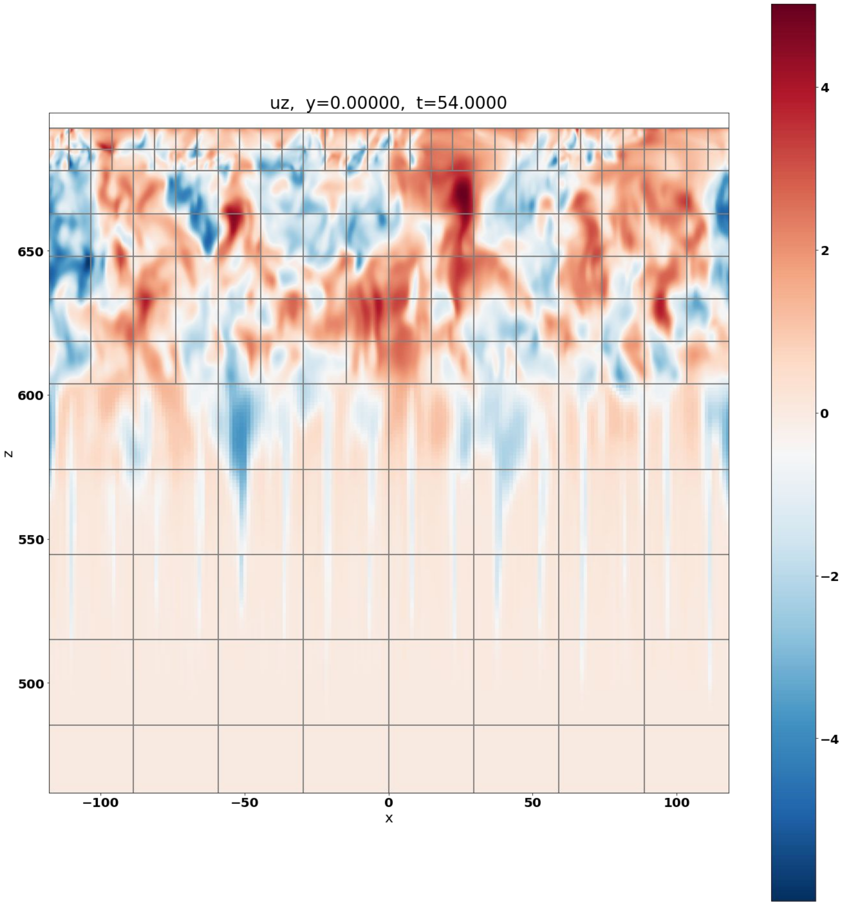
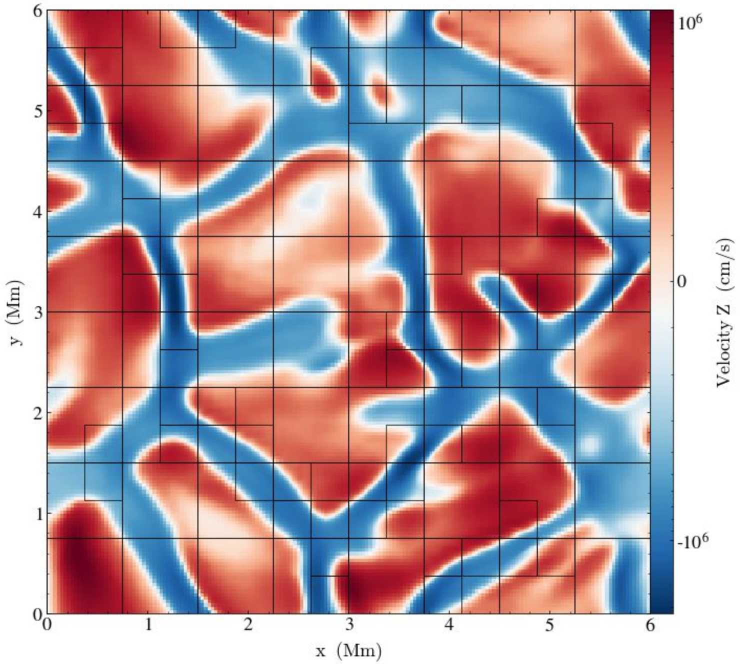


Figure credit: Mikolaj Szydlarski

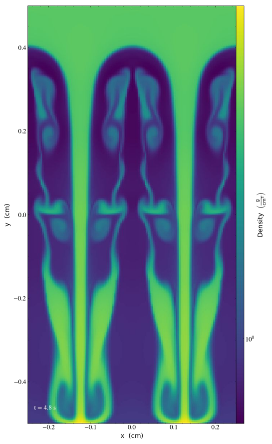
Mesh refinement

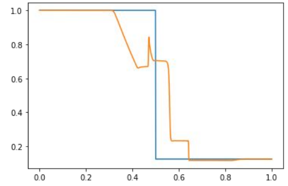


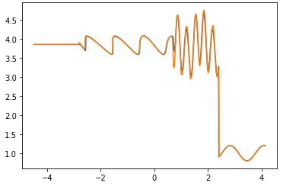


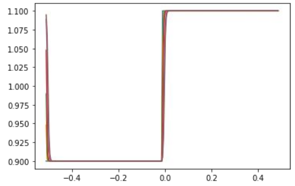
Approximate entropy based HLLD solver

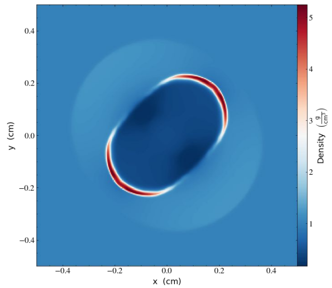
- ➢ *Entropy wave*
- ➢ *Shu & Osher shocktube*
- ➢ *Brio & Wu shocktube*
- ➢ *Rayleigh-Taylor instability*
- ➢ *Kelvin-Helmholtz instability*
- ➢ *MHD blast*
- ➢ *Orszag-Tang vortex*
- ➢ *Current sheet*
- ➢ *Magnetic field loop advection*
- ➢ *Hydrodynamic convection*
- ➢ *….*

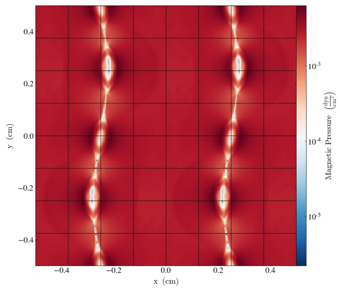


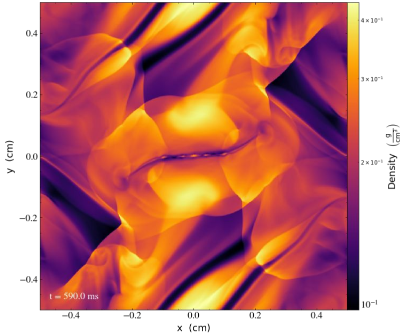


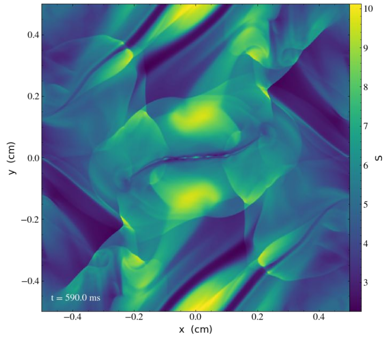












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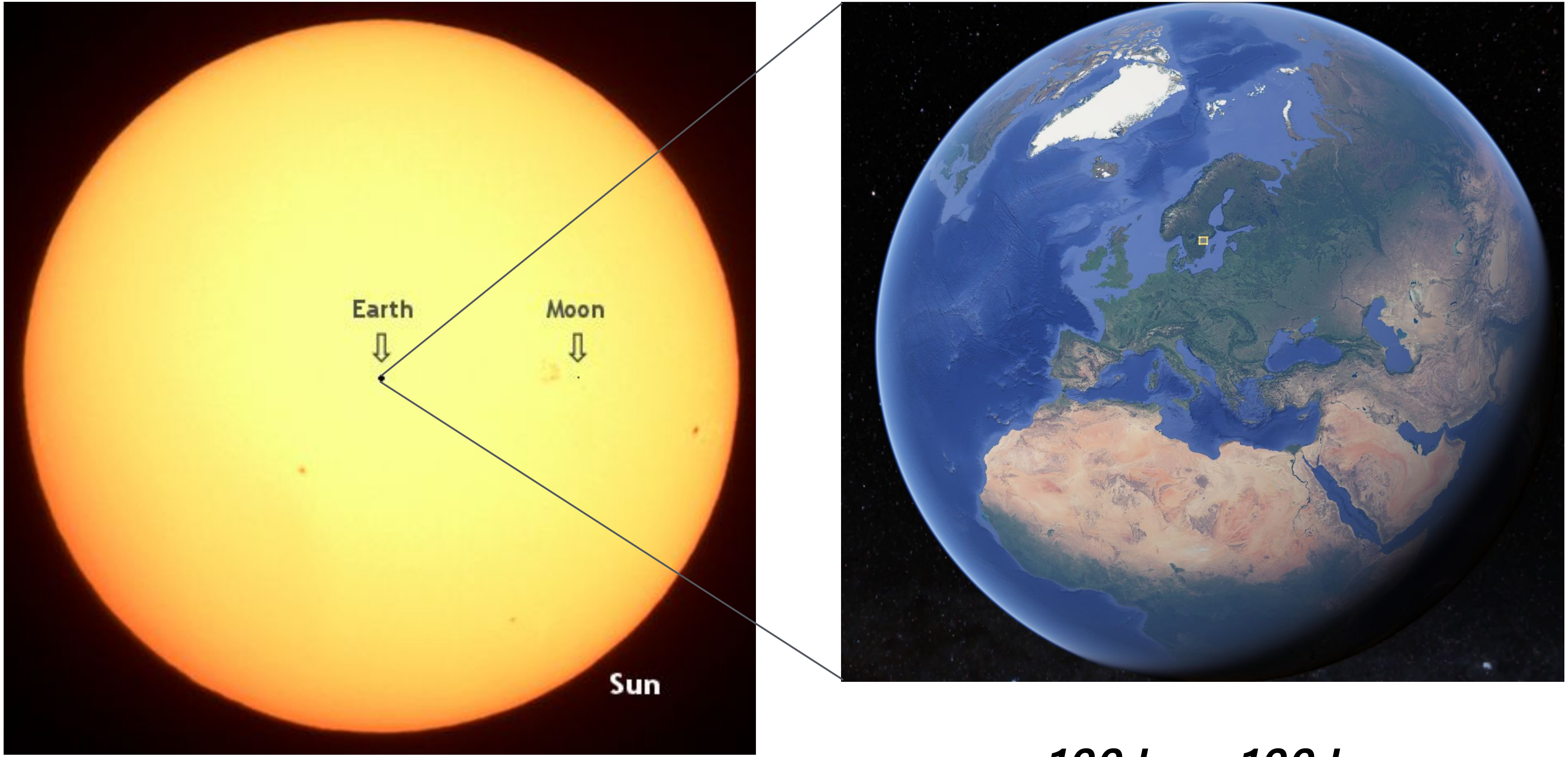
The production runs



100 km x 100 km