dyablo-Whole Sun

A new simulation code on AMR grids for the simulation of the Sun and solar-like stars on exascale architectures

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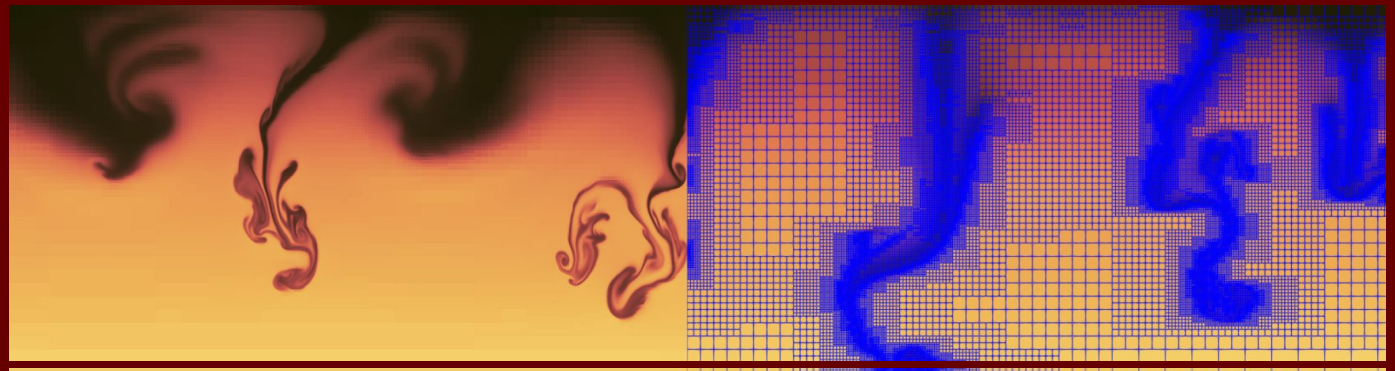
Journées SF2A - S11 - Besançon - 09/06/2022

Collaborateurs: Allan-Sacha Brun, Arnaud Durocher, Pierre Kestener, Antoine Strugarek



LDE3

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

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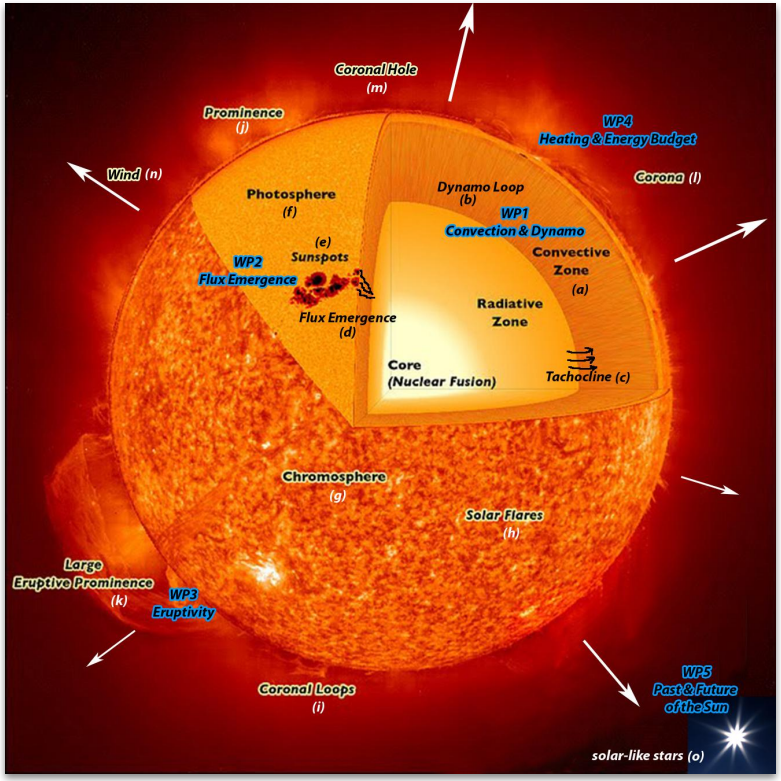
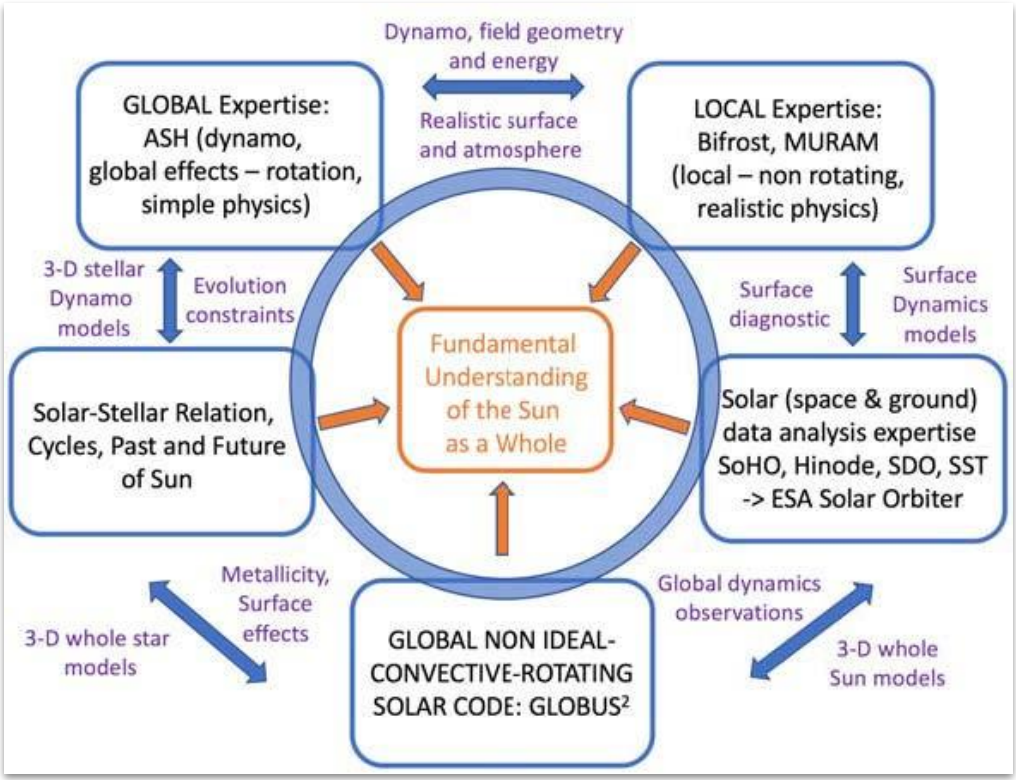
erc

WHOLE

Yet another code ?

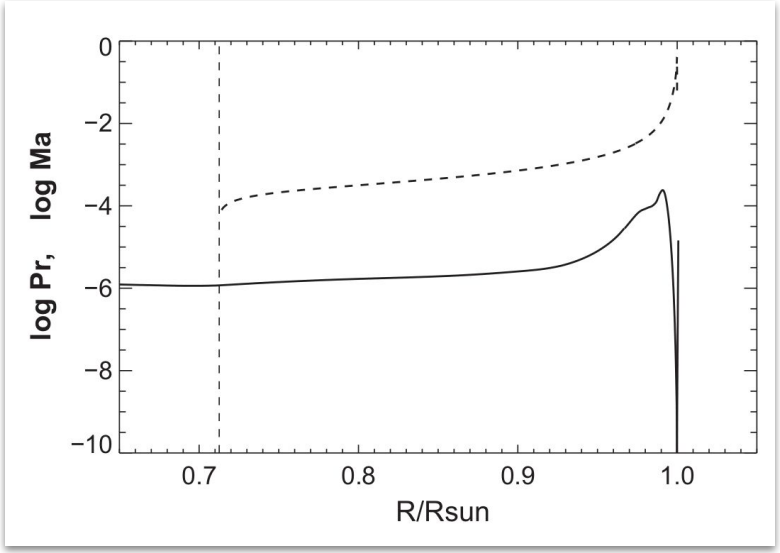


Source: [Whole Sun website]



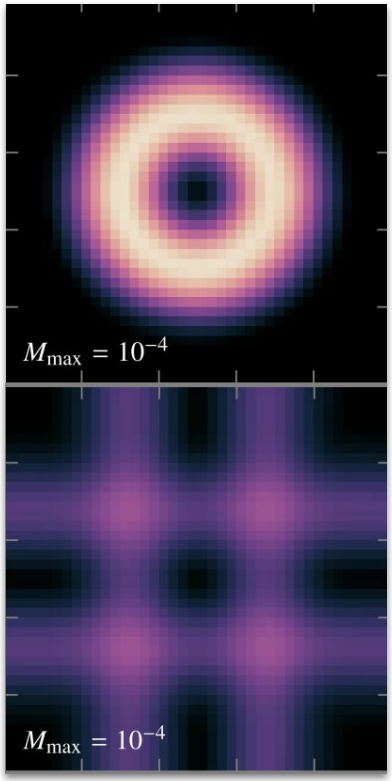
Source: [Whole Sun website]

Why is it so difficult ?



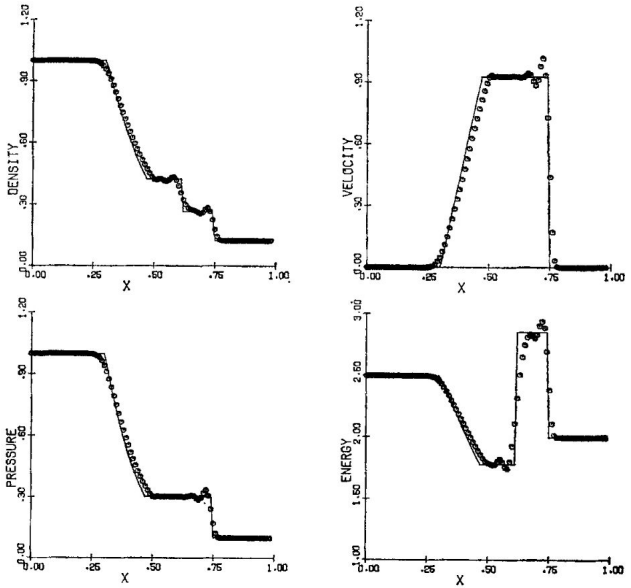
Freytag et al 2012

Low Mach end



Miczek et at 2015

High Mach end



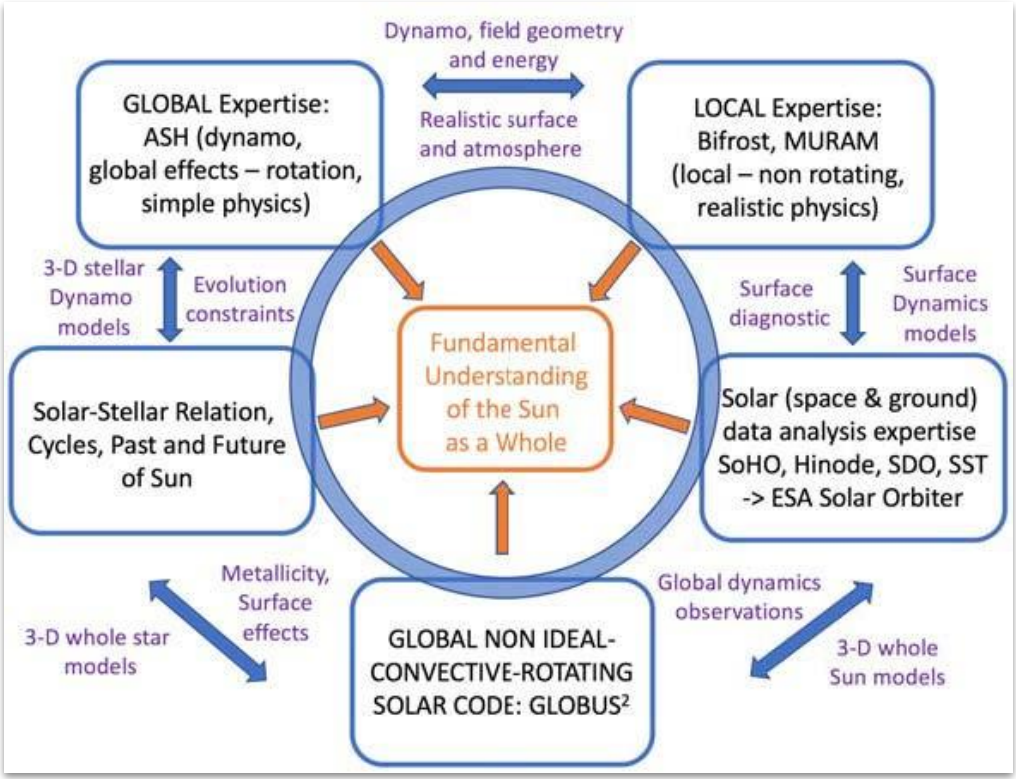
Sod 1978

And a lot of very good other reasons

Incentive:

- **Global simulations of the Sun**
  - Radiative zone → Corona
- **Multi-scale/multi-physics dynamics**
  - Large variation of temporal and spatial scales
  - Different regimes corresponding to different regions
- **Modularity and ease of use**
  - Testing and implementing new physics
- **Performance portability**
  - Being able to run and be efficient on “”“any””” cluster

New code = Modern algorithmics + modern numerical methods



Source: [Whole Sun website]

dyablo-Whole Sun: design goals and wishlist [2022]

Physics

- **Objective:** Global simulation of the Sun, from the radiative interior to the corona
- **Ingredients:** MHD, viscosity, gravity, thermal conduction, radiative-transfer, rotation, all-Mach

Numerical methods

- Geometry: **Adaptive mesh refinement**, multiple geometries
- **Finite-volumes**, with godunov-type method, multiple solvers (muscl-hancock, rk2/rk3, euler)
- Explicit integration of sources (purely explicit, STS, RKL) or IMEX methods

Software engineering

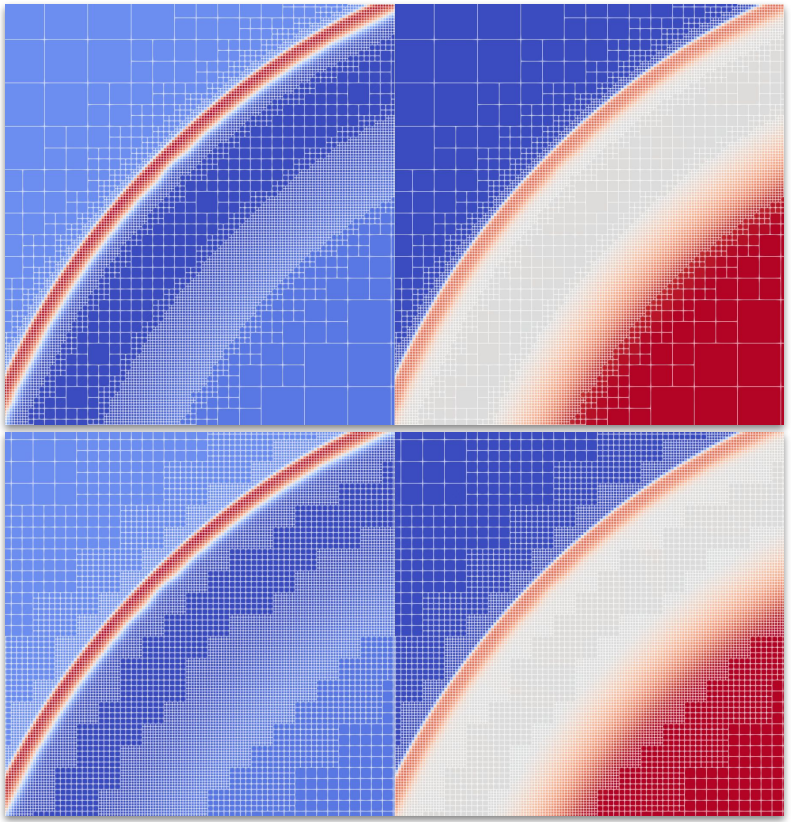
- Performance portable: MPI + shared parallelism
- *"Separation of Concerns"*: Generic AMR tree traversals/reductions
- Modularity: Plugins and factories system

AMR ?

Adaptive **M**esh **R**efinement :

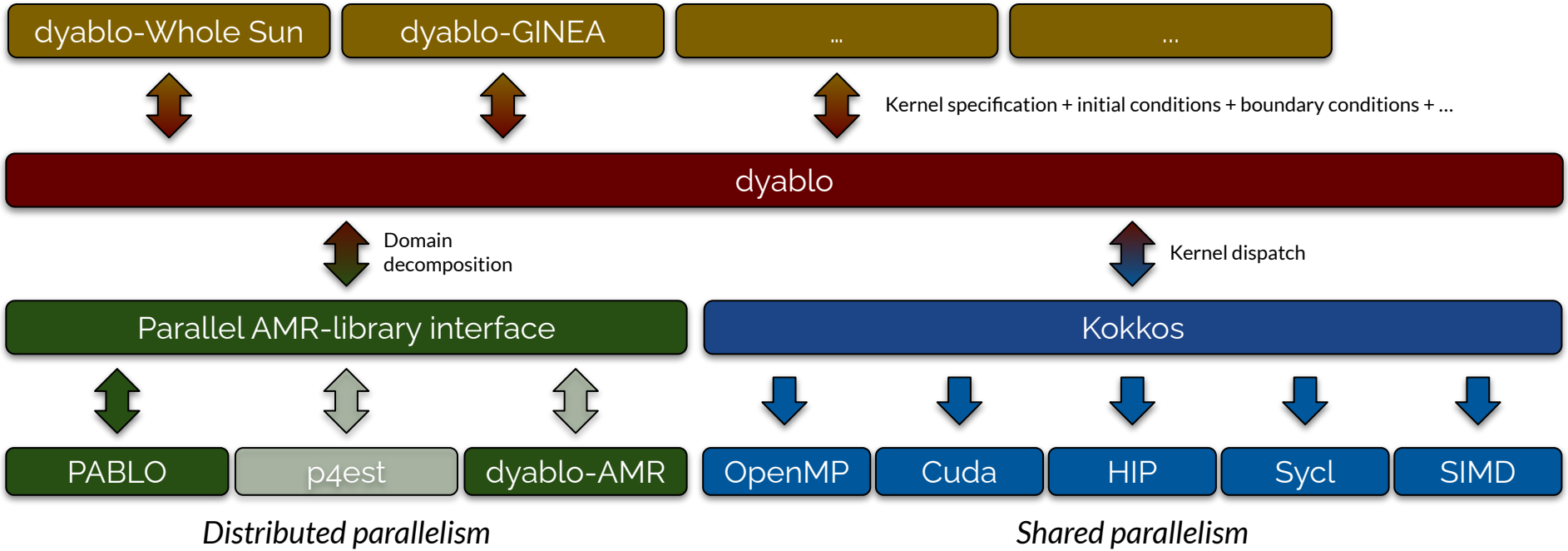
- Allocates more points in interesting[*definition needed*] regions
- Allows to fit large problems in memory
- Many flavors :
  - **Cell-based**
  - **Block-based**
  - Patch-based
- Main challenges :
  - More difficult algorithmics
  - More complex numerical schemes
  - Difficult to parallelize
  - Usually slower than regular grids
  - What's a sensible refinement criterion ?

Cell-based AMR



Block-based AMR

dyablo: a high-performance AMR framework



Historically, DYABLO := DYnamics Adaptive mesh refinement CFD applications with PABLO

dyablo-Whole Sun: current state [2022]

Physics

- **Objective:** Global simulation of the Sun, from the radiative interior to the corona
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Numerical methods

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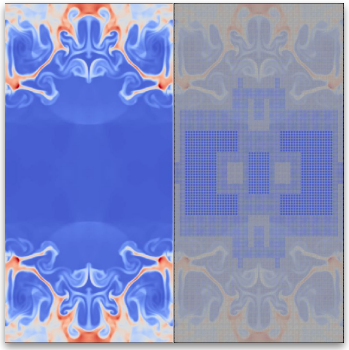
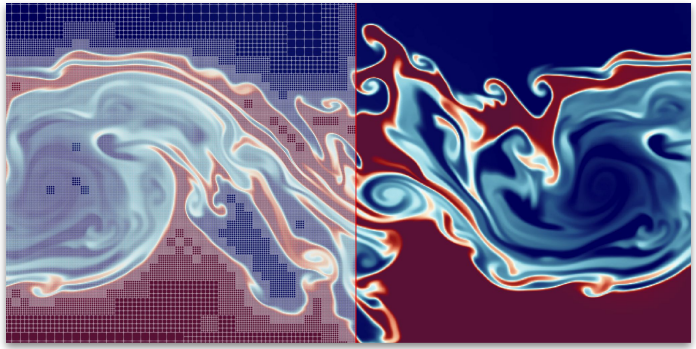
- Explicit integration of sources (**purely explicit**, STS, RKL) or IMEX methods

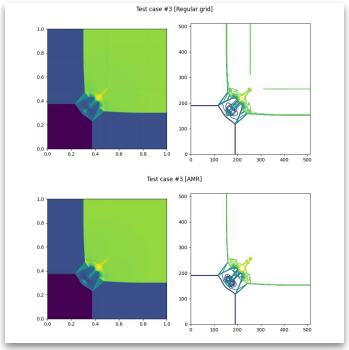
Software engineering

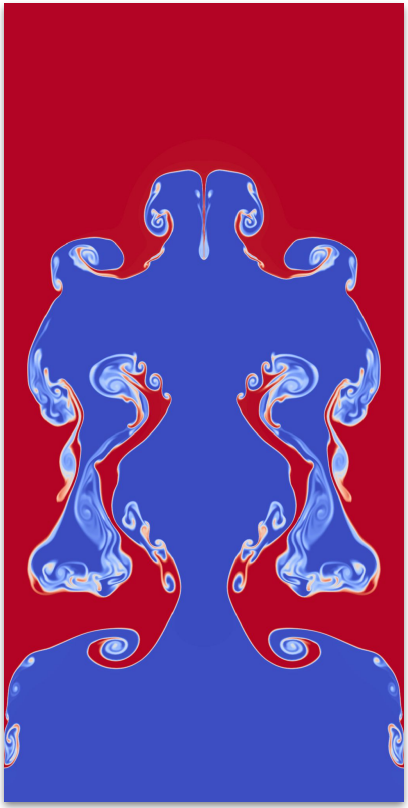
- Performance portable: **MPI + shared parallelism [CPU intel/AMD; GPU Nvidia]**
- *Separation of Concerns*: **Generic AMR tree traversals/reductions**
- Modularity: **Plugins and factories system**

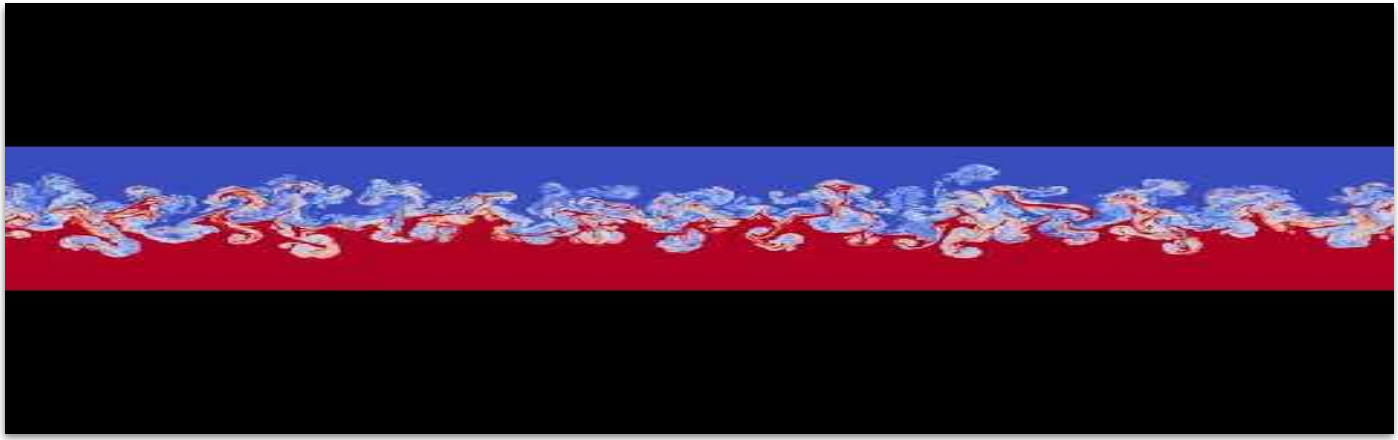
dyablo-Whole Sun: Hydrodynamics tests







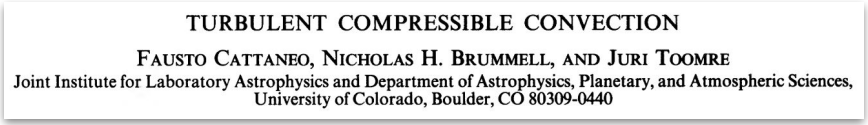




Convective hydrodynamics benchmark

Setup

- Inspired from Hurlburt 1984, **Cattaneo et al 1991**, Brummell et al. 1996 and 2002



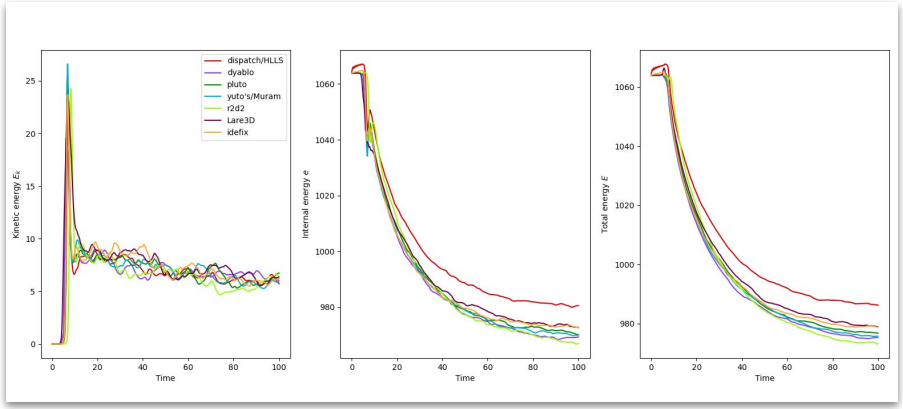
TURBULENT COMPRESSIBLE CONVECTION

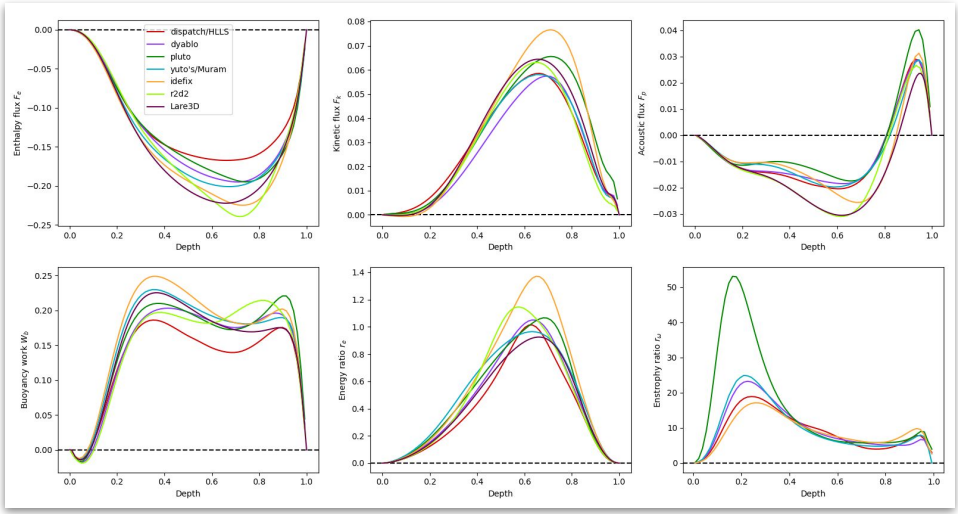
FAUSTO CATTANEO, NICHOLAS H. BRUMMELL, AND JURI TOOMRE

Joint Institute for Laboratory Astrophysics and Department of Astrophysics, Planetary, and Atmospheric Sciences, University of Colorado, Boulder, CO 80309-0440

- **Ingredients**: Compressible hydrodynamics, viscosity, gravity and thermal conduction
- **Domain:** Convective near-surface slab. Highly stratified spanning multiple density scale-heights.
  - Horizontal dimension spans 4 times the vertical dimension
  - Fixed grid resolution: 256^2x64
  - Initial conditions: Polytropic model, hydrostatic equilibrium, random perturbation on pressure
  - Horizontal BCs: periodic
  - Vertical BCs:
    - Imposed temperature at top, Imposed temperature flux at bottom
    - Stress-free impenetrable walls
    - Density recovered from continuity
- Benchmark inputs:
  - Stratification θ
  - Prandtl number σ
- 9 codes involved : dedalus, dispatch, dyablo, hps, idefix, lare3d, muram, pluto, r2d2

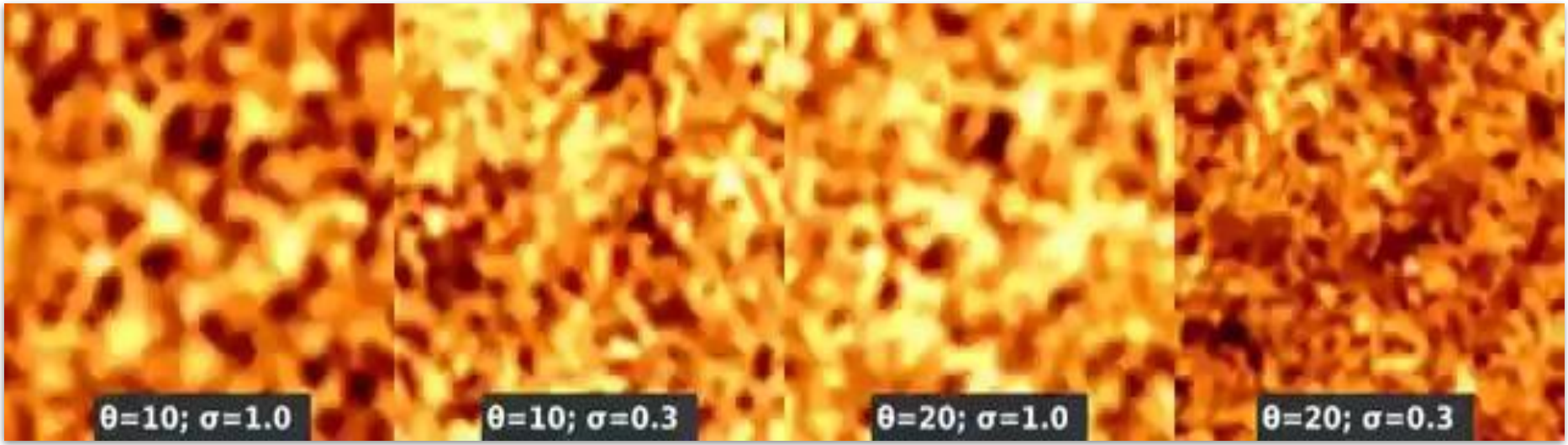
Convection benchmark





Increasing Ra

Horizontal cuts at z=0.1

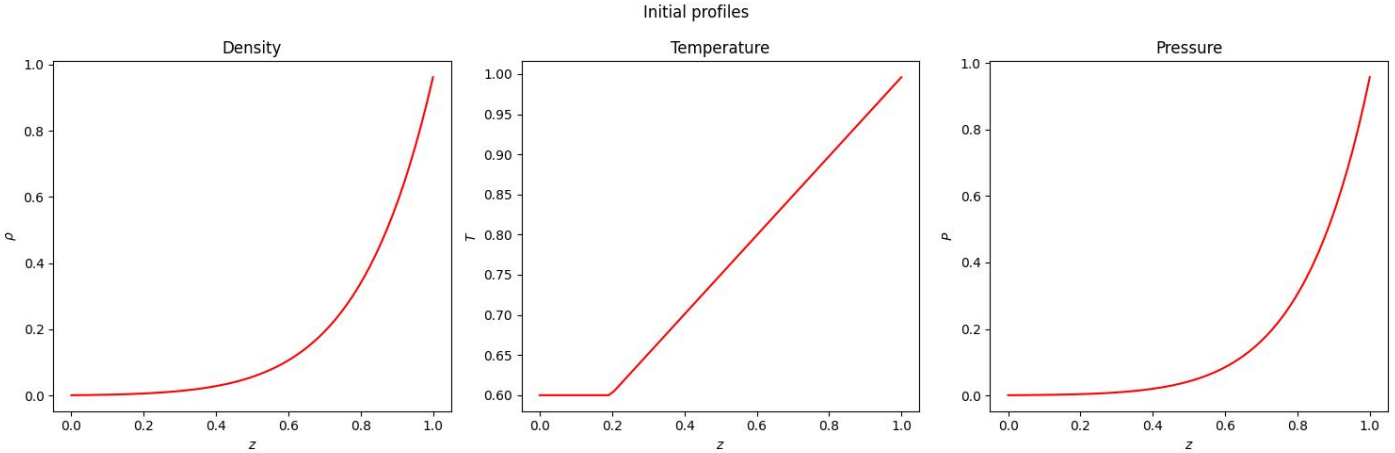


Ra = 4.9×10^4 | Ra = 1.6×10^5 | Ra = 3.6×10^5 | Ra = 1.6×10^6

Surface cooling driven convection benchmark

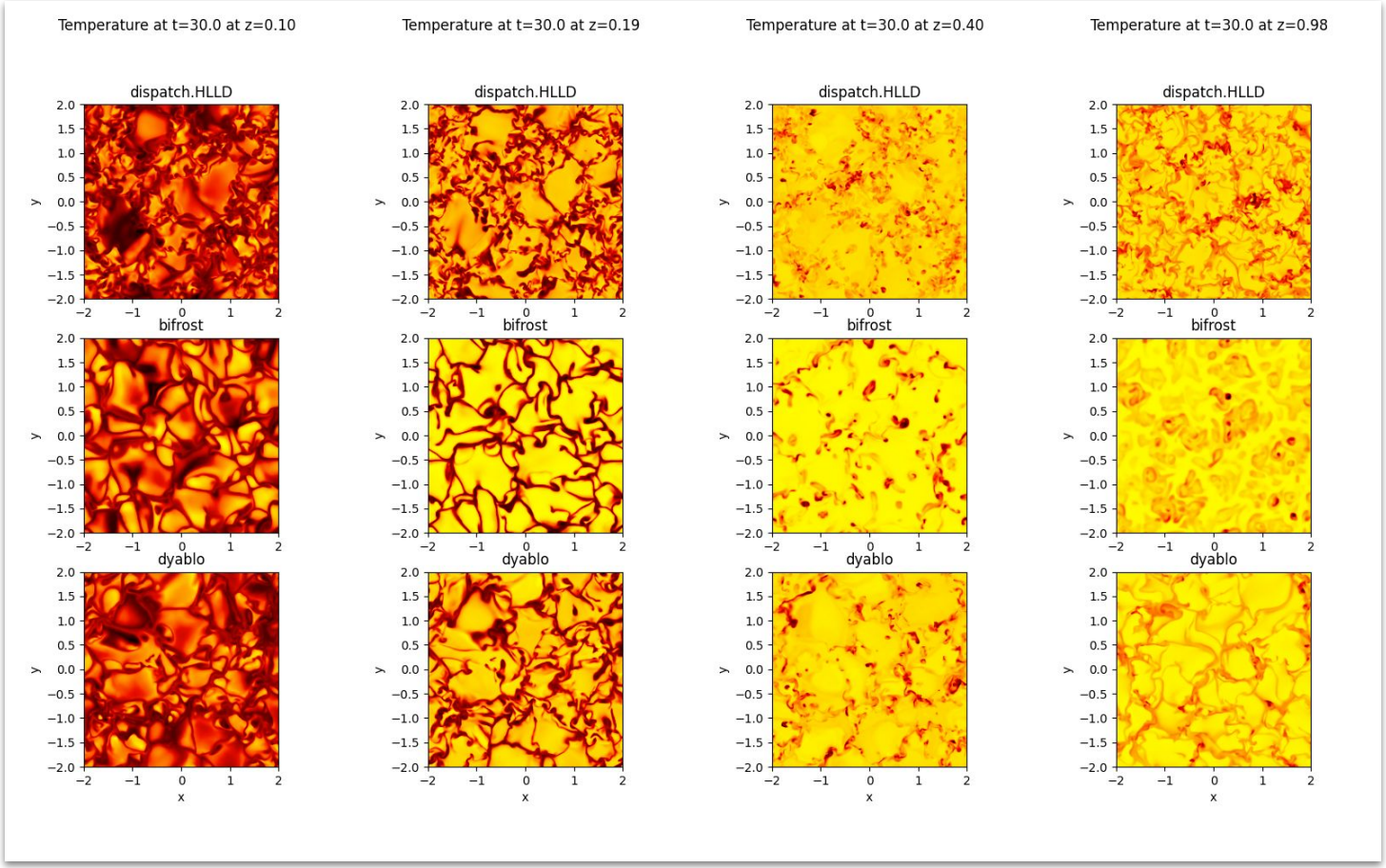
Setup

- Derived by Åke Nordlund in the context of Whole-Sun. Coordinated by Mikolaj Szydlarski
- **Ingredients**: Compressible hydrodynamics + Newtonian cooling
- **ICs** :
  - Polytropic model from the base of the convection zone to the cooling layer,
  - Constant temperature above
  - Deterministic perturbation to trigger instability
- Participating codes : bifrost, dispatch, dyablo, (CO)-Mancha



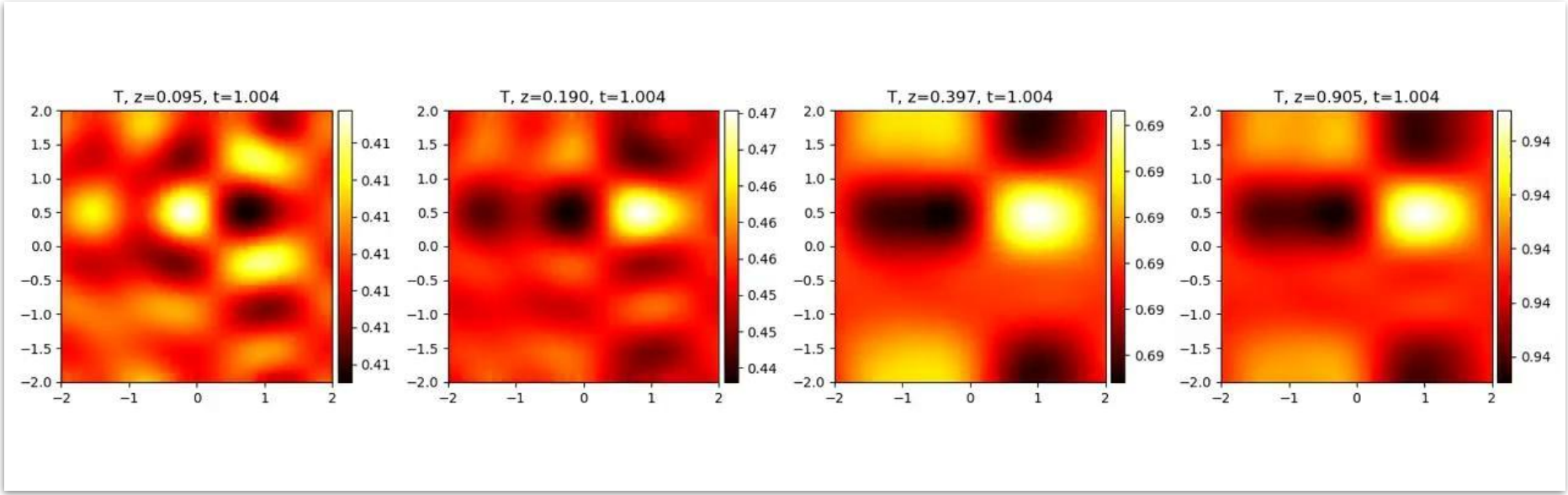
Surface cooling driven convection benchmark

Runs



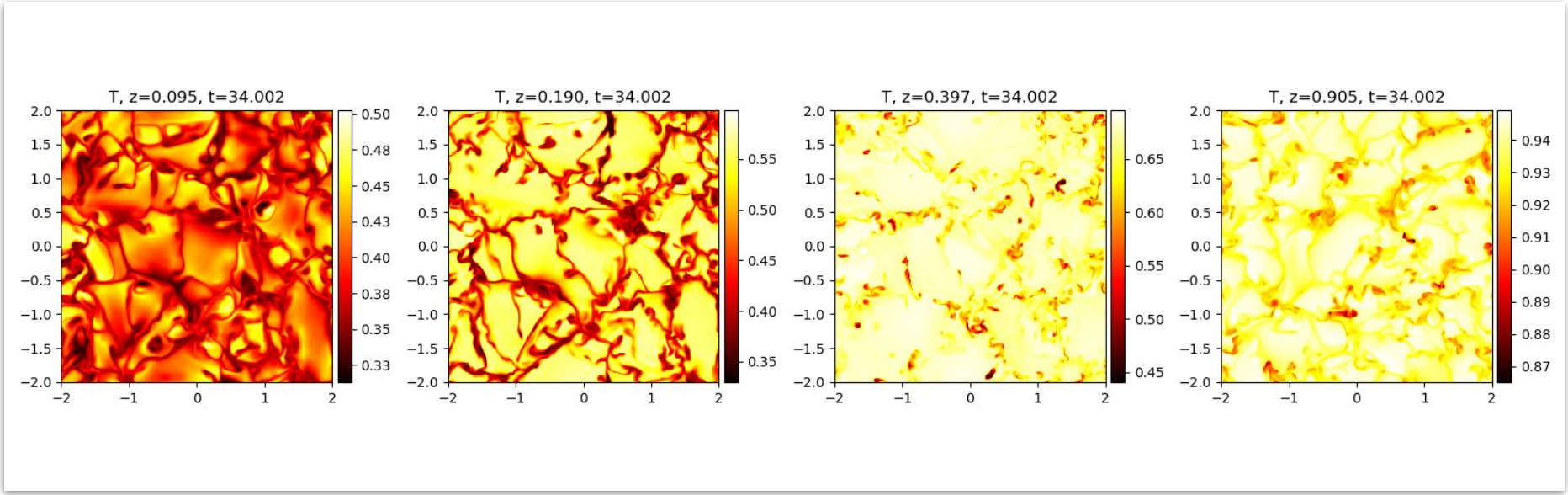
Surface cooling driven convection benchmark

Runs



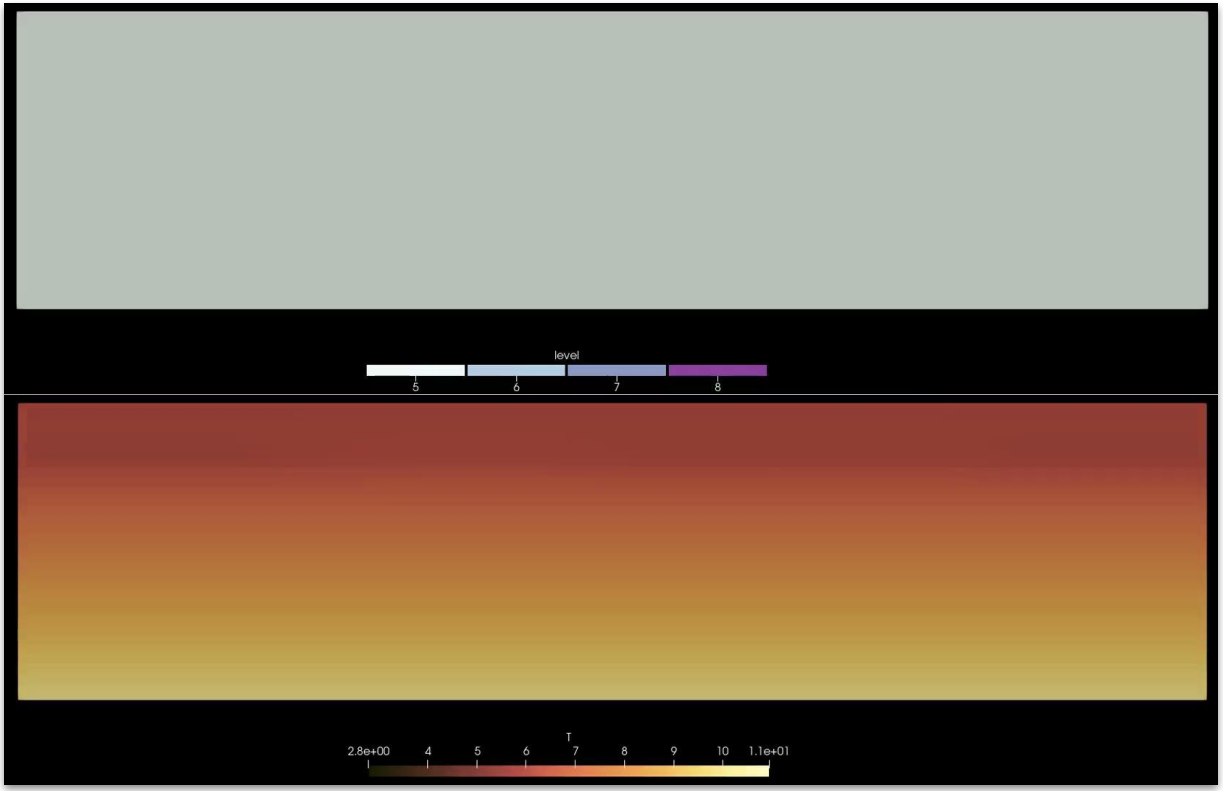
Surface cooling driven convection benchmark

Runs



Surface cooling driven convection benchmark

AMR Runs (2d)

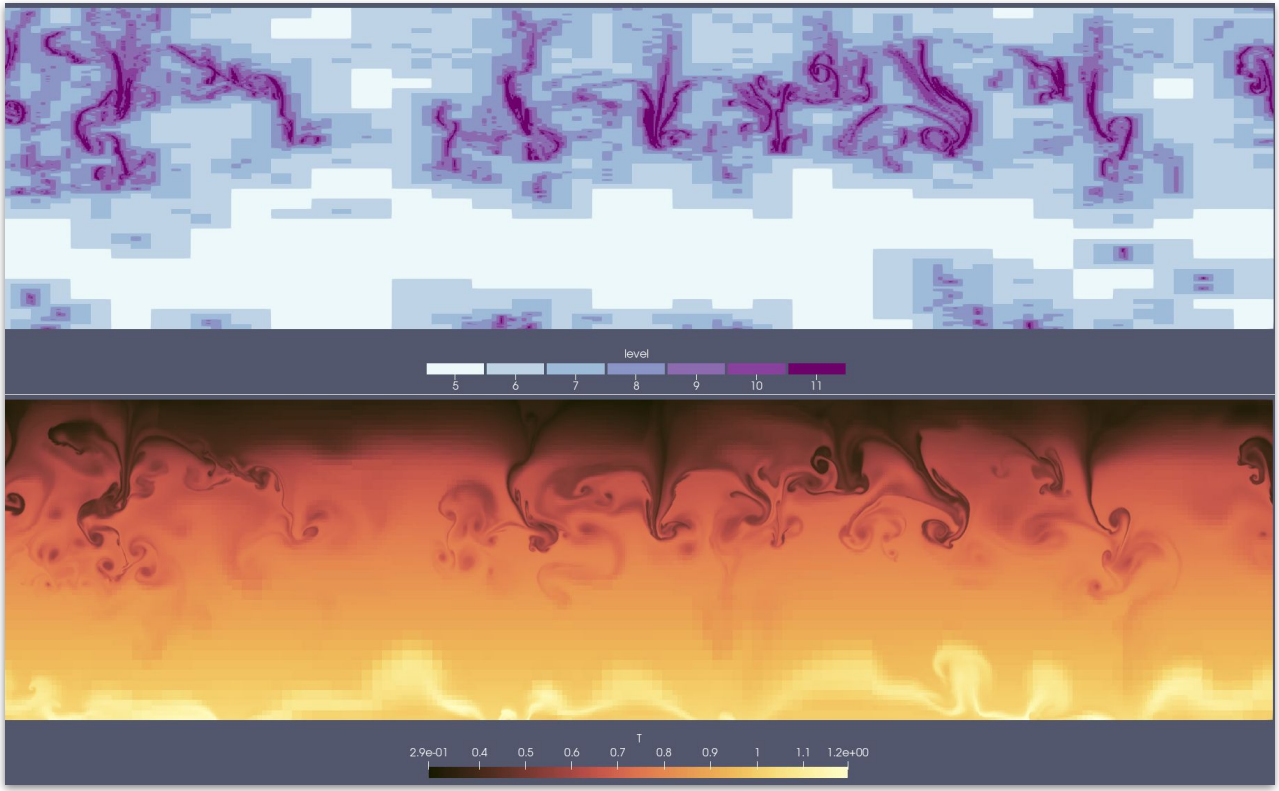


Base resolution:
128x32

Max resolution:
1024x256

Surface cooling driven convection benchmark

AMR Runs (2d)

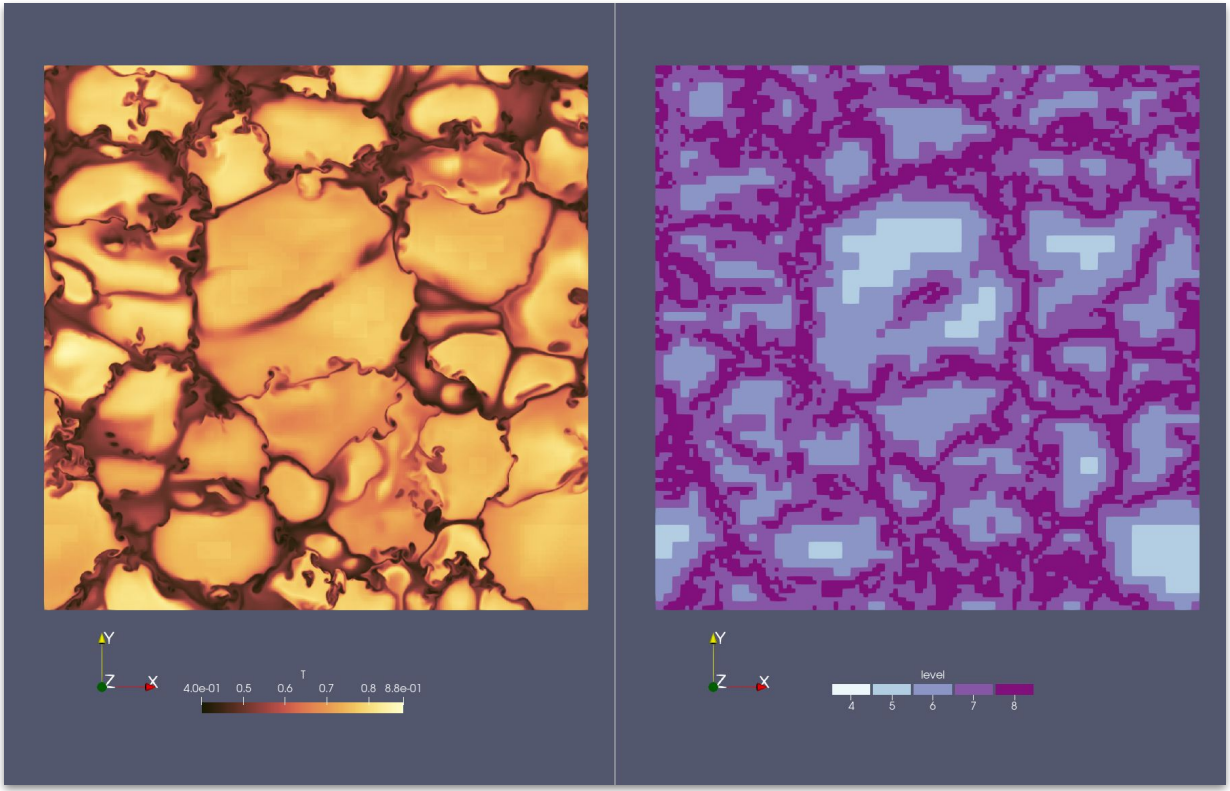


Base resolution:
128x32

Max resolution:
8192x2048

Surface cooling driven convection benchmark

AMR Runs [base level of fixed run is 6]

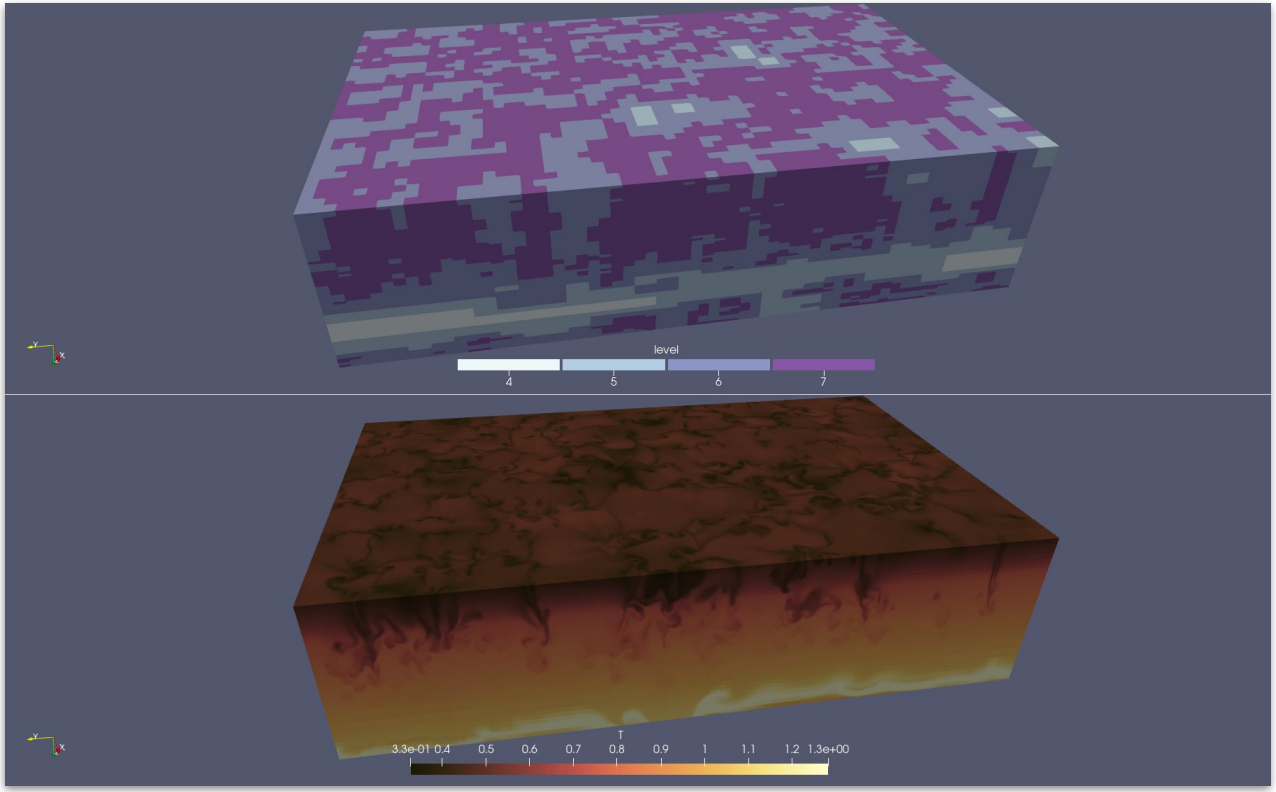


Base resolution:
64x64x16

Max resolution:
1024x1024x256

Surface cooling driven convection benchmark

AMR Runs [base level of fixed run is 6]

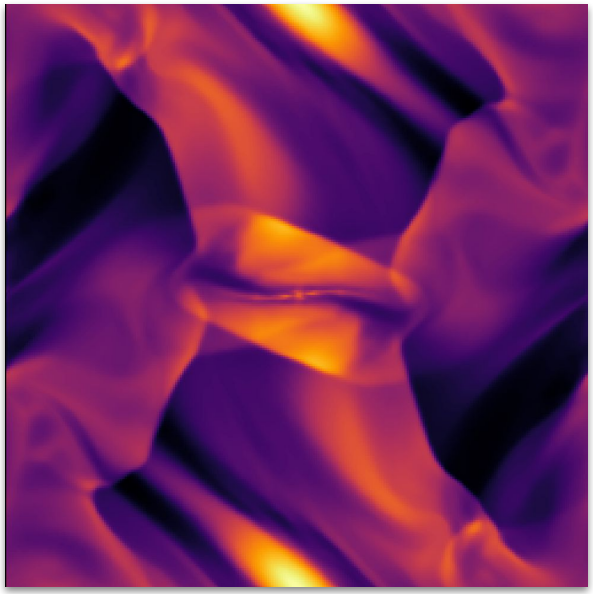


Base resolution:
64x64x16

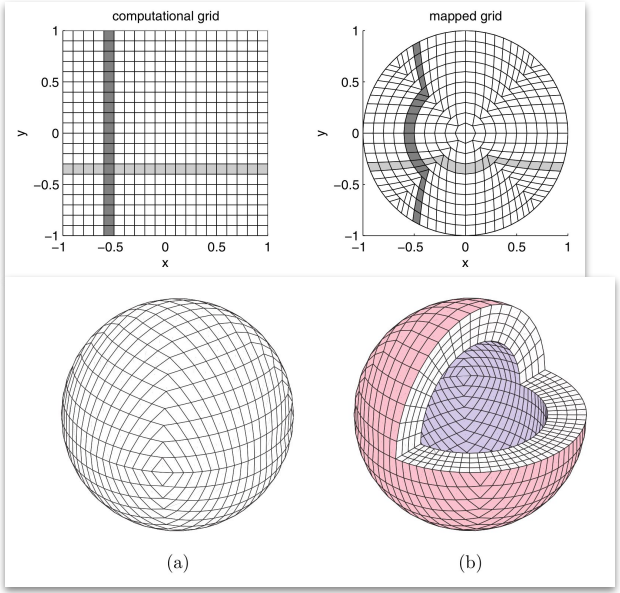
Max resolution:
512x512x128

dyablo-Whole Sun:

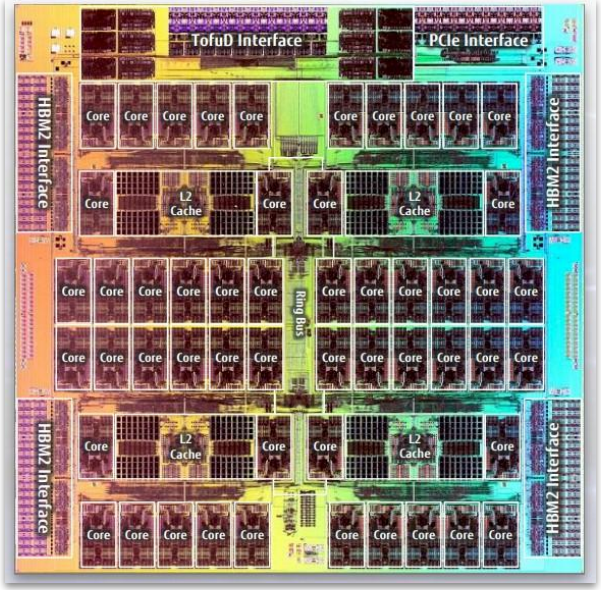
What's next ?



Tremblin et. al (in prep)



[Calhoun et. al 2008]



(+ Tons of debugging/improvements/testing)

Thank you for your attention

Questions ?