Tracing the evolution of radiation-MHD simulations of the solar atmosphere in the Lagrangian frame

Jorrit Leenaarts

Stockholm University

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

Studying radiation-MHD simulations in the Lagrangian frame

Jorrit Leenaarts[1]

[1] *Institute for Solar Physics, Stockholm University, AlbaNova University Centre, SE-106 91 Stockholm, Sweden*

Radiation-MHD simulations of the solar atmosphere are a powerful tool to study physical processes. Such simulations are often analysed in the Eulerian frame, i.e., quantities are analysed on the computational grid. For certain classes of problems this is not the optimal choice.
If one is interested in the evolution of a given fluid parcel instead of the evolution at a given location in the simulation, then a description in the Lagrangian frame is more natural. Typical examples where a Lagrangian description is useful are mass flows during flux emergence, mass loading of chromospheric fibrils, mass and energy cycling between the chromosphere and the corona, and flow acceleration during reconnection.
I will present a method to analyse simulations in the Lagrangian frame based on tracer particles. It allows tracking the history and future of the postion, velocity, all forces, and all energy losses and gains of any gas parcel starting at any given time and any location in the simulation. In addition I will present results using this method on the mass loading of the chromosphere and the mass cycling between the chromosphere and the corona.

Tracing the evolution of radiation-MHD simulations of the solar atmosphere in the Lagrangian frame

Jorrit Leenaarts

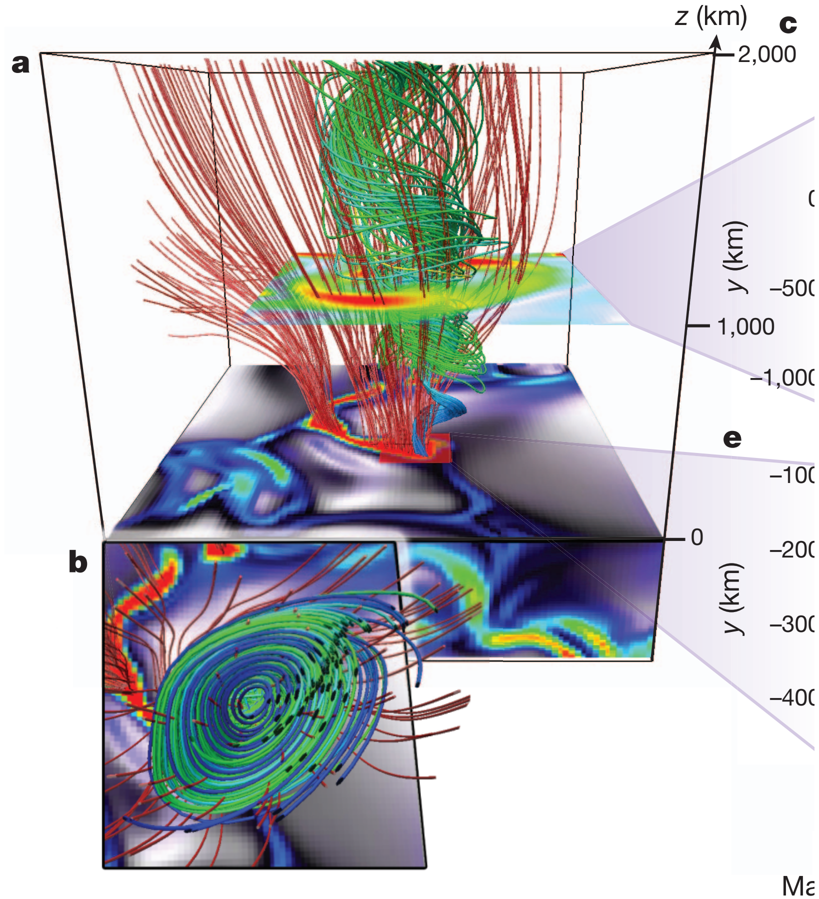
Stockholm University

Why Lagrangian frame?

- evolution of a given fluid parcel instead of the evolution at a given location in the simulation, e.g.:
  - mass flows during magnetic flux emergence,
  - mass loading of chromospheric fibrils,
  - mass and energy cycling between the chromosphere and the corona,
  - flow acceleration and heating during reconnection.

Why Lagrangian frame?

- avoid confusion streamlines vs. pathlines, e.g., waves or tornadoes?



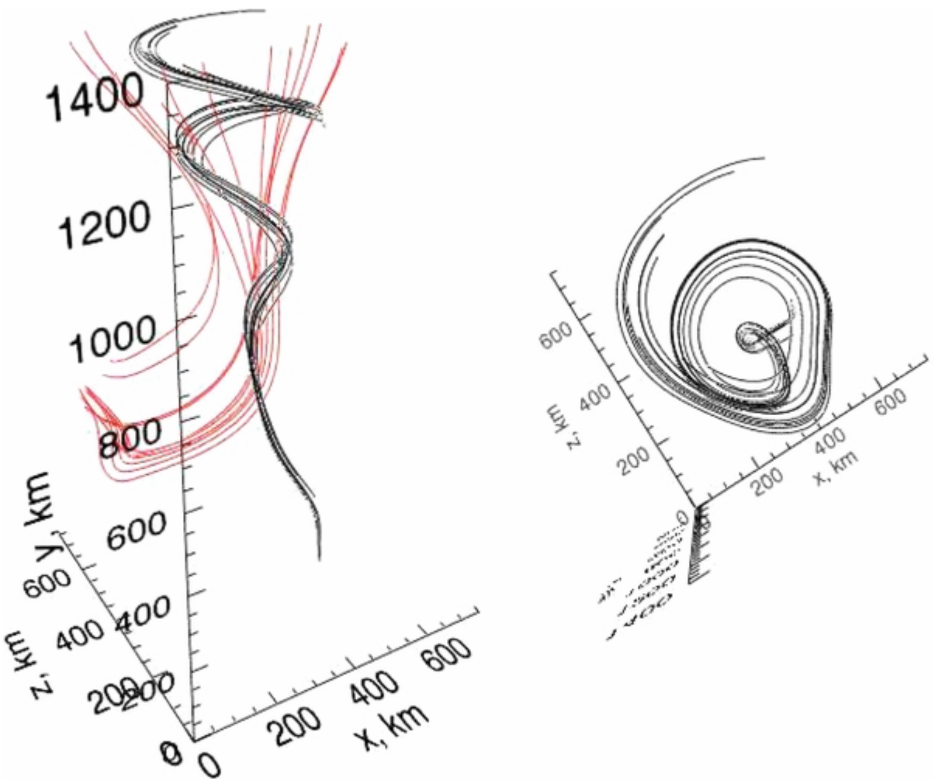
Wedemeyer et al., 2012

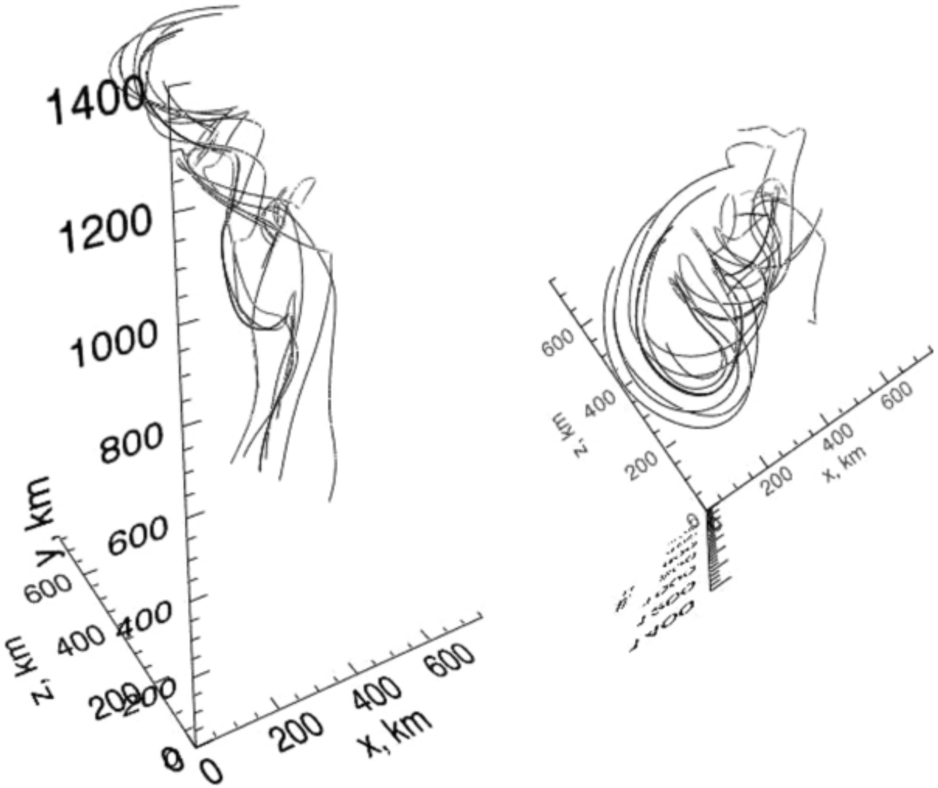
Why Lagrangian frame?

- avoid confusion streamlines vs. pathlines, e.g., waves or tornadoes?

streamline: $$\frac{\partial \vec{r}}{\partial s} = \frac{\vec{u}}{||\vec{u}||}$$

pathline: $$\frac{\partial \vec{r}}{\partial t} = \vec{u}(\vec{r}, t)$$





Shelyag et al., 2013

Why Lagrangian frame?

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho \boldsymbol{\nabla} \cdot \boldsymbol{u}$$

density change

$$\frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} = -\frac{\boldsymbol{\nabla} P}{\rho} - \frac{\boldsymbol{\nabla} \cdot \tau}{\rho} + \frac{\boldsymbol{J} \times \boldsymbol{B}}{\rho} + \boldsymbol{g}$$

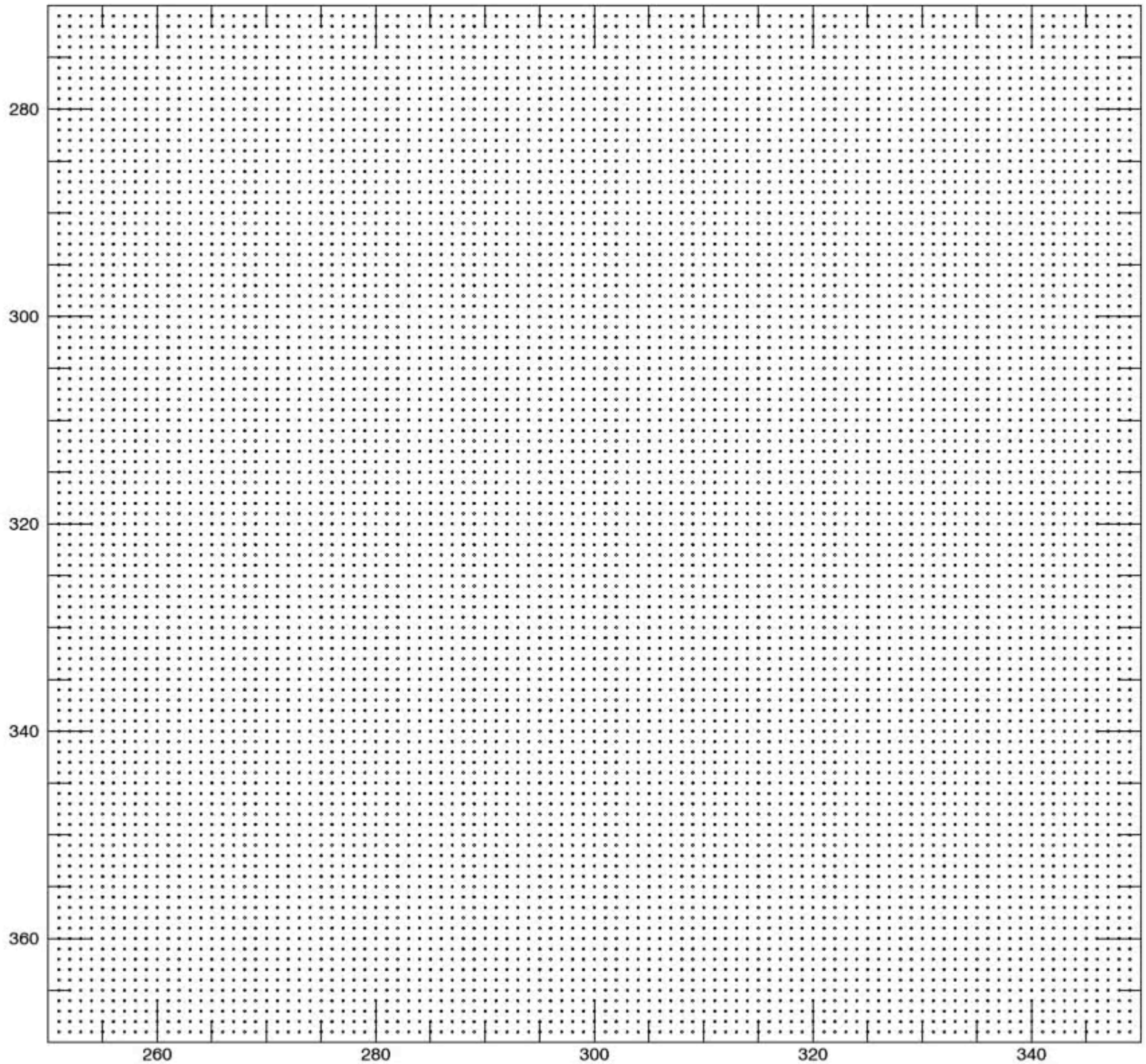
forces acting on parcel

$$\frac{\mathrm{d}E}{\mathrm{d}t} = -\frac{P}{\rho} \boldsymbol{\nabla} \cdot \boldsymbol{u} + \frac{Q}{\rho}$$

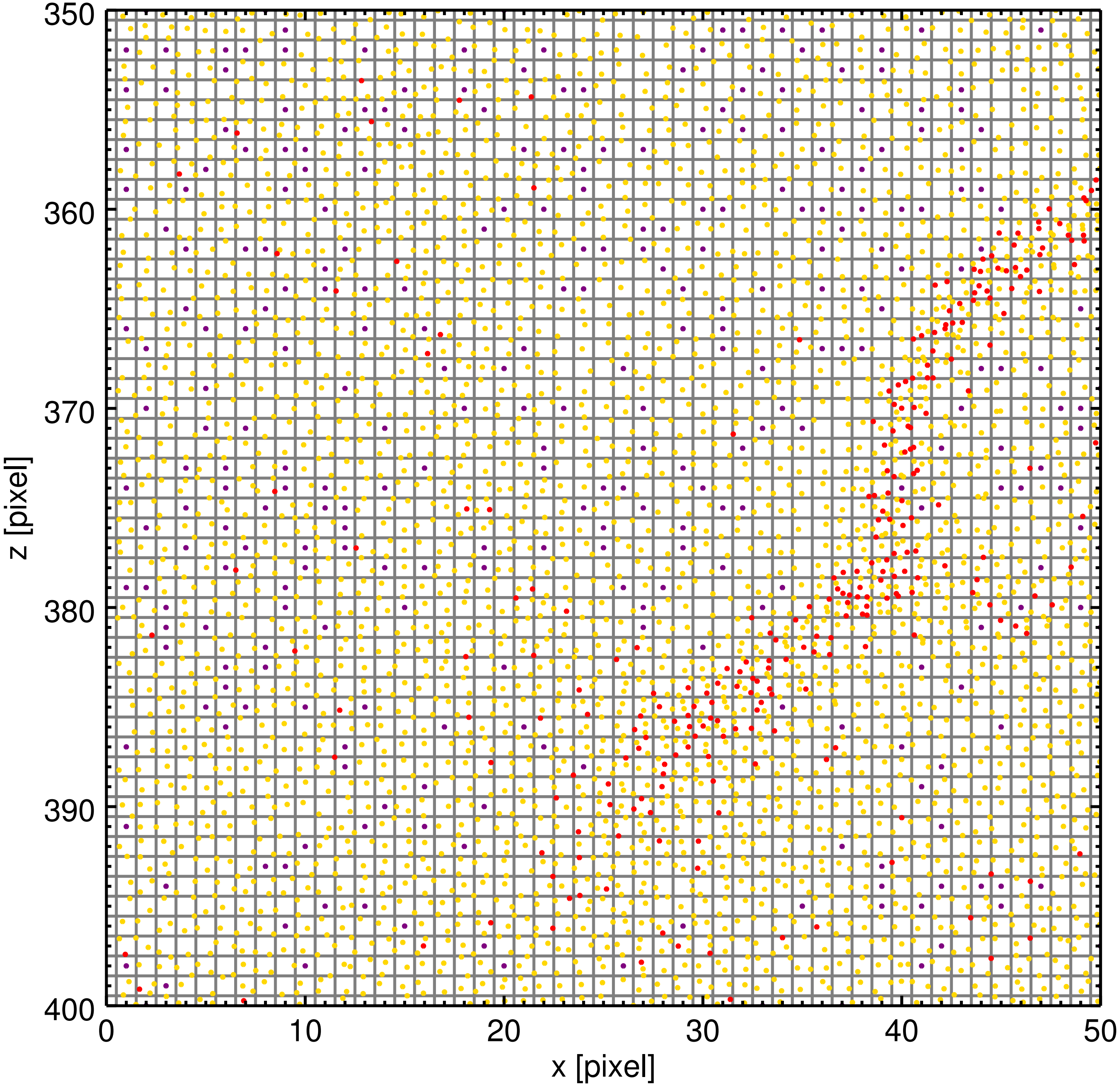
heating of parcel

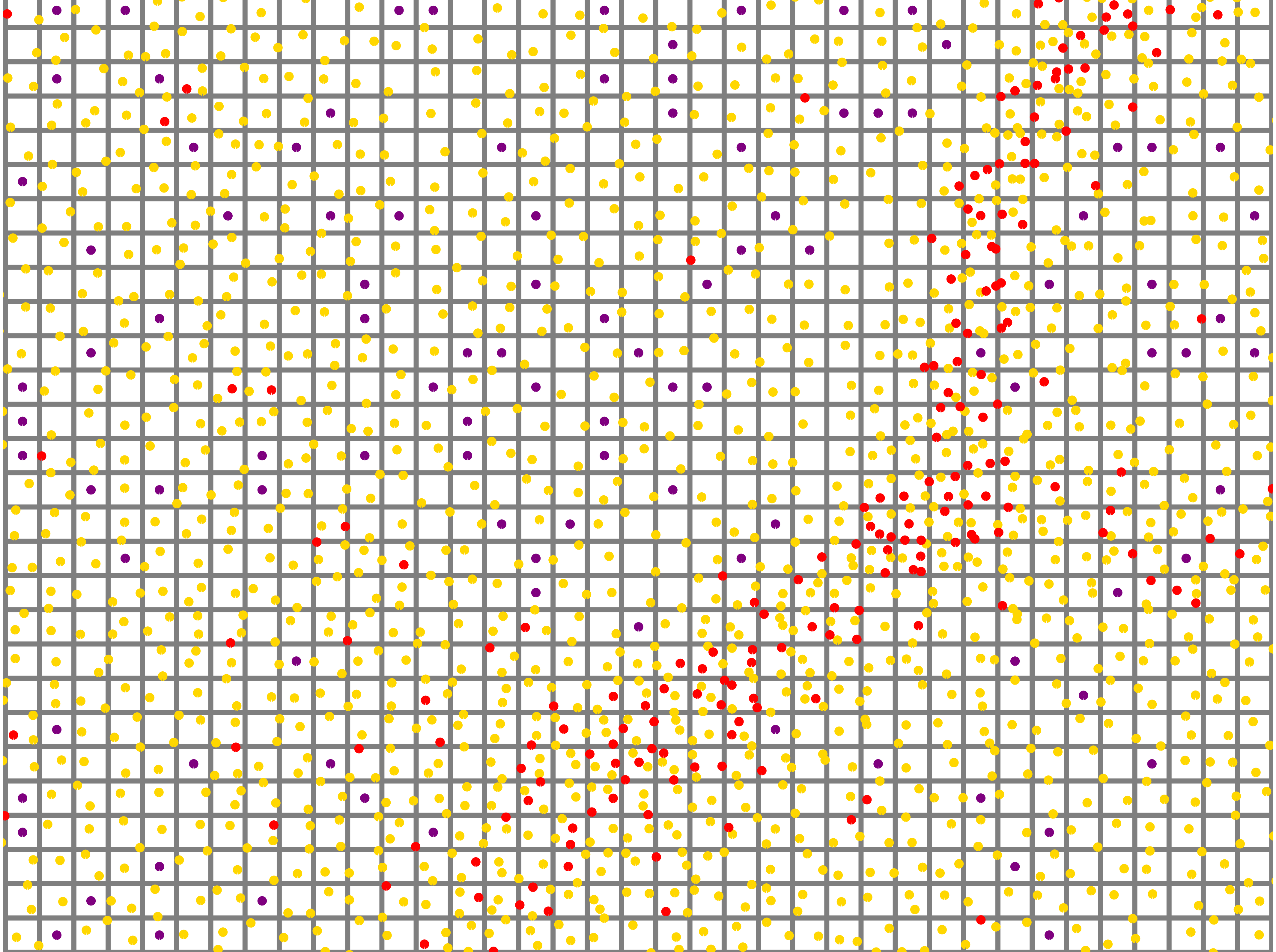
Implementation: tracer particles

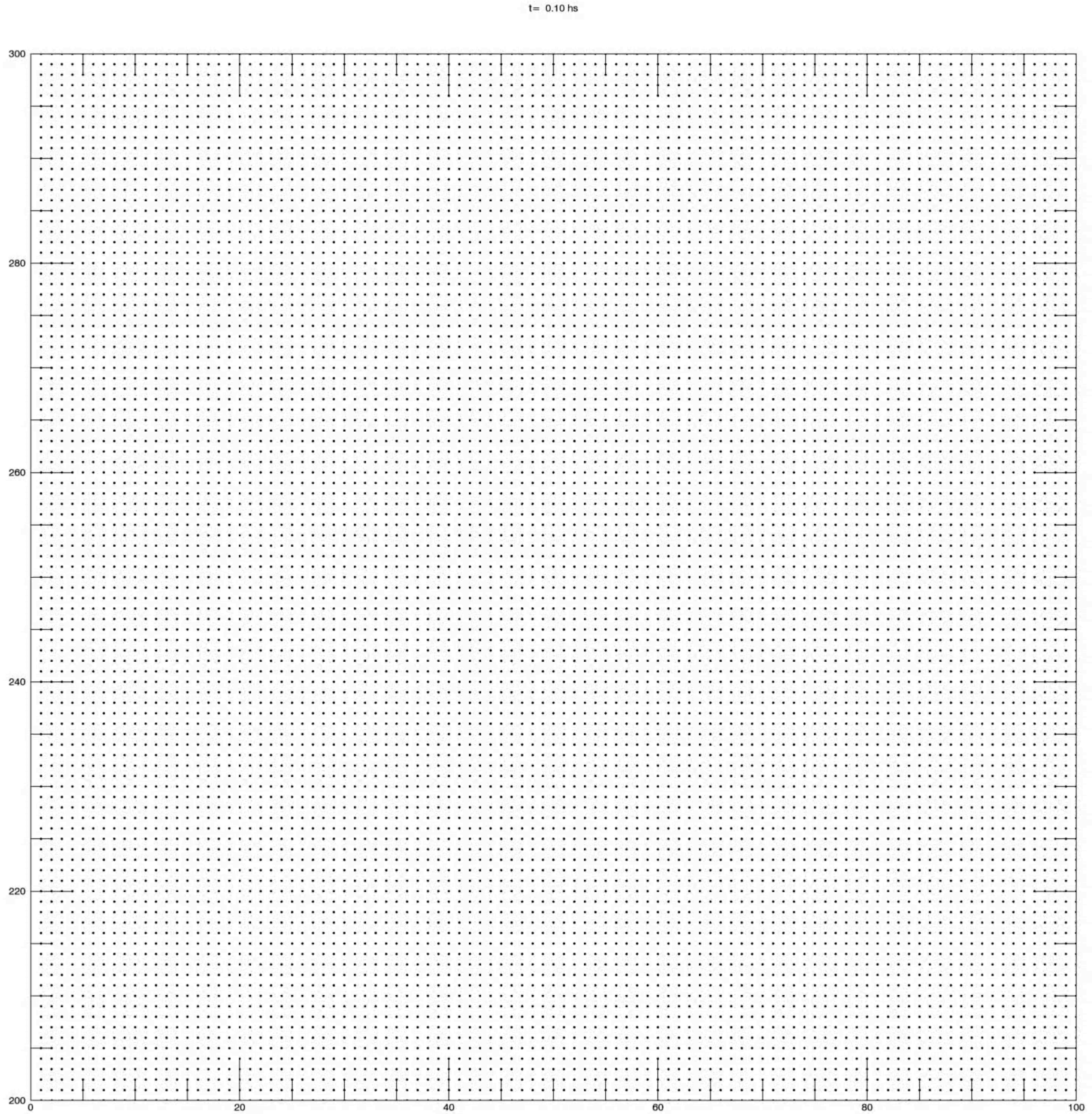
- follow path lines $\frac{\partial \boldsymbol{r}_i(t)}{\partial t} = \boldsymbol{u}(\boldsymbol{r}_i, t),$
- Inject once
- Evolve simulation
- Problem:
  - simulation is strongly compressive: voids and overdense regions


280
300
320
340
360
260
280
300
320
340

Solution: cork injection and removal

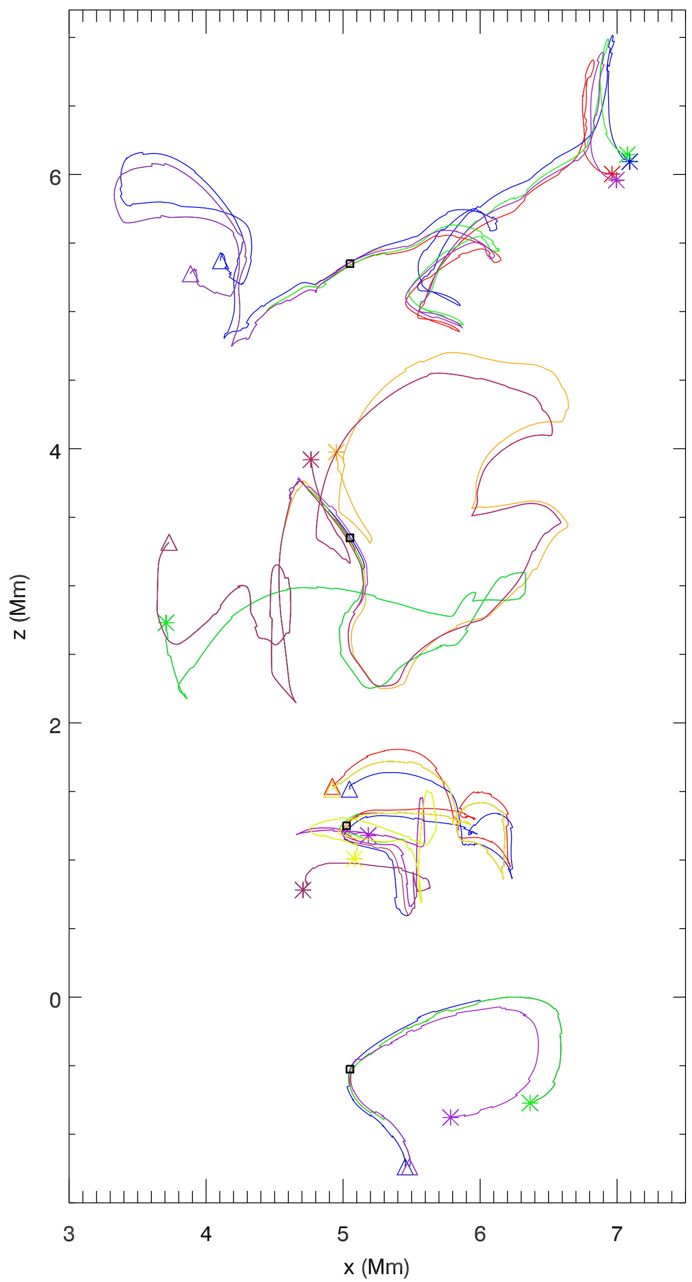




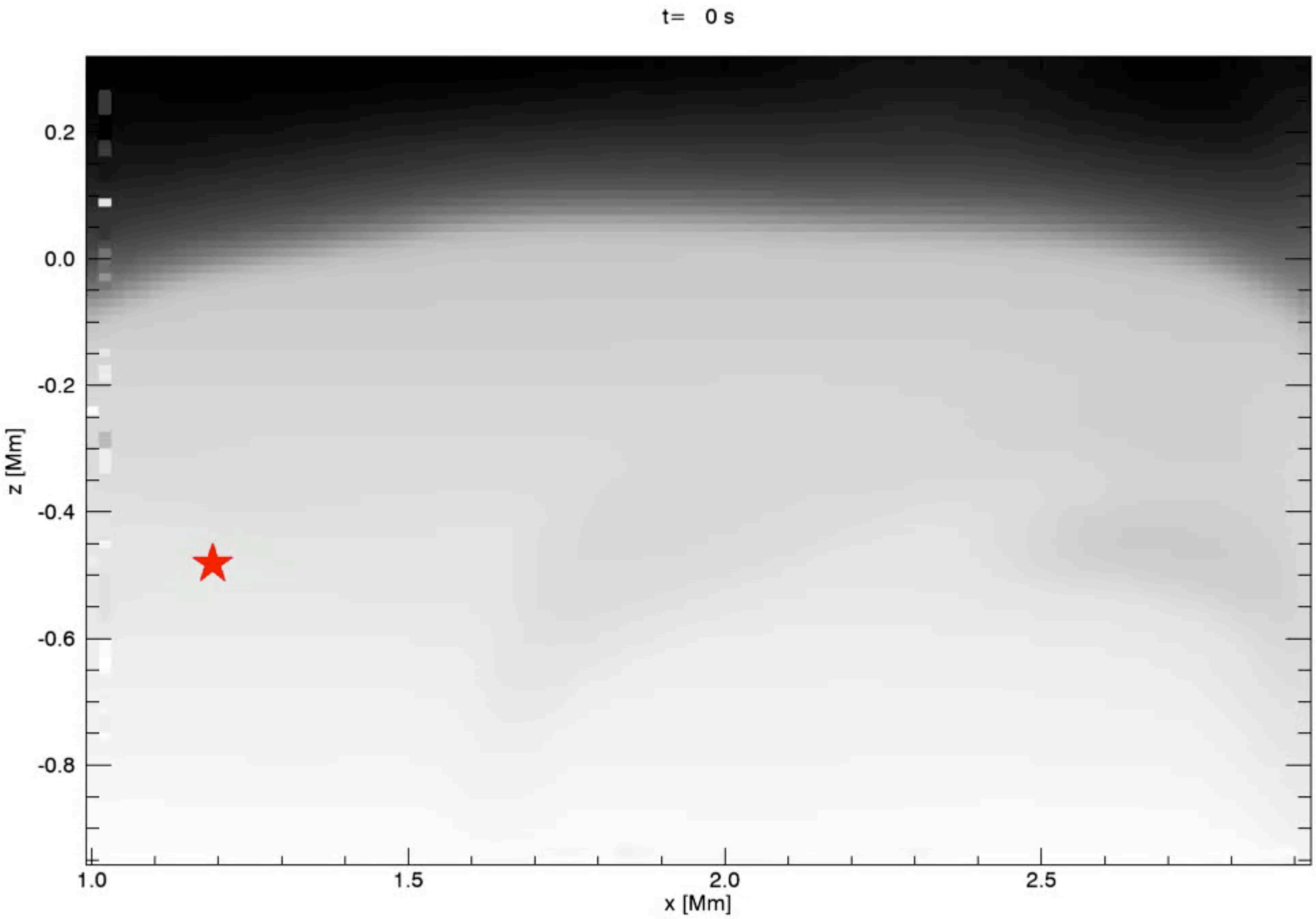


t= 0.10 hs
300
280
260
240
220
200
0
20
40
60
80
100

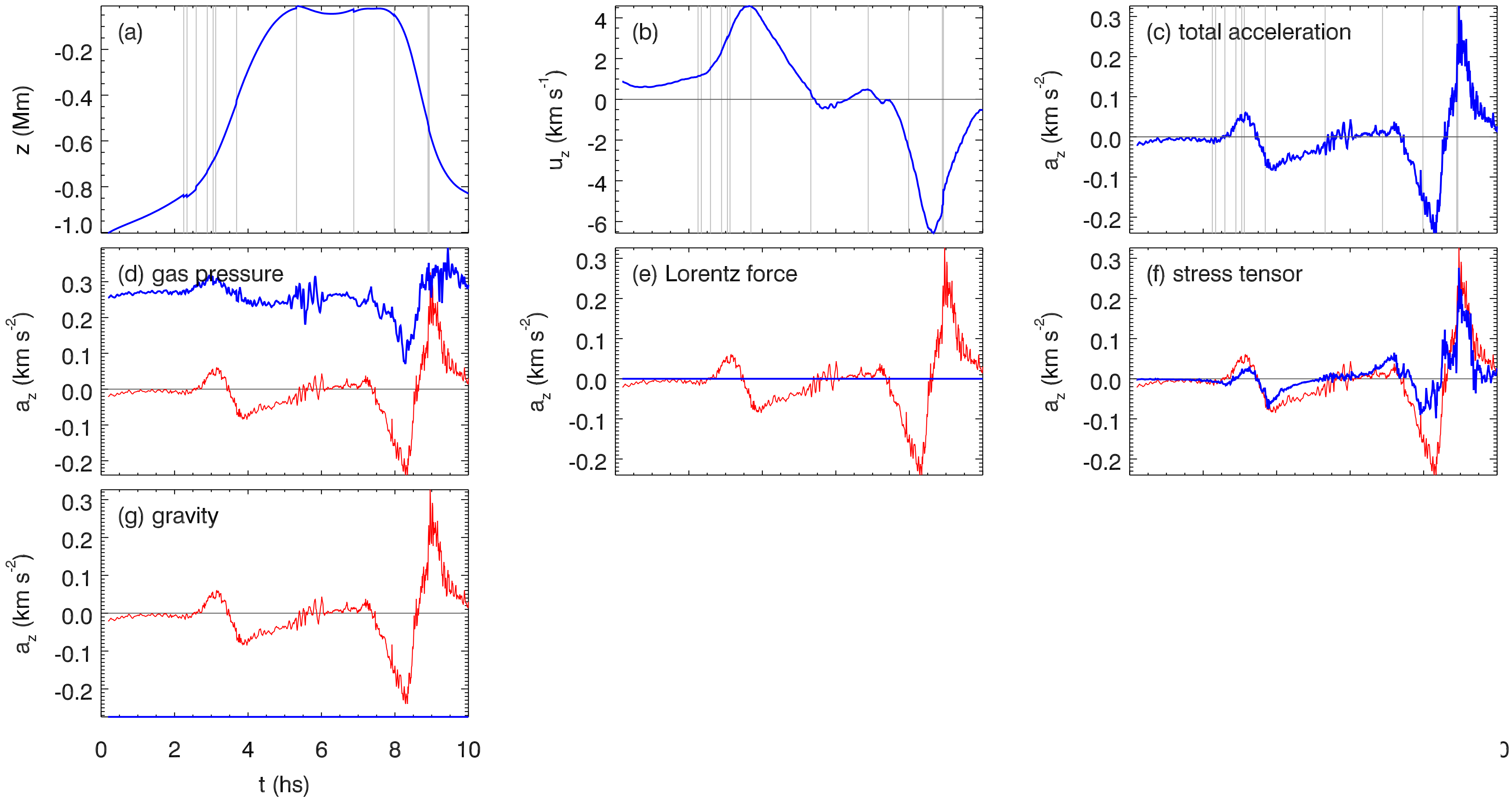
- corks follow path lines
- jump to next nearest cork in case of removal/injection
- limits accuracy
- still voids, but often small



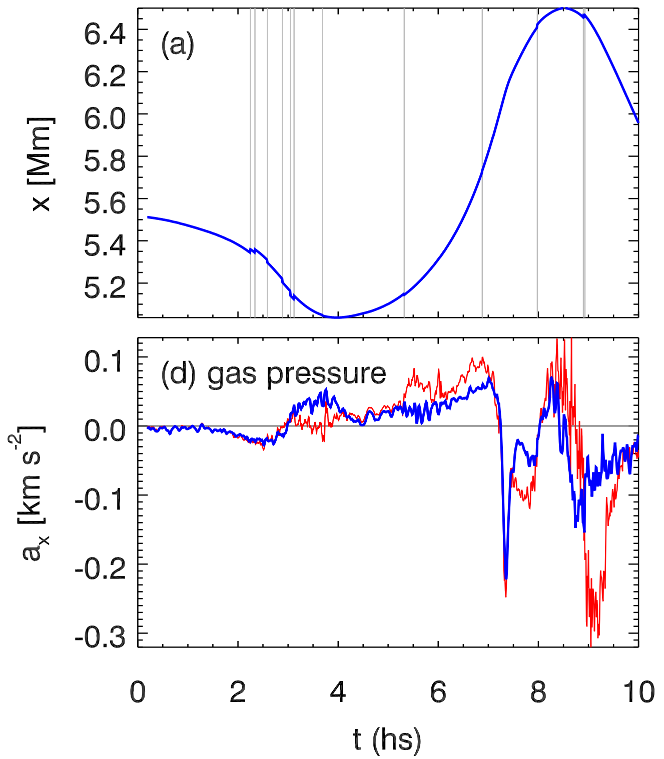
Example: overturning convection



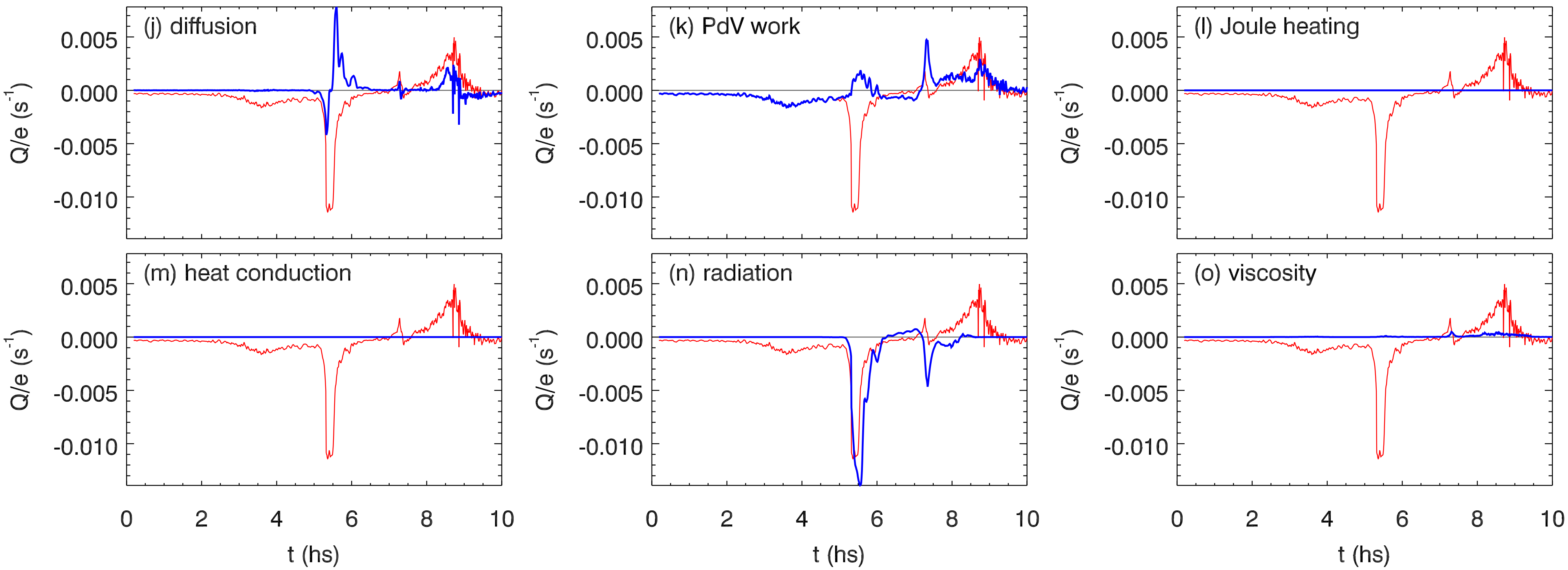
Example: overturning convection



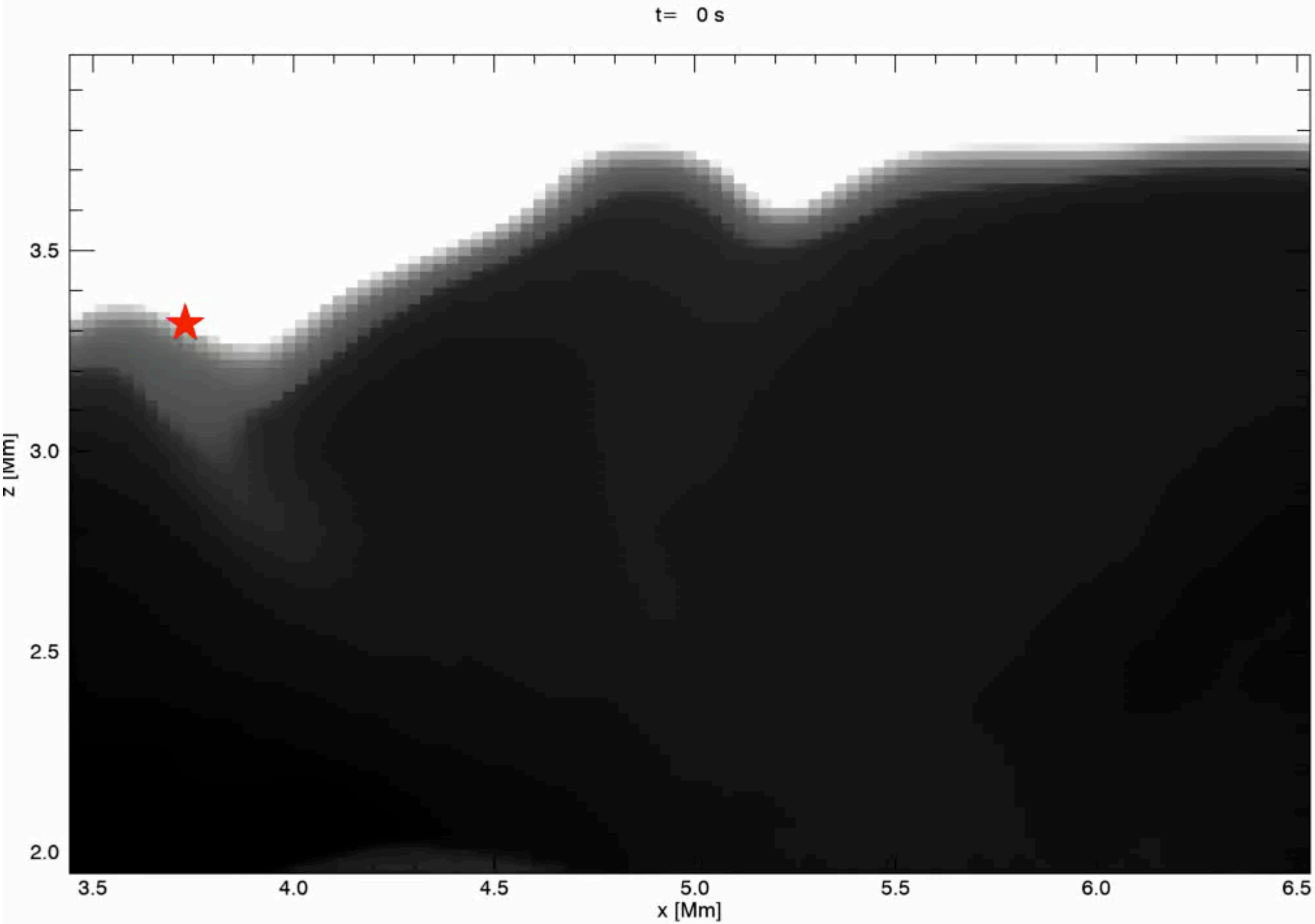
Example: overturning convection



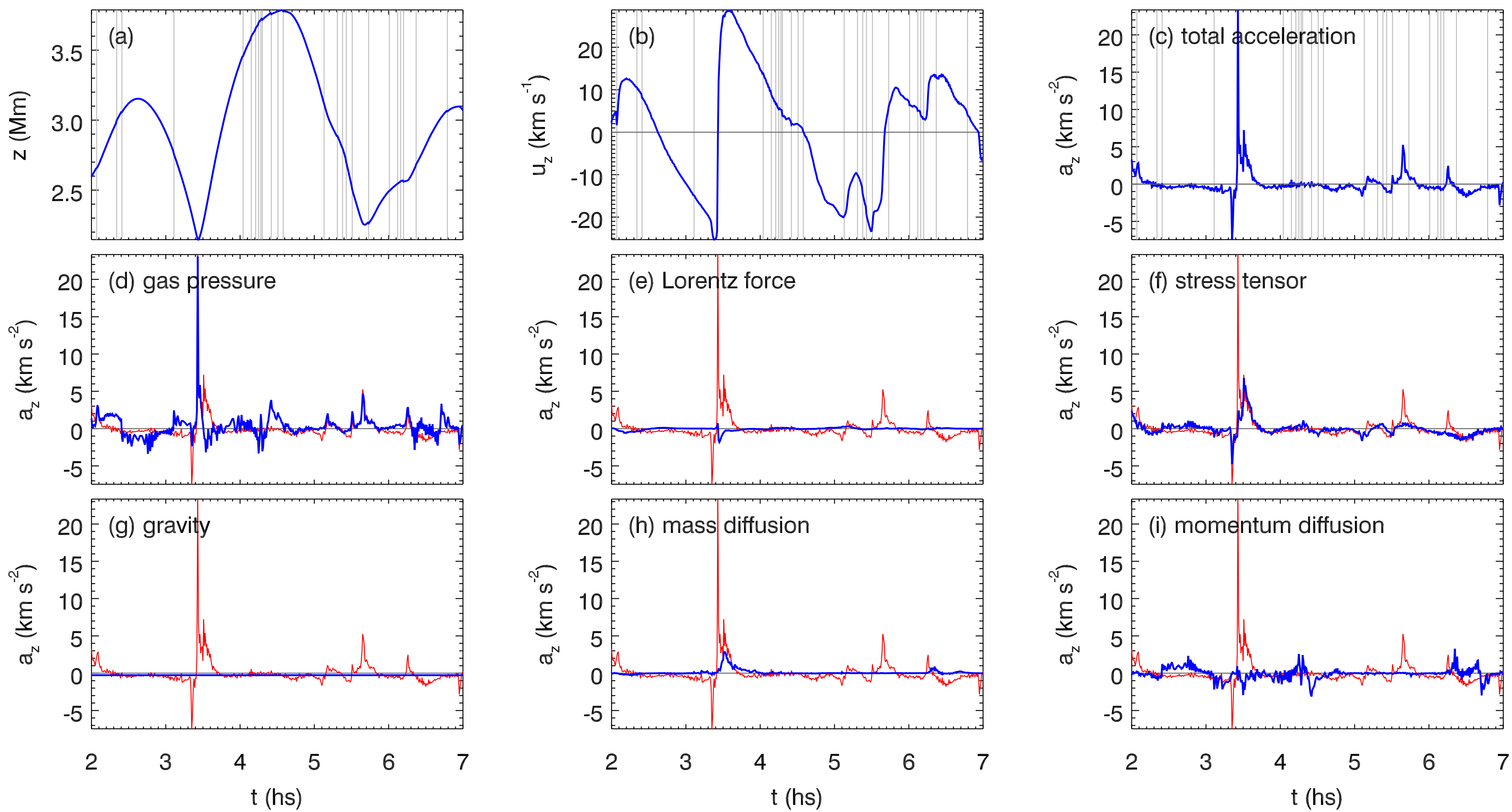
Example: overturning convection



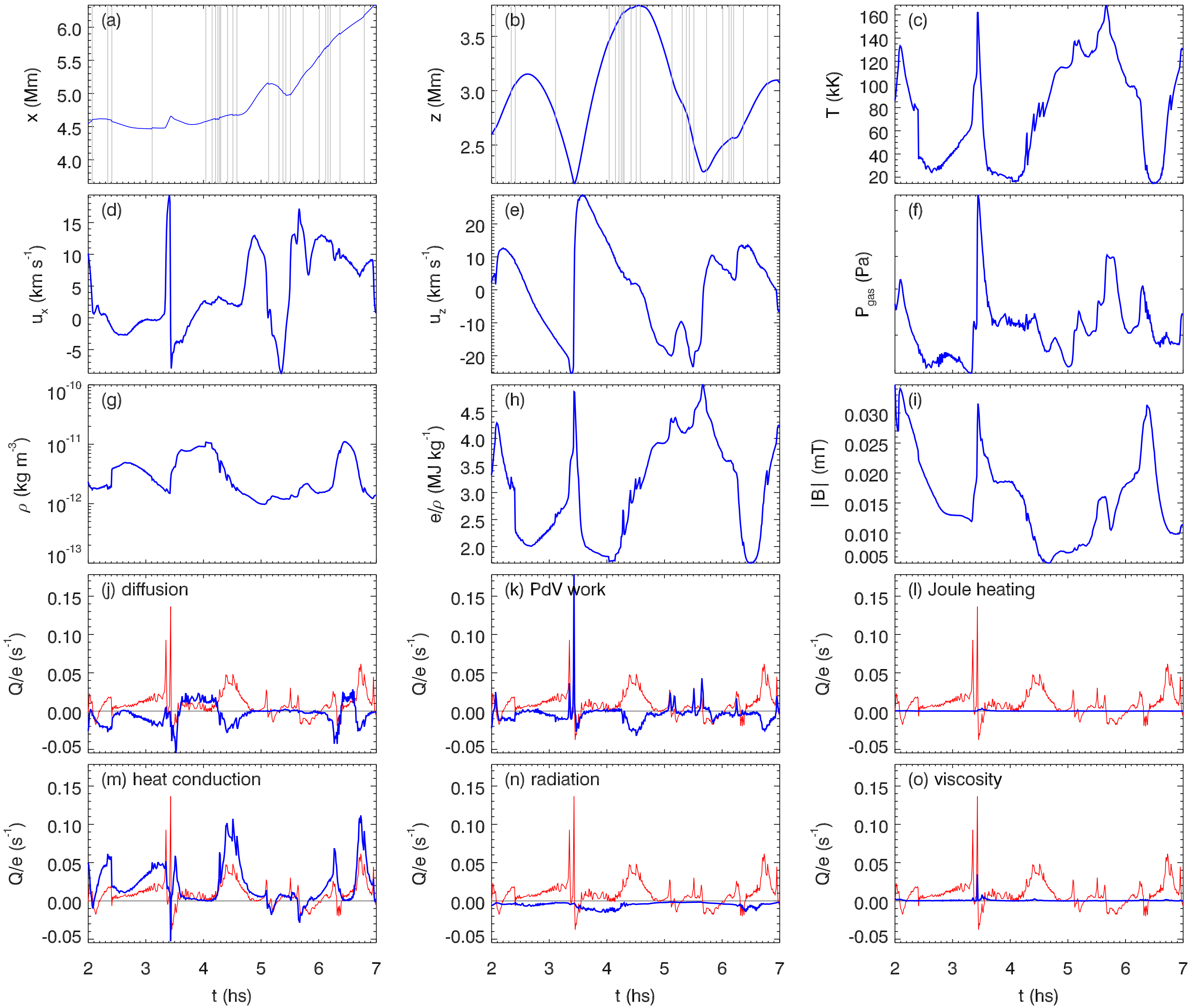
Example: TR shock waves



Example: TR shock waves



Example: TR shock waves



Conclusions

- tracer particles with continuous injection and removal allow tracing all flows startling rom any place and any time in a simulation
- applications:
  - mass loading of fibrils
  - mass flows in flux emergence
  - chromospheric evaporation
  - reconnection