

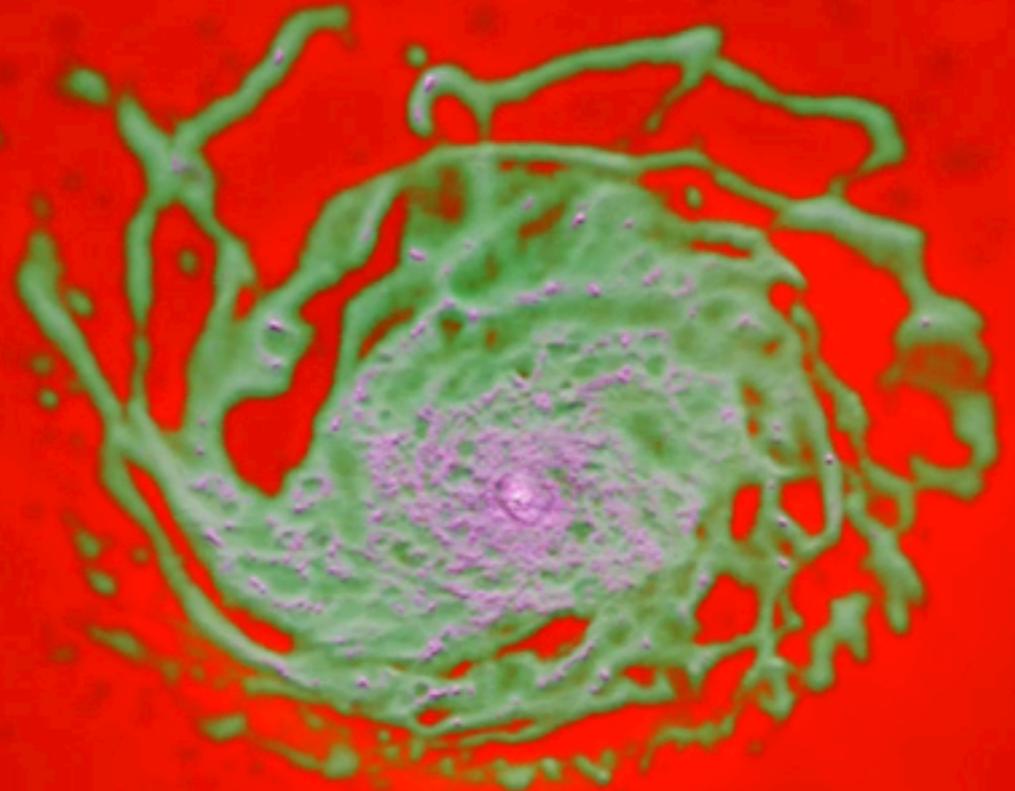
GIZMO:

New Methods and The Status of SPH

$z=0.21$



$z=0.21$



Phil Hopkins (Caltech)

www.tapir.caltech.edu/~phopkins



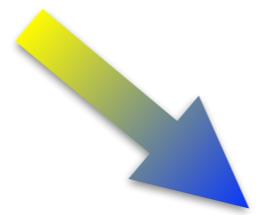
Tree-SPH

Gadget



AREPO

Gadget-3



P-SPH



GIZMO



The Evolution of Code....

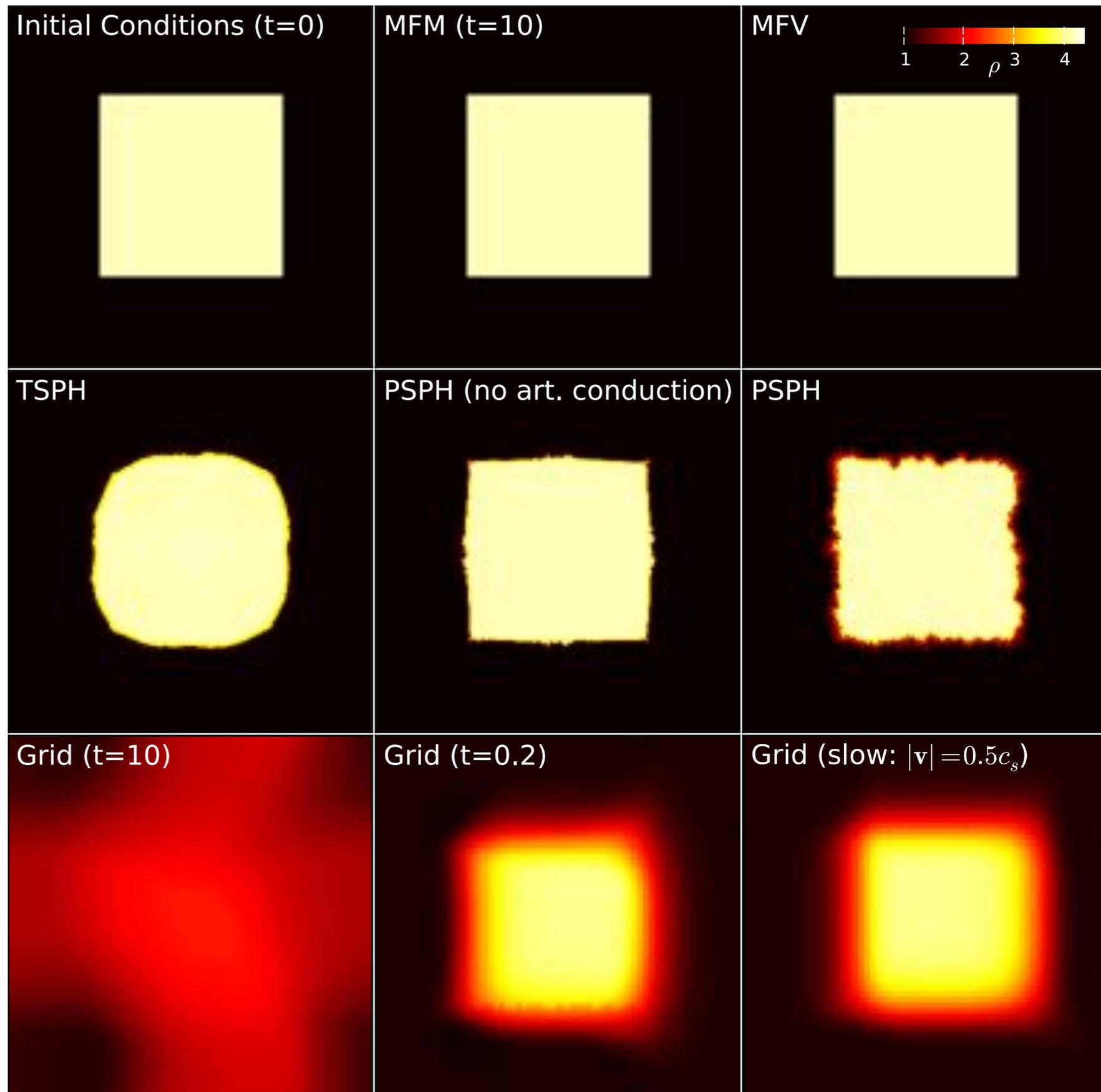
GIZMO:

(to appear very soon)

➤ You choose:

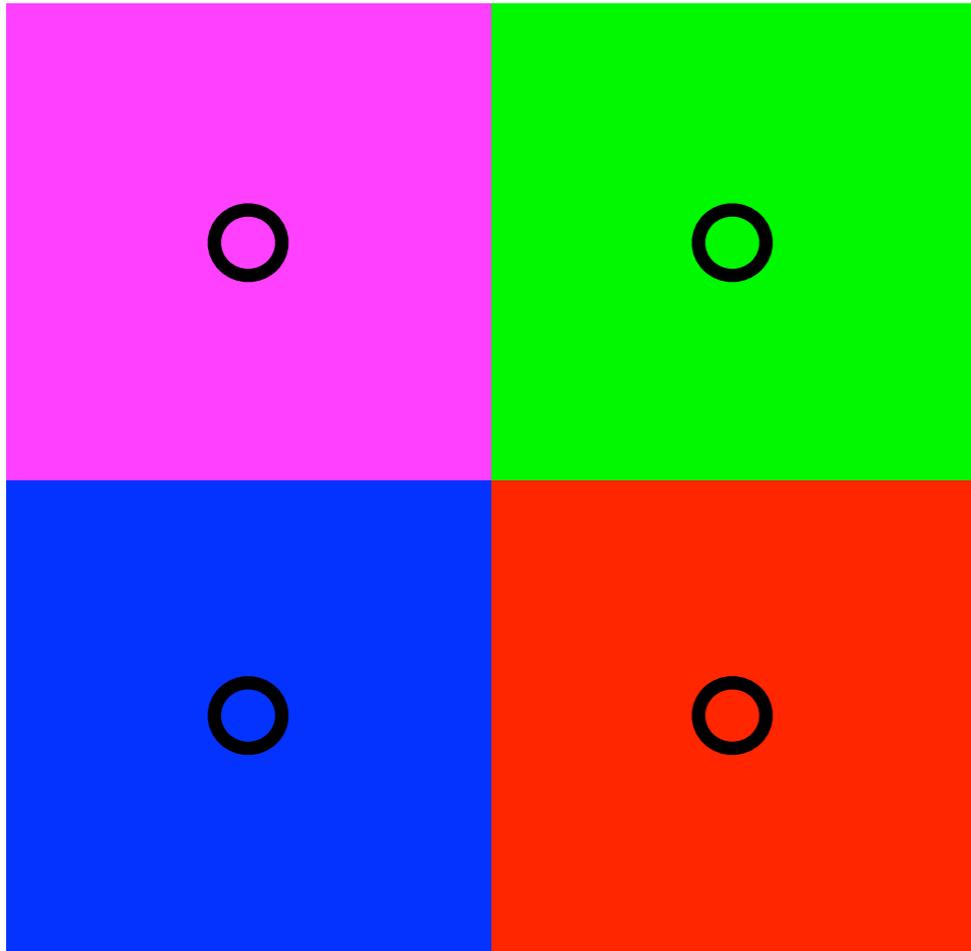
- ‘Traditional’ SPH
- ‘Modern’ P-SPH
- “Meshless Finite Volume”
- “Meshless Finite Mass”

- **100% compatible**
with GADGET ICs/snaps

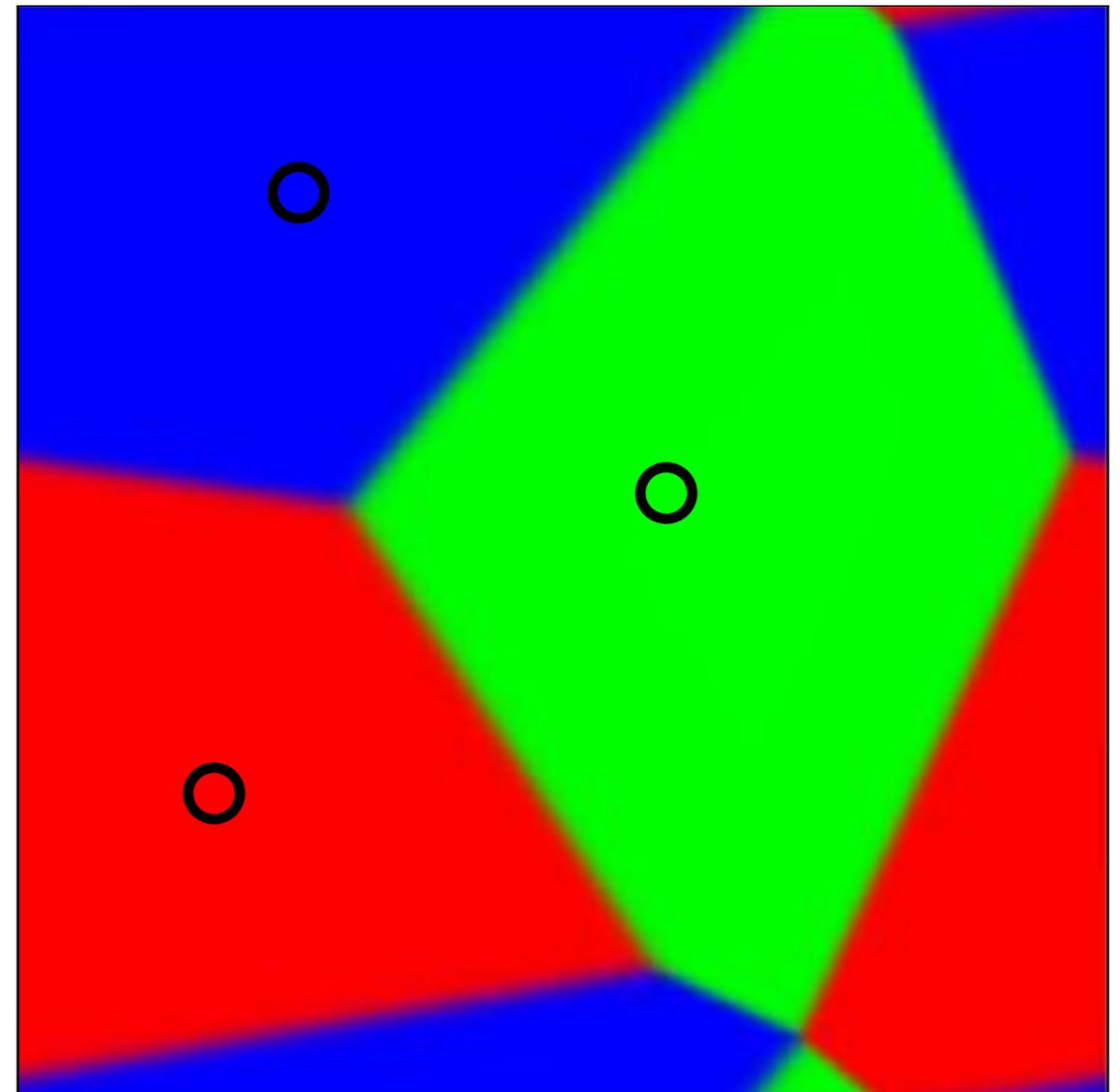


Mesh-Based Methods:

“Standard” (regular, non-moving) Grids



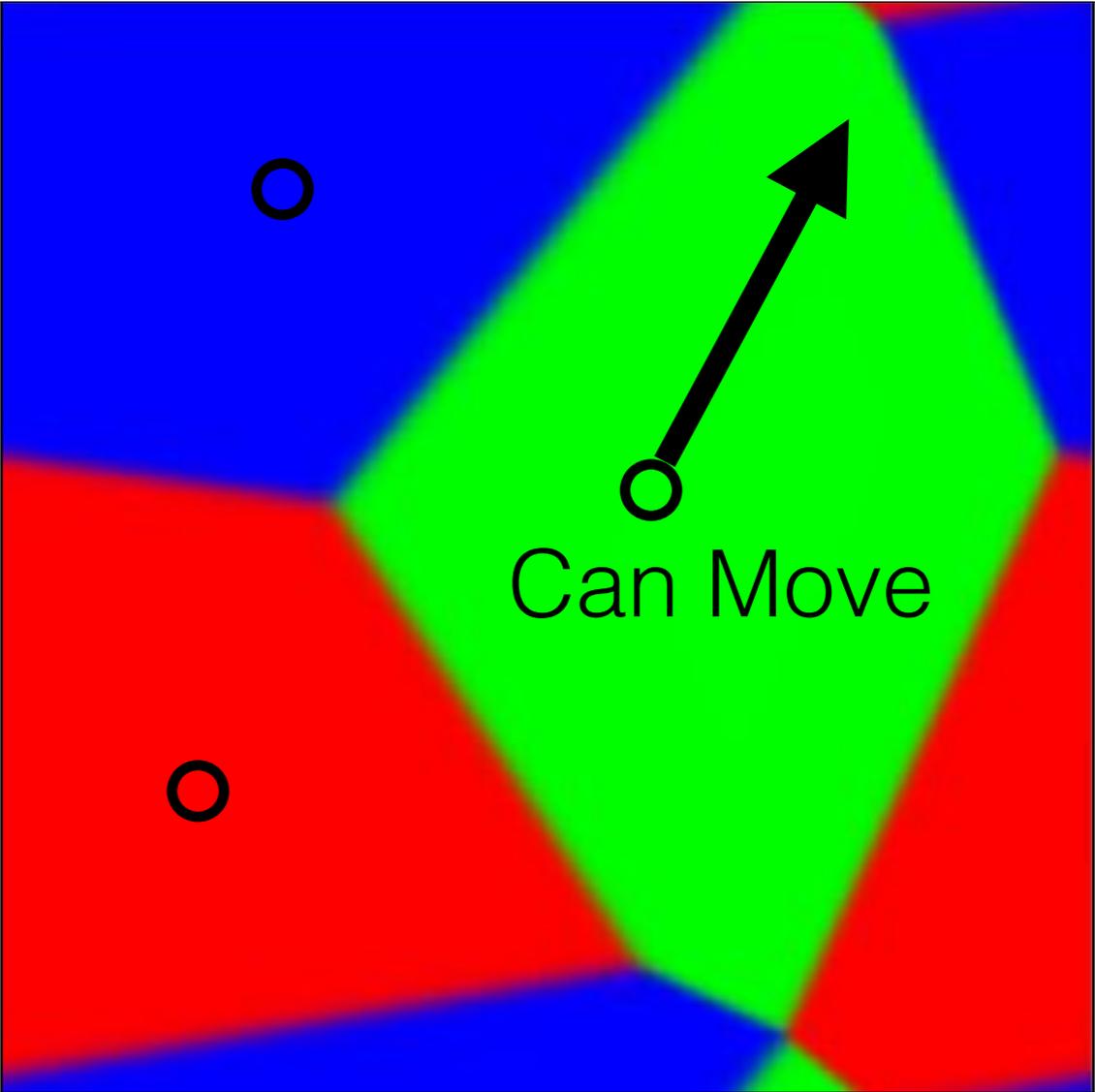
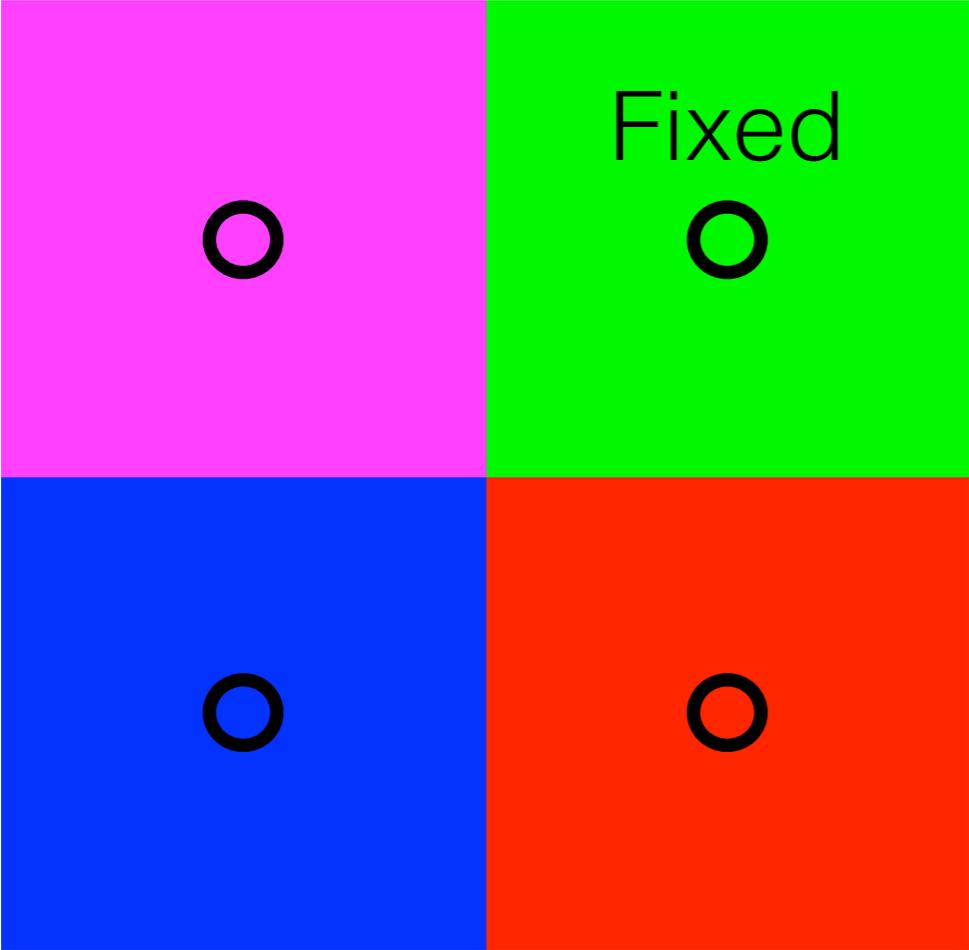
Each cell carries conserved quantities (mass m_i , etc) inside volume V_i



Unstructured / Moving–Mesh Methods

Mesh-Based Methods:

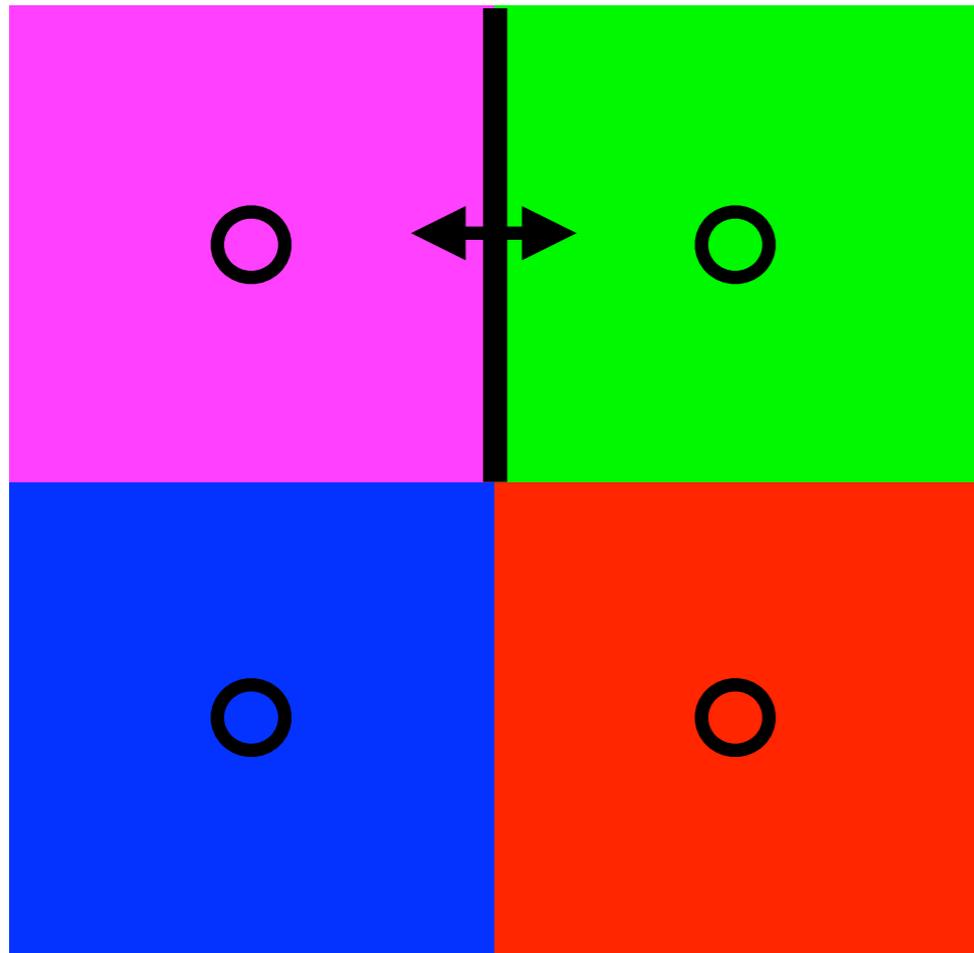
“Standard” (regular, non-moving) Grids



Unstructured / Moving-Mesh Methods

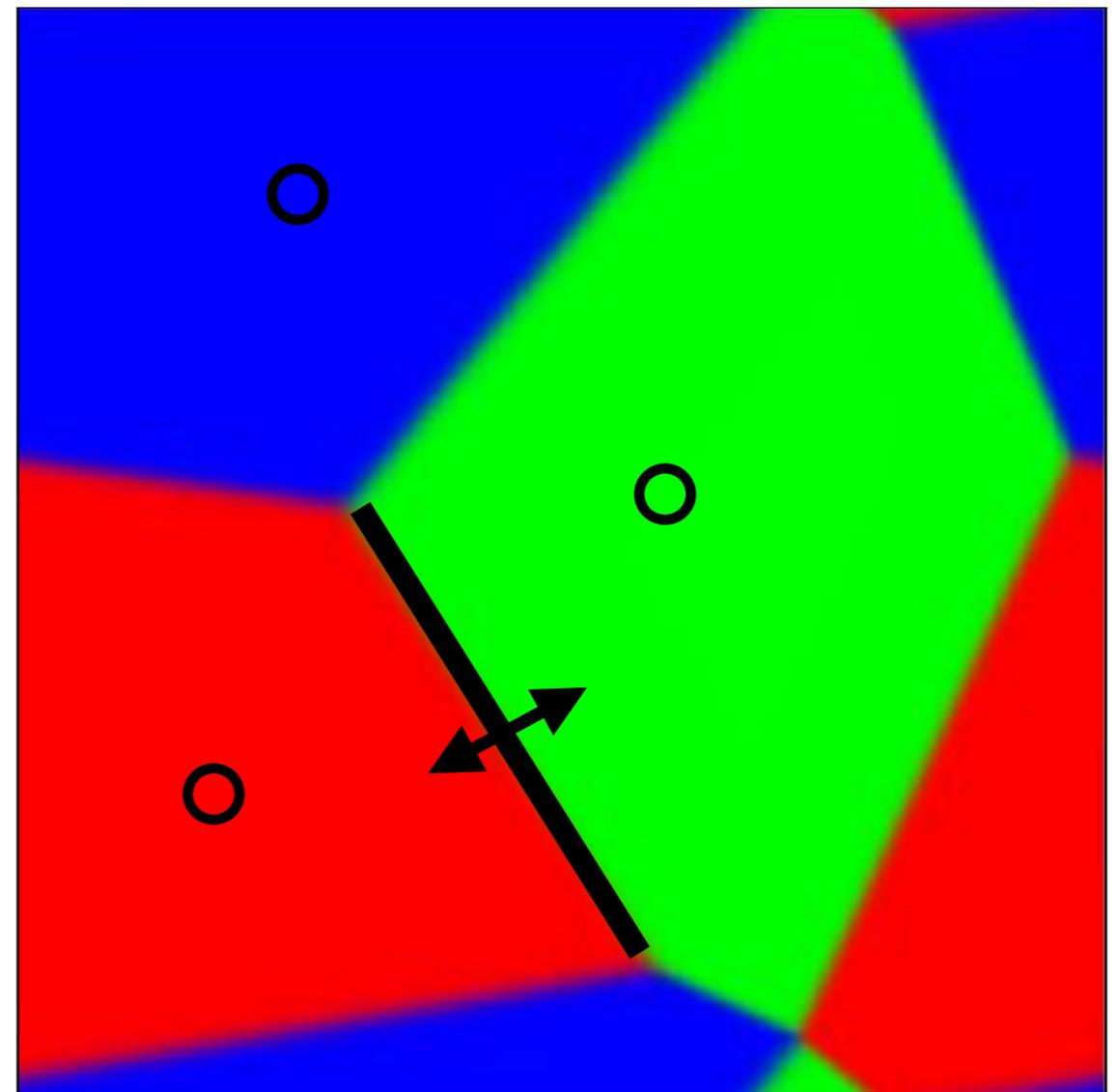
Mesh-Based Methods:

“Standard” (regular, non-moving) Grids



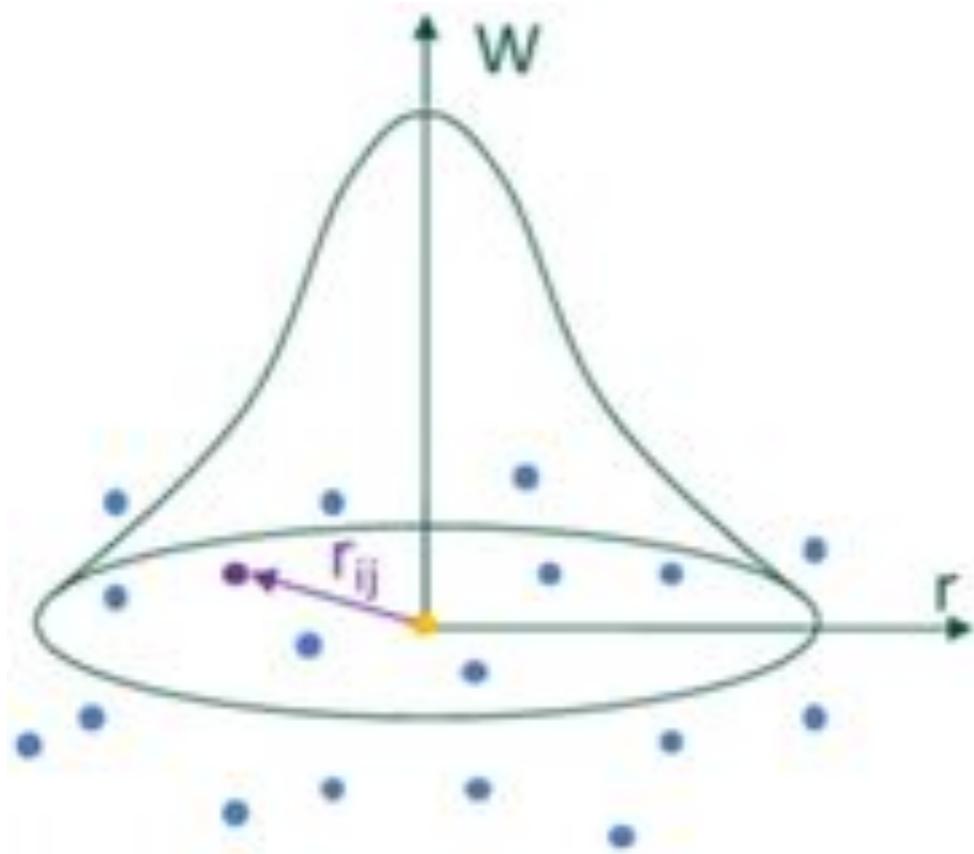
Solve Riemann problem
between cells

$$\Delta m_i = \int_{\text{cell}} \frac{\partial \rho}{\partial t} d^3 \mathbf{x} = - \int_{\text{cell}} \nabla \cdot (\rho \mathbf{v}) d^3 \mathbf{x}$$

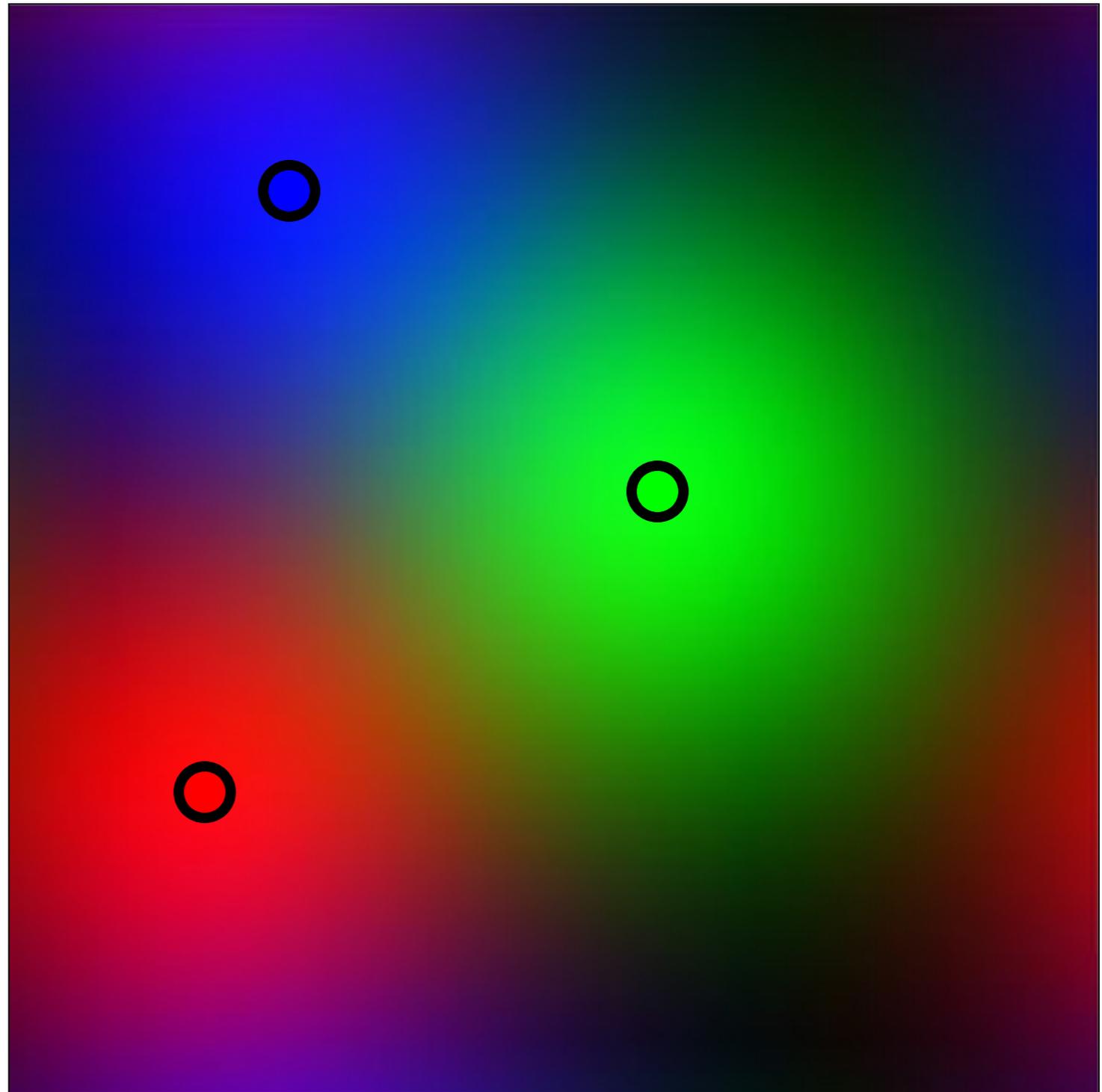


Unstructured / Moving-Mesh Methods

SPH Methods:

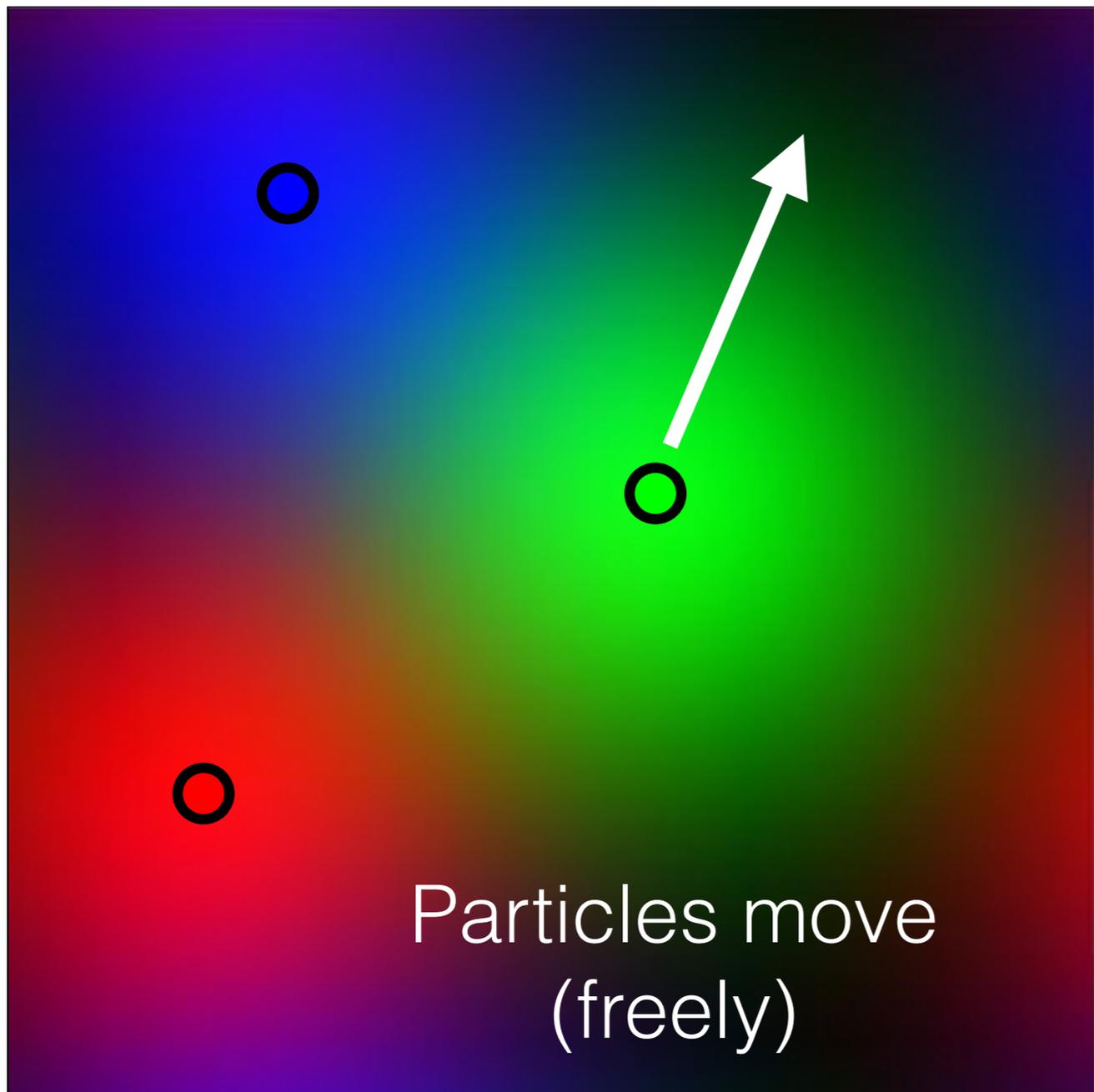


No real “volume partition”:
discrete particle quantities
(m_i , etc) are “smoothed”



Smoothed-Particle Hydrodynamics

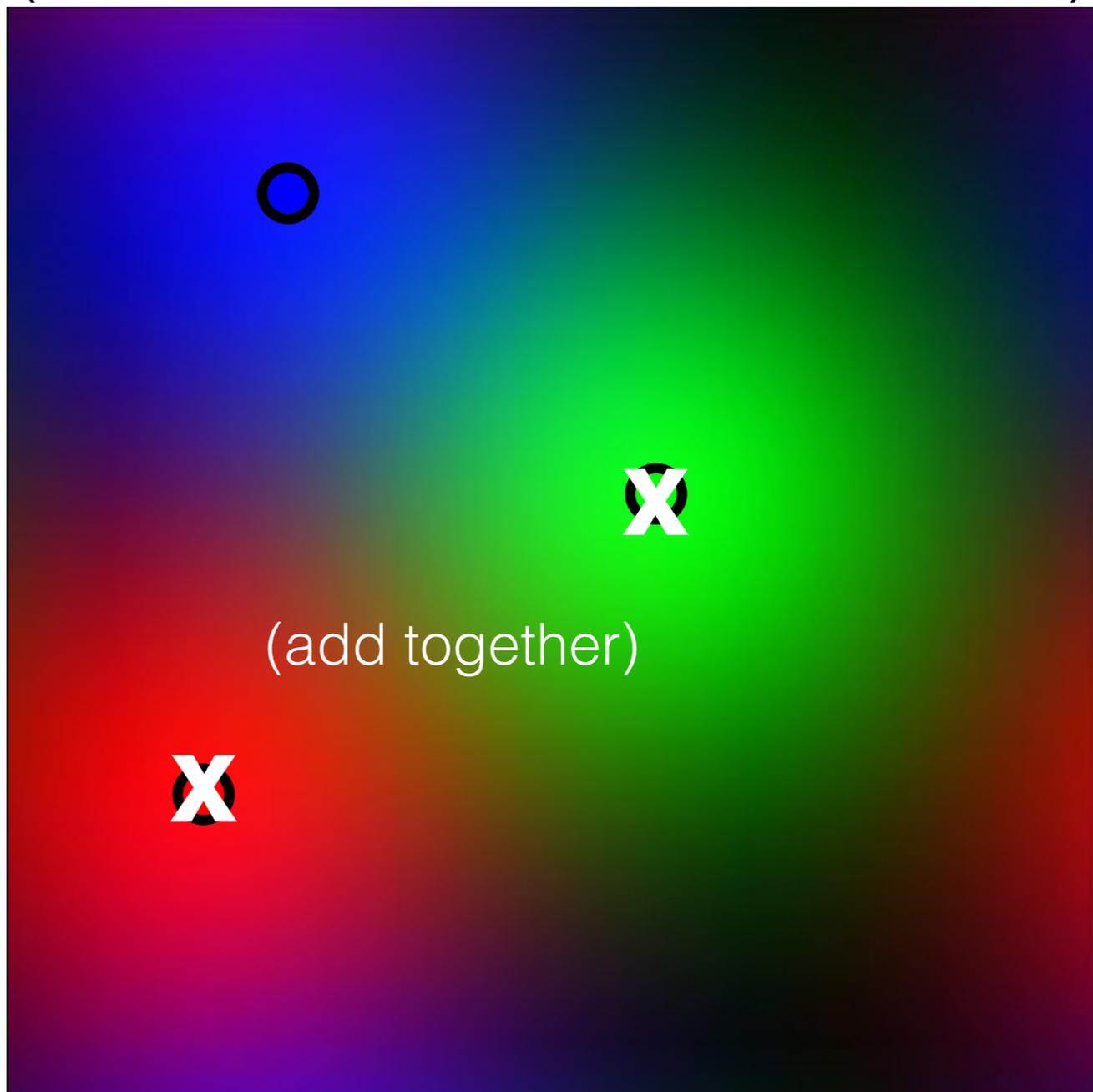
SPH Methods:



Smoothed-Particle Hydrodynamics

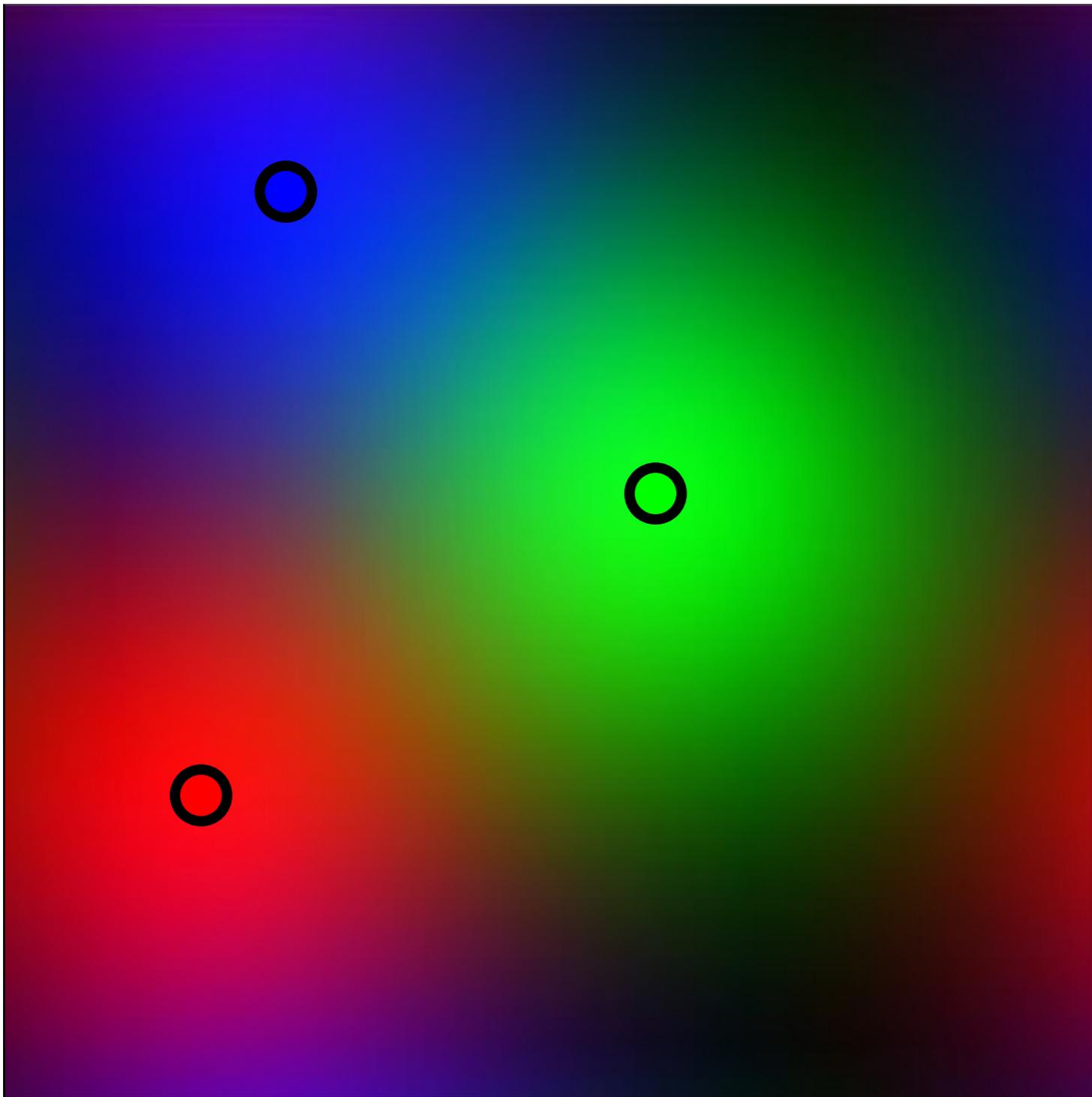
$$\frac{\partial \mathbf{v}_i}{\partial t} = \frac{\nabla P}{\rho} \Big|_{\mathbf{x}_i}$$

Solve EOM
at particle locations
(stabilize with artificial diffusion)



Smoothed-Particle Hydrodynamics

SPH Methods:



Smoothed-Particle Hydrodynamics

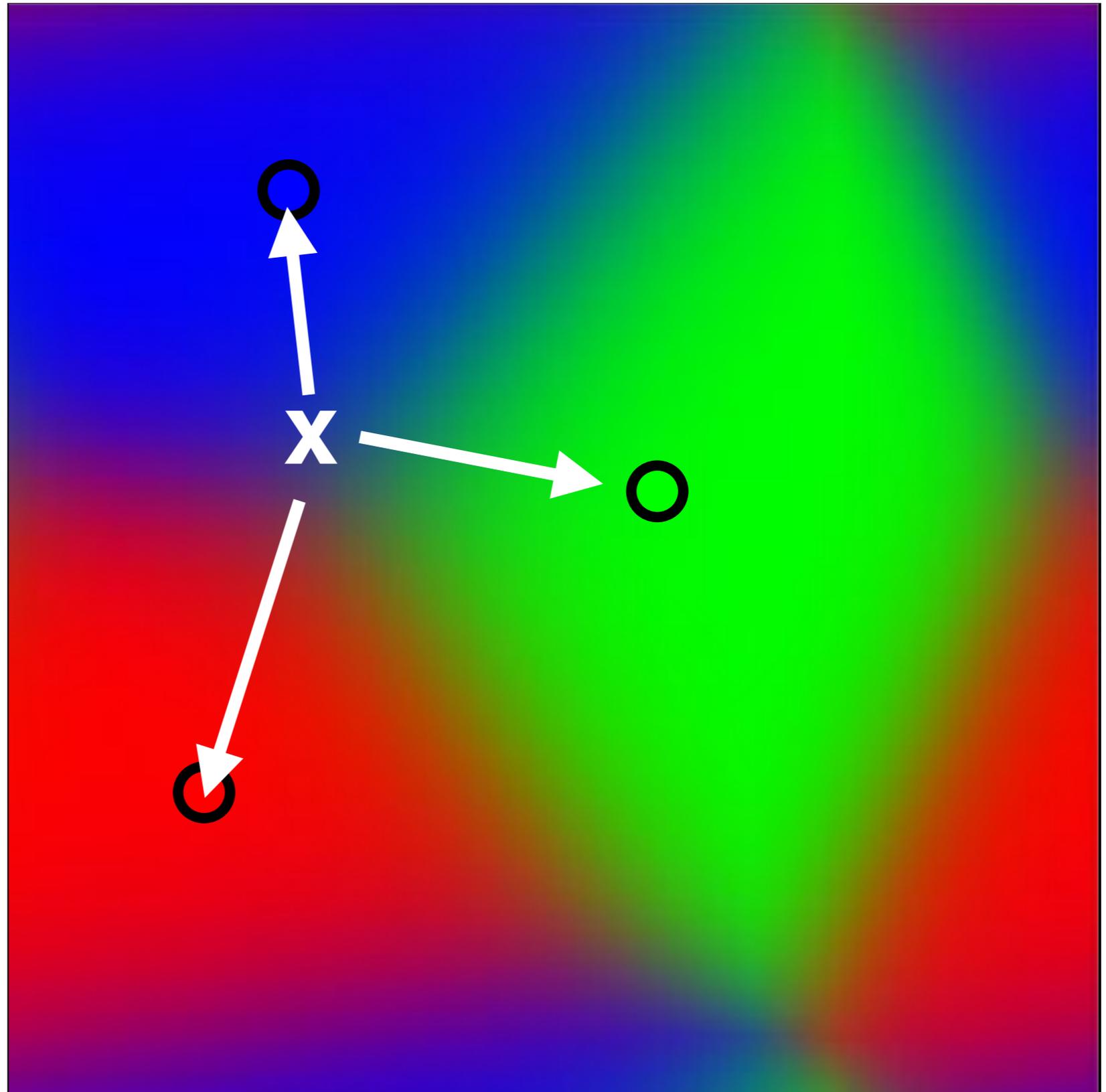
- **“Traditional SPH”**
 - GADGET/GASOLINE
 - ~32 neighbors (cubic spline)
 - constant artificial viscosity
 - “density” formulation
- **“Modern SPH”**
 - P-SPH/SPHS/PHANTOM
 - ~128-500 neighbors (alt. kernels)
(many people: Read, Dehnen)
 - high-order switches
(Cullen+Dehnen)
 - “pressure” formulation
(Hopkins, Saitoh+Makino)
 - artificial diffusion for entropy
(Price, Wadsley)

New Meshless Methods:

- Lanson & Vila 2008
- Gaburov & Nitadori 2010
- PFH 2014 (soon!)

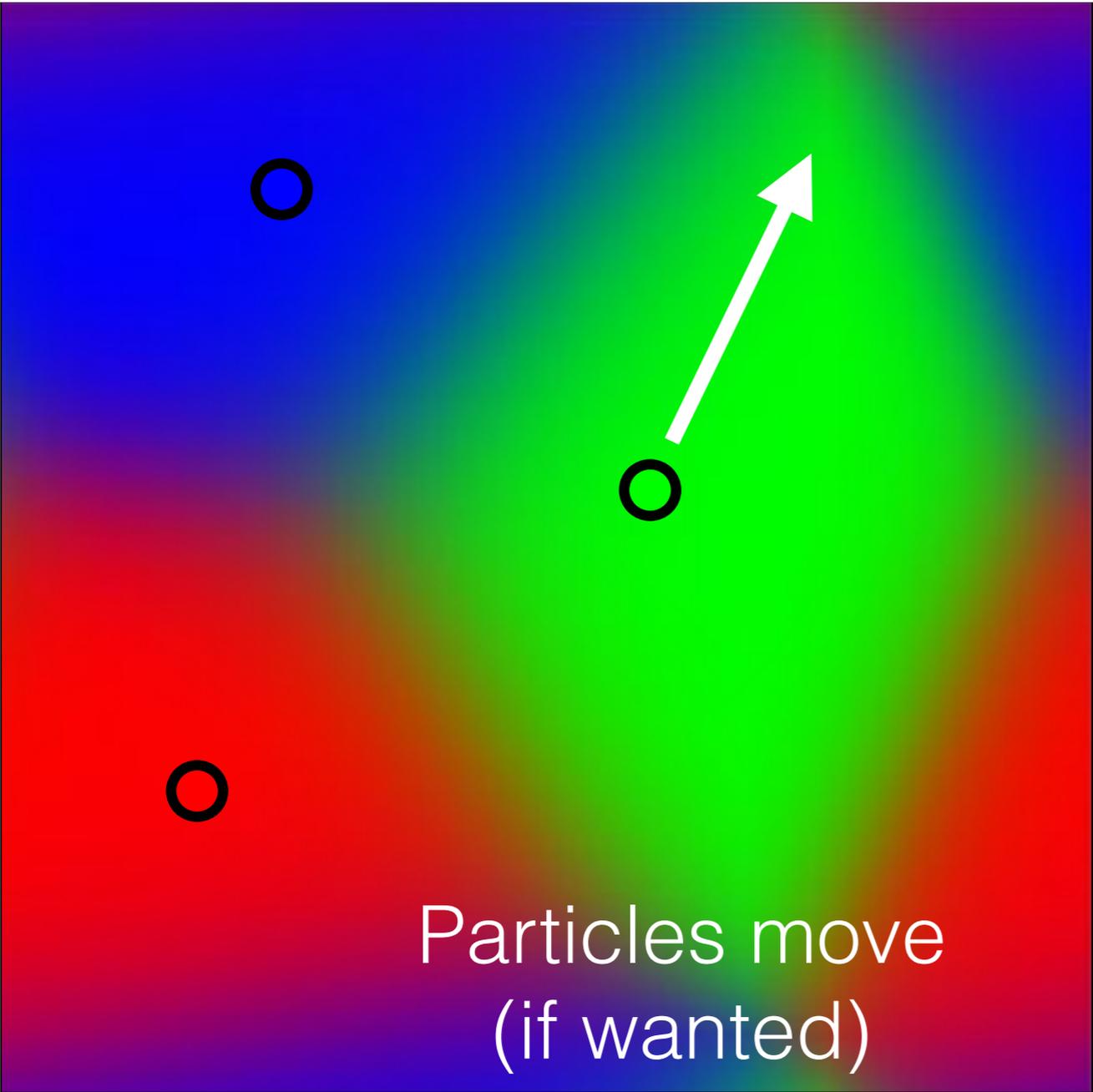
$$dVol = d^3 \mathbf{x}$$

$$dVol_{i,j,k} = d^3 \mathbf{x} \frac{W(\mathbf{x} - \mathbf{x}_{i,j,k})}{\sum W_{i,j,k}}$$



New Meshless Methods Here (MFV, MFM)

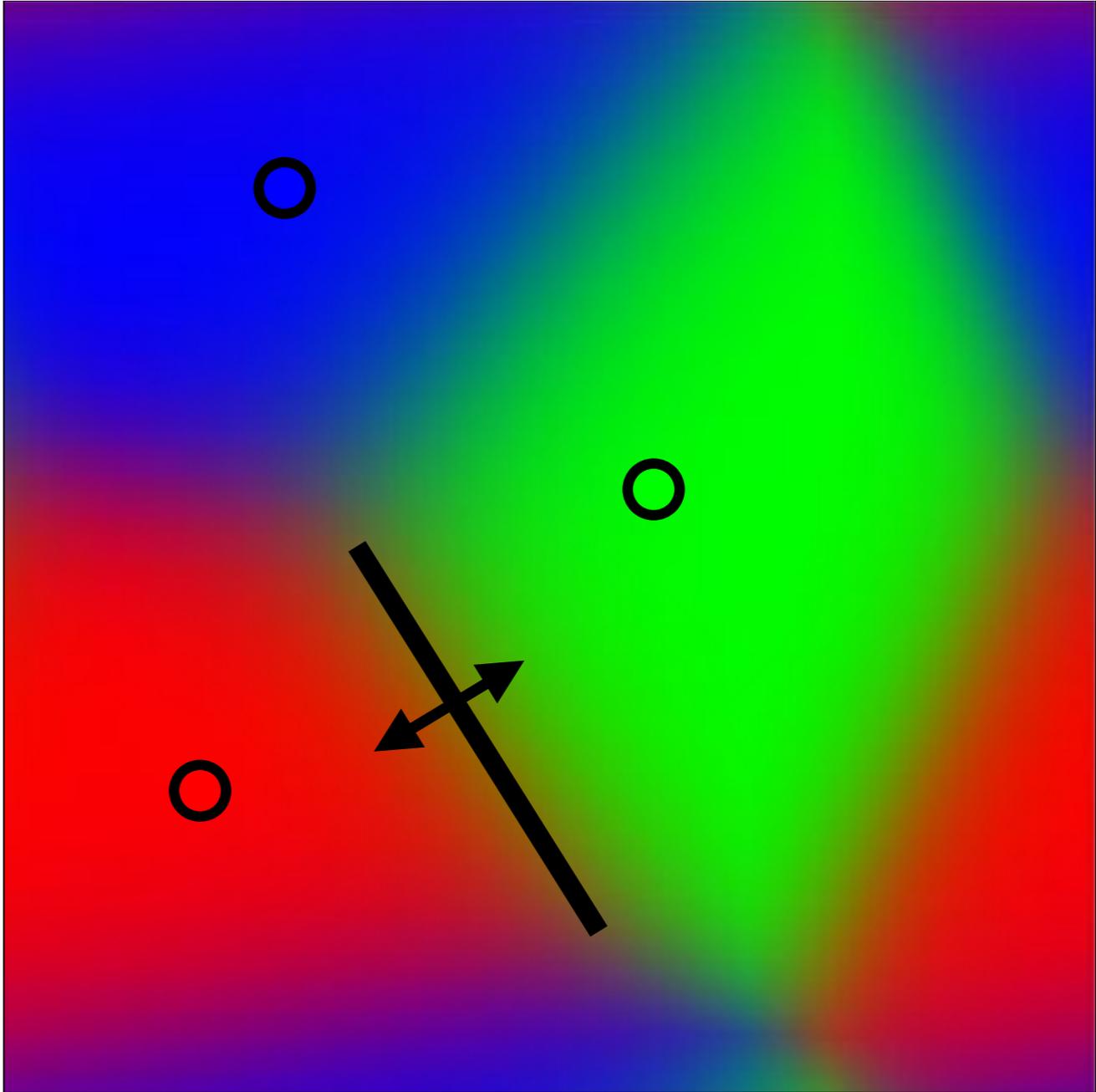
New Meshless Methods (MFM, MFV):



New Meshless Methods Here (MFV, MFM)

$$\Delta m_i = \int_{\text{vol}} \frac{\partial \rho}{\partial t} d^3 \mathbf{x} = - \int_{\text{vol}} \nabla \cdot (\rho \mathbf{v}) d^3 \mathbf{x}$$

Integrate EOM over volume:
Reimann problem at “effective face”



New Meshless Methods Here (MFV, MFM)

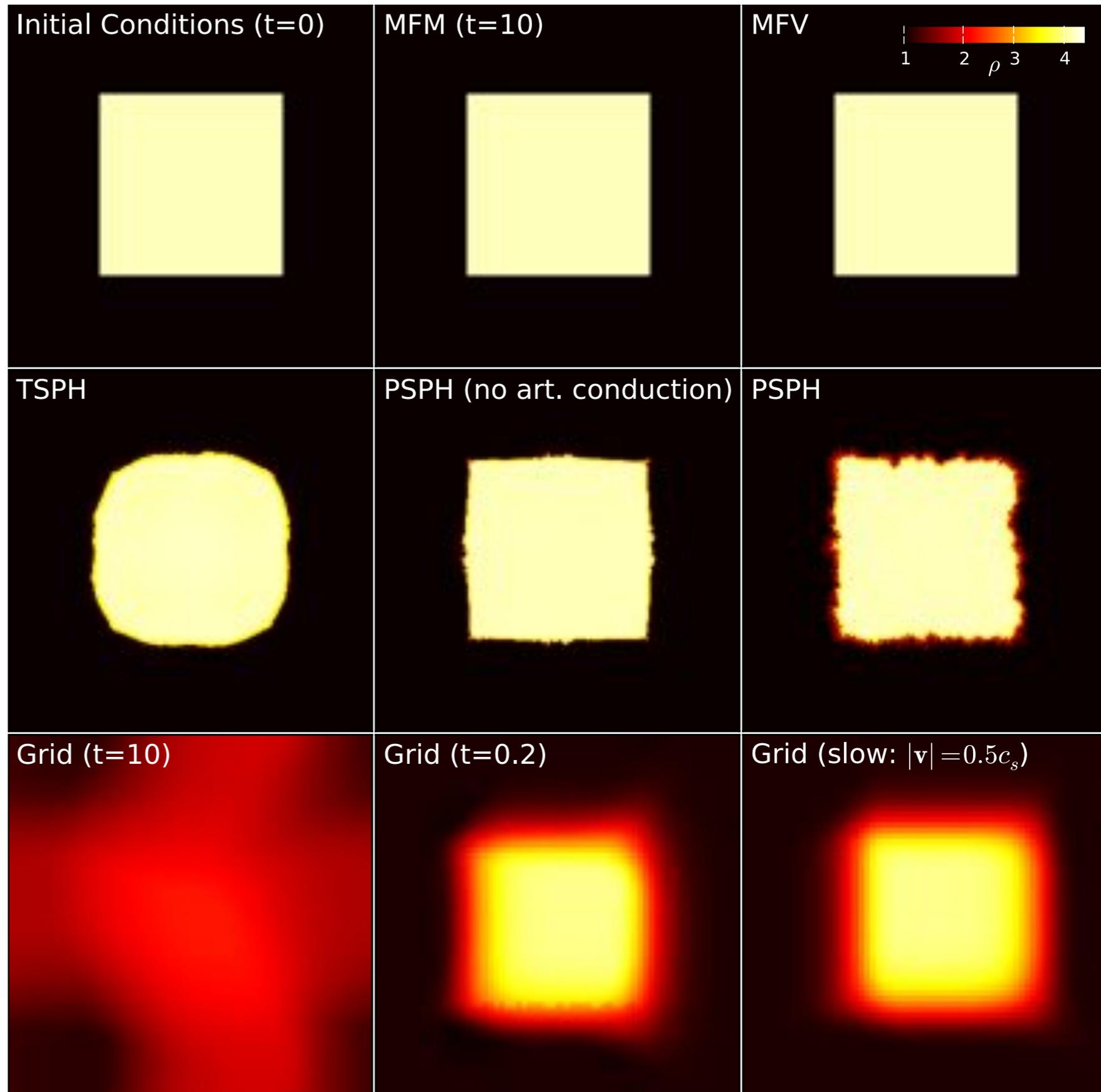
GIZMO: Some results

(www.tapir.caltech.edu/~phopkins)

➤ You choose:

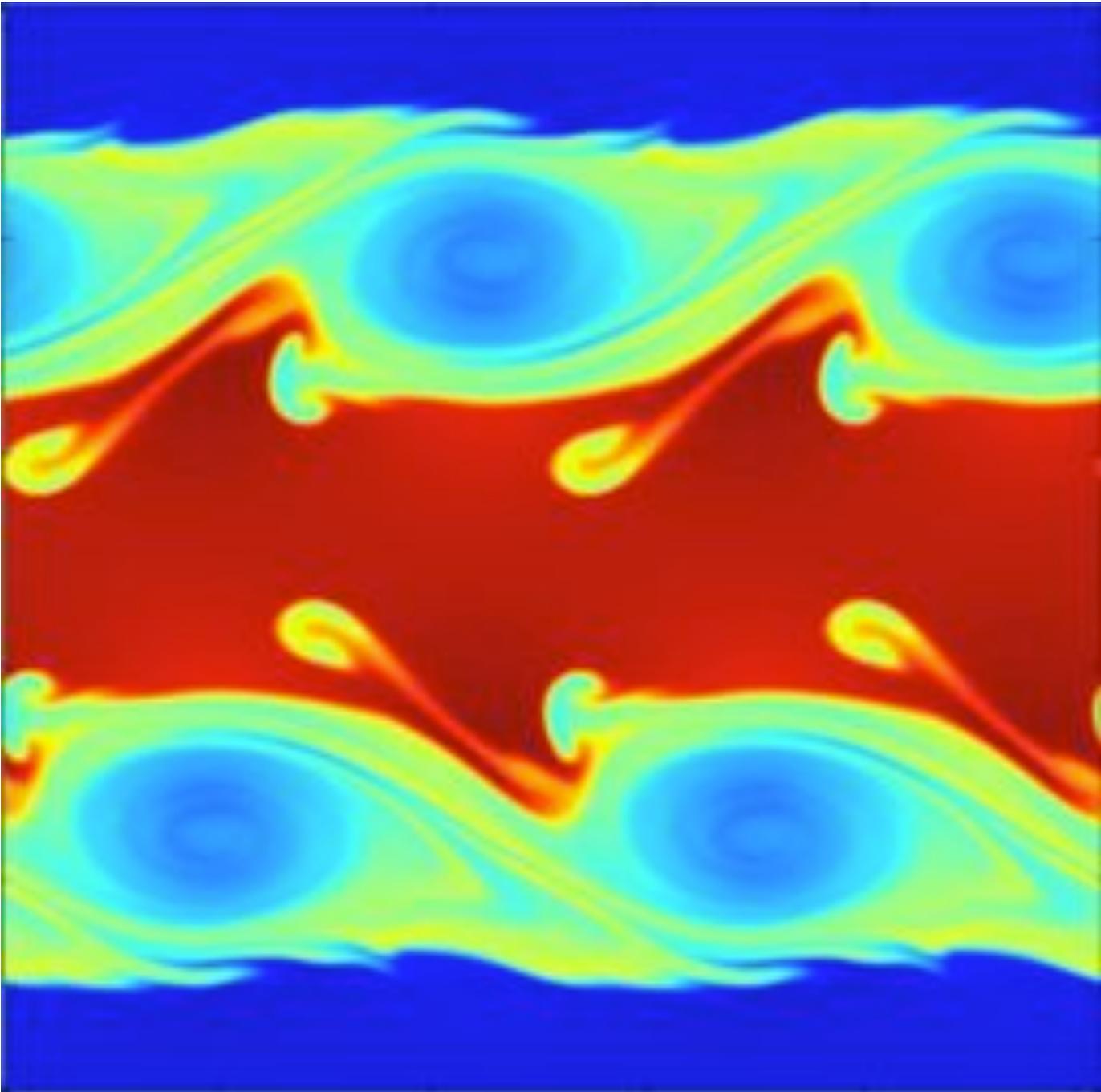
- ‘Traditional’ T-SPH
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- “Meshless Finite Volume”
- “Meshless Finite Mass”

- **100% compatible**
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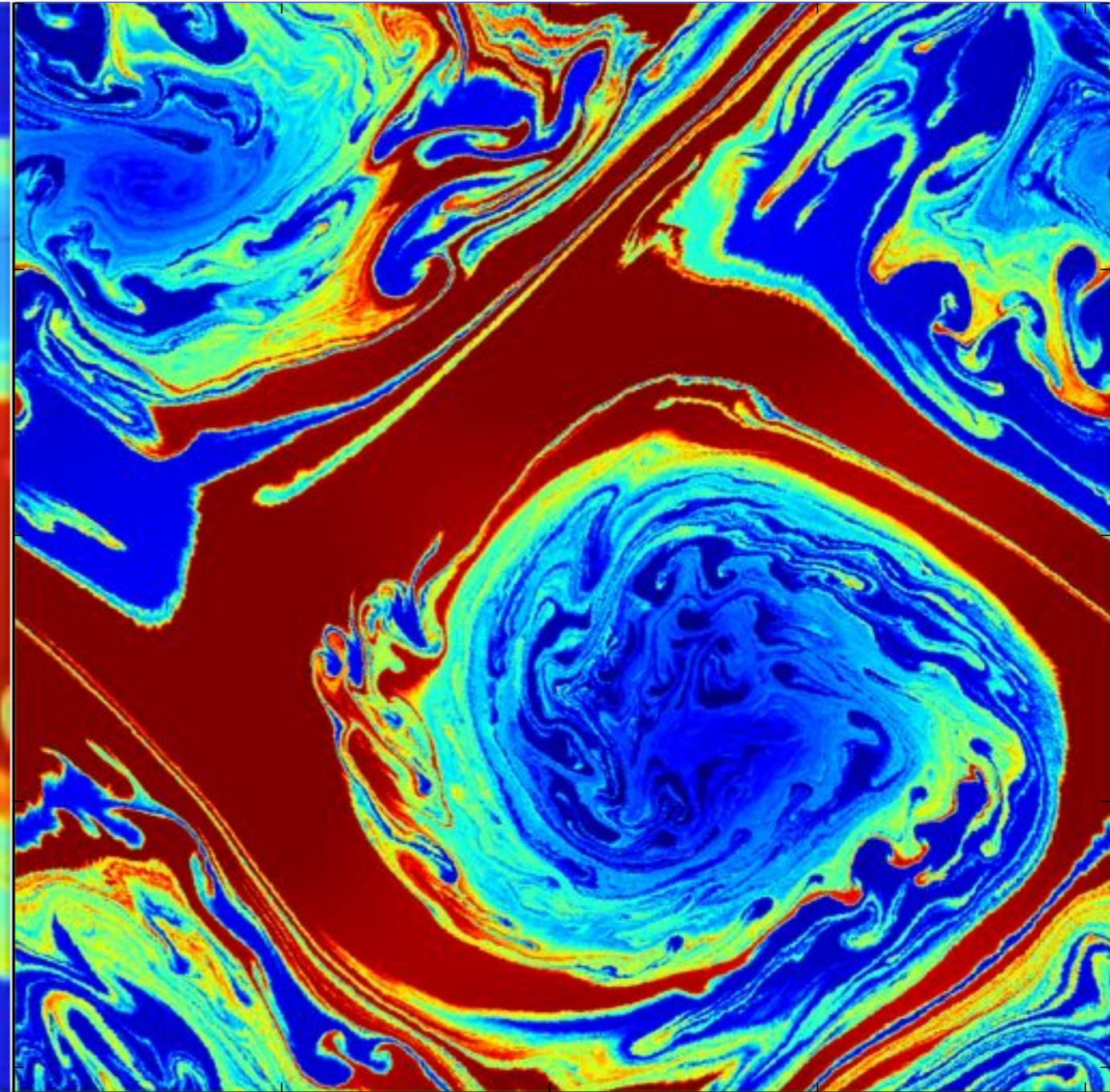


GIZMO: New Meshless Methods & Fluid Mixing

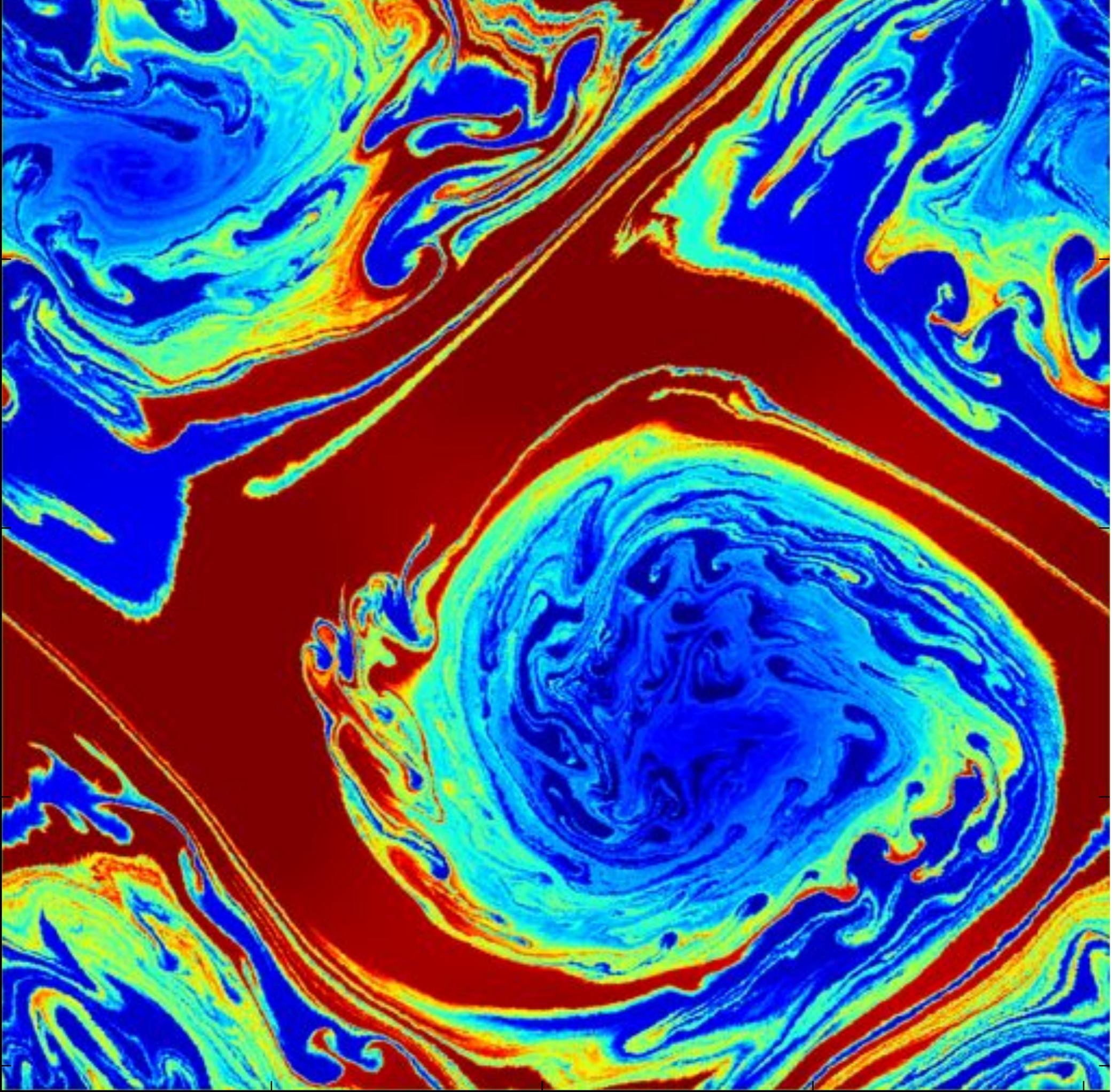
(www.tapir.caltech.edu/~phopkins)

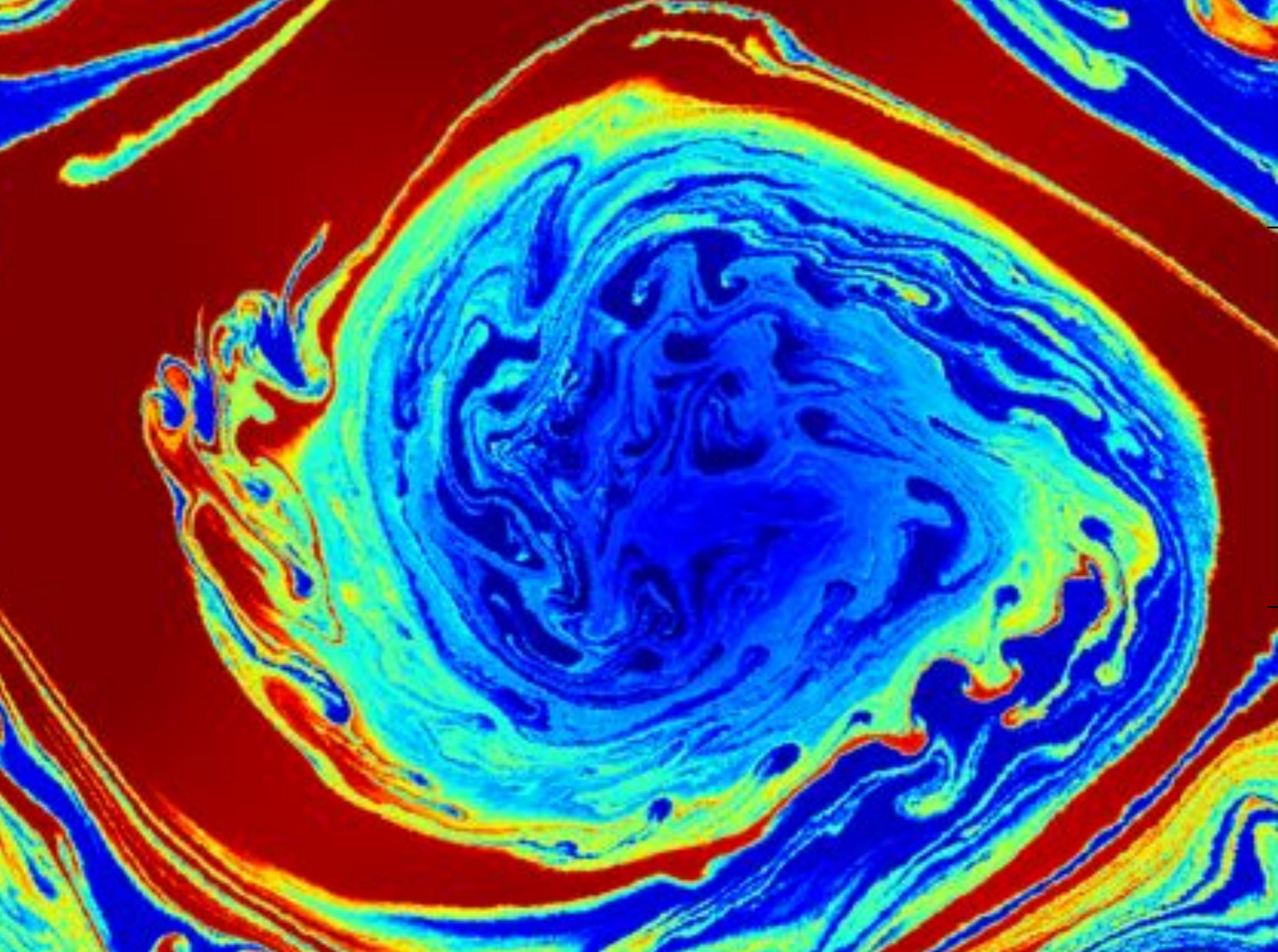


Cartesian Grid



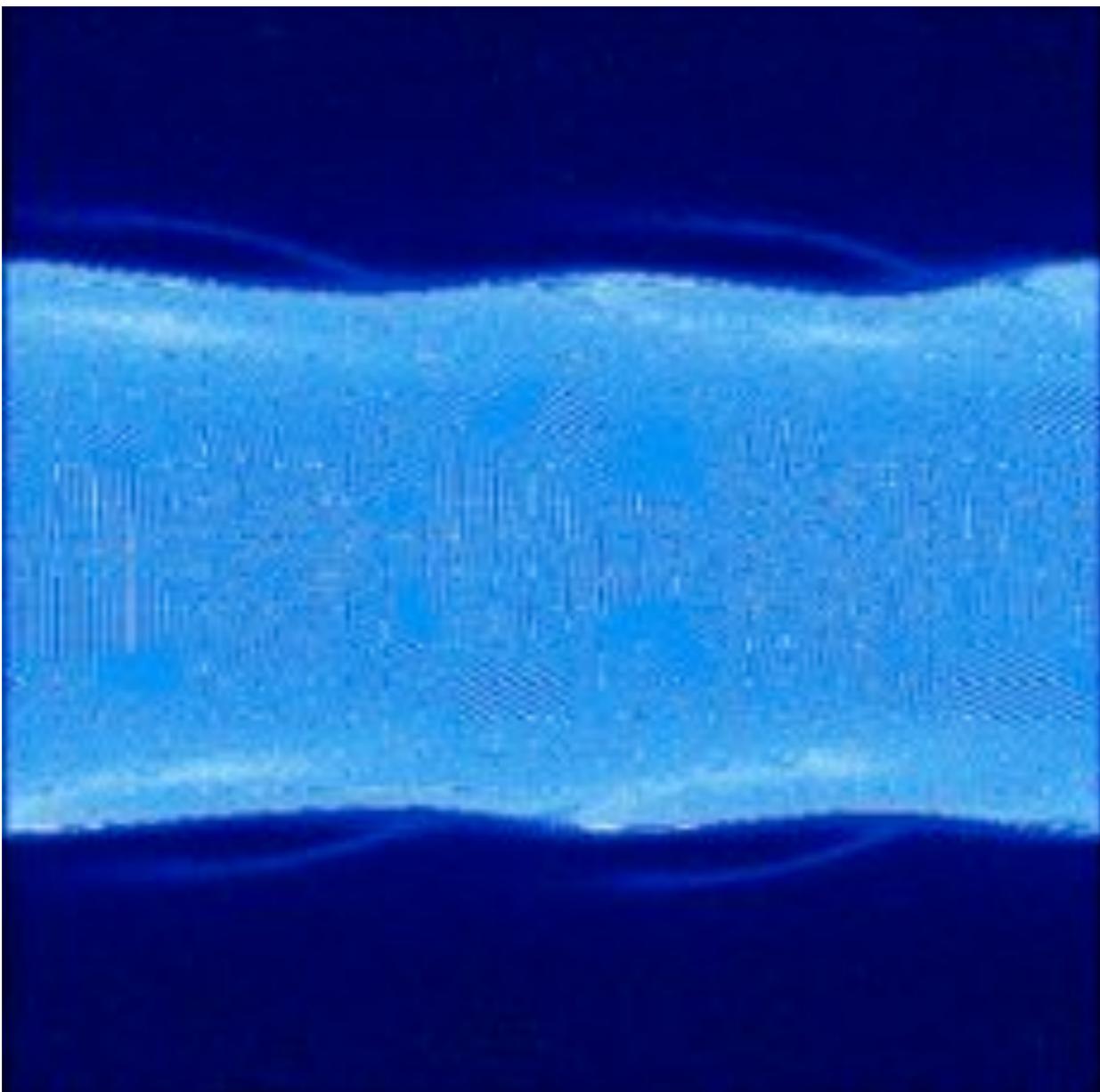
Meshless Finite Volume



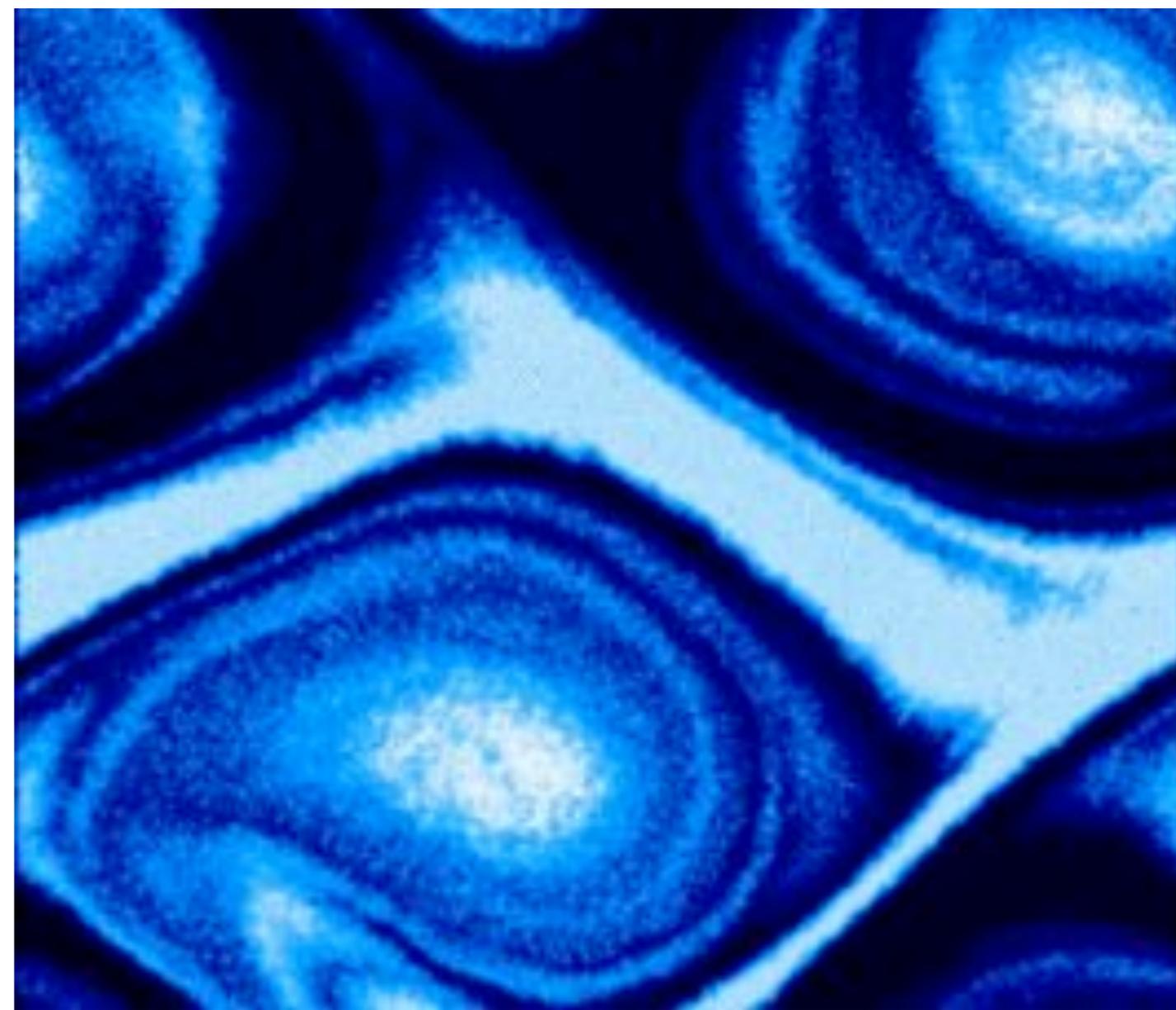


SPH?

SURFACE TENSION IS FIX-ABLE, E0 ERRORS CAN BE REDUCED



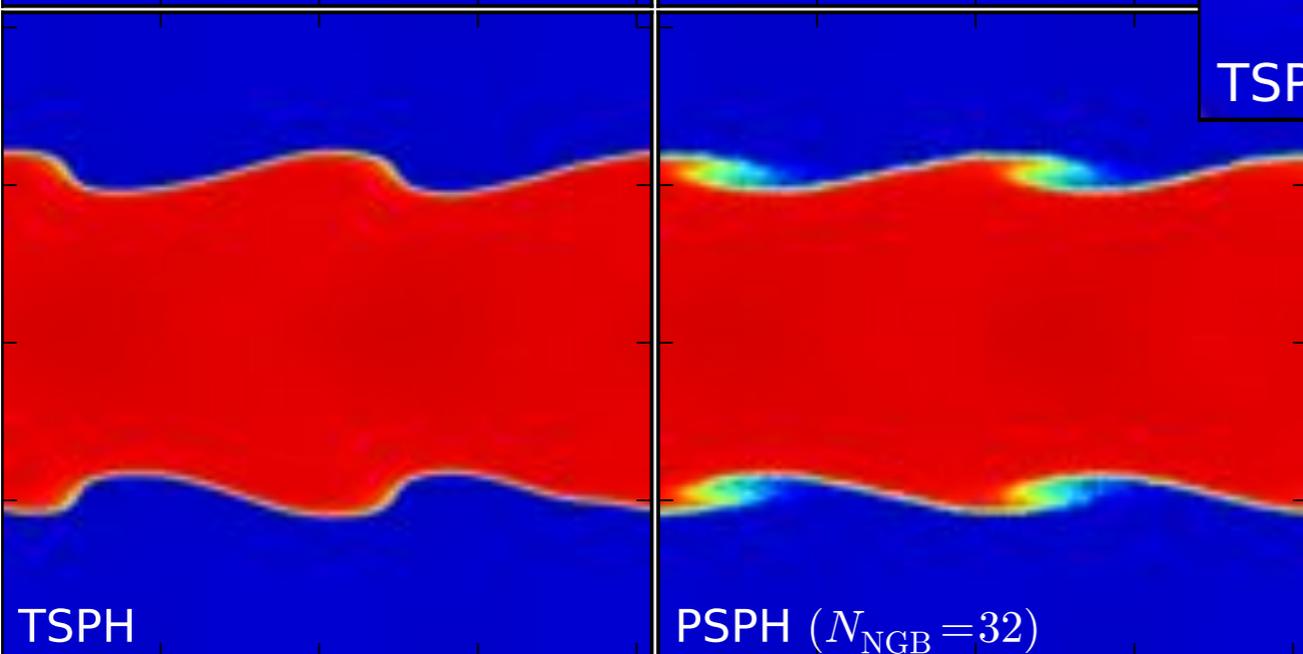
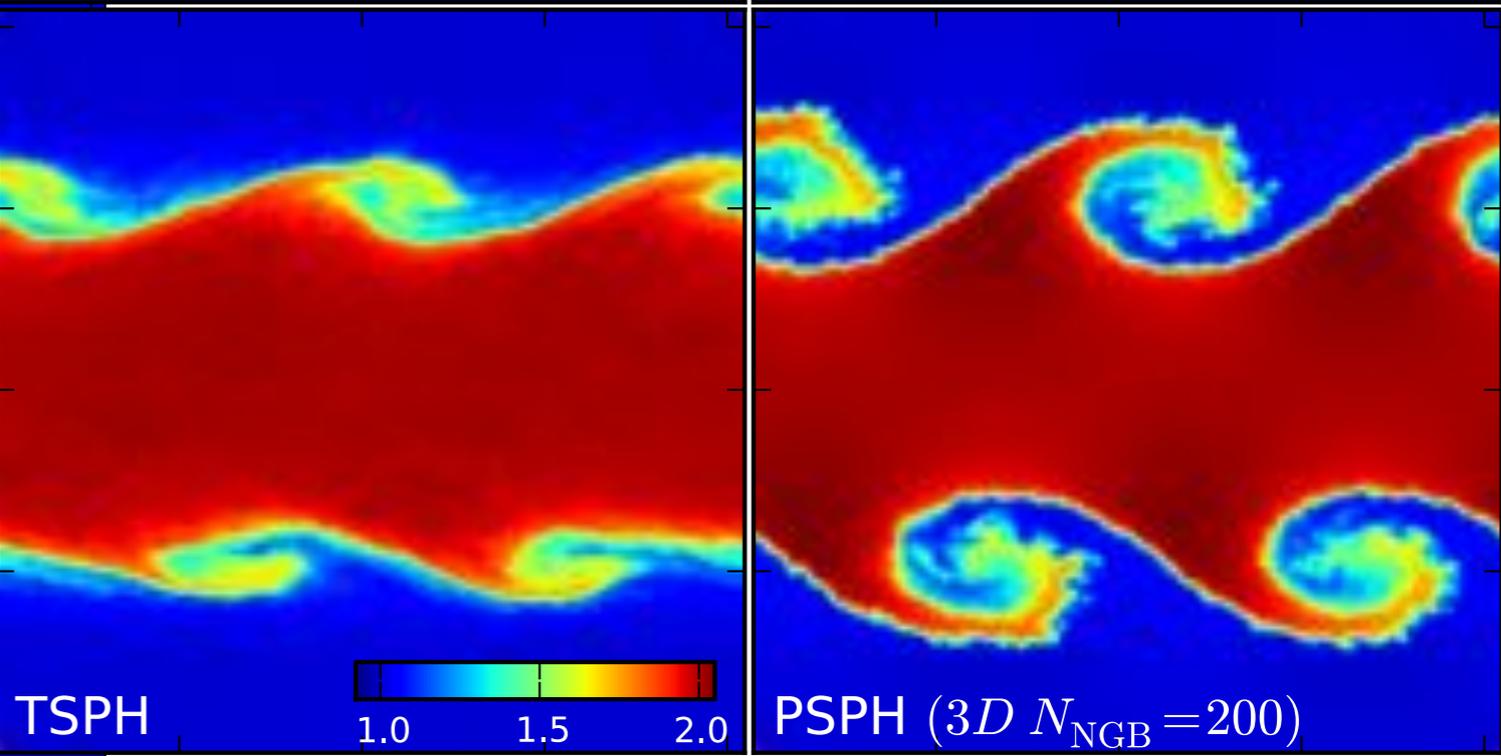
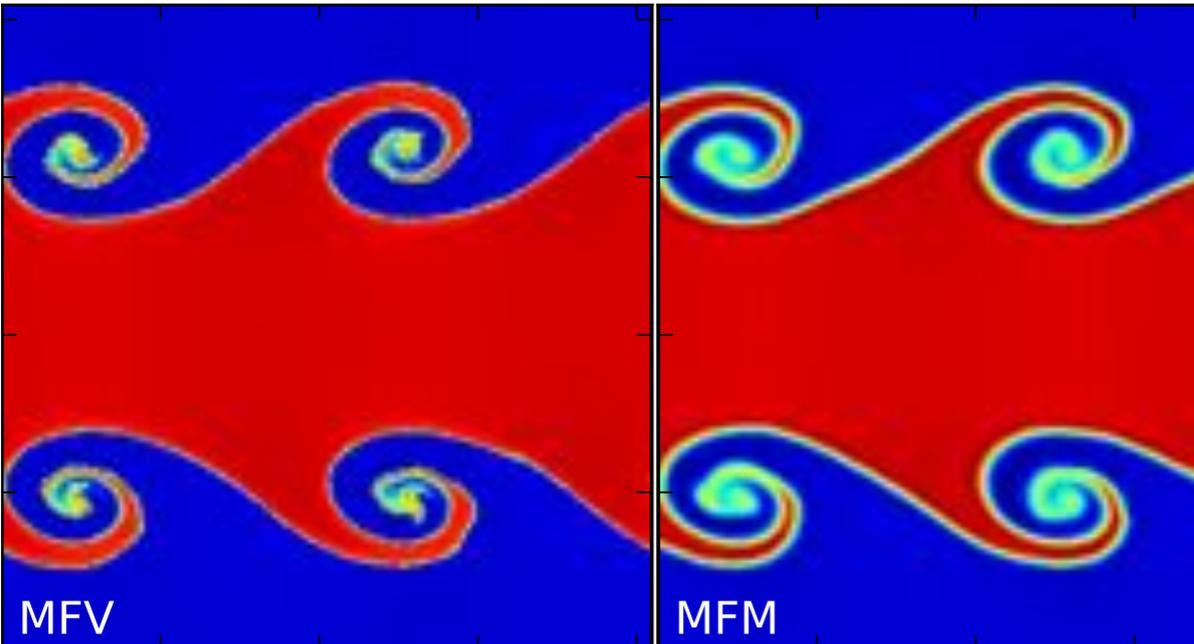
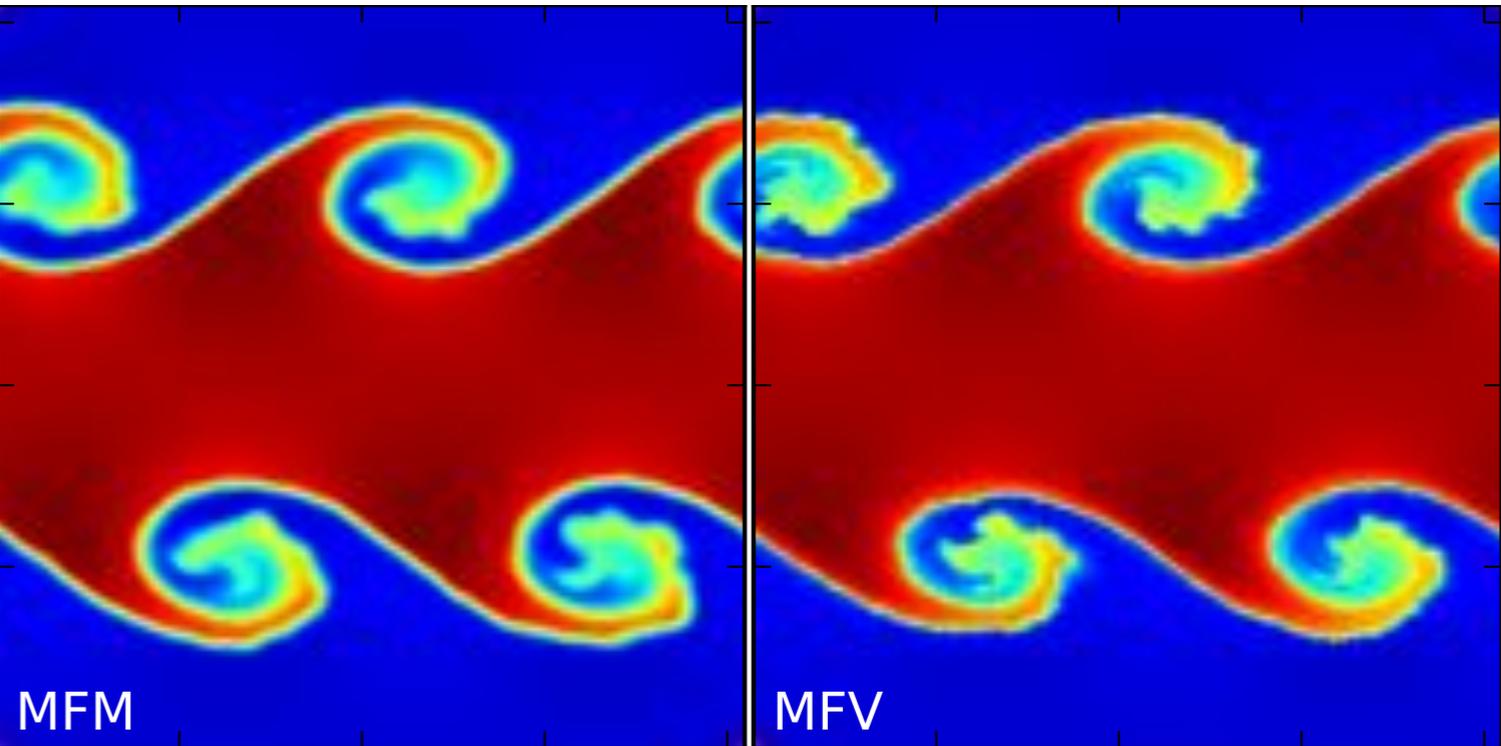
Density Formulation
("Old" GADGET / TSPH)



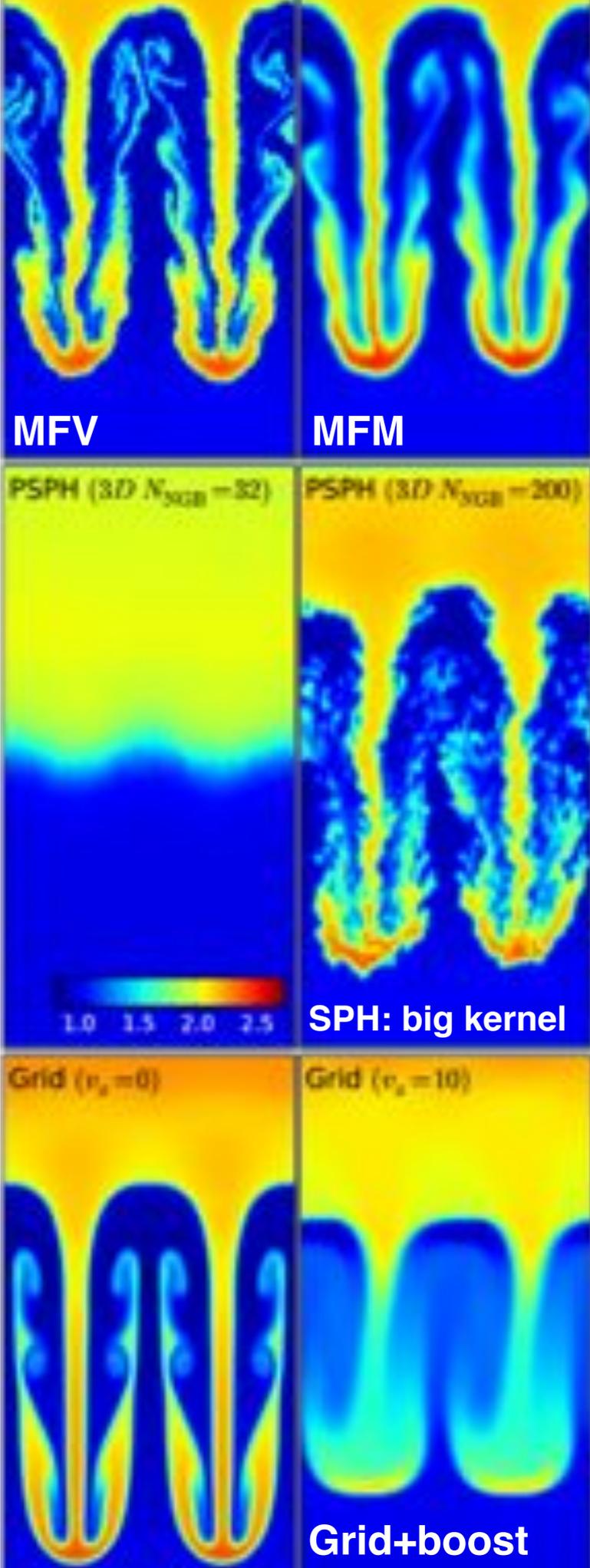
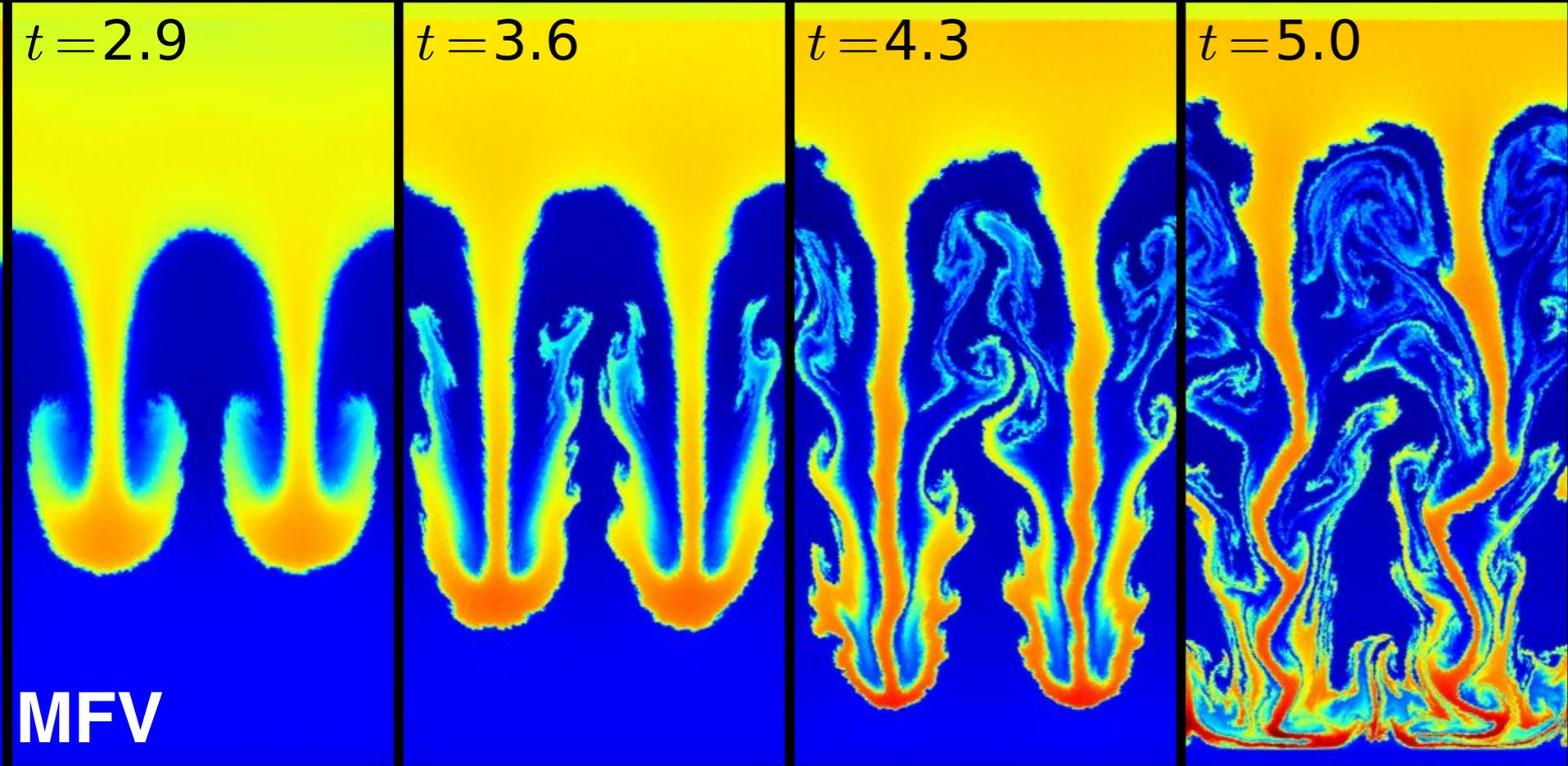
Pressure-Entropy Formulation
(P-SPH)

But.....

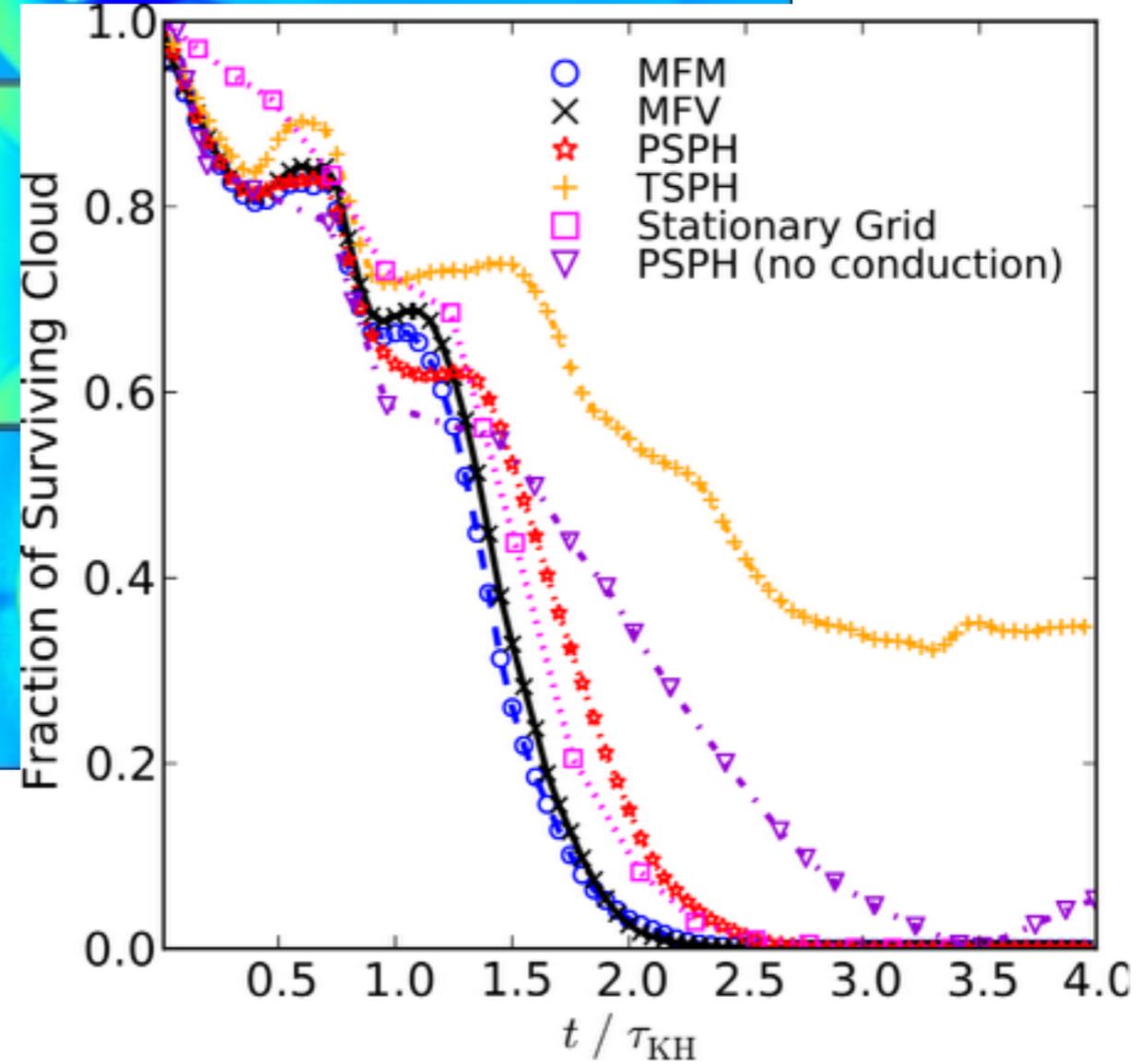
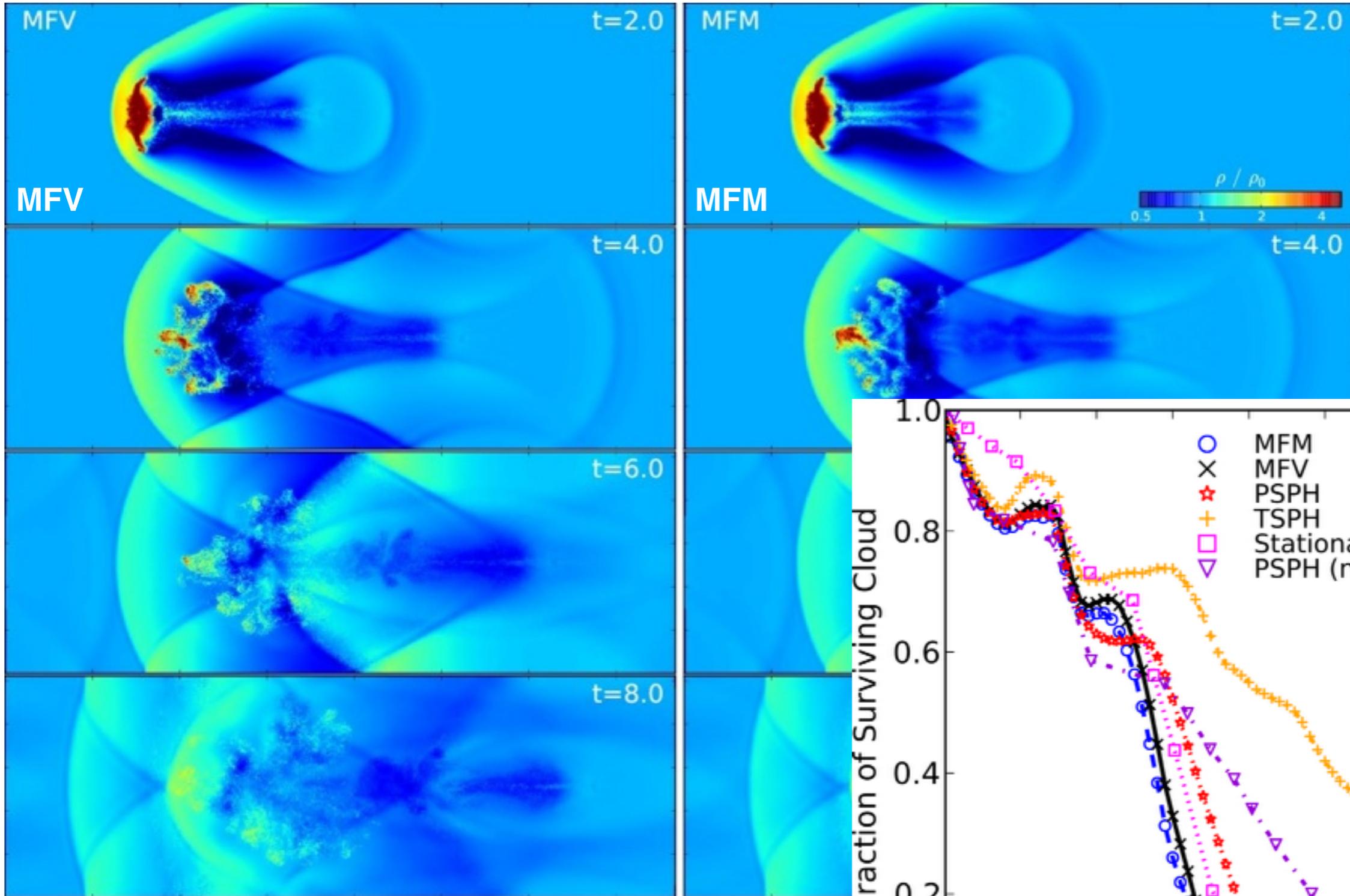
SPH really needs those neighbors



Rayleigh-Taylor Instabilities

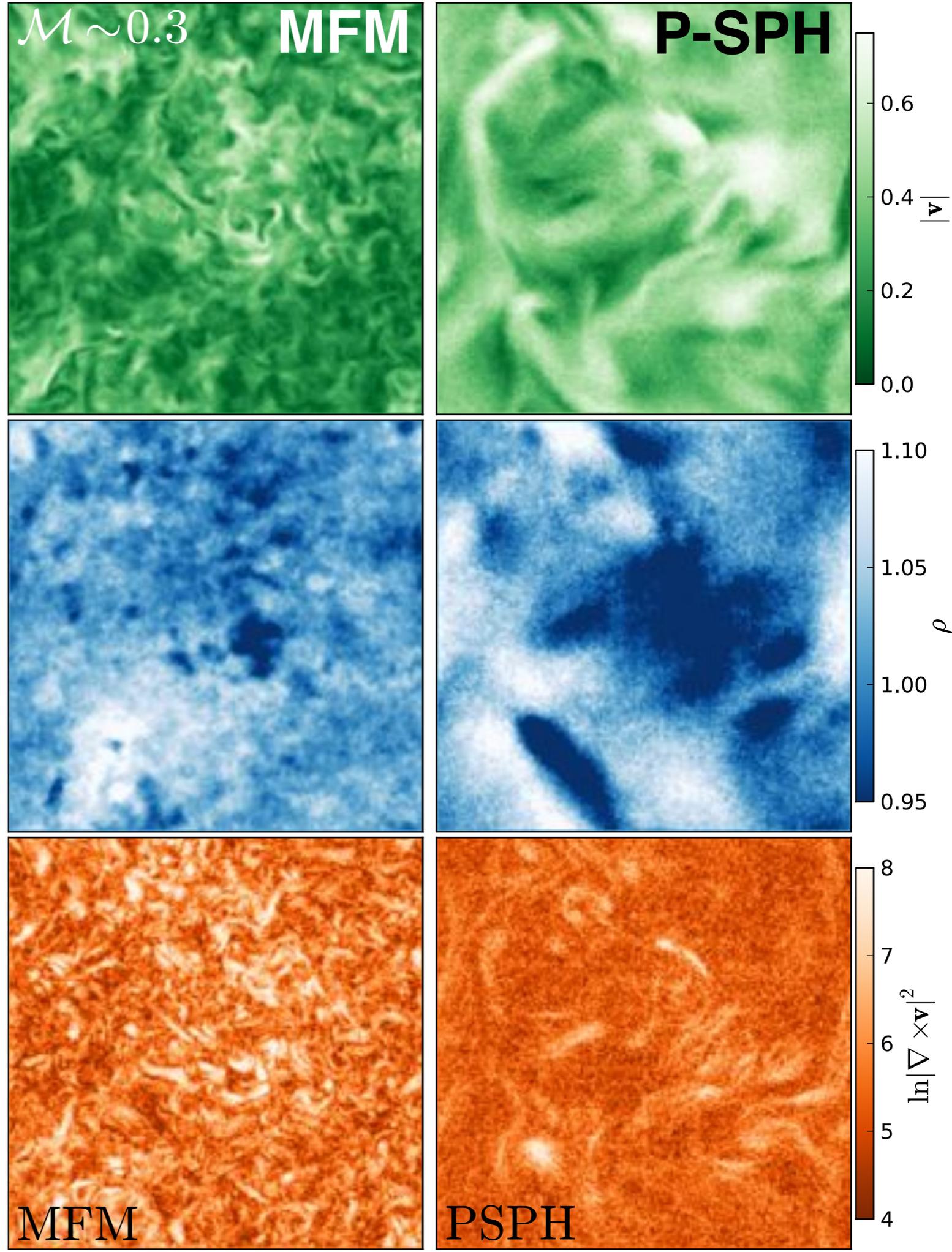


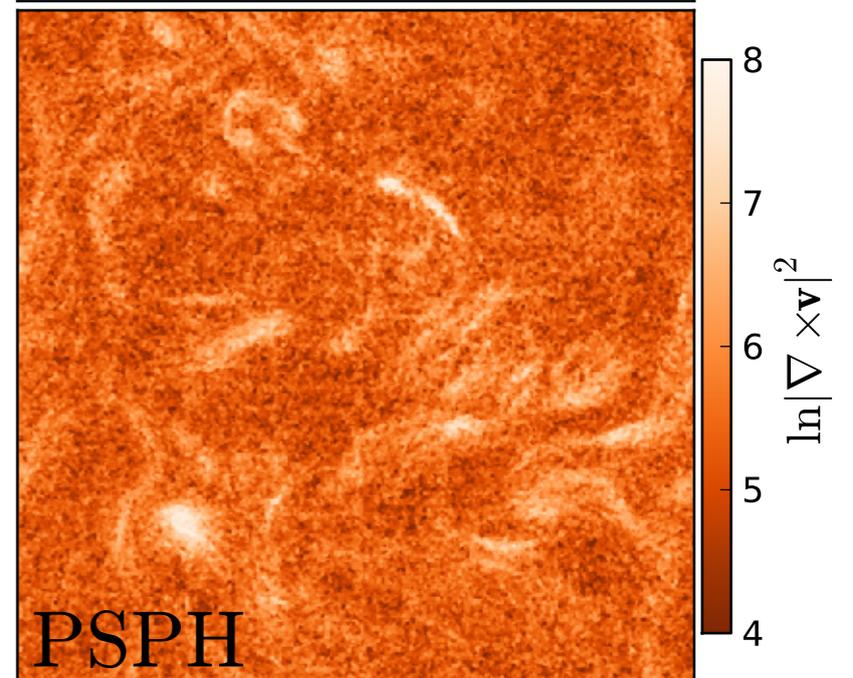
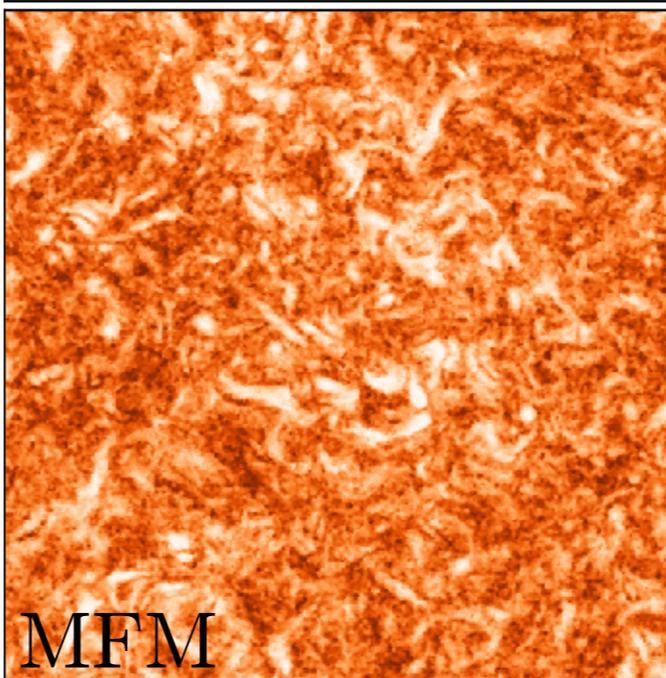
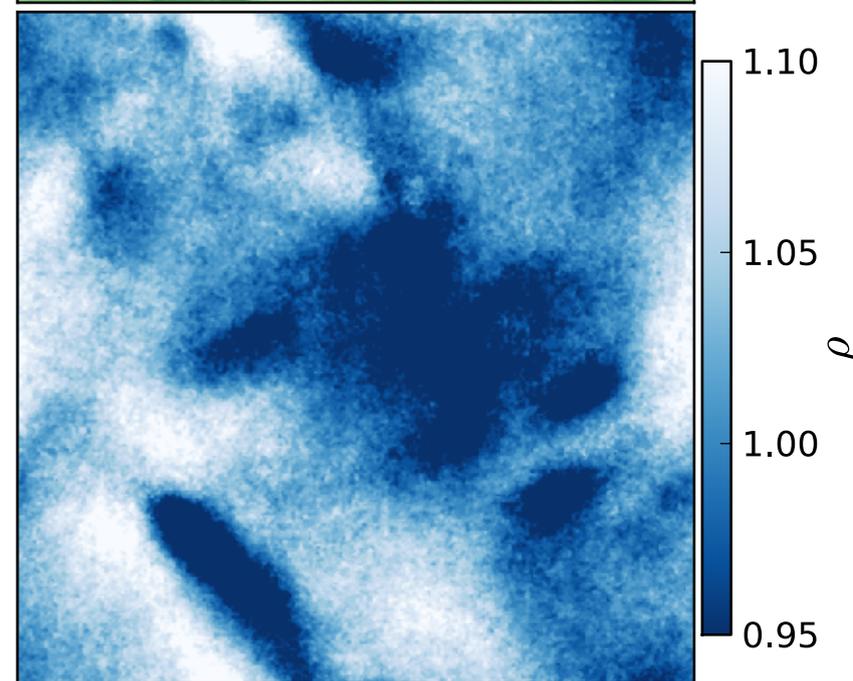
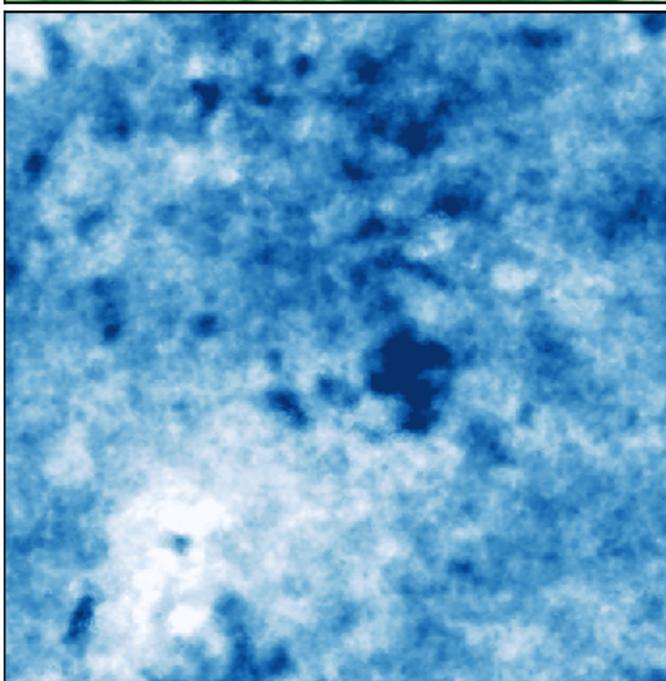
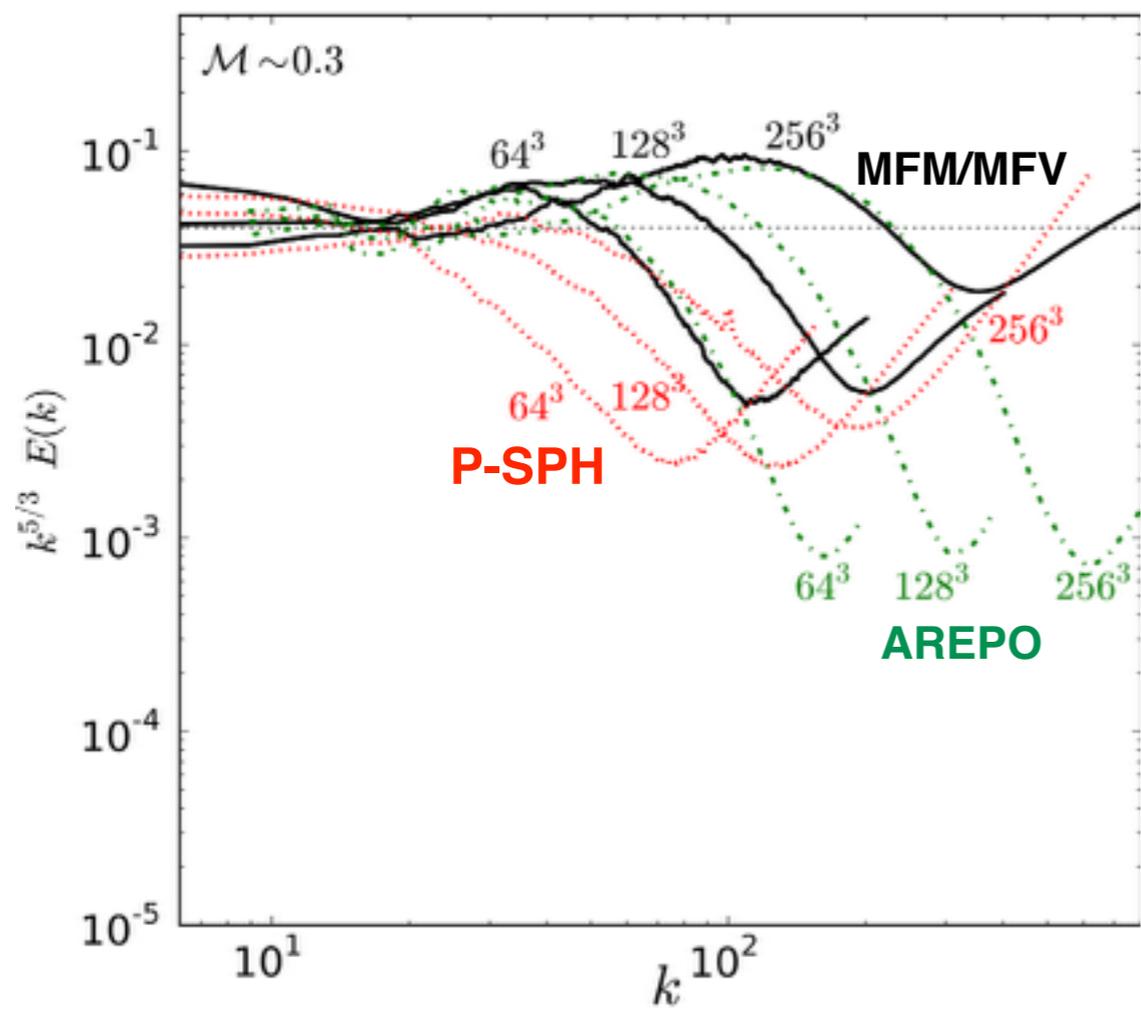
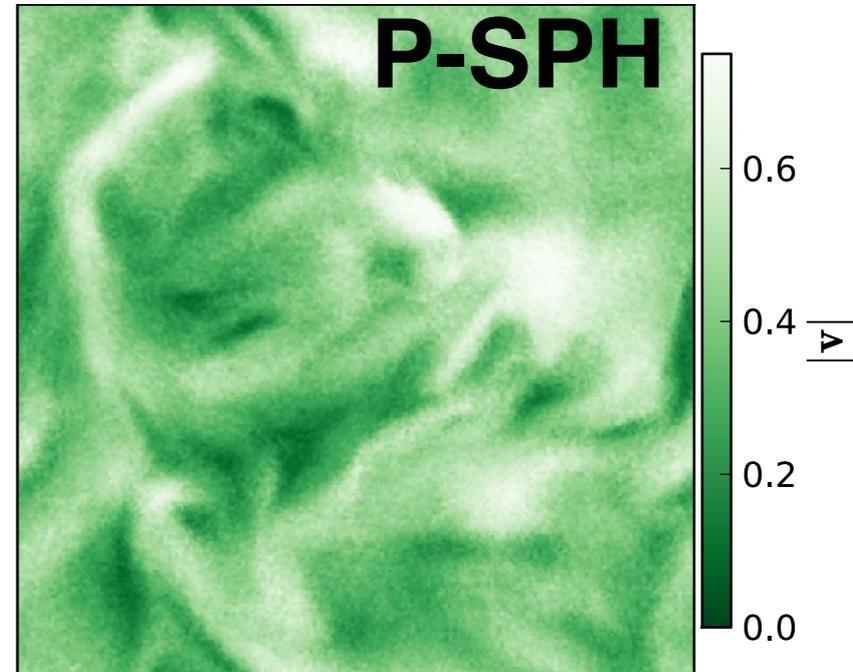
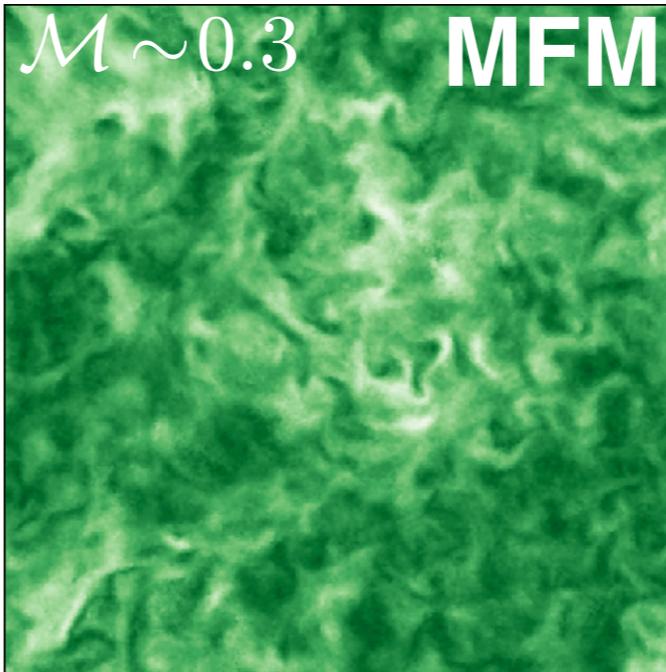
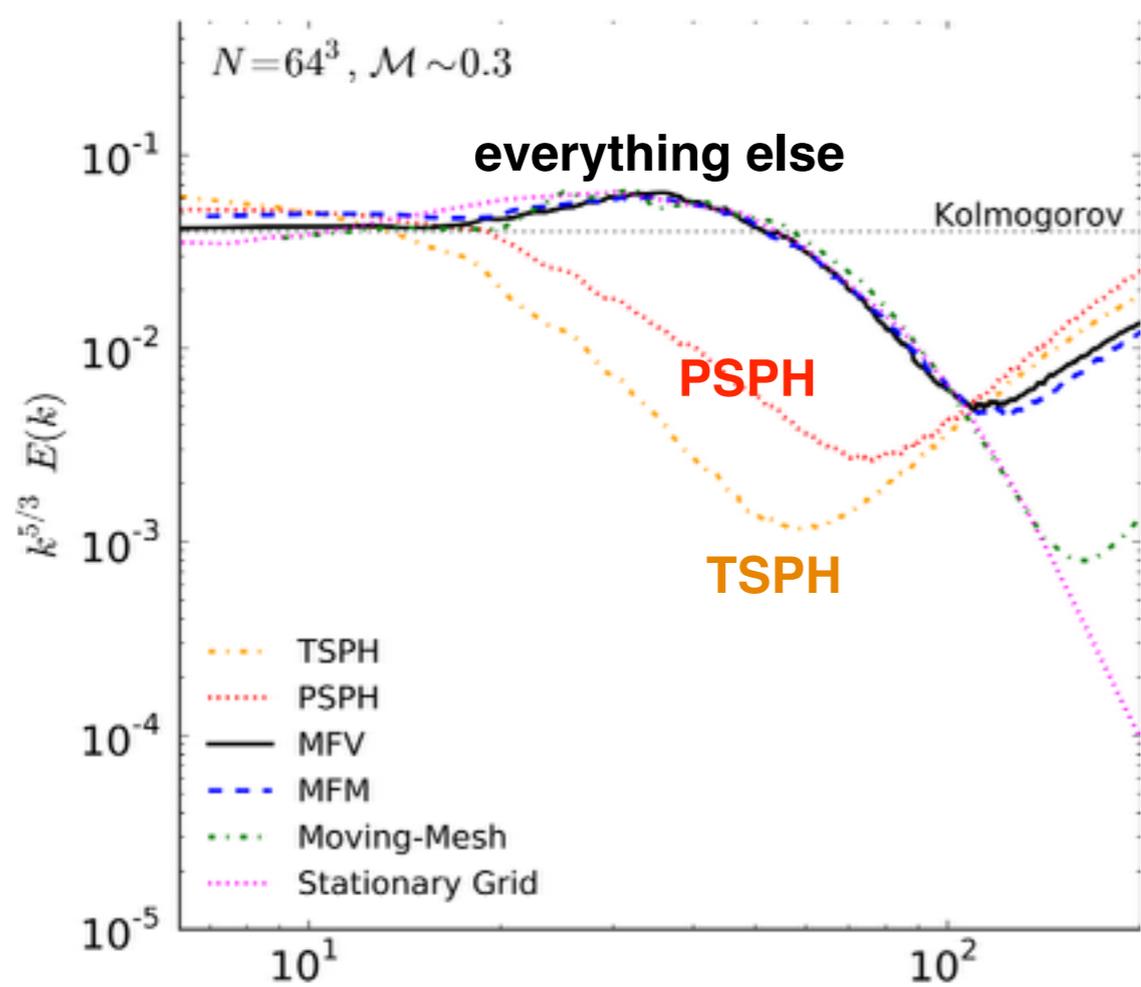
“The Blob” (Agertz et al.)

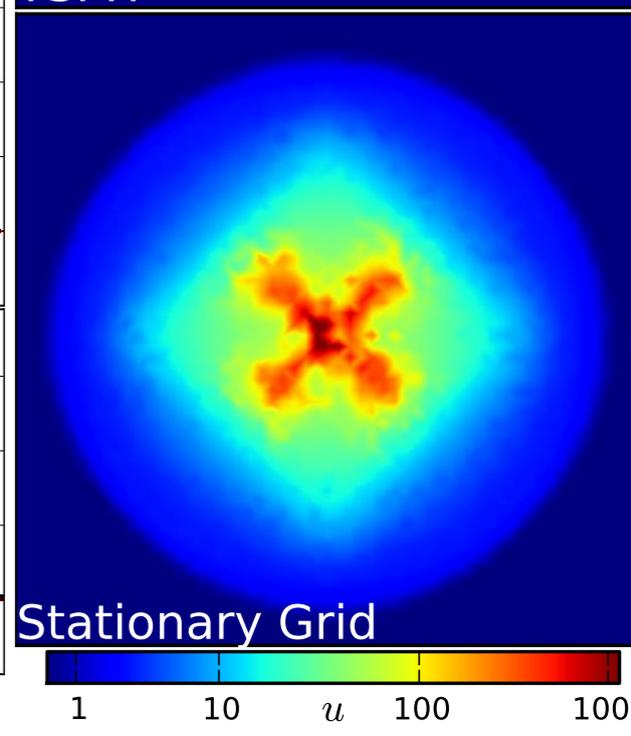
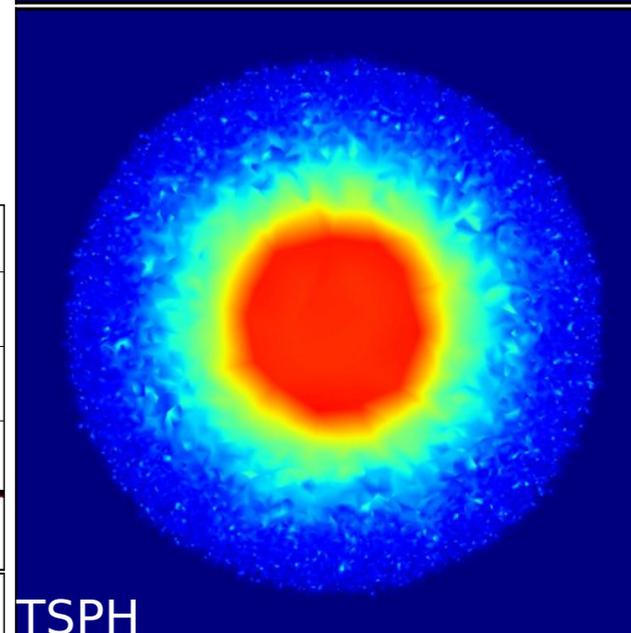
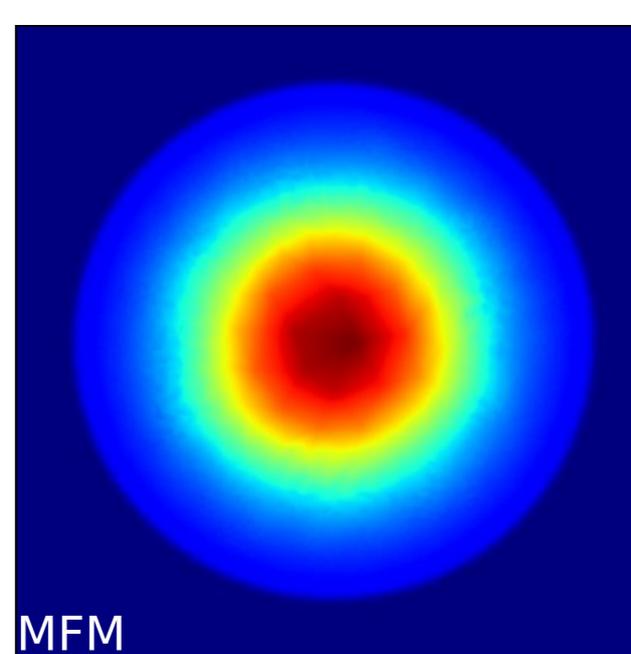
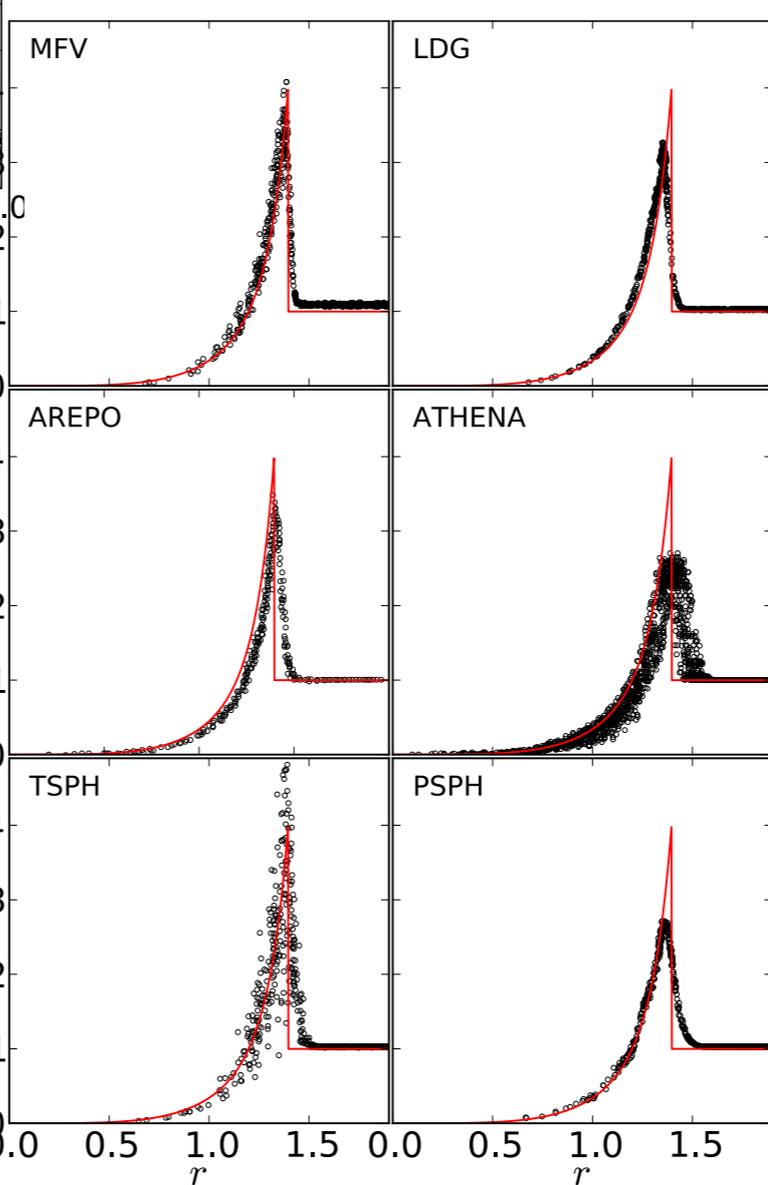
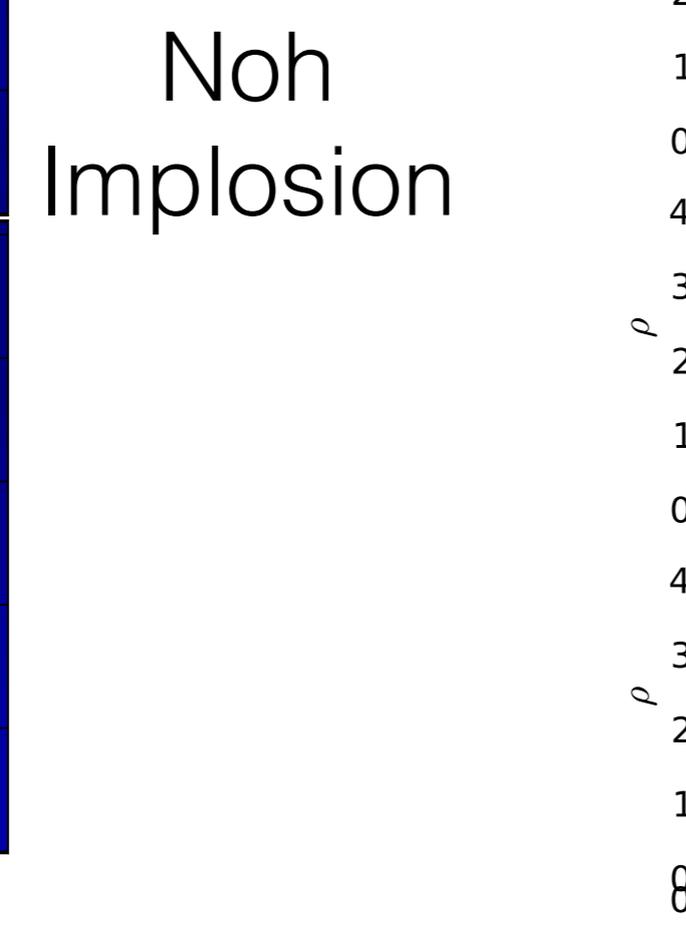
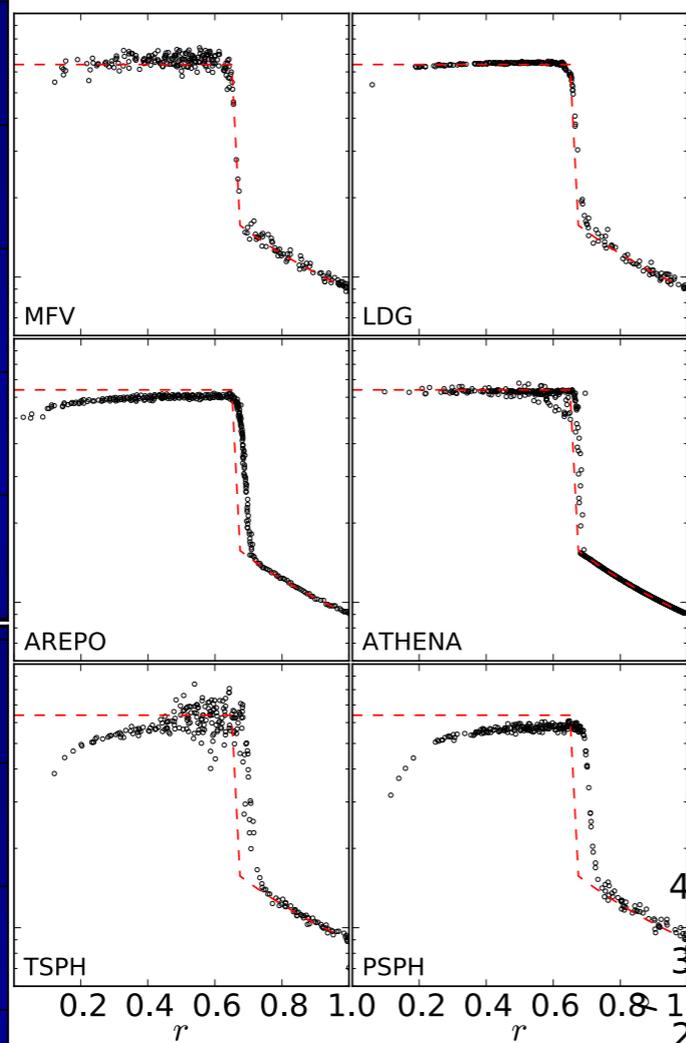
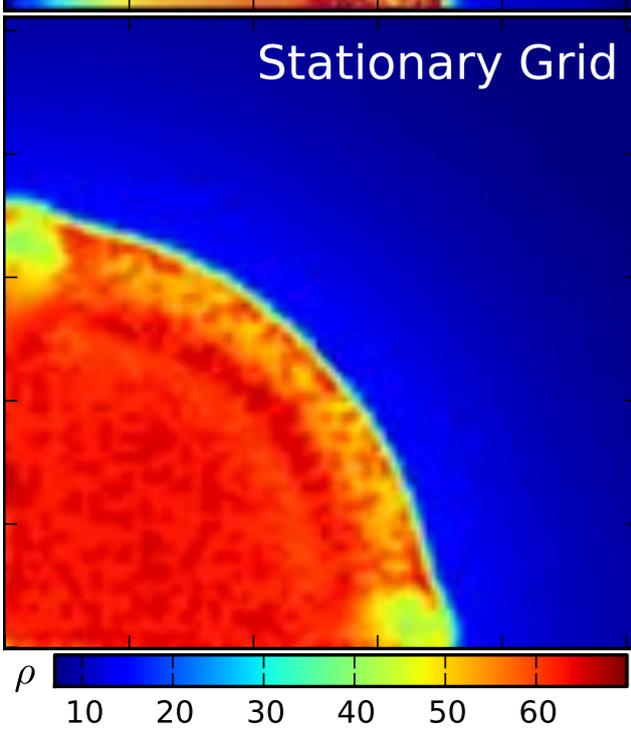
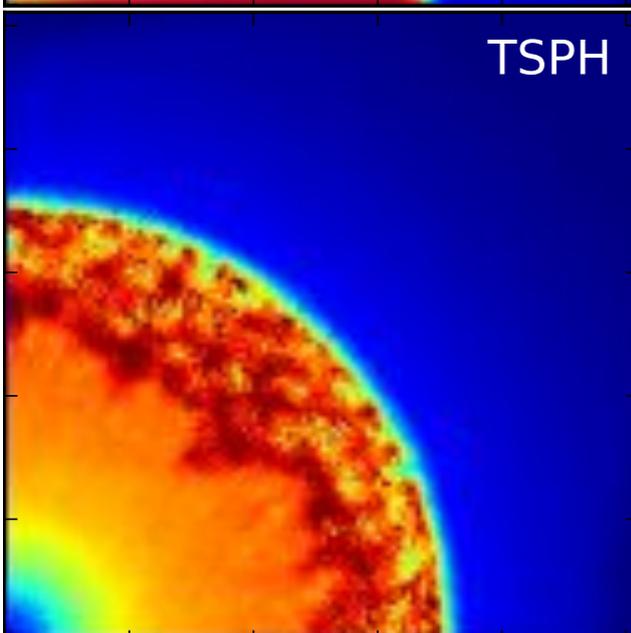
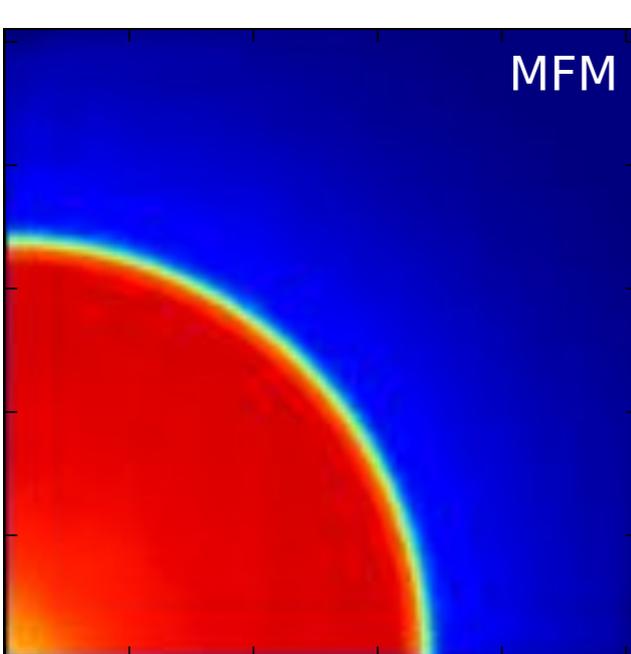


Subsonic Turbulence:

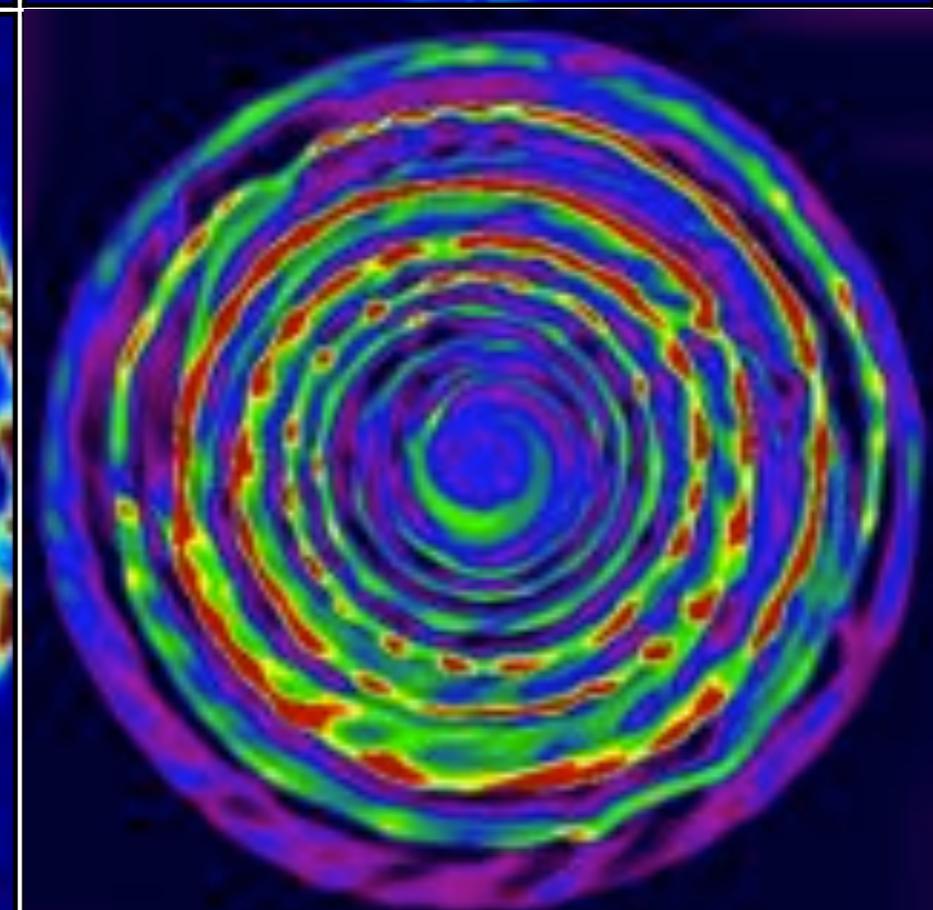
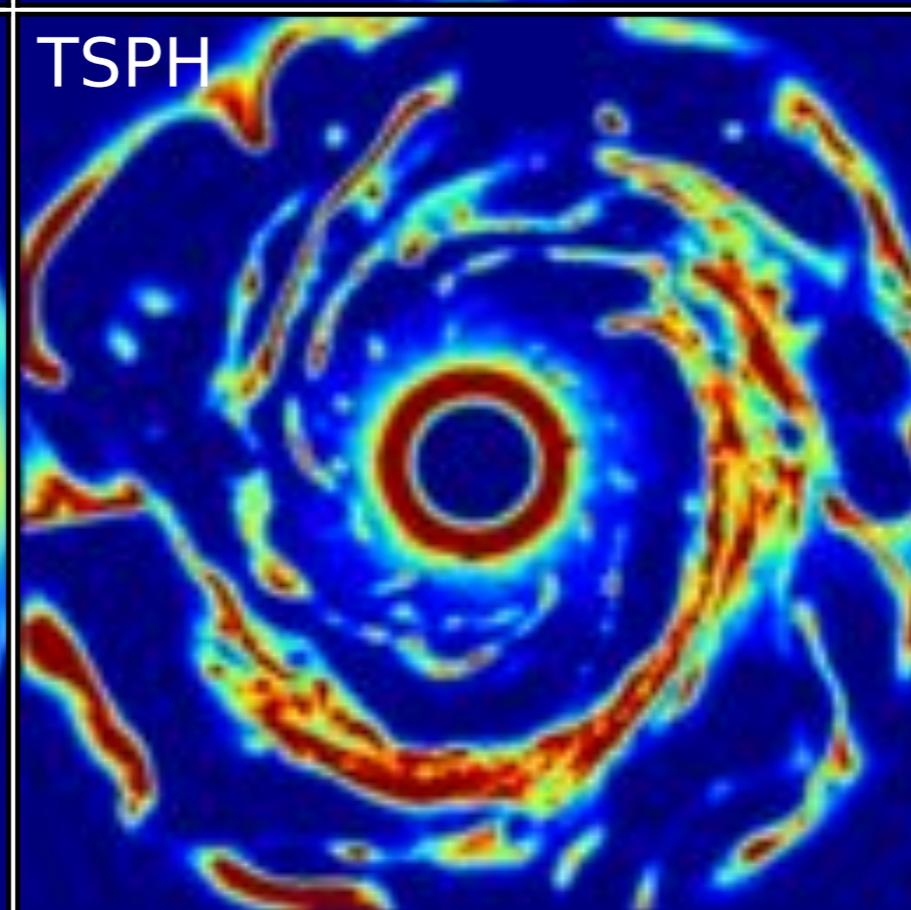
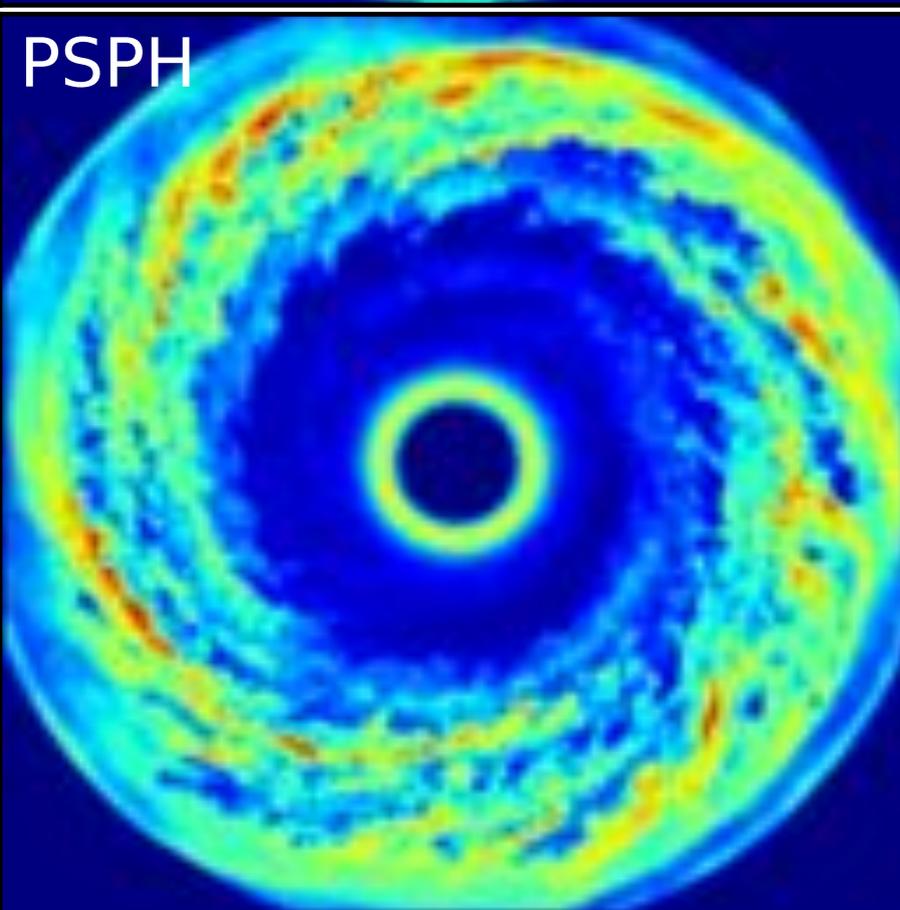
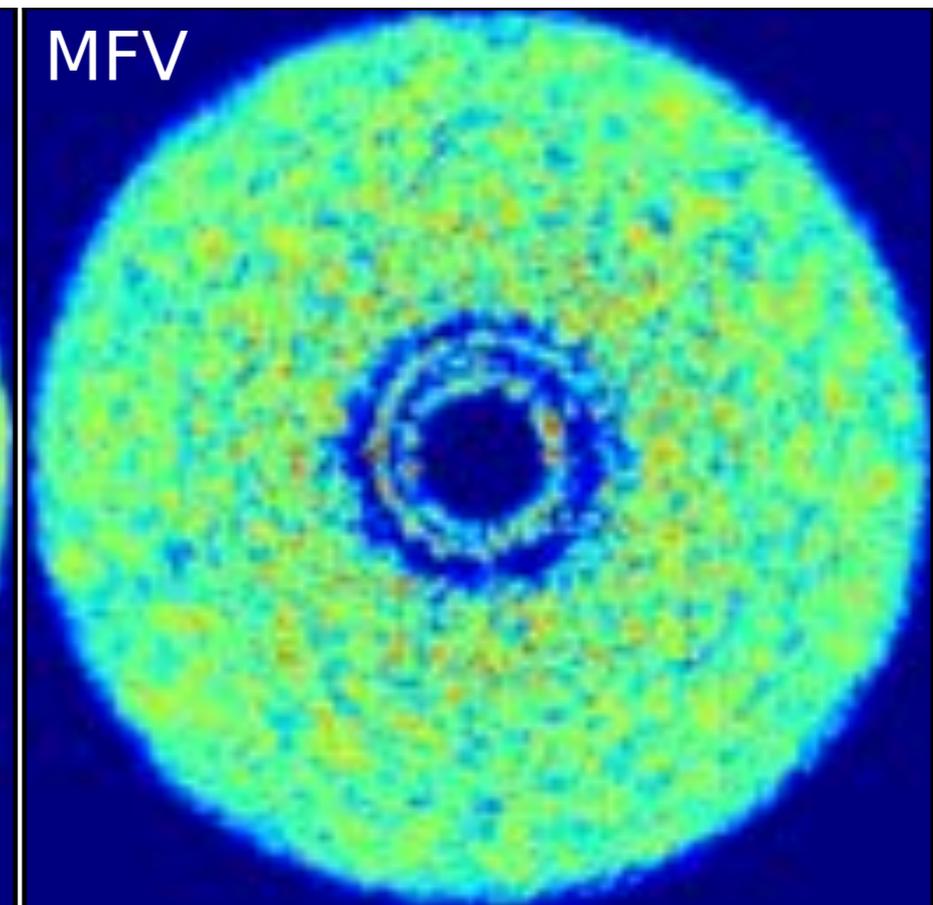
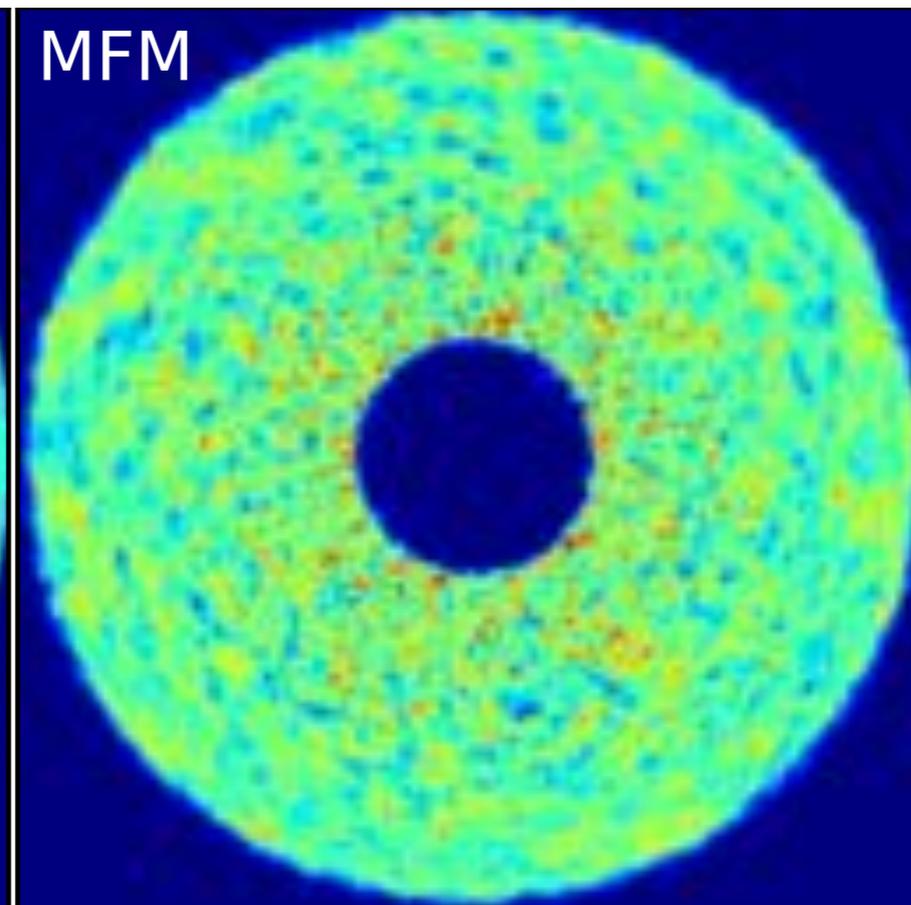
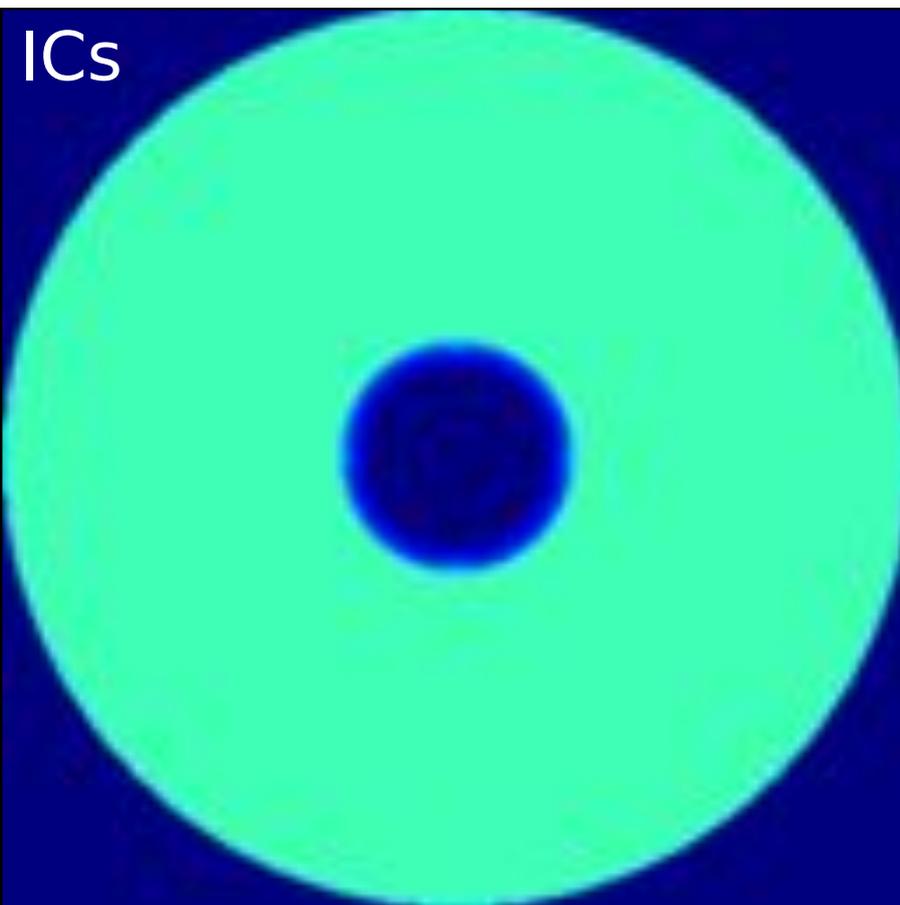
Bauer & Springel test:





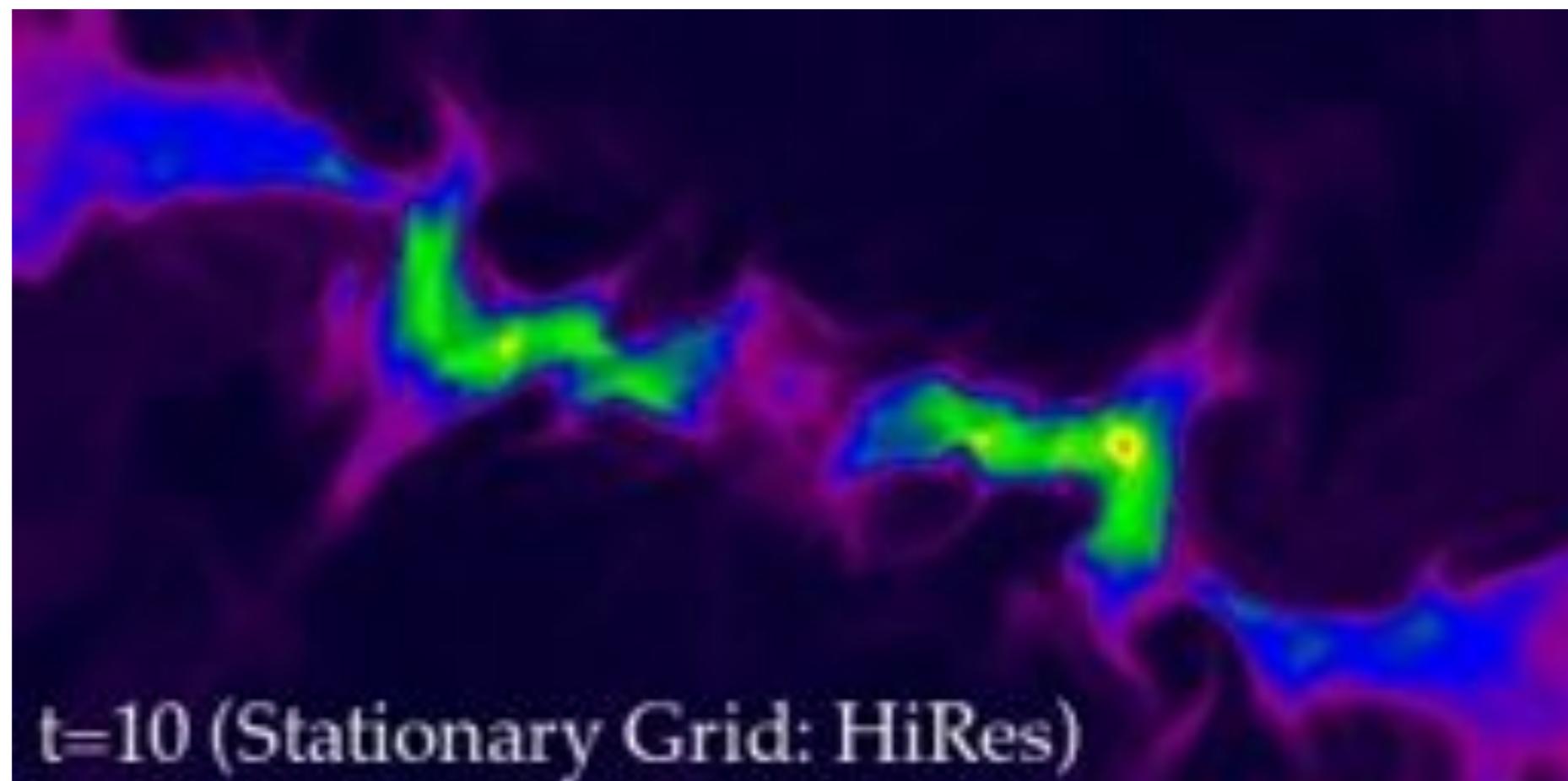
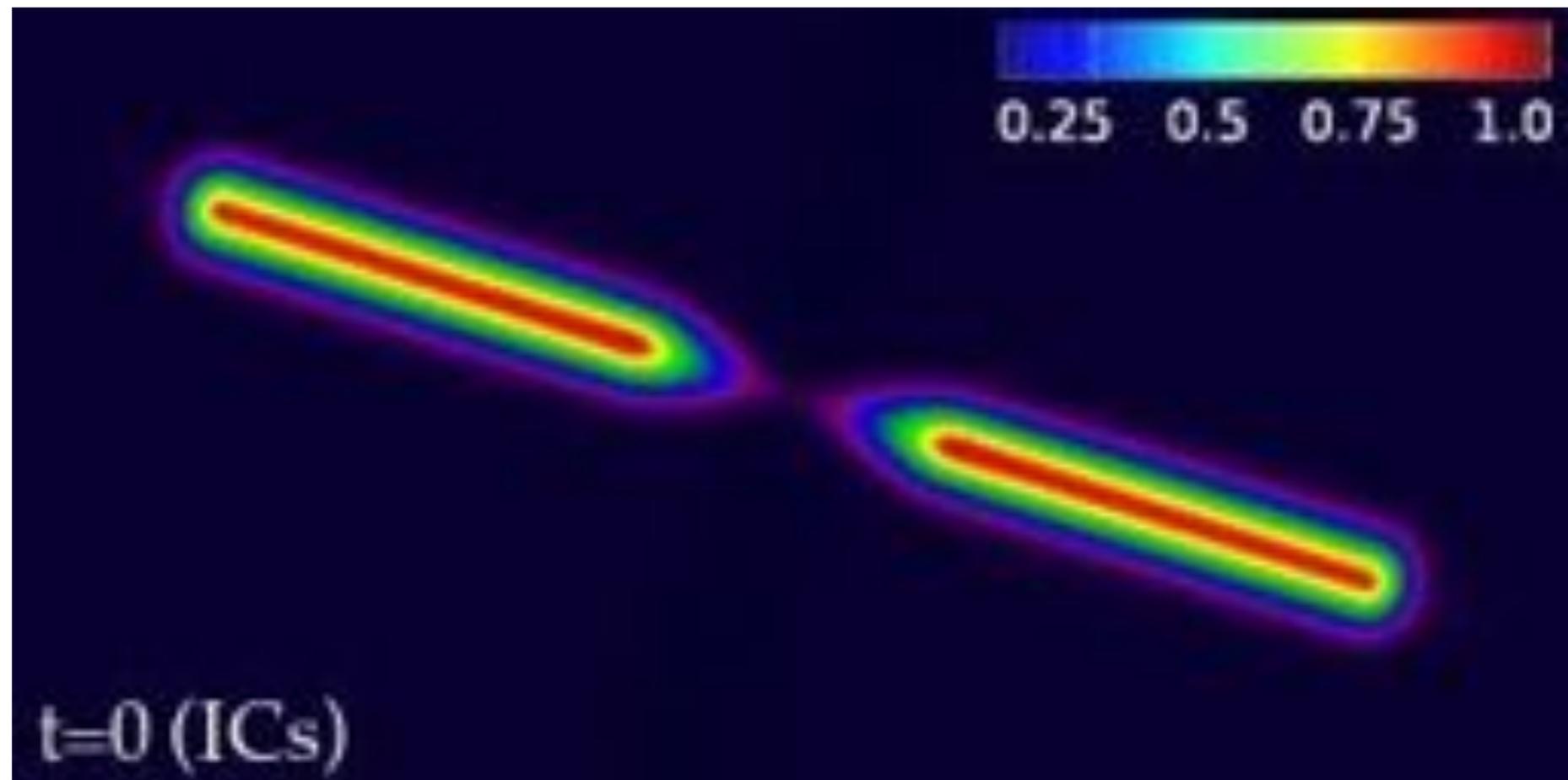


Comparing methods in GIZMO: Angular Momentum



Comparing methods in GIZMO:

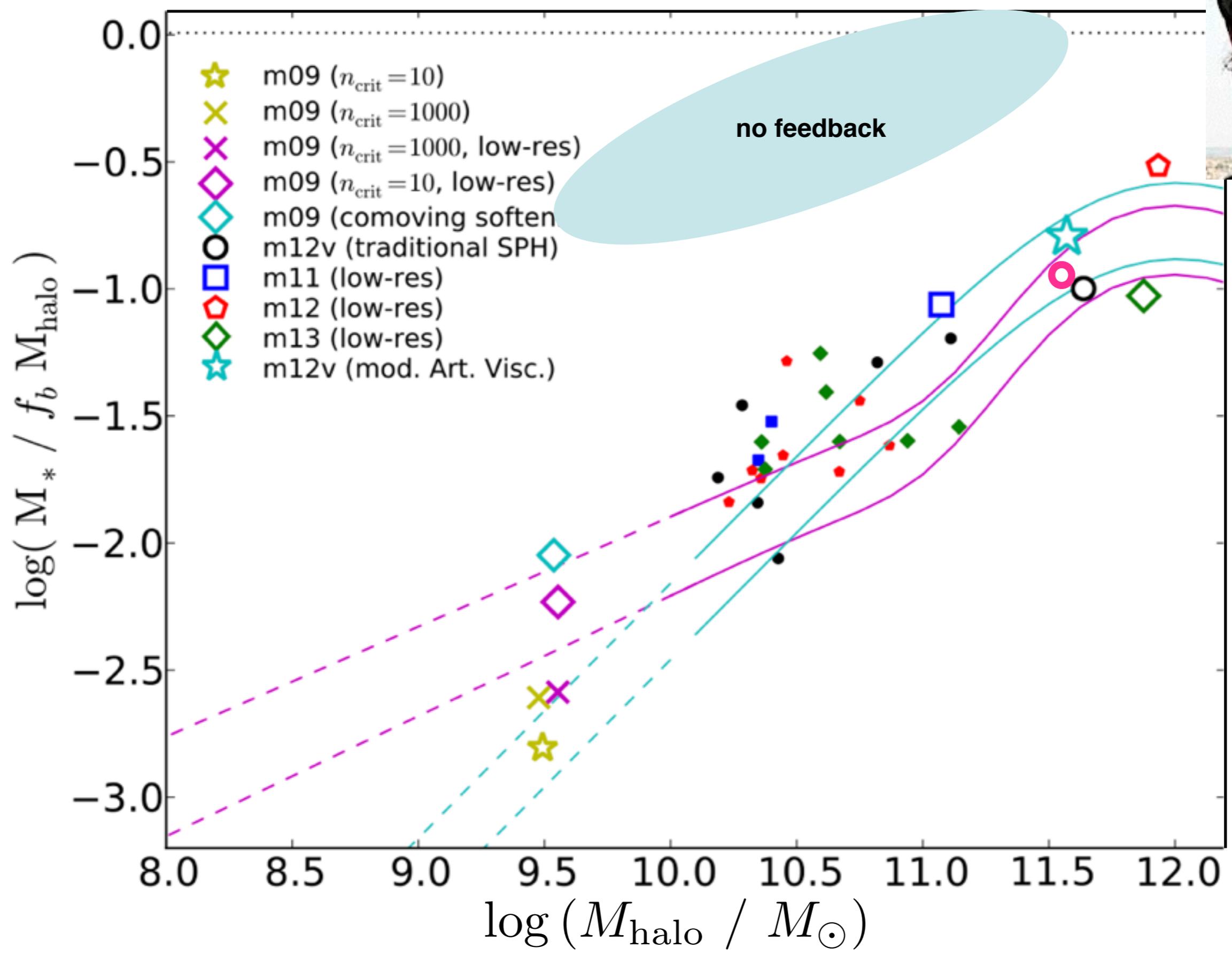
Grid
Alignment
in
Cartesian
meshes



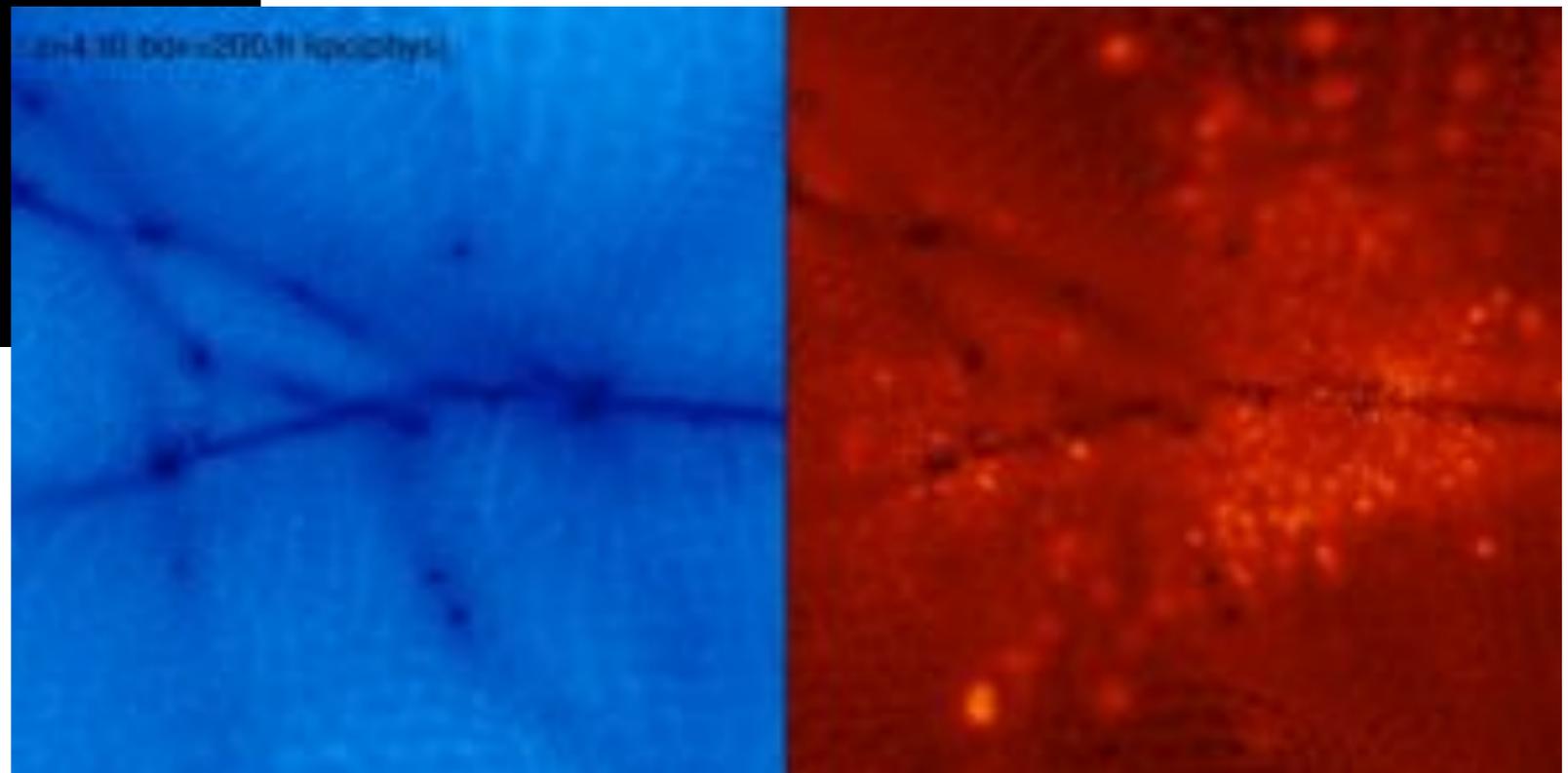
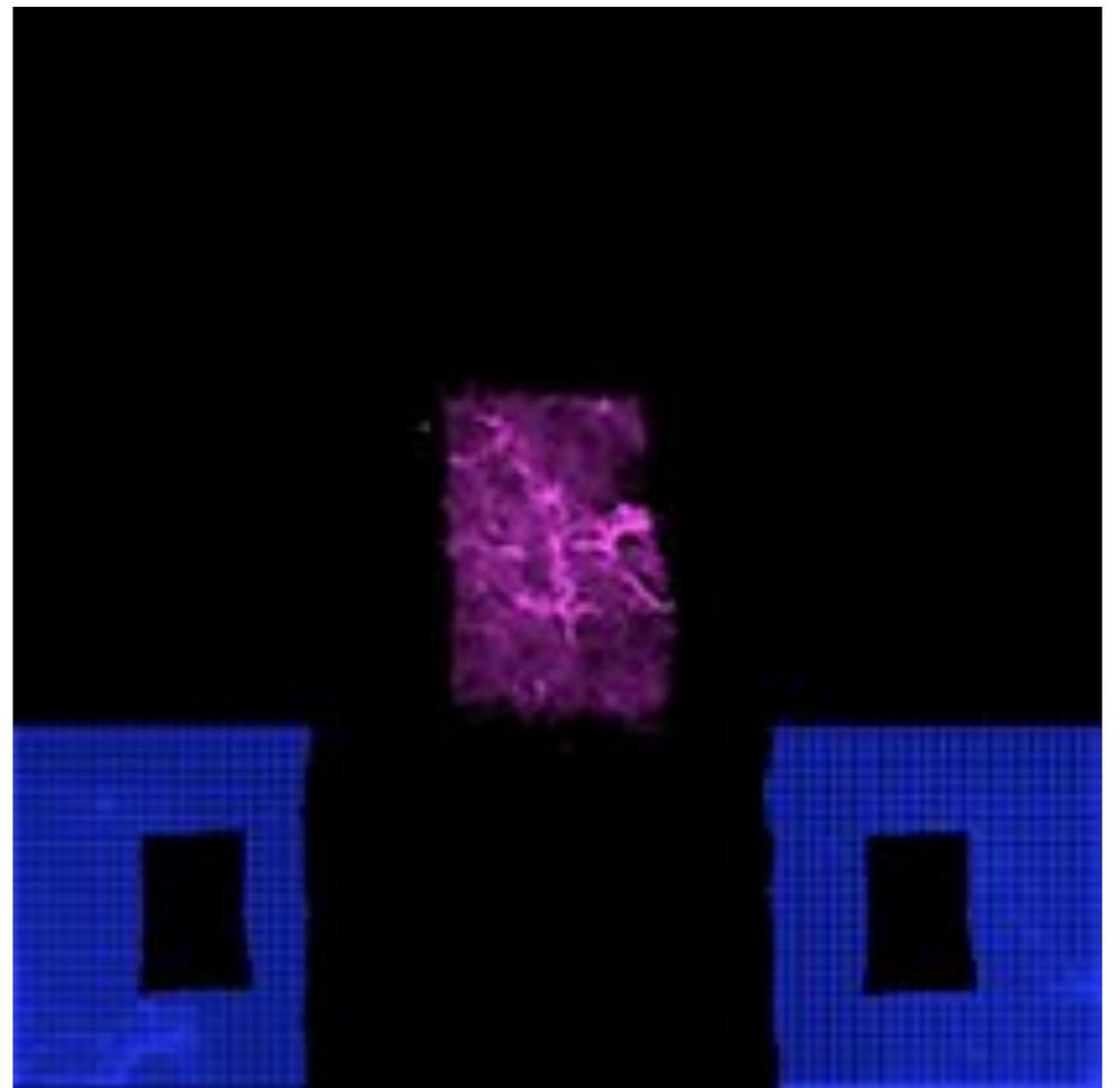
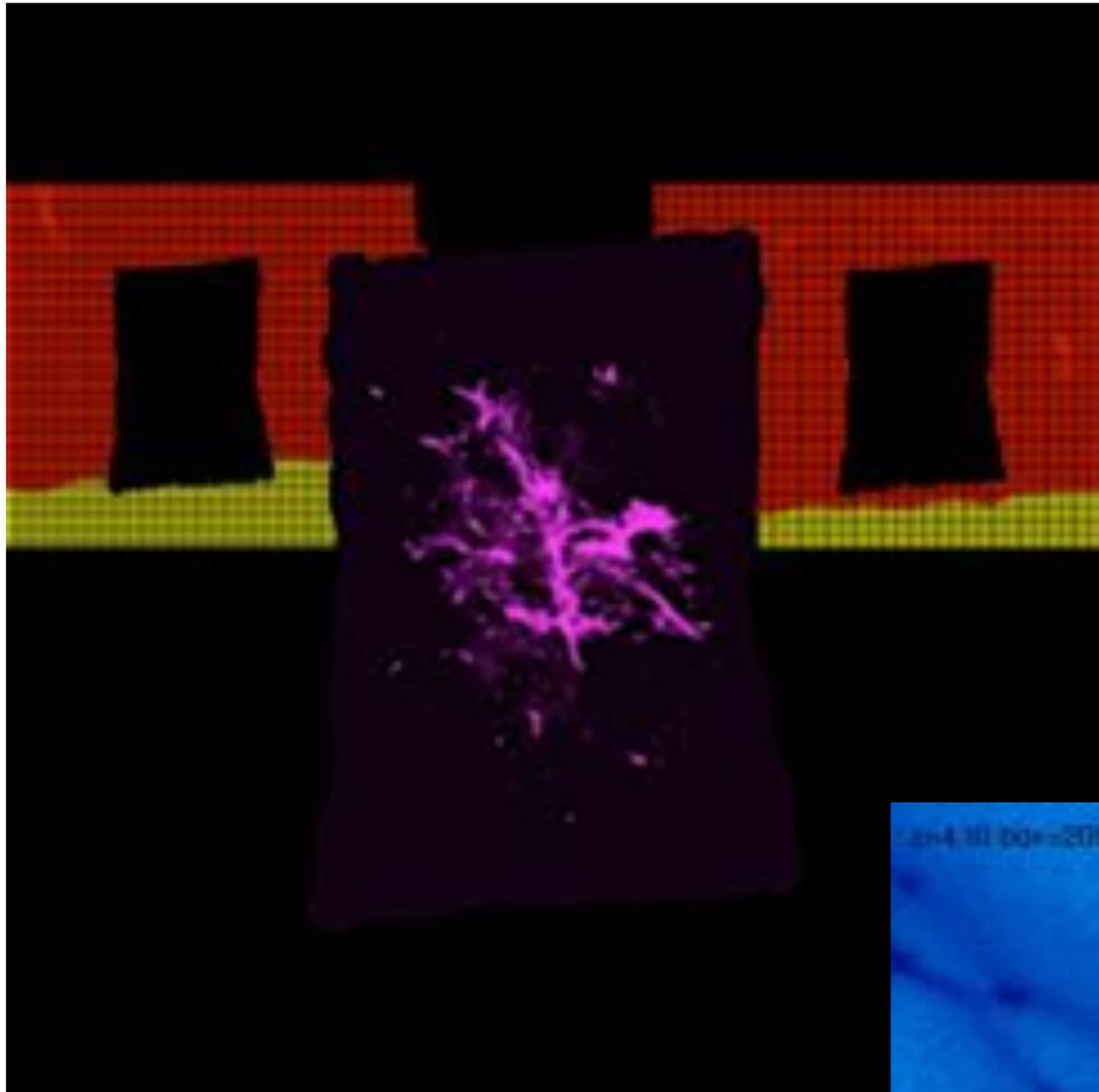
On Some Problems, Feedback Matters More

“ALGORITHMIC” CHOICES NOT DOMINANT

Keres et al.,
in prep



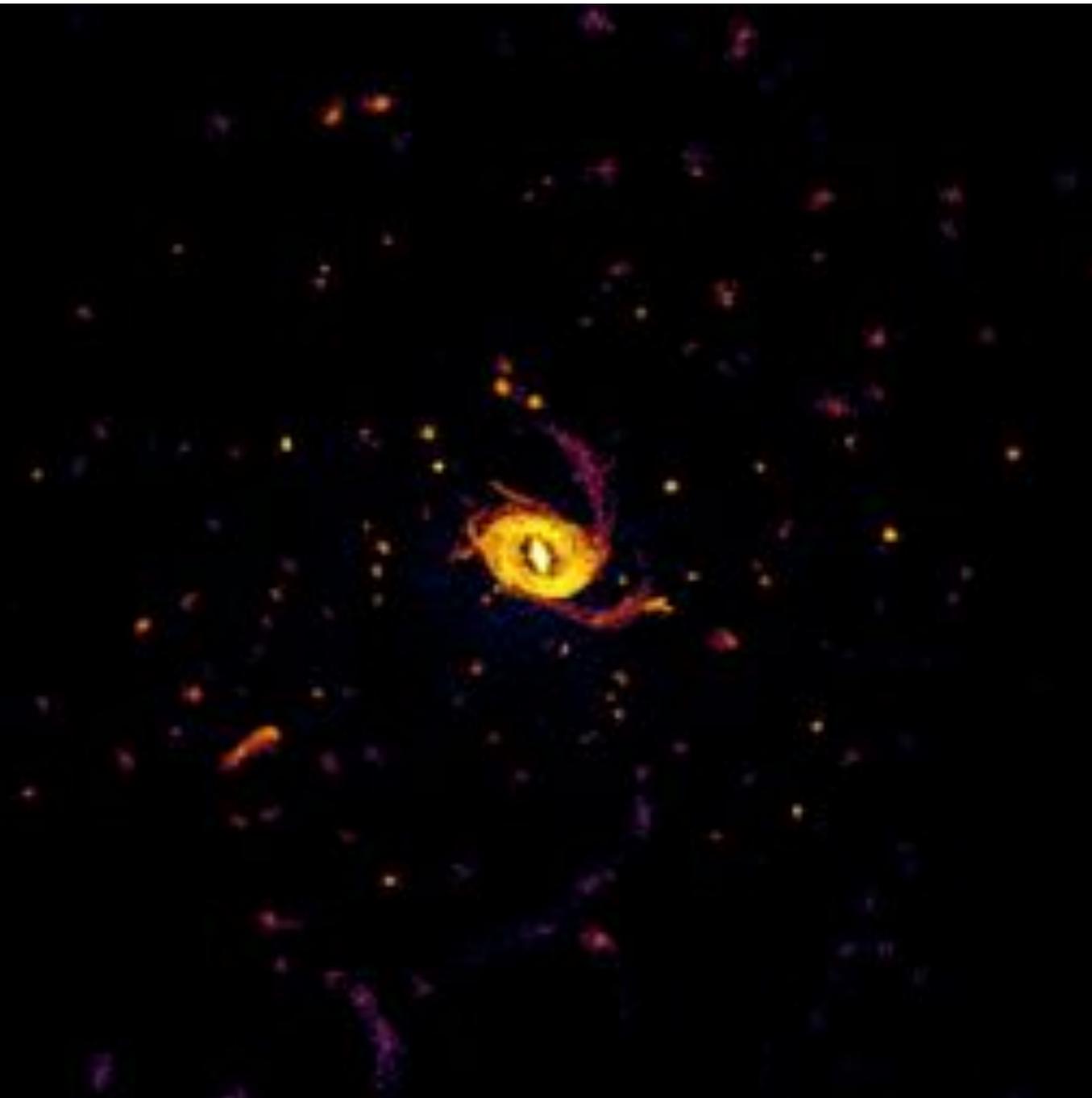
... up to a point ...



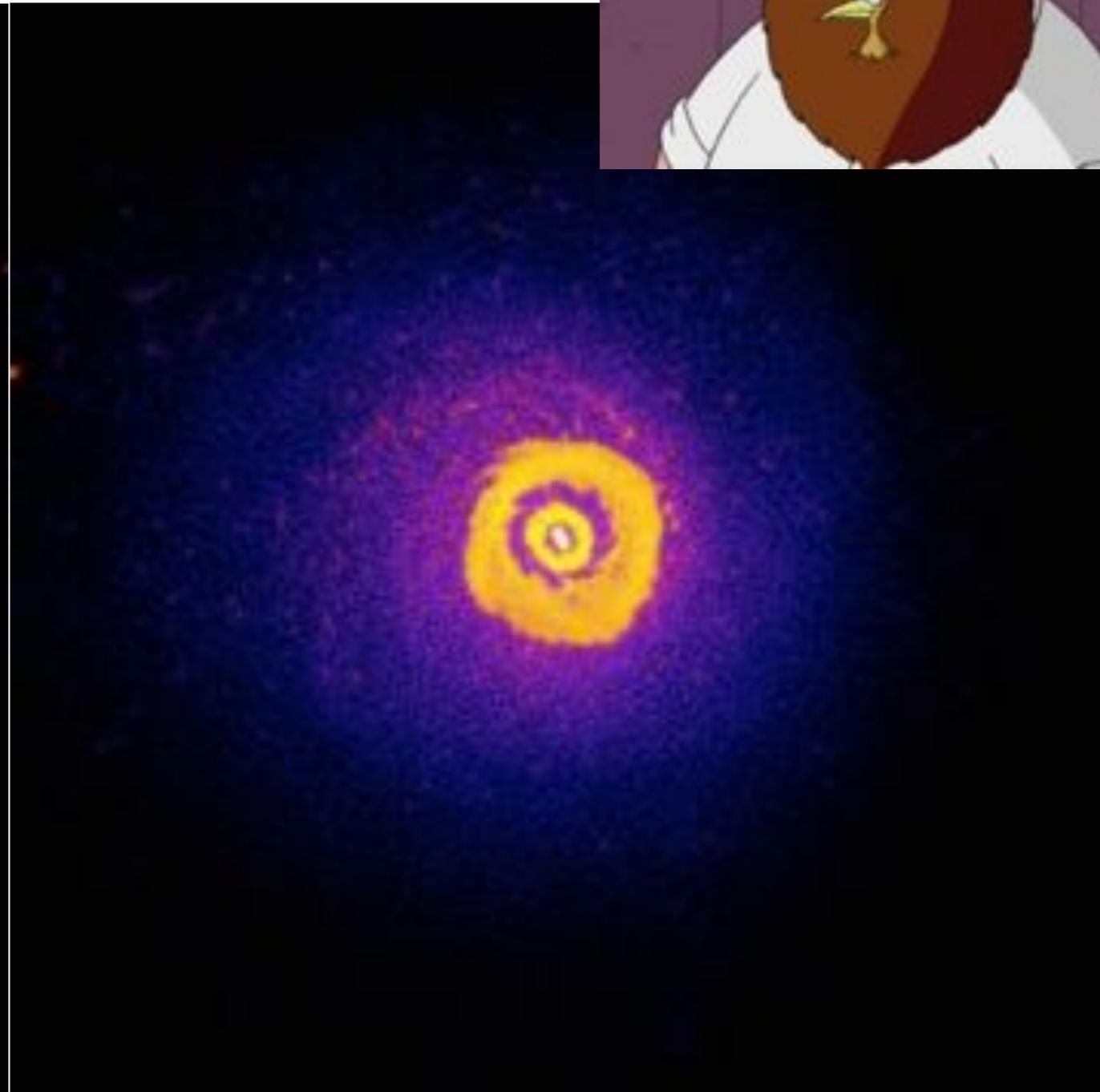
Gravitational Heating & Mixing

NOT AS MANY CLUMPS THESE DAYS!

Keres et al.,
(newer picture)



Density Formulation
("Old" GADGET)



Pressure-Entropy Formulation
(GIZMO)

Cooling from hot halo *is* sensitive to numerics

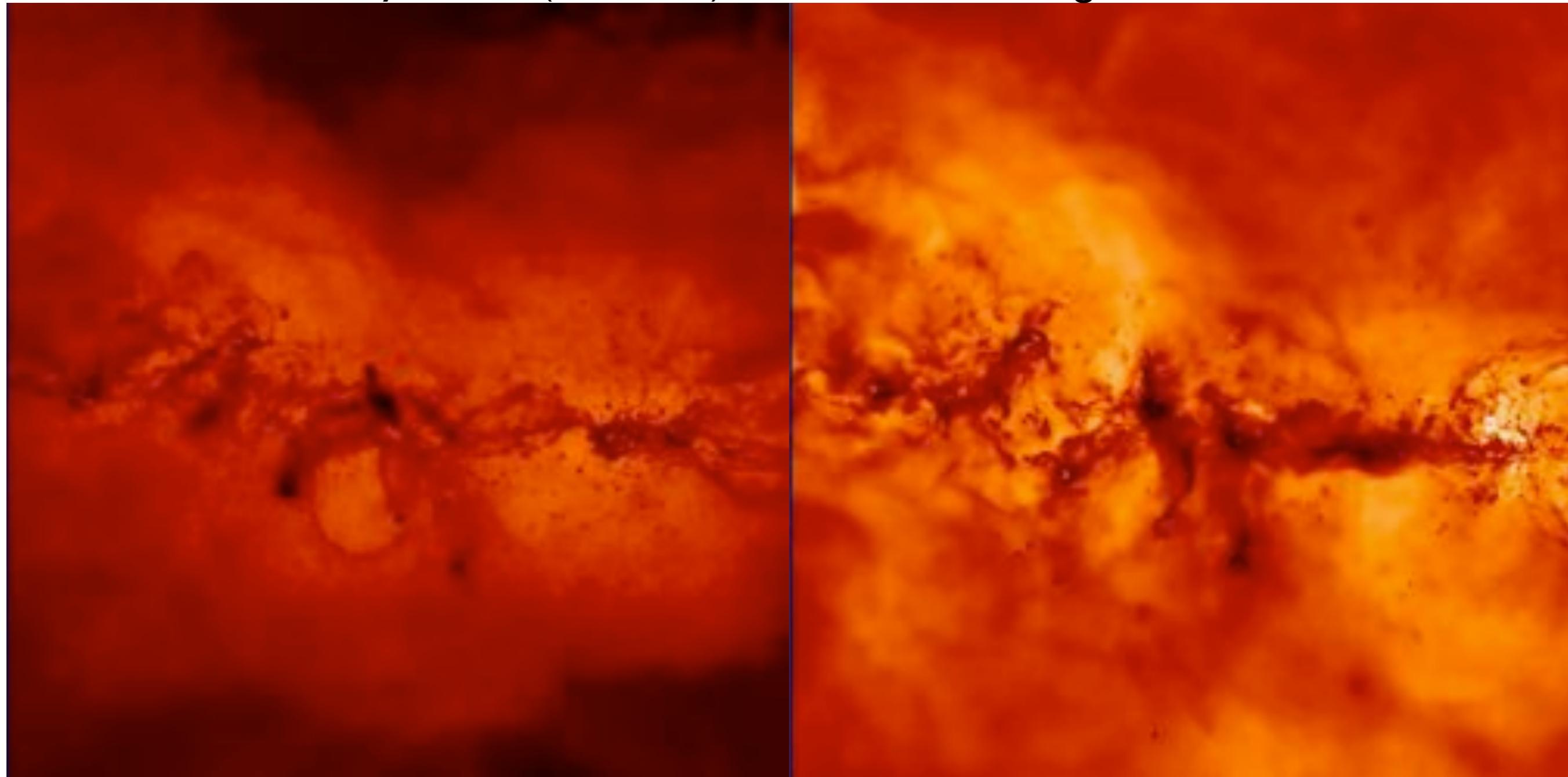
Sub-Grid vs. Explicit Physics

THIS MAY BE MORE IMPORTANT FOR IGM THAN NUMERICS

Proto-MW: Gas Temperature:

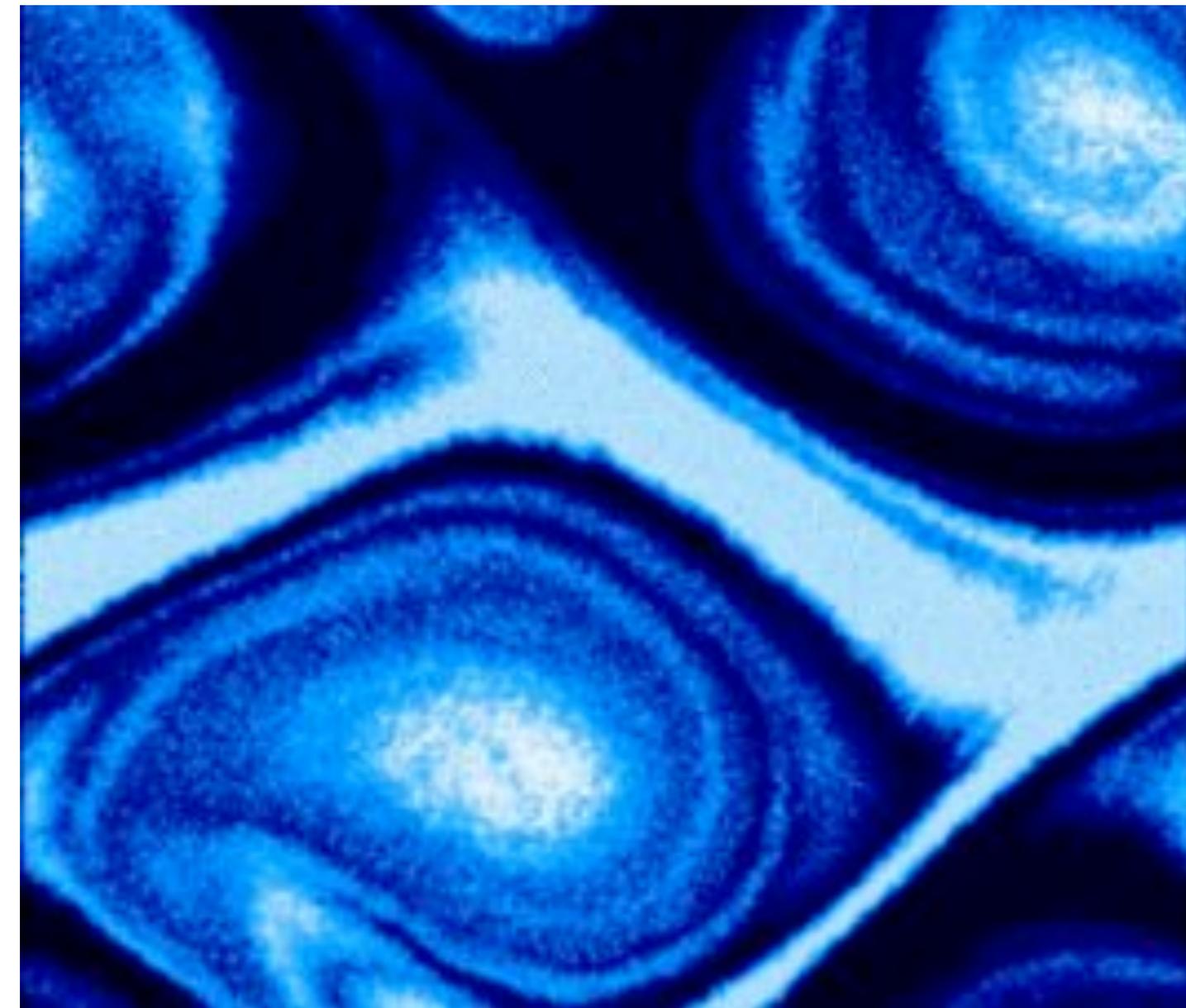
Insert Winds “By Hand” (Sub-Grid)

Following Full Feedback

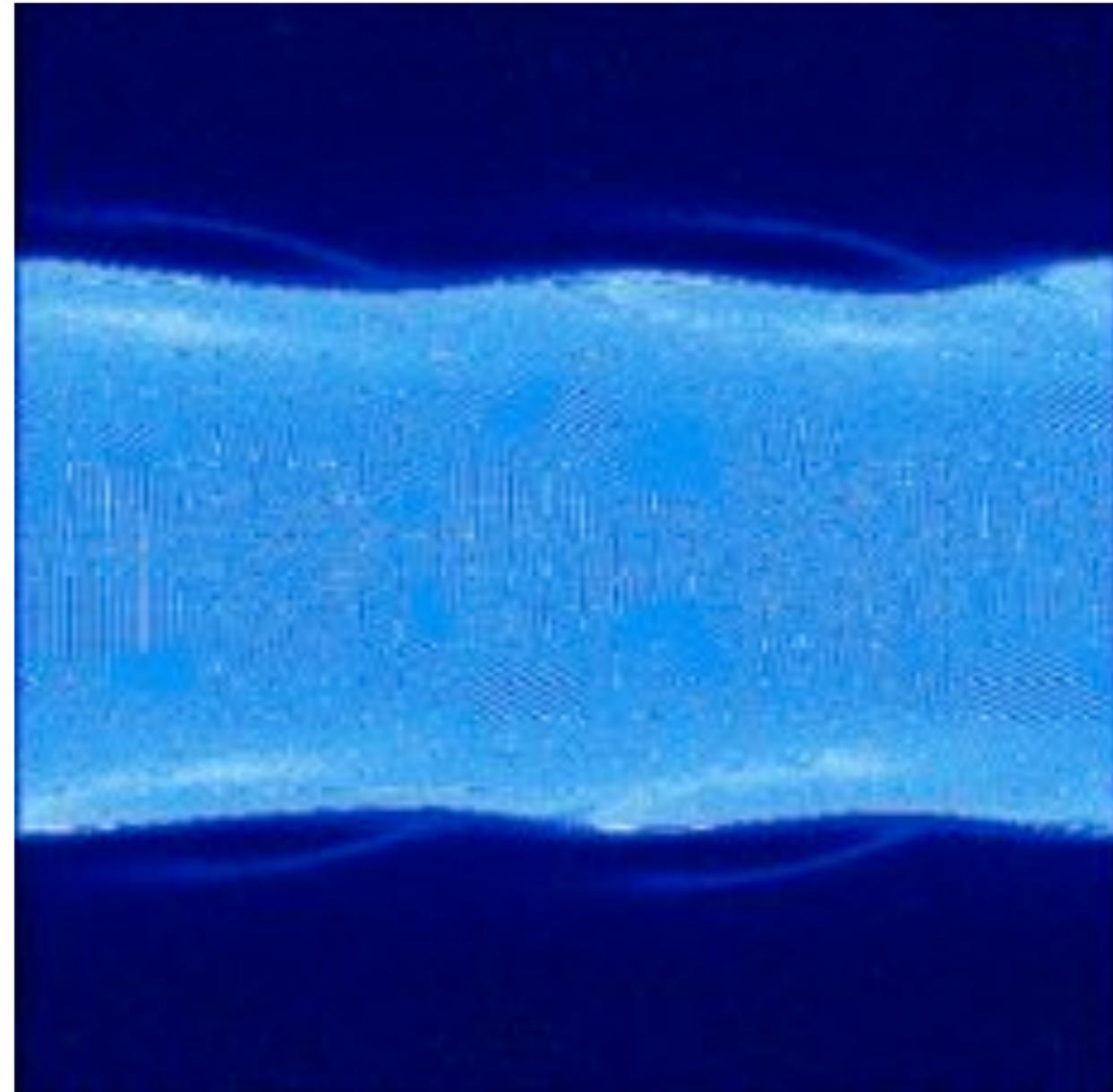


A Caution:

DON'T MISTAKE NUMERICAL "PRECISION" FOR PHYSICAL ACCURACY!



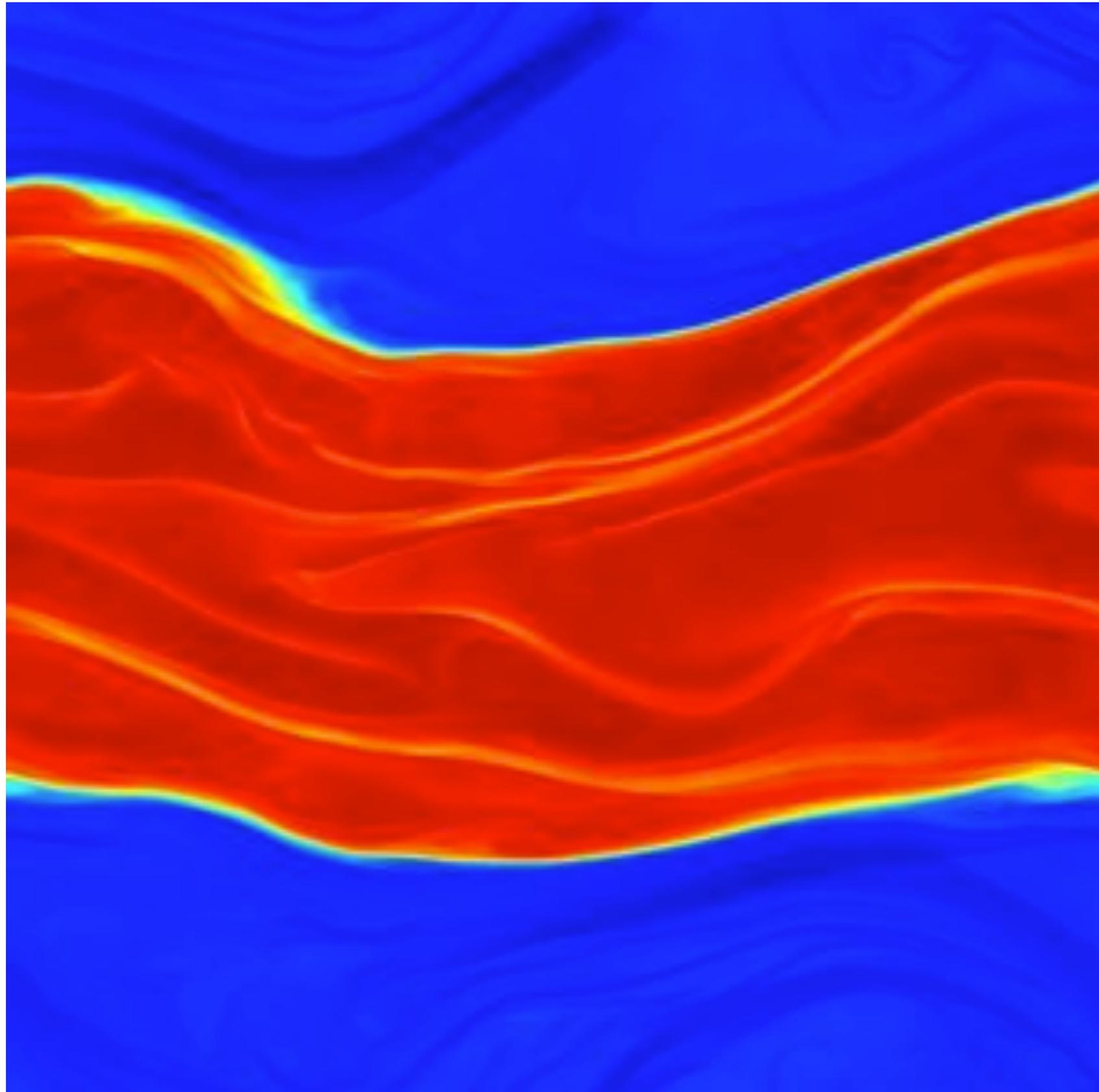
Pressure-Entropy Formulation
(P-SPH)



Density Formulation
("Old" GADGET)

A Caution:

DON'T MISTAKE NUMERICAL "PRECISION" FOR PHYSICAL ACCURACY!



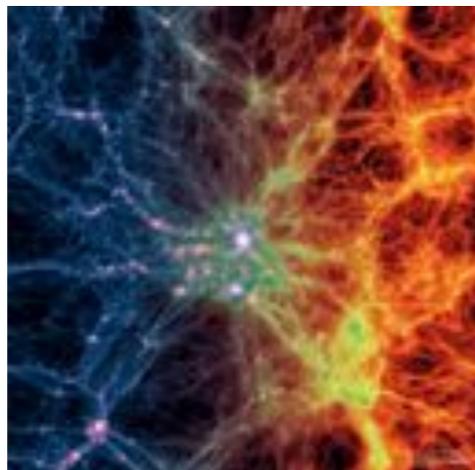
Magnetic KH (Athena)
(Equipartition field)

- **Important:**
 - non-ideal MHD
 - conduction
 - physical viscosity
 - radiation hydro
 - multi-phase structure (feedback, cooling)
 - dust-gas coupling
 - plasma effects
 - cosmic rays

Summary

- **Meshless methods are not dead!**
 - “Modern” SPH is ok for a lot of problems, but neighbor-number is a barrier
 - New: MFM, MFV may compete with moving-meshes
- **Advantages?**
 - Free surfaces (air-water, edge of star)
 - “Smooth” re-meshing
 - Constant-mass (follow gas, better gravity)
 - Angular momentum (for “irregular” config)
- **Disadvantages?**
 - Volume ‘re-meshing’ noise (Mach ~ 0.01)
 - Hard (‘wall’) boundaries
 - MHD? (is CT possible?)
- **Should you switch?**
 - *Why?* AREPO is great! But if there are *physics* you need to use (not in AREPO), there are other options
- **We are *physics-limited***
 - Better numerics doesn’t always mean “more realistic”!

Illustris
(large-scale,
statistics)



+



FIRE
(small-scale,
microphysics)