Attempts at characterizing the structures of high dissipation in the ISM

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Motivation / Outline

- The diffuse ISM contains a lot of complex molecules and they are excited (e.g. bright CO, warm H2).
- Large scale turbulent motions dissipate at small scales, with intense bursts of heating.
- How much of the molecular content can be explained by this localised heating ?
- How can we characterize observationnaly these strongly dissipative structures ?

I) 3D simulations to probe their geometry and statistics

II) 2D simulations to start probing their chemistry

Characteristics of the ISM

- Diffuse $n_H \sim 30/cm^3$, Molecular $n_H \sim 200/cm^3$
- $\langle u^2 \rangle \sim \langle b^2/\rho \rangle$ (Alfvénic Mach number ~ 1)
- Sonic Mach number ~ 4

Decaying turbulence simulations:

- Incompressible with $\langle u^2 \rangle \sim \langle b^2/\rho \rangle$ [code ANK]
- Compressible isothermal with Mach ~ 4 [DUMSES]

Dissipation in the ISM

- Viscous friction: $Re=LU/\nu \sim 2.10^{7}$
- Resistivity: $Re_m=LU/\eta \sim 2.10^{17}$
- Ambipolar diffusion: $Re_a=L/Ut_a \sim 10^{2}\text{-}10^{3}$
- $L\sim 3 – 10\ pc >> l_a >> l_\nu >> l_\eta$

Dissipation in our simulations

- Viscous friction: $Re = LU/\nu \sim 2.10^{7}$ 10^{3}
- Resistivity: $Re_m = LU/\eta \sim 2.10^{17}$ 10^{3}
- Ambipolar diffusion: $Re_a = L/Ut_a \sim 10^{2}$-$10^{3}$
- $L >> l_a >> l_\nu \sim l_\eta$

Note: no Ambipolar Diffusion (A.D.) in DUMSES yet.

Dissipation is localised

30% of the total dissipation happens in 3% of the volume

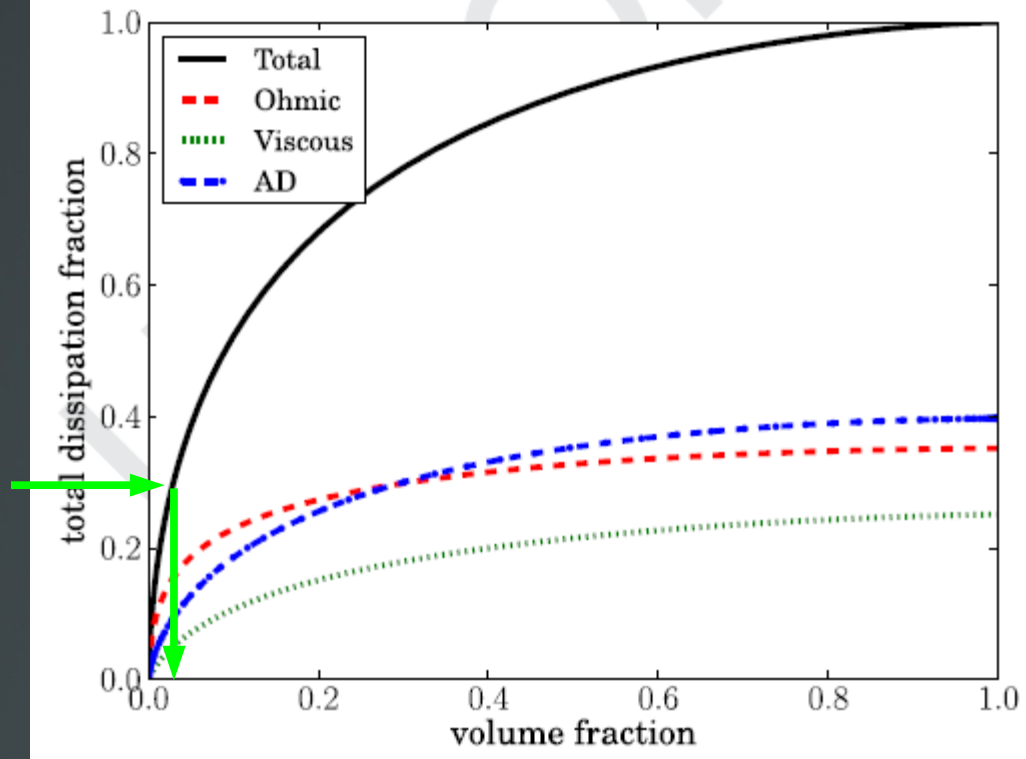
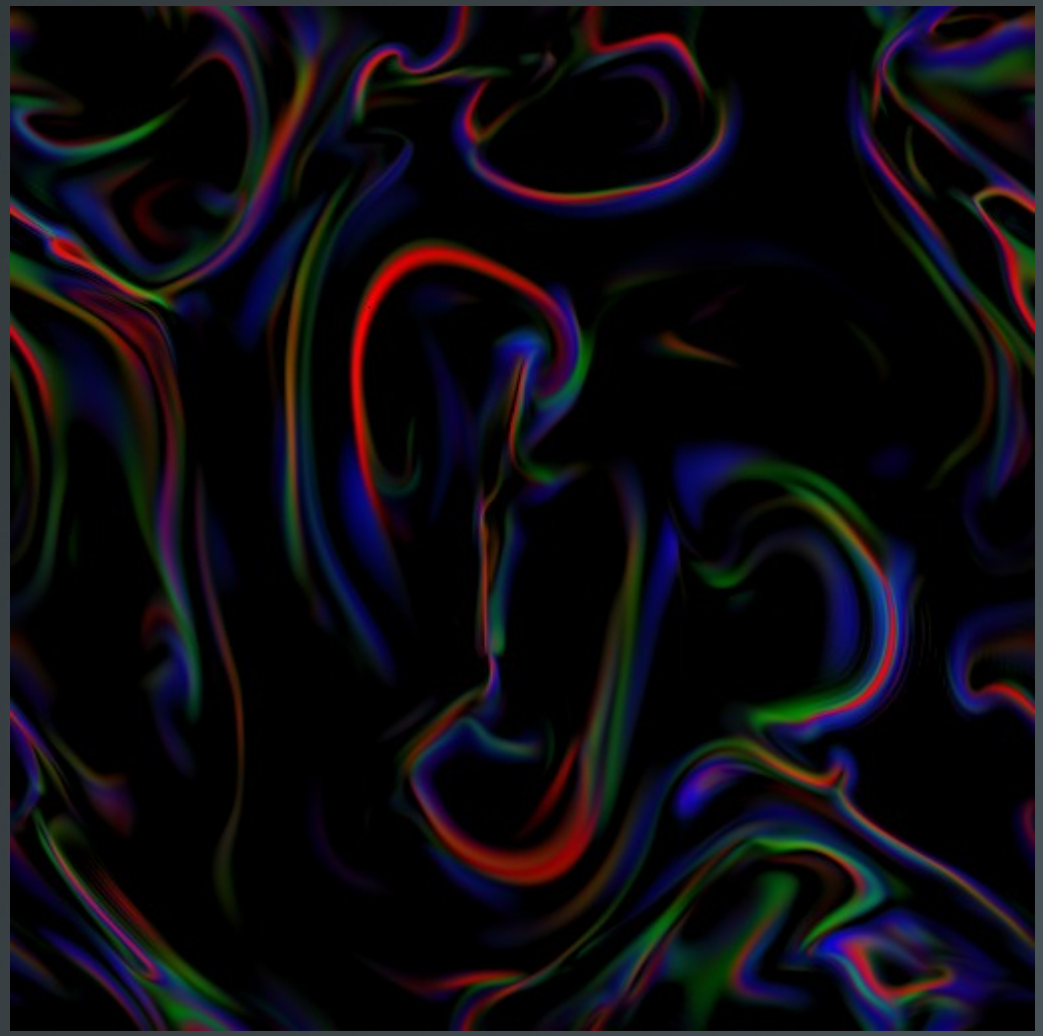


Figure 19. We look at the subset of pixels above a given threshold of total dissipation in run 12 (AD-OT, $\mathrm{Re_a} = 100$) at the dissipation peak. For each value of the threshold, we plot the fraction of the total energy dissipation on this subset versus the volume of this subset (black curve). We also give the fraction of the total dissipation on this subset for each nature of dissipation (red: Ohmic, green: viscous, blue: AD).

Momferratos et al. (2014)

Nature of the dissipation



$$\varepsilon_t = \varepsilon_v + \varepsilon_o + \varepsilon_a$$

Dissipative heatings:

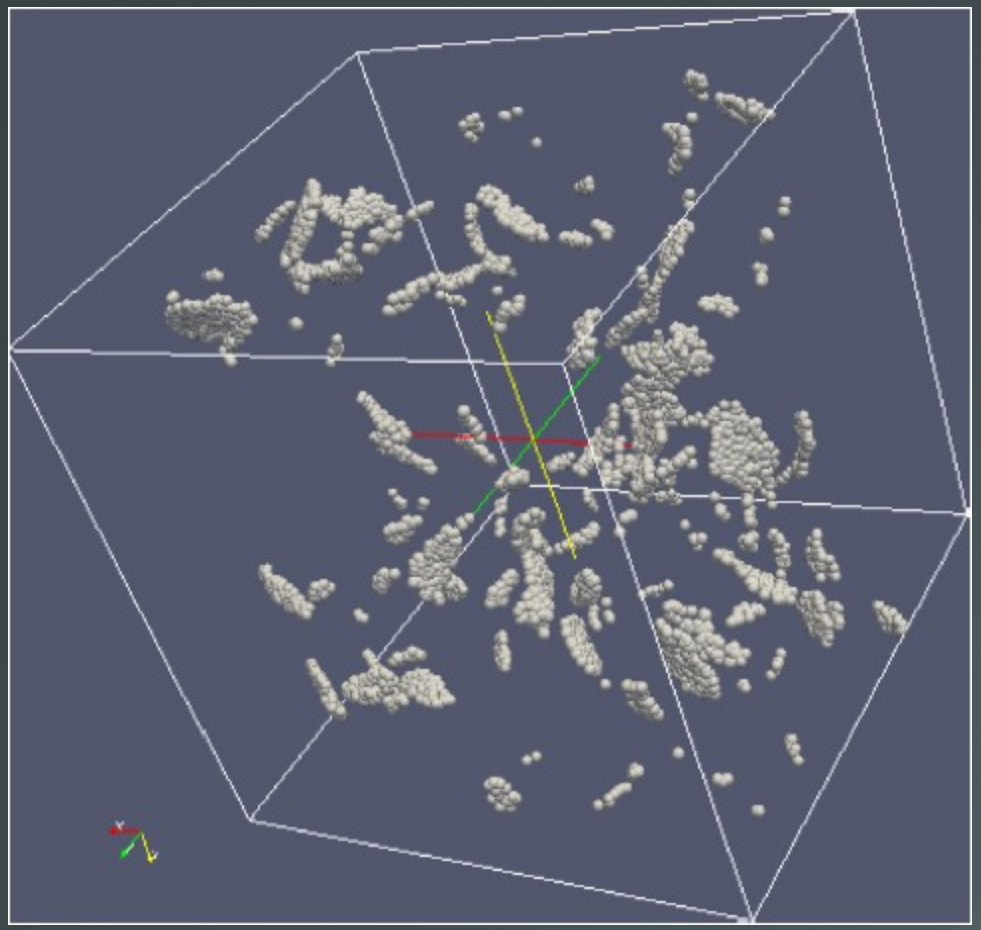
- **Green**: viscous
- **Red**: ohmic
- Blue: ion-neutral drift

2D Slice of a 512^3 pseudo-spectral 3D incompressible MHD + A.D. Decaying turbulence from an Orzag-Tang vortex.
Snapshot **at peak dissipation.**

G. Momferratos

Structures extraction

Connected sets above threshold of total dissipation
(> mean + 2 sigma) are defined as strong dissipation structures.



All inertial range structures

Scaling relations

Total dissipation in a structure ~ Length ^{D}
with D=2.1 +/- 0.3

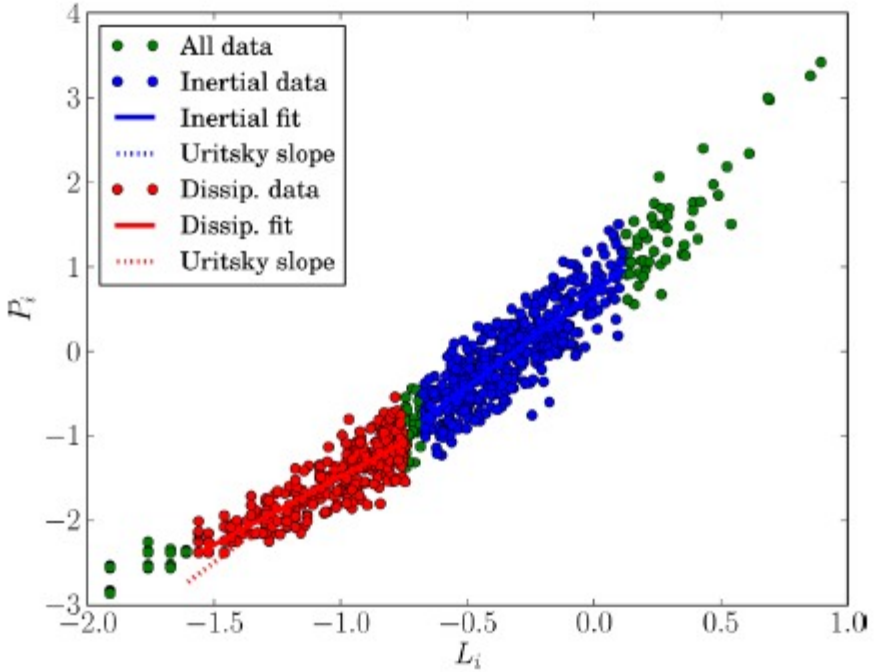


Figure 17. Scaling relations $P_i \propto L_i^{D_P}$ from run 12 (AD-OT), at the peak of dissipation, with a threshold of two standard deviations above the mean value. The dotted line shows the effect of adopting the slope found by UR10 instead of our own slope.

Momferratos et al. (2014)

Integrated Observables

Centroid velocity: first moment of the l.o.s. velocity

$$\mathrm{CV}(x,y) = \int_0^L u_z(x,y,z)\ dz$$

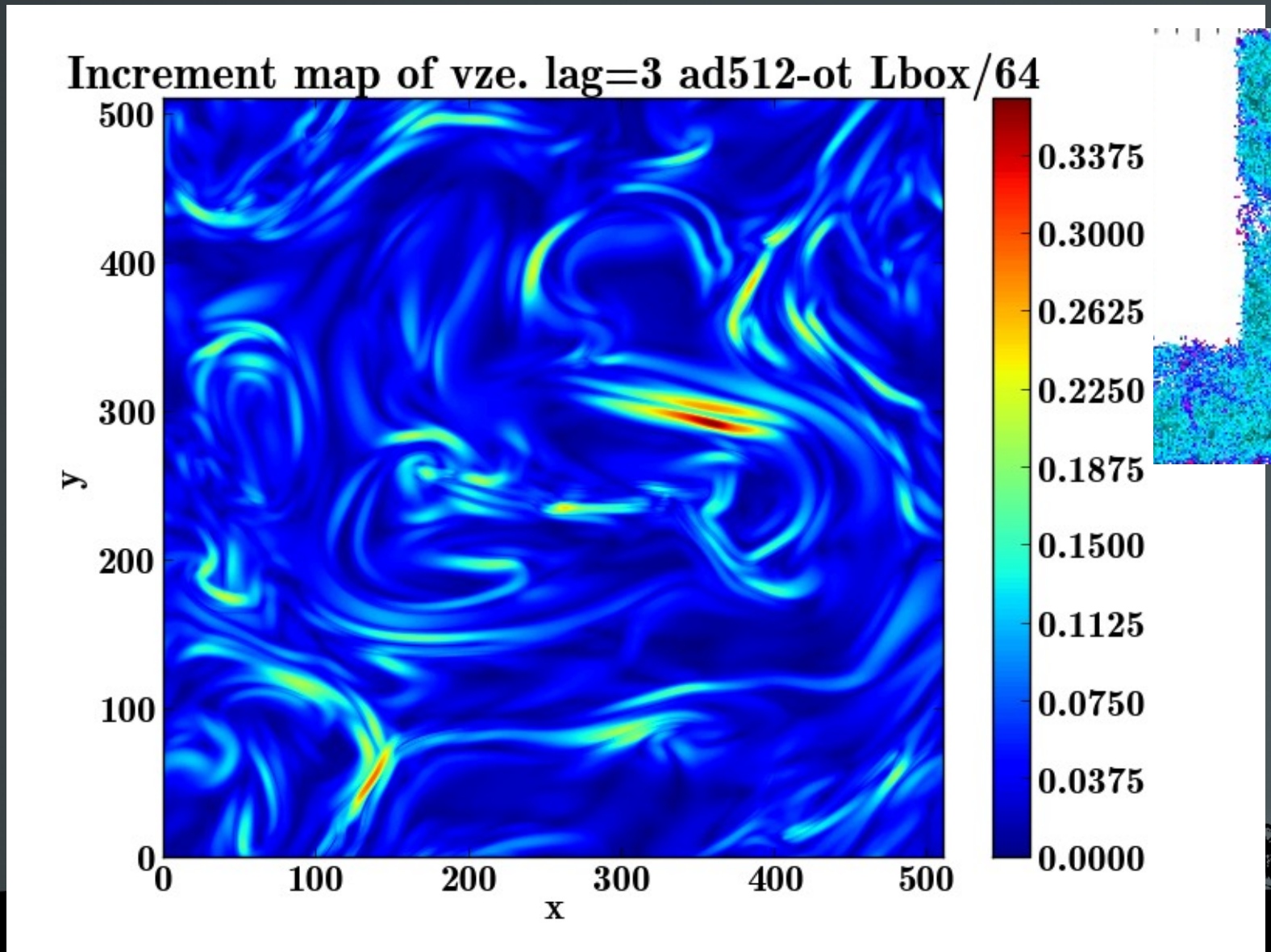
Assuming that total dissipation powers the line
(or that a chemical tracer appears right where there is heating):

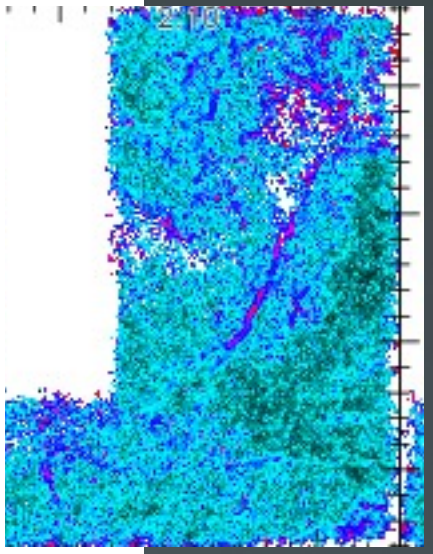
$$\mathrm{CV}_w(x,y) = \frac{1}{\langle\varepsilon\rangle}\int_0^L \varepsilon(x,y,z)\ u_z(x,y,z)\ dz$$

Other variables:
Stokes parameters of the polarization (Q, U, I, P)...

Increments of Integrated Observables

They probe the variation of an observable in the p.o.s. over a given lag.

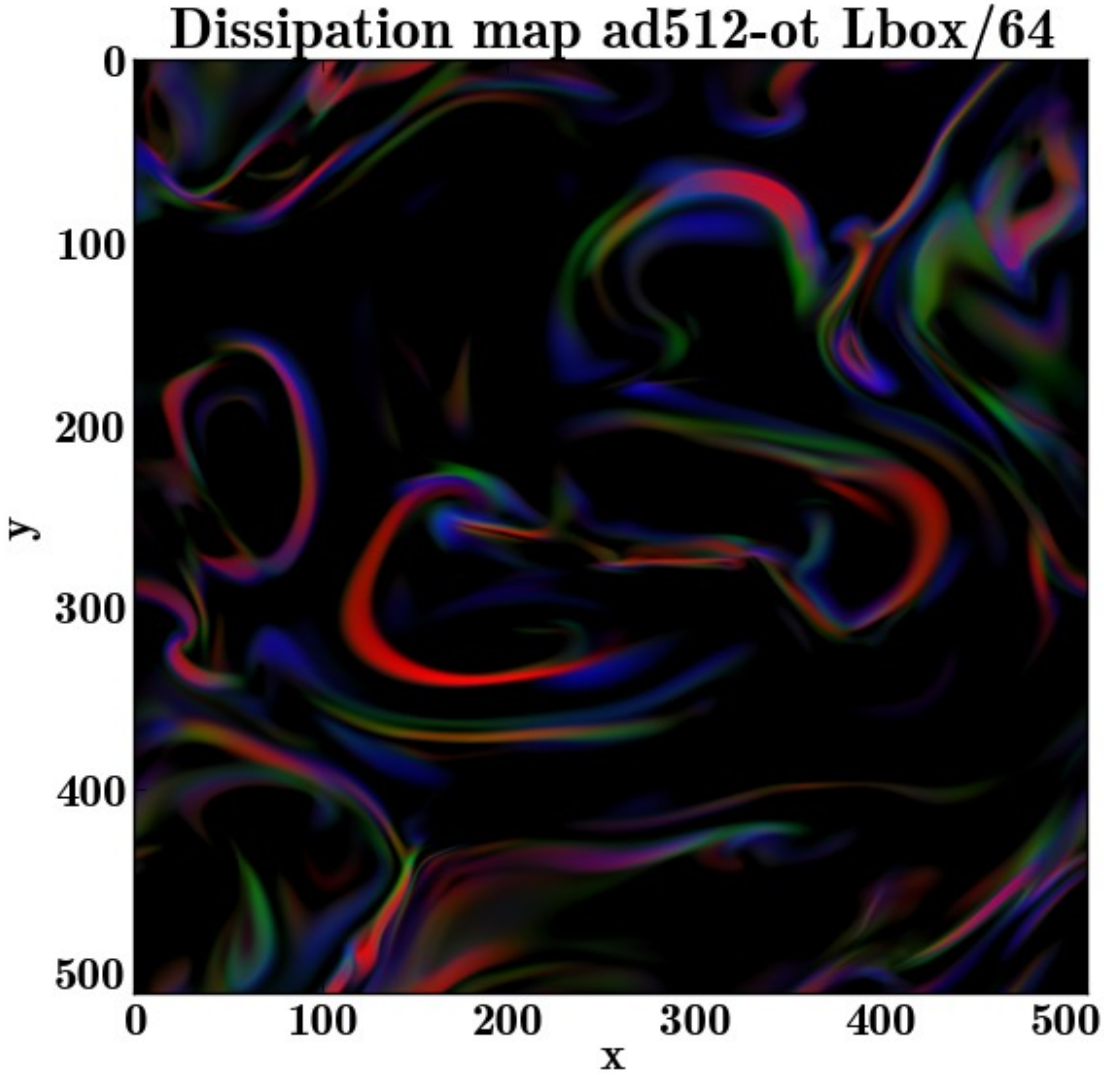




Polaris
Hily-Blant
(2008)

Increments of Integrated Observables

Are correlated with structures of strong dissipation.



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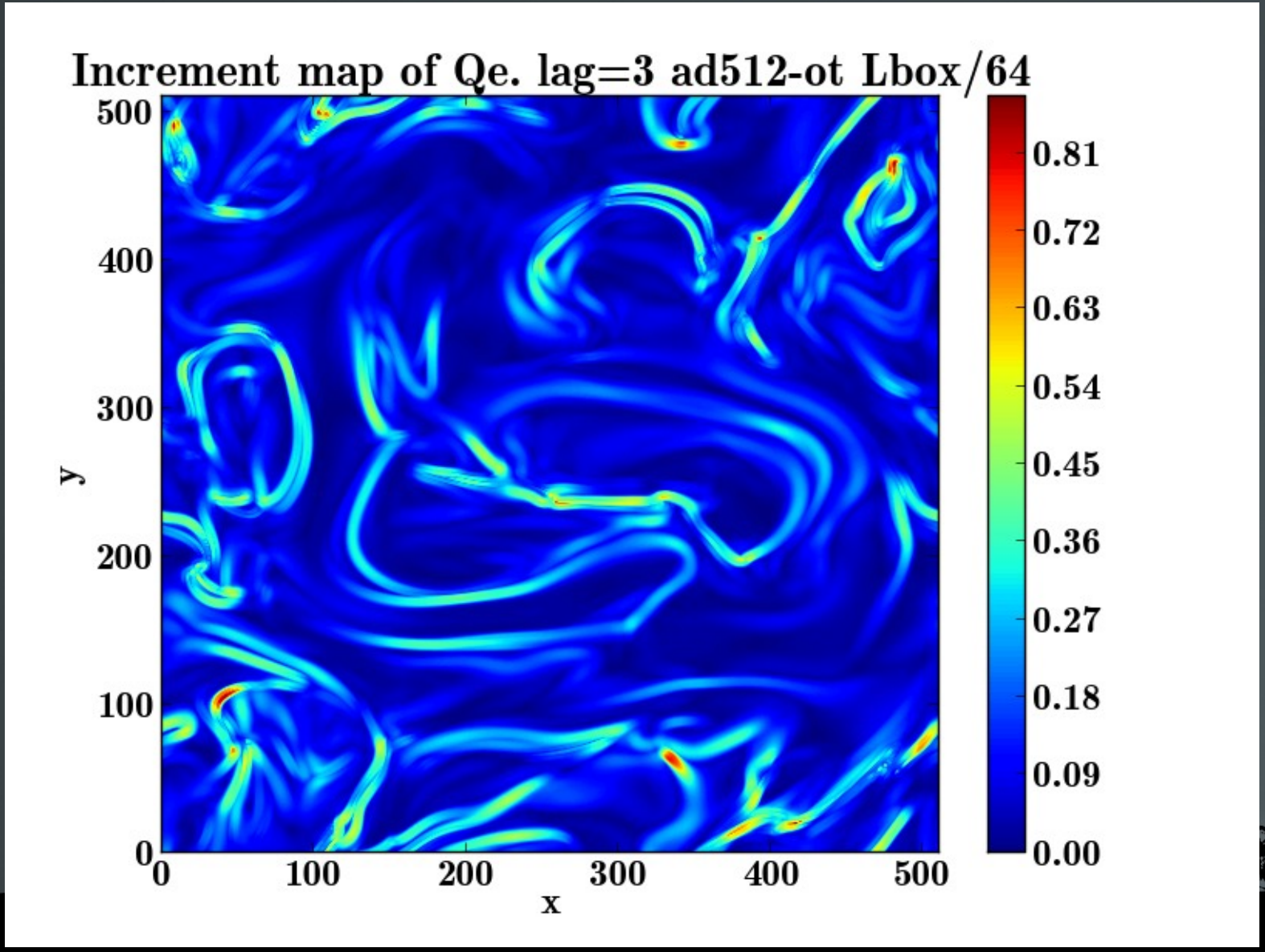

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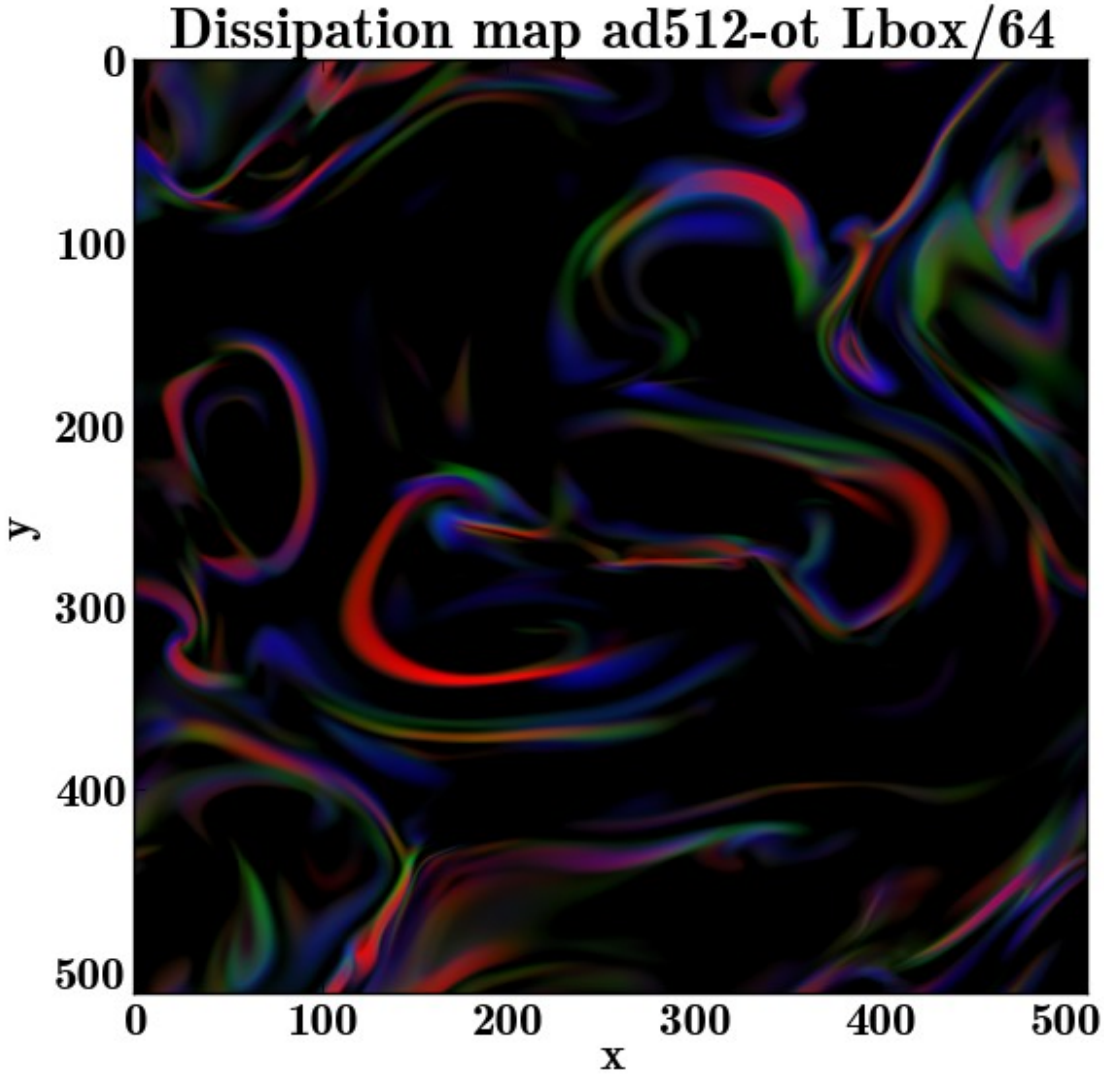

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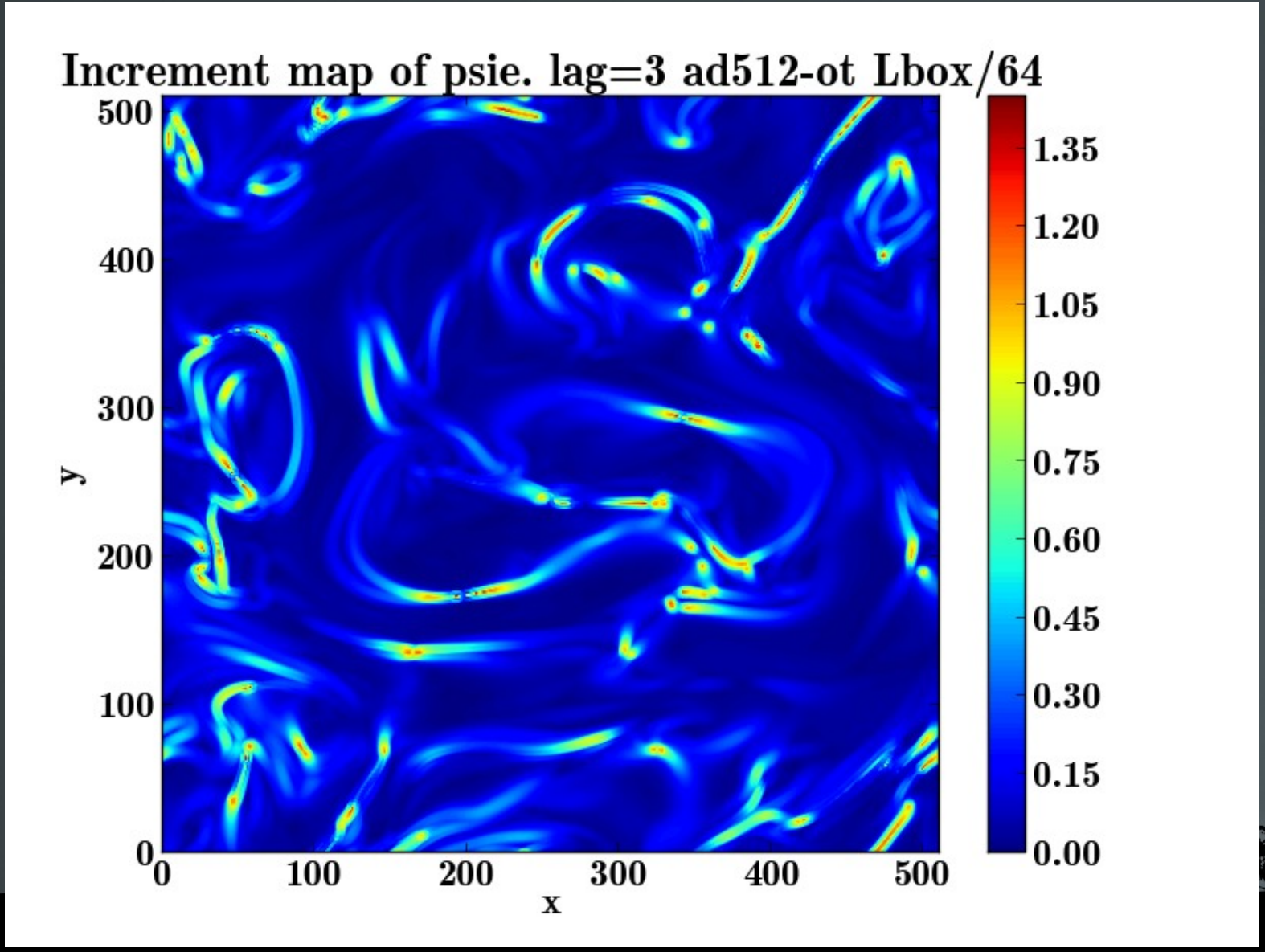

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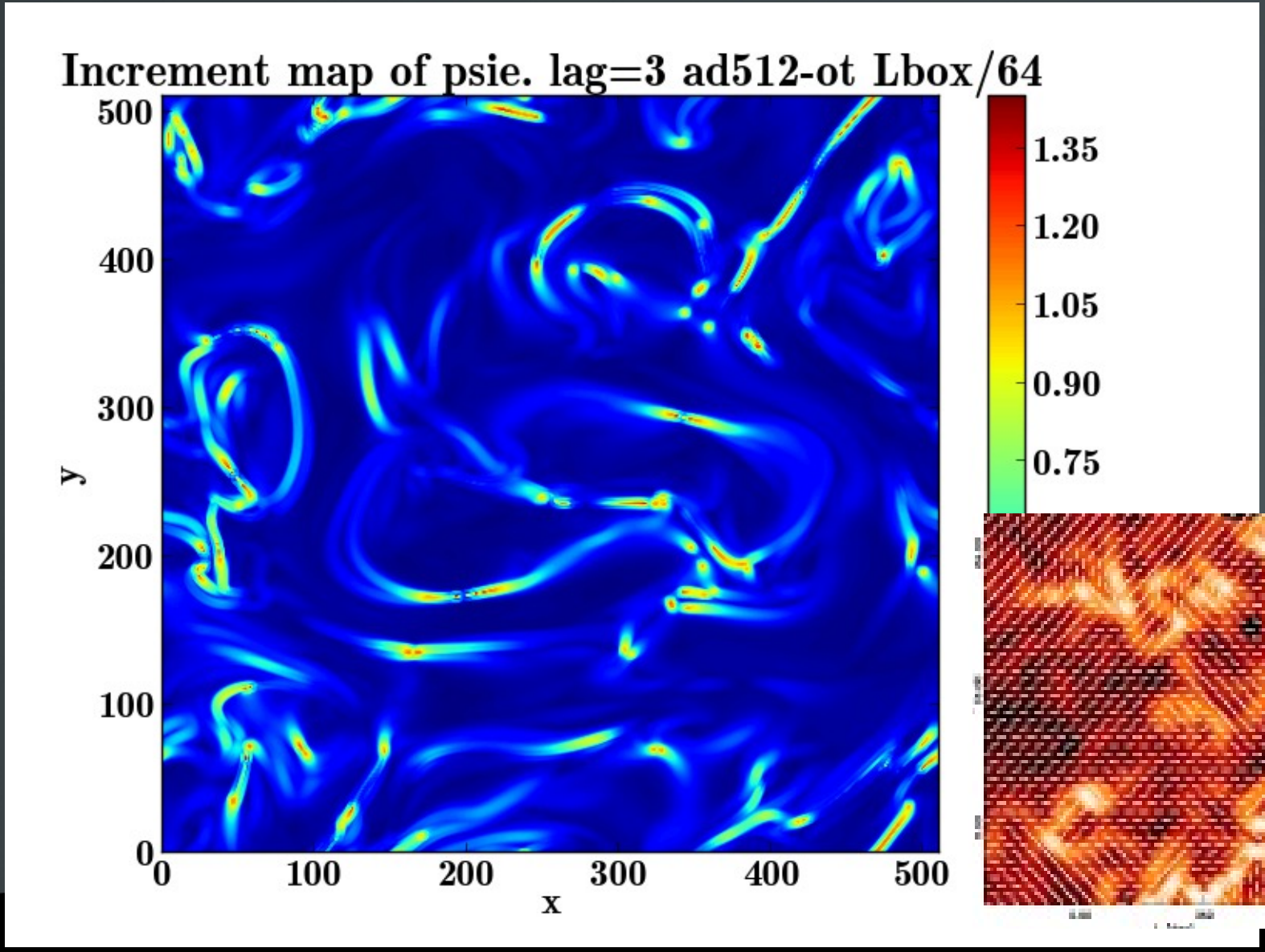
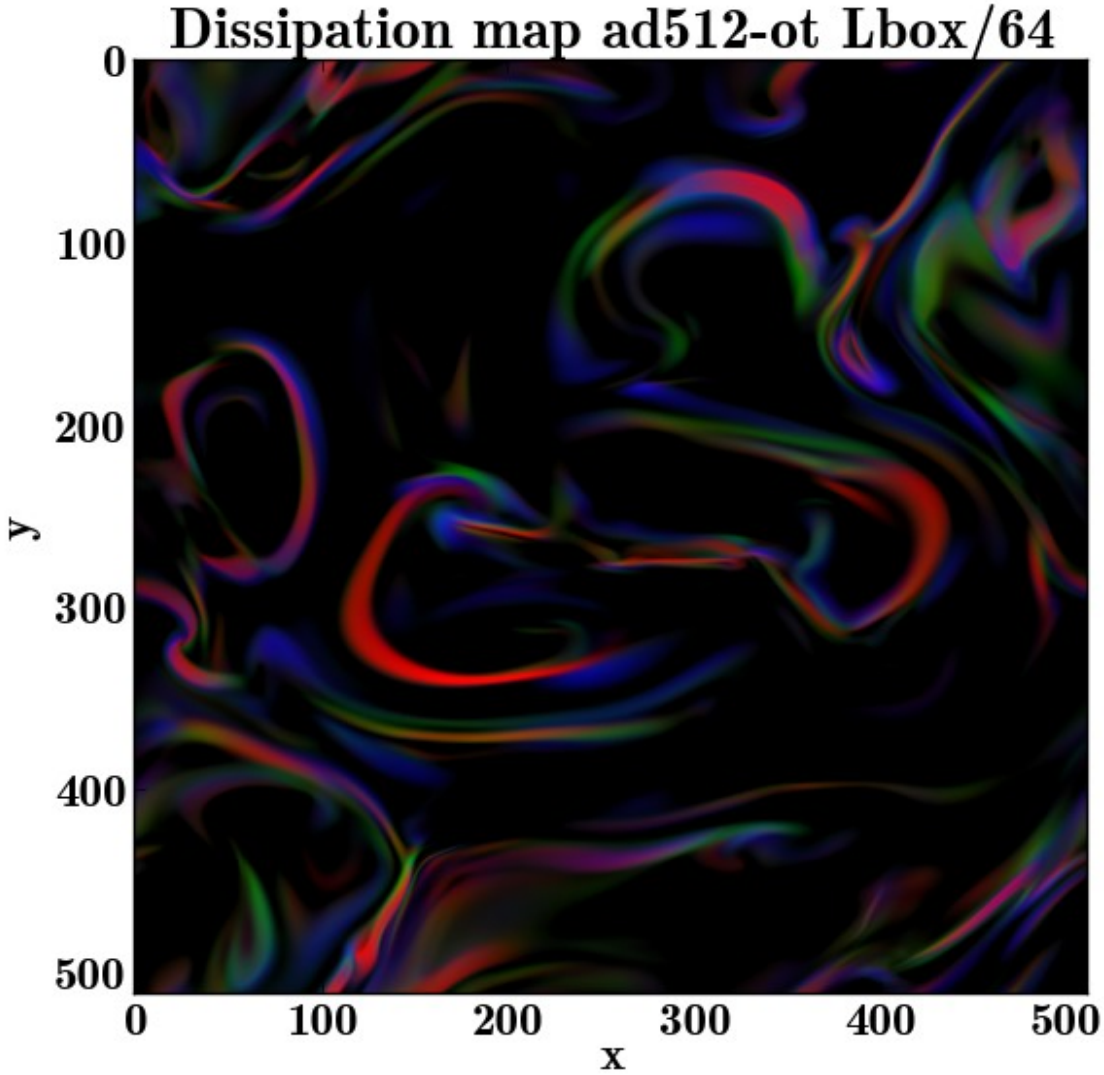


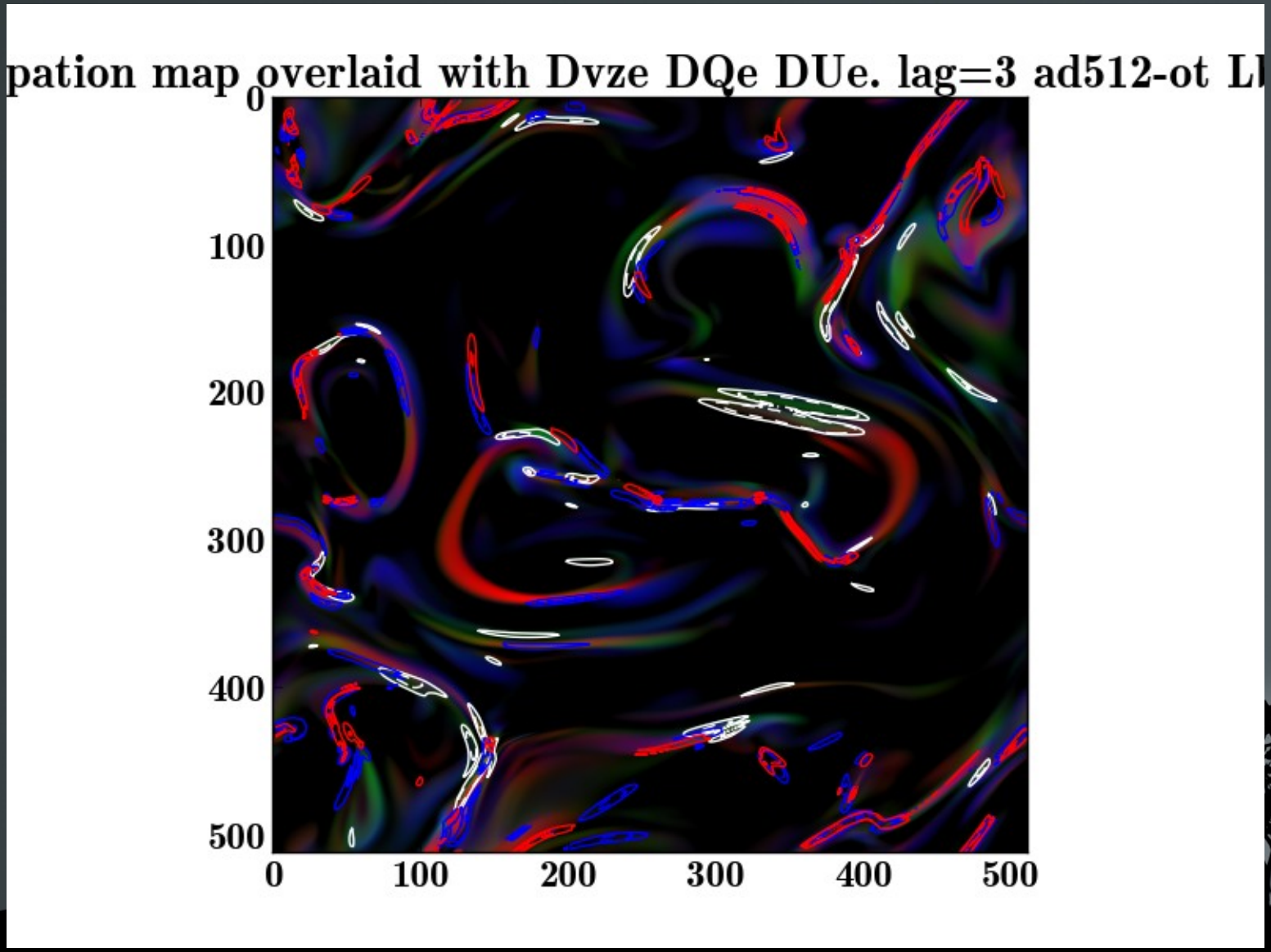
Increments of Integrated Observables

Are correlated with structures of strong dissipation.



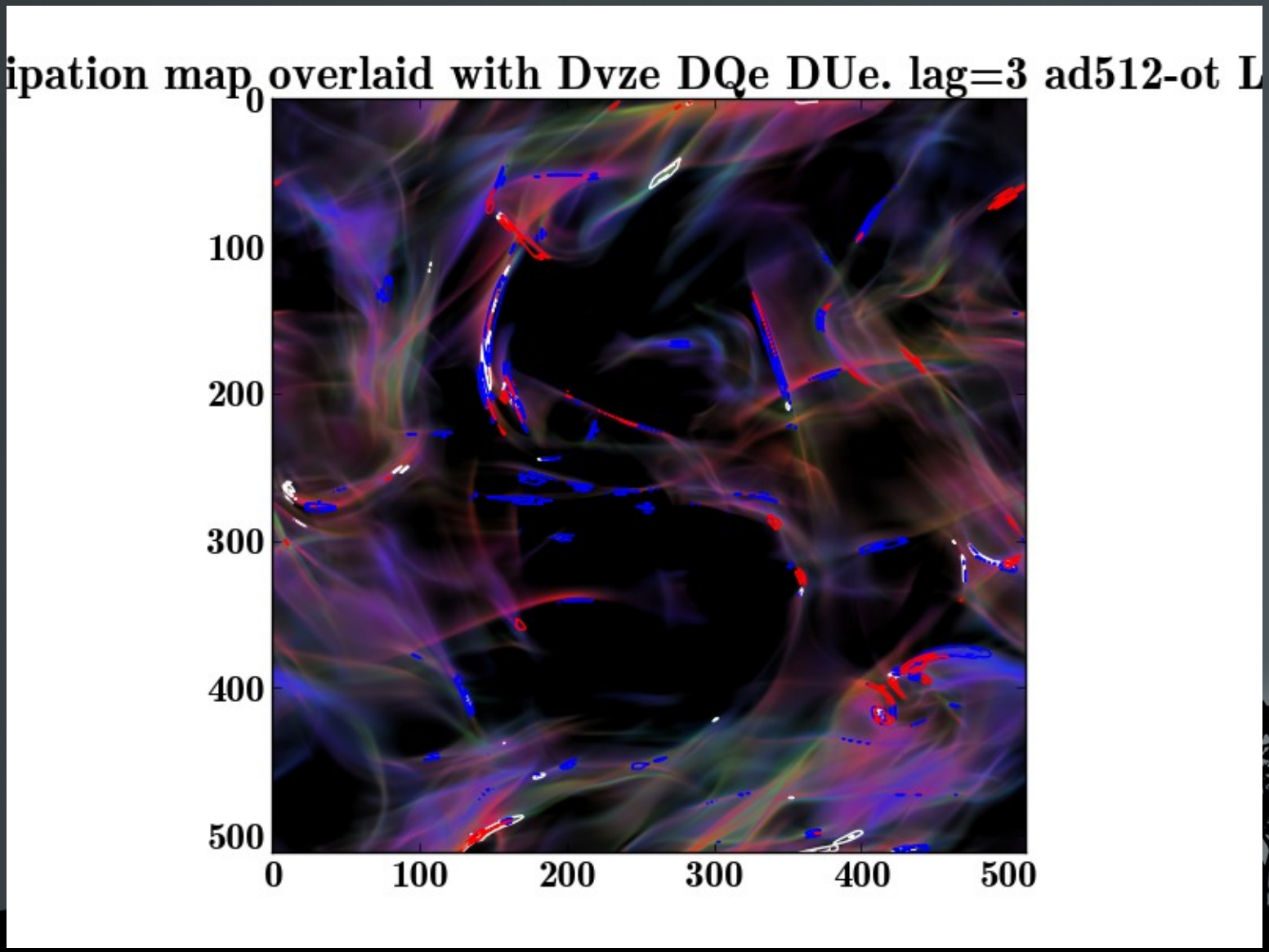
Different increments point to different structures

Are correlated with structures of strong dissipation.



Lbox/64

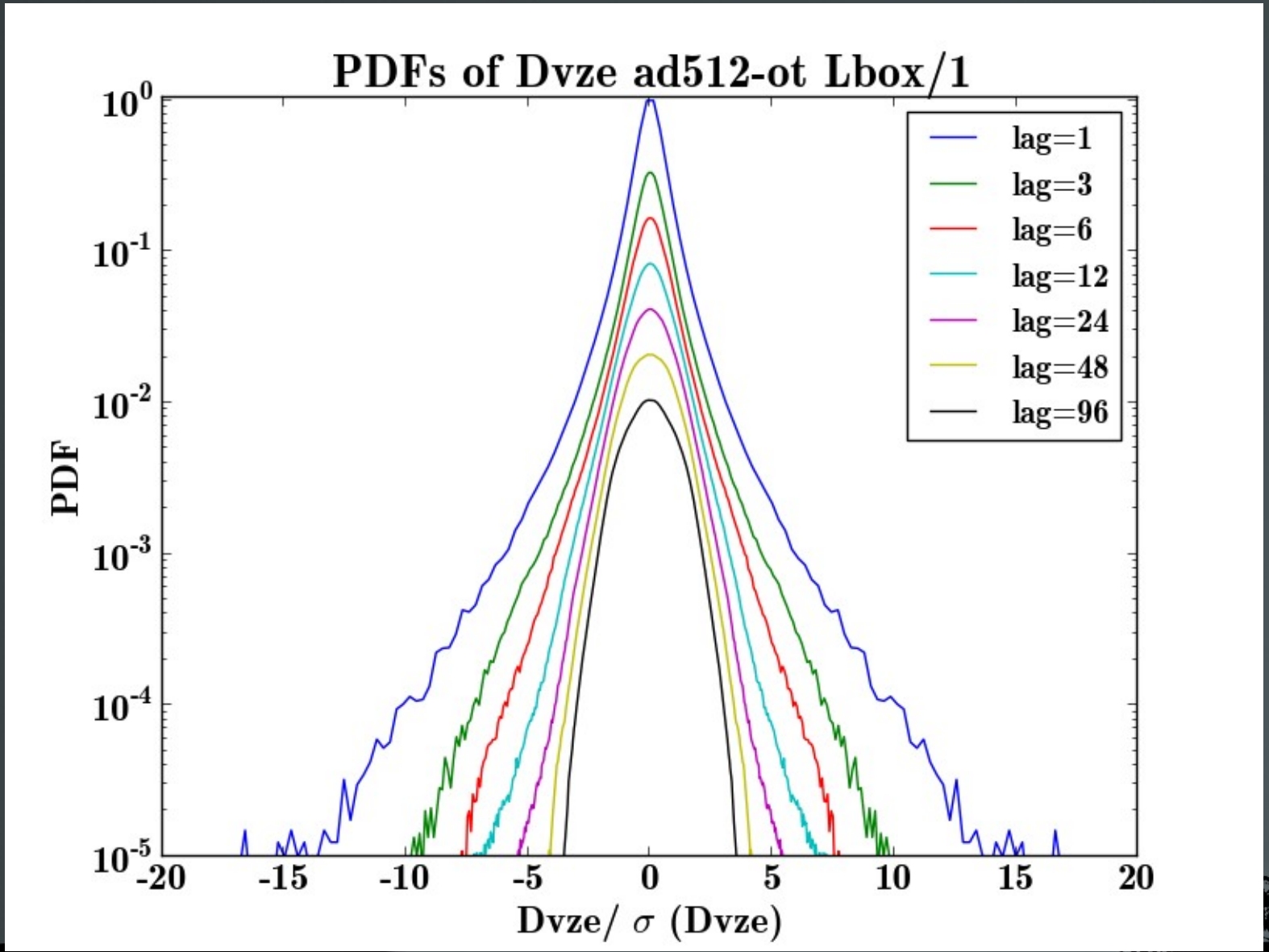
Correlation remains for thick slices



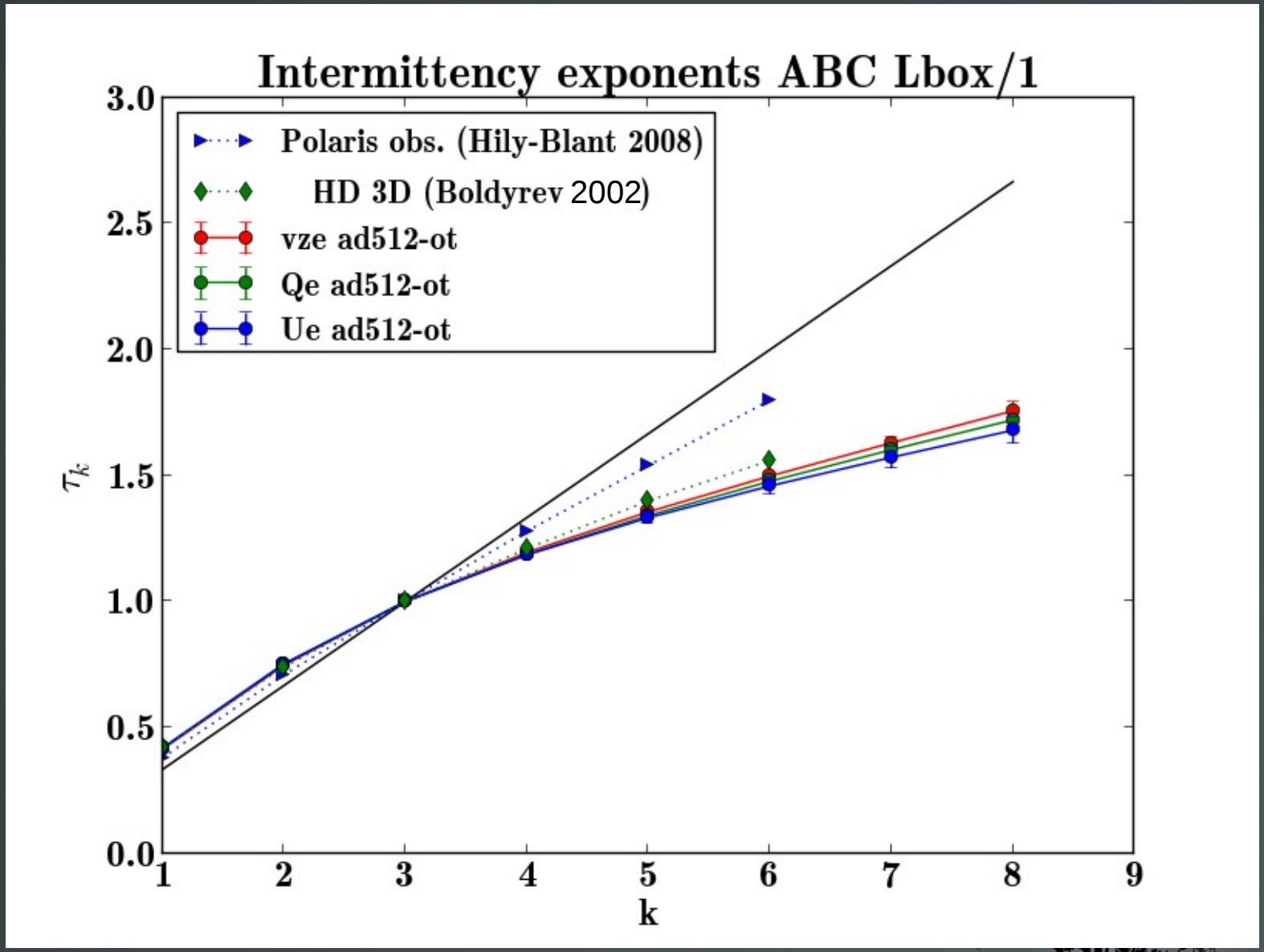
Lbox/1

PDFs of increments

From Gaussian to exponential wings → signature of intermittency

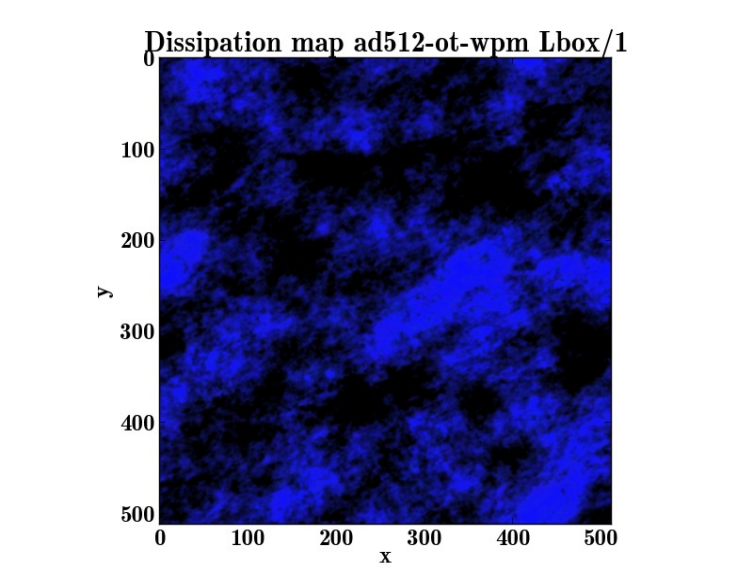


Intermittency exponents

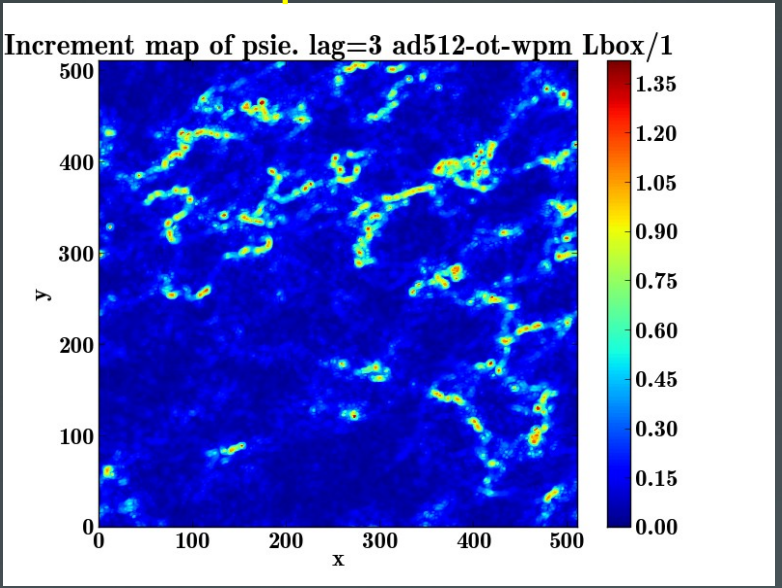


Mix the phases and everything disappears...

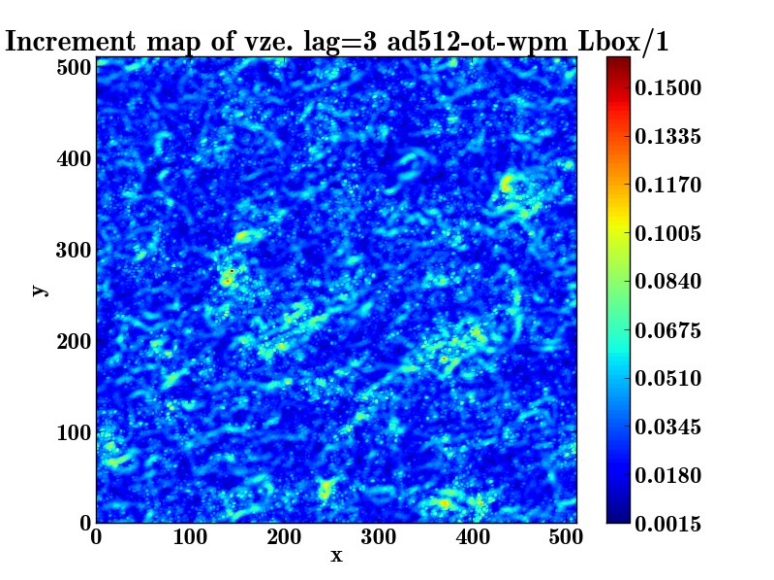
Dissipation

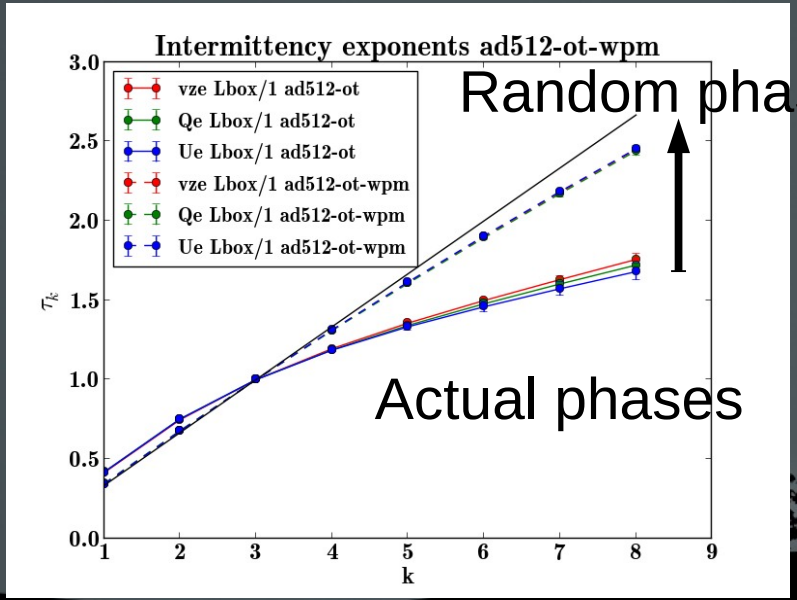


Dpsie



Dvze





Conclusions I

We did 3D MHD simulations with dissipation in the conditions of the ISM except ν and η are hugely enhanced.

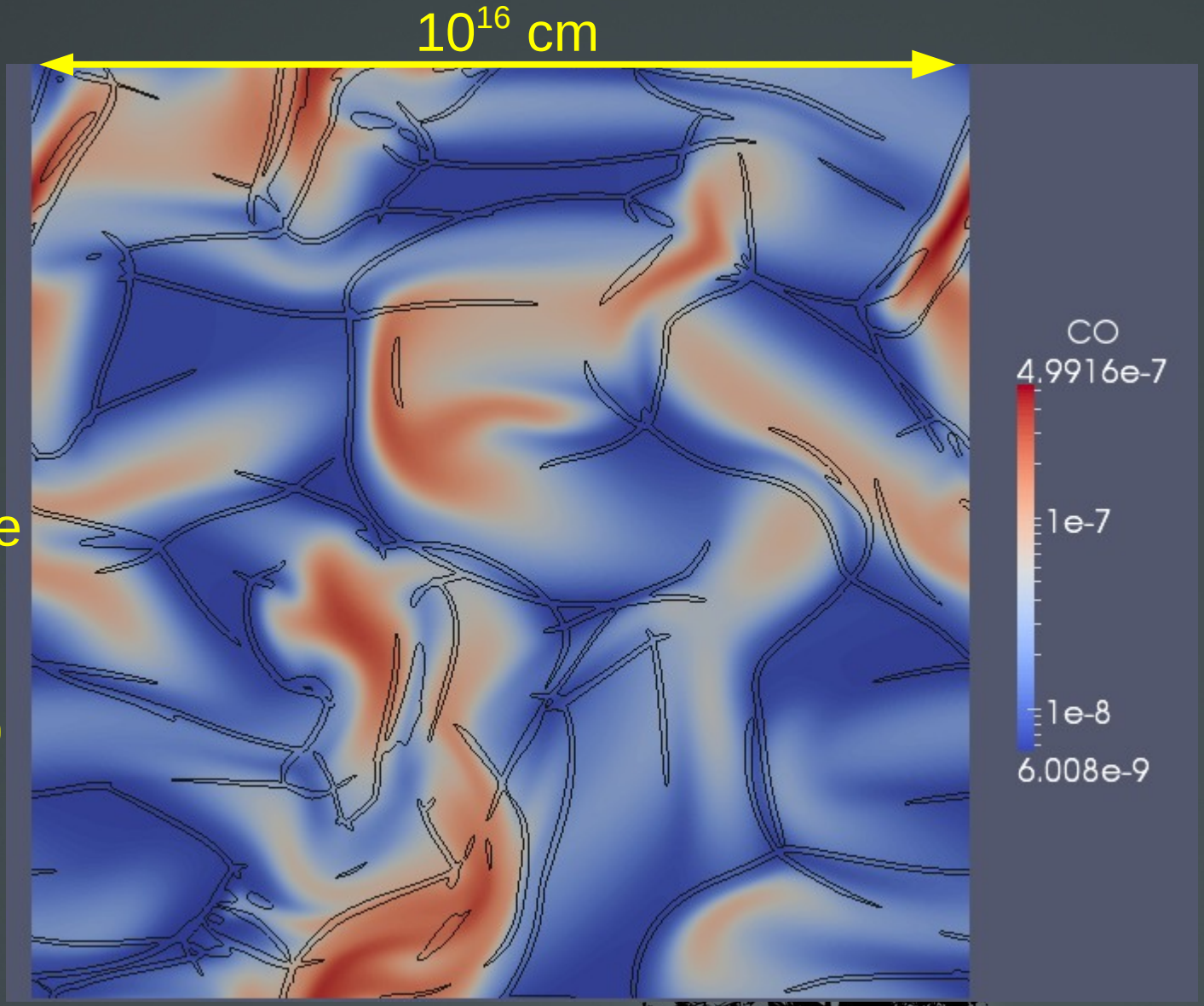
- Dissipative structures are single flavoured sheets, coherent, with remarkable scalings
- Increment maps and dissipative structures are strongly linked.
- Intermittency in integrated maps is stronger than is observed in the ISM.

Chemical Signatures
CHEMSES = DUMSES + Paris-Durham

ACTUAL viscous diffusion

32 species,
7 H_2 levels
1024^2 pixels,
decaying 2D turbulence
U_{rms} ~2 km/s
(way above average,
But think intermittency)

Homogeneous
Irradiation:
G0=1, Av=0.1
=> CO should not survive



The Paris-Durham code (online thanks to A. Gusdorf)

- Follow a fluid parcel through a steady shock structure :

J-shock : trigger viscous jump

C-shock : charge and neutral velocities free to differ

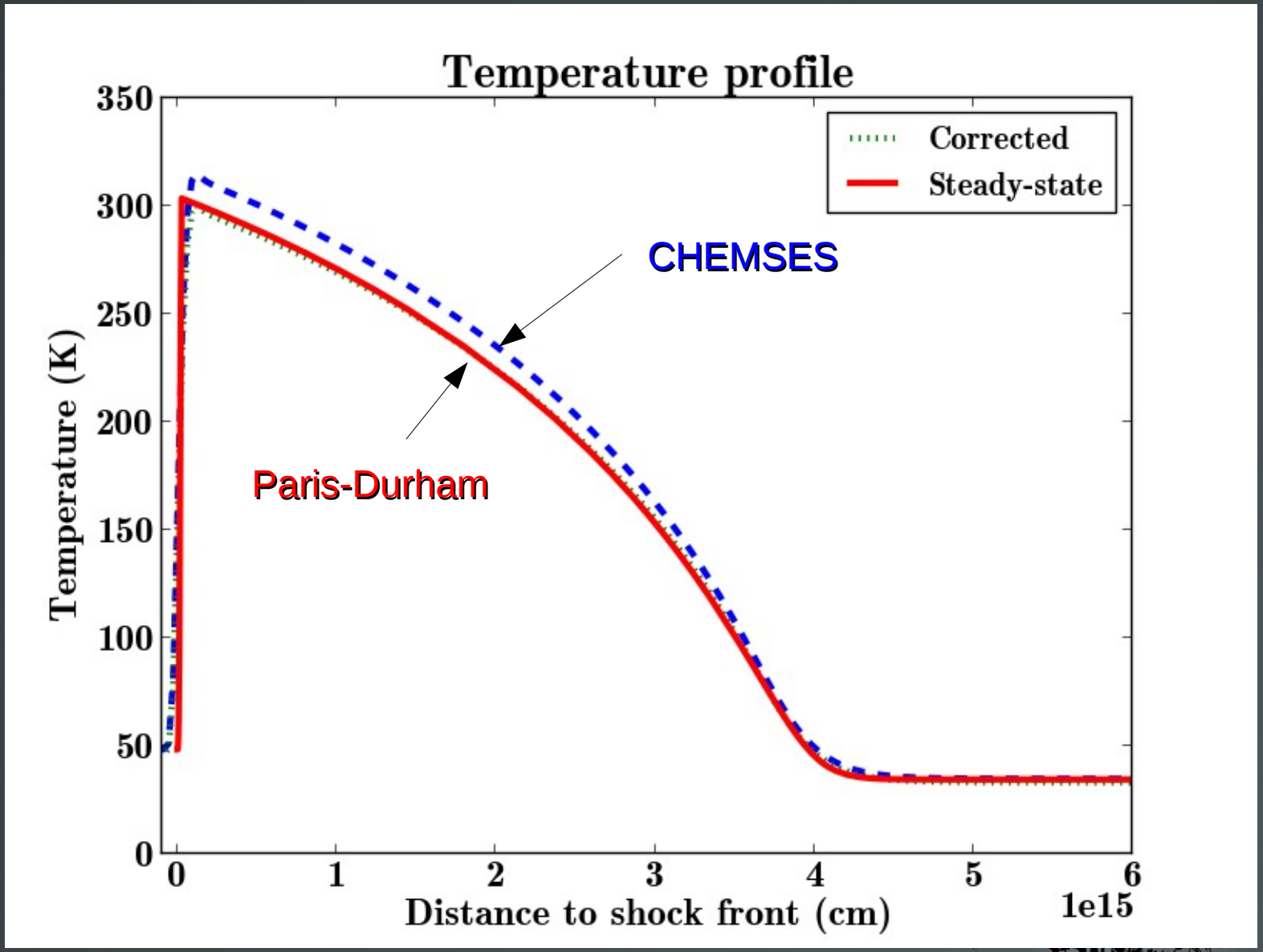
- Cooling / Heating

- Chemical network : 140 species, 1000 reactions

- 150 H_2 levels followed

=> Temperature and chemical structure, line emissivities...

Code validation: steady-state shock at 3 km/s



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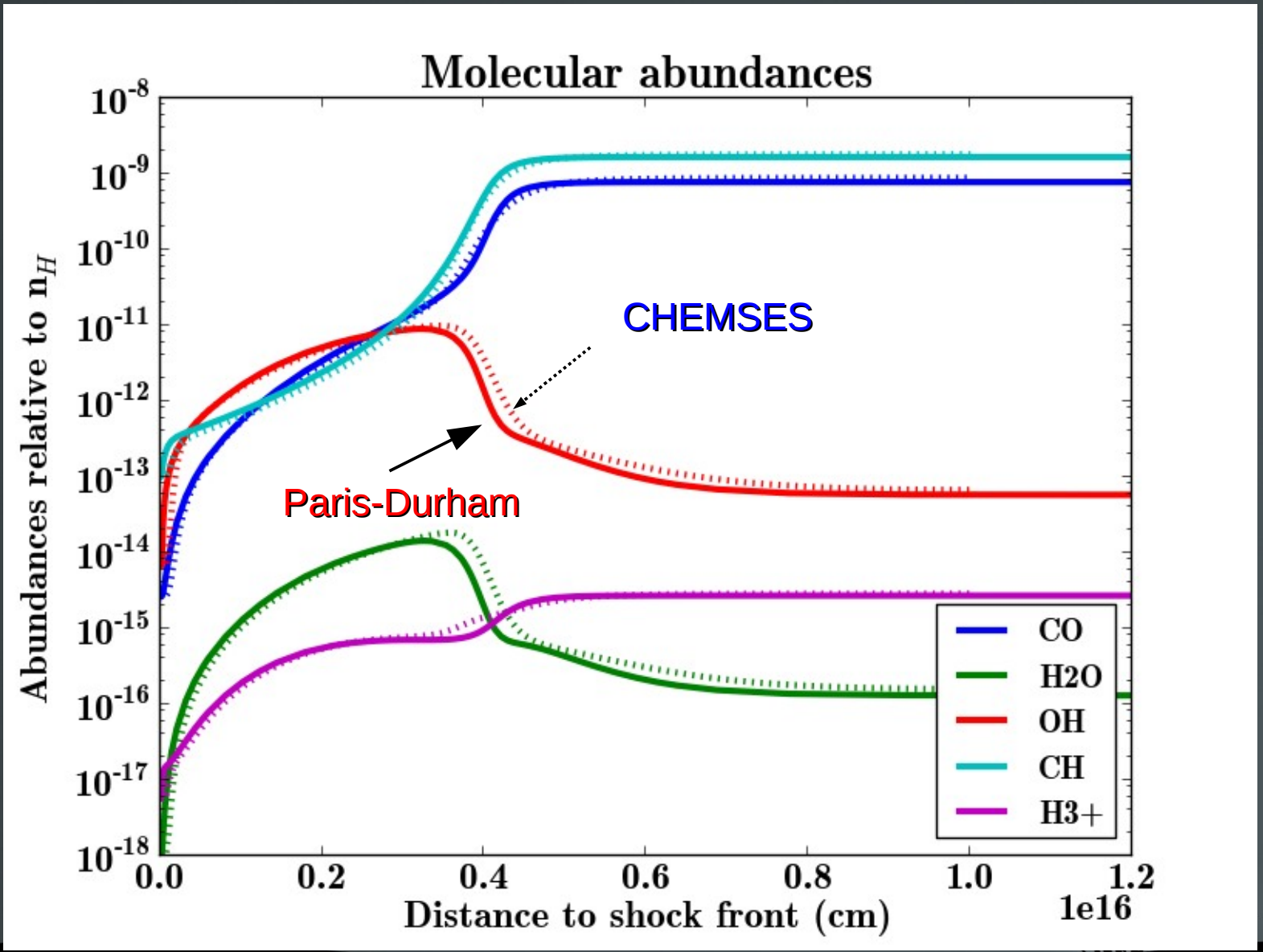

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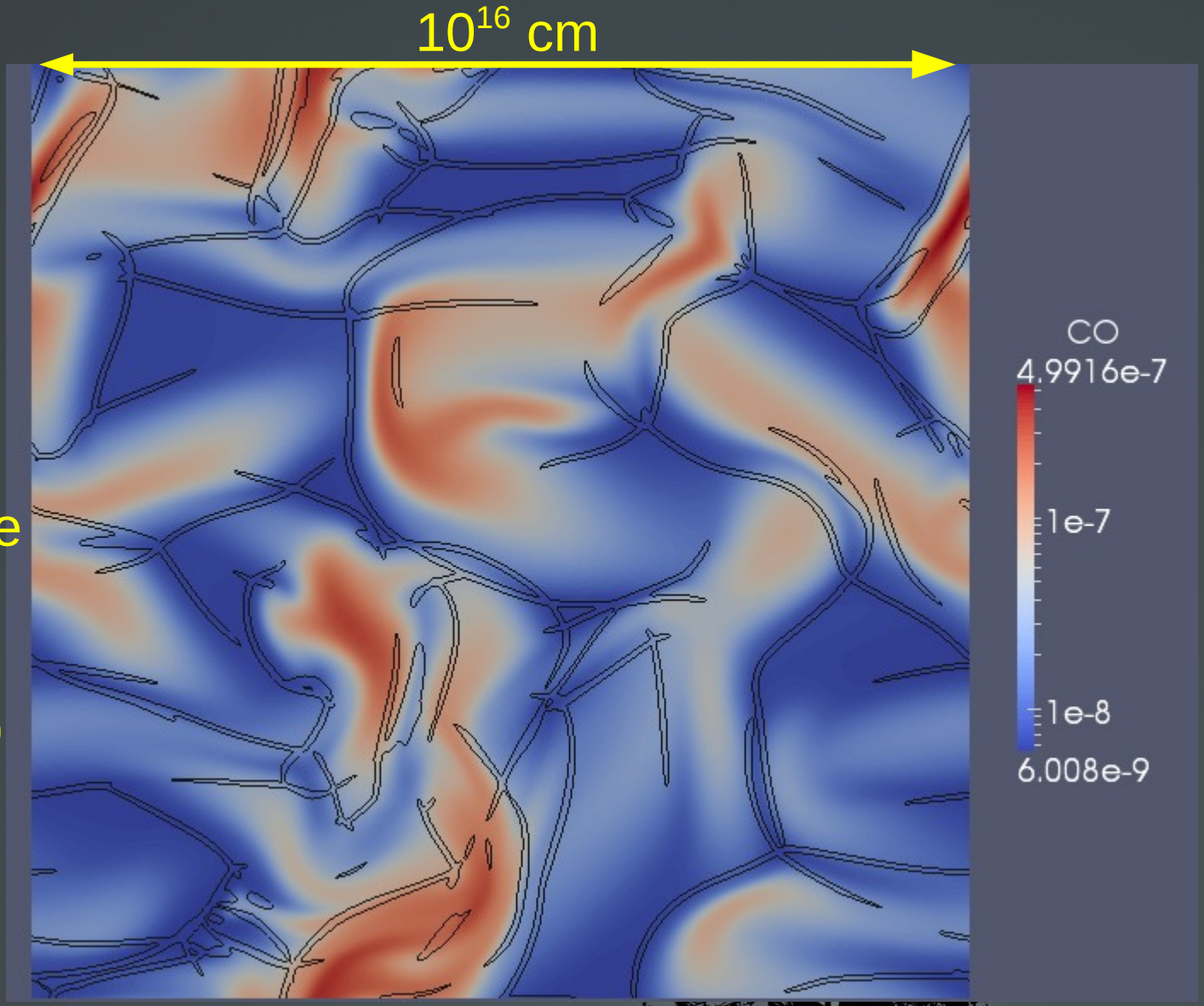
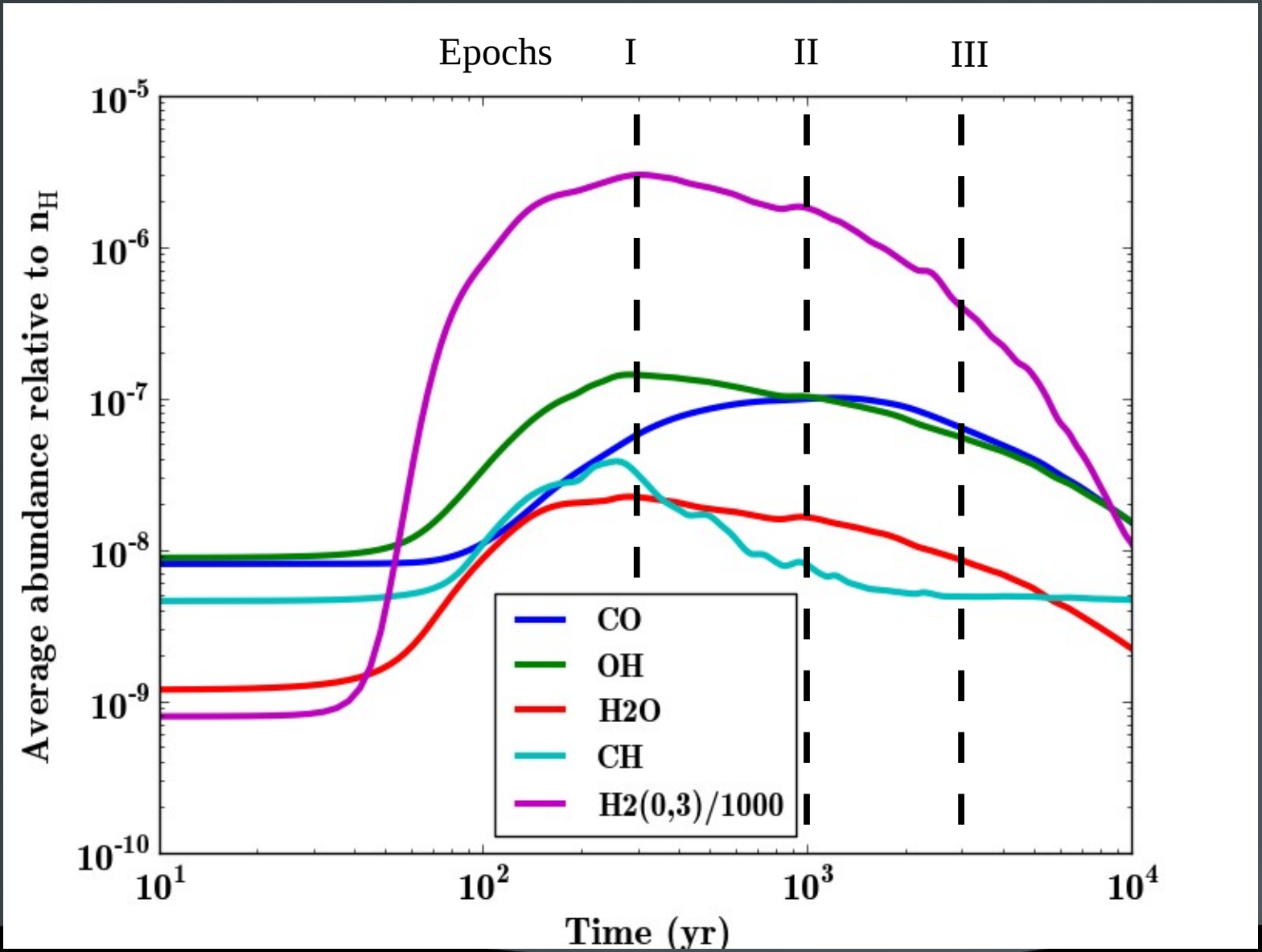
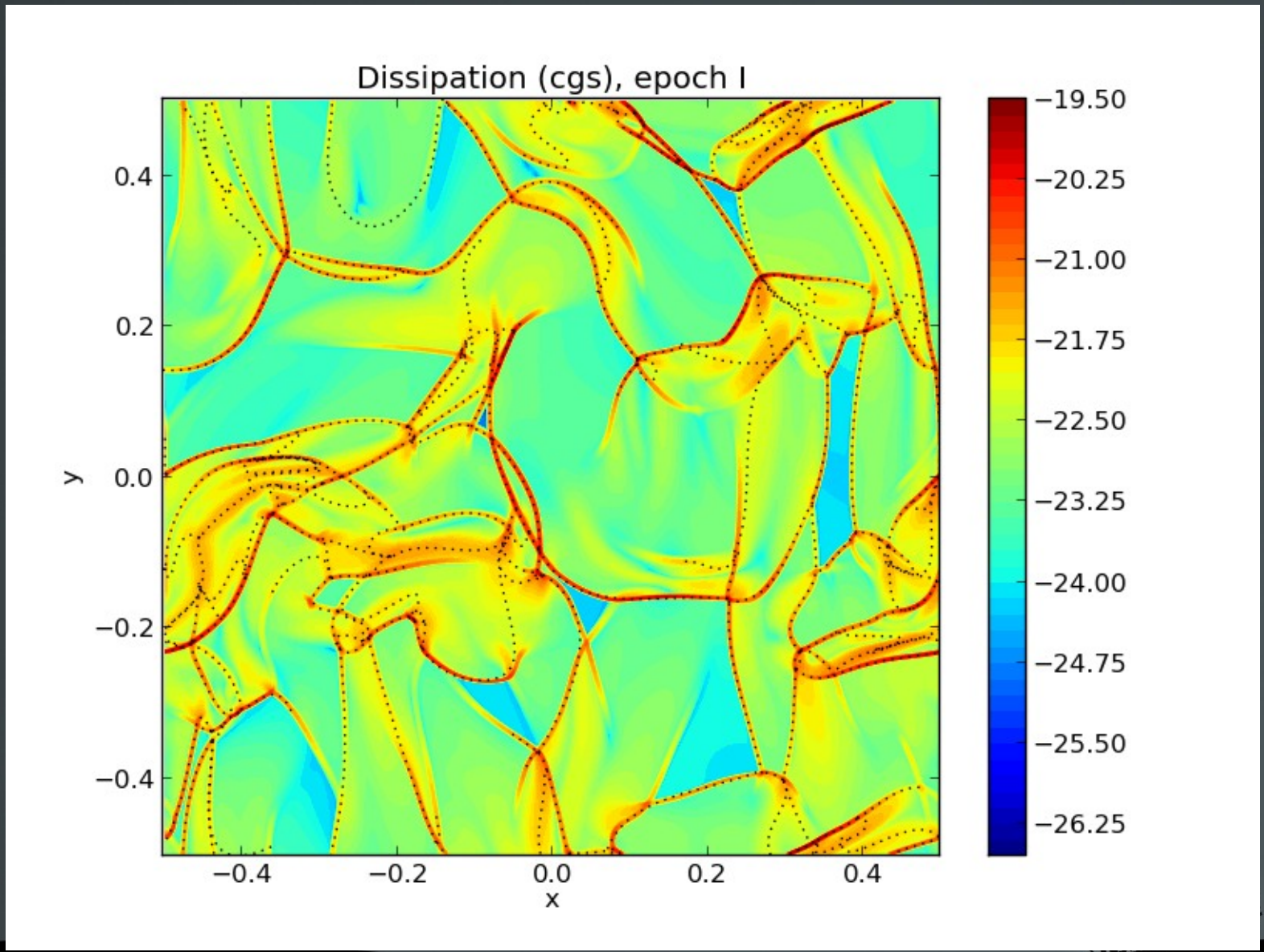


Molecules enhanced by dissipation of 2D turbulence

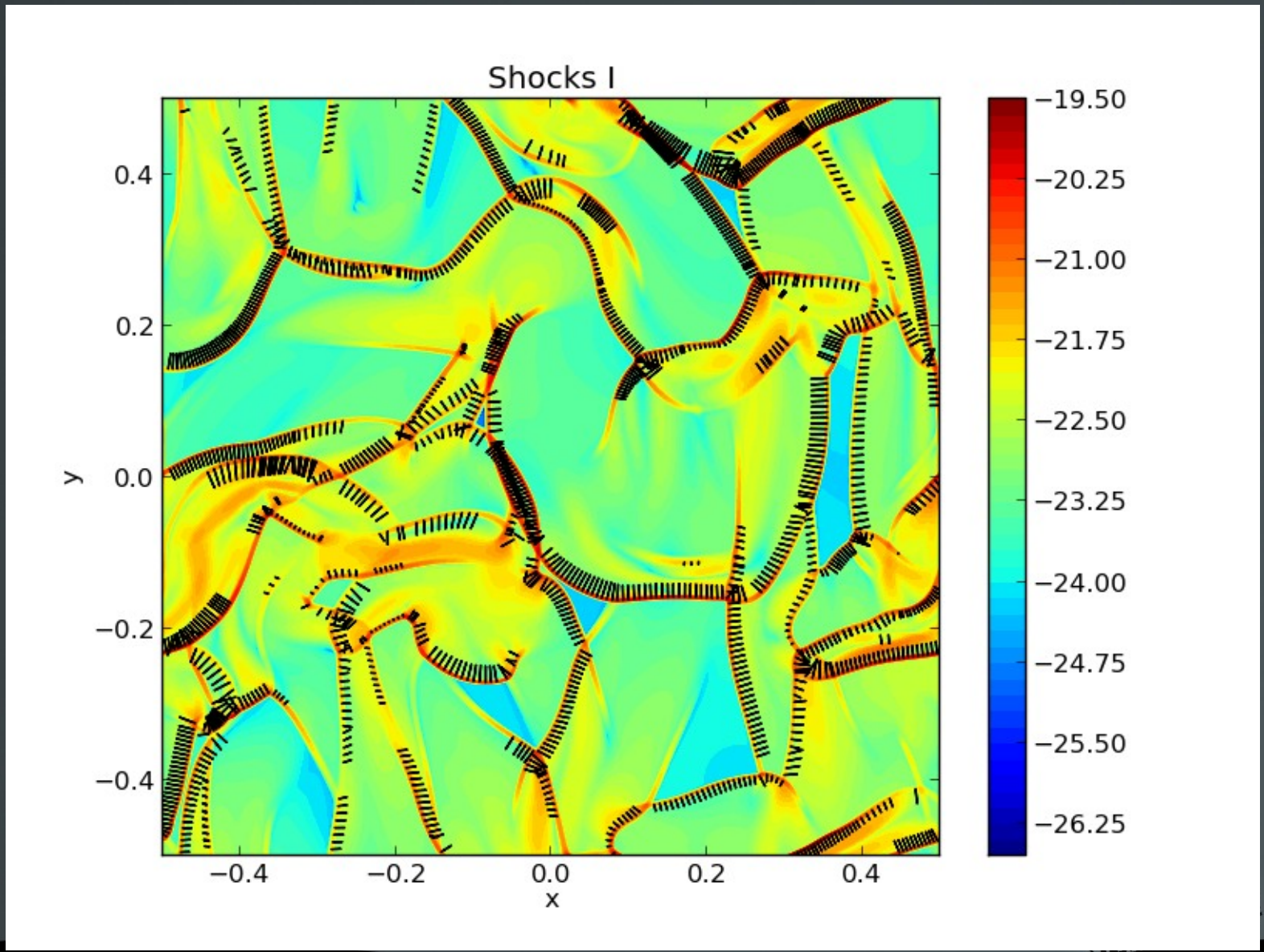
G_0=1
Av=0.1



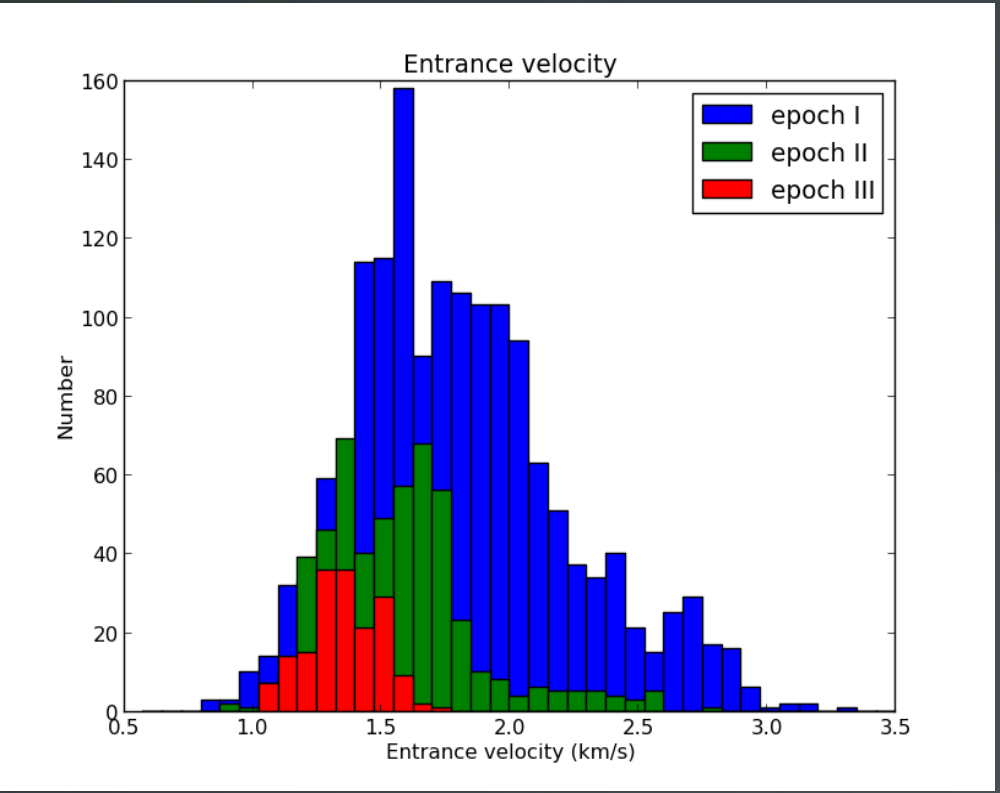
Find the ridges of dissipation (DISPERSE, by Thierry Sousbie)

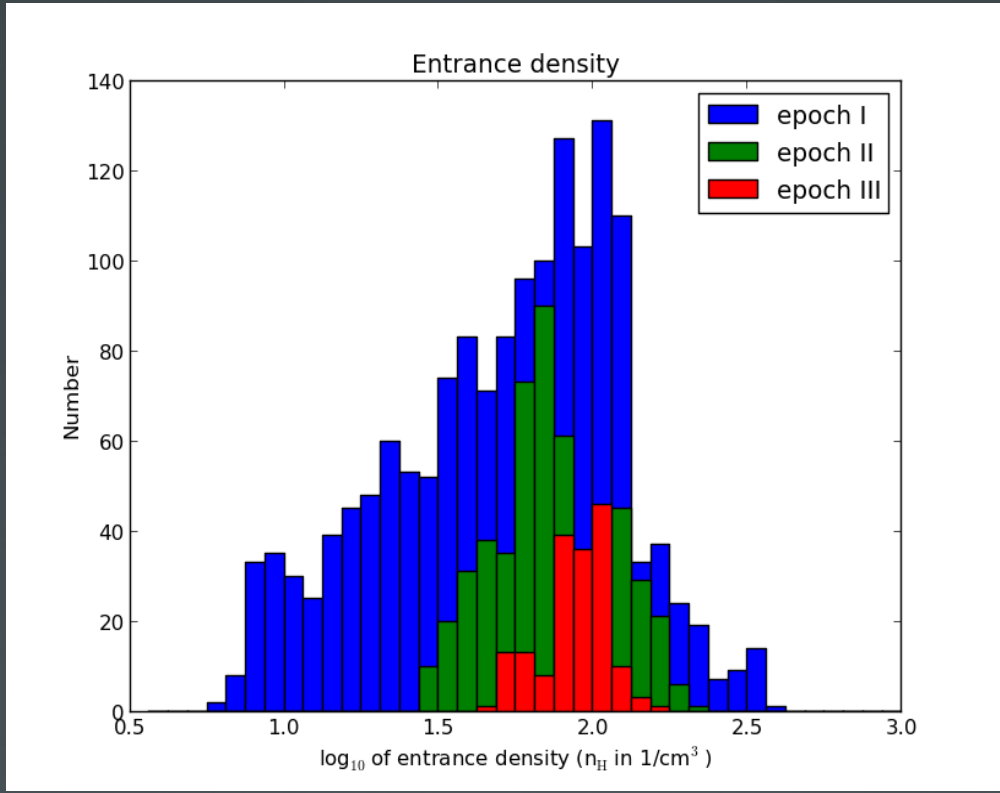


Fit steady-state shocks



Look at shock statistics





Distributions are skewed:
- to high velocities (intermittency?)
- to low densities (mass conservation ?)

How much is due to shocks ?

Energy dissipated near detected *filaments* / Total:

I: 83% II: 72% III: 50%

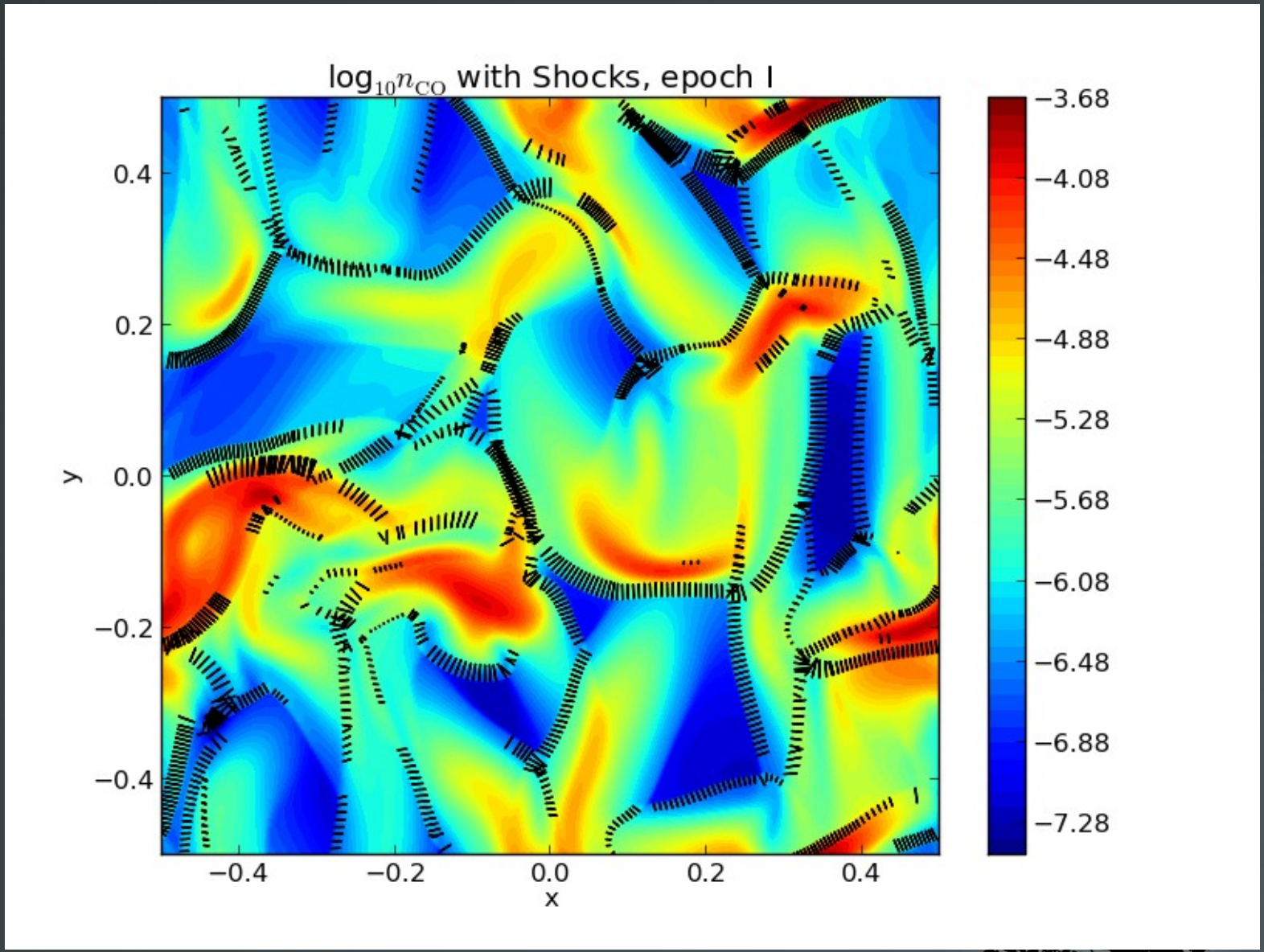
Energy dissipated near detected *shocks* / Total:

I: 67% II: 51% III: 26%

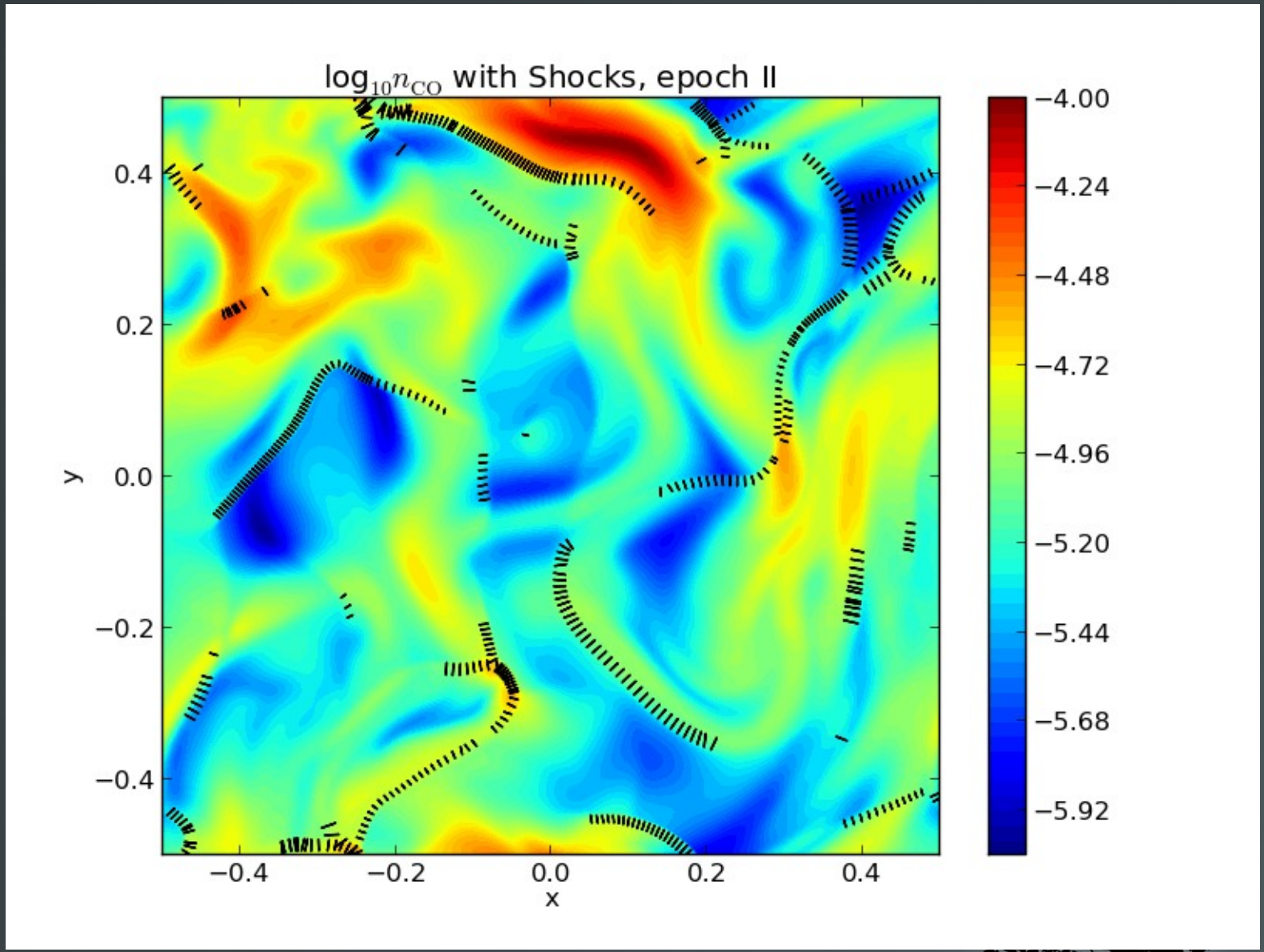
Modeled CO from truncated steady shocks / Actual

I: x 2.1 II: x 3.2 III: x 4.4

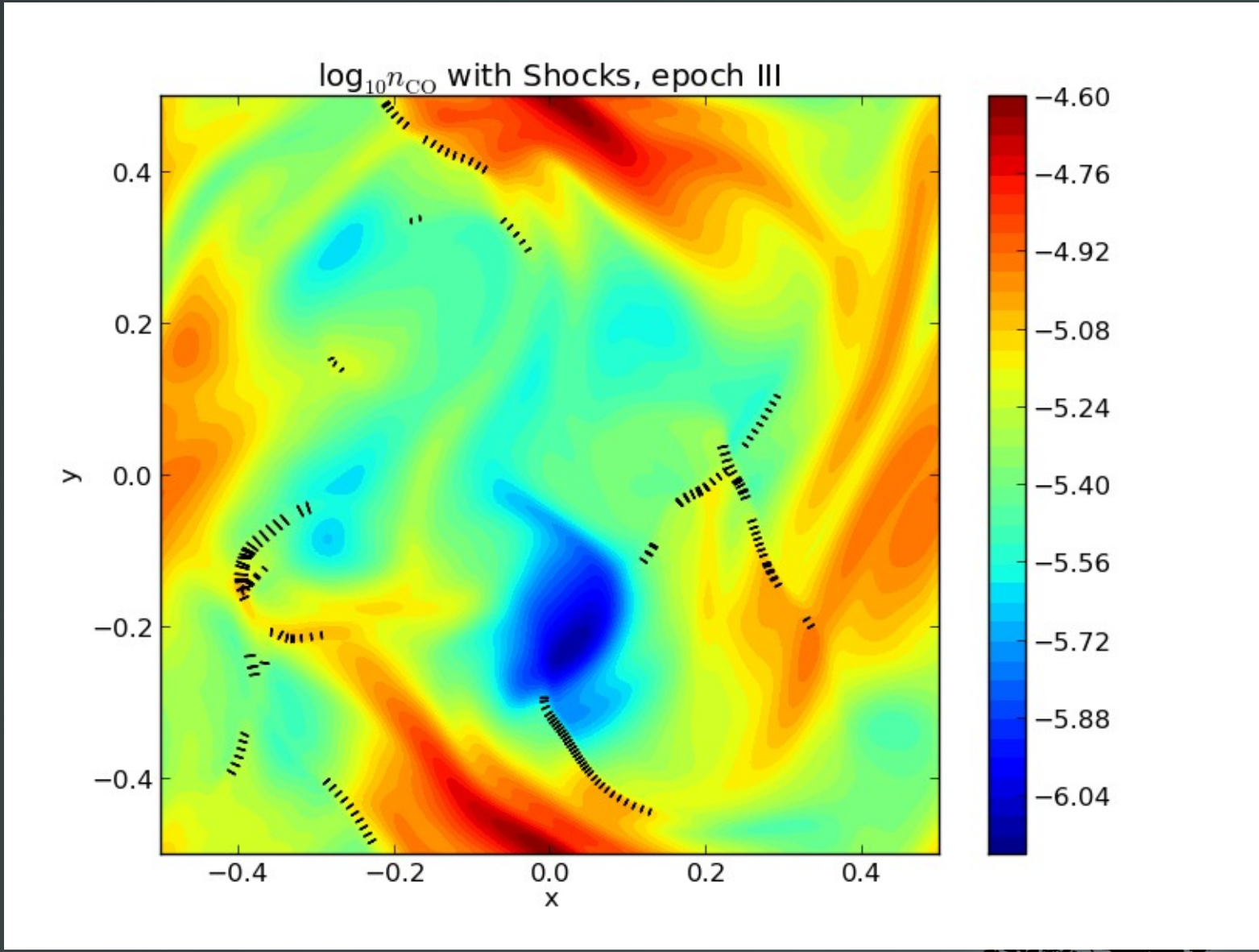
CO in shocks ?


log10nCO with Shocks, epoch I
0.4
0.2
0.0
−0.2
−0.4
y
−0.4
−0.2
0.0
0.2
0.4
x
−3.68
−4.08
−4.48
−4.88
−5.28
−5.68
−6.08
−6.48
−6.88
−7.28

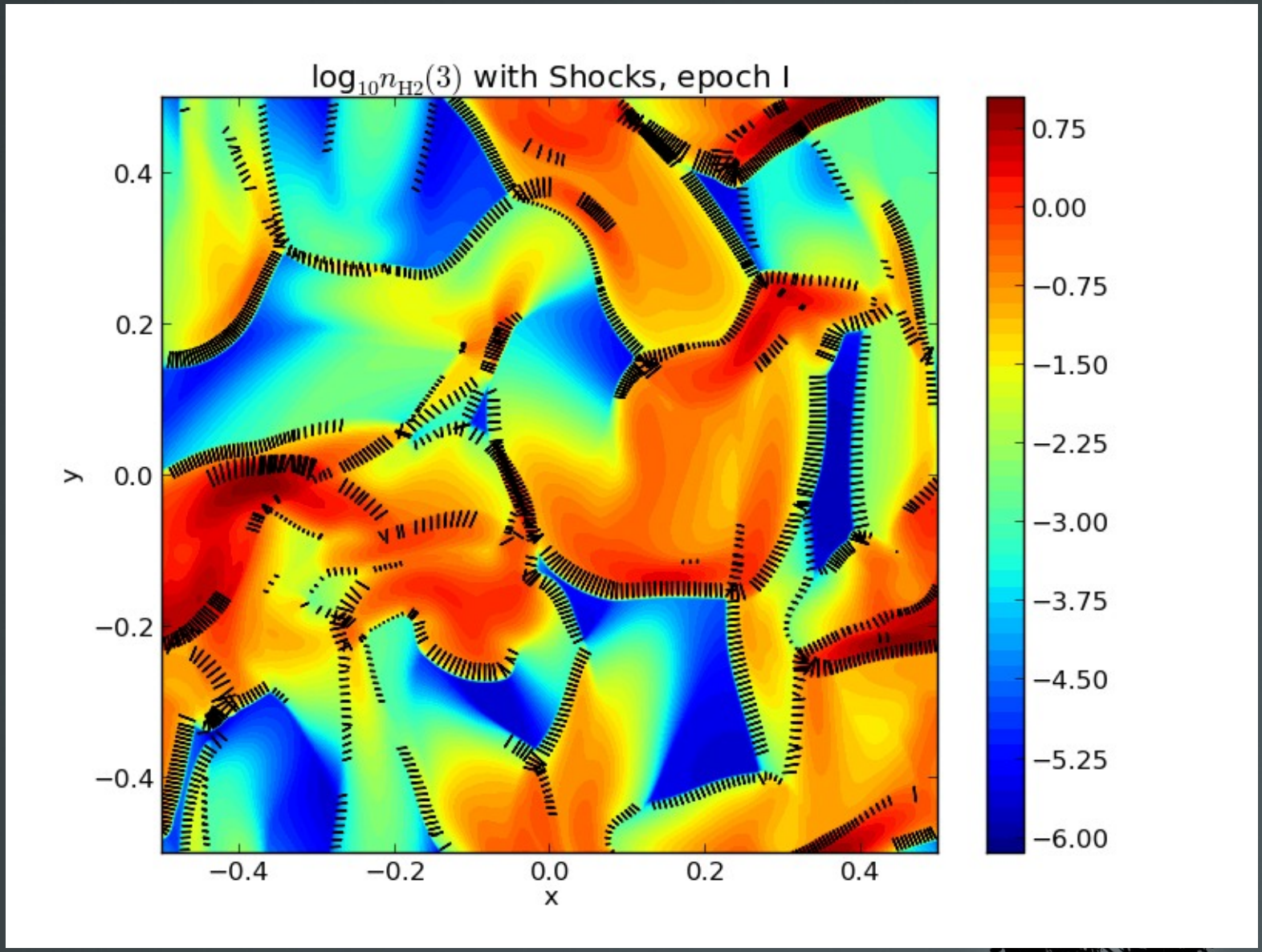
CO in shocks ?


log10nCO with Shocks, epoch II
0.4
0.2
0.0
−0.2
−0.4
y
−0.4
−0.2
0.0
0.2
0.4
x
−4.00
−4.24
−4.48
−4.72
−4.96
−5.20
−5.44
−5.68
−5.92

CO in shocks ?


log10nCO with Shocks, epoch III
0.4
0.2
0.0
−0.2
−0.4
y
−0.4
−0.2
0.0
0.2
0.4
x
−4.60
−4.76
−4.92
−5.08
−5.24
−5.40
−5.56
−5.72
−5.88
−6.04

Excited H2 in shocks ?

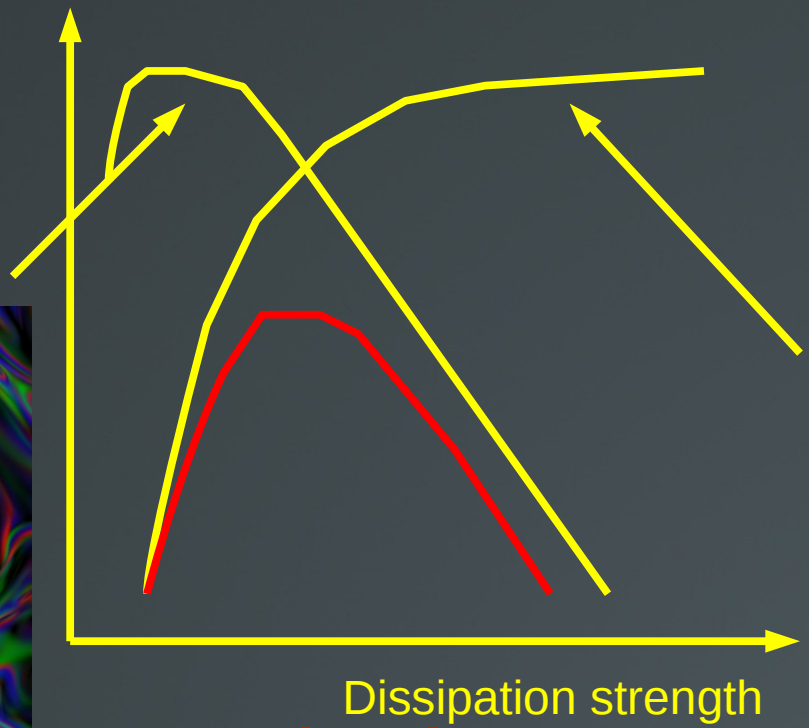


Conclusions II

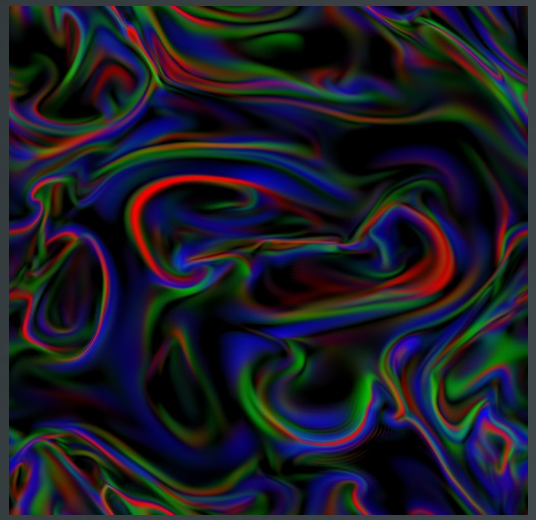
- Many molecules are sensitive to dissipation (amongst others, CO and H2)
- This chemistry needs extreme spatial resolution, and is absent from current large scale simulations.
- A statistical collection of steady-shocks can explain part of the dissipation, but too much CO.
- Shearing-sheets ?

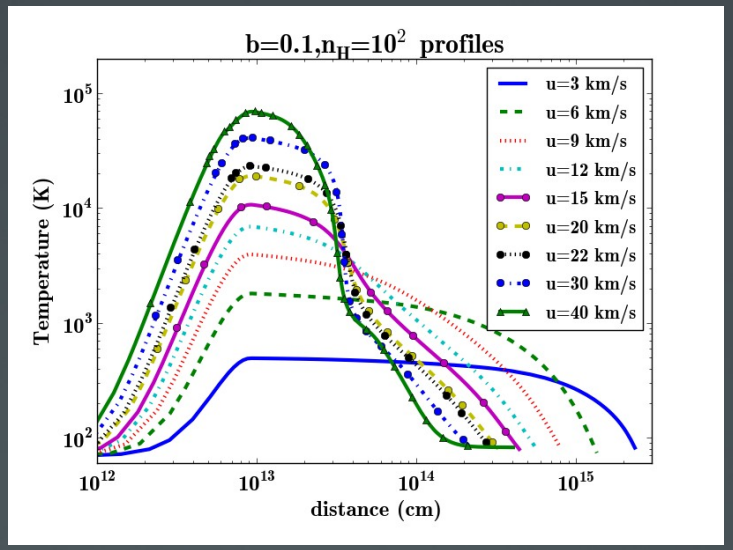
The cunning plan...

Intermittent statistics of the dissipation



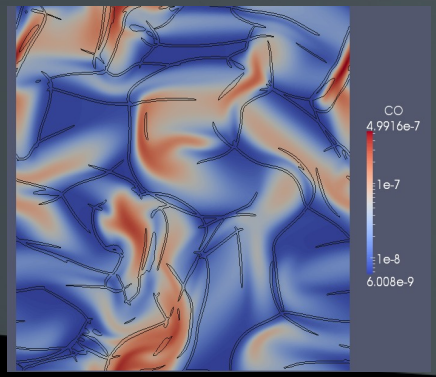
Molecular yields from Shocks (for example)





=> Molecules
Formation + excitation

G. Momferratos



Thanks !