Hydrides in decaying 2D hydrodynamic turbulence

Pierre Lesaffre,

F. Levrier, B. Godard

V. Valdivia, N. Dziourkevitch,

A. Gusdorf, M. Gerin

G. Momferratos, E. Falgarone, G. Pineau des Forêts

Motivation

- The diffuse ISM contains a lot of complex molecules, some of them excited (e.g. bright CO, warm H2), amongst them: hydrides (OH, H_2O, CH+, ...)
- 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 use steady-state shock models to reproduce the molecular yields ?

CH^+ formation channels: means to overcome the (C^+,H_2) barrier.

- H_3^+: PDR models and Cosmic Rays ζ
- Ion-neutral drift
  - C-type shocks (Flower et al. 1986)
  - Turbulent Dissipation models (Godard et al. 2009)
- Warm H2
  - Turbulent diffusion (Lesaffre et al. 2007)
  - Turbulent transport (Valdivia et al. 2016)
- Excited H2
  - J-type shocks (here)
  - PDRs via pumping

Dissipation in decaying turbulence.
Isothermal 3D MHD (Mach 4, ABC)

~1 pc

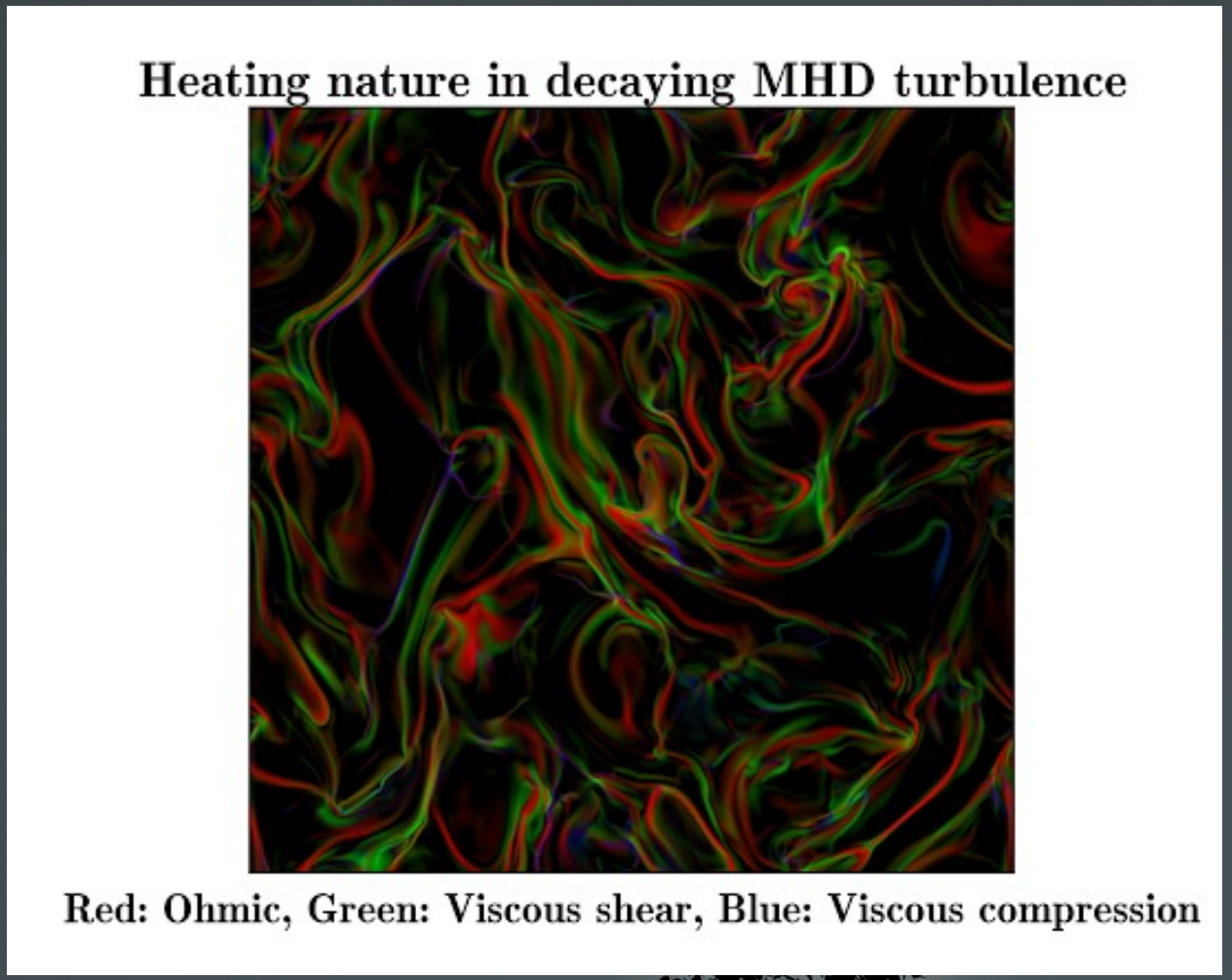
$n_H \sim 100/cm^3$

$\langle u^2 \rangle \sim \langle b^2/\rho \rangle$

$Re = LU/\nu \sim 2.10^7 \; 10^3$

$Re_m = LU/\eta \sim 2.10^{17} \; 10^3$

$(1020^3$ pixels)



(Momferratos PhD thesis:
DUMSES simulations with careful treatment of vicous and resistive dissipation)

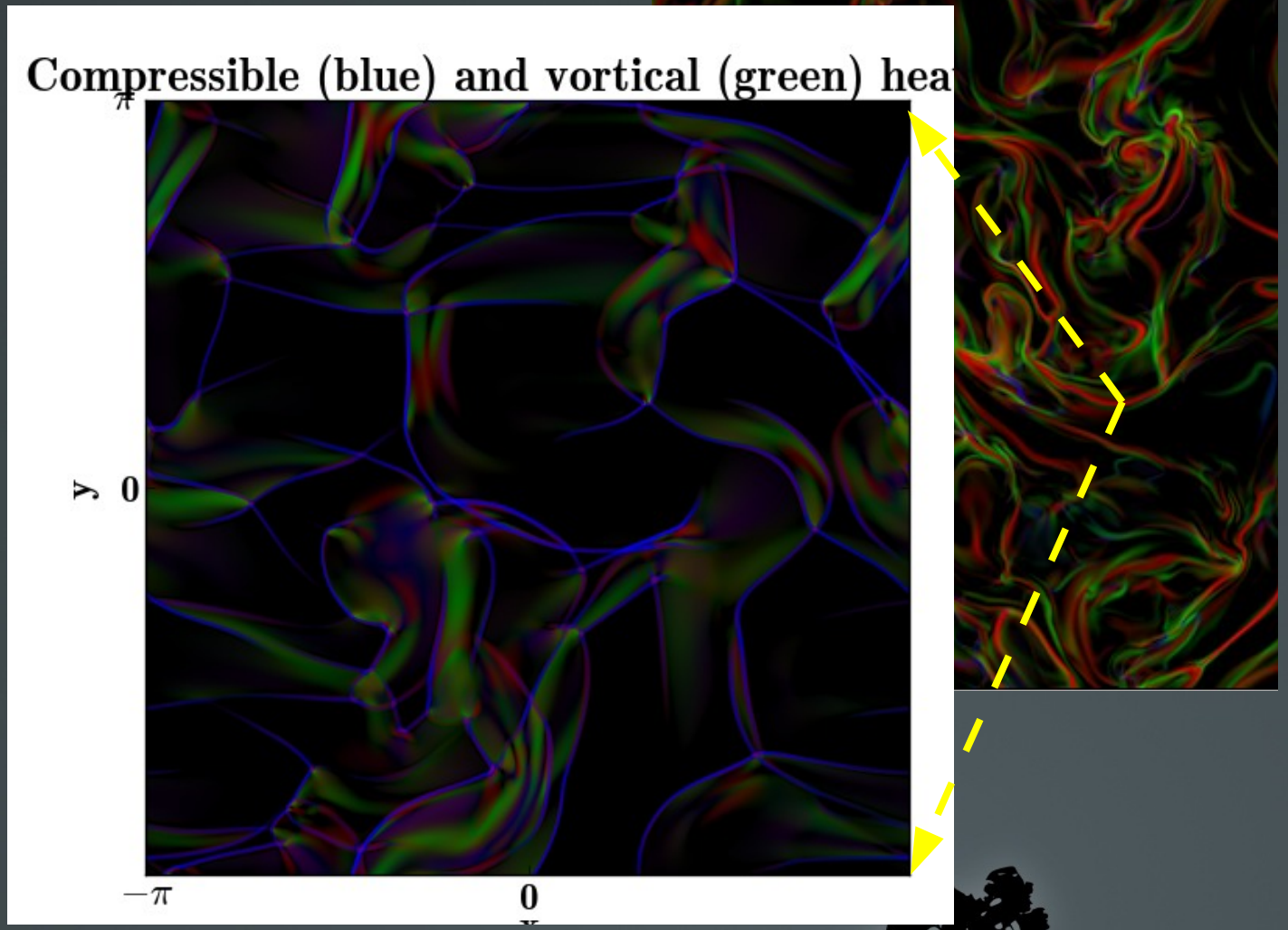
Decaying turbulence (2D runs)

$n_H \sim 100/cm^3$

ACTUAL ν

No B field.

10^{16} cm



Decaying 2D turbulence from U_{rms}~2 km/s
(way above average, But think intermittency)

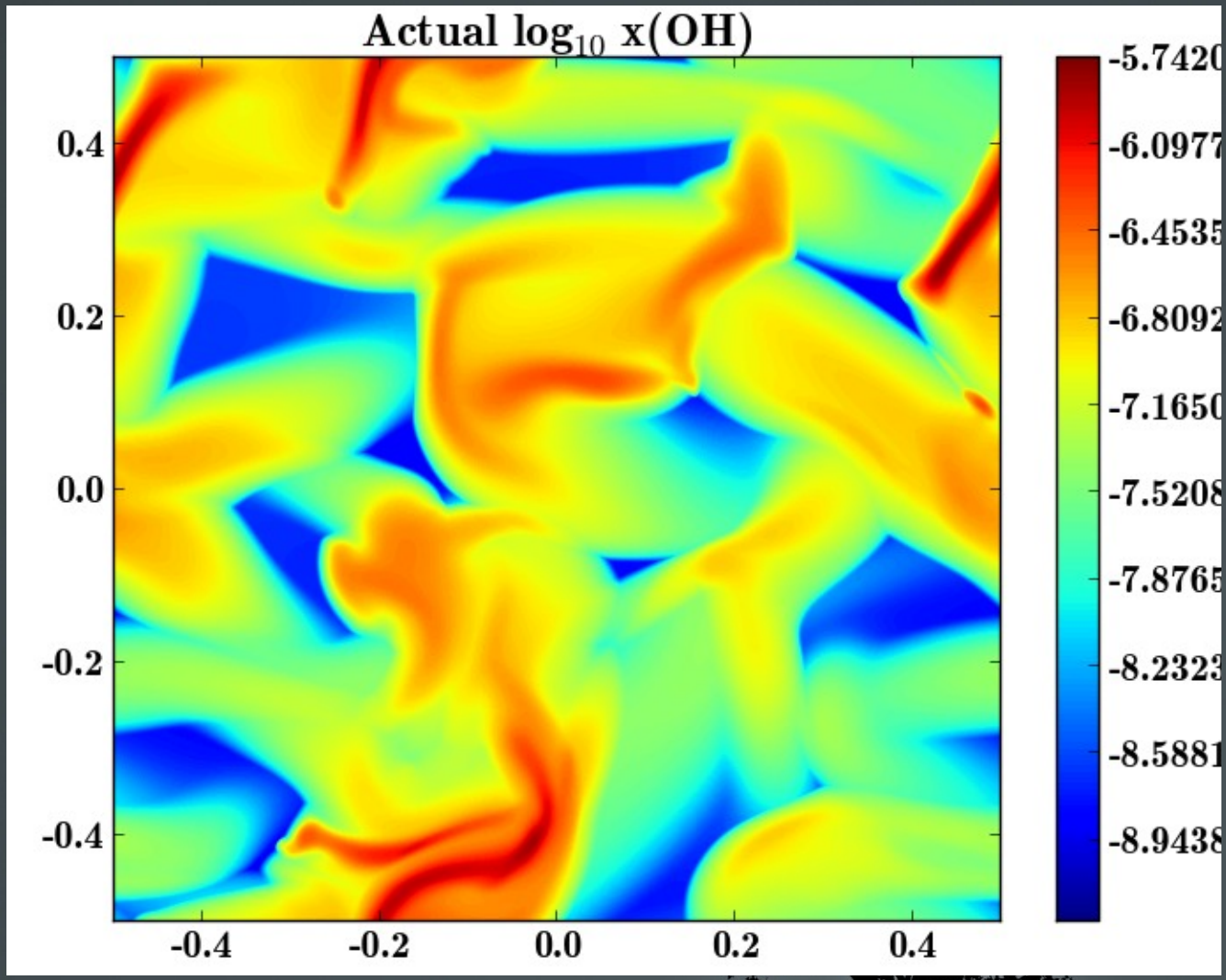
Coupling chemistry and MHD: CHEMSES = DUMSES + Paris-Durham

10^{16} cm

ACTUAL
viscous dissipation

32 species,
7 H_2 levels
1024^2 pixels,

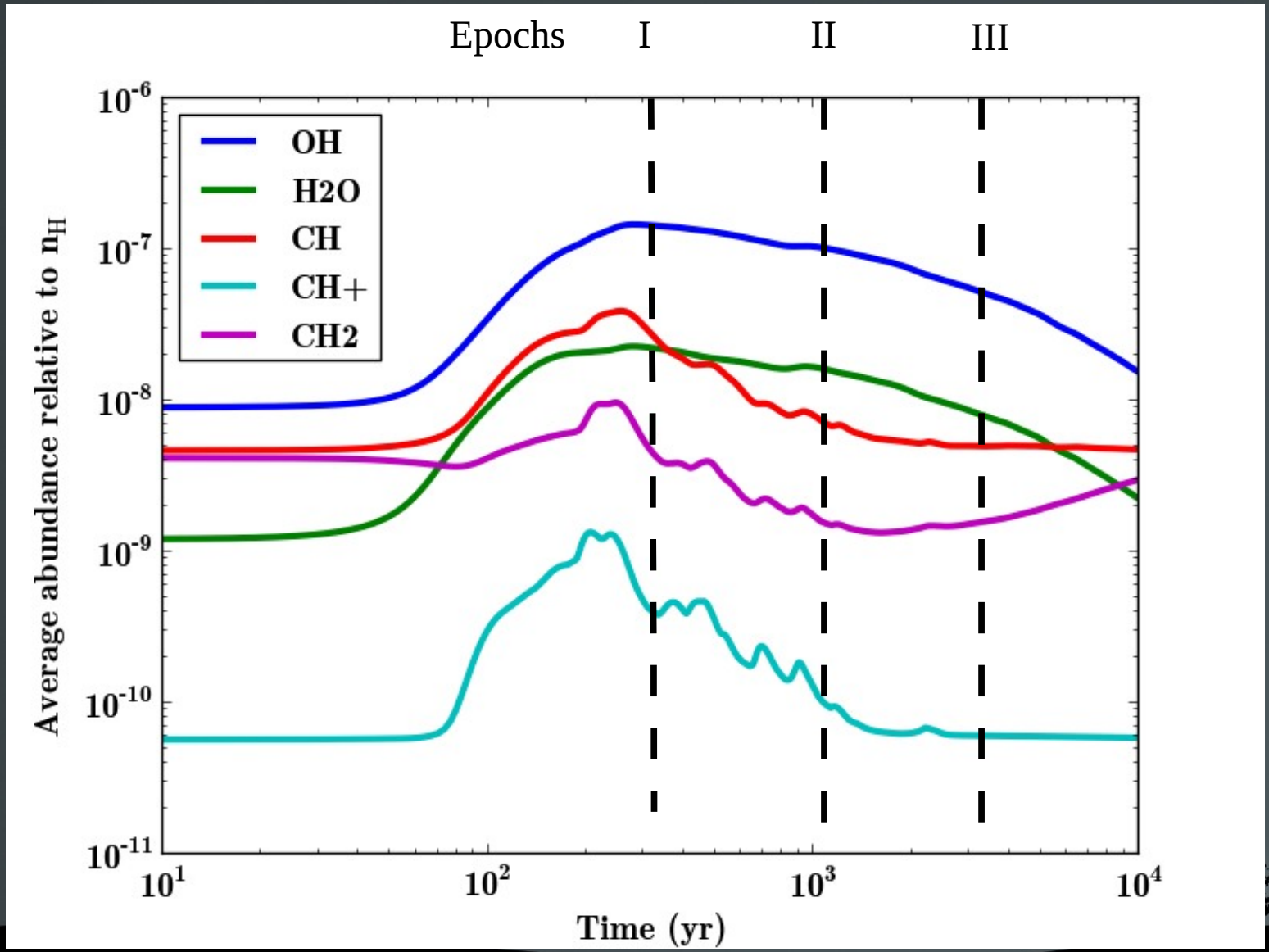
Uniform Irradiation:
G_0=1, Av=0.1
n_H ~ 100/cm^3
=> molecular, but without CO.



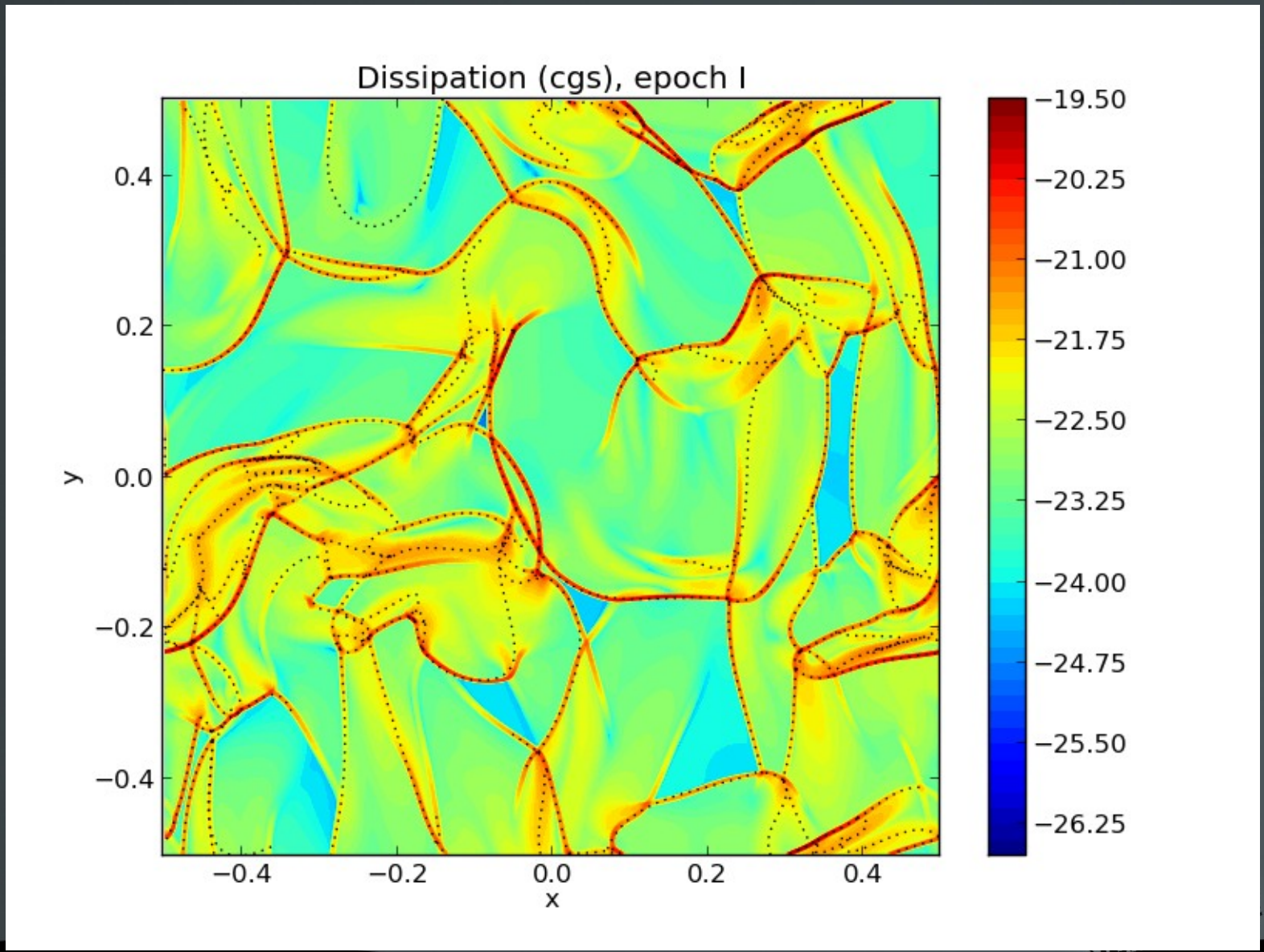
Map of OH

Hydrides produced by dissipation of 2D turbulence

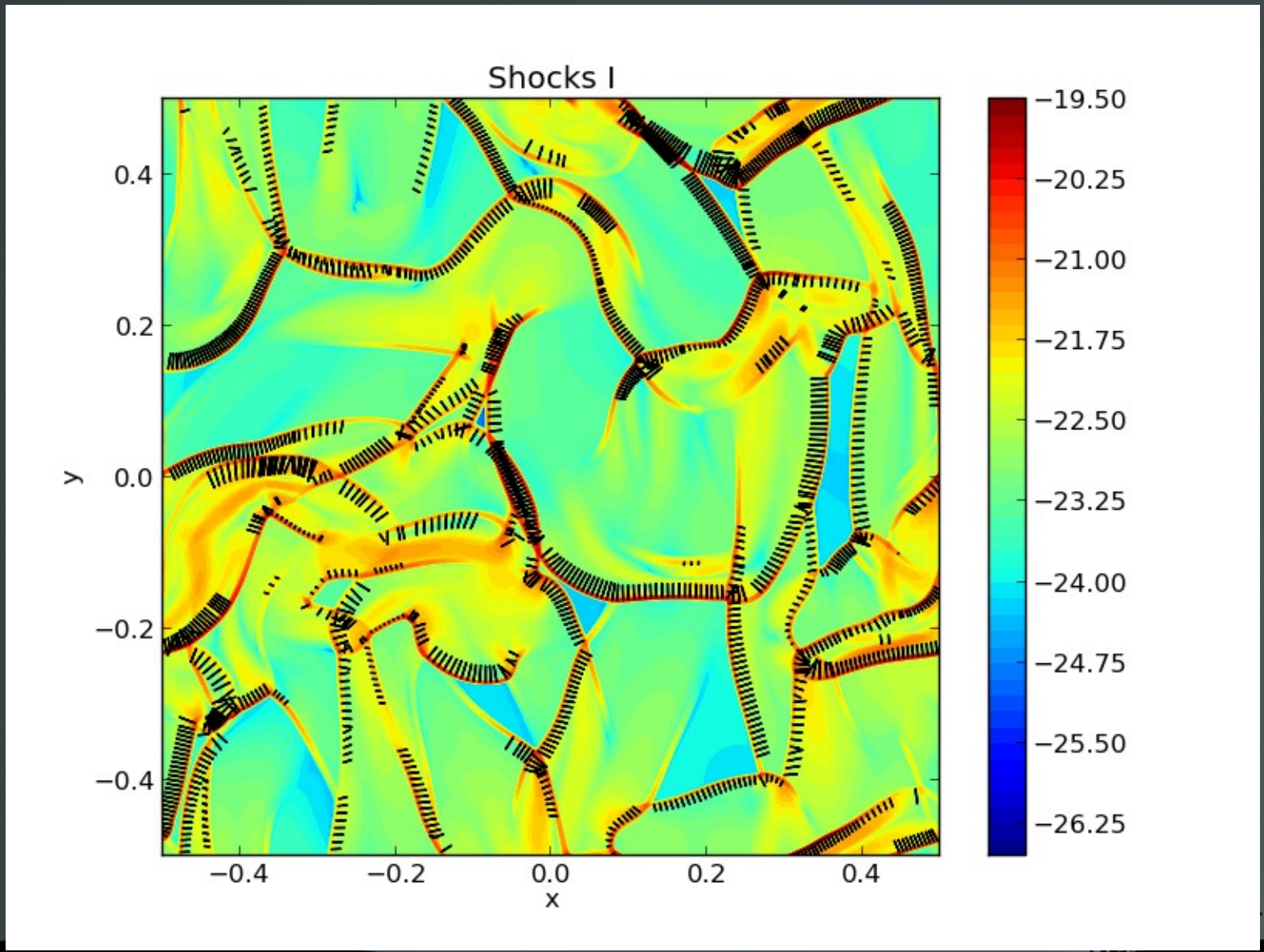
G_0=1
Av=0.1



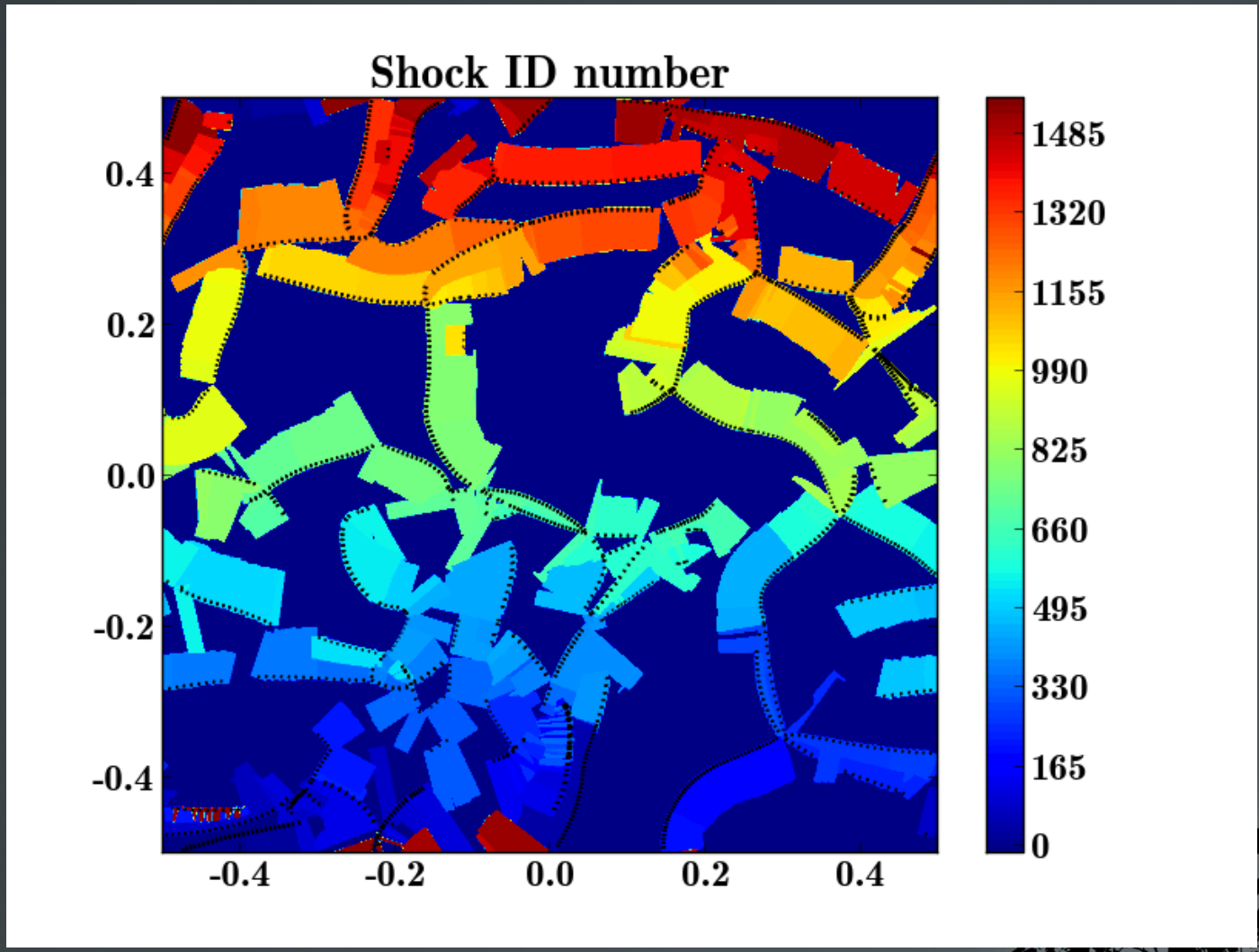
Find the ridges of dissipation
(using DISPERSE, by Thierry Sousbie)



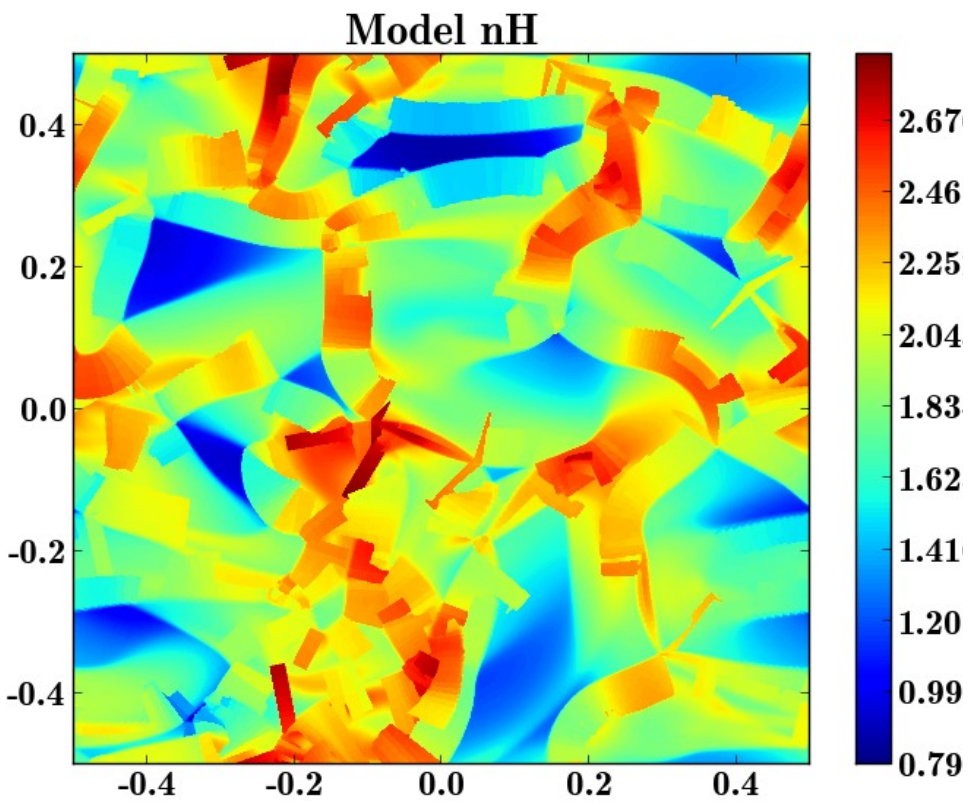
Find steady-state shocks
(local fit of adiabatic fronts)

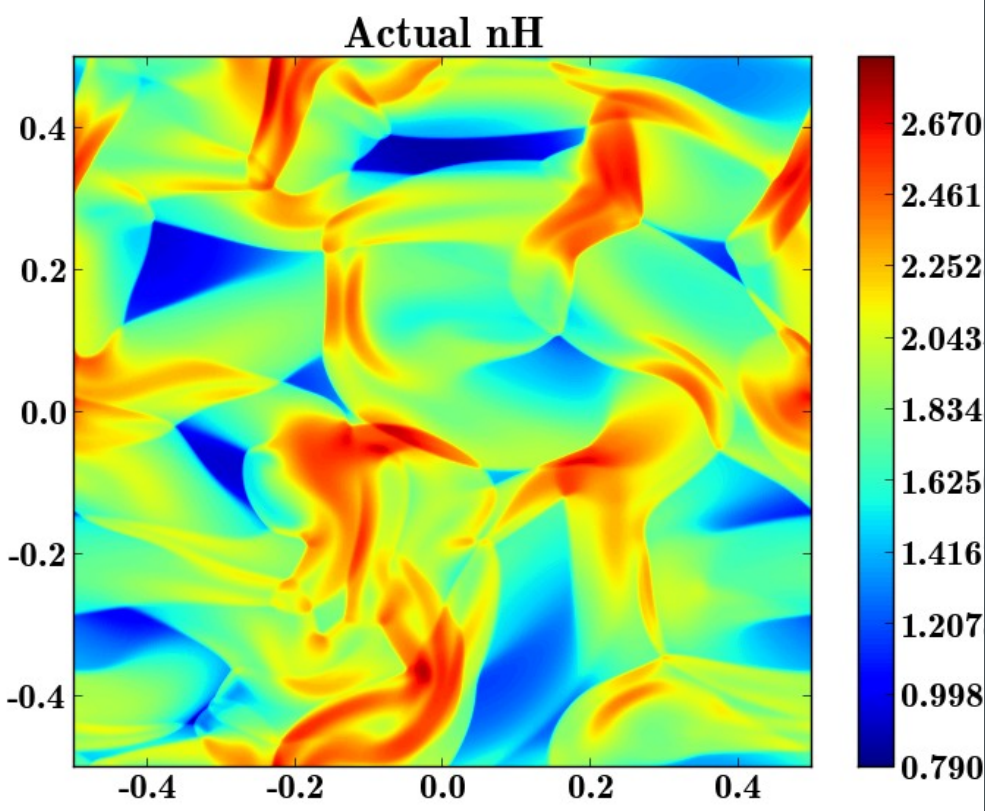


Affect each point to a shock
(=> define background and shocked regions)

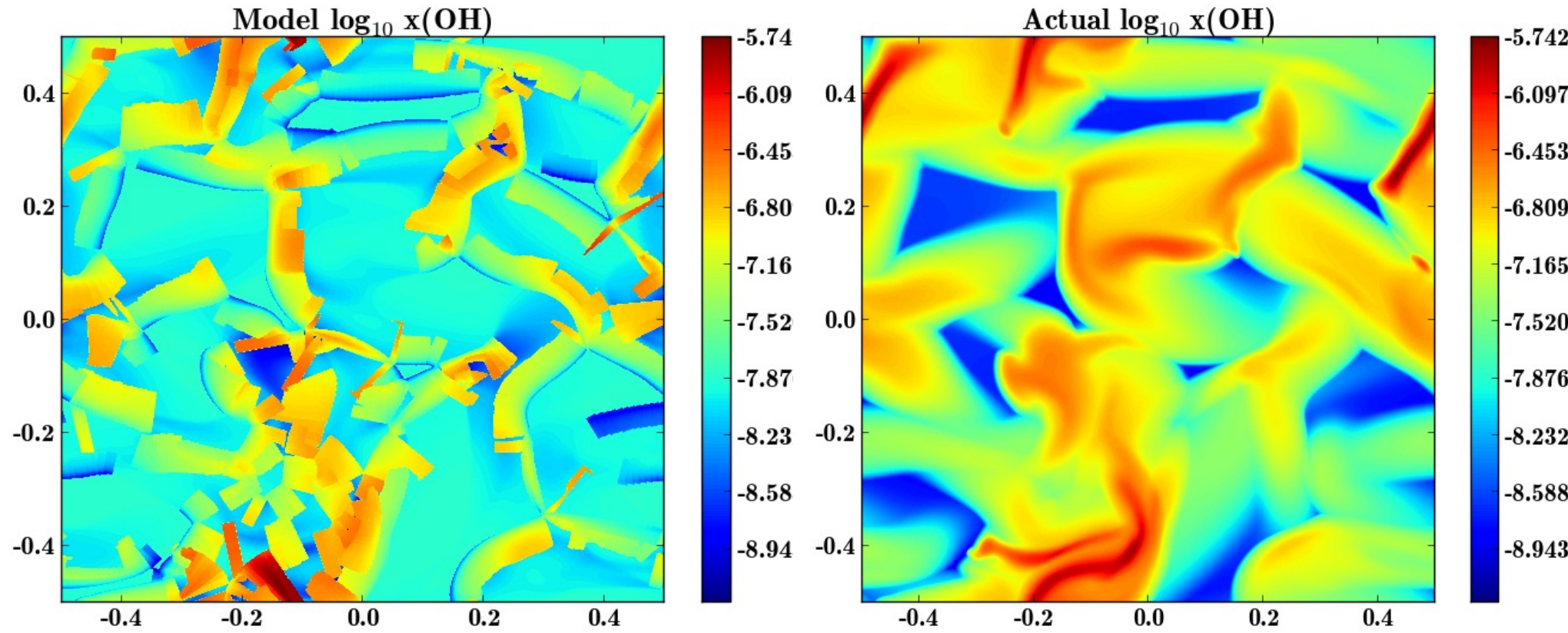


Use steady shock models in the shocked region e.g. here: mass density ($\log_{10} n_H$)

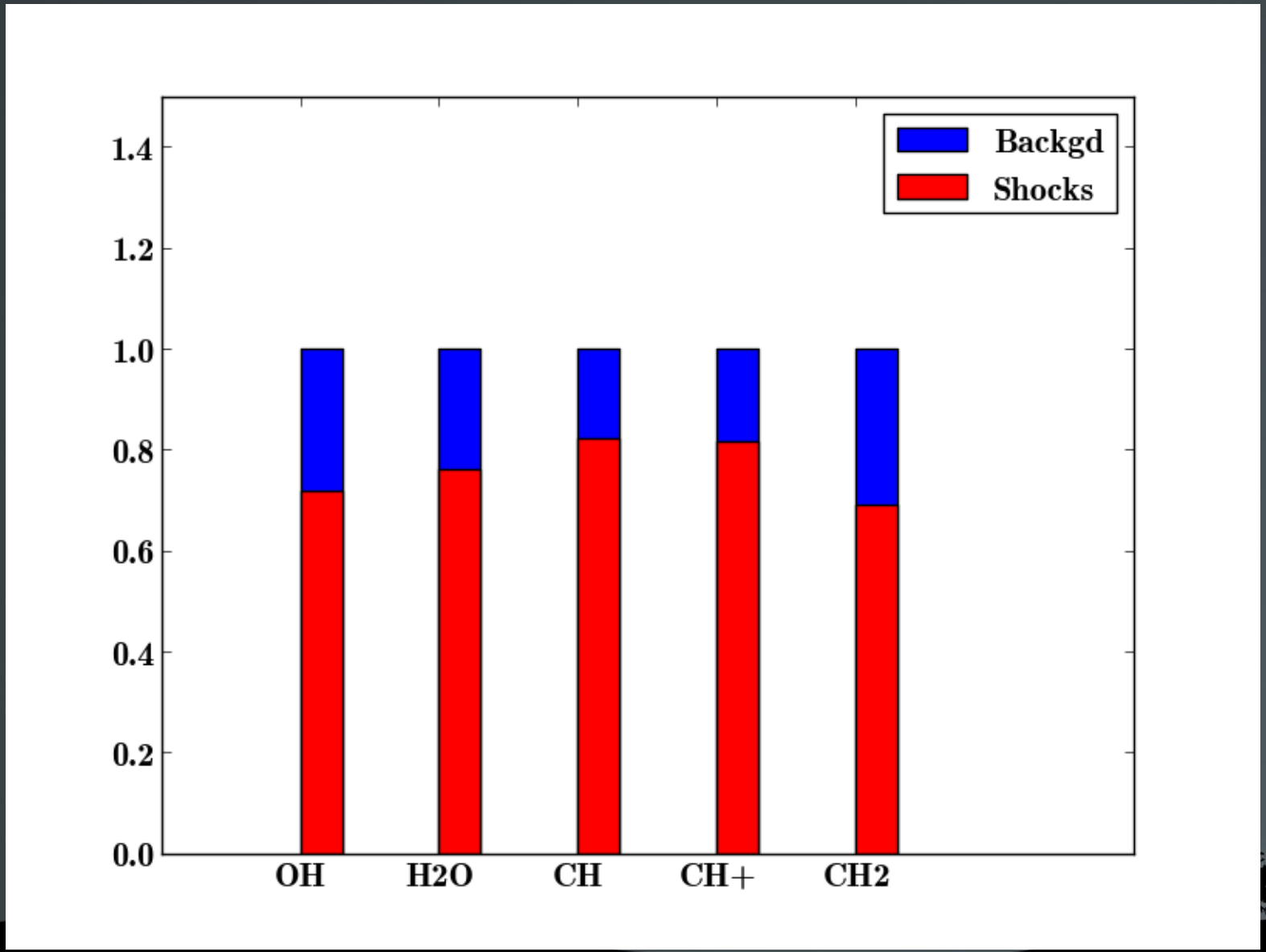




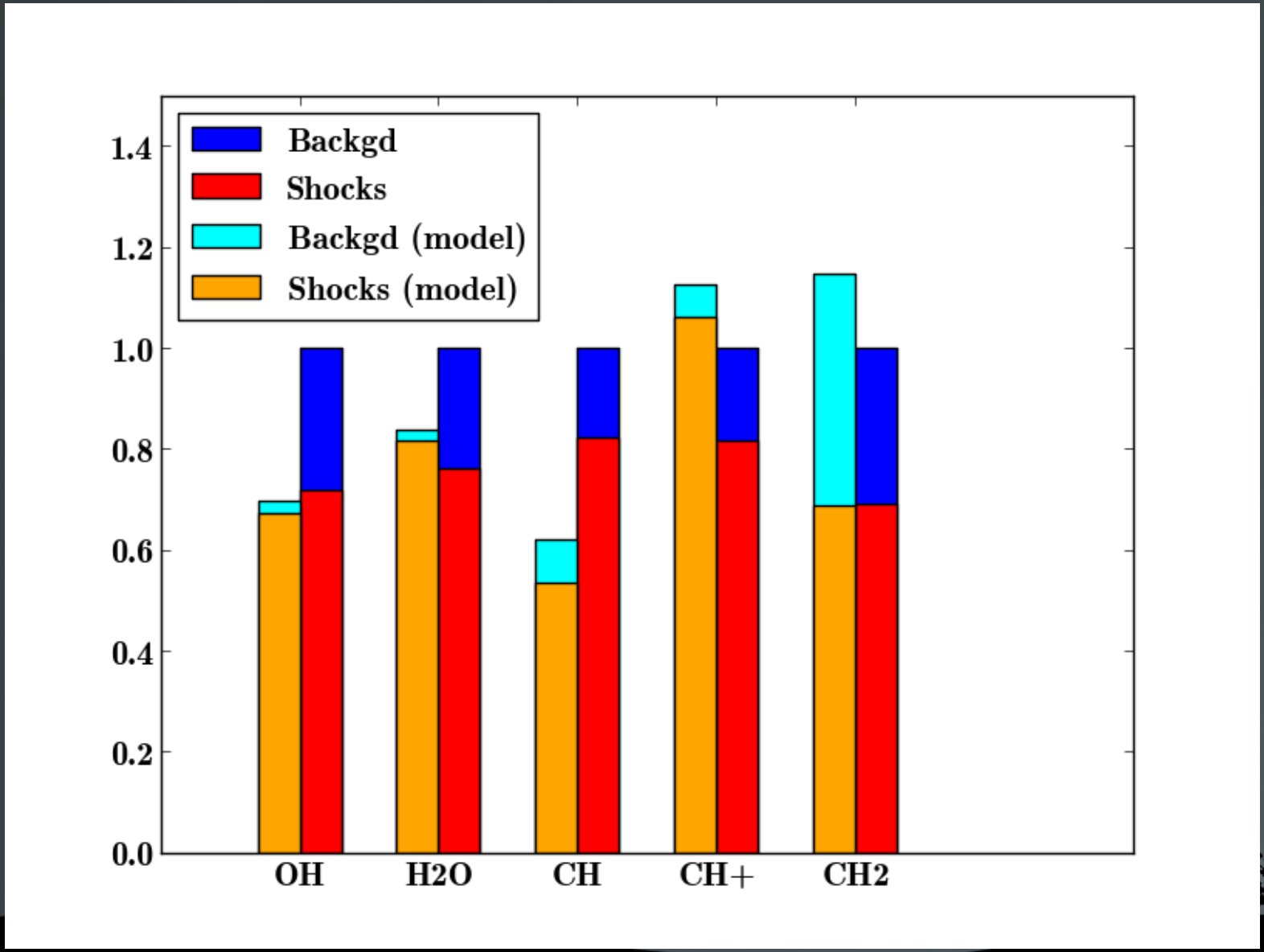
The map of OH relative abundance (chemical equilibrium used outside shocks)



Fraction of hydrides in background and shocked region



Model performance on average for hydrides



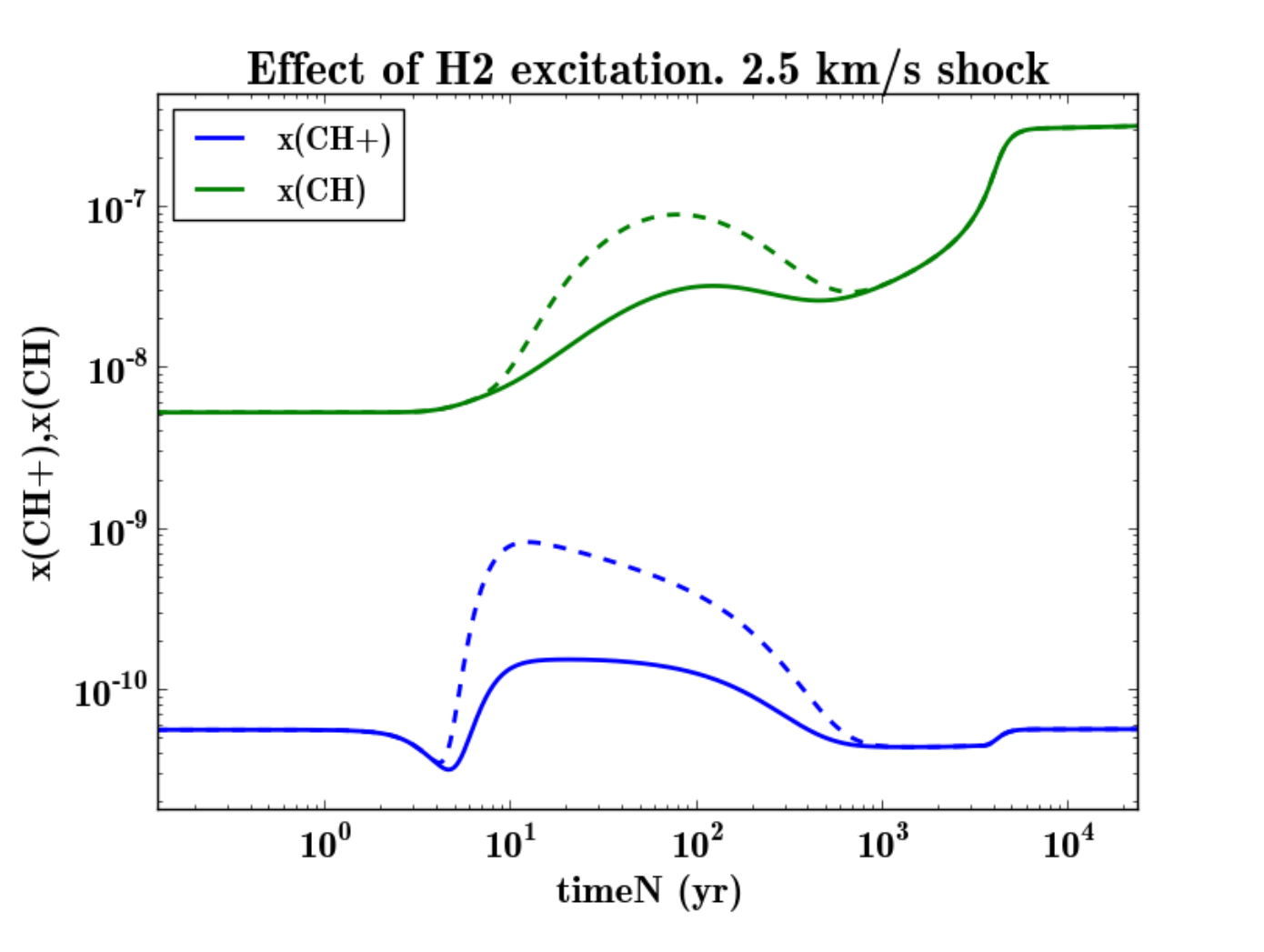
What really matters ?

- Entrance conditions
  - Temperature (Mach number => compression)
  - Chemical equilibrium
  - Entrance H2 levels (ortho/para ratio)
  - Entrance H2 fraction (H/H2)
- Shock extent
- ~~Trajectory of the shock (oblique ? Normal ?)~~
- ~~Curvature~~
- ~~Sideways gradients~~
- ~~Compression / dilatation along the shock~~
- Intrinsic unsteadyness (matters for background)

Importance of H_2 excitation

Solid: Hierl et al. (1997) ~ exp (- 4540 K / T)

Dashed: Agúndez et al. (2010) state ~ exp [- (4830 K - E_{vJ}^{H2} /kb) / T]



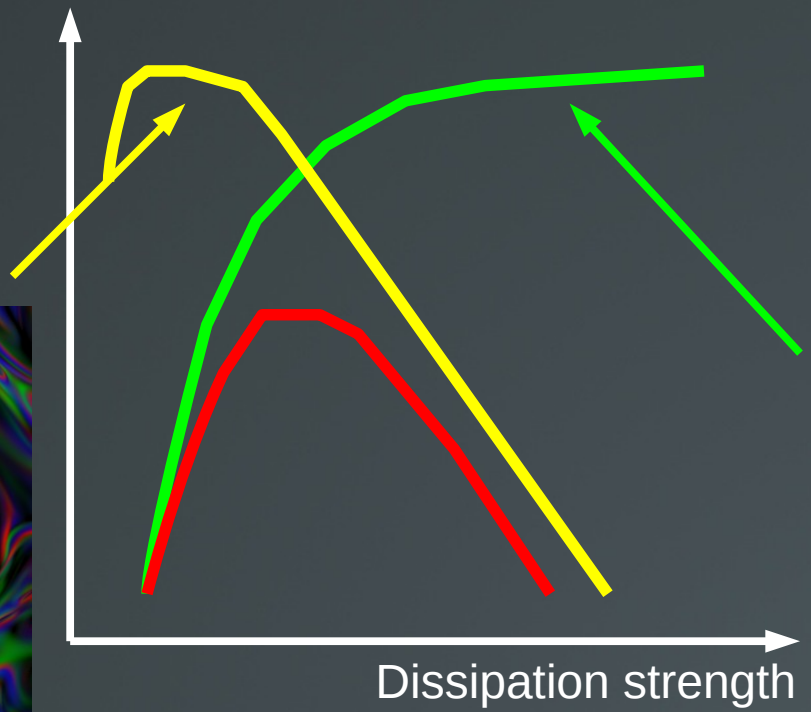
Conclusions

- Many hydrides are sensitive to dissipation (amongst others, OH, H_2O and CH+).
- This chemistry requires extreme spatial resolution, and is absent from current large scale simulations.
- Distributions of steady-shocks are a good tool to model the sub-grid molecular chemistry.
- H_2 excitation in J-shocks can be important for the $CH_n^{(+)}$ chain.
- TODO:

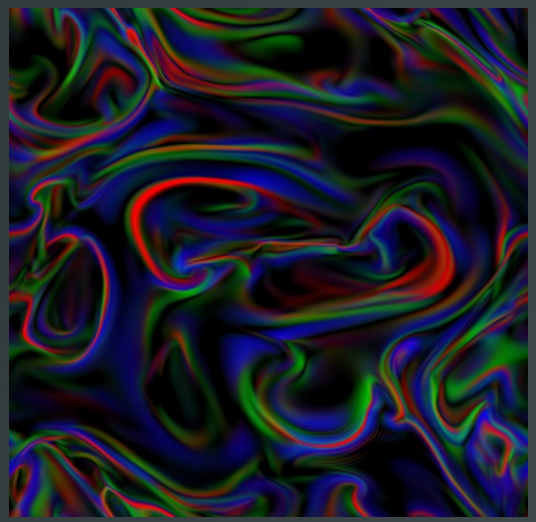
check B field and ambipolar diffusion.

Prospects

Intermittent statistics of the dissipation

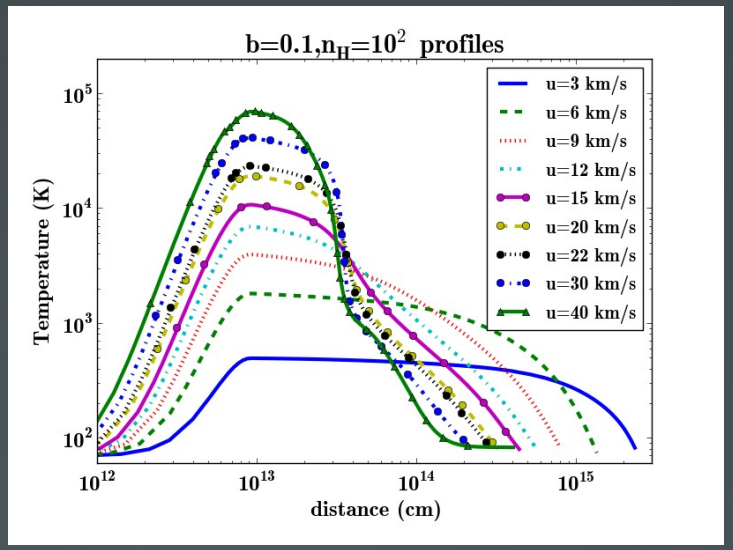


Molecular yields from Shocks (for example)

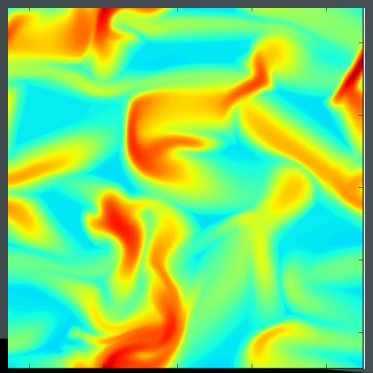


3D simulations

=> Molecules Formation + excitation



1D simulations



CO map

Validation with 2D simulations

Thanks !