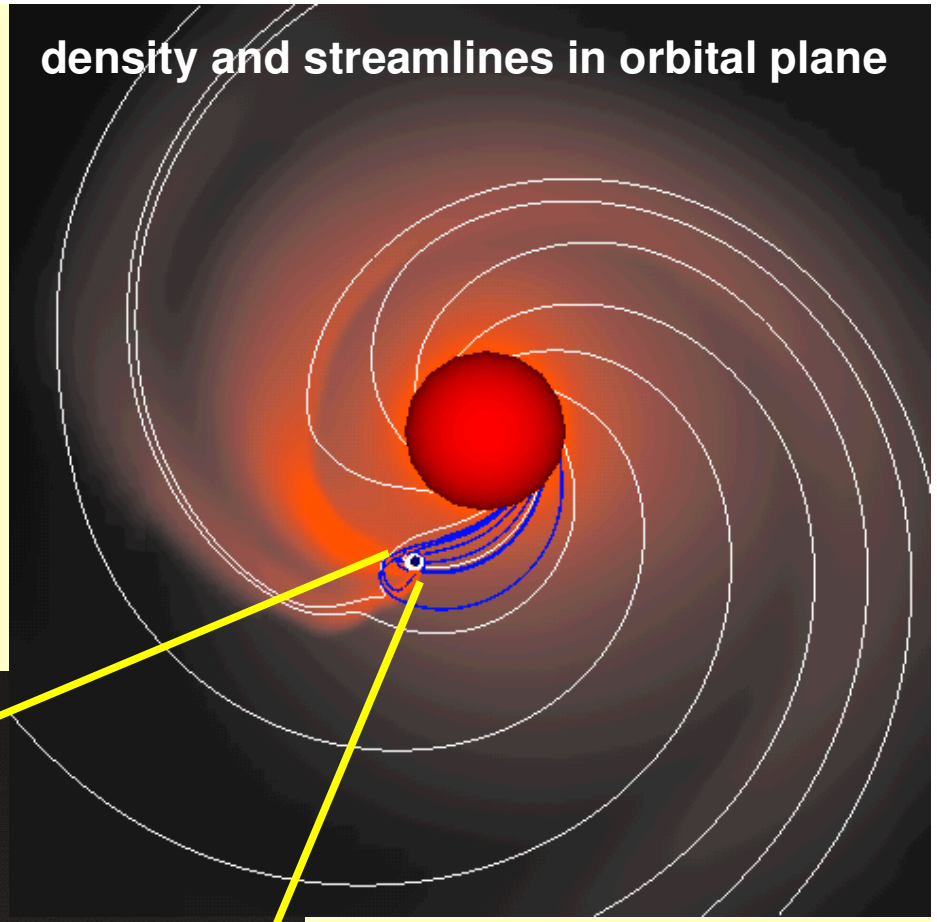
Code validation

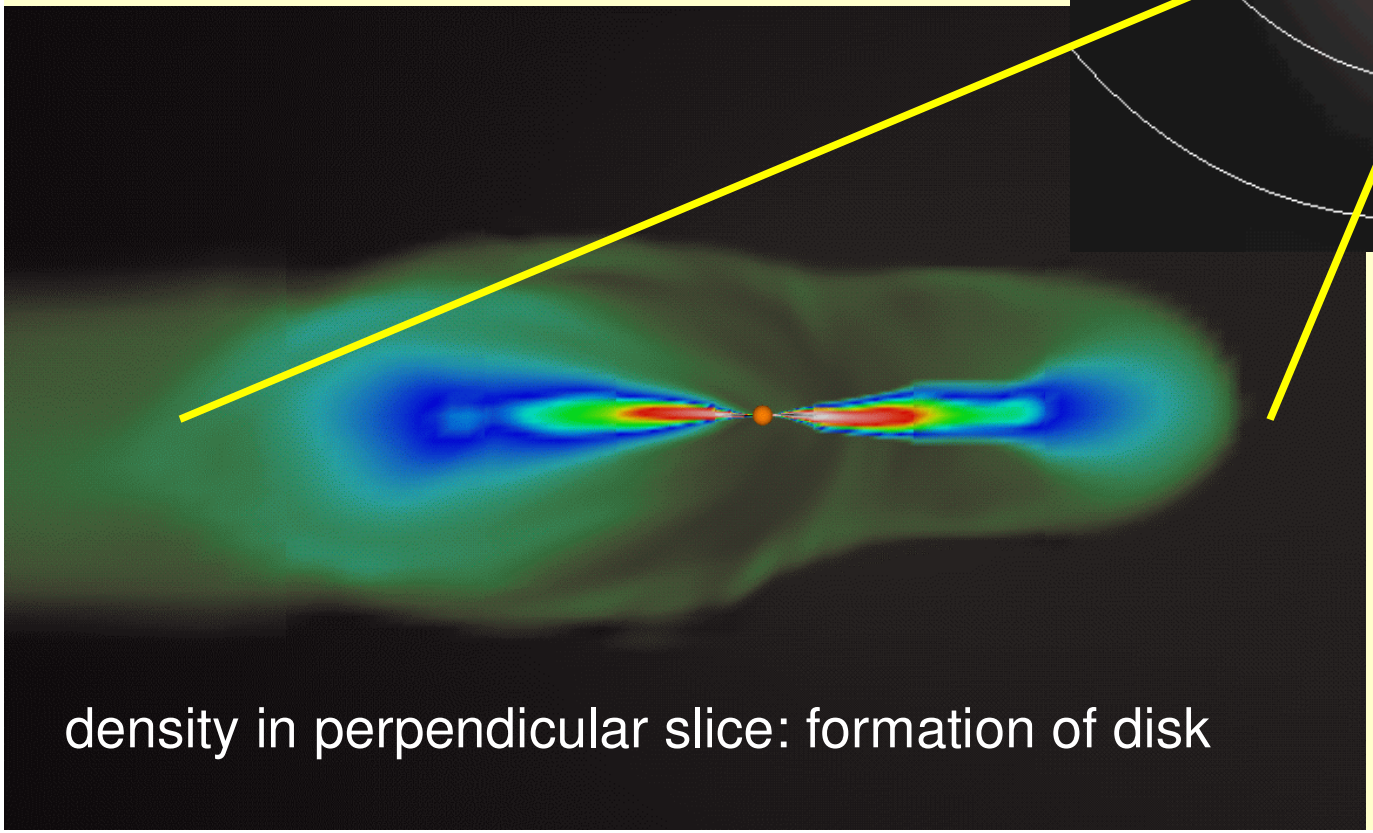
Some failures of state of the art codes

Accuracy and numerical resolution

Testing and validation
- Comparison with analytical solution
- Comparison with experiments
- Comparison with other codes and numerical methods
- grid studies
- Comparison with your physical intuition and your physical understanding

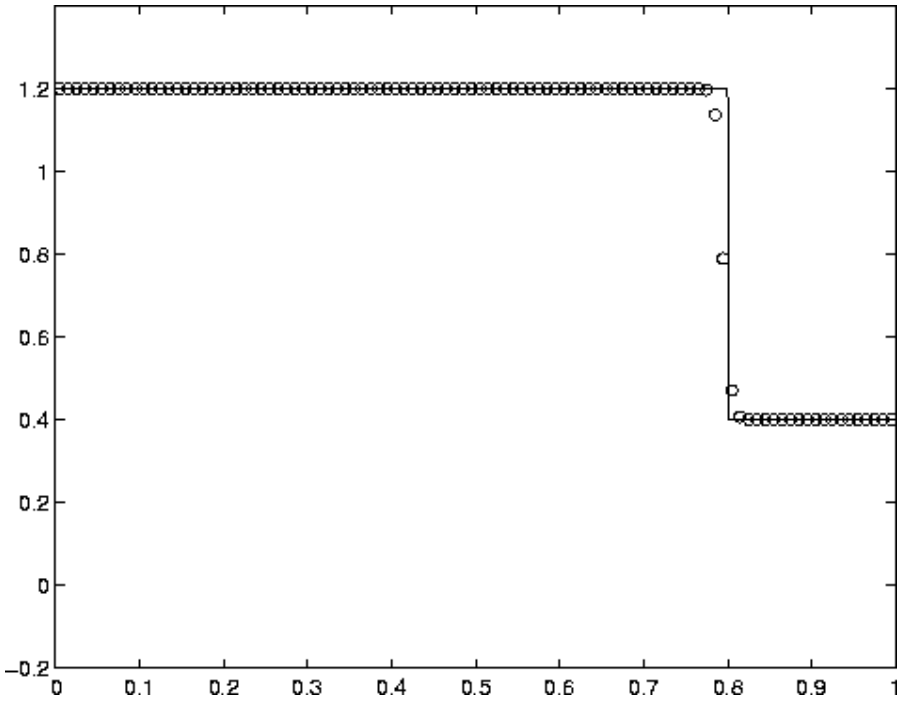
How to validate a complex simulation?



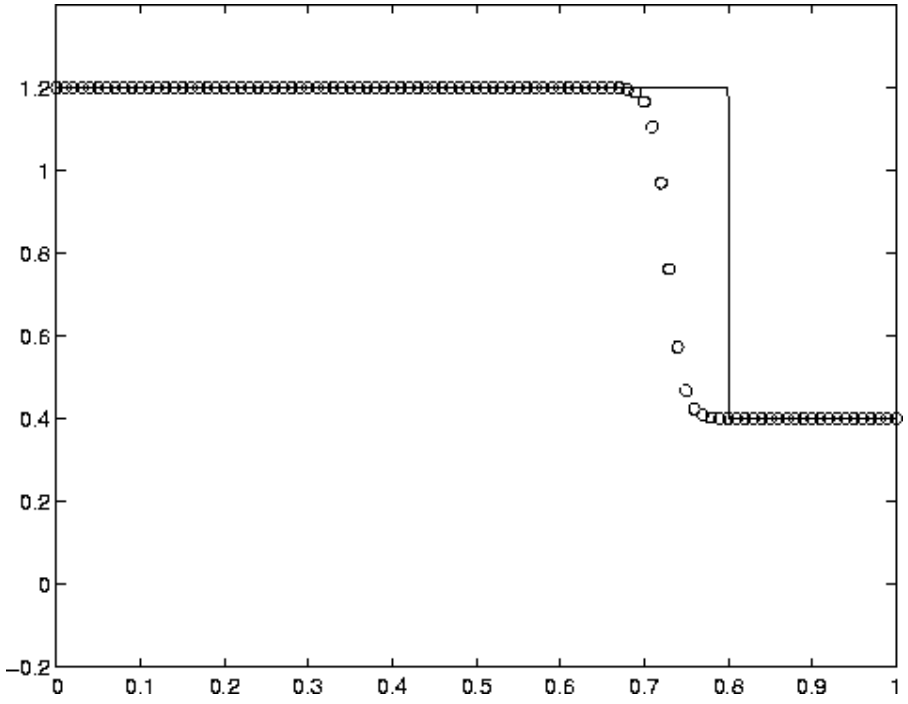


Chose the right method I

shock-capturing schemes: conservative methods!



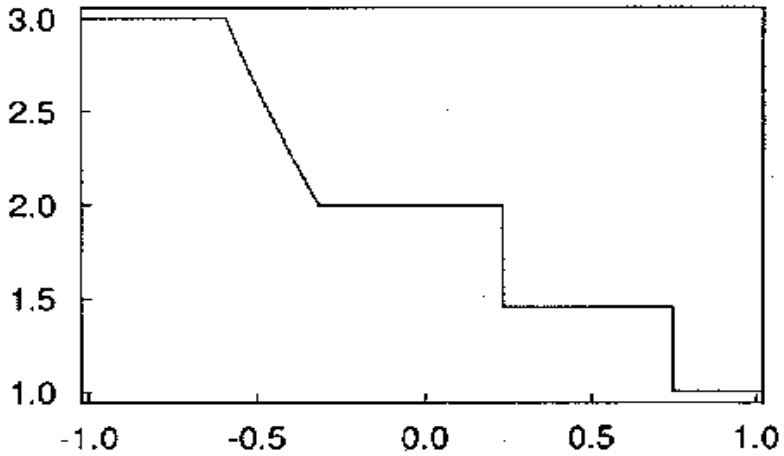
conservative scheme



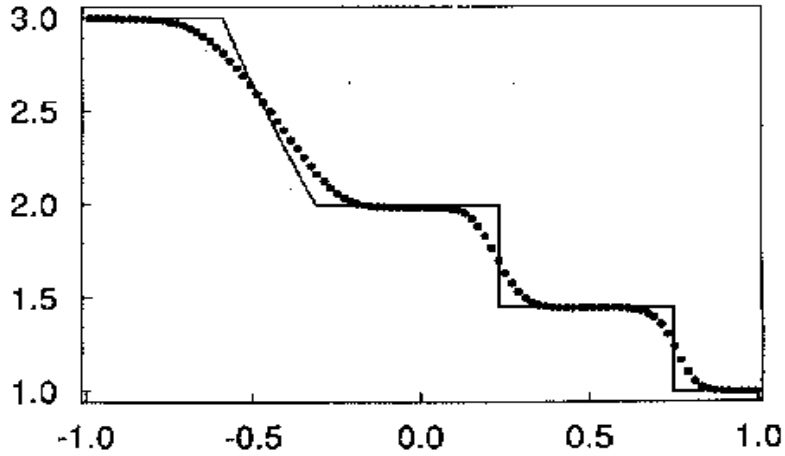
non- conservative scheme

Chose the right method II

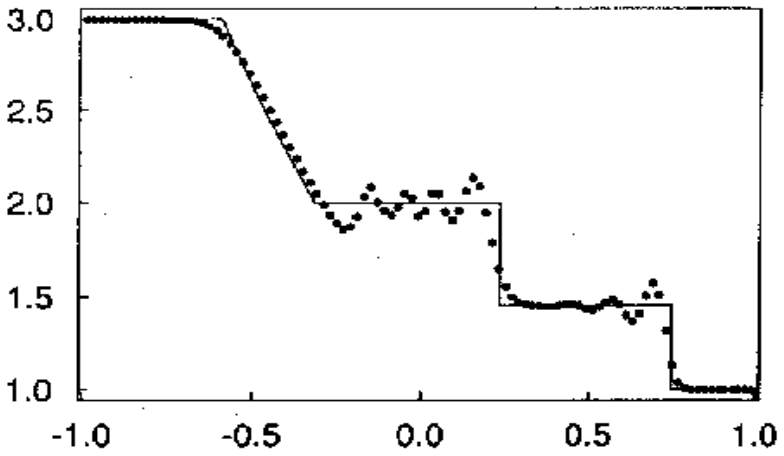
true density profile



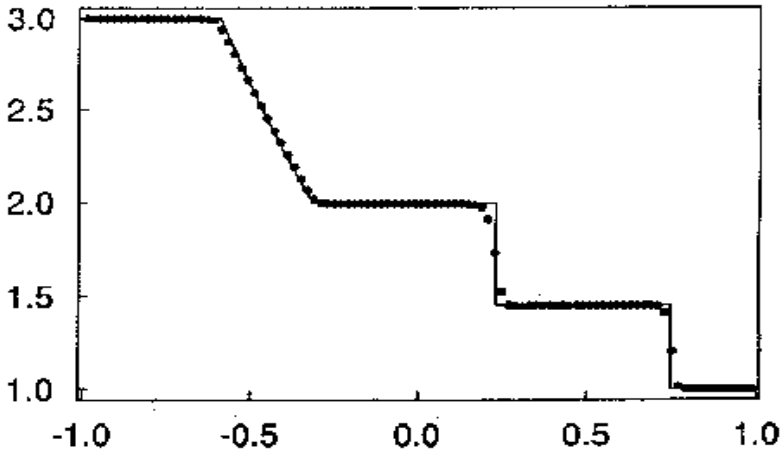
first order upwind: Godunov



second order centered



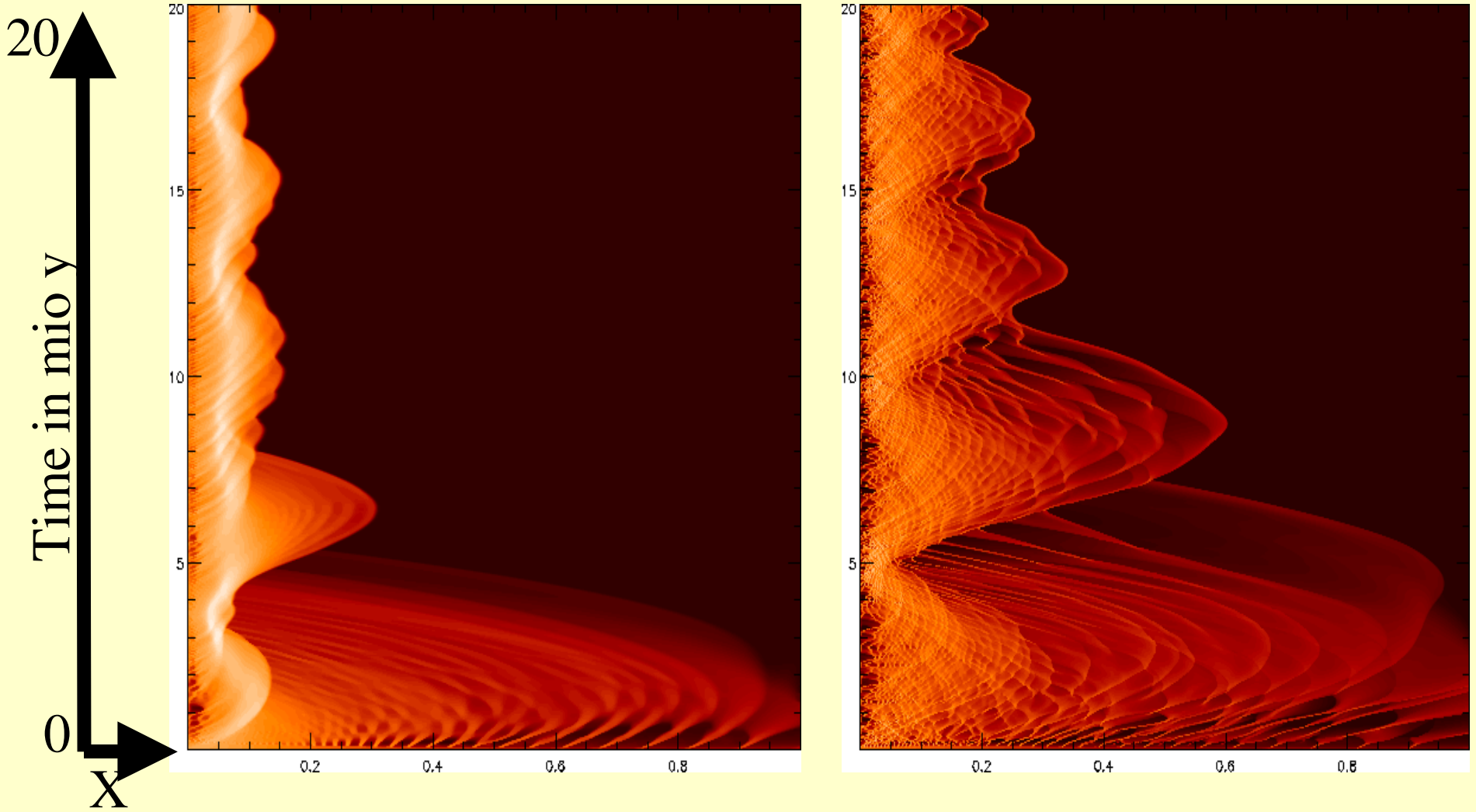
second order upwind



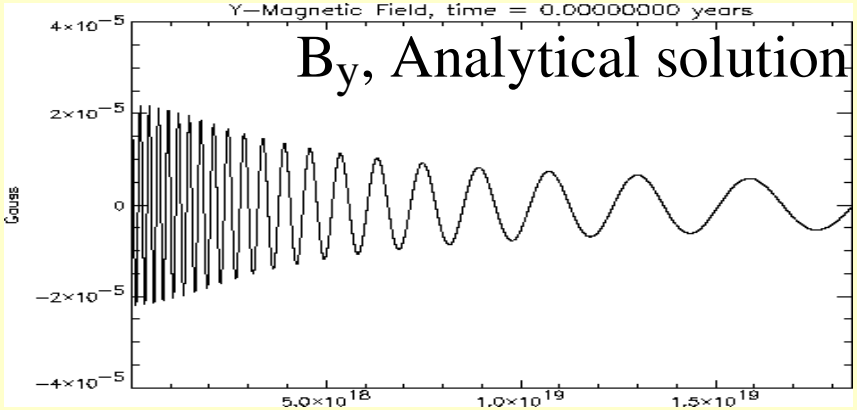
Chose the right discretization I

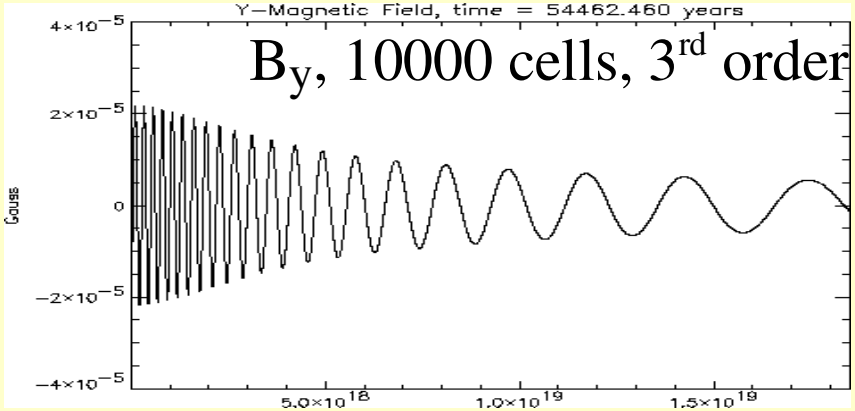
1000 cells, ΔM ≈ 2.0%

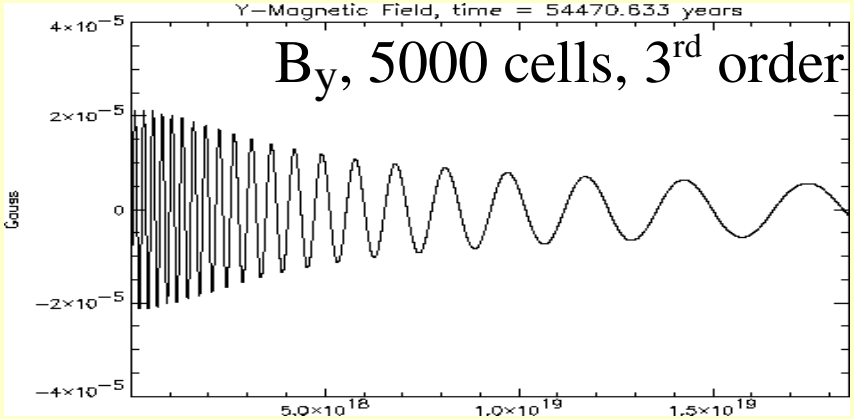
5000 cells, ΔM ≈ 0.0%

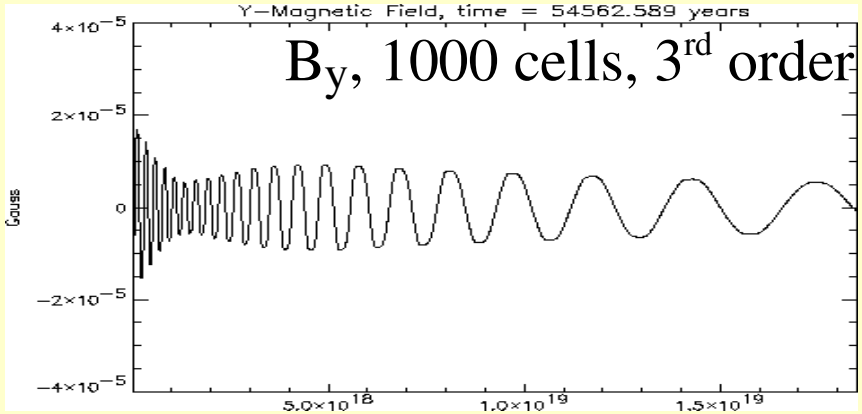


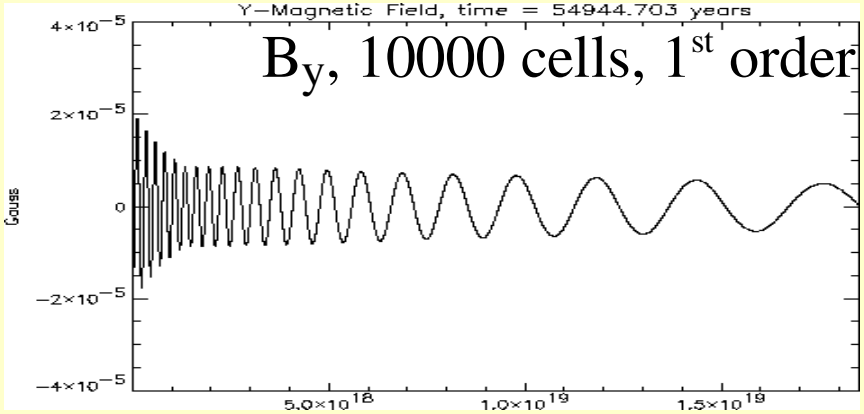
Chose the right discretization II





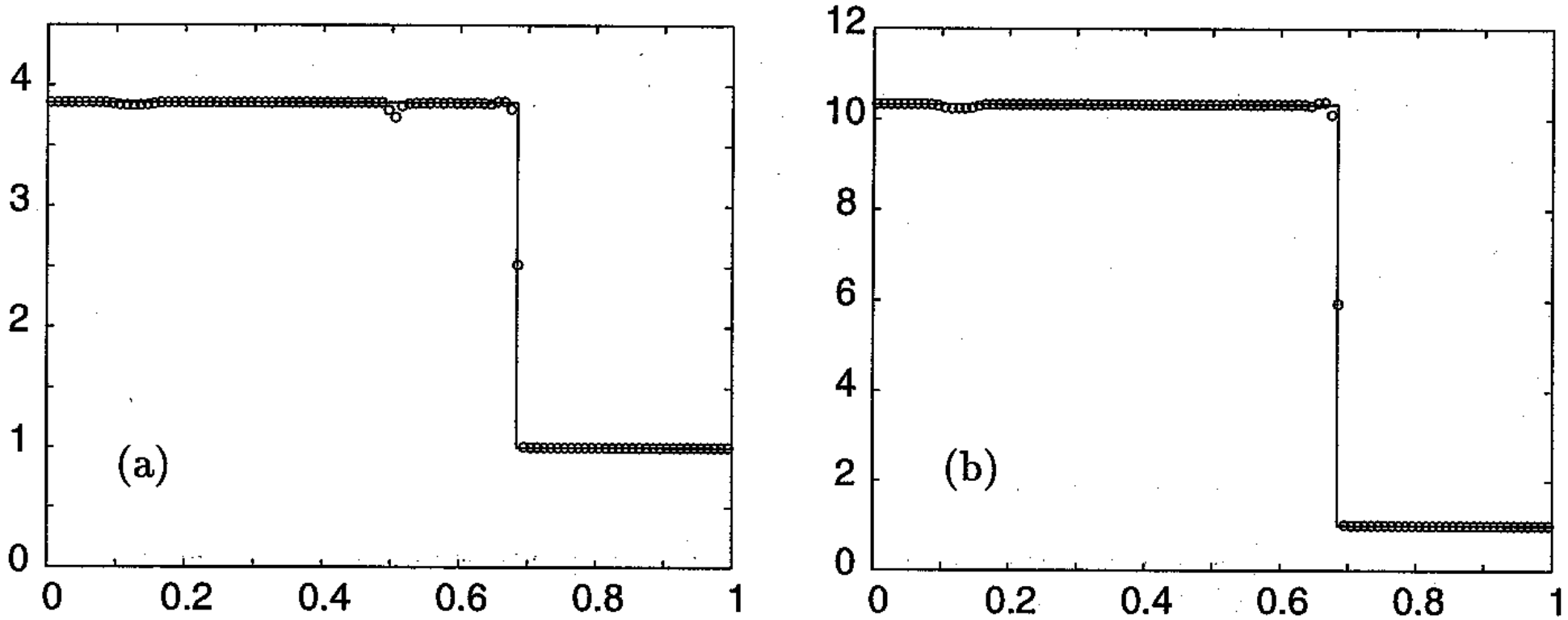






Some well known problems with `state of the art' - methods

start- up- errors

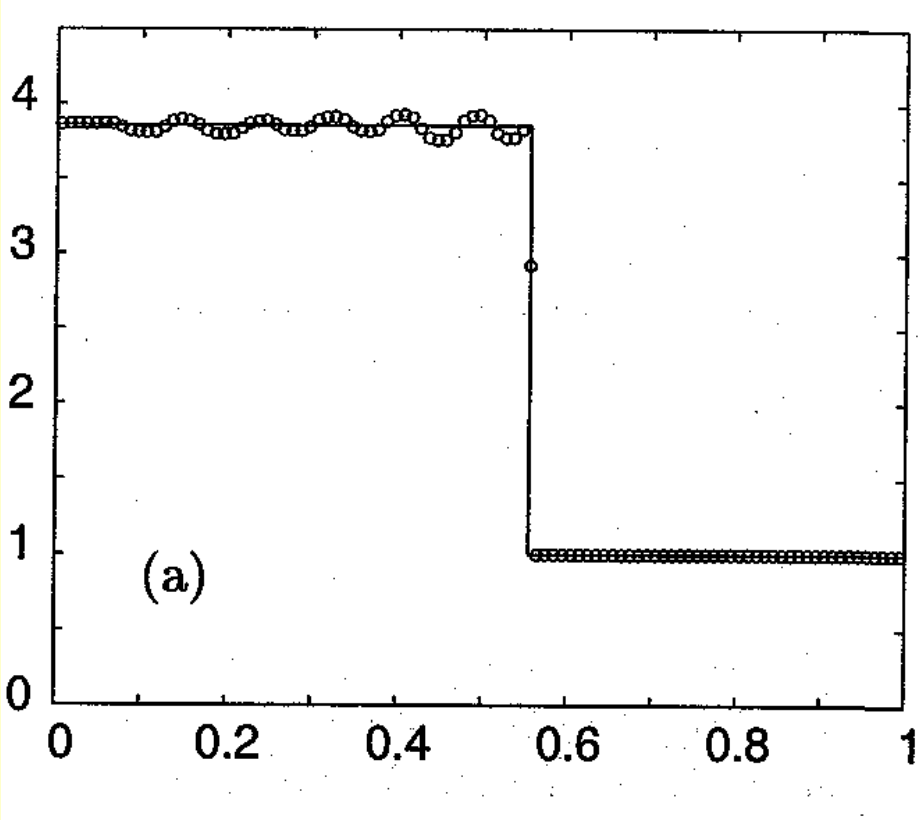


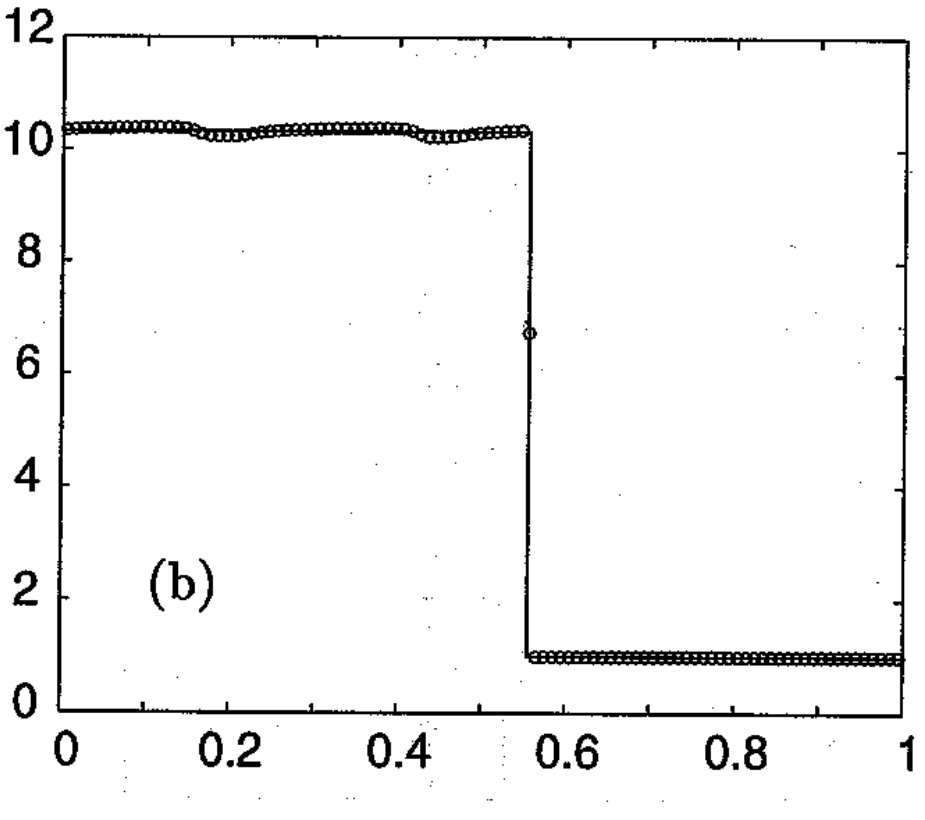
This and the following slides are taken from

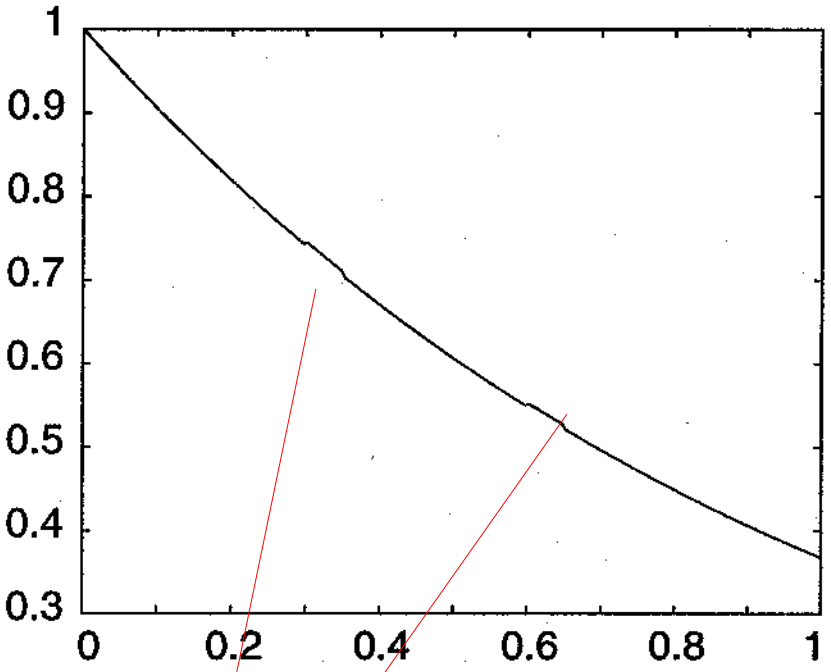
R.J. Leveque:

in R.J. LeVeque, D. Mihalas, E.A. Dorfi, and E. Müller :
Computational Methods for Astrophysical Fluid Flow
Saas- Fee Advanced Course 27 Swiss Society for Astrophysics and Astronomy,Springer, 1997

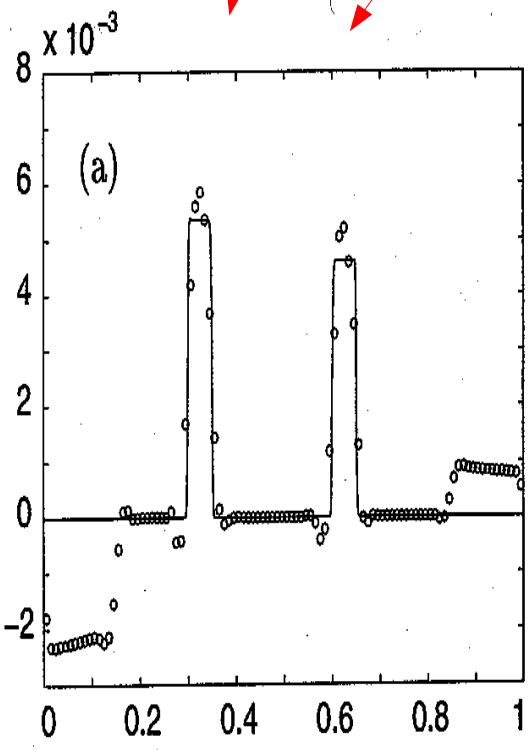
slow shock

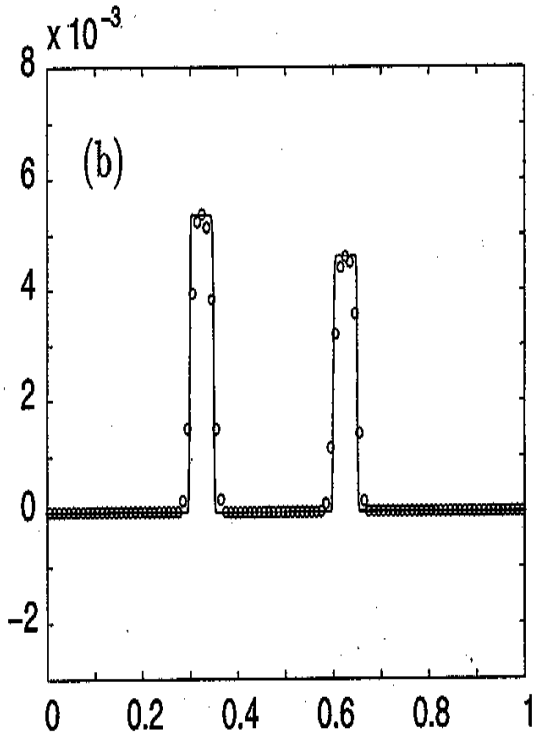






static atmosphere





enlarged (see scale!)

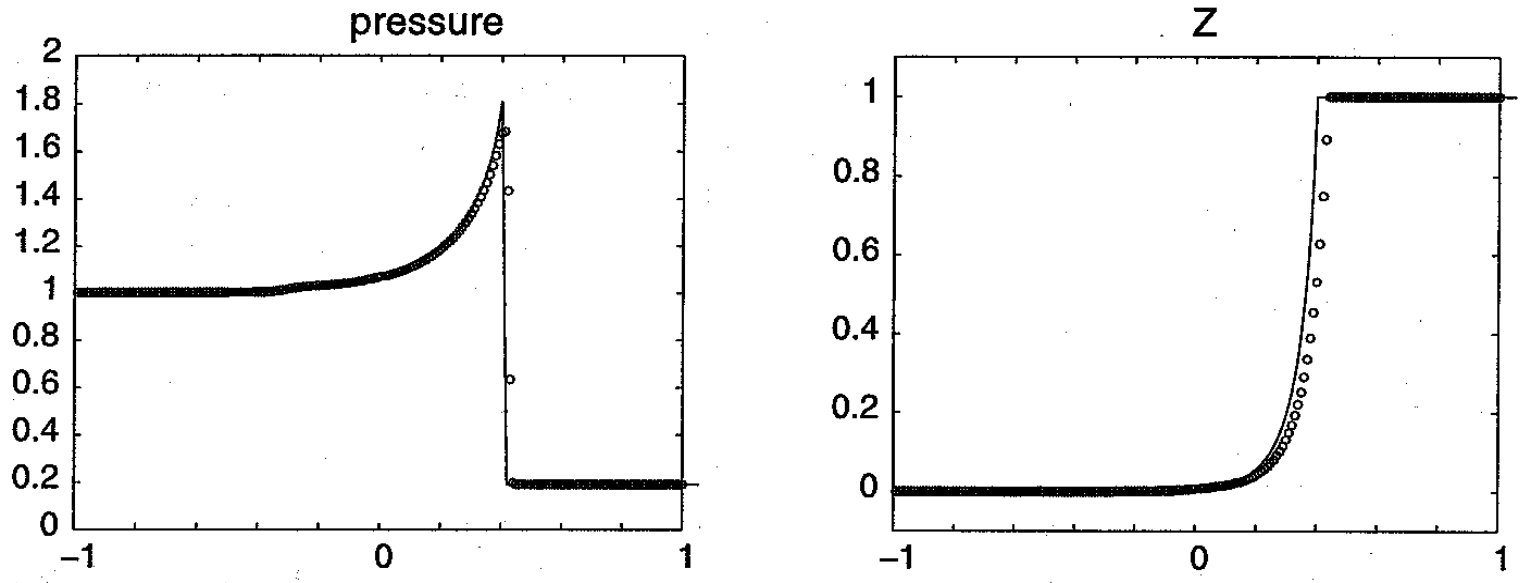


Fig. 5.1. True ZND structure (solid line) and numerical solution to the combustion problem with $\tau = 0.1$

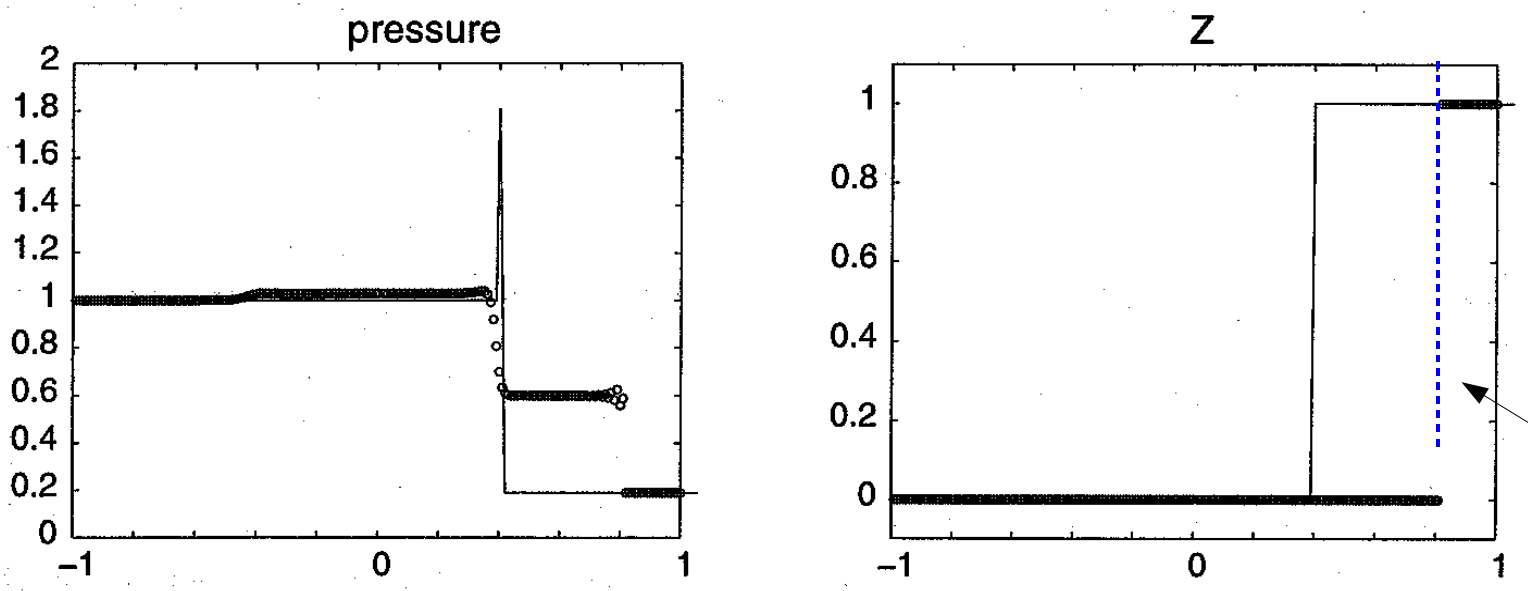


Fig. 5.2. True ZND structure (solid line) and numerical solution to the combustion problem with $\tau = 10^{-6}$

stiff sources

the same method, but

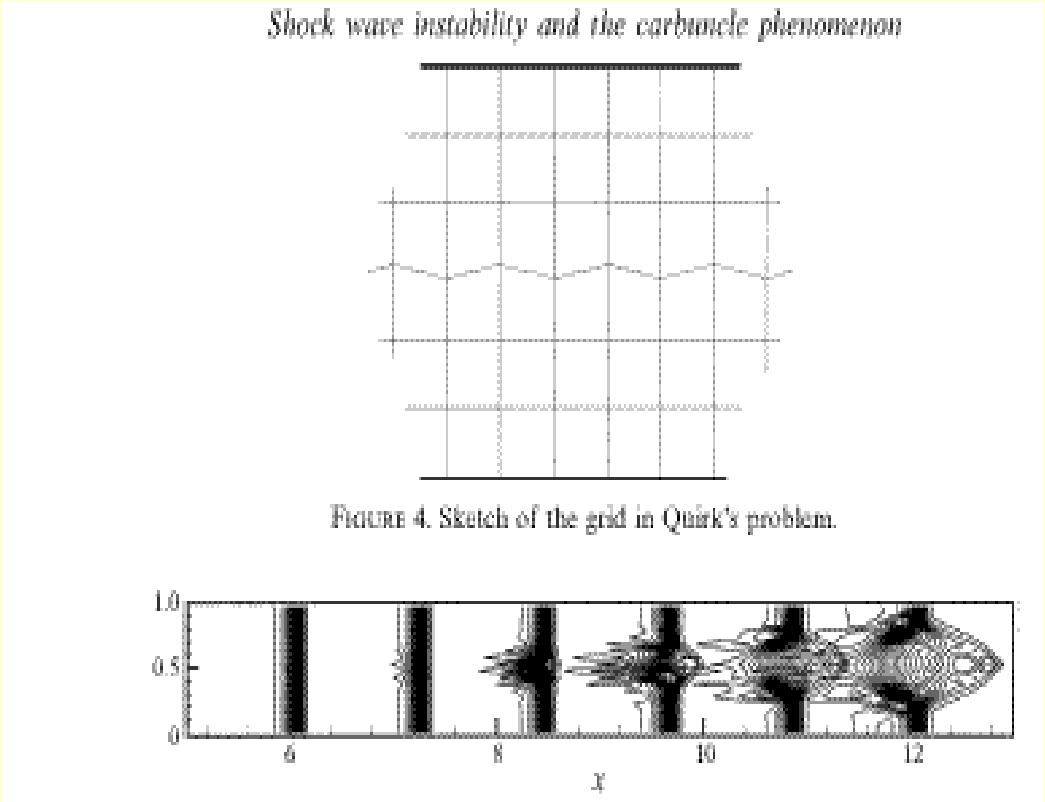
- combustion time- scale ~ hydro- time- scale

- combustion time- scale 10^6 faster than hydro- time- scale

burning front at wrong position

R.J. LeVeque & H.C. Yee, JCP 86, 187- 210 (1990)

Carbuncle



J.- Ch. Robinet, J. Gressier, G. Casalis, & J.-M. Moschetta
Shock wave instability and the carbuncle phenomenon: same intrinsic origin?
J. Fluid Mech. 417, 237- 263, 2000

Carbuncle: a shock instability

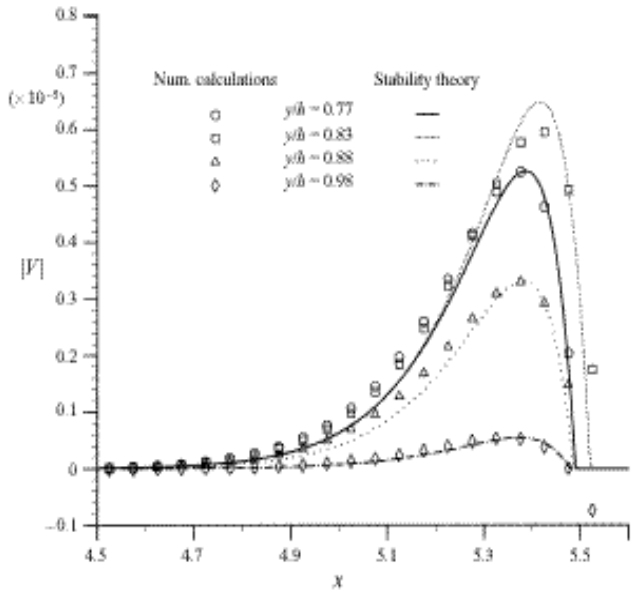


FIGURE 13. Transversal velocity comparison ($t = 1$ s).

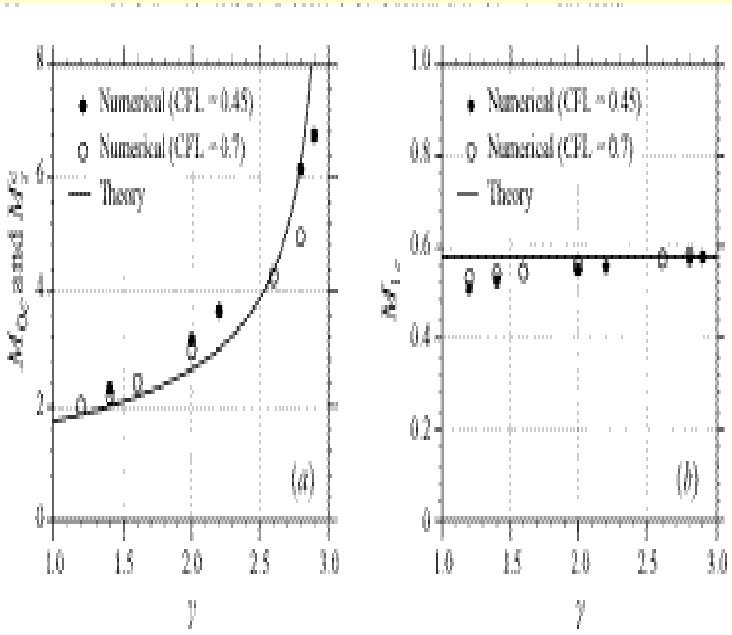
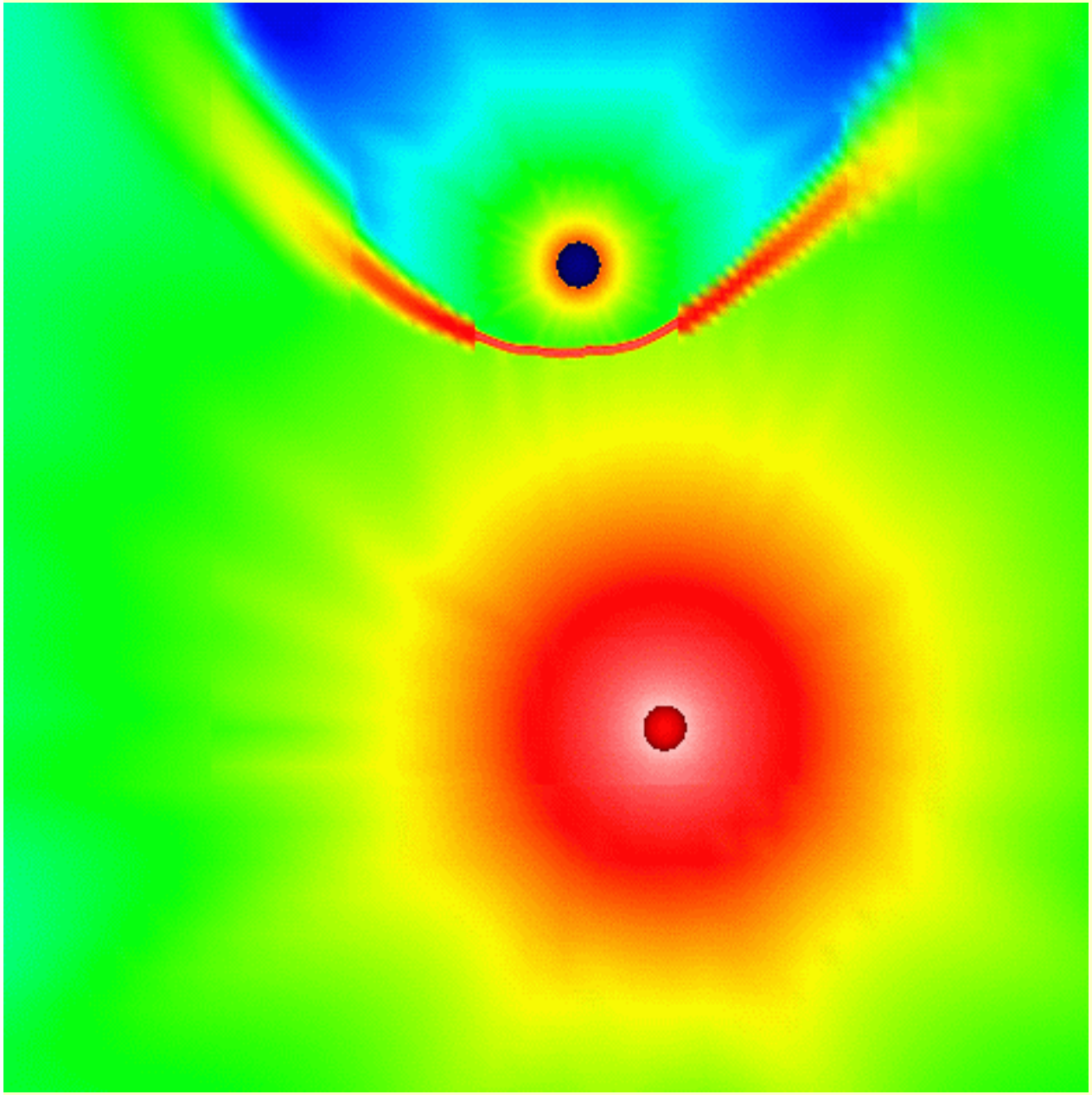


FIGURE 15. (a) Upstream and (b) downstream instability threshold versus γ (Roe's scheme).

J.- Ch. Robinet, J. Gressier, G. Casalis, & J.-M. Moschetta
Shock wave instability and the carbuncle phenomenon: same intrinsic origin?
J. Fluid Mech. 417, 237- 263, 2000



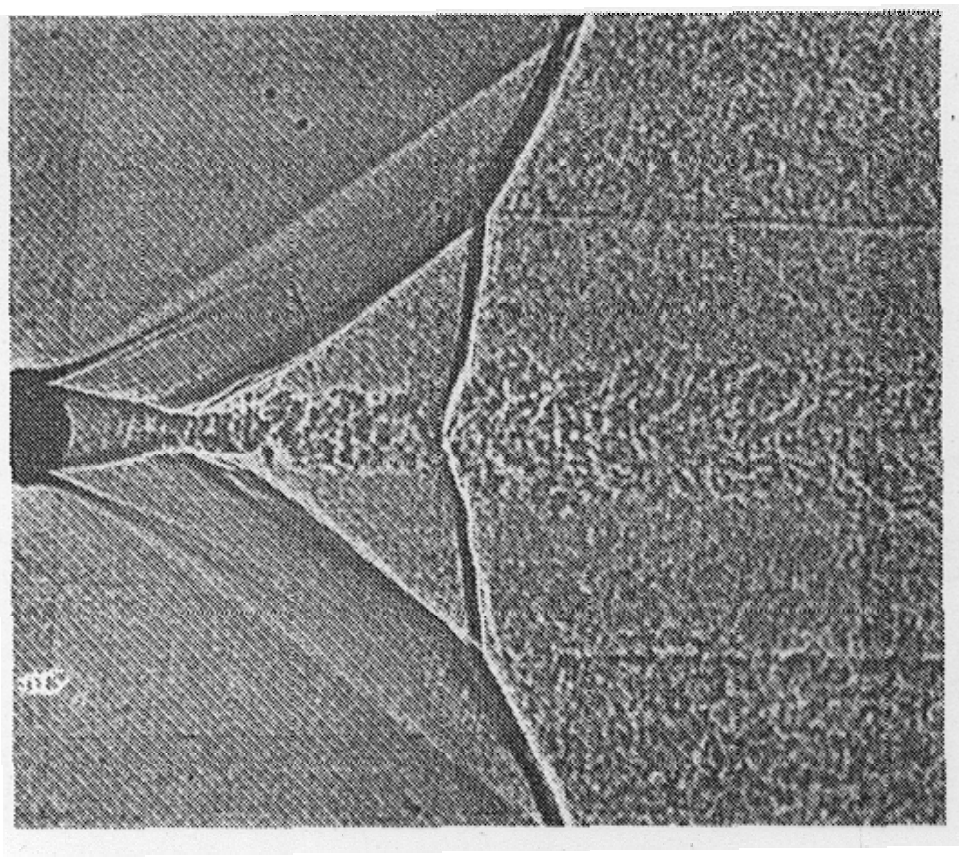
- grid alignement effects of shocks if equation of state is very stiff

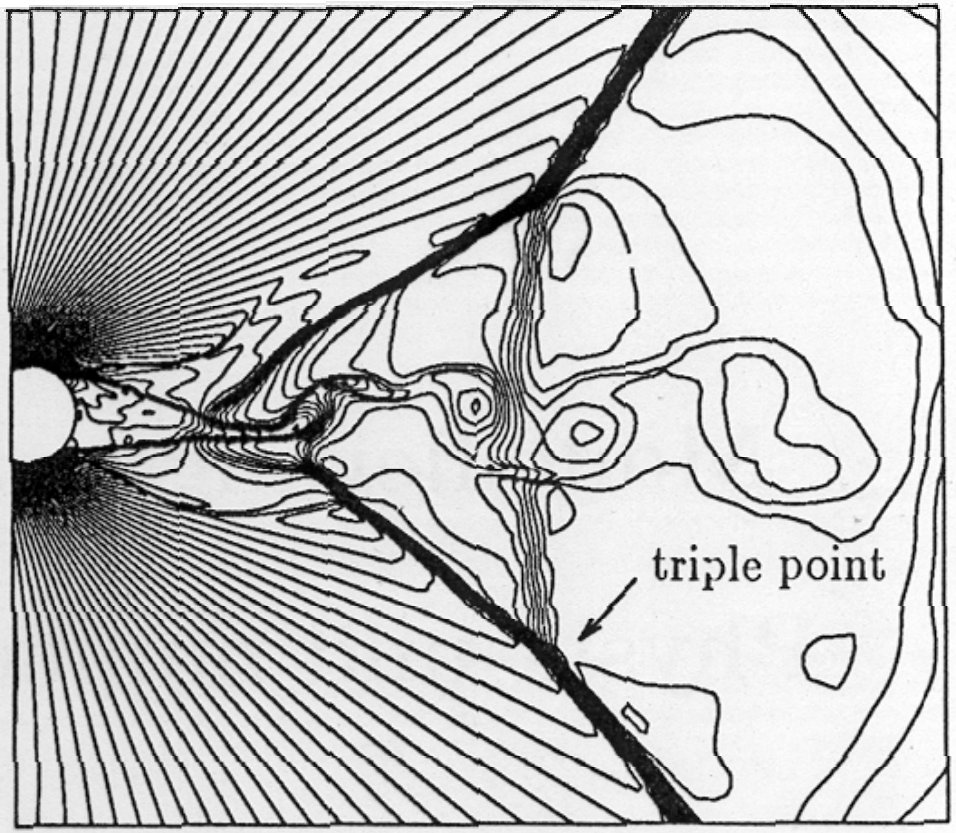
- grid- boundaries between fine and coarse meshes may lead to severe oscillations

- grid alignement effects of hypersonic spherical flows on Cartesian meshes

- numerical under-resolution of flow features may give wrong results

Code validation





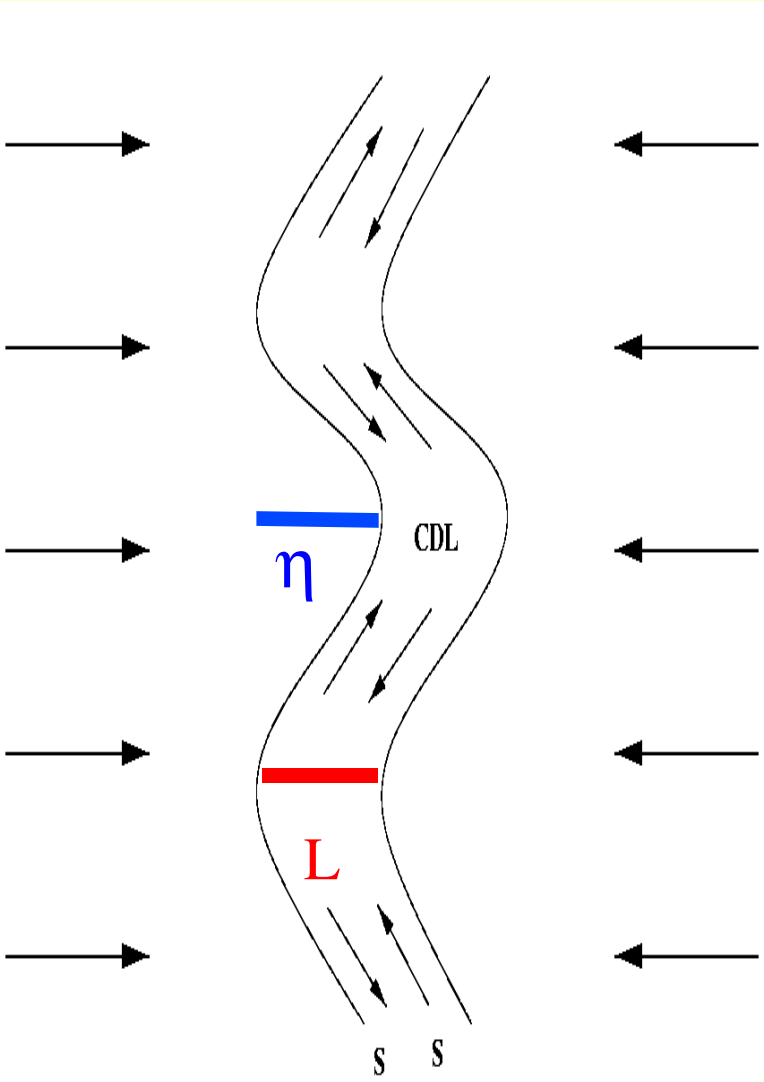
Nicola Botta

- ✗ Test code by comparing with analytical solutions
- ✗ Test code by comparing with experimental data
- ✗ Compute the same problem with two different methods
- ✗ Do grid- studies: different spatial and temporal resolutions
- ✗ Check code part by part
- ✗ Check code in debugger

Compare with your physical intuition and understanding

Possibility 1:
Comparison with analytical results

An analytical model of the exciting instability (Non-linear thin shell instability, NTSI)

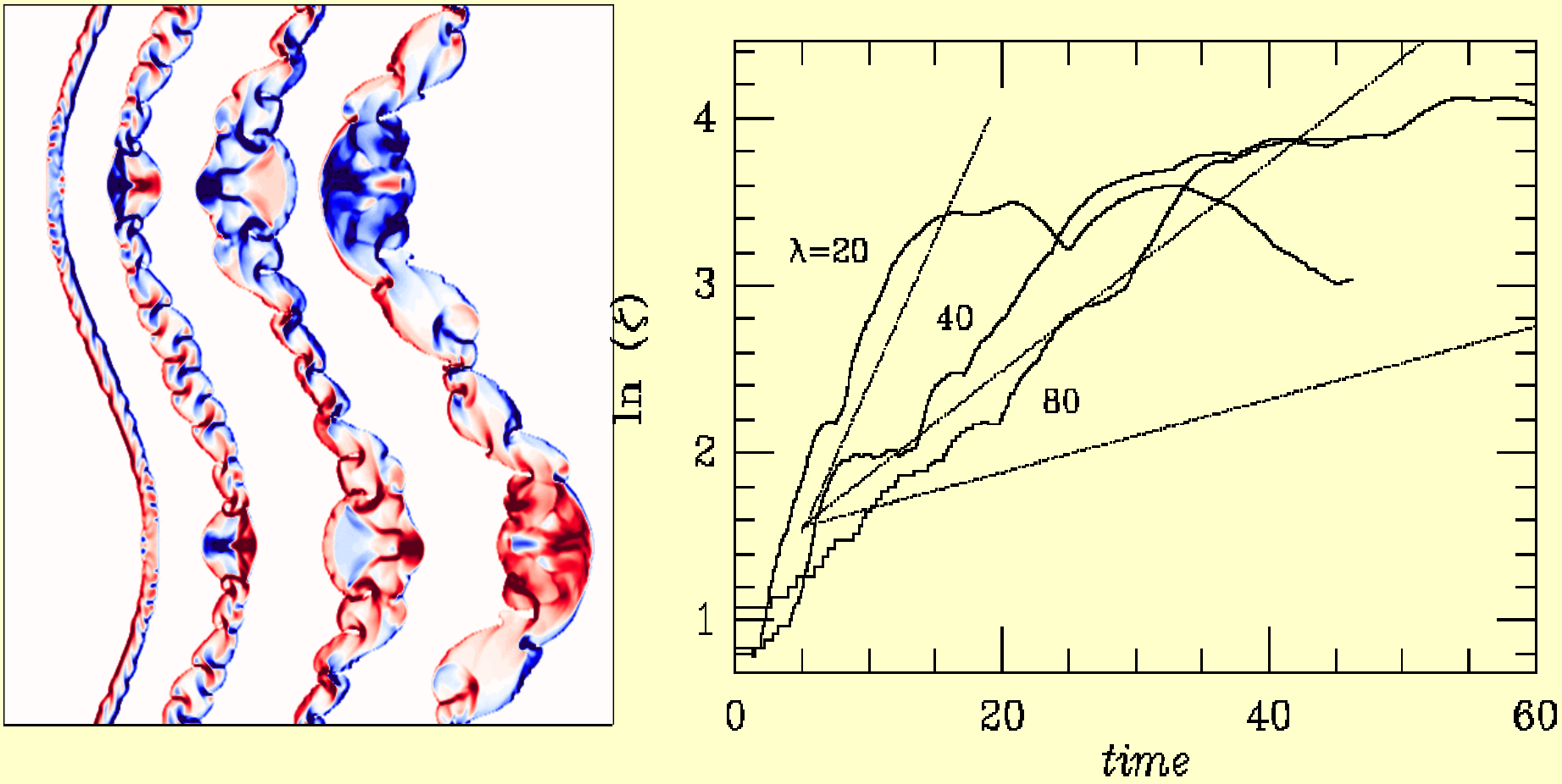


- isotropic, steady,subsonic turbulence
- linearly stable
- non-linearly unstable to disturbances of the size of the slab thickness and small bending angles
- growth rate:

$$\tau_G^{-1} \sim c_s\, k\, (k\eta)^{1/2}$$

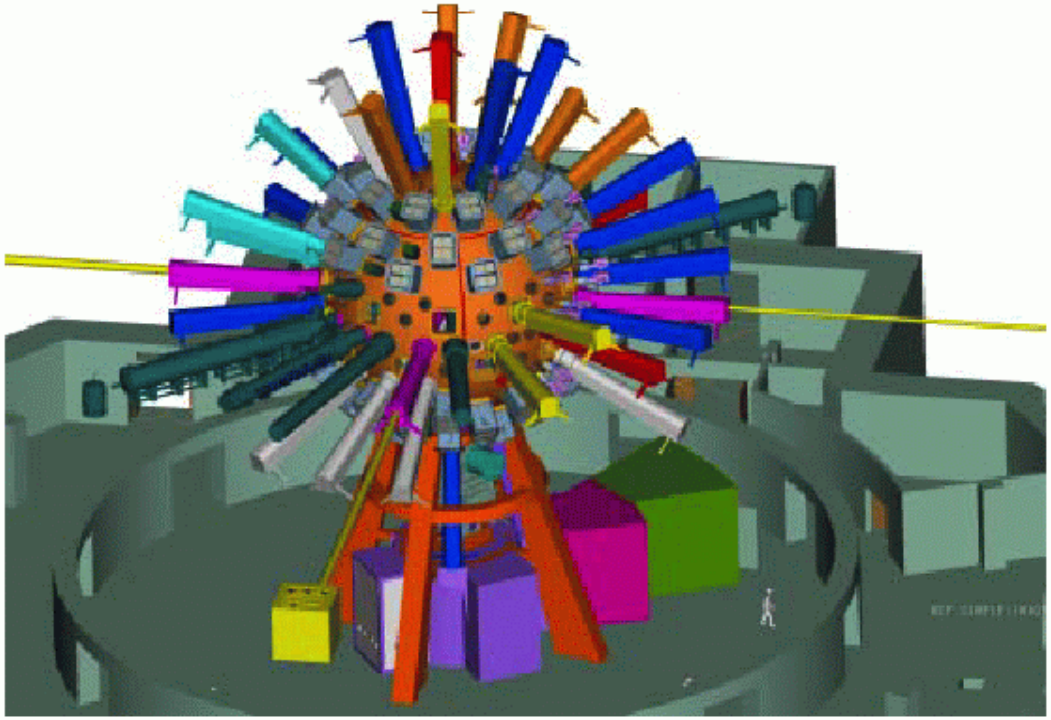
E. Vishniac, ApJ 428, 486, 1994

Numerical study



Blondin & Marks, New Astronomy, 1, 325, 1996

Possibility 2:
Comparison with the experiment

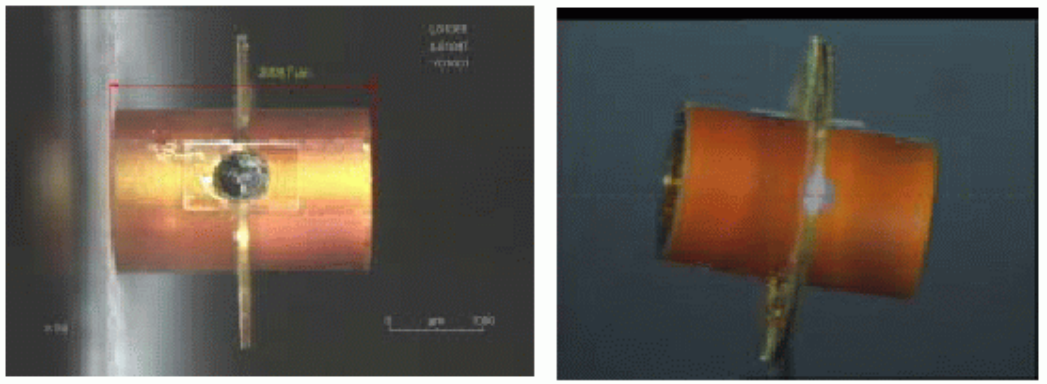


Maquette numérique de la chambre d'expérience du futur laser Mégajoule. Cette sphère de 10 mètres de diamètre supporte les optiques qui focaliseront les 240 faisceaux laser dans la cavité. On distingue également les dispositifs qui accueilleront les nombreux appareils de mesure.

laser experiments
to test shock physics

Planned French- American
Mega- joule Laser facility

http://www.cea.fr/fr/presse/dossier.asp



Cette cavité utilisée lors d'expériences menées en collaboration avec l'Université de Rochester (USA) est en or et elle a 2,7 mm de longueur. Les 25 kJ délivrés par 40 des 60 faisceaux du laser Omega ont permis d'atteindre et de mesurer des températures de 2 millions de degrés.

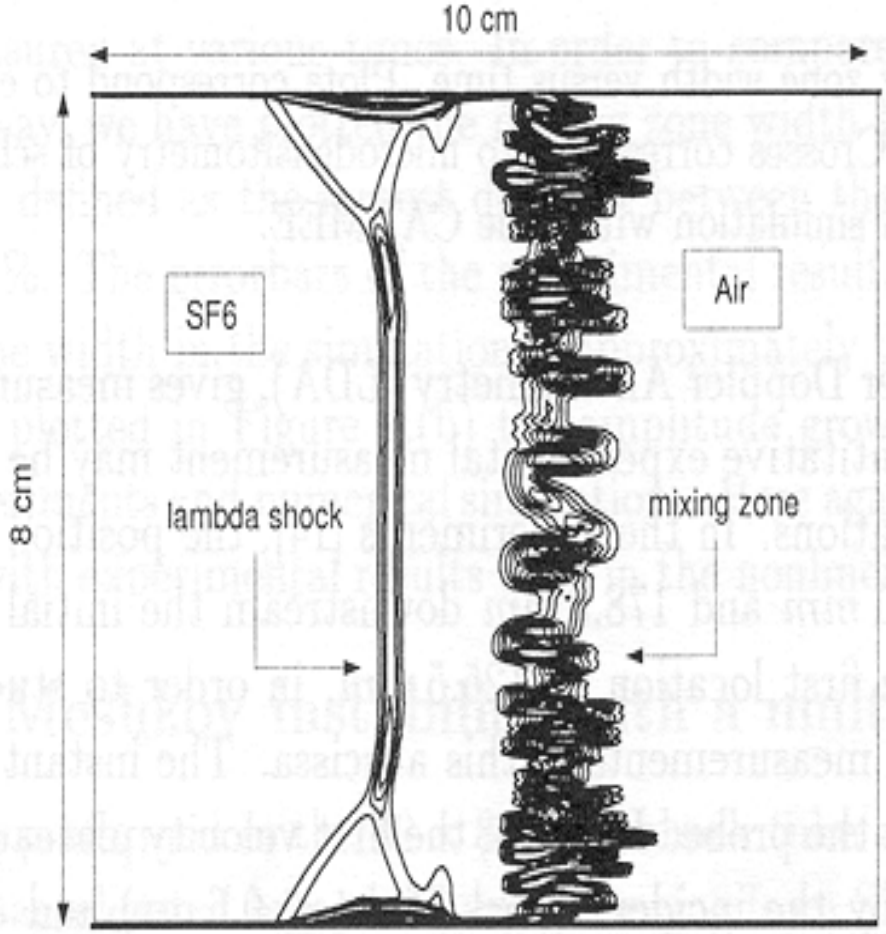


Figure 5. Numerical schlieren picture at a time t just after the first reflected shock wave/mixing zone interaction. Because of its interaction with the boundary layer, the transmitted shock in the SF6 bifurcates.

Müggler & Gauthier pp 256

6th international workshop on the pysics
of compressible turbulent mixing
G. Jourdan and L. Houas, eds.
IUSTI/CNRS Université de Provence

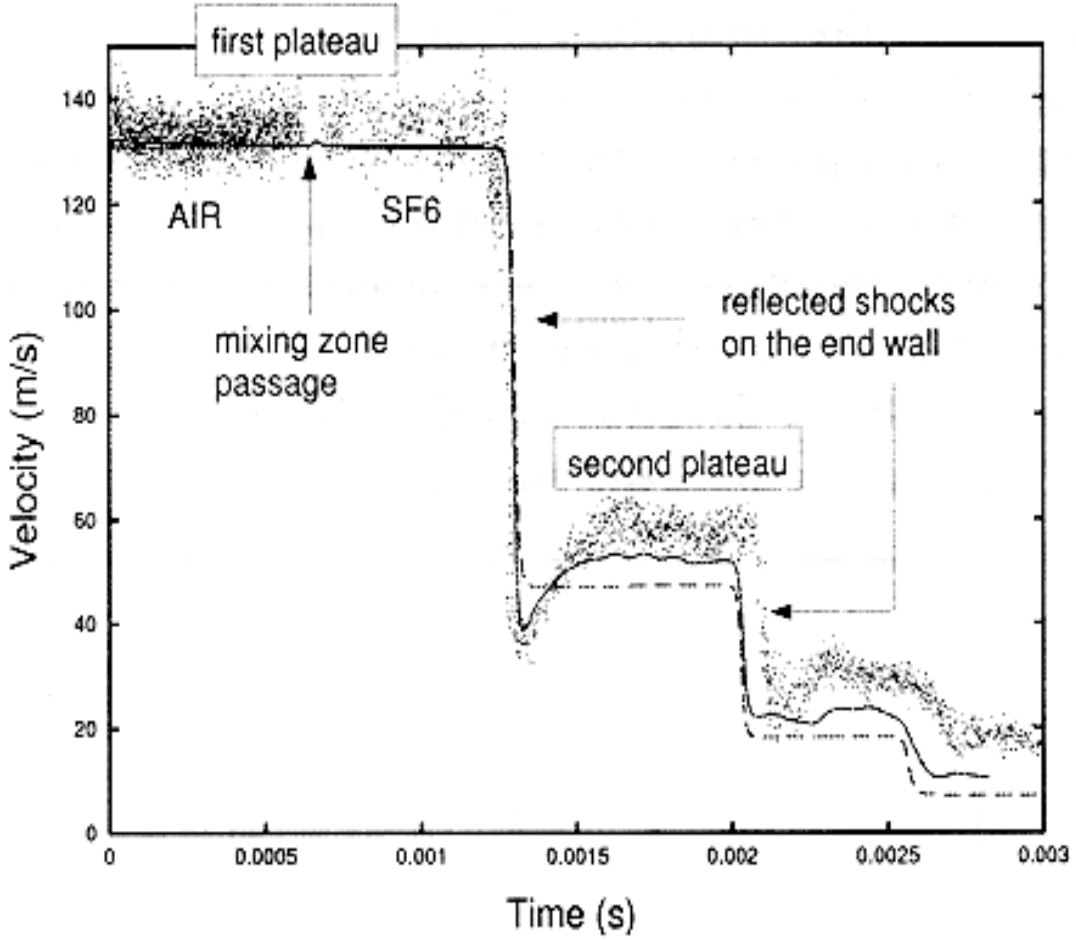


Figure 4. Velocity measurements at 125 mm. Dots correspond to experimental results. Full and dashed lines correspond to numerical simulations respectively with and without turbulent boundary layers.

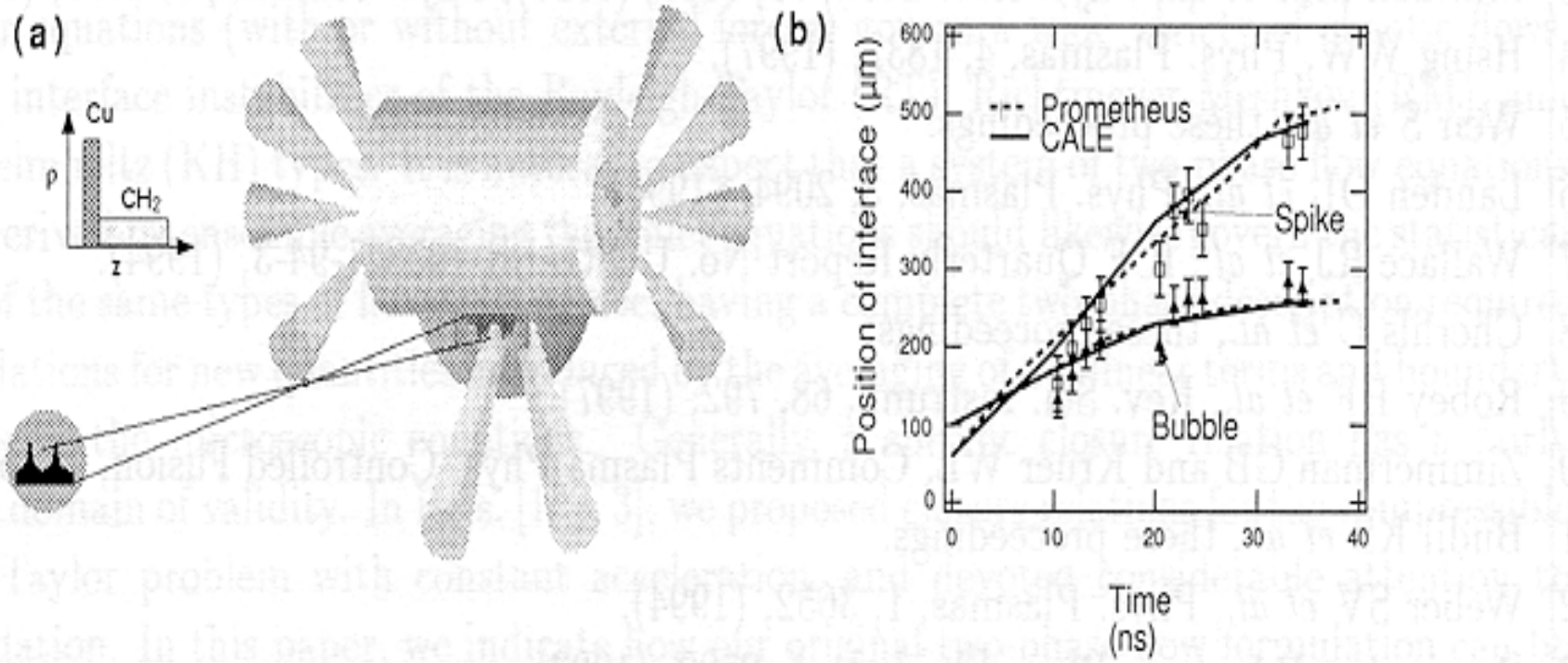


Figure 6. (a) Experimental configuration for the supernova RM-RT experiment. (b) RM-RT experiment, compared with simulations with CALE and PROMETHEUS.

Glendinning et al., pp 173

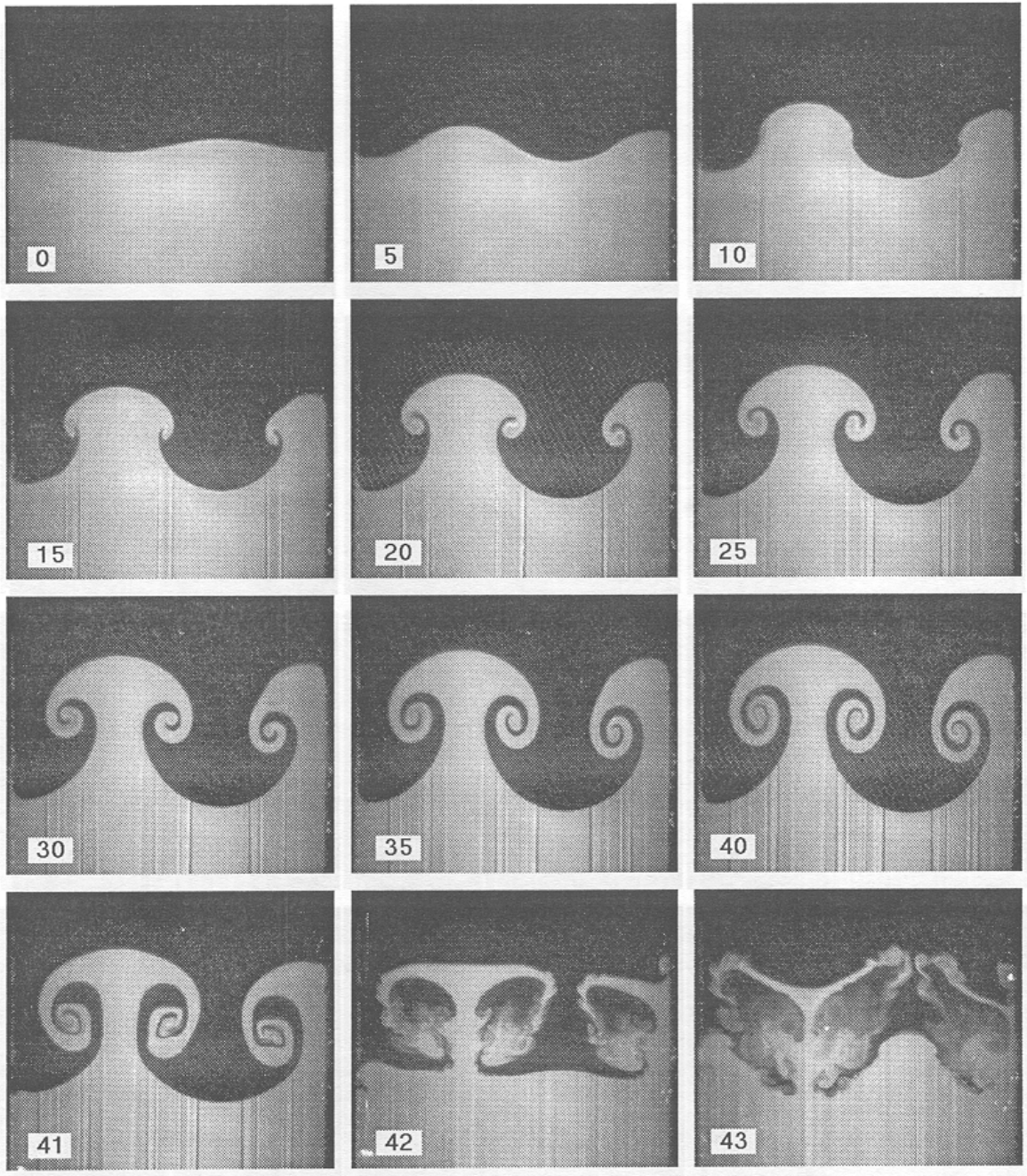


Figure 2. A sequence of PLIF images from an experiment initiated with a single-mode initial perturbation. Each image is marked with a frame number (each frame increment corresponds to a 1/60 s time increment). Note that this and the following sequences are not uniformly spaced in time.

Jacobs & Niederhaus pp 214

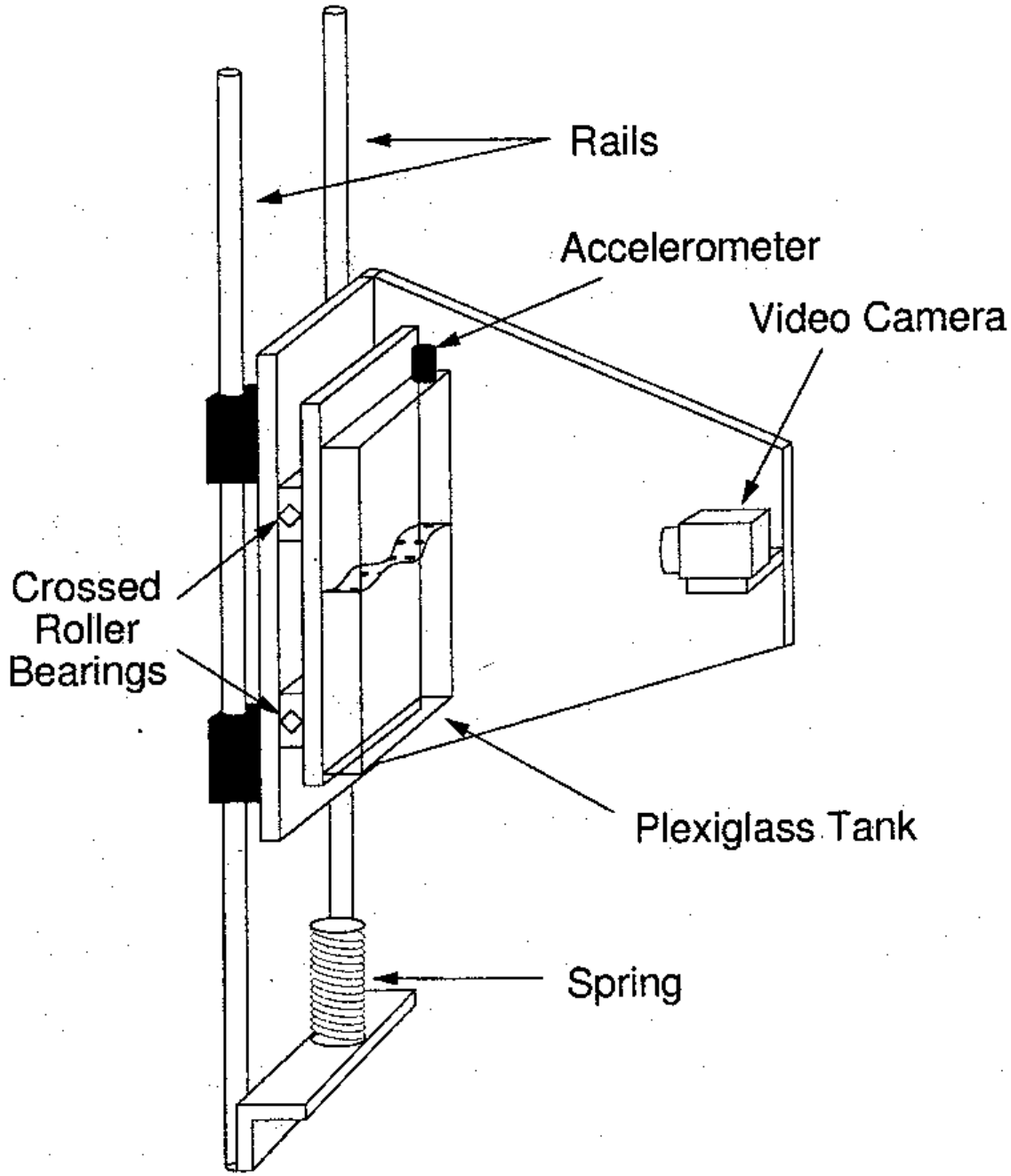


Figure 1. The experimental apparatus.

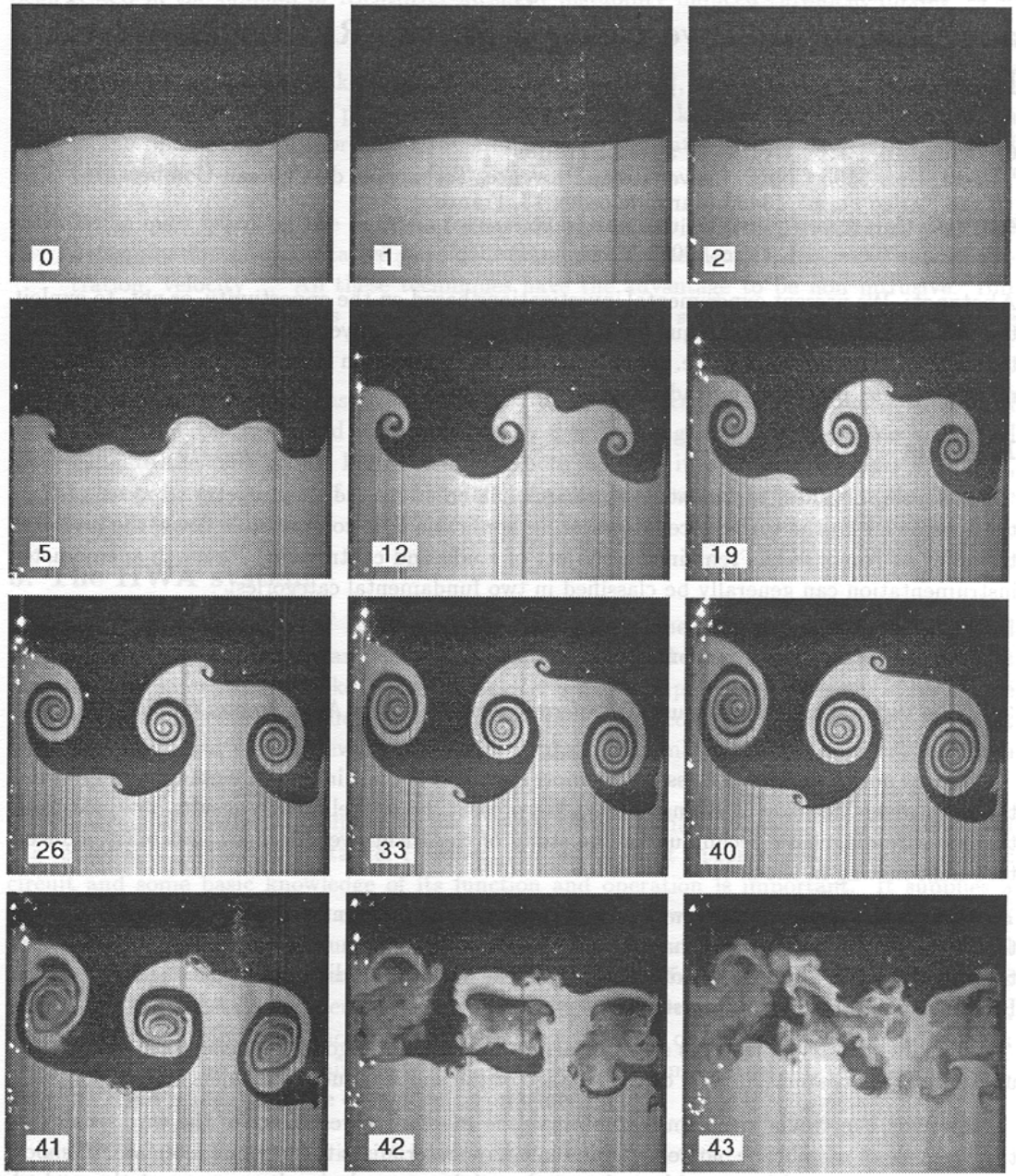
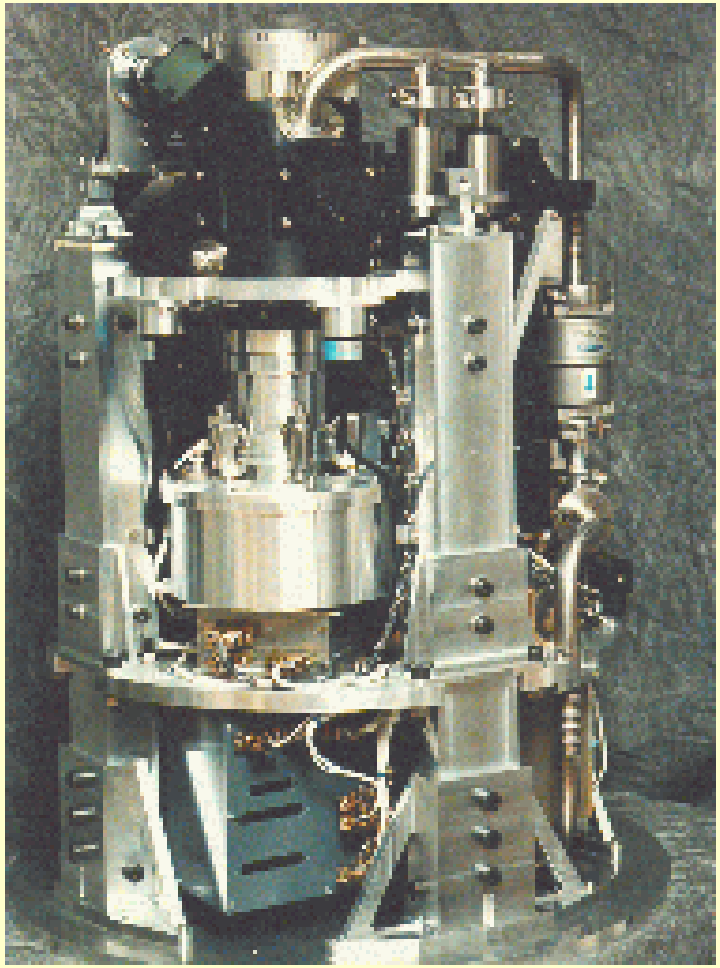
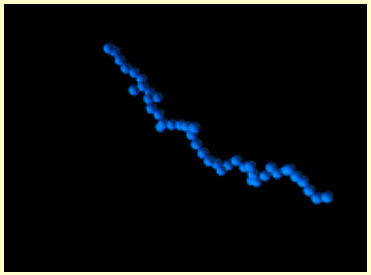
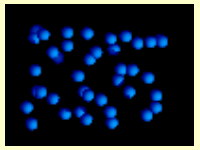
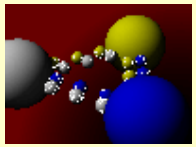


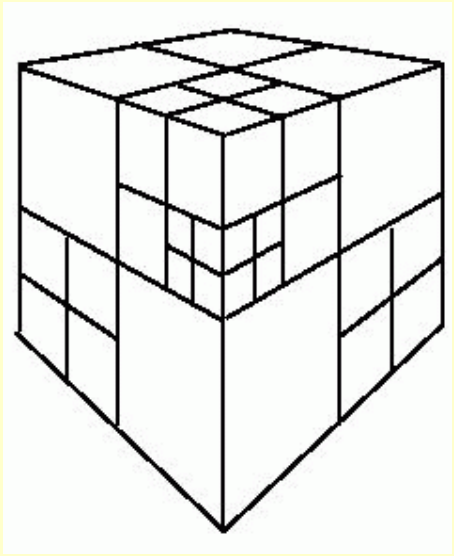
Figure 4. A sequence of PLIF images from an experiment initiated with a multi-mode initial perturbation consisting of a combination of the $1\frac{1}{2}$ wavelengths and $3\frac{1}{2}$ wavelengths modes.

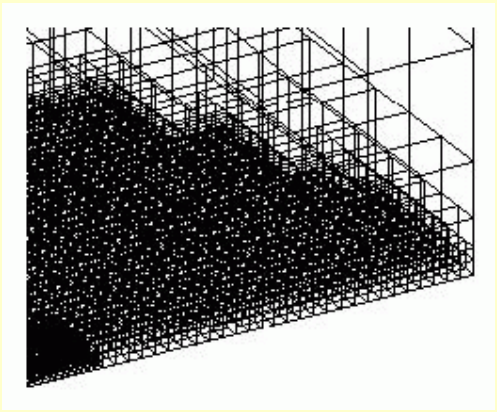












Dust nucleation
Jena astrophysical institute

J. Steinacker

Possibility 3:
Comparison between different codes

The three codes
prometheus
FronTier
RAGE
in comparison

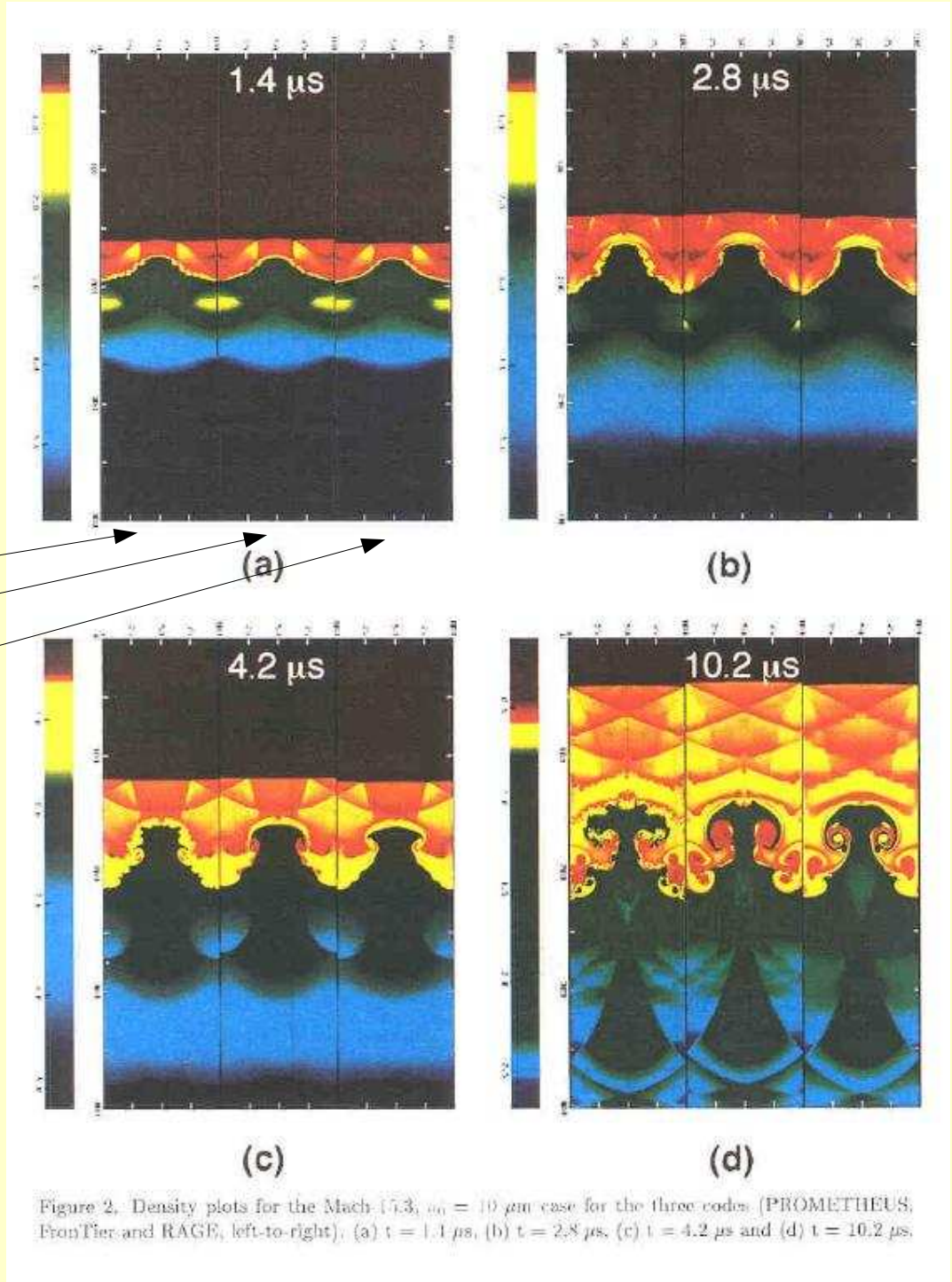
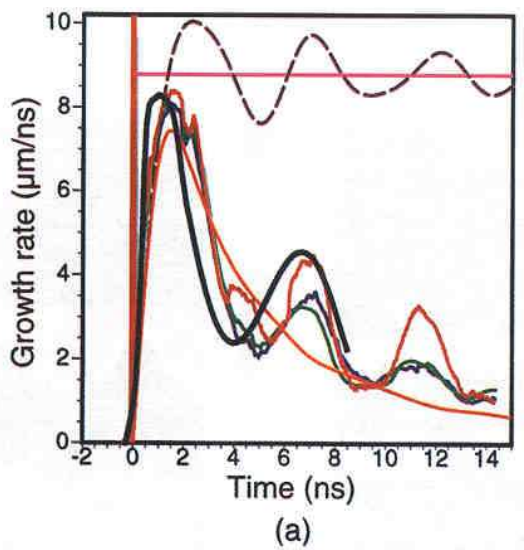
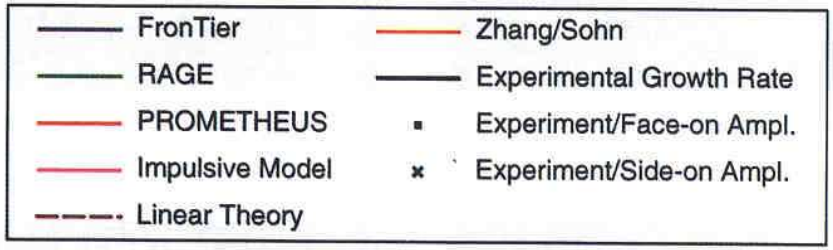


Figure 2. Density plots for the Mach 1.3, $a_0 = 10$ μm case for the three codes (PROMETHEUS, FronTier and RAGE, left-to-right). (a) $t = 1.4$ μs, (b) $t = 2.8$ μs, (c) $t = 4.2$ μs and (d) $t = 10.2$ μs.

Holmes et al. pp 197





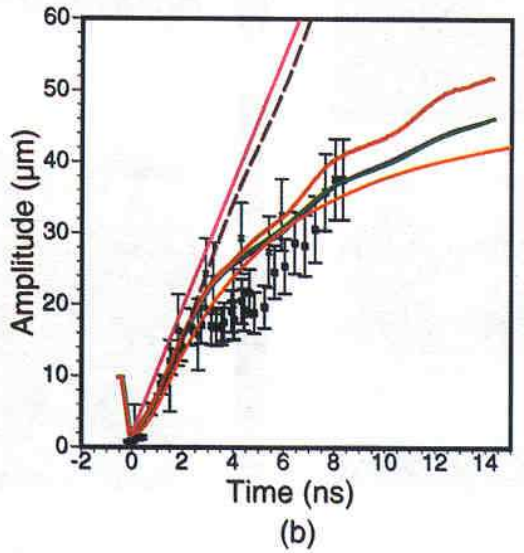
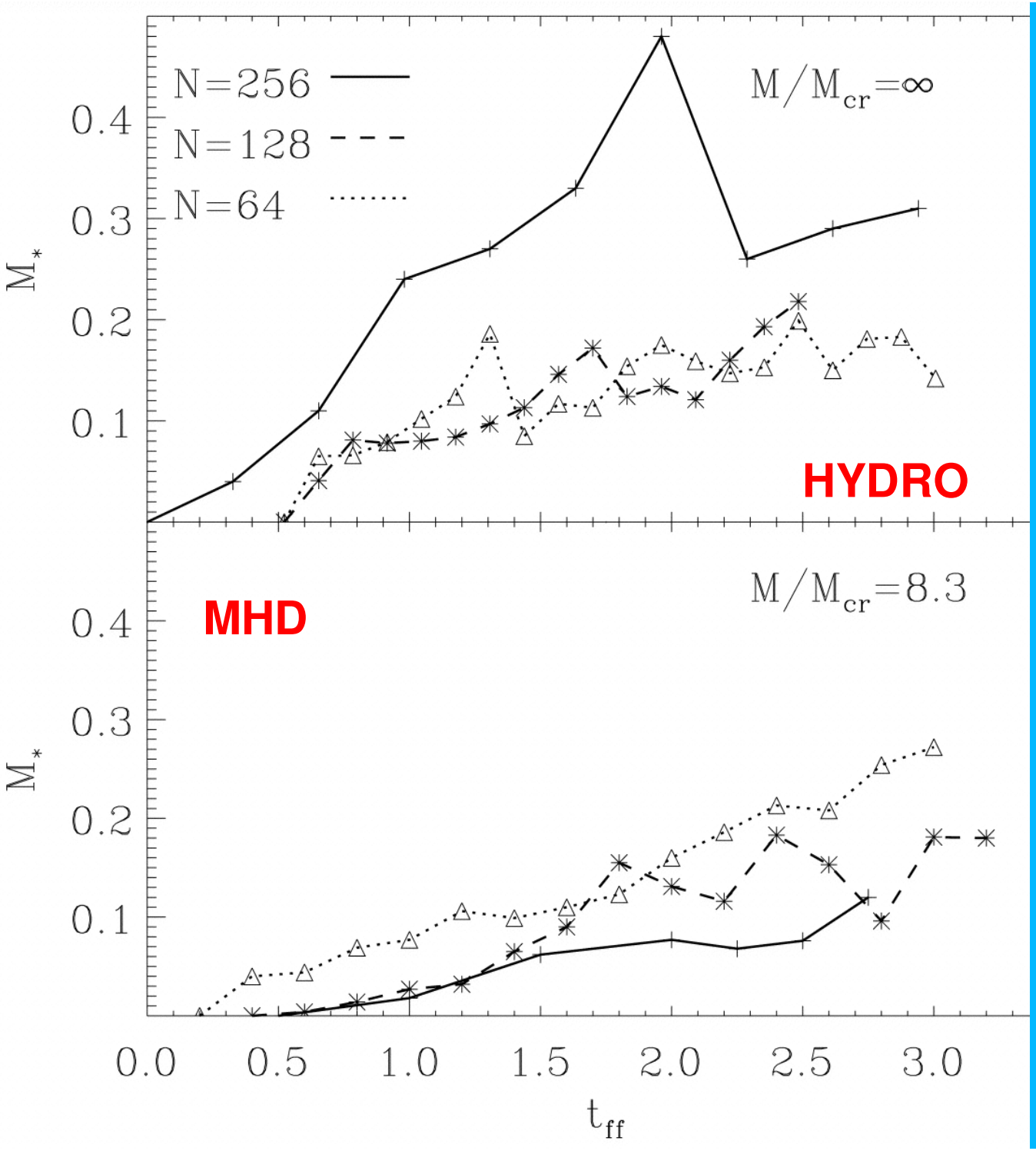


Figure 1. Experimental, simulation and theoretical perturbation growth for the Mach 15.3. $a_0 = 10\ \mu m$ case. Top figure: growth rate. Bottom figure: amplitude. Time $t = 0$ occurs when the refraction completes. The experimental growth rate curve is estimated to be accurate to within 1.5 μ/ns.

Possibility 4:
Grid studies



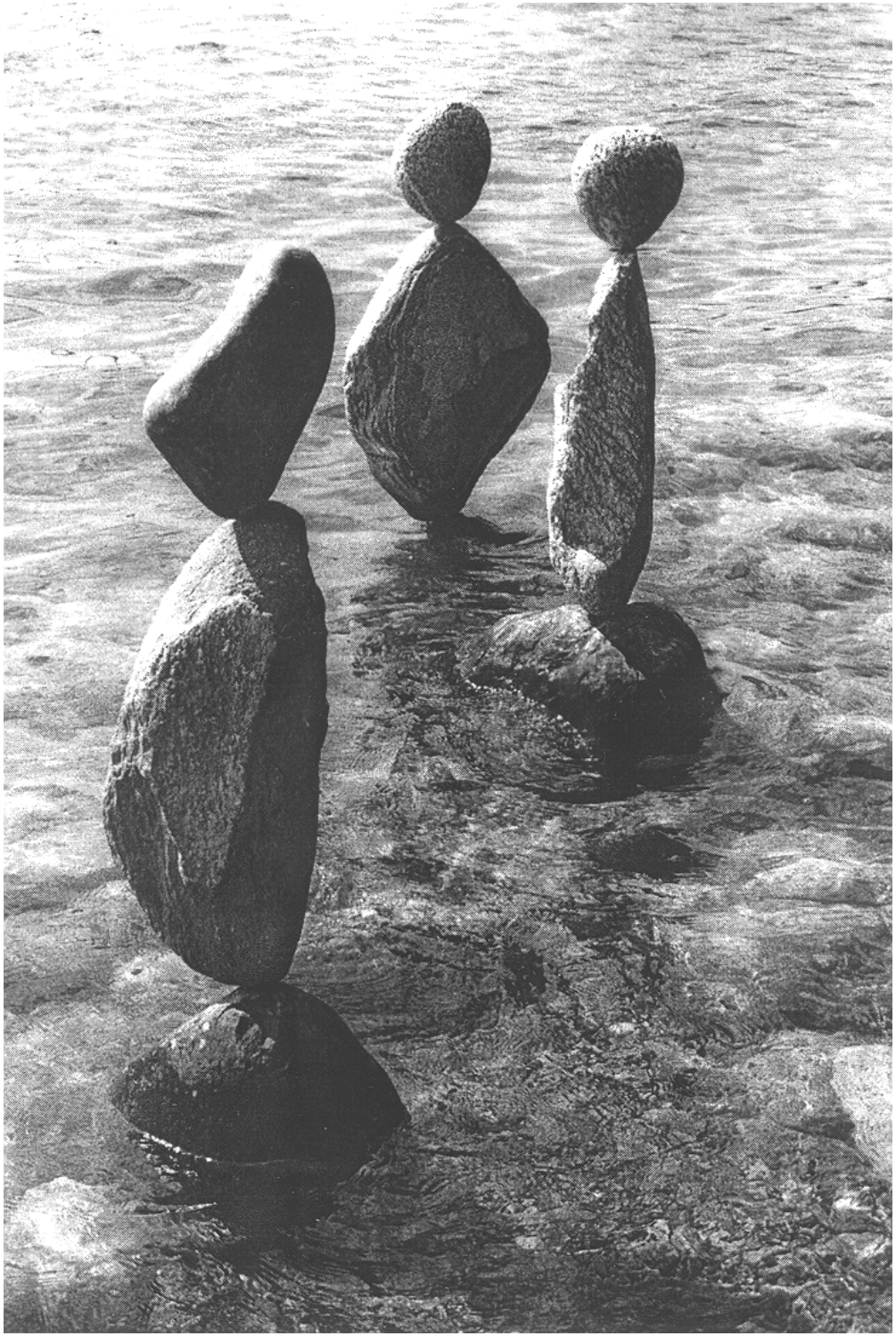
Akkretion on pre - stellar cores

Gravitational collapse in turbulent molecular clouds
F.Heitsch
M.- M. MaxLow, and
R. S. Klessen,
ApJ 547, 280- 291
2001

Finally:
The ultimative thing to do:

Think physically, understand physically

Physically correct ?



Summary

- validate codes on selected problems:
  - analytical solutions
  - experiments
  - other codes
- grid studies:
  - this is mandatory for each paper/ new problem!
- think in physical terms!
- test part problems!

Some literature to numerical methods in fluid mechanics

R.J. LeVeque, D. Mihalas, E.A. Dorfi, and E. Müller :
Computational Methods for Astrophysical Fluid Flow
Saas- Fee Advanced Course 27, Swiss Society for Astrophysics&Astronomy, Springer, 1997

R.J. LeVeque, *Numerical Methods for Conservation Laws*, Birkhauser, Basel, 1992

C.A.J. Fletcher, *Computational Techniques for Fluid Dynamics I+II*, Springer 1997

C. Hirsch, *Computational Methods for Inviscid and Viscous Flowscal Methods I+II*,
Wiley & Sons, 1994

E. Hairer and G. Wanner, *Solving Ordinary Differential Equations I+II,*
***including programs and discettes*, Springer1996**

K. Eriksson, D. Estep, P. Hansbo, C. Johnson, *Computational Differential Equations,*
Cambridge University Press, 1996