An introduction to RAMSES

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Plan of the lectures

Monday
description, technical and practical advices to use RAMSES.
tests and problems

Tuesday
Numerical schemes, hydro and mhd solvers, stability

Wednesday
More about numerical schemes – The issue of div B

Thursday
AMR issues and gravity

Friday
Formation of disks and binaries during the collapse of magnetized dense cores
The issue of magnetic braking

History of RAMSES

RAMSES has been written by Romain Teyssier (Teyssier 2002)

Originally designed for cosmology simulations
Amongst the largest cosmology simulations have been done with RAMSES

The first version handled dark matter particles (interaction only through gravity) and hydrodynamics

The particles are projected onto the mesh and the gravitational potential can be calculated using grid techniques (unlike what is generally done in SPH for example)

The adaptive mesh refinement (AMR) scheme allows to calculate accurately the gravitational potential in regions where there are important small scale variations

Cosmology with AMR

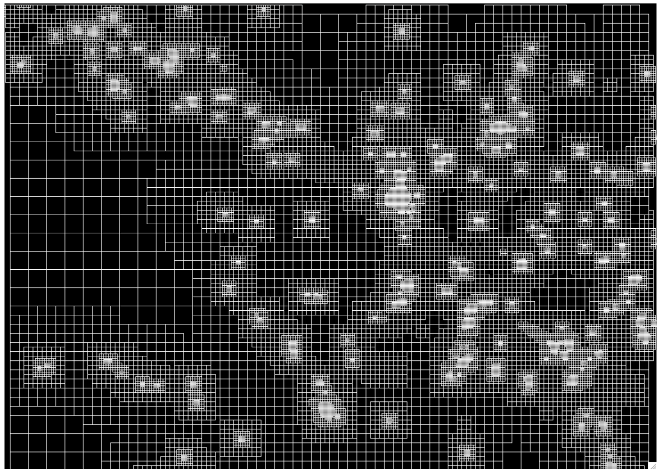
Particle-Mesh on AMR grids:
Cloud size equal to the local mesh spacing

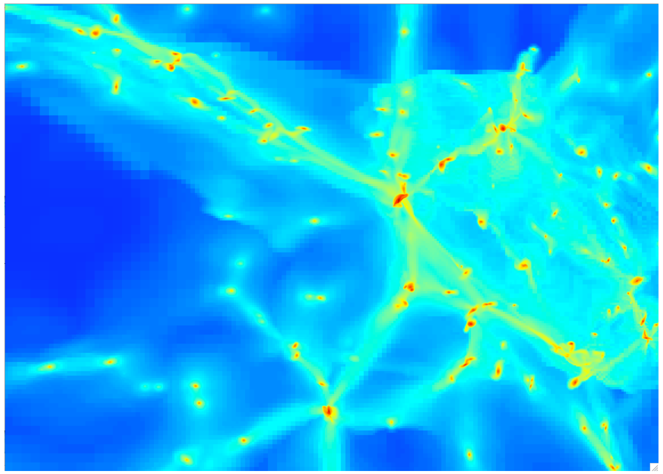
Poisson solver on the AMR grid
Multigrid or Conjugate Gradient
Interpolation to get Dirichlet boundary conditions (one way interface)

Quasi-Lagrangian mesh evolution:
roughly constant number of particles per cell

$$n = \frac{\rho_{DM}}{m_{DM}} + \frac{\rho_{gas}}{m_{gas}} + \frac{\rho_*}{m_*}$$

Trigger new refinement when n > 10-40 particles. The fractal dimension is close to 1.5 at large scale (filaments) and is less than 1 at small scales (clumps).





Further developments of RAMSES: magnetic field

The magnetic field has been introduced in the ideal MHD limit

Teyssier, Fromang, Dormy, 2006 : kinetic field (study dynamo)
Fromang, Hennebelle & Teyssier 2006 : ideal MHD

Use finite volume methods, 2nd order accuracy in time and space
Constraint transport schemes

Non ideal MHD effects have been introduced

Masson, Teyssier, Mulet-Marquis, Hennebelle and Chabrier 2012

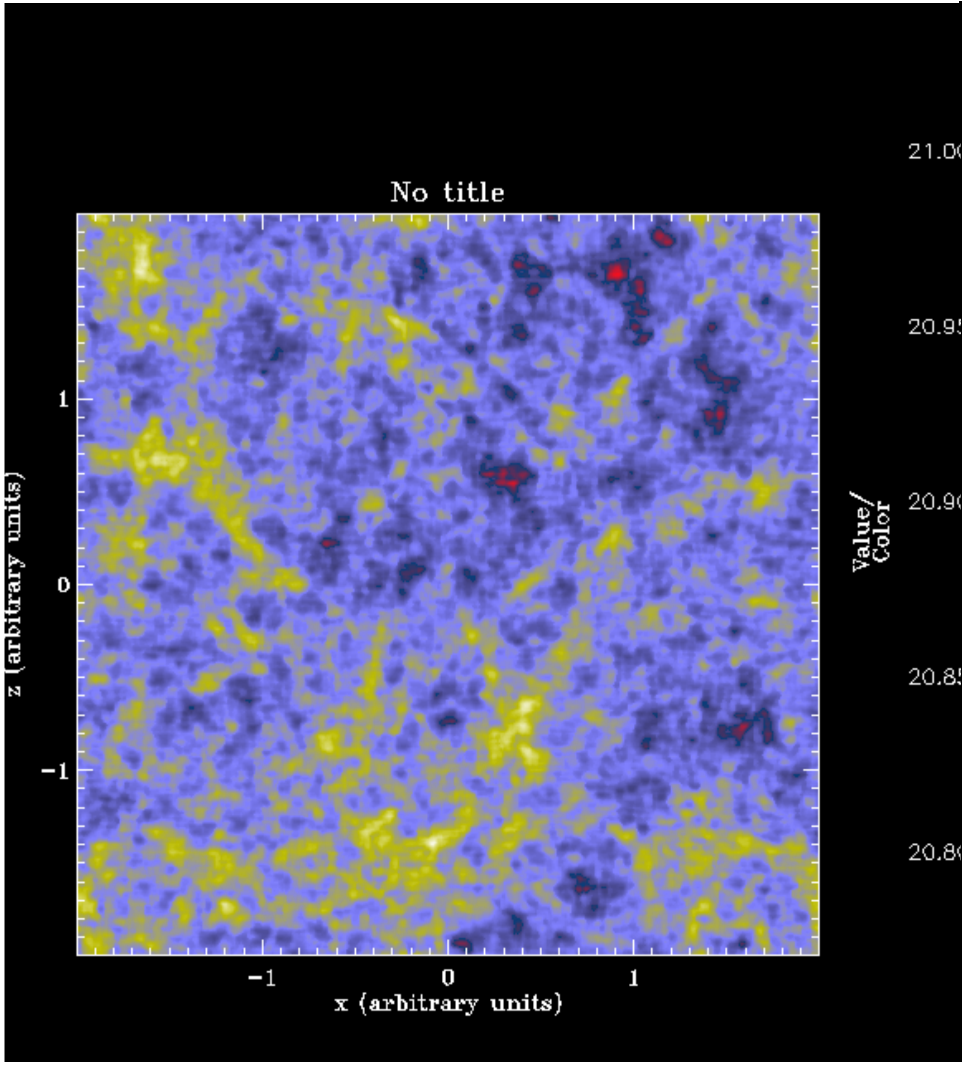
Explicit treatment of the non-ideal mhd terms

Comparison between hydro and MHD simulations

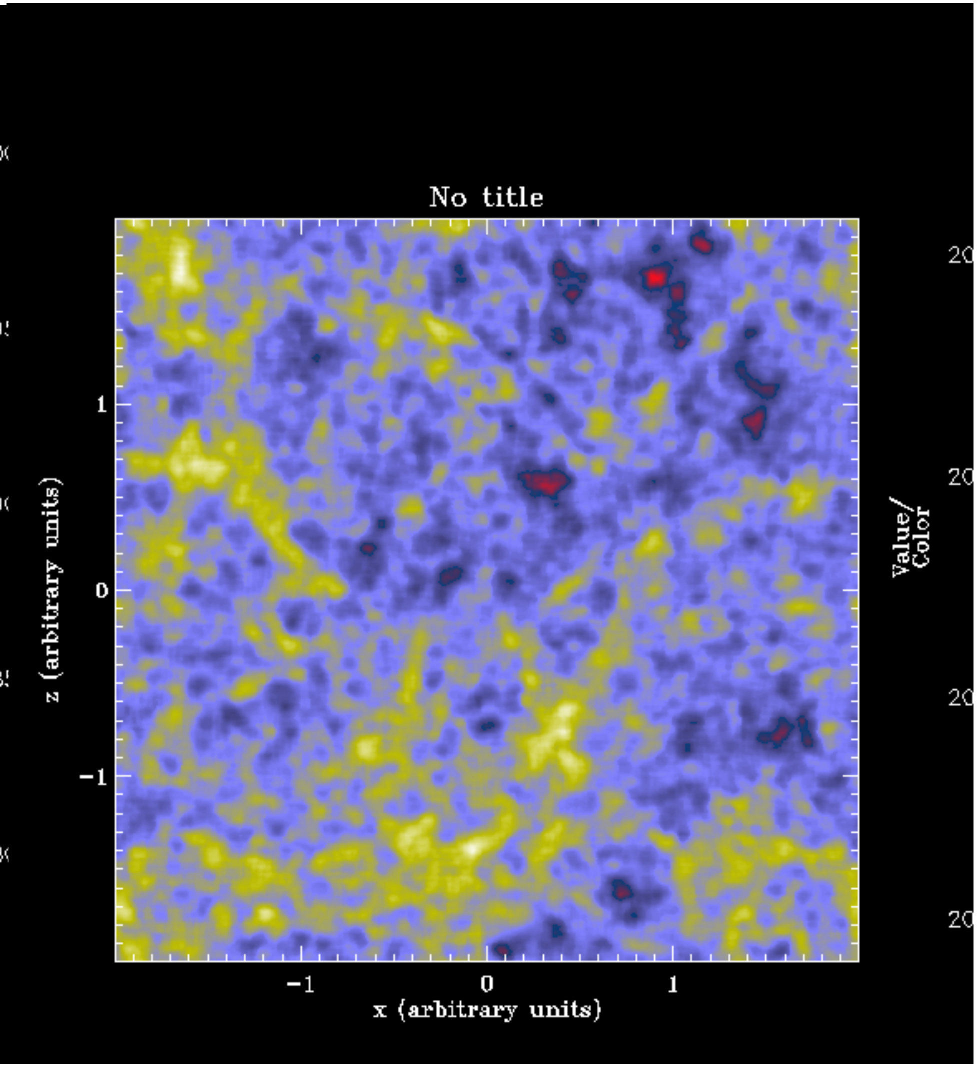
Decaying turbulence, 2 phase-medium, no gravity, 5 cm^{-3}

Initial Mach (wrt cold gas) : 10, B=0 or 5 μG

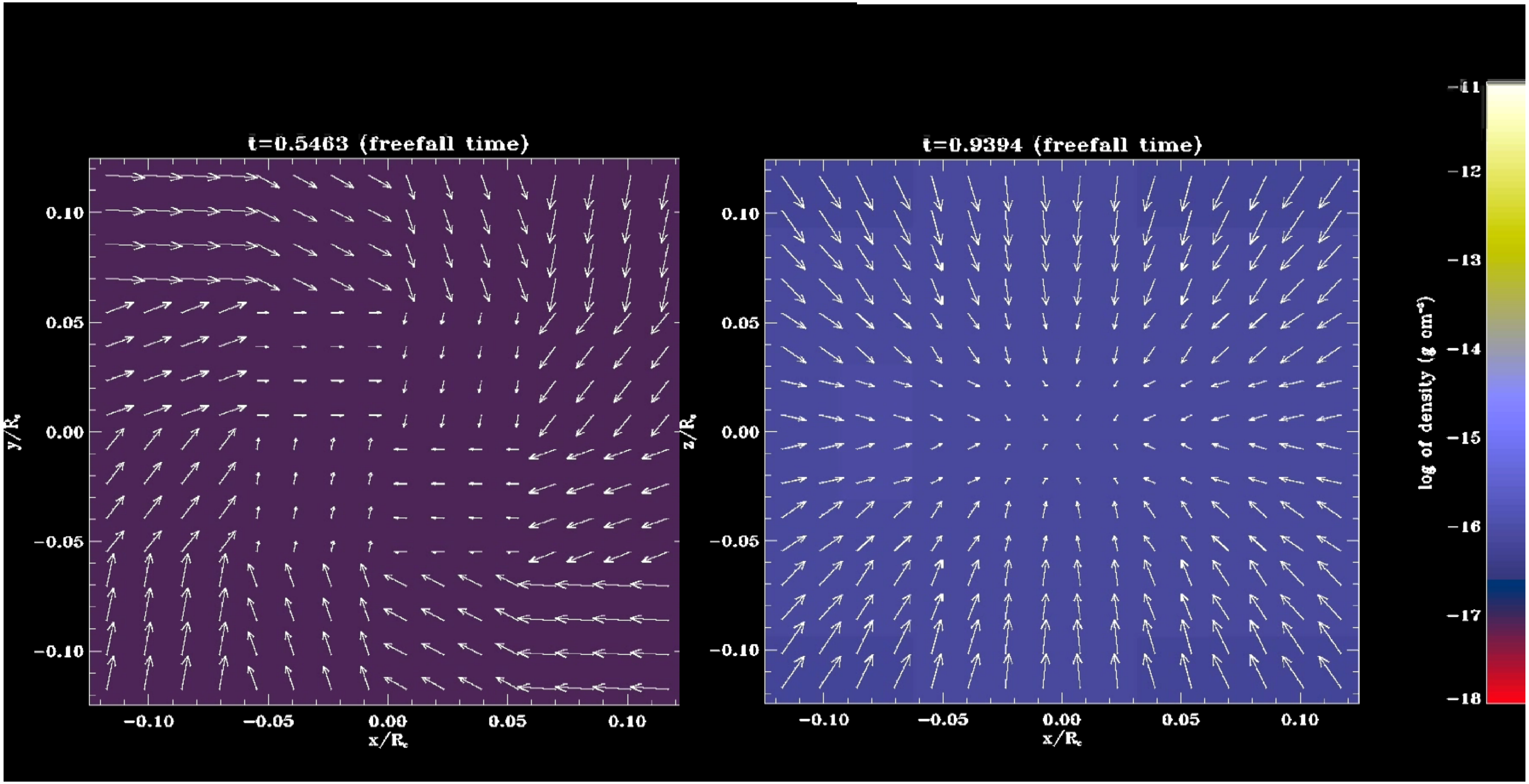
HYDRO



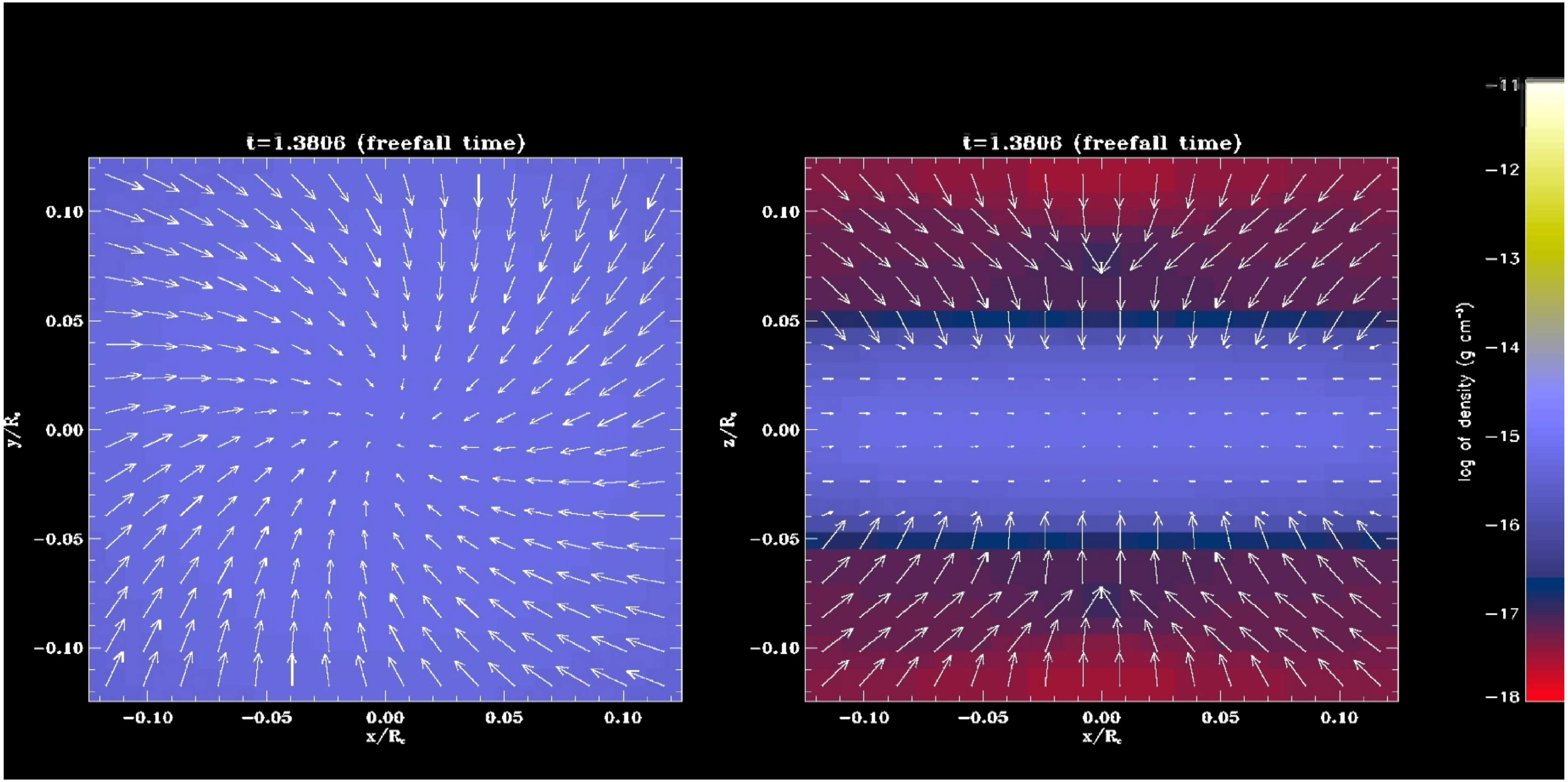
MHD



Dense core collapse: hydrodynamical case



Dense core collapse: MHD case



Further developments of RAMSES: radiative transfer

Explicit treatment

Aubert & Teyssier 2010

Rosdahl et al. 2010

Implicit treatment

Commerçon et al. 2011
grey transfer and diffusion approximation
Not publically available yet

The code structure

amr: contains all the amr related files
contains “amr_step” the heart of ramses

hydro/mhd:

pm: particle mesh

poisson: gravity

bin: Makefile

namelist: contains various problems already setup

patch: where you put the routine that you modified to setup your problem
Several problems already set up

utils: post-processing

To compile:

Select the dimension NDIM (1,2 3)

Select the number of variables (typically 5 in 3D for hydro and 8 for MHD)

Choose you SOLVER : HYDRO or MHD

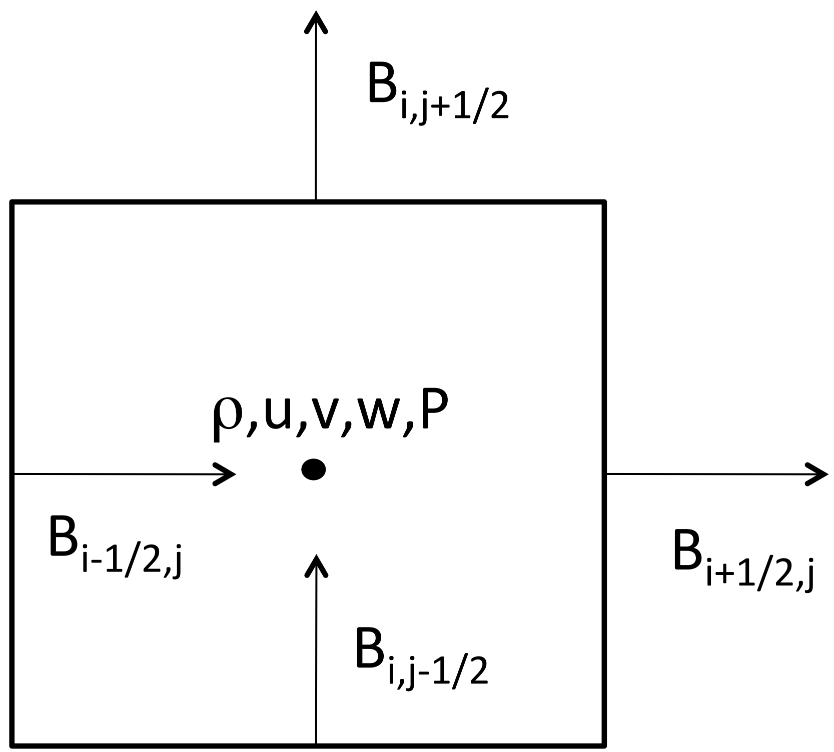
Define the PATH of your PATCH
Ex: ../PATCH/mhd/ot

(**WARNING** : often a source of problem)

To launch it:

mpirun -np xx ramses3d namelist.nml > run.log
In 1D run.log contains the data
In 2 and 3D data are written in output_xxxxx directory

Structure of the variables: staggered mesh



Consequences: due to AMR constraints, effectively in the code (and in the output) there are 11 variables (3*2 magnetic field components)

The namelist

Parameters do not need to be all specified (default is then used)
Order does not matter.

-control the modules (poisson, hydro etc..)

-choose the solvers

-define the amr parameters

-many problems can be setup solely from the namelist

It is organised in a few sub-namelist

Look in the ramses doc (ramses_ug.pdf) or directly in the read_hydro_params, read_parameters routines

```
&RUN_PARAMS
hydro=.true.
nremap=0               frequency of load balancing
ncontrol=100           frequency of timestep information display
nsubcycle=4*1,         no multiple timestepping
/

&AMR_PARAMS
levelmin=7             coarse grid reffinement
levelmax=11            maximum grid reffinement
ngridmax=10000         allocation memory (largest number of grid allowed)
nexpand=1              distance of neighbours for which refinement is applied
boxlen=1.0
/

&BOUNDARY_PARAMS
nboundary=2            defined the number of boundaries to be considered
ibound_min=-1,+1       defined their coordinates
ibound_max=-1,+1
bound_type= 2, 2       vanishing gradient
/
```

```
&INIT_PARAMS
nregion=2
region_type(1)='square'
region_type(2)='square'
x_center=0.25,0.75
length_x=0.5,0.5
d_region=1.08,1.
u_region=1.2,0.
v_region=0.01,0
w_region=0.5,0.0
p_region=0.95,1.
A_region=0.56418955,0.56418955
B_region=1.01554120,1.12837911
C_region=0.56418955,0.56418955
/
```

allows you to setup easily many simple problems without modifying condinit.f90

```
&OUTPUT_PARAMS
foutput=100
noutput=1
tout=0.2
```

frequency of output

&HYDRO_PARAMS	
gamma=1.6666667	
courant_factor=0.8	*courant condition*
slope_type=2	*slope of the reconstruction (0 no reconstruction, 1 standard)*
riemann='hlld'	*solver (llf, hll, roe)*
/	
&REFINE_PARAMS	*amr refinement parameters*
err_grad_d=0.01	
err_grad_u=0.01	
err_grad_b=0.01	*refine on gradients*
err_grad_c=0.01	
err_grad_p=0.01	
interpol_var=0	*conservative or primitive variables when introduce new cells*
interpol_type=2	*slope of the extrapolation*
/	

Reading and analysing RAMSES data

Because of the AMR, the data structure is not simple (essentially 1D list)
Moreover the standard output is a home made binary format.
=> Reading RAMSES data is not straighforward but many tools have been developed

Solution 1:
Use the fortran routines provided in utils/f90

Ex: amr2cube (does a 3D uniform data cube)

Just type amr2cube and you will be told the input format

Then you need to use another sofware to visualize your data

Solution 2:

Use the idl package provided in utils/idl

Certainly the easiest in the context of this school

Typically you have to run the following sequence :

```
rd_amr  ,a3d,file=dir+amr_file
rd_hydro,h3d,file=dir+hydro_file

amr2cell, a3d, h3d, cell, lmin=lmin,lmax=lmax

RAY3D, a3d, h3d, /yproj, type=1, lmin=lmin, lmax=lmax

cut3d, a3d, h3d, axy, hxy, z=zc
tv2d, axy, hxy, type=1,lmin=lmin,lmax=lmax,save=d
```

Solution 3:

Use “Pymses “ a nice PYTHON package developed by former PhD students who did not like idl. You can dowload it at : http://irfu.cea.fr/Projets/PYMSES
but does not read mhd so far.

Alternatively I installed a version which reads mhd at :
~hennebel/pmmhd_complete_3.1.0   (thought some problems remain)

Very nice for advanced studies but many simple cases have not been developed (1D, 2D…)

Typically you have to run the following sequence :
~hennebel/pymses_example.pdf

Tests and homework

code testing is tremendously important:

-check that the equations are correctly implemented

-understand the limits of the methods (algorithms and resolutions)

In particular, the finite resolution introduced numerical dissipation/diffusion that may or may not affect the problem.

It is therefore necessary to repeat the calculations with various methods and various resolutions. The comparison between the results helps to understand what aspects of the calculations are trustable.

Whenever possible, it is a good idea to **confront the numerical models with analytical results**.

Code comparison is very important especially when the methods are very different

Several tests are proposed below. Depending on your current knowledge and interest you can decide which are the most interesting for you.

Most of the tests have already been performed and corresponding namelists and patches are available.

Feel free to select any test from the literature.

Advices:

-select a simple problem already coded in RAMSES and perform a series of runs to ensure you understand the influence of the namelist parameters, control the output and data analysis

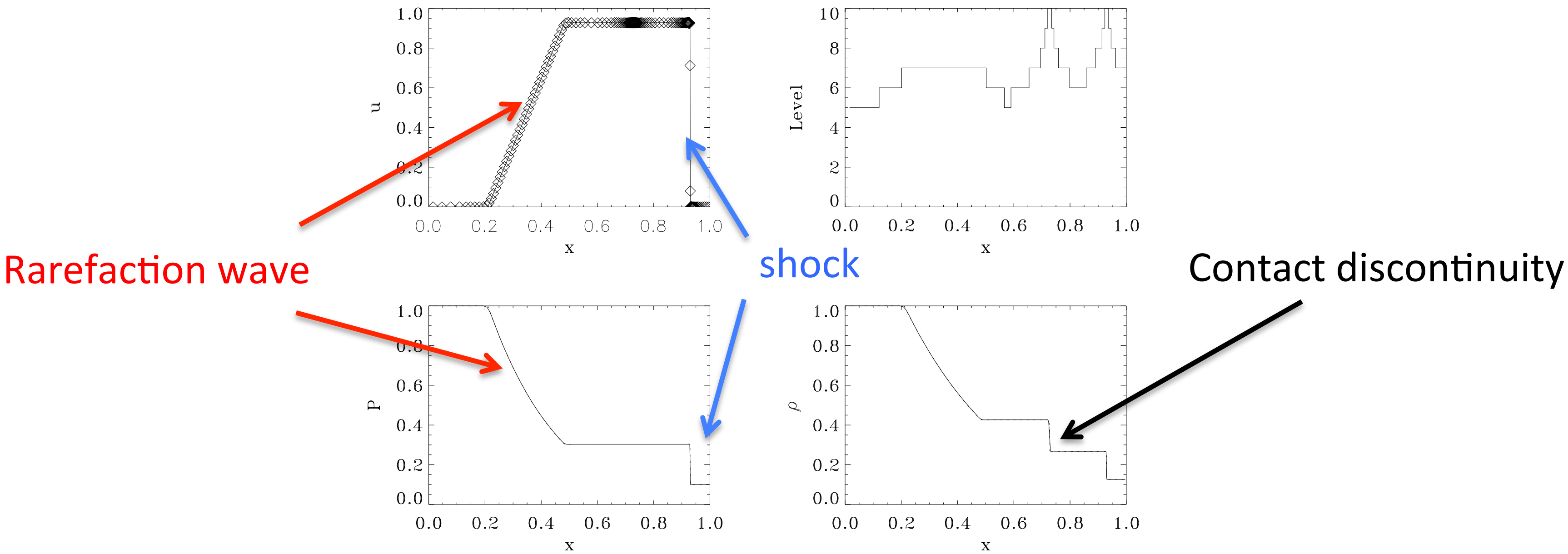
-select at least one problem that you try to code from scratch and study deeply by changing resolution and solvers.

Shock tube tests

namelist/tube1d.nml
use tube.pro for comparison with analytical solutions

2 uniform states (left and right) which evolve

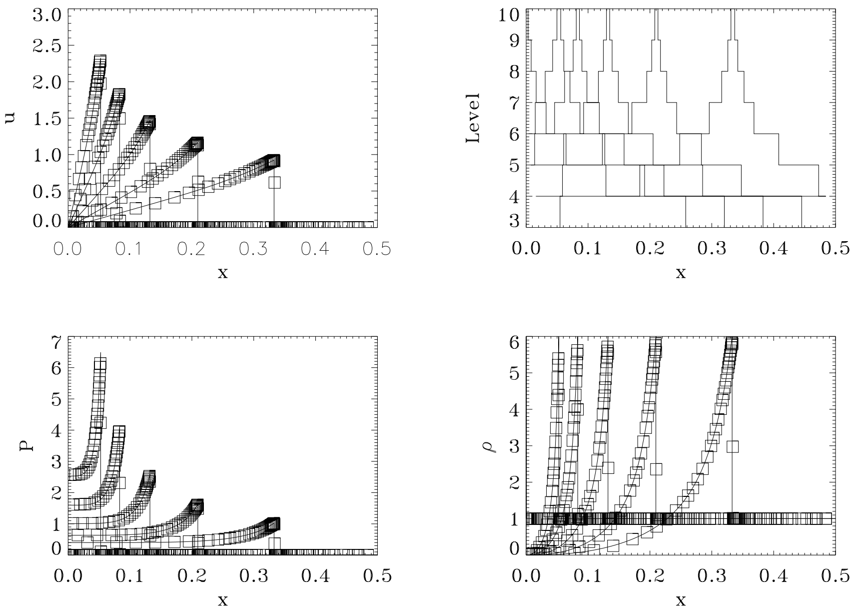
Left: d=1,   u=0, P=1
Right: d=0.125, u=0, P=0.1

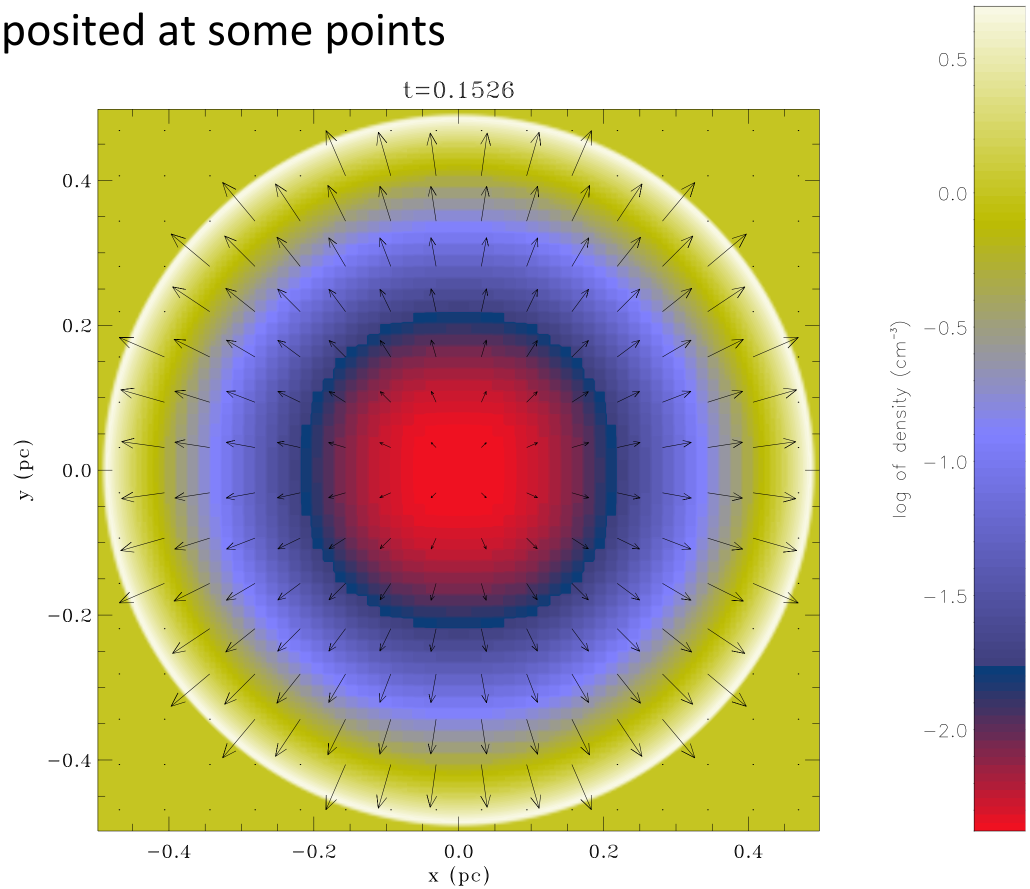


Sedov tests

namelist/sedov1d.nml
use sedov1d.pro for comparison with analytical solutions

a pulse of energy is deposited at some points



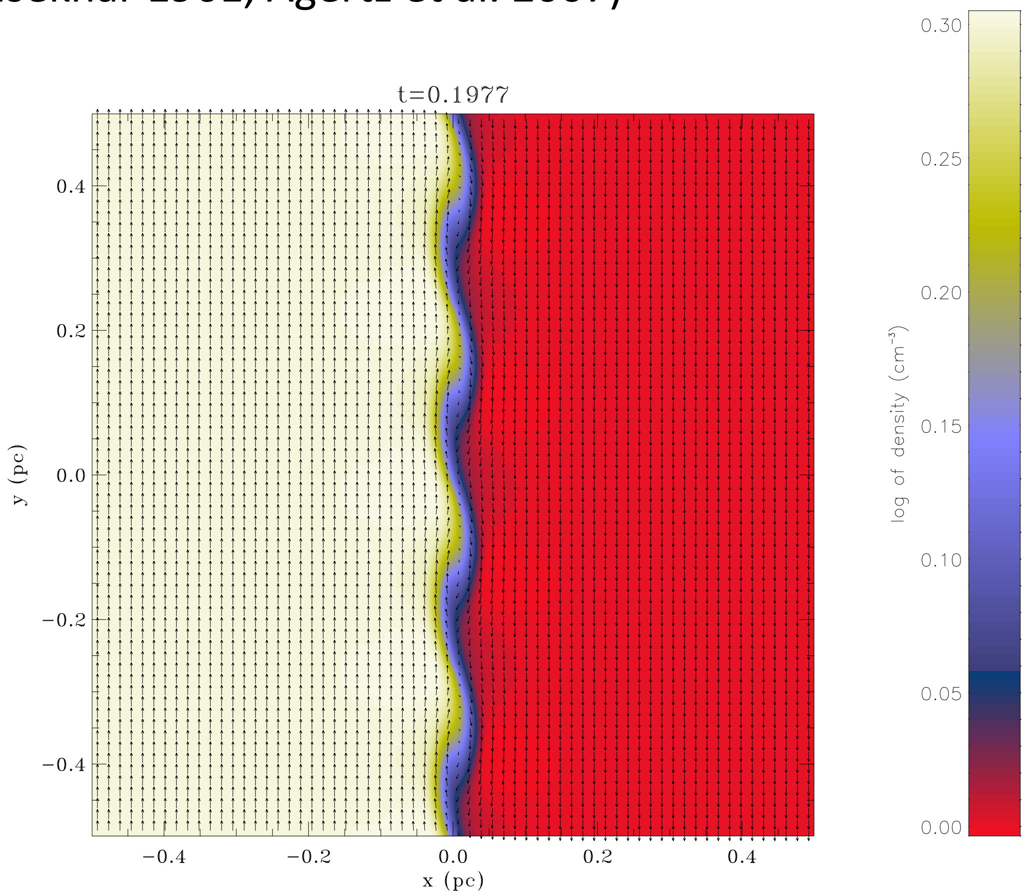


Study supernovae explosion with magnetic field ?

Development of the Kelvin-Helmholz instability

patch/insta

Famous and fundamental instability which develops in shear flows (Chandrasekhar 1961, Agertz et al. 2007)

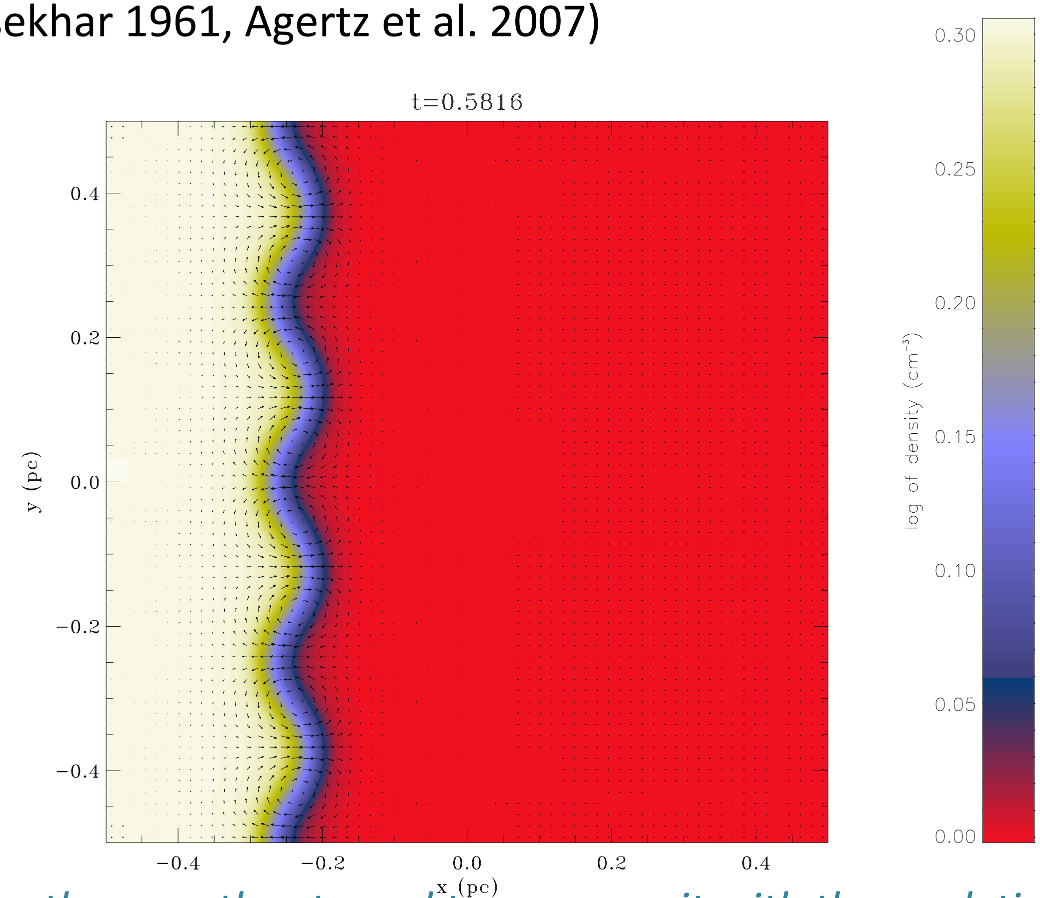


Try to measure the growth rate and to compare it with the analytical results

Development of the Rayleigh-Taylor instability

patch/insta

Famous and fundamental instability triggered by gravity which develops when a heavy fluid is located on top of a light one
(Chandrasekhar 1961, Agertz et al. 2007)

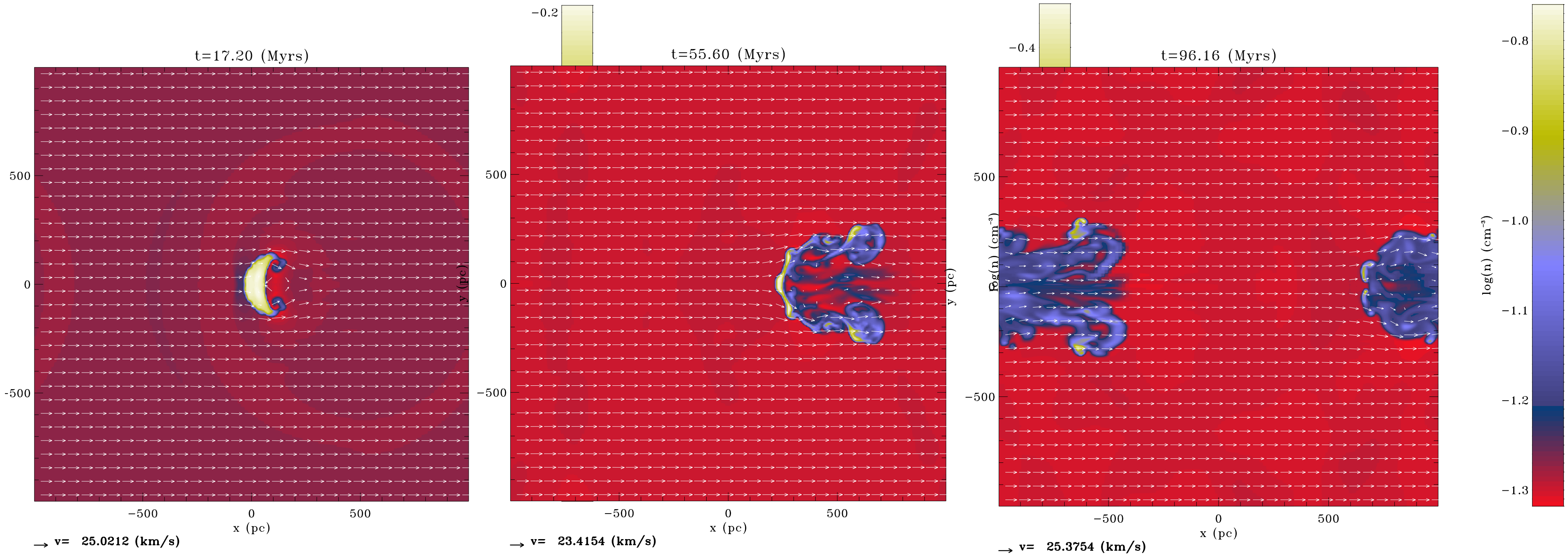


Try to measure the growth rate and to compare it with the analytical results

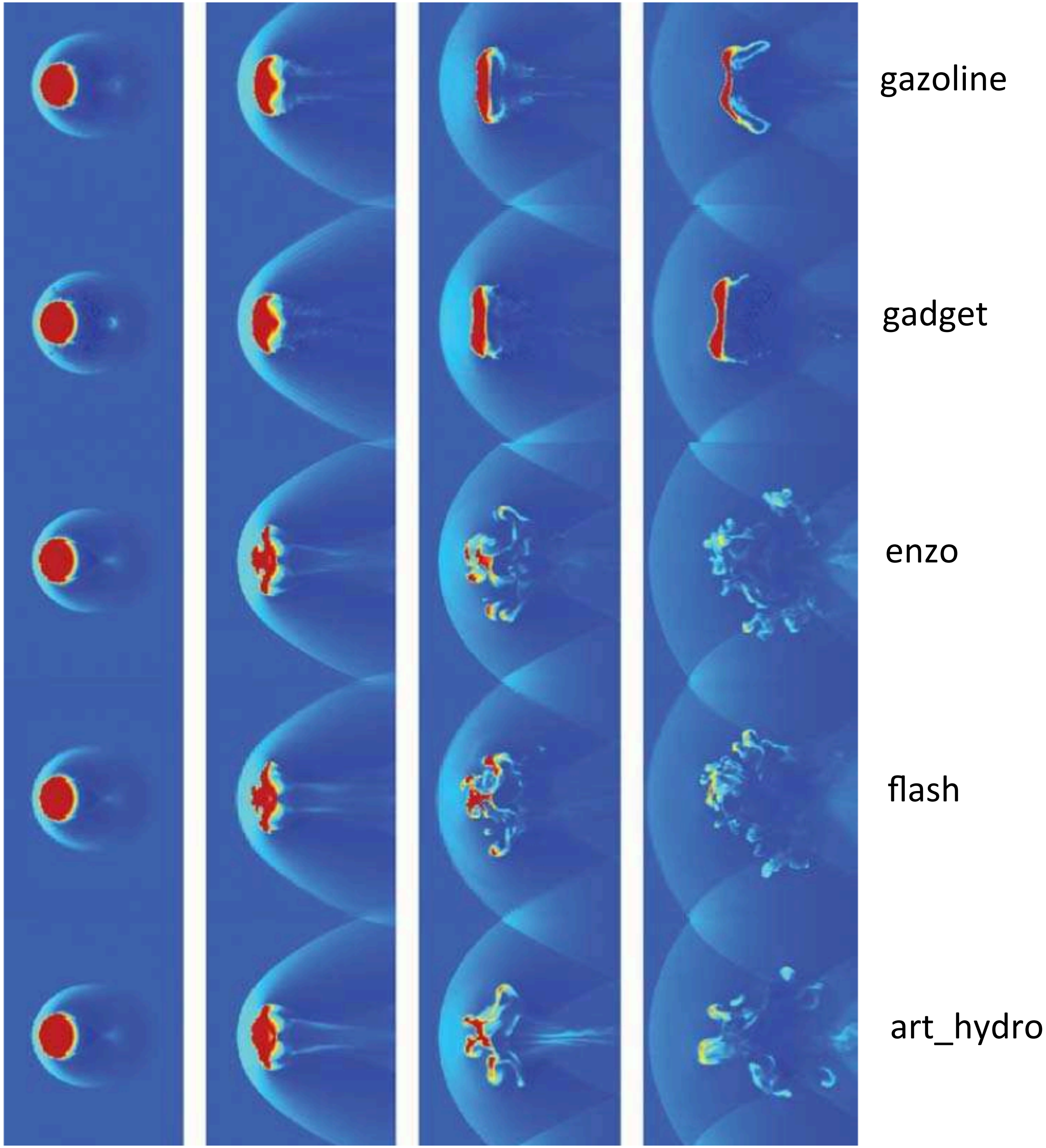
The blob test

No patch

Important test which has been performed for code comparison (Agertz et al. 2007). A dense blob moves supersonically in a diffuse gas. RT and KH instabilities develop and destroy the blob



Repeat the blob test with the various codes presented during the school to confirm this figure.



Agertz et al. 2007

1D Tests for MHD

patch/nl_alfven

The non-linear circularly polarized Alfvén wave

(e.g. Fromang et al. 2006)

This is an exact and explicit solution

of MHD equation

=>very convenient to test the codes

Can be written as:

$$B_x = cst, V_x = 0,$$

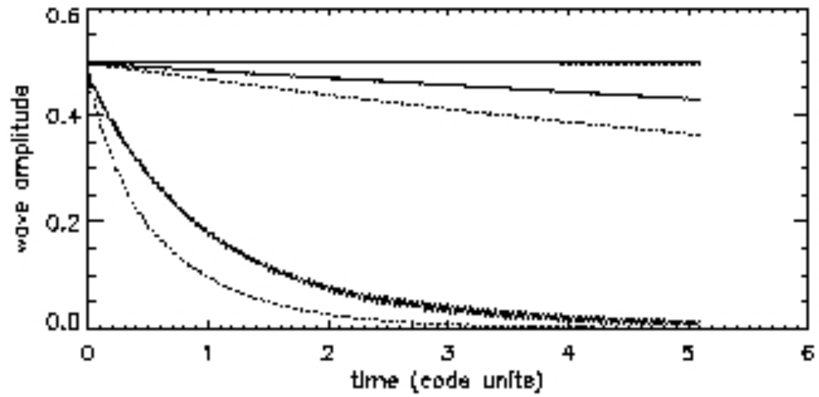
$$V_y = A \times V_a \cos(\omega t - kx),$$

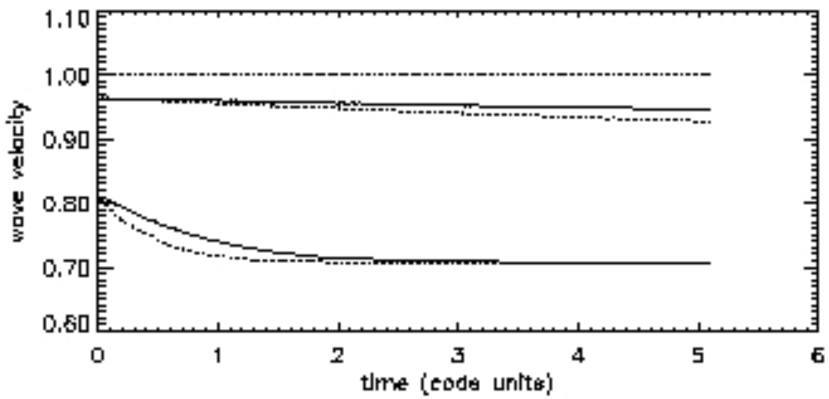
$$B_y = A \times B_x \cos(\omega t - kx),$$

$$V_z = A \times V_a \sin(\omega t - kx),$$

$$B_z = A \times B_x \sin(\omega t - kx),$$

$$\frac{\omega}{k} = V_a$$





Measure the decay of the wave and its dependence with resolution

1D Tests for MHD: Shock tube tests

Miyoshi & Kuzano 2005

Comparison between

HLL, ROE, HLLD

2 fast shocks (fast waves)

2 Alfven waves

2 slow waves

1 entropy wave

The 3 solvers do equaly well for the fast waves

Roe and HLLD do better than

HLL for the other waves

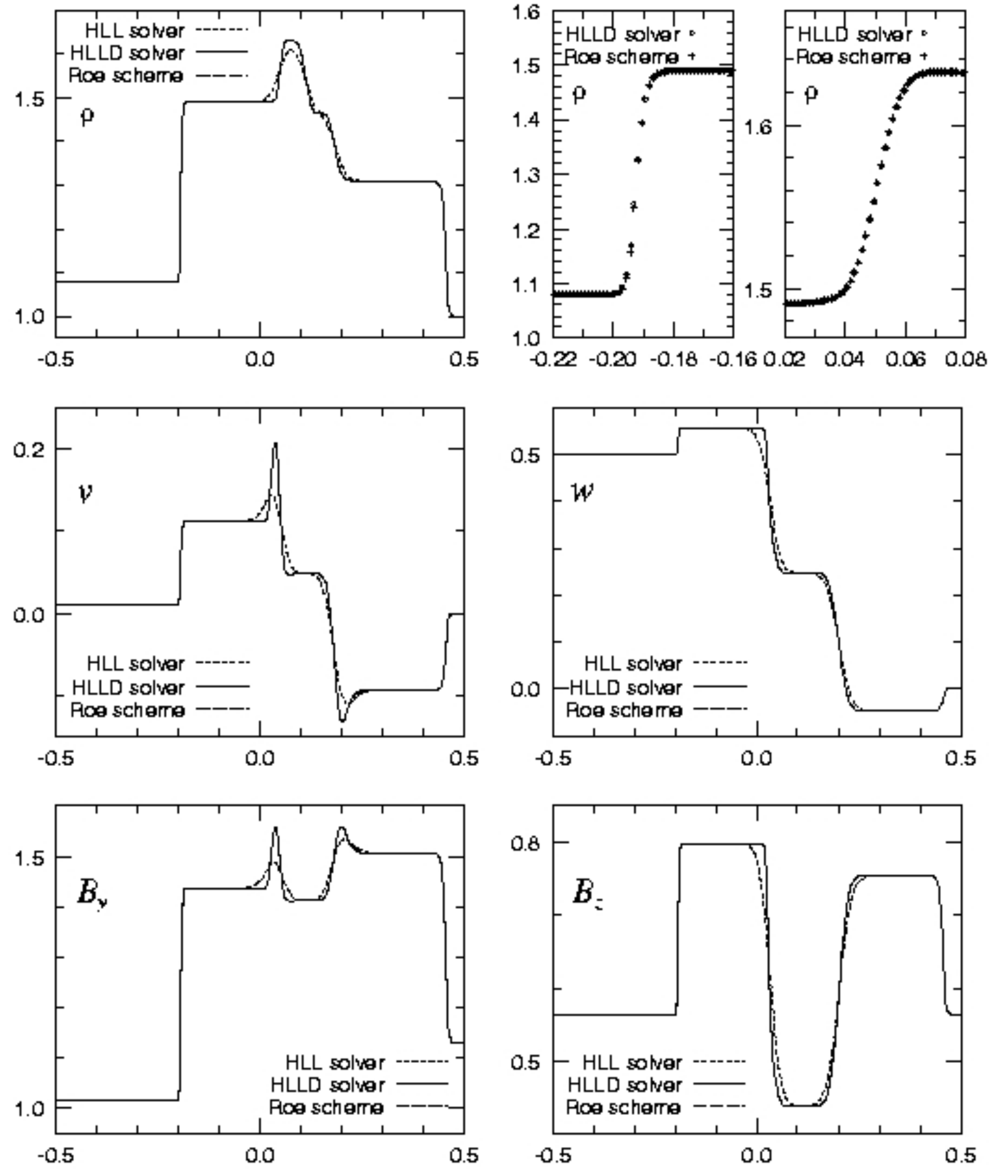


Fig. 5. Results of one-dimensional shock tube test with the initial left states $(\rho, p, u, v, w, B_y, B_z) = (1.08, 0.95, 1.2, 0.01, 0.5, 3.6/\sqrt{4\pi}, 2/\sqrt{4\pi})$, the right states $(1, 1, 0, 0, 0, 4/\sqrt{4\pi}, 2/\sqrt{4\pi})$, and $B_x = 4/\sqrt{4\pi}$. Numerical solutions of the **HLL** solver, the **HLLD** solver, and the Roe scheme are plotted at $t = 0.2$. (Top left) ρ, (middle left) v, (middle right) w, (bottom left) B_y, (bottom right) B_z, (top middle) ρ around the left fast shock, (top right) ρ around the left slow shock are shown.

1D Tests for MHD: Shock tube tests

Influence of the scheme order

HLLD first and second order

HLLC first and second order

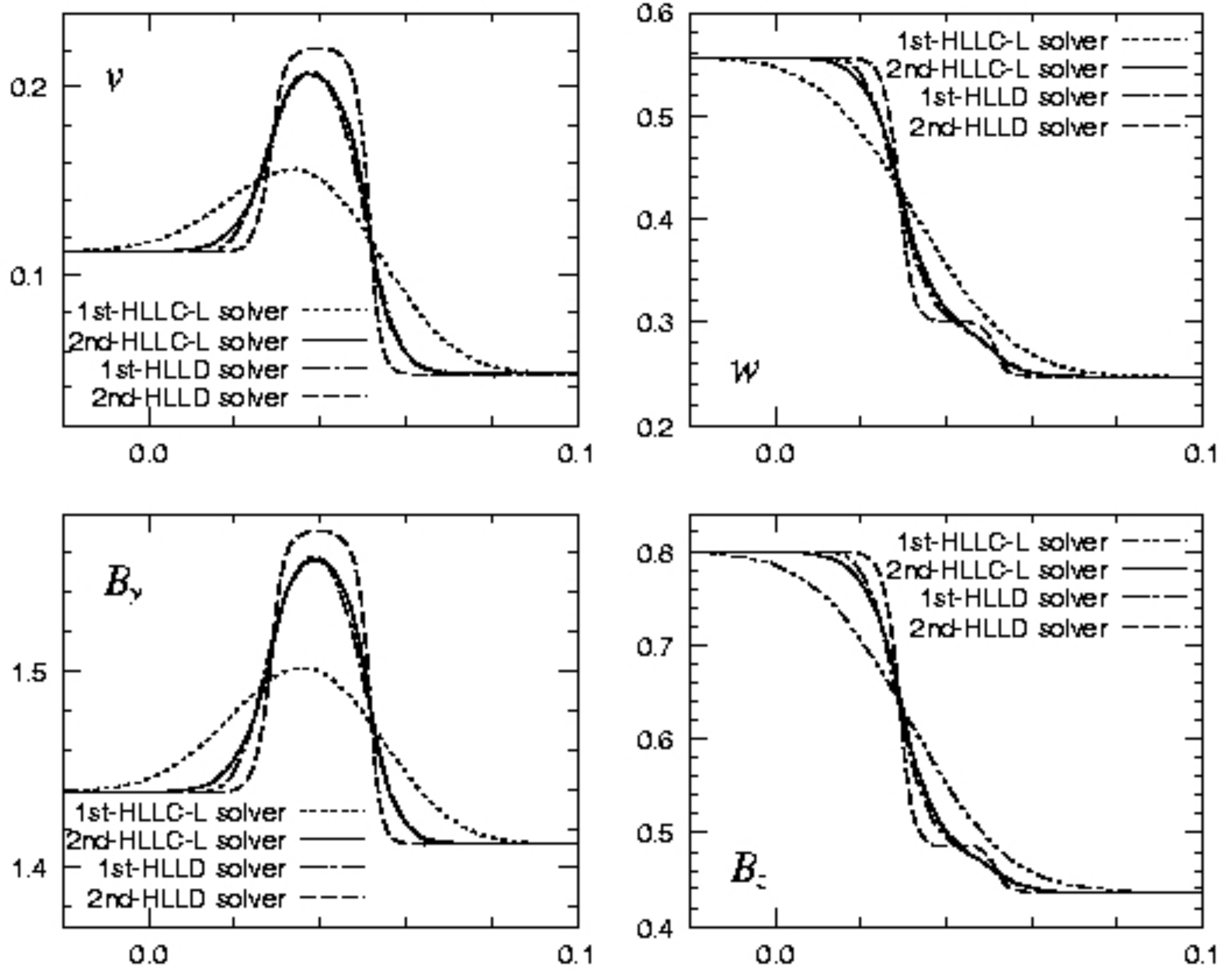


Fig. 7. Results of one-dimensional shock tube test with the same initial states as in Fig. 5. Numerical solutions of the first- and second-order **HLLC**-type solver by Li (1st- and 2nd-**HLLC-L**) [19], the first- and second-order **HLLD** solver (1st- and 2nd-**HLLD**) are plotted at $t = 0.2$. (Top left) v, (top right) w, (bottom left) B_y, (bottom right) B_z are shown within $-0.02 < x < 0.1$.

2D Tests for MHD: Orszag-Tang vortex test

342 T. Miyoshi, K. Kusano / Journal of Computational Physics 208 (2005) 315–344

patch/mhd/ot

Famous 2D tests

$$\rho = \gamma P_0,$$
$$v = (-\sin 2\pi y, \sin 2\pi x),$$
$$B = (-B_0 \sin 2\pi x, \sin 4\pi y)$$
$$\gamma = \frac{5}{3}, P_0 = \frac{5}{12\pi}, B_0 = \frac{1}{\sqrt{4\pi}}$$

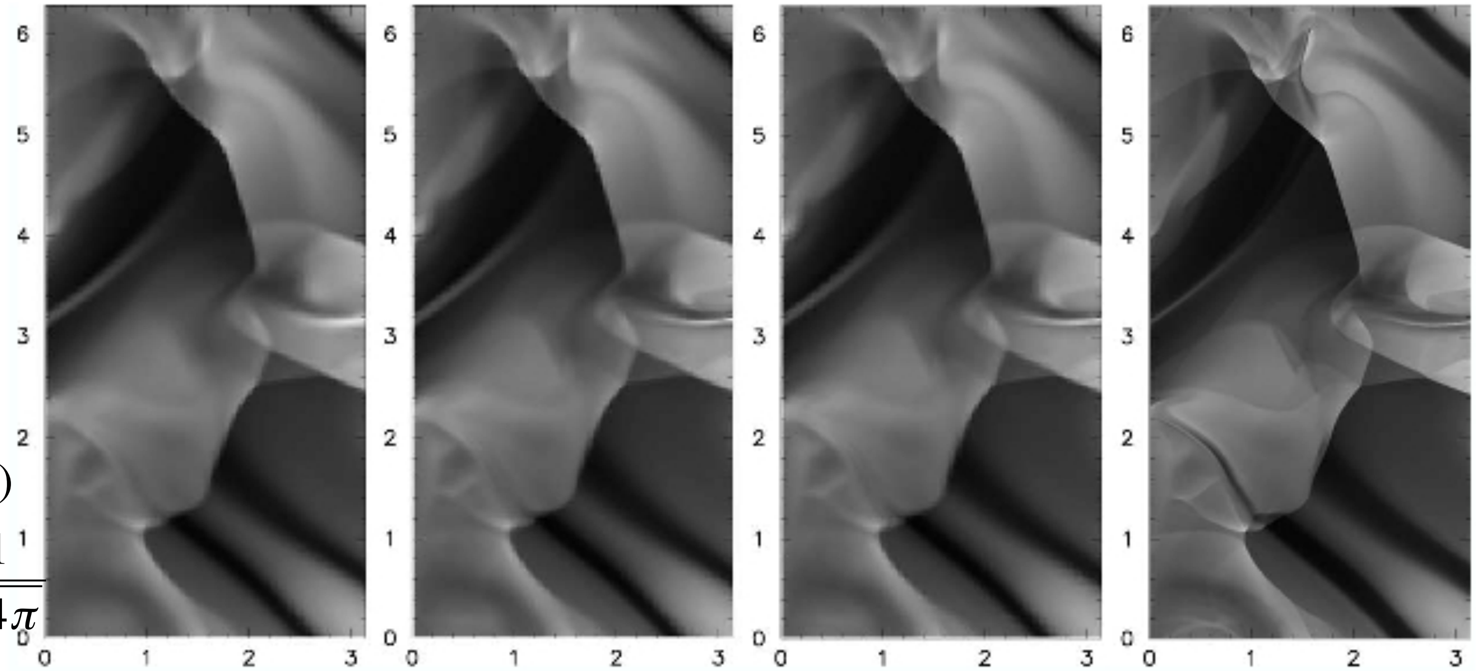


Fig. 12. Gray-scale images of the temperature distribution in the Orszag–Tang vortex problem at $t = \pi$ for (left to right) the **HLL** solver, the **HLLD** solver, the Roe scheme at $N = 200$, and the reference solution. The left half of the domain is shown.

Comparison between HLL, HLLD and ROE

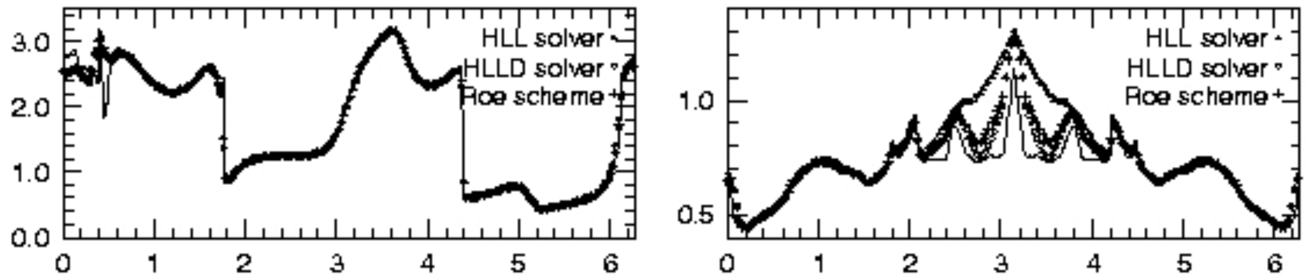
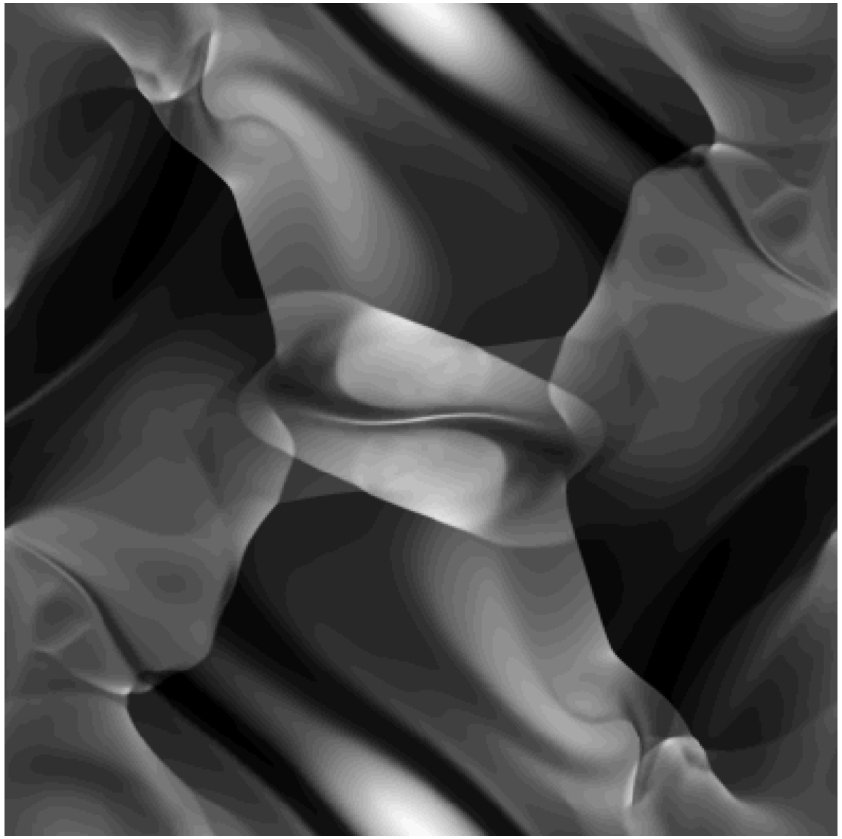


Fig. 13. One-dimensional temperature distribution in the same problem as in Fig. 12 along (left) $y = 0.64\pi$, (right) $y = \pi$, for the **HLL** solver, the **HLLD** solver, and the Roe scheme. The solid line shows the reference solution in each panel.

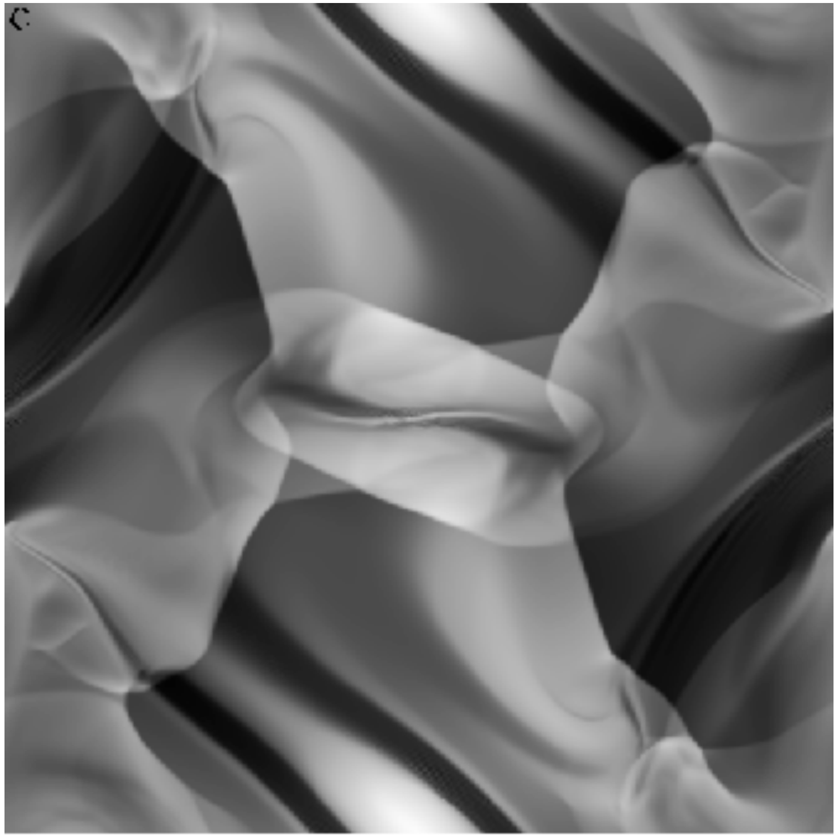
2D tests: code comparison

Orszag-Tang vortex resolution 512

Fromang et al. 2006 (Ramses)



Dai & Woodwards 1998

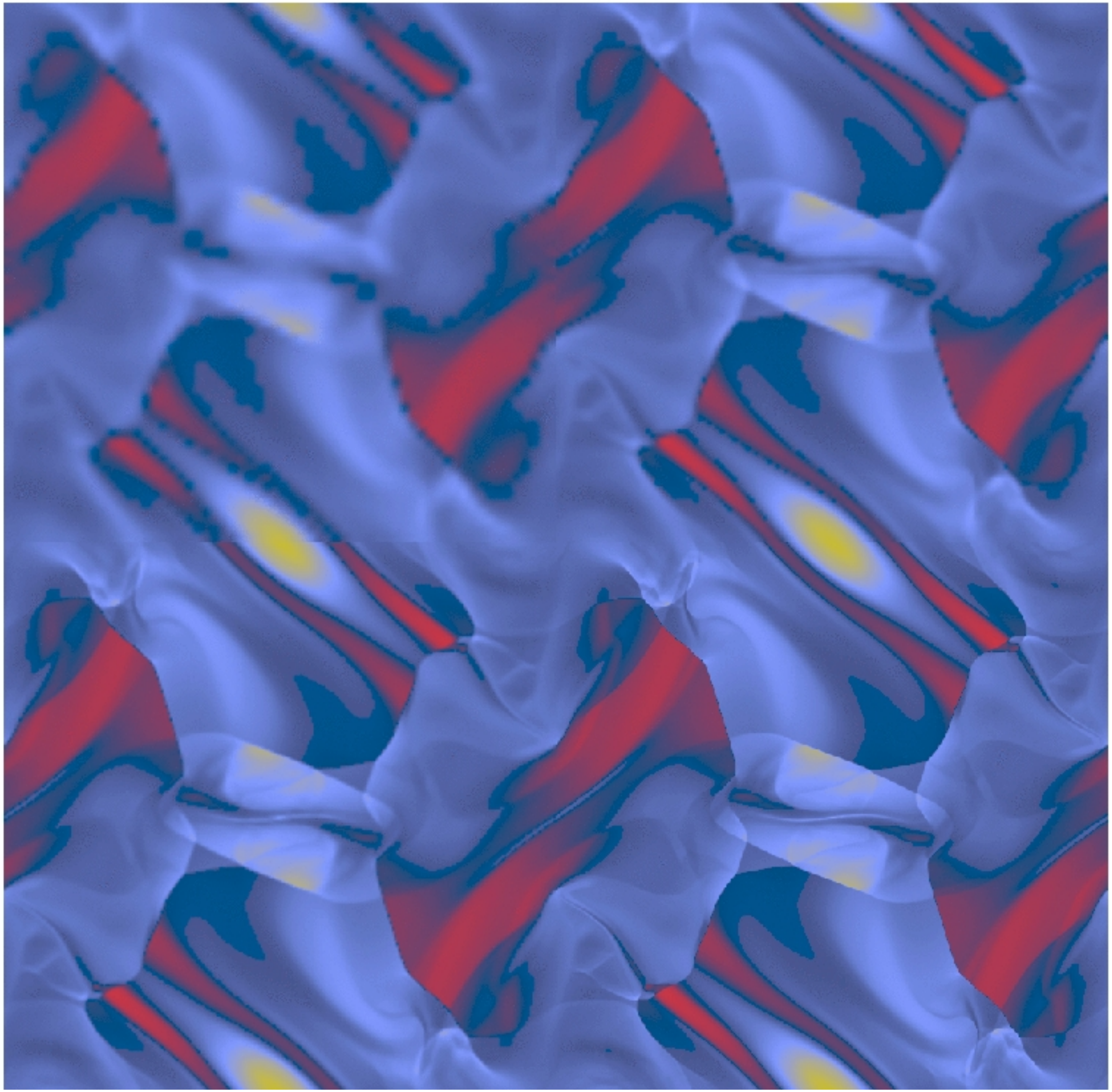


Athena code
(Gardiner & Stone 2005)

Ortzag-Tang Vortex

4 resolutions 64,128,256, 512

Repeat this series of calculations for different resolutions and codes



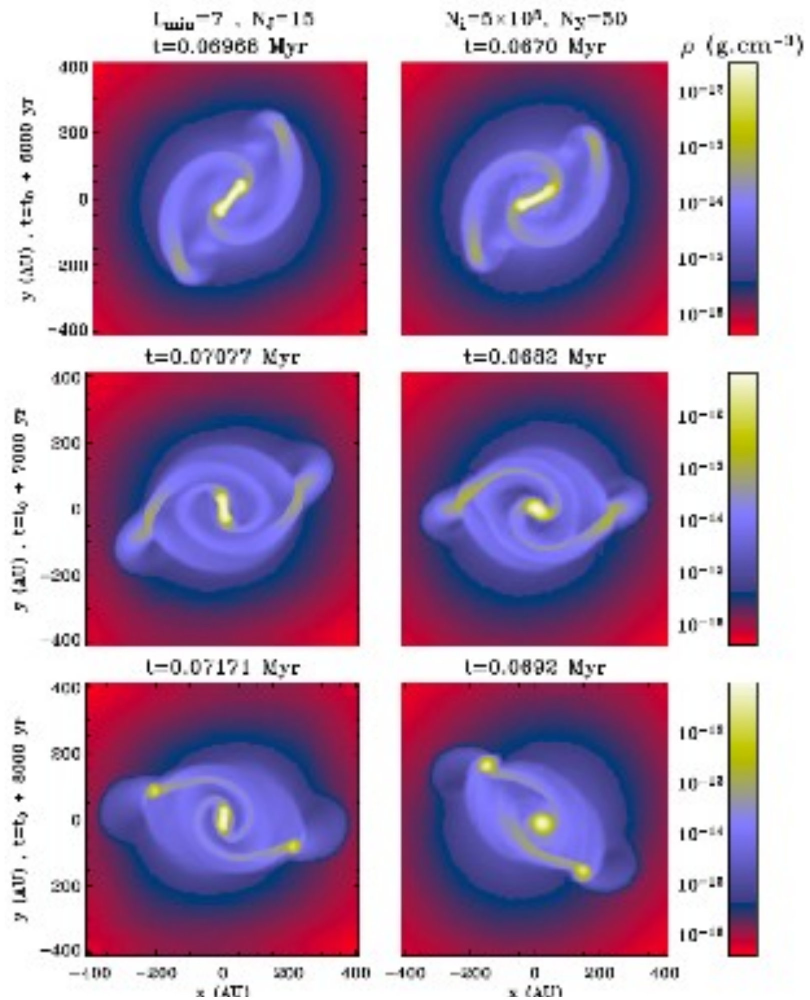
Dense core collapse calculations

A gravitationally unstable; slowly rotating core collapses.
AMR very useful in this problem ! patch/mhd/coeur
Initial conditions (see e.g. Commerçon et al. 2008) :
Uniform density sphere, solid body rotation
0.3-0.5 thermal/gravitational energy, 0.02-0.04: rotation/grav, m=2 perturbation

AMR

time

SPH



300 AU

Perform a series of calculations for different resolutions and codes

Introduce B ?

Do you see an outflow ?