Hands-on session using RAMSES:
MHD simulations of shocks and instabilities

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RAMSES (Teyssier 2002)
“Raffinement Adaptatif de Maillage Sans Effort Surhumain”

- Eulerian code for solving MHD + gravity
- Sub-grid models for baryonic physics, galaxy evolution, ISM cooling, …
- MHD equations are conservation equations:

\[ \frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot \mathbf{F(\mathbf{U})} = 0 \]

- Solve Riemann problem between cell interfaces:

[Diagram showing piece-wise linear reconstruction]

Springel 2021

Hu et al. 2023
RAMSES EXERCISES
1D implementation using RAMSES:

The Taylor-von Neumann-Sedov blastwave

- Blast wave induced by strong energy injection
- Self-similar solution - dimensions scalable!
1D implementation using RAMSES:

The Taylor-von Neumann-Sedov blastwave

\[ P_{\text{explosion}} = 10^5 P_{\text{ambient}} \]
3D Sedov Blast Wave interacting with Magnetic Field (MF)

Propagation of the blast wave as a function of time, colored by density + MF lines.
→ `yt.SlicePlot(dat, projection = "x", field = ("gas", "density"))`

Only Bz  
Bx, By, Bz ≠ 0

3D Representation  
Colored by density, under the effect of uniform MF.

Post processing using yt (Turk et al. 2011)

`yt.create_scene(dat, field=("gas", "density"), lens_type="perspective")`
Impact of different injection parameters
(Collision of shock fronts)

Injection parameters:

- density = 0.1
  - pressure = 1e4
  - tmax = 0.015

- density = 2.0 (amb)
  - pressure = 1e5
  - tmax = 0.036

- density = 2.0 (amb)
  - pressure = 1e4
  - tmax = 0.049

Quickier expansion / larger momentum

Even faster expansion

All values in code units

Pierre Nürnberg
Molecular Cloud in a Dense Wind

Projection volume weighted density along $L_z = 1$ with same side lengths $L_x = L_y = 1$

$R_2 = 0.2$
$R_1 = 0.04$
$ho_2 = 0.9$
$ho_1 = 0.9$
$ho_3 = 0.2$
$P_2 = 10^{-5}$
$P_1 = 20$
$P_3 = 10^{-5}$
$v_2 = 0$
$v_1 = 0$
$v_{3,y} = 2$
$B_{2,x} = 2$
$B_{1,x} = 2$
$B_{3,x} = 2$
Kelvin-Helmholtz Instabilities: RAMSES vs AREPO

Velocity perturbation (Springel, 2010):

\[ v_y(x, y) = w_0 \sin(4\pi x) \]

Gas density projection:

\[ \times \left\{ \exp\left[ -\frac{(y - 0.25)^2}{2\sigma^2} \right] + \exp\left[ -\frac{(y - 0.75)^2}{2\sigma^2} \right] \right\} \]

(Springel, 2010)
Thank you!