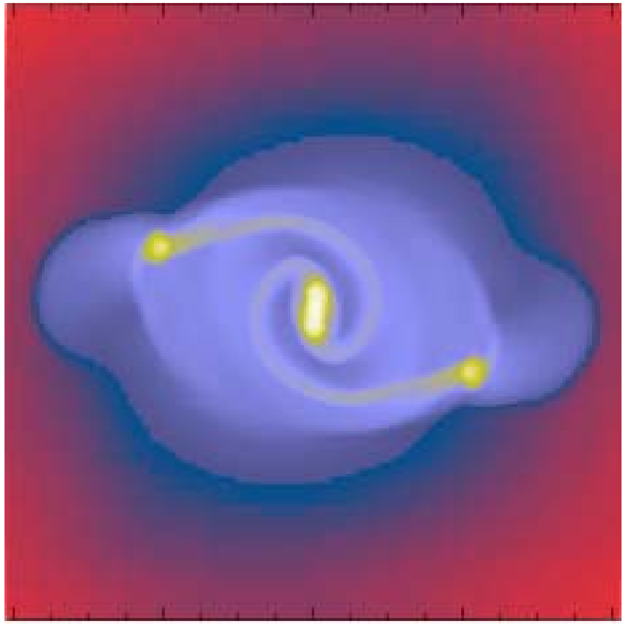
Protostellar collapse: a comparison between SPH and AMR calculations



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Outlines

- ✓ Overview – Hydrodynamics
- ✓ Numerical methods for collapse issue
- ✓ Angular momentum conservation issue
- ✓ Prestellar core fragmentation:
  - Usual case
  - Low thermal support

- Star formation : interstellar cycle driving force

- **Highly non linear and multiscale phenomena:**
  - 6 orders of magnitude
  - Jeans length/mass description

- **Star formation calculation:**
  - High complexity process ==> need adapted tools
  - No analytic solution: invalidated tools
  - Need to test and compare methods

AMR vs. SPH : Context

- Numerical calculations studies: 2 methods
  - **Smoothed Particle Hydrodynamics**: DRAGON code (Goodwin et al. 2004)

Advantages :
- ✓ natural adaptive skill
- ✓ Lagrangian approach
- ✓ (quite easy to implement)

Disadvantages :
- ✓ implementation less studied
- ✓ low resolution in low density region
- ✓ noise, dissipative

  - **Adaptive Mesh Refinement**: RAMSES code (Teyssier 2002, Fromang et al. 2006)

Advantages :
- ✓ accuracy
- ✓ shock description
- ✓ refinement criteria

Disadvantages :
- ✓ (headache)
- ✓ mix informations

Are the methods: - appropriate to study structure formation?
- converging individually? together?

- **AIM : Comparison with a simple collapse model, i.e. uniform density isothermal sphere in solid rotation**
  - ✓ Initial conditions care
  - ✓ axisymmetric ==> local conservation of angular momentum
  - ✓ Perturbation m=2 ==> fragmentation issue

Gas equations

- **Euler equation + Gravity for a perfect gas:**
  - Continuity
  - Momentum conservation
  - Total energy conservation

- **Barotropic equation of state:** $$\frac{P}{\rho} = C_s^2 = C_0^2\left[1 + \left(\frac{\rho}{\rho_c}\right)^{2/3}\right]$$

$$\begin{cases} -\ \gamma = 1 & \text{if } \rho < \rho_c = 1\times10^{-13}\,\text{g.cm}^{-3} \rightarrow \textbf{ISOTHERMAL} \\ -\ \gamma = 5/3 & \text{if } \rho > \rho_c \rightarrow \textbf{ADIABATIC} \end{cases}$$

Jeans length: $\lambda_J = c_s\sqrt{\dfrac{\pi}{G\rho_0}}$

Numerical criteria on Jeans length and mass

AMR: 1/ refinement criteria N_J as a function of the Jeans length :

$$N_J \,.\, \Delta x < \lambda_{Jeans}$$

↪ Truelove criteria (Truelove et al. 1997): $N_J \geq 4$

2/ initial resolution of the sphere (radius = 1/4 box length)

i.e. : $(2^6)^3 = 64^3$ cells

SPH: total mass of the system particle + $2\ N_N$ (M_{res}) neighbours should be lower than the local Jeans mass M_{Jeans} (Bate & Burkert 1997)

↪ 2 parameters: N_p number of particles

N_N number of neighbours

↪ Compare SPH with AMR resolution: $N_J^3 = M_{Jeans}/M_{res}$

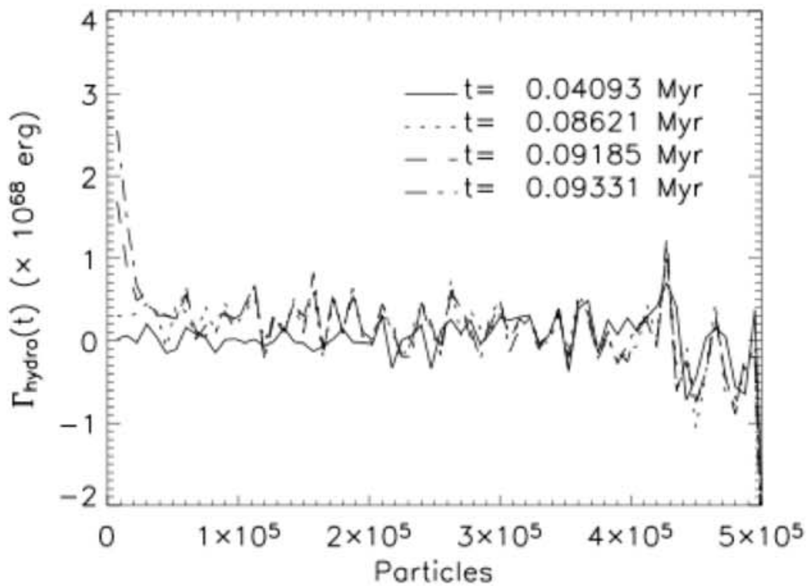
Angular momentum conservation issue

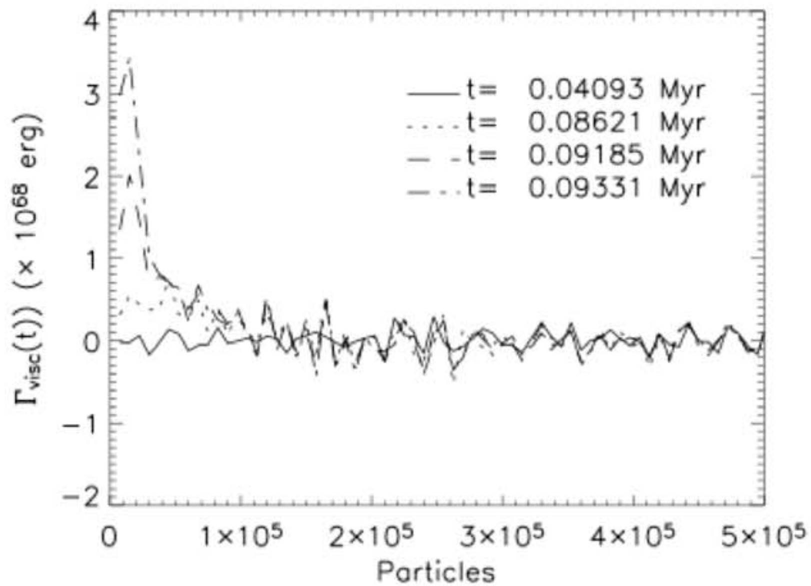
- Isothermal sphere in solid rotation, uniform density
- Angular momentum conservation + SPH particles carry on their own momentum

➥ "*corrected* angular velocity": $v_{\theta,\mathrm{th}} = \frac{J_0}{r}$

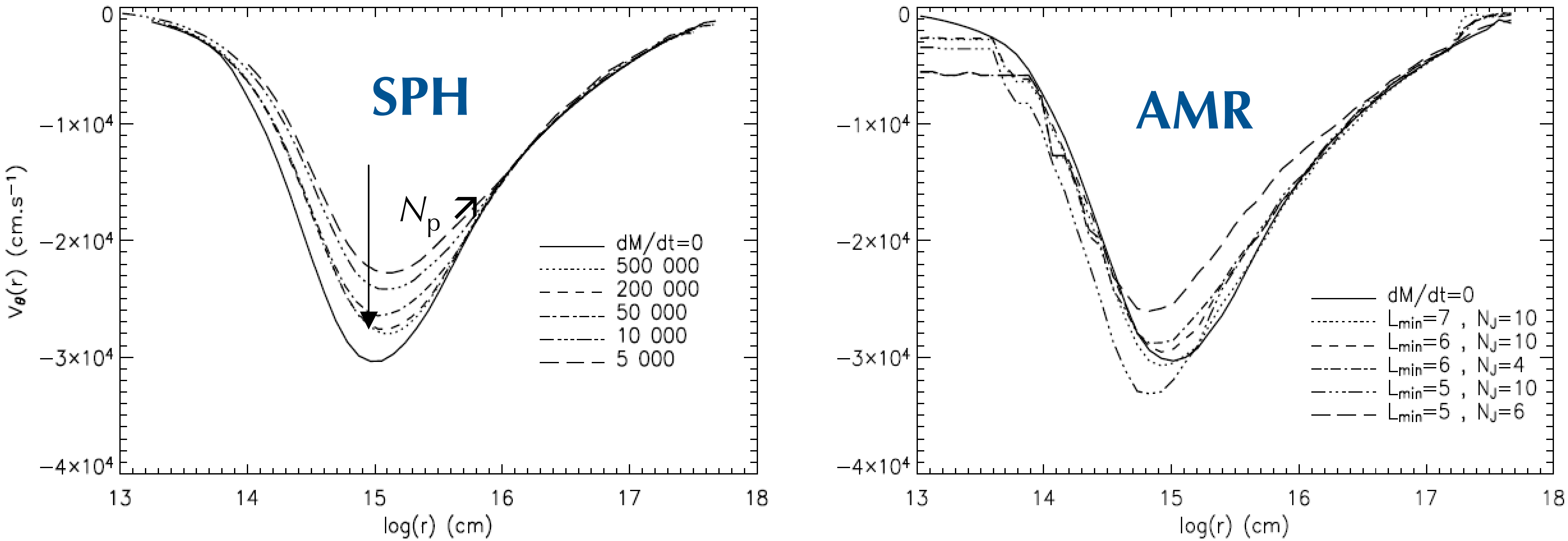
- t_{ff}=0.086 Myr ; t_{rot}= 2.8 Myr

SPH

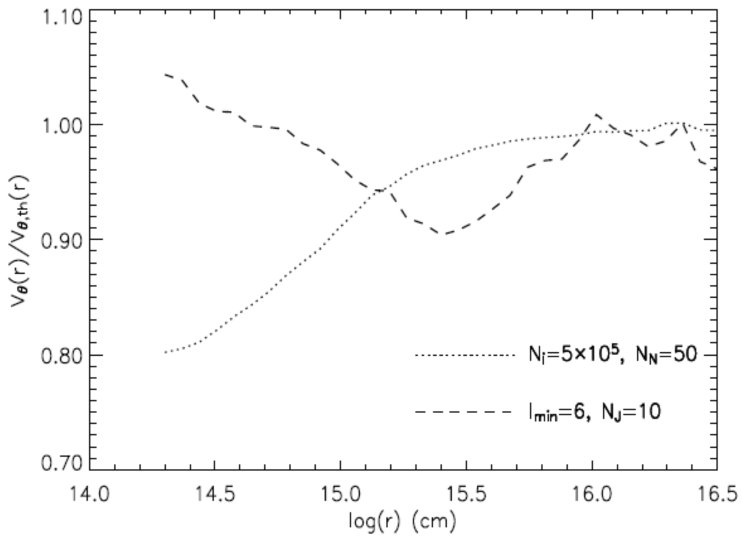




SPH vs. AMR: Angular momentum conservation



Azimuthal velocity profile as a function of the radius in the equatorial plane for various numerical resolutions



Ratio between numerical and corrected azimuthal velocities at t_0 in the equatorial plane for AMR calculations (128^3, $N_J=10$) et SPH ($N_p=5x10^5$, $N_N=50$).

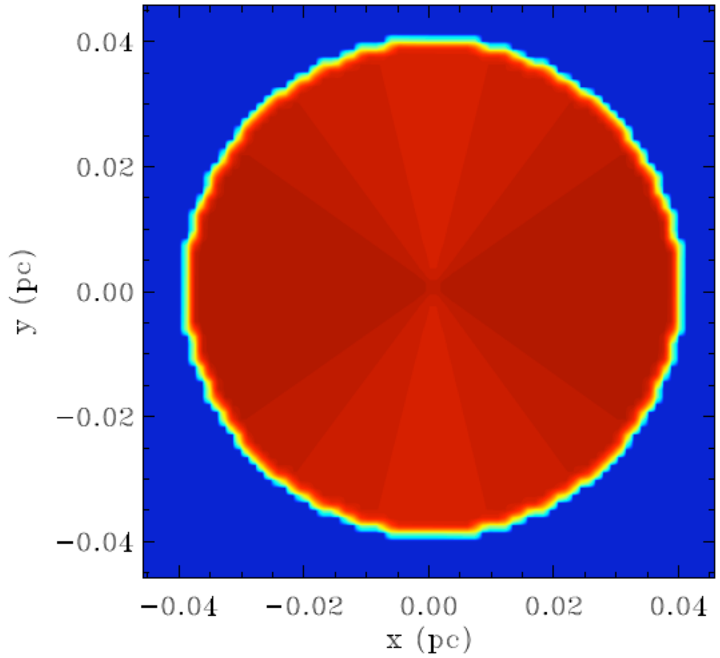
(Commerçon et al. 2007, submitted to A&A)

Collapse with a *m*=2 perturbation - Model

Fragmentation : IMF, disk stability

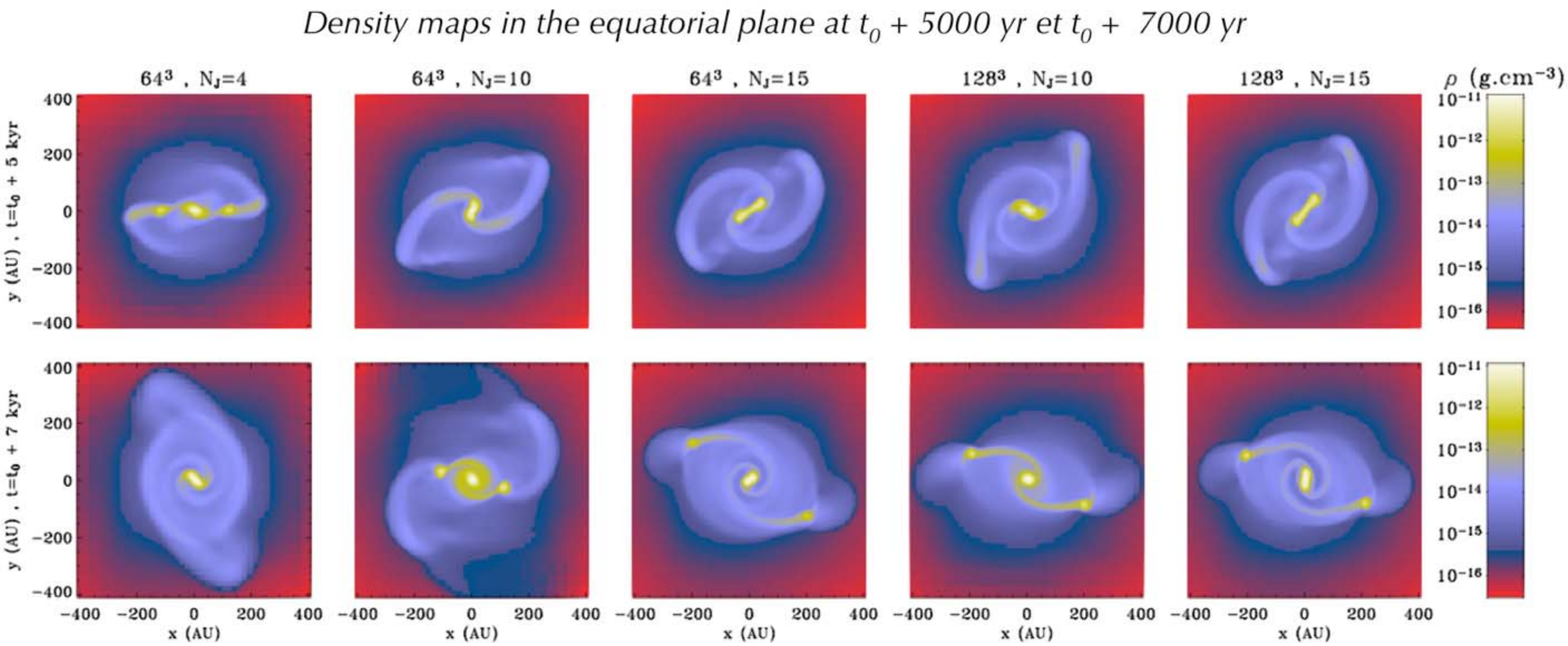
- **AIM**: study the dependency of the results on numerical parameters
- Azimuthal density perturbation ==> symmetry break
  - Sphere in solid rotation
  - Perturbation m=2, amplitude A=0.1

$$\rho = \rho_0[1 + A cos(m\theta)]$$



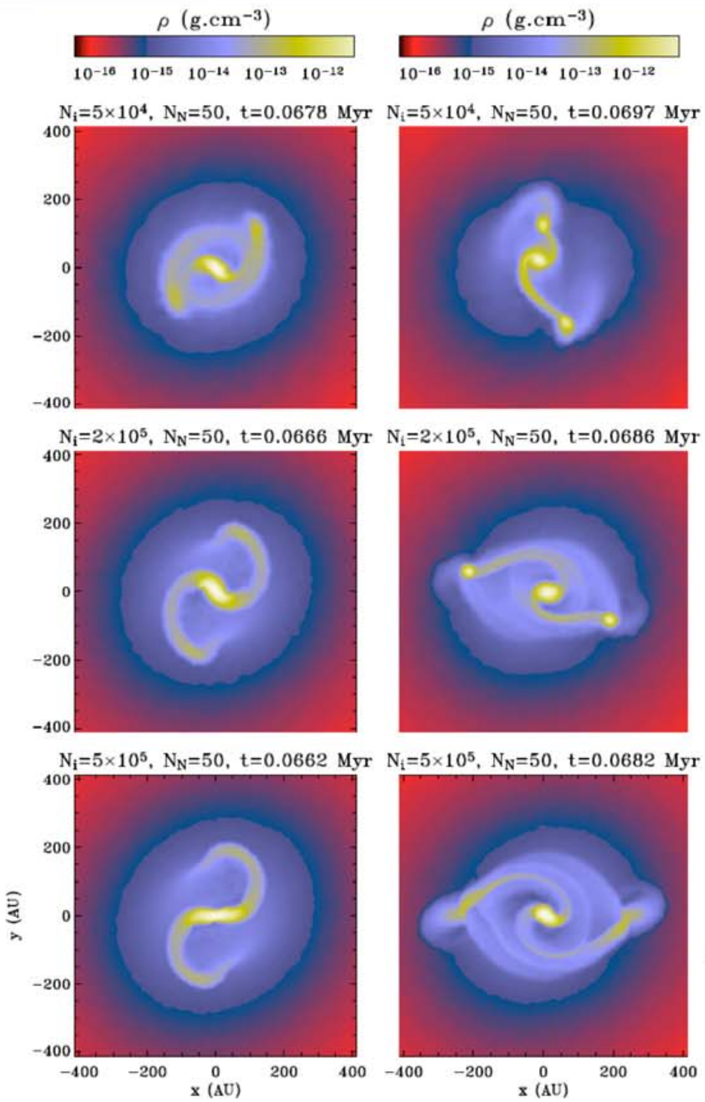
- 2 parameters to set the system
  - Thermal support: α = 0.5 & 0.35 (E_{th}/E_{grav})
  - Rotational support: β = 0.04 (E_{rot}/E_{grav})
  - Tsuribe & Inutsuka (1999): $\alpha < 0.55 - 0.65\beta$
- Synchronisation at t_0

AMR (α=0.5)



- Early fragmentation with N_J=4, fragments together <== angular momentum conservation
- Convergence between initial resolution of 64^3, N_J=15 and 128^3 , $N_J \geq 10$
- 1 central object + 2 satellites

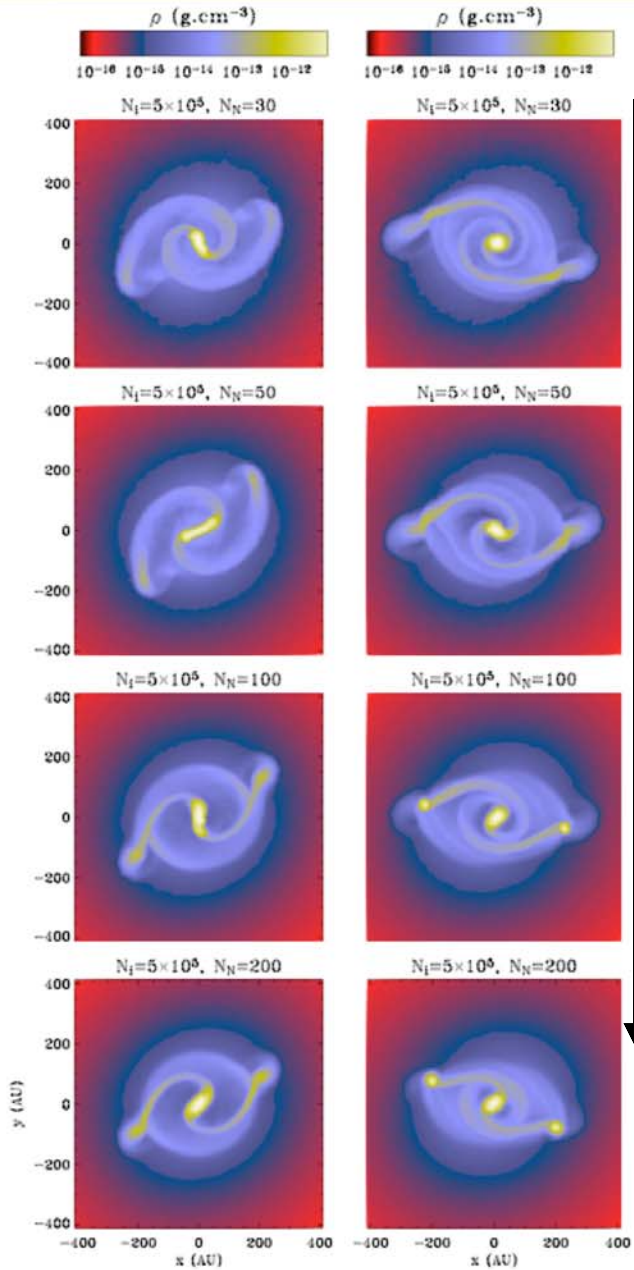
SPH (α=0.5)



Density maps at t_0 + 4000 yr et t_0 + 6000 yr

N_p ↗

$N_N = 50$



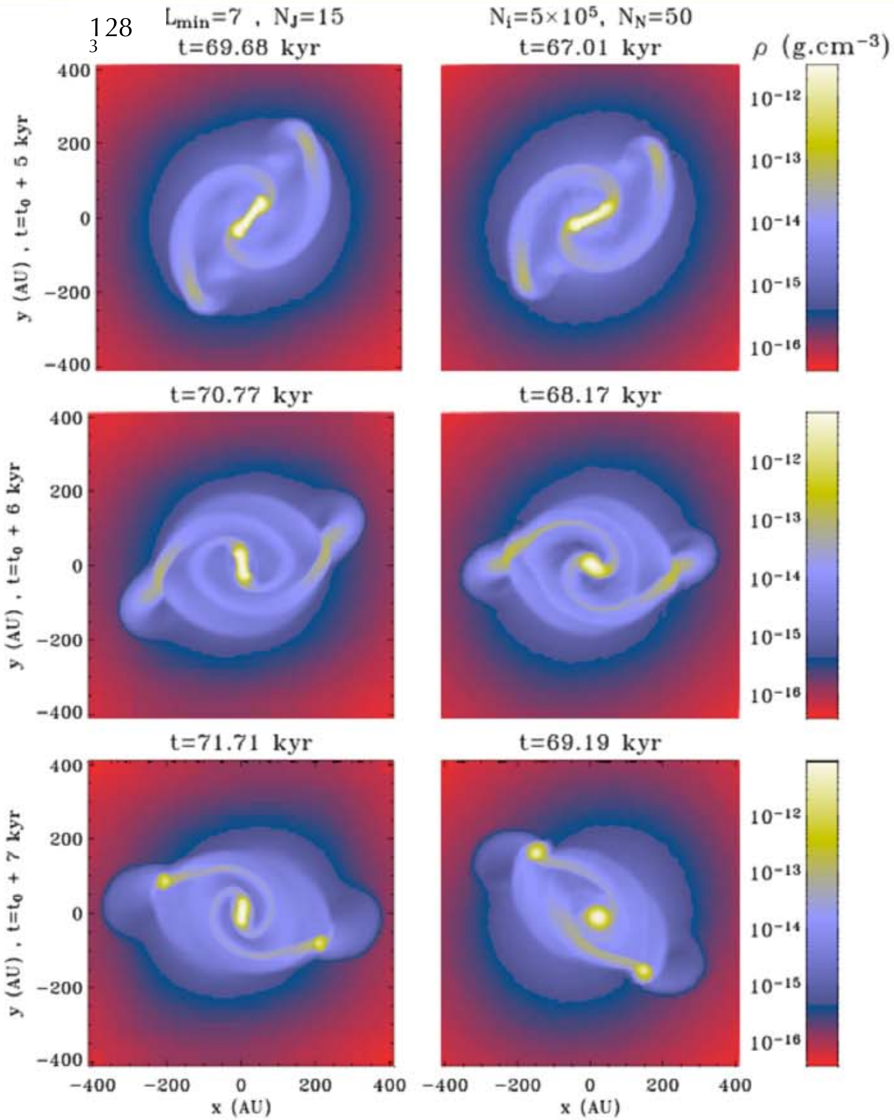
Density maps at t_0 + 5000 yr and t_0 + 6000 yr

N_N ↗

$N_p = 5x10^5$

- Artificial fragmentation with N_p=5x10^4
- Convergence if N_p ↗, N_N ↗ and $N_N/N_p \rightarrow 0$
- 1 central object + 2 satellites

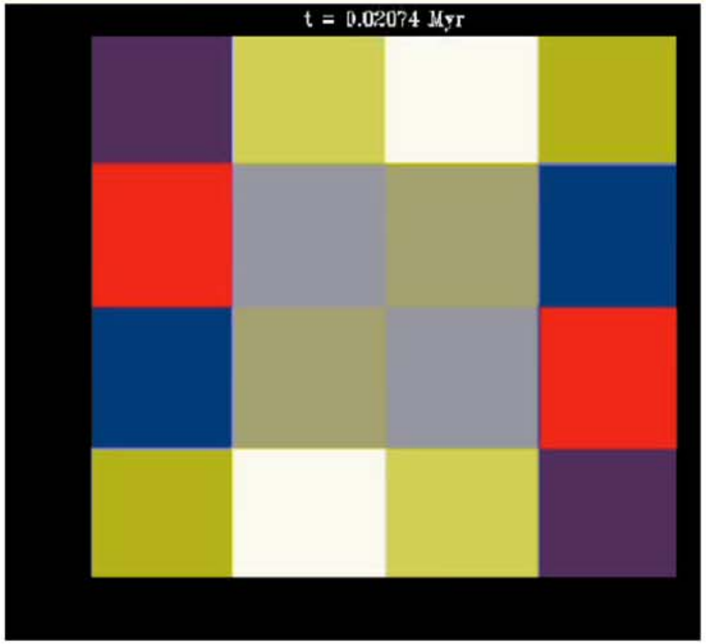
AMR vs. SPH



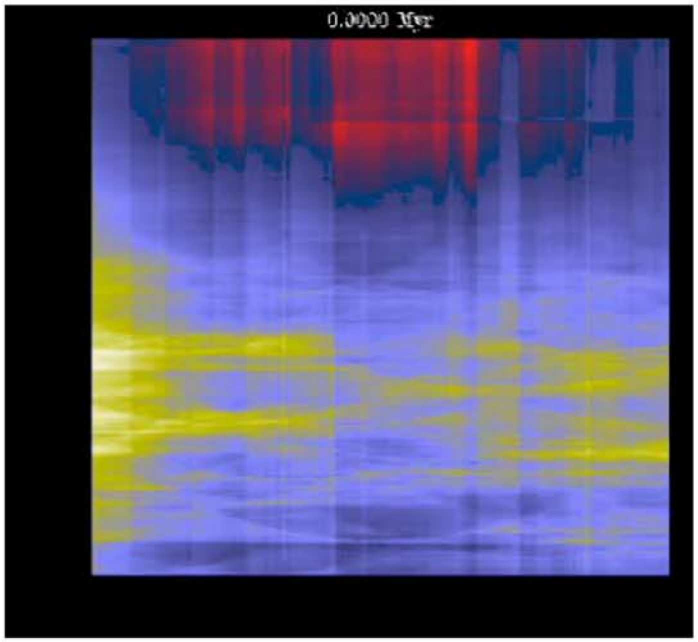
AMR: 64^3 (L_{min}=6) ; N_J=15

SPH: N_p=5x10^5 ; N_N=50

i.e. ~ 5300 particles/Jeans mass



AMR

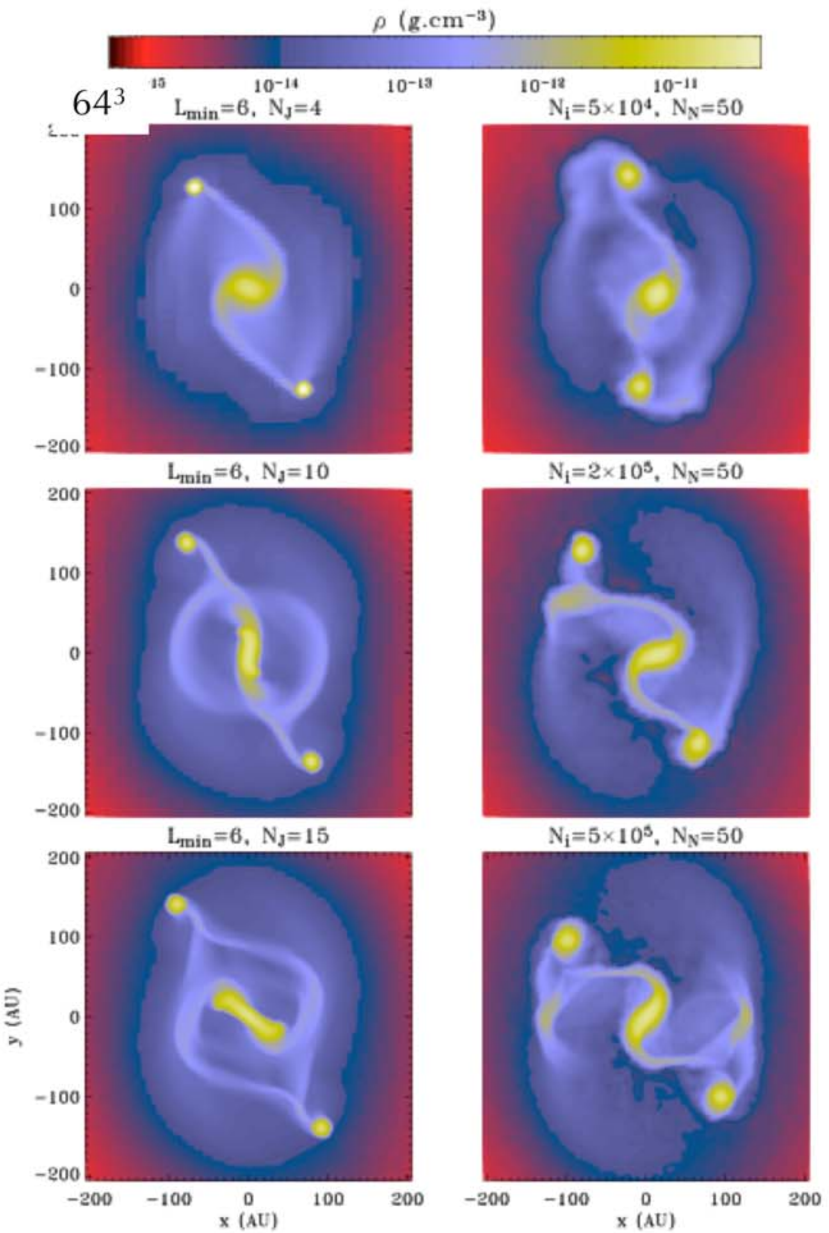


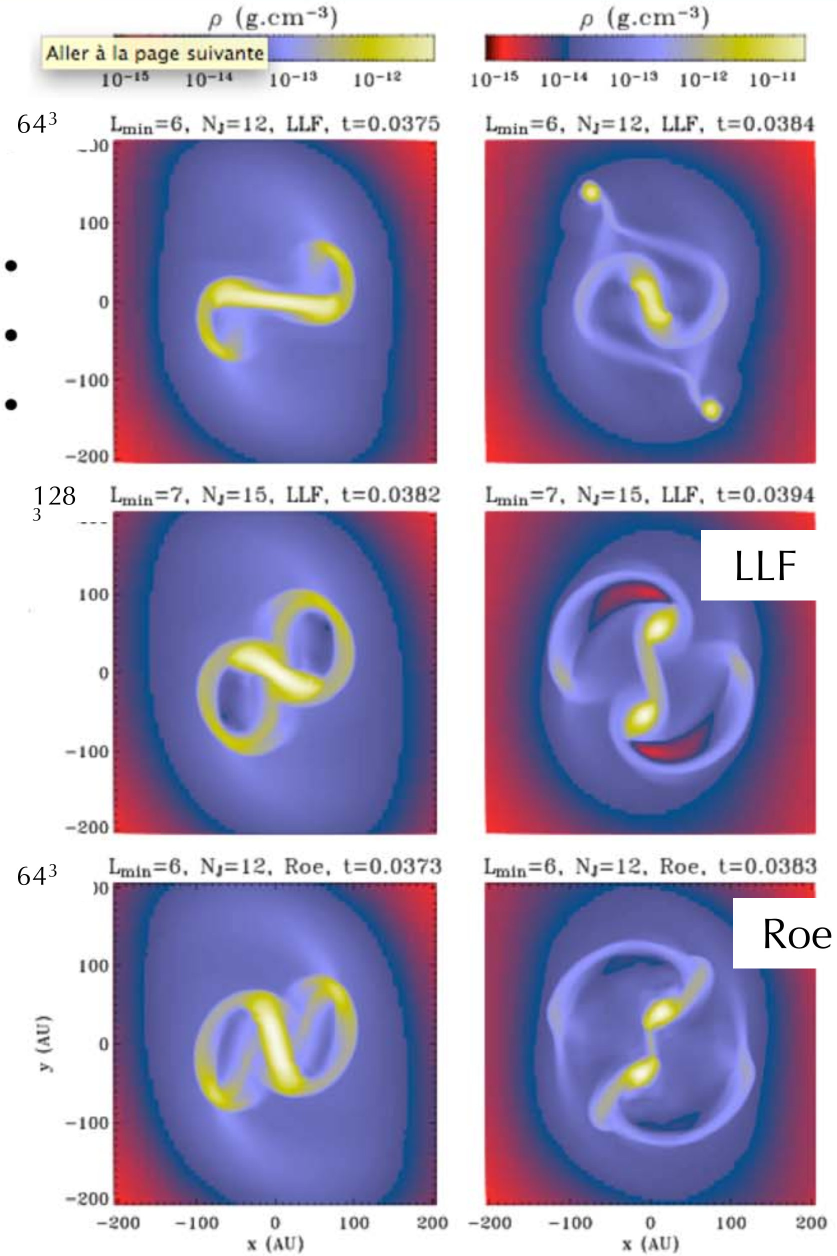
SPH

Low thermal support: α=0.35

dapnia SAp

saclay





Density maps at t_0 + 3000 yr

Conclusions

- At equivalent resolution, AMR seems to carry on better angular momentum

- Fragmentation: CONVERGENCE
  - Numerical resolution to reach convergence very high
  - Short horizon of predictability for low thermal support

- Future:
  - AMR with RMHD
  - High mass star formation and fragmentation issue, 2nd collapse