Star Cluster Formation SPH simulations

Nicolas Petitclerc, James Wadsley and Alison Sills

McMaster University; petitcn, wadsley, asills@mcmaster.ca

Most stars form in a cluster and are observed to be gravitationally bound binary or multiple systems. Therefore a better understanding of gravitational interactions of the gas and the stars is important for star formation theory. This complex dynamic can be studied computationally. We performed SPH simulations of the collapse of a turbulent clump typical of what is found in molecular clouds. We used similar parameters to Bate, Bonnell & Bromm 2003, MNRAS, 339, 557 to compare our hydrodynamic codes, we use GASOLINE (Wadsley, Stadel & Quinn 2004, NewA., 9, 137).

Our initial conditions were a 50 M_{sun} uniform density sphere, 77 400 AU in diameter with supersonic turbulence with RMS Mach number of 6.4 and a power spectrum of $P(k) \alpha k^{-4}$. We used a polytropic equation of state assuming isothermality $T = 10$ K for $\rho \leq 10^{-13}$ g/cm^3 and $T \alpha \rho^{7/5}$ for $\rho > 10^{-13}$ g/cm^3. We use sink particles with a radius of 5 AU to simulate the forming stars when the gas reach a density of 10^{-11} g/cm^3. The sink particles accretes the gas particles crossing the accretion radius if they satisfy our two binding criteria:

$$E_{Grav} + E_{Kin} + E_{Thermal} < 0 \qquad\qquad E_{Thermal} \leq \left|\frac{E_G}{2}\right|$$

So far we don't use any special boundary conditions for the sinks and stars are not allowed to merge.

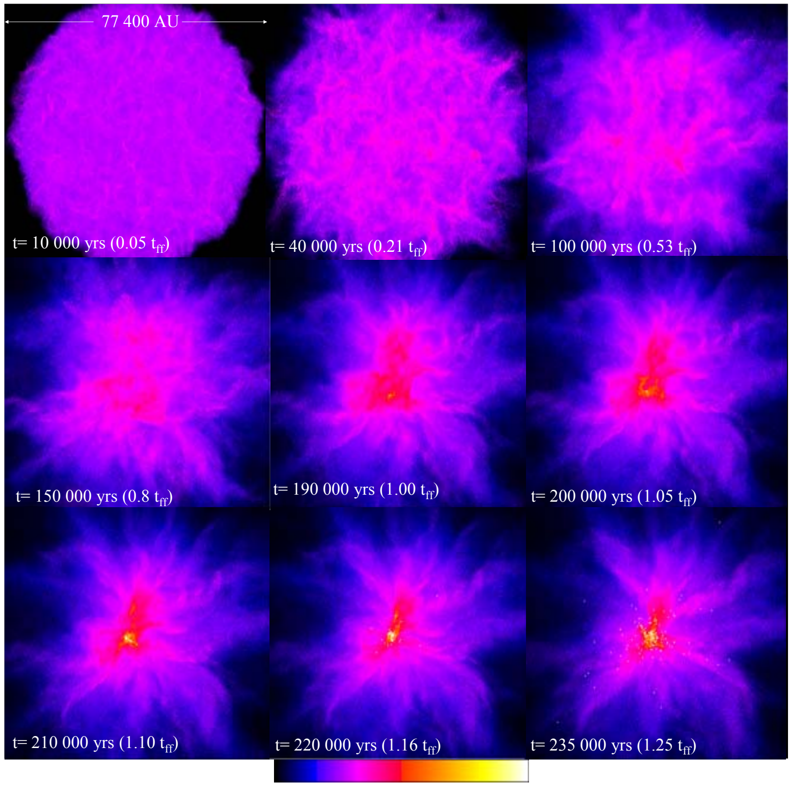


Figure 1 – Snapshots of the evolution of the star forming clump. The density of gas is plotted on a log scale $-21.2 \leq \log_{10} \rho \leq -11.2$ g/cm^3 on the z axis. Each panel is 77 400 AU across and the stars shows as white dots on the later evolution time steps. The time for each snapshot is indicated in years and in freefall time (t_{ff}) fraction.

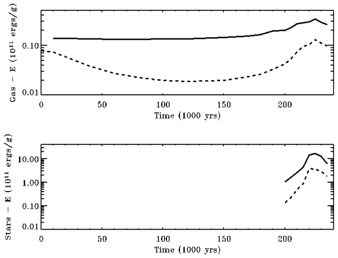


Figure 2 - We first observe the decay of the initial turbulent kinetic energy (dashed line) of the gas (top box). This allow the global collapse of the clump and provide substantial re-injection of kinetic energy into the gas. The first stars start appearing after 190 000 yrs (bottom box) and can also contribute to stir the gas. The gravitational energy is also plotted for comparison (full line).

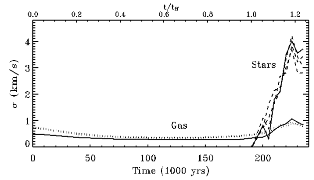


Figure 5 – Velocity dispersion for the gas and stars (full lines) and x, y, z components (dotted or dashed lines). Velocity dispersion probably has a density dependence that should be looked into to compare with various observable tracers (CO, N_2H^+).

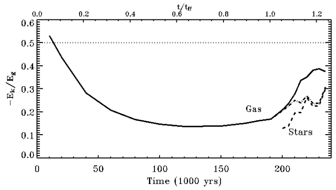


Figure 3 – The energy ratios of the gas (full line), the stars (dashed) and for both combined (dot-dashed). The initially supersonic gas starts with excess of kinetic energy compared to virial (dotted straight line). The ratio decreases as the turbulence decays and then goes back up to a significant fraction of virial ratio. The stars also evolve towards the virialized state.

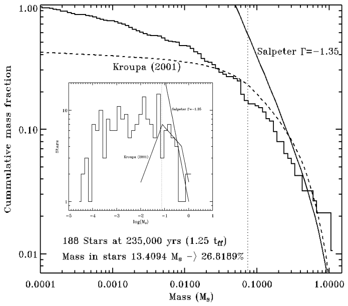


Figure 6- The cumulative initial mass function (IMF) represent the fraction of stars in the clump with a larger mass. The normal IMF is also plotted in the small box. The Salpeter and Kroupa distribution are normalized and show a good agreement for the massive end. However, our simulation form a large excess of very low mass objects. The limit between stars and Brown Dwarfs is shown (dotted line).

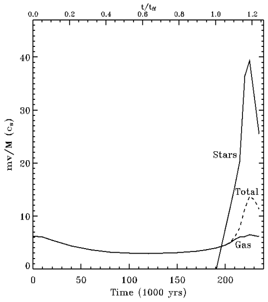


Figure 4 – The evolution of specific scalar momentum in units of Mach number ($c_s = 1.84 \times 10^4$ cm/s at 10 K). The gas has an initial turbulent Mach number of 6.4, it decreases down to 3 and then goes back up even higher (6.5) than its initial value. This exceeds recent results with explicit feedback (outflow) by Nakamura & Li, 2007 astro-ph.

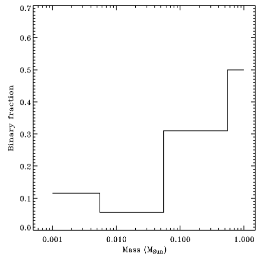
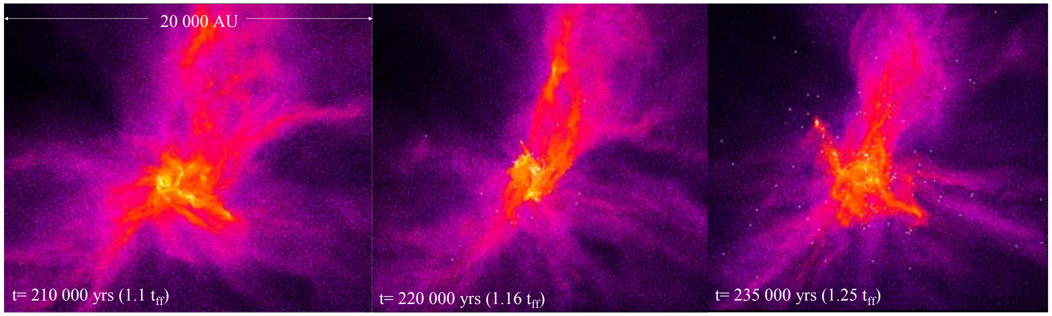


Figure 7 – The binary fraction in function of mass follow the observed trend for multiplicity. Our simulations resolution should enable us to get interesting statistics on multiplicity in star forming regions

Figure 8 – (Below) Same as figure 1, but for the inner 20 000 AU. All stars form originally near the center, but some are kicked out by strong gravitational interactions.



Overall our simulation is in good agreement with Bate, Bonnell & Bromm 2003, MNRAS, 339, 557, but two important differences are found. Our sink particles have a lower accretion rate and our star forming efficiency is much higher (27% after 1.25 t_{ff} compared to 12% after 1.4 t_{ff}). We are currently looking into these issues. In the future, we want to include some feedback from the stars (outflows) to study its effect on the gas turbulence and the overall star formation process. For more realism, we also want to enable stars to merge, since we noticed many close encounters.