Clumpy Structure in Molecular Clouds

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Abstract

Clumpy structure is ubiquitous in star forming regions at all size-scales. However, the dynamical stability of clumps is unclear, and thus their relevance as an origin for stellar masses is also unclear. Recently, André et al 2007 find that the majority of observed clumps in the Ophiuchus cloud are gravitationally bound. In this poster we present preliminary results of the evolution of clumpy structure in an SPH simulation of a collapsing molecular cloud with decaying turbulence. At present we find that only a small fraction of our clumps are bound pre-stellar cores: most are transient.

The Simulation

To simulate decaying turbulence in a molecular cloud, we generated self-consistent initial conditions (Figure 1), by driving turbulent velocities in a uniform box without self-gravity. After 0.531 t_{ff} the density field has a lognormal pdf and the velocity field has a power spectra of $P(k) = k^{-4}$. Previous simulations in this area (Clark & Bonnell 2005) used less self-consistent initial conditions, however the results found here do not differ significantly.

The simulation was then restarted with self-gravity and without further driving. Sink particles were used to model sites of star formation, and also to prevent us from going beyond our resolution. Figure 2 shows the central region of the simulation just before sink particles were formed.

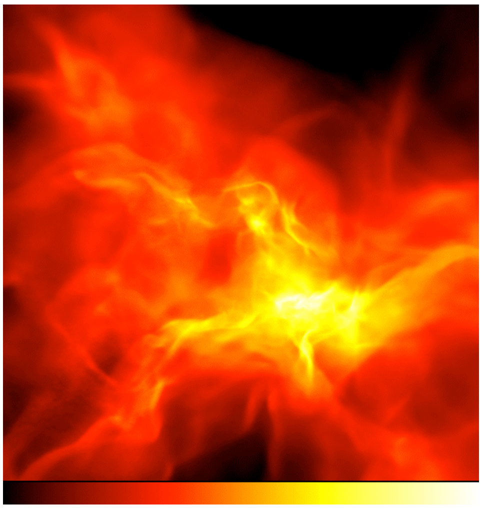

Figure 2: The central parsec of the simulation at t=1.063 t_{ff}, just before sink particles are formed. Denser regions are shown in lighter colours, the scale is logarithmic covers the ran

Identifying The Clumps

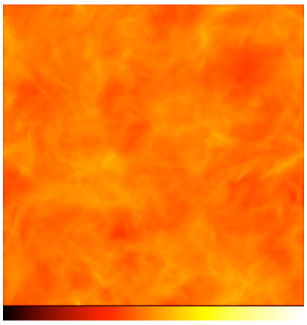

Figure 1: The initial density field generated by driving turbulence in a uniform $(2\ pc)^3$ box. Denser regions are shown in lighter colours, the scale is logarithmic and covers the range 0.27 gcm^{-2} to 2.1 × 10^{-3} gcm^{-2} , this corresponds to the max. density range in Figure 2.

Clumps were identified using two Clumpfind algorithms. The first interpolates the SPH particle data onto a 2D grid, allowing clumps to be found in a similar manner to observational clump-finding methods. The grid had a cell size of 5 × 10^{-3} pc, chosen to match typical beam resolutions. The other clump-finding method used the SPH particles directly in 3D, and in this case clumps are resolved down to a mass of 2.36 × 10^{-3} solar masses. As noted by several authors (e.g Ballesteros-Paredes & Mac Low 2002) it is likely that clumps in 2D are superpositions of structures along the line of sight. Our simulation supports these previous findings, as the number of clumps in the 2D case is typically of the order of a few tens, while for the 3D case it is a few hundreds. This effect has probably been emphasized by the improved 3D clumpfind resolution, which allows finer substructure to be identified. Figures 3 & 4 show a comparison of the clumpfinds for the region shown in Figure 2. The Clump Mass Function is poorly defined for the 2D case as there were only 35 clumps, however it is clear that the clumps are about an order of magnitude more massive as well as being more spatially extended.

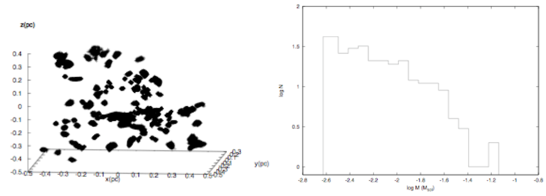

Figure 3: The positions of dense clumps found in the 3D clumpfind & the resulting Clump Mass Function.

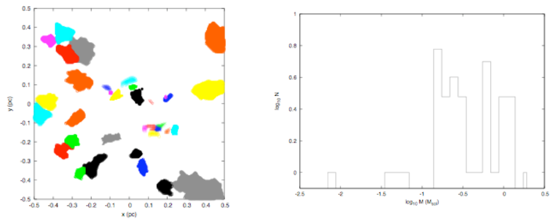

Figure 4: The position of clumps found in the 2D clumpfind (individual clumps are shown in different colours) & the resulting Clump Mass Function.

Transient Clumps

In the 3D clumpfind, for the vast majority of the simulation (about a free fall time), the clumps are unbound and therefore transient objects. In the distribution shown in Fig. 2, none of the clumps are bound. However, the mass function of the clumps is similar to the IMF. Figure 5a shows subsequent positions of the SPH particles that made up the densest clump in Fig. 3, and it can be seen that they are dispersing. Figure 5b shows the subsequent positions of particles in the first bound clump to form at t=1.084 t_{ff}. This clump forms sink particles and accretes mass from its surrounding environment, however, every other clump at this timestep remains unbound. These preliminary results support the supposition that clumps are short lived dynamical objects (Ballesteros-Paredes, Vazquez-Semadeni & Scalo 1998) .

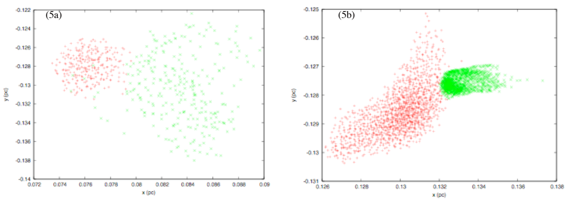

Figure 5: The original positions of the particles in the x-y plane for the densest clump (red) at a timestep and their subsequent positions 0.015 t_{ff} later (green). (5a) Shows an unbound clump at t=1.063 t_{ff} and (5b) shows the first bound clump which was formed at t=1.084 t_{ff}.

The 2D clumpfind has yet to have its clump history traced, subsequent work will address this issue and extend the analysis of the 3D case. The history of the 2D clumps is of particular interest as it may be compared to observational studies (e.g. Motte, André & Neri 1998, André et al 2007)

Clump Velocities

The internal 1-dimensional particle velocities of a typical clump from the 3D clumpfind are shown in Figure 6. The velocities are calculated relative to the centre of velocity of the clump. Since the sound speed is 0.18 kms^{-1}, the internal motions are subsonic. This is true for all the clumps so far examined for the 3D case. In the 2D case it is more accurate to take the velocity dispersion of the central cell to avoid confusion with surrounding structure, typically 1-dimensional velocity dispersions of around 0.3 - 0.4 kms^{-1} are found. This difference is due to the increased size of the 2D clumps along the line of sight.

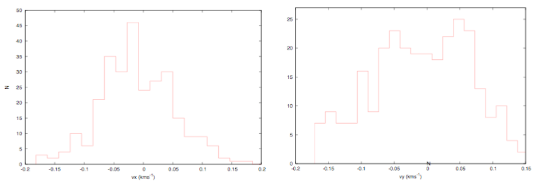

Figure 6: The velocities of the clump shown in Fig 5a in the x and y directions. The sound speed is 0.18 kms^{-1}

Summary

1) Improved initial conditions have been used to investigate clump formation in a molecular cloud with decaying turbulence.
2) The number of clumps and their sizes is very different when found in 2D and 3D .
3) The vast majority of the clumps identified with the 3D clumpfinding algorithm were unbound and thus transient.
4) The internal clump velocities are subsonic for the 3D case.
5) Further analysis is still to be carried out on this data.

References:

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