Clustered Star Formation in Magnetic Clouds: Properties of Dense Cores Formed in Outflow-Driven Turbulence

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Millimeter and submillimeter observations of dense cores in nearby parsec-scale cluster-forming clumps have shown that the core mass function (CMF) resembles the stellar initial mass function (IMF). This suggests that the observed dense cores may be the direct progenitors of individual stars and the bulk of the stellar IMF may be at least partly determined by cloud fragmentation in the parsec-scale dense clumps. Thus, understanding the formation process of dense cores is a key step towards a full understanding of how stars form.

In this study, we investigate the physical properties of dense cores formed in turbulent, magnetized, parsec-scale clumps of molecular clouds, using three-dimensional numerical simulations that include protostellar outflow feedback. In a cluster-forming clump, protostellar outflow feedback can play an important role in turbulence regeneration. In our previous studies, we demonstrated that protostellar outflows can resupply the supersonic turbulence, keeping the clumps near a quasi-virial equilibrium state for a relatively long time [1,2].

Figure 1 compares the column density distributions along the y-axis for the three models with different initial magnetic field strengths, at a stage when the star formation efficiency has reached 16%. Figure 1 indicates that the global density distribution depends on the initial magnetic field strength. In the presence of a moderatelystrong magnetic field, the cloud material condenses preferentially along the magnetic field lines into a large-scale filamentary structure that is nearly perpendicular to the initial magnetic field direction. The dense cores are distributed primarily along the main filament.

Then, we identified dense cores using the CLUMPFIND algorithm and found the following.

1. Dense cores do not follow Larson's linewidth-size relation. We find that the velocity dispersions of dense cores show little correlation with core radius, irrespective of the strength of the magnetic field and outflow feedback. In the absence of a magnetic field, the majority of the cores have supersonic velocity dispersions, whereas in the presence of a moderately-strong magnetic field, the cores tend to be subsonic or at most transonic.

2. We find that most of the cores are out of virial equilibrium, with the external pressure due to ambient turbulence dominating the self-gravity. The core formation and evolution is largely controlled by the dynamical compression due to outflow-driven turbulence. Such a situation is contrast to the strongly-magnetized (magnetically subcritical) case, where the self-gravity plays a more important role in the core dynamics, particularly for massive cores.

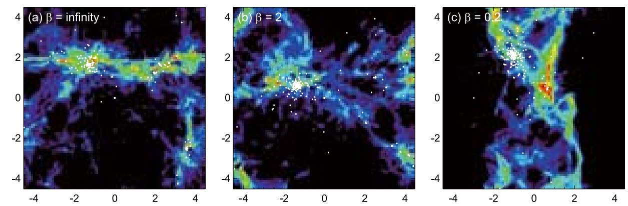

Figure 1: Column density snapshots on the x-z plane for (a) model N1 ($t = 4.6t_{\rm ff,c} \sim 0.9$ Myr), (b) W1 ($t = 6.5t_{\rm ff,c} \sim 1.2$ Myr), and (c) S1 ($t = 7.4t_{\rm ff,c} \sim 1.4$ Myr) at the stage when 16 % of the total mass has been converted into stars. The positions of the formed stars are overlaid with the dots. The units of length are the central Jeans length $L_J = (\pi c_s^2 / G\rho_0)^{1/2} \simeq 0.17(T/20\mathrm{K})^{1/2}(n_{\mathrm{H_2},0}/2.69 \times 10^4\,\mathrm{cm}^{-3})^{-1/2}$ pc.

3. Even an initially-weak magnetic field can retard star formation significantly, because the field is amplified by supersonic turbulence to an equipartition strength. In such an initially weak field, the distorted field component dominates the uniform one. In contrast, for a moderately-strong field, the uniform component remains dominant. Such a difference in the magnetic structure can be observed in simulated polarization maps of dust thermal emission. Recent polarization measurements show that the field lines in nearby cluster-forming clumps are spatially well-ordered, indicative of a moderately-strong, dynamically-important, field.

Our simulations indicate that in clustered star formation moderately strong magnetic field is needed to reproduce the physical properties of dense cores [3].

References

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