Gravitational fragmentation and the formation of brown dwarfs in stellar clusters

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ABSTRACT
We investigate the formation of brown dwarfs and very low mass stars through the gravitational fragmentation of infalling gas into stellar clusters. The gravitational potential of a forming stellar cluster provides the focus that attracts gas from the surrounding molecular cloud. Structures present in the gas grow, forming filaments flowing into the cluster centre. These filaments attain high gas densities due to the combination of the cluster potential and local self-gravity. The resultant Jeans masses are low, allowing the formation of very low mass fragments. The tidal shear and high-velocity dispersion present in the cluster preclude any subsequent accretion, thus resulting in the formation of brown dwarfs or very low mass stars. Ejections are not required as the brown dwarfs enter the cluster with high relative velocities, suggesting that their disc and binary properties should be similar to that of low-mass stars. This mechanism requires the presence of a strong gravitational potential due to the stellar cluster implying that brown-dwarf formation should be more frequent in stellar clusters than in distributed populations of young stars. Brown dwarfs formed in isolation would require another formation mechanism such as due to turbulent fragmentation.

Key words: stars: formation – stars: low-mass, brown dwarfs – stars: luminosity function, mass function – ISM: clouds – globular clusters: general.

1 INTRODUCTION
Brown dwarfs, having masses less than 0.08 M⊙, are seen to be nearly as frequent as stars and to have many of the same properties during their youth, such as circumstellar discs, binary companions and chromospheric activity (Scholz, Jayawardhana & Wood 2006; Burgasser et al. 2007; Luhman et al. 2007). There have been several proposed mechanisms to explain the origin of brown dwarfs (Whitworth et al. 2007). These have involved such diverse physical processes as turbulent fragmentation, disc fragmentation, the ejection of stellar embryos and the photoevaporation of a collapsing pre-stellar core. These different mechanisms all rely in forming a hence high gas density in the pre-stellar cores and thus a low Jeans mass, and/or in the halting of accretion once a low-mass fragment has formed.

Turbulent fragmentation (Padoan & Nordlund 2002) envisions that strong, magnetic shocks produce high-density post-shock gas which will have low Jeans masses and therefore form brown dwarfs directly from the turbulence (Padoan & Nordlund 2004). One of the potential difficulties with this model is that a straight shock only compresses the gas in one dimension. This does not affect the overall gravitational radius of the gas and thus has a negligible effect of the Jeans mass as the gravitational and thermal energies are basically unchanged (Elmegreen & Elmegreen 1978; Lubow & Pringle 1993; Clarke 1999). Several roughly coincidental shocks are required in order to get three-dimensional compression and a reduction in the Jeans mass. The turbulent compression model also neglects any residual internal turbulence generated from the shocks (Clark & Bonnell 2005).

Disc fragmentation (Bate, Bonnell & Bromm 2002; Whitworth & Stamatellos 2006; Goodwin & Whitworth 2007; Stamatellos, Hubber & Whitworth 2007) occurs when a massive circumstellar disc is unstable to gravitational fragmentation, potentially induced by a stellar fly-by (but see Clarke, Harper-Clark & Lodato 2007). The disc provides the high-density material such that the Jeans mass is necessarily low. Post-formation accretion from the massive disc on to the brown dwarf could increase the mass significantly while forming brown dwarves in single systems is more difficult.

Ejection of newly formed fragments in multiple systems (Reipurth & Clarke 2001; Bate et al. 2002; Bate & Bonnell 2005) can halt any post-formation accretion such that the fragment maintains a low mass. This still requires that the Jeans mass at the point of fragmentation is of the order of a brown-dwarf mass such as occurs in circumstellar discs and infalling filaments. One of the potential difficulties in this mechanism is that the ejection will tend
to truncate discs at radii of the order of 10 au, and likewise disrupt any binaries with separations comparable or larger to this.

One final mechanism is the photoevaporation of collapsing cores (Whitworth & Zinnecker 2004). This mechanism envisions that a collapsing core in the proximity of an O star will be photoeroded before it can fully collapse. The outer layer of the core will be ionized and unbound while adding a pressure term on to the inner collapsing core ensuring that a lower-mass object is formed. The primary difficulty with this mechanism is that it would need to be finely tuned such that the radiation field is strong enough to have an effect but not so strong such that it would completely destroy the core. Furthermore, it requires the presence of an ionizing source of radiation such that it could only explain brown dwarfs in the presence of O stars.

In this paper, we present some recent results on the formation of low-mass stars and brown dwarfs due to the presence of stellar clusters. We show that brown dwarfs form in an analogous manner to low-mass stars, due to the gravitational fragmentation of high-density gas as it infalls into a stellar cluster. The primary differences with our previous work (Bate et al. 2002) are that we stress how the low fragmentation is reached due to gravitational compression, and that subsequent accretion is limited due to the high virial velocities in clusters such that ejections are not needed. Our calculations are presented in Section 2, while the primary results are presented in Section 3. Section 4 dissects the role of the stellar cluster in forming brown dwarfs while Section 5 presents some observational signatures of the process described here.

2 Calculations

The results presented here are based on a large-scale smoothed particle hydrodynamics (SPH) simulation of a cylindrical $10^3 M_\odot$ molecular cloud 10 pc in length and 3 pc in cylindrical diameter.

We have chosen an elongated cloud rather than the more standard spherical cloud as most molecular clouds are non-spherical and commonly elongated (e.g. Orion A). This also allows for the physical properties to be varied along the cloud in a straightforward manner. The cloud has a linear density gradient along its major axis with maximum/minimum values, at each end of the cylinder, 33 per cent high/lower than the average gas density. The gas has internal turbulence following a Larson-type $P(k) \sim k^{-4}$ power law and is normalized such that the total kinetic energy balances the total gravitational energy in the cloud. The density gradient then results in one end of the cloud being over bound (still super virial) while the other end of the cloud is unbound.

The cloud is populated with 15.5 million SPH particles on two levels, providing high resolution in regions of interest. We initially performed a lower resolution run with 5 million SPH particles producing an average mass resolution of 0.15 $M_\odot$. Upon completion of this low-resolution simulation, we used three criteria to identify the regions that required higher resolution. This included the particles that formed sinks, and those that were accreted on to sinks. It also included particles which attained sufficiently high density such that their local Jeans mass was no longer resolved in the low-resolution run. All of these particles were identified and from the initial conditions of the low-resolution run, they were split into nine particles each to create the initial conditions for the high-resolution simulations. This particle splitting was performed on the initial conditions to ensure that the physical quantities of mass, momentum, energy and the energy spectrum were preserved. Note that the particle splitting does not introduce finer structure in the turbulent energy spectrum. This produced a mass resolution for the regions involved in star formation of 0.0167 $M_\odot$, sufficient to resolve the formation of brown dwarfs, equivalent to a total number of $4.5 \times 10^7$ SPH particles. The equation of state (below) was specified in order to ensure that the Jeans mass in the higher resolution run did not descend below this mass resolution.

This simulation was rerun from the beginning to ensure that the particle splitting did not affect the ongoing evolution. Particle splitting results in a marked increase in resolution without unmanageable computational costs (Kitsionas & Whitworth 2002, 2007). Note, however, some of the unsplit particles, which in the low-resolution run neither exceeded their Jeans mass limit nor became involved in the star formation, did get accreted by the additional stars in the high-resolution run. This is to be expected as there are now additional locations of star formation not present in the low-resolution run and these additional sinks will necessarily accrete unsplit particles.

The simulation follows a barotropic equation of state of the form

$$P = k \rho^\gamma$$

where

$$\gamma = 0.75; \quad \rho \leq \rho_1$$
$$\gamma = 1.0; \quad \rho_1 \leq \rho \leq \rho_2$$
$$\gamma = 1.4; \quad \rho_2 \leq \rho \leq \rho_3$$
$$\gamma = 1.0; \quad \rho \geq \rho_3,$$

and $\rho_1 = 5.5 \times 10^{-19}$ g cm$^{-3}$, $\rho_2 = 5.5 \times 10^{-15}$ g cm$^{-3}$ and $\rho_3 = 2 \times 10^{-13}$ g cm$^{-3}$.

The initial cooling part of the equation of state mimics the effects of line cooling and ensures that the Jeans mass at the point of fragmentation is appropriate for characteristic stellar mass (Larson 2005; Jappsen et al. 2005; Bonnell, Clarke & Bate 2006a). The $\gamma = 1.0$ approximates the effect of dust cooling (Larson 2005) while the $\gamma = 1.4$ mimics the effects of when the collapsing core is optically thick to IR radiation, although its location at $\rho = 5.5 \times 10^{-15}$ g cm$^{-3}$, at lower densities than is typical, is in order to ensure that the Jeans mass is always fully resolved and that a single self-gravitating fragment is turned into a sink particle. A higher critical density for this optically thick phase where heating occurs would likely result in an increase in the numbers of brown dwarfs formed. The physical processes described would be unchanged. The final isothermal phase of the equation of state is simply in order to allow sink-particle formation to occur, which requires a subvirial collapsing fragment.

Star formation in the cloud is modelled through the introduction of sink particles (Bate, Bonnell & Price 1995). Sink-particles formation is allowed once the gas density of a collapsing fragment reaches $\rho \geq 6.8 \times 10^{-14}$ g cm$^{-3}$, although the equation of state ensures that this requires $\rho \geq 2 \times 10^{-13}$ g cm$^{-3}$. The neighbouring SPH particles need to be within a radius of $1 \times 10^{-3}$ pc and that fragment must be subvirial and collapsing. Once created, the sinks accrete bound gas within $1 \times 10^{-3}$ pc and all gas that comes within $2 \times 10^{-4}$ pc. The sinks have their mutual gravitational interactions smoothed to $2 \times 10^{-4}$ pc or 40 au. No interactions including binary or disc disruptions can occur within this radius.

3 Brown-Dwarf Formation in Turbulent Molecular Clouds

The simulation was followed for 1.02 free-fall times or $\approx 6.6 \times 10^5$ and $\approx 3.9 \times 10^3$ yr after the first stars formed. During this time, 2542 stars were formed with masses between 0.017 and 30 $M_\odot$. Of these,
Most formation mechanisms for brown dwarfs envision that the physical conditions in the pre-fragmented gas are such that the Jeans mass, the minimum mass to be gravitationally bound, be of the order of a brown-dwarf mass (Elmegreen 2004; Bonnell et al. 2007; Whitworth et al. 2007). Fig. 2 plots the median gas density, and respective Jeans mass, within 0.05 pc (a typical Jeans length) of where the sink particle will form. These values are calculated from the gas distribution just prior (within 2300 yr) to the formation of the sink particle. The gas densities and Jeans masses are plotted against the final masses that these sinks attain by the end of the simulation. We see that the moderate-mass sinks (0.5–2 M⊕) form in low-density gas where the Jeans mass is of the order of 0.1 to almost 1.0 M⊙. In contrast, the lower-mass sinks form from higher density gas and thus from low Jeans masses. Note that there is not a perfect one-to-one correspondence between the Jeans masses and the final masses even for small masses due to the somewhat arbitrariness of evaluating the physical conditions within a fixed radius of 0.05 pc. What is important is that the physical properties in the gas are appropriate to give very low mass fragments such that forming brown dwarfs in these regions is natural. Subsequent accretion can also increase the final masses from the low value generated at the point of the fragmentation. This is more evident for the high-mass sinks where the vast majority of their final masses come from the subsequent competitive accretion (Bonnell et al. 2001; Bonnell, Vine & Bate 2004; Bonnell & Bate 2006).

The first conclusion we can make is that the brown dwarfs form as lower-mass stars do, from the fragmentation of a gas cloud where the thermal Jeans mass is of the order of the mass of the object formed. The next question is what drives the gas to such densities that brown dwarfs can form. One possibility is that turbulent compression leads to the formation of dense cores and thus brown dwarfs (Padoan & Nordlund 2004). The spatial distribution of the brown dwarfs in Fig. 1 argues against this as the brown dwarfs are not located randomly throughout the cloud but are located in the vicinity of stellar clusters. Furthermore, as SPH is Lagrangian, we can trace the particles that form individual sinks backwards in time. We can estimate the fraction of an individual sink’s mass that is brought to the point of formation by the turbulent flows. This shows that the turbulent flows are responsible for transporting only of the order

≈23 per cent have masses below 0.08 M⊙ but only ≈10 per cent (243 objects) have m ≤ 0.08 M⊙ and have stopped accreting. A further 3 per cent are likely to maintain m ≤ 0.08 M⊙ given their final accretion rates and assuming that this accretion is sustained over the next free-fall time. This gives an expected final number of brown dwarfs of 342 or 13 per cent of the stars formed. Fig. 1 shows the spatial distribution of the brown dwarfs at the end of the simulation. They are primarily in or around forming stellar clusters. We will investigate the process by which they form in the following sections.

Figure 1. The final distribution of the gas and stars in the simulation is shown in the 8 by 8 pc image. The stars are indicated by the yellow filled circles while the brown dwarfs are indicated by the filled blue circles with white edges. The brown dwarfs are located primarily in clustered regions as these provide the necessary physical properties to form low-mass objects. The gas column densities are also plotted from 0.01 (black) to 100 (white) g cm⁻².

Figure 2. The gas density (left-hand panel) and Jeans mass (right-hand panel) are plotted against the final stellar masses for the 2542 sinks formed. Both the gas density and Jeans mass are calculated within a radius of 0.05 pc from the incipient sink particle within ≈2300 yr prior to the sink formation. The gas densities are higher, and the Jeans masses lower, for the low-mass sinks formed as is expected when the physical conditions of the gas determine the fragment masses.
of 1 per cent of the fragment’s mass to within 0.04 pc of where the sink eventually forms. Instead, additional acceleration, such as occurs when the gas enters the gravitational potential of the cluster, is necessary. We can therefore conclude that, in this simulation, turbulence does not lead to the formation of brown dwarfs.

4 BROWN-DWARF FORMATION IN STELLAR CLUSTERS

Gravity provides an alternative to turbulence in generating the high gas-density conditions conducive to forming brown dwarfs. Gravity has the distinct advantage over turbulence in that it is intrinsically convergent and therefore better able to compress gas into small volumes. It also has the tendency of compressing a three-dimensional volume into two-dimensional sheets, one-dimensional filaments and eventually to point sources (Larson 1985; Bonnell 1999). The stellar clusters forming in the simulation provide a strong gravitation potential into which flowing gas can be compressed to much higher densities. Fig. 3 shows the stellar-mass density within 0.25 pc, a typical size scale of a stellar cluster, of the forming sink particles just prior to sink formation. We see that while the moderate- and high-mass sinks form in regions where the mass density of stars is low, low-mass stars and brown dwarfs form in regions of high stellar-mass density. This occurs as the moderate- to higher-mass stars form first while the eventual low-mass stars and brown dwarfs only form as gas infalls into pre-existing stellar clusters. It is therefore the presence of the stellar cluster that is driving the formation of these objects. The higher-mass stars form the basis for the forming cluster and thus also end up inside a region of high stellar-mass density.

Fig. 4 shows the spatial distribution of the gas and stars within 0.05 pc of a forming brown dwarf. We see a large filament formed through the amplification of structure in the infalling gas due to the combination of the cluster potential and its self-gravity. Several knots of gas are forming along the filament, some of which go on to form brown dwarves while the others collapse to form low-mass stars. Such an occurrence of a filamentary structure infalling into the cluster is relatively common, although often some degree

![Figure 3](image3.png)

**Figure 3.** The mass density of stars within 0.25 pc of the forming sink particle is plotted as a function of the final mass in the sink particle. The moderate- and high-mass sinks form in regions of low stellar-mass density whereas the low-mass stars and brown dwarves appear to require the presence of a stellar cluster and its strong gravitational potential in order to form. The gravitational potential of the cluster generates the high-gas densities needed for forming low-mass objects. The stellar mass densities are calculated within ~2000 yr prior to the sink formation. Regions completely devoid of stars prior to the sink formation are given a stellar-mass density of 1 M⊙ pc⁻³. Note that although the high-mass stars form in regions of low stellar-mass density, they end up in the centre of the clusters that form subsequently around them.

![Figure 4](image4.png)

**Figure 4.** In the top panel, we show a column density image of a gaseous filament which is forming brown dwarves as it accretes on to a rich cluster. The position (0,0) in the co-ordinates shows the formation site of one of the new brown dwarves. The column density scale runs from 0.5 to 50 g cm⁻². The bottom panel shows a position–velocity diagram for the same region where the x-positions are centred on the same brown dwarf as in the upper panel. The velocities are calculated projected along the vector joining the brown dwarf at position x = 0 to the centre of mass of the cluster, and are again centred on the brown dwarf. Note that the colours in the bottom panel scale from 5 to 500 g cm⁻¹ km⁻¹ s. The diagonal form of the filament in position–velocity diagram reveals that the gas is accelerating into the cluster while being tidally sheared away from the objects that are forming within. Relative to the formation site of the brown dwarf, the vast majority of the filament is moving away: gas at negative positions has negative relative velocities, while gas at positive positions has positive relative velocities. Only in the immediate region surrounding the still-forming brown dwarf can one see a reversal of this velocity signature, which denotes the gas falling on to the new object. This feature can be seen in several other points along the filament, showing the formation sites of other brown dwarves or low-mass stars.
of tangential motion and thus angular momentum results in the filament being wound up around the protocluster as it infalls and forms low-mass objects.

Fig. 4 also plots the associated position–velocity diagram of the infalling filament centred on the position and velocity of one of the forming brown dwarfs. The negative slope shows that the filament is falling into the cluster located at \( \approx -0.035 \) pc and \( \approx +2 \) \( \text{km s}^{-1} \). The gas is accelerated into the cluster such that material at negative (positive) positions relative to the forming brown dwarf has negative (positive) relative velocities, respectively. This divergent flow, as well as the large virial velocity the forming brown dwarf receives due to the cluster potential, restricts any subsequent accretion and thus maintains the low mass of the object. On smaller scales, gravitational collapse reverses this pattern in the position velocity diagram. Material at negative positions has positive relative velocities while material at positive positions has negative relative velocities indicating collapse.

This tidal shearing of the filament acts to limit the mass of the object. Gas that would normally fall into the forming fragment is now pulled away by the large-scale potential. As a result, only the very high gas-density fragments, and hence with low Jeans masses, form in such a shear flow. Fig. 5 plots the Jeans mass of the 2542 sinks at the point of formation as a function of the stellar-mass density within 0.05 pc. We see that the Jeans masses decrease as the cluster stellar-mass density increases indicating the prevalence for forming low-mass objects in dense stellar clusters. Also plotted in Fig. 5 is the Jeans mass if the gas density was equal to the stellar-mass density. This is the tidal limit for forming a fragment and provides an upper limit to the distribution of Jeans masses of the forming fragments. Higher-mass fragments cannot form as their high Jeans masses and low gas densities would result in their being tidally disrupted before they could collapse.

The growth of a stellar cluster acts to continually decrease the Jeans mass and thus the fragmentation mass in the infalling gas. As more stars form or fall into the cluster, the increase in the stellar density increases the tidal shearing and thus necessitates higher gas densities in order for the fragments to be bound. Thus, the fragment mass should decrease with time and with the growth of a cluster. Subsequent accretion on to some of these objects will significantly increase their masses.

5 CLUSTER DYNAMICS AND ACCRETION

In the previous section, we saw that the low-mass sinks form as the gas infalls into an already formed stellar cluster. This has important implications as to why they remain low-mass objects of the typical mass of a brown dwarf rather than accreting from the abundant reservoir of gas in the stellar cluster. Fig. 4 shows the gas being accelerated to high (negative) velocities as it infalls into the cluster’s gravitational potential. Thus, any newly formed fragment will enter the cluster at high velocity and therefore have difficulty in accreting from the reservoir of gas in the cluster. Fig. 6 shows the relative velocity of each forming sink compared to its environment within 0.25 pc. The sinks that remain of low mass have high relative velocity, of the order of several \( \text{km s}^{-1} \) at the point of formation. In contrast, the sinks that ultimately attain moderate and high mass form with low relative velocities. This difference occurs as the low-mass sinks form from gas infalling into an already formed cluster whereas the sinks that attain high mass form before any stellar cluster is present. They are the first stars around which the cluster is built, and due to their low relative velocity they are able to accrete significant amounts of gas and become high-mass objects.

The low-mass sinks cannot accrete significantly due to their high relative velocity and thus remain low-mass objects. Estimated accretion rates for a low-mass star \((m \leq 0.1 \, \text{M}_\odot)\) travelling at a high
velocity \((v \geq 2 \text{ km s}^{-1})\) in a gas reservoir of \(10^{-17} \text{ g cm}^{-3}\) is \(\approx 5 \times 10^{-8} \text{ M}_\odot \text{ yr}^{-1}\), which is too small to significantly alter the star’s final mass over accretion times of \(t_{\text{acc}} \lesssim 10^6 \text{ yr}\) (cf. Bonnell & Bate 2006).

In this scenario, the forming brown dwarfs and low-mass stars do not require any subsequent interactions or ejections to terminate their accretion processes. It is the acceleration due to the cluster potential that ensures that they have low accretion rates and remain low-mass objects. Brown dwarfs and low-mass stars thus form in the same way from low Jeans mass fragments which subsequently accrete little mass. If ejections are not required, then the disc and binary properties of these objects need not be affected and should form a continuous distribution with slightly higher-mass stars.

### 6 OBSERVATIONAL SIGNATURES

The brown dwarfs that form in the scenario described here form in an analogous manner as do very low mass stars (Elmegreen 2004). There is nothing specific to being a brown dwarf that makes their formation distinct from stars. They form from gas that has low Jeans masses due to its compression as it enters a stellar cluster, and subsequent accretion is generally low due to the high infall velocity imparted from the cluster potential. There is no need for close interactions or ejections to ensure their low mass. This implies that the properties of brown dwarfs will generally resemble those of low-mass stars. As such, their circumstellar disc and multiplicity properties should form a continuum with low-mass stars. This process can occur in any strong potential such as that of a small-N cluster where the Jeans mass becomes small and that the virial velocity limits subsequent accretion (Bonnell et al. 1997, 2001; Bate et al. 2002; Bonnell & Bate 2006). Ejections can occur but are not fundamental to the process.

The velocities of the brown dwarfs and other low-mass objects are also similar to those of the other stars as both simply reflect the overall gravitational potential. Although the brown dwarfs form at higher relative velocities than do the higher mass objects, this is simply due to the presence or absence of a well-defined gravitational potential at the point of formation. The velocities of the higher mass objects are initially low as they form before the cluster develops. Their velocities increase over time due to the infall of other stars into the growing cluster. Virial equilibrium ensures that they all have similar velocity dispersions.

One significant observable feature is that the brown dwarfs, and for that matter the very low mass stars, require a gravitational potential to compress the gas to sufficiently high densities to attain low Jeans masses. This means that they form in regions of high stellar densities as shown in Fig. 3. There is some subsequent dynamical evolution, and brown dwarfs, like low-mass stars, are more likely to be ejected in any dynamical event. Nevertheless, the brown dwarfs formed are more commonly found in a clustered environment. Fig. 7 shows the fractional abundance of brown dwarfs as a function of stellar density. The stellar density is calculated from the distance to the 10 nearest neighbours of each sink particle. The abundance of brown dwarfs is plotted for all sinks that have masses in the range a brown dwarf mass and also for those that given their final accretion rates are likely to remain brown dwarfs over the following free-fall time, \(\approx 6.5 \times 10^5 \text{ yr}\). We see that the frequency of brown dwarfs is significantly higher in the clustered than in the non-clustered regions, with a peak abundance of \(\approx 25\) per cent at high stellar densities which decreases to \(\lesssim 10\) per cent in isolated or regions of low stellar densities.

In general, the brown-dwarf mass sinks in the lower density bins are those that have been ejected from their natal clusters. This small number is thus likely to evolve with time from basically zero at the point of formation, and should increase somewhat over our final value as more low-mass cluster members are ejected from the clusters. Nevertheless, we expect that an observable signature of the process described here is that the fractional abundance of brown dwarfs should increase with stellar density, and should be lowest amongst the isolated population of young stars. It is worth noting that the fractional abundance of brown dwarfs actually decreases in the highest stellar density bins as the stars in the cores of the stellar clusters are predominantly higher mass stars due to the ongoing (competitive) accretion there.

### 7 CONCLUSIONS

We have investigated the formation of brown dwarfs in a numerical simulation of a self-gravitating turbulent molecular cloud. We find that the brown dwarfs form, as do low-mass stars, due to the fragmentation of high-density gas that arises as it infalls into the gravitational potential of a stellar cluster. Approximately 23 per cent of the objects formed have final masses in the brown-dwarf mass range, although only \(\approx 10\) per cent have brown-dwarf masses and have stopped mass accretion.

The turbulent velocities present in the cloud do not contribute directly to the formation of the brown-dwarf mass fragments. Instead, these fragments form through the gravitational compression of gas as it infalls into a stellar cluster. This intrinsically three-dimensional compression produces high gas densities and thus low thermal Jeans masses in the range of brown dwarfs and low-mass stars. The tidal shear of the cluster, and the velocity imparted on the fragment from the cluster potential, acts to limit any subsequent mass increase due to accretion. There is no need for any subsequent
ejections to halt the accretion implying that the circumstellar disc and binary properties of brown dwarfs should form a continuum with low-mass stars.

Brown dwarfs formed through this mechanism should be preferentially located in regions of high stellar density. The fractional abundance of brown dwarfs in stellar clusters is of the order of 25 per cent in highly clustered regions whereas it decreases to the order of 10 per cent in isolated regions. This fraction is likely to increase somewhat due to subsequent ejections of brown dwarfs and low-mass stars from the clusters.

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