Star formation through gravitational collapse and competitive accretion

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ABSTRACT

Competitive accretion, a process to explain the origin of the IMF, occurs when stars in a common gravitational potential accrete from a distributed gaseous component. Stars located near the centre of the potential benefit from the gravitational attraction of the full potential and accrete at much higher rates than do isolated stars. We show that concerns recently raised on the efficiency of competitive accretion are incorrect as they use globally averaged properties which are inappropriate for the detailed physics of a forming stellar cluster. A full treatment requires a realistic treatment of the cluster potential, the distribution of turbulent velocities and gas densities. Accreting gas does not travel at the global virial velocity of the system due to the velocity-sizescale relation inherent in turbulent gas and due to the lower velocity dispersion of small-N clusters in which much of the accretion occurs. Accretion occurs due to the effect of the local potential in funneling gas down to the centre. Stars located in the gas-rich centres of such systems initially accrete from low relative velocity gas attaining larger masses before needing to accrete the higher velocity gas. Stars not in the centres of such potentials, or that enter the cluster later when the velocity dispersion is higher, do not accrete significantly and thus retain their low-masses. In competitive accretion, most stars do not continue to accrete significantly such that their masses are set from the fragmentation process. It is the few stars which continue to accrete that become higher-mass stars. Competitive accretion is therefore likely to be responsible for the formation of higher-mass stars and can explain the mass distribution, mass segregation and binary frequency of these stars. Global kinematics of competitive accretion models include large-scale mass infall, with mean inflow velocities of order $\approx 0.5$ km/s at scales of 0.5 pc, but infall signatures are likely to be confused by the large tangential velocities and the velocity dispersion present. Finally, we discuss potential limitations of competitive accretion and conclude that competitive accretion is currently the most likely model for the origin of the high-mass end of the IMF.

Key words: stars: formation – stars: luminosity function, mass function – globular clusters and associations: general.

1 INTRODUCTION

One of the primary goals of a complete theory for star formation is to explain the origin of the distribution of stellar masses, the initial mass function (IMF). There have been many theories for the IMF that have involved a variety of physical processes from fragmentation (Zinnecker 1984; Larson 1985, Elmegreen 1997, Klessen, Burkert & Bate 1998; Klessen 2001; Bate, Bonnell & Bromm 2003; Bonnell, Clarke & Bate 2006), turbulence (Elmegreen 1993; Padoan & Nordlund 2002) accretion (Zinnecker 1982, Larson 1992, Bonnell et al. 1997, 2001b; Klessen & Burkert 2000; Bate & Bonnell 2005), feedback (Silk 1995, Adams & Fatuzzo 1996), magnetic fields (Shu, Li & Allen 2004) and a combination of these (Adams & Fatuzzo 1996). The simplest possible mechanism that can explain the origin of the IMF is one that relies primarily on the physics of gravity, namely fragmentation, accretion and dynamical interactions (Bonnell, Larson & Zinnecker 2006). In this scenario, gravitational fragmentation of molecular clouds sets the mean stellar mass at $\approx 0.5M_\odot$. Lower-mass stars and brown dwarfs arise due to the small Jeans masses produced in collapsing regions (fila-
ments, discs), followed by stellar interactions and potentially ejections to stop any subsequent accretion (Bate, Bonnell & Bromm 2002a; Reipurth & Clarke 2001). Higher-mass stars form due to continued accretion in a clustered environment where the overall system potential funnels gas down to the centre of the potential, to be accreted by the proto-massive stars located there. Not only can this reproduce the stellar IMF, but it also is able to account for the mass segregation of young stellar clusters and the binary properties of low and high-mass stars (Bonnell & Bate 2005; Bonnell & Bromm 2002b).

Turbulent fragmentation has also been suggested as an alternative mechanism whereby the masses of stars are determined by the size and densities of turbulent shocks (Padoan & Nordlund 2002). Lower velocity shocks produce weak but large shocks and hence result in higher mass clumps/stars whereas high-velocity shocks produce strong but narrow shocks and hence lower mass clumps/stars. One difficulty with this model (see also Ballesteros-Paredes et al.2006) is that the massive stars should form well separated and hence in relative isolation, not in the centre of dense stellar clusters. Indeed, in turbulent fragmentation, it is the lower-mass cores that are expected to form in such densely packed regions.

Competitive accretion relies on the inefficiency of fragmentation such that there is a large common reservoir of gas from which the protostars can accrete (e.g. Bonnell et al.2001a). Observations of pre-stellar structures and of young stellar clusters both support this view with the large majority of the total mass being in a distributed gaseous form (Motte et al. 1998; Johnstone et al. 2000, 2004; Lada & Lada 2003; Bastian & Goodwin 2006). The second requirement is that the gas be free to move under the same gravitational acceleration as the stars. If the gas is fixed in place due to magnetic fields then accretion will be limited. When these two requirements are filled, the dynamical timescale for accretion and evolution are similar such that a significant amount of gas can be accreted. Models of the formation of a stellar cluster show that the initial fragmentation produces objects of order the Jeans mass of the cloud, even in the presence of turbulent velocities (Bonnell, Vine & Bate 2004). Accretion of nearby low relative velocity material within their tidal radii increase these masses somewhat and helps produce the shallow IMF for low-mass stars (Bonnell et al.2001b; Klessen & Burkert 2000). The stars then fall together to form small stellar clusters which grow by accreting stars and gas (Bonnell et al.2003, 2004). This produces a strong correlation between the number of stars in the cluster and the mass of the most massive star it contains, as is found in young stellar clusters (Weidner & Kroupa 2006). Stars near the centre of the clusters benefit from the full potential which funnels gas down to them, increasing the local gas density. Once the stars establish a stellar dominated region in the centre of the clusters, they virialise and have higher relative gas velocities such that the Bondi-Hoyle radius, based on local parameters, now determines the accretion rate. Accretion in this regime produces the higher-mass stars (Bonnell et al.2004) as well as the Salpeter-like high-mass IMF (Bonnell et al.2001b; Bonnell et al.2003). Furthermore, the stellar dynamics maintain the accreting massive star in the centre of the system, and hence with a low relative velocity compared to the cluster potential.

Recently, Krumholz, Klein & McKee (2005a) have cast some doubt on this process by claiming that, accretion in such environments cannot significantly increase a star’s mass and therefore does not play a role in establishing the stellar IMF. In part this is correct as with competitive accretion, most stars do not continue to accrete. It is the few that do that are important in terms of forming higher mass stars and the IMF. We have reanalysed our results in view of their work in order to show why accretion does occur to form higher-mass stars in our simulations and to establish if this is a realistic outcome of star formation. The principle difference is that the Krumholz et al. analysis used global parameters for the gas properties which can be significantly different from the local properties of a forming stellar cluster. We find that using global properties significantly underestimates the correct accretion rates for the few stars that achieve higher masses. In §2 we discuss the Krumholz et al. analysis and point out some limitations in their approach. In §3 we reanalyse our numerical simulations. In §4 we discuss observational constraints of the models and in §5 we investigate potential limitations of competitive accretion. Finally, we summarise our current understanding of competitive accretion in §6.

2 ANALYTICAL ESTIMATES OF THE ACCRETION RATES

The Krumholz et al. (2005a) approach considers accretion in a molecular cloud supported against self-gravity by its internal turbulent motions. In order to make the problem analytically tractable, they use globally averaged properties of the gas and relative velocities. In order to do this, they first assume that the gas is not globally self-gravitating. This implies that that the gas mass is then less than the mass in stars, and under such circumstances it is obvious that accretion cannot significantly alter a stars mass. They also neglect the larger scale cluster potential as being anything but a boundary to keep the gas within the system. Together, these assumptions ignore the similar accelerations that both the gas and star undergo in a cluster potential, and which to a large degree determine the relative velocities.

The accretion rates can be estimated from the Bondi-Hoyle formalism where the accretion rate, $\dot{M}$, is given by

$$\dot{M} \approx 4\pi \rho \frac{(GM_\star)^2}{v^3},$$

where $M_\star$ is the stellar mass, $\rho$ the gas density, $G$ the gravitational constant and $v$ the relative velocity of the gas. Using such a formalism thus depends on having accurate values for the gas density, stellar masses and relative velocities. Unfortunately, Krumholz et al. (2005a) use globally averaged estimates for the gas density and the velocity instead of the local variables as used in the Bonnell et al. (2001a, 2004) numerical simulations. This causes the many order of magnitude differences in the calculated accretion rates.

A stellar cluster or other self-gravitating system is not of uniform density but has a significantly increased density near the centre of the gravitational potential. For example, the mass density in the centre of the Orion nebula Clus-
Table 1. Accretion rates for global and local properties

| Property                  | Global  | Local   |
|---------------------------|---------|---------|
| Gas density (g cm⁻³)      | 2 × 10⁻¹⁹ | 10⁻¹⁷   |
| Velocity dispersion (km s⁻¹) | 2     | 0.4    |
| Stellar mass (M☉)         | 0.1    | 0.5    |
| Accretion rate (M☉ yr⁻¹)  | 10⁻⁹   | 10⁻⁴   |

Competitive accretion

ster (ONC) is approximately 50 times the mean mass density of the system (Hillenbrand & Hartmann 1998). Similar central condensations are produced in simulations of turbulent fragmentation and cluster formation (Bonnell et al. 2003). Indeed, in competing models of massive star formation through the pressure-induced compression of turbulent cores, the central mass density is much higher than this (McKee & Tan 2003). Using a global virial velocity for the relative gas velocity is also problematic as it neglects that turbulence has a velocity size-scale relation and thus much local gas travels at significantly lower velocities. Furthermore, if a core is formed through turbulent shocks, then much of the kinetic energy in the surrounding gas will also have been dissipated. The velocities of the forming stars are also not large for the same reason and even once they fall into local potential minima to form small-N clusters, the velocity dispersion is low. A forming cluster into local potential minima to form small-N clusters, the velocity dispersion in these systems is low. A forming cluster will have a velocity dispersion of order 0.4 km/s instead of 2 km/s for the ONC. In terms of 10 stars in a 0.1 pc radius will have a velocity dispersion of 5 km/s, this accretion rate is more than in the simulations where the mean initial masses are M∗ ≈ 0.1M⊙. Thus, in terms of a Bondi-Hoyle accretion yields

\[
\frac{\dot{M}_*}{M_{\text{glob}}^*} = \frac{\rho}{\rho_{\text{glob}}} \left( \frac{M_*}{M_{\text{glob}}^*} \right)^2 \left( \frac{v}{v_{\text{glob}}} \right)^{-3},
\]

which when we incorporate the differences between local and global values gives

\[
\frac{\dot{M}_*}{M_{\text{glob}}^*} = 50 \times 5^2 \times 5^3 \approx 1.5 \times 10^{5}.
\]

This difference of 1 × 10⁵ in the accretion rates is more than sufficient to explain why the Krumholz et al. analytical analysis significantly underestimated the accretion rates from the numerical simulations. Thus, for example, using a relative gas velocity of v = 0.4 km/s, a stellar mass of M∗ = 0.5M⊙ and a gas density of ρ = 10⁻¹⁷ g cm⁻³ (≈ the mass density in the core of the ONC), the accretion rate is then \( \dot{M}_* \approx 10^{-4} \) M⊙ yr⁻¹; whereas with v = 2 km/s, M∗ = 0.1M⊙ and ρ = 2 × 10⁻¹⁹ g cm⁻³, in line with Krumholz et al. (2005a), the estimated accretion rate is then \( \dot{M}_* \approx 10^{-5} \) M⊙ yr⁻¹. These values are summarised in Table 1. Such a large difference in accretion rates for seemingly small changes in the physical parameters highlights the danger of using global properties to predict what is, after all, a very local physical process. It also highlights the power of competitive accretion as small changes in the local properties such as an acceleration from a stellar encounter and even the ejection into a lower gas-density region, can effectively halt the continued accretion.

We can estimate the timescale for accretion to form a massive star by considering that a star forms with masses typical of the local Jeans mass which is near the median stellar mass (M∗ ≈ 0.5M⊙). We further consider that the relative gas velocity is initially low as expressed above (0.4 km/s) and that it follows a turbulent velocity size-scale relation of the form (Larson 1981; Heyer & Brunt 2004)

\[
v \propto R^{1/2}.
\]

Assuming the mass distribution follows that of a centrally condensed ρ ∝ R⁻² sphere such that M ∝ R (see Fig. 4 of Bonnell et al. 2004), provides a relation between the turbulent velocity and the mass of the region considered

\[
v \propto M^{1/2}.
\]

Combining this with equation (1) above gives

\[
\frac{dM_*}{dt} \approx 4\pi \rho \left( \frac{G M_*}{v} \right)^2 (v_i)^3 \left( \frac{M_*}{M_i} \right)^{5/2},
\]

which can be integrated to yield an accretion timescale to form a star of final mass M∗ of

\[
t_M = \frac{2v^3 \left( M_{1/2}^* - M_i^{1/2} \right)}{4\pi \rho M_i^{1/2} G^2}.
\]

For typical values found in the numerical simulations of \( v_i \approx 0.5 \) km/s, \( \rho_{\text{clus}} \approx 10^{-17} \) g cm⁻³ and \( M_i \approx 0.5M_\odot \), this reduces to

\[
t_M \approx 10^{5} \left[ \left( \frac{M_*}{0.5M_\odot} \right)^{1/2} - 1 \right] \text{ years}.
\]

This accretion timescale is plotted as a function of the final stellar mass in Figure 1. Thus to form a 10M⊙ star requires \( \approx 3.3 \times 10^4 \) years while a 50M⊙ star requires \( \approx 9 \times 10^4 \) years. These are certainly reasonable numbers suggesting that competitive accretion can indeed account for the formation of higher mass stars. There is still the issue of radiation
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Figure 2. The 3-D velocity dispersion of the accreted gas is plotted (left) as a function of the cumulative accreted gas mass (in M⊙) for four massive stars. The velocity dispersion is low for low masses due to the nature of turbulence and the low velocity dispersions in small-N clusters where much of the accretion occurs. The velocity dispersion increases with accreted mass due to the velocity-size-scale relation for turbulent clouds. The accretion timescale, \( t_{\text{acc}} \approx \frac{M_*}{\dot{M}_*} \), is plotted as a function of accreted mass (right) showing that accretion occurs on relatively short timescales and thus determines the final masses of high-mass stars.

### 3 NUMERICAL MODELS OF COMPETITIVE ACCRETION

One of the advantages of using the smoothed particle hydrodynamic (SPH) technique to follow star formation is that it is Lagrangian and therefore allows for the direct tracing of the fluid flow. We can thus directly probe the physical conditions of the accretion and assess what is occurring. In this section, we re-analyse the results from our previous simulation of the fragmentation of a turbulent cloud and the formation of a stellar cluster (Bonnell et al. 2003). It is this simulation which showed how massive stars can form through competitive accretion in the centre of the forming clusters (Bonnell et al. 2004).

The SPH technique uses sink-particles (Bate et al. 1995) to follow the formation of stars and any continuing gas accretion onto them by adding the mass (and linear/angular momentum) of accreted particles to that of the sink-particle. It is therefore straightforward to track the evolution of the gas before it was accreted. In this way, we can determine the physical properties of the gas that formed a given star at all stages before it is accreted. For example, the physical distribution of this mass is shown in Bonnell et al. (2004). Here, we analyse the velocity dispersion of the gas in order to determine how the accretion proceeds.

In Figure 2 we plot the 3-D velocity dispersion, at the time the sink-particle forms, of the gas which eventually comprises four massive stars. This shows the velocity dispersion of all the gas which is yet to accrete onto the star at the time the star first forms, and is plotted as a function of the mass in order of its accretion history. This therefore neglects any subsequent decrease in the gas’s kinetic energy due to shocks. We see from figure 2 that the velocity dispersion is flat at \( \approx 0.5 \) km/s for low-masses until \( M_* \approx 0.5 \) M⊙. This is approximately the mean fragment mass (0.5 M⊙) in the turbulent simulation and the velocity dispersion can be understood as being due to the gravitational collapse of the fragment at the size-scale of the fragment of several hundred AU. Accretion and higher-mass star formation accompanies the formation of a stellar cluster (Bonnell et al. 2004), such that the growth from low-masses starts in small-N clusters where the velocity dispersion is intrinsically low. Beyond this mass, the velocity dispersion increases with mass, as one expects for a turbulent medium, until nearly reaching the system velocity dispersion of 2 km/s. The actual increase in the velocity dispersion approximately follows the \( v \propto M^{1/2} \), as discussed above. This is in keeping with a turbulent medium where the gas kinematics have not been overly affected by any dissipation, and further reinforces our choice of the initial velocity dispersion above of 0.5 km/s.

We can use the above velocity dispersion as a function of accreted gas mass to evaluate typical accretion timescales. Figure 2 also shows the accretion timescale for a star to accrete its own mass from

\[
t_{\text{acc}} \approx \frac{M_*}{\dot{M}_*},
\]

where \( \dot{M}_* \) is calculated from equation (1) using the velocity dispersion and accreted mass from the simulations and assuming a gas density of \( 10^{-17} \) g cm\(^{-3}\). At any given
time during the simulation after star formation has commenced, at least $50 - 100 M_{\odot}$ of gas has densities greater than this value. We can see from Figure 2 that the accretion timescale is between $10^4$ to $10^5$ years for masses greater than the initial fragment mass of $\approx 0.5 M_{\odot}$. From equation (8), the estimated timescale for a star to double its mass is $t_{\text{acc}} \approx 1.4 \times 10^4$ years, on par with some of the smaller values for $t_{\text{acc}}$ in Figure 2. These timescale are sufficiently short that there is no difficulty forming higher mass stars from continued accretion in a clustered environment. The simulation formed two $\approx 30 M_{\odot}$ stars and a number of $m > 10 M_{\odot}$ stars in a few $\times 10^5$ years. The accretion rates ($\propto M^2/v^3$) actually increase with stellar mass, even though the gas now comes with larger velocity dispersions. This is due to the $v \propto M^{1/2}$ seen in Figure 2. We can therefore conclude that it is essential to use local quantities to correctly evaluate the accretion rates.

4 INFALL AND LARGE-SCALE KINEMATICS

Krumholz et al.(2005a) have argued that one way that competitive accretion could occur is if the system was significantly subvirial such that the relative gas velocities are then very small, and the whole system is in a state of radial collapse. We have seen above that this is not necessary due to the velocity-sizescale relation observed in turbulent molecular clouds such that smaller scales naturally have lower velocity dispersions. Furthermore, as the initial burst of accretion occurs in small-N clusters where the stellar velocity dispersion is low, accreting stars can grow to higher-masses before needing to accrete higher velocity dispersion gas. Nevertheless, there must be some inflow into the central regions in order for the mass to arrive at where the massive star is forming. This, in fact is not unique to competitive accretion models as any model of massive star formation in the centre of a stellar cluster must at some point have inflow of mass to the cluster centre. In the McKee & Tan (2003) model for example, this inflow is simply presumed to have occurred at an earlier stage.

We have analysed the gas kinematics from a simulation of a forming stellar cluster (Bonell et al.2003). We find, in contradiction to the prediction of Krumholz et al.(2005a), that the system maintains approximate global virial equilibrium (i.e., $\alpha_{\text{vir}} = E_{\text{kin}}/|E_{\text{pot}}| \approx 0.5$). This can be easily understood in the terms of gravitational dynamics where even a cold collisionless system forms a virialised system at half its initial radius. In terms of a forming stellar cluster, as long as the gas is highly structured, and especially as it contains significant initial tangential motions, then it too will maintain a near-virial configuration. The kinetic energy of the system is initially equal to the potential energy. The subsequent decay of kinetic energy in shocks allows the system to become globally bound. Once gravity forms local potential wells into which the stars and gas fall, the gravitational acceleration increases both the radial and the tangential velocities such that the gas has larger, and still highly disordered motions. In order to attain the evolution suggested in Krumholz et al.(2005a), there would have to be no initial tangential motions or no conservation of angular momentum during infall.

In order to quantify the kinematics, we plot in Figure 3 the mean radial and tangential velocities as a function of radius from the accreting massive star. The SPH particles are binned as a function of radial shells and the mean radial and tangential velocities are calculated along with the dispersion in radial velocity. The mean radial velocity is inwards from $\approx 0.6$ pc with a typical value of $0.5 - 1$ km/s. The velocities outside this radius are generally outwards due to the large kinetic energy in the initial conditions. The dispersion in the radial velocity is actually larger ($\pm 1$ km/s) than this inward velocity indicating that the motions are very chaotic. The tangential velocities are also larger than the radial velocity demonstrating that the system is not undergoing a simple collapse process but involves significant chaotic/turbulent motions and is kinematically hot. The system is significantly different from the cold collapse model suggested by Krumholz et al.(2005a).

Observational studies have searched for infall signatures in massive star formation. Recently, Fuller et al. (2005), Motte et al. (2005) and Peretto et al. (2006) have detected of such motions through asymmetric line profiles, and by spatially resolved kinematics, respectively. The estimated infall velocities are of the order 0.1 to 2 km/s, in rough agreement with the mean inward velocities seen in the numerical simulations.

Observed linewidths in regions of massive star formation have been found to be of order a few km/s (e.g. Garay 2005; Beuther et al.2006). This is significantly larger than the values discussed above in terms of the local velocity dispersion of the gas on relatively small scales. The difference can be understood as being due to the large lengthscale of the core probed along the line of sight. Even when small areas of the core are observed, the gas is likely to lie along

![Figure 3.](image-url)
an extended. This effect shown in Figure 4 where we plot the line of sight velocity distribution of the gas mass within a projected areas of radius 0.1 pc centred on the forming massive star. This effective velocity profile for an optically thin tracer has a line width of several km/s in agreement with observations. Thus, although the small-scale velocity dispersion in a 3-D volume can be fairly low, the line of sight velocity dispersion in a 2-D projected area is much larger due to the greater sizescale probed. The existence of multiple distinct clumps can also be seen in the right hand panel where two clumps are now kinematically distinct. Such highly structured profiles which can be observed along some lines of sight are due to the hierarchical fragmentation of the turbulent cloud (Bonnell et al. 2003).

5 POTENTIAL LIMITATIONS OF COMPETITIVE ACCRETION

We have seen above that competitive accretion arises naturally from the fragmentation of a turbulent molecular cloud where there is a common (cluster) potential such that stars near the centre of the potential accrete from high density gas and generally have lower relative velocities. The relative gas velocities are low due to the nature of turbulence and its velocity-sizescale relation with lower velocities on smaller sizescales. In order for competitive accretion not to work as suggested by Krumholz et al. (2005a), requires that the local gas velocities are very high, generally as high as the turbulent velocity on the largest scale of the cloud. Neglecting that this would violate the velocity-sizescale relation \( \nu \propto R^{1/2} \), we discuss here potential mechanisms that could decouple the gas and stellar kinematics.

In order to completely decouple the stellar and gas kinematics requires a driving source for the gas motions. Such a driving source, potentially related to maintaining the turbulent support for many dynamical lifetimes, is often speculated to be the internal feedback from low-mass stars. The problem is that although the energetics from low-mass stellar jets and outflows are sufficient to offset the decay of turbulent energy, it is very unclear if they can input sufficient kinetic energy into the system without completely removing the gas (Arce et al. 2006). Jets are commonly found to escape the bounds of their natal clouds suggesting that the majority of their momenta is deposited at large distances, outside the main star forming region (Stanke et al. 2000; see also Arce et al. 2006; Bally et al. 2006). Even the intrinsically isotropic feedback from high-mass stars escapes in preferential directions due to the non-uniform gas distributions (Dale et al. 2005; Krumholz et al. 2005c). The feedback decreases the accretion rates but does not halt accretion. Indeed, in the toy-model feedback simulation by Li & Nakamura (2005), the energy injection is sufficient to disrupt the core but is quickly damped from the system allowing it to continue its unimpeded collapse.

A further problem is one of balancing the timescales. Energy injection from jets and outflows is relatively quick with typical dynamical times of the flows is generally of order \( 10^3 \) to \( 10^4 \) years (e.g. Reipurth & Bally 2001; Beuther et al. 2002). Giant outflows have longer dynamical timescales but considering outflow velocities of 10 to 100 km/s, the energy injection timescale of an outflow before it leaves a limited size of a forming stellar cluster is at most a few \( 10^4 \) years. This timescale is smaller than the dynamical timescale of the system as a whole (few \( 10^5 \) years). It is difficult to envision how the feedback can be exactly tuned to support the system without disrupting it. If excessive energy is deposited by the feedback, there is no opportunity for the cluster to adapt before the gas is dispersed. Likewise, if insufficient energy is deposited, then the system will continue to form stars. As the timescale for star formation is similar to the dynamical timescale of the cluster, it cannot be halted on the dynamical timescales of the outflows such that feedback is highly likely to overshoot the energy balance and completely unbind the system. Indeed, observations suggest that this is common (Arce et al. 2006) and that there is actually no need for long lifetimes as star formation appears to generally occur on dynamical timescales (Elmegreen 2000).

6 CONCLUSIONS

We have shown that concerns raised about the efficacy of competitive accretion are misplaced due to the misuse of global variables to estimate what is a local physical process. In competitive accretion, it is the few stars located early on in the centre of local stellar systems that become higher-mass stars. Competitive accretion starts with the accretion of low relative velocity gas due to the nature of turbulence and the low velocity dispersion in small-N clusters. Accretion proceeds to higher relative velocity gas once the star has attained sufficient mass to maintain a high accretion rate. Stars that enter a stellar cluster later or that reside far from the centre of the potential do not accrete significantly and hence lose the competition to accrete from the distributed gas. In this way, competitive accretion sets the distribution of stellar masses by determining which stars accrete to attain higher-masses and which do not so that they remain lower-mass stars. Although infall does occur, as it needs to in any model for massive star formation in the centre of a cluster, emission line signatures are likely to be confused due to the large chaotic and tangential motions present. The
forming cluster never approaches the status of a cold, radially collapsing system.

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