DYNAMICAL MODELS OF STAR FORMATION AND THE INITIAL MASS FUNCTION

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Abstract
Numerical simulations highlight that star formation is a dynamical process in which stars interact during their formation. Of particular interest is that accretion in a clustered environment is non-uniform in that stars located in the centre of the potential accrete more and become more massive. This competitive accretion process can explain the initial mass function of stars, including a shallower slope for low-mass stars and a steeper Salpeter-like slope for higher-mass stars. Numerical simulations of the fragmentation and formation of a stellar cluster show that the final stellar masses are due to competitive accretion and that this results in a realistic IMF. Competitive accretion also naturally results in a direct correlation between the richness of a cluster and the mass of the most massive star therein. Shallower IMFs are possible if the Jeans mass is significantly higher than one $M_\odot$.

1. Introduction

Our understanding of the star-formation process has recently undergone a paradigm shift from the older quasi-static models where stars form singly and in isolation (Shu, Adams & Lizano 1987) to one where we recognise that stars form predominantly in groups (Lada & Lada 2003), and that dynamics play an important role in determining the stellar products (Clarke, Bonnell & Hillenbrand 2000, Larson 2003, Maclow & Klessen 2004). The advent of large-scale numerical simulations of star formation now allows us to study not just the dynamics of turbulent molecular clouds (Vázquez-Semadeni et al. 2000) but crucially, the development of self-gravitating cores and subsequent star formation therein (Bate, Bonnell & Bromm 2003, Bonnell, Bate & Vine 2003). Here, I review how dynamical models for star formation lead to an understanding of the origin of the initial mass function (IMF) for stars.
2. Turbulence and the IMF

One possible origin for the IMF is from the direct fragmentation of molecular clouds due to their internal “turbulent” motions (Padoan & Nordlund 2002). These motions are highly supersonic, and thus induce shocks in the clouds. The resulting structure can form the basis for the IMF if we associate a Jeans mass with the gas at a given density (for an isothermal gas): \( M_J \propto \rho^{-1/2} \). The inferred mass function is then of a log-normal variety, mimicking the density distribution. This mechanism is particularly attractive as observations of starless cores in Ophiuchus appear to follow a stellar-like IMF (Motte et al. 1998) although this does not appear to be true in some regions of Orion (Coppin et al. 2000).

One problem with a fragmentation model for the IMF is that the more massive cores must be less dense if they contain just one Jeans mass, and are thus not going to fragment into several smaller pieces. This implies that more massive stars should be well separated at distances greater than the Jeans radius, the minimum radius for an object to be gravitationally bound: \( R_J \propto \rho^{-1/2} \). This would result in an inverse mass segregation where the more massive stars are in low-density regions, in direct opposition to observations (Clarke et al. 2000). Another potential problem with a turbulently driven origin for the IMF is that simulations of such clouds shows that only a small subset of the generated cores are actually bound, and that the masses of these cores are approximately the mean Jeans mass of the cloud (Clark & Bonnell 2005). Furthermore, these bound cores commonly fragment to form multiple systems. There is therefore no one-to-one mapping of the pre-stellar core mass distribution to the stellar IMF.

3. Competitive accretion and the IMF

An alternative explanation is that the IMF originates due to competitive accretion in stellar clusters. Competitive accretion arises as many stars, or other sources of gravity, compete to accrete from the same reservoir of gas. This occurs in any system where both the stars and gas are free to move under their combined gravitational influence. In systems where the communal reservoir contains significant mass, competitive accretion can determine the final distribution of stellar masses.

Competitive accretion takes two forms depending on whether the gas or the stars dominate the local stellar potential (Bonnell et al. 2001a). In gas-dominated potentials, the stars and gas have similar velocities and the accretion rate onto an individual star is limited by its tidal radius relative to the other stars and the cluster as a whole. In such cases, the stars need not be moving, as it is their ability to attract the gas which provides the competition. In contrast, when stars dominate the cluster potential, as inevitably occurs due to the accretion,