Geometrical simulations of cloud fragmentation and possible implications for the IMF

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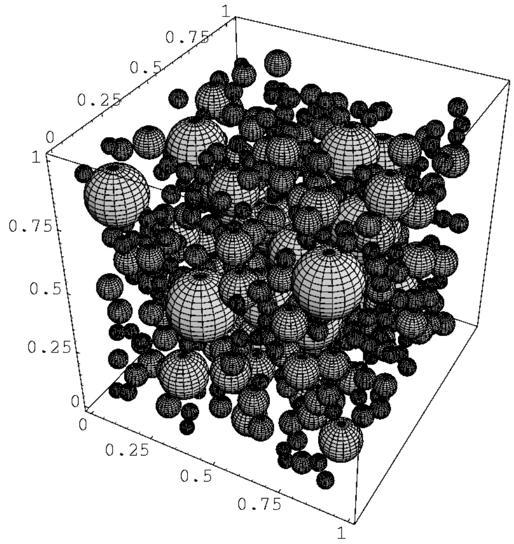
Abstract. We present studies of geometrical models of the fragmentation of molecular clouds. Motivated by the seemingly universal mass spectrum of molecular cloud clumps, $dN/dM \propto M^{-1.6}$, we use the concept of "domain packing" as a method of simulating a stochastic mass fractionation process. Our results show that a power-law mass spectrum, $dN/dM \propto M^{-2}$, develops for an increasing part of the considered mass interval as the filling factor increases, independently of the extent of the considered mass interval. Assuming that molecular clouds are not ideal spheres, but rather filamentary or flattened structures, we have introduced corresponding boundary effects in the model. As expected, saturation effects make the distributions shallower in the high mass region, and thus, closer to observations. In order to approach the steeper *stellar* IMF, subfragmentation of the cloud clumps has been modeled in three different ways. The effects on the input spectra are generally to steepen the IMF in the high mass region and to produce turnovers at a critical low mass.

1. Introduction

Initial mass functions (IMFs) of molecular cloud clumps, density condensations believed to be the progenitors of stars, have been obtained for several giant molecular clouds by independent workers. Blitz (1991) found an average power–law $dN/dM \propto M^{-1.6}$ with an uncertainty of only 10 % over three orders of magnitude in mass. These cloud clump IMFs are considerably shallower than the *stellar* IMFs (between 1 and 10 $M_\odot$) obtained for field stars and stellar clusters. To date, there is no convincing observational evidence against the hypothesis that the IMF is universal.

We present studies of simple, geometrical models of the fragmentation of molecular clouds. The cloud clump IMF is simulated by stochastic "domain packing", and a subsequent fragmentation stage of the clumps, suggested to explain the steeper *stellar* IMF (Zinnecker, 1990), is modeled geometrically by a method we simply call "subfragmentation".

Figure 1. Domain packing model at a volume filling factor of 20 % visualized with Mathematica.



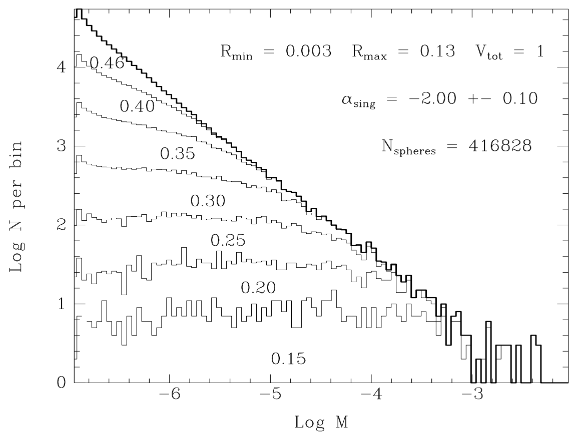
2. Domain packing

The concept of domain packing was introduced into astronomy in an innovative paper by Richtler (1994). We designed an independent program to perform the domain packing process, i.e. placing spheres into a larger master volume, see Figure 1, where sphere sizes and positions are randomly selected, limited within a given size-distribution. The spheres are allowed to touch each other in one point but they cannot intersect. Neither can smaller spheres be packed into larger ones.

Volumes are interpreted as masses on the assumption of constant density, thus, the outcome of domain packing is interpreted as an IMF. A number of models have been tested and an example is shown in Figure 2. Detailed description and discussion is given in Kaas, Östlin & Kristen (1997). Note that the scaling is fully arbitrary, normalized by the master volume. Starting with a radius interval [R_{min},R_{max}] and a constant probability distribution in radii, the IMF is initially described by $dN/dM \sim M^{-2/3}$. Domain packing modifies the IMF, however, as the volume filling factor (f) increases because the space needed for the larger spheres decreases most rapidly, biasing the distribution towards smaller sizes. With increasing f a larger part of the mass interval is influenced by domain packing, and the IMF in this region can be described by a single power–law exponent, α_{sing}. The fact that all models, irrespective of input [R_{min},R_{max}], approach the same exponent $\alpha_{sing} \approx -2$ is remarkable and demonstrates the scale invariance of the process.

Letting the master volume be of disk or filamentary shape introduces boundary effects and makes the high mass region somewhat flatter. Deviations from a *constant* initial probability distribution in radii, do not violate the above result,

Figure 2. IMF from domain packing simulation for one of our models plotted for different values of the volume filling factor (f).



unless the deviations are significant, e.g. a *gaussian* has to be very narrow or peaked at very small radii, otherwise the domain packing process will wipe out any initially preferred scale.

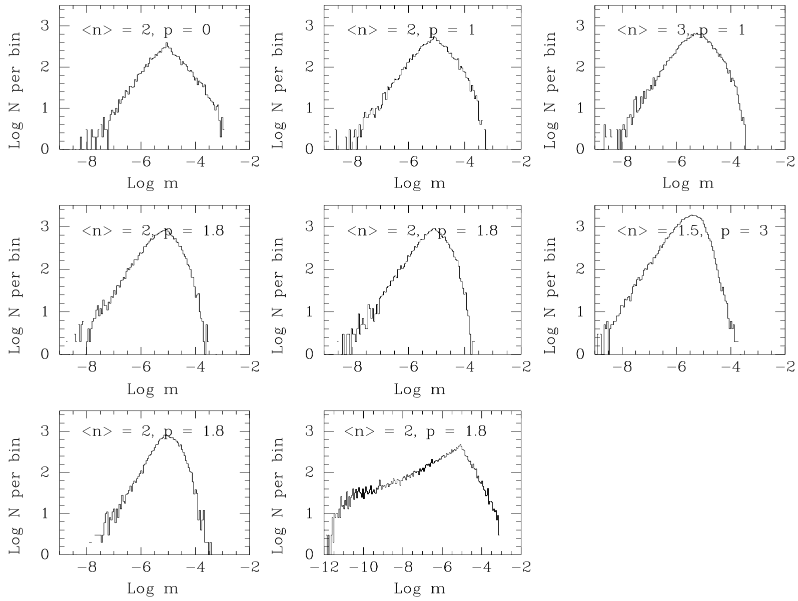
3. Subfragmentation

Larson (1995) studied the statistical distribution of separations in binaries and found a break in the otherwise scale invariant spectrum at a physical separation of 0.04 pc, corresponding to a characteristic mass (m_c) of ~ 0.8 M$_\odot$.

Using as input the clump IMF obtained from a domain packing model at an f where most of the interval can be described by $\alpha_{\rm sing}$, we assume the low mass cutoff to be at $\sim m_c$ and let smaller units form from fragmentation of the larger ones. This is modeled in a simple manner, letting observations of multiple stars constrain $< n >$, the average expected number of fragments per clump, and parametrizing its possible scaling with the clump size by p as $(r/r_0)^p$, where r_0 is a normalization radius. Partition of mass among the fragments is made in 3 different ways: 1) Produce $n-1$ random numbers in the range $[0,m_{\rm clump}]$. Sort them and let the mass of each fragment be determined by the difference between two adjacent numbers. 2) Distribute sizes normally around $m_{\rm clump}/n$ with a given dispersion. 3) The mass of the first fragment (m_1) is found as the smallest piece obtained by cutting the interval $[0,m_{\rm clump}]$ at a random position. The mass of the next is found by cutting $[0,m_{\rm clump}-m_1]$, and so on. Figure 3 shows the outcome for 6 different parameter combinations of model 1, all giving quite similar results. The 2 last IMFs come from model 2 and 3, respectively, and model 3 is shown to produce more low mass objects. The input clump mass spectrum ranged from -5.1 < log m < -2, and the turnover occurs roughly at m_c. The most sensitive parameter is p and a value of 1.8 is consistent with observations.

The general result of all 3 methods is to modify the input IMF by making it steeper at the high mass region, creating a turnover close to the imposed

Figure 3. IMFs from subfragmentation of a clump mass spectrum. See text.



characteristic mass, m_c, and producing relatively few low mass objects. In this model the evolution from clumps to smaller clumps conserves all mass, while a large fraction of the mass is expected to be lost in the subsequent process from dense small cores to stars. This can be adjusted by introducing a star formation efficiency factor. See Östlin, Kristen & Kaas (1997) for a detailed description.

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