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THE DEPENDENCE OF PRESTELLAR CORE MASS DISTRIBUTIONS ON THE STRUCTURE OF THE PARENTAL CLOUD

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ABSTRACT

The mass distribution of prestellar cores is obtained for clouds with arbitrary internal mass distributions using a selection criterion based on the thermal and turbulent Jeans mass and applied hierarchically from small to large scales. We have checked this methodology by comparing our results for a log-normal density probability distribution function with the theoretical core mass function (CMF) derived by Hennebelle & Chabrier, namely a power law at large scales and a log-normal cutoff at low scales, but our method can be applied to any mass distributions representing a star-forming cloud. This methodology enables us to connect the parental cloud structure with the mass distribution of the cores and their spatial distribution, providing an efficient tool for investigating the physical properties of the molecular clouds that give rise to the prestellar core distributions observed. Simulated fractional Brownian motion (fBm) clouds with the Hurst exponent close to the value $H = 1/3$ give the best agreement with the theoretical CMF derived by Hennebelle & Chabrier and Chabrier’s system initial mass function. Likewise, the spatial distribution of the cores derived from our methodology shows a surface density of companions compatible with those observed in Trapezium and Ophiucus star-forming regions. This method also allows us to analyze the properties of the mass distribution of cores for different realizations. We found that the variations in the number of cores formed in different realizations of fBm clouds (with the same Hurst exponent) are much larger than the expected root $N$ statistical fluctuations, increasing with $H$.

Key words: evolution – ISM: structure – stars: formation – stars: luminosity function, mass function

1. INTRODUCTION

Is the stellar initial mass function (IMF) universal? This question has been in the literature for a long time, and is now extended to the core mass function (CMF) since a close relation between the IMF and the CMF has been recognized (Motte et al. 1998; Testi & Sargent 1998; Alves et al. 2007; Chabrier & Hennebelle 2010; Michel et al. 2011). Compared to the CMF, the mass function of stellar systems seems to be shifted to lower masses by a factor that does not depend on the core mass. The currently favored conversion efficiency of the progenitor core mass to the stellar system is $\sim 1/3$. However, the origin of this conversion efficiency is still controversial (Adams & Fatuzzo 1996; Matzner & McKee 2000; Enoch et al. 2008; Dib et al. 2011). Significant variations in the mass function of young clusters are observed in the disk of the Galaxy (e.g., Scalo 1998), but most of these variations are consistent with random sampling from a universal IMF (Elmegreen 1997, 1999; Kroupa 2002; Bastian et al. 2010; Parravano et al. 2011). The non-linear processes involved in the star formation process determine on the one hand the universal form of the IMF and on the other hand the range of expected variations of the mass function around this universal form. These fluctuations arise naturally in IMF models based on deterministic chaos (Sánchez & Parravano 1999) and are also observed in three-dimensional hydrodynamic simulations. Recently Girichidis et al. (2011) performed a parameter study of the fragmentation properties of collapsing isothermal gas cores with different initial conditions and showed that the density profile strongly determines the number of stars formed, the onset of star formation, the stellar mass distribution, and the spatial stellar distribution. Furthermore, the random setup of the turbulent velocity field in hydrodynamic simulation has a major impact in the different morphology of the filamentary structure, and consequently on the number of sink particles as shown by Girichidis et al. (2011, 2012a, 2012b).

The ever increasing resolution of magnetohydrodynamic numerical simulations will provide the answer to many of these questions (Elmegreen 2011). Nevertheless, theoretical IMF models, such as those proposed by Padoan et al. (1997), Padoan & Nordlund (2002) or Hennebelle & Chabrier (2008, 2009), provide analytical solutions that help elucidate the contribution of the various physical processes involved, but to obtain these analytic solutions it is necessary to adopt a series of assumptions that limit their application to specific cases. The predictions of these theories have been compared to the numerical data from simulations. In particular, Padoan & Nordlund (2004) and Padoan et al. (2007) compared the analytical solutions of their theory to numerical simulations. Schmidt et al. (2010) have also compared the results from their simulations to the predictions of these theories and have shown how the clump mass distribution depends on the turbulence driving mechanism. In between these two approaches are the phenomenological models, such as the one presented here, that allow one to address some of the questions stated above, in particular that of sensitivity to the initial conditions. The method consists of a selection criterion based on the thermal and turbulent Jeans mass which is applied hierarchically from small to large scales.

1.1. Aim of the Paper

The methodology proposed in this work enables a direct connection between the structure of molecular clouds and the distributions of generated cores in both mass and space. Thus our first aim is to check that the results obtained using our methodology are consistent with those obtained using other methods proposed in the literature and that have produced...
reliable results. In particular, we will compare our results for a log-normal density probability distribution function (PDF) with the theoretical CMF derived by Hennebelle & Chabrier (2008, hereafter HC08), but using two different spatial distributions of the cloud mass: (1) a random cloud and (2) what we have called a “corner” distribution where the voxel mass decreases with the distance to a preselected corner. This exercise allows us to evaluate the virtue of the method and how the geometry of the cloud defines the dependence of the standard deviation of the log-normal density PDF with the smoothing scale $R$. We have chosen these two very different spatial structures so as to make it clear how the analytic formulation of HC08 and the phenomenology presented here are connected through the scale dependence of the density PDF.

Second, we will explore the formation of cores for different parent clouds, but considering that the geometry that best describes the spatial structure of the clouds is fractal. Observations of close star-forming clouds indicate that the mass distribution in them can be described as having a fractal structure (Falgarone et al. 1992; Sánchez et al. 2005). The analysis will be carried out for fractional Brownian motion (fBm) clouds with a wide range of fractal dimensions. Specifically, we will focus on the comparative analysis of the following properties: (1) empirical dependence of density PDF on the smoothing scale, (2) mass distribution of the cores, (3) spatial distribution of the generated cores as measured by the surface density of companions, and (4) cloud core properties averaged over several realizations for each $H$.

The paper is organized into five sections, this Introduction being the first. Section 2 describes the method and defines the main physical variables of the problem and their range of values in our simulations. In Section 3, we check the virtue of our methodology in reproducing the CMF derived analytically by HC08, and in Section 4, we show the application of this methodology to fractal clouds generated as fBm clouds with different Hurst exponents and compare the results with previous approaches to the same physical systems. Finally, Section 5 is devoted to summarizing the main conclusions.

2. A DISCRETE METHOD FOR A HIERARCHICAL COLLAPSING SEQUENCE (HCS METHOD)

Following the nomenclature in McKee & Tan (2003) we define a star-forming clump as a massive region of molecular gas out of which a star cluster is forming; a core is a region of molecular gas that will form a single star (or a multiple star system such as a binary). The resolution at which a distribution of matter is described can be limited by the procedure used to generate or measure the distribution, the capacity of storage of information, or simply can be chosen to meet a given level of description. In our case, the distribution of matter is given in a three-dimensional lattice cube of length $L$ with $N^3_{\text{vox}}$ identical cubic voxels. The volume associated with each voxel is $l^{3}_{\text{vox}}$, where $l_{\text{vox}} = L/N_{\text{vox}}$. The mass of gas contained in a voxel centered at coordinates $r = l_{\text{vox}} \times [ix, jy, kz]$ is denoted as $m_{i,j,k}$, where $i, j,$ and $k$ run from 1 to $N_{\text{vox}}$.

If we assume that the densest voxel contains a mass $m_{\text{max}}$, and that the physical conditions in that voxel are such that it is gravitationally unstable,\(^5\) (i.e., the Jeans length equals $l_{\text{vox}}$), then the thermal Jeans mass $M_{J,\text{th}} \propto \rho^{-1/2}$ for a larger cube of $d^3$ voxels is

$$M_{J,\text{th}} = \frac{m_{\text{max}}^{3/2}}{\sqrt{m_{\text{cube}}/d^3}}, \quad (1)$$

where $m_{\text{cube}} = \sum_{i,j,k \in V} m_{i,j,k}$ is the mass contained in the volume $V$ whose shape is a cube of side $d \times l_{\text{vox}}$. Note that we are implicitly assuming that the temperature and the molecular weight are the same in the $d^3$ voxels in the cube.

The turbulent Jeans mass can be expressed in terms of the thermal Jeans mass as

$$M_{J,\text{turb}} = M_{J,\text{th}} \left( \frac{V^3}{3^3/3^2} \frac{R}{C_s} \right)^{3\eta} = M_{J,\text{th}} \left( \frac{d}{d_{\text{eq}}} \right)^{3\eta}, \quad (2)$$

where $d_{\text{eq}}$ is the length (in $l_{\text{rms}}$ units) at which the thermal support and the turbulent support are equal, $V_0 \simeq 1$ km s$^{-1}$ is the turbulent rms velocity at 1 pc scale, and $C_s = \sqrt{\gamma R_{\text{th}}/\mu m_{\text{H}_2}} \simeq 0.22(T/10\text{ K})^{1/2}(\mu/2.33)^{-1/2}$ km s$^{-1}$ is the sound speed, where $\gamma_{\text{th}}$ is the adiabatic index and $\mu$ is the molecular weight. The exponent $\eta$ is the exponent of Larson’s (1981) velocity dispersion versus size relation and is related to the three-dimensional power spectrum index of the velocity field $\eta = (n - 3)/2$, where $n = 11/3$ for the Kolmogorov case and 4 for the Burgers case. Kritsuk et al. (2007) estimate $\eta \sim 3.8-3.9$ ($\eta \sim 0.4-0.45$) from high-resolution hydrodynamic simulations of isothermal supersonic turbulence, in agreement with Schmidt et al. (2009) who estimate $\eta \sim 0.45$ from simulations of supersonic isothermal turbulence driven by mostly compressive large-scale forcing. Federrath et al. (2010) showed that $\eta$ depends on the nature of the turbulence forcing mechanism, being 0.43 for solenoidal forcing and 0.47 for compressive forcing.

Myers & Fuller (1992) first included both thermal and non-thermal motions in a model of star formation in dense cores. McKee & Tan (2003) focused on the non-thermal part in their turbulent core model for massive star formation, but then showed how it is possible to smoothly join on to the thermal Jeans mass. Following HC08, who explicitly included both thermal and non-thermal motions, the Jeans mass can be expressed as

$$M_J = M_{J,\text{th}} \left( 1 + \left( \frac{d}{d_{\text{eq}}} \right)^{2\eta} \right)^{3/2}. \quad (3)$$

To apply the Jeans criterion in Equation (3) to any cube in the array it is only necessary to know $m_{i,j,k}$ for all $i, j, k$ in the array and the parameters $m_{\text{max}}$ and $d_{\text{eq}}$. Note that the physical size $l_{\text{vox}}$ of the voxels is not needed to determine whether a given cube is Jeans unstable. However, as shown below, the parameter $d_{\text{eq}}$ depends on the physical conditions that determine $l_{\text{vox}}$ and on the increase of the velocity dispersion with distance.

We propose here a procedure to obtain the prestellar core mass distribution which is based on a hierarchical collapsing sequence (hereafter the HCS method) in which the densest regions collapses first and form the smaller objects. At small scales, thermal support dominates and determines the core mass distribution at low masses, whereas at the largest scales turbulence dominates the support and determines the mass distribution at high masses, as in the analytical theory of the IMF proposed by HC08. The discrete mass distribution $m_{i,j,k}$ is checked at all scales starting with the smallest, that is at the scale of one voxel, i.e., $d = 1$. By construction only the densest

\(^5\) Larson (1981) noted that “if there is a minimum size of bound condensations produced by supersonic compression processes, this may lead to a lower limit of the stellar masses.”
voxel (the one with mass $m_{\text{max}}$) is marginally unstable under the thermal Jeans criterion; however the small turbulent support is enough to suppress the collapse at one voxel scale. Then, cubes of side $d = 2$ are checked to find those that fulfill the condition $m_{\text{cube}} \geq M_f$. In the cubes fulfilling this condition, a core of mass $m_{\text{core}} = M_f$ is assumed to form giving rise to a stellar system of mass $m_* \approx \epsilon m_{\text{core}}$. The remaining gas $m_{\text{cube}} - \epsilon M_f$ is assumed to become inactive. After this, cubes of side $d = 3, 4, \ldots, N_{\text{vox}}/d$ are considered consecutively. Note that the properties of the velocity field are not considered explicitly, but are taken into account implicitly by means of the parameters $d_{\text{eq}}$ and $\eta$.

To fix the voxel length $l_{\text{vox}}$ we use the assumption that the mass $m_{\text{max}}$ contained in the densest voxel is gravitationally marginally stable. The radius of a Bonnor–Ebert sphere is $R_{\text{BE}} \simeq 0.486 R_G$, and the thermal Jeans length is $l_{J,\text{th}} = \sqrt{T R_G}$, where $R_G$, the gravitational length (McKee & Ostriker 2007), is

$$R_G = \frac{\sigma_\text{th}}{(G \rho)^{1/2}} \approx 0.21 \left(\frac{T}{10 \text{ K}}\right)^{1/2} \left(\frac{\mu}{2.33}\right)^{-1/2} \times \left(\frac{n_H}{10^4 \text{ cm}^{-3}}\right)^{-1/2},$$

where and $n_H$ is the hydrogen nucleus number density.

Since the density in the densest voxel is $n_H \simeq 41(m_{\text{max}}/M_\odot)/(l_{\text{vox}}/1 \text{ pc})^3 \text{ cm}^{-3}$, the voxel length is

$$l_{\text{vox}} = l_1 \left(\frac{m_{\text{max}}}{M_\odot}\right) \left(\frac{10 \text{ K}}{T}\right)^{1/2} \left(\frac{\mu}{2.33}\right),$$

where $l_1 = 0.15$ if $l_{\text{vox}}^{3D} = (4/3)\pi R_{\text{BE}}^3$. Note that this value is close to the value $l_1 = 0.18$ obtained if $l_{\text{vox}}^{3D} = (4/3)\pi (l_{J,\text{th}}/4)^3$. We adopt $l_1 = 0.15$ here.6

Finally, the parameter $d_{\text{eq}}$ depends on the turbulent rms velocity which is assumed to increase with the size $R$ of the region following the Larson relation \(V_{\text{rms}}^2 = V_0^2 \times (R/1 \text{ pc})^{3/2}\), where $V_0 \simeq 1 \text{ km s}^{-1}$. The value $R_{\text{eq}}$ at which thermal and turbulent support are equal can be expressed in terms of the sound speed $C_s$ as $R_{\text{eq}}/l_1 \text{ pc} = (\sqrt{3}C_s/V_0)^{1/3}$. Therefore, in terms of the Mach number at 1 pc scale, $M_{1\text{pc}} = V_0/C_s$, the number of voxels $d_{\text{eq}}$ for which thermal and turbulent support are equal is

$$d_{\text{eq}} \equiv R_{\text{eq}}/l_{\text{vox}} = (\sqrt{3}/M_{1\text{pc}})^{3/5} / l_{\text{vox}}(1/1 \text{ pc}).$$

We apply the HCS procedure first to mass distributions with a log-normal density PDF in order to compare our numerical results to the analytical CMFs derived by HC08. Later the procedure is applied to fractal clouds with density PDFs that are not necessarily log-normal.

3. COMPARISON TO THE HC08 ANALYTICAL CMFs THEORY

The analytical theory for the IMF developed in HC08 is based on an extension of the Press & Schechter (1974) statistical formalism applied in cosmology. When applied to the mass function of molecular cloud cores, the original Press–Schechter formalism has the problem that structures inside structures are not counted. This cloud-in-cloud problem was overcome by assuming a conditional probability of finding a collapsed region of mass $M$ inside a collapsed region of mass $M'$ (Inutsuka 2001, and references therein). Additionally, in the Press–Schechter theory the structures are identified with overdensities in a random field of density fluctuations, i.e., a normal distribution in density. Instead, HC08 assume a log-normal distribution in density, as suggested by numerical simulations of non-self-gravitating supersonic isothermal turbulence (Vázquez-Semadeni 1994; Padoan et al. 1997; Passot & Vázquez-Semadeni 1998; Ostriker et al. 2001; Kritsuk et al. 2007) and observations (Kainulainen et al. 2009, 2011). Finally, HC08 assume that at any smoothing scale $R$ the mass distribution in the cloud is such that the density PDF is always log-normal but with a standard deviation $\sigma(R)$ that decreases with $R$ as

$$\sigma^2(R) = \frac{\sigma_0^2}{1 - \left(\frac{R}{L_i}\right)^2},$$

where $L_i$ is the injection scale and $\sigma_0$ is the width of the density distribution at maximum resolution $R \ll L_i$. The density PDF at resolution $R$ is then

$$P_\rho(\rho, R) = \frac{1}{\sqrt{2\pi } \sigma^2(R)} \exp \left\{-\frac{(\rho - \mu_\rho(R))^2}{2\sigma^2(R)}\right\},$$

where $\rho = \ln(\rho/\bar{\rho})$ and $\bar{\rho}$ is the cloud mean density. For this scale-dependent density PDF their theory identifies gravitationally bound prestellar cores with regions that have a density threshold given by the requirement that a fluctuation contains at least one local (thermal or turbulent) Jeans mass. As before, the turbulent rms velocity is assumed to correlate with size $R$ following the Larson power law \(V_{\text{rms}}^2 = V_0^2 \times (R/1 \text{ pc})^{3/2}\). The places where the average density at scale $R$ is larger than the density threshold contain more than one Jeans mass and are expected to form prestellar cores of mass smaller than or equal to the mass contained in that region. This is because at smaller scales it may happen that the region is not uniform but composed of smaller, denser regions embedded into a more diffuse medium. If these denser regions contain one Jeans mass, the end product of the collapse is likely to be a cluster of objects whose mass is close to the mass of the smaller/denser regions and not to the mass in the volume at scale $R$. Taking into account the probability of finding these unstable sub-structures, HC08 express their CMF as

$$\psi_{\text{HC}}(m) \equiv \int \frac{dN}{d \ln m} \propto \frac{1}{N_{\text{tot}}} \frac{\bar{R}}{\bar{R}_{\text{Jeans}}} \left[1 + (1 - \eta)M_*^2 \bar{R}_{\text{Jeans}}^2ight] \times \exp \left\{-\frac{[\ln(m/\bar{R}_{\text{Jeans}})]^2}{2\sigma_0^2} - \frac{\sigma_0^2}{8}\right\},$$

where

$$\bar{m} \equiv \frac{m}{m_j} = \bar{R} \left(1 + M_*^2 \bar{R}_{\text{Jeans}}^2\right),$$

$m_j$ is the Jeans mass at the average cloud density, $\bar{R}$ is the radius of the clump in units of the Jeans length at the average cloud density, $M_*$ is the characteristic Mach number at the Jeans scale, and $\eta (\sim 0.4-0.45)$ is the exponent of the linewidth–size relation. The $\psi_{\text{HC}}(\bar{m})$ mass distribution in Equations (9) and (10) represents the stellar IMF, whereas $\psi_{\text{HC}}(m)$ represents the CMF.
At low masses ($\tilde{m} < 1$), the form of $\psi_{HC}$ is log-normal. At moderately high masses ($m \gtrsim m_T^0$) the IMF approaches the power law

$$\psi_{HC} \propto \tilde{m}^{-(\eta+2)/(2\eta+1)} \equiv \tilde{m}^{-\Gamma_{HC}}(\tilde{m} \gtrsim 1),$$

which gives $\Gamma_{HC} \simeq 1.3$ for the value $\eta \simeq 0.4$ they adopt, in agreement with the Salpeter (1955) value. At very high masses ($\tilde{m} \gg 1$) the IMF drops off more steeply with mass, becoming a log-normal type distribution again. Their results for a non-isothermal equation of state are considerably more complicated, but they are qualitatively consistent with the isothermal theory (Hennebelle & Chabrier 2009).

Note that only the scale-dependent log-normal PDF of the density and the properties of turbulence are considered in the HC08 theory. The detailed spatial distribution of matter is irrelevant, even when, implicitly, their results refer to the kind of gas distributions associated with turbulence. Instead, the HCS method proposed here explicitly takes into account the spatial distribution of the matter and, as shown below, the resulting core mass distribution is sensitive to this distribution.

For the moment we do not consider the radiative feedback (Hollenbach & Tielens 1999; Gorti & Hollenbach 2002; Krumholz et al. 2007, 2011; Bate 2009, 2012; Price & Bate 2009), but it is expected that its efficiency also greatly depends on the spatial distribution of the matter.

### 3.1. Artificial Mass Distributions with Log-normal Density PDFs: “Corner” and “Random” Clouds

To compare with HC08 we first consider two extreme mass distributions that are useful for showing the importance of the spatial structure of the cloud on the resulting mass function of collapsing cores. The first is a “random cloud” in which the masses $m(i, j, k)$ and the positions $(i, j, k)$ are uncorrelated. The second is a “corner cloud” in which the locations of the mass voxels $m(i, j, k)$ are ordered in such a way that the density decreases as the sum $i + j + k$ increases.

Since the lattice is regular and the voxel size $l_{vox}$ is fixed by $m_{max}$, the mass distribution of the voxels (that is the number of voxels with a given mass) is proportional to the density PDF, and therefore the standard deviation $\sigma_0$ is the same for the PDF of the masses $m(i, j, k)$ and for the PDF of the gas density, and has the same meaning as in Equation (9). The PDFs of the masses $m(i, j, k)$ in both types of clouds follow the same log-normal function

$$dN/d\ln m = \frac{N^3_{vox}}{\sigma_0^{3/2}\sqrt{2\pi}} \exp \left[ -\frac{(\ln(m/\tilde{m}) - \sigma_0^2/2)^2}{2\sigma_0^2} \right],$$

where $\tilde{m}$ is the mean mass per voxel and the peak of the distribution occurs at $\ln(m_0) = \ln(\tilde{m}) - \sigma_0^2/2$. However, the dependence of the standard deviation $\sigma(R)$ on the smoothing scale $R$ is, as shown in Figure 1, very different. The smooth gradients in the mass distribution of the “corner cloud” produce a $\sigma(R)$ that is close to the HC08 dependence in Equation (7). In the “random cloud” case, $\sigma(R)$ rapidly drops to zero due to the unphysical discontinuous densities that make the average density in any volume containing a relatively small number of voxels very close to $\tilde{\rho}$.

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**Figure 1.** Dependence of the standard deviation on the smoothing scale for two different mass distributions and the dependence assumed by HC08 in Equation (7) with $L_i = L$ and $\sigma_0$ calculated from Equations (15) and (16). The parameters in the three cases are $N_{vox} = 2^{18}$, $m_{max} = 0.07M_\odot$, $T = 10K$, $\mu = 2.33$, and $\eta = 0.4$, corresponding to the third case in Table 1.

**3.2. Comparison of HC08 and HCS CMFs for Equivalent Clouds**

To compare the CMF corresponding to a particular mass distribution $m_{i,j,k}$ with $\psi_{HC}$ we have to determine the set of HC08 parameters ($N_0$, $m_0^1$, $M_0$) from the HCS input parameters ($N_{vox}$, $m_{max}$, $T$, $\mu$, $\eta$).

The voxel size $l_{vox}(m_{max}, T, \mu)$ is calculated from Equation (5), and the mean cloud density is $\tilde{n}_H = \sum m_{i,j,k} / (m_{H}L^3)$ with $L = N_{vox} \times l_{vox}$.

Following HC08 (see also Hennebelle & Chabrier 2009) the Mach number at the Jeans scale on the cloud mean density $\tilde{n}_H$ is

$$M^2 \simeq (T/10K)^{-1} (\tilde{n}_H/10^4 \text{ cm}^{-3})^{-\eta}$$

and the Jeans mass at the cloud mean density $\tilde{n}_H$ is

$$m^1_0 = m_1(T/10K)^{3/2}(\mu/2.33)^{-3/2}(\tilde{n}_H/10^4 \text{ cm}^{-3})^{-1/2} M_\odot,$$

where the value of $m_1$ depends on the definition of the Jeans mass. HC08 adopt $m_1 \sim 1$, but if $m_0^0$ is assumed to be the mass in a sphere of diameter $l_{th} = \sqrt{\pi}R_G$ then $m_1 \simeq 6.6$. If instead $m_0^0$ is assumed to be the mass in a sphere of diameter $l_{th}/2$ then $m_1 \simeq 0.8$, close to the value adopted in HC08. We assume $m_1 = 1.08$, corresponding to the case in which $m_0^1$ is assumed to be the mass in a Bonnor–Ebert sphere.

The Mach number at the cloud scale $M = (V_0/C_s)(L/1 \text{ pc})^\nu$ is

$$M \simeq (1/0.22)(T/10K)^{-1/2}(\mu/2.33)^{1/2}(L/1 \text{ pc})^\nu,$$

and the width of the density distribution $\sigma_0$ at the cloud scale is

$$\sigma_0^2 = \ln(1 + b^2 M^2),$$

where $b^2 \approx 0.25$ (see also Hennebelle & Chabrier 2009).
requiring that the mass in the densest voxel is $m_{\text{max}}$. The parameter values are those in the second and third lines of Table 1. The continuous gray curve at the left of each panel is a log-normal with the appropriate values $\sigma_0$ and $m_{\text{max}}$. The continuous gray curve at the right of each panel is $\psi_{\text{HC}}(m)$ and the dashed gray curve is the normalized HC08 IMF $\psi_{\text{HC}}(m/m_0^0)$.

Table 1

| \( N_{\text{vox}} \) | \( T \) | \( m_{\text{max}} \) | \( \rho_{\text{eq}} \) | \( M_{\text{cl}} \) | \( L \) | \( \bar{n}_{\text{H}} \) | \( \sigma_0 \) | \( M \) | \( M_\ast \) | \( m_{\text{min}} \) |
|---|---|---|---|---|---|---|---|---|---|---|
| 64 | 10 | 0.109 | 5.67 | 156 | 1.05 | 5616 | 1.42 | 5.09 | 1.12 | 1.44 |
| 128 | 10 | 0.088 | 7.02 | 370 | 1.69 | 3166 | 1.53 | 6.17 | 1.26 | 1.92 |
| 256 | 10 | 0.070 | 8.83 | 862 | 2.69 | 1831 | 1.64 | 7.43 | 1.40 | 2.52 |
| 512 | 8 | 0.042 | 9.81 | 521 | 2.02 | 2622 | 1.64 | 7.40 | 1.40 | 1.51 |
| 1024 | 12 | 0.106 | 8.79 | 1301 | 3.39 | 1375 | 1.64 | 7.44 | 1.41 | 3.83 |

Figure 2. Histograms of the PDF of mass in voxels and the resulting core mass function for the “corner cloud” case for two array sizes, \( N_{\text{vox}} = 128 \) (a) and 256 (b). The parameter values are those in the second and third lines of Table 1. The continuous gray curve at the left of each panel is a log-normal with the appropriate values $\sigma_0$ and $m_{\text{max}}$. The continuous gray curve at the right of each panel is $\psi_{\text{HC}}(m)$ and the dashed gray curve is the normalized HC08 IMF $\psi_{\text{HC}}(m/m_0^0)$.

For a given set of parameters $\sigma_0$ and $m_{\text{max}}$, the masses in the $N_{\text{vox}}$ voxels in the “random” or the “corner” clouds can be assigned following the log-normal distribution in Equation (12), requiring that the mass in the densest voxel is $m_{\text{max}}$. Then the resulting CMF for $m_{i,j,k}$ can be compared to $\psi_{\text{HC}}$. However, what is the appropriate value for $m_{i,j,k}$ to make the comparison? We assume that the appropriate value of $m_{\text{max}}$ is the value for which the mean cloud density $\bar{n}_\text{H}$ is such that the whole cloud is close to virial equilibrium; that is, the virial parameter (Larson 1981; Bertoldi & McKee 1992), defined as $\alpha_{\text{vir}} = 5\sigma_{\text{eq}}^2 R/(GM_\odot) \simeq 5(\Delta v/2)^2(L/2)/(GM_\odot)$, is equal to one. Therefore, $(M_{\text{cl}}/1M_\odot) \simeq 150(L/1\text{pc})^2(\Delta v/1\text{km s}^{-1})^{-2} \simeq (L/1\text{pc})^3$. The cloud mass $M_{\text{cl}} = \sum m_{i,j,k}$ depends on the form of the density PDF, on the number of voxels in the lattice, and on $m_{\text{max}}$. The lattice size $L$ depends on $m_{\text{max}}$ through $L_{\text{vox}}(m_{\text{max}})$ in Equation (5).

Table 1 gives the $m_{\text{max}}$ values that fulfill the above two conditions when the PDF of the mass in voxels is log-normal. Table 1 also gives various derived quantities and the corresponding HC08 parameters. Note that the virial parameter is calculated omitting the effect of the pressure produced by the medium surrounding the cloud. Kaunitz et al. 2011 estimate that the pressures supporting the clumps against dispersal amount in total to about one third of the pressure driving their dispersal. Therefore, cloud masses in Table 1 exceed the Jeans masses in Equation (3) since $M_{\text{J,th}}$ is based on the stability of a Bonnor–Ebert sphere.

For the “corner cloud” and two array sizes, $N_{\text{vox}} = 128$ and 256, Figure 2 shows the histograms of the PDF of voxel masses $m_{i,j,k}$ and the core masses obtained with the HCS method. Figure 2 also shows the analytical PDF and CMF from HC08; the dashed gray curve is $\psi_{\text{HC}}$ from Equation (9) as a function of $\bar{m} = m/m_0^0$, whereas the continuous gray curve is not normalized to $m_0^0$. Agreement with the non-normalized HC08 CMF is good for all cases in Table 1. The rapid falloff of the CMF at low $m$ is due to the fact that by construction we have set the most massive voxel to a mass of about 0.06, and that sets the minimum mass of a core. At high $m$ the rapid falloff is because the highest mass of a core is limited by the mass of the cloud that remains after the formation of the smaller cores. Results very similar to those in Figure 2 are obtained for spherically symmetric distributions in which the densest voxel with mass $m_{\text{max}}$ is located at the center of the array and the mass of the remaining voxels decreases from the center in accord with the log-normal PDF. These results indicate that the HCS numerical method captures the main features of the HC08 analytical theory. However, the HCS method is not restricted to mass distributions with density PDFs following Equations (7) and (8).

HC08 express their stellar IMF in terms of $m_0^0$ which is about $3M_\odot$. For a mean cloud density $\bar{n}_\text{H} \sim 1000\text{ cm}^{-3}$. Instead of normalizing masses to $m_0^0$ we assume that the non-normalized function $\psi_{\text{HC}}(m)$ represents the CMF and that the mass function of stellar systems is shifted to lower masses by a factor $\epsilon$ of about 1/3. The evolution of the CMF to the IMF has not been definitively established but magnetically driven outflows (Matzner & McKee 2000) are expected to produce a mass-independent efficiency factor in the range 30%–50%; we assume a value of $\epsilon \simeq 1/3$. Note that our procedure for obtaining the stellar mass function for a particular gas distribution, as well as the theories of the IMF such as those of Padoan & Nordlund (2002; see also Padoan et al. 2007) and HC08, predict the system IMF, whereas observations that cannot resolve close binaries determine an effective IMF since unresolved binaries are counted as single stars with an effective mass. The determination of the individual star IMF, in which each star that is a member of a multiple system is counted separately (Parravano et al. 2011), is beyond the scope of the present study. The fraction of the cloud mass that eventually becomes collapsing cores ($\sim 0.6$), as well as the number of these cores,
depends weakly on the gas temperature but the mean core mass is proportional to $(T/10\,K)^{-1/7}$.

Contrary to the “corner cloud” or the spherically symmetric distributions, a “random cloud” that has the same density PDF does not produce low-mass collapsing cores, showing that the spatial structure of the cloud is very important not only for the spatial distribution of the protostellar objects, but also for the efficiency and mass function of the star-forming objects. For the PDF of mass in voxels in Figure 2(b), the lowest mass core that collapses in the random cloud is $1.3\,M_\odot \sim 20\,m_{\text{max}}$, whereas for the corner cloud it is $0.12\,M_\odot \sim 2\,m_{\text{max}}$. If the virial parameter of the cloud is increased to $\alpha_{\text{vir}} = 2.5$ (i.e., $M_{\text{vir}} \simeq 1000\,M_\odot$ and $L \simeq 5\,pc$), then the random cloud produces only a couple of high-mass cores ($m \sim 100\,M_\odot$) but the corner cloud still produces a similar number of cores as in the $\alpha_{\text{vir}} = 1$ case.

It is important to point out that these results show that the dependence of the dispersion of the density PDF on the smoothing scale strongly affects the resulting mass distribution of collapsing cores. Federrath et al. (2010) showed that the density PDFs in their simulations are roughly consistent with log-normal distributions for both solenoidal and compressive forcings, even when the distributions clearly exhibit non-Gaussian higher-order moments. However, the dispersion of the density PDF is highly sensitive to the turbulence forcing, and therefore they conclude that the theoretical CMF/IMF derived by Hennebelle & Chabrier (2009) is strongly affected by the assumed turbulence forcing mechanism. In the following we consider fractal mass distributions with roughly log-normal distributions, but with adjustable $\sigma(R)$ functions.

4. FRACTAL CLOUDS

Fractal clouds are known to be a good representation of star-forming regions (Sánchez et al. 2007a, 2007b; Elmegreen 2002, 2010). These kinds of clouds are easy to construct by means of recurrence procedures that produce hierarchical self-similar mass distributions. Fractal distributions are observed over a wide range of scales, from dense cores to giant molecular clouds (Bergin & Tafalla 2007). In particular, numerical simulations of supersonic isothermal turbulence (Kritsuk et al. 2007; Federrath et al. 2009) showed that the density field has an approximately fractal structure.

We focus on fractional Brownian motion clouds (fBm clouds; Stutzki et al. 1998; Elmegreen 2002; Miville-Deschênes et al. 2003; Sánchez et al. 2010) that have been used to represent the internal structure of molecular clouds. The fBm clouds are generated following the procedure described in Miville-Deschênes et al. (2003). That is, a field with Gaussian distribution intensity $\tilde{I}_{i,j,k}$ is obtained by first filling a lattice in wavenumber space $(k_x, k_y, k_z)$ with a random phase and Fourier amplitudes proportional to $|k|^{-(H+1)/2}$, where $|k| = (k_x^2 + k_y^2 + k_z^2)^{1/2}$, $H$ is the drift (or Hurst) exponent, and $E$ is the dimension of the lattice. Subsequently, an inverse fast Fourier transform is applied to generate an intensity distribution $I_{i,j,k}$ in real space with a Gaussian intensity distribution. Since intensities must be real values, the Fourier amplitudes and phases in the wavenumber space have to match the appropriate symmetry conditions (Stutzki et al. 1998). The exponent $H$ corresponds to a power spectrum of the intensity distribution $\gamma = 2H + E$. High-resolution numerical experiments of supersonic isothermal turbulence driven by solenoidal forcing, obtained by Federrath et al. (2009), have been characterized by a Hurst exponent $H = 0.39$, correspond-
Figure 3. Dependence of the standard deviation on the smoothing scale $\sigma^2(R)$ in FBM clouds with three different values of the Hurst parameter $H$. Each curve with error bars corresponds to the average value for ten FBM clouds with the same $H$. The dashed area represents the HC08 values of $\sigma^2$ given by Equation (7) with an injection scale length in the range $L/2 \leq L \leq 2L$. The curve with the label HC08 corresponds to Equation (7) with $L_i = L$ and $\sigma_0$ calculated from Equations (15) and (16). The parameters used are $N_{\star \star} = 2^8$, $m_{\max} = 0.07 M_\odot$, $T = 10$ K, $\mu = 2.33$ and $\eta = 0.4$, which correspond to $L = 2.7$ pc, $M_d = 860 M_\odot$, $\sigma_0 = 1.64$, as in the case of the third line of Table 1.

Figure 4. Mass distribution of the cores formed in a total of 20 different simulations of FBM clouds. The solid (dashed) line histogram corresponds to the mass function of FBM clouds with $H = 1/3$ ($H = 1/6$). The parameter values in all simulations are $N_{\star \star} = 2^8$, $m_{\max} = 0.07 M_\odot$, $T = 10$ K, and $\mu = 2.33$. The contrast factor $\alpha$ in each simulation is adjusted to produce a cloud with a mass of $860 M_\odot$ that corresponds to these parameter values (see the third line in Table 1). As in Figure 2, the sharp rise at core mass of about $0.1 M_\odot$ is due to the adopted $m_{\max}$ value. The continuous curve shows $\psi_{HC}(m)$ for these parameter values.

Table 2

| $H$ | $N_{\text{cores}}$ | $m_{\text{core}}$ | $F_{\text{ms}^{\text{c}}}$ | $F_{\text{H,ms}^{\text{d}}}$ |
|-----|------------------|------------------|------------------|------------------|
| 0   | 28 ± 6           | 16.28 ± 4.90     | 0.49 ± 0.06      | 0.13 ± 0.05      |
| 1/6 | 89 ± 25          | 5.07 ± 1.96      | 0.47 ± 0.06      | 0.022 ± 0.02     |
| 1/5 | 101 ± 29         | 4.47 ± 1.78      | 0.47 ± 0.07      | 0.017 ± 0.013    |
| 1/4 | 132 ± 38         | 3.43 ± 1.43      | 0.47 ± 0.06      | 0.009 ± 0.009    |
| 1/3 | 201 ± 57         | 2.42 ± 0.87      | 0.51 ± 0.06      | 0.005 ± 0.005    |
| 1/2 | 405 ± 110        | 1.31 ± 0.42      | 0.57 ± 0.06      | 0.0006 ± 0.0015  |
| 3/4 | 797 ± 177        | 0.76 ± 0.17      | 0.67 ± 0.05      | 0.0000 ± 0.0000  |

Notes. For each value of $H$, the values quoted correspond to the average over 20 simulations of FBM clouds with different random phase but identical parameter values $N_{\star \star} = 2^8$, $m_{\max} = 0.07 M_\odot$, $T = 10$ K, $\mu = 2.33$, and $\eta = 0.4$, that correspond to $L = 2.7$ pc, $M_d = 860 M_\odot$, $\sigma_0 = 1.64$, as in the third case in Table 1. The errors indicate the standard deviation of the 20 values of each parameter for each value of $H$.

a Number of cores per cloud.
b Average mass of cores in a cloud in solar masses.
c Fraction of the mass of the cloud that collapses in cores.
d Fraction of stars with masses over $8 M_\odot$ estimated with Equation (17).

around $\beta$ and at these densities and sizes only massive cores can form. Note that the curve $\sigma^2(R; H = 1/3)$ intersects the HC08 curve at a larger scale and that is why a FBM cloud with $H = 1/3$ produces in general more low-mass cores than that predicted by the HC08 theory. These results highlight the importance of the spatial distribution of the gas on the resulting mass distribution of collapsing objects.

A complex interplay of physical processes determines the final mass of the stars that form from a particular configuration of cores in a star-forming region. However, the scaling observed between the CMF and the stellar IMF indicates that some average relations between these two distributions can be established. For example, the fraction $F_{\text{ms}^{\text{c}}}$ of individual main-sequence stars that will end as core collapse supernovae or the mean mass $\bar{m}_s$ of stars in the IMF can be estimated in terms of core to stellar system efficiency ($\epsilon \sim 1/3$, Matzner & McKee 2000), and the dependence of the binary fraction on the system mass (Lada 2006).

The stellar mean mass can be approximated as $\bar{m}_s \approx (\epsilon/R_s)m_{\text{core}}$, where $R_s$ is the mean number of stars per system in the IMF. In other words, $R_s$ is defined as the ratio of the total number of stars to the total number of systems (single star systems + multiple star systems). Parravano et al. (2011) estimate that the mean mass of the objects in the individual star IMF is $\bar{m}_s \approx 0.75 M_\odot$, so that, assuming that $R_s \approx 1.3$ (Lada 2006), the corresponding mean core mass is $m_{\text{core}} \approx 3 M_\odot$. Note that this estimate of $m_{\text{core}}$ assumes that the core to star efficiency does not depend on the mass of the core or on the number of stellar objects formed.

The fraction of individual main-sequence stars formed with masses over $m_h \sim 8 M_\odot$ can be estimated as

$$F_{\text{H,ms}} \approx \frac{R_{N,h} N(m_{\text{core}} > R_{\delta h} m_h/\epsilon)}{R_s N(m_{\text{core}} > m_{\text{bd}}/\epsilon)},$$

(17)

where $R_{N,h}$ is the mean number of high-mass stars ($m > m_h$) formed in high-mass cores $(m_{\text{core}} > R_{\delta h} m_h/\epsilon$). The values quoted in Table 2 correspond to $R_s \approx 1.3$ and $R_{N,h} \approx 2$. Note that Equation (17) assumes that the stellar system formed in a core does not disaggregate. Additionally, Equation (17) neglects the high-mass primary stars in systems with companions having masses below $m_h$. However, the error introduced is small because most high-mass stars have a companion of similar mass (Maiz Apellaniz 2008). Equation (17) also neglects very low-mass primaries with brown dwarf companions ($m < m_{\text{bd}} \approx 0.08 M_\odot$). Nonetheless, since the binary fraction of very
low-mass stars is small (∼0.2, Reid et al. 2006; Burgasser et al. 2007), the vast majority of systems with \( m > m_{\text{bd}} \) have main-sequence primaries. Parravano et al. (2011) estimate that the binary separation \( \Delta R \) is less than \( l_{\text{box}} \) with a probability distribution \( p(R) \propto \Delta R^{-1/2} \). The two segment power-law gray lines represent the surface density of companions for the Orion Trapezium and Ophiuchus star formation regions (Simon 1997).

For seven values of the Hurst exponent \( H \), Table 2 summarizes the average properties of the cores formed in sets of 20 simulations of fBm clouds with the same mass \( M_{\text{cl}} \) but a different setup of the random Fourier phases. For the parameter values used for the simulations in Table 2, fBm clouds with \( 1/4 \leq H \leq 1/3 \) produce an average core mass distribution that agrees both with the theoretical HC08 CMF and with the expected values in the range considered in Figure 5.

Note also that as \( H \) increases the number of cores increases and their average mass decreases. Figure 5 shows the dependence of the relative variation of the number of cores \( \Delta N_{\text{cores}} / N_{\text{cores}} \) as a function of \( H \), where \( \Delta N_{\text{cores}} \) is the standard deviation of \( N_{\text{cores}} \) in the 20 simulations. Except for \( H = 0 \) the variations in the number of cores largely exceed the expected \( \sqrt{N} \) statistical variations. The analysis of the dependence of these variations on the physical processes and cloud structure considered is out of the scope of the present study. However, we note here that for a fixed volume of simulation and a constant cloud mass the relative variation \( \Delta N_{\text{cores}} / N_{\text{cores}} \) is about constant for fBm clouds with \( H \) values in the range considered in Figure 5.

### 4.1. Spatial Distribution of Cores

The spatial distribution of the collapsing cores can be characterized by the surface density of companions (SDC) measured on a two-dimensional projection of the positions of the cores by sampling all pair of cores over bins of separation \( \Delta R \). In order to compare with the SDC in young clusters (Simon 1997) we assume that half of the cores fragment to form two stars with three-dimensional separations \( \Delta R \leq l_{\text{box}} \) following a probability distribution \( p(R) \propto \Delta R^{-1/2} \). Figure 6 shows the surface density of companions for a single simulation of an fBm cloud with \( H = 1/3 \) and the same parameter values used in Figure 4 and the case \( H = 1/3 \) in Table 2. The labeled power laws in Figure 6 are the SDCs reported by Simon (1997) for the Orion Trapezium star formation region and for the Ophiuchus star formation region. The SDC for this particular simulation is in between the observed SDCs for these two regions. The fall of the SDC at large radii is due to edge effects when \( \Delta R \) is of the order of size \( L \) of the simulation. For other simulations with the same parameter values the SDCs are similar, but when the parameter \( H \) is increased the SDC curves shift upward.

### 5. CONCLUSIONS

We have proposed a procedure to obtain the prestellar core mass distribution that results from the collapse of prestellar cores in clumps by assuming that the densest regions collapse first and form the smaller objects. At small scales, thermal support dominates and determines the mass distribution of cores at low masses, whereas at the largest scales turbulence dominates the support and determines the mass distribution at high masses. The numerical method proposed here make use of a small number of parameters, namely \( N_{\text{vox}}, T, \mu, \eta, \) together with the cloud properties (i.e., \( M_{\text{cl}} \) and \( H \)) and the assumptions that the mass in the densest voxel \( m_{\text{max}} \) is equal to the Jeans mass and that the cloud as a whole is marginally stable. When the proposed method is applied to a mass distribution whose density PDF is a log-normal at all smoothing scales \( R \) and its standard deviation \( \sigma(R) \) is given by Equation (7), the average mass distribution agrees with the CMF predicted by the analytical theory of the IMF proposed by HC08. The HCS method can be seen as a numerical version of the HC08 theory, and there is univocal correspondence between the parameters in both models.
Both the Padoan–Nordlund IMF and the Hennebelle–Chabrier IMF apply to particular star-forming cloud conditions. In order to determine an average IMF that can be compared with observations of stars from different clouds, it is necessary to average their theoretical IMFs for a distribution of cloud temperatures, densities, and Mach numbers. The core mass distribution from our method is even more dependent on cloud property since, as we have shown, the masses of the resulting cores also depend on the particular distribution of mass within the cloud. Large variations in the resulting core mass distribution are observed in fBm clouds with the same mass $M_0$ and Hurst exponent $H$, but a different setup of the random Fourier phases. As shown in Table 2 and Figure 5, the number of cores in a set of 20 simulations display variations that largely exceed the expected $\sqrt{N}$ statistical variations. Due to its simplicity the HCS method is computationally efficient at obtaining the mass and position of the cores that collapse in an arbitrary distribution of gas. Therefore the HCS method is well suited to analyzing the effects produced by changes in the physics over a large number of initial conditions.

We have applied the HCS method to lattices with a number of cells up to $2^{20}$, which represent clumps of mass $\sim 10^4 M_\odot$ and size $\sim 3$ pc, but larger lattices can be processed. There is no restriction in the way the mass in the voxels is assigned, but we have focused on fBm clouds that have been used as analogs of real interstellar clouds. We confirm that fBm clouds with $H \simeq 1/3$, corresponding to $y = 11/3$ (Elmegreen 2002), give better agreement with the theoretical CMF derived by Hennebelle and Chabrier and the observed IMF. We have also shown that the spatial distribution of the cores for fBm clouds with $H = 1/3$ has a surface density of companions that resembles that of young stellar clusters (Simon 1997). Since the HCS method provides the sequence and location of newly formed stars, the method can be easily modified to consider radiative feedback effects.

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REFERENCES

Adams, F. C., & Fatuzzo, M. 1996, ApJ, 464, 256
Alves, J., Lombardi, M., & Lada, C. J. 2007, A&A, 462, L17
Bastian, N., Covey, K. R., & Meyer, M. R. 2010, ARA&A, 48, 339
Bate, M. R. 2009, MNRAS, 397, 232
Bate, M. R. 2012, MNRAS, 419, 3115
Bergin, E. A., & Tafalla, M. 2007, ARA&A, 45, 339
Bertoldi, F., & McKee, C. F. 1992, ApJ, 395, 140
Burgasser, A. J., Reid, I. N., Siegler, N., et al. 2007, in Protostars and Planets V, ed. B. Reipurth, D. Jewitt, & K. Keil (Tucson, AZ: Univ. Arizona Press), 427
Chabrier, G., & Hennebelle, P. 2010, ApJ, 725, L79
Dib, S., Piau, L., Mohanty, S., & Braine, J. 2011, MNRAS, 415, 3439
Elmegreen, B. G. 1997, ApJ, 486, 944
Elmegreen, B. G. 1999, ApJ, 515, 323
Elmegreen, B. G. 2002, ApJ, 564, 773
Elmegreen, B. G. 2010, IAU Symp. 266, Star Clusters: Basic Galactic Building Blocks Throughout Time and Space, ed. R. de Grijs & J. R. D. Lépine (Cambridge: Cambridge Univ. Press), 3
Elmegreen, B. G. 2011, in IAU Symp. 270, Computational Star Formation, ed. J. Alves, B. Elmegreen, & V. Trimmle (Cambridge: Cambridge Univ. Press), 407
Enoch, M. L., Evans, N. J., II, Sargent, A. I., et al. 2008, ApJ, 684, 1240
Falgarone, E., Puget, J.-L., & Perault, M. 1992, A&A, 257, 715
Federrath, C., Klessen, R. S., & Schmidt, W. 2009, ApJ, 692, 364
Federrath, C., Roman-Duval, J., Klessen, R. S., Schmidt, W., & Mac Low, M. M. 2010, A&A, 512, 81
Girichidis, P., Federrath, C., Allison, R., Banerjee, R., & Klessen, R. S. 2012a, MNRAS, 420, 3264
Girichidis, P., Federrath, C., Banerjee, R., & Klessen, R. S. 2012b, MNRAS, 420, 613
Gorti, U., & Hollenbach, D. J. 2002, ApJ, 573, 215
Hennebelle, P., & Chabrier, G. 2008, ApJ, 684, 395
Hennebelle, P., & Chabrier, G. 2009, ApJ, 702, 1428
Hollenbach, D. J., & Tielens, A. G. G. M. 1999, Rev. Mod. Phys., 71, 173
Inutsuka, S. 2001, ApJ, 559, L149
Kainulainen, J., Beuther, H., Banerjee, R., Federrath, C., & Henning, T. 2011, A&A, 530, 64
Kainulainen, J., Beuther, H., Henning, T., & Plume, R. 2009, A&A, 508, 35
Kauffmann, J., Pillai, T., Shetty, R., Myers, P. C., & Goodman, A. A. 2010, ApJ, 716, 433
Kritsuk, A. G., Norman, M. L., Padoan, P., & Wagner, R. 2007, ApJ, 665, 416
Kroupa, P. 2002, Science, 295, 82
Krumholz, M. R., Klein, R. I., & McKee, C. F. 2007, ApJ, 656, 959
Krumholz, M. R., Klein, R. I., & McKee, C. F. 2011, ApJ, 740, 74
Lada, C. J. 2006, ApJ, 640, L63
Lane, N. S., Alfaro, E. J., & Pérez, E. 2005, ApJ, 625, 849
Maiz Apellániz, J. 2008, ApJ, 677, 1278
Matzner, C. D., & McKee, C. F. 2000, ApJ, 545, 364
McKee, C. F., & Ostriker, E. C. 2007, ApJ, 656, 81
Padoan, P., & Nordlund, Å. 2004, ApJ, 617, 1278
Padoan, P., Nordlund, Å., & Jones, B. J. T. 1997, MNRAS, 288, 145
Padoan, P., Nordlund, Å., & Jones, B. J. T. 1997, MNRAS, 288, 145
Parravano, A., McKee, C. F., & Hollenbach, D. J. 2011, ApJ, 726, 77
Passot, T., & Vázquez-Semadeni, E. 1998, Phys. Rev. E, 58, 4501
Price, D. J., & Bate, M. R. 2009, MNRAS, 398, 33
Reid, I. N., Lewitus, E., Allen, P. R., Cruz, K. L., & Burgasser, A. J. 2006, AJ, 132, 891
Sanchez, A. P., & Bate, M. R. 2000, MNRAS, 317, 903
S´anchez, N., Alfaro, E. J., Elias, F., Delgado, A. J., & Cabrera-Ca˜no, J. 2007a, ApJ, 661, 972
S´anchez, N., Alfaro, E. J., & Looney, L. W. 2007b, ApJ, 665, 222
S´anchez, N., Alfaro, E. J., & Looney, L. W. 2007c, ApJ, 661, 972
S´anchez, N., & Parravano, A. 1999, ApJ, 510, 795
S´anchez, N., & Parravano, A. 2010, ApJ, 726, 27
Scalo, J. M. 1998, in ASP Conf. Ser. 142, The Stellar Initial Mass Function, ed. J. Alves, B. Elmegreen, & V. Trimble (Cambridge: Cambridge Univ. Press), 3
Scalo, J. M. 1998, in ASP Conf. Ser. 142, The Stellar Initial Mass Function, ed. J. Alves, B. Elmegreen, & V. Trimble (Cambridge: Cambridge Univ. Press), 3