CAN HYDROSTATIC CORES FORM WITHIN ISOTHERMAL MOLECULAR CLOUDS?

ENRIQUE VÁZQUEZ-SEMADENI¹, MOHSEN SHADMERHI² AND JAVIER BALLESTEROS-PAREDES¹

¹Instituto de Astronomía, UNAM, Apdo. Postal 72-3 (Xangari), Morelia, Michoacana 58089, México
evazquez, j.ballesteros@astrosmo.unam.mx
²Department of Physics, School of Science, Ferdowsi University, Mashhad, Iran
mshadmehri@science1.um.ac.ir
Submitted to The Astrophysical Journal

ABSTRACT

Under the assumptions that molecular clouds are nearly spatially and temporally isothermal and that the density peaks ("cores") within them are formed by turbulent fluctuations, we argue that cores cannot reach a hydrostatic (or magneto-static) state as a consequence of their formation process. In the non-magnetic case, this is a consequence of the fact that, for cores at the same temperature of the clouds, the necessary Bonnor-Ebert truncation at a finite radius is not feasible, unless it amounts to a shock, which is clearly a dynamical feature, or the core is really embedded in hotter gas. Otherwise, quiescent cores must have non-discontinuous density profiles until they merge with their parent cloud, constituting extended structures. For these, we argue that any equilibrium configuration with non-vanishing central density is unstable. Since the cores’ environment (the molecular cloud) is turbulent, no reason exists for them to settle into an unstable equilibrium. Instead, in this case, cores must be dynamical entities that can either be pushed into collapse, or else "rebound" towards the mean pressure and density as the parent cloud. Nevertheless, rebounding cores are delayed in their re-expansion by their own self-gravity. We give a crude estimate for the re-expansion time as a function of the closeness of the final compression state to the threshold of instability, finding typical values ∼ 1 Myr, i.e., of the order of a few free-fall times. Our results support the notion that not all cores observed in molecular clouds need to be on route to forming stars, but that instead a class of “failed cores” should exist, which must eventually re-expand and disperse, and which can be identified with observed starless cores. In the magnetic case, recent observational and theoretical work suggests that all cores are critical or supercritical, and are thus qualitatively equivalent to the non-magnetic case. This is, however, not a problem for the efficiency of star formation: within the turbulent scenario the low efficiency of star formation does not need to rely on magnetic support of the cores, but instead is a consequence of the low probability of forming collapsing cores in a medium that is globally supported by turbulence. Our results support the notion that the entire star formation process is dynamical, with no intermediate hydrostatic stages.

Subject headings: ISM: structure - stars: formation - hydrodynamics - turbulence

1. INTRODUCTION

One of the most important goals in the study of star formation is to understand the state and physical conditions of the molecular cloud cores from which the stars form. The prevailing view concerning low-mass-star-forming cores is that they are quasi-static equilibrium configurations supported against gravitational collapse by a combination of magnetic, thermal and turbulent pressures (e.g., Mouschovias 1976a,b; Shu, Adams & Lizano 1987). When considering only thermal pressure, two variants of the equilibrium structures are usually discussed: either singular isothermal structures, with diverging central densities and smooth $r^{-2}$ density dependence extending to infinity (e.g., Shu et al. 1987), or finite-central density structures, truncated at some finite radius and confined by the pressure of some external medium, generally assumed to be at higher temperatures and lower densities than the isothermal core (Ebert 1955; Bonnor 1956). More recently, the equilibrium of non-axisymmetric configurations have also been studied (e.g., Fiege & Pudritz 2000; Curry 2000; Galli et al. 2001; Shadmehri & Ghanbari 2001; Lombardi & Bertin 2001; Curry & Stahler 2001).

The support from magnetic fields is generally included through the consideration of the mass-to-magnetic flux ratio of the core, since, assuming that the latter has a fixed mass, the flux freezing condition implies that its mass-to-flux ratio is constant (Chandrasekhar & Fermi 1953; Mestel & Spitzer 1956). Under isothermal conditions, the magnetic pressure and the gravitational energy scale as the same power of the core’s volume; thus, self-gravity cannot overcome the magnetic support if the mass-to-flux ratio is smaller than some critical value, and collapse can only occur as the magnetic flux diffuses out of the cloud by ambipolar diffusion (see, e.g., Mouschovias & Spitzer 1976; Shu, Adams & Lizano 1987).

On the other hand, it is well established that the molecular clouds within which the cores form are turbulent, with linewidths that are supersonic for scales $\gtrsim 0.1$ pc (e.g., Larson 1981), and with (magnetohydrodynamic) turbulent motions providing most of the support against gravity, with only a minor role of thermal pressure at all but the smallest ($\lesssim 0.1$ pc) scales. Thus, there appears to be a conceptual gap between the turbulent nature of the clouds and the quasi-hydrostatic assumed nature of the cores. The cores in molecular clouds must be subject to global motions and distortions, as well as mass exchange with its surroundings (in general, to continuous “morphing”), and, in fact, are likely to be them-
selves the turbulent density fluctuations within the clouds (von Weizsäcker 1951; Bania & Lyon 1980; Scalo 1987; Elmegreen 1993; Ballesteros-Paredes, Vázquez-Semadeni & Scalo 1999, hereafter BVS99; Padoan et al. 2001). At present, one interpretation is that the cores are the dissipative end of the turbulent cascade, because the velocity dispersion within them becomes sonic or subsonic (e.g., Goodman et al. 1998). However, in actuality, substructure is seen down to the smallest resolved scales (e.g., Falgarone, Puget & Pérault 1992), and appears even within what were previously considered to be “smooth” cores, as the resolution is improved (Wilner et al. 2000). Also, inflow motions, themselves with substructure, are generally seen around these cores (e.g. Myers, Evans & Ohashi 2000). Moreover, if the transonic cores are part of a compressible cascade, they do not need to be the dissipative end of it, but may simply mark the transition to a regime of nearly incompressible turbulence (Vázquez-Semadeni, Ballesteros-Paredes & Klessen 2002, 2003).

This issue also poses a problem for the idea of confining clumps by turbulent pressure, since the latter is in general anisotropic and transient at large scales. In this regard, it is worth remarking that a frequent interpretation of the role of turbulent pressure in “confining” cores is that the total thermal-plus-turbulent pressure is larger outside a core than inside it, because the turbulent velocity dispersion increases with size. This is, however, an incorrect interpretation, as the dependence of turbulent pressure with size scale is a non-local property referring to statistical averages over domains of a given size, not to a gradient of the local value of the velocity dispersion as larger distances from the core’s center are considered.

If the density peaks (clumps and cores) within molecular clouds have a dynamic origin, then an immediate question is whether they can ever reach hydrostatic equilibrium. Several pieces of evidence suggest that this is not possible. First, Tohline et al. (1987) considered the potential energy curve of an initially gravitationally-stable fluid parcel in a radiative medium characterized by an effective adiabatic (or “polytropic”) exponent, showing that it has a “thermal energy barrier” that must be overcome, say by an increase in the external turbulent ram pressure, in order to push the parcel into gravitational collapse. In particular, these authors estimated the Mach numbers required for this to occur. Although those authors did not discuss it, the production of a hydrostatic configuration within this framework would require hitting precisely the tip of such “barrier”, the probability of which is vanishingly small, because the tips of potential barriers constitute unstable equilibria.

Second, although Shu (1977) has argued that the singular isothermal sphere is the state asymptotically approached by the flow as it seeks to establish detailed mechanical balance when its parts can communicate subsonically with one another, the maintenance of this configuration for long times seems highly unlikely, as this configuration constitutes an unstable equilibrium, being the precursor of gravitational collapse. If the formation of the core is a dynamical process, no reason exists for the flow to relax onto an unstable equilibrium. Such a state can be used as an initial condition in simulations of gravitational collapse, but does not represent itself a realistic state that can be reached by a gas parcel in a turbulent medium.

Third, Clarke & Pringle (1997) have pointed out that cores cool mainly through optically thick lines, but are heated by cosmic rays, and therefore may be dynamically unstable, as velocity gradients may enhance local cooling.

Fourth, numerical simulations of self-gravitating, turbulent clouds (e.g., Vázquez-Semadeni et al. 1996; Klessen, Heitsch & Mac Low 2000; Heitsch, Mac Low & Klessen 2001; Bate et al. 2002) never show the production of hydrostatic objects. Instead, once a fluid parcel is compressed strongly enough to become gravitationally bound, it proceeds to collapse right away. Specifically, BVS99 suggested that hydrostatic structures cannot be formed by turbulent compressions in polytropic flows, in which the pressure is given by $P \propto \rho^{\gamma}$, where $\rho$ is the mass density and $\gamma$ is the effective polytropic exponent. This is because the collapse of an initially stable gas parcel can only be induced (i.e., the parcel made unstable) by a (strong enough) mechanical compression if $\gamma < \gamma_c$, where the value of $\gamma_c$ depends on the dimensionality of the compression and the specific heat ratio of the gas (see, e.g., Vázquez-Semadeni, Passot & Pouquet 1996). However, once collapse has been initiated, it cannot be halted unless $\gamma$ changes in the process, to become larger than $\gamma_c$ again. In other words, for non-isothermal situations, with $\gamma > \gamma_c$, equilibria can be found even if the external pressure is time variable. This is why stars can be formed as stable entities from highly anisotropic, dynamic, time-dependent accretion (Hartmann, Ballesteros-Paredes & Bergin 2001). For systems that are much closer to isothermal, such as molecular cloud cores, the boundary pressures are indispensable in establishing stable equilibria, which are therefore not expected to exist in an isothermal turbulent medium with a fluctuating ram pressure. In fact, an analysis of the energy contents of the clouds in numerical simulations shows that they are in near energy equipartition but nowhere near virial equilibrium (VE) (see Ballesteros-Paredes & Vázquez-Semadeni 1995; 1997; Shadmehr, Vázquez-Semadeni & Ballesteros-Paredes 2003). This suggests that observations of rough energy equipartition (e.g., Myers & Goodman 1988) does not necessarily imply that clouds are in such detailed mechanical balance.

The only case when numerical studies show the formation of (magnetic)static structures occurs in simulations of super-Jeans, yet subcritical clouds (e.g., Ostriker, Gammie & Stone 1999), in which the whole box is subcritical. However, as we discuss in §3, we believe that this is an artifact of the simulations being performed in closed boxes that do not allow further mass accretion until the system becomes supercritical.

In this paper, we provide further arguments against the possibility of molecular cloud cores being hydrostatic entities, and argue in favor of them being instead transients, although with low (subsonic) internal velocity dispersion. The plan of the paper is as follows: In §2.1 we argue against the possibility of truncated Bonnor-Ebert-type configurations arising in nearly single-temperature molecular clouds, suggesting instead that cores must either be shock-confined or else have smooth(extended) density profiles, and then discuss the stability of extended structures, noting that unstable equilibria are not expected to arise in
turbulent media. In §2.2 we give a crude estimate of the re-expansion time of density peaks (cores) that are not sufficiently compressed to undergo gravitational collapse. In §3 we then discuss the magnetic case, arguing that the subcritical case is also just a transient, on the basis of previous results existing in the literature. Then, in §4 we discuss how the proposed dynamical nature of the cores is not inconsistent with observations, and finally, in §5, we summarize our results and give some conclusions.

2. THE NON-MAGNETIC CASE

2.1. Truncated versus extended configurations

The notion that molecular cloud cores are nearly hydrostatic structures can probably be traced back to the classical work of Ebert (1955) and Bonnor (1956). These authors independently studied the stability against gravitational collapse of truncated isothermal configurations (Bonnor-Ebert, or BE, spheres) bounded by a wall or by a tenuous hot medium capable of maintaining pressure balance at the sphere’s boundary but without contributing appreciably to the self-gravity of the system. The BE analysis shows that such structures are stable for ξ ≤ 6.5, where ξ = r / [2πL1(ρc)] is a nondimensional radial variable, normalized by the Jeans length at the central density ρc. A less remembered fact is that the presence of the wall or hot confining medium is indispensable in order to prevent instability towards reexpansion. Indeed, a simple application of the Virial Theorem to the case of a hydrostatic self-gravitating sphere in the absence of a confining medium shows that this case is always unstable for media obeying a polytropic equation (P ∝ ργ) with γ < 4/3 (which includes the isothermal case, γ = 1). Upon a perturbation in its volume, such a hydrostatic sphere will engage in either runaway expansion or runaway contraction (collapse).

Now, since molecular clouds are quite close to being isothermal (e.g., Myers 1978; Pratap et al. 1997; Scalo et al. 1998), the cores within them are essentially at the same temperature as their “confining” medium. Thus, no thermal discontinuity can occur analogous to that required by the BE configuration. The only possibility for a discontinuity within a single-temperature medium is for there to exist a shock at the boundary, across which both the density and the pressure change discontinuously, with the pressure jump being supplemented by ram pressure. In what follows, we do not discuss this possibility any further, as it already amounts to a dynamic, rather than hydrostatic, situation.

We should note that another possibility exists for the realization of a BE-type configuration, namely that the core is really “trapped” within a hotter region, as is the case of the well known globule Barnard 68 (Alves, Lada & Lada 2001). In this case, the surrounding medium can indeed confine the globule without contributing significantly to the gravitational potential. However, in the general molecular-cloud case of a confining medium at the same temperature as the core, this possibility is excluded. Thus, we conclude that the cores within molecular clouds must either be shock-confined (and thus transient), or have smooth density profiles, extending in principle to infinity, asymptotically approaching a zero background density. We refer to these as “extended” profiles. In practice, molecular cloud cores have densities at least 100 times larger than the average molecular cloud density, so the assumption of vanishing background density appears reasonable.

We now wish to consider the stability of extended density configurations. The best-known of these is the singular isothermal sphere, which has an r−2 density profile, and is known to be gravitationally unstable (see, e.g., Shu 1977). Since we are interested in density fluctuations produced by turbulent compressions, we require them to have a finite central density. These configurations can be obtained by numerically integrating the Lane-Emden equation to arbitrarily large radii. However, this implies that they are equivalent to a BE sphere of arbitrarily large radius, and are thus gravitationally unstable (Bonnor 1956)1 (we thank D. Galli for suggesting this argument). We conclude that all extended hydrostatic configurations in a single-temperature medium are gravitationally unstable.

It is worth comparing this situation with that of the BE configurations, which have a well-defined range of ratios of central-to-boundary densities for which the configuration is stable. This occurs because the confinement of the sphere by a hot tenuous medium circumvents the need to satisfy hydrostatic equilibrium at all distances from the center; i.e., the hydrostatic condition is only imposed out to the “boundary” radius. We see that the existence of a stable range of BE spheres is precisely allowed by the truncation.

In the standard picture of low-mass star formation, some equilibrium state of the kind described above is usually taken as the initial condition for subsequent collapse. However, we see that, since extended configurations are unstable, no reason exists for them to ever be reached if they are originated by dynamic turbulent compressions.2 Moreover, as we have discussed, truncated configurations are inapplicable within single-temperature media. Thus, the above arguments are suggestive that the initial conditions for star formation should be dynamical in general, rather than quasi-static.

2.2. Re-expansion time of “failed” compressions

The arguments above would seem to suggest that all density fluctuations within a turbulent molecular cloud should collapse. However, it is easy to see that this need not be the case, if one is willing to relax the requirement of hydrostatic equilibrium. For example, consider any stable BE sphere, i.e., of radius smaller than the critical one, and surround it with a medium with a steeper density profile than that of equilibrium, say a power law r−n, with n < −2, but maintaining pressure continuity. In this case, the configuration has less than one Jeans mass at every radius,1

1 Again, in practice, a central-to-background density ratio of ~100 is well into the unstable regime for BE-spheres.
2 Note that Hunter (1977) has shown that states unstable under the BE criterion need not readily collapse, but may undergo large-amplitude radial oscillations. However, his initial conditions were very different than those expected from turbulent formation of the cores (our basic working hypothesis here): while he was (again) taking the hydrostatic state as the initial condition and then perturbed it, in a turbulent cloud core formation is expected to occur dynamically, so that the static situation is never realized. Only if the hydrostatic state is a stable equilibrium can it then become an attractor of the dynamical evolution, and cause the static configuration to appear.
and will proceed to re-expansion. Thus, if such a configuration is produced by a turbulent compression, its fate is to re-expand, after the compression subsides.

It is important to note, however, that the re-expansion process must occur on a longer time scale than the compression because of the retarding action of self-gravity. This implies that cores that are compressed to conditions close to those of instability are expected to have somewhat longer lifetimes than those that proceed to collapse, and thus suggests that possibly the majority of the cores observed in molecular clouds are not on their way to collapse, but rather towards re-expansion and merging into their ambient medium. It is thus of interest to estimate their extended lifetimes.

A crude estimate of the re-expansion time can be given in terms of the Virial Theorem (VT), because in this case we are interested in the characteristic growth time of an unstable equilibrium configuration. The VT allows the description of this situation, in particular of the case in which the evolution is towards re-expansion, by consideration of a gas sphere in equilibrium between its self-gravity and internal pressure exclusively. As mentioned above, this configuration is unstable, and can evolve either towards collapse or re-expansion upon a perturbation of the sphere’s volume. Thus, the VT in this case provides a reasonable approximation to the case of an unstable extended sphere’s volume. Thus, the VT in this case provides a reasonable approximation to the case of an unstable extended configuration. We can then proceed as follows. The VT for an isothermal spherical gas mass (“cloud”) of volume $V$ and mean density $\bar{\rho}$ in empty space is

$$\frac{1}{2} I = 3M c^2 - \alpha GM^2 / R,$$

where the overdot indicates time derivatives, $M = \int_V \rho dV$ is the cloud’s mass, $R$ is its radius, $I = \int_V \rho r^2 dV$ is its moment of inertia, $c$ is the sound speed, and $\alpha$ is a factor of order unity. We can obtain an evolution equation for the cloud’s radius by replacing the radius-dependent density by its mean value in the expression for $I$, to find $I \approx MR^2$. Thus,

$$\frac{1}{2} I \approx M \left[ R(t) \dot{R}(t) + \ddot{R}(t) \right].$$

Equating equations (1) and (2), we obtain

$$[R(t) \dot{R}(t) + \ddot{R}(t)] = 3c^2 - \alpha GM / R.$$

This equation can be integrated analytically, with solution

$$\tau = \frac{1}{\sqrt{3}} \left[ \sqrt{(r_2 - 1)^2 - (r_1 - 1)^2} + \ln \left( \frac{r_2 - 1 + \sqrt{(r_2 - 1)^2 - (r_1 - 1)^2}}{r_1 - 1} \right) \right],$$

where $r_1$ and $r_2$ are the initial and final radii of expansion, normalized to the equilibrium radius $R_0 = \alpha GM / 3c^2$, and $\tau = t/t_{ff}$ is the time, non-dimensionalized to the free-fall time $t_{ff} = R_0 / c$. The characteristic re-expansion time can be defined as the time required to double the initial radius (i.e., $r_2 = 2r_1$), starting from an initial condition $r_1 > 1$. Figure 1 shows this characteristic time as a function of $r_1$. We see that when $r_1$ is very close to unity (i.e., linear perturbations from the equilibrium radius), the re-expansion time can be up to a few times the free-fall time. Moderately nonlinear perturbations have the shortest re-expansion times, because the initial force imbalance is greater, yet the final size is still not much larger than twice the equilibrium radius. Finally, for larger initial radii (far from the equilibrium value), the re-expansion time approaches that of free expansion at the sound speed. We conclude that the re-expansion time is at least larger than twice the free-fall time, making the probability of observing a core in this process larger by this factor than that of observing a free-falling core, in agreement with the fact that molecular clouds are generally observed to contain more starless than star-forming cores (e.g., Taylor, Morata & Williams 1996; Lee & Myers 1999; see also Evans 1999 and references therein).

3. THE MAGNETIC CASE

In the magnetic case, the classical Virial-Theorem (VT) analysis (Chandrasekhar & Fermi 1953; Spitzer 1968; Mouschovias 1976a,b; Mouschovias & Spitzer 1976; Zweibel 1990) predicts the existence of sub- and supercritical configurations (Shu et al. 1987; Lizano & Shu 1989) depending on whether the mass-to-magnetic flux ratio is below or above a critical value $(M / \phi_c)$. Subcritical configurations are known not to be able to collapse gravitationally unless the magnetic flux is lost by some process such as ambipolar diffusion. Supercritical configurations, on the other hand, are analogous to the non-magnetic case, except for the fact that the cloud behaves as if having an “effective” mass, reduced by an amount equal to the critical mass (which depends on the magnetic field strength). The VT analysis, however, has the same problem as the BE treatment in that it neglects to satisfy the hydrostatic condition beyond the cloud radius, and so it is not applicable for cores within clouds at their same temperature. We are thus faced again with the need to consider extended configurations.

The equilibria of magnetically supported cores is significantly more complicated than that of non-magnetic ones because of the anisotropy introduced by the field, and the many possible field geometries. Instability analyses of extended magneto-static layers and cylinders with a variety of geometrical field configurations have been performed by many workers (e.g., Chandrasekhar & Fermi 1953; Nakamura, Hanawa & Nakano 1991, 1993; Nakajima & Hanawa 1996; Gehman, Adams & Watkins 1996; Nagai, Inutsuka & Miyama 1998). The layers are in general unstable, although long-lived intermediate filamentary states in route to collapse have been reported (Nakajima & Hanawa 1996). Nevertheless, it is clear that in a turbulent medium, there is no reason for the unstable equilibrium configurations to arise. The structures of greatest interest here may be the intermediate, long-lived structures mentioned above, arising not from the collapse of magneto-static initial states, but of dynamically-produced structures. Moreover, additional considerations suggest that the very concept of subcritical cores may not be realized in practice within molecular clouds if the latter are supercritical as a whole, as it appears to be both from observations (Crutcher 1999; Bourke et al. 2001; Crutcher, Heiles & Troland 2002) and from theoretical considerations (Nakano 1998). Indeed, the VT treatment giving stability below the critical mass-flux ratio assumes a fixed mass for the cloud or core under consideration.
a core that forms part of a larger cloud, has a mass that is not fixed, and continued accretion along magnetic field lines can occur until the core becomes supercritical (Hartmann et al. 2001).

This possibility appears to be supported by recent numerical simulations of MHD turbulent flows (Padoan & Nordlund 1999; Ostriker, Stone & Gammie 2001; Passot & Vázquez-Semadeni 2002), which have shown that the magnetic field is essentially decorrelated from the density. Passot & Vázquez-Semadeni (2002) have explained this phenomenon in terms of the different scalings of the magnetic pressure with density for the different MHD wave modes, and shown that for the slow mode the magnetic pressure can actually be anti-correlated with the density. Additionally, numerical simulations in which the entire computational domain is supercritical systematically show the collapse of the local density peaks (Heitsch, Mac Low & Klessen 2001), while magnetostatic cores are not observed (R. Klessen, 2002, private communication). Only when the entire computational box is artificially constrained to be subcritical by the (usually periodic) boundary conditions (which do not allow further accretion along field lines) the collapse of both the large and the small scales is prevented (e.g., Ostriker et al. 1999), giving rise to flattened structures, and having led some groups to consider two-dimensional models of molecular clouds (e.g., Shu et al. 1999). However, if accretion were allowed from the surrounding medium, a supercritical configuration can eventually be reached, provided the entire cloud is supercritical, in order for there to be enough mass available. These considerations suggest that the subcritical state is in fact a transient stage prior to the formation of supercritical structures that can subsequently collapse.

4. THE DYNAMIC SCENARIO

The suggestion that molecular cloud cores cannot be in hydrostatic equilibrium immediately raises two questions: One, how should we then interpret the low (subsonic) velocity dispersions observed within the cores? Two, if the time scale for external pressure variations were sufficiently large, should we not then expect quasi-hydrostatic cores that are hydrostatic for all practical purposes?

The answer to the first question can be found in the scenario outlined in BVS99 and Vázquez-Semadeni et al. (2002, 2003). This is based on the suggestion that turbulence plays a dual role in structures from giant molecular clouds to cloud clumps (Sasao 1973; Falgarone et al. 1992; Vázquez-Semadeni & Passot 1999; Klessen et al. 2000), in such a way that it contributes to the global support while promoting fragmentation into smaller-scale structures. The process is hierarchical, repeating itself towards smaller scales (Kormreich & Scalo 2000) until the turbulent velocity dispersion within the next level of structures becomes subsonic, as dictated by a turbulent cascade in which smaller have smaller velocity dispersions. At this point, no further sub-fragmentation can occur, because subsonic isothermal turbulence cannot produce large density fluctuations, and moreover it becomes sub-dominant in the support of the structure (Padoan 1995). In this scenario, a core is made by an initially supersonic velocity fluctuation at larger scale, but during the process the compression slows down, because of generation of smaller-scale motions, dissipation, and transfer to internal energy, which is however readily radiated away. Thus, in this scenario, subsonic cores (some of them collapsing, some re-expanding) are a natural outcome and the ending point of the compressible, lossy turbulent cascade. Work is in progress for the formulation of a quantitative model.

Concerning the second question, it is important to remark that, in order to make a significant density fluctuation from a turbulent compression, the latter must have an appreciable (> 1) external Mach number. Therefore, the formation of the cores is expected to occur on short time scales, of the order of the crossing time of the next large scales in the hierarchy (Elmegreen 1993), and the possibility of long time scales for the pressure variations is excluded.

5. CONCLUSIONS

In this paper we have argued that the final state of isothermal fluid parcels compressed into “cores” by turbulent velocity fluctuations cannot remain in equilibrium. In the non-magnetic case, this is due to the isothermality of the flow, which implies that the a continuous pressure profile requires a continuous density profile, except if it is supplemented by ram pressure in a shock. Since shocks are already non-hydrostatic features, thus agreeing with our claim, we focus on continuous-profile (“extended”) structures. For these, we argued that all equilibrium configurations are unstable, contrary to the stability range found for truncated BE-type structures, and thus are not expected to arise in a dynamic, fluctuating medium. Thus, cores must in general collapse or re-expand, but cannot remain in equilibrium, unless they happen to enter (or be “captured” in) a hotter region, as is the case of the much-discussed B68 globule. In the magnetic case, we have recalled several recent results suggesting that all cores are critical or supercritical, thus being qualitatively equivalent to the non-magnetic case regarding their possibility of collapse.

Although our arguments are conceptually very simple, we believe they have been overlooked in the literature because the hydrostatic state is normally considered as an initial condition, accepted without questioning how such state can be arrived at, and because the turbulent pressure is implicitly assumed to be “microscopic” (i.e., of characteristic scales much smaller than the core), neglecting the fact that molecular clouds are globally turbulent and that the bulk of the turbulent energy is at the largest scales, as clearly suggested by the observed velocity dispersion-size scaling relation (Larson 1981), implying that the cores themselves are the turbulent density fluctuations.

Our results have the implication that many observed cores are not on route to forming stars, but instead “fail”, and must re-expand and merge back into the general molecular cloud medium. For these, the re-expansion time is expected to be larger than the compression time due to the retarding action of self-gravity. A simple estimate based on virial balance suggests that the re-expansion time

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3 The “external” qualification means that this is the Mach number of the turbulent compression that makes the core. Inside the core, the velocity dispersion is expected to be reduced by the dissipation that ensues from the shocks produced. This is what is meant by a “lossy” compressible cascade.
is of the order of a few free-fall times. This is consistent with the facts that molecular clouds typically contain more starless than star-forming cores (e.g., Taylor, Morata & Williams 1996; Lee & Myers 1999; see also Evans 1999 and references therein), and that most of the cores do not appear to be gravitationally bound (e.g., Blitz & Williams 1999).

It is worthwhile to note that these time scales are over one order of magnitude shorter than estimates based on ambipolar diffusion (see, e.g., McKee et al. 1993). Indeed, the long ambipolar diffusion time scales were necessary to explain the low efficiency of star formation in the old hydrostatic paradigm, but in the dynamic scenario of star formation, the low efficiency is a natural consequence that only a small fraction of the mass in a molecular cloud is deposited by the turbulence in collapsing cores (Padoan 1995; Vázquez-Semadeni et al. 2002, 2003), and does not need to rely on magnetic support of the cores.

We thus suggest that hydrostatic configurations have no room in the process of star formation in turbulent, isothermal molecular clouds. Theories of core structure and star formation should consider the fact that core formation is a dynamical process. This probably implies that the density profile in cores is a function of time, and therefore not unique. This may be in agreement with the fact that recent surveys find distributions of the scaling exponent, rather than clearly defined unique values (e.g., Shirley et al. 2002). Another implication is that fundamental properties like the star formation efficiency may be statistical consequences of the turbulence in molecular clouds (Elmegreen 1993; Padoan 1995; Vázquez-Semadeni et al. 2002), rather than depending on ambipolar diffusion to break the equilibrium state.

We have benefited from comments and criticisms by Shantanu Basu, Daniele Galli, Susana Lizano and Lee Mundy. We especially thank Lee Hartmann, for valuable suggestions for the contents and presentation. We also thank the anonymous referee for an exceptionally deep report (including plots and calculations!) which showed holes in the arguments presented in the initial version of the paper, prompting us to find a more direct argumentation. We acknowledge partial financial support from CONACYT grants 27752-E to E.V.-S and I 39318-E to J. B.-P., and from Fordwsi University to M.S. This work has made extensive use of NASA’s Astrophysics Abstract Data Service.

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Fig. 1.— Re-expansion time of a core, in units of the free-fall time, defined as the time necessary to double the initial core’s radius, as a function of the initial radius $r_1$, normalized to the equilibrium radius.