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Filament Formation in Molecular Clouds as a Scale-Free Process

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Abstract. We discuss the formation of filaments in molecular clouds (MCs) as the result of large-scale collapse in the clouds. We first give arguments suggesting that self-gravity dominates the nonthermal motions, and then briefly describe the resulting structure, similar to that found in molecular-line and dust observations of the filaments in the clouds. The filaments exhibit a hierarchical structure in both density and velocity, suggesting a scale-free nature, similar to that of the cosmic web, resulting from the domination of self-gravity from the MC down to the core scale.

Keywords. Gravitation, ISM: clouds, ISM: structure

1. Introduction

Recent dust-continuum emission observations of MCs have shown the ubiquitous presence of filamentary structures (see, e.g., the review by André *et al.* 2014), and molecular-line observations have begun to shed light on the filament kinematics, suggesting that material from the filaments' environment flows towards them, while the material *in* the filaments flows towards cores that inhabit the filaments (e.g., Schneider *et al.* 2010; Kirk *et al.* 2013). The formation mechanism for the MC filaments is not generally agreed upon, although Gómez & Vázquez-Semadeni (2014, hereafter GV14) have suggested that the filaments may form as a consequence of global gravitational collapse of the MCs. Specifically, these authors noted that, when a cloud forms by the collision of warm atomic gas streams ("colliding flows"; e.g., Ballesteros-Paredes *et al.* 1999; Hennebelle & Pérault 1999), it undergoes a phase transition that causes its density ρ to increase by a factor $\sim 10^2$ and its temperature T to *decrease* by roughly the same factor, so that its Jeans mass, which is proportional to $\rho^{-1/2}T^{3/2}$, drops by a factor $\sim 10^4$. This implies that the newly formed cloud rapidly accumulates many Jeans masses in times much shorter than its free-fall time (e.g., Vázquez-Semadeni *et al.* 2007, hereafter VS+07; GV14). In this case, the thermal pressure is negligible, and the clouds are essentially free-falling.

2. The structure of the filaments

GV14 performed a colliding-flow simulation, in which the newly-formed cloud becomes turbulent through the action of several instabilities in the shocked layer (e.g., Heitsch *et al.* 2005; Vázquez-Semadeni *et al.* 2006). However, the level of turbulence generated by this process is insufficient to support the cloud once it exceeds its Jeans mass (VS+07), and so it quickly proceeds to global collapse afterwards. Moreover, because the cloud soon acquires many Jeans masses, the collapse proceeds in a nearly pressureless fashion. In this case, it is well known that the collapse magnifies any anisotropies present, because it proceeds first along the shortest dimension of a triaxial object (Lin *et al.* 1965).

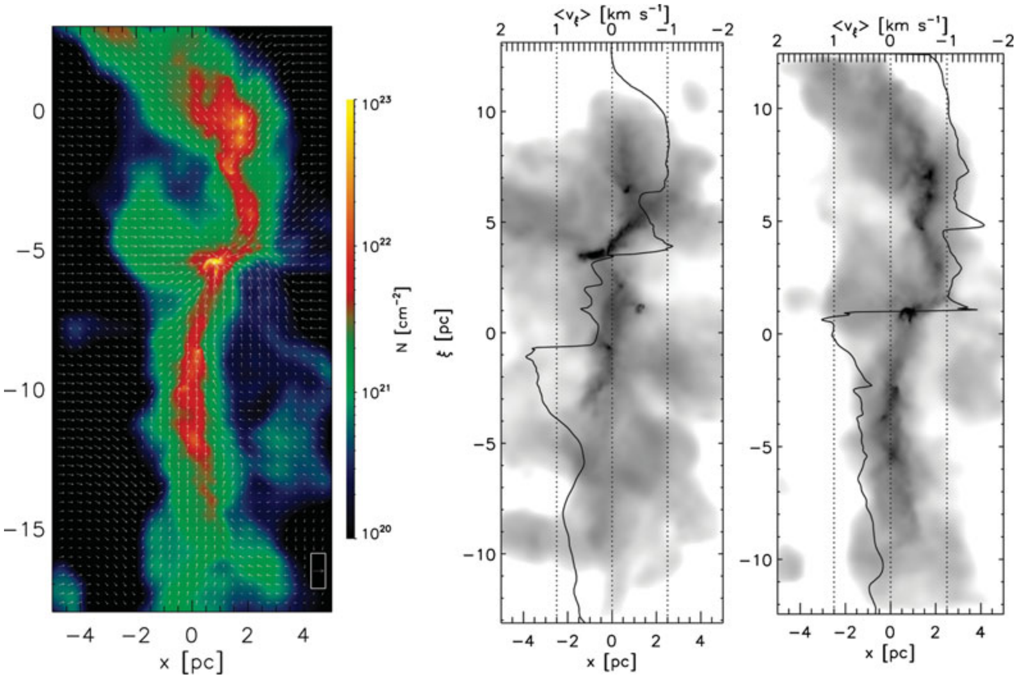

Figure 1. *Left panel:* Column density and velocity field, projected on the (x, y) plane, of one of the filaments formed in the simulation. *Middle and right panels:* Column density and angle-averaged component of the velocity (upper horizontal axis) along a coordinate (ξ) that runs through the central axis of the filament, for two different filaments.

Figure 1 shows, on the left panel, the column density and velocity field, projected on the (x, y) plane, of one of the filaments formed in the simulation. It is clearly seen that the filament is accreting from the surrounding material, and the flow changes direction in the filament, becoming longitudinal, and accreting onto the main clump. The middle and right panels show the column density and the mean longitudinal velocity for two different filaments. This component exhibits jumps at the clumps indicating the accretion onto them. The jumps are seen to be larger the larger the mass of the clump involved, and the accretion onto the secondary clumps along the filament is seen to "ride" on top of the global accretion onto the larger clumps (see, e.g., the minor jumps at $\xi \approx 5$ and ≈ -2.5 pc on the right panel). This hierarchy of clump/jump systems suggests that the process is scale-free.

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