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Growth of Massive Molecular Filament by Accretion Flows: New mechanism to Support a Supercritical Filament against Radial Collapse

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Stars are formed in dense regions in molecular clouds [1] Observations by the *Herschel* space telescope of molecular clouds indicate that dense filaments are the sites for present-day star formation [2]. Additionally, star-forming cores and young stellar objects are embedded along the filaments, which indicates their crucial role in star formation [3]. Therefore, it is crucial to understand filament formation and evolution, as these filaments provide the initial conditions for star formation.

The filament width determines the most unstable scale for self-gravitational fragmentation and influences the stellar mass to be formed. Observations suggest that the width has a universal value of 0.1 pc, regardless of the filament's line mass [4]. However, theoretical predictions suggest that the width of massive filaments (> 17 solar masses / pc) should contract due to self-gravity. Most simulations show a much narrower width due to strong gravity for massive filaments, and why massive filaments maintain their width of 0.1 pc has remained unexplained. Recent studies suggest that massive filaments (~100 solar masses / pc) are bound by "slow (mode) shocks" resulting from accretion flows onto the filaments. The wavefront of the slow mode shock is known to be unstable, and the corrugation of the shock front grows [5]. This corrugation converts the accretion flow's ram pressure into thermal/turbulent pressure across the shock front, possibly maintaining the filament's width. Additionally, turbulence within such filaments plays a crucial role in determining the core's angular momentum, which ultimately influences the size of the forming protoplanetary disk and the rotation of the star.

In this study, we perform magnetohydrodynamics simulations to investigate filament evolution via slow-shock instability (see Figure 1), considering ambipolar diffusion (ion-neutral friction), which is effective in dense filaments. We reveal that ambipolar diffusion allows the gas in the filament to flow across the magnetic fields around the shock front, forming dense blobs behind the concave points of the shock front. We name this blob "hail" because the blobs resemble hails that are ejected like a hailstorm into the filament. The hails transfer momentum that drives internal turbulence (Figure 2). The results that slow-shock instability including ambipolar diffusion drives anisotropic turbulence in the massive filament, named this new mechanism the "STORM (Slow-shock instability driven Turbulent flOw reinforced by Magnetic diffusion)." We also found that the STORM mechanism can sustain a realistic filament width, even for a filament as massive as ~100 solar masses per pc. We propose that the width is maintained by the STORM and may solve the puzzling of 0.1 pc universality.

References

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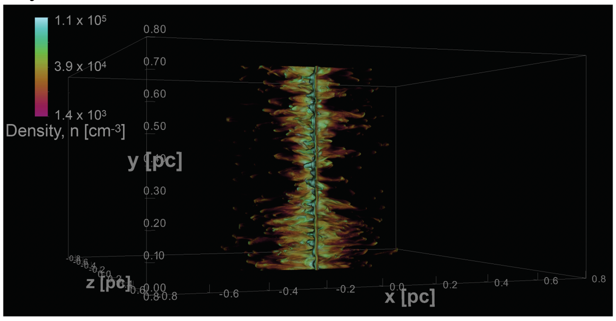

Figure 1. Volume rendering plot of density of the 3D SSI simulation with self-gravity and ambipolar diffusion

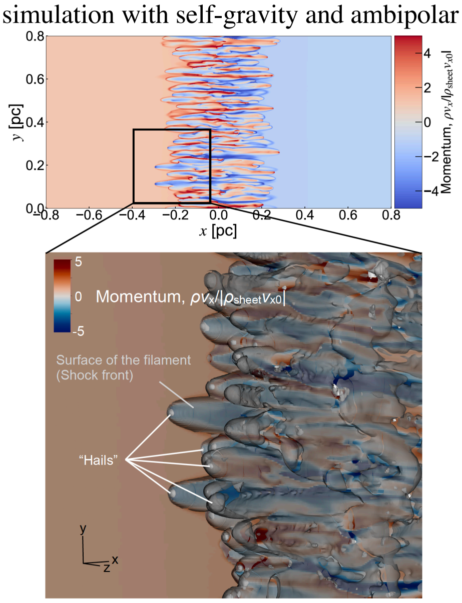

Figure 2. Top: The x-component momentum slice from the simulation. Bottom: A similar slice plot to the top panel, along with contour plots of density at 6.8e3 cm^{-3} (gray, corresponding to the surface of the filament) and 6.8e4 cm^{-3} (white, corresponding to hails).