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Non-thermal states in models of filaments: a dynamical study

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Abstract. We study the origin of the non-thermal profiles observed in filamentary structures in Galactic molecular clouds by means of numerical dynamical simulations. We find that such profiles are intrinsic features of the end products of dissipationless collapse in cylindrical symmetry. Moreover, for sufficiently cold initial conditions, we obtain end states characterized by markedly anticorrelated radial density and temperature profiles. Gravitational, dissipationless dynamics alone is thus sufficient to reproduce, at least qualitatively, many of the properties of the observed non-thermal structures.

1. Introduction

Filaments in Galactic molecular clouds are (at least in their initial stages) mainly gravitationally supported structures, that also harbor star-forming cores (see e.g. Federrath et al. 2016). Remarkably, observations suggest that filaments are in non-thermal states Arzoumanian et al. 2011; a good description seems to be given by polytropic equations of state $\rho \propto T^n$ or $P \propto \rho^\gamma$ (Toci & Galli 2014a,b). In general it is believed that this is due to the interplay between local turbulence, stellar feedback, radiation transport, and magnetic fields.

As a very simple model of a filament we have considered an infinite self-gravitating cylinder, whose dynamics is thus mapped onto that of a two-dimensional system of self-gravitating particles with logarithmic interactions (Di Cintio, Gupta & Casetti 2017), neglecting all contributions arising from magnetic fields and radiation. We have performed numerical simulations of the dynamics by means of direct N-body integration as well as of 2D particle-in-cell (PIC), also including multiparticle collisions (MPC) (see Di Cintio et al. 2015, 2017). We follow the collapse of a cold and gravitationally unstable (i.e., with initial virial ratio $2K/|W| < 1$) cylindrically symmetric overdensity with Gaussian radial density profile. After a violent contraction phase, the system relaxes to a structure with radial density profile fitted (see Fig. 1) by $\rho(r) = \rho_c r_c^\alpha (r_c^2 + r^2)^{-\alpha/2}$, where ρ_c and r_c are the core density and core radius, respectively. The latter nicely approximates the density profile of a polytropic filament. For sufficiently low initial kinetic temperatures (cor-

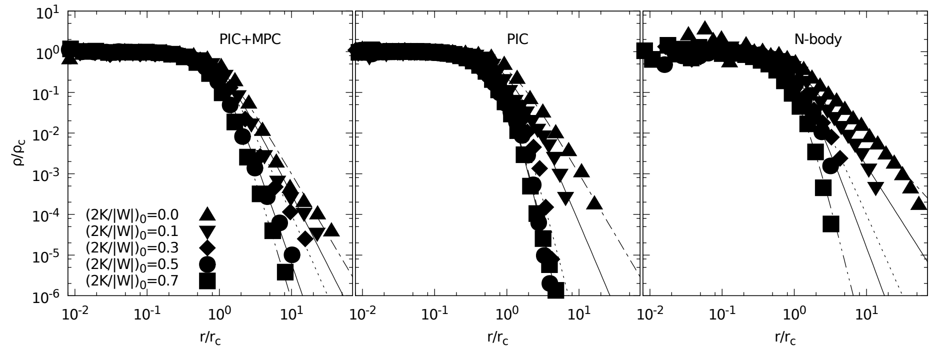

Fig. 1. Radial density profile of the end states of collapsing Gaussian overdensities with different values of the initial virial ratio (points) and best fit curves (lines) for (from left to right) PIC+MPC, PIC and $N-$body simulation protocols.

responding to $2K/|W| \leqslant 0.1$), we find values of α of the order of 2 (Di Cintio, Gupta & Casetti 2017), rather close to the observed systems (see Arzoumanian et al. 2011). Moreover the kinetic temperature profiles of such systems have strongly increasing gradients for increasing r. Such feature is also observed in real filaments, and in the end-products of simulations where an isothermal (Ostriker 1964) filament suffers a strong radial perturbation. Moreover, anticorrelated density vs. temperature profiles have been also found in non-astrophysical contexts, for instance in mean-field models kicked out of equilibrium by an impulsive perturbation (Casetti & Gupta 2014; Teles et al. 2015) or in condensed matter systems (Gupta & Casetti 2016). As a possible mechanism to explain why these non-thermal states exhibit temperature inversion Teles et al. (2015) suggested that during the initial violent relaxation phase the interaction of the particles with the collective oscillations may produce suprathermal tails in the velocity distribution function. In an inhomogeneous system, this may trigger a "velocity filtration" mechanism (Scudder 1992a) broadening the velocity distribution function where the system is less dense, because only sufficiently fast particles may escape the potential well produced by the central concentration. In conclusion, it appears that dissipationless collapse alone can produce dynamically supported non-thermal end states qualitatively similar to those observed in filaments. Some instances exhibit marked anticorrelated temperature and density profiles, and non-thermal long-lived states with these features may occur in any long-range-interacting system after the damping of collective oscillations.

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