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Interstellar Turbulence driven by Thermal Instability

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Abstract

We study the fundamental property of thermal instability (TI) in interstellar two-phase medium. We perform two-dimensional hydrodynamic simulations with radiative heating/cooling, thermal conduction and physical viscosity to explore the nonlinear development of TI. Turbulent motions attain saturation in the simulations. We find that the saturation amplitude depends on box size, radiative strength, and Prandtl number.

Introduction

In our previous work [1,2], we proposed that a mechanism based on thermal instability (TI) to generate and maintain clouds with supersonic velocity dispersion in a shock-compressed layer of ISM. On the other hand, Piontek & Ostriker (2004) [4] demonstrated that TI-driven turbulent motions saturate at subsonic amplitudes. In this paper, we present the detailed numerical analysis of TI to understand the saturation mechanisms of TI.

Numerical Method

We solve the following hydrodynamic equations:

$$\frac{\partial \rho}{\partial t} + \nabla_j(\rho u_j) = 0,$$

$$\frac{\partial \rho u_i}{\partial t} + \nabla_j(\rho u_i u_j - \sigma_{ij}) = -\nabla_i P,$$

$$\frac{\partial E}{\partial t} + \nabla_j\left[(E+P)u_j - \sigma_{ij}u_i - K\nabla_j T\right] = f_\Gamma\left[n\Gamma - n^2\Lambda(T)\right],$$

$$E = \frac{P}{\gamma - 1} + \frac{\rho u_k u_k}{2},$$

$$P = n k_B T,$$

$$\sigma_{ij} = \mu\left[(\nabla_j u_i + \nabla_i u_j) - \frac{2}{3}\delta_{ij}\nabla_k u_k\right],$$

$$\mathrm{Pr} = \frac{\gamma}{\gamma - 1}\frac{k_B}{m_H}\frac{\mu}{K}.$$

***Transport coefficient*:** classical, mono atomic molecules

***Initial condition*:** thermally unstable equilibrium (ρ =4.3 cm^{-3}, T=423K) with small density perturbations.

***Boundary condition*:** Periodic

Results

Fig 1 presents

- Turbulence driven by TI develops and attains saturation.
- *Left*: Inviscid calculations show that the results are resolution dependent because numerical viscosity depends on the grid spacing.
- *Right*: When physical viscosity is included, the numerical solutions show convergence with increasing resolutions. 1024 grid number corresponds to the grid spacing, Δx = 0.001pc≒ $\lambda_{F,min}$/3, where λ_F =$(KT/\rho^2\Lambda)^{1/2}$ is the characteristic length scale of TI (see [3]).

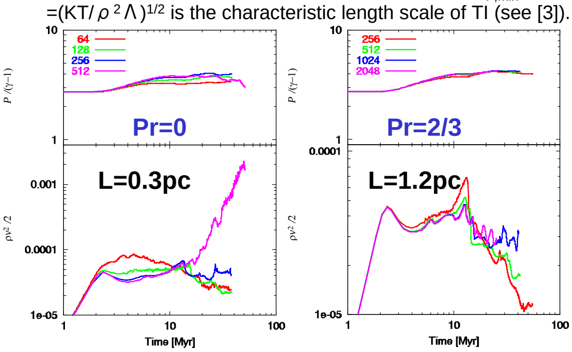

Fig. 1 Evolution of thermal and kinetic energy.

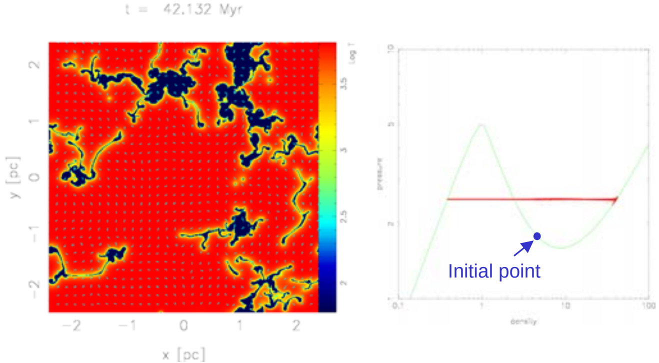

Fig 2. Snapshot at t=42Myr. L=4.8pc, Pr=2/3, 2048^2 grids. *Left*: Log T distribution. *Right*: n-P distribution.

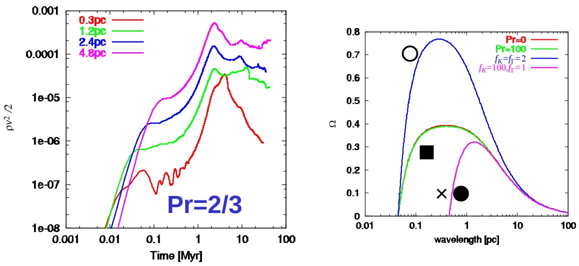

Fig 3. *Left*: Dependence on box size L. *Right*: Dispersion relation of TI at the initial condition.

Saturation level of TI

Left panel of Fig 3 shows

- Saturation occurs when the box size is larger than ～0.5 pc.
- Large saturation amplitude is obtained by the simulation with large box size.

The critical box size of saturation is the most unstable wavelength of TI.

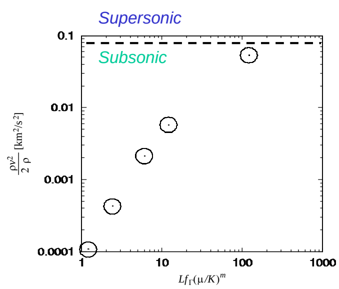

Fig. 4. Saturation amplitudes.

We examine the dependence of the saturation level on physical quantities (Fig 4.).

■ box size L, Pr=2/3 (K and μ =const.)
● L∝K$^{1/2}$, Pr=2/3
○ f_Γ∝K, Pr=2/3
× L∝K$^{1/2}$, μ =const.

The numerical analysis indicates that the saturation amplitude is a function of a quantity, $Lf_\Gamma(\mathrm{Pr})^{-0.75}$.

Concluding Remarks

1. The turbulence driven by TI develops and saturates. This indicates that the TI is a continuous driving mechanism of ISM.
2. The inclusion of physical viscosity is necessary to attain the convergence of the turbulent motions.
3. The saturation amplitude of TI depends on box size (L), radiation strength (f_Γ), and Prandtl number (Pr): Larger turbulent amplitude is obtained by larger scale simulation.

References

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