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Hydrodynamical Instabilities in Strongly Magnetized Plasma
強磁場下での流体不安定性

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In this paper, the effects of a magnetic field on hydrodynamical interfacial instabilities, such as the Richtmyer-Meshkov and Rayleigh-Taylor instability, is reviewed briefly. Especially, the suppression mechanism of the unstable growth and the critical condition for the field strength are discussed.

1. Backgrounds

Turbulent mixing driven by interfacial instabilities often plays a crucial role in many research fields such as inertial confinement fusion (ICF), astrophysical phenomena, and interplanetary plasmas [1,2]. Space plasmas are commonly magnetized and the dynamical effects of a magnetic field cannot be negligible. Recently, inclusion of an external magnetic field is considered intensely for the laboratory experiments [3]. Therefore, it is an urgent need to understand the magnetohydrodynamical (MHD) evolutions of the interfacial instabilities in terms of these applications.

Introduction of a magnetic field brings two important consequences into the turbulent mixing process, which are the amplification of an ambient field [4] and the suppression of the unstable motions [5]. In this paper, we will pay attention to the latter effect mainly.

2. Suppression by a Magnetic Field

Richtmyer-Meshkov instability (RMI) is one of the interfacial instabilities, which occurs when an incident shock strikes a corrugated contact discontinuity separating two fluids with different densities. Because of the corrugation of the interface, the surface profiles of the transmitted and reflected waves (shock or rarefaction) are also rippled. The RMI is driven by the vorticity left by these rippled shocks at the interface and in the fluids. The fluctuations of the interface grow linearly with time and the growth velocity $v_{\rm lin}$ can be determined by the Mach number of the incident shock, density ratio at the interface, and corrugation amplitude [2,6].

When a uniform magnetic field parallel to the shock velocity exists initially, the RMI can be stabilized as a result of the extraction of vorticity from the interface. A useful formula describing a critical condition for MHD RMI has been derived based on the results of direct numerical simulations [5]. The stability condition is given by the Alfven number $A = v_{\rm A}/v_{\rm lin} > 0.1$ where $v_{\rm A}$ is the Alfven speed (see Fig. 1). Interestingly, this criterion is independent of any parameters for the initial conditions. Then the critical field strength to suppress the RMI can be written as $B_{\rm crit} = 0.1(4\pi\rho)^{1/2} v_{\rm lin} \fallingdotseq 0.01\rho^{1/2} U_{\rm i}$, where $U_{\rm i}$ is the incident shock velocity. The RMI growth velocity is usually an order of magnitude smaller than $U_{\rm i}$, so a relation $v_{\rm lin} = 0.1 U_{\rm i}$ is assumed for this estimation.

Rayleigh-Taylor instability (RTI) can be also stabilized by a strong magnetic field [7]. The magnetic tension force suppresses the RTI growth for the fluctuations shorter than the critical wavelength $\lambda_{\rm crit} = 2\pi v_{\rm A}^2/(A_t\, g)$, where A_t is the Atwood number and g is the gravitational acceleration (see Fig. 2). If the critical wavelength is longer than the system size L, no growth of the RTI can be expected. Then the critical strength for RTI is given by $B_{\rm crit} = (2\rho A_t\, g\, L)^{1/2}$.

These criteria are quite useful for the design of experimental setup controlling the growth of the instabilities. For the case of ICF condition, the critical strength is roughly of the order of 0.1-1 kT.

3. Other Effects of a Magnetic Field

It have been demonstrated that a magnetic field can be amplified efficiently through the stretching motions caused by the interfacial instabilities. For the case of RMI, the maximum field strength is more than two orders of magnitude higher than the initial size, and it appears associated with the interface as well as the bulk vorticity left by the rippled transmitted shock [4]. The amplified field could modify largely the nonlinear evolutions of turbulent mixing.

Heat conduction is also affected by the presence of a magnetic field. The thermal conductivity in magnetized plasmas is anisotropic with respect to the direction of the magnetic field. Rapid temperature diffusion could govern the dynamics of RM or RT unstable system [8]. Then it would be an interesting future work to study the effect of the anisotropic diffusion by numerical simulations and also by laser plasma experiments.

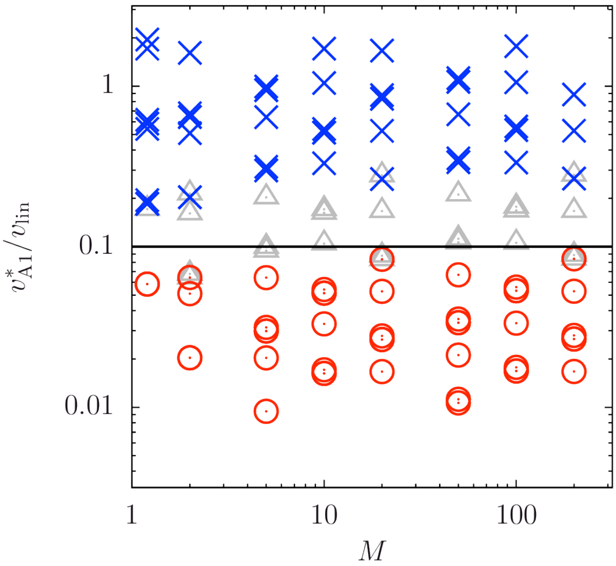

Fig.1. Nonlinear stability of the RMI performed by two-dimensional MHD simulations for single-mode analysis. The circles denote the unstable models that exhibit the nonlinear growth of RMI in the numerical simulations, whereas the crosses stand for the models which are stabilized by the ambient magnetic field. The critical condition for RMI growth can be given by the Alfven number $A < 0.1$, and which is independent of the Mach number, density ratio, corrugation amplitude, and even the direction of the initial magnetic field.

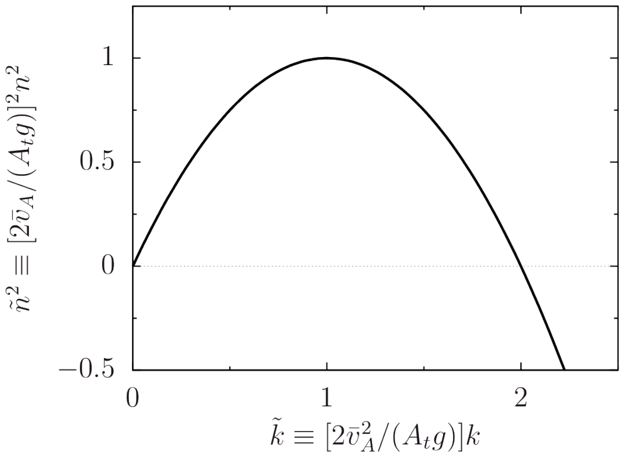

Fig.2. Dispersion relation of the linear stability for MHD RTI, in which $n^2 > 0$ denotes exponential unstable growth of the perturbations. Because of the suppression by magnetic tension force, fluctuations with the shorter wavelength can be stabilized.

References

[1] M. Brouillette, Annu. Rev. Fluid Mech. **34** (2002) 445.

[2] K. Nishihara, J. G. Wouchuk, C. Matsuoka, R. Ishizaki, and V.V. Zhakhovsky, Phil. Trans. R. Soc. A **368** (2010) 1769.

[3] L. J. Perkins, B. G. Logan, G. B. Zimmerman and C. J. Werner, Phys. Plasmas **20** (2013) 072708.

[4] T. Sano, K. Nishihara, C. Matsuoka, and T. Inoue: Astrophys. J. **758** (2012) 126.

[5] T. Sano, T. Inoue, and K. Nishihara: Phys. Rev. Lett. **111** (2013) 205001.

[6] J. G. Wouchuk and K. Nishihara, Phys. Plasmas **3** (1996) 3761; Phys. Plasmas **4** (1997) 1028.

[7] S. Chandrasekhar, *Hydrodynamic and Hydromagnetic Stability* (Oxford University Press, Oxford, 1961)

[8] D. Lecoanet, I. J. Parrish, E. Quataert, Mon. Not. R. Astron. Soc. **403** (2012) 1866.