Linear Thermal Instability and Fluctuations in Molecular Clouds

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ABSTRACT
Evidence of small-scale condensations in the magnetic molecular clouds has been accumulating over the past decades through radio and optical/ultraviolet observations. The origin and shape of these small-scale condensations is a disputable issue. Nejad-Asghar & Ghanbari (2004 hereafter NG) have recently studied the effect of the linear thermal instability on the formation of fluctuations in molecular clouds. The authors inferred that under certain conditions (e.g., depending on expansion or contraction of the background) thermal instability and ambipolar diffusion can produce spherical, oblate, or prolate condensations.

Key words: ISM: molecules, ISM: structure, instabilities

1 INTRODUCTION
Firstly, about presence of these fluctuations. We have two method to find them: (1) direct imaging of nearby clouds reveals substructures on scales to lengths of 0.01 pc and masses of $0.01 M_\odot$ (Peng et al. 1998; Sakamoto & Sunada 2003), (2) studies of the time variability of absorption lines indicates the presence of fluctuations on scales of $10^{-4} \text{pc}$ (5-50 AU) and masses of $10^{-8} M_\odot$ (Moore & Marscher 1995; Boissé et al. 2005).

How these fluctuations may be formed and is the thermal instability important? To answer the question, first, we must consider time-scales. According to the prior results of Gilden (1984), thermal instability time-scale in molecular clouds is in the order of $10^{4} - 10^{5}$ year. On the other hand, Larson (1981) showed that dynamical time-scale for transient structure of molecular clouds is in order of $10^{7}$ year. Thermal instability time-scale is very smaller than dynamical time-scale. Thus, it is reasonable to consider thermal instability as an important mechanism in formation of small fluctuations in molecular clouds.

It is now accepted that the magnetic field is very important in dynamical evolution of all ISM. It will affect on ions directly and on neutral particles indirectly, via collision with ions. In molecular clouds, ionization degree is very small, thus, drift of neutral particles between tied ions is important. It can heat the medium. In this way, for complete investigation of the thermal instability in molecular clouds, we must consider plasma drift (ambipolar diffusion).

2 NET COOLING FUNCTION AND PERTURBATION
The most important parameter in thermal instability is the net cooling function. A good fitted result for cooling in molecular clouds is $\Lambda(\rho, T) = \Lambda_0 \rho^\delta T^\beta$ (Goldsmith & Langer 1978; Neufeld et al. 1995), where the values of $\delta$ and $\beta$ is given by the Fig. 1 of NG.

About heating rate, we turn our attention to gravitational expansion/contraction work and ambipolar diffusion heating rate. The gravitational heating rate is found by setting the rate of compressional/expansional work per particle, equal to the rate of change of gravitational energy per particle. For ambipolar diffusion heating rate, we have

$$\Gamma_{AD} = \frac{f_d \cdot v_d}{\rho_n}$$

where $f_d = \eta \epsilon \rho^{1+\nu}$ is the drag force (per unit volume) with $\eta$ as collision drag, and $v_d$ is the drift velocity of ions relative to neutral particles. In order of magnitude, if $\kappa B_0$ changes on a typical scale of $\lambda$, and if we choose $\rho_n \sim \epsilon \rho_\lambda^\nu$ (Umebayashi & Nakano 1980), ambipolar diffusion heating rate, in a good estimate, is given by

$$\Gamma_{AD} = \Gamma_0 \rho^{-(2+\nu)}; \quad \Gamma_0 \equiv \frac{(\kappa B_0)^4}{16\pi^2 \eta \epsilon \lambda^2}.$$ (2)

In this way, the net cooling function in molecular clouds is given by (for more detail see NG)

$$\Omega(\rho, T) = \Lambda_0 \rho^\delta T^\beta - \Gamma_0 \rho^{3/2} - \Gamma_0 \rho^{-(2+\nu)}.$$ (3)

Instability condition depends on the different values of $\beta$, $\delta$, and $\nu$.

We use the perturbation method to investigate the oc-
occurrence of thermal instability in molecular clouds and formation of fluctuations. We choose an expanding/contracting molecular cloud with uniform magnetic field $B_0$. Perturbation on this medium results to a five-degree linear characteristic equation, which its coefficients depend on the importance of ambipolar diffusion and gravitational heating rate

$$\xi \equiv \frac{\Gamma_{AD}}{\Lambda(n_0, T_0)}, \quad \chi \equiv \frac{\Gamma_{grav}}{\Lambda(n_0, T_0)}$$

and some time-scales that are investigated in details at subsection 3.2 of NG. By introducing the non-dimensional quantities

$$y \equiv h\tau_s, \quad \sigma_p \equiv \frac{\tau_s}{\tau_{cT}}, \quad \sigma_T \equiv \frac{\tau_s}{\tau_{cp}} + \frac{\tau_s}{\tau_K},$$

$$\alpha \equiv \left(\frac{\tau_s}{\tau_{AL}}\right)^2, \quad D \equiv \frac{\tau_s}{\tau_{AL}^2}, \quad G_\sigma \equiv \left(\frac{\tau_s}{\tau_{grav}}\right)^2, \quad E_c \equiv \frac{\tau_s}{\tau_{e}},$$

we use the Laguerre method to find five roots of the characteristic equation (7).

3 RESULTS AND PROSPECTS

If we consider the effect of the self gravity without expansion/contraction of the background, the isobaric instability criterion (line $OA$ of Fig. 1) is modified, because, self-gravity causes to increase the internal pressure.

If the background is expanding ($E_c > 0$), its expansion energy causes to stabilize the medium. This case is shown in Fig. 2 for a typical value of $\alpha = 5.0$ and $D = 1.0$. In the isentropic instability criterion (line $OB$), expansion energy causes to stabilize the medium in the direction of the magnetic field and perpendicular to it. In the isobaric instability criterion (line $OA$), it only causes to stabilize the medium in perpendicular to the magnetic field, corresponding to decreased pressure via ion-neutral friction.

For contracting background ($E_c < 0$), contraction energy injected to the medium, thus, its stability is decreased and converted to a prolate instability. Diffusion of neutrals relative to the freezeed ions in the perpendicular direction of the magnetic field is the reason of this prolate instability. This case is shown in Fig. 3 for a typical value of $\alpha = 5.0$ and $D = 1.0$. When the parameters of a magnetic molecular cloud set, locally, in this region of $\sigma_T - \sigma_p$ plane, plane condensation may be produced via thermal instability.

Investigation of this problem in the linear prospect is not completely OK, because, ambipolar diffusion is a nonlinear effect and density fluctuation ratios are in the order of 10. But, we see that linear study can give us a good idea about the conditions for occurrence of thermal instability.

For complete study we must work in nonlinear regime.

REFERENCES

Boissé P. et al., 2005, A&A 429, 509
Gilden D.L., 1984, ApJ 283, 679
Goldsmith P.F., Langer W.D., 1978, ApJ 222, 881
Larson R.B., 1981, MNRAS 194, 809
Moore E.M., Marscher A.P., 1995, ApJ 452, 679
Nejad-Asghar M., Ghanbari J., 2004, BASI 32, 169 (NG)
Neufeld D.A. et al., 1995, ApJS 100, 132
Peng R., et al., 1998, ApJ 497, 842
Sakamoto S., Sunada K., 2003, ApJ 594, 340
Umebayashi T., Nakano T., 1980, PASJ 32, 405