THE DEVELOPMENT OF MODES OF THERMAL INSTABILITY IN A NON-STATIONARY MEDIUM (PRODUCTION OF OH MASER CONDENSATIONS)

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ABSTRACT. In a nonstationary medium (behind the shock front, for instance) the development of isobaric and adiabatic modes of the thermal instability are more preferable. Some examples of the fragmentation of the medium on clouds in case of OH masers are given.

In a nonstationary medium the development of modes of thermal instability is more stable than in a stationary that and the increments of increase of perturbation may be rather high (Hunter, 1970; Burdyuzha, Ruzmaikina, 1974; Schekinov, 1978). In real conditions the situation with nonperturbation nonstationary state is realized more often. That kind the state of gas is after passage of shock waves. The production of maser condensations OH in envelopes of young massive stars and in envelopes of IR stars by means of the fragmentation of the medium in result of thermal instability behind the shock front was considered in papers (Burdyuzha, Ruzmaikina, 1974; Burdyuzha, Ruzmaikina, 1975). It seems that the fragmentation of the medium on clouds in envelopes of young massive stars (the cloudy structure is observational fact Reid (1990)) takes place probably because of realization of condensational (isobaric) mode of thermal instability since in the case the perturbation for the cooling from $T_2 \sim 10^4$ K to $T \sim 10^2$ K can increase from 10^2 to 10^4 times if the law of them the increase is

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$$\frac{\delta n}{n} = - \frac{\delta T}{T} \sim \left(\frac{T_2}{T}\right)^{2-\alpha} \qquad (1)$$

here $0 \leqslant \alpha \leqslant 1$ (see in detail Burdyuzha, Ruzmaikina, 1974).

Let's consider and compare the role of condensational and adiabatic mode of thermal instability forming behind the shock wave front; for instance in IR stars envelope. The criterion of condensation mode development of thermal instability, that is formed behind the shock wave front, is fulfilled in the following inequality

$$\left(\frac{\partial L}{\partial T}\right)_P - \frac{L}{T} < 0 \,, \qquad (2)$$

where L - is the function of cooling. The criterion of adiabatic mode development is fulfilled in the following inequality

$$\frac{1}{\gamma-1} \frac{\rho}{T} \left(\frac{\partial Z}{\partial \rho}\right)_T + \left(\frac{\partial Z}{\partial T}\right)_\rho - \frac{Z}{T} < \frac{\gamma}{(\gamma-1)^2} \frac{R}{\mu} \left(4 \frac{d\ln\rho}{dt} - \frac{1}{2} \frac{d\ln T}{dt}\right), \qquad (3)$$

where γ is adiabatic index; R is equal to universal gas constant; $Z = (L-\Gamma)$ is the generalized loss function; L and Γ is the cooling and heating velocity per mass unit.

Because of the critical scale defined by thermal conductivity the additional condition of thermal instability is the fulfillment of the following inequality $\lambda > l_{cr}$

$$l_{cr} \sim \left(\frac{\varkappa T}{\mu m_p n L}\right)^{1/2} , \qquad (4)$$

where $\varkappa$ is the coefficient of thermal conductivity, m_p - is mass of proton.

In case of adiabatic mode

$$l_{cr} < \lambda_{adiab} \ll \lambda_{cold} \qquad (5)$$

and in case of isobaric mode

$$l_{cr} < \lambda_{isob} \simeq \lambda_{cold} \qquad (6)$$

where $\lambda_{cold} \approx c\,\tau_{cold}$ (c - is sound velocity).

We have $\lambda_{adiab} \approx \beta\, c\, \tau_{cold}$; $\beta \ll 1$ (7)

for adiabatic perturbations.

If $\lambda_{adiab} > l_{cr}$, then

$$\beta > \left(\frac{\varkappa T}{\mu m_p n L}\right)^{1/2} \frac{1}{c\,\tau_{cold}} > \frac{1}{c}\left(\frac{\varkappa}{k n \tau_{cold}}\right)^{1/2}, \quad (8)$$

where k is Boltzman constant.
The velocities of shock waves in giant envelopes are unlikely to be more than $V_{sh} < 20$ km/s (the t^o behind the front is estimated as follows $T_2 \approx 3500\ [V_{sh}/10\ \mathrm{km/s}]^2$ Shull, Hollenbach (1978)). At the degree of ionization $x \gtrsim 10^{-2}$ since $T_2 \gtrsim 10^4$K the cooling time may be estimated using our formula (Burdyuzha, Ruzmaikina, 1974)

$$\tau_{cold} \approx \frac{5\ 10^7 T_2}{x\ n} \quad s \quad . \quad (9)$$

By substituting the value of electron thermal conductivity $\varkappa \sim 2\ 10^{-6} T^{5/2}$ since the general role is due to electron excitation of $n < 10^5\ \mathrm{cm}^{-3}$, and τ_{cold} and n in (8) we'll have $\beta > 0.017$ what is compatible to the inequality $\beta \ll 1$. Therefore $\lambda_{cold} \sim 5\ 10^{13}$ cm, $\lambda_{adiab} \sim 10^{12}$ cm, $l_{cr} \sim 7\ 10^{11}$ cm.

The fulfillement of the criterion (3) appeares to be more favorable than that of (2) for isōbaric perturbations increase. It is explained by the fact that gas temperature behind shock front is decreased because of radiation. The density increases with the characteristic time close to cooling time because of the pressure being stable. Therefore the positive value is placed in the right part of inequality (3). Besides adiabatic mode of thermal instability can easily develop in stationary medium with heating source. By using the formula of heating rate in gas due to collision with dust (Oppenheimer, 1977) we have

$$\Gamma = 1/2\ n_{H_2} n_g \sigma_g v\ k\ (T_d - T_{kin}) \quad (10)$$

have $\sigma_g v \sim 3\ 10^{-6} T^{1/2}$; $n_g \sim 3\ 10^{-12} n_{H_2}$.

At $n_{H_2} \sim 10^5$ cm^{-3} , $T_d \sim 200$ K, $T_{kin} \sim 100$ K

we have $\Gamma \sim 6\ 10^{-21}$ erg/cm^{3}s .

At this value of heating rate the isobaric mode of thermal instability may develope under very specific conditions only. Therefore in case shock waves in giant and supergiant envelopes are not avar lable the adiabatic mode will cause medium fragmentation. The presence of condensed and rare gas regions is the characteristic feature of adiabatic mode development. The variability of some OH sources in IR stars may be understood in this way. The characteristic time of adiabatic mode development is much less than cooling time i.e. $t_h=(kc)^{-1} \ll \tau_{cold}$. At sound velocity $c \sim 10^5$ cm/s and $k = 1/\lambda_{adiab} \sim 10^{-12}$cm^{-1} t_h is equal to 10^7 s . Cooling rate $\tau_{cold} \sim 5\ 10^8$ s if $n \sim 10^5$ cm^{-3} , $x \sim 10^{-2}$, $T \sim 10^4$ K.

Therefore the maser condensation OH in envelopes of young massive stars and in envelopes a giants and supergiants can be produced for the fragmentation in result of the development of isobaric or adiabatic modes of thermal instability both in nonstationary and in stationary medium.

References

Burdyuzha V.V., Ruzmaikina T.V. 1974, Soviet. Astron. 18, 201.

Burdyuzha V.V., Ruzmaikina T.V. 1975, Astron. Astrophys. 40, 233.

Hunter J.H. 1970, Astrophys. J. 161, 451.

Oppenheimer M. 1977, Astrophys. J., 211, 400.

Reid M.J. The Paper at the Thirg Haystack conference,1990

Schekinov Yu.A. 1979, Astrophysica, 15, 347.

Shull J.H., Hollenbach D.J. 1978,Astrophys. J., 220, 525.

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