Generation of dust acoustic shock wave due to nonadiabatic dust charge variation in astrophysical plasma

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Abstract

The effect of nonadiabaticity of dust charge variation on large amplitude nonlinear dust acoustic wave have been investigated. Nonadiabaticity generated dissipative effect causes generation of dust acoustic shock wave. The dust density shows rapid increase with Mach number (M) and dust condensation becomes very intense as M tends to the maximum Mach number. According to the current theory such dust acoustic shock induced intense dust condensation in intersteller dust cloud may suffice to initiate gravitional contraction leading to star formation.

The charge Q_d on the dust grain is an extra dynamical variable, which controls the grain motion but itself is to be determined from the grain charging equation

$$\frac{dQ_d}{d\left(t\omega_{pd}\right)} = \left(\frac{\nu_{ch}}{\omega_{pd}}\right)\frac{I_e + I_i}{\nu_{ch}} \tag{1}$$

where I_e and I_i are the plasma electron and ion current flowing to the dust surface, ω_{pd} is the dust plasma frequency and ν_{ch} is the grain charging frequency. In the adiabatic dust charge variation limit [1], it is assumed that $\frac{\omega_{pd}}{\nu_{ch}} \approx 0$ so that the dust charging equation (1) reduces to $I_e + I_i = 0$. The scenario changes drastically, when nonadiabaticity [2, 3] of the dust charge variation is taken into account by considering the nonzero value of $\frac{\omega_{pd}}{\nu_{ch}}$.

Before proceeding further, in the wave frame $\zeta = X - \lambda T$, we consider the following non dimensionalized dust fluid equations[2]

$$\frac{dN}{d\zeta} = \frac{1}{\alpha_d}\left(\frac{N^3}{u^2}\right)\left[-1 + \Delta Q\right]\frac{d\Phi}{d\zeta} \tag{2}$$

Poission's equation

$$\frac{d^2\Phi}{d\zeta^2} = -\frac{\sigma}{(\sigma+\delta)}\left[\delta exp\left(-\frac{\Phi}{\sigma}\right) - exp\left(\Phi\right) + \left(\delta - 1\right)N\left(-1 + \Delta Q\right)\right] \tag{3}$$

and the grain charging equation

$$\left(\frac{\omega_{pd}}{\nu_{ch}}\right)\left(\frac{u}{N}\right)\frac{d\Delta Q}{d\zeta} = \frac{1}{\nu_{ch}}\frac{\left(I_e + I_i\right)}{z_d e} \tag{4}$$

where normalized(normalized by equilibrium dust charge $-z_d e$) dust charge $Q=-1+\Delta Q$, $X=x/\lambda_D$, $T=\omega_{pd}t$, λ is the wave velocity, $u=V_{dr}-\lambda$, where V_{dr} is the dust drift velocity, $N=n_d/n_{d0}$ and $\alpha_d=z_d n_{d0}/\left(n_{e0}+\frac{T_e n_{i0}}{T_i}\right)$. Numerical integration of the above system of equations by Runge-Kutta-Fehlberg method of order five, it is seen that the perturbation develops into a shock wave provided the dust velocity V_{dr} far upstream exceeds the phase velocity λ of the wave. The numerical integration shows that $N\rightarrow\infty$ as Mach number $M=\frac{V_{dr}}{\lambda}$ tends to its maxumum value M_{max}. Condensation of dust density resulting from propagation of dust acoustic shock wave through dust molecular clouds and the consequent enhanced gravitational interaction is considered as a viable process for star formation in intersteller dust cloud[4]. Hence, the variation of dust density resulting from propagation of dust acoustic shock waves is however of significant importance in astrophysical context.

References

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