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Kinetic theory of Jeans' gravitational instability in millicharged dark matter system

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The possibility of baryons cooled by a millicharged dark matter (mDM) via mDM–baryons scattering has recently been proposed to explain the observation discrepancy from the experiment to detect the global epoch of reionization signature (EDGES). In this sense, we analyze the Jeans instability of self-gravitational systems in the background of mDM under kinetic regime that the collisionless Boltzmann equation and Poisson equation have been combined to obtain the modified dispersion relation. It is shown that the effect of mDM is significant on the dynamics of gravitational collapse, i.e., the presence of mDM makes the self-gravitational systems more difficult to collapse relatively.

Keywords: self-gravitating systems, millicharged dark matter, Jeans instability

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1. Introduction

An open question, worthy of in-depth study, is whether the evolution and dynamics of interstellar gas clouds are strongly influenced by the unknown non-baryonic particles, or so called the dark matter (DM) with a total mass about five times of all the baryons.[1,2] Note that many observations and indirect experiments have confirmed the existence of DM in our universe, including the cosmic microwave background radiation, galaxy rotation curves, gravitational lensing and cluster observations, etc.[2–5] The Jeans instability, proposed firstly by Jeans,[6] describes the criteria for gravitational collapse and evolution of a self-gravitating system in linear regime, and has been extensively studied.[7–10] So, to examine DM's role on the evolution of interstellar gas clouds, most of works have restudied the Jeans instability of self-gravitational systems in the background of DM.[11–14] For example, it has been proposed[11] that the Jeans mass and length of interstellar gas clouds will be modified by DM. Based on the framework of kinetic theory, Kremer *et al*.[12,13] have studied the Jeans instability of self-gravitational systems in the background of cold DM and indicated that the perturbation of baryons will catch up the DM perturbation at later period of structure formation.

The particle DM that obtains a small electric charge $|q_{\rm d}|$ from the standard model photon is always called as mDM. In the past, many works have only focused mainly on the traditionally favored classes of DM candidates having only short-range interactions with baryons, such as the weakly interacting massive particles (WIMPs), sterile neutrino or axion. An important focus is that whether DM has any non-gravitational interactions with the standard model particles, but a vast array of observations[4,15,16] have come to grief over lack of conclusive evidence before the appearance of mDM. The cosmic 21-cm absorption signal obtained by the experiment to detect the global epoch of reionization signature (EDGES)[17] is an informative and powerful evidence to prove the possibility of mDM, which motivates researchers interest on the exploration of DM with fractional charge.[18–20] This observations by the EDGES collaboration showed a stronger absorption spectrum than the maximum predicted value of standard cosmological model at a confidence level of 3.8 standard deviations.[17] To explain this discrepancy, Muñoz *et al*. have recently proposed the mDM could cool the baryons in the early universe via mDM-baryon scattering.[18] Based on his work, Li *et al*. have further found signal of mDM in supernova remnants and proposed the interaction between mDMs with the interstellar medium and electromagnetic fields within galaxies.[21] If confirmed, mDM would has unique phenomenological consequences due to its long-range electromagnetic interactions with the baryons and background magnetic field, which are easily occurred in astrophysical environments. In fact, the concept of charged dark matter has early been proposed by Rújula in Ref. [22], that is, a stable particle having a unit charged and high mass can be viewed as a collisionless dark matter. Subsequent experiments[23] using both terrestrial and satellite data failed in the exploration, which shakes researchers faith in the possibility of charged dark matter. Recently, Chuzhoy *et al*. indicated that the reason why the existence of charged massive particles (CHAMPs) can not be detected is that CHAMPs having the charge and mass in the range of $100(q_{\rm d}/e)^2 \leq m_{\rm d} \leq 10^8(q_{\rm d}/e)$ TeV will interact with galactic magnetic fields, so they will evacuate from the galactic disk.[24] And they also further showed that

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the presence of CHAMPs is a reasonable way to solve several long-standing astrophysical problems, such as the underabundance of dwarf galaxies,[25] the cores of the dwarf galaxies with the too shallow density profiles[26] or other questions. Subsequently, the direct detection experiments of sub-GeV DM further prove that mDM obtains a sizeable scattering rates via DM–electron scattering.[27] The fraction, mass or charge of mDM are severely constrained by relevant observational phenomena and experimental results, such as the big bang nucleosynthesis (BBN),[28,29] stellar cooling,[30] SN1987A[31] and accelerator experiments.[32] In order to satisfy the constraint requirement for explaining the EDGES measurement,[18] while remaining consistent with the existing findings,[33–35] we have limited mDM to a viable range, with the fraction $(m_{\rm d}/{\rm MeV})0.0115\% \leq f_{\rm dm} \leq 0.4\%$, mass $0.1\ {\rm MeV} \leq m_{\rm d} \leq 10\ {\rm MeV}$, and charge $10^{-6}e \leq q_{\rm d} \leq 10^{-4}e$, where $f_{\rm dm} = n_{\rm md0}/n_{\rm d0}$.

In light of the current understanding of generation mechanisms of mDM, kinetic mixing between a nearly massless dark photon and the standard model photon is the major mechanism to induce an effective electric charge for DM.[36] Some works have been reported that because of the tiny charges, mDM generally exists in supernova remnants in the form of a dark plasma instead of bound states.[21] Implicit in this scenario is the possibility that the interactions of dark plasma with interstellar medium gas may effectively influence the process of star formation. If, on the other hand, a supernova explosion happen around the nearby interstellar gas clouds, the strong shock waves generated by supernova explosion will sweep up the ambient interstellar medium and impact on the nearby interstellar gas clouds.[37,38] It can provide essential matters and energy for collapse of dense cloud core and then a new star is born. Similarly, mDM diffused in interstellar medium is also swept by the shock waves. Consideration of the existence of mDM around the interstellar gas clouds sheds light on one key question: whether the shocked mDM particles influences the process of a new star formation due to its electrostatic interaction. It is, thus, significant to study the role of charged dark matter in the evolution of interstellar gas clouds, as it may be a key to reveal the process of structure formation.

The rest of this paper is organized as follows: the derivation of the modified dispersion relation is shown in Section 2. In Section 3, we present the numerical results for the growth rate of Jeans instability. Conclusion and discussion are stated in Section 4.

2. Analysis of self-gravitational system with millicharged dark matter

Along the standard lines of kinetic theory, the dynamic behavior of self-gravitating system can be described by the collisionless Boltzmann equation which can be written in following way:

$$\frac{\partial f_\alpha(\boldsymbol{v},\boldsymbol{r},t)}{\partial t} + \boldsymbol{v}\cdot\frac{\partial f_\alpha(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{r}} - \nabla\psi\cdot\frac{\partial f_\alpha(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{v}} = 0, \quad (1)$$

$$\rho_\alpha(\boldsymbol{r},t) = m_\alpha \int f_\alpha(\boldsymbol{v},\boldsymbol{r},t)\,{\rm d}\boldsymbol{v} = m_\alpha n_\alpha, \quad (2)$$

where $f_\alpha(\boldsymbol{v},\boldsymbol{r},t)$, $\rho_\alpha(\boldsymbol{r},t)$ and m_α are the distribution function, density and mass of α particle, respectively. The subscript $\alpha = {\rm b},{\rm d}$ denotes two key ingredients, baryons matter (BM) and DM, respectively. Category of BM in our work usually indicates the matter composed by standard model particles, such as interstellar gas clouds. The gravitational potential ψ is governed by Poisson equation

$$\nabla^2\psi = 4\pi G\sum_{\alpha={\rm b,d}}\rho_\alpha(\boldsymbol{r},t), \quad (3)$$

where G the gravitational constant. Consideration of the presence of mDM will result in a long-range electromagnetic interactions between DMs, which allows Eq. (1) to be re-written as

$$\begin{cases} \dfrac{\partial f_{\rm d}(\boldsymbol{v},\boldsymbol{r},t)}{\partial t} + \boldsymbol{v}\cdot\dfrac{\partial f_{\rm d}(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{r}} \\ \quad -(\nabla\psi - \dfrac{q_{\rm d}}{m_{\rm d}}\nabla\varphi)\cdot\dfrac{\partial f_{\rm d}(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{v}} = 0, \\ \dfrac{\partial f_{\rm b}(\boldsymbol{v},\boldsymbol{r},t)}{\partial t} + \boldsymbol{v}\cdot\dfrac{\partial f_{\rm b}(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{r}} \\ \quad -\nabla\psi\cdot\dfrac{\partial f_{\rm b}(\boldsymbol{v},\boldsymbol{r},t)}{\partial \boldsymbol{v}} = 0, \end{cases} \quad (4)$$

where electrostatic potential φ induced by mDMs can be calculated by following equation:

$$\nabla^2\varphi = 4\pi q_{\rm d}\int f_{\rm d}(\boldsymbol{v},\boldsymbol{r},t)\,{\rm d}\boldsymbol{v}. \quad (5)$$

For an infinite self-gravitational collisionless system with small perturbations, we assume equilibrium state is homogeneous and time-independent (i.e., $f_{\alpha0}(\boldsymbol{v},\boldsymbol{r},t) = f_{\alpha0}(\boldsymbol{v})$), so particle distribution functions, gravitational and electrostatic potentials can be expanded as

$$f_\alpha = f_{\alpha0}(\boldsymbol{v}) + f_{\alpha1}(\boldsymbol{v},\boldsymbol{r},t), \quad (6)$$

$$\psi = \psi_0(\boldsymbol{r}) + \psi_1(\boldsymbol{r}), \quad (7)$$

$$\varphi = \varphi_0(\boldsymbol{r}) + \varphi_1(\boldsymbol{r}). \quad (8)$$

The equilibrium distribution of the self-gravitational system is described by the zero order term $f_{\alpha0}(\boldsymbol{v})$, while the term of perturbation is showed by the first order correction $f_{\alpha1}(\boldsymbol{v},\boldsymbol{r},t)$ $(\ll f_{\alpha0}(\boldsymbol{v}))$. In addition, the unperturbed gravitational potential at equilibrium state and its first order correction are indicated by $\psi_0(\boldsymbol{r})$ and $\psi_1(\boldsymbol{r})$, respectively. Invoking Jeans swindle,[40] the unperturbed gravitational potential $\psi_0(\boldsymbol{r})$ can be regarded as a locally constant in system, so we have $\nabla\psi_0(\boldsymbol{r}) = 0$. Combining Eqs. (2)–(8) and making the fourier analyzing with plane wave ansatz, i.e., $X_1 \propto \exp[-{\rm i}(\omega t - \boldsymbol{k}\cdot\boldsymbol{r})]$ $(X = f,\phi)$, where ω and $\boldsymbol{k}$ are the

frequency and wavenumber of the perturbations, one obtains the dispersion relation

$$\left[1-\sum_{\alpha}\frac{4\pi G m_{\alpha}}{k^2}\int\frac{\boldsymbol{k}}{\boldsymbol{\omega}-\boldsymbol{k}\cdot\boldsymbol{v}}\cdot\frac{\partial f_{\alpha 0}(\boldsymbol{v})}{\partial \boldsymbol{v}}\mathrm{d}\boldsymbol{v}\right]\times\left[1+\frac{4\pi q_{\mathrm{d}}^2}{k^2 m_{\mathrm{d}}}\int\frac{\boldsymbol{k}}{\boldsymbol{\omega}-\boldsymbol{k}\cdot\boldsymbol{v}}\cdot\frac{\partial f_{\mathrm{d}0}(\boldsymbol{v})}{\partial \boldsymbol{v}}\mathrm{d}\boldsymbol{v}\right]+\frac{16\pi^2 G}{k^2}\left(\int\frac{q_{\mathrm{d}}}{\boldsymbol{\omega}-\boldsymbol{k}\cdot\boldsymbol{v}}\cdot\frac{\partial f_{\mathrm{d}0}(\boldsymbol{v})}{\partial \boldsymbol{v}}\mathrm{d}\boldsymbol{v}\right)^2=0. \tag{9}$$

Without loss of generality, one can treat Jeans modes in one-dimensional geometry, i.e., one can let $\boldsymbol{v}=v_x\boldsymbol{e}_x$ and $\boldsymbol{k}=k\boldsymbol{e}_x$,[8,9] then Eq. (9) is transformed to the one-dimensional form

$$\left[1-\sum_{\alpha}\frac{4\pi G m_{\alpha}}{k^2}\int\frac{k}{\omega-kv_x}\frac{\partial f_{\alpha 0}(v_x)}{\partial v_x}\mathrm{d}v_x\right]\times\left[1+\frac{4\pi q_{\mathrm{d}}^2}{k^2 m_{\mathrm{d}}}\int\frac{k}{\omega-kv_{\mathrm{d}x}}\frac{\partial f_{\mathrm{d}0}(v_x)}{\partial v_x}\mathrm{d}v_x\right]+\frac{16\pi^2 G q_{\mathrm{d}}^2}{k^2}\left(\int\frac{1}{\omega-kv_x}\frac{\partial f_{\mathrm{d}0}(v_x)}{\partial v_x}\mathrm{d}v_x\right)^2=0. \tag{10}$$

The one-dimensional velocity distribution function of particles $f_{\alpha 0}(v_x)$ $(=\int f_{\alpha 0}(\boldsymbol{v})\mathrm{d}v_y\mathrm{d}v_z)$ can be described by the one-dimensional Maxwell–Boltzman distribution

$$f_{\alpha 0}(v_x)=\frac{n_{\alpha 0}}{(2\pi\sigma_{\alpha}^2)^{\frac{1}{2}}}\mathrm{e}^{-\frac{v_x^2}{2\sigma_{\alpha}^2}}, \tag{11}$$

where $n_{\alpha 0}$ and σ_{α} are the number density and dispersion velocity of α particles at equilibrium state, respectively. Putting Eq. (11) into Eq. (10), one can get one more compact form

$$1+\frac{\omega_{\mathrm{Jd}}^2-\omega_{\mathrm{pd}}^2}{k^2\sigma_{\mathrm{d}}^2}Z(\xi_{\mathrm{d}})+\frac{\omega_{\mathrm{Jb}}^2}{k^2\sigma_{\mathrm{b}}^2}Z(\xi_{\mathrm{b}})-\frac{\omega_{\mathrm{Jb}}^2\omega_{\mathrm{pd}}^2}{k^4\sigma_{\mathrm{b}}^2\sigma_{\mathrm{d}}^2}Z(\xi_{\mathrm{b}})Z(\xi_{\mathrm{d}})=0, \tag{12}$$

where $\omega_{\mathrm{J}\alpha}^2=4\pi G m_{\alpha}n_{\alpha 0}$ denotes the Jeans frequency of α particles, and $\omega_{\mathrm{pd}}^2=\frac{4\pi n_{\mathrm{md}0}q_{\mathrm{d}}^2}{m_{\mathrm{d}}}$ is mDM oscillation frequency driven by electrostatic interaction between mDMs. In addition, the dispersion function $Z(\xi_{\alpha})$ is expressed as

$$Z(\xi_{\alpha})=\frac{1}{\pi^{\frac{1}{2}}}\int\frac{X}{\xi_{\alpha}-X}\mathrm{e}^{-\frac{X^2}{2}}\mathrm{d}X, \tag{13}$$

where $\xi_{\alpha}=\frac{\omega}{\sqrt{2}k\sigma_{\alpha}}$. In the limit analysis of Jeans' gravitational systems, the boundary for collapse is achieved by setting $\omega=0$ in Eq. (12). Specifically, in the case of BM alone, setting $\omega=0$, one has classical Jeans critical wave-number

$$k_{\mathrm{J}}^2=\frac{4\pi G\rho_0}{\sigma^2}, \tag{14}$$

which is equivalent to k_{Jb}^2 in present work. Note that the Jeans critical mass need for collapse is function of Jeans critical wave-number,

$$M_{\mathrm{Jb}}=\frac{4\pi\rho_{\mathrm{b}0}}{3}\left(\frac{\lambda_{\mathrm{Jb}}}{2}\right)^3=\frac{4\pi^4\rho_{\mathrm{b}0}}{3k_{\mathrm{Jb}}^3}. \tag{15}$$

Putting $\omega=0$ (that is, $Z(\xi_{\alpha})=-1$) into Eq. (12) one obtains modified Jeans critical wave-number

$$k_{\mathrm{Jcorrect}}^2=\frac{\left(1+\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1-\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1\eta_2\right)^2+\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1\eta_2}{\left(1+\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1-\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1\eta_2\right)}k_{\mathrm{Jb}}^2=Ak_{\mathrm{Jb}}^2, \tag{16}$$

and the corresponding modified Jeans mass

$$M_{\mathrm{Jcorrect}}=\frac{(\rho_{\mathrm{b}0}+\rho_{\mathrm{d}0})}{\rho_{\mathrm{b}0}}\frac{k_{\mathrm{Jb}}^3}{k_{\mathrm{Jcorrect}}^3}M_{\mathrm{Jb}}=(1+\eta_1)A^{2/3}M_{\mathrm{Jb}}, \tag{17}$$

where $\eta_1=\frac{\rho_{\mathrm{d}0}}{\rho_{\mathrm{b}0}}$ and $\eta_2=\frac{n_{\mathrm{md}0}q_{\mathrm{d}}^2}{n_{\mathrm{d}0}Gm_{\mathrm{d}}^2}$. According to current report of the European space agency's Planck satellite,[41] we can approximatively treat density ratio η_1 as the ratio between the present-day mass density of DM and visible matter, that is, $\eta_1\approx 5.5$. It is obvious to see from Eq. (16) that consideration of mDM in the self-gravitational systems of interstellar gas clouds will result in an additional factor A, that is to say, what extent mDM changes Jeans critical wave-number is dependent on it.

3. Instability analysis of self-gravitational system

We hereinafter focus our attention on Jeans instability of self-gravitational systems in the background of mDM. To deduce the dispersion relation of unstable modes, we split ω into its real and imaginary parts ($\omega=\omega_{\mathrm{R}}+\mathrm{i}\gamma$) and set $\omega_{\mathrm{R}}=0$, i.e., $\xi_{\alpha}=\frac{\mathrm{i}\gamma}{\sqrt{2}k\sigma_{\alpha}}=\mathrm{i}\beta_{\alpha}$, where γ is real positive. Then the dispersion function Eq. (14) can be rewritten as

$$Z(\xi_{\alpha})=-1+\frac{1}{\sqrt{\pi}}Z(\beta_{\alpha}), \tag{18}$$

where $Z(\beta_{\alpha})=\int\frac{\beta_{\alpha}^2}{\beta_{\alpha}^2+X^2}\mathrm{e}^{-X^2}\mathrm{d}X$. By introducing the normalized wave-number k_* $(=\frac{\sigma_{\mathrm{b}}k}{\sqrt{4\pi G\rho_{\mathrm{b}0}}})$ and frequency ω_* $(=\frac{\gamma}{\sqrt{4\pi G\rho_{\mathrm{b}0}}})$, Eq. (12) will be converted to

$$k_*^4-\left[\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1(1-\eta_2)\left(1-\frac{Z(\beta_{\mathrm{d}})}{\sqrt{\pi}}\right)+\left(1-\frac{Z(\beta_{\mathrm{b}})}{\sqrt{\pi}}\right)\right]k_*^2-\frac{\sigma_{\mathrm{b}}^2}{\sigma_{\mathrm{d}}^2}\eta_1\eta_2\left[1-\frac{Z(\beta_{\mathrm{d}})}{\sqrt{\pi}}\right]^2=0, \tag{19}$$

which is the modified dispersion relation for Jeans modes involving mDM. Combining the integral formula (see Ref. [42], Eq. (3.466))

$$\int_0^{\infty}\frac{x^2\mathrm{e}^{-\mu^2x^2}}{x^2+\beta^2}\mathrm{d}x=\frac{\sqrt{\pi}}{2\mu}-\frac{\pi\beta}{2}\mathrm{e}^{\beta^2}\mathrm{erfc}(\beta\mu), \tag{20}$$

we have

$$Z(\beta_\alpha) = \pi\beta_\alpha \mathrm{e}^{\beta_\alpha^2}\mathrm{erfc}(\beta_\alpha). \tag{21}$$

By substituting Eq. (21) into Eq. (19) and only considering the presence of interstellar gas cloud, Eq. (19) can be rewritten as

$$k_*^2 = 1 - \sqrt{\pi}\beta_\alpha \mathrm{e}^{\beta_\alpha^2}\mathrm{erfc}(\beta_\alpha), \tag{22}$$

which is the classical dispersion relation for stellar systems firstly proposed by Binney *et al.*[40] In addition, one can see that Eq. (19) predictably recovers to the neutral DM model[12] if we ignore the effect of mDM,

$$k_*^2 = \frac{\sigma_\mathrm{b}^2\rho_{\mathrm{d}0}}{\sigma_\mathrm{d}^2\rho_{\mathrm{b}0}}\left[1 - \frac{Z(\beta_\mathrm{d})}{\sqrt{\pi}}\right] + \left[1 - \frac{Z(\beta_\mathrm{b})}{\sqrt{\pi}}\right], \tag{23}$$

which further proves the rationality of Eq. (19).

Then, let us now discuss in more detail the unstable modes. It can be found that from Eq. (19) the solution depends on σ_b and σ_d as well as $q_\mathrm{d}/m_\mathrm{d}$. It has been reported that in a typical type Ia supernova remnants,[21] the velocity of shock v_sh begins to slow down to $v_\mathrm{sh} \sim 200$ km/s and the shocked particles obtain kinetic energy via interaction with the ejecta. In this frame, the internal thermal speed of mDM particles approximate to the Milky way virial speed, $\sigma_\mathrm{d} \approx 220$ km/s,[43] and we have assumed here that BM have thermal speed $\sim 0.69 v_\mathrm{sh}$, that is, $\sigma_\mathrm{b} \approx 138$ km/s.[21] Based on the strict constraint of mDM mass and charge, here we adopt the upper value of mDM charge-to-mass ratio $q_\mathrm{d}/m_\mathrm{d} \approx 10^{-3}\ e/\mathrm{MeV}$, as previously mentioned. The numerical results of Eq. (19) are shown in Fig. 1. Here, we plot the normalized frequency ω_*^2 vs. normalized wave-number k_*^2 for different parameter f_dm ($\equiv n_{\mathrm{md}0}/n_{\mathrm{d}0}$). The black curve indicates the dispersion relation for the self-gravitational systems with BM alone, while other lines denote the dispersion relation curves with different f_dm and fixed value of $q_\mathrm{d}/m_\mathrm{d}$. It should be pointed out that the black curve corresponds to the classical result of stellar systems, which is identical to the black line in Fig. 5-1 of Ref. [40]. The dashed-blue curve corresponds to the dispersion relation for self-gravitational systems composed by BM and neutral DM. As can be seen, with the existence of neutral DM, the self-gravitational systems is more unstable even for wave-numbers of the perturbation greater than the classical critical Jeans number (k_Jb). In other words, the interaction between the BM and neutral DM allows the self-gravitational systems to become more unstable than the one only composed by BM, and therefore, structures are more easily formed in self-gravitational systems dominated by DM. This phenomenon occurs because DM is more easily to agglomerate comparing to the BM and then gravitational field generated from this initial agglomerate will rapidly attracts those BM to form a preliminary structure.[11] In addition, endowing the DM with a small fractional 'mini-charge' modifies the dispersion relation of self-gravitational systems, i.e., with the increasing of the parameter f_dm, the dispersion relation constantly rise along the ω_*^2-axis, which means that self-gravitational systems will become more and more stable accompanying the increasing of mDM particles, in other words, mDM plays a significant role on the process of star formation. Physically, it can be viewed as the result of competition between the electromagnetic interaction and gravitational interaction: the electrostatic force generated by mDM oscillation resists gravitational force to inhibit formation of the initial agglomerate, and therefore, the structure formation will become more difficult in the presence of mDM.

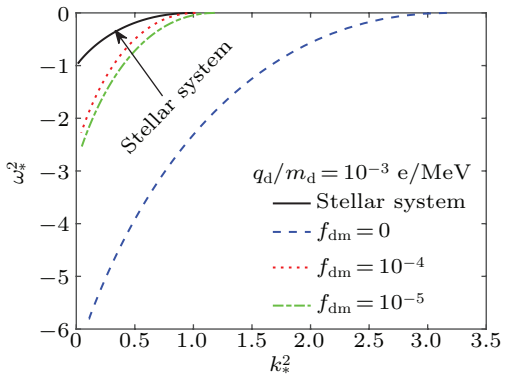


Fig. 1. The normalized frequency $\omega_*^2 = \gamma^2/4\pi G\rho_{\mathrm{b}0}$ versus the normalized wave number $k_*^2 = k^2/k_\mathrm{Jb}^2$ for different values of f_dm parameter, where the black curve corresponds to the classical dispersion relation line in the interstellar systems.

4. Discussion and conclusion

We have discussed the impact of the recently proposed mDM particles on the gravitational collapse of a self gravitatioanl system in the framework of kinetic theory. The collisionless Boltzmann equation together with Poisson equation have been combined to obtain the dispersion relation for Jeans instability of the self gravitational systems composed by the mDM and BM. And then, the new modified Jeans critical wave-number and mass are obtained. It is generally known that if the perturbation's wave-number k is smaller than Jeans critical wave-number k_J or the mass M is larger than Jeans critical mass M_J, the interstellar gas clouds will collapse to form proto-stars under the effect of self-gravity, and the collapse time scale is the free fall time scale $\tau_\mathrm{ff} = \sqrt{r^3/GM}$. For a typical interstellar gas cloud with size ~ 2 pc, density $\sim 10^{-19}$ kg$\cdot$m^{-3} and Jeans length $\lambda_\mathrm{J} \approx 30$ pc, it will keep stable to against gravitational instability.[11] However, in the light of current observation results, there have found some gigantic cold gas clouds whose age is larger than their typical Jeans time.[44] Conversely, some research[45] has shown that the collapse time for entire clouds is much shorter than its free-fall time if a large number of energy stored in entire clouds are dissipated by some external factors. To explain this discrepancy, Mac Low *et al.*[46] have performed numerical studies of decaying turbulence with and without magnetic fields to indicate

that the long lifetimes in clouds may be the results of external driving. On the other hand, the gravitational microlensing phenomenon of the stars in the large magellanic has proved the existence of DM halo in our universe. Combining the results in our work, the consideration of mDM around the interstellar gas clouds allows the evolution of interstellar gas clouds to become more enigmatic, because the electric field forces generated by charged DM will interact with other particles and background magnetic field to protect the gigan tic molecular clouds from gravitational collapse. We can, thus, conclude that consideration of mDM in self-gravitational systems may provide a promising way to overcome some discrepancies in the evolution and dynamics of interstellar gas clouds.

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