CHAPTER-1

AN OVERVIEW OF SELF-GRAVITATING DUSTY PLASMAS: DUST MOLECULAR CLOUDS

Abstract: *This chapter highlights on self-gravitating dust molecular clouds, their types and various involved kinetic processes. The most relevant properties of astrophysical context like dust-charging, instabilities and physical characteristics are concisely summarized. Finally, it throws light on why we are enthusiastically motivated towards in-depth exploration of astrophysical dusty plasmas with the modern computational techniques in different realistic astrophysical situations.*

1.1 INTRODUCTION

Astrophysicists, astronomers and space scientists have confirmed long ago that plasma, the unique state of matter rich in collective kinetic degrees of freedom, is predominant almost everywhere in the universe. Its appearance varies from diffused interstellar clouds through stellar coronas to dense interiors of stellar structures. It is well known that much of the solid part of the universe is in the form of dust. The major form of the astrophysical structures and their atmospheres lie in dusty plasmas. Therefore, plasma and dust are the two main ingredients of the galactic structures in the universe. The interaction between both has unfolded many new research areas of emerging dusty plasmas, equilibria and stability properties. The dusty plasma is a normal electron-ion plasma with an additional component of micron or submicron sized impurity particles. The presence of dust in astrophysical environments has been known for a long time on the basis of different types of remote-sensing observations, astronomical detections and many space-based *in-situ* measurements [1-10]. Thus, dust is a ubiquitous component of space, found in interstellar clouds, circumstellar media, nebulae, solar system, cometary tails, planetary rings and noctilucent clouds.

1.2 PHYSICAL PROPERTIES OF THE DUST

We usually observe large dark regions in the photograph of galaxies. The presence of dark regions is attributable to the dust-blocking of the light between us and radiating stars. In other words, these regions evolve due to the extinction of light upon the dust particulates. This is a strong evidence displaying the presence of enormous quantity of dust grains in space and astrophysical environments [6-10]. The grains are not uniformly distributed in the interstellar media, rather they are mostly confined to interstellar clouds known as Dust Molecular Clouds (DMCs). The DMCs are the dense molecular phase regions of the self-gravitating Inter-Stellar Medium (ISM), which are well-shielded against the dissociating effects of interstellar ultraviolet radiations [6-7]. Stars, planets and other galactic objects are born exclusively within this molecular phase region of the ISM. The cool and dense characteristics of the DMCs relative to the interstellar media makes them unique to initiate star formulation mechanisms by satisfying the Jeans criterion of self-gravitational collapse [6-8]. Recently, the observations from the Hubble telescope have shown the possibility of the existence of such DMCs in the HII region [2] of ISM. In the DMCs, the presence of ionized gas and dust makes them very complex, by changing all the collective physical properties of ideal two-component plasma. Thus, before going to discuss the various physical mechanisms of the DMCs leading to star and other galactic objects formation, it is indeed necessary to discuss the various physical properties of the interstellar grains.

The dust composition in the interstellar media can be divided into two classes on the basis of their formation origin [5, 7-9].

(1) Dust originating from Carbon-rich Giants (C-Gs), Oxygen-rich Giants (O-Gs), Planetary Nebulae (PN), Novae (N) and, possibly, Supernovae (SN):

Silicates ($(SiO_4)^{4-}$), Graphite (C), Amorphous Carbon (aC), Polycyclic Aromatic Hydrocarbon molecules (PAH), Silicon Carbide (SiC) and Magnesium Sulfide (MgS).

(2) Dust originating from interstellar media itself:

Icy grain mantles, consisting of simple molecules (e.g., H_2O, NH_3, CH_3OH and CO) and organic refractory grain mantles, which are rich in carbon and oxygen.

Usually, to avoid complications, spherical grain model is used for depicting the shape of the grains as shown in figure 1.1. But, the observed polarization of light passing through the grains demands that grains are not perfect spheres. If the grains were perfect spheres, there would be no preferred direction, and there would be no way of producing the polarization. Therefore, in reality, grains are apparently elongated (rod-like), like cigars, or flattened like disks [5, 7-9]. These types of non-spherical dust grains mostly consists of amorphous silicates along with carbonaceous component, such as graphite, amorphous carbon (e.g., soot), organic grain mantles (e.g., mixed polymers), and so forth [5, 7-9]. The existing evidences indicate that grains are usually nonuniform in composition [5, 7-9], they are composed of heterogeneous multilayers of different constituents starting from the grain core to outer surface as shown in schematic diagram (Figure 1.1) below.

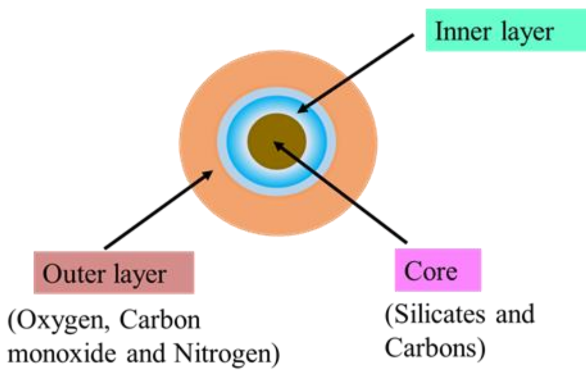

Figure 1.1 *Schematic diagram of the morphological shape of a spherical dust gain at normal temperature (T_n K) in interstellar space. All the concentric shielding layers, composed of different chemical substances, get evaporated and ionized at plasma temperature (T_p K >> T_n K), leaving behind only the dust core electrically charged in the space.*

The core is made up of silicates and carbons. The inner surface, just adjacent after the core, is formed with water and ammonia at normal temperature (T_p K >> T_n K); and the outer surface with oxygen, carbon monoxide and nitrogen [5, 8-9]. They are massive ($\sim 10^9$ times the protonic mass) and their average scale-size length lies in the range $\sim 10^{-9}$ - 10^{-3} m [1, 4-5, 10-12]. The mass of the grains may vary between 10^{-21} - 10^{-9} kg in the ISM [1, 4-5, 9-12]. The upper limit of the dust mass density in the ISM is $\rho_d = m_d n_d \sim 3\times10^{-21}$ kg m^{-3} [4-5, 9-12]. For instant perception, all the physical properties of the grains [1, 4-5, 10-12] are presented in Table 1.1 below.

Table 1.1: Physical properties of interstellar dust grains

Number density n_d (m^{-3})	Temperature T_d (eV)	Scale-size length L_d (m)	Mass m_d (kg)	Charge q_d (C)
$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-2}$	$10^{-9} - 10^{-3}$	$10^{-21} - 10^{-9}$	$\pm1.6\times10^{-19} - 1.6\times10^{-15}$

1.3 DUST CHARGING MECHANISMS

In the interstellar media, the charge acquired by the grains is principal for the understanding of the various interesting physical phenomena of astrophysical environments [1-12]. It is well known that, near the interstellar DMCs, we have new born stars, associated emission nebula or other ionizing sources. As a result, some part of the gas in the DMCs are always ionized and the dust grains present there gets charged by the electron-ion bombardment mechanism [3-12]. The other important processes that provide the dust grains with a charge are the secondary electron emission, photoemission, thermionic emission, field emission, and impact ionization with neutrals [3-12]. Due to the higher random flux of the electrons, the grains typically are negatively charged in the plasma [3-12]. However, positive dust-charges may also be achieved when photoemission or the emission of secondary electrons are dominant in the clouds. When the dust are negatively charged in the DMCs, a large part of the electrons are absorbed by the grains, and there will be an overweight of free positively charged ions compared to the free electrons. In such a situation, the escaping of the ions from the clouds is halted due to the balance between the ionic pressure and negative potential of the charged grains [3-12]. More precisely, the cloud dust particles get electrically charged mainly via the following mechanisms.

1.3.1 Plasma Particles Sticking Mechanism

The plasma particles bombardment on the dust surface makes them electrically charged. In the DMCs, at any given temperature, the dust grains get negatively charged due to the higher thermal velocity of the electrons as compared to that of the heavier ions [3-12]. The impinging plasma particles onto a dust grain can also induce the electron and ion currents to the surface. These currents are functions of the surface potential (ϕ_s) of a grain, and the sum of the currents due to different charging processes determines the charging rate (dq_d/dt) of the grain [3-12]. Here, q_d is the charge of the grain. A particle with zero charge that is immersed in a plasma will gradually charge up by collecting the electron and ion currents according to the relation,

$$\frac{dq_d}{dt} = I_e + I_i, \tag{1.1}$$

where, I_e, and I_i are the local microscopic electron and ion currents entering the dust grains. The characteristic time-scale for dust motion is small ($\sim 10^{-3}$ s), whereas the dust-charging time is further small ($\sim 10^{-8}$ s) in normal plasma conditions [13]. Thus, the dust motion is too slow to neutralize the electron-ion currents [14]. It follows that $dq_d/dt << I_e$ and I_i. Therefore, the current balance equation (1.1) become,

$$\frac{dq_d}{dt} = I_e + I_i = 0. \tag{1.2}$$

The charge equilibrium occurs when equation (1.2) is fulfilled. The charge of the dust grain is related to the surface potential by $q_d = C\phi_s$, where C is the capacitance of a grain in a plasma [3-12]. When the plasma ions are sticking on the grains, they get positively charged, which tends to raise the grain surface potential. The grain surface potential affects the currents of the electrons and the ions. The surface potential is often negative, repelling electrons and attracting ions [3-12]. The electron current is then reduced and the ion current gets enhanced. Charging of micron-sized grains can lead to several thousand electron charges, for masses of million to billion proton masses. Due to the electric charge attained by the dust grains in the plasma, they can interact with the plasma electric field or with the electron and ion flows, as well as with each other via electric forces. The electron and ion currents for the charging of the grains are calculated by using the orbital motion limited theory [3-4] as follows,

$$I_e = -\pi e n_e a^2 \sqrt{\frac{8T_e}{\pi m_e}} \exp\left(\frac{e\phi_f}{T_e}\right), \text{ and} \tag{1.3}$$

$$I_i = \pi e n_i a^2 \sqrt{\frac{8T_i}{\pi m_i}} \left(1 - \frac{e\phi_f}{T_i}\right), \tag{1.4}$$

where, a is the grain radius. ϕ_f is the grain floating potential, where the electron, and the ion current neutralize each other. T_e and T_i are temperatures (in eV) of the electrons (mass m_e), and the ions (mass m_i), respectively.

1.3.2 Secondary Electron Emission

The secondary electron emission is a process, which occurs due to the high energetic electrons and ions bombardment to the grain surface [3-12]. The energetic plasma particles ionize the grain material and eject the electrons from the surface. The flux of the secondary electrons depends on the energy of the plasma particles and on the material properties of the grains. The emission of the secondary electrons can be caused both by the electrons and ions. When the high energetic electrons strike the grain surface, it excites the electrons of grain material, and finally knock them out from the surface. Generally, one sufficiently energetic electron can produce several secondary electrons. When the electron strikes the dust grain surface, several things can happen: an electron may be scattered or reflected back by the grain surface without penetration. It may stop and stick to the grain surface. If the electron penetrates the dust grain surface, it may excite other electrons which may then be emitted at the surface. Some electrons may pass through the grain and leave with a little loss of energy. When the low energy ions (< 1 keV) are incident on a grain surface, they may become neutralized by the electrons tunneling from within the grain across the potential barrier. The energy released can then excite other electrons leading to surface emission.

1.3.3 Photoemission

The DMCs in the interstellar media are always in exposure with various interstellar and cosmical radiative effects. The constituent dust grains are electrically charged by the impact of those radiations [3-12]. In addition, the ultraviolet radiations get incident on the grain surface, which get absorbed thereby releasing electrons termed as 'photoelectrons'. The release of photoelectrons makes the grains positively charged. Photoelectrons can be emitted from the surface of a dust grain when there is an incoming flux of photons with energy $h\nu$ (h is Planck's constant and ν is the photon frequency) exceeding the photoelectric work function of the grain (W_f). The emission of photoelectrons depend on (i) the frequency (energy) of the incident photons, (ii) the grain surface area, (iii) the material properties of the grain, i.e., its photoemission efficiency, and (iv) the positive grain surface potential, which may in principle, recapture a fraction of photoelectrons.

1.3.4 Other Charging Processes

The DMCs are now known to be electrically charged by a number of physical processes as discussed above. In addition to above, many other physical processes in the ISM can also make the grains electrically charged [3-12]. Few of them, such as thermionic emission, field emission, radioactivity, and impact ionization, can be technically important under circumstances which are mostly relevant under the extreme conditions especially for space and astrophysical environments.

In the interstellar clouds, the charge of the dust is not static: it may vary spatiotemporally due to the collective charging processes as discussed above. So, the grain charge $q_d = Z_d e$, for example, may fluctuate between $\pm 1e$ and 0 in the cold (dark) clouds at plasma temperature $T_p < 3\times10^{-3}$ eV; and $q_d > 100e$ in the HII region, where $T_p \sim 1$ eV [3-10]. The grain charge in the normal interstellar media may vary in the range $q_d \sim \pm 1e - 10^4 e$ ($\pm 1.6\times10^{-19} - 1.6\times10^{-15}$C) [3-12]. Thus, the grain charge behaves as a dynamical variable owing mainly due to the random attachment of the electrons and ions to grain surface. In some cases, for simplicity, charge of the dust grain is considered static under the approximation that the dust charging time scale (τ_{ch} ~ 10^{-8} s) is much smaller than the massive dust response time scale ($\tau_{dr} \sim 10^{-3}$ s), which is typically the wave time scale of low-frequency dust-acoustic mode [4-5, 13].

It has been found that the presence of charged dust grains (with or without charge fluctuations) in not only modifies the usually existing plasma wave spectra [1, 3-7], but also gives rise to different low-frequency waves and oscillations [1, 4, 12, 15]. The modification of the wave spectra occurs due to the reduction in number density of the plasma thermal species; and due to subsequent introduction of new time scales [1, 4, 12, 15]. The existence of such modified eigenmodes in diverse situations has been studied theoretically [12-15] as well as experimentally [16] in different realistic situations. To name a few, *Rao et al*. have first theoretically predicted the existence of low-frequency nonlinear eigenmodes in unmagnetized dust-electron-ion plasma, where the charged grains provide the inertia; and the pressure of the inertialess electrons and ions provides the corresponding restoring force triggering longitudinal plasma sound modes [17].

1.4 JEANS INSTABILITY AND STAR FORMATION

In the dense sites of the ISM, the gravity is responsible for gathering large-scale gaseous matter into the form of self-gravitating structures through the well-established process of gravitational condensation [18-20]. In a gravitationally bounded DMC in spherically symmetric geometry, there are two major operating forces acting in opposite directions discussed as in the following.

(1) Gravitational force (F_g):

Gravitational force (F_g) arises due to the presence of the massive-dust grains. The contribution of the electrons and ions to the F_g are generally neglected due to their very small gravitational masses as compared to that of the dust grains. Gravity always plays a role to pull the cloud constituents in the inward direction. The effect of inward pulling increases with increase in the grain mass density $\rho_d = m_d n_d$ contributing to the net cloud mass. Thus, denser the cloud, stronger F_g will be acting on it.

(2) Repulsive force (F_r):

Repulsive force (F_r) in the clouds arises due to the thermal motion of the atoms, molecules, and other constituents. The name itself reveals that, this force tends to push the gaseous matter of the clouds outwards. The F_r is the resulting force due to the gas and magnetic pressure inside the clouds. As a consequence, higher the temperature of the cloud, stronger is the F_r-effect.

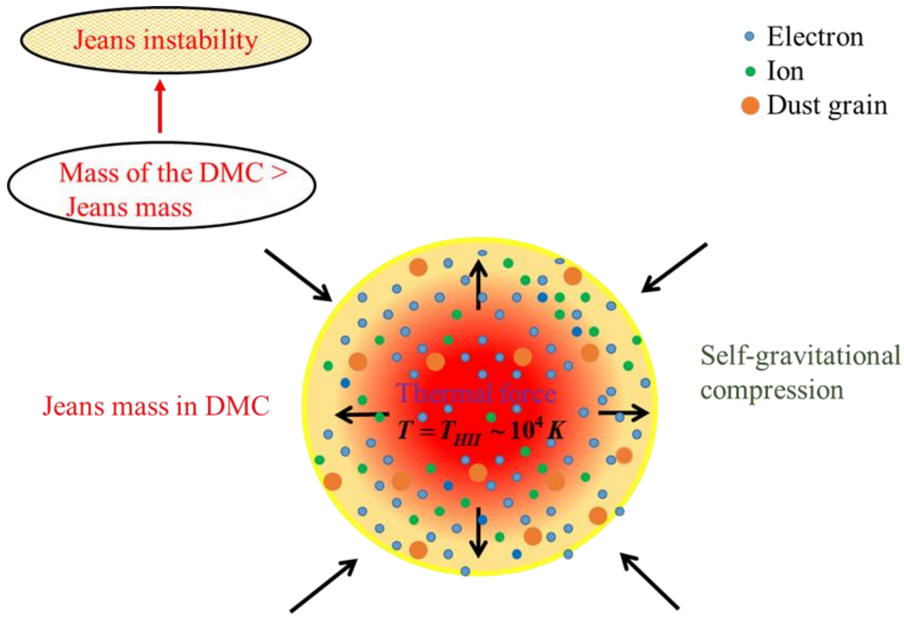

Figure 1.2 *Schematic diagram of a normal spherical DMC.*

The DMCs are in bounded equilibrium state, when both the forces balance each other [18-20]. Figure 1.2 pictorially shows a normal DMC in hydrostatic equilibrium. It consists of dust grains as the inertial species and electrons (ions) as the thermal species. The star and other galactic unit formation in such DMCs occurs mainly due to the self-gravitational collapse in fulfilment with the Jeans criterion [20]. The self-gravitational collapse occurs when F_g overcomes F_r (i.e., $F_g > F_r$). Thus, it is important to have a comprehensive conceptional background of the various instabilities that are caused by the self-gravitational collapse mechanism thereby leading to galactic unit formation. The instability caused due to the self-gravitational collapse is known as the Jeans instability, after Jeans, who for the first time has predicted the instability of self-gravitating nebular systems leading to condensation [21]. The Jeans instability is defined as a process in which a slight rearrangement of uniform distribution of mass by the effect of self-gravitation leads to the further localized condensation of the gaseous constituents [6-7, 18, 21]. The basic criteria for the onset of the Jeans instability is that the mass of the DMC must be greater than the critical Jeans mass [6-7, 18, 21]. Now, to have a clearer idea about the Jeans instability, we consider a simplified unmagnetized model of a DMC under fluid model as follows,

$$\frac{\partial \rho_d}{\partial t} + \nabla.(\rho_d \boldsymbol{v}_d) = 0 \text{, and} \tag{1.5}$$

$$\rho_d \left[\frac{\partial \boldsymbol{v}_d}{\partial t} + (\boldsymbol{v}_d . \nabla) \boldsymbol{v}_d \right] = -\nabla P - \rho_d \nabla \Psi \ . \tag{1.6}$$

where, the gravitational acceleration is $g = -\nabla \Psi$, and the self-gravitational potential Ψ satisfies the coupling Poisson equation as shown below,

$$\nabla^2 \Psi = 4\pi G \rho_d \ . \tag{1.7}$$

Here, $\rho_d = m_d n_d$ is the grain mass density, v_d is the flow velocity of the grains, P is the thermal pressure of the DMC, and G is the universal gravitational constant. We suppose that there exists an equilibrium set of steady-state solutions, as $\rho_{d0}(r)$, $v_{d0}(r)$, $P_0(r)$, and $\Psi_0(r)$, satisfying equations (1.5)-(1.7) with $\partial v_{d0} / \partial t = \partial \rho_{d0} / \partial t = 0$. To determine the conditions under which this equilibrium solution is unstable to gravitational effects, we introduce methodologically linear perturbation to the dependent parameters of equations (1.5)-(1.7) around the equilibrium point. Now, by applying standard methodology of the Fourier analysis, we obtain the linear dispersion relation of the Jeans instability as given below.

$$\omega^2 = c_s^2 k^2 - 4\pi G \rho_{do} , \tag{1.8}$$

where, c_s is the sound speed. Defining $k_J = \sqrt{4\pi G \rho_{do}} / c_s$ as the critical Jeans wave number, equation (1.8) now becomes,

$$\omega^2 = (k^2 - k_J^2) c_s^2 \ . \tag{1.9}$$

Now, a closed inspection into equation (1.9) allows us to distinguish two different cases:

Case 1: If $k > k_J$, then ω is real. The perturbation varies periodically with time and the equilibrium is stable with respect to this perturbation.

Case 2: If $k < k_J$, then ω becomes imaginary, corresponding to exponential growth. Therefore, there exist perturbations which grow exponentially with time, i.e., the equilibrium is unstable. A dense region in the cloud becomes denser and denser, leading to the gravitational collapse. The Jeans instability, therefore, occurs for wavelength defined as,

$$\lambda > \lambda_J = c_s \sqrt{\frac{\pi}{G\rho_{do}}} \ . \tag{1.10}$$

The critical wavelength λ_J is called the Jeans length. All spatial scales larger than λ_J are gravitationally unstable. The mass contained within a spherical volume having a diameter equal to that of the Jeans length is called the Jeans mass, which is calculated as,

$$M_J = \frac{4\pi}{3}\rho_{do}\left(\frac{1}{2}\lambda_J\right)^3 = \frac{\pi^{5/2}}{6}\frac{c_s^3}{G^{3/2}\rho_{do}^{1/2}} \ . \tag{1.11}$$

In astrophysical scenario, if the mass of the cloud is greater than the critical Jeans mass, it becomes unstable and starts collapsing [6-7, 18-21]. Ordinary clouds absorb light from nearby stars, which heats them up, raising their internal pressure, and preventing them from collapsing. The DMCs are so big and dense that their outer layers completely block the light from surrounding stars. Deep inside them, temperature drops so low that the repulsive force becomes very weak. If a small region inside cloud becomes a little denser than the average value, the self-gravitational force exceeds the repulsive force and begins to pull the cloud inwards on itself. The cores are the regions where gravitational collapse starts. Once it gets started, the process feeds on itself. As the cloud collapses, it becomes denser, which increases the gravitational force pulling it inwards, causes it to collapse further. This results in increasing its density even more and so on. A collapsing core fragments into many pieces having size on the Jeans length order, each of which continues to collapse on its own self-gravity. Subsequently, the temperature of the sub-structures formed via fragmentation processes of the cloud increases enormously due to self-gravitational contraction, which in turn, results in giving birth to prestellar cores or protostars (optically thick initial stellar stage).

1.4.1 Jeans swindle

Jeans in 1902 has derived the condition for the widely known Jeans instability by considering the gaseous cloud under homogeneous equilibrium configuration. In homogeneous equilibrium, $\nabla \Psi_0 = 0$, which is completely unphysical. If $\nabla \Psi_0 = 0$ everywhere, then we should have $\nabla^2 \Psi_0 = 0$, and therefore $\rho_{d0} = 0$, which is the condition for a vacuum. Thus, the fault in the above calculation has been corrected by considering the term 'Jeans swindle'. This physically means that self-gravitational potential is sourced only by density fluctuations of the infinite uniform homogeneous background medium [6-7, 18, 22-23]. The Jeans assumption (ad hoc) for the self-gravitating uniform homogeneous medium on the zeroth-order may not be the most suitable one, but it allows us to treat the self-gravitating inhomogeneous plasma dynamics analytically in a simplified way [18, 22-23]. The results based on this initially homogenization assumption in most of the astrophysical cases have been found to lie close to realistic picture [22-23].

1.5 TYPES OF MOLECULAR CLOUDS

Interstellar Molecular Clouds (IMCs) are very important for understanding the formation mechanism of stars, planets, and other galactic objects due to their unique physical properties relative to the rest of the ISM. The IMCs are very cool and dense parts of the ISM, which make them suitable for the birth process of new protostellar cores. Based mainly on their physical properties, the IMCs are categorized into different classes [6-7, 24] discussed as follows.

(1) Globular Clouds (GCs):

Globular clouds (GCs) are the isolated dark cores consisting of dense cosmic dust and gaseous matter in which star formation takes place [6-7, 24]. The GCs have been first observed by famous astronomer, Bart Bok, in 1940. So, after his name, the globules are sometimes called 'Bok globules'. They are found in the HII regions of the clouds, and typically have an average (mean fluid) population density lying in the range $n_{GC} \sim 10^{9}$-10^{10} m^{-3}, temperature $T_{GC} \sim 10^{-3}$ eV, net mass $M_{GC} \sim 10^{32}$-10^{33} kg, and scale-size length $L_{GC} \sim 3.08\times10^{16}$ m [6-7, 24]. The Bok globules generally have a simple, round structure, which makes them fascinating to explore. The GCs can physically be detected by probing spectral lines and associated spectroscopic signatures corresponding to molecules like CO, CS, and so on. For instance, B335 is an example of the GCs.

(2) Dark Clouds (DCs):

Dark clouds (DCs) are dormant, low-mass clouds. The DCs have an average population density $n_{DC} \sim 10^{9}$ m^{-3} and temperature $T_{DC} \sim 10^{-3}$ eV, which are similar to those of the GCs [6-7, 24]. The scale-size length of the cloud lies in the range $L_{DC} = 1.54\times10^{17}$-$3.08\times10^{17}$ m [6-7, 24]. It is very challenging to define the actual dimension of the DCs due to the typical arrangement of numbers of small sub-clouds inside them. The net mass of the dark cloud is $M_{DC} \sim 1.98\times10^{34}$ kg, which is $\sim 10^{4}$ times the solar mass. The DCs are experimentally detected by dark patches, infrared emissions, spectroscopic signatures corresponding to constituent molecules, and so forth. To name a few, examples of the DCs are Taurus-Auriga, B1, and so forth.

(3) Giant Molecular Clouds (GMCs):

Large, dense molecular clouds in the ISM are called Giant Molecular Clouds (GMCs). These are composed mainly of molecular hydrogen and helium, with small fraction of heavier gases [6-7, 24]. The GMCs are known to be the birth places of new stars, planets, and other astrophysical objects depending on the interplaying binding forces leading to equilibrium structures. From morphological point of view, these are generally elongated in shape, with scale-size length lying in the range $L_{GMC} \sim 1.54\times10^{18}$ - 3.08×10^{18} m. The average number density of the cloud is $n_{GMC} > 3\times10^{8}$ m^{-3}, but slightly less than the DCs. These giant clouds are relatively warmer, with temperature lying in the range $T_{GMC} \sim 1.4\times10^{-3} - 5.0\times10^{-3}$ eV [6-7, 24]. The GMCs are essentially compound structures, which are created through the aggregation of smaller clumps of gases into larger structures. The clumps are relatively high-density areas of the GMCs as compared with the inter-clump media. The GMC net mass is $M_{GMC} \sim 10^{35}$ kg, which is $\sim 10^{5}$ times larger than the solar mass. They are detected by long-wavelength spectrometer aboard the Infrared Space Observatory (ISO), which map the infrared emission spectrum from them. The most common and well known example of the GMC is the Orion molecular cloud.

(4) Dense Dust Clouds (DDCs):

Dense Dust clouds (DDCs) are the dense compact molecular cores, which reside in some larger molecular complex structures like the GMCs. These are denser and warmer than the surrounding clouds [6-7, 24]. The DDCs have average population density lying in the range $n_{DDC} \sim 10^{11}$-10^{12} m^{-3}, temperature $T_{DDC} \sim 3.0\times10^{-3}$-$1.0\times10^{-2}$ eV, net mass $M_{DDC} \sim 10^{33}$ kg, and scale-size length $L_{DDC} \sim 3.08\times10^{16}$ m [6-7, 24]. These DDCs are the places in the GMCs, where the star formation mechanism takes place. Some dense cores are also found to exist in the DCs and GCs. The DDCs are observed and analyzed by probing the spectral lines and associated spectroscopic signatures originated from the constituent molecules like CO, CS, H_2CO, and so on. For an instance, TMC-1 is a well-known example of the DDCs.

(5) Diffuse Dust Molecular Clouds (DDMCs):

Diffuse Molecular Clouds (DDMCs) are present in the ISM. The DDMCs have average population density $n_{DDMC} > 10^{7}$ m^{-3}, temperature in the range $T_{DDMC} \sim 5.0\times10^{-3}$-$1.0\times10^{-2}$ eV, net mass $M_{DDMC} \sim 10^{31}$ kg, and scale-size length $L_{DDMC} \sim 9.25\times10^{16}$ m [6-7, 24]. They are detected by optical and ultraviolet absorption lines, 21 cm observations. One of the most familiar example of the DDMCs is the ξ-Ophiuchi.

(6) Cirrus Clouds (CCs):

Cirrus clouds (CCs) are considerably smaller clouds with low visual extinction, and therefore, not easily detected by their obscuration of stars [6-7, 24]. Their nomenclature originates from their appearance in the infrared as observed by the Infrared Astronomical Satellite (IRAS). Most of the CCs contain only cold HI gas. The DCs have average number density in the range $n_{CC} \sim 10^7\text{-}10^9$ m^{-3}, and temperature $T_{CC} \sim 10^{-3}\text{-}10^{-2}$ eV [6-7, 24].

(7) Supernova Remnant Clouds (SRCs):

Supernova Remnant Clouds (SRCs) are warm clouds with low densities [6-7, 24]. The SNRs have average population density $n_{SRC} \sim 10^6$ m^{-3}, and temperature in the range $T_{SRC} \sim 1\text{-}10^3$ eV [6-7, 24]. These clouds are experimentally observed by the Radio and X-ray astronomies.

1.6 MOTIVATION

Based on the present academic structures and curricula, it is felt that, in Indian colleges and universities, there are some noticeable lacking in teaching-learning processes to develop the basic conceptual frameworks interactively to the students on subjects, particularly concerned with space and astrophysical scenario. Apart from that, to my knowledge and experience, main drawbacks of the present education system are as follows.

(1) Present education system focuses more on scores rather than creative knowledge.

(2) In India, it may be noticed that youngsters generally prefer to teaching profession because mainly of no-vacancy elsewhere. So, in such circumstances, the teaching-class is neither trained well to teach, nor do they have much knowledge about the concerned subjects.

(3) Besides, it is understood that teachers are overloaded with many non-academic unavoidable responsibilities, which prevent them from advanced intellectual up-gradation of innovative scientific wisdom to be shared with the taught-class. It indicates that only the persons with prior updated experience and exhaustive knowledge coming to teaching profession can make proper justice to their primary jobs.

(4) Further, most of our educational organizations have good infrastructure and good faculty members, but motivation to the students towards scientific research seems to be weak.

(5) Lastly, the course structures and syllabi indeed require regular revisions and updates for proper teaching-learning exchange processes, which has yet to be timely followed.

Thus, after realizing the above lacunae, I strongly believe that there is a great need for fruitful and creative efforts to be made in improving the educational system being traditionally followed in educational institutes for our national growth. In addition, I feel that the conventionally followed-up strategy in class rooms could be much better, if assisted with modern technology and equipment like computer graphics, multi-media, animated slide-show, etc. It has been known to me from school days that advanced tech-academic training is well earned during Ph.D. period only. This belief and prior knowledge motivate me to do scientific exploration and research with a view to gather requisite technological experiences, so that I can become a part of the educational system to do welfare of the students in tech-academic interface like what demand the current scenario; innovatively, creatively, and productively.

Besides, the teaching as a career has been very attractive to me since childhood. It has been my long-lasting dream to motivate the student communities towards the quality education and influencing them for innovative investigations by explaining various interesting physical phenomena of the space and astrophysical environments in a simpler demonstrative way. In parallel to the inner zeal to serve the society, some other justified reasons also motivate me thoroughly towards the scientific exploration complied in the present thesis discussed as below.

In the interstellar self-gravitating DMCs, a rich spectrum of linear and nonlinear collective eigenmodes, oscillations and fluctuations are well-known to exist in different space and astrophysical conditions. The equilibrium dynamics of such DMCs is also very complex. It may, however, be noted that the equilibria and full spatiotemporal evolutionary dynamics of fluctuation eigenmodes of self-gravitating clouds are still not completely understood. The cloud dynamics is extremely important in astrophysical situations because it ultimately produces the initial conditions for the Jeans instability and helps in understanding the basic physics behind the formation mechanism of fascinating stars, planets, and so on. So, we are motivated towards this thesis work by developing interest in understanding the spatiotemporal excitation and evolution of various eigenmode structures in self-gravitating DMCs, including all the realistic agencies in a quasi-neutral configuration on the Jeans scale. We are also motivated by the curiosity of understanding the role of gravito-electrostatic eigenmodes in the collapse of DMCs and microphysical processes behind the birth of new protostars and the formation of the universe as a whole.

1.7 OBJECTIVES

It is seen that interstellar DMCs are very complicated inhomogeneous self-gravitating systems. To the best of my knowledge, the equilibria and stability analyses of such systems in different realistic astrophysical environments is not known completely till now. The objective of this thesis is to develop strategic theoretical models to explore the equilibria and fluctuations systematically from new unavoidable perspectives to understand the mystery of our dusty universe and its formation.

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