CHAPTER-1

AN OVERVIEW OF ASTROPHYSICAL COMPLEX FLUIDS

Abstract: *This Chapter presents a brief overview of complex plasma fluids and their physical properties in the astrophysical scenarios. The existence of dusty plasmas in various space and astrophysical domains of the Universe is specially highlighted. The dynamical mechanisms behind the excitation of various collective modes in such plasmas are concisely summarised. The significance of the Jeans instability and the basic mechanism behind subsequent proto-structure formation are concisely described. The viscoelastic behaviour of strongly correlated dusty plasmas is elaborately reviewed. This review is relevant to various compact astrostructures and their circumvent environments. It widely includes white dwarf stars, neutron stars, Jovian planetary interiors, and so forth.*

1.1 INTRODUCTION

It is well known that the plasma is a unique state of matter in comparison with the common state of matter, such as solid, liquid, and gaseous phase of matter. It is an electrically quasi-neutral admixture of statistically large number of charged particles (electrons and ions) and small number of neutrals [1, 2]. It shows collective behaviour due to the presence of long-range electromagnetic forces acting among the charged particles, thereby allowing them to interact simultaneously. It is in contrast with the short-range Vander Waal interaction forces dominant in neutral gaseous fluids. The term "quasi-neutral" means that there are approximately equal number of negative charge (electrons) and positive charge (ions) making the whole plasma electrically neutral [1, 2]. This quasi-neutrality hold goods on super-critical or hyper-critical scale lengths over the plasma Debye screening scale length. In Greek, the word 'plasma' means 'something molded or fabricated' [1, 2]. In 1929, it was first named by, an American physical chemist, Irving Langmuir in analogy with blood plasma carrying the red blood cells (RBCs), white blood cells (WBCs), platelets to describe the innermost equilibrium part of the gas-filled mercury discharge tubes [1, 2].

It is extensively seen that 99.99% of the visible matter of the Universe is in the plasma state. The interstellar medium (ISM), which is the space between the galaxies, is filled up with matter and radiation. But, matter coupled with intense radiations gets ionized to form the plasma state. It is well known accordingly that about 99% of the ISM is in the plasma state (mostly hydrogen (91%), helium (8.9%), other heavier elements (0.1%)), and remaining 1% is of micron-submicron sized dust grains in the solid phase [3-5].

The presence of dust particulates in plasmas increase the complexity of the dynamical processes occurring therein. This normal plasma with dust particulates can be classified as "dust in a plasma" or as "dusty plasma" depending on the order of its characteristic lengths: the dust grain radius (R), average intergrain distance (a_d), and Debye length (λ_D). The plasma system with $R << \lambda_D < a_d$ is termed as "dust in a plasma" where the charged dust grain is considered as a collection of isolated screened dust grain. In contrast, the plasma system with $R << a_d < \lambda_D$ is termed as "dusty plasma" where charged dust grains show collective behaviour [4, 5]. A few examples of dusty plasmas existing in diverse astrophysical and space environs are dust molecular clouds (DMCs), interplanetary space, comets, planetary rings, circumstellar rings, and so forth [4, 6].

The geometrical dust grain size varies from micron to submicron in various laboratory and astrophysical environments [4-6]. They are generally composed of silicate (SiO_3), oxides of silicon, magnesium, and iron (e.g., SiO_2, MgO, Fe_3O_4), graphite, amorphous carbon, polycyclic aromatic hydrocarbon (PAH), silicon carbide (SiC), magnesium sulphide (MgS), metallic iron, etc. [4, 6]. These grains are electrically charged, either negatively or positively, depending on their interactions with the surrounding plasma environments. The grains become negatively charged by the inflow of electron thermal currents onto the dust surface, field emission of ions from the highly positive charged dust grains, and so forth. In contrast, dust can be positively charged by a number of processes, such as inflow of ion thermal currents onto the dust surface, field emission of electron from highly negative charged dust grain, photoemission of electrons due to incident of ultraviolet photons flux, thermionic emission induced by radiative heating, secondary emission of electrons from the surface of the dust grains, and so forth [2-3, 7]. In reality, the dust-charge fluctuates (dust number, $Z_d \sim 10 - 10^4$) due to the continuous random bombarding of electron and ion thermal currents onto the grain surfaces [7-10]. In most situations, the dust charge can be considered as "static". This happens when the perturbation frequency is more than the dust-charging frequency [11-15]. The presence of such dust grains in a plasma medium changes many of the physical properties of the contaminated plasma. As a result, the collective behaviour of the dusts excites various types of waves, oscillations, and instabilities. Plasma instabilities have become an active research area of growing interest not only in plasma physics but also in plasma technology, plasma engineering, development of plasma devices for thermonuclear power generation, space plasmas, and diversified bounded stellar structures including their surrounding complex environments [1, 2].

1.2 WAVES IN DUSTY PLASMAS

The interactions of dust grains with other constitutive particles (electron, ion, and dust) of the dusty plasma system under some constraints excite various types of dusty modes as:

a) *Dust ion acoustic wave (DIAW):*

It is a low-frequency dispersive acoustic (electrostatic) mode. It is generated mainly due to the motion of the ions in a pre-existing stable hydrostatic equilibrium background of electrons modified due to the presence of massive dust grains [4, 5]. The inertialess electrons oscillate about the ions, while the dust grains are in the static background. It is because the ion-plasma frequency is much larger than the dust-plasma frequency. In other words, in order to drive the DIAW, the restoring (elastic) force provided by the effective thermal pressure of the electrons and the inertia by the ions modified by the static dust grains. The DIAW has phase velocity smaller than the electron thermal velocity but, larger than those of the ion and dust grains [4, 5]. The DIAW frequency, considering laboratory plasma parameters, is estimated on the order of 10 kHz [4, 5].

b) *Dust acoustic wave (DAW):*

It is a very low-frequency dispersive electrostatic mode excitable in dusty plasmas having constituent massless (inertialess) electrons and massless (inertialess) ions; and massive (inertial) dust grains. All these constitutive species are coupled altogether via the electrostatic Poisson formalism. It is generated due to the motion of the dust particulates with the electrons and the ions oscillate about the dust grains owing to the electrostatic charge neutrality condition. In other words, these are the longitudinal disturbances triggered in the plasma system by the restoring (elastic) force provided jointly by the electrons and ions; and the driving (inertial) force individually by the massive dust grains [4, 5]. The frequency of the DAW is smaller than both the dust-plasma frequency and the DIAW frequency. Also, the phase velocity of the DAWs is smaller than the thermal speeds of both electrons and ions. The observed frequency of the DAW ranges as 10-20 Hz. In the case of dusty plasmas charge-fluctuating dust grains, the DAWs exist in the weakly coupled tenuous plasma when the wave frequency is much less than the dust-charging frequency; and also, in the weakly coupled dilute regime, when the wave frequency is greater than the dust-charging frequency [4, 5].

c) Dust Coulomb wave (DCW):

It is an ultra-low frequency dispersive electrostatic dust mode associated with the dust-charge fluctuations in a dense dusty plasma system in the high-fugacity (supercritical Debye number) regime [11, 12, 15]. The DCW exists only when the system wave frequency is much smaller than the dust-charging frequency; otherwise, the dust-charge remains practically constant. In dense dusty plasmas with high dust-charge ($Z_d >> 1$) and small dust-dust intergrain separation ($a_d << \lambda_D$), the dust-dust Coulomb-repulsive interaction dominates over the thermal pressure force. It, thereby, lays out the restoring force (Coulombic in origin) with the inertial force (non-Coulombic in origin) sourced in the dust mass to drive electrostatics modes known as the DCW modes [11, 12, 15]. In other words, the DCW is an electrostatic mode excited in such complex plasmas due to the streaming instabilities among the constitutive charge-fluctuating dust grains in the presence of active Coulombic interactions. Here, both the thermal (screening) and inertial (screened) species are the dust grains themselves. Such DCWs are excited due to the dust-charge fluctuation dynamics in the ultra-low-frequency regime (lower the usual DAW frequency). The DCW has a unique feature that its phase velocity is determined entirely by the grain parameters [11, 12, 15], namely the dust-charge (q_d) , dust mass (m_d), and dust size (R) as $C_{DC} = q_{d0} (4\pi \varepsilon_0 m_d R)^{-1/2}$. In contrast, the DAW phase velocity is determined by the plasma characteristics as $C_{DA} = \omega_{pd} \lambda_D$. Here, ω_{pd} is the dust-plasma oscillation frequency. One more distinction of the DCW-DAW modes is in their respective scale-lengths $(\lambda_R, \lambda_D, \lambda_R << \lambda_D)$. The former depends on the dust intergrain separation, dust size, and dust-charging frequency (δ) as $\lambda_R = a_d (a_d / 3R\delta)^{1/2}$. Such waves can exist in the high-fugacity regime of both the weakly and strongly coupled dusty plasmas in diverse circumstances [11, 12, 15].

d) Dust lattice wave (DLW):

The DLW exists in the strongly coupled tenuous dusty plasmas when dust crystal (lattice) structures are formed with the intergrain separations lying on the order of the plasma Debye length [11, 12, 15]. Here, the dust grains are of constant electric charge and interact only with the near neighbouring constituent particles. The dust grains oscillate about their respective equilibrium positions. As a result, the DLW is excited, thereby exhibiting propagatory features. The phase velocity of the DLW in the customary notations [16] is given as $C_{DL} = [2\, q_{d0}^2 / 4\pi\, \varepsilon_0 m_d\, a_d]^{1/2}$. This velocity is also entirely dependent on the basic grain parameters. It is to be noted here that C_{DC} is greater than the C_{DL} by a factor of $(a_d / 2R)^{1/2}$. Interestingly, if $a_d = 2R$, with $a_d << \lambda_D$; then, $C_{DC} \cong C_{DL}$ in the active presence of dust-charge fluctuations [11, 12, 15].

e) *Dust charge density wave (DCDW):*

The DCDWs are excited in the dilute plasma region where both the DAW and DCW merge into a single mode [11, 12, 15]. It happens in the condition that the wave frequency is less than the dust-charging frequency. In the opposite wave frequency case, only the DAW mode exists in the dilute plasma region.

f) *Dust thermal wave (DTW):*

The DTWs are weakly damped transverse waves excited due to the dust-temperature fluctuations, exist in the super-dense regime in hot dusty plasmas [11, 12, 15]. Both the thermal and inertial species are provided by the dust grains themselves as in the case of the DCWs, but now in the presence of the dust-temperature variations. The DTW excitation mechanism is different from the DCW one on the grounds that the frequency of the former is larger than the dust-charging frequency with the supercritical condition of dust-dust separation being well fulfilled ($a_d >> \lambda_D$) [11, 12, 15]. In such conditions, the dust-thermal pressure is superdominant over the repulsive dust-dust Coulombic one.

g) *Dust density wave (DDW):*

The DDW is a modified DAW in a complex (dusty) plasma system having dust-neutral and ion-neutral collisions in the presence of ion-dust streaming. In such dust-neutral collision systems, the DAW mode gets usually damped due to collisional effects [17]. If the ion drift velocity is high enough (exceeding the ion thermal velocity) to overcome the collisional (dust-neutral) damping, the DDWs are excited. In the DAW case, the massive dust plays as the inertial species; whereas, the inertialess electrons and ions act as the shielding (thermal) species. In contrast, in the self-excited DDWs, the electrostatic shielding of the dust is provided by the streaming constitutive ions [17].

h) *Dust ionization wave (DIW):*

The DIW is a transverse wave excited due to the electric charge-separation (polarisation) effects at the dust grain surfaces in a complex (dusty) plasma system. Such waves result from bifold inhomogeneity factors: (a) the Dust distribution, and (b) the Electron-ion recombination rate at the grain surface [18, 19]. The DIWs have higher phase velocity as compared to the DAWs. It is found that, the DIWs are long-wavelength modes with their wavenumbers independent of frequency. In contrast, the DAWs are short-wavelength modes with their wavenumbers dependent on the wave frequency. It may be pertinent to note here that the self-excitation of the DIWs against their external excitations is usually not possible as the wave damping in reality is independent of the instability growth coefficient in the dusty plasma system [18, 19].

1.3 DUST MOLECULAR CLOUDS AND STAR FORMATION

It is well-known that the DMCs are the best sites of the ISM acting as the nurseries for stars, planets, etc. They are magnetized, turbulent and highly dynamics in nature. They consist of gas and micron-sized dust grains. The mean dust-to-gas ratio in the DMCs differs from the canonical ISM value of 1% to 20%-30% [20, 21]. This is due to the presence of larger dust grains (~0.1-10 µm) in the clouds for which the self-gravity of the dust grains come into play [22, 23]. As a result, the abundance of dust grains varies locally due to various dust accumulative processes, such as the Jeans accretion, Bondi accretion, and so forth [20, 21]. Depending on their various relevant physical properties (i.e., dust number density (n_d), dust temperature (T_d), etc.), the DMCs can be classified into various categories [24-26]. The major DMCs along with main properties are enlisted in Table 1.1.

The star-forming mechanism in the DMCs is due to the gravitational instability, popularly known as the Jeans instability, named after its pioneer *Sir James Hopwood Jeans*, reported in 1902 [27]. Jeans was the first person to predict this instability for self-gravitating spherical gaseous nebulae leading to the gravitational condensation and consequent structure formation [27]. This instability in the DMCs arises due to the perturbation in material density by the self-gravity sourced in massive dust grains. As a result, the cloud undergoes contraction in the inward direction under its own self-gravity [27-29]. Self-gravitational contraction makes the central region of the DMCs denser and hotter. As a consequence, thermonuclear reaction occurs at the centre of the DMCs exerting thermal pressure force in the outward anti-centric directions [27-29]. When the inward gravitational pressure force is counterbalanced by the outward thermal pressure force, the DMCs remain stable. This situation is known as the hydrostatic equilibrium configuration. When the mass of the DMCs exceeds a critical mass known as Jeans mass, the DMCs become unstable. In other words, the inward gravitational force dominates over the outward thermal pressure force. This is called the Jeans criterion for bounded structure formation. It results in self-gravitational condensation leading to bounded equilibrium structures, such as stars, planets, comets, nebulae, and so forth [27-29].

Table 1.1 Dust molecular clouds with their physical properties

Molecular Clouds	Dust density (n_d in m^{-3})	Temperature (T_d in K)	Mass (M in kg)	Dimension (L in m)
Globular Clouds (GCs)	$10^9 - 10^{10}$	10	$10^{32} - 10^{33}$	10^{16}
Dark Clouds (DCs)	10^9	10	10^{34}	10^{17}
Giant Molecular Clouds (GMCs)	$> 3\times10^8$	$15-50$	10^{35}	10^{18}
Dense Dust Clouds (DDCs)	$10^{11} - 10^{12}$	$30-100$	10^{33}	10^{16}
Diffuse Dust Molecular Clouds (DDMCs)	$> 10^7$	$50-100$	10^{31}	10^{17}

The Jeans criterion for self-gravitational collapse gets modified significantly [7-10], subject to the different circumstances, such as the presence of charged dust grains ($Z_d \sim 10 - 10^4$), magnetic field $(B \sim 10^{-6}\ G)$ in the DMCs, and so forth. The contact electrification with the random electron-ion thermal currents renders the dust grains in the plasma background electrically so-charged [7-10]. The resulting long-range electric repulsive force (outward) among the constitutive like-charged dust grains modifies the Jeans instability due to self-gravity (inward) in the form of a new hybrid (pulsational) mode amid the gravito-electrostatic coupling [30-32]. As a result, both the onset instability threshold and propagation dynamics are drastically changed due to the charged dust [30-

32]. Such astrophysical plasma environs are well confirmed to exist in the H $_{\text{II}}$ regions in the DMCs as per the observations made by the Hubble space telescope [7-10].

It is well known that bounded structures are formed via the gravito-electrostatic interplay provided the electrostatic (acoustic) and self-gravitational (mechanical) forces operate on the same overlapping scales. This gravito-electrostatic overlapped interplay is a consequence of gravito-electrostatic force balancing resulting from the dust specific charge value given in the custormary notations as $q_d / m_d \sim G^{1/2}$ [33]. Here, $q_d = -Z_d e$ is the dust charge and $m_d = \rho_d / n_d$ is the dust mass. $G = 6.67\times10^{-11}$ N m^2 kg^{-2} is the universal gravitational coupling constant in the customary notations [33]. In other words, the same pulsating mode gets excited for an unmagnetized overlapped Jeans-plasma frequency as $\omega_{Jd} / \omega_{pd} \sim +1$ [33]. Here, $\omega_{pd} = \{n_{d0} (Z_d e)^2 / m_d \varepsilon_0\}^{1/2}$ is the dust-plasma oscillation frequency and $\omega_{Jd} = (4\pi G \rho_{d0})^{1/2}$ is the critical Jeans frequency. Bounded structures are formed in magnetized DMCs through the process of gravito-electro-magnetic coupling under the fulfilment of the specific charge condition: $q_d / m_d \sim G^{1/2} (c / v_d)$ [34]. The corresponding hybrid gravito-electro-magnetic mode evolves now with a modified frequency, ω_{Jd} overlapped with ω_{pd} as: $(\omega_{Jd} / \omega_{pd}) \approx (v_d / c)$ [34]. Here, v_d and c denote the dust thermal velocity and vacuum speed of light, respectively.

It is noteworthy that the constitutive charged dust grains in the DMCs interact among themselves through the long-range electrostatic force. The strength of their interactions is given by the Coulomb coupling parameter defined mathematically as, $\Gamma_{Cou} = (1/4\pi\varepsilon_0)\{(Z_d e)^2 /(a_d k_B T_d)\}$. Here, $a_d = (3/4\pi n_d)^{1/3}$ is the Wigner-Seitz radius of the constitutive identical solid dust grains. It signifies the average distance between the dust-dust grains without dust-charge fluctuations. The grains are either weakly coupled (WC) or strongly coupled (SC), depending on $\Gamma_{Cou} << 1$, or $\Gamma_{Cou} >> 1$, respectively. In the regime, $1 \le \Gamma_{Cou} \le 160$ [35, 36], the dust fluid shows “viscoelasticity” [37]. It hereby exhibits simultaneously the properties of both liquid (via viscosity, energy dissipation source) and solid (via elasticity, energy restoration agency) in a generalized hydrodynamic (GH) landscape. Their conjoint conjugate action results in the excitation of a rich spectrum of collective oscillations, waves and instabilities [38-41]. To name a few, such instability classes include the viscoelastic relaxation instability [38], viscoelastic pulsational instability mode [39], gravito-acoustic instability [40], Buneman instability [41], Kelvin-Helmholtz (shear) instability, and so forth.

It is well known to all of us that the main sequence star are consists of flowing viscous matter, and superdense compact degenerate star matter (like white dwarf, neutron star, etc.) are regarded to be made up of elastic solid matter [42]. Their elastic (solid) behaviour is the manifested by shear (torsional) oscillation. Thus, in the transition stage between the viscous liquid state and the elastic solid state, the characteristics of stellar matter is of a viscoelastic fluid [43]. Moreover, the cosmic fluids are highly viscoelastic in nature offering a plethora of collective wave excitation [38]. The viscoelasticity behaviour is in reality relevant to various compact astrostructures and their circumvent environs, such as the white dwarf stars, neutron stars, Jovian planetary interior structures, plasma effects associated with neutrino emission in the gravitational collapse, and so forth [5, 44, 45].

It is reported in the past that $Z_d \sim 10-10^2$ in the H I region and $Z_d \sim 10-10^4$ in the H II region [7]. The DMCs can be both strongly coupled and weakly coupled depending on the electric charge acquired by the constituent dust grains. For comparative examples, let us estimate Γ_{Cou} with $Z_d = 10^3, 10^2, 10^1, 1$ [7]. As a result, one finds Γ_{Cou} = 2.69×10^3, 2.69×10, 2.69×10^{-1}, 2.69×10^{-3} for both GCs and DCs; Γ_{Cou} = 8.9×10^2, 8.90, 8.9×10^{-2}, 8.9×10^{-4} for GMCs; Γ_{Cou} = 4.12×10^3, 4.12×10, 4.12×10^{-1}, 4.12×10^{-3} for DDCs ; Γ_{Cou} = 1.15×10^2, 1.15, 1.15×10^{-2}, 1.15×10^{-4} for DDMCs; Γ_{Cou} = 5.79×10^2, 5.79, 5.79×10^{-2} 5.79×10^{-4} for CCs; respectively. It is now quite clearly justifiable that these dusty clouds in the H II region with $Z_d = 10^3$ can behave as strongly coupled plasma fluids.

A good number of researchers have investigated the Jeansian gravitational instabilities and involved acoustic instability dynamics in strongly coupled (viscoelastic) plasma fluids on both laboratory (micro-gravity) and astrophysical (self-gravity) spatiotemporal scales. The underlying diversified stabilizing and destabilizing agents playing a significant role in the overall dynamics have been reported. In this context, Rosenberg and Kalman have investigated the effects of strong dust-dust correlation on DAWs using quasi-localized charged approximation (QLCA) [46]. It softens the DAWs mode dispersion with decreasing phase speed in the domain ($k\lambda_D << 1$, hydrodynamic). In contrast, in the domain ($k\lambda_D >> 1$, kinetic), the dust-plasma frequency reduces and negative dispersion of DAW mode is obtained [46]. A similar investigation on the propagation of DAWs has been developed in the correlated GH framework [47]. It shows that the strong correlation reduces the overall frequency and phase velocity of the DAW. In addition, it excites transverse shear mode in which correlation energy acts as an elasticity modulus [47]. The viscosity gradient in such dusty plasmas due to the shear flow destabilized the excited shear mode [48]. The dust shear flow excites Kelvin-Helmholtz (KH) instability in incompressible viscoelastic dusty plasma. It is found that the viscosity (energy dissipative factor) stabilizes the plasma system against self-gravity; whereas, the elasticity (restoring force) plays the counter role [49]. Moreover, the KH instability gets stabilized with the increase in the Coulomb coupling parameter, thereby, acting as a stabilizing agent [50].

The effect of non-local self-gravity in neutral viscoelastic fluid media has been studied in the past [43]. The role of plasma effects in such wave activities has been ignored therein on the grounds that astro-cosmic fluids on a large scale are neutral in nature because of the negligible value of the ratio between the plasma Debye length, termed as the plasma shielding length and the gravitational instability scale length, termed as the Jeans length [51]. It has been found that the threshold for the onset of the Jeans instability occurs at lower wavenumbers against the conventional pure inviscid nebular fluid picture [43]. The elastic effects lower the growth rate of the instability in such fluid [43]. In magnetized viscoelastic fluid, the Jeans criterion gets modified in the transverse mode of propagation only. The viscosity, magnetic field, and elasticity act as stabilizing agents [52]. However, in the longitudinal mode, the Jeans criterion remains unaffected by the magnetic field. Such instability is also investigated in the magnetized finitely conducting viscoelastic fluid. It is found that the electrical resistivity acts as a destabilizing agent and it removes the magnetic field effect in the instability [53]. In rotating viscoelastic fluid, the rotation does not alter the Jeans criterion, but, it acts as a stabilizing agent of the instability [54]. The IAW stability has been analyzed in the viscoelastic medium. It is found that the elasticity stabilizes the wave dynamics [55]. The instability of a gravitationally coupled viscoelastic system of neutral fluid and dark matter fluid has been addressed both in the linear regime [56, 57] as well as the non-linear regime [40]. It shows that, in the hydrodynamic regime, the neutral and dark matter rotations have stabilizing effects; whereas, in the kinetic regime, it shows destabilizing effects [57]. In the non-linear regime, the composite fluid system evolves as soliton-shock-like amalgamated hybrid structures as atypical eigen-patterns [40]. It has been shown semi-analytically that the Jeans instability has been significantly affected by the combined action of both the fluid viscosity and relaxation effects in a noticeable way.

1.4 MOTIVATION

The study of strongly coupled (viscoelastic) fluids in diversified astrophysical domains has become an actively growing area of research recently. The conjoint action of viscosity and elasticity of such viscoelastic fluids excite various collective waves, oscillations, and instabilities. Such mechanical instabilities in self-gravitating viscoelastic fluids initiate the non-local gravitational collapse mechanism. It subsequently results into the formation of diverse compact bounded structures in astrophysical circumstances, such as white dwarf stars, neutron stars, Jovian planetary interiors, and so forth [5, 42]. The dynamics of viscoelastic fluid nature on self-gravitational collapse mechanisms has already been studied from different angles. It mainly includes neutral fluid dynamics [43], magnetized viscoelastic fluid [52, 53], rotating viscoelastic fluids [54], coupled dark matter and neutral fluids [56, 57], and so forth. But there still remains a good number of problems, particularly on gravitational collapse theory, but long-lying unaddressed. The linear and non-linear wave analyses of complex unbounded inhomogeneous viscoelastic astroclouds, in the presence of all the possible realistic agencies, such as polytropicity, buoyancy, thermal fluctuations, volumetric expansion, magnetic field, etc. in various geometric configuration has still been remaining as an unaddressed, unsolved and unexplored problem for years. The coupled dynamics of the DCWs and DAWs in the strongly coupled (viscoelastic) self-gravitating magnetized non-thermal (with κ - distributed electrons and ions) dusty plasmas in the high-fugacity regime still remains unexplored and unanswered [57, 58]. The linear stability analyses of compact stars (neutron stars) from the hydrodynamic viewpoint has still been remain unsolved. The investigations of these mentioned scenarios to have a clear picture of the waves, oscillations, and instabilities excited in the self-gravitating viscoelastic fluids is the main motivation behind the proposed compiled thesis.

1.5 OBJECTIVES

The viscoelastic behaviours of complex astrofluids are generally found in dense compact structures, such as neutron stars, white dwarfs, and their circumvent atmospheres, etc. It is seen that various types of waves and instabilities are excited therein. Thus, the objective of this thesis work is to focus on the stability analysis of such mysterious viscoelastic astrofluids in various new environs from the macrophysical fluidic point of view. In fluid dynamics, the characteristic mean free path is asymptotically zero (characteristic length/system length ~ 0). The analyses are carried out in the framework of analytical, graphical, and numerical strategies. The main objectives of the thesis are highlighted as:

(a) Study of linear stability dynamics in complex viscoelastic astrofluids,
(b) Investigation of non-linear fluctuation dynamics in complex viscoelastic astrofluids,
(c) A generalized magnetohydrodynamic model formalism of gravitational instability in spherical astroclouds,
(d) Stability of magnetized complex astrofluids with atypical dust-fugacity effects, and
(e) A hybrid GNA instability mode in neutron star interiors.

It is noteworthy herewith that this thesis, as a whole, provides an important compilation of a rich spectrum of collective waves and instabilities of self-gravitational origin excited in diversified astrophysical environments yet to be well understood.

1.6 SUMMARY

We present here a snapshot overview of diverse complex plasma fluids, its physical properties, and their existence in various realistic astrophysical circumstances. The dynamical mechanisms behind the excitation of various collective acoustic modes are concisely highlighted and summarised. The significance of the gravitational (Jeans) instability in the DMCs responsible for bounded structure formation are briefly outlined. The viscoelastic behaviours of strongly correlated dusty plasmas are elaborately reviewed. The main motivation behind the compiled thesis along with its objectives are reinforced.

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