Abstract

Stars, planets and other galactic objects are born in the dense molecular phase regions of the self-gravitating interstellar media called Dust Molecular Clouds (DMCs). The DMCs are very complex self-gravitating inhomogeneous astrophysical plasma atmospheres contaminated with wide population spectrum of dust. They are indeed rich in various collective waves, oscillations and fluctuations in different astrophysical situations. Both the equilibria and fluctuations of such complex self-gravitationally confined plasmas are very complicated to handle with the existing local formalisms, centered around presumed homogeneous equilibria, for analytic simplicity.

The study of excitation and evolution processes of such waves and oscillations supported in the DMCs are extremely important because they ultimately produce the initial conditions for the formation of astrophysical objects bounded by the Jeans instability, gravito-electrostatic instability, etc. Although, such collective instabilities are responsible for galaxy formation mechanisms, they are not well understood till today, to the best of our knowledge, because of their large-scale inhomogeneties, Jeans-scale dispersions and associated complications in modelling real picture properly.

This thesis, inspired and motivated by the above observations and analytic complications, systematically focuses on the equilibrium, excitation of various wave kinetics and evolutionary processes of bounded structures originally initiated in self-gravitating astrophysical plasmas from new physical and mathematical perspectives. The methodological investigations presented here are allowed to include all the realistic agencies relevant in the astrophysical scenarios, hitherto remaining untouched, leading to galactic structure formation and evolution. Besides, new mathematical tools based on the existing analytical techniques are also constructed in order to incorporate possibly all the realistic scale-dependent complications encountered on the astrophysical scales of space and time. The chapter-wise summery of the entire thesis compiled from new explorative works is presented concisely as in the following.

Chapter-1:

This chapter highlights on an overview of self-gravitating dust molecular clouds, their types and various involved kinetic processes. The most relevant properties in the astrophysical context, like dust-charging, instabilities and physical characteristics, are concisely summarized. Finally, it throws light on why we are enthusiastically motivated towards an in-depth exploration of

astrophysical dusty plasmas with the modern computational techniques in different realistic space and astrophysical situations.

Chapter-2:

We study the equilibrium electromagnetic properties of a spherically symmetric charged dust molecular cloud (DMC) structure with the help of a new technique based on the modified Lane-Emden equation (m-LEE) of polytropic configuration on the gravitational scale of practical importance. First, we methodologically derive the m-LEE under the framework of exact gravito-electrostatic pressure balancing condition. The weak but finite efficacious inertial roles of the thermal species (electrons and ions) on the lowest-order are taken into account carefully. Then, a detailed characterization of the lowest-order cloud surface boundary (CSB) and associated significant parameters on the Jeans scale is numerically obtained and presented. The multi-order extremizations of the m-LEE solutions specify the CSB existence at a radial point 8.58×10^{12} *m relative to the cloud centre. It is shown that the CSB gets biased negatively due to the interplay of plasma-boundary wall interaction (global) and plasma sheath-sheath coupling (local) processes. It acts as an interfacial transition layer coupling the bounded and unbounded scale-dynamics of the cloud. The geometrical patterns of the bi-scale plasma coupling are elaborately analyzed. Diversified application of our technique to neutron stars, other observed DMCs and double layers validating our model is shown together with future scopes.*

Chapter-3:

Application of local stability theory in self-gravitating astrophysical plasmas is indeed inadequate due to their non-uniform nature confirmed mainly by the differential scale-heights of the gravitationally stratified constituent species in establishing gravito-thermal equilibrium. Thus, gravity-induced ambipolar electrostatic space-charge polarization effects in the plasmas with large-scale non-zero equilibrium electric field must be considered. We formulate exact non-local linear analysis for identifying the global gravito-electrostatic modes, discrete oscillations and associated instabilities in interstellar charged dust molecular cloud (DMC) sphere with mass-radius above the critical values. The realistic effects like equilibrium inhomogeneities, diverse gradient forces and dust flow-convection dynamics are included. The dispersion relations (eigenvalues) and amplitude-variations (eigenfunctions) are Fourier*-methodologically derived, explored and analyzed. We see that the entire cloud supports spectrally heterogeneous mixture of* *the Jeans and electrostatic modes. It is shown that the lowest-order non-rigid diffused cloud surface boundary (CSB) is the most unstable interfacial layer due to enhanced coupling strength of bipolar electrostatic repulsion and unipolar self-gravitational attraction. Three distinct and spatio-spectrally isolated classes of global eigenmodes-dispersive, nondispersive and hybrid types-are identified and characterized together with prolific features. Dispersive features are found prominent in the ultra-high k-regime; whereas, non-dispersive characteristics in the ultra-low k-regime. Numerical illustrations demonstrate that the grain-charge plays destabilizing influential role for the electrostatic fluctuations, but stabilizing role for the self-gravitational counterparts. In contrast, the grain-mass plays stabilizing influence for the former, but destabilizing influence for the latter. The results can be useful to realize complex nonlocal astrophysical fluctuations from a new perspective of plasma-wall interaction philosophy.*

Chapter-4:

A hydrodynamical model to study the nonlinear self-gravitational eigenmode excitations in a spherical charged dust molecular cloud with full convective flow-dynamics is strategically developed. The spherically symmetric cloud mass is assumed to be greater than the critical mass limit required to exhibit collective fluctuation dynamics. The eigenmode patterns evolve as new damped oscillatory shock-like structures governed by a unique form of modified Korteweg-de Vries Burger (m-KdVB) equation with self-consistent derivative source consistently involved in it. Their formation mechanisms, distinctive features, and tentative astrophysical applicability leading to protostellar (or, prestellar) cores are summarily indicated.

Chapter-5:

In this Chapter, an inertia-centric theoretical model is proposed for investigating the basic features of nonlinear pulsational mode stability in a planar, partially ionized dust molecular cloud (DMC) within the framework of the Jeans homogenization (on the zeroth-order) assumption. The active inertial roles of the thermal species are included. The grain-charge is assumed for simplicity not to vary in the fluctuation evolution time scale. It is shown that the electrostatic and self-gravitational eigenmodes co-exist as solitary spectral patterns governed by a pair of Korteweg–de Vries (KdV) equations relevant for such clouds. In addition, all the relevant classical conserved quantities associated with the newly constructed KdV system under translational invariance are methodologically derived and numerically analyzed. It is demonstrated that the solitary mass, *momentum and energy densities also evolve like solitary spectral patterns, but with different characteristic features (like amplitude, width, etc.) discussed here. They remain conserved throughout the spatiotemporal scales of the fluctuation dynamics. Astrophysical and space environments relevant to the findings are briefly highlighted.*

Chapter-6:

A new evolutionary analytic model for investigating the nonlinear gravito-electrostatic waves in a self-gravitating inhomogeneous planar collisional dust molecular cloud (DMC) on the Jeans scales of space and time is built up. It includes dust-charge variation and weak but finite inertia of the thermal electrons and ions on the stability time scale. All the equilibrium gradients and inhomogeneities arising from the dynamics of the plasma constituents are considered. Thus, any conventional homogenization assumption, like the Jeans swindle for mathematical simplification, is avoided to depict the actual scenario on the small-amplitude fluctuations. By standard inhomogeneous multiple scaling techniques, it is methodologically shown that the fluctuations are collectively governed by a unique gravito-electrostatically coupled pair of driven Korteweg-de Vries (d-KdV) equations with new gradient-driven variable coefficients and self-consistent linear driving sources. A numerical analysis portrays the co-existing eigenmode excitations as oscillatory shock- and soliton-like structures. In addition, depending on the explicit regions of the varied plasma parameter space and inhomogeneities, a new shape-transition from soliton to shock and vice-versa, is noticed. The exact results obtained in this investigation can rigorously be applied to explain diverse multispace satellite observations and predictions made by others in space and astrophysical environments.

Chapter-7:

The Sun is a mysterious stellar structure (plasma ball) formed due to self-gravitational instability of interstellar dust molecular cloud. Even after formation of its equilibrium structure by the instability, it is under constant self-gravitational effects, as reflected via helioseismic modes and surface oscillations. In this chapter, we develop a theoretical evolutionary model for investigating new nonlinear self-gravitational fluctuations associated with the bounded solar plasma system with the lowest-order inertial correction of the plasma thermal electrons. Application of multiscale analysis over the coupled gravito-electrostatic equilibrium solar structure equations results in a unique type of driven Korteweg-de Vries Burger (d-KdVB) equation, revealing mainly monotonous *shock-like eigenmodes. The self-consistent new and unique nonlinear driving source here appears due to the inclusion of weak but finite electron inertia. The observed self-gravitational fluctuations are in good agreement with multispace satellite and imaging detections made by others in recent past. The results are significant for probing intrinsic structural properties of the solar, stellar, or other astrophysical media through which the fluctuations co-evolve and co-propagate.*

Chapter-8:

The plasmas in space and astrophysical environments are well-known to consist of numerous massive ionic components contributing to various wave-instability phenomena. So, the ion-inertial effects need to be incorporated in realistic analyses rather than treating the gravitating ionic species traditionally as the Boltzmann-distributed fluid. Herein, we present an atypical theoretical model setup to study gravito-electrostatic mode-fluctuations in self-gravitating inhomogeneous interstellar dust molecular cloud (DMC) on the astrophysical fluid scales of space and time. The main goal is focused on investigating the influence of self-consistent dynamic ion-inertial effects on the stability. Methodological application of standard multiple scaling techniques reduces the basic plasma structure equations into a unique pair of the decoupled Korteweg-de Vries (KdV) system for the weakly nonlinear fluctuations. In contrast, the fully nonlinear counterparts are shown to evolve as a new gravito-electrostatically coupled pair of the Sagdeev energy-integral equations. Excitation of two distinct eigenmode classes--electrostatic compressive solitons and self-gravitational rarefactive solitons with unusual parametric features--is demonstrated and portrayed. The graphical shape-analysis reflects new plasma conditions in realistic interstellar parameter window previously remaining unexplored. It is seen that the inertial ions play a destabilizing influential role leading to enhanced fluctuations towards establishing reorganized gravito-electrostatic equilibrium structure. A substantially good qualitative correspondence exists in consistence with existent inertialess ion-theories and multispace satellite-based observations. The main implications relevant to non-trivial aspects in space and astrophysical contexts are summarily highlighted together with emphasized future directions.

Chapter-9:

Finally, in this Chapter, main conclusive remarks and future scopes are highlighted with focused pin-pointed directions toward imminent explorations.