Chapter-7

CONCLUSIONS AND FUTURE DIRECTIONS

A theoretical study of equilibrium and perturbation plasma dynamics in diversified plasma environments starting from laboratory to astrophysical scales of space and time is proposed. The main focus of the compiled thesis is based on three different plasma environments. The first category comprises of the magnetized plasma sheath structures on the laboratory fluid scales of space and time. Next, the second category emphasizes on the nonlinear structural properties of dust molecular clouds (DMCs) of infinite spatial extension. Finally, the third part focusses on the solar plasma system and associated evolutionary dynamics on the gravitational spatiotemporal scales. We apply all the possible analytical, graphical and numerical techniques to investigate the equilibrium and fluctuation dynamics in such diversified plasma fluids. The main conclusive remarks which can be drawn from the compiled thesis together with future directions are concisely summarized as follows.

7.1 CONCLUDING REMARKS

1. We investigate the equilibrium structural features of steady-state plasma sheath in the presence of weak electron-inertia in magnetized plasma configurations. It is shown that the inclusion of electron-inertia, alongside the Lorentz gyro-kinetic effects, enhances the threshold ion Mach number (typically, $M_{io} \geq 1.139$) towards the sheath entrance. The quasi-neutrality breaks down, as the sheath edge is reached, with increase in the magnetic field strength. In contrast, the deviation from quasi-neutrality (indicated by curvature) decreases with increase in ion temperature. The sheath formalism presented here can be used as an accurate element in the formalism of nonlinear structures, such as shocks, double layers, etc.

2. The local Bohm criterion is revisited in quasi-neutral magnetized collisionless plasmas in the presence of electron-inertial dynamics. The electron-inertia is incorporated via a regular perturbation of the electronic fluid dynamics only relative to a new smallness parameter (δ) employed to signify the weak inertial-to-electromagnetic strengths. It is found that the perturbative correction for electron-inertia on the lowest order yields a modified Boltzmann

distribution law. The mutualistic action of electron-inertia amid gyro-kinetic effects slightly enhances the ion-flow Mach threshold value (typically, $M_{i0} \geq 1.140$), against the normal Mach value of unity. The sheath structure investigated here can be intimately related with ion-acoustic shock development, because a travelling sheath would pertain to shock wave propagation, despite dissimilar boundary conditions. It may, thus, give an alternative modified sheath-based viewpoint of hydrodynamic shocks and their evolutionary dynamics.

3. We study the weakly nonlinear gravito-electrostatic waves in a field-free polytropic dust molecular cloud in quasi-hydrostatic equilibrium. The nonlinear eigen-mode patterns of a charged polytropic dust cloud dynamically evolve as a new coupled pair of *m*-KdV dynamics with self-consistent nonlinear sources involving intermixed gravito-electrostatic interactions. It is seen that the electrostatic eigen-modes evolve as rarefactive soliton-like structures (bi-periodic); whereas, self-gravitational fluctuations evolve as extended compressive solitonic structures (uni-periodic). The associated field, curvature and scale length support that both quasi-neutrality and mass-neutrality deviations become maximum at a radial distance 7.5 (on Jeans scale) relative to the center of the entire cloud mass distribution. The presented solitary spectral patterns are in partial and qualitative agreement with the various spacecraft instrumentations, on-board multi-space satellite reports, and experimental findings. Examples of such clouds are *Lynds 204 Complex*, *Barnard 68*, and so forth.

4. The well-established gravito-electrostatic sheath (GES) model is reexamined in the presence of nonextensive electrons and nonlinear fluid pressure (turbulence). We demonstrate specifically that the GES field strength for the bounded solar solution on the self-gravity as a dynamical variable to exist, paving the way for the SSB formation, decreases by 21.67%, and the electrostatic potential by 30%. Moreover, it is interestingly found that the supersonic SWP flow dynamics with the nonextensive electrons is a two-step process, instead of the earlier three-step (subsonic-supersonic transition via transonic zone of width ~ $37\lambda_J$) process treated with the isothermal inertialess electrons. The analysis presented here may find extensive application in the SWP flow dynamics from a new thermostatistical description of plasma wall interaction-based mechanism in the presence of both nonextensive electrons and nonlinear plasma fluid pressure effects.

5. We develop a simplified theoretical model for the linear stability analysis of the polytropic solar wind in the fabric of hydrodynamic equilibrium configuration incorporating data from the Advanced Composition Explorer (ACE) spacecraft. Based on the methodologically derived dispersion relation, the explicit form of the associated growth rate is seen to evolve dynamically as a nonlinear function of the polytropic index and radial distance. Furthermore, the growth for higher flow velocity of the wind is interestingly found to be greater; and vice-versa. The fluctuations are randomized (with no phase and amplitude coordination), and hence, averaged out to zero in non-isentropic regions elsewhere in the solar plasma system.

7.2 FUTURE DIRECTIONS

We recognize that the proposed chapters compiling the thesis stem from some idealizing approximations and need further refinements to deal with more realistic situations. Thus, there exists a wide horizon for futuristic ameliorations as chapter-wise highlighted below.

1. The theoretical analysis for magnetized plasma sheath characterization, as in **Chapter-2**, considers two distinct isothermal electron-ion fluids. It is against a recent hydro-kinetic study reporting that, at the vicinity of the sheath edge, the ion temperature may change appreciably [1]. Thus, we must include non-thermal constitutive fluids with proper equations of state to see the evolutionary dynamics of sheath structure in real plasma systems.

2. As proposed in **Chapter-3**, a collisionless magnetized plasma sheath configuration is improper and inadequate to handle with practical situations. This is because the inter-species collisions could play an important role in deciding the magnetic field effects on the upper and lower limits of the Bohm sheath criterion [2, 3]. It implicates that a more in-depth sheath-study in the presence of all the possible collisional transport effects needs to be formulated.

3. It is admitted in **Chapter-4** that, the investigation of nonlinear fluctuation dynamics in polytropic molecular clouds is based on local analysis valid under the approximation of weak nonlinearity. But, it would require nonlocal analyses due to diverse equilibrium gradient forces [4]. Thus, a non-local stability analysis would be more appropriate in such situations.

4. In **Chapter-5**, a theoretical model of the nonextensive GES structure is formulated. But, we know that the self-gravitationally confined solar plasma volume is highly turbulent in character giving rise to diversified small-scale waves, instabilities and oscillations [5]. The

role of fluid turbulence could be investigated mainly by employing a fully nonlinear power spectral-law analysis [6]. Thus, our model formalism needs to consider all the types of constituent heterogeneous species in diversified long-range force fields, and large-scale gradient forces and nonlinear turbulence effects in futuristic direction.

5. As in **Chapter-6**, we present a simplified theoretical proposition for understanding the solar instability within the framework of a new polytropic hydrodynamic perspective. However, it is to be noted that such models fall short of explaining the coronal mass ejection driven shocks as energy conservation has not been used. Therefore, a full MHD simulation [7] would be more suitable to understand the shock propagation dynamics and shock-induced instabilities, against the existing polytropic models, to describe the solar plasma system.

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