ANALYTICAL STUDY OF ACOUSTIC WAVES AND INSTABILITIES IN COMPACT ASTROOBJECTS

A thesis submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

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Chapter-7

CONCLUSIONS AND FUTURE PROSPECTS

It is noteworthy that all the main results and conclusions piece-wise drawn from the investigations compiling the thesis are Chapter-wise presented. This concluding Chapter vividly offers the overall conclusions and future prospects in a concise integrated form. It summarily ends with a new prospect in a continued future direction of astronomical value.

7.1 CONCLUDING REMARKS

The focal aim of the compiled thesis, as already mentioned before elaborately, is to investigate the different waves, oscillations, and instabilities excitable in compact astrophysical objects and their environments. It refers to the realistic situations of white dwarfs, brown dwarfs, neutron stars, and so on. Generalized hydrodynamic models are formulated to investigate them in both the classical and quantum regimes. Accordingly, generalized linear dispersion relations of various degrees are procedurally analyzed. The underlying methodology involves the application of non-planar (spherical and cylindrical) normal mode treatment. Numerical illustrative platforms are used for dispersion analyses in multiparametric domains. Thorough semi-analytic investigations are carried out to critically analyze the differences between nucleus-acoustic waves and ion-acoustic waves. It is found that the collective stability dynamics of the considered systems are affected by the major realistic key factors, like Coriolis rotational effects, viscoelasticity, magnetic field, electrostatic confinement pressure, etc. Several findings could illuminate the observed effects of increase in rotation of dwarf stars towards their collapsing stage. The main results from the compiling explorative studies are briefly recast in a Chapter-wise form as follows.

Chapter-1

Acoustic waves and instabilities in quantum plasmas: A concise overview

(a) This Chapter offers a brief overview of plasma physics along with a clear distinction between its classical and quantum domains followed by diverse realistic applications.

(b) It highlights gravito-acoustic waves and instabilities in different astro-space circumstances including collective correlative effects in quantum plasma forms.

(c) It pinpoints the motivation, objectives, and methodologies of the compiled thesis.

Chapter-2:

Jeans instability in astrophysical viscoelastic fluids with geometrical curvature effects

(a) It mainly establishes that spherical geometry and viscoelasticity stabilize compact astrophysical fluids in diverse situations.

(b) The viscoelastic relaxation time stabilizes the compact astrological fluids.

(c) This Chapter theoretically supports that the viscoelasticity associated with stellar nuclear matter provides a plausible explanation of pulsar glitches in addition to its presence in other compact astrophysical objects [1].

Chapter-3:

Nucleus-acoustic waves in gyrogravitating electrospherically confined degenerate quantum plasmas

(a) Nucleus-acoustic waves are the longitudinal propagatory normal modes excited in white dwarf stars and other compact astrophysical objects.

(b) This Chapter investigates the main characteristic features of such waves in the non-relativistic and the ultra-relativistic regimes.

(c) The stabilization is provided by the charge density ratio of the heavy-to-light nuclear species; whereas, the destabilization by the charge-to-mass coupling parameter of the heavy-to-light nuclear species and Coriolis force (observationally supported [2]).

Chapter-4:

Behaviours of ion-acoustic waves in relativistic gyromagnetoactive quantum plasmas

(a) This Chapter reveals significant results about the stability of relativistic degenerate quantum plasma fluids in terms of ion-acoustic wave dynamics.

(b) The Coriolis force and ionic gyrofrequency fully destabilize; the equilibrium density partially destabilize in the low-wavenumber regime, unlike the high-wavenumber case.

(c) The investigated relativistic results seem to have promising applicability in dense astrophysical objects, like white dwarfs, brown dwarfs, etc.

Chapter-5:

Nucleus-acoustic waves in degenerate ONe and CO white dwarf cores and nearly degenerate envelopes

(a) It shows that a main-sequence star, after undergoing the red giant phase, sheds its outer layers forming the planetary nebula (classical, completely non-degenerate); while, the remnant core with no fuel forms a white dwarf (quantum, completely degenerate).

(b) It highlights the intermediate-degeneracy transition zone between the fully degenerate white dwarf cores (quantum) and ambient fully non-degenerate nebulae (classical).

(c) In the low-wavenumber regime, the nucleus-acoustic waves are unstable (non-propagatory); but, stable (propagatory) in the high-wavenumber regime.

(d) The ONe white dwarfs are found to be more sensitive to temperature changes than the CO white dwarfs. The background plasma in dispersive in both the cases.

Chapter-6:

Acoustic stability of astrophysical gyromagnetoactive viscous cylindrical plasmas

(a) This Chapter describes the acoustic waves excitable in an axisymmetric rotating self-gravitating cylinder with magnetic field acting longitudinally using Hankel function formalism in four distinct regimes dictated by degeneracy and geometry effects.

(b) The equilibrium number density, Coriolis rotational force, and temperature destabilize the system against the kinematic viscosity.

(c) The magnetic field shows mixed behaviour (quantum non-planar), peaks and dips (quantum planar), stabilizing influence (classical non-planar), and destabilizing influence (classical planar).

(c) Axisymmetric cylinders under self-gravity illuminates the evolution of elongated molecular clouds, magnetized arms of spiral galaxies, circumnuclear starburst rings, and filamentary structures on diverse astrocosmic scales [3-5].

A detailed comparison between the nucleus-acoustic waves and the ion-acoustic waves are summarily presented as

Table 7.1: Comparison between ion-acoustic waves and nucleus-acoustic waves

S. No.	Item	Ion-acoustic waves	Nucleus-acoustic waves
1.	Origin	Classical [6]	Quantum-mechanical [7, 8]
2.	Electron statistics	Boltzmann (classical) [6]	Fermi-Dirac (quantum) [9]
3.	Restoring force	Electron thermal pressure (classical) [6]	Electron degeneracy pressure (quantum) [7, 8, 10, 11]
4.	Heavier species	Ions as inertial species [6]	Heavy nuclei as inertial species [7, 8, 10, 11]
5.	Existence at absolute zero ($T_e \sim 0$ K)	Not possible [6]	Possible [12]
6.	Modal type	Compression and rarefaction of ionic species (longitudinal) [6]	Compression and rarefaction of nuclear species (longitudinal) [7, 8]
7.	Comparison with normal sound mode	Result of heterogeneous classical coupling between electrons and ions (unlike the homogeneous species for usual sounds) [6]	Result of heterogeneous quantum-mechanical interplay among degenerate electronic species, heavy nuclear species, and light nuclear species (unlike the homogeneous species for usual sounds) [7, 8, 10, 11]
8.	Main driver	Electrons thermal pressure [6]	Electron degeneracy pressure [7]
9.	Normal existence condition	Non-isothermal plasmas ($T_i \ll T_e$, electron thermal pressure dominant) [6]	Dense plasmas ($T_e \sim 0$ K, electron degeneracy pressure dominant) [12]

7.2 FUTURE PROSPECTS

Before going into future prospects, we should admit that our theoretical investigations need several model refinements to obtain a more realistic scenario of compact astrophysical objects and correlated surroundings. All the studies considered herein have been conducted in the linear regime. Thus, non-linear analysis of each of the considered studies, along with inclusion of several other realistic factors, like turbulence [13], collisions [14], cosmic ray effects [15], differential rotation [16], and so on, would be rather interesting to see. The main region of application of all the semi-analytic investigations considered herein is the compact astrophysical objects, where the particle motions are mostly relativistic. Thus, application of relativistic correction to all the particle motions would be another positive refinement in the given direction. In the same context, replacement of non-relativistic Newtonian gravity by the relativistic formalism suggested by Einstein would be more applicable in modelling of the compact astrophysical objects considered herein.

In the asterometric perspective, white-dwarfs experience at least one period of variability during which their global pulsations enable astronomers to look inside them, providing information on their deep internal structure [17, 18]. Several such pulsations have been discovered observationally afresh in carbon-dominated white dwarf atmosphere [19]. In addition, several non-radial pulsations and *g*-modes have been discovered [20, 21]. Theoretically, several important characteristics of white dwarfs, like stellar mass, radius, and so on, have been computed [22]. These theoretical studies have found intensive applications in white dwarf models [23]. Observational detection systems have already been devised to probe the *p*-mode oscillations in white dwarfs, although in infancy stage, but with growing resolution refinements [24]. It hereby opens fair possibilities for the astrometric measurements of the various characteristics of collective waves and instabilities theoretically investigated to exist in white dwarfs in the proposed thesis.

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