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Breather structures and Peregrine solitons in a polarized space dusty plasma

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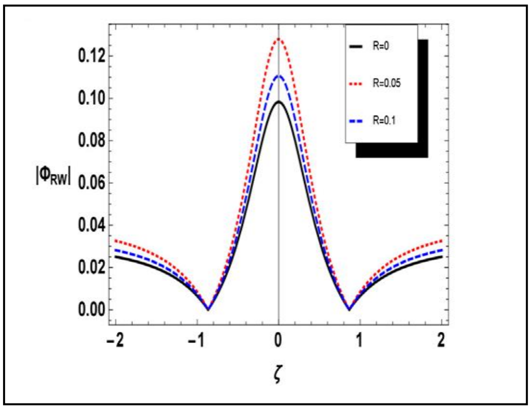
Dusty plasmas are ubiquitous not only in laboratory, space and astrophysical environments but also have potential applications in industry, technology and other areas of modern science. The existence of different kinds of wave modes and their coupling have made it possible to understand the plasma collective oscillations at different scales and the salient features of associated nonlinear waves and instabilities in these plasma environments. The polarization force plays a crucial role in plasma behavior and dynamics, influencing various processes and phenomena in both laboratory and astrophysical plasmas. Understanding the polarization force is essential for accurately modeling plasma behavior and for designing and optimizing plasma-based technologies and processes across a wide range of applications, from industrial manufacturing to space propulsion and controlled fusion energy. The rational solutions of the nonlinear Schrodinger equation (NLSE) describe broad range of spatially and temporally localized sets of soliton solutions. One of such rational solutions is called Peregrine soliton or prototype of the rogue waves (RWs) resulting from counterbalance between nonlinearity and group velocity dispersion. The investigation of rogue waves has enhanced comprehensive understanding of evolution and formation of these mysterious waves in the ocean. It is reported that rogue waves are usually singular and large amplitude waves with draconian effects on living creatures. The rogue waves are known for their sudden appearance as a deep hole and huge crest in a serial pattern. Rogue waves have extremely large amplitude waves that evolve suddenly and then collapse without clue. Such kinds of waves are also observed in nonlinear optics, superfluids, and Bose–Einstein condensates. Further, it is also illustrated that the breather solutions of NLSE can be categorized as Kuznetsov–Ma breathers (space localized patterns and periodic in time) and the second class of breathers is the Akhmediev breather (which is periodic in space and localized in time). It is demonstrated that the Peregrine breather plays a pivotal role for exclusive study of rogue waves. In this study, we explore the intricate interplay between the nonthermal enhancement of polarization forces and their impact on the modulational instability (MI) of dust acoustic waves (DAWs), as well as on various types of dust acoustic (DA) breathers within a dusty plasma environment.

This environment comprises negatively charged dust particles treated as a fluid, alongside Maxwellian electrons and ions that follow nonthermal distribution. We find that the nonthermal characteristics of the ions significantly modify the polarization force's strength. Through the application of the multiple-scale perturbation method, we derive the nonlinear Schrödinger equation to investigate the modulational instability of DAWs. Our findings reveal that the polarization force's influence effectively narrows the wave number range susceptible to MI. The rational solutions of NLSE bring to light the emergence of DA breathers, including the Akhmediev breather, the Kuznetsov–Ma breather, and Peregrine solitons, also known as rogue waves. Additionally, we delve into the formation of super rogue waves through the nonlinear superposition of DA triplet rogue waves.

Our analysis underscores that the combined effects of changes in polarization force and ion nonthermality profoundly shape the development of diverse DA breather types. It is observed that the characteristics of RWs and breathers are significantly influenced by the variation of different plasma parameters. The polarization force also plays significant role for change in the amplitudes of different kinds of rogue waves as shown in figure. This theoretical exploration sheds light on the significant role of nonlinear dynamics in generating various DA breathers, offering valuable insights for experimental observations and understanding phenomena in different space environments, such as planetary spokes and cometary tails.



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