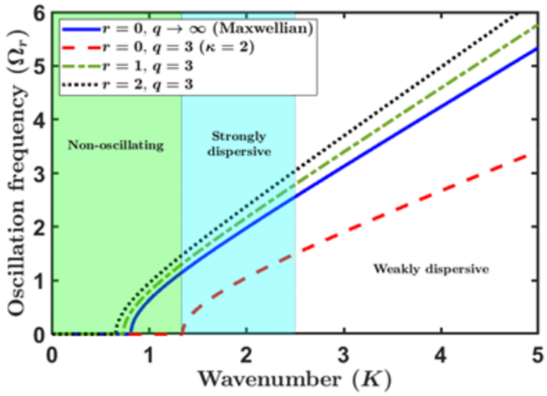
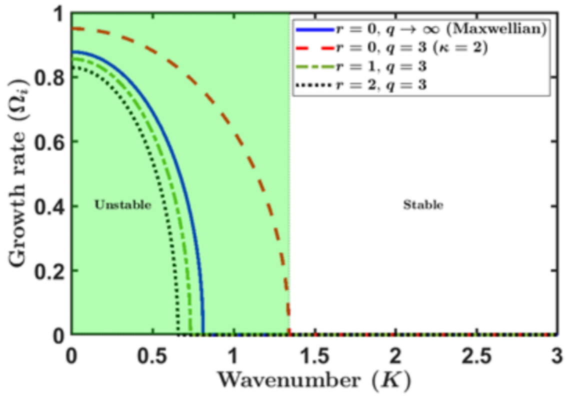
Solar Surface Oscillations and Energy Transports with Nonthermal Electronic Thermostatistics

Souvik Das[1], Pralay Kumar Karmakar[1]

[1]Tezpur University, Tezpur, India





The ubiquitous five-minute solar p-mode oscillations, excited at the photosphere, play a fundamental role in driving coronal instabilities and facilitating upward energy transport in the solar atmosphere [1]. These oscillations are strongly modulated by the presence of nonthermal electron populations, which significantly alter the collective plasma response. In this work, we employ a generalized double-spectral thermostatistical framework based on the (r, q)-distribution to investigate the oscillation dynamics, growth characteristics, and mechanical energy transport properties of longitudinal helioseismic modes at the solar surface [2]. A local linear perturbative analysis is carried out for an inhomogeneous, viscous, turbulent, and nonthermal plasma environment, leading to the derivation of a cubic eigenmode equation representing the linear dispersion relation of the system [3]. This formulation captures a wide spectrum of collective oscillatory behaviours, including both stable and weakly unstable modes. The effects of key physical parameters—namely the nonthermality indices (r, q), electron temperature, and ion dynamic viscosity—on wave dispersion and mode stability are systematically examined. Our numerical analysis reveals that the coupled dynamics of low-energy (thermal) and high-energy (suprathermal) electron populations play a decisive role in shaping solar surface oscillations. In particular, the nonthermality indices (r, q) act as effective mode accelerators, enhancing wave propagation and partially compensating for dissipative damping arising from thermal and viscous effects. High-frequency p-modes are found to carry substantial acoustic energy fluxes, exceeding $10^6\ \mathrm{W\,m^{-2}}$ in the lower photosphere, thereby providing sufficient energy to power chromospheric heating and contribute to coronal energy requirements. This supports the excitation of fine-scale dynamic structures such as spicules, microspicules, and coronal loop oscillations. In contrast, low-frequency g-modes exhibit minimal contribution to coronal heating processes due to their weak energy transport efficiency. To quantify the vertical evolution of wave energy, a hybrid power-law decay formalism is developed to describe the attenuation of p-mode energy flux with increasing height. Complementary two-dimensional simulations further illustrate the spatiotemporal evolution of the vertical energy flux under the influence of nonthermal electron distributions, highlighting the role of turbulence-modified transport mechanisms. The theoretical predictions are found to be in good agreement with previously reported Doppler velocity observations from SDO/HMI, thereby reinforcing the validity of the present model in explaining observed helioseismic and coronal phenomena.

References:

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