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Expanding MRI Heating Models for Stratified Accretion Disks to Include Parker Instability

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Accretion disks are key structures underlying a broad range of astrophysical phenomena, from protostellar evolution to active galactic nuclei. As disk gas spirals toward the central object, angular momentum must be transported inward while gravitational energy is released and dissipated, producing a hot plasma. The magnetorotational instability(MRI) is widely regarded as the primary engine that drives both angular-momentum transport and plasma heating[1]. MRI-driven turbulence behaves as an effective viscosity and cascades energy to small scales, where it is finally converted into thermal and non-thermal energy.

In hot, weakly collisional disks—such as those around Sgr A* and M87—the fraction of dissipated energy imparted to ion versus electron Qi/Qe strongly influences the emergent spectrum, motivating intense theoretical work[2][3]. In particular, Kawazura et al.[4] analyzed energy dissipation in MRI-driven turbulence and evaluated the ion-to-electron heating ratio by tracing the energy flux through Alfvénic and slow-mode cascades.

Most previous studies that addressed the ion versus electron heating, however, ignore or simplify the disk's vertical stratification. In reality, gravity, pressure gradients, and magnetic fields produce vertical variations in density, pressure, and field strength. In such stratified media, a horizontal field can trigger the Parker instability[5], which lifts magnetic flux tubes and drives gas motions that may significantly affect disk dynamics and energy transport.

The aim of this study is to incorporate the effects of vertical stratification—specifically, the contribution of the Parker instability—into the existing MRI-based heating framework of Kawazura et al.[4] and Satapathy et al.[6], thereby constructing a more realistic model of accretion-disk heating.

Building on linear analyses of the previous study[7], we have conducted a theoretical investigation of systems in which MRI and Parker instability coexist. We derived eigenfunctions under stratified conditions and obtained the energy injection rate which plays an important role in the ion versus electron heating. These results provide a foundation for quantifying how stratification alters the production and dissipation of turbulent energy and, in particular, how the interaction between MRI and the Parker instability reshapes energy pathways.

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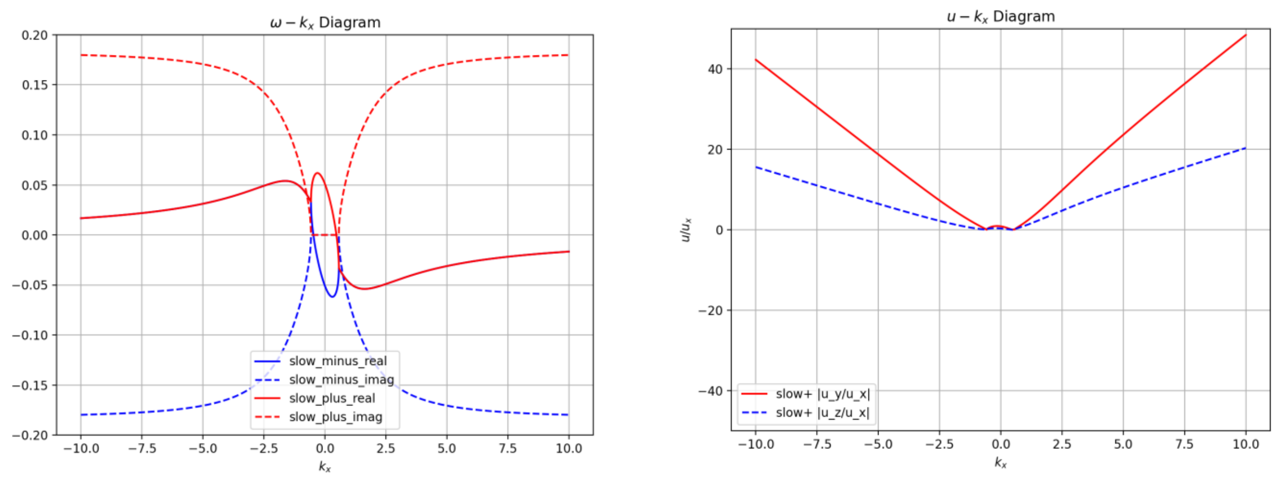

Figure 1. Dispersion relations for unstable modes and their eigenfunctions. The eigenfunctions represent the disturbance component of velocity and are normalized by the disk radial velocity.