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Turbulent Diffusion of Gravitationally Unstable Astrophysical Disks

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The dynamics of flat, rapidly and nonuniformly rotating self-gravitating systems has now been studied quite thoroughly. This research has aimed above all to explain the origin of various observed structures: spiral formation in galaxies, the rapid planetary formation, the fine-scale ~ 100 m structure of Saturn's main rings. It has been shown analytically that the evolution of these systems are dominated by the instabilities of gravity perturbations (e.g., those produced by a spontaneous disturbance or, in rare cases, a companion system). In particular, growing (that is, unstable) density waves can be self-excited in the main domain of the disk between the inner and outer Lindblad resonances via the gravitational Jeans-type instability in a nonresonant wave–"fluid" interaction.

Although the evolution of astrophysical disk systems is controlled by angular momentum transport, the mechanism by which this transport is achieved is still unclear. Ordinary molecular viscosity is too low to have much of an effect. Various processes for generating turbulence in disks have been suggested over the years, namely vertical convective instability, linear Rossby wave instability, baroclinic instability, and linear stratorotational instability. Also, the so-called magnetorotational instability has been extensively studied in the past decade or so, as the most promising source of turbulence in astrophysical disks. The recent realization on the possible existence of a "dead-zone" in circumstellar disks (where magnetohydrodynamic dynamics processes are inactive by lack of sufficient ionization and accretion would be shut down) has revived interest in other processes. Thus, the problem of momentum and mass transport in astrophysical disks is widely believed to require hydrodynamic turbulence for its resolution. The origin of this turbulence may be sought in the instability of small gravity perturbations.

This paper purports to provide new insight into turbulent diffusion induced by instabilities in astrophysical systems through application of an approximate linear hydrodynamical analysis. We develop the hydrodynamic theory of Jeans instability of both axisymmetric and nonaxisymmetric perturbations of a dynamically cold subsystem (identified as the "gaseous" component) of a rapidly and differentially rotating astrophysical disk. It is shown that in self-gravitating, rotationally flattened configurations, such as gaseous disks of spiral galaxies, protostellar and protoplanetary gas-and-dust disks, and, finally, Saturn's ring disk of particles the anomalous *turbulent* diffusion arising by Jeans' gravitational instability may exceed the ordinary *microscopic* diffusion substantially. Redistribution of the matter under the influence of rotating potentials of Jeans-unstable perturbations is therefore crucial to the understanding of the dynamics of these systems. This might be also important to the understanding of the fuelling mechanism of active galactic nuclei and supermassive black holes in galaxies.

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