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MRI induced turbulence and nonlinear structures in protoplanetary disks

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The basic physics of evolution of a protoplanetary disk (PPD) system and the formation of planetesimals in still a subject of active research that the theoretical physicists are trying to comprehend. It has been widely accepted that the magnetic field plays a crucial role in an accretion disk leading to different nonlinear plasma phenomena. Magentorotational instability (MRI) is now considered to be the key process taking place in a PPD which is the reason behind the coupling between magnetic field and the protoplanetary plasma [1]. Balbus and Hawley, in 1991 , were able to explain that accretion disks undergo a powerful shearing instability transmitted by a weak magnetic field that is responsible for the origin of turbulent viscosity in accretion disks which they termed as magnetorotational instability [2]. In a protoplanetary disk system, various nonlinear magnetic activities that are taking place, are strongly subjected to non-ideal magnetohydrodynamics (MHD) effects due to the low ionisation of the disk plasma [1]. Early investigations have also reported that MHD turbulence excited by MRI in the disk is anticipated to propel disk winds from the surface which is expected to play a crucial role in its evolution [3, 4]. Theoretical studies by various authors in the past have revealed that the saturation level of the MRI-driven turbulence controlled by the net magnetic field significantly govern the strength of the transport of angular momentum, resulting mass accretion [4, 5].

The magnetic activities in a protoplanetary disk can actually have an impact on its state of ionization [1]. MRI in the dead zones of a protoplanetary disk is revived by the ionized gas that is transported to the less ionized regions of the disk by turbulence, under suitable conditions [6]. Dead zones in an accretion disk is the zone, where presence of dust particles prevent the onset of MRI. There are other processes, such as Joule heating by MRI turbulence, that can essentially alter the temperature profile of the PPD as well as the location of the dead zone inner edge [6, 7]. Inutsuka and Sano, in 2005, showed that in a weakly ionized PPD, the MRI-driven turbulence produces a strong electric field in the neutral comoving frame which leads to plasma heating at some parts of the disk [6]. In 2015, Okuzumi and Inutsuka reported that this plasma heating reduces the electric conductivity J/E before the onset of impact ionization. Also, the influence of the plasma heating on ionization degree of the gas results the Ohm's law to be nonlinear in E [1]. It has been observed that this plasma heating triggered by the electric field eventually leads to an asymmetric electron distribution in the protoplanetary disk which can be represented by the Davydov distribution function [8, 9].

In this work, we investigate this effect and show how this can lead to formation of nonlinear structures which may eventually break up the disk.

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