3D radiation hydrodynamics simulations of gravito-turbulence in protoplanetary disks

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Angular momentum transport in protoplanetary disks controls their time evolution and thus strongly affects the planet formation process within them. In some cold and massive protoplanetary disks, angular momentum can be transported by shear stresses associated with the gravitational instability (GI). A natural consequence of the long-range nature of gravity is formation of spiral arms as a result of GI, which globally transport angular momentum. On the other hand, Gammie (2001) showed another nonlinear outcome of GI, called gravito-turbulence, in which angular momentum transport can be described locally as in the alpha disk model (Shakura & Sunyaev 1973). Following Gammie (2001), many authors have studied numerically various aspects of the gravito-turbulence, but, in most cases, a simple cooling function with a constant cooling time has been used as in Gammie (2001).

In this paper, we present 3D radiation hydrodynamics simulations in a local shearing box to explore the outcome of self-gravity in a protoplanetary disk with realistic thermodynamics. We found that gravito-turbulence is sustained for a finite range of the surface density, from 20 to 50 times the one in the minimum mass solar nebula at 50AU, when the grazing angle of the irradiation is 0.02. The flow is laminar below the range while fragmentation occurs above the range. In the range of gravito-turbulence, the Toomre parameter decreases monotonically from 1 to 0.7 as the surface density increases while an effective cooling time takes an almost constant value that depends on the radius. The turbulent motions are supersonic at all heights, which dissipates through both shock waves and compressional heating. The compressional motions, occurring near the midplane, create upward flows, which not only contribute to supporting the disk but also to transporting the dissipated energy to the disk surfaces. We also show that the simple cooling function with a constant cooling time does not approximate the realistic cooling.

Keywords: protoplanetary disk, gravitational instability, turbulence

