THERMALLY INDUCED WAVES IN IRRADIATED PROTOPLANETARY DISKS. Sei-ichiro Watanabe[1] and D. N. C. Lin[2], [1]Department of Earth and Planetary Sciences, Nagoya University, Chikusa-ku, Nagoya 464-8601 Japan; seicoro@eps.nagoya-u.ac.jp, [2]UCO/Lick Observatory, University of California, Santa Cruz, CA 95064; lin@ucolik.org.

Introduction: We calculate the quasi-static thermal evolution of irradiated protoplanetary disks by directly integrating the radial optical depth to determine the optical surface and find that in disks with modest mass accretion rates, thermal waves are spontaneously excited in the outer disk, propagate inward, and dissipate at small radii [1].

Dusty protoplanetary disks are considered to beheated by radiation from the central star . The two-layer disk models (superheated dust layers above and below the disk midplane [2]) cleary explain the silicate and water ice emission bands in the observed spectral energy distributions (SEDs) of Herbig Ae/Be and T Tauri stars [3]. Despite their triumph, these models are based on the assumption that optical surface height is proportional to vertical gas scale height and that the intercepted fraction of stellar radiation is determined from the local grazing angle. We show that these assumption may not be generally valid and more general treatment reveal the unstable nature of the irradiated disks.

Procedure: We perform a set of one-dimensional radial calculation of two-layer axisymmetric disks to examine the thermal evolution of hydrostatic disks, using the direct integration of optical depth to determine the optical surface and total emitting area-filling factor of a superheated layer. We assume that the thermal timescale is much longer than the dynamical time but much shorter than the viscous evolution time, so that we can regard the whole region of the disk as always in hydrostatic equilibrium in the vertical direction and as having time-indepenfdent surface densities. We also consider the effects of oblique radiative transfer from superheated dust within the adjacent regions.

Results: The initial state obtained by a fixed ratio of optical surface height to gas scale height evolves spontaneously to a state in which thermal waves grow. The disks evolve to a quasi-periodic state where thermal waves continuously propagate from 100 AU to 0.25 AU in about 100 years.

The mechanism driving this thermal instability is “a shadowing effect” in which the surface where most of the stellar radiation is intercepted at any given radial location may be affected by the vertical structure in the disk regions interior to that radius. This quasi-periodic state is stabilized by viscous dissipation associated with the mass accretion through the disk. For the cases of the mass accretion rate to be 10^{-7} solar mass per year, wave excitation and propagation are suppressed and the disk reaches approximately steady states.

The result that quasi-periodic wave-propagating states exist in disks with modest disk accretion rates is robust to variation in the disks’ structural parameters, such as their surface density profile, opacity law, and vertical dust distribution. Whereas these parameters weakly affect the positions of the inner and outer boundaries of the wave-propagating domains, they do not affect the basic features of the waves such as their amplitude and shape.

In passive protoplanetary disks, especially transitional disks, these waves induce significant episodic changes in SED, on time-scales of decades, because the midplane temperature can vary by a factor of 2 between the exposed and shadowed regions. The transitory peaks and troughs in the potential vorticity distribution can lead to baroclinic instabilities, which may excite turbulence in the planet-forming regions.

References:

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