EPSC Abstracts
Vol. 15, EPSC2021-161, 2021
https://doi.org/10.5194/epsc2021-161
Europlanet Science Congress 2021

Planetesimal formation by the “no-drift” mechanism

Ryuki Hyodo[1], Shigeru Ida[2], and Tristan Guillot[3]
[1]ISAS/JAXA, Solar System Sciences, Sagamihara Kanagawa, Japan (hyodo@elsi.jp)
[2]Earth-Life Science Institute, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8550, Japan
[3]Laboratoire J.-L. Lagrange, Université Côte d’Azur, Observatoire de la Côte d’Azur, CNRS, 06304 Nice, France

A notable challenge of planet formation is to find a path to directly form planetesimals from small particles. Small particles are, in general, challenged to grow beyond meter size due to the “growth barrier” and the “drift barrier”.

Over the last few decades, magnetohydrodynamic (MHD) simulations have shown that a region where ionization is too low for the magneto-rotational instability (MRI) to operate (i.e., a “dead zone”) might ubiquitously exist in the inner part of the disk midplane, and that only surface layers are magnetically active, supporting accretion. These indicate a nonuniform turbulence structure.

In this study, we aim to understand how drifting pebbles pile up in a protoplanetary disk with a nonuniform turbulence structure (Figure 1). We consider a disk structure in which the midplane turbulence viscosity (i.e., diffusion of pebbles is characterized by a distinct non-dimensional parameter (α_{mid})) increases with the radius in protoplanetary disks, such as in the outer region of a dead zone. We consider that the gas accretion toward the central star is characterized by a distinct non-dimensional parameter (α_{acc}). We perform 1D diffusion-advection simulations of pebbles that include back-reaction (the inertia) to the radial drift and the vertical and radial diffusions of pebbles for a given pebble-to-gas mass flux ($F_{p/g}$).

We report a new mechanism, the “no-drift” runaway pile-up (i.e., instability), that leads to a runaway accumulation of pebbles in disks, thus favoring the formation of planetesimals by streaming and/or gravitational instabilities. This occurs when pebbles drifting in from the outer disk and entering a dead zone experience a decrease in vertical turbulence. Consequently, the scale height of the pebble then decreases, and, for small enough values of the turbulence in the dead zone and high values of the pebble-to-gas flux ratio, the back-reaction of pebbles on gas leads to a significant decrease in their drift velocity and thus their non-steady-state accumulation (i.e., a local runaway pile-up of pebbles). This process is independent of the existence of a pressure bump and/or pebble growth.

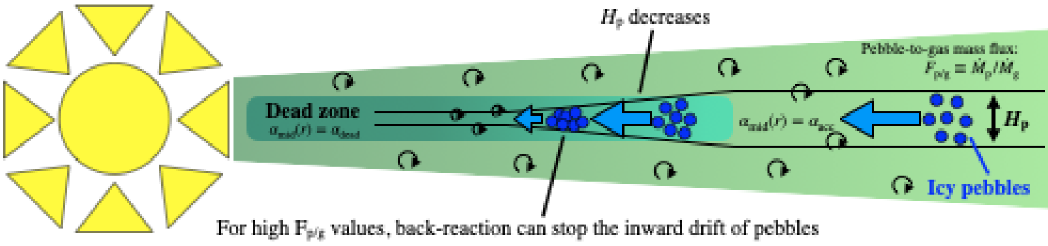

Figure 1: Schematic illustration of pebble drift and its pile-up within a protoplanetary disk with a dead zone. The disk gas accretion is characterized by alpha-parameter (α_{acc}), while the midplane diffusivity, being a dead zone ($\alpha_{dead} << \alpha_{acc}$) in the inner region, is characterized by α_{mid}. During the inward drift of pebbles, the pebble scale height H_p decreases as H_p is proportional to $\alpha_{acc}^{1/2}$ until a KH instability prevents it from becoming smaller. A smaller H_p leads to an elevated local midplane concentration of pebbles within a thinner midplane layer. The elevated midplane pebble-to-gas ratio causes the back-reaction to be more effective in reducing the radial drift velocity of pebbles. Such a physical interplay with a sufficiently large pebble-to-gas mass flux results in a continuous accumulation of pebbles in a runaway fashion (i.e., the "no-drift" runaway pile-up). Redrawn from Hyodo, Ida, Guillot (2021) A&A, 645, L9.