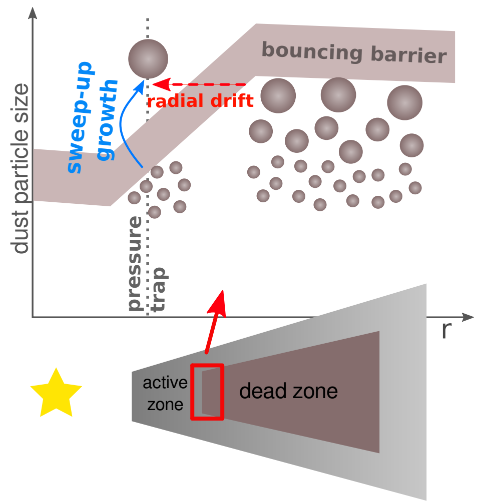
PLANETESIMAL FORMATION VIA SWEEP-UP GROWTH AT THE INNER EDGE OF DEAD ZONES

JOANNA DRĄŻKOWSKA*, FREDRIK WINDMARK, AND KEES DULLEMOND

HEIDELBERG UNIVERSITY, CENTER FOR ASTRONOMY, INSTITUTE FOR THEORETICAL ASTROPHYSICS, HEIDELBERG, GERMANY *DRAZKOWSKA@UNI-HEIDELBERG.DE

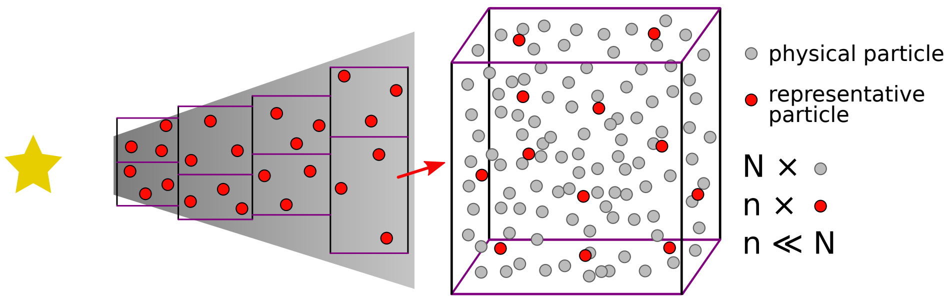
IDEA



- Steep decline in turbulent strength toward large orbital radius [2,3]
- Associated pressure bump
- As turbulence is a major source of impact velocities for small dust particles, the aggregates grow to larger sizes in the dead zone than in the MRI active zone
- Radial drift shifts the big aggregates through the bouncing regime, to the pressure trap
- The big aggregates proceed to grow thanks to fragmentation with mass transfer [4,5]
- See the neighboring poster by Fredrik Windmark for more information about the sweep-up growth!

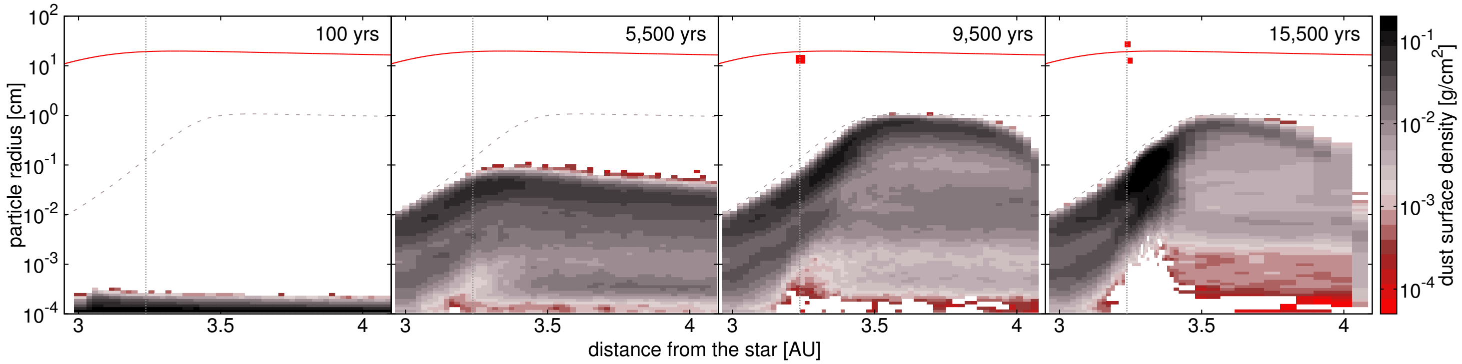
METHOD

• 2D (r+z) model • Representative particles (RP) description for dust • Analytical model for gas • Each particle described by (m_i, r_i, z_i) • Collisions performed with the Monte Carlo algorithm • Relative velocity sources: Brownian motion, turbulence, radial, vertical and azimuthal drift • Advection: radial drift, vertical settling, turbulent diffusion • Particles treated as compact spheres • RPs binned using an adaptive grid routine • Code parallelization with OpenMP



We use representative particle approach [6] to describe the dust. The protoplanetary disk is assumed to be axisymmetric. First, the vertical walls are established so that the number of RPs in each radial zone is equal. Then, the horizontal walls are set up for each radial zone individually in order to preserve equal number of RPs in each cell. The grid is renewed after every advection timestep. This approach allows us to automatically gain higher spatial resolution in the important, high density regions. Furthermore, keeping the number of RPs per cell constant assures that we always have a sufficient amount of bodies to resolve the coagulation properly. As the Monte Carlo algorithm is an O(n^2) method, the adaptive grid approach reduces computational cost of simulations.

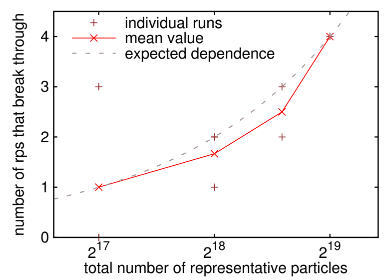
RESULTS

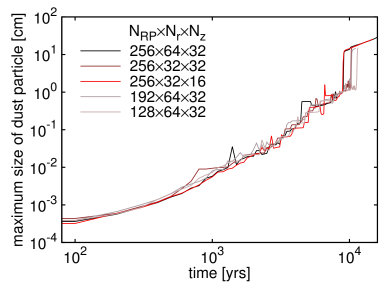


Vertically integrated dust density at different stages of evolution. The red solid line shows the particle size corresponding to the Stokes number of unity. This line is proportional to the gas surface density. The dashed line shows approximate position of the bouncing barrier. The dotted line indicates location of the pressure trap. Although most of the dust particles stop to grow because of the bouncing barrier, some of them manage to break through and continue to grow by sweep-up while being trapped in the pressure bump.

We start the simulation with identical μm-sized monomers distributed between 3 and 4.2 AU. We use 2^{19} (over 5×10^5) RPs distributed over 64 radial and 32 vertical cells. We use disk model based on [3], employing an ad hoc α viscosity change near the snow line located at 3 AU. Our collision scheme is similar to [4], including sticking, bouncing, fragmentation, and mass transfer.
Particles undergo drift and collisions. After a few thousand years, most of particles are kept small by the bouncing and evolve by slowly drifting inwards. Particles halted by the bouncing barrier in the dead zone are automatically shifted to fragmentation/mass transfer regime in the MRI active zone. Most of these particles fragment due to equal-size collisions and their sizes go back to the bouncing barrier position. Because of a smooth transition between sticking and bouncing, a limited number of particles manage to grow to a maximum size before they have drifted inwards. These particles have a chance to avoid the equal-size collisions, as the largest particles are drifting the fastest. Thus **some "lucky" aggregates can reach position where the fragmenting collisions are very unlikely and proceed to grow by sweeping up smaller particles**. In the presented model we observe four such seeds. We estimate that they would reach meter sizes within less than 10^5 years.
See our recent publication [1] for more details!

RESOLUTION TESTS





Total mass of seeds should be independent on resolution. Thus, number of RPs that break through has to change with the total number of RPs. The points show results of runs with identical setup but different nr of RPs and the solid line represents the average value for equal number of RPs. The dashed line shows the expected dependence, which is consistent with our results.

The figure shows time evolution of the maximum particle size in several runs, resolution of each is specified as number of RPs × number of radial cells × number of vertical cells. The evolution is nearly identical in all the cases. We find that the time after which the first particle break through is independent on the resolution used to perform the models.

REFERENCES

[1] Drążkowska, J., Windmark, F., Dullemond, C.P. 2013, *A.&A.* in press, arXiv:1306.3412

[2] Dzyurkevich, N., Turner, N.J., Henning, T., et al. 2013, *ApJ*, **765**, 114

[3] Kretke, K.A., Lin, D.N.C. 2007, *ApJL*, **664**, 55

[4] Windmark, F., Birnstiel, T., Güttler, C., et al. 2012, *A.&A.*, **540**, A73

[5] Wurm, G., Paraskov, G., Krauss, O. 2005, *Icarus*, **178**, 253

[6] Zsom, A., Dullemond, C.P. 2008, *A.&A.*, **489**, 931

http://tinyurl.com/qdcg3y9