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Dust accumulation caused by thermal interaction between gas and dust in gas shock regions

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Meteorites are important clues to investigate the environment of the early solar system. Chondrules are 0.1mm ? 1mm sized spherical igneous structure which are abundantly found in chondritic meteorites. Chondrule precursor dust grains once experienced melting caused by certain heating event, then recrystallized and formed their spherical form. Experimental constrains suggest that heating event was intense, heating duration is of the order of a few minutes and these events continued intermittently about three million years. This heating process was surely dominant in the early solar system but details are still unknown.

The most promising heating source for chondrule formation is gas shock wave heating in the protoplanetary disk. Previous works showed that gas shock waves can heat up the precursor dust grain temperature above melting point due to frictional heating. Iida et al. (2001) also showed that the gas temperature is higher than the dust temperature when the dust stops in the gas and its temperature attains maximum. In such a situation, the dust acts as coolant for the gas.

The gas in a relatively high dust density region is preferentially subjected to cooling by the dust. This preferential cooling makes the gas pressure minimum. Then the gas flows into the region because of the gas pressure gradient. This flow drags the dust into the high dust density region and it leads to further dust density enhancement. This one way thermal instability process may cause dust accumulation. Previous works concerning the gas shock wave heating model did not consider this process at all.

Here we investigate the possibility of dust accumulation by gas dust thermal interaction. To this aim we consider a gas dust two component fluid. We carry out one dimensional numerical calculation which includes both momentum and energy interaction between the gas and dust.

In our model, the gas loses energy via thermal collision with the dust due to the gas dust temperature difference. The dust gains energy from the gas and emits energy to outside of the system by radiation. Only the dust absorbs radiation from surrounding radiation field. The dust receives gas drag force and the gas receives back reaction. Only the gas feels self pressure gradient.

As initial condition we assume that there is a dust density maximum in the gas. We add dust density profile with Gaussian form on uniformly distributed dust density. The gas density is constant. The dust to gas mass ratio is unity at the maximum of the dust density, and one percent at far from the dust density maximum. We adopt typical gas and dust temperature, which are plausible after dust heating by gas shock waves. The gas temperature is higher than the dust temperature. The gas and dust velocity is assumed to be zero at first. From this initial setting we evaluate time evolution of the system.

We find that the gas in high dust density region cools faster than the gas in low dust density region. This difference of the cooling time scale of the gas makes pressure gradient of the gas. The gas begins to flow into the low gas pressure region and the gas density increases in the region. Drag force induces the dust inflow and the dust density also increases there. Gas and dust density enhancement lasts until the minimum gas temperature attains the temperature of the surrounding radiation field and decreasing of minimum gas temperature stops. In our setting, we show that the maximum gas and dust density increase is around five times larger than the initial density.

The gas density increases as to the system becomes isobaric. Isobaric condition shows that the gas density enhancement is several times larger than the initial gas density. Drag force can enhance the dust density as the same order of the gas density increase.

Future work is to investigate the consequence of this dust density enhancement.

Keywords: protoplanetary disks, chondrule, shock wave heating, dust accumulation, thermal instability