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Formation of planetesimals due to gravitational instability occurring with the dissipation of gas in the protoplanetary disk

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As the dissipation of nebular gas proceeds, the density of dust around the mid-plane increases. This is because the region where the dust density is greater than the gas density spreads and the shear instability only occurs by very steep density gradient in this region. Thus the dust density around the mid-plane exceeds the critical density of the gravitational instability. We propose a new model of planetesimal formation due to dissipation of the nebular gas.

Two different processes of planetesimal formation have been considered: (1) mutual sticking of dust particles due to inter-material forces, and (2) the gravitational instabilities. Ordinary chondrites are mainly composed of chondrules. Chondrules are mm-sized silicate spheres. Ordinary chondrites do not have signs that they contained abundant water. Thus their parent bodies are considered to have been made in the region near the Sun. The parent bodies might be formed by collisional aggregation of planetesimals due to gravitational force. However, the planetesimals themselves are considered to have been formed firstly by one of the above mentioned processes (1) and (2). It is difficult to form planetesimals in the region where water does not condense. Sticking due to carbonaceous materials may be considered, but it is not well known whether mm-sized particles as chondrules could stick each other. Here we propose a model that the planetesimals were formed by gravitational instabilities in the region near the Sun within 2AU.

A fluid element in the solar nebula revolves slightly slower than the circular Keplerian velocity due to the pressure gradient. Chondrules in the gaseous disk settle toward the mid-plane by z-component of the solar gravity, where z-axis is perpendicular to the mid-plane of the disk. As the dust to gas ratio increases around the mid-plane, the pressure effect decreases, and the revolution velocity increases. Then shear-induced turbulence occurs due to velocity difference of the region around the mid-plane and other regions. Sizes of chondrules are large to stick by material forces, but are small enough to be stirred by the turbulence. Thus the settling stops and the density around the mid-plane does not exceed the critical density of the gravitational instability. It is difficult to suppose the formation of planetesimals due to gravitational instabilities before the dissipation of nebular gas.

As the dissipation of nebular gas proceeds, the density of dust around the mid-plane increases. This is because the region where the dust density is greater than the gas density spreads and the shear instability only occurs by very steep density gradient in this region. Thus the dust density around the mid-plane exceeds the critical density of the gravitational instability. We propose a new model of planetesimal formation due to dissipation of the nebular gas.