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Thermal instability of gas-dust fluid system

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We carry out hydrodynamics linear stability analysis of 1-dimensional gas-dust fluid system. We focus on the thermal instability caused by the radiative cooling. If the cooling in a region takes place effectively, the gas temperature and the pressure decrease, and a flow converging to the region is driven. Then the dust particle number density in the region is enhanced by the gas drag force, and the cooling rate from the region can be raised as well because the cooling rate is proportional to the dust number density. This one-way process would lead to instability.

As an initial state, we assume that the system is static and the gas temperature is higher than the dust temperature. For retaining this state, we assume a hypothetical heat function for gas that is a function of the gas temperature and the gas density. As the cooling mechanism of the system, we suppose that the radiation from dust particle leaves the system without being absorbed again. Thermal energy is transferred between the gas and the dust particle by gas-dust collisions. At the same time the gas and the dust particles are dynamically coupled by drag force.

As a result of our linear analysis, we obtain a dispersion relation. We find that when a gas-temperature derivative and a gas-density derivative of the heat function satisfy certain criteria, an unstable mode emerges. When the instability takes place, the fluctuation of the dust particle number density grows.

Our result implies that if a realistic heat function meets the obtained criteria, a dust accumulation may occur in a protoplanetary disk. And this accumulation may lead to the planetesimal formation.

Keywords: hydrodynamics linear stability analysis, dust accumulation, chondrule formation, planetesimal formation