Static compression of porous dust aggregates

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Abstract

To understand the structure evolution of dust aggregates is a key in the planetesimal formation. Dust grains become fluffy by coagulation in protoplanetary disks. However, once they become fluffy, they are not sufficiently compressed by collisional compression to form compact planetesimals (Okuzumi et al. 2012, ApJ, 752, 106). Thus, some other compression mechanisms are required to form planetesimals.

We investigate the static compression of highly porous aggregates. First, we derive the compressive strength by numerical N-body simulations (Kataoka et al. 2013, A&A, 554, 4). Then, we apply the strength to protoplanetary disks, supposing that the highly porous aggregates can be quiasi-statically compressed by ram pressure of the disk gas and the self gravity. As a result, we find the pathway of the dust structure evolution from dust grains via fluffy aggregates to compact planetesimals. Moreover, we find that the fluffy aggregates overcome the barriers in planetesimal formation, which are radial drift, fragmentation, and bouncing barriers.

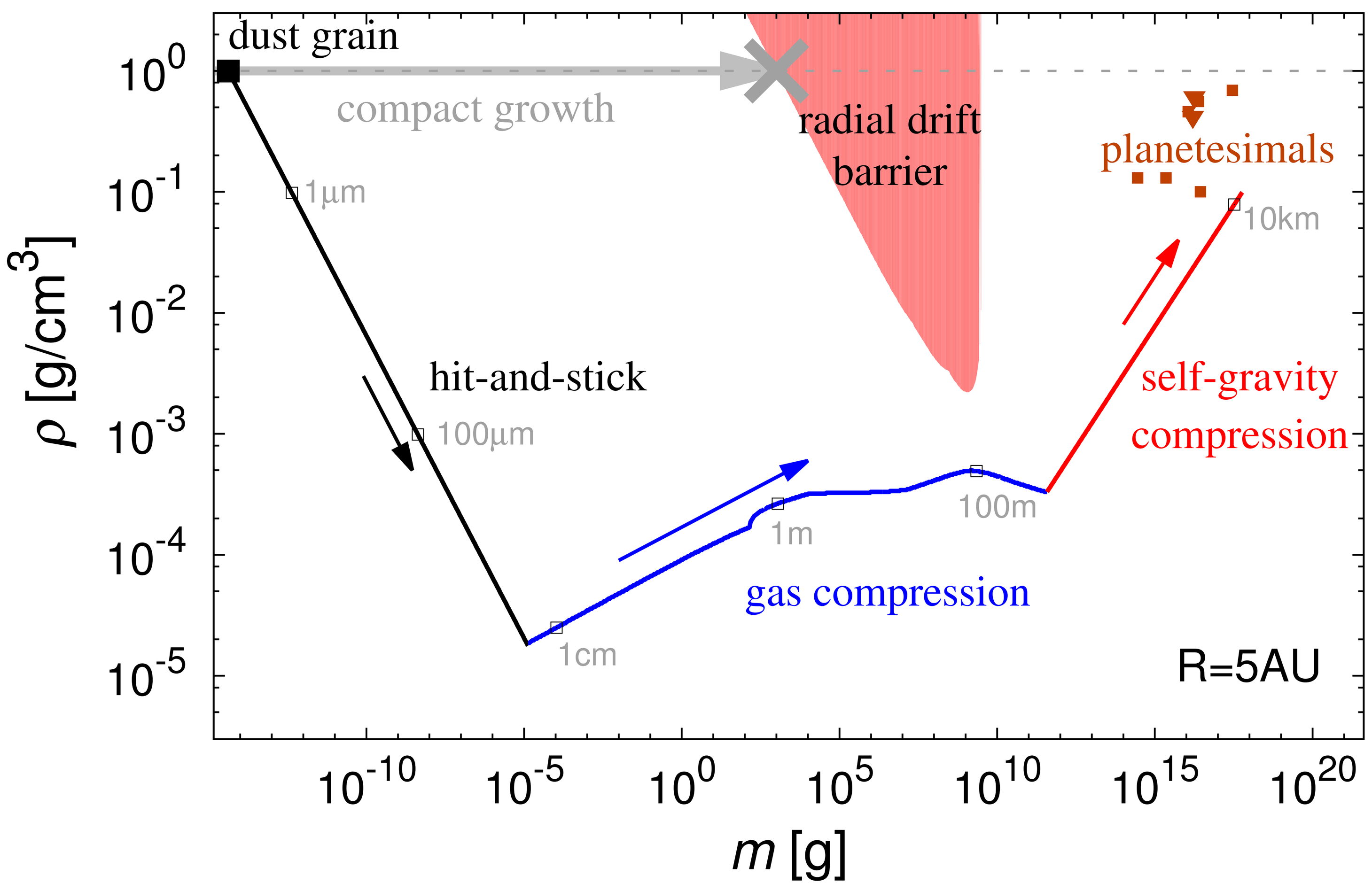


Fig.1. The dust mean internal density against the dust mass on the pathway of porosity evolution at 5 AU in MMSN by considering static compression.

The compressive strength derived from N-body simulations

(Kataoka et al. 2013, A&A, 554, A4)

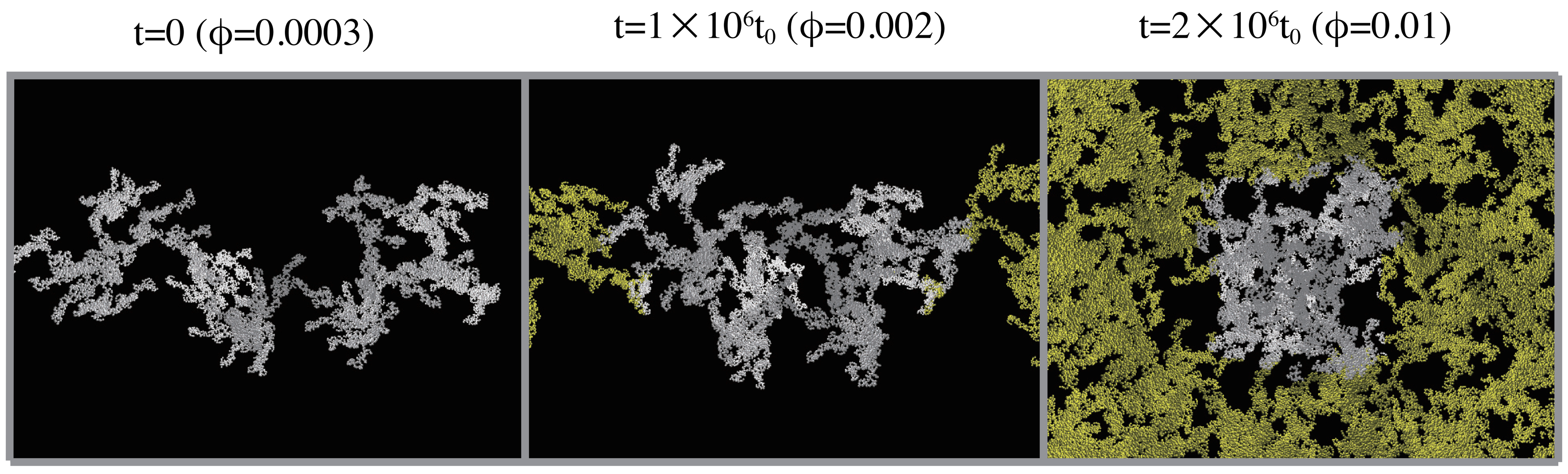


Fig.2. Snapshots of the evolution of an aggregate under compression in the case where N = 16384. The white particles are inside the computational region enclosed by the periodic boundaries, while the yellow particles are in the neighbor copy regions.

The compressive strength has been investigated in high-density region (ϕ > 0.1; Seizinger et al. 2012). However, there has been no study on the compressive strength highly porous aggregates (ϕ < 0.1).

In order to obtain the compressive strength of highly porous aggregates, we perform three dimensional numerical simulations of compression of a dust aggregate consisting of a number of spherical icy monomers. We solve all interactions between monomers in contact (Dominik & Tielens 1997; Wada et al. 2007)

Results

We derive the compressive strength as

$$P = \frac{E_{\rm roll}}{r_0^3}\phi^3.$$

where r_0 is the monomer radius and E_{roll} is the rolling energy, which is the energy for rolling of a particle over a quarter of the circumference of another particle in contact.

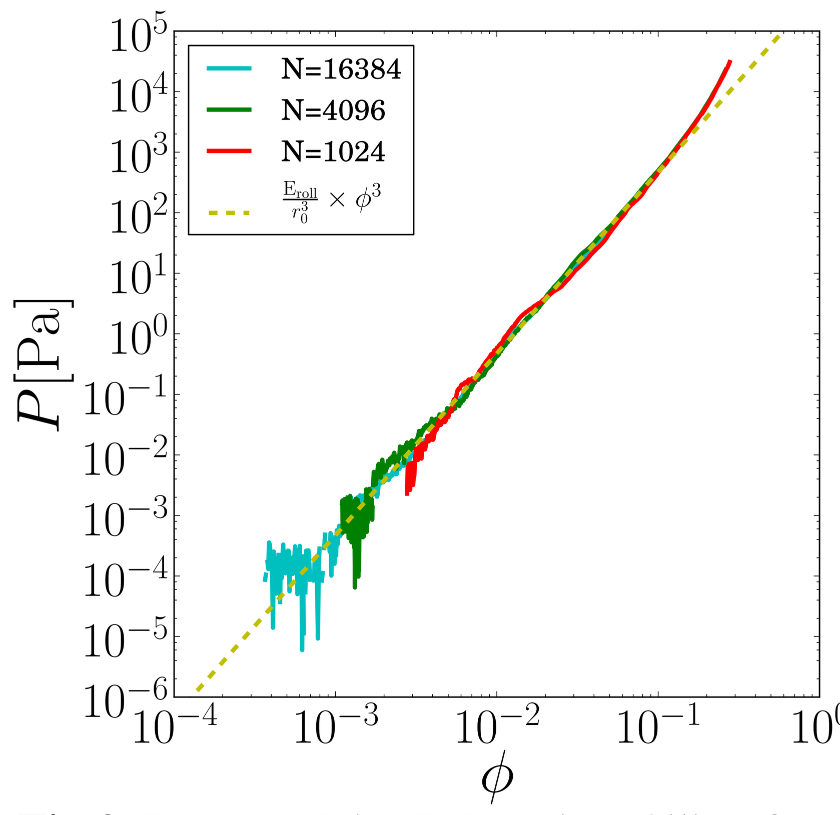


Fig.3. Pressure P in [Pa] against filling factor ϕ. The yellow dashed line shows the derived compressive strength formula.

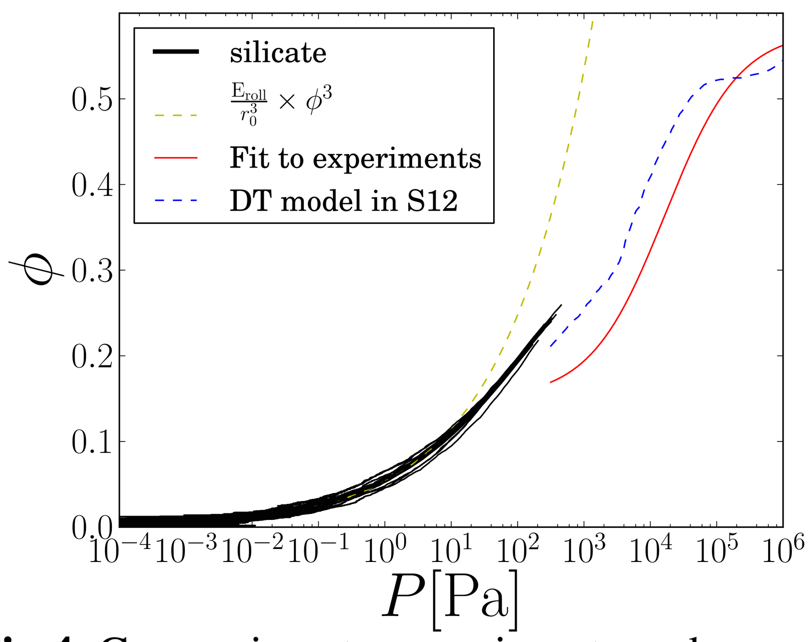
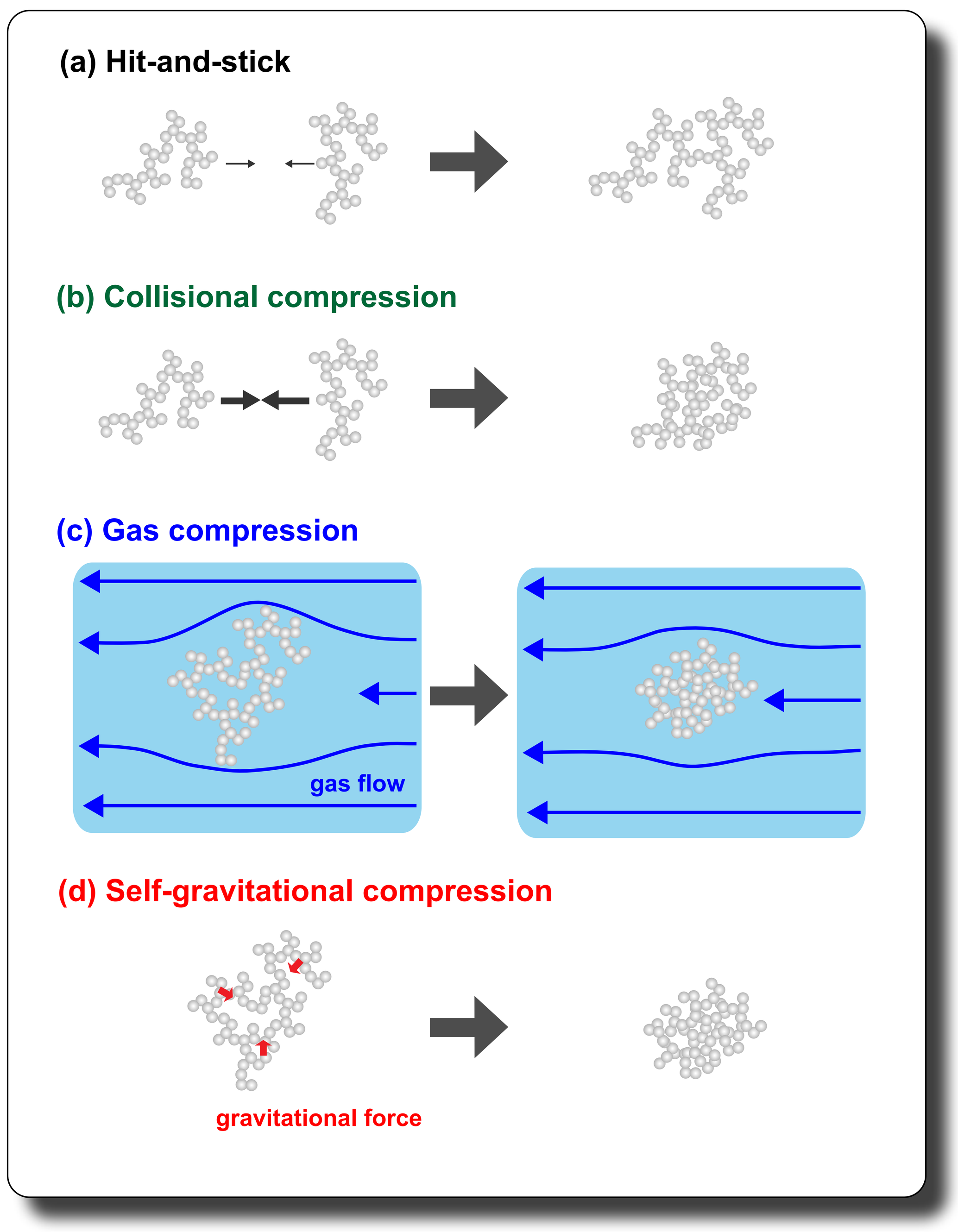


Fig.4. Comparison to experiments and numerical simulations in high-density region (Seizinger et al. 2012)

Fluffy dust forms icy planetesimals via static compression

(Kataoka et al., submitted to A&A Letter)



Porosity evolution in protoplanetary disks

When a dust aggregate feels a pressure which is higher than its compressive strength, the aggregate is quasi-statically compressed until its strength equals to the pressure. As a source of the pressure, we consider that due to ram pressure of the disk gas or self gravity of the aggregate. We analytically derive the pathway of internal density evolution.

As dust aggregates coagulate, they initially grow fractal, then gas pressure compress aggregates. Finally, when they become massive, they are compressed by self gravity to form compact planetesimals. Moreover, we show that fluffy aggregates avoid radial drift barriers (Fig.1 and Fig.6).

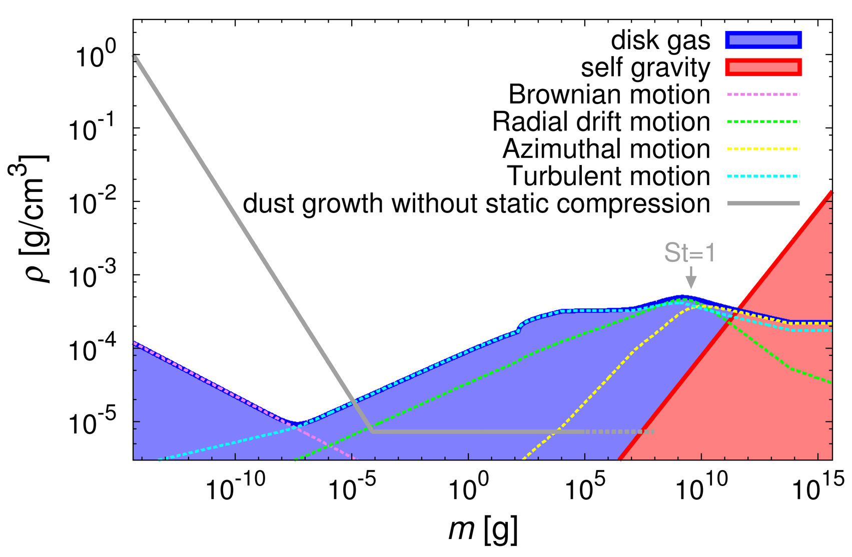


Fig.5. The dust density where the compressive strength is equal to surrounding pressure.

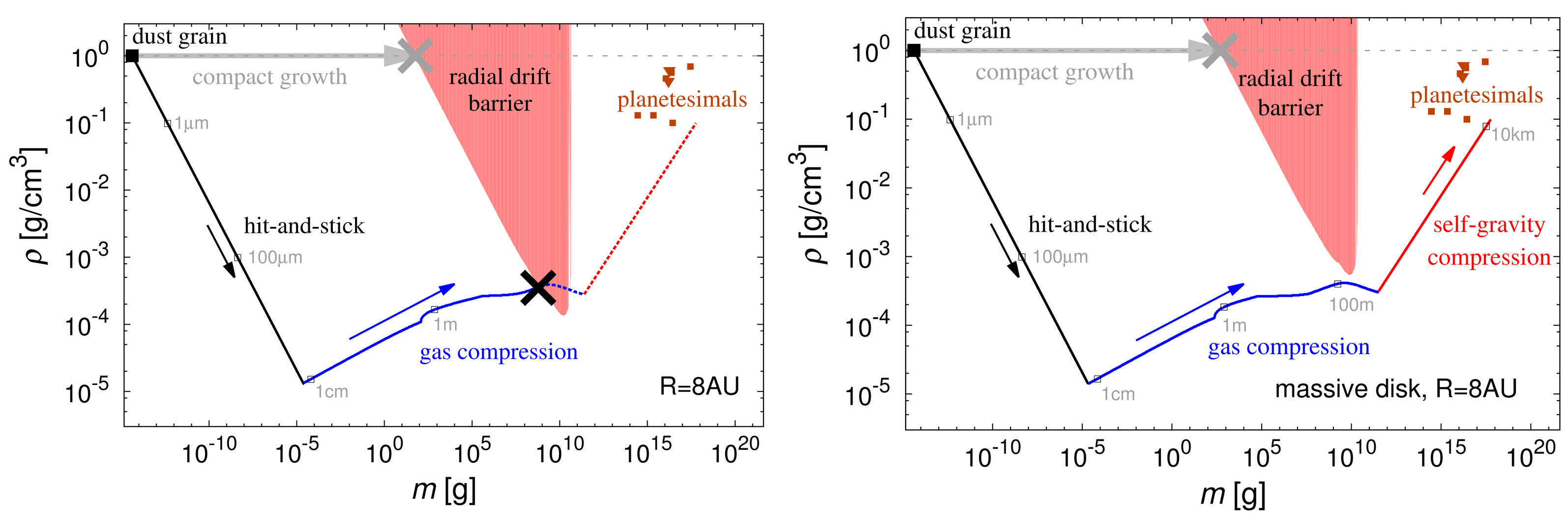


Fig.6. Porosity evolution at 8 AU in MMSN (left) and in two times as massive as MMSN (right).