Static Compression Process of Dust Aggregates in Protoplanetary disks

Akimasa Kataoka (SOKENDAI/NAOJ)
H.Tanaka (Hokkaido Univ.), S.Okuzumi (Nagoya Univ.), Koji Wada (Chibatech)
Planet Formation Theory

Dust Coagulation

Interstellar Medium

Protoplanetary disk

"Planetesimals"

Planets

Radial drift barrier

Dust structure (size and density) is important!

- Brownian motion
- Differential drift, settling, & turbulence

Jump? (Self-gravity?)

Runaway growth

Oligarchic growth

0.1μm

1m

1km

10^{2-4} km

migrate
dust

migrate
Recent studies have shown that dust grains grow to highly porous aggregates:

Other compression mechanisms are required.

Collisional Compression

internal density

1 g/cm³

10⁻⁵ g/cm³

1 μm

ISM

1 m

1 km

10²⁻⁴ km

radius


Planetesimal formation with fluffy aggregates
Aim of this work

This study investigates static compression process of highly porous aggregates

Static compression by gas pressure

Static compression by Self-gravity

Planetesimals

radius

10^{-5} g/cm^3

ISM

1 μm

1 g/cm^3

internal density

This study investigates static compression process of highly porous aggregates
Simulation model

Particle-particle interaction

(a) Repulsion / Adhesion
(b) Rolling
(c) Sliding
(d) Twisting

We use N-body simulation to investigate compression process

cf). Dominik & Tielens 1997, Wada et al. 2007

Initial condition: BCCA
Particle number: $6 \times 10^4$
Monomer: 0.1$\mu$m, ice
Independent from parameters, we derive the equation of state in static compression process.
Pressure in protoplanetary disks

Gas pressure

\[ \rho_{\text{equi, gas}} = 10^2 \left( \frac{R}{1 \text{[km]}} \right)^4 [\text{g/cm}^3]. \]

Self-gravity

\[ \rho_{\text{equi, grav}} = 10^{-2} \left( \frac{R}{1 \text{[km]}} \right)^2 [\text{g/cm}^3], \]
Planetesimal formation via fluffy aggregates

- **Internal density**

- **ISM**

- **BCCA aggregation**

- **Collisional compression**

- **Planetesimals**

  - **Static compression by self-gravity**

  \[ \rho_{\text{equi,grav}} = 10^{-2} \left( \frac{R}{1[\text{km}]} \right)^2 \text{[g/cm}^3] \]

  - **Static compression by gas pressure**

  \[ \rho_{\text{equi,gas}} = 10^2 \left( \frac{R}{1[\text{km}]} \right)^4 \text{[g/cm}^3] \]

**Successful pathway of planetesimal formation**

This diagram illustrates the process of planetesimal formation via fluffy aggregates, focusing on the internal density, the transition from the interstellar medium (ISM) to planetesimals, and the role of static compression by self-gravity and gas pressure. The equations for the equilibrium density under gravitational and gas pressures are also provided.
Conclusion

- We investigate the growth process from highly porous aggregates to planetesimals.
- We perform N-body simulations with particle-particle interaction.
- We derive the equation of state of dust aggregates in static compression process.
- Using the equation of state, we showed the successful pathway from highly porous aggregates to planetesimals in protoplanetary disks.