

Compound chondrule formation in the shock-wave heating model: three-dimensional hydrodynamics simulation of disruption of the molten dust particle.

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Summary

We performed **three-dimensional hydrodynamics simulations** to examine the disruption of the half-molten dust particle exposed to high velocity gas flow and dynamics of ejectors in the framework of shock-wave heating model. With these results, we tested "Fragment-collision model", which is new model for compound chondrule formation (Miura et al. *submitted*). We found that (1) **Collisions among ejectors can occur** due to the "shadow effect", (2) **Almost all collisions are satisfied with collision condition**, and (3) **Collision frequency (under the typical parameters, ~0.50) is much higher than existence frequency of compound chondrules**. We conclude that "Fragment-collision model" can be one of the strongest candidates for the compound chondrule formation.

Introduction

Compound chondrule

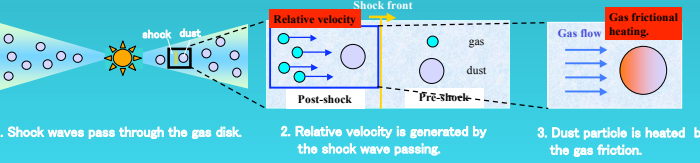
Two or more chondrules are attached.
A few % in all chondrules.
Two chondrules collide during the heating event.

Difficult to collide among dust particles in the solar nebula. (Sekiya and Nakamura 1996, Wasson et al. 1995)

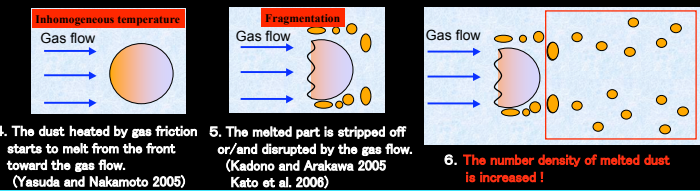
Collision section (σ) $\sim 10^{-1} \text{ cm}^2$
Relative velocity (Δv) $< \sim 10^2 \text{ cm/s}$
Collision frequency of melted dust $P_{\text{coll}} = n_d \sigma \Delta v t$
Heating duration (t) $< \sim 10^2 \text{ sec}$
Number density (n_d) $\sim 10^9 \text{ cm}^{-3}$ @3AU/MMSN
 $P_{\text{coll}} < \sim 10^{-6}!!$

Fragment-Collision model (Miura et al. *submitted*)
Note that the phenomenon of fragmentation of molten dust in the shock-wave heating model (see right panel).
Assuming random collision among ejectors.....
 $P_{\text{coll}} \sim 0.67 \gg \text{a few \%}$

Shock-wave heating model (Plausible model for chondrule formation)



Fragment-Collision model (New model for compound chondrule formation)



Collisions among ejectors

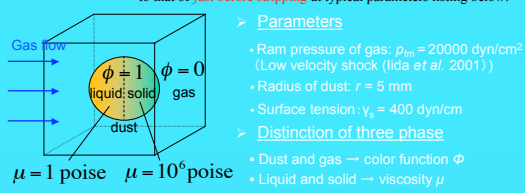
We do not know that....
1. Whether the ejectors really collide each other or not.
2. If the collisions occur, do two ejectors attach?
Collision velocity: If the collision velocity is too fast, two ejectors crumble.
Collision angle: If the collision is off-set, two ejectors does not attach.

In order to discuss, we need to know the time evolution of the position, velocity, and size of ejectors.

Purpose of this study

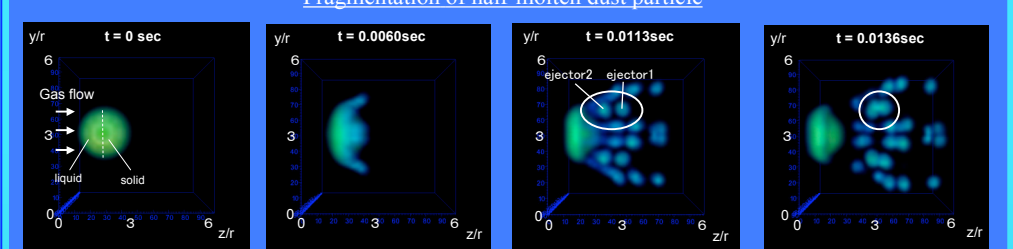
- To examine the **disruption of the dust particle and the dynamics of the ejectors** in detail in the shock model.
- To discuss whether the disruption event can contribute the compound chondrule formation or not.
 - Are collisions among ejectors really occurred?
 - Are these collisions satisfied with collision condition?
 - Is collision frequency more than existence frequency?

Initial settings We assume half-molten dust at initial. This condition is correspond to that of just before stripping at typical parameters listing below.

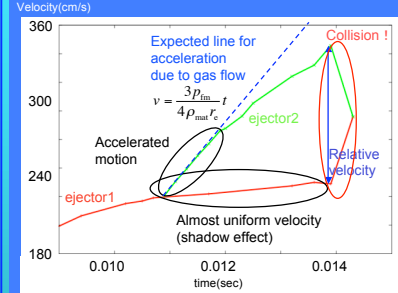


Basic equations
Integrate by CIP-CSL2 (Nakamura et al. 2001) and Pressure base method (Yabe and Wang 1991).

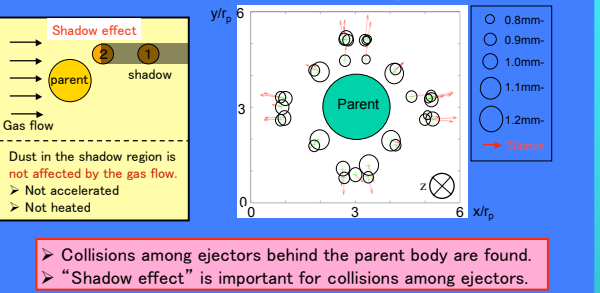
Fragmentation of half-molten dust particle



Evolution of velocities of gas direction

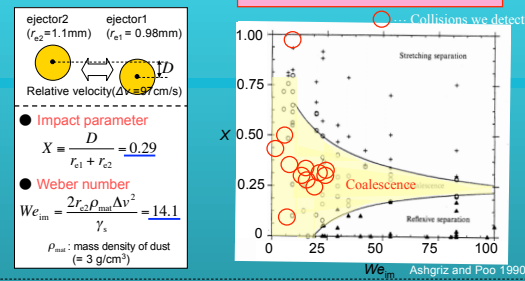


Information of all ejectors (t = 0.0135sec)



1. Collision condition

Almost all collisions are satisfied with collision condition.



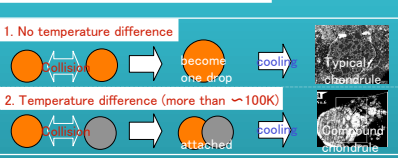
2. Collision frequency

Collision frequency is sufficient for the compound chondrule fraction.

Collision frequency \gg Compound chondrule fraction

$$\frac{\text{The number of ejectors which have experienced collision (11)}}{\text{The number of ejectors in the end of our simulation (22)}} \gg \frac{\text{The number of compound chondrules}}{\text{The number of all chondrules}} = 0.50 \gg \sim 0.05$$

3. Temperature difference



Assumptions:
• When the ejector2 is ejected, two ejectors have same temperature.
• The ejector2 is not cooled because of balance of gas drag heating and radiative cooling.
• The ejector2 is cooled by radiative cooling due to the "shadow effect".

$$\Delta T = \frac{3e\sigma T^4}{4r_e\rho_{\text{max}}C} t = 0.39 \left(\frac{t}{1} \right) \left(\frac{T}{1900\text{K}} \right)^4 \left(\frac{r_e}{1\text{mm}} \right)^{-1} \text{K}$$
 The temperature difference is not sufficient under these assumptions!

4. Two possibilities

I. Collisions far from the parent particle.
The temperature difference becomes sufficient if ejectors collide ~1sec after ejection. However...
• typical distance between ejectors \rightarrow size of parent particle (1cm)
• typical relative velocity decided by shadow effect $\rightarrow \sim 100 \text{ cm/s}$
• Typical timescale of collisions $\rightarrow \sim 10^{-2} \text{ sec}$ Much less than ~1sec

II. Temperature difference among the ejectors.
Result of 3D thermo-hydrodynamics simulation (x-z plane). $n_d = 2 \times 10^{15} \text{ cm}^{-3}$, $v_{\text{sh}} = 7 \text{ km/s}$, $r_p = 2 \text{ cm}$
 t=19.3 sec, t=38.7 sec, t=66.8 sec
 Temperature difference in the liquid layer is More than 100K.
 This code is now developed... In the future, we will see the disruption event including temperature.

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