

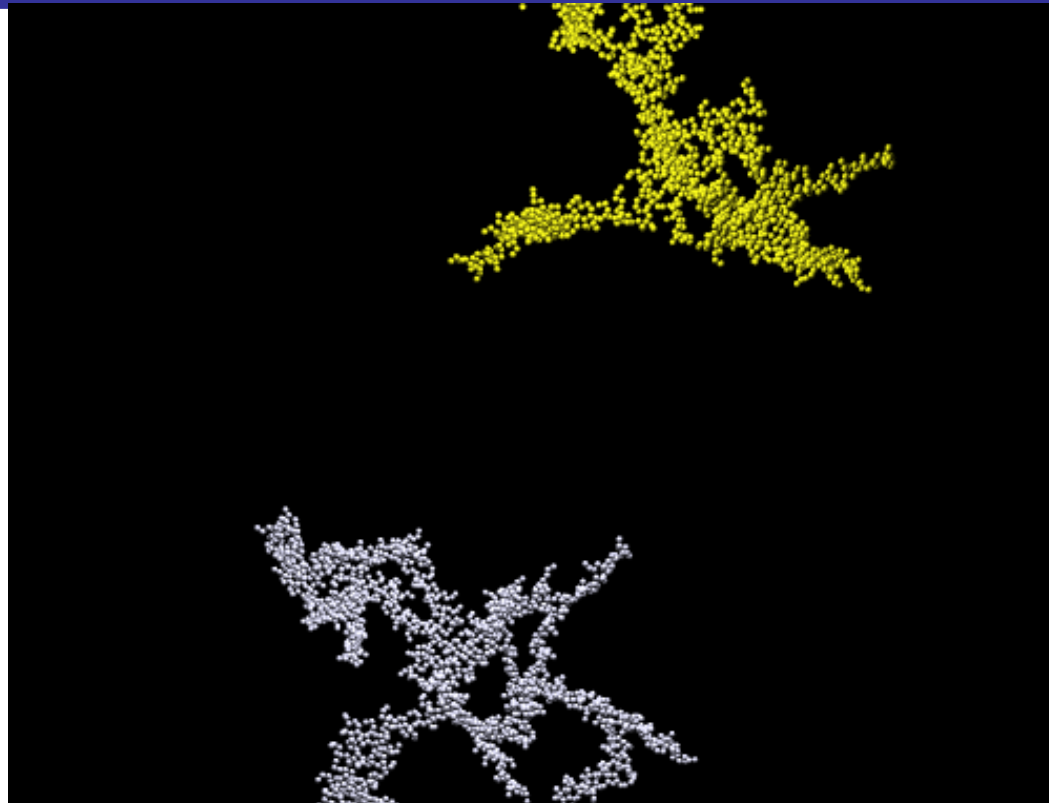
# *SIZE AND STRUCTURE EVOLUTION OF DUST IN NEBULA DISKS*

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N-body Simulation of  
Aggregate Collisions



**WHEN & HOW** are  
dust aggregates compacted  
in Nebula disks?



# Introduction

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- Structure evolution of dust aggregates changes **density**, strength, optical property, etc.
- **BCCAs** are formed in the early growth stage.
  - low velocity ( $\sim 0.01$  mm/s, 1AU in the minimum-mass nebula)
  - orderly growth (i.e., not runaway)

**WHEN & HOW are BCCAs compacted  
in nebula disks?**

**My talk:**

- Simple estimate of dust size at which compaction starts
- Simulation of aggregate collision & compression

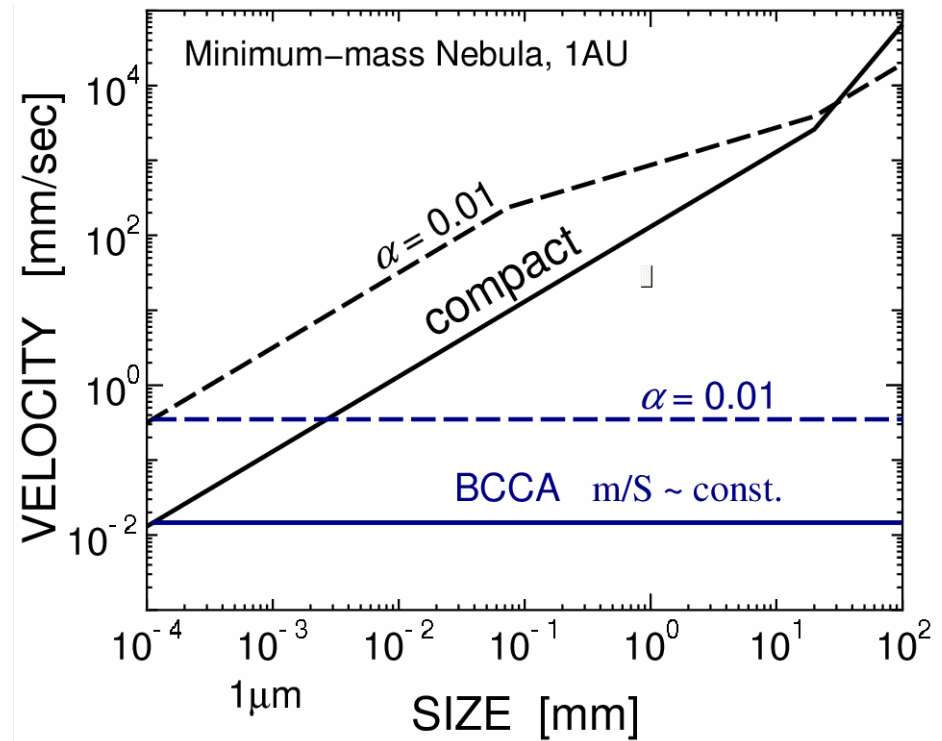
# Collision Velocity of Dust in Nebula Disks

Collision Velocity  $\propto m/S$   
(under Epstein's drag law)

$m$ : aggregate mass  
 $S$ : cross section  
for gas drag

Because of large cross section,  
BCCA's velocity is kept very low.

*This prevents compaction  
of BCCAs.*



# Compression Size of BCCAs : Simple Estimate

- **Compaction is caused by “rolling deformation”.**
- **Criterion for start of compression**

(Dominik & Tielens 1997)

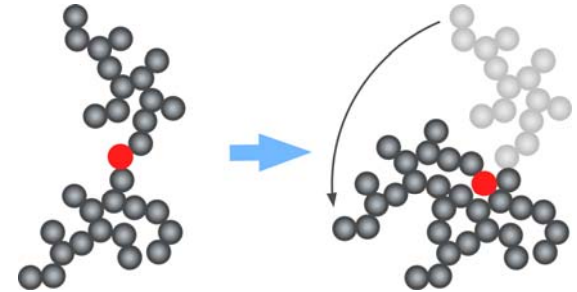
$$\frac{1}{2} m v^2 \sim E_{\text{roll}}$$

- **Compression Size**

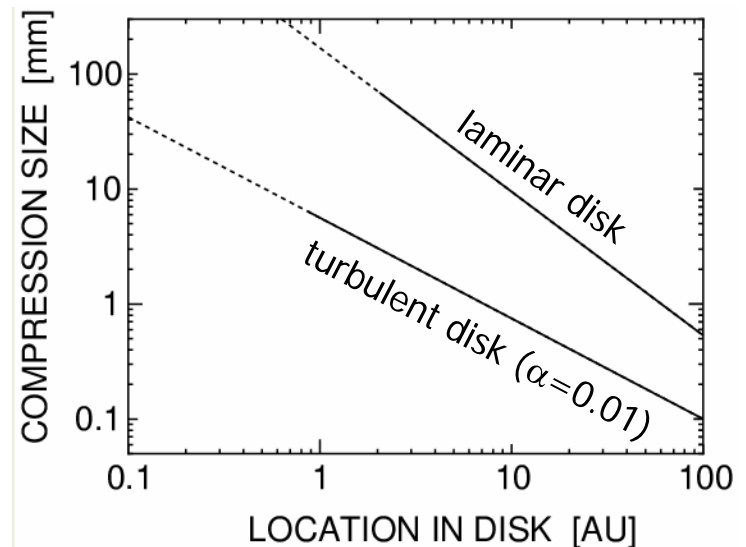
$$\begin{cases} \sim 10\text{cm} & : \text{laminar case (1AU)} \\ \sim 1\text{cm} & : \text{turbulent case} \\ & (\alpha=0.01, 1\text{AU}) \end{cases}$$

*After compaction they have chondrule size.*

*This is a lower limit. Maybe, larger.*



$E_{\text{roll}}$  : energy for rolling deformation  
 $\sim 10^{-8}$  erg  
for  $0.1\mu\text{m}$  ice monomers  
(DT1997, Heim et al. 1999)

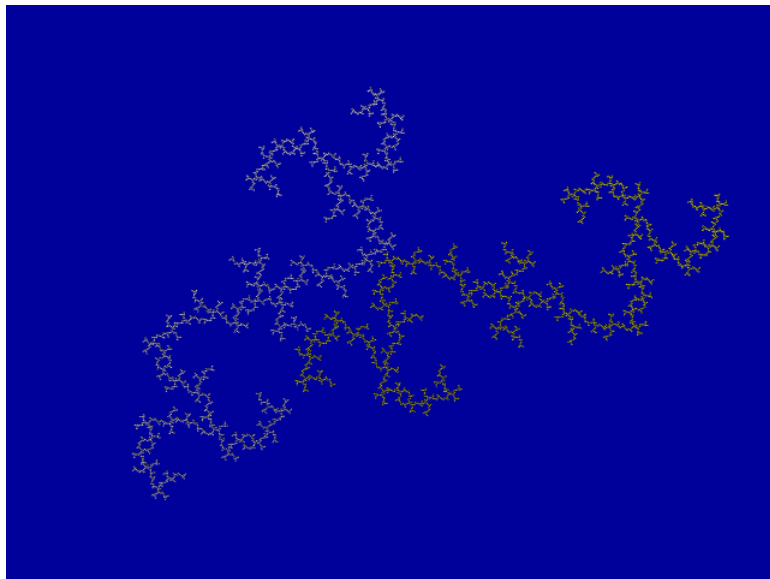


# *N-body Simulations of Aggregate Collision*

## I. 2D **head-on** collisions of BCCAs (Wada et al. 2006 in prep.) (2048+2048 **ice** monomers)

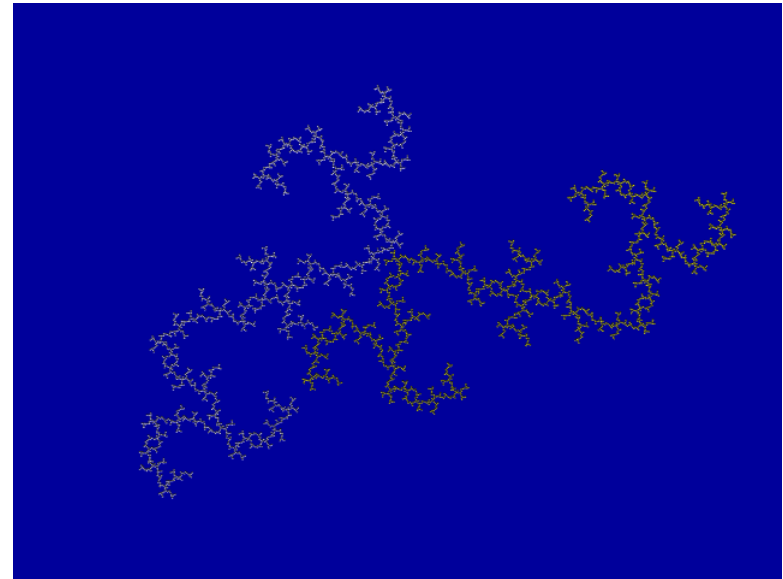
Monomer interaction  $\Rightarrow$  Model of Dominik & Tielens (1997)

Low Velocity Case (17.5 m/s)



**Stick!**

High Velocity Case (35 m/s)



**Break!**

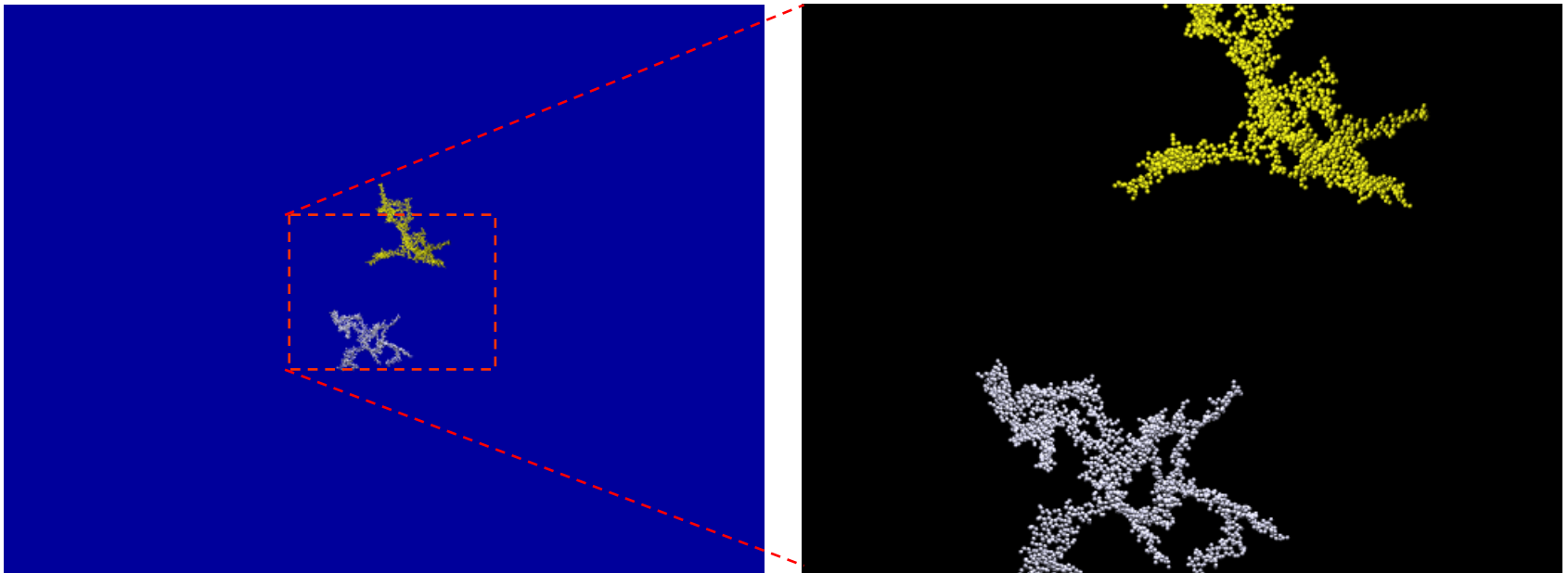
Agree well with Dominik & Tielens's breaking criterion!

# *N-body Simulations of Aggregate Collision*

## II. 3D **off-set** collisions of BCCAs (Wada et al. 2006 in prep.) (1024+1024 **silicate** monomers)

Monomer interaction  $\Rightarrow$  Model of Dominik & Tielens (1997)

$V=2.6\text{m/sec}$

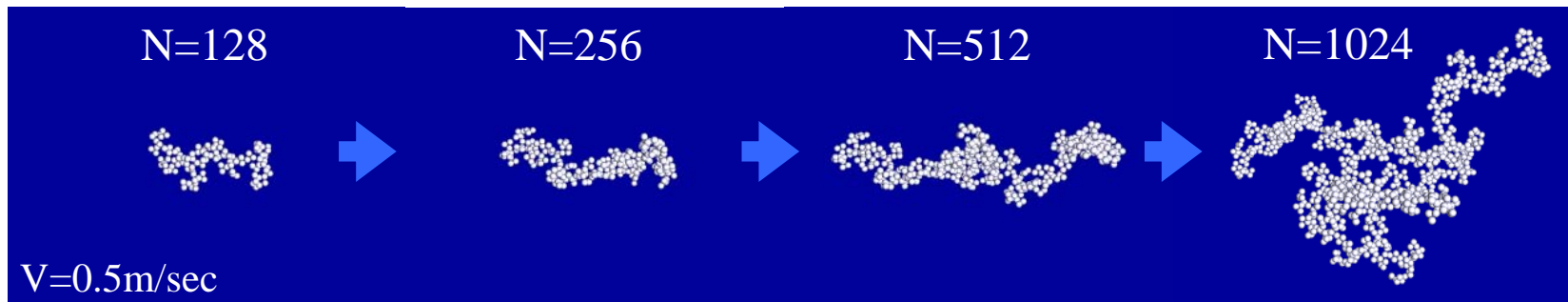


Off-set collision makes string-like aggregates.  
Expand rather than compaction!

# *N-body Simulations of Aggregate Collision*

III. A sequent of 3D head-on collisions (See Suyama's poster!)  
(2+2 **ice** monomers  $\rightarrow$  4+4  $\rightarrow$  8+8, ..., up to 512+512.)

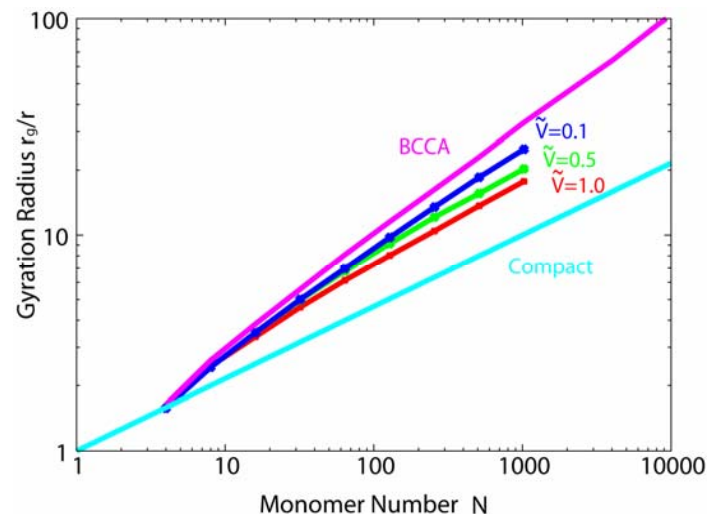
$\Rightarrow$  Density evolution of growing aggregate



Gyration radius:

$$r_g = \sqrt{\sum_i (\mathbf{x}_i - \mathbf{x}_c)^2 / N}$$

**Aggregate density decreases to a certain value in the course of growth.**



# SUMMARY

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1. Simple estimate of compression size of BCCAs :  
10cm at 1AU (laminar minimum-mass disk)  
→ After compaction, they becomes chondrule size.
2. Numerical simulations of BCCA collisions
  - Head-on collisions with intermediate velocities cause compaction.  
(Our results are well described by Dominik & Tielens's criterions.)
  - Off-set collisions produce 'string-like' aggregates  
Deformation does not always result in compression.
  - A sequence of collisions reduce the aggregate density to a certain value which depends on the collision velocity.

