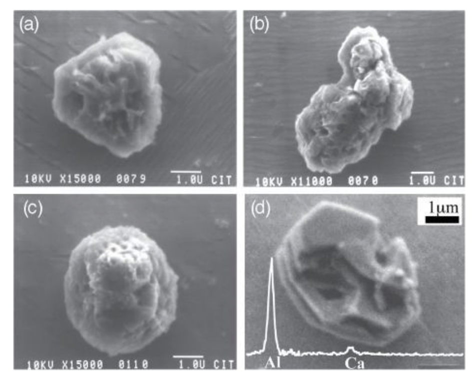
Diffusion process in thermally evolving planetesimals for presolar silicate grains.

S. Wakita (CfCA/NAOJ), T. Nozawa (DTA/NAOJ) and Y. Hasegawa (Caltech/JPL)

Introduction

Presolar grain

Tiny materials (typical size: 0.1 to 1 μm) found in meteorites.
Their isotopic composions are different from those of materials in the Solar System.
[ref., Zinner 2003, Hynes & Gyngard 2009, Nguyen et al. 2009, Leitner et al. 2012, Hoppe et al. 2015]

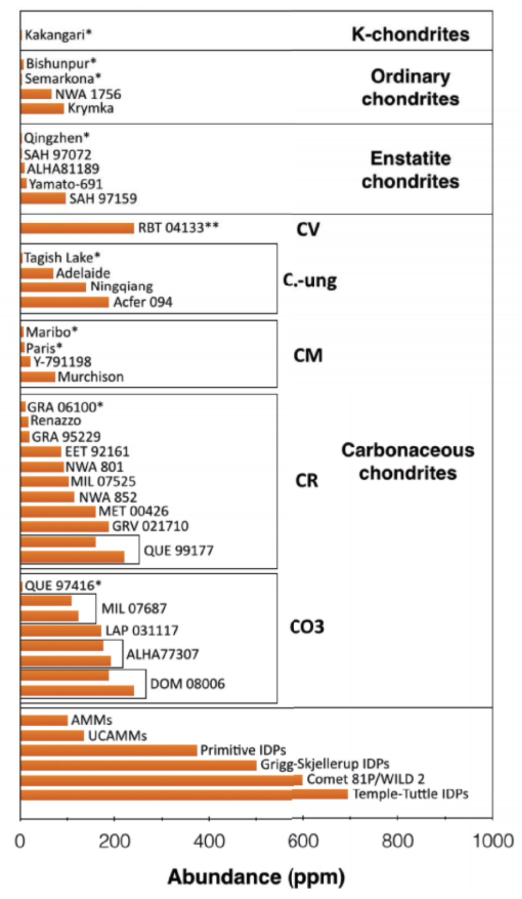


[Figure from McSween & Huss 2010]

Originated from nearby stars (supernovae and/or asymptotic giant branch stars); such stars could generate grains of 0.1 to 1 μm.
[ref., Nozawa et al. 2007, Yasuda & Kozasa 2012]

Abundance of presolar grain

Petrologic type 3 chondrites: the most abundant presolar grains among chondrites.
As type number increases from 3 to 6, their abundance decreases. [ref., Huss 1990]
Those type number comes from the degree of thermal metamorphism which their host meteorites experienced in their parent bodies.



[Figure from Floss & Haenecour 2016]

There might be a connection between **abundance of presolar grains** and **thermal history of parent bodies of their host meteorites**.

We explore that the diffusion process in thermally evolvin planetesimals can wash out the isotopic composition of presolar silicate grains.

Results

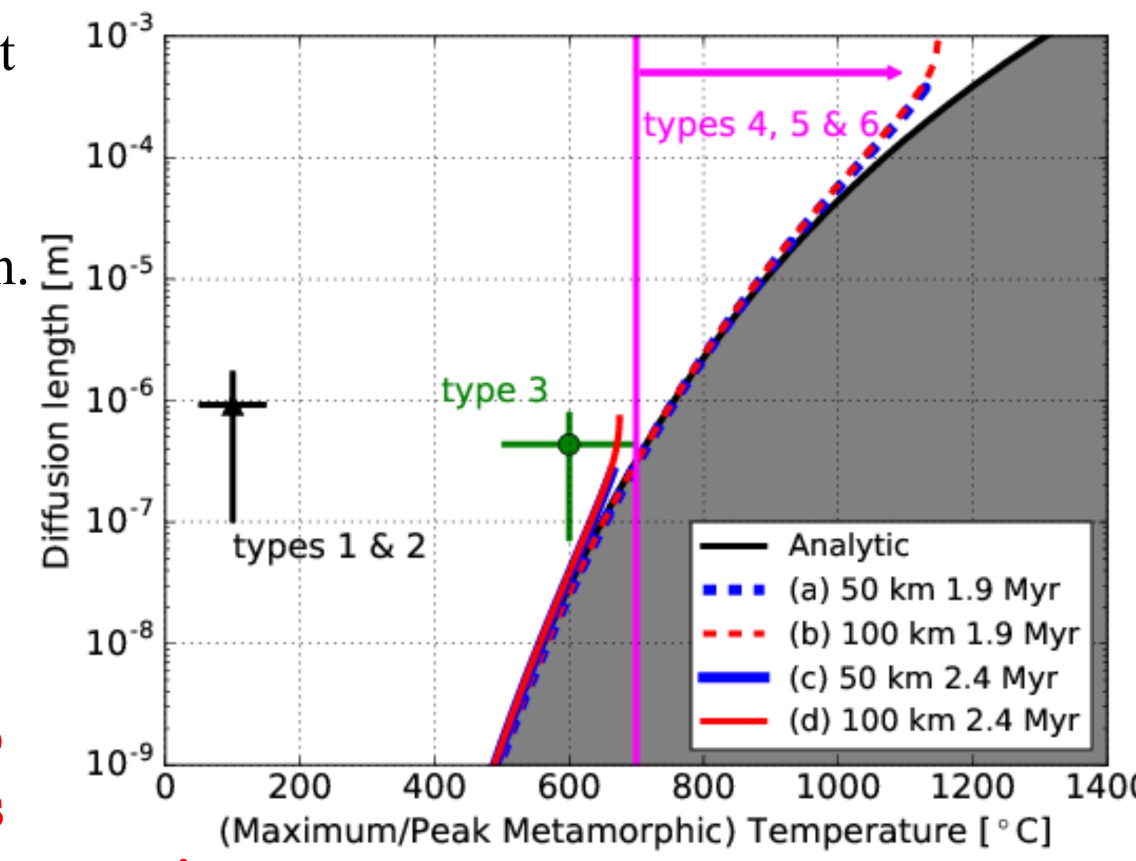
We find the isotopic diffusion process can organize size distribution of presolar grains.

Comparing the expected diffusion lengths from our results with the peak metamptphic temperature of host chondrites
- Type 3: 0.001 - 0.3 μm with T_{peak} of 500 - 700 °C
- Types 1 & 2: extremly short with T_{peak} ~ 150 °C
- Types 4, 5 & 6: longer than 0.3 μm with T_{peak} > 700 °C

Symbols with error bars represent presolar silicate grains found in chondrites, and our results can explain their size distribution.

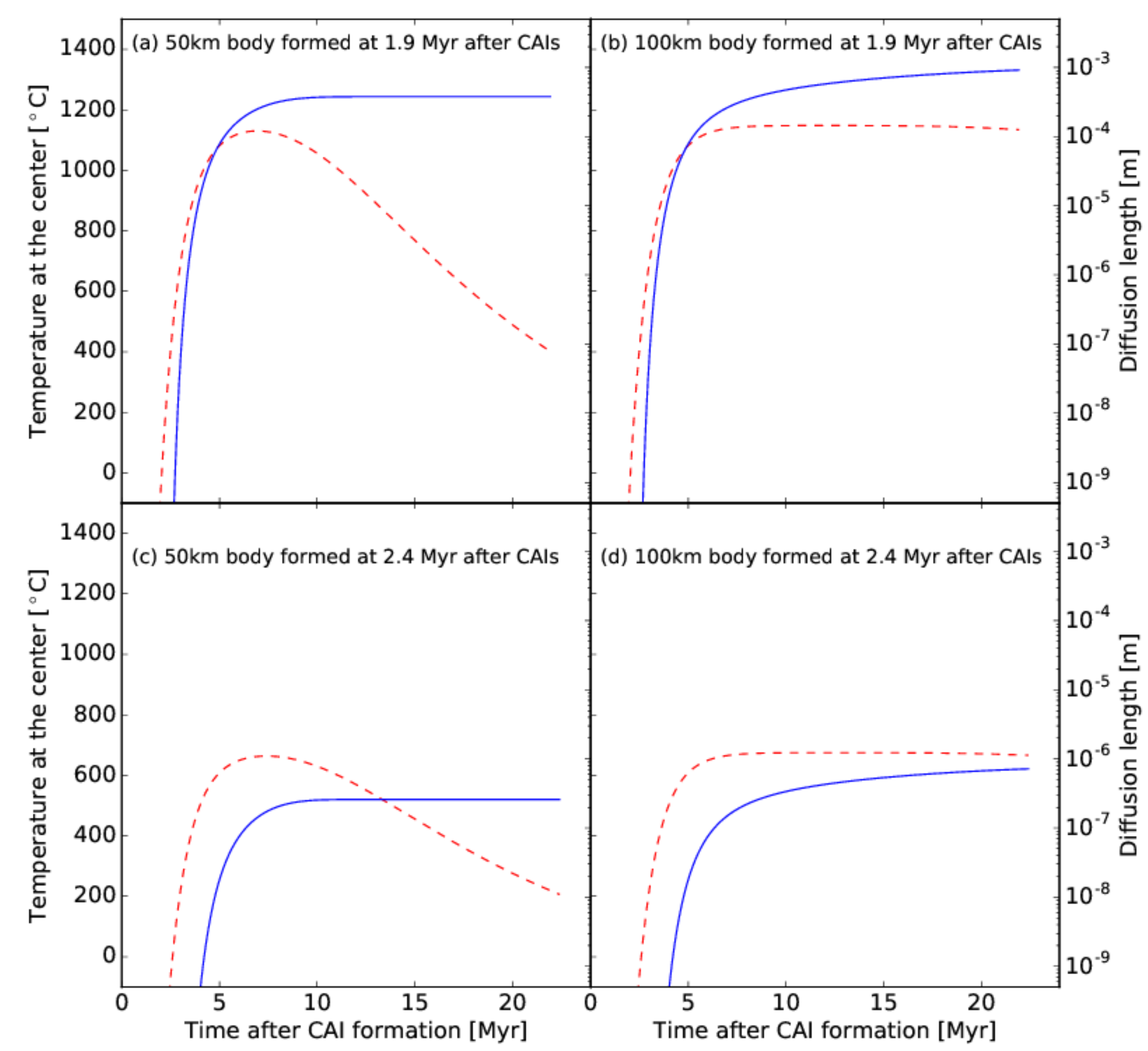
Our results can also explain that the abundance difference of presolar grains between type 3 chondrites and interplanetary dust particles.

Our methodology can apply to any other isotopes in minerals when their diffusion coefficients are given.



The maximum temperature would be an index to examine the diffusion length.
We can estimate it analytically. $L^2 = D(T_{\max})\Delta t_{\max}$
The analytic formula explains the numerical results very well.

As the temperature (dashed) increases, the diffusion length (solid) also increases.
When the temperature starts to decreases, the diffusion length keeps its value.



The formation time of planetesimals is more effective on the maximum temperature and the diffusion length than the radius of them (see belows).

Models

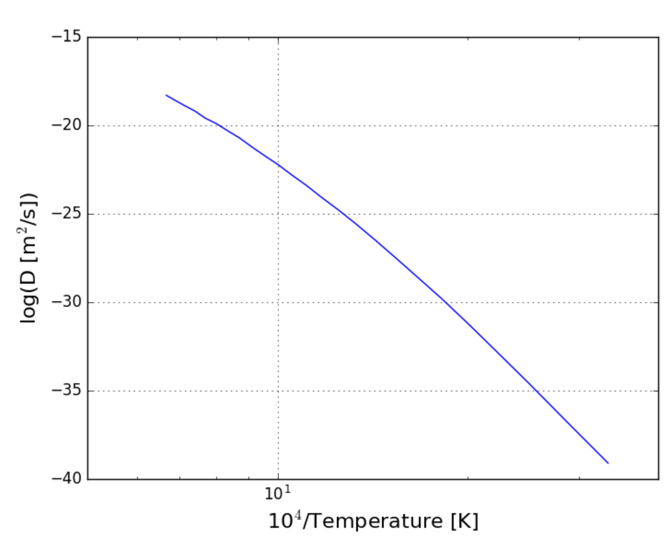
Diffusion process

We examine the diffusion length of ^{18}O in presolar silicate grains.
The diffusion coefficient ($D(T)$) of ^{18}O in olivine is used [Dohmen et al. 2012].
This is obtaded in a temerature range from 1100°C to 1500 °C.
We extrapolate it to lower temperature.

The diffusion coefficient (D) strongly depends on the temperature (T).

$$D(T) = 10^{-8.34}\exp(-3.38\times10^5/RT)$$

It takes 10^3 year to diffuse ^{18}O in the grains of 1 μm at 1000°C, and 10^9 years to do for the ones at 600 °C.



The accumulated diffusion length (L) can be calculated as follows:

$dL^2 = D(T)\ dt$: diffusion length at each time step during thermal evolution of planetesimals

$L^2 = \Sigma_{time}\, d\, L^2$: accumulated diffusion length

Thermal evolution of planetesimals

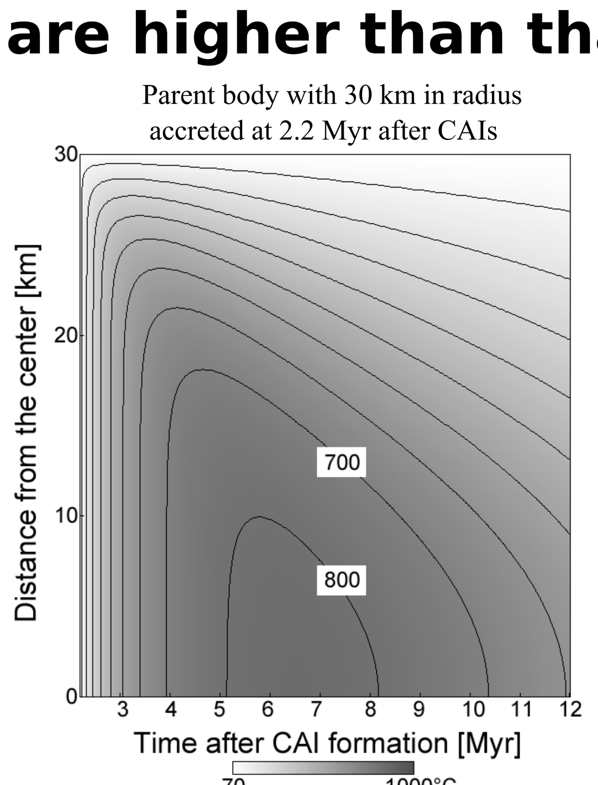
The model of thermally evolving planetesimals is based on our previous work: four figures on the below are results of thermal evolutions of planetesimlas from Wakita et al. 2014.

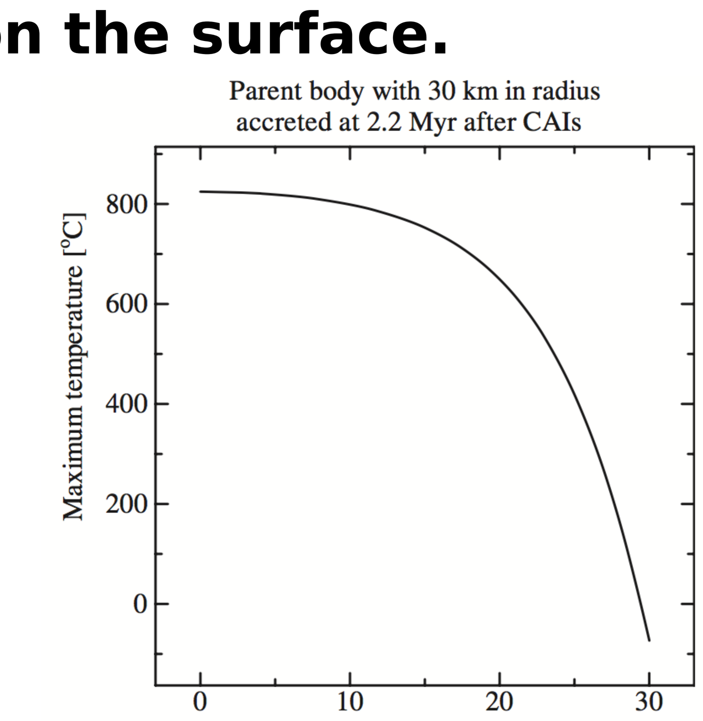
Parameter sets of thermal evolution of planetesimals
- planetesimals: spherically-symmetric bodies
- **size: radius of 50 km and 100 km**
- **formation time: 1.9 and 2.4 Myr after Ca-Al-rich inclusions (CAIs)**
- heat source: short-lived radionuclide (^{26}Al: half-life 0.72 Myr)

We numerically solve the heat conduction equation.

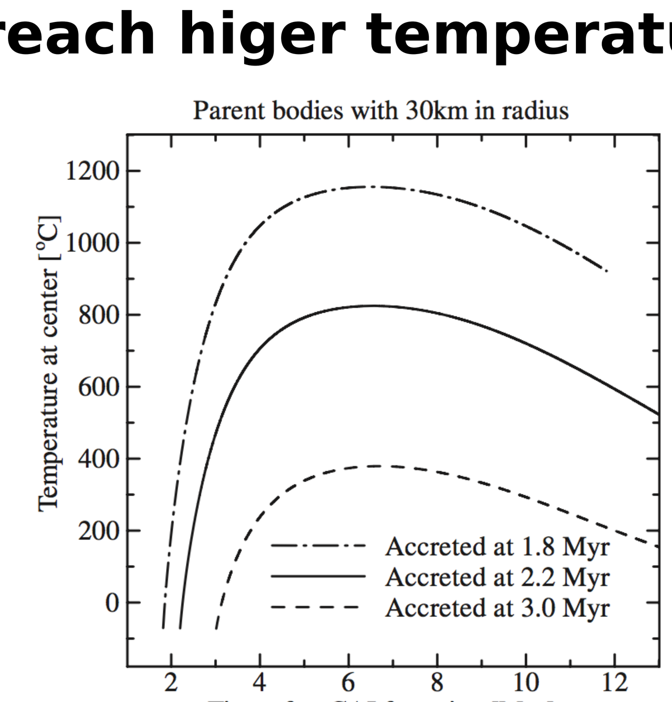
$$\rho c\frac{\partial T}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2K\frac{\partial T}{\partial r}\right) + A\exp(-\lambda t)$$

Maximum temperature at the center are higher than that on the surface.

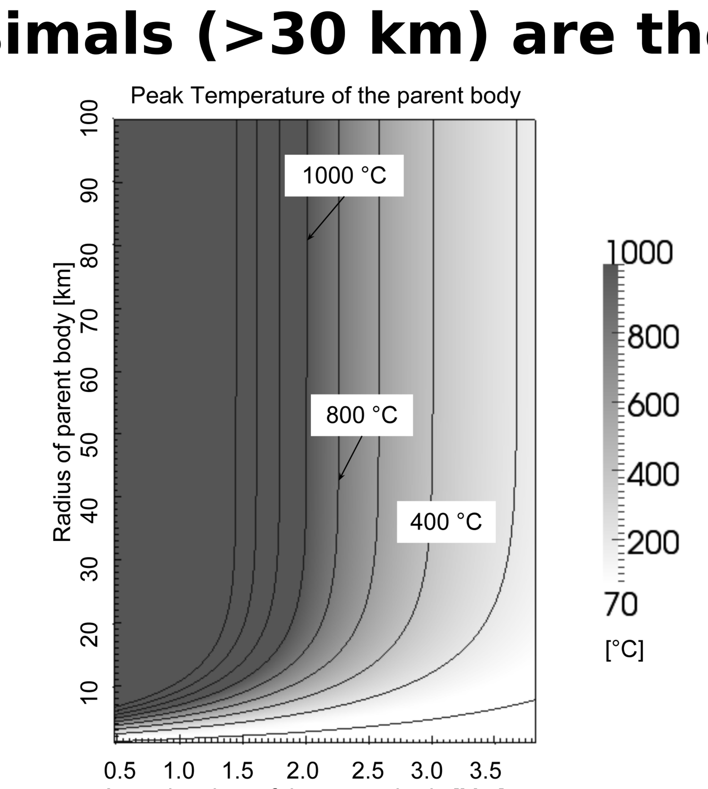




Earlier formed planetesimals can reach higer temperature.



Maximum temperature at the center of planetesimals (>30 km) are the same.



Acknowledgement: Numerical simulations are carried out on the PC cluster at CfCA/NAOJ.