GROWTH OF DUST GRAINS IN A LOW-METALLICITY GAS AND ITS EFFECT ON THE CLOUD FRAGMENTATION

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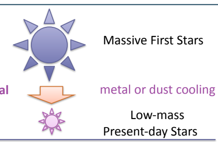
Abstract

We study formation of low-mass star ($<M_\odot$) in an extremely metal-poor gas ($Z\sim10^{-5}\,Z_\odot$) in the early universe. Our study is motivated by the recent discovery of a low-mass ($M_* \le 0.8\,M_\odot$) and extremely metal-poor ($Z \le 4.5\times10^{-5}\,Z_\odot$) star in the Galactic halo by Caffau et al. In such a low-metallicity gas, dust cooling is considered to trigger instability even in an extremely low- metallicity cloud ($Z<10^{-4}\,Z_\odot$). However, in the early universe, the sites where grains are formed are limited and thus dust abundance is smaller than present-day. We propose a model that the accretion of heavy elements onto grain surfaces (grain growth) can induce dust cooling. **We calculate cloud evolution and grain growth self-consistently. As a result, grain growth in a gas cloud can eventually enhance dust amount and induce dust cooling for the metallicity** $4.5\times10^{-5}\,Z_\odot$.

Introduction

First stars are considered to be massive for a lack of coolant[1], while present-day stars are low-mass[2].

Some researchers have investigated the effect of metal (dust) cooling on the transition of mass scale[3]. (additional cooling can reduce the Jeans mass).



Recently, Caffau et al. [4] discovered a long-lived (**low-mass;** $M_* \le 0.8\,M_\odot$) and **extremely metal-deficient** ($Z \le 4.5\times10^{-5}\,Z_\odot$) star**,** SDSS J102915+172927, in the halo of the Galaxy.

The formation of low-mass stars is considered to be triggered by **dust cooling** in a extremely metal-deficient gas [5].

However, the amount of dust in the early universe is uncertain, but it is thought that dust grains are supplied by earlier supernovae (right figure) [6].

Schneider et al. [7] (hereafter, S12) investigate the cloud collapse with initial dust composition predicted by their supernova models. They find dust cooling are not effective for models with small dust composition for metallicity $Z = 4.5\times10^{-5}\,Z_\odot$.

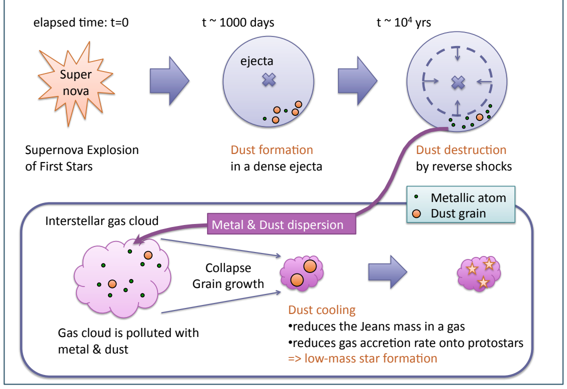
S12 assume that dust amount is constant in the course of collapse. However, grains can grow in collapsing gas cloud by accretion of heavy elements onto grains (**grain growth**) [8]!

Q. Can **grain growth** enhance the dust cooling in such a metal-poor gas ($Z = 4.5\times10^{-5}\,Z_\odot$)?

To see this, we follow the thermal evolution of cloud core and grain growth self-consistently. The initial dust amount is set the value of the supernova models by S12.

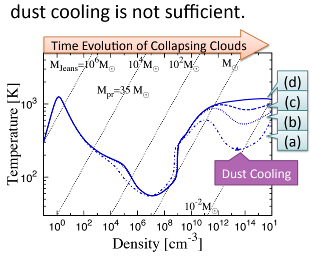
Life of Dust in the Early Universe

Dust grains in the early universe are considered to be supplied mainly by supernova [6].
However, in supernova, grains can be destroyed [7].
Then, grains grow in collapsing gas clouds [8].



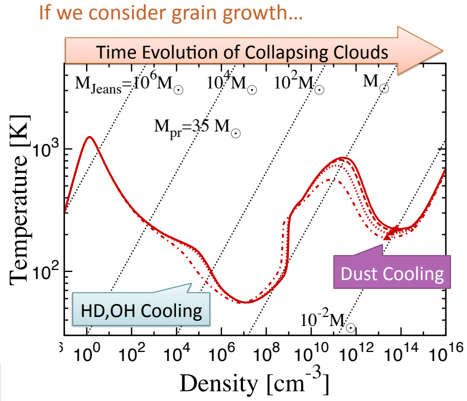
Results

If we do not consider grain growth, for the models with small amount of dust (models (b), (c), and (d)) , dust cooling is not sufficient.

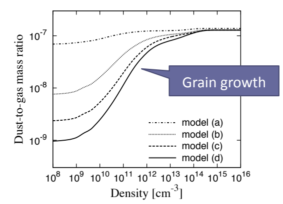


Models:
■initial dust-to-gas mass ratios
- (a) $D = 6.84\times10^{-8}$
- (b) $D = 7.39\times10^{-9}$
- (c) $D = 2.29\times10^{-9}$
- (d) $D = 9.27\times10^{-10}$
- • taken from supernova models of S12.

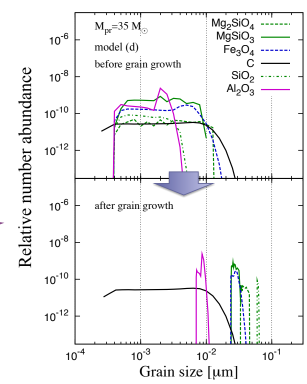
If we consider grain growth…



Dust cooling becomes effective even if initial dust amount is small!!



Evolution of Dust-to-gas mass ratio.
We can see that grains grow sufficiently for all models.



Evolution of Size distribution functions.

A. **Yes!** Dust cooling is induced by grain growth even if initial dust amount is small!

Conclusions

- Recently, long-lived (low-mass) star with extremely low metallicity ($Z \le 4.5\times10^{-5}\,Z_\odot$) is discovered.
- in such a low metallicity gas, dust cooling can trigger the formation of low-mass clumps.
- S12 investigate the cloud collapse with initial dust composition predicted by their supernova models. They find dust cooling are not effective for models with small dust composition for metallicity $Z = 4.5\times10^{-5}\,Z_\odot$.
- S12 assumed that the dust amount is constant. However, the dust amount can increase by grain growth.
- To see if grain growth can enhance dust cooling, we calculate the thermal evolution of gas clouds and grain growth, self-consistently.
- As a result, we show that the dust cooling becomes sufficient by grain growth even if the initial dust amount is small.
- Furthermore, the results are insensitive to the initial dust amount.

Future works

- To investigate the effect of grain growth for wider range of metallicity and various supernova models.
- To employ three-dimensional simulations to follow the evolution of gas clouds with dust cooling.

References

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