The Formation and Evolution of the Cosmic Dust

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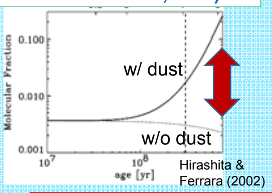
Abstract

When and how the formation and evolution of galaxies proceeded is one of the most important problems in astrophysics. From the point of view of the chemical evolution of galaxies, galaxies evolve from a state with low abundance of metals and dust grains to a state with high abundance through the star formation in galaxies. Thus, the understanding of dust evolution is crucially importance to understand the formation and evolution of galaxies. However, despite of its importance, most of the previous works have examined the dust evolution by using some oversimplied assumptions. In this work, we explore the evolution of dust contents, in particular, the total dust amount, the grain size distribution, and the extinction curve in galaxies by constructing a novel theoretical model which includes various processes aecting dust properties in a unified framework.

1.Introduction

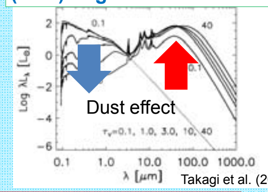
Importance of grain size distribution (GSD)

Molecular formation efficiency (Star Formation Rate; SFR)



Hirashita & Ferrara (2002)

Spectral Energy Distribution (SED) of galaxies



Takagi et al. (2003)

These properties depend on the total dust mass and the GSD in galaxies!!

What is the controlling mechanism of the GSD at each stage of galaxy evolution?

2.Dust evolution model

Model assumptions

- **One-zone model**
  - We consider **two ISM phases** : Warm neutral medium (WNM) and Cold neutral medium (CNM)

  WNM : 0.3 cm^{-3} , 6000 K
  CNM : 30 cm^{-3} , 100 K

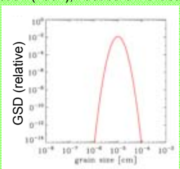
- **Closed box model**
  - Total baryon mass (stellar mass and ISM mass) is a constant.
- **Schmidt law :** $\mathrm{SFR} \propto M_{\mathrm{ISM}}^{n}$
  - $\mathrm{SFR}(t) = \frac{M_{\mathrm{ISM}}(t)}{\tau_{\mathrm{SF}}}$ n=1 for simplicity

Processes affecting the GSD in our model

AGB star

- log-normal distribution
- large size grains are produced

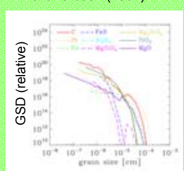
Winters et al. (1997), Yasuda & Kozasa (2012)



Type II Supernovae (SNe II)

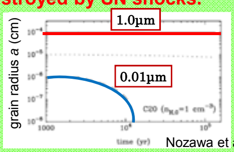
- broken power-law
- biased to large grains

Nozawa et al. (2007)



Dust destruction by SN shocks

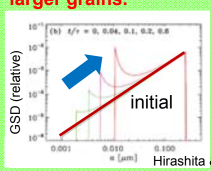
Smaller grains are predominantly destroyed by SN shocks.



Nozawa et al. (2006)

Metal accretion onto grains

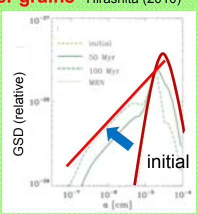
Smaller grains grow to larger grains.



Hirashita & Kuo (2011)

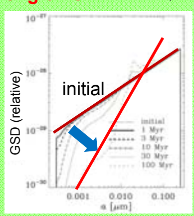
Shattering

Smaller grains are produced by larger grains Hirashita (2010)



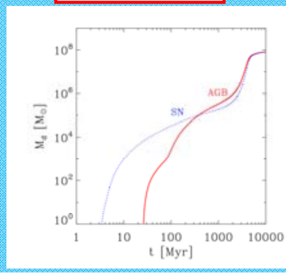
Coagulation

Larger grains are produced by smaller grains Hirashita (2012)



3.Results

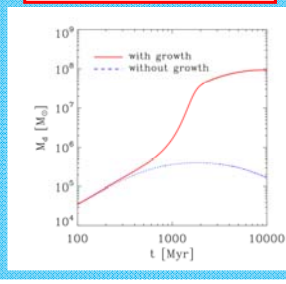
AGB vs. SN



The contribution of AGB (Zhukovska et al. 2008) stars catches up SNe II (Bianchi et al 2007) at t ~ 500 Myr.

AGB stars are significant sources of dust in young galaxies.

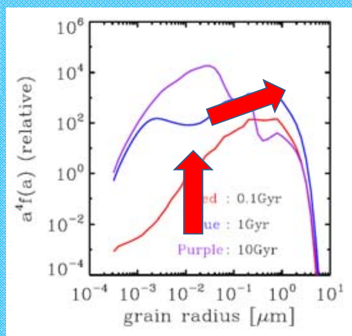
The grain growth



At t > 1 Gyr, the grain growth becomes dominant as a source of dust mass supply.

The dust evolution is dominated on the grain growth in nearby galaxies.

Evolution of GSD



At the early stage of galaxy evolution, the GSD is biased to large grains. This effect is from stars. As time passes, smaller grains increase due to shattering and grain growth. After that, the peak shifts to the larger size by coagulation.

Dominant sources of GSD change with galaxy evolution!!

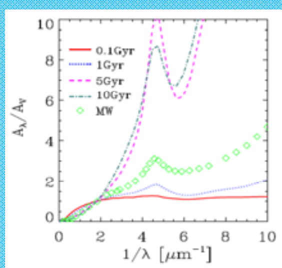
Early stage : stars
Later stage : ISM processes

Evolution of extinction curve

$$A_\lambda = 1.086 \sum_j \tau_{j,\lambda}$$

$$\tau_{\lambda,j} = \int_0^\infty \pi a^2 Q_{\mathrm{ext},j}(\lambda, a)\, C f_j(a)\, da$$

λ: wavelength
a : radius of a grain
j : grain species



- Early stage of evolution
  Flat shape due to large grains produced by stars
- Middle stage of evolution
  Steep slope and large bump due to shattering and grain growth
- Later stage of evolution
  The bump and slope become small and calm by coagulation

The extinction curve drastically changes through the galaxy evolution because of the evolution of the grain size distribution !!

Reference

- Asano et al., 2013a, EP&S, 65, 213
- Asano et al., 2013b, MNRAS, 432, 637
- Asano et al., MNRAS,.440, 134