Evolution of the grain size distribution in galaxies

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Collaborators

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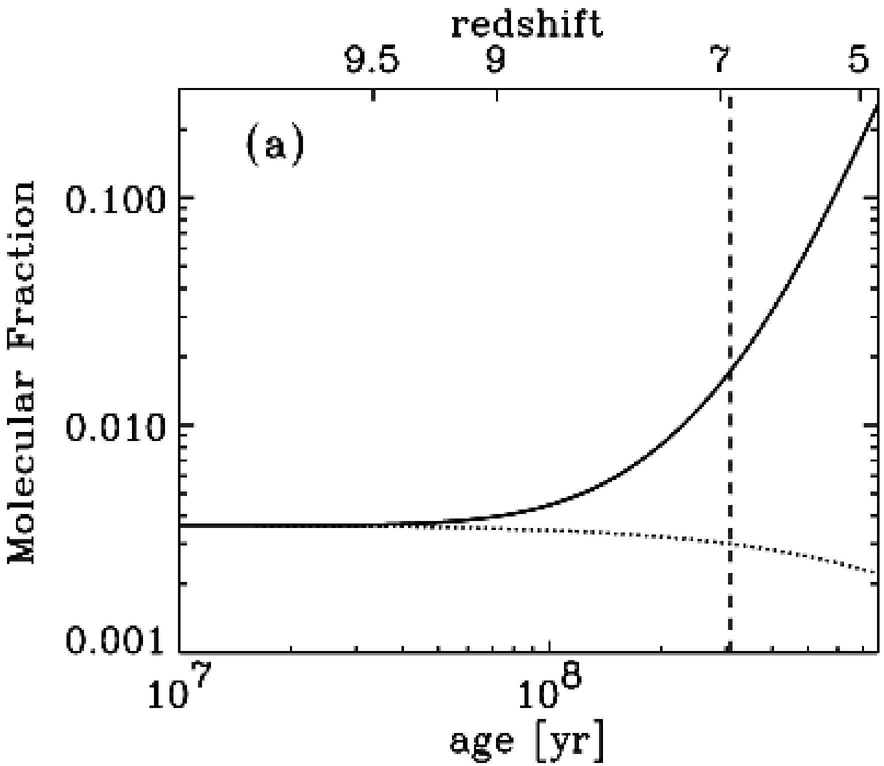
Introduction

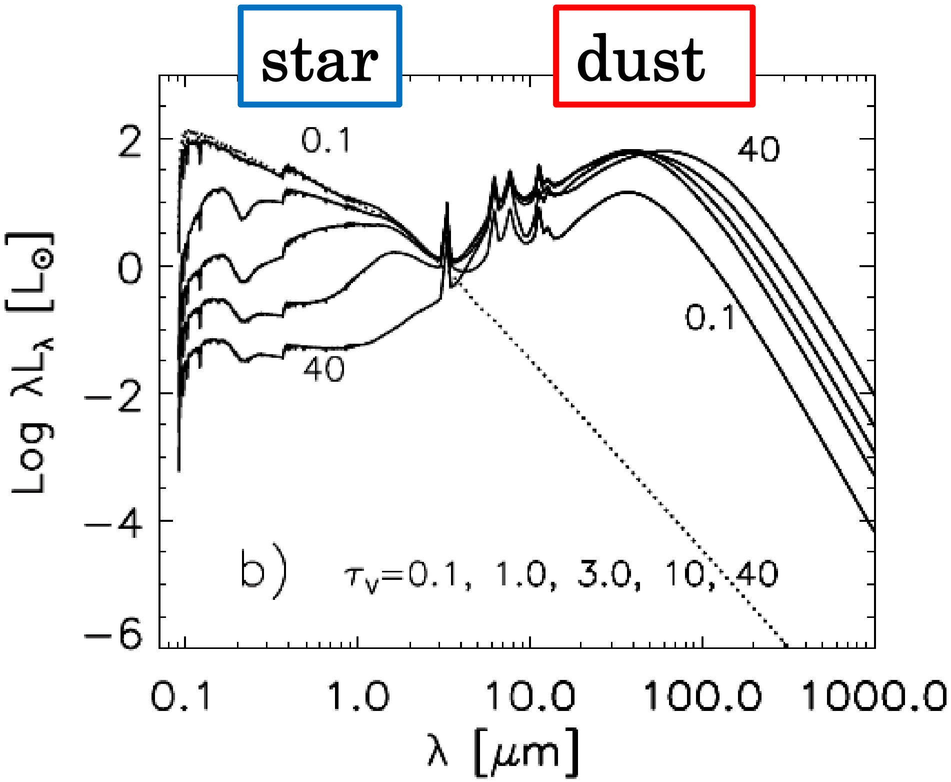
Importance of dust in galaxies

Molecular formation efficiency (Star Formation Rate; SFR)



Hirashita & Ferrara (2002)

Spectral Energy Distribution (SED) of galaxies



Takagi et al. (2003)

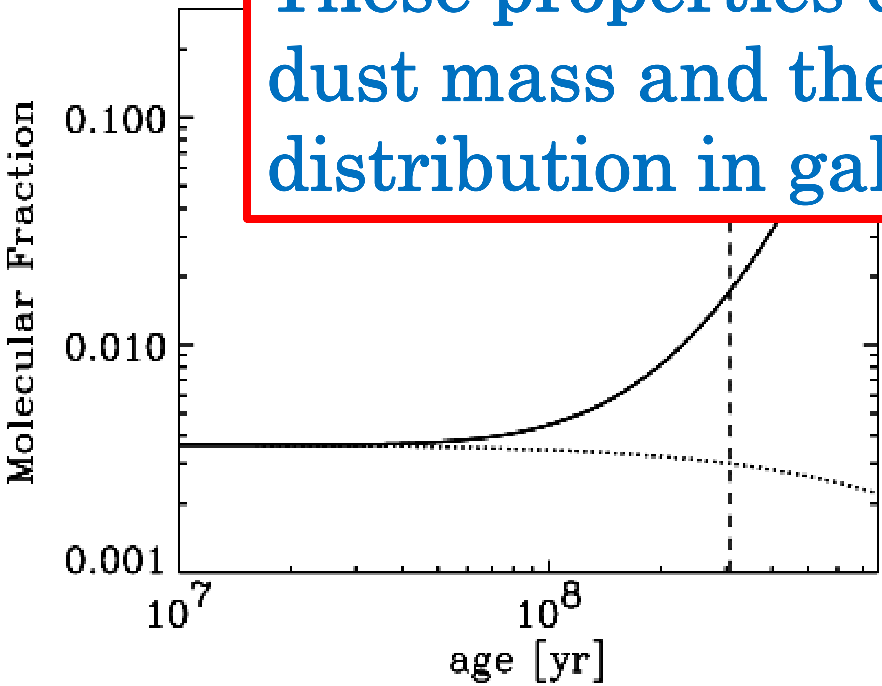
Introduction

Importance of dust in galaxies

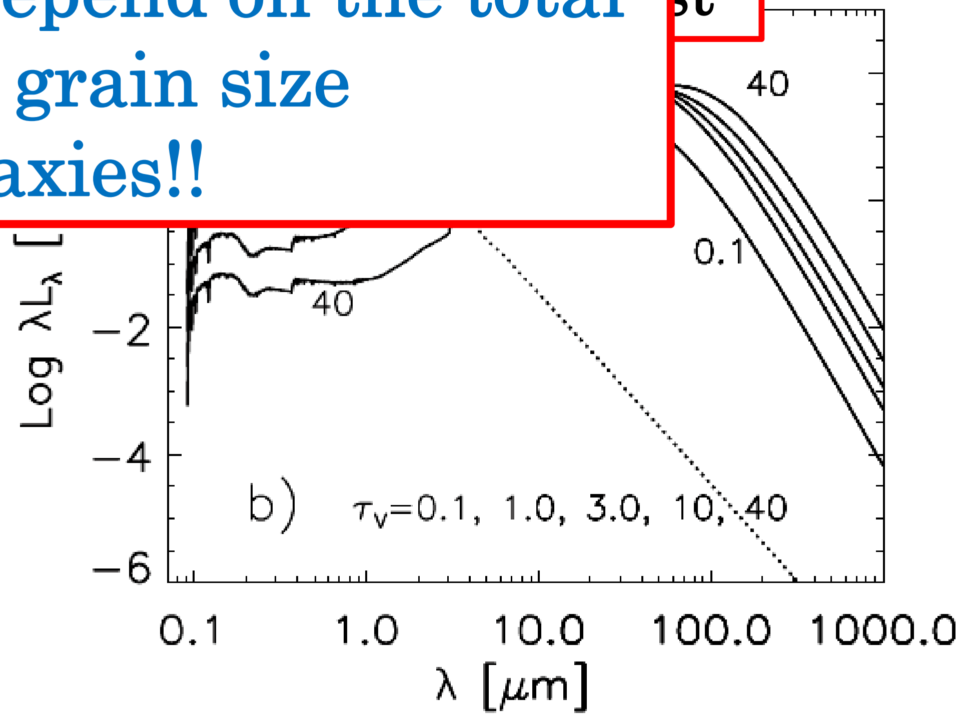
Molecular formation efficiency (Star Formation Rate; SFR)

Spectral Energy Distribution (SED) of galaxies

These properties depend on the total dust mass and the grain size distribution in galaxies!!

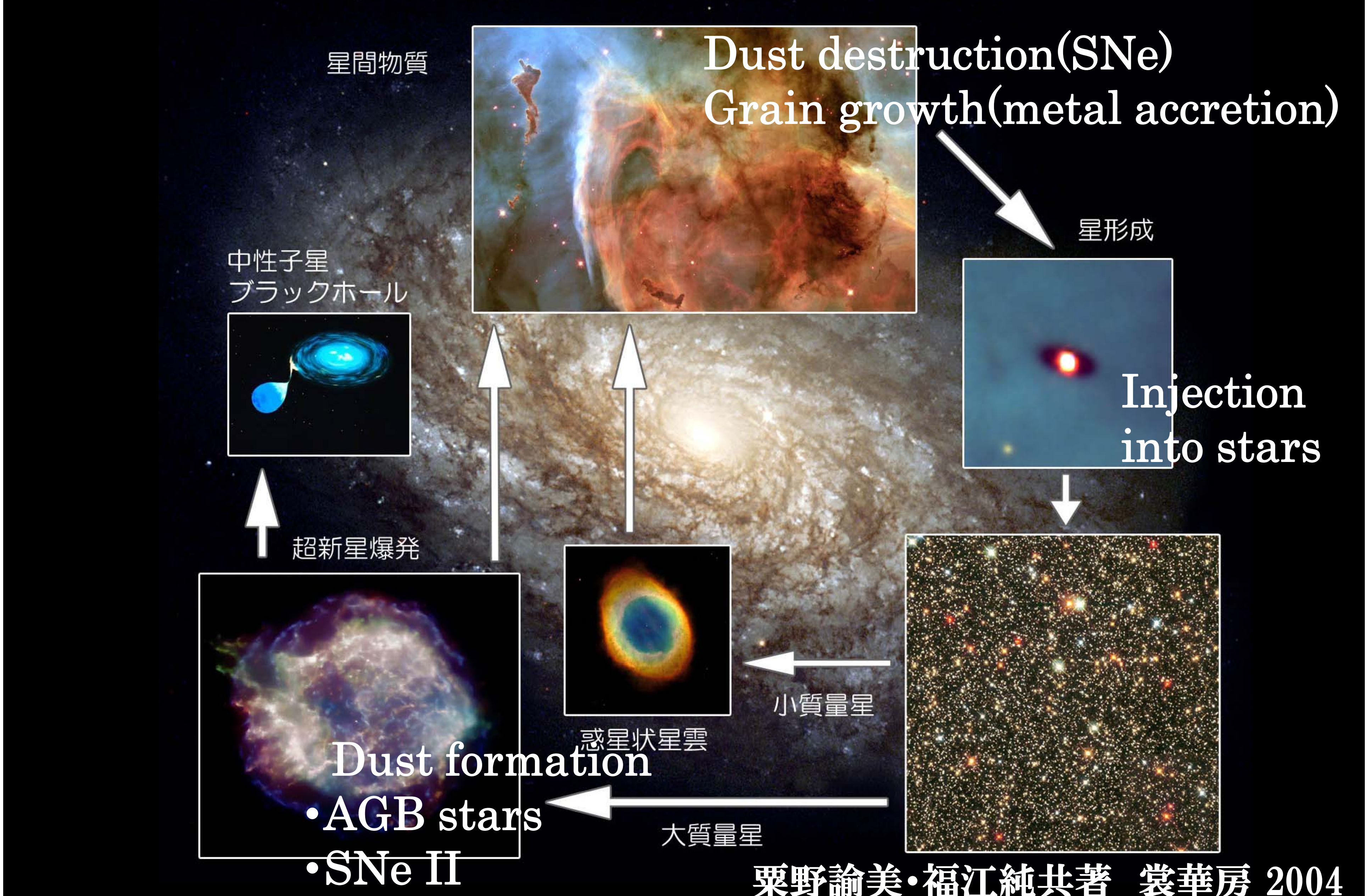


Hirashita & Ferrara (2002)



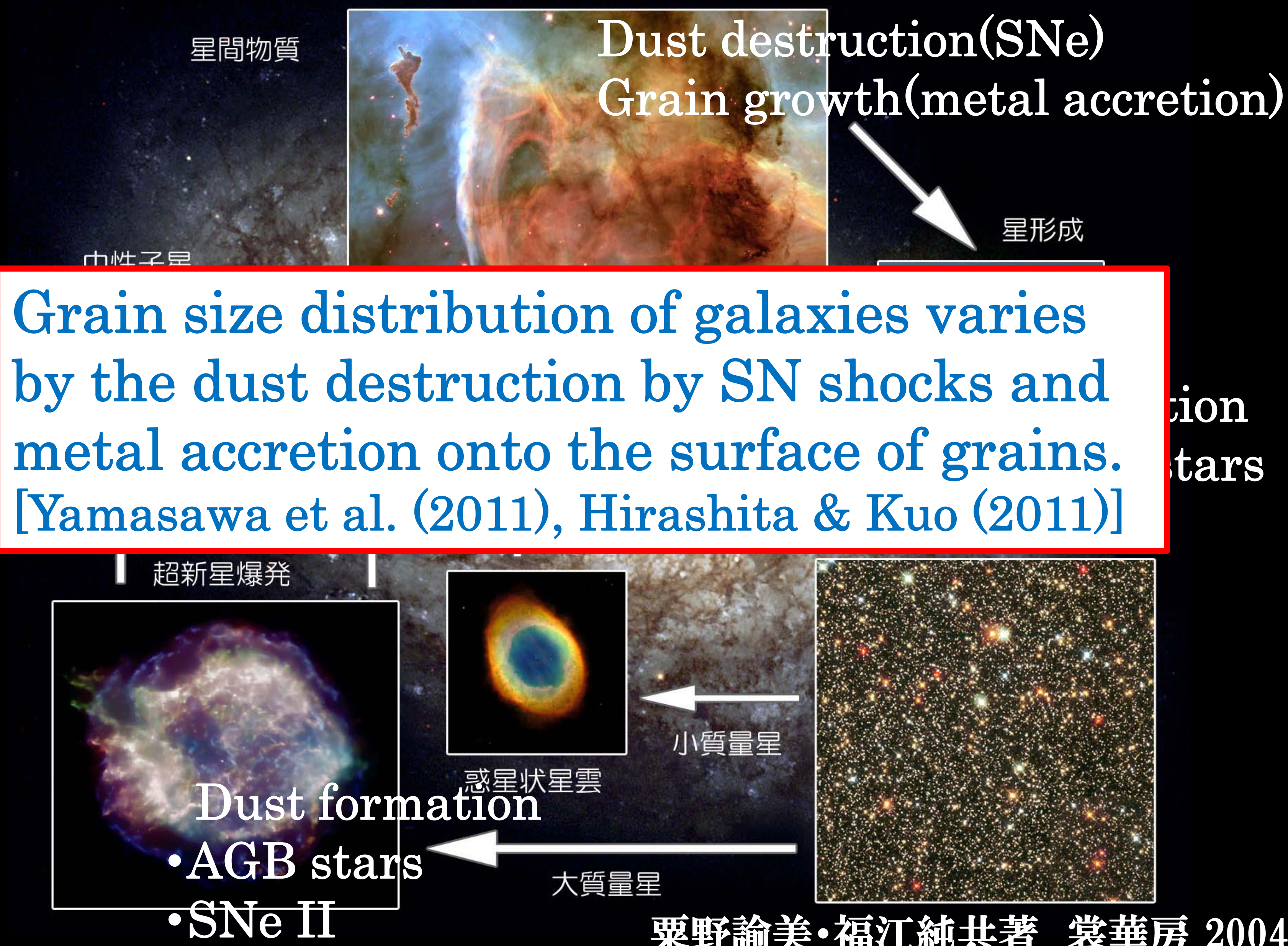
Takagi et al. (2003)

The dust circulation in galaxies



粟野諭美・福江純共著　裳華房 2004

The dust circulation in galaxies



Grain size distribution of galaxies varies by the dust destruction by SN shocks and metal accretion onto the surface of grains.
[Yamasawa et al. (2011), Hirashita & Kuo (2011)]

粟野諭美・福江純共著　裳華房 2004

Aim of this study

Star formation history and the SED history of galaxies depend strongly on the total dust mass and the grain size distribution of galaxies.

We investigate the evolution of dust mass and the grain size distribution in galaxies by constructing a dust evolution model.

We consider the effects of AGB stars, SNe II, dust destruction, and grain growth.

Dust production source(1)

Asymptotic Giant Branch stars (AGB)

- progenitor mass $\leq 8\ M_\odot$
- lifetime > 10^9 yr
- dust formation around stars
- Main dust
  Carbon, Silicates
  SiC, Fe

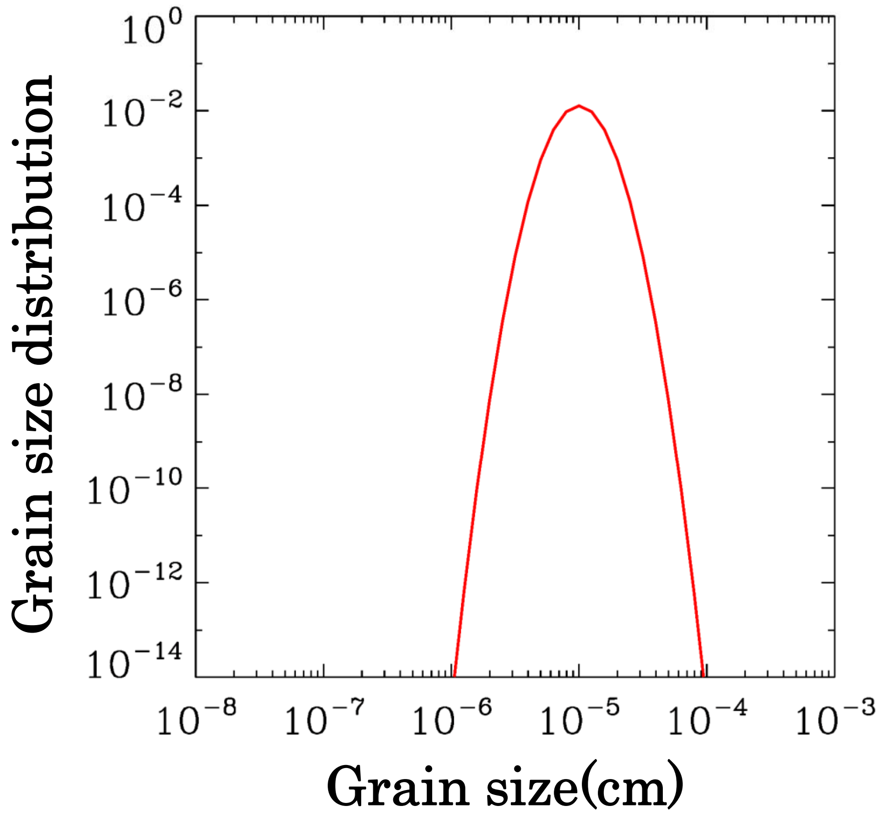
(Ferrarotti & Gail, 2006)

Grain size distribution is peaked

Winters et al. (1997)
Yasuda & Kozasa (2011)

Dust mass

Zhukovska et al. (2008)



Dust production source(2)

Type II Supernovae (SNe II)

- progenitor mass > 8 $M_\odot$
- lifetime < 10^8 yr
- dust formation in the ejecta
- Main dust
  Carbon, Silicates, etc.

(Nozawa et al. 2003, 2007)

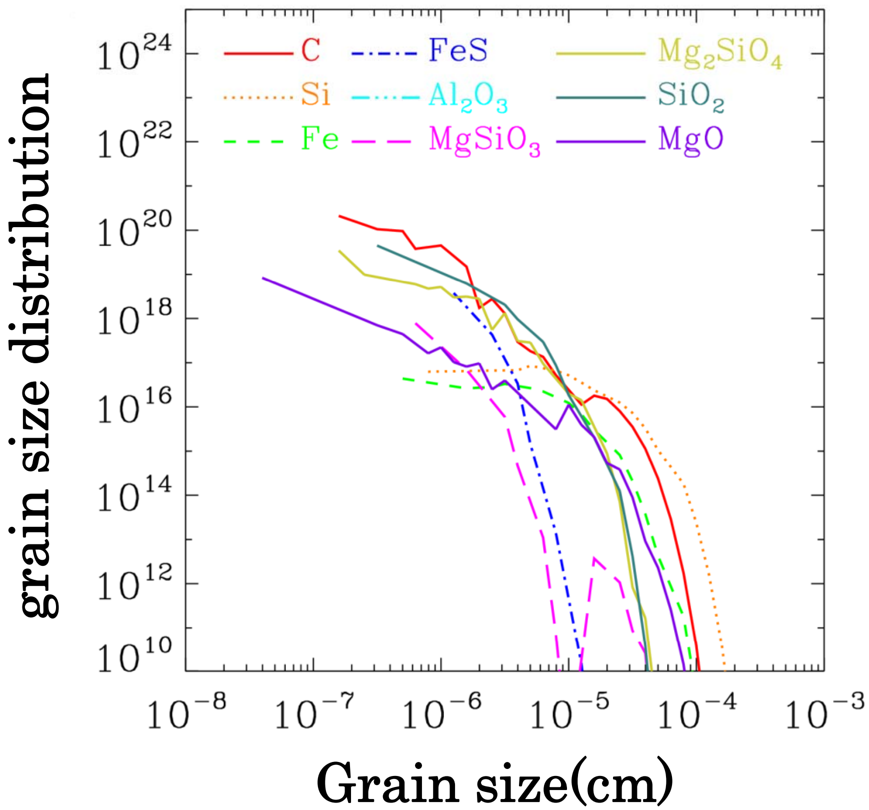
Grain size distribution is broken power-law

Nozawa et al. (2007)

Dust mass

Nozawa et al. (2007)

Grain size distribution produced by a supernova with mass 20$M_\odot$(broken power-law)



Dust destruction by SN shocks

Destruction mechanism

Sputtering due to the passage of SN shock

The change in the number of dust grains with radii [a, a+da] after the passage of a SN shock : dN(a)

$$\mathrm{d}N(a) = \int_0^{\infty} \xi(a, a')f(a')\mathrm{d}a' - f(a)\mathrm{d}a$$

Yamasawa et al. (2011)

$\xi(a, a')$: dust destruction efficiency

(a' → a) (If a'< a, ξ = 0)

Nozawa et al. (2006)

$f(a)\mathrm{d}a$: number of dust grains with radii[a, a+da]

The swept mass by a SN shock : M_{swept}

$$M_{swept} = 1535 n_{SN}^{-0.202}[(Z/Z_{\odot}) + 0.039]^{-0.289}\ [M_{\odot}]$$

n_{SN} : ISM density surrounding the SN

Z : metallicity

Yamasawa et al. (2011)

Grain growth in the ISM

$$m(a) = \frac{4\pi a^3}{3}\rho_{\mathrm{j}}$$

Grain growth mechanism

Accretion metals onto the surface of grains

Assumption:
grains are spherical

$$\frac{\partial f(a,t)}{\partial t} + \frac{\partial}{\partial a}[f(a,t)\dot{a}] = 0$$

Hirashita & Kuo (2011)

Growth rate of
a grain radius

$$\dot{a} \equiv \frac{\mathrm{d}a}{\mathrm{d}t} = \frac{\alpha \rho_{\mathrm{ISM}}^{\mathrm{cl}} Z(1-\delta)\langle v \rangle}{4\rho_{\mathrm{j}}}$$

The growth rate does not depend on the grain size.

α : sticking coefficient

δ : dust mass /metal mass

ρ_{j} : material density

$\rho_{\mathrm{ISM}}^{\mathrm{cl}}$: averaged mass density of clouds where the accretion occurs

$\langle v \rangle$: mean velocity of metals in gas phase

We only treat the grain growth of refractory dust in this study.

Star Formation Rate (SFR) and Initial Mass Function (IMF)

Star Formaion Rate (SFR)

stellar masses produced in unit time

Schmidt law (1959) $\mathrm{SFR(t)} \propto \mathrm{M}_{\mathrm{ISM}}^{\mathrm{n}}$ $(1 < \mathrm{n} < 2)$

We assume n = 1 for simplicity.

Initial Mass Function (IMF)

mass distribution function of produced stars

Larson IMF (1998) $\phi(m) \propto m^{-(\alpha+1.0)} \exp\left(-\frac{m_{\mathrm{ch}}}{m}\right)$

Normalization: $\int_{0.1\,\mathrm{M}_\odot}^{100\,\mathrm{M}_\odot} m\phi(m)\mathrm{d}m = 1$

We adopt $\alpha = 1.35$ and $m_{\mathrm{ch}} = 0.35\ \mathrm{M}_\odot$ in our study.

Dust mass evolution with grain size distribution of galaxies

$$\mathrm{SFR}(t) = \frac{M_{\mathrm{ISM}}(t)}{\tau_{\mathrm{SF}}}$$

Evolution of mass of dust grains (species j) with radii [a, a+da]: $M_{d,j}(a,t)$

$$\frac{\mathrm{d}M_{\mathrm{d,j}}(a,t)}{\mathrm{d}t} = -\frac{M_{\mathrm{d,j}}(a,t)}{M_{\mathrm{ISM}}(t)}\mathrm{SFR}(t)$$

Injection into stars

$$+\frac{\mathrm{d}Y_{\mathrm{d,j}}(a,t)}{\mathrm{d}t}$$

Supply from stars

$$-\frac{M_{\mathrm{swept}}}{M_{\mathrm{ISM}}(t)}\gamma_{\mathrm{SN}}(t)\left[M_{\mathrm{d,j}}(a,t) - \frac{4\pi}{3}a^3\rho_{\mathrm{j}}\int_0^\infty \xi_j(a,a')f_j(a',t)\mathrm{d}a'\right]$$

Destruction by SN shocks

$$-\eta\frac{4\pi}{3}a^3\rho_{\mathrm{j}}\frac{\partial}{\partial a}[f_j(a,t)\dot{a}]$$

Grain growth

Dust mass evolution with grain size distribution of galaxies

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Supply from stars

SN rate

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Destruction by SN shocks

Mass fraction of the interstellar clouds

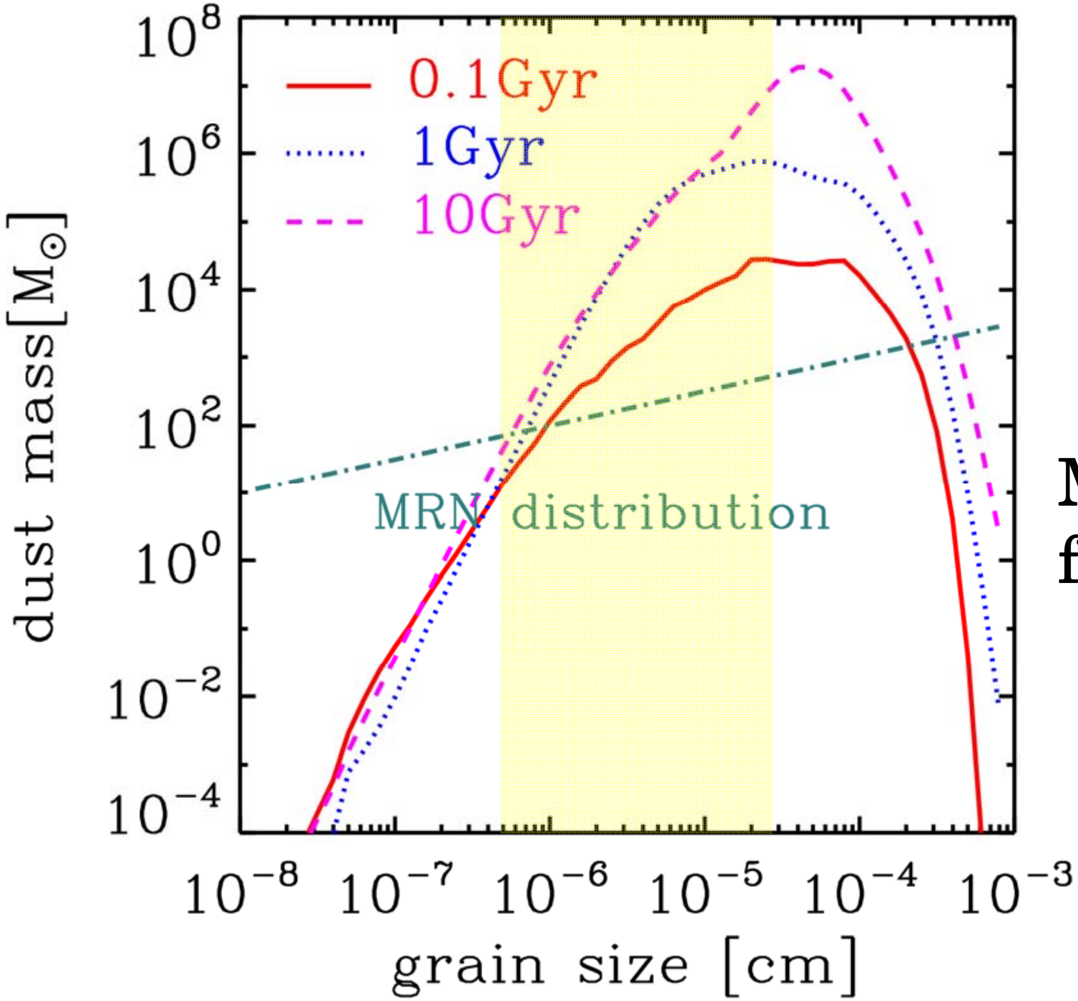
$$-\eta\frac{4\pi}{3}a^3\rho_{\mathrm{j}}\frac{\partial}{\partial a}[f_j(a,t)\dot{a}]$$

Grain growth

Results

Parameter setting
Total baryon mass : 10^{10} $M_\odot$
Star formation timescale : 5 Gyr
Mass fraction of clouds : 1.00

supply from stars + destruction + growth



MRN distribution
$f(a)da \propto a^{-3.5}\,da$

Mathis, Rumpl & Nordsieck (1977)

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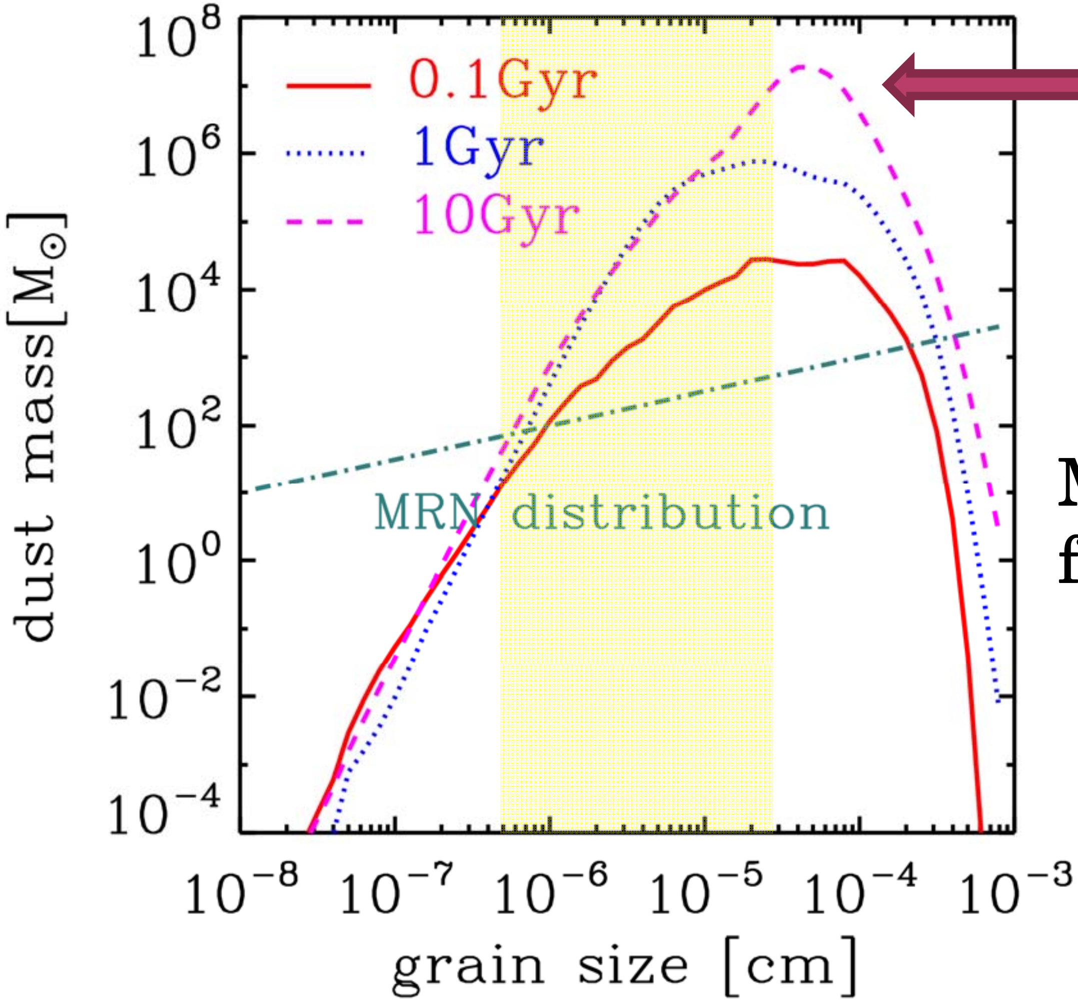

0.4-0.6μm

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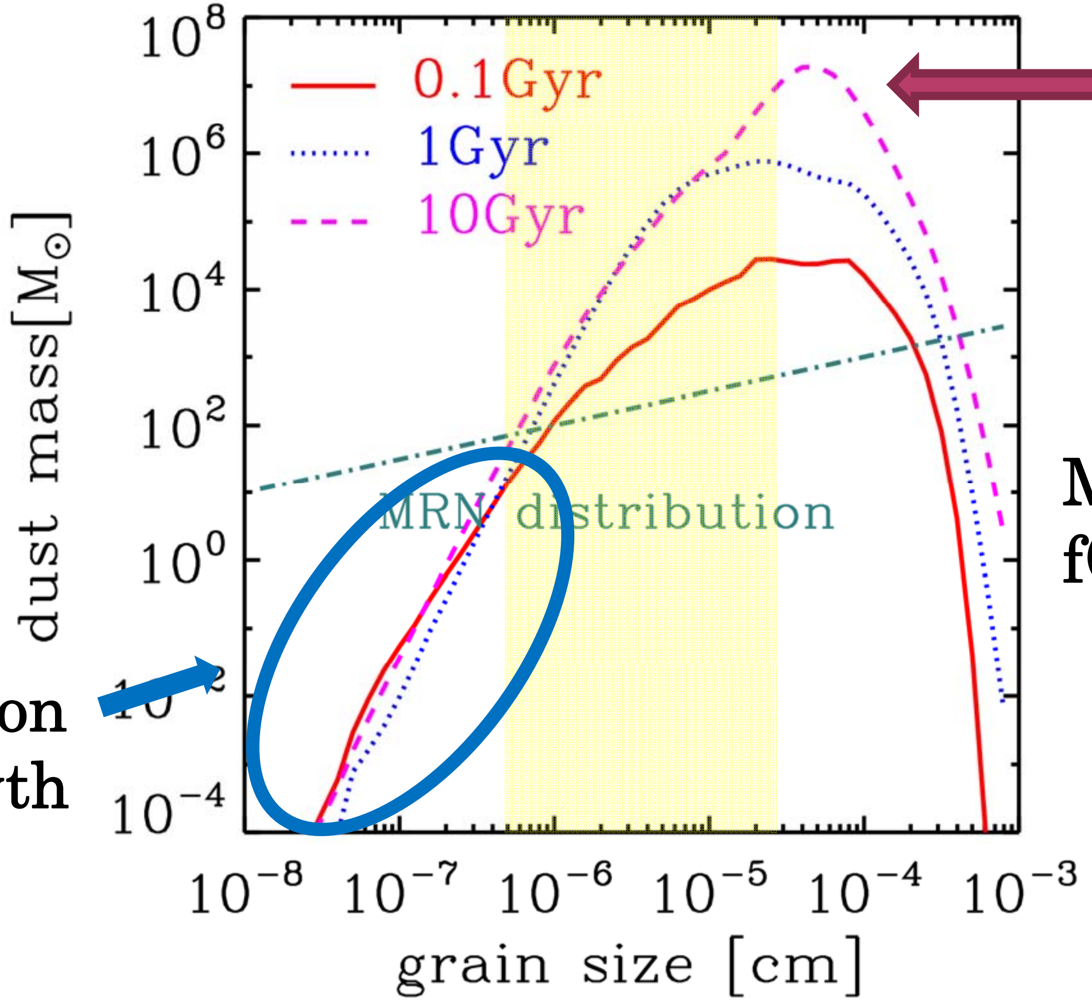

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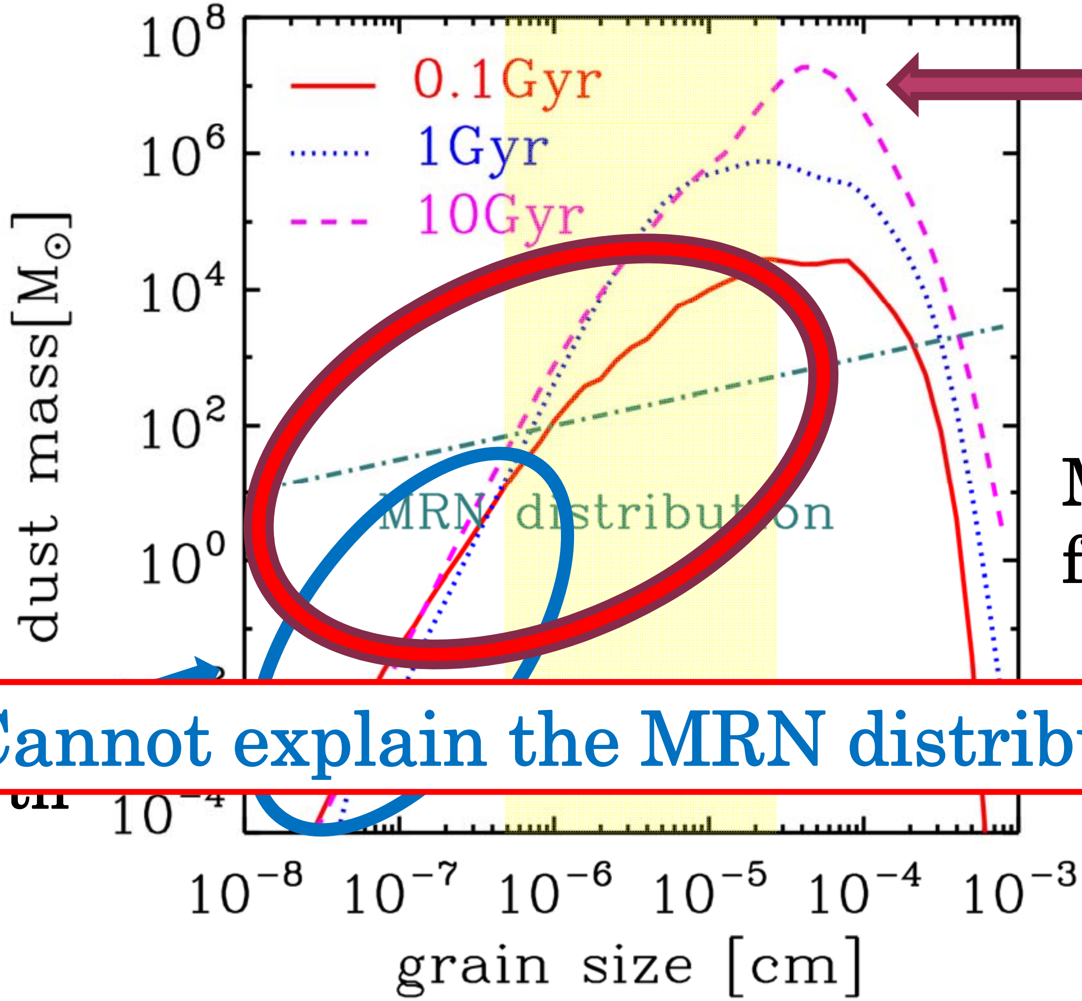

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and gro

Cannot explain the MRN distribution!?

Summary

We constructed a dust evolution model by taking into account the grain size distribution, and investigate the evolution of the grain size distribution in galaxies.

1. After the grain growth occurs, the grains with radius 0.4 - 0.6μm become dominant on the dust mass in galaxies.
2. The increase of the number of smaller grains are suppressed by the processes of destruction and metal accretion.
3. We found that the effects of stars, SN destruction and the grain growth cannot reproduce the MRN distribution.

Shattering and coagulation

(These processes do not change the total dust mass in galaxies.)