Effects of dust size evolution on early galaxy evolution

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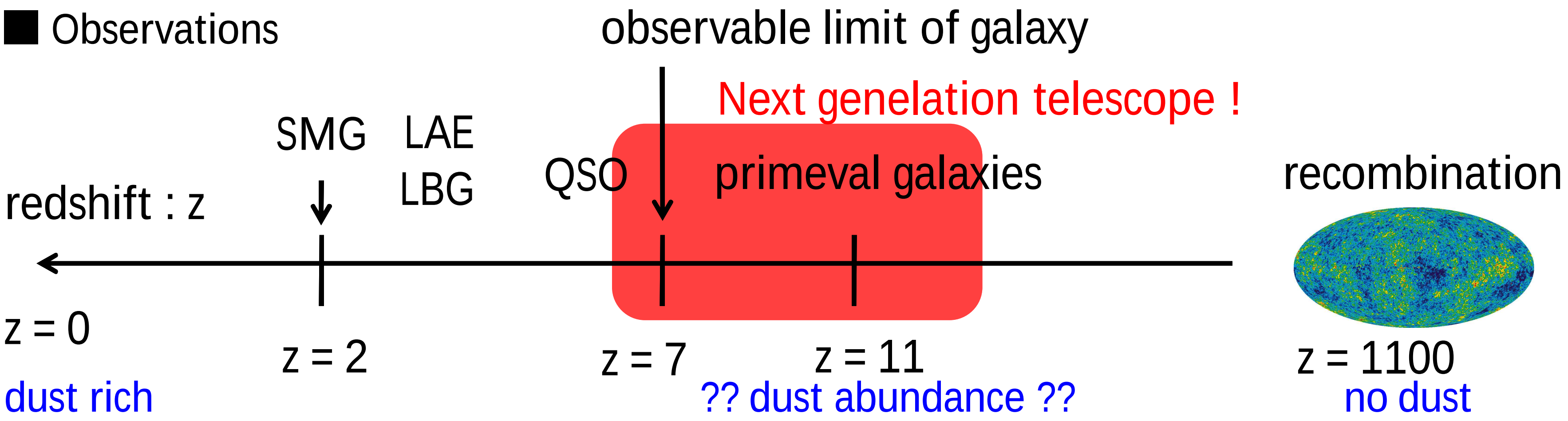
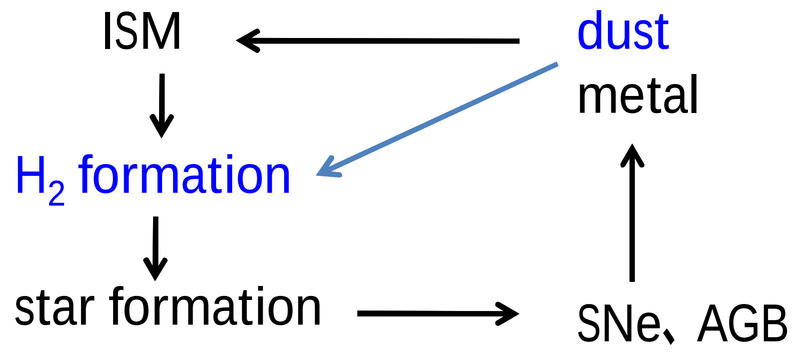
High-redshift galaxies

- Observations



- How stars form in high-redshift, primeval galaxies ?



Effect of dust on high-redshift galaxies

more efficient H_2 formation
on dust grains than in gas phase !

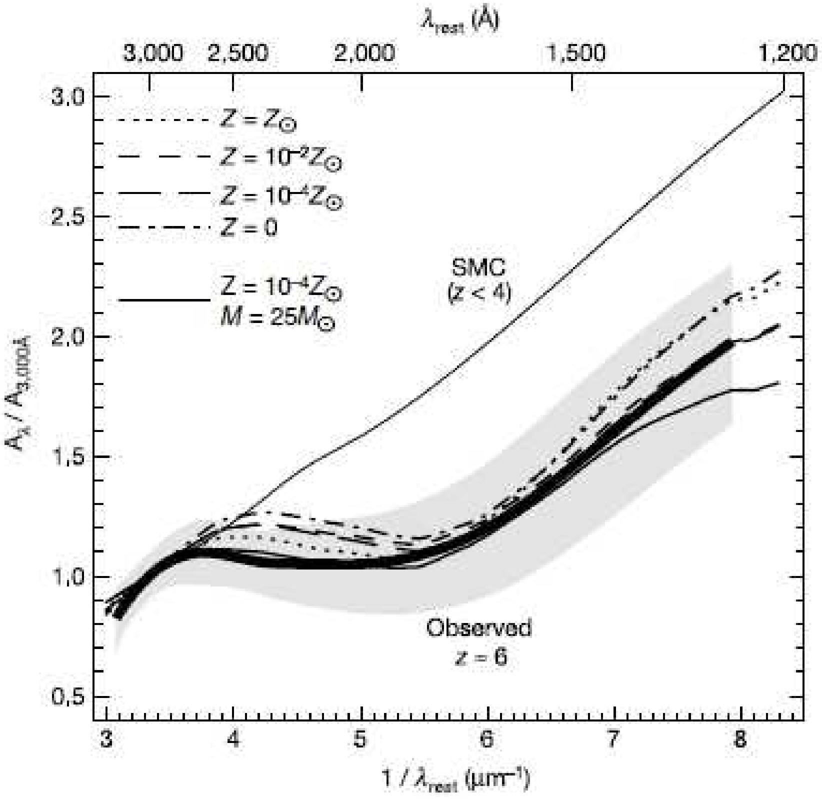
key : dust abundance

Dust production source (z > 5)

- a large amount of dust reaching up to 10^8- 10^9 M_{sun} in the quasars (z > 4.9) (Maiolino+ 04)

- Dust production source
  - high-redshift (z >～ 5) → SNe origin
  - z < 5 → AGB origin

＜extinction curve QSO (z = 6.2) ＞



Maiolino+ 04

→ nicely fitted by SN II dust model

Dust size evolution

- Dust production by SN II and PISN

  Nozawa+ 03 , Schneider+ 04

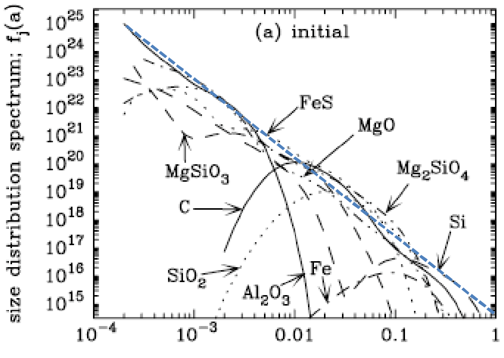
- Dust destruction in ISM by a forward shock

  Nozawa+ 06

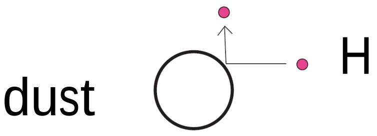
- Dust destruction by reverse shock

  1-D : Bianchi and Schneider 07
  Nozawa+ 07
  Nath+ 08

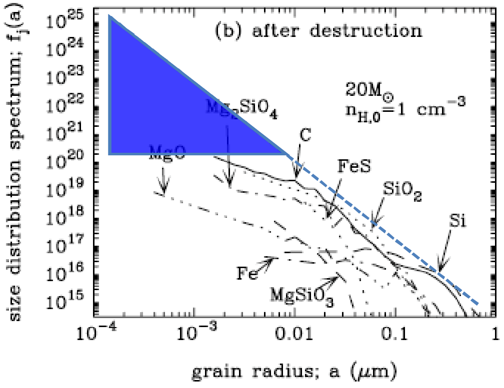
  3-D : Silva+ 10 (arXiv)



Small grains are predominantly destryed.



sputtering



Nozawa+ 07

key : dust size distribution

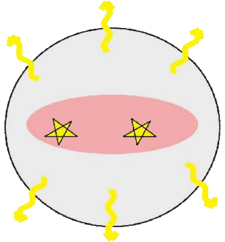
The formation efficiency of H_2 depends on the dust size distribution.
→ Dust size evolution by the shocks is essential !

One-zone galaxy model

■ Star formation (Hirashita and Ferrara 02)

$$\Psi(t) = \epsilon \frac{M_{\mathrm{H_2}}(t)}{\tau_{\mathrm{disc}}(z)}$$

M_{H2} : molecular mass in a galaxy
τ_{disc} : dynamical time of disc
<assume> $\epsilon = 1$.



Salpeter IMF： 0.1 – 60 M_{sun}
→ SN II (8- 40 M_{sun})

■ Chemothermal evolution

- chemical network of H_2 formation in gas phase (Hirashita and Ferrara 02)
- thermal evolution = cooling (H_2, H, C_I, C_{II}, O_I) + heating (radiation)
  (initial - virial temperature)

■ ISM evolution

$$\begin{aligned}
\frac{\mathrm{d}M_{\mathrm{gas}}(t)}{\mathrm{d}t} &= -\Psi(t)\frac{M_{\mathrm{gas}}(t)}{M_{\mathrm{ISM}}(t)} + m_{\mathrm{gas}}\gamma_{\mathrm{SN}}(t) \\
\frac{\mathrm{d}M_{\mathrm{star}}(t)}{\mathrm{d}t} &= \Psi(t) - m_{\mathrm{ejecta}}\gamma_{\mathrm{SN}}(t) \\
\frac{\mathrm{d}M_{\mathrm{m},i}}{\mathrm{d}t} &= -\Psi(t)\frac{M_{\mathrm{m},i}(t)}{M_{\mathrm{ISM}}(t)} + m_{\mathrm{m},i}\gamma_{\mathrm{SN}}(t)
\end{aligned}$$

γ_{SN} : SN rate
m_{gas} : gas yield
$m_{m,i}$: metal yields of species i
$M_{ISM} = M_{gas} + \Sigma_i M_{m,i}$
$m_{ejecta} = m_{gas} + \Sigma_i m_{m,i}$

H_2 formation on dust grains

- H_2 formation taking into account dust size evolution

$$\left[\frac{\mathrm{d}f_{\mathrm{H}_2}}{\mathrm{d}t}\right]_{\mathrm{dust}} = 2R_{\mathrm{dust}}\mathcal{D}n_{\mathrm{H}}f_0$$

$$= \int f_0 f_j(a)\pi a^2 \bar{v} S \mathrm{d}a$$

$$\mathcal{D} \equiv \int \frac{4\pi a^3 \rho_j f_j(a)}{3n_{\mathrm{H}}m_H}\mathrm{d}a$$

f_{H2} : molecular fraction
D : dust-to-gas mass ratio
n_H : hydrogen number density
f_0 : neutral hydrogen fraction
$f_j(a)= dn_{j,dust}(a)/da$
a : dust grain size
j : index of dust species
v : thermal velocity
S : sticking efficiency
(assume : 0.2 for $T_{gas} < 300K$)
ρ_j : density of species j

reaction rate : $$\underline{R_{\mathrm{dust}}(a)}\mathcal{D} = \int \underline{\left(\frac{3m_{\mathrm{H}}\bar{v}S}{8\boxed{a}\rho_j}\right)} \left(\frac{4\pi a^3 \rho_j f_j(a)}{3n_{\mathrm{H}}m_H}\right)\mathrm{d}a,$$

a : grain size

If fraction of smaller grains is larger, effective reaction rate should be more efficient.

Dust model

■ Dust size evolution by SNe II

$M_d(a)$ evolution

$$= m_d(a)\gamma_{\rm SN} - \boxed{\frac{M_{\rm swept}}{M_{\rm ISM}}\gamma_{\rm SN}\left\{M_{\rm d}(a) - \int_{M(a)}^{\infty}\frac{a^3}{a'^3}\eta(a,a')dM_{\rm d}(a')\right.}\left.\vphantom{\int_{M(a)}^{\infty}}\right\} - SFR\frac{M_{\rm d}(a)}{M_{\rm ISM}}$$

production

destruction by forward shocks

star

$f_{fin}(a)da = \eta(a, a') f_{ini}(a')da'$

$m_d(a)$: dust yield

M_{swept} : mass swept by a SN

■ Dust production, m_d (a) : Nozawa+ 03

■ Dust desruction

- reverse shock → m_d (a) : Nozawa+ 07
- forward shock → η (a, a') : based on model of Nozawa+ 06

(η(a,a') is independent on initial size distribution)

■ parameter

assume : $E_{51} = 1$

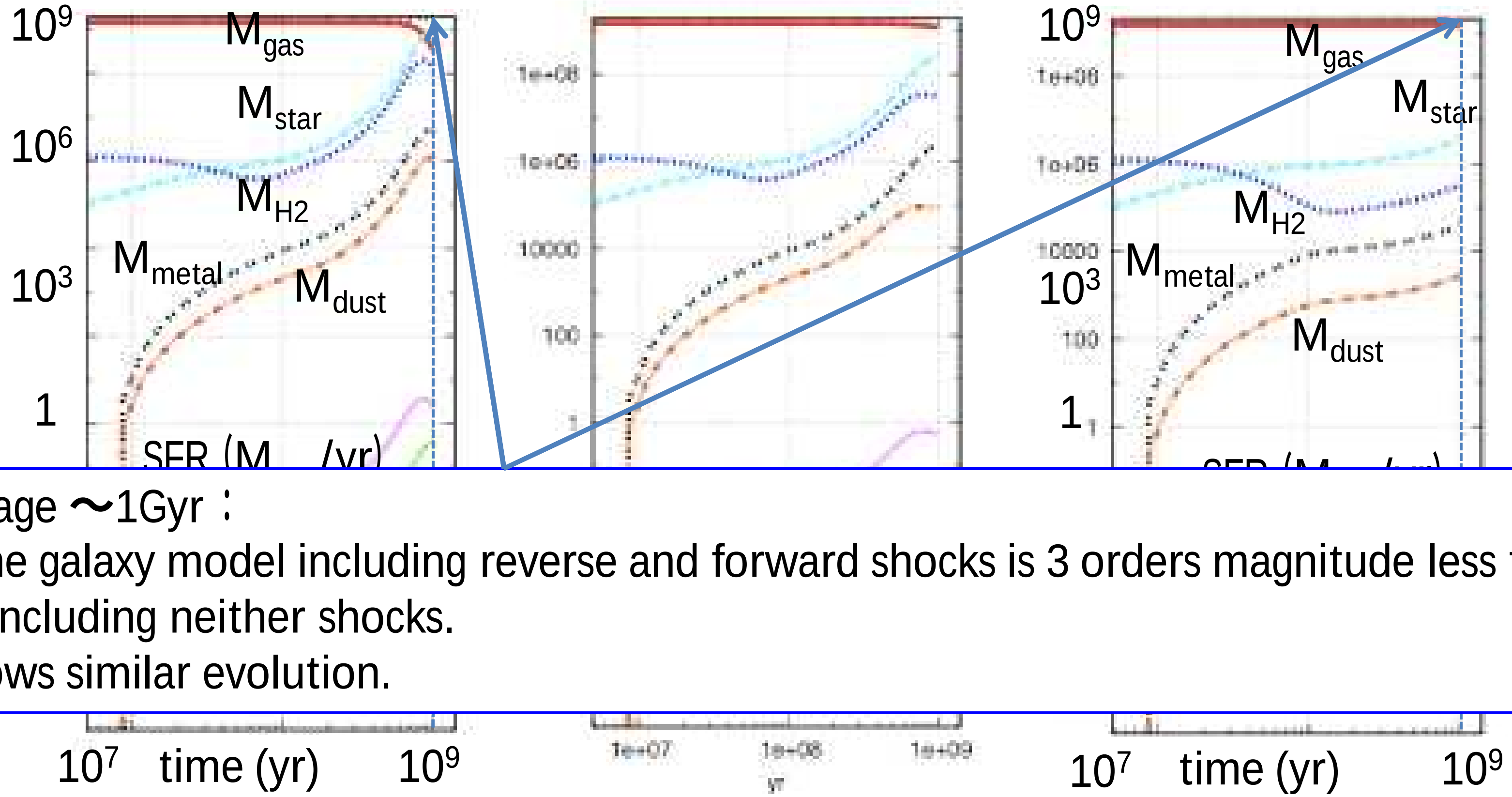
$n_{ISM} = 0.1, 1\ cm^{-3}$

Effects of shocks ①

■ (M_{vir}, z_{vir}) = (10^{10} M_{sun} , 15)

< shocks : n_{ISM} = 1 cm^{-3} >

reverse	×	×	○
forward	×	○	○



■ galaxy age ∼1Gyr：

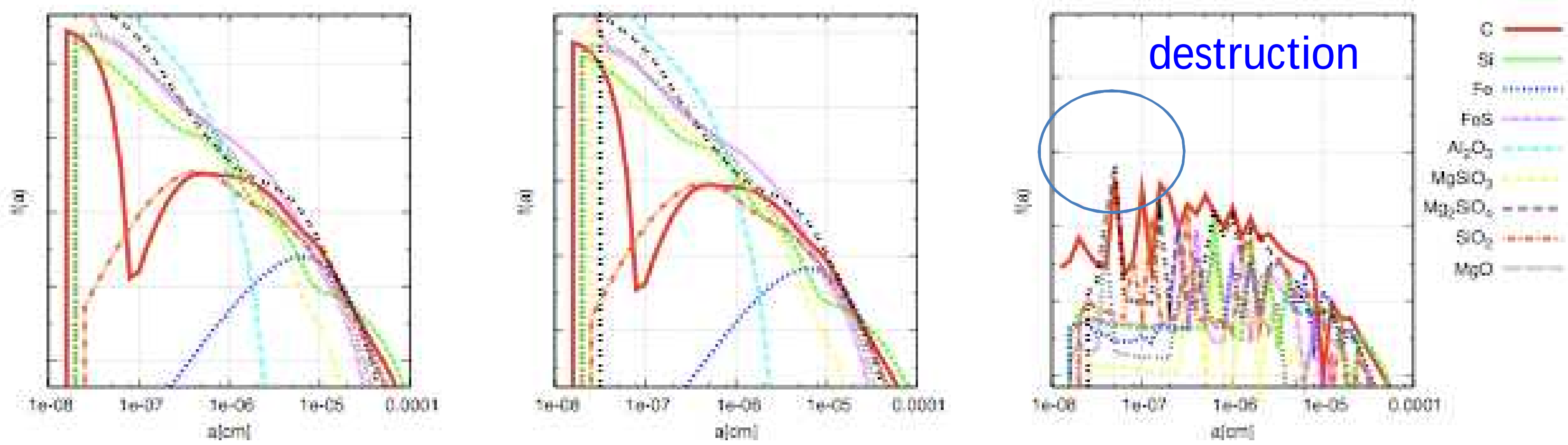
→ f_{H2} in the galaxy model including reverse and forward shocks is 3 orders magnitude less than that including neither shocks.

→ SFR shows similar evolution.

Effects of shocks ②

reverse	×	×	○
forward	×	○	○

t = 1 Gyr



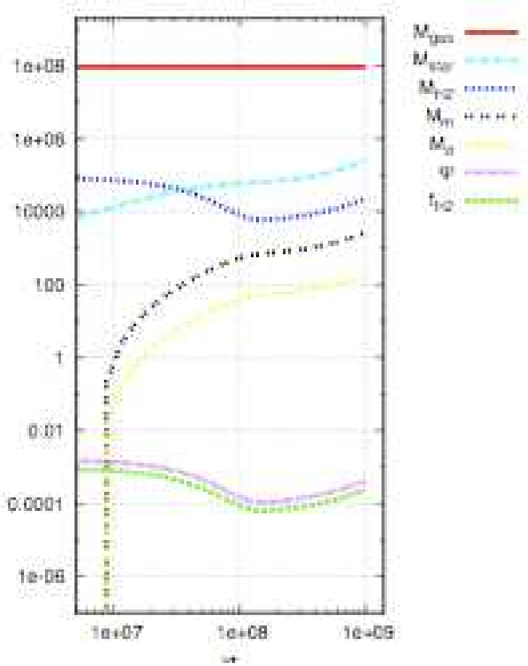
$\langle a \rangle = 4.0 \times 10^{-6}$ cm $\langle a \rangle = 3.9 \times 10^{-6}$ cm $\langle a \rangle = 1.8 \times 10^{-4}$ cm

■ Reverse shocks change dust size distribution.
■ Forward shocks hardly affects dust size distribution,
since dust-to-gas mass ratio, $D < 10^{4}$.

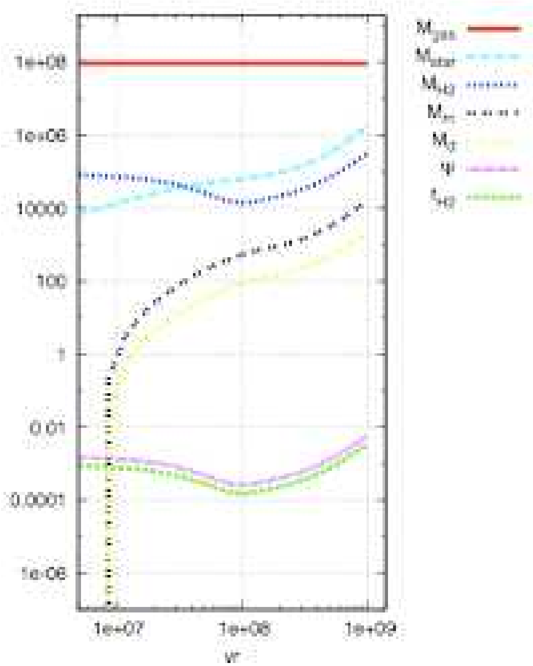
Effects of n_{ISM}

- (M_{vir}, z_{vir}) = (10^9 M_{sun} , 15)

reverse : n_{ISM} = 1 cm^{-3}



reverse : n_{ISM} = 0.1 cm^{-3}



f_{H2} in the galaxy model including reverse shocks with n_{ISM} = 0.1 cm^{-3} is 1 order magnitude larger than that with n_{ISM} = 1 cm^{-3}.

SUMMARY

- We investigate dust size evolution and the resulting H_2 formation on dust grains in the high-redshift galaxy ($z > 5$).

- One-zone galaxy model :
  - H2 formation on dust grains taking into account dust size distribution
  - chemical network of H_2
  - thermal evolution
  - SFR related to the mass of H_2 and τ_{disc}.

- Dust model :
  - SN II dust production
  - destruction by reverse shocks and forward shocks

- Main result :

  We show that in the galaxy model including both reverse shocks and forward shocks, H_2 formation preceeds 3 order of magnitude more moderately than in the model without dust destruction.

end

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