Inoue & Kamaya 2008, EPS, submitted

銀河間ダスト光電効果加熱

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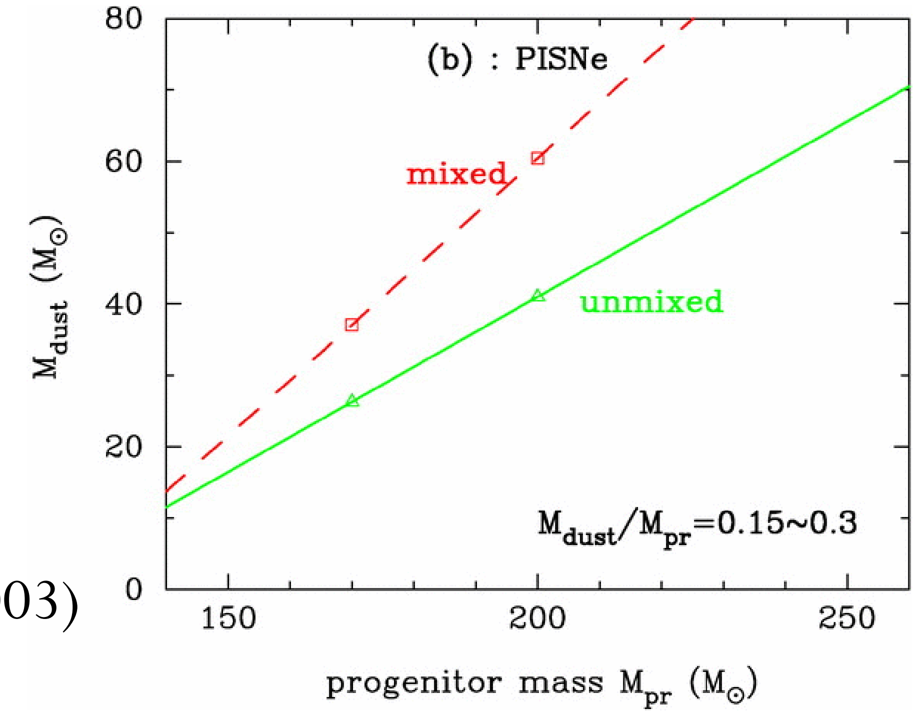
初代星とダスト

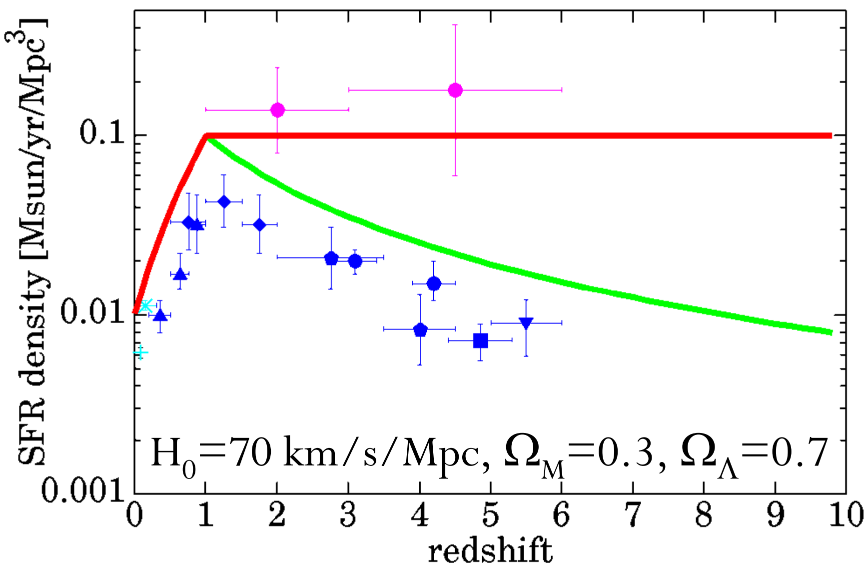
- **超新星爆発でダスト粒子が形成される**
  - **ただし、観測的に直接示されてはいない**
  - **間接的にはｚ＝６ＱＳＯのダスト量など**
  - **ＳＮ２００６ｊｃの観測からも冷たいダストは検証されていない**

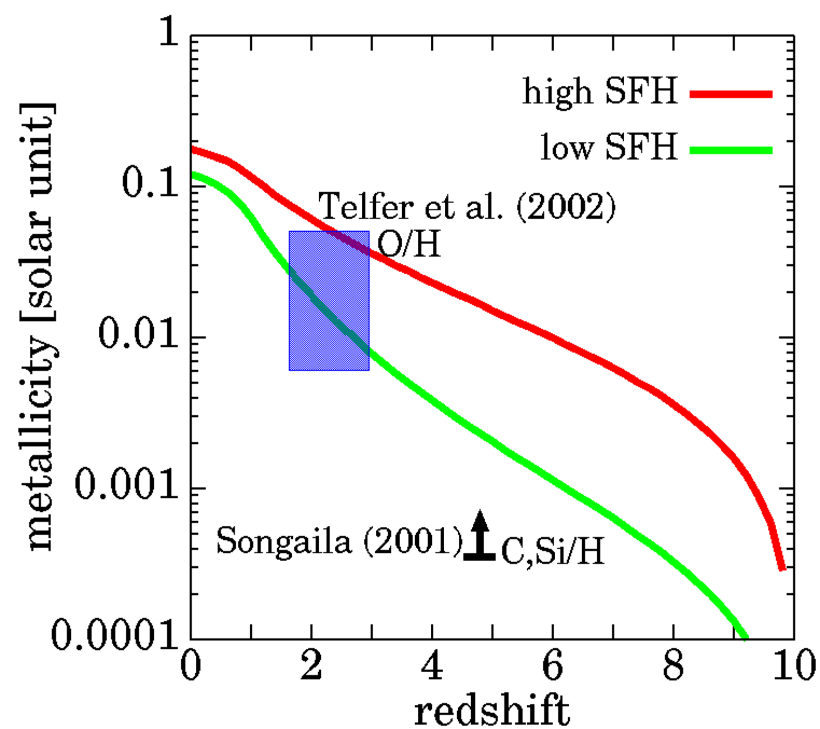


Nozawa et al.(2003)

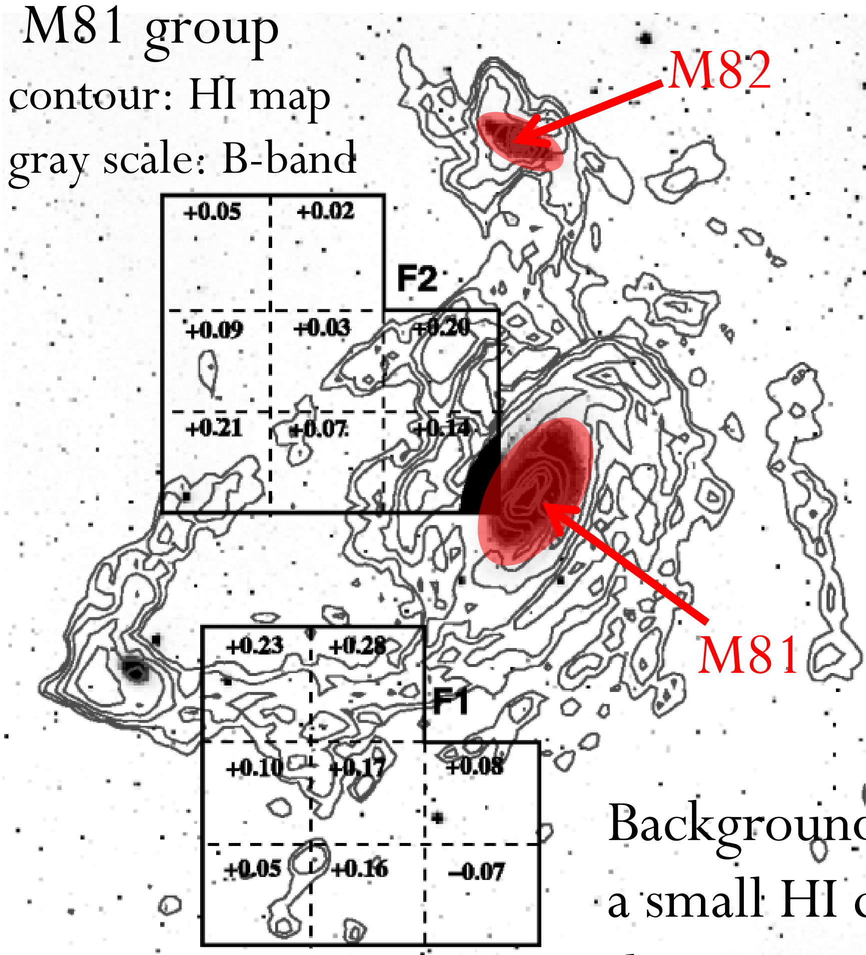
Why Intergalactic Dust (IGD)?

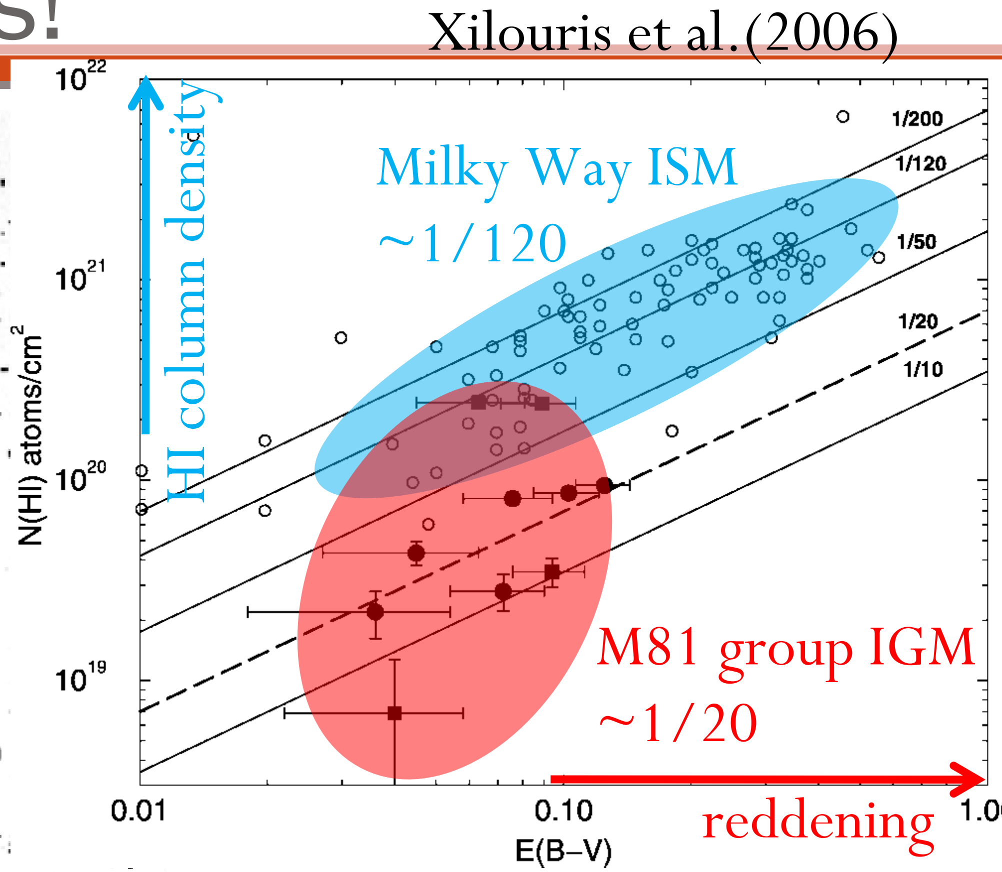
- Metal in the IGM is surprisingly abundant; all the metal produced by stars could be out of galaxies!
- IGD is also abundant?





IGD really exists!

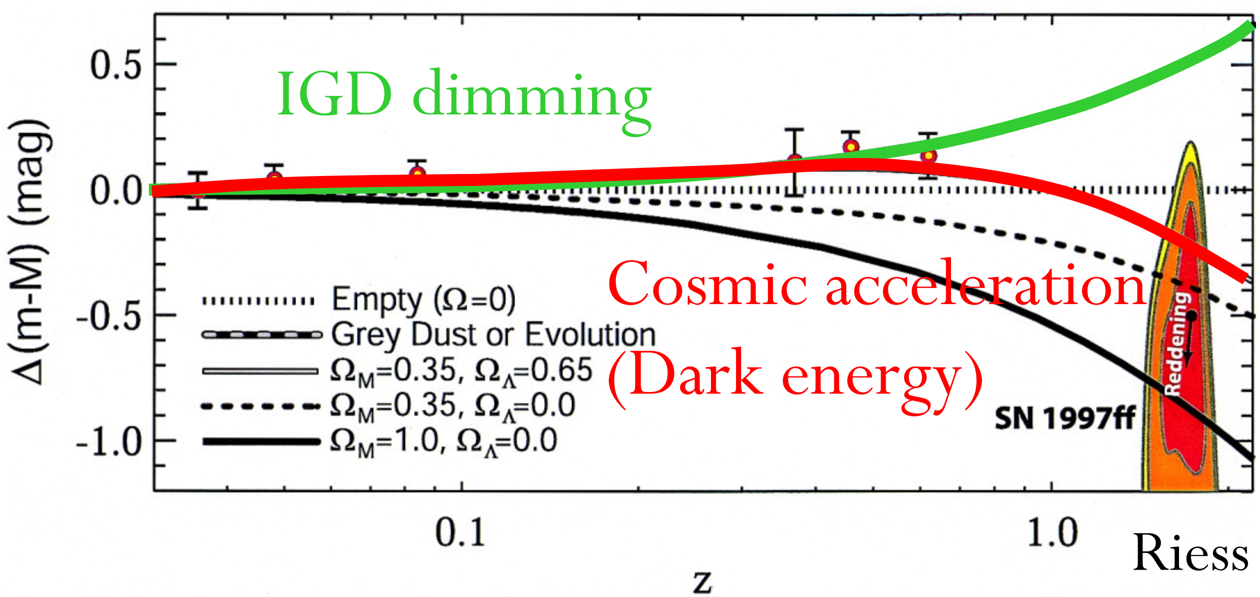




Background galaxies show a modest reddening against a small HI column density: larger dust-to-gas ratio in the M81 group IGM than the Milky Way's ISM!

IGD and Cosmology

- High-redshift objects are suffer from dimming by IGD.
- Supernova cosmology may be affected by IGD.

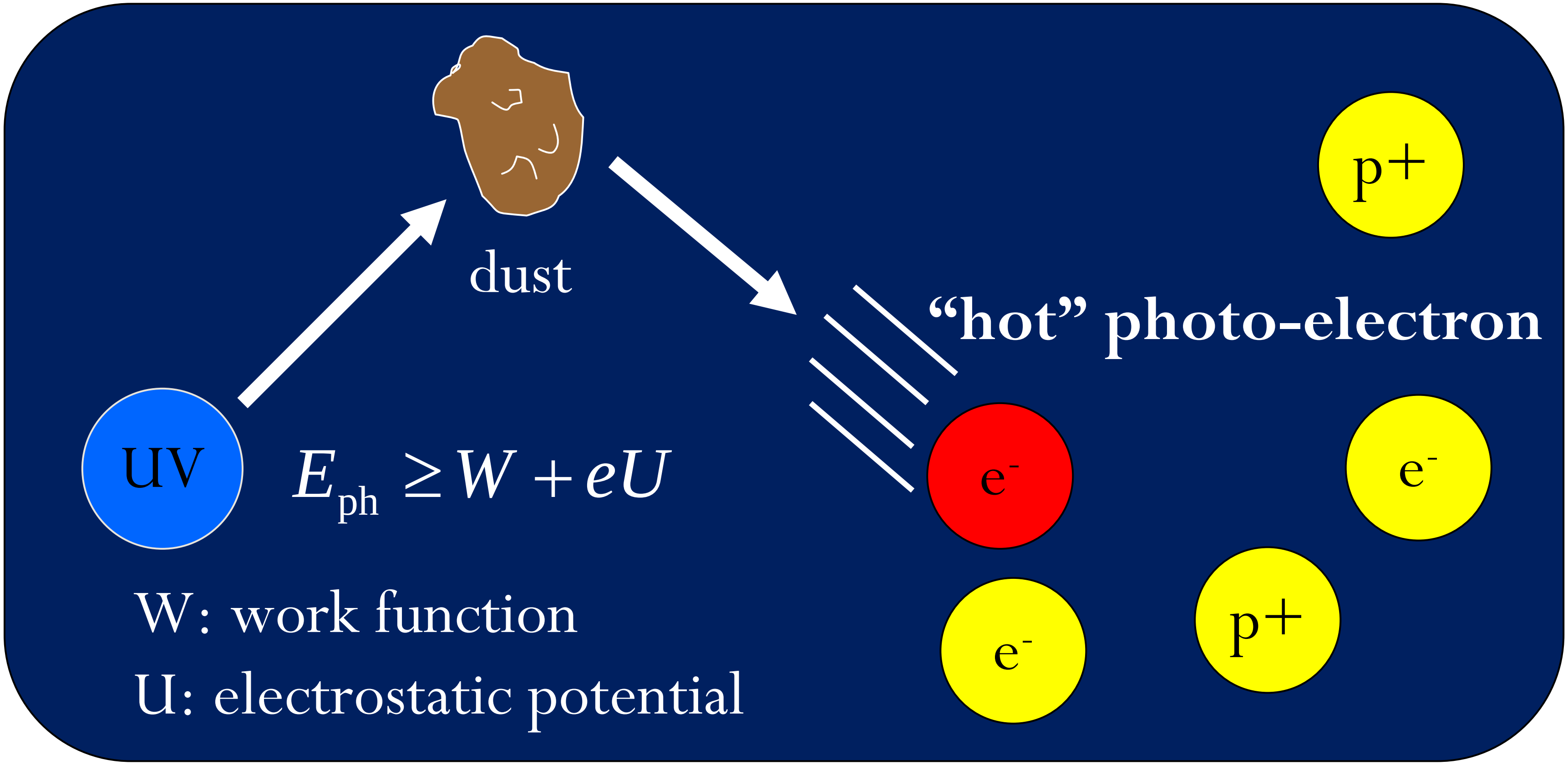


Riess et al.(2001)

Future investigation of the 'equation of state' of the Dark energy will be still affected by IGD dimming (Corasaniti 2006).

Photoelectric effect of IGD

- IGD is an energy convertor from photon to gas.



$$E_{ph} \geq W + eU$$

W: work function

U: electrostatic potential

Grain charging process

- Equilibrium charge equation: $$\sum_i R_i + R_{\mathrm{ph}} = 0$$
  - charging time-scale: ~10—100 yrs
- Collisional charging rate:

$$R_i = \pi a^2 Z_i s_i n_i \int_{\mathrm{v}_{\min}}^{\infty} \sigma_i(\mathrm{v}_i, Z_i, Z_{\mathrm{d}}) \mathrm{v}_i f(\mathrm{v}_i) d\mathrm{v}_i$$

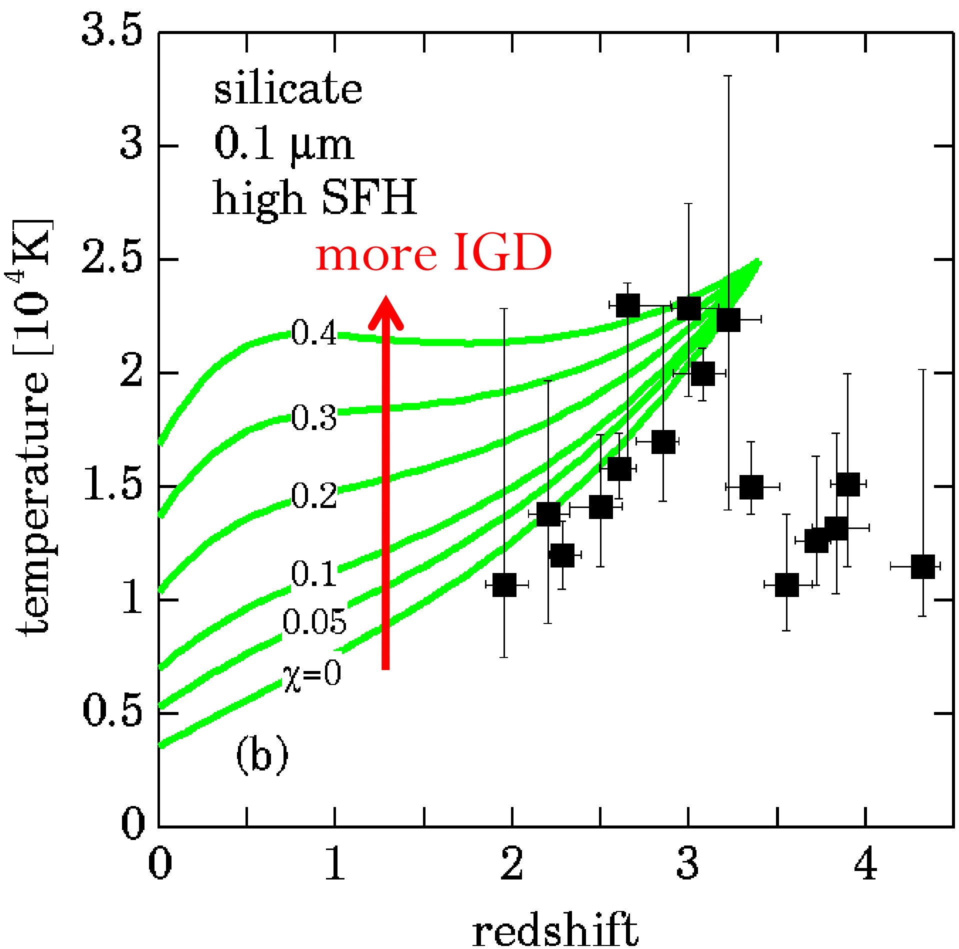
- Photoelectric charging rate:

$$R_{\mathrm{ph}} = \pi a^2 \int_{\nu_{\min}}^{\nu_{\max}} Q(a,\nu) Y(a,\nu,Z_{\mathrm{d}}) \frac{4\pi J_\nu}{h\nu} d\nu$$

  - grain properties: Draine & Lee model
  - photoelectric yield: Weingartner & Draine (2001)

→ Z_{d}

IGD and thermal history of IGM



$$\chi \equiv \frac{\text{IG dust mass}}{\text{metal mass}}$$

Data: Schaye et al.(2000)

Model: Inoue & Kamaya (2004)

We can obtain an upper limit on the IGD amount with the IGM thermal history (Inoue & Kamaya 2003, 2004).

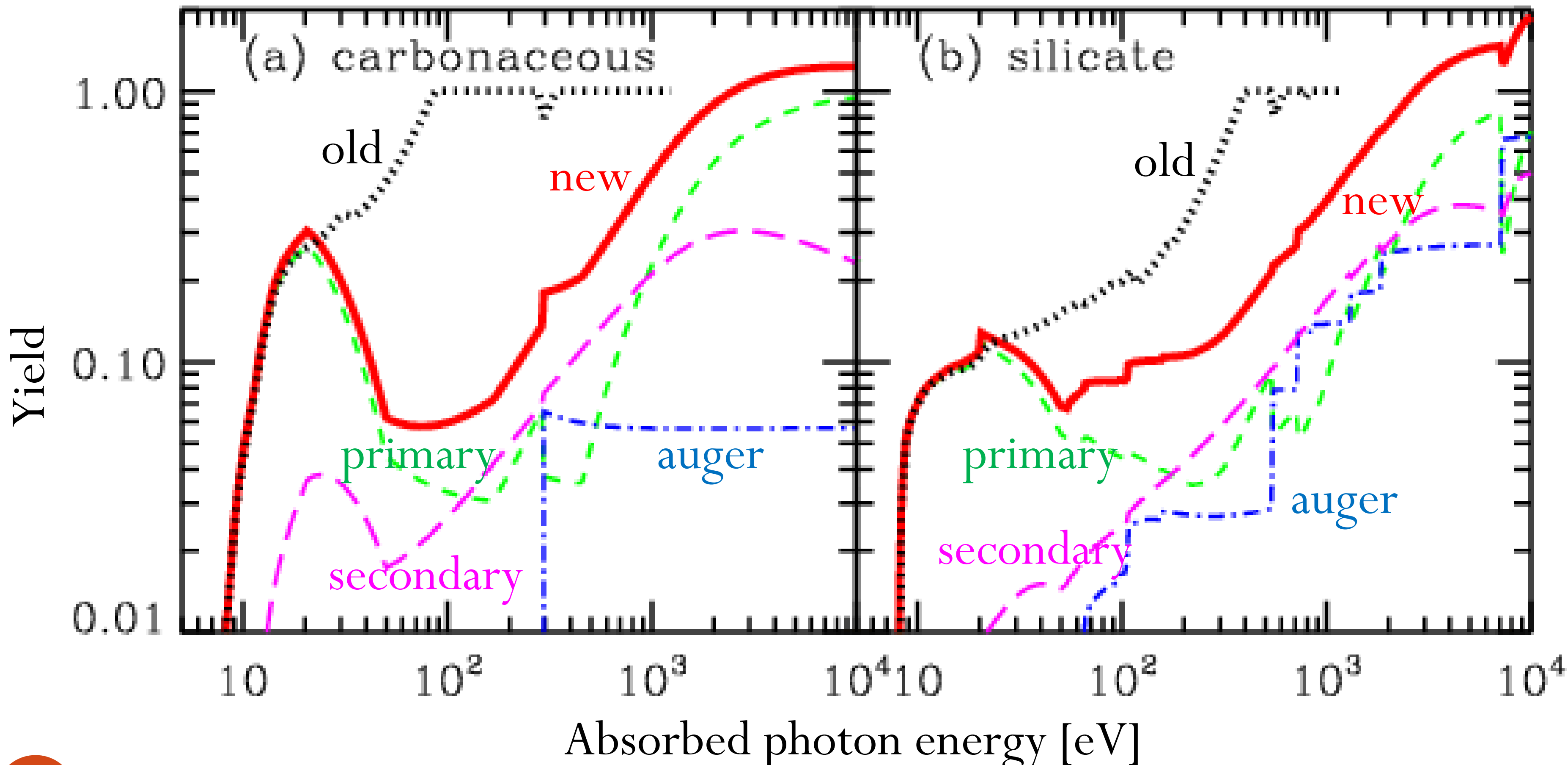
New model of photoelectric yield(Y)

- Weingartner & Draine (2001) yield:
  - only primary electron from the band structure is considered.

- Weingartner et al. (2006) yield:
  - primary electron from inner shells of atoms making up grains as well as from the band structure
  - Auger electron
  - secondary electron
  - photon and electron transfer in a grain
  - but still large uncertainty because of the lack of experiments.

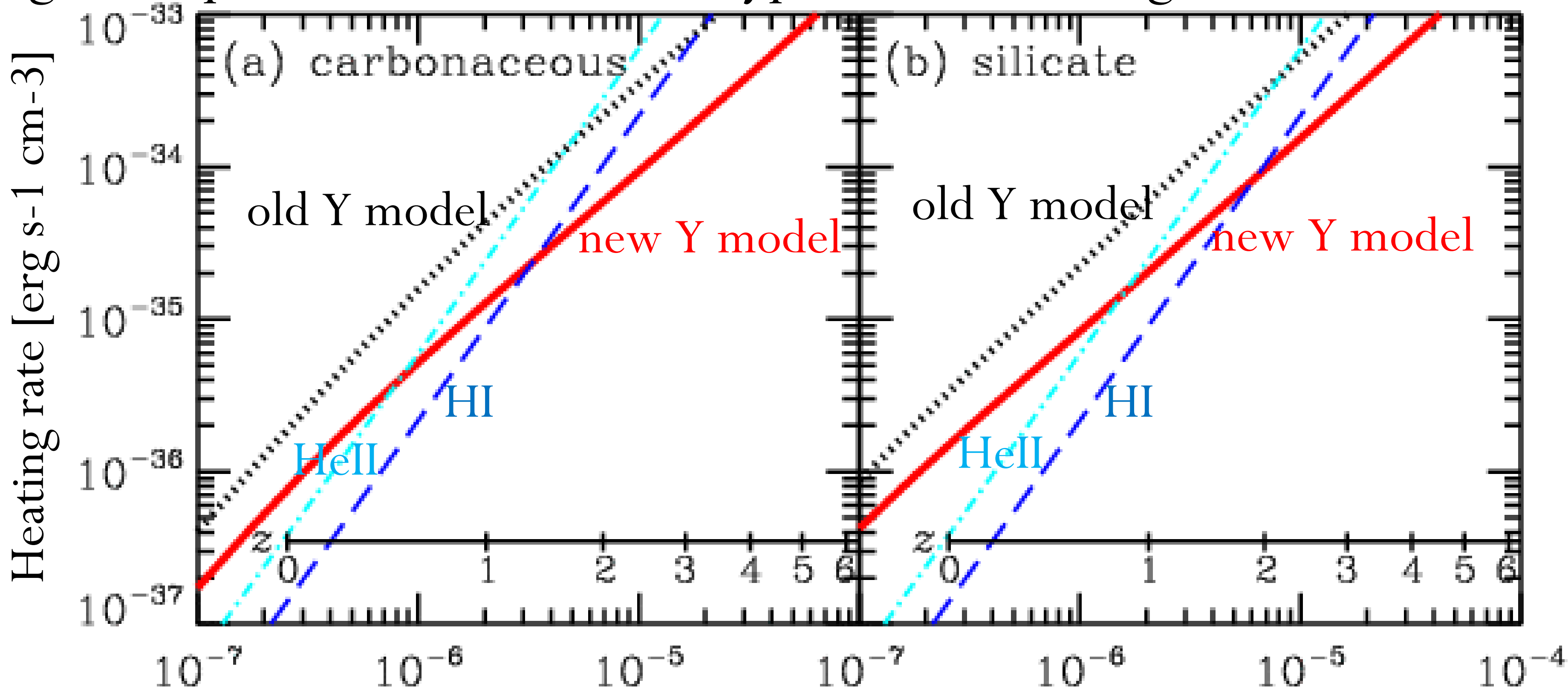
New model of photoelectric yield(Y)

0.1 micron, neutral grain



Photoelectric heating with new Y

Dust-to-gas ratio: 1% of the Milky Way, MRN size distribution, gas temperature of 10,000 K, typical UV-X background radiation



Gas number density [cm-3]

Effect of grain size distribution

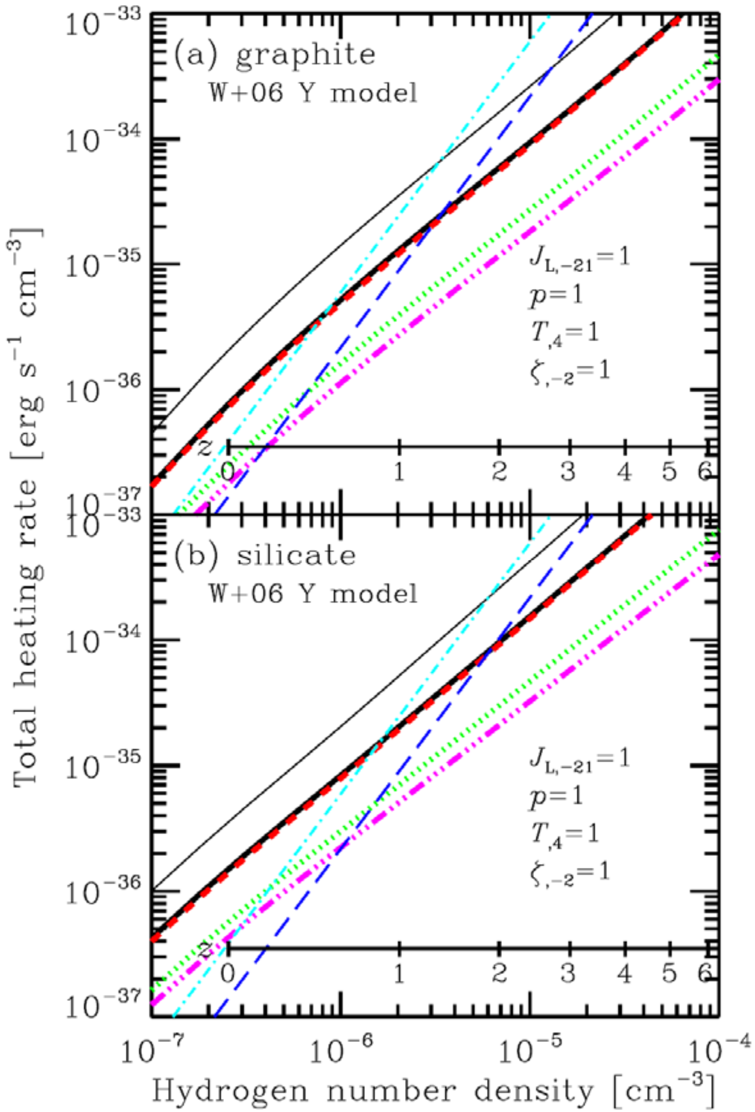


Table 1. Possible size distributions of the intergalactic dust.

MRN	Mathis, Rumpl, & Nordsieck (1977)
single power law[a]	
q	3.5
$a_{\min}$	50 Å
$a_{\max}$	0.25 μm
$\langle a \rangle$	350 Å
BF05	Bianchi & Ferrara (2005)
single power law[a]	
q	3.5
$a_{\min}$	0.1 μm
$a_{\max}$	0.25 μm
$\langle a \rangle$	0.16 μm
N03	Nozawa et al. (2003)
double power law[b]	
q_1 ($a \le a_c$)	2.5
q_2 ($a > a_c$)	3.5
$a_{\min}$	2 Å
$a_{\max}$	0.3 μm
a_c	0.01 μm
$\langle a \rangle$	290 Å
N07	Nozawa et al. (2007)
double power law[b]	
q_1 ($a \le a_c$)	1.0
q_2 ($a > a_c$)	2.5
$a_{\min}$	10 Å
$a_{\max}$	0.3 μm
a_c	0.01 μm
$\langle a \rangle$	0.12 μm
SG	—
single power law[a]	
q	3.5
$a_{\min}$	50 Å
$a_{\max}$	0.025 μm
$\langle a \rangle$	110 Å

[a] The grain size distribution $n(a) \propto a^{-q}$.
[b] The grain size distribution $n(a) \propto a^{-q_1}$ for $a \le a_c$ and $\propto a^{-q_2}$ for $a > a_c$.

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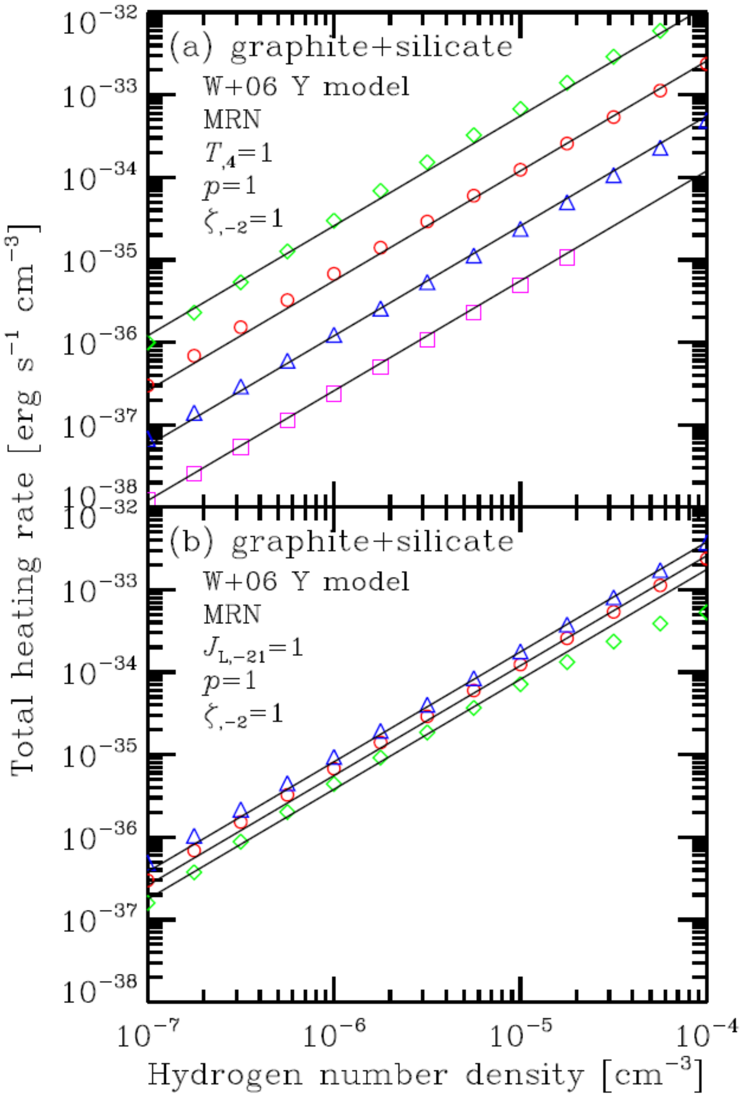
2008年9月10日

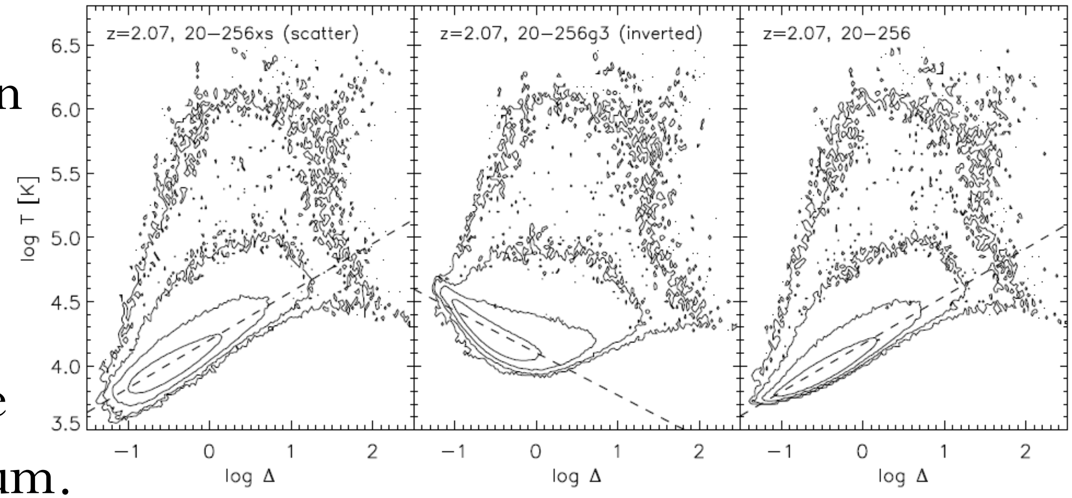
Useful formula



$$\Gamma_{\rm pe} = 1.2 \times 10^{-34}\ {\rm erg\ s^{-1}\ cm^{-3}} \times \left(\frac{\mathcal{D}}{10^{-4}}\right)\left(\frac{n_{\rm H}}{10^{-5}\ {\rm cm^{-3}}}\right)^{4/3}\left(\frac{T}{10^4\ {\rm K}}\right)^{-1/6} \times \left(\frac{J_{\rm L}}{10^{-21}\ {\rm erg\ s^{-1}\ cm^{-2}\ Hz^{-1}\ sr^{-1}}}\right)^{2/3},$$

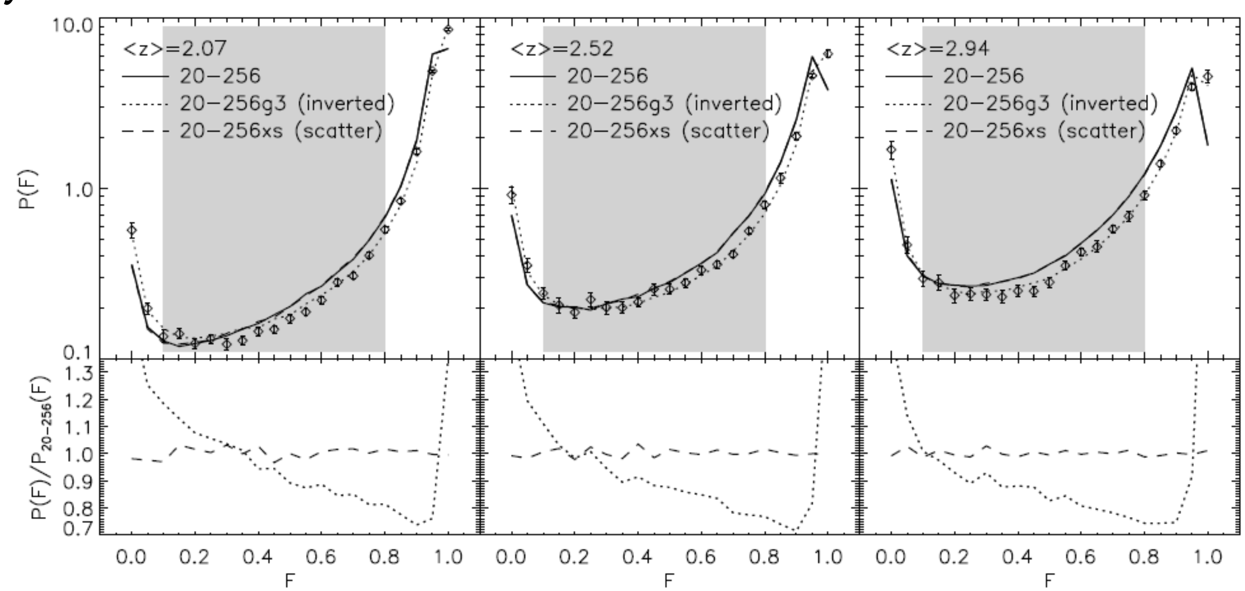
Inverted T-ρ relation in the IGM

Bolton et al.(2008) suggested an inverted temperature—density relation in low-density IGM.



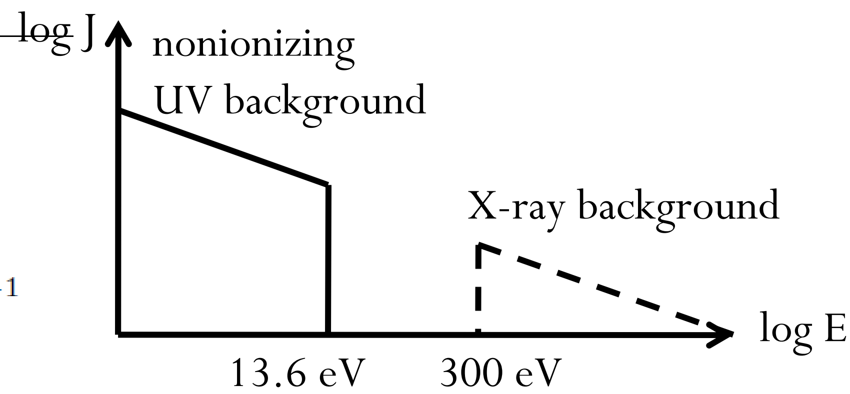
We need a heating source more efficient in lower density medium.

IGD heating?



IGD heating before the reionization

Common setting	
z	10
$n_{\rm H}$	3×10^{-4} cm^{-3}
$\mathcal{D}$	10^{-4}
size distribution	MRN
$J_{\rm L}$	1×10^{-21} erg s^{-1} cm^{-2} Hz^{-1} sr^{-1}
p	1
$E_{\rm UV}^{\rm max}$	13.6 eV
Nonionizing UV only	
T	30 K
$x_{\rm e}$	10^{-4}
$\Gamma_{\rm pe}$	7×10^{-36} erg s^{-1} cm^{-3}
$t_{\rm pe}$	9×10^{9} yr
With X-ray background	
$E_{\rm X}^{\rm min}$	300 eV
T	10^{4} K
$x_{\rm e}$	0.3
$\Gamma_{\rm pe}$	2×10^{-33} erg s^{-1} cm^{-3}
$\Gamma_{\rm pi,X}^{\rm HI}$	2×10^{-30} erg s^{-1} cm^{-3}



temperature doubling time-scale

Summary

- Intergalactic Dust (IGD) may be abundant.
- IGD dimming may affect determinations of cosmological parameters.
- In general, the dust photoelectric heating is efficient in low density medium with hard radiation, e.g., the IGM.
- IGD photoelectric heating may affect the thermal history of the IGM. From this, we can constrain the IGD amount.
- A new photoelectric yield for X-ray reduces the heating rate significantly.
- Grain size distribution is important for the heating rate.
- A fitting formula of the IGD heating rate is presented.
- IGD may cause an inverted temperature-density relation.
- IGD heating is not important before the reionization.