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Galaxy simulation with the evolution of grain size distribution

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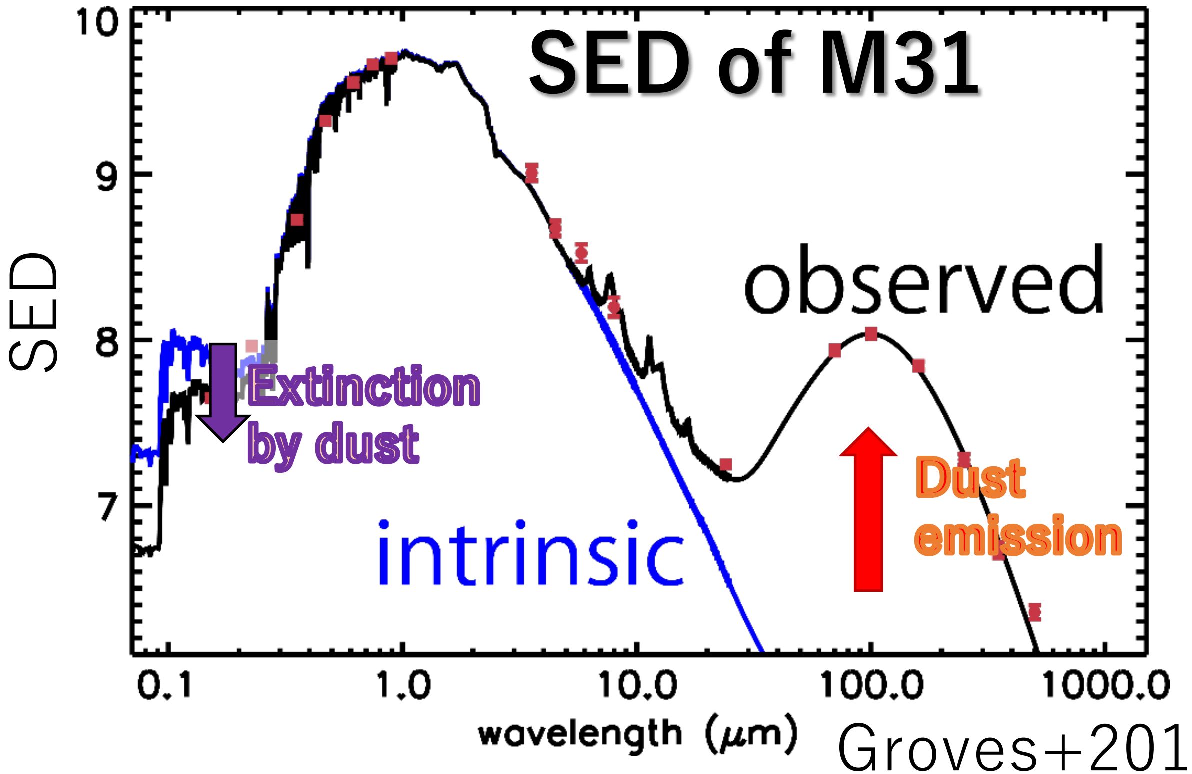
Based on Aoyama *et al.* MNRAS submitted (2019b)
arXiv: **1906.01917**

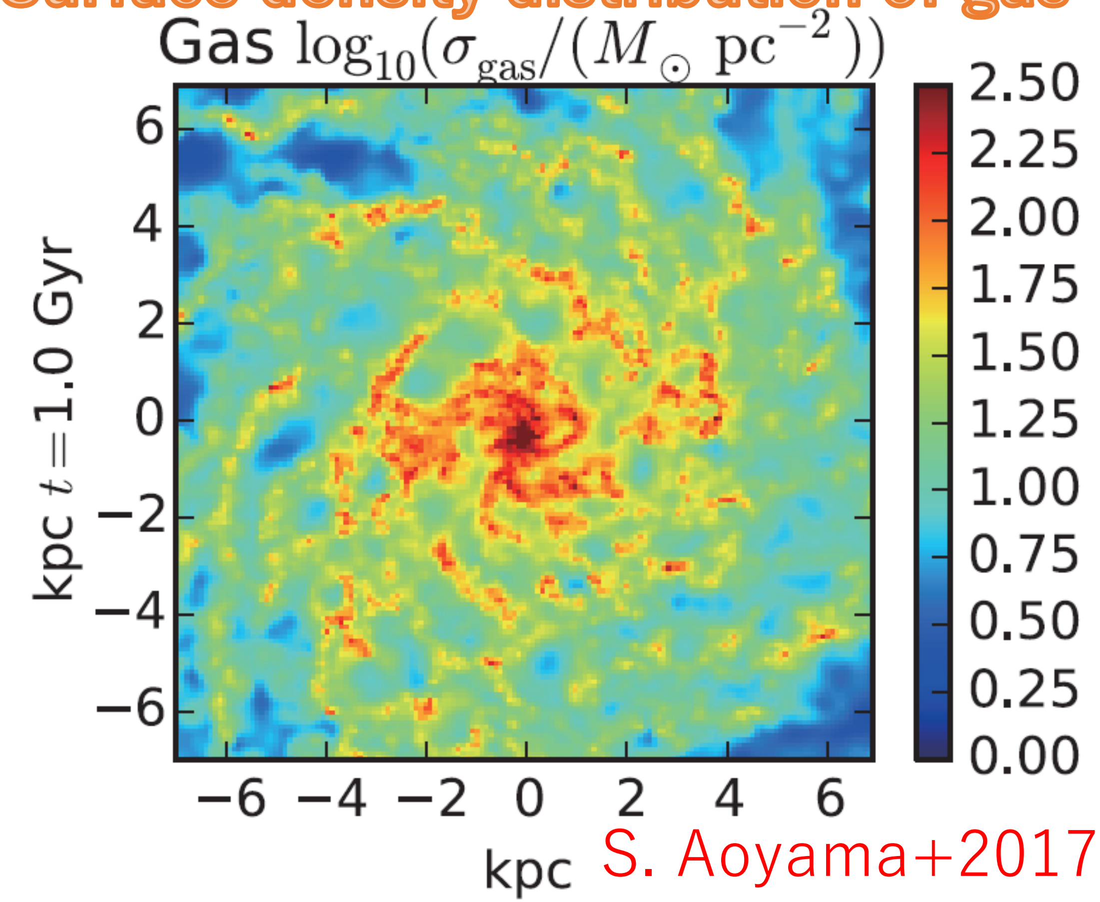
Introduction

- Dust grains are essential for star formation and understanding the extinction of UV. (Ms. S. Nagasaki's talks)
- Hydro-dynamical simulations are a very powerful tool to reveal ISM physics.



Groves+2012

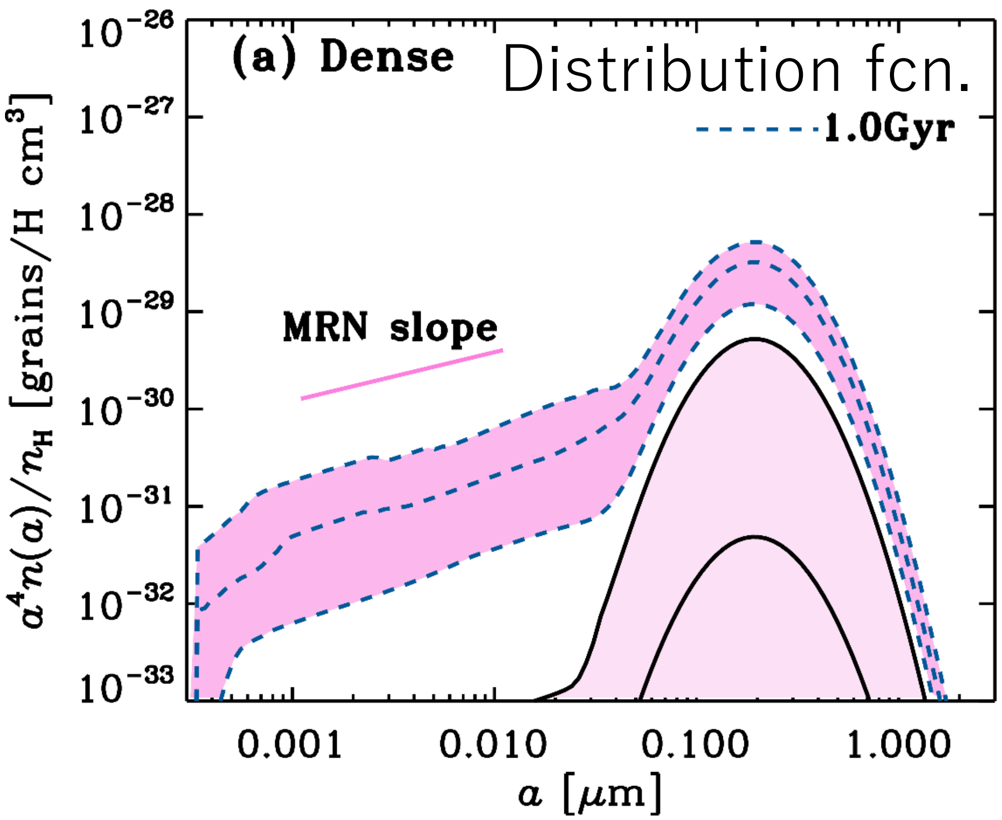
Surface density distribution of gas



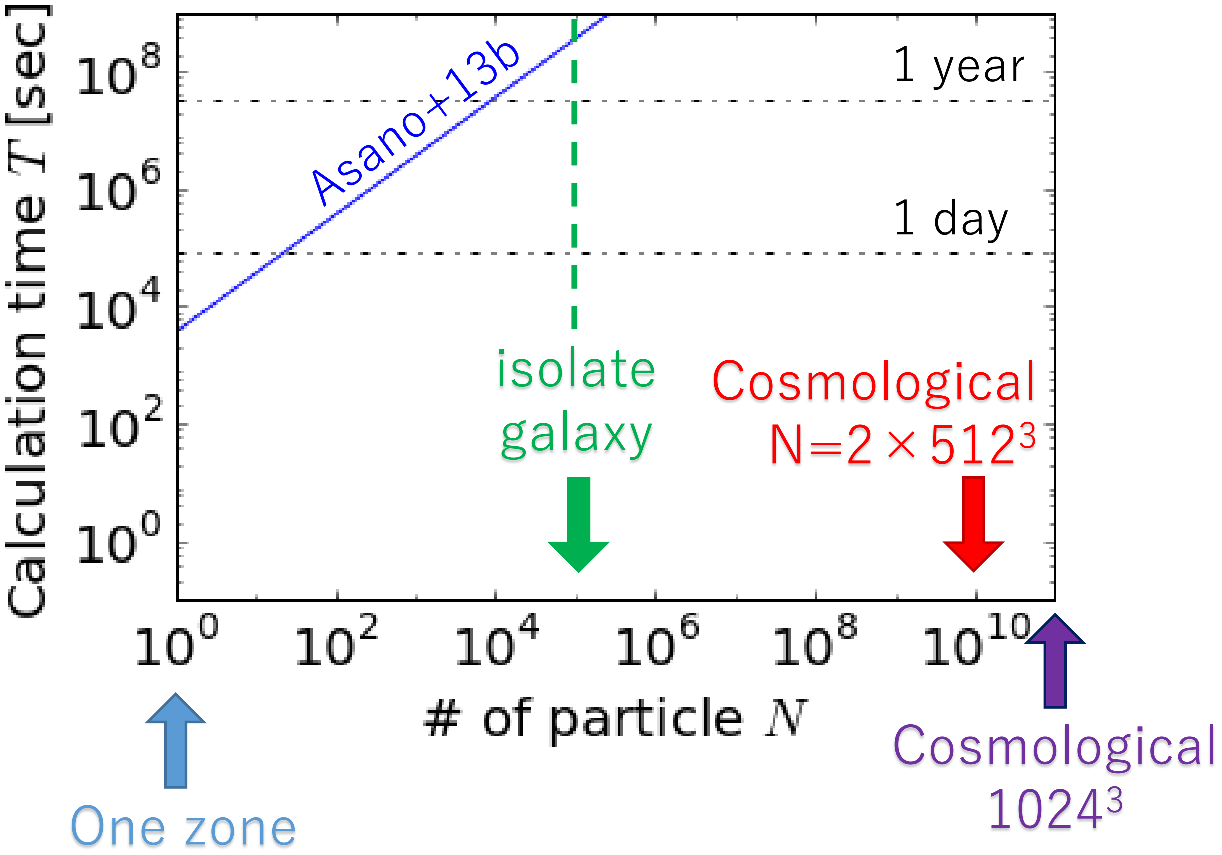
S. Aoyama+2017

Introduction

- Evolution of dust size distribution is essential for understanding observations.
(e.g. Asano et al. 2013b, 2014, Hirashita 2015, S. Aoyama+17 (A17), 18, 19a)
- Reduction of computational cost (optimization) is crucial for hydro-dynamical simulations.



Hirashita & S. Aoyama (2019)

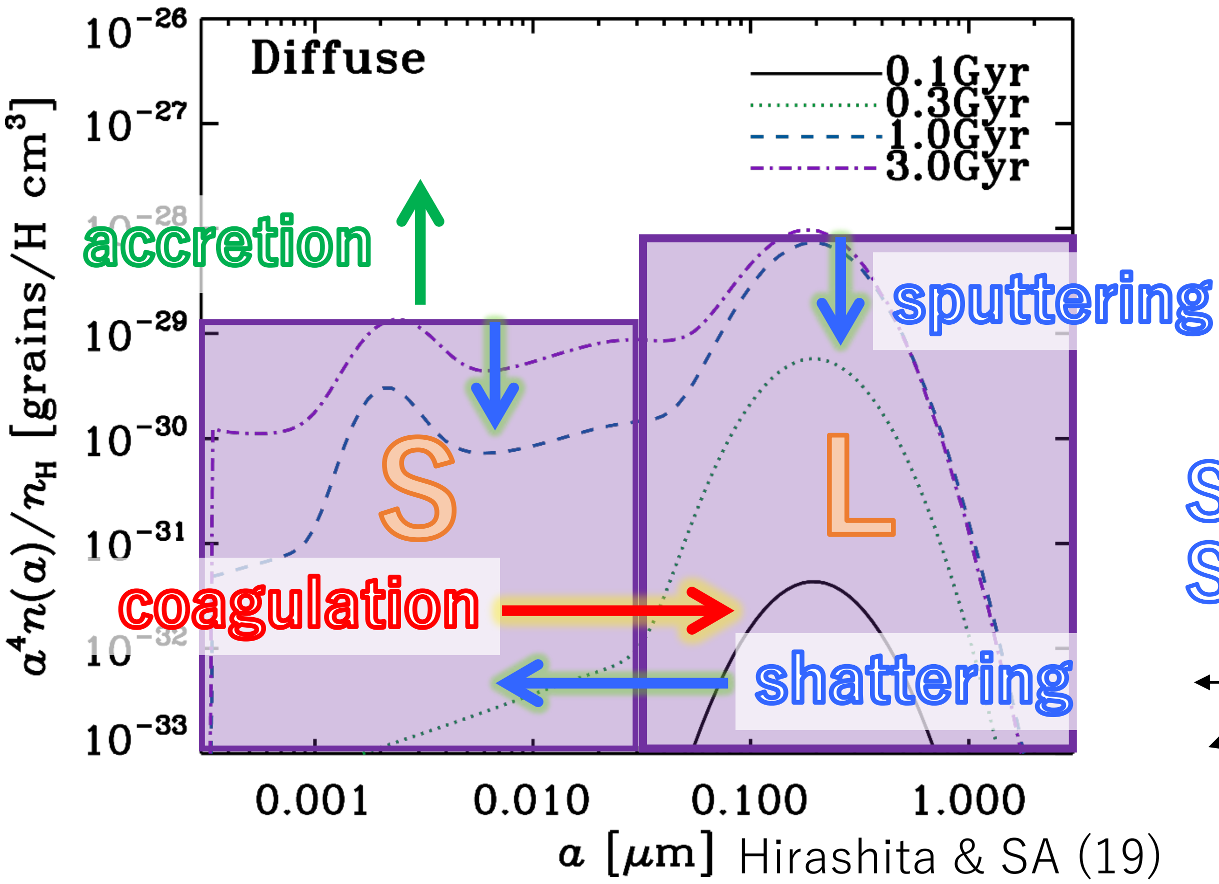


Private communication to a collaborator of R. S. Asano

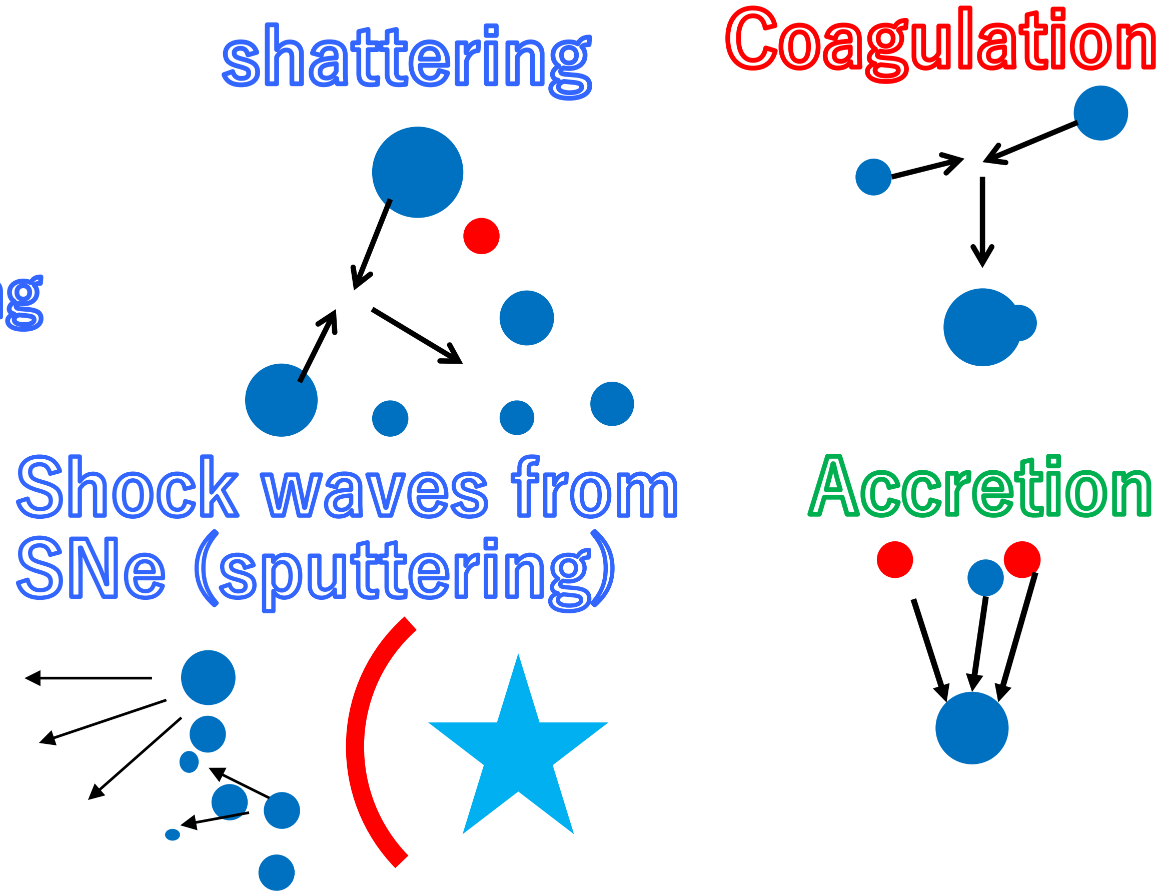
Two size approximation (Hirashita 2015)

(See also S. Aoyama+17 (A17), 18, 19a, K-C Hou+17, 19)

- Grain size distribution are represented as two modes (Large, Small).
- Grain-Grain interaction (shattering, coagulation) can be implemented in the simplest way. **Total # of bins: 2**



Hirashita & SA (19)

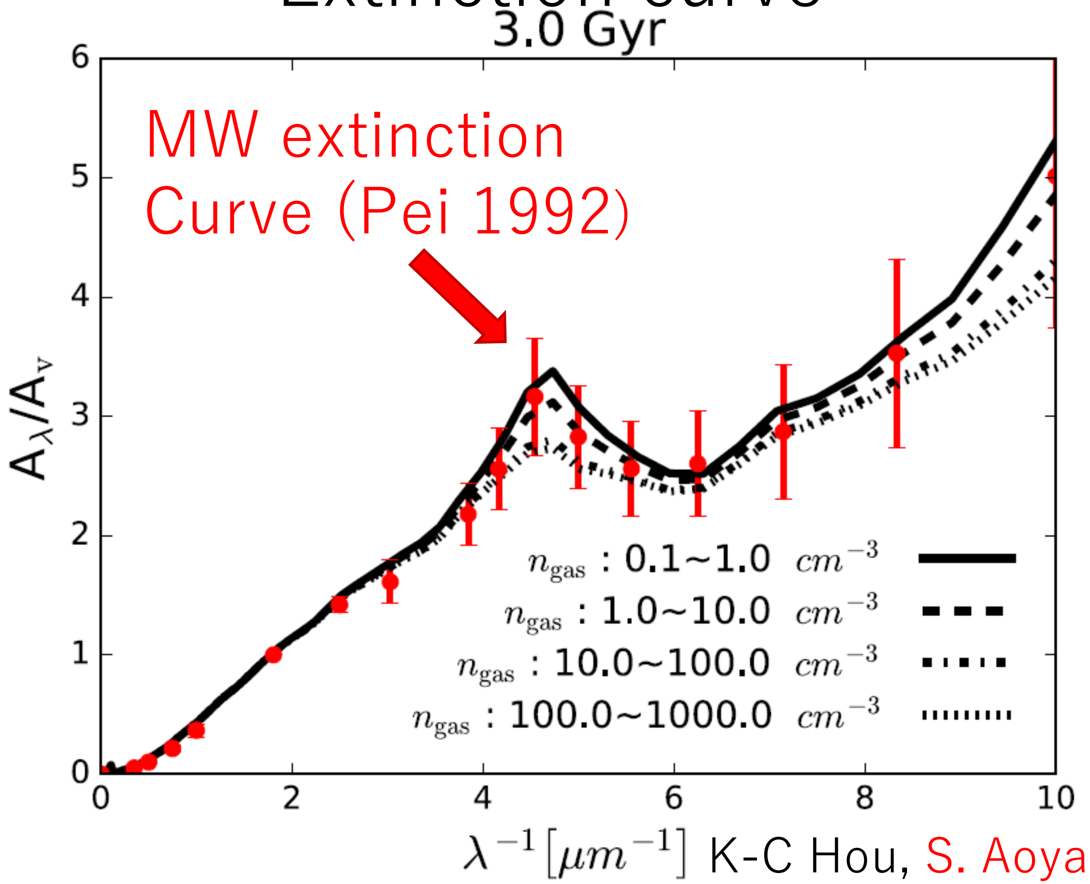


Two size approximation (Hirashita 2015)

(See also S. Aoyama+17 (A17), 18, 19a, K-C Hou+17, 19)

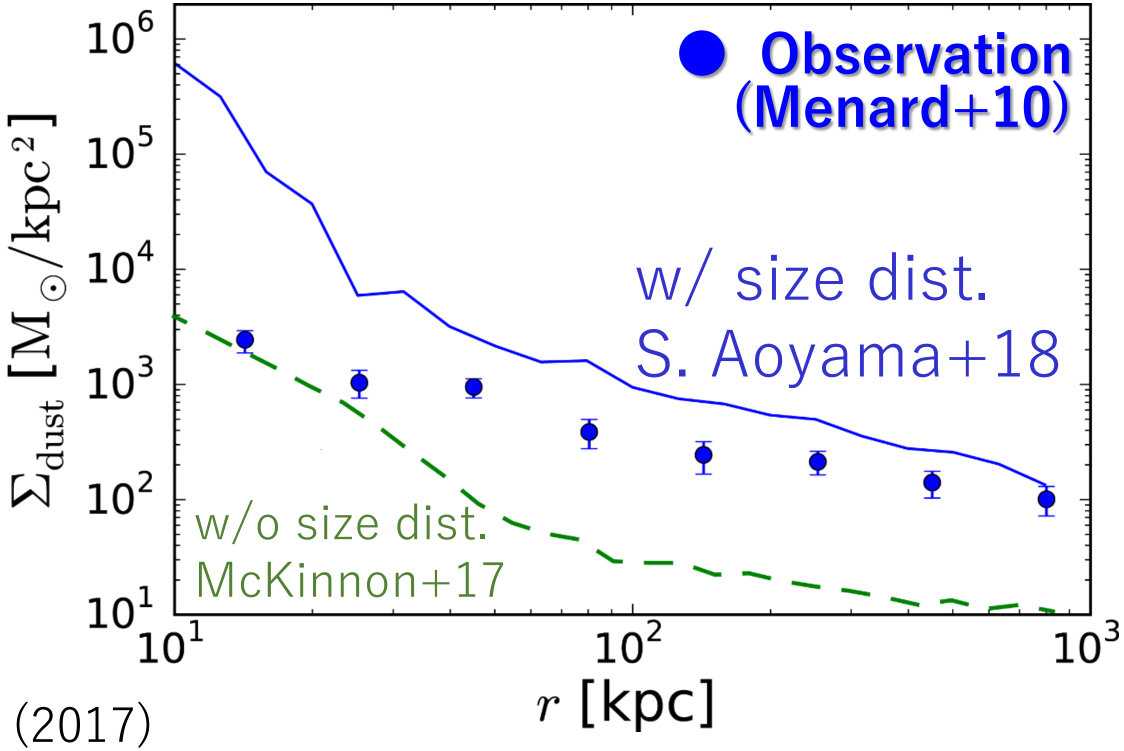
- Many observed quantities can be explained by two size approximation.
- The evolution of spatial distribution of grain distribution is also available.

Extinction curve



K-C Hou, S. Aoyama et al. (2017)

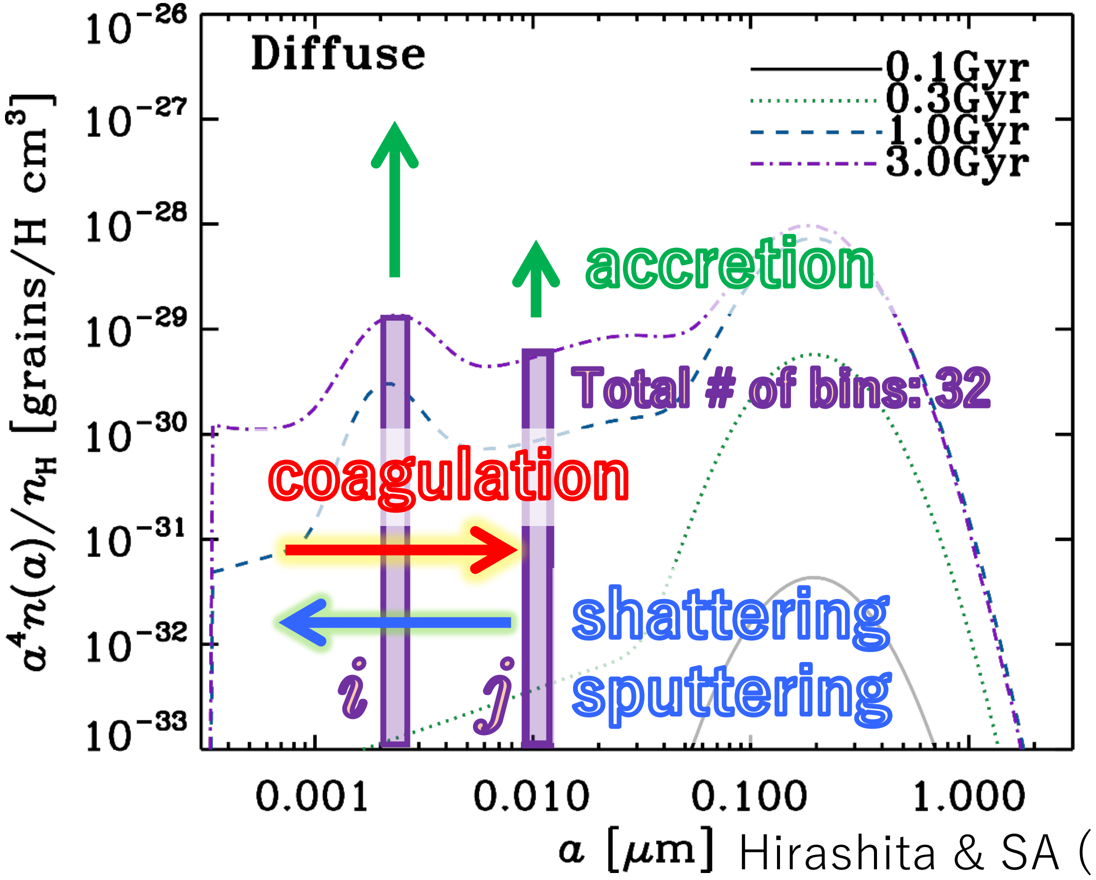
Radial profile of dust surface density around gals.



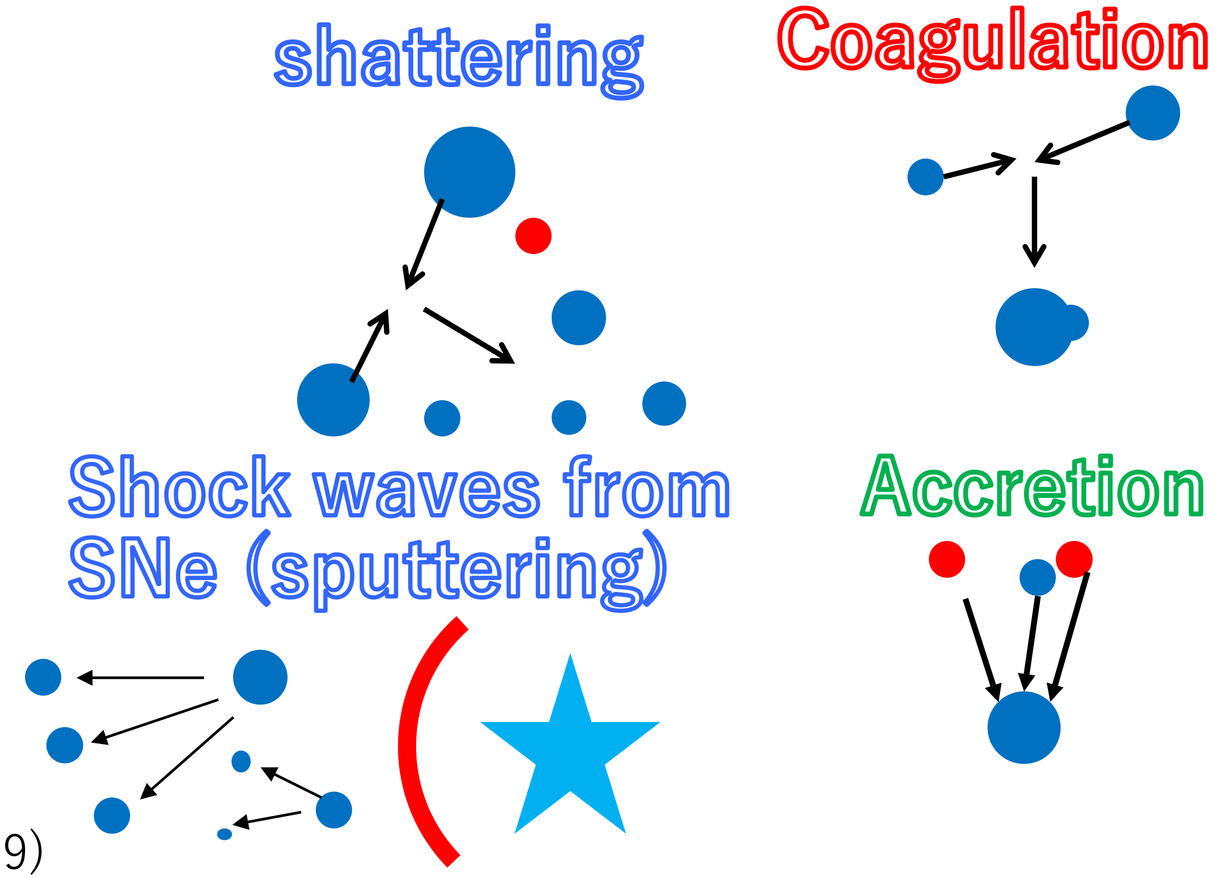
Full grain size distribution

(Asano+13b, 14, McKinnon+18, Hirashita & S. Aoyama 19)

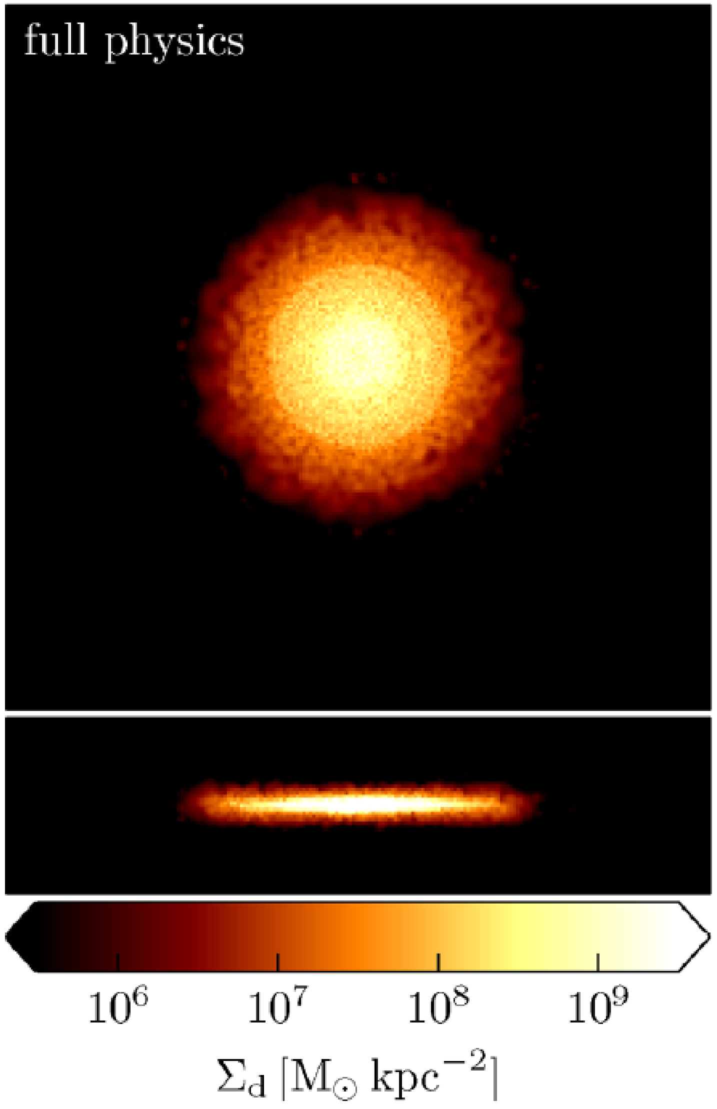
- In reality, dust grains has continuous distribution from 0.3 nm to 3 μm.
- Grain growth/destruction can be described as communication between different size bins.



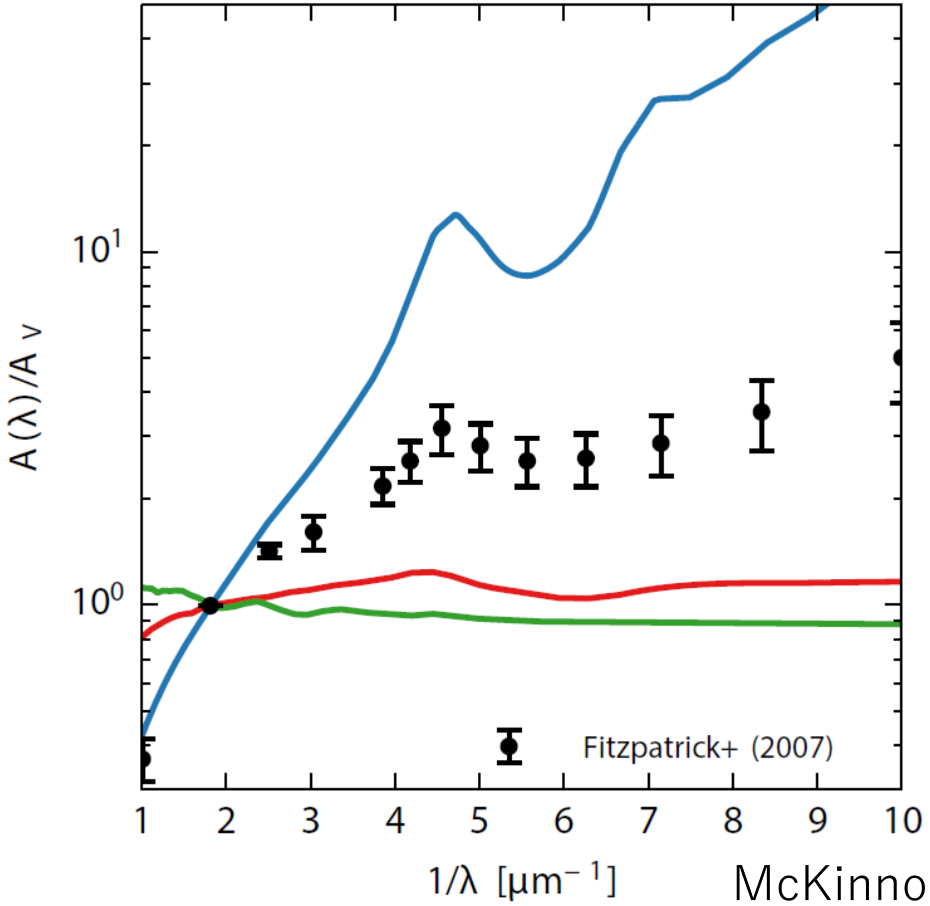
Hirashita & SA (19)



Full grain size distribution
(Asano+13b, 14, McKinnon+18, Hirashita & S. Aoyama 19)



- They firstly implemented the evolution of full size distribution into hydro-dynamical simulations (mesh).

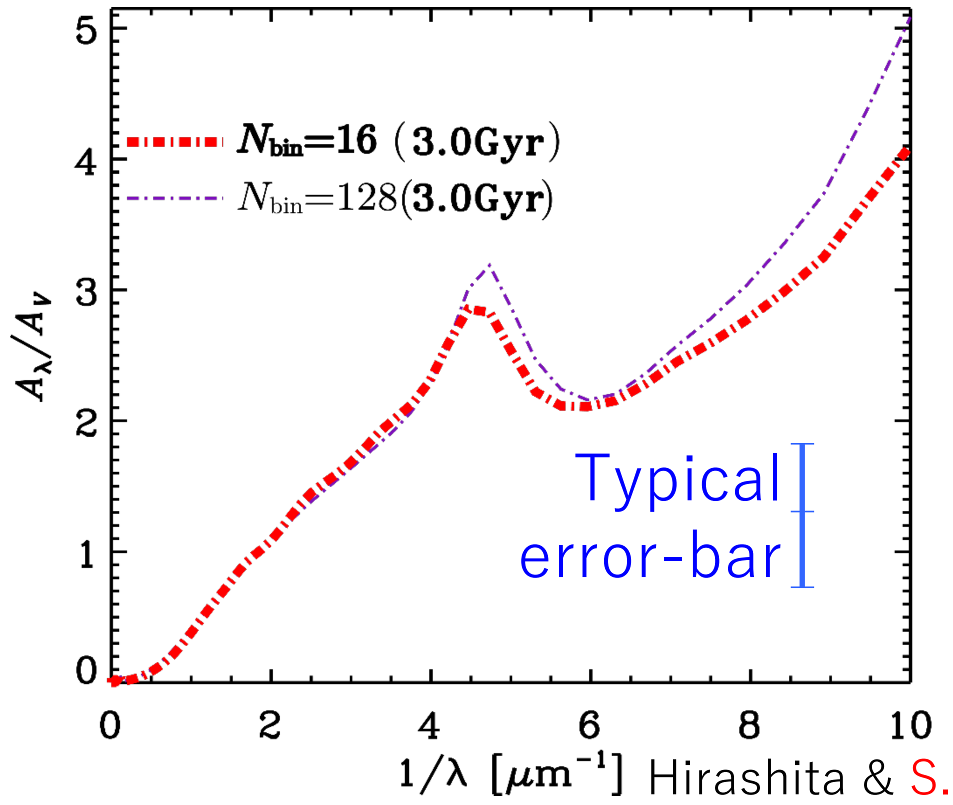


McKinnon et al. (2018)

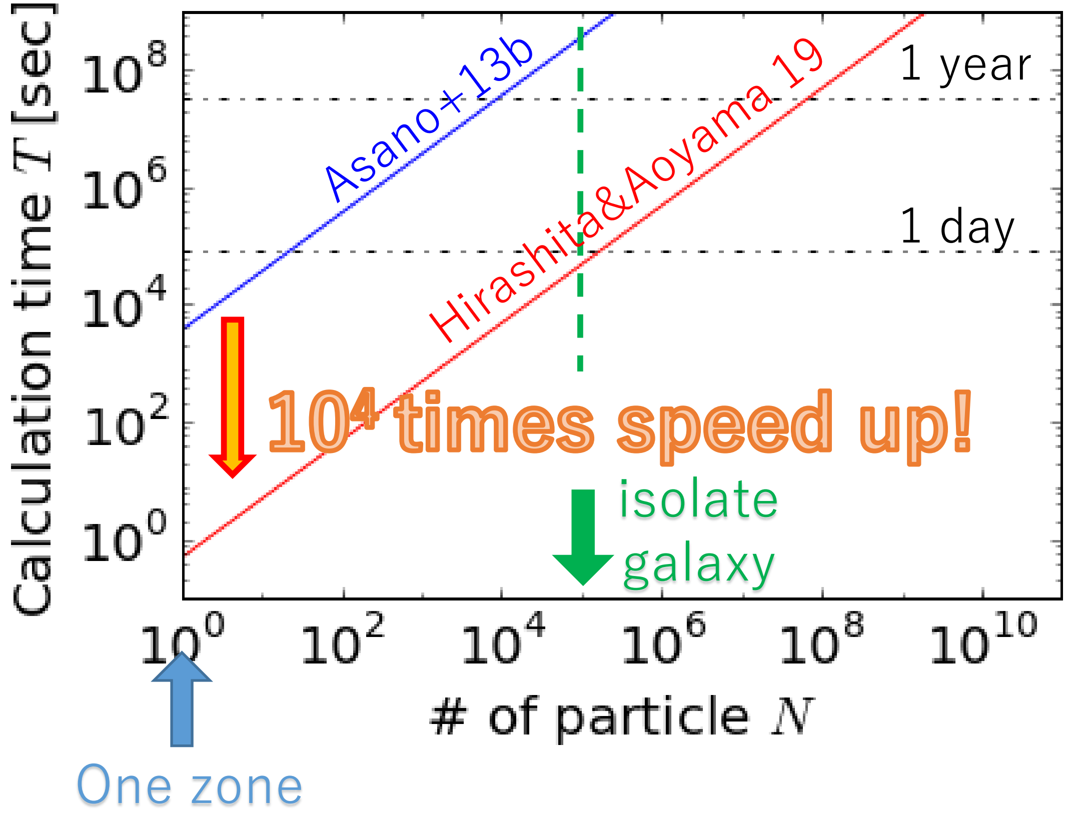
Calculation cost

- Our model works even in the simulations with 16 grid points. (Hirashita & S. Aoyama 2019)
- Remark $T_{cal} \propto N_{bin}^2$
- We use 32 grid points for describing grain size distribution.

Extinction curve of a MW-like galaxy



Hirashita & S. Aoyama (2019)



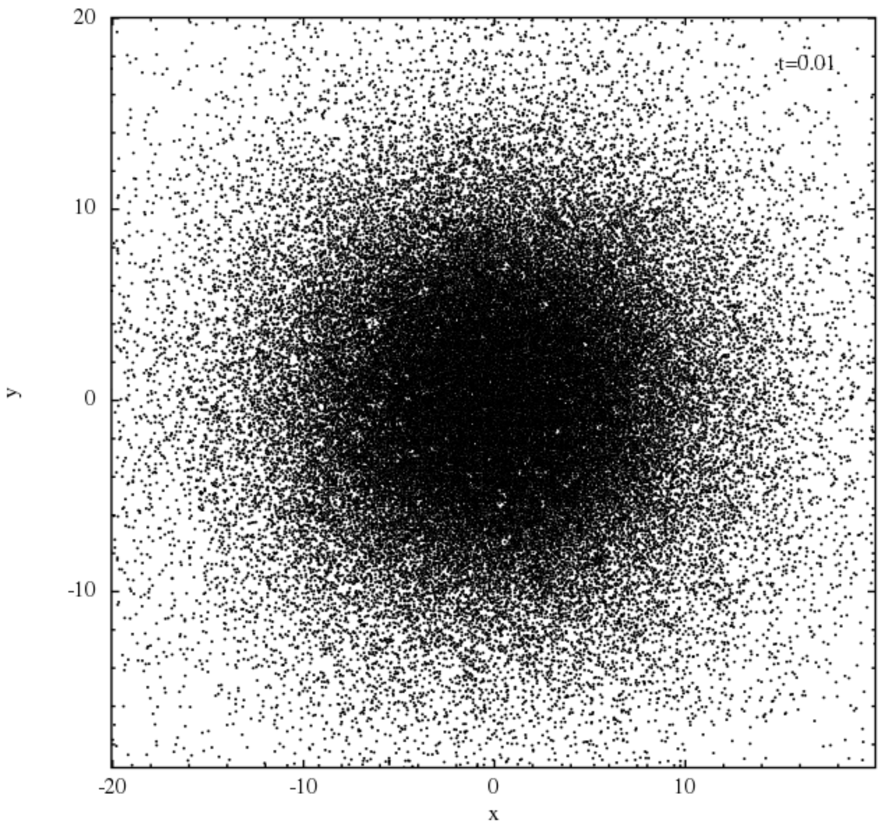
Simulation setup

- Dust module has been remodeled in Hirashita & S. Aoyama 19.
- The dust module is implemented into GADGET3-Osaka (Shimizu+19).
- We performed a simulations with an isolate spiral galaxy.

Initial condition (AGORA project; Kim+16)

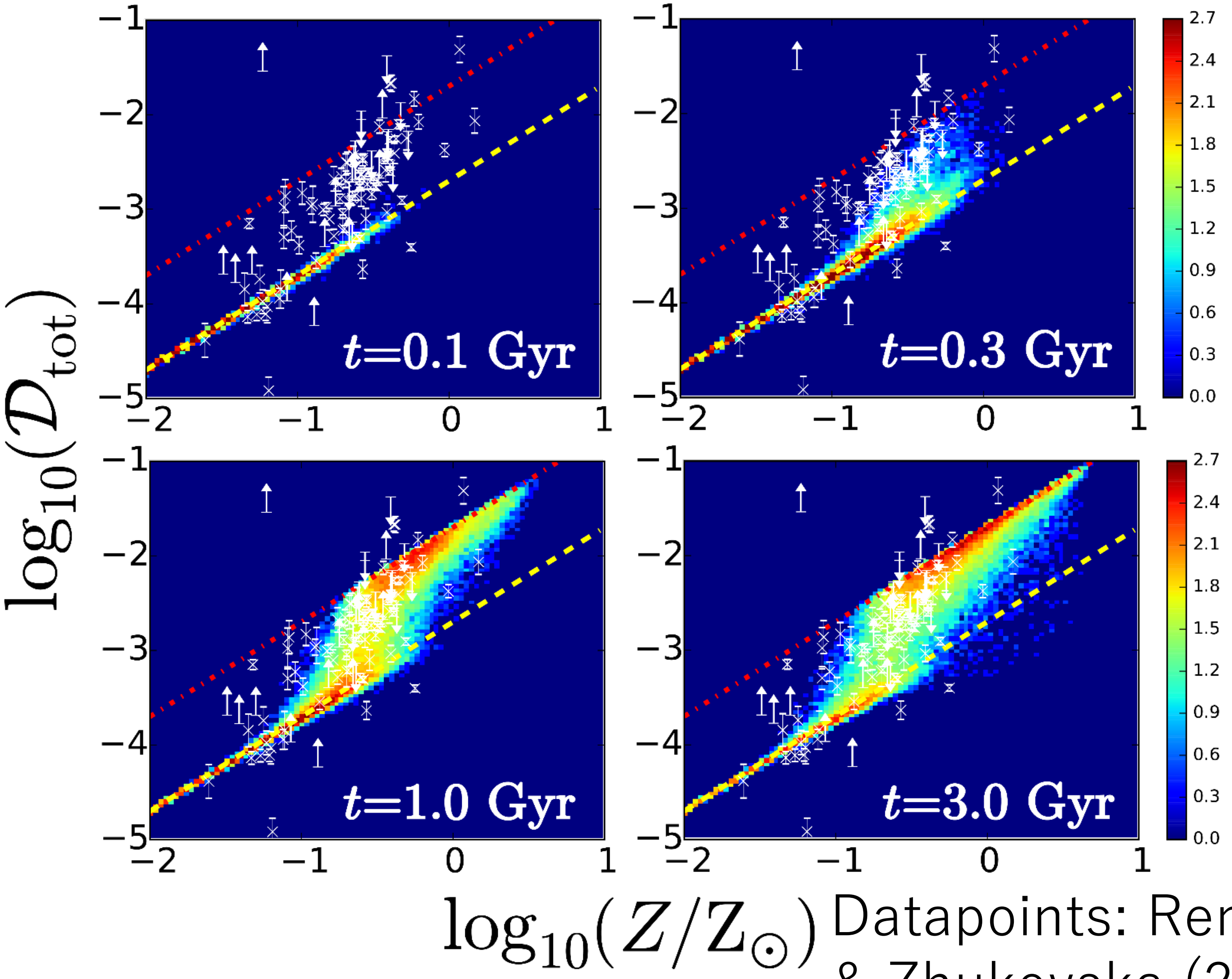
MW-like galaxy ($M_{tot} \sim 10^{12}\ M_{\odot}$)

- $N_{gas} = 10^5$
- $N_{dm} = 10^5$
- $m_{gas} = 8.59 \times 10^4\ M_{\odot}$
- $m_{dm} = 1.25 \times 10^7\ M_{\odot}$
- softening length $\varepsilon_{grav} = 80$ pc



Distribution of Gas particles

Time evolutions of dust-to-gas mass ratio

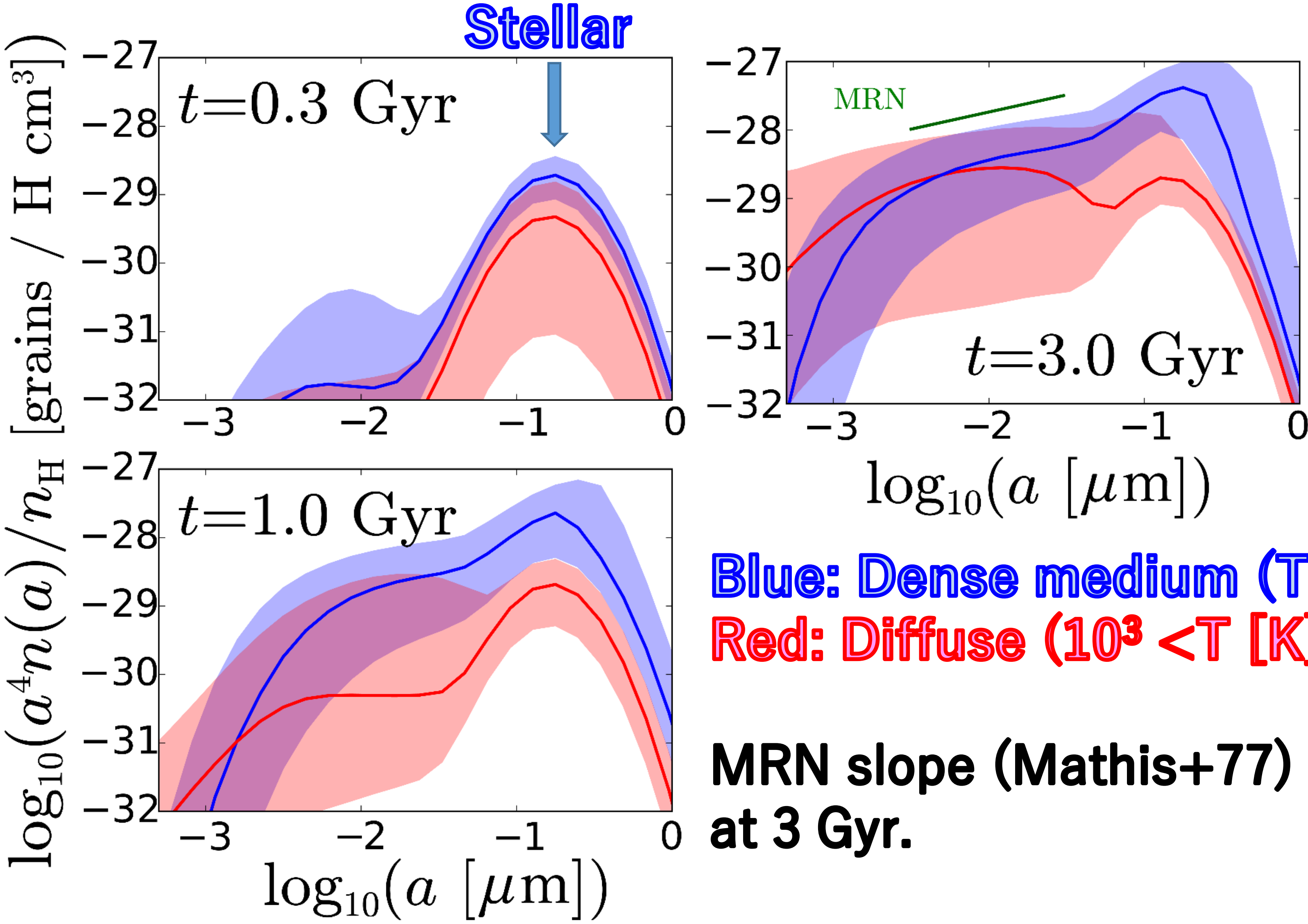


- t $\lesssim$ 0.3 Gyr, the stellar dust production ($D_{tot} = f_{in}Z$).
- t $\gtrsim$ 1 Gyr, asymptotically approaching to D_{tot} = Z. (Same trend of A17)

- S. Aoyama+17 over-predicts accretion at metallicity Z< 0.1 $Z_\odot$. (Different trend of A17) a risk in the two-size distribution

Datapoints: Remy-Ruyer et al.(2014) & Zhukovska (2014)

Time evolutions of size distribution of grains

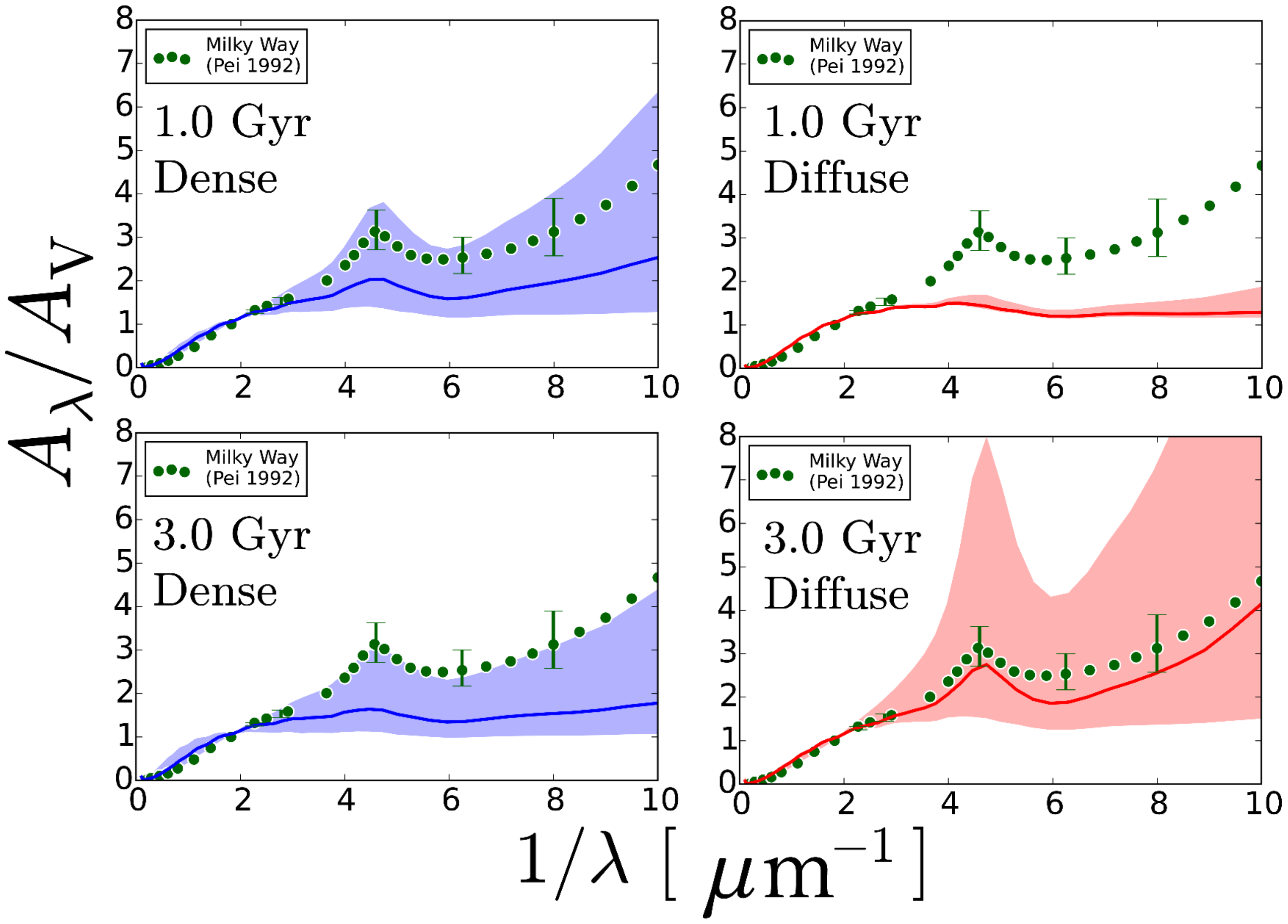


Blue: Dense medium (T<10^3 K & n > 10 cm^{-3})

Red: Diffuse (10^3 <T [K] < 10^4 K & 0.1 < n[cm^{-3}] < 1)

MRN slope (Mathis+77) is realized in dense medium at 3 Gyr.

Time evolutions of extinction curves



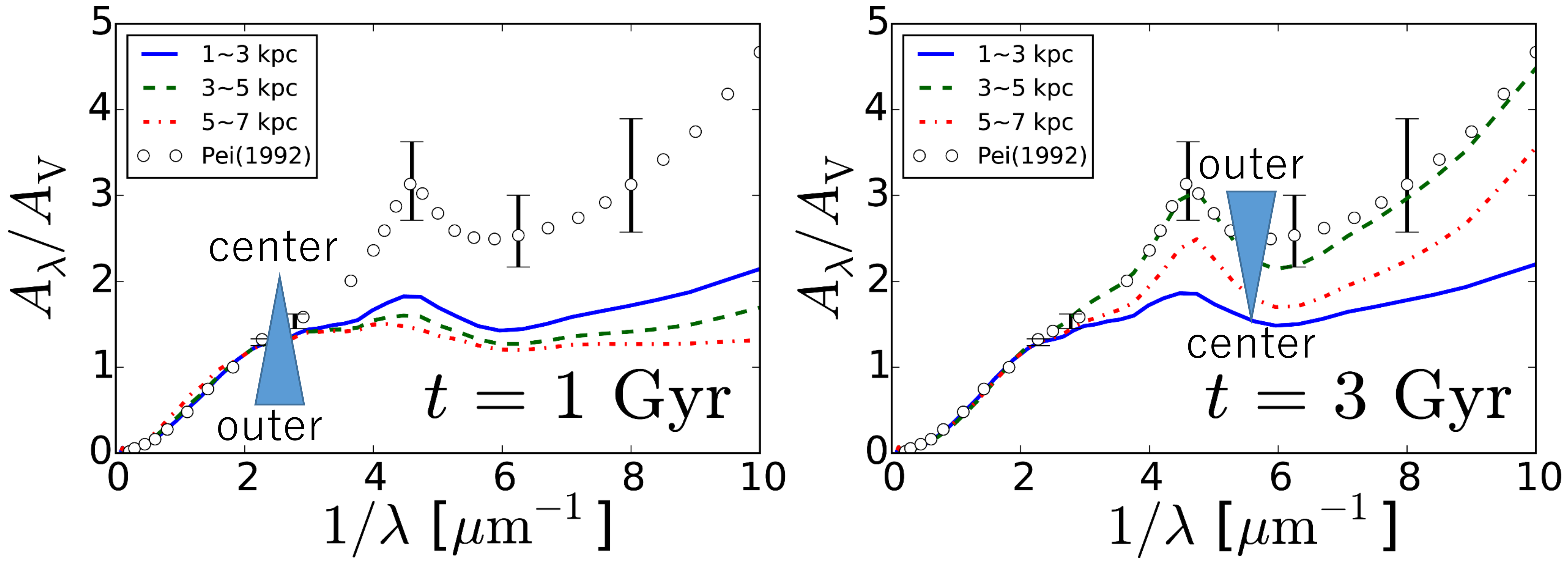
The median in the diffuse medium ($t = 3$ Gyr) broadly explains the Milky Way extinction curve (Pei 1992).

It suggests that there are massive galaxies at z=2 ($t_{age} \simeq 3$Gyr) that have a Milky-Way-like extinction.

Radial dependence of extinction curves

The trend of the radial dependence of extinction curve is the same as a previous work (Hou et al. 17)

Extinction curve at 3 kpc < R < 5 kpc at 3 Gyr is responsible for observational one (Pei 1992).



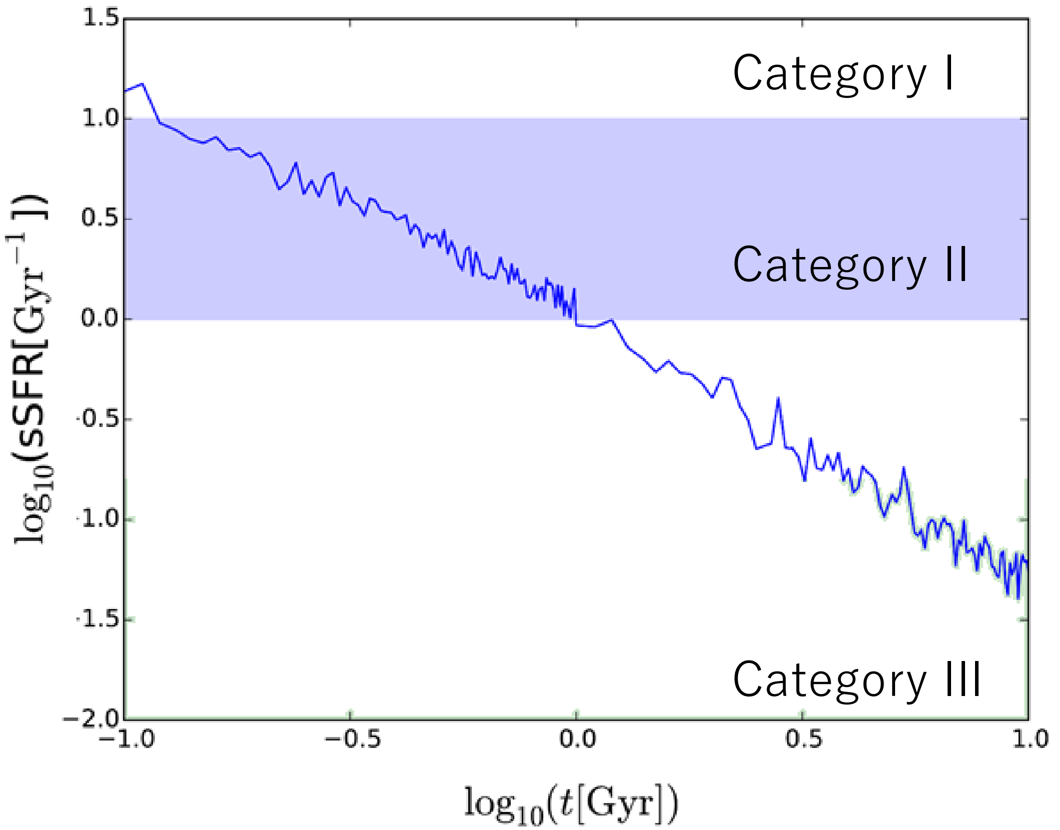
Comparison with observations:

Categorization of galaxies

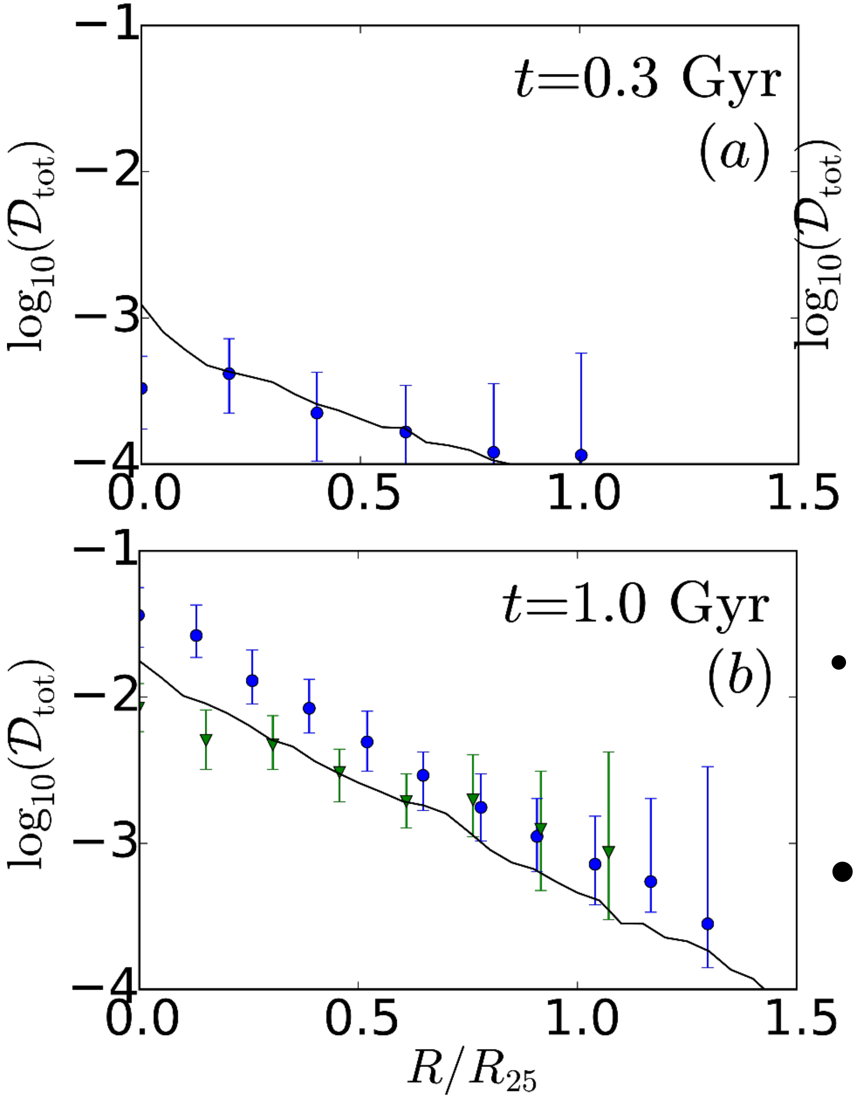
sSFR	Category
10 Gyr^{-1} < sSFR	I
1 Gyr^{-1} < sSFR < 10 Gyr^{-1}	II
sSFR < 1 Gyr^{-1}	III

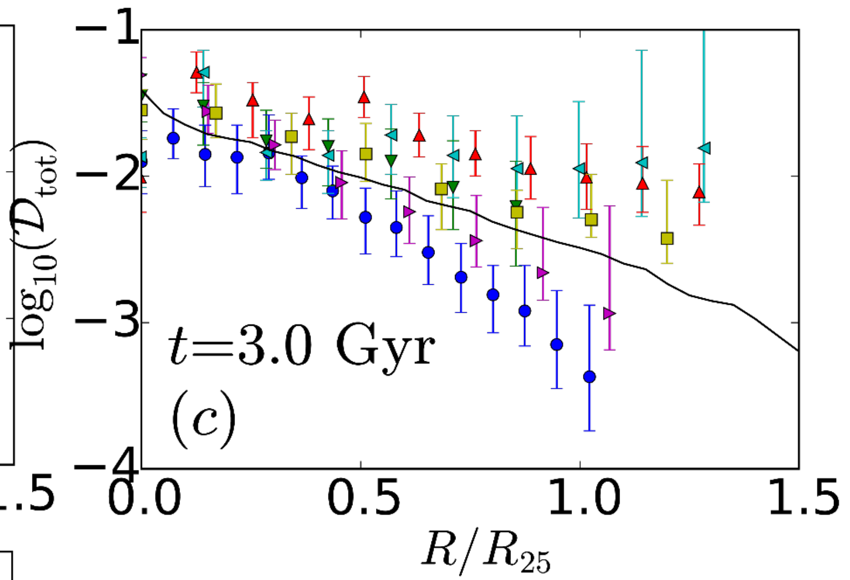
$$\mathrm{sSFR} = \frac{\mathrm{SFR}}{M_*} \quad [\mathrm{Gyr}^{-1}]$$

Galaxy	m_* $[10^9 \mathrm{M}_\odot]$	ψ $[\mathrm{M}_\odot/\mathrm{yr}]$	sSFR $[\mathrm{Gyr}^{-1}]$	Category
HolmbergII	0.20 (1)	6.61 (1)	33.128 (1)	I
NGC925	7.94 (1)	10.72 (1)	1.350 (1)	II
NGC3621	58.88 (2)	125.89 (3)	2.138	II
NGC628	12.59 (1)	9.77 (1)	0.776 (1)	III
NGC2403	2.14 (4)	1.74 (4)	0.813 (4)	III
NGC4736	19.95 (1)	7.76 (1)	0.389 (1)	III
NGC5055	63.10 (1)	11.75 (1)	0.186 (1)	III
NGC5194	39.81 (1)	7.76 (1)	0.195 (1)	III
NGC7793	3.39 (2)	3.16 (3)	0.933	III



Radial profile of the dust-to-gas ratio



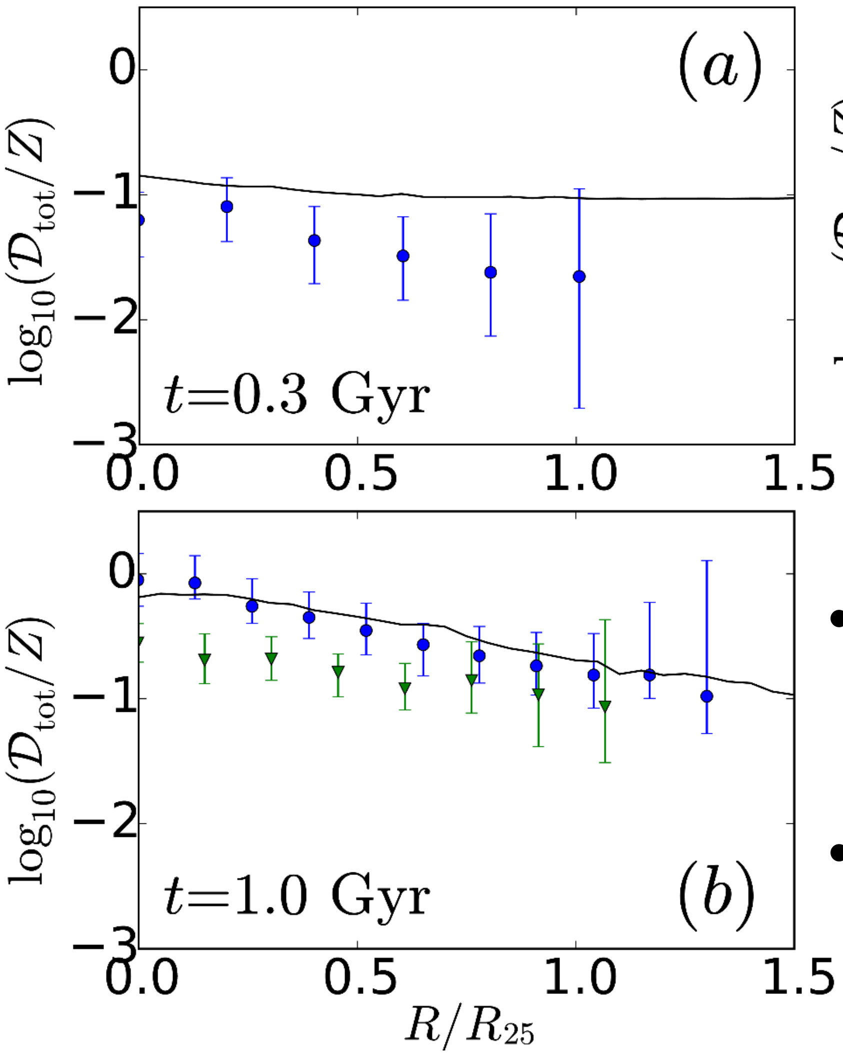


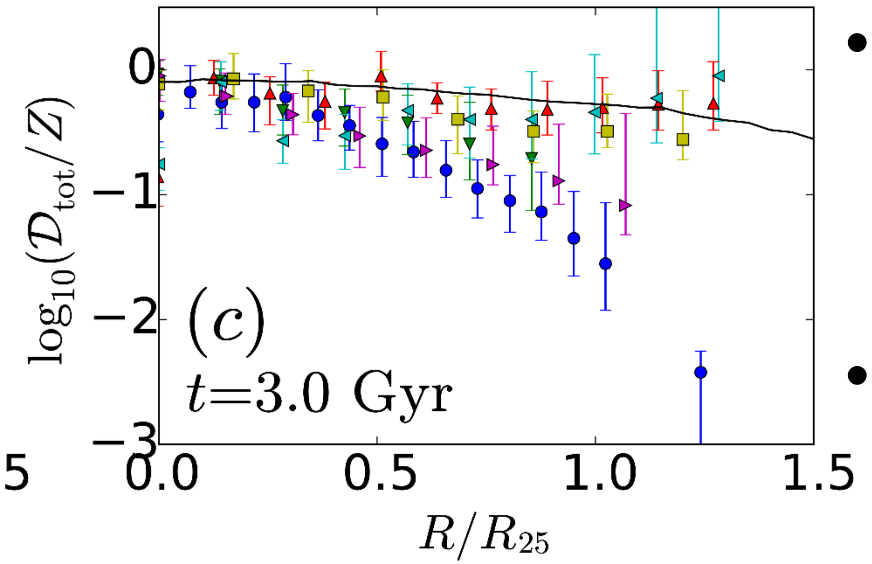
We can explain a typical galaxy's behavior.
-> not only dust size but also dust transport is also solved similarly as observational ones.

- R_{25} : the radius at which surface brightness falls to 25 mag arcsec^{-2}
- $R_{25} \simeq 4\ R_*$ (Elmegreen 1998) $\simeq 7$ kpc (in this simulation)

Datapoints: Mattsson & Andersen (2012)

Radial profile of the dust-to-metal ratio

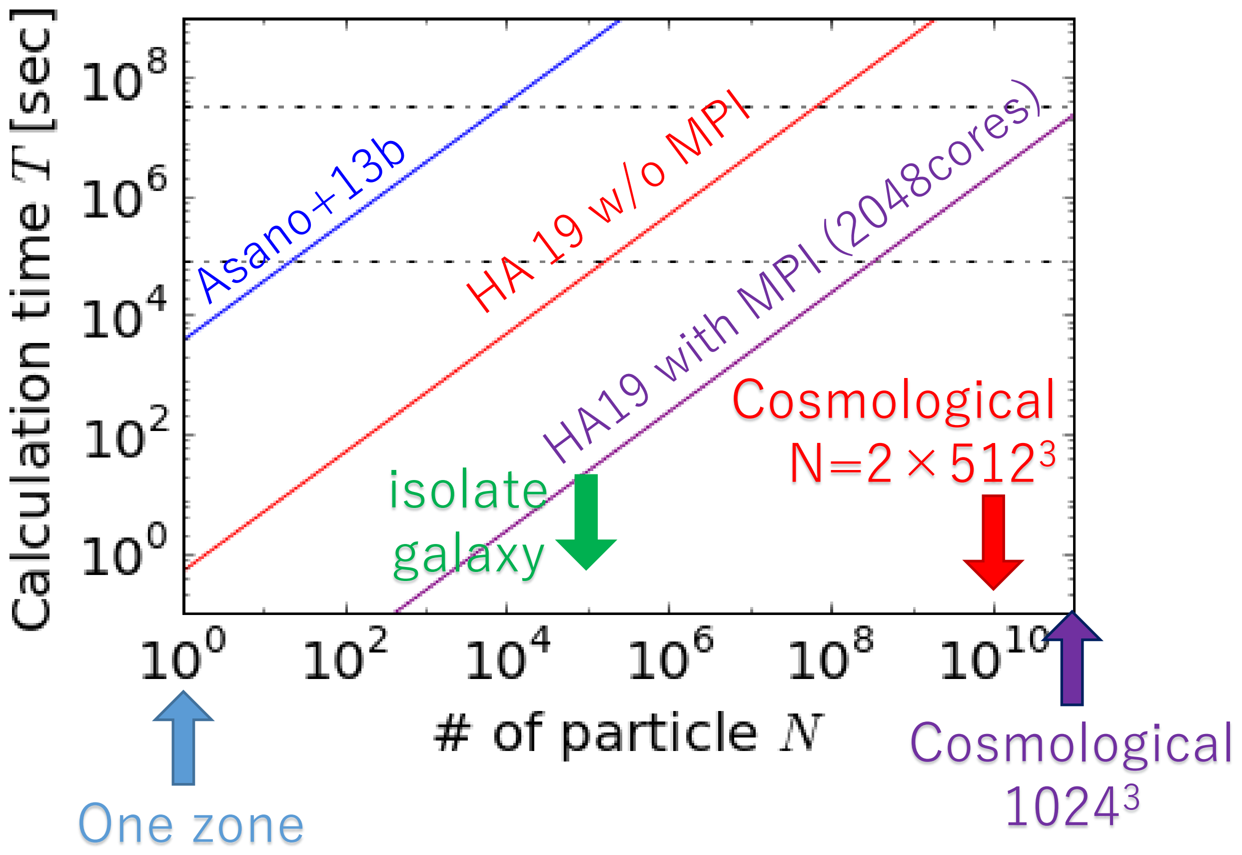




- Broadly consistent with the observational data t=1 Gyr.
- Over-prediction dust-to-metal at large radii because the effect of accretion to larger radii at t= 3Gyr.

- R_{25} : the radius at which surface brightness falls to 25 mag arcsec^{-2}
- $R_{25} \simeq 4\ R_*$ (Elmegreen 1998) $\simeq$ 7 kpc (in this simulation)

Future prospect: Cosmological simulations



Summary

- We have implemented full size distribution into SPH simulations and investigated spatially resolved evolution.
- We reproduced observational results (extinction curves, radial distribution of D_{tot})
- Many of results based on the two-size approximation can be justified based on full size distribution treatments.
- Extinction curves similar to Milky Way can be found in $z \simeq 2$ Universe.
- However risks for adopting two-size approx. are also found.