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東北大学

ダスト形成を考慮した孤立系銀河シミュレーションと観測量との比較

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SA *et al*. to be submitted.
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Introduction: cosmic dust (dust)

- Dust consists of heavy elements such as carbon and silicate, floating in the interstellar medium.

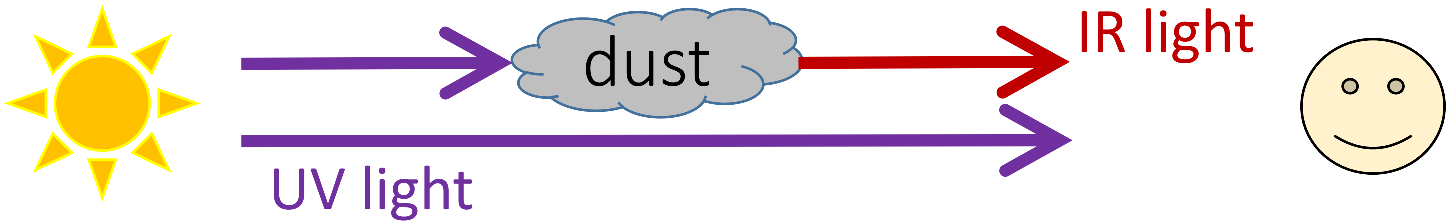
- It is generated in the nucleosynthesis of heavy elements at the end of the massive stars.

http://www.drcom.co.jp/blog/wp-content/uploads/2013/12/zz3.png

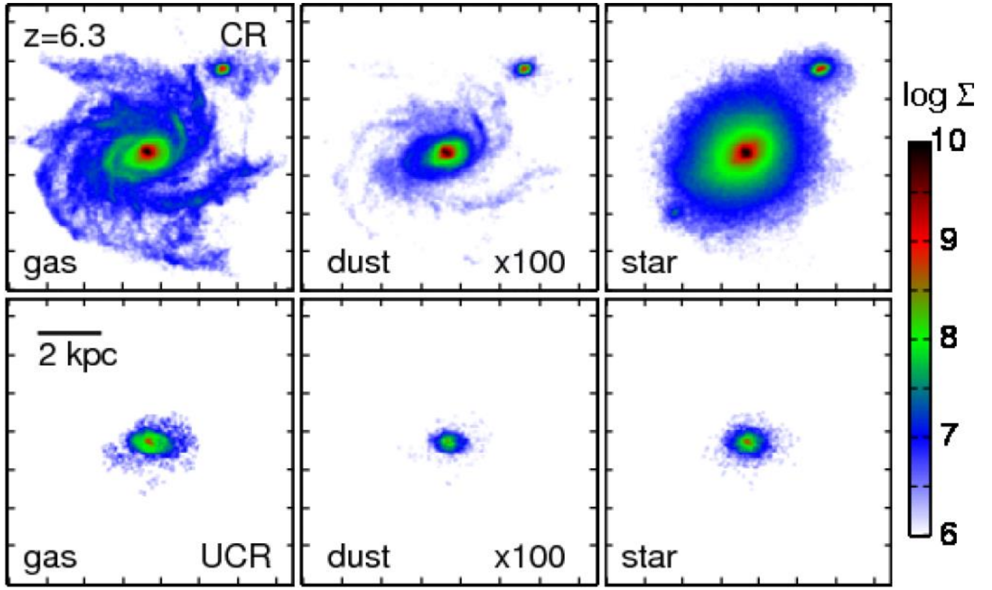
- Dust plays important role in ISM as follows:

1. Highly efficient catalyst of H_2 formation, necessary for star formation.

2. Absorption of the UV light and reemitting in the infrared (IR).



Introduction: previous works



Yajima et al (2015) [1411.2626]

- Yajima et al.(2015) *MNRAS*, **451**, 418

Cosmological zoom-in simulation(z=199→6)

Radiation transfer is calculated with dust.

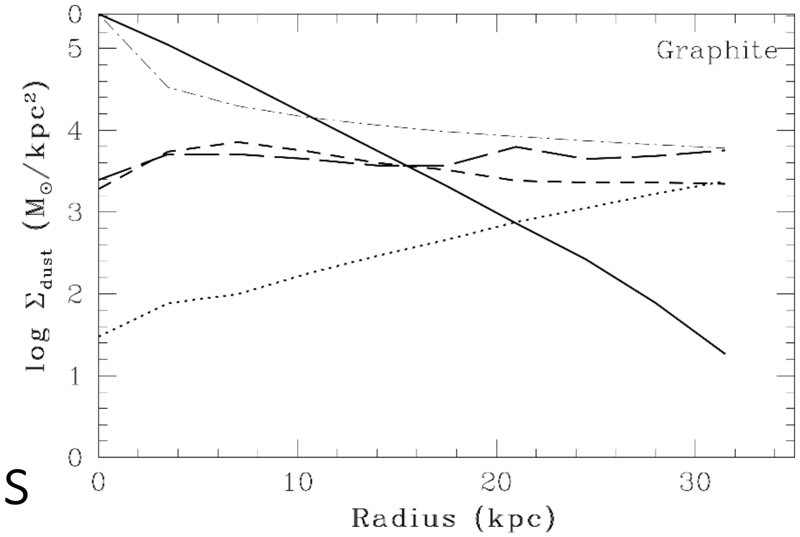
Constant dust-to-metal mass ratio.

- Bekki (2015) *MNRAS*, **449**, 1625

Dust **particles** are included in SPH simulation.

The formation, growth, and destruction
by AGB stars, supernovae (SNe) and ISM are included.

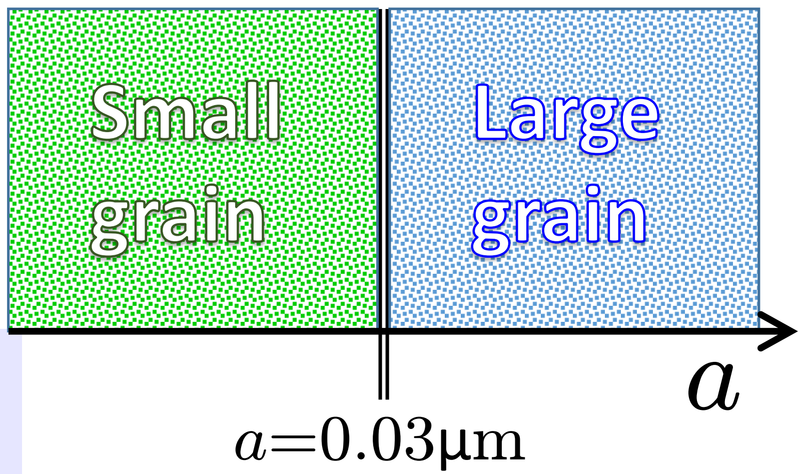
Some of interactions of dust (coagulation, shattering) has not been included yet.



Bekki (2015) [1501.05459]

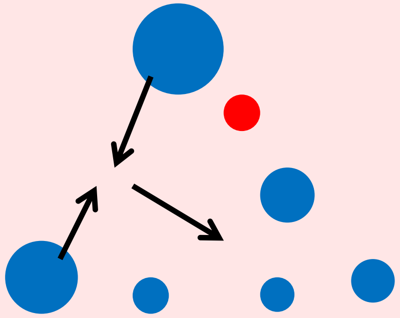
Hirashita (2015) 2-component model [*MNRAS*, **447**, 2937]

Hirashita categorizes dusts into two sizes:
large / small dusts
(a > 0.03μm , a < 0.03μm).

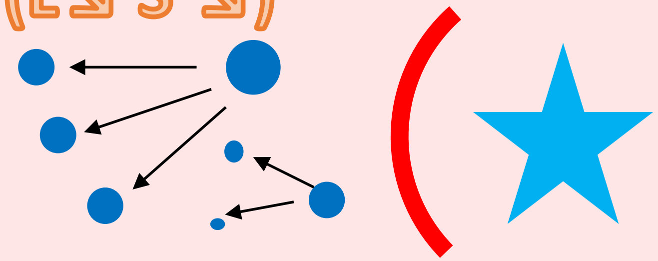


- Shattering (L↘ S↗)

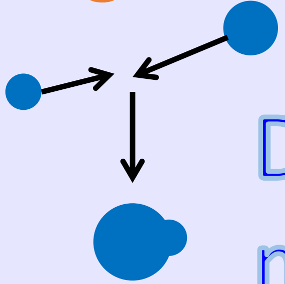
Diffuse medium



- Shock waves from SNe (L↘ S ↘)

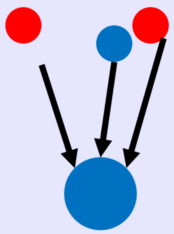


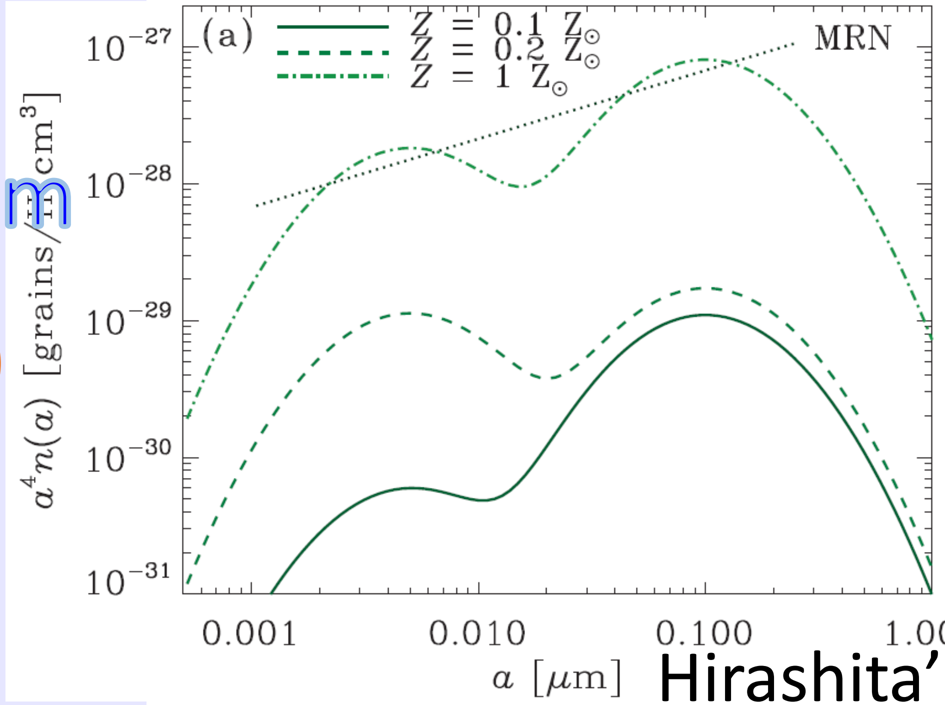
- Coagulation (L↗ S↘)



Dense medium

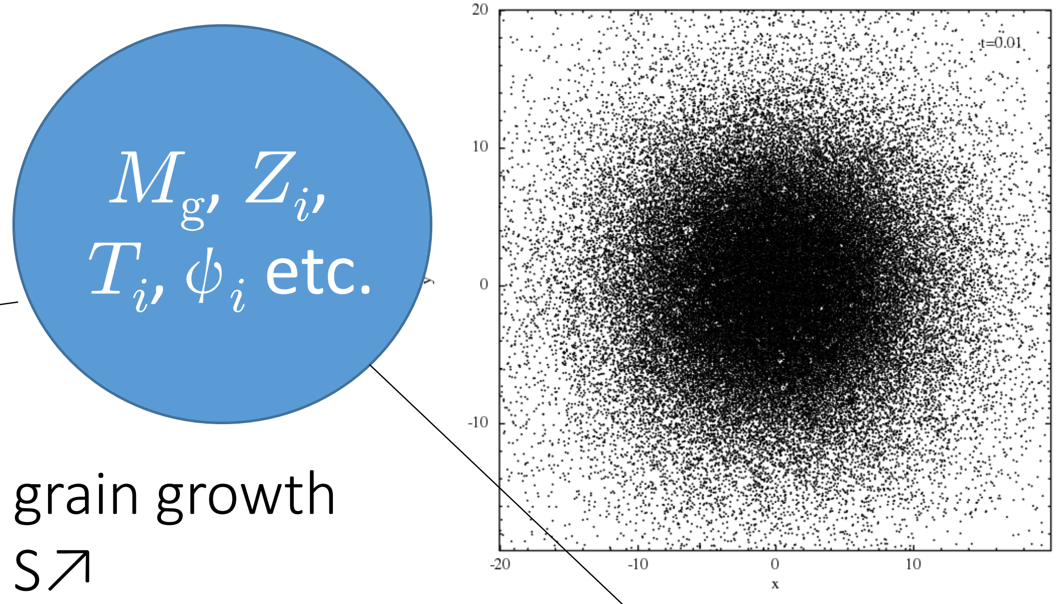
- Accretion (S↗)





Hirashita'15

In this work, we use
the **GADGET3-Osaka** SPH code
(Springel '05 + modification).



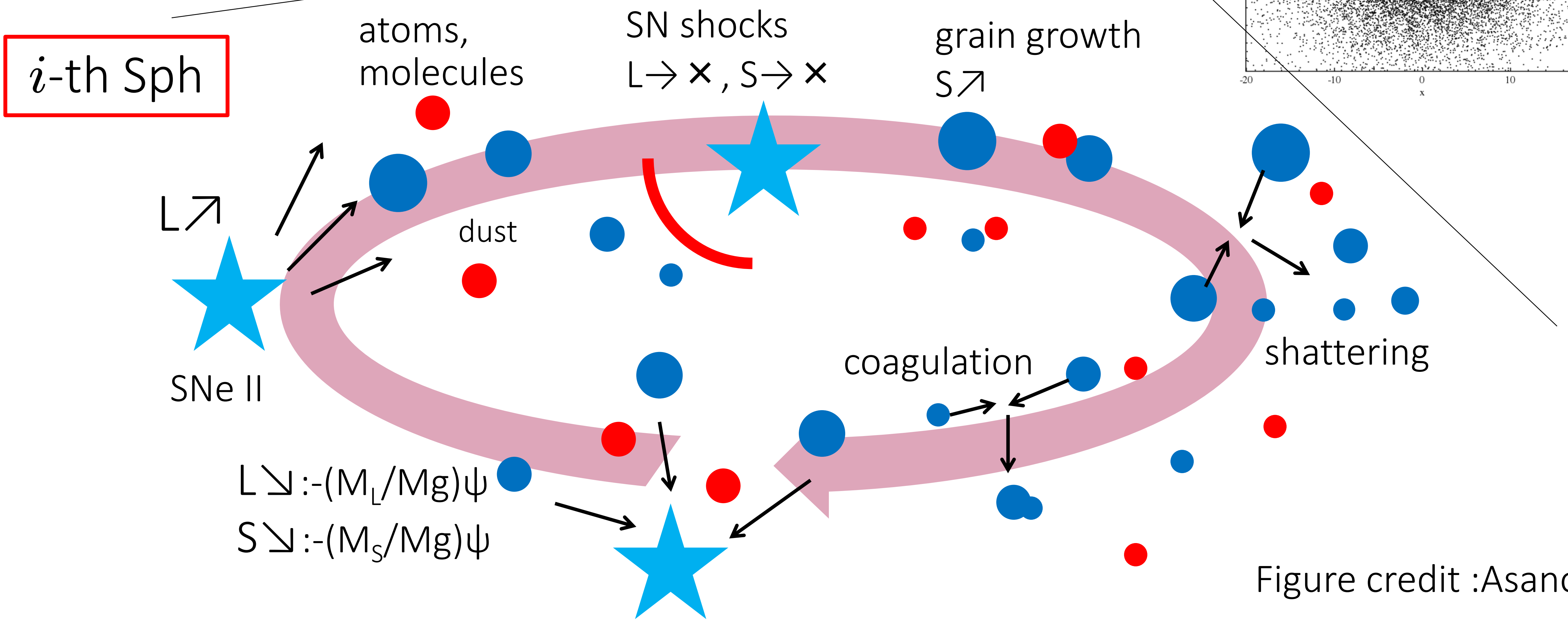
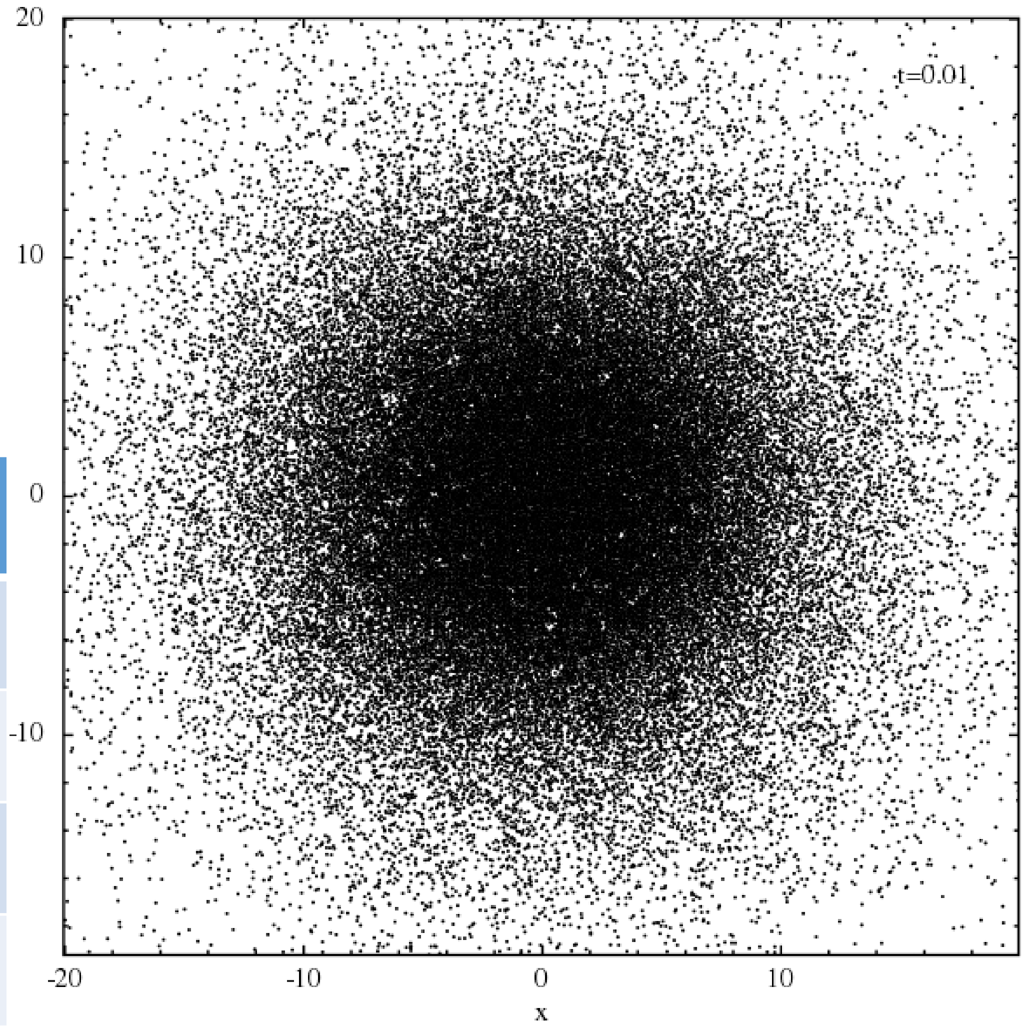


Figure credit :Asano

Initial condition

- AGORA initial condition (Kim et al. 2014)
- M_{gas}=8.6 × 10^9 $M_\odot$
- N_{gas} =10^5

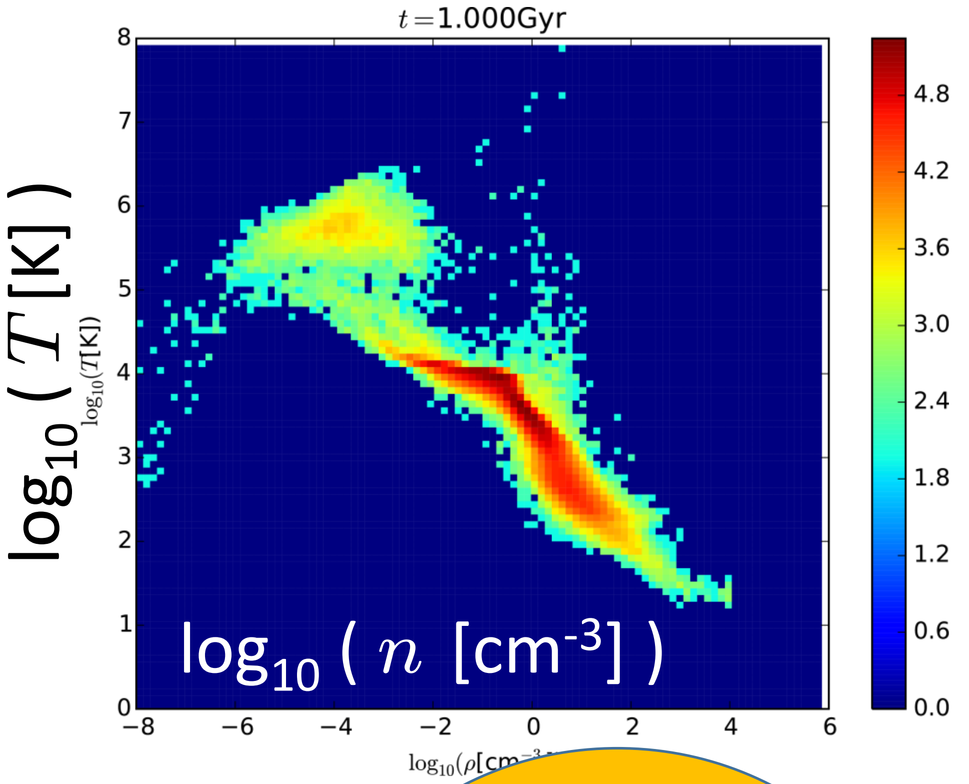
Type	Total Mass	# of particles
Gas	8.6 × 10^9 $M_\odot$	10^5
Halo	1.3 × 10^{12} $M_\odot$	10^5
Disk	4.3 × 10^{10} $M_\odot$	10^5
Bulge	5.4 × 10^9 $M_\odot$	1.25 × 10^4
Stars	0	0



Distribution of Gas particles

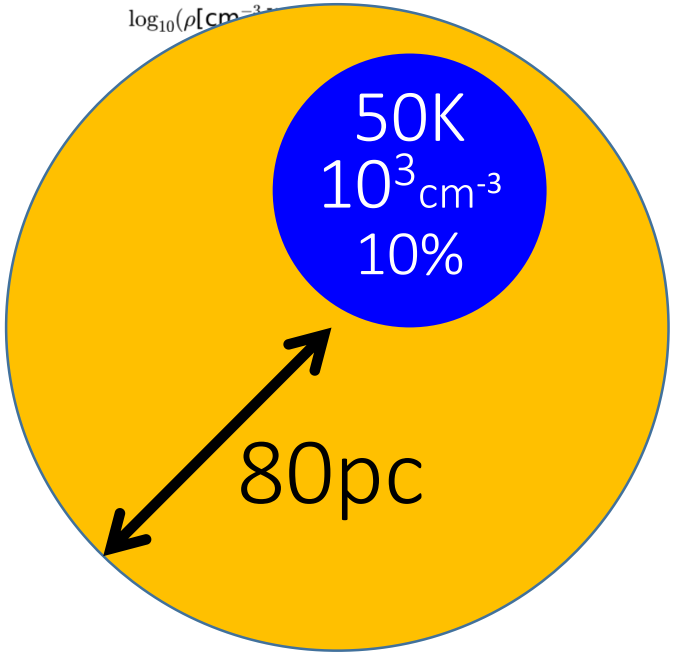
Sub-grid model for accretion

- Resolution of our simulation (~ 80pc) is too low to treat the physical processes in molecular clouds (*e.g.* accretion).
- We assume that the 10% of mass of SPH particles is molecular clouds with T=50K and n=10^3 cm^{-3}.
- In addition, the accretion occurs only in this molecular cloud.



$$\tau_a = 2.1 \times 10^7 \left(\frac{Z}{Z_\odot}\right)^{-1} \left(\frac{a}{0.1\mu m}\right) \times \left(\frac{T_{\rm cloud}}{50{\rm K}}\right)^{-1/2} \left(\frac{n_{\rm cloud}}{10^3{\rm cm}^{-3}}\right)^{-1} \left(\frac{S}{0.3}\right) \ [{\rm yr}],$$

Hirashita (2015)
Hirashita&Kuo(2011)
[1105.4930]



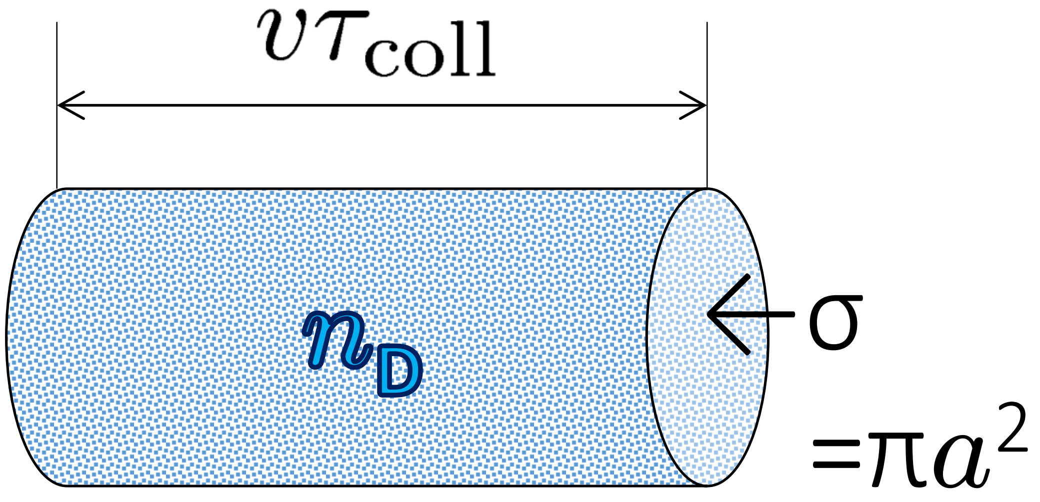
Sub-grid model for collisional processes

- Coagulation / shattering [collision]

$$n_{\rm D}\sigma v\tau_{\rm coll} = 1$$

$$\tau_{\rm coll} = (n_{\rm D}\sigma v)^{-1}$$

$$n_{\rm D} = \frac{\mathcal{D}\mu m_{\rm H}}{\frac{4}{3}\pi a^3 s}$$



$$= 5.408\times 10^7\,{\rm yr}\left(\frac{a}{0.1\ \mu{\rm m}}\right)\left(\frac{v}{10\ {\rm km\ s^{-1}}}\right)^{-1}$$

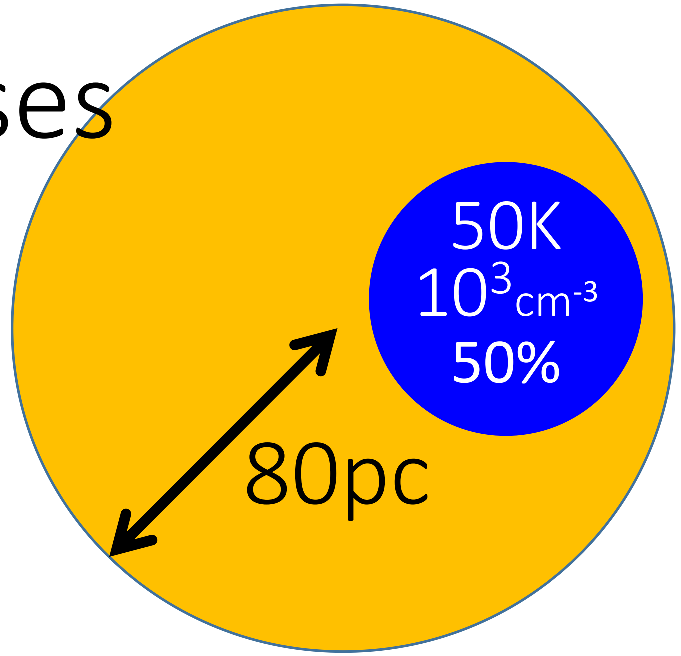
$$\times\left(\frac{\mathcal{D}}{0.01}\right)^{-1}\left(\frac{n_{\rm H}}{1\ {\rm cm^{-3}}}\right)^{-1}$$

We fix the velocity to 10 km/sec.

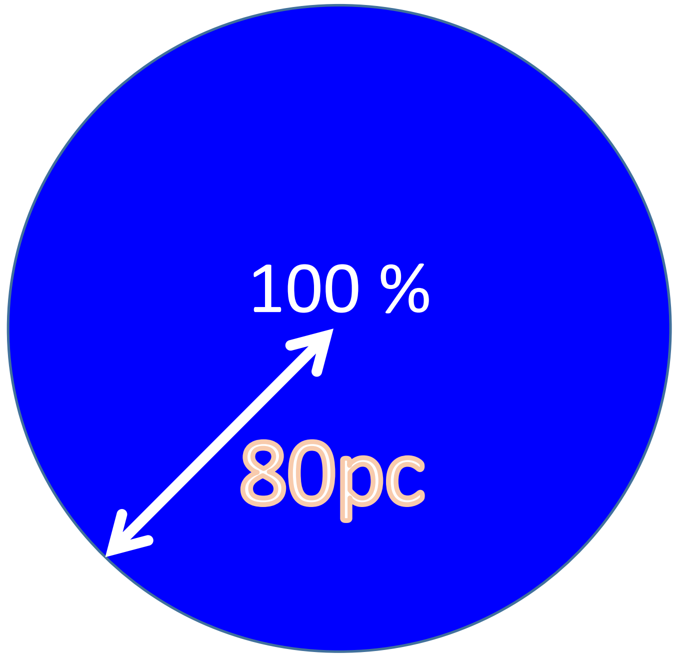
process	Dust species	representative radius
coagulation	Small	0.005 μm
shuttering	Large	0.1 μm

Sub-grid model for collisional processes

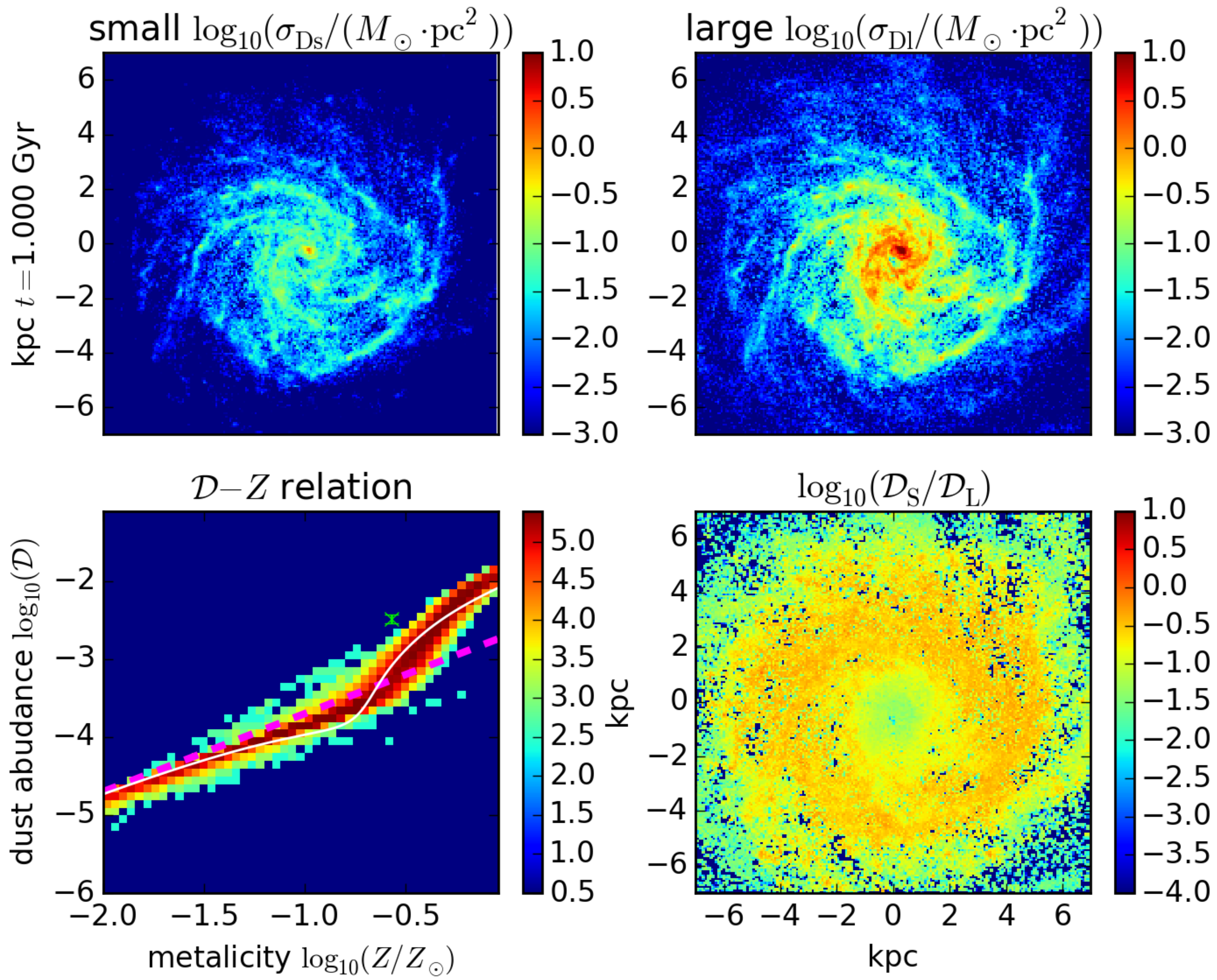
- Shattering (significant only in diffuse gas)
  $n_{Sph} < 1\ cc^{-1}$: $\tau = \tau_{coll(L)}$
  $n_{Sph} > 1\ cc^{-1}$: $\tau = \infty$ [No reaction]



- Coagulation (significant only in dense medium)
  $T_{Sph} > 100$ K : $\tau = 0.5 \times \tau_{coll(S)}(n{=}10^3\ cc^{-1}, T{=}50\ K)$
  $T_{Sph} < 100$ K : $\tau = \tau_{coll(S)}(n_{SPH}, T_{SPH})$



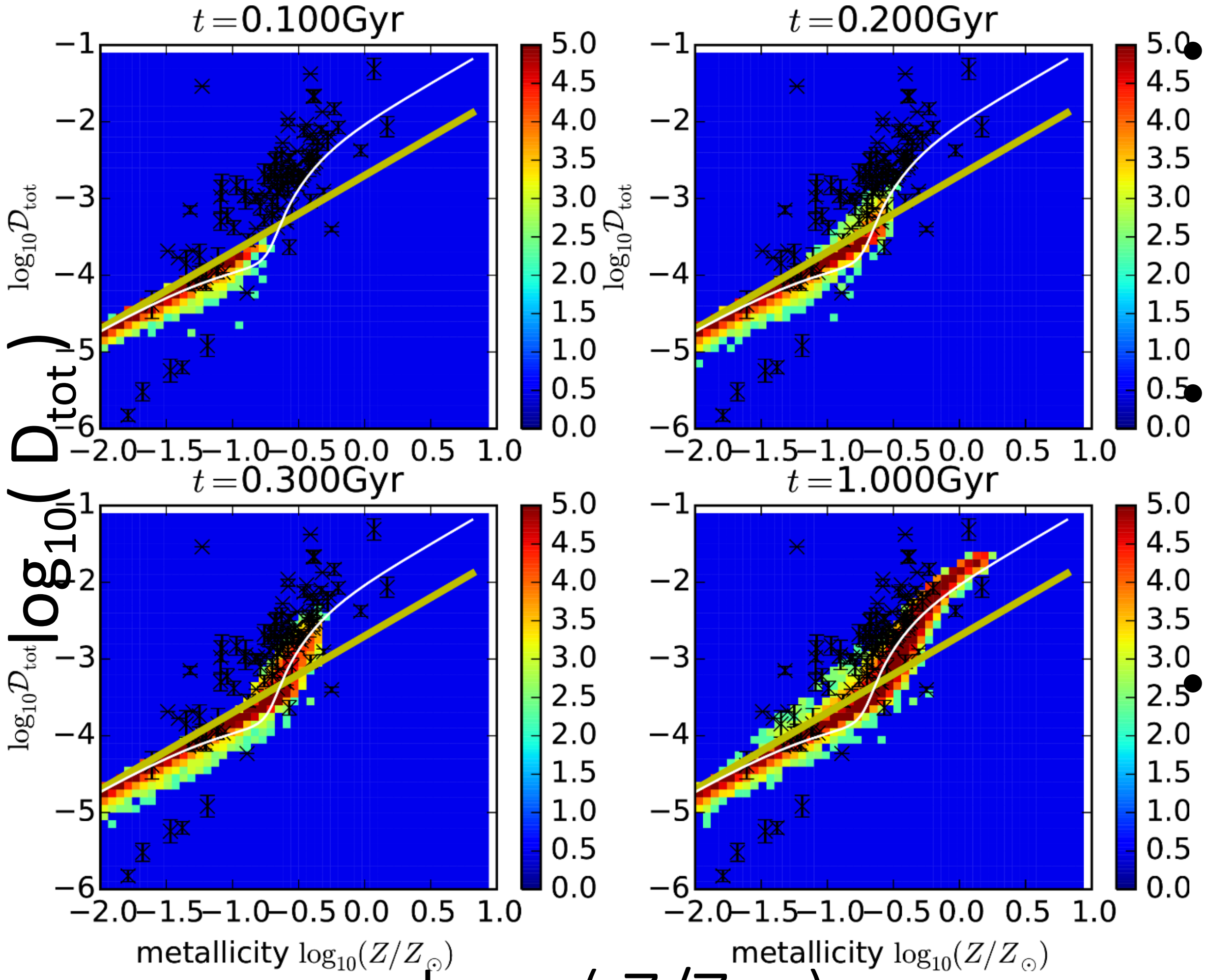
Small/Large dust distribution (z-projection map)



We redistribute dust and metal to neighboring SPH particles with the Kernel weight at each time step.

Data points:
Remy-Ruyer et al. (2014) A&A, 563, A31

Total dust-to-gas ratio vs metallicity



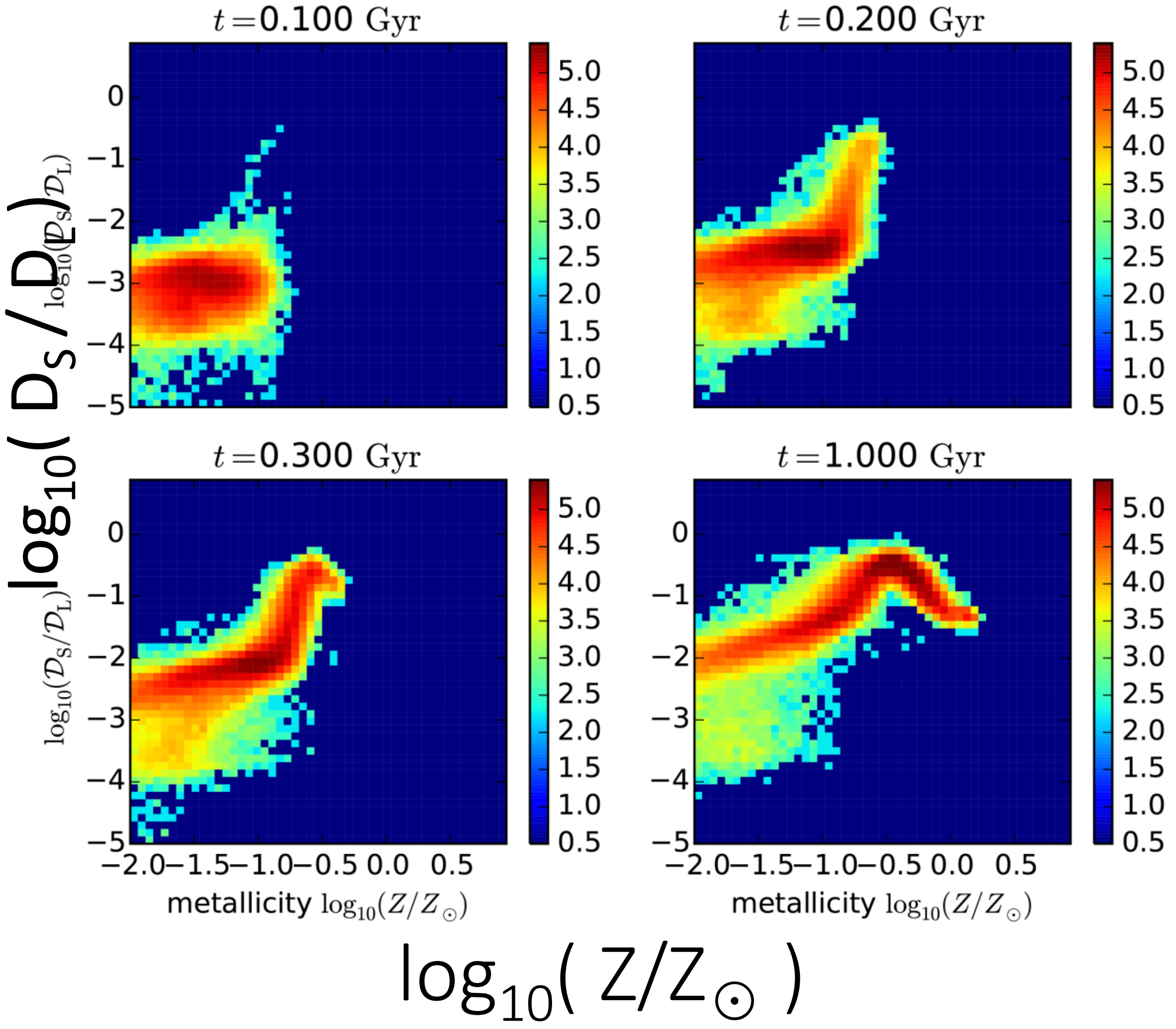
$\log_{10}(Z/Z_{\odot})$

Data points:

Remy-Ruyer et al. (2014) A&A, 563, A31

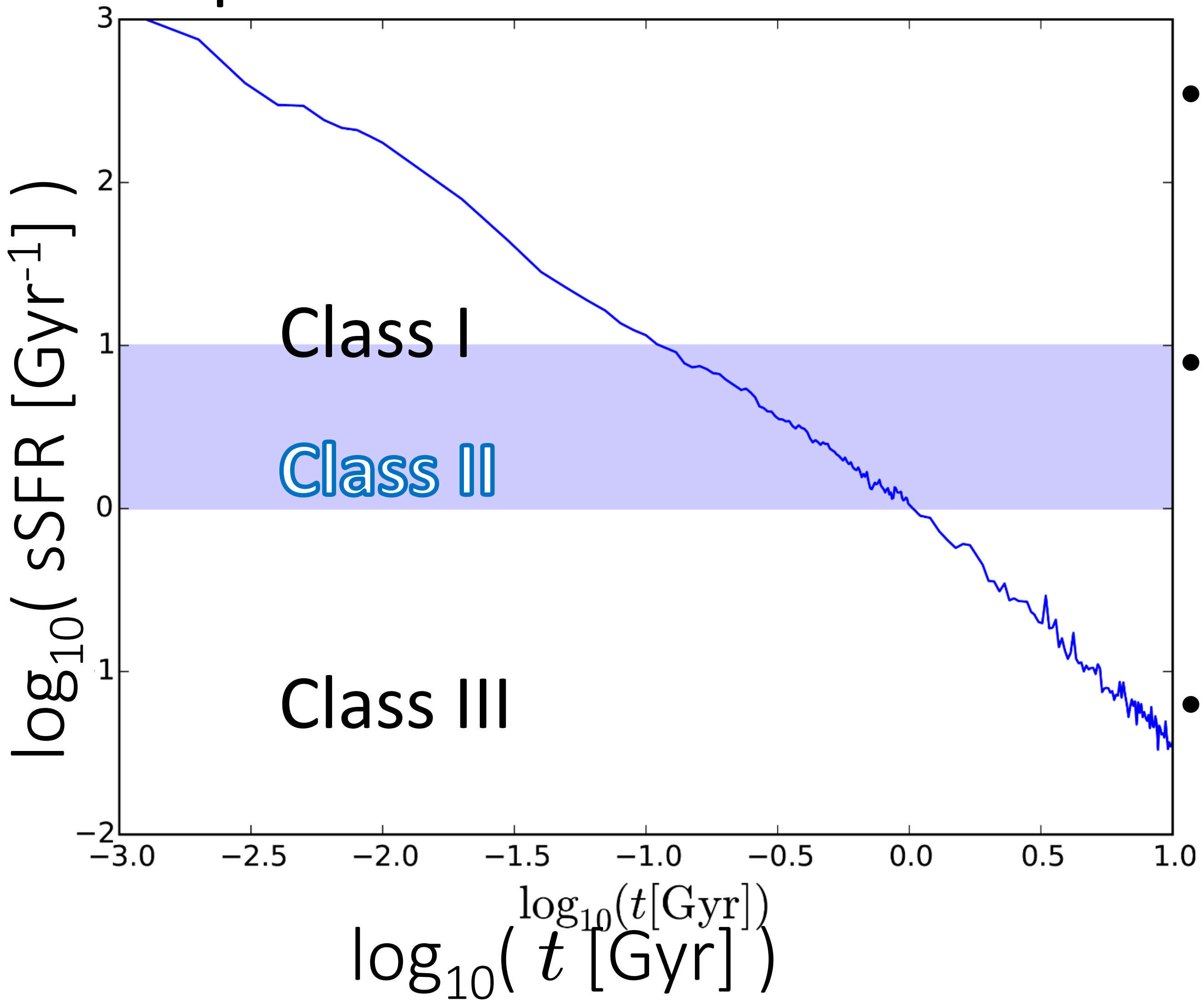
- t $\lesssim$ 0.2 Gyr, Dtot $\propto$ Z, $i.e.$ fixed dust-to-metal mass ratio is good approximation.
- T $\gtrsim$ 0.2 Gyr, accretion becomes significant and the previous approx. is no longer valid.
- T $\gtrsim$ 1.0 Gyr, coagulation and shattering is in balance. Many data points can be explained by this snapshot.

Small to large grain ratio vs metallicity



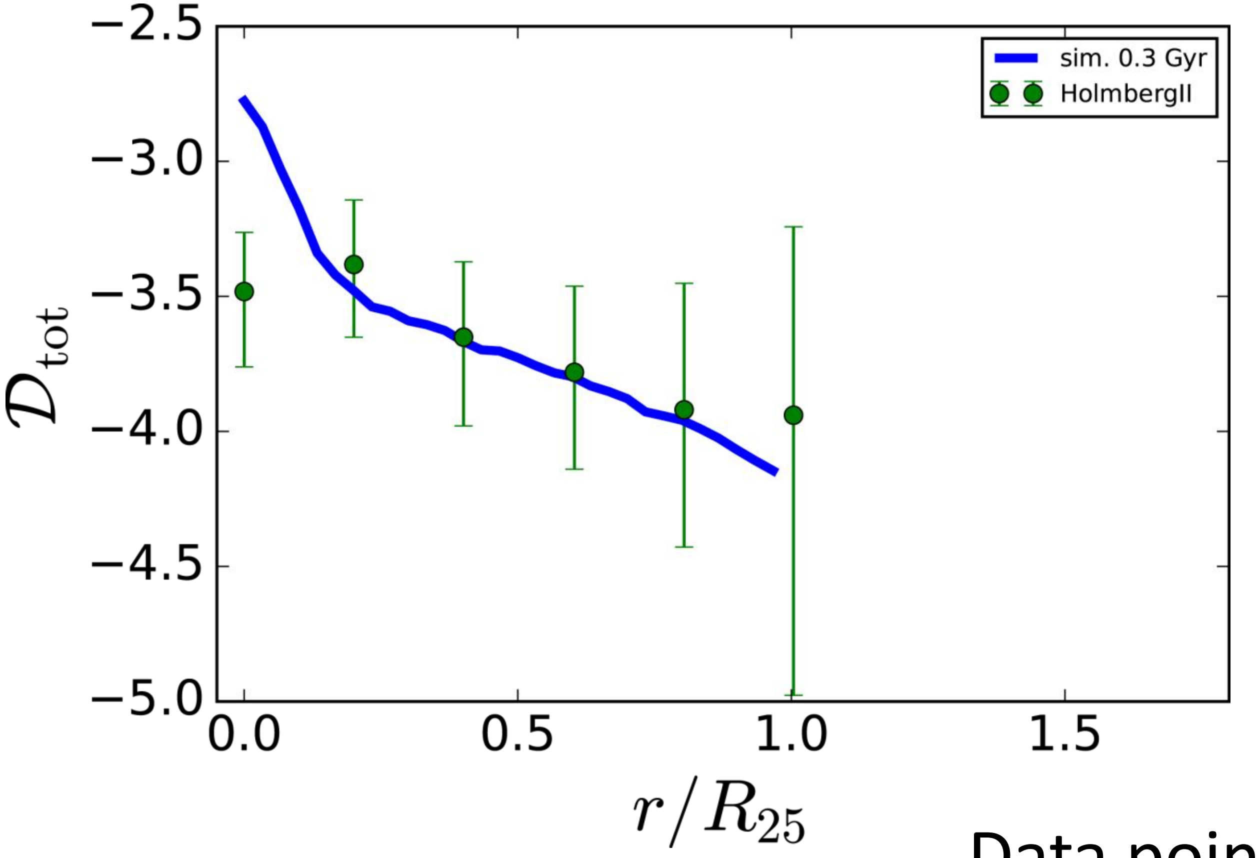
- t $\lesssim$ 0.1 Gyr, small grain is only created via shattering and the abundance is small.
- t ~ 0.2 Gyr, accretion comes in, and small grain abundance dramatically increase due to accretion.
- t $\gtrsim$ 1.0 Gyr, coagulation and shattering is in balance, and the small abundance is suppressed due to coagulation (S -> L).

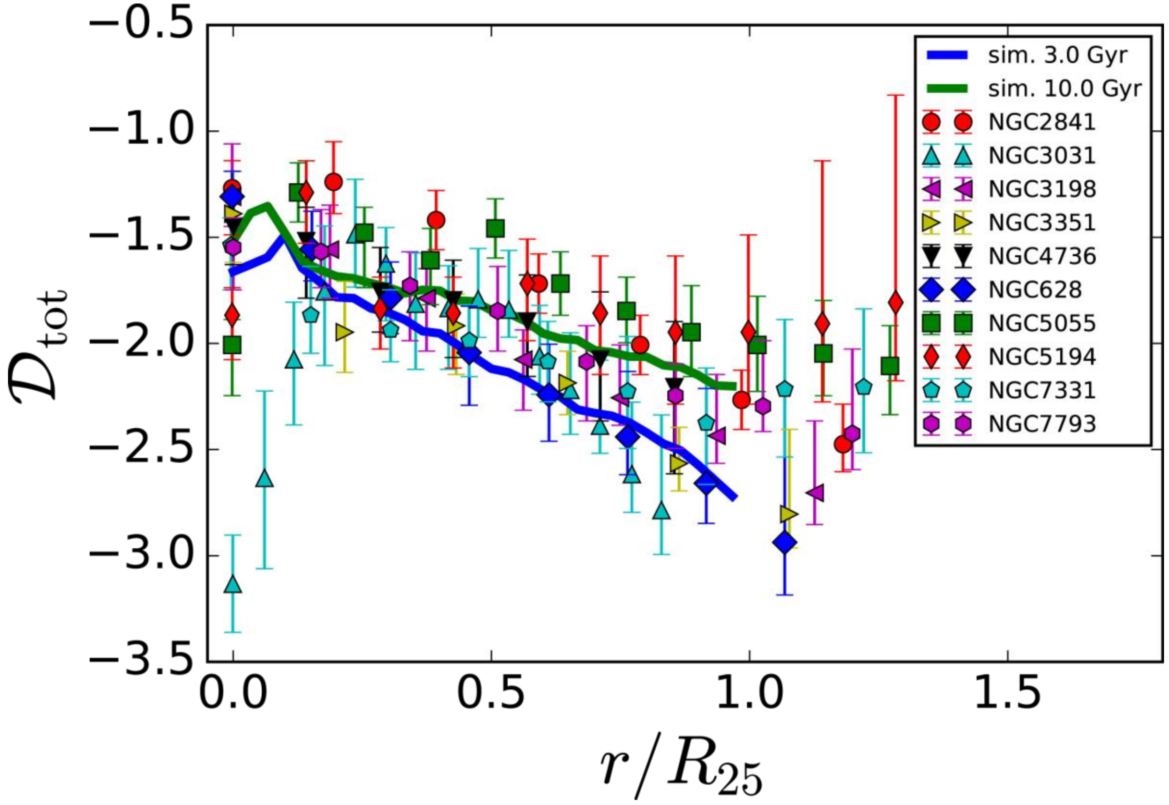
Time evolution of Specific Star formation Rate (sSFR)



- In our simulation, sSFR ~ 1 Gyr^{-1} when age is 1 Gyr.
- We categorize the galaxies according to sSFR : Class I, II and III
- We assign the simulation results whose age are 0.3, 1.0, 3.0 (10) Gyr to the classes, respectively.

Comparison with observational result 1.
Dust abundance $\log_{10}(\mathcal{D}_{\rm tot})$

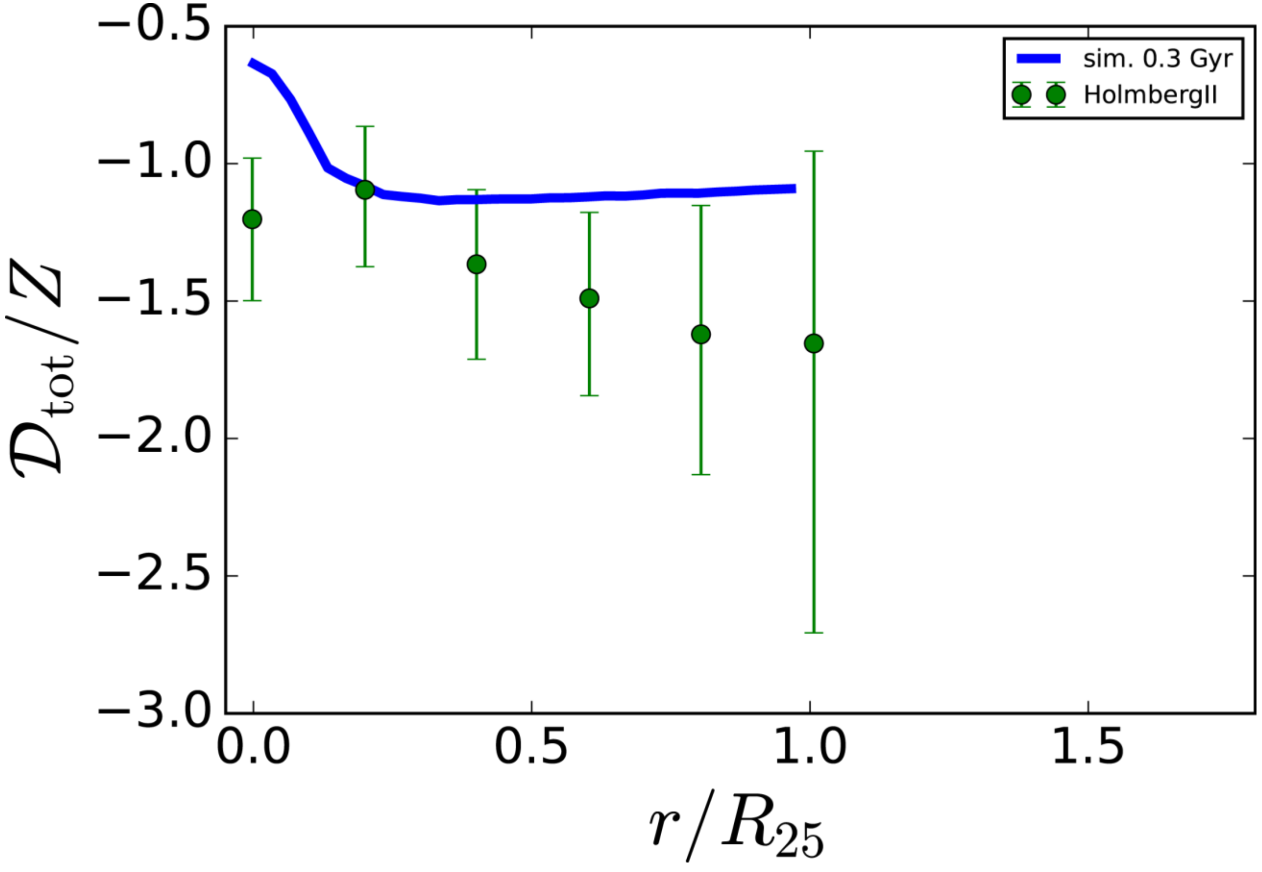


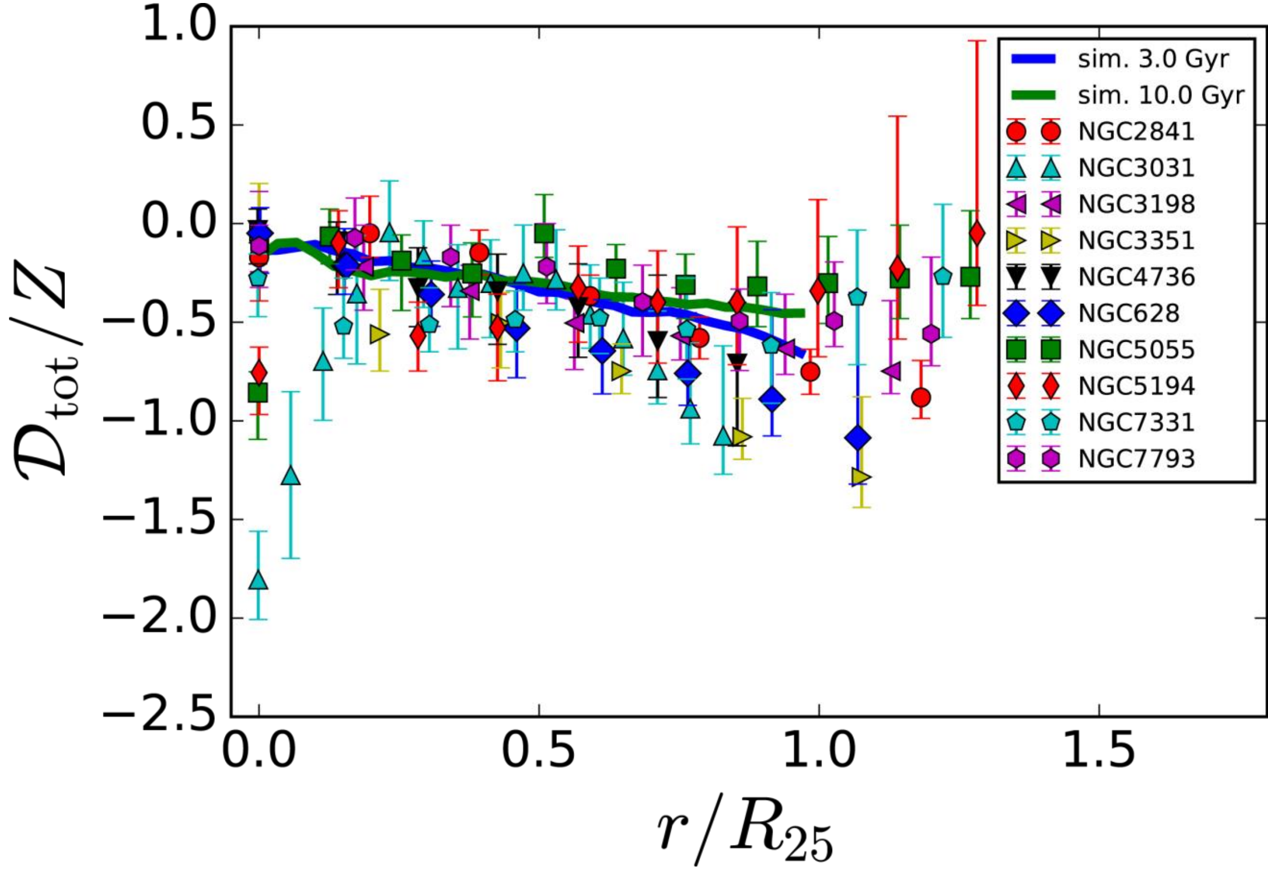


Data points Mattsson et al. (2012b) [1201.3374]

The observed radial profiles of dust abundance approximately agree with our simulations.

Comparison with observational result 2.
Depletion : $\log_{10}(\mathcal{D}_{\rm tot}/Z)$





Data points Mattsson et al. (2012b)[1201.3374]

The observed radial profiles of depletion also approximately agree with our simulations.

Conclusions

- We investigate the time evolution and spatial distribution of large and small dust grain in an isolated galaxy based on Hirashita (2015) 2-component dust model using **GADGET3-Osaka**.
- We have implemented sub-grid models for coagulation, shattering and accretion.
- Our simulation can reproduce observational results such as radial profile of total dust abundance and depletion (D_{tot}/Z).
- Dynamical evolution of dust properties
- Some issues remain (e.g. metal/dust diffusion).

Back up

Estimation of R_{25} from a simulation.

- The R_{25} is related to Rd Elmegreen(1998)

  $R_{25} \simeq 4\ R_d$.

- This relation can be checked by the data shown in de Vaucouleurs & Pence (1978).

- R_d is easily obtained by fitting the radial profile of stars.