Cosmological Simulation with Dust Evolution

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EAYAM in Ishigaki, Japen
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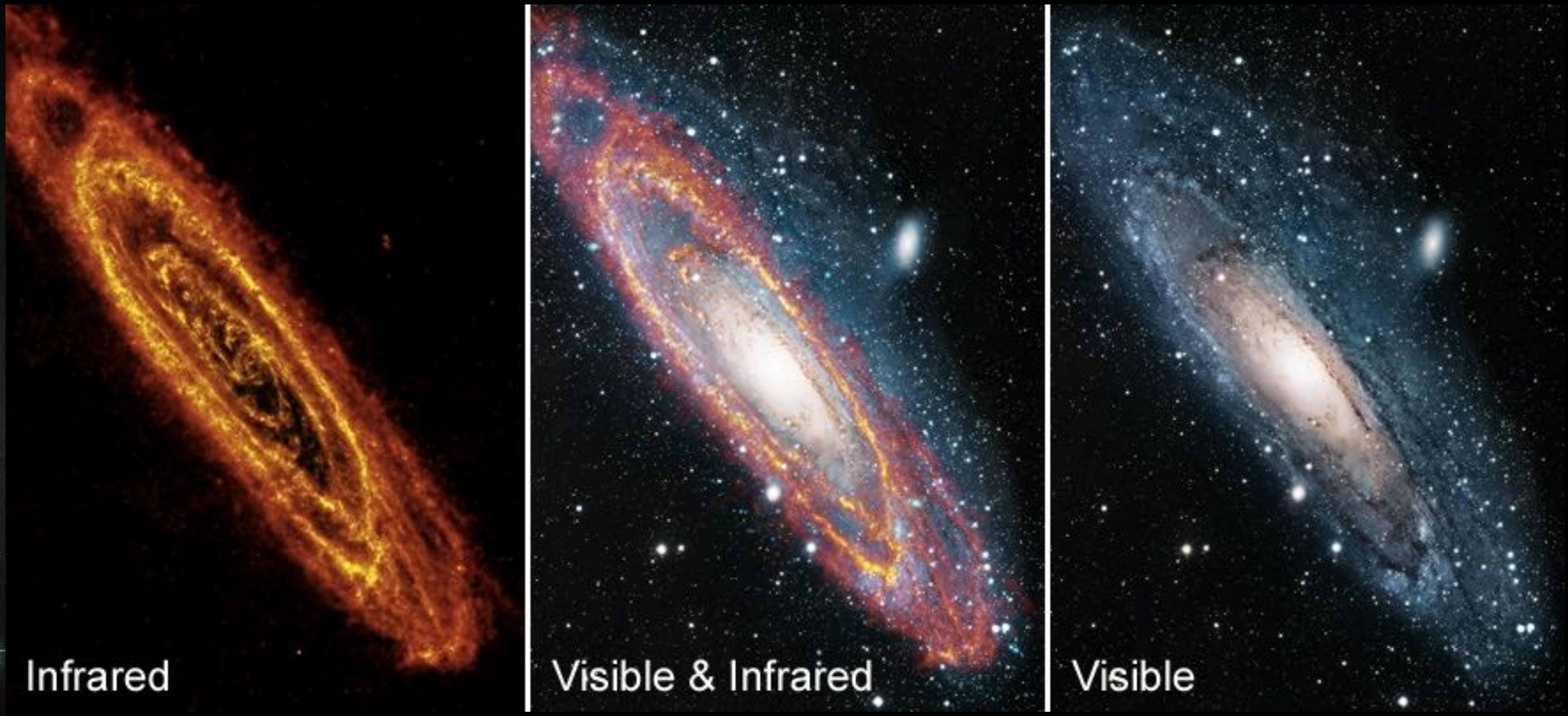
Importance of Dust

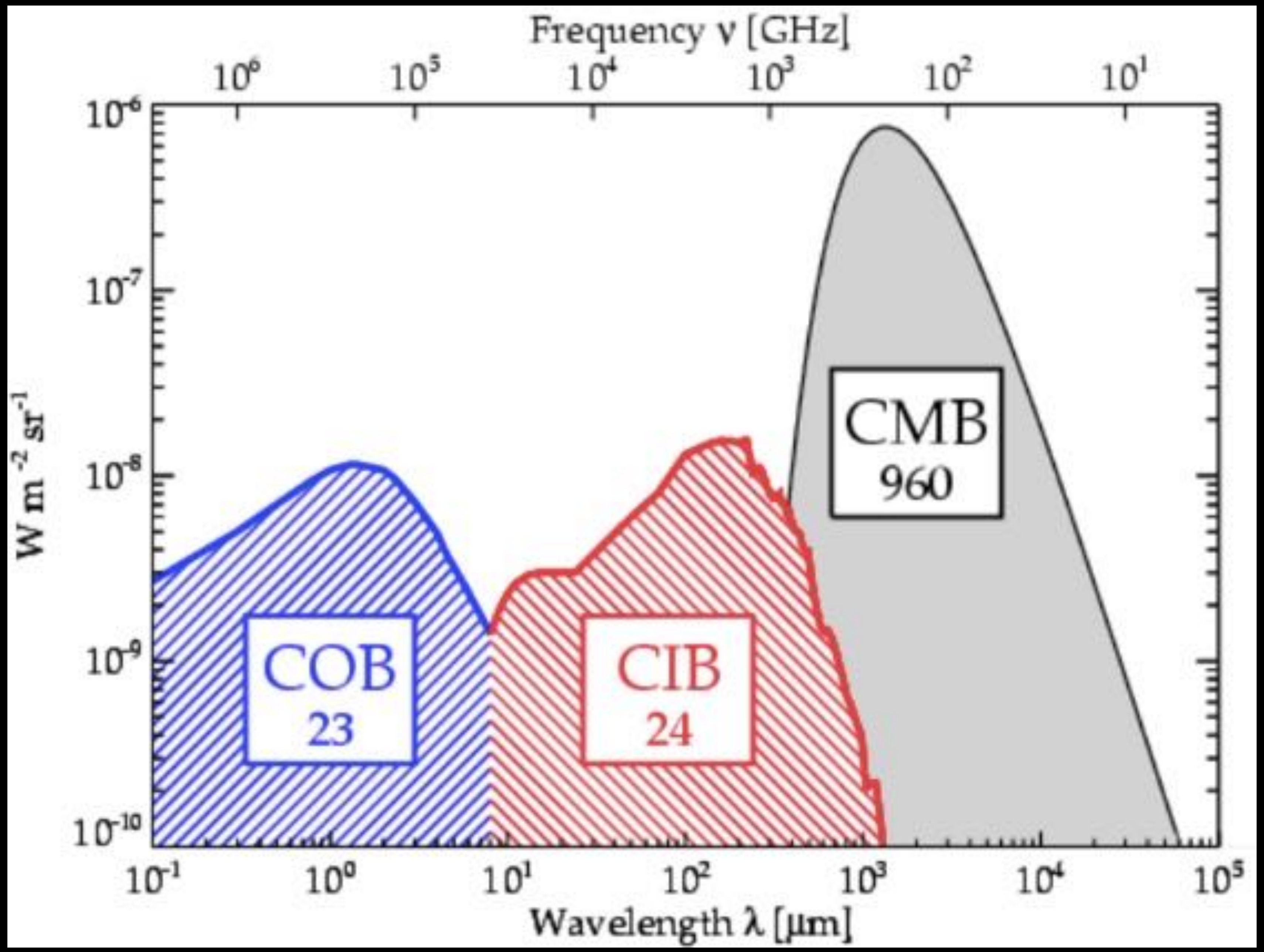
- Obscure the starlight (optical—UV) & Re-emit IR
- Shape the SED

Hubblesite's News Releases on Galaxies

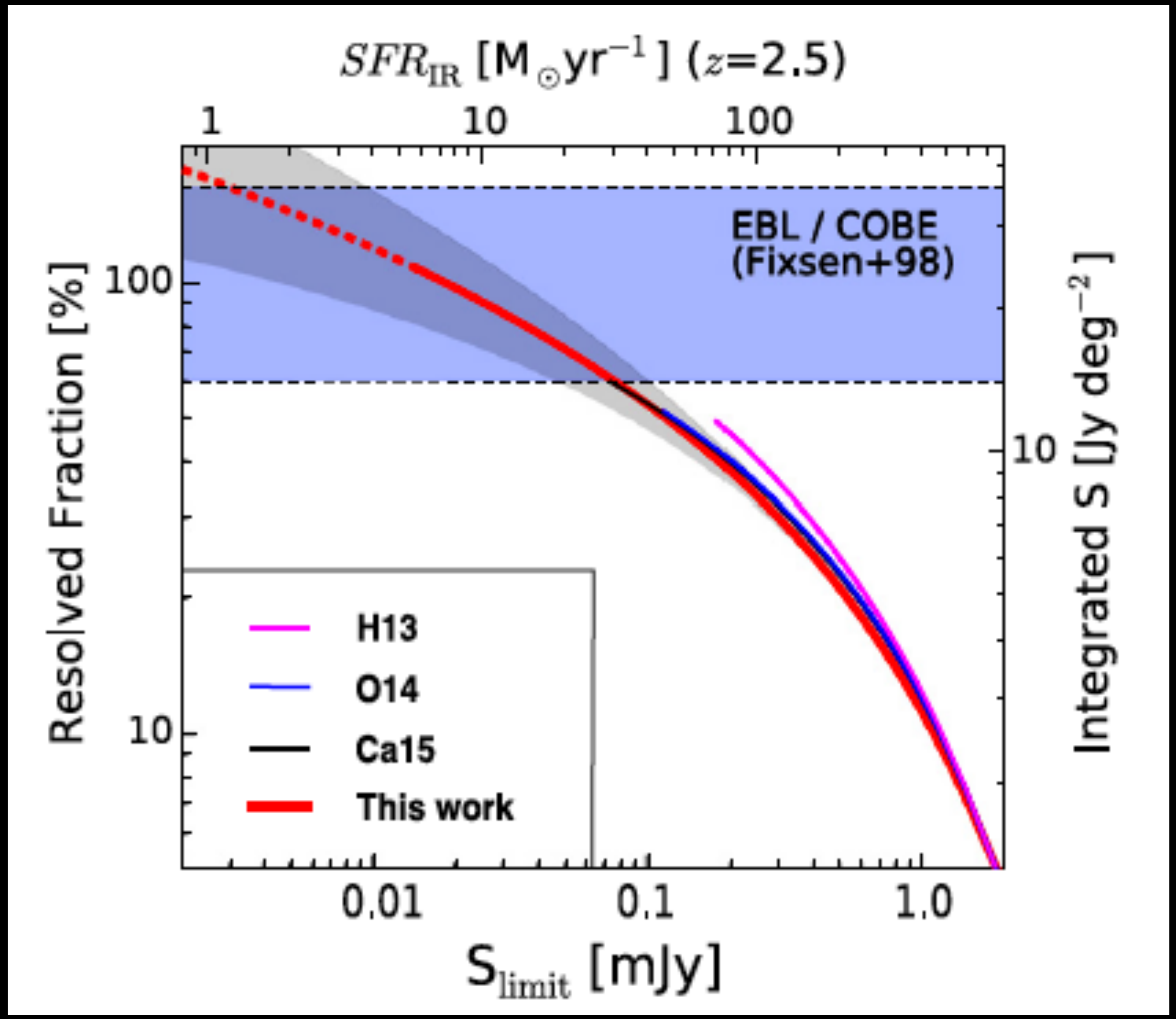


(ESA/HERSCHEL/PACS & SPIRE CONSORTIUM, O. KRAUSE, HSC, H.

- Cosmic infrared background
    - ALMA starts to resolve the faint IR sources
- history of obscured SFR



H. Dole et al., IAS



Fujimoto+ 2016

Motivation

- The nature of the faint IR galaxies
- Evolution of dust in galaxies
- The relation between dust and other galaxy properties statistically

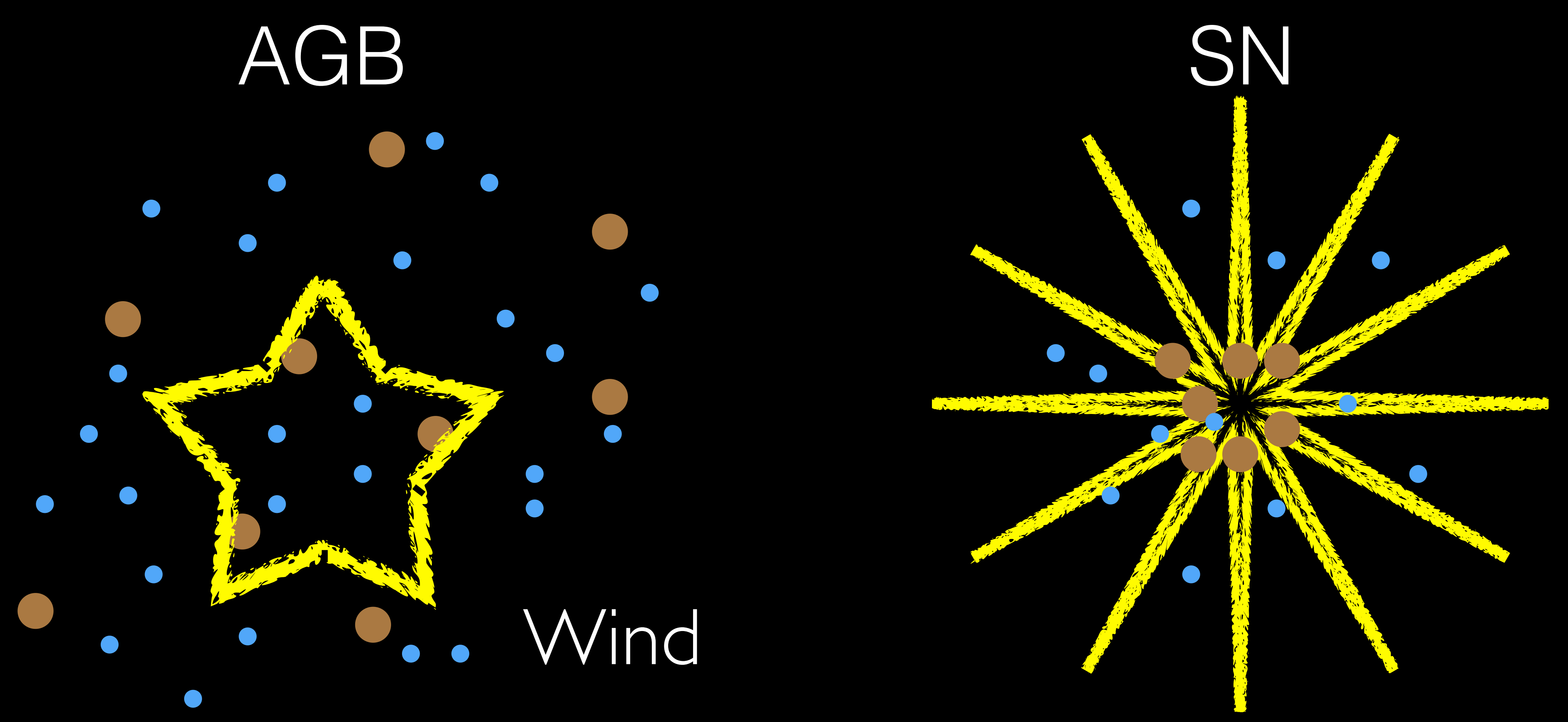
Implement all relevant processes driving dust evolution in cosmological simulation

Dust model + Simulation

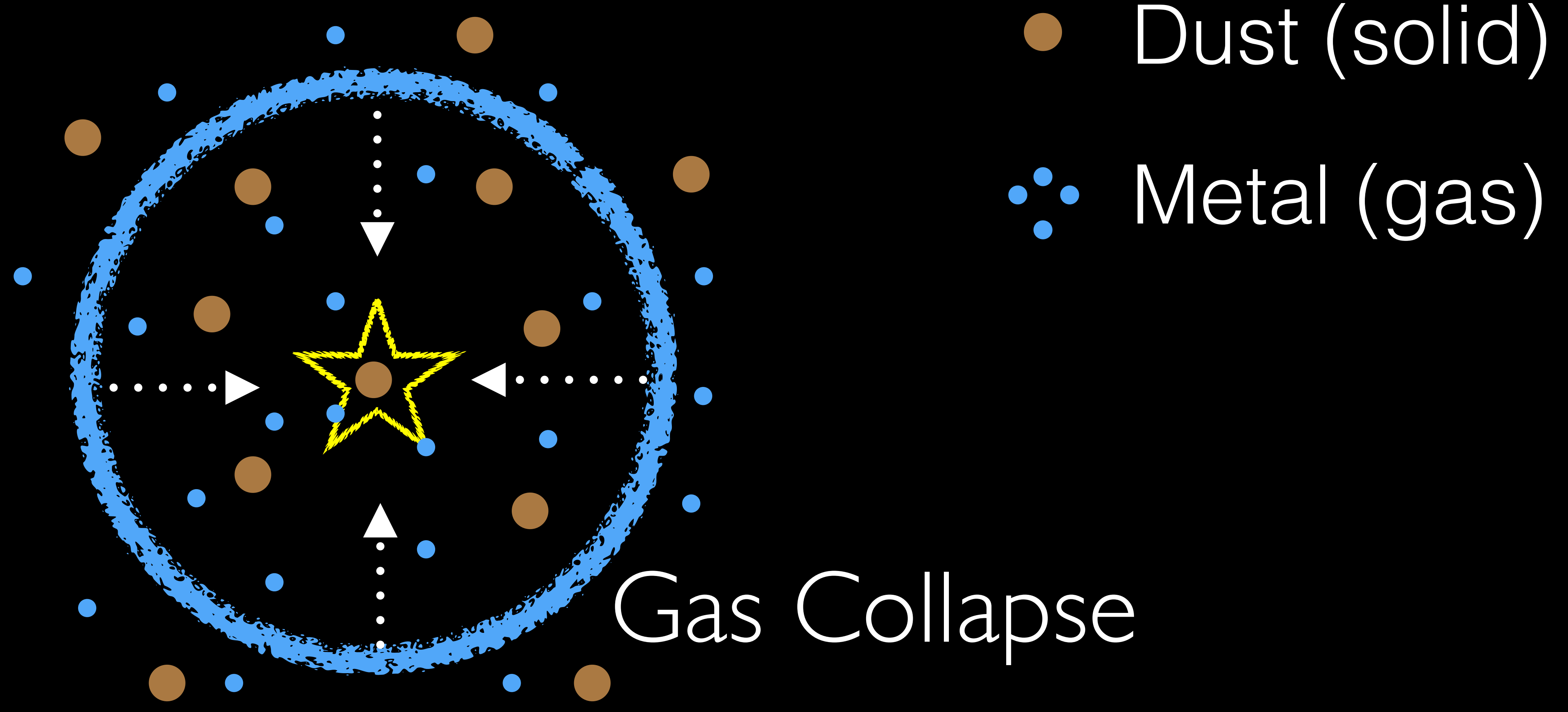
- Smoothed Particle Hydrodynamic simulation → GADGET 3
  - Springel 2005, modified
  - ΛCDM; Star formation & Stellar feedback
  - 50^3 $(\mathrm{Mpc}/h)^3$; 2×512^3 particles
- Dust and metal production are treated consistently with star formation
- ISM processes: SN destruction, accretion, shattering and coagulation
- Grain size distribution is represented by **small** and **large** grains (divided at ~0.03 μm; Hou+ 2017)

Dust processes

Stellar production



Astration



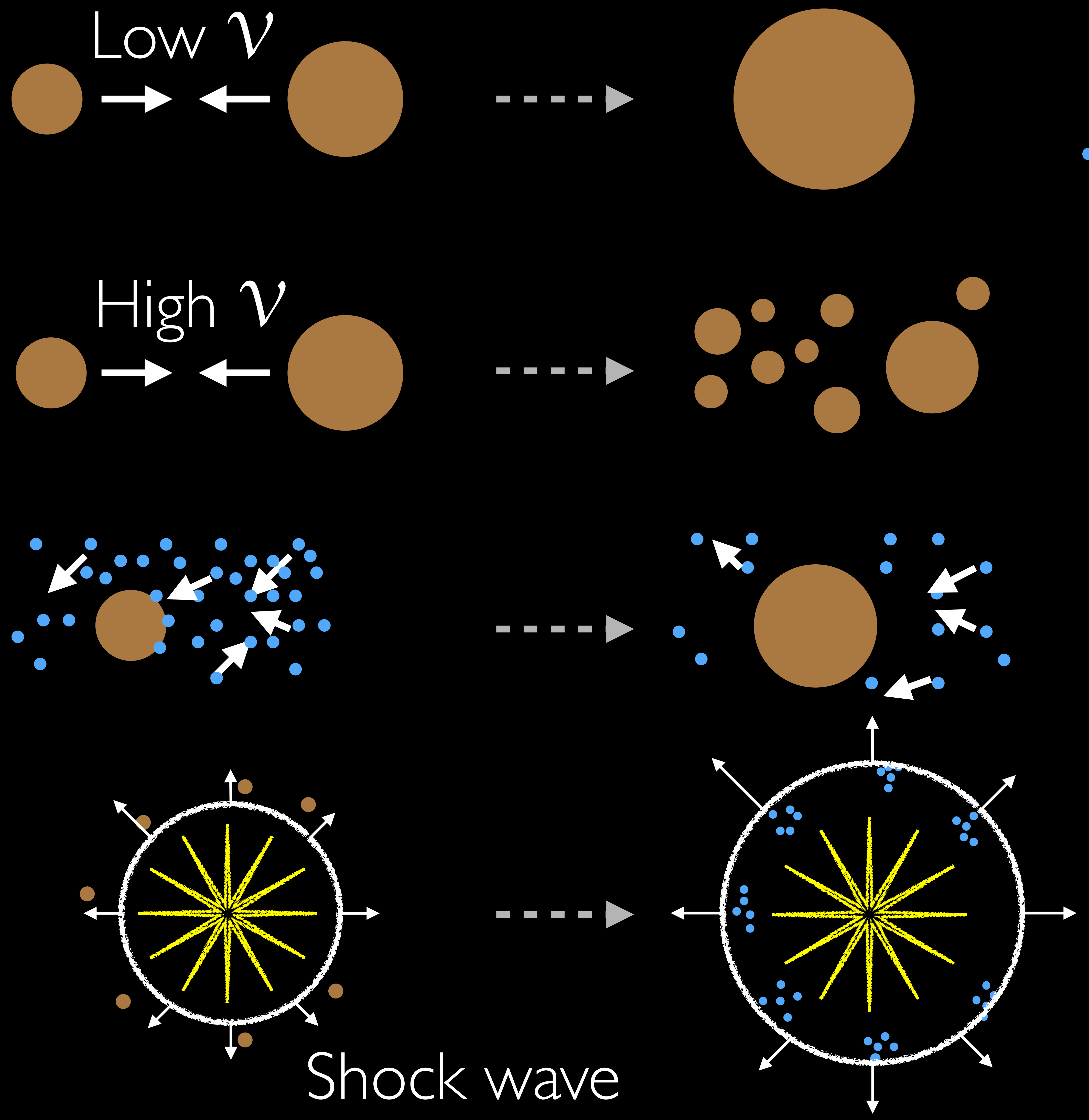
Dust processes

Coagulation

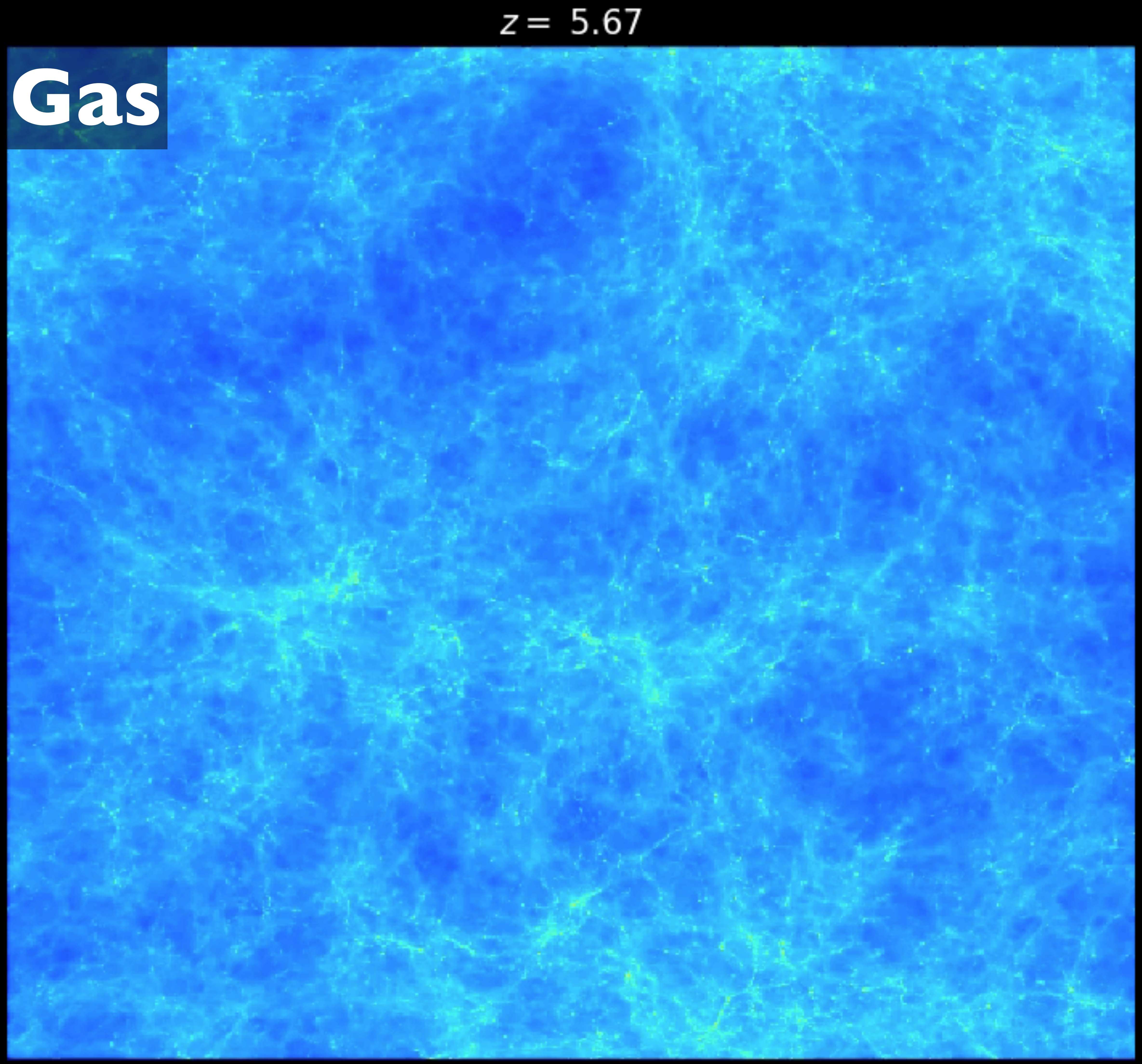
Shattering

Accretion

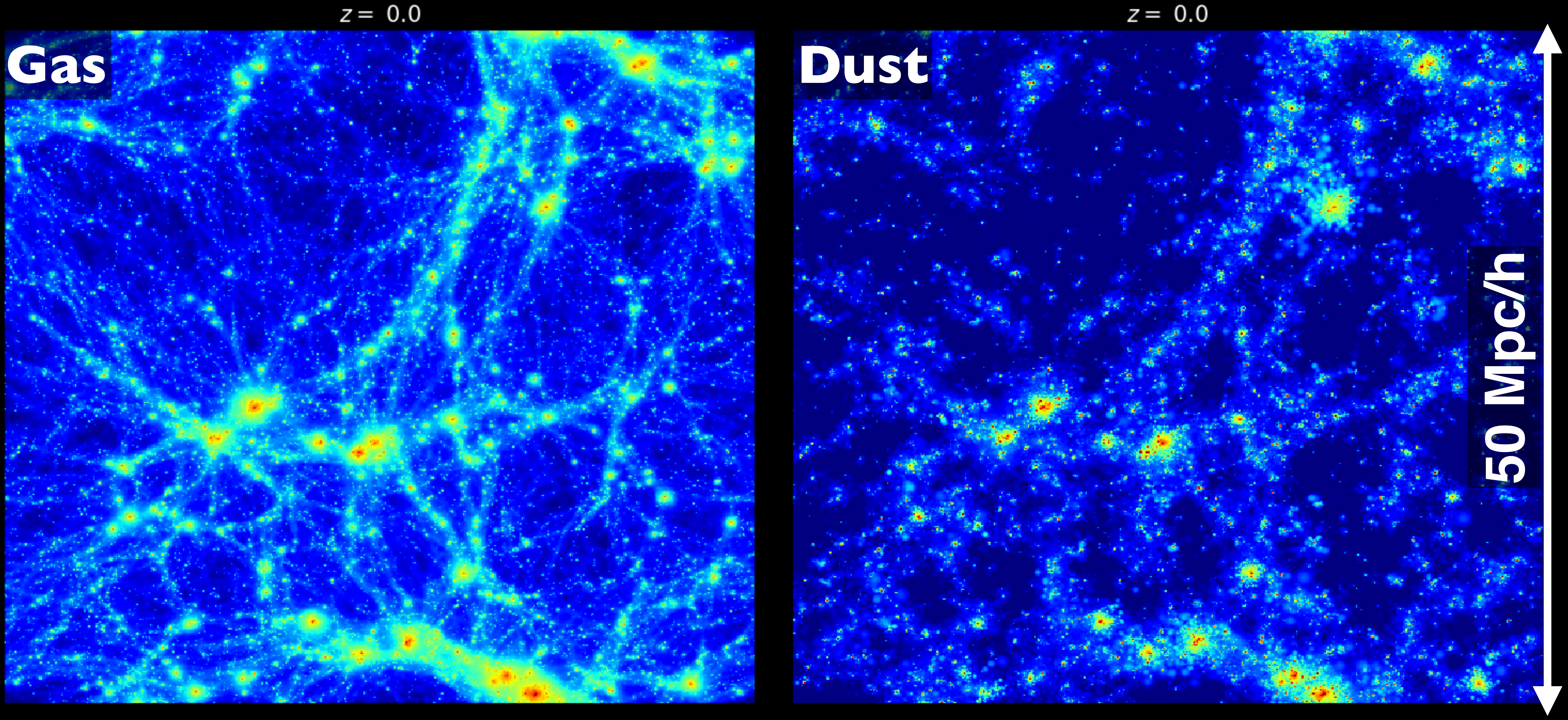
SN destruction



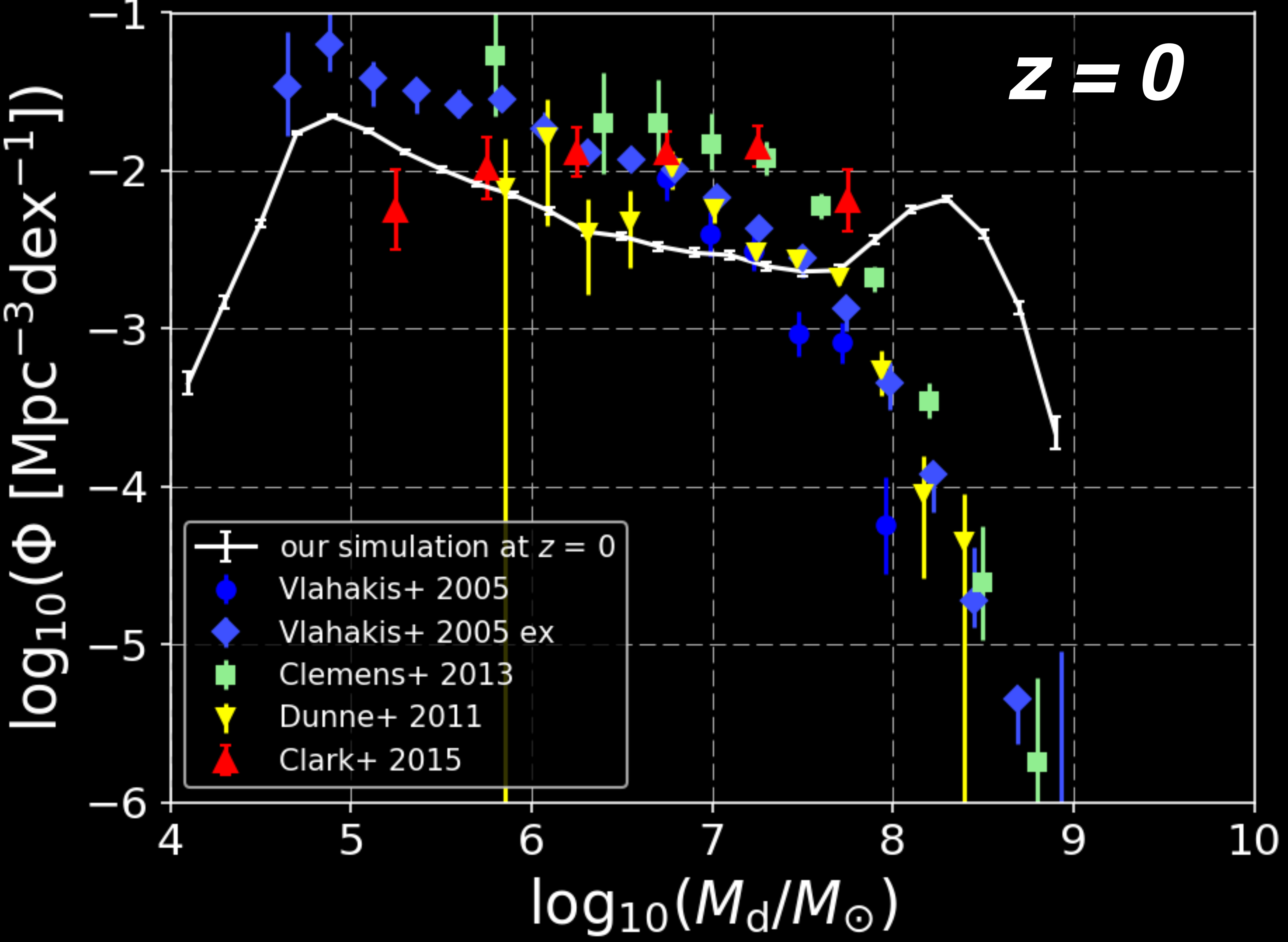
Gas and Dust distribution



Gas and Dust distribution at z = 0



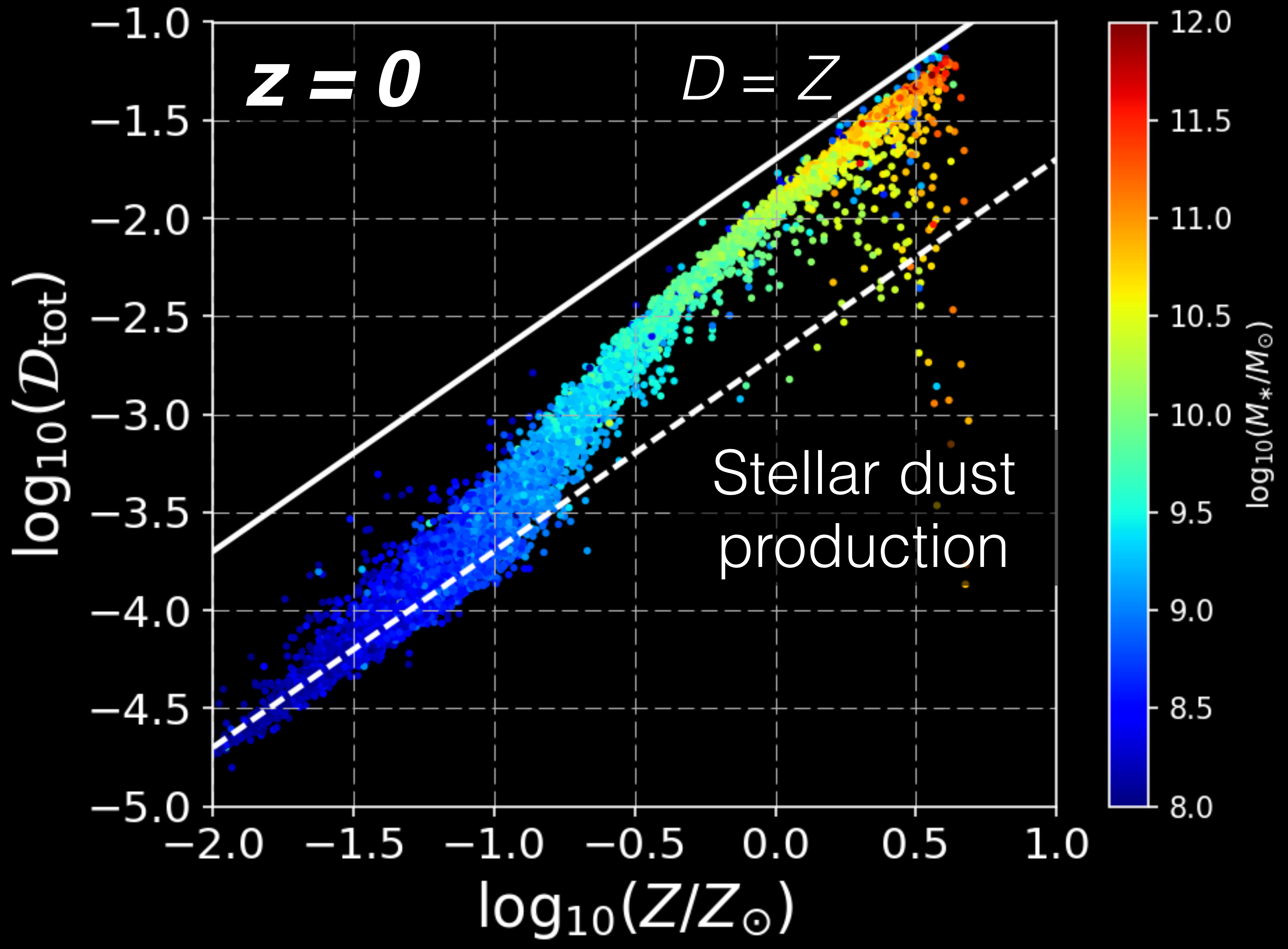
Dust Mass Function



- Agree with observations at $M_d \lesssim 10^8\ M_\odot$.
- Excess in the high mass end -> A lack of AGN feedback
- Observation data (Vlahakis+ 2005, Dunne+ 2011, Clemens+ 2013 and Clark+ 2015)

Dust and Metal relation

- Condensation efficiency is 0.1 in stellar yield
- Low metallicity galaxies follow the stellar dust production
- Most of metal condense into dust in high metallicity galaxies
- Consistent with observation of nearby galaxies (Remy-Ruyer+ 2014)



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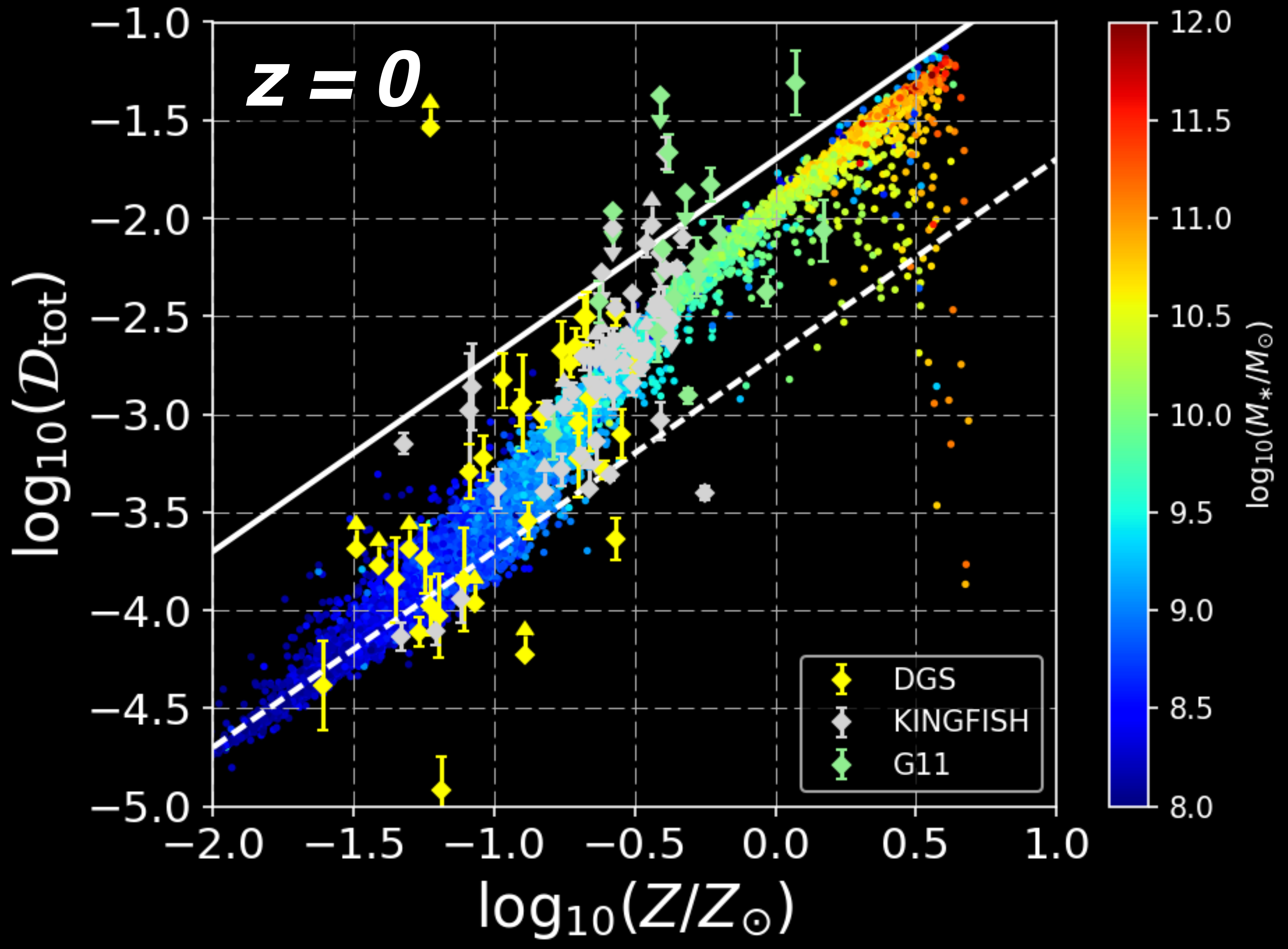
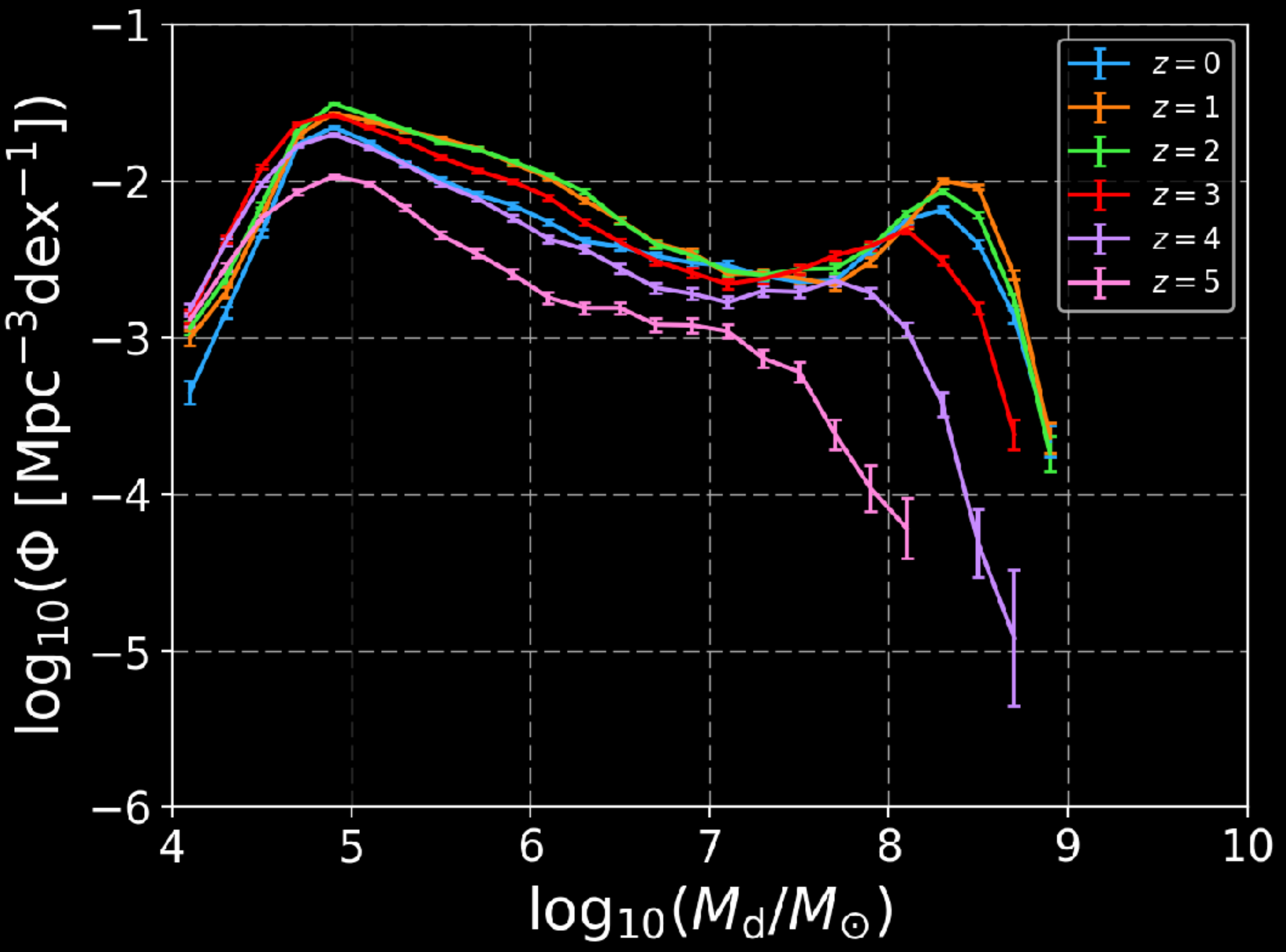


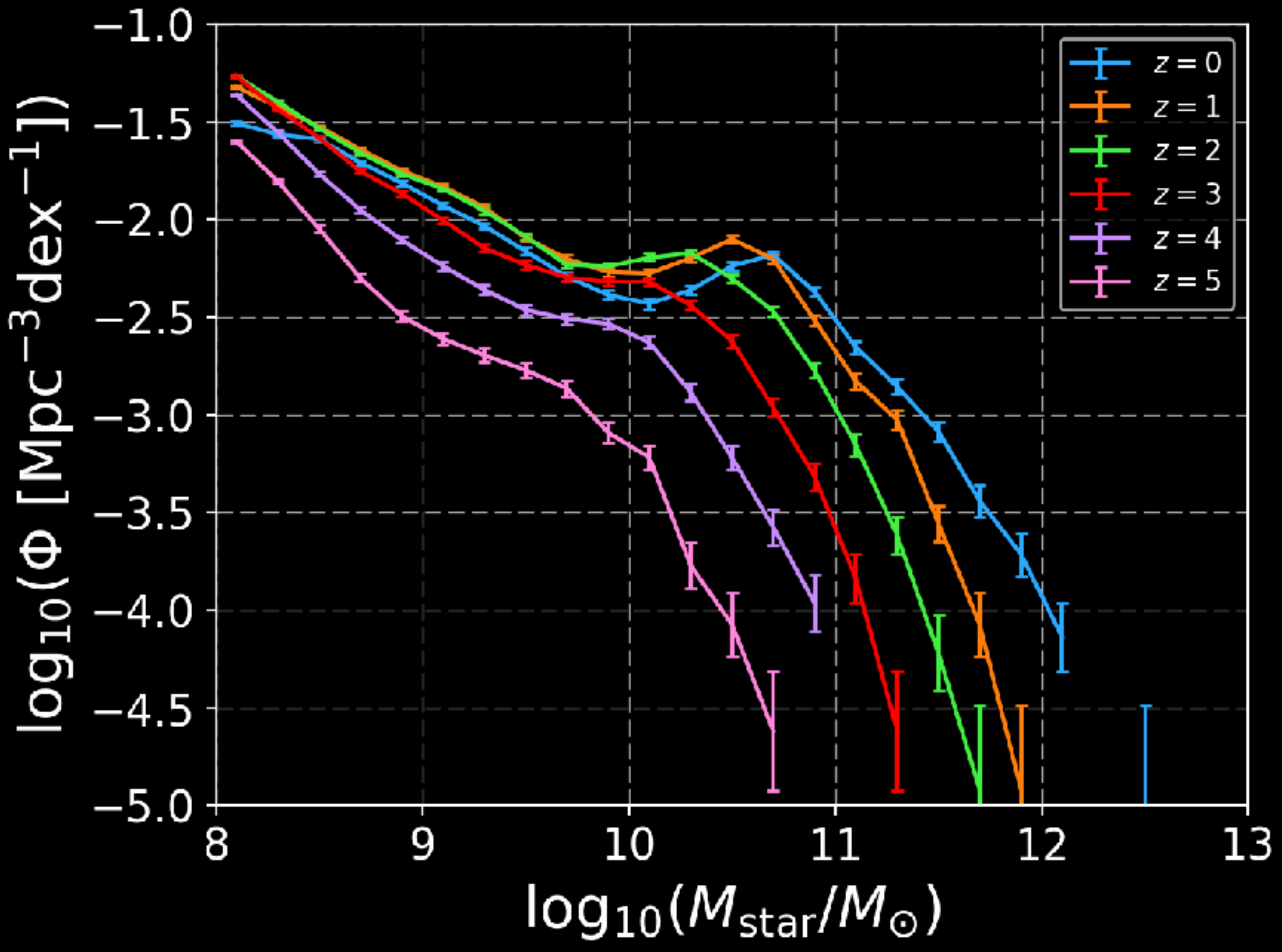
Redshift evolution

- Dust Mass Function up to $z \sim 5$
- Galaxy number density increases from $z \sim 5$ to 2; decreases from $z \sim 1$ to 0
- Astration and grain growth by accretion cause a bump.
- Galaxies have the most abundant dust at $z \sim 2$ - 1

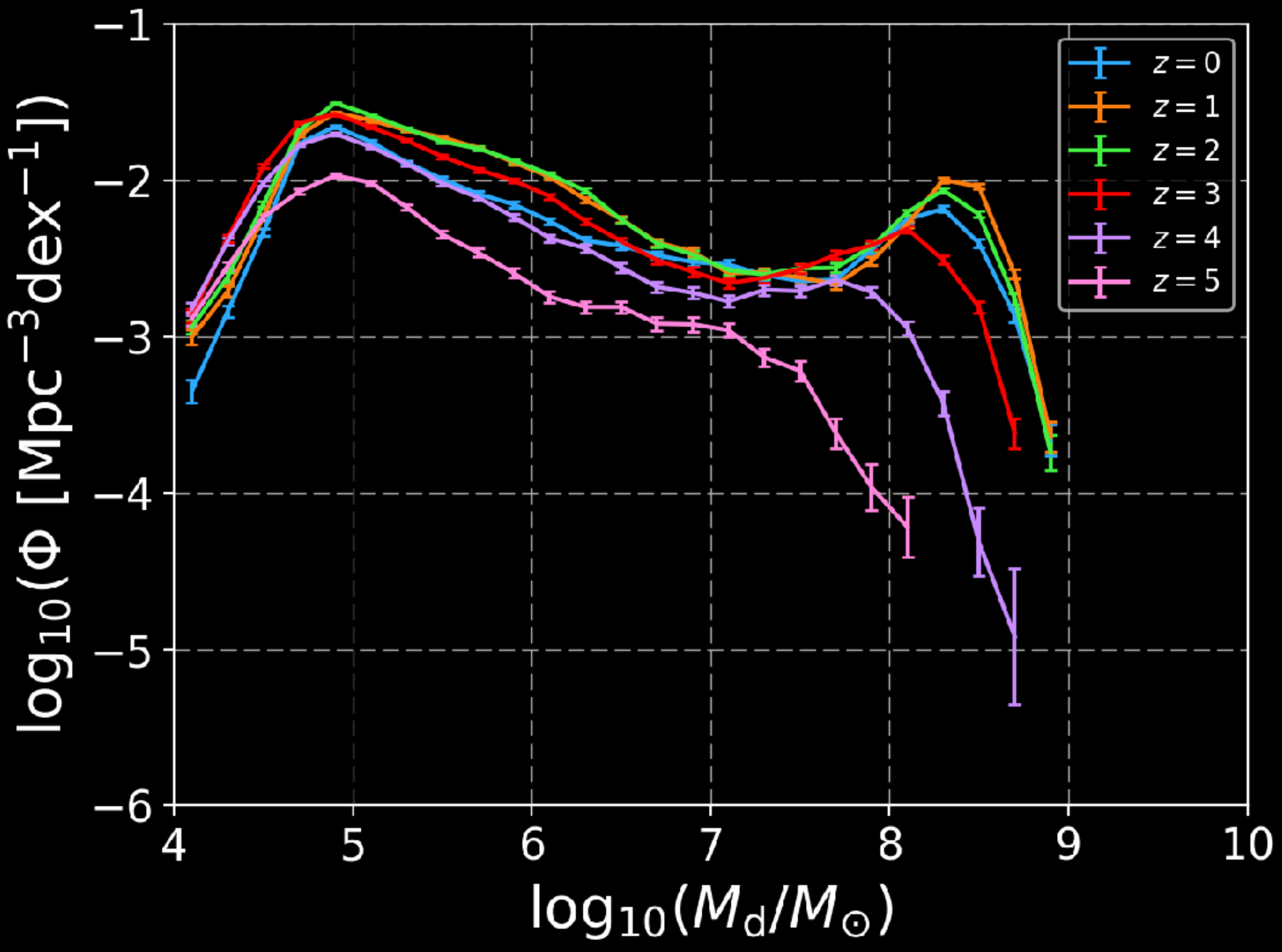


Redshift evolution

Stellar mass function



Dust mass function



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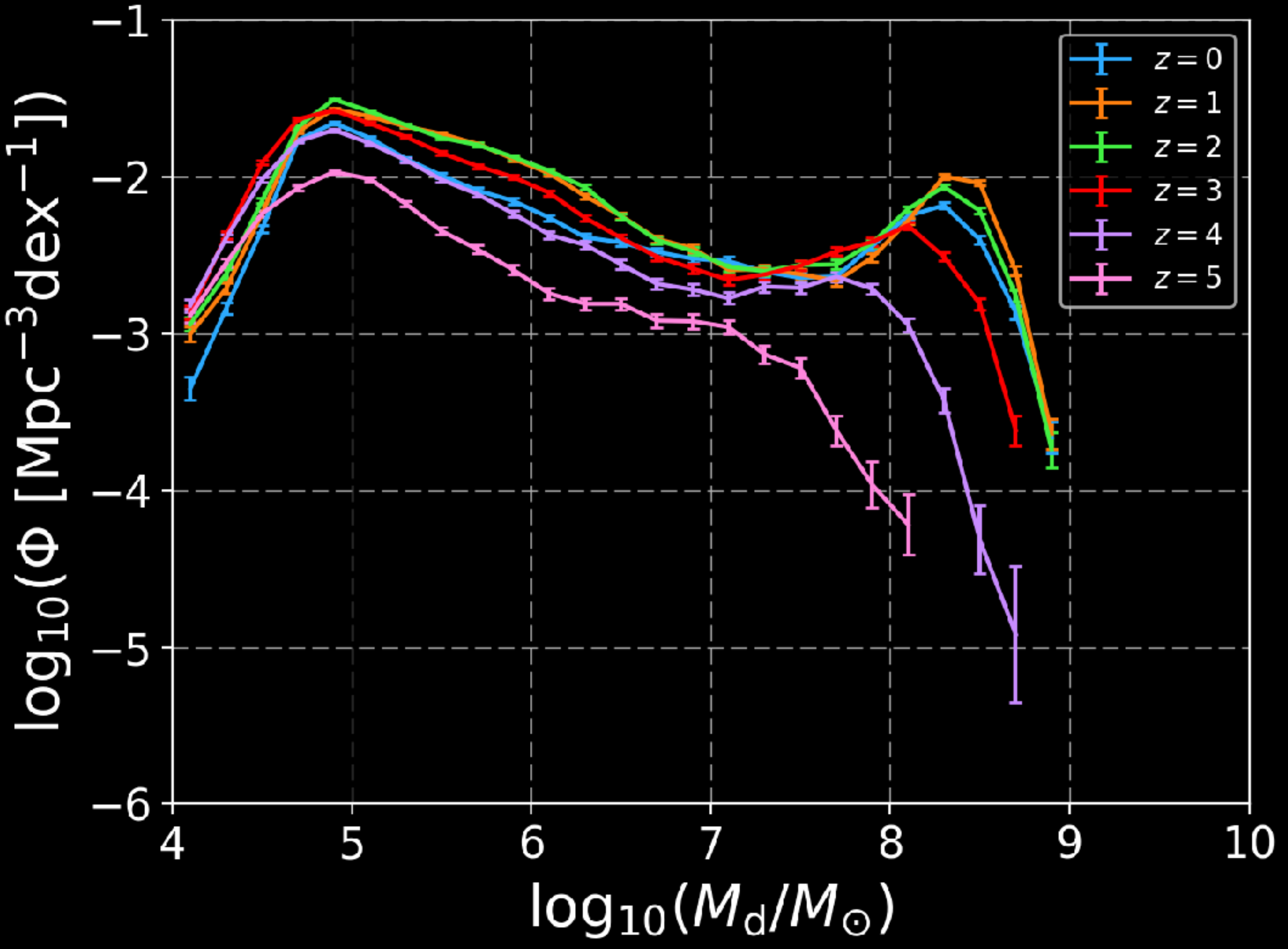
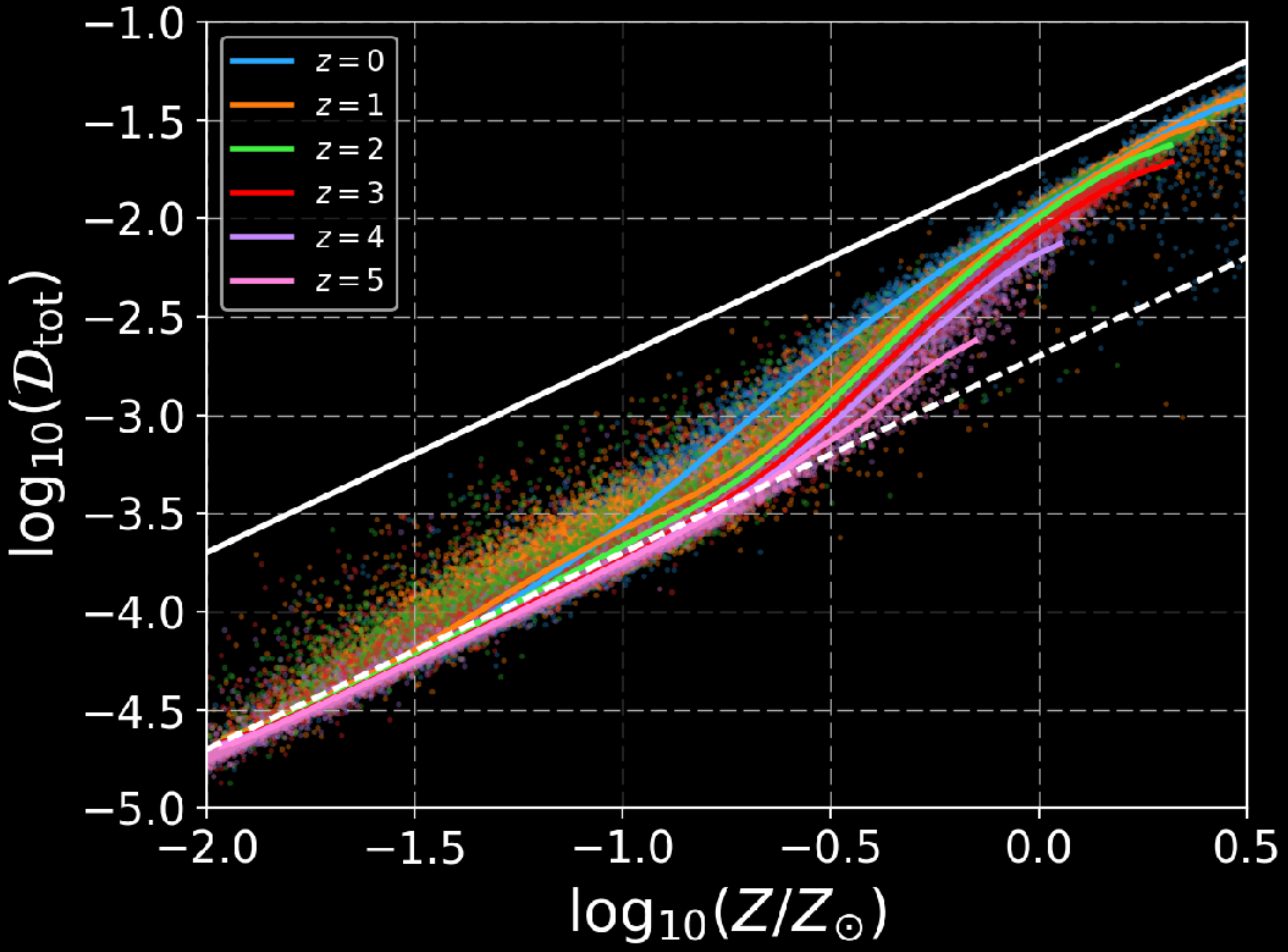


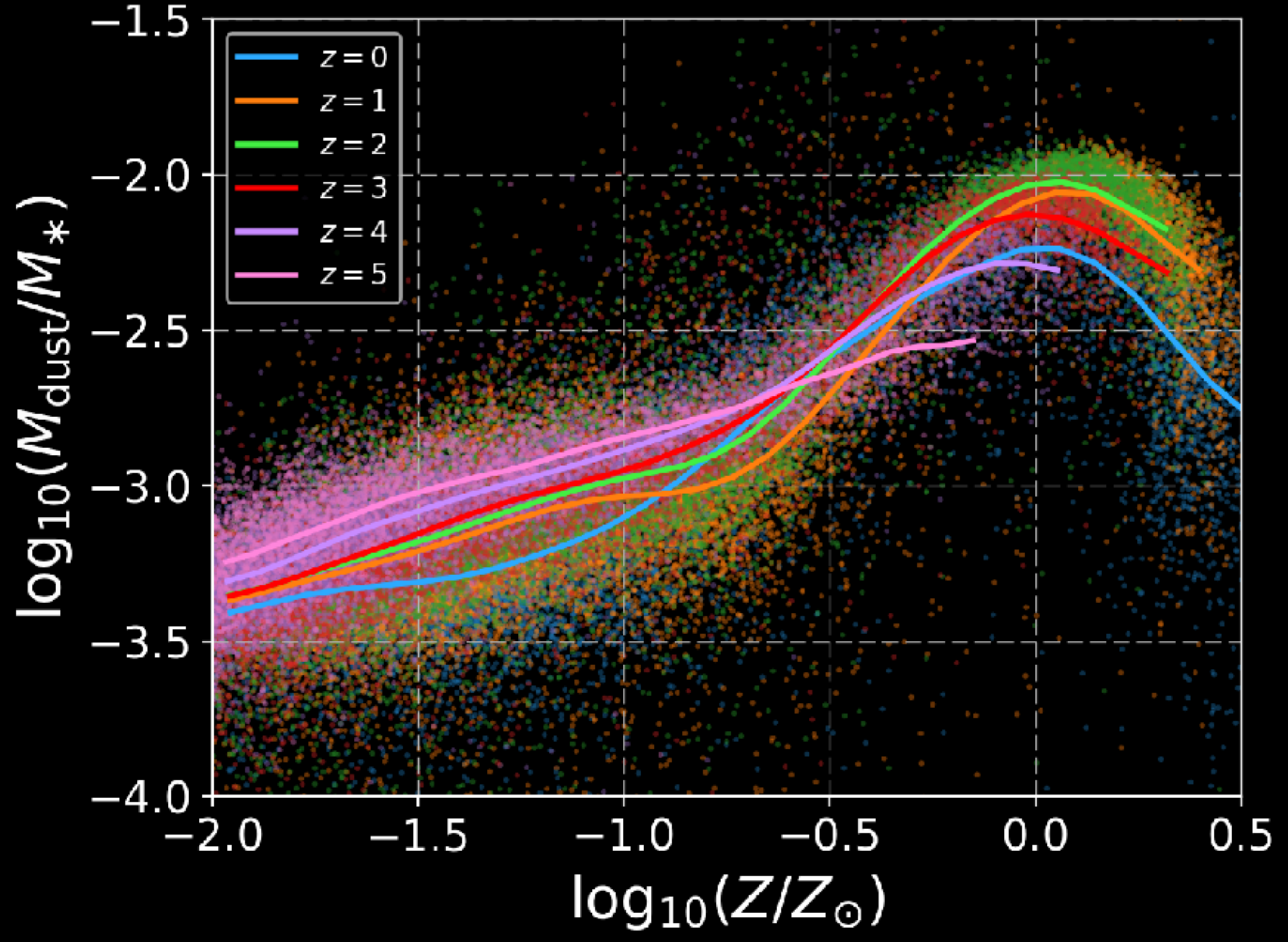
Redshift evolution

- Dust and Metal relation
- Balance between SF and accretion
- Stronger SN destruction at higher redshift
- Accretion turning point shift to higher metallicity

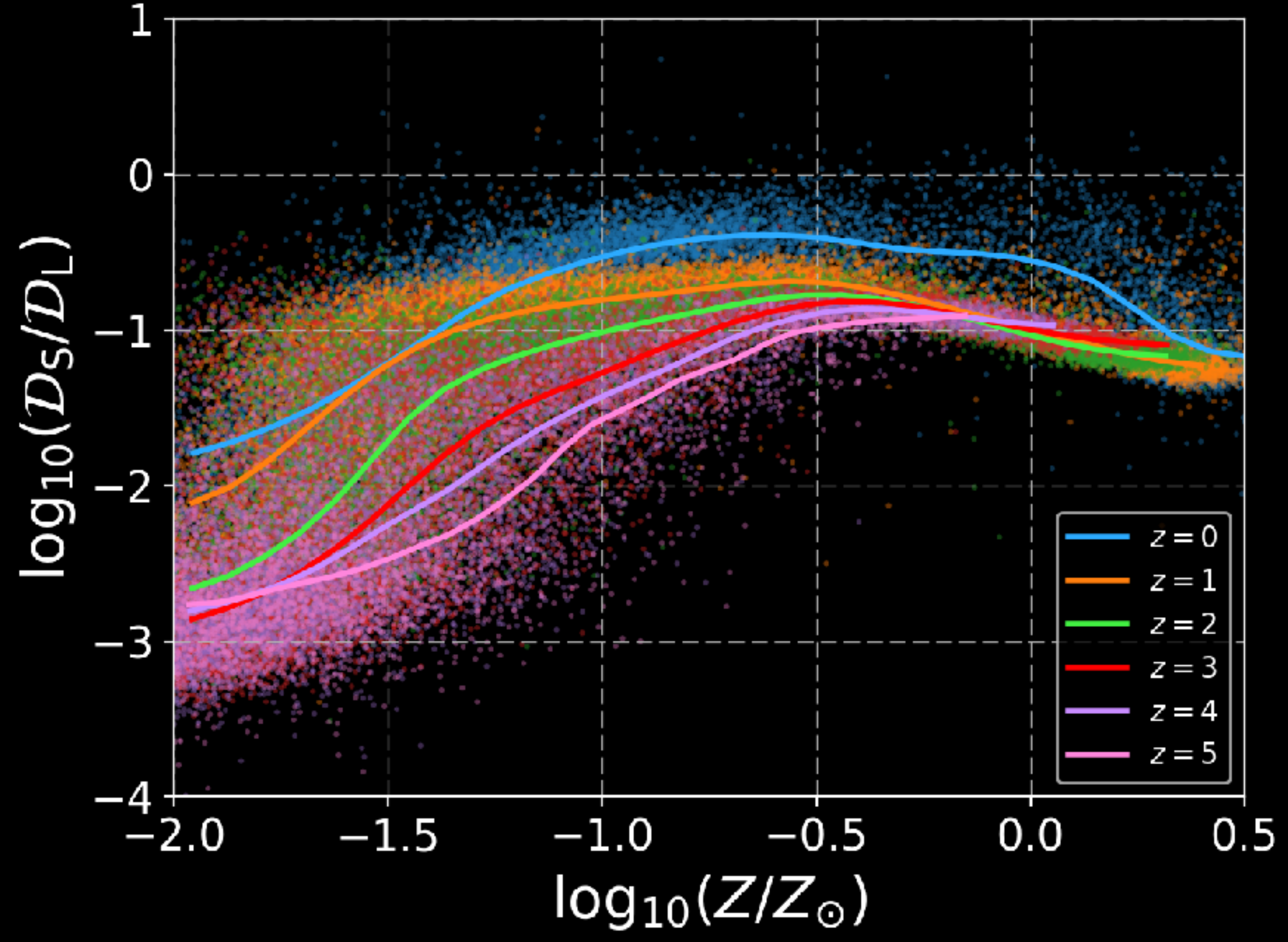


Redshift evolution

M_{dust}/M_{star} — Z



D_{Small}/D_{Large} — Z



Summary

- Perform the cosmological simulation with the dust enrichment model
  - Solving time evolution of dust formation and destruction together with gas dynamics.
  - Predicted dust abundances in galaxies up to $z \sim 5$
- Produced the dust mass function
- Reproduced the nonlinearity of the Dust-to-gas mass ratio and Metallicity relation
- Predicted the redshift evolution of the relation between dust and galaxy quantities, e.g., Z, M_* → to be tested by future observations

Thank you

Dust abundances in the i-th particle from t to t + Δt :

$$\mathcal{D}_{\mathrm{L,X}}(t+\Delta t) = \mathcal{D}_{\mathrm{L,X}}(t) - \Delta\mathcal{D}_{\mathrm{L,X}}^{\mathrm{SNe}} - \left(\frac{\mathcal{D}_{\mathrm{L,X}}(t)}{\tau_{\mathrm{Sh}}} - \frac{\mathcal{D}_{\mathrm{S,X}}(t)}{\tau_{\mathrm{co}}}\right)\Delta t + f_{\mathrm{in,X}}\mathcal{Y}_{\mathrm{X}}'\frac{\Delta M_{\mathrm{return}}}{m_{\mathrm{g}}}(1-\delta)$$

$$\mathcal{D}_{\mathrm{S,X}}(t+\Delta t) = \mathcal{D}_{\mathrm{S,X}}(t) - \Delta\mathcal{D}_{\mathrm{S,X}}^{\mathrm{SNe}} + \left(\frac{\mathcal{D}_{\mathrm{L,X}}(t)}{\tau_{\mathrm{Sh}}} - \frac{\mathcal{D}_{\mathrm{S,X}}(t)}{\tau_{\mathrm{co}}} + \frac{\mathcal{D}_{\mathrm{S,X}}(t)}{\tau_{\mathrm{acc}}}\right)\Delta t$$

- Softening length : 5 kpc
- Minimum gas smoothing is 0.1 softening length
- Star formation efficiency : 0.05

Extinction curves

Adapt silicate-graphite dust species model