Effects of Dust Evolution on the CO and H_2 Abundances in Galaxies

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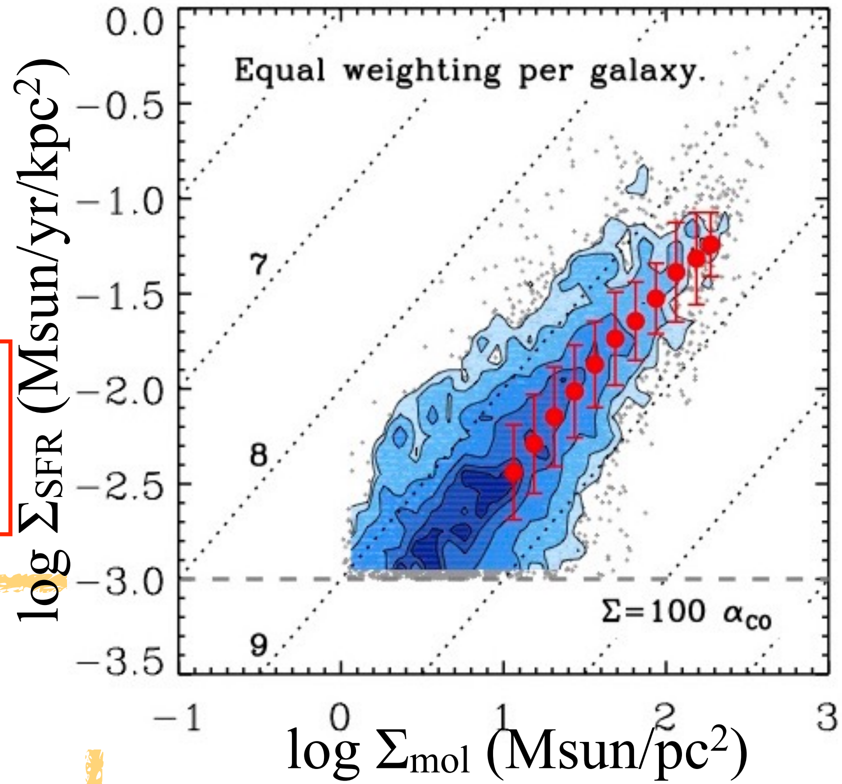
1. Introduction

Molecular Clouds:
Star-forming places

-H_2: difficult to observe directly
-CO: used as a tracer of H_2

Dust (abundance + grain size distribution) is important.
H_2: Formation on dust surfaces.
H_2 and CO: Dissociating radiation is shielded by dust.



Leroy et al. (2013)

→ **Dust evolution is important to understand the evolution of H_2 and CO in galaxies.**

Goal

Clarifying the effect of dust evolution on the H_2 and CO abundances (and also on the conversion factor).

2. Formulation

D–Z relation: Relation between dust-to-gas ratio and metallicity is calculated by considering

- Dust production by stars
- Shock destruction
- Accretion of gas-phase metals
- Coagulation (sticking)
- Shattering (disruption)

2. Formulation

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Solved for small and large grains separately to preserve the information of grain size distribution:

$dD(\mathrm{small})/dt = \Sigma(D/\tau_i)$

$dD(\mathrm{large})/dt = \Sigma(D/\tau_i)$

i: processes

τ_i: time-scale ($\tau_i > 0$: increase; $\tau_i < 0$:decrease)

Formulation

H_2 fraction (f_{H2}): fraction of H in the form of H_2

- Formation: dust surface reaction (dependence on grain size included)
- Destruction: photodissociation (Habing intensity) (considering self-shielding + dust shielding)

➡ Obtain the equilibrium H_2 fraction

CO fraction (x_{CO}): number ratio of CO to H

Use the calculated data in Glover & Mac Low (2011), following the formulation by Feldman et al. (2012).

- Formation: gas phase reaction
- Destruction: photodissociation (considering self-shielding + dust shielding)

Formulation

CO-to-H_2 conversion factor: $X_{CO} = N_{H2}/W_{CO}$

- W_{CO} ⬅️ Given by radiation temperature ($T_{gas} = 10$ K), velocity dispersion (3 km/s) + calculated x_{CO}
- N_{H2} ⬅️ Calculated above ($= f_{H2} N_H/2$)

3. Results

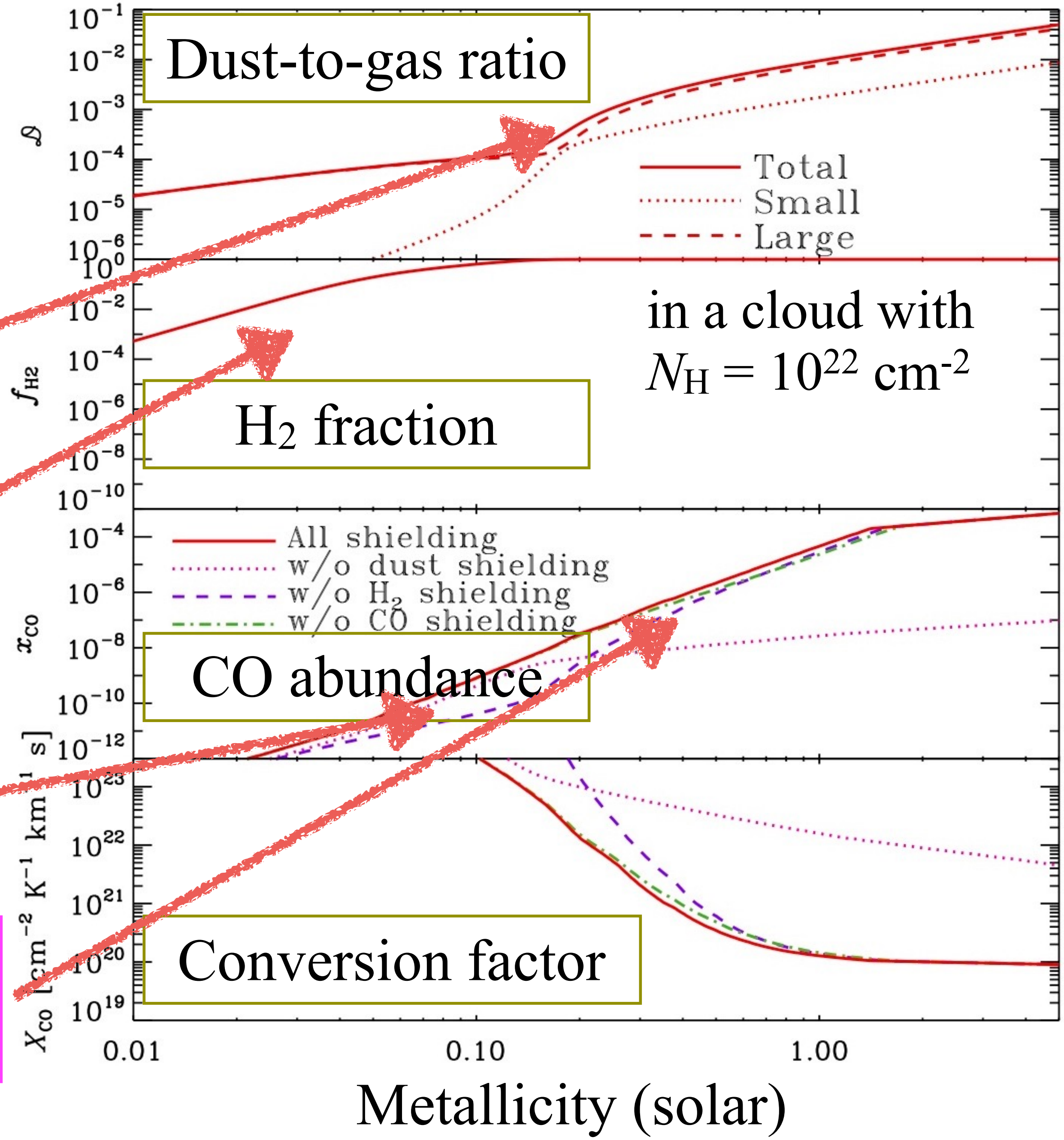
Basic features

Dust growth

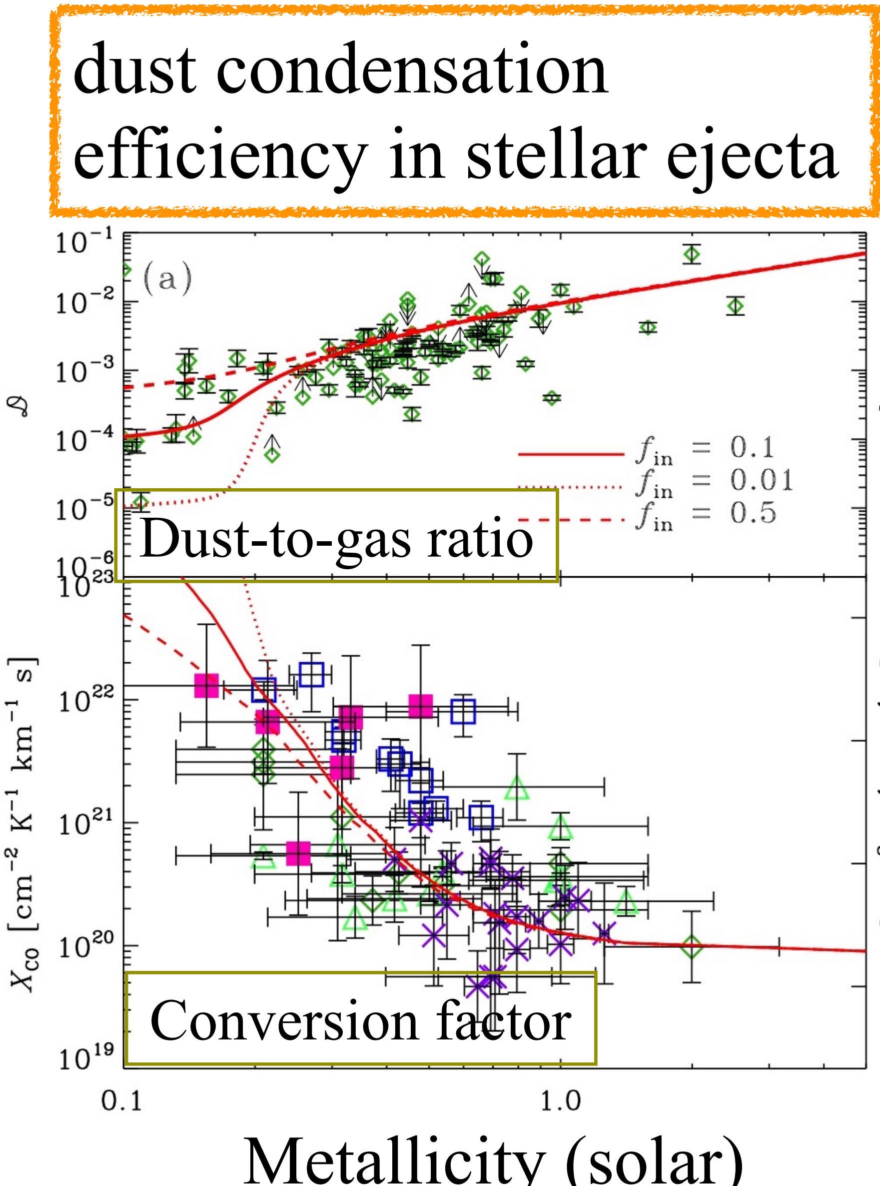
Self-shielding

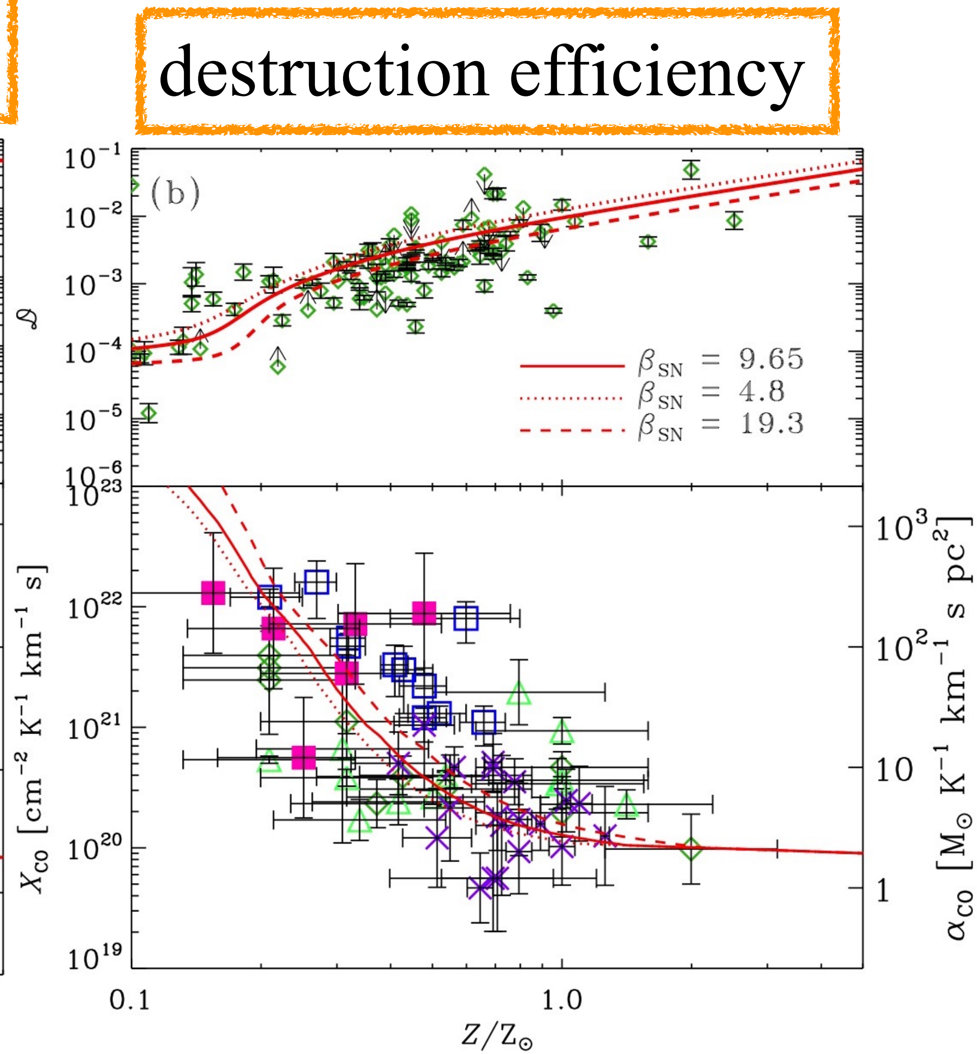
Shielding by H_2 is important.

Dust shielding is important.

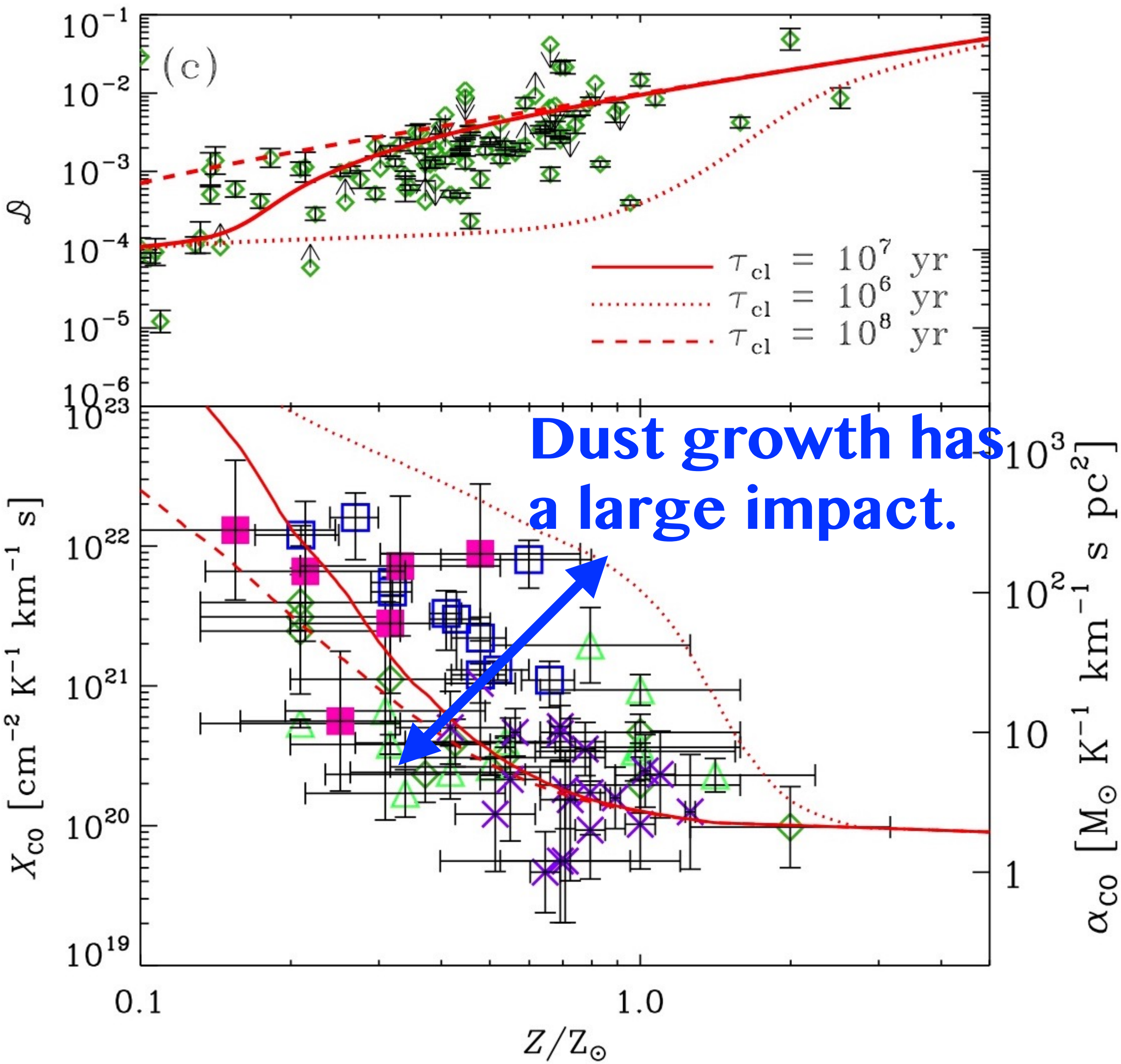


Effect of Dust Evolution on X_{CO}–Z Relation



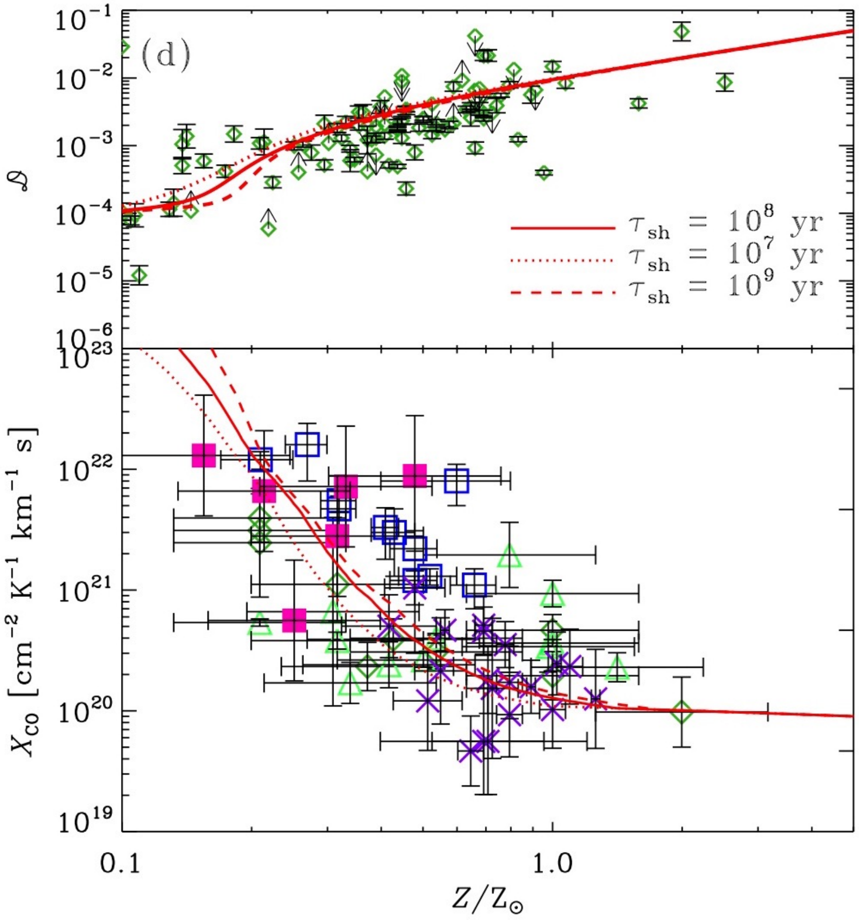


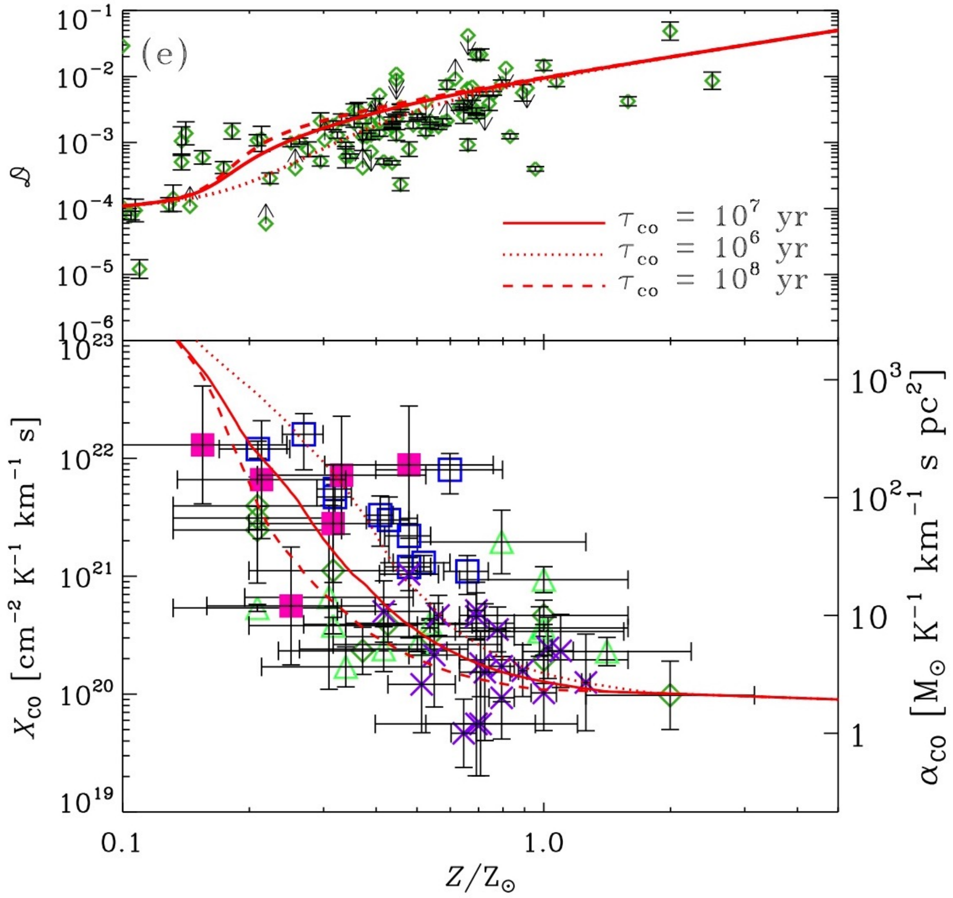
Efficiency of dust growth by accretion



shattering timescale

coagulation timescale

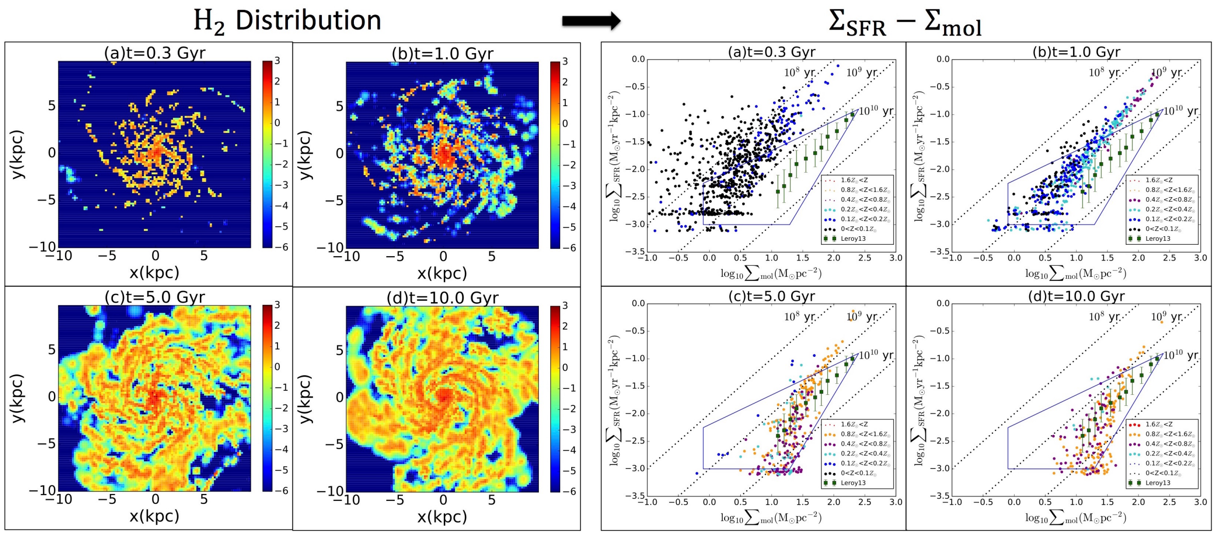




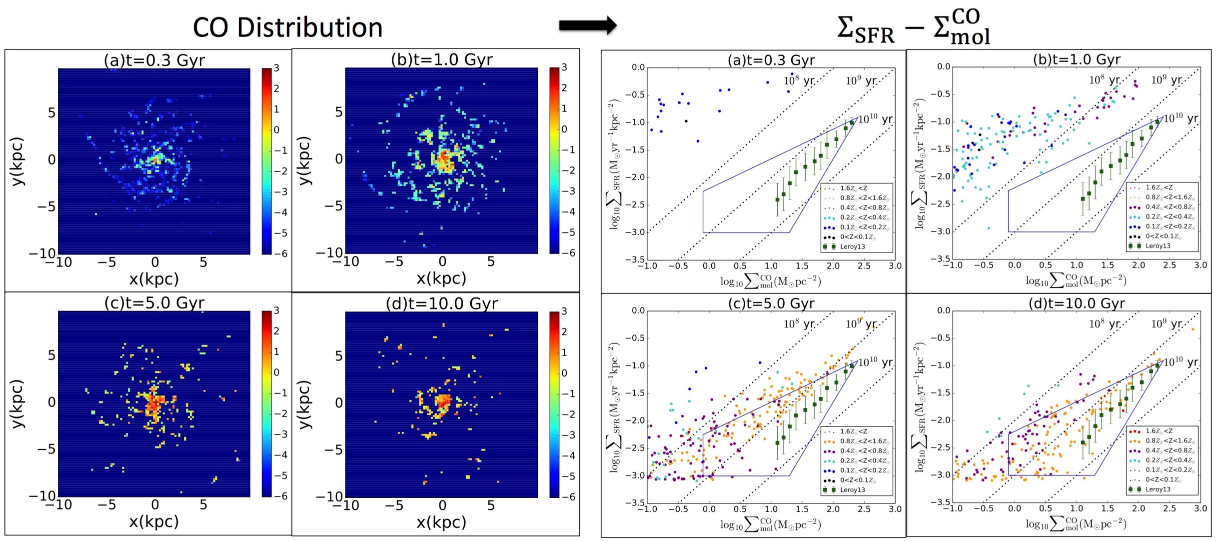
Summary of the Results

- Reproduced the metallicity dependence of CO-to-H_2 conversion factor (X_{CO}–Z relation).
- Grain growth by accretion has a large impact of the X_{CO}–Z relation.
- The other processes concerning the dust evolution have minor effects on the X_{CO}–Z relation.
- A cloud with $N_{H2} \sim 10^{22}$ cm^{-2} (typical column density of Galactic molecular clouds) is not fully molecular at $\lesssim 0.1\ Z_{\odot}$ and regulated strongly by the dust condensation efficiency in stellar ejecta.

4. Future: Numerical Simulation



Chen, Hirashita, et al. (2017)



Implemented the above processes into the dust evolution simulation in Aoyama et al. (2017, P4-39)/Hou et al. (2017, S4-3-4).