SIMONS FOUNDATION

FLATIRON INSTITUTE

Dust sputtering by supernova shocks in hydrodynamical simulations

arXiv:1902.01368

Chia-Yu Hu (CCA)

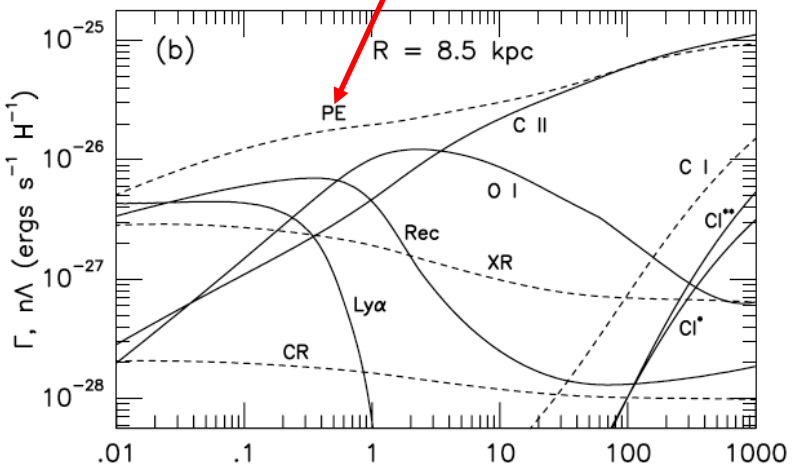
with Svitlana Zhukovska, Rachel Somerville, Thorsten Naab

Dusting the Universe, UA, Tucson

04.03.2019

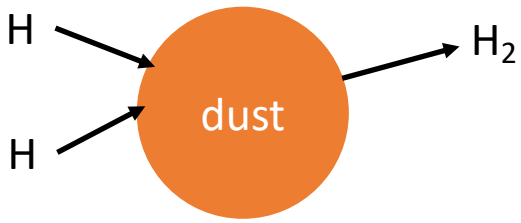
Dust is an important component of the ISM

Dust provides **photoelectric heating**

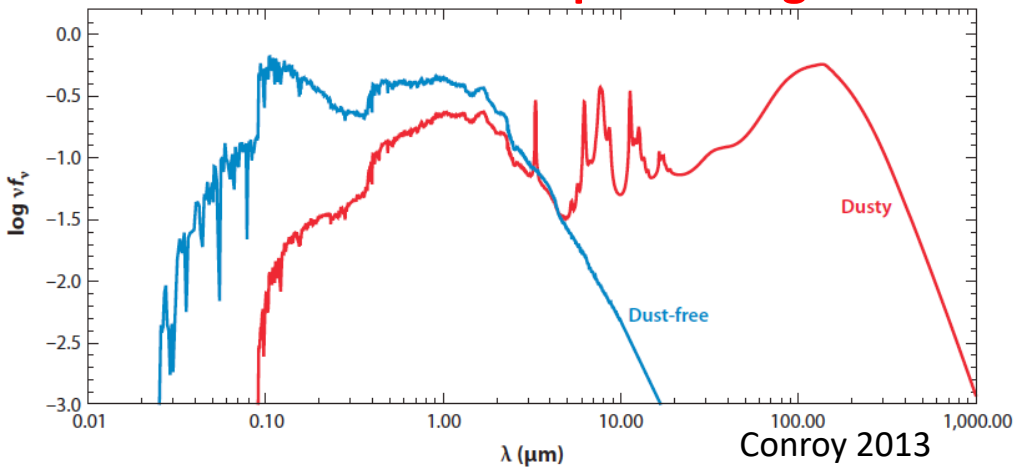


Wolfire 2003

Molecular hydrogen (H_2) forms on the surfaces of dust



Dust modifies the **spectra of galaxies**

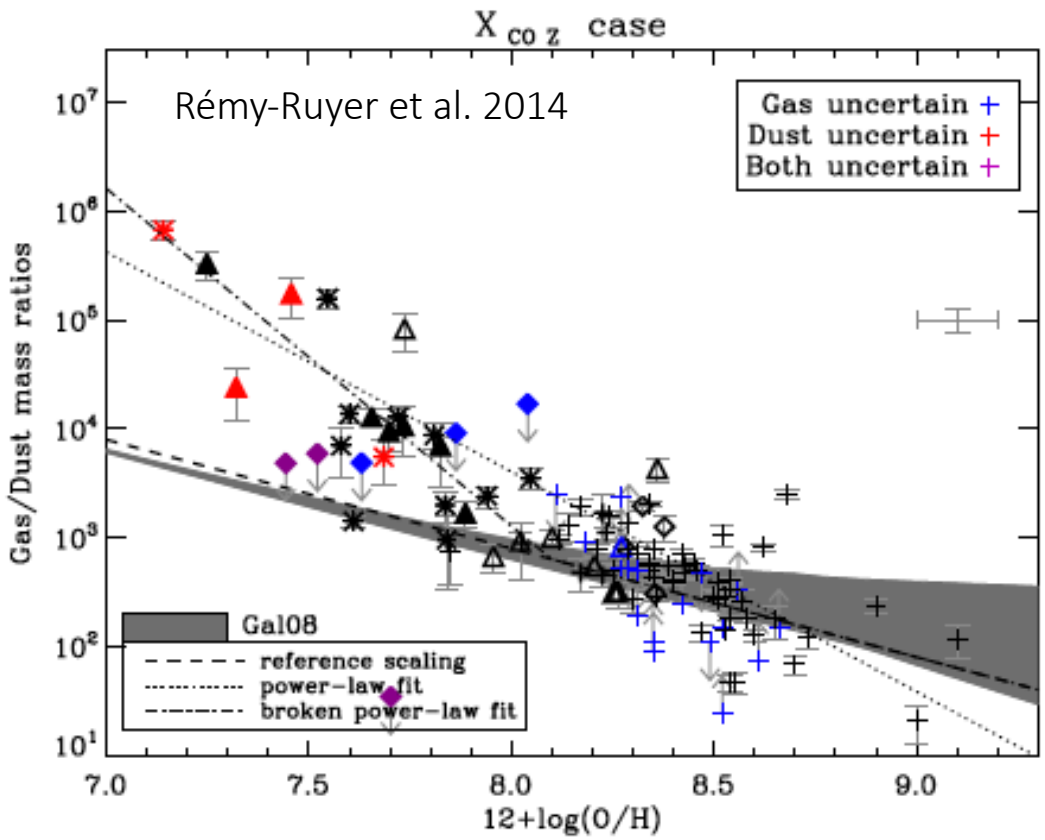


Conroy 2013

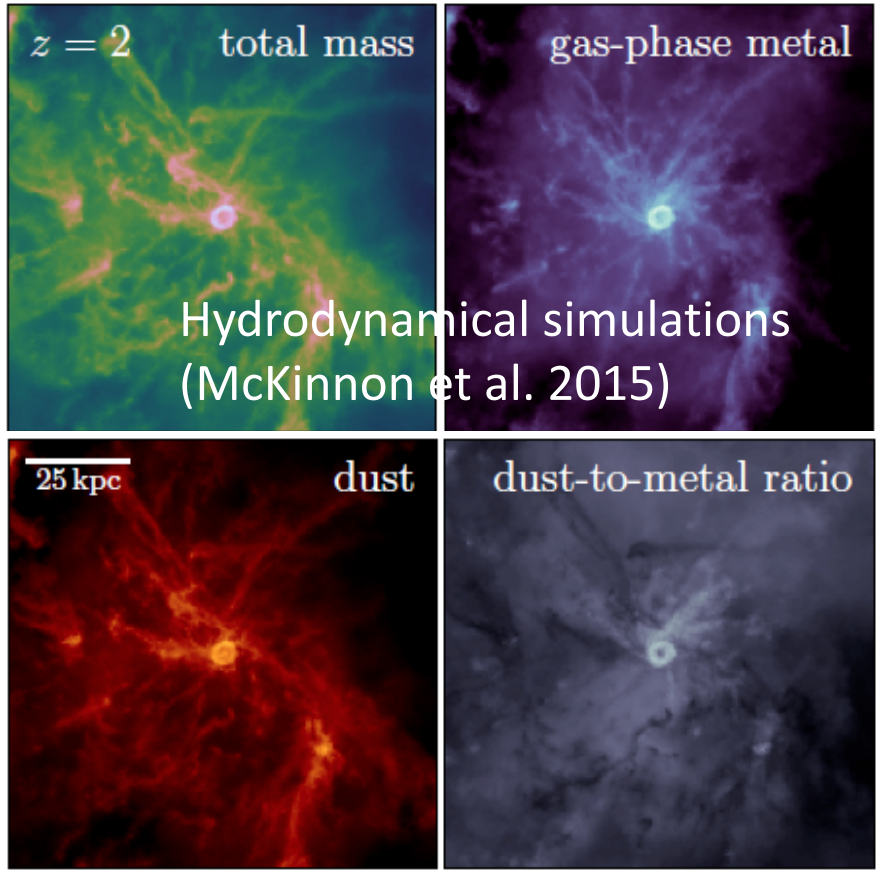
Dust is an important component of the ISM

However, dust is either totally neglected in galaxy formation simulations, or is assumed to linearly scales with metals, which is an oversimplification

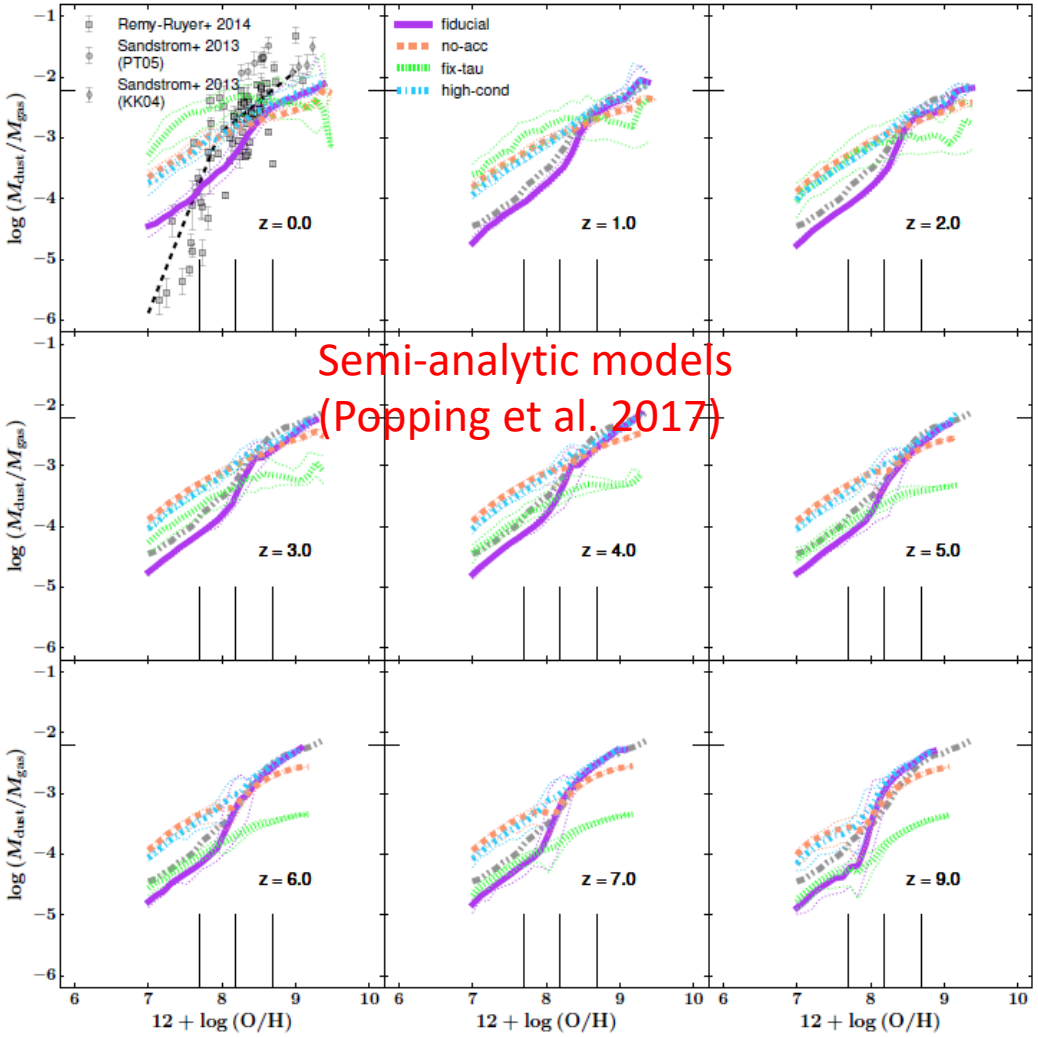
Need to account for dust evolution in galaxy formation simulations!



Dust evolution in cosmological simulations



Hydrodynamical simulations
(McKinnon et al. 2015)



Semi-analytic models
(Popping et al. 2017)

Dust evolution in cosmological simulations

Large-scale cosmological simulations can only reach ~kpc resolution, which is too poor to follow the small-scale physics, e.g. **dust destruction in SN shocks**, dust growth in the ISM, etc.

Therefore, very crude sub-grid models have to be adopted to follow dust evolution

$$\left(\frac{\mathrm{d}M_{i,\mathrm{dust}}}{\mathrm{d}t}\right)_{\mathrm{d}} = -\frac{M_{i,\mathrm{dust}}}{\boxed{\tau_{\mathrm{d}}}}$$

Modeling the small-scale physics directly

Sputtering: collision between gas and dust
return dust material into gas phase

$$\frac{\mathrm{d}m_{\mathrm{dust}}}{\mathrm{d}t} = \frac{3n_{\mathrm{H}}m_{\mathrm{dust}}}{a}\boxed{Y_{\mathrm{tot}}}$$

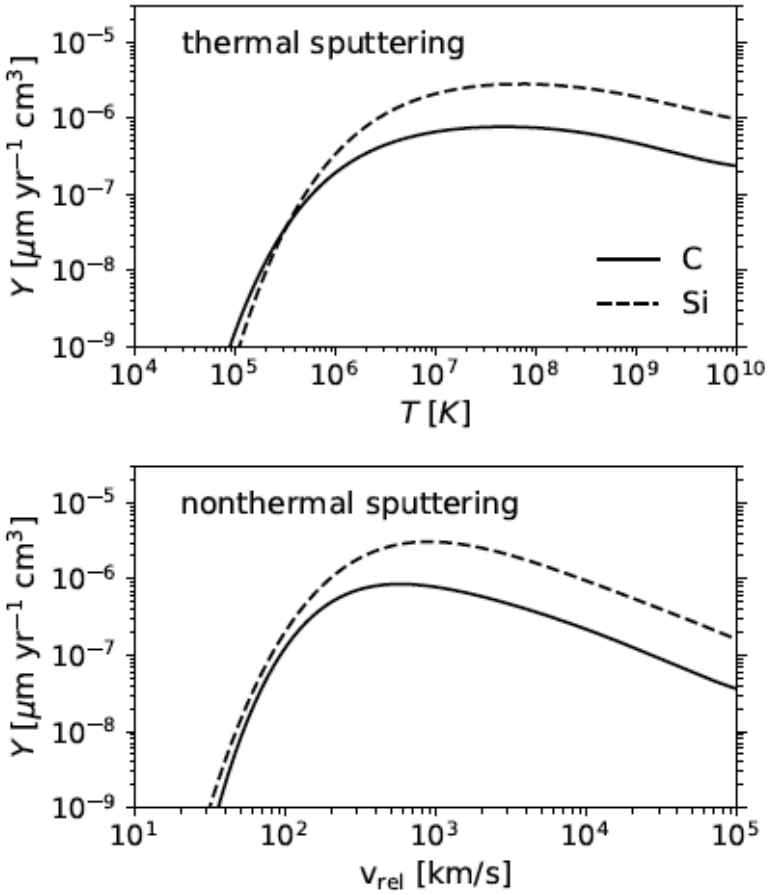
One-fluid approach:
dust is spatially coupled with gas

But with nonzero dust-gas relative velocity v_{rel}
-> integrate the equation of motion for dust

$$\frac{\mathrm{d}\mathbf{v}_{\mathrm{rel}}}{\mathrm{d}t} = \mathbf{a}_{\mathrm{drag}} + \mathbf{a}_{\mathrm{beta}} - \mathbf{a}_{\mathrm{hydro}}$$

direct collision
+
plasma drag

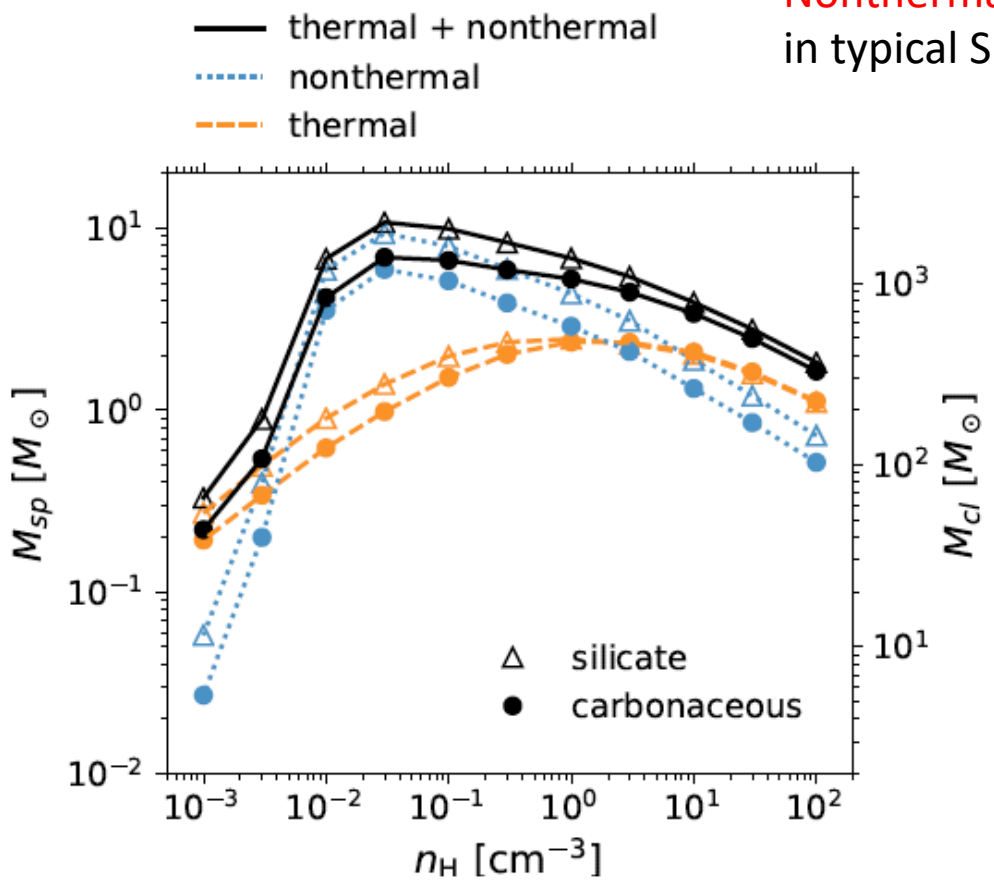
betatron
acceleration



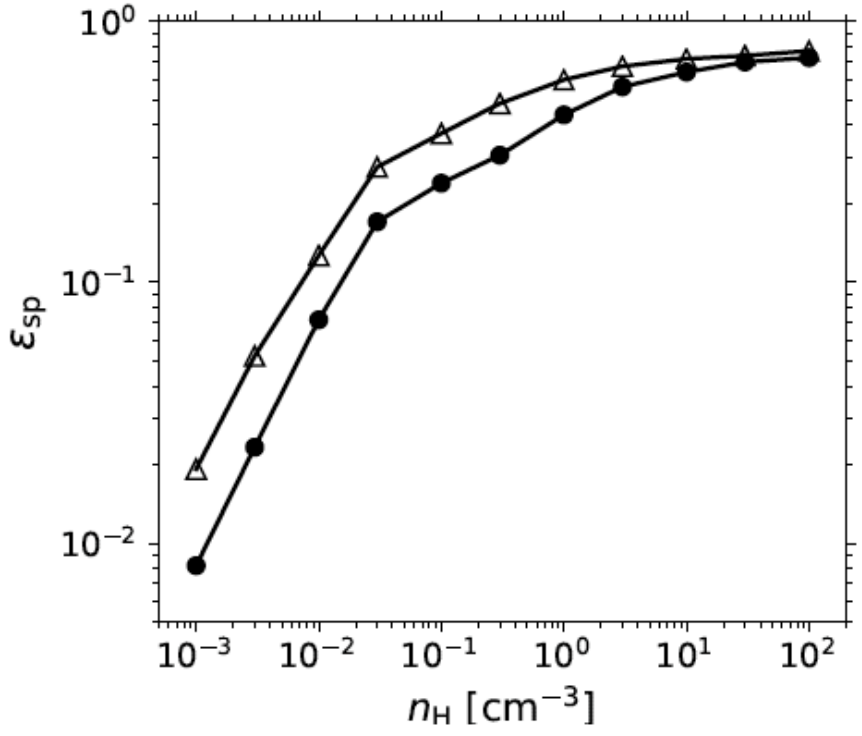
Dust destruction by single SN in a uniform medium

Nonthermal sputtering dominates
in typical SN environments

destroyed
dust mass



ambient density

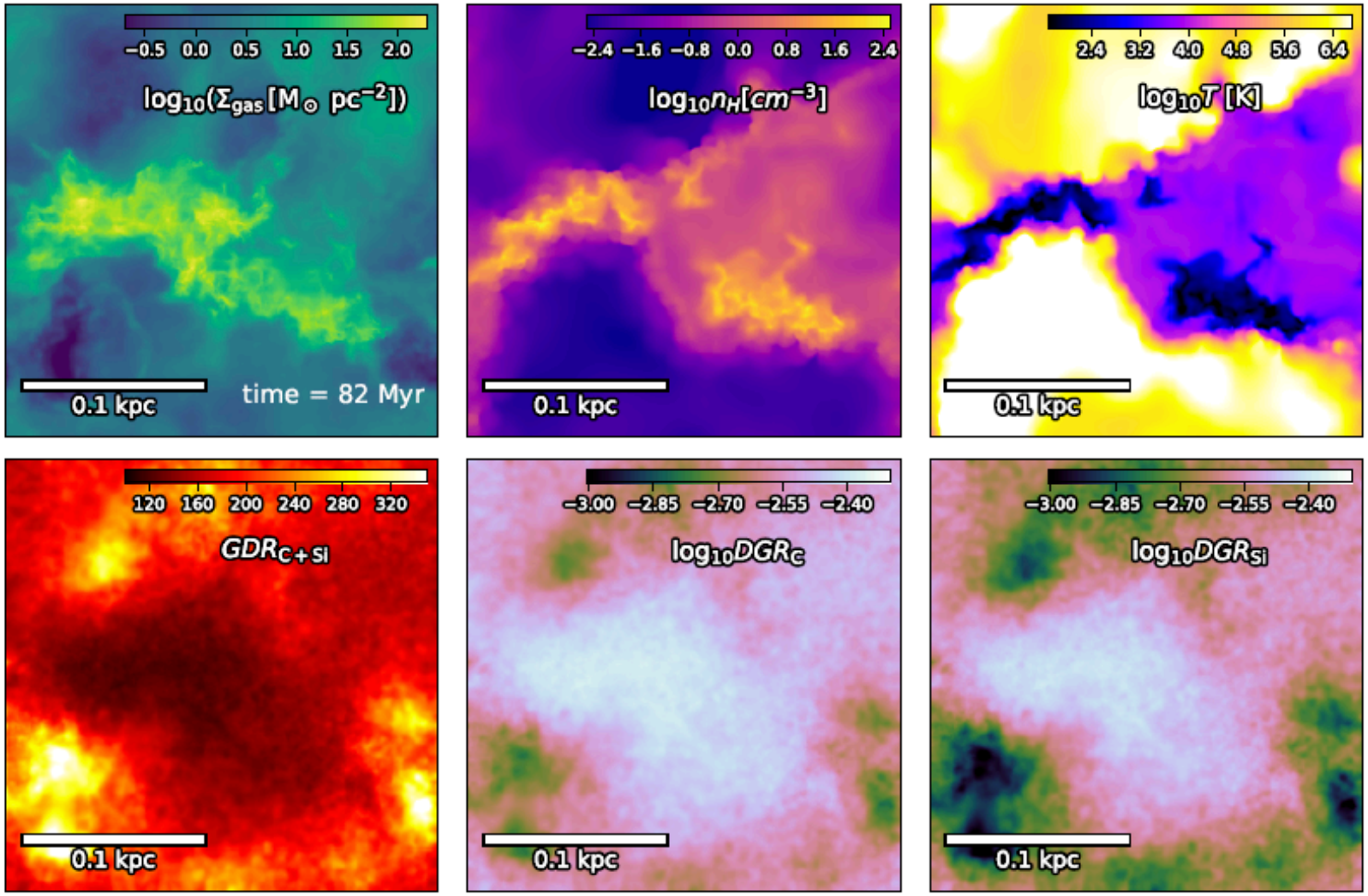


Dust destruction in a multiphase ISM

solar neighborhood conditions

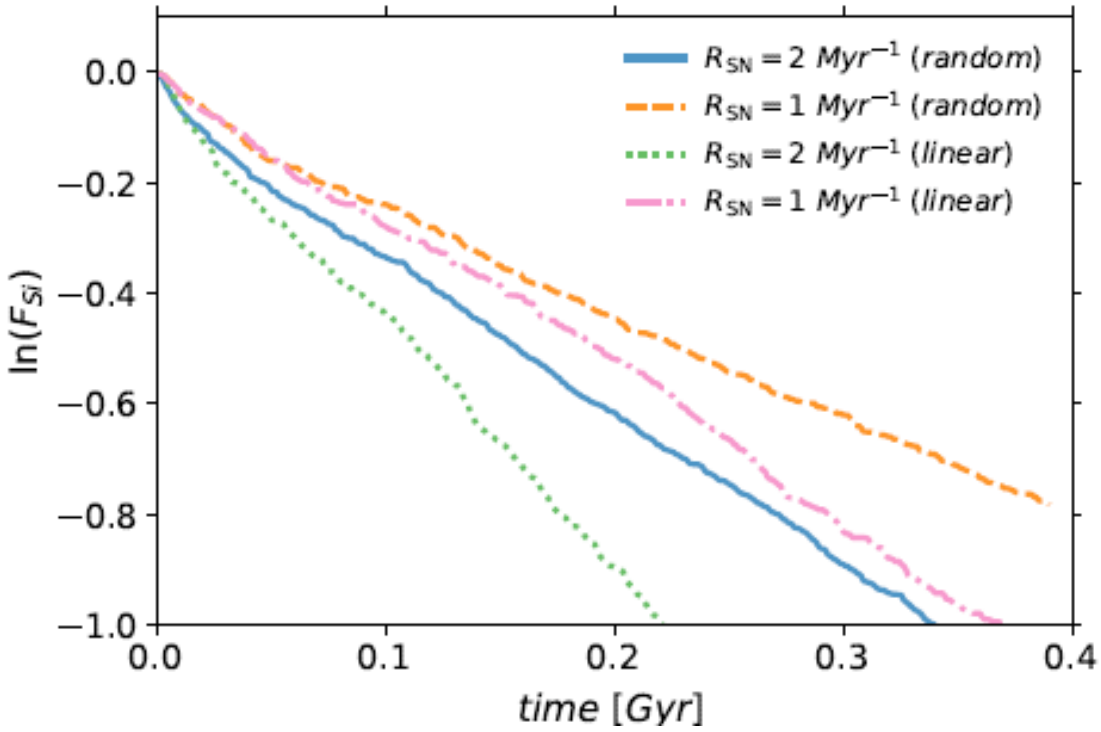
gas properties:

dust properties:



movie here

Dust destruction timescales

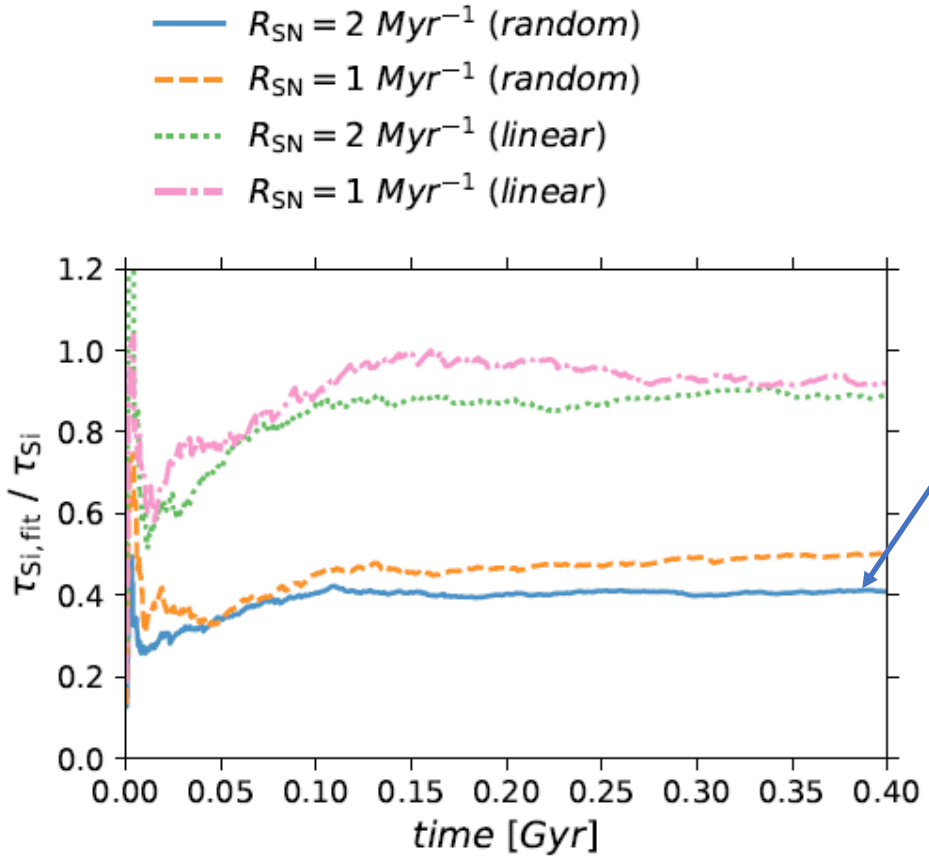


	R2-rand	*R1-rand*	*R2-lin*	*R1-lin*
$\tau_{\rm Si}$ (Gyr)	0.35	0.50	0.23	0.36
$\tau_{\rm C}$ (Gyr)	0.44	0.64	0.29	0.46

(N.B. depending on the assumed SN rate and energy!)

$$\tau = \frac{M_{\rm gas}}{\delta_{\rm SN} R_{\rm SN} M_{\rm cl}}$$

Comparing to the single SN results



Applying the results of single SN to the SNe in the multi-phase ISM, destruction times become ~ 40% lower than the actual values

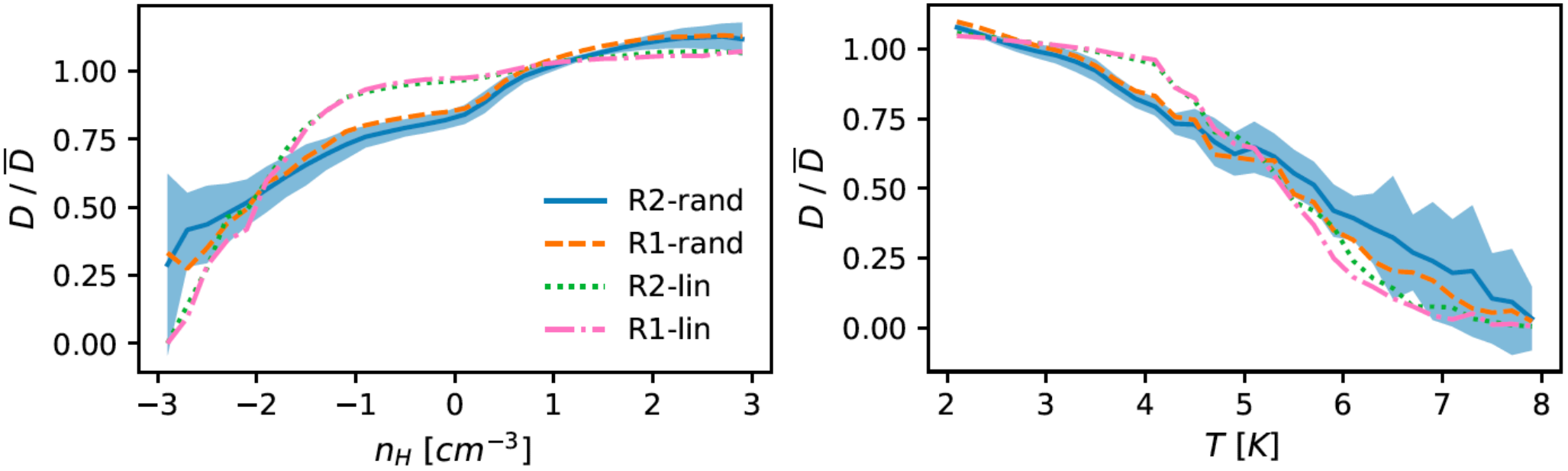
SNe that occur in preexisting bubbles do not destroy dust as efficiently since **there is little dust left**

- Effectively reduce the SN rate by 0.4

DGR spatial variations

Dust destruction + incomplete turbulent gas mixing

25% DGR deficit in the volume-filling warm phase (10^4K) relative to the cold clouds (10^2K)



Summary

First attempt in following the dust destruction directly in 3D hydro simulations:

- nonthermal sputtering dominates for typical SN environments
- $\tau \sim$ 0.4 Gyr for solar-neighborhood conditions (slightly faster for silicate dust)
- SN correction factor $\sim$ 0.4 comes out naturally from simulations
- DGR deficit $\sim$ 25% in the warm phase (10^4K) relative to the cold phase (10^2K)

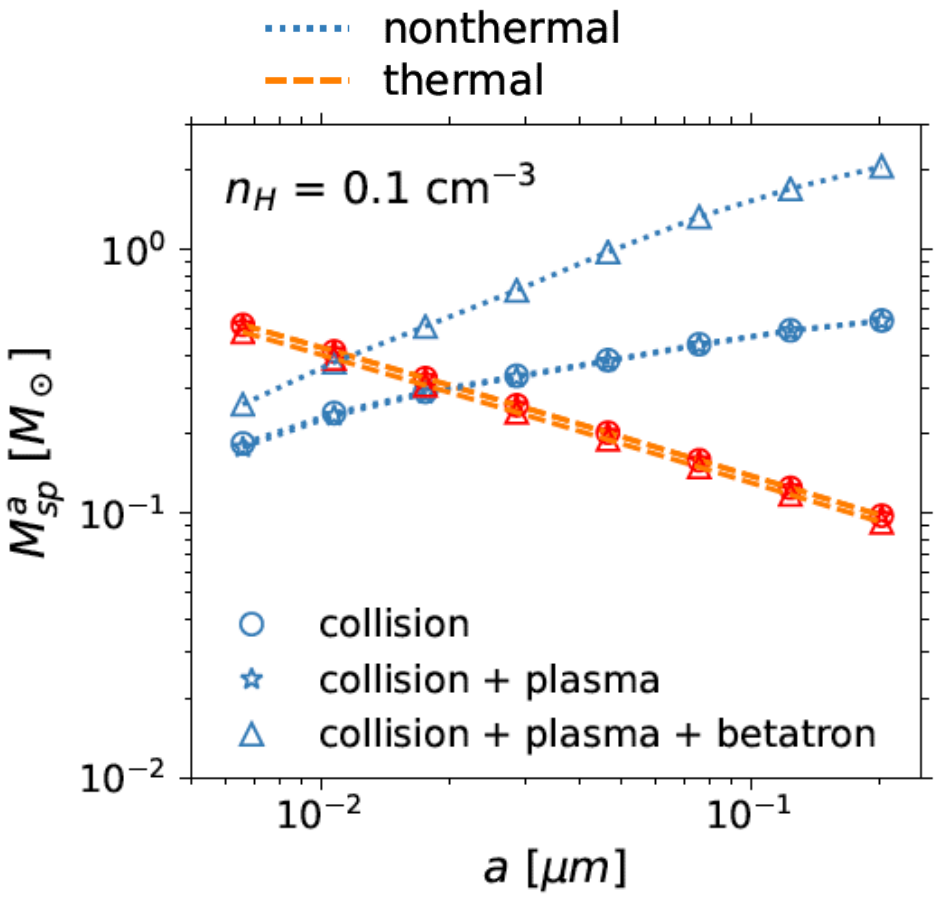
Future directions:

- dust growth in the ISM, AGB dust
- evolution of size distribution
- applications to dwarf galaxies, high-z galaxies

Backup slides

Dust destruction by single SN in a uniform medium

destroyed dust mass

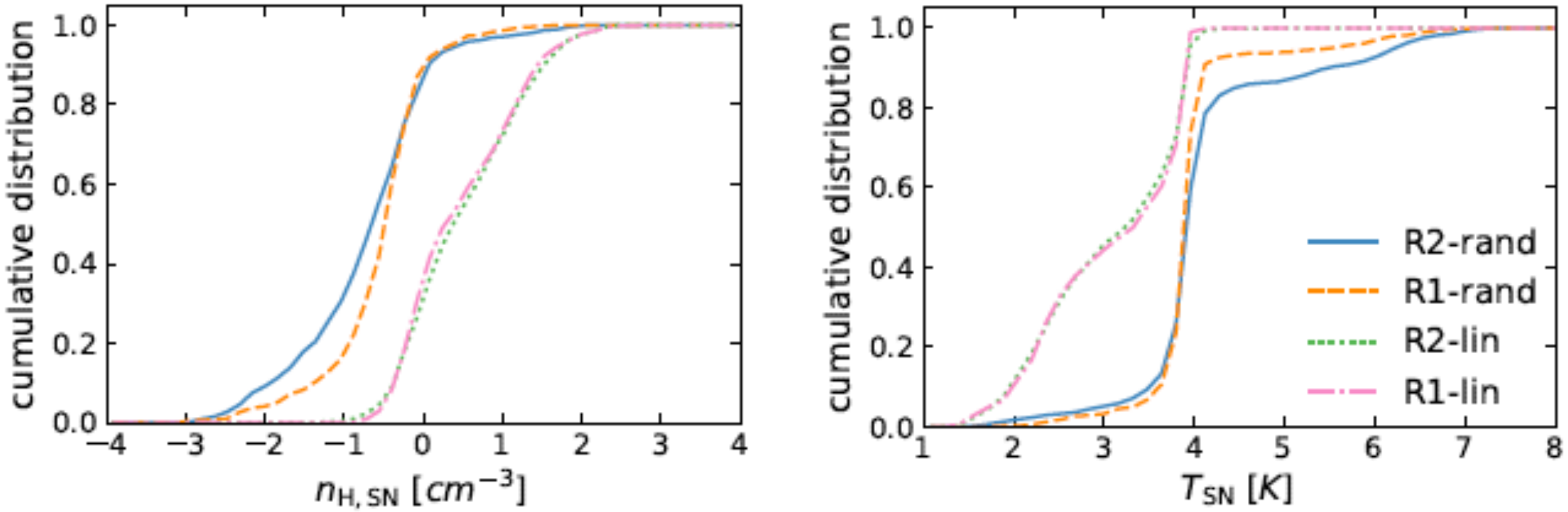


Grain size

$$\frac{\mathrm{d}m_{\mathrm{dust}}}{\mathrm{d}t} = \frac{3n_{\mathrm{H}}m_{\mathrm{dust}}}{a}Y_{\mathrm{tot}}$$

Small / Large grains destroyed via thermal / nonthermal sputtering

SN environments



Convergence study for single SN sputtering