Depletion of refractory carbon using Monte Carlo models for dust coagulation

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The Pledge

- Inner Solar System is severely depleted in refractory carbon, i.e. carbonaceous compounds locked in the solid phase. ***We don't know how!***
- Processes early during the formation of the Solar System set the tone for the chemical composition of the rocky objects of the Solar System. Understanding them can help us broaden our perspectives of planet formation.

The Turn

- We use a 1-Dimensional Monte Carlo code to simulate the dust evolution in protoplanetary disks at 1 AU.
- We implement a carbon depletion process called photolysis, where carbonaceous material in the surface of the dust grains is removed when exposed to FUV photons.
- For the FUV flux, we implement a simple analytical model and benchmark it with FUV flux data from thermochemical radiative transfer code DALI

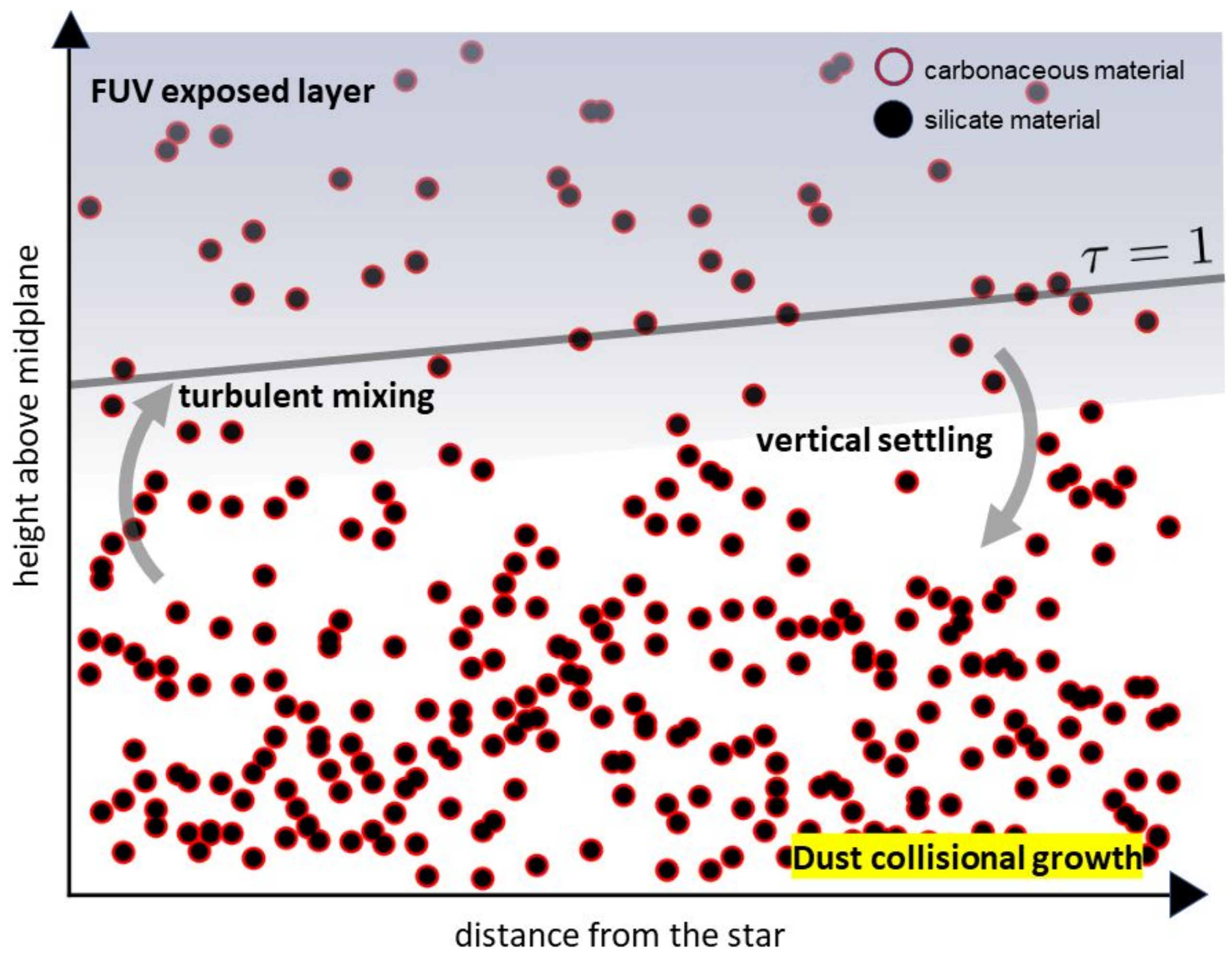

Figure 1. A vertical slice showing the different processes involved in our model. We simulate a vertical column at 1 AU.

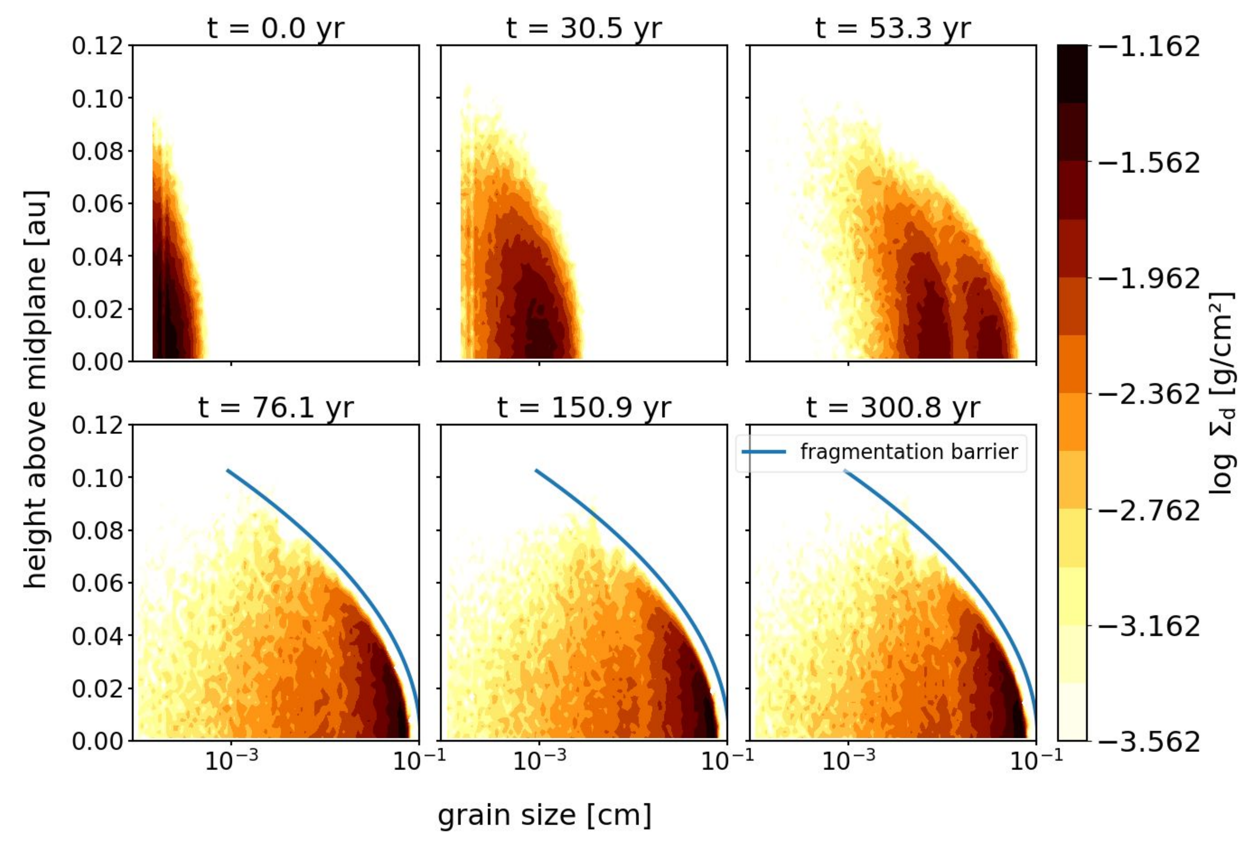

Figure 2. The time evolution of dust surface density with grain size and vertical height in the x and y axis. Here we only include coagulation and fragmentation as collisional outcomes.

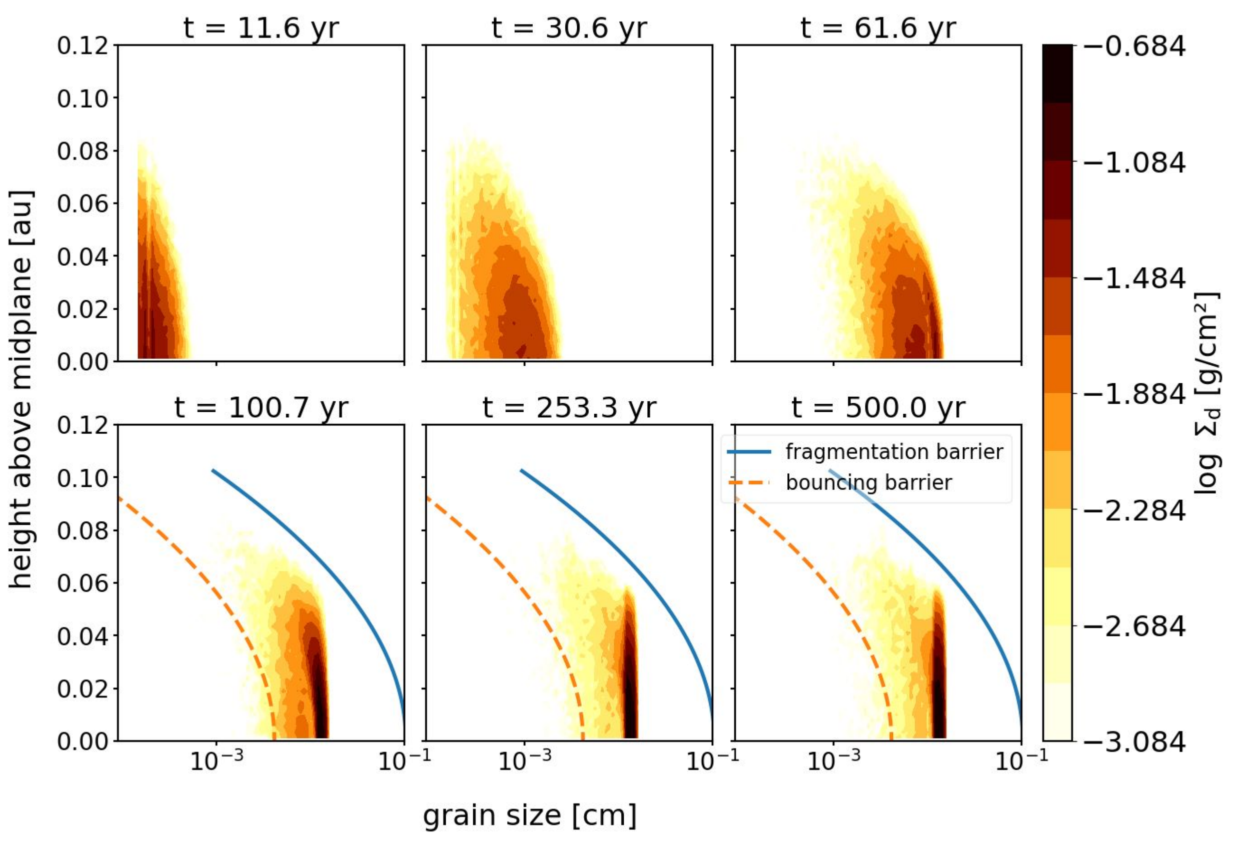

Figure 3. Same as Figure 2 but with bouncing as an additional dust collisional outcome.

Bouncing reduces the small grain population and this has implications for dust chemistry.

The Prestige

- Mass redistribution due to collisional growth accelerates the depletion process by replenishing carbon in the FUV exposed layer.
- We calculated carbon depletion timescales similar to Binkert and Birnstiel 2023 and arrived at 100-300 kyr depending on the strength of the turbulence.
- Bouncing decelerates the depletion of carbon!

VIEW MOVIES

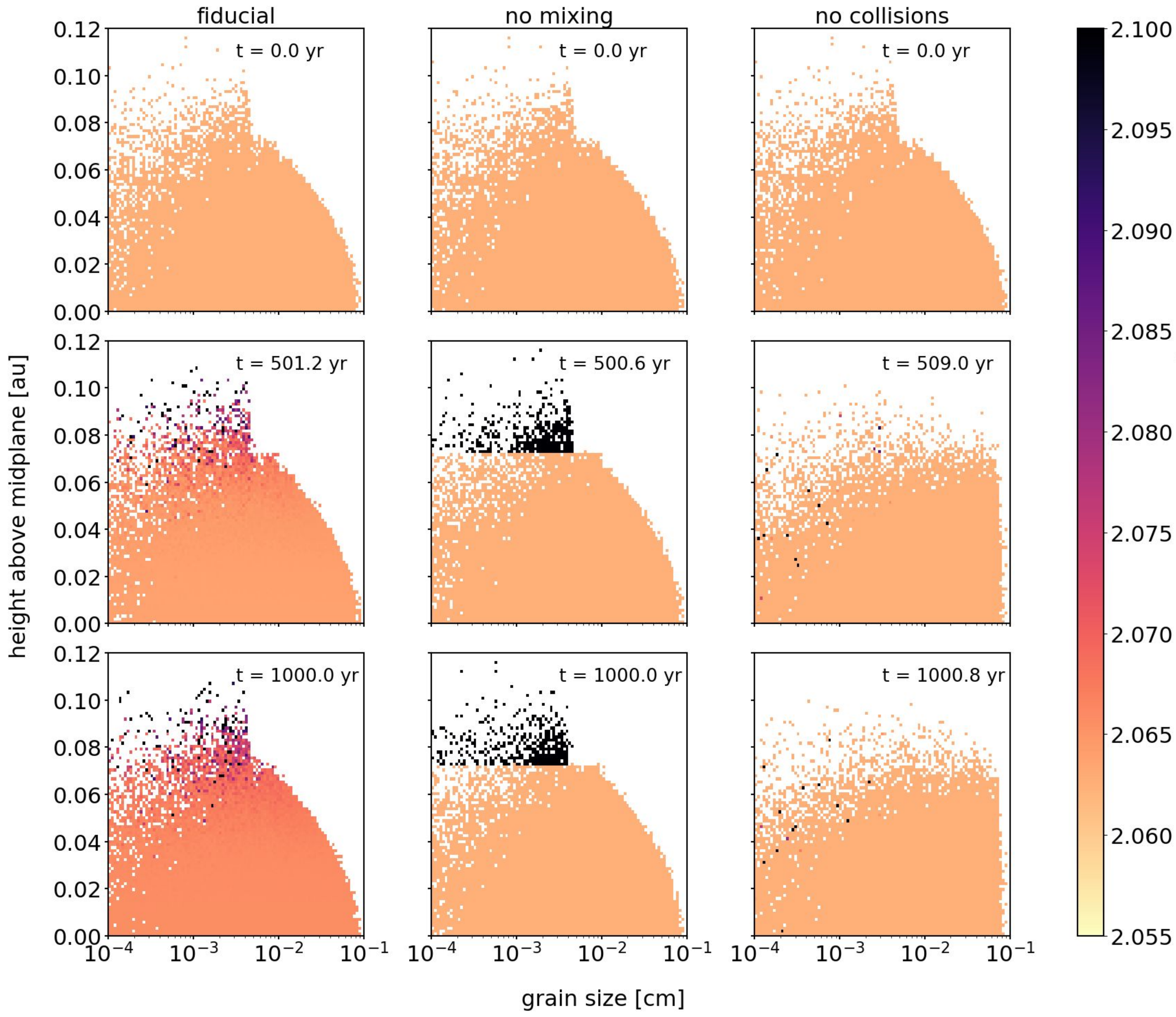

Figure 4. Time evolution of internal density of the swarms with grain size and vertical height in the x and y axis. Higher the internal density, higher the depletion. Fiducial case is where collisions and mixing are included. We show that both processes are important for refractory carbon depletion.

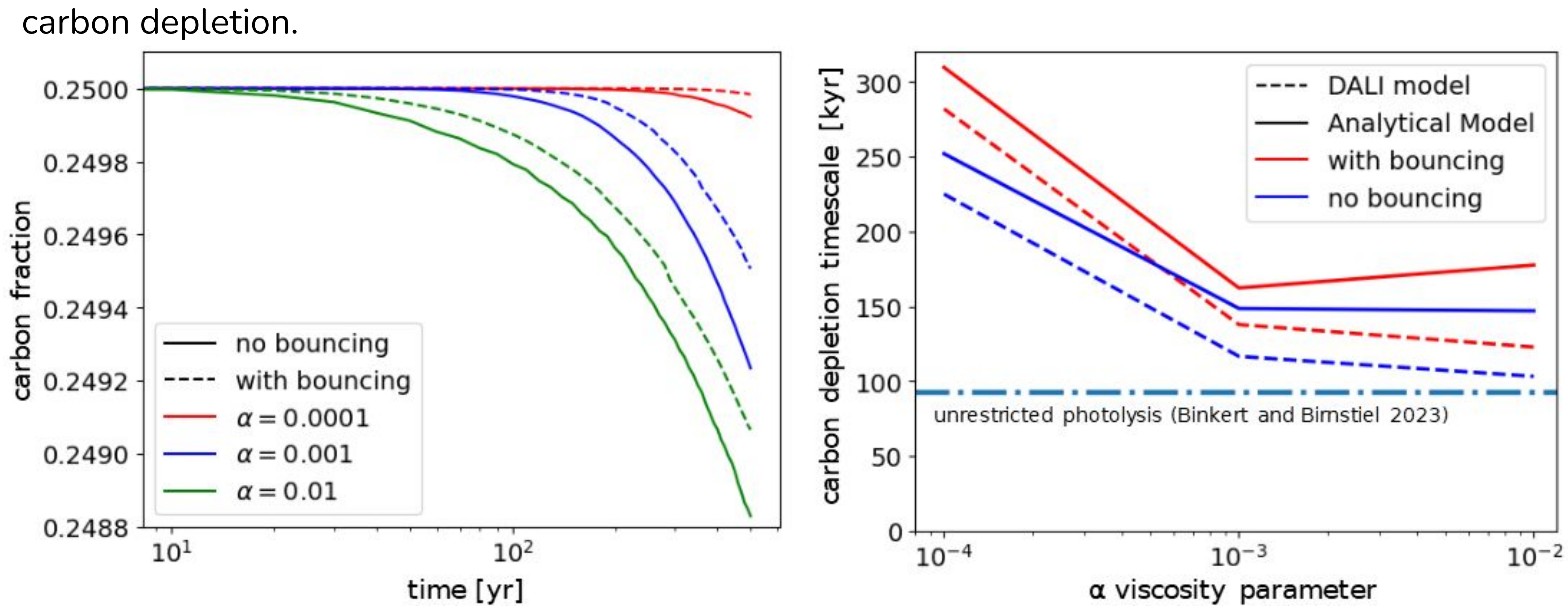

Figure 5. (Left) Evolution of carbon mass fraction for simulations with fragmentation and bouncing and different turbulence strengths. (Right) Carbon depletion timescales for the simulations with different turbulence strength. The solid lines are for the analytical FUV flux prescription and the dashed lines are for FUV flux from a simulation in DALI.

Conclusions

- Photolysis could explain the depletion of refractory carbon in the inner Solar System only in combination with another process.
- Bouncing slows surface level chemical reactions making it an important collision outcome to be included in simulations. (Fig. 5)
- Mass redistribution during collisional growth is an important process to be taken into account for dust chemistry. (Fig. 4)

Credit Roll

Binkert, Fabian, and Til Birnstiel. "Carbon Depletion in the Early Solar System." *Monthly Notices of the Royal Astronomical Society* 520, no. 2 (February 7, 2023): 2055–80. https://doi.org/10.1093/mnras/stad182.

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