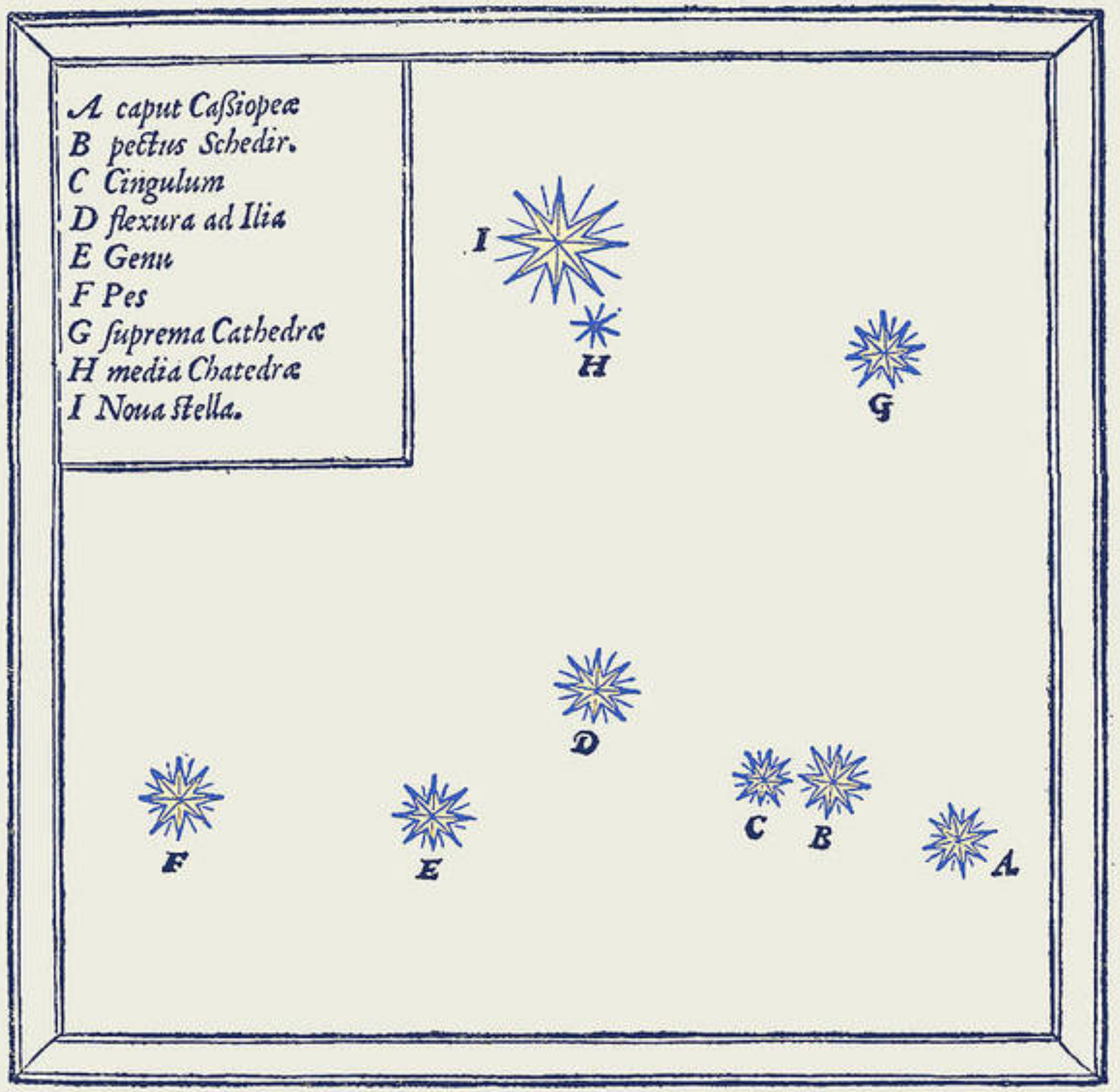
MODELING DUST FORMATION IN SUPERNOVAE

Arka Sarangi

DARK, Niles Bohr Institute

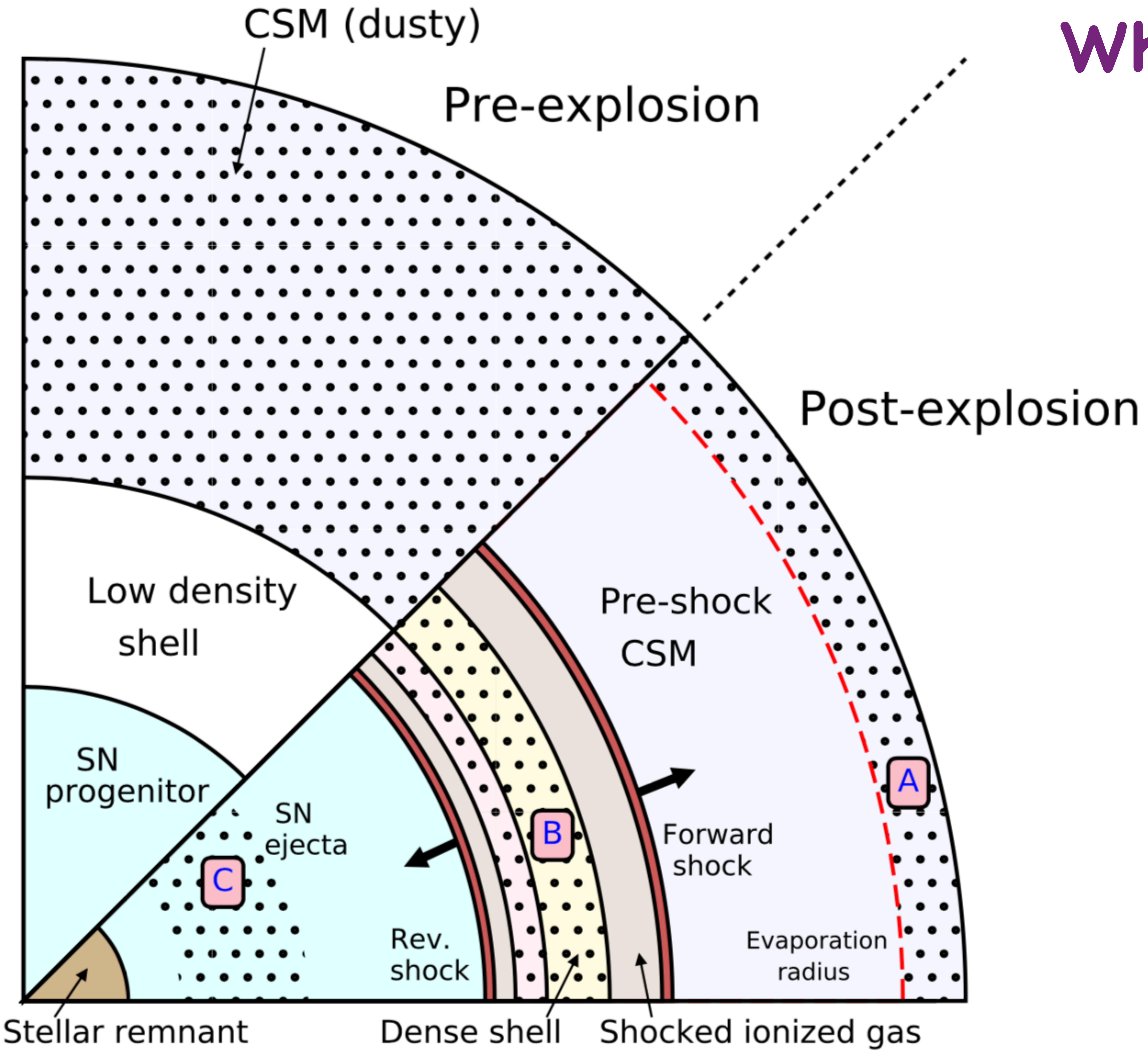
Copenhagen



Diſtantiam verò huius ſtellæ à fixis aliquibus in hac Caſsiopeiæ conſtellatione, exquiſito inſtrumento, & omnium minutorum capacj, aliquoties obſeruaui. Inueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir appellata B, 7. partibus & 55. minutis: à ſuperiori verò

They are here !

Where is the dust located?



A) Pre-existing dust

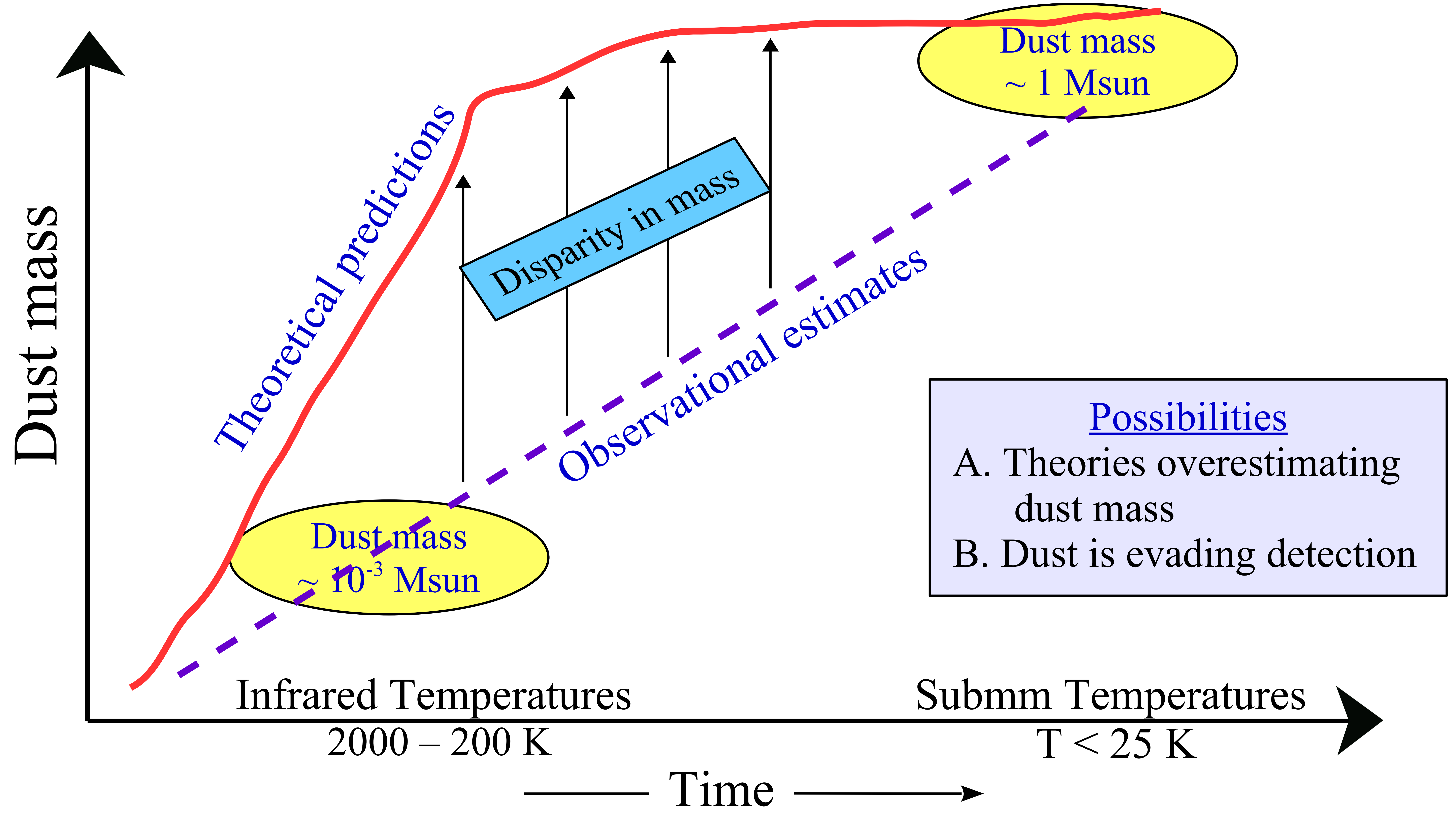
B.1) Newly formed in the shocked ejecta

B.2) Newly formed in shocked circumstellar gas

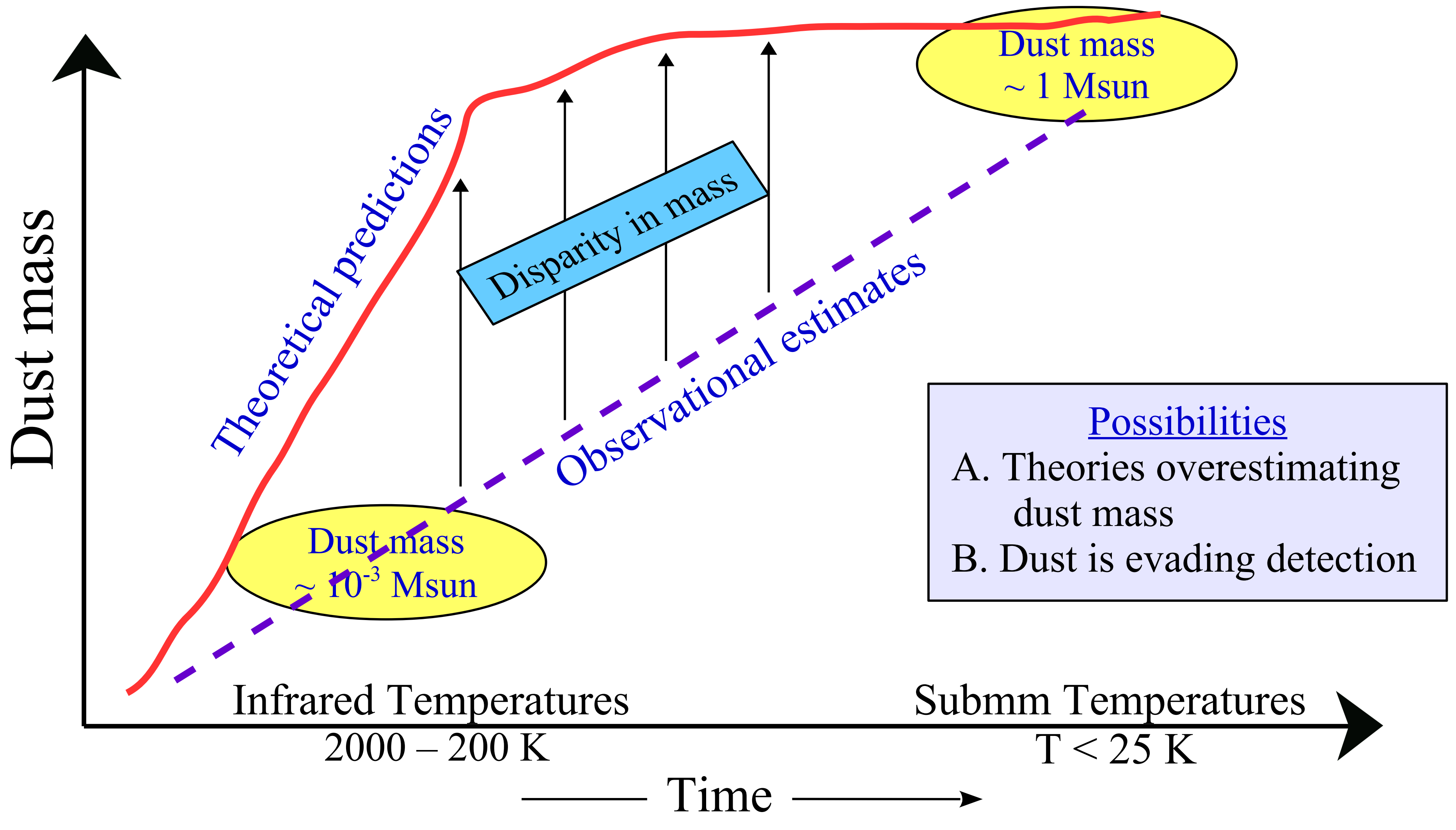
C) Newly formed in ejecta

Sarangi & Cherchneff 2015, Sarangi et al. 2018b, Sarangi & Slavin 2022

How much dust is formed?



Gall et al. 2014
Matsuura et al. 2015, 2017
Sarangi et al. 2015, 2018a, 2022
Szalai et al. 2013, 2019
De Looze et al. 2019
Wesson and Bevan 2021
Niculescu-Duvaz et al. 2021
Dwek and Arendt 2015
Dwek, Sarangi and Arendt 2019



Grain size distribution is very much dependent on the time of dust formation and respective gas densities. The evolution of the SNR, dust processing in the reverse shock, all will depend on dust formation timescales.

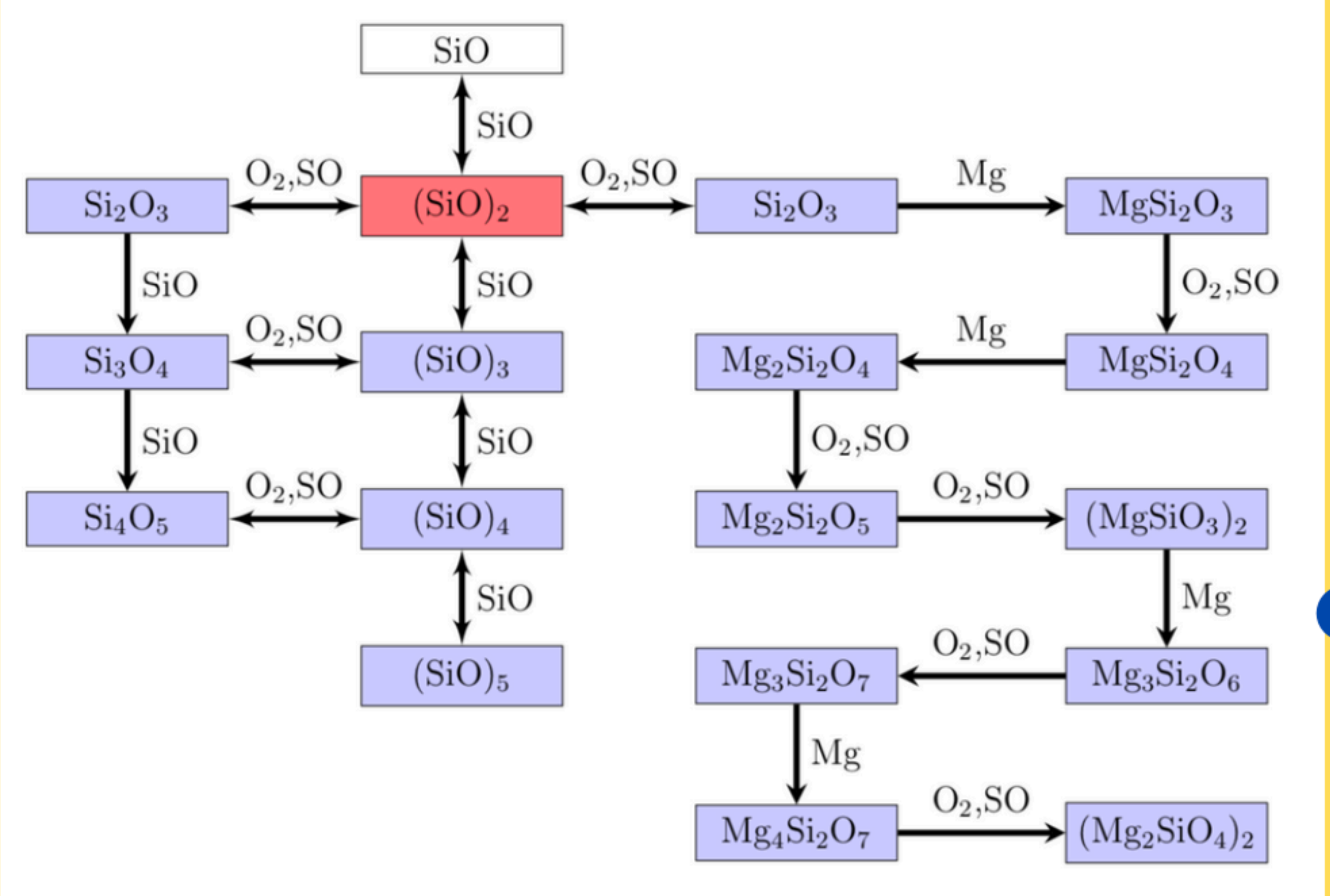
Chemical bonds formed at low temperatures are most often only through physisorption which are very unstable, will not survive in evolution timescales

The tetrahedral Si-O bonds giving rise of 9.7 and 18 micron silicate features Are result of condensation at high temperature - accounting for SiO abundances

Dust formation is dynamical and not phenomenological : otherwise dust would have formed in Type Ia's and stripped envelope SNe at the same efficiency

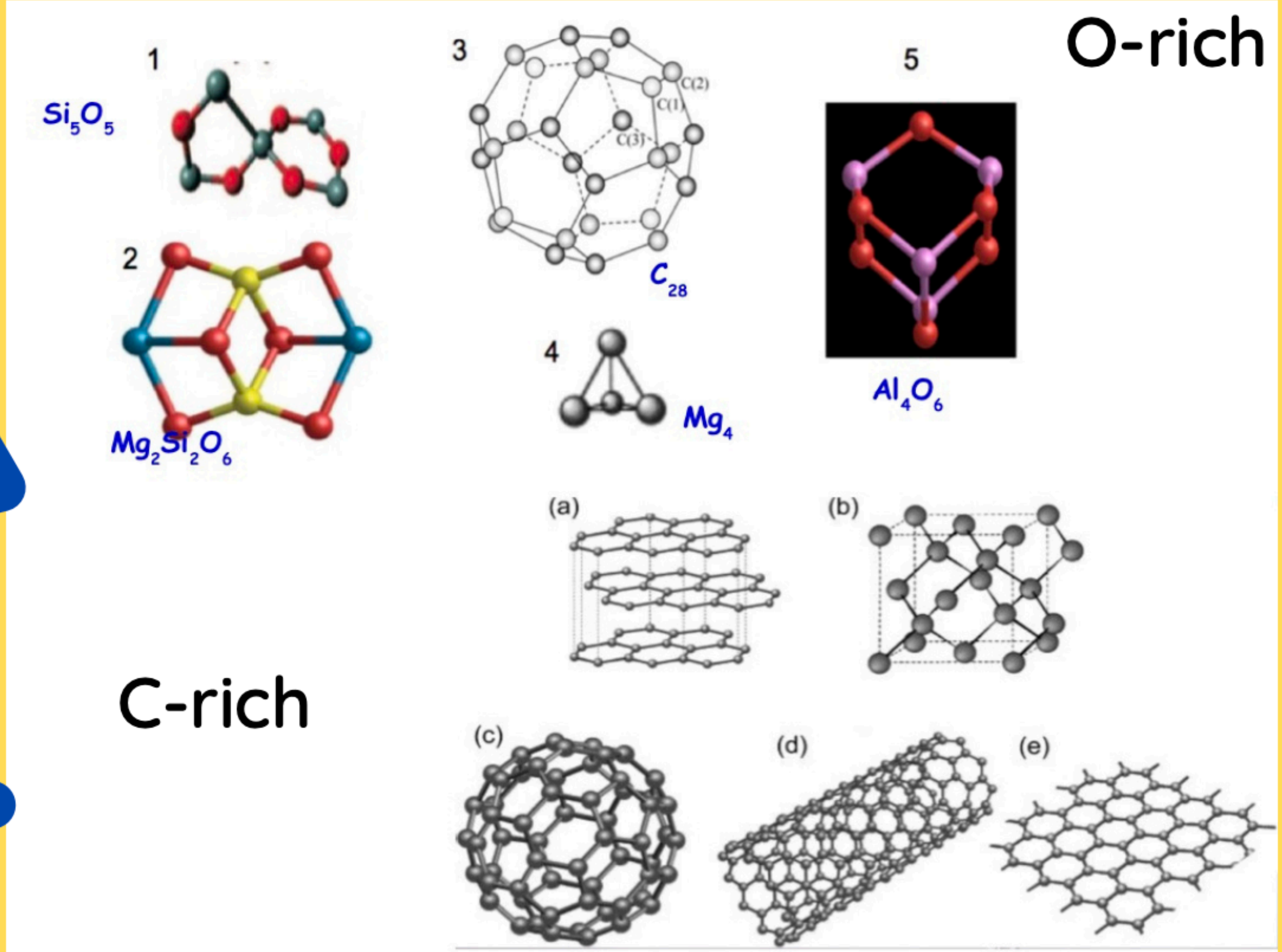
Controlled rate of dust formation helps in explaining systematic asymmetries in atomic lines.

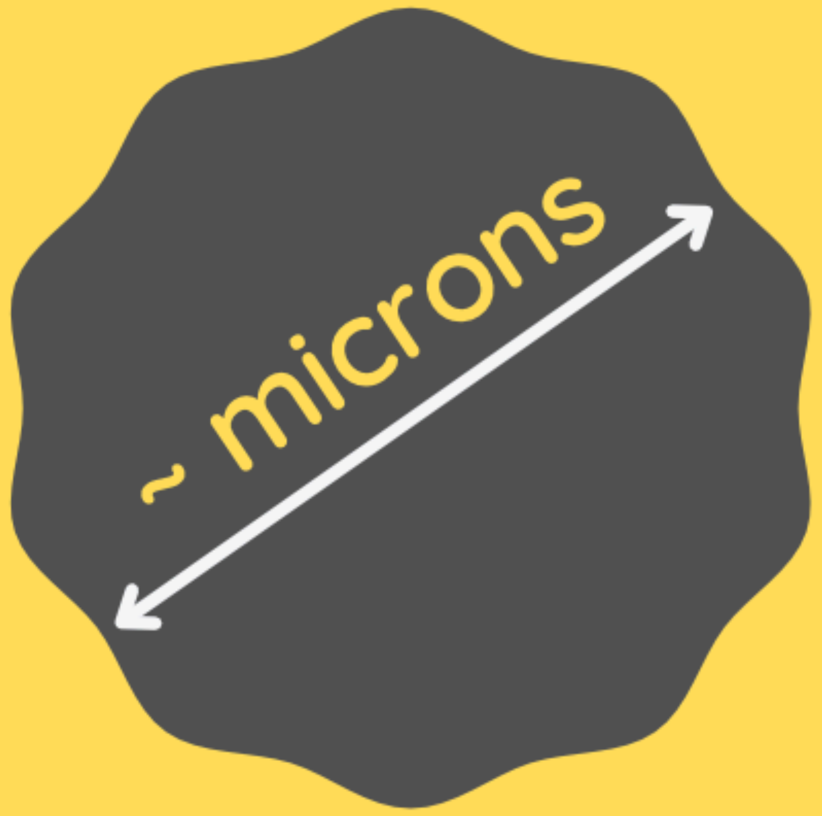
From gas to dust



Sarangi & Cherchneff 2015

Nucleation





Condensation : coagulation, coalescence , late accretion

Species of interest

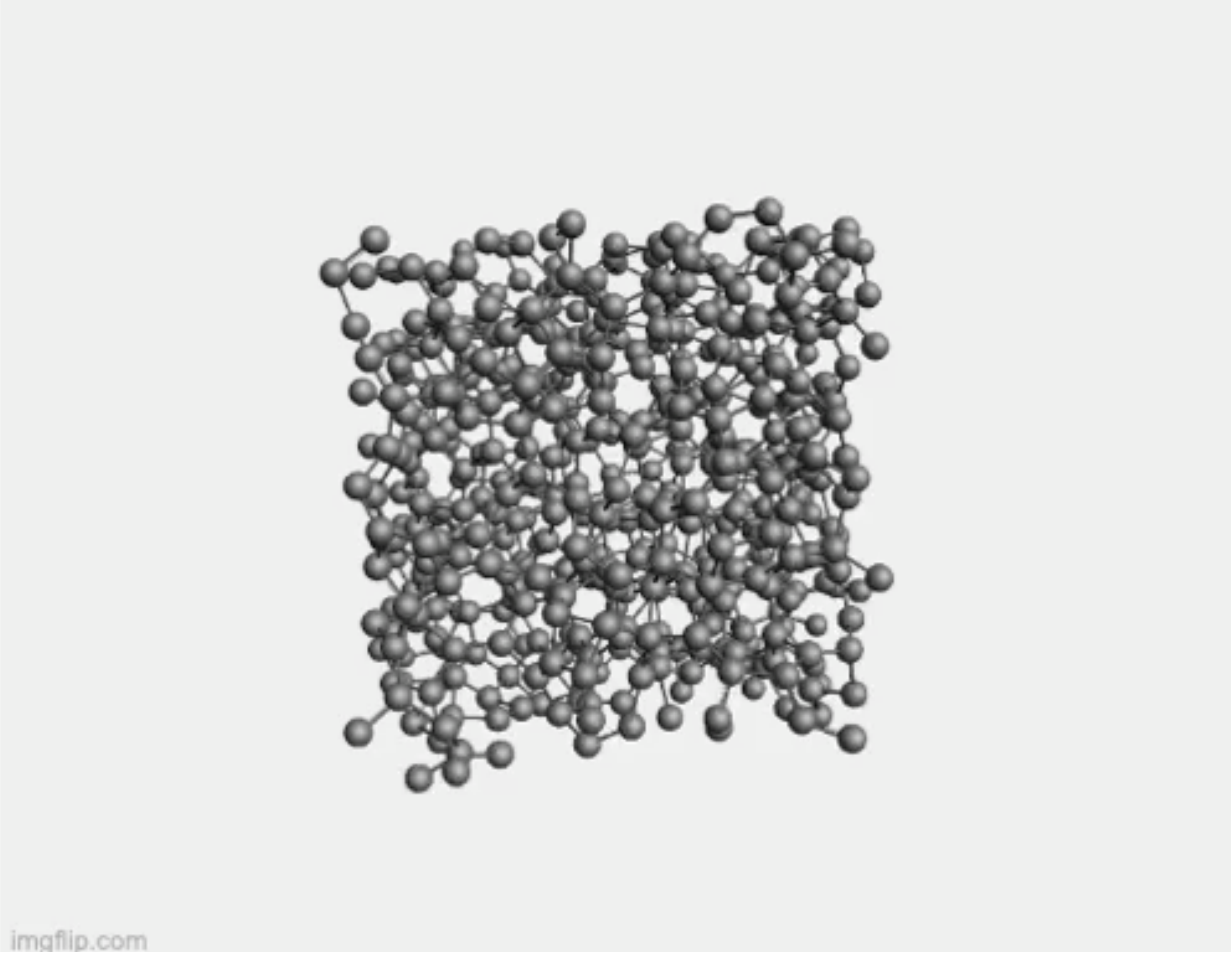
Among ~ 200 species, the important ones are the following:

Molecules

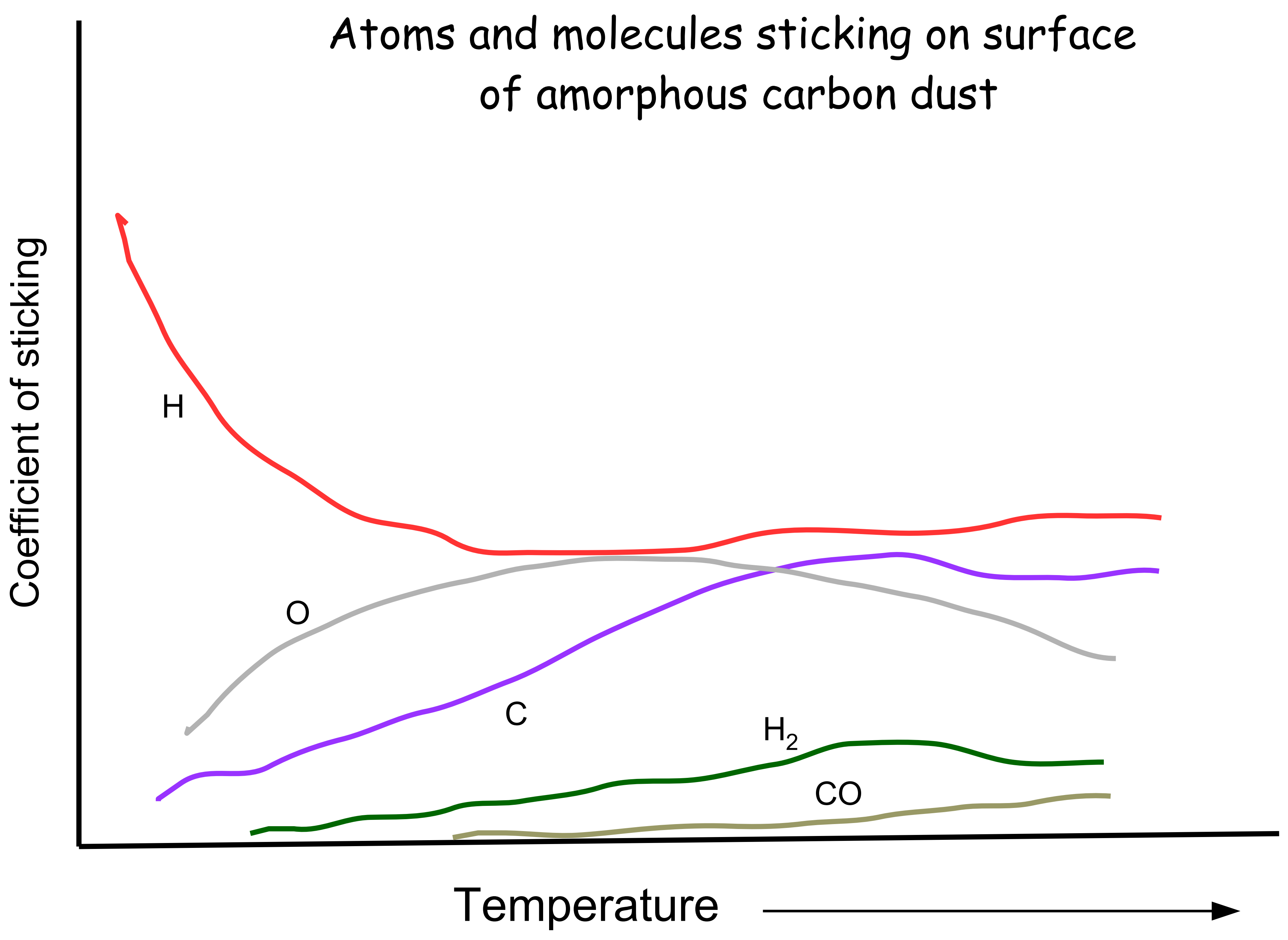
SiO, CO, O_2, SiS, SO, SiC
CS, CO_2, N_2, NO, Si_mO_n

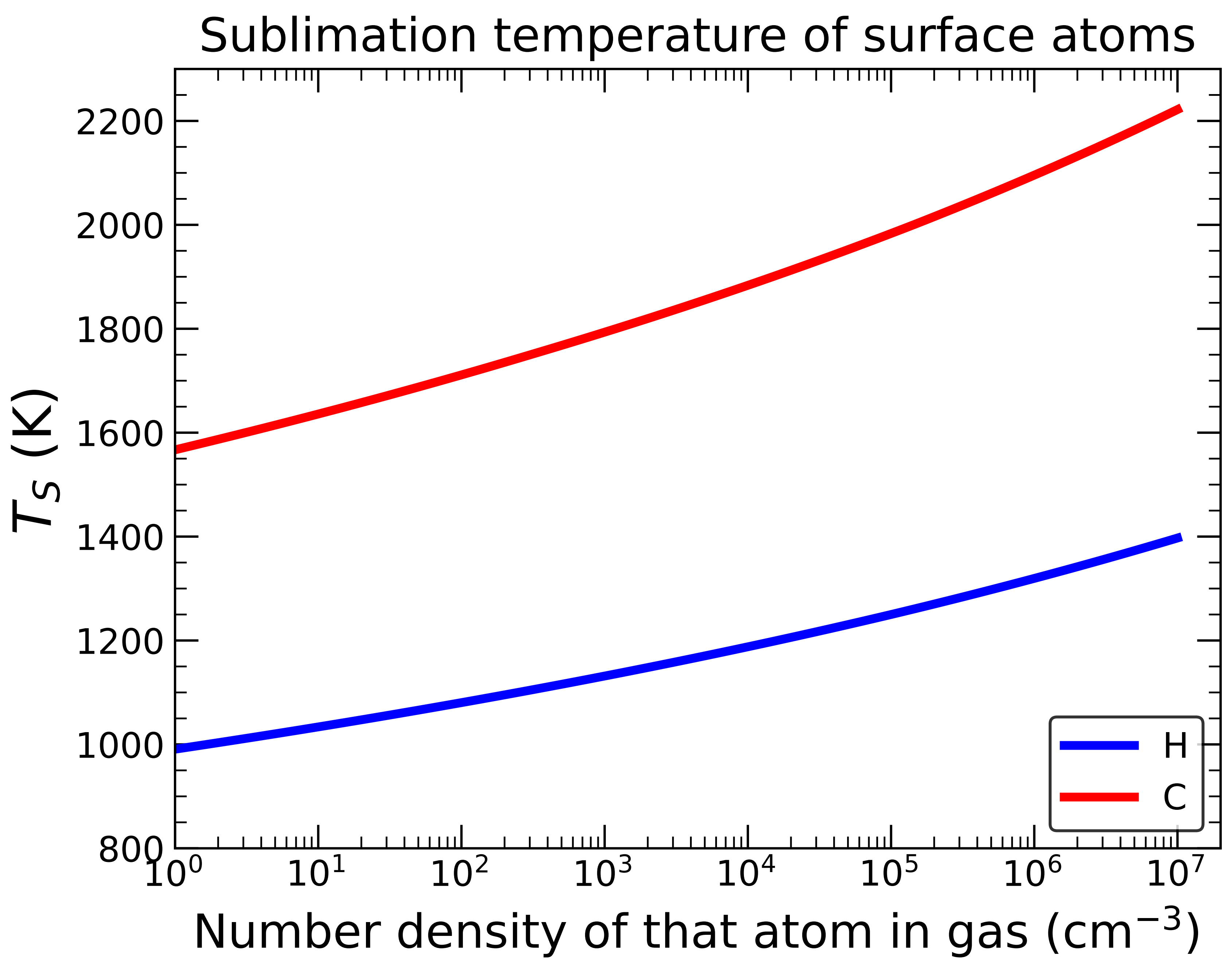
Dust type	Precursor
Mg-silicates	$(Mg_2SiO_4)_2$
Alumina	$(Al_2O_3)_4$
Amorphous Carbon	C_{28}
Silicon Carbide	$(SiC)_4$
Pure Silicon	Si_4
Pure Iron	Fe_4
Pure Magnesium	Mg_4
Iron Sulphide	$(FeS)_4$

Growth of carbonaceous dust

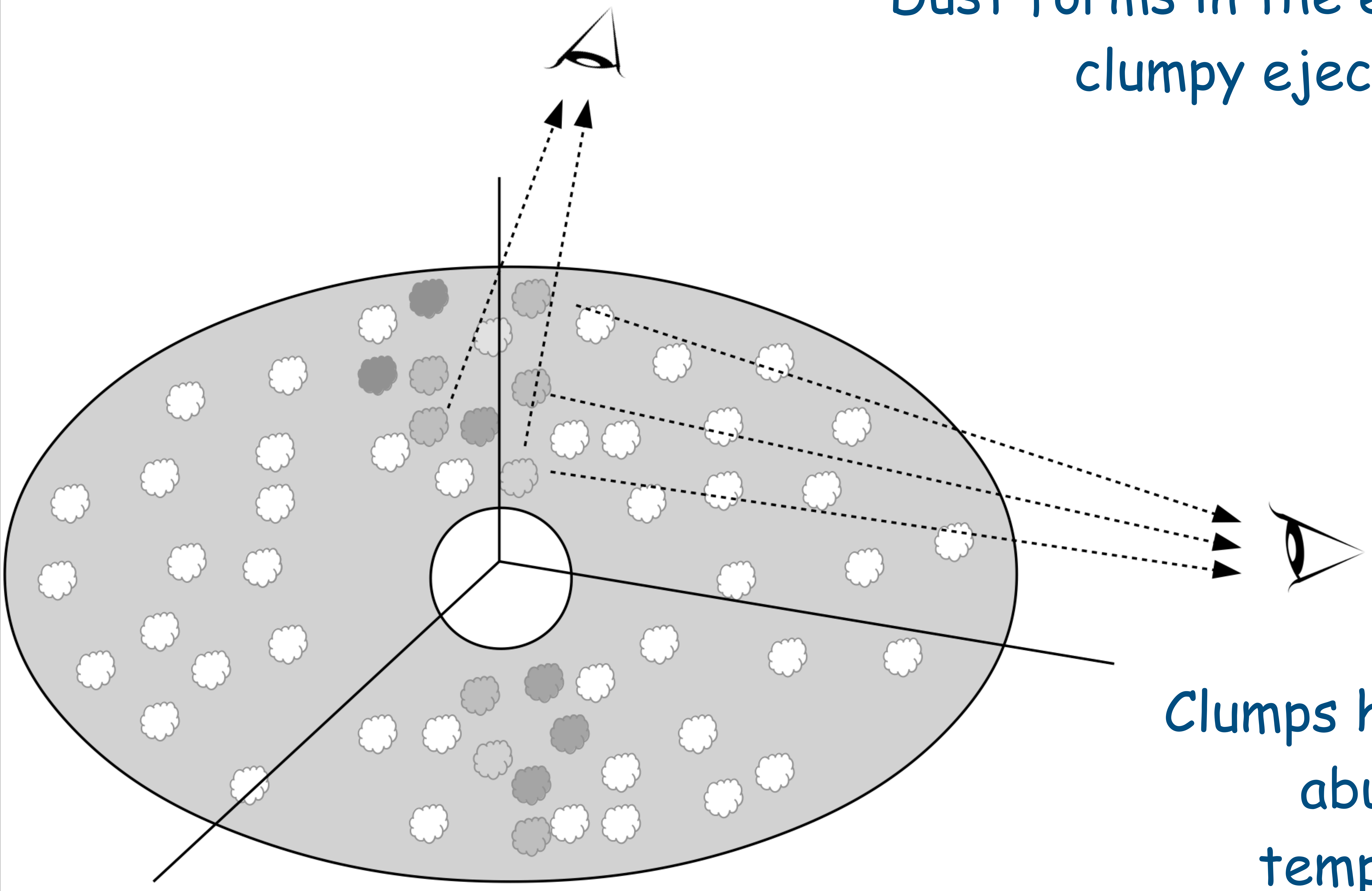


Bossion, Sarangi and Nyman 2024 (in review)





Dust forms in the expanding clumpy ejecta

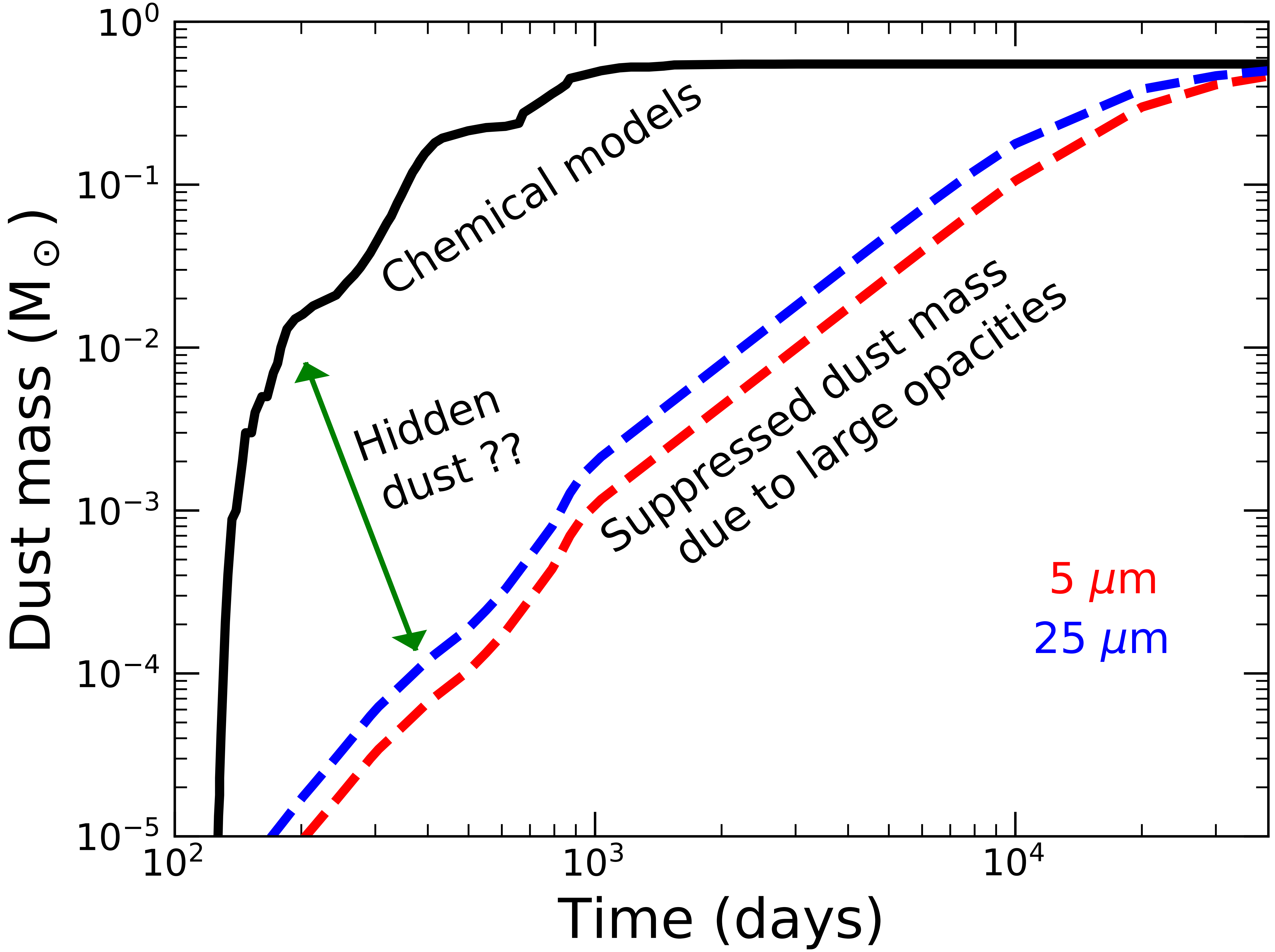


Clumps have different velocities, abundances, densities, temperatures, mass of Ni

Dust evolution and IR spectra

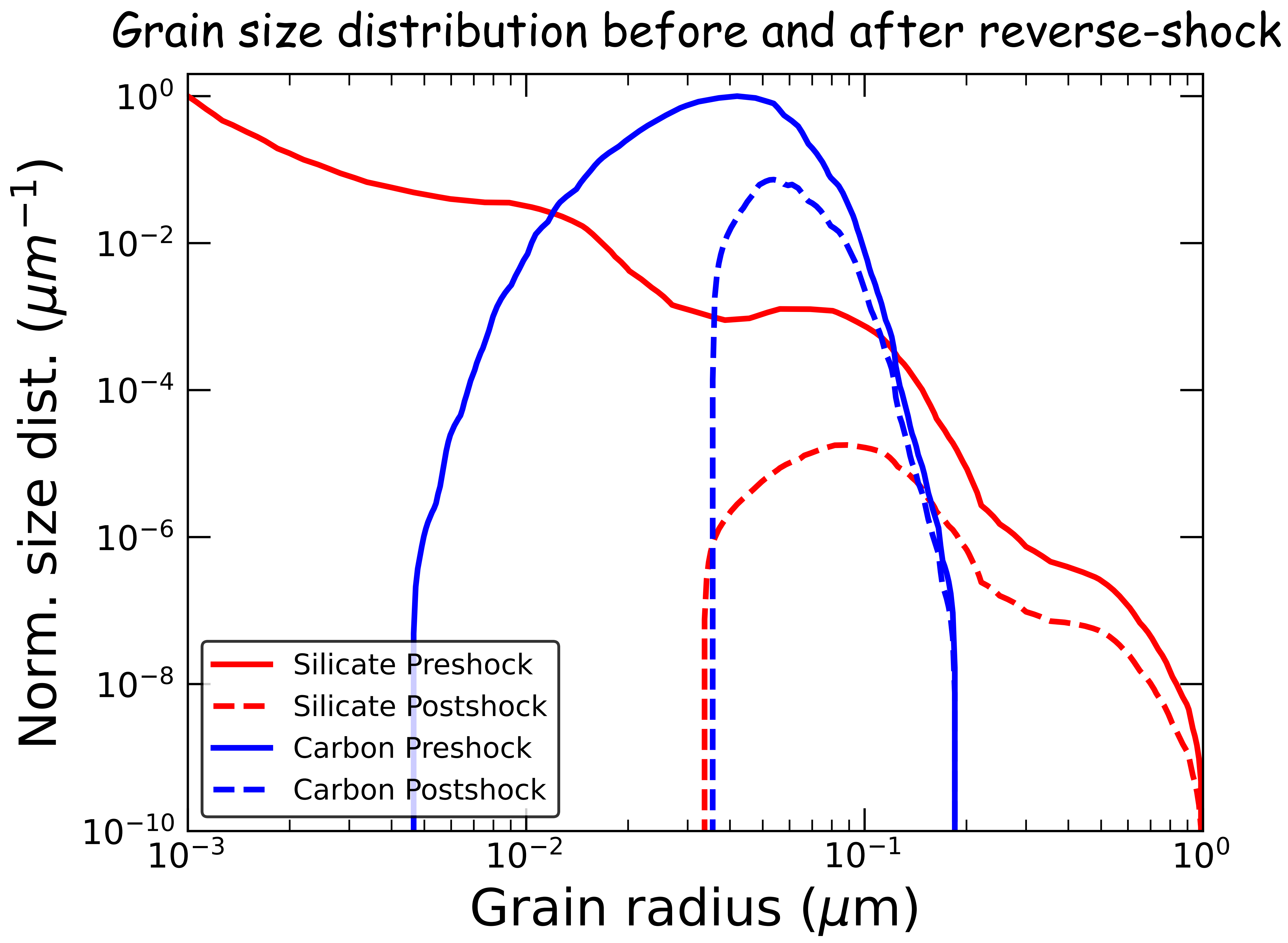
Sarangi 2022

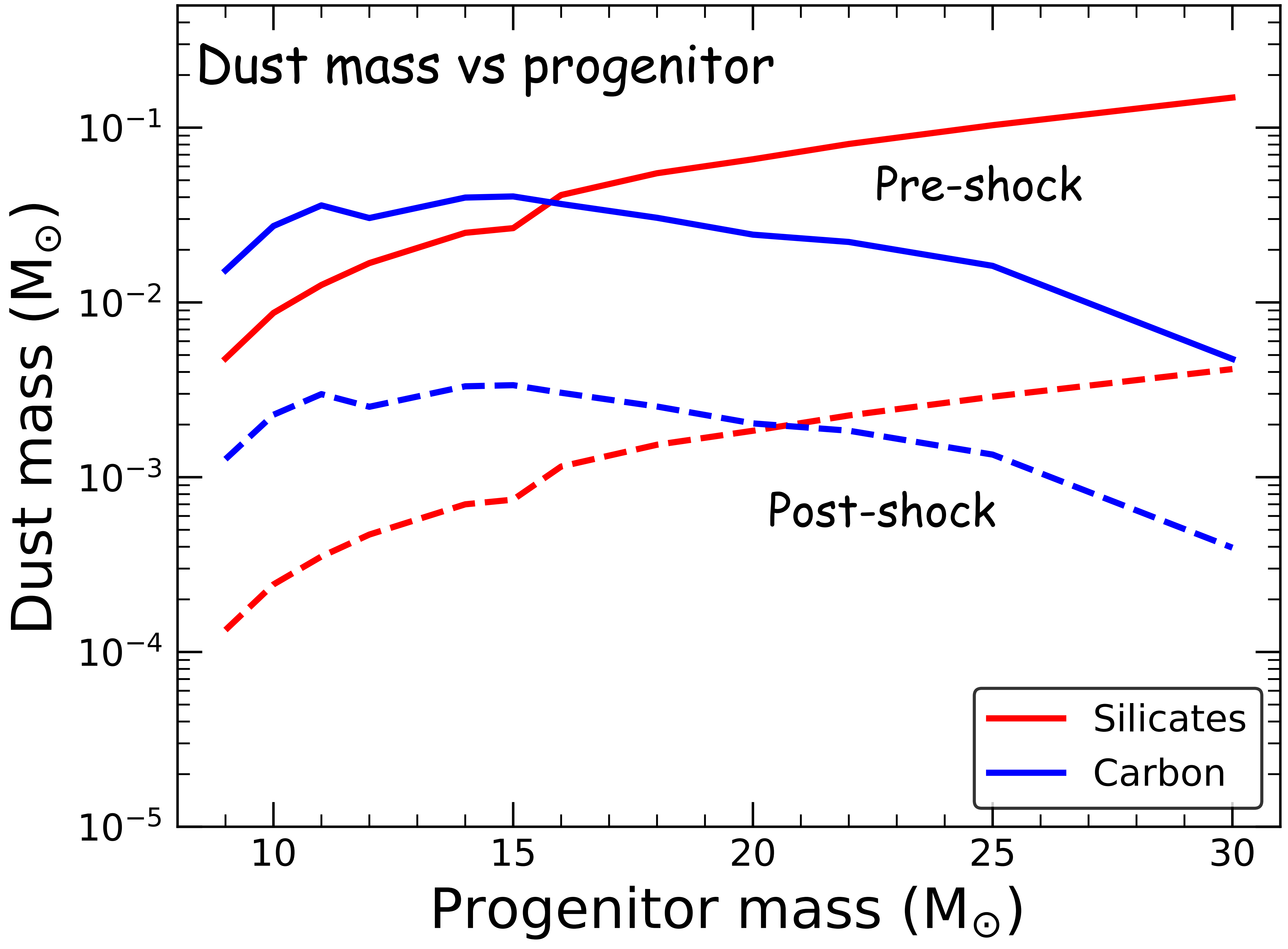
Effect of optical depth on dust masses

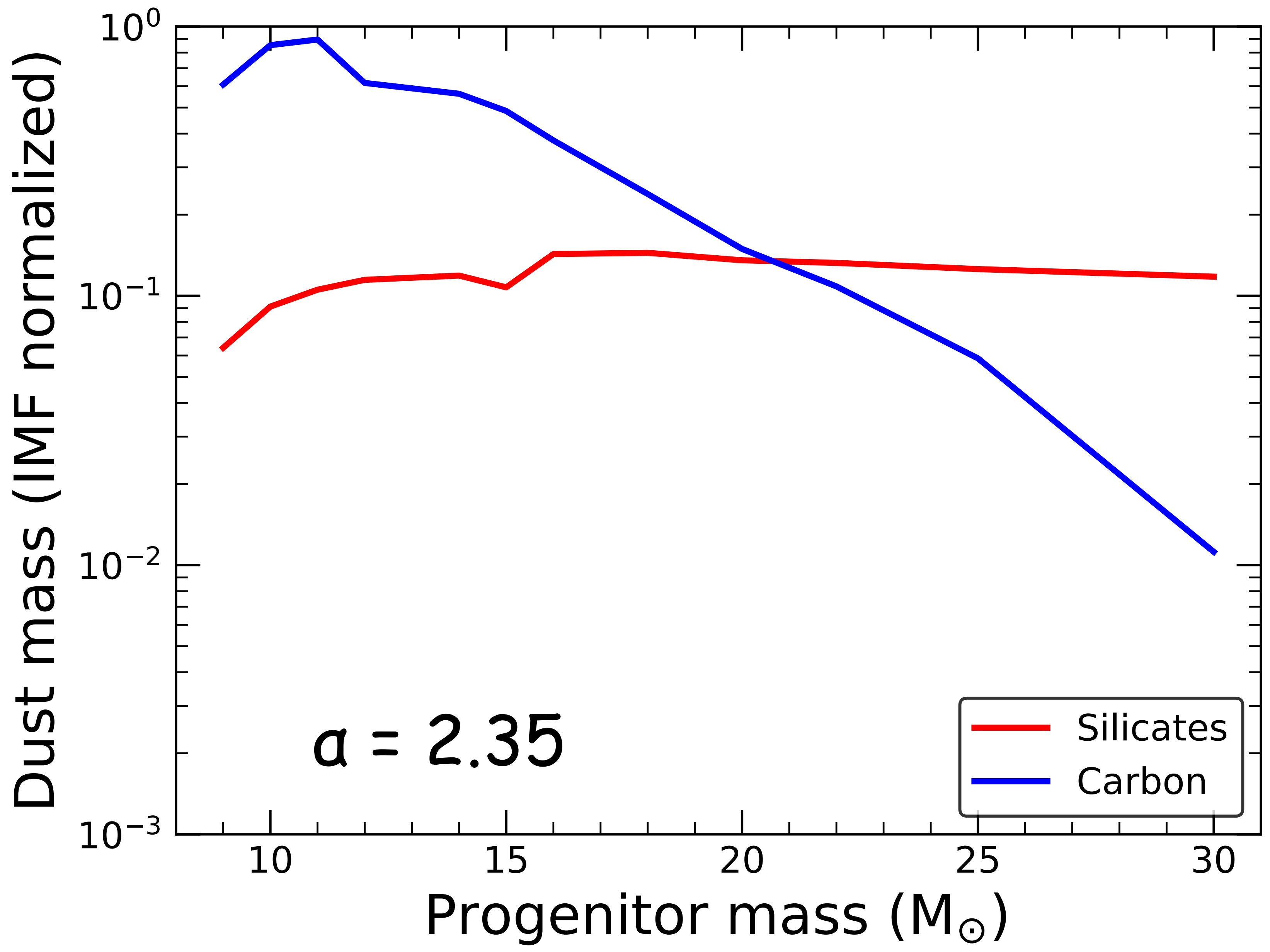


Dwek, Sarangi & Arendt 2019

Dust masses for various progenitor masses



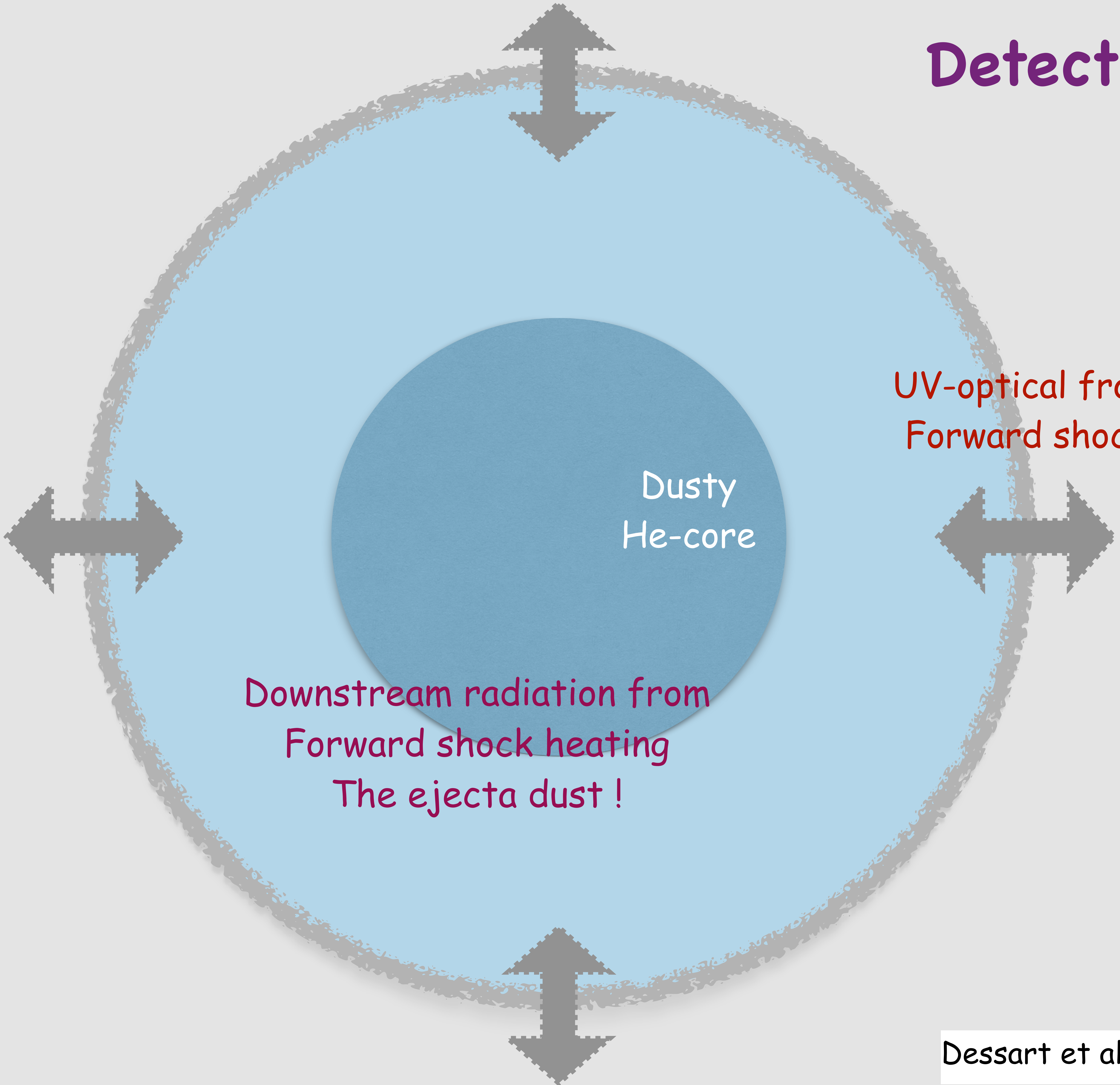




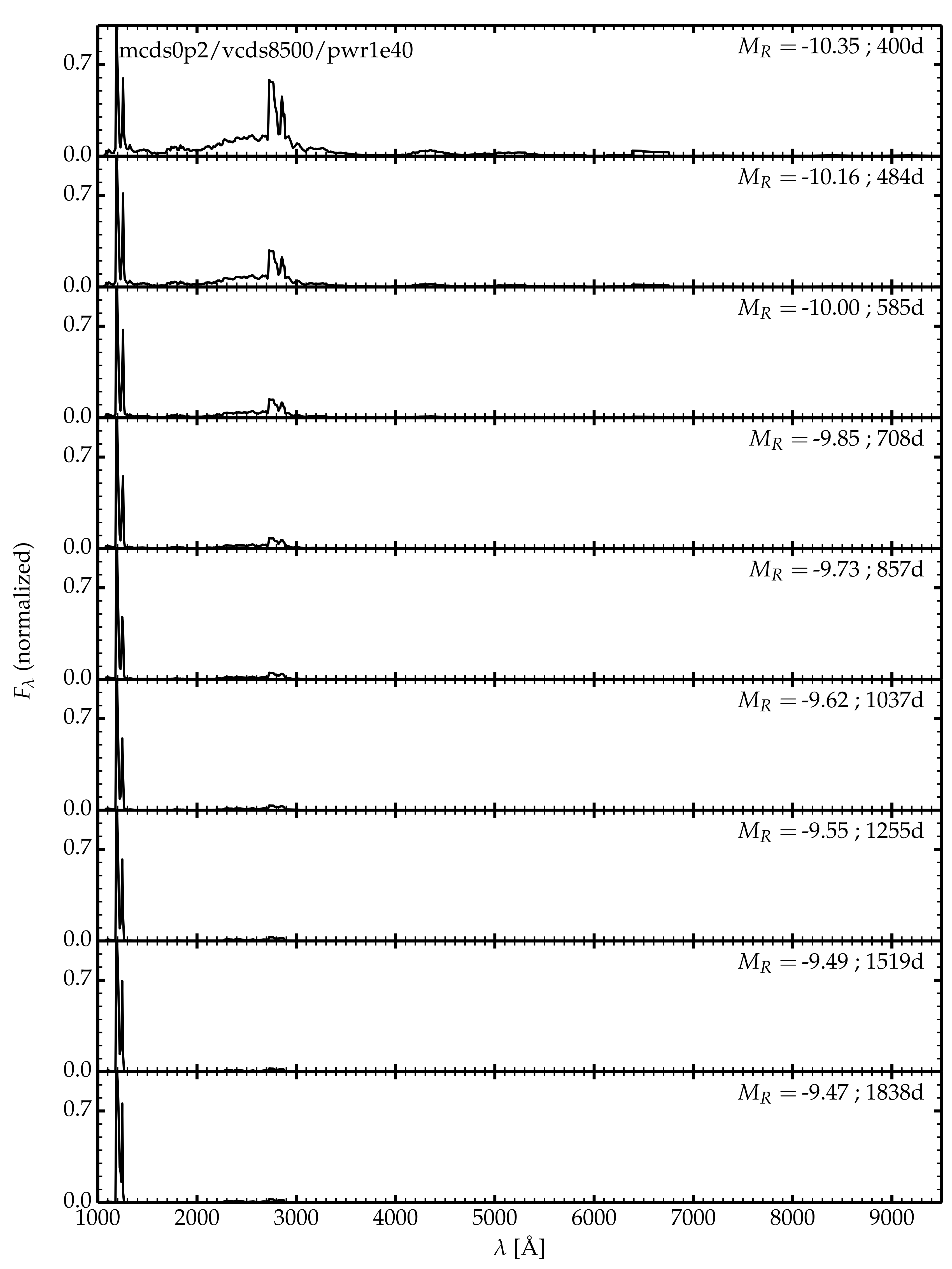
Dust destruction model: Slavin et al. 2020

Progenitor masses: Sukhbold et al. 2016

Detecting dust after a decade ..

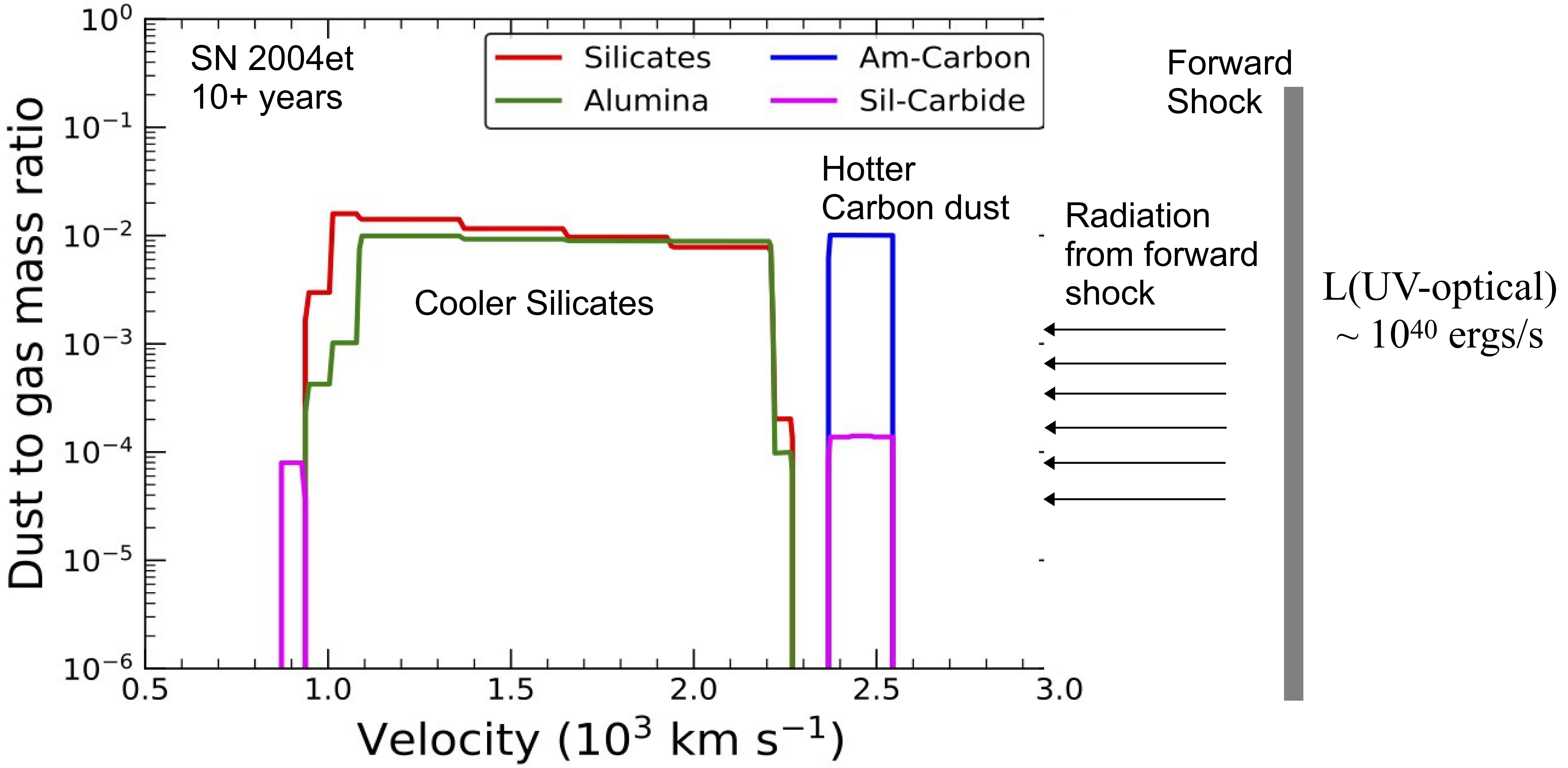


Forward shock interaction powered spectra

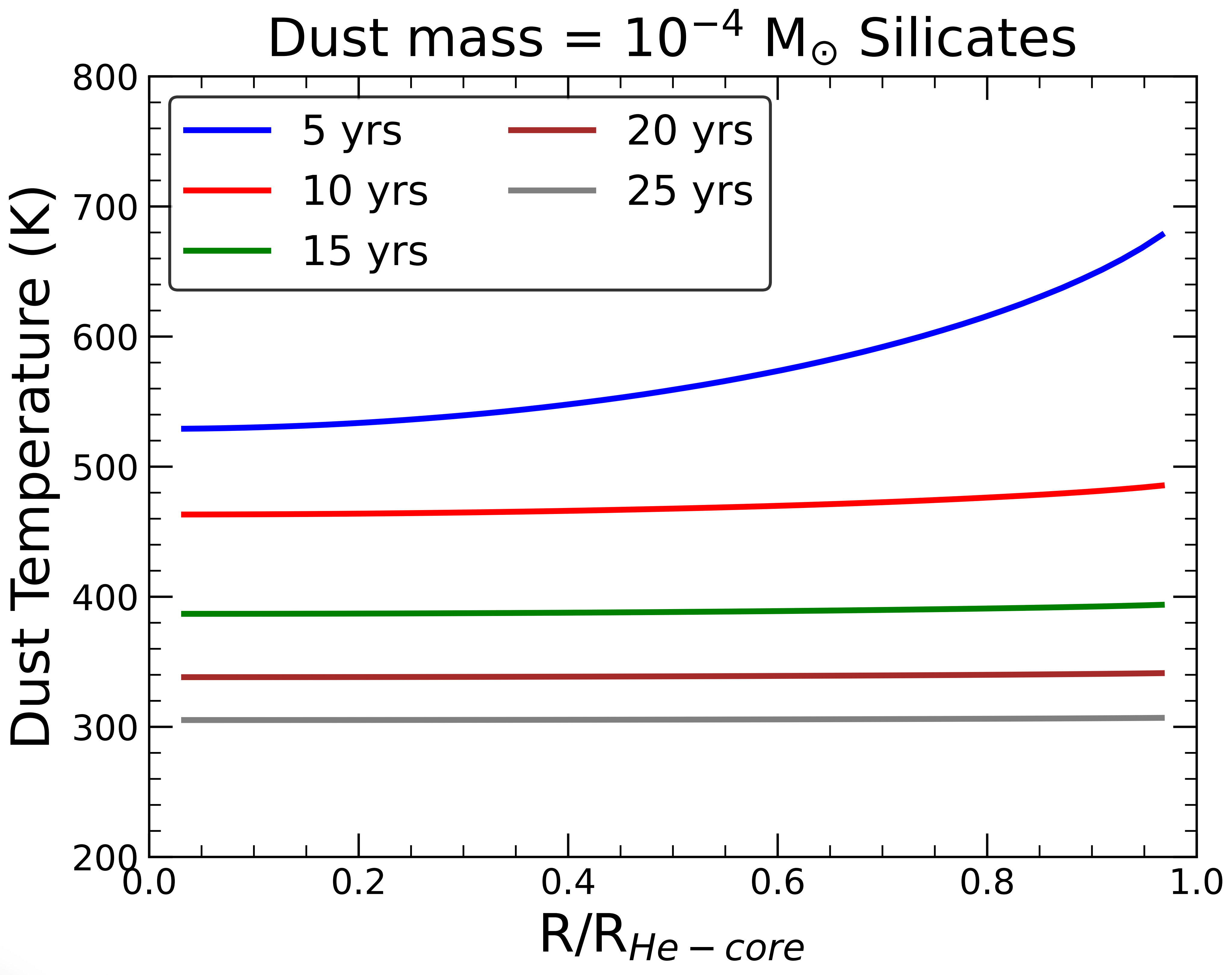


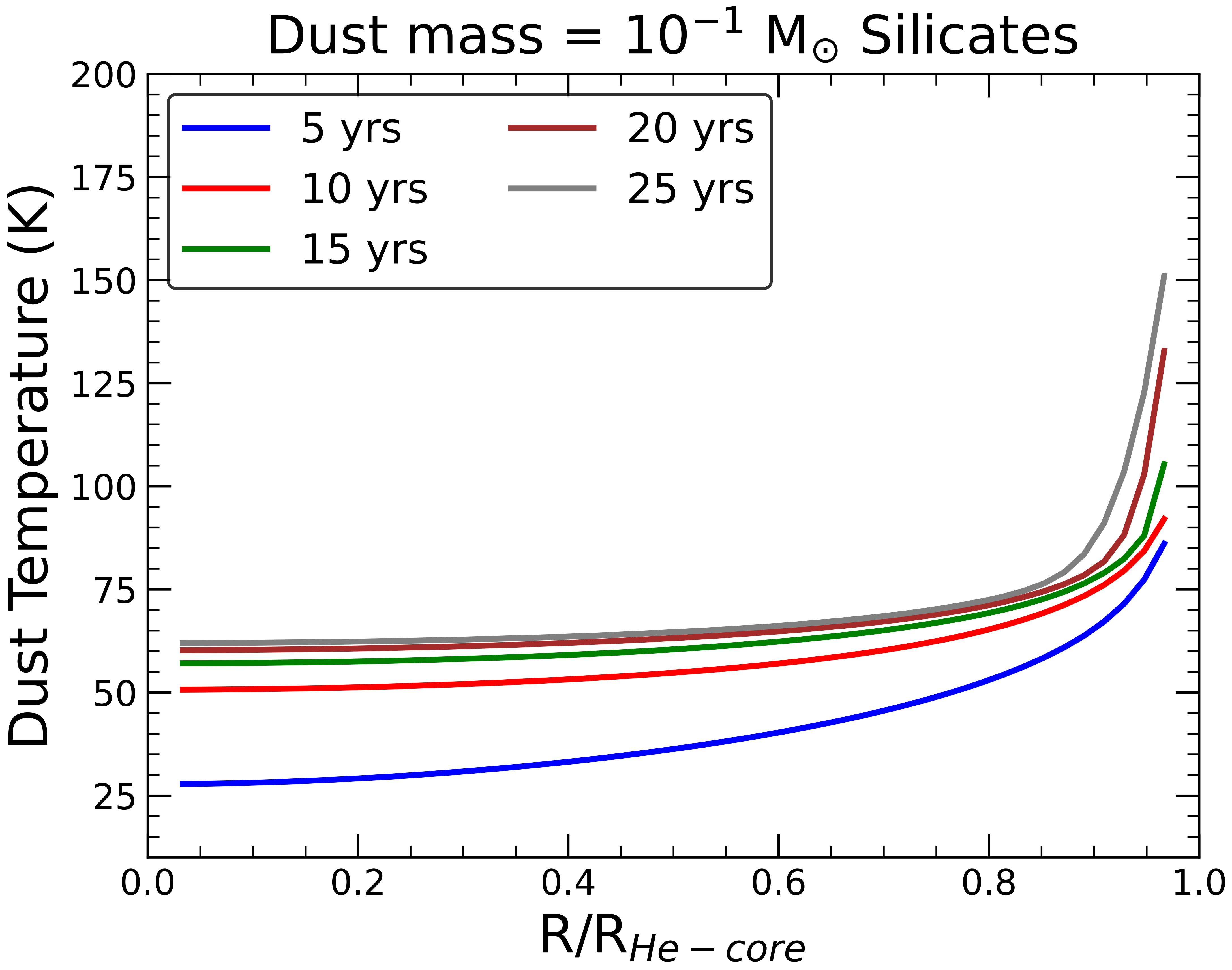
Dessart et al. 2023

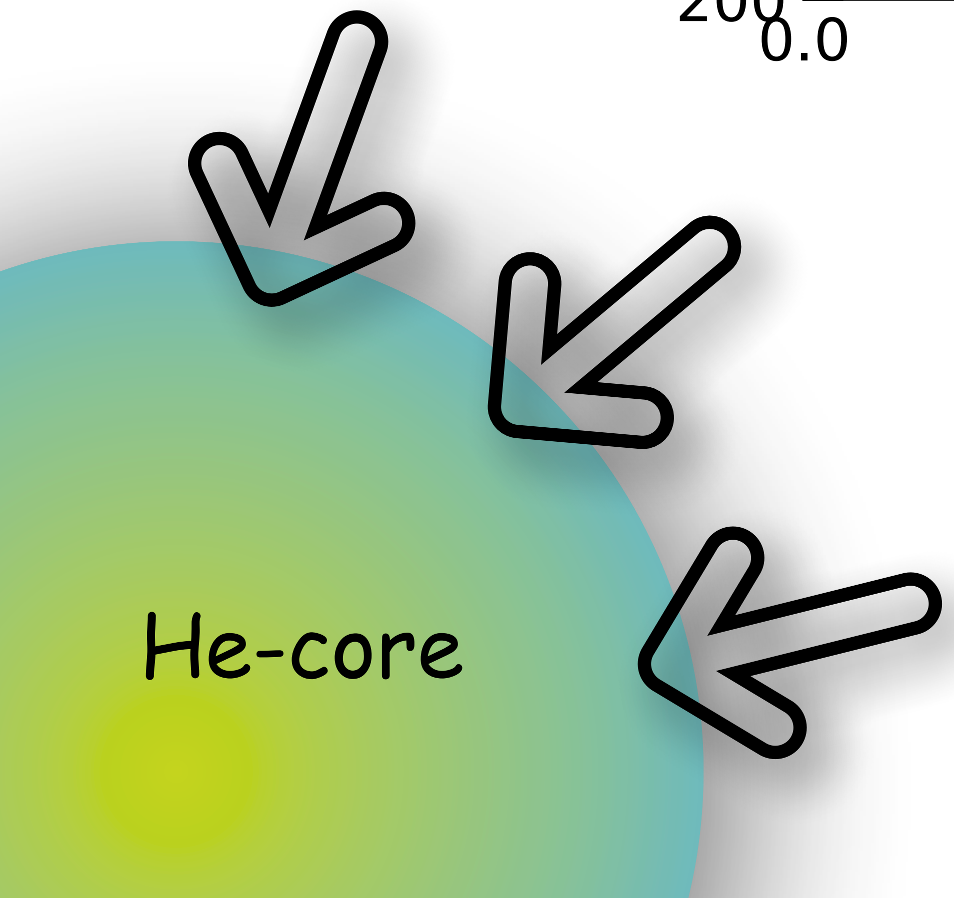
Ejecta Dust heated by forward shock



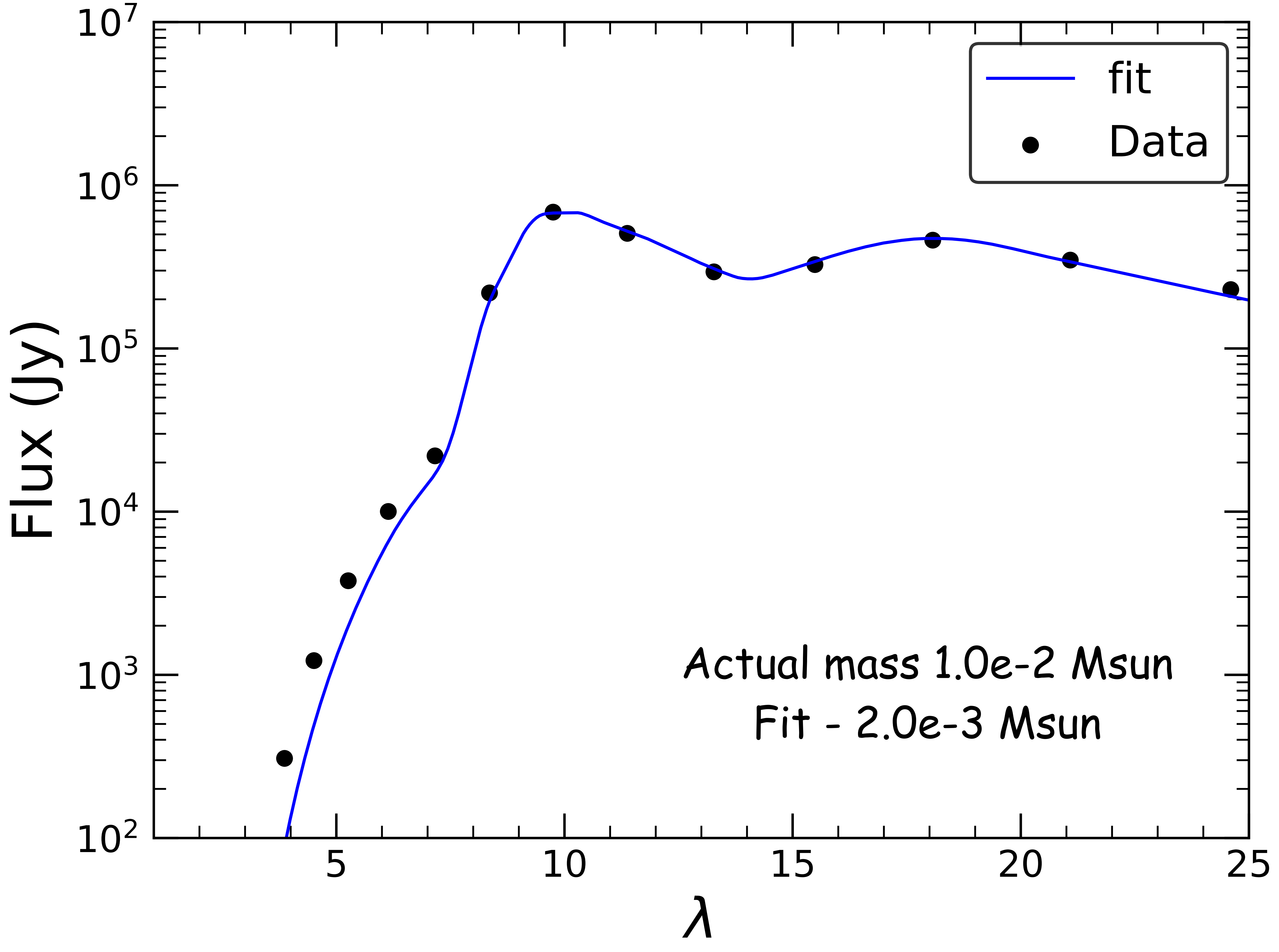
Silicate Dust temperatures in ejecta when external heated by an external shock

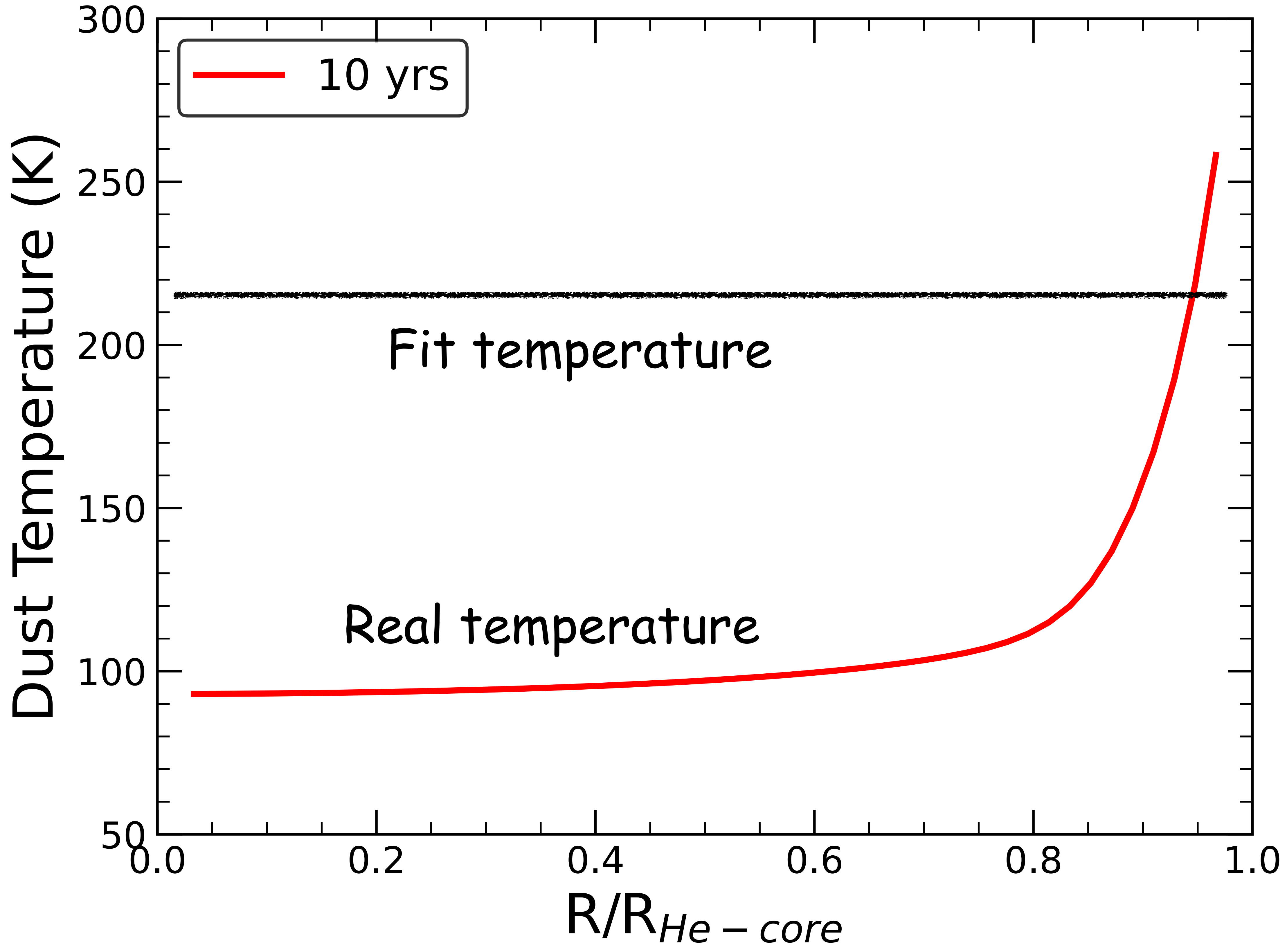






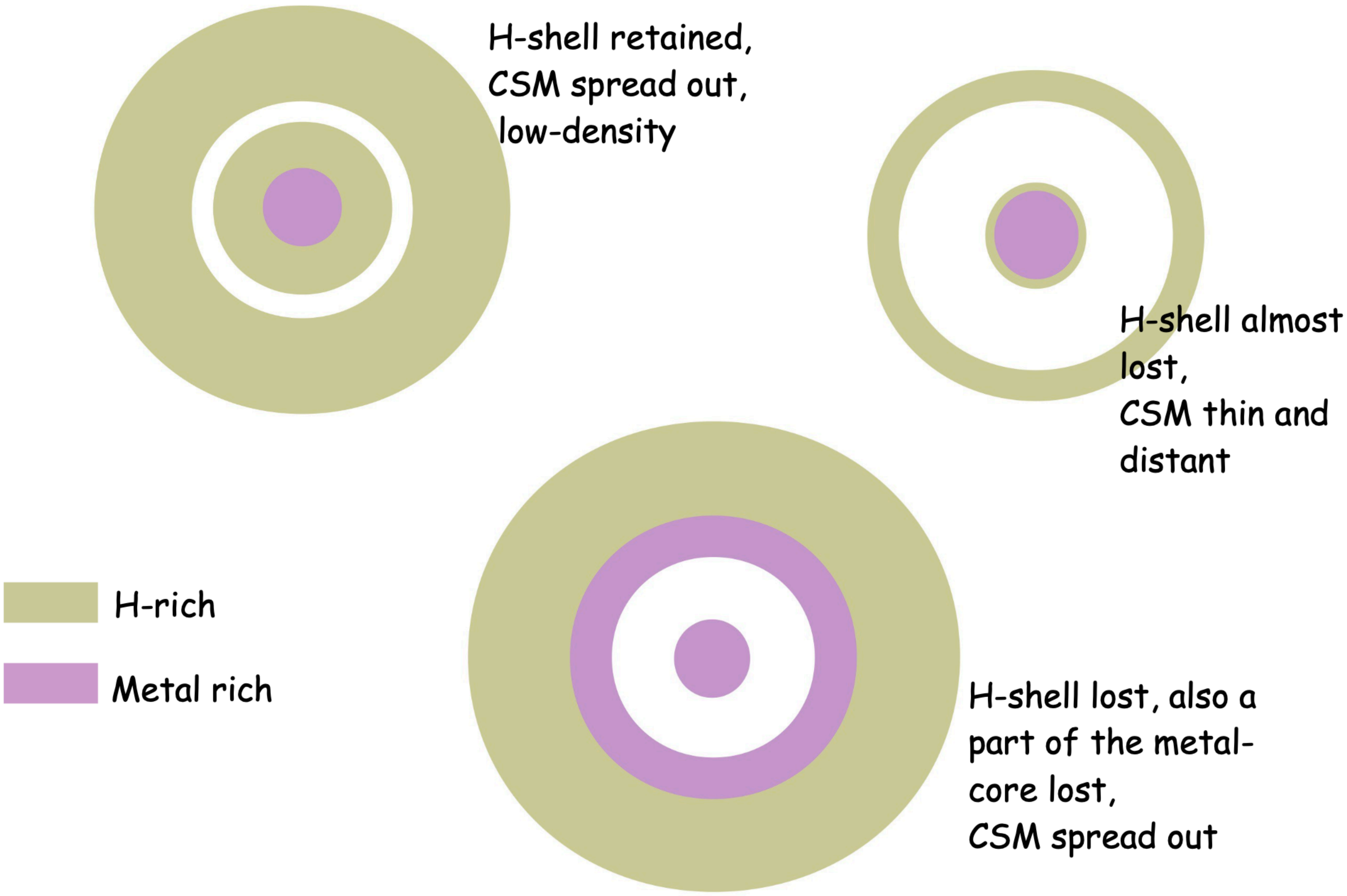
Suppressed dust mass - cooler dust



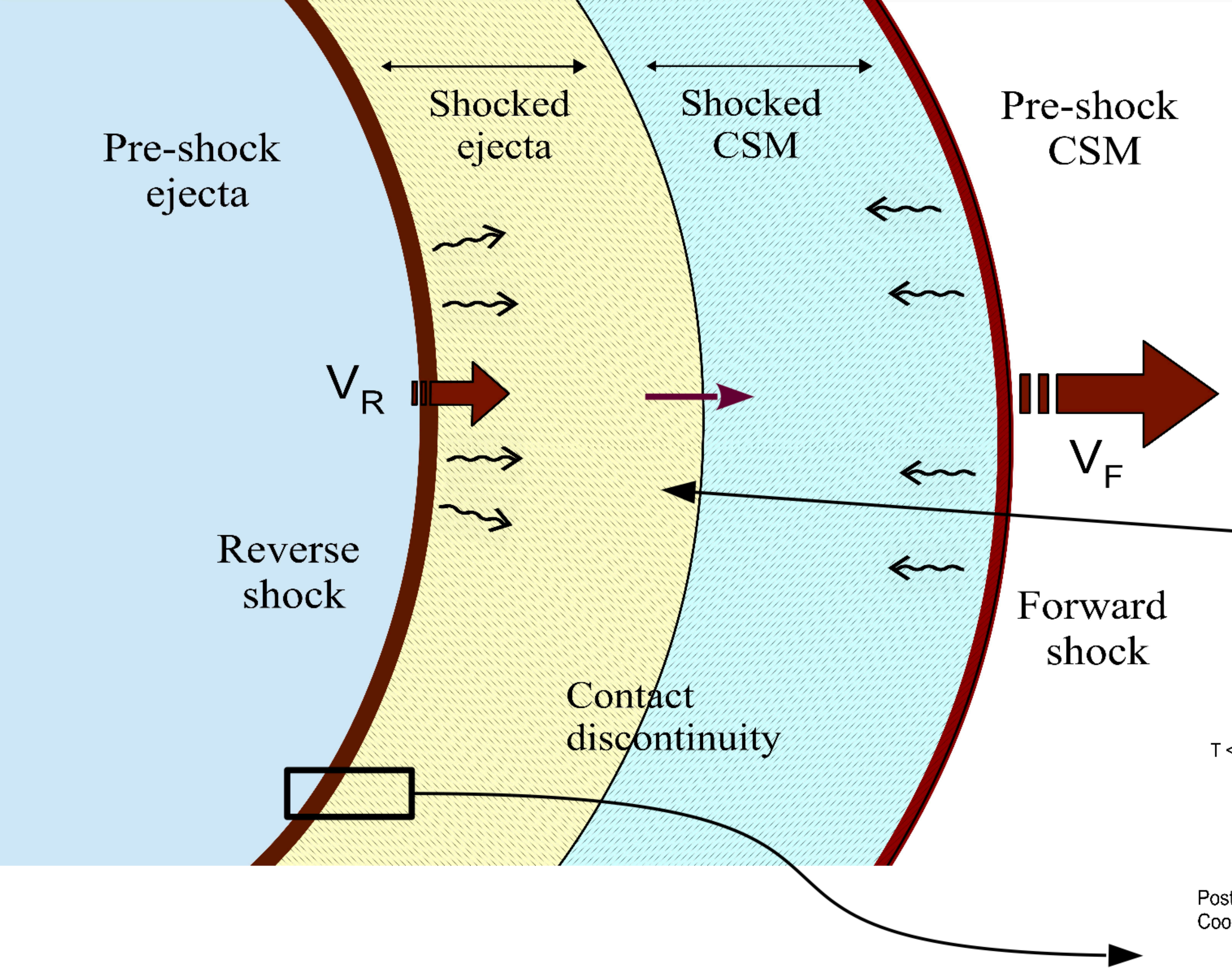


Externally heated dust is unlikely to be thick to self radiation - But there can be undetected cool dust !

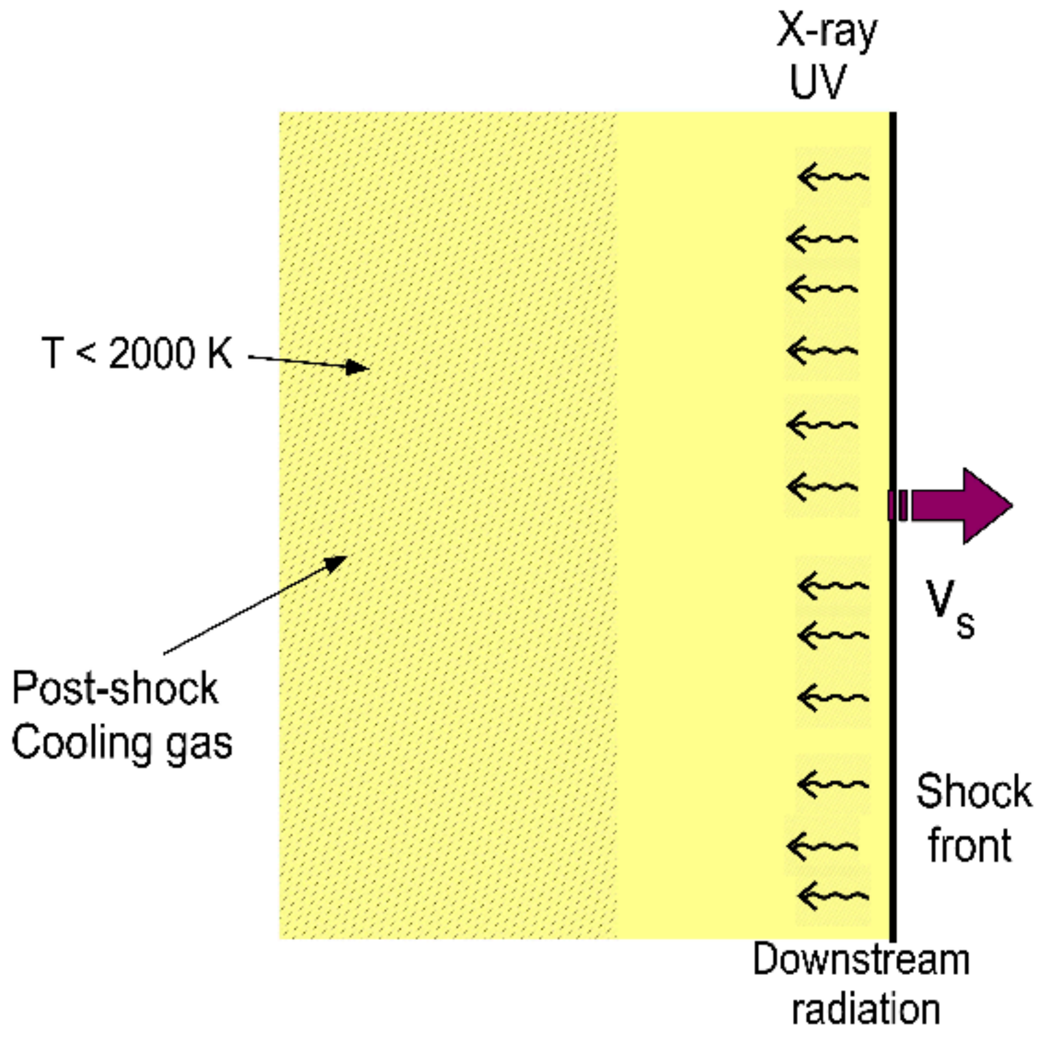
Interacting/Non-interacting Supernovae



Ejecta-CSM interaction



A very thin, warm dense shell !

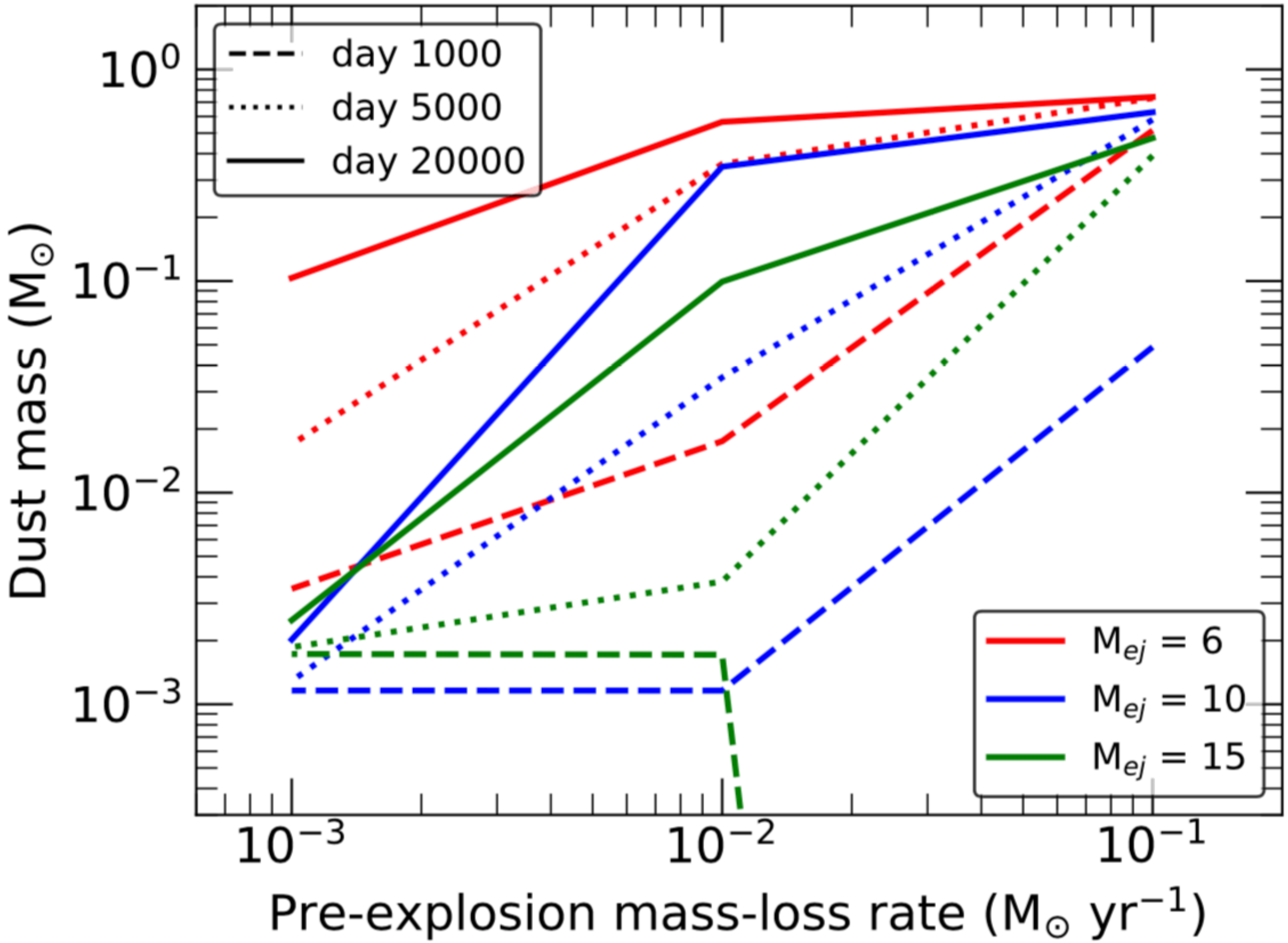


Sarangi et al 2018b

Mass-loss rate
Mass of the ejecta – H stripping
Explosion energy

Sarangi & Slavin 2022

Dust masses in the dense shell



Sarangi and Slavin 2022

Take away …

Dust formation is a dynamic event -
Dust masses depend on pre-explosion activities, progenitor mass, explosion energy, Ni-mass, clumpiness, mixing etc.

Timescale of dust production determines its evolution in the SNR and injection in the ISM

James Webb is largely useful to account for optical depths and hidden cool dust in the ejecta

Vote for dust in supernovae !