Dust formation and processing in the clumpy SNR Cas A

Chiara Biscaro
Dark Cosmology Centre
University of Copenhagen

Dark Cosmology Centre

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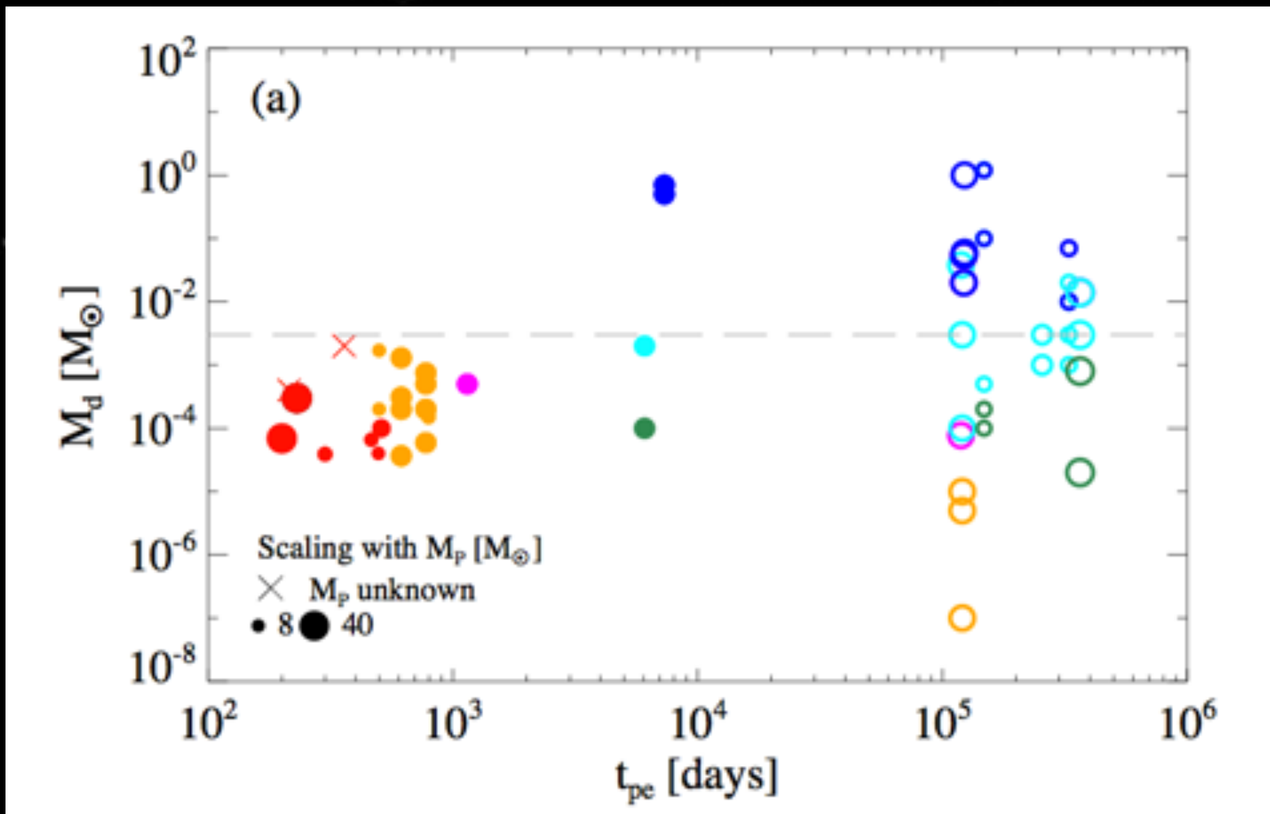
Collaborators:
I. Cherchneff, R. Cabezon (Basel)

Fifty-One Erg 2/6/15

Discrepancy between SNe observations and models

Gall et al 2011

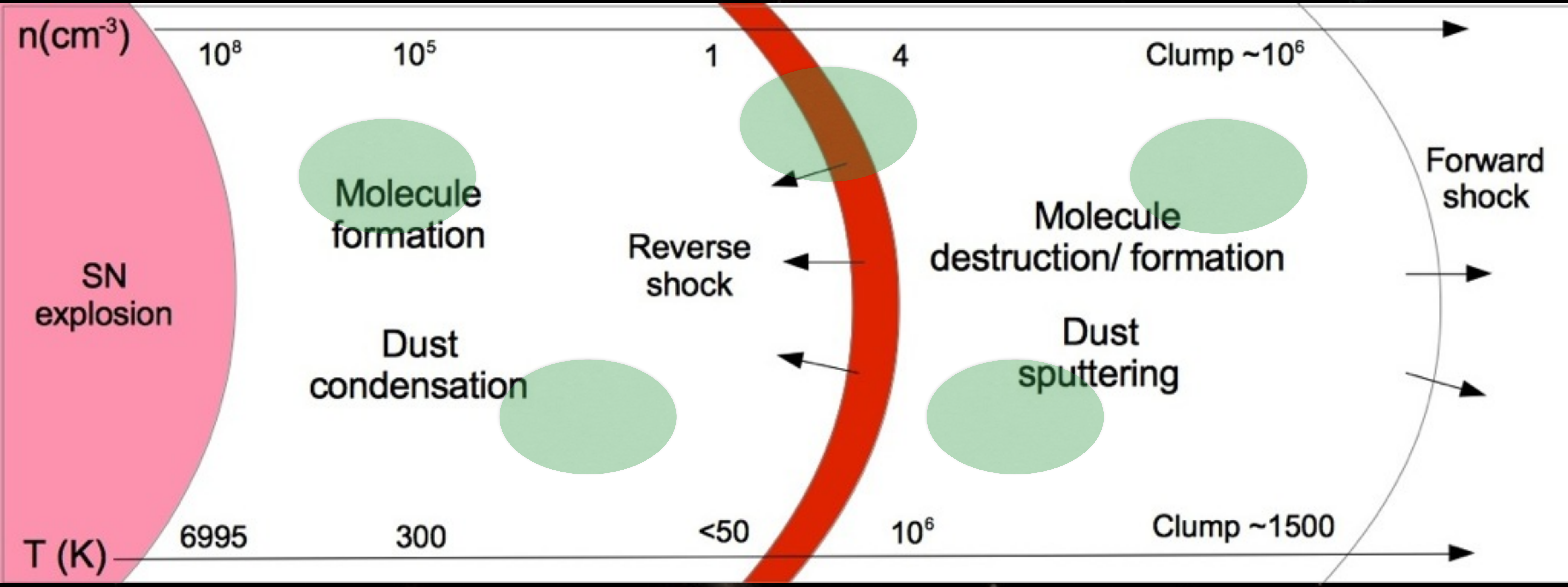


Observations show warm dust at ~ 10^{-4} M_{sun} and cool dust in SNRs at ~ 0.1 M_{sun}.

Theoretical models that use classical nucleation theory form in a few hundred days dust with mass in the range 0.1 - 1 M_{sun} (Todini & Ferrara 2001, Nozawa et al. 2010)

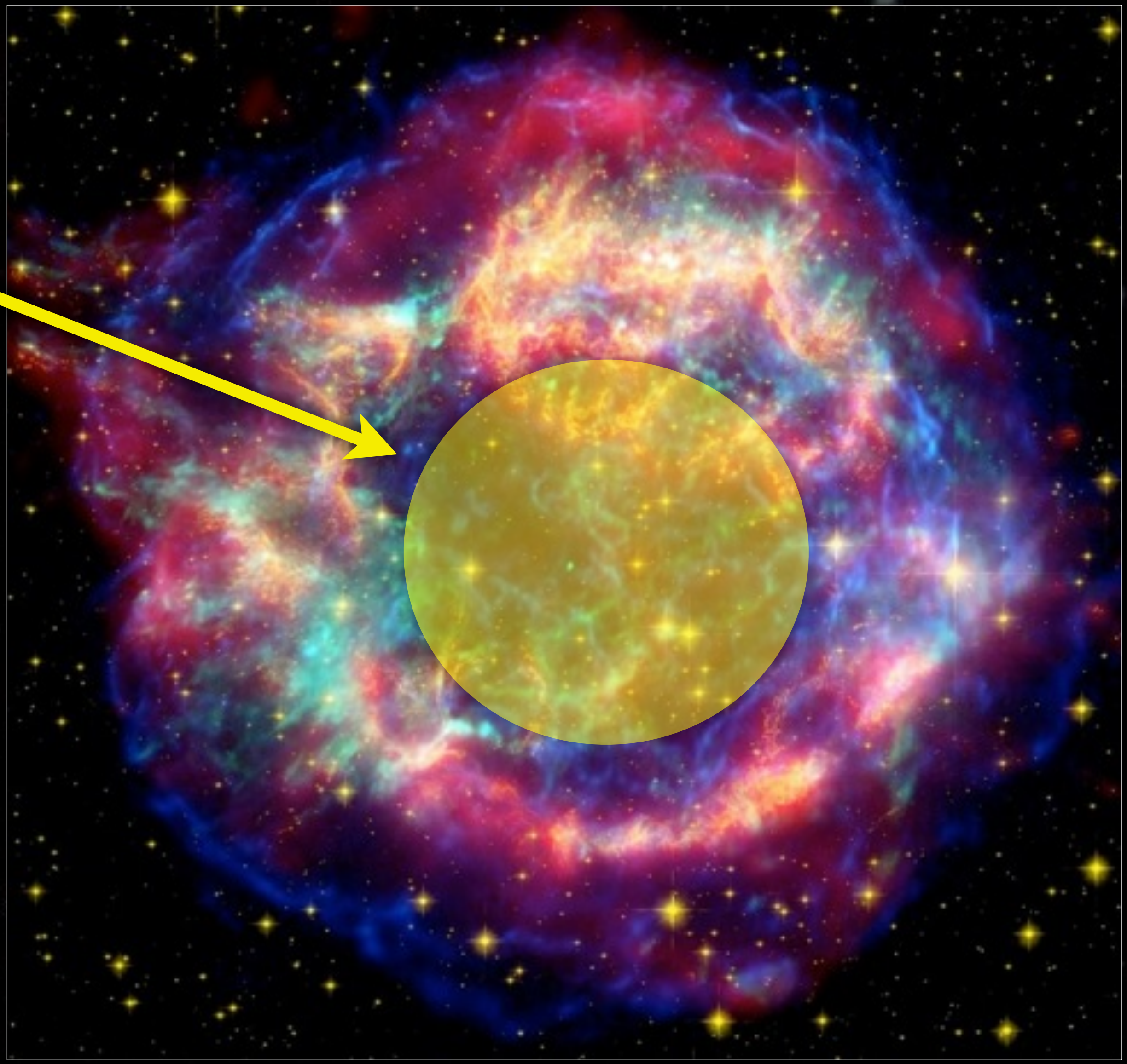
Recent models based on chemical kinetics predict dust mass in the range 0.01-0.1 M_{sun} (Cherchneff & Dwek 2010, Sarangi & Cherchneff 2015)

Modeling SNRs



Outline

- ★ Find out which molecules and clusters form in the ejecta
- ★ Input parameters for the crossing of the reverse shock
- ★ Explore dust sputtering by the shock in a clump and the inter-clump medium and molecule reformation in the post-shock gas.

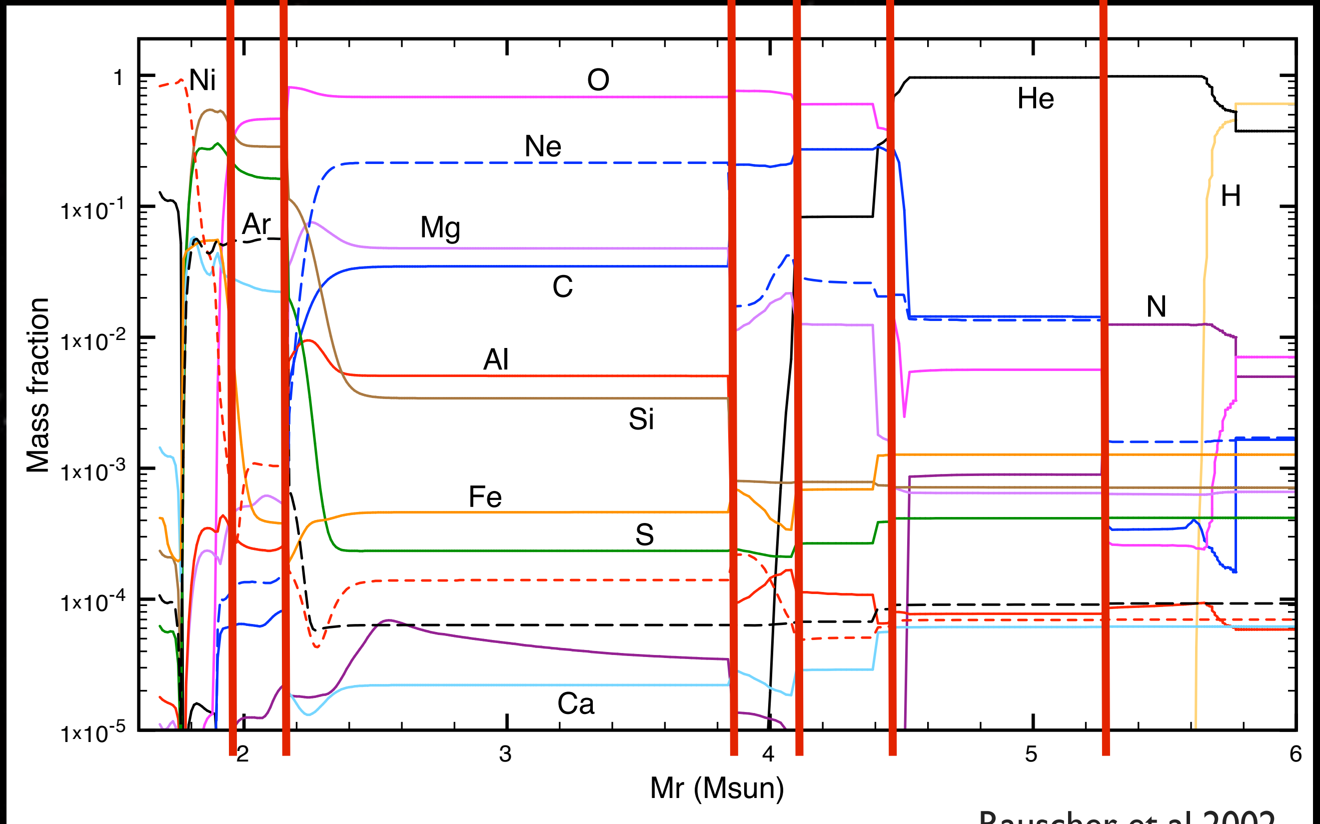


Initial conditions

- ★ Progenitor mass: 19 $M_{\odot}$
- ★ Explosion energy: 10^{51} erg
- ★ Chemical kinetic approach, for the nucleation phase: termolecular , neutral-neutral, ion-molecule, charge exchange, and radiative association reactions for formation. Destruction by thermal fragmentation and reactions with inert gas ions.

Nozawa et al. 2010

Time (days)	Density (cm-3)	T (K)
100	10^7-10^8	6664
1000	10^4-10^5	330
3000	10^3-10^4	80

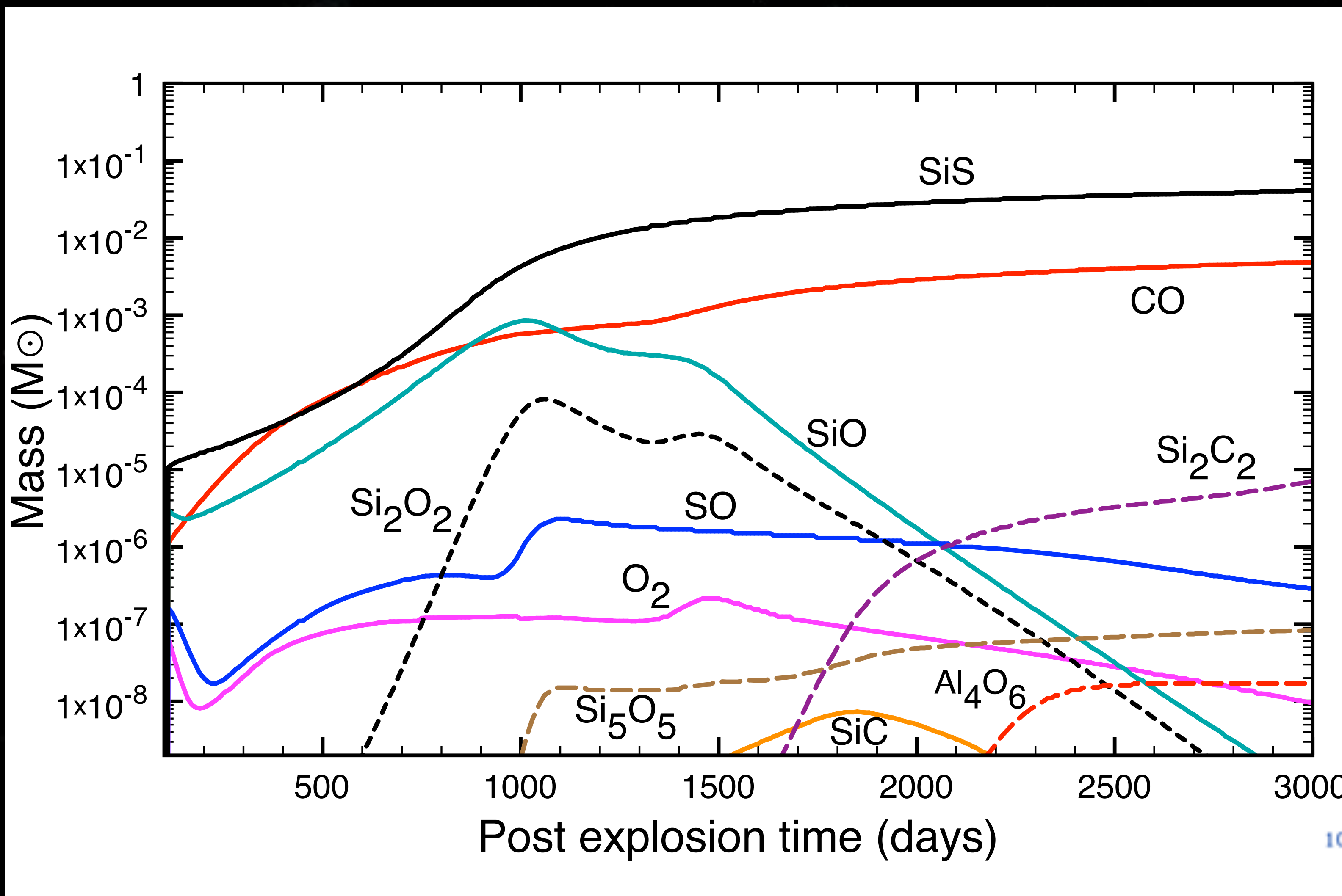


Rauscher et al 2002

- ★ Two types of chemistry: hot (above 300K) and cold

Results

Biscaro & Cherchneff 2014



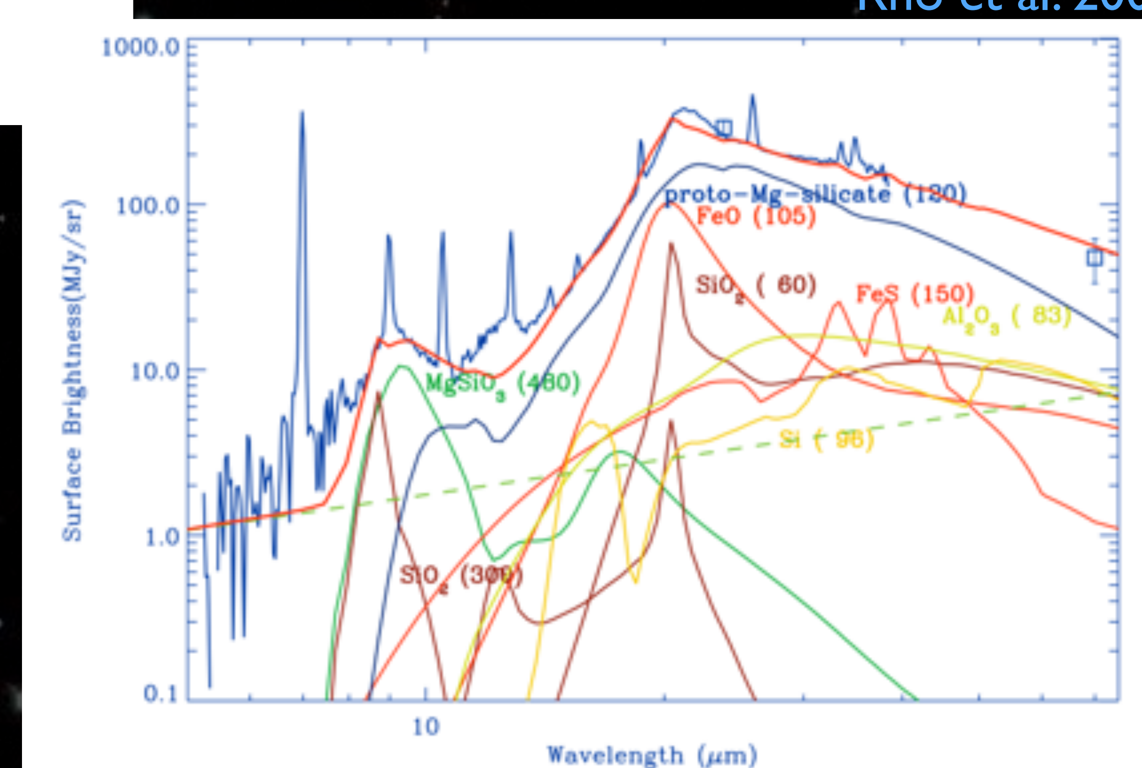
Total clusters mass ($M_\odot$)

$(SiO)_5$	$(SiC)_2$
9×10^{-8}	7×10^{-6}

Al_4O_6
2×10^{-8}

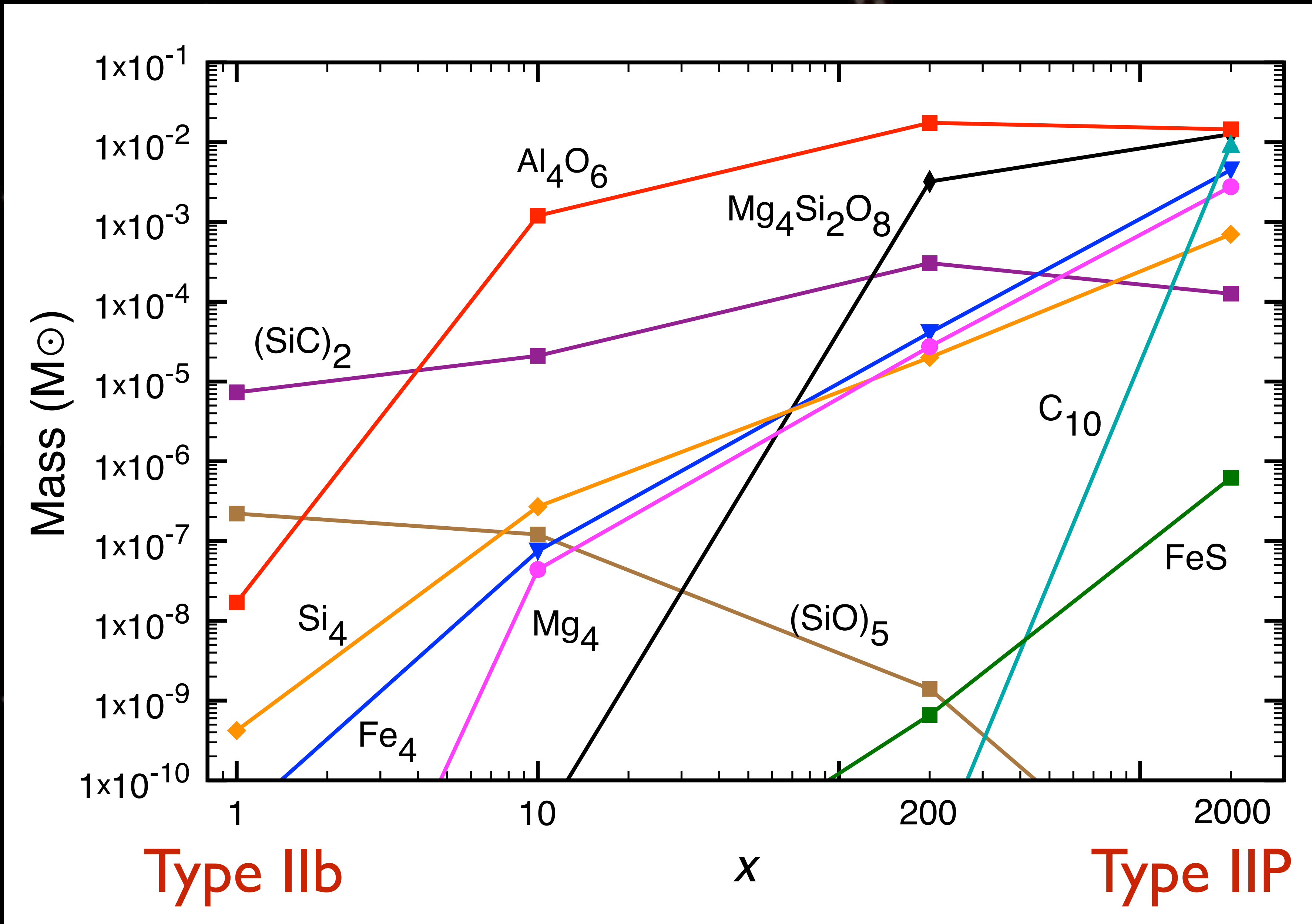
The derived dust mass and the chemical complexity of clusters are not able to explain the observations

Rho et al. 2008



Impact of density

(Biscaro & Cherchneff 2014)



It is possible to form dust clusters only if the ejecta has clumps of higher density.

The chemical complexity of clusters increases with gas densities

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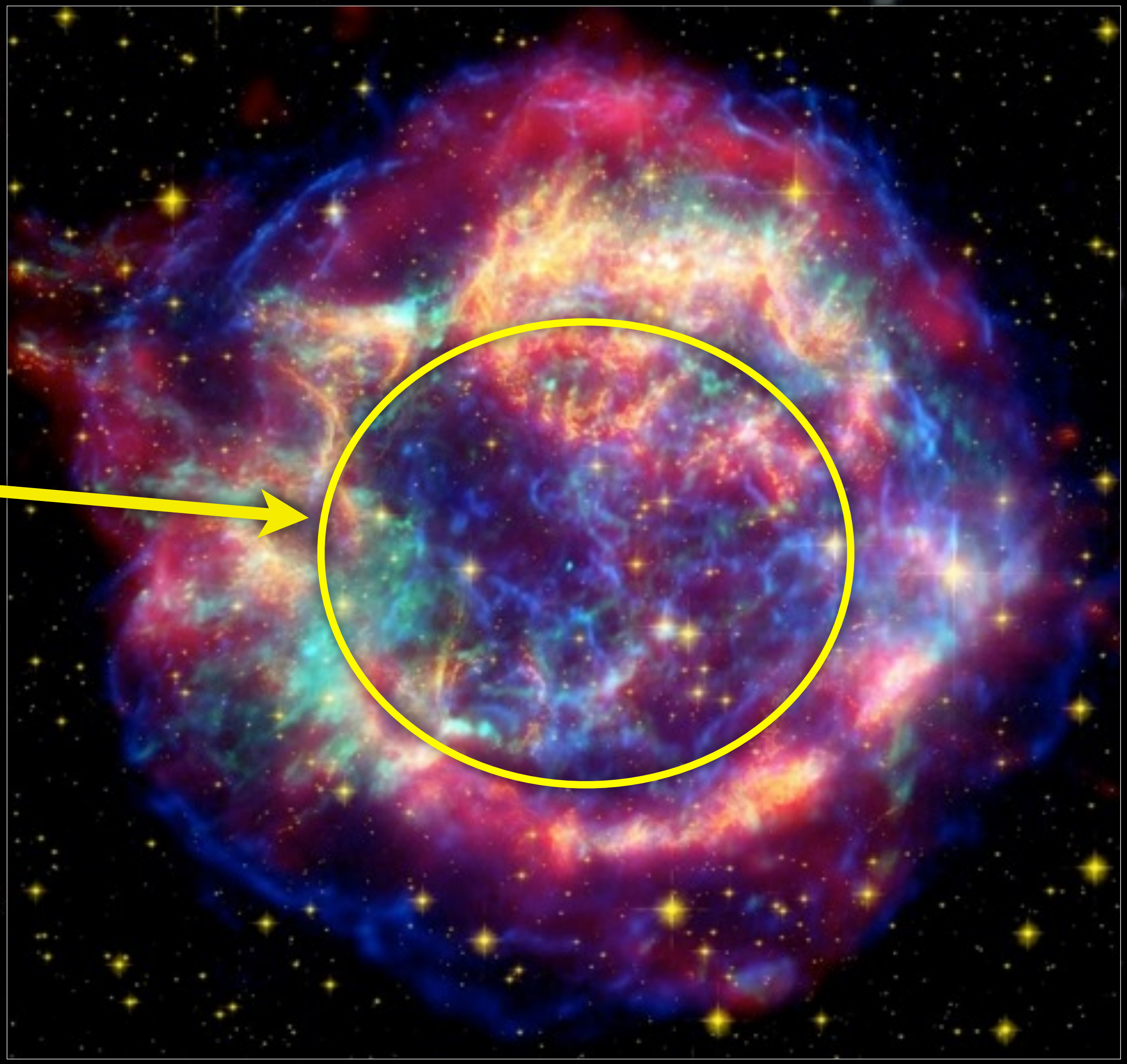
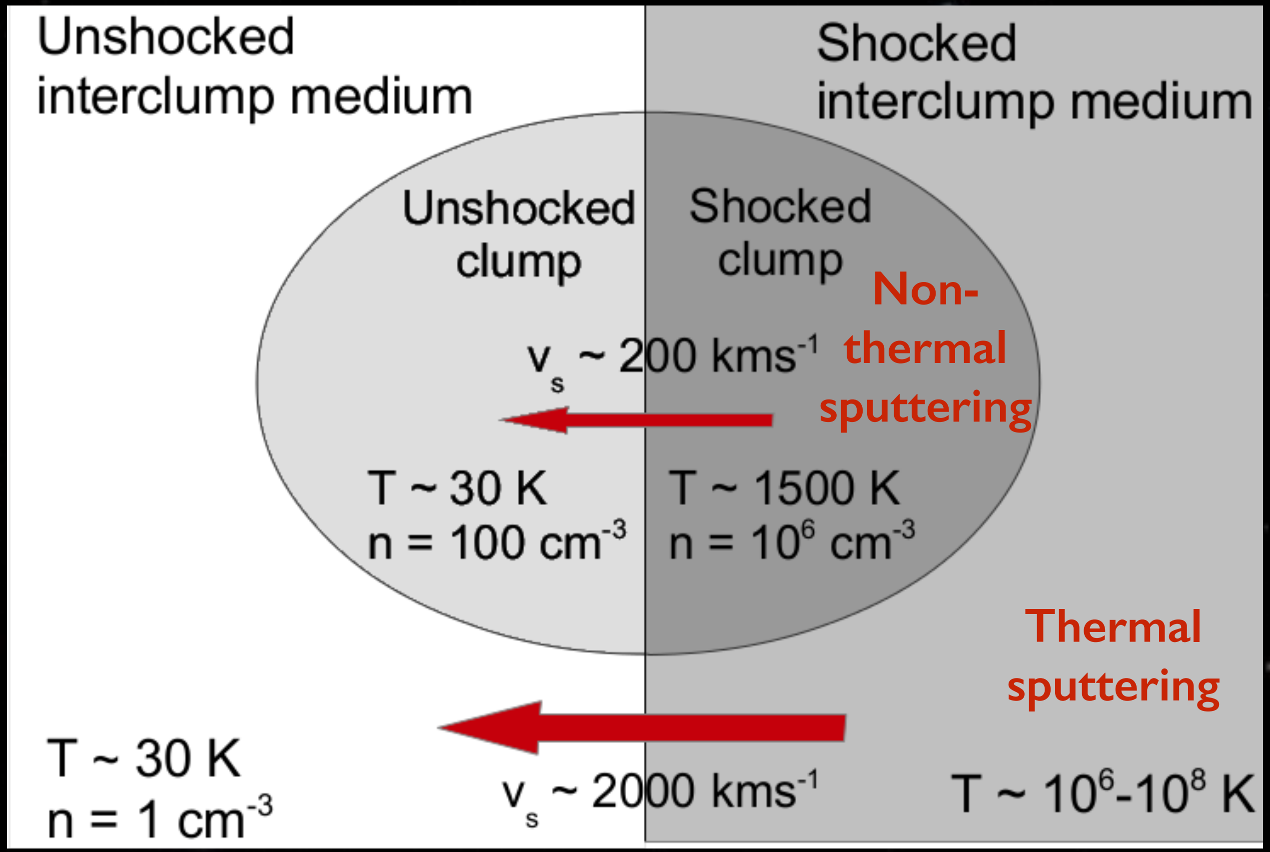


Sputtering model

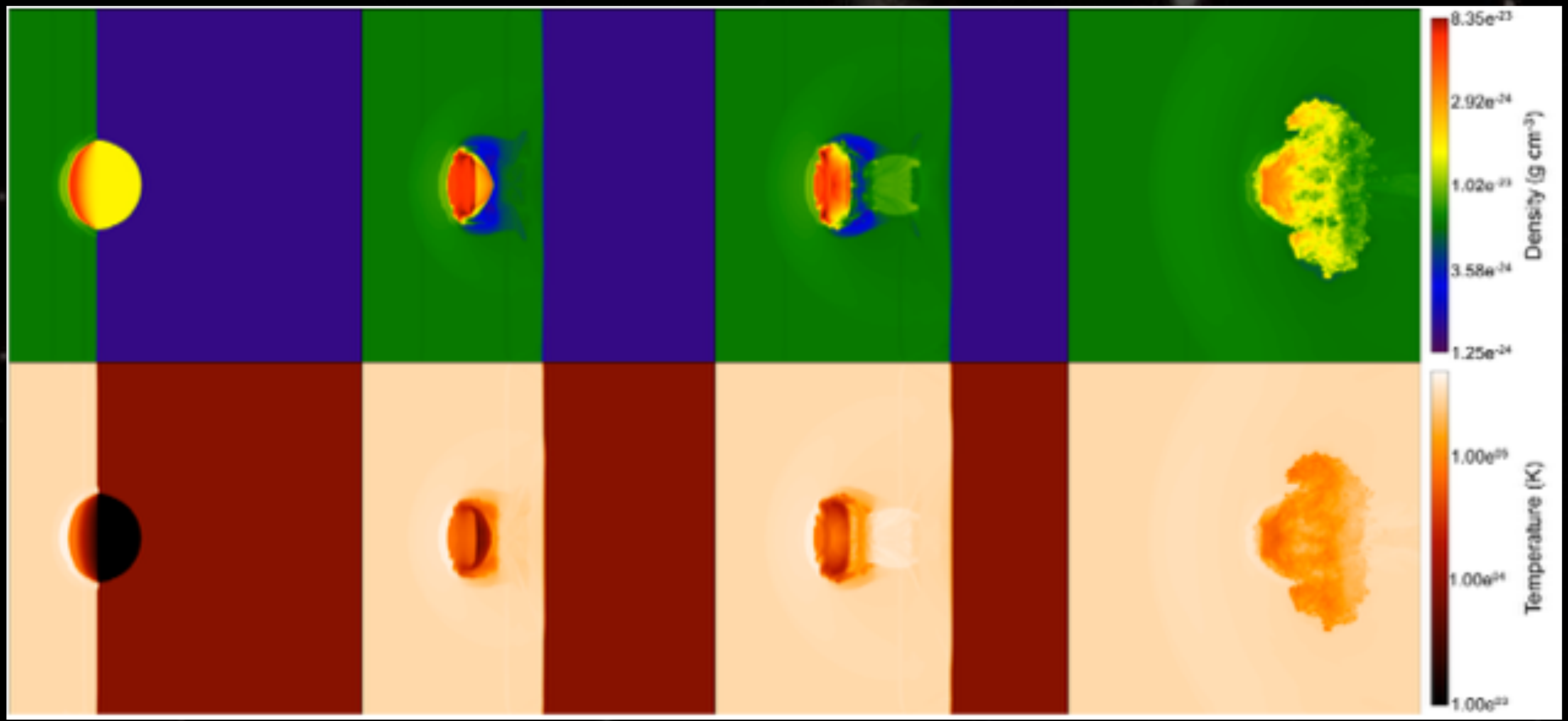
★ Shock velocity in the clump: 200, 140, 100 km s^{-1}

★ Interclump temperatures, between 1 - 3 x 10^7 K for Cas A (Hwang & Laming 2012)

★ Clump destroyed after ~400 yrs



Biscaro & Cherchneff, in prep.



Silvia et al. 2010

★ Dust sputtered in the hot inter clump ejecta for ~4000 yrs

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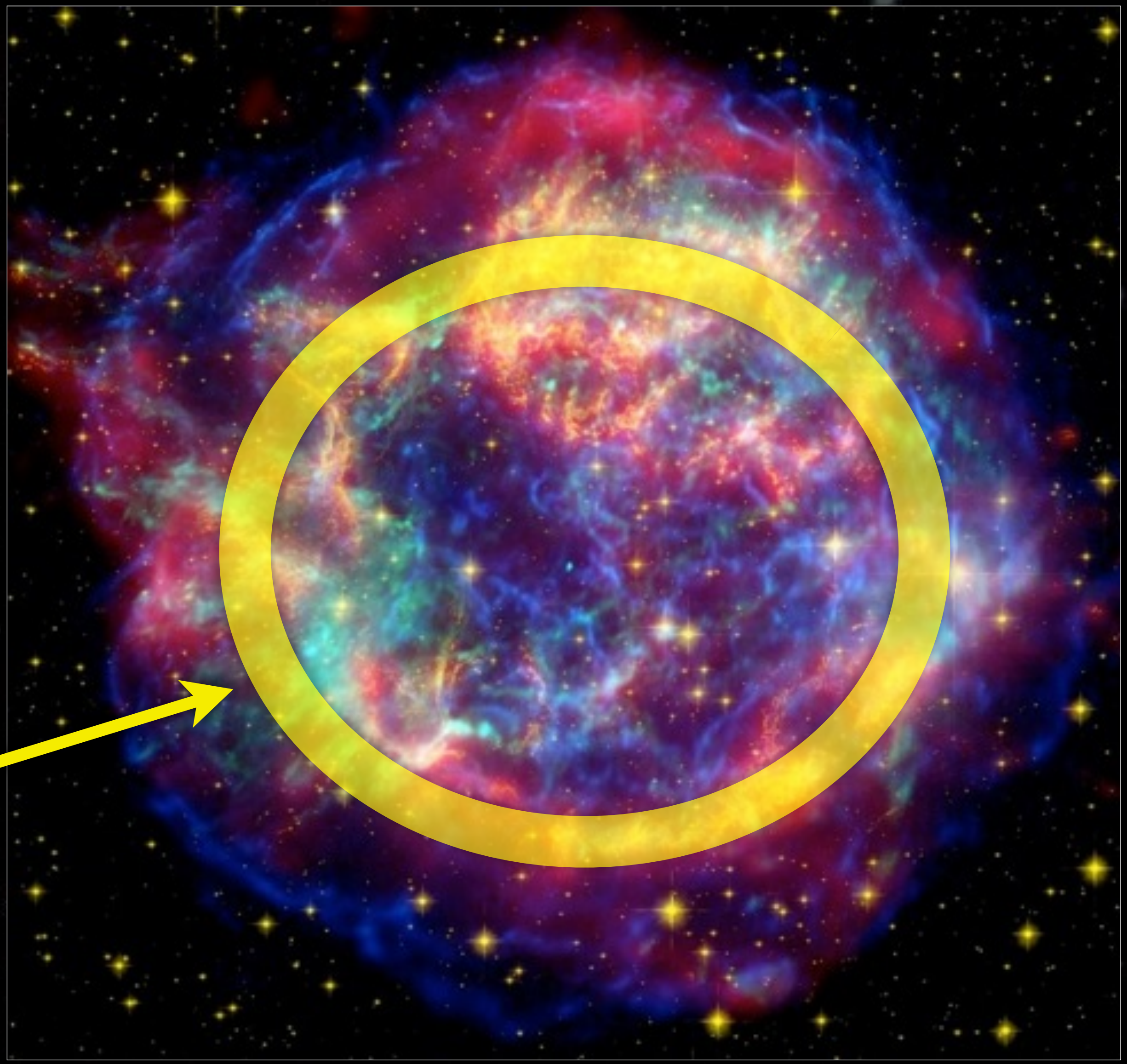
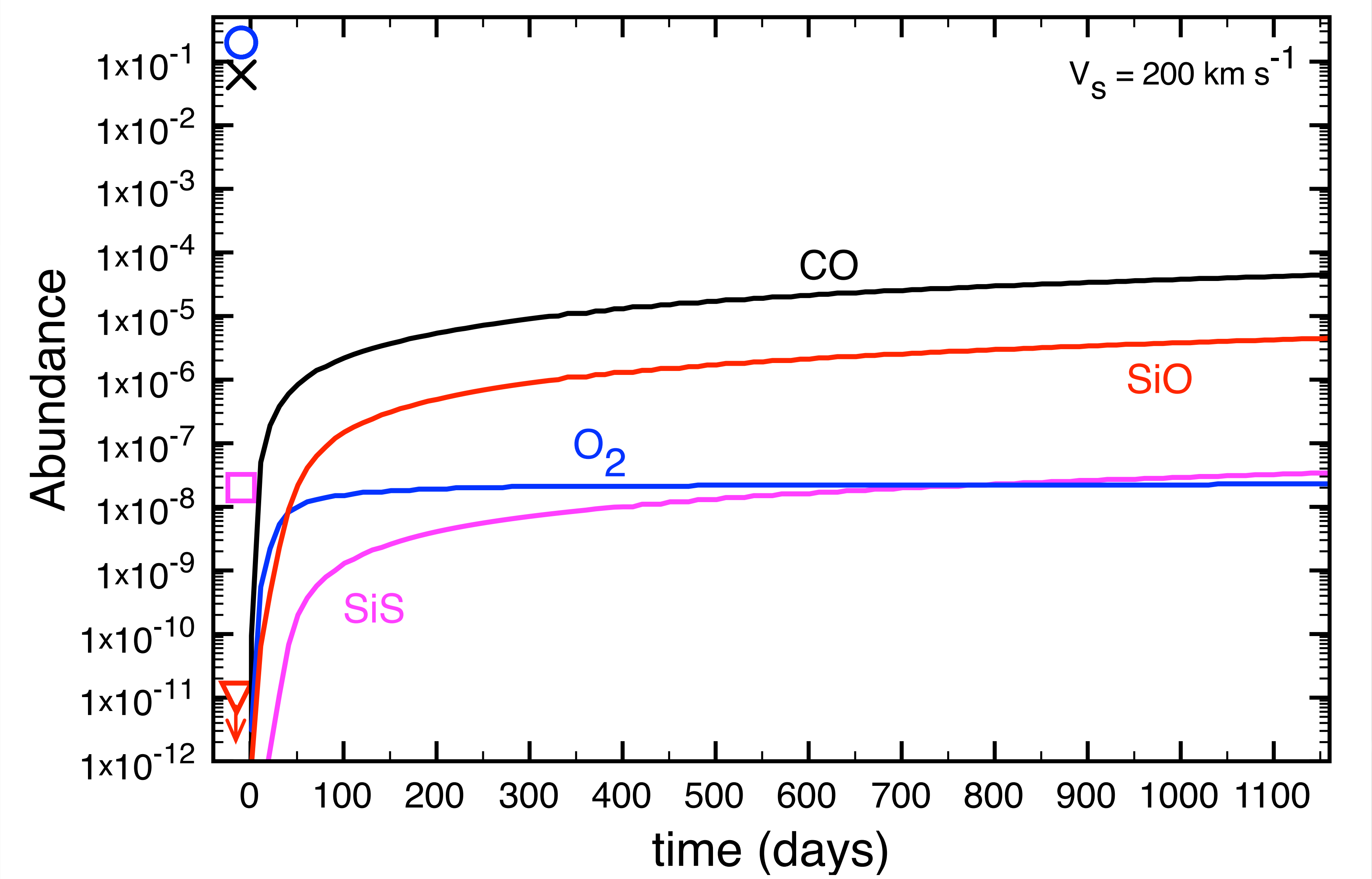


After the shock

Biscaro & Cherchneff 2014



Shock velocity
200 km/s

Ionization fraction
(O+/O) ~ 21%

Density: 10^6 cm^{-3}

(Docenko&Sunyaev 2010)

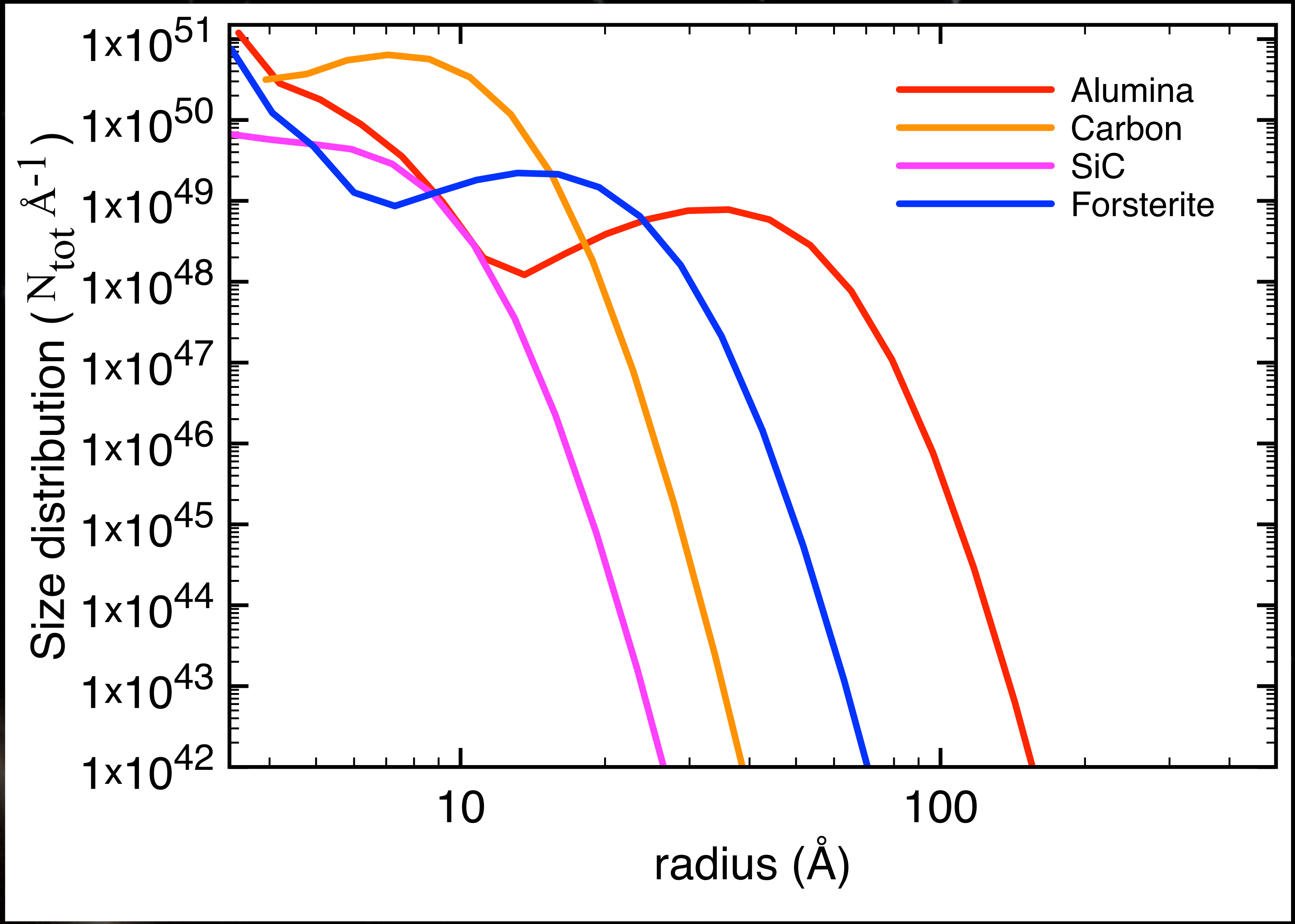
- ★ The shock ionizes and destroys everything
- ★ CO, SiO and O_2 all reform mainly by radiative association
- ★ CO abundances agree with most recent Herschel data (Walström, et al. 2013).
- ★ No dust clusters reform from the gas phase

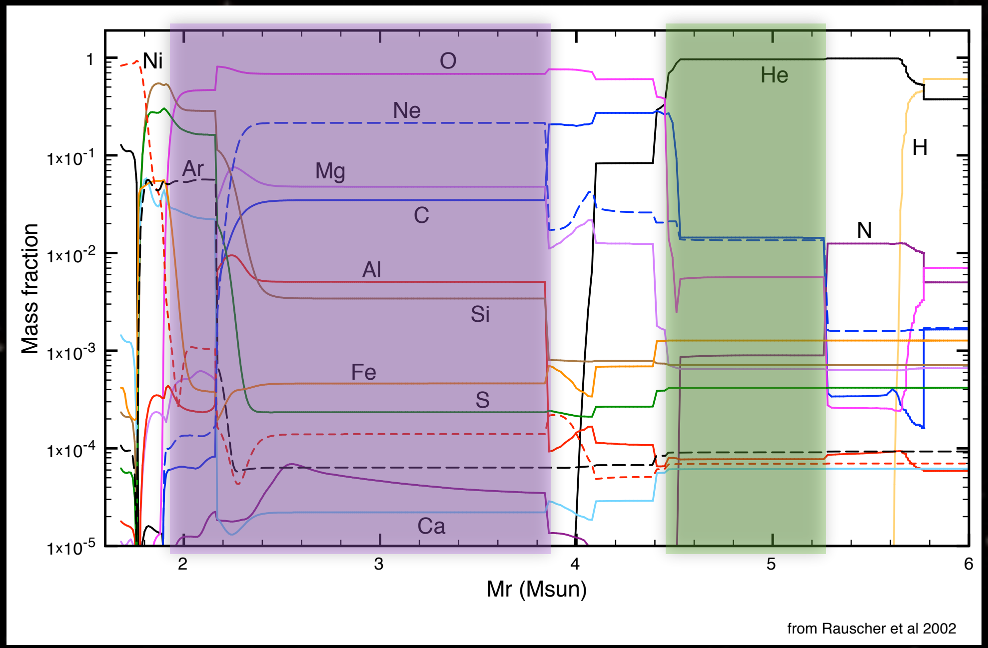
Sputtering model

Initial conditions

Sarangi & Cherchneff, 2015

- ★ Oxygen rich clump:
  - Zone 2 + 1b
  - Sputtering by O+
  - Mass = 1.97 M_{sun}
- ★ Carbon rich clump:
  - Zone 4a
  - Sputtering by He+
  - Mass = 0.75 M_{sun}





Dust formed until 4000 days post explosion, density 10^{10}-10^{11} cm^{-3} (x200)

Sputtering model

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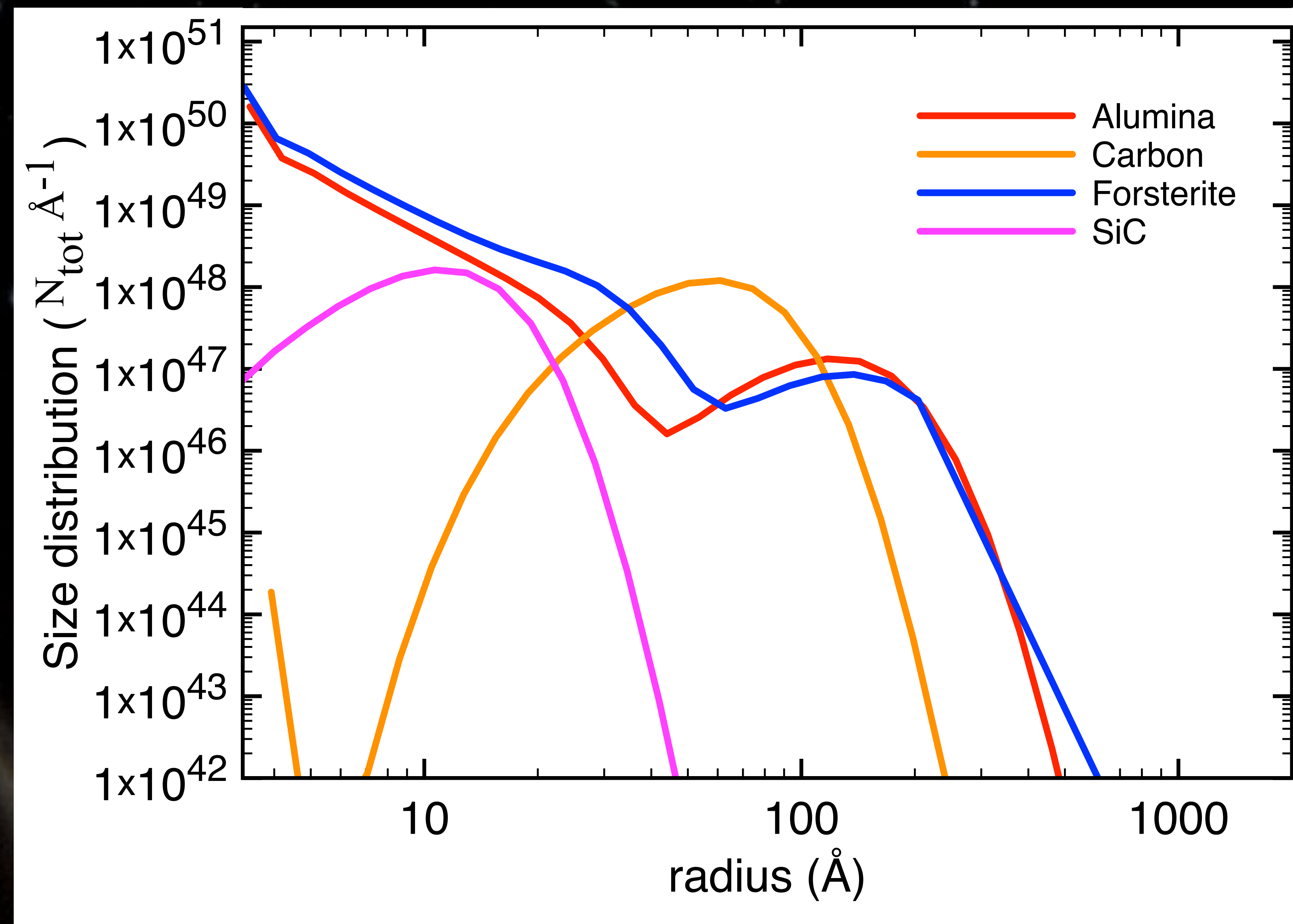
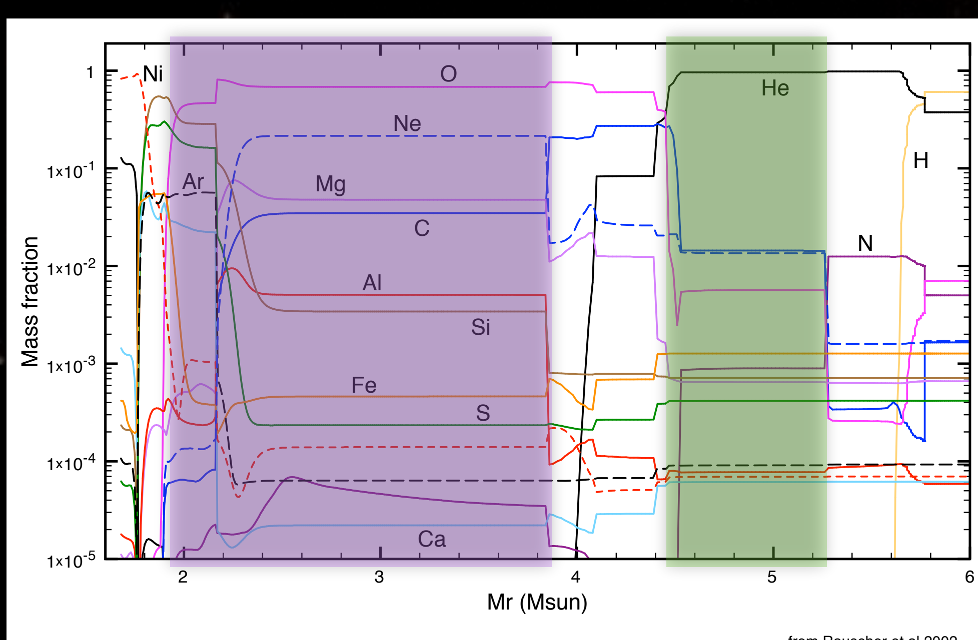




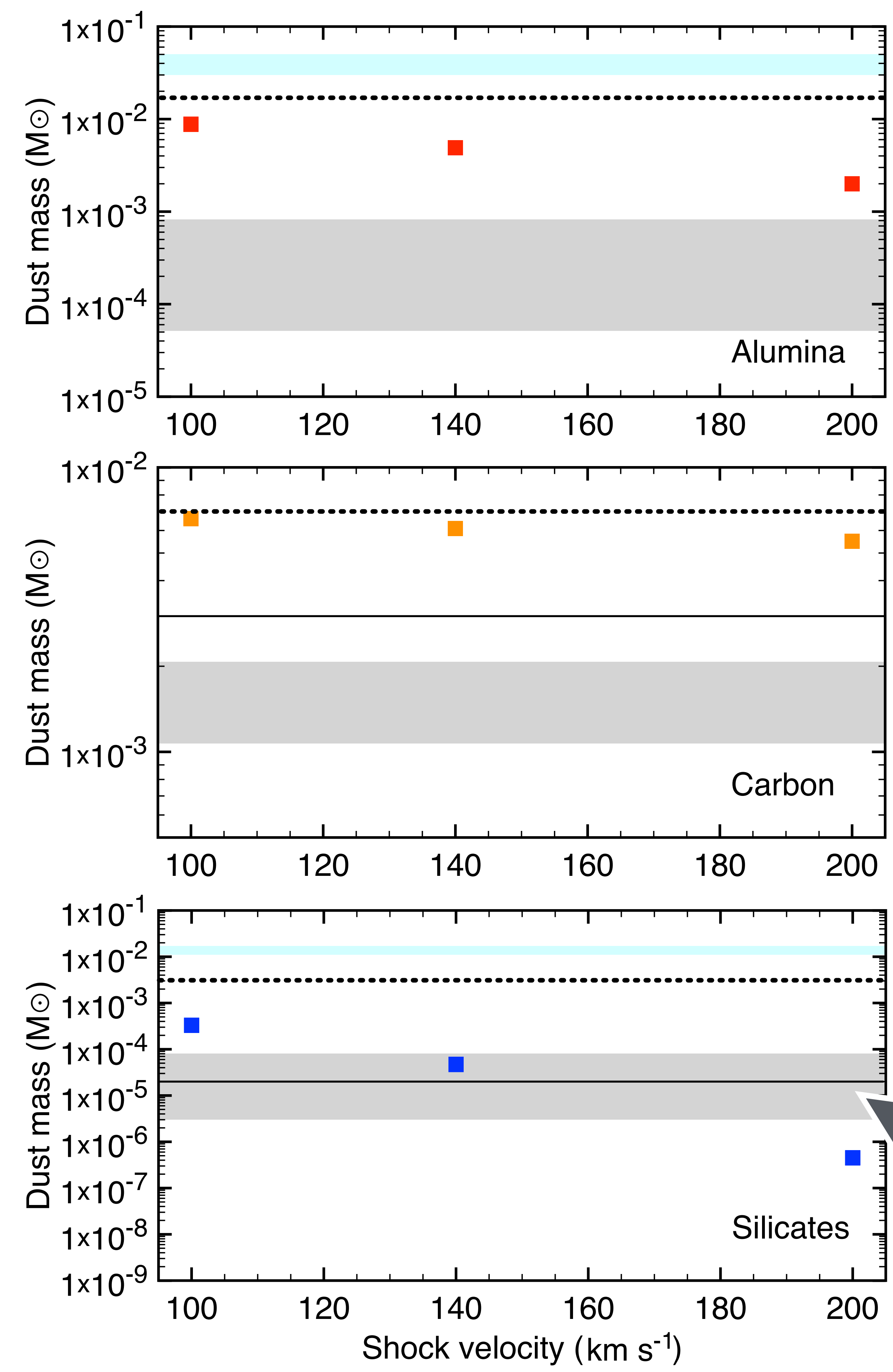
Dust formed until 4000 days post explosion, density 10^{11}-10^{12} cm^{-3} (x2000)

Results

Cas A today

★ Dust observations at time ~330 yr after explosion (Rho et al. 2008, Arendt et al, 2014)

★ Sandstrom et. al 2008 observe the ejecta-reverse shock interaction in SNR 1E 0102.2, which has the same progenitor as Cas A



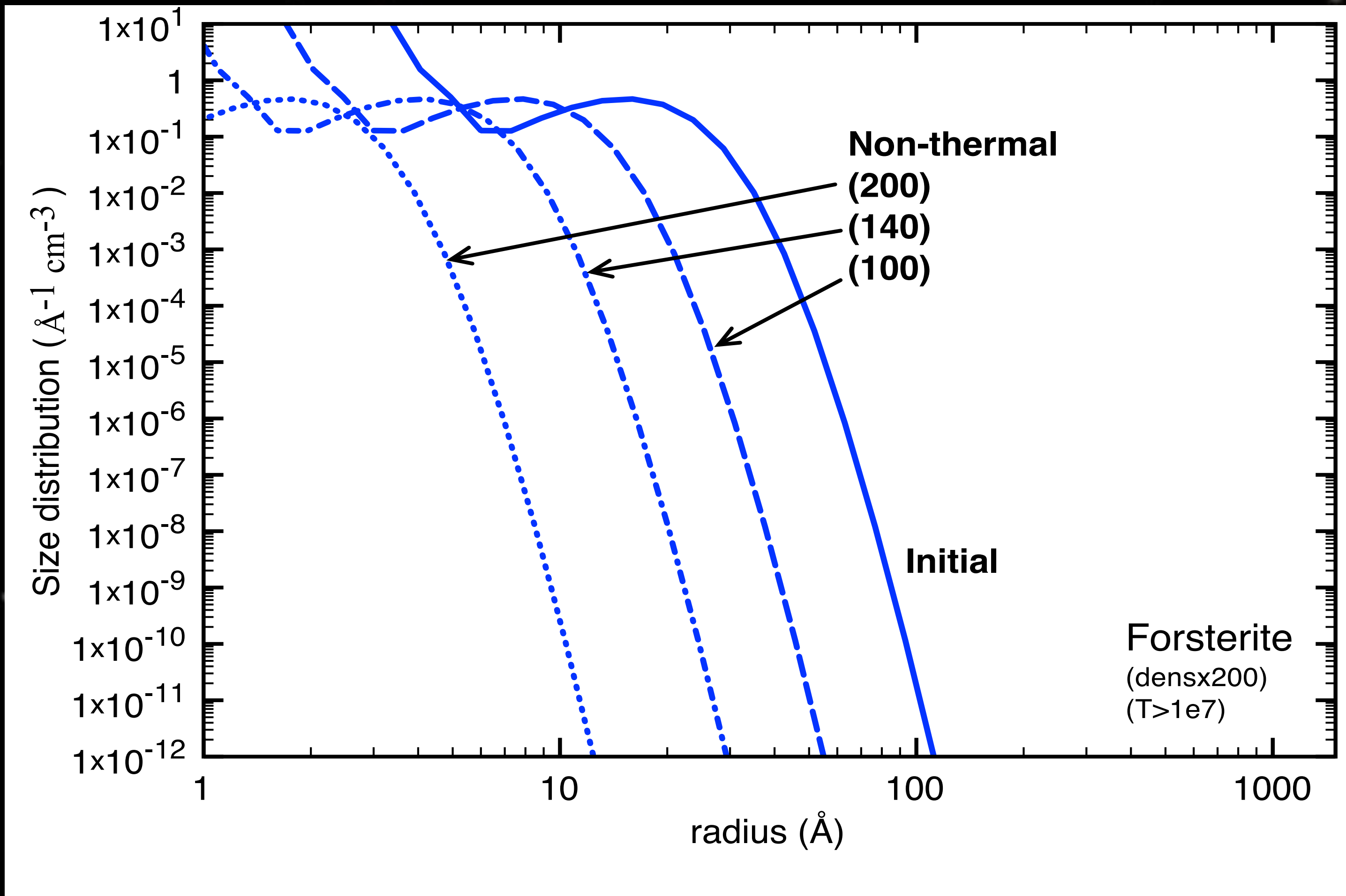
Arendt et al. 2014

Rho et al. 2008

Sandstrom et al. 2008

Biscaro & Cherchneff, in prep.

Forsterite

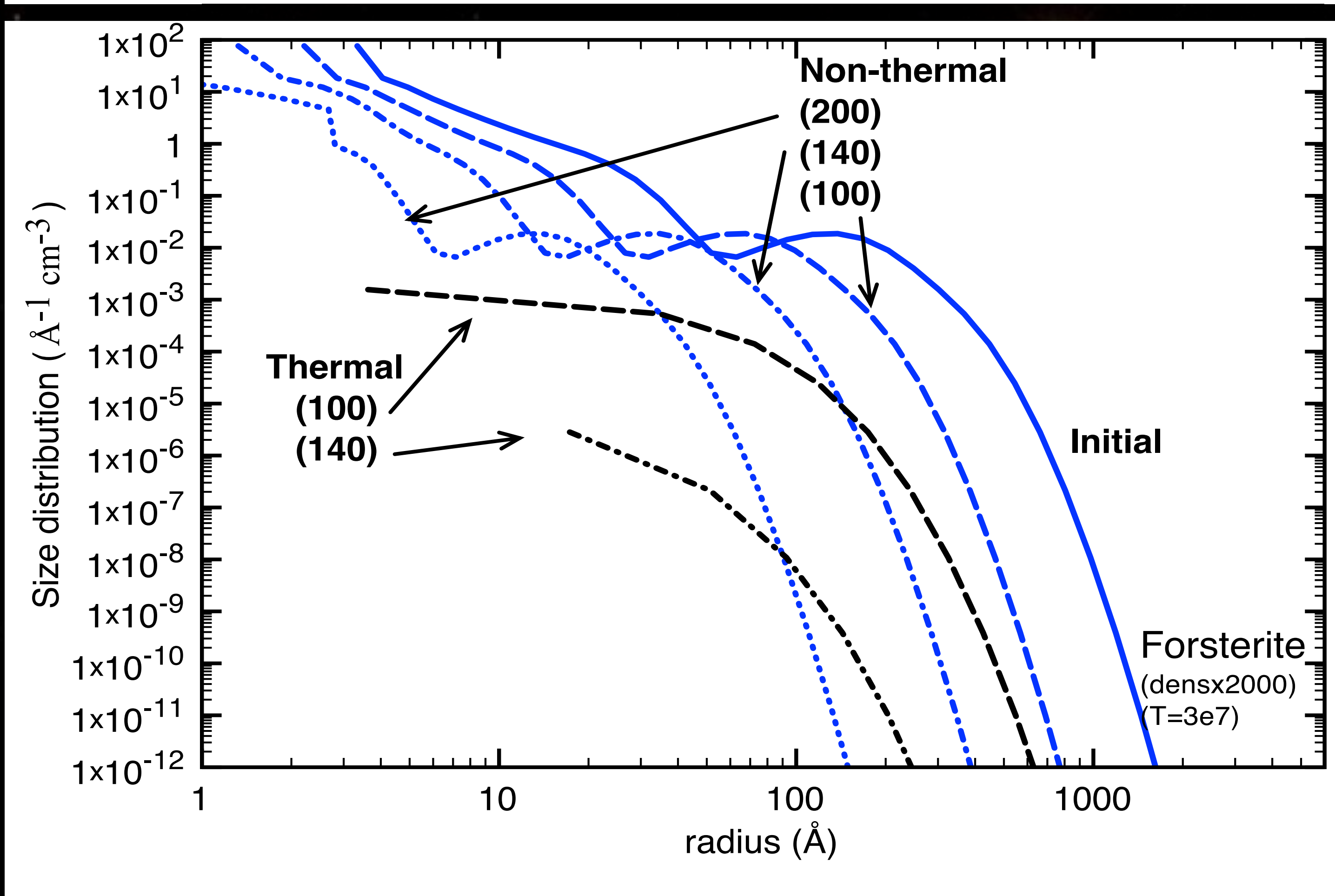


Density x 200

Survival

0 %

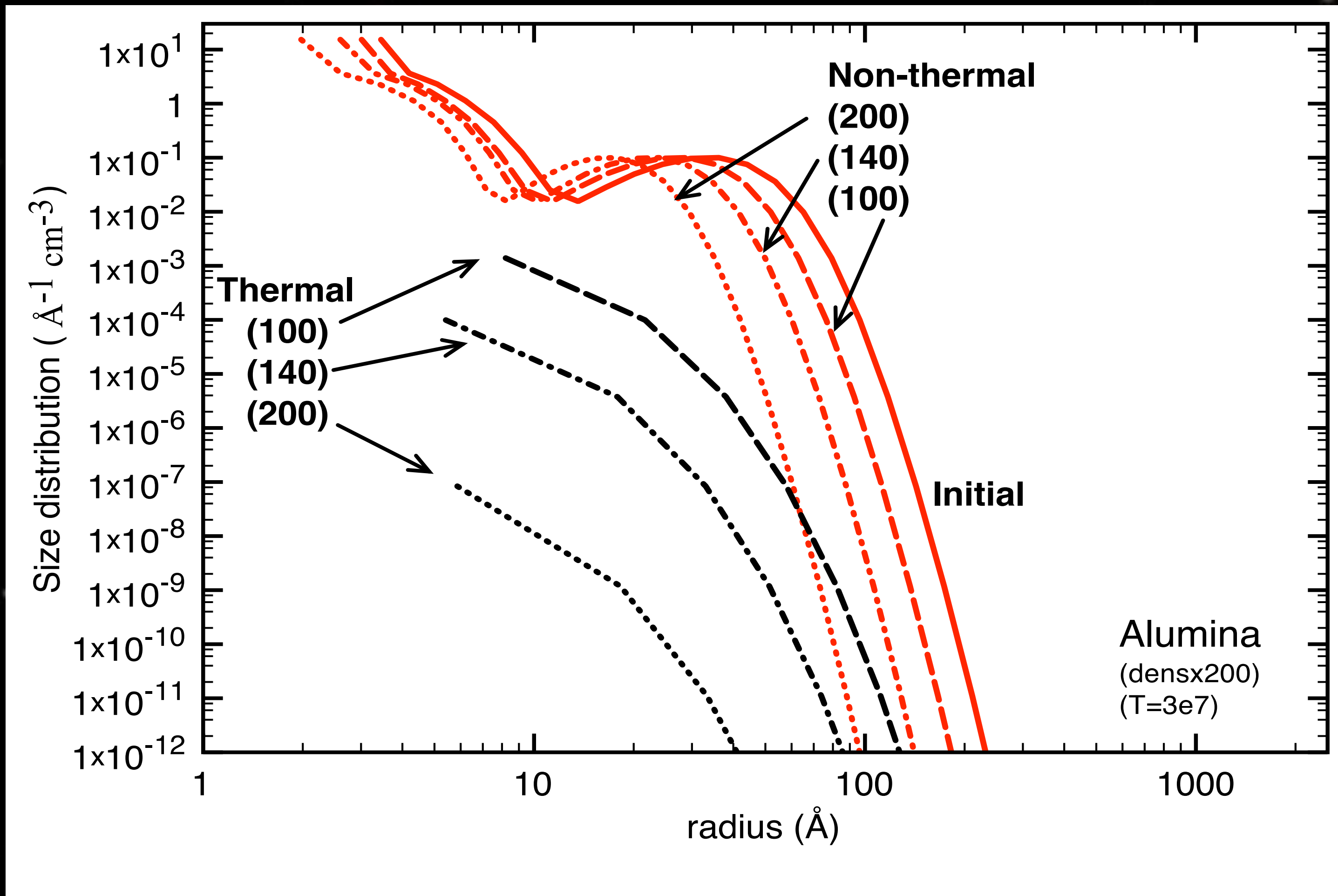
Biscaro & Cherchneff, in prep.

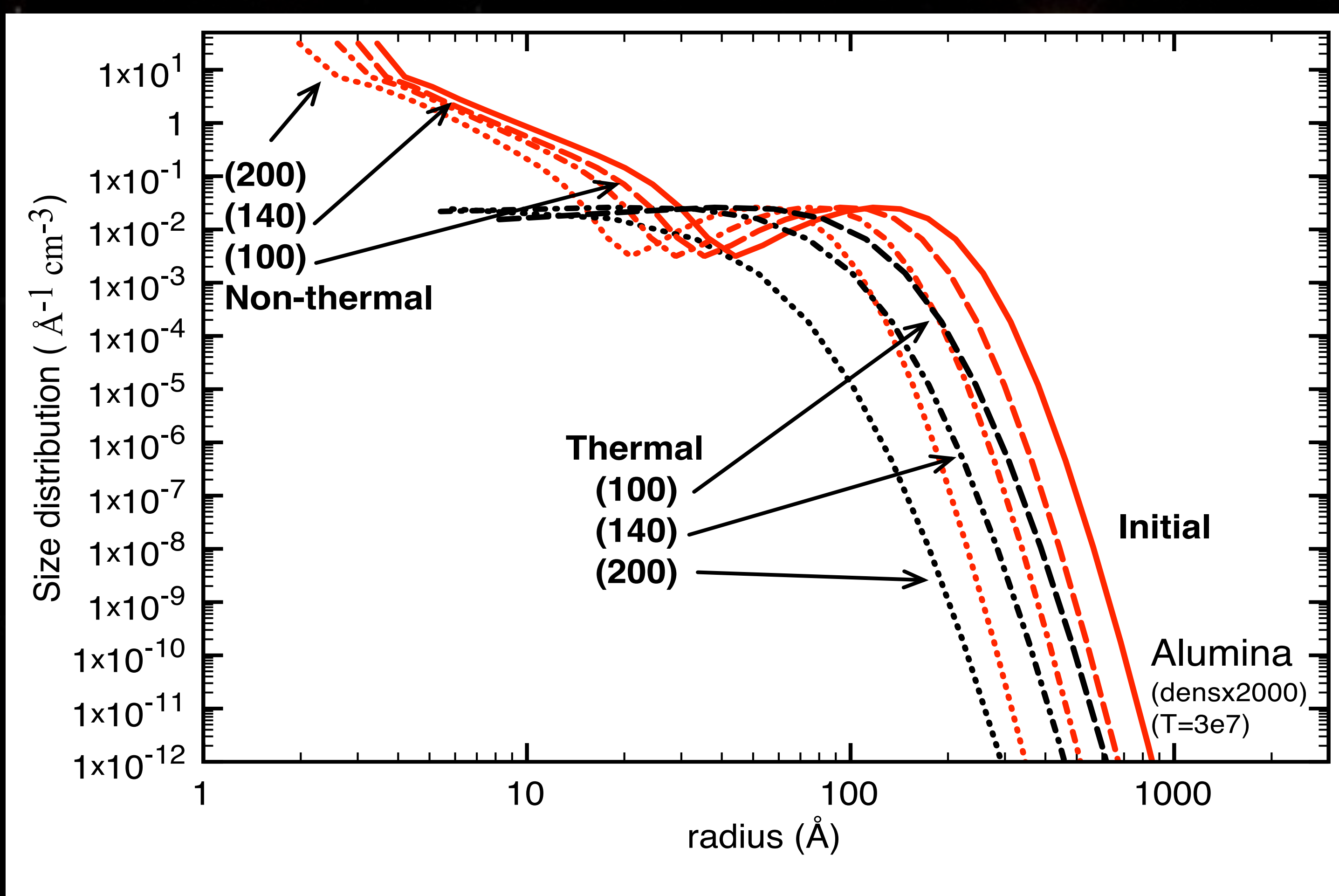


Density x 2000

Survival

~ 0 %





Alumina

Density x 200

Survival

200 km s^{-1} : ~0 %

140 km s^{-1} : 0.4 %

100 km s^{-1} : 2.0 %

Biscaro & Cherchneff, in prep.

Density x 2000

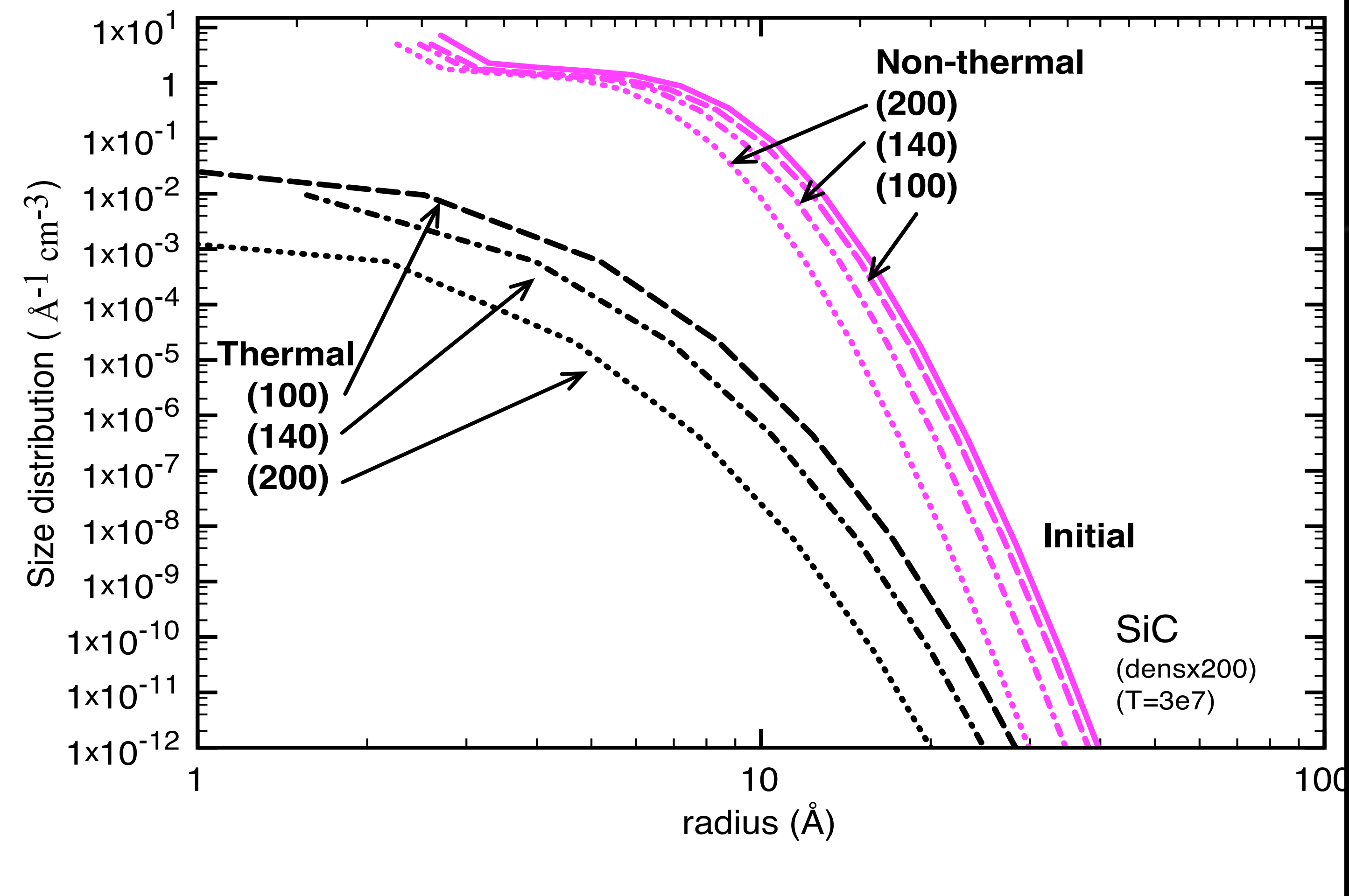
Survival

200 km s^{-1} : 0.2 %

140 km s^{-1} : 9.1 %

100 km s^{-1} : 24 %

Silicon Carbide



Density x 200

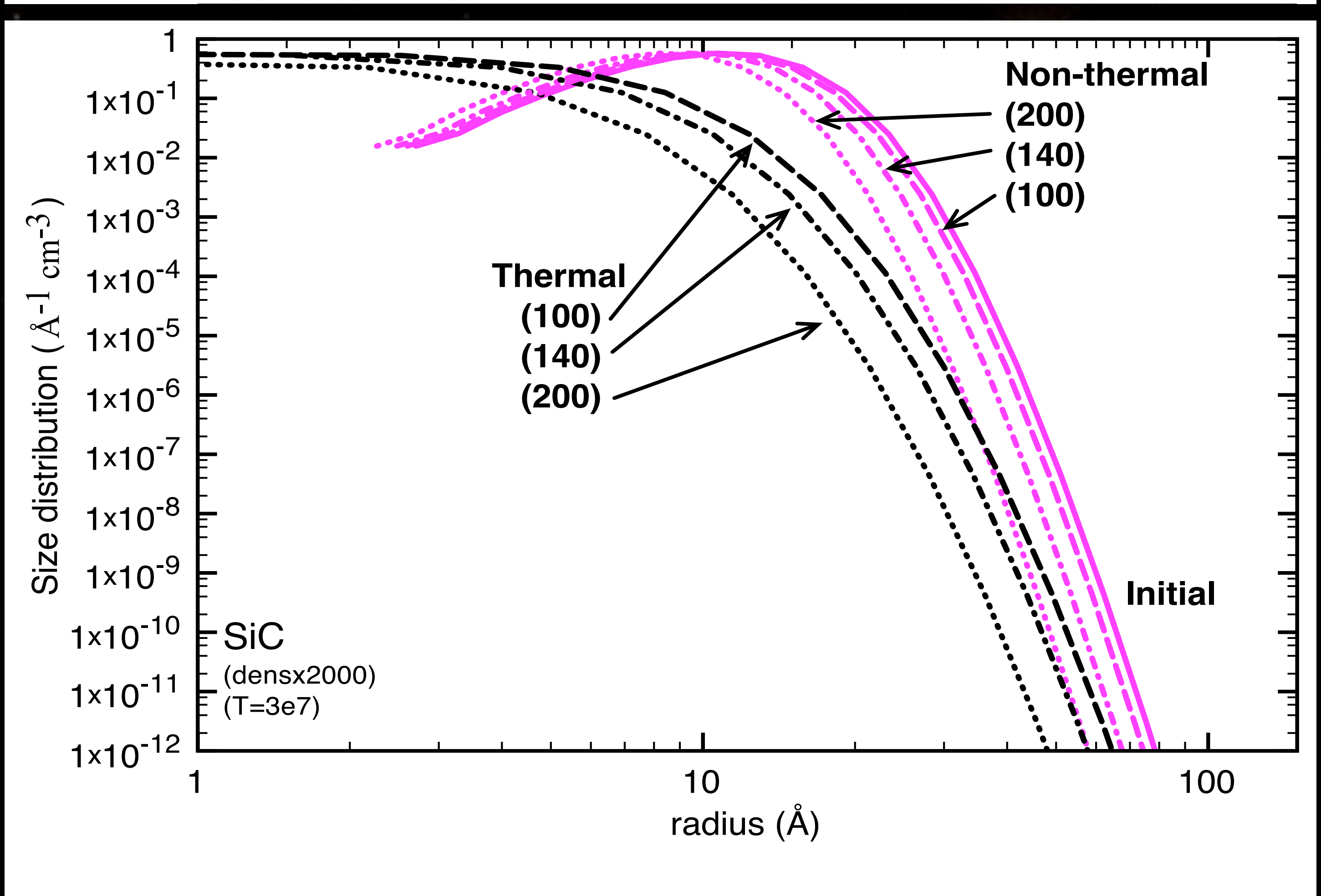
Survival

200 km s^{-1} : ~0 %

140 km s^{-1} : 0.1 %

100 km s^{-1} : 0.3 %

Biscaro & Cherchneff, in prep.



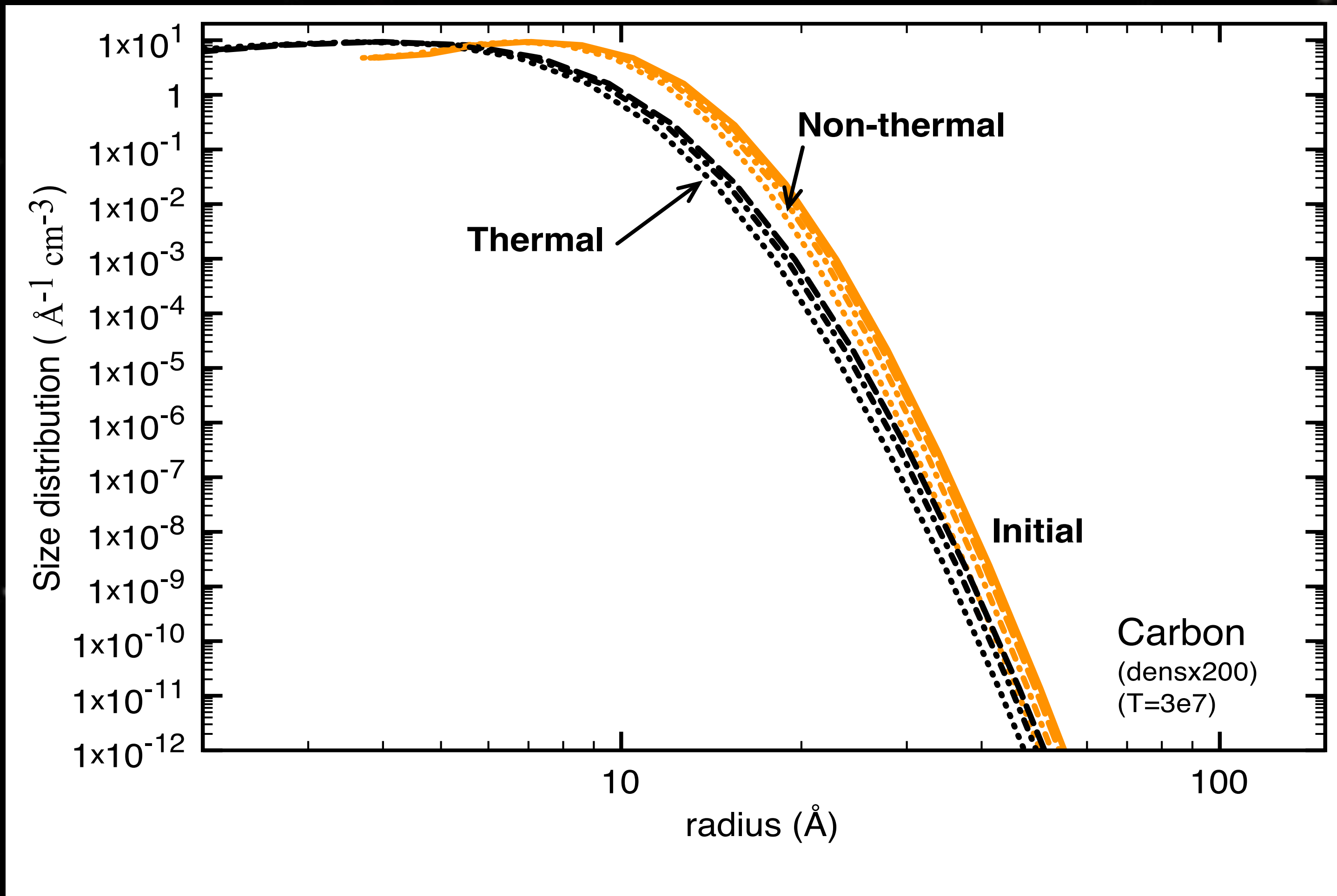
Density x 2000

Survival

200 km s^{-1} : 3 %

140 km s^{-1} : 7 %

100 km s^{-1} : 11 %



Carbon

Density x 200

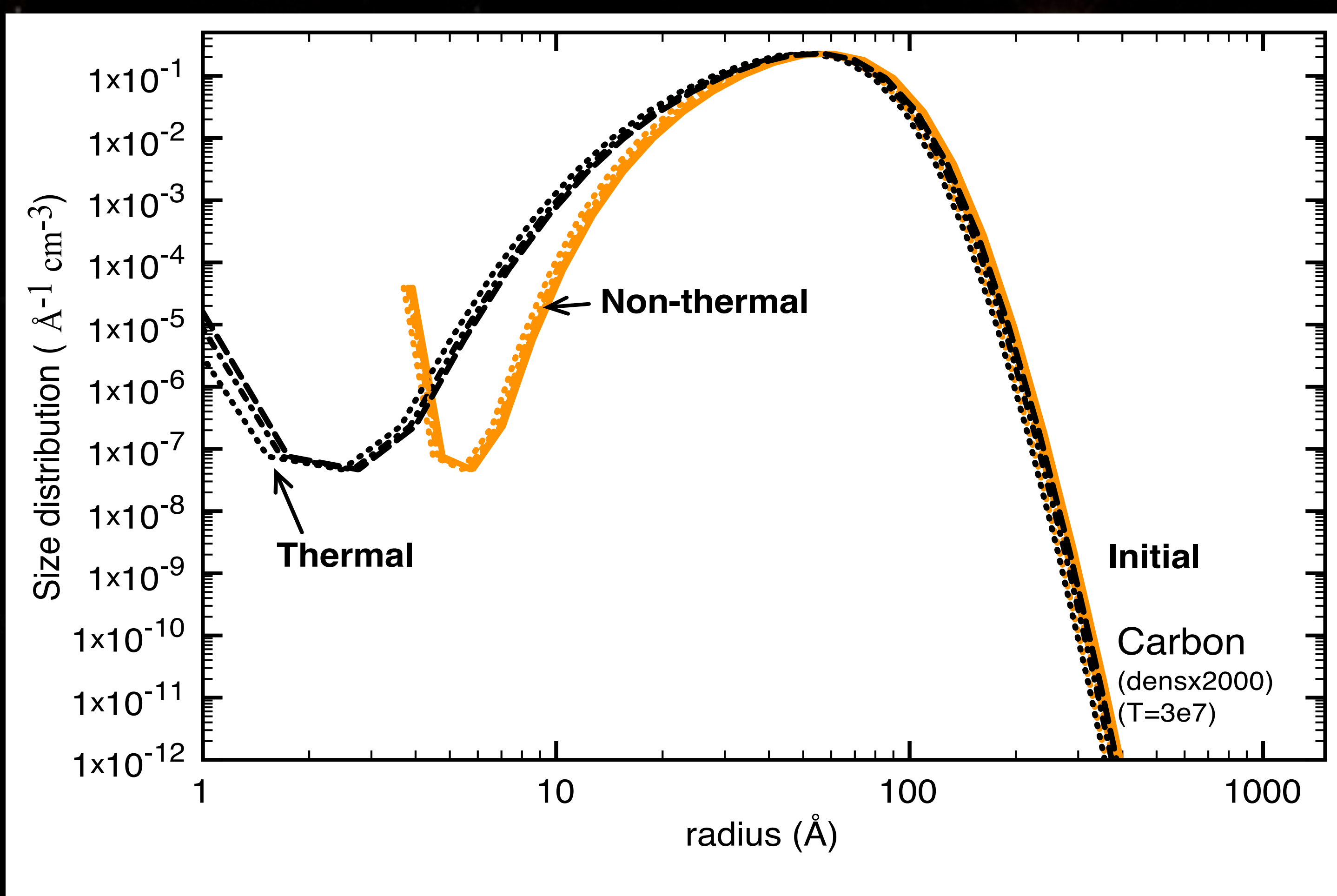
Survival

200 km s^{-1} : 21 %

140 km s^{-1} : 23 %

100 km s^{-1} : 28 %

Biscaro & Cherchneff, in prep.



Density x 2000

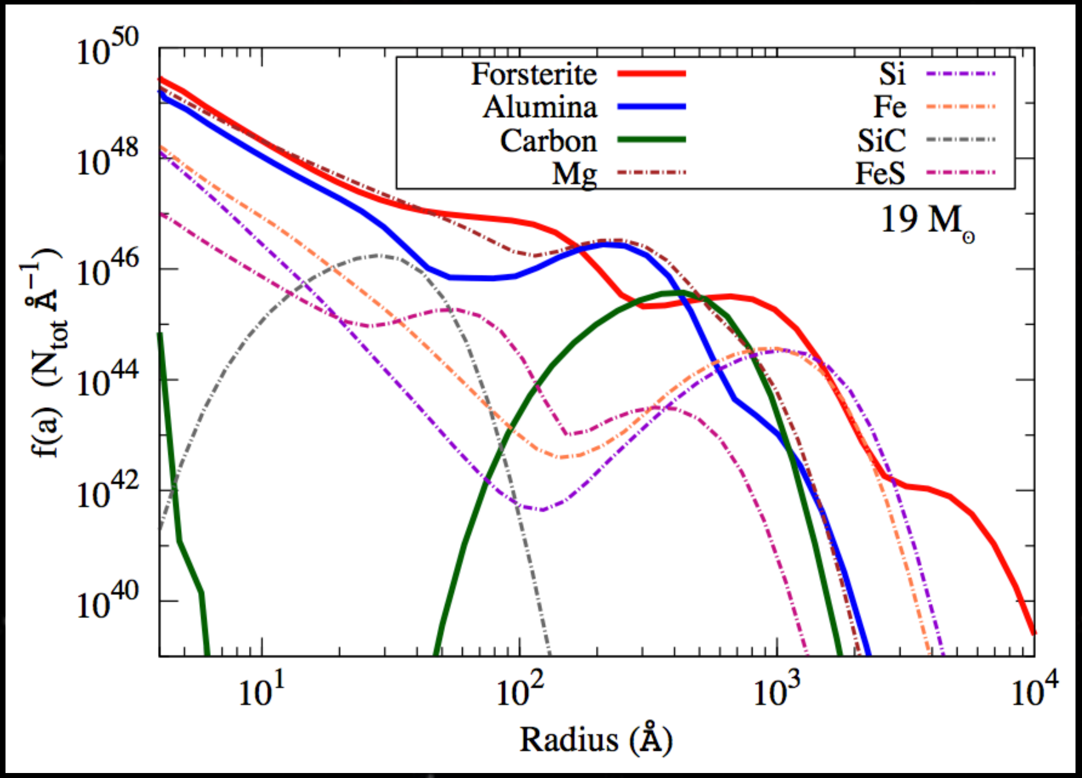
Survival

200 km s^{-1} : 65 %

140 km s^{-1} : 75 %

100 km s^{-1} : 83 %

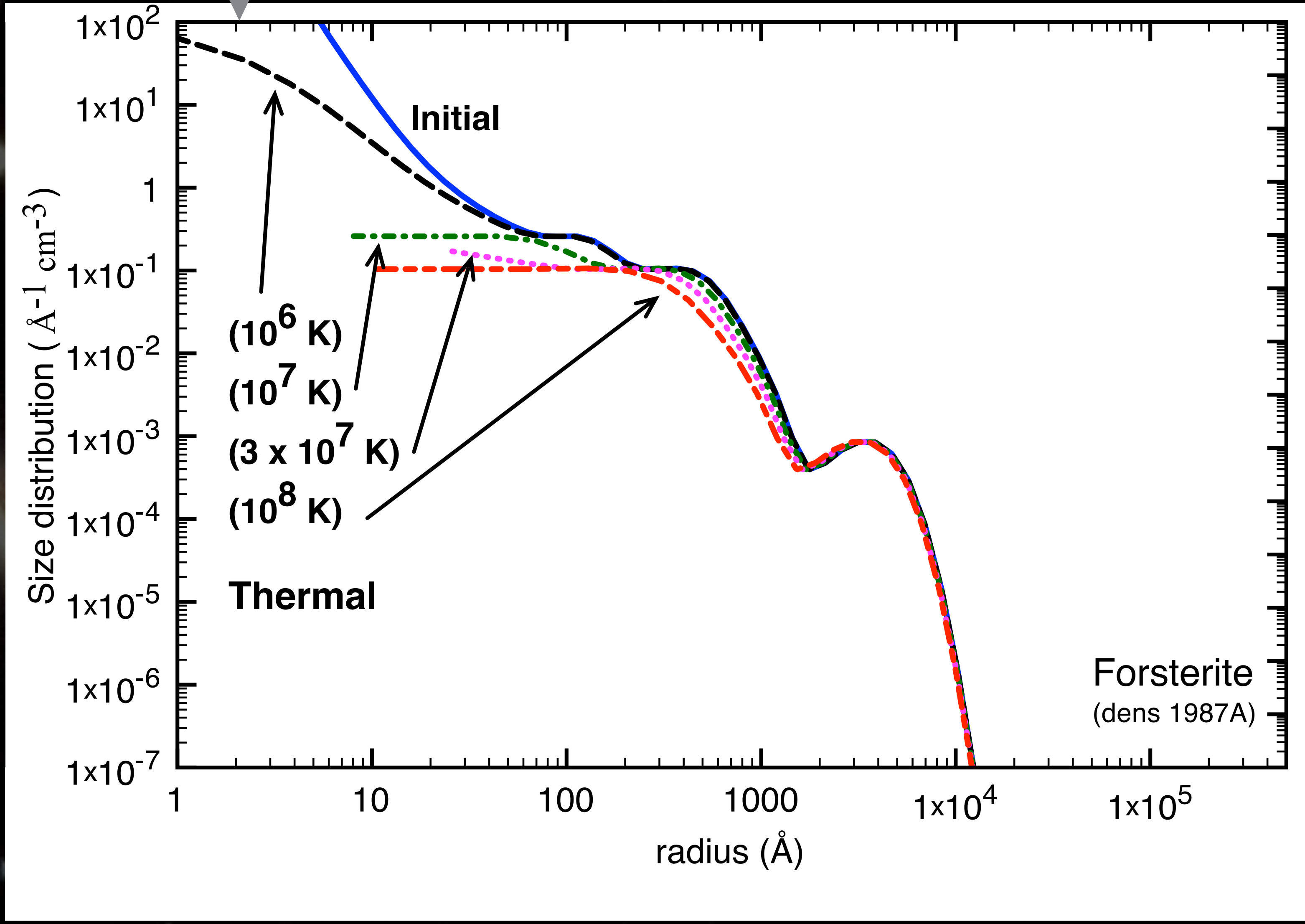
Presolar silicates grains with SN origin are found in meteorites



Sarangi & Cherchneff, 2015

SNe of Type IIP form very large grains that can survive the reverse shock and thermal sputtering at the high inter-clump temperatures

Survival :
10^6 K : 97 %
10^7 K : 86 %
3×10^7 K : 78 %
10^8 K : 69 %

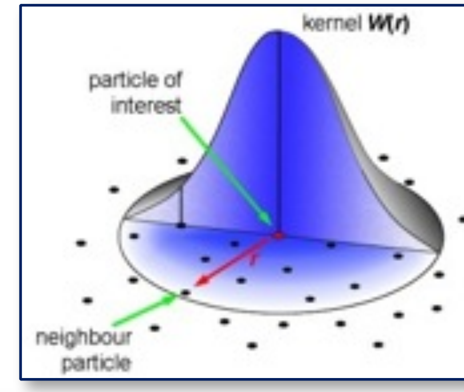


Conclusions

- ★ Density has a major impact on molecule and dust synthesis, and on the dust chemical complexity -> Clumpy SN ejecta
- ★ Silicate, alumina and carbon clusters do not reform in the post-shock -> dust cannot form from the gas-phase in the SN remnant.
- ★ Non-thermal and thermal sputtering efficiently reprocess the dust formed in the ejecta knots. Alumina is the most abundant dust species that survives the SNR phase.
- ★ High density clumps are required for the survival of silicate dust in the SN remnant phase to explain presolar silicate SN grains in meteorites

ONE LAST THING…

- ❑ SPHYNX is a fully lagrangian SPH hydrocode.
- ❑ The system is discretized into particles that evolve with the fluid, following the HD equations.
- ❑ Physical properties, in every particle position, are retrieved through interpolation over close neighbors.



$$< f(\mathbf{r}) > = \int f(\mathbf{r}')W(\mathbf{r}' - \mathbf{r})d\mathbf{r}'$$

$$f_a(\mathbf{r}) = \sum_{b=1}^{n_v} \frac{m_b}{\rho_b} f_b(\mathbf{r})W(\mathbf{r}_{ab}, h)$$

SPHYNX

3D SPH MPI + OpenMP **+ GPU**:

- Adaptive smoothing-length.
- Burns-Hut octal tree for 3D multipolar self-gravity
- *sinc* (harmonic) Kernels. Cabezón, García-Senz, Relaño 2008
- Integral Approach to Derivatives (IAD).
  García-Senz, Cabezón, Escartín 2012

- Preparatory stage / work in progress:
  - 2D / 3D
  - 160,000 particles / ~ 10^6 particles
  - 100x density jump
  - Post-processing of dust sputtering/ Coupled chemical network