Dust formation in the ejecta of type II-P supernovae

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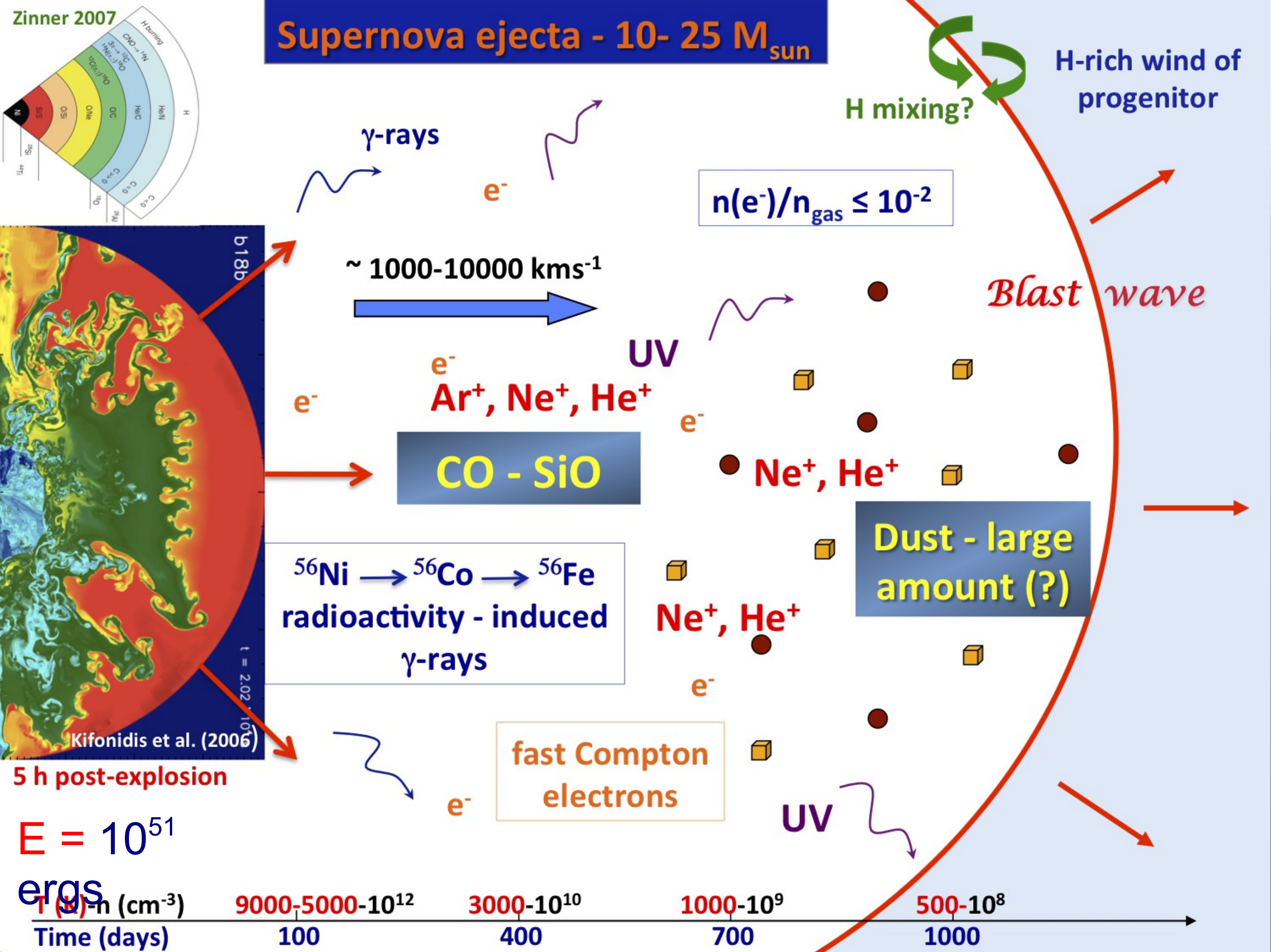
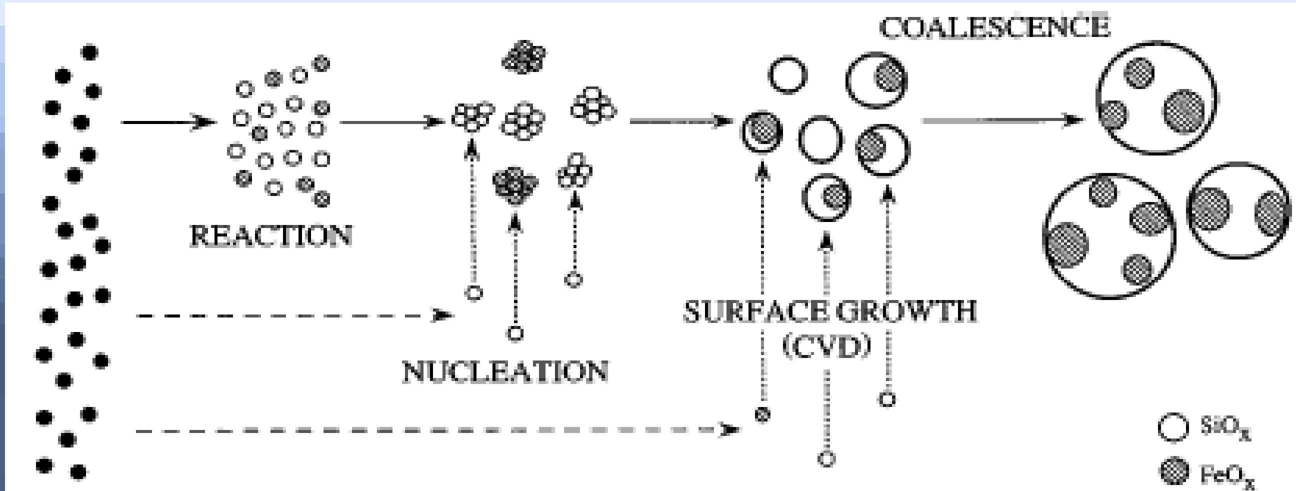
Overview

- Physics and chemistry of supernovae (type II-P) explosion model
- Chemical Kinetics: Linking molecules to dust
- Molecules as tracers of dust formation?
- Addressing the dust dilemma in supernovae
- A nucleation scheme to link gas phase with dust
- The fluxes at IR & sub-mm from our dust composition & comparison with observations


Zinner 2007
Supernova ejecta - 10- 25 M$_{sun}$
H mixing?
H-rich wind of progenitor
γ-rays
e$^-$
n(e$^-$)/n$_{gas}$ ≤ 10^{-2}
b18b
~ 1000-10000 kms^{-1}
Blast wave
UV
e$^-$
Ar$^+$, Ne$^+$, He$^+$
e$^-$
e$^-$
CO - SiO
Ne$^+$, He$^+$
^{56}Ni → ^{56}Co → ^{56}Fe
radioactivity - induced
γ-rays
Dust - large amount (?)
Ne$^+$, He$^+$
e$^-$
Kifonidis et al. (2006)
5 h post-explosion
fast Compton electrons
e$^-$
UV
E = 10^{51} ergs
T (K)-n (cm^{-3})
9000-5000-10^{12}
3000-10^{10}
1000-10^9
500-10^8
Time (days)
100
400
700
1000

Modeling Supernova Ejecta: Chemical Kinetics

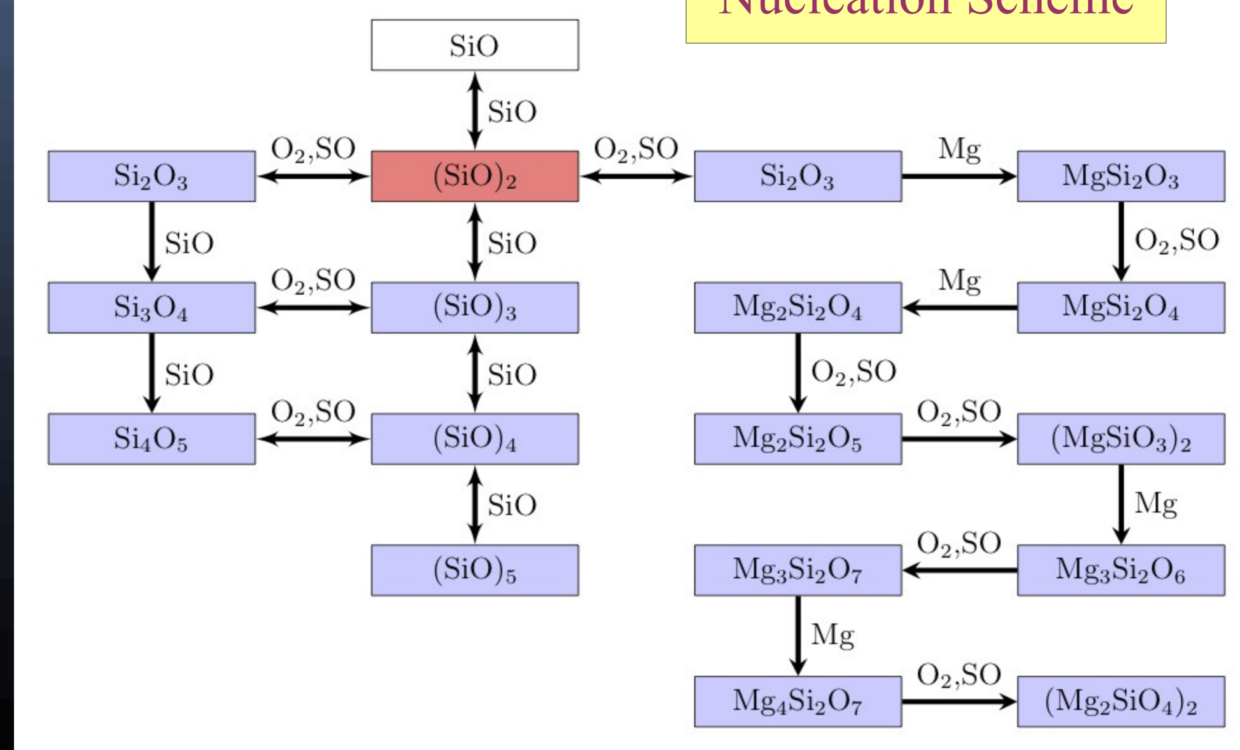


Gas phase & solid phase are chemically coupled through nucleation and Condensation phases

High temperature & high density chemistry

Termolecular processes
Neutral-neutral
Radiative association
Ion-molecule
Charge exchange
Thermal fragmentation
Dissociation by Compton
Electron and UV photon

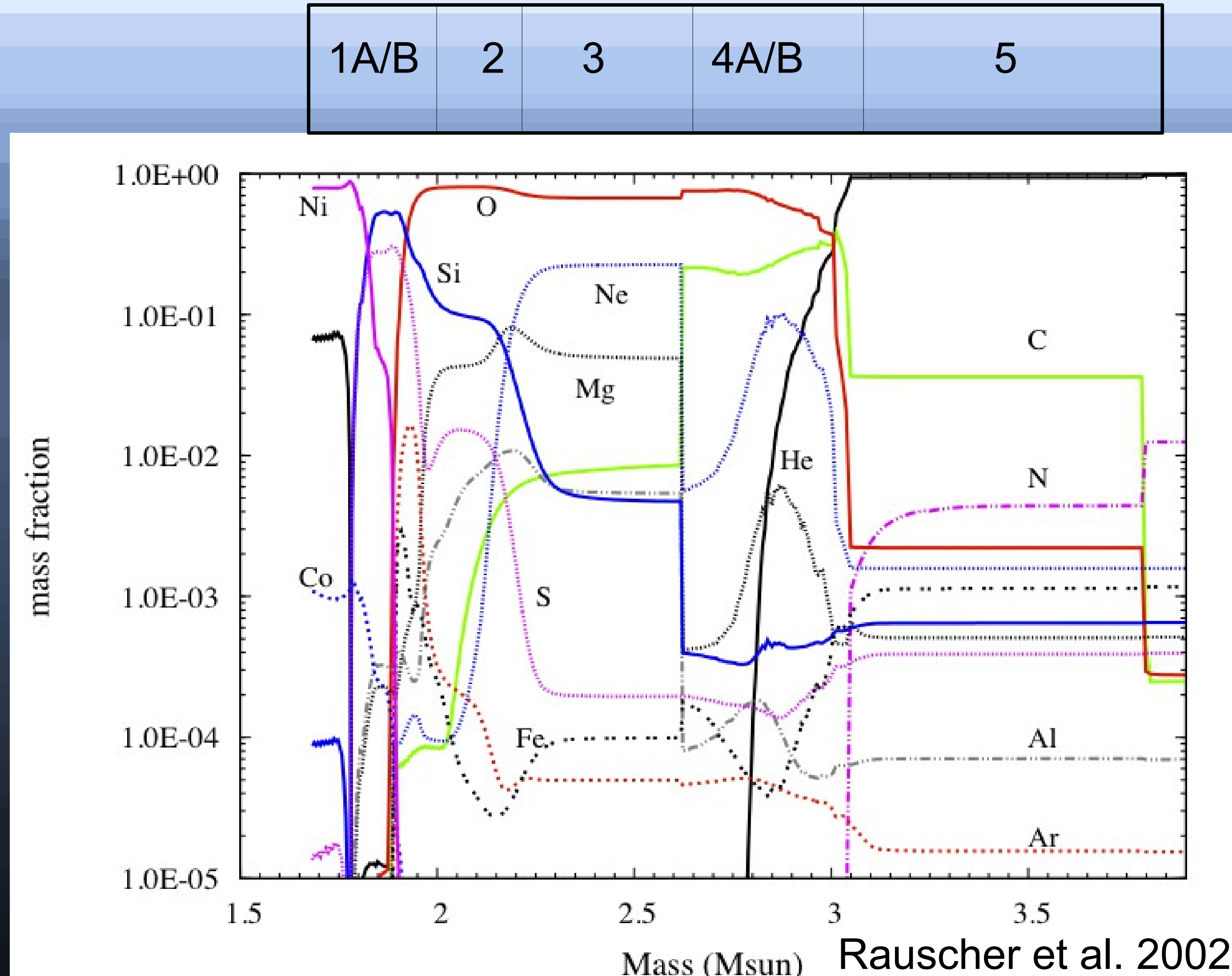
Nucleation Scheme



Modeling a Typical Type IIP Supernova Ejecta

Progenitor
15 M_{sun}
Helium Core
4.14 M_{sun}

1A(Si/S/Fe)
1B(Si/O)
2(O/Mg/Si)
3(O/Ne/Mg)
4A(O/C)
4B(He/O/C)
5(He/C)



Rauscher et al. 2002

Microscopically mixed zones, stratified ejecta, no inter-zonal mixing

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1A/B	2	3	4A/B	5

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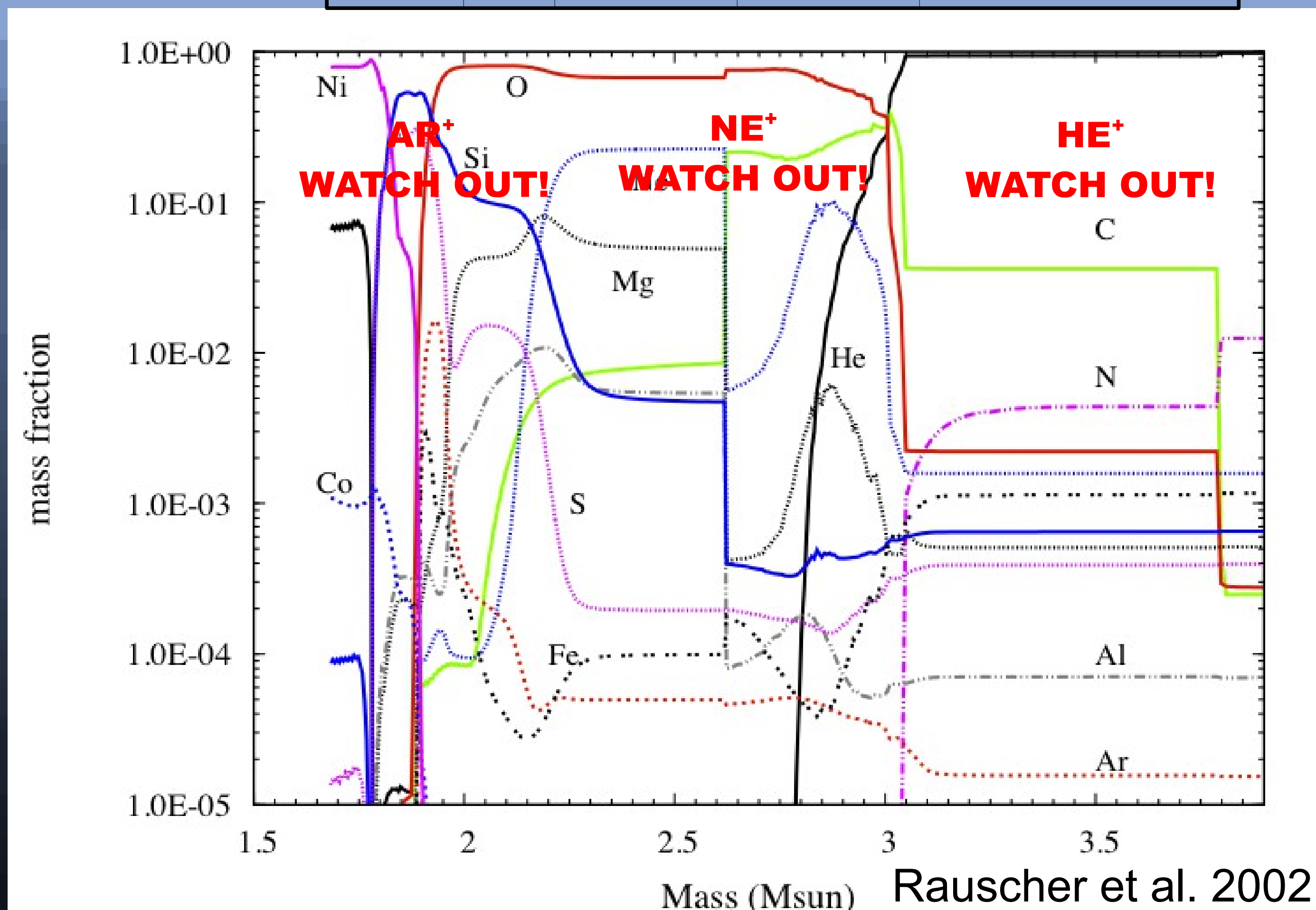

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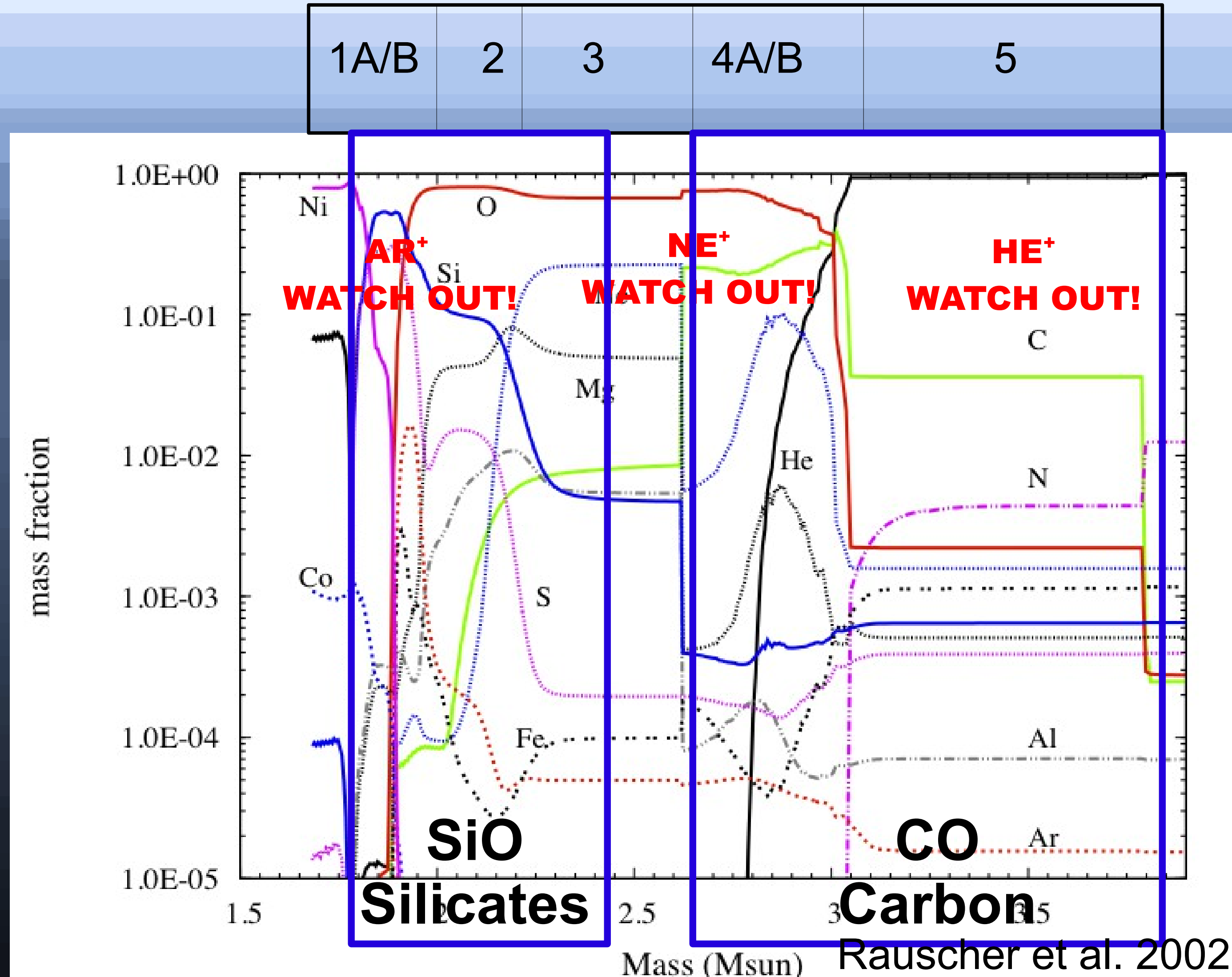

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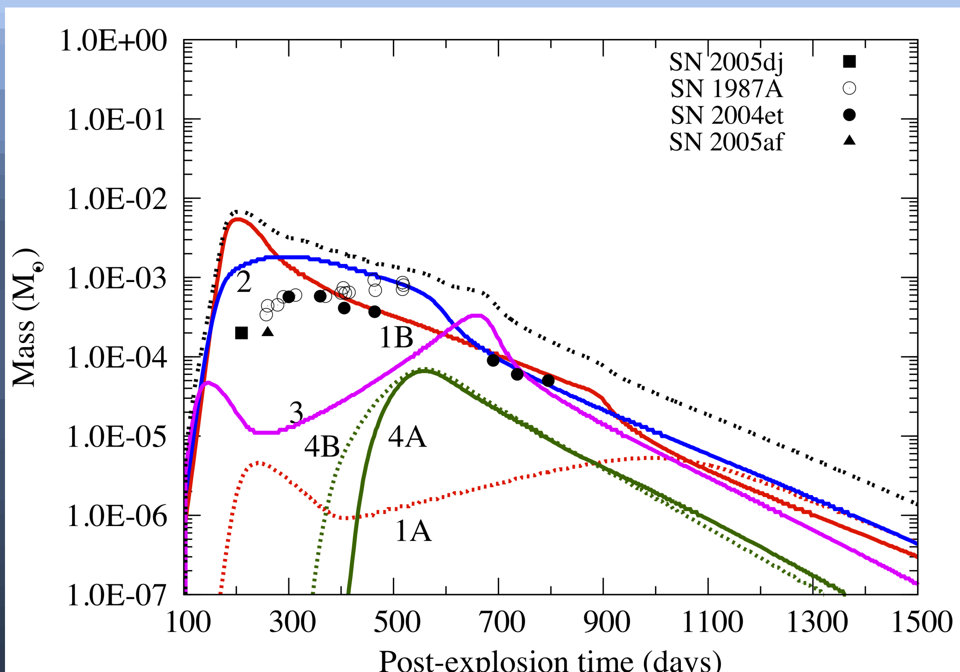
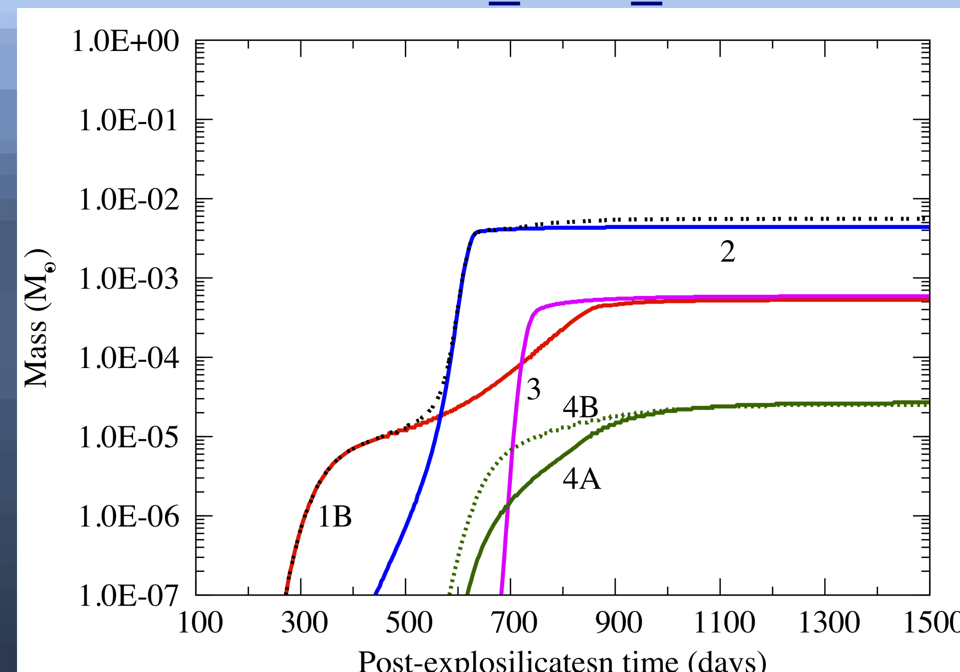
Molecules as Tracers of Dust Formation

SiO



Forsterite (Mg_2SiO_4) Dimers



SiO mass are in good agreement with observations of several SNe

Decrease of SiO is consistent with formation of silicates

Forsterite formation delayed due to late O_2 synthesis

SiO molecule is direct tracer of silicate synthesis

in supernova ejecta

Sarangi & Cherchneff 2013 ApJ. submitted

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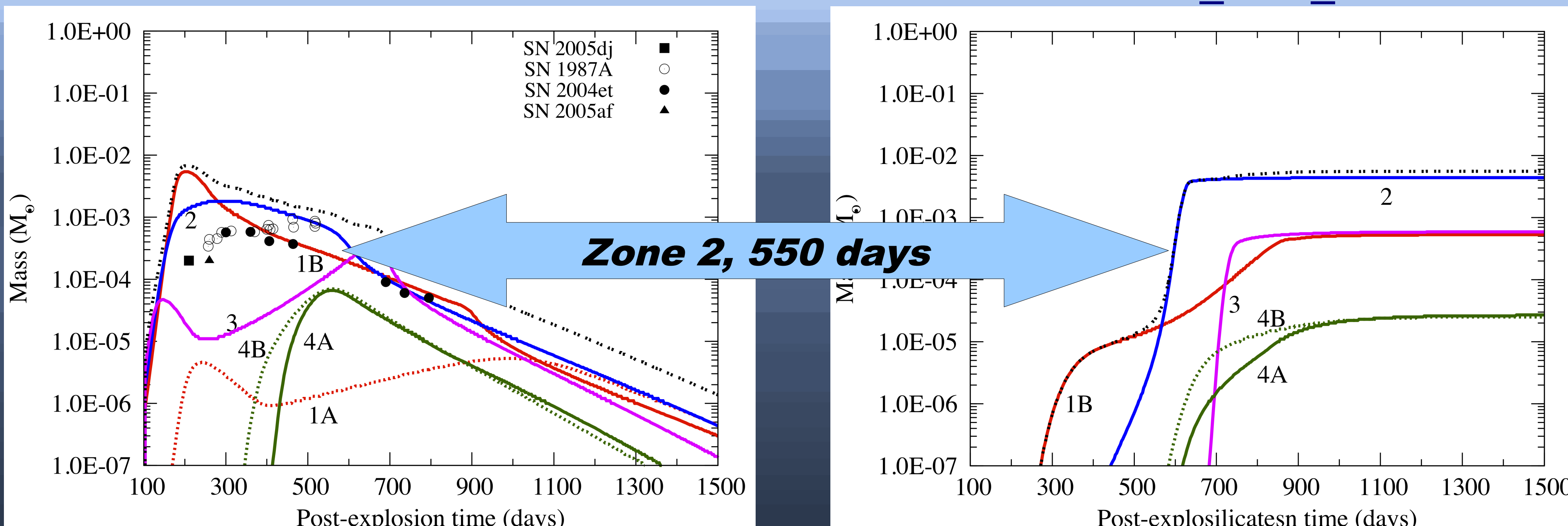

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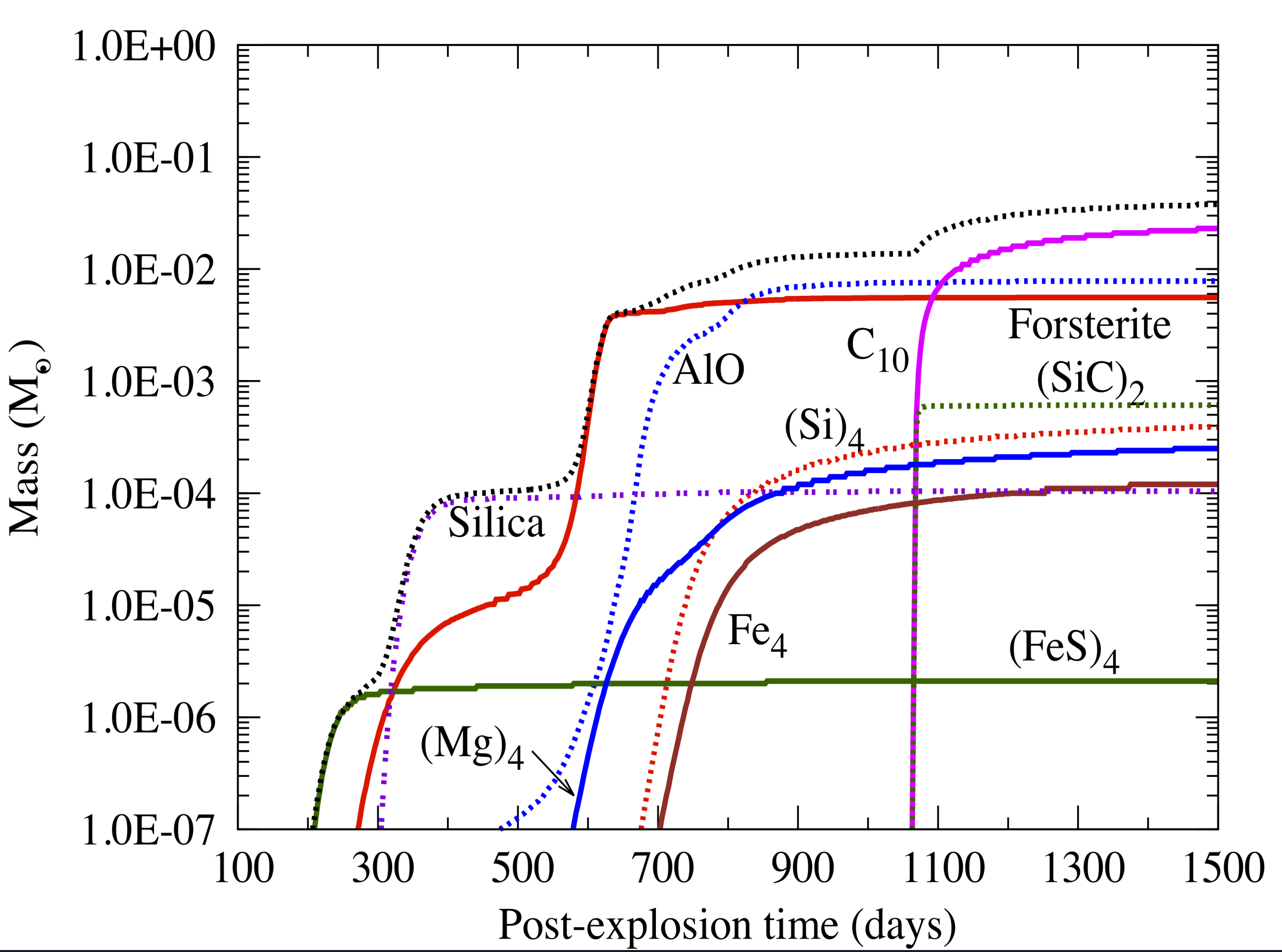
Total Dust Budget: Possible answer to the dust dilemma??

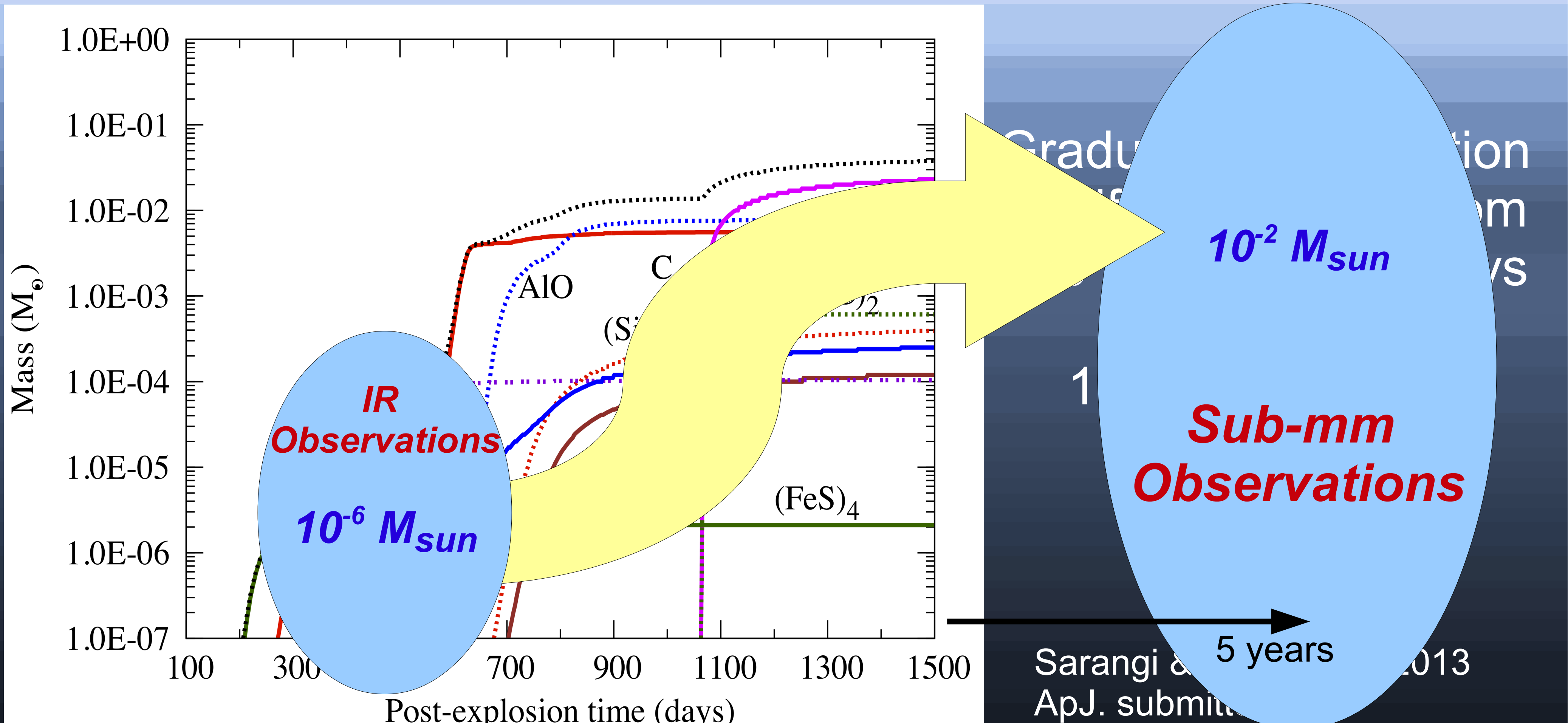


Gradual dust formation in Different zones from 200 days to 1200 days ranges from 10^{-6} to $\sim 10^{-1}$ M_{sun}

Sarangi & Cherchneff 2013 ApJ. submitted

- ★ Good agreement with IR observations ~ 600 days
- ★ Consistency with final dust mass in SNe remnants ~ 5 years post explosion

Total Dust Budget:
Possible answer to the dust dilemma??



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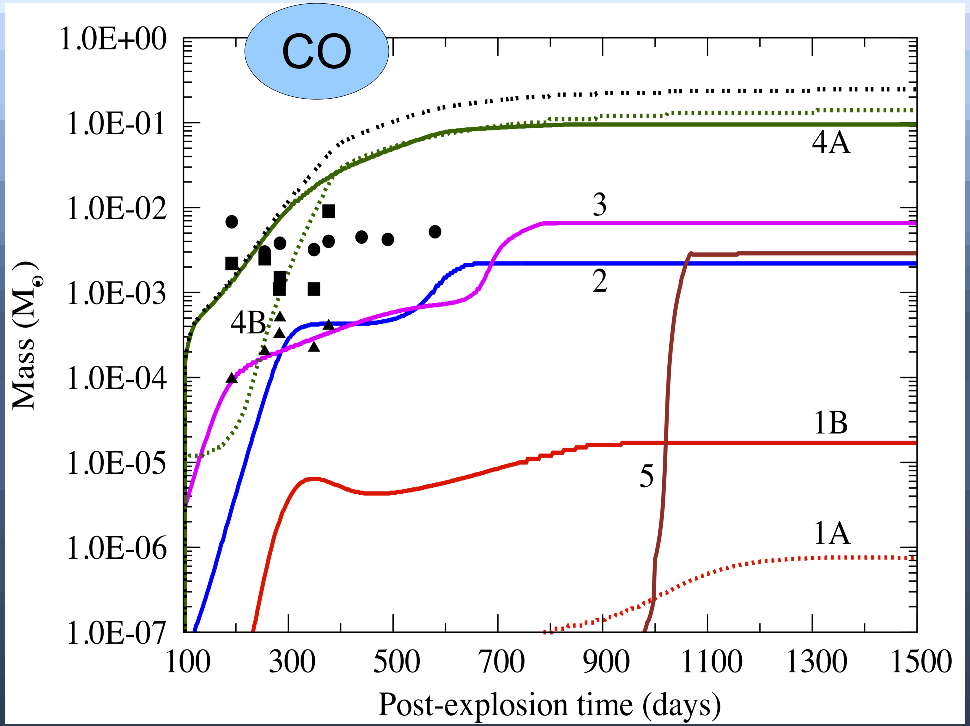
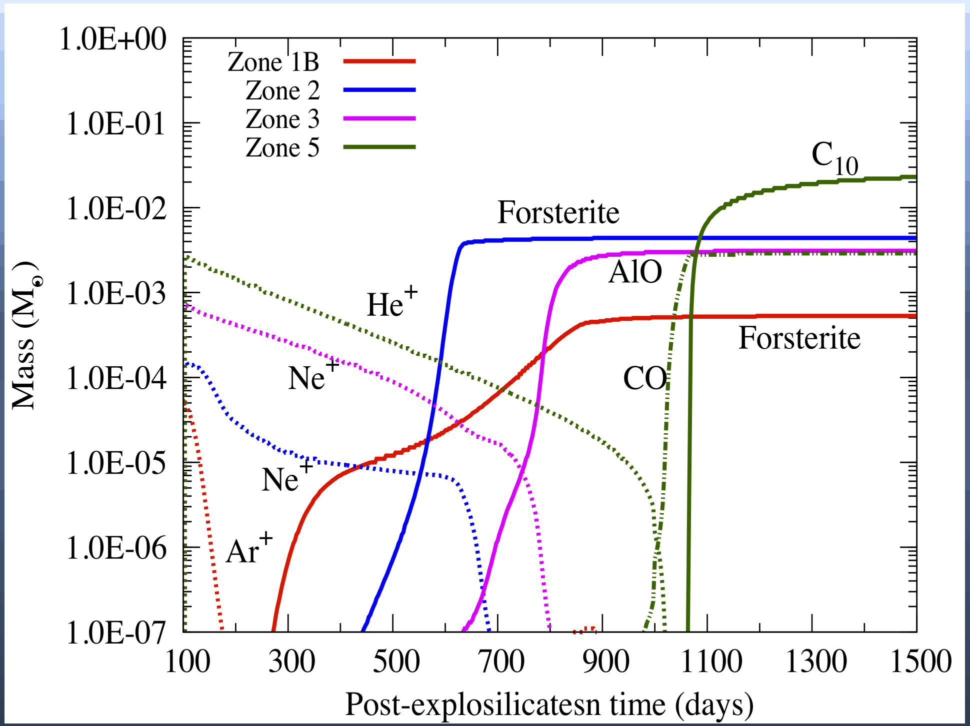
Role of Ions (Ar^+,Ne^+,He^+) on the Ejecta Chemistry

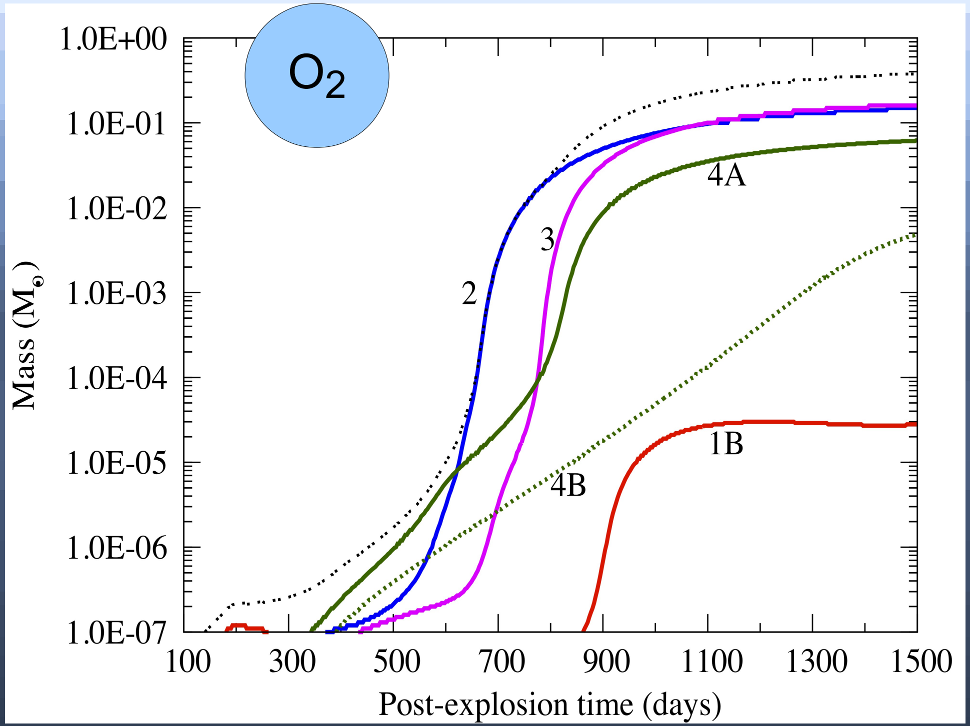


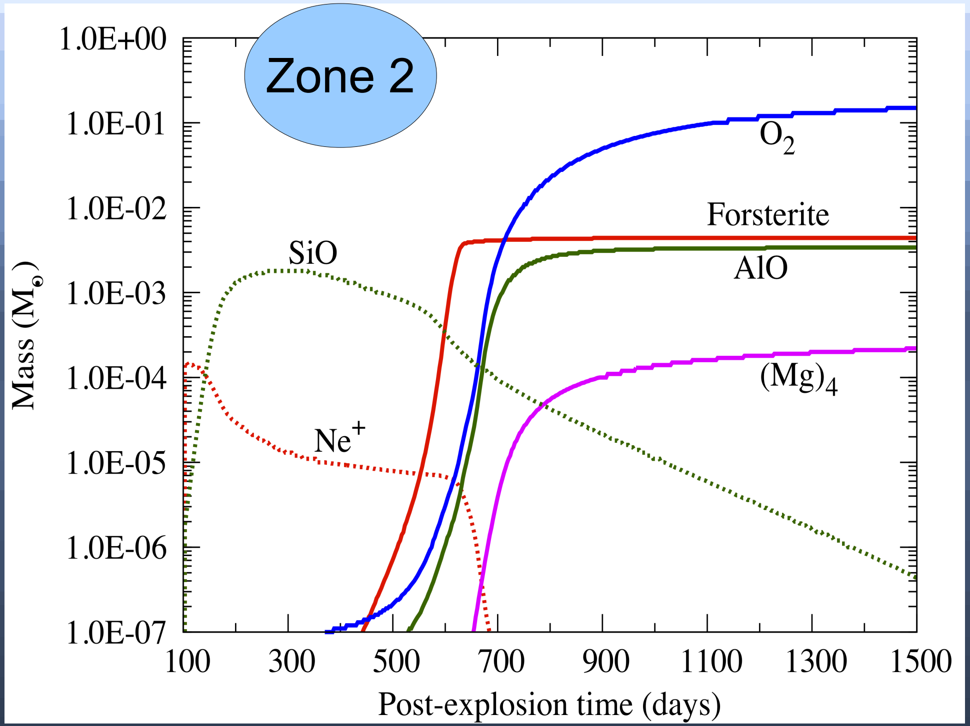


- Efficient formation of CO in zone 4A/B whereas Carbon chains in zone 5
- Presence of Ar^+,Ne^+,He^+ in the ejecta delays the formation of molecules and clusters

Sarangi & Cherchneff 2013 ApJ. submitted

O_2 and the O-rich Zone





Delayed formation of O_2 and other molecules due to presence of Ne^+

Total mass of molecules ~ 0.69 M_{sun}

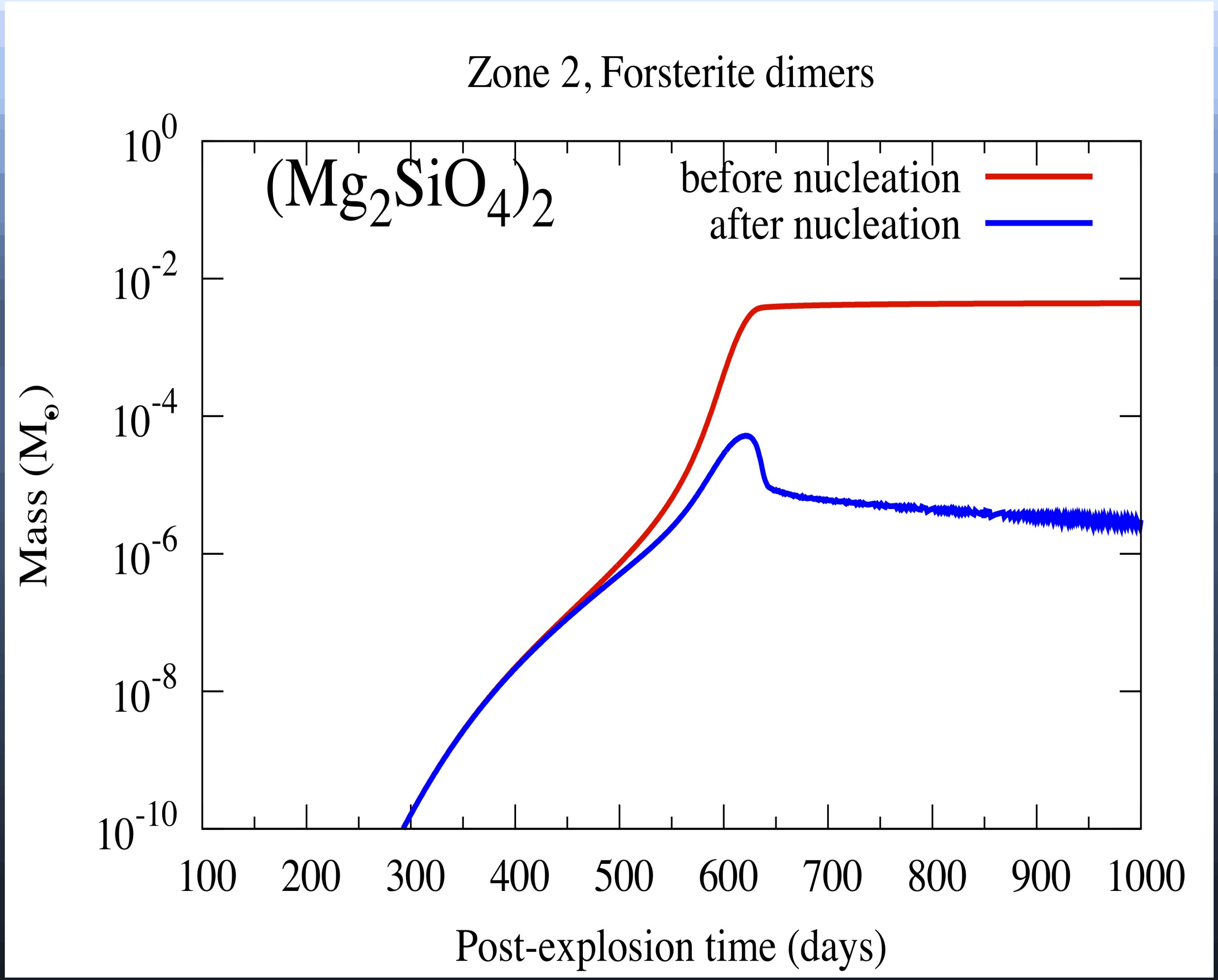
Efficiency of formation: 29%

Total mass of dust ~ 0.04 M_{sun}

Efficiency of formation: 1.7%

Sarangi & Cherchneff 2013 ApJ. submitted

Nucleation Scheme for Forsterite Grains



Coagulation

Volume conserved!

Spherical grains!

Forsterite dimers taken as the seed of the nucleation scheme

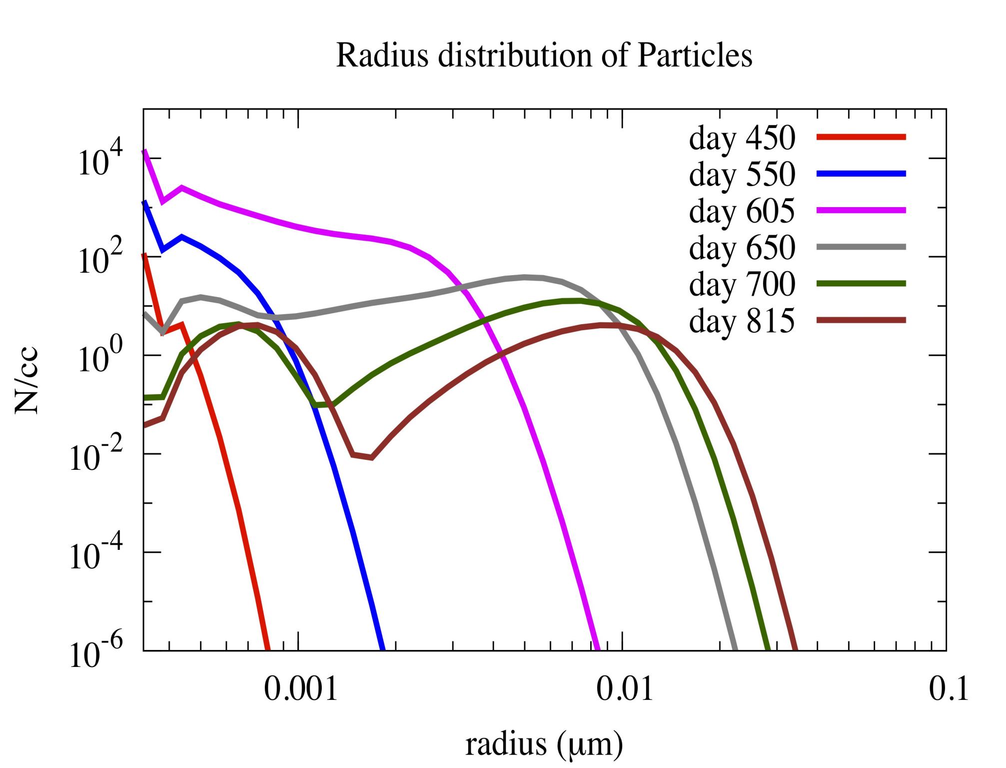
Radius distribution studied against time

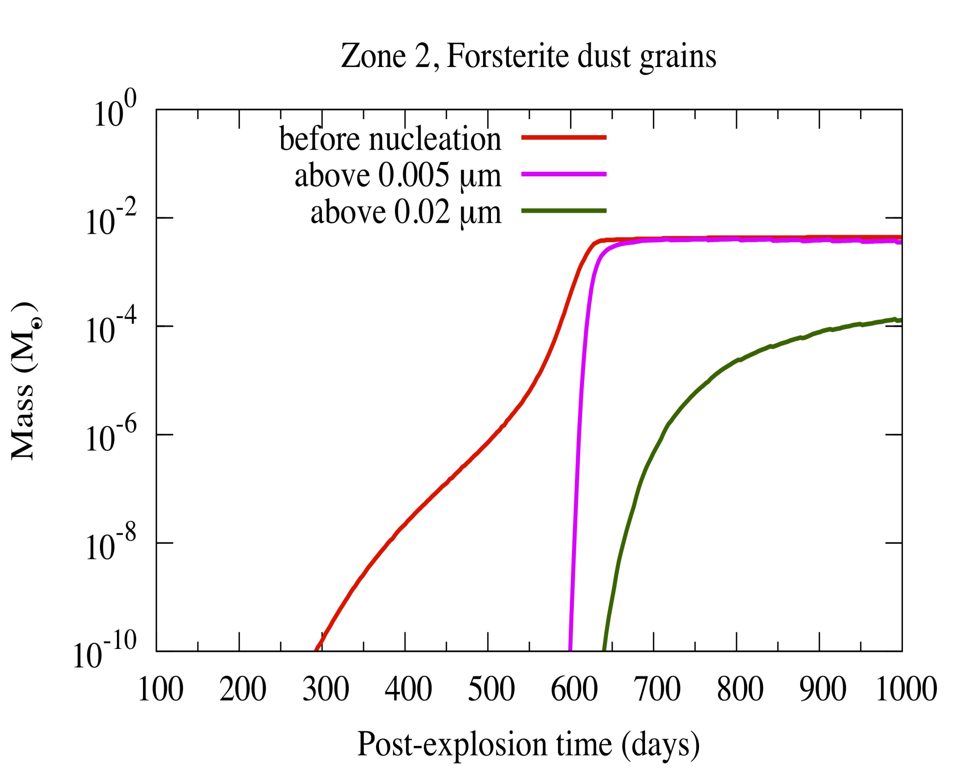
v	v.r	v.r^2	v.r^3	v.r^4	v.r^5

. . . .

(Jacobson 2005)

Radius Distribution (Zone 2)

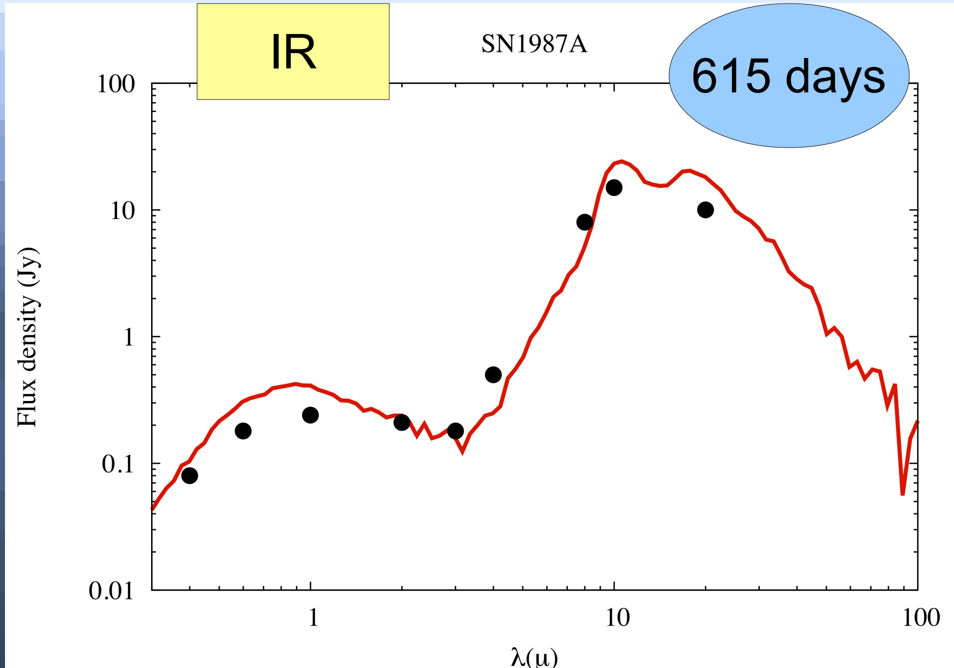




Average particle radius lies in *between 0.005 microns and 0.02 microns*
Dust formation triggers ~ *650 days*

Different zones with different abundances of the seed particle
will have different distribution Vs time

IR and Sub-mm Fluxes Revisited (SN1987A)



MOCASSIN: 3-D radiative transfer code

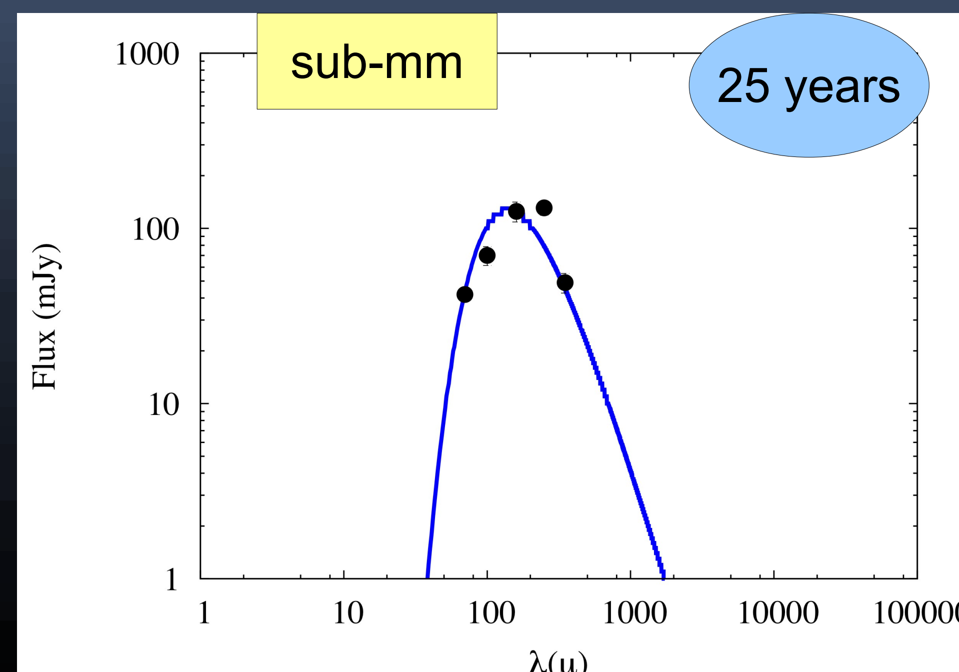
Rin	Rout	Luminosity	Blackbody	Mass	Composition
(10^{15} cm)	(10^{15} cm)	($L_{\odot}$)	(K)	(10^{-3} $M_{\odot}$)	Silicate/Alumina (%)
9.5	45	5.7e5	8000	1.5	99/1

- Smooth ejecta
  Density profile: r^{-2}
  Grain size: 0.05-0.005 microns

Herschel observations of SN1987A

$$L_i(\lambda) = \frac{4\pi M_i}{\rho_i} k_\lambda \lambda B_\lambda(T)$$

M_d = 0.11 M_{sun}
(0.7 M_{sun} Matsuura et al 2011)
T = 28 K

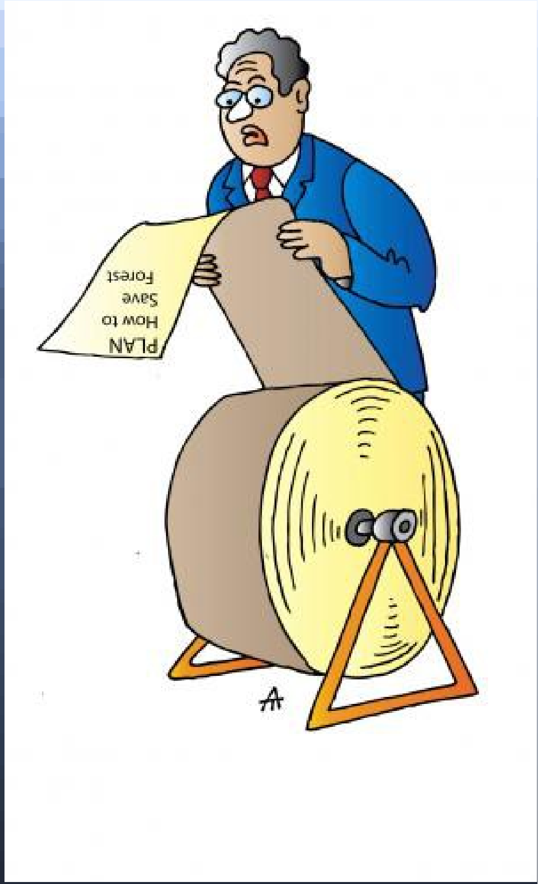


Projects in Pipeline

- To build a consistent condensation scheme *(with coagulation, coalescence, surface growth)* to model dust formation in different types of dust species

- To study the contribution of clumps in the flux at IR as well as submm

- Study the chemistry of dust formation in the clumps 3-D model from explosion model



A complete physical model linking the the gas phase phase chemistry to dust

Take Away

- Chemistry dependent on amount of ^{56}Ni and progenitor mass
- Role of inert gases in the chemistry of the ejecta
- SiO is a tracer of silicate dust while CO is not a carbon dust tracer
- Gradual growth of dust in the nebular phase which reconciles IR and submm observations

Supernovae are efficient but moderate dust producers in the galaxy