Dance into the Fire:
Dust survival inside Supernova Remnants

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Outlook

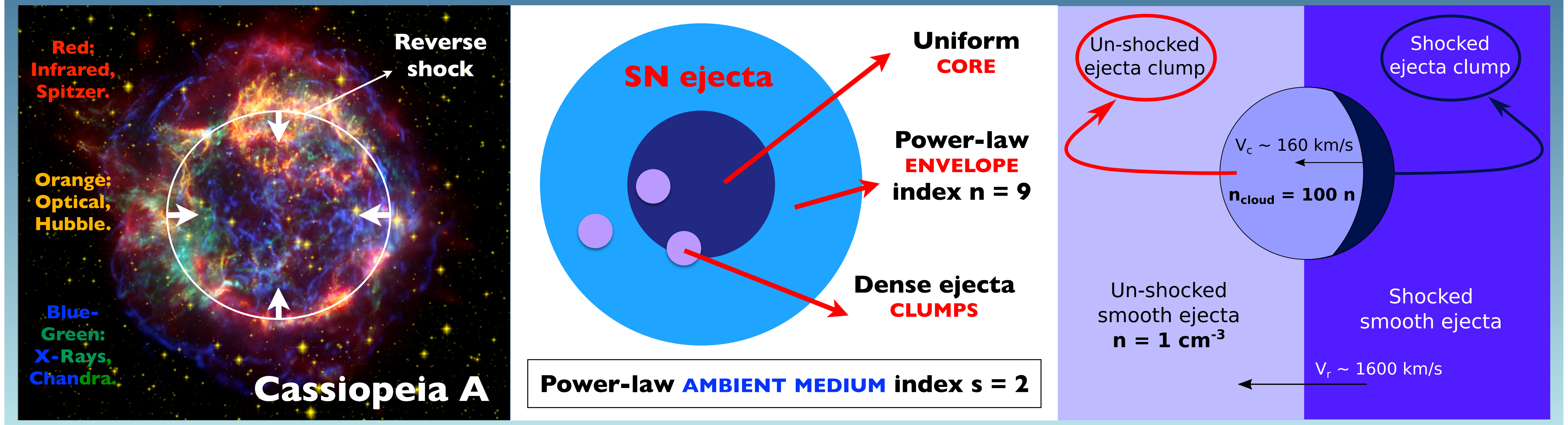
Context: Supernovae are efficient dust factories but the net amount of dust reaching the ISM is still unknown. Such information is crucial to understand the origin and evolution of dust in the local and high-redshift Universe.

Observational facts: Newly formed dust is observed in the ejecta clumps of Cas A. Dust in clumps encounters the reverse shock traveling through the ejecta toward the center of the supernova. The fate of dust is still unclear.

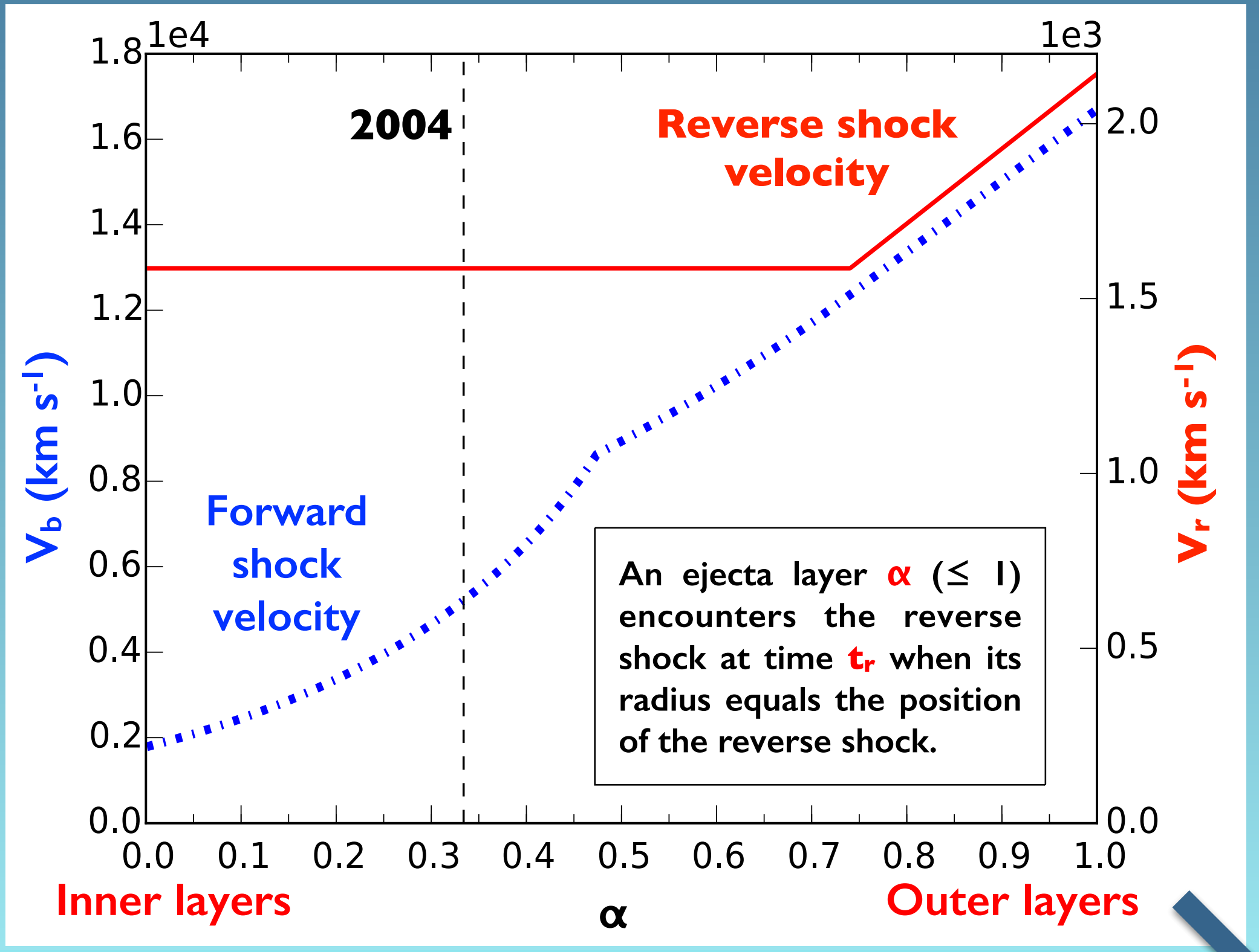
Aim: Our goal is to investigate the dust destruction mechanisms in the ejecta and derive the net amount of dust that survives the passage of the reverse shock at the different evolutionary stages of the remnant.

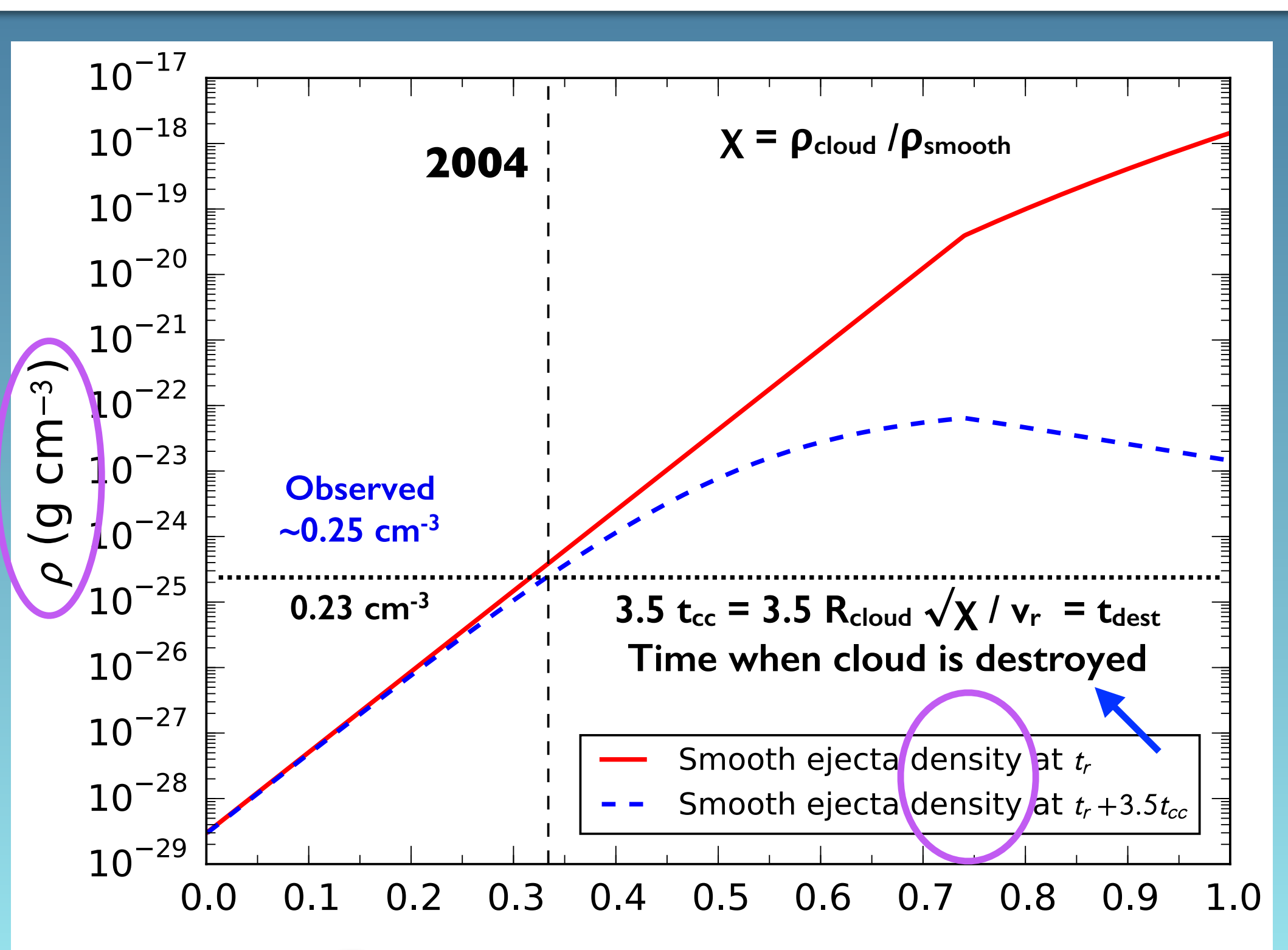
Methods: We model the evolution of a supernova blast wave and of the reverse shock with special application to the clumpy ejecta of Cas A. The dust resides in ejecta clumps, surrounded by hot X-ray emitting smooth ejecta, and consists of silicates (MgSiO3) and amorphous carbon (Am C) grains. We study the processing of dust in such an evolving supernova remnant.

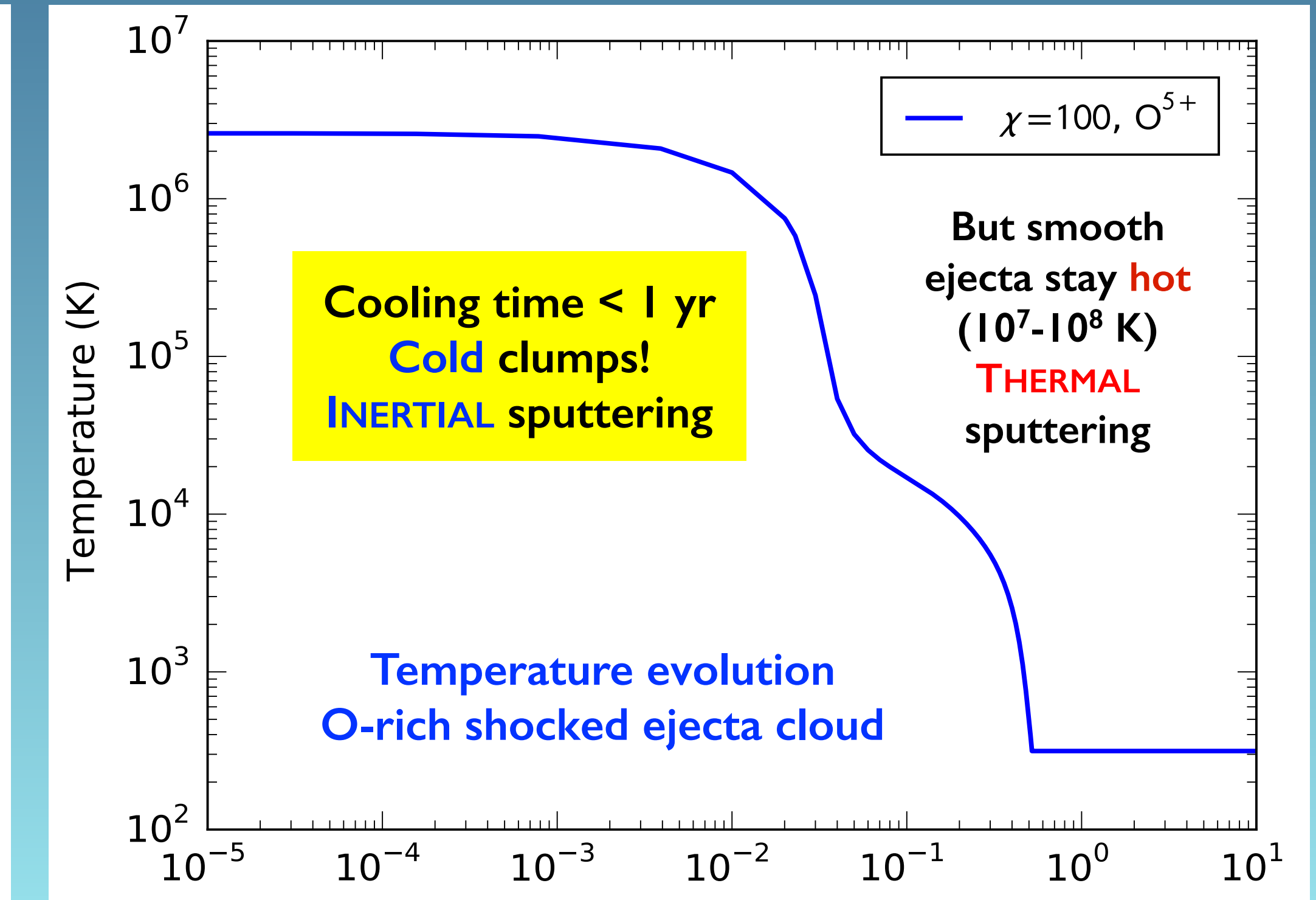
Model: Inhomogeneous ejecta + non-uniform medium



Global approach: Dust processing in evolving SNR

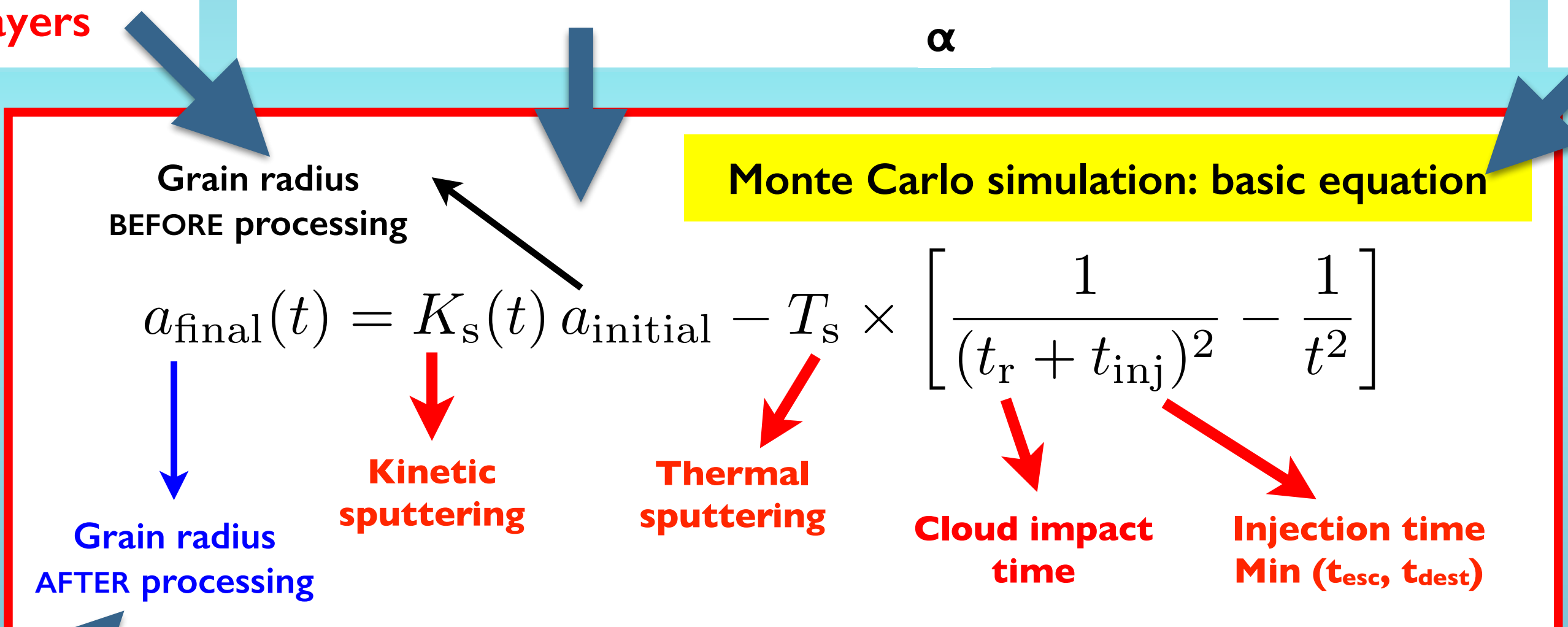






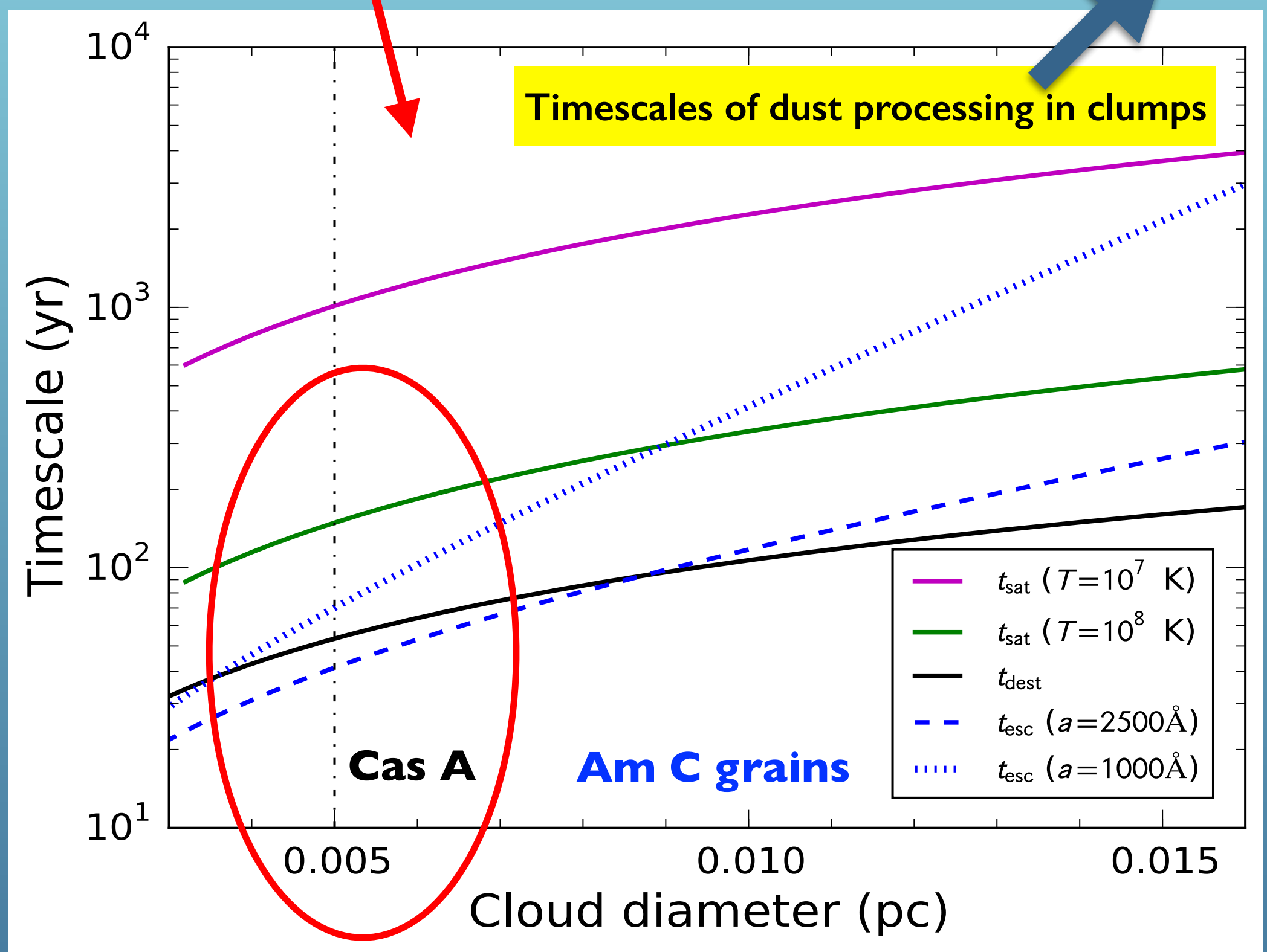
INERTIAL sputtering stops when dust leaves the clouds. This happens because of:

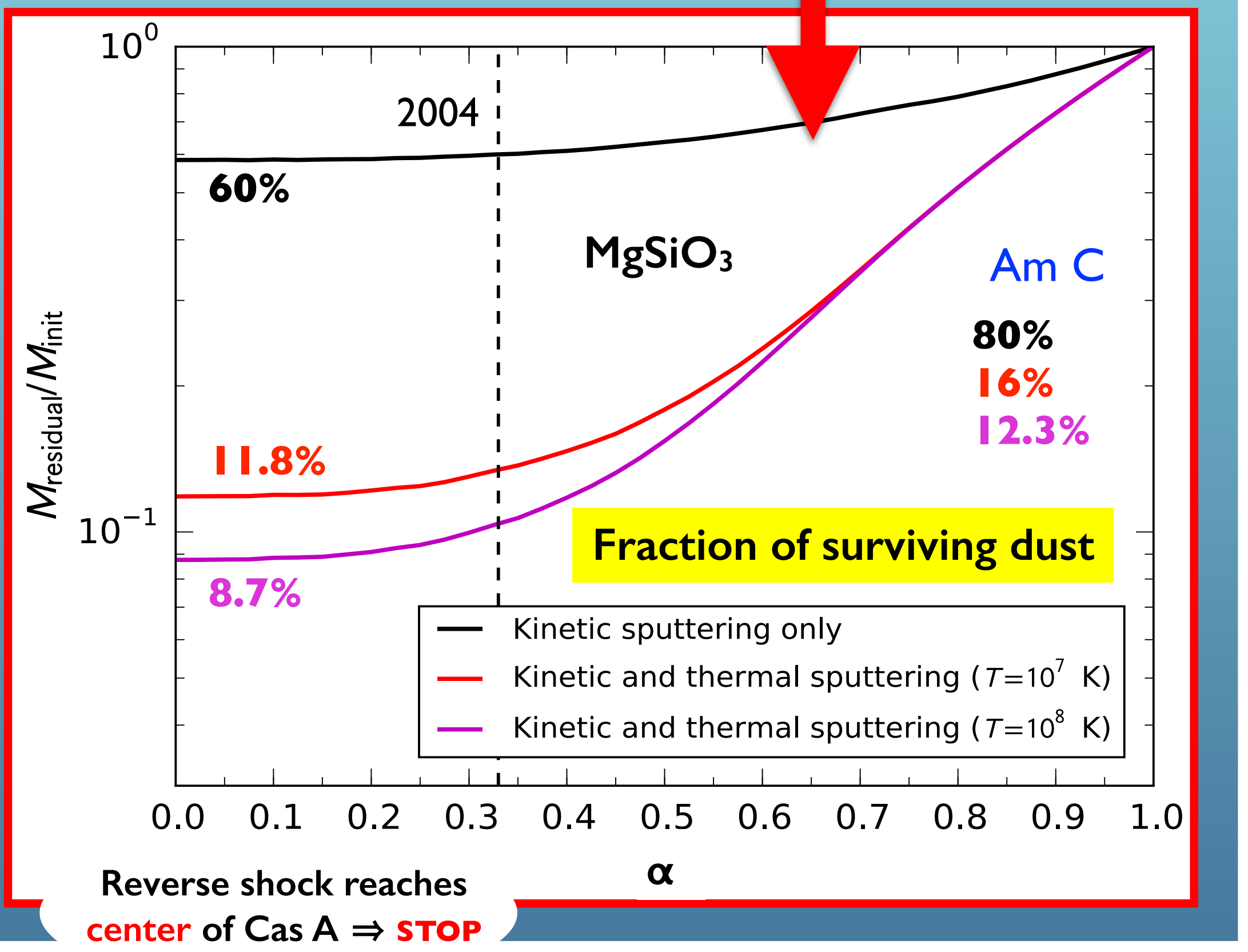
- Grains' own ballistic velocities → t_{esc}
- Cloud thermal evaporation → t_{sat}
- Cloud dynamical fragmentation → t_{dest}



Monte Carlo simulation: basic equation

$$\underbrace{a_{\rm final}(t)}_{\text{Grain radius AFTER processing}} = \underbrace{K_{\rm s}(t)}_{\text{Kinetic sputtering}}\, \overset{\text{Grain radius BEFORE processing}}{a_{\rm initial}} - \underbrace{T_{\rm s}}_{\text{Thermal sputtering}} \times \left[\frac{1}{(\underbrace{t_{\rm r}}_{\text{Cloud impact time}} + \underbrace{t_{\rm inj}}_{\text{Injection time Min }(t_{esc},\, t_{dest})})^2} - \frac{1}{t^2}\right]$$





Reverse shock reaches center of Cas A ⇒ STOP

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Summary

- We study the survival of freshly formed dust against processing by the reverse shock inside the cavity of SNRs, where dust is formed.
- We derive analytical expressions for the evolution of Cas A: inhomogeneous ejecta + non-uniform ambient medium → more realistic description.
- First time: effect of clumpy ejecta on dust survival.
- Our adopted set of parameters allows to reproduce dynamics, and density and temperature profile of Cas A ejecta, as deduced by recent observations.
- Dust eroded via **sputtering** (collisions with energetic ions) → **mass loss & size reduction.**
- Clumps heated up by cloud shock generated by impact between clumps and reverse shock. **Oxygen-rich clumps** → **fast cooling** → low temperature → **inertial sputtering** (relative gas-grain velocities).
- **Smooth ejecta** remain **hot** → **thermal sputtering** (thermal velocities) once grains are injected into the smooth ejecta because of their ballistic velocities or cloud destruction (instabilities vs. evaporation).
- Monte Carlo approach to derive mass and size distribution of processed dust during progression of the reverse shock inside Cas A. Dust sputtering is calculated across the remnant and during its evolution, using the appropriate derived profiles for e. g. reverse shock velocity and ejecta density.
- Simulation starts when reverse shock touches the outer layer of ejecta (α = 1, ~0.9 yr after explosion); stops when reverse shock reaches centre of remnant (α = 0, ~8000 yr after explosion).
- Our fractions of surviving dust imply the formation of **~0.8–1 $M_\odot$ of dust in Cas A ejecta.**
- Surviving mass fractions depend on morphology of ejecta and ambient medium, and dust composition and size distribution. **Results**, therefore, **differ** for **different types** of supernova.
- Our framework can be **adapted** to study dust processing and survival in **other supernova remnants**, both young (SN 1985A, the Crab Nebula, Kepler and Tycho) and more evolved (Cygnus Loop).