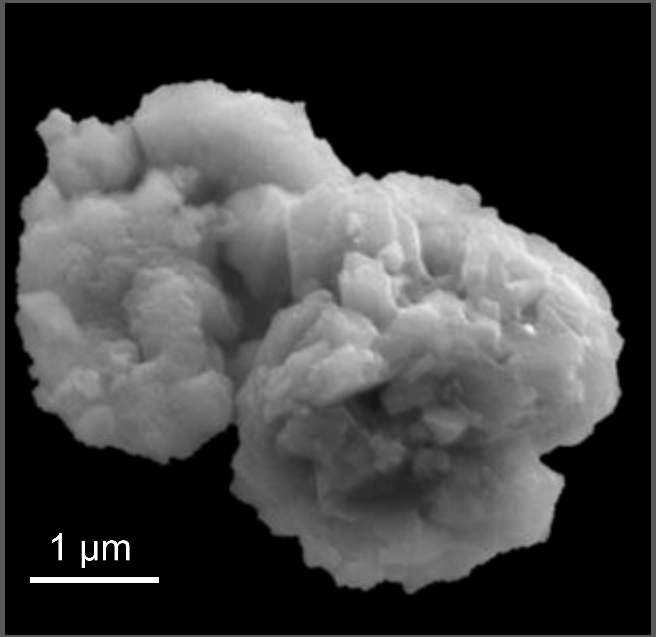
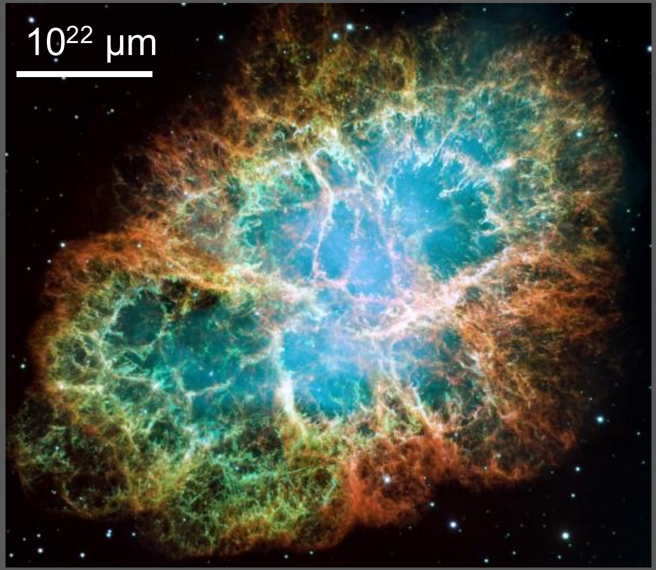



# Presolar Grains from Supernovae

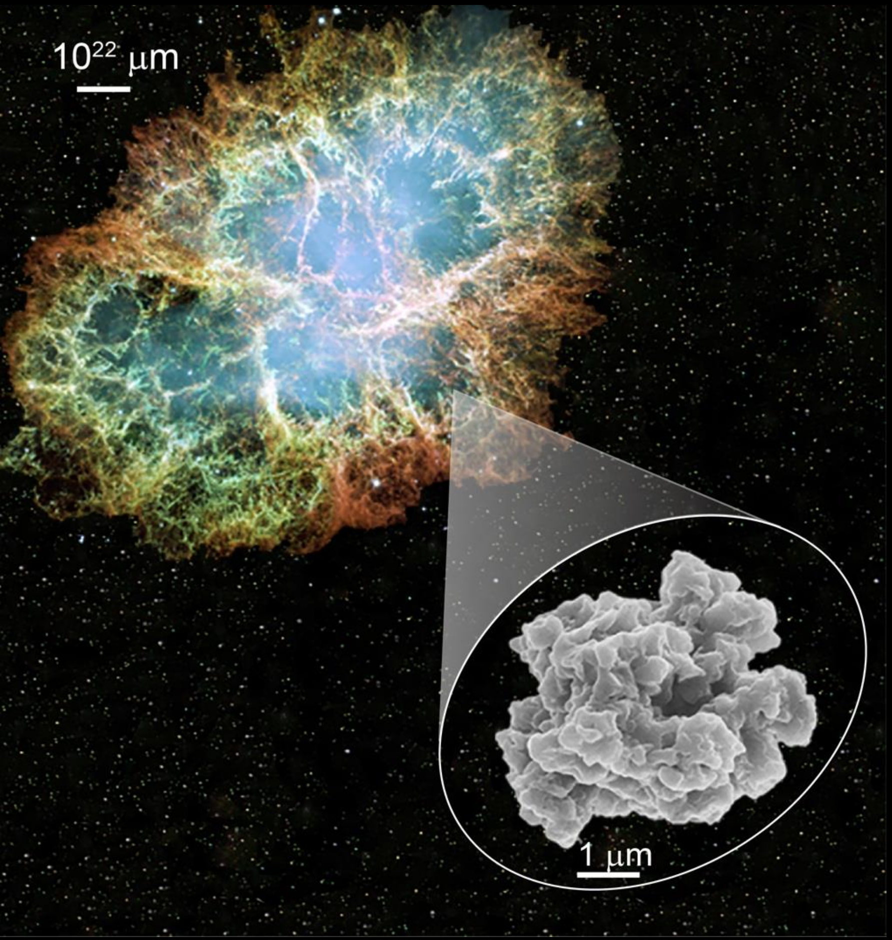
Nan Liu, Boston University

Space Science Reviews (2024) 220:88
https://doi.org/10.1007/s11214-024-01122-w

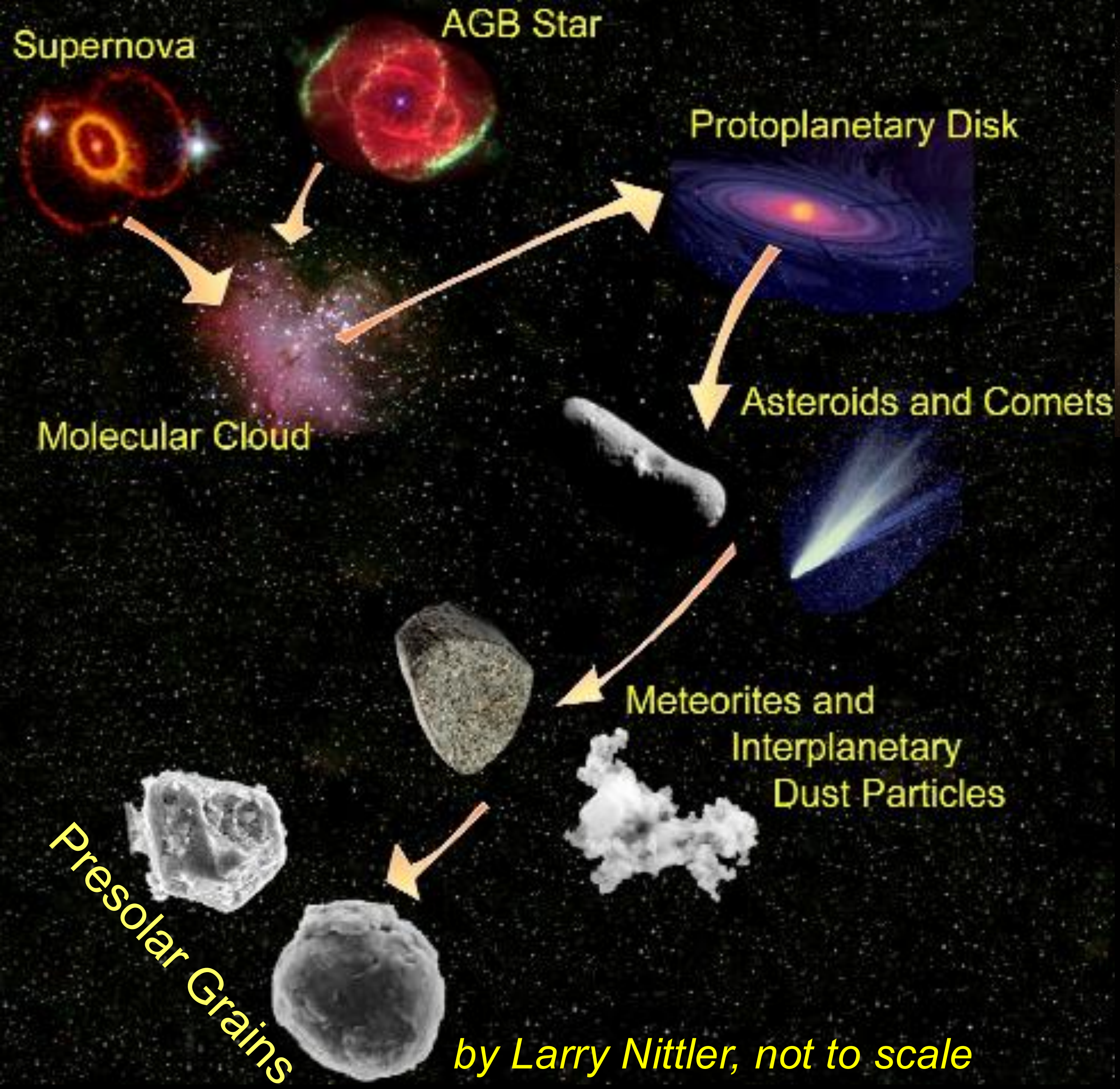
## Presolar Grains as Probes of Supernova Nucleosynthesis

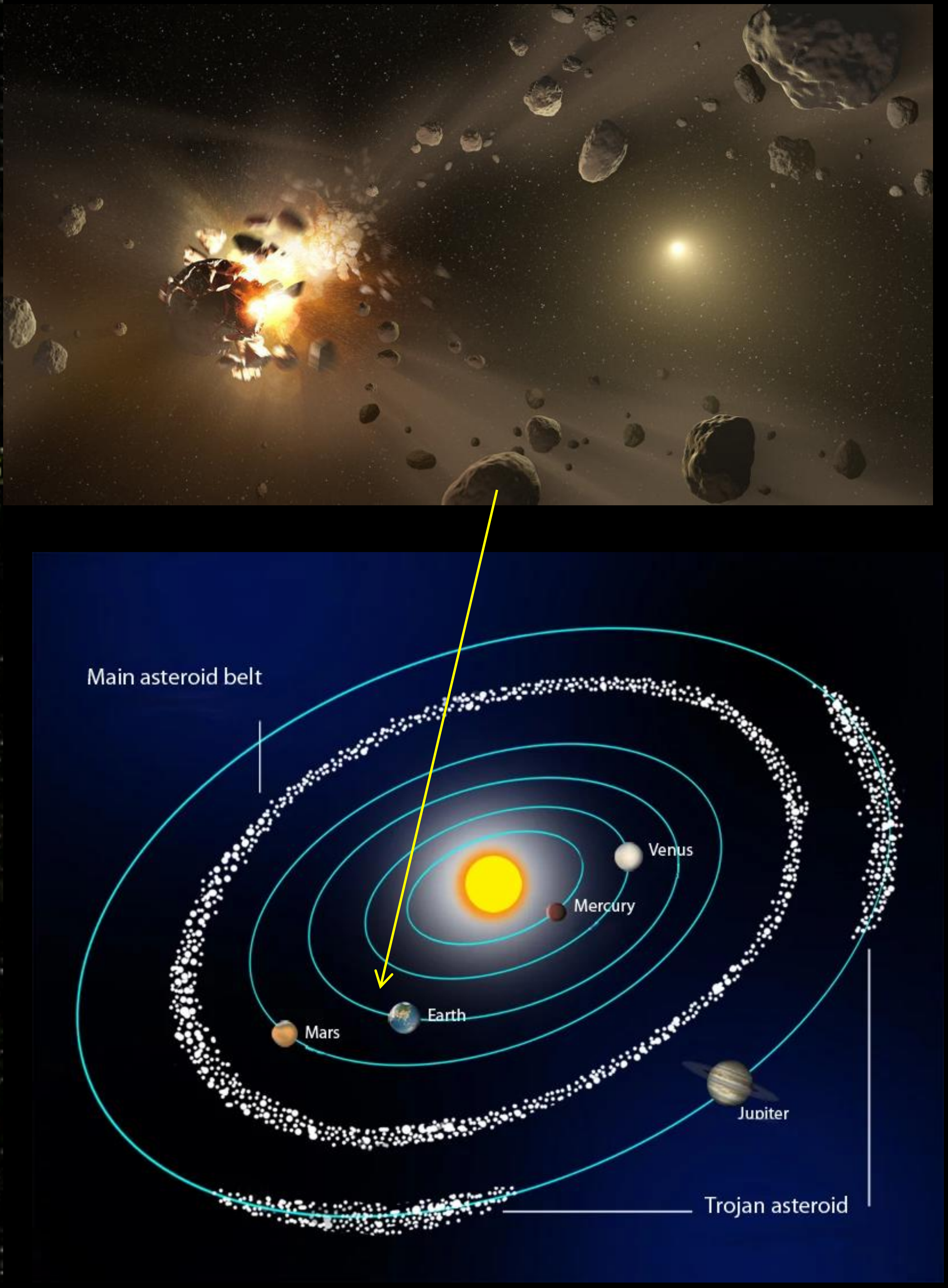
Nan Liu[1] · Maria Lugaro[2,3,4,5] · Jan Leitner[6,7] · Bradley S. Meyer[8] · Maria Schönbächler[9]

# Overview

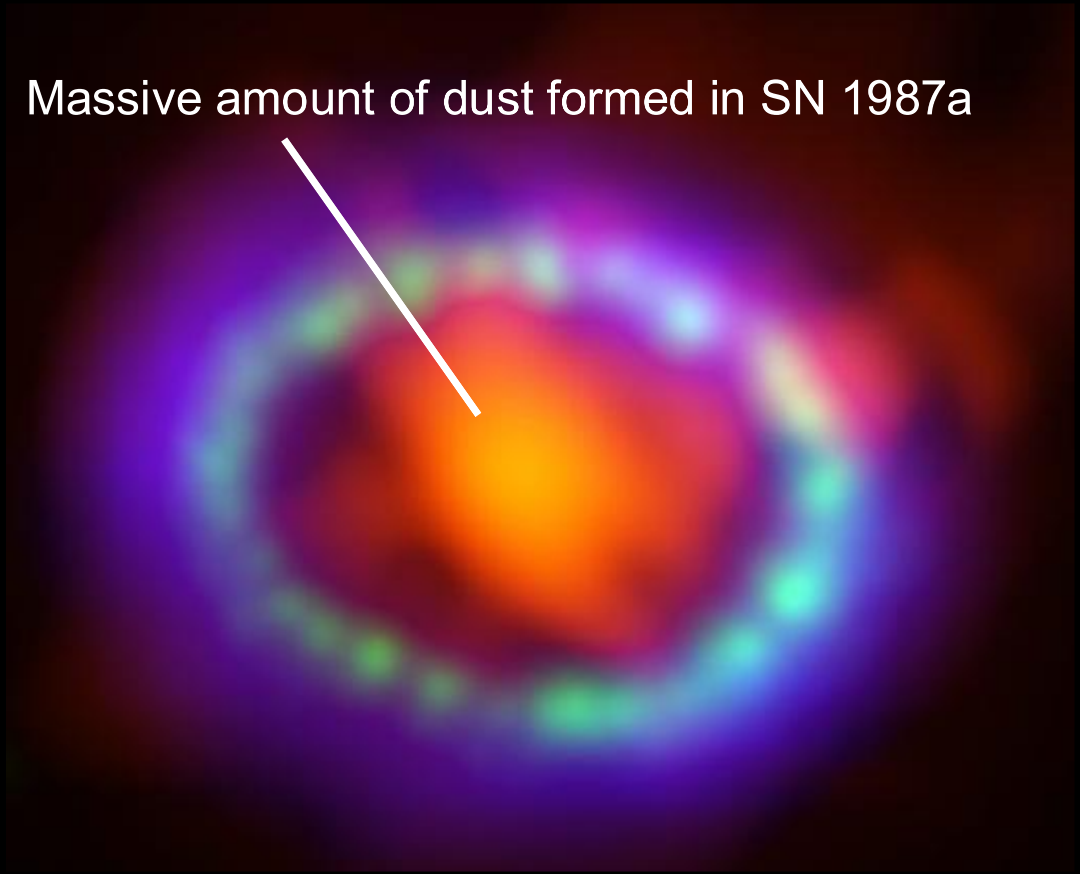


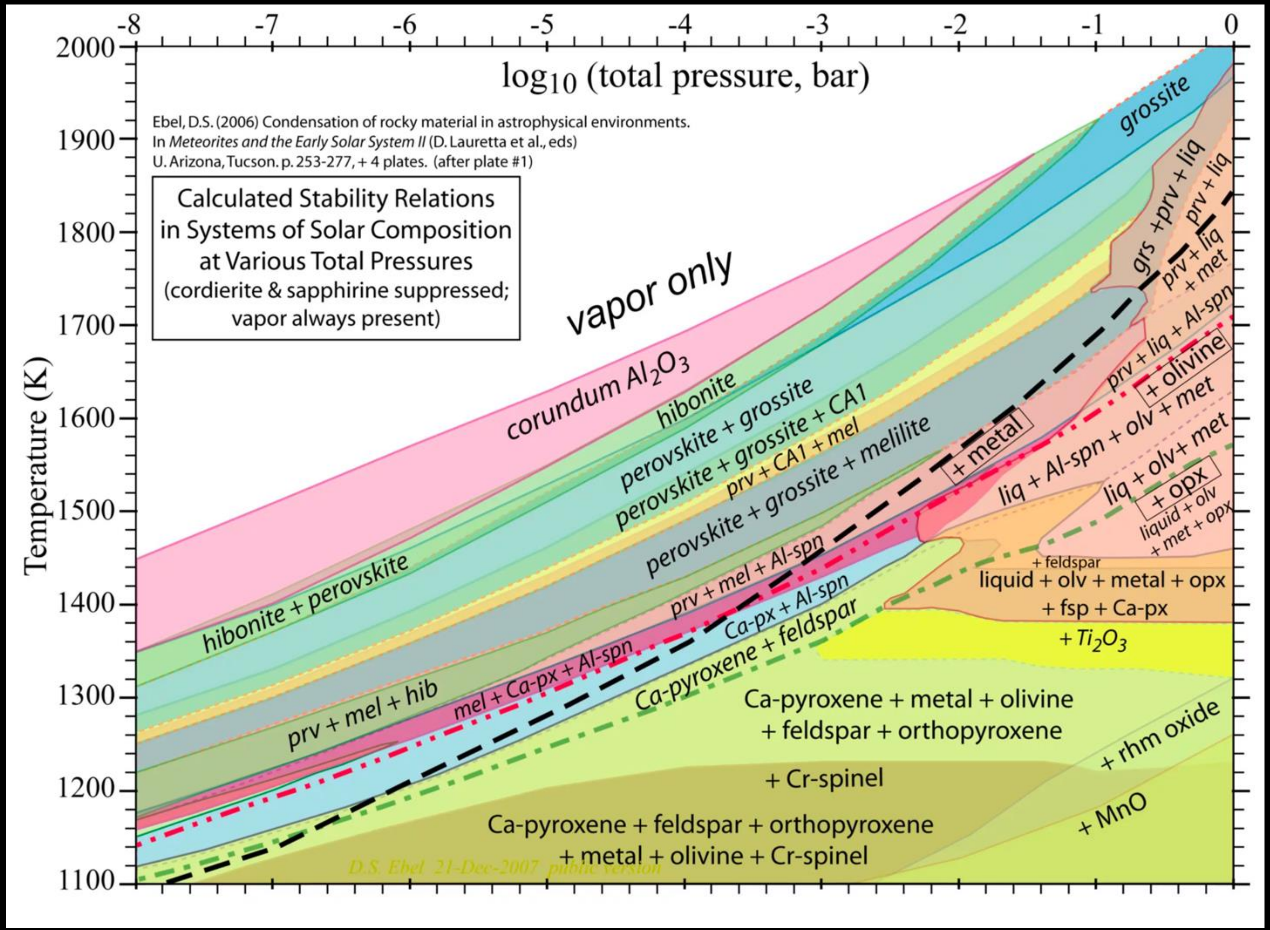

- **Basics of Presolar Stardust Grains**
- **Supernovae and Their Stardust**
  - Titanium-44 in SNe II
  - Explosive nucleosynthesis in SNe II
  - Stardust from other supernovae?


Supernova
AGB Star
Protoplanetary Disk
Molecular Cloud
Asteroids and Comets
Meteorites and
Interplanetary
Dust Particles
Presolar Grains
by Larry Nittler, not to scale


Main asteroid belt
Venus
Mercury
Earth
Mars
Jupiter
Trojan asteroid

# Dust Formation After Supernova Explosion



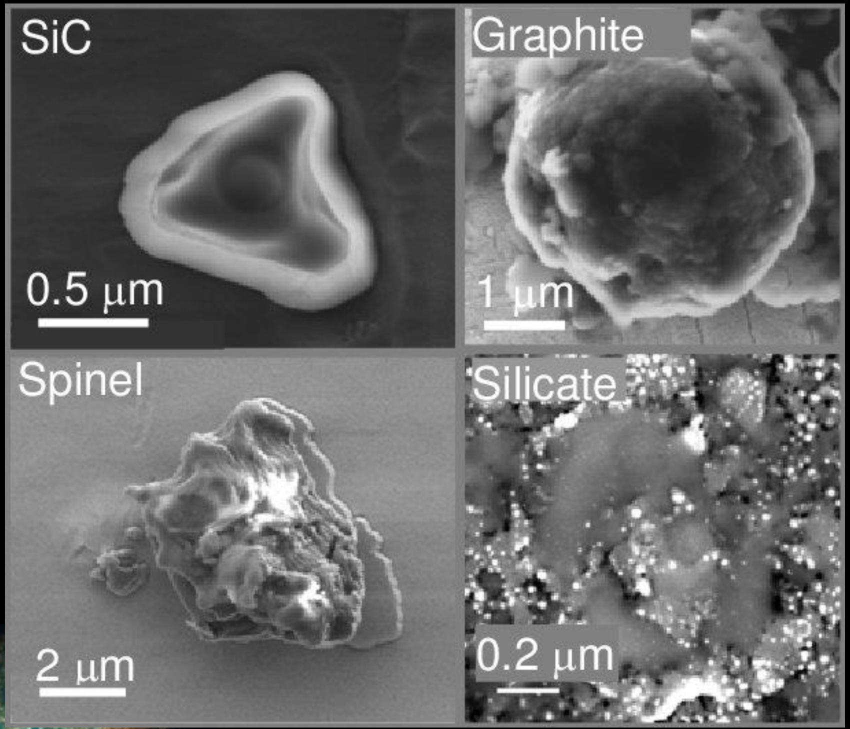

- The elemental composition of a grain is determined by both the gas composition and condensation condition (P/T)
- The isotopic composition of a gran is determined by that of the ejecta from which the grain condensed

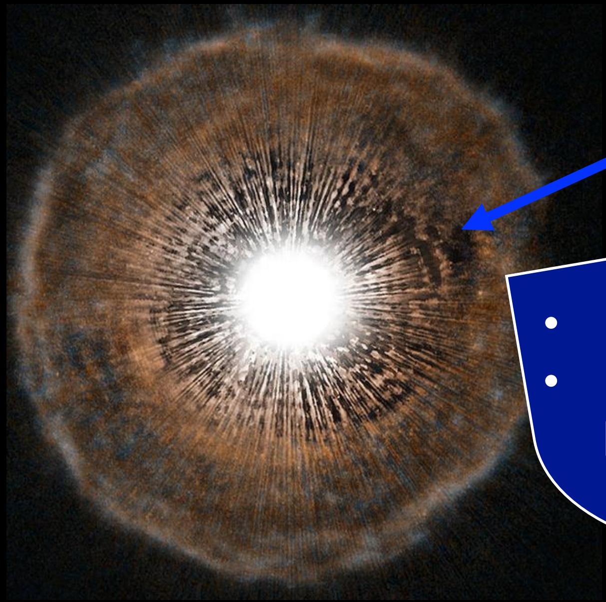
# Stellar Origins of Presolar Grains

from Liu (2025) *Presolar Grains*

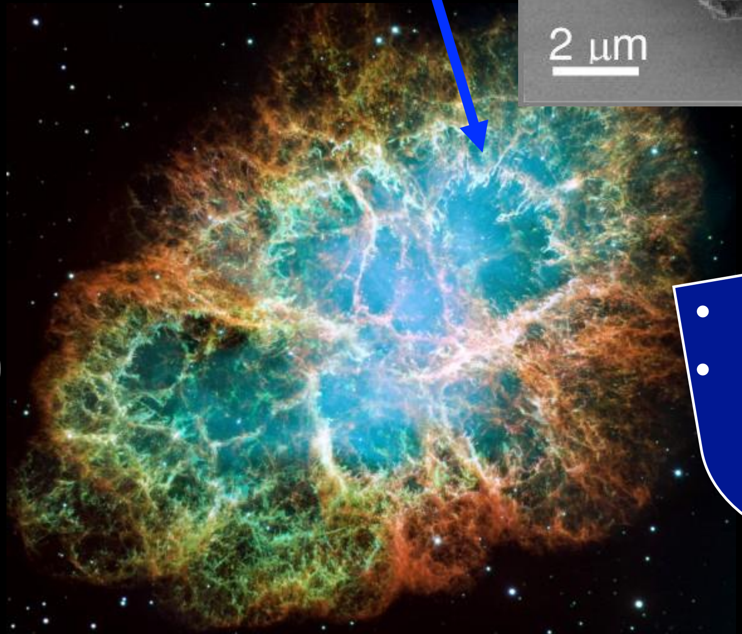
**Table 1** Presolar phases from primitive meteorites.

| *Presolar phase* | *Maximum abundance* | *Main stellar source* |
|---|---|---|
| SiC | ~30 ppm | AGB stars (>90%) |
| Graphite | up to 10 ppm | AGB stars and CCSNe |
| $Si_3N_4$ | ≪1 ppm | CCSNe (100%) |
| Silicates | ~200 ppm | AGB stars and CCSNe |
| Oxides | ~10 ppm | AGB stars and CCSNe |
| Nanodiamond | ~1400 ppm | Ambiguous |



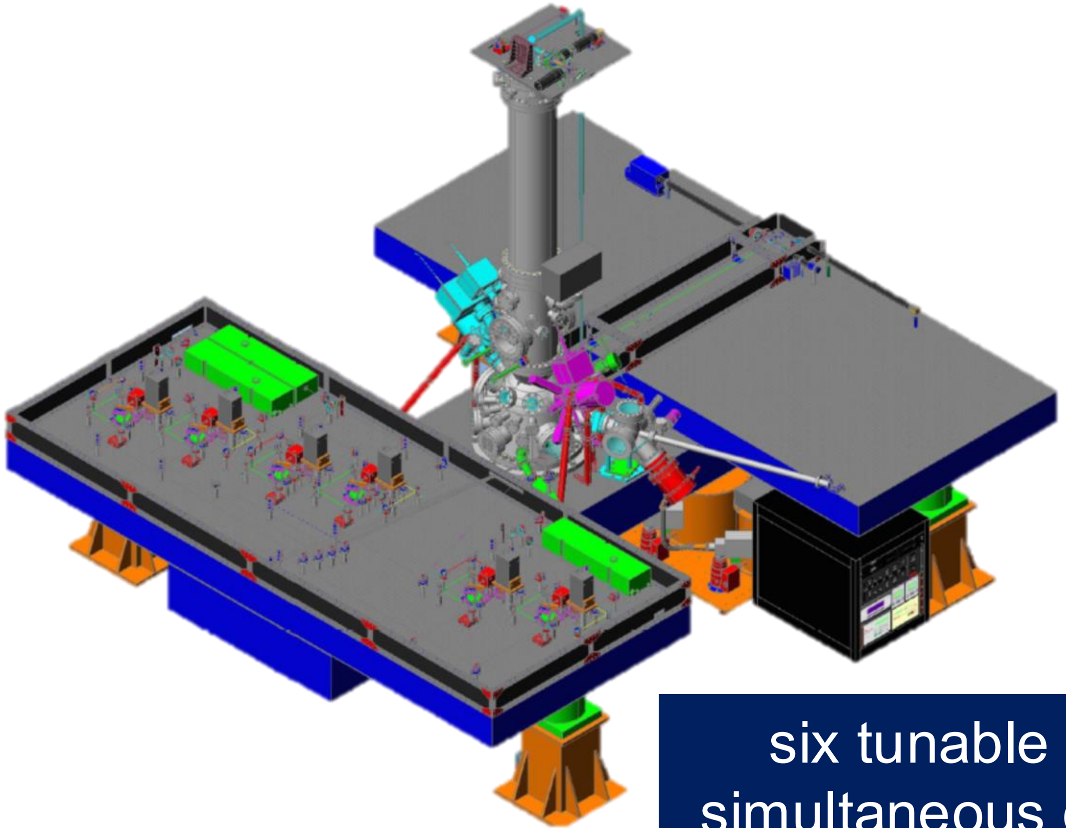
- Prolific dust producers
- Low-mass stars, i.e., high in abundance



- Prolific dust producers
- Massive stars, i.e., large amounts of ejected mass

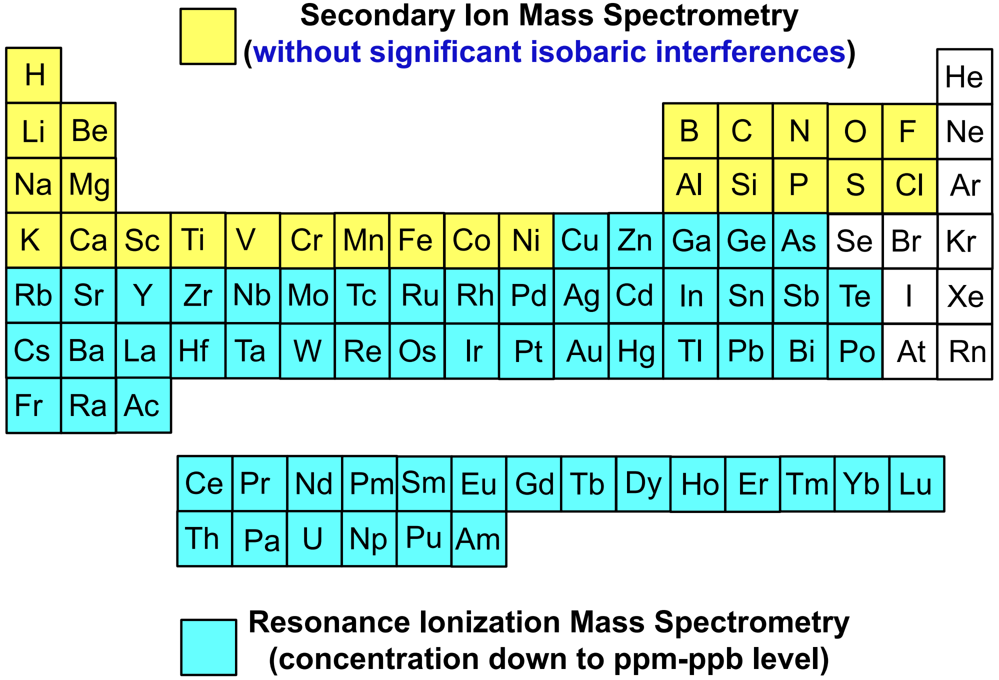
# Presolar Grain Analysis in Laboratory

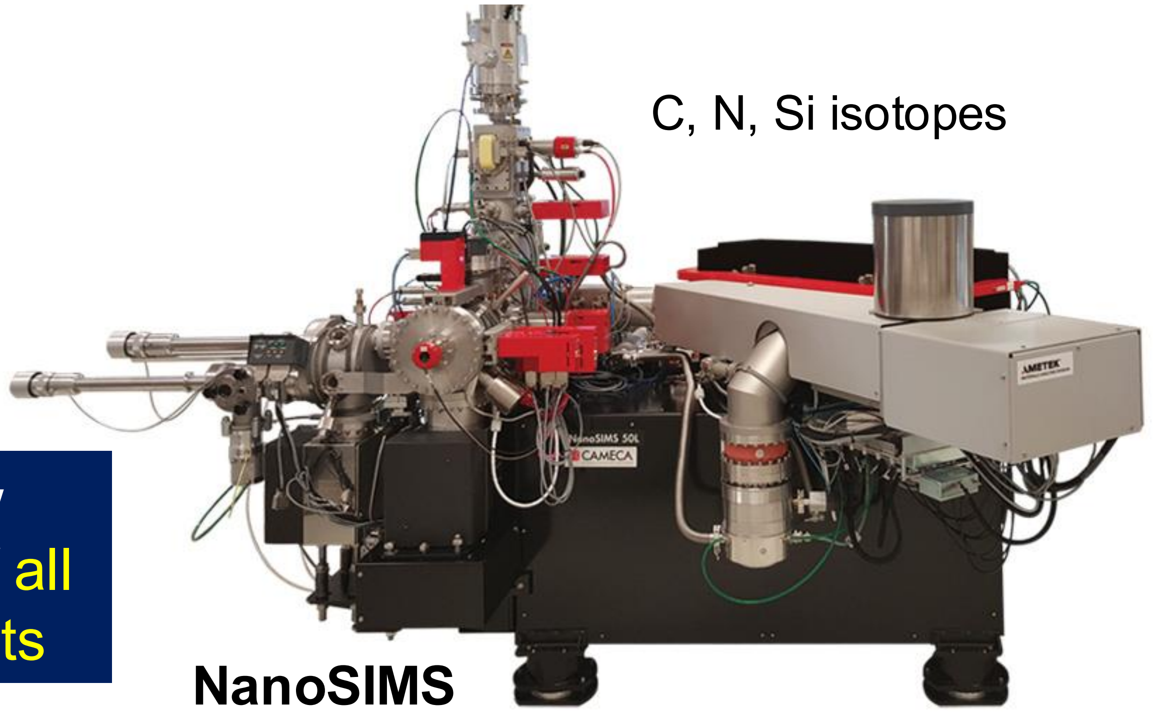
**CHILI**
**(Chicago Instrument for Laser Ionization)**



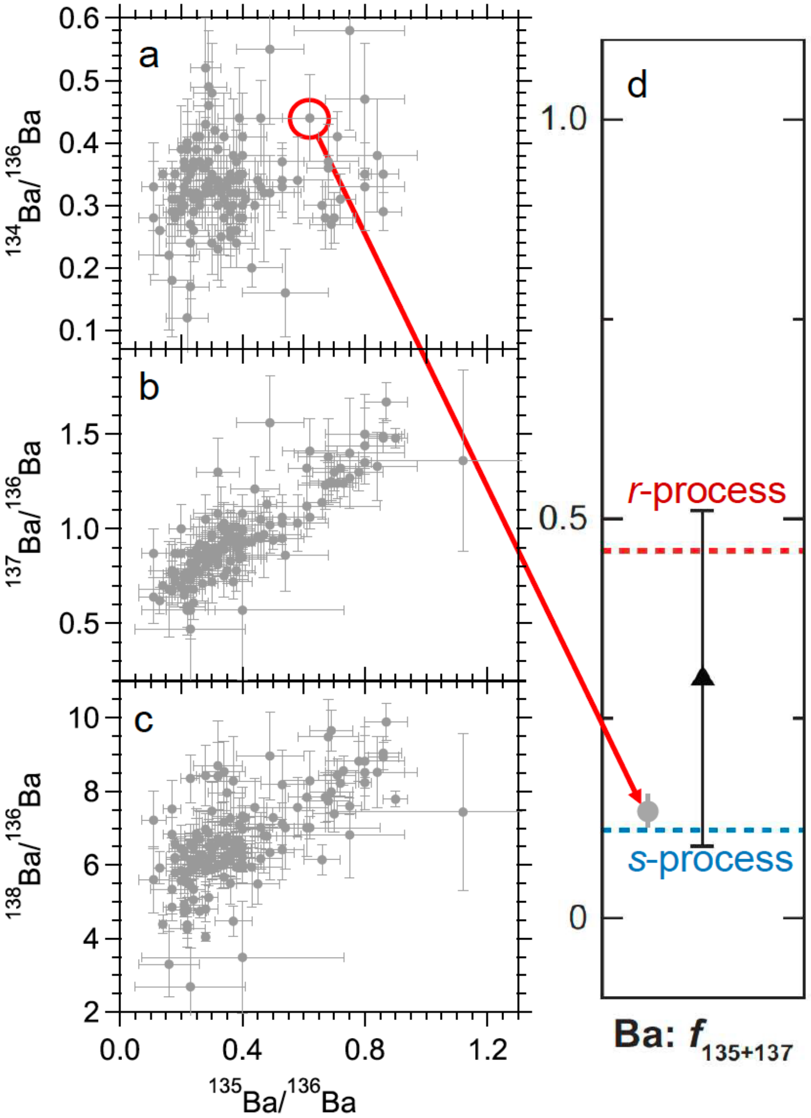
Stephan et al. (2016) *IJMS*

six tunable lasers allow simultaneous detection of all isotopes of three elements



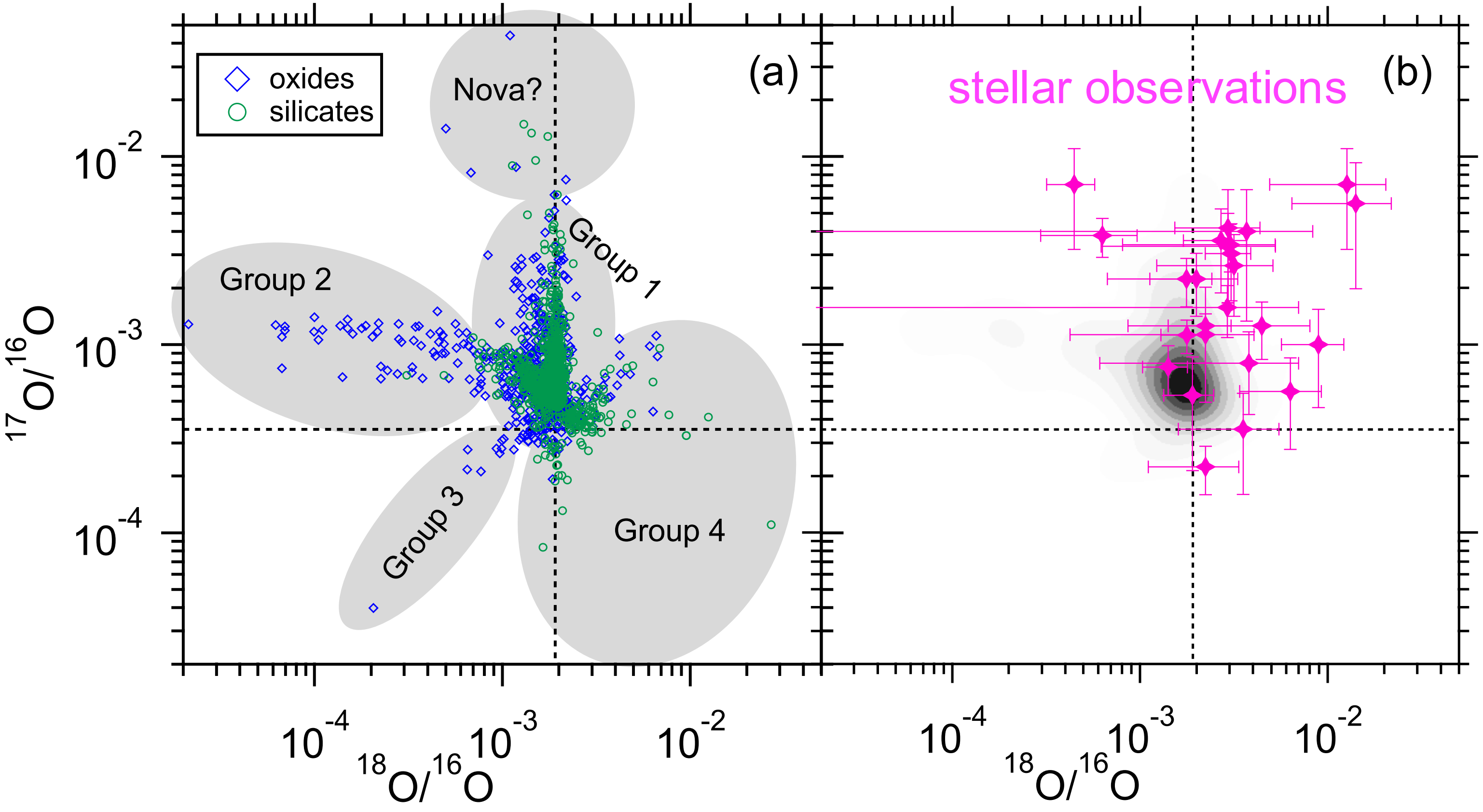



# Microscope vs Telescope Isotope Analysis

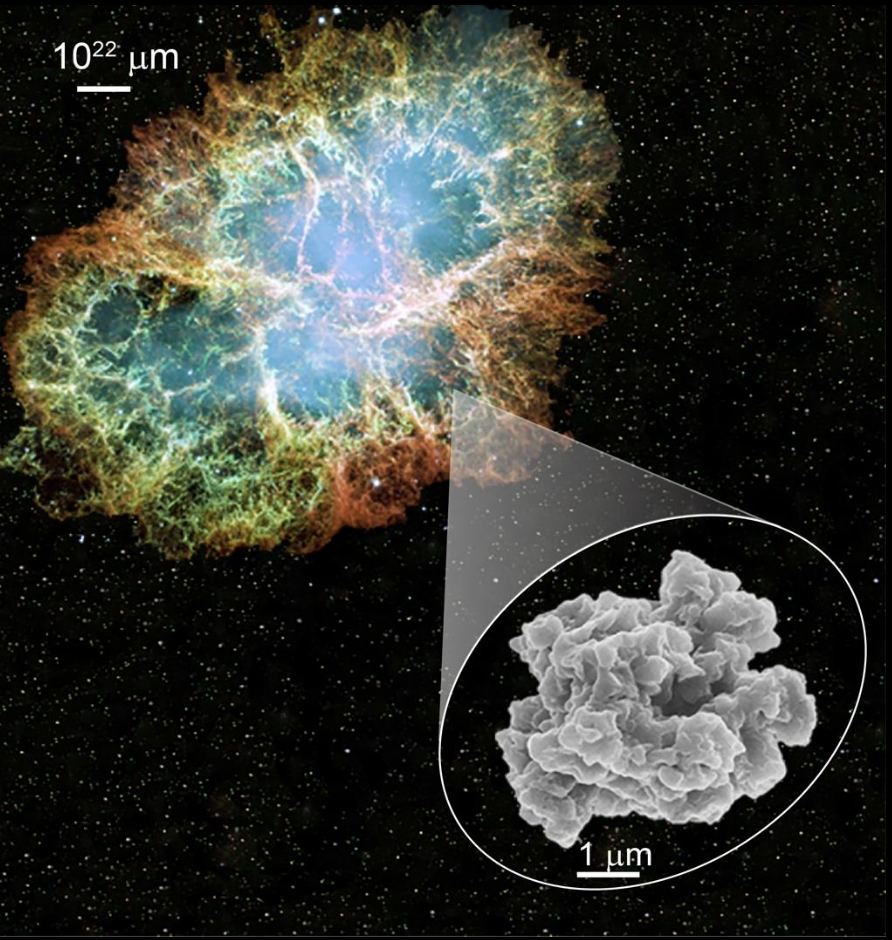



*from Liu et al. (2022) Universe*

*Plots above based on data from presolar grain database (Hynes and Gyngard 2009) and stellar observations from Lebzelter et al. (2015) and Hinkle et al. (2016)*



# Overview

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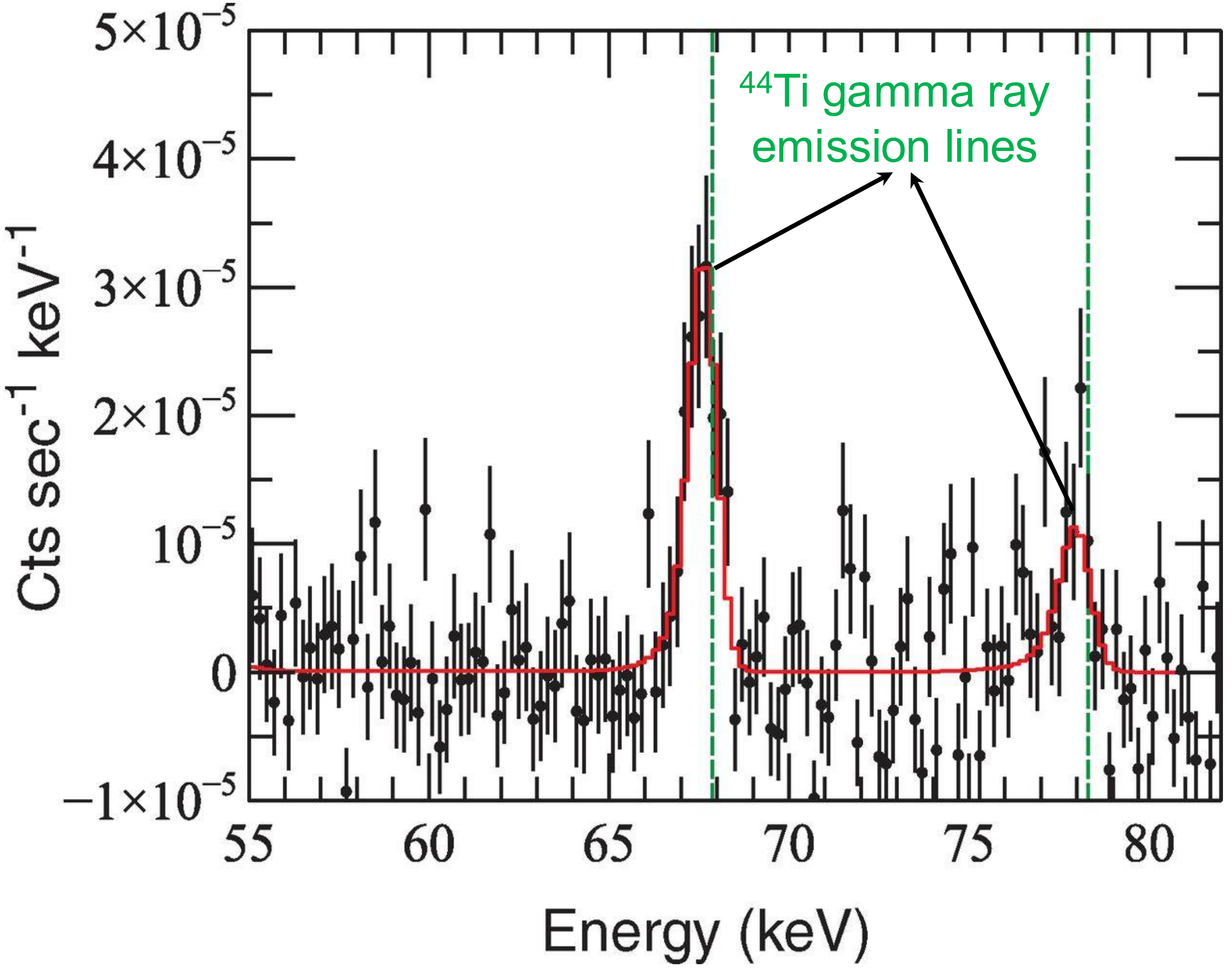
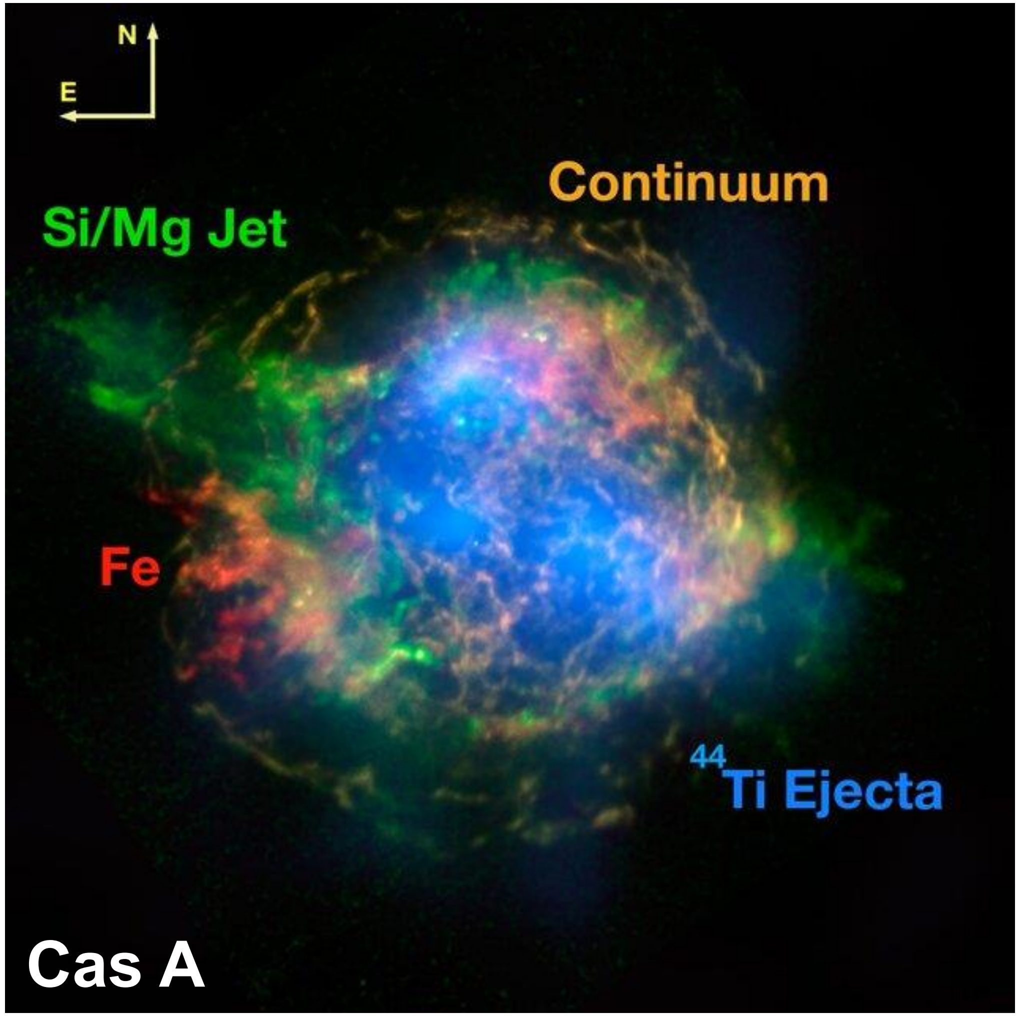
# Titanium-44: Smoking Gun of Supernova Nucleosynthesis

**SN 1987A**




*from Boggs et al. (2015) Science*




*from Grefenstette et al. (2016) ApJ*

# Inferred Initial Presence of $^{44}$Ti in Type-X SiC Grains

$\delta^{44}Ca = \{[(^{44}Ca/^{40}Ca)_{grain}/(^{44}Ca/^{40}Ca)_{solar}]-1\}\times 1000$

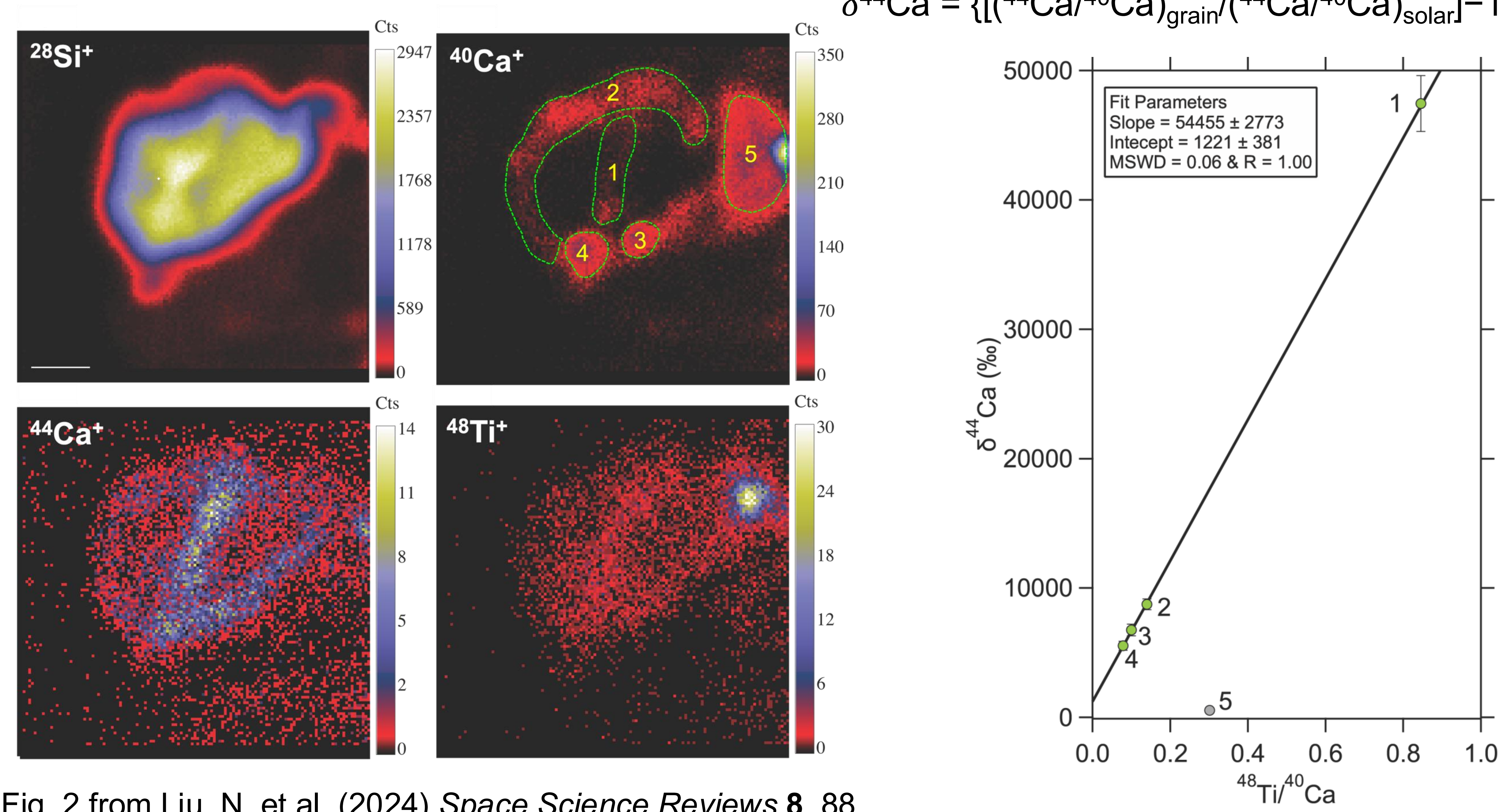
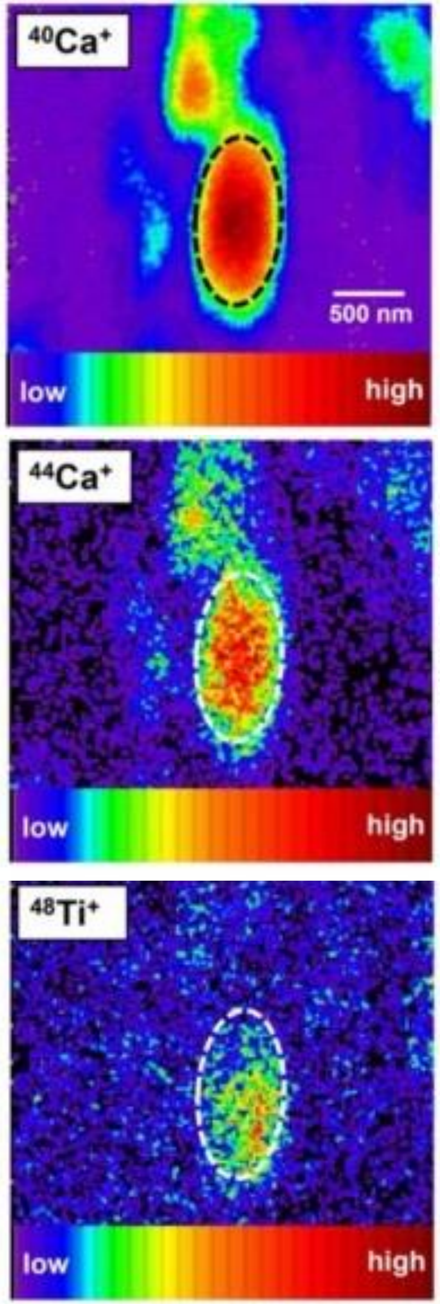



Fig. 2 from Liu, N. et al. (2024) *Space Science Reviews* **8**, 88

# No Initial Presence of $^{44}$Ti in Presolar Silicate Grains




No spatial correlation between $^{44}Ca^+$ and $^{48}Ti^+$

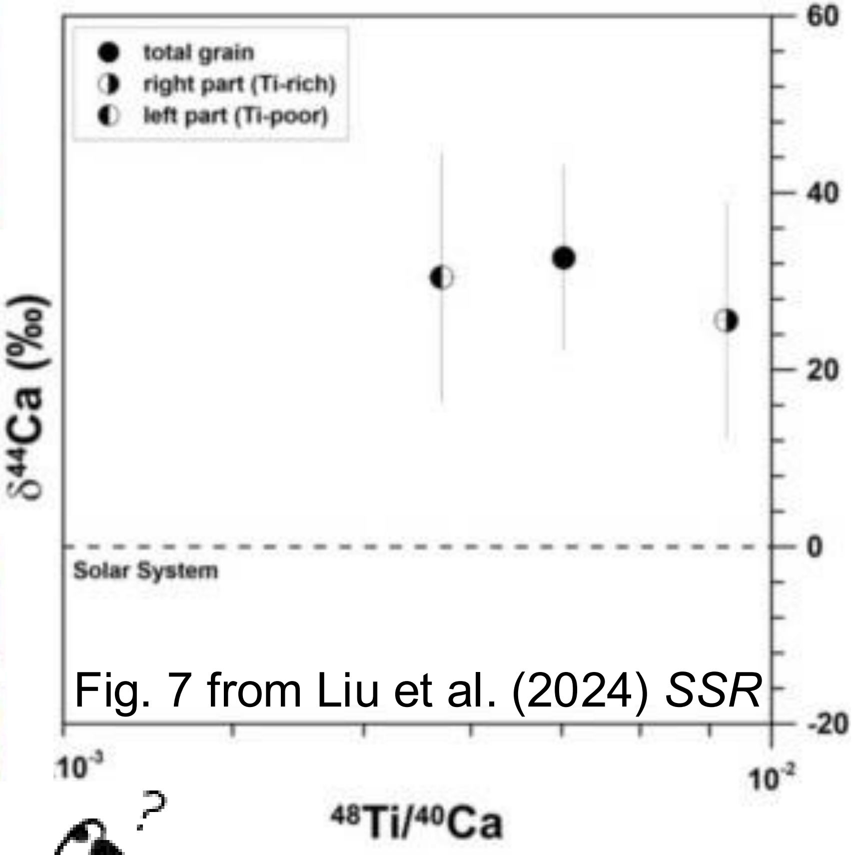
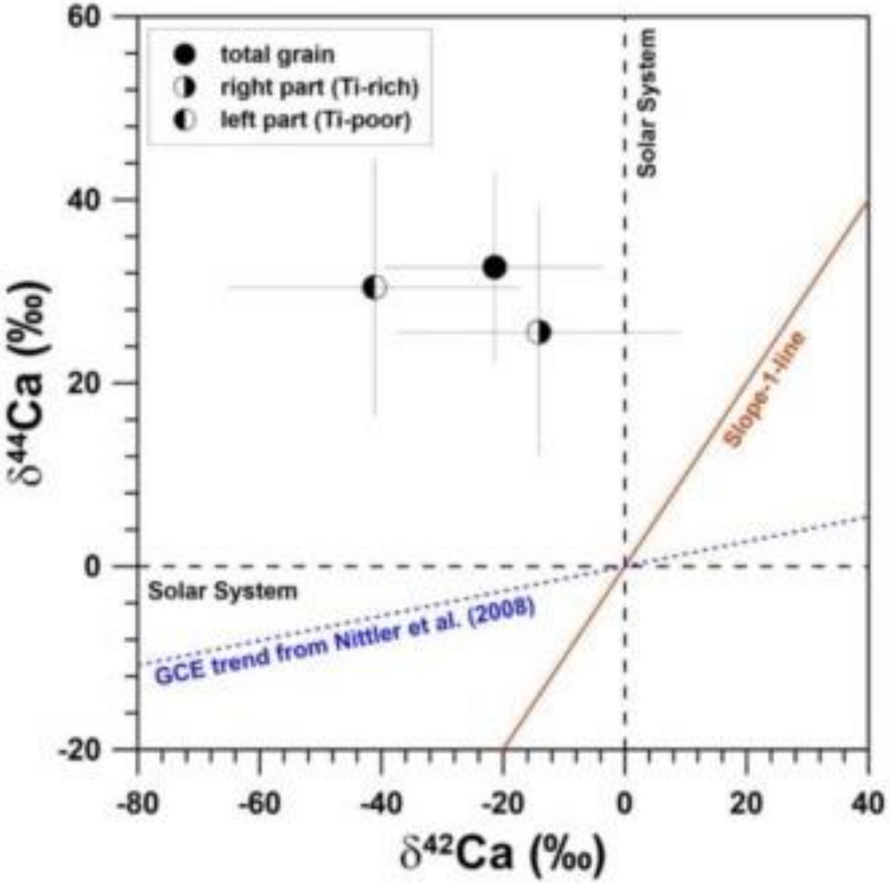



Fig. 7 from Liu et al. (2024) *SSR*

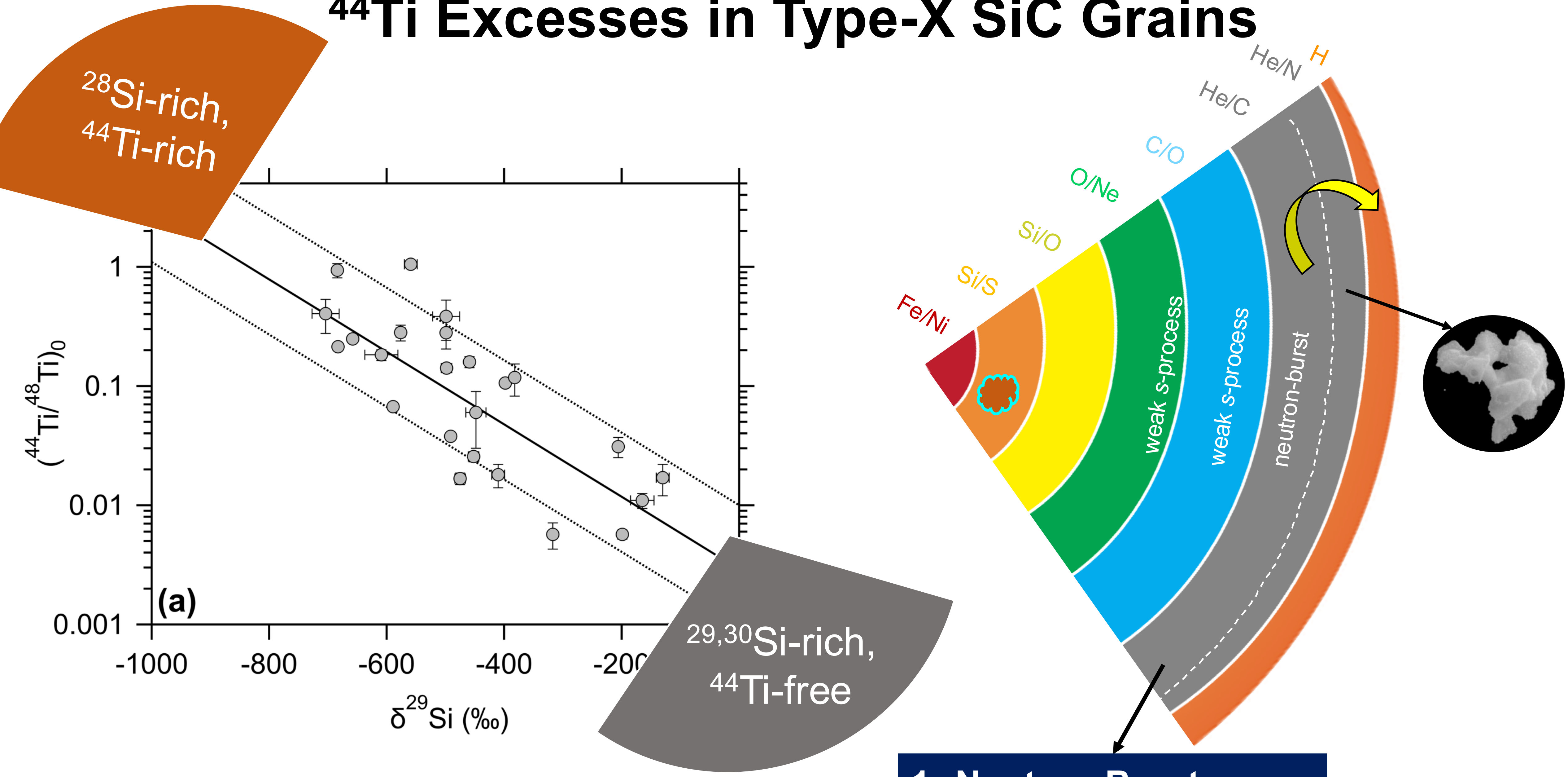
Heterogenous GCE?





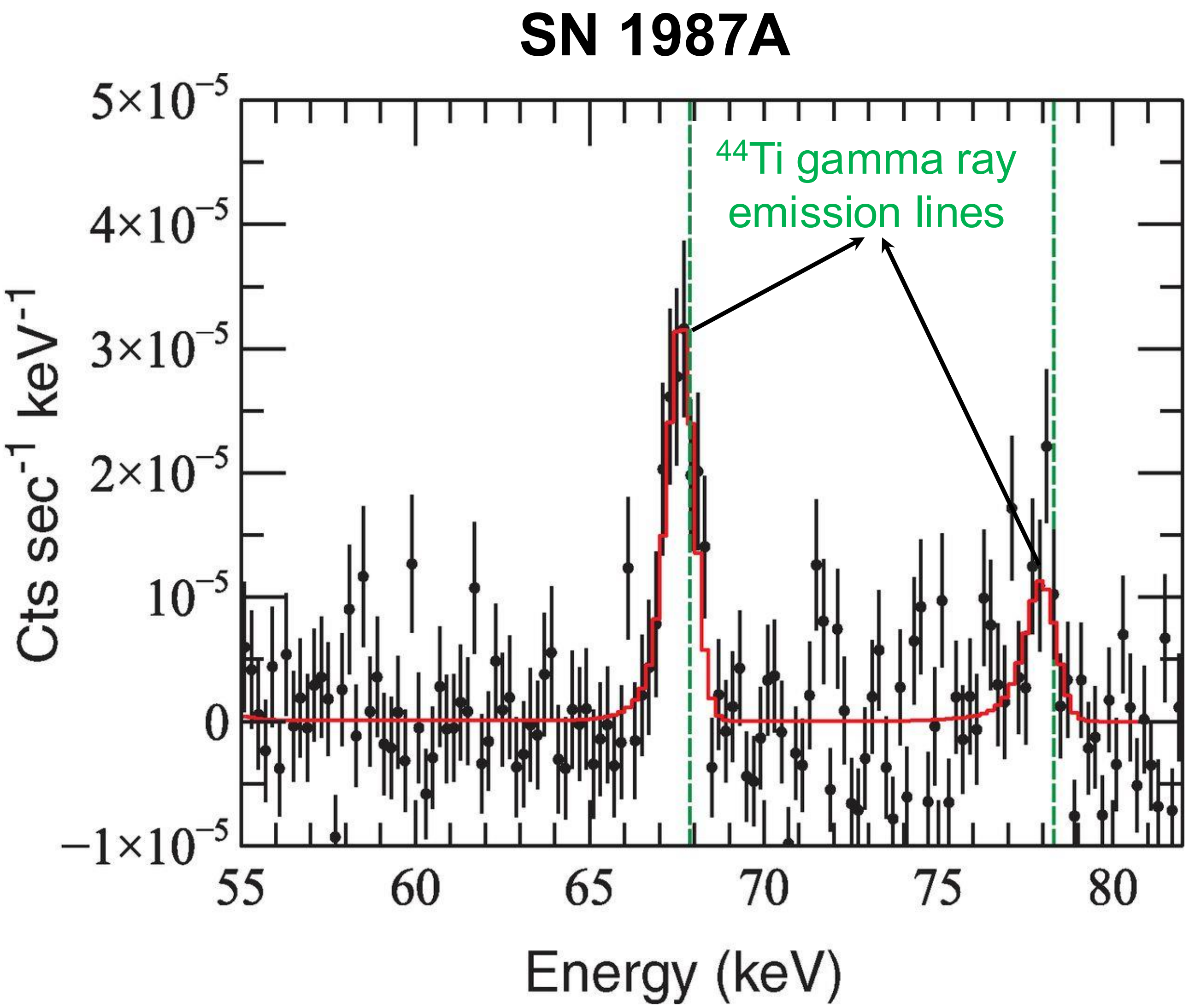
**What is the stellar contributor for the heterogenous GCE effect on $^{44}$Ca? (not typical Type II SNe)**

# $^{44}$Ti Excesses in Type-X SiC Grains

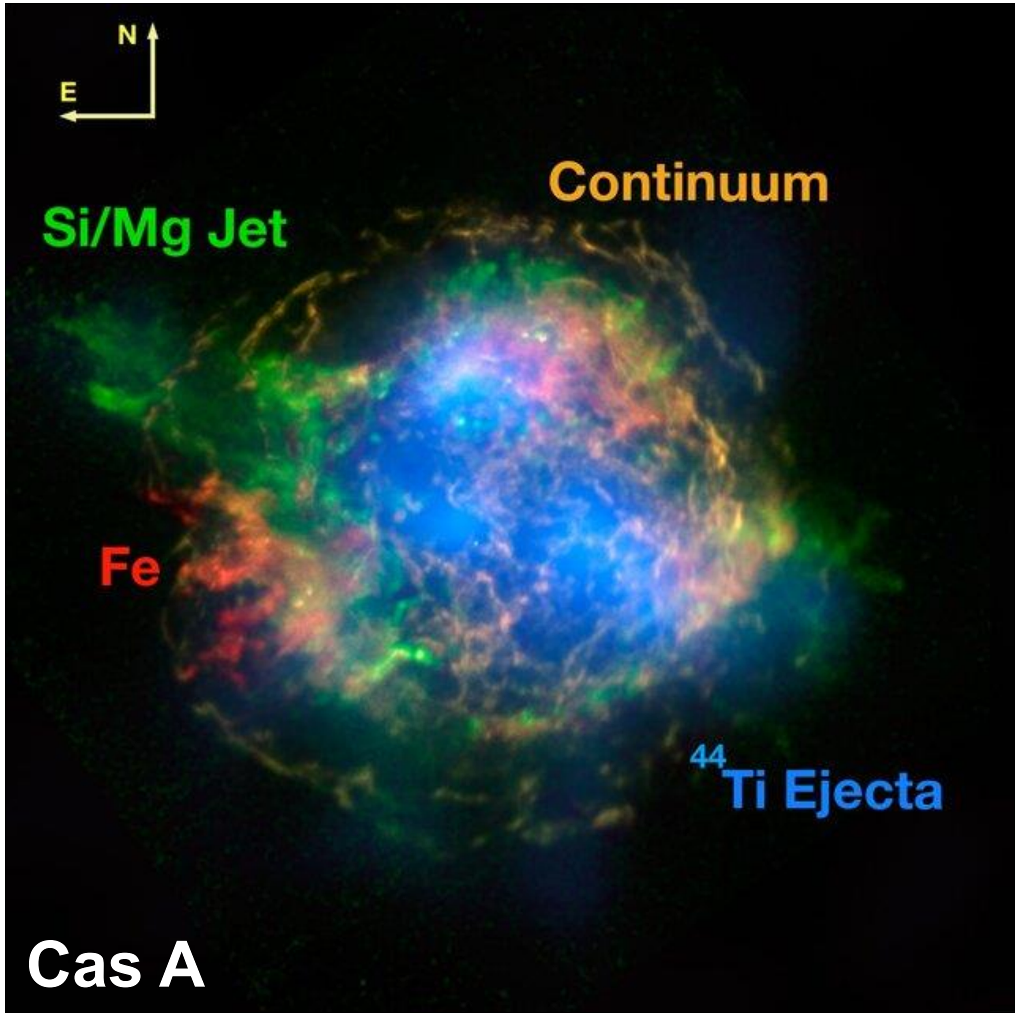



1. **Neutron Burst**
2. **Explosive H Burning**

# Titanium-44: Smoking Gun of Supernova Nucleosynthesis

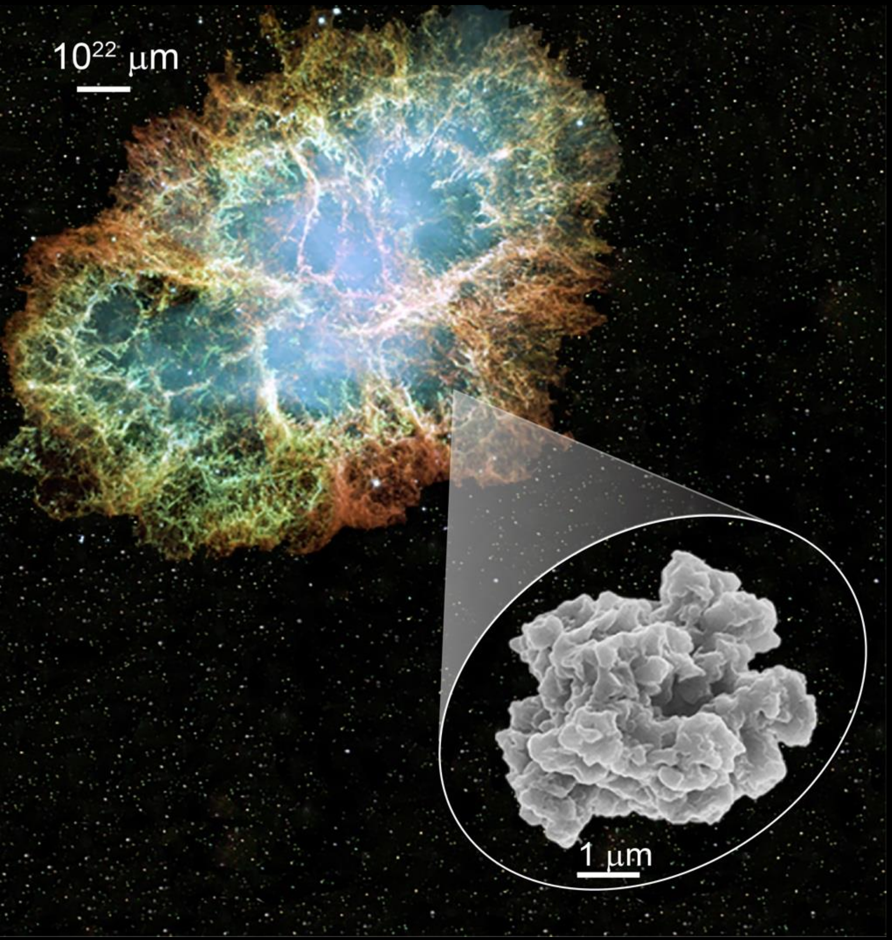



*from Boggs et al. (2015) Science*




*from Grefenstette et al. (2016) ApJ*

# Overview

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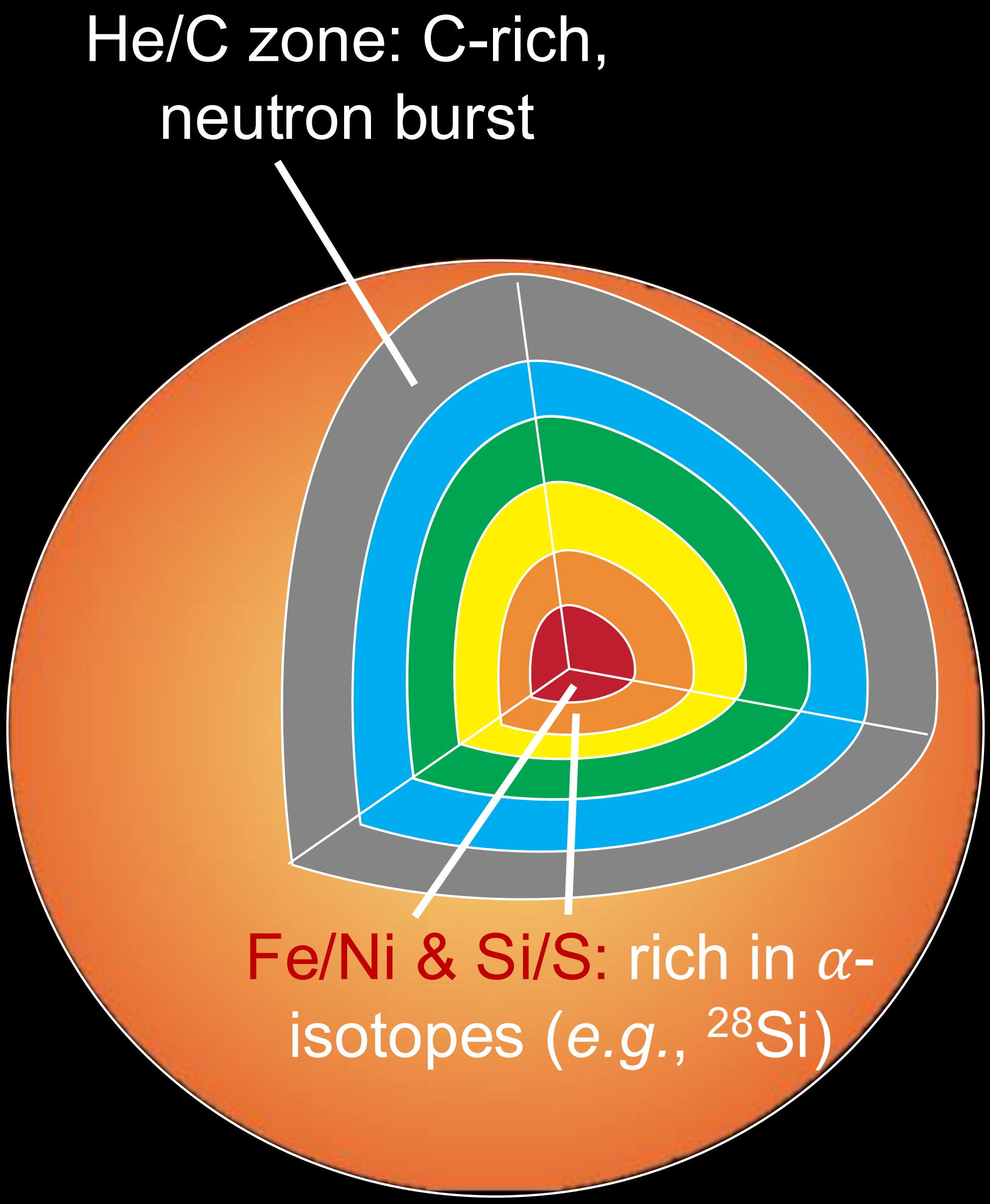
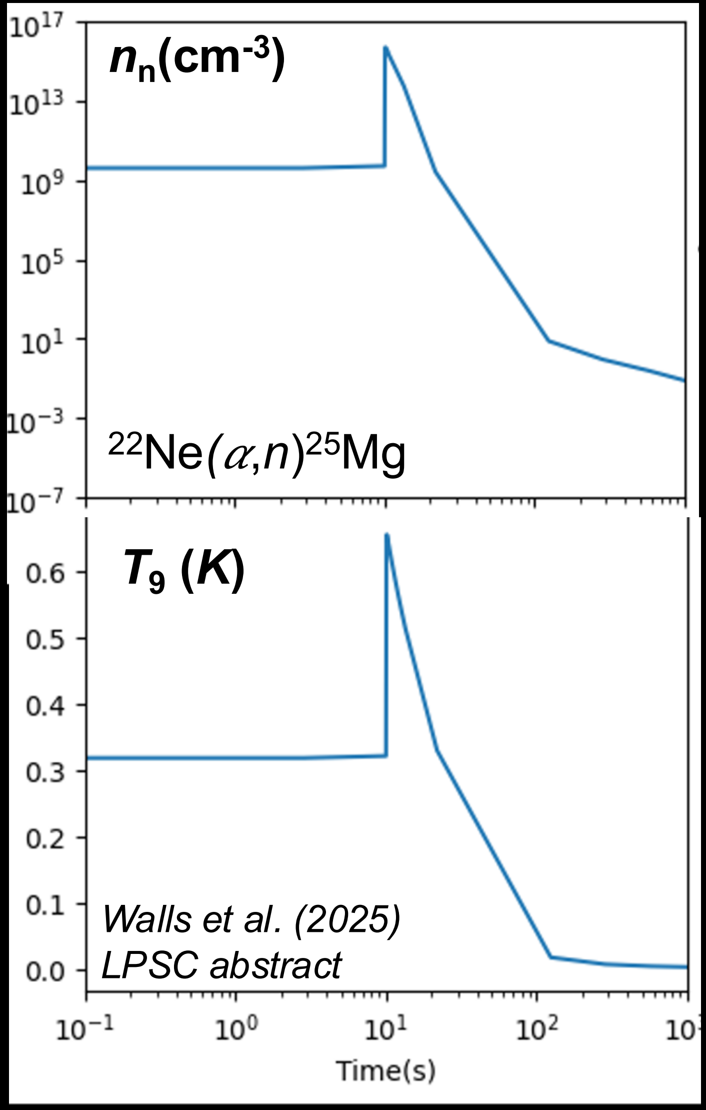
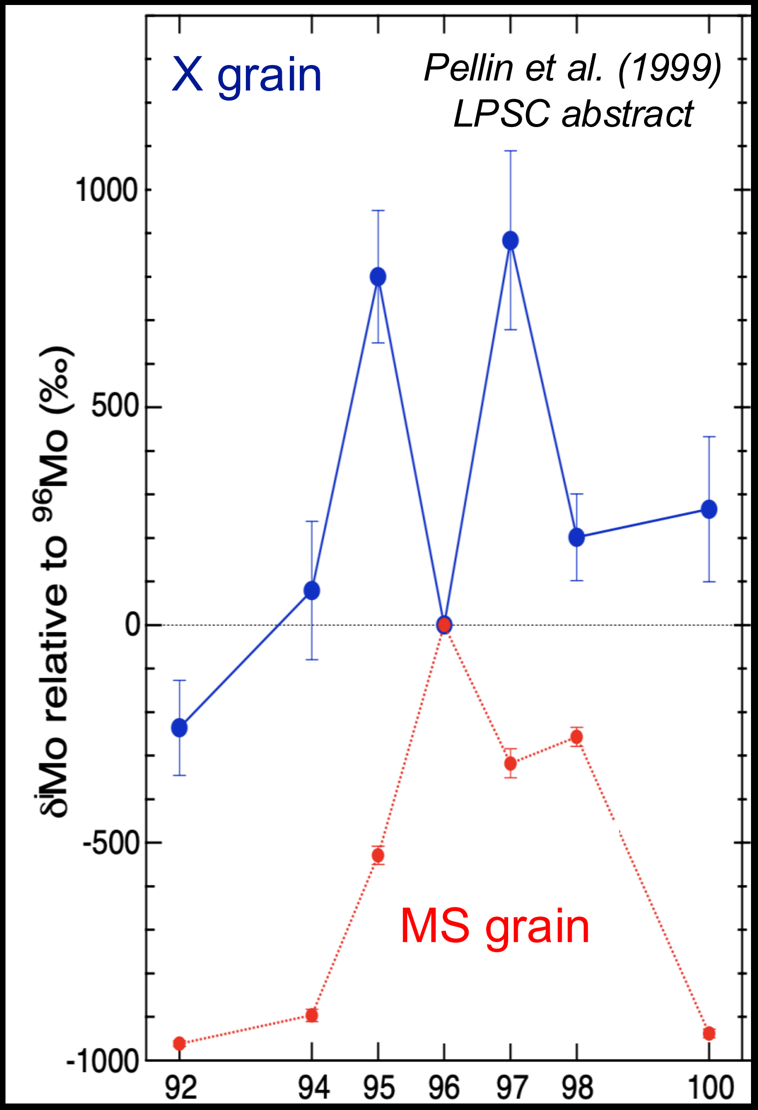
# Neutron Burst in He/C Zone



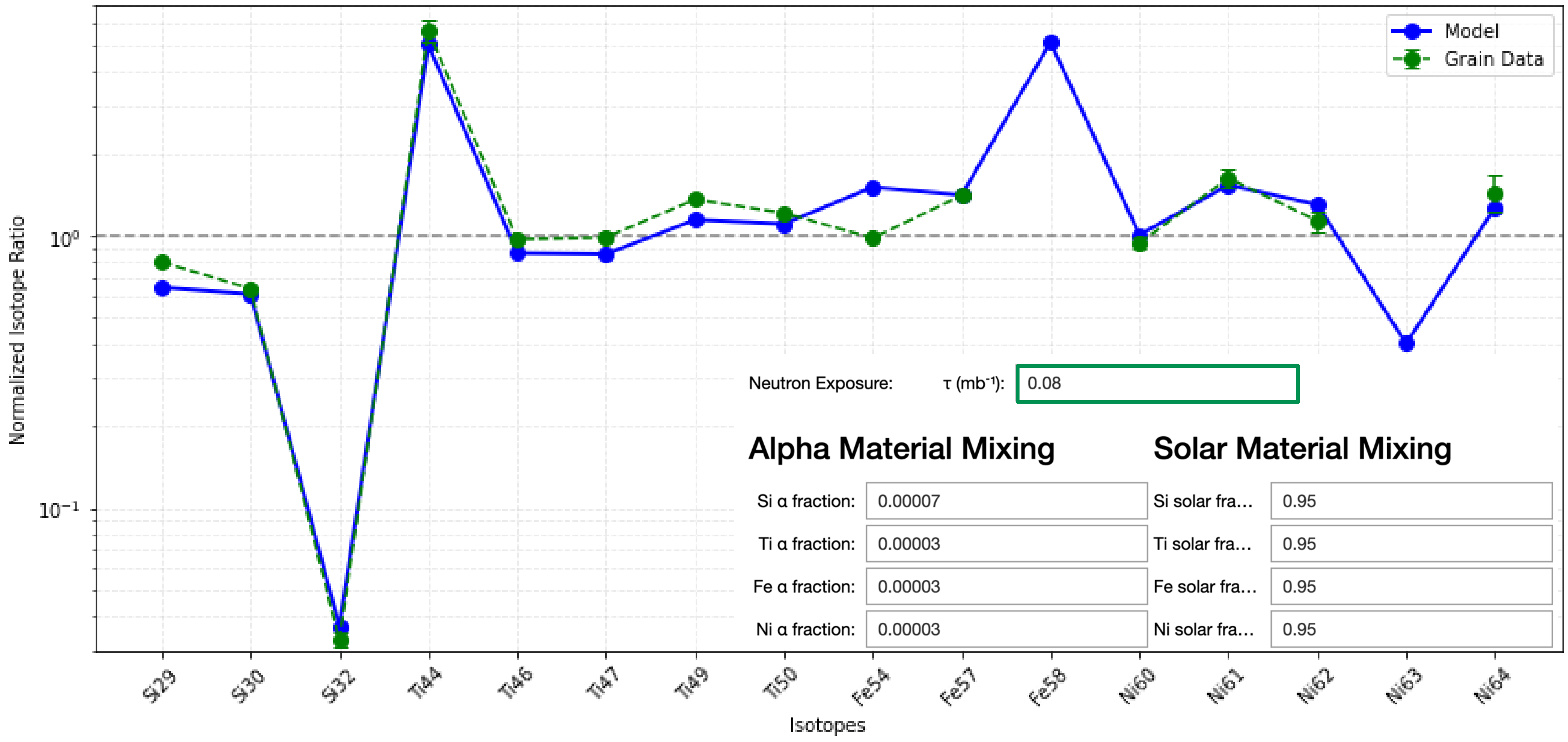

Neutron Burst




Mo Isotope Data



# X Grains Incorporated He/C, Si/S, and Solar Material




See poster "Presolar Grains as Probes of Supernova Nucleosynthesis" by Liu et al. for details

# losive H Burning Occurs He/C or He/N zone?

$^{28}$Si-rich,
$^{12}$C-rich

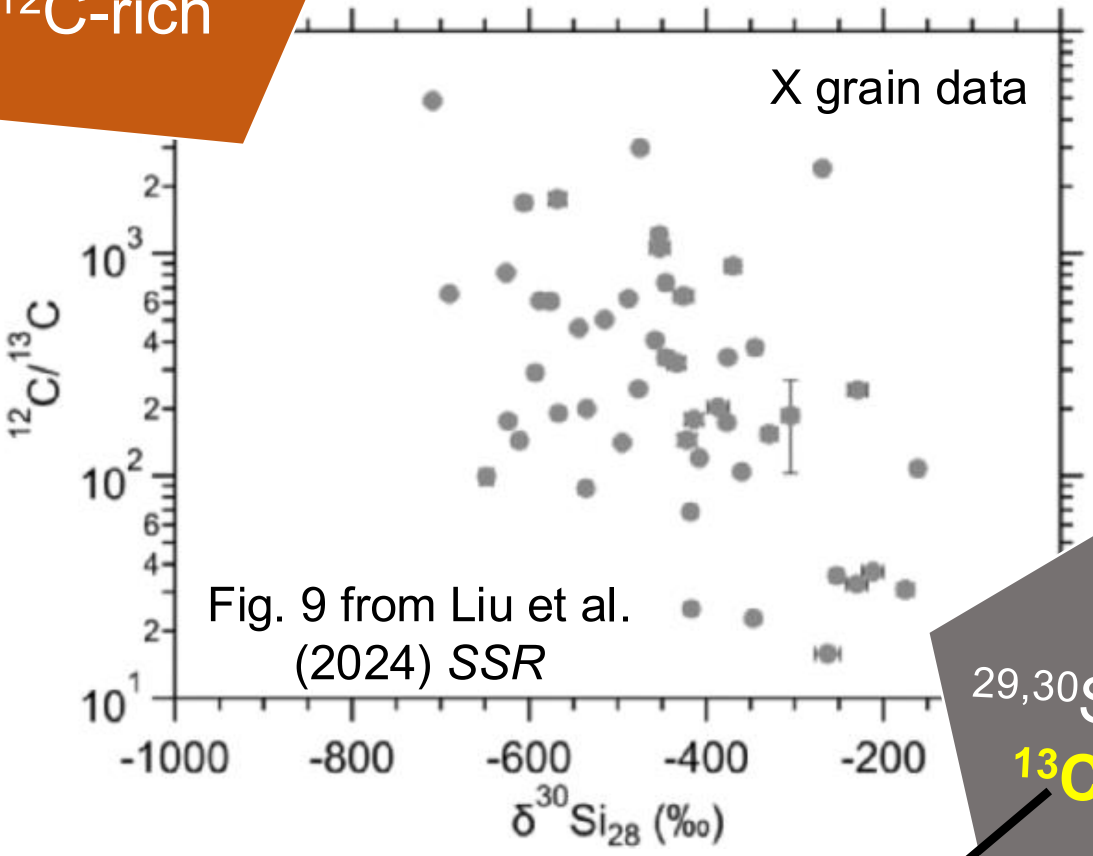
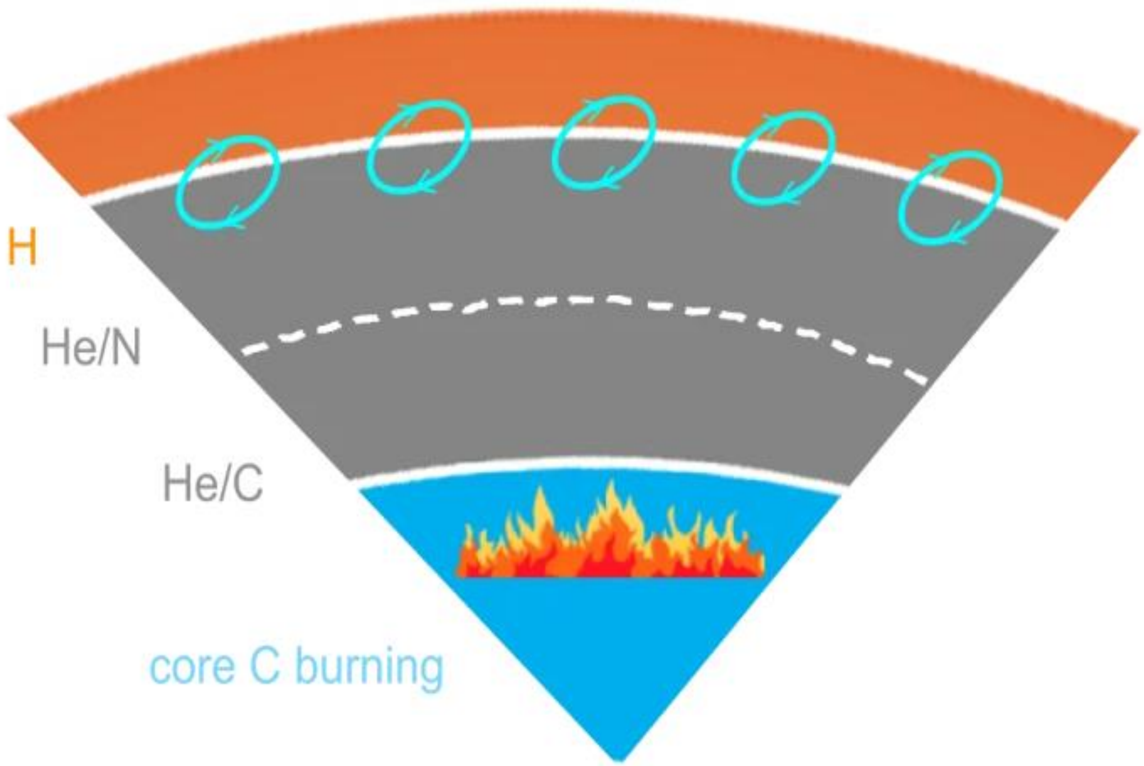



Fig. 9 from Liu et al. (2024) *SSR*

$^{29,30}$Si-rich,
$^{13}$**C**-rich

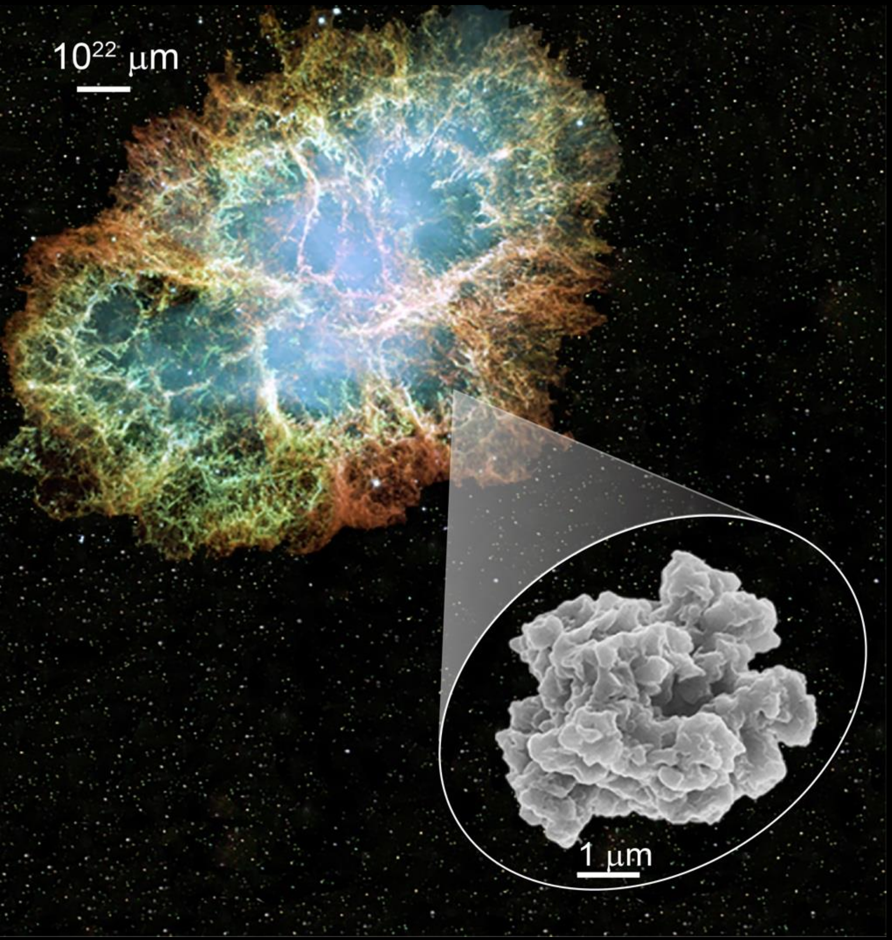
- Triple alpha reaction leads to pure $^{12}$C in He-rich shells
- $^{12}C(p,\gamma)^{13}N(\beta^{-})^{13}C$

**$^{22}Ne(p,\gamma)^{23}Na > {}^{22}Ne(\alpha,n)^{25}Mg$ at $T_9$ *K***




**The preservation of neutron-burst signatures in X grains favor explosive H burning in He/N zone**

# Overview

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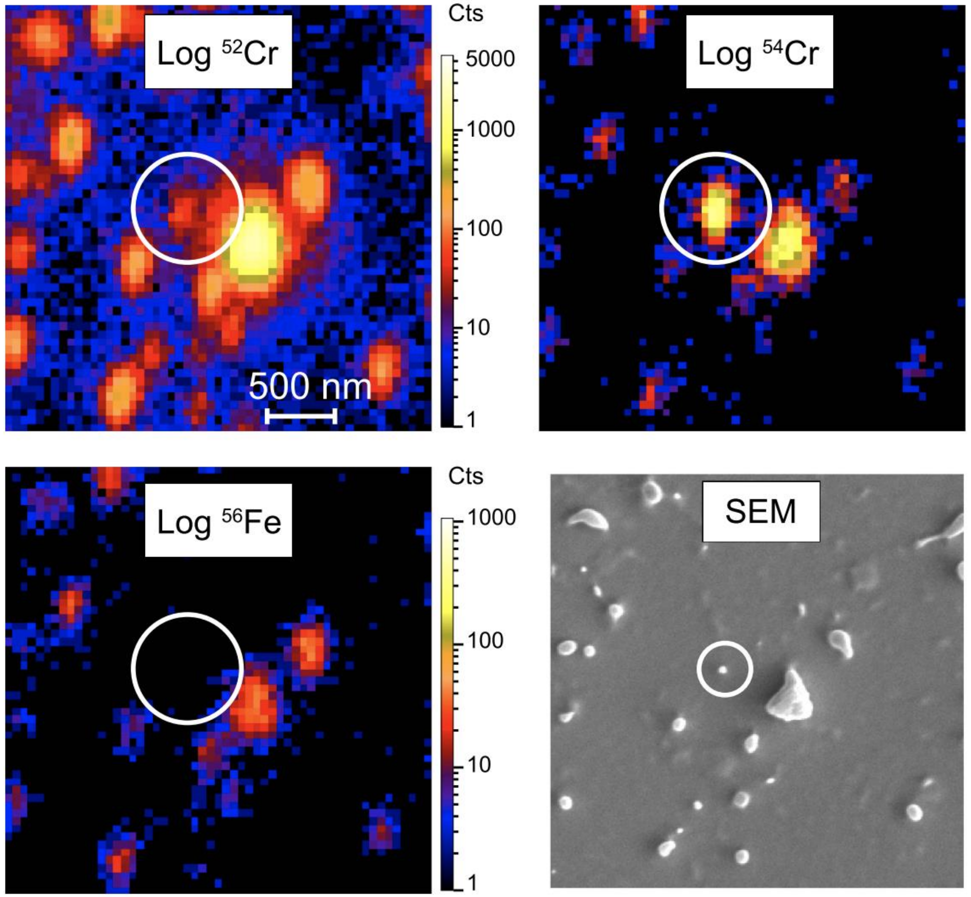
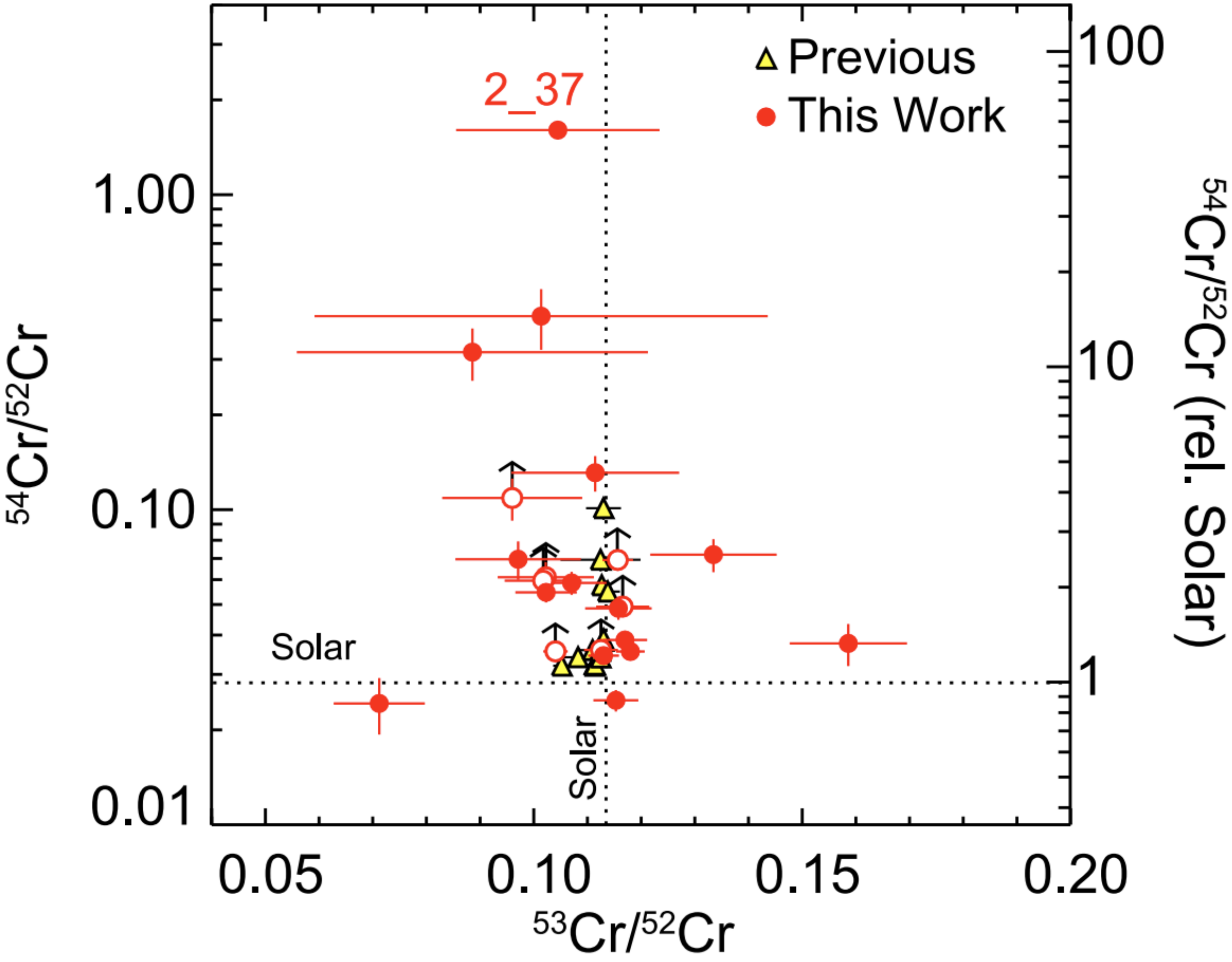
# Presolar Nanospinel Grains

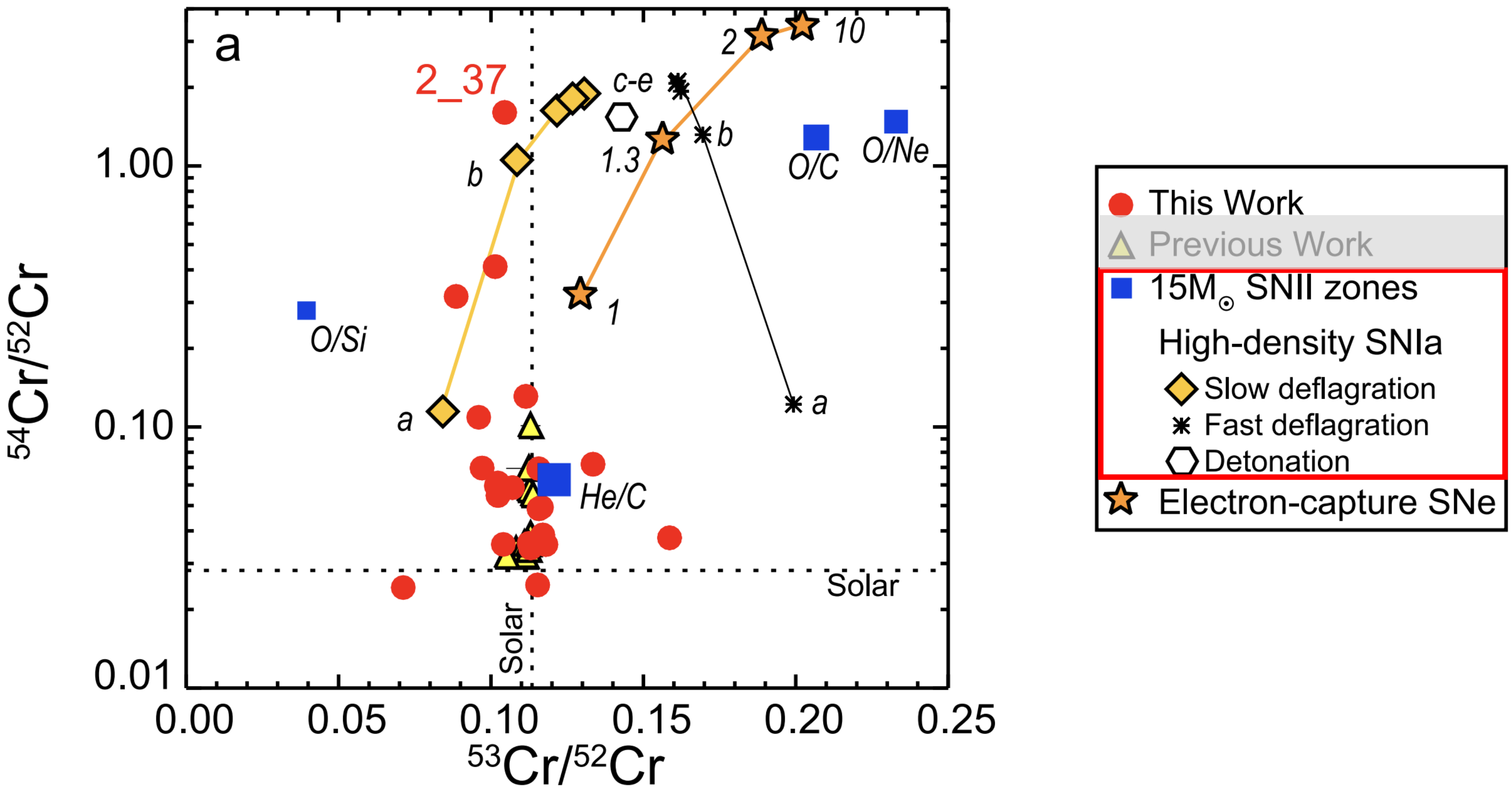
from Nittler et al. (2018) *ApJL*



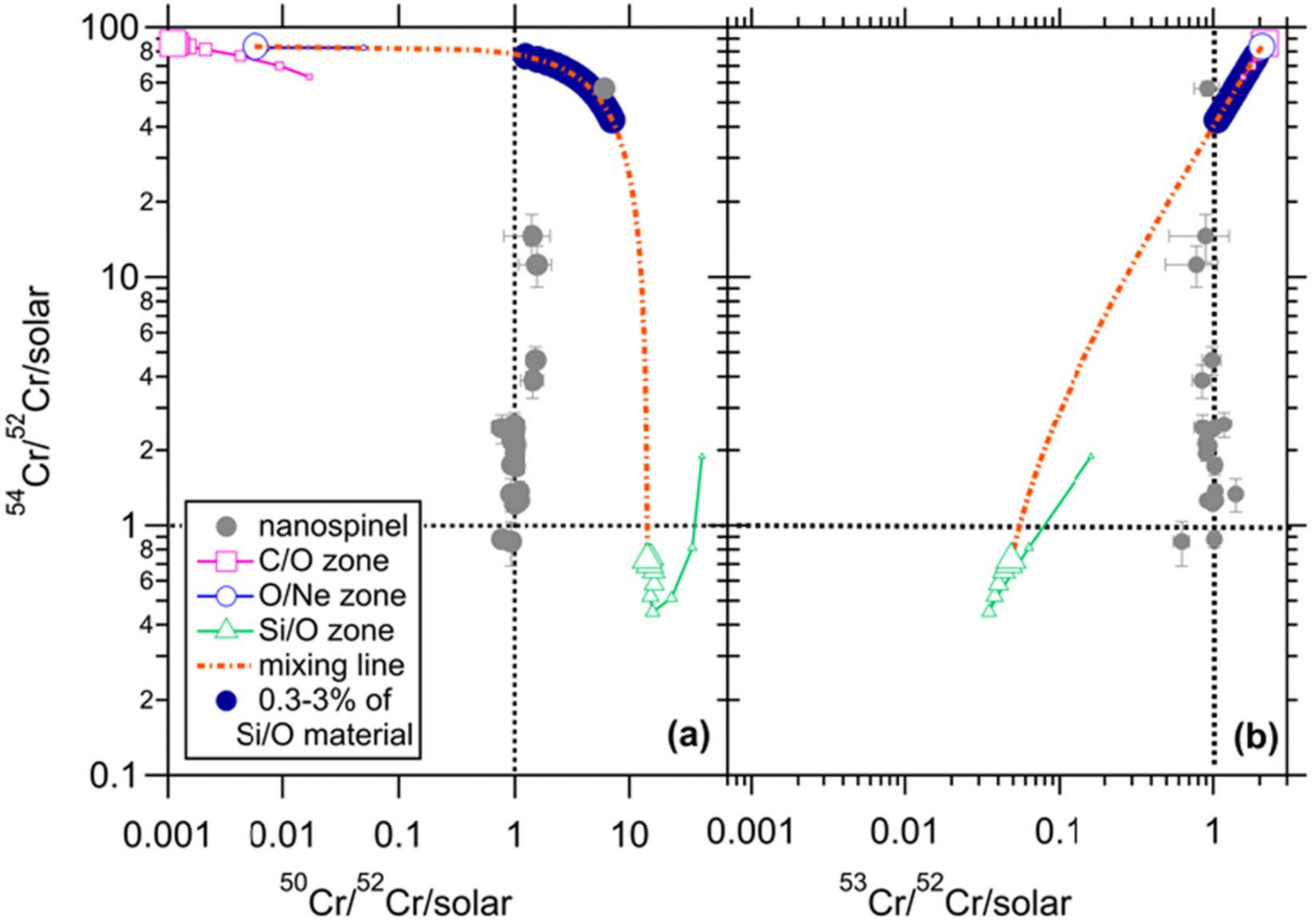

Potential origins include Chandra SNIa, electron-capture SNe, and Type II SNe

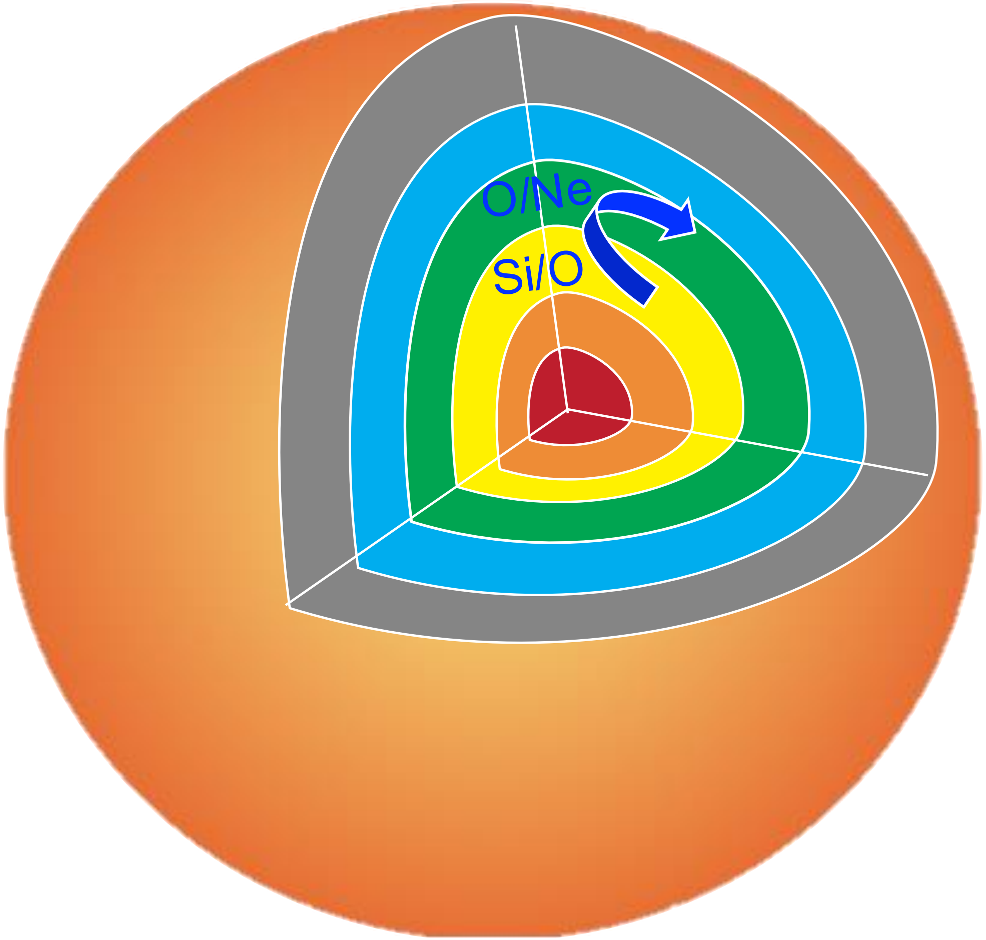
# Type Ia and Electron-capture Supernovae




from Nittler et al. (2018) *ApJL*

# Type II Supernovae are Also Possible!



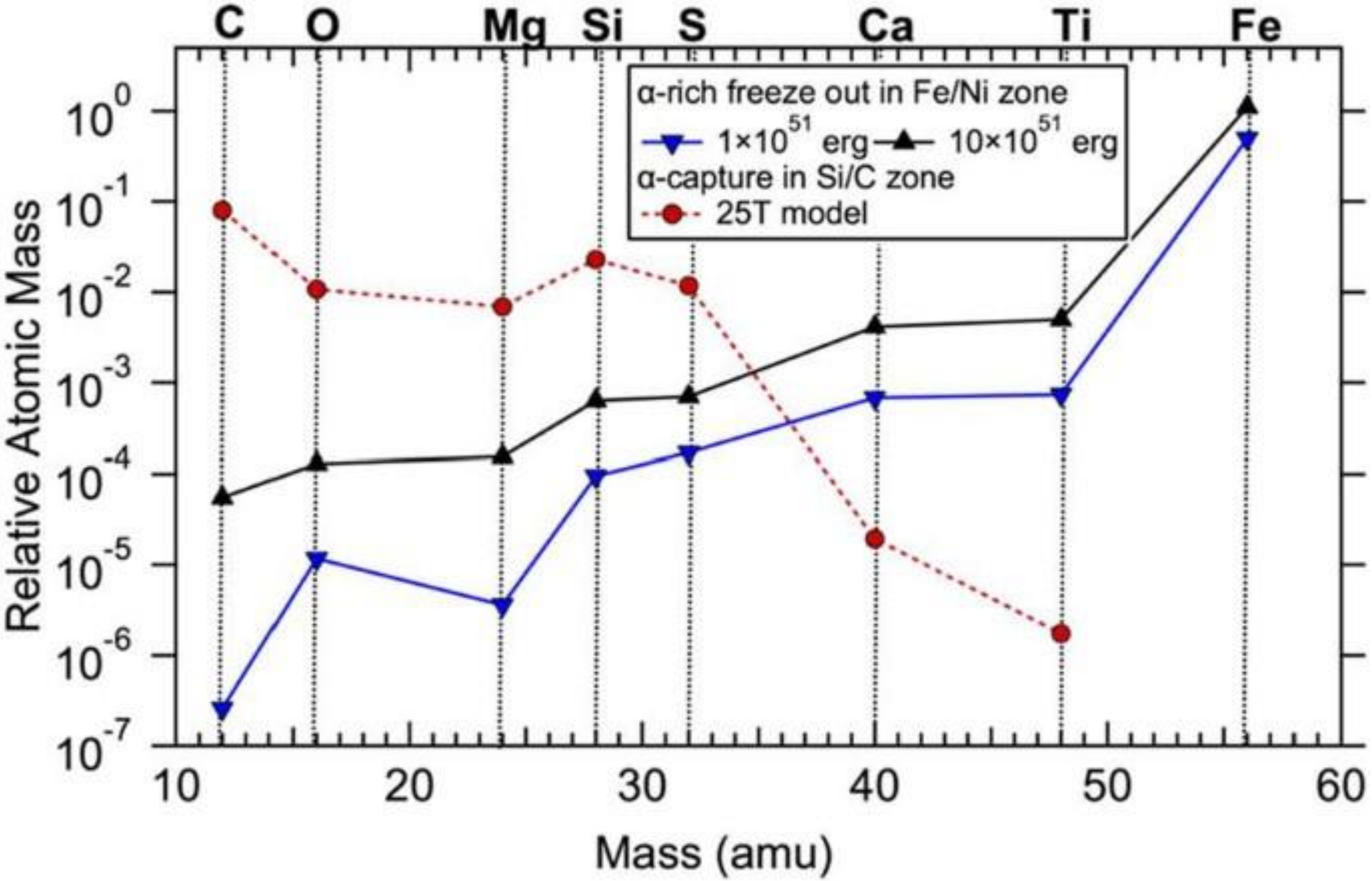




from Liu et al. (2024) *SSR*

# Conclusions

- $^{44}Ti$ is the smoking gun of supernova nucleosynthesis and confirms the Type II supernova origins for presolar X SiC grains
- X grains' isotopic signatures constrains the neutron exposure (≤0.8 $mb^{-1}$) for neutron-burst and the location of explosive H-burning (He/N zone) in He-rich zones of Type II supernovae
- X grains' multi-element isotope data allow us to disentangle mixing between different supernova zones and place constraints on key nuclear reaction rates
- While nanospinel grains may suggest origins in Type Ia or electron-capture supernovae, a Type II origin remains plausible with zone-specific mixing, underscoring the importance of 3D hydrodynamic simulations

# Backup Slides


C
O
Mg
Si
S
Ca
Ti
Fe
α-rich freeze out in Fe/Ni zone
1×10^51 erg
10×10^51 erg
α-capture in Si/C zone
25T model
Relative Atomic Mass
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10
20
30
40
50
60
Mass (amu)