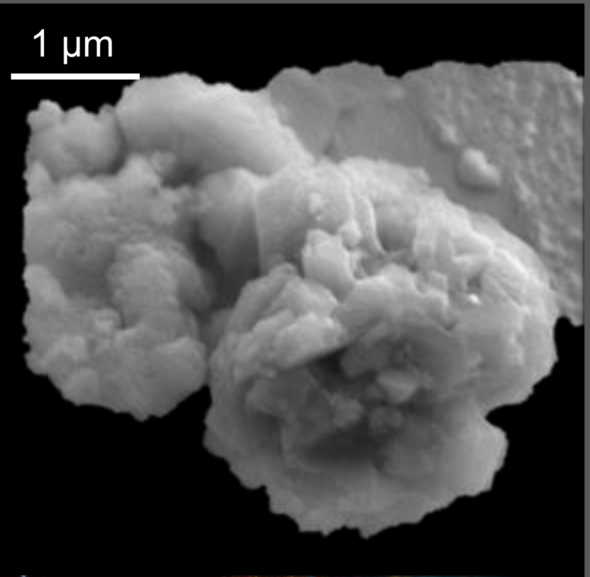
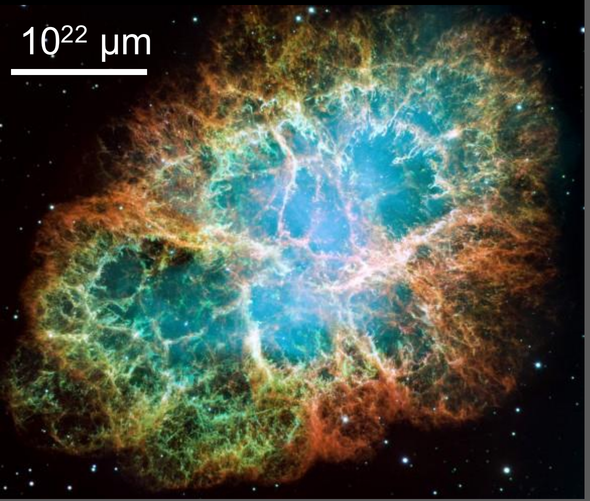
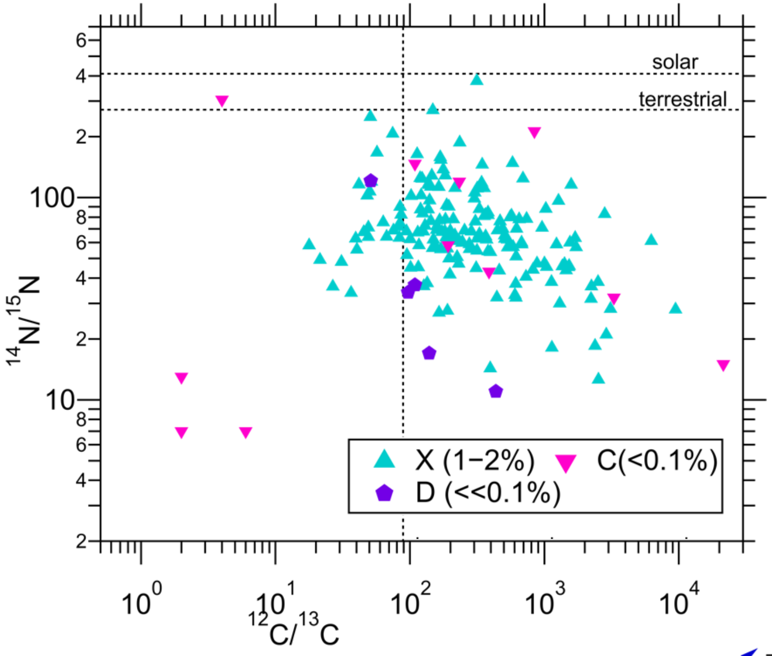




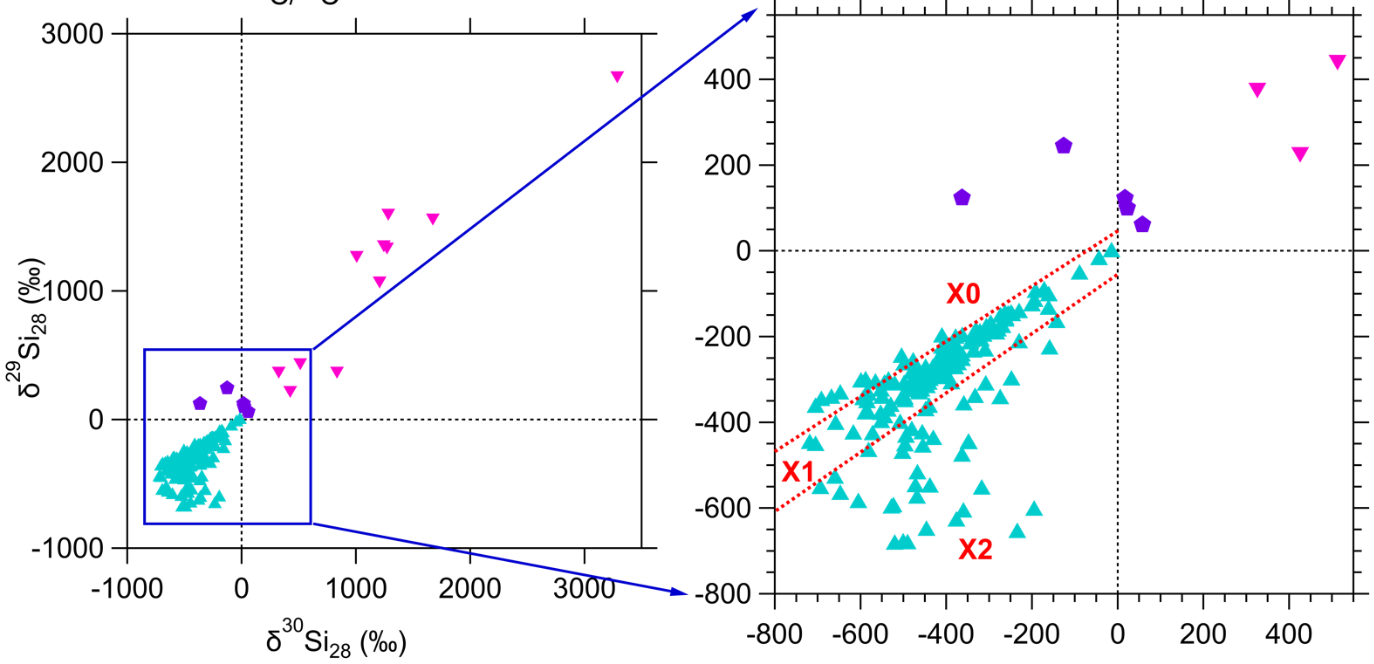
Diverse Neutron-capture Isotopic Signatures Recorded in Supernova Silicon Carbide Grains

Nan Liu, Boston University
Conel Alexander & Jianhua Wang, Carnegie Institution
Sergio Cristallo & Diego Vescovi, Osservatorio Astronomico d'Abruzzo
Bradley Meyer & Lucas Walls, Clemson University

Different Groups of Supernova SiC Grains

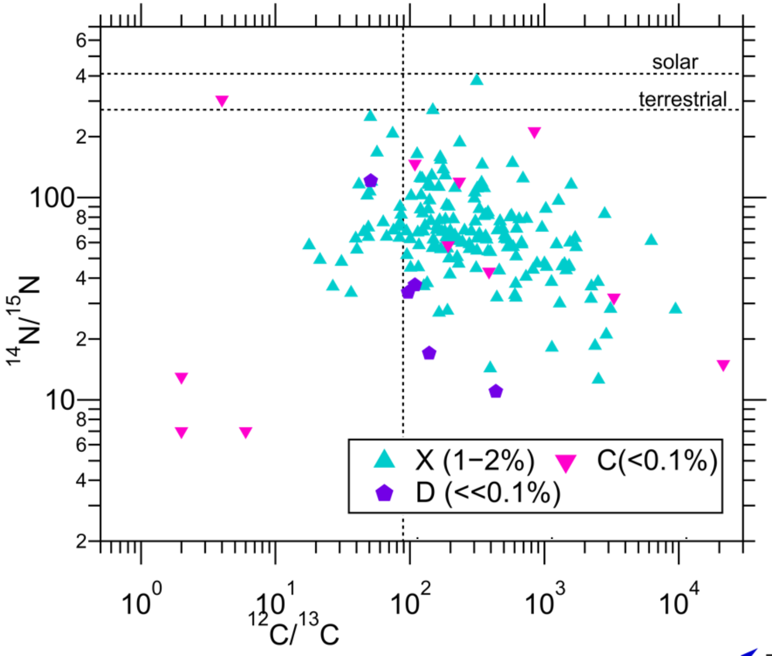


The initial presence of ^{44}Ti has been inferred for X, C, and D grains, confirming their supernova origins.



figures from Liu (2024) presolar grains

Different Groups of Supernova SiC Grains



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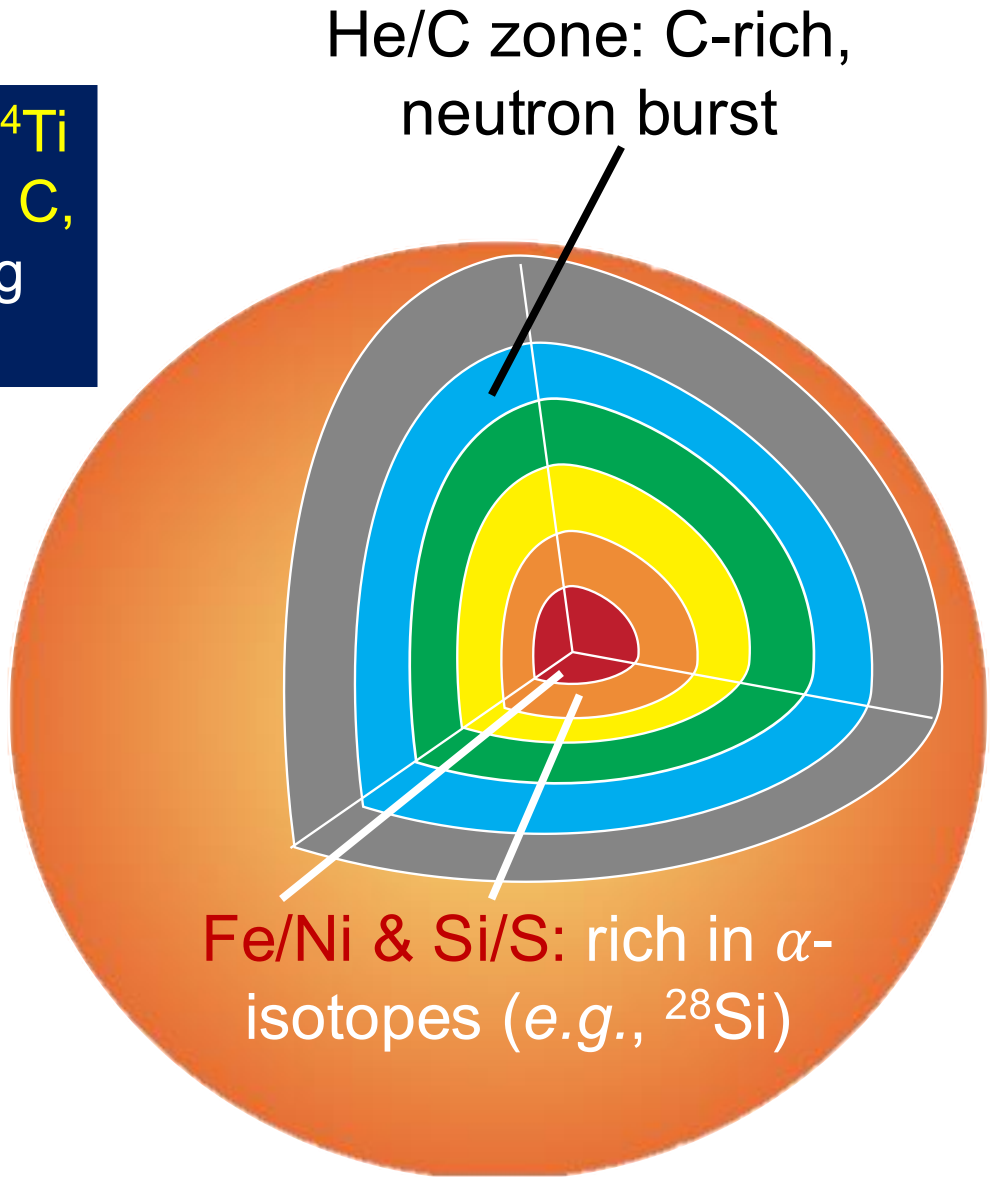
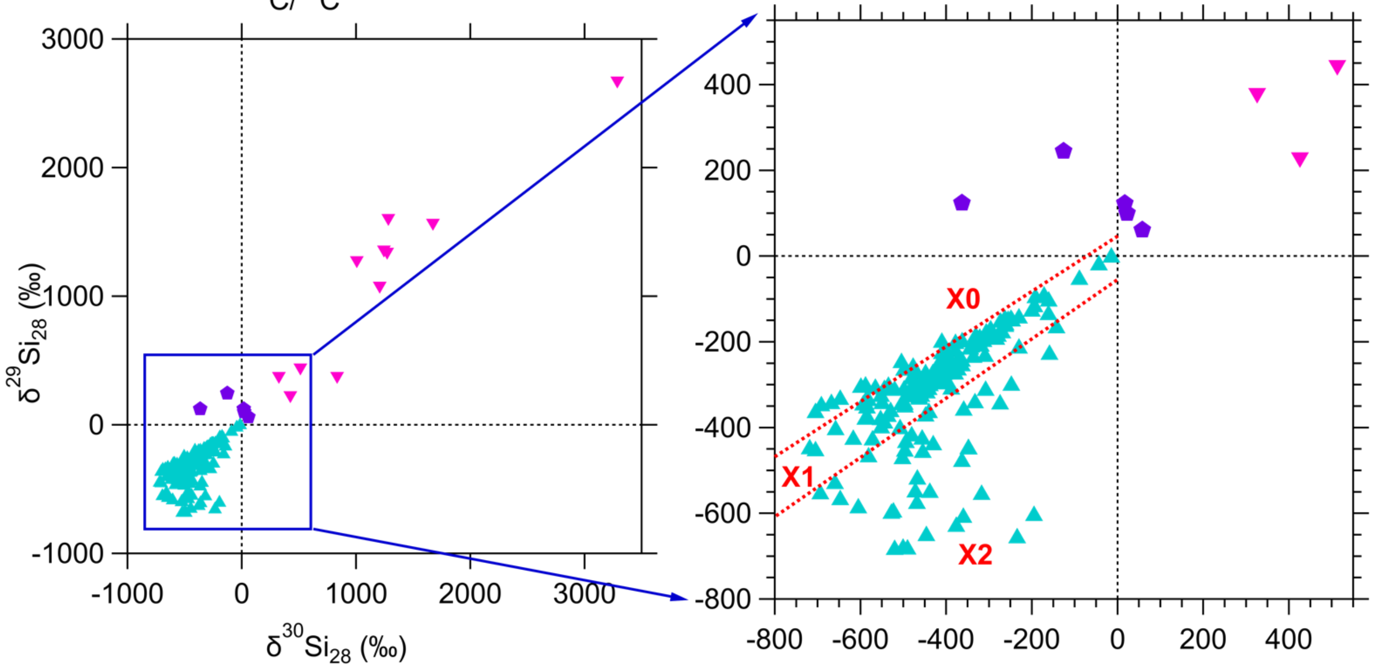
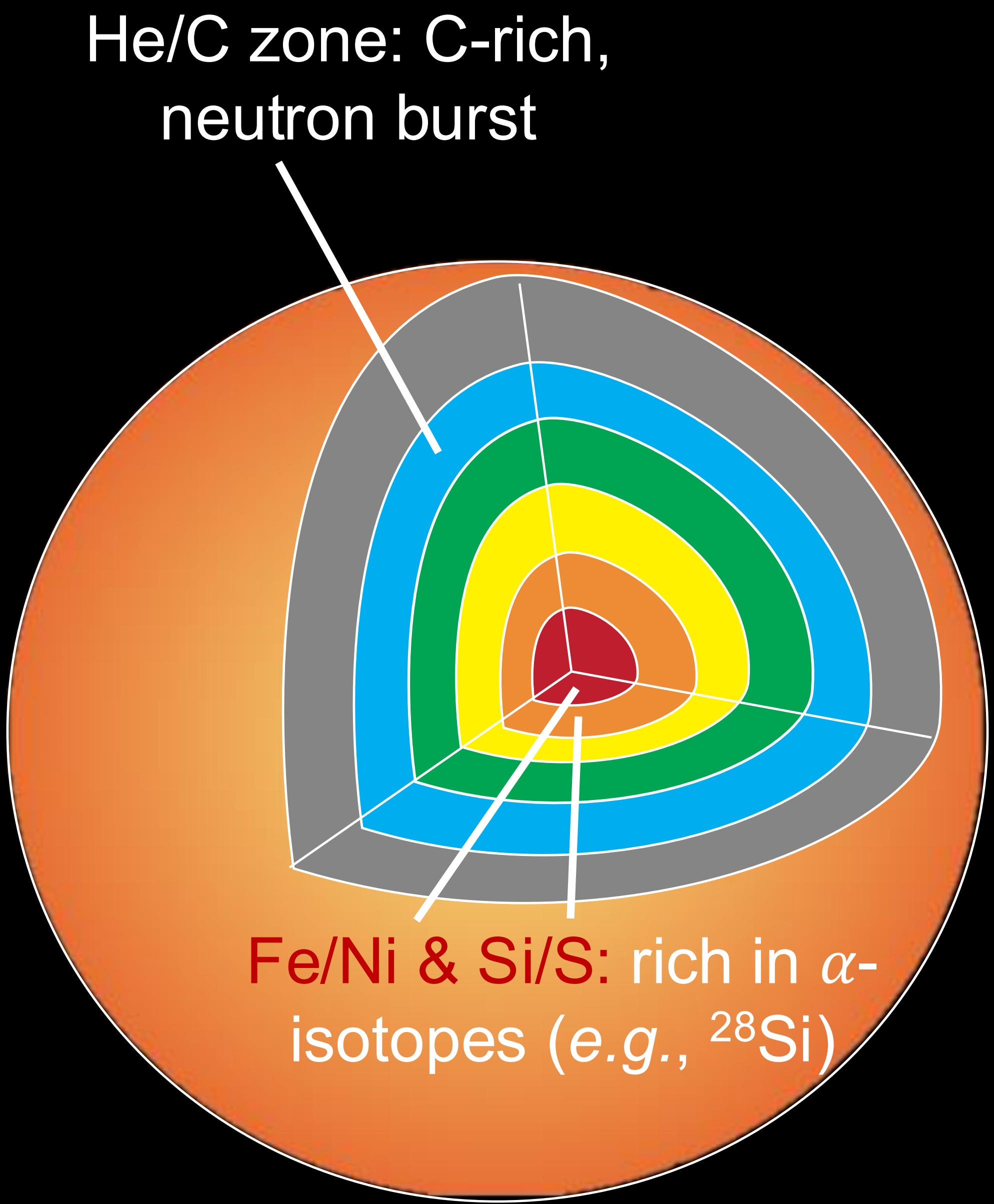


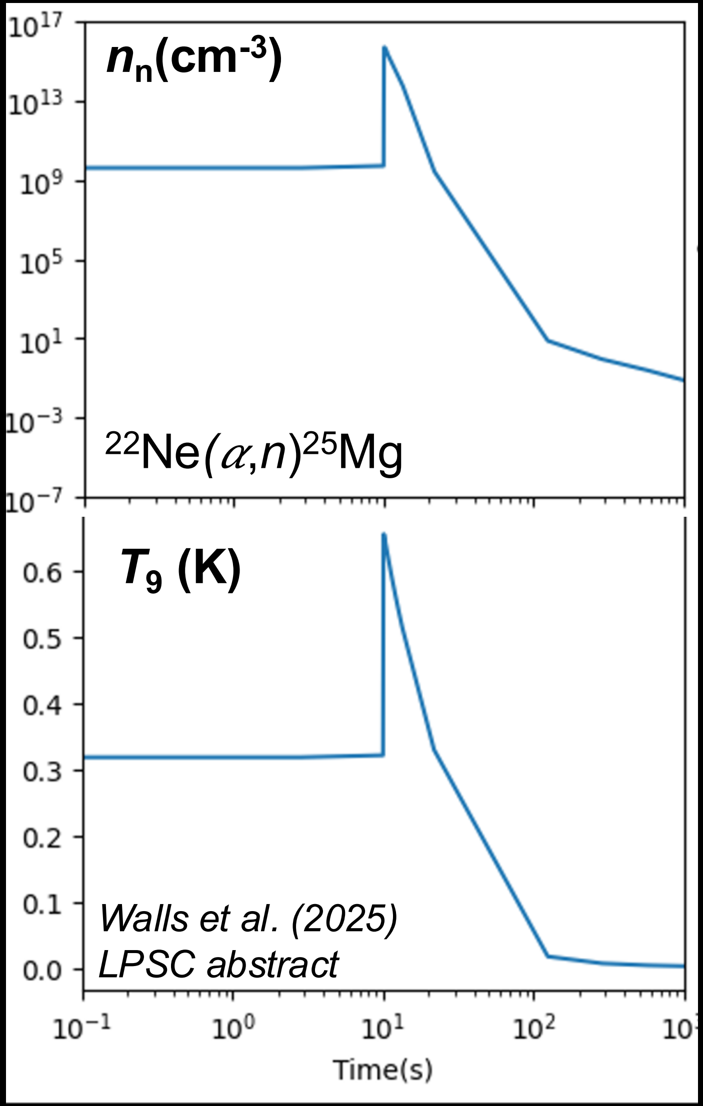


figures from Liu (2024) presolar grains

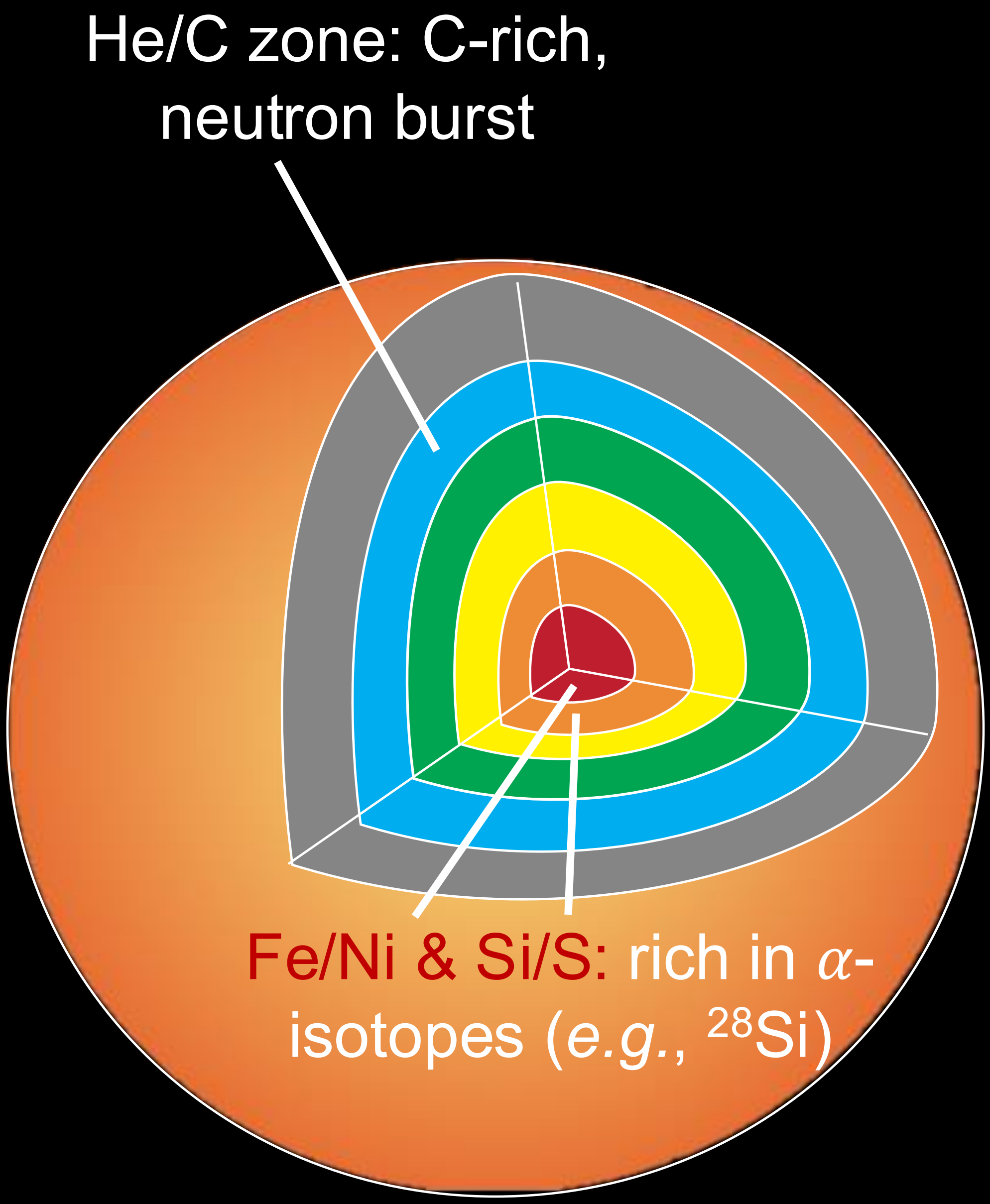
Neutron Burst in He/C Zone



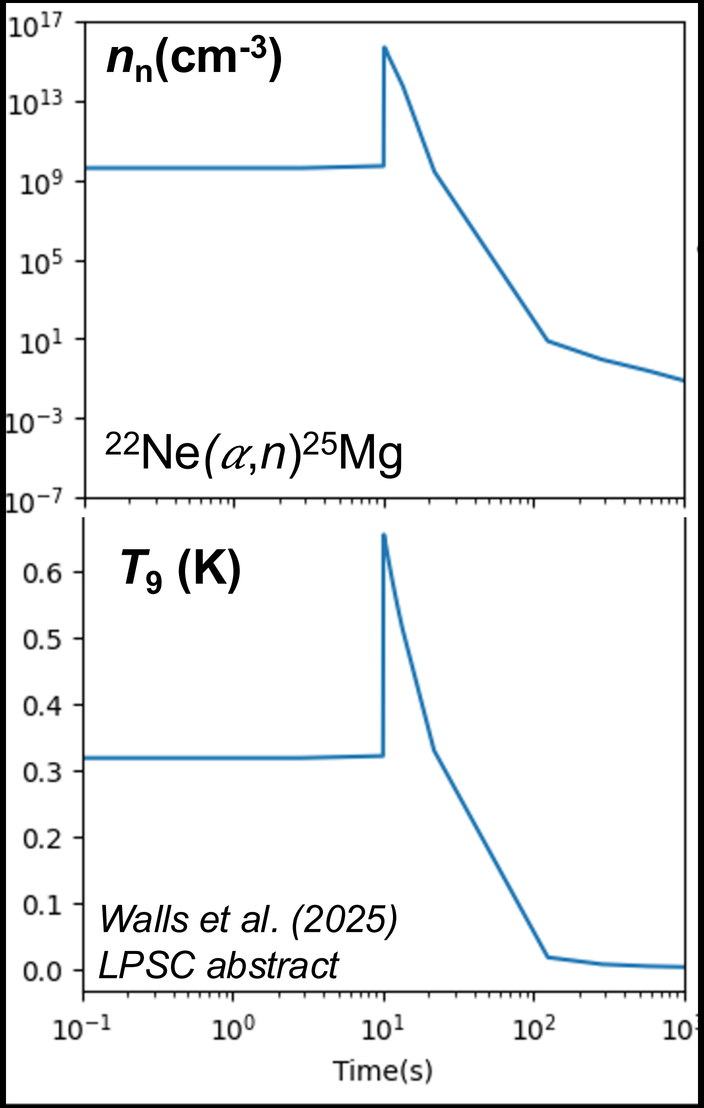
Neutron Burst



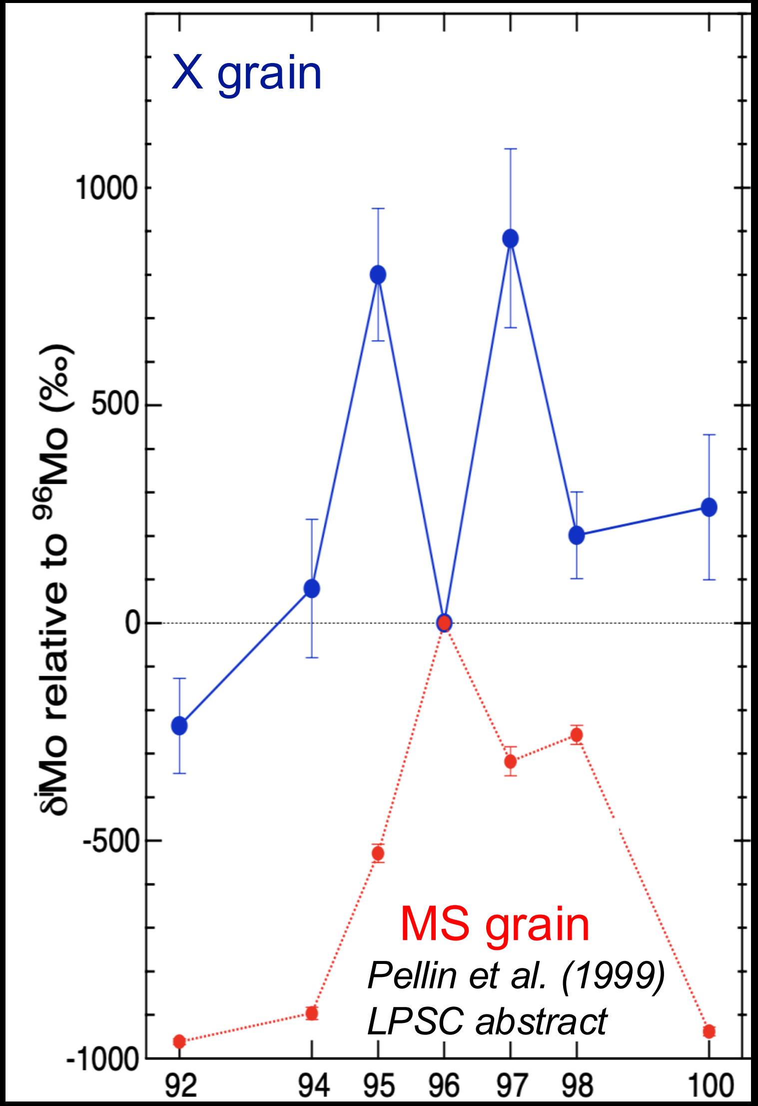
Neutron Burst in He/C Zone



Neutron Burst



Mo Isotope Data



New Data and Neutron-burst Code

1. **New Nickel Isotope Data**
   - Analytical Methods
   - Different Signatures

2. **Python Code for Data Comparison**
   - Neutron burst: neutron exposure (τ), (n,γ) cross section
   - Mixing calculations

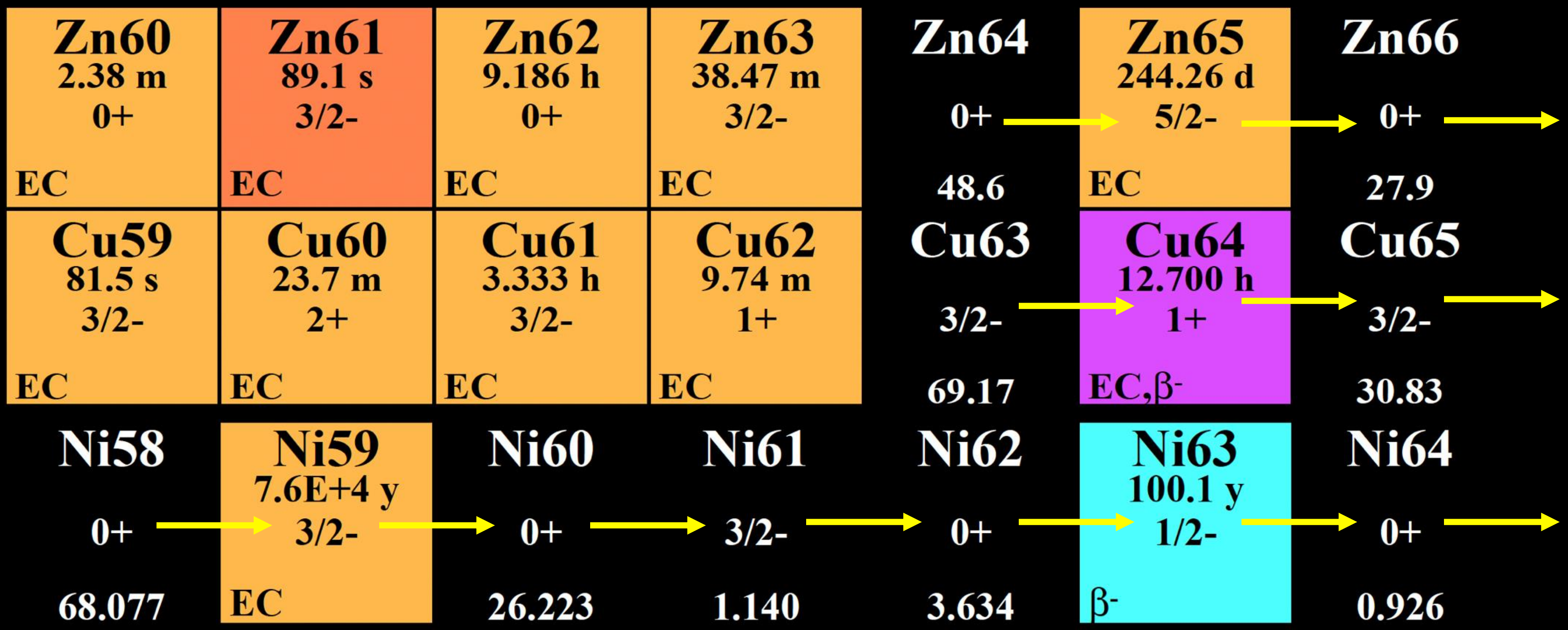
$X \times$ Neutron burst + $Y \times$ solar + $(1-X-Y) \times \alpha$ material

calculated in step 1

shells above He/C (mainly envelope)

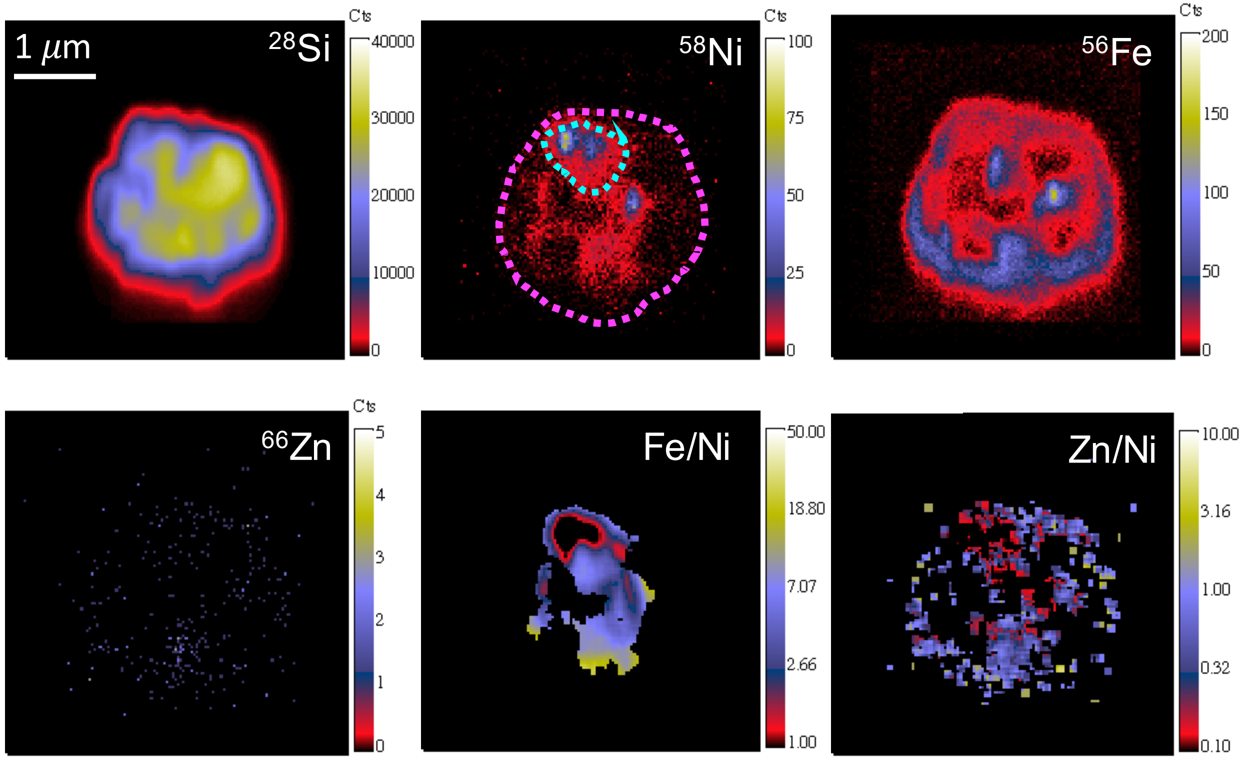
Fe/Ni and/or Si/S

Neutron-burst in Ni-Cu-Zn Region



- $^{60\text{-}64}$Ni are produced during neutron burst that lasts for a few seconds ($\rho_{peak} \cong 10^{17}$ neutron/cm^{-3}) (*Meyer et al. 2000, ApJL*)
- ^{63}Ni decays to ^{63}Cu after the burst and grain formation (within 10s of years)
- Ni-Cu isotope analyses allowed obtaining all Ni isotope ratios

High-resolution NanoSIMS Isotope Imaging



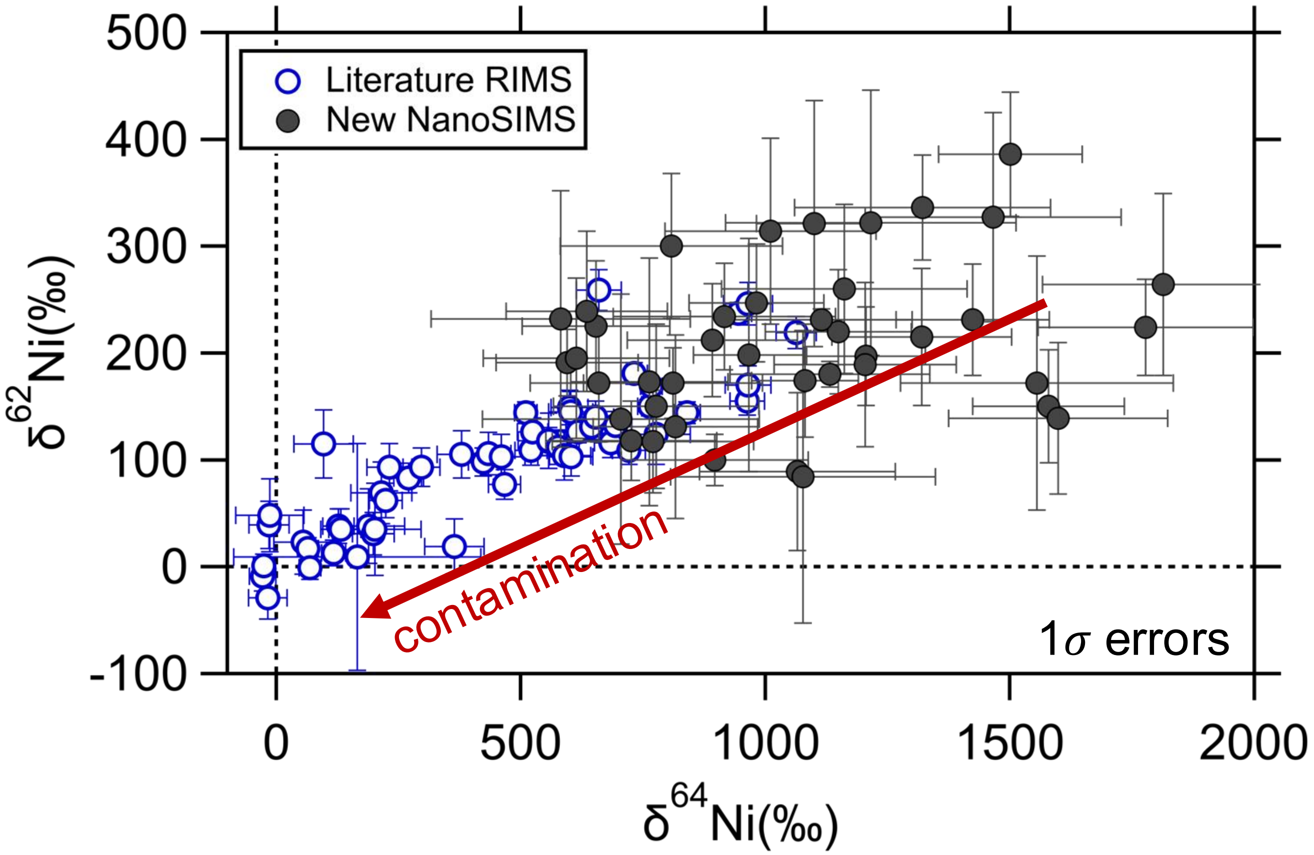
Fe/Ni =5.9
Zn/Ni = 0.3

Fe/Ni =0.9
Zn/Ni = 0.08

$X(^{58}Fe) = 0.9\%$, $X(^{64}Zn) = 25.7\%$

- Presolar SiC grains are enriched in Ni
- Fe and Zn are mainly contamination
- Small regions of interest suppressed interferences and contamination
- δ^{64}Ni were calculated for grains with $X(^{64}Zn) < 50\%$; $X(^{64}Zn) = 19\%$ on average

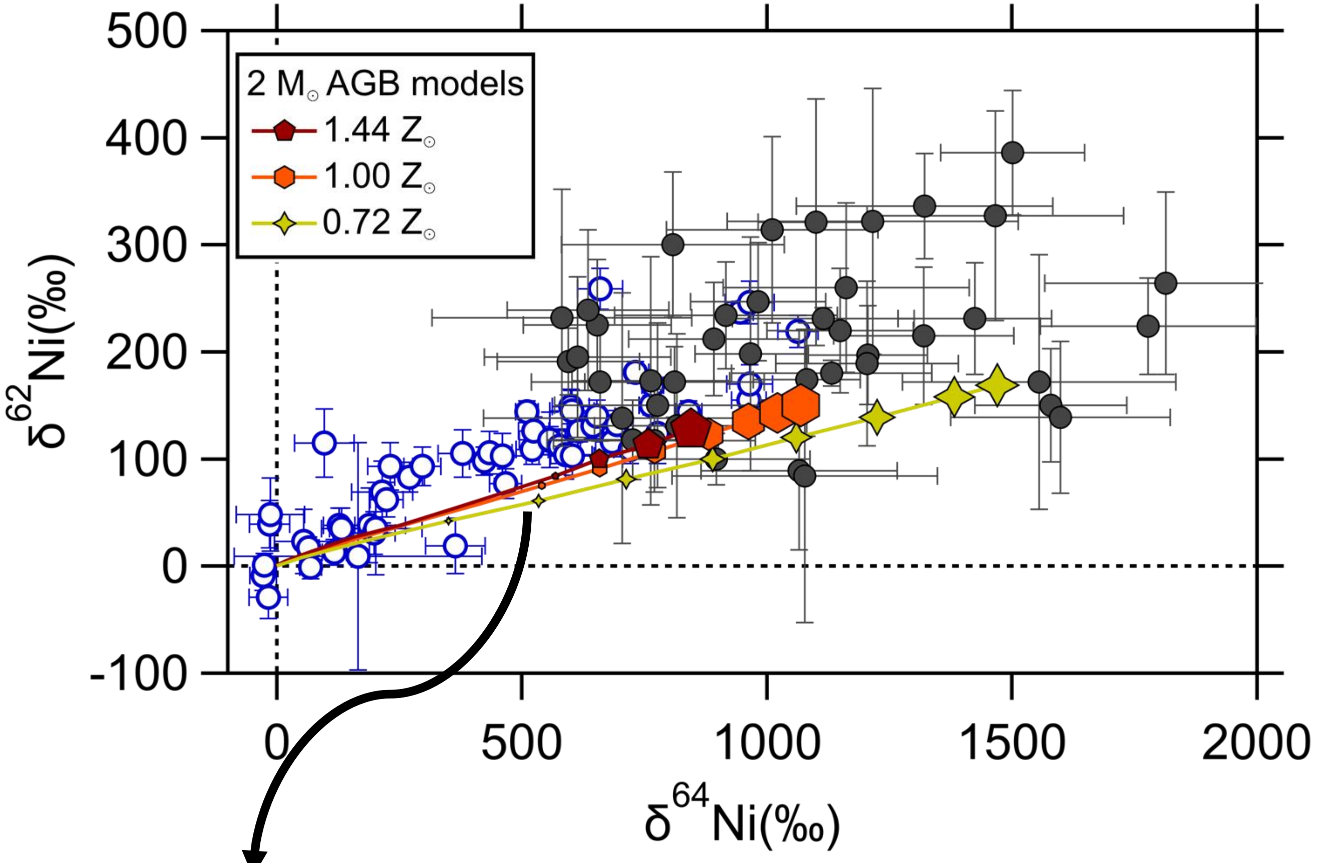
New MS Grain Data Agree Better with AGB Models



Literature data are from Trappitsch et al. (2018)

- RIMS analysis enables efficient ionization of Ni isotopes, leading to small statistical errors
- NanoSIMS analysis allows for high-resolution imaging, suppressing Ni contamination

New MS Grain Data Agree Better with AGB Models



THE ASTROPHYSICAL JOURNAL LETTERS, 897:L25 (8pp), 2020 July 10 https://doi.org/10.3847/2041-8213/ab9fa1

CrossMark

Magnetic-buoyancy-induced Mixing in AGB Stars: Presolar SiC Grains

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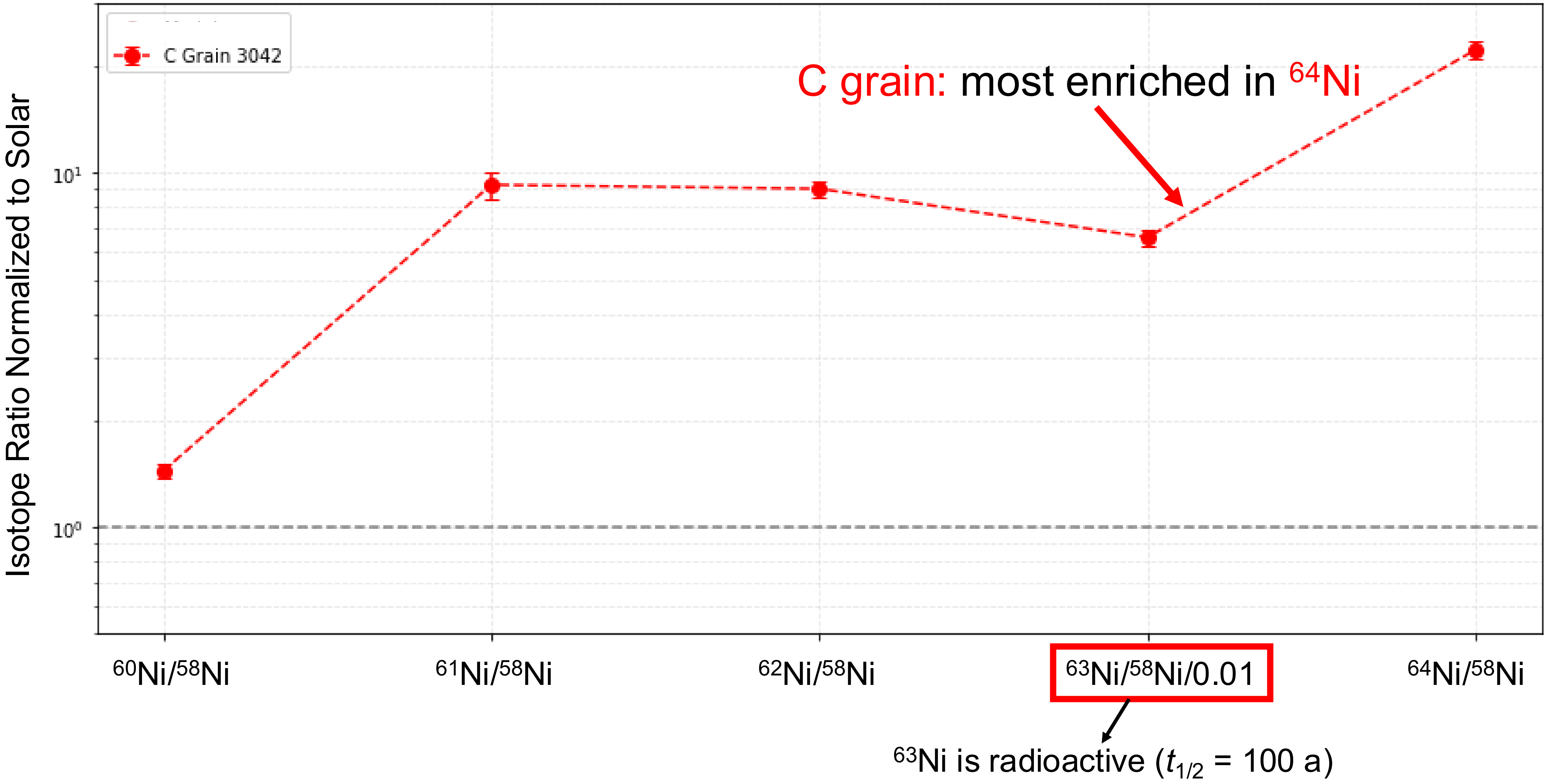
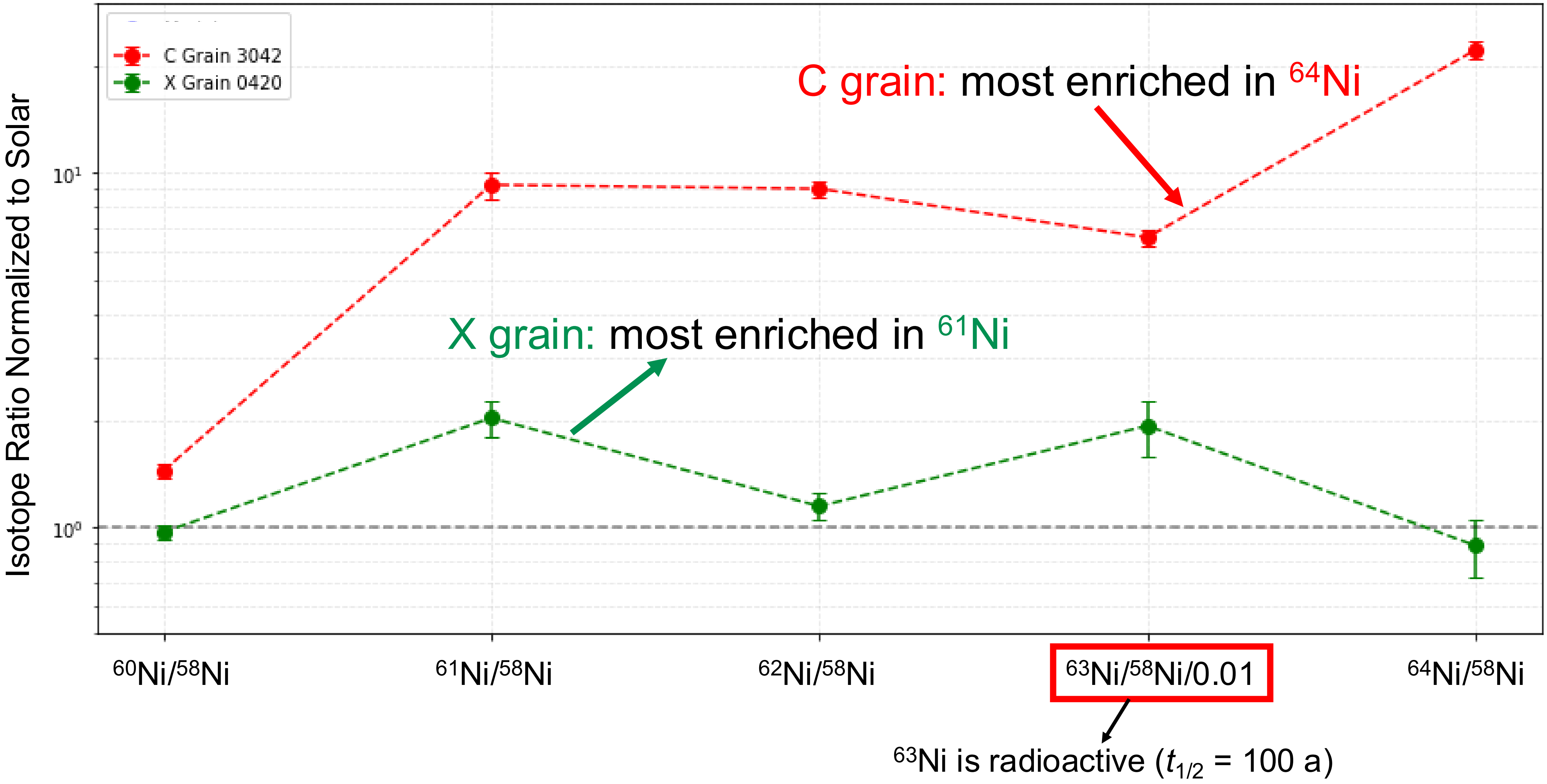
Received 2020 May 25; revised 2020 June 18; accepted 2020 June 24; published 2020 July 9

- RIMS analysis enables efficient ionization of Ni isotopes, leading to small statistical errors
- NanoSIMS analysis allows for high-resolution imaging, suppressing Ni contamination
- Our new NanoSIMS data agree better with the AGB model calculations that were calibrated against the heavy-element isotope data of MS grains

Ni Isotope Data Point to Varying Exposures



Ni Isotope Data Point to Varying Exposures



Analytical and Modeling Progress

1. **New Nickel Isotope Data**
   - Analytical Methods
   - Different Signatures

2. **Python Code for Data Comparison**
   - Neutron burst: neutron exposure (τ), (n,γ) cross section (Walls et al. 2025) *available at https://github.com/lucaswalls18/neutron_burst*
   - Mixing calculations

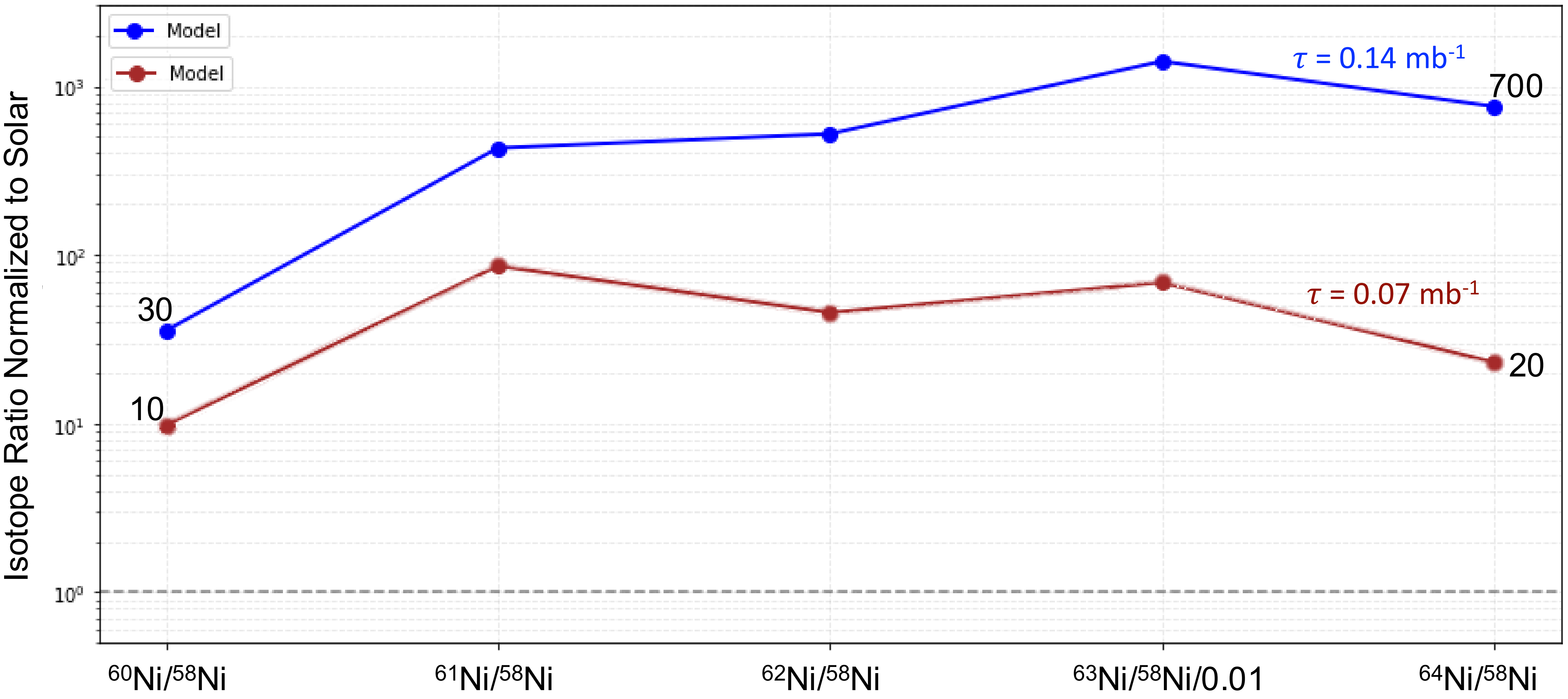
$X \times$ Neutron burst + $Y \times$ solar + $(1-X-Y) \times \alpha$ material

calculated in step 1

shells above He/C (mainly envelope)

Fe/Ni and/or Si/S

Nikel Isotopic Pattern Constrains Neutron Exposure



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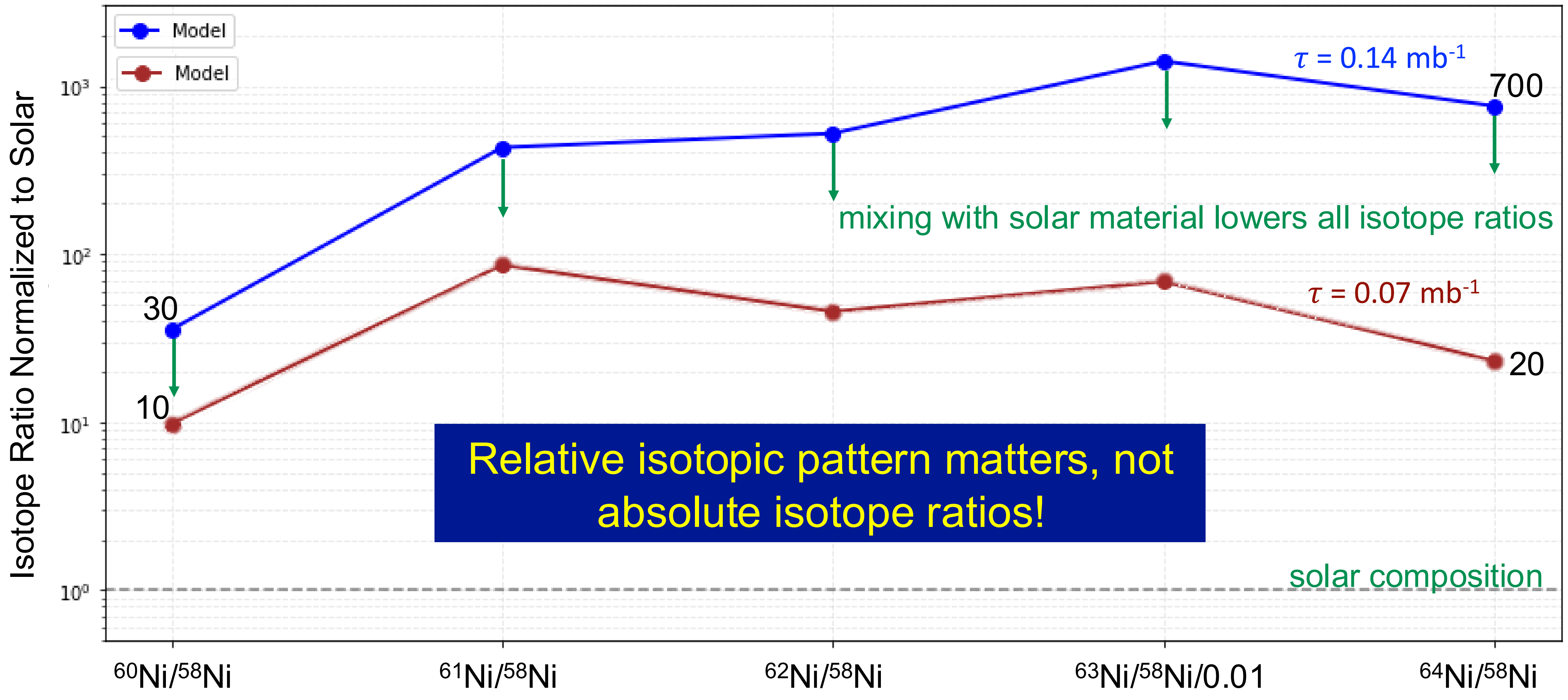
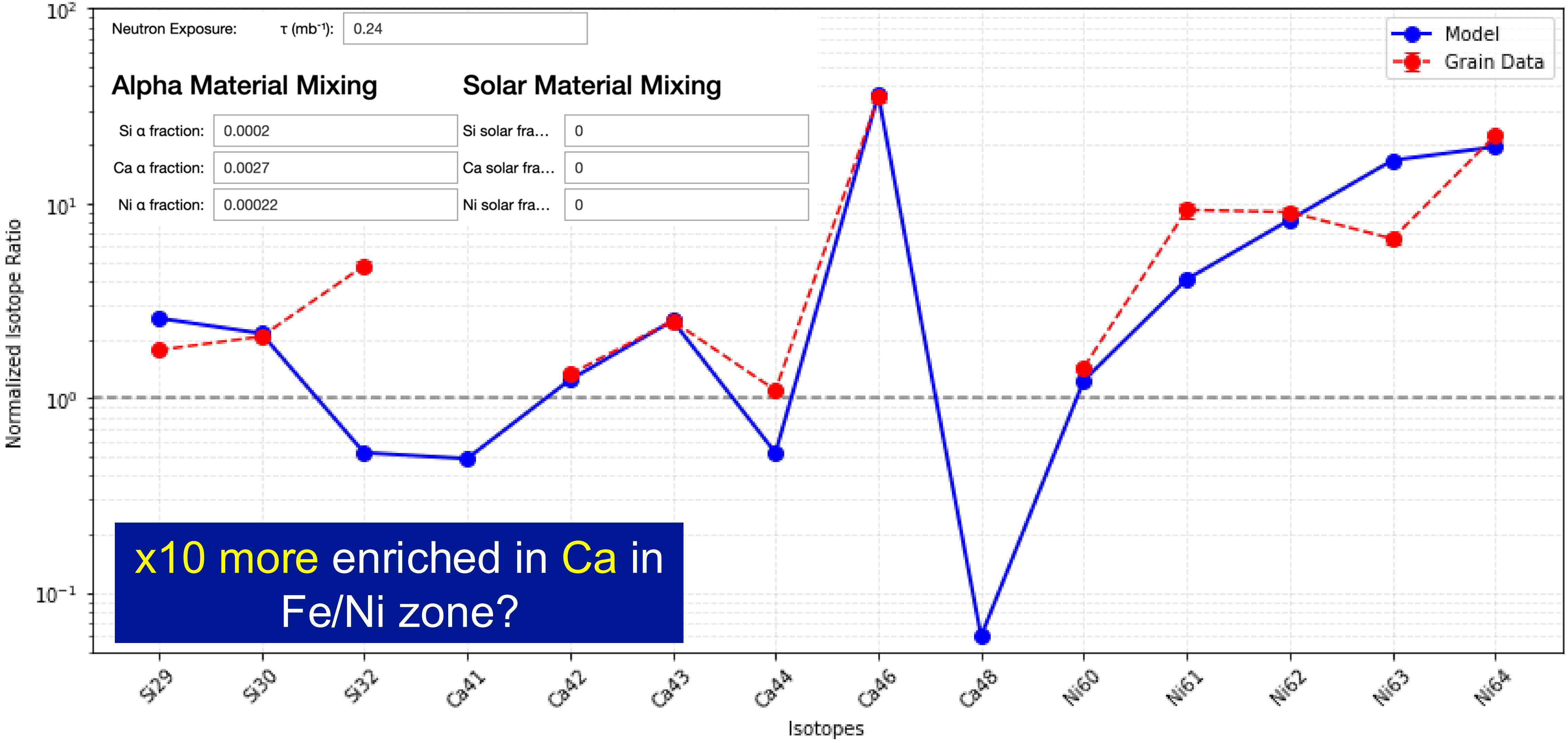


C Grain: Mix of Neutron-burst and Fe/Ni Material

Alpha material: Fe/Ni zonal composition in the 25 $M_\odot$ model of Rauscher et al. (2002)



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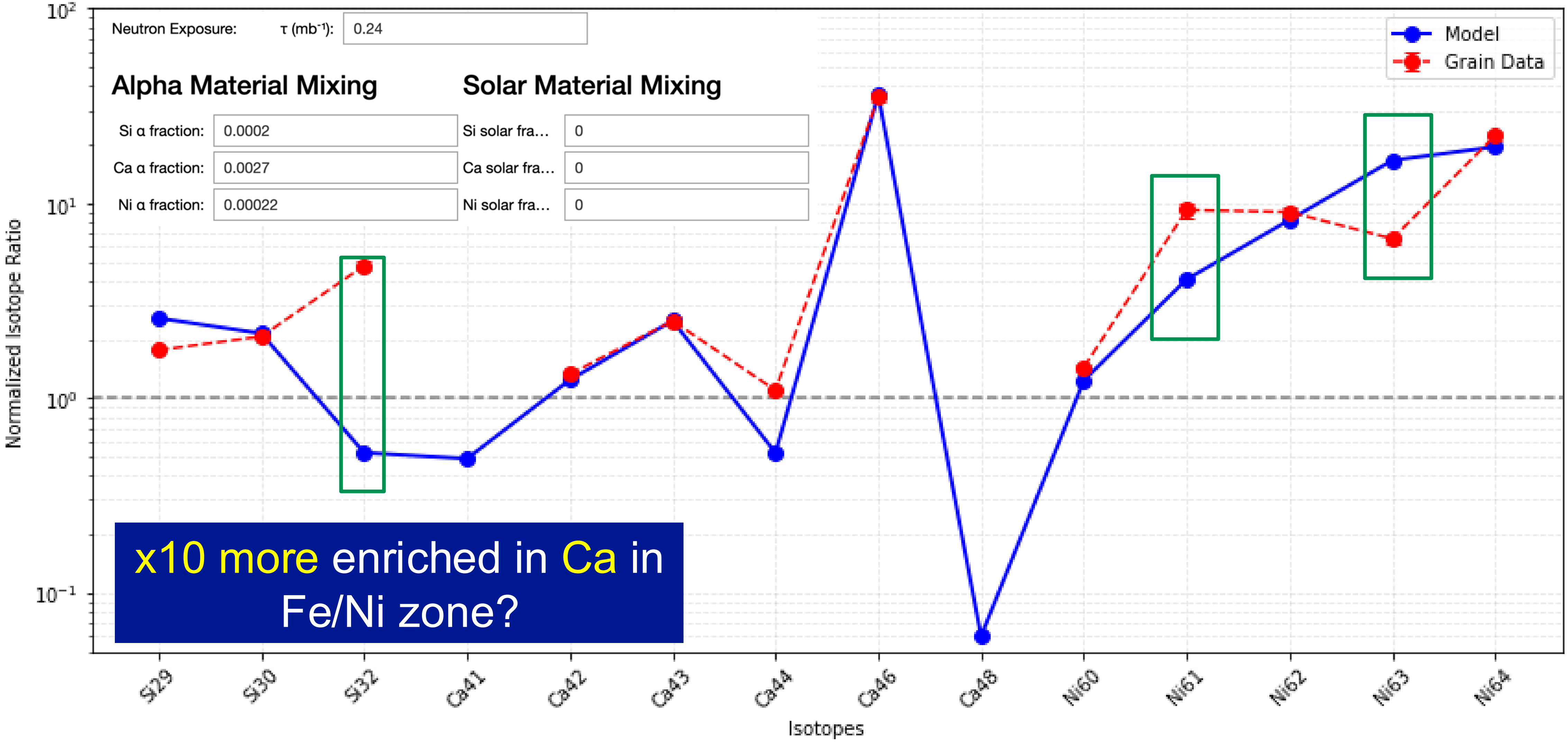
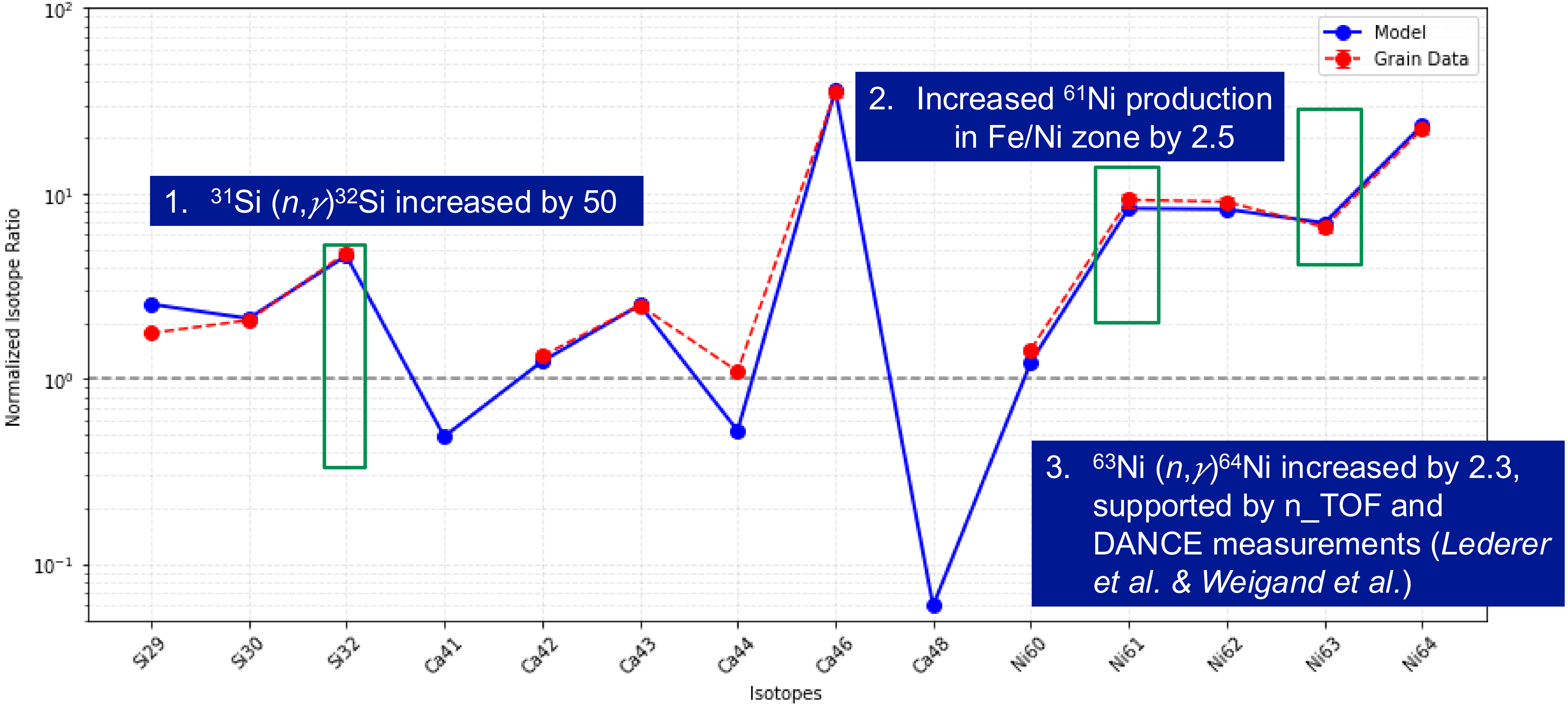
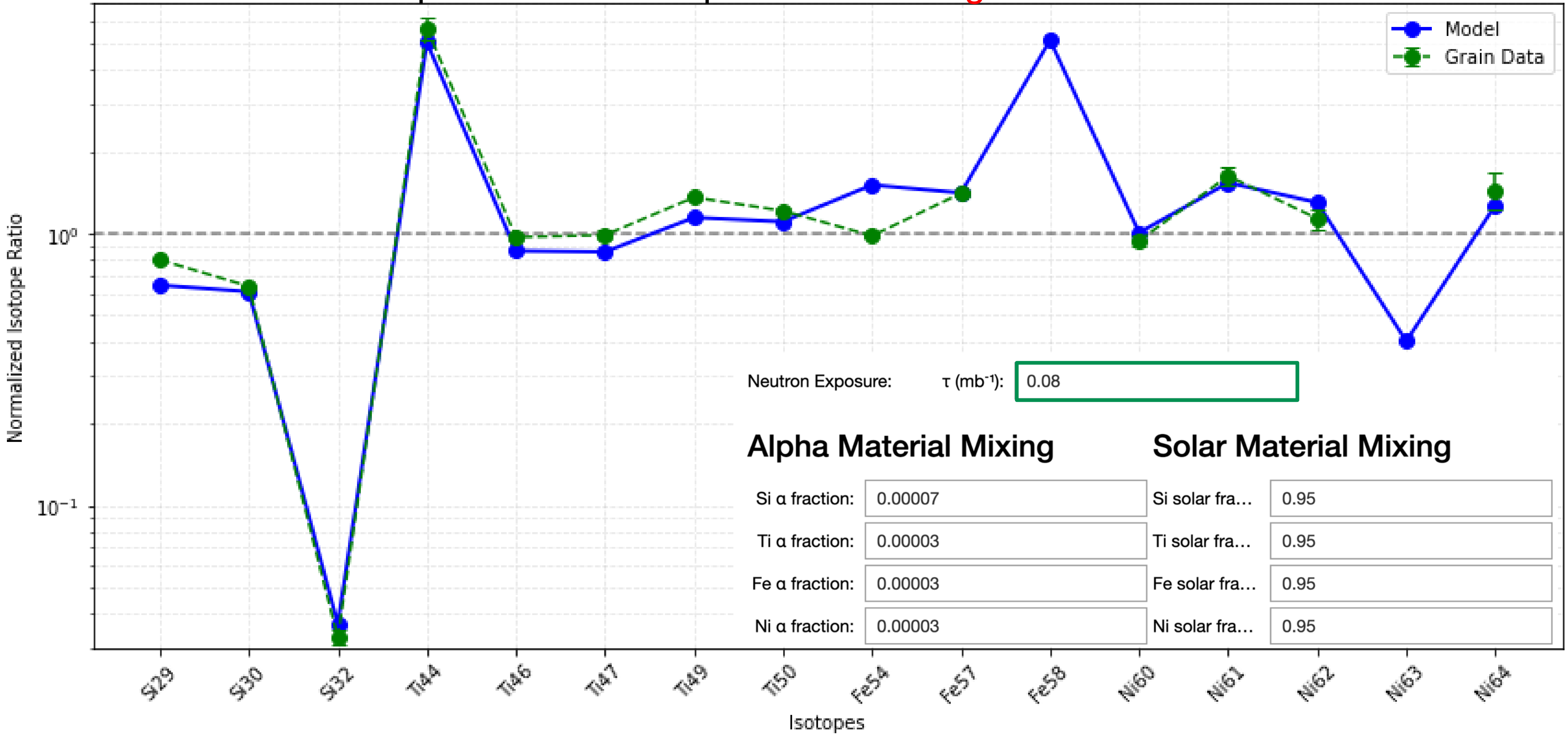


C Grain: Mix of Neutron-burst and Fe/Ni Material



X Grains: Mix of Burst, Si/S, and Solar Material

Alpha material: Inner Si/S zonal composition in the 25 $M_\odot$ model of Rauscher et al. (2002)
Reaction rates: Adopted those that reproduced the C grain data



Constraints on Model Fit Parameters

Type	Tau (mb^{-1})	Burst		Fe/Ni or Si/S		Solar	
		Si (%)	Ni(%)	Si(%)	Ni(%)	Si(%)	Ni(%)
C	0.24	50	29	50	71	0	0
X	0.08	3	24	40	22	57	54
	0.07	5	20	49	59	46	21
	0.07	7	57	61	17	32	27
	0.06	2	24	44	7	54	69
	0.04	8	67	61	2	32	31
	0.04	11	34	44	50	45	16
	0.04	5	31	44	37	51	33
	0.04	4	24	22	22	74	54
	0.03	4	12	57	13	38	45

Constraints on Model Fit Parameters

Type	Tau (mb^{-1})	Burst		Fe/Ni or Si/S		Solar	
		Si (%)	Ni(%)	Si(%)	Ni(%)	Si(%)	Ni(%)
C	0.24	50	29	50	71	0	0
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	0.04	8	67	61	2	32	31
	0.04	11	34	44	50	45	16
	0.04	5	31	44	37	51	33
	0.04	4	24	22	22	74	54
	0.03	4	12	57	13	38	45

C

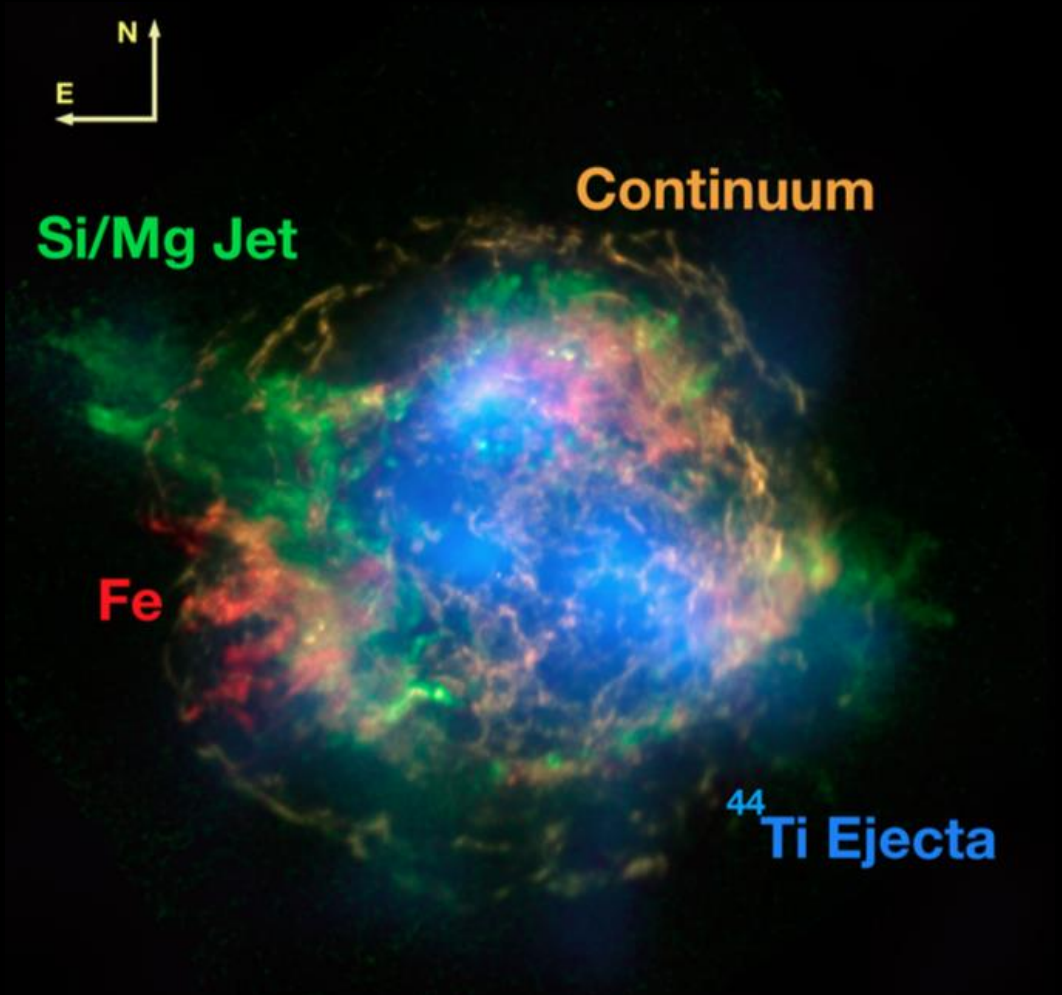
- Strongest neutron exposure
- Incorporated Fe/Ni material
- Incorporated no envelope material

X

- Much lowered neutron exposures
- Incorporated inner Si/S material
- Incorporated significant envelope material

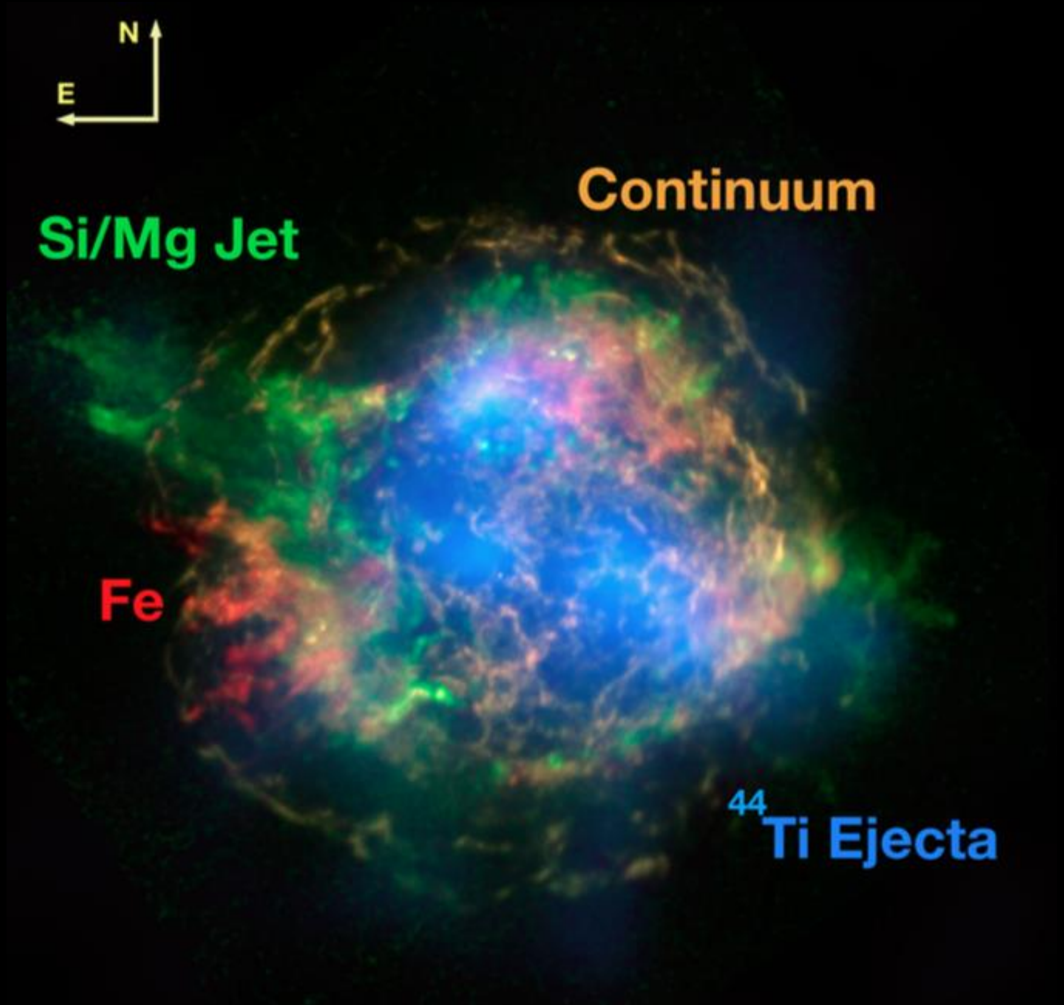
What physical processes led to the different mixing scenarios for C versus X grains?

What are the Underlying Physical Mechanisms?



Grefenstette et al. (2016) *ApJ*

What are the Underlying Physical Mechanisms?



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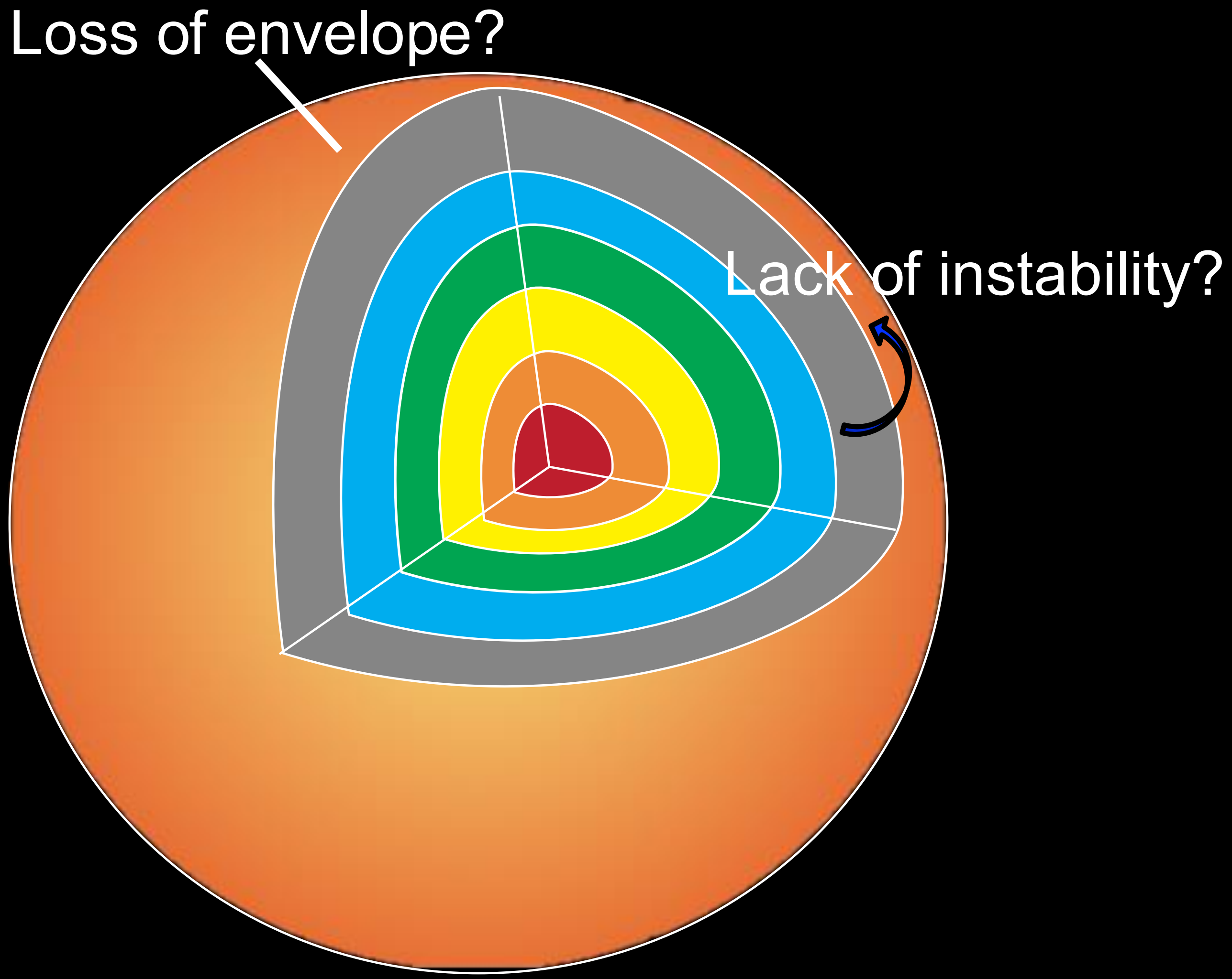

Conclusions

- The C grain data are in favor of the increased $^{63}Ni(n,\gamma)^{64}Ni$ reaction rate suggested by n_TOF and DANCE measurements and suggest at least a factor of 50 increase in the $^{31}Si(n,\gamma)^{32}Si$ reaction rate
- The C grain data suggest that Fe/Ni zone was more enriched in ^{40}Ca and ^{61}Ni than predicted in Rauscher et al. models
- The C grain incorporated materials from Fe/Ni zone and recorded the strongest neutron-burst signatures, pointing to the highest neutron exposure
- X grains sampled materials from He/C (and shells above) zones with substantial contributions from Si/S zone