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Unveiling the Stellar Origins of Types Y and Z Silicon Carbide Grains: New Isotope Insights

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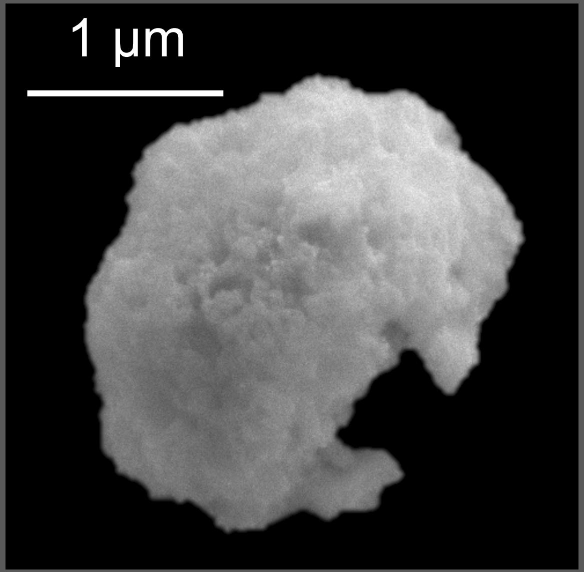
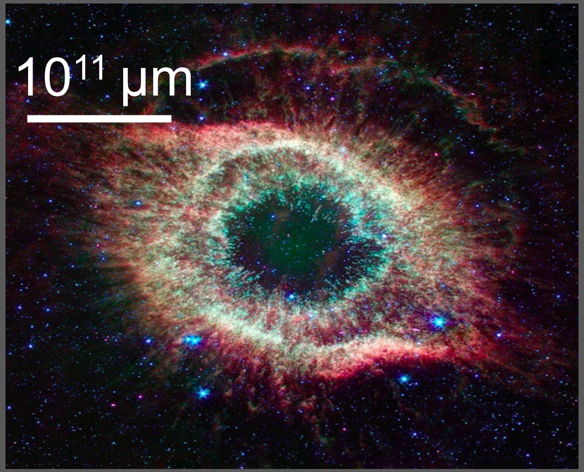
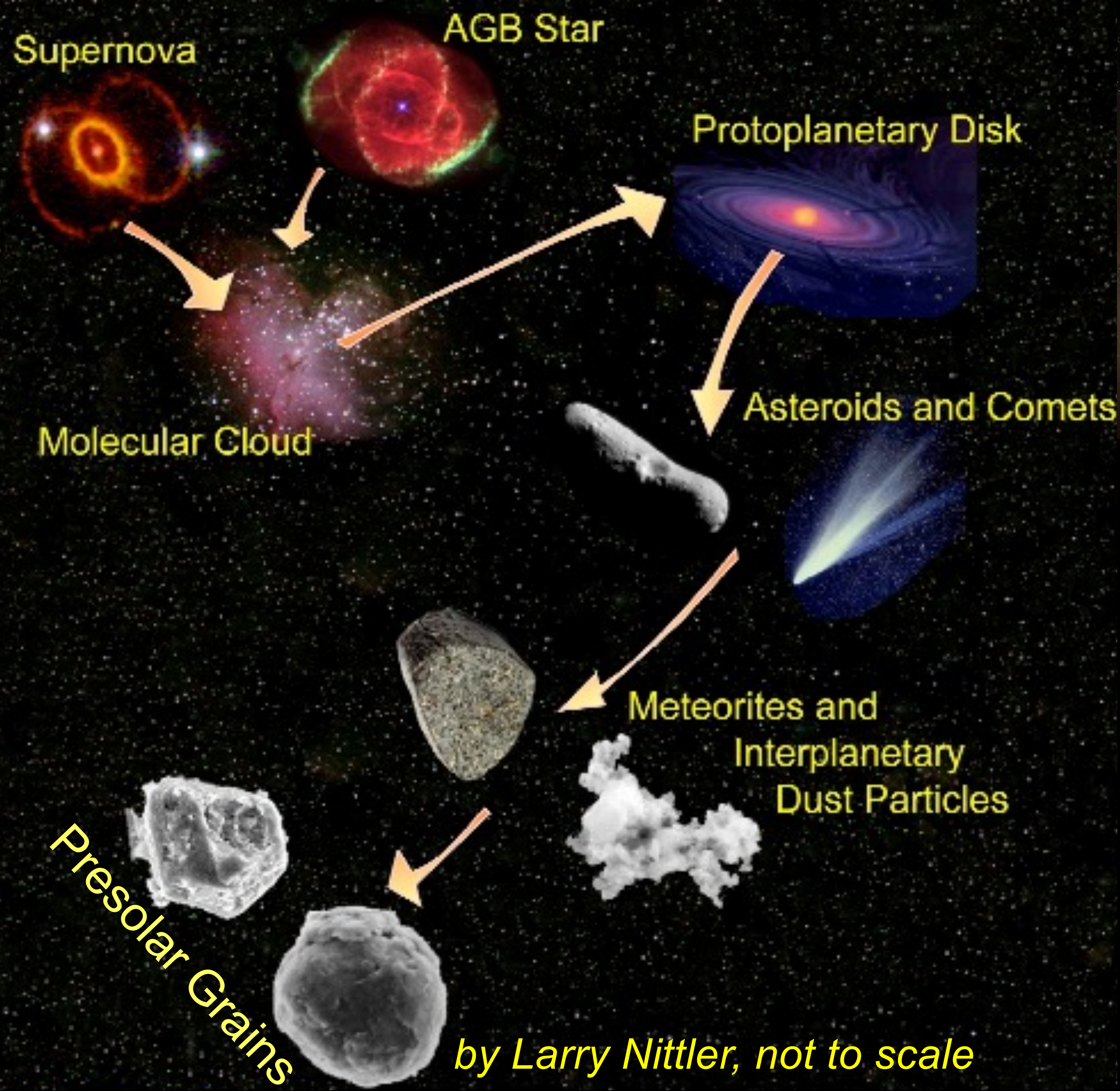
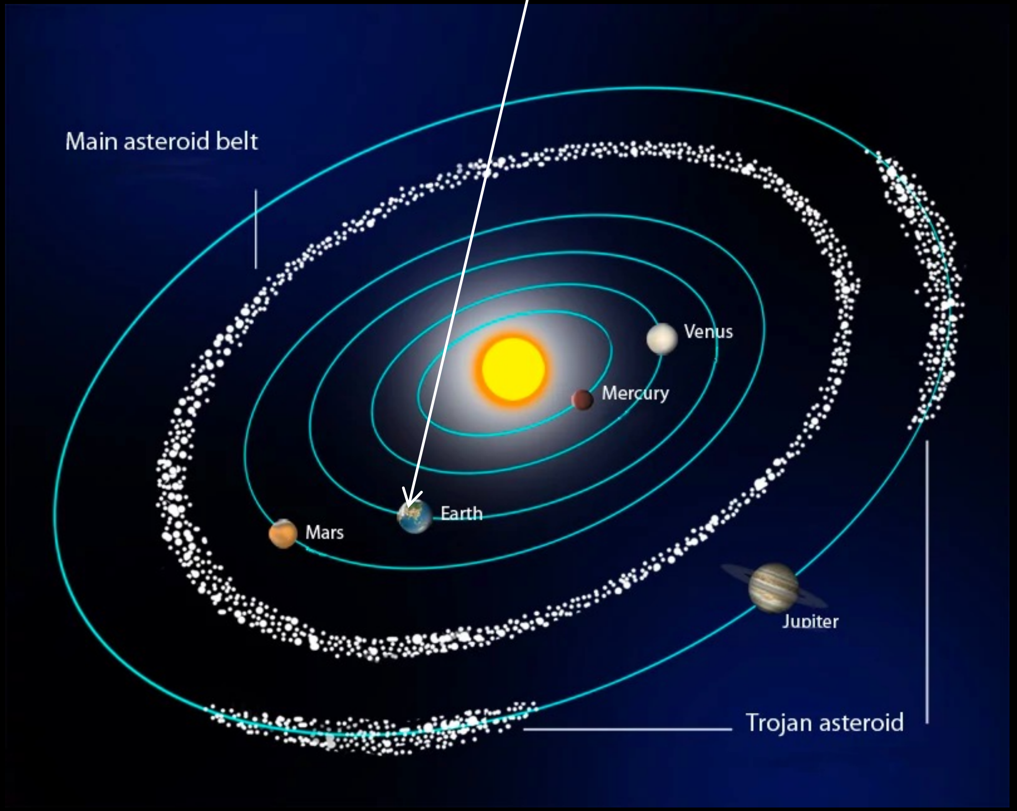
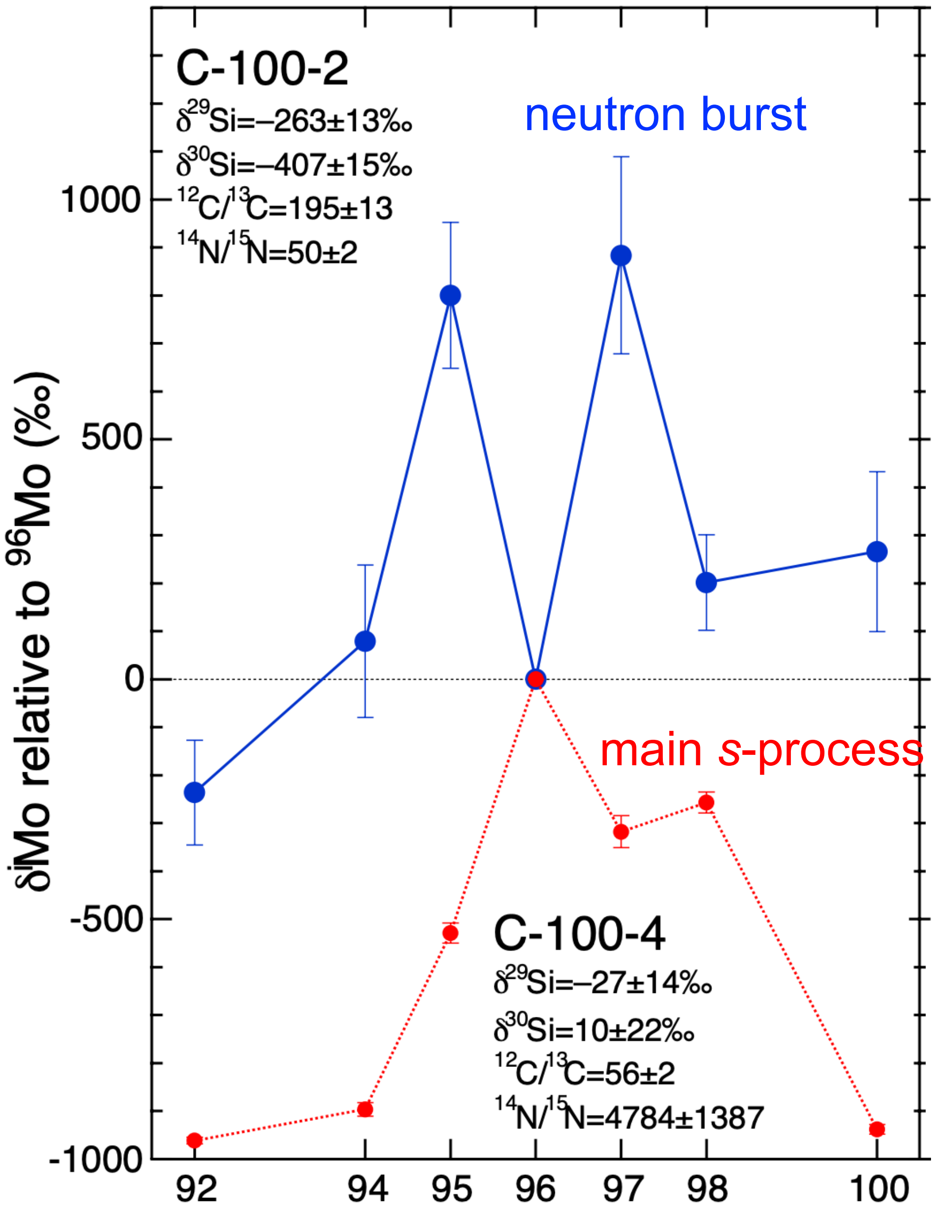





Supernova
AGB Star
Protoplanetary Disk
Molecular Cloud
Asteroids and Comets
Meteorites and
Interplanetary
Dust Particles
Presolar Grains
by Larry Nittler, not to scale


Main asteroid belt
Venus
Mercury
Earth
Mars
Jupiter
Trojan asteroid

Heavy-element Isotopic Compositions

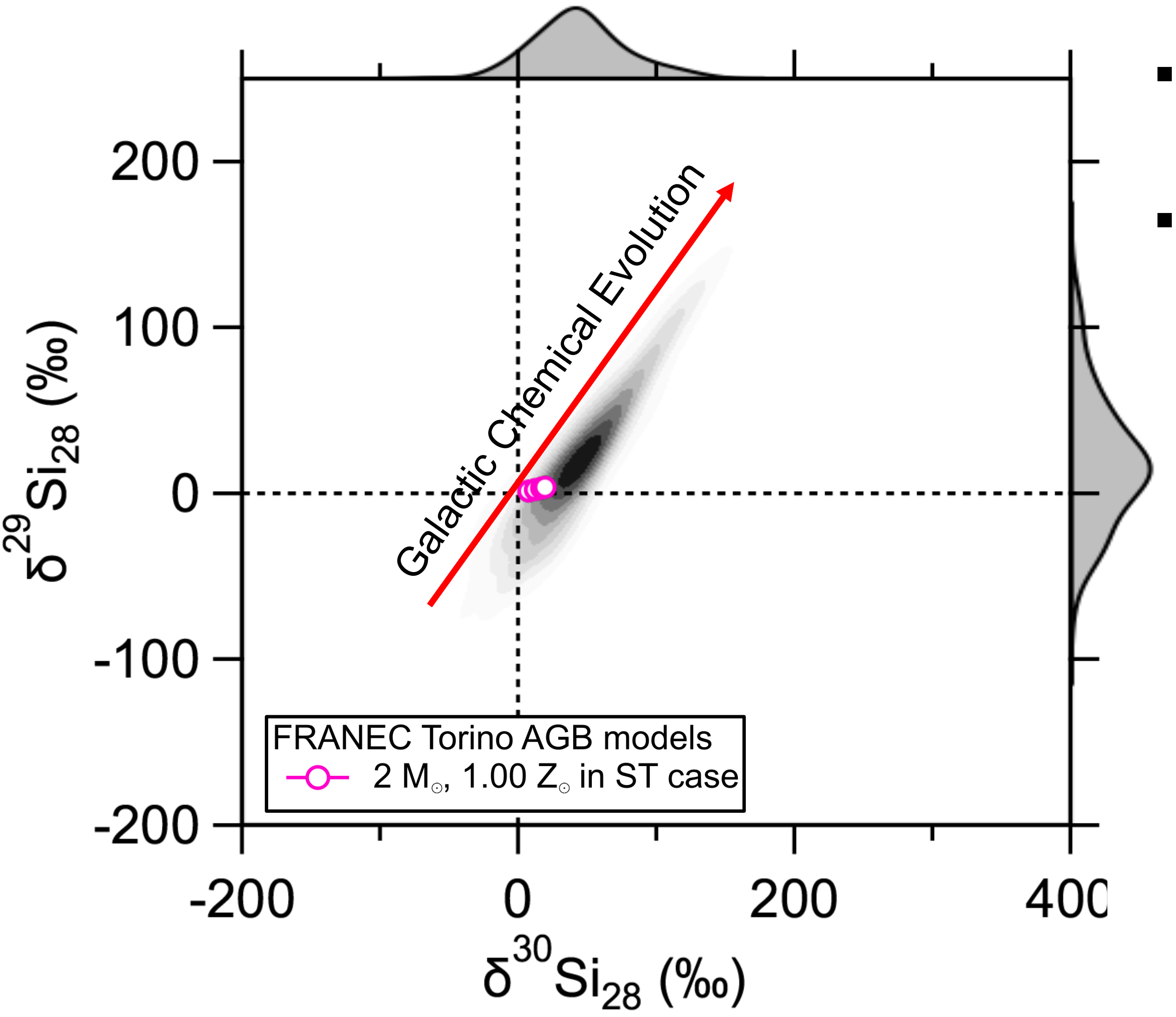


Pellin et al. (1999)

Neutron Bursts

- $\delta^{i}\mathrm{Mo} = \left[\frac{\left(\frac{^{i}Mo}{^{96}Mo}\right)_{grain}}{\left(\frac{^{i}Mo}{^{96}Mo}\right)_{sun}} - 1\right] \times 1000$
- powered by ^{22}Ne(α,n)^{25}Mg
- neutron density of 10^{17} n/cm^3 at T ~ 10^9 K (Meyer et al. 2000)
- could occur in He/C zone during explosion (e.g., Liu et al. 2018)

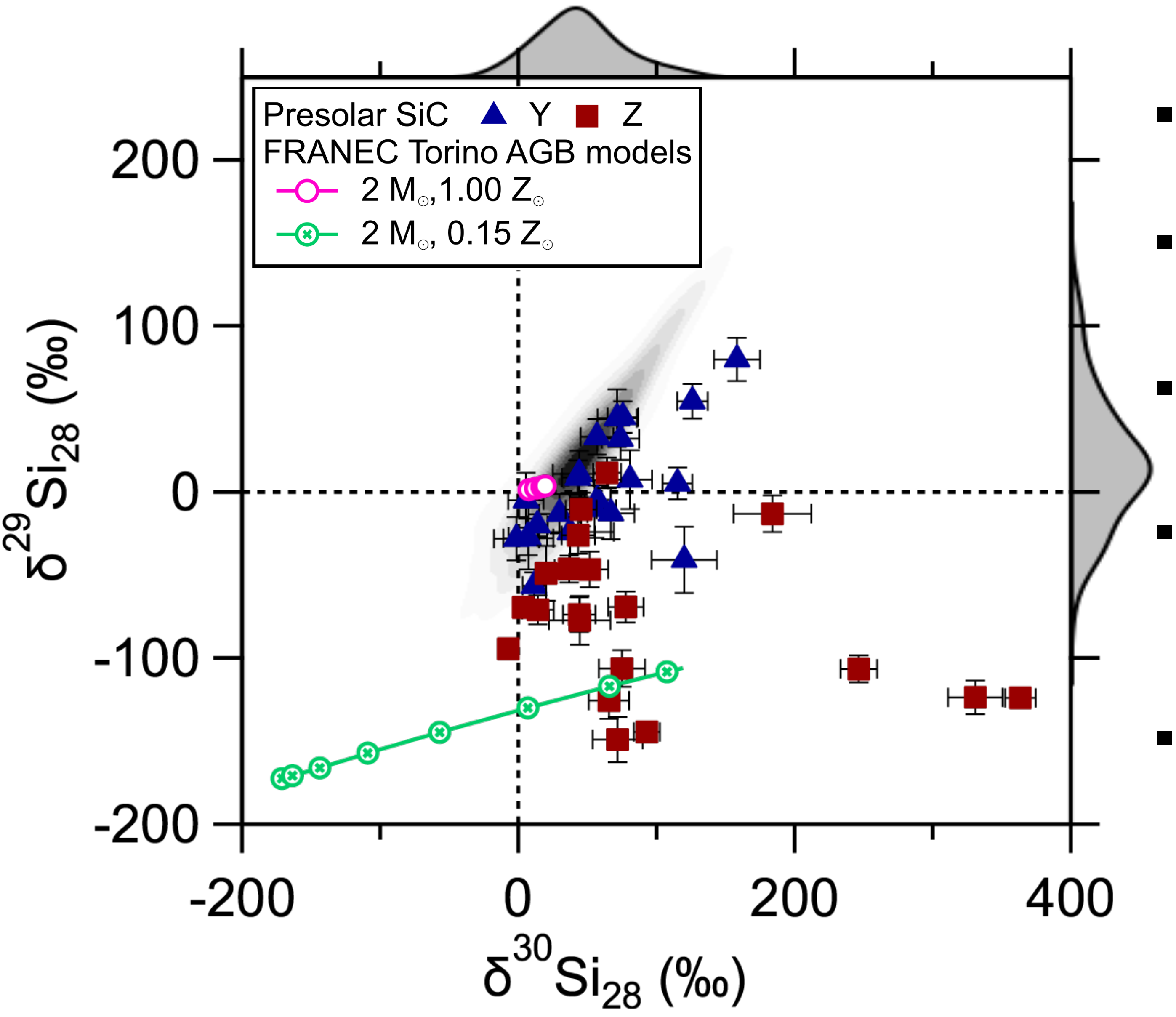
Mainstream Grains – Major AGB Silicon Carbide Dust



- **Mainstream (MS) grains**: ~90% of AGB grains, shown in density map
- **Si isotopes of MS grains**: Controlled by GCE effect

MS SiC data from Presolar Grain Database (Stephan et al. 2024, ApJS)

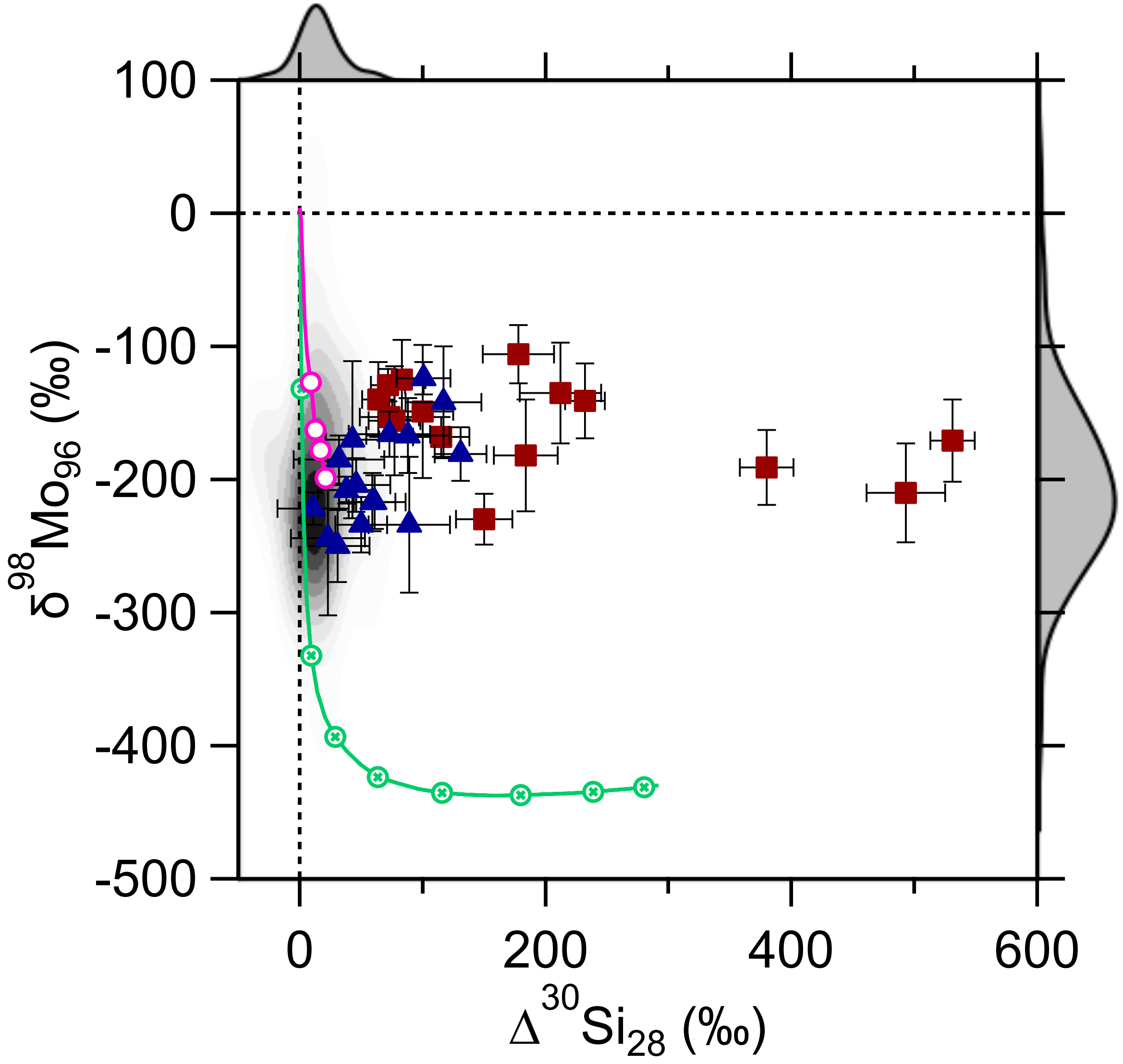
Y and Z Grains Characterized by ^{30}Si Excesses



- $\delta^{29}\mathrm{Si}_{28} = [\frac{\left(\frac{^{29}Si}{^{28}Si}\right)_{grain}}{\left(\frac{^{29}Si}{^{28}Si}\right)_{sun}} - 1] \times 1000$
- **Mainstream (MS) grains**: ~90% of presolar SiC grains, shown in density map
- **Si isotopes of MS grains**: Controlled by GCE effect
- **Y and Z grains**: 1–5% of presolar SiC grains; the percentage increases with decreasing grain size
- **Si isotopes of Y and Z grains**: More efficient production of ^{30}Si in lower-metallicity AGB stars

Y and Z SiC data from Liu et al. (2019) ApJ and Liu et al. (2022) EPJA

Heavy-element Isotope Data Challenge Low-Z Origins



Y and Z SiC data from Liu et al. (2019) ApJ

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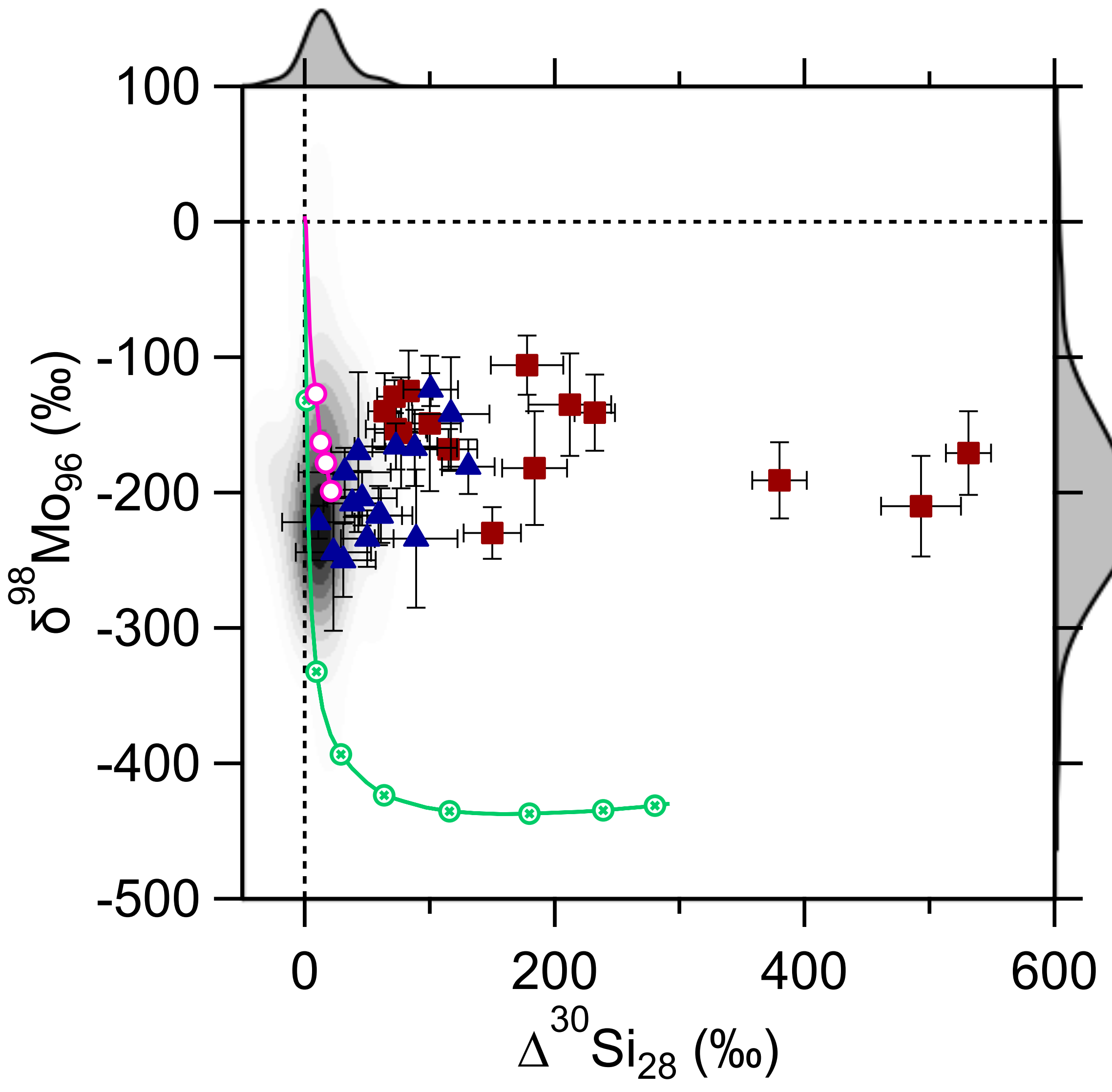
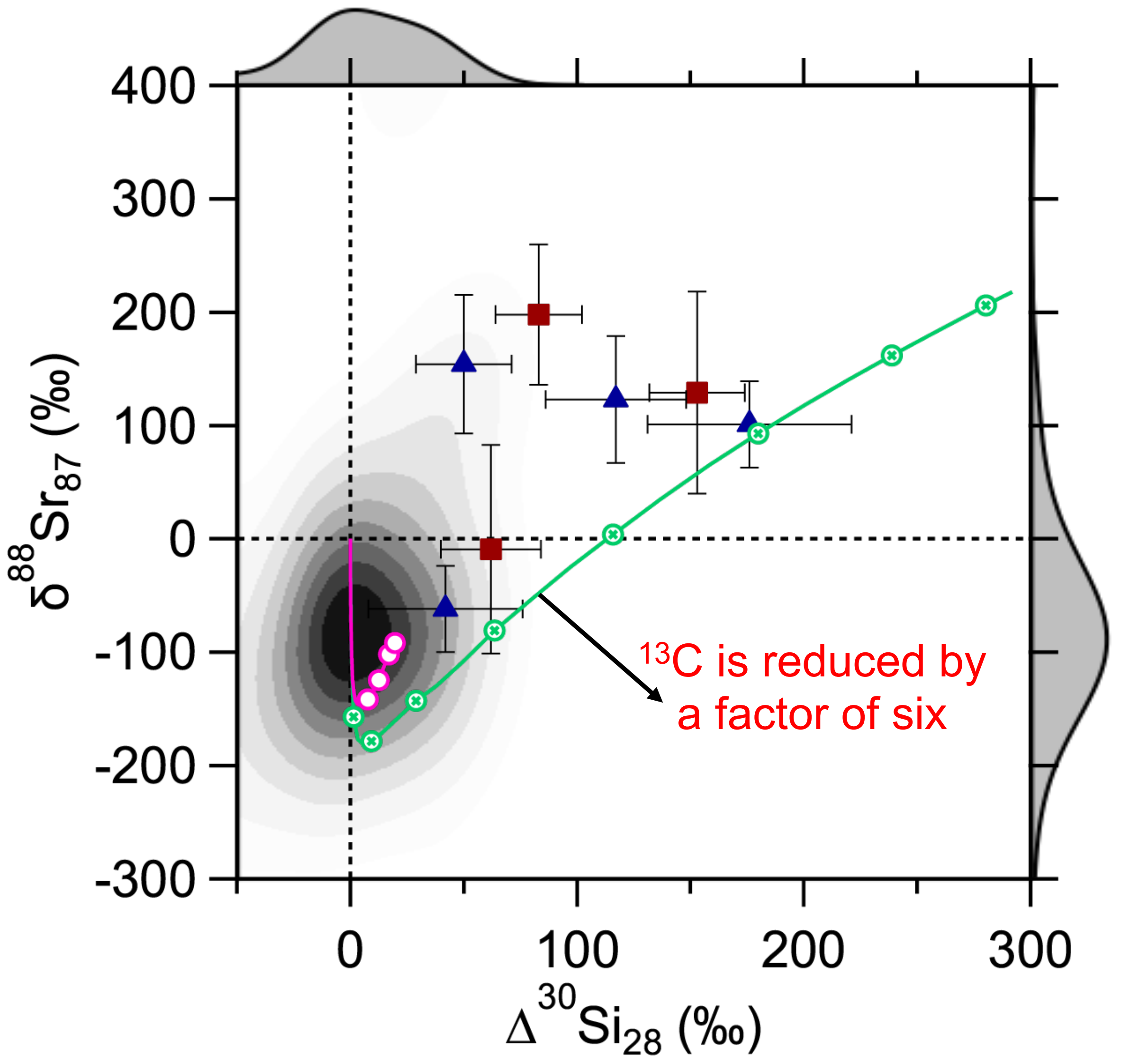
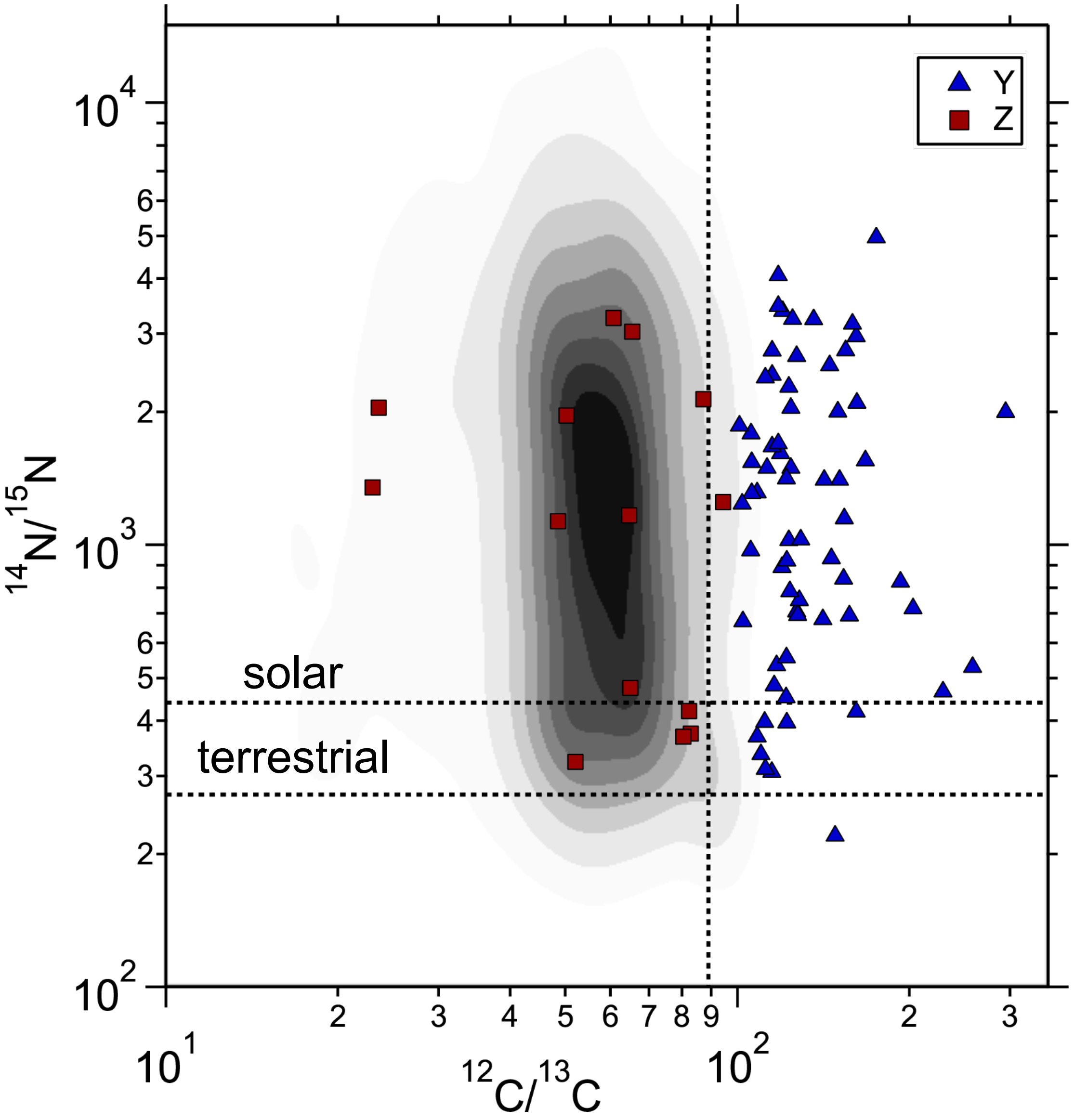


Y and Z SiC data from Liu et al. (2019) ApJ



Y and Z SiC data from Liu et al. (2022) EPJL

Are MS, Y, and Z Grains Different in $^{14}N/^{15}N$ and $^{26}Al/^{27}Al$?



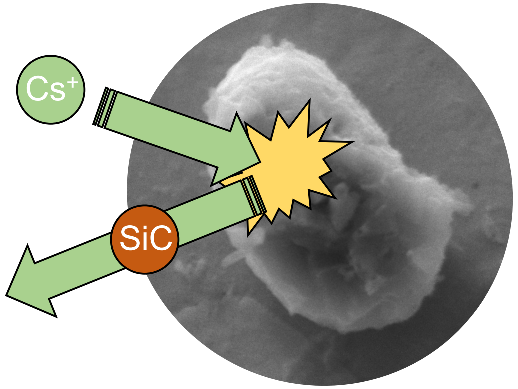
- Y grains are defined to have $^{12}C/^{13}C \geq 100$, and Z grains <100
- Literature data suggest the three types of grains are similar in the N isotopic ratio, and $^{26}Al/^{27}Al$ data for Y and Z grains are sparse

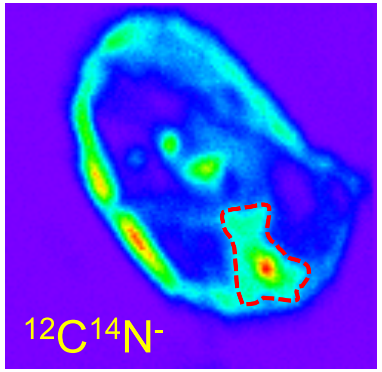
Problems in Literature Data

- Varying degrees of N and Al contamination (*Liu et al. 2021 ApJL*)
- Inaccurate determination of inferred initial $^{26}Al/^{27}Al$ due to uncertain calibration of analytical measurements of SiC grains (*Hoppe et al. 2023 ApJL*)
- Challenges in defining Z grains (*Stephan et al. 2024 ApJS*)

SiC data from Presolar Grain Database (Stephan et al. 2024, ApJS)

New NanoSIMS Investigation of N and Al Isotopes





Addressing Problems in Literature Data

- Suppressing contamination by sufficient presputtering and high-resolution imaging (*Liu et al. 2021 ApJL*)

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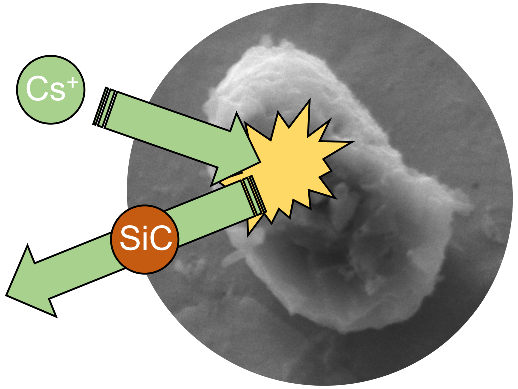
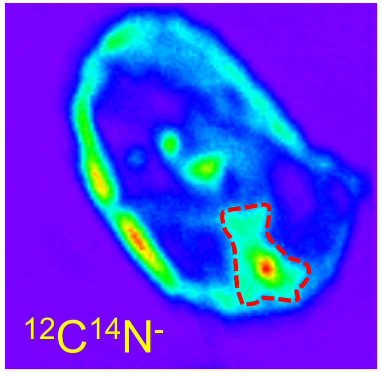
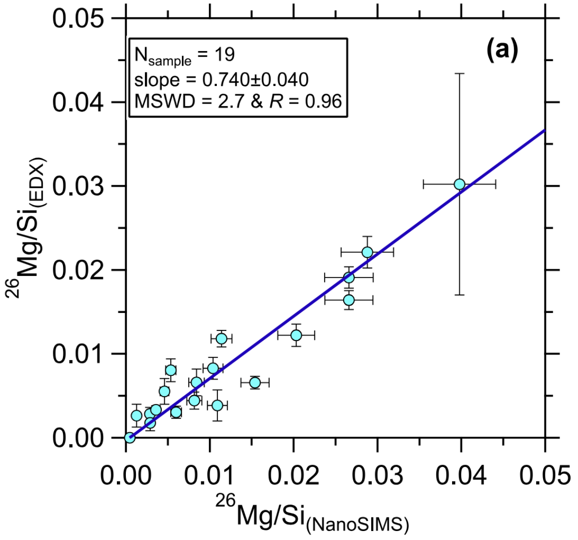
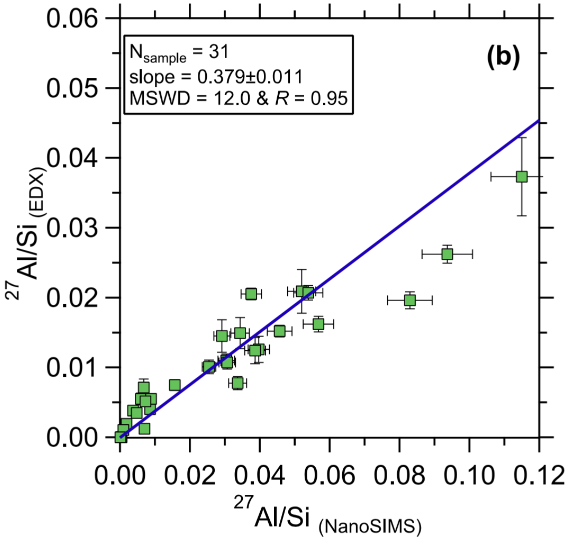




Addressing Problems in Literature Data

- Suppressing contamination by sufficient presputtering and high-resolution imaging (*Liu et al. 2021 ApJL*)
- Better calibration of analytical measurements of SiC grains (*Liu et al. 2024 ApJL*), suggesting a factor of two increase in inferred initial $^{26}Al/^{27}Al$ ratios for SiC grains





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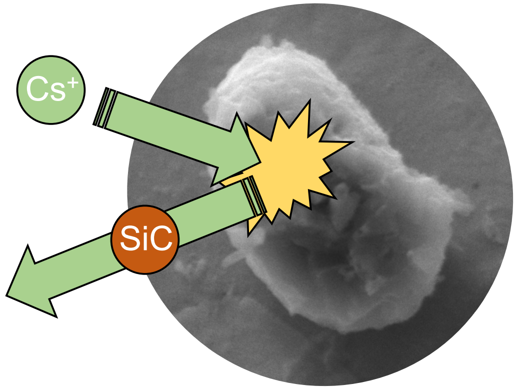
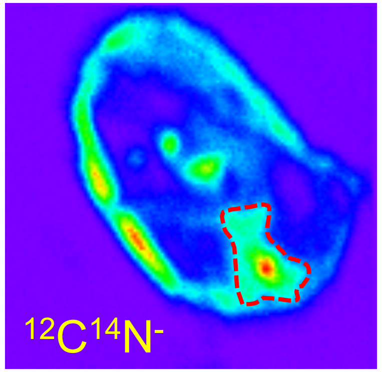
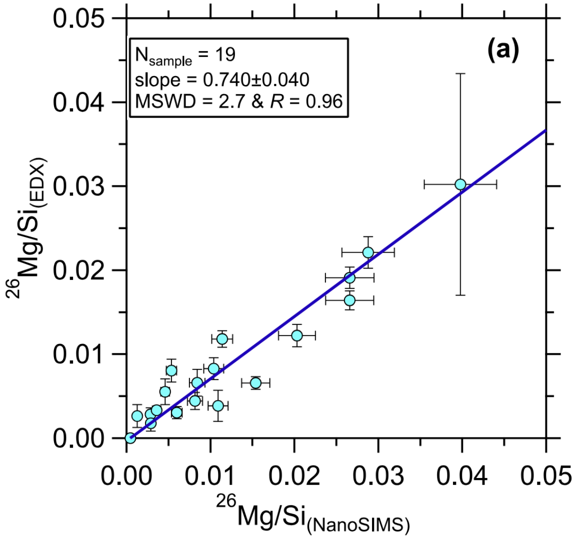
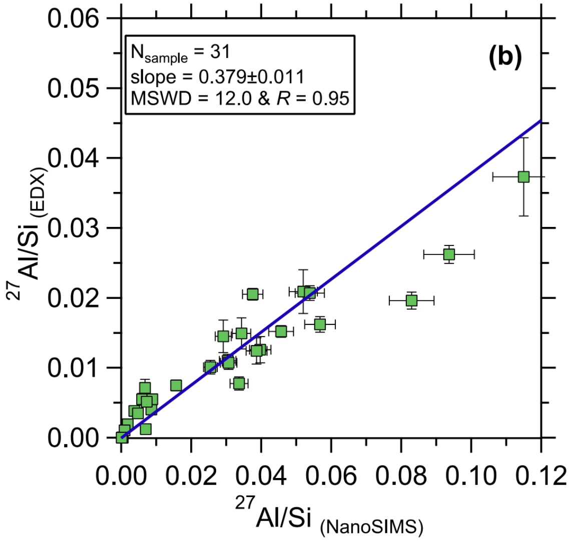








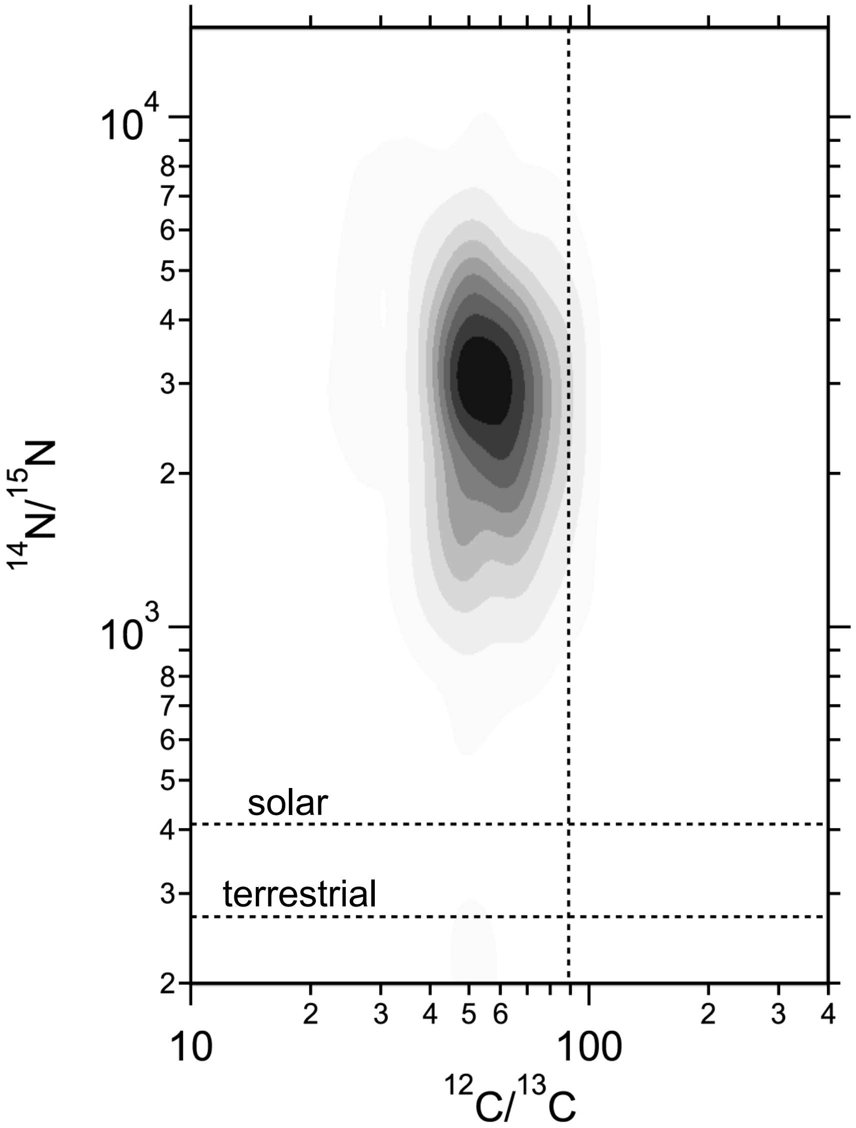
Addressing Problems in Literature Data

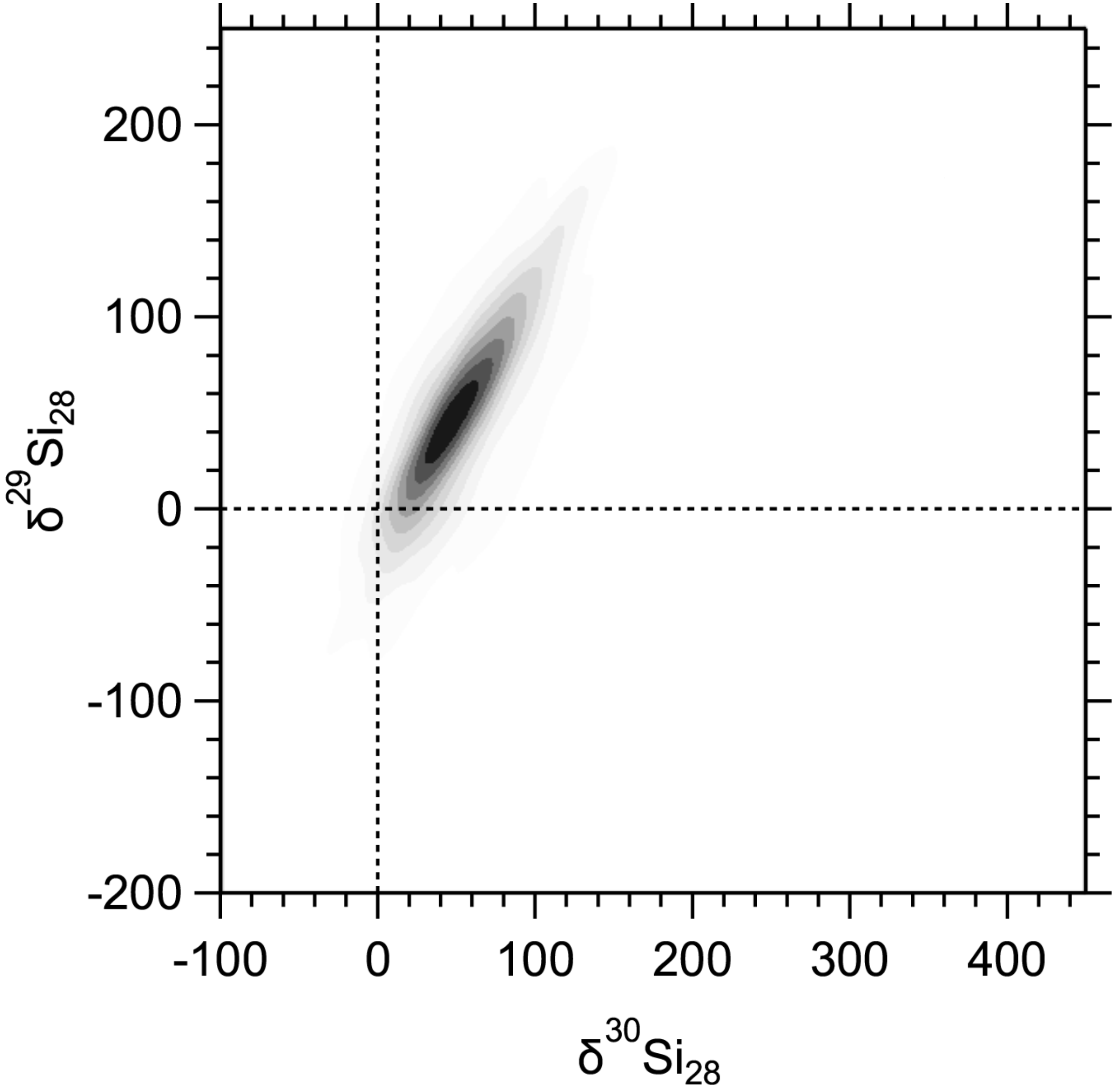
- Suppressing contamination by sufficient presputtering and high-resolution imaging (*Liu et al. 2021 ApJL*)
- Better calibration of analytical measurements of SiC grains (*Liu et al. 2024 ApJL*), suggesting a factor of two increase in inferred initial $^{26}Al/^{27}Al$ ratios for SiC grains
- Si isotopes were measured twice to improve the accuracy so that Z grains can be better recognized

NanoSIMS Analysis Conditions

1. $^{12}C_2^-$, $^{13}C_2^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$, $^{29}Si^-$, $^{30}Si^-$
2. $^{24}Mg^+$, $^{25}Mg^+$, $^{26}Mg^+$,$^{27}Al^+$, $^{28}Si^+$,$^{29}Si^+$,$^{30}Si^+$

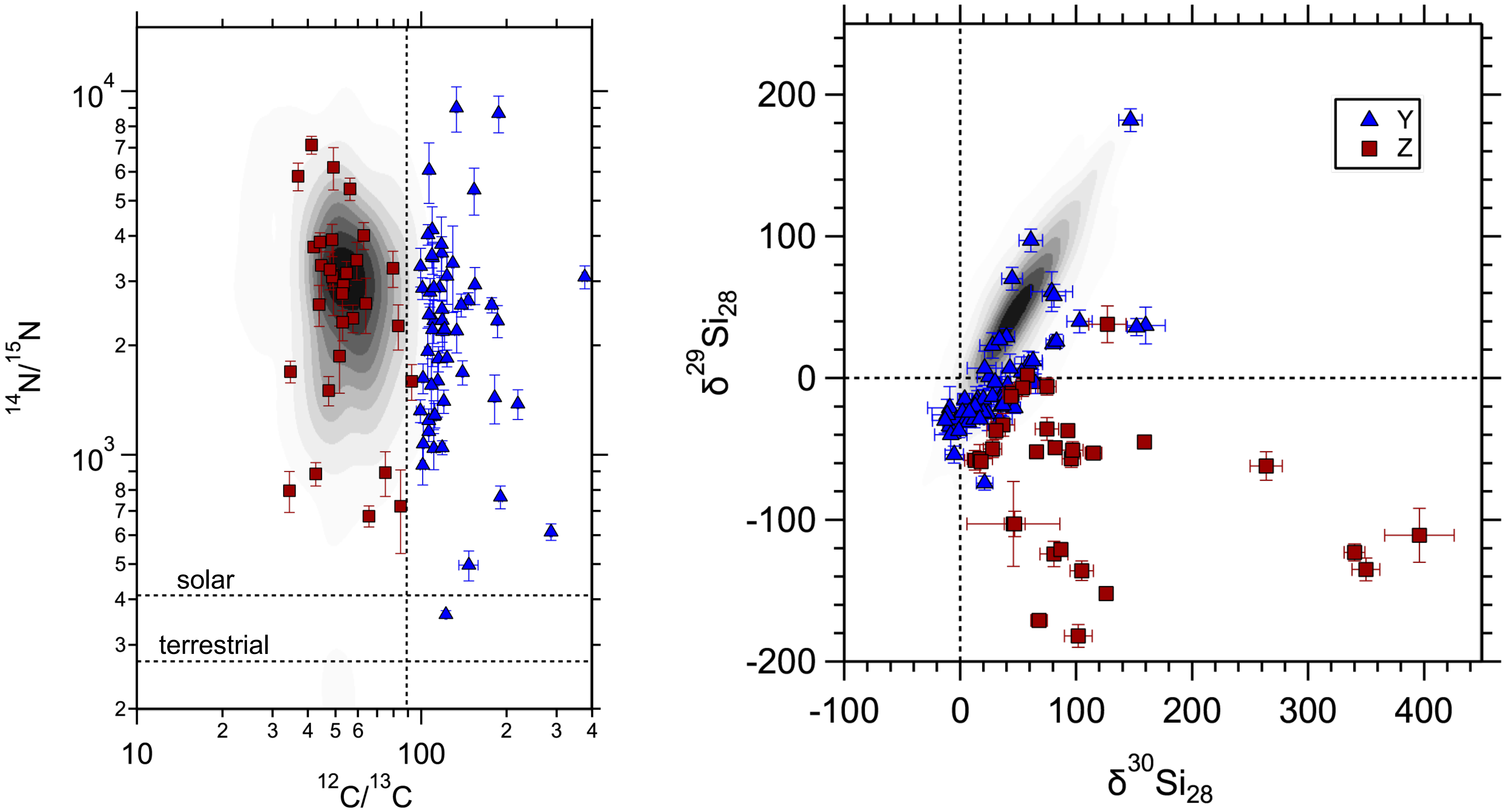
More Restricted N Isotope Distribution of MS Grains





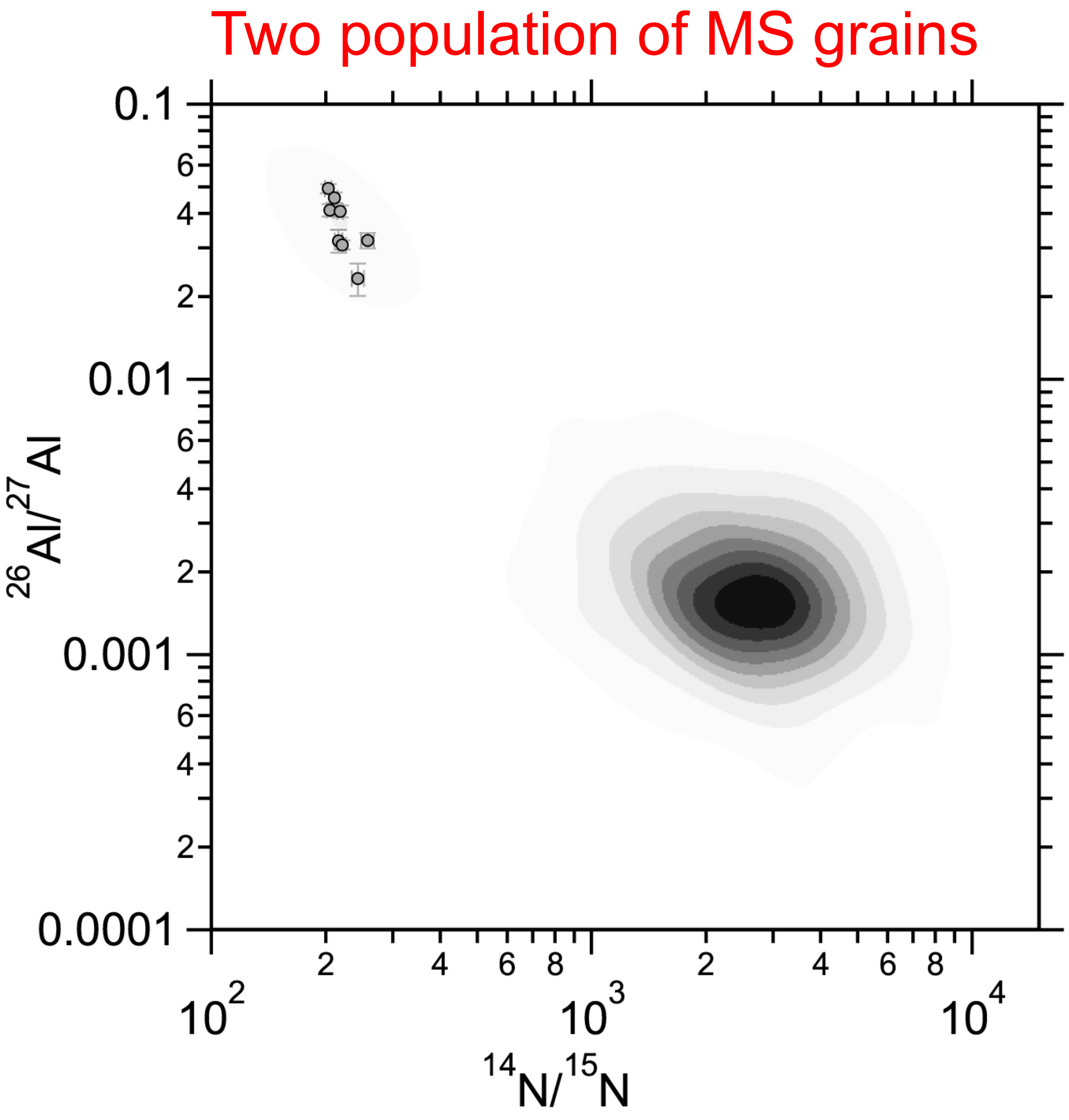
911 new MS grains from this study

No Significant Differences in $^{14}N/^{15}N$



56 new Y and 28 new Z grains from this study

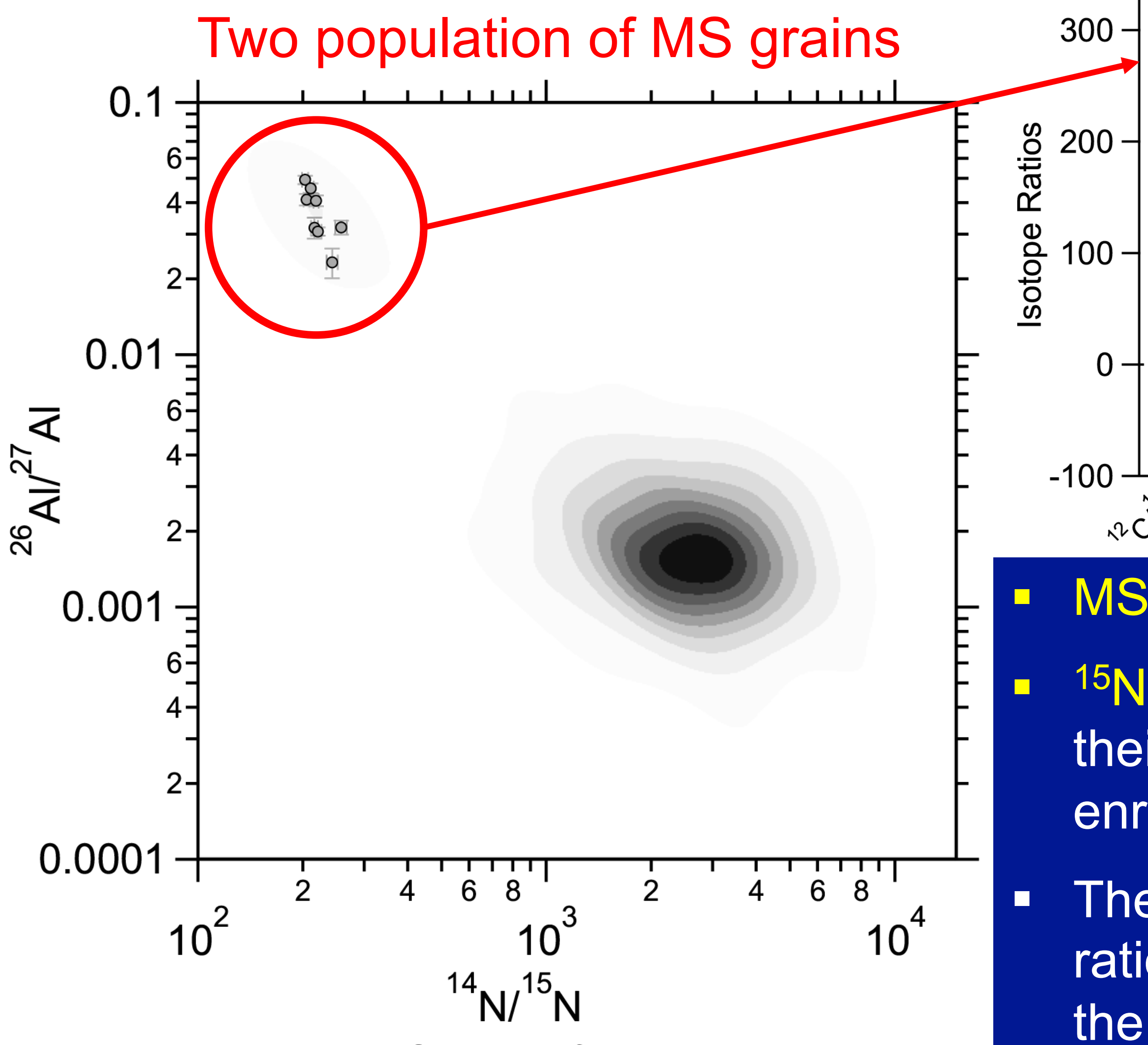
Restricted $^{26}Al/^{27}Al$ Distribution of MS Grains



250 new MS grains from this study

- MS grains form two well-separated populations

Restricted $^{26}Al/^{27}Al$ Distribution of MS Grains



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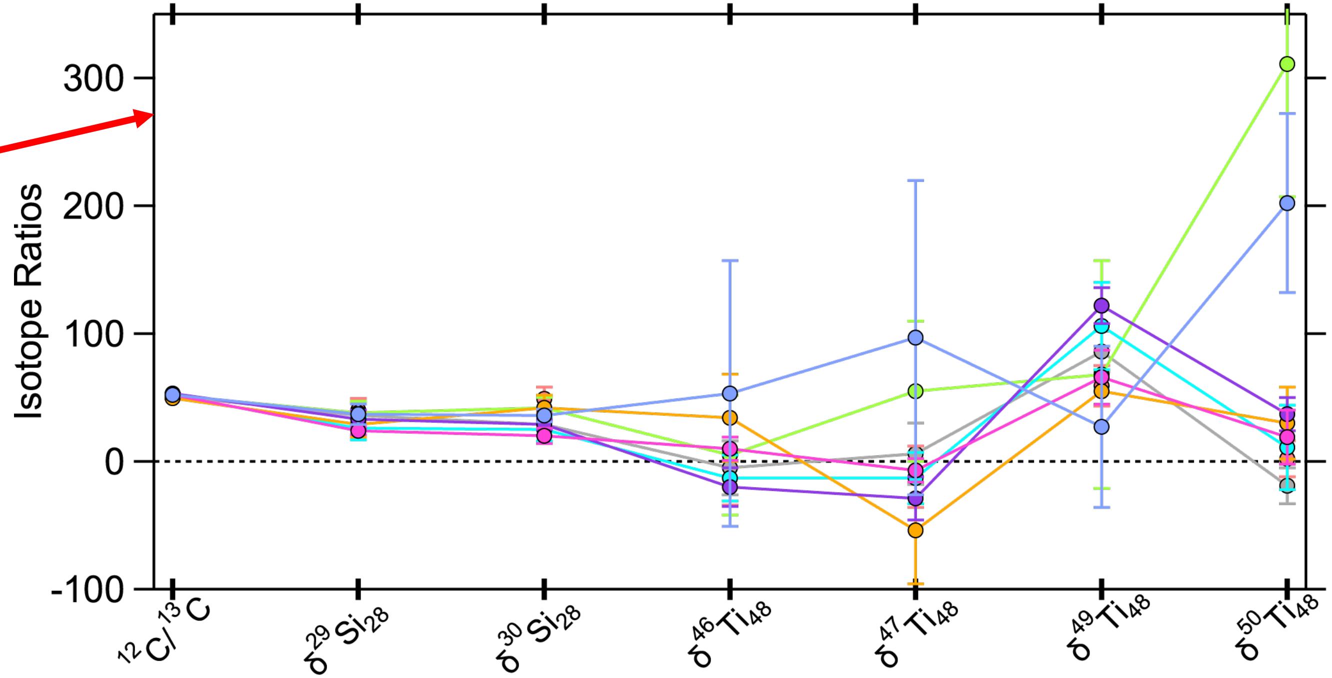
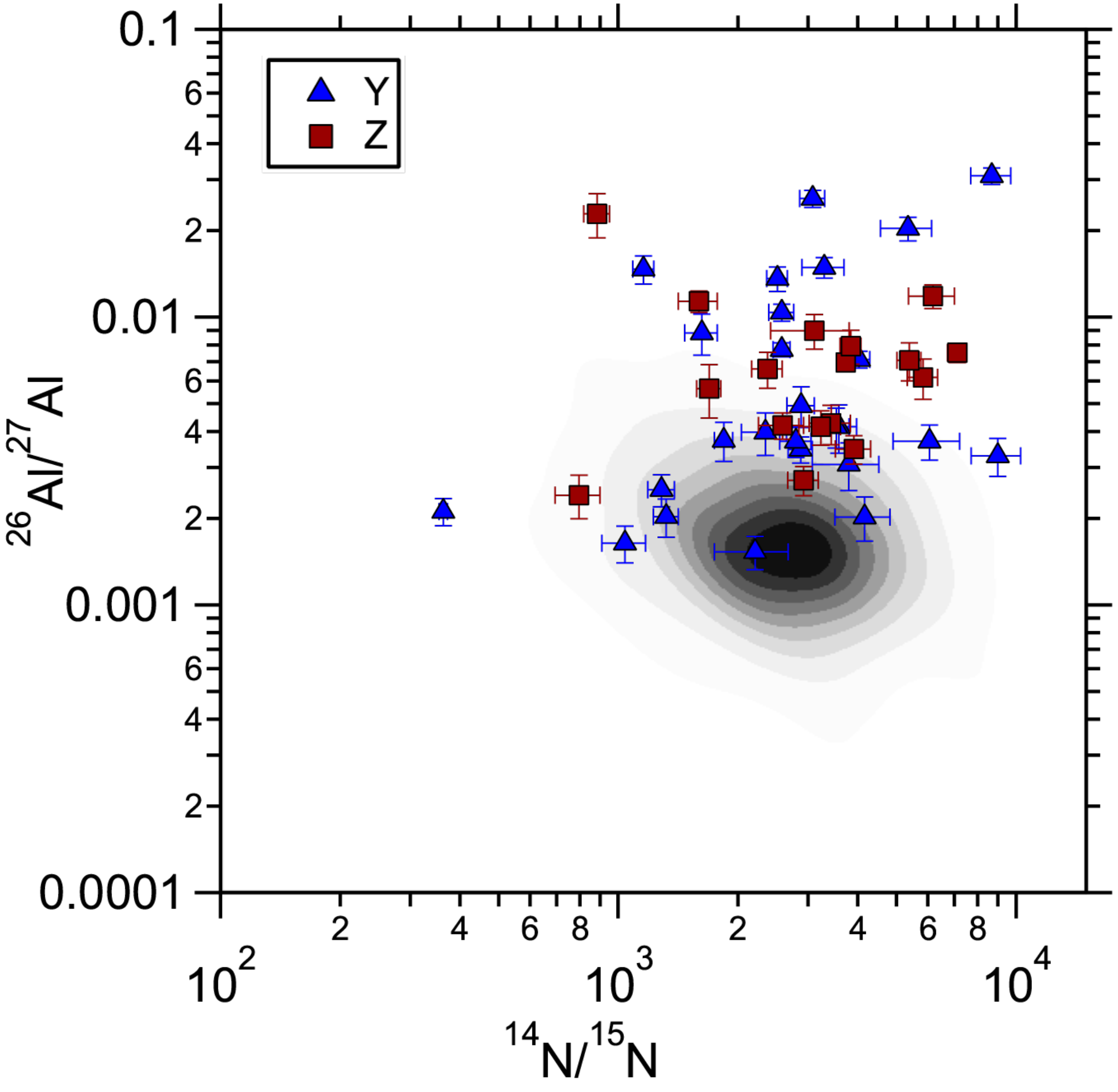
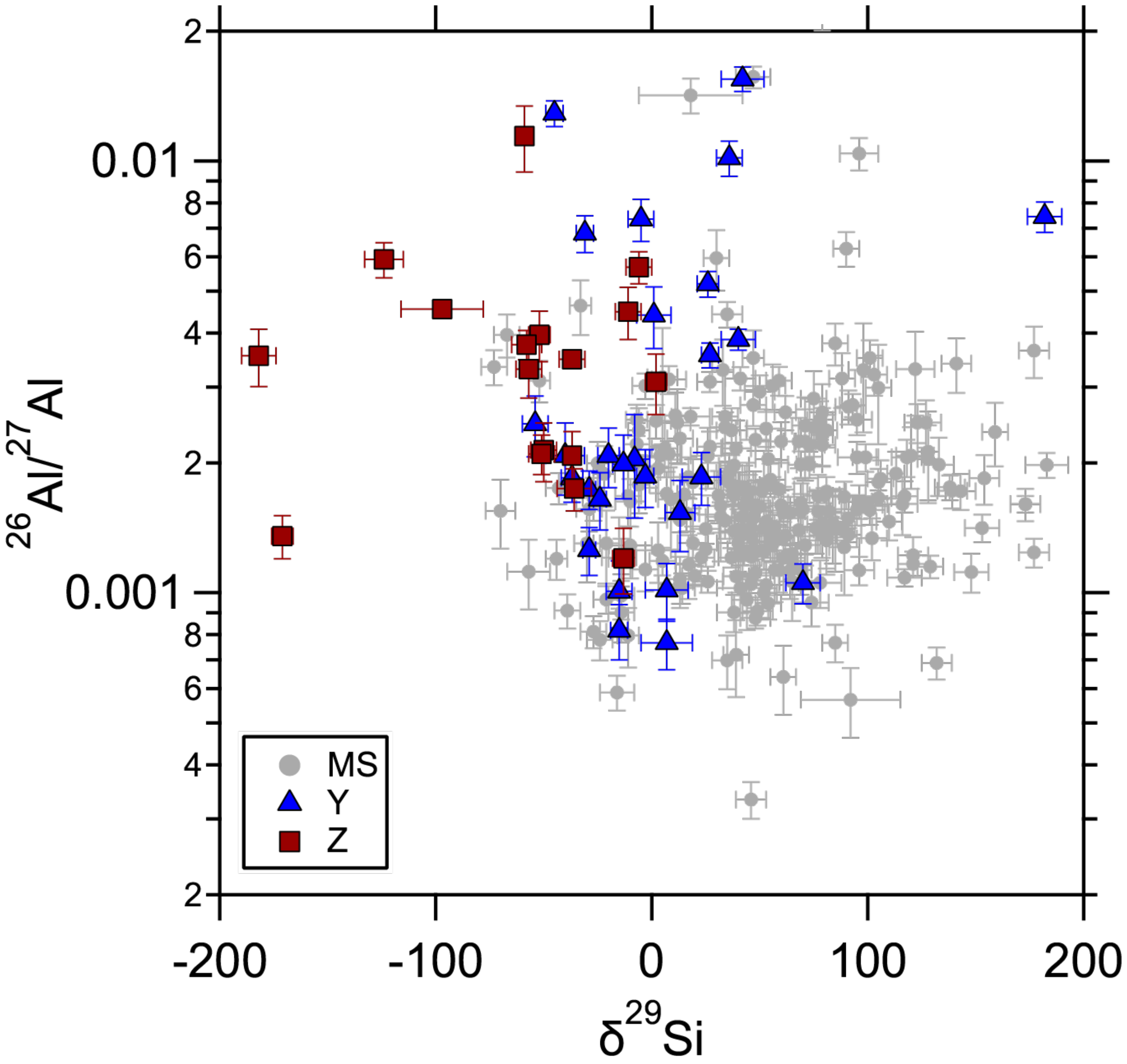


- MS grains form two well-separated populations
- ^{15}N-rich MS grains are extremely similar in their isotopic compositions except for their ^{50}Ti enrichments
- The two ^{50}Ti-rich grains have similar $^{51}V/^{48}Ti$ ratios (~1.0) significantly higher than those of the other ^{15}N-rich MS grains (~0.2).

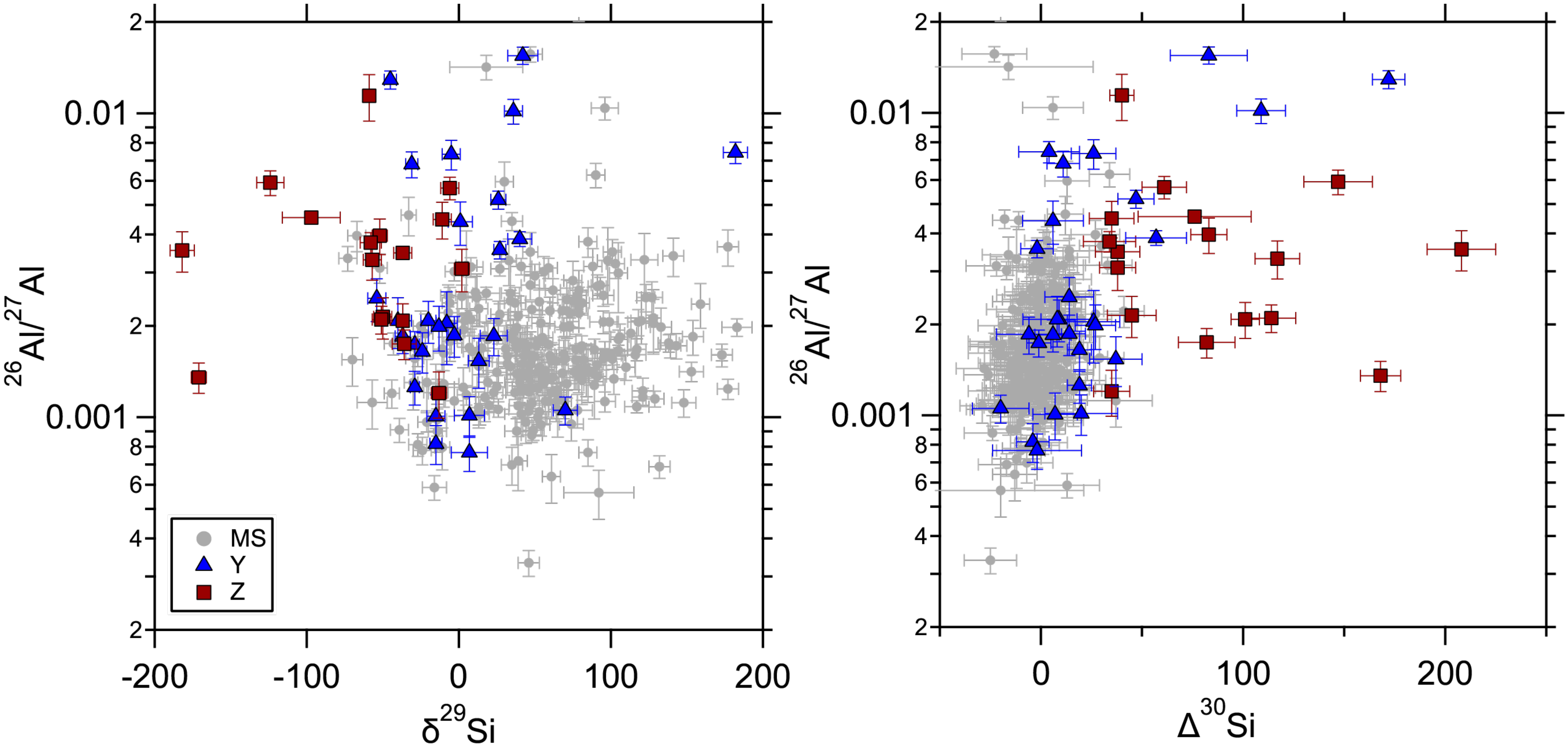
Y and Z Grains Have **Higher** Initial $^{26}Al/^{27}Al$ Ratios

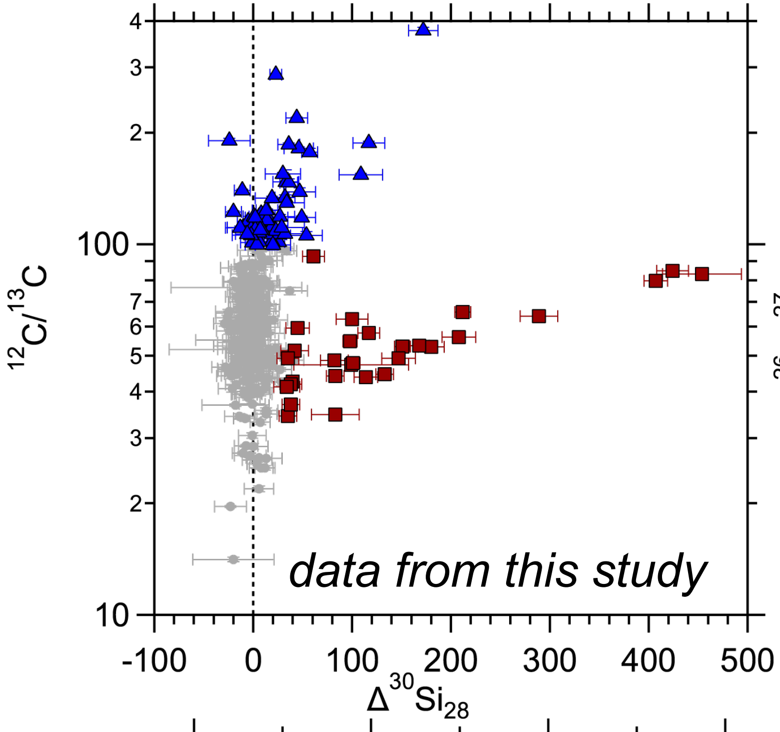


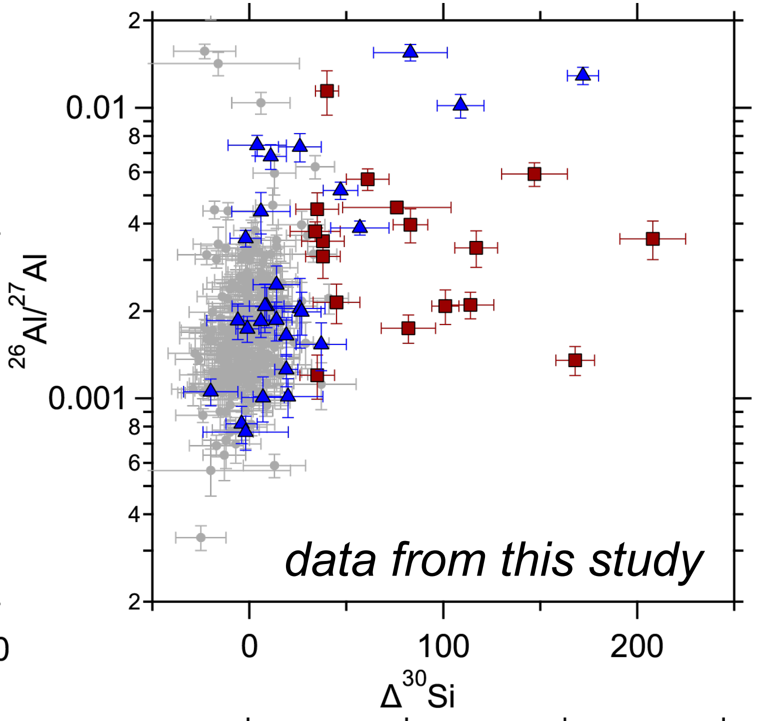
No Correlation between $^{26}Al/^{27}Al$ and Initial Metallicity



Positive Trend between $^{26}Al/^{27}Al$ and ^{30}Si Excess

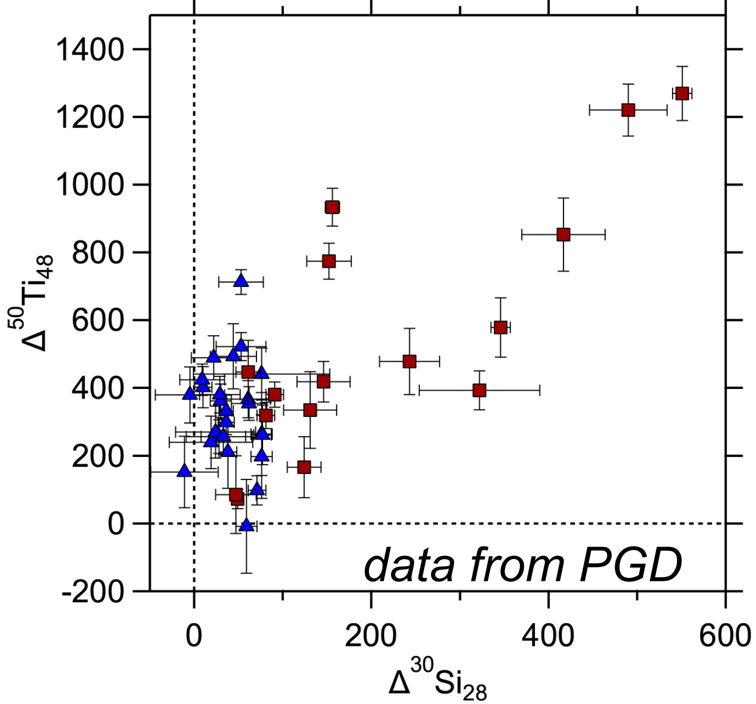


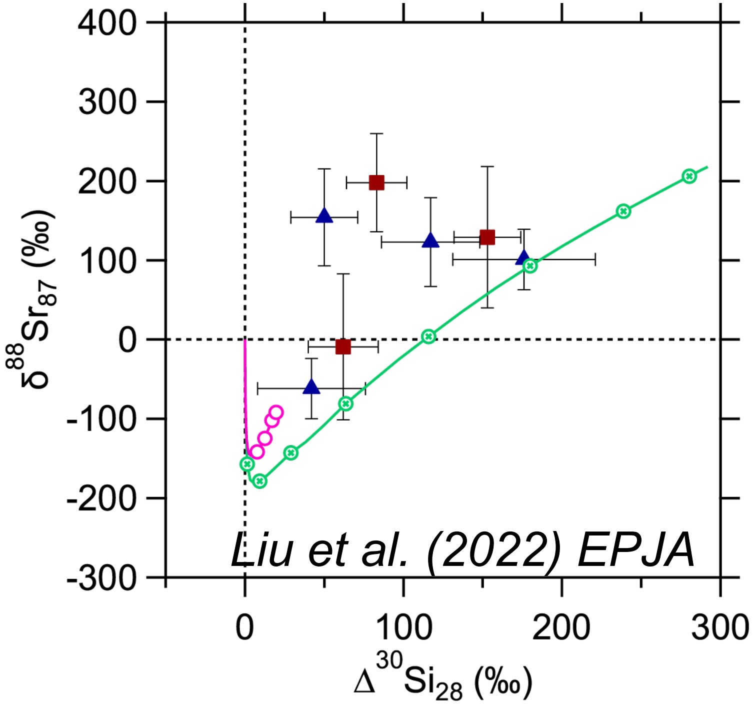




Conclusions

- $\Delta^{30}Si_{28}$: max T
- $^{12}C/^{13}C$: cool bottom processing (CBP), H burning, and He burning
- $^{26}Al/^{27}Al$: H burning, and He burning and, perhaps, CBP
- $\Delta^{50}Ti_{48}$: ^{13}C pocket
- $\delta^{88}Sr_{87}$: ^{13}C pocket





Question: Instead of originating in low-metallicity AGB stars, perhaps Y and Z grains' parent stars simply are more enriched in AGB nucleosynthesis products at the surface?