THE PRESOLAR GRAIN DATABASE FOR SILICON CARBIDE—GRAIN TYPE ASSIGNMENTS.

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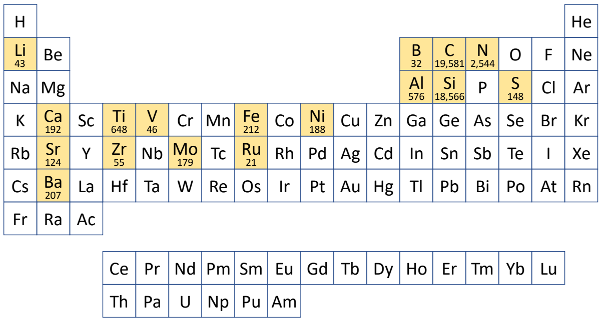
Introduction: Since introduction of the updated Presolar Grain Database (PGD) last year [1], isotope data for another 3,976 presolar SiC grains have been added. The current version (PGD_SiC_2021-01-10) is available at: https://presolar.physics.wustl.edu/presolar-grain-database/.

Based on data for a total of 19,976 presolar SiC grains, we are reviewing current classification schemes to unify the various definitions of grain types used over the years. Figure 1 shows for each element the number of grains for which isotope data in the PGD exist. For most grains, isotopic data are available for the two major elements C and Si, followed by N. Isotope ratios of these elements, which cover ranges of several orders of magnitude for C and N, have been the primary means of classification of presolar SiC grains (Fig. 2).



H																	He
Li 43	Be											B 32	C 19,581	N 2,544	O	F	Ne
Na	Mg											Al 576	Si 18,566	P	S 148	Cl	Ar
K	Ca 192	Sc	Ti 648	V 46	Cr	Mn	Fe 212	Co	Ni 188	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr 124	Y	Zr 55	Nb	Mo 179	Tc	Ru 21	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba 207	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am									

Figure 1: Table of the elements showing for each element the number of SiC grains with isotope data in the PGD.

M, Y, and Z grains: Mainstream (M), Y and Z grains represent about 95 % of presolar SiC grains found in primitive meteorites. They are usually attributed to low-mass asymptotic giant branch (AGB) stars with approximately solar (M) and perhaps subsolar (Y and Z) metallicities [2, 3]. For M grains, we observe a maximum in the $^{12}C/^{13}C$ distribution at a ratio of ~51. Type Y grains are defined as having $^{12}C/^{13}C > 100$, and Si isotopes are to the right of the mainstream correlation line [2]; type Z grains have even larger ^{30}Si excesses relative to ^{29}Si but are indistinguishable from M grains in C and N (Fig. 2) [2]. The data in the PGD show some overlap among these types in C, N, and Si isotopes, and using $^{12}C/^{13}C = 100$ as a divider between Y grains and the other two types seems arbitrary. Cluster analysis of the PGD data also showed no clear separation between these types [4]. A reassessment of the discrimination between M, Y and Z grains in the PGD is ongoing, and current assignments, which are in most cases directly taken from the original work on these grains, should be taken with a grain of salt.

X grains: Type X grains, attributed to core-collapse (Type II) supernovae (SNII), are distinctive in C and N isotopes (Fig. 2a) and subdivided based on Si isotopes into three subtypes, X0 (7 %), X1 (61 %), and X2 (32 %), as previously suggested [5]. We used the following two lines as dividers between the subtypes (Fig. 2c):

X0-X1: $\delta^{29}Si_{28} = (2/3 - 0.05)\ \delta^{30}Si_{28} + 30$ ‰

X1-X2: $\delta^{29}Si_{28} = (2/3 + 0.05)\ \delta^{30}Si_{28} - 30$ ‰

AB grains: Type AB grains have low $^{12}C/^{13}C$ and were originally defined as two different types, A and B, based on C isotopes, with $(^{12}C/^{13}C)_A < 3.5 < (^{12}C/^{13}C)_B < 10$ [6], but were later combined into one type. Among proposed stellar origins of these grains are J-type carbon stars, born-again AGB stars, and SNII. Liu et al. [7, 8] suggested division of AB grains into AB1 (^{15}N-rich) and AB2 (^{15}N-poor) subgroups based on N isotopes, using the solar value of $^{14}N/^{15}N = 441$ [9] as a divider. Cluster analysis showed that AB grains make up two clusters, which can be described as relatively $^{13}C+^{15}N$-rich and $^{13}C+^{15}N$-poor with significant overlap in C and especially in N isotope ratios [4]. The solar $^{14}N/^{15}N$ ratio seems poorly suited as a divider. From our assessment of the grain data, we propose to use $^{12}C/^{13}C = 12.3$ as the cutoff value between AB and M/Z grains, but grains with ratios up to ~25 could belong to either type. Furthermore, we suggest two subtypes A1 and B2, using $^{12}C/^{13}C < 4.5$ and $^{14}N/^{15}N < 441$ (solar value) as upper limits for A1, and $^{12}C/^{13}C \geq 4.5$ and $^{14}N/^{15}N \geq 272$ (terrestrial value) as lower limits for B2 regimes. Using these limits, 90 % of the AB grains would be consistent with either of these subtypes (33 % A1, 56 % B2, 1 % consistent with both A1 and B2). This definition of subtypes, which is currently used in the PGD, should be regarded as preliminary, as data from heavier elements are probably necessary to subdivide AB grains according to their stellar sources. Silicon isotopes cannot be used to better define these subtypes, as they show a rather uniform distribution similar to M grains. Inferred initial $^{26}Al/^{27}Al$ ratios are on average higher for A1 than for B2 grains, but there is no clear separation of these subtypes in the Al data. However, higher $^{26}Al/^{27}Al$ for A1 grains support the idea of a SNII origin of these grains [10]. Near-normal isotopic compositions for elements like Sr, Mo, and Ba have linked B2 grains to J-type carbon stars [7], but SNII may also have contributed to these [11]. A pronounced *s*-process pattern in Mo for one B2 grain rather suggests a born-again AGB star as a likely source at least for this specific grain [12].

C grains: This rare type of grain is characterized by large excesses in ^{29}Si and ^{30}Si, larger than those in M or AB grains, and has been suggested to form in SNII [2]. A recently described [13] subtype C2 is characterized by $^{12}C/^{13}C < 10$ and clearly separated from other C grains (now named C1) that have much higher $^{12}C/^{13}C$.

N grains: Putative nova grains (type N) are characterized by very low $^{12}C/^{13}C$ and $^{14}N/^{15}N$, high $^{26}Al/^{27}Al$, and often have large ^{30}Si excesses [2]. If they are really connected to novae or rather originated in SNII is still debated. There are no apparent subtypes.

Unknown grains: Among grains with no clear assignment to any major presolar SiC grain type, there is a population to the left of the mainstream correlation line in Si isotopes, mirroring the distribution for Z grains (Fig. 2d). These might define a new grain type.

Conclusions: Further assessment of grain types and subtypes from the data provided by the continuously growing PGD will help to better classify presolar SiC grains in order to link them to their stellar origins.

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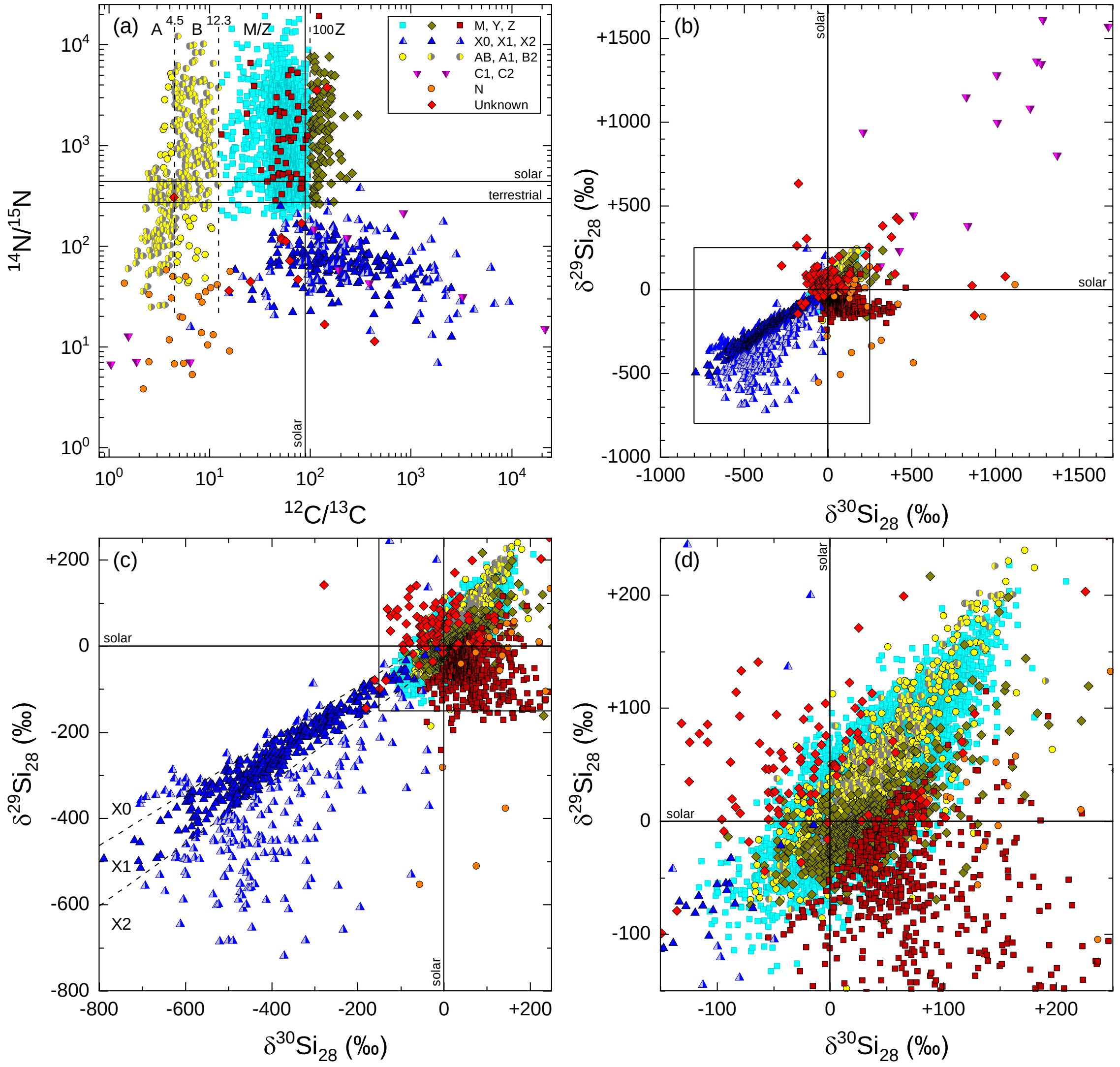

Figure 2: Nitrogen versus C (a) and Si (b–d) isotope data for SiC grains from the PGD. Dashed lines show limits for separation of types A, B, M/Z, and Y in panel (a) and separation of subtypes X0, X1, and X2 in panel (c). For clarity, we omitted data for M, AB, X, Y, and Z grains with uncertainties >30 ‰ in at least one of the Si isotope ratios (b–d).