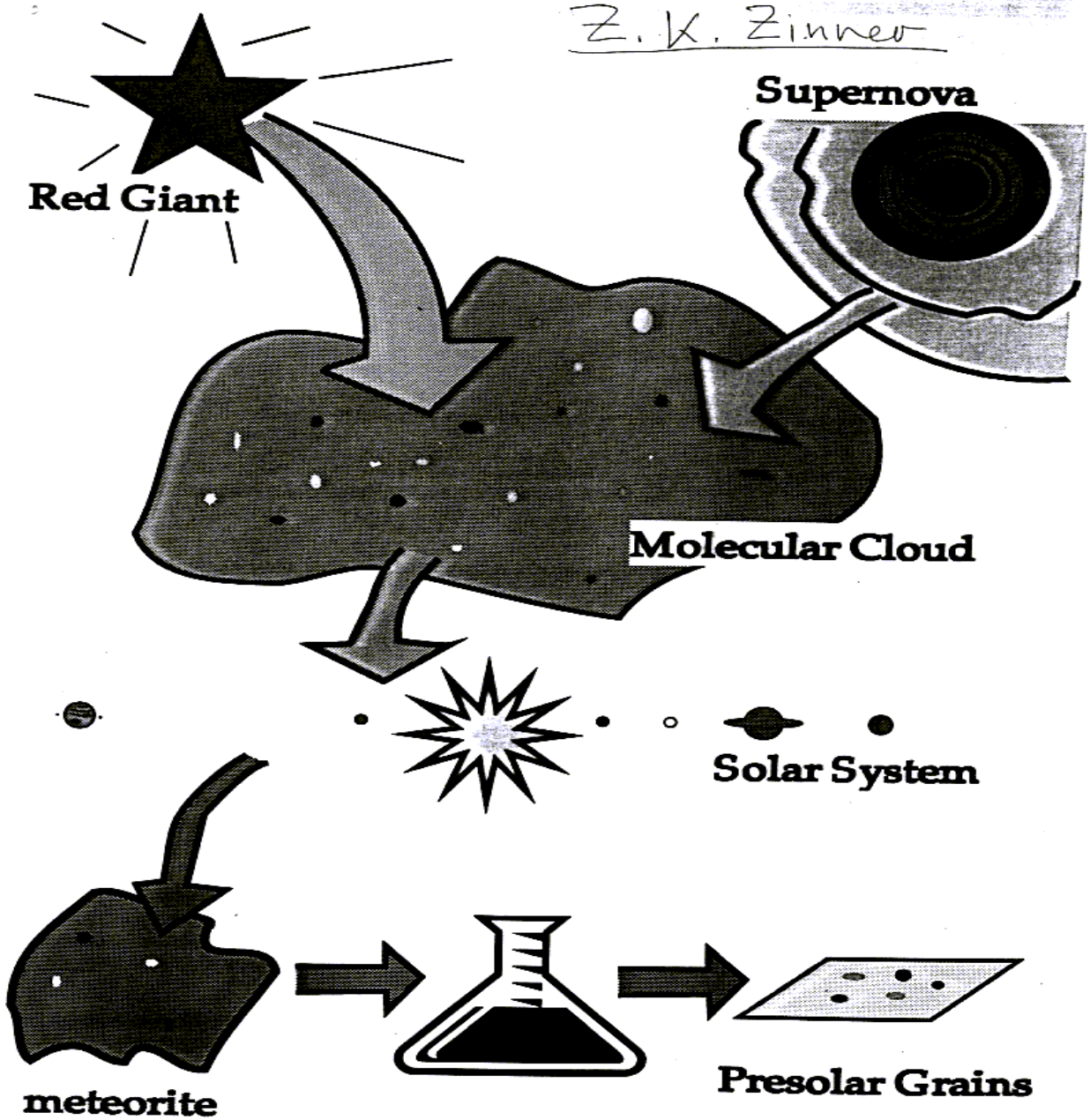
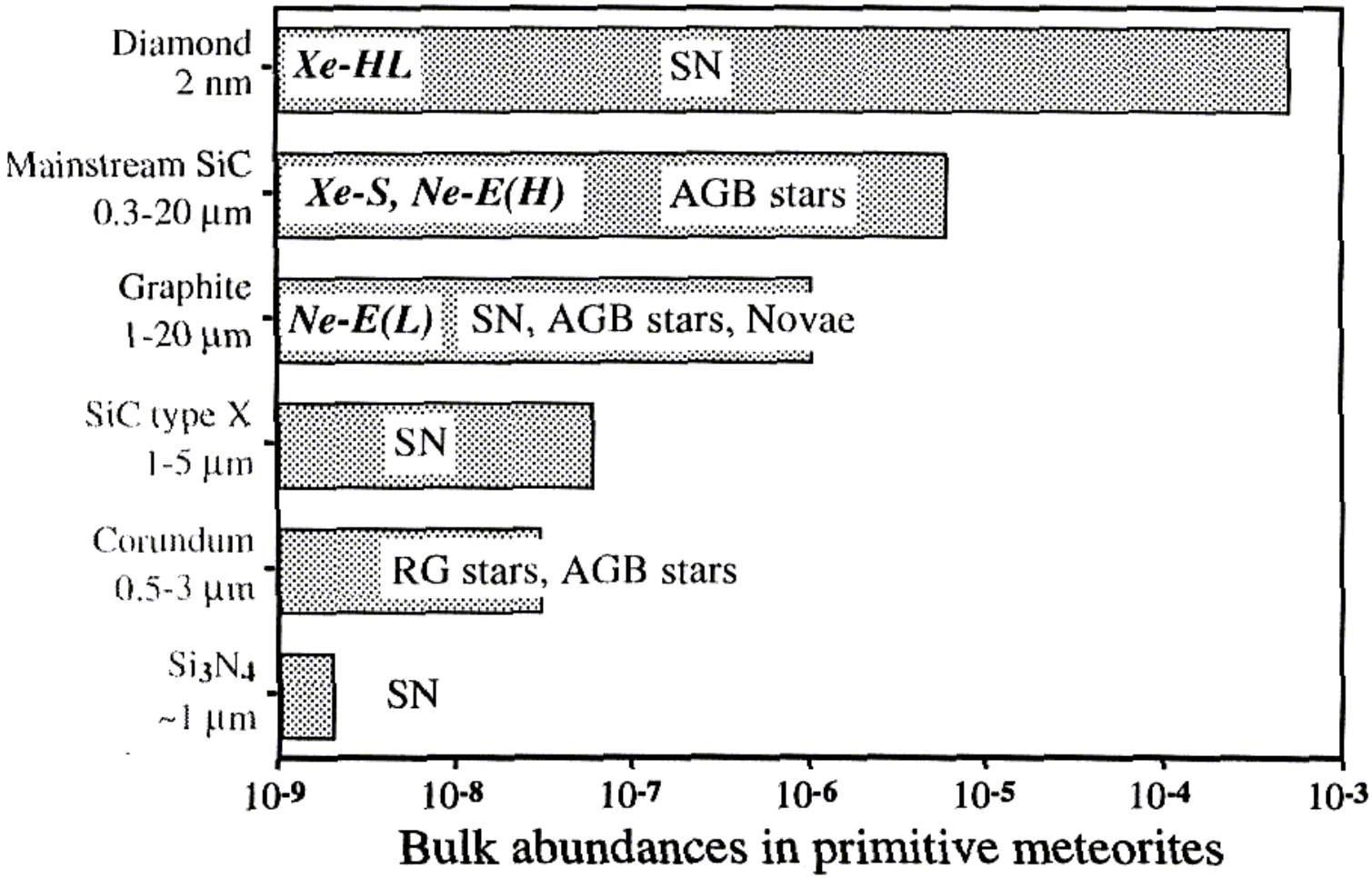
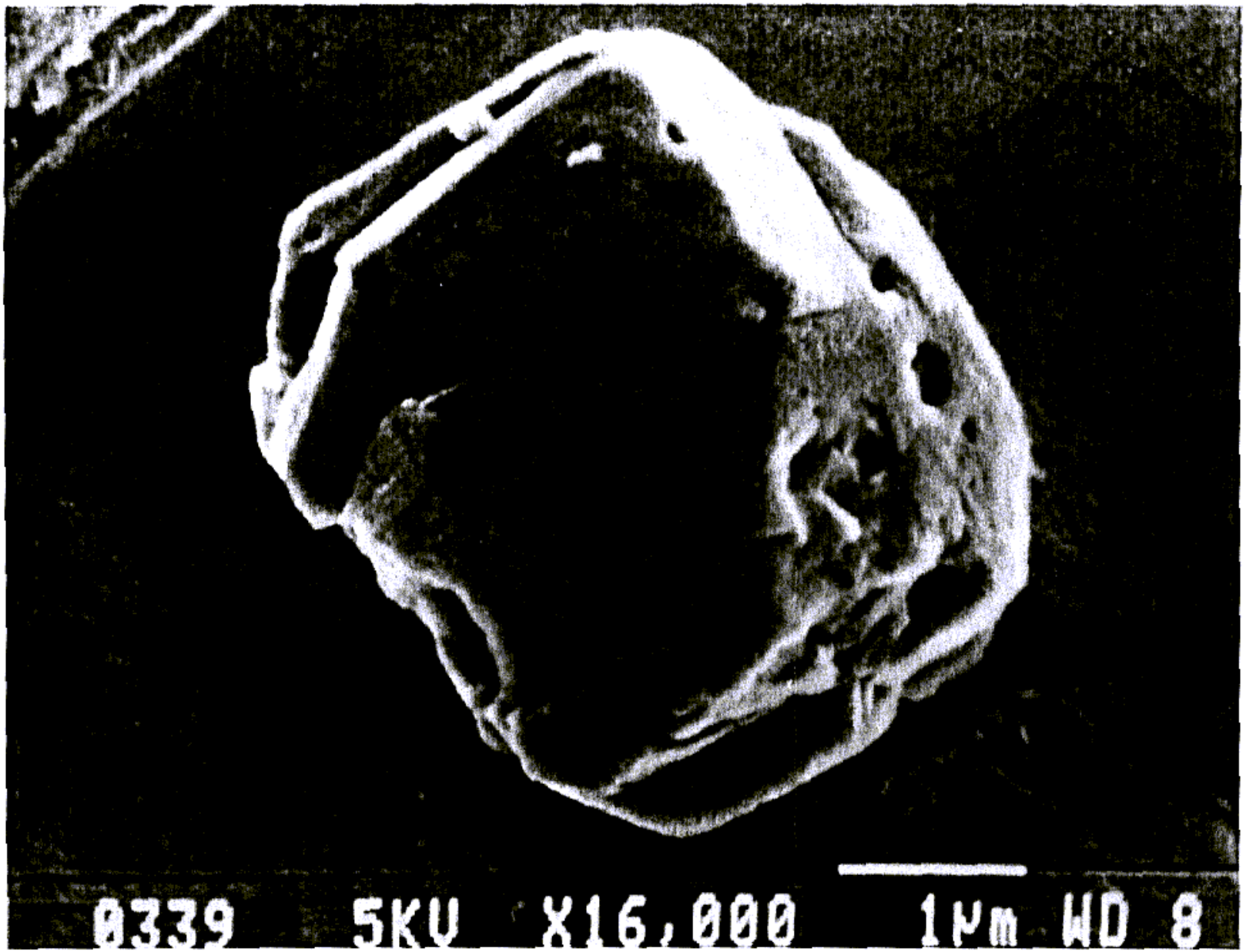
Presolar grains from meteorites: A new window to the stars

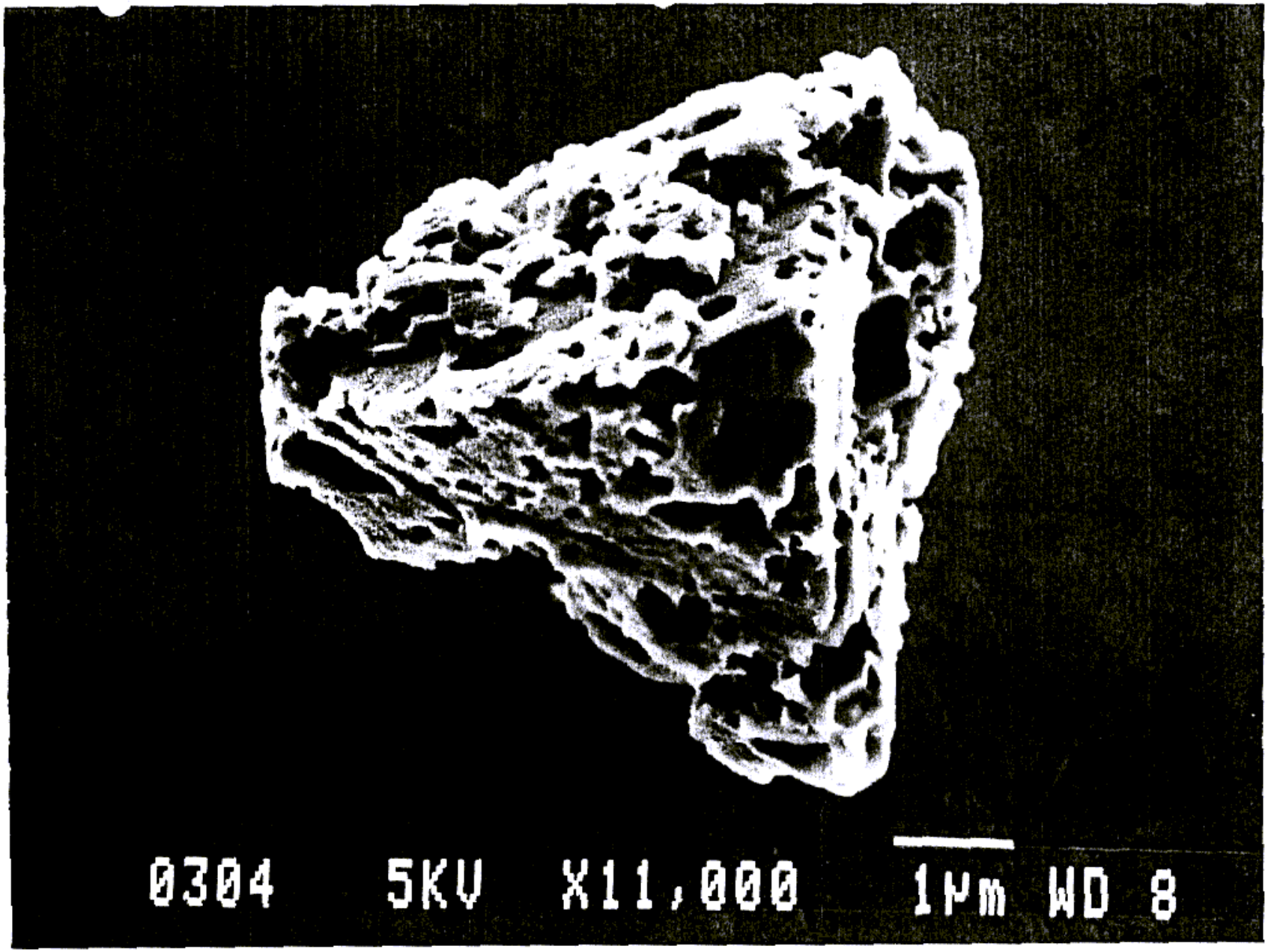
E. K. Zinner

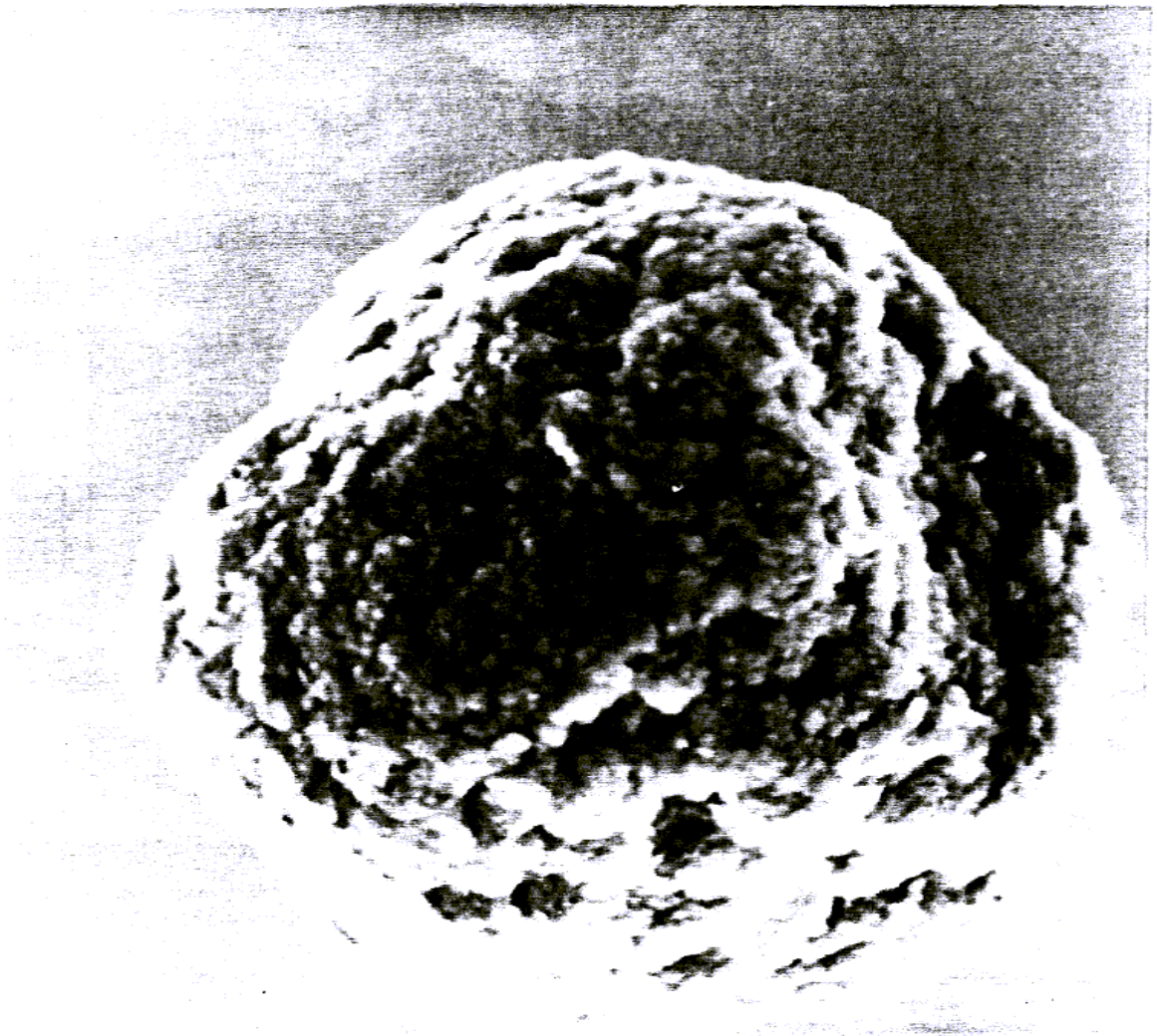
Z. K. Zinner

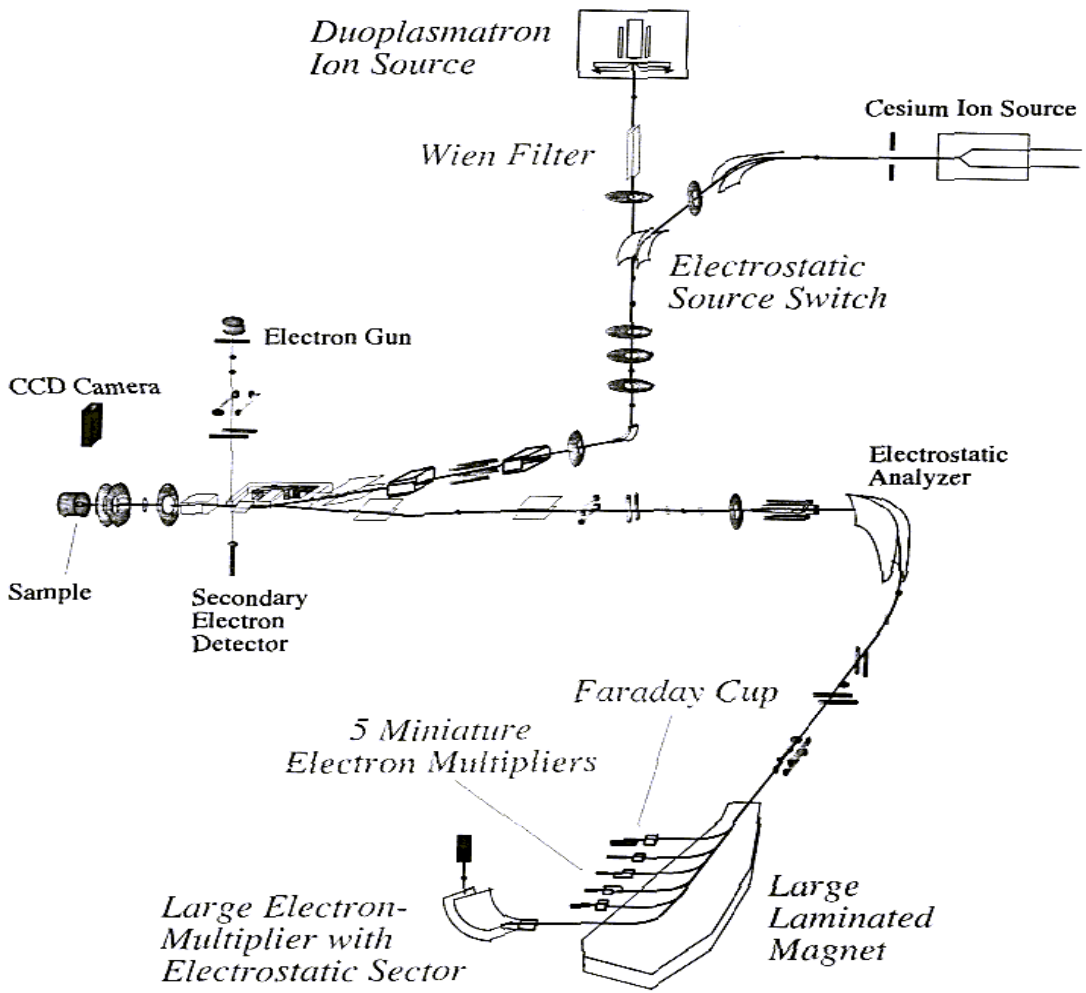

Supernova
Red Giant
Molecular Cloud
Solar System
meteorite
Presolar Grains

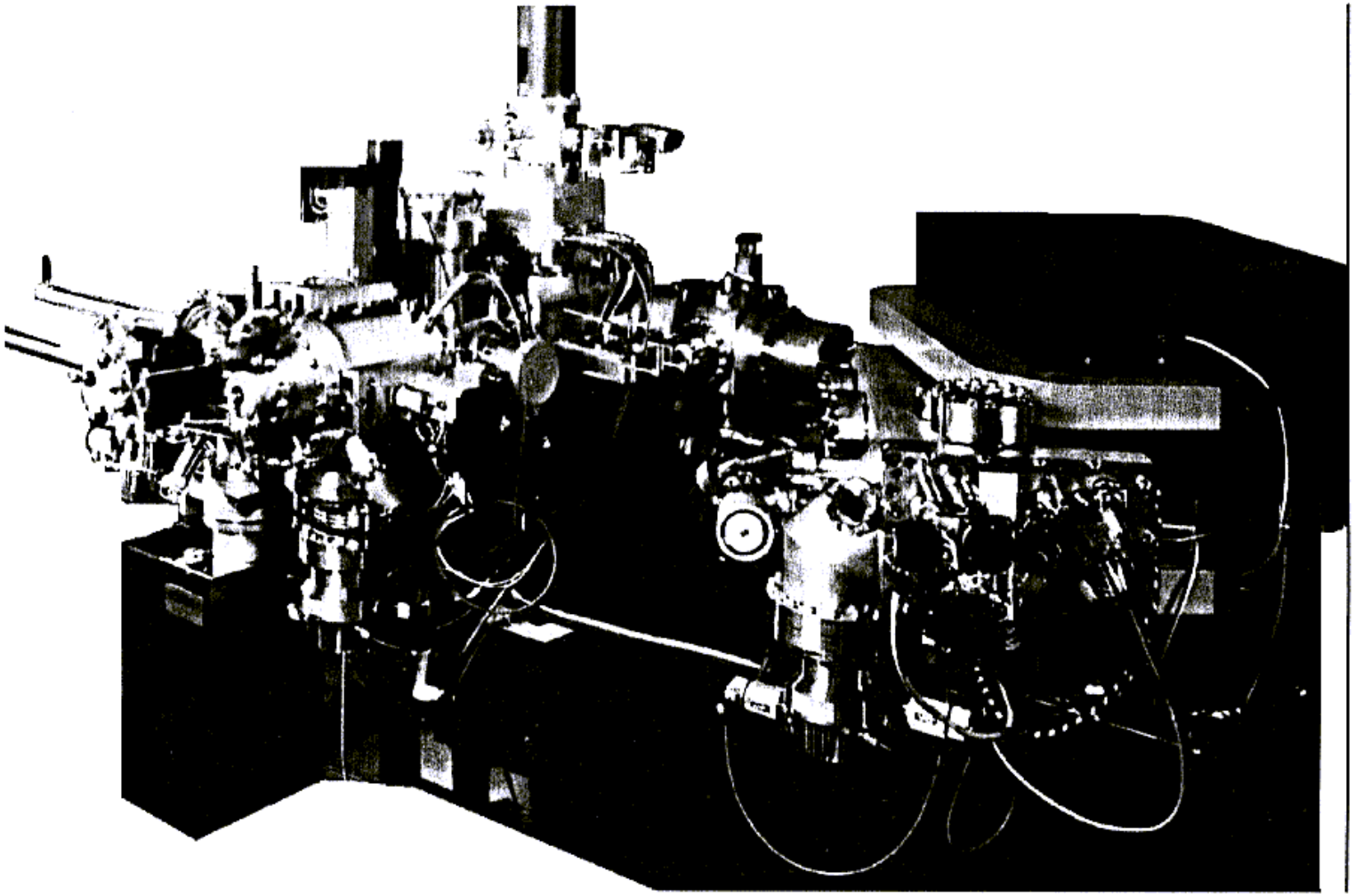

Diamond
2 nm
Xe-HL
SN
Mainstream SiC
0.3-20 µm
Xe-S, Ne-E(H)
AGB stars
Graphite
1-20 µm
Ne-E(L)
SN, AGB stars, Novae
SiC type X
1-5 µm
SN
Corundum
0.5-3 µm
RG stars, AGB stars
Si3N4
~1 µm
SN
10-9
10-8
10-7
10-6
10-5
10-4
10-3
Bulk abundances in primitive meteorites


0339 5KU X16,000 1μm WD 8


0304 5KV X11,000 1μm WD 8

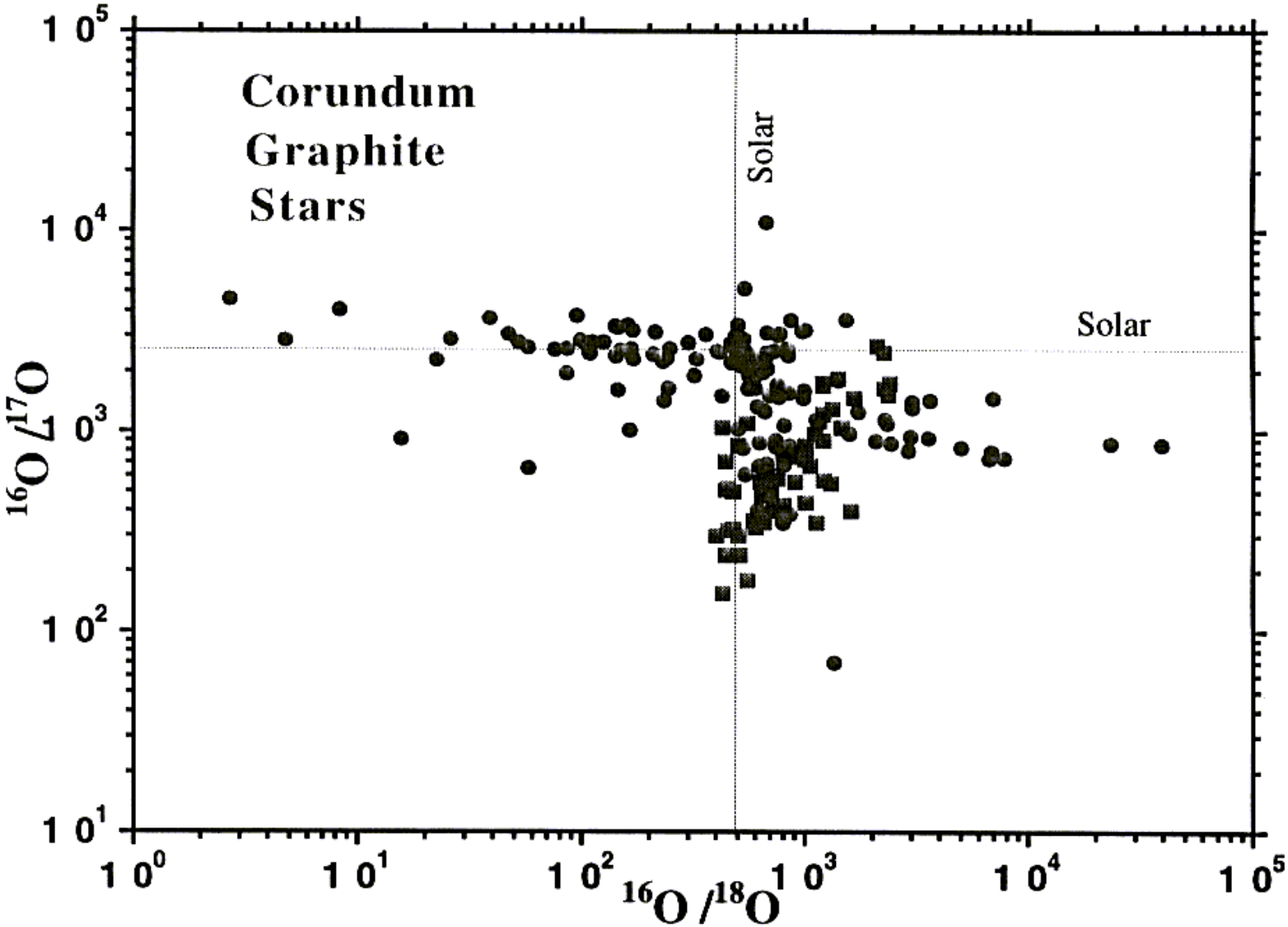



Duoplasmatron
Ion Source
Cesium Ion Source
Wien Filter
Electrostatic
Source Switch
Electron Gun
CCD Camera
Electrostatic
Analyzer
Sample
Secondary
Electron
Detector
Faraday Cup
5 Miniature
Electron Multipliers
Large Electron-
Multiplier with
Electrostatic Sector
Large
Laminated
Magnet



Isotopic Measurements on Single Presolar Grains

Grain Type	Element	Grain size	Number of analyses	Instrument
SiC	C, Si, N	≥0.5μm	>1000	Ion Probe
	Mg, ^{26}Al	>1μm	several hundred	Ion Probe
	K, Ca, Ti	>1μm	Few grains	Ion Probe
	He, Ne	>3μm	>100	Laser evap. + gas MS
	Sr, Zr, Mo, Ba	>3μm	few grains	Laser RIMS
Graphite	C, N	≥0.8 μm	>1000	Ion Probe
	Mg, ^{26}Al	≥2 μm	>100	Ion Probe
	O, Si		selected grains	Ion Probe
	K, Ca, Ti		few grains	Ion Probe
	He, Ne	>3μm	>100	Laser evap. + gas MS
	Zr, Mo	>3μm	few grains	Laser RIMS
Oxide	O	≥ 0.5 μm	>100	Ion Probe
	^{26}Al		~30	Ion Probe
	Mg, Ti, K		few grains	Ion Probe
Si_3N_4	N, Si, C	≥0.5 μm	few grains	Ion Probe
	^{26}Al	≥0.5 μm	few grains	Ion Probe


Corundum
Graphite
Stars
Solar
Solar
10^5
10^4
10^3
10^2
10^1
$^{16}O/^{17}O$
10^0
10^1
10^2
10^3
10^4
10^5
$^{16}O/^{18}O$

ZINNER

STELLAR SOURCES OF PRESOLAR GRAINS

A) **Red Giant Stars**

1) Mainstream SiC: Carbon Stars

2) Corundum Grains: RG stars before and during the TP AGB phase, some with CBP

B) Type II Supernovae

Low-density Graphite

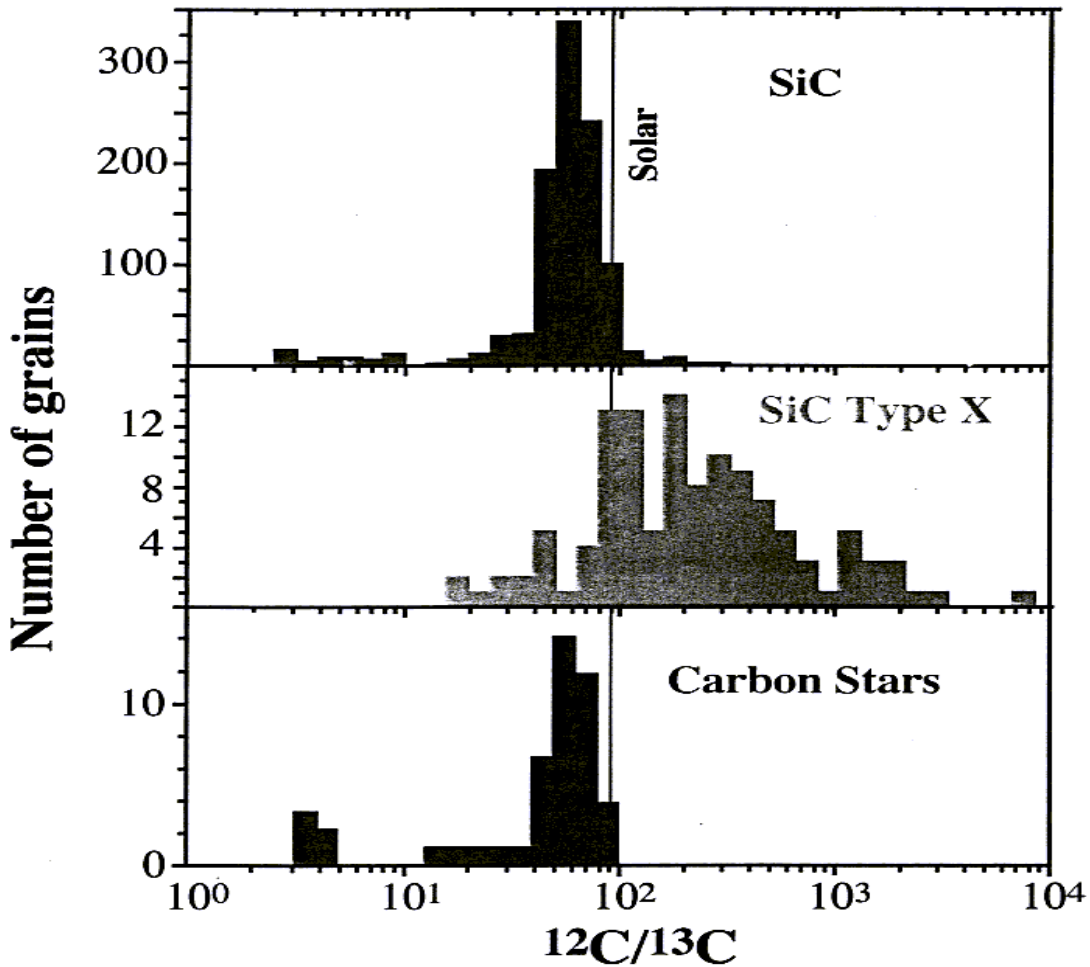
Silicon Carbide of Type X

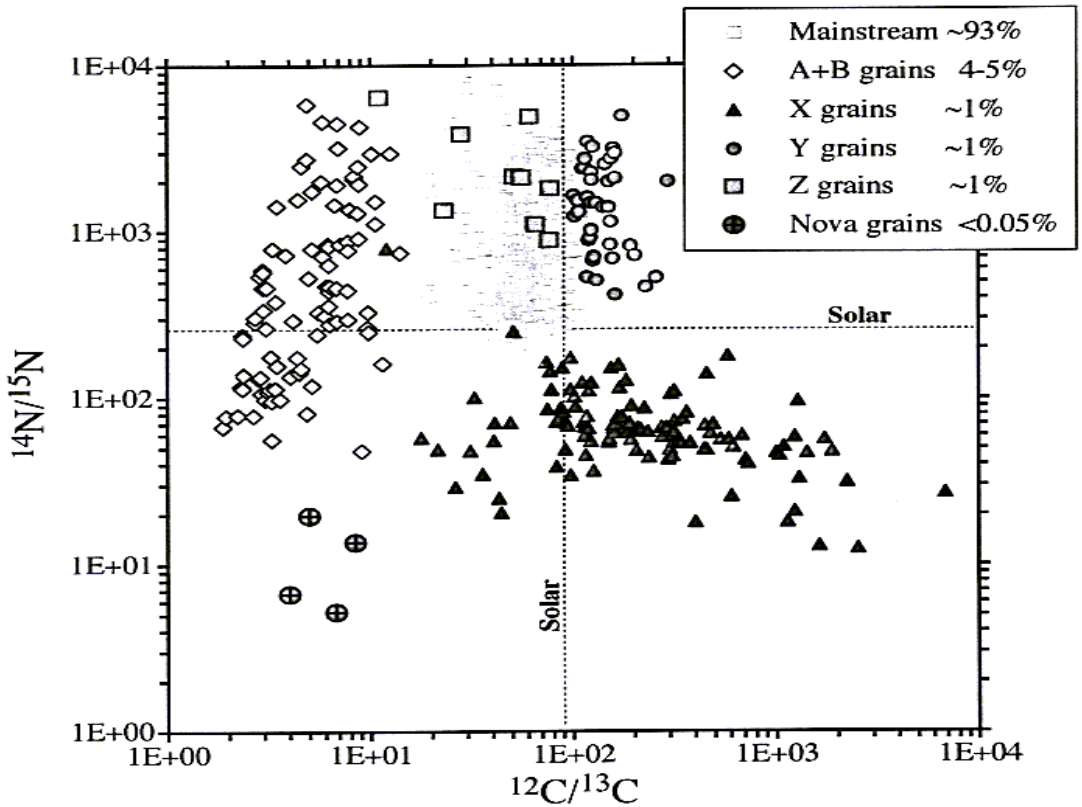
Silicon Nitride

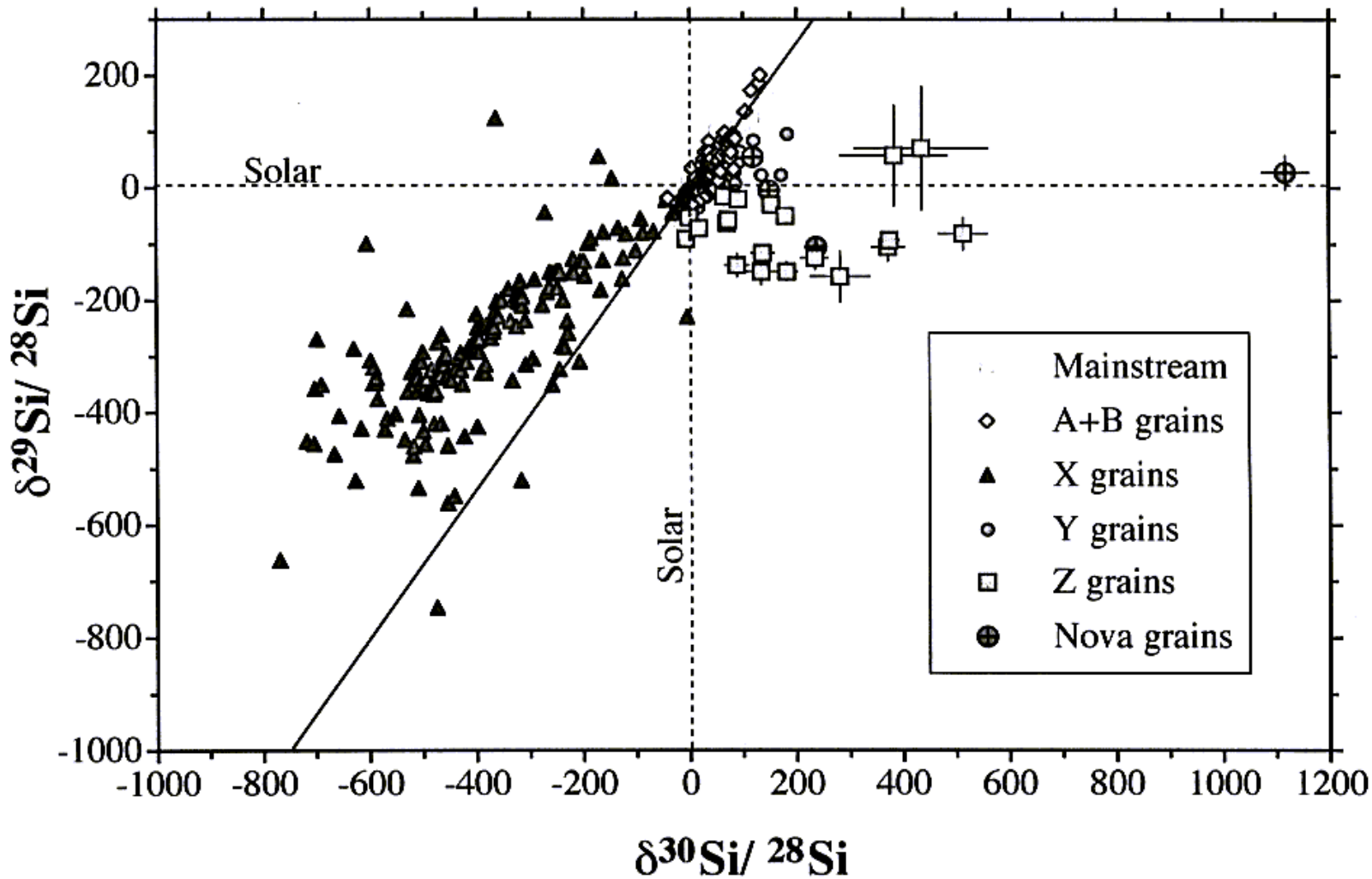
C) Novae

Possibly Graphite Grain with high $^{22}Ne/^{20}Ne$ and SiC grains with large ^{30}Si excesses

D) Wolf-Rayet Stars ??


SiC
Solar
SiC Type X
Carbon Stars
Number of grains
300
200
100
12
8
4
10
0
10^0
10^1
10^2
10^3
10^4
$^{12}C/^{13}C$

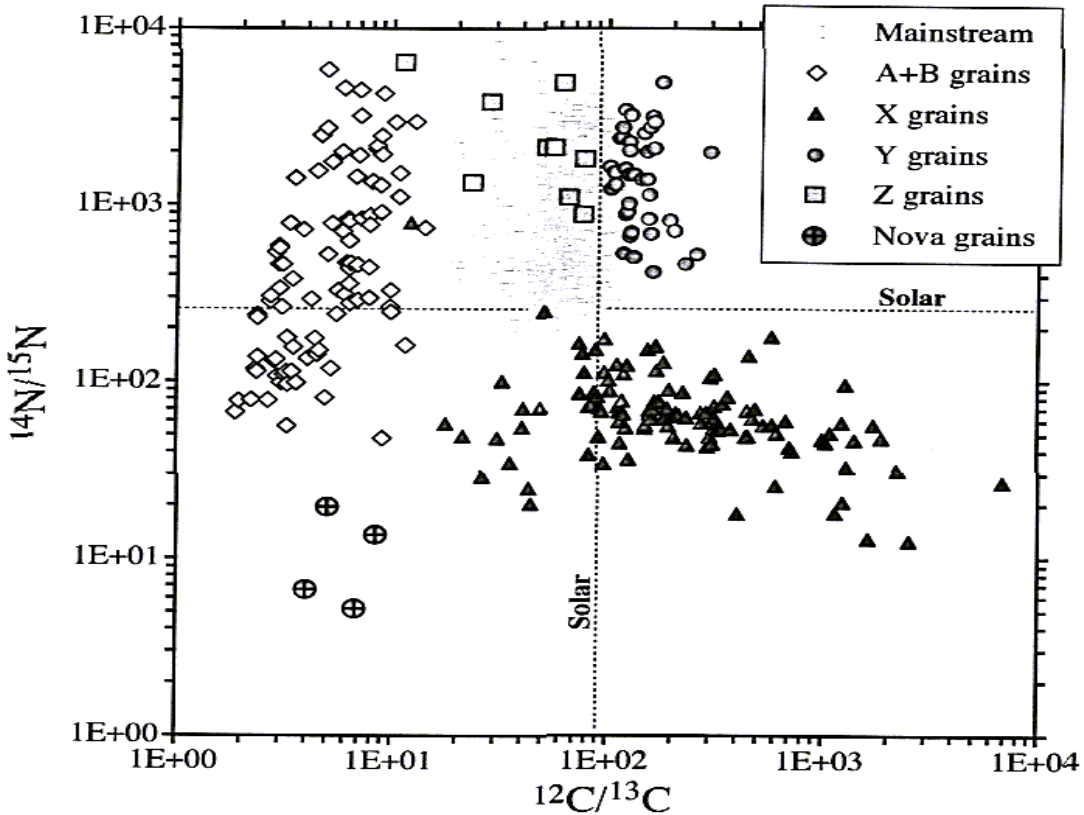

Mainstream ~93%
A+B grains 4-5%
X grains ~1%
Y grains ~1%
Z grains ~1%
Nova grains <0.05%
Solar
Solar
1E+04
1E+03
1E+02
1E+01
1E+00
1E+00
1E+01
1E+02
1E+03
1E+04
$^{14}N/^{15}N$
$^{12}C/^{13}C$

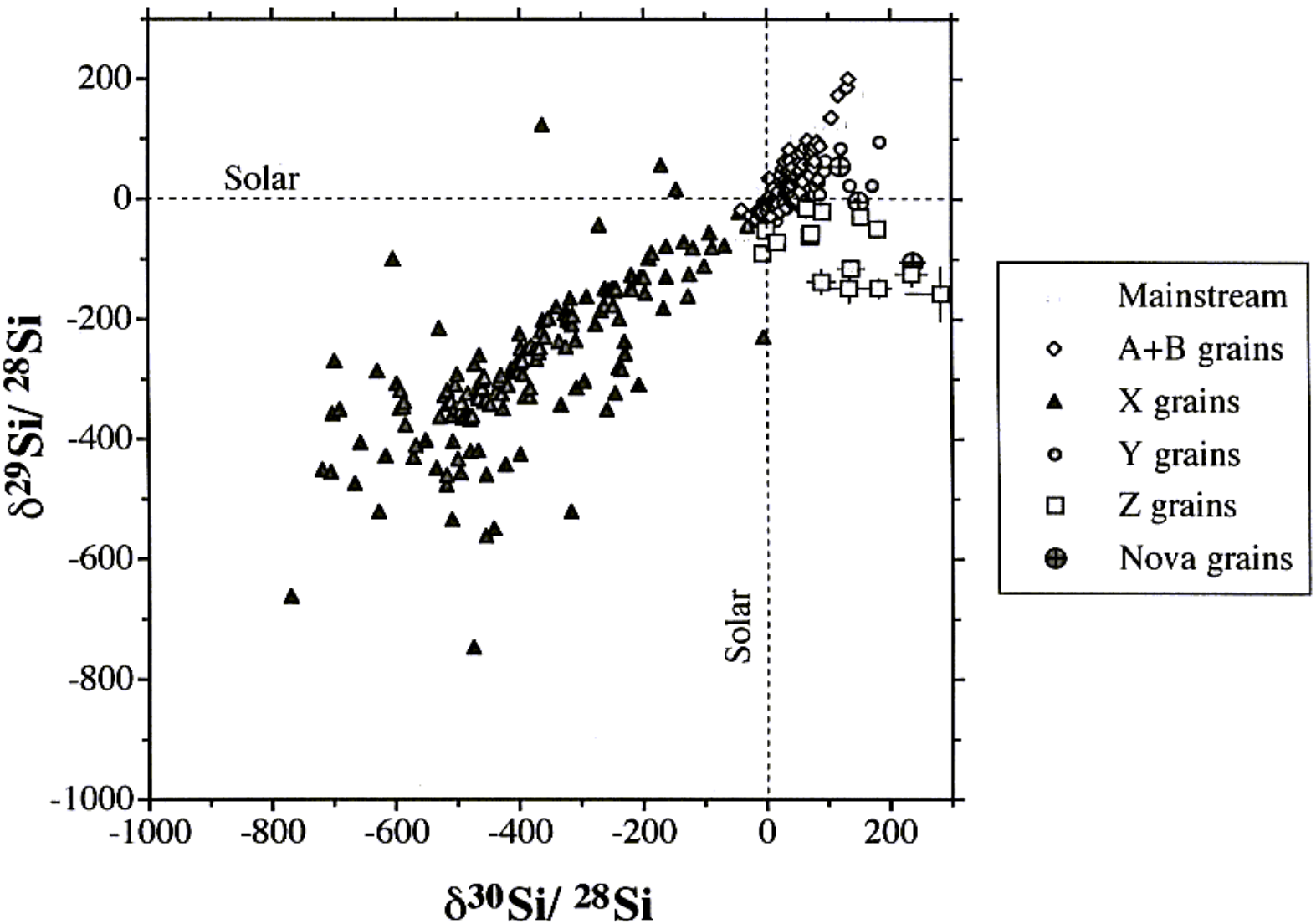

Solar
Solar
Mainstream
A+B grains
X grains
Y grains
Z grains
Nova grains
200
0
-200
-400
-600
-800
-1000
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
1200
δ29Si/ 28Si
δ30Si/ 28Si

Supernova (SN) grains

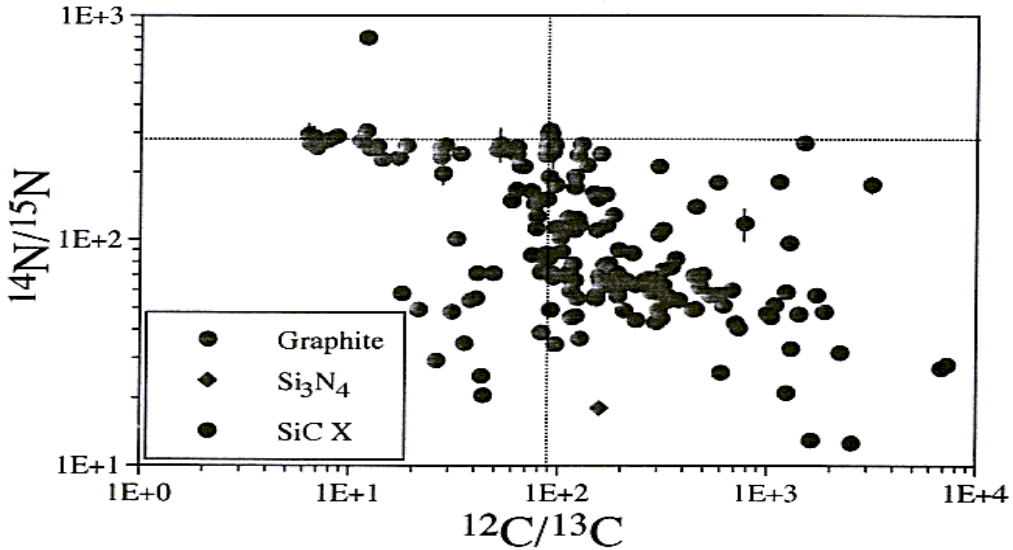
Grain type	Size (μm)	Abundance[1]
Diamond	0.0016	5×10^{-4}
Low-density graphite (1.7-2.10 gcm^{-3})	0.8 - 20	$<1\times10^{-6}$
SiC type X (~1% of total SiC)	0.2 - 9	6×10^{-8}
Si_3N_4	0.5 - 5	2×10^{-9}
Oxide[2]	< 1	3×10^{-10}

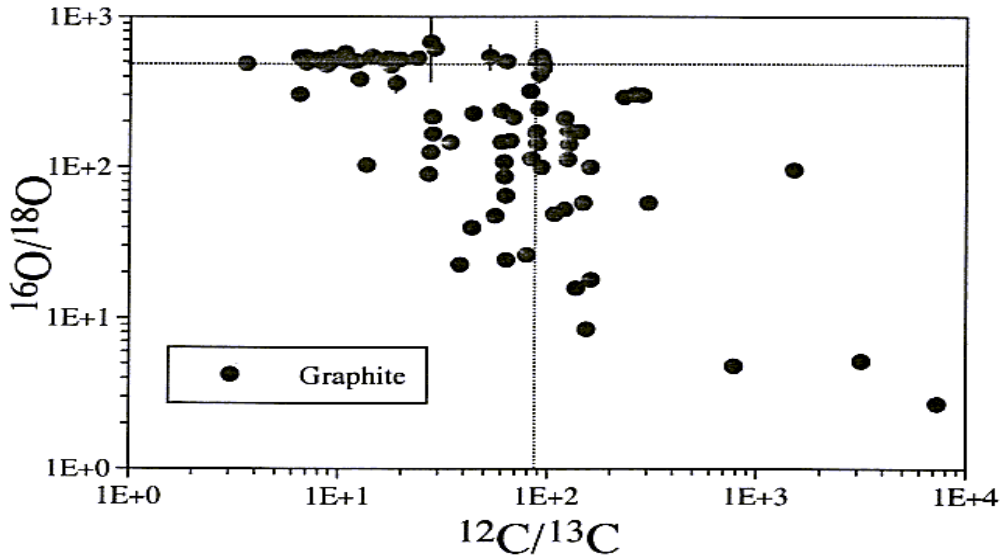
1 Abundances relative to whole meteorites. All values are derived from the Murchison meteorite.
2 One grain identified by Nittler et al. (1997)

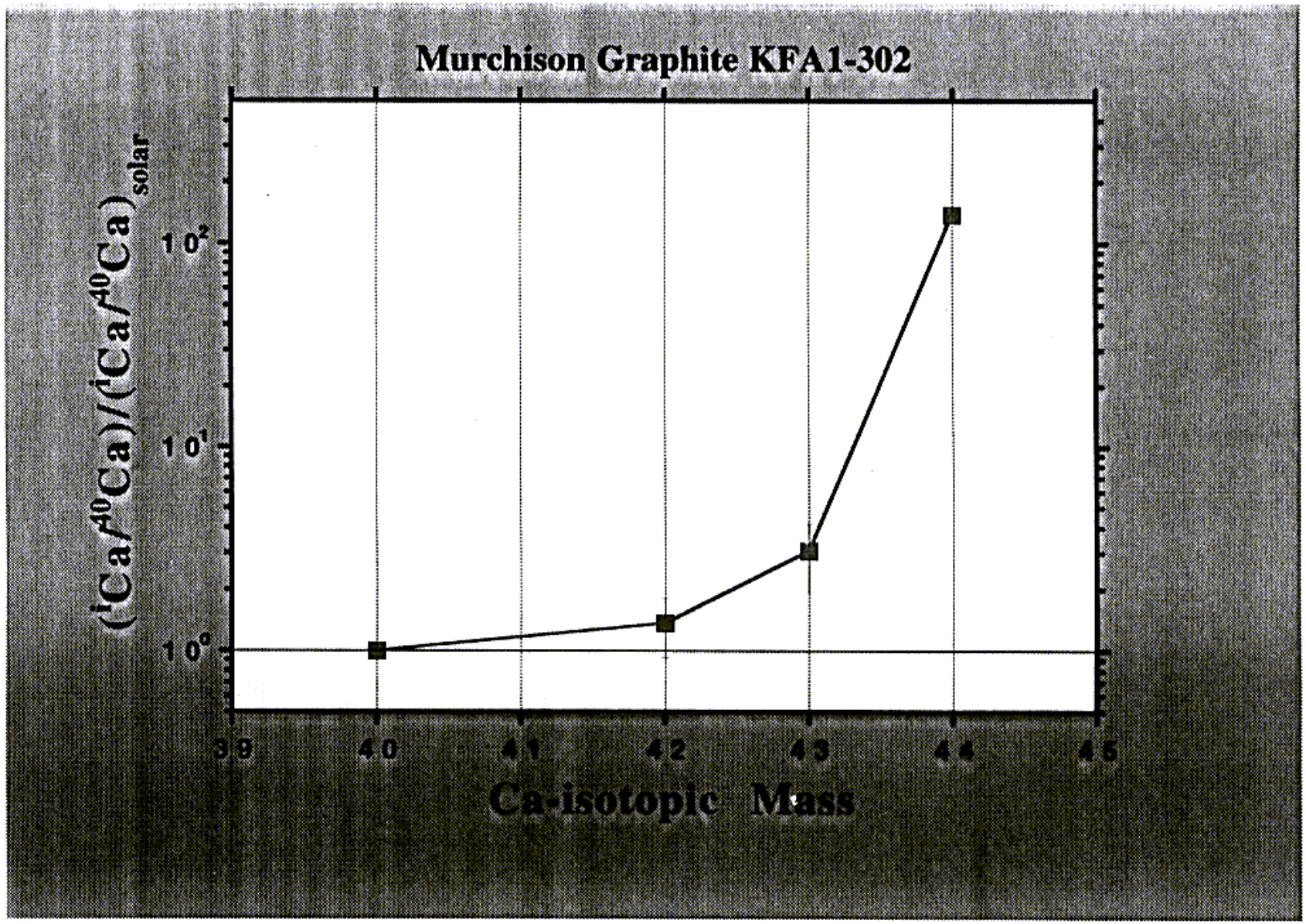

Mainstream
A+B grains
X grains
Y grains
Z grains
Nova grains
Solar
Solar
1E+04
1E+03
1E+02
1E+01
1E+00
1E+00
1E+01
1E+02
1E+03
1E+04
$^{14}N/^{15}N$
$^{12}C/^{13}C$

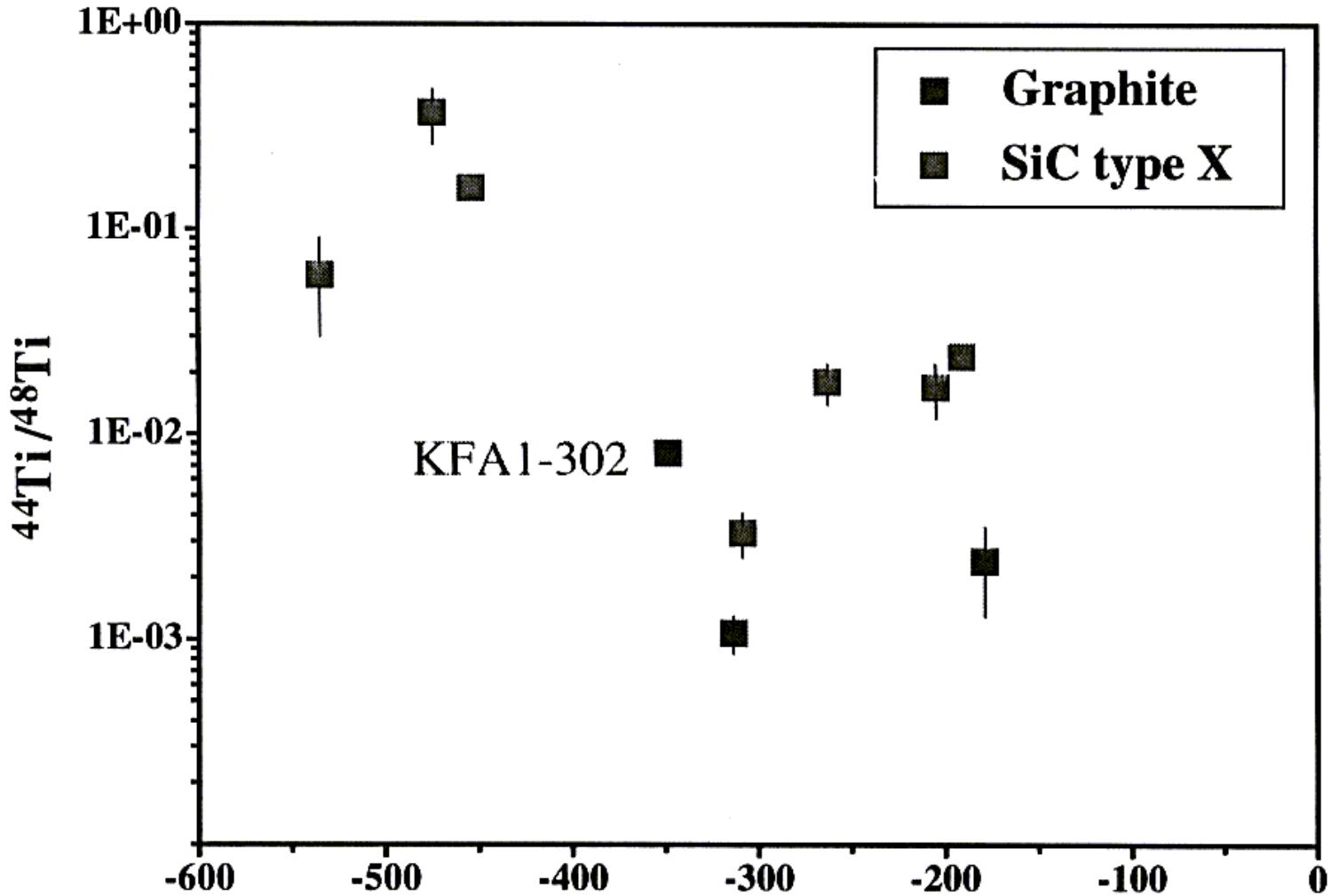

200
0
-200
-400
-600
-800
-1000
Solar
Solar
-1000
-800
-600
-400
-200
0
200
δ29Si/ 28Si
δ30Si/ 28Si
Mainstream
A+B grains
X grains
Y grains
Z grains
Nova grains

Grains from supernovae

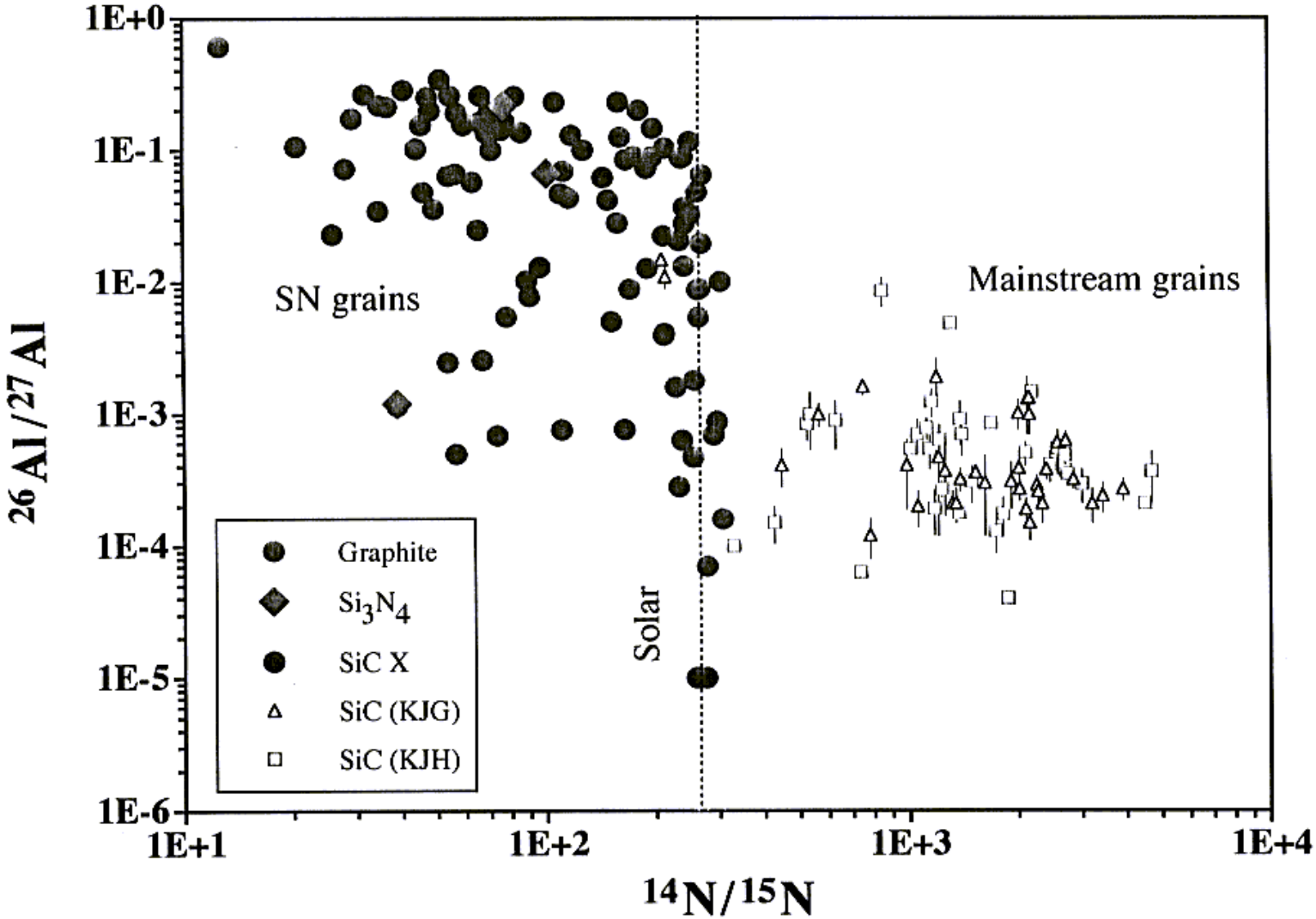


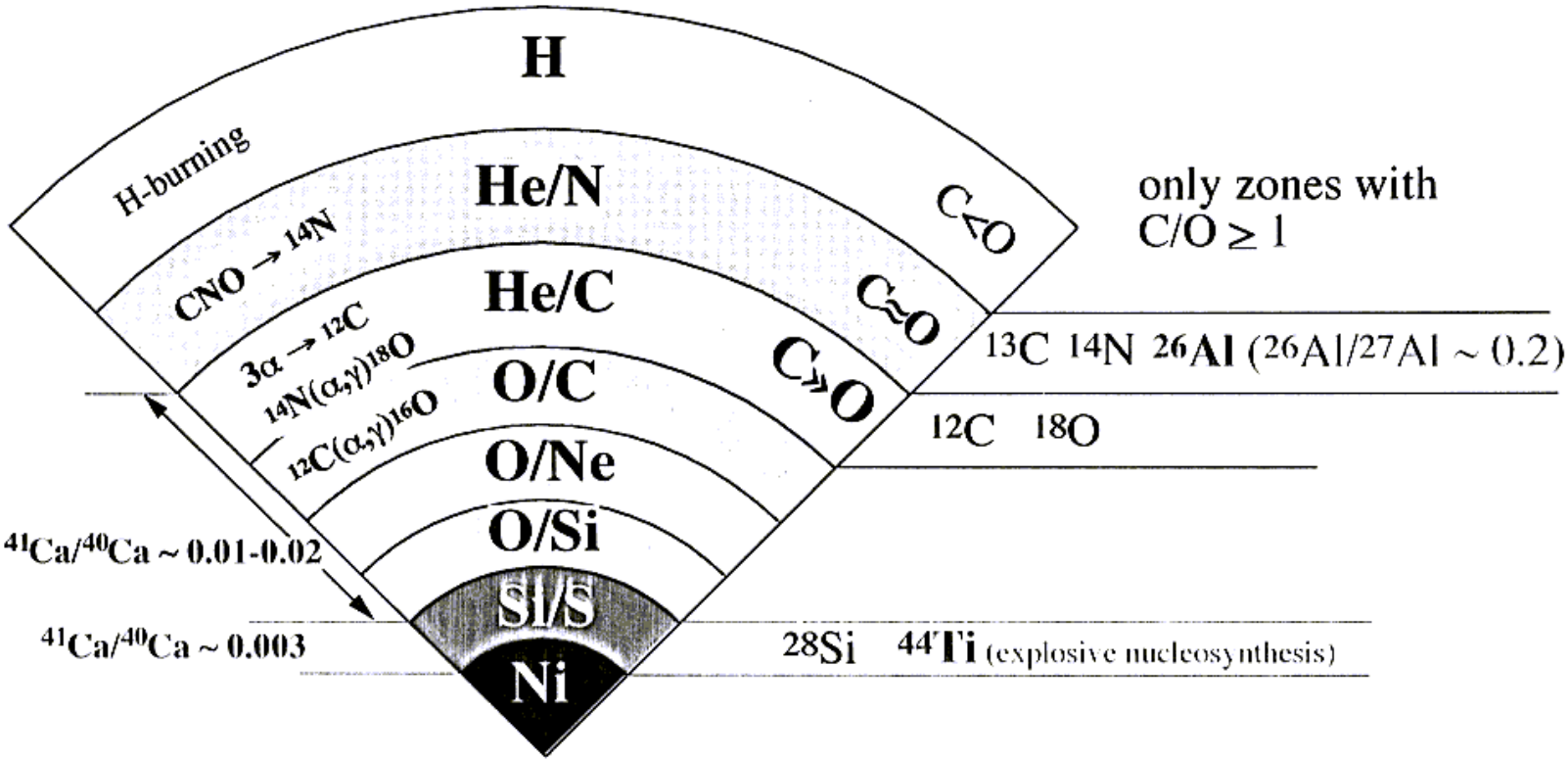



Murchison Graphite KFA1-302
$(^iCa/^{40}Ca)/(^iCa/^{40}Ca)_{solar}$
10^2
10^1
10^0
39
40
41
42
43
44
45
Ca-isotopic Mass



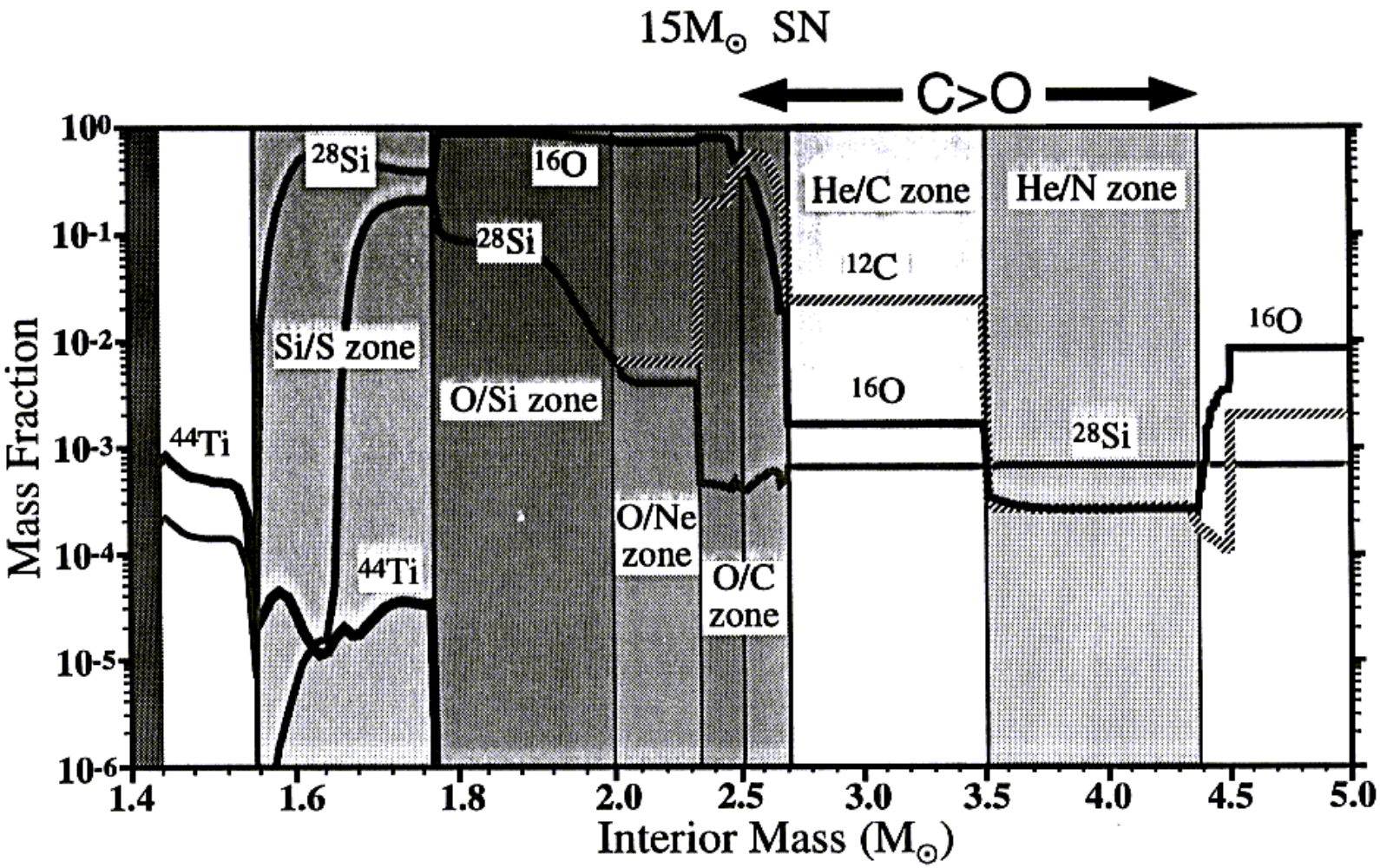
(Nittler et al., ApJ 462 L31-L34 (1996))

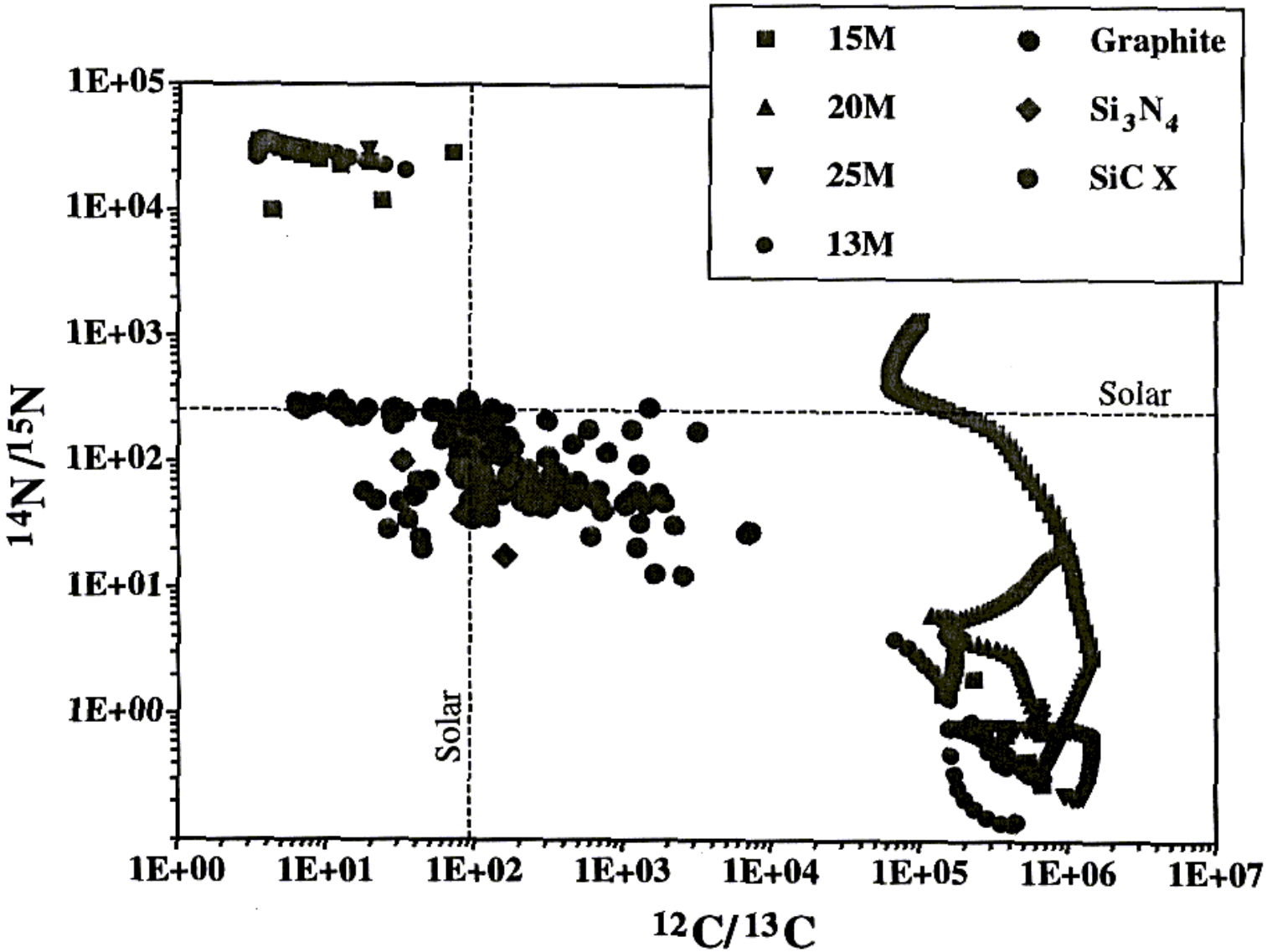

1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E+1
1E+2
1E+3
1E+4
$^{26}Al/^{27}Al$
$^{14}N/^{15}N$
SN grains
Mainstream grains
Solar
Graphite
Si_3N_4
SiC X
SiC (KJG)
SiC (KJH)



Schematic Structure of 15M$_\odot$ Star Before Explosion

(Meyer et al., 1995)


15M⊙ SN
C>O
Mass Fraction
Interior Mass (M⊙)
28Si
16O
28Si
44Ti
44Ti
Si/S zone
O/Si zone
O/Ne zone
O/C zone
He/C zone
He/N zone
12C
16O
28Si
16O


15M
20M
25M
13M
Graphite
Si_3N_4
SiC X
Solar
Solar
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
$^{14}N/^{15}N$
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
1E+06
1E+07
$^{12}C/^{13}C$

Conditions of mixing

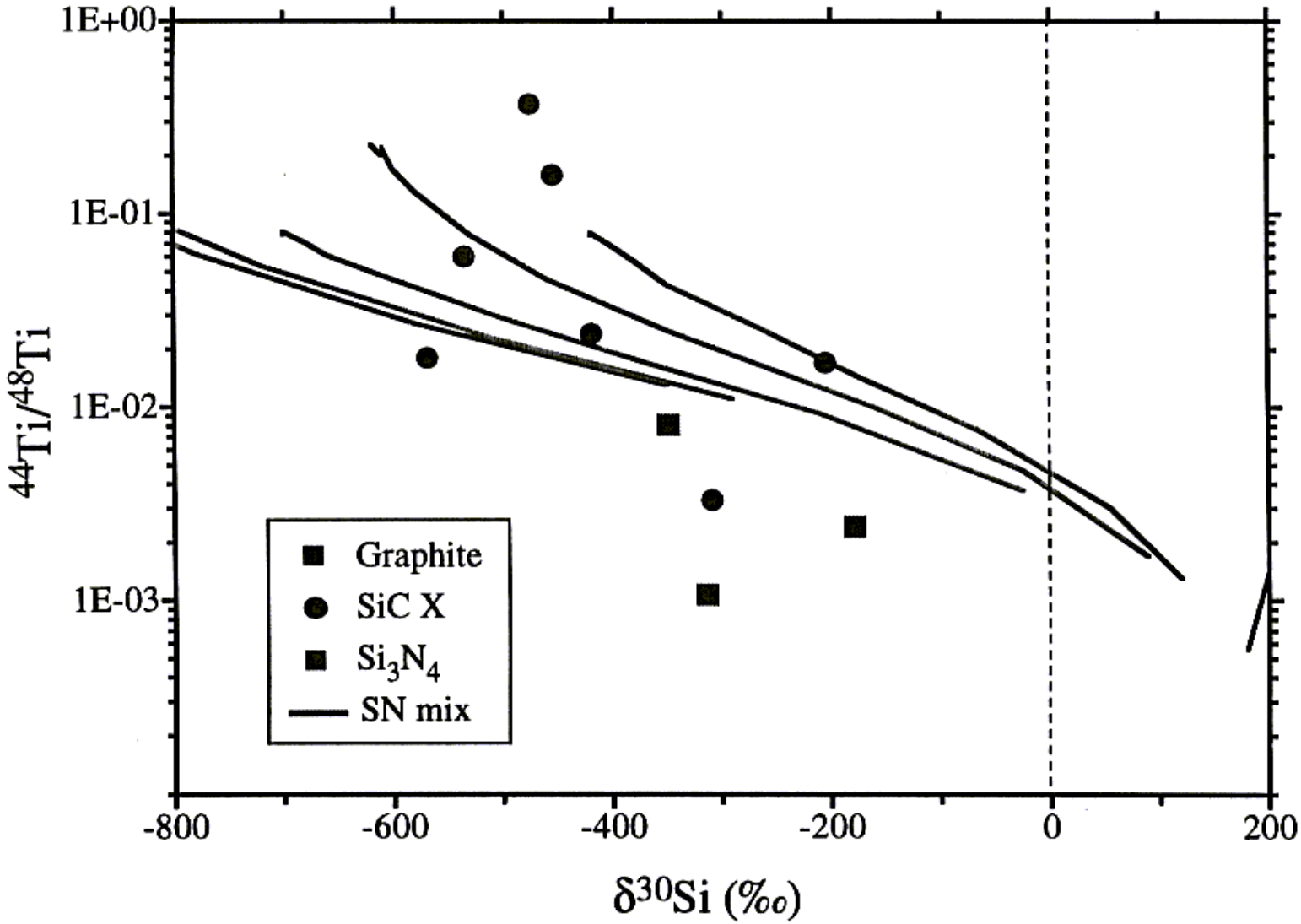
Vary:

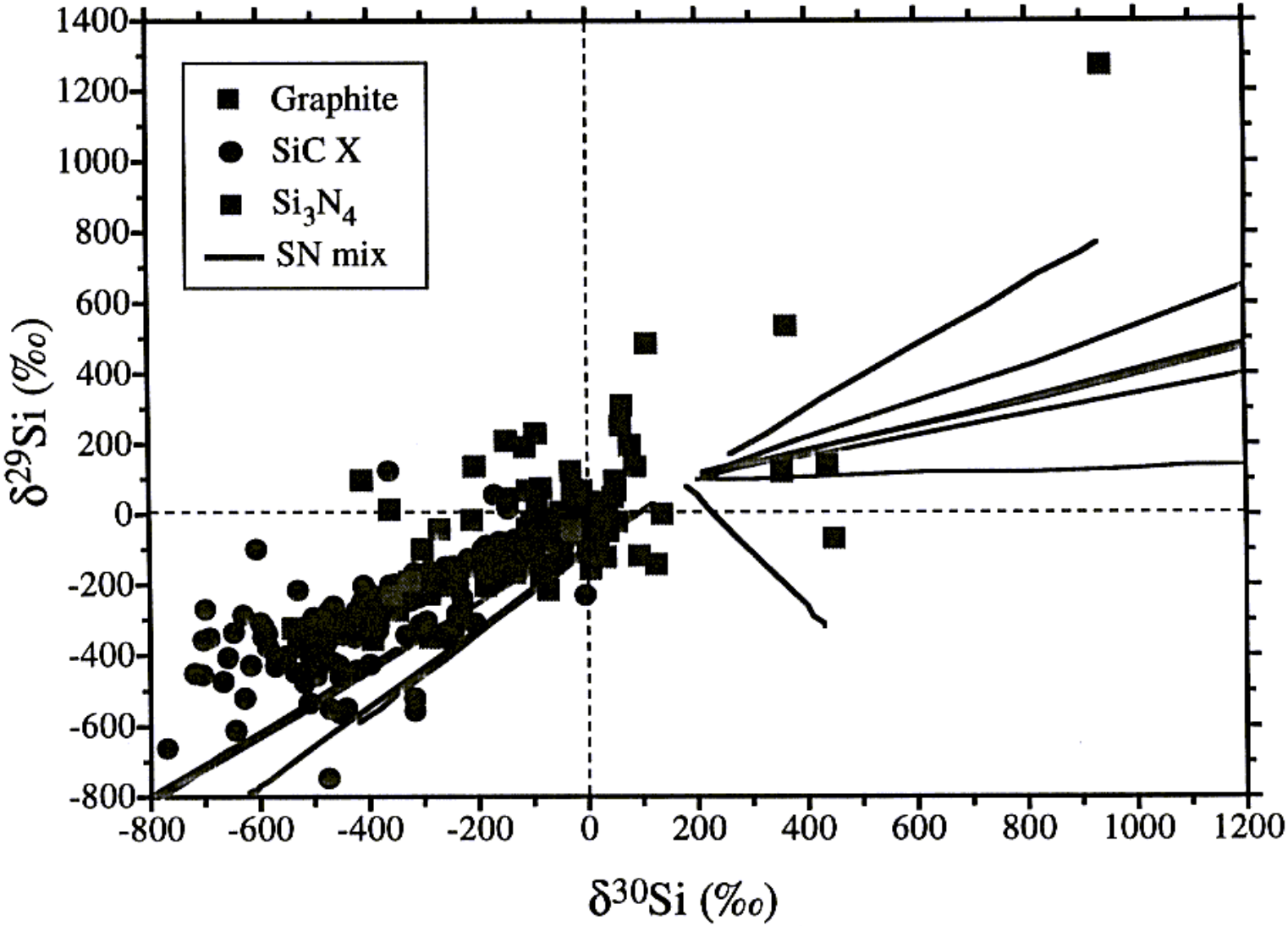
C/O:	1, 2, 3
$^{12}C/^{13}C$:	from 5 to 10^4
M4/M2:	0 and 0.05
M5/M2:	0, 0.005, 0.01, 0.05, 0.1, 0.5
M6/M2:	0, 0.005, 0.01, 0.05, 0.1

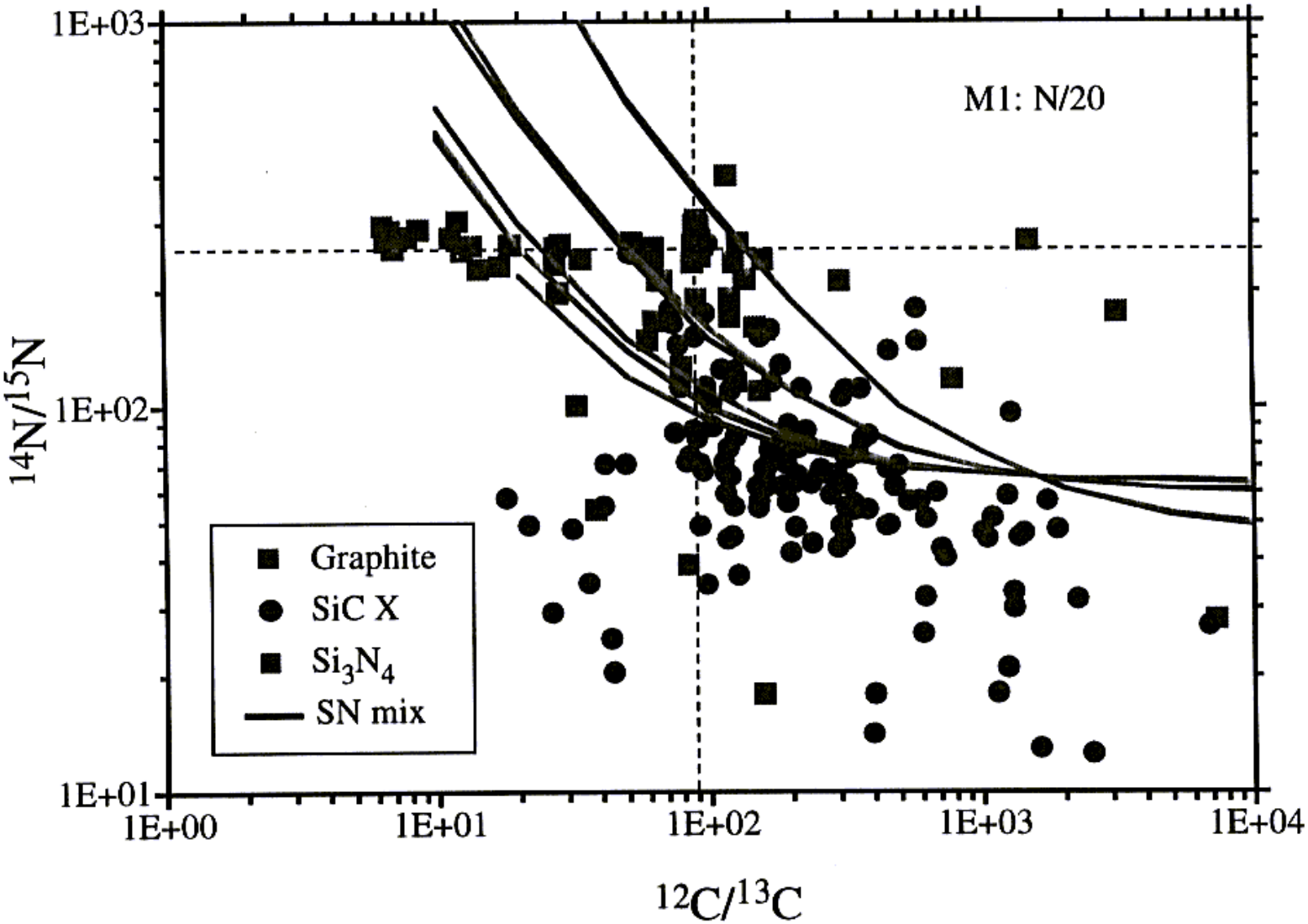
All plots shown are for a $15M_\odot$ supernova model with

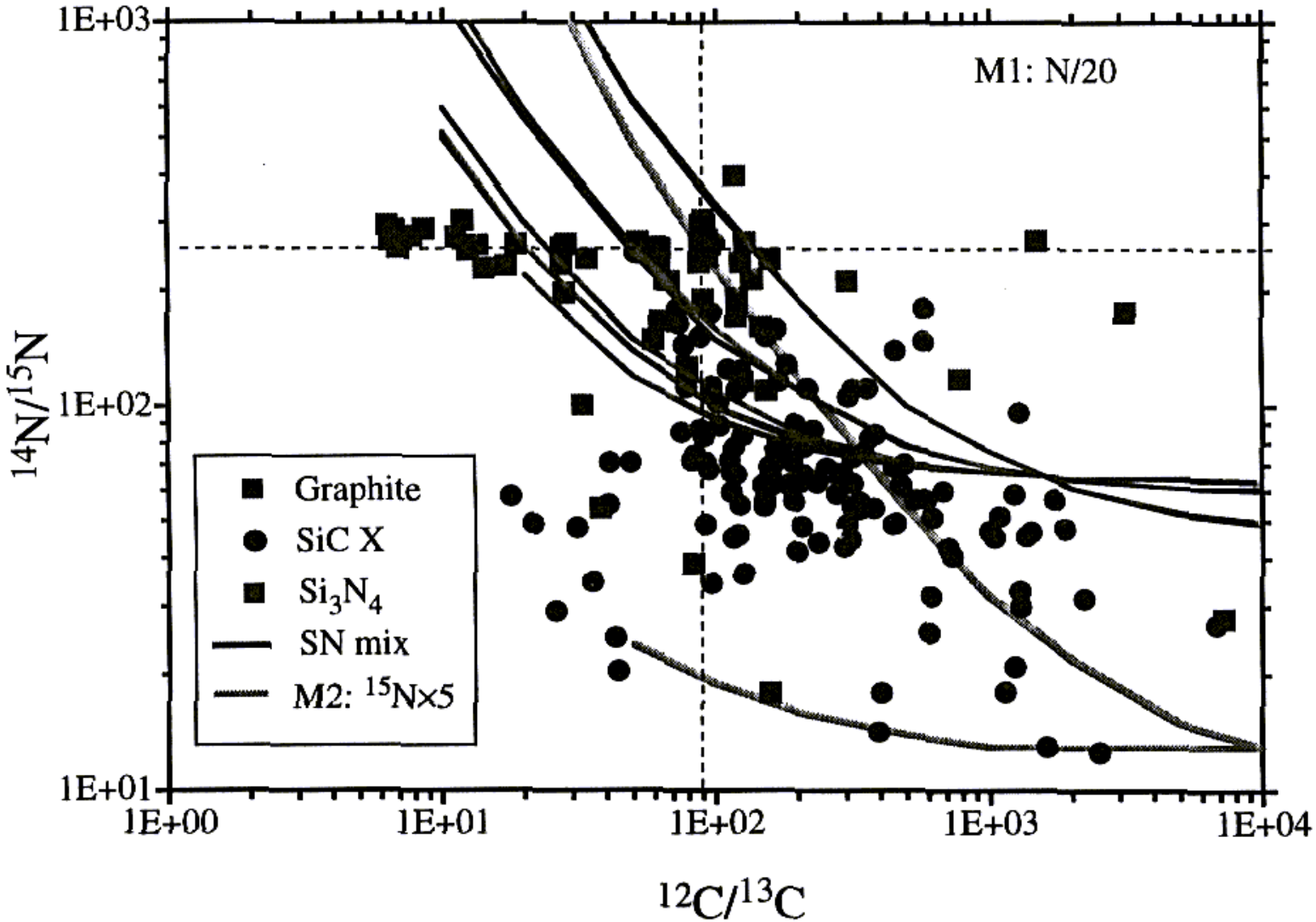
C/O = 1, M4/M2 = 0.05

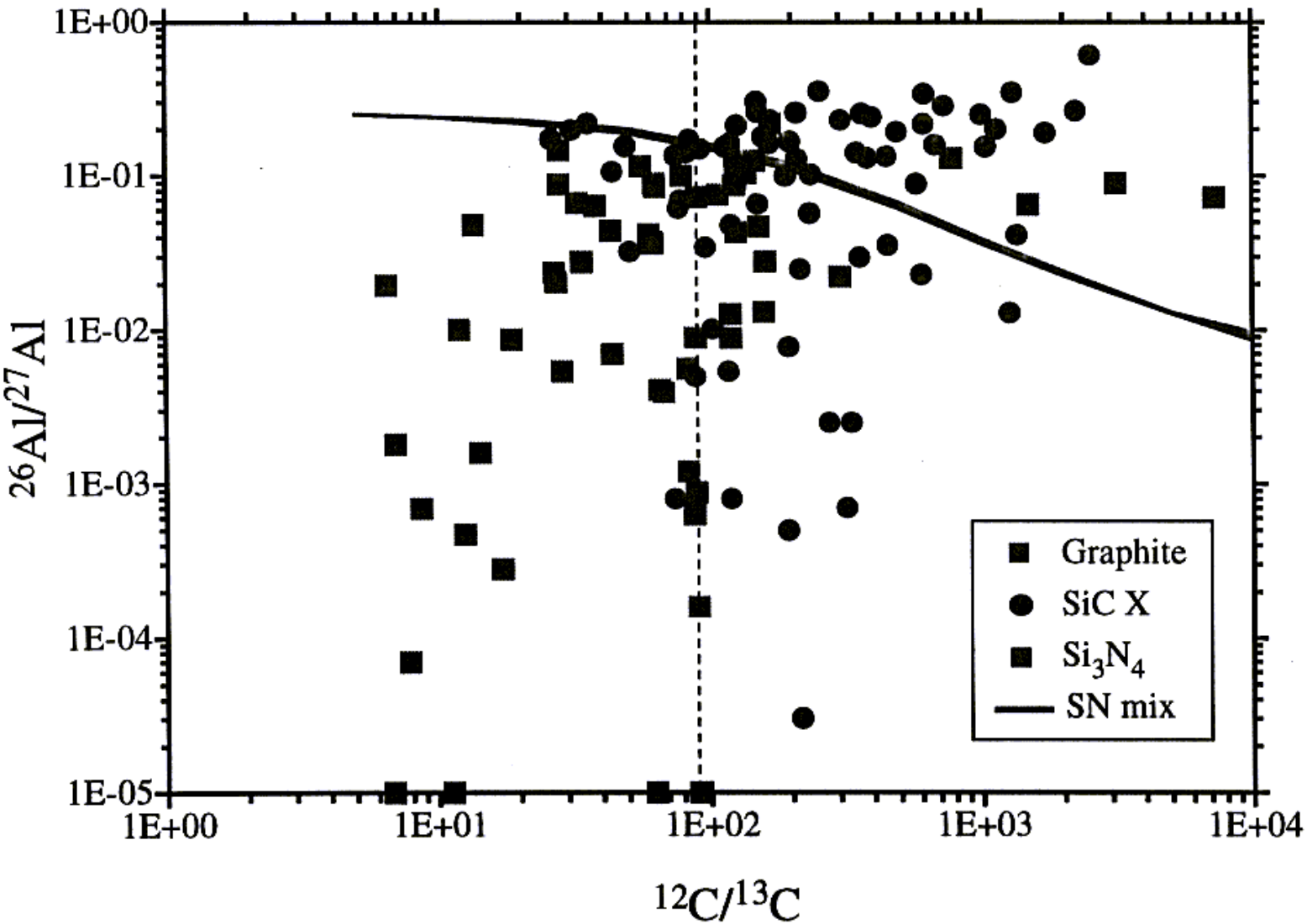
Nitrogen in zone M1 is reduced by a factor of 20

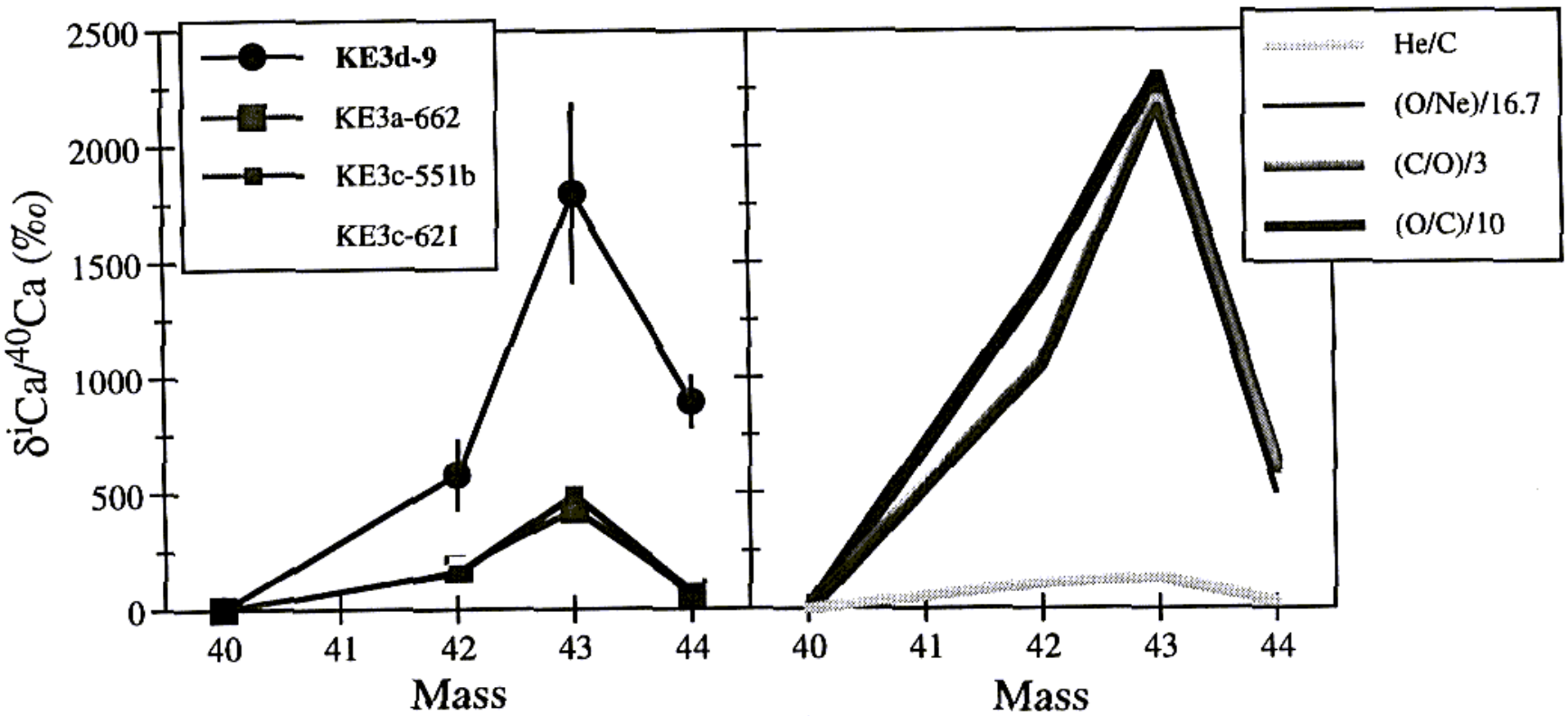

1E+00
1E-01
1E-02
1E-03
$^{44}Ti/^{48}Ti$
-800
-600
-400
-200
0
200
$\delta^{30}Si$ (‰)
Graphite
SiC X
Si_3N_4
SN mix

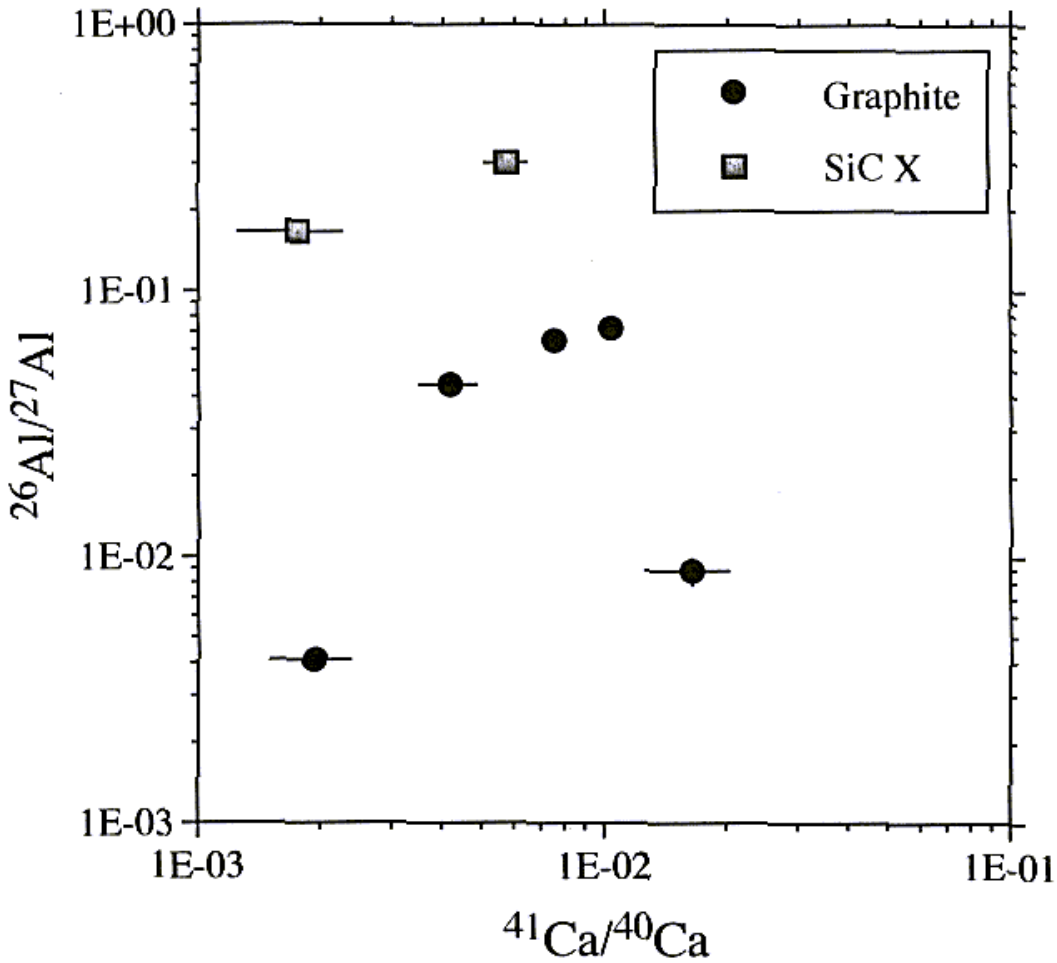

Graphite
SiC X
Si_3N_4
SN mix
$\delta^{29}Si$ (‰)
$\delta^{30}Si$ (‰)
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800
1000
1200

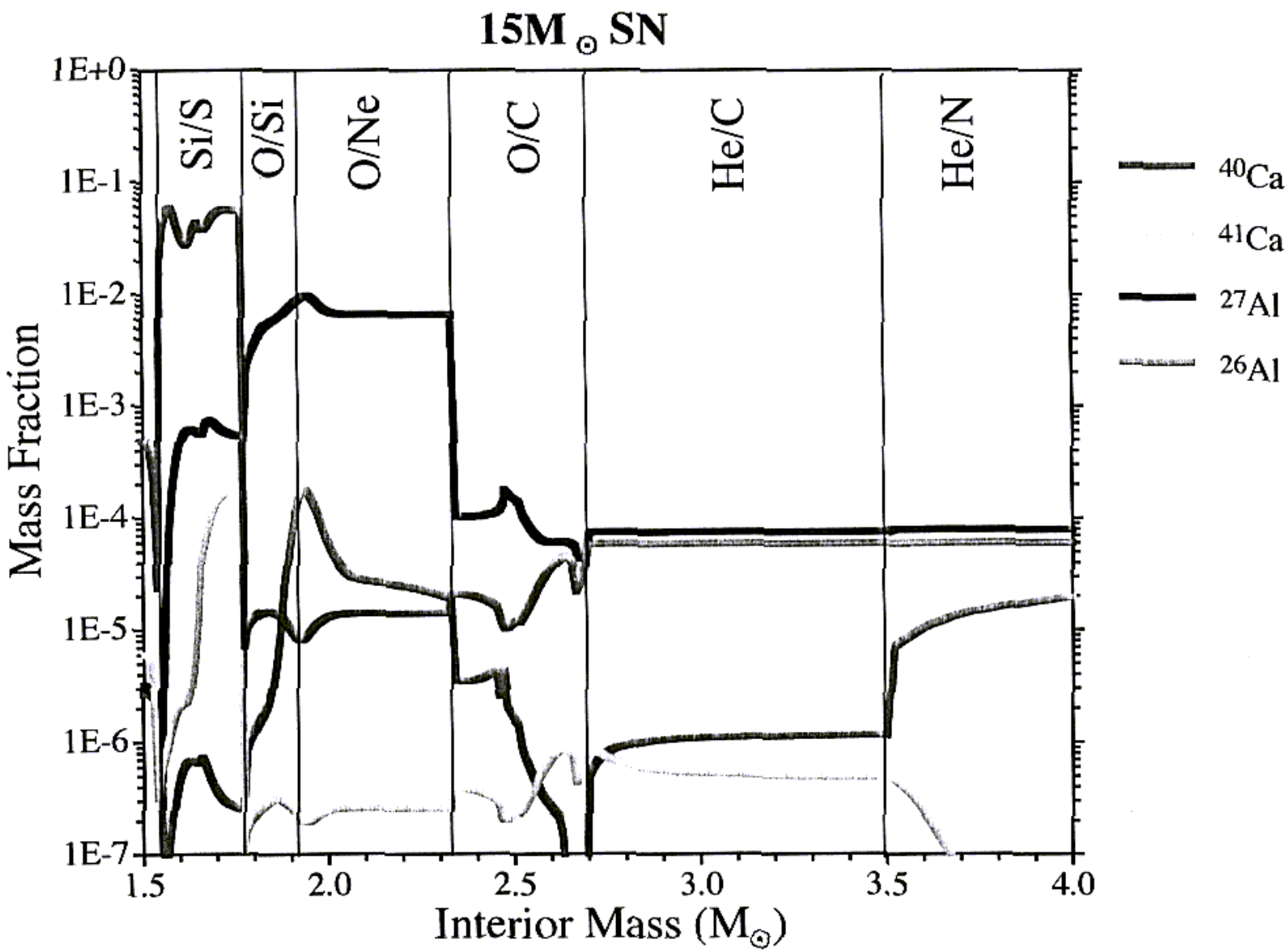

M1: N/20
Graphite
SiC X
Si_3N_4
SN mix
1E+03
1E+02
1E+01
1E+00
1E+01
1E+02
1E+03
1E+04
$^{14}N/^{15}N$
$^{12}C/^{13}C$

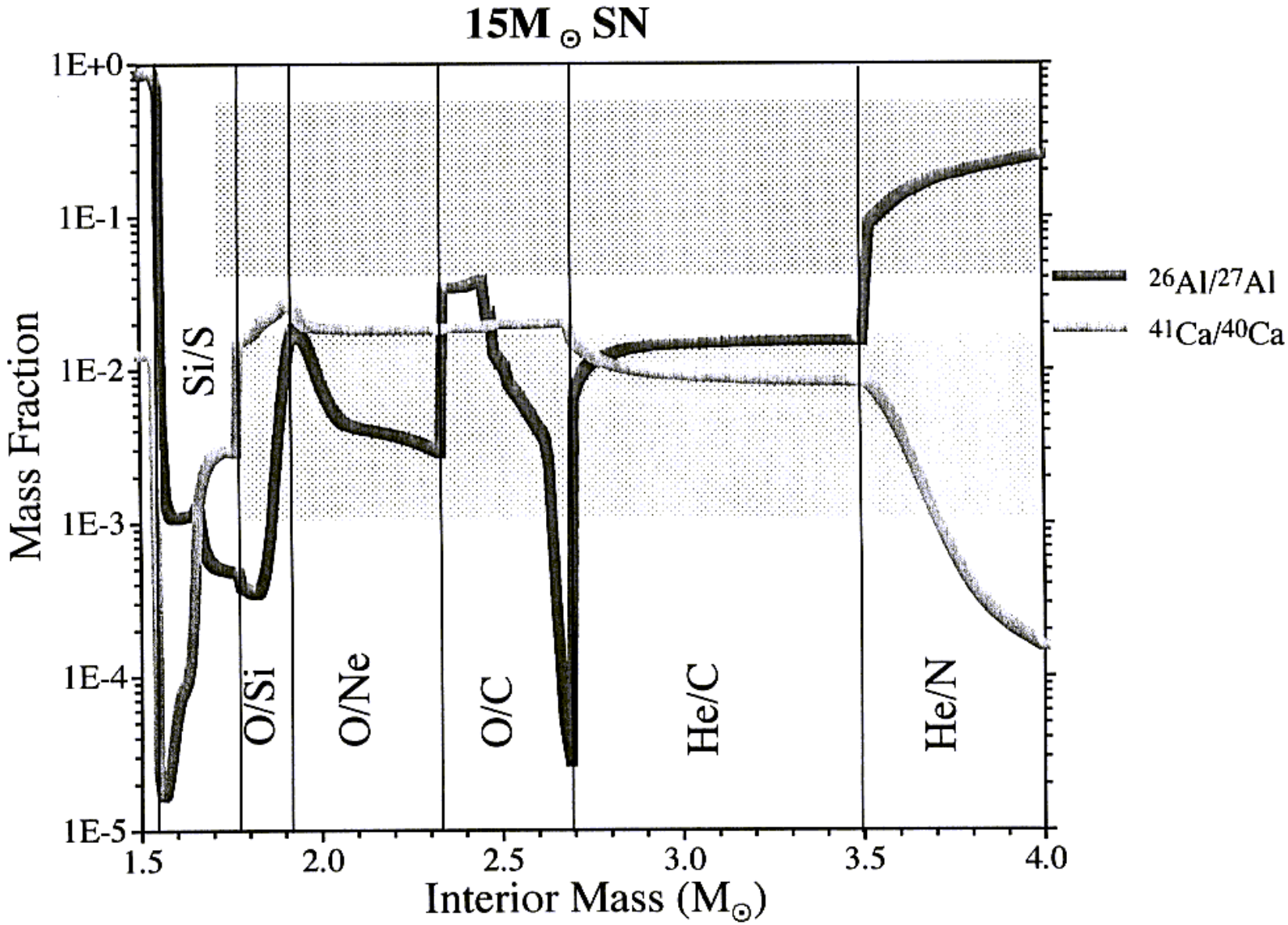

1E+03
1E+02
1E+01
1E+00
1E+01
1E+02
1E+03
1E+04
M1: N/20
Graphite
SiC X
Si_3N_4
SN mix
M2: $^{15}N\times5$
$^{14}N/^{15}N$
$^{12}C/^{13}C$


1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E+00
1E+01
1E+02
1E+03
1E+04
$^{26}Al/^{27}Al$
$^{12}C/^{13}C$
Graphite
SiC X
Si_3N_4
SN mix


2500
2000
1500
1000
500
0
$\delta^{i}Ca/^{40}Ca$ (‰)
KE3d-9
KE3a-662
KE3c-551b
KE3c-621
40
41
42
43
44
Mass
He/C
(O/Ne)/16.7
(C/O)/3
(O/C)/10
40
41
42
43
44
Mass


1E+00
1E-01
1E-02
1E-03
1E-03
1E-02
1E-01
$^{26}Al/^{27}Al$
$^{41}Ca/^{40}Ca$
Graphite
SiC X


15M⊙ SN
Si/S
O/Si
O/Ne
O/C
He/C
He/N
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
Mass Fraction
1.5
2.0
2.5
3.0
3.5
4.0
Interior Mass (M⊙)
40Ca
41Ca
27Al
26Al


15M⊙ SN
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
Mass Fraction
1.5
2.0
2.5
3.0
3.5
4.0
Interior Mass (M⊙)
Si/S
O/Si
O/Ne
O/C
He/C
He/N
26Al/27Al
41Ca/40Ca

Problems

1) Not enough ^{15}N in models
2) Not enough ^{26}Al, wrong correlation with C and N ratios
3) Not enough ^{29}Si
4) Not enough s-process nuclei from O-rich zone (^{43}Ca, ^{49}Ti, ^{50}Ti)
5) Lack of SN oxides among presolar grains

Possible fixes

1) Nuclear reaction rates. Possibly for ^{15}N and ^{29}Si.
2) Rotation, different convection criteria.
3) Elemental fractionation during mixing. E.g., selective condensation of certain elements. Chemical processes have to be better understood.
4) Apply multidimensional SN models. Mixing before explosion.