The C/O ratio in the formation location of presolar X grains from supernova

- SiC, graphite, Si_3N_4, TiC (inside graphites)
- about 1-2% of all SiC are X grains
- contain isotopic fingerprints of supernova
  - ^{28}Si, ^{12}C, ^{15}N
  - initial presence of large amounts of short-lived radionuclides such as ^{44}Ti (60 yr), ^{26}Al (716,000 yr), ^{49}V (330 days)

- focus on SiC and TiC here
- look at C/O ratios needed to make grains
- look at T effects on trace element patterns

Research supported by NSF Astronomy Division

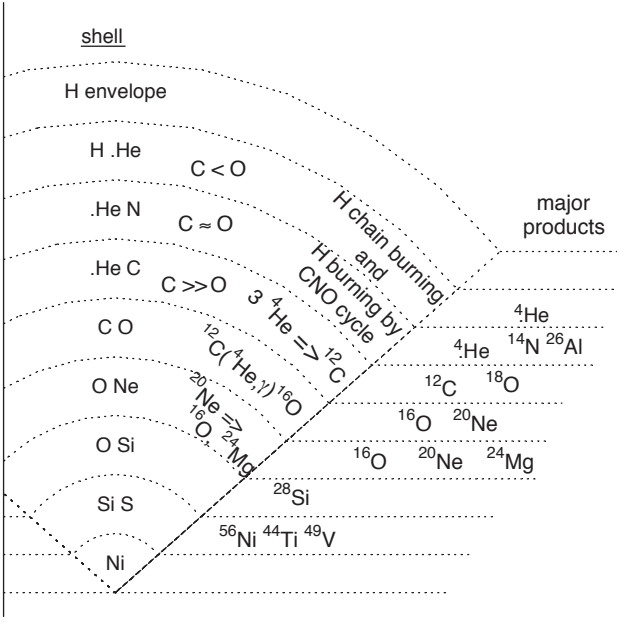
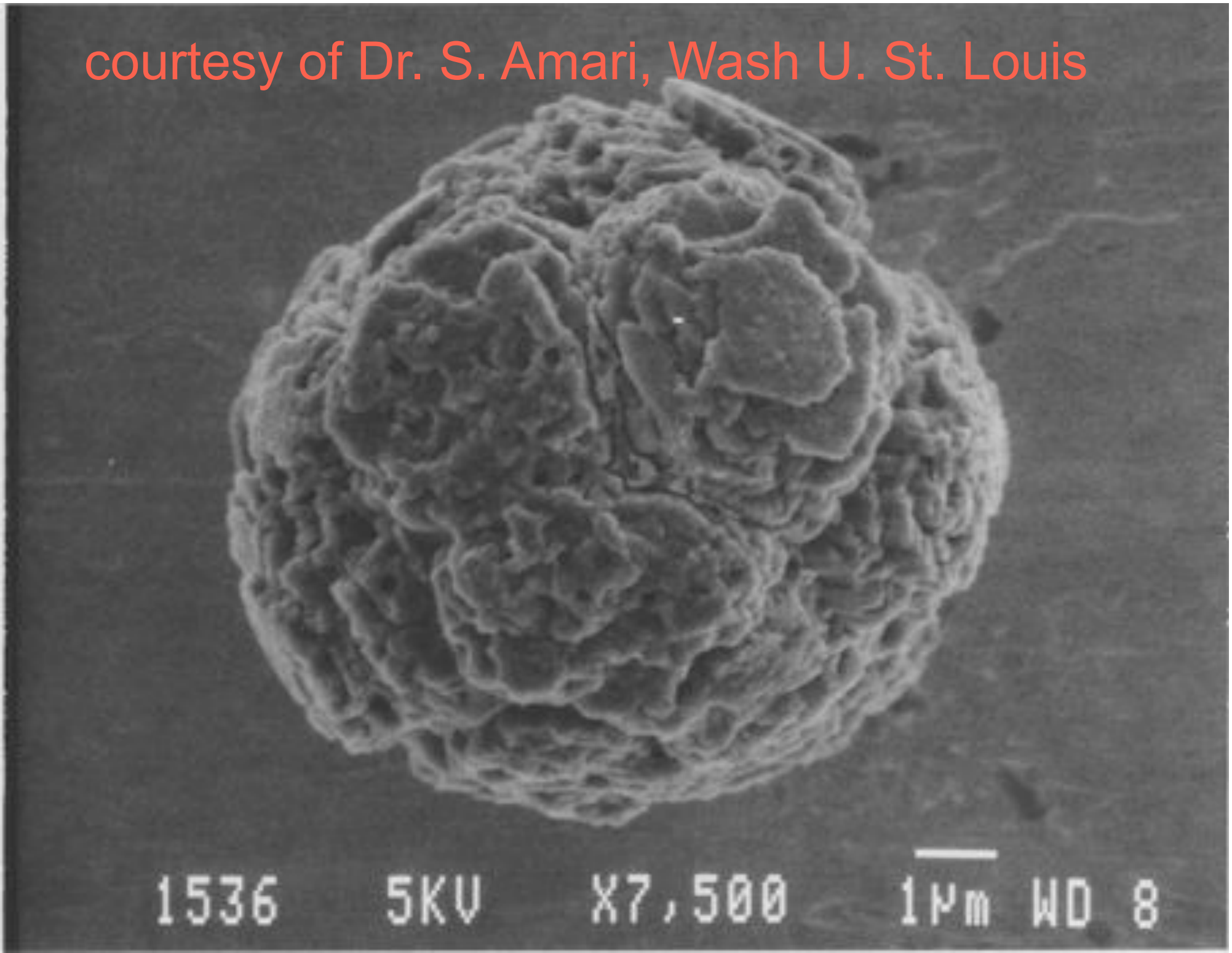
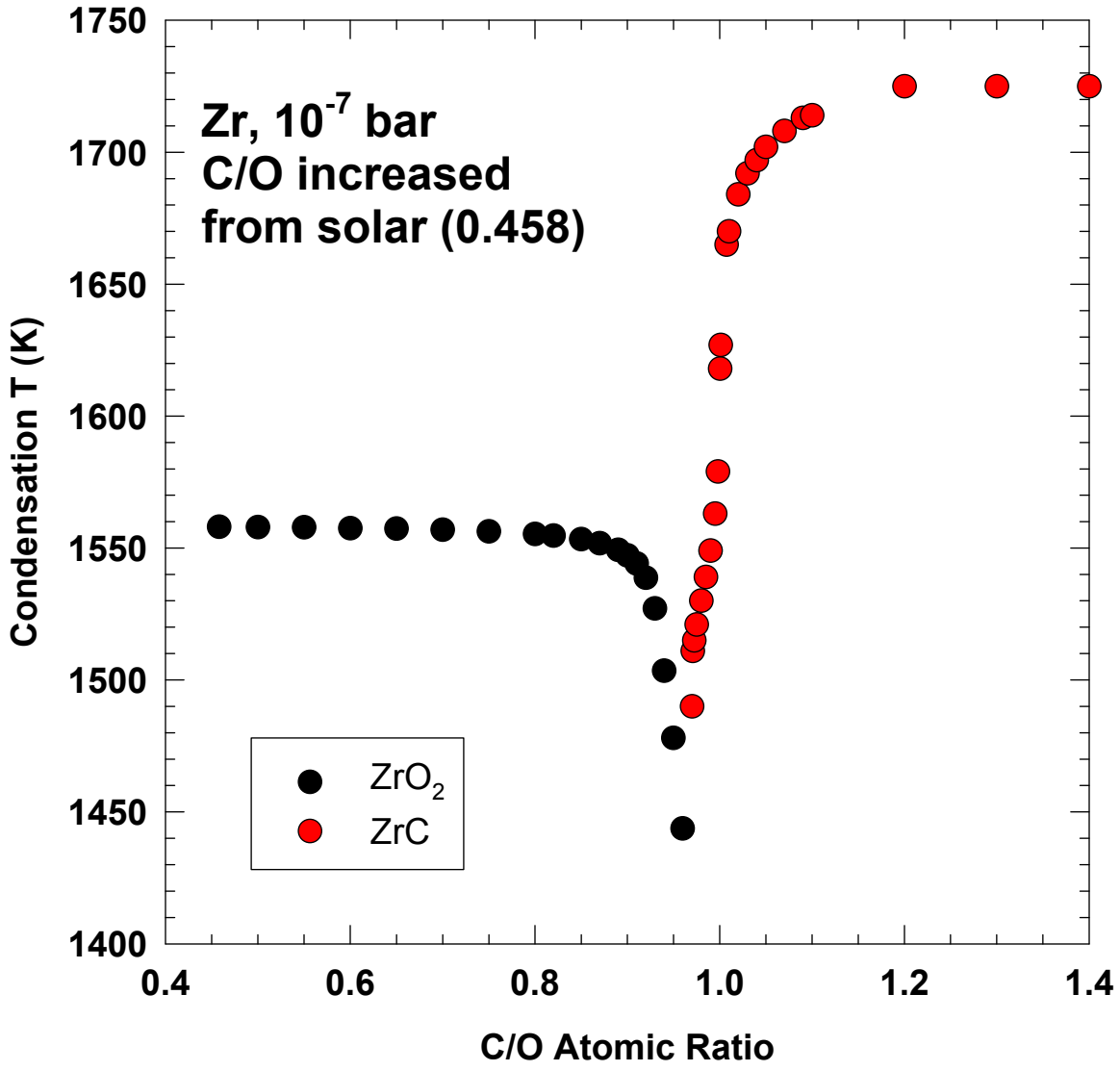


Fig. 23. The compositional zones resulting from nucleosynthesis in massive stars before they go supernovae are conveniently visualized in an "onion shell" diagram. Zones are labeled with the elements that make the major nuclear fuel and products. Some nuclear reactions and products of interest to presolar grain studies are indicated.

courtesy of Dr. S. Amari, Wash U. St. Louis




Zr, 10-7 bar
C/O increased
from solar (0.458)
ZrO2
ZrC
Condensation T (K)
C/O Atomic Ratio
1750
1700
1650
1600
1550
1500
1450
1400
0.4
0.6
0.8
1.0
1.2
1.4

Zr-VarCO.SPW

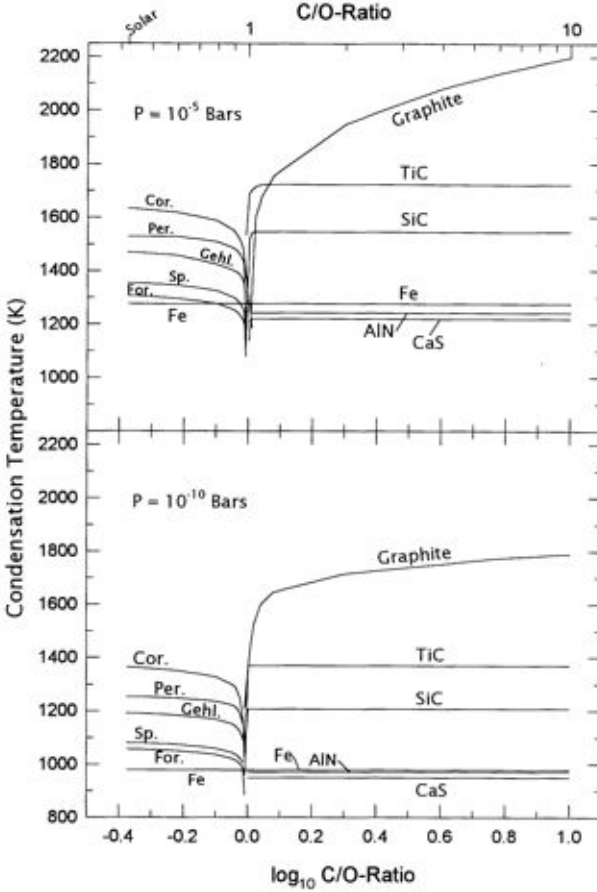
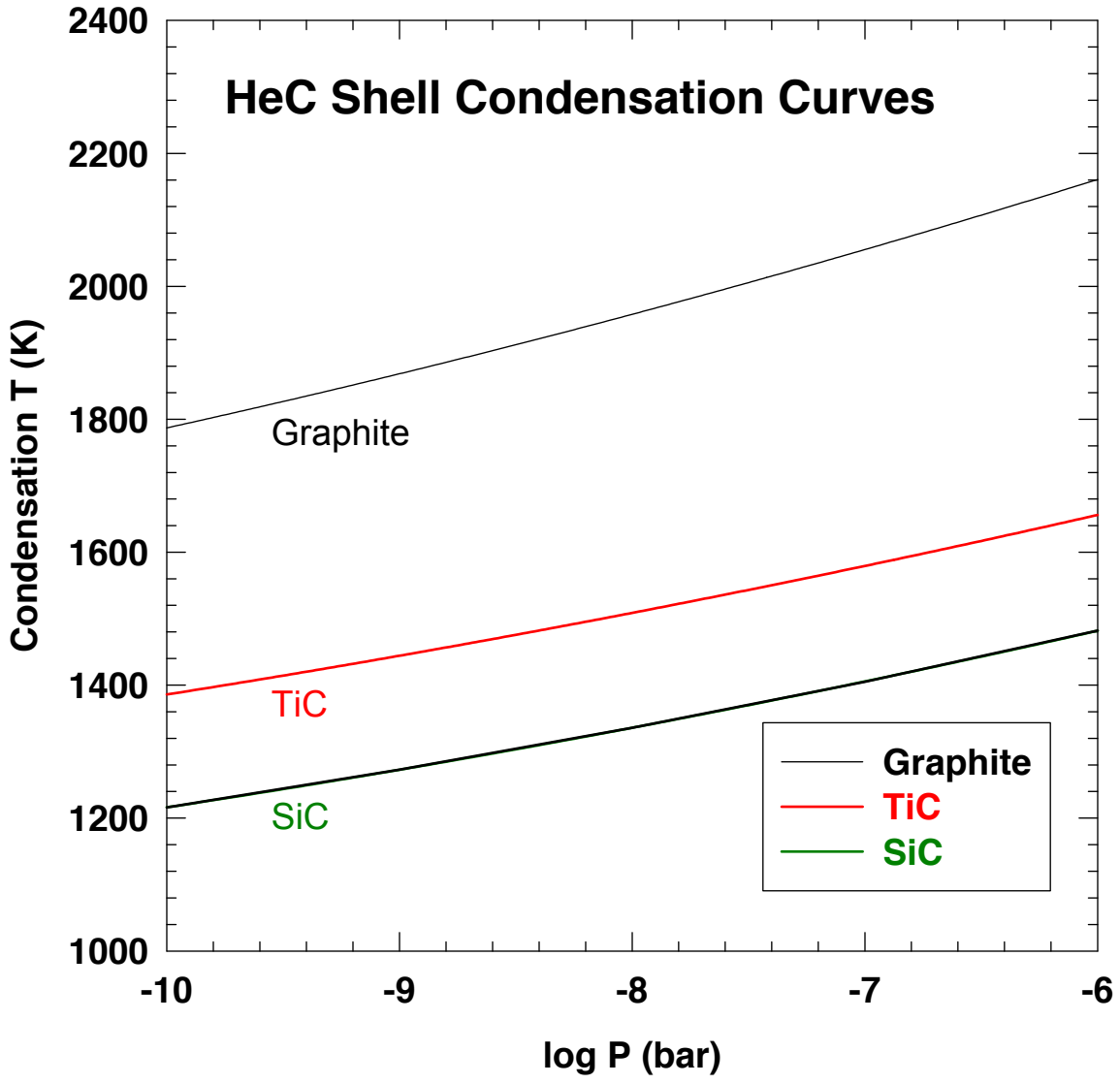
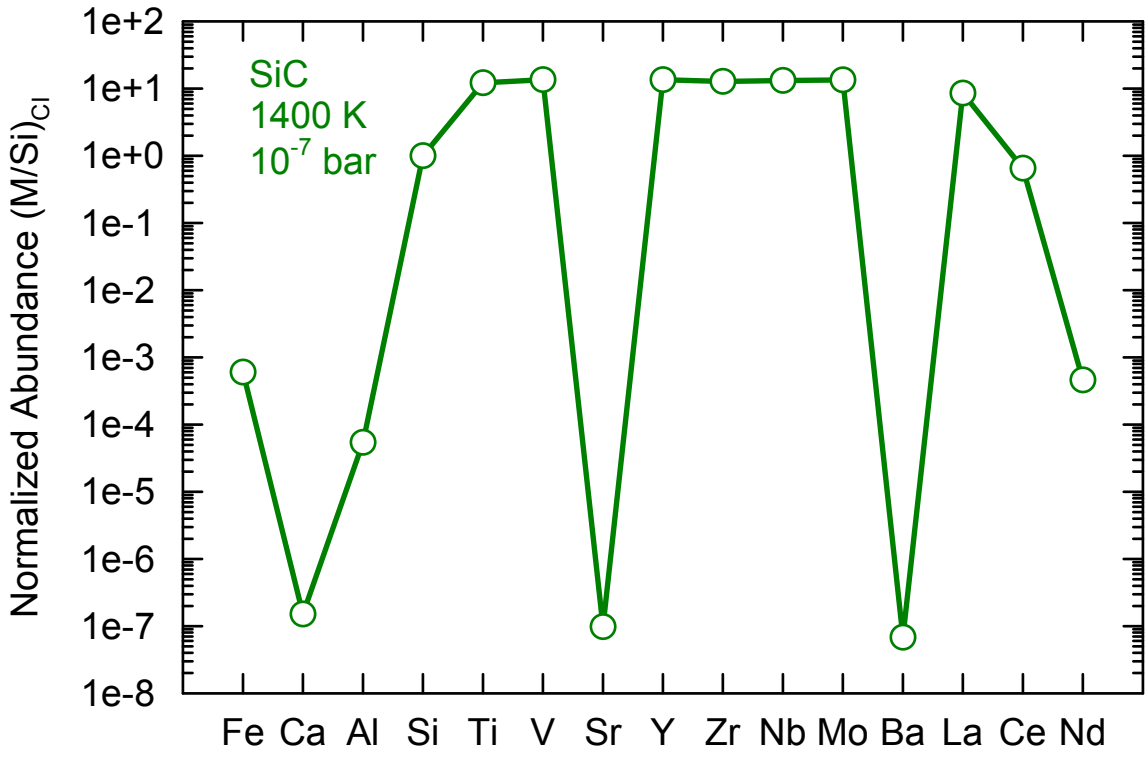


FIG. 2. Condensation temperatures of major elements as a function of C/O ratio for total pressures of 10^{-5} bars (top) and 10^{-10} bars (bottom). Lower total pressures generally decrease condensation temperatures. In both cases, low C/O ratios favor the formation of oxidized condensates, while high C/O ratios ≥ 0.98 lead to the formation of reduced condensates.

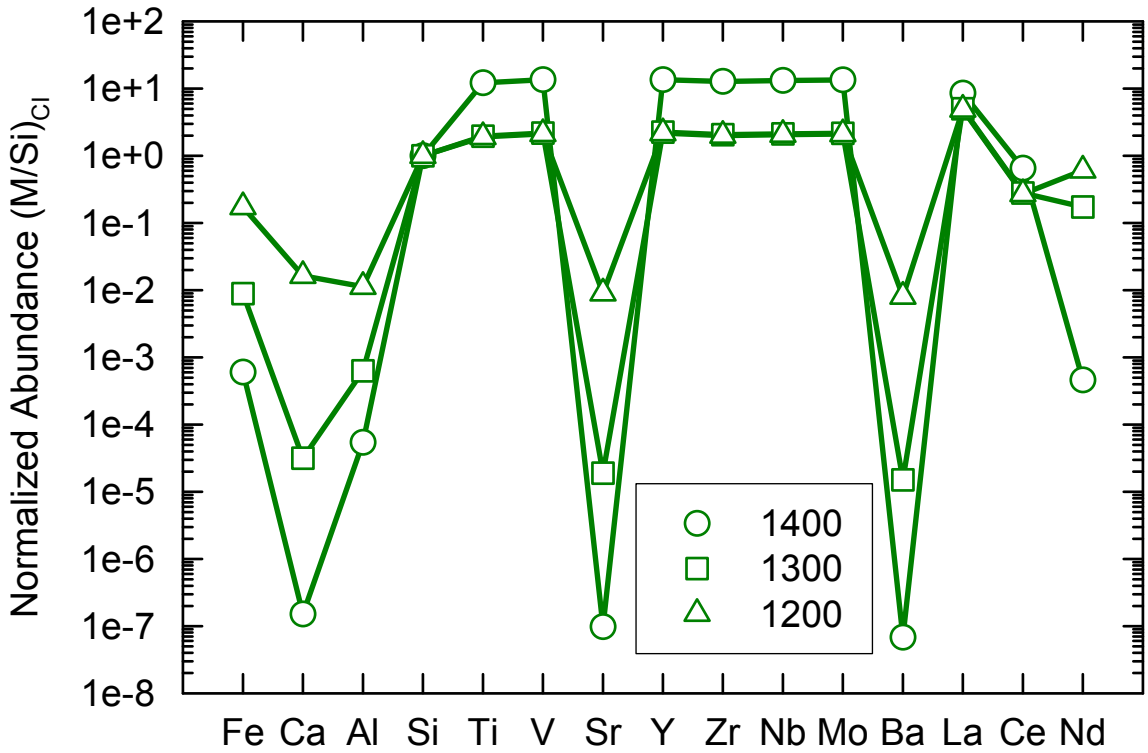


HeCShell.SPW



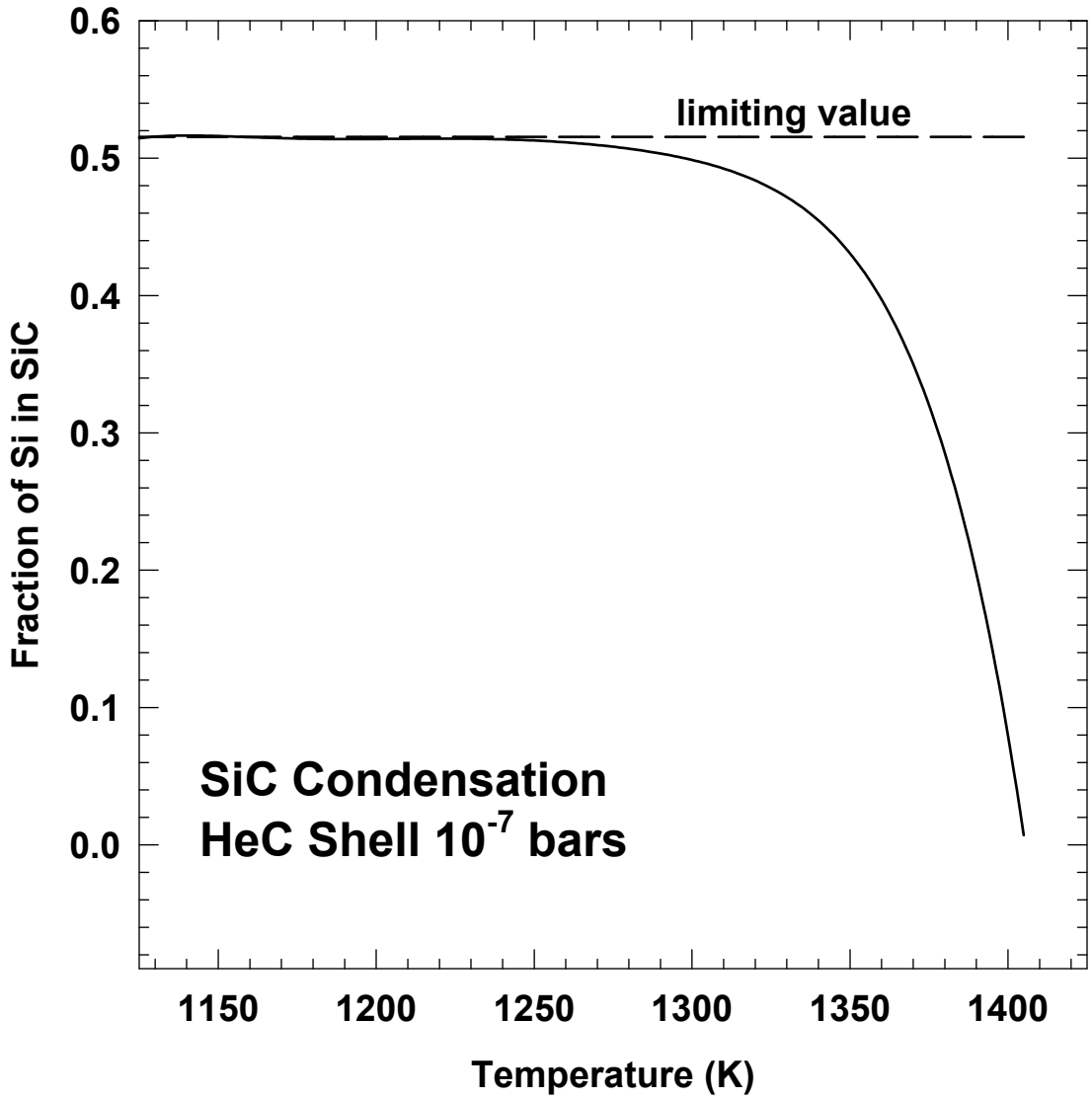
Ignores prior condensation of trace elements
into (Zr,Ti)C at higher temperature

SiC1400K

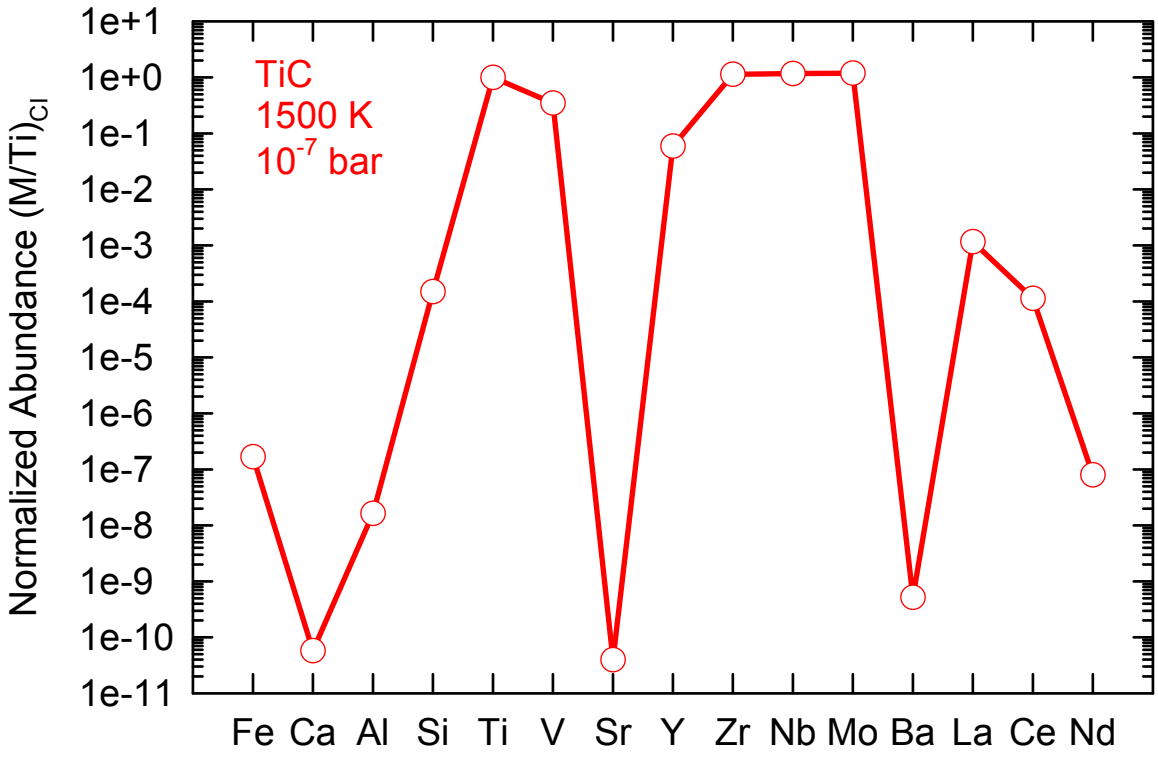


Elemental abundance patterns in SiC
HeC shell 10^{-7} bar and variable T (K)

SiC1400K


0.6
0.5
0.4
0.3
0.2
0.1
0.0
Fraction of Si in SiC
limiting value
SiC Condensation
HeC Shell 10-7 bars
1150
1200
1250
1300
1350
1400
Temperature (K)

SiCFrac.SPW


TiC
1500 K
10-7 bar
Normalized Abundance (M/Ti)CI
1e+1
1e+0
1e-1
1e-2
1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
1e-9
1e-10
1e-11
Fe Ca Al Si Ti V Sr Y Zr Nb Mo Ba La Ce Nd

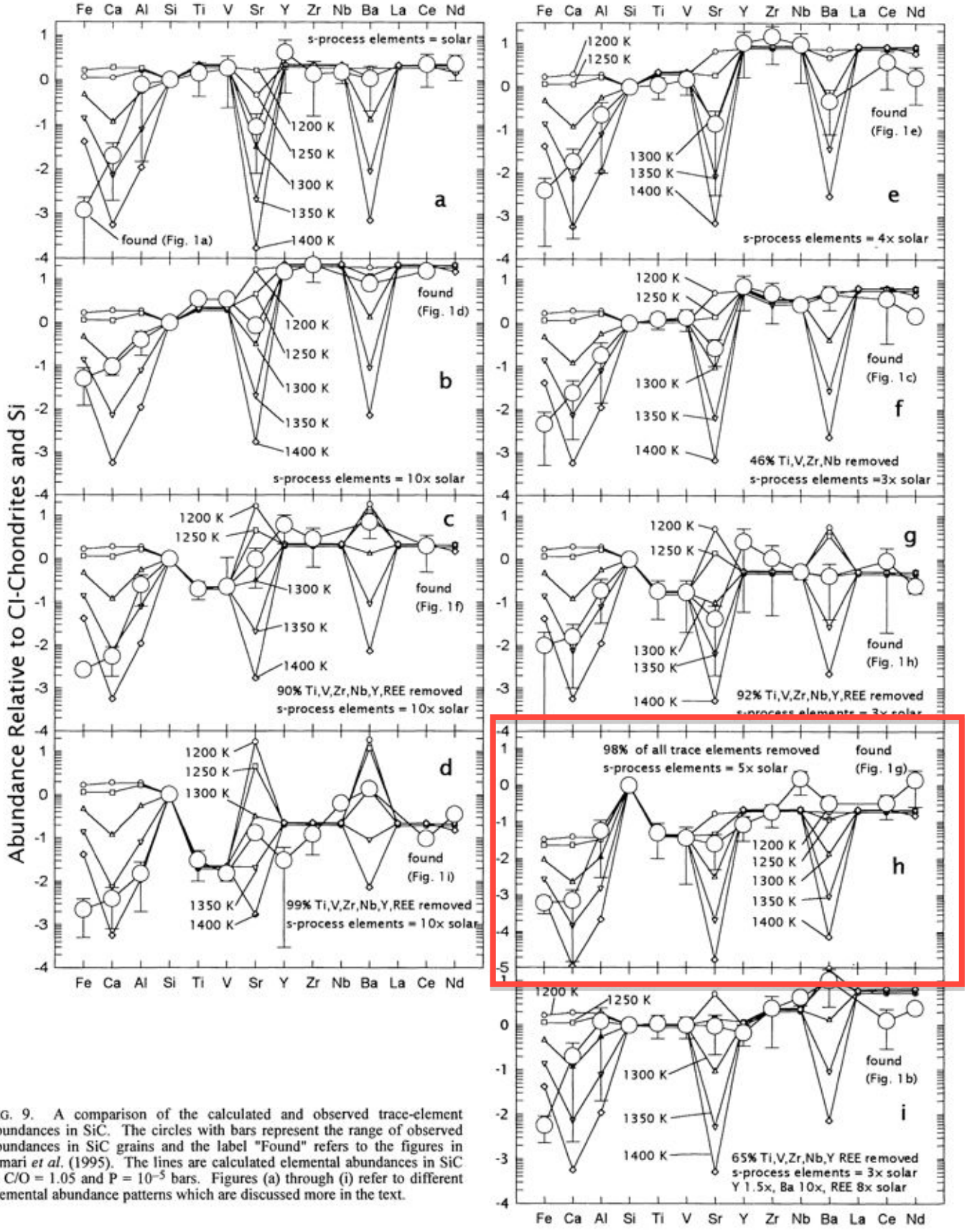


FIG. 9. A comparison of the calculated and observed trace-element abundances in SiC. The circles with bars represent the range of observed abundances in SiC grains and the label "Found" refers to the figures in Amari *et al.* (1995). The lines are calculated elemental abundances in SiC at C/O = 1.05 and P = 10^{-5} bars. Figures (a) through (i) refer to different elemental abundance patterns which are discussed more in the text.

Carbonaceous Dust – Formation vs. Destruction

Clayton et al propose growth of carbonaceous dust in supernova ejecta shell with O/C >1 via reactions such as

(1) $C + C_2 \rightarrow C_3 + h\nu$ $\qquad k_1 = 10^{-17}\ cm^3\ s^{-1}$

R_1 = rate of reaction 1

[C] = number density of C atoms

$R_1 = k_1[C][C_2]$

In this model, successive addition reactions build up carbon molecule chains that condense to form graphite grains.

However, O atoms rapidly oxidize C_2 to CO and C atoms

(2) $O + C_2 \rightarrow CO + C$ $\qquad k_2 = 6.0 \times 10^{-10} \exp(-1420/T)\ cm^3\ s^{-1}$

$R_2 = k_2[O][C_2]$

$R_2/R_1 = (k_2/k_1)([O]/[C]) = k_2/k_1$ if C/O = 1 and is larger for O/C >1

Oxidation proceeds faster than C atom addition

Hence no carbon chain growth in O-rich regions

Similar arguments show oxidation of SiC is rapid where O/C >1

Summary

C/O ratios greater than or equal to unity required to form C-bearing presolar grains (SiC, TiC, graphite)

Refractory trace element abundance patterns in the grains constrain formation conditions (T, P, C/O ratio)

Kinetic model for C-bearing grain formation at C/O < 1 does not appear feasible