PRESOLAR GRAPHITE FROM THE MURCHISON METEORITE: NOBLE GASES REVISITED.

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Introduction: Ne-E(L) is one of the anomalous noble gas components that ultimately led to the discovery of presolar grains in meteorites. The component is extremely enriched in ^{22}Ne and this fact prompted the idea that the ^{22}Ne is from the decay of ^{22}Na [1]. The carrier of Ne-E(L) is presolar graphite [2], which has been extracted from Murchison [3] and Orgueil [4]. There are four graphite-rich Murchison separates with a range of density (1.6–2.2 g/cm^3): KE1 (1.6–2.05 g/cm^3), KFA1 (2.05–2.10 g/cm^3), KFB1 (2.10–2.15 g/cm^3) and KFC1 (2.15–2.20 g/cm^3) [3]. KE1 was further separated to improve purity, yielding KE3 (1.65-1.72 g/cm^3) [5]. Thus, isotopic features of KE1 and KE3 can be regarded as the same.

One of the most interesting characteristics of presolar graphite is that isotopic features depend on density. Low-density graphite grains, which are characterized by ^{18}O excesses, Si isotopic anomalies (mainly in the form of ^{28}Si excesses) and high inferred ^{26}Al/^{27}Al ratios (up to 0.1), are believed to have formed in Type II supernovae [6]. On the other hand, high-density graphite grains from KFC1, with their high ^{12}C/^{13}C ratios and ^{30}Si excesses, most likely formed in low-metallicity AGB (asymptotic giant branch) stars [7]. In this paper, we will reexamine noble gas data previously obtained on the Murchison separates.

Data Sources: Two noble gas analyses were performed: Amari et al. [8] analyzed Ne, Ar, Kr and Xe in bulk (≡aggregates) samples from KE1, KFA1, KFB1 and KFC1 by stepwise heating. Nichols et al. [9] analyzed ^{4}He and ^{20,22}Ne in single grains from KE3, KFB1 and KFC1.

Discussion: We will mainly focus on the data on KE1 and KE3.

Neon-22. Amari et al. [8] concluded that the ^{22}Ne in presolar graphite is dominantly from ^{22}Na, but portion of it originated from the He-shell and that the proportion of ^{22}Ne of the two origins depend on density. Nichols et al. [9] found 9 ^{22}Ne-rich grains out of 21 KE3 grains and were able to obtain an upper limit of the ^{20}Ne/^{22}Ne ratio of 0.01 for grain KE3a-573. Of the 9 grains, 8 grains were previously analyzed for their C, O, and Si isotopic ratios with ion probe. Seven grains show ^{18}O/^{16}O ratios higher than the solar ratio (2×10^{-3}), ranging from 6.83×10^{-3} to 0.119. Inferred ^{44}Ti/^{48}Ti ratios of two of the seven grains are $(1.06\pm0.22)\times10^{-3}$ and $(2.4\pm1.1)\times10^{-3}$. The grain with the normal ^{18}O/^{16}O ratio shows ^{28}Si excess (δ^{29}Si = –235±97 ‰, δ^{30}Si = –327±128 ‰). All ^{22}Ne-rich grains show ^{18}O excesses and/or ^{28}Si excesses, indicating they formed in supernovae.

The lowest ^{20}Ne/^{22}Ne ratio is found in the He/C zone in supernovae, where ^{14}N is converted to ^{22}Ne. The ^{20}Ne/^{22}Ne ratio in the zone is expected to be 0.096 in a 25M$_\odot$ model with the solar metallicty by Heger et al. [10] and 0.088 by Chieffi and Limongi [11], which are much higher than an upper limit of the ^{20}Ne/^{22}Ne ratio of grain KE3a-573. This indicates that the ^{22}Ne in the grain was originally incorporated as ^{22}Na, not as ^{22}Ne implanted onto the grain. If the latter was the case, ^{20}Ne should also have been implanted, resulting in a much higher ^{20}Ne/^{22}Ne ratio than 0.01.

Although upper limits of ^{20}Ne/^{22}Ne ratios of the other grains are not available, the portion of ^{22}Ne from ^{22}Na can be determined from the Ne isotopic ratios of KE1 (^{20}Ne/^{22}Ne = 0.0301±0.0018, ^{21}Ne/^{22}Ne = 0.000118±0.000017). Assuming that the Ne in KE1 is a mixture of ^{22}Ne from ^{22}Na, Ne from the He-shell and solar Ne, more than 99% of the ^{22}Ne in KE1 originated from ^{22}Na. Thus, all ^{22}Ne-rich grains contain ^{22}Ne from ^{22}Na, as first suggested by Nichols et al. [9]. ^{22}Na is produced in the O/Ne zone during the hydrostatic burning by ^{21}Ne(p,γ)^{22}Na, where ^{21}Ne is produced by ^{20}Ne(n,γ)^{21}Ne and protons are produced by ^{12}C(^{12}C,p)^{23}Na [11].

Krypton. ^{86}Kr/^{82}Kr and ^{80}Kr/^{82}Kr are very sensitive to nucleosynthetic conditions. When an unstable isotope ^{85}Kr is at the ground state, it decays to ^{85}Rb with the half-life of 11 years. When it is at the isomeric state, it decays faster to ^{85}Rb ($T_{1/2}$ = 4.48h). During core He burning, the ground and the isomeric states are not thermalized and need to be treated independently. During shell C burning, there is full thermalization between the ground state and the isomeric state [12]. In any case, ^{86}Kr yields depend on neutron density. The half-life of ^{79}Se strongly depends on temperature. It is much shorter at stellar conditions (one month at ~1×10^9K) than in terrestrial conditions (650,000 years) [13]. As a consequence, ^{80}Kr yields depend on neutron density and temperature.

Amari et al. [8] have found that the four Murchison separates are enriched *s*-process Kr (Kr-S) and that in a ^{86}Kr/^{82}Kr–^{83}Kr/^{82}Kr plot, KE1+KFA1 and KFC1 form two distinct lines, indicating there are two Kr-S components: Kr-SH in KFC1 and Kr-SL in the lower density separate. To infer Kr-SH, we assumed (^{83}Kr/^{82}Kr)s ≡ 0.375 instead of 0.30 used by Amari et al. [8], reflecting the improvement of precisions of analyses in neutron capture cross sections (Table 1). Kr-SH, with a high ^{86}Kr/^{82}Kr ratio, most likely originated from low-metallicity AGB stars as concluded by Amari et al. [8]. Kr-SL was originally associated with high-metallicity AGB stars or a mixture of AGB and massive stars, thus its isotopic ratios were inferred by assuming ^{83}Kr/^{82}Kr = 0.30. Since this value (as well as 0.375) is derived for the main *s*-process component, it is necessary to reevaluate the ^{83}Kr/^{82}Kr to apply for low-density graphite grains, which formed in supernovae. Since the lowest ^{86}Kr/^{82}Kr and ^{83}Kr/^{82}Kr ratios observed in the grains are 1 and 0.7, respectively [8], Kr-SL must have smaller ratios than those.

Table 1. Krypton isotopic ratios

	80/82	83/82	84/82	86/82
KE1+KFA1	0.070 ±0.045	≡0.334	1.26 ±0.65	0.02 ±0.26
KE1+KFA1	0.127 ±0.023	≡0.623	2.86 ±0.33	0.67 ±0.14
KFC1	0.030 ±0.047	≡0.375	2.58 ±0.41	4.43 ±0.46
O/C*	0.405	0.334	1.41	0.0938
O/Ne*	0.0656	0.623	1.97	0.726

* A 25M$_{\odot}$ model by [11]

Chieffi and Limongi constructed a set of explosive yields of massive stars of solar metallicity in the mass range of 11–120M$_{\odot}$, using the FRANEC code that includes a nuclear network extending to ^{98}Mo [11]. Their 15M$_{\odot}$ model can be excluded from a source of the Kr in the low-density grains because the ^{86}Kr/^{82}Kr ratio in the O/Ne zone is 5.05 and the ^{83}Kr/^{82}Kr ratio of the bottom of the O/C zone is 2.504. In their 25M$_{\odot}$ and 35M$_{\odot}$ models, the ^{83}Kr/^{82}Kr ratio is ~0.3 (0.334 in 25M$_{\odot}$ and 0.310 for 35M$_{\odot}$) in the O/C zone (6.2–6.6M$_{\odot}$ in Fig. 1), and ~0.6 (0.623 in 25M$_{\odot}$ and 0.597 in 35M$_{\odot}$) in the O/Ne zone (2.6–6.2M$_{\odot}$ in Fig. 1). The average neutron density in the O/C zone is $\leq 10^6$ n/cm^3 [14], whereas that in the O/Ne zone reaches 10^{12} n/cm^3 [15], which by far exceeds the range of a classical notion of the *s*-process. The KE1+KFA1 data were extrapolated to ^{83}Kr/^{82}Kr = 0.334 and 0.623 to examine the zone where the Kr in the grains originated (Table 1). When extrapolated to 0.334 (hence assuming the Kr was produced in the O/C zone), both ^{80}Kr/^{82}Kr and ^{86}Kr/^{82}Kr ratios are close to zero, whereas the model predicts a much higher ^{80}Kr/^{82}Kr ratio. When extrapolated to 0.623, the ^{80}Kr/^{82}Kr ratio from the grains is still higher than the ratio from the model.

It is difficult to conclude which zone is responsible for the Kr in the grains because of huge uncertainties in ^{86}Kr and ^{80}Kr yields. The neutron capture cross section of ^{85}Kr is theoretically estimated with ~80 % uncertainty [16]. The cross section of ^{79}Se is theoretically determined with a huge uncertainty up to 50 %. Moreover, as the half-life of ^{79}Se strongly depends on temperature, a slight difference in temperature can result in a big difference in ^{80}Kr yields.

Summary: Two stellar sources of ^{22}Na of Ne-E(L) are novae and supernovae. Supernovae are a dominant stellar source of ^{22}Na in low-density graphite grains. The Kr in the grains shows a signature of neutron capture in supernovae. Its detailed origin is remained to be seen.

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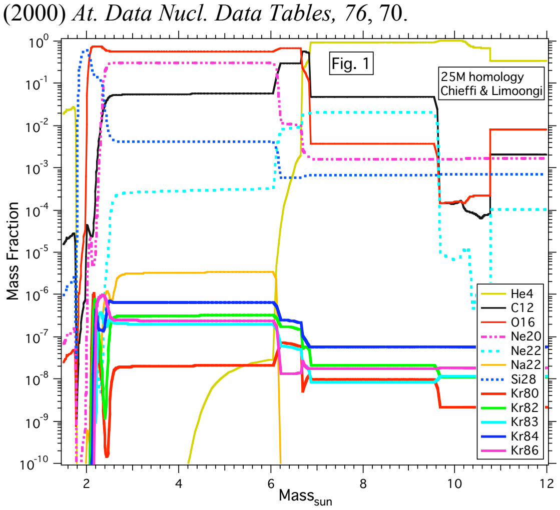

Fig. 1