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IRON ISOTOPIC DIAGNOSTICS OF PRESOLAR SUPERNOVA GRAINS. D.D. Clayton, B. S. Meyer, L.-S. The, *Department of Physics and Astronomy, Clemson University, Clemson SC 29634-0978*.

Introduction. The most thoroughly studied of the isotopically anomalous presolar grains are silicon-carbide crystals (1). Both X-type SiC and low-density graphite grains condensed within the interiors of supernovae during their expansion and cooling (2). This paper concerns itself with iron in those supernova condensates (SUNOCONs), for which Fe anomalies was an early prediction (3). A major problem in SUNOCON interpretation has been that although the grains clearly represent supernova interiors, it is not clear from which parcels of gas the grains condensed. The presence of 60-yr ^{44}Ti in SUNOCONs as a major isotope of Ti demonstrates the prompt condensation of titanium, long before supernova ejecta have mixed with circumstellar matter, and even long before the reverse shock reheats the supernovae ejecta. To try to simultaneously condense ^{15}N-rich, ^{28}Si-rich and ^{13}C-bearing carbonaceous SUNOCONs, some authors have argued that the velocity mixing observed among bulk fluid elements within supernova ejecta can be taken to also imply molecular mixing, and thus have taken mixed gaseous mixtures from disparate supernova shells as appropriate condensing matter. But Clayton (4) has argued that mixing at the molecular level is too slow to establish mixed gaseous compositions except along the turbulent boundaries. We suggest the possibility of mixing of a different type; namely, initial condensates later penetrating into different supernova zones and acquiring trace elements appropriate to them. Measurements of the isotopic composition of iron within SUNOCONs can help identify the supernova zones that contributed the iron. Measurements of Fe concentrations within SiC grains (5) show them to be sufficiently abundant for secondary-ion mass spectroscopy (SIMS).

Iron is of three types within supernovae: initial iron, s-process iron, and "new iron". The initial iron, which may have approximately solar isotopic composition, will persist unchanged within the presupernova star to the depth at which helium burning begins. In a 25M$_\odot$ star this is roughly the outer 15M$_\odot$. The s-process iron exists in the inner 10M$_\odot$ of the presupernova matter, being established by helium burning in the convective core, followed by helium burning in the convective He shell, followed by carbon burning in the core and later in a carbon burning shell surrounding the carbon-exhausted core. The concentration of Fe will be slightly decreased by these processes. Thirdly, the "new Fe" is created by the central explosive nucleosynthesis.

Iron in s-process shells. The structure of the 25M$_\odot$ preSN before core collapse has been calculated by Woosley and Weaver (6) and by The et al. (7). All matter that has ever burned helium has been exposed to the s process, with variable neutron fluence depending on the exact location. The overabundance (X/X$_\odot$) of each isotope (^{54}Fe, ^{56}Fe, ^{57}Fe, ^{58}Fe resp.) in three large defined zones of the presupernova are: He-shell (0.66, 0.91, 3.0, 11.8); CO core (0.001, 0.11, 1.81, 71); C-shell (0.0005, 0.056, 1.73, 54). These numbers show that the inner 9M$_\odot$ of the 25M$_\odot$ supernovae are characterized throughout by large ^{58}Fe excess at the time when oxygen and silicon burning begins in the center. The total depletion of Fe reaches only 1/4 of solar, however, because the depleted ^{56}Fe is mostly moved to ^{58}Fe. The mass range for these zones in the presupernova star are (with some variations owing to differing treatments of convection by various authors) : 3<m<5.7 for the C-burning shell; 5.7<m<6.5 for the He-exhausted CO; and 6.5<m< 9 for the He-burning shell with m in M$_\odot$ units. The He shell may be cosmochemically implicated as the only portion of the supernova that is carbon-rich and ^{18}O-rich, since ^{18}O-richness is also a common diagnostic of supernova grains. Unless the new Fe synthesized by the central explosive burning is incorporated into the supernova condensates (SUNOCONs), the primary expectation will clearly be for ^{58}Fe richness of trace iron.

Explosively synthesized iron. The sequence of iron nucleosynthesis was solved three decades ago (8,9). More than half of the galactic content has been produced in Type Ia supernovae. We focus on core-collapse Type II supernovae, because those provide more plausible condensation sites for the presolar SUNOCONs in meteorites (but see (10) for the possibility of Type Ia SUNOCONs). Within Type II events the iron originates in silicon burning and from the alpha-rich reassembly of matter broken down by the shock wave into alpha particles and neutrons. This is triggered by the temperature jump associated with the passage of the shock wave (6). Owing to the gradient of the post-shock temperature (6), the concentrations of iron isotopes vary widely within the inner three solar masses of ejecta, as shown in Fig. 1.

Focus first on the peak in ^{54}Fe concentration between mass coordinates (m = 1.9 and m=2.3M$_\odot$). At m>2.8 the ^{54}Fe mass fraction is less than solar (7.3 x 10^{-5} g/g) owing to the destructive prior effects of the s process, as described above. For 1.9 <m<2.2 the flat peak of ^{54}Fe represents the silicon-burning ejecta. This region is the main source of supernova synthesis of ^{54}Fe, which is greatly in excess there relative to ^{56}Fe. Some ^{44}Ti also lies in this zone, but at only 1-2% of ^{48}Ti. In the inner portions of completed silicon burning (m=1.9) the ^{56}Fe isotope dominates the mass; but in partial Si burning (m=2.1) ^{54}Fe is even the most abundant isotope of iron and Si is the most abundant element. This transition is explained by (8, Fig. 12) and by (9, Fig. 19). If SUNOCON growth incorporates matter from this range, large positive excess in ^{54}Fe/^{56}Fe ratio can be expected, accompanied by negligible ^{58}Fe and interesting variations of the ^{57}Fe/^{56}Fe ratio. This matter is also ^{28}Si-rich because ^{28}Si/^{30}Si changes from less than solar for m>2.6 to greater than solar inward from m=2.6. Inward from the same m=2.6 border the ^{12}C/^{13}C ratio changes from greater than 600 to less than 600, also an interesting number for SUNOCON carbon. This entire range is ^{15}N-rich from neutrino interactions with O. These similarities to SUNOCONs offer hope for

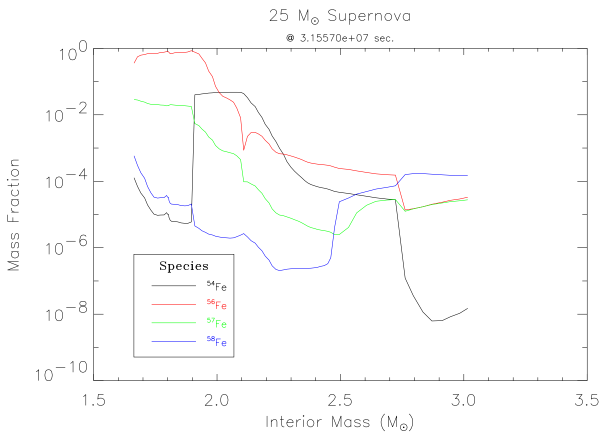

Figure 1: *The mass fractions of each iron isotope in the region of explosive nucleosynthesis in a 25*$M_\odot$ *supernova (6). This figure can be reconstructed from the Clemson web site for Galactic Chemical Evolution (http://photon.phys.clemson.edu/gce.html), where tabulated values may also be obtained. Iron concentration is much enriched. Solar mass fractions* $X_\odot$ *of each isotope (*^{54}*Fe,* ^{56}*Fe,* ^{57}*Fe,* ^{58}*Fe, resp.) are 7.3x10*$^{-5}$*, 1.2x10*$^{-3}$*, 2.9x10*$^{-5}$*, 3.7x10*$^{-6}$*. Alpha-rich freezeout occurs at m<1.9. Silicon burning producing* ^{54}*Fe occurs at 1.9<m<2.3.*

getting the Si, N and C isotopes in SUNOCONs from this same general region. But what about iron?

Inside of m=1.9 the material has reassembled in an alpha-rich freezeout. It is here that the largest fractions of ^{44}Ti relative to ^{48}Ti exist, up to 30%. ^{56}Fe and ^{57}Fe dominate the abundances in nearly solar relative proportions (initially as ^{56}Ni and ^{57}Ni before their decays); and both ^{54}Fe and ^{58}Fe are of such low abundance that they are essentially absent. If SUNOCON growth incorporates iron from this zone, large correlated deficits of ^{54}Fe and ^{58}Fe can be expected. Very evidently, iron carries high diagnostic potential for location of the source iron.

A Conjecture on Mixing. We speculate that the unidentified mixing involves grain transport across boundaries. In the alpha-rich freezeout Ti is even more abundant than either Si or C, so that TiC may be the major initial SUNOCON in that zone. TiC subgrains are known to occur within SUNOCONs (12). These may begin as ^{44}Ti-bearing and ^{13}C-rich TiC grains and grow larger by being enveloped in graphite after turbulent transport into the C-rich CO zone. Trace Fe may initially condense with only very low concentration in these thermal crystals owing to high temperature. But then the grain assembly may, as it grows, sweep up Fe atoms more efficiently from cooled overlying shells penetrated by the turbulence, so that more Fe of differing isotopic signature may be engulfed by continuously growing graphite. Capture of small FeC crystals by the growing graphite may even occur. The consequence could be SUNOCONs bearing the predicted sign of the Fe anomalies but of much smaller magnitude than those of the distinct shells from which the Ti, N and C condensed. By such a sequence the Fe atoms may not derive primarily from the zones providing the Ti, C and Si from which SUNOCON growth began. Such dilution of anomaly size was seen in the Mo isotopic anomalies in SUNOCONs (11), and we speculate that a similar effect in Fe may well be encountered.

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