SUPERNOVA NUCLEOSYNTHESIS AND APPLICATION TO THE ISOTOPIC RATIOS OF INDIVIDUAL PRESOLAR GRAINS FROM SUPERNOVAE. T. Yoshida and M. Hashimoto, *Department of Physics, Kyushu University, Ropponmatsu, Fukuoka 810-8560, Japan, (tyoshida@gemini.rc.kyushu-u.ac.jp).*

Introduction: Presolar grains found in primitive meteorites have large isotopic heterogeneities of orders of magnitude. Because of the large heterogeneities, presolar grains are thought to have traces of the nucleosynthesis before they were formed [1]. Silicon carbide (SiC), low density graphite, and silicon nitride are believed to be formed in the ejecta of type II supernovae [1,2]. Their isotopic ratios are characterized by excesses of ^{12}C, ^{15}N, and ^{28}Si, and the traces of extinct ^{26}Al. Some of the grains have the traces of extinct ^{44}Ti which were considered to be produced through the explosive nucleosynthesis of type II supernovae [1-4]. Quantitative comparison of distributions of the isotopic ratios of SiC X grains [5] and low density graphite grains [6] with possible ranges of the isotopic ratios in supernova ejecta has been carried out using the supernova nucleosynthesis models in [7]. It is found that the large scale mixing between the outer carbon-rich He-layer and inner Si-rich layer is required in order to reproduce the characteristics of the isotopic ratios.

In the present study, we will investigate isotopic ratios of presolar grains from supernovae by considering the characteristics of individual grains rather than their distribution. It is important to clarify how many kinds of isotopic ratios of a grain is reproduced by an appropriate mixing in the supernova ejecta. We pursue both the calculation of the stellar evolution and that of the supernova explosion of a massive star. The calculation of the detailed nucleosynthesis is carried out by the post-processing using the thermal evolution and explosion profiles. Then, we compare the isotopic ratios of eleven SiC X grains and four low density graphite grains included the traces of extinct ^{44}Ti with the mixture of the supernova ejecta having various mixing ratios. The isotopic ratios adopted in this study are ^{12}C/^{13}C, ^{14}N/^{15}N, ^{26}Al/^{27}Al, ^{29}Si/^{28}Si, ^{30}Si/^{28}Si, and ^{44}Ti/^{48}Ti. Finally, we clarify how many kinds of the isotopic ratios of each grain are reproduced using the above mixing model.

Numerical Simulations: In order to investigate the possible isotopic ratios in the mixture of the supernova ejecta, we pursue the nucleosynthesis during the evolution of a massive star and its supernova explosion numerically. We simulate the stellar evolution and the supernova explosion of a 4 $M_\odot$ He star which corresponds to the He core of the advanced stages of a 15 $M_\odot$ zero-age main sequence star [8,9]. The numerical simulation of the supernova explosion is carried out using a spherically symmetrical Lagrangian PPM code [10,11]. Using the obtained temperature and density profiles, we perform the detailed nucleosynthesis calculations during the stellar evolution and the supernova explosion by the post-processing. We note that the nuclear reaction network for the calculation consists of 515 species of nuclei from n, H, up to Zr. Then, we obtain the mass fraction distribution of the supernova ejecta.

Figure 1 shows the mass fraction distributions of Si isotopes, ^{44}Ti, and ^{48}Ti inside the supernova ejecta. When we

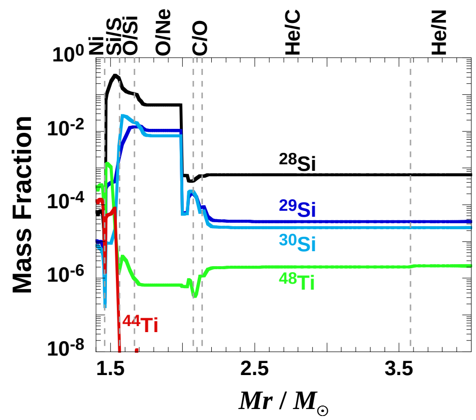

Figure 1: Mass fraction distributions of ^{28}Si, ^{29}Si, ^{30}Si, ^{44}Ti, and ^{48}Ti in the interior of the 4 $M_\odot$ He star model after its supernova explosion.

mix the ejecta, we divide the mass coordinate of the supernova ejecta into seven zones based on the distribution of dominant compositions as [5] and [6] have done. The main characteristics of the abundances of Si and Ti isotopes are as follows. Large ^{28}Si excesses found in supernova originating grains is also found in the Si/S and O/Si zones. The ratio of ^{29}Si/^{30}Si in the O/Ne zone is larger than that in the other zones. The abundances of Si isotopes in the He/N zone are equal to those of the solar system abundances. Extinct ^{44}Ti is abundantly produced in both the Ni and Si/S zones through the explosive nucleosynthesis in the supernova. In these zones ^{48}Ti is also produced as ^{48}Cr; ^{44}Ti/^{48}Ti ratio is large enough to reproduce those found in some of the grains. The production of ^{44}Ti is negligible exterior to the Si/S zone.

We take account of the mixing of four zones in the ejecta in order to compare the isotopic ratios with those of presolar grains. We choose two cases of the components of the mixture: the one consists of Ni, Si/S, He/C, and He/N zones (case A) and the other consists of Si/S, O/Ne, He/C, and He/N zones (case B). Both the ^{28}Si rich zone and ^{44}Ti rich zone are included in these cases. Contribution from the He/C and He/N zones makes the mixture carbon rich rather than oxygen rich. Slightly large ^{29}Si/^{30}Si ratio found in most of the grains is obtained in the O/Ne zone. It is noted that we take the averaged composition in each zone in the process of the mixing.

Results and Discussion: As the presolar grains from supernovae, we select eleven SiC X grains and four low density graphite grains, which contain the traces of extinct ^{44}Ti. The SiC X grains we have chosen are KJGM2-66-3, 2-243-9, 2-290-2, 4-205-12, and 4-271-3 from [4], KJH X2 taken from [3,4], KJD57 from [3,5,12], KJC58, 59, 72, and 74 from [5]. The low density graphite grains are KE3a-321 and 322, KE3c-242, and KFA1f-302 from [4,6]. The isotopic ratios to be compared are ^{12}C/^{13}C, ^{14}N/^{15}N, ^{26}Al/^{27}Al, ^{29}Si/^{28}Si, ^{30}Si/^{28}Si, and ^{44}Ti/^{48}Ti. For KJC58, 59, 72, and 74, both the Si isotopic ratios and the ^{44}Ti/^{48}Ti ratio are measured; ^{26}Al/^{27}Al is also measured for KJD57.

Figs. 2a and 2b show the relations in δ^{30}Si/^{28}Si-δ^{29}Si/^{28}Si and those in δ^{30}Si/^{28}Si-^{44}Ti/^{48}Ti of SiC X grains, graphite grains, and the mixture of the supernova ejecta for various mixing ratios. In these figures, solid lines and dashed lines denote the mixture of case A and that of case B, respectively. The ratio of carbon to oxygen in the mixture is assumed to be 1. For a fixed δ^{30}Si/^{28}Si ratio, the line with the same color and kind in each figure corresponds to the isotopic ratios of the mixture with a definite mixing ratio. We see that δ^{29}Si/^{28}Si, δ^{30}Si/^{28}Si, and ^{44}Ti/^{48}Ti ratios of KJC 58, 59, 72, and 74 are reproduced when we consider the mixing. The isotopic ratios of KJC58 and KJC74 are expressed using the mixture of case A (for KJC58, see the blue circle denoted by 58 overlapped with the solid yellow-green line in each figure). Those of KJC59 and KJC72 are expressed in both of the two cases. However, the three isotopic ratios of the other grains cannot be reproduced by any mixture cases.

In order to investigate how many kinds of isotopic ratios of a grain are reproduced by the mixture of the supernova ejecta, we consider the two-dimensional plane which consists of the mixing ratios of the He/C and He/N zones. We assume the C/O ratio equal to 1 or 1.5 and consider that the sum of the mixing ratios of four zones is equal to 1. Then, we can make regions corresponding to every isotopic ratios of a grain in the plane. Each region is limited by the isotopic ratio and its error bar. The region overlapped with the regions formed by each isotopic ratio denotes the mixing ratios of He/C and He/N zones. The isotopic ratios forming the overlapped region indicate those reproduced by the mixture.

For five SiC X grains taken from [3,4] and two low density graphite grains taken from [4,6], three kinds of isotopic ratios in the six kinds are reproduced at most by the mixing for each definite mixing ratio. Four of the SiC X grains are reproduced by the mixture of case A. Another SiC X grain and one of the graphite grains are reproduced by that of case B. Another graphite is reproduced in both of the two cases.

For SiC X grains of KJC 58, 59, 72, and 74, δ^{29}Si/^{28}Si, δ^{30}Si/^{28}Si, and ^{44}Ti/^{48}Ti are reproduced by the mixture with the corresponding mixing ratios. Although both δ^{29}Si/^{28}Si and δ^{30}Si/^{28}Si of KJD57 cannot be reproduced by the mixture with any mixing ratios, three kinds of the ratios, namely, ^{26}Al/^{27}Al, δ^{29}Si/^{28}Si, ^{44}Ti/^{48}Ti, or ^{26}Al/^{27}Al, δ^{30}Si/^{28}Si, ^{44}Ti/^{48}Ti are reproduced with different mixing ratios.

Among the grains of which three kinds of the isotopic ratios are reproduced, the mixing ratio of the He/N zone is larger than 0.9. The second dominant zone for the reproduction is the He/C zone in most grains. Even if large scale mixing between the outer He-rich region and deep Ni or Si rich region is considered, only a small amount of the injection of the deep layers shows the isotopic characteristics of the grains. For three grains, the isotopic ratios are reproduced without the injection of the compositions in Ni zones though traces of ^{44}Ti is found in the grains. The above characteristic does not change if we consider the variation of the C/O ratio.

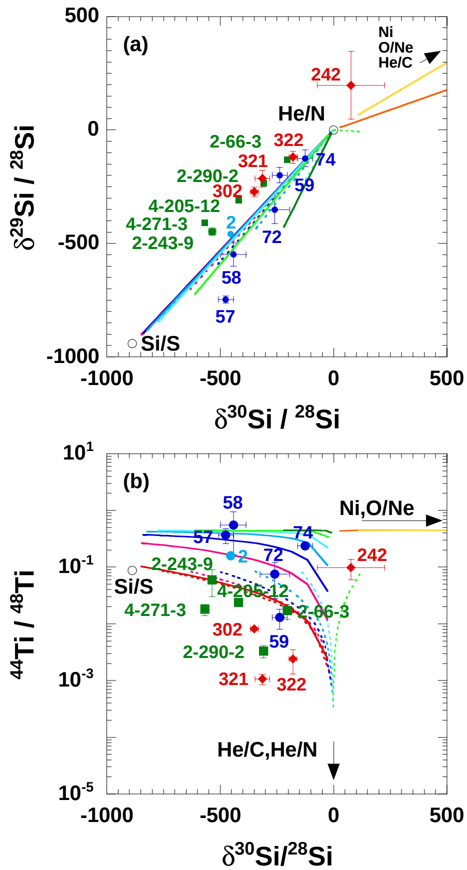

Figure 2: Panel (a): δ^{30}Si/^{28}Si ratio vs. δ^{29}Si/^{28}Si ratio. Panel (b): δ^{30}Si/^{28}Si ratio vs. ^{44}Ti/^{48}Ti ratio. Open circles show the isotopic ratios of each zone. The isotopic ratios outside the figures are denoted by arrows with abbreviations. Solid lines and dashed lines are the isotopic ratios of the mixture for Ni, Si/S, He/C, and He/N zones (case A) and Si/S, O/Ne, He/C, and He/N zones (case B), respectively, with different mixing ratios. Closed circles with error bars and numbers are the isotopic ratios of grains.

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