CHRONOLOGY OF PRESOLAR SILICON CARBIDE: ASSESSING THE VIABILITY OF THE U-Th-Pb SYSTEM.

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Introduction: Presolar grains are refractory phases that condensed at very high temperatures (1300-2000K) directly from the gas phase present in ancient stellar outflows, and thus became part of the interstellar medium from which our Solar System formed about 4.6×10^9yr ago. These grains can be recovered from primitive meteorites, and their study in the laboratory has provided new and complementary information to that commonly obtained by astronomers and astrophysicists on stellar nucleosynthesis, mixing in supernovae, galactic chemical evolution, dust formation in stellar environments, dust processing in the interstellar medium and formation of the Solar System [1; 2]. Constraints on the time of formation of presolar grains in stellar outflows before arriving in the solar nebula would be very useful, but obtaining chronological data on presolar grains is extremely difficult. This is because for many of the long-lived decay schemes, e.g. ^{87}Rb-^{87}Sr, the parent isotope does not condense at the high temperatures at which presolar grains form in stellar outflows. Secondly, the abundance of a particular radionuclide can be affected by a number of variables, such as the composition of the stellar outflows, the thermochemical behavior of the radionuclide under varying chemical and physical conditions of the stellar atmosphere, and its mechanism of incorporation into presolar grains. Finally, concentrations of potential chronometers are near the detection limit for most analytical techniques. However, depending on the stellar mass and metallicity of the grain's parent stars, presolar grains can incorporate trace amounts of U and Th, which can be used to trace r-process nucleosynthesis and serve as stellar chronometers. Once U and Th are incorporated into SiC grains, their isotope ratios will only be modified by their decay rates and their daughter isotopes of Pb build up in the grains and can potentially be detected. The utility of U-Th-Pb chronometry on presolar grains will depend on the concentration of the isotopes of these elements, precise measurements of their isotopic compositions, and the knowledge of their production ratios. Of prime importance is that measurable amounts of U, Th and Pb might exist in certain types of presolar grains.

X grains and supernovae: Type X SiC grains, which comprise ~1% of all presolar SiC [3], are believed to condense within expanding supernova ejecta [4]. The isotopic signatures of the X grains suggest deep and inhomogeneous mixing of matter from very different stellar zones in the SN ejecta [5]. The U and Th content of X grains will critically depend whether or not freshly synthesized r-process matter was available during grain formation. It is known that some isotopes formed only by r-process, such as ^{100}Mo, do not show the expected overabundance in X grains, a result that is not consistent with production in a canonical r-process [6]. The Mo isotopic pattern found by [6] in X grains can be successfully explained by a neutron-burst model [4]. However, there is still a possibility of incorporation of U and Th into type X SiC during their formation, and further ion implantation of heavy ions as the grains overtake the overlaying layers [7].

Mainstream grains and AGB stars: Mainstream grains, which comprise ~93% of all presolar SiC [8], are thought to have originated in the outflows of C-rich red giant stars during the asymptotic giant branch (AGB) phase of evolution [9]. Because U and Th are not synthesized in AGB stars, their content in mainstream SiC grains will reflect the composition of the precursor molecular cloud at the time of stellar formation, the decay of ^{238}U, ^{235}U and ^{232}Th during their stellar lifetime, and the time elapsed since grain formation. The U and Th isotopic compositions of AGB stars are not significantly modified by nucleosynthesis because most of the envelope material did not experience much neutron exposure.

Experimental considerations: U, Th and Pb are potentially present in measurable amounts in presolar SiC grains. However, the abundance of most heavy elements in presolar SiC is not known. The precise measurement of abundances and isotopic ratios of heavy elements in SiC grains presents a series of analytical challenges. First, SiC are usually very small (<20μm, with most of them being <1μm), hence single grain analysis is difficult. Secondly, the abundance of heavy elements, and in particular U, Th and Pb, in single grains is expected to be very low and close to the lower limit of detection of most current analytical methods. Third, background contributions from the substrate on which grains are analyzed, and also potential contamination of SiC acid residues by the meteorite matrix have to be considered. Finally, standards of SiC doped with heavy elements do not exist.

Here we propose to assess the potential of the U-Th-Pb system in presolar SiC grains using sensitive high-resolution ion microprobe (SHRIMP) measurements. SHRIMP is suitable for this task because: (i) it has high sensitivity, mass and spatial resolution, (ii) it enables a wide range of stable and radiogenic isotopes, plus trace elements, to be analyzed with precision, (iii) it has demonstrated capability in the measurement of U-Th-Pb systematics.

Our initial experiments will focus on “bulk” measurements of SiC grains. Depending on the results, single grain analysis of large SiC will also be attempted. Initial results will be presented at the meeting.

References:

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