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Microanalysis of Star Dust Using Laser Desorption Postionization MS: A Microprobe to Study Stellar Nucleosynthesis

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Traditionally the study of the composition and nucleosynthesis in stars has been limited to telescopic observation. Today the composition and consequently the nucleosynthesis occurring within stars can also be studied in the laboratory with microprobe techniques on three unique classes of samples. The first type of sample, presolar grains, has been identified in primitive meteorites on the basis of their extreme isotopic deviations from solar compositions [1, 2]. These grains, which formed in the mass-losing envelopes of stars or in supernova ejecta, survived formation of the solar system and retained the isotopic signatures of their parent stars. A second set of samples has recently been returned from space by the Stardust Discovery Mission with the expectation that at least a fraction of the material collected also has survived the formation of the solar system and retain a geminate record of their parent star [3]. A third type of star sample has become available with the return to Earth of solar wind samples by the Genesis Discovery Mission [4, 5]. The various high purity materials which acted as collectors for solar wind were returned to Earth in September 2004 and are now available for analysis. These samples contain a record of the elemental and isotopic abundances of the solar wind implanted in the near surface region of the collectors.

These three sample sets provide very different information about their geminate stars. Each presolar grain or Stardust grain provides an intimate record of the nucleosynthesis of a single stellar source at the moment when the grain material was ejected. Thus correlated information can come only from individual grain analyses since one can assume that each grain comes from a different star. A premium is thus placed on the ability to measure the elemental and isotopic abundance of many elements in individual grains. A premium is thus placed on the ability to measure trace elements with high useful yield (the fraction of atoms contented) while maintaining high discrimination. Discrimination is necessary since most elements are present in these micron sized grains at concentrations at or below ppm. The Genesis samples will allow the most accurate determination to date of the abundance of the elements in the universe. This abundance record has traditionally been used as a measure of the average nucleosynthesis of stars in our galaxy [6-9]. The Genesis return samples have been measured for Mg with the depth profiles of an implant standard and the #60178 demonstrated in Figures 1 and 2 below. Generally, Genesis samples have been found to be contaminated by a thin film deposited during flight and by particles introduced when the Sample Return Capsule was breached during its crash landing. The need to discriminate against surface contamination introduces an additional requirement beyond the high lateral resolution (to simply navigate around particulates). Analysis requires depth resolutions much smaller than the expected 30 nm implant peak depth.

A new secondary neutral mass spectrometry (SNMS) instrument implementing resonance enhanced multiphoton ionization (REMPI) of ion sputtered and laser desorbed neutral species has been developed and constructed for the specific purpose of quantitative analysis of metallic elements at ultra trace levels in each of these samples of stellar matter. This resonance ionization mass spectrometry (RIMS) instrument has been described elsewhere in detail [10] Since accurate quantitative analysis is compromised by sample contamination, several features have been built into the new RIMS instrument to mitigate this difficulty [11] The main advantages of the RIMS instrument are its sensitivity, accuracy and selectivity. The RIMS technique has been shown to be capable of quantitative sub-parts per billion determinations while consuming only a factor of 3-4 more sample than required by Poisson statistics [12].

We have used this instrument to analyze both SiC stardust isolated from the Murchison meteorite and samples returned from space by the Genesis spacecraft. These samples are providing important new information on the nucleosynthetic processing of stars[13, 14].

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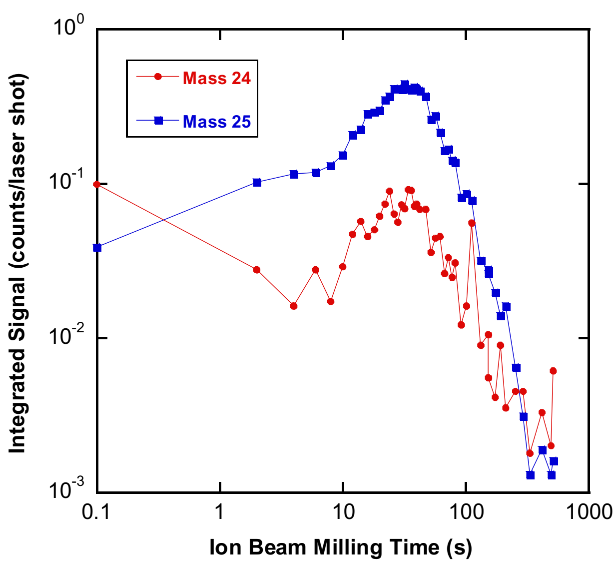

Figure 1. RIMS depth profile of implant standard.

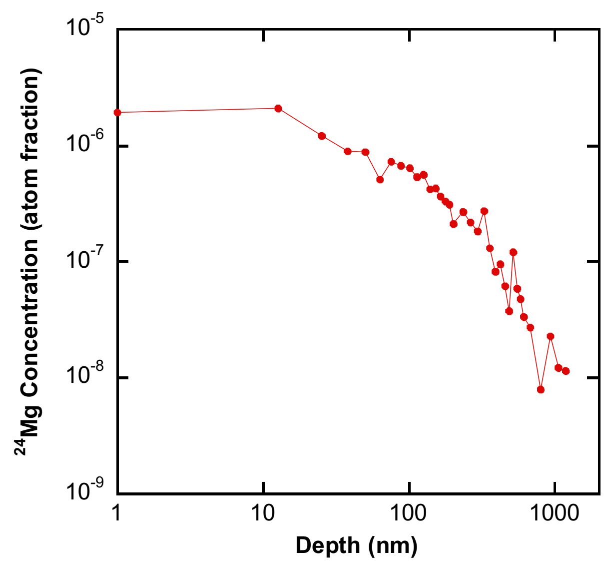

Figure 2. Concentration of ^{24}Mg versus depth in Genesis sample 60178 as determined by

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