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NASA NAG5-4083
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30 October 2001

DEVELOPMENT AND APPLICATION OF THE ION MICROPROBE FOR ANALYSIS OF EXTRATERRESTRIAL MATERIALS

FINAL TECHNICAL REPORT

This report covers the work carried out under NASA Grant NAG5-4083. The research was directed toward analyses of early solar system material, of presolar grains preserved in meteorites, and toward theoretical studies of nucleosynthesis in stars related to the chemical evolution of the galaxy and the formation of the solar system. The work was carried out over the time period 15 February 1998 – 31 May 2001 and involved the participation of the following individuals: M. Busso, Visiting Associate, Professor of Astrophysics, Perugia University, Italy; B.-G. Choi, research fellow, now Associate Professor at Seoul National University, Korea; H. C. Connolly, research fellow, now at Kingsborough Community College, CUNY; R. Gallino, Visiting Associate, Professor of Astrophysics, University of Torino; Y. Guan, Smithsonian Institution; C. Hohenberg, Professor of Physics, Washington University, St. Louis; M. Heinrich, electronics and systems engineer, Caltech; W. Hsu, research fellow, Caltech; T. LaTourrette, research fellow, now at Rand Corporation; G. R. Huss, Senior Research Scientist, now at Arizona State University; N. Krestina, research fellow in geochemistry, Caltech; G. J. MacPherson, Smithsonian Institution; K. Nollett, research fellow in astrophysics; Y.-Z. Qian, Professor of Physics, University of Minnesota; G. Srinivasan, research fellow, now Research Scientist, Physical Research Laboratory, Ahmedabad, India.

This program has been very successful and has resulted in numerous publications. A complete list of scientific papers, extended abstracts, and short abstracts is given in the appendix. The work has covered is summarized below.

1) The first study of the distribution of platinum group elements in metal phases in chondrules and matrix was successfully carried out using the PANURGE Ion Probe in conjunction with a detailed petrographic and petrochemical study (Connolly, Huss and Wasserburg, 2001). This study showed the results of reduction of Fe metal in CR2 chondrules, the relationship to PGE concentration, the metal loss from chondrules by liquid droplet transport, and the condensation of FeNi metal on chondrule surfaces.

2) The diffusion coefficient of Mg in anorthite was determined and the implications for effects of autometamorphism in planetary bodies due to heating by ^{26}Al was developed. It was shown that only the exteriors of bodies greater than ~50 km radius could preserve evidence of ^{26}Al in Al-rich phases, because of diffusive interchange with abundant Mg-rich phases in the planetary interior. The role of leaky pressure cooker evolution in planets heated by ^{26}Al was presented (LaTourrette and Wasserburg, 1998).

3) An ^{26}Al study was conducted using a CAI which had been recognized to be the result of a multi-stage formation based on petrographic grounds. It was found that the different sequential zones were formed over a time interval of several hundred thousand years. This observation appears to show that a time resolution of $\sim 10^5$ years is possible in some early solar system samples and is supportive of some planetary processing in the formation of CAIs (Hsu, Wasserburg, and Huss, 2000).

4) The study of entstatite chondrites showed that ^{26}Al was present in CAIs in these objects. These chondrites were considered to have formed under distinctive reducing

conditions at locations in the early solar system. It was found that $^{26}Al/^{27}Al \sim 5\times10^{-5}$ was present in these CAIs and that such material was therefore either widespread or widely distributed throughout the early solar system (Guan et al., 2000).

5) An extensive study of ^{26}Al abundances in both chondrules and CAIs was carried out. This extended the data on CAIs and showed that some low levels of $^{26}Al/^{27}Al$ (typically less than 10^{-6}) were present in some chondrules (Huss et al., 2001).

6) Measurements of circumstellar dust grains were made using a more advanced, automated SEM scanning system and precise coordinate transformation system for the ion probe (cf Heinrich et al., 1998; Krestina et al., 2001). This resulted in the discovery of hibonite and spinel grains formed as circumstellar condensates As determined from the oxygen isotopic composition. In particular, it was possible to measure Ca, K, Mg and Ti isotopes in the hibonite grain. The measurements showed the clear presence of ^{41}Ca ($\bar{\tau}$ = 1.5×10^5 y) and ^{26}Al ($\bar{\tau} = 1.05\times10^6$ y) in the grain at the time of its formation. These results permitted the first direct comparison of the abundances of different short-lived nuclei in the same circumstellar dust grain, and hence constitute a direct test of models of nucleosynthesis in AGB stars (Choi et al., 1999).

7) With regard to theoretical studies, extensive work was carried out and resulted in a major, invited report on nucleosynthesis in AGB stars that appeared in Annual Reviews of Astronomy and Astrophysics, 1999. This report covered both the advances in understanding AGB evolution, nucleosynthesis in AGB stars, and contributions from AGB stars to galactic enrichment and to the solar system.

8) A study of supernovae contributions using the model of multiple (at least two) *r*-processes in different supernovae, SNII(H) and SNII(L), was carried forward and applied to

the evolution of oxygen and iron in the galaxy (Qian and Wasserburg, 2001). This model of SNII(H) and SNII(L) was used to explain the extremely high U, Os and Ir abundances found in a very low metallicity star. This was the first observation of U in a star (Cayrel et al. 2001, Qian and Wasserburg, 2001). This observation was applied to the evolution of "metallicity" in the early universe and showed that the abundances of [Fe/H] as a function of red shift, as observed in damped Lyman-α clouds could be explained as a result of the delays in galaxy formation subsequent to t = 0 (Big Bang) (Wasserburg and Qian, 2000). This phenomenological approach was then extended to the evolution and abundances of all "*r*-elements" in low metallicity stars (Qian and Wasserburg, 2001).

This summarizes about all that we have accomplished under this grant.

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