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Principal Investigator: Conel M. O'D. Alexander
Department of Terrestrial Magnetism
Carnegie institution of Washington
5241 Broad Branch Road, N.W.
Washington, DC 20015

Introduction

The discovery of presolar grains in meteorites is one of the most exciting recent developments in meteoritics. Six types of presolar grain have been discovered: diamond, SiC, graphite, Si_3N_4, Al_2O_3 and $MgAl_2O_4$ (NITTLER, 2003). These grains have been identified as presolar because their isotopic compositions are very different from those of Solar System materials. Comparison of their isotopic compositions with astronomical observations and theoretical models indicates that most of the grains formed in the envelopes of highly evolved stars. They are, therefore, a new source of information with which to test astrophysical models of the evolution of these stars. In fact, because several elements can often be measured in the same grain, including elements that are not measurable spectroscopically in stars, the grain data provide some very stringent constraints for these models.

Our primary goal is to create large, unbiased, multi-isotope databases of single presolar SiC, Si_3N_4, oxide and graphite grains in meteorites, as well as any new presolar grain types that are identified in the future. These will be used to: (i) test stellar and nucleosynthetic models, (ii) constrain the galactic chemical evolution (GCE) paths of the isotopes of Si, Ti, O and Mg, (iii) establish how many stellar sources contributed to the Solar System, (iv) constrain relative dust production rates of various stellar types and (v) assess how representative of galactic dust production the record in meteorites is. The primary tool for this project is a highly automated grain analysis system on the Carnegie 6f ion probe. This proposal was part of a long-standing research effort that is still ongoing.

Progress

The search for presolar silicates and the ^{54}Cr carrier.

Leaching experiments indicate that the ^{54}Cr carrier is concentrated in the organics-rich residues of Orgueil, Murchison and Tagish Lake (ALEXANDER, 2002; ALEXANDER et al., 2001). It is likely that the carrier is organic. It is more likely to be a Cr-rich mineral grain trapped in the organics. We conducted an initial ion probe survey of micron-sized grains in the ^{54}Cr-rich residue of Orgueil, from which the organics were removed by plasma ashing (NITTLER and ALEXANDER, 2003b). Automated O-isotope mapping of ~260 grains identified three ^{17}O-rich oxide grains, including two members of a new presolar phase, a solid solution of spinel and magnesiochromite ($MgCr_2O_4$). This is the first discovery of a Cr-rich presolar grain and brings the number of known O-rich presolar grain types to seven. This phase is not sufficiently soluble in HCl to be the dominant carrier of ^{54}Cr excesses, but this mineral and its more recently discovered Fe-rich variant remain the subject of vigorous research.

Isotopic compositions of presolar Al_2O_3 and $MgAl_2O_4$ grains

In addition to the discovery of presolar magnesiochromite, we have used the Mainz and Washington University NanoSIMS (with collaborator Drs. Hoppe and Zinner) to measure Ti, Mg and O isotopic ratios in presolar oxide grains. Ti was measured in three presolar Al_2O_3 grains from our Tieschitz and ordinary chondrite mounts and one Al_2O_3 grain identified in Mainz (HOPPE et al., 2003). The aim is to search for correlations between the isotopic compositions of these three elements to elucidate the processes of Galactic chemical evolution (GCE) and nucleosynthesis in low-mass red giants and AGB stars. The Ti and O data are broadly consistent with expectations for GCE and nucleosynthesis. The apparent correlation between Ti isotopes and metallicity estimated from the O isotopes is particularly exciting. The behavior of Mg appears to be more complex and there is no simple correlation of its isotopic composition with those of O (NITTLER et al., 2003; ZINNER et al., 2004). The lack of a simple relationship between Mg and O isotopes probably reflects the fact that a number of different nucleosynthetic proceses can affect the Mg isotopes. Nevertheless, the Mg data are suggestive that the $^{25}Mg/^{24}Mg$ ratio of the Galaxy evolves much more slowly than predicted by numerical models of Galactic chemical evolution. This result is consistent with previous data for presolar SiC, presolar Al_2O_3 and main sequence stars, and might have important implications for nucleosynthesis in the early stages of our Galaxy.

Presolar SiC and Si_3N_4 Grains

We have now used our automated analysis system to acquire Si- and C-isotopic data for ~3,300 1-5 μm SiC grains isolated from the Murchison meteorite, with ~90% of these grains being isolated using our new CsF technique (NITTLER and ALEXANDER, 2003a). This is more than twice the total number of individual grains for which both Si and C data have previously been obtained. Isotopic ratios of both of these elements are needed to unambiguously identify all known SiC sub-groups and we identified a large number of X, Y, Z and A+B grains. In addition, we identified a few grains of probable nova origin, three presolar Si_3N_4 grains, and a highly unusual grain with a 2x^{30}Si enrichment, modest ^{29}Si enrichment and isotopically light C (NITTLER and HOPPE, 2004a, 2004b). The key conclusions of our work are: i) the new data are broadly similar to previous observations in terms of ranges of isotopic ratios and compositions and abundances of sub-groups; ii) Minor differences in isotopic distributions between our data and prior data can be partially explained by terrestrial contamination and grain aggregation on sample mounts. However, some of the differences are probably intrinsic to the samples, possibly due to the different chemical techniques used to prepare samples. iii) The abundance of presolar Si_3N_4 in our sample is ~3 times higher than that previously observed in Murchison, indicating that this mineral survives the new acid treatments better than the standard ones. iv) There is a striking correlation between the inferred initial metallicity and inferred amount of He-shell material dredged-up in the parent AGB stars of the Z-type SiC grains. This trend smoothly connects the Z, Y and mainstream grains, consistent with the belief that these types formed in AGB stars with a range of metallicities. v) The isotopic data for Z grains indicates that many of their parent stars must have undergone strong CNO-cycle H-burning during the early AGB phase, consistent with either cool-bottom processing in low-mass stellar parents or hot-bottom burning in intermediate mass parents. vi) The trend of $^{12}C/^{13}C$ ratios as a function of $^{29}Si/^{28}Si$ ratios for SiC grains indicates a sharp increase in the maximum mass of the parent stars with decreasing metallicity, in contrast to expectations from GCE theory.

The large numbers of different types of grain we have discovered have enabled us to select several grains from microstructural studies. These will help constrain the conditions of grain growth in various stellar environments and how the grains may have been modified in the ISM and early solar System. X Grains are of particular interest and very is known about the supernova environments in which they formed. Electron transparent TEM sections of two X grains were prepared using a focused ion beam technique (STROUD et al., 2004). Unlike SiC grains from AGB stars, the X Grains are made up of 10-100 nm crystallites. However, the two X grains are otherwise rather different, with one being very porous while the other is densely packed. At present, what this reveals about the conditions under which they formed is uncertain, but clearly they were very different to those experienced by grains forming around AGB stars.

The acid treatments used to isolate the presolar SiC grains will have removed any surficial oxide layers or other features that may reveal how the grains were processed in the ISM and early Solar System. There has been speculation that a oxide layer is necessary for the SiC grains to survive in these environments. We have begun to address this problem by finding SiC grains in situ in thin sections or by finding them in physical separates (STROUD et al., 2003). Initial results suggest that oxide layers are not ubiquitous.

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