Trace element analysis of presolar stardust grains via combined Synchrotron-based photoelectron spectroscopic and TOF-SIMS investigations

T. Berg[1], N. Erdmann[2], J. Maul[1], Ch. Sudek[3], G. Schönhense[1], P. Bernhard[1], U. Ott[3]

[1] Institut für Physik, Universität Mainz, D-55128 Mainz, Germany; [2] Institut für Kernchemie, Universität Mainz, D-55128 Mainz, Germany; [3] Max-Planck-Institut für Chemie, D-55128 Mainz

Primitive meteorites contain small amounts of presolar dust consisting of nano-diamonds, silicon carbide (SiC), graphite, corundum (Al_2O_3), silicon nitride (Si_3N_4) [1] and very recently found silicates. This material survived the formation of the solar system without being affected by the isotope homogenisation process. Therefore the isotopic composition not only of the bulk elements, but also of diagnostic trace elements [2] is highly anomalous and indicative of the stellar origin of the analysed „stardust" grains. Laboratory studies of the nucleosynthetic fingerprint of single grains can thus provide information on stellar evolution, the chemical evolution of the galaxy as a whole and on grain growth in stellar atmospheres and ejecta of explosive events like supernovae.

Isotopic analysis is carried out with secondary ion mass spectrometry (SIMS) [3],[4], respectively resonance ionisation mass spectrometry (RIMS) [5]. However, these methods are destructive and, at sufficient mass resolution, only capable of simultaneous analysis of a small number of isotopes. Thus non-destructive identification of single μm-sized grains containing interesting trace elements prior to isotopic analysis is of extreme importance.

Two methods of choice are therefore synchrotron based μ-NEXAFS (near edge x-ray absorption fine structure) and μ-XPS, respectively nano-XPS (x-ray photoelectron spectroscopy). These techniques are suitable for elemental mapping of a large number of grains with high trace element sensitivity.

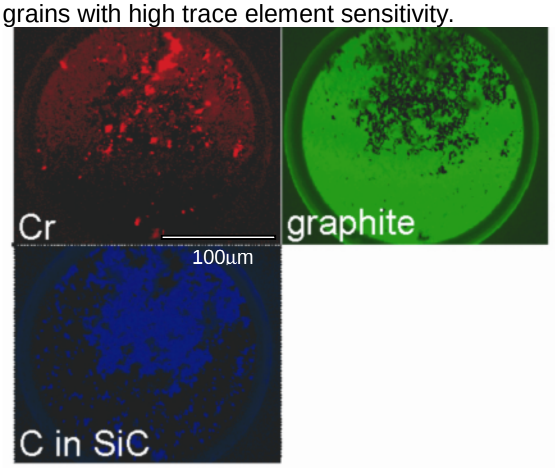

Fig.1: *Elemental mapping of a SiC-rich sample of extraterrestrial origin via Synchrotron-based μ-NEXAFS (WERA-Beamline at the ANKA Synchrotron / Forschungszentrum Karlsruhe).*

Prior to high-resolution isotopic analysis of selected trace elements, a mass spectroscopic confirmation of the μ-NEXAFS, respectively μ-XPS results is necessary to avoid a misinterpretation of the photoelectron spectroscopic trace element spectra. These studies are carried out with minimum sample consumption and sufficient lateral resolution at the Institut für Kernchemie using time-of-flight SIMS (TOF-SIMS) [6]. Unlike the nano-SIMS, which is used for the analysis of selected elements afterwards, this technique is capable of elemental mapping of a, in principle, unlimited number of masses over a wide field of view (up to 500 x 500 μm^2) with a lateral resolution better than 1 μm.

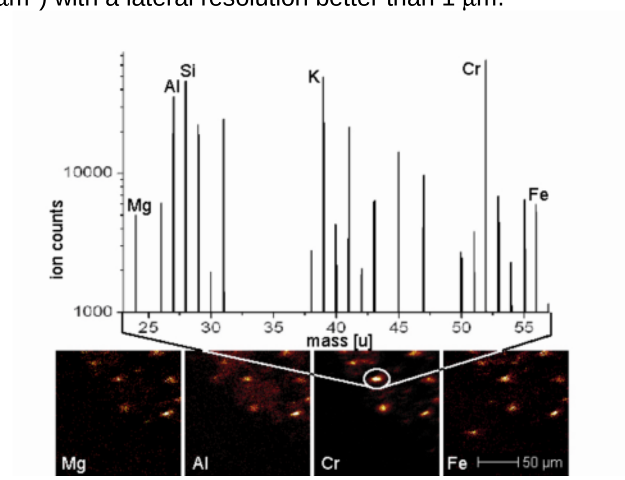

Fig.2: *TOF-SIMS mappings of presolar dust grains at m/z = 24, 27, 52 and 56. Additionally a part of the related mass spectrum is shown (integrated over marked area).*

In combination with the synchrotron based measurements, distinct identification of trace elements in single stardust grains can be achieved. Subsequent isotopic analysis is performed with the Nano-SIMS ion probe at the Max-Planck-Institut für Chemie. Up to five isotopes can be investigated with highest mass resolution and a lateral resolution of 50 nm.

In single grain analysis this combination of non-destructive photoelectron spectroscopic measurements with subsequent isotopic analysis has never been used so far and offers new insights into a variety of astrophysical questions.

References

[1] U.Ott, Nature 364(1993)25
[2] E.Zinner, Annu. Rev. Earth Planet Sci. 26(1998)147
[3] K.K.Marhas, P.Hoppe, U.Ott, Meteorit.Planet.Sci. 38(2003)A58
[4] T. Stephan, Planet. and Space Sci. 49(2001)859-906
[5] M.R.Savina et al., Geochim. Cosmochim. Acta 67(2003)3201
[6] N.Erdmann et al., this report.