# Coordinated analysis of planetary materials at the nanoscale

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Spatially resolved analysis of meteorites and other planetary materials is fundamental to cosmochemical research. Over the past decade, advances in ion and electron optics have led to the development of a new generation of instruments capable of providing chemical and structural information on planetary materials at increasingly smaller spatial scales. Secondary ion mass spectrometry (SIMS) with a NanoSIMS can provide isotopic information on samples down to 50 nm. Aberration-corrected and monochromated electron optics in the transmission electron microscope (TEM) coupled with electron energy-loss and large solid-angle energy-dispersive X-ray spectroscopy (EELS, EDS, respectively) have enabled direct imaging of atomic structure and atomic-column spectroscopy. By themselves, the data provided by these instruments have enabled new insights into the origins of planetary materials, but coordination of these data sets, via the focused-ion-beam scanning-electron-microscope (FIB-SEM), has become an extremely powerful tool for cosmochemical research. Coordinated analysis will be essential for returned sample investigation.

Figure 1 illustrates the coordinated approach to studying a presolar stardust spinel grain from a primitive meteorite. The grain measures 146 × 420 nm (Fig. 1a). NanoSIMS analysis reveals that it has an anomalous O isotopic composition consistent with formation in a low-mass (<1.4 $M_{\odot}$) asymptotic giant branch star. Using the FIB-SEM, we cross sectioned the grain (along arrowheads, Fig. 1a) and thinned it to electron transparency (<100 nm) for detailed analysis using TEM (Fig. 1b). Electron-diffraction patterns acquired across the grain show that it is a single crystal with minor stacking disorder and EDS indicates it is nearly pure and stoichiometric Mg-Al spinel. The crystallinity and chemistry of UOC-S2, combined with equilibrium thermodynamic calculations, suggest that the grain could have condensed inside its circumstellar envelope at a temperature between 1161 and 1221 K assuming corresponding total gas pressures of $1\times10^{-6}$ and $1\times10^{-3}$ atm, respetively. The implications of this result for circumstellar processes, together with other examples of coordinated analytical studies, will be discussed.