

MICROMETEOROID IMPACTS ON THE HUBBLE SPACE TELESCOPE WIDE FIELD AND PLANETARY CAMERA 2: ION BEAM ANALYSIS OF SUBTLE IMPACTOR TRACES.

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Introduction: Recognition of origin for particles responsible for impact damage on spacecraft such as the Hubble Space Telescope (HST) relies upon post-flight analysis of returned materials. A unique opportunity arose in 2009 with collection of the Wide Field and Planetary Camera 2 (WFPC2) from HST by shuttle mission STS-125. A preliminary optical survey confirmed that there were hundreds of impact features on the radiator surface [1]. Following extensive discussion between NASA, ESA, NHM and IBC, a collaborative research program was initiated [2], employing scanning electron microscopy (SEM) and ion beam analysis (IBA) to determine the nature of the impacting grains. Even though some WFPC2 impact features are large, and easily seen without the use of a microscope (e.g. Fig. 1), impactor remnants may be hard to find.

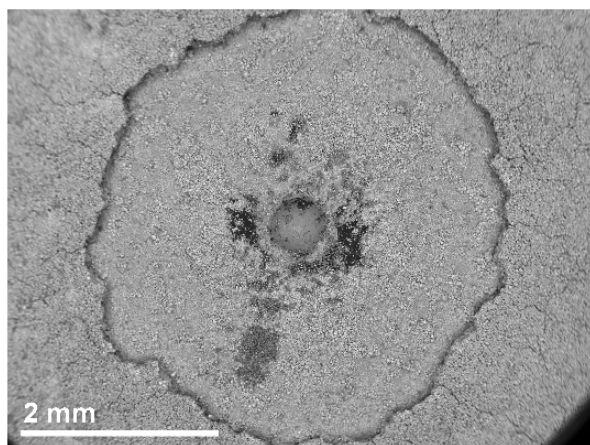


Fig. 1. Impact feature 462, on a core cut from the surface of the WFPC2 radiator shield, backscattered electron image (BEI). Note the large area of paint loss around a central bowl-shaped pit in underlying alloy.

Samples, prepared as cores at JSC [2], were first examined in a Zeiss EVO 15 LS SEM at NHM. Energy Dispersive X-ray (EDX) maps and spectra were collected from areas that showed evidence of impact melting, as well as from unaltered background materials. In many cases the EDX spectra revealed unambiguous enrichments of elements (e.g. Mg and Fe) that could only easily be explained as incorporated remnants from micrometeoroid (MM) impactors [3,4]. A few small

impacts [e.g. 4] did not show obvious impactor traces, and were set aside for IBA. Many larger impact features [3] contained impact melt with Mg, Al, Cr, Mn and Fe (all present in varying amounts within the radiator alloy) as well as O, Si, K, Ti and Zn (from the white paint surface). Although graphical plots of light gas gun (LGG) experimental impacts [5] show that the relative contents of these elements can provide evidence of projectile incorporation, the higher velocity of particle collisions with WFPC2 in low Earth orbit (LEO) can leave more subtle traces. Even long duration EDX analysis in the SEM [3] may not always be able to yield sufficient diagnostic evidence to identify traces of the impactor, and thus IBA [6] was used to give better-defined diagnostic ratios than could be seen in SEM-EDX. Here we explain how it helps us to recognise subtle impactor traces in WFPC2 samples, enhancing interpretation of micrometeoroid impactors.

IBA Methods: The 2 MV Tandem accelerator at the University of Surrey was used to generate a 2.5 MeV proton ion beam of ~0.5 nA current. The focused beam was scanned in a fixed-demagnification ion-optical system, over a square of 256x256 or 512 x 512 pixels across 1x1 mm or 1.5x1.5 mm areas, for 4-5 hours per data set. Sample alignment was achieved using secondary electron imagery, and the sample was rotated around the vertical axis, to generate a pair of data sets for stereo reconstruction of element distribution across the impact topography. The Oxford Microbeams Ltd. OMDAQ2007 data acquisition system collected Particle Induced X-ray Emission (PIXE) data from a liquid-nitrogen-cooled Li-drifted Si EDX detector (Gresham, 80mm², minimum distance 17 mm, maximum solid angle of 276 msr; 120 μm Be window to exclude backscattered protons). Data were collected on an event-by-event (list mode) basis, allowing subsequent interrogation off-line, to create maps for elements (including any not anticipated during data collection), and to extract spectra from selected sub-areas of the map. Quantitation of metal composition was performed through the GUPIX code [6] which uses a Fundamental Parameters approach to the X-ray spectra, recognising the line patterns for the elements present as well as secondary effects (escape and pileup peaks).

Results: 4 test samples and 32 impacts were analysed by PIXE in this study, WFPC2-462 (Fig. 1) is a good example. SEM-EDX of the pit surface had shown enrichment of Mg, Si and Fe above alloy composition (Fig. 2a and b), but was unable to detect other elements that might indicate whether this MM was only silicate, or might also contain sulfide or metal components.

Acquisition of PIXE data from the central area of the impact allowed elemental maps and spectra to be extracted from: specific areas on the surface of the melt pit; and the metal alloy (where exhumed by spallation of the paint layer). Comparison of the spectra revealed not only enrichment of Fe (Fig 2c, also seen in the earlier SEM-EDX spectra 2a and b), but also nickel (Fig. 2d). The extracted Ni map (Fig. 3) shows localisation within the melt pit. Coincidence with Fe distribution strongly suggests a second MM material is present, probably Fe+Ni metal, possibly a remnant of kamacite.

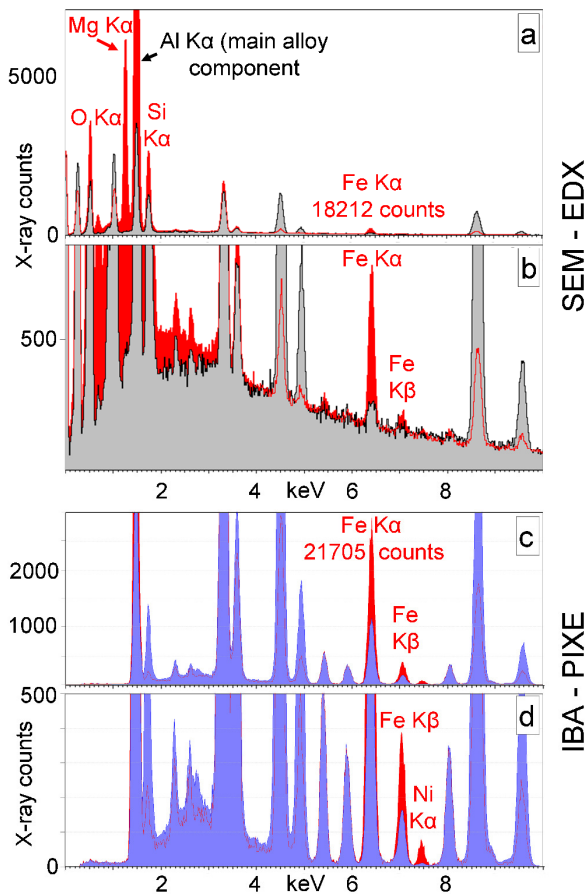


Fig. 2. WFPC2 sample 462: a) and b) SEM-EDX spectrum of metal in pit (red) compared to surrounding metal (grey); c) and d) PIXE spectrum of metal area inside pit (red) compared to surrounding metal (blue). The SEM-EDX spectra are normalized to the background between Cr K α and Cr K β . The PIXE spectra are normalized to the Cr K α peak area.

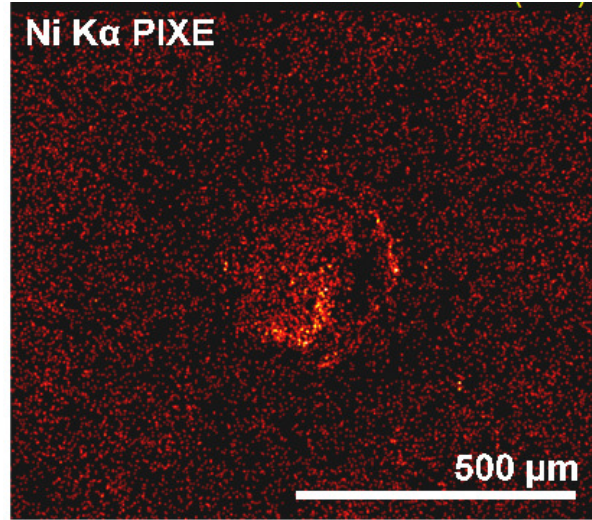


Fig. 3. WFPC2 sample 462: PIXE map of nickel distribution across the central pit.

Discussion and conclusions: Success of IBA in finding very low concentration impactor signatures is due to the nature of particle interactions involved. On entering a sample, SEM beam electrons lose energy by X-ray emission, creating a distinctive background (e.g. Fig. 3b). Where channel by channel variation is high (especially in short data collection), this background may have a ‘ragged’ appearance. Because a characteristic X-ray line peak area must reach 3 times background variation (sigma) for positive identification as above detection limit, in ‘noisy’ SEM-EDX spectra small X-ray peaks may fail to be recognized. Even with long collection times (e.g. 200 secs [3]), although the background becomes much smoother (sigma reduced as a proportion of peak area), it does still limit determination of elements to > 0.05 wt %. However, irradiation with an energetic beam of protons, as in PIXE, does not generate an appreciable X-ray background (Fig. 2c and d), and even very low count rates at characteristic energies can be recognized and quantified. (PIXE) is thus a much more sensitive technique, especially for trace analysis of transition metals [6], and can reveal subtle impactor traces, invisible to SEM-EDX.

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References: [1] Opiela J. et al. (2012) *NASA/TP-2012-217359* [2] Anz-Meador P. et al. (2013) Proc. 6th European Conf. Space Debris, ESA SP 723: s1b_anzme.pdf, CD-ROM [3] Kearsley A. T. et al. (2014) *LPSC 45* abstract #CCCC [4] Ross D. K. et al. (2014) *LPSC 45* abstract #DDDD [5] Kearsley A. T. et al. *MAPS submitted* [6] Jeynes C. et al. (2011) *Rev. Accelerator Sci. Tech.* 4 ; 41-82. [7] Campbell J. L. et al. (2010) *Nucl. Instrum. Methods B* 268: 3356-3363.