IMPACTS ON THE HUBBLE SPACE TELESCOPE WIDE FIELD AND PLANETARY CAMERA 2: MICROANALYSIS AND RECOGNITION OF MICROMETEOROID COMPOSITIONS.

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Introduction: Postflight surveys of the Wide Field and Planetary Camera 2 (WFPC2) on the Hubble Space Telescope have located hundreds of features on the 2.2 by 0.8 m curved plate (Fig. 1), evidence of hypervelocity impact by small particles during 16 years of exposure to space in low Earth orbit (LEO) [1,2].

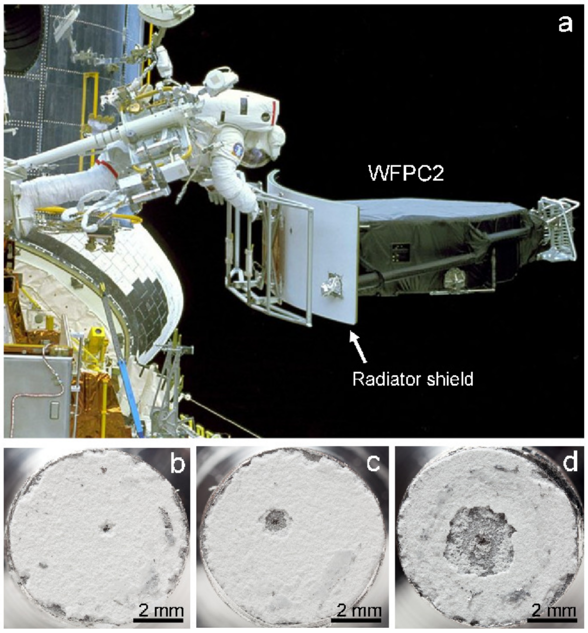

Fig. 1. a) WFPC2 is removed from the Hubble Space Telescope during service mission 2 (STS-125) in 2009; b-d) diverse sizes of impact structure on WFPC2 cores.

The radiator has a 100 – 200 µm surface layer of white paint, overlying 4 mm thick Al alloy, which was not fully penetrated by any impact. Over 460 WFPC2 samples were extracted by coring at JSC, using the method of [2]. About half were sent to NHM in a collaborative program with NASA, ESA and IBC. The structural and compositional heterogeneity at micrometre scale required microanalysis by electron and ion beam microscopes to determine the nature of the impactors (artificial orbital debris, or natural micrometeoroids, MM). Examples of MM impacts are described by [3,4]. Here we describe the development of novel electron beam analysis protocols [5], required to recognise the subtle traces of MM residues.

Methods: Two cores were mounted in resin blocks, cut and polished to make vertical sections through the radiator structure. The sections were mapped and analysed using energy dispersive X-ray (EDX) microanalysis in a Zeiss EVO 15LS scanning electron microscope (SEM) at NHM and by particle induced X-ray emission (PIXE) using a 2.5 MeV proton beam at IBC. With point analyses of small areas, this revealed the compositional signatures from all layers of the substrate, against which extraneous contributions from the impacting particle could be recognised.

The main SEM-EDX analysis protocol used on impact features [4] employed a 20 keV electron beam of 3 nA current, to produce long duration (200s) X-ray spectra from points selected as showing evidence of impact melting. The large number of X-ray counts in the spectra resulted in very low background variation, and statistical detection limits corresponding to ~ 0.06 wt % for Mg and Fe. However, due to the complex surface topography and high porosity of the frothy solidified melt, full matrix correction was not attempted in this study. Instead, characteristic element peak areas and background variation were determined by deconvolution routines in the Oxford Instruments INCA software (version 18d). Using these data, two types of graphical plot were developed to reveal subtle traces that would indicate incorporation of impactor residues with melted radiator materials. Type 1: Mg/Al vs Cr/Fe X-ray counts, a measure largely insensitive to topographic influence on matrix absorption and fluorescence effects; and Type 2: Mg counts/counts for Mg detection limit vs Fe counts/counts for Fe detection limit, which requires high quality spectra. Where no diagnostic X-ray signature was found by SEM, the sample was mapped using PIXE at IBC, with the superior detection limits revealing areas of very low concentration and giving diagnostic transition metal ratios [6].

Results: The vertical section (Fig. 2) showed that the paint is a mixture of porous zinc titanate grains (2 types), bound with potassium silicate, and containing reactive K salts. The alloy bulk composition is: ~ 97 wt % Al; 0.86 % Mg; 0.76 % Si; 0.25% Cr; 0.13 % Mn; 0.58% Fe and 0.39% Cu; trace P, Ti, V, Ni, Ga and Rh. Alloy inclusions of µm scale are rich in Mg + Si (~ 0.3% alloy volume), and Fe+Cr+Mn (~1.8 % volume).

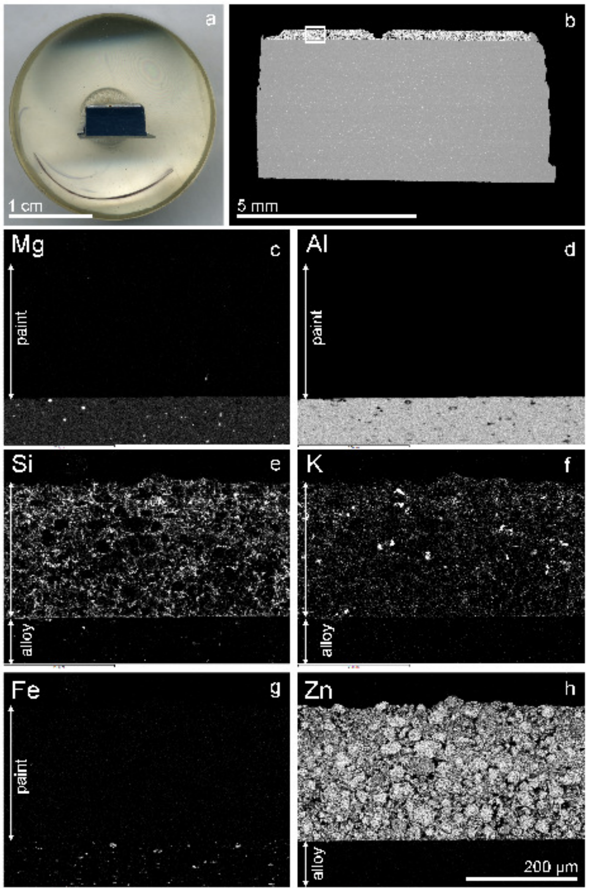

Fig. 2. Vertical cross section: a) optical image; b) BEI; and c) to h) EDX maps showing paint and alloy layers.

1300 spectra taken from points on polished metal, and from areas on exhumed alloy seen on other cores, gave a very tight clustering of Mg/Al values (Fig. 3).

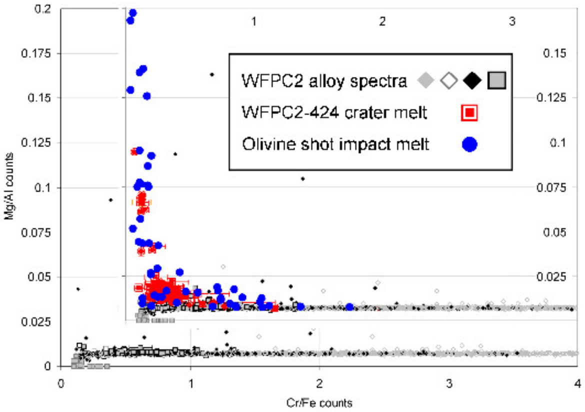

Fig. 3. Mg/Al vs Cr/Fe X-ray counts for: alloy (grey and black); and (inset) melt from experimental olivine impact (blue); and melt in WFPC2 sample 424 (red).

Analyses of metal-rich melts created by laboratory impact of olivine [5] fall well outside the plot position of the alloy (Fig. 3), as do the captured silicate grain (olivine?) and alloy melt in sample WFPC2-424 [2,4].

To calibrate a second plot type, for frothy paint melt, 200 spectra were taken from a clean paint surface (and areas on the polished vertical section) giving a tight cluster (Fig. 4). Fe was not found above detection limit, and Mg in only a few spectra (all > 2 x detection limit, ~ 0.1 wt %). ZOT paint is therefore a good medium for recognition of the most abundant (i.e. Mg- and Fe-rich) MM materials. The higher the proportion of impactor material in the melt, the further the analysis population deviates from the substrate, as seen in crater 124 (Fig. 4). However, if alloy was also melted, caution is required, as Mg- and Fe–rich inclusions may be included, and the Mg/Al vs Cr/Fe plot is more useful.

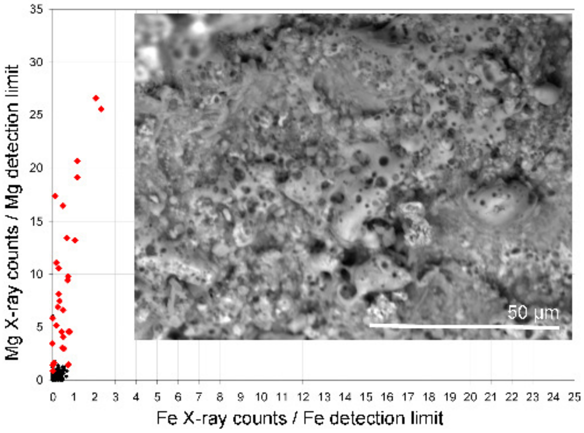

Fig. 4. Plot of Mg vs Fe X-ray counts above detection limits on: clean WFPC2 paint (black); frothy paint-rich melt from a small WFPC2 impact, sample 124 (red).

In most of the small impacts examined, elemental enrichment was so obvious in raw EDX spectra that a plot was not required. In the larger impacts, especially where abundant frothy melt was scarce, plots were very useful. In all, an extraneous compositional signature was recognized in ~ 90% of impact features.

Conclusions: The WFPC2 radiator has acted as a surprisingly good collector of MM impact remnants. Despite the intimate mixture of particle residue with paint and alloy melt of complex composition, by the collection of high quality EDX spectra and the use of carefully calibrated plots, it is possible to tease out subtle compositional signatures, revealing distinctive major element chemistry of micrometeoroid impactors.

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References: [1] Opiela, J.N. et al. (2012) *NASA/TP-2012-217359* [2] Anz-Meador et al. (2013) Proc. 6th European Conf. Space Debris, ESA SP 723: s1b_anzme.pdf, CD-ROM [3] Ross D. K. et al. (2014) *LPSC* 45 Abstract #CCCC [4] Kearsley A.T. et al. (2014) *LPSC* 45 Abstract #DDDD [5] Kearsley A. T. et al. *MAPS* submitted [6] Grime G. et al. (2014) *LPSC* 45 Abstract #EEEE.