Presentation Preference:
Oral

14th Hypervelocity Impact Symposium
April 24th – 28th, 2017
University of Kent, Canterbury, UK

HYPERVELOCITY IMPACT IN LOW EARTH ORBIT: FINDING SUBTLE IMPACTOR SIGNATURES ON THE HUBBLE SPACE TELESCOPE

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ABSTRACT

Introduction

Return of large surface area components from the Hubble Space Telescope (HST) during shuttle orbiter service missions has allowed inspection of large numbers of hypervelocity impact features from long exposure in low Earth orbit. Particular attention has been paid to impacted particle origins: artificial Orbital Debris (OD) or natural Micrometeoroid (MM). Extensive studies have been made of solar cells (Graham et al., 2001; Kearsley et al 2005, Moussi et al., 2005) and recently, the painted metal surface of the Wide Field and Planetary Camera 2 (WFPC2) radiator shield (Anz-Meador et al., 2013; Colaux et al., 2014; Kearsley et al., 2014a; Ross et al., 2014). Both these materials have layers of complex chemical composition, into which particle fragments and melt may infiltrate during impact.

Experimental light gas gun (LGG) impacts (Price et al., 2014) show impactor remains may be dispersed and dilute, often as very thin and patchy coatings within an irregular impact-generated pit. In previous studies, low concentration of particle residue, rugged impact feature topography, and especially the complex multi-element composition of the impacted surface proved significant barriers to recognising impactor traces. Analysis was both difficult and time consuming (e.g. Graham et al., 2001); a substantial proportion of impactors (25-65%) could not be identified. Recent advances in energy dispersive X-ray microanalysis (EDX), especially high count rate silicon drift (SDD) and annular pole-piece detectors now permit routine identification of impactor origins even in deep crater shapes, using scanning electron microscope (SEM) and particle induced X-ray emission (PIXE) instruments (Kearsley et al., 2012, 2014b). Here we demonstrate how these techniques allowed us to determine the particle source for large numbers of WFPC2 impacts.

Methods

We used two main SEM instruments: Zeiss EVO 15LS at NHM and JEOL 7600F (field emission) at NASA-JSC; both fitted with SDD detectors. To isolate subtle impact melt signatures on the zinc orthotitanate (ZOT) and aluminium alloy (Al-6061) of the WFPC2 radiator shield we used Oxford Instruments INCA software to separate peak and background X-ray counts for specified X-ray emission lines. From tables of likely OD and MM signature elements (e.g. Kearsley et al., 2005), and knowledge of pristine WFPC paint and alloy compositions, we extracted data for: Mg, Al, Si, S, K, Ca, Ti, Cr, Mn, Fe, Ni, Cu and Zn. Two types of graphical plot were developed, to highlight extraneous element signatures in small impacts on the ZOT paint (Fig. 1), and larger craters in the Al-alloy (Fig. 2). Impactor origin was then classified by a suite of decision trees (Kearsley et al., 2012). A Bruker FLATQUAD

XFlash SDD EDX detector was also used to examine the interior of deeper craters. PIXE maps and spectra were acquired in the Ion Beam Centre, University of Surrey (Colaux et al., 2014).

Results

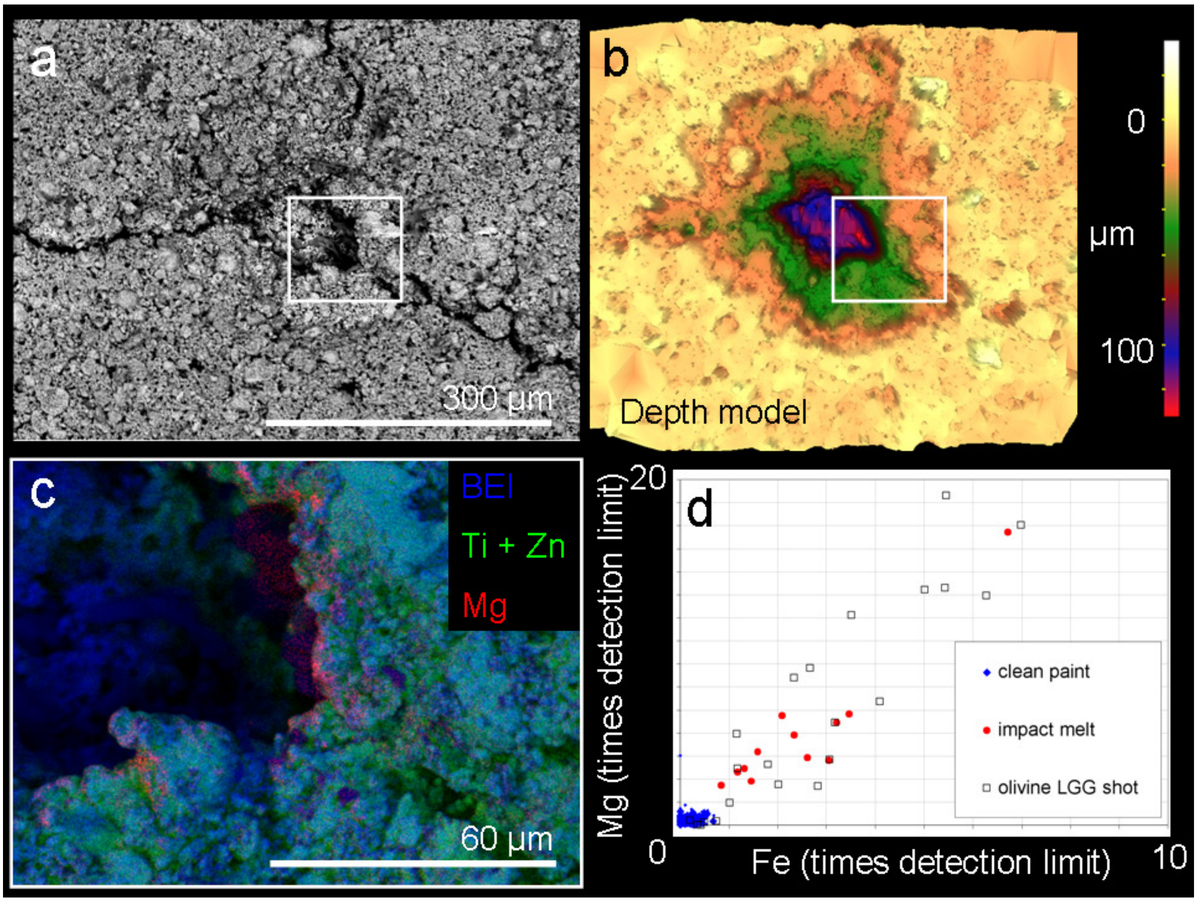

Figure 1. WFPC2 impact 339: a) SEM backscattered electron (BE) image; b) depth model; c) SEM-EDX maps show Mg in impact melt lining the impact feature d) plots of SEM-EDX X-ray counts for Mg and Fe show much higher levels in impact melt (red) than in clean ZOT paint (blue), and similar to impact residue from LGG impacts of olivine grains (open black squares). Excess Mg and Fe in frothy impact melt show impactor was a micrometeoroid.

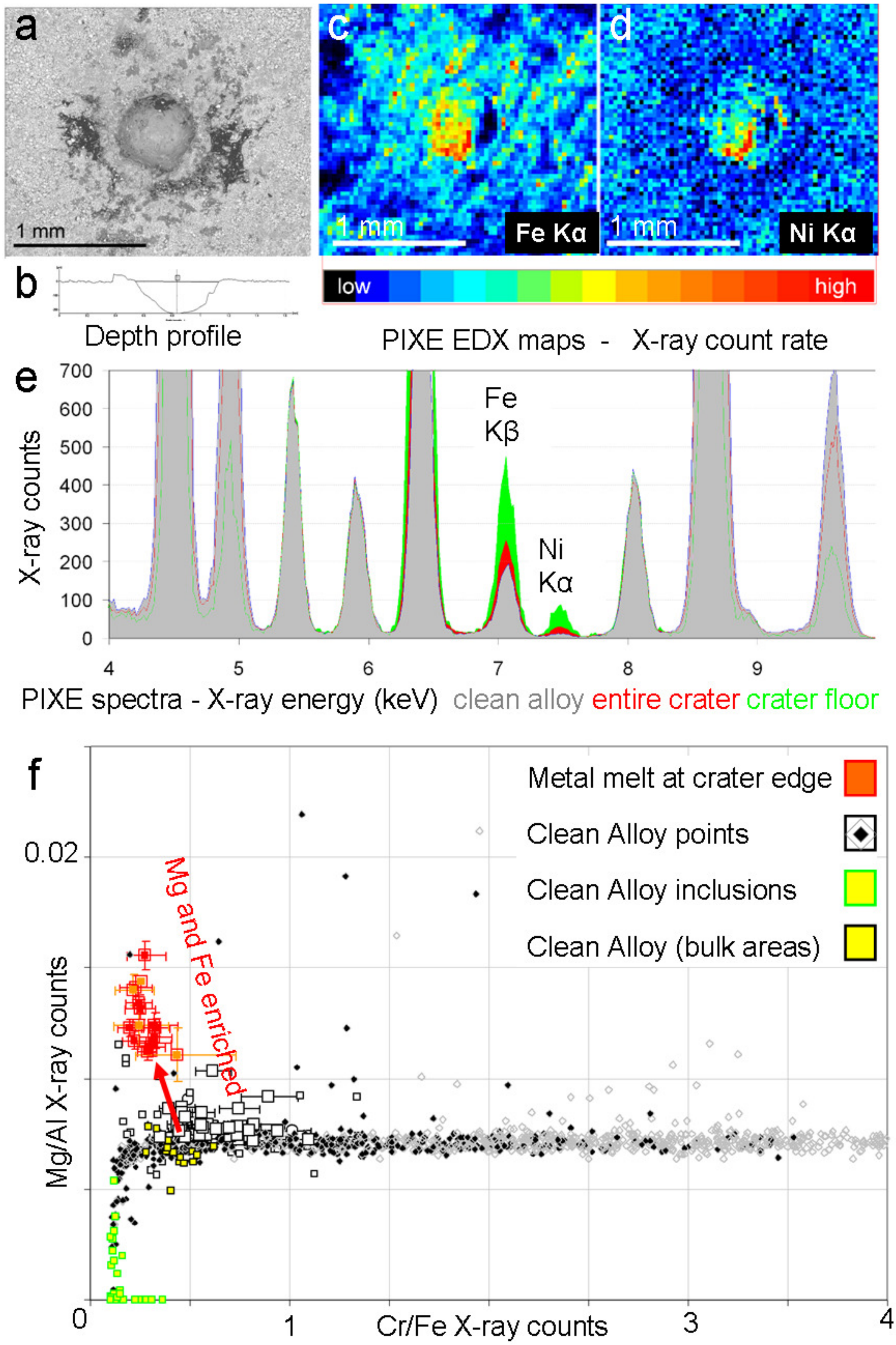
a
1 mm
c
1 mm
Fe Kα
d
1 mm
Ni Kα
low
high
b
Depth profile
PIXE EDX maps - X-ray count rate
e
X-ray counts
700
600
500
400
300
200
100
0
Fe Kβ
Ni Kα
4
5
6
7
8
9
PIXE spectra - X-ray energy (keV) clean alloy entire crater crater floor
f
0.02
Mg and Fe enriched
Metal melt at crater edge
Clean Alloy points
Clean Alloy inclusions
Clean Alloy (bulk areas)
Mg/Al X-ray counts
0
1
Cr/Fe X-ray counts
3
4

Figure 2). WFPC2 impact 462: a) SEM BE image; b) SEM depth profile; c and d) PIXE EDX maps show Fe and Ni, some iron-rich inclusions in Al alloy, but Ni only enriched in pit; e) PIXE EDX spectra show high Fe and Ni on crater floor, similar to micrometeoroid metal composition; f) plot of Mg/Al versus Cr/Fe X-ray counts in SEM-EDX spectra from crater edge (red) shows enrichment of Mg and Fe over alloy composition (black, grey, yellow and green), indicating a mafic silicate component also added from the impacted micrometeoroid.

Summary and conclusions

Results from 224 WFPC2 samples examined at NASA- JSC showed 177 MM residues, 1 OD residue, and 46 features with no definitive evidence for the impactor type. In the UK, SEM-EDX and PIXE-EDX maps, spectra and X-ray count plots showed 166 MM residues and 2 OD residues in 188 impact features on WFPC2, ~ 90% of those examined, considerable enhancement of impactor recognition over an earlier study of HST impacts (~75% identified as MM or OD in origin, Kearsley et al., 2005).

Acknowledgements

ESA contract *40001105713/12/NL/GE* awarded to NHM and the University of Surrey; T Goral for help with the FLATQUAD X-Flash SDD at NHM.

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