SPACE DEBRIS: ORBITAL MICROPARTICULATES IMPACTING LDEF EXPERIMENTS FAVOUR A NATURAL EXTRATERRESTRIAL ORIGIN

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Introduction

The results of work carried out at the Unit for Space Sciences at the University of Kent at Canterbury, United Kingdom, on the micrometeoroid and space debris environment of near Earth space are described in this article. The primary data for the research programme is supplied by an examination of several types of exposed surface from the NASA Long Duration Exposure Facility (LDEF) including an experiment dedicated to the detection of micrometeoroids and space debris provided by the University.

Extended Press Abstract

In the years leading up to the return of LDEF, work in examining retrieved surfaces from the repaired Solar Maximum Mission satellite had yielded the result that space debris was the most abundant component in the particle population in sizes ranging from 10^{-14} grammes (≈0.2 microns in diameter) to 10^{-9} grammes (≈9 microns diameter). A review of the interpretation of this data has cast doubts on that conclusion, and the examination of LDEF surfaces is beginning to provide a definitive answer both by trajectory analysis enabled by the attitude stabilisation of LDEF, and spectroscopy conducted at individual impact sites, yielding element and isotope chemistry.

The accompanying plot (figure 1) shows trends both in the number of Earth orbiting satellites and in the small particle population as observed by several spaceborne particle detection projects[†]. From this plot, there is no unambiguous indication that the small particle population encountered in low Earth orbit is in any way correlated with the satellite population (as would be the case with space debris) and seems to remain constant over a timescale of years; an expected characteristic of the natural interplanetary component.

Sufficient data will ultimately be derived from an examination of LDEF surfaces which will support or contradict this hypothesis on the basis of impactor chemistry; a generally unambiguous indicator of origin, extra-terrestrial or otherwise. Chemistry of impactor residues are derived from measurements made by X-ray and mass spectrometers at the University of Kent at Canterbury and elsewhere.

Good statistics have yet to be obtained from LDEF impact site chemical classifications; but the trend analysis presented above, and statistically sound flux data from several experiments plus analysis of engineering surfaces on LDEF,

[†] Note for Editors:

A simplification of this diagram would be to reproduce only the solid curve labelled 'Satellites' along with the three dotted curves labelled '5µm', '20µm' and '40µm'. These latter three should be re-labelled as 'greater than 2 picogrammes', 'greater than 130 picogrammes' and 'greater than 1000 picogrammes' respectively. These masses are those of the smallest particle that can perforate Aluminium foil of the given thickness at the typical velocities encountered in low Earth orbit (several kilometres per second or tens of thousands of miles per hour). A picogramme is one million millionth of a gramme or 28,375,000,000,000 to the ounce. A micron is one millionth of a metre, or 25,400 to the inch.

are beginning to indicate that an excess of natural small particles above the simple interplanetary mass distribution exists.Surprisingly, perhaps, these particles could be orbiting the Earth .

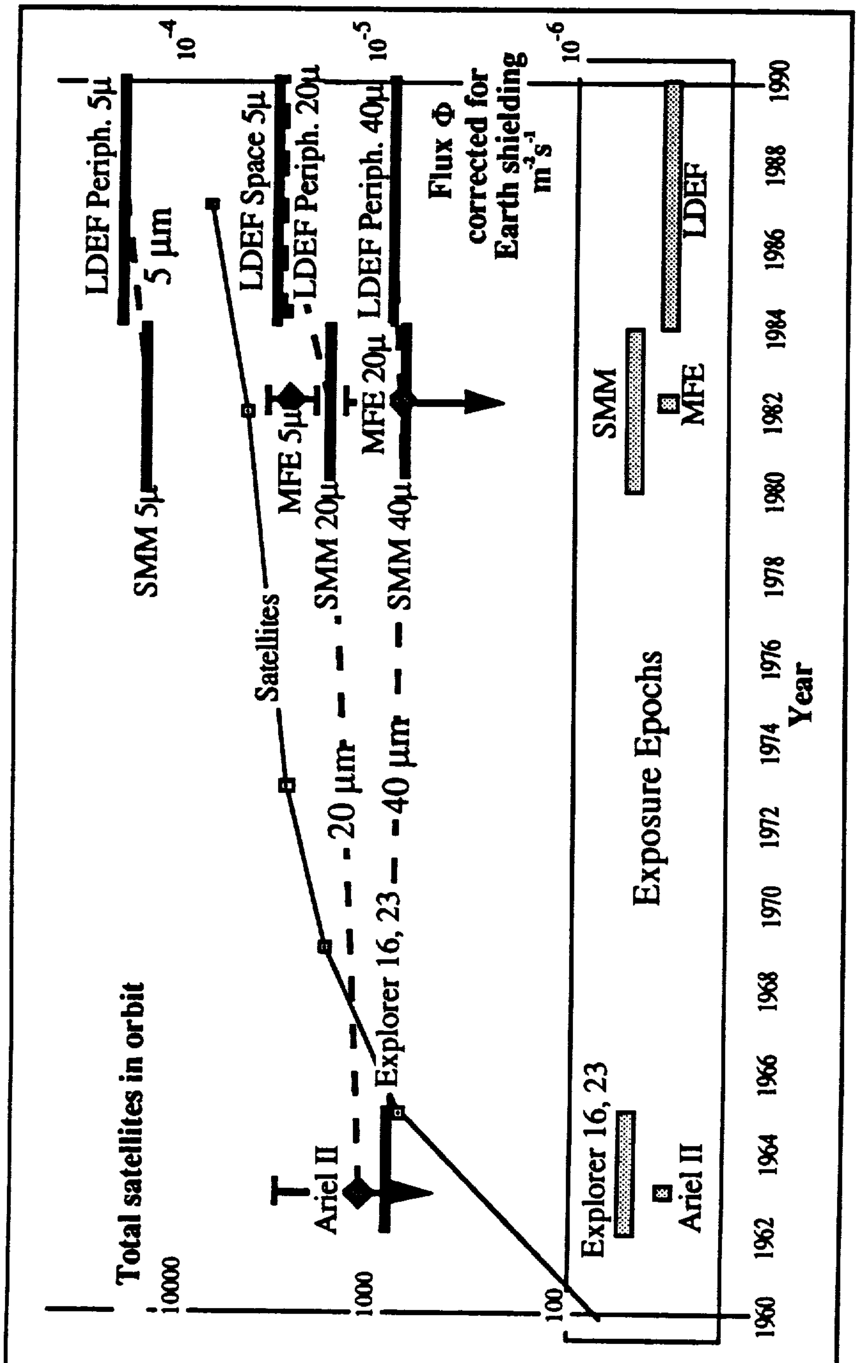


Figure 1. The long term evolution of the number of orbiting bodies in four size regimes; namely deliberately deployed satellites, and particles of such a size that they are capable of penetrating Aluminium foils of the three thicknesses. These latter three items of data, expressed as fluxes of particles per unit area per unit time, are cumulative in size. The term cumulative in this context refers to the fact that each point represents all particles larger than the minimum size to achieve perforation.

This interim conclusion revives the once popular concept of a terrestrial dust belt, the origin of which is, as yet, unclear. Asteroidal and/or cometary sources are definite candidates, and the answer to this question may be derived from the chemistry of the debris found associated with impact sites. A description of the processes involved in this analysis follows.

Analytical techniques

In the range of particle sizes under discussion (micron scale), the damage experienced by spacecraft surfaces is in the form of minute craters (perforations in foils) of a characteristic form. This form invariably incorporates a lip or rim around the crater, either continuous or made up of separate 'petals'. The profiles of craters, (the morphology) are symptomatic of 'hypervelocity' impact; that is an impactor velocity of greater than 3-4 kilometres per second. This distinguishing aspect allows the discrimination of damage caused on orbit from surface defects and other localised features. It is therefore important to image potential sites at high magnification, with a large depth of field; requirements which suggest the use of the Scanning Electron Microscope (SEM). This examination yields the size of the crater site, which by use of mathematical techniques verified in the laboratory over many years, yields the size of the impacting particle.

Conventionally, the SEM technique requires that the specimen be rendered electrically conducting by surface coating, but the University of Kent is equipped with an instrument whose performance allows operation in a regime where this is unnecessary. This latter is important where highly sensitive surface chemistry techniques are to be employed subsequent to the site location, classification and imaging stages in the analysis.

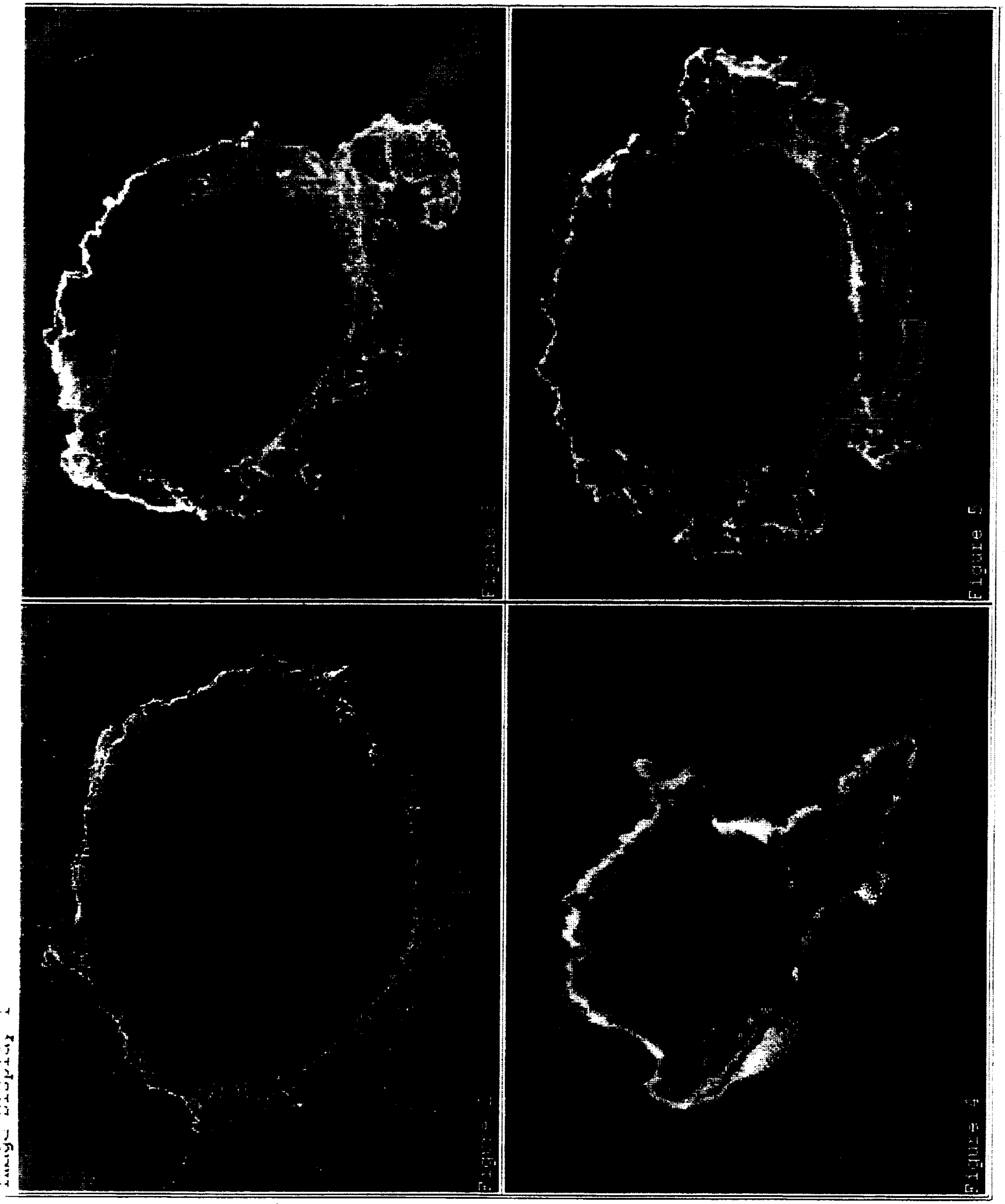
The first of these techniques is carried out in the SEM, by analysing the soft X-rays emitted by the specimen when the electron beam irradiates it. The energy distribution of these X-rays indicates the elements present in a thin layer on the order of a micron thick, and can be used to locate and identify areas of impactor debris deposits. These usually represent a very small fraction of the mass of the impactor, but some arrangements of target (the impacted surface) material, particularly thin foils, retain a significant proportion of impactor matter in a localised form. The University of Kent MicroAbrasion Package (MAP) experiment is just such an arrangement, and is thus a prime candidate to provide significant statistics on impactor chemical classes.

The most important classification in this context is that between space debris and natural micrometeoroids. While this was done with great success at impact sites on components of the Solar Maximum Mission satellite, chemical differences are not always clear cut. It is already known that major contributors to the micron sized debris population are Aluminium Oxide spherules, an effluent of upper stage solid rocket motor burns, and thermal control paint fragments whose chemistry includes Titanium Oxide. It is expected that many sites caused by impacts from such particles will be identified. Sites due to micrometeoroid impact, where impactor debris is extant, will have more complex chemistry, bearing some relation to the known compositions of stratospheric (Brownlee) cosmic dust particles and other extraterrestrial materials brought to Earth by various means.

Debris deposits, where the total amount is sufficient for the analyses, will be subjected to further techniques, notably mass spectroscopy which yields isotopic composition. This analysis can produce not only evidence of extraterrestrial origin but also detect the signature of an interstellar particle - that is material originating from a different stellar interior than that of the matter which formed our Solar System. The unambiguous identification of such an impactor has yet to be achieved from LDEF examination.

Epilogue

Data gathering on the low Earth orbit particle environment from LDEF surfaces continues apace at the University of Kent and elsewhere. In addition to the confirmation or contradiction of pre-LDEF conclusions on the composition of this population, much new information on the orbital distributions is emerging. The volume of potential data is such that some controversies will continue to rage for several more years, but already the puzzle has begun to unravel - aiding simultaneously the safe and efficient exploitation of near Earth space and our understanding of the origins of the Solar System. Technology driven needs such as the design of Space Station Freedom are looking to this LDEF data for design inputs on the hazards of this low Earth orbit particulate population.



Caption for micrographs

Scanning Electron Microscopy images of hypervelocity impact craters puncturing the Canterbury MAP experiment. Though shown at high magnification, larger particulates could be expected to impact on Space Station Freedom and could penetrate its protective shield.

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