IN-FLIGHT AND POST-FLIGHT IMPACT DATA ANALYSIS FROM DEBIE2 (DEBRIS-IN-ORBIT-EVALUATOR) ON BOARD OF ISS

Alessandra Menicucci[(1)], **Gerhard Drolshagen**[(2)], **Juha Kuitunen**[(3)], **Yuriy Butenko**[(4)], **and Cathal Mooney**[(4)]

[(1)] *ESA/ESTEC and Rhea System s.a., The Netherlands, Email: alessandra.menicucci@esa.int*
[(2)] *ESA/ESTEC, The Netherlands, Email: gerhard.drolshagen@esa.int*
[(3)] *Patria Systems Oy, Finland, Email: juha.kuitunen@patria.fi*
[(4)] *ESA/ESTEC and MODIS, The Netherlands, Email: yuriy.butenko@esa.int*

ABSTRACT

DEBIE2 (Debris-in-orbit-evaluator) was launched in February 2008 as part of the European Technology Exposure Facility (EuTEF) and installed on the exterior of Columbus on ISS. DEBIE2 is an active detector, composed by 3 sensor units able to monitor the sub-micron micro-meteoroid and debris population in space. Each DEBIE sensor consists of a thin aluminium foil coupled with 2 wire grids sensitive to the plasma generated by particles impacting on the foil where also 2 piezoelectric sensors are glued. If the particle penetrates the foil, this can be detected by a third electron plasma detector located just behind the foil. The combination of these information allows to estimate the micro-particles and debris fluxes. EuTEF and DEBIE2 were retrieved after 18 months in flight and returned to Earth with the Space Shuttle Mission STS-128. In this paper, the results of the analysis of in-flight impact data are presented as well as the comparison with the models. The DEBIE2 sensor pointing the Zenith direction, was found to have one wire of the upper grid cut in two pieces by an impact. The postflight analysis focused on this sensor and included optical and SEM/EDX scanning. The results from this inspection will be also presented in this paper.

Key words: space debris; micrometeoroids; in-situ measurements.

1. INTRODUCTION

Space debris and meteoroid particles constitute one of the main hazards caused by the space environment to any spacecraft orbiting in Earth orbit. There are around 22000 pieces of debris larger than 5 cm orbiting in near-Earth space that are tracked from the ground with radar or by optical detectors. In addition there is a much larger number of items too small to be detected from the ground.
While the risk of collision with a large piece of debris or a large meteoroid is very small, particles less than one millimetre in size impacting with velocities as high as 10 km/s for space debris and 20 km/s for meteoroids in size cause craters visible to the naked eye. Larger particles can penetrate the outer shielding of a spacecraft and can damage its internal equipment. As a result of this threat, designers have to consider the risk of particle impacts and design dedicated shielding structures. Particle fluxes in space are also of considerable scientific interest.
Most of what is known about the millimetre and micron sized orbital population has been gained through the analysis of spacecraft material and passive detectors returned from space.
Another possibility is to investigate in-situ the micrometeroids and debris populations by means of active detectors.
Patria Finavitec together with UniSpace Kent under an ESA contract have developed the DEBIE (DEBris In-orbit Evaluator) instrument capable of actively determining the parameters of sub-millimetre sized space debris and micrometeoroids in-situ by their impact with a detecting surface. The first of the DEBIE series, DEBIE1, was launched in 2001 on-board of the ESA Technology demostration satellite PROBA1 in a 600 km orbit.
A second instrument DEBIE2, was launched as part of EuTEF (EUropean Technology Exposure Facility) together with Columbus on STS-122 on 7th February 2008 and deployed during an EVA on 15th February 2008. EuTEF carried a suite of 9 different experiments requiring the exposure to the space environment and was retrieved to Earth in September 2009 after about 18 months (see Fig. 1).

2. THE DEBIE2 SENSOR

In DEBIE2 there are 4 elements: a Data Processing Unit (DPU) and 3 Sensor Units (SU) that were placed on different sides of EuTEF to detect particle impacts from the starboard (SU1), the Zenith (SU2) and the RAM (SU4) directions (see Fig. 2 and Fig. 3). The idea is to combine in the sensor unit a basic impact detector measuring the plasma generated by the impacts, the momentum and penetration of a thin aluminium foil.
The detection area of each sensor is 10 cm x 10 cm.

Proc. '6th European Conference on Space Debris'
Darmstadt, Germany, 22–25 April 2013 (ESA SP-723, August 2013)

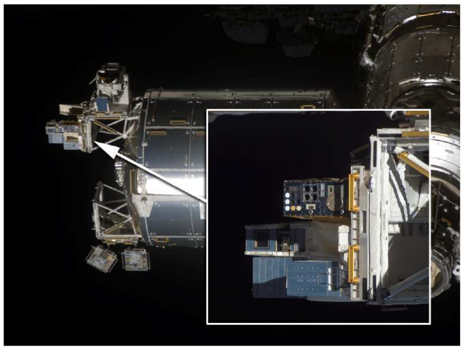

Figure 1. EuTEF outside Columbus.

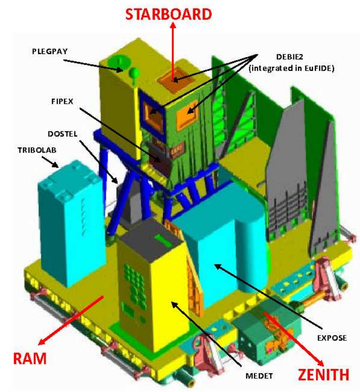

Figure 3. Accomodation of the 3 DEBIE2 sensors on EUTEF.

Two plasma detectors are placed in front of a thin aluminium foil, only 6 μm in the case of the SU2 and SU4 and 50 μm for SU1. The plasma channels are composed by 2 separated grids of charge collection wires which measure the plasma generated by the particle impacts on the foil, one for electrons and one for positive ions. Two piezoelectric transducers are coupled mechanically to the foil and measure the momentum of the impact. Particles with sufficient energy to penetrate the foil are detected by the third plasma detector (electrons) placed behind the foil.
The particle velocity and mass can be estimated from the measured parameters using pre-flight calibration data. The instrument sensitivity depends on the impact velocity: the plasma detectors can detect particles with a mass of $10^{-15}g$ or larger and the signal is $\propto mv^{3.5}$, while the PZT are sensitive to particle of at $10^{-11}g$ or larger and the signal is $\propto mv$. The relative timing measurements between the plasma and the PZT channels are also recorded. The coincidence measurement in all different channels provides detailed information on impact parameters and allows the distinction between real impacts and noise events. The data from each particle impact is classified and logged by the Data Processing Unit for further telemetry transmission to the ground station via the EuTEF/ISS on-board data handling.

Figure 2. DEBIE2: the 3 Sensor Units and the DPU.

3. ANALYSIS OF DATA

The collected data sample is highly dominated by noise events. False events are on DEBIE2 mainly due to the space environment (e.g. plasma and thermal environment) and ISS.
A typical DEBIE2 data sample (unfiltered) shows a periodicity of about 92 min, the ISS orbital period. It appears that potential impact events are not randomly distributed but often arrive in "clusters" within 1-1.5 min at a time.
In DEBIE2 the on-board software performs a classification of the detected events by giving a classification level from 1 (low) to 9 (high). However further filtering of the data is necessary off-line. It has been observed during the calibration campaigns that the 4 time delays between the different DEBIE2 signals are the best parameters on which a good noise discrimination can be based. During 2009 a total of 1260109 events have been recorded and the application of the selection criteria based on certain values for the time delays, allowed to filter out 931 candidate impacts events. This means that only 0.07% of the raw data are selected for further analysis. Fig. 4 shows the number of candidate impact events recorded per week in 2009. The fluxes predicted by the MASTER 2009 model [3, 4] are significantly lower: the flux for particle of 1-10 μm size on a randomly tumbling plate (RTP) at the ISS orbit is 864 impacts$/m^2/yr$ and for a RAM facing surface is 1794 impacts$/m^2/yr$. The rather high number of impacts seen by DEBIE2 is probably due to some extend to a residual contamination of noise events in the sample, but it is also possible that the model underestimate the debris population around the ISS. The measured fluxes by the sensors units facing the starboard and RAM directions are about a factor 10-20 higher than the fluxes predicted by the MASTER2009 model. On the Zenith facing sensor unit, the measured flux is a factor 100 higher than the predicted vaue but since this is the sensor damaged by an

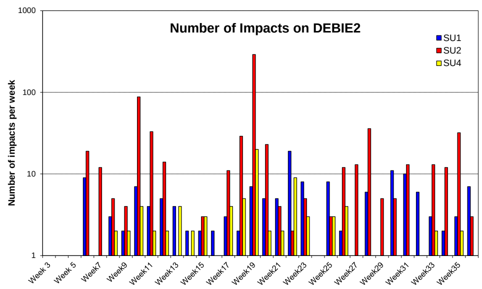

Figure 4. DEBIE2: number of candidate impact events per week in 2009.

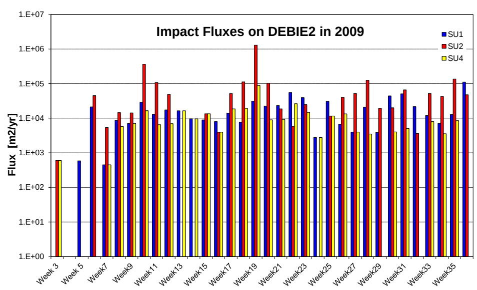

Figure 5. DEBIE2: measured fluxes on the 3 DEBIE2 sensors per week in 2009.

impact it is possible that after the event its sensitivity has been modified.

In addition, DEBIE2 will also record secondary ejecta from impacts on other parts of EuTEF or the ISS. Fluxes of ejecta can easily exceed those from direct hits if the sensor is located on complex structures.

A detailed comparison of the data acquired by SODAD [5], another experiment for the detection of micrometeroids and debris which flown together with DEBIE2 on EuTEF, might help understanding better the measurements and will be performed in the future.

4. RETRIEVAL AND POST-FLIGHT ANALYSIS

The retrieval of EuTEF/DEBIE2 was performed during the STS-128 mission with a spacewalk on 2nd September 2009. EuTEF was then returned to Earth aboard of the Discovery shuttle and shipped to the premises of the prime contractor Carlo Gavazzi Space. Already during the first inspection at NASA-KSC, it was found that one wire of the upper grid on SU2 (the sensor unit pointing to the Zenith) had been cut in two pieces. From the pictures taken by the astronauts performing the retrieval spacewalk, it is confimred that the damage has happened while in space, by an impacting particle.

DEBIE2 was then returned to ESA/ESTEC for the post-flight analysis. It was checked that besides the broken wire, DEBIE2 DPU and the 3 senors units were still fully functional.

Afterwards, the analysis has been then focused on the sensor with the broken wire. Since the impacted wire has a diameter of 75 um, one can derive that the impactor should have had a minimum size of 25 um and a maximum size of about 50 um, otherwise it should have caused larger impact damage on the foil.

A simple test with transmitted light for the back side of the Aluminum foil has shown humdreds of holes in the area beneath the broken wire, indicating that the particle was completely fragmented during the impact.

Another interesting feature visible from the optical scanning is the presence of a shadow created by a couple of wires close to the impact location. Part of the wires in the vicinity acted as shielding for the secondary ejected fragments as shown in Fig. 8.

More detailed analysis has been performed with the SEM and EDX equipment are still on-going. An example of an EDX spectrum taken from a crater rim is shown in Fig.9. It is hoped that these EDX spectra, which reveal the chemical composition of impact residues, will allow to characterize the impactor and determines whether it was a natural meteoroid or man-made debris particle.

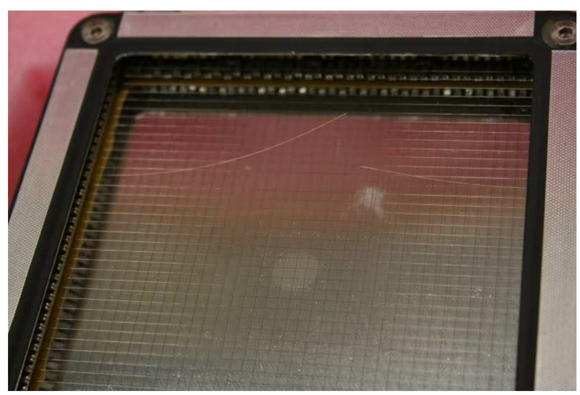

Figure 6. DEBIE2 Zenith sensor with a broken wire in the upper grid.

5. CONCLUSIONS

DEBIE2 has been flying outside of ISS for about 18 months. The in-flight data have been analysed and noise events filtered, leaving out 0.07% of the original data sample. The measured fluxes are significantly higher than the values predicted by the models. This discrepancy will

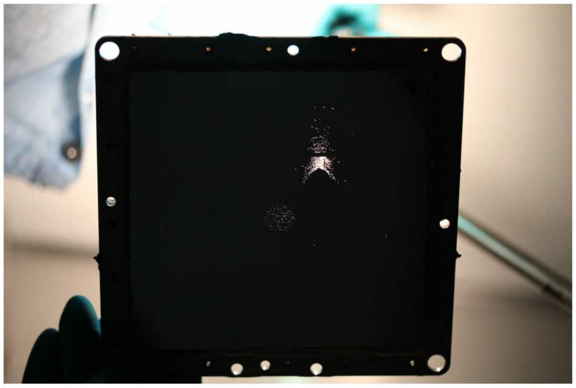

Figure 7. The disassembled DEBIE2 Zenith sensor illuminated from the back side with transmitted light. Two major impact locations are visible: the round-central one has been created during the pre-flight calibration campaign, while the second one (slightly above the centre) corresponds to the broken wire.

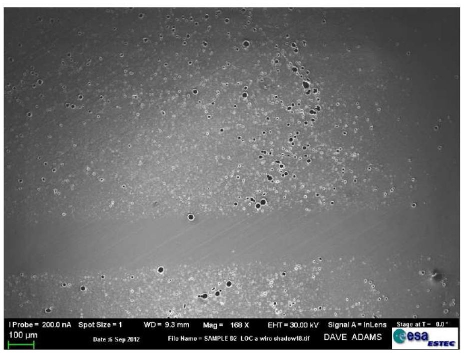

Figure 8. SEM image of the area beneath the broken wire showing the shadowing effect of a perpendicular wire of the lower grid.

need to be investigated in more details. A post-flight analysis has been carried out after the retrieval of DEBIE2 and the preliminary results show very interesting features resulting from the impact of an hypervelocity particle able to cut a wire of in the upper grounded grid.

ACKNOWLEDGMENTS

The authors would like to thank the colleagues of the ESA Material Space Evaluation and Radiation Effects Section (TEC-QTE) for the support provided during the DEBIE2 post-flight analysis.

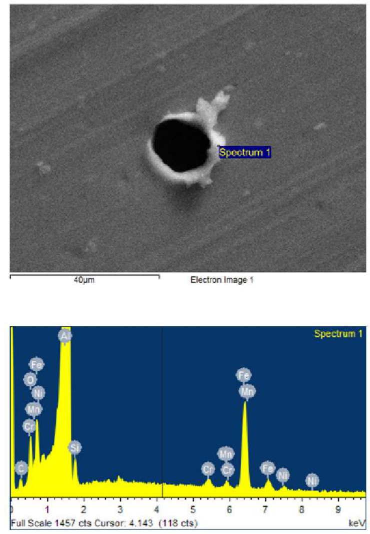

Figure 9. SEM image of an impact hole in the main location with associated EDX analysis. In this location some amount of Fe, Mn, Ni and Cr are present on top of Aluminum.

REFERENCES

1. J. Kuitunen, G. Drolshagen, J.A.M. McDonnell, H. Svedhem, M. Leese, H. Mannermaa, M. Kaipiainen, V. Sipinen. *"DEBIE - First Standard In-Situ Debris Monitoring instrument"* Proceedings of the Third European Conference on Space Debris, 19 - 21 March 2001, Darmstadt, Germany.
2. Schwanethal, J.P., et al., *"Analysis of impact data from the DEBIE (DEBris In orbit Evaluator) sensor in polar low Earth orbit"*, Proceedings of the 4th European Conference on Space Debris, ESA SP-587, 177-182 (2005).
3. S. K. Flegel, P. Krisko, J. Gelhaus, C. Wiedemann, M. Moeckel, H. Krag, H. Klinkrad, Y. L. Xu, M. Horstman, M. Matney, P. Vorsmann, *"Modeling the space debris environment with MASTER-2009 and ORDEM2010"*, 38th COSPAR Scientific Assembly, 2010, COSPAR Meeting, 38, 3922.
4. http://www.master-model.de/index.html
5. C. Durin, J.C. Mandeville, *"SODAD: First Results and Post-Flight Analysis"* Proceedings of 11th International Symposium on materials in a Space Environment, 15-18 September 2009, Aix-en-Provence, France.