

OVERVIEW OF RESULTS FROM THE MATERIALS EXPOSURE AND DEGRADATION EXPERIMENT (MEDET) AFTER 18 MONTHS IN ORBIT ON THE ISS

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ABSTRACT

This paper gives an overview of the MEDET results as the experiment reaches the end of its in-orbit operations phase on the ISS. Examples of data acquired by the different instruments are presented and analysis methods are discussed. A total of 11 impact events were recorded by the SODAD space debris detector. The pressure gauge results show the dependence of the measured pressure on the orientation of the Space Station, and the effect of the visiting Space Shuttle. The analysis of the Spectrometer data has focussed on the UV degradation characteristics of the materials, and erosion data is presented. The calorimeter results show the relative trends in the degradation behaviour of the materials during the 18+ months exposure to the space environment, though further thermal modelling will be required to refine the data. The preliminary results from the QCM contamination monitors indicate that no significant molecular contamination deposition occurred during this period. The status of the STORM radiation monitor will also be summarised. Reference is made to dedicated papers in the same proceedings for the spectrometer, SODAD and pressure gauge experiments.

1 INTRODUCTION

MEDET is an active in-flight experiment which was designed to investigate the effects of the complex Low Earth Orbit space environment on material properties, investigate material degradation due to contamination,

and measure the local micro-particle flux [1]. It operated successfully for about 19 months as an integrated part of the European Technology Exposure Facility (EuTEF), located on the outside of ESA's Columbus Module on the International Space Station (ISS). EuTEF was launched by STS-122 on 7th February 2008 and it was returned by STS-128 on 11th September 2009.

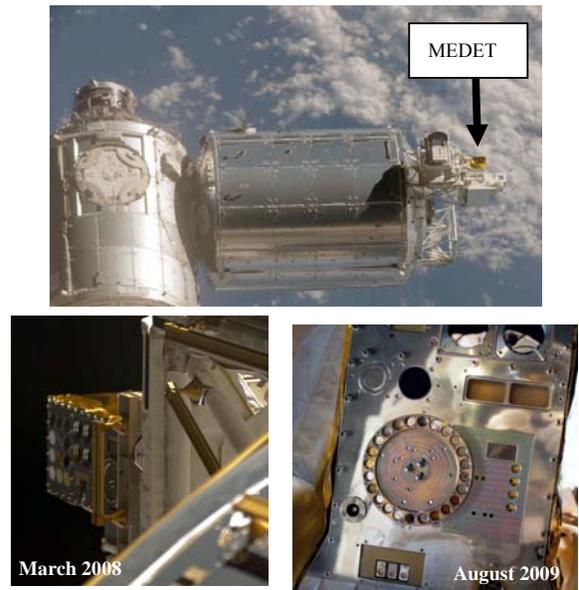


Fig. 1 MEDET in orbit on the outside of the Columbus Module (Photo Credits : NASA)

2 EXPERIMENT DEFINITION

The MEDET experiment consists of a collection of seven instruments, with active sensors and material samples. These were mostly exposed in the nominal ram direction on the ISS, with some sensors also pointing towards the zenith. A central power and logic unit enabled autonomous in-orbit operation and data was frequently downlinked to the ground via EuTEF [1, 2]. The experiment is shown in Fig. 2 and Fig. 3 and the function of each instrument is summarised below.

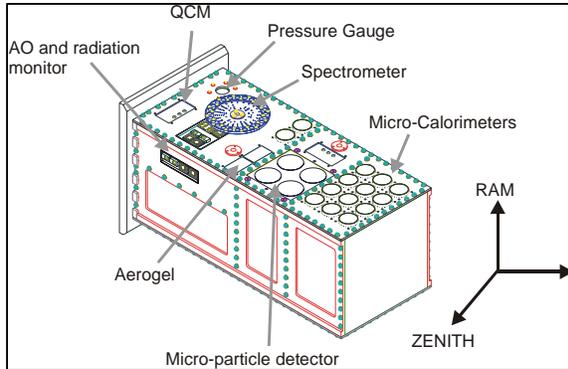


Fig. 2 Schematic showing the MEDET instruments

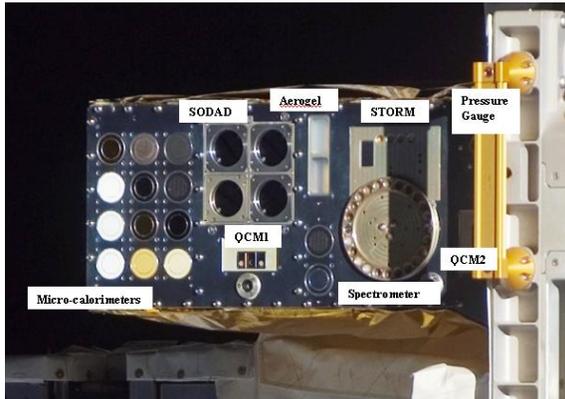


Fig. 3 In-orbit image of MEDET, March 2008 (Photo Credit : NASA)

SODAD is a MOS type impact detector, to characterise the properties of micro meteoroids and orbital debris particles [7].

Spectrometer is a UV-VIS-NIR optical transmission spectrometer system, to measure changes in the optical properties of transparent materials [3].

QCM is a collection of quartz crystal microbalances, for measurement of the atomic oxygen and contamination flux.

Pressure Gauge is a cold cathode type gauge, to measure the local pressure. It is based on a standard commercial gauge used in the laboratory, which has been adapted for space use.

AEROGEL is a passive detector, to capture micro meteoroid and orbital debris particles.

Micro-Calorimeters is a collection of 14 active microcalorimeters, which are used to measure the changes in the thermo-optical properties of thermal control coatings.

STORM is a collection of active detectors to measure the atomic oxygen, UV and X-ray flux [9].

3 MATERIALS

The material samples consist of a selection of thermal control paints and foils, optical glasses, thin solar sail materials and metallic anodisations. There are 12 micro-calorimeter samples approximately 50 mm in diameter (Fig. 4, Fig. 5) and 20 spectrometer samples approximately 12 mm in diameter (Fig. 6, Fig. 7). In addition, the MEDET MLI and radiator surfaces have the MAPATOX and RSR atomic oxygen protection coatings developed by CNES/MAP [10], and these materials also form part of the investigations.

Sample	Material Type
SG121FD	White silicone thermal control paint
PCBE	White silicate thermal control paint
PSBN	White silicate thermal control paint
ITO / 25 micron Kapton	Polyimide with conductive coating
25 micron Uplex S / VDA	Polyimide
MAPATOX / 25 micron Kapton HN / VDA	Polyimide with atomic oxygen protection coating
RSF/VDA/25 micron Kapton HN	Polysiloxane resin on aluminium coated polyimide
RSR/polished aluminium	Polysiloxane resin on polished aluminium
Kerolite	Black thermal control coating
Elastocor	Black thermal control coating
Second Surface Mirror	Silver coated SiO ₂
Y100	Experimental Polyimide

Fig. 4 List of the calorimeter materials

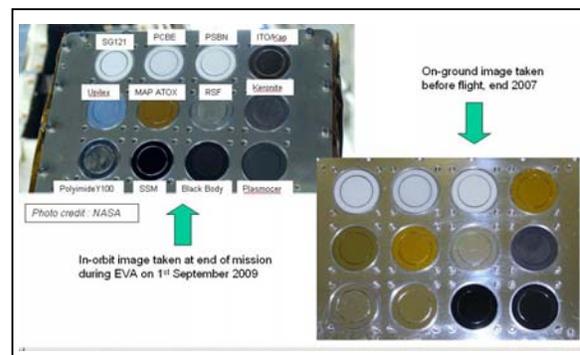


Fig. 5 Images of the calorimeter materials taken at the start and end of the in-orbit phase of the mission

Material	Application
RSF-F	Flexible thermal control coating
RTV-S690	Solar cell cover glass adhesive
RTV-S695	Solar cell cover glass adhesive
Uvollex 25S	Thermal control foil
Kapton HN + MAPATOX 41B	Atomic oxygen protection coating
Kapton HN + MAPATOX K	Atomic oxygen protection coating
KF01C01	Multilayer polymeric film for inflatable structures
COVEX	Polymeric film for inflatable structures
PEN	Polymeric film for inflatable structures

Fig. 6 Selection of the spectrometer materials.
For further details, see [4].



Fig. 7 Images of the spectrometer materials taken at the start and end of the in-orbit phase of the mission.

4 MISSION OVERVIEW

The MEDET operation was controlled from the User Home Base (UHB) in ONERA, Toulouse (France) which had a direct link to the EuTEF Erasmus Control Centre in ESTEC (The Netherlands). The data was downloaded to the UHB about once per week, and from there it was distributed to the science teams. The UHB was also used to upload tele-commands to occasionally change the operating parameters of the experiments, such as the acquisition frequency of the micro-calorimeters, the threshold levels of the illumination sensors and the sampling time of the spectrometers.

During the 19th months of in-orbit operation, the experiment operated successfully, although it was switched off several times for reasons such as EVAs in the vicinity (safety procedure), EuTEF troubleshooting and the MEDET temperature falling below the minimum operating limit of -15°C . In each case, the survival heaters maintained the instruments within their non-operating temperature limits. The results presented in this paper and the accompanying papers in the proceedings include an overview of :

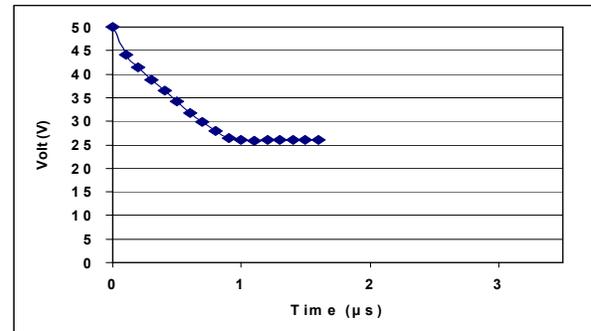
- SODAD impacts
- Pressure gauge measurements
- Atomic oxygen flux measurements using carbon coated QCM

- Contamination measurements using gold coated QCMs
- Changes in transmission of selected spectrometer materials
- Status of the STORM experiment
- Changes in thermo-optical properties of calorimeter materials

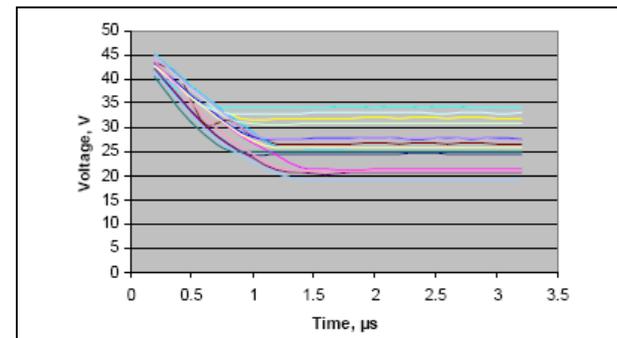
5 RESULTS

5.1 SODAD

SODAD performed as expected and was nearly fully operational at the end of the in-orbit phase of the mission. A total of 11 impact events were recorded. Ground based simulations are being performed to compare these results with predictions from the MASTER model [11], and an analysis of the influence of operational parameters is on-going (e.g. attitude control, time off for docking). An example of a flight impact compared to a ground based test result is shown in Fig. 8 and further information is provided in a dedicated SODAD paper in this proceedings [6].



In flight impact (2008-04-16), RAM position, F=10MHz



Ground based impact experiment

Projectile : Carbonyl-iron, Diameter =0.4 to 1.2 μm .

Fig. 8 Typical results from SODAD, showing a comparison between an in-flight impact (above) and a ground based impact experiment (below)

5.2 Pressure Gauge

The pressure gauge was powered on and recorded data continuously at a rate of one reading every 5 seconds throughout the mission except for the intermittent interruptions described in Section 4. For the majority of the time, the pressure gauge was in the nominal ram direction, and the average pressure per orbit was around 5×10^{-6} mbar to 10^{-7} mbar, as shown in Fig. 9 (a recalibration of the data has been performed since the preliminary results were reported in [2]). The acquisition rate was high enough to resolve detailed features in the signal. Diurnal pressure fluctuations were observed with a time period equal to the orbital period of the ISS and it was seen that Space Station orbital manoeuvres have a significant influence on the measured pressure. In particular, a pressure difference of about 2-3 orders of magnitude was measured between the ram and the wake during Station manoeuvres (Fig. 10). Further detailed information can be found in a dedicated Pressure Gauge paper in this proceedings [5].

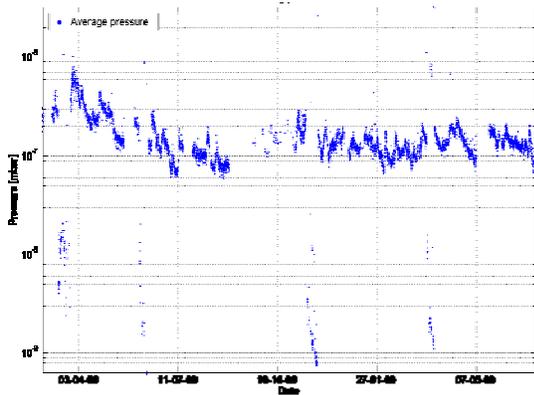


Fig. 9 Average pressure per orbit recorded using the MEDET pressure gauge

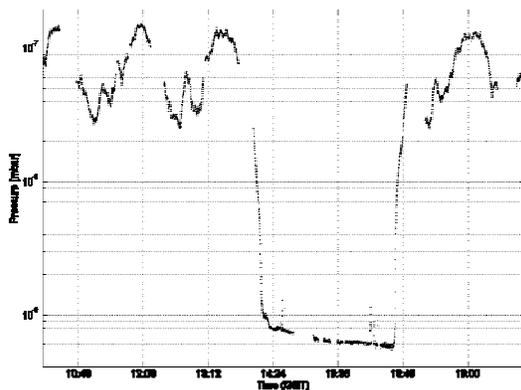


Fig. 10 Ram-wake effect due to reorientation of the Station by 180° (from +XVV to -XVV) during ATV debris avoidance manoeuvre on 27th August 2008

5.3 Spectrometer

The IR and UV spectrometers acquired in-orbit data once or twice per day over the course of the mission. A typical in-flight result is shown in Fig. 11. The analysis so far has concentrated on the evolution of the UV spectra for the different materials in order to highlight degradation phenomena such as yellowing or erosion. Comparisons will be made with ground based measurements performed on the samples after flight. Further information is provided in a dedicated Spectrometer paper in this proceedings [4].

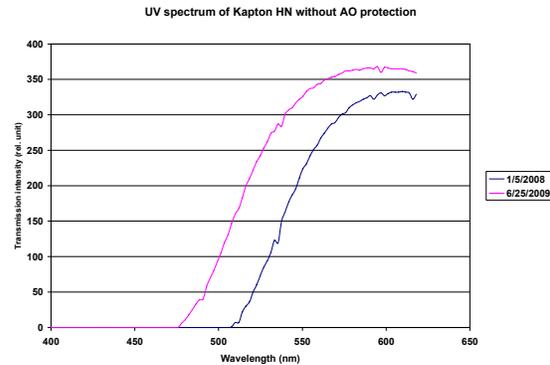


Fig. 11 Typical in-flight result from the Spectrometer experiment, showing the UV spectra of Kapton HN without AO protection near the beginning and end of the mission.

5.4 QCM (Quartz Crystal Microbalance)

There are two groups of three QCMs on MEDET, and they all acquired data at a rate of one reading every 4 minutes over the course of the mission. In each group, there is one gold-coated QCM for contamination monitoring, one carbon coated QCM for atomic oxygen measurement and one QCM with a high sensitivity to temperature. This third QCM will be called the "temperature QCM".

Fig. 12 compares the data from one group of contamination and temperature QCMs over the course of the mission. The similarity between the two data sets, albeit over different frequency ranges, shows clearly that there is a temperature related modulation of the contamination QCM data. The aim of the initial data analysis was to correct for this effect, using the fact that the temperature QCM is about ten times more sensitive to temperature than the contamination QCM.

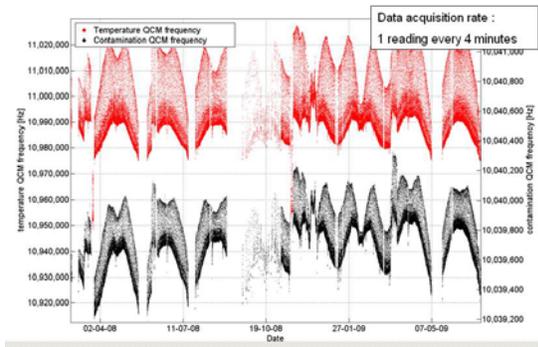


Fig. 12 Overview of data from one group of contamination and temperature sensitive QCMs

In Fig. 13 it can be seen that over short time scales, the QCM temperature cycles with a time period roughly equal to the orbital period of the ISS (day/night effect) and over longer time scales the temperature also varies according to the changing attitude and orientation of the Station (in particular the β -angle). Also in this figure, the frequency of the temperature QCM is compared with the reading from the PT100 sensor placed under the QCM device. As expected, it can be seen that the "PT100 temperature" lags behind the "frequency temperature" due to the thermal mass of the device.

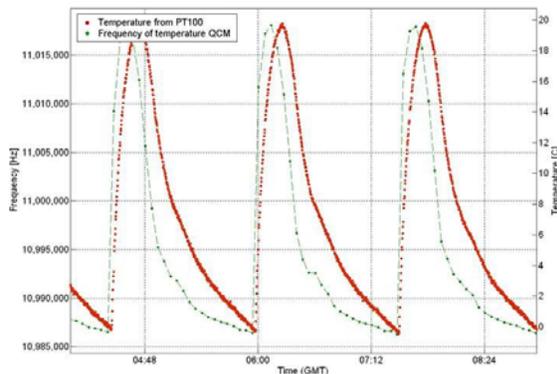


Fig. 13 Temperature QCM frequency compared with PT100 sensor temperature, for a period of several orbits. The day/night effect can be seen

In order to derive any information about the contamination flux, a correction for the temperature effect must be applied to the contamination QCM data. In Fig. 14, the frequency of the temperature QCM is plotted against the frequency of the contamination QCM, for different orbital cycles over a period of several weeks, and in Fig. 15 the same relationship is plotted for all of the cycles over the complete duration of the mission. It can be seen that over several consecutive cycles, a linear relationship between the frequencies is observed, but there is a vertical shift between cycles over longer time periods. This vertical

shift is related to a change in the frequency of the contamination QCM which is not directly proportional to the frequency of the temperature QCM. The variation in this shift over the course of the mission can be seen by plotting the contamination QCM frequency against time for given intercepts with the X-axis on the graph in Fig. 15. These results are displayed in Fig. 16. At this stage of the data analysis, it is not clear if this result is really showing the effects of some dynamic absorption/desorption phenomena related to molecular contamination, or whether some other non-linear temperature related effect is at play that has not been taken into account. However, it can be seen that over the course of the mission the overall trend is for the frequency to increase slightly, and so it can be concluded that no significant accumulation of deposited molecular contamination has been measured on the QCMs (a deposition would actually cause a net decrease in the frequency).

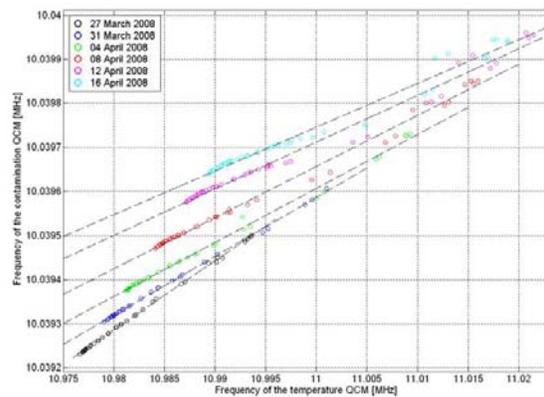


Fig. 14 Temperature vs Contamination frequency for selected cycles over a period of several weeks

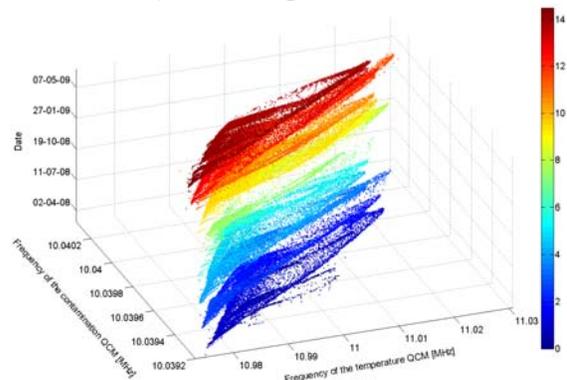


Fig. 15 Temperature vs Contamination frequency plotted for all cycles over the course of the mission. The right hand vertical scale is in months

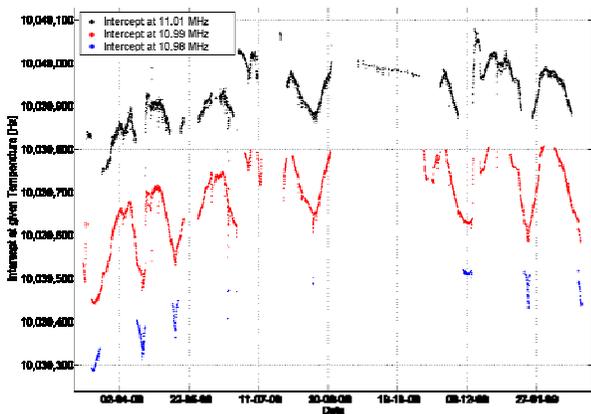


Fig. 16 Trends in contamination QCM frequency over the course of the mission for specific temperature QCM frequencies. Average sensitivity of contamination QCM = 4×10^{-9} g/cm²/Hz (approx)

An overview of the data from the two carbon-coated QCMs is shown in Fig. 17, together with images of one set of sensors taken before flight and in-orbit at the end of the mission. In the first 2-3 weeks, a linear increase in frequency was observed, which indicates a linear decrease in the mass of carbon. As previously reported, it has been estimated that the atomic oxygen fluence was approximately 1.0×10^{20} atoms/cm² for 16 days of exposure. However, further calibration measurements will be performed on the sensors after retrieval in order to confirm this value. Towards the middle of April 2008, the curves become non-linear and then flatten. This can be attributed to the complete erosion of the carbon, which was expected given the limited 2 μ m thickness of the deposited layer. This is also confirmed by the images acquired before flight and in-orbit at the end of the mission.

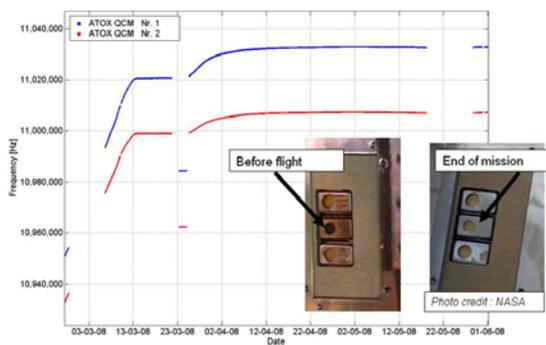


Fig. 17 Overview of data from the carbon-coated QCM sensors

This QCM data also covers the period when the Space Shuttle STS-123 docked to the ISS in March 2008. It is interesting to note that the erosion appears to stop at the moment the Shuttle docks, and then continues after the Shuttle has undocked. This corroborates the evidence from the pressure gauge (Fig. 18). Previously, this was attributed to a possible shielding effect caused by the Space Shuttle [9]. However, it is now believed to be due to a "ram/wake" effect, caused by re-orientation of the Station during the Shuttle docking.

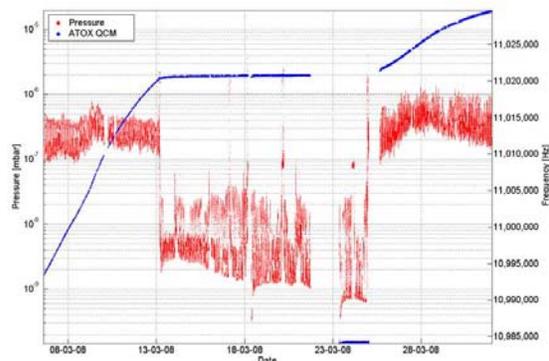


Fig. 18 Correlation between pressure gauge and QCM data, showing Ram/Wake effect due to reorientation of the Station during the docking of the Space Shuttle STS-13 in March 2008

5.5 STORM

All of the STORM data has been downloaded and a preliminary analysis has been performed.

The ZnO Atomic Oxygen Sensors were responsive to the in-orbit LEO environment although it took several months for the resistances to stabilise (due to possible desorption of atmospheric species accumulated on the sensors during ground storage). It has also been found that there is a temperature dependent effect. Further analysis is required to quantify the AO response.

The Carbon Atomic Oxygen Sensors showed no significant change in resistance over the duration of mission. These are unexpected results based on ground based measurements made before flight and a detailed materials analysis will be performed on the sensors after their return to try and explain the behaviour.

The X-ray and UV sensors were responsive to the diurnal variations in the solar illumination (as also recorded by the MEDET illumination sensors) but no significant solar events have so far been identified. However the data set is large and further analysis is ongoing.

5.6 Micro-calorimeters

For the majority of the time, the calorimeter data was acquired at an acquisition rate of one reading every 12 hours (depending on the illumination conditions). Periodically the acquisition rate was increased for several days via tele-command to one reading every 3 minutes in order to see the thermal cycling behaviour of the materials over several orbits. An overview of all of the data for one of the samples (as an example) is shown in Fig. 19 and a selection of this data for one of the high frequency cycling periods is shown in Fig. 20.

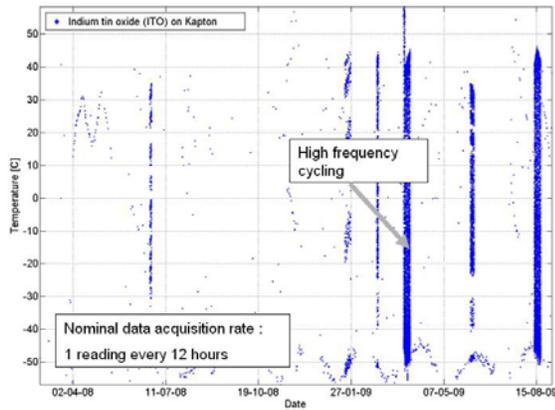


Fig. 19 Overview of all data from one of the micro-calorimeters (ITO kapton shown as an example)

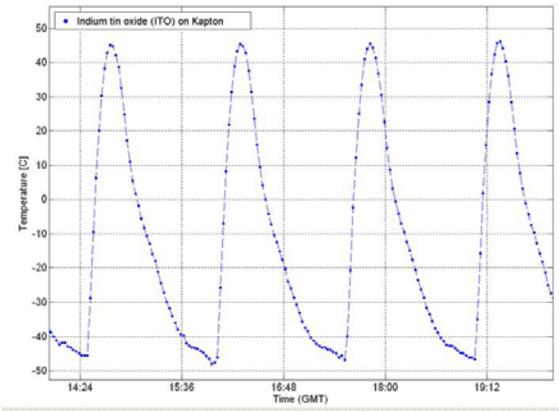


Fig. 20 Example of the data acquired at a higher frequency in order to see the thermal cycling behaviour of the micro-calorimeters

Although not listed in Fig. 4, two of the micro-calorimeter samples are actually "black bodies" consisting of thin black metallic sheets folded in a concertina pattern in order to give an α / ε ratio close to

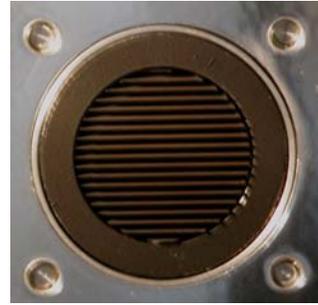


Fig. 21 One of the "black body" micro-calorimeters

1.0 (see Fig. 21). The ultimate goal of the micro-calorimeter data analysis is to derive the changes in the thermo-optical properties of the materials from the temperature data, using the black body calorimeters as references. To perform this analysis, a detailed thermal model of the micro-calorimeter/ISS system will need to be constructed, and this was beyond the scope of the work presented in this paper. However, a simplified treatment of the temperature data has been performed in order to display the general trends in the properties of the materials over the course of the mission. This analysis has been based only on the data acquired during the high frequency cycling periods.

Fig. 22 shows the maximum temperature per orbit for each material over the course of the mission, where each data point is the average for 15 consecutive orbits within the cycling period. These results show that at the start of the mission the materials are behaving as expected, with a distribution of temperatures according to the different thermo-optical properties of the materials. For example, the SSM and white paints are the coldest and the black paints are the hottest.

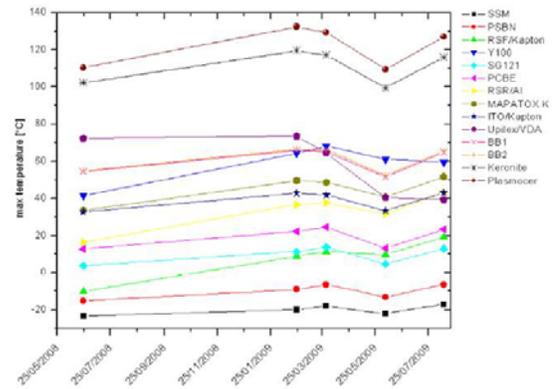


Fig. 22 Maximum temperature per orbit for the micro-calorimeter materials at different stages of the mission (data acquired during cycling periods only)

However, although some of the temperature trends in Fig. 22 may be related to changes in the properties of the materials, the temperature will also be influenced by the changing orbital parameters of the ISS (such as the β -angle). Therefore this data cannot be used to deduce the behaviour of the materials without correction.

In order to try and quantify the changes in solar absorptance for the materials, the initial idea was to compare the temperature response of each material with that of the black body micro-calorimeters. However, this approach did not give realistic values for the absorptance, possibly because the black bodies do not reach thermal equilibrium within each orbit. Therefore, instead of using the black bodies as a reference, the materials were divided into three groups with similar pre-flight absorptance values, as shown in Table 1. In each group, a reasonably "stable" material was chosen, and relative absorptance values were calculated using this material as a reference, with the assumption of constant emittance (Fig. 23, Fig. 24 and Fig. 25). Using this approach, the calculated absorptance values were much more realistic, although still not highly accurate (in particular, for the cases where significant erosion has occurred, it is not valid to assume constant emittance).

Table 1 Grouping of materials according to pre-flight absorptance measurements

Material	Pre-flight α_s ⁽¹⁾	Reference used
SSM	0.084	
PSBN	0.122	SSM
RSF	0.115	SSM
Y100	0.150	SSM
SG121	0.189	SSM
ITO/Kapton	0.335	
PCBE	0.267	ITO/Kapton
RSR	0.237	ITO/Kapton
MAPATOX	0.361	ITO/Kapton
Upilex	0.387	ITO/Kapton
Keronite	0.844	
Black Body 1	0.991	Keronite
Black Body 2	0.991	Keronite
Plasmocer	0.958	Keronite

⁽¹⁾ Pre-flight measurements on ground, using Cary500 UV-VIS-NIR spectrophotometer

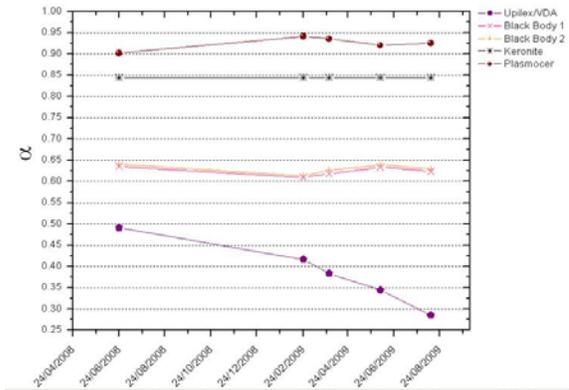


Fig. 23 Relative changes in the absorptance of selected micro-calorimeter materials using the Keronite sample as the stable reference

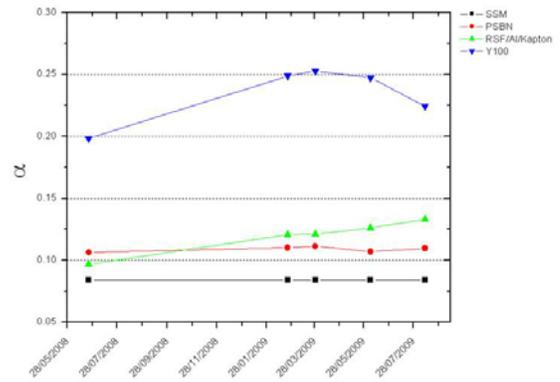


Fig. 24 Relative changes in the absorptance of selected micro-calorimeter materials using the SSM sample as the stable reference

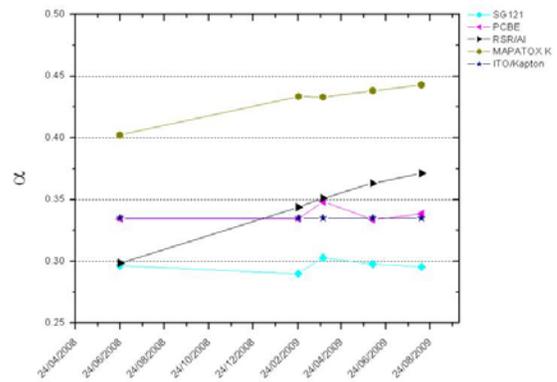


Fig. 25 Relative changes in the absorptance of selected micro-calorimeter materials using the ITO coated Kapton sample as the stable reference

Despite the lack of accuracy for this initial analysis, the results show the general trends in the material behaviour. These can be summarised as follows :

- No significant degradation of the white paints
- No significant degradation of the Plasmocer
- No significant degradation of the black bodies
- Complete erosion of the Upilex S
- Darkening of the Y100 polyimide followed by a decrease in absorptance
- Small increase in absorptance of the RSR, MAPATOX and RSF coatings

These preliminary results will need to be refined using a more detailed analysis, and a comparison will also be made with the post-flight measurements after return of the samples.

6 CONCLUSIONS

MEDET operated successfully in-orbit for nearly 19th months over the period February 2008 - September 2009. An overview of the in-orbit results acquired over the course of the mission has been presented, at a time when the experiment has just been returned to Earth. Materials degradation data has been evaluated for the spectrometer and micro-calorimeter samples, and the preliminary analyses have shown the relative trends in the absorptance and transmittance of these materials. However, more detailed modeling will be required in order to acquire more accurate values for their thermo-optical properties.

The space debris experiment SODAD recorded 11 impact events during the mission, and these flight results are being correlated with predictions from the MASTER model.

The results from the environmental sensors on MEDET, and in particular the pressure gauge, have been used to show the influence which Space Station orbital manoeuvres and the docking of the Space Shuttle has on the local ISS environment.

Further analysis is on-going to analyse the in-orbit behaviour of the materials, and to determine synergies between the different types of data. The in-orbit results will be complemented with ground based measurements of the material samples once the experiment is returned to Europe for de-integration. The passive Aerogel sample will also be analysed to look for impact features.

7 ACKNOWLEDGMENTS

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