THE MUNICH DUST COUNTER MDC – AN EXPERIMENT FOR THE MEASUREMENT OF MICROMETEOROIDS AND SPACE DEBRIS

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ABSTRACT

The Munich Dust Counter (MDC) is a scientific space experiment on board the Japanese HITEN satellite (MUSES-A mission). The MDC is also on board the German satellite BREM-SAT of the Center of Applied Space Technology and Microgravity (ZARM). The plasma, that is generated by the impact of cosmic dust particles on a target, is measured to dermine mass, velocity and crude flight direction of cosmic dust particles. After a short introduction describing the experiment setup the measurement principle, the sensitivity range and the accuracy of the calculation of the velocity and mass are presented. It is shown that the MDC can measure cosmic dust particles or Space Debris in a mass range of 10^{-15} g to 10^{-7} g. An overview of the MUSES-A mission and the mission of BREM-SAT will be given and some results of the MDC measurements on board HITEN are summarized.

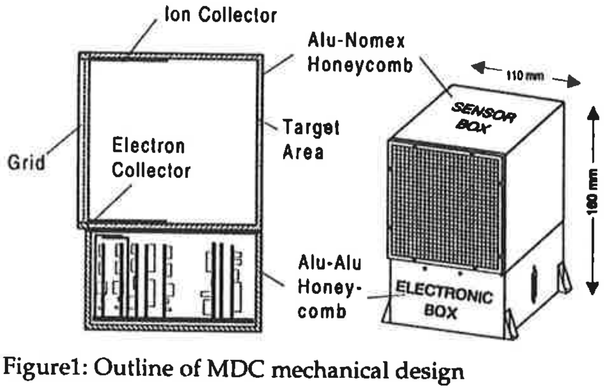

Figure1: Outline of MDC mechanical design

1. THE MUNICH DUST COUNTER

The Munich Dust Counter (MDC) is a scientific space experiment on board of the HITEN Satellite of the MUSES-A mission of the Institute of Space and Astronautical Science (ISAS) of Japan. As the MDC works perfect and because of it excellent data from dust impacts on the MUSES-A mission the MDC will also fly on board the German BREM-SAT in a Low Earth Orbit. The MDC has been developed by the Chair for Astronautics of the Technical University Munich (TUM) of Germany with support by the European Space Research and Technology Centre (ESTEC) of ESA, by the German Federal Ministry for Research and Technology and the German industry. The MDC has been designed to determine mass and velocity of cosmic dust particles by measuring the impact charges generated by high velocity impacts (v>2 km/s) of those particles on a gold target. (Ref. 1) The mass of the MDC Flight Unit is 0.6 kg, its power consumption is below 2 W. The dimensions of the MDC are 105 x 110 x 160 mm. The actual sensor area is 100 mm x 100 mm.

The general outline of the mechanical design of the MDC is shown in figure 1. The instrument consists of two boxes made of lightweight honeycomb structure. The lower box houses all electronics and is fixed to the satellite platform. The upper box serves as particle detector or sensor box. The open front is covered by a grounded steel grid. The inside is gold plated, all five inner sides serve as target area for particle impacts, including the collector plates. These locations avoid the sunlight shining directly on the collector plates, as the spin axis of the satellite is perpendicular to the collector plates.

2. MEASUREMENT PRINCIPLE

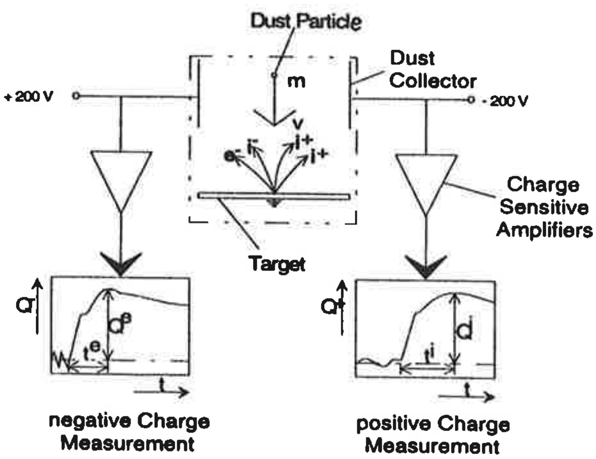

Figure 2: MDC measurement principle

The MDC experiment measures the electrical charges generated by high velocity impacts of small masses on a gold surface. The setup as shown in fig. 2 consists of a target and two charge collector plates which are biased by negative and positive voltages. The impact plasma is separated into positive ions on the negative collector and electrons and negative ions on the positive collector. The charges are measured by two independent channels. Charge sensitive amplifiers convert the impact charges of the ion and electron channels to an output voltage. This output is digitized and stored by a transient recorder consisting of two 8 bit A/D converters, clocked with 5 MHz each and using a FIFO memory. In order to minimize the error when converting four decades of input charges to 8bit data, the charge sensitive amplifiers have logarithmic response curves and two sensitivity ranges switched within 0.2 µs. Thus the digitizing error is less than 3% over the whole operating range. A microprocessor system, 80C85 CPU with 2 KByte ROM and 32 KByte RAM, processes measured signals, controls the spacecraft interface and monitors voltages and temperatures.

Generally this design allows to record and store the whole particle impact signals of the ion and electron channel. The amount of impact data is 1 KByte per signal or 512 Byte per channel, giving a total measurement time of 100 µs. Together with the impact data calibration and housekeeping data valid for the time of impact are stored and transmitted down to ground, giving the opportunity to inspect the real signals measured in space.
During the evaluation of each charge signal, amplitude and risetime are determined. The mass m and velocity v of the dust particles can be derived from these parameters using the following empirical formulae, first found by Friichtenicht and Slattery (Ref. 2) and adapted for the particular setup by Iglseder (Ref. 1):

$$t = c_g * v^{\eta}$$
$$\pm Q/m = c_r * v^{\beta}$$

with: m particle mass; v particle velocity; Q maximum charge; t signal risetime; c_r, c_g, β, η calibration constants.

There are two signals measured for one particle impact, the ion and the electron signal. These give two values for particle mass and velocity, from these an average value can be calculated.

The used charge sensitive amplifiers are capable to measure charges between $5*10^{-15}$ Cb and $5*10^{-11}$ Cb, which corresponds to a mass range of appr. 10^{-14} g to 10^{-9} g or a diameter of appr. 0.5°µm to 50 µm at a velocity of 10 km/s. In figure 3 the sensitivity range of the MUSES-A MDC is displayed. The MDC Flight Unit is a little bit more sensitive as the MDC Flight Spare Unit. The BREM-SAT MDC (MDC-BS) has approximately the same sensitivity range as the MDC Flight Unit.

3. CALIBRATION

For the calibration of the MDC instrument facilities are required which accelerate particles with masses between 10^{-7} and 10^{-15} g to velocities between 1 and 70 km/s. For the experiments described here two such facilities were used. One is the electrostatic particle accelerator of the Max-Planck-Institut für Kernphysik in Heidelberg, the other is the plasmadynamic particle accelerator of the Lehrstuhl für Raumfahrttechnik of Technische Universität München. Both facilities together cover the sensitivity range of the MDC instrument quite good, as can be seen in fig. 3. The calibration experiments have been performed partly with the MDC Flight Unit before launch to ensure the function and characteristics of the flight instrument. A greater part of the experiments has been done with the MDC Flight Spare Unit (Ref. 3) after the launch of the mission MUSES-A. This was done not only due to a very tight schedule before launch, but also to be able to simulate particle impacts encountered in space with the facilities on ground. The scope of the calibration of the MDC instrument is not only to determine as accurate as possible the coefficients c_r, c_g, β and η. Nearly as important is the requirement to prove that specific signals measured in space are really due to particle impacts and not due to noise. Therefore the actual signals measured in space are continuously compared to the data gathered during the calibration tests. Additionally there have been some experiments with the MDC-BS to verify the function of the BREM-SAT MDC and to get more calibration data with typical velocities of Space Debris.

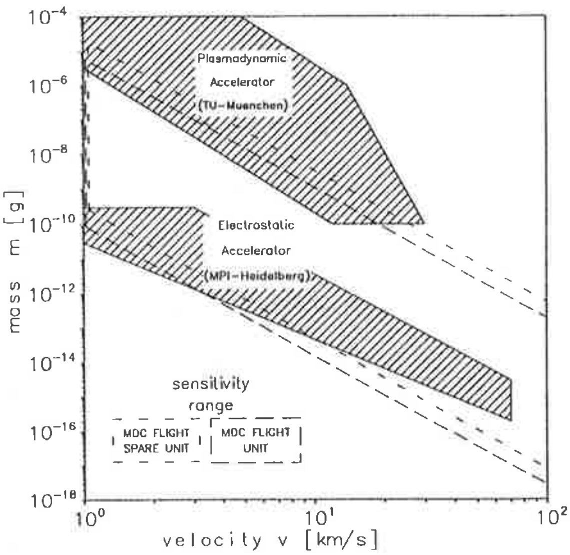

Figure 3: Sensitivity range of the MUSES-A MDC and capabiltiy of the accelerators which are used for calibration.

4. RESULTS OF CALIBRATION EXPERIMENTS

Here the results of several series of calibration experiments in Heidelberg and Munich are comprised. The results presented here consist of 906 particle impact measurements. The masses of the particles were between 10^{-15} and 10^{-5} g, the velocities between 1.8 and 65 km/s.

4.1. Impact Location Dependence

During the calibration experiments we did not only measure impacts in the center of the target area at the back side of the sensor box, but also on several other locations inside the sensor box, even on the charge collector plates. It turned out that the measured signals were quite dependant from the location of the particle impact inside the sensor box. These tests were performed at the electrostatic accelerator in Heidelberg, as the location of the particle beam is defined there within an accuracy of ±5 mm.

The impact locations at which particle impact tests were performed during MDC calibration are shown in figure 7 Here the sensor box is shown unfolded, with the target area (back side) at the center, the top side with the ion collector above it and the bottom side with the electron collector below it. The different impact locations were accomplished by moving the MDC up and down relative to the particle beam and by turning it around an axis perpendicular to the particle beam. This was done in three different ways as shown in figure 7 to see also the influence of the impact direction relative to the sensor box. Thus the locations no. 1 to 6 and 23 to 25 were measured in configuration a), the locations 7 to 18 in configuration b) and locations 19 to 22 in configuration c).

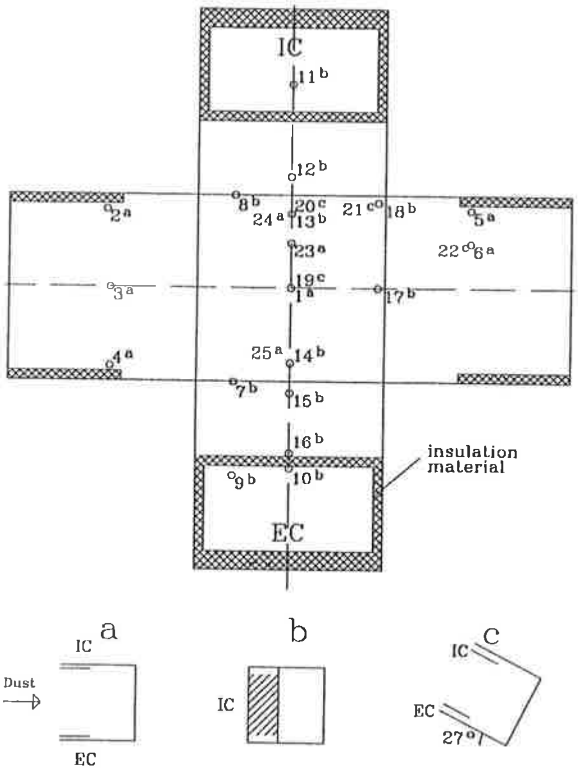

Figure 4: Different impact positions inside the sensor box

The result of these tests in general was that there are three groups of impact locations, which have very similar behaviour. They can be separated into the TOP group, the CENTER group and the BOTTOM group in the following way:

TOP:	2, 5, 8, 11, 12, 13, 18, 20, 21, 22, 24;
CENTER:	1, 3, 6, 17, 19, 23;
BOTTOM:	4, 7, 9, 14, 15, 16, 25;

Location 10 was excluded from the further evaluation, because it was on the insulation material around the electron collector, which is GRP. There the charge yield is much lower than with impacts on gold. That means of course that if particles impact the insulation material, which makes up some 6 % of the total area, their mass will be calculated by a factor of five too small.

In the figure 5 to 7 typical impacts of these three groups are shown as examples. All impacts have very similar parameters in terms of mass and velocity of the particle, but result in quite different sets of impact signals.

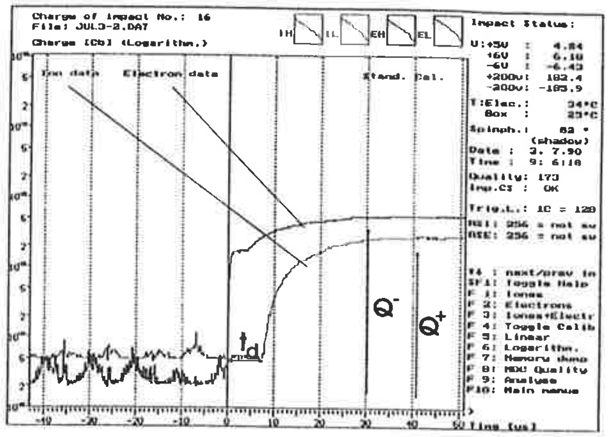

Figure 5: Center position: m = 4,1 E-12 g, v = 5,95 km/s.

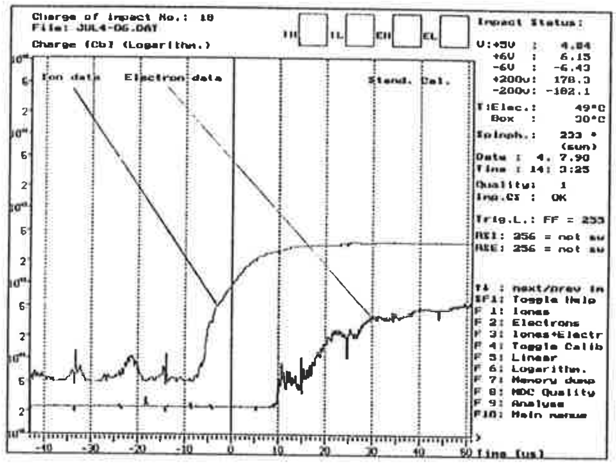

Figure 6: Top position: m = 3,8 E-12 g, v = 6,30 km/s.

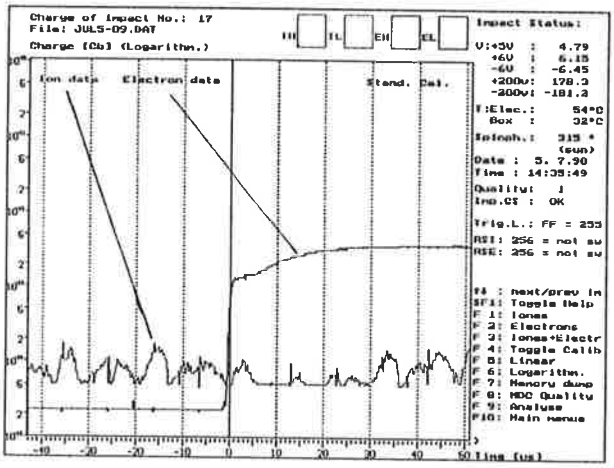

Figure 7: Bottom position: m = 2,3 E-12 g, v = 6,30 km/s.

The impact shown in fig. 5, measured in the CENTER at location 1, shows the expected charge signals. The ion signal rising with a short delay after the electron signal, due to the lower velocity of the ions, to about the same level as the electron signal. A typical example of an impact of the TOP group, measured at location 8, is shown in fig. 6. Here mainly the ion signal rises, while clearly less electron charges are collected during the measurement time of 100 µs. The opposite to this behaviour is encountered at the BOTTOM. The signals shown in Fig. 7 were measured at location 15. In this case only the electron channel is measuring impact charges, no ion charges are seen in most cases of the BOTTOM group.

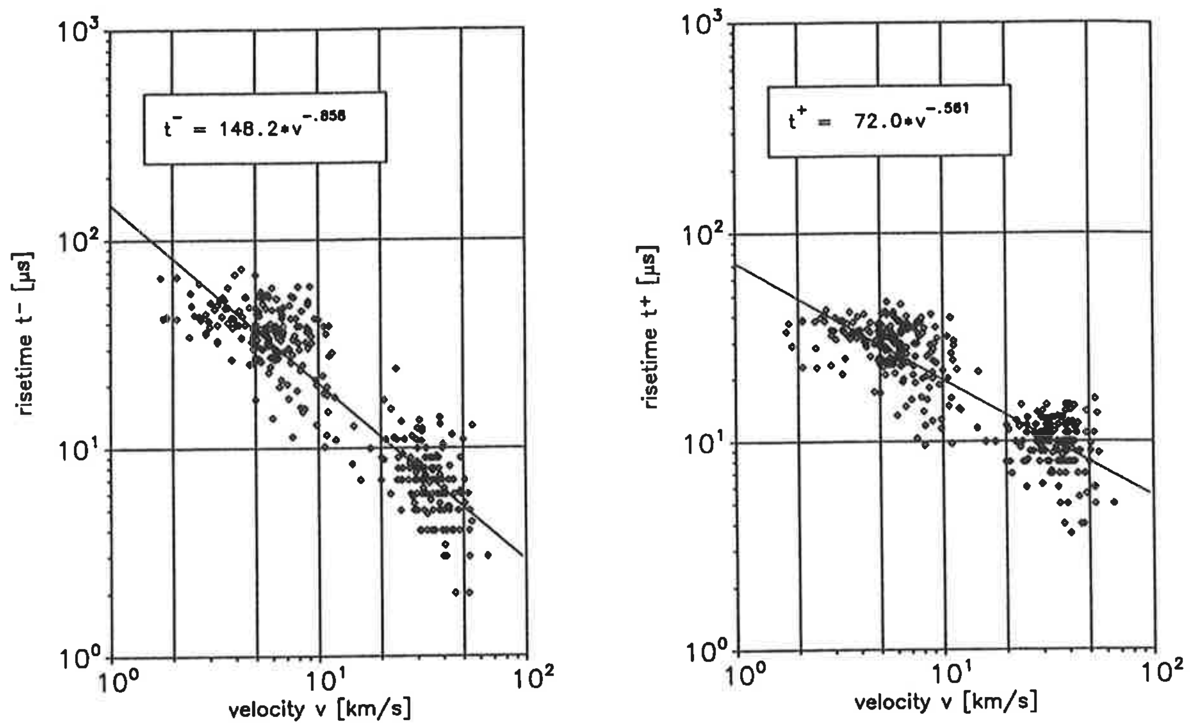

Figure 8: Risetime as a function of impact velocity for the CENTER group

4.2. Determination of calibration coefficients

The examples shown in the figure 5 to 7 make it clear that it is not possible to use the same calibration for all impact locations. Therefore the results of the groups CENTER, TOP and BOTTOM have been evaluated separately in terms of rise times t+ and t- over impact velocity and in terms of charge to-mass ratios Q+/m and Q-/m as a function of impact velocity for the three groups. In fig. 9 the measured rise times and in fig. 9 the charge to mass ratios as a function of impact velocity are shown for the CENTER group. A least square fit line has been calculated through all values with the coefficients given in each diagram. It can be seen that in the CENTER case both signals, ion and electron charges, with t+ and t- resp. Q+/m and Q-/m, can be used to determine the particle velocity and mass with reasonable accuracy. At the TOP group only the ion channel with t+ and Q+/m shows a reasonable behaviour, while the electron channel with t- and Q-/m is not useful for the determination of particle velocity and mass. At the BOTTOM group the electron channel with t- and Q-/m is the only way to determine velocity and mass of the impacting particle. There are much less data points in the t+ and Q+/m versus velocity diagrams, because there was no ion charge at all in many cases.To show this in detail the number of

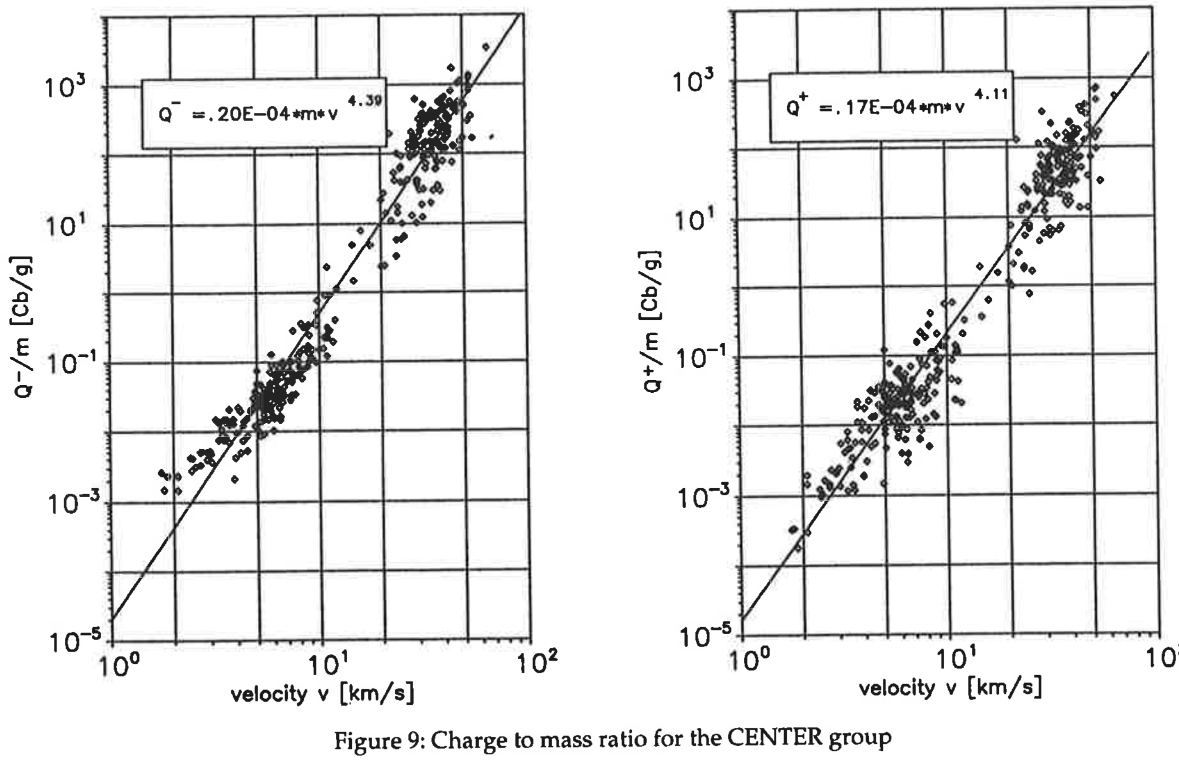

Figure 9: Charge to mass ratio for the CENTER group

data points which were possible to evaluate for the three different groups and the two channels are given here:

	TOP	CENTER	BOTTOM
Ion Ch.	358	335	85
Electr. Ch.	332	336	212

4.3. Determination of impact location

In the laboratory it is of course easy to associate specific sets of charge signals with given impact locations, as it has been done in the previous section. But during the operation of the MDC experiment in space, the impact location of a cosmic dust particle inside the MDC sensor box is not known a priori. To be able to select the appropriate calibration group, TOP CENTER or BOTTOM, we have to find a way to relate a given set of impact signals to one of these groups.

This can be done by analyzing both signals, ion and electron charge, and their relation to each other. In Fig. 17 a typical impact signal measured in space is shown. Here the relevant parameters for this evaluation are indicated, which are the delay time between electron and ion channel, t_D, and the maximum charge values Q+ and Q-. The delay time t_D is defined as positive, if the ion channel is rising after the electron channel. If the charge ratio of Q+/Q- (for Q+ being less than Q-), resp. Q-/Q+ (for Q+ being greater than Q-), and the delay time t_D is evaluated for all particle impact measurements at all locations, the dependence of these parameters of the impact location gets evident. It can be seen in fig. 11, where the delay time t_D is plotted over the charge ratios Q+/Q-, resp. Q-/Q+. Here the three groups TOP, CENTER and BOTTOM show a quite different behaviour.

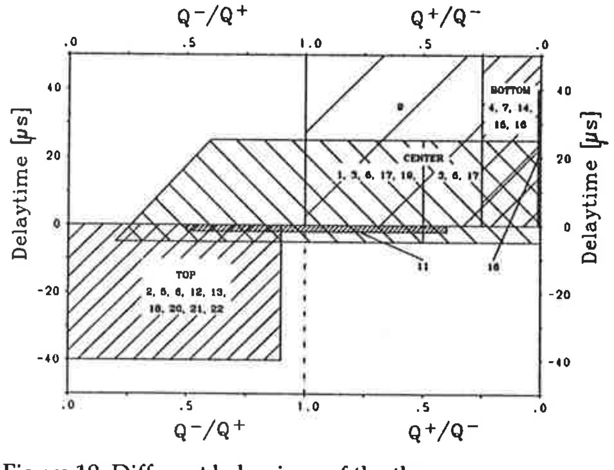

Figure 10: Different behaviour of the three groups.

The group TOP shows generally charge ratios of Q-/Q+ below 0.9 and negative delay times. It is very clear defined and has very little overlapping with other areas. The CENTER group has a wide range of charge ratios and positive delay times in most cases. The BOTTOM group only has charge ratios Q+/Q- of less than 0.3 and positive delay times. But there is a small area where CENTER and BOTTOM are overlapping.

There is some special behaviour of impacts directly on the collector plates. The location 9 was on the electron collector. Here delay times between 0 and 50 μs, depending on the impact velocity, and charge ratios Q+/Q- between 1 and 0 were found, overlapping the CENTER group in a wide area. The location 11, the ion collector, entirely lies within the CENTER group, but has only very small delay times, independent from the impact velocity. The reason for this behaviour is the optimum electric field just between the two charge collectors. In the case of impact on the electron collector, also ions may reach the ion collector, depending on the impact velocity. In the same way electrons are accelerated towards the electron collector in the case of an impact on the ion collector, but as the electrons having very small masses compared to ions and thus getting fast, the delay time in this case is very small. Therefore impacts on the charge collectors may be misinterpreted as belonging to the CENTER group, decreasing slightly the accuracy in these special cases. However the area of the collector plates compared to the total inner area of the sensor box is only 16.2 %.

This impact location dependence opens up the possibility to get some information about the flight direction of the impacting particles. Of course, the field of view of the MDC experiment is approximately 150° and the flight direction determination is only accurate to this order. But if an impact belongs to the TOP group, the probability is high that the particle was coming from below, which is from the southern hemisphere of the sky as viewed from the satellite.

In the same way a BOTTOM particle is likely to come from the northern hemisphere. By applying statistical methods on many such measurements, additional information about the directional distribution of the cosmic dust particles not only in the ecliptic plane but also in the north-south direction can be obtained.

4.4 Accuracy of measurement

With the coefficients C_R, C_G, β and η known, the general way to determine the particle velocity and mass by the impact charge measurement is the following:

First the impact has to be associated with one of the groups TOP, CENTER or BOTTOM according to fig. 11 by an evaluation of delay time t_D and charge ratio Q+/Q-, resp. Q-/Q+. As there is a wide range of ground impact measurements, it is possible to confirm this by comparing the data with similar data measured on ground. Next the signal rise times t+ and t- are determined to calculate the particle velocity. With this velocity and by using the coefficients C_R and β the charge to mass ratios Q+/m and Q-/m can be calculated. The maximum charge values Q+ and Q- finally lead to the particle mass.

In general, using the two curves of the ion and electron channel with two different sets of coefficients (specific for the given location) two different particle velocities and two different particle masses will be obtained. In the case of the CENTER group we will use the mean value of velocity and mass to get the best accuracy.

All the data of the three groups TOP, CENTER and BOTTOM has been evaluated according to the scheme described above and using the appropriate coefficients. Thus the evaluated data could be compared to the particle data measured at the accelerator facilities and the overall measurement accuracy could be determined.

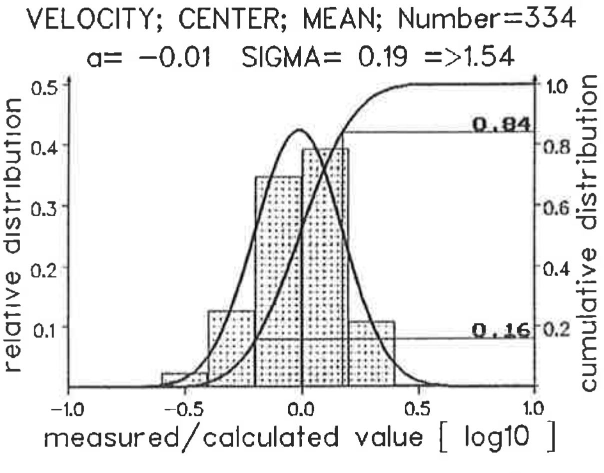

Figure 11: Standarddeviation of the velocity. (10^{σ}= 1,5)

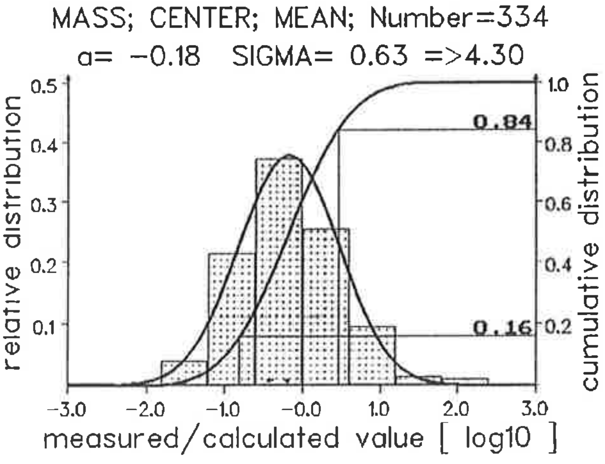

Figure 12: Standarddeviation of the mass. (10^{σ}= 4,3)

Table I lists the coefficients c_g and η for the ion and electron channels and the three different groups together with the deviations of the calculated particle velocity using t+ or t- from the measured velocity.

velocity	electron channel			ion channel		
	c_g	η	10^{σ}	c_g	η	10^{σ}
TOP	67.8	-.351	2.9	70.9	-.577	1.6
CENTER	148.	-.858	1.6	72.0	-.561	1.8
BOTTOM	117.	-.831	1.6	63.4	-.630	2.3

Table 1: Calibration constants and deviation of velocity calculation

mass	electron channel			ion channel		
	c_r	β	10^{σ}	c_r	β	10^{σ}
TOP	1.72e-5	3.75	51.2	6.73e-5	3.79	8.9
CENTER	2.04e-5	4.39	7.6	1.65e-5	4.11	10.7
BOTTOM	11.0e-5	3.69	8.0	0.58e-5	3.97	28.8

Table 2: Calibration constants and deviation of mass calculation

In table II the coefficients c_r and β for both channels and the three groups are given. Again the deviations of the calculated particle mass from the measured mass are shown. Here the calculated and not the measured particle velocities were used, therefore the velocity inaccuracy, which is listed in table I, is included in the given numbers.

5. THE BREM-SAT MISSION

BREM-SAT is a micro-satellite (ϕ=0.49 m, h=0.52 m, m=64 kg) of the Center of Applied Space Technology and Microgravity (ZARM) in Bremen. It will be launched in a GAS-GAP container by the Shuttle and inserted in a LEO with a spring mechanism. Initially BREM-SAT should be launched together with the German D2-Mission, but the BREM-SAT with the GAS container was removed from the STS 55 (D2-Mission) because of malfunction of NASA subsystems of the GAS container. The launch could be now with STS 60 (November 1993) in a higher orbit (app. 370 km, i = 57°) with higher inclination. This has the advantage of a longer life time of the satellite, more than 6 month instead of 2 month. BREM-SAT is a spinning spacecraft with a period between 1 and 10 minutes.

We have calculated with the ESABASE Meteoroid / Debris software the expected debris flux from debris with more than 0.5 µm diameter and the meteoroid flux of particles with more than 1e-15 g mass. With 100 cm^2 opening area of the MDC we will get about 600 debris and 360 meteoroids impacts per year.

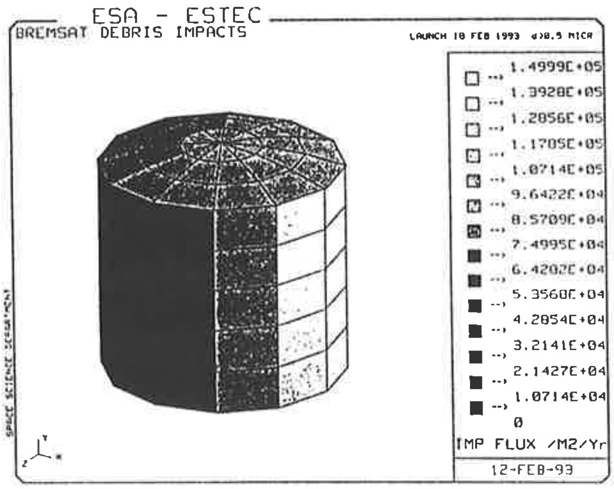

Figure 13: Predicted flux of space debris particles on BREM-SAT

6. THE MUSES-A MISSION (HITEN)

The MUSES-A spacecraft is the 13th scientific satellite developed by ISAS. It is a spin-stabilised spacecraft, with a diameter of 1.4 m, a height of 0.8 m and a mass of 197 kg. The MDC is installed on the main instrument platform behind an aperture of 12 cm x 12 cm in the solar cell panel. As the MDC is mounted on the perimeter of the spinning spacecraft, it scans the ecliptic plane within one revolution of the satellite. The spin period is 3 seconds. The spin axis of the spacecraft is perpendicular to the ecliptic plane.

The Satellite HITEN was launched from the Kagoshima Space Center, Japan, on January 24, 1990, into a highly-elliptical orbit around the Earth with perigees between some thousand and 100000 km, and apogees between 300000 and 1.53 million km. A sub-satellite (HAGOROMO) was inserted into an orbit around the Moon and a total of 8 lunar swingbys has been carried out in the first phase of the mission. The first phase ended in March 1991 with an aerobrake maneuver in the Earth's atmosphere.

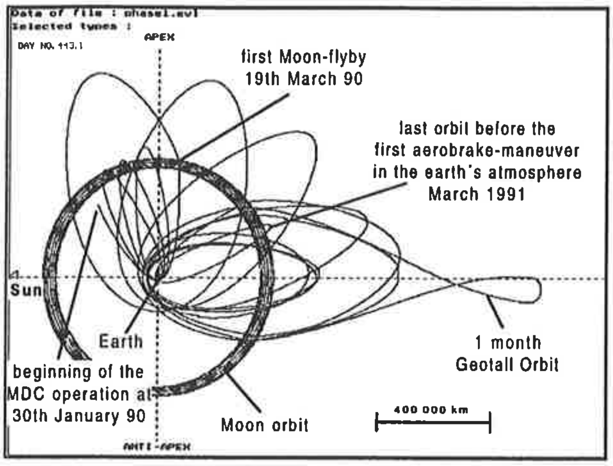

Figure 14: MUSES-A orbit first phase

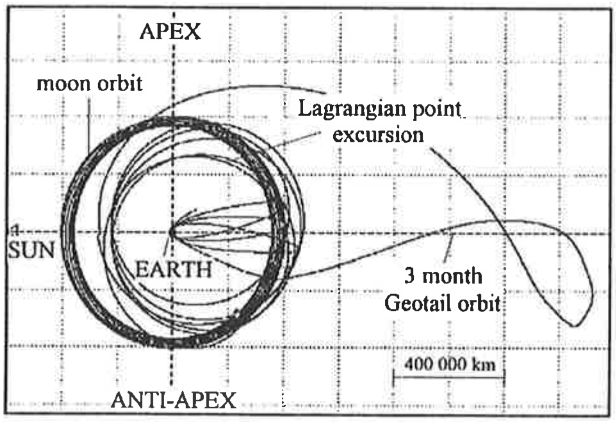

Figure 15: MUSES-A orbit second phase

The next mission objectives has been an excursion to the lagrangian points L4 and L5 of the Earth-Moon-system. This second phase ended at 15th February 1992 with an insertion of HITEN around the Moon. More than one year after the insertion in the moon orbit the spacecraft HITEN performed on 30th March 1993 it last ΔV maneuver in order to crash onto the Moon at 10th of April 1993.

6.1 Summary of the achieved results (Ref. 7)

- Determination of the mass-, velocity- and angular distribution of cosmic dust particles and β-meteoroids in the Earth-Moon system.
- Detection of pro- and retrograde beta-meteoroids in the solar system.
- Accurate measurements of the cumulative particle flux of cosmic dust particles and β-meteoroids and particles with high inclinations.
- Evidence of swarms, groups and random particles. Enormous variations of the instantaneous fluxes and impact rates of micrometeoroids.
- No significant indications for dust clouds near the Lagrangian-points L4 and L5 (Kordylewsky-clouds).
- Indications of the existence of interstellar particles.

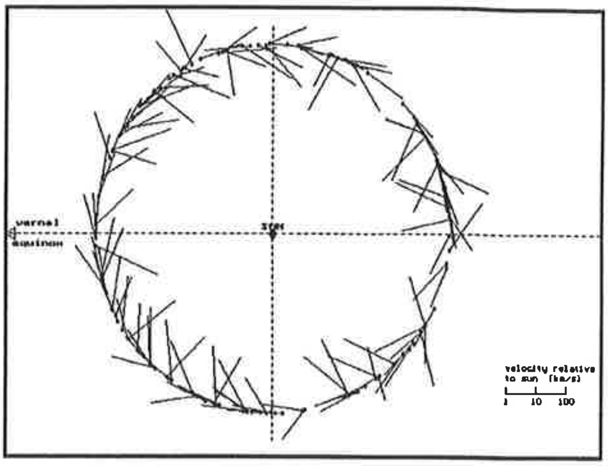

Figure 16: Heliocentric impact locations for types 1-4

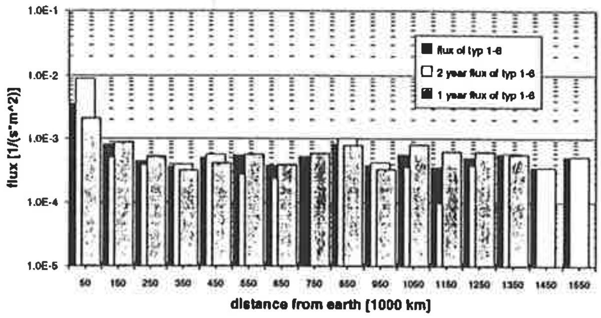

Figure 17: Cumulative particle flux versus distance from Earth for $m>10^{-16}$.

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