MEASUREMENTS OF COSMIC DUST AND MICRO-DEBRIS WITH THE GORID IMPACT DETECTOR IN GEO

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ABSTRACT

Measurements and analysis results from the GORID impact detector for the period April 1997 to end of 2000 are presented. The GORID detector was in a geostationary location at 80^o Eastern longitude until June 2000 and has then be moved to 103^o East. The average number of events with the highest classification (where all signals agree with pre launch calibration values for true impacts) is 2.4 per day. The daily number of impacts varied between 0 to more than 40. In addition, many impacts occur clustered in time and sometimes reappear at about the same time for one or more days after their first appearance. The most likely source of these clusters are exhaust particles from solid rocket motor firings. The large majority of the impacts occurred during local night times. At local night times GORID points to some extend into the Earth apex direction and this will result in increased fluxes from natural meteoroids. Between May and July increased event numbers are recorded during the local morning hours. At these times during the summer a portion of GORID's detecting surfaces faces the sun indicating that these impacts could be from beta particles arriving from the sun direction. So far no conclusive impacts from meteor stream particles have been registered. Some observations are not yet well understood. These include a certain percentage of impacting particles with apparently a high negative charge and a large percentage of impacts with a long signal rise time which normally indicates a relatively low impact velocity. The data analysis is complicated by potentially disturbing effects like impacts on the detector baffle and noise induced by the surrounding space environment and the spacecraft itself.

1. INTRODUCTION

Instruments to detect impacts from natural meteoroids and man made space debris particles have been flown in Low Earth Orbits (LEO) (e.g. on LDEF, EURECA, MIR, BREMSAT) and on interplanetary missions (e.g. Pioneers, Giotto, Vega, Ulysses, Galileo, Hiten). However, very little information on the particulate environment for Earth orbits above about 600 km altitude is available. Especially the space debris environment in the important geostationary ring is largely unknown. Ground based detection in GEO is limited to objects larger than about 0.5-1 m. Some in-situ measurements in GEO over a period of 10 months were reported in [1]. To obtain information on the sub-micron to millimetre size particle population in GEO the GORID (Geostationary Orbit Impact Detector) experiment was initiated. GORID is a joint project between ESA, the Max-Planck Institut (MPI) für Kernphysik in Heidelberg, the Scientific Production Association of Applied Mechanics (NPO-PM) from Krasnoyarsk and the Novosibirsk State University (NSU).

2. THE GORID INSTRUMENT AND MISSION

The GORID impact detector launched is the refurbished engineering model of the Ulysses detector (which is essentially identical to the Galileo instrument). GORID is an impact ionisation detector. A particle impacting at hypervelocity speed creates a plasma of electrons and ions. The electrons and ions generated during the impact are measured separately. The velocity and mass of the impactor can be deduced, respectively, from the rise time and total intensity of the measured plasma signals by use of empirical calibration curves. The detection surface is roughly hemispherical in shape and has an area of 0.1 m^2. The detector opening has a diameter of 43 cm. The gold coated sensor surface acts also as collector of the electrons of the impact plasma. In addition, there are two grids at the detector entrance to shield from external plasma noise and another grid to measure the electrostatic charge (positive or negative) potentially carried by an entering particle.

The total weight of the instrument is 4480 grams, including 820 grams for the cover and opening mechanism. The detector requires 2.2 Watts of continuous power plus up to 1.2 Watts for the two heaters. The viewing cone of the sensor has a full angle of 140^o. The effective solid angle interval covered is 1.45 steradian [2].

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2.1 Measured Parameters and Calibration

The extracted parameters include particle charge, mass, velocity and crude impact direction. Each impact creates a cloud of vapour and plasma. The ions are accelerated towards the centre of the hemisphere where they are collected. A few ions are further intensified and measured by a channeltron behind the main ion collector grid. The most important measured parameters are the negative (electron) and positive (ion) charges generated upon impact (range 10^{-14} to 10^{-8} C) the channeltron output (intensified part of the positive charge) and the rise times of the negative and positive charge signals (range 10 - 100 μs). If a charged particle enters the detector its charge can be measured by the charge grid. In addition, the time difference between the triggering of the positive and negative signals and the induced charge (for electrically charged impactors) is measured.

Each event recorded by the instrument is classified according to its ion signal amplitude into 6 amplitude intervals (A1 to A6) of about one decade width each. In addition each event is categorised by one out of four event confidence classes. Class C0 are all events (including noise events and some unusual impact events, e.g. from hits of the sensors internal structure). For classes C1 through C3 the measured parameters and their relations to each other are increasingly restricted, so that the highest classes generally represent only true impact events. On ground tests the ion signal was usually found to be the most reliable and the least affected by electromagnetic noise. Electromagnetic noise has to be carefully considered for GORID in its geostationary orbit where the density of space plasma is much higher than in interplanetary space.

The time of an impact event can be recorded to an accuracy of 2 seconds. All information on recorded events is contained in packets of 16 bytes of science data.

Full signal information is stored for 8 events between read-outs. Additional events are then just classified and counted.

More detailed and complete information on the instrument design and data handling is given in [2]. A full description of the instrument calibration and events classification is given in [3].

2.2 The GORID Mission

GORID/Express-2 was launched on 26 September, 1996 with a Proton rocket from Baikonur. The spacecraft was then moved into its geostationary position at 80^{o} Eastern longitude. Following some testing and optimisation of instrument settings, GORID is in normal operation since 22 April 1997. At The end of 1999 the high voltage level of the channeltron was raised to increase the sensitivity. GORID stayed at this location until June 2000 when it was moved to a new location at 103^{o} East.

Figure 1 shows a drawing of the GORID/Express system. The main viewing direction of GORID is pointing 65^{o} away from the flight direction towards North. In addition it points 5^{o} out of the plane parallel to the Earth surface, towards Earth.

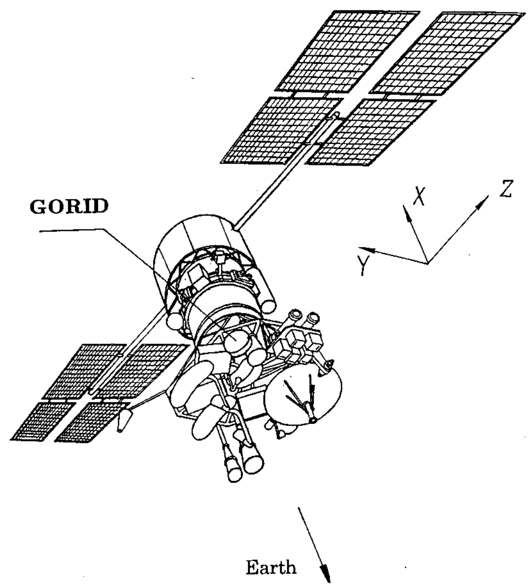

Fig. 1. Geometry of GORID/Express in orbit (correct scale). The +Y-axis points towards the flight direction.

During normal operation the data are read out from the instrument every 12 hours. This read out frequency can be increased to once per hour if desired (e.g. to monitor a meteoroid stream). Every ten days the data are downlinked to Earth and sent to the NSU in Novosibirsk where some pre-processing takes place. From the NSU the data are forwarded to ESTEC via the Internet.

The lifetime of the GORID experiment should in practice be limited by the Express satellite which has a design lifetime of 5 - 7 years.

3. IN-ORBIT MEASUREMENTS

The results reported in this section were obtained during the period 1997-2000. Mainly class 3 events are presented and discussed here. These are the events having the highest probability of being real impacts. Many more events were recorded with a weaker signal in a lower class. However, all those events need a closer evaluation before noise and true impacts can be separated. In the following class 3 events will usually be denoted as impacts, but the reader should be aware of some small remaining uncertainty about the true nature of these events.

3.1 Total Number of Impacts

Figure 2 shows the total number of recorded events per day in the highest confidence class 3 for the years 1997-2000. These events include all ion signal amplitude ranges. These plots clearly show the large variability of the impact fluxes. Gaps indicate that no data are available for these periods. The data loss in Oct-Nov. 2000 was caused by a shut down of the satellite. The other missing GORID data were lost during telemetry or ground processing.

The average number of recorded impacts was 2.4 per day. In 2000 this average was somewhat higher than in the previous years mainly as a result of several large cluster of events. There appear to be increased fluxes during the fall and spring of each year.

The larger peaks are mainly caused by cluster of events occurring within about 1 hour. They are discussed in more detail below.

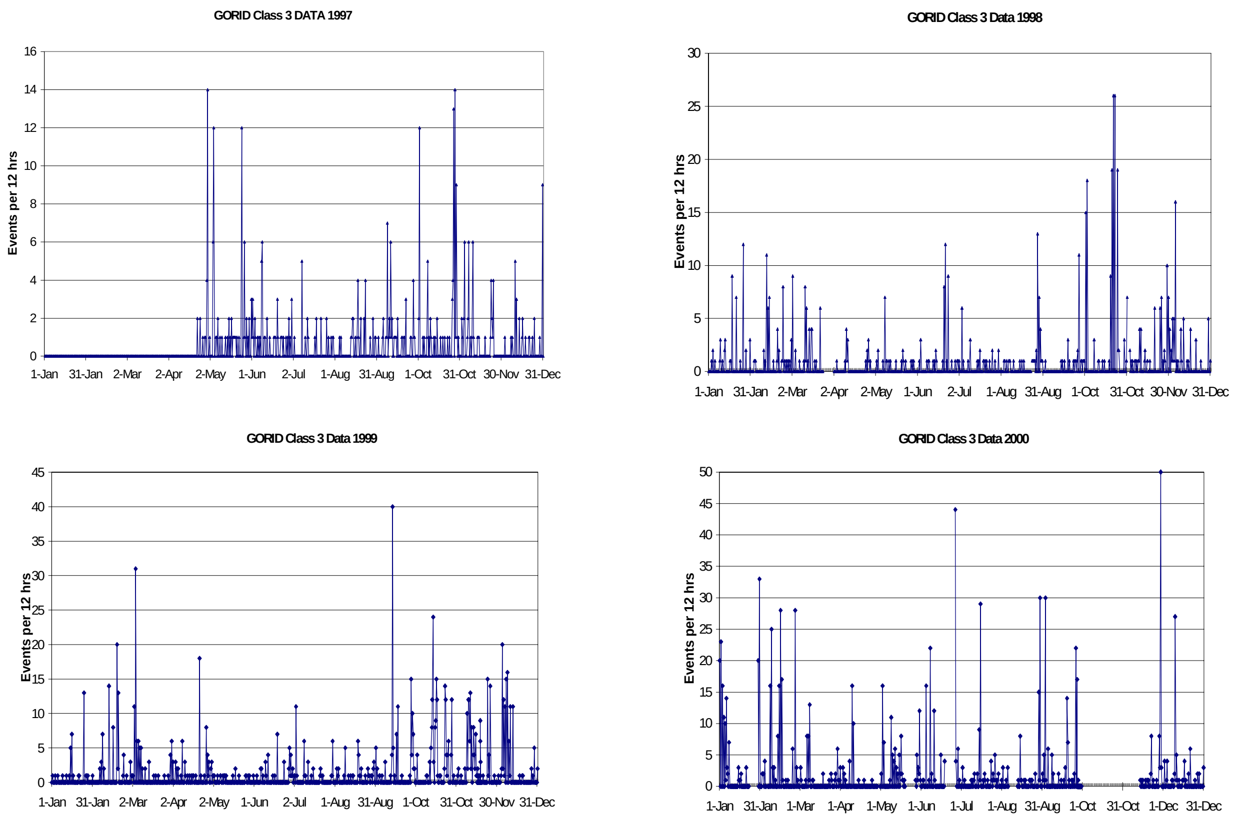

Fig. 2. Events recorded by GORID between 22 April 1997 and 31 December 2000 as function of the day of occurrence. Shown are all events registered in the highest confidence class C3 and for all 6 ion amplitude ranges.

So far no significant increase in the number of impacts was observed at times of known meteoroid streams. During the peak time of the Leonid stream in 1998 GORID was pointing in a direction which would have allowed to detect Leonid impacts but none was recorded. During the main peak of the Leonid storm in 1999 (around 2:00 UT on 18 Nov.) the spacecraft flight vector faced more than 90^{o} degrees away from the Leonid direction.

3.2 Class 2 Events

Figure 3 shows the distribution of class 2 events. Class 2 events a characterised by having a signal in all channels but also a noisy background. Most of these class 2 events are likely due to noise and not true impacts.

As seen in Fig. 3 the number of class 2 events (which are available since end 1996) drops drastically in mid 1997 and again in early 1998 to a level close to zero. An exception are some persisting individual large peaks of events which are often evenly spaced, as best seen for the year. We believe that the most likely cause of these peaks is the operation of Stationary Plasma Thrusters (SPT) which are used for station keeping of the Express satellite.

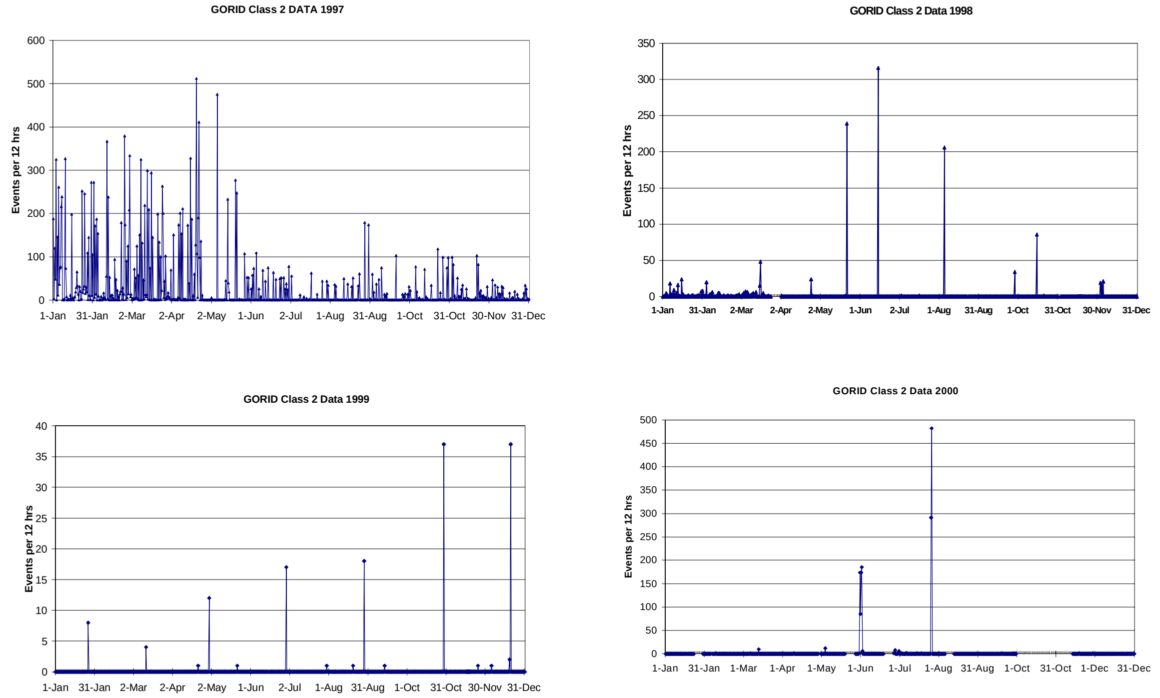

Fig. 3 Class C2 events recorded by GORID

The reduction of the number of noise events during the early mission phases could result from a changing interaction of the spacecraft with the space plasma environment. Due to outgassing and charged particle radiation spacecraft materials can become more conducting and surfaces acquire less and more evenly distributed electrostatic potentials. This leads to a reduced number of electric discharges and anomalies which could lead to interference with GORID. Such an 'electrostatic healing' of spacecraft in orbit is not unusual.

It should be pointed out that the distribution of class 3 events in Fig. 2 does not show a systematic change like the class 2 events and the peaks in the class 3 and class 2 distributions are not correlated.

<u>3.3 Local Time Distribution of Impacts</u>

Figure 4 shows the spacecraft local times (LT) when the impact events occurred. These data are based on all the events until the end of 2000 for which a full set of signal parameters is available. There is a marked increase of detected events in the hours around local midnight. At local midnight the spacecraft moves into the Earth apex direction, i.e. its velocity vector points towards the direction of the Earth's motion around the sun. From this

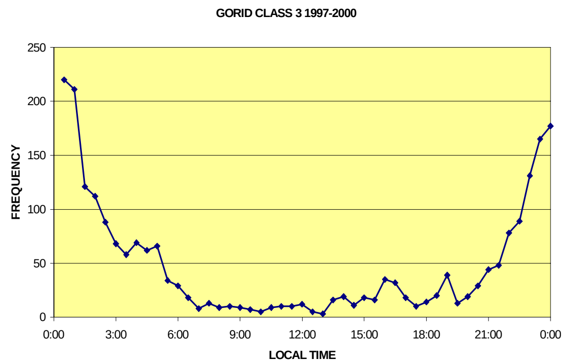

Fig. 4. Local time distribution of class C3 events recorded by GORID.

effect a certain increase of the impacting meteoroid flux is expected but it still has to be investigated to what extend the observed increase of events can be explained by this effect alone.

A second, smaller, peak is observed during the local morning hours, between about 3.5 and 6.5 hours local time. Increased fluxes at these times were mainly registered between May and July of each year. At this time of the year a part of the detecting surface of GORID faces the sun during local morning hours and the observed impacts could be particles arriving from the sun-direction which are driven outwards by solar radiation pressure (beta-particles).

Figure 5 gives a summary of the times of occurrence for all impacts. Plotted is the local time versus the time of year for each of the fully recorded class 3 events. This 2-D summary plot shows again all the main features discussed above. Most impacts were recorded during local night times. Another increase is seen around May, June and early July during the local morning hours. Several impact clusters are seen as a series of events occurring at the same day within a relatively short LT interval.

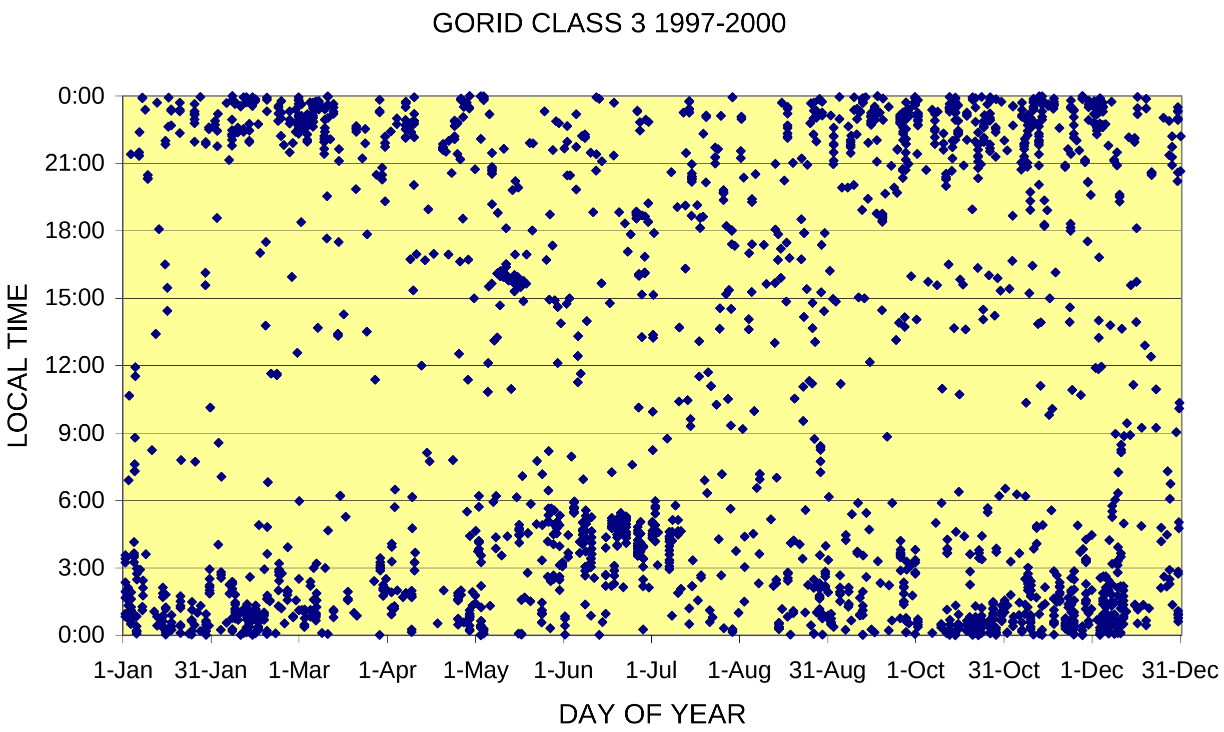

Fig. 5: Summary of the times of occurrence for impacts detected by GORID. Plotted is the local time versus the time of year for each of the fully recorded class 3 events.

3.4 Velocity Distribution

The rise time bin distribution of the fully characterised class 3 events is shown in Figure 6. Lower bin numbers mean shorter rise times and correspond to higher impact velocities. The conversion from measured rise times to velocities for the Ulysses detector is given in [3]. The rise time - velocity correlation for GORID is shifted somewhat (typically by one bin) towards lower bin numbers relative to the Ulysses values. The 2 bins with the longest rise times (bins 13 and 14) should correspond to velocities below 5 km/s. The broad maximum around bins 8-10 corresponds to impact velocities of about 15-30 km/s.

In principle the impact velocity can be used to distinguish natural meteoroids from man made space debris particles. Space debris within the geostationary ring is subject to perturbing forces and will oscillate between up to +/- 15 degrees in latitude. Such debris particles could impact the GORID detector with a maximum velocity of about 800 m/s. Debris in elliptical orbits like (e.g. GTO or Molniya type) can impact with higher velocities when crossing the GEO ring. The maximum impact velocity on GORID for this type of debris is in the order of 3-5 km/s. Most meteoroids will impact with higher velocities between 10-30 km/s. A few could have even higher velocities.

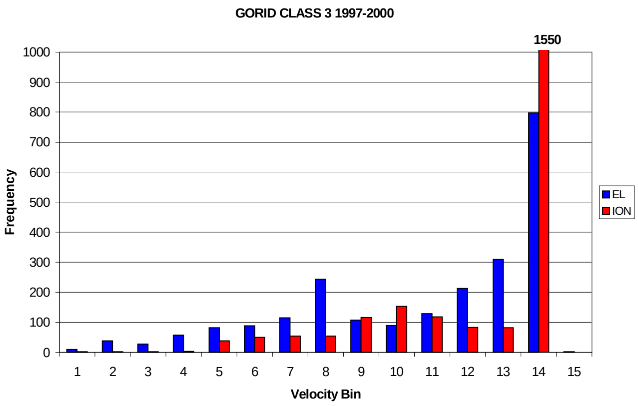

Fig. 6. Signal rise time distribution of class C3 events. Lower bin numbers mean shorter rise times and correspond to higher impact velocities

The recorded signal rise times have to be treated with caution. It is known from the impact calibration shots that velocity measurements can have large uncertainties even under controlled laboratory conditions. Under true space conditions noisy signals could be recorded as having superficially long rise times. In addition, recent calibration tests have shown that impacts on the detector side walls will be recorded by GORID as true impact events (what they are) but with a long rise time even for fast particles. Numerical simulations have shown that in the case of GORID more particles will actually hit the inside of the detector walls than the sensor surface. Electrically charged particles could also lead to misleading rise times. As a consequence of all these factors we believe that measurements of the signal rise time and the derived impact velocities are not very reliable for GORID.

3.5 Charged Meteoroids and Debris Particles

A certain percentage of the class 3 event particles detected by GORID apparently carried a large negative charge when entering the detector. This is measured as induced charge on the entrance grid. In some cases the negative charge exceeded the saturation limit for this signal (about $5x10^{-10}$ C). The number of such events with high negative charge has dropped drastically with time. Figure 7 shows the percentage of impact events with an induced charge of more than $1x10^{-10}$ C (measured at the entrance grid) in monthly bins. From an initial value of about 60 % for the first few months in 1997 for which full data are available this percentage dropped to around 10 %. In 2000 it increased again.

The local time behaviour of events with a high negative charge is similar to that for all particles as shown in Figure 4. The increase around local mid-night appears somewhat less pronounced.

It is conceivable that charged particles are easier to detect by GORID than neutral objects. Auto emission and induced charge could trigger the impact plasma signals even before the particle actually impacts the target surface and greatly enhance the signals which otherwise might have been undetected, e.g. for low impact velocities. An increased signal from charged particles was suggested in [5] and also experimentally observed by [6]. A more recent experimental study for a set-up simulating the GORID geometry has confirmed that even very slow particles charged to a few KV will lead to an auto emission plasma signal which should be detectable by GORID [7].

In addition, charged particles will trigger the electron channel well before they actually hit the detecting surface and therefore give a misleading rise time value. This effect could be (partly) responsible for the strong peak in the signal channels for the long rise times corresponding to very low impact velocities.

3.5.1 Charging of Small Particles

The maximum negative charge of incident particles as measured by GORID was in the range 10^{-10} – 10^{-9} C. Several dozens of such events were recorded during the

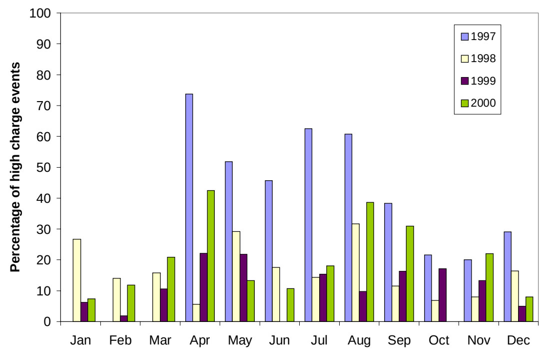

Fig. 7: Percentage of class 3 events with a negative charge larger than $1x10^{-10}$ C.

first year of operation. While only the charge and not the actual potential of the particles is measured, it is obvious that fairly large particles are required to carry such a charge. For a conducting sphere the charge, Q, is given by Q [C] = 1.1 10^{-10} R [m] V [V], where R is the radius and V the potential of the sphere.

While particles can charge up to Kilovolt levels during geomagnetic substorms this still requires particles hundreds of microns in size to carry a charge exceeding 10^{-10} C. According to the present reference model for meteoroids [8] impacts from such large particles should be rare events. For GORID this model predicts a few hundred impacts of micron sized particles per year and only some tens of impacts for particle sizes of 10 micron or larger.

Spacecraft can charge negatively to KV levels over time periods of less than a second. However, charging times will be much longer for small particles. Given a typical substorm charging current of 10^{-6} A/m^2, it would take 10^5 s, or more than a day, to charge a particle with a cross section of 1000 μm^2 to a level of 10^{-10} C.
A more detailed discussion of the charging of small particles is given in [7].

The coincidence between the number of charged events and the noise level (as indicated by the C2 events in Fig. 3) is also intriguing. It indicates that there is a relation between these events and the spacecraft charging environment.

There are at least two possibilities to explain the events with high charge:

a) These are true impact events from slow and relatively large debris particles. These particles were either released by the spacecraft itself or they were charged up upon approach by the spacecraft before entering GORID. These particles were only detected because their charge lead to auto emission. As the EXPRESS stopped releasing particles and/or became electrically cleaner the number of these events was reduced.
b) These are really noise events caused by electrostatic interference from the spacecraft. Such interference could result from electrostatic discharges and also from the firing of ion thrusters. Again, such events became less frequent as the spacecraft became electrostatically cleaner.

At present the true nature of the events with high charge remains unclear.

3.6 Cluster of Impacts

On several occasions, a series of impacts occurred within a relatively short period of about ½ hour (see Fig. 5). Most of these events produced a similar ion signal amplitude and rise time reading. In addition, these cluster events sometimes were repeated for 2 or 3 consecutive days at similar local times. Most of the strong peaks in the plot of events per day in Figure 2 result from such clusters of events.

Figure 8 shows such a cluster event resolved in time. Plotted are the impacts as function of the Universal Time and Local Time of occurrence. These measurements indicate that GORID encountered some particle clouds.

Recurrent cluster events in the GORID data were first reported in [4]. It was suspected that they could be caused by the encounter of clouds of orbiting Aluminium oxide debris particles as produced by the firing of solid rocket motors (SRM).

For a more detailed analysis of debris clouds from SRM apogee boost firings the orbital evolution of such clouds was simulated. The results were applied to GORID with the help of the analysis tool DIADEM (Divine based Analytical Debris Environment Model) [7]. The results fully support the idea that these clusters are the results from impacts of SRM exhaust particle clouds [10].

4. CONCLUSIONS

The meteoroid/debris impact detector GORID has successfully completed almost 4 years of operation in GEO and continuous to perform nominally. The main results can be summarised as follows:

The number of detected events per day ranged from 0 to more than 40 with an average around 2.4 per day.

No obvious correlation was observed with the occurrence of major meteoroid streams.

The local time distribution of events shows a strong peak during the hours around local midnight.

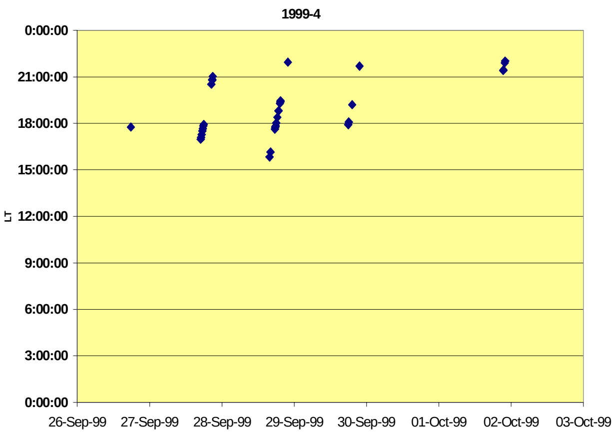

Fig. 8: Example of cluster of events recorded by GORID. Each diamond symbol marks the time of a recorded class 3 event.

Between May and June a second, smaller peak, is observed between about 3.5 and 6.5 hours local time. At this time of the year a part of the detecting surface of GORID faces the sun during local morning hours and the observed impacts are likely beta-particles arriving from the sun-direction.

On several occasions cluster of events were detected which sometimes reoccurred at about the same local time on consecutive days. A potential explanation is the encounter of clouds of orbiting Aluminium oxide debris particles as produced by the firing of solid rocket apogee boost motors.

The majority of the recorded impact events shows a large signal rise time which in principle means a low impact velocity. Space debris particles will have relatively low impact velocities consistent with these measurements. However, impacts on the detector side walls and induced noise could also lead to artificially large signal rise-times even for fast impacts. The velocity measurements are therefore seen as unreliable.

A certain number of events apparently resulted from particles carrying a large negative charge with values in excess of 10^{-10} C on arrival. The observed large charge on the impacting particles would basically require a population of orbiting particles in the size range of tens or hundreds of microns which far exceeds the predictions from present meteoroid models.

These ‘charged events’ seem to be correlated with the number of noise events on the spacecraft, at least in 1997 and 1998. At present, the true nature of these events remains unclear. Possible explanations are the release of particles from the spacecraft itself or electromagnetic interference.

Application of the meteoroid model in [8] to the GORID mission predicts an average number of detectable direct impacts of about 1.1 per day [7]. This agrees with the measurements of the identical detector on Ulysses [10] near Earth of about 1 impact per day dropping to around 0.4 per day during the outward cruise phase. Because of more impacts on the inner side walls, resulting from its attitude, the total figure should be somewhat higher for GORID. In addition to these ‘background events’ GORID encountered event clusters which account for 30-50% of the total and which are attributed to debris clouds. The observed event rate of 2.4 per day is consistent with the sum of these two contributions.

5. REFERENCES

1. Novikov, L.S et al., Measurements of Solid Micro-Particle Fluxes in Geosynchronous Orbit, Proceed. of *Symp. on Environment Modelling for Space-based Applications*, ESTEC 18-20 Nov. 1996, ESA SP-392, 1996.

2. Grün, E. et al., The Ulysses Dust Experiment, *Astron. Astrophys. Suppl*. Series, **92**, pp.411- 423, 1992.

3. Grün, E. et al., Reduction of Galileo and Ulysses Dust Data, Report of the Max-Planck-Institut für Kernphysik, Heidelberg ,1994.

4. Svedhem, H. et al., New Results From In Situ Measurements of Cosmic Dust – Data from the GORID Experiment, *Adv. Space Res*. Vol. **25**, No.2, pp. 309-314, 2000.

5. Sysoev, A.A. et al., Mass Spectra Formation from Charged Microparticles, *Nucl. Instr. And Meth. In Phys. Res. B*, **122**, p.79 (1997).

6. Burchell, M.J., Cole M.L., and McDonnell J.A.M., Role of Particle Charge in Impact Ionization by Charged Microparticles**,** *Nuc. Instr. Methods in Phys. Res. B*, 143, pp.311-318, 1998.

7. McDonnell, J.A.M. , editor, Update of Statistical Meteoroid/Debris Models for GEO, *Final Report of ESA contr. 13145/98/NL/WK*, 2000.

8. Grün, E.et al., Collisional Balance of the Meteoritic Complex, *Icarus*, **62**, pp. 244-277, 1985.

9. Drolshagen, G. et al. , Measurements of Cosmic Dust and Micro-Debris in GEO, COSPAR 2000, Warsaw, to be published in *Adv. Space Res*., 2001.

10. Grün, E. et al., Two years of Ulysses dust data, Planet. Space Sci, Vol. 43, No. 8, pp.971-999, 1995.