IN SITU MEASUREMENT OF COSMIC DUST AND SPACE DEBRIS IN THE GEOSTATIONARY ORBIT

G. Drolshagen, H. Svedhem, ESA/ESTEC, Noordwijk
E. Grün, MPI f. Kernphysik, Heidelberg
O. Grafodatsky, V. Verhoturov, NPO-PM, Krasnoyarsk
U. Prokopiev, V. Gusyelnikov, Novosibirsk State University, Novosibirsk

ABSTRACT

On 26 September 1996 the Russian Express-2 telecommunications spacecraft was launched into geostationary orbit (GEO). A Cosmic Dust/Space Debris detector was included as a piggyback instrument. The instrument consists of a plasma type detector and associated electronics and is essentially identical to the Dust detectors flying on the Ulysses and Galileo spacecraft. The aperture size is 0.1 m^2 and the instrument is capable of detecting particles with a mass down to 10^{-14} g (velocity dependent). The detector is stationed at 80° Eastern longitude. It has a fixed viewing direction which is 65° away from the flight direction towards North. The extracted parameters include particle mass, velocity and crude impact direction. Orbital debris and natural meteoroids can be separated by the impact velocity which at the GEO altitude is typically below 5 km/s for debris and higher for meteoroids. In this paper preliminary results of the first 3 months of operation are presented. The design life of the Express satellite is 5 to 7 years.

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. 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 m. Some in situ measurements in GEO over a period of 10 months were reported in Ref. 1. To obtain some information on the submicron 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 Institute (MPI) fuer Kernphysik in Heidelberg, the Scientific Production Association of Applied Mechanics (NPO-PM) from Krasnoyarsk and the Novosibirsk State University (NSU).Main objectives of the experiment are to:

- monitor the space debris environment in the geostationary orbit and its long term variation.
- monitor the meteoroid flux at 1 AU heliocentric distance , its dependence on the season and its long term variation.
- Investigate the small particle mass region of meteor streams and its relation to the position of the parent bodies.
- Act as a third point for simultaneous measurements with the corresponding Ulysses (out of the ecliptic) and Galileo (at Jupiter) instruments.

2. THE GORID INSTRUMENT

The impact detector launched is the flight quality engineering model of the Ulysses detector (which is essentially identical to the Galileo instrument). Fig. 1 shows a view of the detector. 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 times and total intensities of the measured plasma signals by use of empirical calibration curves.
The detecting surface is of roughly hemispherical 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.
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°. The effective solid angle interval covered is 1.45 sr (ref. 2).

2.1 Measured parameters and calibration

Figure 2 shows schematically the configuration of the detector and the measured quantities.

Proceedings of the Second European Conference on Space Debris, ESOC, Darmstadt, Germany, 17-19 March 1997, (ESA SP-393, May 1997)

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). In addition, the time between the positive and negative signals and the induced charge (for impactors which are electrically charged) is measured.

The impact generated charge signals are binned into 48 logarithmic steps. For the rise times
16 steps are used. The rise times of the pulses, which are independent of the particle mass, decrease with increasing particle speed. Extensive calibrations have been performed for the Ulysses and Galileo detectors to obtain empirical calibration curves between the rise times and impact velocities and between the intensity of the charge signals and the speed and mass of the impactor. For GORID (which is the engineering model of the Ulysses detector) additional calibration tests were carried out at the hypervelocity impact facility of the MPI in Heidelberg which confirmed that the established calibration curves were still applicable.

Table 1 gives the empirically determined rise times, t_i and t_e, and the corresponding impact velocities v_i and v_e for the Ulysses impact detector as function of the digitization steps (here denoted IT and ET for the ion and electron signal, respectively). These values are taken from ref. 3. According to ref. 2 the average uncertainty in the velocity measurement is about a factor 2 for one signal (electron or ion rise times) and about 1.6 for measurements with good coincidence for both signals.

Similar calibration results have been experimentally obtained for the ion and electron charge signals as function of the impact speed for different impactor materials. (see ref. 3).
While extensive calibration tests have been performed for the Ulysses and Galileo detectors most of these tests were at relatively high velocities which were most relevant for these missions. Some tests were performed with velocities down to about 1 km/s but low velocity test data are sparse. For the analysis of the GORID data, where space debris impacts with velocities of a few km/s or below are expected, some (cautious) extrapolation will be required.

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. 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.
The ion signal was usually found to be the most reliable and the least susceptible to 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.

Table 1: Rise times t_i and t_e and corresponding velocities v_i and v_e for the Ulysses dust detector as obtained by calibration tests (taken from ref. 3).

IT	t_i [µ s]	v_i [km/s]	ET	t_e [µ s]	v_e [km/s]
0	< 10.0	70.0	0	< 10.0	70.0
1	13.4	70.0	1	13.4	70.0
2	15.7	70.0	2	15.7	70.0
3	18.2	70.0	3	18.2	70.0
4	20.9	70.0	4	20.9	70.0
5	23.8	70.0	5	23.8	70.0
6	27.1	43.5	6	27.1	70.0
7	30.7	34.1	7	30.7	56.0
8	34.9	21.4	8	34.9	36.7
9	39.7	14.1	9	39.7	31.3
10	45.2	10.4	10	45.2	26.5
11	51.6	7.8	11	51.6	20.2
12	59.7	5.0	12	59.7	11.8
13	70.5	2.5	13	70.5	7.7
14	86.3	2.0	14	86.3	3.2
15	>96.5	2.0	15	>96.5	2.3

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.

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

4. GORID MISSION

GORID/Express-2 was launched successfully on 26 September, 1996 with a Proton rocket from Baikonur. The spacecraft was then moved into its geostationary position at 80° Eastern longitude. Figure 3 shows a drawing of the GORID/Express system. The main viewing direction of GORID is pointing 65° away from the flight direction towards North.

The cover of GORID was opened on 18 October. All initial tests were successfully completed. The first impact was measured on 29 October. Its relatively low velocity of below 5 km/s indicates that most likely it was a space debris particle. By mid-November all planned tests had been completed. GORID was found to be fully operational. Some instrument settings (channeltron voltage, signal threshold levels, classification criteria, etc.) were still changed during the reporting period.

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 send to the NSU in Novosibirsk where some preprocessing takes place. From the NSU the data are forwarded to ESTEC via an electronic mail connection.

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

4. FIRST RESULTS

In this chapter preliminary results obtained during the first 118 days of operation, from 3 November 1996 to 28 February 1997 are reported. Only the 'big' impacts with ion signals of range interval A3 or larger will be considered here. These are the events which have the highest probability of being real impacts. Many more events were recorded with a weaker signal. However, all events need a closer evaluation before noise and true impacts can be separated.

During the reporting period of the first 118 days a total of 915 events were recorded in the ion signal amplitude ranges A3 or larger.
Out of these events 92 were in class 0, 652 in class 1 and 171 in class 2 or 3 (the initial software settings have prevented a proper separation of classes 2 and 3).
For a subset of 135 of the 915 events the detailed event parameters like rise times, signal amplitudes and noise levels were recorded. The other events are just classified and counted.

Fig. 4 shows the number of recorded impacts in all confidence classes (0-3) as function of the day of occurrence.

The plot shows some pronounced peaks together with a more steady (but also variable) background count rate of 1- 5 events per day. The strongest peak with 313 events was recorded on 23 February 1997. On 27 November 1996, 148 events were registered and 107 on 28 February 1997.
Further analysis is needed to distinguish real impacts from other events which could have triggered the detector. Such spurious events could be electrostatic discharges, effects from firing of the ion thrusters which are used for spacecraft attitude control or other interaction of GORID (which, after all, is an impact plasma detector) with the space environment in GEO.

Fig. 5 gives the number of recorded events in class 2 (which should also include the class 3 events). These events have the highest confidence of being real impacts. When compared to Fig. 4, most of the peaks do remain recognizable though they are less pronounced.
Two large peaks remain at the end of February 1997. During that period there were no special disturbances of the magnetosphere and no extreme fluxes of energetic charged particles. This implies that these numerous events are either real impacts (e.g. caused by passing through a space debris cloud) or are caused by some as yet unknown interaction with the local plasma environment of the Express satellite.

The rise time distribution of the fully characterised 135 events is shown in Fig. 6. The conversion to velocities is given in Table 1. Again these data have to be seen as preliminary.
The rise time distribution of the electron signals (shaded bars) is in line with the expectations and could be explained by a combination of faster meteoroids and slower debris particles. The distribution of the ion rise times (solid bars) with the strong peak in the long rise time bin No 14 appears unrealistic and in contradiction to the electron rise time distribution. Ideally the two distributions should be similar. Perhaps the noise from the local plasma environment prevents an accurate measurement of the ion rise time.

More detailed evaluations of the signals is ongoing. We believe that, while each individual impact velocity will have a considerable uncertainty, the total distribution should still be fairly accurate when large numbers of impacts are recorded.

The velocity distribution can eventually 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 about +/- 15 degrees in latitude and within 180 degrees of

longitude. Such debris particles could impact the GORID detector with a maximum velocity of about 800 m/s. Debris with some extra velocity obtained during its creation (e.g. by an explosion could impact with higher velocities, as could space debris in GTO or Molniya type orbits when crossing the GEO ring. The maximum impact velocity on GORID for these type of debris is in the order of 4-5 km/s.
Most meteoroids will impact with higher velocities even though some could hit GORID with speeds more typical for debris impacts.
To a first approximation it probably can be assumed that the majority of impacts recorded with impact velocities below about 5 km/s are due to space debris particles.

It is clear that the distinction between meteoroids and debris by their velocities is one of the key objectives of the GORID experiment. A proper analysis of the measured velocity distribution, which is planned for the future, will have to account for the spacecraft attitude, the meteoroid velocity distribution at the GEO altitude, uncertainties in the measured rise times and also for the relative lack of calibration data at low velocities.

5. CONCLUSIONS

The meteoroid/debris impact detector GORID was successfully launched into GEO on board the Russian Express-2 telecommunications satellite. Its main objectives are to monitor the largely unknown small size space debris population in GEO and to gain new information on the mass distribution and the directional and temporal dependence of meteoroids and meteoroid streams. GORID is fully operational and should remain functional during the expected 5-7 years lifetime of the Express satellite. During the first 118 days of operation several hundred events were recorded. Many of these events show all signs of real impacts while others likely will have to be attributed to noise or other 'non-impact' processes. Judging from the electron rise time distribution 20 - 30% of the impacts could result from space debris particles with the remaining being natural dust.
A detailed analysis of the events has started to distinguish real impacts from spurious events and to determine the measured parameters which have the highest reliability. The impact database should increase steadily over the coming months and years.

6. REFERENCES

1. Novikov, L.S., Voronov, K.E., Semkin, N.D. Verkhoturov,V.M., Grafodatsky, O.S. and Maksimov, I.A., 'Measurements of Solid Micro-Particle Fluxes in Geosynchronous Orbit', proceedings of symp. on 'Environment Modelling for Space-based Applications', ESTEC 18-20 Nov. 1996, ESA SP-392, 1996

2. Grün, E., Fechtig, H., Giese, R.H., Kissel, J., Linkert, D., Maas, D., McDonnell, J.A.M., Morfill, G.E., Schwehm, G. and Zook, H.A., 'The Ulysses Dust Experiment', Astron. Astrophys. Suppl. Series 92, 411-423, 1992

3. Grün, E., Baguhl, M., Hamilton, D.P., Kissel, J., Linkert, D., Linkert, G. and Riemann, R., ' Reduction of Galileo and Ulysses Dust Data', Report of the Max-Planck-Institut für Kernphysik, Heidelberg, September 1994.

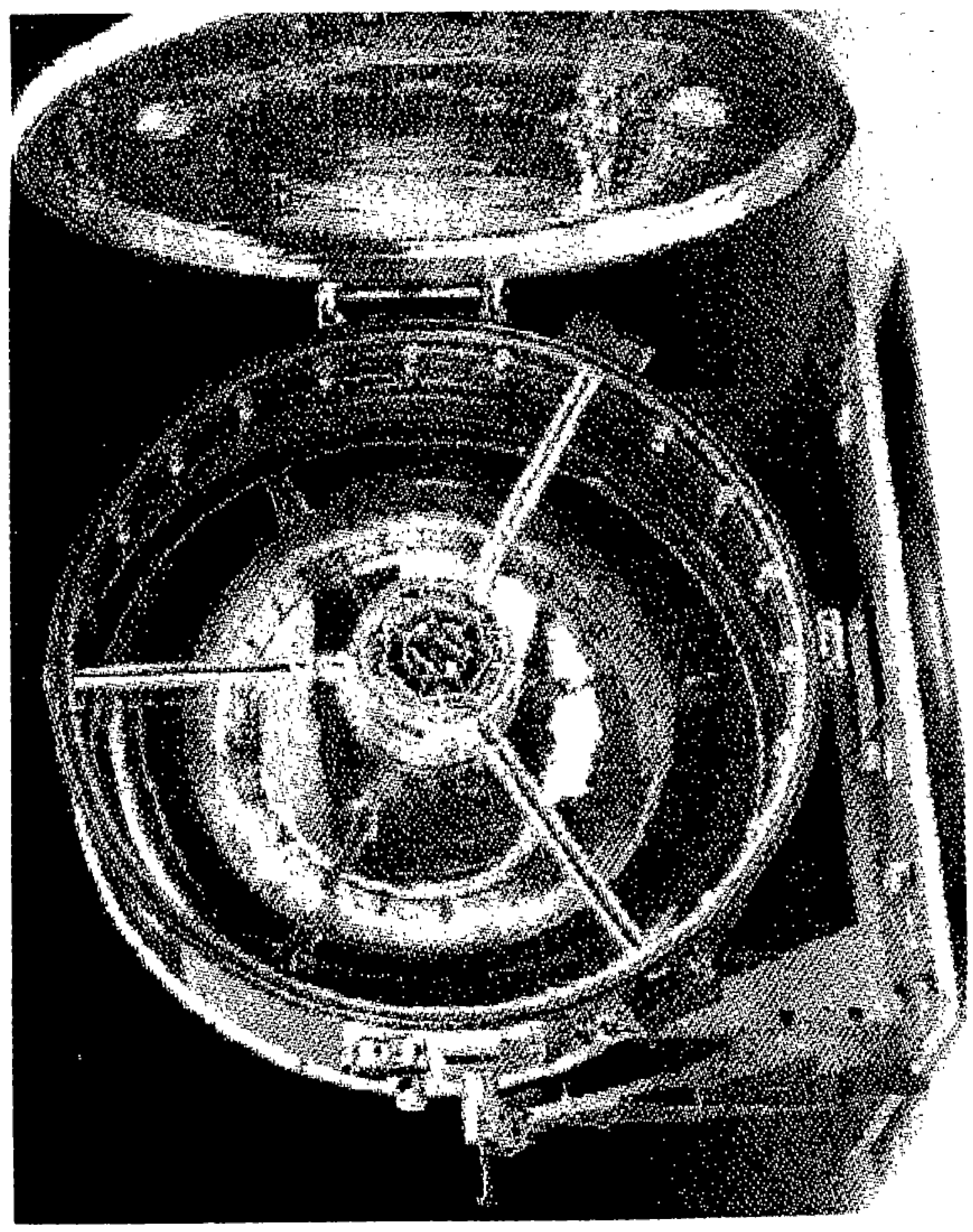

Fig. 1: The meteoroid/debris impact detector GORID. The opening diameter is 43 cm.

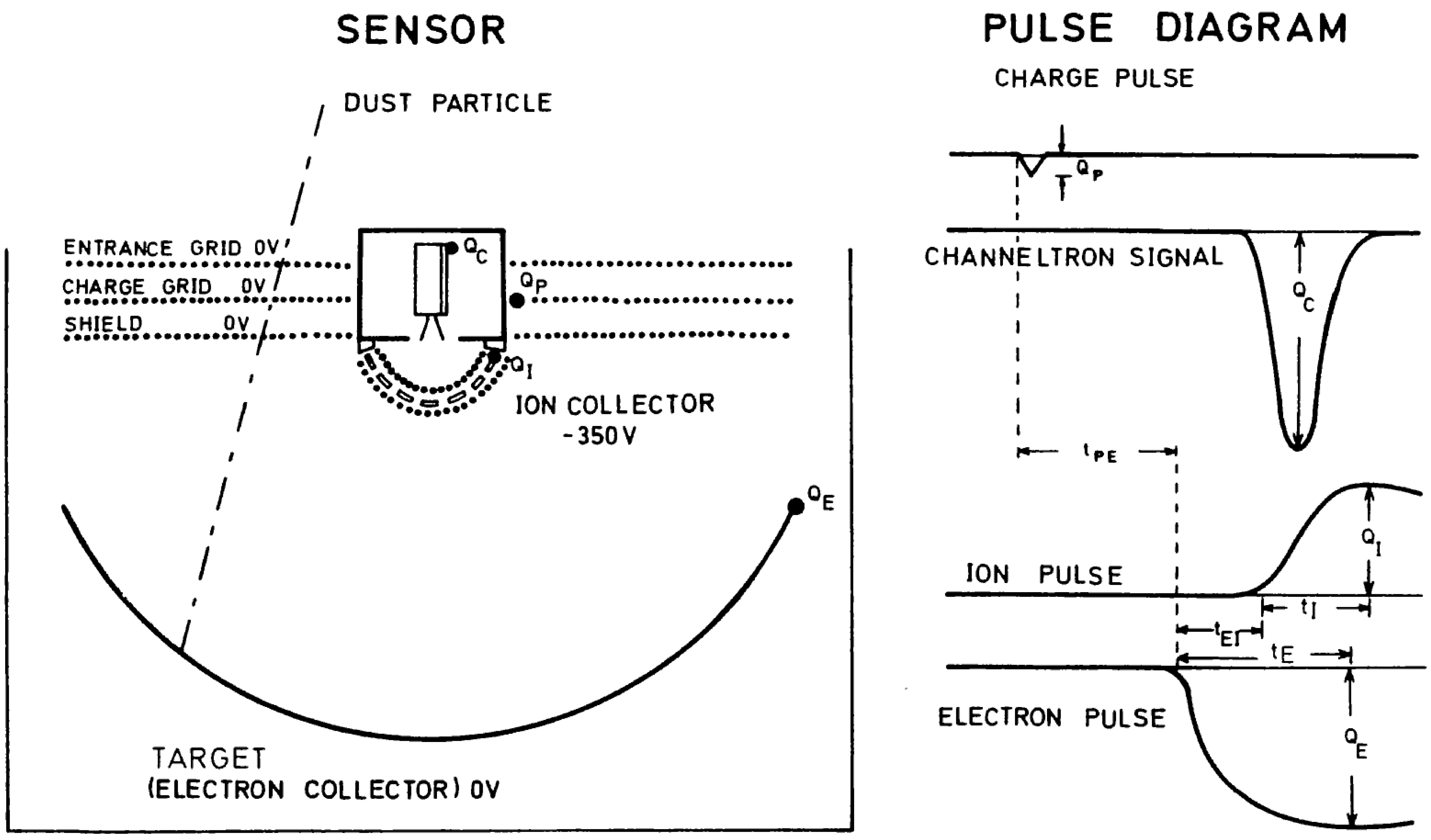

Fig. 2: Schematic drawing of the detector configuration and of measured quantities.

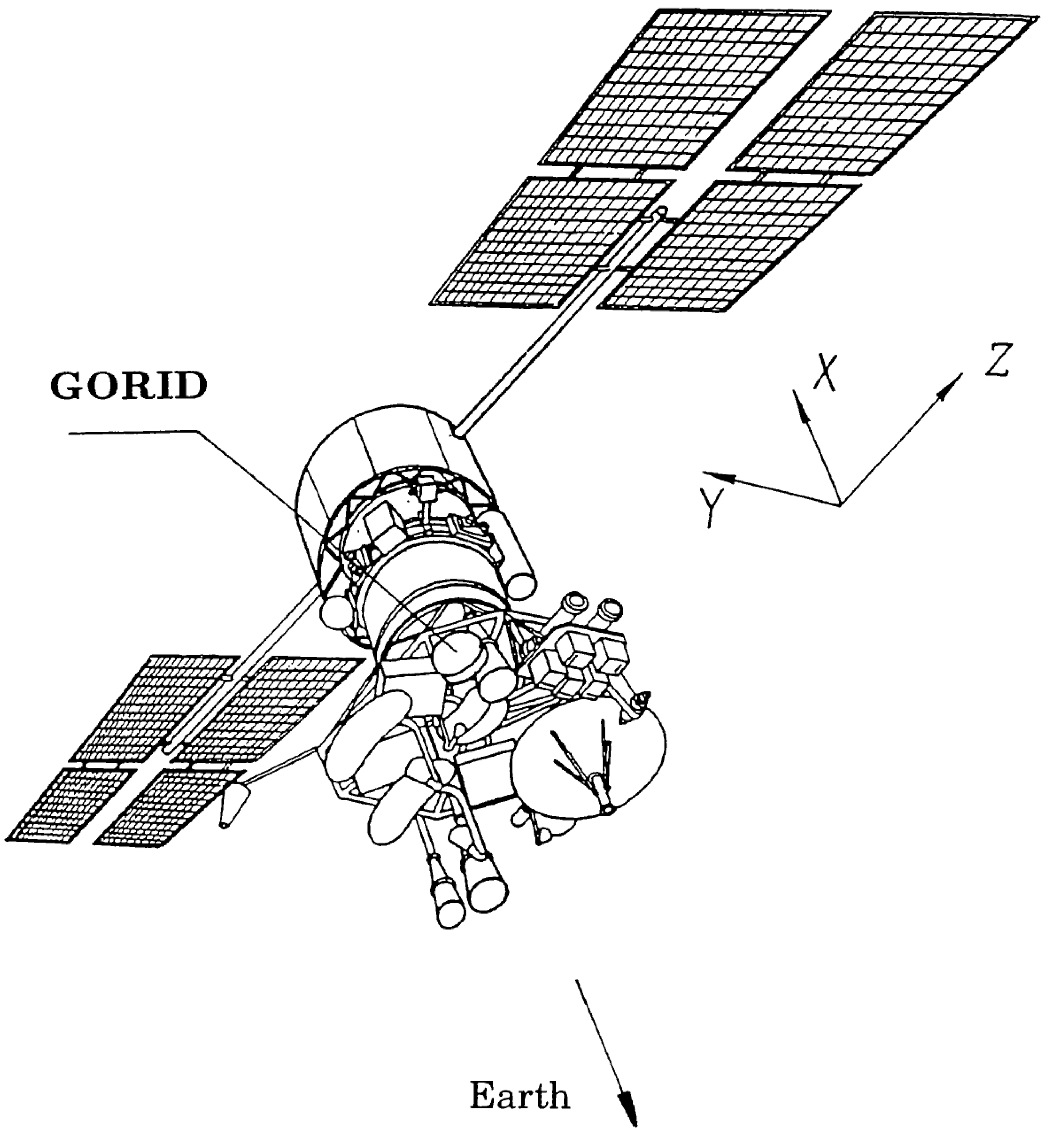

Fig. 3: Geometry of GORID/Express in orbit (correct scale).

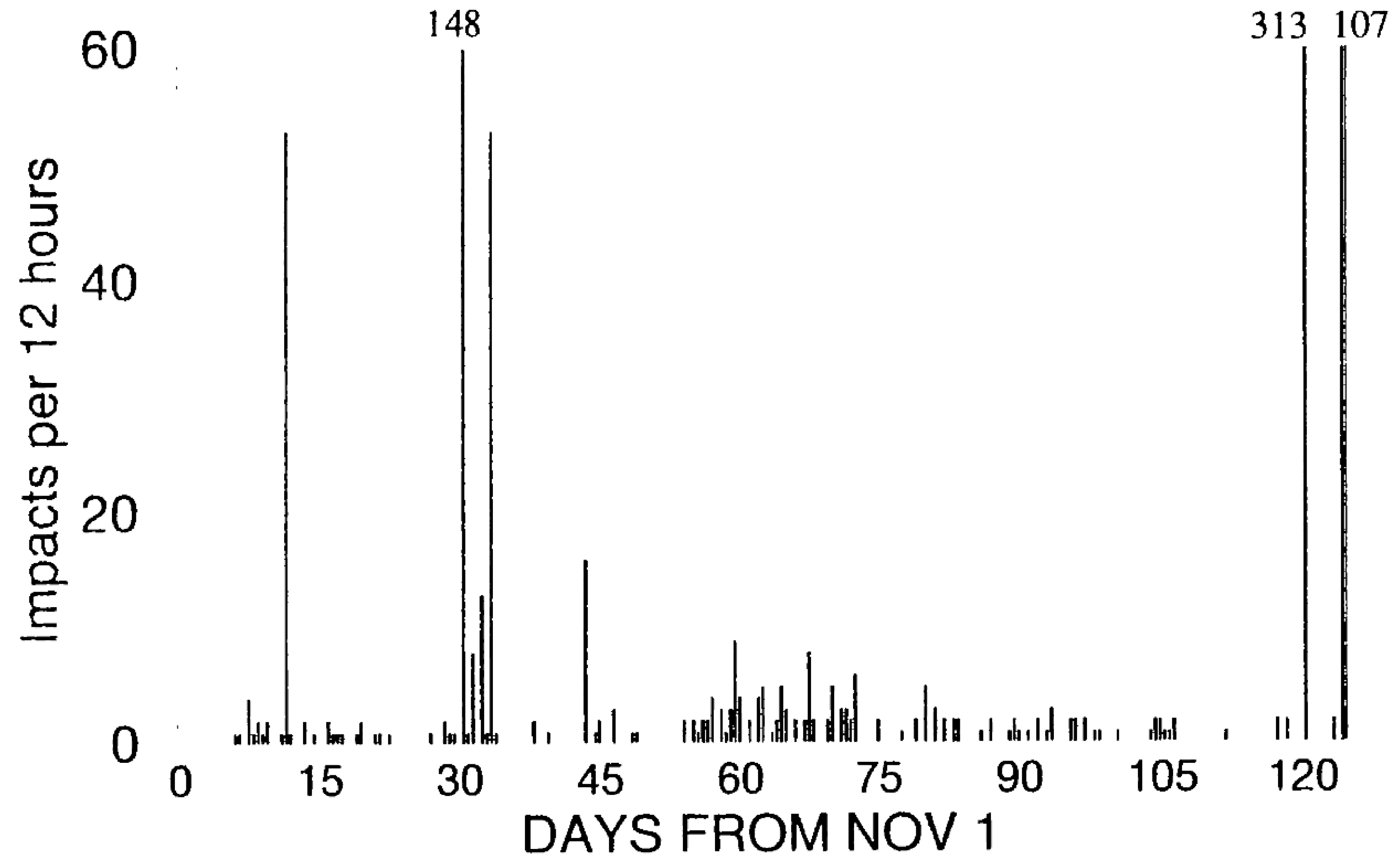

Fig. 4: Events recorded by GORID between 3 November 1996 and 28 February 1997 (in 12 hours bins) as function of the day of occurrence. Shown are all events registered in the 4 highest (out of 6) ion amplitude ranges.

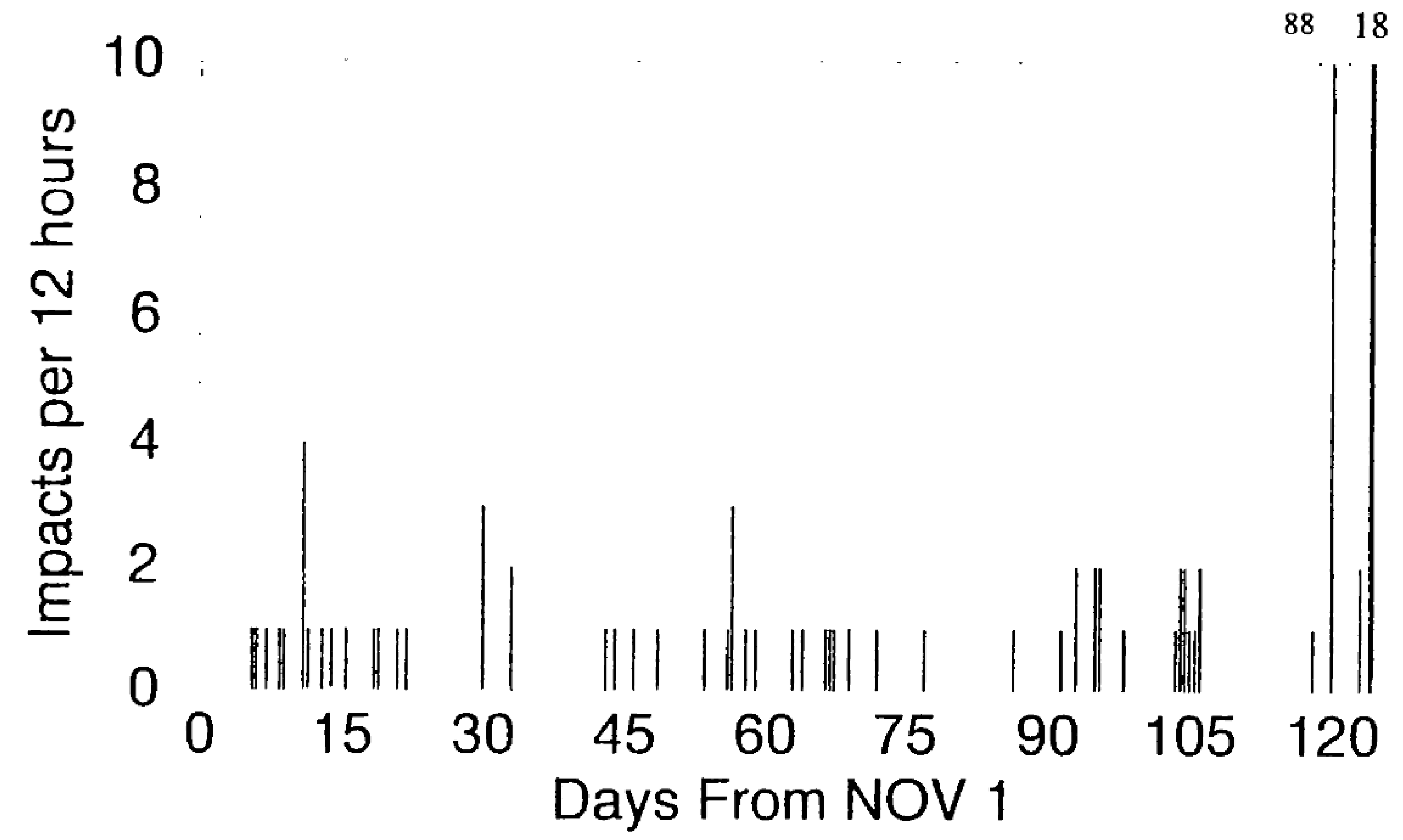

Fig. 5: Events recorded by GORID between 3 November 1996 and 28 February 1997 (in 12 hours bins) as function of the day of occurrence. Shown are the events registered in the 4 highest (out of 6) ion amplitude ranges and in the highest confidence classes 2 and 3.

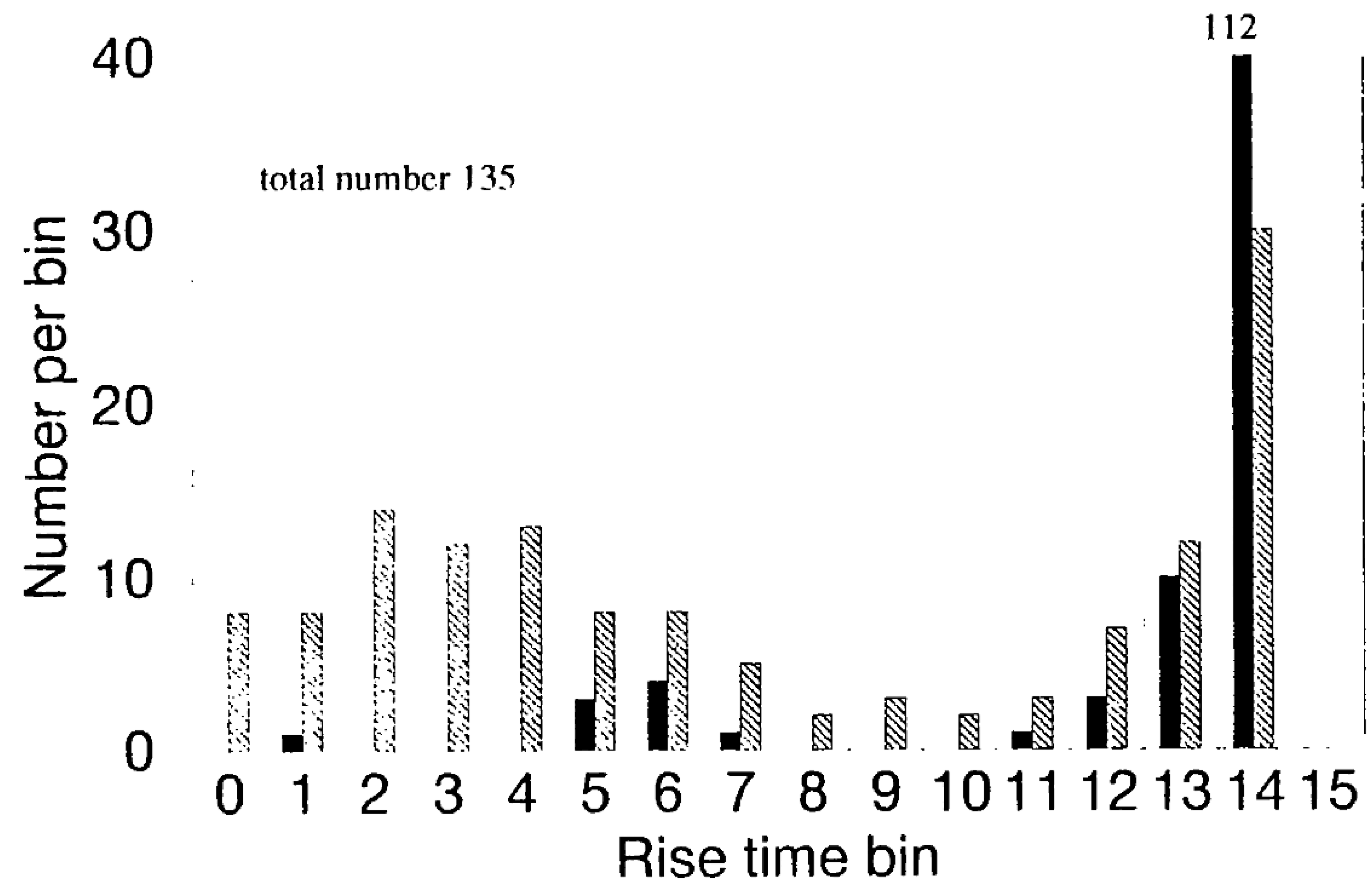

Fig. 6: The 135 fully characterized events as function of the rise time bin. Use Table 1 to convert to velocities. Shaded bars are for the electron signal rise times, solid bars are for the ion signal rise times. The difference between the two distributions is under investigations.