DEGLITCHING METHODS BY THE ISOPHOT INTERACTIVE ANALYSIS (PIA)[1]

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Abstract. The ISOPHOT detectors were continuously exposed to high energy cosmic particles hits, resulting in an average hit rate frequency of an event per every 7 seconds. The net effect is a disturbance of the readout voltages, which decreases the signal–to–noise ratio and hence the photometric accuracy level. Thanks to the highly redundant readout method of ISOPHOT it is relatively easy to identify cosmic particle hits which have enough energy to produce a noticeable deviation in the readouts. The most energetic particles can cause a short term change in the detector response. Different algorithms are implemented into PIA to cope with this problem. PIA provides handy interfaces to perform individual treatment of the data and optimize the parameters of the deglitching algorithms.

[1]Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

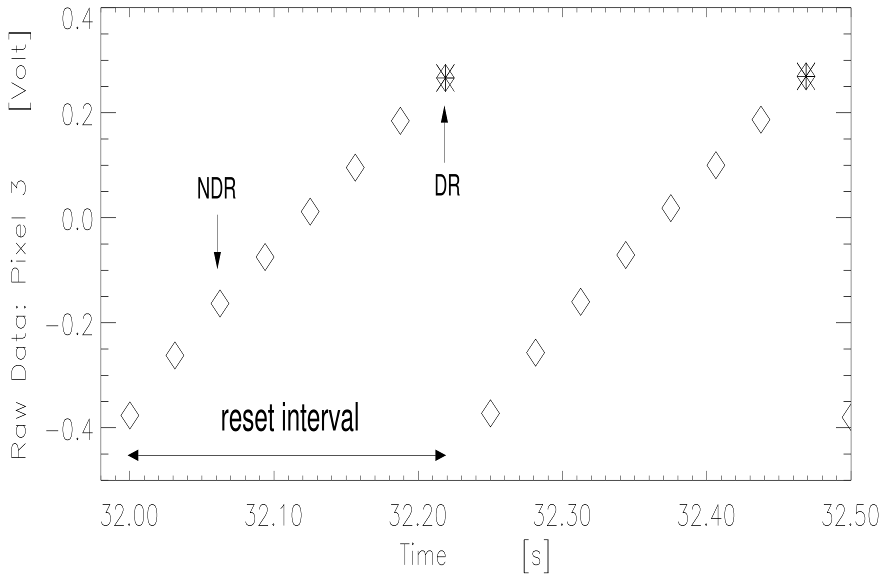

Figure 1. ISOPHOT integration ramps at the raw data level

1. Introduction

ISOPHOT (Lemke *et al.* , 1996) was one of the four instruments operating on board the Infrared Space Observatory ISO (Kessler *et al.* , 1996). The ISO satellite was launched by ESA in November 1995 and ended its operations successfully in April 1998. ISOPHOT is composed of different sub-instruments with photoconductive detector units based on Si and Ge (see Table 1). These are optimized for observations in different wavelength ranges over the full ISO range of 2–240 μm.

All ISOPHOT detectors are coupled to a Cold Readout Electronics (CRE) unit, whose function is to pre–amplify and sample the photocurrent generated by the detector. When the detector is illuminated by infrared (IR) photons the voltage on the integration capacity increases with time. The slope is proportional to the photocurrent in the detector, which in turn is proportional to the IR power received by the detector. The voltage is sampled by periodic pulses which are called Non–destructive readouts (NDR). However, since the voltage has to be ADC converted, it has to stay within a limited range and needs to reset periodically using "reset pulses", called Destructive readouts (DR). These features give the characteristic integration ramps at the raw data level, which is usually referred to as Edited Raw Data (**ERD**), as illustrated in Fig. 1.

The read-out frequencies range from 1 to 64 Hz, whereas a typical integration time at a given sky position is in the range of minutes, which implies a high redundancy in the ISOPHOT data acquisition. The important quantity for an observer is the slope of the voltage increase, which will hereafter be referred to as the "signal". The signals are determined by fitting a straight line to each ramp or to portions of it. This second level of data structure is referred to as Signal per Ramp Data (**SRD**). The scatter of the measured read-outs around this line is a measure of the system noise and in the ideal case determined by the photon noise.

On the ISO orbit all ISOPHOT detectors were continuously affected by the hits of high energy cosmic particles and secondary particles generated by hits into the satellite shielding. This effect constitutes one of the main sources of signal disturbance. The flux of high energy particles depends on the orbital position of the satellite with respect to the radiation belts and the space weather conditions. Every cosmic particle carrying enough energy to produce a band transition is able to cause a sudden jump in the temporal sequence of signals, generally called "glitch". The main effect of glitches is a degradation of the signal–to–noise ratio, which results in a reduced photometric accuracy.

Efficient ways of filtering out the most serious effects produced by glitches take advantage of the high redundancy of the detector voltage read–out procedure and the short time nature of the cosmic ray hits. Their functionality, efficiency and limitation within the ISO**P**HOT **I**nteractive **A**nalysis (**PIA**)[2] (Gabriel *et al.* , 1997) will be described in this paper.

2. Effects of glitches on ISOPHOT data

The continuous hits of high energy particles affect the data in different ways:

i Decrease of the signal–to–noise ratio: The most common effects of glitches are discontinuities appearing in the integration ramps (see for instance Fig. 2). This leads to a poorer determination of the signal from the affected ramps and hence a degradation of the signal–to–noise ratio. Such affected parts of a ramp have to be identified and excluded from the signal determination.

ii Short term variation of the detector response: The disturbance of the integration ramps depends on the relative ratio of the energy deposited by the cosmic particle in the detector to the amount of incoming IR radiation. For a high IR flux level and normal space weather conditions a hit affects only a few readouts, *i.e.* the relaxation time is relatively short. However, if the charged carrier generated by a cosmic particle is large compared to the photocurrent produced by the IR photons then

[2]PIA is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium.

a hysteresis effect appears. The relaxation time lasts for several integration ramps generating a tail-like signal excess, which is interpreted as a momentary response variation. These glitches are more difficult to identify and to correct for. Severe cases occur if the affected signals constitute an important fraction of the whole signal sequence on a certain sky position, or if the relaxation time becomes as long as the time interval between consecutive glitches.

iii Long term increase of the responsivity: During the preflight calibration it was found that the responsivity of the detectors changed after exposing them to high energy radiation (see Lemke et al, 1993). The same behaviour was found in flight, affecting mostly detectors based on Ge:Ga (P3 and C100), whereas those based on Si are less affected (P1, P2 and SS/SL).

iv Increase of the detector "dark signal": Low energy glitches affect the measurements by increasing the level of the signal measured under zero illumination. The consequence is an increase of the minimum measurable signal, or equivalently, a decrease of the sensitivity limit (see Section 6 in Lemke *et al.*, 1996). The value of the dark signal, including a mean variation along the ISO revolution has been calibrated for each detector/pixel and is available both in the PIA as well as in the Off–line Pipeline Processing (OLP).

3. Detection of glitches

As explained above the ISOPHOT detector output data are integration ramps with high readout frequencies and therefore with a high data redundancy. Taking into account the fact that on average the disturbance by an individual glitch lasts for a fraction of a second, and a typical glitch frequency is one event every 10 seconds, it can be concluded that statistical analysis is a good way of eliminating glitch effects in the data (here we refer to those described in sections 2 **i** and **ii**).

The various algorithms developed so far, which are based on statistical analysis, constitute basically of a search for deviating values within a distribution of differences between consecutive readouts or on a higher level between signals. For a constant illumination the measured signals should approximately form a gaussian distribution, whereas glitches show up as tails in such distributions. However, there are two facts to be taken into account when searching for deviant values in the signal distribution:

- the signal transient effects, which are induced by every illumination change, making the signal distribution highly non-gaussian (for a description of transient effects see Acosta et al, 1998) and:

– the hysteresis effect observed after a glitch, which can be described as a sudden change of responsivity with a long relaxation time.

All PIA deglitching algorithms contain three basic steps:

i Preparation of the data for glitch detection: The detector signals may suffer from transient effects which broaden the signal distribution and therefore small level glitches cannot easily be recognized. As an attempt to minimize this effect we remove the baseline trend, for instance by using the smoothed signal sequence after applying a median filter. Another limiting effect is non–linearities in the integration ramps, especially when a large part of the available dynamical range in voltage is used. In this case the difference between consecutive readouts will reflect any uncorrected ramp non–linearity, which is modulated with the reset frequency.

ii Detection of outlying points: The average and standard deviations of the signal distribution for a constant illumination are computed, and the points outside a few standard deviations from the average are flagged as bad. The use of minimum–maximum clipping (not using the extremes of the distribution) makes the recognition of deviant points more efficient.

iii Glitch tail recognition: Detection of the main glitches is performed very efficiently via step **ii**, however in most cases the tails after a strong glitch cannot be recognized in the same way. There are several ways to cope with these cases: One possibility is the iteration of step **ii** eliminating the discarded values from the sample. Another possibility is to look explicitly at the signals which follow a glitch event. Those signals will be accepted only when their deviation from the mean signal falls below a second threshold, which is set to a smaller value than the one used for detecting the prime glitch event (this algorithm was originally proposed by Haas *et al.* , 1996).

These steps are combined differently within the reduction methods currently implemented in PIA, which will be described in the following section.

4. Implementation in PIA

There are two deglitching routines working on the ERD level of the data processing and one on the SRD level. The basic idea behind these algorithms is to mask all data points affected by glitches, and at the same time to keep a maximum of unaffected data. None of the algorithms try to restore the affected data.

In practice, it has been shown that the use of one of these algorithms is in general sufficient to identify most of the glitches; however, the best results are obtained by the application of one correction at ERD level followed by the correction at SRD level.

4.1. CORRECTION ON ERD LEVEL

There are two ways of deglitching the data at ERD level: a simple approach which discards deviating signals above a certain threshold, and a more sophisticated approach, which identifies the glitch and also looks for a possible subsequent tail discarding deviating signals above a second threshold. After all affected readouts have been masked, the integration ramps are reconstructed by computing local mean values of the differential signal. This is done in order to use most of the unaffected data and to have a better sampling of the dynamical range of voltage. This is especially important when there are only few integration ramps within the frame of a single measurement.

4.1.1. *Simple approach*

This algorithm works on a per ramp basis and hence it requires a sufficient number of read–outs per ramp to use statistical analysis. This means that it cannot be applied to measurements of very bright sources for which ramps contain only few readouts. The separation in ramps minimizes the possible dispersion due to signal transients. The signals are derived from consecutive read–out differences and then the mean and the standard deviation (σ) of those values are computed. Several iterations (default is 4) can be done after rejecting signals deviating by more than a few σ (default is 4.5).

This algorithm works very well for glitches which affect a small number of read-outs within a ramp and do not show long tails. This is the case for observations of intermediate brightness sources. We present an example in Fig. 2, where the affected ramps are shown before and after deglitching.

4.1.2. *Complete approach*

In this second implementation differential signals are also computed from pairs of consecutive read–outs but several ramps are used at once, in practise all those belonging to a constant illumination level, with the same filter and at the same sky position. This feature extends the deglitching at ERD level to those measurements with only a few read–outs per ramp, which cannot be handled by the simple method.

In order to minimize the scatter introduced by transient effects within the signal distribution, the temporal signal sequence is normalized by a smoothed sequence which results from applying median filtering.

The basic difference w.r.t. the previous method is the use of two thresholds to detect the glitch effects: one is used for detecting the primary glitch event (default: 3σ), and the other is used for rejecting affected data follow-

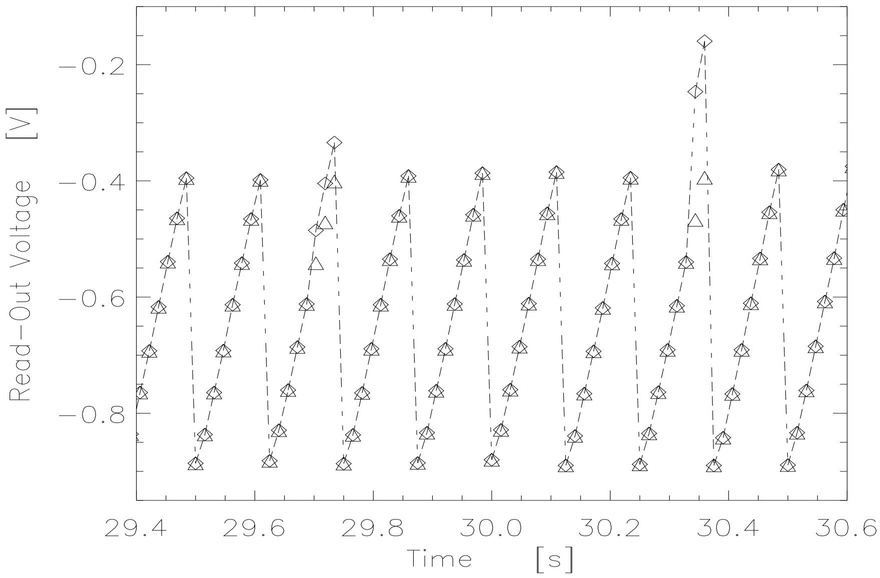

Figure 2. Details of a deglitched measurement, showing affected ramps, before (diamonds, dashed line) and after deglitching (triangles) with the simple ERD correction algorithm (the values which are different after deglitching are computed using the mean voltage difference between read-outs of the not affected part of the ramp)

ing primary glitches (default: 1σ). In this way most of the tails following strong glitches can be detected.

This method is well suited for observations of low flux sources when glitches produce long tails and only a small part of the voltage dynamical range is used, thus avoiding the effect of non–linearities in the integration ramp. Figure 3 shows a normalized distribution of signals together with the two thresholds and a group of flagged read-outs by using this method.

4.2. SRD LEVEL

In general both of the previously described algorithms produce reliable results, and the signals obtained after ramp fitting are relatively free of glitches. However, there are cases in which residual effects are still present. In most cases, the number of signals corresponding to a given flux level allows sensible statistics.

The glitch detection is done by computing a 'running mean', which considers simultaneously a certain number of consecutive data points which are shifted along the whole measurement (the box size is configurable). Whithin the so chosen box, all data points are flagged, which are outside a certain number of standard deviations from the mean value of the box. An

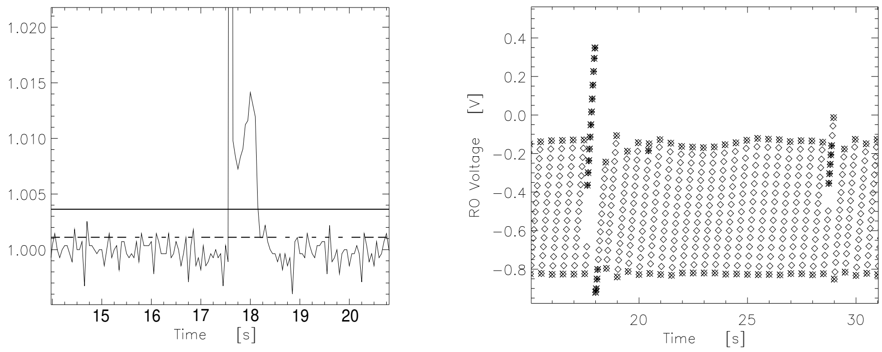

Figure 3. On the left, a normalized distribution of signals (thin solid line) together with the two thresholds found for this distribution: a first threshold of 4 sigmas (thick solid line) and a second of 1 sigma (dashed line). On the right, read-outs flagged by the algorithm (asterisks) in the ramps (diamonds). [Discarded read-outs in addition (because of general selection criteria) are marked with crosses]. Note the two deglitched regions, the first one comprising parts of two ramps (and corresponding to the plot on the left), the second one only a portion of one ramp.

additional condition can be set stipulating that data points are considered to be affected by glitches if they are detected in different boxes (by default in two). This process can also be iterated a number of times discarding the masked points in previous iterations.

This method was originally developed for the ISOPHOT Off-line Processing Pipeline (Guest, 1993), and was later adapted to get full interactive capabilities within PIA. The application of this correction to an already read-out deglitched distribution is shown in Fig.4, in which the signals obtained without any deglitching are also shown. While some points were completely corrected by one of the methods at ERD level, there were still residuals which were identified and masked from further processing.

4.3. RESULTS OBTAINED AFTER DEGLITCHING

Applying deglitching procedures significantly increases the data quality. Typically, an improvement of a factor of two in the signal–to–noise ratio can be achieved by the application of one deglitching procedure and up to a factor of three when combining deglitching at the ERD and SRD levels of the data reduction.

The deglitching procedures vary in efficiency depending on several observing conditions, like illumination level, orbital position and space weather conditions at the time of the observation. There were only very few cases in which extreme conditions, especially strong geomagnetic storms make the data unrecoverable (Castañeda & Klaas, 1998). Under such conditions the glitch frequency is as high as the read–out frequency, which makes it

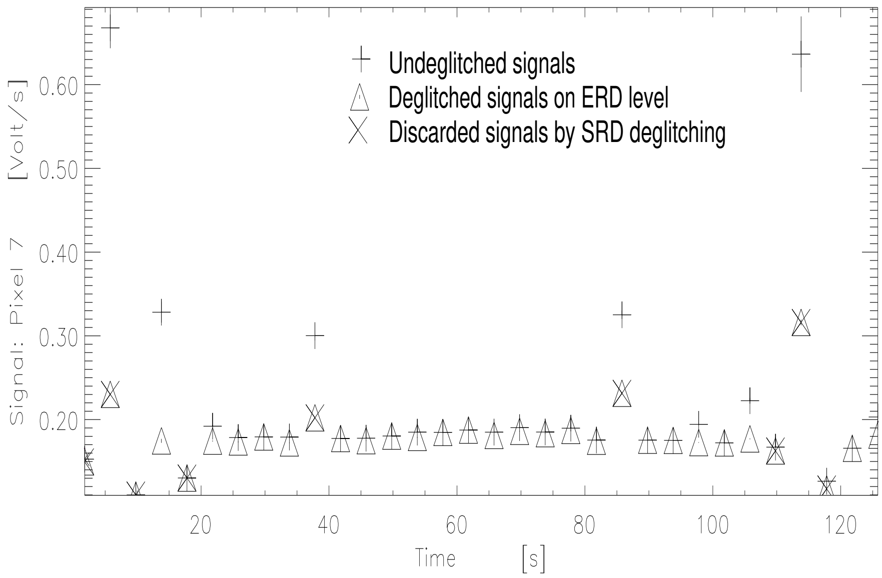

Figure 4. Comparison of signals from the same measurement, processed with (triangles) and without (plus symbols) read-out deglitching procedure. Although most of the data disturbances produced by glitches are corrected at ramp (ERD) level, residual effects are still present, which are recognized and flagged (crosses) by the signal deglitching procedure

very difficult to distinguish glitches from the voltage increase by the IR photocurrent.

Another important feature in the data reduction which helps to get rid of glitch effects is the use of "weighted means" to obtain a final signal for a given observation. Signals from ramps containing glitches hereby get a very low weight and impact only minimally the final value.

The weighting factors are the inverse of the squares of the signal uncertainties.

5. The graphical interfaces

The ISOPHOT instrument provides a wide wavelength range coverage and offers a large dynamic range. For these reasons the data set is not uniform; data are gathered with different detectors and readout electronic configurations and under various space weather conditions. Therefore, it is extremely important for different correction algorithms, especially deglitching, to be tested as well as their relevant parameters. PIA offers several graphical user interfaces, which make it possible to test different algorithms and to tune parameters. These interfaces comprise comprehensive plots and tables. In Fig. 5 we present the interface for the deglitching method described in Sec-

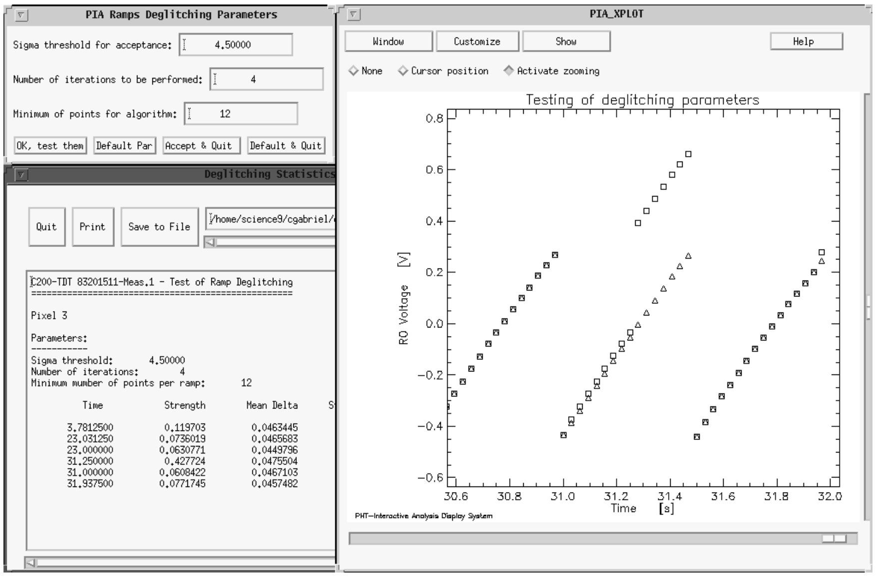

Figure 5. PIA interface for single threshold deglitching of read-outs. Left side: text windows for glitch parameter set-up (above) and glitch statistics (below). Right side: display of test run (original data in squares, deglitched data in triangles)

tion 4.1.1. When running the testing option, a plot with the original ramps is displayed, over–plotted with the corrected ones. At the same time a table with the statistics of the deglitching procedure is presented. These tables contain the following information for every glitch found:

- the time of the glitch occurrence within the measurement
- the strength of the glitch (amplitude of the detected outlying jump in readout voltage)
- the mean readout voltage difference
- a glitch counter per ramp, (in the simple method at ERD level)
- the number of consecutive affected points and the length of a glitch in time (in the complete method at ERD level)

All this information can easily be saved as ASCII tables for detailed data analysis.

Similar interfaces for the signal deglitching correction are shown in Fig.6. In this case the discarded signals are marked on the resulting plot, and the number of discarded signals are given in a text window.

6. Statistical studies of glitches

The main motivation for developing deglitching techniques is to eliminate them efficiently from the data. However the characterization of glitches and

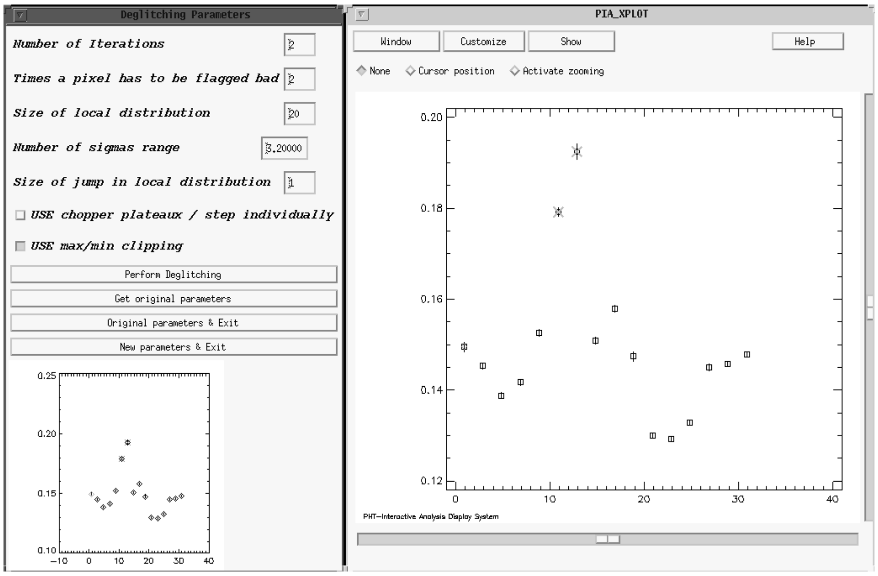

Figure 6. PIA interface for signal deglitching algorithm. Left side: text/plot window for glitch parameter set-up and original distribution. Right side: display of test run (the two highest points and the lowest one have been flagged as residual glitches)

their effects can be very valuable for studies of several topics, *e.g.* the cosmic particle radiation, detector properties with regard to glitches, improvement of shielding against cosmic particle hits for future space missions. The data gathered throughout the ISO mission by the four instruments constitutes an excellent database for such studies.

In order to make statistical studies more comfortable, a set of special routines were written, which enable detailed information about glitch detection to be stored in as many data sets as required. For each detection the following information is kept:

– the universal time, permitting long term studies,
– the satellite revolution number, for relating glitch rates changes eg to solar activity,
– orbital position (distance to the Earth's radiation belts),
– glitch strength,
– mean detector signal.

Additional data can be analysed and easily merged into the existing database. These routines, together with selection and analysis tools, constitute a special package within the PIA environment. The graphical interface is shown in Fig. 7.

In this paper we present some preliminary results. The results have to be taken in so far carefully, since they are very dependent on the success

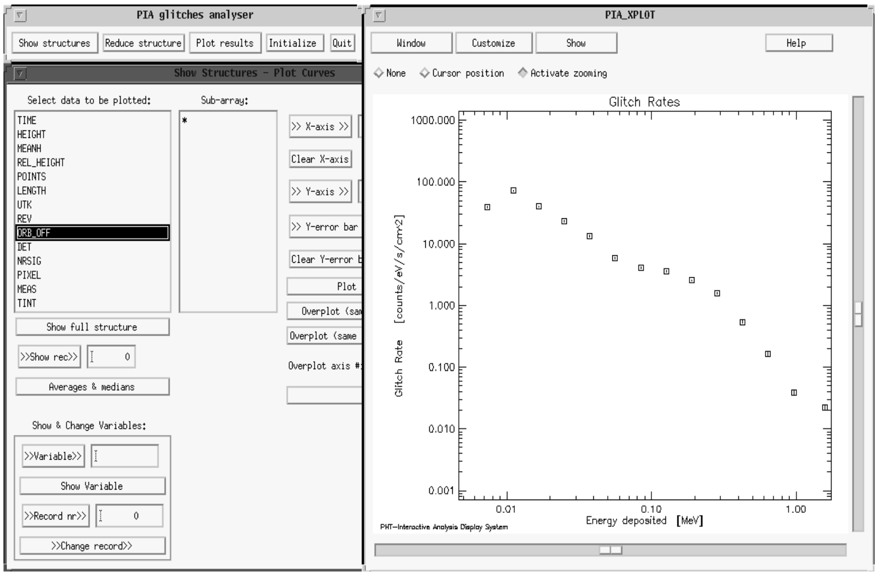

Figure 7. PIA interfaces for accessing glitch detection databases, enabling correlations between the different variables to be plotted, ranges of variables to be selected, etc. The plot shows an energy deposition spectrum of a selected detector in a given orbital position range

to detect low level glitches, which in turn depends on several factors as the criterium (number of sigmas) to identify glitch events or the detector readout noise. We have determined the glitch rate for the different detectors using observations of same type repeated over the full mission (medium flux level and central orbital position) and results are presented in Table 1 per detector volume and per effective area, defined as the sum of the surfaces of all detector pixel faces divided by four. Note the very good agreement among the same type detectors.

Glitches are detected in the ISOPHOT data with a frequency of one event every 5 to 20 s. The frequency depends on the space weather and the orbital position. Another important issue is the energy deposition spectrum, derived from the glitch amplitude (*i.e.* the measured voltage difference). A comparison of the spectra for the ISOPHOT long wavelength detectors C100, C200 and P3 is shown in Fig. 8. The spectral differences between C100/P3 on the one side and C200 on the other side are remarkable. One of the reasons for the shift in the spectrum is the smaller bias applied to C200, which cause a different conversion factor between cosmic particle energy deposition and photocurrent achieved. The larger readout noise level of P3 is reflected in a higher cutoff value for the recognition of glitches.

These are the first examples towards more detailed studies which are

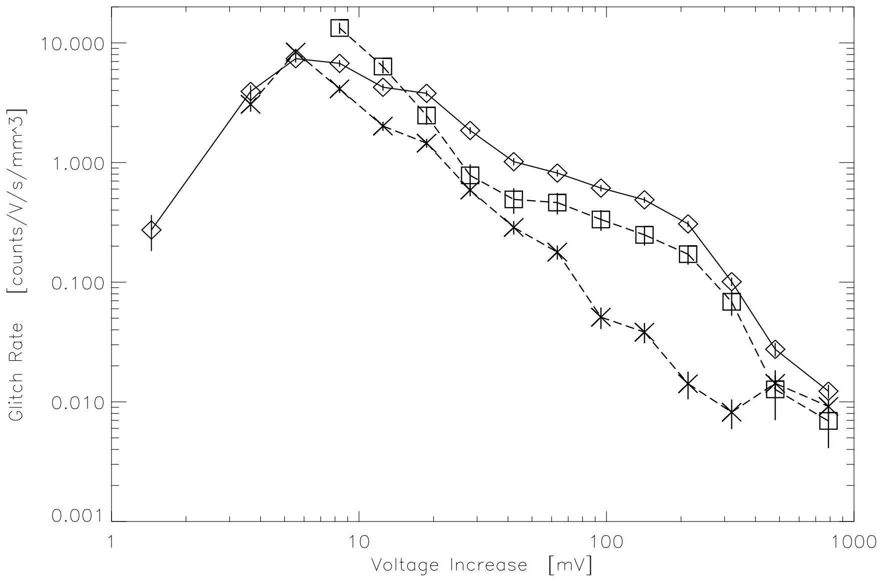

Figure 8. Glitch energy deposition spectra of P3 (squares, dashed line), C100 (diamonds, solid line) and C200 (crosses, dash-pointed line)

TABLE 1. Glitch rates for the different ISOPHOT detectors.

Detector	Material	Volume $[mm^3]$	Glitch Rate $[N/s/mm^3]$	Glitch Rate $[N/s/cm^2]$
P1	(Si:Ga)	$1. \times 1. \times 1.$	0.11 ± 0.01	7.3 ± 0.5
P2	(Si:B)	$1. \times 1. \times 1.$	0.10 ± 0.01	6.9 ± 0.5
P3	(Ge:Ga)	$1. \times 1. \times 1.$	0.18 ± 0.01	12.0 ± 0.8
C100	(Ge:Ga)	$0.7. \times 0.7 \times 1.0$	0.24 ± 0.01	12.7 ± 0.8
C200	stressed (Ge:Ga)	$1. \times 1. \times 1.$	0.09 ± 0.01	6.0 ± 0.4
SS/SL	(Si:Ga)	$0.31 \times 0.37 \times 1.8$	0.24 ± 0.01	7.3 ± 0.5

outside the scope of this paper. Furthermore, these data will serve for numerical modeling of cosmic rays and their interaction with instruments on board satellites (see for instance contributions by Daly and by Nieminen and Sorensen in these proceedings). Data from the C200 detector are being used for detailed studies of cosmic radiation effects (Eckardt 1998) for an optimized design of an instrument on board the satellite FIRST (the next ESA mission in infrared astronomy).

7. Summary

We have described the different deglitching algorithms used by the ISOPHOT Interactive Analysis PIA and have presented various graphical interfaces which enable their use to be optimized. Due to the high data redundancy in the ISOPHOT data, the combination of different algorithms on different levels of data reduction results in a very efficient glitch detection with a gain in signal–to–noise by factors 2–3. The underlying idea is to discard a minimum of data combined with an efficient rejection of glitches, which leads to a substantial increase in the signal–to–noise ratio.

In addition, a PIA based system for detailed analysis of glitch effects on very large statistical samples is presented.

8. Acknowledgments

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