GLITCH EFFECTS IN ISOCAM DETECTORS

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Abstract. One of the main limitations to the sensitivity of observations carried out with the ISOCAM infrared camera comes from the responsivity variations and glitches caused by impacts of charged particles. After more than 28 months of successful operations, the predicted glitch rate has been re-evaluated and compared to in-flight measurements. Glitch properties have been studied in order to improve the removal algorithms, and thus the ultimate sensitivity of ISOCAM. All informations about the glitch phenomenon are very useful in order to prepare next space experiments.

1. Introduction

The ISOCAM infrared camera [1] is one of the four instruments on board of the Infrared Space Observatory (ISO) [2] which was launched successfully on 1995 November 17. Developed by the French Service d'Astrophysique of CEA Saclay, ISOCAM has operated successfully until 1998 April 9, during more than 28 months instead of the required 18 months. The camera was designed to operate in the 2.5-17 μm range with two detectors: (a) a short wave (SW) detector using a InSb substrate and a Charge Injection Device readout method, for 2.5-5 μm wavelengths, and (b) a long wave (LW) detector using a Si:Ga substrate with a Direct Readout Output circuit, for 4-17 μm wavelengths.

A limitation of ISOCAM sensitivity is due to the responsivity variations and glitches caused by impacts of charged particles. There are two separate problems: (a) the response variation after the perigee passage due to the very high radiation dose coming from trapped particles in the van Allen

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belts, and (b) the glitches due to the impact of single particle from galactic cosmic rays all along the good part of the orbit, i.e. outside the van Allen belts. Since the variation of the detector response is already addressed in [3], we propose to review in this paper the glitch effects.

Spatial and temporal properties of glitches are described in Section 2. Glitch rate predictions are given and compared with measurements in Section 3. A review of algorithms used for glitch removal is also given (Section 4). Since the *ISO detector workshop*, a glitch working group (GWG) has been created. The four instruments on board ISO are represented in GWG. Ongoing work relative to GWG/ISOCAM is presented in Section 5.

2. Glitch Properties

A glitch is the result of an energy deposit from a charged particles in ISOCAM detectors. This energy deposit is spatially localized and it takes a limited period of time to the detector to recover for it (see Figure 1). A glitch can thus be detected by using spatial and/or temporal criteria (see Section 4). Spatial and temporal properties of glitches depend of the origin of the incident particle.

A library containing the most common glitches, as well as other interesting glitches for illustration purpose, was built [4]. This library is accessible to the community.

Glitches can be divided into 3 families based on their temporal profile. Temporal families defined for LW detector are given below:

- Type-A, common glitches (see Figure 3)
- Type-B, faders: the pixel value decreases slowly until a stabilized value is reached (see Figure 4)
- Type-C, dippers: the pixel value decreases first below the stabilized value, and then increase slowly until the stabilized value is reached (see Figure 5)

Glitches of SW detector often display a long decay (see Figure 6). The others look like Type-A glitches.

Some other families could be considered taking into account the origin of the glitch impact (proton, electron, heavy ion, ...). Some glitches display some extensions or a curved shape (see Figure 2) depending of the nature and energy of incident particle. Note also that there are probably low level glitches, much more difficult to detect, but nevertheless affecting the detector noise. Just before or after the end of scientific window, glitches induced

by electrons are more numerous and the glitch distribution is slightly different than the standard one (see Figure 7). In the same way, the glitch rate was very high during the solar flare of revolution 722 (see Figure 8 and [5] for more details).

3. Glitch Rate

3.1. PREDICTED GLITCH RATE

The reader is referred to [6] for more details about computations of glitch rate. Main ideas and results about the predicted glitch rate are presented in this section.

Along the orbit, the perturbations came from cosmic rays and trapped particles in the van Allen belts. Their fluxes are defined within a factor of 2, depending on the solar activity. Primary particles passing through the surrounding material also produce about 50% of additional events either by nuclear reactions or δ-ray emissions[1]. Latest predictions can be summarized as following:

- $\boxed{0.36\ \text{sec}^{-1}\ \text{of direct impacts}}$ from cosmological particles
- $\boxed{0.18\ \text{sec}^{-1}\ \text{of secondary particles and}\ \delta\text{-rays}}$ from materials near the detector and activated by cosmological particles (contribution is $\approx$50% of direct impacts)
- Still unknown contribution from activated materials in the body of spacecraft

The previous estimation[1, 7, 8] of direct impacts was a bit less than this one (0.28 sec^{-1} instead of 0.36 sec^{-1}). This is due to a different estimation of the number of trapped particles. In this paper, the number of direct impacts is based on new measurements by the KET[2] on board of the Ulysses spacecraft (Oct-1997 and Feb-1998, when it was close to the ecliptic plane).

In addition to these external particles, the anti-reflection coating of the lens contains Thorium, which generates a flux of low energy particles. This flux depends on the solid angle of the lens viewed from the array, and is maximum for the 12 arcsec/pixel lens:

- 0.35 sec^{-1} of α-particles from the 12 arcsec/pixel lens
- $\boxed{0.16\ \text{sec}^{-1}\ \alpha\text{-particles from the 6 arcsec/pixel lens}}$

[1] δ-rays are electrons emitted along the track of particles with sub-relativistic velocity. δ-ray emission is proportional to Z^2 of the incoming particle.

[2] Kinetic Electron Telescope

- 0.02 sec^{-1} of α-particles from the 3 arcsec/pixel lens
- 0.002 sec^{-1} of α-particles from the 1.5 arcsec/pixel lens

Neither the electro-magnetic showers, nor the secondary particles and δ-ray emissions from the body of spacecraft have been taken into account here. These last contributions are more difficult to derive and requires Monte-Carlo simulations. It is very likely that a few tenths of glitch/sec might be added. Based on the above numbers, the latest estimation of glitch rate is given in Table 1. Since uncertainties about the contributions of secondary particles and δ-rays still remain, these results should be taken only as orders of magnitude, and at least as lower limits.

3.2. COMPARISON WITH IN-FLIGHT MEASUREMENTS

Some key numbers about ISOCAM glitches, as observed in flight, are:

- Average glitch rate = $\boxed{\text{1 glitch/sec}}$
- Average number of hit pixels = $\boxed{\text{8 pixels/glitch}}$

These numbers are mean values and correspond to what should be observed during a standard ISOCAM observation. The glitch occurrence follows Poisson statistics but depends also of the space weather. The glitch rate and/or number of hit pixels are of course orbital position and solar activity dependent (see Figures 7 and 8).

These numbers have been derived from algorithms which are used to remove glitch effect in ISOCAM data (see below Section 4). These algorithms detect a glitch as a different temporal profile or/and spatial pattern than the expected signal (astronomical background + source + dark current + memory effect). This implies that they do not detect glitches separately (2 or more glitches can be considered as a single one, and also several high value pixels can be considered as many different glitches whereas they belong to the same one). Thus, these algorithms can not be used to derive properties of individual glitches, such as the actual duration, number of hit pixels, rising time, and so on. Nevertheless, some effects can compensate each other and the above numbers can be considered as representative.

3.3. SENSITIVITY LOSS

Considering only the number of masked pixels, a rule of thumb is 2% loss for 2.1 sec images, 5% loss for 5.04 sec images, 10% loss for 10.08 sec images. For 20 sec images, it appears that it is very difficult to deglitch data due to the high number of glitches per image. It was advised to ISOCAM observers to avoid using 20 sec integration time. For 0.28 sec images, one

TABLE 1. Predicted glitch rates (unit sec^{-1}). The contribution of secondary particles and δ-rays has been taken equal to 50% of direct contribution. It could be more, up to 60-70%. Furthermore, neither the electro-magnetic showers, nor the secondary particles and δ-ray emissions from the body of spacecraft have been taken into account here (see text).

Contribution	1.5" lens[1]	3" lens	6" lens	12" lens[2]
Only direct impacts	0.36	0.36	0.36	0.36
Secondary particles and δ-rays	0.18	0.18	0.18	0.18
α-particles from Thorium	0.002	0.02	0.16	0.35
TOTAL	**0.54**	**0.56**	**0.70**	**0.89**

[1] Contribution of 1.5 arcsec/pixel is completely negligible ($\approx$ 0.002 sec^{-1}).
[2] 12 arcsec/pixel lens was used for very few observations.

could expect less than 1 glitch per image, but since 4 images are co-added on board before being down-linked, there is around 1 glitch per image, corresponding to a sensitivity loss of 1%.

The actual sensitivity loss is higher than the above values due to glitch tails, gain variation, heavy particles, ... It is very difficult to assess the global sensitivity loss due to glitches, especially if one consider the robustness of algorithms for faint source detection.

4. Glitch Removal Methods

4.1. MANUAL METHOD

Glitch can be recognized by the eye and pixels masked manually. This method is robust but of course very long. It can be used as a second run after an automatic method.

4.2. TEMPORAL CRITERION

Let m and σ be the mean and standard deviation for each pixel value $v(t)$. The temporal criterion is: if $|v(t) - m| > k \times \sigma$ then the pixel is considered as a glitch and is masked. This method is simple but not robust. The mean value is indeed biased due to transient behavior and glitch tail.

4.3. SPATIAL AND TEMPORAL CRITERION

Let $cube(x, y, t)$ be a set of pixelized (x, y) images, recorded at different times t. Let $\Delta cube(x, y, t) = cube(x, y, t) - cube(x, y, t-1)$, $m(t)$ and $\sigma(t)$ be the mean and standard deviation for each frame of $\Delta cube$, $m = median(m(t))$ and $\sigma = median(\sigma(t))$. The spatial and temporal criterion is: if $\Delta cube(x, y, t) > m + k \times \sigma$ then the pixel is considered as a glitch and is masked. This method is relatively efficient for non stabilized data. But it is not efficient neither for long glitches (Type-B or C) nor for successive glitches in a short period of time.

4.4. MULTI-RESOLUTION MEDIAN TRANSFORM

As the glitch structures can have different sizes, we need a multi-resolution tool in order to perform efficient automatic detection. The idea developed here is the following: as we observe the same position in the sky during N exposures, we cannot have any structure in the signal which has a temporal size less than $N \times T_{int}$ ($\mathrm{T_{int}}$ being the exposure time of a single frame). It means that all the significant structures (i.e. not due to the noise) at small temporal scales are due to glitches. The multi-resolution median transform (MMT) consists of a series of smoothings of the input image, with successively broader kernels. Each successive smoothing provides a new resolution scale. The multi-resolution coefficient values constructed from differencing images at successive resolution scales, are not necessarily of zero mean, and so the potential artifact-creation difficulties related to this aspect of wavelet transforms do not arise. See [10] for more details about the MMT, and [11] for a full description of this deglitching method.

The method is robust and works for non-stabilized data. The only real limitation is that we cannot detect glitches which last for a time longer than or equal to $N \times T_{int}$. That means that the more frames we have per camera configuration, the better the deglitching will be. In case of faders and dippers, the stabilization can be very slow, and the deglitching method presented here does not correct for this effect.

Figure 9 shows the results of such a treatment. Figure 9 (top) shows the values of a pixel of the camera as time elapses. The x-axis represents the frame number (time/$\mathrm{T_{int}}$), and the y-axis is the signal (ADU^3/sec). These data were collected during a raster observation during which the satellite pointed the same sky position for about 20 frames, and T_{int} was 2.1 sec. A source is at the limit of detection (frames 130 to 150). All peaks

[3] Analog to Digital Unit

are due to cosmic ray impacts. Note that the intensity of a cosmic ray can range all values between a few ADU to more than one thousand ADU. Figure 9 (middle) shows the same data after the glitch suppression. Figure 9 (bottom) shows both data and deglitched data over-plotted. The noise and the signal are not modified during this operation.

4.5. PATTERN RECOGNITION

In some raster observations, the signal can modelized as a simple sum of few components: background + point sources + glitches. It is the case of main deep surveys carried out with ISOCAM. Then each component can be reconstructed separately from its multi-resolution coefficients, and can be classified following different criteria. This pattern recognition approach[12] allows to eliminates faders and dippers in a automatic and robust way, but can unfortunately not be applied to all types of data.

Figure 10 presents the result (bottom panel) after applying such a treatment to original data (top panel). Figure 11 shows the decomposition of the original signal into its principal components: (a), (b), and (d) are features (short glitch, glitch negative tail, and baseline) which are not very relevant for faint source detection, and (c) and (e) (source and noise) which must be considered. The noise must also be kept because faint sources could be undetectable in a single temporal signal, but detectable after co-addition of the data. The simple sum of the fives components is exactly equal to the original data (see top panel of Figure 10). The calibrated background free data (see bottom panel of Figure 10) are then obtained by addition of (c) and (e).

5. Glitch Working Group

There are two main objectives for the on going work about glitches. First objective is to improve the glitch removal methods. At longer term, second objective is to get as much as possible informations on glitches in order to prepare next space experiments such as FIRST, INTEGRAL, ... This last objective motivated the creation of the GWG which is supposed to centralize all informations about glitches as observed by the four instruments on board of ISO. On the other hand, all studies of glitch phenomenon are likely to improve the knowledge of the cosmic ray environment, trapped electron and proton fluxes, and other space environmental parameters.

Improvement of glitch removal methods should be possible by deriving proper statistics on individual glitches, in order to determine to which family they belong, and then predict their temporal and spatial behavior.

Proton and heavy ions glitches can be easily removed from the observation by a filtering technique. The worst problem is the responsivity variation after the glitch, especially for heavy ions. A model of these effects is under investigation. This seems mandatory for improving removal of Type-B and Type-C glitches. The difficulty comes from the necessity of detecting glitches individually, in order to build these statistics first, then model their temporal behavior, and finally apply it to individually detected glitches. We can reasonably hope that this will be fulfilled at least for strongest glitches (easier to detect), even if the model concerns only a subset of all glitches.

Around 1.5 hour of ISOCAM calibration time has been dedicated to the glitch study (revolution 832, 1998 February 24). The observing configuration was a bit unusual, with an integration time of 1.12 sec, but observations were carried out successfully[4]. This configuration was suited for minimizing the number of glitches per image, in order to derive proper statistics on individual glitches. With 1.12 sec integration time, a bit more than 1 glitch/sec can be found in images. This minimizes the number of glitch overheads. The key numbers given above (1 glitch/sec and 8 pixels/glitch) were easily confirmed. The next step is much more complicated and requires a 3-D analysis for glitch detection and statistics. Glitches are often removed using the multi-resolution method which is based on a temporal criteria only. In spite of being very powerful to remove glitch from ISOCAM data, this method is not good enough to isolate glitches in a 3-D data cube. Thus, proper statistics on individual glitch can not be derived yet, but this should be done in next couple of months. New detection methods, probably very CPU-intensive, remain to be developed.

6. Conclusion

The main ideas about the glitch knowledge right at the end of the ISO mission have been outlined. Most relevant glitch properties have been presented and centralized in a library which is accessible to the community. Glitch rate has been re-evaluated taking into account recent data about cosmic particles. The predicted value is rather close to the measured one. Several removal methods available in CIA[5] have been presented. The ideal removal method still does not exist since detailed glitch properties have to be derived first. These properties are under investigation by the glitch working group.

[4]Special thanks to the CIDT team in Vilspa for accepting such unusual configuration.
[5]CAM Interactive Analysis

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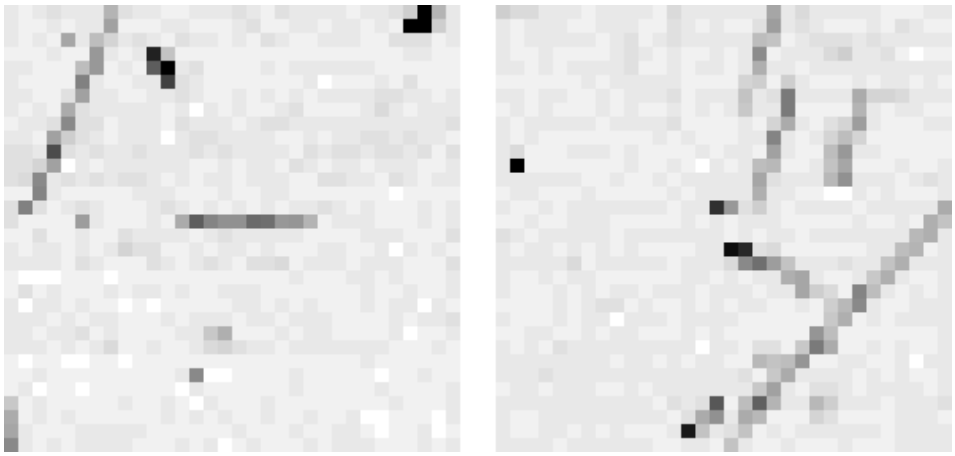

Figure 1. Images of LW detector for 5.04 sec (left panel) and 10.08 sec (right panel) integration time. There are twice more glitches in 10.08 sec images than in 5.04 sec images. More precisely, there is around 1 glitch/sec in LW images and 8 hitted pixel per glitch (see Section 3).

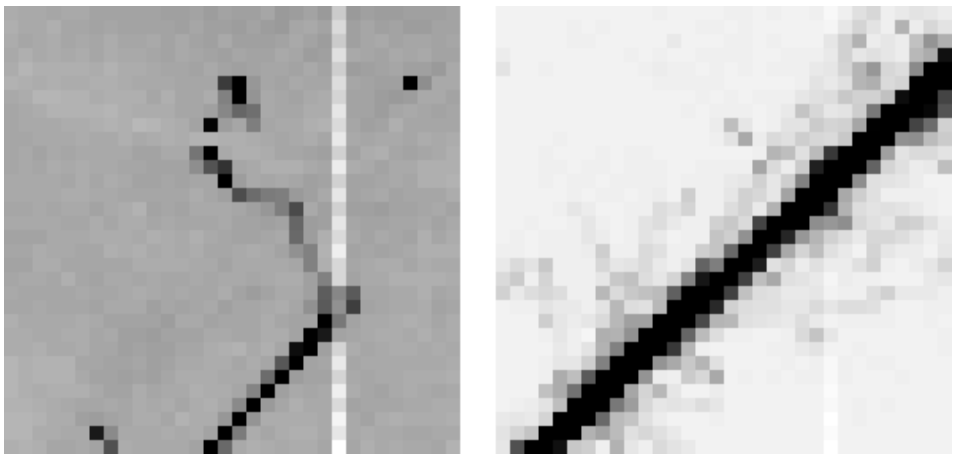

Figure 2. On the left panel, a low energy particle has probably stopped inside the detector. Apparently the incoming particle has collided a nucleus of the detector and the faint track might result of this recoil nucleus. Typical high energy heavy ion passing through the detector is visible on right panel. δ-rays are likely emitted along the track and could be responsible of various pixels hitted along the heavy ion track.

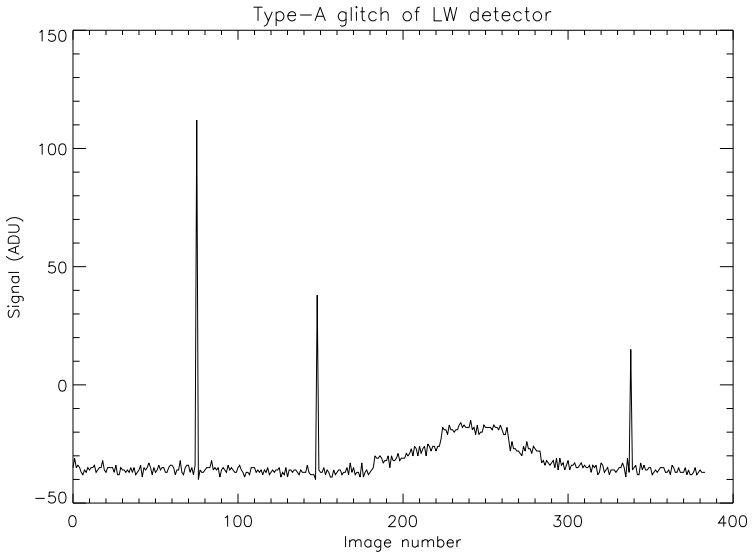

Figure 3. The decay time is roughly as short as the rise time for common glitches (Type-A) of LW detector. The large structure corresponds to a source detection.

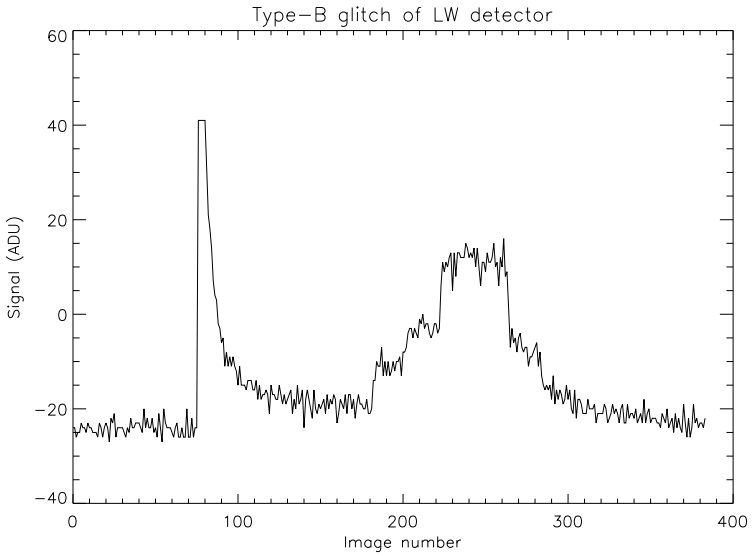

Figure 4. The decay time is much longer than the rise time and has a exponential profile for fader glitches (Type-B) of LW detector. The large structure corresponds to a source detection.

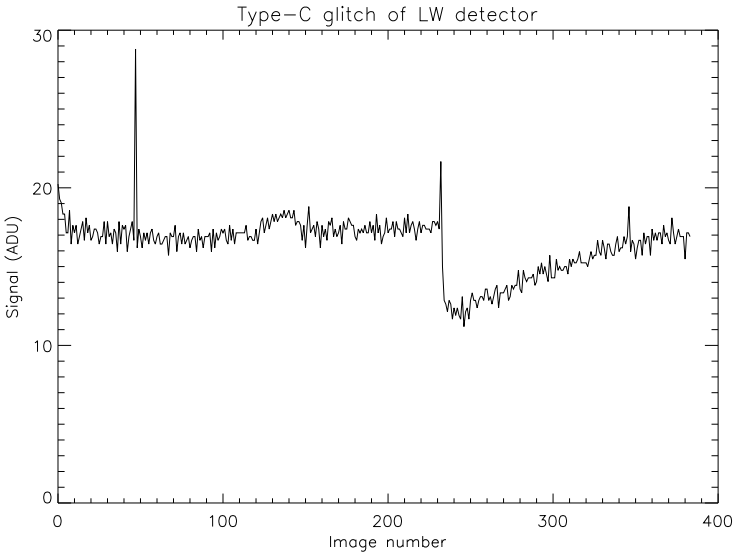

Figure 5. The detector gain is affected and the nominal sensitivity is recovered only after several readouts for dipper glitches (Type-C) of LW detector. This gain variation can be interpreted as a transient behavior by transient correction algorithms and thus lead to false source detection. Note also that Type-C glitches are not necessarily the strongest ones in amplitude.

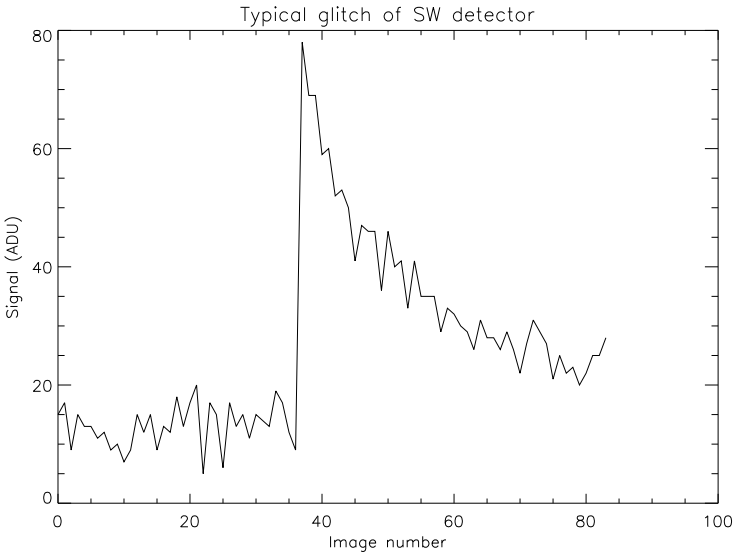

Figure 6. Most glitches of SW detector look like Type-B glitch of LW detector, with a long decay time. This profile corresponds to 20 sec integration time.

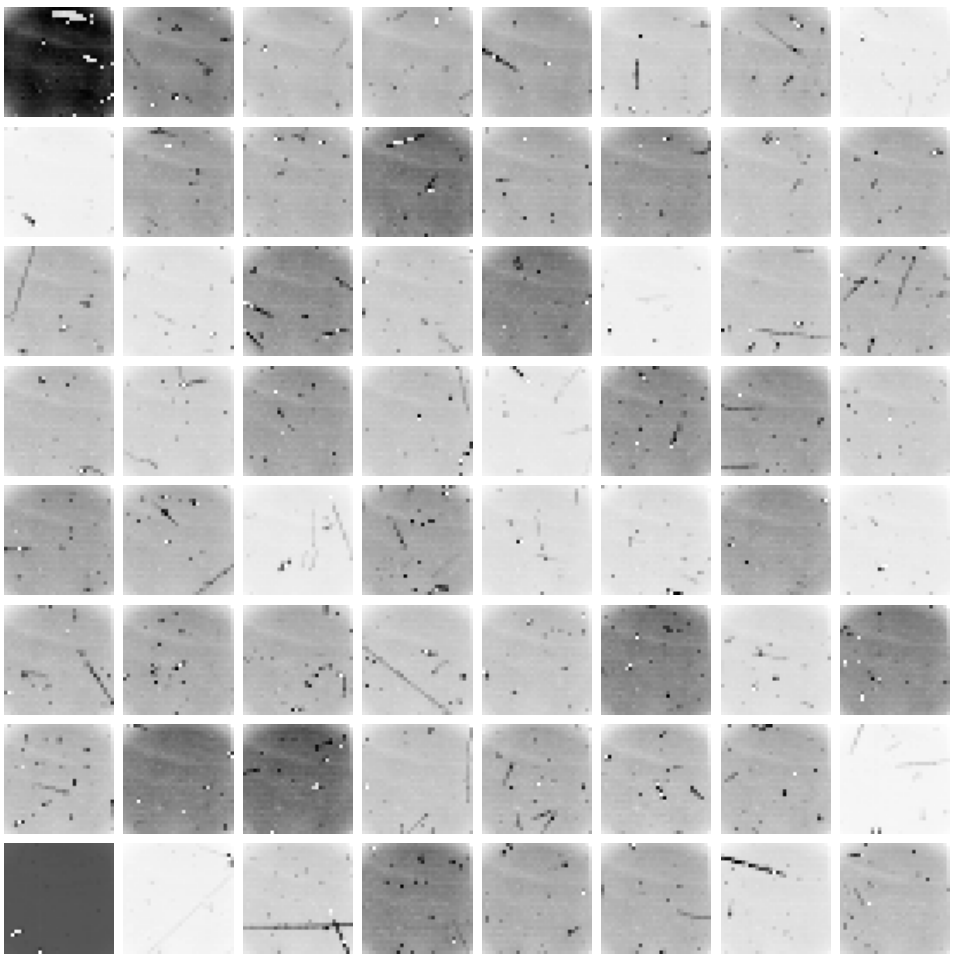

Figure 7. Some glitches just before the end of scientific window: an increase of point-like glitches can be noted. These glitches are likely produced by electrons in the van Allen belts.

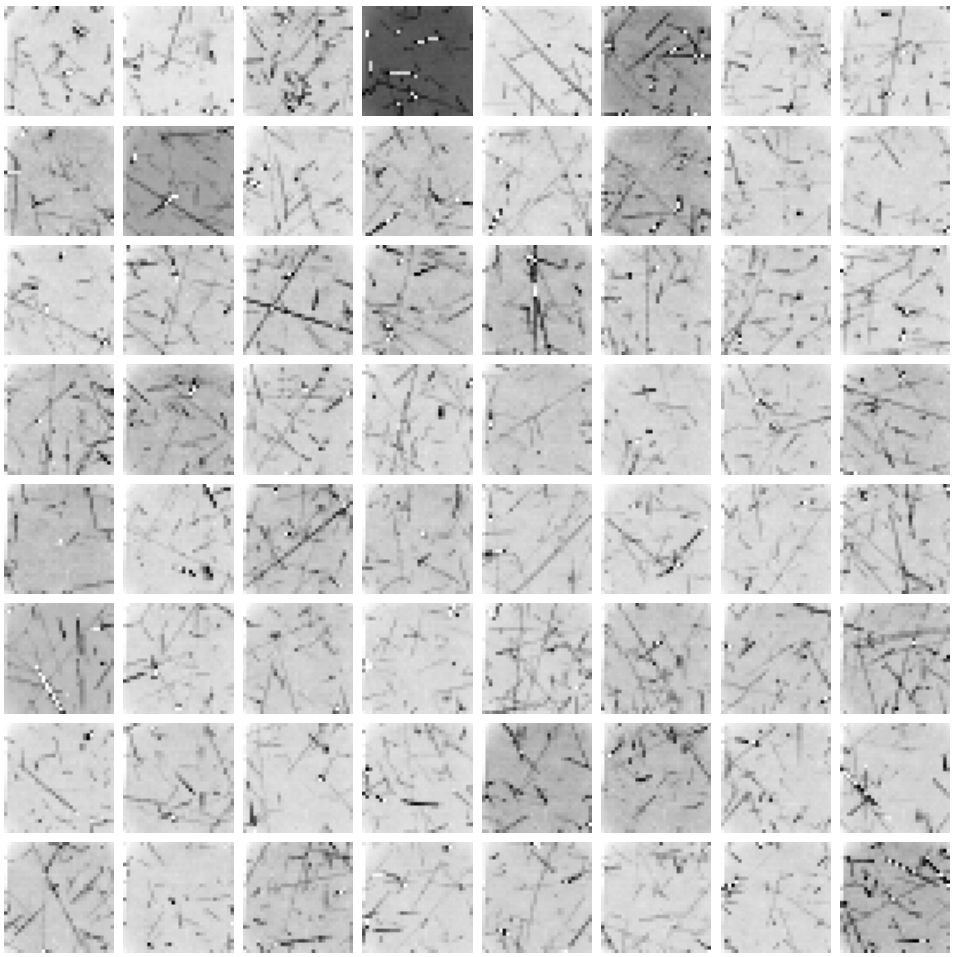

Figure 8. Some glitches during the solar flare of revolution 722. The glitch rate has increased by a factor of at least 7, and probably around 10.

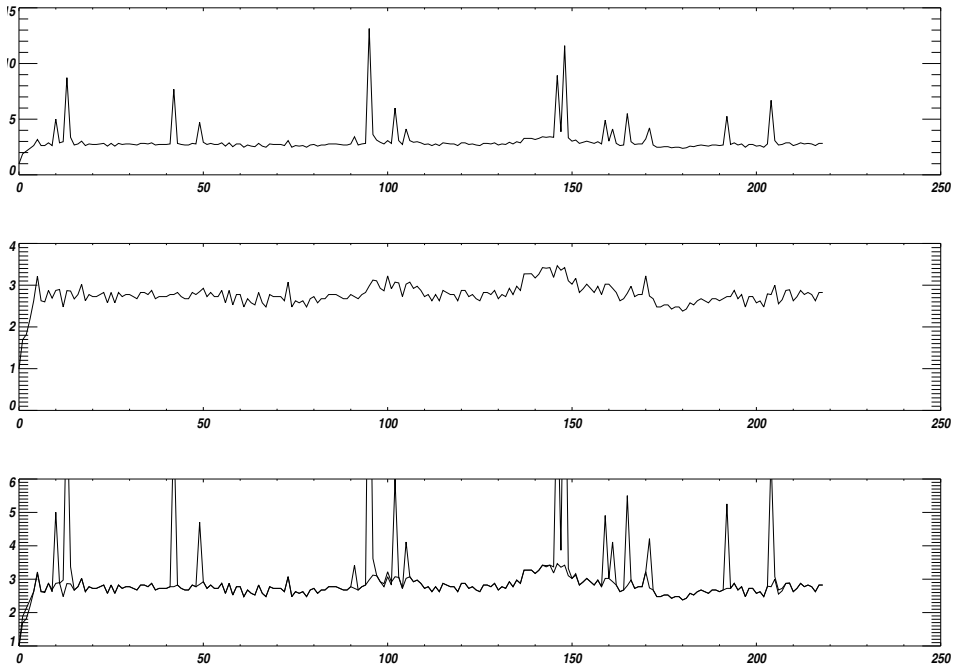

Figure 9. Original data (top), deglitched data (middle), and both over-plotted (bottom).

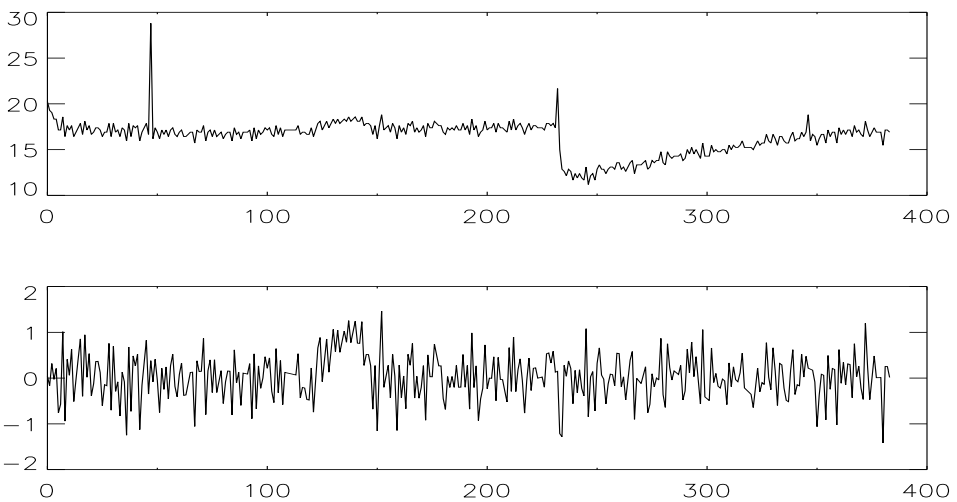

Figure 10. Original data (top panel) and calibrated (i.e. background free) data (bottom panel). Note the gain variation of about 5 ADU which appears after the second glitch.

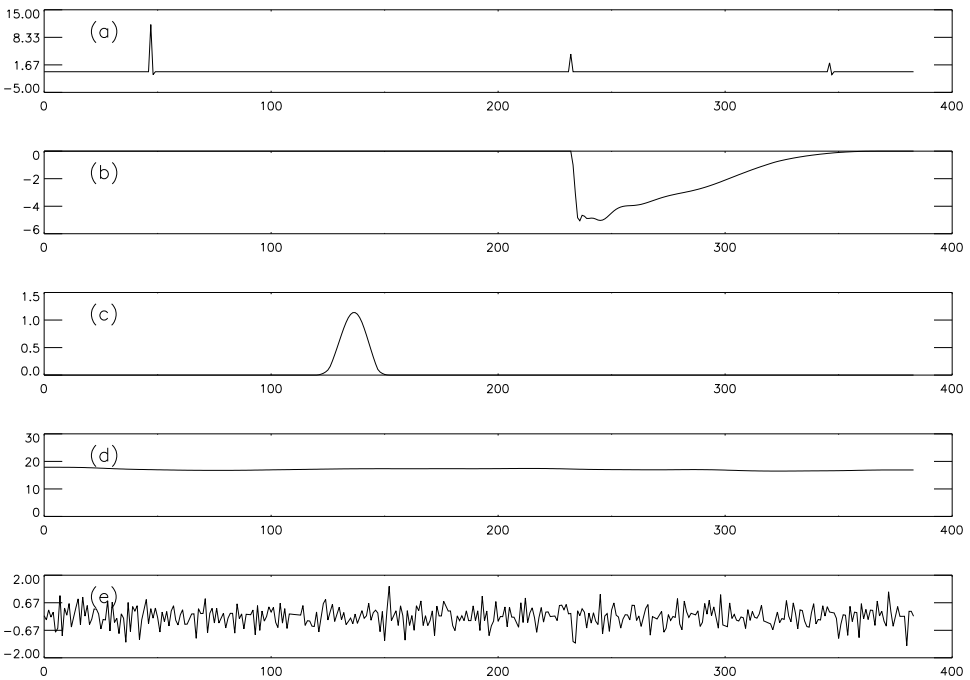

Figure 11. Decomposition of the signal into its principal components: (a) short glitch, (b) glitch negative tail, (c) source, (d) baseline, (e) noise. The simple sum of the fives components is exactly equal to the original data. The calibrated (i.e. background free) data are obtained by addition of signals (c) and (e).