A short assessment of the impact of Rev. 722 Solar Flare on ISOCAM

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1 Conclusions

However odd it may seem to start with conclusions, let me do it anyway since (1) that is where most of the interesting information resides and (2) that is what most people will actually read.

I have carefully monitored, and sometimes (see later) analysed in details, ISOCAM data taken on revolutions affected by the solar flare (revolutions 720 to 724). Based on this analysis I can draw the following conclusions:

- Only Revolution 722 is seriously affected by the flare. Revolution 721 is normal from all points of view (glitch rate, glitch type, dark current and sensitivity) as I could see from a detailed analysis of the last CAM observation taken during that orbit (AOMONT.ISOGAL 3P68M7). Revolution 720, during which CAM mostly did 5.04 s darks is also unaffected by the flare. On revolution 723, the glitch activity is gone back to a more normal rate, though it appears that we still see an increase in the number of glitches leaving an imprint on the detector.

- CAM observations on revolution 722 (MROWANRO.ISOHDFS HDF-4 LW3 and HDF-2 LW3) are useless. In fact, during such an event, it is pointless to do CAM observations: only bright sources can be observed, with a very short integration time, but nothing more than detection can be achieved as the gain of any pixel strongly varies on timescales of a few tens of seconds due to the impacts. Considering that, the decision was taken to re-schedule all observations from revolution 722.

- CAM recovers quite nicely from these particle showers: No impact is seen either on the sensitivity or on the dark current after revolution 722. This implies that there is no need to switch it off during such events. Yet, as it is impossible to observe during such showers, if one can predict their occurence with a reasonnable accuracy, one might as well turn off the instrument. Given the doubts we have on the predictibility of the events however, we do not recommend switching off of the instrument.

2 Detailed comparisons

2.1 The Datasets

In a sense we are quite lucky as the observations that were mostly affected by the flare turn out to have almost identical counterparts done in more normal conditions during revolutions 222 and 224. I have thus extracted these data from the archive and used it to assess the quality of CAM data on revolution 722 and 723. Table 1 lists the relevant parameters of the set of observations considered here.

2.2 Raw data

Since CAM is an imager, and since the event we are expecting is a particle shower, the easiest way to get a rapid idea of the event's impact is to look at CAM's images (here corrected for dark with the CALG dark). This is done on figure 1 where I show 64 images of 22202606, i.e. normal 5.04 integrations, and 64 images of 72200108, identical configuration though it is clear that the number of particles has "somewhat" increased. The change in aspect from one image to the other is not due to a rapid background variation but to the fact that the lookup table is adjusted each time to the full intensity of the image, which in turn is totally dominated by the glitches.

The second CAM observation on revolution 722 is identical to the first one, both in setup and in degradation, thus for the rest of this report I will not consider it. The 5.04 s observation that was done on revolution 723 has the same aspect as that of revolution 222, thus to save space I will not display it. Similarly, there are no *visible* differences between the images taken at 10.08 s in revolution 224 and those from 723, apart from the change in background level (a factor of $\sim$4). But there is more here than meets the eye.

2.3 (Not so well) deglitched data

For deglitching, I have only used the multi-resolution median transform algorithm (also called mm or mr1d_deglitch) as it is the best adapted to that sort of data: constant background, isolated point sources, glitches leaving long lasting imprints on the detector. Furthermore as the sources are extremely weak I can relax the constraint on the number of scales inspected for glitches.

For the LW3 observations, with 20 exposures per raster positions, the scale parameter can be raised to 4. As for the sigma parameter, experience shows that at 5.04 s integration time, a value of 6 is a good choice (efficient deglitching and few noise spikes removed). Applying these parameters on revolution 222 indeed gives excellent results. 5% of the array is affected by glitches.

The same parameter set on revolution 723 also produces quite satisfatory results with again about 5% of the detector being masked.

This is no longer the case for revolution 722. This choice of parameters removes part of the glitches, but only to show that more are still remaining on the array. In fact to clean the array to an acceptable (see later in what sense) level I had to perform 2 successive rounds of deglitching up to scale number 4 and down to 3-σ deviations. It is worth mentionning here that such a processing would very likely affect source signals in the field, except maybe the faintest ones, and is therefore not recommended when one has science in mind. At the end of this process, 36% of the array has been rejected due to glitches and inspection of the data shows (see e.g. fig. 2) that glitches still remain on the detector.

Table 1: The data that was used to assess the impact of the Solar flare. Note that on Rev 722 there were only 2 CAM observations right at the start of the revolution, and that on rev 723 the CAM observations used here are the first CAM observations in the revolution and were done $\sim$ 6 hrs after the activation. This is not the case for the "reference" observations which were done around the handover time. Also note that the reference LW2 observation is done with a smaller pixel field of view.

TDT number	ObsId	Obs. Type	Filter	lens	T_{int}	N_{exp}
22202606	MROWANRO	8×8 raster	LW3	6″/pix	5.04	20
72200108	MROWANRO	8×8 raster	LW3	6″/pix	5.04	20
72200204	MROWANRO	8×8 raster	LW3	6″/pix	5.04	20
72300706	MROWANRO	8×8 raster	LW3	6″/pix	5.04	20
22401403	MROWANRO	8×8 raster	LW2	**3″/pix**	10.04	9
72300605	MROWANRO	8×8 raster	LW2	6″/pix	10.04	9

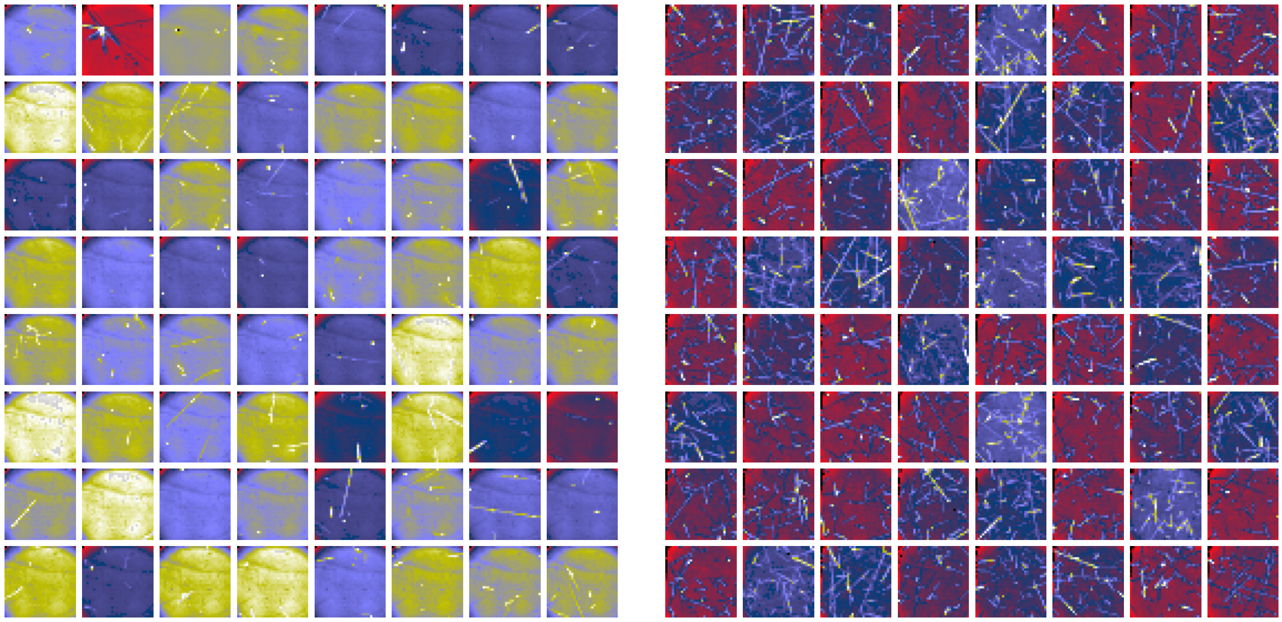

Figure 1: Dark corrected images in LW3, 5.04 s integration, 6″/pix for a “normal” revolution on the left and during revolution 722 on the right. The raw 10.08 s data taken either on revolution 224 or 723 show much less glitches than what can be seen here during revolution 722! The display actually does not do justice to the glitch fireworks of revolution 722...

Therefore we can conclude from these numbers that we have seen during revolution 722 an increase in the rate of glitches by a factor of at least 7, and probably around 10. We were back to a normal rate of glitch impact at the start of revolution 723.

For the LW2 data, taken at 10.08 s, the small number of exposures taken would restrict the number of scales to be used for deglitching to 3. With such a small number, it is impossible to properly deglitch either the revolution 224 or 723 data with the multi-resolution method. Thus I have assumed that the sources are faint enough so that they do not show on individual frames and thus I can increase the number of scales up to 4. I also have had to decrease the sigma parameter to 3 to produce efficient deglitching for both revolutions. Thus the final setup was *Nscale=4* and *Nsigma=3* for both revolutions.

It produces very similar results on both revolutions, i.e. most of the glitches are gone, though long-lasting ones are obviously still there, and approximately 10% of the array is flagged as glitched, indicating once again a normal behavior in terms of glitch rate for revolution 723.

2.4 Data quality

Assuming one can deglitch the data obtained during such a storm, one may wish to know whether the resulting data can be used scientifically, i.e. is CAM in a state where the calibration measurements apply? The answer here is quite certainly no. The global increase in the number of glitches imply a similar increase in the number of glitches affecting the gain of the detector. As a result the latter varies quite significantly and stochastically during the observations, on scales as small as 1 minute. Therefore the data will be quite difficult, if not impossible, to calibrate.

This rapid variation is illustrated in figure 2 for the 5.04 s integrations, and figure 3 for the 10.08 s integrations. On these figures I have plotted the dark-corrected, deglitched as indicated above, signal from a representative pixel near the center of the array. For the 5.04 s integrations the solid line is for revolution 722, the dash-dotted one for revolution 723 and the dotted one for revolution 222. For the 10.08 s integrations, we have no data on revolution 722, so the solid line is for revolution 723 and the dotted one for revolution 224. Offsets have been used to put all these signals on the same plots.

On figure 2, where I remind that no multiplicative scaling has been applied, the degradation

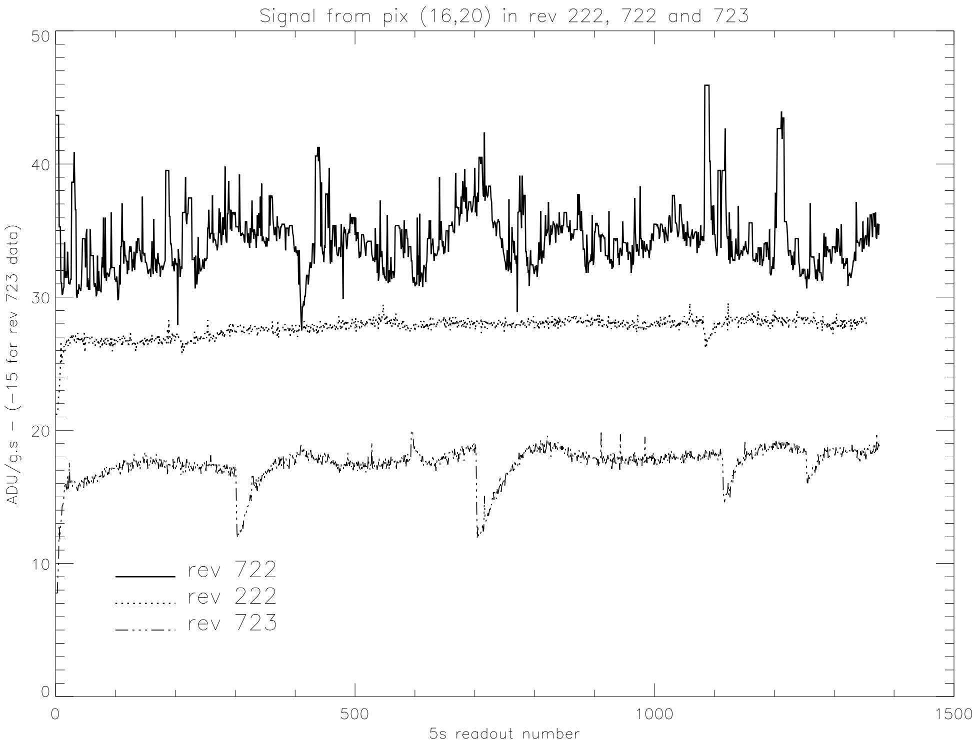

Figure 2: For the 5.04 s readouts, signal from a representative pixel (16,20) in the three revolutions used here: 722, solid line, 723 dot-dashed line and 222, dotted line. 15 ADU/g.s have been subtracted from rev 723's output to place it on the same graph. Variation of the mean flux level between revolutions is due to the fact that the zodiacal light contribution depends on the date of the observation and pointing direction.

of data quality is obvious. More precisely, signal from revolution 722 is highly unstable, probably because glitches with positive tails (e.g. the pseudo-sources near readout number 1100 and 1200) pile up in time with glitches with negative tails (e.g. at readout number 400). It is doubtful that any photometry can be done with such an unstable array. The contrast is stricking with signal from revolution 222 or even with that of revolution 723.

It is also apparent on this graph, that, though the improvement is dramatic from revolution 722 to 723, we still are not in ideal conditions: there is a larger number of glitches with negative tails. In principle, faint source analysis is able to deal with these glitches.

A more quantitative assessment of the data quality can be made by comparing the ratio of mean intensity in the cube over rms in the data cube, a sort of Signal to Noise (S/N) ratio, for these three observations. To do that, I have flat-fielded the data with the CALG flat-field, and, since it is not very adequate on the edges of the detector, I have used only the area (10:21,10:21). Table 2 summarizes the results obtained this way.

For the 5.04 s observations, the setup is strictly identical in the three observations, and the background only changes by $\sim$10%, which should have a minimal impact on the resulting S/N. Yet one can clearly see that this ratio has decreased by a factor of 3 from revolution 222 to revolution 722. This reinforces the previous statement that is quite useless to try and do science under such conditions. As was also hinted at before, we can see that revolution 723 represents a noticeable step toward full recovery but we are not quite there yet: the S/N is still significantly lower, reflecting the higher number of glitches with negative tails.

For the 10.08 s integration time, we have no data taken on revolution 722. However, comparison of 10.08 s data from revolution 224 and 723 with their corresponding 5.04 s data (i.e revolution 222 and 723) shows that the trends should be quite similar. As can be seen on figure 3, data from revolution 723 are still quite noisy, indicating that the array still sees a higher number of glitches with tails compared to normal operating conditions. This is confirmed by the comparison of S/N in

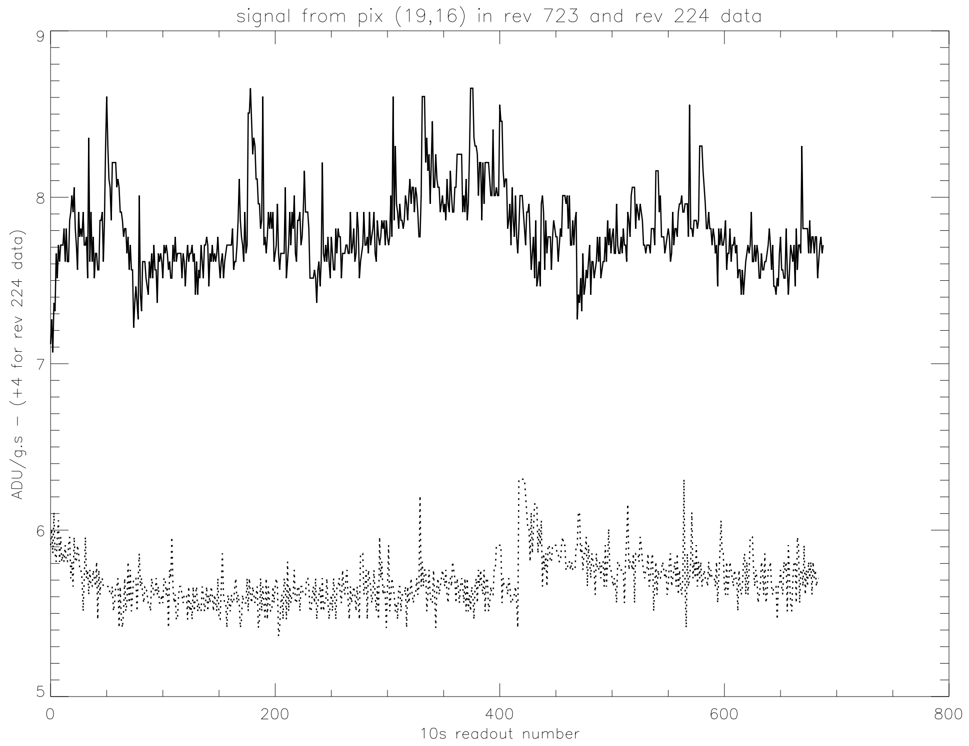

Figure 3: For the 10.08 s readouts, signal from a representative pixel (19,16) in the two revolutions used here: 723, solid line, and 224, dotted line. 4 ADU/g.s have been added to rev 224's output to place it on the same graph. Variation of the mean flux level between revolutions is mostly due here to the two different pixel field-of-views used.

table 2: as the flux increases by a factor of 4 due to the use of the $6''$/pix lens, we expect and increase of the S/N by a factor of 2[1]. Such is not the case, the increase is only a factor 1.22. The data from revolution 723 appears significantly more chaotic in figure 3 than in figure 2. That is probably due to two facts: (1) the 10.08 s observation is done before the 5.04 s one (both last approximately 2 hrs) and (2) the x axis is not equivalent on both graphs, that of figure 3 should be multiplied by 2 to be brought on the same scale as that of figure 2.

[1]Assuming photon noise dominates in both cases.

Table 2: Mean intensity, and "S/N on the background", for the observations studied here. Note that the two 10.08 s observations were not done with the same lens, $3''$/pix for the 224 observation and $6''$/pix for the 723 one. As a result the mean flux is almost exactly a factor a 4 higher but the S/N clearly does not follow that trend: we expect a factor of 2, while we only find a factor of 1.22. Also note the dramatically low S/N value for rev 722 compared to both revolutions 222 and 723.

TDT	$I_{\rm mean}$	$I_{\rm mean}/\sigma$
22202606	27.8	36.1
72200106	35.5	11.5
72300706	33.9	30.3
22401403	1.60	11.8
72300605	6.90	14.4

3 Impact on the daily calibrations

It is part of the regular ISO orbit to perform CAM calibrations. These are mainly used to monitor the trends in the detectors status. At the activation of the detectors, i.e. switch-on, we perform dark measurements (as well as a curing which I will not use here as it is close to saturation anyway). At the deactivation, i.e. switch-off, we perform dark as well as flat-field measurements.

Both the activation and deactivation are done in a part of the orbit which is close to the Earth's radiation belt and where we know that the glitch rate is higher than along the rest of the orbit, even under normal conditions. We also know already that dark currents at deactivation are correlated with the electron fluence as monitored by GOES. This will have some importance later on.

We also make LW dark measurements at the change of ground station, in the middle of the orbit. This is called the Handover. These handover darks have been shown to be more representative of the "real" dark than the activation or deactivation darks. They are actually used for scientific calibration purposes.

In the following, I have extracted from our archive the daily calibrations obtained for revolution 700 to 729. In all the plots that I will show, I have used some sort of normalization in order to amplify the changes from one revolution to the other.

- **Darks:** For each calibration sequence I construct a reference dark as the mean of the darks taken from revolution 700 to 709. The reference dark is then *subtracted* to all the dark images. The median and rms plotted in the figures 4 to 6 are computed on the *whole image*.
- **Flat-Fields:** Here again I construct a reference flat-field for each calibration as the mean of the flat-fields taken from revolution 700 to 709. Then all the flat-field images are *divided* by this reference flat-field. The median and rms plotted in figures 7 and 8 are computed on the *central part of the image*, i.e. pixel area (10:21,10:21).

For various reasons, not all the daily calibrations are performed. Therefore in the figures I have used symbols to mark the location of the revolutions on which we do have data.

Let us now examine these calibrations in detail, starting with the dark as they are the most straight-forward data (flat-fields contain a further processing step, they have been dark-subtracted, and this will have its importance).

3.1 Dark current measurements

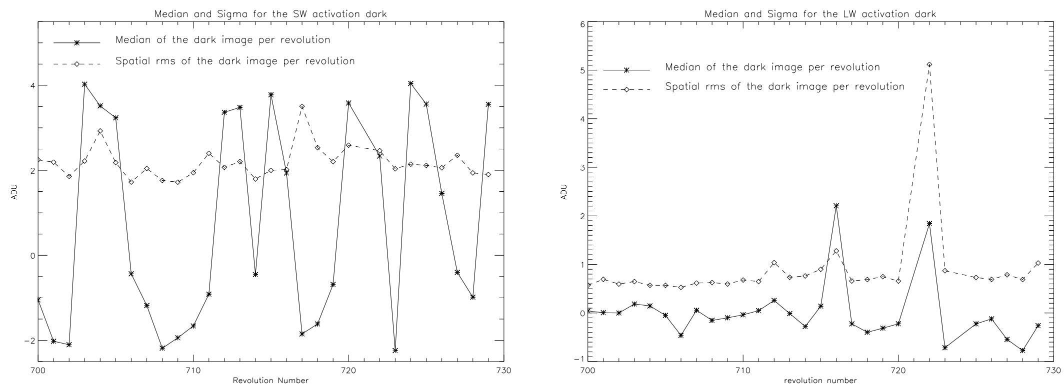

Figure 4: The activation dark measurements on the SW detector, left, and the LW detector, right. The full line shows the evolution of the median in the image (asterisks mark the revolution where we have data) while the dashed line shows the evolution of the spatial rms in the image (diamonds mark the revolutions where we have data). The bimodal character of the median in SW is due to the automatic data processing. The integration time for these sequences is 2.1 s.

Figure 4 shows the activation dark for the SW and LW detectors. In SW, the solar flare produced no effects. This is most likely because the SW detector is much thinner than the LW one, and is thus less sensitive to glitches. The spike in the rms at revolution 717 is due to a glitch remaining on the reduced data. In LW revolution 722 is clearly detected, especially in the rms. This is due to an increase in the number of glitches remaining on the data after the reduction processes have been applied. That glitches can remain after the treatment even under normal conditions is exemplified by revolution 716 where here also the spike is due to a glitch that affected a large nunber of pixels.

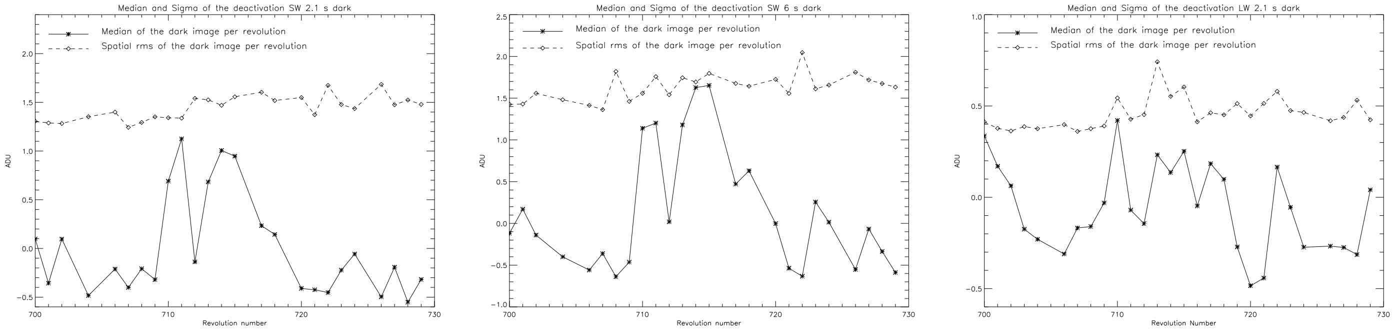

Figure 5: The deactivation dark measurements on the SW detector at integration times of 2.1 s, left, and 6.02 s, middle, and on the LW detector at an integration time of 2.1 s, right. The full line shows the evolution of the median in the image (asterisks mark the revolution where we have data) while the dashed line shows the evolution of the spatial rms in the image (diamonds mark the revolutions where we have data).

At deactivation, figure 5 paints a slightly different picture of the solar flare event: The SW data still show no specific change of the median value at revolution 722 though there is a peak in the spatial rms, probably indicating either that low-level glitches resisted the reduction processes or that the detector has suffered a bit from a revolution spent receiving particles. It is clear however from the data on following revolutions that the detector and associated electronics have recovered. One should also note that revolution 722 is rather negligible compared to the bump that appears betwen revolution 710 and 718 (which by the way can also be seen on the LW detector). This is what was mentioned earlier: the sensitivity of the deactivation dark measurements to the local space weather. Such events, most of them stronger, have already been recorded in the past and leave no trace on the detector.

The LW data (right panel of figure 5) show a clear increase in the mean for revolution 722 (the fact that revolution 723 seems to be part of the peak cannot be considered significant, given the large variation of the dark current recorded on LW). Here again inspection of the image shows that this increase is related to glitches on the array, rather than to a global effect on the electronics. All other peaks in the rms lines are related to individual glitches that can be seen directly in the dark images.

Finally figure 6 shows the trend observed during the handover. Here revolution 722 can be quite clearly seen, mostly because handover measurements are free from all other perturbing sources that affect activation and deactivation (nearby radiation belts, electrical effects related to the switch on and flooding of the detector. . .). Inspection of the individual images reveals once again that the increase in dark level and/or rms is due to individual glitches on the array. It is much stronger in the 5.04 s data because these are almost impossible to deglitch correcly, whereas at two seconds the higher sampling rate helps.

These figures also show that the dark level was significantly lower than “normal” on revolution 706, 713, 720[2], 726, and 728. Inspection of the frames do not reveal any suspicious impact that could explain these low values. The effect appears to be global, i.e. affecting the whole array, as confirmed by the fact that the rms has not significantly changed for these revolutions. Such drops were already seen in previous revolutions, but their origin is not known.

[2] On revolution 720 there are also glitches remaining, hence the higher rms.

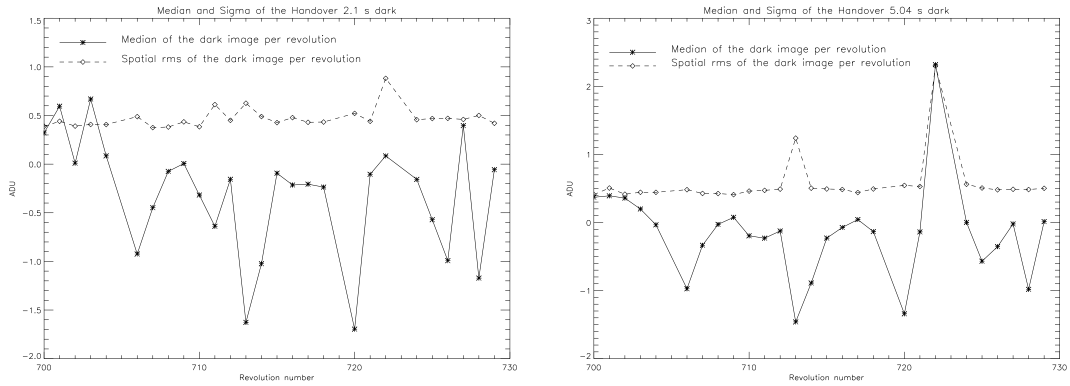

Figure 6: The handover measurements on the LW detector at integration times of 2.1 s, left, and 5.04, right. The full line shows the evolution of the median in the image (asterisks mark the revolution where we have data) while the dashed line shows the evolution of the spatial rms in the image (diamonds mark the revolutions where we have data).

Coming back to revolution 722, we can conclude that, from activation, deactivation or handover data, the electronic systems have not been affected by the array in another way than a simple, though large, increase in the number of particle impacts. Data taken in the following revolutions show that their properties have remained unchanged.

3.2 Responsivity measurements

What can be feared is that such a particle bombing leads to a permanent decrease in ISOCAM's responsivity, as some glitches have the ability to affect CAM's pixels gain (though for a limited amount of time). We can search for this effect using the flat-field measurements that are done during the deactivation sequence at the end of the revolution.

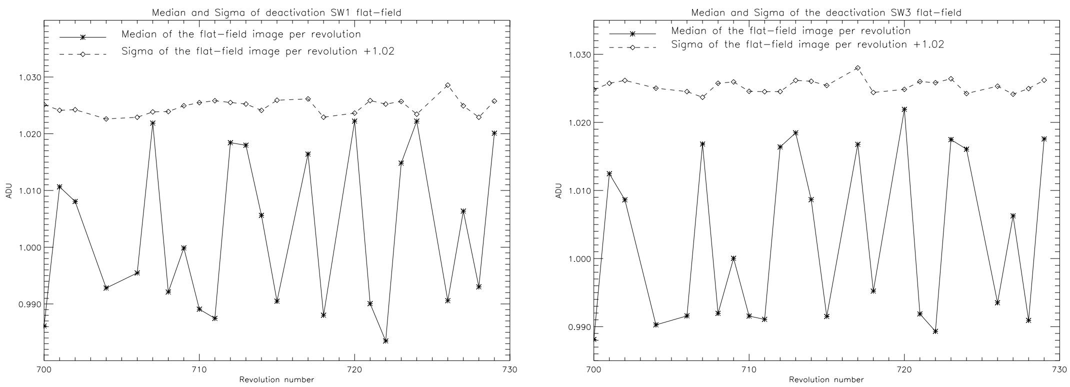

Figure 7: The deactivation flat-field of the SW detector, obtained at 2.1 s through the SW1, left, and SW3, right, filters. The full line shows the evolution of the median in the image (asterisks mark the revolution where we have data) while the dashed line shows the evolution of the spatial rms in the image (diamonds mark the revolutions where we have data). Note that we have added 1.02 ADU to the rms to plot it on the same graph.

Figure 7 shows the trend of the SW detector flat-fields. Nothing special can be seen apart from the apparent bimodality of the level, which again is related to the treatments of the data: The signal after the event shows the same properties as before the event, i.e. the SW array responsivity has not been affected by the solar flare.

Figure 8 shows the same trends for the LW detector. The most obvious feature is that the responsivity appears to drop on revolutions 707, 714, 719, 720, and 728 for the LW2 flat-field (left

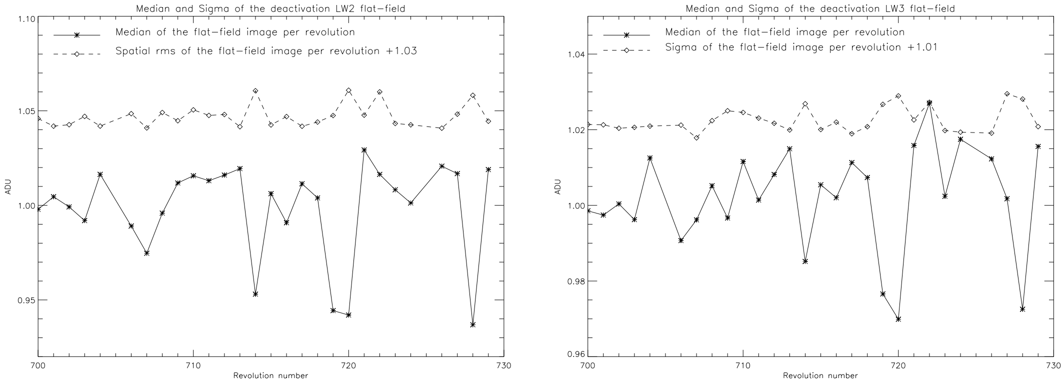

Figure 8: The deactivation flat-field of the LW detector, obtained at 2.1 s through the LW2, left, and LW3, right, filters. The full line shows the evolution of the median in the image (asterisks mark the revolution where we have data) while the dashed line shows the evolution of the spatial rms in the image (diamonds mark the revolutions where we have data). Note that we have added 1.03, respectively, 1.01, ADU to the rms to plot it on the same graph.

panel of figure 8) and 706, 714, 719, 720 and 728 for the LW3 flat-field. These revolutions are quite close to, or even right on, those where the handover dark showed unexplained low values (see figure 6, left panel). If indeed the dark level is significantly lower around these revolutions than the standard dark which is used to process the flat-fields, then the median of the flat-field image will also be significantly lower than on other revolutions. This is most likely what we see here.

Discarding these revolutions from our inspection of the figures does not make revolution 722 stand out much clearer above the trend. It in only in the LW3 data that we have a hint of an increase. But nothing is seen in the following revolutions that would indicate that the LW array has suffered from the event.

Therefore we can conclude that responsivity either of SW or LW was not significantly by the solar flare. ISOCAM has fully recovered from the event.

3.3 Memory dump

Just for completeness, I mention that the memory dump performed at the end of revolution 722 revealed no errors.