JEM-X Microstrip Detectors

In-flight Evolution. II

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N. Lund, S. Brandt, C.-A. Oxborrow J. Chenevez,
C. Budtz-Jørgensen and I. L. Rasmussen
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1) Summary

One year after launch the JEM-X detectors are working fine, but a number of features have emerged for which adequate explanations are missing.

The anode erosion problem, initially feared to present a serious limitation to the lifetime of the detectors has been practically cured by the reduction of the operating voltage. As a consequence of the concern during the early mission phase about detector lifetime it was decided to operate initially with only one of the two JEM-X units, keeping the other unit in reserve in a dormant state.

However, after a few months of operation it was noticed that the gain of the operating unit was steadily increasing (at constant operating voltage) whereas the dormant unit was apparently more stable. The gain increase might have been caused by a leak in the detector or by a significant loss of quench gas (possibly as a result of cracking), again raising the issue of the lifetime of the microstrip detectors in space. Tests carried out in the laboratory, although confirming the gain increase during irradiation, have, however, demonstrated that the increase is not caused by a change in the quench gas concentration.

Another peculiarity is that the the short term gain excursions, caused by the switch-on of the detector high voltage have changed character. Initially the detectors came on first with a high gain value, and thenshowed a decrease of the gain of 20 to 30% within the first few hours. Today, they turn on with a low gain value increasing by 10 to 15% in the first hour of operation.

A more serious problem for the users of the JEM-X data is that the energy resolution of the operating unit is slowly decreasing. The fact that the degradation of the energy resolution takes place simultaneously with the continuing long term increase of the detector gain argues against gas "poisoning" as the cause of the resolution problem. We believe that at least part of the problem is related to mm-scale local gain variations on the microstrip plate which do not track across the entire active area. If this is confirmed it should be possible to recover some of the loss by regenerating the gain correction map across the detector surface. This is, however, a slow process, because the data must be collected over very many science windows.

We believe that the best course for the near future is to switch from JEM-X2 to JEM-X1 as the active unit. According to the data from the last Crab calibration (where both units were operated in parallel) the JEM-X1 unit has retained its initial energy resolution. Changing from JEM-X2 to JEM-X1 will therefore give the INTEGRAL users better data and allow the instrument team the possibility to monitor the evolution of JEM-X2 in a non-operational state over the next six months.

2) Anode erosion status

The current microstrip anode status is given below (numbers in parentheses are from April 9 2003):

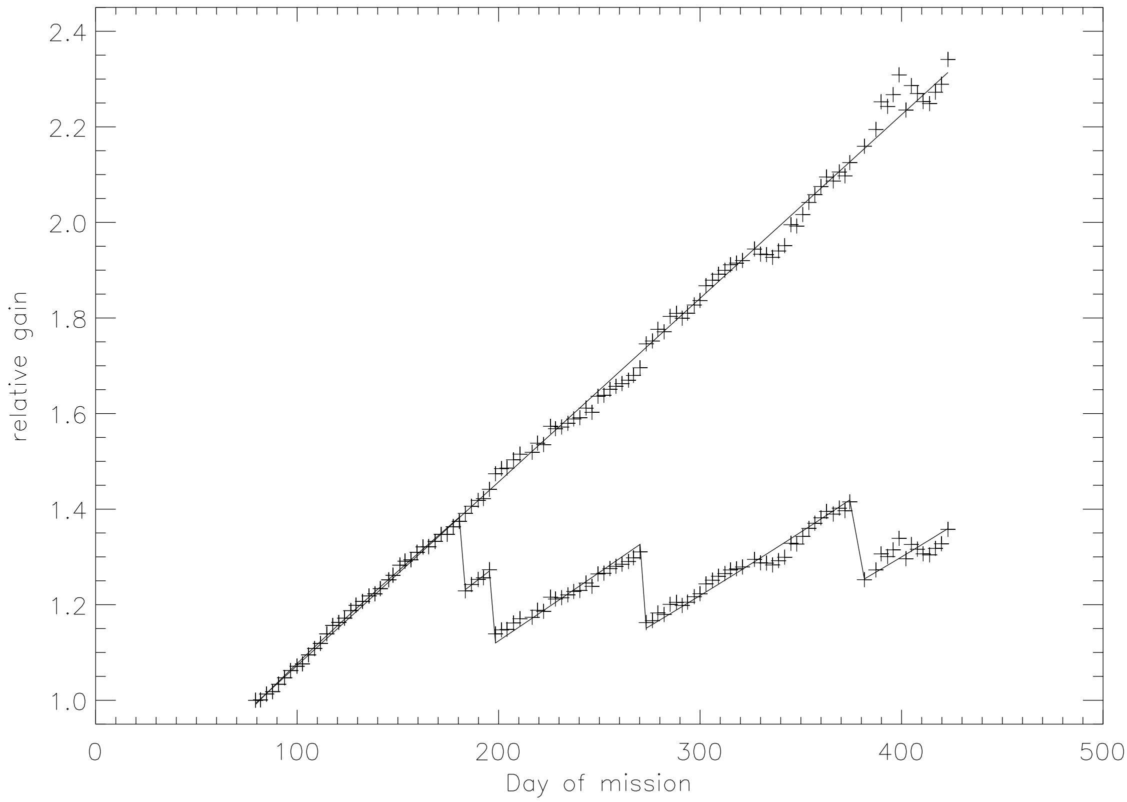
	Anodes eliminated during manufacture	Anodes lost after launch	Unstable anodes	Low efficiency anodes
JEM-X1:	4	12 (12)	6	10 (10)
JEM-X2:	9	18 (16)	3	15 (15)

Since April 2003 only two anodes in JEM-X2 have shown a decrease in counting efficiency. JEM-X1 which has only been working briefly during the Crab calibration periods has not shown any degradation.

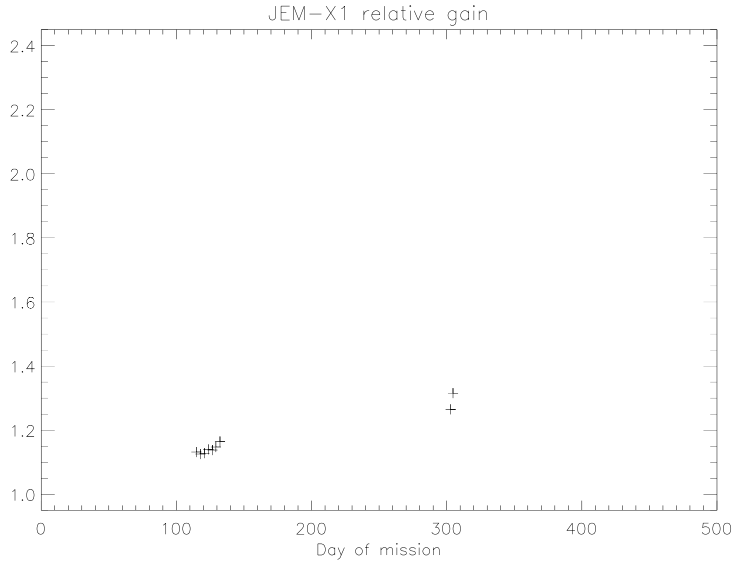
The anode loss problem has therefore practically disappeared.

3) Long term gain increase

The gas gain of the JEM-X2 instrument has been steadily increasing since the beginning of normal operations (upper curve of Figure 1). Due to the risk of anode erosion we do not allow the gain to increase more than about 20 % relative to its value in February 2002 (Crab calibration). We have therefore lowered the voltage four times since February 2002 (lower curve on Figure 1).



Figur 1 JEM-X2 relative gain versus mission day



Figur 2 JEM-X1 relative gain versus mission day

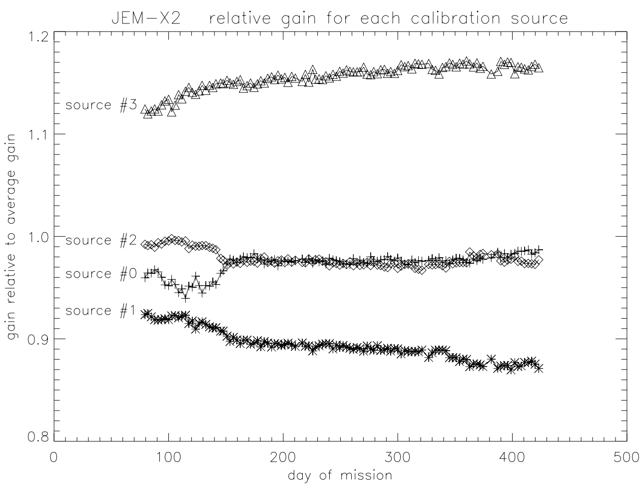
JEM-X1, which has been idle for most of the time, has shown a much smaller gain change effect, see Figure 2. We have not made any voltage adjustments in JEM-X1 since day 54 of the mission (Dec 2002).

We are monitoring the gas pressure in the detectors and in both units the pressure has been stable. (A small leak in JEM-X2 was indicated early on, but according to the latest data the pressure has remained stable to better than 1% since launch).

Another reason for a change in gas gain may be a decrease in the partial pressure of the methane quenching gas. This could possibly result from cracking of the methane. To effect a change of a factor 2.5 in gain we would need to reduce the methane fraction from 10 to approximately 4%. If the cracking products were solid this should result in a 6% pressure drop which is not observed. As described below we have performed a laboratory test which did not show any significant reduction of the methane fraction for a detector even after receiving a severe radiation dose.

We have compared the gain drift for the four calibration sources in JEM-X2. This is illustrated in Figure 3 which shows the gain of each of the four sources relative to the mean gain for the four. Some differences are evident in the time evolution particularly before day 140, but compared to the large overall gain change the four sources track each other reasonably well. The differences are maybe not surprising considering the "local" nature of the microstrip gain discussed in the following section.

For the moment we do not have a good explanation for the gain increase, but at the moment we don't see this effect as a threat to the detector lifetime in view of the elimination of a leak or substantial loss of quench gas as the cause of this feature.



Figur 3 Relative gain drift for the four cal. sources

4) Laboratory tests

In order to study the behaviour of the detectors under long term radiation exposure we set up a laboratory test with the spare JEM-X model. The detector was operated at the nominal high voltage.

The test was initiated on May 21, 2003. By that time the spare unit had not been operated for about 6 months. The behaviour of the detector at the first HV switch-on was unusual since the gain increased by a factor 2.5 over the first 3 hours - the normal behaviour under laboratory conditions is a gain drop of about 25% over the first hour or so. The unusual behaviour was repeated on the following day, and our conclusion was that the comparison of the behaviour of the flight detectors and the laboratory detector must be done with care. We cannot exclude that the laboratory unit behaves in its own way as a result of the partial short circuit of the microstrip plate which was the reason for taking this unit off INTEGRAL in the first place.

We placed a 1 mCurie Sr-90 source 25 cm above the detector such that it illuminated a square, 4 by 4 cm in size. The illuminated region included one of the calibration sources, allowing monitoring of the evolution of the detector gain. The count rate caused by the source was about 16000 counts/s which is 10 times the normal cosmic ray background rate for the flight detectors. The actual radiation period with high voltage on lasted about 70 days - corresponding to about two years of exposure in orbit. The total radiation dose in orbit may be higher since there are additional contributions from the radiation belts and from solar flares, but during these exposures the detectors are off. Thus, if electrochemistry is the key agent for changing the gas composition, then the dominant contribution will come from the cosmic radiation during normal observations, where the high voltage is switched on.

We note that we could not monitor the calibration signals when the radiation from the Sr-90 was present because of the extremely high countrate. Only when the radiation source was blocked off could we check the gas gain. After 70 days the gas gain had increased by about 35%, this rate of change is about twice the rate seen in the flight instruments. We performed an analysis of the gas composition in the detector and found that the partial pressure of methane had changd by less than 5% and that no new gas contaminants could be detected with certainty. A small amount of water was seen, but this could well be consistent the background level in the gas analyzer. In any case, water is certainly not expected to increase the gas gain in an xenon filled detector.

We noted, however, another change in the detector charateristics following the radiation exposure. We made a sequence of measurements with a pencil beam of 22 keV X-rays in order to see if the detector gain change was uniform across the microstrip plate - the Sr-90 illumination was on purpose concentrated on a small area (20 cm^2). The measurements did not detect any significant nonuniformity of the detector gain – illuminated and non-illuminated areas behaved the same. However, a strong dependence of the gain with the local count rate was noted. The gain decayed by factors of two or more in the first 10 minutes after setting up the pencil beam on a particular spot. After the gain had stabilized to its low value, a position shift of the beam by just a few mm allowed the signal to recover to its original amplitude temporarily, but the gain of the new irradiated region then immediately began to decrease. Measurements at the first spot after 10 or 15 minutes demonstrated that the gain had recovered to its "virgin" value.

This illustrates that the gain of the JEM-X microstrips is very "local" and dependent on the radiation history experienced locally. It must, however, also be noted that the average radiation intensities in space are much smaller than the ones we use in the laboratory. But we must expect that with each passage of a heavily ionizing iron nucleus there will be a narrow strip of low gain running across the plate, a strip which will fade over the following minutes. The simplest interpretation of these effects is that surface charges can persist on the plate for minutes, and that the electric field above the plate forces these charges to accumulate in regions where they reduce the electric field in the local gas volume, and hence reduce the gain.

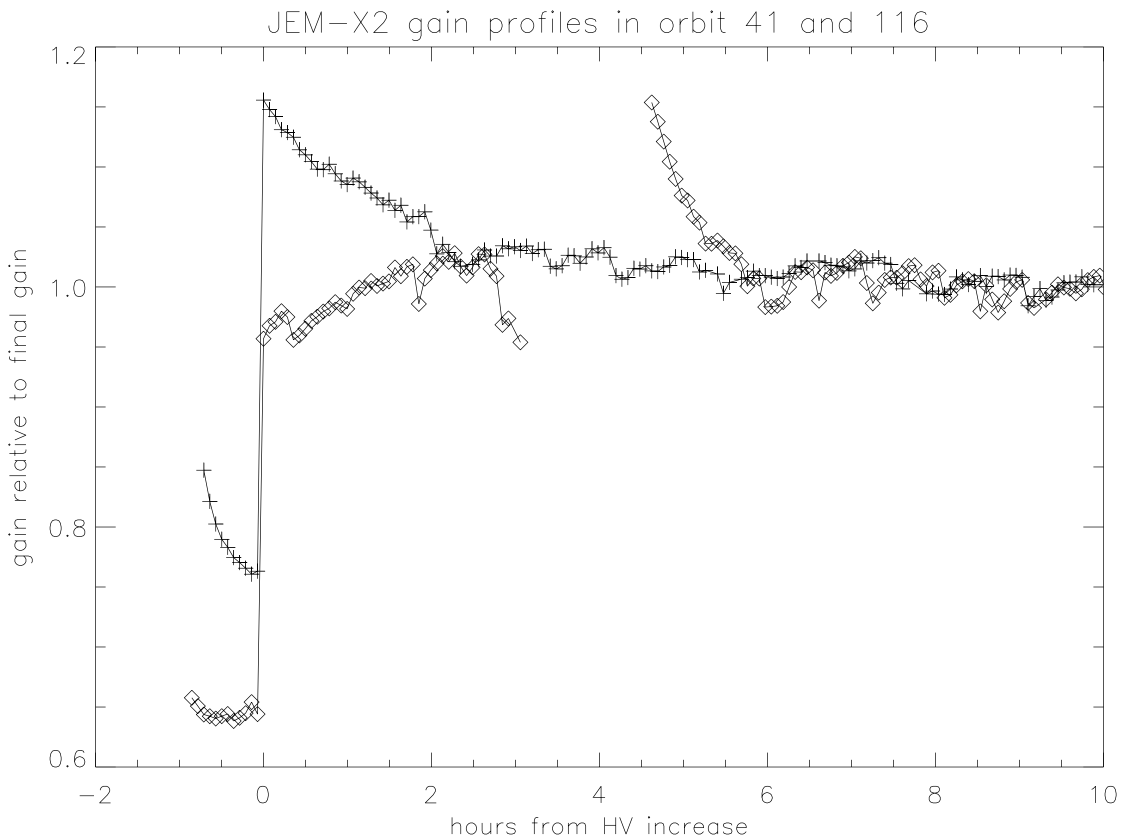
5) Gain evolution after HV switch-on.

Analysis of the behaviour of the active JEM-X2 detector at exit from the radiation belt has demonstrated another unexpected effect: During the ground testing and in the early phases of the mission the normal behaviour was a higher than normal gain immediately after switch-on and a 20 to 25% decrease of the gain during the first couple of hours of operation. This behaviour forced us to introduce the two step switch-on procedure: First we apply nominal voltage minus 30 V for 10 to 30 minutes, then we increase the voltage to its full nominal value.

But during the first year this switch-on behaviour gradually changed. Today, at each radiation belt exit we see first a small gain decrease and then a larger gain increase. This is illustrated in Figure 4.

One surprising effect, also illustrated in Figure 4, is that if the high voltage is interrupted in the middle of an orbit (due to enhanced radiation levels), and then quickly reactivated by MOC, then the "classical" behaviour reappears, with an initial high gain level decaying over a couple of hours to the nominal level. This behaviour, following non-planned switch-off/switch-on is holding us back from proposing the elimination of the (operationally cumbersome) two step switch-on procedure.

At present we are unable to say whether the different behaviours are related to an evolution in the radiation environment since launch or due to internal effects in the detector. Changing the operational unit from JEM-X2 to JEM-X1 may hopefully gives us a clue to the origin of these effects.



Figur 4 Gain changes after HV switch-on. Perigee passage is at about -3 hours

6) Energy resolution problem

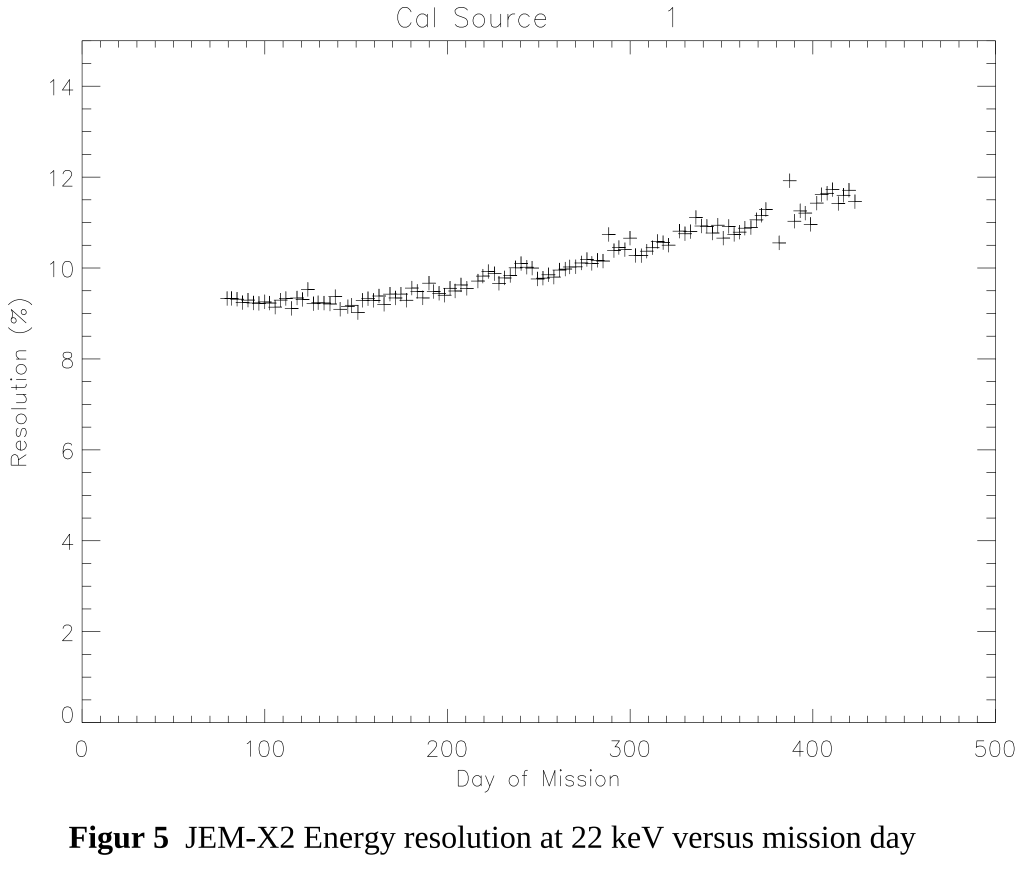
The energy resolution of JEM-X2 appears to be slowly degrading with time. Since the start of the mission the energy resolution of the calibration source spectra has been degrading from a FWHM of 9.5% to 11.5% (at 22 keV). This is illustrated in Figure 5.

Before launch the detector spatial gain variations were mapped in great detail using collimated radioactive sources and beams from X-ray generators. Part of the current degradation may be caused by nonuniform changes in the local gas gain. Considering that the overall detector gain has changed by more than a factor two since launch, such variations do not appear unlikely.

Data obtained during a "calibration source engineering session" in December 2003 confirms that local nonuniformities exist. In principle this type of nonuniformity can be removed in the ground processing of the data, but the necessary calibration data can only be obtained through a massive analysis effort using the 30 keV Xenon fluorescense line as collected through a very large set of observations. We intend to carry out this task, but it will take a couple of month before results can be expected. Because of the necessary long integration times needed to collect this data, transient gain drops ("glitches") caused by heavy cosmic rays cannot be corrected.

At the present time we cannot quantify how much of the resolution loss is caused by gain nonuniformities and how much is due to other effects.

The little data we have from JEM-X1 indicate that this instrument is not as much affected as JEM-X2, and we propose as an immediate corrective measure to switch from JEM-X2 to JEM-X1 as the active instrument in connection with the Crab calibration in February 2004. We believe that this will provide the INTEGRAL users with data of nominal resolution.



Figur 5 JEM-X2 Energy resolution at 22 keV versus mission day

7) Gain "glitches" seen in the calibration source signals

A final effect we want to mention is the short term dips in gas gain observed frequently in the data from the four calibration sources. These "glitches" demonstrate that very localised sharp drops in gain,by up to 30%, are possible. It takes several minutes to an hour for the area affected to recover its previous gain level. Though these glitches can only be observed within the calibration areas of the the detector plates, it is likely that such events occur all over the plate as the result of the bombardment with heavy cosmic ray particles We can only assume that this is due to very localized charge accumulations on the glass plate. These glitches may be part of the explanation for the decreasing energy resolution. There are indications that the glitches are increasing in both size and frequency, maybe as a consequence of permanent changes in the glass plate by the cosmic ray bombardment. Unfortunately, we can neither measaure nor correct for these transient glitches because of their very localised nature in both time and space.

8) Hotspots

Both of the JEM-X detectors have exhibited transient pulsating hotspots which occur after passage through the radiation belts and persist for many hours thereafter. These hotspots produce large quantities of low energy events, localised to small areas along a few adjacent anodes, and seems frequently to recur in the same area on the microstrip plate. These events are easily weeded out of the data since the problems seem to arise always in the same locations and produce spurious events of very low energy that do not resemble the spectrum of astronomical events. One interesting feature of these hotspots is the way in which they pulsate during the science windows in which they are active and also regulary increase and decrease in strength in successive science windows before eventually dying out. It would appear that activation is triggered by some event in the radiation belts.

8) Conclusions

The JEM-X detectors exhibit a number of "interesting" features, most of which appear to be related to the properties of the glass substrate on which the microstrip pattern is deposited.

The long term gain changes brings to mind the "memory"-effect of the classical glass capacitors (Leydner flasks). We may be seeing the combined effects of surface conductivity of the glass, of slow polarization build up in the bulk of the glass, and build up of trapped charges also deep inside the glass under the effects of penetrating radiation. Apparently some of these effects act so as to lower the electric field near the microstrip pattern, and other effects enhance the field. The time scales covers a large range from minutes to months. We hope that the proposed change from JEM-X2 to JEM-X1 as the active unit will allow us to study these competing effects further, and at the same time provide the INTEGRAL users with better quality data.

We feel that our lack of understanding of the observed degradation of the detector energy resolution suggest prudence regarding simultaneous use of the two JEM-X detectors. Until it is more clearly established whether the resolution loss in JEM-X2 is permanent or temporary we recommend to operate with only one JEM-X unit.

The JEM-X detectors are the first application of the microstrip detector technique to X-ray imaging in space. We should not be surprised to meet unexpected features, and we are sure that the experienced gained will ultimately benefit similar missions in the future.