Long term performance of doped Ge:Ga photoconductors in the space environment

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ABSTRACT

The Long Wavelength Spectrometer on board the ESA Infrared Space Observatory employs doped gemanium photoconductors to perform spectroscopy in the 43 to 197 μm waveband. The instrument has been in continuous on orbit operation for over two years - longer than any other experiment in this waveband. Invaluable data have been gathered on the long term performance of a beryllium doped germanium detector and both stressed and unstressed gallium doped germanium detectors in the presence of ionising radiation in the form of cosmic rays and charged particles trapped in the Earth's magnetic fields. In this paper we report on the in-orbit performance of the detectors and in particular on the long term behavior of the dark current and responsivity.

Keywords: Detectors, Instrumentation, Far Infrared, Space Environment

1. INTRODUCTION

ISO has provided a unique opportunity to monitor the performance of far-infrared detectors over a long time period. Previous missions such as the IRTS[1] have provided information of the performance of stressed Ga:Ge detectors over several months and have found good performance with the exception of a higher than expected noise level. The 2.5 year mission of ISO has been the first opportunity for long term assessment of behaviour which will also aid future long term missions such as SIRTF. The ISO satellite was launched in November 1995 and has been in continuous operation up to the present. It has an orbital period of just under 24 hours with an apogee height of 70600 km and a perigee height of 1000 km. The ISO payload consists of four instruments, a photometer, a camera and two spectrometers. As the ISO orbit passes through the Earths radiation belts around perigee, the ISO instruments are switched off for this period and are activated each revolution just after ISO emerges from the radiation belts.

The ISO Long Wavelength Spectrometer[2] operates in the wavelength range 43 to 197 microns and has 10 detectors which overlap in wavelength range and operate simultaneously[3] to cover the entire spectral range. The flux calibration is achieved by individually referencing each detector to a model of Uranus (ref 4). Internal illuminator sources are used to correct for the difference in responsivity between the time of an observation and the time of the reference Uranus observation. The detector response in linear over most of its range and this has allowed for this calibration to be applied without further correction. The exception is for strong sources (greater than 100,000Jy) where a correction factor de-biasing causing non-linear ramps is additionally applied. The LWS detectors are cured twice during each revolution, during activation and during the period of groundstation handover from Vilspa to Goldstone, approximately eight hours after activation. The initial performance was different to expectations from ground tests (see Sect. 2), however optimal pararameters for operation were established in the performance verification phase in the first few months of the ISO mission. Since the start of routine operations in revolution 79 the LWS detectors have remained stable with an accurate and repeatable calibration. The following sections describe the long term behaviour of the dark current and responsivity. There is an outstanding problem in the calibration of transient behaviour and this is briefly described along with the effect of the space weather.

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Table 1. The LWS detectors.

Detector Name	Type	Wavelength Range	Nominal Bias (mV)
SW1	Ge:Be	43-51	700
SW2	Ge:Ga	49-67	247
SW3	Ge:Ga	55-77	197
SW4	Ge:Ga	64-86	197
SW5	Ge:Ga	74-95	197
LW1	Ge:Ga	80-125	197
LW2	Ge:Ga (s)	102-142	40
LW3	Ge:Ga (s)	120-167	60
LW4	Ge:Ga (s)	138-182	60
LW5	Ge:Ga (s)	157-197	40

2. INITIAL PERFORMANCE

The LWS has 10 detectors (see table 1), which use JF4 integrating amplifier readouts. The Ge:Be detector and the Ge:Ga detector are held at 3K on a temperature controlled stage. The stressed Ge:Ga detector is directly connected to the ISO Helium tank and held at 1.8 K. The curing is done by using a high bias voltage to break down the material.

Optimum operating parameters had been determined in ground tests, however when the LWS was first switched on it was established that the apparent glitch rate, the noise and the dark background were higher than expected. In the case of the glitch rate, this was a factor 10 higher than expected. The cause of this was established to be due to spontaneous spiking in the detectors. Fortunately the LWS was designed with an adjustable bias which allowed the bias to be reduced. This improved the performance by removing the spiking behaviour and allowing for a stable baseline. It was also found during the checkout period that reducing the ramp length and having more resets shortened the recovery time from a glitch, however this was done at a cost of noise increase. The average performance in terms of NEP is a factor of 4 worse than ground tests with the worse affected detector LW5. The other stressed detectors are about a factor 2 worse and the non-stressed Ge:Ga and Ge:Be detectors about a factor 4 worse.

3. DARK CURRENTS

3.1. Dark measurements and straylight

The dark position for the LWS is obtained by moving the interchange wheel to an FP position and putting the etalons at maximum offset. This measurement is performed at the start and end of each observation just before the illuminator sequence (see Ref. 3 for details of how observations are performed). As the LWS is pointing at a source, this measurement can be contaminated by straylight. For most detectors the FPS allows less straylight than FPL and the FPS was used until revolution 378 when the LWS wheel started to lose position (see Ref. 5). This problem was determined to be due to loss of traction with a build up of lubricant. The solution of this problem was to operate the wheel stepper motor at a lower frequency (a reduction from 250 to 150 Hz) and to use the FPL position for the dark background determination. Several dedicated measurements have been performed to determine the actual dark current such as by observing a dark sky position. These measurements are reported in Ref. 3. However there may be a contribution from the electronics and an observation at zero bias will be performed in revolution 832 to determine if this is significant.

3.2. Behaviour Within A Revolution

Before launch all ground tests indicated that both dark current and responsivity would gradually increase between sucessive curings. However in flight this has not proved to be the case. Although the responsivity shows a slow

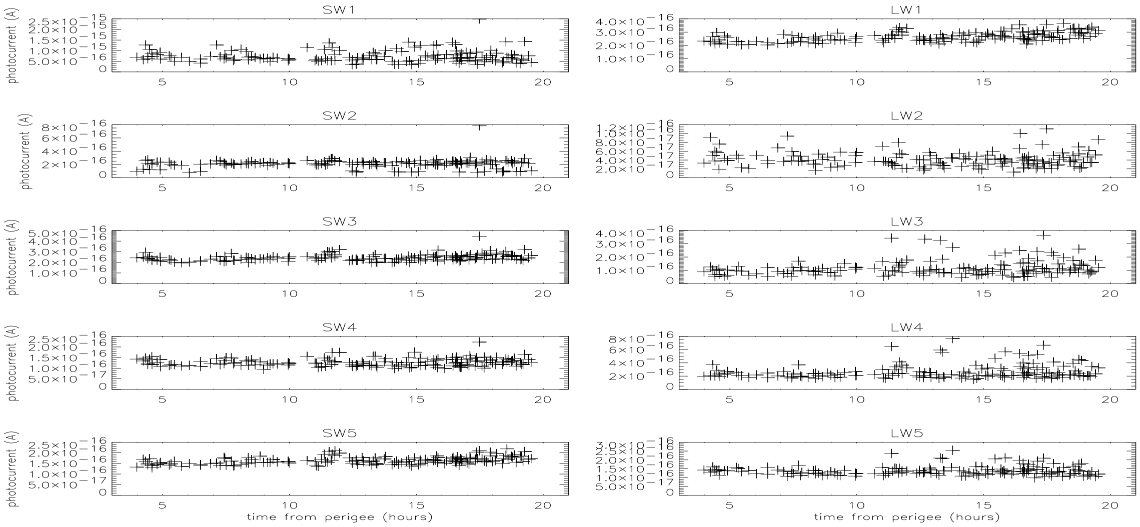

Figure 1. Dark backgrounds taken from calibration observations throughout the mission combined to compare with time in revolution.

orbital drift (see Sect. 4) the dark current for all detectors has remained at a constant value within the measurement accuracy. The dark background can be tracked throughout a revolution in two ways, by use of the parallel mode data and by monitoring the dark positions taken during the illuminator sequences. Figure 1 shows all dark current measurements for all calibration observations, with the majority of calibration measurements taken in the second half of the revolution. The dark background measurements from the parallel mode also indicate a constant dark background during a revolution (see Ref. 3).

3.3. Behaviour Over ISO Mission

The dark background measurements have remained constant over the whole ISO mission, with no noticable degradation in noise performance. The long term behaviour of the dark background is mainly monitored through the background taken just before illuminator flashes immediately before and after the mid revolution curing. Figure 2 shows the dark current measurements taken during the sequence just before mid-revolution curing plotted as a function of revolution number with an offset introduced to allow visibility of the detectors separately. There is a hint from figure 2 that for some detectors such as LW4 the dark background measurements may become more noisy each year i.e. around revolutions 330 and 700 however this is not significant.

4. RESPONSIVITY

The calibration strategy of the LWS does not require the responsivity to be determined directly. Instead all observations are corrected to a standard responsivity which is defined as the responsivity of the detectors at the time when the calibration standard was observed i.e. all observations are referenced directly to an observation of Uranus on revolution 317. In fact optical problems such as fringing have led to an uncertainty in the beam measurement hence the actual responsivity can only be derived for point sources and estimated for extended sources. The current best estimates are given in Ref. 3.

4.1. Response Changes Within a Revolution

The responsivity of LWS detectors is influenced by the hits of ionising radiation and drifts upwards during the eight hours of observations after each curing. The mid-revolution curing procedure works well in returning the responsivity to that at the start of the orbit. As this drift was known before launch, a sequence of flashes from internal illuminator sources was planned before and after each LWS observation to monitor and calibrate for, the drift.[3] Figure 3 shows the output photocurrent of both an unstressed (SW4) and a stressed (LW5) Ge:Ga detector from flashes of the

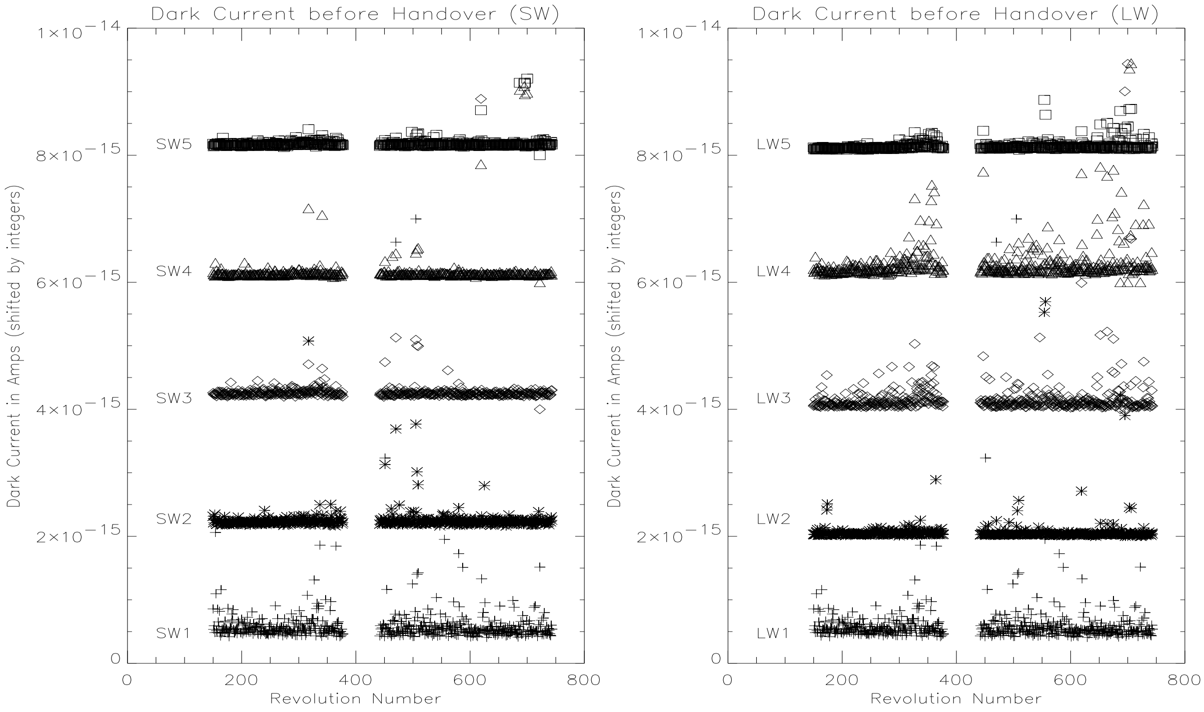

Figure 2. Dark currents taken from before handover illuminator flashes plotted as a function of revolution number.

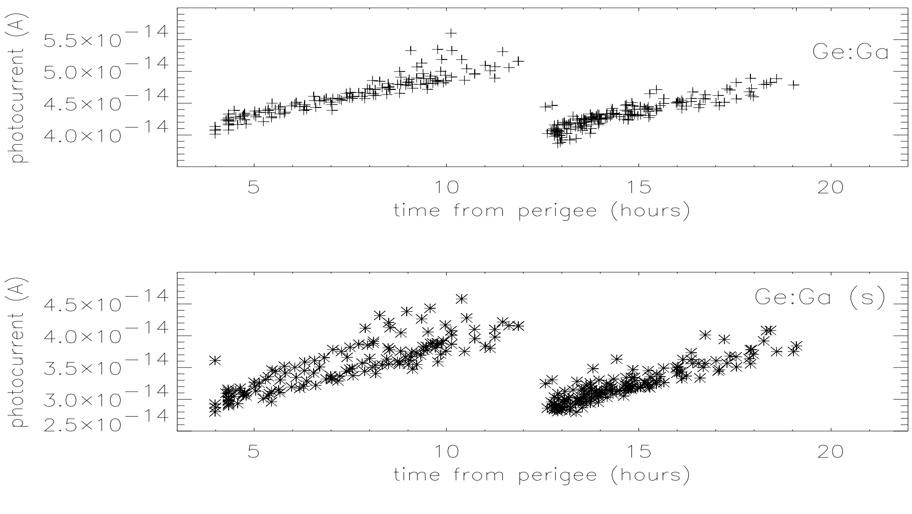

Figure 3. The output signal from internal illuminator sources shows the responsivity drift of the detectors during the orbit, caused by the hits of ionising radiation.

internal illuminators as a function of the time from perigee. To increase the statistics, data from observations in different calibration revolutions from rev 442 to 734 are plotted together. It was assured, from handover flashes, that the responsivity changes are of the same order in all the revolutions, with no change in the Ge:Be detector (SW1). Table 2 shows the average percentage increase in responsivity measured from the calibration observations in the period between start of revolution and ground station handover and the period after ground station handover and the end of the LWS science window. For the period between activation and handover calibration measurements are available for the whole 8 hour period. For the period after handover calibration measurements are available for only 6.5 hours.

The drift is also confirmed by analysis of the data from the illuminator sequence which is performed in each revolution before and after mid-revolution curing, with the before curing value being higher than the value after curing. These measurements are performed at the same position in every orbit.

Table 2. Relative increase in responsivity of LWS detectors over 8 hours.

Detector	Before Handover Curing (%)	After Handover Curing (%)
SW1	0	0
SW2	23	18
SW3	31	29
SW4	28	22
SW5	29	26
LW1	35	30
LW2	11	16
LW3	48	37
LW4	35	29
LW5	43	36

4.2. Long term stability of responsivity

The mid-revolution illuminator flashes have shown that the detector responsivities have remained stable throughout the mission. Like the dark current the response to a illuminator flash is measured just before and after the mid-revolution curing. The long term behaviour of both these responses has beed that they have remained stable with one exception. The exception is detector LW2 the shortest wavelength range (102-142μm) stressed Ge:Ga detector which underwent a 40% responsivity decrease during the period LWS was suspended from operations (revs 378-442) due the a problem with the interchange wheel. Since operations have resumed the responsivity of this detector has remained stable at the new value. Figure 4 shows the response to handover flashes.

4.3. Stability of illuminator flashes

The stability of illuminator flashes can be checked by ratioeing with astronomical sources, with the assumption that the astronomical sources exhibit long term stability. The illuminator power is measured on a relative non-linear scale and in order to improve the calibration accuracy, a commanded level of 180 was used after revolution 442 instead of two levels of 100 and 220 for the first part of the mission. Therefore the ratioes with astronomical sources can only be used to track the two periods separately. The 100 and 220 levels have been retained for the mid-revolution flashes. Figure 5 shows for the 10 detectors, the average photocurrent obtained when observing NGC 6543 ratioed with the average photocurrent from the illuminator flashes just before the observation in the period revolution 450 to 800. All monitoring of the stability have shown that the illuminator sources have not changed.

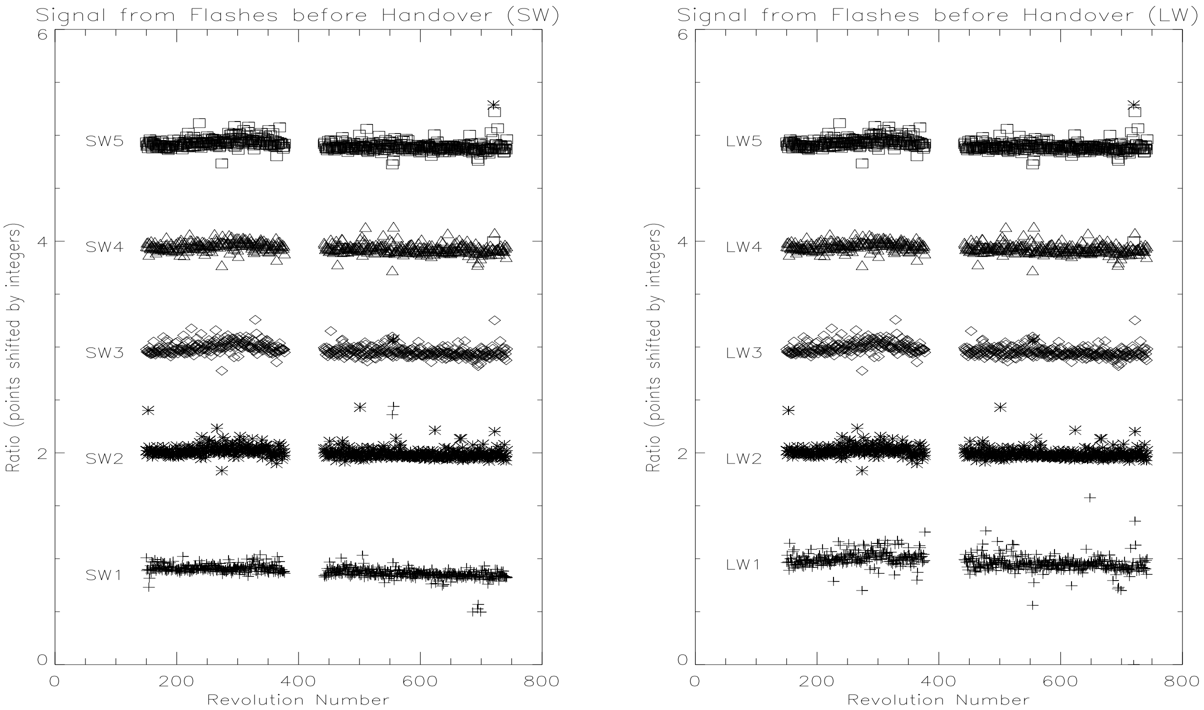

Figure 4. Photocurrent from internal illuminators taken before handover curing plotted as a function of revolution number.

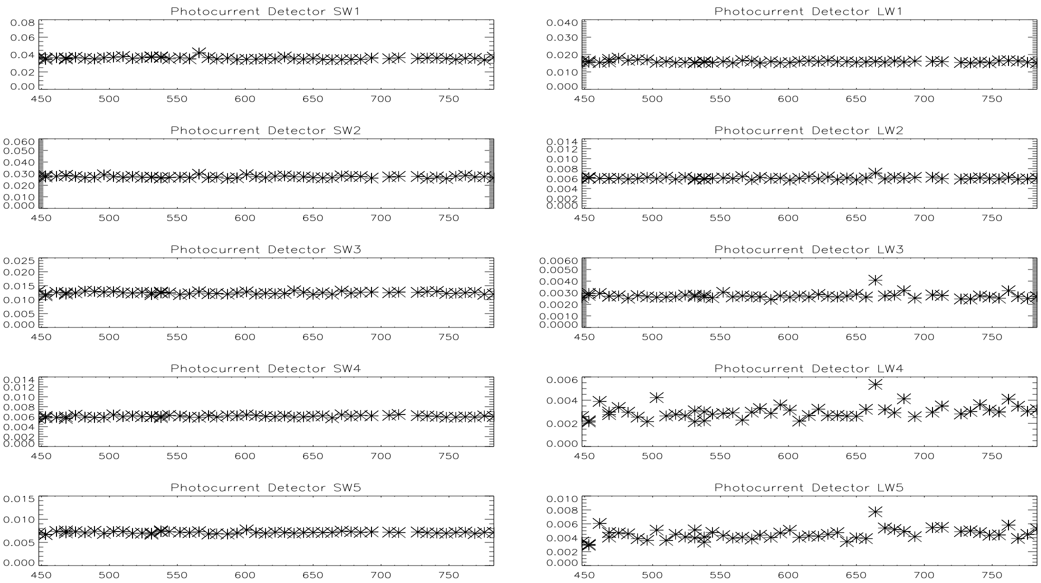

Figure 5. Ratio of source flux to illuminator flux for observations of NGC 6543 as a function of revolution number.

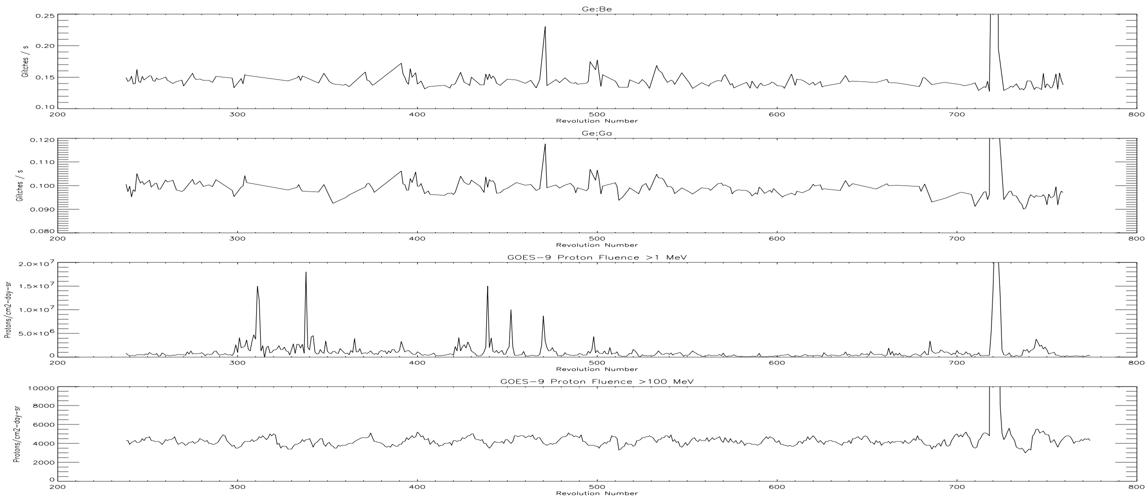

Figure 6. Average glitch rate for each of the two LWS detector materials (Ge:Be and Ge:Ga) as a function of revolution number. For comparison the bottom plot shows the proton fluence at two different energies as measured by the GOES-9 satellite as a function of time (data from the U.S. Dept. of Commerce, NOAA, Space Environment Center, gopher://solar.sec.noaa.gov:70/11/indices/old_indices).

5. PARTICLE HITS

The average time between hits by highly energetic particles in any LWS detector is 10 sec. This rate is constant for most of the science window, but glitches become more frequent near the start and end. The method of glitch detection, both in prime and parallel mode is discussed in Ref. 5 along with a detailed discussion of how this has been used for trend analysis. As the detectors in the LWS have a particularly large surface area (6 mm^2), the high glitch rate at the end of the ISO science window has led to change in operations where the LWS is operated for one hour less than the other ISO instruments. The change of glitch rate when the satellite is approaching or leaving perigee can happen at different speeds in different revolutions. In isolated cases a longer time is needed to reach the nominal glitch rate.

5.1. Correlation of Glitch Rate With Space Weather

Except for a unique event in revolution 722 there is no significant correlation between the average glitch rate within a revolution and the electron or proton fluence as measured by the GOES-9 satellite (see figure 6). The main reason for this is that the GOES-9 satellite observes the space weather at a height of 36,000 km whereas ISO is operating out to 70,000 km, where variations in the Van Allen belts are not felt any more. Changes of the electron fluence were not expected to have an impact on the detectors, anyway, since these particles are completely absorbed in the surrounding material of the satellite.

5.2. Rev 722

A particularly strong solar flare, caused the flux of $\geq$10MeV protons in revolution 722 to be more than two orders of magnitude higher than usual. This led to a strongly enhanced glitch rate during the whole revolution and rendered most ramps useless and as a consequence, all LWS observations had to be repeated. Although the measurements of responsivity and dark current were strongly disturbed as well, it could be shown they both had values that were several orders of magnitude higher than usual. In the following revolution 723 they had returned within a factor of two to the nominal values, and the scientific observations produced valid results. Five revolutions later dedicated calibration observations showed that the photometric calibration had not changed and that the proton event of revolution 722 had not caused lasting damage.

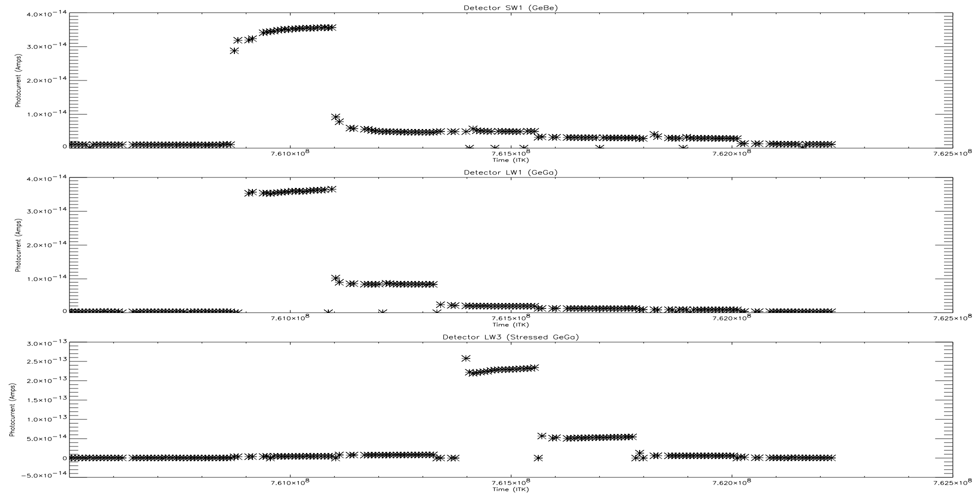

Figure 7. The response of the three detector types to an illuminator sequence.

6. TRANSIENTS

All LWS detectors exhibit transient behaviour. This falls into two main categories, a long term transient due to the steady accumulation of particle hits during each revolution (discussed in Sect 4) and a short term transients caused by changes in flux. In terms of calibration the transients cause two problems, the correct determination of line strength and wavelength and the determination and application of a steep edged spectral response function.

6.1. Characterisation

The normal operation of LWS is with either the grating or one of the Fabry-Perots to be doing a spectral scan. However there is an observation type where the grating position is fixed and the instrument essentially is in staring mode. The grating also does not scan during illuminator flashes. Figure 7 shows the response of the three detector types to a illuminator sequence (see Sect. 1). The Ge:Be detector SW1 has a long time constant (several minutes) in response to illuminator 1 and this is also apparent when the illuminator is switched off. The unstressed detectors have a fairly flat response whereas the stressed detectors have a hook response. At this time no attempt has yet been made to model the transient behaviour with an empirical approach to calibration being preffered.

6.2. Affect of Transients on Spectral Lines

The transient behaviour of the detectors affects the line flux accuracy, however the affect is dependent on both the line flux and illumination history, and at this time no correction is done. The affect however is minor with the worst case stressed Ge:Ga detectors only affecting the line flux by a few percent. The unstressed Ge:Ga detectors although exhibiting transient behaviour have very short time constants and have a negligible effect on line fluxes. The detector most affected is the Ge:Be detector which has time constants of the order of minutes, however very few bright lines have been observed in this wavelength range (43-51μm).

6.3. Determination of the Relative Spectral Response Function

One of the major affects of transient behaviour has been in the determination and application of the relative spectral response function (RSRF). LWS is operated in a mode where the grating is scanned forward and backward through the spectral range. For most detectors the scans pass through steep sided RSRFs and the resultant profiles are clearly split with the photocurrent dependent on scan direction. The calibration stategy up to now in the derivation of the spectral response function has been to average all data before dividing by the Uranus model. However when this averaged RSRF is applied in the pipeline it leads to scan dependent behaviour in the resultant spectra. Figure 8 shows a spectrum of Uranus for the two worse affected detectors SW1 (Ge:Be) and LW2 (Ge:Ga(s)). In the case

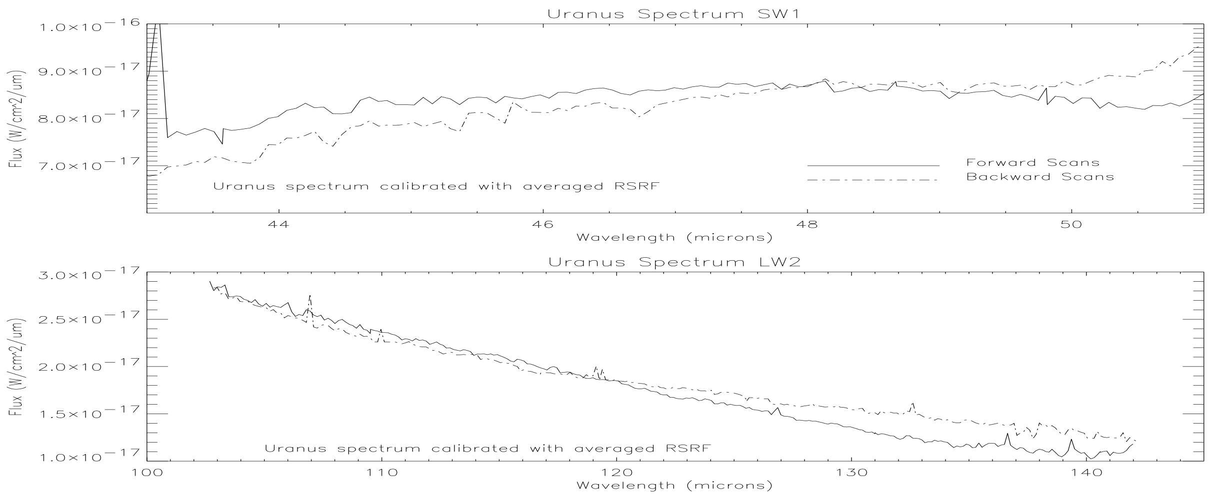

Figure 8. Spectrum of Uranus showing split between forward and backward scans for the two detectors worse affected by transient behaviour.

of SW1 the response function is triangular leading to a cross over affect at the top of the response function (around 48 microns). LW2 has a steep sided response at the long wavelength side and has a relatively long time constant (a few seconds). One possible approach is to use two RSRF functions, each derived only from scans in one direction. Attempts at this calibration stategy have so far led to promising results.

7. CONCLUSIONS

The initial performance of the LWS detectors has led to a mission where the detectors have been operated at a lower bias, giving a lower NEP than pre-launch estimates. The transient behaviour and glitch rates have been as predicted, however the major surprise has been that the dark current does not change with time during a revolution. The long term performance of all LWS detectors in orbit has been satisfactory and stable. There have been no long term trends in the mission either in responsivity or dark current. The long term behaviour of the glitch rate has remained stable, with no degradation in detector performance leading to spontaneous spiking. Apart from the large solar coronal mass ejection affecting revolution 722 there has been no behaviour which significantly correlates with the either the solar proton flux or the solar electron flux. All three detector types have proved to be useful and good choices for a mission of this type.

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