THE ISO DETECTORS AND THE SPACE RADIATION ENVIRONMENT*

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ABSTRACT

We present a statistical study of the glitch rates and glitch characteristics as derived from the data of the four instruments on board the Infrared Space Observatory (ISO), and compare the results from each instrument and for different detector materials. The evolution of the glitch rates and some instrument performance parameters are analyzed as a function of time in the mission and ISO's position in orbit, including the effects of the only important solar proton event during ISO's lifetime on 6 November 1997. It is found that the observed glitch rates are 1.5-4 times higher than the value predicted by the CREME96 model for the cosmic ray integral flux. Moreover, when comparing the deposited energy distribution associated with the observed glitches and the results from ray-tracing simulations including only direct cosmic rays, it becomes apparent that the contribution from the lower deposited energy hits is larger than in the purely cosmic ray-based models (although there is a good agreement for the higher energies in Ge detectors). These facts, together with the correlations found between glitch rates and the electron flux measured by the GOES 9 spacecraft, lead to the conclusion that between 30 and 75% of the observed glitches are caused by δ-rays and other secondary particles produced in the detector and in the instrument and satellite shields. Future missions using similar detectors must take into account this result to define the appropriate shielding.

Key words: space environment; infrared detectors; radiation effects.

1. INTRODUCTION

On 17 November 1995, the Infrared Space Observatory (ISO) was launched into a highly eccentric elliptic orbit, with a perigee height of 1000 km, an apogee height of 70600 km and a period of 24 hours. The ISO scientific payload (e.g. Kessler et al., 1996, and references therein) consisted of four instruments: a camera, ISOCAM, an imaging photopolarimeter, ISOPHOT, a long wavelength spectrometer, LWS, and a short wavelength spectrometer, SWS. In order to avoid damage induced by the trapped proton belts and the most intense fluxes of trapped electrons, the instruments were switched off routinely around perigee. However, out of this region (altitude > 26500 km), galactic cosmic rays and interplanetary and belt electrons still affected the detectors, causing glitches in the measured voltages as a result of the energy deposited. This effect increased the noise in the scientific observations to a level that depended on the detector material and size. As an example, Figure 1 shows the tracks produced by a particle hit on the ISOCAM LW pixel array. Since ISO was operational during the solar minimum, the contribution from solar energetic particles to the observed glitch rates was not significant, with the exception of the big event on 6 November 1997 (see section 3.2).

2. OBSERVED GLITCH RATES AND COMPARISON WITH MODELS

The analysis of glitch rates observed by different instruments must take into account the detector material, the size of the detector and the instrument electronics, that is, the minimum deposited energy necessary to produce a glitch. The fact that this energy is as low as ≈ 1 keV (see second column of Table 1), implies that the detectors may register impacts from a broad range of particles, including δ-rays (i.e. secondary electrons), other secondary particles, and the typical spectrum of cosmic rays. Table 1 shows the glitch rates per unit area (effective area = total det. area/4) averaged during the mission,

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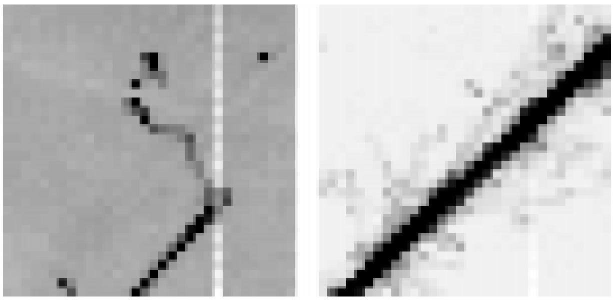

Figure 1. Examples of particle impacts on the ISOCAM instrument. On the left panel a low energy particle has probably stopped in the detector, while on the right panel a heavy ion passing through can be seen.

observed around apogee for different detector materials. For comparison, the CREME96 model (Tylka et al., 1997) provides a value for the cosmic ray proton integral flux during the time period considered of ≈4 particles/cm^2/s (E > 30 MeV) (Nieminen & Sørensen, 1998).

Table 1. Observed glitch rates

Instrument	Glitch rate (cm^{-2} s^{-1})	Min. E deposited (keV)
Si:Ga		
CAM	14.9	-
PHT-P1	6.5	1
PHT-S	5.8	1
SWS	10.0	1
Ge:Be		
LWS	6.3	1.9
SWS	17.8	0.95
SWS-FP	10.1	0.95
Ge:Ga		
PHT-P3	10.1	1
PHT-C100	12.5	1
LWS	7.0	1.2
PHT-C200 (stressed)	7.3	1
LWS (stressed)	6.7	1.3

As can be seen, the observed glitch rates are between 1.5 and 4 times higher than the predicted value, which includes the contribution of direct cosmic rays alone. In order to investigate the reason for this difference, we have derived the deposited energy distribution for the observed glitch rates. The transformation between measured voltage jump and energy has been done assuming an energy loss per electron-hole pair produced of 3.6 eV for Si and 2.9 eV for Ge (see Metcalfe & Kessler, 1991, for a detailed explanation). Figure 2, 3 and 4 show the results for SWS, ISOPHOT and LWS, respectively, together with the output from Monte Carlo ray tracing simulations combined with the CREME96 cosmic ray model. Average values for the energy deposited per unit length of 0.4 MeV/mm in Si and 0.72 MeV/mm in Ge have been adopted. While the simulations reproduce well the distribution for high energy impacts in SWS and ISOPHOT, the predicted glitch rate is drastically underestimated for the lower deposited energies in all cases. Taking into account that the average energy deposited in the SWS Ge:Be detectors by a secondary electron is lower than 0.1 MeV, we can explain the difference between model and observations as due to the δ-rays and other secondary particles produced in the detectors and in the shield (the ISO shielding was modeled by a sphere of 15 mm Al + 2 mm Pb + 2 mm Al), which affect strongly the detectors but are not included in the simulations. In the Si:Ga detectors the model provides lower glitch rates in almost the whole energy range considered. This fact also supports that the secondary particles are responsible for the difference, since in Si detectors the average energies deposited by secondary electrons and cosmic rays are closer than for Ge. Also Dzitko et al. (1998) concluded from their modeling of ISOCAM glitch rates that more than 50% of the glitches were due to secondary particles.

When comparing between different instruments for the same detector material, the glitch rates agree within a factor of 2, the differences being probably related to shielding. Instrument shielding may also be the reason why the distribution of glitches for the higher deposited energies in LWS (Figure 4) is lower than the predicted value, unlike in the other instruments. Other factors to be considered in the glitch rates calculations are the residual cross-talk between detectors in an array, which would increase erroneously the counting of impacts, and the efficiency of the algorithms used in the detection of small or multiple glitches in a ramp.

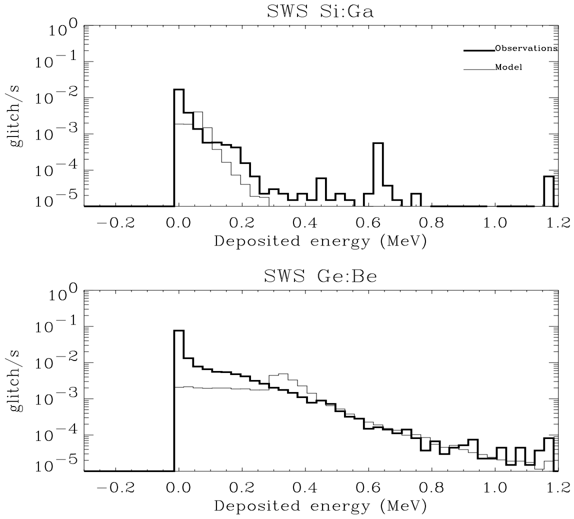

Figure 2. Deposited energy distribution of the observed glitches in the SWS instrument and the results from a ray-tracing simulation.

3. SPACE WEATHER EFFECTS

The radiation environment affecting the ISO scientific observations consisted mainly of galactic cosmic

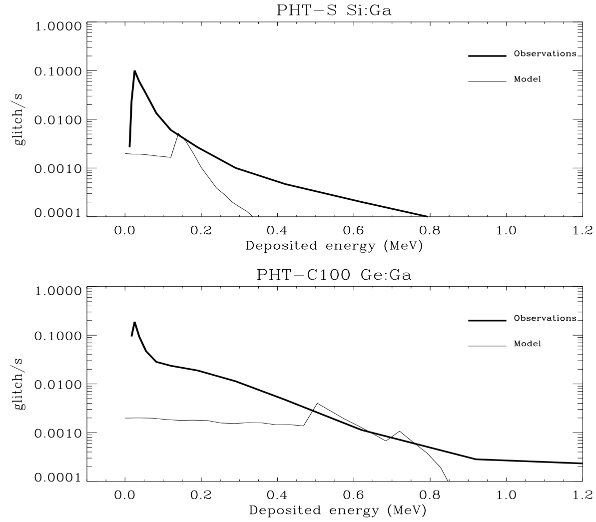

Figure 3. The same as Figure 2 for two subsystems of the ISOPHOT instrument.

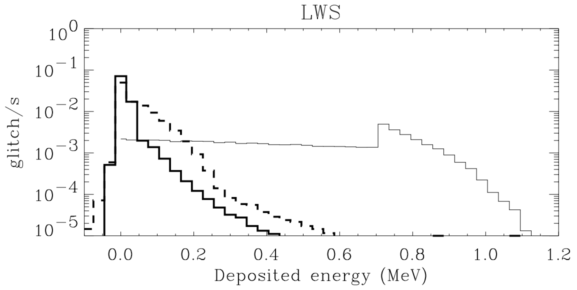

Figure 4. Deposited energy distribution of the observed glitches in the LWS instrument for the Ge:Be detector (thick line) and for the Ge:Ga detectors (thick dashed line). The output of the ray-tracing simulation is represented by a thin line.

rays and electrons from the radiation belts. Since the ISO mission was carried out during solar minimum, the solar energetic particle contribution was not significant. Figure 5 shows this quiet proton flux conditions, just perturbed by a soft event in April 1996 (revolution 152) and by the only energetic event on 4-6 November 1997 (revolution 720-722), during which the proton flux for E < 10 MeV and E < 100 MeV increased by almost three orders and an order of magnitude, respectively, with respect to its average value.

3.1. Electrons

In spite of the quiet environment, an analysis of the glitch rate evolution shows in some detectors a clear dependency on the electron flux observed. The glitch rate measured in the SWS Ge:Be detectors around 3 hours after perigee, correlates rather well with the E > 2 MeV electron flux measured by the GOES 9 satellite, located at a similar altitude (see Figure 6). However the correlation disappears when glitch rates at ISO apogee are considered, which indicates a different and more quiet electron environment in this region. Unfortunately we do not have electron flux measurements at that location. The LWS detectors (Ge) were especially affected by particle impacts around the start and end of the science observation window, at altitudes lower than ≈43000 km. Above this position the glitch rate decreased by a factor of two abruptly, keeping to a constant level afterwards, a behaviour that seems to be related to the structure of the electron belts. These glitch rate correlations with the electron flux add another argument to support that a large fraction of the impacts detected are δ-rays produced in the detector and the shield.

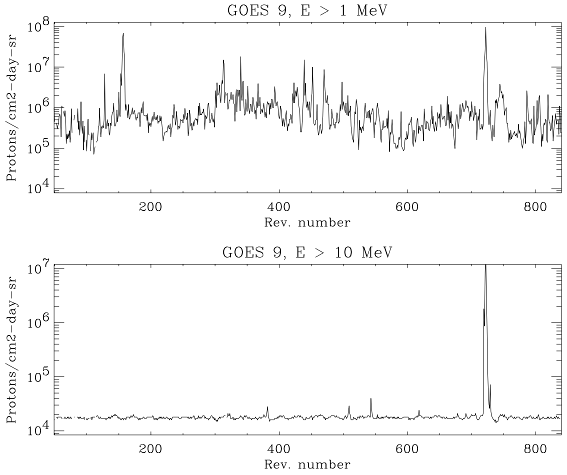

Figure 5. Daily proton fluence measured by the GOES 9 satellite (Space Environment Center, NOAA) during the ISO mission.

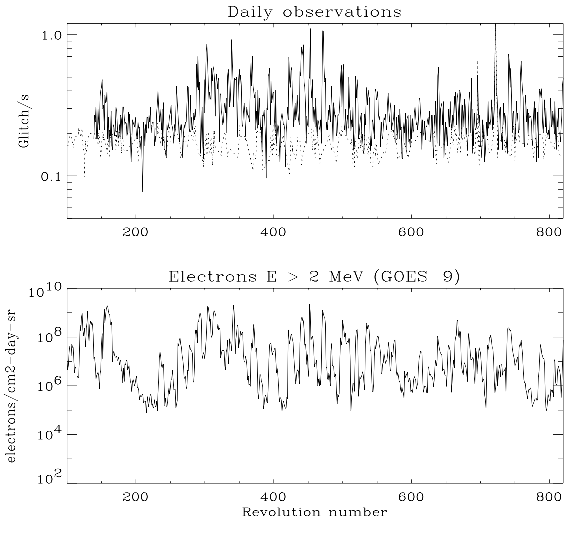

Figure 6. SWS Ge:Be detector. Top panel: Glitch rates as a function of time (revolution number) measured close to perigee during instrument activation (solid line) and around apogee (dashed line). Bottom panel: Electron flux measured by the GOES 9 satellite.

In some cases the space weather also influenced the instrument performance. Particularly the responsivity check signals in the Ge:Ga ISOPHOT P3, C100 and C200 detectors were clearly correlated with the geomagnetic activity and the electron fluxes (see Figure 7), the increase in responsivity taking place one or two days after the onset of a geomagnetic storm. As a consequence the responsivity showed a periodicity of 26-29 days, a period that was also identified in the dark currents of the ISOCAM LW detector, and that is associated with the 27-day recurrent electron events detected by the GOES 9 spacecraft.

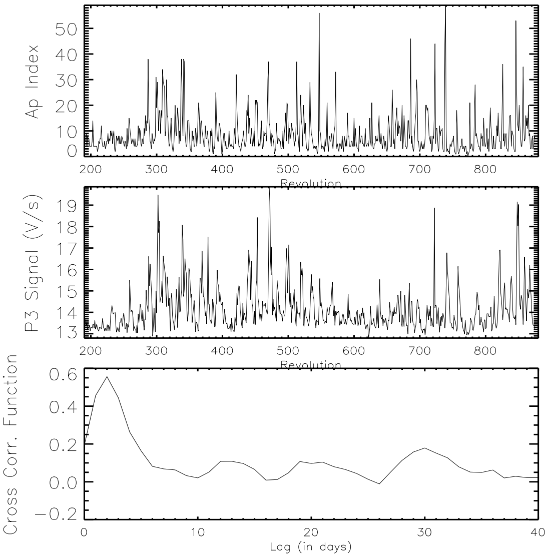

Figure 7. Variation of the Ap index (top panel) and of the responsivity signal for P3 (middle panel) as a function of time. In the bottom panel the cross correlation between the Ap index and the P3 signal is shown.

3.2. The 6 November 1997 solar proton event

As mentioned above, this is the most intense event occurred during the ISO mission. The dark currents, dark current noise and glitch rates of all instruments increased so dramatically that most observational data were corrupted and all observations during revolution 722 were declared failed. For example, the dark current noise increased by 200% in all SWS bands and the glitch rate became between 5 and 10 times the nominal value. Paradoxically, the SWS responsivity decreased during the event between 30 and 15%, while it increased in the other instruments. All parameters were back to normal values in the following revolution, but for LWS, in which the dark currents and responses were still slightly higher. It must be noted that the evolution of the detector parameters was better correlated with the proton flux the higher the energy considered (> 30 MeV), in agreement with the fact that low energy protons could not penetrate the shield. Moreover there seemed to be a threshold for the $E > 30$ MeV proton flux of about 100 protons/cm^2/s/sr, below which there were no noticeable effects on the detectors. In fact all parameters were nominal during the previous proton event starting on November 4 and also during the several days long decrease phase of the November 6 event, although the proton flux was still rather high. An explanation is that protons with energies well above 30 MeV and electrons, which showed higher fluxes especially during the first day of the November 6 event, were the main responsible for the increase of the glitch rate.

4. CONCLUSIONS

We have made a statistical study of the glitch rates and glitch characteristics as derived from the data of the four instruments on board the Infrared Space Observatory (ISO). The main conclusions are:

- The observed glitch rates are 1.5-4 times higher than the value predicted by the CREME96 model for direct cosmic ray integral flux.
- Ray tracing simulations that include direct cosmic rays alone reproduce well the deposited energy distribution in SWS and ISOPHOT Ge detectors for the higher energies but underestimate the lower deposited energy hits in all instruments. In the case of Si, the simulations underestimate the glitch rate in almost the whole energy range considered.
- In some cases a clear correlation is found between glitch rates, detector performance and electron flux as measured by the GOES 9 spacecraft.
- The only solar energetic particle event during the ISO mission (6 November 1997) affected the instruments such that all observations were declared failed.

Summarizing, our results show that between 30 and 75% of the observed glitches are associated with δ-rays and other secondary particles produced in the detector and the instrument and satellite shields. Future missions using similar detectors must take this high percentage into account to define an appropriate shielding.

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