LONG-TERM DATA AND SIMULATIONS ON ISOCAM LONG-WAVE DETECTOR GLITCHES

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ABSTRACT

In this work, the affected pixel number distribution of the ISOCAM Long-Wave (LW) detector onboard the Infrared Space Observatory (ISO) in direct, cosmic ray-induced glitches is calculated. The methods employed are Monte Carlo ray-tracing techniques and the taxi metric, which allows direct calculation of the number of affected pixels based on the knowledge of entry and exit points of a ray. The simulation results are compared to long-term experimental LW glitch data from November 1995 to October 1997, obtained from ESA/Vilspa (E). Based on the simulations combined with the CREME96 cosmic ray model for solar quiet period, it is estimated that the detector is on average traversed by ~0.3 cosmic ray protons per second. From the experimental glitch data, a corresponding minimum bound of ~0.14 cosmic ray protons per second is obtained. Due to the nature of the data, corresponding maximum on the other hand cannot be calculated. The mean number of pixels affected in a glitch are calculated to be ~8.4 and ~9.0 for the theoretical and experimental cases, respectively. The overall agreement between the simulated and observed pixel number distributions is relatively good, with some deviations. Possible reasons for these deviations are discussed.

1. INTRODUCTION

ESA's Infrared Space Observatory (ISO) housed four instruments, one of which was the CEA-Saclay coordinated ISOCAM (Ref. 1). This consisted of two detector configurations, denoted as Short Wave (SW) and Long Wave (LW). The LW detector was a 32 x 32 element Si:Ga substrate hybridised by an Iridium bump array, with a pixel size of 100 x 100 μm^2 and a thickness of 500 μm. In the space environment, this detector suffered from occasional "glitches". A glitch in this context is defined as a spurious signal caused by the ever-present cosmic rays or, during periods of high solar activity, by energetic solar particles. Quiet-time interplanetary electrons, and secondary particles created within the spacecraft may also be responsible.

In this paper, we report on ray-tracing Monte Carlo analysis performed on the ISOCAM LW detector volume using the GEANT particle transport package. Results between experimental glitch data, on one hand, and simulations combined with CREME96 cosmic ray model predictions, on the other hand, are compared.

2. GLITCH DATA

The orbit of ISO was highly elliptical and geosynchronous, with an apogee and perigee of ~70500 and ~1000 km, respectively, and a mean period of ~24 h. The time spent per orbit outside the radiation belts, when useful observations were feasible, was about 16 hours. The experimental ISOCAM LW glitch data, referred to as the CGLITCH table, (Ref. 2) that we have used has been derived by the following algorithm (Ref. 3), independently for each pixel:

1. Extract the pixel count vs. time. This yields the raw time-dependent data.
2. Smooth the data with a median filter of width 5.
3. Calculate the difference $d(t)$ between the raw and smoothed data.
4. Calculate the standard deviation σ of the difference $d(t)$.
5. Identify glitches by the criterion $|d(t)|>5\sigma$.

This particular algorithm is by no means the only possible one. Other, more complex approaches available for ISOCAM glitch recognition have been reported e.g. by Claret et al (Ref. 4). There are a number of parameters listed in the CGLITCH data table. For the present work, the parameters of interest are the UTK time (a special time unit, given in 1/24 seconds), the integration time, and the number of pixels affected during that integration. The starting epoch of the data set is 28 November 1995, and the last entry was logged on 18 October 1997. The data therefore represents nearly the whole ISO mission.

As indicated by Nieminen and Sørensen (Ref. 5) in a more detailed account of the present work, the space environmental conditions during the time frame in question were very quiet. There were no major solar proton events (the event on 4-9 November 1997 occurred after the last CGLITCH entry) or interplanetary magnetic field disturbances. There have been reports, however, on correlation of ISO detector effects with electrons of quiet-time solar origin (Ref. 6).

3. RAY-TRACING SIMULATIONS AND TAXI METRIC

To determine the number distribution of ISOCAM LW detector pixels affected by cosmic ray-induced glitches, we have used Monte Carlo ray-tracing simulations by the GEANT3.21 particle transport code (Ref. 7). By combining the result of a single ray-tracing simulation with the pixel calculation by the so-called "taxi metric"[1], the total number of pixels involved can be determined. The approach in the simulations was the following:

1) The incident particle origins were uniformly distributed onto a sphere surrounding the detector volume. From this sphere the individual, isotropic directional vectors were chosen within a cone large enough to cover the set-up from any entrance angle.
2) The rays created this way were non-interacting, i.e. all of the physical processes treated normally in GEANT were excluded. The rays entered the detector from a given point, and followed a straight track until the exit point was reached. For cosmic rays, this is a fair first approximation, since their energies are high enough such that the energy deposit per unit length in the detector is not a strong function of particle incident energy. The same method has

[1] Taxi metric is a two-dimensional metric where only rectangular transitions in the plane are allowed, and where distance calculation (or, in this case, pixel number calculation), does not follow Euclidean rules.

also been used for simulations on other ISO detectors, as reported by Heras et al. (Ref. 8).

3) Knowing the entrance and exit points, the number of pixels n_0 lying along the track was calculated by the taxi metric equation

$$n_0 = | \operatorname{int}(x_1 / L) - \operatorname{int}(x_0 / L) | + | \operatorname{int}(y_1 / L) - \operatorname{int}(y_0 / L) | + 1 \qquad (1)$$

where L is the side length of the pixel (100 µm), and (x_0,y_0) and (x_1,y_1) are the particle entry and exit points, respectively, projected onto a plane parallel to the surface of the detector.

4) The Monte Carlo process was repeated one entry at a time, until a statistically significant output distribution was accumulated. We have used 10^5 incident particle entries.

Based on this procedure, we calculate the purely mathematical mean number of pixels affected in a glitch to be ~8.4. This is the same value as determined earlier by Agnèse et al. (Ref. 9), who also used a Monte Carlo method. The CGLITCH experimental data, on the other hand, yields a value of ~9.0, but this figure is based on the number of pixels affected during a given integration time that may contain several unresolved individual glitches, and/or overlaps of one or more pixels from different tracks.

The quiet-time cosmic ray proton flux was estimated by the CREME96 model (Ref. 10, and references therein) to be ~4 particles/cm^{2}s (>30 MeV). Following the count rate equation for a convex volume

$$R = \frac{\Phi A}{4} \qquad (2)$$

where Φ is the incident particle flux and A the surface area of the volume, the cosmic ray prediction consequently translates to an average of ~0.3 cosmic ray protons traversing the LW detector every second. We have used this purely geometrical result to verify our GEANT ray-tracing simulation, which also yields the same value.

On the other hand, using the mean integration time of 7.18 seconds calculated for the CGLITCH data set, a corresponding minimum experimental bound of ~0.14 is obtained. This value is simply the inverse of 7.18 seconds, and the rationale is as follows: it is known that, on average, a 7.18 seconds integration time corresponds to a single glitch entry. However, that single entry may well consist of more than one incident particles. Therefore, the value 0.14, representing the case for a single proton, is the minimum estimate of protons traversing the detector per second. Due to the nature of the data, no maximum experimental bound on the other hand can be inferred.

These theoretical and experimental results can be compared to values reported by other authors. Cesarsky et al. (Ref. 1) obtained 0.28 protons (>30 MeV)/s] based on data from the KET instrument onboard Ulysses. The latest results reported by Claret et al. (Ref. 4) and Dzitko et al. (Ref. 11), following re-analysis of that same data set, indicate a total of 0.36 cosmic ray protons and α-particles passing through the detector per second. Given the uncertainties in the cosmic ray models, and the use of differing data sets, the agreement of these experimental results to the GEANT and CREME96-based estimates is encouraging. There is a larger difference to the value calculated using the CGLITCH data set, but as mentioned, this represents an absolute minimum bound, whereas a corresponding maximum cannot be determined.

4. PIXEL NUMBER DISTRIBUTIONS

The normalised CGLITCH and ray-tracing-based pixel number distributions are shown in Figure 1. The normalisation point was chosen at 10 pixels, which is close to the means of both distributions. (It would also be possible to choose alternatively 8 or 9 pixels, but as can be seen from the Figure, the change in the relative amplitudes of the two distributions would be negligible). The overall agreement between the two curves is relatively good. There are some deviations that are next discussed.

Figure 1. *ISOCAM LW affected pixel number distributions as determined by the CGLITCH data table (solid line), and by ray-tracing simulation (dashed line).*

Figure 2. *ISOCAM LW track length distribution for isotropic incident rays.*

4.1. Low number of pixels affected

There is a difference in the low number (1-3 pixels affected) part of the distribution between data and the simulation. Possible explanations for this difference include low-energy secondary particles, fake counts in the specific ISOCAM LW de-glitching algorithm used, and/or counts of α-particles emitted from the naturally radioactive Thorium coating in the lens system of the instrument. In decaying, the isotope ^{232}Th produces α-particles of energy ~4 MeV, which are stopped in less than 20 μm of Silicon. Since the LW detector pixel area is 100 x 100 μm^2, it is conceivable that an excess of glitches with a low number of pixels affected could be produced via this mechanism. Further analysis on the rate of α-particles hitting the detector has been performed by Dzitko et al. (Ref. 11).

4.2. Knee at ~40 pixels affected

The simulated distribution shows also a knee at ~40 pixels that is not visible in the CGLITCH data. The knee results from the fact that the track length distribution within a parallelepiped, although being continuous, is not a monotonous but a peaked one, as shown in Figure 2. This histogram has also been produced by GEANT. The type of double-peaked distribution illustrated here is typical for rectangular volumes where two dimensions are equal, but the third is different. There is a first peak at ≥0.5 mm, corresponding to the relatively large number of rays penetrating the detector along the depth dimension, and a second, smaller peak at ≥3.2 mm, where rays are traversing the detector sideways. It is this second peak that corresponds to the knee seen in the pixel number distribution of Figure 2. (For analytical considerations on track length distributions in various volumes, see e.g. Kellerer (Ref. 12) and references therein). It is unclear why this feature is not visible in the data. Possible explanations include secondary particle production, broadening the distribution, and non-uniformity of the local shielding around the detector. Such non-uniformity may have an effect on the directionality of the incoming radiation, and hence on the particle track length distribution.

4.3. Large number of pixels affected

Finally, the fact that the simulated curve ends at 64 pixels, whereas the real data shows an extended tail towards the maximum affected pixel number of 1024, is due to the mathematical simulation model. The maximum number of pixels traversed by a non-interacting ray, 64, corresponds to the case where the entry and exit points lie in diagonally opposite corners of the detector volume. In reality, especially with heavier ions, the charge liberated by the particle within this detector type may in fact diffuse as far as four elements away (Ref. 9), leading to events with a large total number of pixels affected. An energetic incident particle may also generate an extensive shower of secondaries, covering large portions, or the whole of the detector. Such events are nevertheless several orders of magnitude less frequent than the dominating ones where a few or some tens of pixels are affected.

5. CONCLUSIONS

We have performed ray-tracing simulations of cosmic ray-induced glitches experienced by the ISOCAM LW detector, and compared the results to long-term experimental glitch data. The results on the affected pixel number distribution obtained by simulation are encouraging. The mean number of pixels affected in a glitch was found with this approach to be ~8.4, whereas the CGLITCH data set, with the reservations stated above, yields ~9.0 pixels. The average number of cosmic ray protons traversing the LW detector per second was calculated to be ~0.3 using both geometrical considerations and the ray-tracing method, combined with cosmic ray integral flux value of ~4 particles/cm^2s (>30 MeV) from the CREME96 model. On the other hand, from the CGLITCH data we inferred a corresponding minimum bound of ~0.14, while the nature of the data did not allow us to determine a corresponding upper bound. It was found that there is a good qualitative agreement between the measured and simulated pixel number distributions, although certain deviations remain due to secondary particle production, decay of the radioactive Thorium in the instrument lens coating, and/or the specific instrumental de-glitching algorithm employed.

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