TRANSIENT EFFECTS OF IR PHOTODETECTORS: THE LESSONS FROM ISO

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ABSTRACT

A large number of low background photodetectors were used on the ISO satellite, covering wavelengths from 2 to 200 microns. All these detectors were affected by transient responses after changes of incoming flux. For several detectors, it is possible to reproduce these transient responses using physical or empirical models, with a typical accuracy of a few percents. In that cases, the data can be corrected with a comparable accuracy, so that the limiting factors become the effects of high energetic particles and the absolute sensitivity of the instruments.

We have shown that the accuracy of the modeling of the transient effects is strongly related to: (1) the design and the quality of the whole system (electronic linearity, optics, temperature control, ...), (2) the quality of the detectors and the choice of the setups, which are needed to obtain reproducible transients (3) the adequations of the tests, in order to check and improve the design of the whole instruments and also to provide accurate data for transient modeling.

This experience from ISO should be useful for the next missions.

INTRODUCTION: CONDITIONS TO HAVE REPRODUCIBLE TRANSIENTS

All the ISO detectors (see Table 1 in [4]) were affected by transient response, at different levels, which may bias the output by factors of ~10-40 %. Depending on the nature and the intensity of the variations, the time constants go from 10^{-6} s to hours.

The transient responses of all these detectors depend on the evolution of the incoming flux, but also on several other changes: temperature, voltages, non-stabilized electrical crosstalking inside bulk, High Energetic Particles (HEP), ... Since the physical equations describing these detectors are non-linear[28,11,15], any change of one of these parameters adds non-linear effects in the detector output. Therefore all these parameters must be as constant as possible. The HEP rate cannot be changed in space, but the sensitivity of the detectors to HEP can be optimized. The temperature must be fixed in order to have reproducible transient[α]. Voltages (direct and grid) applied to the detectors must also be fixed in order to avoid the Long Term Drifts (LTD) which appear systematically after voltage switch-on[β].

Once the temperature and voltage are fixed, and if the voltage is not too close to the avalanche breakdown (to be less sensitive to HEP, see discussion[5]) and for a long time after the last curing or switching on, the response to flux changes is reproducible. Unfortunately, several ISO detectors were not working in optimal conditions for transients, especially the SWS[16] and the LWS[21] detectors which were too close to the avalanche breakdown, and the PHT detectors due to frequent switches off/on[29]. In these cases the study of the transient response is strongly complicated because different non-linear effects overlap.

Here we assume that (1) the system did not add extra problems like optical fringing nor non-linearities due to the readout electronic[γ] and (2) the quality of the detector is ``close'' to optimal, not only for the bulk but also for the contacts (e.g. CAM contacts versus Fouks' theory).

MODELIZATION OF TRANSIENTS

The developments of models of transient have allowed significant progresses (1) to understand the nature of transients, (2) to evidence other effects, not due to the detectors, which may affect the response, (3) to

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[α] See the consequences of temperature variations on the transient response for PHT[10,13].

[β] See comparison between CAM and PHT behaviors and setups[5].

[γ] E.g. : non-linearities in ramps of PHT C-100 and C-200[22,26].

define the calibration strategies both for Ground Based Tests (GBT) and in-orbit tests, (4) to optimize the observing strategy, and (5) to process systematically the data.

A methodology for studying transients under uniform illumination is detailed[4]. For non-uniform illumination, drifts and Small Amplitude Oscillations (SAO), a preliminary approach is discussed[5].

In order to adjust the models, the basic tests are made of sequences with upward and downward steps of flux. The dark level must be precisely known, since the response generally depends on the absolute level above the dark level. Then the models can be modified in order to work on quasi-continuously variable data (e.g. CAM LW CVF observations, see explanations[4]).

Several analytical models were derived from the physical equations assuming uniform illumination of the pixel surface[28,9]. In such a case, electrical crosstalk inside bulk between adjacent pixels compensate each others. In order to use these models, the illumination profiles of the pixel surfaces should be as uniform as possible in order to avoid extra non-linear effects due to physical effects inside detector bulk. This condition may be difficult when cavities or light concentrator are used. These extra complications were encountered by PHT C-200 and LWS (cavities), SWS and LWS (beam effects) (see discussion and references[5]). For non-uniform illumination, specific models have to be developed (see below), or the Point Spread Function must be oversampled by a significant factor.

TRANSIENTS OF SI:GA DETECTORS

The Si:Ga detectors cover a wavelength range of ~5-18 µm. While the results with this kind of detectors are not directly transposable to Ge:Ga detectors, they are very interesting because Si:Ga and Ge:Ga detectors present similar transient and memory effects. Moreover, working with different kinds of detectors is very useful to define a systematic methodology in order to study the transient effects and correct the data.

In 1992-1994, it has been shown during the GBT of PHT that the transient response of PHT Si:Ga detectors (PHT-S and PHT-P) can be described at a percent level by one of the Fouks' transient models[28], for a wide range of initial and final levels of incoming flux[25,13]. This model was very useful to evidence other problems in the PHT instrument like thermal heating and crosstalking inside MosFETs[10]. Unfortunately, a clear departure between the transient responses in flight and on the ground was observed. From published works[1,29,14] and our CAM experience, we believe that different problems were mixed together which strongly complicate the behavior of the Si:Ga PHT detectors in flight. During the flight, the optical configuration was different than during the GBT. Moreover, due to the flight operations, the PHT detectors were frequently switched off and on, which produced strong LTD. Furthermore, the PHT Si:Ga electrical setup was optimize in order to produce a fast response[δ], not to reduce the sensitivity to HEP. Therefore the data were affected by HEP.

In 1998, this model was applied to the LW CAM detector after a characterization of the transients on upward and downward steps of flux, using in-flight and ground based data[4]. An alternative approach was given[20], partially based on a similar non-linear differential Riccati equation. In 1999, this model was also used for SWS b2[17]. Several limitations were found because the SWS detector was working close to the avalanche breakdown which gives (1) a faster response but extra non-linearities in transient responses[12] and (2) a higher sensitivity to HEP. Finally, in 2001, the transient response under non-uniform illumination of the CAM matrix array was described with a physical model by Fouks[ε].

Inversions methods were developed: for PHT, based on block by block fitting[1], for CAM, based on readout by readout correction[4] and for SWS, mixing readout per readout and dark polynomial corrections[17,18]. Furthermore, final processing were done in CAM maps at the map making level using the spatial redundancy of the observation strategy[23], in order to remove remaining problems such as LTD, SAO, possible variations of the detector temperature, tails of insufficiently corrected transients of point sources, remaining glitches.

TRANSIENTS OF GE:GA DETECTORS

[δ] The instantaneous jump β is ~ 0.8 for PHT, ~ 0.5 for CAM, see discussion in [5].

[ε] See technical note and figures on http://www.ias.fr/PPERSO/acoulais/ISO_Sources/transients_sources.html. This direct model is available upon request for further processing of CAM data, especially for improving the photometry of sources.

The C-100 detector of PHT is an unstressed Ge:Ga matrix made of 3×3 independent pixels covering a spectral range ~50-105 μm[26,22]. This detector appears very sensitive to HEP. Its instantaneous jump for upward steps of flux is about ~70% of the total step, and the downward step are quasi-instantaneous. The transients of this detector obtained during in-flight calibration measurements were reproduced with a model mixing a physical approach[9] and an empirical one[6,7]. However this model cannot be systematically used for scientific observations because the sampling rate and the ramp length were reduced compared to the calibration measurements, so that problems due to HEP become important (see explanations and curves in [7]). We have explained in [7] that, in order to optimize operation of future Ge:GA detectors, (1) the number of readouts during each ramp must be large enough in order to correct the ramps from HEP (2) the sampling rate has to be optimized in relation with the noise level due to HEP (then the integration time per ramp and the sampling rate must be selected accordingly) and (3) the calibration measurements generally performed just before and/or after the scientific observations (using the Faint Calibration Sources for PHT) must be long enough in order to measure the absolute flux with a good accuracy. An alternative approach was proposed[24], which was discussed[7].

The C-200 detector of PHT is a stressed Ge:Ga matrix made of 2×2 independent pixels covering a spectral range ~120-200 μm[26,22]. In comparison to C-100, C-200 is much less sensitive to HEP, furthermore its instantaneous jump for upward steps of flux is ~85% of the total step, and the downward steps are very fast. As a consequence, it was not critical to develop any transient correction method, at least for quasi flat background fields as the cosmological ones (e.g. [8]). However, it was necessary to remove the remaining drift which could affect long observations. Therefore the timelines were corrected before the map making[19]. The final source photometry was recovered by applying a 15% factor, to compensate the 85% instantaneous jump already mentioned.

Several unstressed and stressed Ge:Ga detectors were used for LWS. Basic observations (and calibrations) with the LWS were done scanning up and down in wavelength. Due to transient effects, the two scans did not overlap. Because such transients are a bias, the mean value of these two scans does not correspond to the true value. An empirical non-linear model was used[3] in order to reduce the difference between the upward and downward scans, but the agreement between the two scans does not demonstrate the validity of the model. Calibration measurements with upward and downward steps of flux are necessary to conclude, but they have not been performed.

OTHER DETECTORS OF ISO

Transients of the short wavelength CID SW CAM detector were studied and modeled[27]. An empirical modelization with an unique exponential allows the fitting of the data.

The Ge:Be SWS b4 was studied[2]. Unfortunately, as for the Ge:Ga LWS detectors (see above), the calibration database is too limited for a proper adjustment of any model.

CONCLUSION

All photodetectors of ISO are affected by transients effects in the measured response after changes of incoming flux. The works performed during these last ten years show that these effects can be described with high accuracy by physical (all Si:Ga, Ge:Ga C100) or empirical models (LWS), once the detectors have been set up so that the transient responses are reproducible.

Ideally, transient modelization and correction should be performed during the ground based calibration tests in order (1) to provide a calibration database which allows a precise adjustment of the models, and (2) to check and improve the design of the whole instruments (detectors, electronic, optic ...). Obviously, these models are very useful to optimize the observation strategy during the flight. We hope the ISO experience will be useful for the next missions (SIRTF, ASTRO-F, Herschel, NGST, ...).

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