ACCURATE PHYSICAL MODEL FOR DIRECT MODELING OF POINT SOURCE TRANSIENTS FOR ISOCAM LW DETECTOR

Boris Fouks[1,2] and Alain Coulais[2,3] and Jonathan Normand[2]

[1]Institute of Radio Engineering and Electronics of Russian Academy of Sciences, 11 Mokhovaya Str., GSP-3, Moscow, 103907, Russia
[2]Institut d'Astrophysique Spatiale (IAS), Batiment 121, Université Paris XI, 91 405 Orsay cedex - France
[3]LERMA, Observatoire de Paris, 61, Av. de l'Observatoire, 75 014 Paris - France

ABSTRACT

Under quasi uniform illumination, the transient response of individual pixel of Si:Ga LW ISOCAM detector is described with high accuracy by one of the Fouks' models, called as Fouks-Schubert model. But this model fails its accuracy if the gradient of illumination between adjacent pixels is high.

We present here a general 3D physical model which allows to describe with a high accuracy most of the cases we have with ISOCAM. Besides the case of quasi uniform illumination it is applicable also to the case of point sources. For the last case, the narrower the source PSF, the higher the accuracy of the 3D model.

This model still uses the (β, λ) parameters which were used for the uniform illumination case. No supplementary parameters are required. But in 3D case, where the exact topology of the detector array should be involved in the account, these two parameters describing the transient properties of each pixel are directly expressed through the parameters characterizing the technological quality of the detector bulk and its contacts. This fact gave the way to optimize future Si:Ga photodetectors.

We present here the direct model and also a preliminary inversion method. We discuss the limitations in the theory, the direct model and the correction method. This new physical model can now be used to reconsider the point source photometry and to remove all the artifact following observation of point sources in the raster maps. It is still important since the LW CAM wavelengths (~5–18 μm) will not be covered by SIRTF and ASTRO-F.

Key words: ISO – CAM LW, Si:Ga, physical model, transient, crosstalk, point sources, photometry

1. INTRODUCTION

It has been shown that, at first order, the transient responses of all the Si:Ga detectors on-board ISO can be described by one model[1] coming form Fouks' theory (Fouks 1992; Fouks 1995) : PHT Si:Ga S and P (Fouks and Schubert 1995), CAM LW (Coulais and Abergel 2000) and SWS b2 (Kester 1999; Kester et al. 2001). This model is a simplification of the Fouks' theory assuming that (1) the illumination of the pixel surface is uniform and (2) the crosstalks between adjacent pixels in the same bulk essentially compensate each other.

It has been observed (Coulais and Abergel 2000; Coulais et al. 2000) for LW CAM that the transient response for point sources cannot be described by this 1D model. Efforts to have a model for modeling the transients of point sources were engaged (Coulais et al. 2000; Coulais and Fouks 2001) with the goal to provide a high accuracy for the photometry of ISO sources (Blommaert 1998; Blommaert et al. 2000).

We report here the availability of such an accurate model. The 3D model is quickly described in Sect. 2, the correction method is explained in Sect. 3. We show examples in Sect. 4 and discussed few problems or limitations not mentioned in Sect. 3. Connections with physical properties are detailed in Sect. 5, and possible application to other Si:Ga photodetectors in Sect. 6.

2. The direct model

The theory and the new full 3D physical model is extensively described in a technical note[2]. Validity ranges are discussed. Second order correction terms are given when the width of the point sources becomes too large in comparison with pixel size.

In order to test it and to apply it quickly to compare with the transient responses of CAM point sources, a simplified 2D model using symmetry properties of the detector array and of the sources was derived. Under uniform illumination, this 2D model was carefully compared with the 1D model and both give the same transients. Without any modification, with the same median $(\overline{\beta}, \overline{\lambda})$ parameters than under uniform illumination, the new model immediately gave the good shape for the transients of the sharpest point sources which are far from the transient response predicted by the 1D model (e.g. TDT 35600501, see Fig. 2).

It has been assumed that the profiles of point sources observed with LW-CAM have, at first order, a circular symmetry. This property was useful to simplify the model from 3D to 2D and to drastically reduce the estimated

[1] The well known so-called Fouks-Schubert model.

[2] This document, annexes and extra examples are available at : `http://www.ias.fr/PPERSO/acoulais/ISO_Sources/`

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computing time. We know this assumption of symmetry is not very exact for CAM (Okumura 1998; Okumura 2000), but (1) we need to use such a 1D profile in order to use the 2D model and (2) the exact shape of the real profile is not well known (Okumura 1998; Okumura 2000) and (3) the errors are not too large and other problems seem to be more critical (see below). On contrary, a good approximation with circular symmetry is available (Okumura 2000).

3. The correction method

Contrary to the 1D case (Coulais and Abergel 2000), no "trivial" and direct correction method can be derived from the equations of this new model. The problem is much more complicated than for the uniform case since we have to process at least the 3×3 pixels centered on the brightest pixel at the same time. In order to extensively check the model on real data, a dichotomic method was setup, in order to find one to three of the six parameters describing one configuration :

- (x, y) position, at scale much smaller than pixel size;
- J_0^b stabilized flux of the background before observing the source;
- J_1^b stabilized flux of the background during observing the source;
- J_1 stabilized flux of the source;
- σ full width at half maximum (FWHM) of the source (possible profiles are Gaussian or Bessel, see below).

Here we have strongly limited the capabilities of the the model since it can take into account a non stabilized initial level and a non uniform initial level, but we did not take into account these extra complications in the method.

We use the following notations: x^i means *initial* value of x, x^e *estimated* value of x, $\widetilde{x}$ *true* value of x.

Estimations for (x, y) and initialization of σ^i are made using 2D Gaussian fitting on each readout in a block, then the median value are used. On simulations, without or with noise, and on real data, this fitting works well. Nevertheless, we made two errors : (1) a very small for (x^i, y^i) which are slighly shifted with respect to $(\widetilde{x}, \widetilde{y})$ depending on the position on the source on the pixel due to inadequate profiles and transient effects and (2) a larger one for σ^i which is not close to $\widetilde{\sigma}$ because of modifications of the source profiles (in σ and in amplitude) during the transient.

The problem to find a good initialization (J_1^i, J_0^i, σ^i) is not simple because the transient response modifies σ and is strongly non linear with J_0^b when J_0^b is close to zero. Furthermore, we can not derive directly J_1^i from data because of transient but also because of effect of PSF width.

Let assume that we know with a high accuracy the J_0^b value. It has been checked on simulations that inside a given range (e.g. $\widetilde{\sigma} \pm 50\%$ and $\widetilde{J_1} \pm 50\%$, constant J_0, x and y) the criterion we used is convex with only one maximum. At large scale (real value $\pm 50\%$), this 2D criteria (with J_1 and σ) has roughly a Gaussian shape with an anti-diagonal orientation. It indicates that we cannot go directly to the optimum with the dichotomy. On the contrary, it has been observed a good property when the estimated values (σ^e, J_1^e) are close (real values $\pm 10\%$) to the true ones (σ^i, J_1^i) : the shape of the criteria becomes similar to a high elliptic Gaussian with axis aligned with σ and J_1. This fact ensure a fast convergence of the dichotomy in the vicinity of the optimum. Furthermore, this indicates that, after the processing of a significant number of sources with different combination of lens and filter, we can tabulate the relationship between the real FWHM PSF $\widetilde{\sigma}$ and the estimated one σ^i during initialization, and concentrate only on J_1 estimation.

During the dichotomy, we use several tests (sign of the difference between the estimations and the data, for the brightest pixel and four closest ones) to indicate simply in which direction we have to move. Because of approximation on the PSF shape, of possible problems due to the specific noise[3] in the transient response for point source, which is much higher than under uniform illumination (Coulais and Fouks 2001) and because we know that for a few number of cases the model is only a first order approximation, several criteria have been considered. It seems that the Least Square Criteria on the brightest pixel and its four closest pixels (i.e. without the four pixels in diagonal) is the best candidate. Because of the approximation due to the non symmetrical PSF, we see that, with a Gaussian PSF, we make the highest errors for them, in comparison to the brightest one and the four closest ones. Furthermore, the diagonal pixels generally did not contribute a lot.

We are currently assuming that the unknown values are: J_0^b, J_1, σ. σ is assumed unknown because : (1) the width of the PSFs are changing during transient responses, (2) we assume now a Gaussian PSF but the real PSFs are closer to the Bessel ones. It is clear that for a given configuration (a lens and a filter) we should have a fixed value for σ in the future. Since we have processed only a limited number of sources, such shortcut can not be done now. But such tabulation will be very useful to speedup later the correction method. This model is also the way to reconsider on firm bases the computation of the FWHM of the PSF by removing the effects of transients in FWHM estimation, and we expect a reduction of error bars for FWHM with the help of this model.

For most of the sources (more than thirty sources) on which we have applied this correction method the adjustment was done with a good accuracy in 20 to 30 iterations. Depending on the number of readouts on which the transients are computed, time for one iteration is $\sim$ 5–30 s.

[3] On pixels under high illumination gradients we have a particular noise with high amplitude in comparison to the noise measured under uniform illumination. This noise is strongly correlated between two adjacent pixels. This exchange of currents (crosstalk) between adjacent pixels reflects the satelitte jitter.

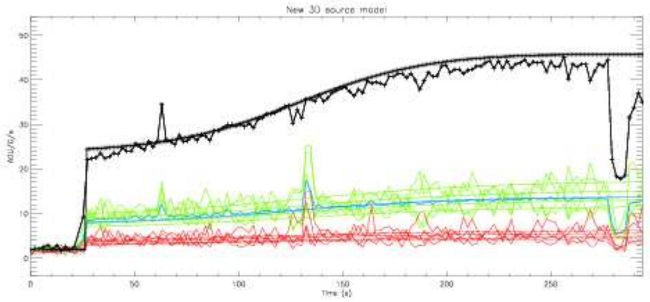

Figure 1. TDT 07803313 is typical of quick observation for IR stars. Only a very limited time before the observation is available which may give problems to accurately determine whether the initial conditions are stabilized. In this case, the stabilization is good, and the illumination before the source observation is also well uniform. In this configuration (lens 1.5 ArcSec and filter LW 6), the PSF width is small enough to ensure a good accuracy for the model.

When the uncertainties on J_0 are high (e.g. when J_0 is close to zero, say, $J_0 \lesssim 5\,\mathrm{ADU}$) or when J_0 is not uniform, we need about two times more iterations.

Since the model did not need to find *adhoc* parameters we are looking only for x, y, J_0, J_1, σ. For a well characterized configuration, J_0 and σ are well known, it is easy to find (x, y) at few percents on few readouts. Then we are looking for J_1 only ! Flux for sources observed with few numbers of readouts can also be very well estimated; it has been confirmed on simulations and on data where we reduce the number of readouts.

4. Examples and limitations

Since the ground based test and in-flight electrical setups are different that results in different (β, λ) parameters (Coulais and Abergel 2001 and references therein), we have applied the model and the correction method only on in-flight data.

Up to now, not all the CAM configurations have been checked (10 filters LW 1–LW 10 and 4 lenses (1.5, 3, 6 and 12 ArcSec)) nor the full range for sources and backgrounds (before and during source observation). Nevertheless, about thirty sources have been successfully processed (in $\sim$ twenty five different TDTs). We give here three independent examples : on Fig. 1, a very simple case; on Fig. 2, a case where the downward transient can be also studied and the Fig. 3 shows one of the worst cases, with the second order correction term.

We say that the larger the PSF, the less accurate the 2D model. We are in the limit of validity for the model for the four CAM configurations giving the largest PSF : lens 1.5 ArcSec and filters LW 3, 9 ,10, 8. Nevertheless the $3{\times}3$ mean transients are in general in good agreement between model and data.

The physical reason of this difference is clear. Because of the topology of the CAM array (very long intercontact

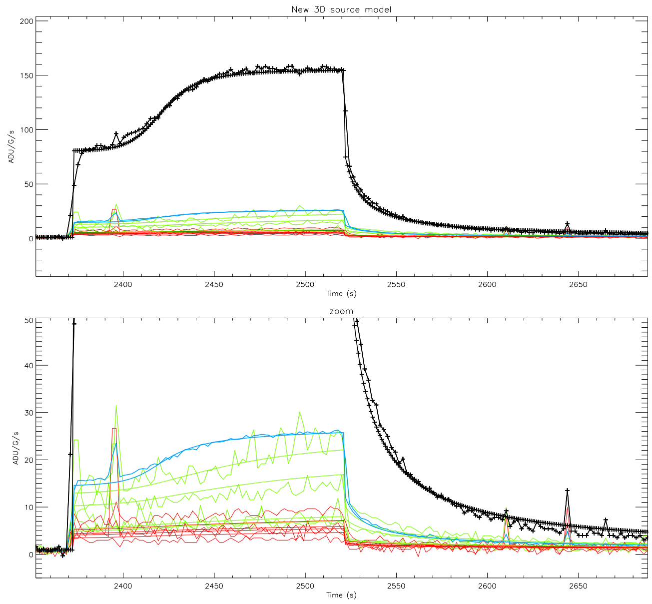

Figure 2. TDT 35600501 is very interesting to check different effects in the model because the same source is observed in the same configuration (Lens 3, Filter LW 2) by different pixels several times (∼36 elementary observations in the same TDT with same background). Data and model are superimposed here for upward and downward transients. Only a fraction of readout gives the shift between data and model for the downward step. On the upper panel, we see the quasi-perfect agreement for the brightest pixel. On the lower panel, the change in Y-scale shown that, despite a good global agreement, we have to improve the agreement for time between 2370-2420. For all the tests reported in this note, we did not take into account the inter-pixel variations for the (β, λ) parameters. This TDT should be useful to study this dependence.

distance if compared with the pixel size, ratio is 5:1) here it is essential the effect of the interpixel currents induced by very small radial fields. This idea, which clearly follows from the physics of the detector operation has been confirmed by the estimations of this effect in limiting cases and their comparison with experimental data. This effect is not considered yet in the used model, but can be taken into account in its following development.

This departure between model and data is clear especially for the overshoot for the brightest pixel during the upward transient. The second order term helps to improve the description the transient response for the brightest pixel. This term clearly improves the description of transients for these four configurations. We show a difficult example on Fig. 3.

It has been mentioned several times that we still have troubles due to limited accuracies in dark correction. It has been explained that the Fouks model allows to derive the absolute levels (see for ex. Coulais and Abergel 2002), unfortunately, only a very limited number of steps of flux under uniform illumination can be processed (Coulais and

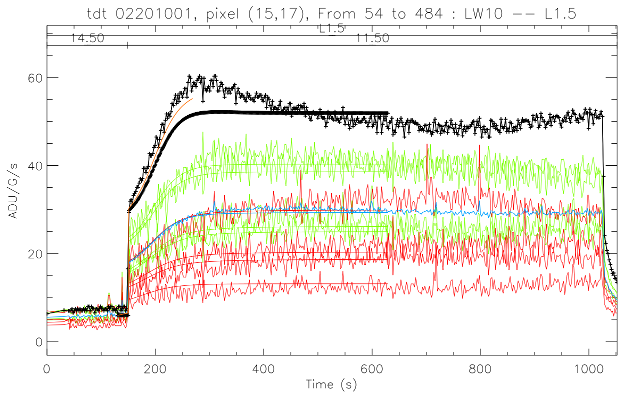

Figure 3. The combination of filter LW10 and lens 1.5 ArcSec gives one of the four bad combinations for the model presented in this paper. In these cases, it is expected that the model underestimated the real transient for the brightest pixel. This effect is described in the Fouks technical note. A second order correction term is computed, and is superimposed here (see the curve limited in range between T=150 and 275, in between the data and the model for the brightest pixel.) Furthermore, the study of this source is very complex because the illumination before the source is not uniform. It is easy to see when changing initial conditions J_0^b in the model how big are the change for the transient shape of brightest pixel. Despite all these problems, the overall responses are not too far from the real responses, and the 3×3 mean curves overlap.

Abergel 2000). From preliminary tests on point sources, it may be possible to use this new model and experimental data of point sources to recover accurate dark level when J_0 is close to zero and too noisy. Two interesting examples we have studied are sources in TDT 10801813 and 35600602. For the first one, the dispersion of the background before observing the source is very high. Transient correction allows to derive a estimation not only of this source but also of the mean background before the source.

As explained in Sect.3, we have written the model only in a 2D way, despite the new model is fully 3D. As a result, the profile of the source can be only a circular one. This simplification was done for simplicity shake and for testability. Nevertheless we are not sure now that the full 3D code gives a higher usefulness than the 2D one, since no simple inversion method can be apply on it. A large number of possible problems must checked before working on the 3D model : dependence to the (x, y) values and the satellite jitter, to the PSF profile, to the limited accuracy of the dark level, to the no uniform no stabilized initial level (J_0).

5. Relation with photodetector technology

This 2D model still uses the (β, λ) parameters used for the 1D model for the uniform illumination case (Coulais and Abergel 2000). No supplementary parameters are required. These parameters are related for each pixel to the instantaneous jump (β) and the time constant (λ) The parameters (β, λ) can be converted into two physical parameters $(E_j, Gain)$ which are directly related to the quality of the contacts and the homogeneity of the bulk, respectively.

These parameters are connected to the detector quality from the technology point of view. Dispersion of these parameters through the array indicates poorly controlled technological processes. Theoretical limits are also known from the Fouks Theory. For ISOCAM (see description of (β, λ) maps in Coulais and Abergel 2000), we have found that (1) the bulk quality of the matrix array is rather good and is well uniform, but (2) the quality of contacts is not uniform and is far from theoretical limits. To be closer to these limits should give a transient response up to five time faster. Nevertheless CAM detector is a good one since it is described by zero and first orders models from the Fouks theory in a large range of incoming flux, which allows an very accurate correction of its transient responses, despite a "small" instantaneous jump and a "long" time constant.

6. Re-use for other Si:Ga photodetectors

This model should be reusable for any Si:Ga detector, when the electrical voltage is not too strong, in order to avoid extra non linear effects. On-board ISO, SWS b2 linear array and PHT S (linear array) and P (single pixel) are Si:Ga too. But from our current understanding of the status of the processing of SWS b2 and PHT S & P, the first priority for SWS b2 is to apply the model for non linearity close to the avalanche breakdown (Kester et al. 2001) and for PHT is to apply the correction method detailed in Coulais and Abergel 2000 and assuming the two parameters (β, λ) are constant.

7. Conclusion

We are now able to model and correct with a high accuracy the transient response for point sources and under uniform illumination for the Si:Ga LW ISOCAM 32×32 array. The transient response of the mean value of the 3×3 pixels centered of the brightest one is described at per-cent level. The transient response of individual pixels are described at few percent level. Worst cases for individual pixels are for lens 1.5 ArcSec and filters LW 3, 9, 10 and 8. One time again it has been proved (1) the power of such physical model and (2) the good quality of CAM detector array.

We are ready to provide this 2D model and to assist any scientist who would like to reconsider the LW CAM point source photometry.

One time again, we mentioned that the Fouks theory was successful for all the Si:Ga but also for all the studied Ge:Ga on-board ISO with models described before ISO flight (Fouks 1992; Coulais et al. 2002). This theory should be useful for the photodetectors in preparation (SIRTF MIPS, Astro-F FIR and FTS, Herschel PACS) even if the theory must be transformed into specific models adapted to the peculiarities of each detectors.

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