TRANSIENT CORRECTION OF THE ISOCAM DATA WITH THE FOUKS-SCHUBERT MODEL : FIRST RESULTS *

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ABSTRACT

We have studied the behavior of the LW ISOCAM detector for the short term transient and applied the Fouks-Schubert model developed for PHT-S, the spectrometer in ISOPHOT. For uniform illumination, this model describes upward and downward steps of flux with an accuracy better than 1%.

For each pixel of the detector, two parameters are used. We have computed their values for the 32x32 pixels of the camera. No evolution is visible during the mission. On the other hand, spatial variations from pixel to pixel are significant.

We present an inversion method of the Fouks-Schubert model. Without any fitting and *for uniform illumination*, data are corrected with a photometric accuracy of $\sim$ 1%. The accuracy of the previous methods was not better than $\sim$ 10% (for instance with the *old IAS model* used up to now to process most of the data). This approach may be used for others ISO detectors.

We are currently working on point sources and the problem of long term drift.

1. ISOCAM TRANSIENTS DESCRIPTION

The transient behavior of the LW ISOCAM detector has been analyzed during ground-based observations at IAS (Pérault et al. 1994) and the current understanding after the mission is detailed in Abergel et al. (1999). The response is made of a short-term transient and a long-term transient, with typical time constants equal to one minute and one hour respectively. This report is focused on the short term transient.

The short term transient is made (1) of a jump of about 60% of the total step and (2) of a signal behavior which depends on the flux history, the amplitude of the current step, the pixel position on the detector matrix and the local spatial gradient illumination (Abergel et al. 1999). An important point is that the short term transient in the upward and the downward directions are not symmetrical (Figure 1). The IAS method (Abergel et al. 1999) which is actually used to process the data has not a precision better than $\sim$ 10%, since it is not able to produce the asymmetry observed in the data.

We have analyzed the asymmetry of the response using data obtained during the preflight characterization (Pérault et al. 1994) and the revolution 16 of the Performance Verification phase (PV phase). Some upward steps from a low level (close to 0) to a high level (from 30 to 800 ADU/gain) are plotted in log/log and their derivatives in lin/lin (Figure 1). In the derivatives, a bell curve clearly appears. For lower jumps (lower than $\simeq$ 50 ADU/gain) this shape is hidden by the noise. For upward steps higher than $\sim$ 100 ADU/gain, a drift due to long term transients is also visible.

Downward steps have been studied as upward steps (Figure 1). The decreases plotted in log/log give always quasi-linear lines a few readouts after the jump of flux. The value of the slope depends on both the initial and the final flux. Therefore, we have concluded that the general shape is more or less hyperbolic. No bell curve is visible in the derivatives. There is no visible long term drift.

2. THE FOUKS-SCHUBERT MODEL (FS MODEL)

2.1. Origin of the Fouks-Schubert model

The ISOPHOT's Si:Ga array of PHT-S channel has been extensively studied by Fouks and Schubert from a theoretical point of view (Fouks 1992; Schubert et al. 1994; Fouks and Schubert 1995; Schubert et al. 1995). It is the result of two decades of efforts (theoretical and experimental) on extrinsic photodetectors by Fouks et al. (Suris and Fouks 1980; Fouks 1981a; Fouks 1981b; Vinokurov and Fouks 1991). The LW ISOCAM detector is a Si:Ga array too, but hybridized with Indium.

*ISO is an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

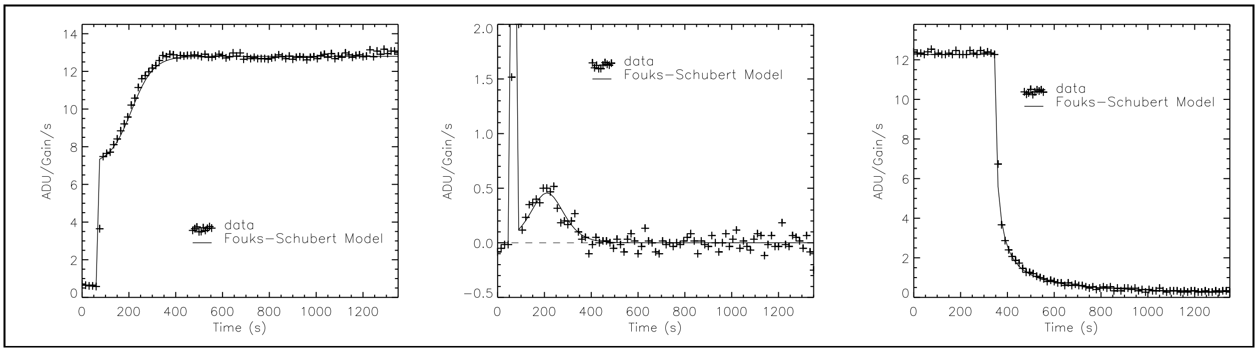

Figure 1. The levels before the flux change is constant and stabilized. Left and middle panels : Upward step. Right panel : Downward step. Left panel : data (+) and Fouks-Schubert model (line) in linear scales. Middle panel : derivative of the data (+) and model (solid line). We have used Equation 1, with : $\beta = 0.55$, $\lambda = 600$ ADU/Gain, $J_0 = 0.67$ ADU/Gain/s and $J_\infty = 12.8$ ADU/Gain/s. For upward and downward steps, the errors are below $\sim$ 3 %.

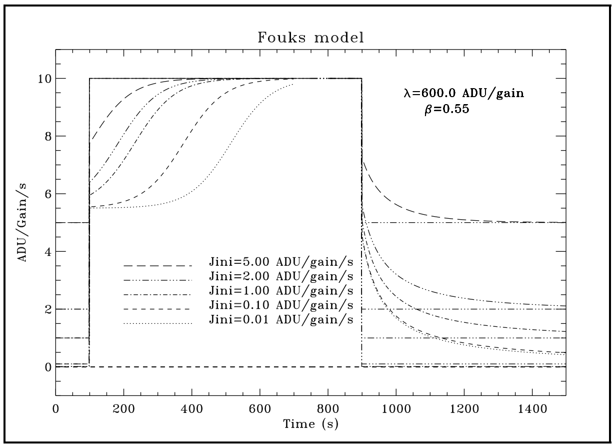

Figure 2. Fouks-Schubert model of the response for upward and downward steps between five different levels (0.01, 0.1, 1.0, 2.0 and 5.0 ADU/gain) to one high level (10 ADU/gain). For all these simulations, β and λ are constant.

2.2. The Fouks-Schubert model

The theoretical model of Fouks and Schubert is based on the first order description of the physics inside the bulk of an extrinsic p-type photo-conductor as the PHT-S channel of ISOPHOT and the LW ISOCAM ones (Fouks and Schubert 1995). The boundaries conditions are taken into account, and, after some hypothesis about the dominant physical processes, a set of conditions and differential equations is obtained. Solving the differential equations that describe what happen inside the detector, they find a non-linear equation.

They give first a model which describes the response to a step of flux from a constant level J^∞_{n-1} to a constant level J^∞_n at time $t = 0$:

$$J_n(t) = \beta J^\infty_n + \frac{(1-\beta) J^\infty_n J^\infty_{n-1}}{J^\infty_{n-1} + (J^\infty_n - J^\infty_{n-1})\ exp(-t/\tau)} \quad (1)$$

where J^∞_n is the stabilized current for the step n (it is the observed flux too !) and β the instantaneous response just after the flux change. Fouks and Schubert point out that the theory gives a simple relationship between the time constant τ and J^∞_n over several orders of magnitude : $\tau = \lambda / J^\infty_n$. They also observe experimentally this dependence which seems to be also applicable to LW ISOCAM data (Abergel et al. 1999).

The bell curve of the derivative of the response after upward steps (see Section 1. and Figure 1) increases with $J^\infty_n - J^\infty_{n-1}$. It is a non-linear effect that cannot be "read" directly in the equation, but easily seen when the detector behavior is studied numerically (Figure 1) or analytically (by derivating Equation 1). This effect produces the asymmetry of the response not described by previous models (*old IAS model*, simplified IPAC model (Ganga et al. 1998), ...). A few examples of the behavior of the FS model are given on Figure 2.

The Equation 1 can only be used for transitions from a stabilized level to another one. The following enhancement allows to describe a not stabilized detector output $J_n(t)$ from a recursive point of view :

$$J_n(t) = \beta J^\infty_n + \frac{(1-\beta)(J^{ini}_n - \beta J^\infty_n) J^\infty_n}{J^{ini}_n - \beta J^\infty_n + (J^\infty_n - J^{ini}_n) e^{-(t-t_n)/\tau}}, \quad (2)$$

with the same notations as in Equation 1 and J^{ini}_n the signal *just after* the jump at time t_n. In this equation, the state of the previous block is contained in J^{ini}_n, which can be related with the previous flux and the current stabilized flux values (J^∞_{n-1} and J^∞_n) and the final previous flux just before the jump J^{end}_{n-1} by the continuity equation :

$$J^{ini}_n = J^{end}_{n-1} + \beta (J^\infty_n - J^\infty_{n-1}). \quad (3)$$

Finally, we obtain from Equation 3 and Equation 2 :

$$J_n(t) = \beta J^\infty_n + ...$$

$$\frac{(1-\beta)(J^{end}_{n-1} - \beta J^\infty_{n-1}) J^\infty_n}{(J^{end}_{n-1} - \beta J^\infty_{n-1}) + ((1-\beta) J^\infty_n - (J^{end}_{n-1} - \beta J^\infty_{n-1})) e^{-(t-t_n)/\tau}}. \quad (4)$$

$J_n(t)$ depends on J^∞_n, J^∞_{n-1} and J^{end}_{n-1}.

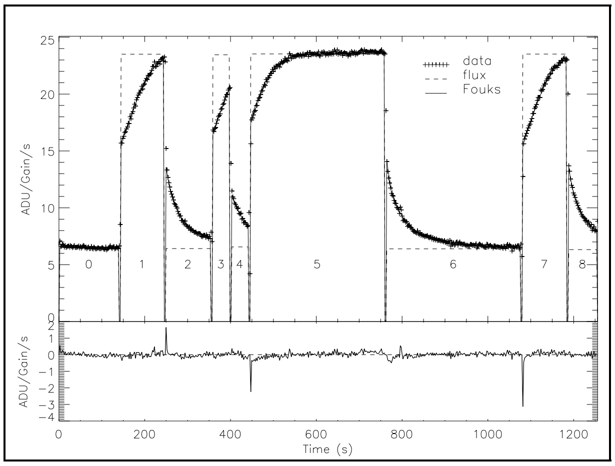

Figure 3. Upper panel : data (+) taken during the Performance Verification phase (Revolution 16), together with the estimated flux (dashed line) and the modeled response (thin continuous line) to the estimated flux. Lower : Residue. Some evidences of a not perfect fitting are seen at the beginning and at the end of block 5.

3. TRANSIENT CORRECTION I : DATA FITTING OF DEDICATED DATA

To check whether the FS model allows to reproduce properly the response of the LW channel on ISOCAM, we have fitted block by block data taken during the PV phase with Equation 1. For each block, the camera configuration and the pointing are constant. We have assumed that β and λ are constant over the whole observation. Their values have been fixed manually. We have adjusted J_n^∞ (and also an offset since for this revolution, the accuracy of the dark level was limited). We see on Figure 3 that the precision is $\sim$1%. This example is only illustrative. We have the same kind of results for different datasets from different revolutions.

4. TRANSIENT CORRECTION II : INVERSION METHODS

We consider a set of N successive readouts $J_n(t)$, where t is the time of the end of each integration. The transient correction we have developed consist to compute, for n going from 0 to $N-1$, J_n^∞ from the measured response $J_n(t)$. By inverting Equation 4, we can compute J_n^∞ from $J_n(t)$, J_{n-1}^∞ and J_{n-1}^{end}. The Equation 4 is non-linear (because of the exponential term). Different methods are possible (Coulais et al. 1999) :

- A second order development of the exponential give a third order polynomial in J_n^∞. The closest root to the measured value $J_n(t)$ is chosen (quickest method);
- using the monotonic property of the Equation 2, iterative solution can be found from initialization of J_n^∞ by $J_n(t)$;

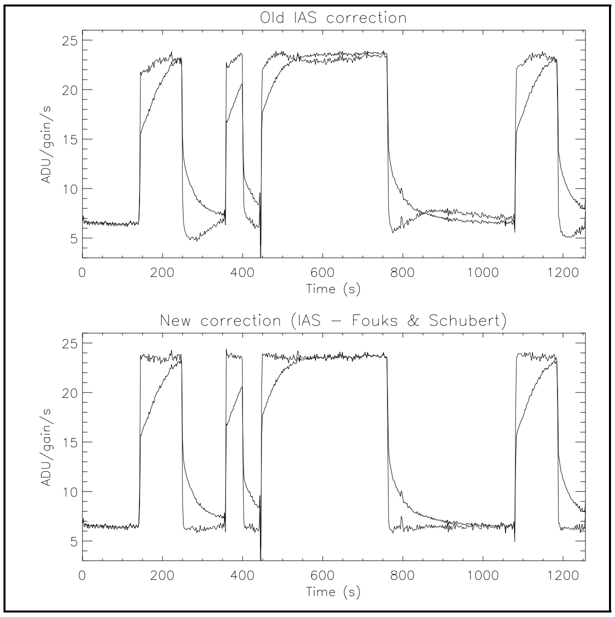

Figure 4. Comparison of inversions with the old IAS method (top) and with the new method (button). The mean value of the central square is plotted as a function of the readout number. These data are taken from revolution 16 of the PV phase. The zodiacal background was continuously observed, and the input sky brightness modulated by moving the filter wheel. The integration time per frame was 2.1 s.

- the Müller routine (in Numerical recipes) finds roots of non-linear equations when three initial points are provided (more time consuming).

Even with the slowest method, the computed times are typically ten times lower than with the *old IAS method* (Abergel et al. 1999), for an accuracy ten time better.

Figures 4 and 5 present two illustrative results, for a two level case and for an observation with the Circular Variable Filter (CVF) : **after correction, we see that the data can now be used on the whole spectral range**. It was generally not the case with previous methods.

5. LIMITATIONS AND WORKS IN PROGRESS

We have significantly enhanced the accuracy of the correction for uniform illuminations. We have also analyzed the spatial and temporal variations of the two parameters β and λ. Two pass fitting was applied on different data sets to computed 32×32 maps of the two parameters. We have obtained $<\beta>=$ 0.53 with a standard dispersion of 0.02 and $<\lambda>=$ 570 ADU/Gain Frame with a standard dispersion of 100 ADU/Gain. We have evidence of spatial variations from pixel to pixel, reproducible on independent datasets (see details in Coulais et al. 1999).

For point sources, the correction fails with the values of β and λ adopted for uniform illumination. We

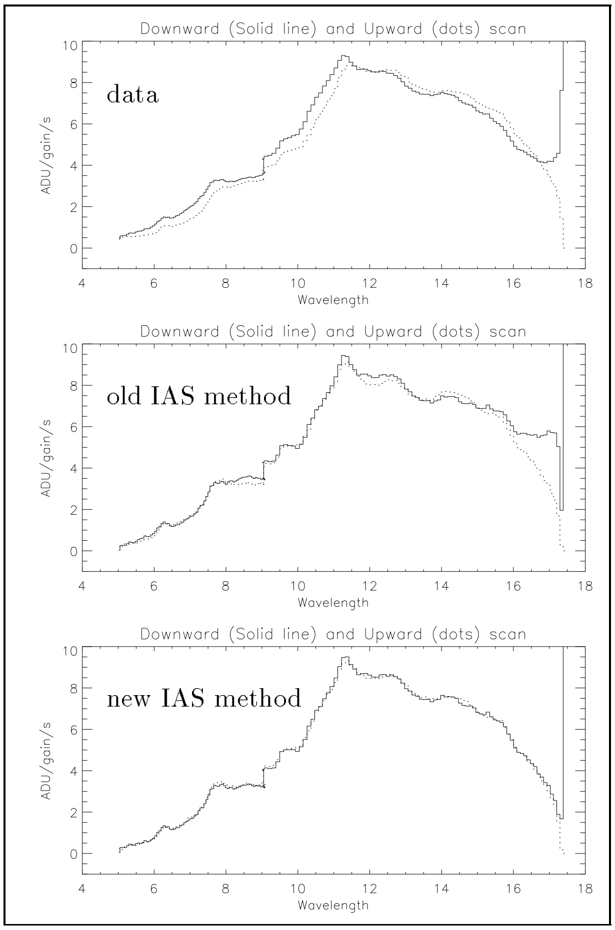

Figure 5. Comparison between the corrections of CVF data with the old IAS method *and the new one, for downward and upward scanning starting from 17.5 µm. Upper panel : Raw data of a full CVF scans (downward and upward scans in wavelength are represented by the solid line and the dots respectively). Middle panel : Correction with the* old IAS method. *The spectral features are at the same position, but the continuum is not correct everywhere. Bottom panel : Correction with the new method we propose : (1) the shape of the downward scan is correct over the full range, even at the beginning of the observation, (2) upward and downward are identical over the full spectral range : the continuum in properly determined.*

believe this is due to the cross-talk between pixels. We are currently working on this problem. The correction fails also for the long term drift, but the FS model has not been developed for that !

6. APPLICATION OF SURIS-FOUKS MODELS FOR OTHER ISO DETECTORS ?

All the ISO detectors (LWS, SWS, PHOT and CAM) are based on extrinsic semiconductors technology working under low illumination. Ground-based tests and in-flight observations show that the non-linear behavior and the temperature dependence of the response curves of these detectors seem perfectly reproducible (same illumination history give same measurements).

Different authors (Suris and Fouks (1980); Fouks (1981a); Fouks (1981b); Vinokurov and Fouks (1991); Fouks (1992)) have solved the solid state equations for different kinds of extrinsic detectors. One of the strongest hypothesis is the bulk thickness : with a thin thickness, an *hook* behavior is predicted.

The transient behavior of others detectors on ISO may also be described by this kind of models. For example, the *hook* behavior in PHT-P1 (Groezinger et al. 1992) seems properly described by an analytical model (Vinokurov and Fouks 1991; Fouks 1992). (for LWS : Church et al. 1992b; Church et al. 1992a; for SWS : Wensink et al. 1992). In our opinion, it is now necessary to check whether these models can be used for the different ISO detectors. We have seen that such analytical models can be analytically or numerically inverted. Therefore a transient correction should also be possible without any fitting or parameters adjustments. It should allow a significant increase of the final accuracy of processed data.

ACKNOWLEDGMENTS

A. Coulais would like to thank the CNES (France) for its financial support.

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