Transient correction of the ISOCAM data with the Fouks-Schubert model: first results

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1 Introduction

The LW channel of the ISOCAM detector is an extrinsic infrared photo-detector working under low background conditions. When a change occurs in the photon flux level, a new stabilized output level will be achieved after a transient phase. For most of the astronomical observations with the ISOCAM detector on board the ISO satellite, the response is NEVER stabilized. In the general case, the stabilized levels have to be estimated from not stabilized observations.

2 Transient behavior

The transient behavior of the LW ISOCAM detector has been analyzed during ground-based observations at IAS (Perault et al., 1994) and the current understanding 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 focus on the short term transient.

The short term transient is made of (1) a jump of about 60% of the total step and (2) 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 transient in the upward and the downward are not symmetrical. The IAS method (Abergel et al., 1999) which is actually used to process the data has not a precision better than $\sim$ 10%, mainly since it is not able to produce any asymmetry.

We have analyzed the asymmetry of the response using the data obtained during the preflight characterization (Perault et al., 1994) and the revolution 16 of the performance Verification Phase.

Some upward steps from a low level (a flux close to zero) to a high level (flux from 30 to 800 ADU/gain) have been plotted in log/log and their derivatives in lin/lin (see fig. 1). In the derivatives, a bell curve clearly appears when the jump is higher than $\simeq$ 50 ADU/gain. In fact, the bell curve at lower levels is hidden by the noise level of the derivatives. For steps higher than $\sim$ 100 ADU/gain, a drift due to long term transients is also visible on the response curve.

Several downward steps have been studied similarly than the upward steps (see fig. 2). The decreases plotted in log/log give always quasi-linear lines a few readout after the flux decrease, with different values of the slope depending on both of the initial and the final flux (flux difference or flux ratio ?). Therefore, we concluded that the general shape is more or less hyperbolic. No bell curve have been seeing in the derivatives.

Finally, we confirm that upward and downward steps are not symmetrical.

3 Transient modelisation

Several empirical models have been proposed to describe and to deal with the short term transient:

- the CEA/SAp model (Delattre et al., 1996);
- the first empirical model developed by IPAC;
- the IAS model (Abergel et al., 1996; Abergel et al., 1999);
- the IRA model (Lari, 1997).

In all theses models, two important parameters are always used: the instantaneous step β (jump) and the time constant τ. Following the first attempts to modelized the physics of the detector, it is supposed that β is constant and τ inversely proportional to the input flux J: $\tau = \lambda/J$, where λ is a constant (which may depend on the pixel number).

For the CEA and IPAC models, the approach is very simple since the are based only on simple exponential equations. These two models fail on some points since they are are symmetrical for upward and downward transients and do not allow to take into account the flux history. The β and λ values are fitted block by block (one block corresponding to a camera configuration so that one block corresponds to one flux value) and are not constant over the useful range. Moreover these models can describe neither the bell shape of the derivative curve for upward steps nor the hyperbolic curve for downward steps.

The IAS model takes into account the history of the input flux, using a temporal integration starting from $t = -\infty$. With the constant parameters $\beta = 0.6$ and $\lambda = 1200$ ADU/Gain/s, this model can be used over a large range of flux with a precision from 5 to 10 % the flux step. However, severe limitations are known (Abergel et al., 1999). As for the two first models, this model is a symmetrical one. Furthermore, it cannot describe fully both upward (no bell curve) and downward steps (not hyperbolic). An interesting point is that the two parameters β and λ are constant over the full dynamical range of the observation.

The IRA model is very different since it is based on a set of two non-linear differential equations. An enhanced version of this model is supposed to be able to remove the glitches too. From an experimental point of view, this approach have some practical limitations since the instantaneous step β and the value of λ are not constant, but must be adjusted for each block. Considering the published results (Lari, 1997), we can see that some transients and glitches seems to have been properly corrected, but it is actually difficult to conclude whether this method can be applied to general cases.

In conclusion, up to now there is no model which allow to describe with a good precision the complex response of the detector. Therefore, the photometric accuracy of the LW channel of ISOCAM is not better than 5 to 10 % (Abergel et al., 1999).

4 Fouks-Schubert transient model

4.1 Why 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 (Schubert et al., 1994; Fouks and Schubert, 1995; Schubert et al., 1995). The LW ISOCAM detector is a Si:Ga array too, but hibridized with Indium.

The goal of this paper is to check whether if the Fouks-Schubert model can be applied for the LW ISOCAM detector. Because the ISOCAM experiment was extensively studied before the launch (Perault et al., 1994; Cesarsky et al., 1996) and with the data recorded during the Performance Verification Phase (revolution 16), we have a lot of data sets which can be used to test this model.

4.2 The Fouks-Schubert models

The Fouks-Schubert model is a theoretical one based on the first order description of what is supposed to happen inside the bulk of an extrinsic p-type photo-conductor a the PHT-S channel of ISOPHOT and the LW ISOCAM ones (Fouks and Schubert, 1995). The boundaries conditions are take 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 step from a constant level J_{n-1}^{∞} to a constant level J_n^{∞} at time zero:

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

where J_n^{∞} is the stabilized current for the step n (it is the observed flux too !), β is the initial step just after the flux change and τ is the time constant in the exponential. Fouks and Schubert point out that the theory gives a simple relationship between τ and J_n^{∞} over several order of magnitude : $\tau = \lambda / J_n^{\infty}$. They also observe experimentally this relation. This relation seems to be also applicable to LW ISOCAM data (Abergel et al., 1999).

This model is not symmetrical because of (1) the difference $(J_n^{\infty} - J_{n-1}^{\infty})$ in the denominator and (2) τ is function of J_n^{∞}.

With a few tests, it is obvious that, with this model, the bell effect increase when the difference $(J_n^{\infty} - J_{n-1}^{\infty})$ increases. It is a non-linear effect that cannot be "read" directly in the equation, but easily seen when the detector behavior is numerically studied (see fig. 1). Another way to quantify this bell curve is to compute analytically the derivative of the eq. 1. It is a new effect that does not appear in the other empirical models describe before (see Sect. 3).

Examples of the behavior of the Fouks-Schubert model are given on fig 3.

This model can be used to study only transitions from a constant level to another different one. The following enhancement allows to describe a not stabilized detector output $J_n(t)$ from a recursive point of view :

$$J_n(t) = \beta J_n^\infty + \frac{(1-\beta)(J_n^{ini} - \beta J_n^\infty)J_n^\infty}{J_n^{ini} - \beta J_n^\infty + (J_n^\infty - J_n^{ini})exp(-(t-t_n)/\tau)}, \tag{2}$$

with the same notations than in eq. 1 and J_n^{ini} the signal *just after* the jump at time t_n. In this equation, the state of the previous block is contained in the J_n^{ini} value, 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_{n-1}^{final} by the continuity equation :

$$J_n^{ini} = J_{n-1}^{final} + \beta(J_n^\infty - J_{n-1}^\infty). \tag{3}$$

Equation 2 allows to describe each block separately, while the consistence between adjusted values for consecutive blocks is tested with eq. 3.

4.3 Comparison with experimental data

We use data obtained during the ISOCAM calibration and the preflight characterization ground phase (Perault et al., 1994) and revolution 16 of the PV phase.

On Figs. 4, 5 and 6 are compared the original data (thick line) taking during the revolution 16 and the responses computed with the Fouks-Schubert model (thin line) and the estimated levels (dashed line). On the figures 4, and 5, the agreement between the data and the Fouks-Schubert model is better than 2% and the apparent drifts are limited (see the residue). These results are very preliminary. We hope to solve the problem on fig. 6 by using the same model but with temperature variations.

5 Transient correction

At that time, this part is the most explorative part of this work. We use a very simple and iterative approach to estimate the successive values of the incident flux from the data. The data cube is supposed to be deglitched and dark subtracted. Each pixel is treated separately, as an independent time series.

Using the OTFLAG information (which indicates whether the satellite is pointing to a given direction or is changing from a direction to another), the time series for each pixel is splitted into several blocks. We start from an initial estimate for each block, for example the median measured value. The Fouks-Schubert model 2 (defined by Eq. 2) is applied with these first estimates to compute what would be the ISOCAM response for all the blocks. A difference is computed block by block between the theoretical response for the initial estimates and the data. A new estimate is computed for the block with the highest difference: we add half the difference to the previous estimate for this block with a constrain of positivity for the lowest levels (the flux is always positive).

Since the parameters β and λ appear to be constant (we have not already checked for pixel to pixel variations), we can actually conclude that this model is very promising. This process converges typically after about 100 to 1500 iterations, for 5 to 15 blocks with different sizes and noise levels. From time to time, errors seem to occur, but their are due to unpredicted features (for instance due to cross-talk) or glitches. We know this recursive approach is not the most efficient. If it appears that this model is optimal for the LW channel of ISOCAM, specific methods will be developed.

The data of Fig. 7 come from the ρ Ophiuchus observation data set. We have applied our iterative method with 1500 iterations. The result can be compared to the IAS method. For example, the decreasing phases is better corrected with the new method.

6 Conclusion

This preliminary analysis shows that the Fouks-Schubert model allows a significant enhancement of the short term transient description. A direct consequence will be a better photometric accuracy. Systematic tests still have to be done to confirm that the Fouks-Schubert is optimal. Then a new correction method will be developed. The problem of long term drifts is still opened. It may be due to temperature variations.

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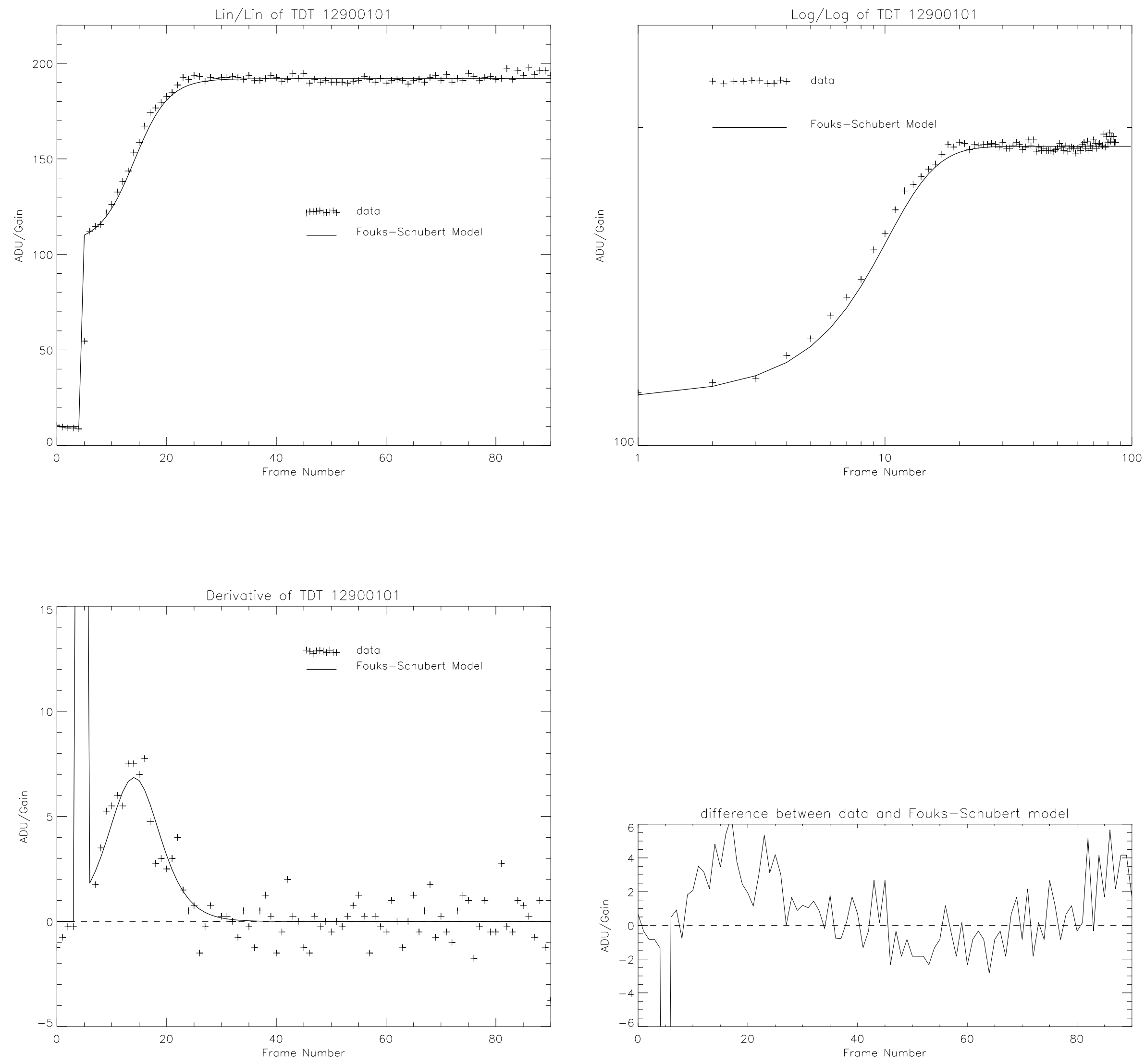

Figure 1: These data were recorded during inflight observations. On the upper left panel are plotted the data (+) and the Fouks-Schubert model (line) in linear scales. The frame range is reduced because we do not study here the long term transient ... On the upper right panel are plotted the data (+) and the Fouks-Schubert model (line) in log/log scales. The levels before and after the flux change are supposed to be constant and quite stabilized. Therefore, we used Eq. 1, with: $\beta = 0.55$, $\lambda = 600.0$ ADU/Gain $\times$ Frame, $J_0 = 10.0$ ADU/Gain and $J_\infty = 192.0$ ADU/Gain. On the lower right panel is plotted the difference between the data and the model. The errors are below ~ 3 %. On the lower left panel is plotted the derivative for the data (+) and for the model (line), the range is limited in order to show the *bell curve* shape.

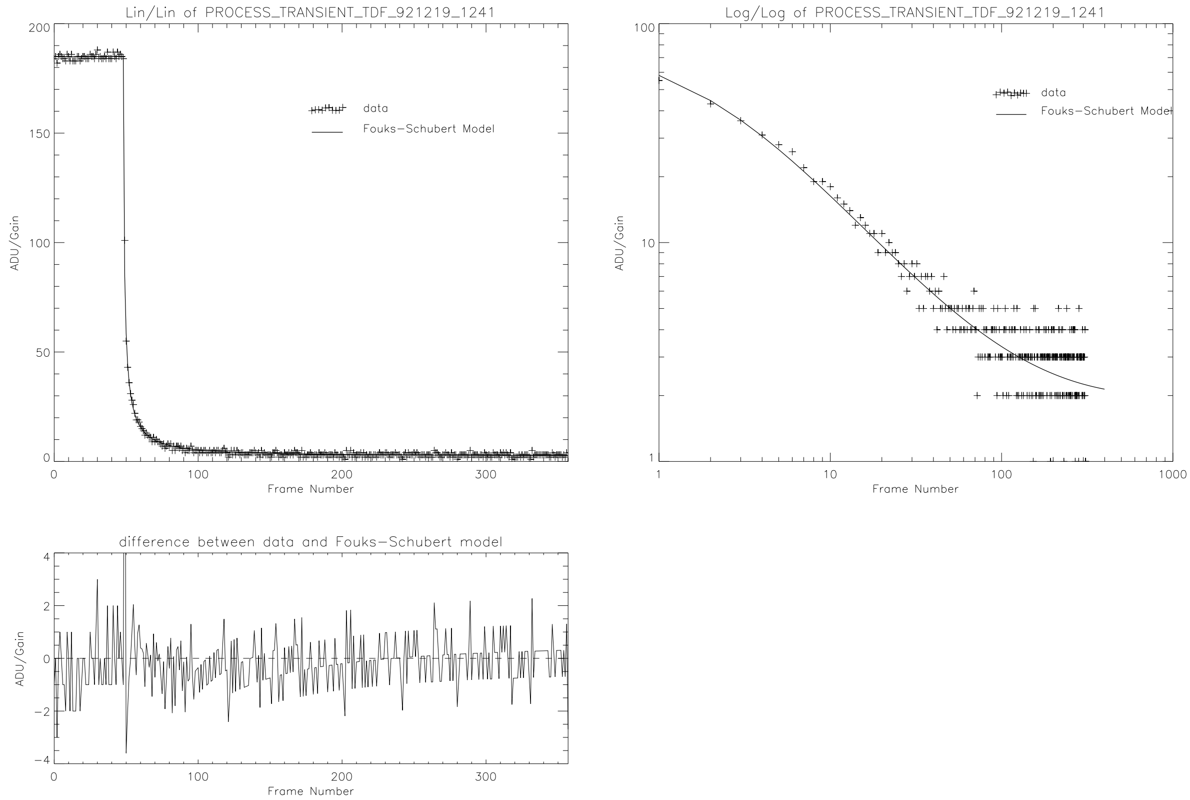

Figure 2: On the upper left panel are plotted the data (+) and the Fouks-Schubert model (line) in linear scales. On the upper right panel are plotted the data (+) and the Fouks-Schubert model (line) in log/log scales, in order to show the quasi linear shape of the downward step. The levels before and after the flux change are supposed to be constant and quite stabilized. Therefore, we used Eq. 1, with: $\beta = 0.55$, $\lambda = 400.0$ ADU/Gain $\times$ Frame, $J_0 = 184.0$ ADU/Gain and $J_\infty = 2.0$ ADU/Gain. On the lower left panel is plotted the difference between the data and the model. The errors are below ~ 1 % !

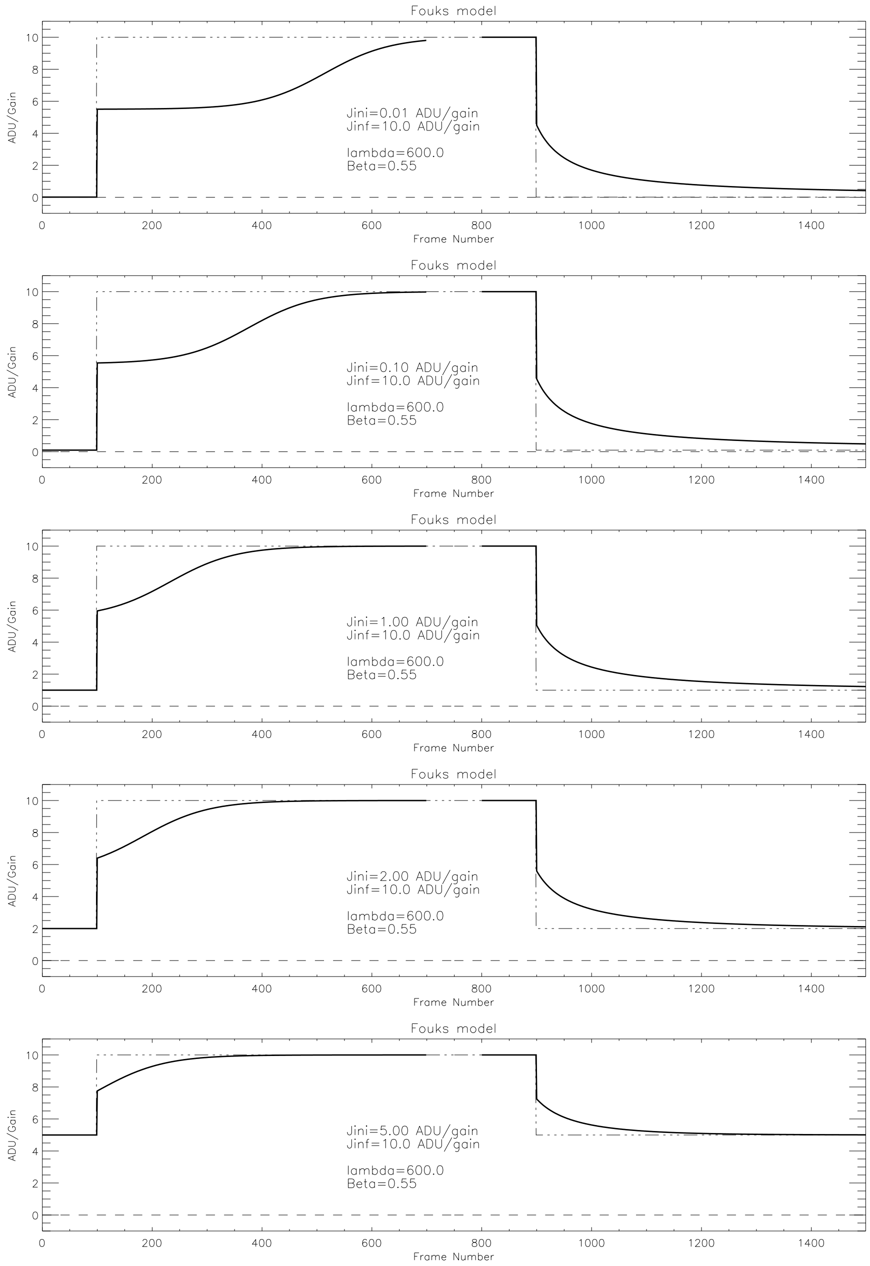

Figure 3: The behavior of the Fouks model is plotted on these five panels for several steps from five different levels (0.01, 0.1, 1.0, 2.0 and 5.0 ADU/gain) to one high level (10 ADU/gain) and go back to the initial levels (at frame number 900). For all these panel, the β and λ parameters are constant. The dashed line represents the steps from low to high levels and back.

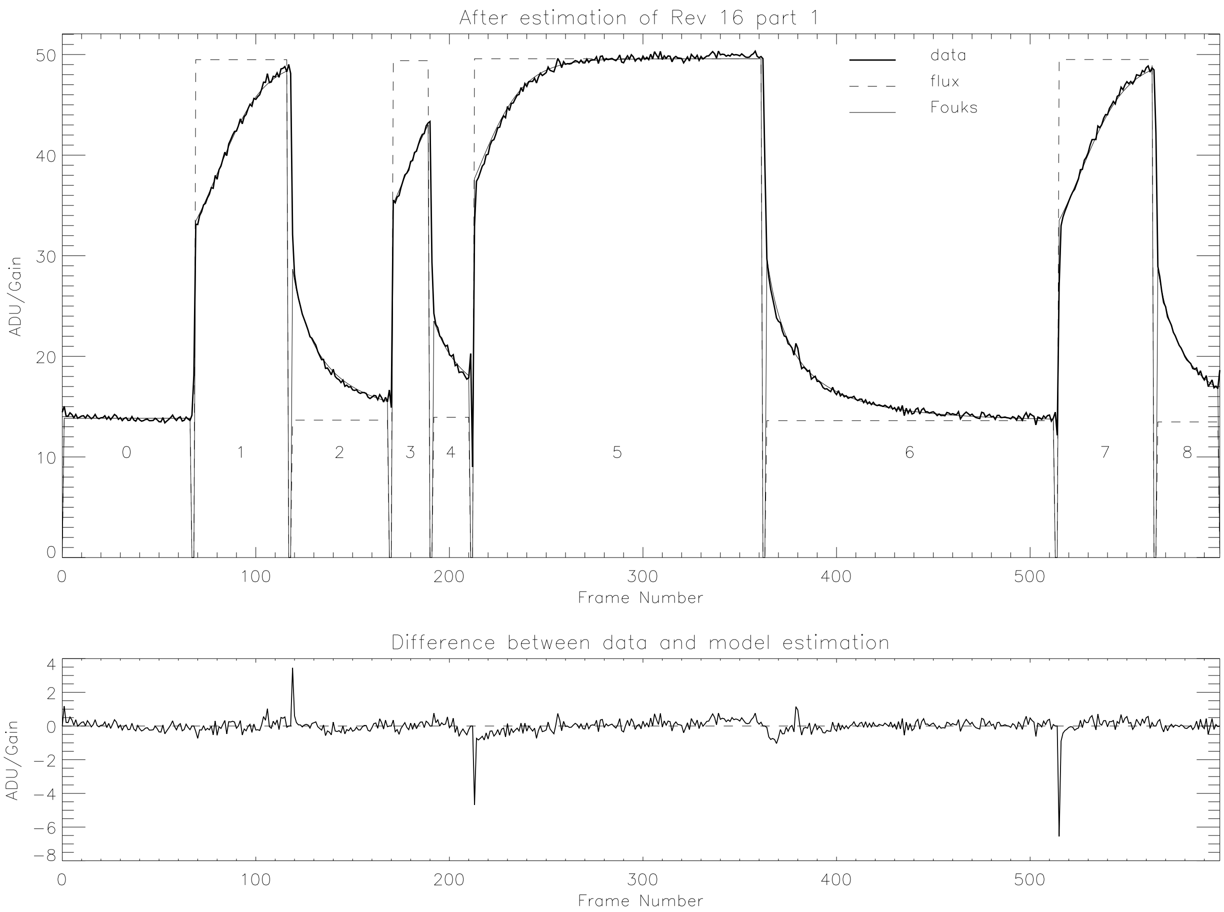

Figure 4: The upper panel show data obtained (thick continuous line) during the Performance Verification Phase (Revolution 16), over plotted with the estimated flux (dashed lined) and the Fouks respond with this estimation (thin continuous line). On the lower panel is plotted the residue. Evidence of a not perfect fitting can be seen at the beginning and at the end of block 5.

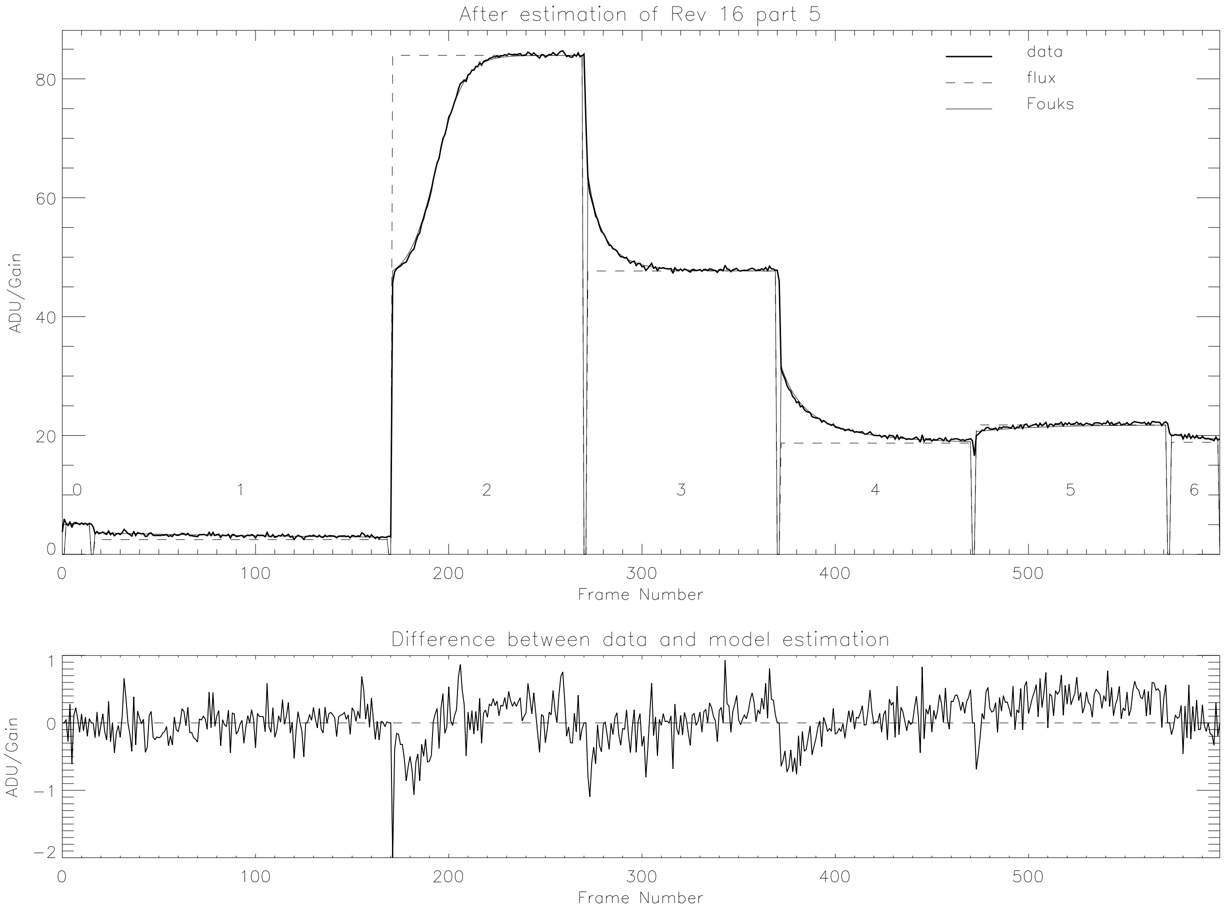

Figure 5: The upper panel show data obtained (thick continuous line) during the Performance Verification Phase (Revolution 16), over plotted with the estimated flux (dashed lined) and the Fouks response with these estimates (thin continuous line). On the lower panel is plotted the residue. Those data corresponding to the mean pixel (computed within the 12×12 central square of the detector). The disymmetrical characteristic of the curve is well predicted by the Fouks-Schubert model. We see in the lower panel that the accuracy of these extremely preliminary fitting is better than 2% for the blocks 2, 3 and 4.

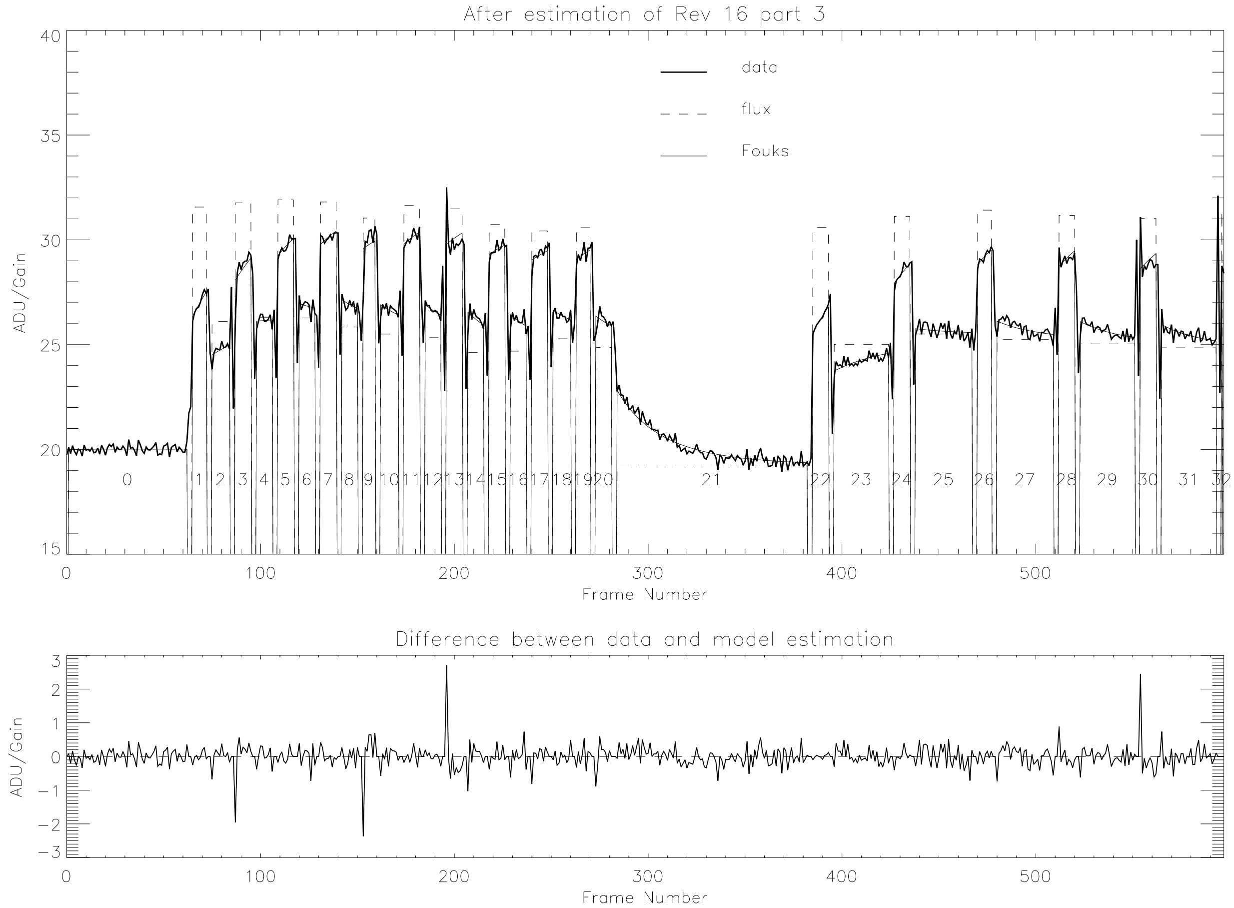

Figure 6: The upper panel show data obtained (thick continuous line) during the Performance Verification Phase (Revolution 16), over plotted with the estimated flux (dashed lined) and the Fouks response with this estimation (thin continuous line). On the lower panel is plotted the residue. Only three levels are supposed to be possible in the observation: the initial flux level (≈ 20. ADU/gain) the intermediate flux level (≈ 25. ADU/gain) and the high flux level (≈ 30. ADU/gain). Therefore, the difference in our estimates while the configuration is the same (for instance blocks 1, 3, 5, ...) is an artifact which may be due to temperature variations (to be checked).

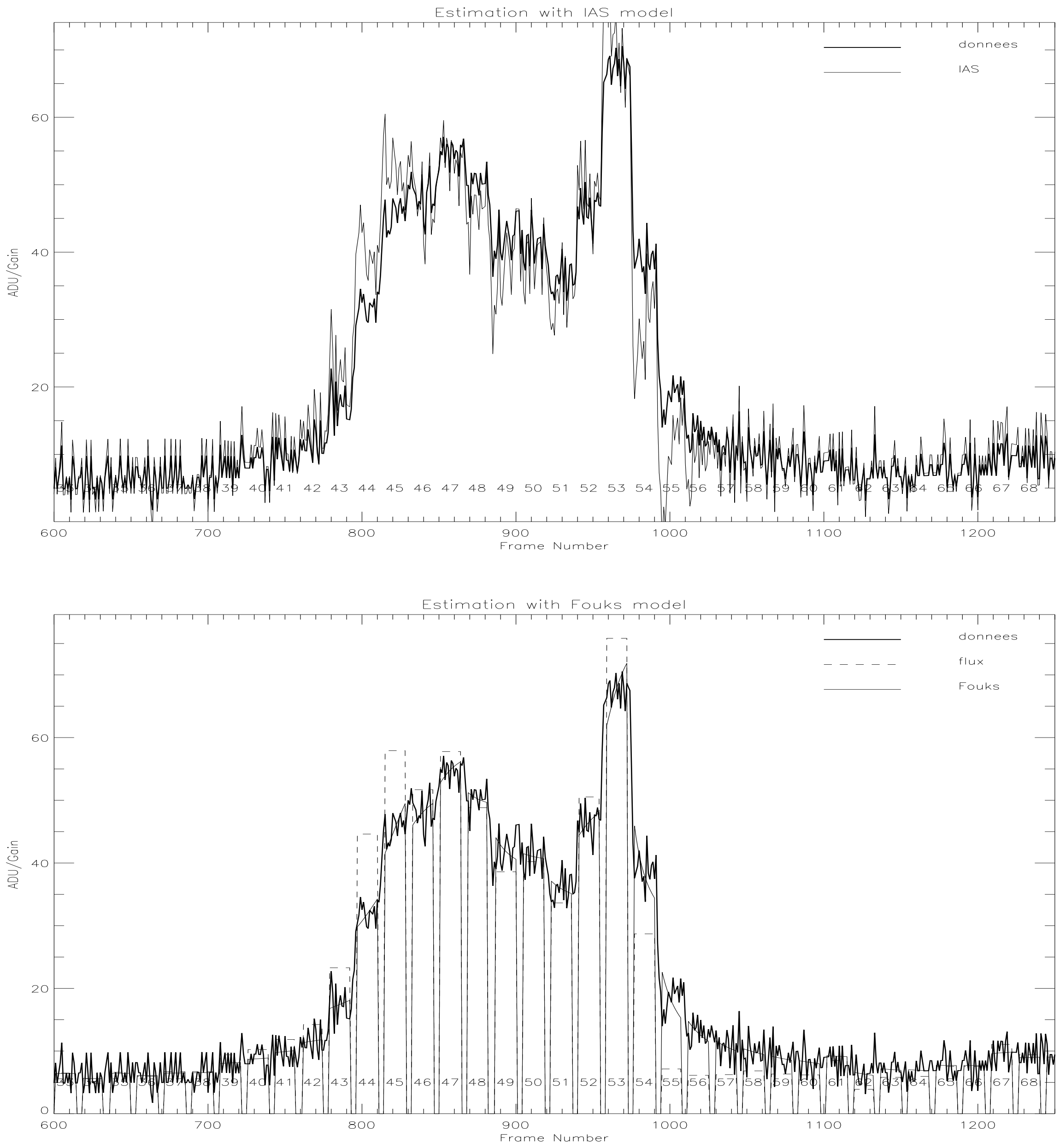

Figure 7: The two panels show the same data (pixel (13,15), tdt number 11301003). Upper panel: IAS model, lower panel: Fouks model. The Fouks model allows to remove a significant part of the trail visible on blocks 55 to 60.