FREQUENTLY–ASK QUESTIONS ABOUT FOUKS MODELS AND TRANSIENT CORRECTION METHODS FOR LW-ISOCAM

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ABSTRACT

At low temperature and at very low (astrophysical) incoming flux, most of the IR detectors are affected by transient response, which delay the response and can strongly bias the estimated flux. The LW detector of ISOCAM is also affected by such an effect. It has been shown that an important component of the transient effects of this detector can be described with high accuracy using a non linear and non symmetrical model coming from the physics. An inversion method is also available. In this FAQ, we review the limitations of this model and the known problems occurring with the correction method, and we give several advices to process the data.

Key words: ISO – CAM, CVF, Fouks model, Si:Ga, transient, memory effect

1. Introduction

It has been shown (Coulais & Abergel 2000) that, if the gradient between adjacent pixels is small, one model[1] coming from the Fouks theory can described with a very good accuracy the transients for the LW matrix detector of ISOCAM (Cesarsky et al. 1996) on-board ISO (Kessler et al. 1996). However several hypotheses and problems are hidden. The goal of this paper is to describe the limitations both of the transient model and of the transient correction method.

Section 2 presents the differences between the direct model and the transient correction method. Section 3 details the limits in the direct model, and Sect. 4 the technical difficulties encountered when the data are processed. The whole section 5 is devoted to the processing of CVFs because which can be difficult for a lot of AOTs. Finally Sect. 6 describes briefly the new 3D model which describes the transients for point sources (Fouks et al. 2002).

[1] The so-called Fouks-Schubert model since it was successfully used for Si:Ga PHOT S and P on ground based data (Fouks 1995; Fouks & Schubert 1995; Schubert 1995).

2. A direct model and an inversion method

Two main softwares have been developed (Coulais & Abergel 2000) and are actually included in CIA (Gastaud et al. 2001) :

- the *direct* Fouks *model*, which describes the transient of LW-ISOCAM for low contrasted illumination (low gradient between adjacent pixels);
- the specific *inversion method* based on the direct model (correction method).

The direct model is able to reproduce the transient response of individual pixels under uniform illuminations. The inversion method has been developed to recover the corrected value for each readout. This method works readout by readout, using the prehistory. No parameter is fitted. Up to now, it is considered that the two parameters β, λ of the direct model are constant for each pixel (32×32 maps of β and λ have been provided). This method is sufficiently reliable on most of good quality CAM data so it is not necessary to use other information, as block by block constrains or redundancy checking (between adjacent pixels or on the sky).

3. Limits in the direct model

First we remind[2] several facts about the direct model :

- the direct model describes well the transient response (*short term transient*) after upward or downward steps of flux under quasi uniform illumination of the matrix array (small gradient between adjacent pixels) for a large range of initial and final levels.
- the direct model does not describe correctly the point sources transients. The higher and the narrower the source, the worst the result (Coulais & Abergel 2000; Coulais et al. 2000). A new 3D model for transients of point sources is now available (Fouks et al. 2002, see also Sect. 6).
- the direct model does not describe at all the long term drift (LTD, e.g. TDT 12900101, cf Fig. 1 in Coulais & Abergel 2000) which may occur after the *fast* transient. Following Fouks theory, the lower the initial level, the longer and the higher the long term drift (Vinokurov

[2] It is mentioned in several papers that this model fails in several cases. But these cases precisely correspond to conditions where the model is not applicable.

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& Fouks 1991). It is actually not possible to model the LTD (see explanations in Coulais & Abergel 2001). A correction method based on the spatial redundancy in raster maps was successfully developed (Miville-Deschênes et al. 2000) to reduce the effects of LTD and to extract low contrasted structures –like faint interstellar clouds– in raster observations with at least two legs.

- the direct model always gives a monotoneous transient response for a block of readouts observing a constant input flux. Moreover, the output of the direct model is always strictly positive (see Coulais & Abergel 2000 for details).
- the direct model does not describe at all the small amplitude oscillations. This effect was clearly exhibited during ground bases tests for upward steps at high amplitude (Coulais et al. 2000). A model for in-flight data was studied by Aussel (Priv. Com.) using Fouks equations (Fouks 1996).
- up to now, an explanation can always be found when the model and the data disagree. Classical problems are : bad initialization or flagged data used as initialization, missing readouts or time discontinuities, negative mean values and inaccurate dark correction.
- the direct model cannot reproduce glitches, which result from the impact of high energetic particles and are usually classified in three categories : the instantaneous ones, the *fader* and the deeper (see in Coulais & Abergel 2001 and references therein).

4. Problems with the transient correction method

Since the inversion method is based on the direct model, it is obvious that this method cannot correct transients that does not fit the direct model. Moreover this method does not test the possible divergences or the consistency of the estimated values of the incoming flux.

4.1. Dark correction

The data must be dark corrected (Biviano et al. 1998). It has been observed that the dark is changing with time, during one orbit but also during the life of ISO (Biviano et al. 1998; Gallais 2001). The accuracy of the dark correction is limited, which can be a problem to use the direct model and the correction method. The closer to zero, the more sensitive to the dark errors. Especially CVF observations close to zero are very sensitive to inaccurate dark subtraction, as detailed in Sect. 5.

If data are very close to zero, or contain negative values after dark correction, a lot of troubles can happen with the transient correction method. It is difficult to add an arbitrary offset level. This offset must take into account the pixel to pixel variations, one of the biggest effect is the fact the odd/even lines have different dark levels because the electronics (Vigroux et al. 1993). Sometimes the odd/even effect is clearly visible in the data after dark correction. For CVF with direct and reverse scannings, the criteria to find such offset is that it improves the superimposition of the two scans. For raster maps, steps of flux are mandatory to check the possible range of offset. For a two steps configuration with J_0 close to zero and $J_1 \gg 0$, it is possible to estimate J_0 with very high accuracy with the help of the direct model, which is strongly no linear close to zero (see Fig. 4 in Coulais & Abergel 2000).

4.2. Negative values

Even if the dark level is perfectly estimated, we may have negative values in data because of the noise. The transient correction method can also diverge due to negative values. Since this divergence is not systematic, some simulations have been performed. In simulations, the occurrence of this divergence is very limited and is still unpredictable in positive data where only Gaussian noise is added (mean value in a moving window is positive). The divergence always occurs when the offset level of the data set is underestimated with negative data (due to the added noise). As a consequence, the lower the level, the higher the requested accuracy of the dark level to avoid divergence of the transient correction method.

It is clear that one large part of the noise is sampling noise, which is smoothable. Temporal filtering before applying the transient correction can reduce such problems. This modification is not included in the official transient correction in the latest versions of CIA.

4.3. Deglitching

It is better to deglitch the data before applying the transient correction method. Nevertheless the correction method is robust to instantaneous glitches. Any deglitching method is OK (3σ clipping, wavelets (Starck et al. 1999)), except the methods who remove the first readout after a change of flux (first readout of an upward step). Two methods can be used to substitute the glichted readouts : change to the temporal median value (or temporal and spatial median value) or to use undefined values to flag the glitches. The transient correction is able to take into account changing delay between two successive readouts.

We have problems for the glitches with positive (*fader*) and negative tails (*deeper*). With 3σ clipping they remain in the time series and are corrected as transient but they are not. It has been reported (Lari 1997; Rodighiero & Lari 2001; Lari et al. 2002) that such *fader* and *deeper* can be corrected. It is not available in CIA.

4.4. Initial conditions and memory effect

One very interesting property of the direct model is that, for each pixel, the whole flux prehistory can be summarized with only one number, corresponding to the output flux before the first readout (details in Coulais & Abergel 2000). For the whole detector, a map "J_{-1}" has to be estimated. Several method can be used.

When the data are clearly stabilized during the first N readouts, we can use for the J_{-1} map the median value, for each pixel, on these N readouts. But at low flux level, an error in J_{-1} can create big artifact with the correction method. This is especially true for CVF starting at low levels.

When the data are not stabilized during the first readouts, the prehistory can be estimated using the direct model. Nevertheless since all the data are yet public, a very good solution is to look at the data just before. If the configuration is the same (i.e. LW-ISOCAM observation) and the time discontinuity small (to be checked carefully to avoid indeterminate states or saturations), data concatenation is also very efficient to find J_{-1}.

It should be noticed that, if J_{-1} map contain negative values for several pixels, the transient correction method diverges systematically for these pixels after a long time ($\sim 10 - 10^3$ readouts). This behavior can be predicted from the analytical equations of the model, and can be easily reproduced with the direct model. Therefore, before applying the transient correction method, it must be checked that J_{-1} does not contain any negative or any zero values.

4.5. Point Sources

Actually transients for uniform illumination and point sources are processed by the same way. As a result, transient corrections fail for point sources. On raster maps, we frequently see the bright "ghosts" due to inaccurately corrected transients after point sources (e.g. TDT 11301003). A direct model for transients of point sources can now be used (see Sect 6 and Fouks et al. 2002).

4.6. Downward steps

The transient correction method can diverge when going from very high levels to a very small one, due to inaccuracy on the β parameter[3] (the instantaneous jump) for some pixels, and also inaccuracy on the dark correction. This effect is due to creation of negative values because of overcorrection of the downward steps, which can create an artificial strong memory effect (It is simple to simulate this kind of problems).

5. The specific case of CVFs correction

The transient correction of CVF observations can be more difficult than the raster one because the levels are frequently very faint. The closer to zero, the longer the memory effect. CVF observations are also affected by the limited accuracy of the dark level : a small error in the faint absolute level can strongly magnify or reduce the transient effects. Furthermore these effects do not linearly depend on the initial level (see Fig. 4 in Coulais & Abergel 2000).

5.1. One-direction CVF

A lot of CVF observations are only upward or downward scannings (in wavelengths). When the levels of these CVF are close to zero (let say less than few ADU), one have to be very cautious when processing them because the possible problems with the transient correction method cannot be checked. These problems like divergence or magnification of the memory effect are due to a wrong dark level. These problems are more critical when starting from a level close to zero (generally at the shortest wavelengths).

Simulations strongly help to understand the complex non linear effects. The problems do not come from the limitations in the model. In any case it is necessary to work on a pixel base, because of odd/even effects in the dark correction.

5.2. Two-directions CVF

For CVF with two directions scannings and levels close to zero, a much better work can be done than for one direction CVF (e.g. the CVF on Fig. 10 in Coulais & Abergel 2000). In case of unproper transient correction (the two scans do not overlap after transient correction), one method to improve the correction is to carefully reestimate the dark level for each pixel. The idea is to estimate the best offset to be added to the dark level in order to have positive values and to have a perfect overlap of the two scans after transient correction. To fix the best dark level, dichotomic approach is certainly the best one. In the CIA software are provided not only the correction method but also the direct model. So simulations and corrections can be done.

6. Point source transient

A direct model was developed (Fouks et al. 2002 and refs. therein) to reproduce the transients of point sources. The accuracy is good enough in order to describe the transients for each pixel for all forty configurations (four lenses and ten filters) except for the four configurations giving the widest PSF : lens 1.5 ArcSec and filters LW 3, 8, 9 and 10. But for these four cases a second order term improves the agreement between data and model. A first correction method based on this model has been developed for isolated sources (Normand 2002). Examples, problems and limitations are detailed in Fouks et al. 2002.

7. Conclusion

The direct model describes the transient response with an high exactness under quasi uniform illumination. Memory

[3] Limitations in the estimation of the fixed parameters (β, λ) were detailed in Coulais & Abergel 2000.

effects due to pre-history of the illumination are also accurately described, even at the lowest levels (e.g. CVFs). Depending on the integration time, the filter wheel, the lens and the accuracy of the dark model, an accuracy better than 1–2 % on the transient description for each readout is generally achieved (direct simulation) for most the pixels. Unfortunately, the pixels along the sides (and especially at the edges) cannot be adjust with a similar accuracy because of edge effects.

Some difficulties can appear when applying the transient correction method without caution, especially because the model is sensitive to the initial conditions (critical for low levels), divergence can occur for negative values, and the errors can propagate. Nevertheless, when the transient correction method is applied on data set well pre-processed (good dark correction, deglitching, correct initialization, ...), the correction accuracy remains in the 3 % error level per readout.

Since the direct model and the correction method are both provided in CIA, it is possible to have training with simulations. One very good final check is to apply the direct model on the estimation to check some significant difference between the observed and the simulated data.

The CVF observations can be more difficult to correct than raster observations due to : (1) inaccurate correction for the dark level (2) low levels and (3) no step of flux to constrain properly the initial conditions are available. The transient model and the transient correction method must not be used to derive flux of points sources but new model and correction are now available (Fouks et al. 2002).

Finally the correction method developed for LW CAM can be used for other Si:Ga detectors (e.g. SWS b2 and PHOT, see explanations in Sect. 4 of Coulais & Abergel 2000), and *a priori* should be adaptable to other direct models without difficulties (e.g. current study for the FTS mode for Astro-F).

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