COMPARISON OF ISOPHOT AND ISOCAM/IAS APPROACHES FOR TRANSIENT CORRECTION

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1 Abstract

This report closes an AI set at the ISO detector workshop held in Jan 98 at VILSPA. The action item required a comparison of the ISOPHOT and ISOCAM approaches to handling transients and its application to ISOPHOT detectors, in particular to the FIR detectors P3, C100 and C200. In this report I will compare the two approaches and show how the ISOPHOT technique can be modified and used in a very similar way as done for ISOCAM data.

2 Introduction

I will briefly describe the two approaches and show how the basic concept of ISOPHOT transient handling can be transformed in a very similar approach to ISOCAM/IAS one.

2.1 ISOCAM/IAS

ISOCAM/IAS approach is based on the inversion of an empirical model. This empirical model describes the response of a detector in two phases: an instantaneous response which accounts only for a part of the final signal plus an exponential–like variation term for the remaining fraction. The latter term includes all the influence from the past illumination history. The flux is recovered after linearization of the equations and resolution of the system of linear equations by LU decomposition. A detailed description can be found in Minutes of CWG #21 and Presentation at ISO detector Workshop (VILSPA, Jan 1998).

2.2 Current ISOPHOT approach

Current ISOPHOT handling of transients for FIR detectors (P3, C100 and C200) is based on fitting an empirical model, composed of a single exponential or in a more refined version of a linear combination of two exponentials to describe better the drifting curve. The time constants have been derived using a large set of measurements (Presentation at ISO detector Workshop, VILSPA, Jan 1998). The method as it is currently implemented in PIA describes the signal variation after a flux change, and the stabilized signal is obtained from the fit. The main advantage of this method is its simplicity and its main usage is to predict the signal for the relatively short FCS measurement which serves for photometric calibration of normal ISOPHOT observations.

2.2.1 New approach

A clear limitation of the later approach is that the illumination history is not taken into account, which is quite relevant when the detector receives different flux levels along the integration time, for example in raster maps or chopped measurements. In order to cope with these cases we have extended the current model including an extra relationship which predicts the signal variation after a step–like flux change. This relation is expressed as:

$$S_n - S_{n-1} = \beta(I_n - I_{n-1}),$$

where β is a detector specific parameter, S and I represent the measured and the stabilized photocurrent, respectively. This relation establishes that the detector always produces an immediate response to a certain fraction of the flux step, which only depends on the new and previous flux levels and the signal level just before the flux step. This formula was derived analytically by Fouks and Schubert (1995, Proc of SPIE 2475, 487) and, later on, a similar result was found through numerical simulations by Haegel, Brennan and White (1996, J. Appl. Phys. 80, 1510).

The above expression combined with an exponential function to describe the behaviour for a constant flux level has been implemented. Preliminary tests show that using such functions real data can be reproduced to some extent. However when the best parameters are determined via a fitting procedure, convergence is not easily found and in most cases odd results are produced. After this test I have tried to work directly with the relationships for individual time intervals, which results in a system of linear equations very similar to those used in the ISOCAM/IAS method. The following expression was obtained[1] (see Appendix for a detailed derivation):

$$S(t_n) = \beta I_n + \sum_{m=1}^{n} a_{nm} I_m + C_n; \quad C_n = (1-\beta) I_0 \prod_{j=2}^{i,i>2} e^{-\frac{t_j - t_{j-1}}{\tau_{j-1}}},$$

where a_{nm} does not depend on I. Therefore the stabilized signal (I) can be derived by solving the linear equation system.

3 Results

3.1 Testing of the procedures

I used both models (ISOCAM/IAS and the one described at Section 2.2.1) to simulate the transient curves for a given flux history, using the same time constant and initial conditions (see Fig 1). I have selected a time constant $\tau = \alpha/I$, with $\alpha = 50$. Surprisingly the two models produce the same results for upwards drift, but they disagree in the downwards case. It should be noticed that the expected time scale for downwards drift is a factor ~ 3 longer than for upwards, if the transient behaviour is mainly driven by the current incident flux. The ISOCAM/IAS model shows a quasi–symmetric response, while the ISOPHOT model shows a non-symmetric behaviour. The reason for such a different behaviour can be found in the different weighting factor which is attributed to the previous flux levels. The ISOCAM/IAS method assumes that the time constant depends not only on the current input flux but also on the the one which was received before. The new ISOPHOT approach assumes that the time constant depends only on the current input flux, and the influence of the previous illumination is taken into account like an initial condition for the current. I have also checked the behaviour of the two models when the time constants are independent of the flux level ($\tau = \alpha$), and both produce the same result for any type of step. In my opinion it is difficult to show which one the two approaches is the most valid. More extensive testing is needed and furthermore theoretical understanding (*e.g.* based on numerical simulations) may help.

3.2 Application to real data

I have applied the two models to correct the transient behaviour of two detectors, C100 (Figs 2 and 3) and C200 (Figs 4 and 5), and for two different flux levels. The time constants were obtained from the single exponential fitting to a large set of measurements, as presented in the ISO detector workshop. The value of parameter β for the detectors C100 and C200 as determined from chopped

[1] I have to thank Do Kester who gave me the idea how to proceed here

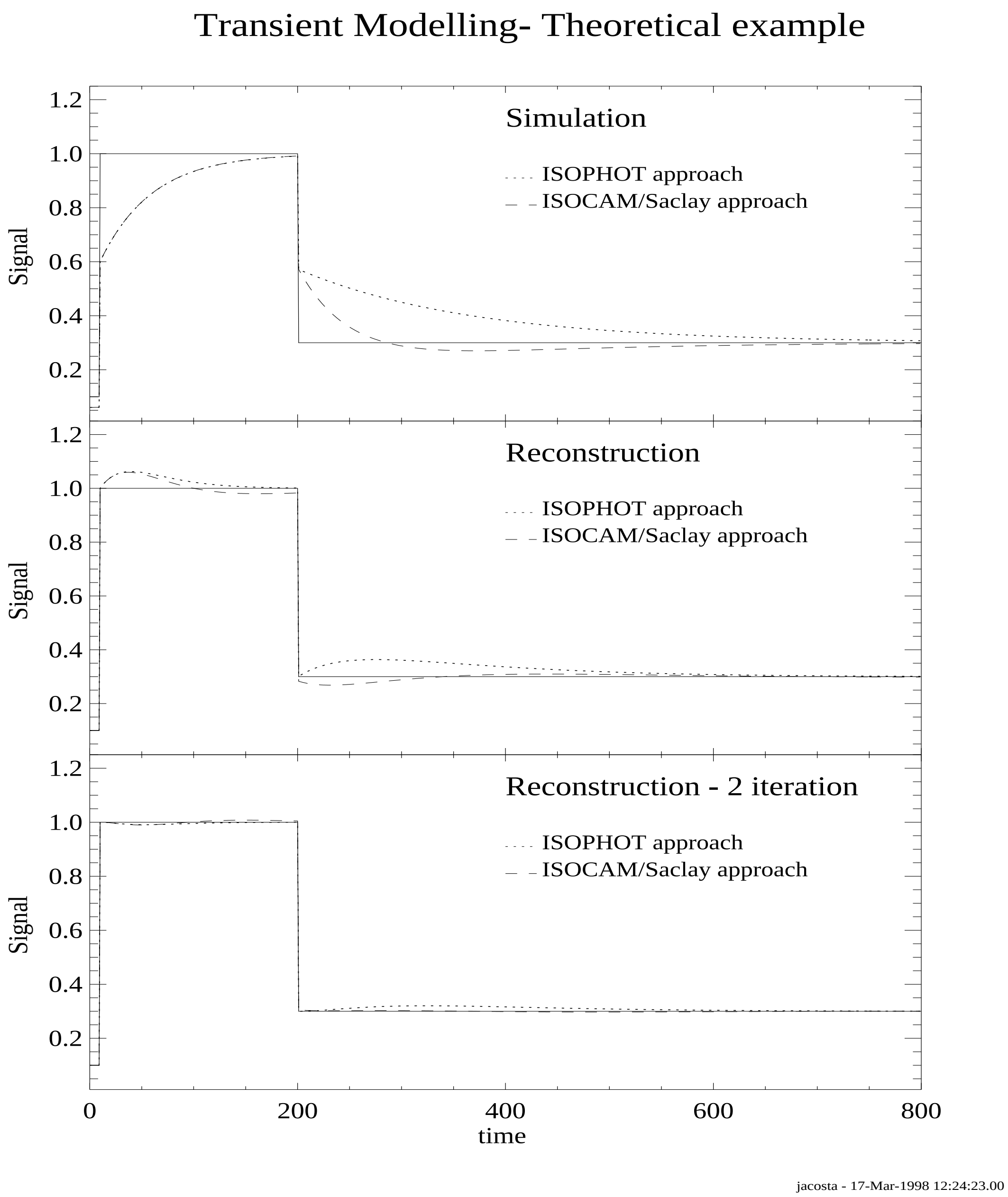

Figure 1: Simulation of a step–like flux history (from 0.1 to 1 to 0.3 ADU) usign the two approaches is presented in the top panel. The following parameters were used in both models: $\alpha = 50$, $p = 1$, $\beta = 0.6$. The reconstruction of the signal for the two simulations is shown in the middle panel. The reconstruction using the results from the first solution of the system is shown in the bottom panel.

measurements is $\sim$ 0.3 and $\sim$ 0.85, respectively. These values were used initially in the transient correction, but in most cases very large overshooting/undershooting appears. A possible explanation for this effect may reside in the fact that in both detectors the actual transient behaviour shows three distinct steps, an initial jump followed by a variation within few seconds and then a longer term variation, up to few hundred seconds. In most cases, the later term is the most relevant part for the final flux determination, and that is the one I have considered here. A model with two time constants should be considered in order to properly describe the variation . For the sake of simplicity and testing purposes I have used instead a larger value of β for C100 ($beta = 0.75$) which mimics the fast response (few seconds) to some extent. The selected examples may be not so illustrative because the flux variations occur at sufficiently large timescales that no dramatic transients have to be corrected. It is also worth noticing that the detector C200 exhibits an initial jump which is very near to the final flux and transient effects are expected to be relatively small.

4 Concluding Remarks

I have derived a general expression which involves the signal jump condition (derived by Fouks and Schubert) plus an exponential variation for a constant flux level. The use of these two expressions led to a system of linear equations. The inversion of a system of linear equations is shown to be a powerful technique for the correction of transients of ISOPHOT detectors, as well as previously shown for ISOCAM.

Furthermore, I have shown that the application of ISOCAM/IAS transient correction is almost equivalent to the ISOPHOT approach of using an exponential, where the time constant does not depend effectively on the flux level. The main advantages of the newly derived expression with respect to the ISOCAM/IAS formulation is that the past illumination history can be described more easily and a wider variety of time constants can be modelled. In principle, this technique can be applied to observing modes where the flux is continuosly changing and the general transient behaviour can be described by an exponential form (it may be useful for LWS detectors).

Further refinements are planned using a linear combination of exponential functions to describe the different transient timescales.

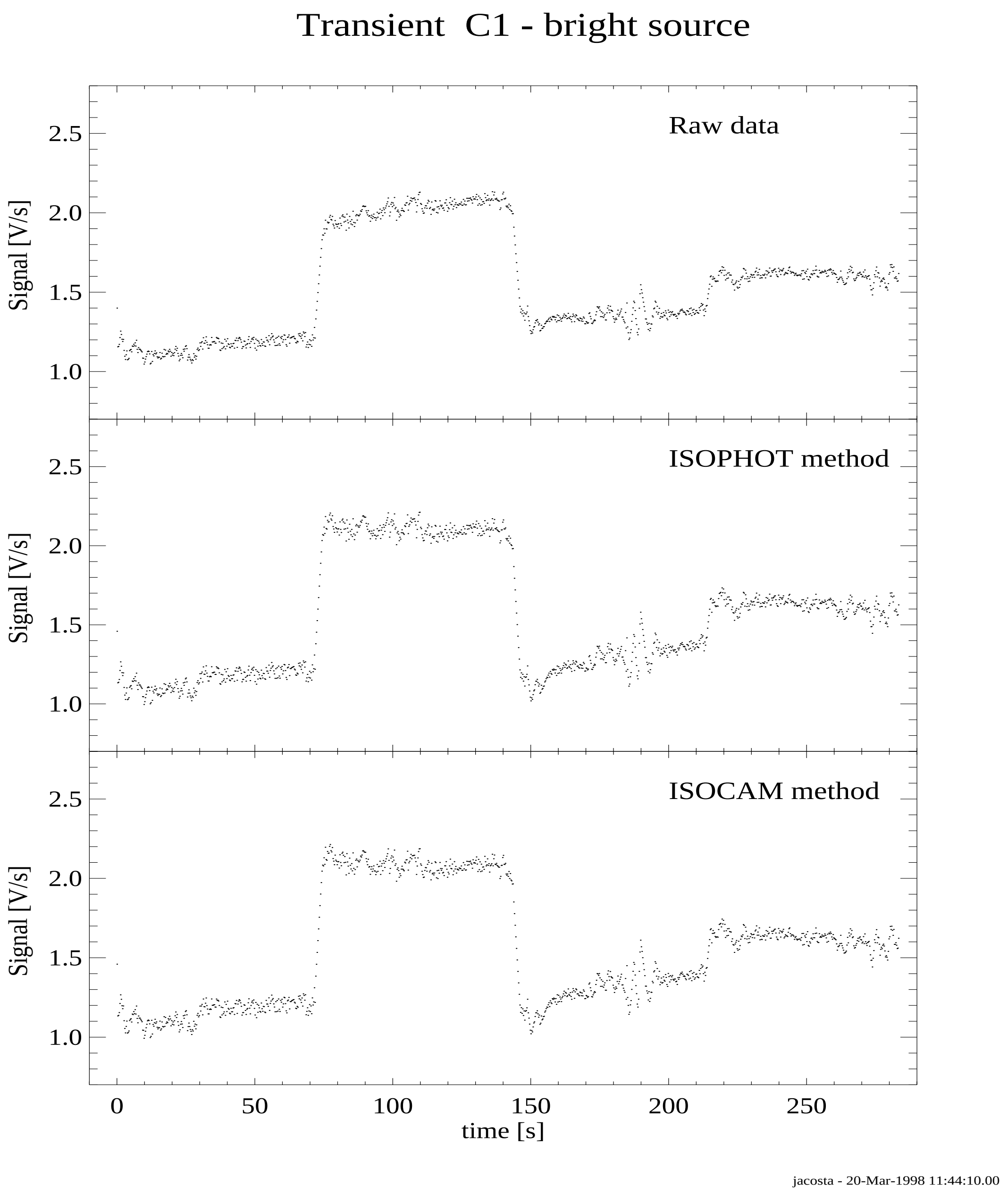

Figure 2: Application of the transient correction models to a raster around a bright source using the C100 detector. The following parameters were used for the modelling: $\alpha = 37$, $p = 0.48$, $\beta = 0.75$. There is a shallow undershooting in the raw data after the high flux was observed which cannot be corrected with any of the models.

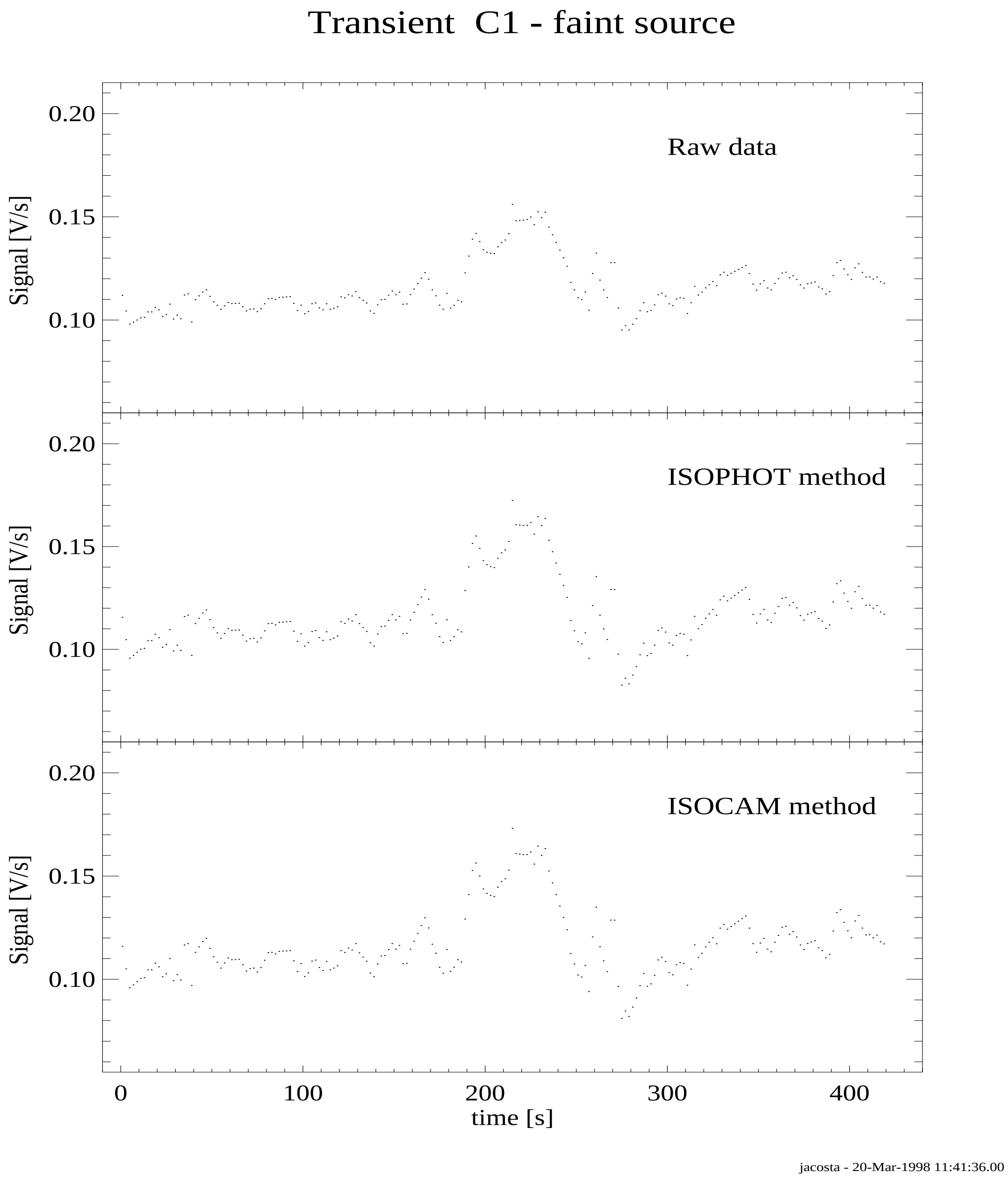

Figure 3: Application of the transient correction models to a raster around a moderate source using the C100 detector. The following parameters were used for the modelling: $\alpha = 37$, $p = 0.48$, $\beta = 0.75$.

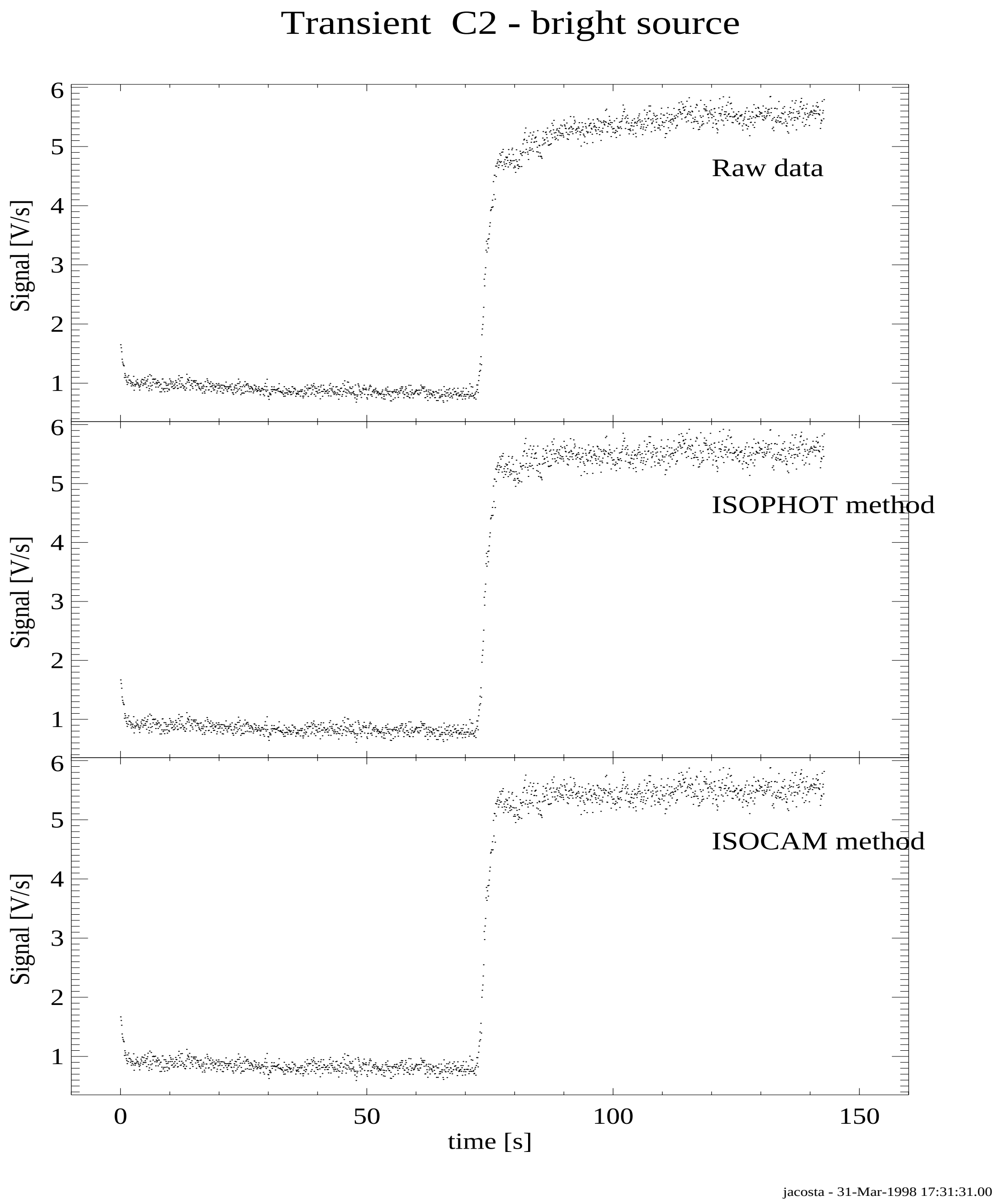

Figure 4: Application of the model to an observation of a bright source using the C200 detector. The following parameters were used for the modelling: $\alpha = 38,\ p = 0.63,\ \beta = 0.85$.

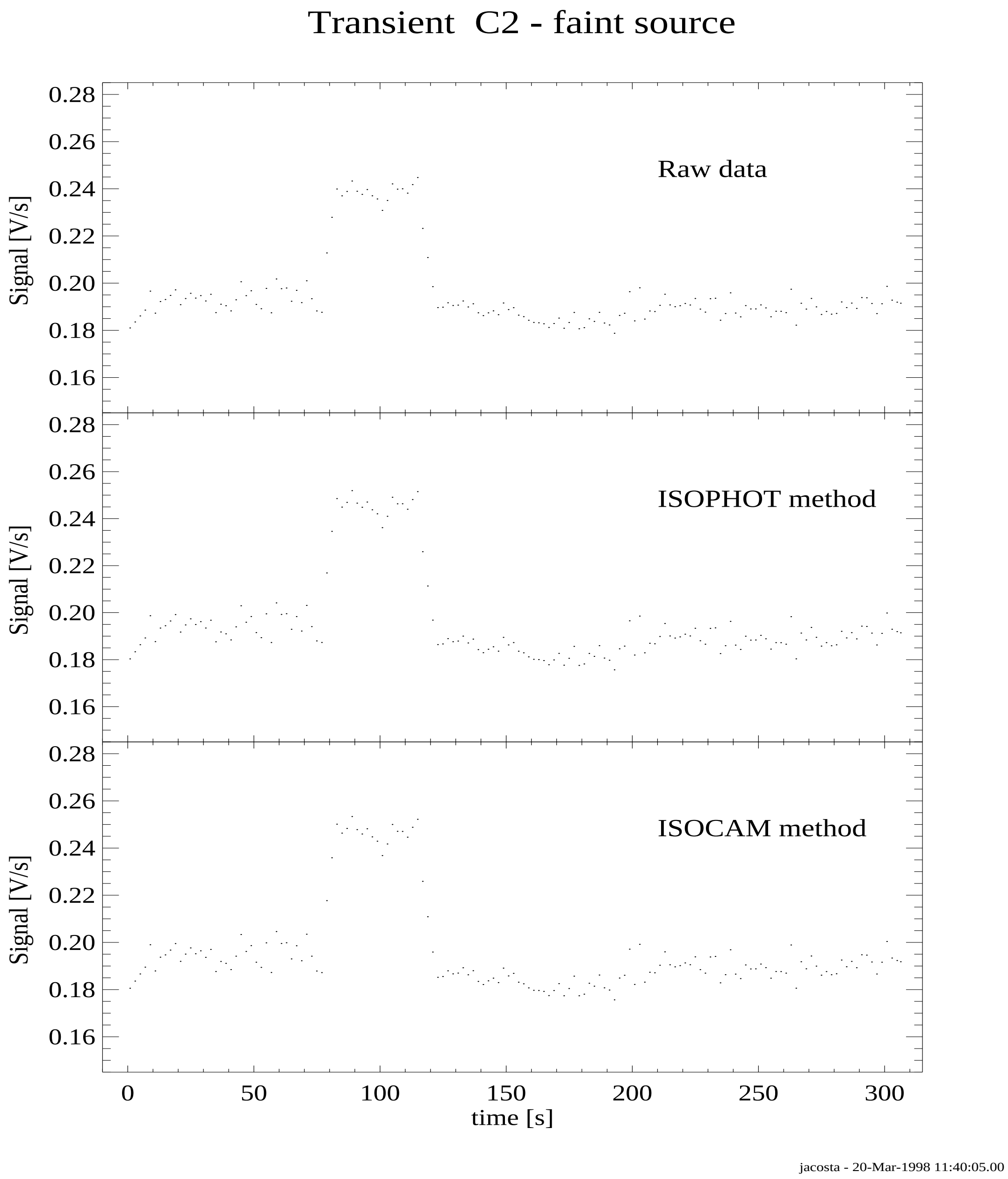

Figure 5: Application of the model to a raster around a faint source using the C200 detector. The following parameters were used for the modelling: $\alpha = 38$, $p = 0.63$, $\beta = 0.85$.

A Detailed derivation of empirical solution

For step–like flux change at time t_n the response of the detector is determined by the new flux (I_n is the incident flux at time t_n) as described by the signal jump condition:

$$S_n = S_{n-1}^{final} + \beta(I_n - I_{n-1})$$

and S_{n-1}^{final} is the signal at time t_n, which is modelled by the exponential function:

$$S_{n-1}^{final} = S_{n-1} + (I_{n-1} - S_{n-1})(1 - e^{-(t_n - t_{n-1})/\tau_{n-1}}) = I_{n-1} - (I_{n-1} - S_{n-1})e^{-(t_n - t_{n-1})/\tau_{n-1}},$$

being I_{n-1} the incident flux during the interval $[t_{n-1}, t_n)$, $\tau_n = E/I_n^p$. Introducing the second equation into the first one, we obtained:

$$S_n = \beta I_n + (1 - \beta - e^{-(t_n - t_{n-1})/\tau_{n-1}})I_{n-1} + S_{n-1}e^{-(t_n - t_{n-1})/\tau_{n-1}}$$

which can be written in a simplified form as:

$$S_n = \beta I_n + \alpha_n$$

where α_n only depends on I_j for $j < n$ After doing some algebraic manipulation we obtain the following recurrence relation for α_n:

$$\alpha_n = (1 - \beta)(1 - e^{-(t_n - t_{n-1})/\tau_{n-1}})I_{n-1} + e^{-(t_n - t_{n-1})/\tau_{n-1}}\alpha_{n-1}$$

Now the whole time sequence can be determined if a value for t_0 is given:

$$S_1 = S_0^{final} + \beta(I_1 - I_0); \quad S_0^{final} = I_0 - (I_0 - S_0)e^{-(t_1 - t_0)/\tau_0}$$

if we assume that before the measurement the detector was stabilized then $S_0 = I_0$ and $\alpha_1 = (1-\beta)I_0$

After more algebraic manipulation the problem can now be written as the following system of linear equations:

$$S_i = \sum_{j=1}^{i} a_{ij} I_j + c_i I_0,$$

where

$$a_{ij} = \begin{cases} 0 & i < j \\ \beta & i = j \\ (1-\beta)(1 - e^{-\frac{t_{j+1} - t_j}{\tau_j}}) \prod_{l=j+2}^{i, i>2} e^{-\frac{t_l - t_{l-1}}{\tau_{l-1}}} & i > j \end{cases}$$

and

$$c_i = (1 - \beta) \prod_{j=2}^{i, i>2} e^{-\frac{t_j - t_{j-1}}{\tau_{j-1}}}$$

Now we approximate I_n by S_n in the computation of τ_n and hence the solution for I_n can be obtained by solving the system of linear equations. Once we have obtained a solution of the system, the recently obtained value for I_n could be used to obtain new τ_n and improve the solution (see Fig 1).