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Non-linear transient models and transient corrections methods for IR low-background photo-detectors

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Abstract. Physical models are used to reproduce and correct transient effects of infrared (IR) photo-detectors in time series after incoming illumination changes. Such photo-detectors, working at low background for IR astronomy in space, cover the ranges 6-15 μm (Si:Ga), 40-110 μm (unstressed Ge:GA) and 120-210 μm (stressed Ge:Ga) and are working at low temperature. We discuss detectors models (direct models) and transients corrections (inversion methods). Some have been successfully applied to ISO data, others are in preparation for SIRTF (MIPS) – launched in August 2003 – and ASTRO-F (FIS) – to be launched in 2005. New results for MIPS 160 μm and the FTS of ASTRO-F/FIS are evidenced.

1. Introduction

Most of the photo-detectors used for low background IR astronomy are working at low temperature (around 1.7 K (Ge:Ga) and 3 K (Si:Ga)) and therefore are affected by memory/transient effects due to the time needed by the detector to reach a new stable state after a change of incoming flux. Depending on the detector but also on the IR level, the time constant can be as long as seconds to hours. Such transient responses are non-linear. Without correcting from this transient effect, the observations can be systematically biased.

In this paper we show that an approach combining analytical models and inversion methods can correct these effects. First we remain the results for Si:Ga detectors, then we discuss the work actually in progress for Ge:Ga ones.

2. Si:Ga photo-detectors

Concerning Si:Ga detectors, several results have been achieved since ISO launch. It has been confirmed on three different detectors (ISO-CAM LW, ISO-SWS b2 and ISO PHOT S&P) that a physical model (Vinokurov and Fouks, 1991; Fouks and Schubert, 1995) can describe at percent level the transient response of such detectors on uniform illumination. This analytical direct model is strongly non-linear, non-symmetrical and includes the long term memory effect. This model is based only on two parameters: the instantaneous jump β and a time constant λ. For all Si:Ga detectors of ISO it was shown that (β,λ) are constant for a given pixel. A readout by readout inversion method achieves accurate correction of these effects (Coulais and Abergel, 2000). Limitations are detailed in Coulais & Abergel (2003a). This inversion method can be applied to any analytical model: e.g. SWS b2 (Kester et al., 2003) where variations of the dark current was included and for Ge:Ga detectors where main problem was coming from memory effect (Caux, 2003).

The Si:Ga model mentioned here does not describe the transients response for non uniform illumination. A new numerical 3D model was derived, based on same physics (Fouks et al., 2003) and a more classical fitting approach was developed to recover the parameters of the observed source.

3. Ge:Ga photo-detectors

While Ge:Ga detectors do not exhibit strong non-linear transient effects as the Si:Ga ones, their models are up to now less accurate. Because polarization voltage is lower for the Ge:Ga ones than for the Si:Ga ones, equations are more complex, then approximations are needed to derived analytical models (Fouks, 1997; Haegel et al., 1999).

The direct models used for Ge:Ga detectors on-board ISO have been reviewed in Coulais et al. (2002). It was also pointed out that results suffer from limited accuracy of ramp processing (Coulais et al., 2003) and limited numbers of dedicated tests (Coulais and Abergel, 2003b).

A new very interesting case appears with the MIPS 70 μm array (Young et al., 2003) This thin detector is affected by a strong continuous drift and a StimFlash is applied every $\sim$2 minutes to continuously calibrate this drift. Unfortunately, the accuracy of this system is limited to a few percents, it adds noise in the data, and transients at small time scales remain uncorrected. Up to now, no simple analytical model can described the complex transients of this detector. Numerical approach was also used for these data (Haegel et al., 2001) but without any quantitative results yet published. Furthermore, it is difficult to build an efficient correction method from such numerical direct model. From our study of the ground based test (GBT) data, the key points in the error and bias grand total appear to be: (1) the sensitivity of the array to glitches (impact of high energetic particles) (2) the accuracy of the latents correction (transients after StimFlash) (3) the accuracy of the calibration based on StimFlash (4) the transients them-selves. As a result, transient modeling and correction for the MIPS 70 μm detector is not the most urgent point.

For the MIPS 160 μm detector, the situation is much more conventional. On the one hand, a first order model based on physics (Fouks, 1992) accurately reproduces upward steps. Moreover, from dedicated GBT, we have shown that the two model parameters are constant for a given pixel. On the other hand, the downward steps are quasi instantaneous. A promising inversion method has been developed (Malaizé, 2003, see Fig. 1). It is founded on a least square

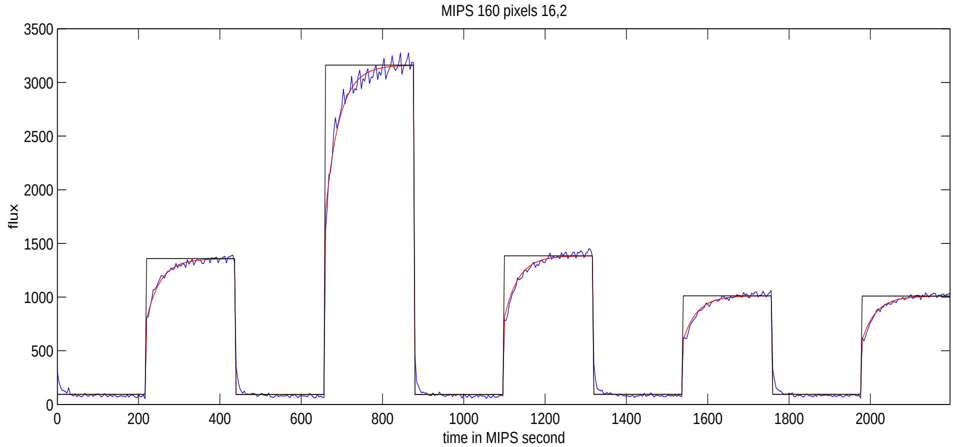

Figure 1. SIRTF MIPS 160 μm data from dedicated GBT : observed data, estimated incoming flux and model output. A series of steps was requested in order to characterize the transient response (to distinguish between different models and to explore a large range of incoming flux).

estimate accounting for first order upward + instantaneous downward models as well as piece-wise constant incoming flux. Obviously the longer the blocks, the more efficient the correction.

ASTRO-F carries two types of focal-plane instruments, one of which is the Far-Infrared Surveyor (FIS) (Takahashi et al., 2000). The FIS adopts a stressed Ge:Ga array (Doi et al., 2002) of 5×15 and monolithic arrays (Matsuura et al., 2002; Fujiwara et al., 2003) of 3×20 and 2×20 pixels to continuously cover 50 to 200 μm in wavelength. The FIS is designed primarily to perform an all-sky survey and additionally to have spectroscopic capability with a Fourier transform spectrometer (FTS) (Takahashi et al., 2003) – using the same detectors than FIS.

Up to now, no one of the models previously used can fit the experimental transient responses. GBT for transient characterization is still an on-going work (Kaneda et al., 2002) Since (1) we know that the Ge:Ga detectors are significantly affected by transient effects and (2) we do not have any direct model, we have studied with two extreme models which effects may be dominant for the FTS mode. One model was the Fouks model for the Si:Ga detectors. This model does not reproduce well the main transient effect for the ASTRO-F detectors, but it is interesting since it is very efficient to introduce strong long term memory effect. The second model was derived by Patrashin (Priv. Com.) from another model (Fouks, 1992). In such a case, the long term memory effect is not strong. We have used a readout per readout correction method in both cases since we have full analytical models. This end-to-end simulator allows us to check the acceptable ranges for scanning speed, noise and also the hint level for glitches.

4. Conclusion

Significant progress has been made during last years in order to correct transient effects of IR photodetectors. Models coming from the physics give high accuracy prediction for the transient response. Models can be used to check problems within systems (detector and associated devices) and also to improve and optimize future detectors. Several methods have been developed to remove the transients effects in scientific data.

The obvious success of such approach for most of the ISO detectors is very useful for present and future space missions, especially SIRTF, ASTRO-F, Herschel and MIRI on-board the NGST. First results for MIPS 160 μm and ASTRO-F are encouraging.

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