ISOCAM Faint Source Report

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Abstract

We describe the problems related to the detection of faint sources in ISOCAM LW raster maps. These problems mainly derive from the global and glitch-induced transient responses in the time histories of the pixels. We describe several data processing methods that have been developed to extract point-like sources on a uniform background. We conclude that ultimate ISOCAM sensitivities which can be reached, are at least similar to pre-launch expectations.

The problem of standard photometry remains one of the most difficult in observational astronomy. If those who work in other fields doubt this, let them ask those who have devoted their lives to it. Photometry has occupied, and absorbed, the ablest and the most ingenious.

Cecilia Payne-Gaposchkin (1984, p. 151)

Contents

1 Introduction

This document applies only to raster maps obtained with the LW (Long Wavelength) channel of the ISOCAM instrument.

We consider as *faint* a source of the order of a few ADUs or below, i.e. of the order of a few mJy or below. In any case faint sources are generally much below the zodiacal background, especially at long wavelengths. In deep cosmological rasters numerous sources down to 100 μJy or below have been detected in LW2 (6.7 μm), LW10 (12 μm) and LW3 (14.3 μm) filters, this being several orders of magnitude below the background. At such faint levels, one has to take into account that signals are affected by responsive transients with long time scales, including an important *global* transient running through the raster observation. The sensitivity of the ISOCAM LW channel is limited (a) in the first instance by the global transient (until its removal) and (b) by responsive transients induced by glitches - which are harder to remove. Understanding the behaviour of the signal stabilisation and the effect of glitches on the detector is essential for properly correcting related effects. Correction for these effects has been attempted with quite some success on the basis of in-flight measurements.

The most important source of noise for CAM LW observations is the cosmic ray impacts (glitches), and the slow response of the detector to flux variations (see e.g. Starck et al. 1998). This was actually understood before the ISO launch (see, e.g., Pérault et al. 1994)

2 ISOCAM LW signal behaviour

2.1 Global transient through the raster

Most of the rasters performed with ISOCAM suffer a global transient through the measurement that is the main limitation for the detection of faint sources. The effect leads to raster maps with a non-uniform background. It varies throughout the raster and therefore limits the sensitivity as faint sources are lost in this background gradient. Thus the first step in trying go deeper with cleaner maps is to correct for this global transient, which is not corrected by the *standard* transient methods (like the IAS method) that deal only with short timescale transients.

2.2 Transients on faint sources

The signal of one ISOCAM LW detector pixel never stabilises completely, because of the *transient* response of the detector. Refer to Abergel et al., 1999 for the best description of the ISOCAM transient responses. At the time of writing this report, a new method to correct ISOCAM-LW transient effects, developed at IAS, and reflecting techniques already applied to PHT data by J.Acosta) appears to give extremely promising results down to a 1% accuracy for short timescale transients.

When an ISOCAM pixel is subject to a change of illumination (by infrared photons), its time behaviour is a function of its illumination and glitch history AND of the illumination step. Without taking into account the charge coupling between pixels, the pixel response to a flux change can be decomposed, in a first approximation, into:

- an instantaneous step to 60% of the flux step
- a variation for the remaining 40%

The variation of the remaining 40% depends on:

1. the flux step, the larger the flux step, the shorter the time constant, and therefore the faster the signal stabilises (towards the theoretical value which would be reached after an infinite time).
2. the background level; the higher the background, the higher the initial stabilisation level (in the first 15 readouts)

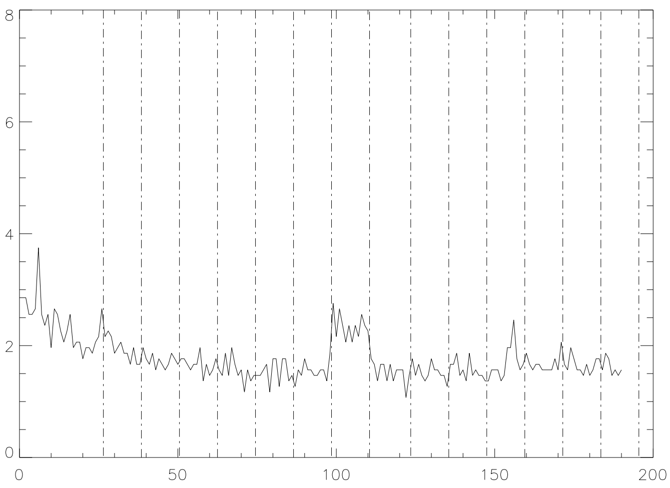

Figure 1: Time history of a pixel on a relatively faint source.

For instance if one models this stabilisation with an exponential variation, the time constant is inversely proportional to the signal and is close to [1200 sec./(signal in ADUs)]. In reality there are several time constants for this stabilisation towards the final level, and they all get longer for fainter signals, i.e. the smaller the flux step, the longer the time constants.

For faint fluxes (of a few ADUs or below) the signal would take a very long time to stabilise and in effect it never stabilises in a reasonable dwell-time. During a limited number of readouts (less than 20), the signal stays almost at a constant level within the noise level. This effect can be seen clearly on Fig. 1, (although the source detected is not so faint here). During the 12 readouts on the source the signal remains rather constant. To a first approximation one can consider that this level is 60% of the final flux that would be reached, but in fact in reality the response step is a function of both the intensity of the source and of the background.

The 60% approximation is good for faint sources on a small background, for instance in narrow filter bands, or at short wavelengths with small PFOV and/or small T_{int}. But when the (zodiacal) background becomes high (as in the LW3 or LW10 filters at $6''$ PFOV) the observed plateau is higher than 60% and can be even higher than 80%.

For brighter sources (say above 2 ADU/G on a pixel), the upward transient can be seen rising across the 12 readouts, as can be seen in Fig. 2. The pixel time history after IAS transient correction is overplotted to show that in this flux range, it is absolutely necessary to make a transient correction to get the right flux. In this case, considering that one sees 60% of the flux would lead to an overestimate of the source flux.

2.3 Glitch-induced transients

It is customary to distinguish among three kinds of glitches, usually called *common, faders* and *dippers* according to their behaviour, decay time and influence on the pixel responsivity (see Claret & Dzitko 1999). It is likely that common glitches are physically associated with impacts of cosmic ray electrons, while faders and dippers are linked to impacts of proton or α particles (see Aussel et al. 1998).

Typically, common glitches only last a few readouts, and the decay time is more-or-less as fast as the rise time. These are easy to remove, and contribute to the noise in the CAM results only because the frames ($\Rightarrow$ readouts $\Rightarrow$ images) affected by these glitches cannot be

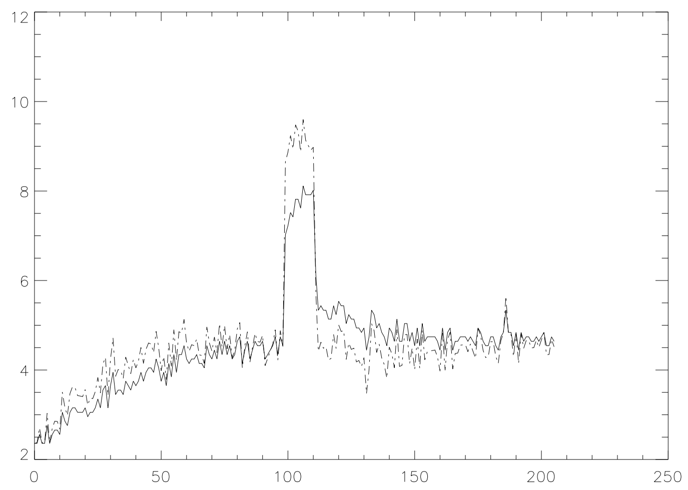

Figure 2: Time history of a pixel on a brighter source with the IAS transient corrected flux overlaid as a dashed line.

used. Based on the observed average glitch rate and the average number of pixels hit by a glitch (see Claret & Dzitko 1999), one can estimate that every pixel will be hit by at least one glitch every $\simeq 120$ s.

On the other hand, faders and dippers have a much longer lasting impact on the pixel sensitivities. Faders are followed by a slow decrease of the signal, while dippers are followed by a reduction of the sensitivity of the pixel, that recovers very slowly afterwards (see figures in Claret & Dzitko 1999). In these two cases, the number of affected frames is much higher, the sensitivity of the pixel taking from tens to hundreds of seconds to fully recover. Fortunately, faders and dippers occur two orders of magnitude less frequently than common glitches.

The impact of faders and dippers on pixel sensitivities is related to the general problem of the transient behaviour of the CAM detector. The fact that the time constants of the detector's response to flux variations were very long, was known since pre-launch calibration (Pérault et al. 1994; see also the "ISOCAM Observer's Manual"). The time constants are different for different flux steps, and for individual pixels. Recall in particular that it takes longer for the signal to stabilise after a given flux step, if it happens against a lower background flux. The coupling of signal between adjacent pixels is a further potential complication, when the array is subject to a non-uniform illumination.

3 Data processing

The most relevant parameters of an LW CAM raster observation for the detection of faint sources are the redundancy, the pixel size, the step size, T_{int}, the integration time (generally 5 or 10 sec.) and N_{exp}, the number of readouts per raster position. The general selection of these parameters and related trade-offs is discussed in Altieri et al., 1999.

Several specific methods have been developed and can be applied to reach the faintest possible levels for an ISOCAM raster observation.

The first approach is to use standard CIA (Ott et al., 1996). This gives a quick preview of raster maps and detects sources down to less than 1 mJy if the raster is deep enough (at least 4x4).

But one quickly realises that the main limitations of sensitivity in the resulting maps are, first, the global transient and, after its removal, the remaining glitches and the responsive transients they leave in the pixel time histories (dippers and faders). That is the reason why additional methods and algorithms have been developed to beat these limitations and to get the cleanest maps possible. These methods involve more powerful tools for deglitching, and means to correct for transients in the pixel responses.

- the PRETI method developed at CEA/Saclay (refer to Starck et al., 1997, "Faint Source Detection with ISOCAM using the PRETI method", for more details and some insights) It uses a multi-resolution median transform from the MR library, and has been one of the first efficient methods developed.
- A tool, developed at VilSpa which combines a temporal median filtering of the detector pixel history (to remove the global transient and reduce glitch-induced transients) with a phase-2 deglitching operation performed on the redundant-detection history of each sky pixel.
- A 'Differential' method, similar in principle to the Désert approach (see below), which essentially removes the global transient by working with some function of the difference between a detector-pixel signal at the current sky position and its signal at some other sky position(s) in the raster. This is implemented, as a user selectable option, in the tool mentioned above.
- Désert method using the classical approach of "triple-beam", together with a least-squares fit to temporal data streams, and to be implemented in CIA. See Désert et al, 1998, "A classical approach to faint extragalactic source extraction from ISOCAM deep surveys"
- Carlo Lari's method, oriented towards an integrated correction of glitches and transients. To be implemented in CIA in the future.
- Other methods have been explored with some encouraging results - for example - building the raster mosaic from the median of the raster-position exposures (not the same as building the individual raster-position exposures from the median of the individual readouts). This simple measure alone rejects residual glitches quite strongly for high redundancy rasters especially, if coupled to certain simple pixel filtering techniques (differentiation of the pixel histories, for example). It has proven particularly useful when applied directly to rasters on diffuse extended sources and so can improve results on extended low-contrast features that the other techniques tend to filter out.

All these methods work on the time-history (data readouts sequence) of all pixels, and in some cases on the history of "sky pixels". The term "sky pixel" refers to a pixel in the finally constructed raster mosaic or sky-image. It is a construct built from the combination of fragmentary histories coming from the (sometimes large number of) detector pixels which have seen that sky position during the course of the raster.

3.1 A first approach: using standard CIA

The method for dealing with rasters in CIA is explained in detail in the 'ISOCAM Interactive Analysis User's Manual', but the step by step methodology is explained here. The detailed usage of the various commands is described in the CIA User's Manual.

3.1.1 Slicing

The first operation consists of slicing the data. When starting from the **cisp** level, you can use **spdtoscd**:

CIA> spdtoscd,'cssc_xxxx.cub',my_sscd,spd_dat='./',/nowrite

You can also start from **cier** level (Edited Raw Data), with the **x_slicer,/here** command, but then you will work directly with a raster structure and not at sscd level, and so lose some functionalities offered by the sscd, such as the potential to make transient correction on a longer timeline, for example.

3.1.2 Dark subtraction

The first stage in the data reduction is the subtraction of the dark current. Although not too relevant for some specific faint-source methods which involve an implicit per-pixel baseline removal, the dark subtraction is still very important in general. The best dark subtraction method available to date takes into account the variations of the dark signal throughout the revolution and throughout the ISO mission. This method, described in "The ISOCAM Dark Current Calibration Report" by A. Biviano et al, 1998 is now the default dark subtraction method in CIA. It models one dark frame per SCD (or raster position for a raster structure), that is subtracted from the cube of data. The calling command is:

CIA> corr_dark,my_sscd,method='model'

For very long rasters (> 1 hour) with long dwell-times per raster position, a running variable dark *per frame* can be subtracted to get an even better dark correction. A set of commands for this purpose can be found in annex 1, but the gain over the standard dark subtraction will be in any case minimal.

3.1.3 Deglitching

The next step is deglitching the cube of data. This is one of the most difficult steps of ISOCAM data processing, and there is no *perfect* method. In the case of rasters in which faint sources are sought on top of a rather uniform background (coming, for example, from the zodiacal light), the *Multi-resolution Median* '**MM**' method gives generally good results. It calls the c++ routine **mr1d_deglitch** where the best parameters *nscale* and *nsigma* are automatically chosen. The calling command is:

CIA> deglitch,my_sscd,method='mm'

The *nscale* and *nsigma* parameters can be tuned for a better deglitching, for instance by decreasing the *nsigma* to lower values, if the background is uniform, this will filter out glitches to a lower level. In principle there is no need to play with *nscale*, which is related to the number of readouts per raster position and is automatically computed.

CIA> deglitch,my_sscd,method='mm',nscale=*nscale*, **nsigma=***nsigma*

Again this deglitching method is not perfect and some obvious glitches can be left out with this method. *All* currently available deglitching algorithms leave residual glitches, and further measures are needed to take account of these. Other methods of deglitching are 'temp', 'tcor', 'deglitch_vilspa', manual ...

3.1.4 IAS model transient correction

At this stage, if desired, the transient correction using the IAS model from Abergel et al, 1996 can be applied. This method corrects the transients in the pixel time histories due to the changes of illumination which occur when a pixel sees a source which then moves on. However the effect of this method for detection of faint sources has not been extensively studied at VILSPA. It may introduce noise for very faint sources, and it does not correct for the important global transient, so it has not been used much for faint-source work at VILSPA. The calling command is:

CIA> stabilise,my_sscd, method='inv'

If the cube of data is big the processing will be very long, as it involves the inversion of triangular matrices. The routine now handles big cubes more efficiently, by cutting the cube in pieces. This is possible because the history of readouts extending more than 200 readouts backwards in time has negligible influence. (The weight factor of previous readouts decreases exponentially).

3.1.5 raster structure creation

The next reduction step consists of importing the data into a raster structure after cleaning the sscd. This is done via the commands:

CIA> clean_sscd = sscd_clean(my_sscd)
CIA> raster = get_sscdraster(clean_sscd(0))

If there is more than one filter in the clean_sscd, apply the same operation for them all (raster = get_sscdraster(clean_sscd(i)), i=1 ...)

3.1.6 'Exposure' generation

This stage generates the exposures per raster position from the images (detector readouts) in the raster.cube component of the CIA raster structure. These exposures fill (somewhat confusingly) the **raster.image** field of the CIA raster structure. The mean or the median of the images can be used for this computation. [However, using the median at this stage tends to 'quantise' the data in steps of fixed fractions of an ADU, with often ugly discretisation of the final mosaic.]

CIA> reduce,raster

for exposures as means of frames in the cube

CIA> reduce,raster,/median

for exposures generated as median of the frames.

In principle using the median might be expected to reject some residual glitches, but by this stage in the processing most of the residual glitches have survived because they are of duration comparable to one SCD or longer. So they appear as much in the median as in the mean when constructing the exposure corresponding to that raster position on the sky. This is not the case when constructing the mosaic from the raster position exposures, for which the usage of the median can have significant benefits for glitch rejection - although it tends also to reduce the amplitude of low level structure in the mosaic, due to its tendency to suppress the effects of outlying data points.

In general we do not recommend to the use of the median for **exposure** creation.

3.1.7 Flat-fielding

The next step is the flat-fielding of the data. For moderate to large rasters on low-contrast sources, the best approach is to estimate automatically a flat-field from the data itself, generating the so called *auto*-flat. This consists of a median filtering through the time history of the pixels, normalized to the mean value of the central part of the array (10:21,10:21). This method gives better results than using the library flat-field extracted from the calg file (flat='calg'), if there is no extended structure in the raster map, and if faint point-like sources are present on relatively high uniform background. It often gives also reasonably good results in the LW2 filter, where the zodiacal background is low - but then the user should check to ensure that the flat-field so-derived has sufficient signal to noise that it does not simply degrade the data. The calling command is:

CIA> corr_flat,raster,method='auto'

Some explorations have been made with algorithms building the flat-field from only those portions of the data cube within some range of readouts of the frame currently being flat-fielded. In this way it might be hoped to obtain a flat-field less distorted at low level by the global transient. At time of writing we have no firm opinion as to the effectiveness of this approach. There are indications that the application of such a "running flat-field" improves results for mosaics built without application of the faint-source algorithms in order to retain extended structure information. Of course, one must be alert to the potential to degrade the S/N of the flat-field, or to leave traces of actual sources in it, if it is too locally-constructed relative to the frame to be corrected.

We encourage users to experiment and to let us know the results they obtain.

3.1.8 Mosaicing

The last step consists of mosaicing the exposures into a raster map (the field **raster.raster** in the CIA raster structure). In the case of a microscanned raster, for which the raster step sizes may not be equal to an integer number of pixels, the raster mosaic (raster.raster) in the raster structure will be constructed with dimensions adapted to (i.e. pixel size equal to) the smallest fraction of a pixel involved in the raster step. The exposures will be rebinned before the mosaicing. The oversampling is used to increase the spatial resolution and to obtain higher sensitivities (see Chapter 5).

The best way to mosaic the images, from the point of view of getting the best source registration, is to use the 'project' option, where the exposures (raster.image) are corrected for field-of-view distortion and then projected onto the raster map, according to their individual coordinates. (Aussel H., 1998b.) The calling command for this last step is :

CIA> raster_scan,raster,method='project'

Currently, 'project' in CIA only works to build the mosaic from the mean of the raster position exposures, not from the median (see Secion 3.5).

This general standard method allows one to get already very good results on most on the ISOCAM raster maps, if the raster is sufficiently large (at least 3×3), in a large band-pass filter, without bright or extended structures in the field, and if the raster is not affected too much by the global transient.

3.2 Better deglitching

The deglitch MM or PRETI methods are not perfect for deglitching, so some phase-2 deglitching on the cube of data can be attempted before building the exposures or the mosaic, using other algorithms available in CIA, like:

- 'spat' for a spatial deglitching
- 'temp' for a temporal deglitching
- 'part' for a particle analysis
- 'tcor' for transient corrected deglitching
- other automatic methods, like sigma-clipping the sky-pixel history (Section 3.4 below)

or simply manual deglitching (deglitch_man), which is extremely time consuming and tedious (992 pixel time histories to examine ...), but can be rewarding.

The observer should note that *all* currently available deglitching algorithms allow a certain fraction of glitches to get past them - for glitch characteristics not captured by the algorithm's parameters. These residual glitches are generally clearly visible upon inspection of the deglitched data cube.

When the images at each individual raster position are averaged to produce one exposure per raster position, each such exposure may show several residual glitches. Building the mosaic from the median of these raster position exposures can help to reduce the impacts of these residual glitches on the final mosaic. Also, the cube of detector readouts (raster.cube) may be sigma-clipped. Alternatively, manual deglitching may be done (deglitch_man). However, both of these techniques may attenuate real sources and should be used only with extreme caution. (See Section 3.2.2 below for a discussion of manual deglitching.)

More recently, a version of phase 2 deglitching has been employed applying filters to the history of a **sky** pixel, and this appears to offer an alternative to manual deglitching or sigma-clipping of the detector pixel history which gives good residual-glitch rejection without significantly impacting source photometry even for bright sources.

3.2.1 Sigma clipping

Once the baseline is subtracted from the time history of a detector pixel (with PRETI or VILSPA median filtering (see below)), residual glitches can be removed by sigma clipping the timelines at 3σ i.e. to mask out all readouts deviating by more than $n\sigma$ (n usually 3) from the baseline. This removes quite well all fader glitches not removed by primary deglitching algorithms because they had durations comparable to source detections in the raster (i.e. they were the size of one SCD). For example, the one left over in figure 4 around readouts 500. This is implemented as temporal deglitching (method ='temp') in CIA.

3.2.2 Manual deglitching

Manual deglitching is extremely tedious and time consuming.

Deglitch_man allows you to mask out pixels in the raster-position exposures (or indeed in the individual images, depending upon how heroic you are!) if they are affected by a residual glitch. Each image is individually deglitched. We refer to this as "spatial" manual deglitching. Results can be very good for the very faintest sources (say around 100 micro Jy or less), which are too faint to be accidentally manually 'zapped'. For brighter sources the technique can be dangerous in terms of photometric reliability.

Manually deglitching a single raster cube of moderate size (say 100 raster-position exposures) this way takes about 8 hours and has been known to involve clicking the cursor over 30000 times !!! (It has been done!). Up to 35% of the recorded data may be removed in this way. Be aware that deglitch_man builds a 'mask' which you can combine with your raster.mask to suppress the bad pixels, but it also modifies the data cube on which the deglitching is done while the mask is built. Therefore it is advised to manually deglitch this way only on a copy of your raster.image cube, and then to take the deglitch mask to use with your data. Do not use the directly modified data cube.

An alternative method of manual deglitching allows you to inspect individually the time history of each pixel (all 992 of them) and to generate a mask with which to suppress bad segments of the pixel's history. This method is less severe than deglitch_man and much safer photometrically. It typically removes 15% of the accumulated data. Unlike deglitch_man it involves about the same effort regardless of the duration of the raster measurement being deglitched, since it always involves the manual cleaning of the time history of each of the 992 active pixels in the array. (1024 - column 24.) Such a manual deglitching takes about 8 hours.

The indications now are that, for most purposes - at least for faint-source raster observations - automatic techniques are available that eliminate the need for manual deglitching. This is a *great* relief!

3.2.3 MMMS deglitching

A new deglitching strategy for faint sources, MMMS (Multi Method, Multi Step) has been developed lately. While the development is still ongoing, deglitch-MMMS had given very encouraging results for the processing of CAM parallel dark revolutions and for faint-source measurements, where the sources are buried within the noise. The calibration star HIC96062 is actually too bright for deglitch-MMMS, so the algorithm was modified to deal with it.

The number of pixels currently suppressed by deglitch-MMMS can be compared to strong manual deglitching: For 2 and 5 seconds integration time around 20% and 35% of pixels are masked respectively, while for CAM parallel 45% of all pixels are suppressed.

See Fig. 3 for an illustration of its capabilities.

3.3 PRETI method

The principle of the method is explained in Starck et al., 1997. It is based on a multi-scale median transform analysis which offers the possibility of separating the different constituents of the signal.

The input file is the cube of dark corrected data. The quality of the dark subtraction is not too important before running PRETI. The tool makes a deglitching of the short term glitches (the most common) and a correction of the long term transients after the *dipper* or *fader* glitches, and finally it removes the baseline from the pixel time history, so removing the very long transients of the pixels and their 'oscillations'. In the process, all very extended features are attenuated or suppressed in the final mosaic with this processing, and the background is subtracted. This processing is designed to extract point sources. Fig 4 gives an example of a good transient correction after a dipper glitch that introduced a negative gain variation. Fig 5 shows how the oscillations of the pixel time history are removed with PRETI. It also shows that two *fader* glitches (positive transients) are left over after the standard PRETI processing, because their time scale is of the order of the number of readouts per raster position (13 in this case). They will pollute the final raster map, so demonstrating an important limitation of the method.

3.4 VILSPA iterative filtering method *(Metcalfe)*

This method combines a temporal median filtering of the detector pixel history with a phase 2 deglitching operation performed on the redundant-detection history of each **sky** pixel.

Currently. at VilSpa, we tend to apply this method and the PRETI method to all faint-source data sets and to compare the results, in that way obtaining a somewhat (though not comletely) independant cross-check of faint detections.

The temporal median filtering offers a simple and easily understood means of removing the long global transient from the pixel time histories, and also the transients with long timescales induced by dipper or fader glitches. It simply takes a 'wide-window' median of the pixel time history and subtracts it from the original time history. The result is background/baseline subtracted and essentially free of the global transient. Short timescale signal-changes (point-source detections) survive well. Longer timescale structures (extended sources and long-timescale transients) are suppressed (as in the case of the PRETI method). There is some impact on photometry (as in the PRETI method) - but it is calibratable. See Section 4.3 below on "Faint Source Photometry".

It is important to select the window for the median filtering with attention to the number of readouts in your raster. The corresponding CIA help file gives appropriate advice on this choice. If the window is chosen to be too small, it will correct well the transients with shorter timescales, but will attenuate even the point sources. If too big, it will allow some of the global transient to pass into the final mosaic as a ripple, and the image quality will be degraded. This filtering is obviously meaningless for staring observations and beam-switch observations.

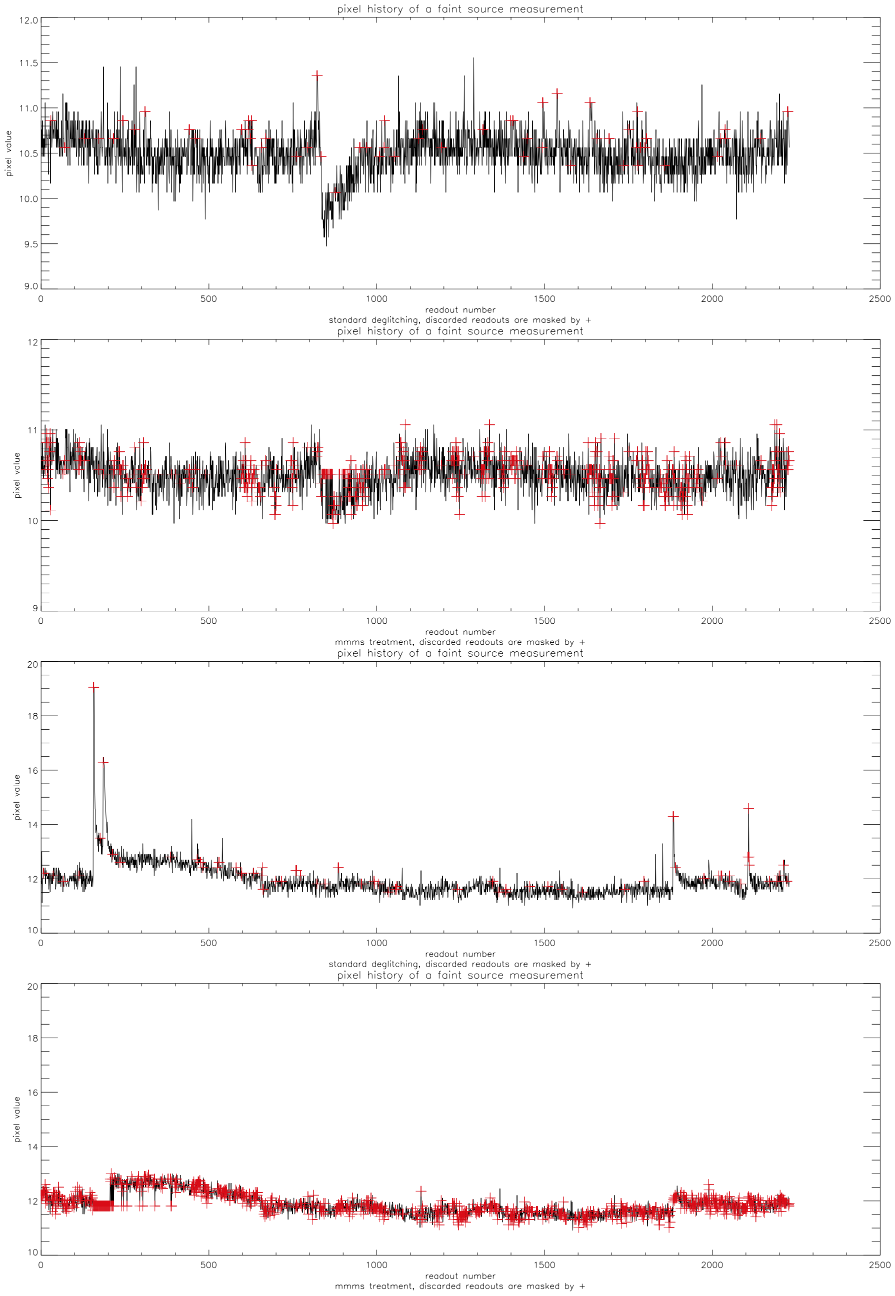

Figure 3: 2 examples of deglitch MMMS on a fader and a dipper

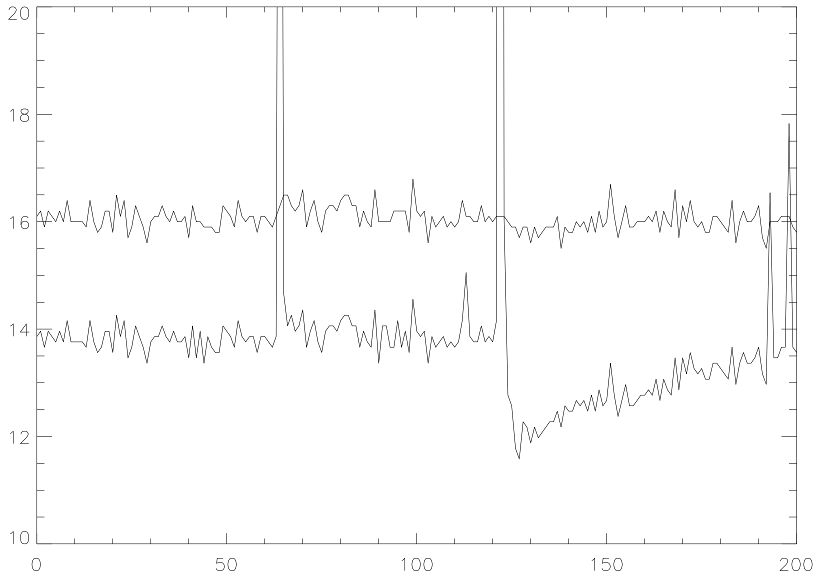

Figure 4: Good 'dipper' glitch correction by the PRETI method.

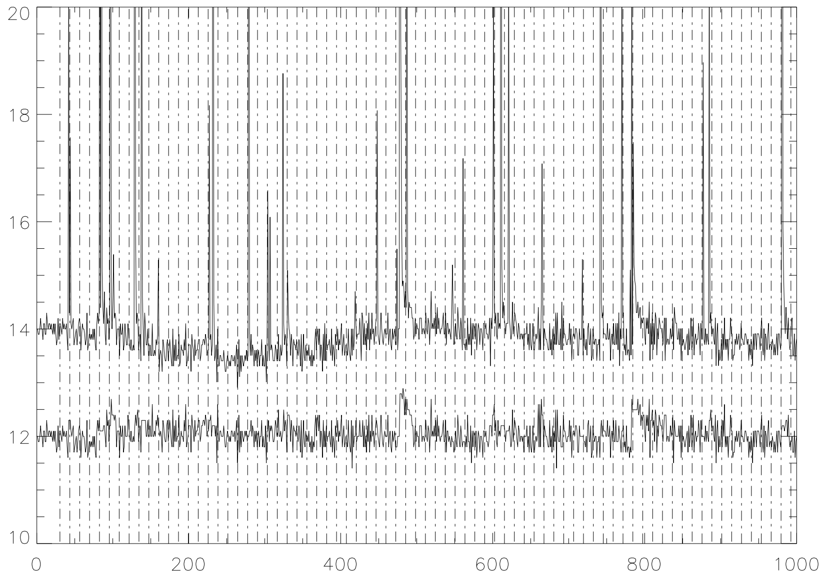

Figure 5: Example of a spurious source detection after standard PRETI processing, around readout 500.

This method operates initially on already deglitched data. Further processing after the temporal median filtering can proceed in many ways and the sections above on deglitching should be read carefully because removal of residual glitches will require careful attention at this stage. Good results have been obtained by following this filtering with manual deglitching, sigma clipping of the detector-pixel histories, or by building the mosaic from the median of the raster position images. (See section 3.6 below.)

However, recently very good results in constructing the raster mosaic have been obtained by first organising the raster position exposures into a cube such that a track through the z-axis of the cube traces the history of a point on the sky as seen by several detector pixels through the raster. Such a path will trace the history of illumination of the detector by a particular point source of portion of the bacground sky for example. The only fluctuations in the signal along such a path are due to fundamental noise sources and glitches. This is different to the case of an individual detector-pixel history which may record the passage of many different sources over the pixel during the raster.

If the sky-pixel history is sigma-clipped with reference to the median of the pixel history, then a very good rejection of residual glitches is achieved without any serious impact on the photometry of the underlying source. The difference in the constructed raster mosaic 'before' and 'after' this phase-2 deglitching is very striking, and the map of sigma values per sky pixel derived during the sigma clipping process serves as a noise map for the final mosaic, tracing the sky pixels whose histories have been most affected by glitches during the measurement.

A limitation of the current implementation is that it doesn't include allowance for image distortion over the CAM fov - so it works well for the 3" pfov but would be likely to give poorer results for the 6" pfov. However, this has not yet been investigated. In any case the aim should be to implement an inversion of the image distortion correction into the algorithm to realise more of its potential.

An important aspect of this approach is the generation of the cube of sky-pixel histories, which may prove to be a starting point for several corrections applicable to data sets that have not been temporally median filtered. There are data sets with extended sources or low-contrast extended structures, which generally suffer from ripple effects in the raster mosaic which may be correctable through corrections applied to the sky-pixel history.

The calling command for temporal median filtering is:

CIA> stabilise,raster,method='med',window=window

where window is the size of the running window. This processing is to be run after de-darking and de-glitching, in place of the 'transient correction' in the above use of standard CIA, or just after, before the flat-fielding.

To apply the full method with phase-2 deglitching requires a tool still under development. Interested users can obtain support with these techniques at the VilSpa ISO data centre.

3.5 VILSPA differential method

At each raster position each detector pixel records a measure of the brightness at some position on the sky. This processing consists of replacing the value in each detector pixel with some function of its current value and its value at other sky positions. To give a trivial example, one of the simplest transformations is $x_{i\_new} = x_i - x_(i-1)$, where x_i is the current value of the pixel, x_{i-1} was its value at the preceeding sky position, and x_{i_new} is its transformed value – and this already works wonders to produce point source detections. But the sources are accompanied by negative artefacts at a distance of one raster step length. The reader is invited to experiment with other transformations, being alert to determine the impacts for photometric calibration. We would be grateful to hear of any interesting results, transformations or new algorithms. For the moment somewhat better results have been obtained with the iterative filtering method described in the previous section.

3.6 Median Mosaicing

The 'differential' method of filtering, as in the case of the 'VilSpa median' approach, requires attention to the removal of residual glitches. It has been found that - even without any phase-2 deglitching - simply building the raster mosaic from the median (rather than the mean) of the raster-position exposures gives very good results in terms of rejection of residual glitches in the final mosaic. The combination of (a) the 'differential' method of filtering the data cube, with (b) this median building of the mosaic, strongly rejects - for (a) residual glitches lasting much longer than one raster dwell time, and - for (b) residual glitches appearing strongly in a single raster position image. So the glitch suppression should be very good. More experience is needed applying these methods, and observers are encouraged to report their experiences or insights.

3.7 *Carlo Lari's* method

This method makes fittings of the pixel time histories with 3 time scales, and is therefore heavily CPU-time consuming. This is also the only method to-date that takes account of the signal coupling between neighbouring pixels. It works only if there is sufficient background in the observations.

As it is very complex and still requires a lot of user interaction, it can not be implemented in CIA yet, but work is progressing at VILSPA/Trieste/Bologna to make it more user friendly and robust. It is intended to import it into CIA in the future .

3.8 IAS *Désert* method

We refer to Désert et al., 1998 for a complete description of the method.

4 Source Detection

4.1 tools

- sextractor, a standard in astronomy for detection and photometry
- mr_detect from the MR package

sextractor (Bertin & Arnouts, 1996) is an easy-to-use tool, with a simple detection algorithm: it searches for n contiguous pixels each having a surface brightness exceeding a threshold σ after subtracting a smooth background signal, and convolving the images with a PSF if needed (n and σ user configurable)

mr_detect (MR package) based on wavelet analysis makes source detection at different scales and is thus powerful for detection of extended structures. It is a good tool to detect faint sources in ISOCAM rasters, but its photometry is strongly non-linear at faint fluxes and difficult to calibrate as it integrates on different scales for various objects.

5 Photometry of faint sources

ISOCAM PSFs in the mid-infrared are still very wide, being diffraction limited to a full width, in arcseconds, at the first Airy minimum, of 0.84λ (λ in microns). It is very easy to underestimate the flux by taking too small an aperture, as the PSF wings are large, especially at long wavelengths. For the larger CAM PFOVs the PSF may also be undersampled.

We refer to the "ISOCAM photometry report" (Blommaert J. et al., 1998) for a full description of the photometry of point-sources with CAM. The main purpose of photometric calibration is (a) to provide the user with the conversion factors (called "sensitiv" factor in the standard files) from instrumental units (ADU/G/s) to physical units (Jy), appropriate to any given filter, (b) to discuss their accuracies and (c) to check for any dependence of these factors on temporal variables, and spectral shapes of the calibration sources.

The photometric calibration measurements were usually done on bright stars, so they can not be immediately extended to the domain of faint source photometry. However it has been shown by various measurements that the ISOCAM LW detector remains very linear until the faintest reachable fluxes:

- Calibration measurements on a relatively faint calibration star from the Ground Based Preparatory Programme, compared to the stallar models (Cohen, Kurucz).
- Science observations of faint brown dwarfs (Altieri et al. 1999). compared to SED models.
- Extensive simulations by Aussel et al. 1998 to test the faint source photometry on the ISOCAM HDF observations. However at the faintest flux levels it was also found that the photometry becomes polluted by weak glitches, therefore a positive bias appears in the photometry.

5.1 Photometry tools

- **xphot** in CIA, a quick interactive widget tool to make fast aperture photometry.
- **sextractor** returns photometry as output.
- other astronomy package tools (MIDAS, IRAF etc ...)

5.2 Photometry of a calibration star

The relatively faint calibration star HIC96062 has been observed in 2 different observating modes to test the internal consistency of the CAM calibration algorithms:

- as for all other ISOCAM calibration stars, in staring mode (a single pointing) with 200 readouts in both the filters LW3 and LW9, at $3''$ PFOV.
- with the AOT 1 (general purpose AOT used by all general observers), in microscanning mode (step size = $13''$) with only 12 readouts per raster pointing.

The raster map mosaics of this star for different data processing approaches are shown in Fig. 7 to 12. For these raster parameters OLP did not take into account the microscanning (third of a pixel resolution in the step) so that the final pixel size is still $3''$. The standard processing in CIA (described above) with transient correction gives already a very good result. No attempt has been made to remove the leftover effects of glitches in these examples, and there is an obvious one remaining above the star which could be removed easily by some of the additional deglitching methods described earlier, in Section 3.

The photometry was done in an aperture of radius $5''$. From tests on model PSF profiles it is found that 65% of the flux is encircled within this radius for the filters in question. See Fig. 6. The LW3 PSF has about the same encircled-flux growth curve as the LW9 one.)

HIC96062 is not a truly faint source as it is above 10 ADUs in LW9, but it is still a good exercise to compare the fluxes given by the several methods.

- Standard CIA gives a very good first approximation to the real flux, if one simply corrects for the 60%, or incomplete, flux stabilisation. This is true as the LW9 background is low, but it is not true in the LW3 filter, for which the signal stabilisation proceeds more quickly.
- The IAS transient correction gives a very similar flux, a good demonstration that the 60% correction was a good first approximation.
- The Acosta method (Acosta J., 1998) gives also a very similar result. The principle of this method is very similar to the IAS one, but less CPU-time consuming.

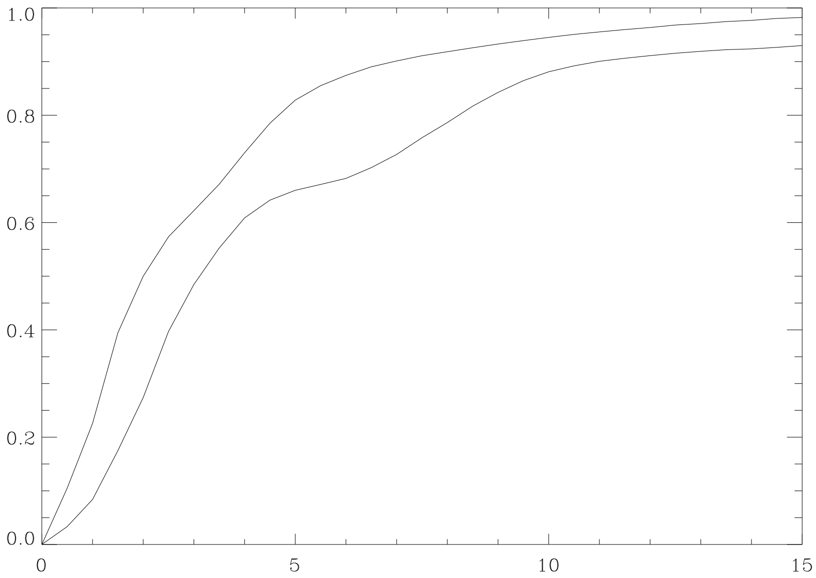

Figure 6: PSF encircled flux growth profile in LW2 and LW3 filters, with aperture radius in arcseconds.

- The PRETI method used with the default parameters, gives a typical flux loss of about 20-25%, but this is expected because the step size of $13''$ is small, so that a pixel can see the stellar PSF a second time in successive raster pointings and so the detection encroaches upon the timescales within the pixel history at which baseline drifts are filtered out. Therefore some flux is filtered out and lost in the baseline. The recovered flux with PRETI is found to be rather constant for various observational set-ups with small step size ($< 15''$), and can be taken as **70%** in a first approximation when PRETI is used with the default parameters. However, only extensive simulation with the actual observation parameters allows more accurate calibration of this factor, which depends mainly on the raster step size and the flux of the sources, but also on the wavelength, PFOV, T_{int} and N_{exp}, and to a lesser extent on the parameters used in mr_isocalib, the PRETI routine.

  The default parameters are *NSigma_Long_Glitch* = 4 and *number_of_scales* = 8. So that a standard way to call mr_isocalib for a microscanning observation with step size a multiple of a third of a PFOV (widely used) is :
  mr_isocalib -S 4 -A -m 3 raster.fits raster_isocalib.fits
  The quality of the PRETI image is such that it is very flat, very low RMS, with the global transient removed, and it is obtained quite quickly with the default parameters.

- The Lari method gives a very nice result and also extremely clean maps (as on other observations) at the expense of an extremely high computer processing time (- hours for a small raster like this one, compared to less than two minutes with PRETI on Sun/Solaris). It corrects transient responses with at least 2 time scales (only one in the IAS method)

  Lari's method performs excellently at these flux levels. Not only does it give the correct photometry, but it reduces the noise by a factor of 3 relative to more routine processing in CIA, to levels comparable to PRETI.

- VILSPA median filtering method gives a good quality image with a flux better preserved than with PRETI. Much less flux in filtered out in the PSF wings. When the redundancy of the rasters is higher this method tends to give raster mosaics which challenge the PRETI method if combined with phase-2 deglitching, as described in Section 3.4 above. The example here has not employed phase-2 deglitching.

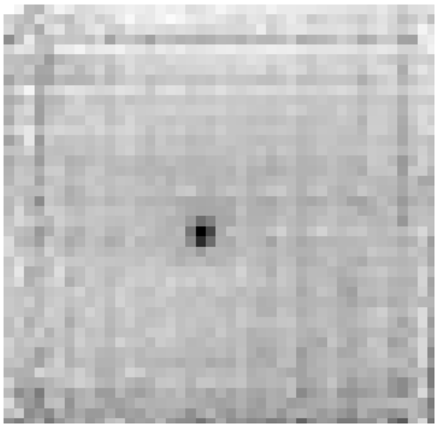

Figure 7: HIC96062 LW9 raster map from OLP v7.0.

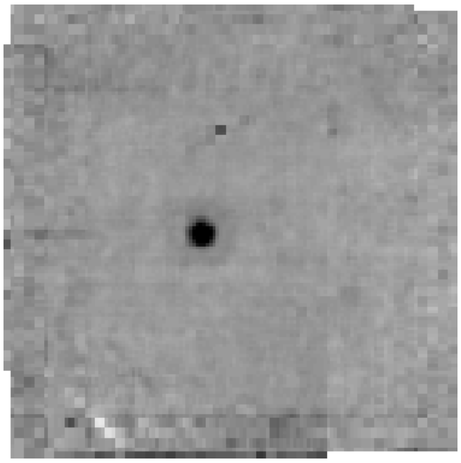

Figure 8: HIC96062 raster map in LW9 with standard CIA + IAS transient correction.

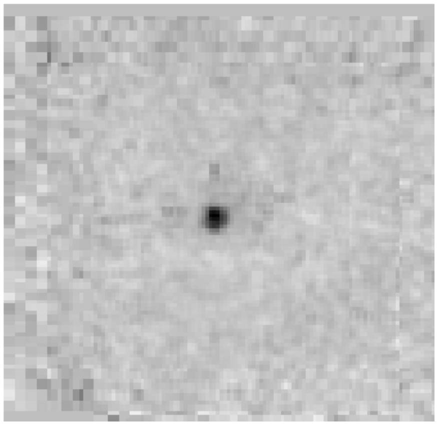

Figure 9: HIC96062 raster map in LW9 with the MMMS deglitching method.

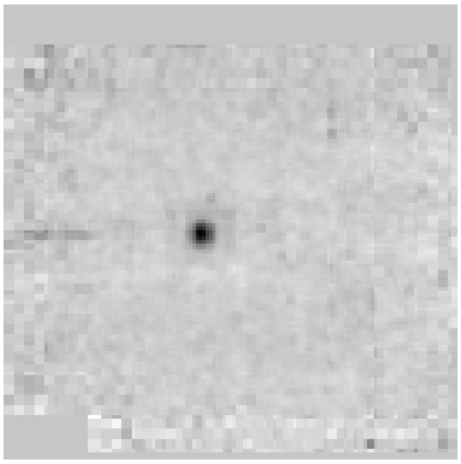

Figure 10: HIC96062 raster map in LW9 with VILSPA temporal median filtering method.

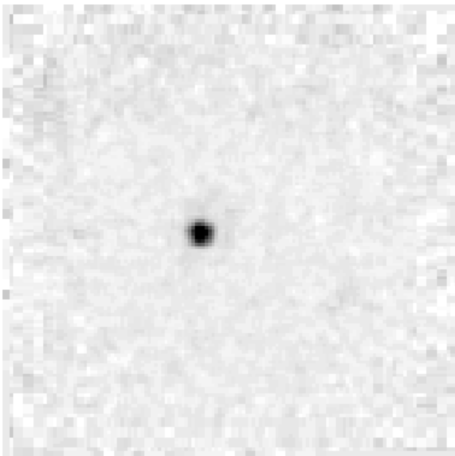

Figure 11: HIC96062 raster map in LW9 from PRETI.

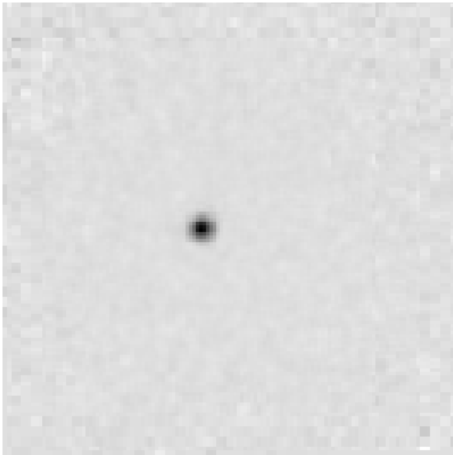

Figure 12: HIC96062 raster map in LW9 reduced with Carlo Lari's method.

Table 1: Comparison of HIC96062 LW9 photometry with several methods

Method	Source flux in R=5″ (ADU/g/s)	stabilisation corrected (ADU/g/s)	PSF corrected flux (ADU/g/s)	pixel-to-pixel rms (ADU/g/s)
CIA	3.9	6.5	10.0	
CIA + IAS	6.4		9.9	0.003
Acosta	6.7		10.3	
PRETI	3.0	5.0	7.7	0.0015
Lari			10.5	~0.002
Metcalfe Median	3.63	6.05	9.3	0.0018
Staring			10.5 ±0.5	
Staring + IAS			11.3 ±0.9	

The results of the photometry are summarized in Table 1. One can see that all methods tend to give lower values than the staring observation photometry, which takes more carefully into account the effects of the PSF to very long radius (and therefore for background subtraction).

The staring observation photometry is highly reliable and is in excellent agreement with results obtained when deriving the SENSITIV parameter value on bright sources.

So we point out a potential to underestimate the fluxes with ISOCAM data (not only for faint sources in fact), due to the combined effects of wide PSF wings, overestimation of the background, transient drifts and filtering in the data processing. Care must be taken to avoid this.

5.3 Linearity to faint fluxes

A good test of absolute CAM photometry is to compare the fluxes found on a non-calibration source with a Spectral Energy Distribution (SED) model. As an example the newly discovered Brown Dwarf was observed by ISOCAM in science time through 4 filters and in microscanning mode. The flux found in LW3 (15 μm) is around 0.5 mJy, and it fits very well to the model (even though the scale is logarithmic !). The error bars of the fluxes in the 4 filter bands are about 20%, see Fig. 13. The LW10 flux density even constrains the model, for relative proportions of molecular absorption versus dust emission.

5.4 Faint Source Photometry

5.4.1 Background on the topic

The main problem with the faint source processing techniques described in chapter 2, is that they involve filtering of the pixel time histories, mostly median filtering. (PRETI for example). This means that *some* flux of the sources is unavoidably filtered out, and therefore the ensuing matter of photometric calibration becomes very complex, as in principle this flux loss can depend on several parameters of the source (flux level, source shape ...) and observational parameters (step size, pixel size, number of readouts per position ...)

In the case of PRETI, used with the default parameters, this factor is approximately constant at about 70%.

However more generally to calibrate the photometry at faint fluxes the best solution is to make simulations (see next section). This means introducing some "fake" (model) sources with known fluxes into the cube of data, with real PSFs and glitches and transient

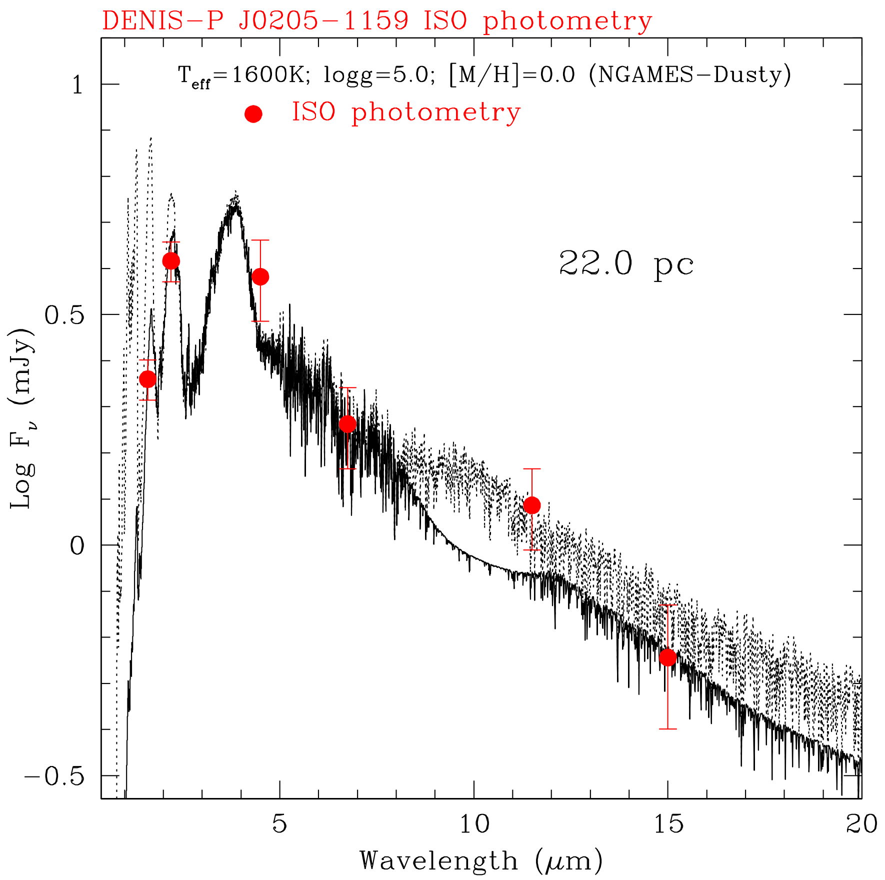

Figure 13: Spectral Energy Distribution of the Brown Dwarf DBD J0205-1159

characteristics, Subsequently applying the same data processing, and measuring in the final raster the flux recovered, to compare it with the simulation input flux.

This exercise has been done in detail, for instance in Aussel et al. 1998, working on the data of the HDF. It is shown that the aperture photometry is linear to faint fluxes, (see Fig. 7a and 8a of Aussel et al. (1998). However at the faint tail of the flux distribution the aperture photometry starts deviating positively from linearity due to the glitch pollution (say sources detected at 4σ or below)

Note that other types of photometry, like elliptic Kron fitting or wavelet multi-resolution photometry (in PRETI) are not at all linear over a much wider flux range, because of variable apertures.

An additional problem is the PSF correction of aperture photometry. The aperture photometry consists of deciding upon a diameter for the source flux integration and by taking the same aperture on measured or synthetic PSFs in the same filter to define the flux actually contained within this aperture (or in other words the flux loss in the PSF wings). Due to the large PSF wings of the ISOCAM sources, which are lost in noise for faint sources, the tendency is always to underestimate the fluxes.

On top of that, most of the faint sources in deep extragalactic surveys have relatively flat or even red spectra (i.e. rising flux densities towards longer wavelengths), whereas the standard PSFs used have been measured on much hotter stars, in the Rayleigh-Jeans part of their spectral energy distributions (i.e. flux densities in λ^{-2}). Therefore the PSFs of the cold redder sources will be wider than those of the standard stars, and thus another mechanism for underestimation of the fluxes arises. This could explain the 20% systematics in the photometry of the HDF sources between Aussel et al and Désert et al..

The faintest sources have sometimes disturbed shapes so that it is not always easy to choose the best aperture. If it is too big it simply adds noise; if the aperture is too small the uncertainty will grow also due to the small number of pixels taken in account and the resultant poor approximation to a true PSF core. A $7''$ diameter aperture is usually found to be a good compromise for observations done at $3''$ pixel-field-of-view in microscanning mode (a third of a pixel resolution in the step size), and having final maps with $1''$ pixels. Usually it will enclose between 45% and 60% of the flux depending on the filter. However, larger aperture diameters such as $9''$ can be used too.

5.4.2 Flux calibration

The main issue concerning the photometry of faint sources (but not their detection) is the calibration of the source transients. Transient correction can be applied, but at faint levels it tends to introduce noise into the signal [TBC] and therefore it is not generally used at VILSPA. The only way to address rigourously this topic is to make simulations. Another way is to adopt a 'fudge' correction factor, almost constant at faint fluxes at about **0.6** in LW2 and **0.8** in LW3. But in principle, this is source-flux and background level dependant.

5.4.3 simulations

The routine **simul_source** (distributed with CIA as a contributed routine) is used to add artificial sources to ISOCAM data. These artificial sources may be user-created or taken from the theoretical ISOCAM PSFs which can be found on the ISO WEB pages or in CIA. Since the artificial source is of known flux, source simulation can be used to: (i) measure the attenuation of source flux due to 'severe' data processing methods, (ii) prove photometric techniques, (iii) check the realism of very faint source photometry. But **simul_source** does not include a simulation of the transient.

After dark correction and flat-fielding, the artificial source is added at the cube level, i.e. to the PDS or raster structure field .CUBE. For example, to prepare the PDS, restore the appropriate PSF and insert it into the data, one would do something like the following.

```
CIA> corr_dark, raster_pds
```

```
CIA> corr_flat, raster_pds, /cube    ; must be done at cube level
CIA> restore, make_psf_name(raster_pds), /verb
CIA> simul_source, raster_pds, psf, 50, 50, factor=100
CIA> deglitch, pds
etc...
```

After the MOSAIC is built the artificial source should be found to be centered at RASTER_PDS.RASTER[50, 50]. The value of the keyword */factor* is multiplied by the artificial source, so in the above example since the PSF is normalized to 1 ADU we are adding a source of 100 ADU to the data. See the function header for more options for **simul_source**.

5.5 Detection limits

The spatial noise in the deep (high redundancy) final raster maps is very close to gaussian. However in most rasters where microscanning has been used, pixel rebinning is used in the construction of the mosaic, to take advantage of the higher spatial resolution available, so that there is a component of pixel-to-pixel correlated noise due to this rebinning. Therefore the noise doesn't always increase with the square root of the numer of pixels taken.

A simple way to derive detection limits on a raster map is to make aperture photometry of a number of blank beams in the map, say n=20, with the same beam used for the sources, This is easy and fast with **xphot**. The standard deviation of these n measurements gives the 1 RMS value1 per beam, directly (after correction for aperture and transients). Usually, the 1 RMS value so-derived is also very close to $1sigma$ - where we remember that 1 RMS has a precise mathematical definition, whereas the terminology "$1sigma$" implies a certain percentage reliability for 1 RMS, and so that terminology assumes gaussian statistics in interpreting the RMS value.

The use of microscanning is fundamental in ISOCAM rasters. It increases the spatial resolution to the level of an arcsecond, and experience suggests that, at the same time, it allows one to reach fainter fluxes, since the flux of faint sources is smeared out by bigger pixels. The typical deep rasters have been performed with $3''$ PFOV which leads to $1''$ pixels in the final raster maps with the use of microscanning steps of integer+one-third of the physical pixel size. Without microscanning but with the same raster parameters otherwise, the sensitivity is apparently degraded by a factor around 2-3.

The aperture photometry accuracy is also strongly degraded due to a much coarser sampling of the PSF.

5.5.1 Flux calibration accuracy

The currently best absolute flux accuracy reachable for faint sources is estimated to be about 30%, including uncertainties in the systematics of responsive transients and filtering processes in data processing. On top of that, the intrinsic error bar of the measurements depends on the aperture and thus the PSF aperture-correction used. Colour-correction, and the dependance of the PSF size with the spectral index increase further the error bars. The rebinning of the pixels in microscanning mode has also a certain influence on the error bars of flux measurements. All these effects make the determination of flux error bars and systematics the most complex topic in photometry of faint ISOCAM sources. But it is felt by various groups at the time of writing this report that the global error bar can currently, generally, be brought to 30% or less at the few hundred μJy level with a very careful analysis.

5.5.2 Completeness

[TBW.]

5.5.3 Confusion

This is a complex topic that will be discussed in a later version of this document. [TBD]

6 Summary/Conclusions

The detection and photometry of faint sources in deep ISOCAM rasters in not straightforward. It requires careful analysis and depends on the observational parameters as well as on the reduction algorithms used and how the are combined. To get the cleanest maps, and therefore the faintest flux for a given raster, median filtering or differential techniques have been applied to the detector pixel histories, followed by phase-2 deglitching techniques, sometimes operating on the sky-pixel histories. Each method requires its own flux calibration generally best derived by using source simulations in the data to link the algorithmic behaviour to the standard ISOCAM calibration.

7 Annex 1

CIA commands to subtract a running dark:

```
CIA> rev = strmid(RASTER.history(2),4,3)
CIA> tsa = get_tsa(raster.utk,rev)
CIA> bestdark = darkmodel(rev,tsa=tsa,tint=raster.tint)
CIA> raster.cube=raster.cube/raster.tint/raster.gain-bestdark
```

8 Annex 2

3-σ clipping of cube for left-over glitches removal after baseline subtraction.

```
calmean,raster.cube,moy,rms
medianraster = median(raster.cube)
indexmax = where(raster.cube(*,*,*) gt medianraster+3.*rms)
indexmin = where(raster.cube(*,*,*) lt medianraster-3.*rms)
raster.mask(indexmax)=1
raster.mask(indexmin)=1
```

References

[1] Abergel A., Désert F.-X., Aussel H. 1996, "IAS model for ISOCAM LW transient correction"

[2] Abergel A. et al, "The transient behaviour of the long wavelength channel of ISOCAM", Experimental Astronomy, to be published in 1999

[3] Acosta J., "Comparison of ISOPHOT and ISOCAM/IAS approaches for transient corrections", ISO internal document.

[4] Altieri B., Metcalfe L., Elbaz et al, 1999, *ISO detector workshop proceedings* to be published in Experimental Astronomy, 1999. 'Ultimate Sensitivity with ISOCAM'

[5] Aussel et al, A&A, 1998a, 'ISOCAM observations of the Hubble Deep Field reduced with the PRETI method'

[6] Aussel H., 'ISOCAM LW Channel Field of View Distortion', version 0.9, August 1998b.

[7] Bertin E. & Arnouts S., 1996, A&A, 177, 393

[8] Blommaert J. et al, 1998 , ISOCAM Photometry report

[9] Biviano et al., 1998, ISOCAM Dark Current Calibration report, (Version 1.0, March 25^{th}th, 1998)

[10] Biviano et al., 1998, ISOCAM error budget

[11] Claret A. & Dzitko H. 1998, "ISOCAM glitch library"

[12] Désert F.-X., Puget J.-L., Clements et al., 1998, A&A, 1998 in press 'A classical approach to faint source extraction from ISOCAM deep surveys'

[13] Ott S. et al., 1997, "Design and implementation of CIA, the ISOCAM interactive analysis system", ASP conference series vol.125

[14] Pérault M. et al. 1994, Optical Engineering, 33, 762

[15] ISOCAM Interactive Analysis User's Manual, SAI-96-5226/Dc.

[16] Starck J.-L., Aussel H., Elbaz D., 1998, in *Extragalactic Astronomy in the Infrared*, Ed. Frontières, Mamon G.A.