FROM A CALIBRATION TOOL TO A FULL SCIENTIFIC ANALYSIS AND PIPELINE SYSTEM: THE ISOPHOT INTERACTIVE ANALYSIS (PIA)

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ABSTRACT

The ISO**P**HOT **I**nteractive **A**nalysis (PIA), originally conceived as a tool for ISOPHOT data processing to be used by calibration experts, rapidly became the software of choice for scientific data reduction of ISOPHOT observations. In this paper we summarize the enhancements of PIA in the last year, and discuss in particular its capabilities for efficiently reducing huge amounts of data in a "pipeline" modus, at the same time keeping all interactive analysis possibilities present and active.

Key words: ISO; ISOPHOT; infrared astronomy; interactive analysis.

1. INTRODUCTION

The spectro-photopolarimeter ISOPHOT (Lemke et al. 1996) was the most complex instrument on board ESA's Infrared Space Observatory ISO (Kessler et al. 1996). Several sub-instruments for performing photometry, polarimetry and imaging covering the full ISO wavelength range ([2.5-240] microns) had as counterparts a large number of observation modes, including spacecraft raster mode, beam chopping and internal calibration (Heinrichsen et al. 1997). A large number of different data products, including calibration files, was also a consequence of the instrument's complexity.

The requirements for a software calibration tool, which was to deal in an efficient way with the ISOPHOT data, had a large commonality with the requirements for a scientific analysis tool. Therefore, from the very beginning of the development of the ISO**P**HOT **I**nteractive **A**nalysis (PIA) the idea of a common system was followed. The result is advantageous both for calibration experts, who find a very user friendly system and can concentrate on their calibration tasks, and for general users, who have deep access to calibration files and internal information. PIA is entirely based on the Interactive Data Language IDL. The general requirements for PIA, its main design concepts and first development are described in Gabriel et al. 1997c. Further publications on PIA describe the general structure of the package and its internal data organization (Gabriel et al. 1997), PIA's image processing capabilities and interfaces (Gabriel et al. 1997b) and the first improvements to the package during the ISO operational phase (Gabriel et al. 1998).

During the ISO mission and on into the ISO post-operational phase (which will last at least 3.5 years) the PIA capabilities are continuously being enhanced. The various areas of data processing, graphical user interfaces, access to the calibration files, automatic analysis sequences, information on and distribution of the package, documentation, have all been upgraded for higher efficiency and for better service to the PIA users. The fact that PIA was distributed freely to the astronomical community from a very early phase of the ISO mission (six months after ISO launch) imposed a high quality level on reliability and documentation of the system, but also helped to increase its capabilities in all areas by the continuous feed-back from the astronomers in the more than 150 scientific institutes which had the package installed.

In this paper we deal mainly with the most recent enhancements of PIA with respect to the scientific data reduction, as well as the establishment of a versatile pipeline system within the system, which increases its efficiency for the analysis of huge data sets.

2. ENHANCEMENTS IN ISOPHOT DATA REDUCTION

The ISOPHOT data reduction consists basically of: (a) Instrumental effects removal; (b) Flux calibration; (c) Data combination into images, spectra, photometric and polarimetric tables.

A full description of all data reduction steps contained in PIA is given in the PIA Users Manual (Gabriel et al. 1998b).

2.1. New aspects in instrumental effects removal

Instrumental features are corrected using either calibration files or parametric algorithms. One of the major advantages of using PIA consists in the possibility of testing and changing the parameters by dedicated menus and showing the results in plot and text.

New algorithms for removal of instrumental effects in PIA are:

- Two thresholds deglitching: cosmic hits are one of the main sources of disturbances in the ISOPHOT data. The introduction into PIA of an algorithm specially suited for detecting (and correcting for) the momentaneous changes in detector responsivity caused by the most energetic hits has further helped to minimize their effects. A dedicated discussion on the PIA treatment of glitches as well as the corresponding graphical user interfaces can be found in Gabriel & Acosta-Pulido 1998.
- Reset interval effect correction: it has been found that the signals obtained from the Cold Readout Electronics output are partly dependent on the reset interval (ramp integration time) used for sampling. Tables for normalizing to the output (hypotetically) obtainable by a fixed integration time have been introduced into PIA. This correction, which has to be applied to every ISOPHOT dataset, has also been used within PIA for the derivation of all calibration files affected by this effect.
- Orbital dependences of dark currents and detector responsivities: using large statistical samples the ISOPHOT calibration experts were able to establish the dependency on the orbital position of both detector dark currents and responsivities. The results, also basically derived using PIA, are condensed in calibration files, which are used by PIA for interpolating to the orbital position of the data to be analyzed.
- Chopper frequency dependence of a differential measured signal: one of the ISOPHOT observational modes is based on the use of the chopper for on-source/off-source observations and the obtention of a differential source measurement. The subtracted value from such observations depends in first approximation on the chopping frequency used (and in second order on the signal difference between both levels). Tables containing the correction factors have been established and are used by PIA.
- Baseline drift corrections: while signal drift modelling on a short timescale can be performed using diverse functions (as referred in Gabriel et al. 1998), there is no functional description for long term baseline drift behaviour, as often affecting long spacecraft raster observations with ISOPHOT. Two procedures are contained in PIA for correcting for this effect:
    1. judgement by eye-balling through a very user interactive approach. The user has the possibility of defining several points within a measurement which should have a similar flux but show different signals. From these points factors are derived for correcting the measurement, interpolating them for every point in the chosen distribution.
    2. median filtering approach. Hereby the observed signal distribution is normalized dividing it by the product of its median filtering using a certain variable width. The re-normalization to the original flux is performed using the integral flux of the original distribution. If the same area was observed with different detector pixels (eg mapping with an ISOPHOT-C detector array) the average total flux can be used for re-normalization, with the consequent automatic flat-fielding effect.

A general new approach was introduced from PIA version 7.0 on concerning the treatment of statistical and systematic uncertainties with respect to earlier versions of the package. A strict separation allows for a correct propagation of statistical uncertainties, while all systematic uncertainties corresponding to the corrections performed on the data are quoted in the corresponding measurement header indicating its relative amount. This gives the user an easy way of calculating final systematic uncertainties, since they depend largely on how data are used and combined in each case.

2.2. New aspects in flux calibration

The main new element hereby is given by the introduction in PIA of an alternative way of calibrating one of the ISOPHOT sub-systems: the spectrophotometer ISOPHOT-S.

The so-called "dynamic calibration" is based on the knowledge that the temporal response (drift behaviour) of an individual detector pixel depends primarily on the illumination level with a high reproducibility under a similar flux history. Since all ISOPHOT-S observations were performed using the astronomical observation template (AOT) P40, in which the sky measurement is preceded by a dark exposure, the flux history (at least immediately) previous to the sky observation can be assumed as very similar.

A series of measurements on calibration stars, covering a very wide flux range (magnitudes $m_K = -3.1$ to $m_K = 7.5$), was used to create a database which includes the temporal behaviour of any of the ISOPHOT-S detector pixels. Two fundamental elements of this method are: a) the drift behaviour of a given detector pixel remains similar for a flux range of 0.5 magnitudes, and b) the chosen calibrators cover more than four orders of magnitude in flux with the necessary density. Therefore a comparison between signals obtained after certain time intervals by an unknown source and by the calibrators makes possible a good determination of the flux corresponding to the unknown source.

A full graphical user interface has been developed within PIA, which allows the user to judge the quality of the calibration performed, choose the mode for combination of results with different calibrators, activate/disactivate individual calibrators, etc.

2.3. New aspects in final data analysis

Many new features concerning final data analysis have been introduced into PIA during the last year. The most important ones are:

- Combination of different datasets: on the last level of data reduction included in PIA (flux/surface brightness per filter/aperture/sky position) it is possible to combine datasets, independently of their AOT type or detector. This feature was already present in an early stage of PIA for staring ISOPHOT-P and ISOPHOT-C observations, used for multi-filter or multi-aperture analysis with several independent data. Now it has been extended to every type of data, making possible eg to construct maps from sparse map observations, but also from different observations, and to concatenate maps in a certain sky region coherently.
- Mapping with ISOPHOT-S data: the possibility of performing raster observations with ISOPHOT-S was given, although it was not very often used. A special GUI within PIA facilitates the construction of maps taking either a determined ISOPHOT-S detector pixel or a wavelength region covered by several pixels. Also spectra from a single point or sky regions covered by the map can be produced.
- Color corrections: this is offered by a GUI with several source spectrum alternatives, eg. blackbody (BB) spectrum (with a choice of temperature of the BB), power-law spectrum (with an index choice) and modified BB spectra with emissivity proportional to nu and nu squared. The colour corrections factors, eg. the calculated factors from folding source spectrum and filter curve, are presented to the user in a text window while correcting the data.
- Mapping algorithms: in addition to the original mapping algorithm, two alternative algorithms have been implemented in PIA V7.3. The original "full coverage" algorithm is based on a simple gridding function which calculates the contribution of every detector pixel signal from the geometric overlap of detector pixel and map pixel. A trapezoidal smearing function which depends on the distance between detector pixel center and the center of the computed image pixel is the general result, which in several cases has the disadvantage of smoothing small real structures present in the map. To reduce this effect, the "distance weighting" algorithm was developed, by which every contribution from a detector pixel to an image pixel gets a weight calculated based on the distance between their centers. A third possibility is a linear or quintic interpolation between neighbouring points defined by a Delaunay triangulation of all central detector pixel positions in the raster data. In this case a re-sampling of the data is performed prior to its use, due to the (more or less) large oversampling present in the ISOPHOT raster maps. Both alternative methods, of course, imply an increase of the map noise, which is the price paid for getting a better spatial resolution. A program for quantifying the expected results by the different mapping algorithms has started, which includes simulations of different mapping strategies.
- Map deconvolution: different deconvolution techniques can be applied to the maps obtained , by using maximum Likelihood or maximum Entropy methods in conjunction with the footprint matrices established for all the different ISOPHOT filters. Generally, the application of deconvolution techniques requires a high degree of interaction for judgement of the obtained results. PIA includes a GUI for deconvolution, from which the different methods can be chosen, the footprint matrix to be used displayed, start parameters for the deconvolution procedure changed and results inspected.

3. PIA AS A PIPELINE SYSTEM

The main advantages of an interactive system like PIA are given by its intrinsic capabilities of accessing every piece of data in their different stages of processing, visualizing and judging the corrections / reductions done, as well as trying corrections with different parameters. However, working with large amounts of data implies the necessity of fast processing with a certain standard set of parameters. In PIA an automatic/batch processing mode was introduced, which represents a pipeline with a very high degree of flexibility, but also making possible the processing of very large and complex amounts of data with an absolute minimum of human intervention.

The start and end levels of such an automatic processing are user defined, and intermediate products can also be fully interactively accessed after the processing sequence is finished, since by default all the intermediate level data is kept within the session. However, to avoid memory and / or performance problems with very large amounts of data it is possible to choose the option of deleting low reduction level data after they have been processed. Input type can be either FITS files (FITS 1990) on disk or measurements already read in by PIA. All intermediate levels can be saved to disk in either FITS or PIA internal files format.

This subpackage within PIA is able to recognize the AOT mode of the data and perform the special processing which is required for some cases. Nevertheless, it works with the data as entered in the processing and neither AOT completeness nor AOT assignment is required. This makes possible the automatic processing of calibration data, independently of how the data was taken.

The high flexibility of this special pipeline is given by several elements, which can be set at the time of starting the procedure, changing the general defaults for processing:

- it is possible to make via dedicated menues (the same ones used in the "normal" interactive system) all kinds of data selections;
- all the corrections applicable to the data can be selected / deselected. Furthermore, parameters involved in the corrections can be customized;

- special data processing algorithms can be chosen;

Although the data processed is kept on memory, allowing for further (re-)processing within the same PIA session, the performance can be considered as very acceptable. For instance, the full analysis of the data used for the PIA system testing procedures (Heinrichsen & Gabriel 1997), comprising all types of AOTs performed with all ISOPHOT sub-systems, takes less than one hour CPU on a SPARC Ultra 5 for data corresponding to an integrated observation time of more than five hours.

The code used for performing the core processing of the automatic/batch procedure is an IDL script distributed to the PIA users, who can change it partially (either adding or deleting or replacing calls to processing routines) and according to their special needs. This shows the high modularity of the system. It also allows us to adapt the whole system easily every time a new correction algorithm is developed for the plain interactive analysis system.

PIA's "pipeline" mode was developed later than and completely independent of the official ISOPHOT specific pipeline (Laureijs et al. 1998). Advantages and disadvantages of this approach are discussed in Gabriel et al. 1997d. From a very early stage of the ISO mission, however, PIA has been pioneering the further development of the official pipeline due to its much higher flexibility and to the much shorter times needed for the introduction and testing of new algorithms.

4. DOCUMENTATION

There are several levels of documentation dealing with PIA, and all of them have been continuously under further development. They are from low to high level:

- Single routines documentation: every PIA routine contains a header, following the general IDL recommendations, including purpose of the routine, parameters and keywords, sub-routines needed, etc. They are grouped into different categories and each category builds a help library, reachable both from a hypertext browser and from the IDL help system.
- The PIA Users Manual: contains a tutorial, a full GUI description, processing algorithms and data structures chapters, etc. Originally written in hypertext format, it is reachable by a browser of the user's choice from the PIA main menu as well as individual chapters are linked to the corresponding graphical interface, to be recalled context sensitive. A LaTeX version of the manual was released mid 1998 for facilitating its use by newcomers.
- The PIA Homepage within the ISO homepage: it has been created to provide the astronomical community with better maintenance and service and as a way for an efficient feedback from that community to the PIA developers. It contains the latest version of PIA together with release notes, the PIA Users Manual in its different versions, help libraries, publications on PIA, frequent asked questions and answers together with a mailbox for receiving bug reports, comments, etc.

5. SUMMARY

The concept of PIA as a calibration tool and scientific analysis system, followed from the very beginning of its development, has proved to be of great value. PIA is not only the main system used for the calibration of ISOPHOT but also the system which has been used for the data reduction by all publications based on ISOPHOT data so far. Its pipeline system mode, which in the full PIA development can be considered as nothing more than a by-product obtained at a very low price, shows a very high flexibility and efficiency.

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