MAP COADDING AND SIMULATION TECHNIQUES WITH THE ISOPHOT INTERACTIVE ANALYSIS (PIA)

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ABSTRACT

The ISOPHOT Interactive Analysis (PIA) contains several map coadding algorithms and flat-fielding techniques that should help optimize the results obtained with ISOPHOT raster data. They are embedded in an environment combining a large flexibility with a very high level of user friendliness.

The many different ways of performing raster observations with ISOPHOT makes an assessment of the reliability of the obtained results somewhat difficult. A map simulator has been developed under the PIA framework, for addressing different questions like the validity of theoretical / experimental beam profiles; detection limits and confusion levels; and optimization of the use of the mapping algorithms by the different raster configurations.

Key words: ISO; infrared astronomy; interactive analysis, mapping, simulations.

1. INTRODUCTION

The most versatile and complex instrument of the ISO mission (Kessler et al. 1996) was the imaging spectro-photopolarimeter ISOPHOT (Lemke et al. 1996). It could be used in different observation modes for mapping regions of the sky, through a combination of ISO raster capabilities, the array structure and the ISOPHOT chopper capability in the case of an observation with one of the long wavelength arrays PHT-C100 or PHT-C200.

The main software available for the primary data reduction and scientific analysis of the ISOPHOT data is the ISO**P**HOT **I**nteractive **A**nalysis (**PIA**). 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). A first description of the early image processing capabilities and interfaces of the package is given in Gabriel et al. (1997b).

In this paper we concentrate on the different map coadding algorithms and flat fielding techniques available in PIA as well as on a map simulation system developed within the PIA framework.

2. MAPPING WITH PIA

PIA provides the user with software specially suited for processing raster measurements. The start point is data in either [Jy] or [MJy/sr], as contained in the so-called PIA AAP level, after the flux calibration has been performed. The data will correspond to one or several sky observations, since concatenation of different measurements is possible.

The primary output of mapping are images either in [Jy/beam] or [MJy/sr], uncertainty maps in the same units and exposure images.

There are four different map co-adding algorithms implemented in PIA as well as four different flat-fielding methods. The PIA user can try to optimize the data analysis according to his/her needs and the configuration used for the performed observation.

2.1. Map co-adding methods

All map co-adding methods use the full pointing information as provided in the internal PIA data buffers. Every data point is computed combining the right ascension and declination of the ISO raster position together with the pixel offset (in case of a detector array). For this the so called "roll angle" has to be used, i.e. the angle of the spacecraft with respect to the RA-DEC coordinate system. In case of a special observation mode which uses chopping in several steps for obtaining a larger spatial resolution (AOT PHT32) the chopper throw also has to be taken into account. What we end with is essentially a number of fluxes corresponding to several sky positions within the mapping area.

Every point extends in two dimensions and the extension is given by the single pixel dimensions in case of a long wavelength detector array PHT C100 or PHT C200, or by the dimension of the used aperture in case of a single detector PHT-P1, -P2 or -P3.

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ISOPHOT maps can have a perfect coverage of the mapping area, or can under- or oversample it. In most cases the observations were planned with a certain oversampling for two different purposes:

- a reduction of instrumental effects using the redundancy given by observing the same sky point with different detector pixels and/or several times,
- obtaining a higher spatial resolution by sampling the beam profile of a detector over distances significantly smaller than the dimensions of the beam.

The combination of the data obtained in a raster measurement can be performed within PIA using different methods:

The full coverage method

This is the traditional application of the shift and add method, by which every element of the gridded map region (image pixel p with brightness B_p) is computed through the co-addition of all the signals collected corresponding to detector positions which were partially or totally covering that image pixel. The brightness B_p is therefore a linear combination of all contributing signals i with a weight W_i:

$$B_p = \frac{\sum_i (B_i \times W_i)}{\sum_i W_i} \tag{1}$$

$$W_i = T_i \times Ov_i \times \frac{B_i^2}{\Delta B_i^2} \tag{2}$$

Every single contribution is weighted by multiplication with the fraction of the image pixel coverage Ov by the detector and the time T of this observation. Since most of the ISOPHOT maps were oversampled, the normal case is that an image pixel is seen entirely several times and therefore several signals contribute with Ov equal to unity. This is specially true by high oversampled maps (e.g. those corresponding to the AOT PHT32) by which the natural grid is based on image pixels which are smaller than the "fat" detector pixel.

In addition every individual signal is weighted in its contribution with the inverse of its uncertainty squared. In this way it is avoided that an individual bad determined signal dominates the resulting flux.

The problem of this method comes from the assumption of a known "beam" (implemented as a box function) which effectively causes a smoothing in the map.

The distance weighting method

This method tries to optimize the angular resolution which can be reached in an oversampled raster observation. A detector exactly centred on a point source, contains more point source flux than a detector which has been pointed off-centre. In the case of large oversampling, an image pixel of the gridded ISOPHOT map has been "seen" a point source at different positions from the centre several times by different detector pixels. To increase the weight of the information gained centrally in that position, the normalized (to the detector pixel size) distances $Dist_i$ between center of image pixel and centers of detector pixels can be used for the weights W_i, when co-adding all the contributing signals, as given in equation 3.

$$W_i = (1 - Dist_i)^3 \tag{3}$$

The power of three taken for the computation of the final signal is merely a pragmatic way of introducing a steep function.

Co-addition of all signals within a fraction distance f (fraction with respect to the detector pixel size) is performed as in Eqn. 1. This "acceptance radius" represents another degree of freedom in the "distance weighting" method, since it is free to the user to change it. The used default value is equal to one third of the pixel size (aperture size in case of mapping with an ISOPHOT-P detector). To avoid empty image pixels, the algorithm automatically increases the acceptance radius by a factor of two or even three in case image pixels are found which are not covered by a detector pixel.

The higher spatial resolution is paid, as expected, with a larger noise in the obtained images.

IDL's Trigrid method

The code for this method is part of the standard set of IDL routines, and is documented in the IDL's User Manual (see Triang and Trigrid functions).

The algorithm is based on a Delaunay triangulation of all positions corresponding to signals in a plane, so that every signal is enclosed by a triangle, representing its value. After definition of the map grid, the brightness corresponding to a cell is computed by interpolation (either linear or quintic) of the neighbour triangles.

In order to avoid interpolations between almost identical positions, observations within a fraction of a detector pixel (configurable parameter) are grouped together prior to the triangulation.

IRAF's Drizzling

An interface to the IRAF analysis S/W from PIA has been written by M. Stickel (MPIA), in order to make use of the so-called "Drizzling method" for map coadding (Hook & Fruchter 1997). This method, developed for image processing of Hubble WFPC2 observations, is based on the use of "shrunk" input pixels. It is an extension of the shift-and-add method, avoiding large smearing of the mapped sky and increasing the angular resolution of the mapped area.

2.2. ISOPHOT C100 and C200 flat-fielding methods

The ISOPHOT calibration takes care of the differences in responses by the detector pixels corresponding to the arrays C100 (3x3 pixels) and C200 (2x2 pixels). However, there are residual effects in the order of 10-20%, which can be significantly reduced by using the redundances present in all raster observations. Depending on the level of redundancy in a given observation and depending on the main purpose of the analysis, one or the other flat-fielding method should be applied, out of four different algorithms implemented in PIA.

Central overlapping Flat Fielding Method:

In this method individual maps per detector pixel (eg. 9 for a C100, 4 for a C200 observation) are obtained using the "full coverage" method. The central portion of the mapped sky region is then integrated in every individual map, yielding a value F_i. The flat-fielding factors FF_i are then obtained through

$$FF_i = \frac{F_i}{< F >} \tag{4}$$

and the full brightness distribution of pixel i is then normalized dividing it by the corresponding FF_i factor.

Required for the use of this method is that the original gridded map has at least nine image pixels in X- and Y-direction. Furthermore, all the image pixels from every sub-map used are valid.

Chosen background normalization

By this method an individual region is chosen for every detector pixel, which should represent the same brightness (eg. a more or less large portion of the measured background). This regions are integrated and normalized with the number of individual points used. The same obtention of flat-fielding factors is then performed using equation 4.

PIA offers a graphical user interface for the choice of user input parameters and for the display of the obtained results for this method.

First quartile normalization

By this method the first quartile (25% percentile) is computed for every detector pixel brightness distribution. This value, normalized through the average of the first quartiles of all pixels, is then taken as representative for the measured background by each pixel and used in the same way as in the former methods.

This is the only method which can be applied to process so-called mini-maps, a very often used observation strategy with the ISOPHOT long wavelength detectors C100 and C200. The other methods require in principle a much larger number of measured sky points than this one. However, a word of caution: since the background regions measured by the different pixels do differ, a gradient in the background or the presence of cirrus can lead to wrong flat-fielding factors.

Median filtering method

This method is the only one trying to account for time dependencies in the flat fielding distributions, these could be caused by different time constants by pixels suffering under long term responsivity changes.

Every single pixel brightness distribution B_i of the raster observation is divided by its median filtered distribution (baseline), which is obtained assuming a certain window size for a running median (configurable parameter). This leads to a distribution around the value of 1, by which sharp fluctuations in the distribution (as caused by observed point sources during the raster) are kept. Re-normalization of the distributions is obtained using the average brightness value of all detector pixels together. In this way automatically a flat-fielding effect is reached.

This method, proposed to the PIA development team by K. Kawara (University of Tokio), can be extremely useful for long observations with several point sources, on which the observer is mainly interested. Large extended structures are smoothed away by its use, as well as the background is flatten along the whole observation.

A full GUI is also offered in this case for differents parameters choices, as well as for data selection and results plotting and printing.

3. THE PIA MAPPING SIMULATION SYSTEM

The variety and complexity of the observing modes used by ISOPHOT (Heinrichsen et al. 1997) together with the instrumental features make the assessment and scientific interpretation of the obtained data difficult. Help can be expected from simulations by being able to quantify several aspects of the image data analysis, including the different data corrections and mapping algorithms which can be used within PIA for obtaining the final images.

We have developed a mapping simulation system within PIA, capable of generating sky images with several point/extended sources on a flat or variable background and simulating what ISOPHOT would have recorded under certain instrument and spacecraft raster configurations.

The mapping simulation system is fully integrated in the latest available version of PIA (V8.2), released on April 7, 2000.

This system should help to test several aspects of the image data analysis:

- to find out which are the detection limits and confusion levels for the different cases, both with respect to instrument configuration and sky characteristics,
- to test the different mapping and correction algorithms in relation to different observation configurations, with the aim of A) improving the data analysis and B) giving recommendations to the users,
- increasing the reliability of the obtained results by real observations,
- to test the validity of the theoretical and experimental beam profiles, as used for the data correction.

While all the above mentioned points are mostly of interest for calibrators and instrument specialists, it is also very important for a general observer to simulate his/her observation by matching the selected observing mode. This requires a high degree of user friendliness of the package and its free distribution to ISOPHOT users.

3.1. Basic outline of the simulation system

The system is divided into three main stages:

- *sky simulation:* a portion of the sky and a number n of sources with their respective positions in the sky, brightnesses and sizes (circular and bar structures are included) are defined. The choice between a flat or a gradient background is also included. Convolution with the footprint of a given filter yields an image of the convolved sky in addition to the pure sky. These images together with the parameter set used to create them are the products of this portion of the simulation, which can be saved as data entities for reuse at any time.
- *observing mode specification:* the observing mode is defined together with the raster parameters (number of raster legs and points per leg, distance between legs and points, central position of the raster). Both the orientation of raster vs sky as well as the orientation of spacecraft vs sky are necessary for establishing the exact positioning of the (square) detectors (and hence the "measured" flux) on the sky at any step of the observation. The result is a PIA data structure which can be used within the PIA environment as any real observation, e.g. deriving the corresponding image.
- *instrumental effects:* the expansion of every spatially "measured" point into a time series of signals as would have been recorded by a real observation is done together with the inclusion of instrumental effects, like the transient behaviour of the ISOPHOT detectors (Acosta-Pulido, Gabriel & Castañeda 1999), the disturbances produced by cosmic rays, different detector pixel response and a random noise contribution. The product, a PIA data structure (on a lower level of data reduction), can then be ingested into PIA for virtually simulating the data analysis.

The parameters included in all three stages of the simulation system are kept in configurable tables, so that changes can be easily done from dedicated GUIs. The model for the transient behaviour (by default the so called "offset exponential function" as explained in the PIA User's Manual[1], see also Acosta-Pulido, Gabriel & Castañeda (1999) can be replaced by any other model function.

3.2. The PIA mapping simulator GUI

The PIA map simulation system includes a widget based graphical user interface, with dedicated menues for each of the three parts of the system referred to in the former section. Visualization of the created sky images with superimposed raster and detector pixel positions is possible from the main menu. The visualization tools attached to this GUI are common to the PIA mapping system, offering the user the main IDL capabilities wrt image display and manipulation from comprehensive menues.

A full description of all features, including associated GUIs, simulated images, etc, can be found in the corresponding chapter (3.7) of the PIA User's Manual.

[1] http://www.iso.vilspa.esa.es/manuals/PHT/pia/um/pia_um.html

REFERENCES

Acosta-Pulido, J., Gabriel, C., Castañeda, H. 1999, accepted for publication in Experimental Astronomy, Kluwer Academic Publishers

Gabriel, C., et al. 1997, Proc. of the ADASS VI, ASP Conf. Ser., Vol. 125, eds. Hunt, G. & Payne, H.E., p. 108

Gabriel, C., et al. 1997, Proc. of the ADASS VI conference, ASP Conf. Series, Vol. 125, Hunt, G. & Payne (Eds.), H.E., p. 116

Gabriel, C., et al., 1997, Proc. of the 5th International Workshop on "Data Analysis in Astronomy", eds. V. Di Gesu et al, in "The Science and Culture Series - Astronomy", World Scientific, p. 409

Heinrichsen, I., et al 1997, Proc. of "The Far Infrared and Submillimetre Universe", ESA SP-401, p. 273

Hook, R.N., Fruchter, A.S., 1997, Proc. of the ADASS VI, ASP Conf. Series 125, G. Hunt and H.E. Payne (Eds.), p147

Kessler, M.F., Steinz, J.A., Anderegg, M.E., et al. 1996, A&A, 315, L27

Lemke, D., Klaas, U., et al. 1996, A&A, 315, L64

Carlos Gabriel, Helmut Feuchtgrüber, Anita Leech and Thibaut LeBertre during the workshop dinner.