



Overview of Post-BCD Processing

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1 Overview

This document briefly describes the capabilities of the Spitzer post-BCD software package designed for, but not restricted to, processing IRAC and MIPS data. For more detailed documentation, please, refer to <http://ssc.spitzer.caltech.edu/archanaly/>

The software in the package processes a set of images. The automated post-BCD pipeline processes images from one AOR only. The off-line version, which will be distributed to the public, can process any set of images. For each wavelength band post-BCD processing yields corrected images co-added into a mosaic image and a list of extracted point sources. The point source lists for different bands and instruments are merged to yield a multi-band point source list.

The post-BCD pipeline takes the following input:

1. A set of images.
2. Associated quality control mask images.
3. Relevant detector Pmask image (permanently damaged pixels).
4. Associated set of uncertainty images.

The main stages of the post-BCD processing are listed as follows:

1. Fiducial image frame (FIF) generation
2. Input image pointing refinement
3. Input image overlap consistency refinement
4. Input image interpolation
5. Multi-frame outlier detection and Rmask generation
6. Mosaic creation
7. Multi-frame point source extraction
8. Band-merging
9. Point Response Function (PRF) estimation

The input images have to be in the FITS format. The following keywords are required in the headers of the input files for the software to work: BITPIX, NAXIS, NAXIS1, NAXIS2, CRVAL1, CRVAL2, CRPIX1, CRPIX2, CTYPE1, CTYPE2. CD-Matrix elements or/and CDEL1, CDEL2, CROTA2 should be also present.

The following projections are implemented so far: "SIN", "TAN", "ZEA" (Lambert's zenithal equal-area), "ARC" (zenithal equidistant), and "STR" (stereographic).

There are no practical restrictions on the size of the sky covered by the set of images in order to be processed by this package. The only nominal restriction is that the set of images should only cover one hemisphere.

The software is available for two platforms: Solaris8 and Red Hat Linux 8.0.

2 Fiducial Image Frame (FIF) Generation

This step creates an image frame for the mosaic image and the associated Cartesian coordinate system, which is used at all post-BCD processing stages. Based on the list of pointing parameters of the input images - CRVAL1, CRVAL2, CRPIX1, CRPIX2, NAXIS1, NAXIS2, CD-matrix or CROTA2, CDELTA1, CDELTA2 - the software generates the pointing parameters for the bounding region of a minimal size, which encloses the input images. This step can be performed with images from multiple bands in cases where one desires to generate images at several bands on identical grids for multi-color rendition and analysis. Even though Spitzer images will use the CD-matrix convention, the mosaic image and by extension the interpolated images will use the set of keywords CDELTA1, CDELTA2, and CROTA2, since the mosaic image is undistorted.

3 Pointing Refinement

The software at this stage performs pointing refinement of the input images. The goal is to improve the pointing of the input images provided by the on-board star-tracker. This goal is achieved by minimizing the discrepancy between the positions of point sources matched in each pair of the images. Global minimization of the cumulative discrepancy with respect to the small changes in the pointing of the input images is implemented using a generic linear sparse matrix solver.

The software has two modes of operation: relative and absolute. In the relative refinement mode the images are made self-consistent. One of the images is used as a reference frame and its pointing is left unchanged. In the absolute mode a list of real point sources is used as one of the input lists. This results in fixing the absolute pointing of the input images.

The processing includes the following steps.

1. Point source extraction. For each input image single frame point source extraction is performed (see Section 8 for more details). A list of point sources is created for each input image. The lists are trimmed using a set of constraints on the parameters of the extracted point sources, such as SNR, flux, goodness-of-fit, positional uncertainties, etc. This processing uses the masks produced by single-frame radhit detection (see Section 1 for more details) or the sample up the ramp (RAW mode) radhit detector in the BCD pipeline to exclude radhits from the single frame point-source lists.
2. In the absolute refinement mode a list of sources with absolute pointing is needed. The FIF produced at the first stage is used to query the 2MASS point source catalog in the IRSA database for such a list. Alternatively, a list of absolute point sources can be compiled independently and specified as input to the program. This provision can be used when running pointing refinement with simulated data. In this case, instead of a list of sources with absolute pointing the truth list of point sources used to simulate the images is supplied.
3. Single band pointing refinement. The point source lists are fed into the *pointingrefine* module. The point source sky coordinates are transformed to a Cartesian coordinate system; normally, the FIF, produced at the first stage, is used for that purpose. The point source matching and minimization of the cumulative discrepancy is performed in the FIF coordinates. The module *pointingrefine* produces an output table with the

refined pointing and pointing uncertainties for each image. The standard pointing keywords in the headers of the input images are not modified, rather new keywords are written in the header of each input image. The automated pipeline is set up to perform relative refinement for MIPS and absolute refinement for IRAC bands 1 and 2. There is no such restriction for the off-line processing.

4. Multi-band pointing refinement. This is performed by the automated pipeline for IRAC only. One of the products of *pointingrefine* is a set of offsets and rotations in the FIF coordinates. The Cartesian offsets and rotations computed for band 1 and 2 are averaged and then applied to all 4 bands of IRAC.

Subsequent steps of image interpolation and point source extraction can be easily configured to use either the standard or the refined pointing keywords for coordinate transformations.

4 BCD Overlap Consistency Refinement

This software uses redundant information in the overlapping input images to estimate a constant offset in each image. The stage consists of three steps.

1. Input image interpolation. The input images are interpolated to a common frame (see Section 5 for more details). Normally the FIF produced at the first stage is used as the common frame. The input images are down-sampled, because using bigger pixels speeds up image interpolation without any detrimental effect to the solution, and only the large scale fluctuations in the images matter.
2. Calculation of the constant offsets. The metric to be minimized is the combined, uncertainty weighted, pixel-by-pixel difference between the overlapping parts of each pair of input images. It is minimized simultaneously with respect to the constant offsets in question.
3. Application of the constant offsets. The offsets are applied to the input images. The value of each offset together with its uncertainty is written in the header of the corresponding corrected image.

5 Input Image Interpolation

The image interpolation module performs projection of input images onto the FIF and interpolation of the input pixel values to the output array of pixels of the user-defined pixel size. It corrects for the optical distortion in the input images. The process is intended, but not restricted, to accept images measuring surface brightness and to yield images in the same units.

The value of an output interpolated pixel is equal to the weighted average of the input pixels overlapping the output pixel. It is weighted with the relative overlap areas.

Three interpolation schemes are implemented. For the first scheme, each output pixel is projected onto the input image frame and the flux from all the input pixels overlapping the output pixels is integrated and then normalized by the output pixel area. For the

second scheme, the input pixels are projected onto the output frame. The flux of the input pixel gets distributed among the output pixels it overlaps. For this scheme the drizzle interpolation with arbitrary drop factor is implemented.

The third scheme is an approximation of the second scheme. A grid of points is placed on the input frame. Each grid point is assigned the value of the pixel to which it belongs. Each grid point is projected onto the output frame and the flux associated with the grid point is added to the output image pixel into which the grid point was projected. The coverage map is also created that keeps track of the number of grid points projected into each output image pixel. After normalization by the coverage map the output image pixels have the values approximating those produced by the second scheme. The main purpose of the last scheme is to get a quick way of creating mosaic images, since the gain in speed can be as great as a factor of 5-10.

Uncertainty images are interpolated in the identical fashion. Coverage maps are created for each interpolated image. They record the fraction of output pixels covered by the input image, which reflects the presence of any input bad pixels or pixels on the edge of the input image.

6 Outlier Detection, Rmask Generation, and Reinterpolation

The post-BCD software employs three methods to detect radiation hits and moving objects. The results of the three methods are combined into one mask – the Rmask.

- 1 The first method is a single frame outlier detection that represents spatial filtering of input images. It is performed on the input images. In the automated pipeline, this step is included in the standard BCD processing. It is designed to detect relatively bright and spatially small radhits. The algorithm is a variant of image segmentation, and is based on the idea that when a relatively low detection threshold is applied, for each bright point source a large number of pixels will be detected above the threshold. Bright detections with small areas are, therefore, classified as radhits.
- 2 The second and third methods are multi-frame outlier detections and therefore require images interpolated to a common grid. Normally, the second method uses the input images interpolated for the subsequent co-addition into a mosaic. The second method represents temporal filtering. For a given pixel position in the interpolated grid, all pixel values from different interpolated images are processed to give a trimmed mean and standard deviation. The pixel values outside of the user-specified asymmetrical multi-sigma envelope are classified as outliers. This method detects both moving objects and radhits. It is not meant to be used in the cases of shallow coverage.
- 3 The third method represents a more complicated dual spatial-temporal filtering. First, all spatial pixel outliers are detected and saved as detection maps. These detection maps include point sources and radhits. Detection maps are interpolated to a common grid. Then for each pixel position in the interpolated grid the values of the interpolated pixels in the detection maps are compared. If in the majority of the detection maps a given pixel location has not been detected by spatial filtering, then in the images, in which this pixel location has been detected, they are declared

outliers. This method detects both moving objects and radhits. This method is expected to be reliable in the shallow coverage case.

The information about outliers detected using the three methods is combined in a single Rmask image. The outlier pixels in each interpolated image are traced back to the corresponding input image frame. Three bits are set in the Rmask, the first one for the single frame outlier detection, the second one for the multi-frame temporal outlier detection, and the third one for the dual outlier detection.

The process of reinterpolation can be performed subsequently, whereby the interpolated images are updated. Only the pixels masked in the Rmask images are recomputed, which makes it much faster than doing interpolation from scratch again.

7 Mosaic Creation

The interpolated images are co-added to create one mosaic image. The pixel values of the mosaic image are set equal to the averaged interpolated pixel values, weighted (when available) with the interpolated uncertainty images. The interpolated uncertainty images are also co-added into one uncertainty mosaic image following the standard assumption of additive variances. The coverage maps are co-added into a single mosaic coverage map. If the input images are units of surface brightness, the final mosaic will be in the same units.

The concept of tiles is used here. Tiles are subsections of the final mosaic image. The size of tiles is set by the user based on the computer memory considerations. It should be small enough so that all input images overlapping one tile can be held in memory without swapping. The software first produces the tiles for each final mosaic image with the tile sizes specified by the user. Then all the tiles are glued together into a single mosaic image.

8 Point Source Extraction

The software in this package performs multi-frame and single frame point source extraction. For multi-frame extraction, point source detection is performed on the co-added images. The main components of point source detection are non-linear matched filtering and image segmentation. They produce a detection list with the estimates of the positions of potential point sources. Subsequent point source estimation is performed by PRF fitting of the potential point sources from the detection list. The fitting is performed simultaneously in all the input images. It features passive and active de-blending. For single frame point source extraction the detection and estimation are performed on a single input image. Point source detection and optionally estimation is performed on the background subtracted images.

8.1 Point Source Detection

A complex algorithm involving non-linear matched filtering and image segmentation has been developed. The purpose of filtering is to reduce fluctuations in the background noise and to enhance point source contributions. The design of the filtering is based on maximizing the SNR in the input images.

Filtered images undergo a process of image segmentation. Contiguous clusters of pixels with values greater than a specified threshold are identified. The threshold is defined in terms of a robust estimate of the background fluctuations in the filtered image. If the number of pixels in a cluster is smaller than a user specified threshold, the cluster is rejected. It is an additional guard against cosmic ray affected pixels and background noise fluctuations. If the number of pixels is greater than another user-specified threshold, the cluster is subject to further segmentation with a higher threshold. For the final clusters, the centroids are calculated and stored in the detection list.

8.2 Point Source Estimation

Final point source position and photometry estimation are performed at this stage for all point source candidates on the detection list. Each detection comes with its own fitting area of a rectangular shape in the vicinity of the detection in each input image. The data in the fitting area are fit with the Point Response Function (PRF). In the multi-frame mode, the fitting is done simultaneously in all the input images containing the point source.

Fitting can be performed simultaneously for more than one point source. This process is called de-blending. The software is designed to perform two kinds of de-blending: passive and active. For passive de-blending the detected point sources, determined to be in a close proximity from one another so that their PRF's overlap, are fit simultaneously. The fitting areas are combined in this case. The classification of the detections as candidates for passive de-blending is done at the point source detection step. Passive de-blending has been proven to be an essential component of point source extraction.

Active de-blending is a process that starts when a single point source is used to fit a single fitting area. The software can be configured to fit the same fitting area with more than one point source, if fitting with a single point source fails. Active de-blending is a very sensitive process and is currently under development.

In order to fit the data, a modified Simplex algorithm is employed. The Simplex algorithm does not use derivatives of the functions involved in minimization. This is a desirable feature since the transformation from local coordinates to global coordinates can be a very complicated function of its arguments.

A provision is made to use a PRF variable in the field of view by employing the so-called PRF maps. It is assumed that several areas in the detector field of view will be identified, such that PRF variation within each area will be negligible and a constant PRF can be used for each area. A PRF map identifies the areas of constant PRF.

The product of this stage is an extraction table that has over 20 columns, including point source positions in the sky and mosaic coordinates, fluxes, positional and flux uncertainties, SNR, etc.

8.3 Aperture Photometry

For each extracted point source, aperture photometry is calculated. The user can specify an arbitrary number of aperture values. The results are appended to the output of the point

source estimation. The aperture photometry is calculated using an exact algorithm to compute a fractional aperture-pixel overlap.

9 Band-Merging

Two or more point source lists are cross-referenced to find common sources based on user selectable criteria.

The band-merging software is based on the 2MASS algorithm, and has extensions for handling more bands. It currently operates on two to seven wavelength bands, from one or two instruments, IRAC and MIPS.

The previously extracted point sources are linked into multiband chains and their positions are refined (merged) if the matching criteria are met. The software consists of the following major steps:

1. Perform band pair-wise point source matching.
2. Perform inconsistent-chain processing in order to ensure that all chains have no more than one point source in a band.
3. Perform linkage-rejection processing in ensure that any two bands in the chain have reciprocal relation, i.e. linked.
4. Perform position refinement of all the matches that have passed all previous tests.
5. Output the band-merged and position-refined source lists. Also, output a statistical summary of merges.

10 Point Response Function (PRF) estimation

This software generates an estimate of the Point Response Function and variance from a set of images that contain a sufficient number of unconfused and high signal-to-noise point sources.

It is assumed that a selected set of images is used in the estimation and that prior to the estimation a point source extraction algorithm has been run on the set of images and a list of point sources for each image had been produced. Based on certain criteria, such as SNR, goodness-of-fit, etc. of extracted point sources, a list of point sources to be used for PRF estimation is created. The list and the input images are input to PRF estimation. In general, PRF is going to vary with the detector pixel position in the focal plane. A PRF Map is also an input to the program.

The main steps of PRF estimation are:

1. Each point source image is shifted and sub-sampled.
2. Preliminary estimates of point sources fluxes.
3. Iterative process of estimating PRF and PRF variance by combining the individual normalized point source images and re-computing fluxes and rejecting “bad” point sources.

The steps above are performed independently for each area of constant PRF identified in the PRF Map file.