The Software Package AIRY 7.0: new efficient deconvolution methods for post-adaptive optics data #9909-297

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Abstract The Software Package AIRY (Astronomical Image Restoration in interferometrY) is a complete tool for simulation and deconvolution of astronomical data, which can be either a post-adaptive-optics image from a single dish telescope or a set of multiple images from a Fizeau interferometer. IDL-based and freely downloadable, the Software Package AIRY is a scientific package of the CAOS Problem-Solving Environment. It is made of different modules, each one performing a specific task: simulation, pre-processing, deconvolution, and analysis of the data. We here present its last version, containing a new optimized method for the deconvolution problem based on the scaled-gradient projection (SGP) algorithm extended with different regularization functions, and a new module based on our multi-component method. Finally, we provide a few example projects describing our multi-step approach recently developed for deblurring of high dynamic range images. By using AIRY v.7.0, users have a powerful tool for simulating the observations and for reconstructing their real data.

Introduction

The Software Package AIRY [1] is a scientific package developed within the IDL-based CAOS Problem-Solving Environment [2, 3] (PSE). The CAOS PSE has been recently renewed (see also the poster presenting the new version of the companion Software Package CAOS [4]). Now released in its version 7.0, AIRY can be considered the most complete public software for post-adaptive optics (AO) image simulation and restoration.

The new version of AIRY

The new CAOS PSE has now a unique main distribution containing its global user interface, its library of routines, and a utility package (where modules from the different packages have been merged). The scientific packages (e.g., the Software Package CAOS and the Software Package AIRY), together with their example projects, are still distributed separately.
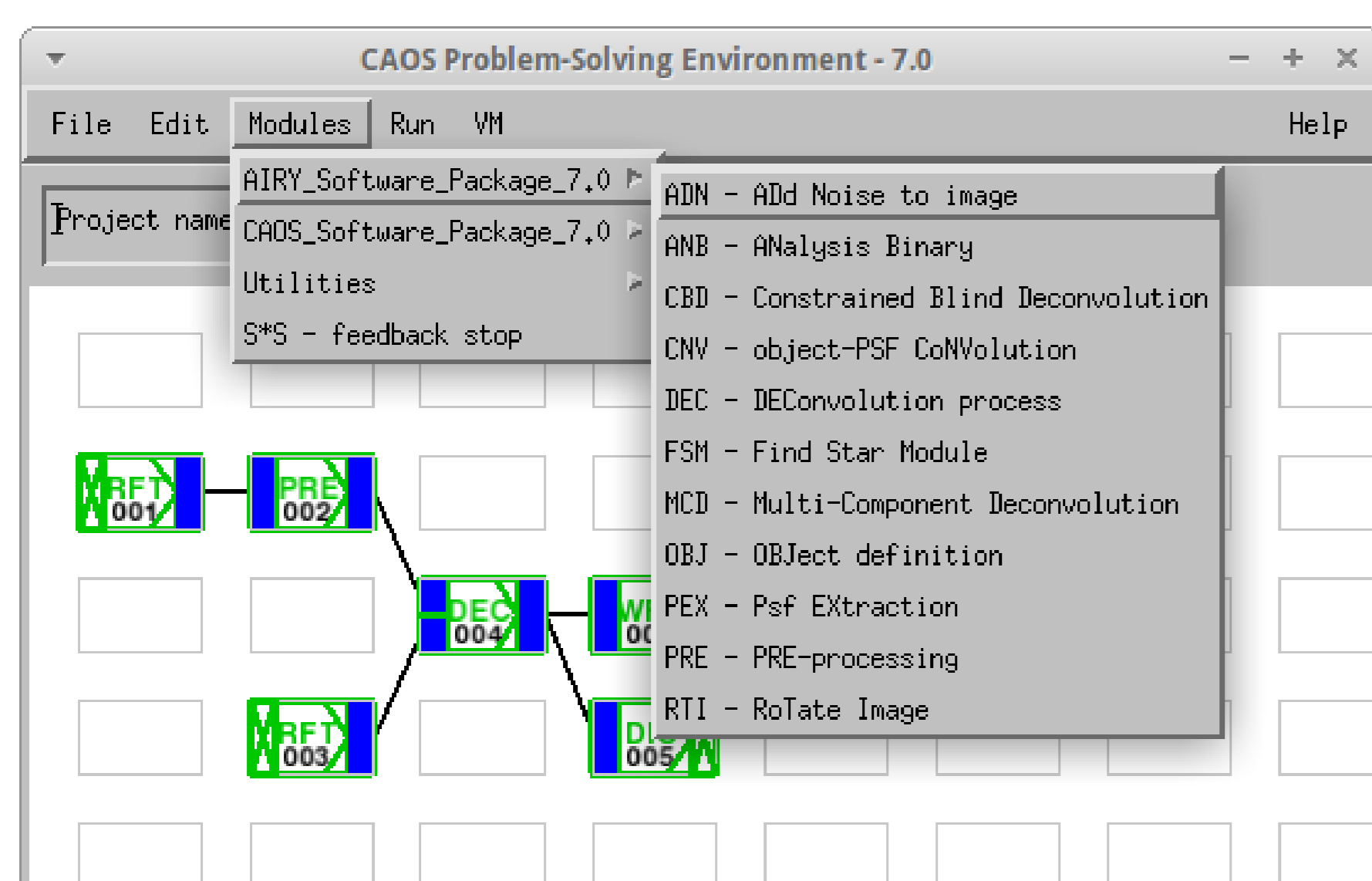
An example of use of the global user interface of the CAOS PSE together with some basic modules of the Software Package AIRY, and utility modules, is shown beside. The updated list of modules of the Software Package AIRY also appears.

The new version of the Software Package AIRY is made of 11 modules, described in the table beside. General improvements are:
- Sky background is stored in an array and loaded in the PRE module.
- Simulation and deconvolution information is saved in the FITS header.

Module	Purpose	Goal
OBJ	OBJect definition	
CNV	CoNVolution between object and psf	Simulation
ADN	ADd Noise to image	
PRE	PREprocessing data	
DEC	DEConvolution	
MCD	Multi-Component Deconvolution [NEW]	Deconvolution
CBD	Constrained Blind Deconvolution	
PEX	Psf extraction and EXtrapolation	
RTI	RoTate Image	
ANB	ANalysis Binary stars	Data
FSM	Find Stars Module	Analysis

The main goal of AIRY is deconvolution. In the previous version we improved the CBD module containing two methods for Strehl Constrained blind deconvolution [5, 6, 7, 8]. This version presents several improvements of the module DEC, and a new module (MCD) containing methods for deconvolving high-dynamic range images (e.g. jets from young stars [9, 10, 11]).

## Deconvolution methods contained in DEC

Within AIRY several methods for reconstructing images in the case of Gaussian or Poisson data are implemented. In particular, the Richardson-Lucy (RL) method, its version for multiple images, the Ordered-Subset Expectation Maximization (OSEM) algorithm, and the recently added Scaled Gradient Projection (SGP) method [12] are available within module DEC. Moreover, in this new version we added several regularizations for SGP.
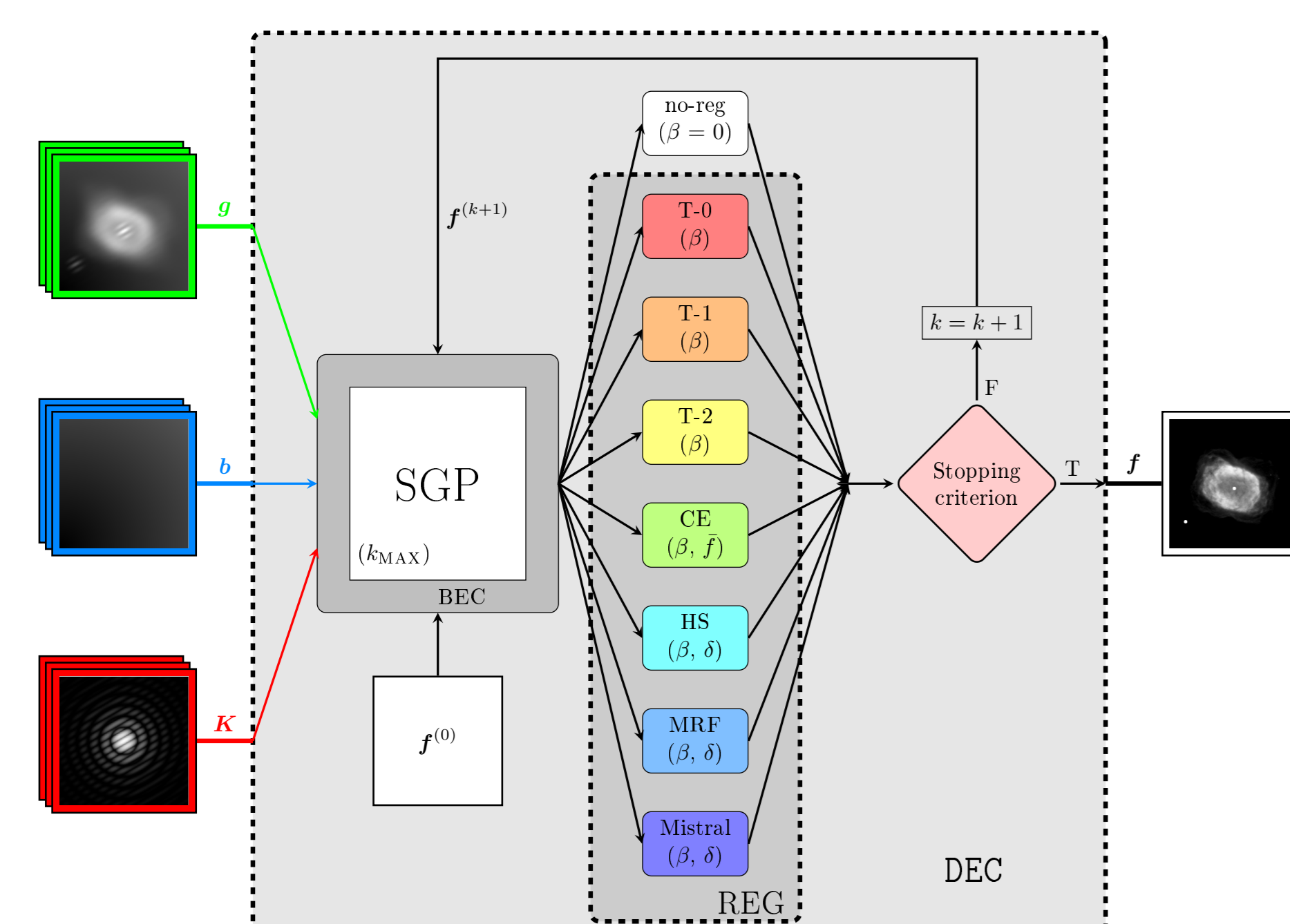
The block diagram of the DEC module. The inputs are: the image(s) $\mathbf{g}$, the PSF(s) $\mathbf{K}$, and the background $\mathbf{b}$. The internal blocks contain the main code (SGP, or the other available methods), the boundary effect correction (BEC), the proposed regularizations (and the case of no regularization) described in the paper, and the stopping rules. The output is the reconstructed object $\mathbf{f}$.

The Multi-Component Deconvolution module

We implemented both the multi-component Richardson-Lucy [9, 10] (MCRL) and the new MC-SGP [13]. Two assumptions are made: a) the unknown object $\mathbf{f}$ is the sum of two *components*: the point-like part $\mathbf{f}_P$ containing the bright sources of the object superimposed on the extended and smooth part $\mathbf{f}_E$, and b) the positions of the bright sources are known. The user must provide a mask $\mathbf{M}_P$ which is 1 in the pixels of the sources and 0 elsewhere.
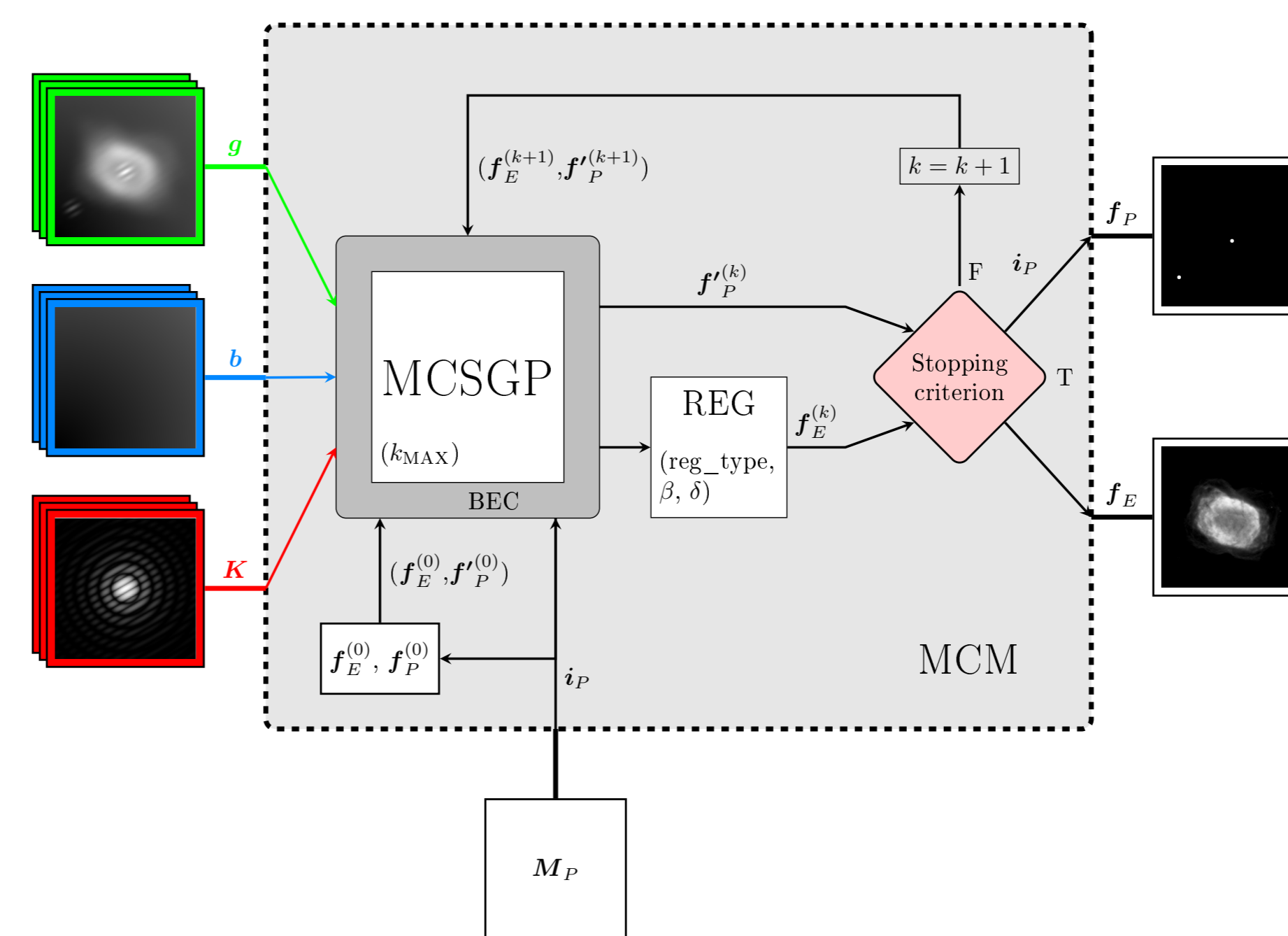
The algorithm computes the N_P positions of the bright sources (indexed by $\mathbf{i}_P$) and defines the default initial arrays: an $N \times N$ image $\mathbf{f}_E^{(0)}$ and an N_P vector $\mathbf{f}_P^{(0)}$. Regularizations can be applied to the diffuse component, while no regularization is needed for the point-wise part. The iterations run until a stopping rule is satisfied and the algorithm gives the two reconstructed components, i.e. $\mathbf{f}_E$ and $\mathbf{f}_P$, as $N \times N$ arrays.

The module MCD has two inputs (for the image and the PSF, as usual) and two outputs for the two components $\mathbf{f}_E$ and $\mathbf{f}_P$. Within the GUI, both MCRL and MCSGP methods can be selected, boundary effects correction is available, and a flux constraint can be applied in the case of SGP.

The Multi-Step Method

In some cases the multi-component method is not directly applicable. In particular, this is true in the case of Io images acquired with LBTI that our group reconstructed [14, 15]. For this reason, we developed a multi-step method [13]. We report it here for sake of completeness.

- Step 1 - Deconvolve the input image, e.g. by using SGP with no regularization.
- Step 2 - Compute the centroids of the bright spots from Step 1 and define the mask $\mathbf{M}_P$.
- Step 3 - Apply the MCD module (with a *good* choice of the regularization function and parameters) and reconstruct $\mathbf{f}_E$.
- Step 4 - Re-define the background array $\mathbf{b}'_j = \mathbf{b}_j + \mathbf{K}_j * \mathbf{f}_E$ and reconstruct $\mathbf{h} = \mathbf{f} - \mathbf{f}_E$ that consists of the bright sources. Again, SGP can be used. At the end, the complete object $\mathbf{f}$ can be obtained by adding the diffuse component to the result (see Figure beside).

Example of use of the Multi-Step approach

The Io-like object at M-band, obtained considering nine hot spots superimposed to a variable smooth surface, the PSF modelling the Keck-II PSF, and the result perturbed with Poisson noise are shown in the Figure beside.
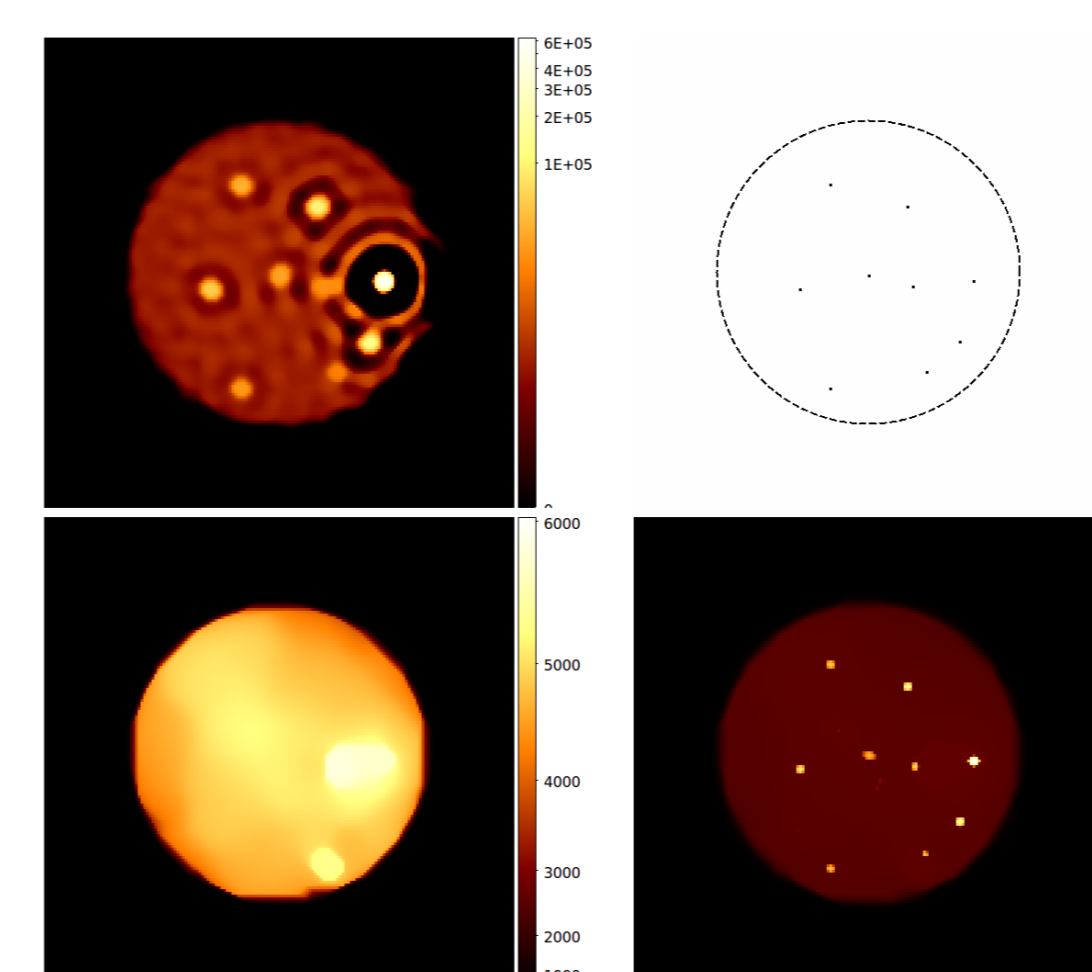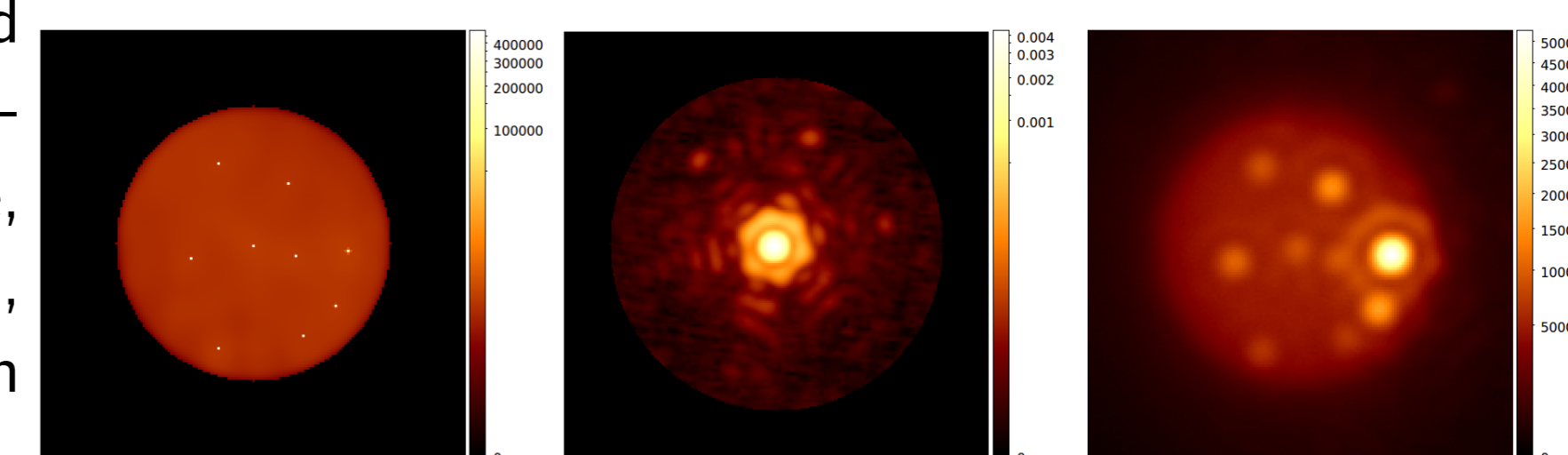

Figure beside: reconstructions of the Io-like image during the four steps. *(Upper left)* The result of the first step has several artifacts around the bright spots. *(Upper right)* The mask $\mathbf{M}_P$ in reverse B/W scale. The dashed circle shows the limb of Io: it is shown for sake of clarity and must not be included in the mask. *(Lower left)* The reconstruction of the surface as obtained at the third step with MRF regularization. *(Lower right)* The complete reconstruction (surface plus the result of the last step).

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Freely download the CAOS PSE and the Software Package AIRY from lagrange.oca.eu/caos