

# User-friendly imaging algorithms for interferometry

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## ABSTRACT

OPTICON currently supports a Joint Research Activity (JRA) dedicated to providing easy to use image reconstruction algorithms for optical/IR interferometric data. This JRA aims to provide state-of-the-art image reconstruction methods with a common interface and comprehensive documentation to the community. These tools will provide the capability to compare the results of using different settings and algorithms in a consistent and unified way. The JRA is also providing tutorials and sample datasets to introduce the principles of image reconstruction and illustrate how to use the software products. We describe the design of the imaging tools, in particular the interface between the graphical user interface and the image reconstruction algorithms, and summarise the current status of their implementation.

**Keywords:** optical interferometry, image reconstruction

## 1. INTRODUCTION

The technique of aperture synthesis imaging, when applied at optical (visible and near-infrared) wavelengths, offers a powerful capability to image astrophysical processes on milliarcsecond angular scales. The state-of-the-art optical interferometers capable of performing such observations, for example VLTI<sup>1</sup> and CHARA,<sup>2</sup> are now mature instruments, and have yielded a number of published images. However, the available image reconstruction software tools are relatively difficult for inexperienced astronomers to use, and this is a significant (but by no means the only) factor limiting the number of model-independent images that are published.

The European Union's Seventh Framework Programme is funding a Joint Research Activity that aims to address this deficiency, by delivering the following products:

- user-friendly implementations of BSMEM, MiRA, and WISARD;
- a common graphical user interface for the above algorithms;
- example datasets; and
- user manuals and cookbooks.

The specification for the interface between the algorithms and the common GUI will be made available to encourage the integration of other algorithms such as SQUEEZE<sup>3</sup> and the Building Block method.<sup>4</sup>

## 2. IMAGING ALGORITHMS

The algorithms being enhanced under the JRA (Table 1) are all mature codes whose performance has been demonstrated, for example in the series of IAU-sponsored imaging “beauty contests”.<sup>5–10</sup> The newest developments are therefore being targeted at improving their user-friendliness and their robustness when presented with a variety of realistic real-world datasets.

In particular, a common graphical interface is being developed as a front-end to any of BSMEM, MiRA, and WISARD. In integrating the algorithms with the GUI, the input parameters for the algorithms have been standardised as far as possible,

**Table 1:** Summary of the image reconstruction algorithms being enhanced under the JRA.

Name	Authors	Optimisation	Regularisation
BSMEM <sup>11</sup>	Baron, Buscher	Trust region gradient	MEM-prior
MiRA <sup>12</sup>	Thiébaud	VMLM-B	Many
WISARD <sup>13</sup>	Meimon, Mugnier, Le Besnerais	VMLM-B + self-cal	Many

based on a unified description of the image reconstruction process that has been written for the JRA. The unified description document is available on GitHub\*.

The robustness of the algorithms will be verified by testing them with specially constructed datasets representative of those from existing and future beam combining instruments at VLTI and CHARA, including AMBER,<sup>14</sup> PIONIER,<sup>15</sup> GRAVITY,<sup>16</sup> MATISSE<sup>17</sup> and VEGA.<sup>18</sup> The test datasets will include examples that follow the new OIFITS version 2 standard,<sup>19</sup> and the algorithms will be modified to take advantages of new features in OIFITS2 where appropriate.

Further development of the algorithms is also planned, for example to implement multi-spectral reconstruction techniques and to simplify the user experience by automatically optimising parameters such as the regularisation weight.

### 3. GRAPHICAL USER INTERFACE

The graphical user interface and the image reconstruction algorithm will run as separate processes, exchanging data by means of files. This approach works on any platform and allows algorithms written in any programming language to be integrated straightforwardly. The diagram in Fig. 1 shows how the two processes interact to reconstruct an image with the user-specified settings and display intermediate and final results. The results will include the latest reconstructed image, scalar parameters such as goodness-of-fit statistics, and model data corresponding to the observed interferometric data.

The data files exchanged between the GUI and algorithm processes conform to the FITS<sup>20</sup> standard, and incorporate interferometric data tables as specified by the OIFITS<sup>21</sup> convention. Further details of the file specification are presented in Section 4.

The current prototype GUI is shown in Fig. 2. The user selects an existing standard OIFITS file, and specifies the algorithm settings and the starting image, which also defines the pixel scale and field of view of the desired image. The GUI allows a subset of the OIFITS data to be selected, for example a range of wavelengths. The user then clicks a button to start the reconstruction. As the reconstruction proceeds, intermediate results are automatically displayed after each iteration. When the algorithm stops, according to its built-in criteria (or encounters an error), final results are displayed to the user.

The current designs assume a monochromatic or grey reconstructed image, but the interface specification described in Section 4 could straightforwardly be adapted to multi-spectral reconstruction algorithms that produce a data cube as output.

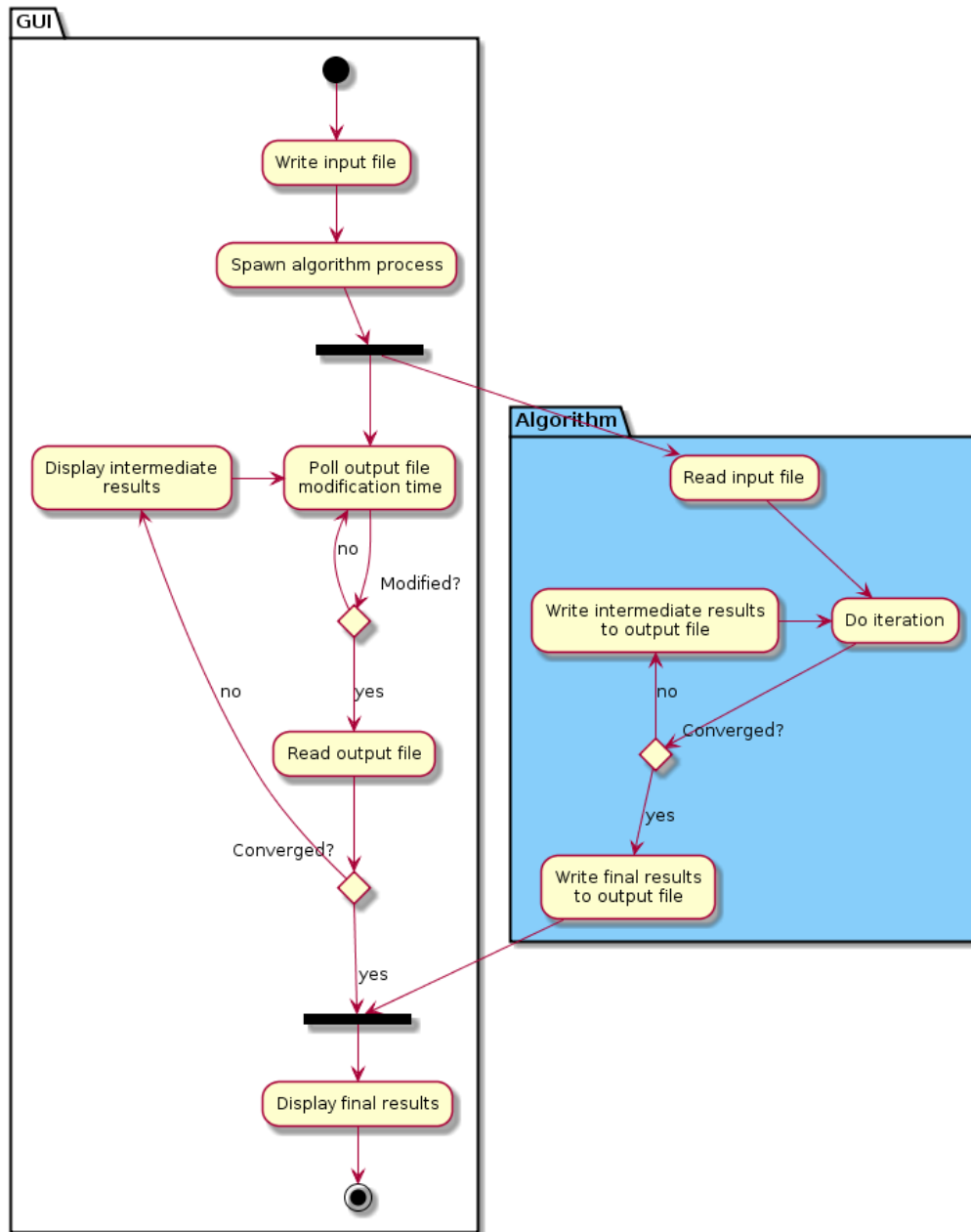
### 4. ALGORITHM INTERFACE USING FITS FILES

The common interface to image reconstruction algorithms is a specification for their input and output files. The specification is currently available in draft form on GitHub<sup>†</sup>. The input file provides the interferometric data and the algorithm parameters. The output file contains either intermediate or final results. These components and their relationships are shown graphically in Fig. 3. The design of the specification is based on the following principles:

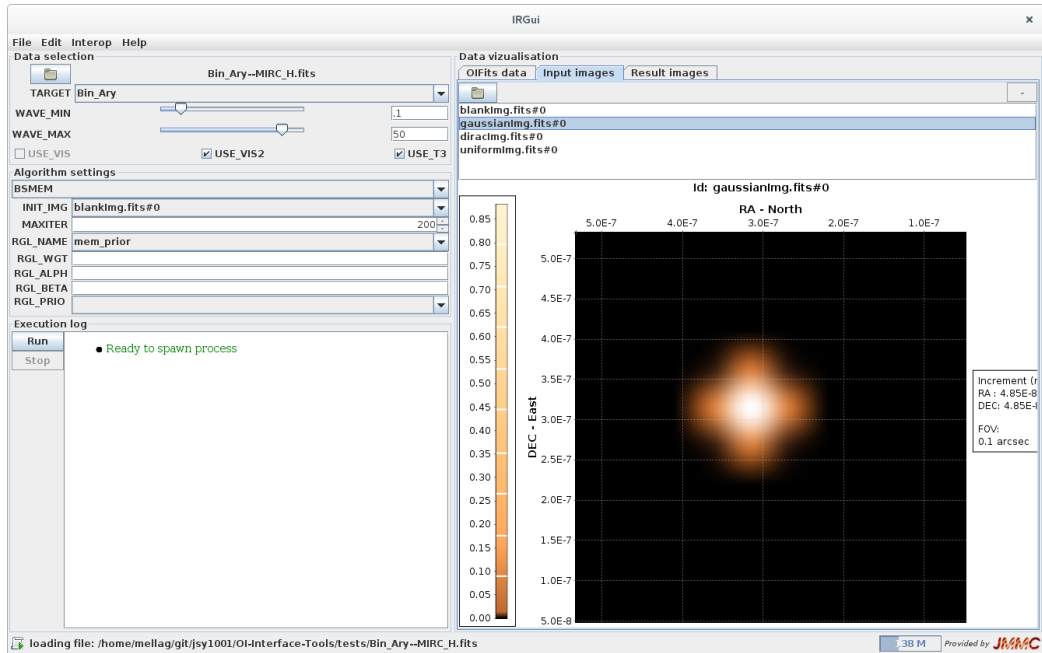
- The output file must also be a valid input file, for traceability and to permit the algorithm to be restarted from where it finished.
- The input and output files must conform to the OIFITS standard, with additional images/tables containing the image reconstruction parameters and results (the OIFITS norm explicitly allows this).
- The outputs must include model data corresponding to the intermediate/final reconstructed image.

\*[https://github.com/emmt/OI-Imaging-JRA/blob/master/doc/unified\\_desc/unified\\_desc.pdf](https://github.com/emmt/OI-Imaging-JRA/blob/master/doc/unified_desc/unified_desc.pdf)

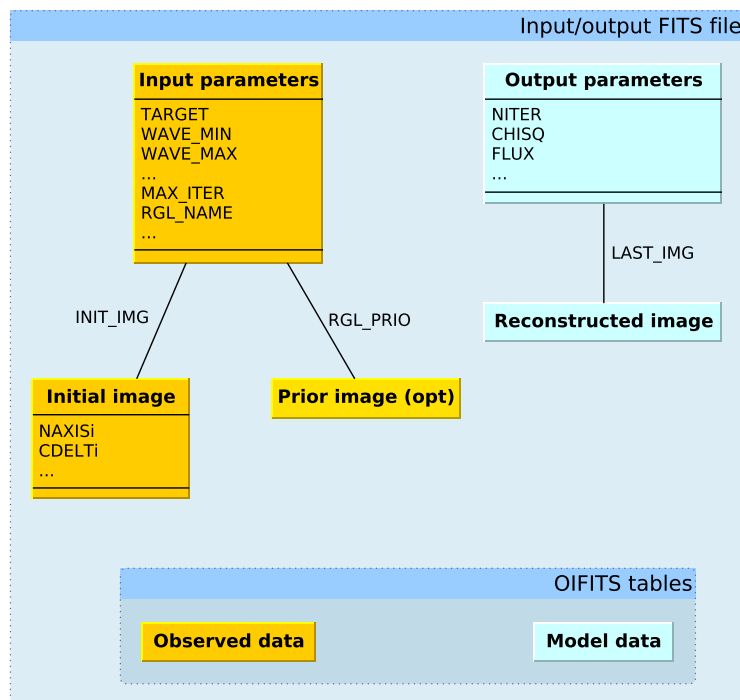
†<https://github.com/emmt/OI-Imaging-JRA/blob/master/doc/interface/OI-Interface.pdf>



**Figure 1:** UML activity diagram showing the steps involved in reconstructing an image using the common Graphical User Interface. The GUI process writes an input file and launches the algorithm process. After each iteration of the reconstruction, the algorithm writes updated intermediate results to an output file. The GUI watches for modifications to the output file and updates its displays after each iteration.



**Figure 2:** Screenshot of a prototype of the image reconstruction user interface. The GUI includes controls for selecting a subset of the interferometric data (by target, wavelength, and kind of data); the algorithm settings (starting image, maximum number of iterations, regularisation); and the initial or reconstructed image).



**Figure 3:** Diagram of the FITS-based file format used for input and output to/from the algorithms. The image reconstruction input and output parameters are stored in dedicated FITS binary tables. For compactness, additional table columns (as permitted by the OIFITS standard) are used to store model data within the OIFITS data tables.

## 5. SUMMARY

We have described an EU-funded Joint Research Activity (JRA) that aims to provide user-friendly image reconstruction algorithms for optical/IR interferometric data. Enhanced versions of BSMEM, MiRA and WISARD with a common graphical user interface will be provided, along with tutorials and sample datasets.

At the time of writing, the common interface between the GUI and the algorithms has been designed, documented and prototyped. A preliminary version of the GUI has been developed, able to be used with a modified version of BSMEM. Similar modifications to MiRA are currently in progress.

## ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2013–2016) under grant agreement number 312430 (OPTICON).

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