The CAOS Problem-Solving Environment: tools for AO numerical modeling and post-AO deconvolution

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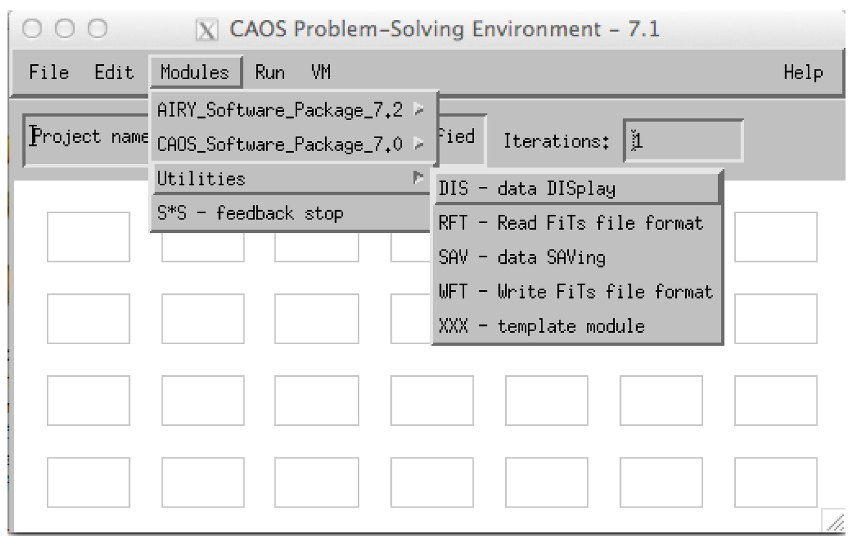
Abstract The status and most recent developments concerning the modular IDL-based CAOS problem-solving environment (PSE), together with its two scientific packages: the Software Package AIRY, a tool for deconvolution of post-AO images, and the eponymous Software Package CAOS, an end-to-end code for AO system simulations, are here presented. Examples of application involving the Software Package AIRY are presented: one tackling high-dynamic range images reconstruction, and the other one real data processing.

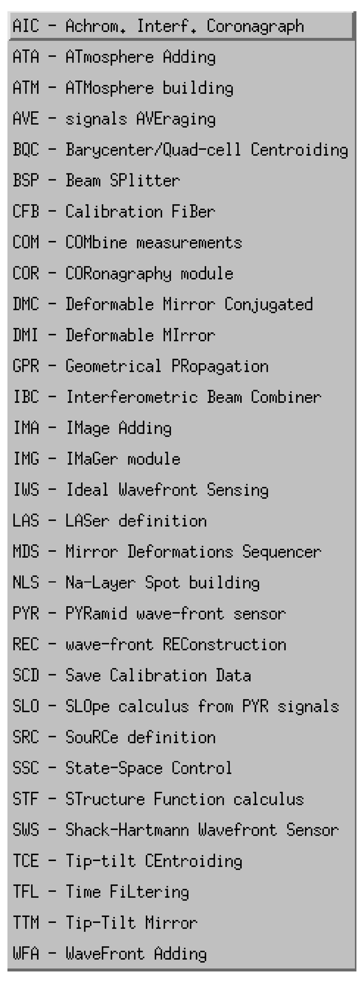
The CAOS PSE, the Software Package CAOS, and the Software Package AIRY

The CAOS PSE [1, 2, 3] has, since version 7.0, a unique basic distribution containing its global user interface (the so-called CAOS Application Builder [4]), its library of routines, and a package Utilities containing utility modules (to display/save/read data). The scientific packages developped beside are presently the eponymous Software Package CAOS [5, 6] and the Software Package AIRY [7, 8, 9]. An example of use of the global user interface of the CAOS PSE together with modules of the Software Package AIRY is shown in next section.

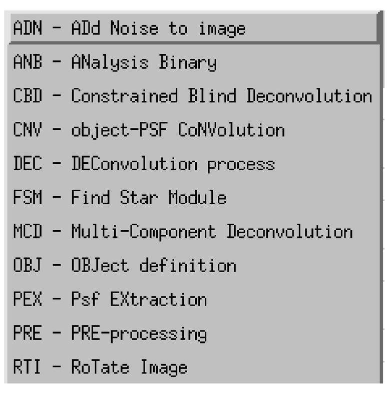
Within the global interface, the list of installed Software Packages is shown thanks to the pull-down menu Modules. From this list, and selecting a particular package (the package Utilities here beside), its modules can be selected and placed into the "worksheet" in order to compose a simulation project by combining together the modules and defining the corresponding data flow.



The IDL code implementing the simulation program is then automatically generated, at the end of the simulation project design step or at any moment, by pushing pull-down button File, and the whole structure of the simulation is saved as a project that can be restored for latter modifications and/or parameters upgrading. Last version of the CAOS PSE, 7.1, includes a number of debugging and/or enhancements of routines from the common library, the global user interface, and the display utility. Note that, together with their specific sets of example projects, the two scientific packages AIRY and CAOS are distributed separately.



The **Software Package CAOS** (Code for Adaptive Optics Systems) is dedicated to end-to-end AO simulations, and includes scientific modules for modeling optical turbulence, image formation, wavefront sensing (with both Shack-Hartman and pyramid), wavefront reconstruction/control/correction, AO system calibration, laser guide stars (with upward/downward propagation and Sodium layer modelling), Fizeau interferometry, and coronagraphy. Wide-field AO is also developed, permitting ground-layer AO simulations and conjugation of deformable mirrors at different altitudes.



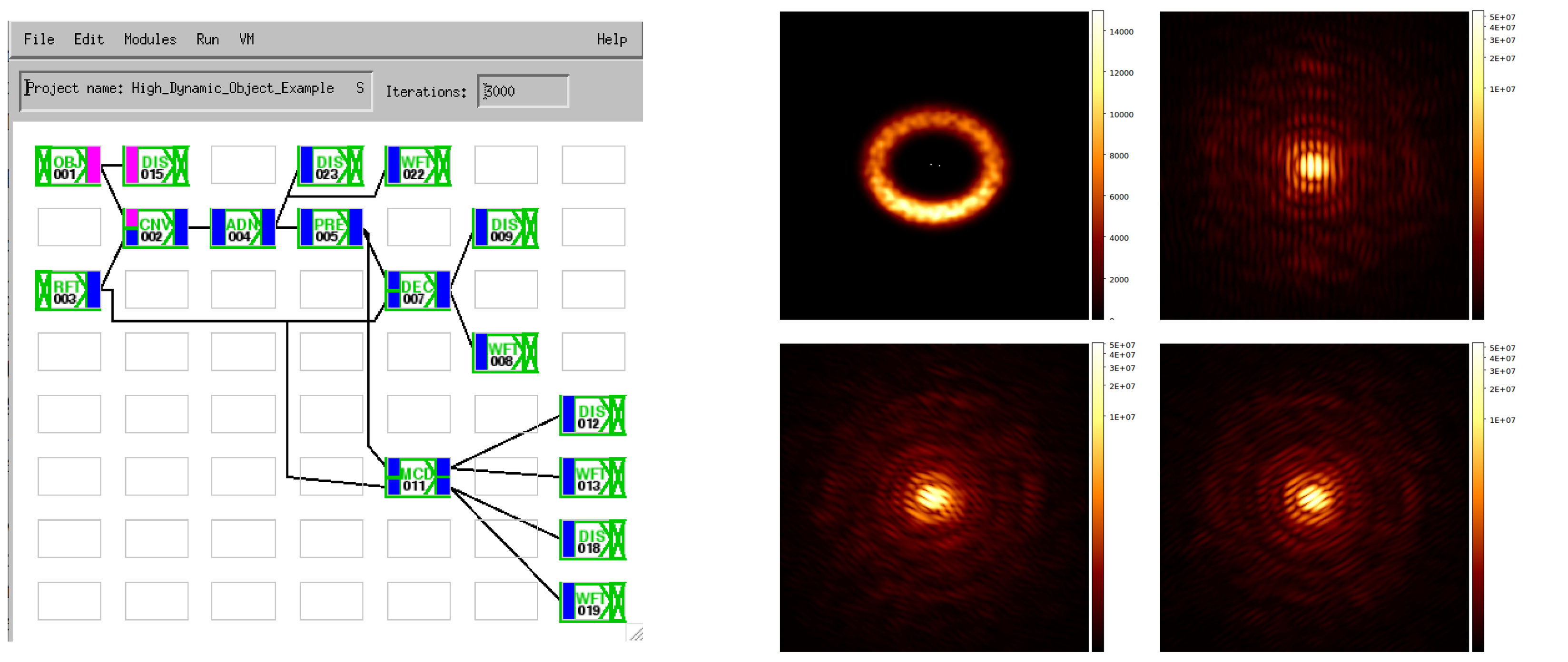
The **Software Package AIRY** (Astronomical Image Restoration with or without interferometrY) now reached version 7.2, and is a complete tool for simulation and deconvolution of astronomical data (either a post-AO image from a single-dish telescope or multiple images from a Fizeau interferometer).

The Software Package AIRY implements several methods for reconstructing images considering Gaussian or Poisson statistics: Richardson-Lucy (RL), Ordered-Subset Expectation Maximisation (OSEM), and the Scaled Gradient Projection (SGP) method [10], with a regularization capabilities and a multi-component (MC) deconvolution module [9]. Remarkable features of AIRY include also a super-resolution method [11, 12], Strehl-constrained blind deconvolution [13, 14], and high dynamic range (HDR) capabilities [15, 16, 17], for which an example of application is detailed in next section.

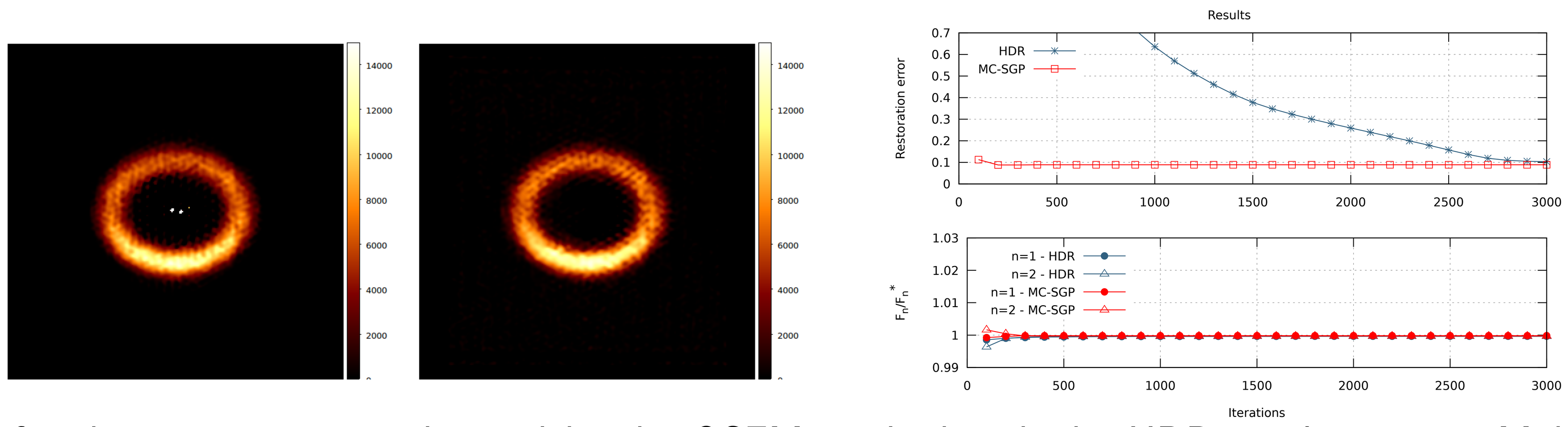
An example of application of AIRY on SPHERE/VLT data of a Wolf-Rayet star in the near-infrared domain is also shown, using the SGP method with an edge-preserving regularization.

Deconvolution of high-dynamic range images with the AIRY package

We here compare two different approaches to the deconvolution of high dynamic range images (here from an LBT-like Fizeau interferometer): one based on an HDR regularization of the OSEM algorithm [18], and an MC method based on SGP able to reconstruct separately the point-like part and the diffuse part of the observed object [16, 9].

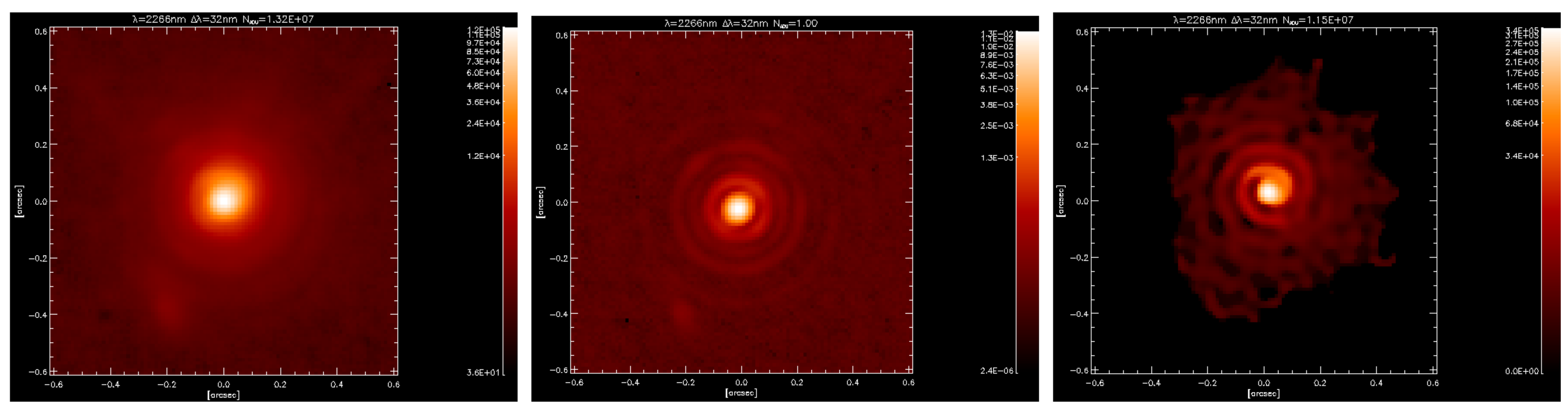


Left: the AIRY project as represented within the CAOS PSE global interface. Right: the ground truth object made of two bright stars (here saturated) and a circumstellar ring (linear scale), and the corresponding three Fizeau interferometric blurred and noisy images (log scale).



Left: the reconstruction obtained by the OSEM method with the HDR regularization. Middle: the diffuse component of the reconstruction obtained by the MC-SGP method (point-like part not shown, linear scale). Right: (top panel) the restoration error of the two reconstructions, and (bottom panel) the error on the fluxes as a function of the number of iterations.

Deconvolution of real data: WR 104 as seen by SPHERE/VLT



From left to right: Observed object (K band), associated point-spread function, reconstruction with SGP and an edge-preserving regularization (data: courtesy A. Soulain et al., more details to be given in a forthcoming paper [19]).

Current applications and further developments

Concerning the Software Package CAOS, it will next include (for its version 7.1) an updated simple embedment of the semi-analytic AO code PAOLA [20]. New modules for wide-field AO modelling will hopefully be finalized, in order to permit to consider multiple sources and multiple sensors within single modules, and hence an easier modelling of GLAO systems, as well as layer-oriented and star-oriented multi-conjugate AO systems. For its part, the Software Package AIRY is being used in a number of astrophysical applications involving post-AO images obtained from various instruments (NACO/VLT, SPHERE/VLT, LMIRcam/LBTI, NIRC2/Keck-II).

References

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