ADONI2017 Workshop
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LABORATORIO NAZIONALE ADONI OTTICA ADATTIVA

The Software Package AIRY v.7.1
New post-AO deconvolution methods and results

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Dibris LAGRANGE

Outline

- Introduction to CAOS & AIRY system
- The Software Package AIRY, version 7.1
- New algorithms and new modules for AIRY
- An example of High Dynamic Range data: deconvolution of Io images

[DEMO on request -> coffee break]

A (very) short introduction

- The Astronomical Image Restoration in interferometrY (AIRY) software was born in 2001 [1] together with the CAOS Problem Solving Environment (PSE) [2,3].
- The CAOS PSE has two updated Software Packages: AIRY and CAOS.
- Available versions online: CAOS PSE 7.0, Soft.Pack. CAOS 7.0, Soft.Pack. AIRY 7.1
- An update of the whole tool will be presented at AO4ELT#5 (please visit the Marcel's poster)

[1] Correia, S., Carbillet, M., Fini, L., et al. 2001, in Astronomical Data Analysis Software and Systems X, 404.

[2] Fini, L., Carbillet, M., & Riccardi, A. 2001, Astron Data Anal Softw Syst X, 238, 253.

[3] Carbillet, M., Verinaud, C., Guarracino, M., et al 2004, SPIE Proc. 5490, 637.

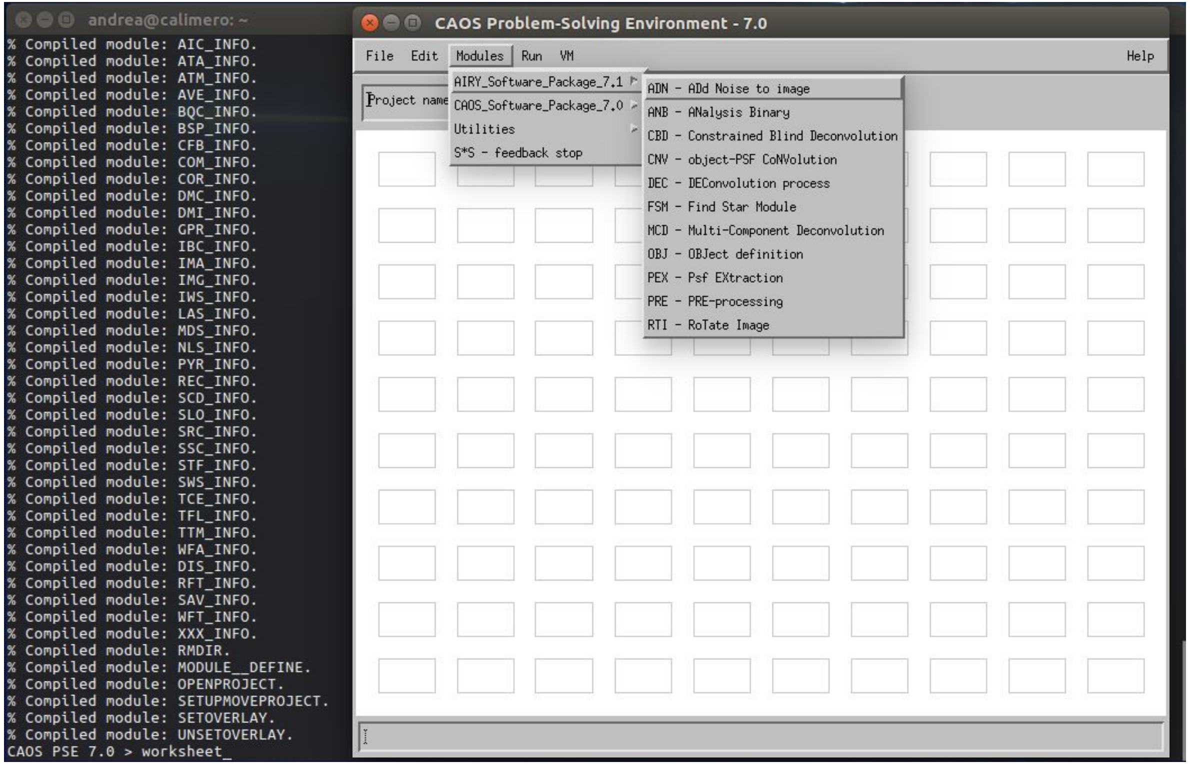
The CAOS Problem Solving Environment

System Requirements:

- Win / Mac / Linux PC
- IDL (at least version 7.0)
- The IDL Astronomy User's Library

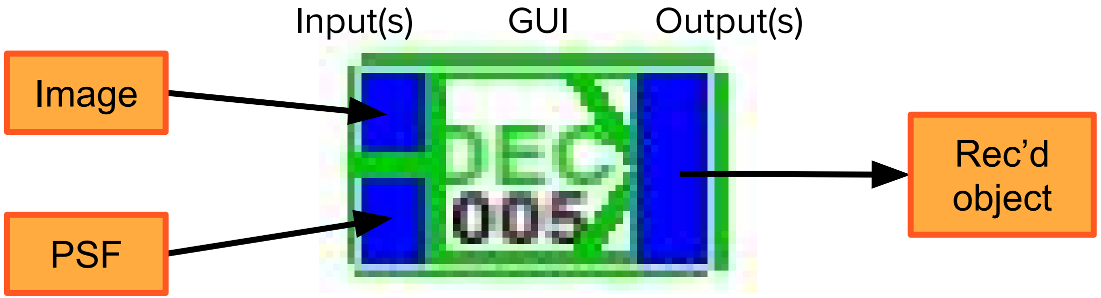
Downloadable from:

http://lagrange.oca.eu/caos



The Software Package AIRY, v. 7.1

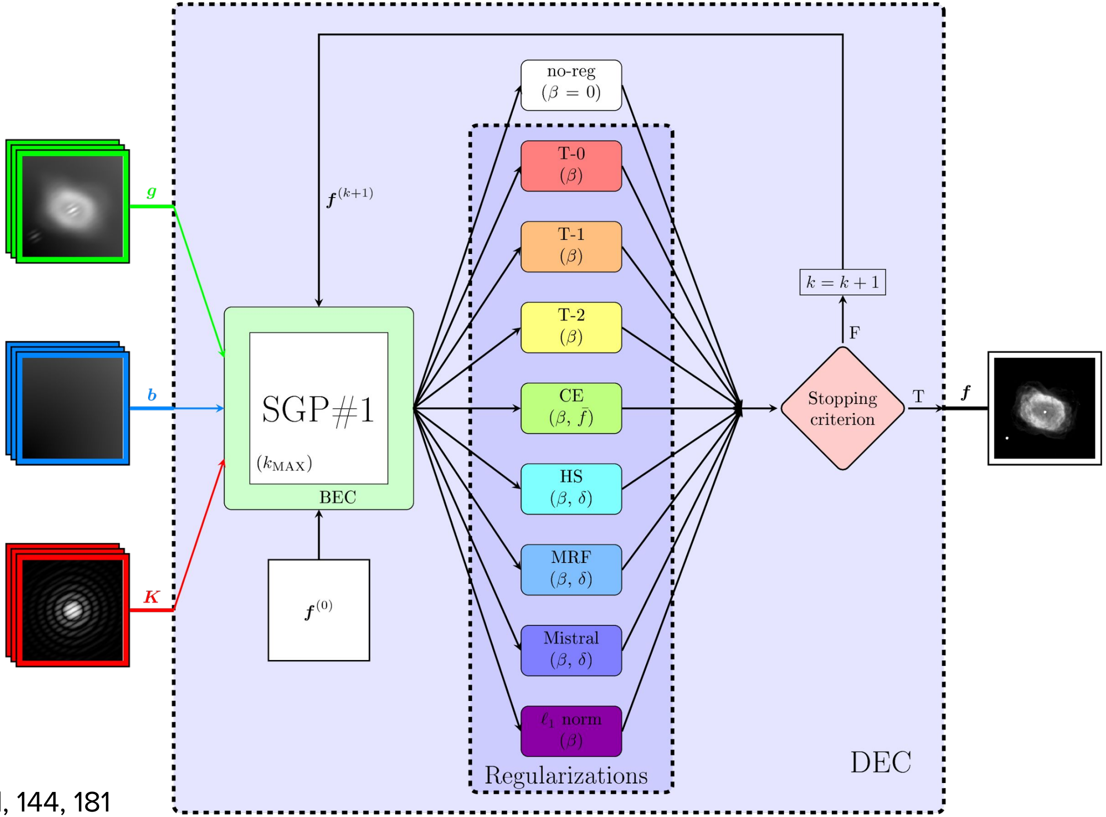
- AIRY contains 11 *modules*, each one performs a task (simulation, deconvolution, data analysis, and utility).
- DEC and MCD are the heart of a deconvolution project.
- Other modules are designed for a specific goal: Constrained Blind Deconvolution, Psf EXtraction



Deconvolution with DEC

DEC contains:

- Standard methods based on RL (+multiple images versions: RLM and OSEM [4]) and SGP [5].
- Boundary Effects Correction
- 9 regularizations
- 4 stopping rules



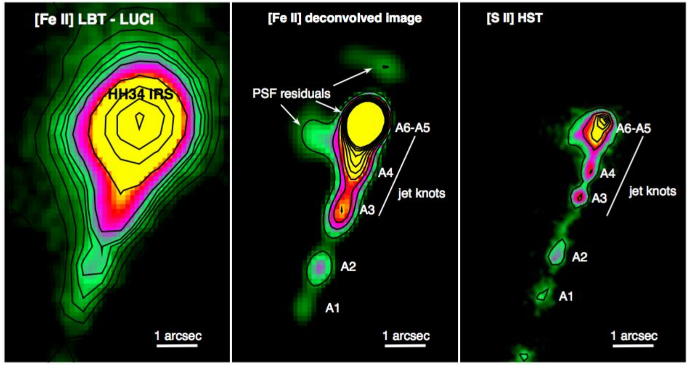
[4] Bertero, M., & Boccacci, P. 2000, Astron Astrophys Suppl, 144, 181

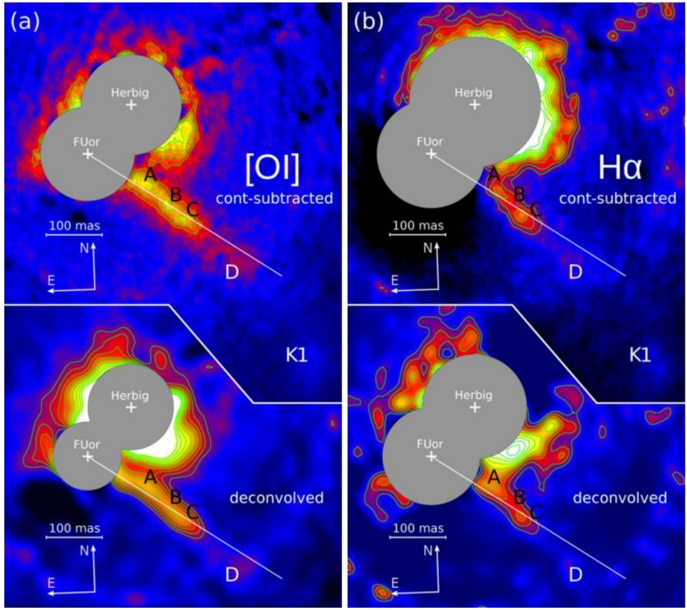
[5] Bonettini, S., Zanella, R., & Zanni, L. 2009, Inverse Probl, 25, 15002

Multi-component method

In the last years we developed a new method for the restoration of the high dynamic range images:

- **Jets from YSO** [6,7,8]: we developed Multi Component RL (MC-RL): an RL-based method able to separately reconstruct the point-like part and the diffuse (or extended) part of the image.





[6] La Camera, A., Antoniucci, S., Bertero, M., et al. 2014, PASP, 126, 180

[7] Antoniucci, S., La Camera, A., Nisini, B., et al. 2014, A&A, 566, A129

[8] Antoniucci, S., Podio, L., Nisini, B., et al. 2016, A&A, 593, L13.

Multi-component method

We assume that the object to be reconstructed (**f**) is the sum of 2 components:

f_P = point-like part: **the star(s)**

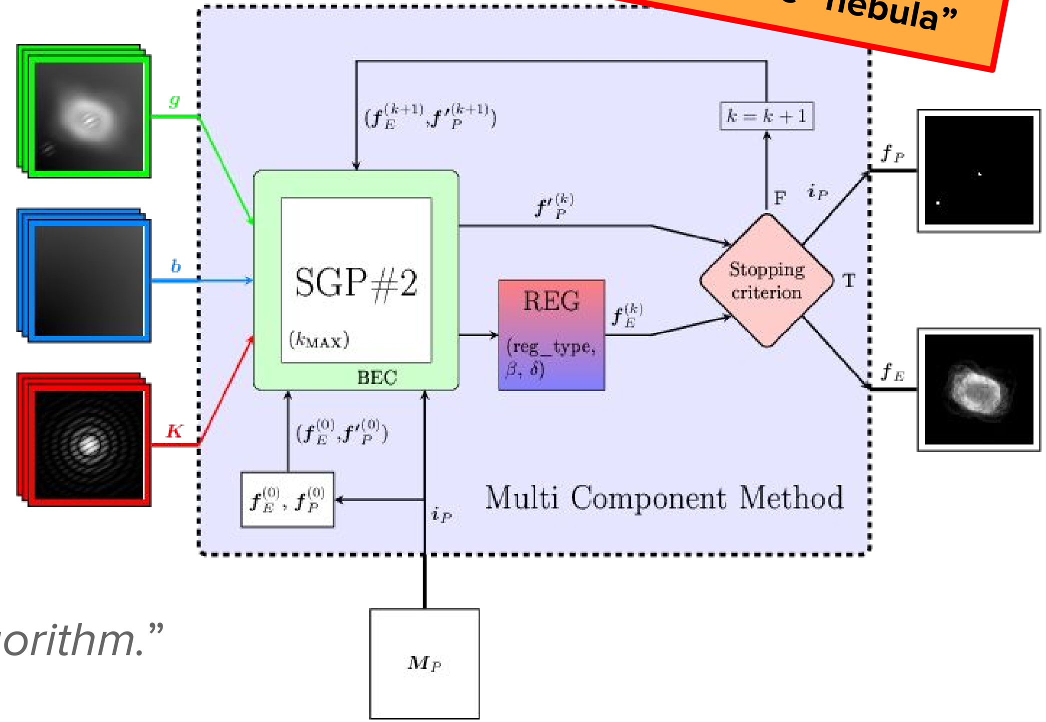
f_E = extended part: **the "nebula"**

We extended SGP with Multi-Component SGP (MC-SGP)

Starting from version 7.0, AIRY has a new module called Multi-Component Deconvolution

We must provide a "mask": i.e. the positions of the point-like sources.

"we knows where they are but their intensities will be determined by the algorithm."

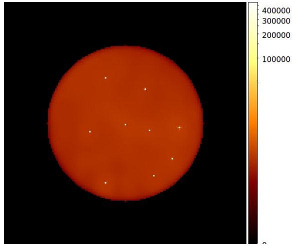


Multi-component method

We start with a simulated observation of Io by Keck-II (M band) to test our method and to better understand how the parameters modify the results.

Nowadays we are applying the new method to other HDR images:

- **The images of Io** [9]: we are working at multiple images (LBTI) and single images (Keck) [Prato et al, *in prep*]
- A **binary star** with a circumstellar **ring**, already analyzed in [10]



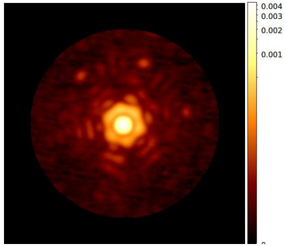
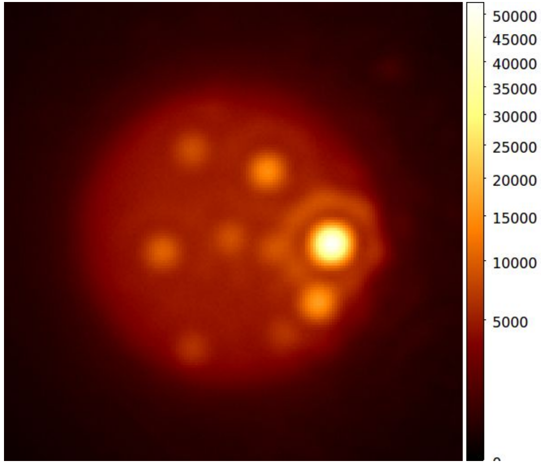


Image = Object * PSF



[9] Conrad, A., de Kleer, K., Leisenring, J., et al. 2015, AJ, 149(5), 175 -- see also ADONI 2016, M. Bertero's talk

[10] Anconelli, B., Bertero, M., Boccacci, P. et al. 2006, A&A 460, 359

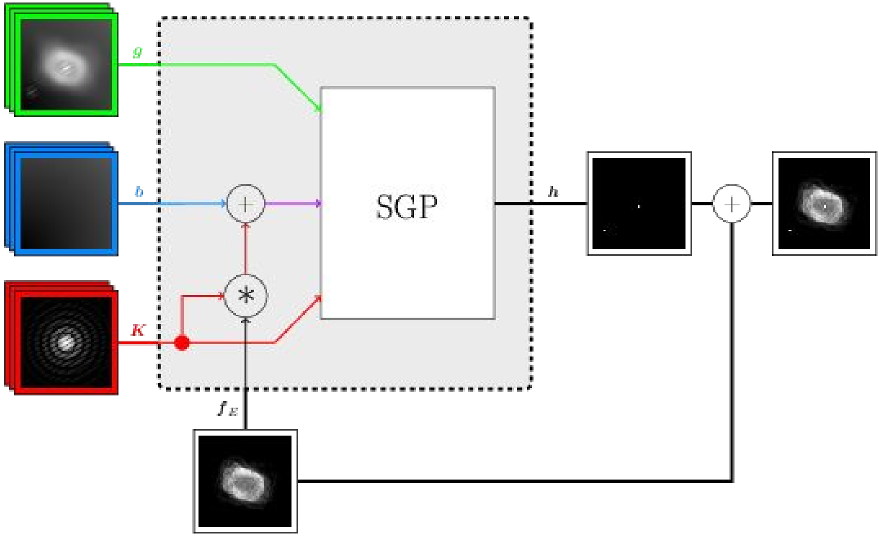
The Multi-Step Method (MSM)

1. Deconvolve the input image by a standard deconvolution method and a regularization, possibly (DEC)

2. Compute the centroids of the bright spots → mask $\mathbf{M_P}$

3. Apply Multi-Component Method (MCD). We need ***good*** choices for the regularization function & parameters. Reconstruct $\mathbf{f_E}$

4. Redefine the background $\mathbf{b' = b + K*f_E}$ and reconstruct (again DEC) $\mathbf{h = f - f_E}$



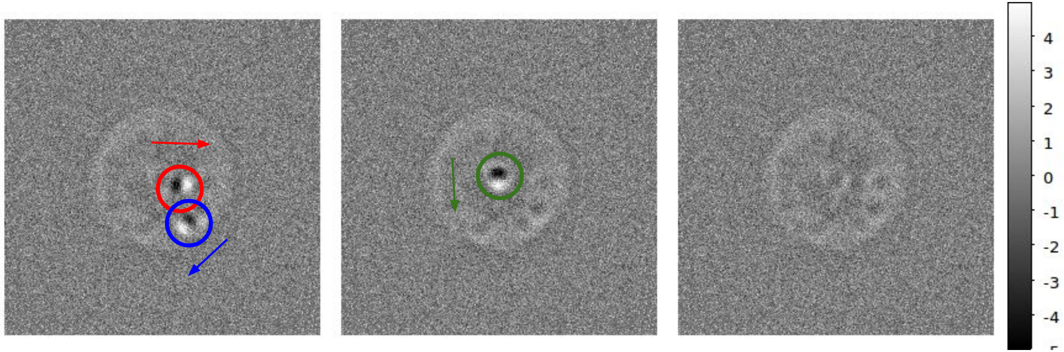
Checkpoint at 3rd step: the residual

In case of Poisson noise and perfect reconstruction, the residual **R** is an array of “white noise” with median 0 and sigma 1.

$$R = \frac{g - (K * f + b)}{\sqrt{K * f + b}}$$

If one (or more) of the point-like sources is placed in a “wrong” position, then the residual shows a “bump”.

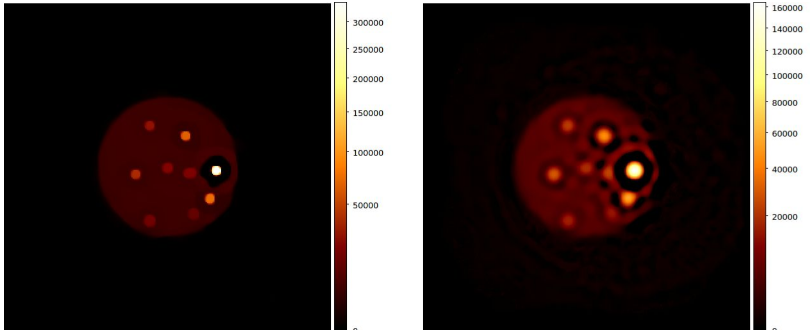
The values (+/-) of the bump give information about the direction.

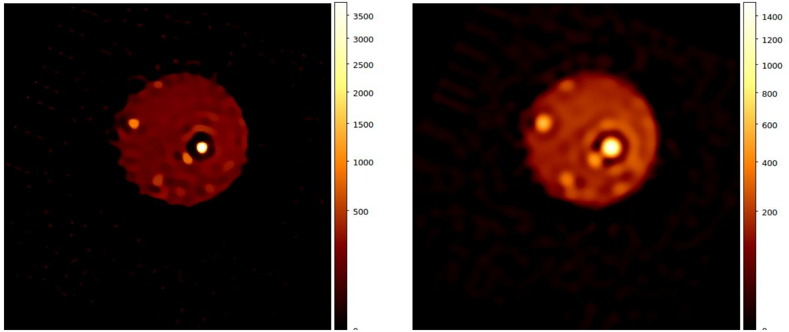


(*left*) Something is “wrong” with S1 and S2; (*middle*) we adjust the positions and the two “bumps” are gone, but S3 (on purpose!) has been moved away from its position; (*right*) a (small) residual disk: something should be changed… (regularization parameters? PSF? Background?)

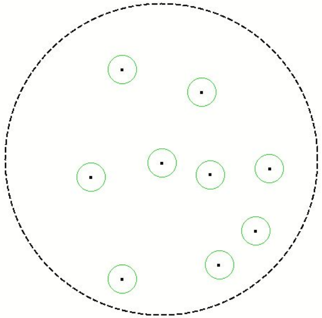
Simulated and Real images

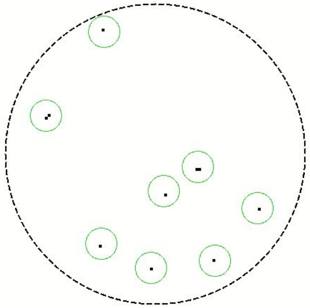
First step: SGP+HS *vs* AIDA: (*left*) simulated image, (*right*) Keck image in band M [11]





Second step: mask definition





[11] De Pater, I., Laver, C., Davies, A. G., et al. 2016 *Icarus*, *264*, 198–212.

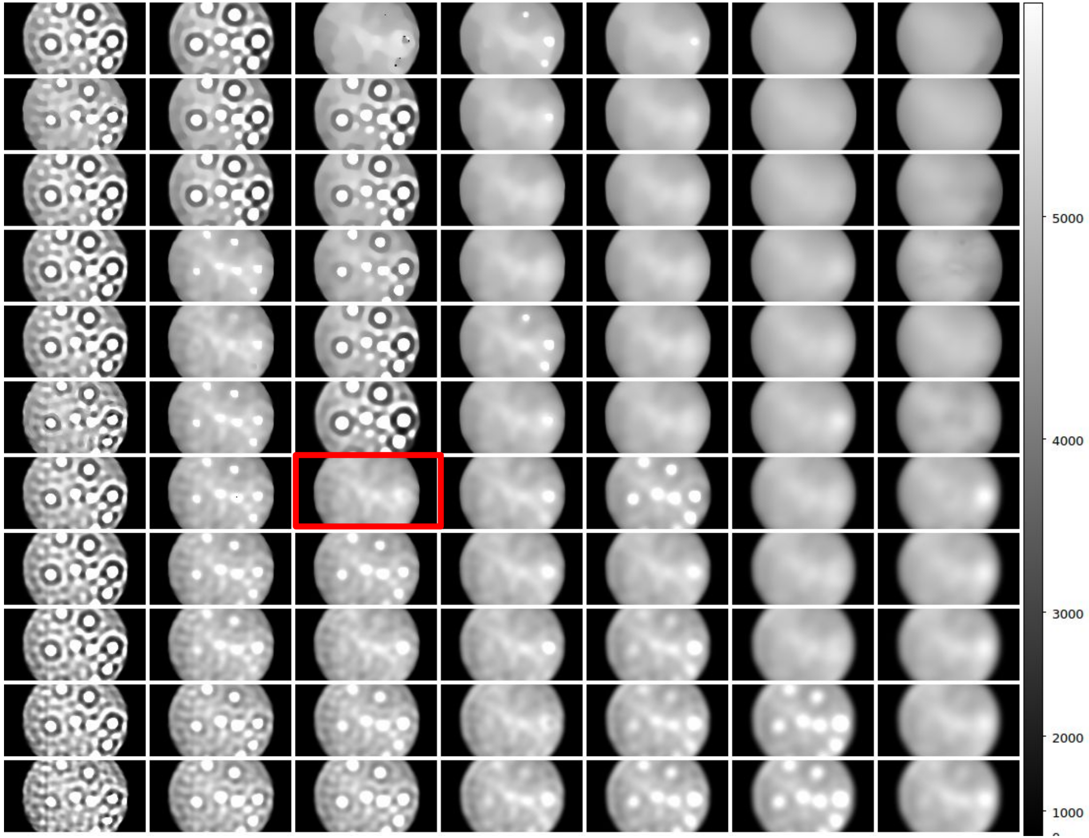
Simulated and Real images

Third step: MC-SGP+HS

In simulation we can explore the parameters space (2D) and find the couple that minimizes the restoration error (of the diffuse part).

(left to right) increasing the regularization parameter we have a smoother reconstruction

(top to bottom): the other parameter is less important



Simulated and Real images

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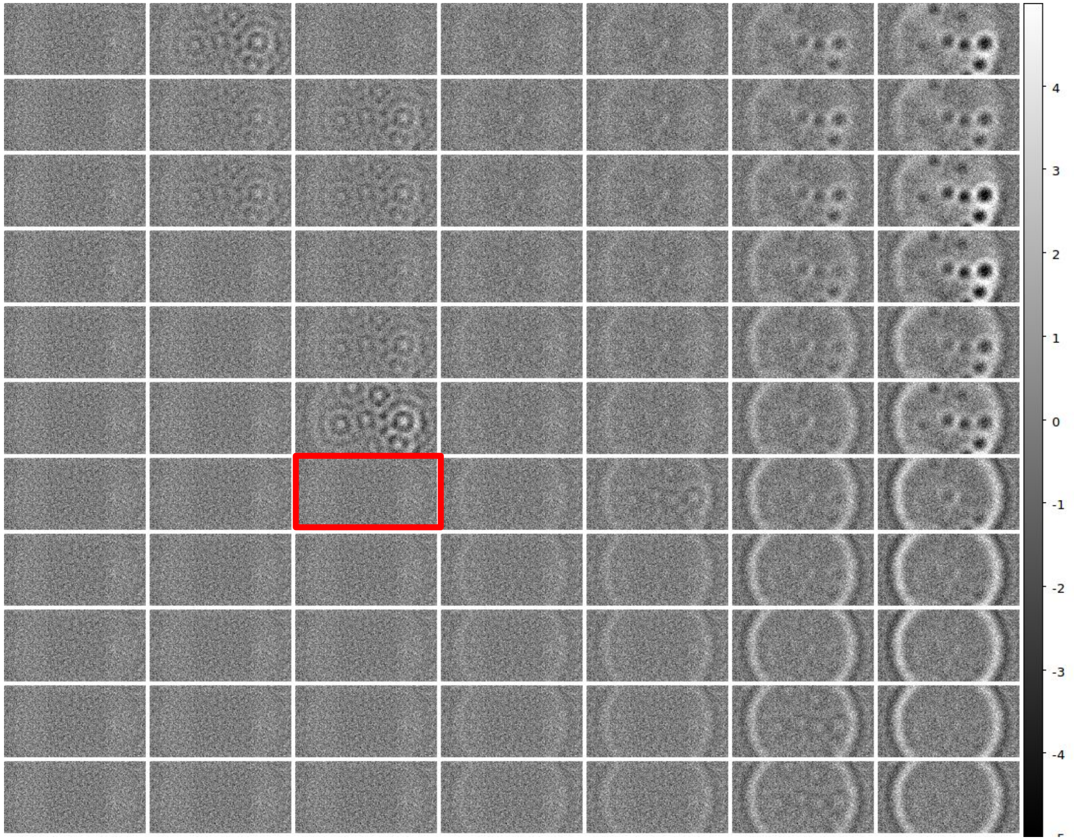


Simulated and Real images

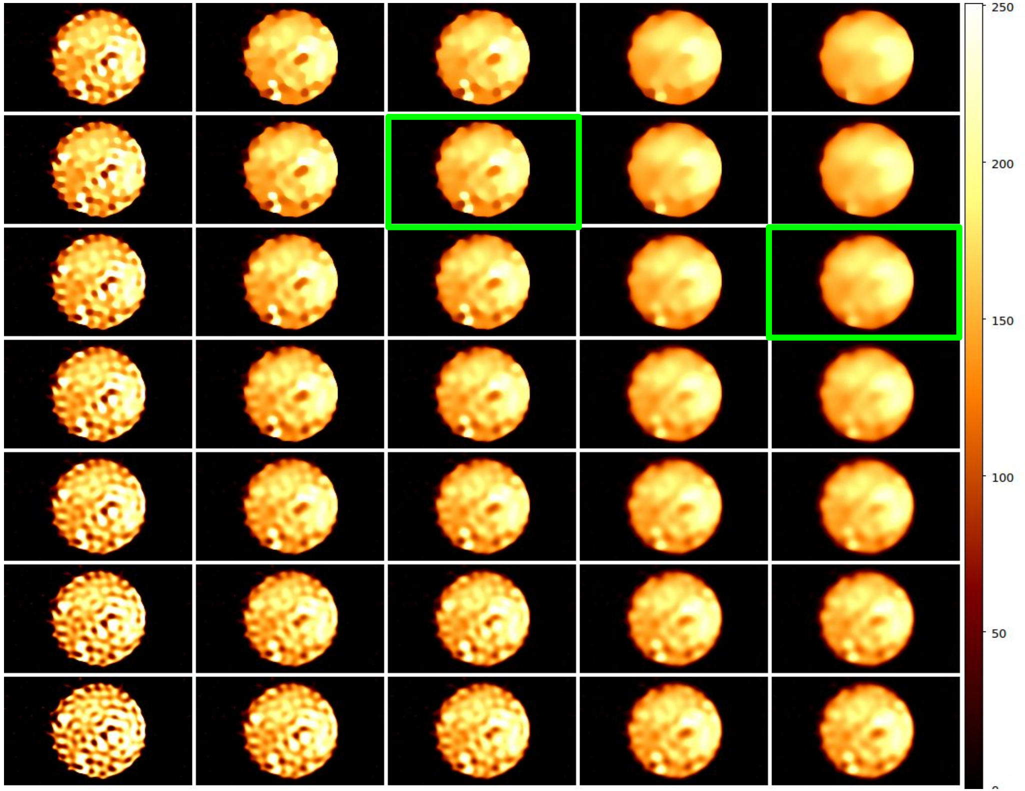
Third step: MC-SGP+HS

In real image we can still explore the 2D space of the parameters...

BUT

in this case, of course, we cannot say which one is the "best" reconstruction.

Again, we can look at the residuals...



Simulated and Real images

Third step: MC-SGP+HS

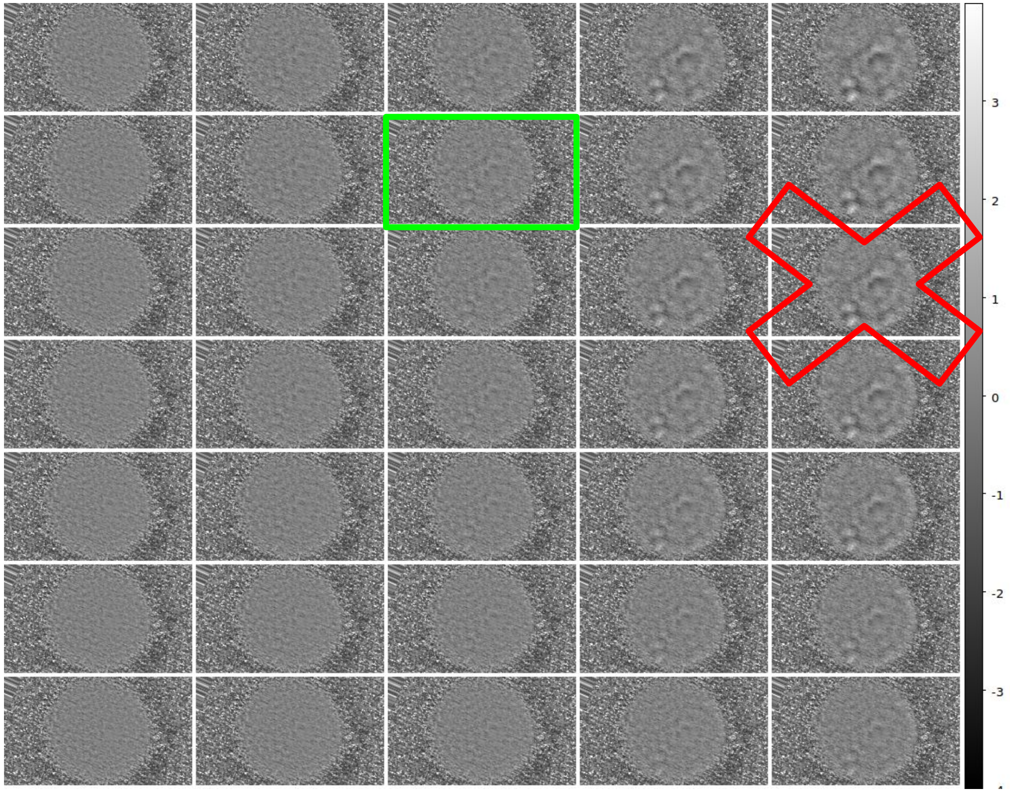
In real image we can still explore the 2D space of the parameters...

BUT

in this case, of course, we cannot say which one is the "best" reconstruction.

Again, we can look at the residuals...

...and find some useful information



Simulated and Real images

Last step: SGP+L1

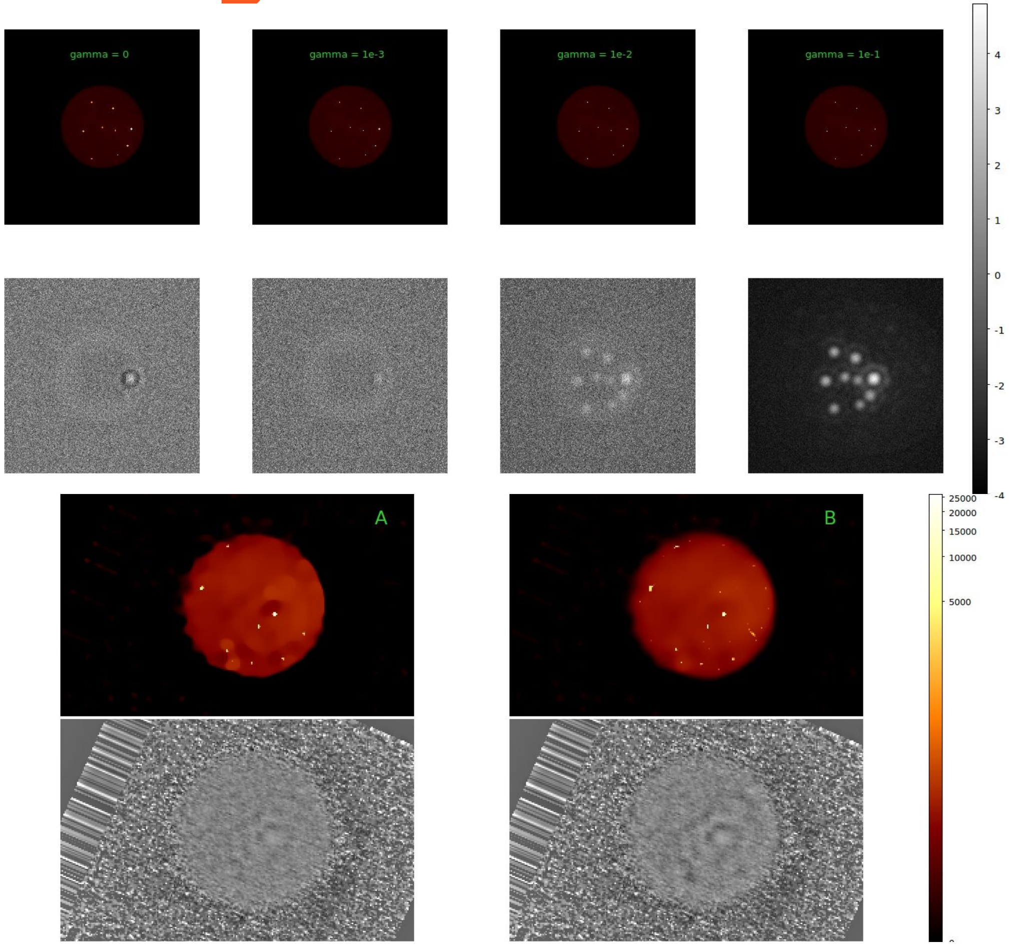
In simulation this step is not needed, we have the object at the 3rd step

BUT

in real image case we cannot say this...

MOREOVER

Also in this case we have a regularization parameter to be found... again the residuals can help us!



Conclusions and future works

In the next months we will have:

- A paper with all the details about our method and the simulations for validating it.
- A new version of the whole CAOS PSE + packages (AO4ELT5 poster)

Deconvolution of:

- Real images of Io, both from LBTI [full-map paper in prep.] and Keck;
- Data from SPHERE/VLT visible and near-infrared;

Further ideas:

- Space-variant deconvolution method for Post-Coronagraph images (SPHERE/VLT)
- We want you! Do you have data that are waiting for a deconvolution?

Thanks for your attention!