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Corinne Fournier

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# Image reconstruction from in-line holograms using inverse problems recipes: tutorial

Fabien Momey<sup>1,\*</sup>, Loïc Denis<sup>1</sup>, Thomas Olivier<sup>1</sup>, Dylan Brault<sup>1</sup>, Anthony Berdeu<sup>1</sup>, and Corinne Fournier<sup>1</sup>

<sup>1</sup> Laboratoire Hubert Curien UMR CNRS 5516, Université Jean Monnet, F-42000 Saint-Étienne, France

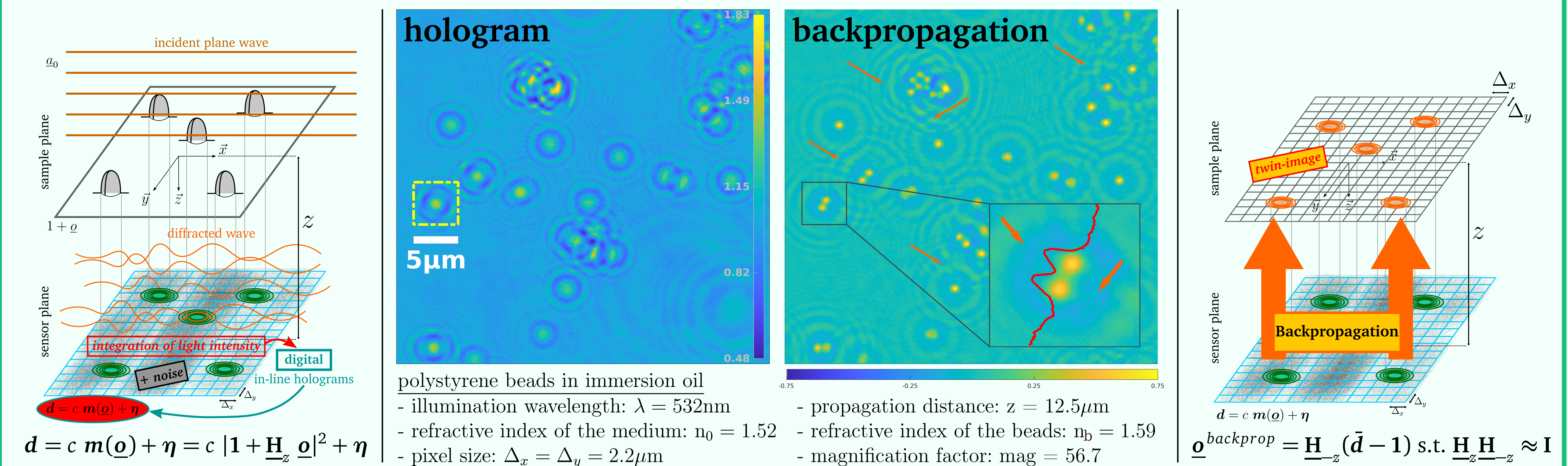
\*corresponding author : fabien.momey@univ-st-etienne.fr

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## Abstract

We present our tutorial [1] for building **inverse problems** based image reconstruction strategies in **digital in-line holography (DH)**, starting from the identification of the connections with the well known **alternated projections** strategies. **In-line DH is of great interest for optical microscopy dedicated to biology, as it constitutes a robust, efficient and label-free tool for imaging transparent living samples.**

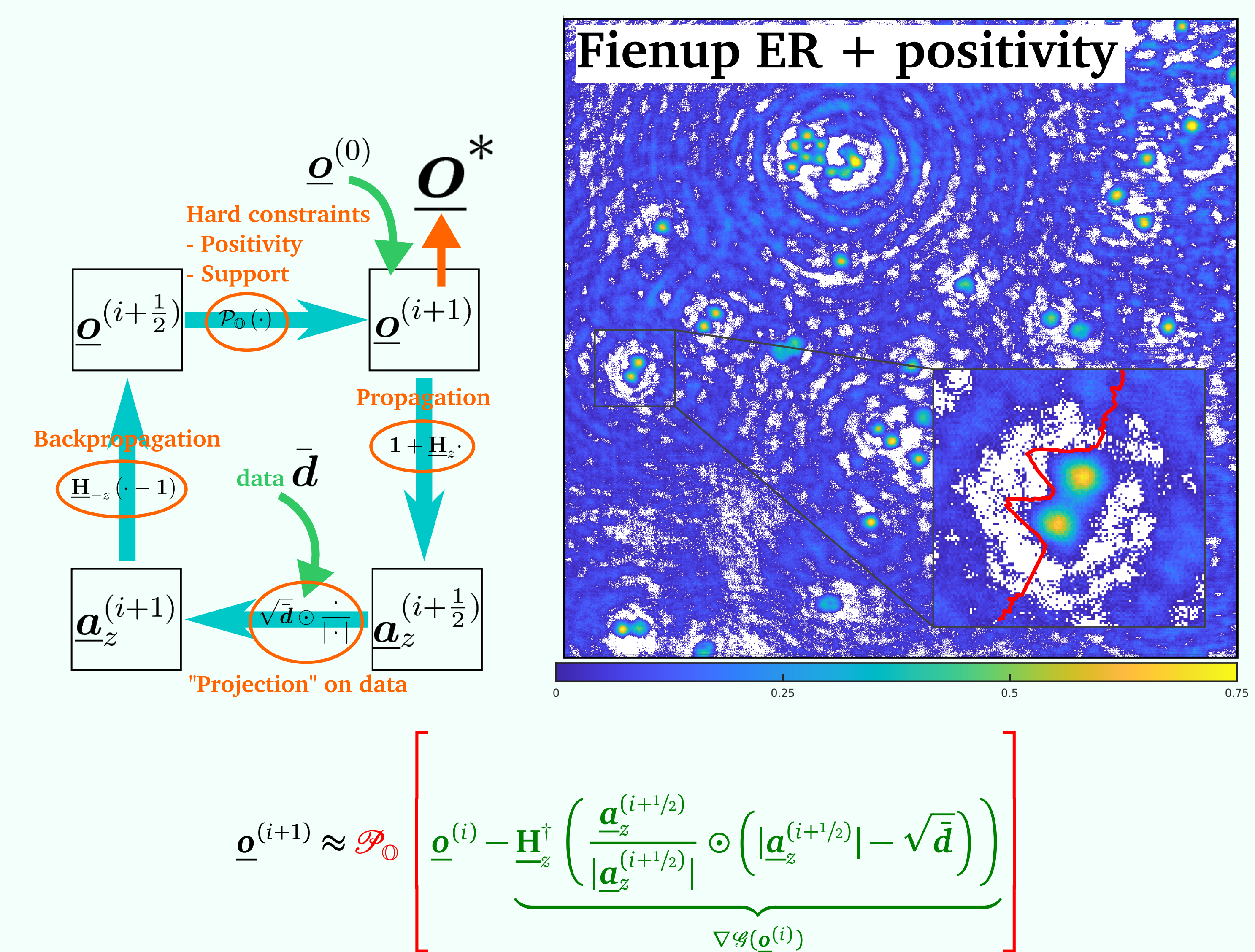
## Digital Holography (DH) and the phase retrieval problem



## Alternated projections

→ Iterative procedure involving a projection step on a feasible domain  $\underline{o} \in \mathcal{O}$  (e.g. positive values of the phase-shift / support constraint) to reduce/suppress twin-image artifacts [2].

→ a popular instance is the **Fienup's Error Reduction algorithm (Fienup ER)**:



→ **gradient descent step** of the data-fidelity criterion  $\mathcal{G}$  at current point  $\underline{o}^{(i)}$ .

→ **projection step**  $\mathcal{P}_{\mathcal{O}}$  on the domain  $\mathcal{O}$ , called **proximal mapping** of the indicator function  $\iota_{\mathcal{O}}$  at point  $\underline{o}^{(i+1/2)}$ .

This resolution method is an instance of the **ISTA algorithm (Iterative Shrinkage Thresholding Algorithm)**, a proximal gradient method.

→ **Fienup ER** is an **Inverse Problems** approach that uses a particular optimization strategy for minimizing the following criterion:

$$\underline{o}^* = \arg \min_{\underline{o}} \underbrace{\| |1 + \underline{H}_z \underline{o}| - \sqrt{\bar{d}} \|_2^2}_{\text{data-fidelity } \mathcal{G}(\underline{o}) \text{ (smooth)}} + \underbrace{\iota_{\mathcal{O}}(\underline{o})}_{\mathcal{H}(\underline{o}) \text{ (non smooth)}}$$

## Towards inverse approaches

**Alternating projections methods such Fienup ER can then benefit from the Inverse Problems framework to gain flexibility and reconstruction quality.**

→ More appropriate **direct image formation model**  $m(\underline{o})$ .

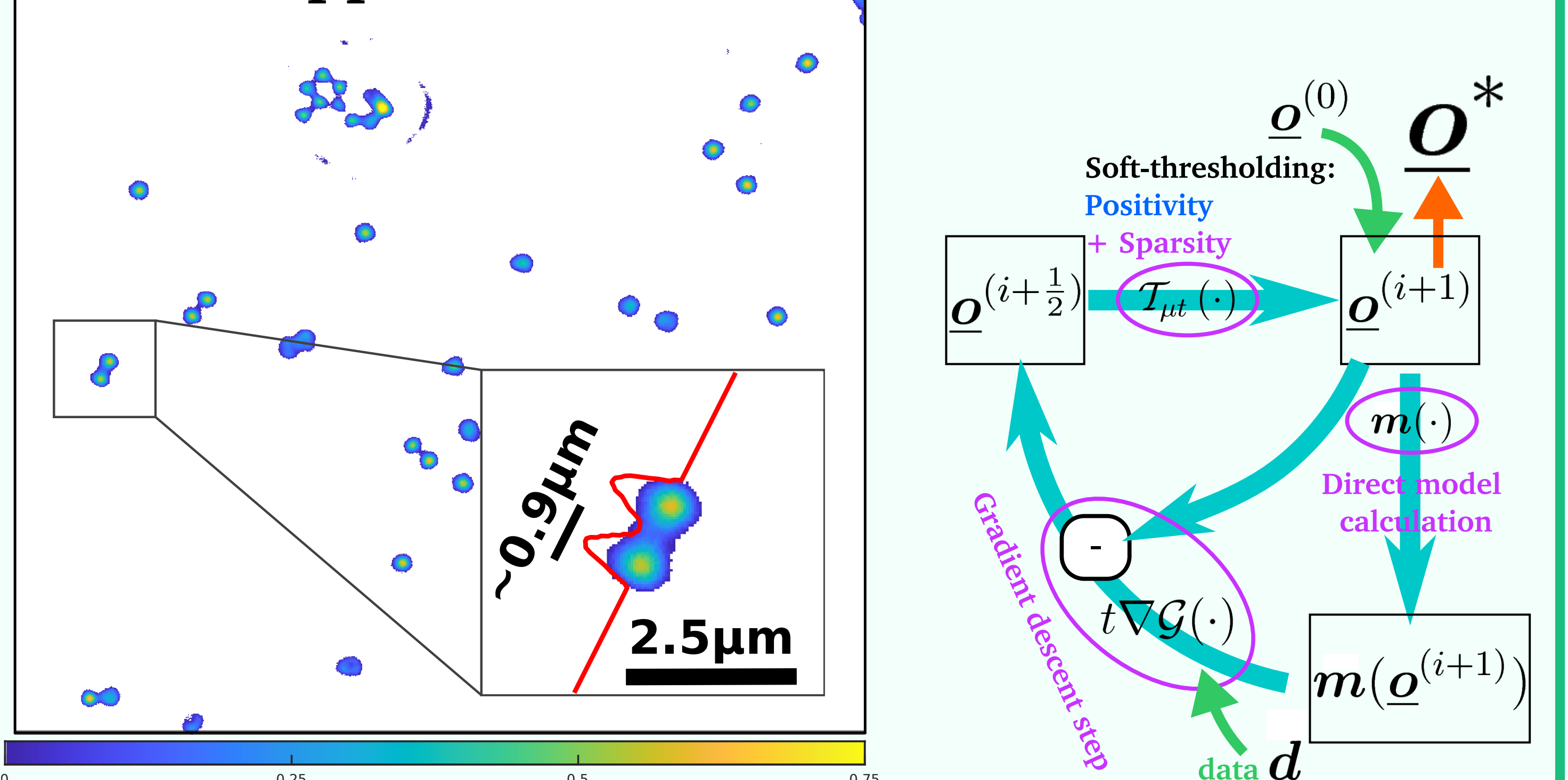
→ **auto-calibration** of model parameters made possible.

→ Taking into account **data uncertainties** (statistical considerations about the **noise**  $\eta$  in the criterion).

→ Inclusion of **more sophisticated non smooth and smooth regularizers**: sparsity constraints ( $\ell_1$ , TV / non smooth), image gradient smoothing (Tikhonov, edge-preserving / smooth).

$$\underline{o}^* = \arg \min_{\underline{o} \geq 0} \underbrace{\| c^* m(\underline{o}) - d \|_W^2 + \mu_{\text{TV}} \sum_q \sqrt{\|\nabla_q \underline{o}\|_2^2 + \epsilon^2}}_{\mathcal{G}(\underline{o}) \text{ (smooth)}} + \underbrace{\mu_{\ell_1} \|\underline{o}\|_1}_{\mathcal{H}(\underline{o}) \text{ (non smooth)}}$$

## Inverse approach



→ Others optimization methods than **ISTA** are possible: **FISTA** ("accelerated" ISTA), **L-BFGS-B** (smooth criterions), etc.

## Conclusion & perspectives

→ **Inverse problems** constitute a rigorous framework for solving image reconstruction and/or parameter estimation tasks in **Digital Holography (DH)**.

→ **Inverse problems** make possible the extension of classical **2D DH** to deal with **multi-dimensional** and **multi-variate data**: fully-3D (diffractive tomography), multi-spectral, polarimetric data, etc.

A **Matlab™** code for **2D DH reconstruction** is available for download at this link:  
[https://github.com/fabienmomey/Inline\\_Hologram\\_Reconstruction\\_by\\_Regularized\\_Inversion.git](https://github.com/fabienmomey/Inline_Hologram_Reconstruction_by_Regularized_Inversion.git)

## References

[1] Momey, F., Denis, L., Olivier, T., and Fournier, C., "From Fienup's phase retrieval techniques to regularized inversion for in-line holography: tutorial," J. Opt. Soc. Am. A 36, D62-D80 (2019).

[2] Fienup, J. R., "Phase retrieval algorithms: a comparison," Appl. Opt., 21, 2758-2769 (1982).