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Document information

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Table of Contents

- 1. Overview of the « few-shot » INSIGHT biprism**
 - 1.1. Original setup of INSIGHT sensor**
 - 1.2. Hardware description of biprism INSIGHT**

- 2. Few-shot plugin**

- 3. Capture: the acquisition software**

- 4. Process: the processing software**



1. Overview of the « few-shot » INSIGHT biprism

Developed by CEA and SourceLAB, the INSIGHT system is a breakthrough metrology sensor to be inserted at the attenuated focus of ultra-short laser systems.

It offers full access to the complex electric field (amplitude and phase) in space-time/frequency, in the far-field and the near-field.

It is associated to state-of-the-art analysis algorithms to support the experimentalists in finding good conditions for their application.

1.1. Original setup of INSIGHT sensor

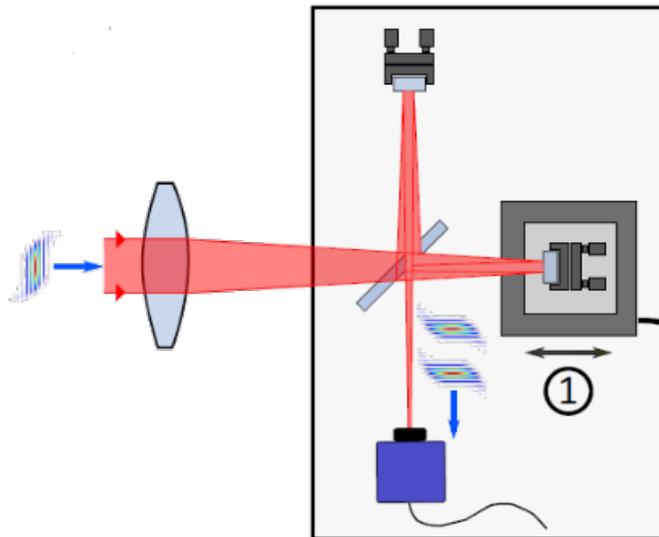


Figure 1

The incoming beam of a laser is separated in two parts with a beamsplitter. One arm of the interferometer is delayed thanks to a piezoelectric delay stage. After recombination, the two beams interfere on the chip of a camera (figure 1).

In that way, we record an interferogram at each pixel on the camera. By using a Fourier transform of this interferogram, it is possible to get the spectrum of the beam at every pixel.

Finally, Insight sensor executes this operation at 3 different planes: at focus ($z=z_0$), and plus and minus three times the Rayleigh range of the beam ($z=z_0-3z_R$ and $z=z_0+3z_R$).

Once this acquisition is done, Insight processing software uses a phase retrieval algorithm to get the spatial phase of the beam. This allows to fully determine the beam in space and frequency.

1.2. Hardware description of biprism INSIGHT

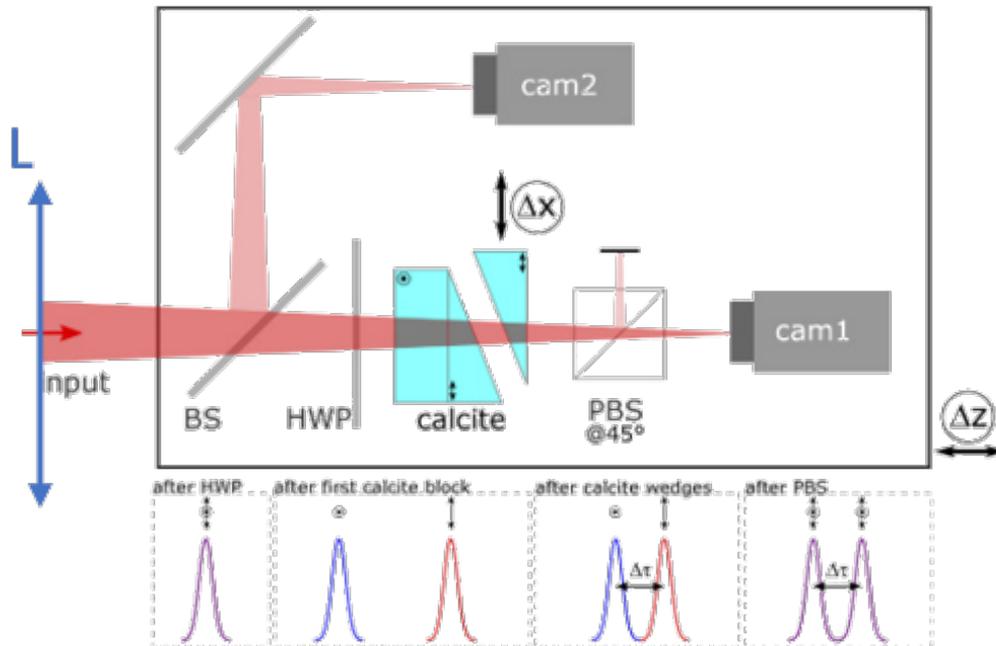


Figure 2

In the biprism configuration, the delay stage is no longer performed by a piezoelectric stage, but with a stack of birefringent optics.

First, the incoming beam, often P-polarized, goes through a half waveplate (HWP in figure 2). This half waveplate rotates the polarization of the beam at 45°.

Second, the beam goes through a calcite plate. As this material is birefringent, the two states of polarization are time-delayed.

By adding two calcite prisms with optical axis orthogonal to the optical axis of the calcite plate and by adjusting the insertion of the second prism, one has precise control over the delay between the two states of polarization.

Finally, a polarized beam splitter (PBS in figure 2) is used at 45° to filter the P-polarized component of the two beams. The interferences of these two beams are recorded on a camera (cam1 in figure 2).

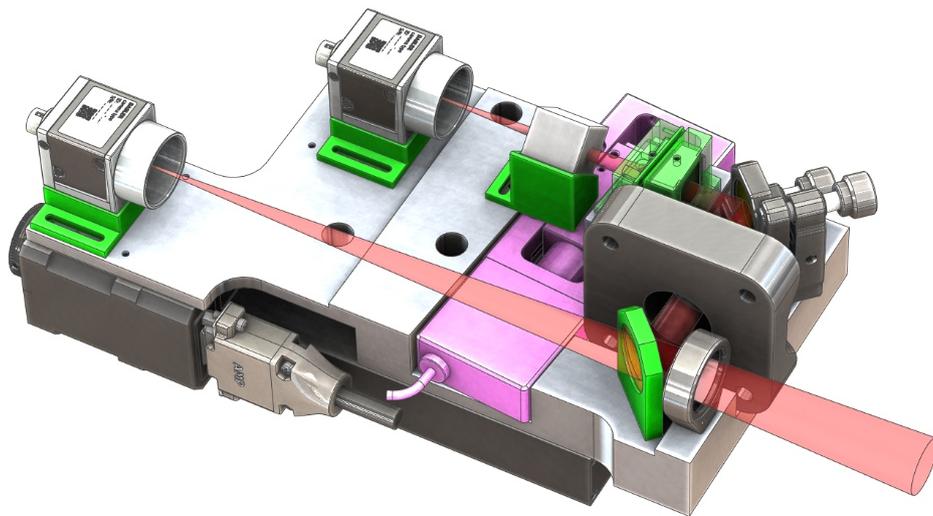


Figure 3

A rendering image of biprism INSIGHT is displayed on figure 3. We see that below the interferometric part, there is a large translation stage to perform the acquisition at the three different planes for the phase-retrieval algorithm.

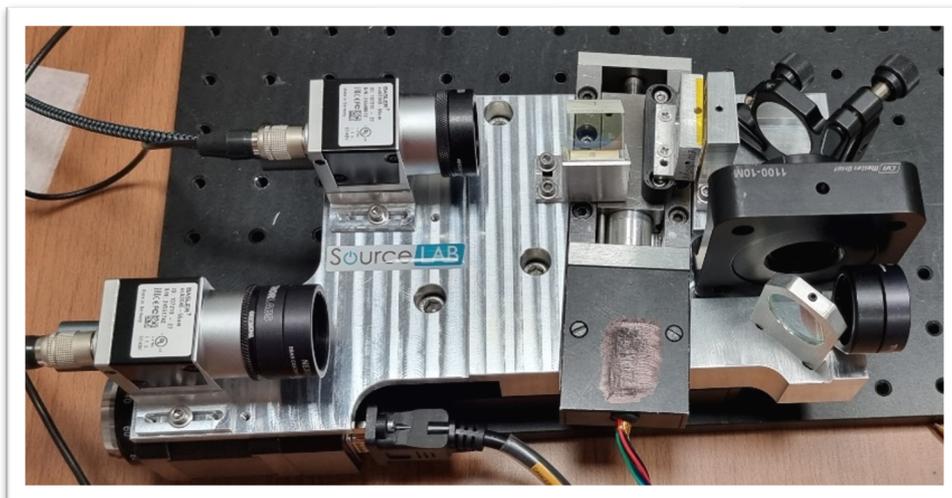


Figure 4: Photograph of the prototype manufactured for the EURIZON project.

This setup has two major benefits compared to the original setup of INSIGHT. Firstly, the dynamic of delay between the two beams is enhanced thanks to the birefringence of the calcite. This allows one to use a standard stepper motor instead of an expensive piezoelectric stage. Secondly, as the scheme of this setup is inline, the two beams are naturally spatially overlapped.

2. Few-shot plugin

As shown before, INSIGHT uses Fourier transform spectroscopy to describe the electric field of the laser in space and frequency. The maximum time step, required for a correct interferogram, is defined by the lowest wavelength in the spectrum of the laser according the Nyquist Criteria. However, in this study, we use a well-known tip of signal processing to recover the spectrum of the laser by sampling below Nyquist frequency.

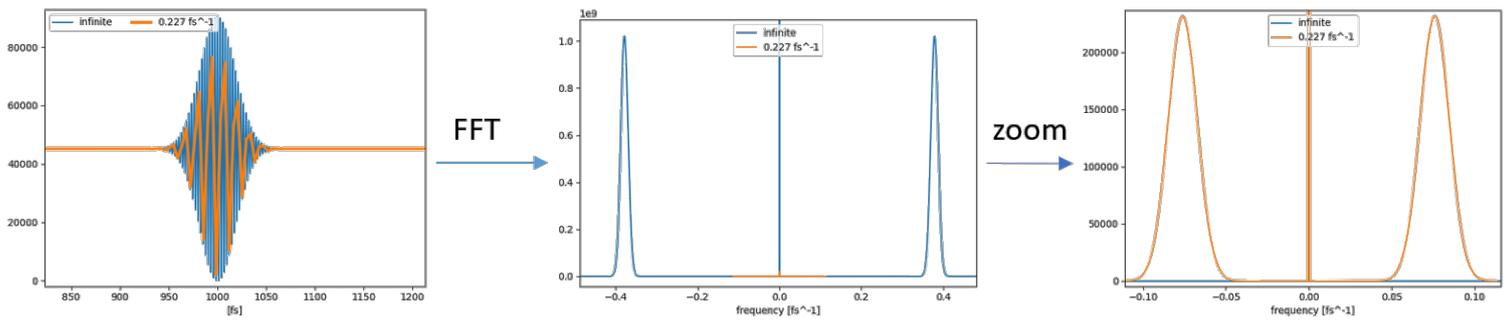


Figure 5

In fact, when a signal is sampled below the Nyquist frequency, aliases of the spectrum appear at low frequencies:

$$f_a = \{|f_s - i f_N\}; i \in \mathbb{N}$$

Where f_a is the aliased frequency. f_s , the signal frequency. f_N , the sampling frequency. i , an integer.

However, the spectrum of an ultrafast laser system does not correspond to a single frequency. For a wide spectrum, the sampling frequency must obey the inequalities:

$$\left\{ \begin{array}{l} \frac{c}{(i + 0.5)\lambda_{min}} \leq f_n \leq \frac{c}{(i - 0.5)\lambda_{max}} \\ \left(f_n \leq \frac{c}{i \lambda_{max}} \right) \text{ OR } \left(f_n \geq \frac{c}{i \lambda_{min}} \right) \end{array} \right.$$

λ_{min} and λ_{max} are, respectively, the lowest and highest wavelength of the laser. c stands for the speed of light.



Example: Ti:Sa laser with a central wavelength at 800nm:

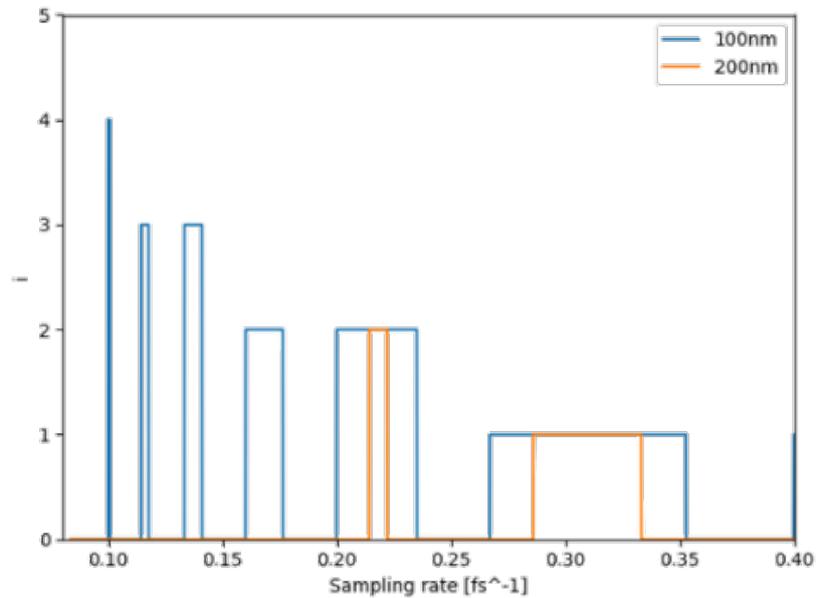


Figure 6

We show two curves on figure 6. The blue curve stands for a spectrum between 750nm and 850nm (100nm bandwidth). The orange curve is for a spectrum between 700nm and 900nm (200nm bandwidth). The broader the spectrum, the less choices we have to sample the signal with an aliased signal.

We see, in this example, that for a common Ti:Sa laser, with a spectrum between 750nm and 850nm, it is possible to sample the signal with a time step of 10 fs. It is 10 times the step used in the standard version of INSIGHT.

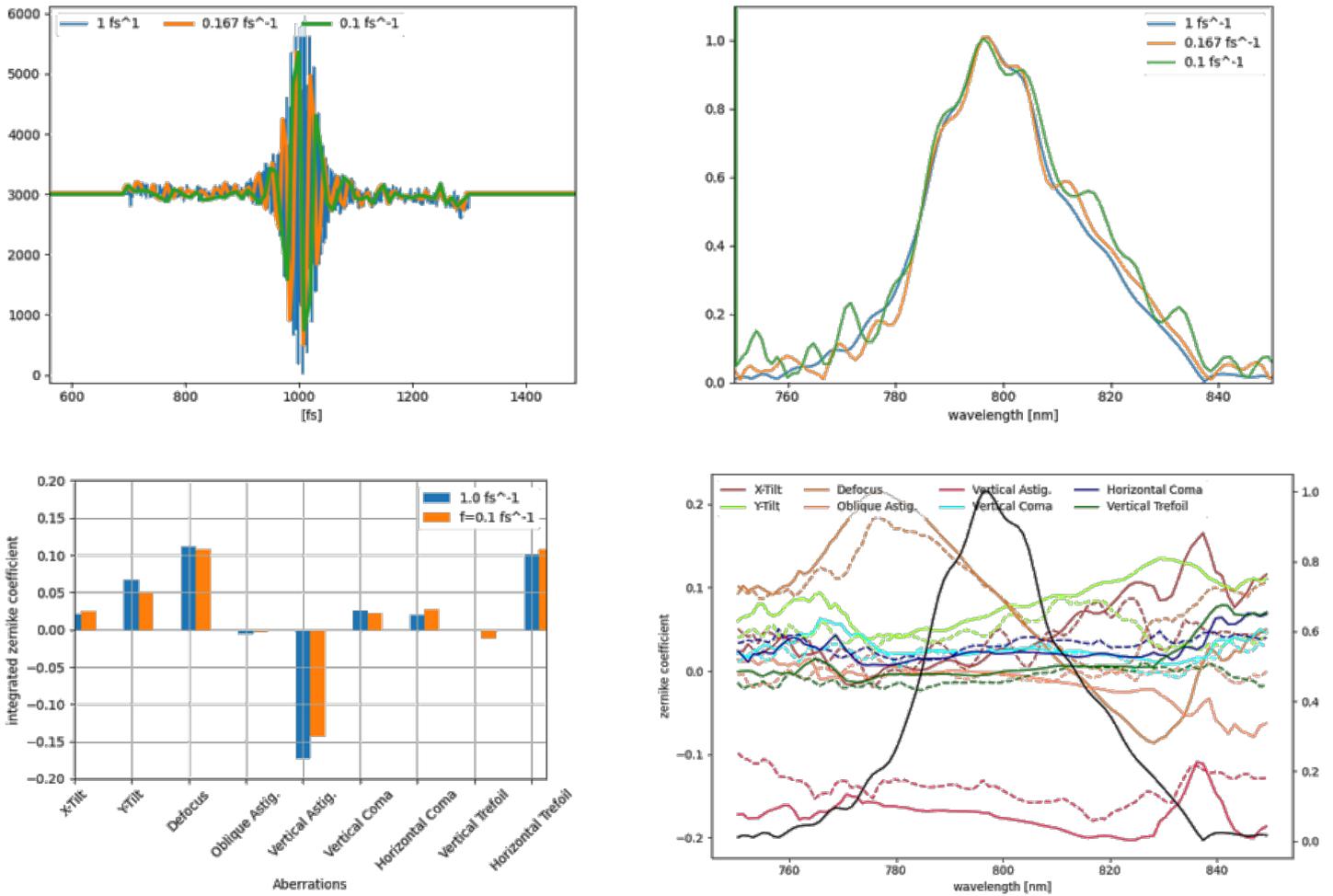


Figure 7

Figure 7 is an acquisition made on an Astrella laser from Coherent. It shows that even when sampling with a step of 10fs, we still get correct information on spectrum and Zernike analysis.

3. Capture: the acquisition software

INSIGHT sensor has two different softwares. Capture, is the one to record the data.

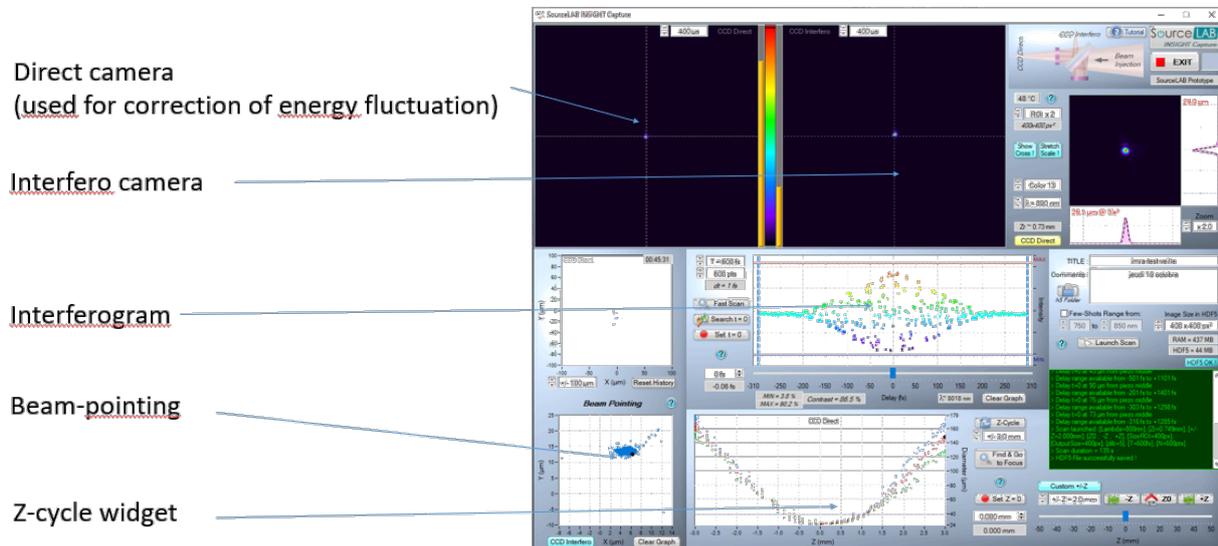


Figure 8

On figure 8, we show the graphical user interface (GUI) for Capture software.

First, the user has to determine the position of the focus. For that purpose, the z-cycle widget must be employed. Once it is done, click on „Set z=0“.

Second, the beam must be sent on the sensor without too much incident angle. The widget „Beam-pointing“ must be used by using a z-cycle. One has to lower as much as possible the beam-pointing extrema during the z-cycle. This is achieved by using two mirrors before INSIGHT to adjust the beam-insertion.

One has to determine the time step for an acquisition. There are two ways to do that.

Either manually enter the time range and the number of points in the interferogram or to enable the „few-shot plugin“ on the GUI. If it is activated, the user has a choice of sampling rates at the left of the interferogram widget.

For the biprism version of INSIGHT, we only see a single beam on the two cameras, due to the inline configuration as previously mentioned. In that case, the user can directly do a fast scan interferogram. The temporal interferogram progressively appears in the dedicated window.

Before launching an acquisition, the user must define the 3 acquisition planes. One is at focus; the two others are symmetrically at around three times the Rayleigh range. This value must be entered on the bottom right of the GUI.

Once everything is set, the acquisition can be launched by clicking on „Launch Scan“.

The data are exported in a h5 file format.



4. Process: the processing software

When launching the Process software, one must look for the h5 file and enter a name for the processing (figure 9).

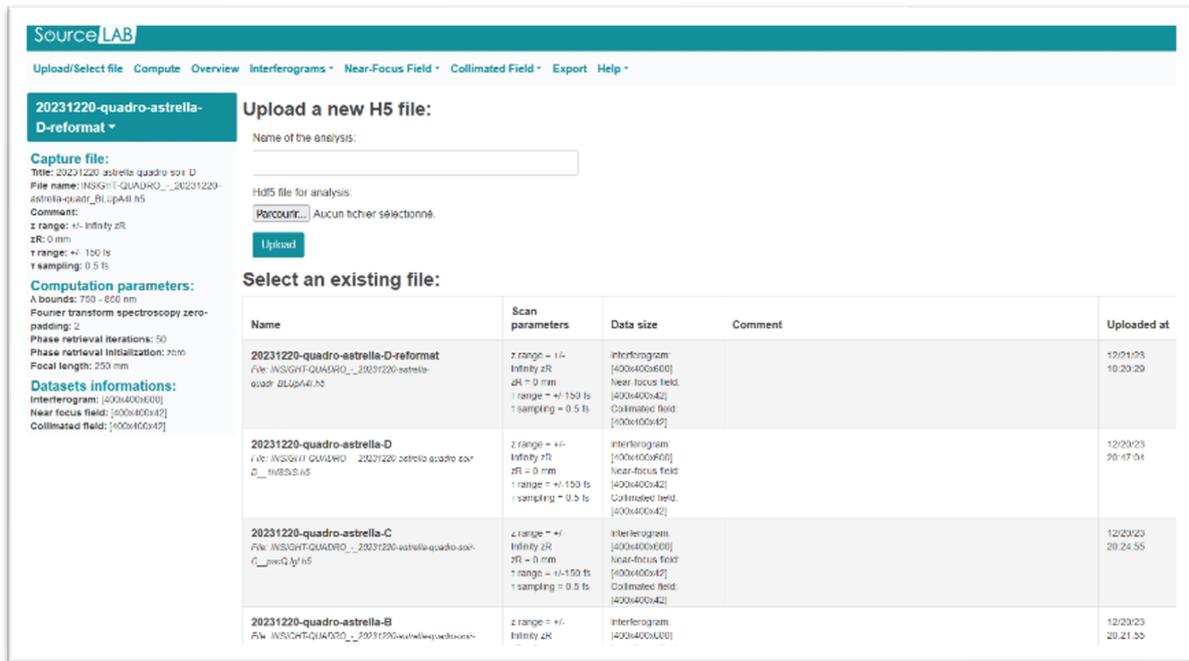


Figure 9

Once uploaded, the user has to enter the range of the spectrum, the focal length used during the acquisition and the number of iterations for the phase-retrieval algorithm (>20 is advised) (figure 10).

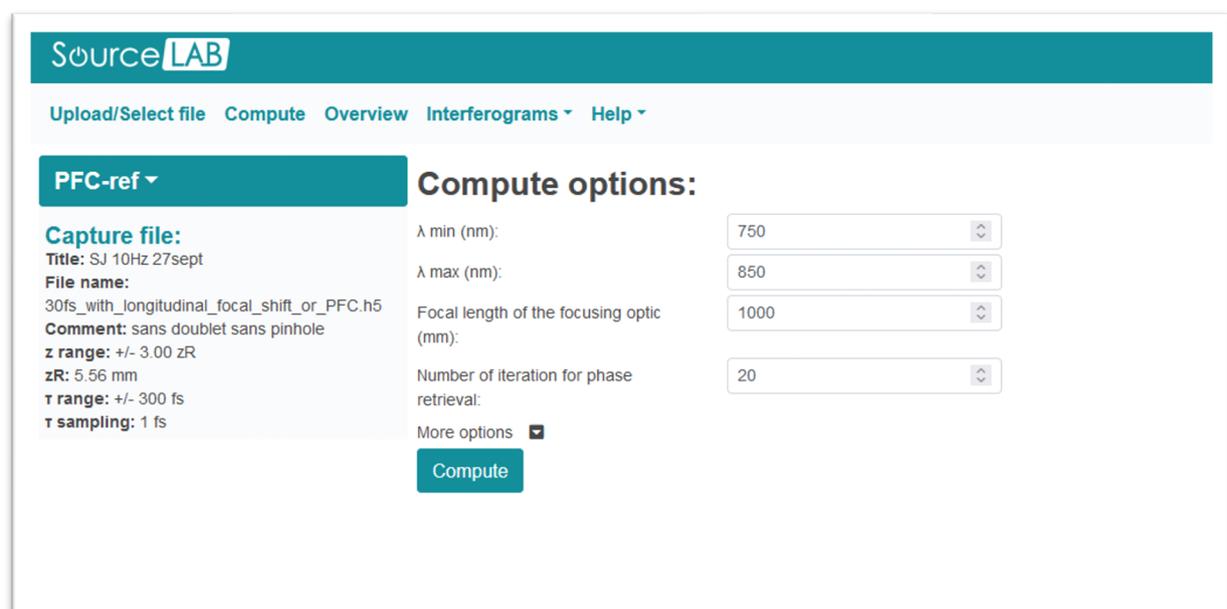


Figure 10



The user starts the processing by clicking on “Compute”. The processing can take up to 2-3 minutes. Once the processing is over, an overview of the spectrum, the far and near-field and the convergence of the algorithm are displayed (figure 11).

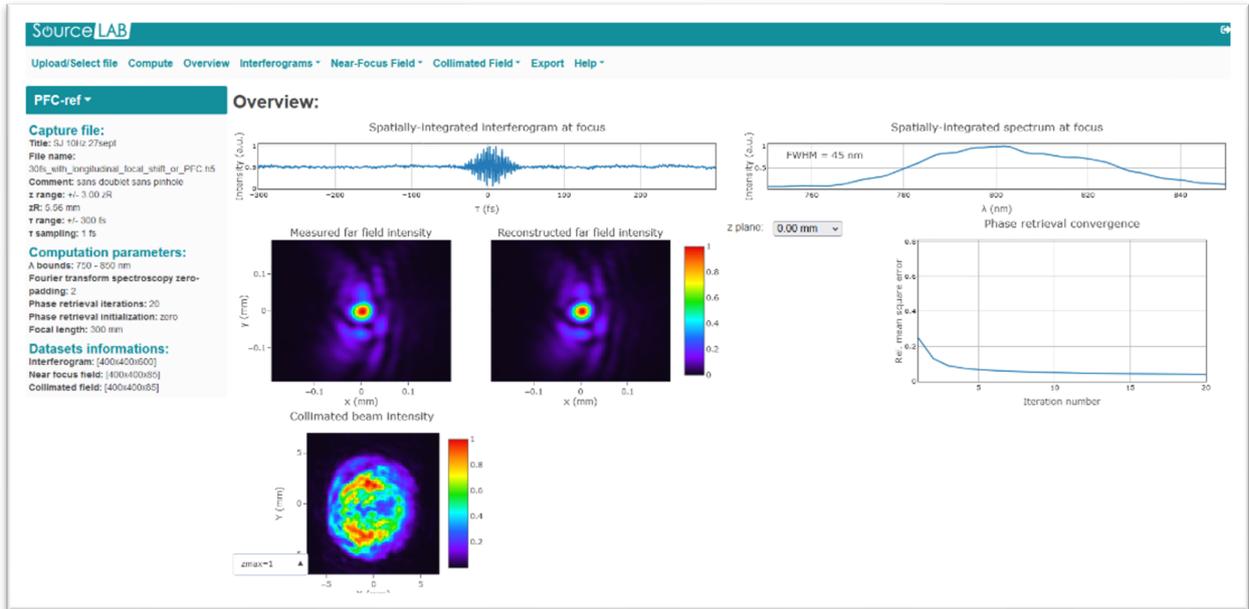


Figure 11

The user can navigate in the different available tabs to see the required quantities that have been computed: spectrally-resolved Zernike analysis, transverse and longitudinal focal shift, spectrally-resolved Strehl ratio, V-parameter, spatio-temporal mapping if an additional spectral phase is included, and much more (figure 12).

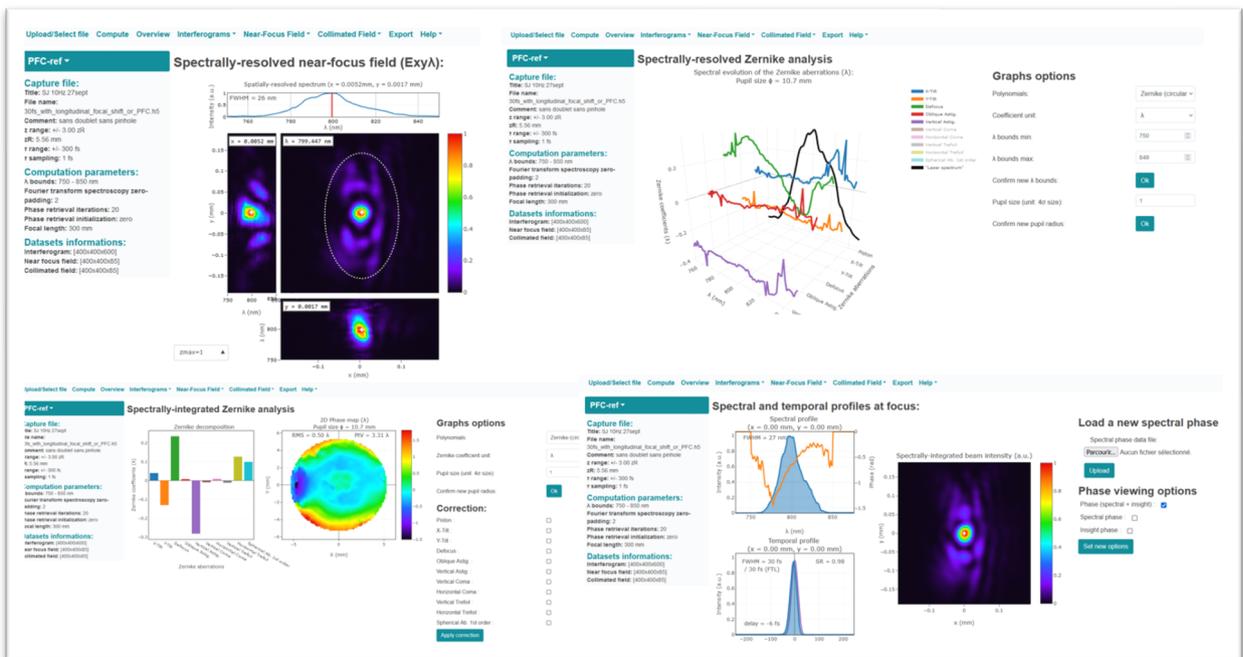


Figure 12

