Forward Modeling and Analysis Suite for Talbot Interferometry

The University of Valladolid has developed a specialized software suite designed for the simulation and post-processing of interferometric data. Originally created to address the challenges of diagnosing High-Energy-Density (HED) plasmas -which are opaque to visible light- using X-ray wavelengths, this technology is now extended to work with visible radiation. The suite offers a dual capability: TIA software (Talbot-Interferometry Analyzer) serves as a forward model to predict experimental results and optimize instrumental parameters, while TIA/TNT (Talbot Numerical Tool) is dedicated to the analysis of real experimental data. Beyond fusion, these tools are highly adaptable for medical imaging and measuring gas densities in industrial or research settings.

Description of the technology

The technology consists of a comprehensive software package developed as a Graphic User Interface in python that simulates the entire experimental chain of a Talbot or Talbot–Lau interferometer. The suite is structured into three main modules:

- Wavefront calculator: Converts 2D hydrodynamic simulation outputs into 3D plasma objects to **calculate the phase shifts and absorption** introduced by the target.
- Diffraction solver: Utilizes the Fresnel diffraction approximation and Fourier transform transfer functions to **propagate the wavefront** through the interferometer gratings to the detector.
- Post-processing module: Decomposes interferometric images into their attenuation, dark field, and phase shift components, allowing for the **precise extraction of electron density gradients**. The software supports both **X-ray energies (1–10 keV)** for dense plasmas and **visible light** for lower-density gas systems. This module can be used independently to analyze experimental data

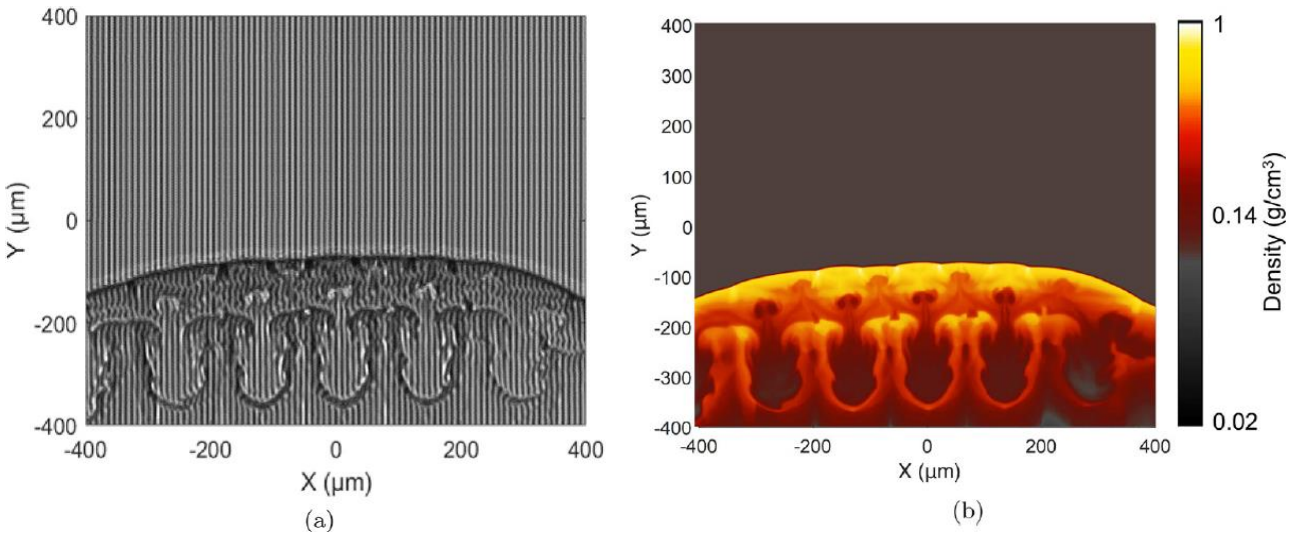

Figure 1: Example simulation: (a) interferometric image generated by TIA and corresponding (b) density map –in logarithmic scale – to show different regions of the expanding plasma.

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Innovation and advantages of the offer

TIA suite can produce highly realistic synthetic interferometry images from complex plasma systems generated by hydrodynamic simulations, moving beyond the simple geometric shapes from previous tools. This forward-modeling approach allows to reliably design and "test" experiments at large-scale laser facilities -where shot time is extremely limited- before they are performed. A key technical advantage is the implementation of Moiré interferometry, which enables single-shot imaging by adjusting the fringe periodicity to match the resolution of standard detectors. Additionally, the code's post-processing algorithms can extract detailed phase information and refraction-enhanced features that are lost in classical absorption radiography, providing a much higher contrast for studying phenomena micro-scaled phenomena.

Non-fusion Applications

Medical Imaging: Talbot–Lau interferometry is a leading technology for clinical X-ray applications, offering enhanced contrast for soft tissue diagnostics.

Industrial Gas Diagnostics: The codes have been successfully applied to visible light systems to measure gas densities with high precision.

Advanced Materials: Useful for non-destructive testing and characterization of surface irregularities.

EUROfusion Heritage

The development of this technology was driven by the fundamental need to characterize the evolution of fuel in Inertial Confinement Fusion (ICF), where extreme conditions require advanced measurement methods. This suite has been instrumental in bridging the gap between theoretical hydrodynamic models and experimental observations. This heritage has allowed the group to build a specialized know-how in radiation transport and the interpretation of complex interference patterns in magnetized and dense plasma environments.

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