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Observing the Sun with micro-interferometric devices: a didactic experiment

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Abstract. Measuring the angular diameter of celestial bodies has long been the main purpose of stellar interferometry and was its historical motivation. Nowadays, stellar interferometry is widely used for various other scientific purposes that require very high angular resolution measurements. In terms of angular spatial scales probed, observing distant stars located 10 to 100 pc away with a large hectometric interferometer is equivalent to observing our Sun with a micrometric baseline. Based on this idea, we have manufactured a set of micro-interferometric devices and tested them on the sky. The micro-interferometers consist of a chrome layer deposited on a glass plate that has been drilled by laser lithography to produce micron-sized holes with configurations corresponding to proposed interferometer projects such as CARLINA, ELSA, KEOPS, and OVLA. In this paper, we describe these interferometric devices and present interferometric observations of the Sun made in the framework of Astrophysics lectures being taught at the Liège University. By means of a simple photographic camera placed behind a micro-interferometric device, we observed the Sun and derived its angular size. This experiment provides a very didactic way to easily obtain fringe patterns similar to those that will be obtained with future large imaging arrays. A program written in C also allows to reproduce the various point spread functions and fringe patterns observed with the micro-interferometric devices for different types of sources, including the Sun.

1. Introduction

The measurement of stellar angular diameters is the historical motivation of stellar interferometry which is now used for various scientific purposes. Since the first interferometric measurement of the angular diameter of a star in December 1920 (Michelson & Pease 1921), a few hundred stars have been measured with various interferometers worldwide. Such experiments are however relatively complex and require ressources generally beyond those available at the University level. Teaching the basics of stellar interferometry then hardly finds an astrophysical application and remains limited to lab experiments with artificial sources. In this context, we have manufactured a set of micro-interferometric devices that can easily be used in the framework of Astrophysics lectures. The idea is that, in terms of spatial scales probed, observing our Sun with a micrometric baseline is equivalent to observing distant stars located 10 to 100 pc away with a large hectometric interferometer. Indeed, the Sun has an angular diameter θ typically ranging between 0.524 and 0.542 degree, depending on the Sun-Earth distance. In order to resolve it in the middle of the visible wavelength range (λ=555.5 nm), a single monolithic pupil should have a linear diameter of approximately 145 μm (according to the Huygens-Fresnel principle). With an interferometer, the baseline (b) leading to fringes with a null visibility can be computed using the expression of the fringe visibility with respect to the baseline length and to the size of the source. Accounting for linear limb-darkening, the fringe visibility can be computed as (Hanbury et al. 1974):

$$\mathcal{V} = \frac{1-u}{(1-u)/2+u/3}\left(\frac{J_1(z)}{z} + u\sqrt{\frac{\pi}{2}}\frac{J_{3/2}(z)}{z}\right), \tag{1}$$

where J_1 is the Bessel function of the first kind, u the limb-darkening coefficient (0.485 in the case of the Sun, Claret et al. 1995), and $z = \pi b\theta/\lambda$. At λ=555.5 nm, it is therefore possible to fully resolve the Sun with a baseline of approximately 80 μm. The expected visibility of the Sun as a function of the baseline length is represented in Fig. 1. By using micro-interferometers with various baselines, it is therefore possible to produce fringes over a wide range of visibilities and derive the diameter of the Sun by model fitting. This experiment has been conducted by students at the Liège University and is described in the present paper.

2. The micro-interferometric devices

The micro-interferometers consist of a single glass plate that has been drilled with micron-sized holes by laser lithography. Typically, the holes present a diameter of approximately 10 μm, and are located several tens of microns from each other to form various kinds of configurations (e.g., 2 holes, 3 holes, VLTI, CARLINA, ELSA, KEOPS, OVLA, ...). A chrome layer is deposited on the plate surface to maximize its opacity around the holes. An example of interferometric plate presenting 49 different hole configurations is shown in Fig. 2 (left) in its mechanical support. To observe the Sun, this support is mounted at the front of a classical digital camera (see Fig. 2, right) and the chosen interferometric configuration aligned properly with micrometric screws. Each configuration can be identified by naked eye or by referring to the blueprint of the device (see Fig 3).

Before observing the Sun with the device, we characterized the PSFs of various configurations. Two examples are shown in Fig 4 with the corresponding configuration displayed in the lower right insets.

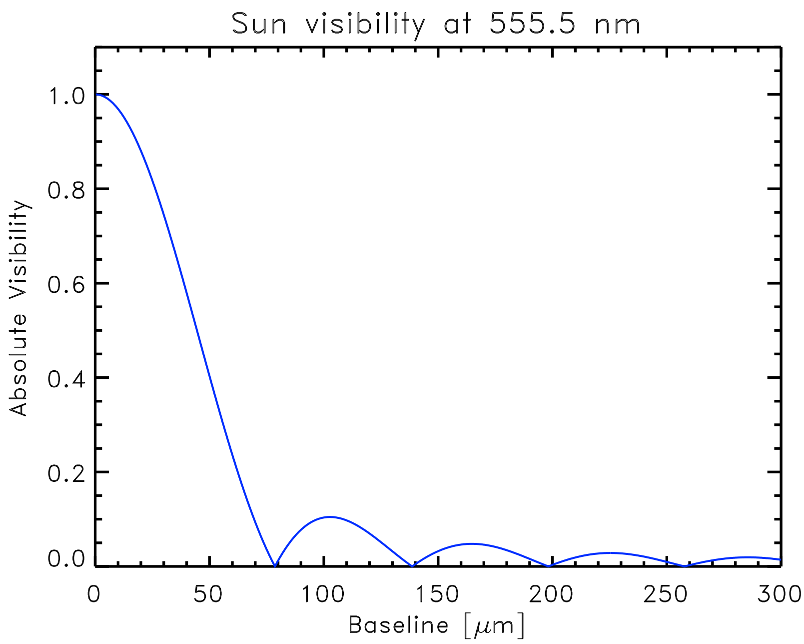

Figure 1.: *Absolute visibility of the Sun with respect to the baseline length at a wavelength of 555.5 nm. Considering a linear limb-darkening coefficient of 0.485 (Claret et al. 1995), the Sun is fully resolved for a baseline of approximately 80 μm.*

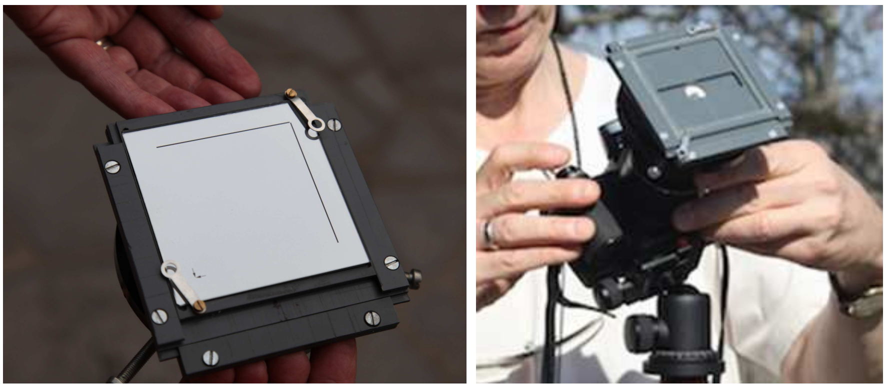

Figure 2.: *Picture of a micro-interferometer plate in its mechanical support (left). This plate contains 49 different interferometric configurations that have been drilled by laser lithography. The plate and its support are mounted at the front of a classical digital camera (right picture).*

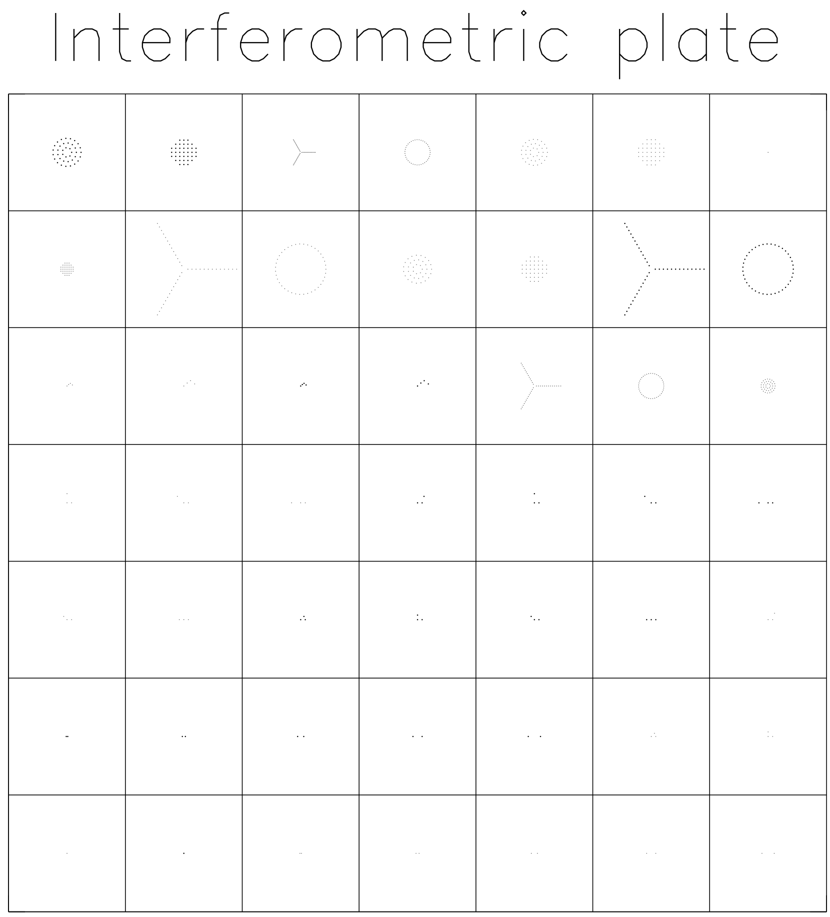

Figure 3.: *Blueprint of the micro-interferometric devices. The hole configurations have been scaled up to match the size of the boxes (preserving the relative scale between each configuration).*

3. Observing the Sun

In the framework of Astrophysics lectures being taught at the Liège University, students observed the Sun with the micro-interferometric device. The main goal was to measure the angular diameter of the Sun. This experiment is ideal to get familiar with the notion of fringe visibility and to learn the main steps of interferometric data reduction (i.e., background subtraction and model fitting). Examples of observations obtained on the Sun are shown in Fig. 5 for the 2-hole and ELSA configurations. Generally, the students have measured the diameter of the Sun within a precision of 10%. Attempts to create a "high-resolution" image of the Sun by quickly rotating the interferometric device have been unsuccessful so far, mainly due to the lack of a good and smooth rotation mechanism.

In parallel to the observations, we developed a little C software to help with the preparation of the observations. The software reproduces the fringe pat-

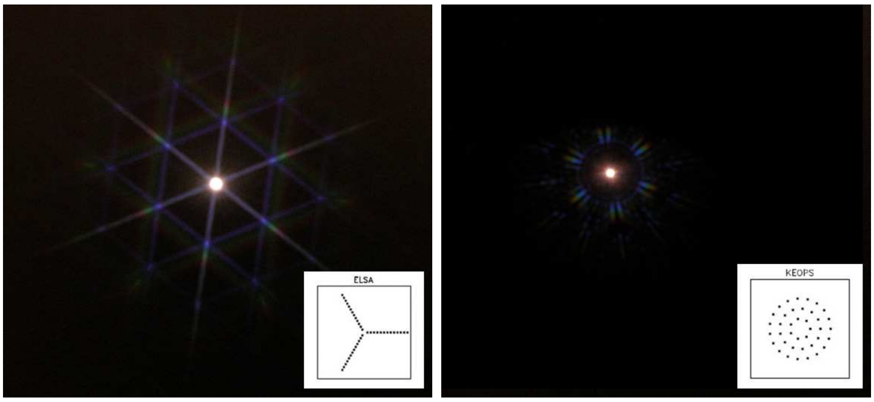

Figure 4.: *Picture of observed PSFs with configurations displayed in the insets (ELSA and KEOPS). The main baseline used is 50 μm and a hole diameter of 14 μm.*

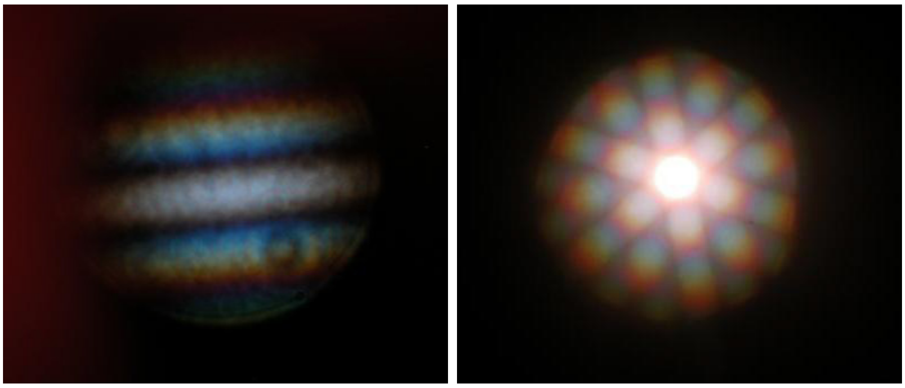

Figure 5.: Left, *First interferometric image of the Sun obtained in April 2010 with a 2-hole configuration (baseline length of 29.4 μm and hole diameter of 11.8 μm).* Right, *Observation of the Sun with the ELSA configuration (main baseline length of 24 μm and hole diameter of 7.2 μm).*

terns observed with the micro-interferometric devices for various kinds of sources and hole configurations. Input images can also be used which provides a good intuition of interferometric imaging. This software is called μIDS (i.e., micro-Interferometric Device Simulator) and can be downloaded on the following website: http://www.aeos.ulg.ac.be/upload/uIDS-setup.rar (only available for PC platforms).

4. Prospects

Various areas of the proposed experiment can still be improved. On the technical side, the opacity of the interferometric plates is currently relatively poor which impairs the quality of the fringes. We are currently exploring the possibility to use a different material for the plate (e.g., aluminium). We also would like to build a reliable rotating mechanical support in order to produce "high-resolution" images of the Sun. On the software side, we intend to adapt the μIDS software to the Mac platform.

References

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