A laboratory analog of the Michelson stellar interferometer

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Abstract: Optical interferometry combines high-accuracy mechanical and advanced optical constructions and therefore it is a difficult task. Michelson's experiment is difficult to be performed in a laboratory exercise for the above reasons. A simple laboratory analog of the Michelson stellar phase interferometer was built at the Laboratory of Applied Optics at the University of Athens. The setup we built is used to measure the angular width of a narrow slit, instead of a stellar target. Furthermore we calculate the coherence length of the light used and we estimate the instrument sensitivity to the path difference of the two light beams. From our experience, the experiment has remarkable educational value, not only for understanding the principals of interferometry, but also for understanding the concepts of the light coherence.

Introduction

A fundamental method for measuring the angular diameter of a star is by the use of the Michelson stellar interferometer (1920). The principle of this method is that if we cover the objective lens of a telescope of focal length F with an aperture with two holes of distance L_0 (Fig. 1a) we will see in the focal plane that the Airy's disk is replaced by thin fringes, which are produced by the interference of the two light beams, entering the telescope from the two holes (Fig. 1b). The distance χ between two successive fringes (Fig. 1c) is given by the equation:

$$\chi=\lambda F/L_0 \qquad (1)$$

where λ is the wavelength of the light.

If we increase the distance of the two holes, the fringes are coming closer and their visibility decreases until they become invisible. If the distance of the two holes when the fringes disappear is L_o, we can prove that the apparent diameter (d) of the star is:

$$d=K(1.22\lambda/L_o)\ (rad) \qquad (2)$$

where K=1,2,3...

The meaning of constant K is that if we increase further the distance L, the fringes disappear and reappear successively at distances of $2L_o$, $3L_o$...

Although L_o can never be less than 2.5m, smaller telescopes can be used, equipped with the device shown in Fig. 1d, where four small mirrors (1,2,3 and 4) are attached in front of the telescope with a special rigid bar. Mirrors 1 and 2 have variable distance, while 3 and 4 are stable and divert the two parallel beams of stellar light into the telescope.

The above ingenious device invented my Michelson, allows the distance L to be increased far over the telescope diameter. An other advantage of this method is that due to the stable mirrors (3 and 4), the density of the fringes in the focal plane is constant, independent of the distance L. This allows an accurate determination of the position where the fringes disappear.

A simple, non astronomical application of the stellar interferometer is the measurement of the angular width d of an illuminated slit, placed faraway. In this case the width d is given by the equation:

$$d=K(\lambda/L_o)\ (rad) \qquad (3)$$

where K=1,2,3...

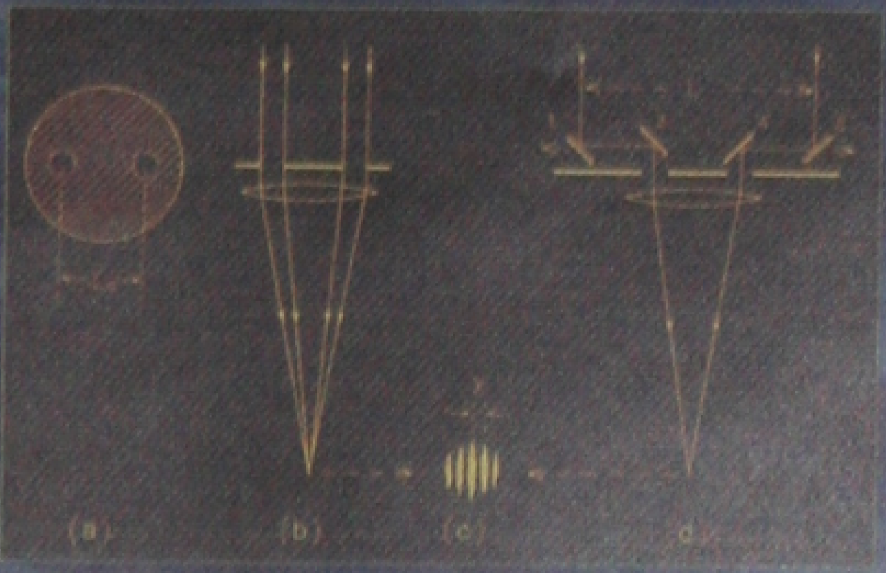

Figure 1. The principle of the Michelson's stellar interferometer. (a): The aperture with the two holes. (b): The two light beams that interfere on the focal plane. (c): A typical interferometric pattern. (d): A schematic diagram of the Michelson's original setup.


Figure 2. The experimental setup. Left: a general view of the optical bench. Right: a close view of the telescope, with the iris and the filter.

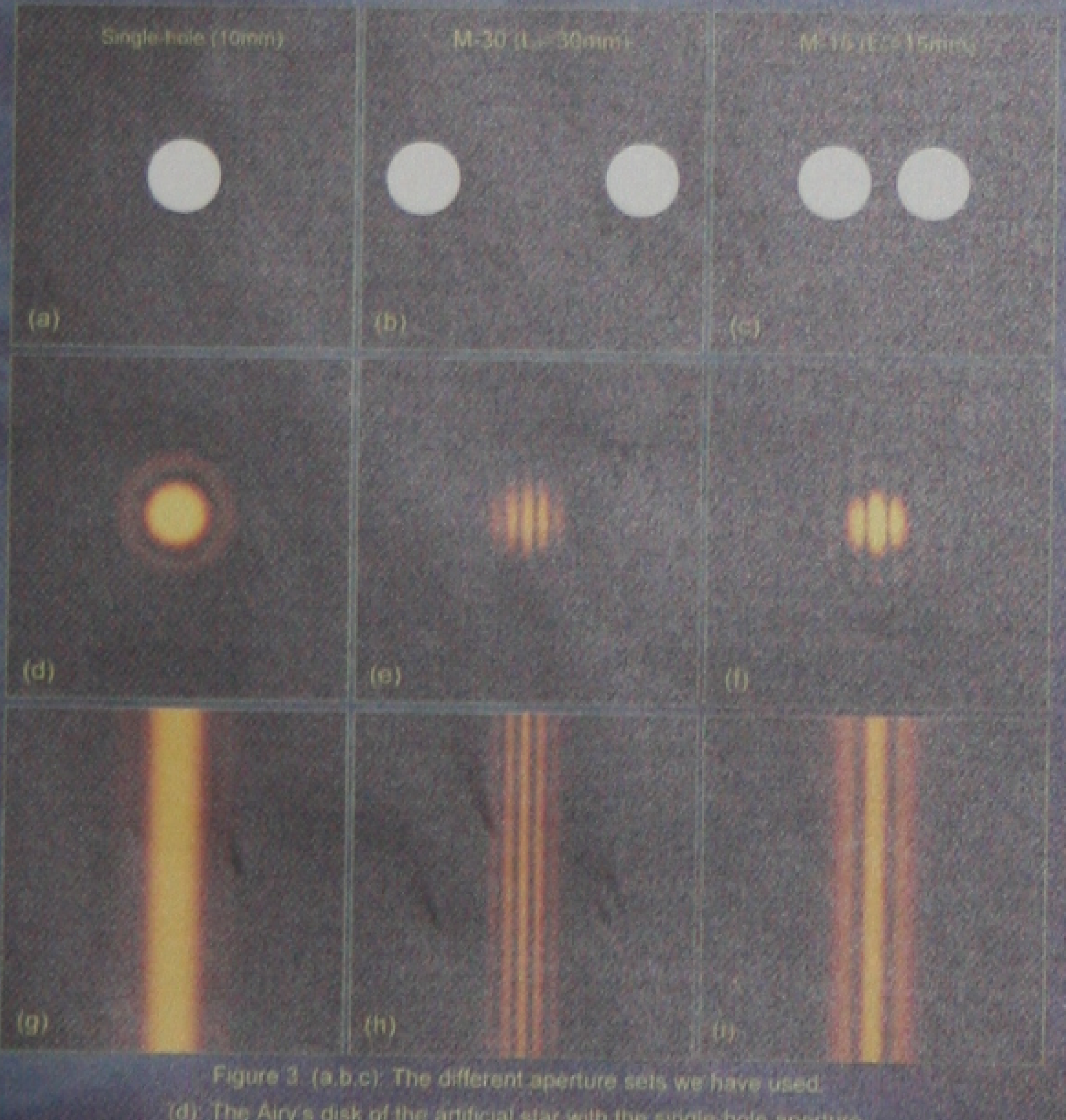

Figure 3. (a,b,c): The different aperture sets we have used.
(d): The Airy's disk of the artificial star with the single-hole aperture.
(e,f): Interference fringes of the artificial star with the M-30 and M-15 apertures respectively.
(g): The diffraction pattern of the slit with the single-hole aperture.
(h,i): Interference fringes of the slit with the M-30 and M-15 apertures respectively.

The experiment

The setup consists of an artificial star (an illuminated 50μm pin-hole), or a spectroscope slit with variable width, placed at the far end of an optical bench (Fig. 2). At the other end, at a distance of *4570mm*, a small telescope (*D=60mm, F=400mm*) is located, with a high magnification eyepiece (*7mm*) and an orange filter. In front of the objective there is a holder, on which we can place an iris or a set of apertures with two *10mm* holes.

First we focus on the artificial star and we place the *M-30* aperture (*30mm* separation between the holes) and then the *M-15* aperture (*15mm*) (Fig 3a, 3b and 3c). The density of the interferometric fringes that we observe, superimposed on the diffraction pattern, varies, according to the holes separation (Fig. 3d, 3e and 3f).

Our device does not have four mirrors, as the original stellar interferometer. Thus, any change of the distance of the two holes, complicates the phenomenon, since not only the contrast, but also the density of the fringes changes. This is why we keep the distance of the holes constant, using only the M-30 aperture in the following steps and we have to change the diameter of the artificial star. This is an invert function of the stellar interferometer, but the principle and equations are the same.

Since it is too difficult to change the diameter of the pin-hole star, we replace the pin-hole with a spectroscope slit, the width of which can be easily adjusted. The effect is again the same, with the only difference that the fringes will be much longer (Fig. 3g, 3h and 3i) and we will use equation 3 instead of equation 2.

We increase gradually the slit width, while we observe the fringes becoming blur until they disappear. Increasing further the slit width, we see the fringes appearing again until a second disappearance occurs (Fig. 4). Using the equation 3, we calculate the slit width for the two positions where the fringes disappeared and we compare it with the real width.

The device is very sensitive and careful movements are required. Optionally, the same device can be used, in order to estimate the sensitivity of the interferometer for the optical path difference and calculate the coherence length of the light we use.

Summary

The laboratory analog of the Michelson stellar phase interferometer has a remarkable educational value. We can show the principles of interferometry with a simple optical setup and can obtain very accurate measurements with a typical error of about 5%.

Figure 4. The interference fringes disappear as the slit width increases from 0.050mm (left) to 0.100mm (third from left). The fringes appear again and a second disappearance occurs at 0.185mm.