Simulation of Multiple Aperture Synthesis

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Abstract

In view of the importance of multiple aperture synthesis in optical astronomy, a laboratory corroborated with the computer simulation of the same is demonstrated. With the fringe patterns obtained through the aperture mask of six and nine holes arranged non-redundantly along a circle, have been reported. The intensity distribution formula at the focal plane , for interference of n beams is presented. The effect of phase randomness on the focal intensity distribution is also experimentally studied.

Introduction

In optical astronomy high angular resolution with sub-milliarcsecond of a point source can be achieved by means of interferometry. After the successfull measurement of the diameter of α-*orionis* with direct stellar interferometry (*Michelson* and Pease, 1921), followed by the diameter of 32 stars by intensity interferometry (Hanbury Brown, 1974), the latter has become a powerfull tool. A baseline with two independent aperture synthesis configuration (Labeyrie, 1975) made it possible to produce many astrophysical results (Blazit et al., 1977; Bonneau et al., 1981; Faucherre et al., 1983). Subsequent success in achieving the interference fringes (Labeyrie et al., 1986a) with a pair of 1.5 metre spherical telescopes proved that large optical arrays can be built.

Beams from the many apertures arranged either in Y (VLA) or in circular mode can be recombined. Baldwin et al., (1986) reported the measurements of fringe visibility and closure phase using aperture-masking of Mauna Kea´s 88 inch telescope. To

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increase the capabilities for observing universe Labeyrie et al., (1986b) presented the concept of optical very large array (OVLA). In view of the growing importance of multiple aperture synthesis we present here a laboratory simulation alongwith a computer simulation of the same arranged in circular mode.

Theory

Let us consider an N aperture interferometer where the apertures lie on the circumference of a circle of radius r, as shown in fig. (1) . Then the electric field at any point (x, y)in the focal plane of the telescope for the n-th beam is,

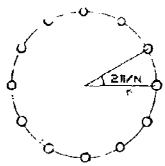


Fig. 1 Concept of N aperture interferometer arranged in a circle.

$$E_n(x, y) = E_o \, \mathrm{Cos} \, [\, 2\pi(s_x^2+s_y^2)^{1/2} \mathrm{Cos} \, (\, \Phi-\Phi_n)] \qquad \text{---} \quad (1)$$

where s_x and s_y are dimensionless quantities,

$$s_x = r \, x / \lambda f, \qquad s_y = r \, y / \lambda f \qquad \text{------------------} \quad (2)$$

with λ the wavelength of light and f the focal length of the focussing device and Φ and Φ_n are the azimuthal angles,

$$\Phi = \mathrm{Sin}^{-1} \, [\, s_y / (\, s_x^2 + s_y^2)^{1/2} \,] \qquad \text{---------} \quad (3)$$

$$\Phi_n = 2 \, \pi \, n \, / \, N \qquad \text{--------} \quad (4)$$

The total electric field is thus,

$$E_{tot}(x, y) = \sum_{n=0}^{N-1} E_n \qquad \text{------} \quad (5)$$

The intensity is then given by,

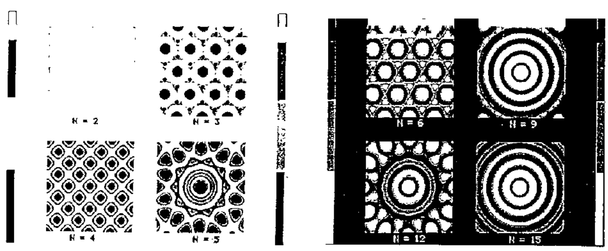
$$I\,(x,\,y) = [\,E_{tot}\,(x,\,y)\,]^2 \qquad \text{----------} \qquad (6)$$

The sum given in equation (5) can be expanded as summations of Bessel functions, the analytical details of which will be presented elsewhere. However, to summarise, one observes that for

$$(s_x^2 + s_y^2)^{1/2} << 1 / N\,,$$

$$I\,(x,\,y) \sim J_0^2[\,2\pi\,(s_x^2 + s_y^2)^{1/2}] \qquad \text{----------} \qquad (7)$$

The simulation presented , here , gives the intensity distribution I (s_x, s_y) from which I (x, y) can be easily deduced. Figure 2a, and 2b respectively depict the computer simulations of fringes produced by the various apertures, namely, N = 2, 3, 4, 5, and N = 6, 9, 12, 15 arranged in a circular mode at a regular interval. It may be mentioned here that the figure 2a has been printed as a negative while figure 2b as a positive.



(a) (b)

Fig. 2 Computer simulations of fringes produced by the various apertures: (a) N = 2, 3, 4, and 5; (b) N = 6, 9, 12, and 15 arranged in a circular mode at a regular interval.

Laboratory Simulation

In order to obtain the light beam from a point source similar to the star in the sky, we have produced an artificial star image by placing a pair of condensing lenses alongwith a pin-hole of 50 μ size in front of a source. The beam was collimated with a Nikkor lens (L_1). The wave fronts from this artificial star enter into a simulated telescope whose focal ratio is 1 : 3.25 (similar to the prime focus of 2.34 meter Vainu Bappu telescope at Kavalur, India). The image was magnified to about 30 times with a microscope objective. In order to reduce the chromatic blurring, an interference filter in the green region with a bandwidth of 100A° was used. Figure 3 depicts the laboratory set up for studying fringes.

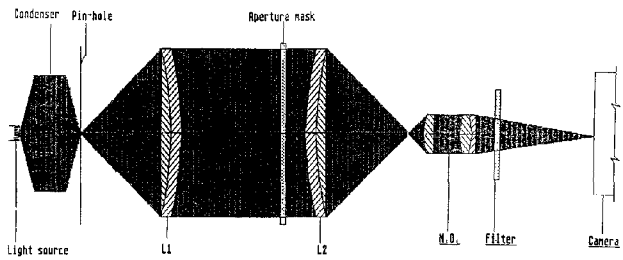
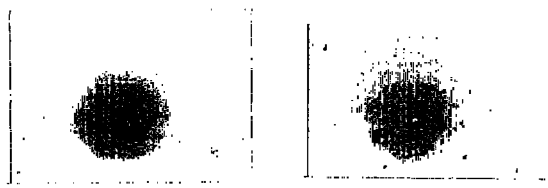


Fig. 3 Laboratory set up for studying fringes.

Figure 4 shows the shapes of the fringes produced by the various apertures arranged in a circular mode in the laboratory. The sizes of the each apertures and the minimum separation between them were 2 mm and 5 mm respectively. The fringes were recorded in a fine grain astronomical film 2415 with Canon camera (without its lens). It is to be noted here that the asymptotic variations of the fringes appeared considerable. Therefore, more integration time were needed to record the side lobes of the fringes. Due to the photon diffusion of the photographic film,the center fringes appeared blurred. The recorded fringes were scanned with the photometric data system (PDS) and were reproduced with the computer.



(a) N = 6 (b) N = 9

Fig.4 Shapes of the fringes taken in the laboratory produced by (a) N = 6 and (b) N = 9 apertures arranged in a circular mode.

Discussion

The main purpose of this kind of simulations is to find out the structure of the fringes of which one can expect while observing universe using multiple aperture synthesis. It is clear from the fig. 2(a) and 2(b) the shape of the fringes are changing according to the increasing number of baselines between the apertures. The number of baselines defines with $N (N - 1) / 2$, where N is the number of aperture. If one uses the aperture more than 9 or so , the shapes of the fringes are becoming circular and the sidelobes can be seen at the outer pheriphery. Similar structure can also be observed from the laboratory simulation [see fig. 4(b)].

The intensity simulations [see fig. 2(a), 2(b)] follow directly from the formulae (1 - 6). In this simulations , the diffraction effects have been neglected. The experiments were, however, performed with holes of 2 mm diameter and hence significant diffraction effects appear. These partly explain the deviation between the computer simulation and the observed data. A simulation with the addition of diffraction will be presented in a future communication.

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