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INTERFERENCE FRINGES OBTAINED ON VEGA WITH TWO OPTICAL TELESCOPES

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ABSTRACT

Two small telescopes spaced by 12 m have been operated as a Michelson stellar interferometer. The system may be expanded progressively into a telescope array. Plans are made for starting a multinational array with a pair of 1.5-m telescopes.

Subject headings: instruments — interferometry

I. INTRODUCTION

The potential astrophysical impact of telescope arrays performing as optical synthetic apertures has been frequently stressed. Several configurations have been proposed for such arrays. Of particular interest is the concept of independent telescopes having a common coudé focus where all images are superposed for increased luminosity and resolution. Odgers and Richardson (1972) and Code (1973) have already studied such configurations for incoherent arrays i.e., arrays where luminosity alone is considered. Coherent work, permitting retrieval of the diffraction-limited resolution of the large synthetic aperture (10^{-3} arcsec for 100-m size) introduces the additional and rather critical requirement for temporal coherence between the several beams made to interfere in the synthetic image.

In order to study the telescope array concept and its suitability for both incoherent and coherent work, I have built a preliminary system involving two small telescopes and which may thus be considered as a Michelson stellar interferometer. This system is now operational at Nice observatory, and routinely produces interference fringes with its 12-m baseline. This *Letter* gives details of the two-telescope system, its operation, and plans for future growth into a full-sized array.

II. INTERFEROMETER DESIGN

The interferometer system evolved from preliminary devices built at Meudon during the last 3 years. As depicted in figures 1, 2 and 3, it consists of two coudé telescopes located respectively north and south of a "focal laboratory" where the coudé beams are received and recombined to produce a synthetic-aperture image of the star observed. The telescopes have servo-driven alt-alt mounts providing a coudé focus with a single flat mirror. Some of the special features in the mechanical design are: a 3-mm aluminum tube with spider arms 10-mm thick supporting the Cassegrain and coudé

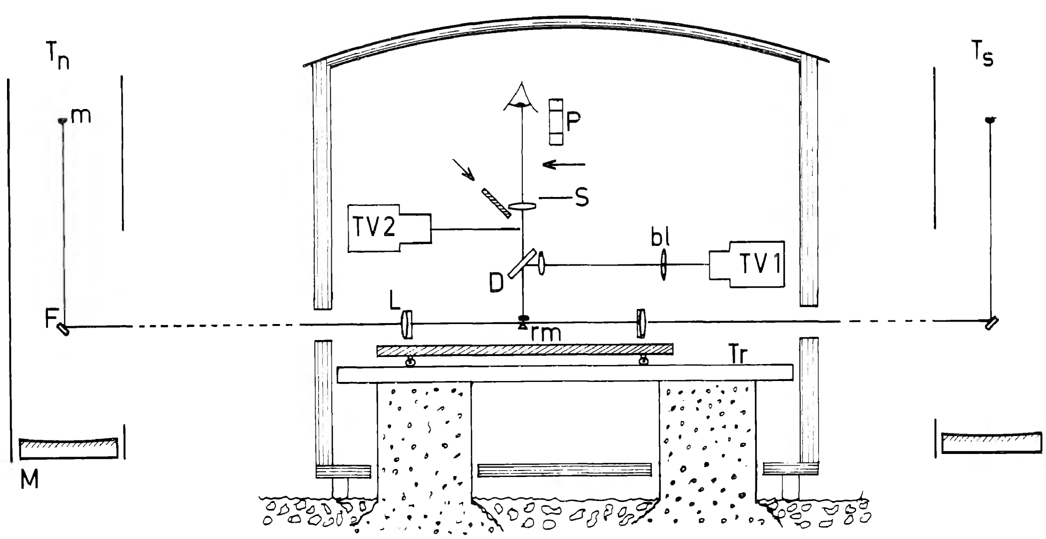

FIG. 1.—Optical layout of the two-telescope interferometer: Tn,Ts: north and south telescopes; M: 250-mm primary mirror (f = 850 mm); m: Cassegrain secondary (f = 7.5 mm); F: coudé flat; L: field lens; rm: roof mirror in pupil plane; D: dichroic mirror; TV1: guiding camera; bl: bi-lens serving to separate the two guiding fields; S and P: slit and direct view prism used for fringe acquisition; TV2: photon-counting camera (tunable filter not represented); Tr: tracks on which table moves (programming mechanism not represented).

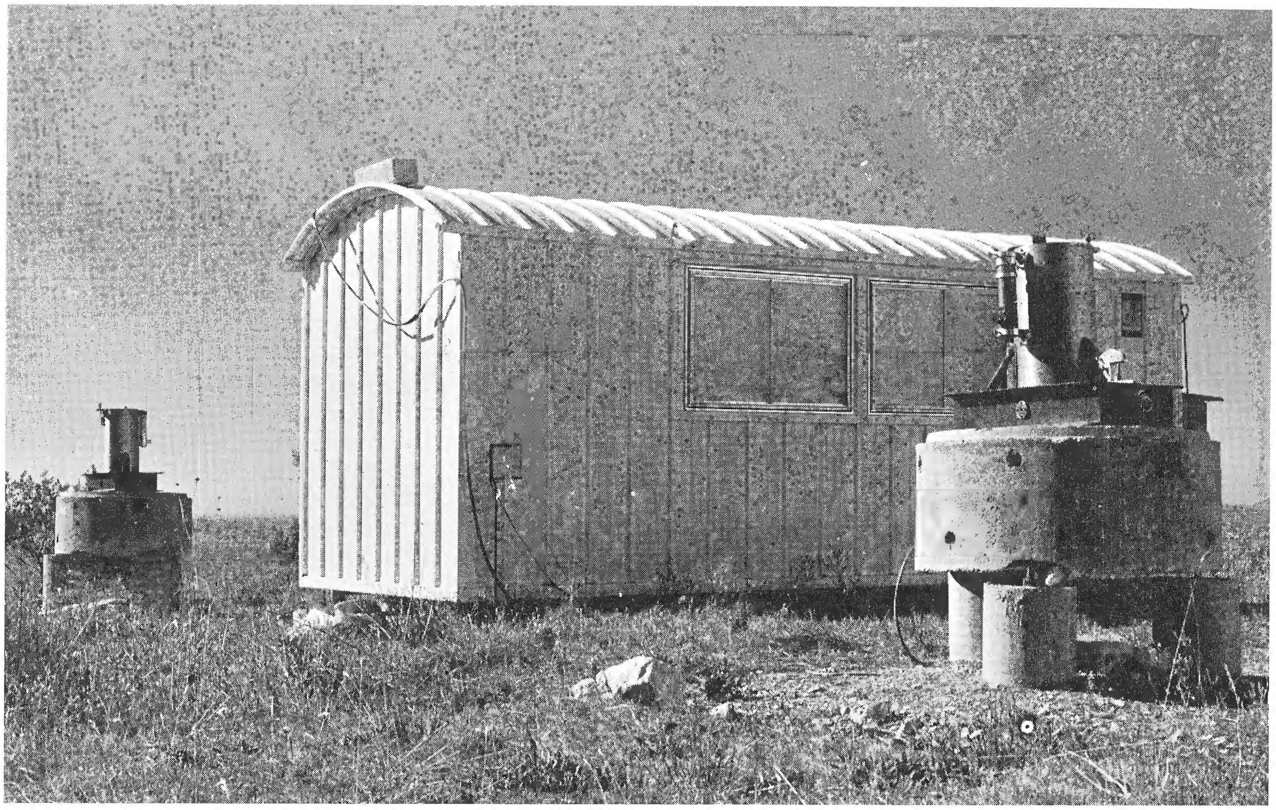

FIG. 2.—Interferometer at Nice observatory, showing the heavy alt-alt yoke mounts with their servo drives. The large concrete elements are commercial pipe sections providing a stable but movable substrate. Not visible is a mechanism which rotates the coudé mirror at half the declination rate, thus providing a fixed coudé output. The construction of 60-m tracks is currently undertaken for a variable baseline.

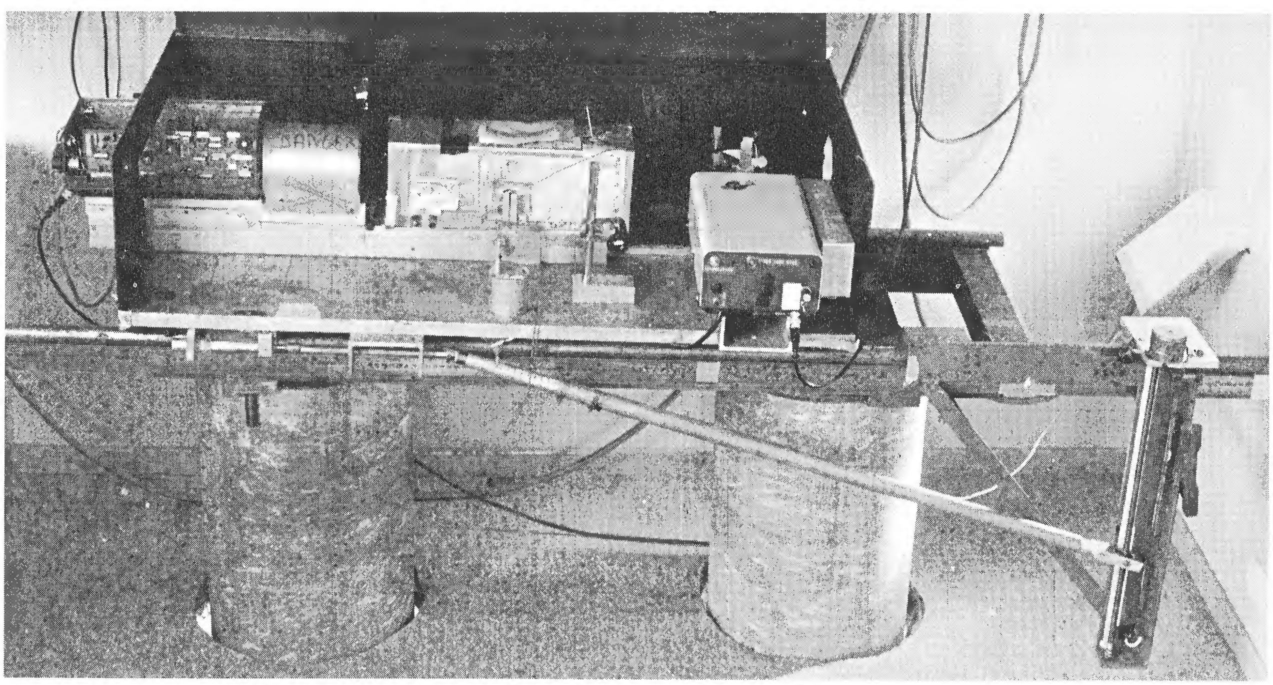

FIG. 3.—Central station, showing the optical table with its tracks, and the fringe-tracking mechanism which approximates the required cosine H displacement law. The concrete piers independent from the building are also visible, as well as the micrometer screw which allows for fine fringe tracking.

mirrors; a very stiff steel yoke; low-speed DC motors on both axes; a pulley gear mechanism serving to rotate the coudé mirror at half the pseudo-declination rate. These features provide good dimensional stability and negligible vibrations at the scale of interference fringes. The optics is Cassegrainian, with a miniature secondary providing a narrow coudé beam at focal ratio f:3000. Due to its diameter the beam is insensitive to seeing in the horizontal path.

The focal laboratory houses an optical table supporting beam recombination optics and two television cameras serving respectively for guiding and for observing the synthetic image in the photon-counting mode. An optical delay mechanism and other accessory equipment are also installed in the laboratory. The photon-counting camera is interfaced, via coaxial cable, to a minicomputer located 40 meters away in a different building. The camera interfacing and computer reduction procedures will be described by Blazit *et al.* (1974) in a subsequent article.

Beams are recombined using a roof-shaped mirror having a sharp edge, on both sides of which the telescope pupils are imaged. In a relayed focal plane, superposition of the two fields occurs, thus producing Young's fringes similar to those observed by Michelson (1920) if coherence is adequate. Atmospheric dispersion is corrected by a glass plate inserted in one of the incident beams. Because the baseline is at an angle with the Earth's rotation axis (the angle is 42°6), optical path variations occur as the star is tracked. This is compensated by displacing the optical table on tracks parallel to the baseline. A simple cam mechanism visible in figure 3 provides coarse tracking by approximating within 0.3 mm the required cosine H displacement law during up to 2 hours of observation. A micrometer screw, and visual feedback, allow fine fringe tracking in dispersed light and also in white light.

The fringes may be observed visually, or (fig. 4) with a photon-counting television camera. The camera system is inspired from that of Boksenberg (1972), but

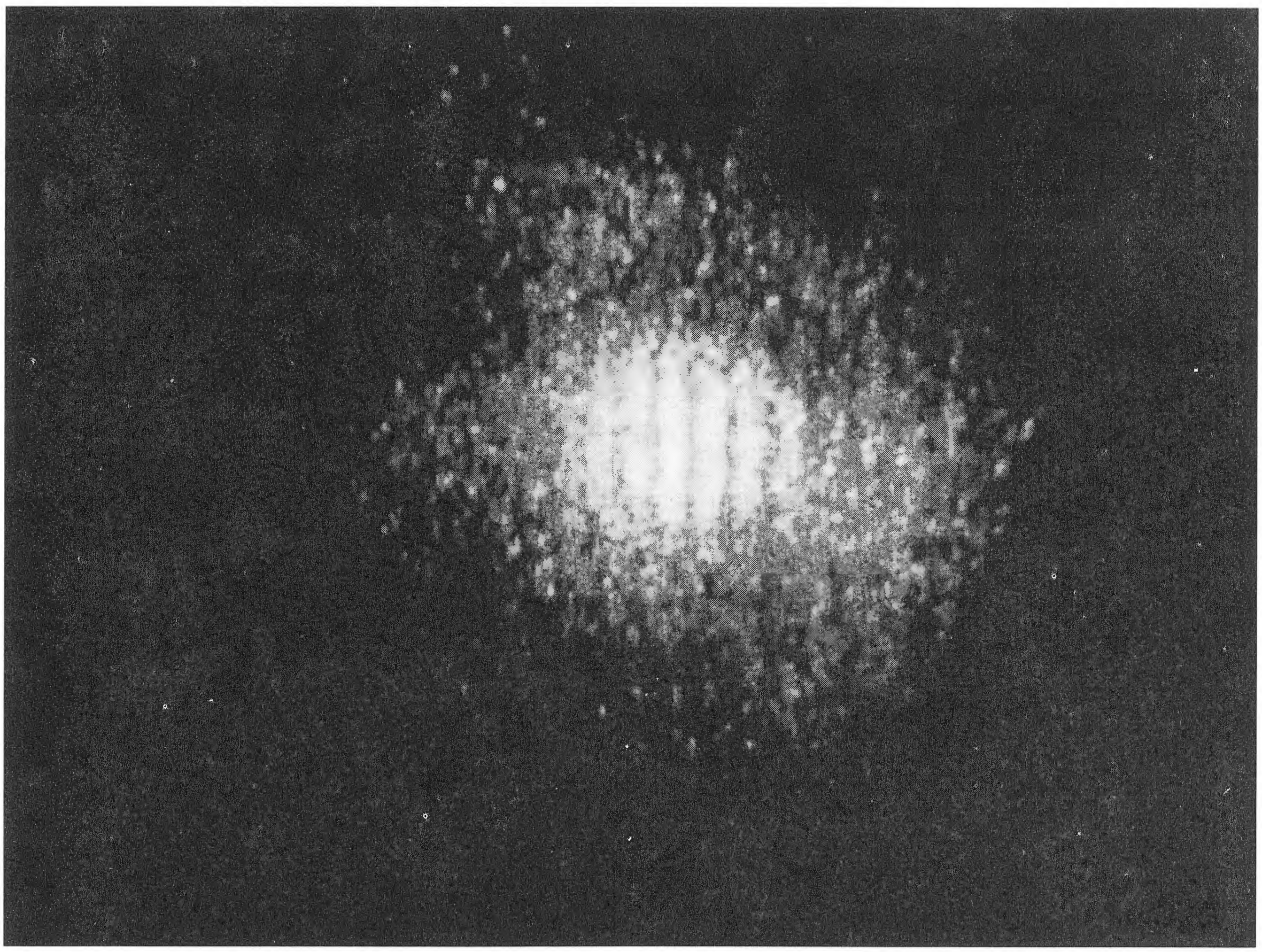

FIG. 4.—Interference fringes (photographed from a television sequence), obtained in the image of Vega with 500 Å bandwidth. In this case, the photon-counting camera is operating at reduced gain in the analog mode. Individual photon events are nevertheless visible as bright points.

has an all-electrostatic tube fitted in a standard commercial television camera (SOFRETEC CF 131). The tube, obtained from Thomson-CSF, consists of a microchannel intensifier section (inverting type) which is fiber-optics coupled to a Nocticon pickup tube, having a silicon target. The camera is interfaced to the computer through a preprocessor for on-line autocorrelation analysis of images containing up to 100 photon-events in each 20-ms exposure.

A slot and direct-view prism may be inserted in the output beam for observing the fringes in dispersed light. As experienced by Michelson, this facilitates considerably the fringe acquisition. Indeed, fringes are still visible in the spectrum with over 50 μ of path difference, and can thus usually be found within minutes since the position uncertainties are in the order of a millimeter. Once acquired in dispersed light, the fringes are easily found in white light. Because the autoguider system which drives both telescopes may be replaced by human guiders, low-cost versions of such interferometers could probably be constructed by experienced amateurs.

III. OBSERVATIONS

Vega was observed frequently between 1974 July 28 and September 12. Because of the well-known image wander effect produced by the atmosphere in small telescopes, the two more or less degraded Airy disks are not frequently superposed. This does not appreciably affect the fringe perception, as long as superposition does occur in the feet of the images. During conditions of ground winds in the 10 m s^{-1} range, images deteriorate appreciably, but fringes suffer only a moderate loss of contrast. When observing in white light during good seeing conditions, the fringe visibility was estimated to be in the order of 0.8, and oscillations in the 0.5–10 Hz frequency band appeared to have less than 0.3 fringe rms amplitude. This is better than could be feared on the basis of existing data and atmospheric models. Pease (1931), in particular, mentioned large visibility losses at long-baseline settings with the 50-foot (15 m) interferometer. It is likely that the self-supporting 50-foot structure vibrated more than the new ground-supported system, and this may account for the improved fringe visibility. Fringe drifts also occur, probably due to imperfections of the crude delay-programming mechanism. Tested in one arm of a laser interferometer, the telescopes themselves had been found to have a rather stable behavior, with very moderate fringe drifts induced when rotating the mounts. In future systems, auxiliary laser interferometers such as suggested by Miller (1966) should allow a more accurate fringe tracking performance, which would be specially valuable for astrometric observations.

Little astrophysical information is yet provided by these observations. The fact that the fringes remain contrasted in the spectral range from 5000 to 7500 Å implies merely that Vega is smaller than 0".005 at all wavelengths in this interval. This confirms the intensity interferometer measurements made at blue wavelengths by Hanbury Brown *et al.* (1967).

We are currently attempting to improve the system's sensitivity for work on fainter objects. This requires modifications of the autoguider system, and computer-assisted fringe monitoring using on-line correlation procedures which treat photon events as digital pulses. Also under way is the construction of 60-m tracks for a variable baseline.

The beam-recombination optics can easily be extrapolated for the case of more than two telescopes. This requires essentially replacing the roof mirror by a pyramid mirror. In the short run, adding a third telescope between the two previous ones would be helpful in suppressing the ambiguity occurring when zero fringe contrast is observed on a resolved star.

The next obvious improvement consists of replacing the small telescopes by large ones, the most cost-effective size being in the order of 1.5 m (60 inches). Speckle interferometry is one way of dealing with the synthetic image (Labeyrie 1974), but active seeing compensation techniques may also be envisaged in the future for superior efficiency on bright objects. While conventional optics is perfectly suitable for these larger telescopes, new types of mounts seem desirable. Currently being studied are (1) an enlarged version of the above-described alt-alt yokes; and (2) a spherical mount made of ferroconcrete. The second solution has potential advantages of reduced cost, better dimensional stability, and improved vibration behavior. It affords enough room inside the sphere for manned observing with photometers or Cassegrain spectrographs, and does not require a dome if precautions are taken to avoid solar heating in the daytime. I am currently building a 1-m concrete sphere. Once ground to a smooth finish, in optical fashion, it will be equipped with a 40-cm mirror in order to develop tracking techniques suitable for larger instruments. An artist's rendering of a future array involving 3.5-m spheres is presented in figure 5. Because astronomers from different countries have already shown a marked tendency to group their national telescopes on common sites, it seems realistic to envisage multinational funding and collaboration for building a telescope array. There appears to be no problem in having component telescopes belonging to different institutions, and serving part of the time for independent conventional observations, as long as some fraction of the time is reserved for collective observing in the incoherent or coherent mode.

Telescope arrays will require joint efforts for fast development. Offers for collaboration, sites or funding are welcome.

C. Richardson and the students, D. Moreau, S. Carrion, and M. Josse, contributed heavily to preliminary testing and attempts with earlier versions of the system; while M. Gaucher benevolently helped to build parts of the final telescopes. Special thanks go to F. and C. Roddier for their invitation to Nice and for the crucial support which their collaborators provided.

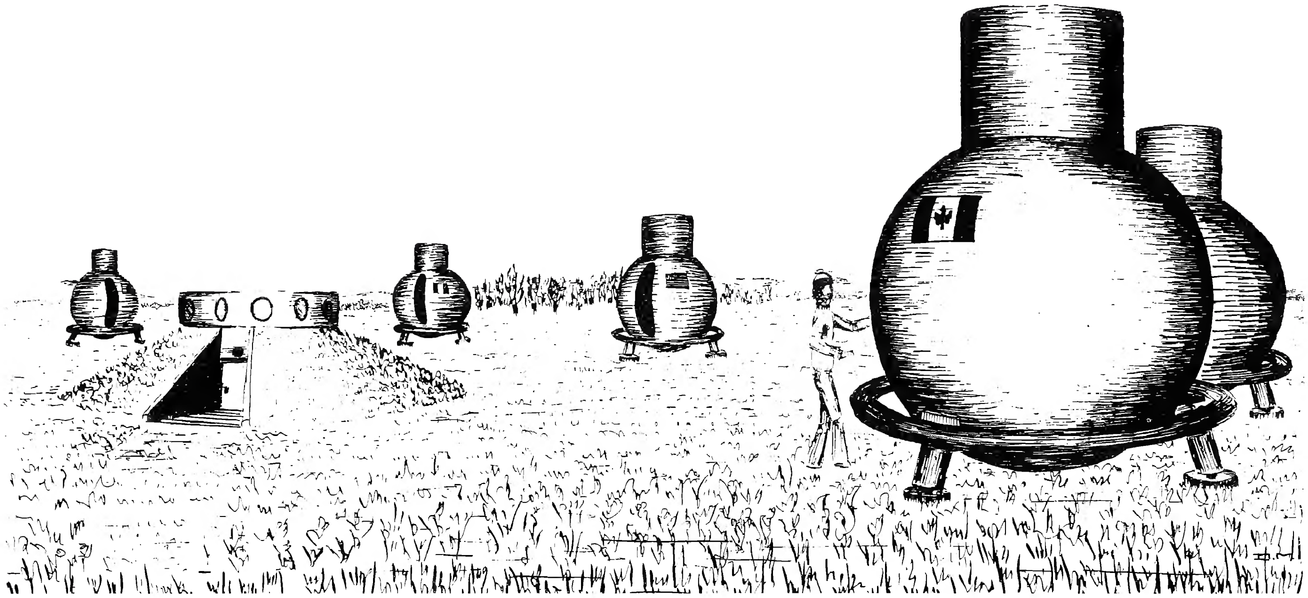

FIG. 5.—Possible configuration for an array of 1.5-m telescopes, showing spherical mounts made of ferroconcrete

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