The Astrophysical Journal, 217:L55–L57, 1977 October 1


# THE ANGULAR DIAMETERS OF CAPELLA A AND B FROM TWO-TELESCOPE INTERFEROMETRY

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*Received 1977 May 27; accepted 1977 July 26*

## ABSTRACT

We have resolved the apparent disks of Capella A and B with the two-telescope interferometer operating at 12 to 20 meter baselines. The angular diameters are respectively 5.2 ± 1.0 and 4.0 ± 2.0 milli-arcsec. Through continued observation, further improvements are possible in the accuracy of diameter and orbital determinations.
*Subject headings:* interferometry — stars: individual

## I. INTRODUCTION

Initial observational tests with a stellar interferometer involving two coudé telescopes were reported previously (Labeyrie 1975). For measuring stellar apparent diameters, the instrument has now been fitted with a variable baseline, currently spanning 20 meters.

To date, fringes have been observed on Capella, Castor, eta Ursae Majoris, epsilon Ursae Majoris, and Vega. On Capella, the periodic appearance and disappearance of fringes at different colors provides accurate positions for the two spectroscopic components and estimates for the angular diameters of both stars.

## II. THE INSTRUMENT

The instrument initially installed at Nice has been relocated at the CERGA site, recently developed near Grasse in southern France. The site, a limestone mesa at 1300 m altitude, allows possible baseline extensions up to 500 m or more. Danjon astrolabes and a network of Blum tiltmeters provide geophysical information on land tides, microseisms, and other possible causes for baseline tilts affecting the position of interferometer fringes.

The interferometer consists of two 25 cm telescopes having a long coudé focus (Labeyrie 1975, 1976). The two star images are superposed at the foci in order to produce Young's fringes similar to those observed by Michelson (1920) and Pease (1931) with their 20 and 50 foot (6.4 and 15.5 m) instruments. Each telescope can be moved on tracks for a variable baseline. The tracks are made of precision-ground steel rods which we have optically aligned to approximately 30 microns straightness on concrete piers. The tracks span 20 meters in the north-south direction.

For tracking the zero path difference, the central table which carries the beam-recombination optics is translated, under computer control, parallel to the baseline. Although purely mechanical positioning has been used for the observations reported in this article, we are attempting to use a fringe-counting laser system of the Metrilas type, obtained from SORO, for a more accurate knowledge of the telescope positions relative to the central table. This is also expected to compensate automatically for the effect of air pressure variations on the optical path.

A pair of photon-counting television cameras serve for guiding and fringe monitoring. The fringe monitoring camera may be connected to the computer or to a wired digital correlator for obtaining a quadratic average of the fringe signal (Blazit *et al.* 1977). However, this cannot provide accurate visibility measurements with the small telescope apertures currently used. The statistics of image wander and speckles in a small telescope are such that true fringe visibility is not simply related to the measured rms average. Indeed, both Airy disks frequently split into speckles and are rarely well superposed. Larger component apertures do not have this problem: the theoretical investigation by Roddier and Roddier (1976) confirms that basic speckle-interferometer data reduction applied to fringes from a pair of large telescopes yields the true visibility with excellent accuracy, in a way which is insensitive to the type of seeing.

With small apertures, more elaborate reduction procedures are necessary for accurate visibility measurements. In the presence of fluctuating fringe contrast, the mental process involved in visual measurements is of particular interest: the visual observer appears to memorize essentially the peak contrast, which occurs briefly at times and image locations where both amplitudes happen to be equal. Similar digital algorithms can probably be developed. Their performance should be compared with active approaches where the cancellation of seeing is attempted by means of movable or deformable optical elements.

Pending the availability of larger telescopes or adequate reduction software, the results presented in this article are based upon visual estimates of the fringe contrast.

## III. RESULTS

Both telescopes being pointed, preferably, at the same star, fringes are searched by varying the path difference within the uncertainty zone amounting to one or two millimeters. As described by Michelson (1920), fringes are best found by looking through a prism. Once acquired, the fringes may be observed in white light and tracked for up to 2 hours.

In contrast with the observation of Pease (1931), we did not find a systematic decrease of fringe visibility with increasing baseline. Highly contrasted fringes were observed on eta Ursae Majoris ($V = 1.86$) at 17 m baseline, a value exceeding Pease's maximum. Thus structural vibrations or acoustic noise may be the origin of Pease's reported effect. Whether or not fringe visibility will remain high for future baselines spanning one or several hundred meters is difficult to predict, but it appears highly probable.

Capella is a conspicuous spectroscopic binary, also well observed interferometrically since it was resolved by Anderson (1920). Recent work was reported by Kulagin (1970) with a 5 meter interferometer, and by speckle interferometer users at Palomar and Kitt Peak (McAlister 1977; Blazit *et al.* 1977).

With baselines above 13 m, we found a progressive decrease of fringe visibility. No fringes could be found above 16 m. Both component disks are therefore resolved. In addition, fringe visibility is modulated as a function of wavelength, owing to the binary structure. Indeed, the fringe systems contributed by both component stars can be in step at certain colors and out of step at intermediate colors, owing to the proportionality of fringe spacing to the wavelength. Within minutes, one observes that the pattern of minima and maxima moves along the spectrum. This is caused by the rotation of the baseline projection on the plane of the sky. The corresponding aperture supersynthesis effect provides some two-dimensional coverage of the object's geometry. Separation measurements made by observing these spectral effects are presented in Figure 1, together with the predicted position computed from the recent orbit of Finsen (1975).

The accuracy of separation measurements on Capella is currently comparable to that of the speckle interferometer, although not in all directions. It should improve by a factor 3 as soon as a calibration scale is installed to measure the wavelengths of fringe visibility extrema. It will also benefit from the permanent availability of the instrument.

For determining the diameters of Capella A and B, the intrinsic fringe visibilities $\gamma_A$ and $\gamma_B$ may be derived from the observed maximum and minimum fringe contrast $C$ and $c$, and the magnitude difference $\Delta V$. The problem generally has two solutions given by:

$$\gamma_A = \tfrac{1}{2}(C + \epsilon c)(1 + 10^{-\Delta V/2.5}) ,$$

$$\gamma_B = \tfrac{1}{2}(C - \epsilon c)(1 + 10^{\Delta V/2.5}) ,$$

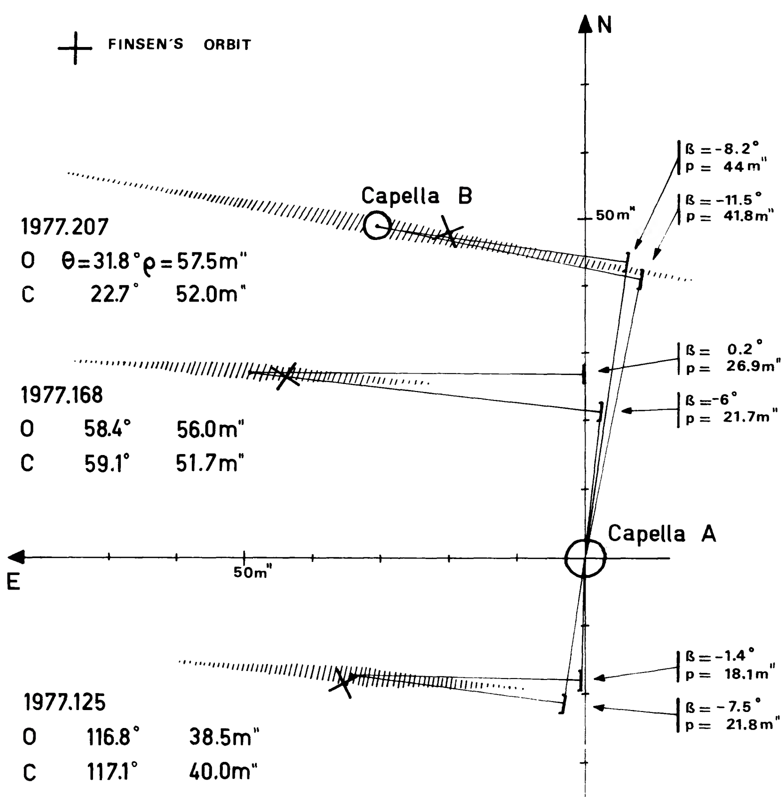


FIG. 1.—Aperture supersynthesis observation of the Capella system: two-dimensional coverage results from the rotation of the projected baseline on the sky during observation ($p$: measured binary spacing projected onto baseline; $\beta$: position angle of the baseline.) Hachured areas in the plane of the apparent orbit indicate uncertainty zones. Observed positions ($O$) are given in comparison with Finsen's orbit ($C$). Circles indicate the measured angular diameters of components.

where $\epsilon$ is equal to 1 if component A is the largest, and equal to $-1$ in the opposite case.

Assuming uniform disk brightness, angular diameters can be derived from a single visibility measurement, the baseline and the wavelength of observation. Adopting the values $C = +0.4 \pm 0.2$, $c = 0.05 \pm 0.05$, estimated from our best observation achieved at epoch 1977.2066, at 0.55 micrometer wavelength, and further adopting $\Delta V = 0.25$ (Wright 1954) (Batten only references Wright's work), we find the results given in Table 1.

TABLE 1

| Solution | Component | Visibility | Angular Diameter (milli-arcsec) |
|---|---|---|---|
| $A>B$......... | A | $0.31\pm0.17$ | $5.2\pm1.0$ |
| | B | $0.51\pm0.36$ | $4.0\pm2.0$ |
| $A<B$......... | A | $0.41\pm0.36$ | $4.7\pm2.0$ |
| | B | $0.39\pm0.17$ | $4.7\pm1.0$ |

The second solution is less probable physically since it implies a marked departure from blackbody emission. Indeed, spectroscopic results quoted by Batten and Ovenden (1968) and Wright (1954) indicate that the most luminous component, Capella A, has the lowest effective temperature, and is therefore the largest if both objects are blackbody sources. Adopting the spectral classification of Wright, which rates Capella A as a G5 III at $T_e = 4650$ K and Capella B as a G0 III at $T_e = 5300$ K, we find a diameter ratio of 1.6, not incompatible with the observed value of 1.3 given by the first solution.

However, repeated observations and better fringe visibility measurement will be necessary to obtain more reliable and accurate values.

We have also observed fringes on the single-line spectroscopic binary Castor A ($V = 1.99$), with 15.87 m baseline. Fringes remained contrasted at all colors, providing no evidence for the spectroscopic companion, and implying that the AI V star is smaller than $0\overset{''}{.}002$. It appears that insertion of a thin glass plate to retard the corresponding beam should allow observing fringes simultaneously on Castor A and Castor B, spaced $1\overset{''}{.}6$ apart. This should give accurate measurements of their separation, possibly evidencing the orbital perturbations to be expected from the additional spectroscopic companions. Doing this would also provide hints on the feasibility of positional astronomy measurements on widely spaced pairs of stars. Lately, Vega has also been resolved.

## IV. CONCLUSION

Although refinements are desirable in the operation of the two-telescope interferometer—mainly concerning digital data reduction—our initial visual measurements provide encouraging results. Particularly, the approximate diameter values obtained for Capella's components open the way to a study of more subtle morphological parameters—limb darkening, oblateness possibly caused by tidal effects, or orbital perturbations such as could be caused by planetary bodies or circumstellar matter.

These observations suggest that much longer baselines can be used. Steps are currently being taken to expand the tracks to 40 m, for $2 \times 10^{-4}$ arcsec resolution. With larger component telescopes, such as the pair of 1.5 m instruments now being developed, it should become possible to tackle a number of interesting astrophysical problems, pending the progressive development of full-size synthetic-aperture arrays.

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