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Speckle interferometry of some bright stars with the 6-meter telescope

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Labeyrie's method of speckle interferometry has been applied to measure stellar diameters and close binary-system separations. An angular diameter of 0".053 is determined for Betelgeuse. For the classical binary Capella, the angular separation and position angle are in good accord with the theoretical orbit.

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Over the past few years the method proposed by Labeyrie[1] in 1970 has been successfully applied in several attempts to determine separations in close binary systems and to measure the apparent diameters of stars.[2–6] In this method a series of quasicoherent images of an object are recorded on film at high magnification. Each frame is then subjected to an optical Fourier transformation, with the square of the modulus of the transform being averaged on an individual plate, that is,

$$\langle | i(f, g)|^2\rangle = |o(f, g)|^2 \langle |\tau(f, g)|^2\rangle, \qquad (1)$$

where i(f, g) denotes the Fourier transform of the image intensity, o(f, g) represents the transform of the intensity of the object itself, and τ(f, g) is the instantaneous transmission function of the telescope–atmosphere optical system. With such a procedure one can establish the autocorrelation of the intensity in the object.

Early in 1977, speckle-interferometer observations of several stars were carried out at the prime focus of the BTA, the 6-m alt-azimuth telescope of the Special Astrophysical Observatory, Academy of Sciences of the USSR, in the Caucasus. A microscope objective yielding an equivalent focal length of 516 m was employed. Filters of 300-500 Å bandwidth in the red spectral region were used (the width of the passband was so selected that $\lambda/\Delta\lambda \geq D/r_0$, where D is the aperture diameter and r_0 is the characteristic scale of the phase irregularities). With exposures of 0.004-0.03 sec together with high-sensitivity isopanchromatic aerial survey film we were able to obtain images of satisfactory density for stars down to 2^m.

Figure 1 exhibits characteristic speckle images for β Geminorum, α Orionis, and α Aurigae, photographed in a band at $\bar{\lambda}$ = 6800 Å with a 0.02-sec exposure. At the time of these observations, in evening twilight, the image quality was approximately 2". The spotty pattern of β Gem is typical of a point object. In the central part of the image the grain diameter is 0".03; the number of grains (several hundred) is given by the quantity $\pi^{-1}(D/r_0)^2$. Atmospheric dispersion is manifested by a distension of the peripheral parts of the image in the direction toward the zenith, an effect for which compensation ought to be introduced in future work. The image of α Ori, a resolved star, differs markedly in character from the preceding one. The spots have much lower contrast here, and their size exceeds the diameter of the diffraction disk. Capella has the most interesting appearance among the speckle images: the doubling of the features due to the duplicity of the star is clearly noticeable to the eye. Each pair of spots may here be regarded as an independent picture of the binary system, as an image within an image; for this reason there seems to be a system of equidistant bands superimposed on the frame.

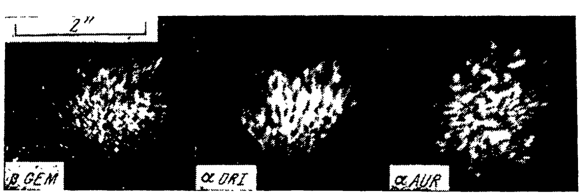

FIG. 1. Speckle images recorded at the prime focus of the 6-m telescope. The first object, β Gem, is an unresolvable single star. The spots comprising its image are distributed at random, and their size is comparable to the diameter of the diffraction disk. For the supergiant α Ori, the disk is resolved by the telescope, while α Aur is a close binary system whose components have an angular separation of about 0".0.4.

By applying coherent laser illumination we have been able to record on a single plate the squared modulus $|i(f, g)|^2$ of the Fourier transform of each frame. Since the transform of an individual speckle image again forms a spot pattern, but with a high level of noise, n independent

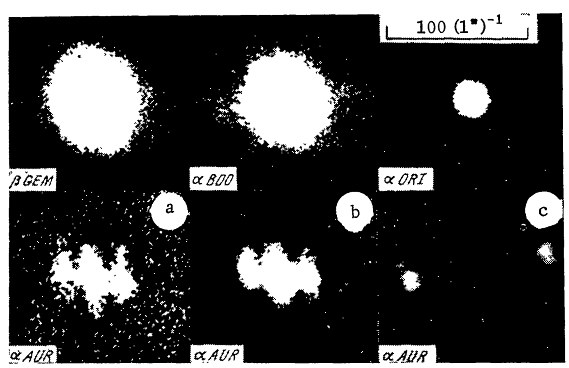

FIG. 2. Fourier transforms of the speckle images, illustrating the resolvability of the disk of α Ori and the duplicity of Capella. The transforms for β Gem, α Boo, and α Ori represent reductions of 30 statistically independent frames with images of these objects. The spectra are elliptical because of uncompensated atmospheric dispersion and optical aberrations. The improvement of the signal/noise ratio is illustrated by frames a and b at the bottom; the first of these results from the superposition of just four Fourier transforms, and the second, from ten. Frame c shows the autocorrelation image of Capella, demonstrating the final outcome of the reduction (the central pencil has been deleted from this frame).

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1977SvAL....3..272B

transforms have to be added together in order for the signal to be discriminated. In this process the signal/noise ratio increases as $\sqrt{n}$. In all cases only the least distorted part of the speckle image has been reduced.

The spatial frequency spectrum of α Ori obtained from the optical reduction shows a loss of high frequencies, which are retained in the image of the pointlike reference star β Gem. If we divide the spectrum of α Ori by the intensity distribution in the Fourier transform of β Gem and compare the resultant profile with the profile computed for a disk-shaped object, we can estimate the apparent size of the supergiant. The diameter of the disk of α Ori in the range $\bar{\lambda}$ = 6800 Å has been found to be 0".053 ± 0".004. This result is not very accurate, mainly because of the nonlinear characteristics of the emulsions. We should also point out that the diameter measurement is based on an assumed uniform brightness distribution over the disk of the star. Insignificant losses of high spatial frequencies have also been systematically observed by us in the spectrum of α Bootis. Data on its diameter can be obtained in the blue spectral region after a correction has been applied for atmospheric dispersion. Fourier transforms of the speckle images are illustrated in Fig. 2.

The spatial frequency spectrum of Capella is characterized by three equidistant bands, which determine the distance and position angle of the system components. If the separation l of the bands from each other is known, one can find the angular distance

$$\rho = 206265'' \frac{\lambda_0 s_0}{l s}, \qquad (2)$$

where λ_0 is the wavelength of the laser, while s and s_0 are the equivalent focal lengths of the telescope and the transforming lens. According to the analysis of observations made on the night of March 28, 1977, the mean values of the distance and position angle of the components are ρ = 0".042 ± 0".002, Θ = 108° ± 5°. This result is in good agreement with classical data on the orbit, as obtained by Merrill[7] with a stellar interferometer.

The autocorrelation of the image may serve as a more graphic illustration of the success in restoring the image of Capella (Fig. 2c). In order to obtain this frame, the pattern of the combined transform (Fig. 2b) was in turn subjected to an optical Fourier transform. The complicated structure of each separate spot in the photograph is attributable to aberrations in the optics, atmospheric dispersion, and diffraction effects of various kinds.

In conclusion we should like to point out that along with raising the penetrating power of ground-based telescopes, the task of further improving their resolving power is a need of prime importance. Speckle interferometry may be considered a most hopeful and quite simple method for this purpose; it ensures that in optical observing programs information can be preserved on the structure of the object until the resolution limited by diffraction is reached.

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[1]A. Labeyrie, "Attainment of diffraction-limited resolution in large telescopes by Fourier-analyzing speckle patterns in star images," Astron. Astrophys. 6, 85-87 (1970).
[2]D. Y. Gezari, A. Labeyrie, and R. V. Stachnik, "Speckle interferometry: diffraction-limited measurements of nine stars with the 200-inch telescope," Astrophys. J. 173, L1-L5 (1972).
[3]A. Labeyrie, D. Bonneau, R. V. Stachnik, and D. Y. Gezari, "Speckle interferometry: high-resolution measurements of 12 close binary systems," Astrophys. J. 194, L147-L151 (1974).
[4]D. R. Beddoes, J. C. Dainty, B. L. Morgan, and R. J. Scaddan, "Speckle interferometry on the 2.5-m Issac Newton telescope," J. Opt. Soc. Am. 66, 1247-51 (1976).
[5]C. R. Lynds, S. P. Worden, and J. W. Harvey, "Digital image reconstruction applied to α Ori," Astrophys. J. 207, 174-180 (1976).
[6]H. A. McAlister, "Speckle interferometry of the Hyades spectroscopic binary 51 Tau," Astrophys. J. 212, 459-461 (1977).
[7]P. W. Merrill, "Interferometer observations of double stars," Astrophys. J. 56, 40-52 (1922).

The first measurements of stellar magnetic fields with the 6-meter telescope

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A circular-polarization analyzer has been developed for the 6-m telescope. Measurements of the magnetic fields of α^2 CVn, β CrB, and 53 Cam agree closely with measurements obtained with other telescopes.

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The first Zeeman circular-polarization analyzer for the main stellar spectrograph of the 6-m telescope at the Special Astrophysical Observatory, USSR Academy of Sciences, was built and tested in 1976. The analyzer is tuned to 4300-Å wavelength and it spreads the incident light beam by 3 mm, which corresponds to 2".7 for the 183-m equivalent focal length of the telescope. The spectrograph design prevents the analyzer from being placed near the slit; it is located 50 cm away from the slit, so that a 20-mm light diameter has been adopted for the analyzer. Since

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