Complementary Approaches to Double and Multiple Star Research, IAU Colloquium 135, ASP Conference Series, Vol. 32, 1992
Harold A. McAlister and William I. Hartkopf (eds.)

Differential Photometry of Binary Stars

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ABSTRACT: Using a short exposure, one dimensional area scanner, a programme of photometry on binary stars with separations $<10''$ has been initiated; using speckle techniques, photometry of binaries with separations $<1''$ is possible. We describe the equipment and techniques and present results acquired during commissioning.

1. INTRODUCTION

Photometry of stars is the simplest technique for determining their astrophysical properties. However, for angularly close binaries ($r<10''$), conventional aperture photometry is impossible: the signal from one star is corrupted because seeing and small telescope tracking errors allow light from the companion to enter the aperture. One technique which overcomes these difficulties is to take one dimensional scans across the image of the binary (Rakos 1965; Warner *et al.* 1983). Using exposures less than the atmospheric coherence time (Léna 1988), the instrument we describe freezes the seeing and any telescope track error.

2. INSTRUMENT DESCRIPTION

Our system, shown in Figure 1, is used on the 1-m Jacobus Kapteyn Telescope on La Palma. Using additional optics placed up-beam of a standard photometer, the image scale of the telescope is magnified to $\sim 2''$ mm^{-1}. The magnified image is focused onto a rotating silvered disk, into which a mask pattern has been etched. The disk is rotated at ~120 rpm. In the classical image scanner, the mask consists of radial slits. As each slit transits the field of view, it samples the intensity distribution across the image. A photomultiplier beneath the disk records the signal passed by the slit as a function of time (equivalent to position in image) using a high speed photometry unit (Dick & Jones 1988). Count rates of up to 5×10^5 cts/sec may be recorded in each pixel, providing excellent linearity; because the photomultiplier is a one pixel detector, no calibration of pixel-to-pixel sensitivity variations is required. Each scan lasts for 13ms, sufficiently short to freeze the seeing and is stored on the

The slit disk is a special case of image plane coding. Given an $N\times1$ image of an object $\mathbf{O}$, an $N\times N$ mask matrix $\mathbf{M}$, an $N\times N$ instrument transfer matrix $\mathbf{T}$ then an encoded form ($\mathbf{C}$) of the image and the reconstruction ($\mathbf{R}$) of the image may be computed from : $\mathbf{C} = \mathbf{T.M.O}$ and $\mathbf{R} = (\mathbf{T.M})^{-1}.\mathbf{C}$.

The slit mask may be replaced by a Hadamard mask (Ibbett *et al.* 1968; Decker & Harwit 1968). It is possible to generate M such that it is circulant: row i of $\mathbf{M}$ is identical to row $i+1$ when rotated by 1 position left or right. Using a circulant matrix for $\mathbf{M}$ means that the encoding pattern on the disk is only 2N-1 elements long and its pattern may be continuous on the disk. The same

https://doi.org/10.1017/S025292110000662X Published online by Cambridge University Press

data acquisition scheme may be used for both slit and Hadamard masks. With the latter, the signal recorded in sample m is: $\mathbf{C}(m = \Sigma_{i=1}^{N}\mathbf{M}(m,i)\mathbf{O}(i)$ rather than $\mathbf{O}(m)$, where m = 1,...,N in the former. The efficiency of the slit mask is the ratio of the sample time (τ_s) (which defines the spatial resolution) to the frame time (τ_f). For the slit system, $\tau_s/\tau_f \approx 1\%$. In comparison, the Hadamard mask has 20 $\approx$ 50% of its elements transmitting, placing the operational limit ~3.5 magnitudes fainter.

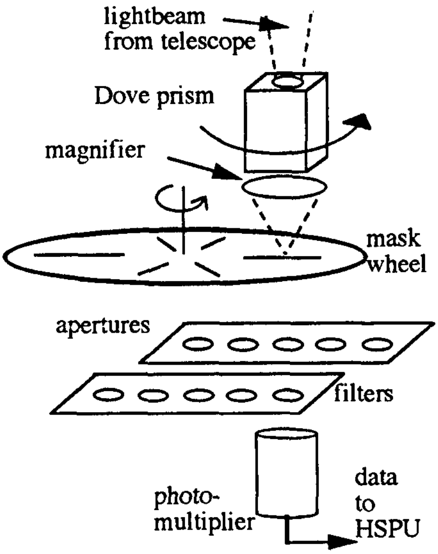

FIGURE 1. Schematic of instrument.

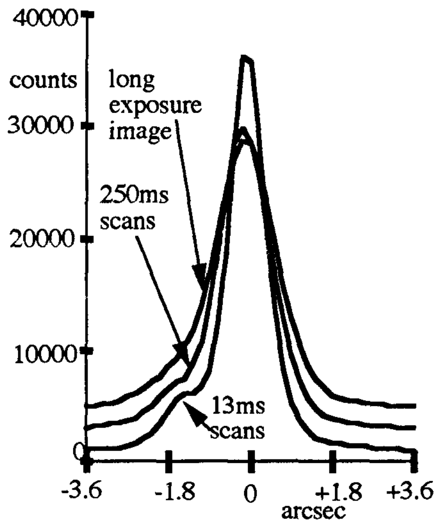

FIGURE 2. Scans of ADS 8148 (1″.5)

3. PHOTOMETRIC REDUCTION

Data may be analysed by speckle interferometric techniques or by co-aligning and adding each of the 13ms scans to form a sharpened image. The increase in resolution using 13ms exposures is apparent in Figure 2, where images of ADS 8148 are shown as a function of exposure time. The reduction procedures for each of these techniques is discussed by Devaney (1992); for binaries with separations ≥0″.8, we have obtained differential photometry by fitting Franz functions (Franz 1973) to each of the stellar profiles. The Franz function is superior to a Gaussian or Lorentzian function because it estimates the wings with greater accuracy; failure to accurately subtract the primary star's wings may seriously degrade the estimate of the secondary's magnitude.

Photometry may be performed using either the Johnson or Strömgren systems. For subsequent analysis using speckle techniques, the Strömgren system is preferred owing to the narrower bandwidth of the filters. Figure 3 shows an observation of ADS 7203 using *UBVRI* filters, taken during instrument commissioning, in February 1991. The differential photometry identifies the binary components as F6V and ~K4V.

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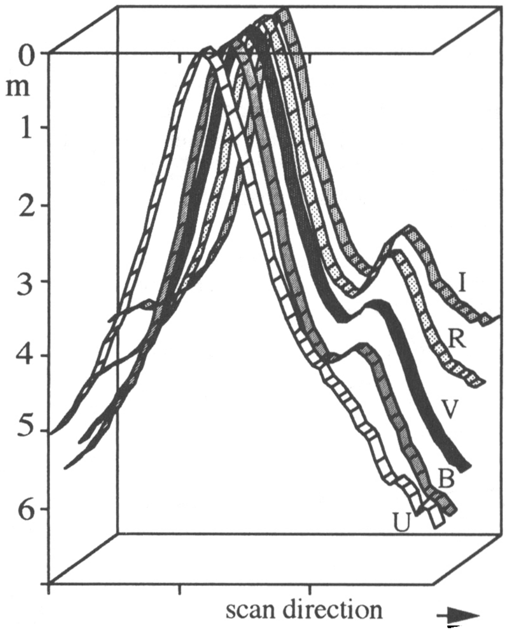

FIGURE 3. Photometric scans across ADS 7203

4. ACKNOWLEDGMENTS

The Jacobus Kapteyn Telescope, on the island of La Palma, is operated by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofisica de Canarias. We would like to thank Anne Charles and Peter Bunclark for assistance with system computer software during commissioning, David Pike for initial development of the data acquisition software, and Percy Terry for studying suitable light sources for instrument calibration in the Observatory's Photometric Laboratory.

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