Measurement of large delta M doubles using an improved coronascope

Serge Hoste

Ghent University, email serge.hoste@ugent.be

Abstract

A coronascope was built along the lines suggested by Daley[1] using a 25mm Plössl eyepiece inserted in an eyepiece-projection unit, used as relay lens. The coronascope was mounted behind a 5X Tele Vue Powermate and attached to a small 102/714 FCD-1 ED apochromatic refractor. An account of the first results is given by measuring the system around 31 Cyg.

1. Introduction

The measurement of large delta M doubles remains challenging using digital methods. The glare of the primary star easily overwhelms any weaker and/or nearby components, particularly so in CCD and CMOS imaging systems. James Daley pioneered a simple but very effective way to reduce this glare using the principles of the Lyot coronagraph for observation of the solar corona. By interposing an appropriately sized, semi-transparent occulter between the camera and the exit pupil of the telescope, a very steep reduction of the intensity of the primary star can be obtained (a factor 100.000) while still allowing sufficient light to pass through the film to allow an accurate measurement of its position. As this film is only 10 microns thick, focus is maintained throughout the field. This method was explored and improved here using a large delta M multiple system 31 Cyg.

2. The coronascope

To bring the background stars to the same focal plane as that of the occulter, James Daley suggested the use of a salvaged 25 mm microscope ocular. In this work, a 25 mm Plössl astronomical eyepiece was mounted into a commercial eyepiece projection unit. An occulter, made using a 0,7-1 mm wide and 40 mm long strip of Baader AstroSolar Film[2] was stretched diametrically over a ring using two dried drops of shellac or household adhesive tape and thus, suspended freely, approximately 2 cm in front of the focal plane of the relay lens. Whereas James Daley fixed the strip directly to the back of the field lens, our setup gives a cleaner image, free from dust specs that are always present on any lens surface. In Daley's tailpiece coronagraph, the distortions of the field introduced by the relay lens were minimized using an unspecified 25mm plano convex lens. This author used a commercial 80 mm focal reducer field lens positioned about 4 cm in front of the occulter strip. The whole setup is mounted on a 5X Tele Vue Barlow lens (Powermate) to generate enough magnification with a refractor of short focal length (nominally 714 mm). The final focal length obtained for the whole coronascope setup used in this work is estimated to be about 2140 mm, short but deemed sufficient for demonstration purposes. The "plate" scale was 0,2827"/pixel. The coronascope assembly is preceded by a flip mirror, allowing easy alignment of the star under scrutiny (see figure 1). A planetary ZWO ASI178MM CMOS camera, exhibiting small pixels (2,4 by 2,4 micron) was chosen as imaging device and was controlled using the software Sharpcap[3]. A careful analysis of field curvature introduced by this field lens allowed the author to reliably measure large delta M doubles with magnitude differences of well over 10 units in the central area of the field of view.

3. Calibration and field curvature

The optical train described above induces appreciable field curvature in the final image, as described in the original article by Daley. Therefore, a careful analysis of this curvature was performed using the Gaia reference star STF 2380. Both rho and theta were measured at 17 randomly but evenly spaced positions chosen around the center of the visual field and plotted as a function of the radial distance from the field center, using the known pixel number positions of the test double. All measurements were performed using the REDUC[4] software on stacks of 100 frames each. Figures 2 and 3 allow us to estimate that a central circular region with a radius of about 600 pixels can be used to provide reliable angular (standard deviation well below 1 degree) and linear separation measurements (standard deviation below 0,3 arcsec). The total field of view of the camera covers 3096 by 2080 pixels and is shown in figure 4. The central part of the field, suitable for astrometry, is a circle of approximately 4 arcmin in diameter, but will vary dependent on the focal length used.

Figure 1. From left to right: flip mirror with 5x Powermate, nose piece with 0,5X reducer field lens, ocular projection unit with Plössl eyepiece and suspended occulter and camera. Overall focus is adjusted using the camera distance from the transfer eyepiece.

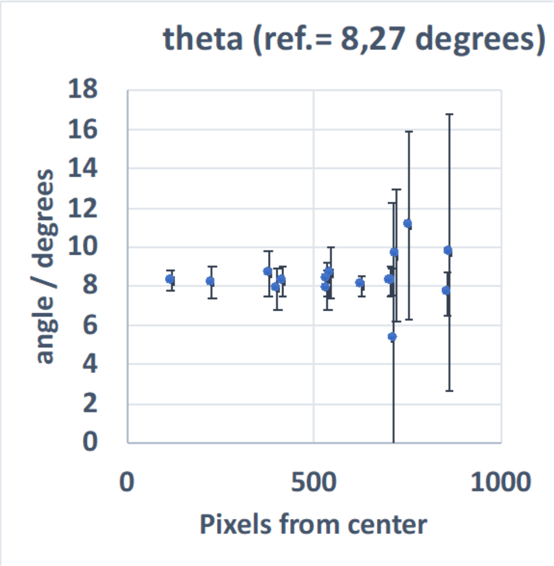

Figure 2. Variation in position angle for the pair STF 2380 measured as a function of radial distance from the center of the field of view. The reference angle is 8,27 degrees. Distribution of angles and the concomitant standard deviations given for each measurement point, suggest that no reliable measurements can be obtained beyond 600 pixels from the center of the image.

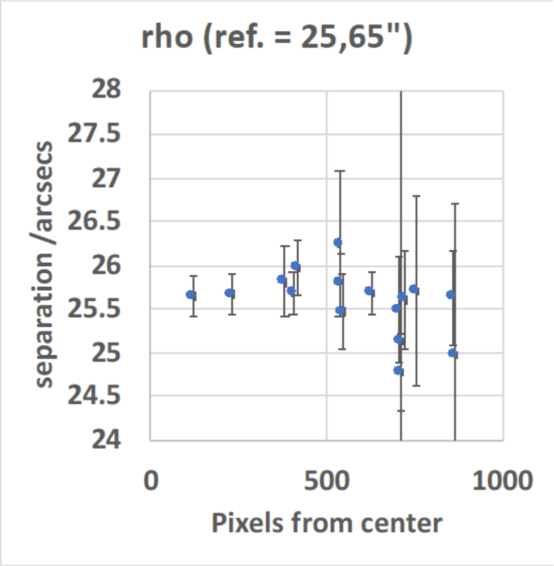

Figure 3. Variation in separation for the pair STF 2380 measured as a function of distance from the center of the field of view. The reference separation is 25,65 arcsec. Distribution of angles and the concomitant standard deviations given for each measurement point, suggest that no reliable measurements can be obtained beyond 500 pixels from the center of the image.

Although some field curvature remains clearly present, there is very little barrel distortion as can be judged from figure 4. Star trails through the central portion of the measurement field run perfectly straight for more than 60 seconds.

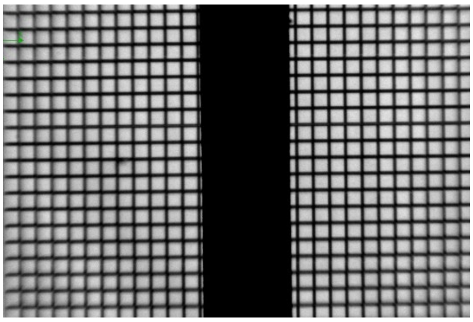

Figure 4: Square grid of A4 size (divisions 1cm by 1cm) viewed from approximately 22m with occulter in vertical position. Comatic distortion becomes quite noticeable towards the edges and corners, but the central area is flat at 0,28"/pixel.

4. Application to 31 Cyg

One advantage of measuring large delta M doubles is that they are easy to find, and their identification is unequivocal. Once brought to the center of the field, the A component is carefully hidden relatively close to the edge of the occulter to allow the closest possible components to be spotted. Aided by a sketch based on the presumed positions as found in the WDS, the occulter is rotated into position, to put the studied companion(s) at right angles to the long axis of the occulter (see figure 4).

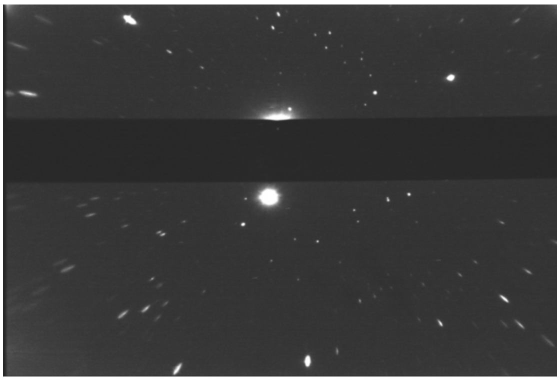

Figure 4. The whole field of the CMOS camera around 31 Cyg. The horizontal, black band is the occulter. It was positioned somewhat above the center the center of the field in this case. The principal star is hidden and the radiant due to field curvature is clearly visible. North is up and West is to the left in all star images.

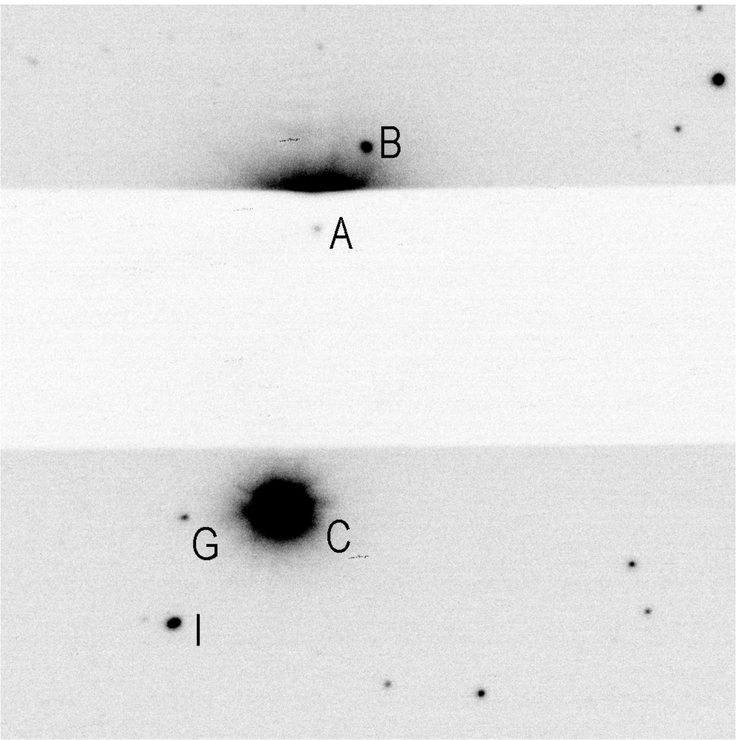

Figure 5. An annotated negative crop of the central portion of the same frame clearly shows the horizontal occulter and the components B, C, G, and I. The companions D and E are outside the field. H and K are absent. The companion F is hidden behind the occulter. North is up and West is to the left. Note that the principal component A exhibits a sharp stellar image through the occulting tape. The component labelled I has an unknown and faint companion (approx. 15th magnitude) to its western side. The great intensity of the principal star induces artefacts near the edge of the occulter. It is therefore safer to keep the star well hidden in order not to disturb the measurement of its position through the film (see below).

The data obtained using this coronascope on three replicate stacked images totaling a 2-minute exposure time of the system 31 Cyg are given in appendix. The film is transparent enough to allow the principal star to be seen (figure 5). Actually, the original Baader film has such a high optical density that it necessitates a rather long exposure time to burn through in those cases where the primary is relatively faint. Therefore, an alternative type of film with a somewhat lower optical density of 3.8 is to be preferred. It allows burning through of 5th magnitude stars in exposures of about 30 sec. Experiments with a circular or square or diamond shaped occulters were also conducted. They do provide much increased flexibility in positioning of the occulter relative to the companion stars. Therefor a new method of supporting the film was developed. Using a fine spring steel wire, a support could be made that fits inside the threaded ring of a 31 mm eyepiece sleeve which easily and securely carries a small rectangle of the Baader film (see figure 6) and it allows better use to the central portion of the field where optical qualities are optimal. In practice, the closest distances measurable between an occulted star and its companion is about 20 arcsec. By combining this coronagraph with a double Gaussian aperture mask, this setup allows stars with a separation of 10 arcsec to be observed. In lucky cases, both primary and even closer secondaries may be seen through the Baader film. A program to revisit all the measurements made by James Daley a decade and more ago, is under way (and passed the 50% mark as of August 2022). From the results obtained so far, additional and interesting effects in proper motion are quite noticeable in several cases.

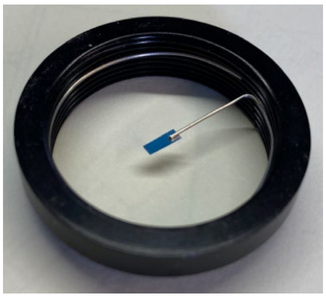

Figure 6. Improved method for carrying a 'free standing' occulter. Here, it is mounted on a separate filter ring but the method is easily transferable to the internal thread of the transfer eyepiece itself.

5. Optical distortion due to the occulter.

The potentially damaging optical distortion induced by the presence of an occulter in the observation field was investigated as follows: two bright couples (Albireo and Nu 2 Dra) with relatively small Δm were selected as test subjects. They were imaged in three different configurations: not occulted, primary occulted and both occulted by the Baader tape with ND 3,8. As can be seen from the data in the following table we may safely assume that the distortion introduced by the occulter is small (if present at all) and not systematic.

NO[a]		PO[b]		BO[c]	
PA	SEP	PA	SEP	PA	SEP
Albireo (m: 3,19 – 4,68)					
54,0	34,9	56,3	35,0	54,2	34,9
Nu 2 Dra (m: 4,87 - 4,90)					
311,0	62,1	311	61,1	309,6	61,7

a: not occulted, b: primary occulted, c: both stars occulted

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.
The author also wishes to acknowledge the use of the inestimable software STELLE DOPPIE[5] to search the WDS catalog and the use of the excellent double star analysis program REDUC. The author is grateful for constructive remarks to the paper by Florent Losse.

Designation	WDS ident	m1	m2	PA (degrees)	WDS PA	SEP (arcsec)	WDS SEP	JD - 2459000
STF 1495 AB	20136+4644	3,93	13,40	328,9	328	36,7	36,5	729.465
STFA 50 AC	20136+4644	3,93	6,97	172,2	172	108,1	108,6	729.465
NN AI	20136+4644	3,93	12,26	161,0	-	148,6	-	729.465
NN AG	20136+4644	3,93	14,20	153,5	-	120,0	-	729.465

---

[1] Daley J., 2007, JDSO vol 3, p159-164

[2] Baader AstroSolar Film, ND 5

[3] Sharp Cap Pro V4 by Robin Glover

[4] Florent Losse, Reduc Version 5.34

[5] Gianluca Sordiglioni, www.stelledoppie.it